Featured Speakers:

Susanne Aalto	Chalmers University of Technology
Fred Baganoff	MIT
John Bally	University of Colorado at Boulder
Avery Broderick	Perimeter Institute / University of Waterloo
Shep Doeleman	MIT Haystack Observatory / SAO
Mathieu de Naurois	LLR Ecole Polytechnique IN2P3/CNRS
Doug Finkbeiner	Harvard CfA
Stefan Gillessen	MPE
Fiona Harrison	Caltech
Woong-Tae Kim	Seoul National University
Timothy Linden	University of Chicago
Steve Longmore	Liverpool John Moores University
Jessica Lu	University of Hawaii
Naomi McClure-Griffiths	CSIRO Astronomy & Space Science
Jim Moran	Smithsonian Astrophysical Observatory
Gabriele Ponti	MPE Garching
Kazushi Sakamoto	ASIAA
Thaisa Storchi-Bergmann	Instituto de Fisica – UFRGS
Gunther Witzel	UCLA

Scientific Organizing Committee:

Michael Burton, co-chair	UNSW
Cornelia Lang, co-chair	University of Iowa
Sera Markoff, co-chair	API / University of Amsterdam
Roland Crocker	Australian National University
Chris Fragile	College of Charleston
Paul Ho	ASIAA
Sungsoo Kim	Kyung Hee University
Jesus Martín-Pintado	Observatorio Astronomico Nacional
David Meier	New Mexico Tech
Mark Morris	University of California, Los Angeles
Jürgen Ott	NRAO
Ylva Philström	University of New Mexico
Loránt Sjouwerman	NRAO
Masato Tsuboi	Institute of Space and Astronautical Science/JAXA

Local Organizing Committee:

Loránt Sjouwerman, co-chair	NRAO
Jürgen Ott, co-chair	NRAO
Cornelia Lang	University of Iowa
Amy Mioduszewski	NRAO
Karen Ransom	NRAO
Greg Taylor	University of New Mexico

Program

Sunday, September 29, 2013

7:30 a.m.	6:00 p.m.	Tour of VLA and LWA

Monday, September 30, 2013

8:00 a.m.	8:45 a.m.	Registration	
8:45 a.m.	9:00 a.m.	Welcome	
Session 1: Recent Galactic Center Results and Highlights			**Chair: C. Lang**
9:00 a.m.	9:30 a.m.	Overview Talk #1: Herschel View of the Galactic Center	John Bally
9:30 a.m.	10:00 a.m.	Overview Talk #2: Physical Conditions and Chemistry of Molecular Gas in Galactic Centers	Susanne Aalto
10:00 a.m.	10:30 a.m.	Overview Talk #3: NuSTAR Results: From the Galactic Center to Local Starbursts	Fiona Harrison
10:30 a.m.	11:00 a.m.	Coffee Break	
11:00 a.m.	11:30 a.m.	Overview Talk #4: Sgr A* X-ray Visionary Project	Fred Baganoff
11:30 a.m.	12:00 p.m.	Overview Talk #5: The H.E.S.S. View on the Galactic Centre	Mathieu de Naurois
12:00 p.m.	1:30 p.m.	Lunch	
Session 2: Global Properties and Dynamics in the Central Molecular Zones of Galactic Nuclei: From Large Scale Studies to the CND			**Chair: M. Tsuboi**
1:30 p.m.	1:55 p.m.	Star Formation in Nuclear Rings of Barred-Spiral Galaxies	Woong-Tae Kim
1:55 p.m.	2:20 p.m.	Atomic Hydrogen in an Outflow from the Galactic Center	Naomi McClure-Griffiths
2:20 p.m.	2:40 p.m.	The Galactic Center: Not an Active Galactic Nucleus	Deokkeun An
2:40 p.m.	3:00 p.m.	Lessons from Comparisons Between the Nuclear Region of the Milky Way and Those in Nearby Spirals	Jay Gallagher
3:00 p.m.	3:15 p.m.	Poster Previews	
3:15 p.m.	3:45 p.m.	Coffee Break	
3:45 p.m.	4:05 p.m.	Gas Motions in Inner 2 pc of Sgr A West	John Lacy
4:05 p.m.	4:25 p.m.	Molecules in the Circumnuclear Disk of the Galactic Center: Implications from Chemical Modeling	Nanase Harada
4:25 p.m.	4:45 p.m.	Opening Again the Debate: the Transient Nature of the Circumnuclear Disk	Miquel Requena-Torres
4:45 p.m.	5:05 p.m.	Regularized OSIRIS 3D Spectroscopy at the Circumnuclear Disk Ionization Front	Thibault Paumard
5:05 p.m.	5:25 p.m.	Discussion (Session 2)	

6:00 p.m.	8:00 p.m.	Opening Reception	NM Museum of Art

Program

Tuesday, October 1, 2013

Session 3: The Formation and Impact of Massive Stars in the Galactic Center			**Chair: F. Yusef-Zadeh**
9:00 a.m.	9:25 a.m.	Conversion of Gas into Stars in the Galactic Center	Steve Longmore
9:25 a.m.	9:45 a.m.	ALMA's View of the Initial Conditions within a Massive Protocluster	Jill Rathborne
9:45 a.m.	10:05 a.m.	Hot Gas, Masers, and Cloud Collisions: The Extreme Properties of Molecular Gas at the Heart of the Milky Way Galaxy	Betsy Mills
10:05 a.m.	10:30 a.m.	Poster Previews	
10:30 a.m.	11:00 a.m.	Coffee Break	
11:00 a.m.	11:25 a.m.	Kinematics and Dynamics of Molecular Gas in Galactic Centers	Kazushi Sakamoto
11:25 a.m.	11:45 p.m.	Disk-Halo Interactions: Molecular Clouds in the Galactic Center Region	Denise Riquelme Vasquez
11:45 p.m.	12:05 p.m.	Large Scale and High Sensitivity Multi Line CO Surveys Toward the Galactic Center	Rei Enokiya
12:05 p.m.	12:30 p.m.	Discussion of Session 3	
12:30 p.m.	2:00 p.m.	Lunch	
Session 4: The Galactic Center Stellar Population			**Chair: S. Kim**
2:00 p.m.	2:30 p.m.	Overview Talk #6: Young Stars in the Central Parsec of Our Galaxy	Jessica Lu
2:30 p.m.	2:50 p.m.	The Milky Way Nuclear Star Cluster Beyond 1 pc	Anja Feldmeier
2:50 p.m.	3:10 p.m.	Unveiling the Massive Stars beyond the Three Young Massive Star Clusters	Hui Dong
3:10 p.m.	3:30 p.m.	On the Origin of Young Stars in the Galactic Center	Ann-Marie Madigan
3:30 p.m.	3:45 p.m.	Poster Previews	
3:45 p.m.	4:15 p.m.	Coffee Break	
4:15 p.m.	4:35 p.m.	The Nuclear Cluster of the Milky Way	Tobias Fritz
4:35 p.m.	4:55 p.m.	Measuring the Physical Properties of th Milky Way Nuclear Star Cluster with 3D Stellar Kinematics	Tuan Do
4:55 p.m.	5:15 p.m.	Star Formation within 0.5 pc of Sgr A*	Mark Wardle
5:15 p.m.	5:35 p.m.	Probing General Relativity with Short Period Stars at the Galactic Center	Andrea Ghez
5:15 p.m.	5:45 p.m.	Discussion of Session 4	

Program

Wednesday, October 2, 2013

Session 5: Astrophysics and Feedback in the Sgr A* Environment and in other Galactic Nuclei			Chair: H. Falcke
9:00 a.m.	9:30 a.m.	Overview Talk #7: Observations of the G2 Cloud at Sgr A*	Stefan Gillessen
9:30 a.m.	9:50 a.m.	Keck Observations of G2 and Sgr A*	Leo Meyer
9:50 a.m.	10:10 a.m.	The Infrared K-band Identification of the DSO/G2 Source from VLT and Keck data	Andreas Eckart
10:10 a.m.	10:30 a.m.	G2 as a Probe of Sgr A*'s Hot Environs: A View from Chandra and VLA	Darryl Haggard
10:30 a.m.	11:00 a.m.	Coffee Break	
11:00 a.m.	11:25 a.m.	NIR Variability of Sgr A*	Gunther Witzel
11:25 a.m.	11:45 a.m.	NIR Polarized Observations of Sagittarius A*	Banafsheh Shahzamanian
11:45 a.m.	12:05 p.m.	Long-term Monitoring of Sgr A* at 43GHz with VERA and KVN+VERA	Kazunori Akiyama
12:05 p.m.	12:25 p.m.	Exploring Plasma Behavior Around Sgr A*	Salomé Dibi
12:25 p.m.	12:45 p.m.	History of High Resolution Imaging of Sgr A*	Jim Moran
12:45 p.m.	1:00 p.m.	Discussion of Session 5 (Part 1)	
1:00 p.m.	2:00 p.m.	Lunch	

6:00 p.m.		Conference Dinner	Coyote Café

Program

Thursday, October 3, 2013

Session 5: Astrophysics and Feedback in the Sgr A* Environment and in other Galactic Nuclei (cont'd)			**Chair: S. Markoff**
9:00 a.m.	9:30 a.m.	Overview Talk #8: Modeling Accretion and Outflows on Horizons Scales for the Event Horizon Telescope	Avery Broderick
9:30 a.m.	9:50 a.m.	Event Horizon Scale Emission Models of Sgr A*	Jason Dexter
9:50 a.m.	10:10 a.m.	Theory of G2 Cloud Multi-wavelength Emission	Roman Shcherbakov
10:10 a.m.	10:30 a.m.	Hydrodynamic Simulations of a Compact Source Scenario for the Galactic Center Cloud G2	Alessandro Ballone
10:30 a.m.	10:45 a.m.	Poster Previews	
10:45 a.m.	11:15 a.m.	Coffee Break	
11:15 a.m.	11:40 a.m.	Study of Sgr A*'s Surroundings to Constrain its Prior Activity	Gabriele Ponti
11:40 a.m.	12:00 p.m.	The Reflection of two Past Outbursts of Sagittarius A* Observed by Chandra during the Last Decade	Maica Clavel
12:00 p.m.	12:20 p.m.	Discovery of a Recombination Dominant Plasma: a Relic of a Giant Flare of Sgr A*?	Shinya Nakashima
12:20 p.m.	12:45 p.m.	Discussion of Session 5 (Part 2)	
12:45 p.m.	2:00 p.m.	Lunch	
Session 5: Astrophysics and Feedback in the Sgr A* Environment and in other Galactic Nuclei (cont'd)			**Chair: C. Fragile**
2:00 p.m.	2:25 p.m.	Resolved Gas Flows and Stellar Population in the Inner 10-100pc of Nearby Active Galaxies	Thaisa Storchi-Bergmann
2:25 p.m.	2:45 p.m.	A New Perspective on the Radio Bright Zone at The Galactic Center -- Feedback from Nuclear Activity	Jun-Hui Zhao
2:45 p.m.	3:05 p.m.	The Origin of the Galactic Center Diffuse X-ray Emission Investigated by Near-infrared Imaging and Polarimetric Observations	Shogo Nishiyama
3:05 p.m.	3:25 p.m.	Gas Dynamics in the Galactic Centre: Clump Accretion and Outflows	Jorge Cuadra
3:25 p.m.	3:45 p.m.	Why are the Sleeping Giants so Quiet? Rotating, Inflow/outflow Solutions for Accreting Black Holes?	Jerry Ostriker
3:45 p.m.	4:15 p.m.	Coffee Break	
4:15 p.m.	4:35 p.m.	The Millimeter-Wavelength Polarization of Sgr A*	Dan Marrone
4:35 p.m.	4:55 p.m	NuSTAR Detection of High-energy X-ray Emission and Rapid Variability from Sagittarius A* Flares	Nicolas Barriere
4:55 p.m.	5:15 p.m.	The 3 Ms Chandra Campaign on Sgr A*: A Census of X-ray Flaring Activity from the Galactic Center	Joey Neilsen
5:15 p.m.	5:45 p.m.	Discussion of Session 5 (Part 3)	

Program

Friday, October 4, 2013

Session 6: High Energy and Magnetic Processes, Strong Gravity and Dark Matter in the Galactic Center			**Chair: R. Crocker**
9:00 a.m.	9:30 a.m.	Overview Talk #9: Fermi Bubbles and Energetic Activity in the Galactic Center	Doug Finkbeiner
9:30 a.m.	9:50 a.m.	The Fermi Bubbles: Gamma-ray, Microwave, and Polarization Signatures of Leptonic AGN Jets	Mateuz Ruszkowski
9:50 a.m.	10:10 a.m.	Sturm und Drang: The Turbulent, Magnetic Tempest in the Galactic Center	Brian Lacki
10:10 a.m.	10:30 a.m.	Origin of Nonthermal Emission from the Fermi Bubbles and Mechanisms of Particle Acceleration There	Vladimir Dogiel
10:30 a.m.	10:45 a.m.	Poster Previews	
10:45 a.m.	11:15 a.m.	Coffee Break	
11:15 a.m.	11:40 p.m.	Dark Matter in the Galactic Center	Timothy Linden
11:40 p.m.	12:00 p.m.	Dark Matter and Pulsar Model Constraints from Galactic Center Fermi-LAT Gamma Ray Observations	Chris Gordon
12:00 p.m.	12:20 p.m.	Mapping the Galactic Centre: Detecting Gravitational Waves from Blackholes Orbiting Sgr A* Using Pulsar Timing	Alak Ray
12:20 p.m.	12:40 p.m.	The Cosmic-ray Ionization Rate in the Central Parsec of the Galaxy -- How We Could Deal with 10^4 Discrepancy?	Miwa Goto
12:40 p.m.	2:00 p.m.	Lunch	
Session 6: High Energy and Magnetic Processes, Strong Gravity and Dark Matter in the Galactic Center (con't)			**Chair: D. Haggard**
2:00 p.m.	2:20 p.m.	The Galactic Centre Molecular Cloud G0.13-0.13: a Laboratory for Understanding Cosmic-ray Electron Acceleration and Interactions	Andrew Lehmann
2:20 p.m.	2:40 p.m.	First Results from the NuSTAR "Mini-Survey" of the Galactic Center Region	Chuck Hailey
2:40 p.m.	3:00 p.m.	Dissecting X-ray-emitting Gas around the Center of our Galaxy	Q. Daniel Wang
3:00 p.m.	3:30 p.m.	Coffee Break	
3:30 p.m.	3:55 p.m.	Science with the Event Horizon Telescope	Shep Doeleman
3:55 p.m.	4:15 p.m.	The Galactic Center Pulsar, SGR 1745-29	Geoffrey Bower
4:15 p.m.	4:35 p.m.	Nonthermal Filamentary Radio Features Within 20 pc of the Galactic Center	Mark Morris
4:35 p.m.	5:00 p.m.	Discussion of Session 6	
5:00 p.m.	5:25 p.m.	Symposium Summary	Mitch Begelman
5:25 p.m.	5:30 p.m.	Closing Remarks	

Oral Presentation Abstracts

John Bally (University of Colorado at Boulder)

Sergio Molinari (INAF-Istituto di Astrofisica e Planetologia Spaziali)
and the Hi-GAL team

HERSCHEL View of the Galactic Center

The 3.5 meter diameter Herschel Space Observatory conducted a ˜720 square-degree survey of the Galactic plane, the Herschel Galactic Plane Survey (Hi-GAL). These data provide the most sensitive and highest resolution observations of the far-IR to sub-mm continuum from the Central Molecular Zone (CMZ) at $\lambda = 70$, 160, 250, 350, and 500 μm obtained to date. Hi-GAL can be used to map the distributions of temperature and column density of dust in CMZ clouds, warm dust in HII regions, and identify highly embedded massive protostars and clusters and the dusty shells ejected by supergiant stars. These data enable classification of sources and re-evaluation of the current and recent star-formation rate in the CMZ. The outer CMZ beyond $|1|= 0.9$ degrees ($R_{gal} > 130$ pc) contains most of the dense ($n > 10^4$ cm^{-3}) gas in the Galaxy but supports very little star formation. The Hi-GAL and Spitzer data show that almost all star formation occurs in clouds moving on x_2 orbits at $R_{gal} < 100$ pc. While the 10^6 M_o Sgr B2 complex, the 50 km s^{-1} cloud near Sgr A, and the Sgr C region are forming clusters of massive stars, other clouds are relatively inactive star formers, despite their high densities, large masses, and compact sizes. The asymmetric distribution of dense gas about Sgr A* on degree scales (most dense CMZ gas and dust is at positive Galactic longitudes and positive V_{LSR}) and compact 24 μm sources (most are at negative longitudes) may indicate that episodic mini-starbursts occasionally 'blow-out' a portion of the gas on these x_2 orbits. The resulting massive-star feedback may fuel the compact 30 pc scale Galactic Center Bubble associated with the Arches and Quintuplet clusters, the several hundred pc scale Sofue-Handa lobe, and the kpc-scale Fermi/LAT bubble, making it the largest 'super-bubble' in the Galaxy. A consequence of this model is that in our Galaxy, instead of the super massive black-hole (SMBH) limiting star formation, star formation may limit the growth of the SMBH.

Susanne Aalto (Chalmers)

Physical Conditions and Chemistry of Molecular Gas in Galactic Centers

Molecular gas plays a fundamental role in feeding and regulating star formation and growth of supermassive black holes (SMBH) in galaxy nuclei and is therefore a primary evolutionary parameter in starburst and AGN activity. Probing the nature and evolution of the molecular interstellar medium requires tracers that penetrate vast columns of dust while enabling unique investigations of chemical and physical conditions in the molecular gas.

In this talk I will present methods of studying galaxy evolution through using molecules as observational tools – exploiting their ability to trace dynamical, chemical and physical conditions. Key molecules in identifying the nature of buried activity and its evolution will be discussed. Recent ALMA and Herschel results will be presented and discussed with a focus on luminous AGN and starburst nuclei - and how their properties compare to the Galactic Center molecular gas.

Fiona Harrison (Caltech)

NuSTAR Results: From the Galactic Center to Local Starbursts

The Nuclear Spectroscopic Telescope Array, the first focusing high-energy X-ray telescope in orbit, extends sensitive X-ray observations above the band pass where Chandra and XMM-Newton operate. In its first year on-orbit NuSTAR has viewed the Galactic Center region as well as performed a survey of local starburst galaxies coordinated with the Chandra observatory. I will provide an overview of NuSTAR, and describe results from observations of flaring activity from Sgr A* and detections of compact objects and nuclear emission in nearby starbursts.

Fred Baganoff (MIT)

Sgr A* X-ray Visionary Project

We present results from the Sgr A* X-ray Visionary Project, which used Chandra/HETGS in 2012 to perform a 3-Ms exposure of Sgr A* and the Central Parsec of the Galaxy. This unprecedented exposure has detected dozens of flares from the supermassive black hole, including the most luminous flare ever seen. We present the properties of this flare and describe several multi-wavelength monitoring campaigns that were performed during the Chandra observations. We also provide a brief update on progress toward assembling from this dataset the first high-resolution spectrum of the accretion flow within the Bondi radius of this ultra-sub-Eddington accreting black hole.

Mathieu de Naurois (LLR Ecole Polytechnique IN2P3/CNRS)

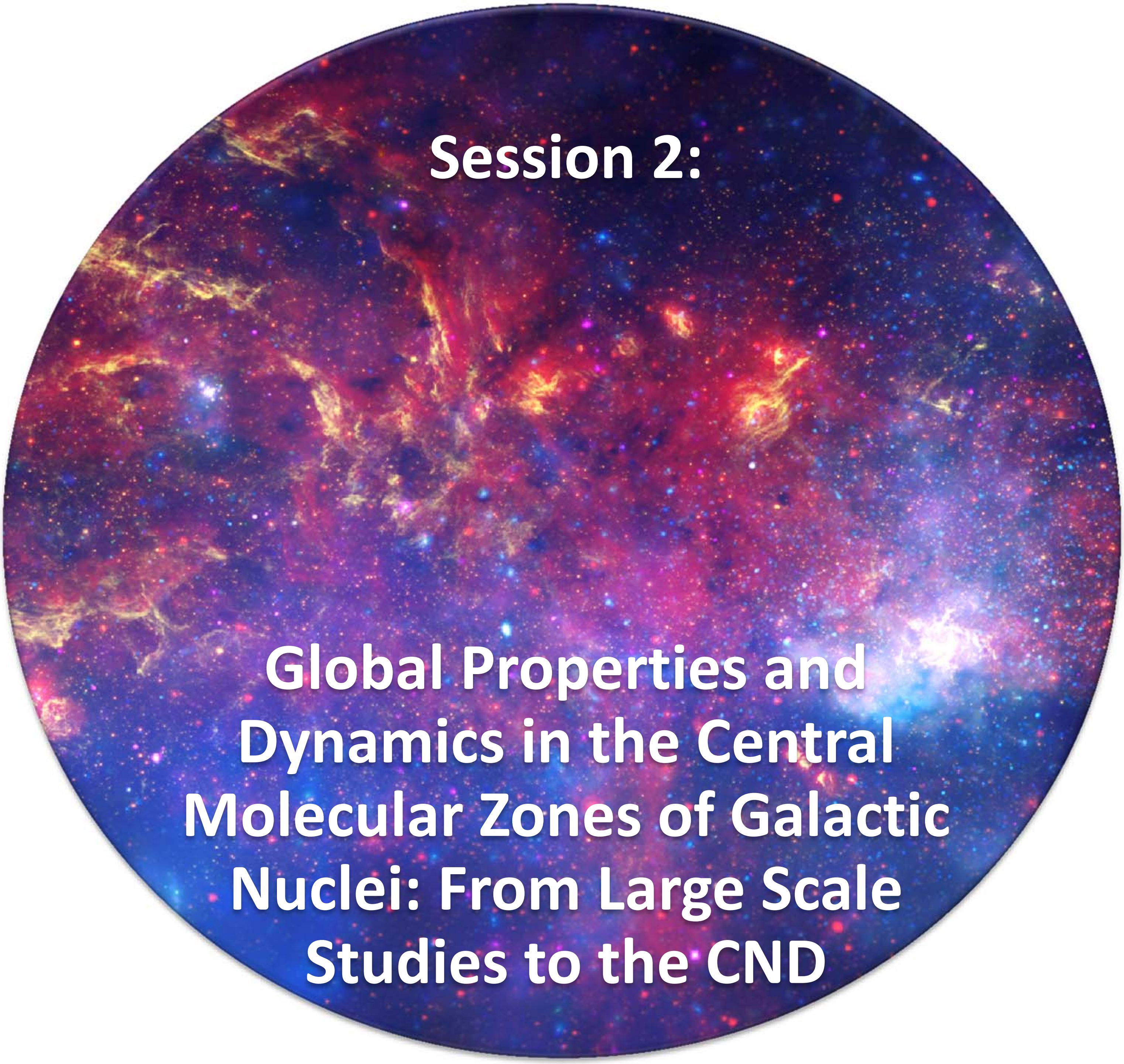
The H.E.S.S. View on the Galactic Centre

The vicinity of the Galactic Centre harbours many potential accelerators of very high energy (VHE) gamma rays, such as pulsar wind nebulae, supernova remnants, binary systems and the central black hole Sgr A*. In addition to these astrophysical sources, annihilation of putative WIMPS concentrated in the gravitational well could lead to significant high-energy emission.

The Galactic Centre region has been observed by the H.E.S.S. system of imaging atmospheric Cherenkov telescopes, installed in Namibia, for the last ten years above 150 GeV. This very large dataset, comprising more than 200 hours of observations, led to the discovery of a point-like source spatially compatible with the supermassive black hole Sgr A*, and to an extended diffuse emission, correlated with molecular clouds and attributed to the interaction of cosmic rays with the interstellar medium.

Results from these ten years of observation will be presented, including the energy spectrum, tests for variability, analysis of the diffuse component and implications for the various (astrophysical and exotic) very-high-energy emission mechanisms.

