Oral Abstracts for

Black Holes and Transient Phenomena

Parallel Session

Black Holes and Transient Phenomena

Tuesday, June 26, 2018

Start	End	Session	Speaker
8:00 AM	9:00 AM	Registration - Grand Ballroom Foyer	
8:45 AM	9:00 AM	Welcome - Grand I	
9:00 AM	10:00 AM	**Plenary: The Formation of Planets in the Terrestrial Zone and Conditions of Habitability**	**Andrea Isella** (B. Matthews, Chair)
10:00 AM	10:20 AM	Poster Flashes - Exoplanets	
10:20 AM	11:00 AM	Break and Posters	
11:00 AM	12:00 PM	**Plenary: The Cosmic Harmony of Galaxies and their Black Holes**	**Alex Pope** (Jackie Hodge, Chair)
12:00 PM	12:20 PM	Poster Flashes - Galaxy Evolution	
12:20 PM	2:00 PM	Lunch	
Black Holes & Transient Phenomena - Tom Maccarone, Chair			
2:00 PM	2:30 PM	**Long GRBs and Core-collapse Supernovae in the ngVLA Era**	**Alessandra Corsi**
2:30 PM	2:50 PM	The Structure and Dynamics of Relativistic Jet	Tanmoy Laskar
2:50 PM	3:20 PM	**Real-time, Commensal, Fast Transient Surveys with the Very Large Array**	**Casey Law**
3:20 PM	4:00 PM	Break & Posters	
Black Holes & Transient Phenomena - Jay Strader, Chair			
4:00 PM	4:20 PM	Radio Transients in the Pilot + Epoch 1.1 of the VLA Sky Survey	Dillon Dong
4:20 PM	4:50 PM	**Electromagnetic Counterparts of Binary Neutron Star Mergers**	**Brian Metzger**
4:50 PM	5:10 PM	Frontiers of Physics with Neutron Stars	Paul Demorest
5:10 PM	5:30 PM	*Exploring Nanohertz Multi-messenger Capabilities of the ngVLA*	*Joseph Lazio*
5:30 PM	6:00 PM	**Pulsar Timing Arrays for Gravitational Wave Detection: How, Why, and When?**	**Maura McLaughlin**
6:00 PM	7:00 PM	Poster Reception	

Bold = Invited Speaker

Italics = ngVLA Community Studies Talk

Andrea Isella (Rice University)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

The Formation of Planets in the Terrestrial Zone and Conditions of Habitability

Astronomical observations have revealed thousands of exo-planets including the first exo-planets located in the habitable zone of their host star. Furthermore, observations of young stellar systems at unprecedented angular resolution have delivered images of newborn planetary systems that unveil the physical processes involved in the assembly of planets. Key challenges for the next decade are to characterize the population of planets in the habitable zone, investigate their formation mechanism, understand how they might acquire the key ingredients for life, and assess their capability to sustain life. Addressing these questions requires a multi-disciplinary approach and a substantial advance in the astronomical instrumentation. In my talk, I will present a review of the study of planets in the terrestrial zone and discuss some of the technical capabilities required to unveil the their formation and the conditions of habitability.

Alexandra Pope (University of Massachusetts Amherst)

Topic: Galaxy Evolution Mechanisms

The Cosmic Harmony of Galaxies and their Black Holes

In this talk, I discuss our picture of how galaxies and their supermassive black holes coevolve over cosmic time, especially during the peak, heavily dust-obscured, epoch of galaxy evolution from z~1-4. The past decade has revealed fundamental relationships that govern how galaxies grow through star formation, and become passive. Observations of active black holes in distant galaxies have increased thanks to a multi-wavelength approach, but our precise understanding of how they coevolve with stars over cosmic time remains limited. Future infrared space telescopes such as JWST and, eventually Origins Space Telescope, will concurrently measure the star formation and black hole accretion rates in typical galaxies out to the highest redshifts.

Alessandra Corsi (Texas Tech University)

Topic: Black Holes & Transient Phenomena

Long GRBs and Core-collapse Supernovae in the ngVLA Era

Broad-lined supernovae of type Ic (BL-Ic SNe) are a rare form of massive star core collapse linked to engine-driven explosions known as long duration gamma-ray bursts (GRBs). After 20 years since the link between GRBs and Ib/c SNe was first recognized, what makes some SNe launch relativistic jets (GRBs) remains a mystery. In this talk, I will discuss how the ngVLA could enable us to fundamentally advance our understanding of the GRB-SN connection, and of the physics of massive star deaths in general.

Tanmoy Laskar (NRAO)

Topic: Black Holes and Transient Phenomena

The Structure and Dynamics of Relativistic Jets

Relativistic jets are ubiquitous in astrophysics, from AGN to tidal disruption flares, and from neutron star mergers to Gamma-ray Bursts (GRBs). The nature of the central engine responsible for launching and collimating these relativistic outflows remains a hotly debated open question. I will present results from multi-wavelength campaigns to isolate and characterize reverse shocks, yielding the first determinations of the Lorentz factor and magnetization of relativistic GRB jets. Coupled with simulations, theoretical analysis and modeling, these new measurements are opening new avenues for understanding relativistic transients in the upcoming era of LSST and gravitational wave observatories.

Casey Law (UC Berkeley)

Geoff Bower (ASIA-A), Sarah Burke-Spolaor (WVU), Bryan Butler (NRAO), Paul Demorest (NRAO), Andrew Halle (UC Berkeley), T. Joseph W. Lazio (JPL), Martin Pokorny (NRAO), James Robnett (NRAO), and Michael Rupen (DRAO)

Topic: Black Holes and Transient Phenomena

Real-time, Commensal, Fast Transient Surveys with the Very Large Array

Radio interferometers have the ability to precisely localize and better characterize the properties of sources. This ability is having a powerful impact on the study of fast radio transients such as Fast Radio Bursts, where a few milliseconds of data is enough to pinpoint a source at cosmological distances. However, recording interferometric data at millisecond cadence produces a terabyte-per-hour data stream that strains networks, computing systems, and archives. The realfast project is building the capability for thousands of hours of fast radio transient surveys through novel data distribution system and a dedicated GPU cluster integrated with the Jansky Very Large Array. This commensal system can detect transients in real time to trigger the recording of data for those rare, brief instants when the transient occurs. This makes it possible to search rapidly and commensally on a data stream that would otherwise be impossible to record. In this talk, I will describe the development of realfast at the VLA, its science scope, and expected outcomes.

Dillon Dong (Caltech)

Gregg Hallinan (Caltech), Kunal Mooley (Caltech/NRAO), Steve Myers (NRAO)

Topic: Black Holes and Transient Phenomena

Radio Transients in the Pilot + Epoch 1.1 of the VLA Sky Survey

The VLA Sky Survey (VLASS) is an ongoing project by the NRAO to map the ~34,000 deg^2 north of δ = -40º at 3GHz, over 3 epochs spanning 6 years. Thus far, 2480 deg^2 have been observed as part of the VLASS Pilot Survey, and ~17,000 deg^2 have been observed in the first half-epoch (Epoch 1.1) of the full VLASS. With a 7σ detection threshold of ~1mJy, each full epoch of VLASS will be ~2 orders of magnitude deeper than previous radio transient surveys of a comparable area on sky, and ~2 orders of magnitude wider than previous radio transient surveys of a comparable sensitivity.

We have developed a semi-automated pipeline to search the overlap between the FIRST and VLASS footprints for radio transients with characteristic decay timescales of ~weeks to ~years, that are associated with galaxies within 200 Mpc. The populations accessible to VLASS include the synchrotron afterglows of supernovae, tidal disruption events, long/ short gamma ray bursts, and AGN flares. These radio afterglows are thought to be roughly extinction-free and isotropic, allowing us to detect transients that would be missed by optical/high energy surveys due to obscuration or off-axis jetting.

Through VLA follow-up at 1.4GHz, we have determined that ~80% of our transient candidates from the VLASS Pilot are bona-fide transients relative to FIRST. To characterize the environments around the highest-priority transients, we have obtained imaging and spectroscopic follow-up observations using the Low Resolution Imaging Spectrograph (LRIS) on Keck I. In this talk, we discuss our selection process for transient candidates, our follow-up methodology, and radio/optical results for the most exciting VLASS transients.