Oral Presentation Abstracts



Woong-Tae Kim (Seoul National University)

Star Formation in Nuclear Rings of Barred-Spiral Galaxies

Barred-spiral galaxies contain substructures such as dust lanes and nuclear rings, with the latter being sites of intense star formation. We study the substructure formation as well as star formation in nuclear rings using numerical simulations. We find that nuclear rings form not by Lindblad resonances, as previously thought, but by the centrifugal barrier that the inflowing gas along dust lanes cannot overcome. This predicts a smaller ring in more strongly barred galaxies, consistent with observations. Star formation rate (SFR) in a nuclear ring is determined by the mass inflow rate to the ring rather than the total gas mass in the ring. In the bar-only models, the SFR typically shows a short (~0.1 Gyr) strong burst associated with the early rapid gas infall before declining to small values. When the SFR is low, ages of young star clusters exhibit an azimuthal gradient along the ring since star formation takes place mostly near the contact points between the dust lanes and the nuclear ring. When the SFR is large, on the other hand, star formation is widely distributed throughout the whole length of the ring, with no apparent age gradient of star clusters. Since observed ring star formation appears long-lived with episodic bursts over ~1-2 Gyr, our results suggest that the bar region should be replenished continually from outside. We will show that the presence of spiral arms can transport gas to the bar region enough to make the ring star formation sustained episodically over a long period of time.

Naomi McClure-Griffiths (CSIRO)

Atomic Hydrogen in an Outflow from the Galactic Center

The Centre of the Milky Way is undoubtedly a dynamic place. The discovery of the Fermi bubbles and the more recent polarized counterparts suggests that a large scale, highly energetic, magnetised wind blows from the Galactic Centre. Using data from the Australia Telescope Compact Array (ATCA) HI Galactic Centre Survey we have discovered an atomic hydrogen counterpart to the Galactic wind. We have found a population of compact, isolated atomic hydrogen clouds at high velocities throughout the inner 1 kpc of the Milky Way. The clouds are about 15 pc in radius and relatively cool (T<4000 K). We interpret the clouds as the remnants of cold, dense gas entrained in the Galactic outflowing wind. Using the measured radial velocities for the clouds we are able to estimate the velocity of the cool wind as ~200 km/s.

Deokkeun An (Ewha Womans University, Korea)

Solange V. Ramirez (NExScI, Caltech)
Kris Sellgren (Ohio State University)

The Galactic Center: Not an Active Galactic Nucleus

We present 10μ - 35μ Spitzer spectra of the interstellar medium in the Central Molecular Zone (CMZ), the central 210 pc x 60 pc of the Galactic Center (GC). We present maps of the CMZ in ionic and H_2 emission, covering a more extensive area than earlier spectroscopic surveys in this region. The radial velocities and intensities of ionic lines and H_2 suggest that most of the H_2 0-0 S(0) emission comes from gas along the line-of-sight, as found by previous work. We compare diagnostic line ratios measured in the Spitzer Infrared Nearby Galaxies Survey to our data. Previous work shows that forbidden line ratios can distinguish star-forming galaxies from low-ionization nuclear emission-line regions (LINERs) and active galactic nuclei (AGNs). Our GC line ratios agree with star-forming galaxies and not with LINERs or AGNs.

John S. Gallagher III (University of Wisconsin-Madison)

Tova M. Yoast-Hull (University of Wisconsin-Madison)
Ellen G. Zweibel (University of Wisconsin-Madison)

Lessons from Comparisons between the Nuclear Region of the Milky Way and Those in Nearby Spirals

The nuclear zone (R≲200-300 pc) of the Milky Way offers a unique opportunity to study the detailed inner workings of a key component of galaxies. A set of 4 nearby (D <5 Mpc) giant barred spiral galaxies, IC 342, M83, Maffei 2, and NGC 253 provide useful comparisons to the Milky Way's nuclear region. A survey of the nuclear region structures of these spirals reveals a wide range in properties; e.g., gas content, stellar populations, and star formation rates. Among these systems, the Milky Way's nuclear region is the most quiescent, while NGC 253 defines the opposite extreme of an active starburst that contributes across the electromagnetic spectrum, including a relatively high gamma ray flux. The differences between these nuclear regions and the Milky Way's nuclear zone offer insights into evolutionary processes possibly linked to short nuclear time scales as well as the role of the host in feeding gas into galaxy centers. It also tests our understanding of links between star formation, environment, possible presence of low level AGNs, and high-energy emission from galaxy centers. This comparison suggests that we could be observing the center of the Milky Way in a relatively short-lived "dry" phase of low gas content and a depressed star formation rate and/or nuclear activity.

We thank the National Science Foundation for partial support of this research through grants AST-0903900 and PHY-0969061.

John Lacy (University of Texas at Austin)

Wesley Irons (Johns Hopkins University)
Matthew Richter (University of California at Davis)

Gas Motions in the Inner 2 pc of Sgr A West

We have obtained a data cube of the [Ne II] (12.8 μm) emission from the inner 2 pc of Sgr A West with 1" and 4 km/s resolution. The data cube has substantially better SNR and velocity resolution than previous observations of the ionized gas. We compared the observations to two proposed models of the gas motions and distribution: flows along tidally stretched streamers, and more nearly circular motions with density wave compression. The density wave model provides a considerably better fit to the observations of the northern arm and western arc. Neither model fits the eastern arm and bar at all well.

To help understand the origin of the spiral pattern we calculated orbits in the potential of a black hole in a star cluster and find that the orbits naturally evolve to set up a one-armed spiral wave very similar to that observed, both spatially and kinematically. Magnetic or other perturbing forces may influence the formation of the spiral wave, but self gravity is not required. Because a density wave evolves on the orbit precession timescale, rather than the orbital timescale, a wave pattern should persist for several 10^5 yr. No net inward motion of the gas is required by the model. If there is inflow, it is much smaller than is suggested by the infalling streamer model.

Nanase Harada (MPI für Radioastronomie, Bonn)

Karl M. Menten (MPI für Radioastronomie, Bonn)
Denise Riquelme (MPI für Radioastronomie, Bonn)
Serena Viti (University College, London)
Miguel Requena-Torres (MPI für Radioastronomie, Bonn)
Rolf Guesten (MPI für Radioastronomie, Bonn)
Stefan Hochgürtel (MPI für Radioastronomie, Bonn)

Molecules in the Circumnuclear Disk of the Galactic Center: Implications from Chemical Modeling

Within a few parsecs around the central Black Hole Sgr A*, chemistry in the dense molecular cloud material of the circumnuclear disk (CND) can be affected by many energetic phenomena such as high UV-flux from the massive central star cluster, X-rays from Sgr A*, shock waves, and an enhanced cosmic-ray flux. Recently, spectroscopic surveys with the IRAM 30 meter and the APEX 12 meter telescopes of substantial parts of the 80–500 GHz frequency range were made toward selected positions in and near the CND (Riquelme et al., in preparation; see also a contribution by Requena-Torres et al.). These datasets contain lines from the molecules HCN, HCO^+, HNC, CS, SO, SiO, NO, CN, H_2CO, HC_3N, N_2H^+, H_3O^+ and others. We conduct Large Velocity Gradient analyses to obtain column densities and total hydrogen densities, n, for each species in molecular clouds located in the southwest lobe of CND. The data for the above mentioned molecules indicate 10^5 cm^{-3} $\lesssim n < 10^6$ cm^{-3}, which shows that the CND is tidally unstable. The derived chemical composition is compared with a chemical model calculated using the UCL˙CHEM code that includes gas and grain reactions, and the effects of shock waves. Models are run for varying shock velocities, cosmic-ray ionization rates, and number densities. The resulting chemical composition is fitted best to an extremely high value of cosmic-ray ionization rate $\zeta \sim 10^{-14}$ s^{-1}, 3 orders of magnitude higher than the value in regular Galactic molecular clouds, if the pre-shock density is $n = 10^5$ cm^{-3}. Although this high value has been previously claimed to be attained in the Galactic Center region, more observational studies and further modeling are needed in order to confirm this result.

Miguel A. Requena-Torres (MPIfR)

R. Guesten (Max-Planck-Institut für Radioastronomie, Germany)
B. Mills (NRAO)
M. Morris (UCLA)
A. Weiss (Max-Planck-Institut für Radioastronomie, Germany)
J. Martin-Pintado (CAB-INTA-CSIC)
A. Harris (Maryland University)

Opening Again the Debate: The Transient Nature of the Circumnuclear Disk

Despite many investigations, the physical characteristics of the molecular gas in the Galactic center Circumnuclear disk (CND) remain a topic of debate. Its mass is highly uncertain, between 10^4 (from dust) and 10^{5-6} M_o (derived from gas tracers), and depending on the probe, density estimates for the dense clumps are 10^{5-8} cm^{-3} and gas temperatures run from 50 to a few hundred K. The range of physical parameters leave open many questions about the nature and fate of the CND. Using a combination of observations from ground-based telescopes, Herschel, and the GREAT instrument on-board SOFIA, we have obtained high-spatial and spectral resolution (22.5”-8” and ˜1 km s^{-1}) CO maps of the Sgr A area covering the CND. The gas densities derived from our CO excitation analysis clearly imply that the CO-emitting clumps in the CND cannot be gravitationally stable against tidal shear, as they are well below the Roche limit of 10^7 cm^{-3}. As such, our models strongly suggest the CND consists of gravitationally-unbound, transient clumps. We will also introduce a state-of-the-art analysis of the denser gas component of the CND using multi-transition observations of HCN and HCO^+ from the APEX telescope (led by E. Mills). Densities derived using these tracers also support the transient nature of the CND everywhere except in one position, where the densities are large enough to allow the material to be gravitationally bound. However, the discovery of vibrationally-excited HCN in another position supports the existence of warm (T˜150 K) dust that may contribute to radiative excitation of HCN, and reduce the densities derived using the HCN molecule.

Thibaut Paumard (LESIA - CNRS / Observatoire de Paris)

Regularized OSIRIS 3D Spectroscopy at the Circumnuclear Disk Ionization Front

The Galactic black hole and the central cluster of young stars are surrounded by a clumpy gas disk (the Circumnuclear Disk, CND) that rotates about them at a distance of $\simeq$1pc. The gas in this warm, turbulent, magnetized disk is ultimately likely to migrate into the central cavity and fuel future star formation and black hole accretion.

We have observed two fields of approximately 20"x20" in the CND at NIR wavelengths with the OSIRIS integral-field spectrometer at Keck Observatory. These two fields are located at the interface between the neutral and the ionized regions. Our data cover two H_2 lines as well as the Brγ line of the HI spectrum. The signal-to-noise ratio per spatial pixel of each line varies a lot across the field and becomes quite low in some regions. In order to avoid degrading the spatial resolution, we have developed a novel three-dimensional method to analyze the data in terms of regularized parameter maps. The method proves very efficient in retrieving all the information contained in the spectral line emission while not degrading the spatial resolution. We will present this new method to analyze 3D spectroscopic data and preliminary results on the structure of the ionized-neutral interface.

Oral Presentation Abstracts

Steven Longmore (U Liverpool)

Conversion of Gas into Stars in the Galactic Center

The star formation rate in the central 500 pc of the Milky Way is lower by a factor of >10 than expected for the substantial amount of dense gas it contains, which challenges current star formation theories. In this talk, I will discuss which physical mechanisms could be causing this observation and put forward a self-consistent cycle of star formation in the CMZ, in which the plausible star formation inhibitors are combined. Their ubiquity suggests that the perception of a lowered central SFR should be a common phenomenon in other galaxies. I will discuss the implications for galactic star formation and supermassive black hole growth. I will then put forward a scenario to explain the presence of super star clusters in the Galactic centre environment, in which their formation is triggered by gas streams passing close to the minimum of the global Galactic gravitational potential at the location of the central supermassive black hole, Sgr A*. If this triggering mechanism can be verified, we can use the known time interval since closest approach to Sgr A* to study the physics of stellar mass assembly in an extreme environment as a function of absolute time. I will show the first results from detailed numerical simulations testing this scenario. Finally, I will show that in terms of the baryonic composition, kinematics, and densities, the gas in the CMZ is indistinguishable from high-redshift clouds and galaxies. As such, the CMZ clouds may therefore be used as templates to make predictions for the evolution (and possibly the life cycle) of high-z clouds.

Jill M. Rathborne (CSIRO Astronomy and Space Science)

S. N. Longmore, J. M. Jackson, J. B. Foster, Y. Contreras, G. Garay, L. Testi, J. F. Alves, J. Bally, N. Bastian, A. Walsh, J. M. D. Kruijssen, E. Bressert

ALMA's View of the Initial Conditions within a Massive Protocluster

Clusters are the building blocks of galaxies and the nurseries of most stellar systems. However, little is known about the formation of the most massive clusters. In recent surveys, one object, G0.25+0.02, stands out as extreme. Identified as a cold, dense, massive molecular clump devoid of obvious star-formation, it has exactly the properties expected for a clump that may form an Arches-like massive cluster. Located at a distance of ∼8.5 kpc, G0.25+0.02 lies ∼100 pc from the Galactic Centre, its location within the harsh Galactic Centre environment may provide clues to the formation of such a massive protocluster and whether star formation can progress within it. What remains unknown is if the influence of strong tidal forces, high turbulence, and extreme magnetic fields within the GC region helps or hinders the formation of a massive cluster. In this talk I will show results from our recent ALMA cycle 0 observations of the 90 GHz continuum and line emission toward G0.25+0.02. The data are spectacular and provide, for the first time, details of the small-scale structure and conditions within this unique protocluster. The discussion will focus on the details revealed by the new ALMA data and how these relate to the potential formation of stars and a cluster within G0.25+0.02.

Betsy Mills (UCLA/NRAO)

Hot Gas, Masers, and Cloud Collisions: The Extreme Properties of Molecular Gas at the Heart of the Milky Way Galaxy

Molecular gas properties in the central 500 parsecs of the Galaxy are markedly different from those in the Galactic disk. Galactic Center gas clouds are characterized by large, turbulent line widths, high temperatures, and substantial densities - however, existing constraints on the extremes of these properties are poor. I will present exciting new results from surveys of Galactic Center molecular gas with the Karl G. Jansky VLA and GBT which probe the Galactic Center ISM at higher resolutions and higher energies than any previous work. Our surveys, primarily using the ammonia molecule, present new limits on the turbulence, temperature, and density in these molecular clouds. Results include the detection of an extremely hot (T˜400-500 K) molecular gas component, new ammonia masers, as well as unexpectedly abundant Class I methanol maser emission which appears to trace large-scale shock structure that may be driving Galactic Center cloud evolution. I will also discuss whether these extreme physical conditions persist in on the scales of individual clumps in these clouds, and whether this may cause star formation in the Galactic Center environment to proceed differently than in the disk of the Galaxy.

Kazushi Sakamoto (ASIAA)

Kinematics and Dynamics of Molecular Gas in Galactic Centers

The Central Molecular Zone (CMZ) in the central half kpc of the Milky Way is by far the most conspicuous concentration of molecular line emission. Although the high line luminosity must be partly due to excitation, CMZ is the most massive molecular gas concentration in our Galaxy. As such, it must be a major cause of the current and past activities in the Galactic Center including formation of massive stars/clusters, AGN feeding, and feedback, etc. Observations of molecular gas in external galaxies do show that many disk galaxies have similar concentrations of molecular gas in their central kpc or so; they also have CMZs. Hence the centers of nearby galaxies can provide complementary information on galactic centers and CMZs in general through comparative studies of multiple galactic centers of different characteristics from various viewing angles. Linear resolutions achieved toward nearby extragalactic CMZs with modern radio interferometers are now approaching to those achieved toward the CMZ of our Galaxy in some of the single-dish surveys. In this talk, I will present and discuss CMZ observations of nearby galaxies and compare them with the observations of our Galaxy.

Denise Riquelme Vásquez (Max-Planck-Institut für Radioastronomie)

Disk-Halo Interactions: Molecular Clouds in Galactic Center Region

We study the disk-halo interaction, in the context of orbits and Giant Molecular loops (GMLs) in the Galactic Center (GC) region.

From a large scale survey of the central kpc of the Galaxy, in SiO(J= 2−1), HCO^+(J= 1−0) and $H^{13}CO^+$ (J= 1−0) molecular emission, we identify shock regions traced by the enhancement of the SiO. We selected 9 positions called by us as interaction regions, because they mark the places where gas in the GC could be interacting with gas coming from higher latitude (disk-halo interaction) or from larger galactocentric radius. These positions were studied using the $^{12}C/^{13}C$ isotopic ratio to trace gas accretion/ejection. We found a systematically higher $^{12}C/^{13}C$ isotopic ratio (> 40) toward the GMLs and the X_1 orbits than for the GC standard molecular clouds (20−25). The high isotopic ratios are consistent with the accretion of the gas from the halo and from the outskirts of the Galactic disk.

From multitransitional observations of NH_3, we derive two kinetic temperature regimes (one warm at ˜200 K and one cold at ˜40 K) for all the positions, except for the GMLs positions where only the warm component is present. The fractional abundances derived from the different molecules support the shock origin of the heating mechanism in the GC.

Finally, we present a detailed study of one molecular cloud placed in the foot points of two well-known giant molecular loops, where two of the previously selected positions are placed. Using 22-Mopra telescope we mapped the molecular cloud M−3.8+0.9 in 3-mm molecular lines. The data show structures at small scale in SiO emission, with narrower line profiles than those of, e.g, HCO^+ or HCN, which indicate that the shocks are dynamically confined. The data also show clear differences between different molecular tracers, e.g., between the SiO and HCO^+ emission, which would indicate differences in the physical properties and chemistry within the cloud.

Rei Enokiya (Nagoya University)

K. Torii (1), M. Schultheis (2), Y. Asahina (3), R. Matsumoto (3), K. Dobashi (4), A. Ohama (1), N. Moribe (1), A. Nishimura (5), H. Yamamoto (1) K. Tachihara (1), T. Okuda (6), A. Kawamura (6), N. Mizuno (6), T. Onishi (5), M.R. Morris (7), and Y. Fukui (1)

1 Nagoya University
2 Observatoire de la Cote d'Azur Laboratoire Lagrange
3 Chiba University
4 Tokyo Gakugei University
5 Osaka Prefecture University
6 National Astronomical Observatory of Japan
7 University of California, Los Angeles

Large Scale and High Sensitivity Multi Line CO Surveys toward the Galactic Center

The Galactic Center (GC) is still the most enigmatic region in the Galaxy and thus many ground–based and satellite telescopes have tenaciously tried to focus their eyes on the region over the past several decades. Nevertheless, a systematic point of view through multiple wavelengths has not yet been acquired. Obtaining a rational understanding of the highly compressed and turbulent molecular cloud complex in the central few hundred parsecs - the CMZ - is one of most important problems we have been faced with. This large reservoir of gas fuels current and past star formation activity and associated high energy phenomena, including cosmic rays. For these reasons, it is naturally important to compare high quality CO data with emission in all other wavelength ranges. Recently Enokiya et al. (2013) carried out large–scale and high–resolution (4 °- 2 degrees and ~ 100" respectively) CO observations toward the CMZ with the NANTEN2 4m radiotelescope and first detected diffuse molecular features located at relatively high galactic latitudes above 0.6° as well as the well–known main components such as the Sgr A, SgrB2 and SgrC clouds. These high–latitude features can be sorted into molecular halos and molecular filaments according to their morphological aspects. A velocity analysis of each feature clearly indicates their location within the GC, and the total mass of them runs up ~ 10 % of that of the CMZ. But what process is responsible for levitating this non–negligible amount of the gas against the strong gravity of the central concentration? Star formation activity? Magnetic activity? A possible origin of these features could perhaps be found by an analogy with molecular filaments associated with the Double Helix Nebula (DHN). The infrared DHN is vertically distributed to the Galactic plane and is apparently a magnetically organized structure that has so far been revealed by the thermal dust emission and radio continuum. We recently found two molecular filaments connecting the DHN and the circumnuclear disk and present a first estimate of the mass and energy involved in the DHN. From these data, one possible scenario to explain the DHN is a magnetic tower model from the circumnuclear disk.

Oral Presentation Abstracts

Jessica Lu (IfA)

Young Stars in the Central Parsec of Our Galaxy

The central parsec of our Galaxy hosts not only a supermassive black hole; but also a large population of young stars (age $<$6 Myr) whose presence is puzzling given how inhospitable the region is for star formation. The strong tidal forces require gas densities many orders of magnitude higher than is found in typical molecular clouds. Kinematic observations of this young nuclear cluster show complex structures including a well-defined inner disk, but also a substantial off-disk population. Spectroscopic and photometric measurements indicate the initial mass function (IMF) differs significantly from the canonical IMF found in the solar neighborhood. These observations have led to a number of proposed star formation scenarios, such as an infalling massive star cluster, a single infalling molecular cloud, or cloud-cloud collisions. I will review recent works on the young stars in the central parsec and discuss connections with young nuclear star clusters in other galaxies, such as M31, and with star formation in the larger central molecular zone.

Anja Feldmeier (European Southern Observatory (ESO))

The Milky Way Nuclear Star Cluster Beyond 1 pc

Within the central 10pc of our Galaxy lies a dense cluster of stars, the nuclear star cluster, forming a distinct component of our Galaxy. Nuclear star clusters are common objects and are detected in ~75% of nearby galaxies. It is, however, not fully understood how nuclear clusters form. Because the Milky Way nuclear star cluster is at a distance of only 8 kpc, we can spatially resolve its stellar populations and kinematics much better than in external galaxies. This makes the Milky Way nuclear star cluster a reference object for understanding the structure and assembly history of all nuclear star clusters.

We have obtained an unparalleled data set using the near-infrared long-slit spectrograph ISAAC (VLT) in a novel drift-scan technique to construct an integral-field spectroscopic map of the central ~10x8 pc of our Galaxy. To complement our data set we also observed fields out to a distance of ~19 pc along the Galactic plane to disentangle the influence of the nuclear stellar disk.

From this data set we extract a stellar kinematic map using the CO bandheads and an emission line kinematic map using H_2 emission lines. Using the stellar kinematics, we set up a kinematic model for the Milky Way nuclear star cluster to derive its mass and constrain the central Galactic potential. Because the black hole mass in the Milky Way is precisely known, this kinematic data set will also serve as a benchmark for testing black hole mass modeling techniques used in external galaxies.

Hui Dong (NOAO)

Unveiling the Massive Stars beyond the Three Young Massive Star Clusters

In this talk, I will review the current status of searching, identifying and understanding the origin of the 'field' evolved massive stars outside the three young massive star clusters in the Galactic Center (GC). In our HST/NICMOS Pα survey of the GC, we found ~180 Pα emitting sources which are roughly equally distributed in and beyond the clusters. These Pα emitting sources should be evolved massive stars, such as O If and WR stars with strong stellar wind. Indeed, follow-up spectroscopic observations confirms the stellar types of 22 Pα emitting sources outside the clusters as new evolved massive stars in the GC, one of which is a LBV star with a ring-like ejecta. We divide our 180 Pα emitting sources into three groups: potential WN, WC and OB supergiants, according to their equivalent width of Pα line and the intrinsic magnitude at HST/NICMOS F190N band. We claim that although all the 'field' WN stars could been identified by existing work, current sample of WC stars and OB supergiants with spectroscopic confirmation beyond the three clusters is far from complete. In order to understanding the origin of these 'field' evolved massive stars, recently, we perform a line-of-sight velocity study of eight O supergiant and O If stars within 10' Galactic West of the Arches cluster, as well as the HII regions surrounding these massive stars by using the H and K band spectra obtained by Gemini GNIRS/NIFS detectors. The line-of-sight velocities of the eight massive stars are blueshift compared to the Arches cluster, as high as ~150 km/s. Two massive stars in the H1/H2 HII regions have similar line-of-sight velocities to the ionized gas and -30-0 km/s molecular clouds, indicating their potentially physical correlation. Instead, the other four massive stars should be just runway massive stars, which pass the nearby molecular clouds; one of these stars ~1.5' away from the Arches cluster has the same K-band spectrum as the O If stars in the Arches cluster. Therefore, our small sample could have various origins: 1) previous members of the Arches cluster, kicked out due to the three body interaction; 2) stars formed in-situ; 3) members of dissolved massive star clusters.