Brian Metzger (Columbia University)

Topic: Black Holes & Transient Phenomena

Electromagnetic Counterparts of Binary Neutron Star Mergers

On August 17 the LIGO gravitational wave observatories detected the first binary neutron star merger event (GW170817), a discovery followed by the most ambitious electromagnetic (EM) follow-up campaign ever conducted. Within 2 seconds of the merger, a weak gamma-ray burst was discovered by Fermi and INTEGRAL. Within 11 hours, a bright but rapidly fading thermal optical counterpart was discovered in the galaxy NGC 4993, the properties of which match remarkably well predictions for "kilonova" emission powered by the radioactive decay of heavy nuclei synthesized in the expanding merger ejecta. Two weeks after the merger, rising non-thermal radio and X-ray emission were detected, consistent with synchrotron afterglow radiation from mildly relativistic ejecta (either from an initially off-axis successful relativistic GRB jet or the "cocoon" of a failed jet). I will describe efforts to create a unified scenario for the range of EM counterparts from GW170817 and their implications for the fate of the merger remnant. I will also preview the upcoming era of multi-messenger astronomy, once Advanced LIGO/Virgo reach design sensitivity and a neutron star merger is detected every few weeks, focusing on the potential diversity of predicted behavior, particularly at radio frequencies.

Paul Demorest (NRAO)

Topic: Black Holes & Transient Phenomena

Frontiers of Physics with Neutron Stars

Astronomical observations of neutron stars have been successfully used for decades as a means of accomplishing a variety of unique experiments in basic physics. Consisting of the densest form of matter known to exist, occurring in strongly-gravitating binary systems, and emitting an extremely regular clock-like signal make neutron stars near-ideal "laboratories" for testing extremes of physics unreachable on Earth or in Solar System based experiments. In particular, measurements of neutron star bulk physical properties (mass, radius, moment of inertia) provide strong constraints on the nuclear matter equation of state and theories of high-density matter. Precise measurements of neutron star orbits test strong-field gravity and general relativity in a number of ways. Despite the already highly successful history of this field, it is far from exhausted. A number of current or planned instruments across the entire electromagnetic -- and now gravitational-wave -- spectrum promise new discoveries in the upcoming decades that will provide qualitatively new physical insight from observations of neutron stars. These will include: sensitive new pulsar searches and ultra-precise timing in the radio; new optical measurements of companion stars; X-ray observations of neutron star surfaces and accretion; gamma-ray views into pulsar magnetospheres; and perhaps most strikingly, gravitational-wave study of neutron star merger events as demonstrated recently by the LIGO detection of GW170817. In this presentation, I will survey the current state of the art of testing nuclear and gravitational physics with neutron stars, and discuss the new instruments and discoveries likely to be possible in the coming years.

Joseph Lazio (JPL/Caltech)

Sarah Burke-Spolaor (West Virginia University)
Joseph Simon (California Institute of Technology)

Topic: Black Holes and Transient Phenomena

Long Baselines for Multi-Messenger Supermassive Black Hole Science

When illuminated as radio-emitting sources, binary supermassive black holes can be detected through their dual radio-emitting cores, by their large-scale jet morphologies, and/or by periodic core variability. So far, the most robust binary identification method has shown to be direct imaging of radio cores. The most massive ($>\sim10^8$ M_{sun}) binary systems will, in the next 5+ years, also become detectable via their gravitational radiation by pulsar timing arrays like the North American Nanohertz Observatory for Gravitational Waves (NANOGrav). We will report results from a simulation of the binary supermassive black hole population in the local ($z<\sim2$) universe for which we have included a predictor of radio emission. Thus, we have the ability to analyze the bulk statistics and properties (mass, distance, etc) of sources that will potentially be detectable by both NANOGrav and by future radio instruments like the ngVLA. Assuming that future radio instruments will aim to resolve dual radio cores, we will demonstrate how effective the ngVLA will be at probing multi-messenger targets as a function of its maximum baseline.

Maura McLaughlin (West Virginia University)

Topic: Black Holes & Transient Phenomena

Pulsar Timing Arrays for Gravitational Wave Detection: How, Why, and When?