Ann-Marie Madigan (UC Berkeley)

On the Origin of Young Stars at the Galactic Center

The center of our galaxy is home to the massive black hole, Sgr A*, and a nuclear star cluster containing stellar populations of various ages. While the late type stars may be too old to have retained memory of their initial orbital configuration, and hence formation mechanism, the kinematics of the early type stars should reflect their original distribution. In this talk I will present a new statistic which uses directly-observable kinematical stellar data to infer orbital parameters for stellar populations, and is capable of distinguishing between different origin scenarios. We use it on a population of B-stars in the Galactic Center that extends out to large radii (˜0.5 pc) from the massive black hole. We find that the high k-magnitude population forms an eccentric distribution, suggestive of a Hills binary-disruption origin.

Tobias Fritz (MPE)

The Nuclear Cluster of the Milky Way

I will present recent results for the nuclear cluster of Milky Way. I mostly concentrate on the old stars which dominate the mass budget. Firstly, I have constructed an extinction corrected stars density and flux map from NACO, WFC3/IR and VIRCAM data covering a field of view of 82 pc. From this map I obtain that the nuclear cluster has a half light radius of about 4.4 pc, a flattening of about 10% and a total luminosity of about 27 million suns. Secondly, I have obtained more than 10000 proper motions and more than 2400 radial velocities out to 4 pc. With Jeans modeling I obtain a mass of (6.02+/-1.09) million suns within 4 pc. Combing mass and light I obtain a mass to light ratio of (0.50+/-0.12) in solar units in the K-band. This ratio is consistent with the Chabrier IMF. I also compare the mass and luminosity of the Milky Way's cluster with extragalactic nuclear clusters. I will also give a first glimpse of spectroscopically detected O- and B-stars outside the central parsec of the cluster.

Tuan Do (U Toronto)

Measuring the Physical Properties of the Milky Way Nuclear Star Cluster with 3D Stellar Kinematics

I will present 3D kinematic observations of individual stars within the central 0.5 pc of the Milky Way nuclear star cluster using imaging and spectroscopy from the Keck Telescopes. Recent observations have shown that the cluster has a shallower surface density profile than expected for a dynamically relaxed cusp, which holds implications for its formation and evolution. However, the true three dimensional profile of the cluster is unknown due to the difficulty in de-projecting the stellar number counts. Here, we use spherical Jeans modeling of proper motions and radial velocities to constrain for the first time, the de-projected spatial density profile, cluster velocity anisotropy, black hole mass (M_{BH}), and distance to the Galactic Center (R_o) simultaneously. We find that the slope of the spatial density profile to be substantially more shallow than the Bahcall & Wolf slope of $\gamma=7/4$, and may even be decreasing toward the center of the cluster. I will also discuss new results from the multi-object infrared spectrograph MOSFIRE that samples kinematic structure of the MW NSC out to a radius of 5 pc.

Mark Wardle (Macquarie)

Farhad Yusef-Zadeh (Northwestern University)
Yoram Lithwick (Northwestern University)

Star Formation within 0.5 pc of Sgr A*

The supermassive black hole Sgr A* at the center of the Galaxy is surrounded by two counter-rotating disks of young, massive stars. The surface density of stars increases steeply towards Sgr A* but is truncated within 1 arcsecond (0.04 pc). We explore the origin of these stars in a scenario in which star formation took place in a disk of gas created through the partial capture of a molecular cloud as it swept through the inner few parsecs of the galaxy and temporarily engulfed Sgr A*.

The cancellation of angular momentum during circularisation naturally gives rise to a steep disk surface density profile, so that self-gravity becomes increasingly important at small rather than large radii. However, between 0.04 and 0.01 pc the inner arc second of the resulting disk is so optically thick that, although gravitationally unstable, it cannot fragment because of inefficient cooling. Instead, it forms a magnetoturbulent accretion disk that accretes onto Sgr A* in 3 Myr. Meanwhile, fragmentation of the gas beyond the central 0.04 pc hole creates the observed young stellar disk.

The estimated stellar ages imply that this capture event occurred 3-6 Myr ago, thus such events occurring over the life time of the Galaxy could significantly contribute to the current mass of Sgr A* and the nuclear star cluster. Implications for extragalactic systems are discussed.

Andrea Ghez (UCLA)

Probing General Relativity with Short-Period Stars at the Galactic Center

We provide an overview of the long-term efforts of the Keck/UCLA Galactic Center group to measure the orbital motions of stars deepest in the Galaxy's central potential. These stars were the ones to reveal the presence of a black hole and now offer the opportunity to test Einstein's Theory of General Relativity (GR), the least tested of the four fundamental forces of nature, in an unexplored regime. This long-term effort is approaching a key time period with the next periapse passage of the short-period star S0-2 in 2018, which would probe the effects of relativity on a scale that is 100 times smaller in terms of gravitational radii than any other test. These measurements also offer a measurement of the line-of-sight distance to the black hole to better than 1% accuracy as well as the detailed orbital structure of the central nuclear cluster at much larger radii than is accessible today.

Oral Presentation Abstracts

Stefan Gillessen (MPE)

Observations of the G2 Cloud at Sgr A*

In 2011, we discovered a compact gas cloud ("G2") with roughly 3 Earth masses that is falling on a near-radial orbit toward the massive black hole in the Galactic Center. The orbit is well constrained and pericenter passage is predicted for early 2014. Our data beautifully show that G2 gets tidally sheared apart due to the massive black hole's force. During the next months, we expect that in addition to the tidal effects, hydrodynamics get important, when G2 collides with the hot ambient gas around Sgr A*. Simulations show that ultimately, the cloud's material will fall into the massive black hole. Predictions for the accretion rate and luminosity evolution, however, are very difficult due to the many unknowns. Nevertheless, this might be a unique opportunity in the next years to observe how gas feeds a massive black hole in a galactic nucleus.

Leo Meyer (UCLA)

Keck Observations of G2 and Sgr A*

We give an update of the observations and analysis of G2 – the gaseous red emission-line object that is fast approaching the central black hole on a very eccentric orbit. The laser guide star Adaptive Optics systems on the W. M. Keck I and II telescopes were used to obtained spectroscopy and imaging at the highest spatial resolution. We present the orbital solution derived from radial velocities in addition to Brγ line astrometry, which we show is more accurate than L' astrometry. We argue that although there is clearly gas associated with it, it seems more likely that the source is ultimately stellar in nature. Since in this case the potential impact on Sgr A*'s accretion flow could be very subtle, we present a statistical analysis that can identify non-obvious variability state changes. This statistical framework has been taken from mathematical finance and is applied to light curves from the Galactic Center black hole for the first time.

Andreas Eckart (Physikalisches Institut, Universität zu Köln / Max-Planck-Institut für Radioastronomie)

M. Horrobin (Physikalisches Institut, Universität zu Köln)
M. Valencia-S. (Physikalisches Institut, Universität zu Köln)
K. Markakis (MPIfR, Physikalisches Institut, Universität zu Köln)
A. Borkar (MPIfR, Physikalisches Institut, Universität zu Köln)
et al.

The Infrared K-band Identification of the DSO/G2 Source from VLT and Keck Data

A fast moving infrared excess source (G2) which is widely interpreted as a core-less gas and dust cloud approaches Sgr A* on a presumably elliptical orbit. VLT Ks band and Keck K'-band data result in clear continuum identifications and proper motions of this ˜19^{m} dusty S-cluster object (DSO). In 2002-2007 it is confused with star S63, but free of confusion again since 2007. Its NIR colors and a comparison to other sources in the field imply that it could rather be an IR excess star with photospheric continuum emission at 2 microns than a core-less gas and dust cloud. Also we find very compact L'-band emission (<0.1'') contrasted by the reported extended (˜0.2) Brγ emission. The presence of a star will change the expected accretion phenomena, since a stellar Roche lobe may retain much of the material during and after the peri-bothron passage. In addition we will report on our VLT, APEX monitoring results of Sgr A* in 2013.

Daryl Haggard (Northwestern/CIERA)

F. Baganoff (MIT), G. Ponti (MPE), C. Heinke (Alberta), F. Yusef-Zadeh (Northwestern/CIERA), D. Roberts (Northwestern/CIERA), W. Cotton (NRAO), Stefan Gillessen (MPE), Reinhard Genzel (MPE), Sera Markoff (API, U. Amsterdam), Michael Nowak (MIT), Norbert Schulz (MIT), Nanda Rea (CSIC-IEEC)

G2 as a Probe of Sgr A*'s Hot Environs: A View from Chandra and VLA

The recent discovery of a dense, cold cloud (dubbed "G2") approaching the SMBH at our Galactic Center offers an unprecedented opportunity to test models of black hole accretion and its associated feedback. G2's orbit is eccentric and the cloud already shows signs of tidal disruption by the black hole. High-energy emission from the Sgr A*/G2 encounter will likely rise toward pericenter (mid-to-late 2013, or early 2014) and continue over the next several years as the material circularizes. This encounter is also likely to enhance Sgr A*'s flare activity across the electromagnetic spectrum. We present preliminary results from our 2013 joint Chandra/VLA monitoring campaigns (>345 ks of Chandra data and ~30 hours from VLA will be in-hand by early fall). Our programs aim to study the radiation properties of Sgr A* as G2 breaks up and feeds the accretion flow, to constrain the rates and emission mechanisms of faint X-ray flares, and to detect G2 itself as it is shocked and heated. No substantial rise in Sgr A*'s X-ray flux has been observed as of early July 2013, but the appearance of a new magnetar (SGR J174540.2-290029, 2.4 arcsec from Sgr A*) and an outburst from a transient LMXB (CXO J174540.0-290005) are already yielding additional exciting science. We discuss the constraints these data place on theoretical models for the Sgr A*/G2 encounter and outline plans for continued monitoring with Chandra, XMM, HST, and VLA in 2014.

Gunther Witzel (UCLA)

NIR Variability of Sgr A*

We discuss recent synchronous observations of Sgr A* with NIRC2@KECKII and OSIRIS@KECKI in L'-band and H-band, respectively. These observations represent the first truly synchronous high cadence dataset to test for time variability of the spectral index within the near infrared. We discovered a time-variable time lag between both bands. Furthermore, these high cadence data show effects on time scales as short as 20 seconds. We discuss the significance of both findings in the framework of a rigorous statistical model of the variability and explore possible physical explanations.

Banafsheh Shahzamanian (U Köln)

NIR Polarized Observations of Sagittarius A*

We present an overview of polarized near-infrared (NIR) observations of Sagittarius A* (Sgr A*) which is associated with the super massive black hole at the center of the Milky Way. The observations have been carried out using NACO adaptive optics instrument at the VLT (ESO) and CIAO NIR camera on the Subaru telescope (from 2004 to 2012). We will present several polarized flares that have been observed during these observations and for the first time will present the statistical properties of NIR polarization of Sgr A*. Linear polarization at 2.2 micron and its variations can help us to constrain the physical conditions of the accretion process around this SMBH.

Kazunori Akiyama (U Tokyo)

Long-term Monitoring of Sgr A* at 43GHz with VERA and KVN+VERA

We present the results of radio monitoring observations of Sgr A* at 43 GHz with VERA, which is a VLBI array in Japan. VERA and KVN+VERA (combined array with Korean VLBI Network) provides angular resolutions on millisecond scales and enables to have a look at structure within ~100 Schwarzschild radii of Sgr A* as well as VLBA. We performed multi-epoch observations of Sgr A* in 2005 - 2008, and started to monitor it again with VERA and KVN+VERA from Jan. 2013 for tracing the current G2 encounter event. We report the results of observations in 2005-2008 (Akiyama et al. 2013, PASJ in press.), and then the preliminary results of a monitor with an interval of 3 weeks started from January 2013.

Salomé Dibi (University of Virginia)

Exploring Plasma Behavior around Sgr A*

We present a new way of describing the flares occurring in the Galactic Center. We model Sgr A* by a one zone cell with a self-consistent calculation of the particle distribution. All the relevant radiative processes are taken into account in the evolution of the electron distribution and in the resulting spectrum. We explore the multi-wavelength spectra of Sgr A* in the quiescent and flaring states and present some spectral modeling for the new X-ray data flares observed by NuStar in July 2012, together with older observations in different wavelengths. We argue on the physical parameters that need to be modified in the plasma in order to move from the quiescent to the flaring state. The results allow us to give an interpretation to the flaring events generated very close to the central super-massive black hole.

We conclude that the flaring state data (including the new X-ray flare) are more likely to be the generated by a weakly magnetized plasma in which particles can be injected and escape. Such a plasma, with prescription for non-thermal acceleration, together with the cooling losses, gives a spectrum with a break between the infra-red and the X-ray, allowing a better simultaneous match in the different wavelengths. Even-though Compton emission for the X-ray flare is not excluded, the parameters favour the non-thermal synchrotron spectrum.

We finish with a modification of Sgr A* spectrum with an increase of the plasma density in order to give an observable prediction of what is likely to be happening when the cloud G2 falls into the Galactic Centre this year.

Jim Moran (Harvard-Smithsonian Center for Astrophysics)

History of High Resolution Imaging of Sgr A*

I will review the development of radio interferometric imaging of Sgr A*, starting with the discovery of its compact structure by Balick and Brown in 1974 at 8 GHz. Their interferometer, the compact three element system in Green Bank, augmented with an outrigger located 45 km away, had poor imaging qualities but had sufficient angular resolution to identify, but not resolve, the compact source amidst the extended emission. The true intrinsic size of the source has only recently been determined with VLBI measurements at frequencies where the smearing of the image due to the plasma scattering is small. This development is parallel to the quest in the 1950s by Jennison and others to resolve the structure of Cygnus A at about a hundred MHz, which led to the implementation of phase closure. A new era of imaging of Sgr A* is about to begin when the tool of phase closure can be applied at short millimeter wavelengths.

Avery Broderick (Perimeter Institute)

Modeling Accretion and Outflows on Horizons Scales for the Event Horizon Telescope

Millimeter-wavelength very long baseline interferometry with the Event Horizon Telescope (EHT) has already probed the structure of the emission regions of Sgr A* and M87 on sub-horizon scales. Presently, inferring physical parameters for the central supermassive black holes and their interactions with surrounding material requires modeling the accretion flow and/or jet-launching region in the vicinity of the horizon. Generically this is a complicated problem, however perhaps surprisingly, a reasonably broad and successful class of models can be constructed, enabling the analysis of EHT data within a robust physical context. I will discuss the kinds of models that have been considered for Sgr A* and M87, why the near-horizon region admits critical simplifications, and how we are beginning to validate the various assumptions that have been made.

Jason Dexter (UC Berkeley)

Event Horizon Scale Emission Models of Sgr A*

Due to its proximity, Sgr A* is an unparalleled laboratory for studying low-luminosity black hole astrophysics. It is the largest black hole in angular size, and very long baseline interferometry observations at millimeter wavelengths have detected source structure on event horizon scales. High spatial resolution, time-domain, and multi-wavelength observations of Sgr A* provide an unprecedented test for black hole accretion theory. I will discuss the direct comparison between some of these observations and images, spectra, and light curves calculated from relativistic MHD simulations. The simulations provide an excellent description of current data, and allow estimates of the parameters of the black hole and its accretion flow. The models predict that we may be on the verge of detecting a black hole shadow, which would constitute the first direct evidence for the existence of an event horizon in the Universe.

Roman Shcherbakov (University of Maryland)

Theory of G2 Cloud Multi-wavelength Emission

A G2 cloud approaching Sgr A* presents a unique opportunity to study the process of tidal disruption and the interaction of cold dense gas with the accretion flow. Proper dynamical modeling and precise treatment of radiation are crucial for such studies. Here we consider the affine tidal disruption model and compute emission from hot forward shock, cool reverse shock, tidal compression shock, and from unshocked G2 cloud material. We consider synchrotron emission, self-Comptonization, external Comptonization, collisional ionization emission, recombination from photoexcitation, and dust irradiation. We revise down formerly predicted high radio and X-ray power, which leads to agreement with observations. Using CLOUDY code we reproduce the observed line ratios and make predictions, for which the IR data will be available at the time of the conference. We address the scenarios of photoionization vs. collisional excitation for Br-γ line.

Alessandro Ballone (Max Planck Institute for Extraterrestrial Physics)

M. Schartmann, A. Burkert, S. Gillessen, R. Genzel, T.K. Fritz, F. Eisenhauer, O. Pfuhl, T. Ott

Hydrodynamic Simulations of a Compact Source Scenario for the Galactic Center Cloud G2

The origin of the dense gas cloud "G2" discovered in the Galactic Center (Gillessen et al. 2012) is still a debated puzzle. G2 might be a diffuse cloud or the result of an outflow from an invisible star embedded in it. I will present the first attempt of detailed simulations of the evolution of winds on G2's orbit, including both the hydrodynamic interaction with the hot atmosphere present in the Galactic Center and the extreme gravitational field of the supermassive black hole: we find that both must be taken in account when modeling such a source scenario. We also find that in this scenario most of the Brγ luminosity is expected to come from the densest part of the wind, which has a highly filamentary structure with low filling factor.

For our assumptions, the observations can be best matched by a mass outflow rate of $dM_w/dt = 8.8 \times 10^{-8}\ M_{sol}/yr$ and a wind velocity of $v_w = 50$ km/s. These values are compatible with those of a young TTauri star wind, as already suggested by Scoville & Burkert (2013).

Gabriele Ponti (MPE Garching)

Mark Morris
Regis Terrier
Andrea Goldwurm

Study of Sgr A*'s Surroundings to Constrain its Prior Activity

The electromagnetic manifestation of the Galactic supermassive black hole, Sgr A*, currently appears as an extremely weak source with a luminosity of $L \sim 10^{-9}\ L_{Edd}$, and is in fact the lowest known Eddington ratio black hole. However, it was not always so; traces of "glorious" active periods can be found in the surrounding medium.

We review here our current understanding of Sgr A*'s past activity (through e.g. X-ray reflection) and its impact on the surrounding material of the Central Molecular Zone, a possible relic AGN torus.

Maïca Clavel (APC Paris – France)

R. Terrier, A. Goldwurm, M. R. Morris, G. Ponti, S. Soldi, G. Trap

The Reflection of two Past Outbursts of Sagittarius A* Observed by Chandra during the Last Decade

The supermassive black hole at the Galactic Center, Sagittarius A*, has experienced periods of higher activity in the past. The reflection of these past outbursts is observed in the molecular material surrounding the black hole but reconstructing its precise lightcurve is difficult since the distribution of clouds is poorly constrained.

Using Chandra high-resolution data collected from 1999 to 2011 we studied both the 6.4 keV and the 4-8 keV emission of the region located between Sgr A* and the Radio Arc, characterizing its variations down to 15'' angular scale and 1-year time scale. The molecular clouds of the region are significantly varying showing either 2-year peaked emission or 10-year linear variations. This is the first time that such fast variations are measured. Based on the cloud parameters we conclude that these two behaviors are likely due to two distinct past outbursts of Sgr A* during which its luminosity went up to at least 10^{39} erg s^{-1}. I will present the analyses we performed and the constraints we derived on these two past events.

Shinya Nakashima (Kyoto University)

Masayoshi Nobukawa (Kyoto University)
Hiroyuki Uchida (Kyoto University)
Takaaki Tanaka (Kyoto University)
Takeshi Go Tsuru (Kyoto University)
Katsuji Koyama (Kyoto University / Osaka University)
Hideki Uchiyama (Shizuoka University)
Hiroshi Murakami (Tohoku Gakuin University)

Discovery of a Recombination Dominant Plasma: a Relic of a Giant Flare of Sgr A*?

One of the most remarkable Galactic Center (GC) activities is past giant flares of the central supermassive black hole, Sagittarius (Sgr) A*. X-ray observations found time-variable Fe I Kα emissions from dense molecular clouds, best interpreted as X-ray echoes of giant Sgr A* flares a few hundred years ago (Inui et al. 2009; Ponti et al 2010). GeV gamma-ray observations revealed a large scale bipolar emission, the so-called “Fermi bubbles”, suggesting a jet-like activity about a million years ago (Su et al. 2010).

If such past Sgr A* activities are common events, another “relic” of a Sgr A* flare should present in the vicinity of the GC. In the Suzaku GC survey data, we detected a diffuse plasma emission at 1.5 degrees south of Sgr A* (Nakashima et al. 2013). Remarkably, this plasma is in a recombination dominant phase, which is not predicted by standard shock heating. A plausible scenario is photoionization due to strong jet-like X-rays from Sgr A* about 10^5 years ago.

Thaisa Storchi-Bergmann (Instituto de Fisica – UFRGS)

Resolved Gas Flows and Stellar Population in the Inner 10-100pc of Nearby Active Galaxies

I will discuss integral field spectroscopic observations of the inner few hundred parsecs of nearby active galaxies in the optical and near infrared at spatial resolutions of a few to tens of parsecs by our research group AGNIFS. Surrounding the lowest luminosity active galactic nuclei (AGN), we have observed gas reservoirs and inflows along nuclear spirals and filaments. We have derived mass inflow rates of 0.1 - 1 M_{sun}/yr along these structures, which are ˜2 - 3 orders of magnitude larger than the mass accretion rate to the supermassive black hole. These inflows can lead, during one activity cycle, to the accumulation of enough gas in the inner few hundred parsecs, to trigger the formation of new stars in the galaxy bulge. The study of the stellar population on these scales indeed reveals the presence of young and intermediated age stars in a number of cases. I also discuss observations of nuclear outflows, which are prevalent around the highest luminosity AGN, but are also observed around a few low-luminosity AGN.

Jun-Hui Zhao (CfA)

M. R. Morris (UCLA)
W. M. Goss (NRAO)

A New Perspective on the Radio Bright Zone at the Galactic Center -- Feedback from Nuclear Activity

We have observed Sgr A with the Jansky VLA in the B and C arrays using the broadband (2 GHz) continuum mode at 5.5 GHz covering the central 13' (30 pc) region of the radio bright zone at the Galactic Center. With the CASA multi-scale and multi-frequency-synthesis (MS-MFS) clean algorithm, we constructed a deep image, achieving an rms noise level of 0.01 mJy/beam, or a dynamic range 80,000:1. Our observations have revealed the detailed structures of both previously known and newly identified radio sources in this region. Numerous compact radio sources have been detected at a level of ~0.1 mJy/beam. Among them, we have identified the radio counterpart of the X-ray object referred to as the "Cannonball", and have imaged its radio structure, yielding its quantitative radio characteristics and proper motion. Our VLA observations are consistent with the plausible model proposed by Park et al. (2005), in which a runaway neutron star surrounded by a pulsar wind nebula was created in the event that produced Sgr A East ~9,000 yrs ago. The deep radio image has been compared with the Chandra X-ray and HST/NICMOS Paschen-α images. In the radio, broad "Wings" extend 100" (4 pc) from the tips of the mini spiral (the Sgr A West HII region) to the NW and SE; the NW Wing, along with several radio emission "Trunks", forms an elongated radio lobe with a size of 6'x3'(14x7 pc), and is oriented perpendicular to the Galactic plane, in projection. In the outer region of the NW lobe, a row of three emission rings is present. The NW radio lobe matches well with its X-ray counterpart (Morris et al. 2002). An amorphous radio emission structure at the tip of the SE Wing and an emission trunk (120" x 20", or 4.6 x 0.8 pc) are located in the SE X-ray lobe, which appears to be confined by the "Streak" and the southern "Curl" filaments (Morris et al., this Symp.). Since the implied accretion rate is far below the Eddington limit, the direct activity from supermassive black hole accretion appears to contribute little to the feedback to the ISM in this region. The bipolar X-ray lobes are likely produced by the winds from the activities within the circumnuclear disk, which we argue are collimated by poloidal magnetic fields. The less-collimated SE lobe, in comparison to the NW one, is perhaps due to the fact that the Sgr A East SN might have locally reconfigured the magnetic field toward negative galactic latitudes. The time-scale of $1x10^4$ yr estimated for the X-ray lobes (Morris et al. 2002) appears to be comparable to the age of the Sgr A East SNR inferred from the VLA observations of the Cannonball.