Pulsars are rapidly rotating neutron stars with phenomenal rotational stability that can be used as celestial clocks in a variety of fundamental physics experiments. One of these experiments involves using an array of precisely timed millisecond pulsars to detect perturbations due to gravitational waves at much lower frequencies than those probed by LIGO. The gravitational waves detectable through pulsar timing will most likely result from an ensemble of supermassive black hole binaries. I will describe how pulsar timing can be used to search for gravitational wave signatures and why the study of low-frequency gravitational waves is critical for our understanding of galaxy formation and evolution. I will also provide an overview of world-wide pulsar timing array efforts and the most recent upper limits on various types of gravitational wave sources and their implications. I will then describe the dramatic gains in sensitivity that are expected from discoveries of millisecond pulsars, more sensitive instrumentation, improved detection algorithms, and international collaboration and show that detection is possible before the end of the decade.

Black Holes and Transient Phenomena

Wednesday, June 27, 2018

Start	End	Session	Speaker
9:00 AM	10:00 AM	**Plenary: Stellar Mass and Supermassive Black Holes in Era of Multi-Messenger Astronomy**	**Sebastian Heinz** (Joe Lazio, Chair)
10:00 AM	10:20 AM	Poster Flashes - Black Holes	
10:20 AM	11:00 AM	Break and Posters	
11:00 AM	12:00 PM	**Plenary: The Evolution of Astrochemistry from Planet Formation Through to Exoplanets**	**Ilse Cleeves** (Laura Fissel, Chair)
12:00 PM	12:20 PM	Poster Flashes - Galaxy Evolution	
12:20 PM	12:30 PM	Conference Photo	
12:30 PM	2:00 PM	Lunch	
Black Holes & Transient Phenomena - Laura Chomiuk, Chair			
2:00 PM	2:30 PM	**Supernovae**	**Shri Kulkarni**
2:30 PM	2:50 PM	Extreme Supernovae from Cosmic Dawn	Ken Chen
2:50 PM	3:20 PM	**Accretion and Explosions on White Dwarfs**	**Michael Rupen**
3:20 PM	4:00 PM	Break & Posters	
Black Holes & Transient Phenomena - Joan Wrobel, Chair			
4:00 PM	4:20 PM	*Classical Novae: A Test Case for ngVLA Stellar Outflow Imaging Capabilities*	*Justin Linford*
4:20 PM	4:50 PM	**The Black Hole Population in our Milky Way**	**Chris Belczynski**
4:50 PM	5:20 PM	**Optical and Infrared Studies of X-ray Binaries in the Gaia Era**	**Jerry Orosz**
5:20 PM	5:40 PM	The MAVERIC Survey: Black Holes in Globular Clusters	Laura Shishkovsky
5:40 PM	6:00 PM	Radio Timing Analysis of the Jet in the Black Hole X-ray Binary Cygnus X-1	Alex Tetarenko
6:30 PM	9:30 PM	Conference Dinner at Punch Bowl Social	

Bold = Invited Speaker

Italics = ngVLA Community Studies Talk

Sebastian Heinz (UW-Madison)

Topic: Black Holes & Transient Phenomena

Stellar Mass and Supermassive Black Holes in Era of Multi-Messenger Astronomy

I will discuss the future of multi-wavelength studies of the growth history of black holes at all mass scales over the coming decades. Just as numerical modeling of accretion and ejection phenomena approach an ab-initio understanding of the innermost regions of black hole atmospheres, the next generation of radio and X-ray telescopes will allow an unprecedented view of non-thermal phenomena that holds the keys to understanding some of the mysteries of black hole growth that have plagued black hole studies for that past five decades. My discussion will be motivated by a modern 3D MHD numerical view into black hole atmospheres.

Ilse Cleeves (Harvard-Smithsonian CfA)

Topic: Exoplanets, the Solar System and the origins of Stars, Planets and Life

The Evolution of Astrochemistry from Planet Formation Through to Exoplanets

Protoplanetary disks are the birthplaces of planetary systems. Studying their physical conditions and compositions provides constraints on how planets form and with what chemical make up: whether they are rocky or gas-rich, whether their atmospheres are carbon or oxygen rich, and so forth. In recent years the unprecedented sensitivity of ALMA has demonstrated a rich diversity in observed molecular emission strength and emitting geometries, hinting at an active disk chemistry during planet formation even for simple molecules. Going forward, we need to understand what the main evolutionary drivers are of this active chemistry (for example, the coupling of ice coated grains and grain growth), and if what we learn for well-studied bright/massive/nearby objects holds for the broader population of disks. Together these explorations will compliment and motivate our understanding of the march toward chemical complexity in disks, where the future highly sensitive ngVLA will shed light on the richer, and potentially prebiotic, organic chemistry of disks.

Shrinivas Kulkarni (Caltech)

Topic: Black Holes and Transient Phenomena

Supernovae

Ten years ago, well into the GRB era, most astronomers had concluded that the book on stellar deaths was close to being finished. Massive stars ended with super-luminous supernovae (pair-instability, magnetars) and dim supernovae (black holes). It was recognized that Type Ia supernovae could arise from both merger of white dwarfs as well as explosion of an accreting white dwarf. However, optical time domain astronomy surveys have discovered a plethora of super-novae phenomenology and sub-classes. Mass loss, not merely during the main sequence phase but also prior to core collapse appears, may be playing a major role in stellar deaths. The Ia story is now quite rich what with the discovery of high speed stars pointing back to supernova remnants! There is with little doubt a new class of fast and luminous supernovae. Finally, as is apparent from the LIGO events, nature appears to readily produce massive stellar black holes. All in all, we seem to be assured of the continuation of a golden era of supernovae.

Ke-jung (Ken) Chen (Academia Sinica Institute of Astronomy and Astrophysics (ASIAA)

Topic: Black Holes & Transient Phenomena

Extreme Supernovae from Cosmic Dawn

Recent all-sky transient searches have discovered new and unexpected explosion types that fall outside traditional SN classification schemes. These exotic outliers in many cases are due to the deaths of massive stars and therefore may have been prevalent in the primordial universe because the Pop III IMF is thought to be top-heavy. Depending on the mass of the progenitor, these outliers may be faint, magnetar-powered, pair-instability, or general relativistic instability SNe, all of which have unique observational signatures. Some of these events are superluminous, 10-100 times brighter than normal supernovae, and may produce energetic UV, X-ray, or gamma-ray bursts. Their extreme luminosities enable their detection at $z > 10$ and they are ideal probes of the primordial universe at cosmic dawn, prior to the advent of the first galaxies. Here, we examine these exotic explosions with state of the art 3D radiation-hydro simulations that bridge all spatial scales from the central engine to breakout into the IGM, where observational signatures can be computed. We discuss the coevolution of radiation and turbulent mixing in SN ejecta and present realistic light curves for these explosions for the coming generation of grand observatories such as JWST, LSST, TMT, GMT, SKA, ngvla, etc.

Michael Rupen (NRC)

Topic: Black Holes & Transient Phenomena

Accretion and Explosions on White Dwarfs

Justin D. Linford (The George Washington University)

Laura Chomiuk (MSU), Michael P. Rupen (Herzberg), Jennifer L. Sokoloski (Columbia), Amy Mioduszewski (NRAO), Koji Mukai (NASA/GSFC), Thomas Nelson (Pitt), Alexander J. van der Horst (GWU), Adam Kawash (MSU)

Topic: Black Holes and Transient Phenomena

The ngVLA and Classical Novae

Classical novae are excellent laboratories for studying many astrophysical phenomena. They have complex structures due to interacting outflows. They produce shocks where these outflows collide. They have both thermal and non-thermal emission. They evolve over long time scales and remain visible at radio wavelengths for two to three years. The Next Generation Very Large Array (ngVLA) will provide unprecedented opportunities to study these complicated eruptions. The ultra-sensitive imaging capabilities for both thermal and non-thermal emission will enable us to trace the expansion of the ejecta and monitor the interactions between the outflows with milliarcsecond resolution. We will demonstrate the exciting capabilities of the ngVLA with simulated images of classical novae at multiple stages of their evolution.