Shogo Nishiyama (NAOJ)

The Origin of the Galactic Center Diffuse X-ray Emission Investigated by Near-infrared Imaging and Polarimetric Observations

The origin of the Galactic Center diffuse X-ray emission (GCDX) is still under intense investigation. In particular, the interpretation of the hot (kT = 7 keV) component of the GCDX, characterized by the strong Fe 6.7 keV line emission, has been contentious. If the hot component originates from a truly diffuse interstellar plasma, not a collection of unresolved point sources, such plasma cannot be gravitationally bound, and its regeneration would require a huge amount of energy. Here, we show that the spatial distribution of the GCDX does not correlate with the number density distribution of an old stellar population traced by near-infrared light, strongly suggesting a significant contribution of the diffuse interstellar plasma. We also show the results of near-infrared polarimetric observations in the central 3 deg × 2 deg region of our Galaxy, and have found that the GCDX region is permeated by a large scale, toroidal magnetic field. Together with observed magnetic field strengths close to energy equipartition, the hot plasma could be magnetically confined, reducing the amount of energy required to sustain it.

Jorge Cuadra (P Univ Católica de Chile)

Gas Dynamics in the Galactic Centre: Clump Accretion and Outflows

We present numerical models of the gas dynamics in the central parsec of the Galaxy, from its origin as stellar winds, until its capture by Sgr A*, the central massive black hole. We show that the gas forms a two-phase medium, with cold clumps embedded in a hot tenuous gas. We find the accretion rate to be variable, due to the effect of the stellar orbits and the stochastic accretion of clumps. We suggest that the recently discovered infalling cloud, G2, could be one of the predicted clumps. We also study the possibility of detecting the effect of a recent outflow from Sgr A*.

Jeremiah Ostriker (Princeton)

Why are the Sleeping Giants so Quiet? Rotating, Inflow/outflow Solutions for Accreting Black Holes

The massive black holes in our own and other nearby galactic centers are very faint, with estimated accretion rates many, many orders of magnitude below the Eddington rate inferred for luminous AGN. Why is this the case? When observations allow the Bondi radius to be resolved, the accretion rate is significantly below the predicted Bondi rate. Why? Some simple analytic solutions have been usefully discussed, but direct integration of the hydro-dynamical equations for a rotating inflow is a particularly difficult problem to study because of the wide range of length scales involved. We use the ZEUS code with Bremsstrahlung cooling, considering, solutions for which the centrifugal balance radius significantly exceeds the Schwarzschild radius, with and without viscous angular momentum transport. Infalling gas is followed from well beyond the Bondi radius down to the vicinity of the black hole. We have found a continuum of solutions with respect to the single parameter $(dM/dt)/(dM/dt)_{Edd}$, and there is a sharp transition between two general classes of solutions at an Eddington ratio of a few times 10^{-2}. The high inflow solutions are very similar to the standard Shakura & Sunyaev results. But the low inflow results are to zeroth order the stationary Papaloizou & Pringle solution, which has *no accretion*. To next order in the small, assumed viscosity they show circulation, with disk and conical wind outflows almost balancing inflow and a small net accretion rate. These solutions are characterized by hot, vertically extended disks, with net accretion at an extremely low rate, only of order the dimensionless viscosity times the inflow rate. These new solutions are consistent with the very low luminosity of the Galactic Center source and other nearby, quiet black holes.

Dan Marrone (University of Arizona)

The Millimeter-Wavelength Polarization of Sgr A*

At a wavelength of 1mm and shorter, Sgr A* shows strong linear polarization and stable circular polarization. The Faraday rotation of the linear polarization has provided constraints on the inner accretion rate onto the black hole, but despite years of monitoring, has not been found to vary as expected for a turbulent accretion flow. The impact of G2 can also be expected to perturb the Faraday rotation measure, and this may be one of the earliest signatures of the arrival of its gas at small radius. We report results from the long-term monitoring of this source, including new measurements using the CARMA and SMA interferometers simultaneously to provide a wider wavelength baseline and more sensitive measurements of the rotation measure.

Nicolas M. Barrière (UC Berkeley / Space Sciences Lab)

John A. Tomsick, Frederick K. Baganoff, Steven E. Boggs, Finn E. Christensen, William W. Craig, Jason Dexter, Brian Grefenstette, Charles J. Hailey, Fiona A. Harrison, Kristin K. Madsen, Kaya Mori, Daniel Stern, William W. Zhang, Andreas Zoglauer

NuSTAR Detection of High-energy X-ray Emission and Rapid Variability from Sagittarius A* Flares

Sagittarius A* is a supermassive black hole that lies at the dynamical center of our Galaxy. Sagittarius A* spends most of its time in a low luminosity emission state but flares frequently in the infrared and X-ray, increasing up to a few hundred fold in brightness for up to a few hours at a time. The physical processes giving rise to the X-ray flares are uncertain.

Here we report the first detection of X-ray flares to energies up to 79 keV with the NuSTAR high-energy X-ray observatory. Four flares of low to medium amplitude were detected in Summer and Fall 2012. Significant difference is found between the photon index of two of the flares. The spectra of the two brightest flares (about 50 times quiescence in the 2-12 keV band) are compared to simple models in an attempt to identify the main physical processes at work, however the data does not permit to significantly discriminate between them. One flare exhibits large and rapid variability (¡ 100 s), which considering the total energy radiated, constrains the location of the flaring region to be very close of the event horizon, within 10 Schwarzschild radii of the black hole.

Joey Neilsen (Boston University)

The 3 Ms Chandra Campaign on Sgr A*: A Census of X-ray Flaring Activity from the Galactic Center

Over the last decade, X-ray observations of Sgr A* have revealed a black hole in a deep sleep, punctuated roughly once per day by brief flares. The extreme X-ray faintness of this supermassive black hole has been a long-standing puzzle in black hole accretion. To study the accretion processes in the Galactic Center, Chandra (in concert with numerous ground- and space-based observatories) undertook a 3 Ms campaign on Sgr A* in 2012. With its excellent observing cadence, sensitivity, and spectral resolution, this Chandra X-ray Visionary Project (XVP) provides an unprecedented opportunity to study the behavior of our closest supermassive black hole. I will present a progress report from our ongoing study of X-ray flares, including the brightest flare ever seen from Sgr A*. Focusing on the statistics of the flares and the quiescent emission, I will discuss the physical implications of X-ray variability in the Galactic Center.

Oral Presentation Abstracts

Douglas Finkbeiner (CfA)

Fermi Bubbles and Energetic Activity in the Galactic Center

I will review various scenarios for the formation of the Fermi Bubbles by AGN activity, star formation, and WIMP annihilation, and discuss data sets from radio to gamma-ray that might help constrain these hypotheses.

Mateusz Ruszkowski (U Michigan)

The Fermi Bubbles: Gamma-ray, Microwave, and Polarization Signatures of Leptonic AGN Jets

The origin of the two large bubbles at the Galactic Center observed by the Fermi Gamma-ray Space Telescope and the spatially-correlated microwave haze emission are yet to be determined. To disentangle different models requires detailed comparisons between theoretical predictions and multi-wavelength observations. Our magnetohydrodynamical (MHD) simulations including cosmic rays (CR), which self-consistently include interactions between cosmic rays and magnetic fields, have demonstrated that the primary features of the Fermi bubbles could be successfully reproduced by a recent jet activity from the central active galactic nucleus (AGN). In this work, we generate gamma-ray and microwave maps and spectra based on the simulated properties of cosmic rays and magnetic fields in order to examine whether the observed bubble and haze emission could be explained by leptons contained in the AGN jets. We also investigate the model predictions of the polarization properties of the Fermi bubbles, including the polarization fractions and the rotation measures (RMs). We find that: (1) The same population of leptons can simultaneously explain the bubble and haze emission given that the magnetic fields within the bubbles are very close to the exponentially distributed ambient field, which can be explained by mixing from the ambient field followed by turbulent field amplification; (2) The centrally peaked microwave profile suggests CR replenishment, which is consistent with the presence of a more recent second jet event; (3) The bubble interior exhibits high degree of polarization because of ordered radial magnetic field lines stretched by elongated vortices behind the shocks; highly-polarized signals could also be observed inside the draping layer; (4) Enhancement of RMs could exist within the shock-compressed layer because of increased gas density and more amplified and ordered magnetic fields, though details depend on projections and the actual field geometry. We discuss the possibility that the deficient haze emission at $b < -35$ degrees is due to the suppression of magnetic fields, which is consistent with the existence of lower-energy CRs causing the polarized emission at 2.3 GHz. Possible AGN jet composition in the leptonic scenario is also discussed.

Brian Lacki (NRAO and IAS)

Sturm und Drang: The Turbulent, Magnetic Tempest in the Galactic Center

The Galactic Center Central Molecular Zone (GCCMZ) bears similarities with extragalactic starburst regions, including a high supernova rate density. As in other starbursts like M82, the frequent supernovae can heat the ISM until it is filled with a hot (~4×10^7 K) superwind. Furthermore, the random forcing supernovae stir up the wind, powering Mach 1 turbulence. I argue that turbulent dynamos can explain the strong magnetic fields in starbursts, and I predict an average B ~70 microGauss in the GCCMZ. I demonstrate how the supernova driving of the ISM leads to equipartition between various pressure components in the ISM. The extreme levels of turbulence may slow down cosmic rays diffusion so much that they are frozen into gas and transport is "Lagrangian". The supernova-heated wind escapes the Center, but I show that it may be stopped in the Galactic halo. I propose that the Fermi Bubbles are the wind's termination shock.

Vladimir A. Dogiel (P.N.Lebedev Institute of Physics)

K.-S.Cheng
D.O.Chernyshov
C.-M.Ko

Origin of Nonthermal Emission from the Fermi Bubbles and Mechanisms of Particle Acceleration There

Recent discovery of the two giant gamma-ray-emitting bubbles elongated perpendicular to the Galactic plane was one of the marvelous discoveries in high energy astrophysics. The gamma-ray spectrum from the bubbles is harder than elsewhere in the Galaxy. This gamma-ray excess in the bubble region correlates with the microwave emission discovered by the WMAP telescope and the residual diffuse emission in the range above 30 GHz found by the Planck satellite. This structure similarity of radio and gamma-ray structures indicates that the bubbles are real and their radio and gamma-ray emissions have common origin. We assume that the origin of this emission is due to activity of the Galactic Center. In processes of star or molecular cloud accretion onto the central black hole a huge energy may release, from 10^{52} to 10^{56} erg. This energy release in the GC provides in the central region of the Galactic halo shocks and an MHD-turbulence, which accelerate particles. We assume that the radio and gamma-ray fluxes from the bubbles are produced by processes of synchrotron and inverse Compton energy losses of accelerated electrons. We analyse different mechanisms of electron acceleration: single and multi-shocks acceleration and the stochastic Fermi acceleration. We derived parameters of these processes needed to produce the observed flux of nonthermal emission from the bubbles.

Tim Linden (UCSC)

Dark Matter in the Galactic Center

In addition to boasting the highest density of baryonic matter in our galaxy, the center of the Milky Way is also believed to contain and extremely high density of dark matter particles. While the dark matter is thought to be gravitationally subdominant to baryons near the Galactic Center, in scenarios where dark matter can annihilate to form relativistic charged particles, dark matter can be a significant source of high energy radiation in the Galactic Center region. In this talk, I will review multiwavelength constraints on dark matter annihilation in the Galactic Center, investigate an interesting gamma-ray signal which is well-fit by models of dark matter annihilation, and discuss methods which can be used to separate dark matter and astrophysical models for high energy emission from the Galactic Center.

Chris Gordon (U Canterbury)

Dark Matter and Pulsar Model Constraints from Galactic Center Fermi-LAT Gamma Ray Observations

Employing Fermi-LAT gamma ray observations, several independent groups have found excess extended gamma ray emission at the Galactic Center (GC). Both, annihilating dark matter (DM) or a population of about 1000 unresolved millisecond pulsars (MSPs) are regarded as well motivated possible explanations. However, there is significant uncertainties in the diffuse galactic background that need to be accounted for. We have performed a revaluation of the DM and MSP models for the extended gamma ray source at the GC by accounting for the systematic uncertainties of the Galactic diffuse emission model. We also marginalized over point source and diffuse background parameters in the region of interest. We showed that the excess emission is significantly more extended than a point source. We found that the DM (or pulsars population) signal is larger than the systematic errors and therefore proceeded to determine the sectors of parameter space that provided an acceptable fit to the data. We found that a population of 1000-2000 MSPs with parameters consistent with the average spectral shape of Fermi-LAT measured MSPs was able to fit the GC excess emission. For DM, we found that a pure tau^+tau^- annihilation channel is not a good fit to the data. But a mixture of tau^+ tau^- and b bbar with a σv of order the thermal relic value and a DM mass of around 20 to 60 GeV provides an adequate fit.

Alak Ray (Tata Institute of Fundamental Research)

Bence Kocsis (Harvard University)
Simon Portegies-Zwart (Leiden University)

Mapping the Galactic Centre: Detecting Gravitational Waves from Blackholes Orbiting Sgr A* Using Pulsar Timing

Black holes orbiting Sgr A* in the Milky-way galaxy centre generate gravitational waves. The spectrum, due to a cusp of stars and black holes, is continuous below 40 nHz while individual BHs within about 200 AU of the central supermassive BH stick out in the spectrum at higher frequencies. The GWs can be detected by timing radio pulsars within a few parsecs of this region. Observations with Square Kilometer Array with a 100 ns - 10 microsec timing accuracy of pulsars up to a pc may be sensitive to signals from intermediate mass BHs in a 3 year observation baseline when challenges of scattering by the interstellar medium on pulse detection can be met.

Miwa Goto (LMU)

The Cosmic-ray Ionization Rate in the Central Parsec of the Galaxy - How We Could Deal with 10^4 Discrepancy?

Measurement of the cosmic-ray flux is a unique place that high-energy astrophysics meets low-energy chemistry. H_3^+ is the best chemical probe of the ionization rate of molecular hydrogen by the cosmic-ray, because the number of reactions involved in the process is minimal (namely, one). In the previous studies, we found a high ionization rate in the Galactic Center (10^{-15} s^{-1} within 30 pc of Sgr A*), which is an order of magnitude higher than the Galactic disk. Meanwhile, new gamma-ray observation identified a point like source near Sgr A*. In order to produce the observed gamma-ray flux discovered by HESS collaboration by a neutral pion decay, one requires the cosmic-ray proton flux $7x10^4$ protons/cm^2/s/str/(nucleon/GeV) in the central parsecs of the Galaxy. Such a high proton flux calls for the hydrogen ionization rate 10^5 times larger than the Galactic disk. However, there is no hint of such enhanced cosmic ray flux in view of chemistry. The elevated ionization in the central parsec of the Galaxy observed by H_3^+ spectroscopy is still 4 orders of magnitude too short to match the gamma-ray observation. The huge discrepancy underscores our limited understanding of high energy environment in the central one parsec of the Galaxy.

Andrew Lehmann (Macquarie University)

The Galactic Centre Molecular Cloud G0.13-0.13: a Laboratory for Understanding Cosmic-ray Electron Acceleration and Interactions

The Galactic Center (GC) molecular cloud G0.13-0.13 exhibits a shell morphology in CS (J=1-0), with ~10^5 solar masses and expansion speed ~20 km/s, yielding a total kinetic energy ~10^{51} erg. Its morphology is also suggestive of an interaction with the nonthermal filaments of the GC Arc. 74 MHz emission indicates the presence of a substantial population of low energy electrons permeating the cloud, which could either be produced by the interaction with the Arc or accelerated in the shock wave responsible for the cloud's expansion. These scenarios are explored using time dependent diffusion models.

With these diffusion models, we determine the penetration of low-energy cosmic-ray electrons accelerated into G0.13-0.13 and calculate the spatial distribution of the cosmic-ray ionization and heating rates. We show that the synchrotron radiation, bremsstrahlung and 6.4 keV Fe Kα line emission associated with the electron population provide observational diagnostics to distinguish these two acceleration scenarios.

We discuss the implications of our results for understanding the distinct character of clouds in the Central Molecular Zone compared to clouds in the Galactic disk, and how GC nonthermal filaments interact with molecular clouds.

Chuck Hailey (Columbia University) for the NuSTAR team

First Results from the NuSTAR "Mini-Survey" of the Galactic Center Region

One of the major science objectives of NuSTAR is to perform the first sub-arcminute, hard X-ray survey of ~ several square degrees of the Galactic plane, centered on a region near the Galactic Center. As a prelude to the full survey, which begins in July 2013, NuSTAR conducted a ~500 ksec "mini-survey" focused on Sgr A* and its environs. We present the first results of the mini-survey. The data reveal the nature of numerous sources in the Galactic Center. In particular, the observations indicate the origin of the TeV emission from the Galactic Center and of the puzzling INTEGRAL source J17546-2901. We also present analysis of numerous candidate PWNe and filaments, all of which are revealed to be intense sources of X-ray emission at >10 keV. We briefly summarize the status of ongoing analysis on hard X-rays from molecular clouds, and the ~dozen hard X-ray point sources uncovered in the mini-survey. Plans for observations of the G2 cloud infall will also be mentioned.

Q. Daniel Wang (University of Massachusetts)

Chandra Sgr A* XVP Collaboration

Dissecting X-ray-emitting Gas around the Center of our Galaxy

Most supermassive black holes (SMBHs) are currently accreting at very low levels, and are thus difficult to distinguish from the center of the galaxies where they reside. Sgr A*, our own Galaxy's SMBH, is typical of this state, with a scant quiescent X-ray luminosity roughly equal to the luminosity of the Sun, or a factor of ~10^{-11} times lower than the canonical maximum Eddington luminosity. Because of its proximity, Sgr A* provides a rare opportunity to study this important stage of SMBH accretion. Currently there are several competing theories to explain the quiescent X-ray emission from Sgr A*, including various models where stellar winds feed an accretion flow as well as direct emission from a cusp of coronally active stars themselves. We present the first results of a study of Sgr A*, based on 3 mega-seconds (~35 days) of Chandra ACIS-S/HETG observations. We rule out the stellar cusp scenario, which predicts fluorescent Fe Kα emission that is not detected.

The observations also reveal an east-west elongation of the diffuse emission, which is distinct from the point-like flaring emission and aligns with the surrounding disk of stars observed in the infrared bands. Together, these results place strong constraints on accretion flow models, and support theories where Sgr A* is accreting directly from stellar winds. The X-ray spectrum of Sgr A* further exhibits distinct lines from Fe XXV Kα as well as S, Ar and Ca, seen for the first time in Sgr A*. But the Fe XXVI Kα line is largely absent, suggesting the presence of a strong outflow from the accretion flow. Moreover, spatial and spectral decompositions of the quiescent X-ray emission indicate that <~20% of it arises from the innermost accretion flow region, which would dominate the radiation in a "normal" active galactic nucleus (AGN). Finally, the spectrum of the Sgr A* surroundings shows evidence for non-thermal X-ray emission, mostly likely representing stellar light inverse-Compton-scattered by relativistic particles from Sgr A*. These results from a close up view of Sgr A* can guide our models of the most prevalent accretion states of SMBHs and their impact on their environments.

Shep Doeleman (MIT)

Science with the Event Horizon Telescope

A convergence of high bandwidth radio instrumentation and newly accessible mm and submm wavelength facilities are enabling assembly of the Event Horizon Telescope (EHT): a short-wavelength Very Long Baseline interferometry (VLBI) array with the capability of observing the nearest supermassive black holes with Schwarzschild Radius resolution. Initial observations with the EHT have revealed event horizon scale structure in Sgr A*, the 4 million solar mass black hole at the Galactic Center, and in the much more luminous and massive black hole at the center of the giant elliptical galaxy M87. Over the next 2-3 years, this international project will add new sites and increase observing bandwidth to focus on astrophysics at the black hole boundary. EHT data products will have an unprecedented combination of sensitivity and resolution with excellent prospects for imaging strong GR signatures, detecting magnetic field structures through full polarization observations, time-resolving black hole orbits, new tests of GR, and modeling black hole accretion, outflow and jet production. This talk will briefly review the technical roadmap and timeline for building out the EHT, and cover the science goals of the project.

Geoffrey C. Bower (UC Berkeley)

Heino Falcke, Adam Deller, Paul Demorest, Andreas Brunthaler, Ralph Eatough, Michael Kramer, K.J. Lee, Laura Spitler

The Galactic Center Pulsar, SGR 1745-29

Radio observations of the recently discovered Galactic Center pulsar, SGR 1745-29, provide a powerful probe of the GC interstellar medium with important consequences for our understanding of Sagittarius A*. Pulsar timing and high resolution VLBA imaging together provide measurements of the dispersion measure (DM), rotation measure (RM), temporal scattering, and angular scattering. This ensemble clearly demonstrates that the pulsar is located near to Sgr A* and shares a similar medium and line of sight. The large RM is demonstrates the existence of a milliGauss field that can power the radio jet. The combination of temporal and angular broadening measurements convincingly demonstrates that the hyperstrong scattering screen is located at a distance of many kpc away from Sgr A*. Finally, we can provide constraints on the origin and ultimate fate of the magnetar through astrometric observations.

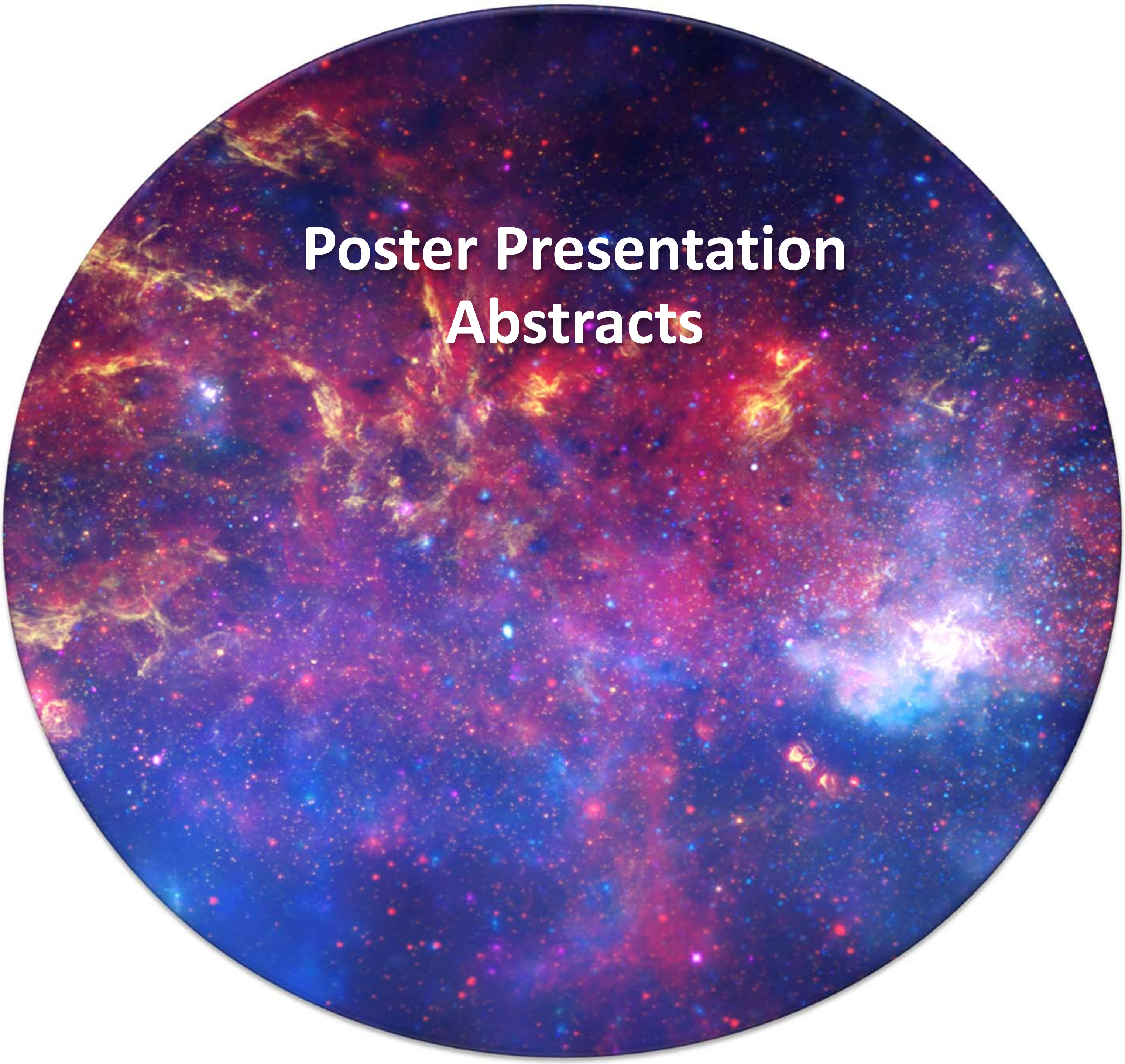
Mark Morris (UCLA)

Jun-Hui Zhao (CfA)
Miller Goss (NRAO)

Nonthermal Filamentary Radio Features within 20 pc of the Galactic Center

The first deep imaging of the Sgr A complex at the Galactic Center at 6 cm wavelength with the B and C configurations of the Karl G. Jansky Very Large Array has achieved unprecedented sensitivity, and has consequently revealed a new population of faint filamentary features, that, like their brighter counterparts seen throughout the Galactic Center on larger scales, can extend up to ~10 parsecs, and in most cases are strikingly uniform in their brightness and curvature. The spectral index map derived from these broad-band observations supports the nonthermal nature of these structures. Previously known nonthermal filaments (NTFs) are seen in the new image to have considerable filamentary substructure. Two well-known radio sources to the south of Sgr A - sources E and F - consist of numerous quasi-parallel filaments that can now be seen as particularly bright portions of a much larger, strongly curved, continuous, nonthermal radio structure that we refer to as the "southern curl". It is therefore unlikely that sources E and F are HII regions or pulsar wind nebulae. The southern curl has a smaller counterpart on the opposite side of the Galactic Center - the northern curl - that, except for its smaller scale and smaller distance from the center, is remarkably point-reflection symmetric with respect to the southern curl. Adopting the current paradigm for the NTFs - that they illuminate local magnetic field lines - we find that the magnetic field in the vicinity of the Sgr A complex does not show the same large-scale trend of being roughly perpendicular to the Galactic plane that has previously been noted for NTFs on larger scales. Furthermore, the curl features indicate that some field lines are presently being strongly distorted, presumably by mass flows. The point symmetry about the center then suggests that the flows originate near the center and are somewhat collimated. Finally, by comparison with earlier 6cm VLA observations, we find that the intensity of the NTFs is time-variable.