Krzysztof Belczynski (Copernicus Center, Warsaw)

Topic: Black Holes & Transient Phenomena

The Black Hole Population in our Milky Way

Despite the fact that only about 20 Galactic black holes are known there must be tens to a hundred millions of black holes in Milky Way. This large population may be very diverse, including not only known accreting black holes in low-mass and high-mass X-ray binaries, but black holes in many different configurations. Galactic surveys may possibly probe not only low-mass black holes that are descendants of Population I stars (disk/bulge), but possibly more massive black holes that were born from Population II stars (bulge/halo) or even from Population III stars (halo). If Galaxy surveys can recover a substantial population of black holes, this will allow to assess a number of open and poorly understood issues. How do low-mass transient X-ray binaries form? Is the first mass gap (between neutron stars and black holes) physical or is it just an observational bias? Do massive black holes of stellar origin exist in Milky Way and how do their properties compare with LIGO/Virgo sources? Is there a second mass gap in black hole mass distribution as predicted by pair-instability supernova theory? I will discuss these and some other related open issues.

Jerome A. Orosz (San Diego State University)

Topic: Black Holes & Transient Phenomena

Optical and Infrared Studies of X-ray Binaries in the Gaia Era

With a few exceptions, the masses of neutron stars and black holes in X-ray binaries are measured without using distance information. Radial velocities of the companion stars derived from optical and/or infrared spectra are combined with optical and/or infrared light curves to place constraints on the geometry of the system. In favorable cases, the period, mass ratio, and inclination of the binary and the radial velocity amplitude of the companion star can be measured, leading to measurements of the mass of the compact object and the mass and radius of the companion star. If the radius and the effective temperature of the star are known, one can compute its absolute magnitude. The distance to the system then follows from the apparent brightness, after suitable corrections for interstellar extinction and contaminating sources of light are applied. For some X-ray binaries that contain a black hole, the distance to the system (along with the inclination of the binary) can be used to estimate the black hole spin from models of the X-ray spectra.

There are a few high-mass X-ray binaries where independent distance measurements are available. For example, the parallax of Cyg X-1 has been measured using VLBI observations, and the distances to M33 X-7, LMC X-1, and LMC X-3 are known by virtue of their memberships in nearby galaxies. For these systems the absolute magnitude of the companion star can be found from the apparent magnitude (once corrections are made for interstellar extinction). The radius of the companion star follows from the luminosity and temperature of the star. The geometrical model that one constructs from all of the observational data (e.g. radial velocity and light curves of the companion star, the rotational velocity of the companion star, etc.) must be consistent with the measured radius of the companion star.

The Gaia mission is expected to provide parallax measurements of an enormous number of stars in the Galaxy, including many X-ray binaries. I will discuss how these distance measurements can be used to improve on measurements of the component masses in a few of the well-studied X-ray binaries. In addition to parallax information, Gaia will also provide proper motion measurements for many X-ray binaries. The availability of distances and three-dimensional space motions for a large sample of X-ray binaries should inform models of the formation of these interesting binary systems.

Laura Shishkovsky (Michigan State University)

Jay Strader (Michigan State University)
Laura Chomiuk (Michigan State University)
Arash Bahramian (Michigan State University)
Evangelia Tremou (Michigan State University)
Vlad Tudor (International Centre for Radio Astronomy Research - Curtin University)
James C.A. Miller-Jones (International Centre for Radio Astronomy Research - Curtin University) Thomas J. Maccarone (Texas Tech University)
Craig O. Heinke (University of Alberta)
Gregory R. Sivakoff (University of Alberta)
Anil Seth (University of Utah)

Topic: Black Holes and Transient Phenomena

The MAVERIC Survey: Black Holes in Globular Clusters

Globular clusters are expected to have large populations of stellar-mass black holes at early stages in their lifetimes. These stellar-mass black holes were long predicted to have been kicked out of globular clusters through gravitational interactions during the clusters' evolution, with some clusters retaining only one or two stellar-mass black holes and most clusters not retaining any. However, recent discoveries of stellar-mass black hole candidates in globular clusters have called this narrative into question. With the goal of assessing the frequency of accreting stellar-mass black hole systems in globular clusters, we have undertaken a deep radio continuum survey of 50 Milky Way globular clusters using the Karl G. Jansky Very Large Array and the Australia Telescope Compact Array. Here we present our method of selecting candidates, preliminary results, and implications for the dynamical formation of binary black holes observable as gravitational wave sources.