Poster Presentation Abstracts



Session 2: Global Properties and Dynamics in the Central Molecular Zones of Galactic Nuclei: From Large Scale Studies to the CND

Anna Ciurlo (Observatoire de Paris, LESIA – CNRS)

P1. Study of the Molecular Gas in the Central Parsec of the Galaxy through Regularized 3D Spectroscopy

In the central parsec of the Galaxy the environment of the black hole presents, besides the star cluster, two different gas structures: the Circumnuclear Disc (CND), composed of neutral gas, and the Minispiral, consisting of ionized gas. In order to study the transition between the two structures we have investigated the presence of neutral gas in the inner part of the CND, where the ionized Minispiral lies. Such study is carried out through spectro-imaging data of the central cavity observed with SPIFFI (SPectrometer for Infrared Faint Field Imaging), the VLT spectrometer (SINFONI without adaptive optics). The observed field of view is 36" x 29", with a spectral resolution R = 1500 in the NIR. Such data cover two H_2 lines and the Brγ line of the HI spectrum. In order to preserve the spatial resolution and avoid edge effects we implemented a new method which consists on a regularized three-dimensional fit, *cf. Regularized OSIRIS 3D spectroscopy at the CND ionization front* abstract, by T. Paumard. The former study investigates the CND area while here its inner part and interface are taken into account. Evidences of H_2 presence in the region and its features are presented.

Pablo García (U Köln)

Robert Simon (U Köln), Jürgen Stutzki (U Köln), Miguel Requena-Torres (MPIfR), Rolf Güsten (MPIfR), Yasuo Fukui (U Nagoya), Hiroaki Yamamoto (U Nagoya), Frank Bertoldi (U Bonn), Michael Burton (UNSW), Leonardo Bronfman (U Chile), Hideo Ogawa (U Osaka)

P2. The Warm ISM in the Sgr A Region: Mid-J CO, Atomic Carbon, Ionized Atomic Carbon, and Ionized Nitrogen Line Observations with the HERSCHEL/HIFI and NANTEN2/SMART Telescopes

The interstellar medium (ISM) in the few central hundred parsecs of the Galaxy has physical properties that differ strongly from the rest of the ISM in the Galaxy: violent motions in dense high temperature gas, strong magnetic and radiation fields, and a rich chemistry make the Galactic Center (GC) of the Milky Way a unique test bed for studies of the ISM and star formation under such extreme conditions and a powerful tool in comprehending the physical processes in the nuclei of galaxies. Observations of bright ISM cooling lines of tracers such as CO and CI will allow to shed new light on its physical parameters and will be the basis for modeling of the emission (excitation, PDR chemistry, shocks). We present HERSCHEL/HIFI Sub-mm atomic carbon (C I $^3P_1$ - $^3P_0$ and C I $^3P_2$ - $^3P_1$), ionized carbon (C II $^2P_{3/2}$ - $^2P_{1/2}$), and ionized nitrogen (N II $^3P_1$ - $^3P_0$) line observations obtained in the frame of the Herschel Guaranteed Time HEXGAL (Herschel EXtraGAlactic) key program (P.I. Rolf Güsten, MPIfR), and NANTEN2/SMART carbon monoxide (CO(J=4-3)) observations of the warm gas around the Sgr A Region. The spectrally resolved emission from all lines, and the corresponding line intensity ratios, show a very complex structures morphology. The determination of spatial and spectral (anti)correlation with known sources in the Sgr A

Region such as the Arched-Filaments, NTF Filaments, The Sickle, Quintuplet Cluster, CND clouds, is an ongoing work, with preliminary results shown on the poster.

Tom R. Geballe (Gemini Observatory, Hilo Hawaii)

F. Najarro (CSIC, Madrid, Spain), D.F. Figer (Rochester Institute of Technology), A.J. Adamson (Gemini Observatory, Hilo Hawaii), M. Rawlings (ALMA-NRAO)

P3. Infrared Diffuse Interstellar Bands and the Carbon Abundance in the Galactic Center

We present spectra of the recently discovered infrared diffuse interstellar bands (DIBs) toward stars in the Galactic Center. The DIBs are formed in multiple locations along the line of sight to the center as well as in the Central Molecular Zone (CMZ). Comparison of velocity-resolved spectra of one of the narrower of these bands toward GCS3-2 and Cygnus OB2 No. 9 allows one to determine the fractional contributions of DIBs from material in the CMZ. Assuming that the abundance of the DIBs carrier(s) is determined by the carbon abundance, we estimate the interstellar carbon abundance in the CMZ and compare it to previous estimates.

Sungsoo Kim (Kyung Hee University)

P4. High-Resolution Simulations of the Formation of the Central Molecular Zone and the Circumnuclear Disk of the Milky Way

We have performed two sets of high-resolution hydrodynamic simulations for the formation of 1) the Central Molecular Zone (CMZ) and 2) the Circumnuclear Disk (CND) of the Milky Way, which result from the inward gas migration from the galactic disk. Our simulations consider gas heating/cooling, star formation, and supernova feedback. The galactic potential was obtained from a snapshot of a 6.3 million particle simulation of a galactic disk at 1 Gyr, which is the most realistic potential model that is used for galactic-scale star-formation simulations. Our high-resolution CMZ simulations show detailed processes of gas infall from the disk to the nuclear bulge including the non-symmetric mass distribution and the vertical gas motion in the CMZ. Our CND simulations suggest that the CND might have formed from a series of infalls of relatively small gas clouds (~10^4 M_{sun}) from the inner CMZ.

David S. Meier (New Mexico Tech, NRAO)

P5. The Nucleus of IC 342 as a Potential Twin of the Galactic Center

The Galactic Center (GC), being the closest nucleus holds a position of privilege in the study of galaxy centers, but because it is edge-on and hidden behind 30 magnitudes of visual extinction it is often difficult to understand the overall structure of the region. Nearby galaxies provide a possible guide to understanding the GC's large scale structure. High spatial resolution maps of CO, HCN, NH3 and CH_3OH line emission along with radio and optical continuum towards the nucleus of the nearby (3 Mpc), face-on spiral IC 342 are discussed. Attention is focused on a comparison of the large-scale morphology, physical conditions, gas chemistry and star formation, between the two nuclei. The case is made that IC 342 is one of the best extragalactic templates for the GC. Both have a star formation rate within a factor of each other and a ISM morphology characterized by a R~300 pc central molecular zone formed from a pair of barred arms laced with a small handful of dense star forming giant molecular clouds. IC

342 also exhibits a distinct nuclear cluster and associated circumnuclear disk. Like the GC, both excitation and gas chemistry reveal quiescent dense gas mixed with an extended, warm shocked molecular medium. Whether the molecular morphology and excitation in IC 342 is an extension of the disk bar, a separate nuclear bar or a result of radiative/mechanical feedback remains conflicted. Evidence for each mechanism is discussed together with their implications for the structure of the GC.

Lydia Moser (U Köln)

P6. Sgr A West in the Light of Molecules, Ionized Gas and Dust

The Galactic Center is, due to its proximity, a unique laboratory to investigate the physics in the vicinity of a supermassive black hole (Sgr A*), i.e. how is the matter transported to the center and how can stars form in such a violent environment. One key research field is the study of the properties and kinematics of the molecular or ionized gas and dust. We present radio continuum and line emission maps of the Galactic Center at ~100 GHz, 230 GHz and 345 GHz obtained with the Combined Array for Research in Millimeter-wave Astronomy (CARMA), the Submillimeter Array (SMA) and - for the first time - with the Atacama Large Millimeter Array (ALMA). Sgr A West (the minispiral) is partially detected in continuum emission by SMA and ALMA and fully by CARMA. The hydrogen recombination line emission maps from all three arrays outline very well the distribution of the ionized gas as well as its radial motion. We show the first high resolution (5'') maps of the Galactic Center region in CO(2-1) (CARMA) and CO(3-2) (SMA) emission - they trace not only the molecular gas in the circumnuclear disk (CND) but also within the cavity (devoid (in gas) region in Sgr A West). In addition, we have a variety of CARMA maps tracing molecular gas in the presence of different physical conditions in the CND, i.e. HNC, SO_3, N_2H^+ and CH_3OH (86-100 GHz), at an up to now unprecedented resolution of <8''. The N_2H^+ and CH_3OH emission coincides with the very dark dust pits (visible in the NIR, e.g. HST NICMOS 1.9 micron) east and south-east at the CND. Especially the presence of N2H+ indicates high densities and very low temperatures at which CO is likely to be frozen out on dust grains. For future analyses of the variability of Sgr A*, I extracted the lightcurves of the Sgr A*. They show a significant difference in the average flux level between the two observations with ALMA and SMA that are separated by only 2.5 hours.

Haruka Nagoshi (Yamaguchi University)

Kenta Fujisawa (Yamaguchi University), Yuzo Kubose (Yamaguchi University)

P7. Radio Continuum and Radio Recombination Line Observations of the Galactic Center Lobe

We have studied the physical property and the formation process of the Galactic Center Lobe (GCL) located in the GC region on the basis of the radio continuum (cont) and radio recombination line (RRL) observations. Here we present the data of the lower part of the GCL ($-1 < l < 0.53$ deg and $0.10 < b < 0.55$ deg) with the Yamaguchi 32-m radio telescope. The intensity distributions of both cont and RRL have two ridges of the east and west forming the GCL. However, the spatial distributions of the cont and RRL ridges are not coincident: ridges at eastern side are widely separated between cont-RRL ridges, while the ridges are closely located and the shape is similar at the western side. We distinguished the radio continuum emission of GCL into two components of thermal and non-thermal emission by assuming the electron temperature of ionized plasma to be 6000 K. As a result, the thermal emission is located inside and surrounded by the non-thermal emission. The estimated electron density of the ionized gas is ˜10 cm^{-3} which is close to that of the giant HII region, the mass of ionized gas is 1.4 x 10^5 $M_\odot$, and the thermal energy of ionized gas is 2.0 x 10^{43} J.

Jürgen Ott (NRAO)

P8. Shock Structure and Shock Heating in the Galactic Central Molecular Zone

The Central Molecular Zone (CMZ) covers the inner ˜500pc of the Milky Way and contains a substantial amount of molecular gas (several 10^7 M_o). Models show that the gas may be funneled along the central Galactic bar into the CMZ and eventually accretes on x_2 orbits that cover the inner ˜200pc. Eventually the gas will be destroyed by environmental influences, during the process of star formation, or, in rare cases, the dense gas will be transported all the way further toward Sgr A*, the central supermassive black hole of the Milky Way. We present maps of a large number of dense molecular gas tracers across the entire CMZ. The data were taken with the CSIRO/CASS Mopra telescope in a Large Project in the 1.3cm, 7mm, and 3mm wavelength regime, where many molecules exhibit their ground state rotational transitions. Here, we focus on the brightness of the shock tracers SiO and HNCO, molecules that are liberated from dust grains under strong (SiO) and soft (HNCO) shocks. We find that their distribution down to the 3rd order is similar but that some regions exhibit remarkable differences. The largest differences are found for the gas that is currently moving along the bar and has not accreted on the x_2 orbit yet. The shocks may have occurred when the gas enters the bar regions and the shock differences are likely a function of the cloud mass. Based on tracers of ionizing photons, it is unlikely that the morphological differences are due to selective photo-dissociation of the molecules. We also observe direct heating of molecular gas in strongly shocked zones, as measured by a high SiO/HNCO ratio, where temperatures are determined through the transitions of ammonia. Strong shocks appear to be the most efficient heating source of molecular gas, apart from high energy emission emitted by the central supermassive black hole Sgr A* and the processes within the extreme star formation region Sgr B2.

Marc W. Pound (University of Maryland)

Farhad Yusef-Zadeh (Northwestern University), Douglas Roberts (Northwestern University)

P9. An Interferometric 3mm Spectral Line and Continuum Survey of the Central Molecular Zone

Because of its large angular extent, the Central Molecular Zone has to date only been mapped at millimeter wavelengths with single-dish telescopes, with resolution about 1.2 pc (30”). We have completed a 3 mm continuum and spectral line interferometric maps made with CARMA of a 90 pc X 50 pc region of the CMZ ($0.6 < l < -0.2$; $0.15 < b < -0.2$), with resolution of ˜0.3 pc. We present here the first results of this survey.

One of the advantages of observing the Galactic Center at 3mm with CARMA is that it allows identification of different classes of objects in this confusing region of the Galaxy. This is the first 3mm continuum survey showing a high concentration of HII complexes, and thermal and nonthermal sources distributed throughout the region. Our continuum survey identifies a number of infrared dark clouds, the most prominent of which is G0.25+0.01, part of a chain of clouds forming a ridge of molecular gas between G0.25+0.01 and Sgr B2. We also see emission from the magnetized filaments in the l =

0.2 Radio Arc.

We combined our spectral line maps of SiO(2-1), HCO^+(1-0), HCN(1-0), N_2H^+(1-0) with the MOPRA single-dish survey so the final maps include all spatial frequencies down to 3". The combined CARMA plus MOPRA maps show a rich structure of both compact and filamentary clouds. We examine the relationship between the distribution of molecular line emission, the 6.4 keV Fe K-α emission, and the nonthermal radio emission and discuss preliminary results of the analysis.

Florent Renaud (CEA-Saclay, Paris)

P10. Galactic Dynamics Feeding the Galactic Center: a Subparsec Resolution Simulation of the Milky Way

The structure and properties of the ISM, and subsequent star formation, in the Galactic Center depend on how the gas is carried to these regions by kpc-scale dynamics. Among them, the bar plays a central role in creating torques and resonances that govern the inflow of gas toward the Galactic Center. Using a hydrodynamic simulation of a Milky Way like galaxy at subparsec resolution, we can capture and monitor the evolution of the gas flows down to small scales, but in a full self-consistent galactic context. Such a resolution allows us to probe the physics of accretion by resolving the sphere of gravitational influence of the black hole (a few parsecs). In particular, we note that resonances in the innermost 500 pc of the disk regulate the feeding of the central black hole, and thus delay the potential fuelling of an AGN. Furthermore, our simulated galaxy does not host star formation in the central kpc, inside the bar, because of the destruction of molecular clouds falling in this region. We find that the strong shear is responsible for dissolving the clouds and thus preventing star formation over a large volume.

Miguel A. Requena-Torres (Max-Planck-Institut für Radioastronomie, Germany)

P. Jones (UNSW, Australia), M. Cunningham (UNSW, Australia), K. Menten (Max-Planck-Institut für Radioastronomie, Germany), and the Mopra CMZ collaboration

P11. Unveiling the Central Molecular Zone with Mopra

We have mapped a 2.5° x 0.5° region of the center of the Galaxy using the Mopra radio telescope in 18 molecular lines emitting from 85 to 93GHz. This incorporates most of the region known as the Central Molecular Zone (CMZ). The molecular maps have 40 arcsec spatial resolution and 2 km s^{-1} spectral resolution, with emission extending to velocities of 220 km s^{-1}. Line profiles are both very wide and complex, and do vary considerably across the CMZ. The analysis of the data has started with three different topics: To quantify the overall emission morphology, and its variation between molecules, we conducted a principal component analysis (PCA) of the integrated emission from 8 brightest species. We have selected apertures around the bright dust cores, as well as for the total region mapped, in order to study line ratio variations and to calculate optical depths so that column densities and molecule masses may be determined. We have study the line luminosities, relative to that of CO. The luminosities are also typically 0.1-10 percent of the corresponding values that have been measured in other galaxies. The full data set, comprising the data cubes for the 20 emission lines, is publicly available for further analysis.

Y. Ao (MPIfR, Germany / NAOJ, Japan), C. Henkel (MPIfR, Germany), K. M. Menten (MPIfR, Germany), **Miguel A. Requena-Torres** (MPIfR, Germany), T. Stanke (ESO, Germany), R. Mauersberger (JAO, Chile), S. Aalto (OSO, Sweden), S. Muehle (AIfA, Germany), J. Mangum (NRAO, USA)

P12. The Thermal State of Molecular Clouds in the Galactic Center: Evidence for Nonphoton-driven Heating

We have used the Atacama Pathfinder Experiment (APEX) 12-m telescope to observe the para-H_2CO triple at 218 GHz simultaneously to determine kinetic temperatures of the dense gas in the Central Molecular Zone of our Galaxy. The map extends over approximately 100pc x 20pc along the galactic plane with a linear resolution of 1.2 pc. Derived gas kinetic temperatures for individual molecular clouds range from 50 K to values in excess of 100 K. For the molecular gas outside the dense clouds, the average kinetic temperature is 65 $\pm$10 K. The high temperatures of molecular clouds over large scales in the GC region may be driven by turbulent energy dissipation and/or cosmic-rays instead of photons. Such a non-photon driven thermal state of the molecular gas provides an excellent template for the more distant vigorous starbursts found in ultraluminous infrared galaxies.

Denise Riquelme Vásquez (Max-Planck-Institute for Radioastronomy)

P13. Unbiased Line Survey in the Galactic Center Molecular Clouds

Using the IRAM 30-m telescope, we perform a 3 mm and 2 mm line survey towards 5 selected positions in the Galactic Center region, including shocked regions, ultraviolet (UV) and X-ray pervaded regions, and positions with rich organic chemistry. These surveys have the potential to be used as chemical templates of different type of activity (PDRs, shocks, XDRs) in complement with the molecular surveys towards extragalactic nuclei done by our group.

Subhashis Roy (NCRA)

P14. Density of Warm Ionized Gas near the Galactic Center: Low Radio Frequency Observations

We have observed the Galactic Center (GC) region at 0.154 and 0.255 GHz with the GMRT. A total of 62 compact likely extragalactic sources were detected. Their scattering sizes go down linearly with increasing angular distance from the GC up to about 1 deg. The apparent scattering sizes of sources are more than an order of magnitude down than predicted earlier by the NE2001 model of Galactic electron distribution within 359.5 deg $<$ l $<$ 0.5 deg and -0.5 deg $<$ b $<$0.5 deg (Hyperstrong scattering region) of the Galaxy. High free-free optical depths are observed towards most of the extended nonthermal sources within 0.6 deg from the GC. Significant variation of optical depth indicate the absorbing medium is patchy at an angular scale of 10' and electron density is ~10 per cc that matches with the NE2001 model. This model predicts the extragalactic (EG) sources to be resolved out from 1.4 GHz interferometric surveys. However, 8 likely EG sources out of 10 expected in the region are present in 1.4 GHz catalog. Ionized interfaces of dense molecular clouds to the ambient medium are most likely responsible for strong scattering and low radio frequency absorption. However, dense GC clouds traced by CS J=1-0 emission are found to have a narrow distribution of ~0.2 deg across the Galactic plane. Angular distribution of most of the EG sources seen through the so called Hyperstrong scattering region are

random in ‘b’, and typically ˜7 out of 10 sources will not be seen through to the dense molecular clouds, and it explains why most of them are not scatter broadened at 1.4 GHz.

Marc J. Royster (Northwestern University)

F. Yusef-Zadeh (Northwestern University)

P15. GBT and VLA Investigation of the Ionized Gas towards the Galactic Center with Radio Recombination Lines at 8-9 GHz

We report the results of a study of the ionized gas toward the Galactic Center (GC) with radio recombination lines (RRLs) at cm wavelengths. Both the GBT and the VLA were used to probe the kinematics of the ionized gas on a global scale for both diffuse and discrete sources. The GBT observations include a complete survey of the inner 300 x 75 pc (lxb) of the GC with spatial resolutions of 73” and 1 km/s spectral resolution. Both frequency and position-switched observing schemes were utilized with velocity ranges exceeding 1000 km/s. A range of RRLs (H86alpha - H92alpha) are employed to investigate the diffuse kinematics of massive star forming regions such as: Sgr B1/B2, the Sickle, the Arches, the Bubble and Sgr C. We find a ˜0 km/s diffuse component that is pervasive in the observed region with a relative broad line width. We discuss possible locations of this velocity component. Beyond the kinematics, we present the distributions of the electron temperature and helium abundances.

The VLA in its D configuration observed H89α - H92α, co-added to double the achieved sensitivity, with a resolution of 15” x 3”. The 7 fields, each with FWHM ˜5’ were Nyquist sampled and combined with the GBT observations to provide an 18 x 18 pc (lxb) map with a velocity range of ˜1500 km/s, as well as a spectral resolution of ˜1.5 km/s for each RRL. This was essential in searching for high-velocity (> 200 km/s) components of ionized gas while disentangling the complex environment found within the inner 18 pc. Included in this environment is the mini-spiral and the chain of HII regions found embedded in the supernova remnant, Sgr A East, as well as newly discovered HII regions associated with the halo of the Sgr A complex. We present the kinematics of the HII regions and identify thermal and non-thermal contributions from the inner 18 pc.

Simona Soldi (APC, Paris)

Maïca Clavel, Andrea Goldwurm, Mark R. Morris, Gabriele Ponti, Regis Terrier, Guillaume Trap

P16. An X-ray Survey of the Central Molecular Zone: Variability of the Fe Kα Emission Line

The bulk of the Fe Kα emission detected in the Central Molecular Zone (CMZ) is thought to be associated with reflection by the central molecular clouds of enhanced past emission from an external X-ray source, most likely Sgr A*. In order to follow the propagation of the reflected emission through the central 200 pc of our Galaxy, we systematically analysed all XMM-Newton observations from 2000 up to the latest scan performed in 2012. We present here the variability analysis of the 6.4 keV emission across the CMZ. The majority of the regions that were bright at 6.4 keV during the 2000-2001 observations is found to have decreased in 2012, while other regions have brightened, providing further potential constraints of the past activity of Sgr A*. We estimate the global fraction of molecular gas that has been emitting at 6.4 keV within the past 12 years of observations, and the fraction of variable 6.4 keV emission, providing hints to the nature and duration of past event(s) responsible for the observed behaviour. In addition, we present preliminary results on some specific molecular complexes, for which the latest 2012 scan provides additional clues to the origin of their Fe Kα emission.

Kazufumi Torii (Nagoya University)

R. Enokiya, Y. Fukui, NANTEN2 consortium

P17. Detailed Distributions of the CO J=2-1/J=1-0 Intensity Ratios towards a Large Area of the Central Molecular Zone

The Central Molecular Zone (CMZ) of the Galactic Center contains huge amount of molecular gas, and understanding 3D gas distribution and dynamics of the gas are crucial. Many molecular observations towards the CMZ with high spatial resolutions have been performed so far, however, they are usually limited in the coverage of the galactic latitude, typically $b < |0.5|$ degree.

In this poster, we present the detailed distributions of the CO J=2-1/J=1-0 intensity ratios of the CMZ, indicating the excitation condition of molecular gas. The large area coverage of 4x2 degree in l and b and high angular resolution of 180" enable us to trace the all components in the CMZ including several filamentary structures perpendicularly to the galactic plane to $b>|0.5|$ degree. The major components of the CMZ, the Sgr A, Sgr B and Sgr C molecular clouds and the molecular ring (e.g., Molinari et al. 2011), shows high average ratios of 0.8, while the local foreground components around 0 km/s shows ratios of less than 0.5. The so called expanding molecular ring (EMR), showing a parallelogram distribution in the longitude-velocity diagram, which is usually discussed as the evidence of the non-circular rotation driven by the bar potential, shows significantly different intensity ratios of 0.55 and 0.65 in its positive and negative velocity components, respectively. The positive velocity component of the EMR also has narrower velocity widths and smaller scale heights than those of the negative one.

These results indicate that the positive and negative velocity components of the EMR are not coherent structures. The vertical molecular filaments show the typical ratios of 0.6-0.7, apparently larger than the local components, meaning they are indeed located in the Galactic Center.

Andrew Walsh (International Centre for Radio Astronomy Research - ICRAR)

P18. Using SPLASH and GASKAP to Map Emission and Absorption of Hydroxyl in the Galactic Centre

SPLASH (the Southern Parkes Large Area Survey in Hydroxyl) is currently mapping the inner Galactic plane in all four ground-state OH transitions with unprecedented sensitivity. As well as ubiquitous masers, we find both thermal emission and absorption across the Galactic plane, particularly towards the Galactic Centre where absorption is both strong and widespread. I will discuss early results from SPLASH, as well as the forthcoming survey GASKAP. Ultimately, we aim to combine SPLASH and GASKAP data to produce the most sensitive, fully-sampled map at 30" resolution. These data can then be used, in combination with emission maps in high density gas tracers, such as NH_3 from HOPS, to produce a high sensitivity and high resolution 3D map of the Centre of our Galaxy.

Michael W. Werner (JPL/Caltech)

C.D.Dowell (JPL/Caltech), the HAWC+ team.

P19. SOFIA/HAWC+: Upcoming capability for detailed mapping of the Galactic Center magnetic field.

Magnetic fields are a key ingredient of the Galactic Central Molecular Zone (CMZ), responsible for or tracing many of the well-known features within. Previous far-IR/submillimeter polarimetry of emission from magnetically-aligned dust has revealed a large scale toroidal geometry for the field in the densest molecular component of the CMZ, provided tentative evidence for a poloidal field in the lower density molecular gas, established a preliminary field model for the Circum-Nuclear Disk (CND), and highlighted the importance of dynamical events such as supernova shells and tidal shearing in shaping structures and the embedded field on cloud scales. However, these polarization mapping efforts are far from complete in surveying the CMZ, and they have also been limited by the previously available angular resolution. SOFIA and the HAWC+ instrument currently under development will offer a substantial increase in capability to overcome these limitations. HAWC+ is a multi-band polarimeter and camera operating at 50 to 220 microns, and its sensitive, state-of-the art 64x40 detector arrays will allow widespread mapping of dust and magnetic fields in the CMZ with many thousands of resolution elements as small as 5 arcsec at the shortest wavelength band. This resolution is sufficient to resolve the clumpy substructure of the CND and the filament spacing of the Sickle cloud as well as to apply statistical methods to estimate the field strength in a variety of Galactic Center sites. The poster will detail the capabilities of HAWC+ for studying the magnetic field at the Galactic Center and summarize the technical features and development/flight schedule for this instrument.

R. Karlsson (Stockholm Observatory), Aa. Sandqvist (Stockholm Observatory), A. Hjalmarson (Onsala Space Observatory, Chalmers University of Technology), **Anders Winnberg** (Onsala Space Observatory, Chalmers University of Technology), K. Fathi (Stockholm Observatory), U. Frisk (Omnisys Instruments AB), M. Olberg (Onsala Space Observatory, Chalmers University of Technology)

P20. Hydroxyl, Water, Ammonia, Carbon Monoxide and Neutral Carbon towards the Sgr A Complex

We have studied the morphology, abundances and kinematics of different species towards the Sgr A complex and the line-of-sight spiral arm features. Strong OH absorption, H_2O emission and absorption lines were seen at all observed positions, and the $-H_2{}^{18}O$ line was detected in absorption towards the +20 and +50 km s^{-1} clouds, the CND, the expanding molecular ring, and the 3-kpc arm. Strong CO, $C^{18}O$ and neutral carbon C II emissions were seen towards the +20 and +50 km s^{-1} clouds. NH_3 was detected in weak absorption only originating in the line-of-sight spiral arm features. The abundances of OH and H_2O indicate that shocks and star formation prevail in the +50 km s^{-1} cloud, and also in the CND where cloud collisions are frequent, and furthermore that the CND is subject to intense UV-radiation emanating from the supermassive black hole and the central star cluster. The CND is rich in H_2O and OH, and these abundances are considerably higher than those in the surrounding clouds. It is likely that PDR chemistry including grain surface reactions, and perhaps also the influences of shocks has led to the observed abundances of the molecular species studied here. In the redward high-velocity line wings of both the +20 and +50 km s^{-1} clouds and the CND, the H_2O abundances are estimated to be similar to the water abundances in outflows of the Orion KL and DR21 molecular clouds, which are said to be caused by the combined action of shock desorption from icy grain mantles and high-temperature,

gas-phase shock chemistry. The compact H II region D, in the eastern part of the +50 km s^{-1} cloud, was observed in OH absorption, and we found two velocity components in the $C^{18}O$ (2-1) line which may indicate a bipolar outflow in this region. A paper on this subject was published recently in Astronomy & Astrophysics (A&A 554, A141, 2013). The paper has 'Open Access' status.

Jiangshui Zhang (Center for Astrophysics, Guangzhou University)

Lulu Sun (Guangzhou University), Jianjie Qiu (Guangzhou University)
Dengrong Lu (Chinese Academy of Sciences), Min Wang (Chinese Academy of Sciences)

P21. Oxygen Isotope Ratio Studies in Galactic Central Region

Using Delinha 13.7m telescope with installed 9-beam SIS superconducting receiver, we carried out mapping in the transition J=1-0 of $C^{18}O$ and $C^{17}O$ toward molecular clouds in central molecular zone (CMZ) and in the halo of our galaxy. From the integrated intensity ratio of $C^{18}O$ and $C^{17}O$, the isotope ratio $^{18}O/^{17}O$ ratio can be estimated, which is considered to be one of the most useful tracers of nuclear processing and metal enrichment. This may be one good method to discriminate between the gas owing towards the disk and gas already residing in the disk of the central galactic plane (Riquelme et al. 2010), which was shown from studies of the gas kinematics of the Galactic central region (e.g., Fukui et al. 2006; Binney et al. 1991; Rodriguez-Fernandez & Combes 2008). Here preliminary results of our targeted molecular clouds are presented, including Sgr A, Sgr B2, Sgr C, Sgr D, 1.°3 complex in CMZ, and M-3.8+0.9, M+5.3-0.3 in the halo.

Session 3: The Formation and Impact of Massive Stars in the Galactic Center

Yanett Contreras (CSIRO)

P23. Structure of the Gas in the Central Molecular Zone from MALT90 Observations

The Millimetre Astronomy Legacy Team 90 GHz (MALT90) survey aims to characterise the physical and chemical evolution of high-mass star-forming clumps. This survey has observed ˜2000 clumps along the Galactic plane, identified from ATLASGAL, using the Mopra 22 m telescope. The observed clumps span the complete range of evolutionary stages from pre-stellar, to protostellar, and on to HII regions. Each clump was mapped simultaneously in 16 molecular line transitions near 90 GHz. The combination of the selected transitions probes a wide range of physical and chemical conditions, revealing a wealth of source morphologies, kinematics and chemistry. This data are publicly available and represents an excellent resource for the community.

Here I will show molecular data from the MALT90 survey, toward several molecular clouds located near the Galactic Centre. I will present the detailed structure of the gas and some of the physical properties for some of the more extreme molecular clouds near the Galactic Centre.

Joanna Corby (University of Virginia)

Anthony Remijan (National Radio Astronomy Observatory), Paul Jones (University of New South Wales), Maria Cunningham (University of New South Wales)

P22. Chemical Differentiation in Sagittarius B2 Revealed by Broad Bandwidth Radio Interferometry

We discuss the chemical structure of Sgr B2, the high mass star forming region in the Galactic Center and the pre-eminent interstellar source of organic chemistry. A combined analysis of broad-bandwidth observations with the Karl G. Jansky Very Large Array, the Australia Telescope Compact Array, and the Robert C. Byrd Green Bank Telescope distinguishes between molecules that are widely distributed, hot core species of the Large Molecule Heimat, and molecules formed near the shells of material thought to be expanding ionization fronts. We briefly discuss these three classes of species, and then focus on a family of molecules found along the shells, namely nitriles (with a C-N triple bond) and their relatives.

Sofia Gallego (Católica Chile)

P24. Satellite Infall and Mass Deposition on the Galactic Center

We modeled the infall of a ˜2×10^5 M_o satellite galaxy on the inner 200 parsec of our Galaxy, to test whether this satellite perturbs previously stable gas clouds in the inner Milky Way disk, as recently proposed by Lang et al. (2011). This process could have driven a gas inflow of ˜10^5 M_o around 10 Myr ago, necessary to explain the past high accretion rate onto the super-massive black hole, and the presence of young stars in the inner parsecs of the Galaxy. Gadget-2 simulations do show inflow of gas, although at a lower rate, inconsistent with expectations.

Adam Ginsburg (U Colorado)

P25. Gas Density within the Central 100 pc

The Brick is one of the highest density clouds in the CMZ, and has been the focus of a great deal of recent interest. While dust maps and bright ammonia emission have indicated that this source may be very high density, and perhaps even a precursor of an Arches or Pistol scale cluster, recent ALMA observations hint that the cloud may not be undergoing gravitational collapse. I present new observations of the cloud using formaldehyde (H_2CO) as a "densitometer", measuring the local density within the cloud as a function of velocity in order to determine whether it is undergoing collapse. This method will be applied to other CMZ clouds to determine whether they are physically analogous to the Brick, being crushed or torn apart.

Behrang Jalali (U Köln)

P26. Star Formation in the Vicinity of Sgr A*

Formation of stars close to black holes at the center of galaxies is often considered not plausible. It is assumed that the strong gravitational field of a massive black hole disrupts the parent molecular cloud and prevents star formation. Surprisingly, young stars (less than 1˜Myr to a few Myr) have been observed across various distances (0.1 to 0.5˜pc) close to the Milky Way's central black hole, Sgr A*. The observed young stars are in different configurations such as warped disks as well as in some distinct smaller groups.

In this work we focus particularly on small young stellar groups such as IRS˜13N, 0.1˜pc away from Sgr A*, that is suggested to contain about five embedded massive young stellar objects (<˜1 Myr). We perform hydrodynamical simulations to follow the evolution of molecular clumps orbiting around Sgr A*, to reproduce and constrain conditions of such young stellar groups.

In our simulations, supposing a clump evolves in a highly eccentric orbit, strong shear from the black hole perpendicular to the clump's orbit (in two-dimensions) causes gas densities to increase to values required for star formation, more significantly than in the case of isolated clump with the same initial conditions. There are more numerous and more massive protostars in a highly eccentric orbiting clump, with respect to isolated model.

I will present details of our modeling and results, including some animations and statistical properties of protostars such as initial mass function, formed stellar groups and SFE depending on the orbit of parent clump. Furthermore, based on our modeling we speculate about possible origin of the observed G2/DSO gas cloud moving towards Sgr A*.

Katharine Johnston (MPIA)

P27. The Star-forming Fate of the Galactic Center Cloud G0.253+0.016

The massive infrared dark cloud G0.253+0.016 projected 45pc from the Galactic Center contains 10^5 M_{sun} of dense gas whilst being devoid, except for a solitary water maser, of observed star formation tracers. Thus G0.253+0.016 violates the "star formation law" of Lada et al. (2010), which suggests a relation between the mass above a column density threshold of 0.024 g cm^{-2} and the observed star formation rate. To scrutinize the gas properties of G0.253+0.016, we have carried out a concerted SMA and IRAM 30m study of this enigmatic cloud in dust continuum, CO isotopologues as low-density tracers, as well as CH_3OH and SiO as shock tracers. In addition to presenting our most recent results, I will discuss how our observations suggest that G0.253+0.016 is colliding with another cloud, which could affect its final star-forming fate, the density structure of the cloud with relation to whether star formation is currently ongoing, and whether it is possible to reconcile the lack of star formation in G0.253+0.016 with the density threshold for star formation found for the Milky Way disk by considering the effects of turbulent support.

Eunbin Kim (Kyung Hee University)

Sungsoo S. Kim (Kyung Hee University), Myung Gyoon Lee (Seoul National University), Gwang-Ho Lee (Seoul National University), Richard de Grijs (Peking University)

P28. Dependence of the Nuclear Star Formation on the Non-Axisymmetric Shape of the Galactic Nucleus

Gas inflow from the galactic disk to the nuclear region can be caused and increased by gravitational perturbation from a neighboring galaxy or by the non-axisymmetric mass distribution in the galactic nucleus (bulge and/or bar), and a large amount of inward gas migration can induce nuclear star formation. We investigate the dependence of the amount (or occurrence) of nuclear star formation on the existence of a bar and on the non-axisymmetry of the bulge. For this, we use a volume-limited sample of spiral galaxies at a redshift between 0.02 and 0.055 from the Sloan Digital Sky Survey Data Release 7. Among 10,547 galaxies with an axis ratio $b/a > 0.6$, we find 964 nuclear star burst galaxies (16%).

Jihane Moultaka (IRAP - OMP, Toulouse, France)

Andreas Eckart (I. Physikalisches Institut, Universität zu Köln), Nadeen Sabha (I. Physikalisches Institut, Universität zu Köln), Koralka Muzic (ESO)

P29. 3D Mid-infrared View of the Central Parsec

We present a mid-infrared 3D view of the central parsec using ISAAC spectrograph (ESO/VLT) with its spectroscopic mode. We mapped the central parsec in L- and M-bands by using 26 and 21 slit positions, respectively that allowed us to build two datacubes of the region in these spectral domains. We also used an original method to distinguish the contribution of the foreground extinction to the absorbed spectra from that of the local extinction in both wavelength ranges. We found that there are residual water and CO ices in the central parsec as well as hydrocarbons and gaseous CO implying very low temperatures of the order of tens of kelvin in the local environment of Sgr A*.

Takeshi Oka

K. Tanaka, S. Matsumura, K. Miura, S. Takekawa, Y. Takahata, T. Nishino

P30. 3 mm Band Line Survey toward the High-Velocity Compact Cloud CO-0.40-0.22

High-velocity compact clouds (HVCCs) are a population of molecular clouds which have compact appearance (d<10 pc) and large velocity width (DV>50 km$_s$) and have been found in the central molecular zone of our Galaxy. Although some of them show clear expanding motion having hints of massive stellar clusters, the nature of the rest of them is unsolved. We performed a 3 mm band line survey toward CO-0.40-0.22, a spatially unresolved HVCC with an extremely large velocity width (DV 100 km/s), using the Mopra 22 m telescope. We surveyed the frequency range between 76 GHz and 116 GHz with a 0.27 MHz frequency resolution. We detected at least 47 lines from 29 molecules. Many line profiles have extremely blueshifted wings, indicating they are emitted by the HVCC. Detections of large molecules are indicative of nonequilibrium chemistry, and abundant methanol might indicate massive star formation in the HVCC. Based on these data set and those previously obtained, the nature of CO-0.40-0.22 will be discussed.

Ylva Pihlström (University of New Mexico)

B. McEwen (UNM), L. Sjouwerman (NRAO)

P31. Methanol Masers in Galactic Center Region Supernova Remnants

Methanol masers can be used to constrain densities and estimate kinematical distances to supernova remnants (SNRs), important parameters in cosmic ray acceleration models. With the goal of testing those models both for SNRs inside and outside the Galactic Center (GC) region, we have used the Very Large Array to search for 36 GHz and 44 GHz methanol lines in Galactic SNRs. We report on the overall results of the maser search, and in particular the results of the GC SNR G1.4-0.1 in which more than 40 masers were found. They may be due to interactions between the SNR and at least two separate molecular clouds. Methanol masers were also detected in W28 and in Sgr A East.

Paolo Pilleri (Los Alamos National Laboratory / Observatorio Astronomico Nacional)

C. Joblin (Université de Toulouse / CNRS), O. Berné (Université de Toulouse / CNRS), J. Montillaud (University of Helsinki), Y. Okada (University of Köln)

P32. The Evolution of PAHs and Carbonaceous Very Small Grains in Photon-dominated Regions

Carbon is an important component of both gas and dust in Photo-Dissociation Regions (PDRs). In the dust component, carbon is tied up in Polycyclic Aromatic Hydrocarbons (PAHs) and amorphous carbon (HAC) grains. Amongst gas-phase species, C^+ and CO are obvious examples of very important species, as C^+ plays a major role in the thermal balance of PDRs and CO is the second most abundant molecule after H_2. Small hydrocarbon species (such as CCH and C_3H_2) have also been observed in PDRs, with abundances that are several orders of magnitudes higher than those predicted by current gas-phase chemical models (Teyssier et al., A&A 2004, Pety et al., A&A 2005).

Rapacioli et al. (A&A 2005) and Berné et al. (A&A 2007) showed that the carriers of the mid-IR bands consist of neutral and cationic PAHs but also of a third population that is chemically connected to them, the so- called evaporating Very Small Grains (eVSGs). Observations show that eVSGs are easily photo-dissociated by UV radiation into PAHs and this process has important consequences in both the chemistry and the physics of PDRs (Pilleri et al., A&A 2012). PAHs and eVSGs are the most efficient species for the heating of the gas by photo-electric effect and therefore their evolution can significantly impact the thermal balance of PDRs (Okada et al.,A&A 2013; Joblin et al., in prep.). From a chemical point of view, the evaporation process can inject fresh hydrocarbons in the gas phase, modifying the chemical balance of these species (Pilleri et al., in prep.).

In this work, we present the existence of a quantitative link between the radiation field and the evolution from VSG to PAH population. To achieve this, we developed a fitting algorithm called PAHTAT (PAH Toulouse Astronomical Templates) to decompose any observed mid-IR spectrum with template spectra of ionized and neutral PAHs, and VSG (Pilleri et al., A&A 2012). We apply this mid-IR decomposition to a sample of PDRs spanning a wide range of irradiation conditions. The spatial distribution of the relative abundance of these populations reflects the evolutionary scenario where PAHs are produced by destruction of VSGs. We show how the fraction of carbon atoms in eVSGs is empirically linked to the local intensity of the UV radiation field.

Nadeen Sabha (I. Physikalisches Institut, University of Cologne / MPIfR)

Andreas Eckart (I. Physikalisches Institut, University of Cologne / MPIfR)

P33. Faint Point Sources and a Bowshock in the Central Parsec: An Infrared View

We analyze highly resolved mid-infrared data of the Galactic Center. The N-band (8.6˜µm & 13.04˜µm) data were obtained using the instrument VISIR on ESO's Very Large Telescope. They cover five GC targets; the central stellar cluster, the Arches, Quintuplet cluster and regions in the Arched Filaments and Sickle. We study faint point sources within these regions to obtain information on star formation, disk candidates, massive young stellar objects, accreting intermediate massive black holes and stellar remnants. In addition, we investigate the alignment of a few dusty comet-like objects inside the central parsec.

Marc Schartmann (USM/MPE Munich)

C. Alig, A. Burkert, K. Dolag

P34. Young Stellar Disks Formed by the Collision of a Molecular Cloud with a Circumnuclear Disk at the GC

A new model for the formation of the two young, counter-rotating sub-parsec scale stellar disks in the Galactic Center is presented: the collisions of a single molecular cloud with a circumnuclear gas disk leads to multiple streams of gas towards the supermassive black hole at the Center of the Milky Way. With the help of Gadget3 simulations, we show that multiple accretion disks are formed, which have angular momenta depending on the ratio of cloud and circumnuclear disk material. They form roughly 1 Myr after one another, which leaves ample time for fragmentation into stars and dispersal before the next disk forms. A similar event might have led to the creation of the so-called mini-spiral in the Galactic Center.

Loránt Sjouwerman (NRAO)

Ylva Pihlström (NRAO / University of New Mexico)

P35. Class I masers in the Galactic Center

We report on the detection of 36 and 44 GHz Class I methanol (CH_3OH) maser emission in the Sagittarius A (Sgr A) complex with the Karl G Jansky Very Large Array (VLA). These VLA observations show that the Sgr A complex harbors at least four different tracers of shocked regions in the radio regime. The 44 GHz masers correlate with the positions and velocities of previously detected 36 GHz CH_3OH masers, but less with 1720 MHz OH masers. Our detections agree with theoretical predictions that the densities and temperatures conducive for 1720 MHz OH masers may also produce 36 and 44 GHz CH_3OH maser emission. However, many 44 GHz masers do not overlap with 36 GHz methanol masers, suggesting that 44 GHz masers also arise in regions too hot and too dense for 36 GHz masers to form. This agrees with the non-detection of 1720 MHz OH masers in the same area, which are thought to be excited under even cooler and less dense conditions. We speculate that the geometry of the 36 GHz masers outlines the current location of a shock front.

Johannes Staguhn (Johns Hopkins University & NASA's Goddard Space Flight Center)

Mark Morris (UCLA), Attila Kovacs (University of Minnesota & Caltech), Dominic Benford (NASA's Goddard Space Flight Center)

P36. Multicolor radio through submillimeter observations of the Galactic Center region

We present new 2 mm Galactic Center observations obtained with the GISMO bolometer camera, new 850 micron observations obtained with LABOCA, both of which were used together with 20 cm observations to generate a spectral index map of the innermost 1.5 degree by 0.5 degrees of our Galaxy. Variations of the spectral index can be used to spatially separate dust emission from free-free and synchrotron emission.

Tova M. Yoast-Hull (University of Wisconsin-Madison)

J. S. Gallagher, III (University of Wisconsin-Madison), Ellen G. Zweibel (University of Wisconsin-Madison)

P37. The Galactic Center: A Model for Cosmic Ray Interactions in Starburst Galaxies?