Alexandra Tetarenko (University of Alberta)

Gregory Sivakoff (University of Alberta), James Miller-Jones (Curtin University), Piergiorgio Casella (INAF-Osservatorio Astronomico di Roma)

Topic: Black Holes and Transient Phenomena

Radio Timing Analysis of the Jet in the Black Hole X-ray Binary Cygnus X-1

Black holes drive the most powerful jets in the universe, from the kiloparsec-scale jets launched by the most massive black holes in Active Galactic Nuclei (AGN), to the smaller-scale jets launched by their stellar mass analogues in black hole X-ray binaries (BHXBs). BHXBs are typically transient in nature, evolving from periods of inactivity into a bright out-bursting state lasting days to months. During an outburst, BHXBs emit across the electromagnetic spectrum, where jet emission dominates in the lower frequency bands (radio, sub-mm) and emission from the accretion flow dominates in the higher frequency bands (optical, X-ray). Time domain observations now offer a promising new way to address the key open questions in jet research (e.g., size scales, geometry, speeds, sequence of events leading to jet launching), contrary to previous works, which have focused primarily on the spectra or morphology of these outflows. However, while time-resolved observations are a staple for BHXB studies at X-ray/optical frequencies, there are many challenges that accompany such studies at radio frequencies (e.g., distinguishing intrinsic source variations from atmospheric variations, having to routinely cycle between a target and calibrator source, limits on the number of frequency bands that can be sampled at once). In this talk, I will present new results from our simultaneous multi-band VLA radio and NuSTAR X-ray observations of the BHXB Cygnus X-1. With these data, we have developed new observational techniques and computational tools designed to overcome the challenges of radio timing analysis, and ultimately connect jet variability properties to internal jet physics. These techniques and tools will help the next generation facilities (e.g., ngVLA, ALMA-2030) drive new discoveries in this field. For example, the ngVLA will be very sensitive at higher frequencies when compared to the current generation of radio facilities, allowing us to sample shorter time bins, and probe the physics closer to the jet base, where the variability will be both higher in amplitude and less smoothed out. In addition, the use of subarrays with the ngVLA can allow for continuous on-source coverage, or enable simultaneous broad-band radio-to-mm coverage, which is needed to measure time delays between frequency bands, and in turn track matter as it propagates from inflow to outflow (revealing how variations in the accretion flow manifest downstream in the jet).

Black Holes and Transient Phenomena

Thursday, June 28, 2018

Start	End	Session	Speaker
9:00 AM	12:20 PM	Working Groups/Free Time	
12:20 PM	2:00 PM	Lunch	
2:00 PM	3:00 PM	**Plenary: Pulsars in the Galactic Center as Fundamental Tests of Gravity**	**Dimitrios Psaltis** (Walter Brisken, Chair)
3:00 PM	3:20 PM	Poster Flashes - Black Holes	
3:20 PM	4:00 PM	Break and Posters	
Black Holes & Transient Phenomena - Greg Sivakoff, Chair			
4:00 PM	4:30 PM	**AGN Jets**	**Tony Readhead**
4:30 PM	4:50 PM	*The Science Case for Simultaneous Wide-Band Coverage in Radio Astronomy*	*Richard Dodson*
4:50 PM	5:20 PM	**Precision Measurements of Black Hole Mass**	**Jonelle Walsh**
5:20 PM	5:40 PM	The Future of Industrial-Scale Echo Mapping of Black Holes	Jonathan Trump
5:40 PM	6:00 PM	Imaging and Time Resolving Black Holes: The Event Horizon Telescope and New Directions	Shep Doeleman

Bold = Invited Speaker

Italics = ngVLA Community Studies Talk

Dimitrios Psaltis (University of Arizona)

Topic: Black Holes and Transient Phenomena

Testing General Relativity with the Event Horizon Telescope, Pulsars, and Stars around Sgr A*

The Event Horizon Telescope is a mm VLBI array that commenced its full array operations in April 2017. Its primary goal is to generate the first images of black holes with horizon-scale resolution for the two primary targets, Sgr A* in the center of the Milky Way and the black hole in the center of M87. Measuring the shape and size of the shadows cast by the black holes allows for testing the no-hair theorem of General Relativity and for searching for large-scale quantum fluctuations of the black-hole metrics. In the case of Sgr A*, tests with the Event Horizon Telescope can be combined with monitoring of orbits of stars and pulsars in its vicinity to provide consistency checks and further constraints on any deviations from General Relativity.