The Galactic Center contains strong magnetic fields, high radiation fields, and dense molecular gas. These conditions are extreme when compared with those in the Galactic disk, as is also the case in starburst galaxies. The close proximity of the Galactic Center allows for more and better observations of the interstellar medium and surrounding environment than for extragalactic sources. This makes the Galactic Center an ideal place for testing models for cosmic ray interactions. We have developed and tested a semi-analytic model of cosmic rays for the starburst galaxy M82. Now, we compare the results of this model for the Galactic Center, with and without a wind, and NGC 253. We present the predicted radio and gamma-ray spectra for the Galactic Center and compare the results with published measurements. In this way we provide a quantitative basis for assessing the degree to which the Galactic Center resembles a starburst system

Session 4: The Galactic Center Stellar Population

Anna Boehle (UCLA)

Rainer Schödel, Leo Meyer, Andrea Ghez

P38. New Orbital Analysis of Stars at the Galactic Center Using Speckle Holography and Orbital Priors

We present initial results of a study that has more than doubled the time baseline for astrometric measurements of faint stars orbiting the supermassive black hole (SMBH) at the Galactic Center. The advent of Adaptive Optics has enabled stars as faint as K~19 mag to be tracked at 50 mas resolution for the last decade. While similar resolution images exist from the prior decade, they were obtained from speckle imaging data analyzed with the technique of shift-and-add, which limited detections to stars brighter than K~16 mag. By improving the speckle data analysis technique with speckle holography and using prior orbital knowledge, we are now able to track stars as faint as ~18 mag at 50 mas resolution through the early Keck speckle data sets (1995-2005). This methodology has already led to the detection of two short-period stars never previously seen in speckle images, such that our data now spans their full orbits. We can now better constrain the orbital parameters of all stars in the intriguing "S-star cluster," which will ultimately give us insight into the origin of these stars and be used to probe the curvature of space-time in the unexplored regime near a SMBH.

Sylvana Yelda (UCLA), **Andrea M. Ghez** (UCLA), **Jessica R. Lu** (Institute for Astronomy, University of Hawaii), **Tuan Do** (University of Toronto), **Leo Meyer** (UCLA), **Mark R. Morris** (UCLA), Keith Matthews (California Institute of Technology)

P39. Properties of the Remnant Clockwise Disk of Young Stars in the Galactic Center

We present new kinematic measurements and modeling of a sample of 116 young stars in the central parsec of the Galaxy in order to investigate the properties of the young stellar disk. The kinematic measurements were derived from a combination of speckle and laser guide star adaptive optics imaging and integral field spectroscopy from the Keck telescopes. Compared to earlier disk studies, the most important kinematic measurement improvement is in the precision of the accelerations in the plane of the sky, which have a factor of six smaller uncertainties (~10 uas/yr^2 or ~0.4 km/s/yr). We have also added the first radial velocity measurements for 8 young stars, increasing the sample at the largest radii (6" - 12") by a factor of 25%. We derive the ensemble properties of the observed stars using Monte-Carlo simulations of mock data sets. There is only one highly significant kinematic feature (~20 sigma), corresponding to the well-known clockwise disk, and no statistically significant feature is detected at the location of the previously claimed counterclockwise disk. The true disk fraction is estimated to be ~20%, a factor of ~2.5 lower than previous claims, suggesting that we may be observing the remnant of what used to be a more densely populated stellar disk. In addition, the intrinsic eccentricity distribution of the disk stars has an average value of $< e > = 0.27 +/- 0.07$. The clockwise disk stars can achieve their present-day orbital eccentricities through dynamical relaxation over their lifetimes in an initially circular disk with a moderately top-heavy mass function.

Jaroslav Haas (Charles University in Prague)

P40. Dynamical Evolution of Dense Star Clusters in Galactic Nuclei

Observations of the innermost parsec of the Milky Way reveal a number of young stars orbiting the central supermassive black hole on near-Keplerian orbits. It is widely accepted that a significant subset of these stars reside in, at least one, coherently rotating disc-like structure that formed in this region several million years ago. It has been further suggested by various authors that the surface density profile of this stellar disc follows a steep power-law: $\Sigma(R) \alpha R^2$. By means of direct numerical N-body modeling, however, we show that the dynamical evolution of a newly formed stellar disc inevitably leads to a surface density profile which is not compatible with the reported power-law within a period of time shorter than the estimated age of the observed young stars. Moreover, the results of our calculations prove that this conclusion is valid for a wide set of parameters that describe the considered stellar system.

Roman Krivonos (UC Berkeley)

John Tomsick, Kaya Mori, Melania Nynka, Fred Baganoff, Arash Bodaghee, Steve Boggs, Finn Christensen, Bill Craig, Chuck Hailey, Fiona Harrison, Daniel Stern, Will Zhang and NuSTAR Team

P41. The Arches Cluster Morphology and Spectral Studies with NuSTAR

The Arches cluster is a young, densely packed massive star cluster in our Galaxy, showing a high level of star formation activity. The nature of the extended non-thermal X-ray emission around the cluster remains unclear. The observed bright Fe Kα line emission at 6.4 keV from material that is neutral or in a low ionization state can be produced either by X-ray photoionization or by cosmic-ray particle bombardment (or both). Previously, the lack of observations above 10 keV did not allow for a definitive conclusion about the ionizing mechanism that causes the X-ray fluorescence. In this paper we report on the first detection of the extended emission around the Arches cluster above 10 keV with the NuSTAR mission and present results on its morphology and spectrum. The spatial distribution of the hard X-ray emission around the Arches cluster is found to be consistent with the broad region around the cluster where the 6.4 keV line is observed. The interpretation of the hard X-ray emission with the X-ray reflection model puts a strong constraint on the luminosity of the possible illuminating hard X-ray source. On the other hand, the properties of the observed emission are in broad agreement with the low-energy cosmic-ray proton excitation scenario.

Devaky Kunneriath (Astronomical Institute Prague)

Rainer Schödel, Susan Stolovy, Anja Feldmeier

P42. Structure of the NSC of the Milky Way Galaxy

Nuclear star clusters are unambiguously detected in about 50-70% of spiral and spheroidal galaxies. They have typical half-light radii of 2-5 pc, dynamical mass ranging from 10^6 - 10^7 $M_\odot$, are brighter than globular clusters, and obey similar scaling relations with host galaxies as supermassive black holes. The Nuclear Stellar Cluster (NSC) which surrounds Sgr A*, the SMBH at the centre of our galaxy, is the nearest nuclear cluster to us, and can be resolved to scales of milliparsecs. The strong and highly variably extinction towards the Galactic Centre makes it very hard to infer the intrinsic properties of the NSC (structure and size). We attempt a new way to infer its properties by using Spitzer MIR images in a wavelength regime (3-8 μm) where the extinction is at a minimum, and the NSC clearly stands out as a separate structure. We present results from our analysis, including extinction-corrected images and surface brightness profiles of the central few hundred parsecs of the Milky Way.

Ryan Lau (Cornell)

T. L. Herter (Cornell), M. R. Morris (UCLA), J. D. Adams (Cornell)

P43. SOFIA/FORCAST Observations of the Luminous Blue Variables Located in and near the Quintuplet Cluster

Three Luminous Blue Variables (LBVs) are located in the vicinity of the Quintuplet Cluster in the Galactic Center: the Pistol star, G0.120-0.048, and qF362. We present imaging at 19, 25, 31, and 37 μm of the region containing these three LBVs obtained with SOFIA using FORCAST. We study the similarities and differences between the three LBVs and address the influence of the hot, massive stars in the adjacent Quintuplet Cluster and the local ambient medium in affecting the morphology, composition, and energetics of dust in the nebulae produced from their outflows. We observe the thermal emission from the Pistol nebula, the asymmetric, compressed shell of hot dust surrounding the Pistol star and provide the first detection of thermal emission from the symmetric, hot dust envelope surrounding G0.120-0.048. However, we do not detect any emission from hot dust surrounding qF362. The Pistol and G0.120-0.048 nebulae share an identical size scale of ˜ 0.7 pc which suggests that they have similar dynamical timescales (˜ 8000 yrs) assuming similar expansion velocities of ˜ 90 km/s. The Pistol nebula exhibits a temperature gradient decreasing from north to south with values ranging from 90 - 120 K. The G0.120-0.048 nebula, which is spherically symmetric about the star, exhibits an average dust temperature of ˜76 K. Fits to the spectral energy distribution (SED) of the Pistol nebula with the DustEm Radiative Transfer code indicate that the nebula is composed of separate distributions of big grains (˜0.075 μm) and small grains (˜10^{-3} μm). DustEm model fits to the SED of the G0.120-0.048 nebula suggest that it is solely composed of a single grain size distribution of big grains (˜0.4 μm). The models predict that the Pistol and G0.120-0.048 nebulae have a total gas mass of ˜$2.7M_\odot$ and ˜$4.5M_\odot$ (assuming $M_g/M_d = 100$), and a total IR luminosity of ˜8×10^5 $L_\odot$ and ˜1.2×10^5 $L_\odot$, respectively.

William Lucas (University of St Andrews)

Ian Bonnell (University of St Andrews), Melvyn Davies (Lund Observatory), Ken Rice (University of Edinburgh)

P44. Forming Misaligned Stellar Discs around a Massive Black Hole: Cloud Infall in the Galactic Centre

The innermost parsec around Sgr A* has been found to play host to two discs or streamers of O and W-R stars. They are misaligned by an angle approaching 90°. That the stars are approximately coeval indicates that they formed in the same event rather than independently. We have performed SPH simulations of the infall of a single prolate cloud towards a massive black hole. As the cloud is disrupted, the large spread in angular momentum can, if conditions allow, lead to the creation of misaligned gas discs. In turn, stars may form within those discs.

Francisco Najarro (Centro de Astrobiologia CSIC-INTA, Torrejon de Ardoz, Spain)

D. de la Fuente (Centro de Astrobiologia CSIC-INTA, Torrejon de Ardoz), T.R. Geballe (Gemini Observatory, Hilo), D.F. Figer (Rochester Institute of Technology)

P45. Metallicity Studies of the Galactic Center: Evidence for a Top-heavy Star Formation History?

The Galactic Center (GC) region hosts three of the most massive resolved young clusters in the Local Group and constitutes a test bed for studying the star formation history of the region and inferring the possibility of top-heavy scenario by means of measuring the alpha-elements and iron absolute abundances and their corresponding ratios. We have developed two different techniques to derive metallicity from infrared observations of LBVs and WR stars. For LBVs, absolute alpha-elements (Si, Mg) and iron abundances may be obtained while for WRs it is possible to derive the alpha-element (oxygen) abundance of the natal cloud. We present results from our ongoing study of the clusters and isolated massive stars in the inner Galactic Center region aiming to extract stellar properties, ages, and abundances and hence address the top-heavy star formation history question.

Masato Tsuboi (ISAS/JAXA)

A. Miyazaki (KASI), T. Handa (Kagishima Univ.)

P46. Cloud-Cloud Collision in the Sagittarius B2 Molecular Cloud Complex

In recent two decades, the young and highly luminous clusters have been found by IR observations in the CMZ. Although it is an open question as to what mechanism is responsible for the formation of such super star clusters in the region, the dense, warm, and turbulent molecular clouds in the CMZ are presumably the cradles of these clusters. The Sgr B2 molecular cloud complex is a most remarkable substructure of the CMZ. We performed simultaneous observations of the molecular cloud complex in SiO J=2-1 and $H^{13}CO^+$ J=1-0 emission lines using the NRO 45-m telescope. We found a filled center and circular feature in the cloud complex, which is centered around l ˜ 0.67d, b ˜ − 0.12d and has a diameter of 20 pc. The central part of the feature has very high $T(SiO)/T(H^{13}CO^+)$ ratio up to ˜ 8, while the ratio on the outer part is 2 − 3. This shows that vast shocked molecular gas exists in the central part. The central part has shifted and wider velocity component rather than the outer part. This suggests that the part is the site of cloud-cloud collision. Because the CMZ is very crowding, the cloud-cloud collision hypothesis for active star formation sounds convincing. A cloud-cloud collision in the cloud complex had been proposed based on the morphology and kinetic features (Hasegawa et al. 1994). The cloud-cloud collision mentioned above is another candidate in the complex.

Session 5: Astrophysics and Feedback in the Sgr A* Environment and in other Galactic Nuclei

Pedro Paulo B. Beaklini (Universidade de São Paulo)

Zulema Abraham

P47. Sgr A* Emission at 7 mm: Variability and Periodicity

We present the result of 7 yr monitoring of Sgr A*, radio source associated with the supermassive black hole at the centre of the Milky Way. Single dish observations were performed with the Itapetinga radio telescope at 7 mm, and the contribution of the Sgr A Complex that surrounds Sgr A* was subtracted and used as instantaneous calibrator. The observations were alternated every 10min with those of the H II region Srg B2, which was also used as a calibrator. The reliability of the detections was tested comparing them with simultaneous observations using interferometric techniques. During the observing period we detected a continuous increase in the Sgr A* flux density starting in 2008, as well as variability in time-scales of days and strong intraday fluctuations. We investigated if the continuous increase in flux density is compatible with free–free emission from the tail of the disrupted compact cloud that is falling towards Sgr A*. Recently, observations at same frequency of NRAO VLA service monitoring of Sgr A* reveal a flux density 1.8 Jy lower from what we detected at the same epoch. We believe that this difference can be attributed to the cloud emission that is also detected in our beam. Statistical analysis of the light curve using Stellingwerf and structure function methods after subtract this increase revealed the existence of two minima, 156 ffi 10 and 220 ffi 10 days. The same statistical tests applied to a simulated light curve constructed from two quadratic sinusoidal functions superimposed to random variability reproduced very well the results obtained with the real light curve, if the periods were 57 and 156 days. Moreover, when a daily sampling was used in the simulated light curve, it was possible to reproduce the 2.3 GHz structure function obtained by Falcke in 1999, which revealed the 57 days period, while the 106 periodicity found by Zhao et al. in 2001 could be a resonance of this period.

Guillaume Belanger (ESA)

P48. On Detecting Transient Phenomena

Transient phenomena are interesting and potentially highly revealing of details about the processes under observation and study that could otherwise go unnoticed. It is therefore important to maximize the sensitivity of the method used to identify such events. In this article, we present a general procedure based on the use of the likelihood function for identifying transients which is particularly suited for real-time applications because it requires no grouping or pre-processing of the data. The method makes use of all the information that is available in the data throughout the statistical decision-making process, and is suitable for a wide range of applications. Here we consider those most common in astrophysics, which involve searching for transient sources, events or features in images, time series, energy spectra, and power spectra, and demonstrate the use of the method in the case of a weak X-ray flare in a time series and a short-lived quasi-periodic oscillation in a power spectrum. We derive a fit statistic that is ideal for fitting arbitrarily shaped models to a power density distribution, which is of general interest in all applications involving periodogram analysis.

Marvin Blank (U Kiel)

Wolfgang J. Duschl (U Kiel / Steward Observatory, U Arizona)

P49. Viscous Time Lags between Starburst and AGN Activity

Recent observations indicate a time lag of order of some 100 Myr between starburst and AGN activity in galaxies. Dynamical time lags have been invoked to explain this. We extend this approach by introducing a viscous time lag the gas additionally needs to flow through the AGN's accretion disc before it reaches the central black hole. Our calculations reproduce the observed time lags and are in agreement with the observed correlation between black hole mass and stellar velocity dispersion.

Maïca Clavel (U Paris)

P50. New Results from the 2012 NIR / X-ray Observation Campaign on the Sgr A* Flaring Activity

Sgr A*, the supermassive black hole at the Galactic Center, is presently in a very quiet state with a persistent X-ray emission that levels off at less than the bolometric luminosity of the sun. However, Sgr A* also displays a flaring activity in both X-ray and infrared frequencies, which allows us to probe the processes occurring near its event horizon.

In March 2012 we performed 5 half nights of observations to monitor Sgr A* simultaneously with XMM-Newton and VLT/NACO. The aim of the campaign was to characterize the spectral shape of the source during its flares in both the X-ray (2-10 keV) and the Near-IR (H, Ks, L' and M filters) bands in order to study the physical processes at work during these events. I will present the results from this observation campaign which allowed us, in particular, to measure the lightcurve of Sgr A* in different NIR bands during several low/mid-intensity flares.

Patrick Crumley (University of Texas at Austin)

P Kumar (University of Texas at Austin)

P51. Radio Emission from Bow-shock of G2

The radio flux from the synchrotron emission of electrons accelerated in the forward bow shock of G2 is expected to peak when the forward shock passes pericenter, possibly 7 to 9 months before the center of mass of G2 reaches pericenter at the Galactic Center. I will present calculations of the radio emission from the forward and reverse shock if G2 is a momentum-supported bow shock of a faint star with a high mass-loss rate as suggested by Scoville & Burkert (2013); Ballone et al. (2013). We find that if G2 is the wind of a star, the radio flux lies well below the quiescent radio flux of Sgr A* and will be difficult to detect. By contrast, in the cloud model of G2, the radio flux of the forward shock is predicted to be much larger than the quiescent radio flux and therefore should have already been detected or will be detected shortly (Narayan et al. 2012; Sadowski et al. 2013b). Therefore, radio measurements can reveal the nature of G2 well before G2 completes its periapsis passage.

Nathalie Degenaar (University of Michigan)

P52. The Swift Monitoring Campaign of the Galactic Center

Starting in 2006, the Galactic Center has been monitored on a nearly daily basis with the X-ray telescope on-board the Swift satellite. The short pointed observations have offered a unique view of the long-term X-ray behavior of Sgr A*, in particular of its X-ray flaring properties. The Swift campaign also provides an excellent setup to closely monitor the interaction of the supermassive black hole with the dense cold gas cloud G2. Because of the unique daily sampling, the Swift program may prove to serve as an important trigger for other observatories at different wavelengths. I will present the results of 8 years of Swift X-ray monitoring of Sgr A*, and discuss how this campaign can be used to study the X-ray emission as G2 breaks up and feeds gas to the supermassive black hole.

P. Chris Fragile (College of Charleston)

Peter Anninos (LLNL), Stephen D. Murray (LLNL)

P53. 3D Moving Mesh Simulations of Galactic Center Cloud G2

Using three-dimensional, moving-mesh simulations, we investigate the future evolution of the recently discovered gas cloud G2 traveling through the galactic center. From our simulations we expect an average feeding rate in the range of $(5-19) \times 10^{-8}$ solar masses per year beginning in 2014. The accretion varies by less than a factor of three on timescales ~1 month, and shows no more than a factor of 10 difference between the maximum and minimum observed rates within any given model. These rates are comparable to the current estimated accretion rate in the immediate vicinity of Sgr A*, although they represent only a small (< 10%) increase over the current expected feeding rate at the effective inner boundary of our simulations ($r = 750\ R_S \sim 10^{15}$ cm), where R_S is the Schwarzschild radius of the black hole. We also produce Br-γ images and light curves from our simulation data, which can be compared directly with observations. Because of tidal compression normal to the orbital plane, all of our models predict significant (factor of 10) enhancements in the Br-γ luminosity of G2 as it approaches pericenter, in conflict with the observational trend of constant luminosity. This puzzle suggests there must be some inconsistency in the assumptions made in our simulations, which we discuss.

Vladimir Karas (Astronomical Institute Prague)

Jaroslav Hamersky (Astronomical Institute Prague / Charles University in Prague)

P54. Effects of Magnetic Field on the Runaway Instability of Relativistic Accretion Tori Near a Rotating Black Hole

Runaway instability operates in accretion tori around black holes, where it affects systems close to the critical (cusp overflowing) configuration. The runaway effect depends on the radial profile l(R) of the angular momentum distribution of the fluid, on the dimension-less spin a of the central black hole ($|a| <= 1$), and other factors, such as self-gravity. Previously it was demonstrated that for the power-law dependence of the radial angular momentum profile, $l(R) \sim R_q$, non-magnetized tori always become runaway stable for a sufficiently high positive value of q. Here we discuss the role of runaway instability within a framework of an axially symmetric model of perfect fluid endowed with a purely toroidal magnetic field.

The gradual accretion of material over the cusp transfers the mass and angular momentum onto the black hole, thereby changing the intrinsic parameters of the Kerr metric. We studied the effect of the plasma parameter beta (ratio of gas to magnetic pressure) and other parameters of the model on the evolution of critical configurations that happen to be just on the verge of cusp overflow.

By contributing to the total pressure, the magnetic field causes small departures from the corresponding non-magnetic configuration in the early phases of accretion. However, we show that the toroidal magnetic component inside an accretion torus does not change the frequency of its oscillations significantly. We identify these oscillations as the radial epicyclic mode. These weak effects can trigger the runaway instability even in situations when the purely hydrodynamical regime of the torus is stable. We discuss examples of the torus evolution depending on the initial magnetization beta, the slope q, and the spin a. Based on a recent paper (A&A 555, id. A32, 2013; arXiv:1305.6515), these calculations are relevant for understanding the accretion process in the inner regions of accretion flows.

Karl Kosack (CEA Saclay)

P55. The Unidentified Galactic Center VHE Gamma-ray Source and its Light-curve during Chandra Sgr A* Flares

We present an overview of Very-High-Energy (VHE) gamma ray observations with the HESS telescope of the Galactic Center, at the position of Sgr A*, including an updated long-term light-curve. The observations, which now span from 2004 through 2012, cover periods during which X-ray flares were observed by Chandra. Though the X-ray observations indicate that the keV flaring is connected to accretion events in black-hole system, the origin of the VHE emission is still not understood, and may arise from a different emission region or even be unrelated to Sgr A*. We explore the possibility of a connection between the X-ray and TeV emission by looking for evidence for TeV variability in our latest data set.

Devaky Kunneriath (Astronomical Institute Prague)

Bozena Czerny, Vladimir Karas, Tapas K. Das

P56. Multiple Accretion Events as a Trigger for Sagittarius A* Activity

Gas clouds are present in the Galactic Centre, where they orbit around the supermassive black hole. Collisions between these clumps reduce their angular momentum, and as a result some of the clumps are set on a plunging trajectory. Constraints can be imposed on the nature of past accretion events based on the currently observed X-ray reflection from the molecular clouds surrounding the Galactic Centre.

We discuss accretion of clouds in the context of enhanced activity of Sagittarius A* during the past few hundred years. We put forward a scenario according to which gas clouds bring material close to the horizon of the black hole on ≤0.1 parsec scale. We applied our scheme to the case of G2 cloud in the Galactic Centre to obtain constraints on the core-less gaseous cloud model. This poster is based on our recently published paper (A&A 555, A97 2013).

Zhiyuan Li (NJU/UCLA)

Mark R. Morris (UCLA), Frederick K. Baganoff (Kavli, MIT)

P57. Evidence for A Parsec-scale Jet from The Galactic Center Black Hole: Interaction with Local Gas

Despite strong physical reasons that they should exist and decades of search, jets from the Galactic Center Black Hole, Sgr A*, have not yet been convincingly detected. Based on high-resolution Very Large Array images and ultra-deep imaging-spectroscopic data produced by the Chandra X-ray Observatory, we report new evidence for the existence of a parsec-scale jet from Sgr A*, by associating a linear feature G359.944-0.052, previously identified in X-ray images of the Galactic Center, with a radio shock front on the Eastern Arm of the Sgr A West HII region. We show that the shock front can be explained in terms of the impact of a jet having a sharp momentum peak along the Galaxy's rotation axis, whereas G359.944-0.052, a quasi-steady feature with a power-law spectrum, can be understood as synchrotron radiation from shock-induced ultrarelativistic electrons cooling in a finite post-shock region downstream along the jet path.

Atsushi Miyazaki (Korea Astronomy and Space Science Institute)

S.-S. Lee, B.W. Sohn, T.-H. Jung (KASI), M. Tsuboi (ISAS/JAXA), T. Tsutsumi (NRAO)

P58. Search for Time Lag in Intra-day Variability of Sgr A*

We searched the time lag between the intra-day variabilities (IDVs) of Sagittarius A* in the 22, 43, and 86 GHz bands using the Korean VLBI Network (KVN) in the winter of 2013. The time lags between the IDV flare peaks at 22 and 43 GHz have been reported, and they suggest that the flare emissions come from adiabatically expanding plasma blobs ejected close to the Galactic center black hole. We searched the time lag between light curves at 90 and 102 GHz using the Nobeyama Millimeter Array (NMA), but could not find such significant time lag. This result suggests that plasma blobs may be widely diverse, especially in optical thickness. In order to detect the diversity of the time lag of Sgr A* flare, we performed observations of Sgr A* in the 22, 43, and 86 GHz bands using the KVN. Because the receiver system of the KVN can observe Sgr A* in these three bands simultaneously, the KVN is very useful to detect the time lag of Sgr A* flare. We would like to report about the results of the NMA and the new KVN observations.

Masayoshi Nobukawa (Kyoto University)

Syukyo G. Ryu (Kyoto University), Takeshi Go Tsuru (Kyoto University), Katsuji Koyama (Kyoto University)

P59. The Past Millennium History of Sagittarius A* Deciphered by X-ray Reflection Nebulae

One of the most interesting phenomena in the Galactic Center region is FeI Ka (6.4 keV) and hard X-rays from giant molecular clouds, which were discovered by past X-ray observatories (e.g. Koyama et al. 1996; Yusef-Zadeh et al. 2007). In order to generate the X-rays, huge energetic injection into the molecular clouds is required. Past X-ray flares of the super-massive black hole, Sagittarius A*, have been proposed as the origin (Nobukawa et al. 2010, 2011; Ponti et al. 2010). However, the detailed history of the past activity has been open issue because measurement of relative positions, in particular in the line of sight, between a molecular cloud and the super-massive black hole has large uncertainty.

High temperature plasma (kT˜1 and 7 keV) distributes over the Galactic Center region. We found that a part of the X-ray emission from the plasma suffers from interstellar absorption due to a molecular cloud in line of sight. The ratio of the plasmas in front of and behind the molecular cloud indicates the relative position. We adopted the method to molecular clouds in Sagittarius B and C regions, and reconstructed the 3-Dimensional position map in the Galactic Center only by the X-ray observational result (Ryu et al. 2009; 2013). In addition, we detected decreasing and increasing X-ray emission in several years from the molecular clouds (Nobukawa et al. 2011; Ryu et al. 2013). From the results, we deciphered that Sagittarius A* had been active from about 1000 to 50 years ago, and flared up at least twice in the duration.

Kristina Nyland (New Mexico Tech)

Katherine Alatalo (UC – Berkeley / Caltech), Lisa M. Young (New Mexico Tech), J. M. Wrobel (NRAO), Raffaella Morganti (Netherlands Institute for Radio Astronomy / University of Groningen), Timothy A. Davis (ESO), P. T. de Zeeuw (ESO / Leiden University), Susana Deustua (STScI)

P60. Detection of a High Brightness Temperature Radio Core in the AGN-Driven Molecular Outflow Candidate NGC 1266

We present new high spatial resolution VLA HI absorption and VLBA continuum observations of the AGN-driven molecular outflow candidate, NGC 1266. Although other well-known systems with molecular outflows may be driven by star formation in the central molecular disk, the molecular mass outflow rate in NGC 1266 of 13 M_{sun}/yr reported in Alatalo et al. (2011) exceeds star formation rate estimates from a variety of tracers. This suggests that an additional energy source, such as an AGN, may play a significant role in powering the outflow. The high spatial resolution HI absorption data reveal compact absorption against the radio continuum core co-located with the putative AGN, and the presence of a blueshifted spectral component re-affirms that gas is indeed flowing out of the system. The VLBA observations at 1.65 GHz revealed one continuum source within the densest portion of the molecular gas with a diameter $d < 8$ mas (1.2 pc), a radio power of $\log(P_{rad}) = 20.17$ W/Hz and a brightness temperature $>1.5 \times 10^7$ K that is most consistent with an AGN origin. The radio continuum energetics implied by the compact VLBA source, as well as archival VLA continuum observations at lower spatial resolution, support the possibility that the AGN in NGC 1266 could be driving the molecular outflow. These findings suggest that even low-level

AGNs, with supermassive black hole masses similar to Sgr A*, may be able to launch massive outflows in their host galaxies.

Thibaut Paumard (LESIA - CNRS / Observatoire de Paris)

P61. Science with GRAVITY, the NIR Interferometric Imager

10-m class telescopes have brought a wealth of advances in high resolution science: orbits of stars in the Galactic Center, morphology of Active Galactic Nuclei, imaging of protostellar accretion disks are but a few of them. The very same telescopes used in interferometric mode and equipped with new instrumentation will provide us with another order of magnitude in spatial resolution and even more in astrometric accuracy. We are currently building GRAVITY, a second generation instrument for the VLT Interferometer. We summarize the basic instrumental concepts behind GRAVITY as well as the many science cases that the instrument will undertake.

Marc Schartmann (USM/MPE Munich)

A. Burkert, A. Ballone, C. Alig, S. Gillessen, R. Genzel, F. Eisenhauer, T. Fritz

P62. Hydrodynamical Simulations of G2 Interpreted as a Diffuse Gas Cloud

Recently the dust and gas cloud ”G2” was discovered on a highly eccentric orbit around the massive black hole in the Galactic Center. The orbit will bring the cloud as close as 2400 Schwarzschild radii to Sgr A* end of 2013 to beginning of 2014. With the help of hydrodynamical simulations using the PLUTO code, we investigate possible origins and the fate of the cloud in the coming years. I will concentrate on a scenario where G2 is interpreted as a diffuse gas cloud and show detailed comparisons to available observations. The near future evolution of the cloud will be a sensitive probe of the conditions of the gas distribution in the milli-parsec environment of the massive black hole in the Galactic Center and will also give us invaluable information of the feeding of black holes and the activation of the central source.

Loránt Sjouwerman (NRAO)

Claire Chandler (NRAO)

P63. NRAO VLA service Monitoring Observations of the Interaction between Sgr A* and G2

We report on an ongoing community service observing program to follow the expected encounter of the G2 cloud with the black hole Sgr A* in 2013. The Karl G Jansky Very Large Array is observing the Sgr A region since 2012 October on roughly a bi-monthly interval, each for two hours, cycling through the standard observing bands at their default 8-bit (i.e., up to 2 GHz bandwidth) continuum frequencies. The data from the monitoring program are publicly available through the NRAO data archive immediately after observing has completed, and the flux densities are published by NRAO staff as soon as the data are reduced. The cumulative results of the monitoring effort are posted on the service observing web page https://science.nrao.edu/science/service-observing and so far do not indicate a significant brightening of the emission from the direction of Sgr A* over the period 2012 October to 2013 August, within the calibration uncertainties.

Shunya Takekawa (Keio University)

T. Oka, M. Sekido

P64. Flux Monitoring Observations of Sgr A* at 8 GHz and 2 GHz with the NICT Kashima-Koganei VLBI System

We are conducting flux monitoring observations of Sgr A* at 8 GHz and 2 GHz using the NICT Kashima-Koganei VLBI system (109 km baseline) since the middle of February 2013 (ATel#5024). The primary objective of the monitoring is a search for flux variation which is expected to be caused by the interaction between the G2 cloud and the accretion disk. Until July 15 2013, we obtained fluxes for 35 days, five hours on each day. Four quasars including NRAO530 are also observed as flux calibrators every 6 minutes. No significant change or variation has been detected in the 8 GHz flux density of Sgr A* yet. The 8 GHz flux density was 0.48±0.05 Jy (preliminary), while no significant 2 GHz emission was detected by our system. We will continue these monitorings as often as possible until at least May 2014. In this poster contribution, we will present the result of our flux monitorings until late September.

Virginia Trimble (U California Irvine & LCOGT)

P65. The Galactic Center from Herschel (William) to Sgr A*

Very long ago, we were at the center of a small, 6000-year old cosmos. More interestingly, from about 1780, William Herschel placed us at the center of a 1000-pc or so Milky Way, probably (and acceptably so to Newton) of infinite age. A hundred years later, we were still there, according to Simon Newcomb (first president of the AAS and arguably the model for Prof. Moriarty), with the realm of the stars in a plane and the realm of the nebulae on either side. Most fun, perhaps, are the galaxies of Cornelis Easton (with the solar system at the center but a spiral arm pattern centered some distance away) and of Alfred Russel Wallace (Darwin's rival; with the solar system at a unique, not-quite-central "Goldilocks" spot). World War I had come and gone (with some of our colleagues in the trenches or trying to get there) before Harlow Shapley succeeded in dragging us out of the center of a Galaxy that he thought was the entire universe, and considerably larger than modern numbers indicate. His exaggerated distance scale fed into an impossibly small age for the universe, and it took the advent of radio astronomy to clarify the size of the Milky Way, its rotation rate, and the precise location of its dynamical center.

Sascha Trippe (Seoul National University)

P66. Interferometric Monitoring of Sagittarius A* with KVN, VERA, and GMVA

Interferometric radio observations, reaching angular resolutions on scales of milliseconds of arc, are essential for addressing the accretion physics of Sgr A* - especially in view of the current G2 pericenter passage / infall event. A combination of high angular resolution, spectral (multi-band) resolution, good time resolution, and polarimetry makes radio interferometers "plasma physics observatories". I present various observation programs aimed at Sgr A* recently initiated at the KVN (Korea), VERA (Japan), and GMVA (global mm-VLBI) radio arrays. We obtained first radio maps in 2012 with KVN+VERA; future, improved observations are supposed to have sensitivities compatible with, and UV coverages superior to, the VLBA. GMVA observations are scheduled for October 2013 using four European stations and aiming at fast (down to time scales of days) structural and polarimetric variability; these observations are supposed to unveil variations related to violent accretion events.

Masato Tsuboi (ISAS/JAXA)

The Sgr A* Daily Monitor Team

P67. Daily Monitor of Sgr A* at 22 GHz with the Japanese VLBI Network

We have been monitoring the flux density of Sgr A* at 22 GHz since 11 Feb. 2013 with a sub-array of Japanese VLBI Network (ATEL#4923, #5013, #5184) in order to search the increase of 22-GHz emission from Sgr A* induced by the interaction of the G2 cloud with the accretion disk (Gillessen et al. 2012, Nature, 481, 51).

The sub-array mainly consists of Mizusawa 10-m RT, Takahagi 32-m RT, and Gifu 11-m RT. Some other antennas had joined it occasionally. Because the projected baselines are 90-140 km, the array can observe the flux density of Sgr A* itself suppressing the contamination from the surrounding extended structure and the flux density decrease by partially resolved-out.

The fringes have been detected almost daily except rainy days although the on-source observation time of Sgr A* is only 10 minute per day. The flux densities observed until 9 July are consistent with the previously observed values. We have detected no large flare by the approaching G2 cloud in the period. The monitor will be continued until May 2014.

Takahiro Tsutsumi (NRAO)

A. Miyazaki (KASI), M. Tsuboi (ISAS/JAXA)

P68. Characteristics of Millimeter Variability of Sgr A*

We present the analysis of flux variations of Sgr A* at millimeter wavelengths based on the long-term monitoring project spanning over a decade using the Nobeyama Millimeter Array. The data were collected between 1996 and 2008 at 2- and 3-mm showing both quiescent and flaring states. We investigate basic characteristics of the flux variability using some standard parameterizations of the data. Such basic properties of the flux variations in the mm-regime can provide valuable information not only for its underlying mechanisms in general but also for understanding observed radio/mm flux measurements during an accretion event.

Session 6: High Energy and Magnetic Processes, Strong Gravity and Dark Matter in the Galactic Center

Wladimir Banda-Barragan (Australian National University)

Ross Parkin, Geoffrey Bicknell, Roland Crocker, Ralph Sutherland - (ANU)

P69. MHD Simulations of Shocks Interacting with Non-Uniform Clouds: Application to the Galactic Centre Non-Thermal Radio Filaments

The interaction between shocks and non-uniform clouds in the interstellar medium has not been thoroughly studied in the past. Here we present a section of the first comprehensive numerical work along this line which is relevant to understanding the formation and peculiar characteristics of the mysterious Non-Thermal Radio Filaments in the Galactic Centre. We explain the Non-Thermal Filaments as due to the interplay between outflows driven by localised star formation and fractal clouds in the surrounding medium. In order to test this hypothesis, a set of two-dimensional and three-dimensional hydrodynamical and magneto-hydrodynamical simulations was carried out with typical parameters of the Galactic Centre interstellar medium as initial conditions. We found that low-density regions inside non-uniform clouds are easily disrupted by the Kelvin-Helmholtz instability while the densest cloud cores are deformed and elongated by the hot wind, thereby surviving longer. The magnetic field strength in cloud gas is amplified due to field compression and pressure gradients arising from cloud material cooling at different temperatures. A magnetised wake with a mix of cloud and ambient material forms and the amplified magnetic field is advected by the flow downstream. The magnetic field in the wake is confined to linearly-shaped regions of low thermal pressure and remains fairly parallel to the direction of the flowing gas, thus resembling the filaments observed at the Galactic Centre. Gas cooling and different magnetic field topologies were introduced into the code in a systematic way to shed light on the processes leading to cloud disruption and the evolution of instabilities under distinct conditions. The Rayleigh-Taylor and Richtmyer-Meshkov instabilities drive the evolution in adiabatic simulations, but they are suppressed once cloud material is allowed to radiate. Gas cooling significantly increases the clouds' lifetime and leads to the formation of longer filamentary structures when it is taken into consideration. Magnetic fields help stabilise the inner structure of clouds by providing additional pressure and are key to modeling and explaining the radio emission from these structures. A collection of filaments with various morphologies were found, and their shape, lifespan and magnetisation parameters are all consistent with those attributed to the Non-Thermal Filaments from observations.

Roland Crocker (ANU)

P70. The Implications of the Giant Magnetised Outflows from the Centre of the Milky Way

The S-band Polarisation All Sky Survey (S-PASS) has uncovered giant, highly-magnetized radio lobes extending 60 degrees north and south of the plane and coincident with the Fermi Bubbles. In this talk I will review the evidence that these structures are energized by nuclear star-formation rather than by activity of the central supermassive black hole. I will also discuss the long, collimated, and highly magnetized filaments that seem to wrap around the outside of the lobes and, in particular, seem to

be connected to the formation and subsequent orbital history of the giant stellar clusters inhabiting the Galactic Centre.

Ernst A. Dorfi (Institut für Astrophysik, Universität Wien)

Daniel Steiner (Institut für Astrophysik, Universität Wien)

P71. High-energy Particles from SN-explosions near the Galactic Center

Several Supernovae exploding in a compact cluster of massive stars generate a galactic outflow with embedded shock waves. Based on numerical simulations for an expanding superbubble above the Galactic Center we find that these individual waves generated by the repeated SN-explosions, interact with each other and finally coalesce into a single strong shock at a distance of a few kpc above the galactic plane at about 10^7 years after outbreak. The resulting shock with a Mach number M $\simeq$10 propagates up to 100 kpc in less than 2 x 10^8 years. The time-dependent mass an energy loss out of the superbubble affects the further evolution of the outflow and we trace this evolution up to several 10^8 years. In such long lasting shock waves energetic particles can be accelerated above the knee of 10^{15} eV already near the galactic plane by a 1.- order Fermi-mechanism. The additional pressure gradients from such cosmic rays lead to further accelerations of the galactic outflow since these ultrarelativistic particles suffer less from the adiabatic losses than the thermal gas. Depending on the initial background structure we find solutions where the galactic outflow ceases shortly after the last SN-explosion because the reverse shock has propagated back to the galactic superbubble.

Namir Kassim (NRL)

Scott Hyman (SBC), Sean Cutchin (NRL-NRC), Joseph Lazio (JPL-Caltech), Paul Ray (NRL)

P72. A New Era for Low Frequency Galactic Center Transient Monitoring

A new VLA meter-wavelength Low Band observing system offers significantly higher sensitivity (> 5X) and frequency coverage (> 10X) than previously available for VLA Galactic Center (GC) transient monitoring. Moreover, a proposed VLA commensal system (Low Band Observatory or LOBO), operating in parallel with all higher frequency observing, would increase annual GC low frequency monitoring significantly. Combined with transient rates deduced from our previous blind surveys with the VLA and GMRT, projections point to future significantly increased detection rates. Complimented by monitoring capabilities provided by emerging instruments of the Long Wavelength Science Consortium, including the co-located Long Wavelength Array (LWA) and Low Frequency All-sky Monitor (LoFASM) stations, the new capabilities offer simultaneous transient monitoring over more than 20 octaves of frequency. We present early, illustrative test observations from our commencing GC monitoring campaign using the new VLA Low Band system, and also from a pilot study using the first LWA station (LWA1). We also review our search for enhanced low frequency radio emission from the G2 cloud passage, including observations with the GMRT.

Cornelia Lang (U Iowa)

James Toomey (U Iowa), Dominic Ludovici (U Iowa), Ann Mao (UW-Madison), Mark Morris (UCLA)

P73. The Nature and Origin of the Galactic Center Radio Arc: A VLA Faraday Study

Despite their discovery almost 30 years ago, the origin of the Galactic Center nonthermal filaments (NTFs) remains poorly understood. The prominent Radio Arc NTFs have an unusually flat spectrum in the centimeter to millimeter spectrum with a predicted turn over between 30-200 GHz, but this has not been well constrained. The improved spectral and wideband capabilities of the VLA provide a fantastic opportunity to make a multifrequency spectral and Faraday study of the Radio Arc. We have observed the Radio Arc at a set of lower frequencies (S, C, X) in order to image both the total and polarized intensity distributions at high angular resolution (2") with continuous coverage from 2-12 GHz. In addition, we have observed the Radio Arc at Ka and Q band up to 45 GHz to determine the spectrum and the high frequency polarization properties. The improved spectral resolution of the VLA will allow us for the first time to carry out a complete RM synthesis of the NTFs and determine the RM distribution and B-field on unprecented spatial scales. Here we present preliminary results from observations made in May and Sept 2013 using the DnC and CnB array configurations. Ultimately, these observations will serve as a pilot polarization study for larger, more complete polarimetric surveys of the Galactic center region.

Resha Parajuli (Clemson University)

Dieter Hartmann (Clemson University)

P74. Black Holes and Galaxy Co-evolution: Milky Way in Context

Almost all galaxies harbor a supermassive black hole at their center. By use of the Virial theorem, it is possible to relate the velocity dispersion (σ) of the galaxy to the mass, M, of the central black hole. The observed tight M-σ relation suggests a causal co-evolution process. We examined a particular co-evolution model (Cen 2012) which suggests that the bulge and its associated super-massive black hole grow in tandem. Parameters such as a galaxy's star formation rate, black hole accretion rate, and their associated histories need to be determined to appraise the validity of such a model. It is known that the Milky Way has had a quiescent center in its recent past. Considering its massive central black hole and an average feeding rate of a mere 10^{-5} $M_{\odot}$ per year, it seems likely that there must have been periods of gas rich events for it to achieve its current mass. My goal is to examine the various ways a quiescent central black hole may feed and the observational signatures associated with them. The Milky Way center, its feeding habits and its current stance, provide useful guidance, and a detailed study of the accretion dynamics of the Galactic center can be used to compare with extragalactic nuclei. I am devising an optimized observational survey to monitor black hole feeding events across galaxies in the local Universe, and determine the survey properties needed for conclusive insights into the mystery of how the ensemble of black holes feed, and how this behavior is related to the properties of their host galaxies.

Matthew Rickert (Northwestern University)

F. Yusef-Zadeh (Northwestern University), C. Brogan (NRAO)

P75. MHz Radio Continuum Observations of the Inner 13 x 7 degrees of the Galactic Center

We present high resolution (114" x 60") 74 MHz multi-configuration VLA observations of the Galactic Center (GC) spanning the inner 13 x 7 degrees. 74 MHz observations allow for the probing of low energy cosmic ray electrons via synchrotron emission, and can be used to show interactions between these electrons and molecular clouds. Accurate knowledge of these electron distributions is important due to the role that cosmic rays play in star formation and can be useful in explaining the origins of gamma and X ray observations. Unlike higher frequencies, 74 MHz is ideal for distinguishing between these synchrotron sources and thermal sources. At higher frequencies the emission from these different sources can overlap and be difficult to distinguish. At 74 MHz the frequency dependence of free-free absorption causes thermal sources to appear opaque and show up as absorption of the bright diffuse nonthermal emission from the GC, while nonthermal synchrotron sources appear as bright emission. We identify and catalog a list of absorption and emission features in this region, three of the more prominent sources are: the molecular cloud G0.13-0.13, Sgr D, and the Omega Lobe. We compared our 74 MHz observations with 330 MHz observations and determined the spectral index distributions. From this we were able to identify that G0.13-0.13 is physically associated with relativistic electrons without being affected by free-free absorption, Sgr D is likely located in front of the Central Molecular Zone, and that the eastern portion of the Omega lobe likely contains a mix of nonthermal emission and free-free absorption. Finally, we also present preliminary results for the total nonthermal emission from the inner 2 x 0.85 degrees of the GC at 74 MHz and compare it to similar values at higher frequencies. Such a value is useful in determining if the thermal and nonthermal components are spatially mixed or separated with respect to each other. Our work thus demonstrates a sample of the usefulness of low frequency radio observations.

Simona Soldi (APC, Paris)

Maïca Clavel, Andrea Goldwurm, Gabriele Ponti, Regis Terrier, Guillaume Trap, Jochen Greiner, Tobias Prinz, Arne Rau, Mathieu Servillat

P76. A new Very Faint X-ray Transient in the Galactic Centre

During the XMM-Newton observations of the Central Molecular Zone in August 2012, a new X-ray source has been detected during a flare that reached a luminosity of L (0.2-12 keV) ~ 10^{35} erg/s for about 1.5 hours (assuming a distance of 8 kpc). The X-ray spectral (highly absorbed power-law spectrum, peak luminosity, quiescent luminosity) and timing (flaring emission, flare duration) properties point towards the association of this object to the class of Very Faint X-ray Transients (VFXT), i.e. Galactic X-ray transients with moderate X-ray luminosities of Lx ~ 10^{34-36} erg/s at the peak and with quiescent luminosities at or below Lx ~ 10^{33} erg/s. No IR counterpart could be unequivocally associated to this transient through a follow-up observation by the GROND instrument at the 2.2m telescope in La Silla, nor in archival IR surveys. Only a dozen of objects are known to be VFXT, making an additional member of this class very interesting for the understanding of these sources, the origin of whose peculiar activity is still debated. We present here the details of the discovery of this source, the results of the X-ray analysis, and discuss its possible identification.

Meng Su (MIT)

P77. Multi-wavelength Observations of Fermi Bubbles and Evidence for Large-scale Gamma-ray Jets from Fermi-LAT

Data from the Fermi-LAT revealed two large gamma-ray bubbles, extending 50 degrees above and below the Galactic Center, with a width of about 40 degrees in longitude. Such structure has been recently observed by Planck in microwave. I will show multi-wavelength studies of the Fermi bubbles including features of polarization emission and rotation measure study of the Fermi bubbles. We observe the edge of the bubbles using XMM-Newton and confirm a sharp edge in X-ray. Furthermore, we recently found evidence for large scale collimated jet structure penetrating through the bubbles from the Galactic Center, using data from Fermi-LAT gamma-ray data, which provides further evidence of a past activity in the Galactic Center.

Greg B. Taylor (UNM)

On behalf of the LWA Collaboration

P78. Observing the Galactic Center with LWA1

The first station of the Long Wavelength Array, called "LWA1", is located near the center of the VLA and has been operating as a stand-alone instrument exploring the Universe in the frequency range 10-88 MHz. The LWA1 can form up to 4 beams on the sky simultaneously with 16 MHz bandwidth in each of two tunings and full polarization. The LWA1 also images the sky in real time using the "transient buffer – narrowband" (TBN) system which is operational with 260 dipoles, and a bandwidth of 70 kHz. I will present observations of the Galactic Center using both all-sky images and beamforming. In particular we monitored the Galactic Center every night during the month of May in 2013. The LWA1 is supported by NSF as a University Radio Observatory and as such is open for use by the community.

Al Wootten (NRAO)

On behalf of the ALMA Commissioning Team

P79. ALMA Fast Dump Observations of the Transient Radio Magnetar J1745-2900

In order to commission short integration time observations with ALMA test observations at Band 3 (average frequency 94.2 GHz) were made on 2013 June 8 and 11 of a region centered on the transient radio magnetar J1745-2900 detected within 3" of the Galactic Center black hole, Sgr A*. Data were dumped at 192ms time sampling, providing 30 time samples across the magnetar pulse period. Details will be provided as data analysis proceeds.

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