Anthony Readhead (Caltech)

Topic: Black Holes and Transient Phenomena

AGN Jets

Active Galactic Nuclei (AGN) are among the most energetic objects in the Universe. Supermassive black holes in their centers, powered by accretion, can generate relativistic jets that emit radiation throughout the electromagnetic spectrum. The observations reveal that the jets can form within about ten Schwarzschild radii and theoretical mechanisms for the formation and collimation of these jets are now being tested through observations and MHD simulations. A summary of the observational and theoretical status of relativistic jets, focusing on recent observations and simulations will be given, and the potential of existing and future instruments for addressing questions of the jet launching mechanism, jet composition, jet collimation and AGN feedback will be discussed with particular emphasis on the EHT, ngVLA, CTA, and JWST.

Richard Dodson & Maria Rioja (ICRAR, Uni. Western Australia)

Topic: Black Holes & Transient Phenomena

Techniques for Precision Calibration with the Next Generation VLA

We report on work we have performed to explore calibration methods that will be of importance to the next generation VLA. With this instrument the baselines are sufficiently long that the atmospheric conditions for different antennas are essentially independent, therefore our experience in VLBI becomes relevant. We have developed new calibration methods for regimes where conventional phase referencing algorithms do not apply: At very high frequencies (mm and sub-mm wavelengths) where the short coherence times have prevented source switching and at low frequencies (cm and m-wavelengths), where direction dependent effects prevent source phase transfer. These methods are Source/Frequency Phase Referencing (SFPR) and Multi-View VLBI (MV) respectively. We will describe both of these techniques, and their advantages and requirements. For instruments such as the Korean VLBI Network, a 500km mm-wavelength interferometric array, the SFPR method has allowed unique astrometrically registered observations and unprecedented coherence times at 130GHz. The MV method has allowed an order of magnitude improvement in astrometric measurements on Methanol (6.7GHz) and OH (1.6GHz) masers, using the VLBA. The design considerations will be discussed.

Jonelle Walsh (Texas A&M University)

Topic: Black Holes & Transient Phenomena

Precision Measurements of Black Hole Mass

Over the past 15 years it has become increasingly clear that supermassive black holes are essential components of galaxies, as demonstrated by the empirical correlations connecting black hole masses and large-scale galaxy properties. Although about 100 dynamical black hole mass measurements have been made to date, the local black hole mass census is highly incomplete. Gaining a more complete picture of black hole demographics and a deeper understanding of the mechanisms that drive black hole/galaxy evolution requires the precise measurement of black holes in a wider range of galaxy types with varied evolutionary histories. In this talk, I will discuss on-going efforts to expand the diversity of host galaxies with robust dynamical black hole mass measurements, as well as the exciting prospects for improving our measurements of black holes in the next decade.

Jonathan Trump (University of Connecticut)

Yasaman Homayouni (UConn), Niel Brandt, Kate Grier (Penn State), Yue Shen (Illinois), Keith Horne (St Andrews), Pat Hall (York), and the SDSS-RM team.

Topic: Black Holes and Transient Phenomena

The Future of Industrial-Scale Echo Mapping Black Holes

I will present the latest results from the pioneering new Sloan Digital Sky Survey Reverberation Mapping (SDSS-RM) project, the first multi-object reverberation mapping campaigns. Time-domain monitoring of quasars is the only way to directly measure black hole mass and accretion-disk structure beyond the local Universe. This makes reverberation mapping projects vital for measuring black hole demographics and growth over cosmic time. In contrast to the focused, single-object mode of reverberation mapping in past work, SDSS-RM has been simultaneously monitoring 850 quasars in spectroscopy and photometry since 2014. Already SDSS-RM has dramatically expanded the number of quasars with reliable black hole masses: doubling the total number and producing the first robust sample of black hole masses at $z>0.3$. SDSS-RM will continue in the 2020s as the Black Hole Mapper key project of SDSS-V. I will also discuss how the photometric echo mapping of SDSS-RM is a pathfinder for LSST, paving the way for direct accretion-disk sizes of thousands of quasars.

Sheperd Doeleman (Harvard Smithsonian Center for Astrophysics)

Topic: Black Holes & Transient Phenomena

Imaging and Time Resolving Black Holes: The Event Horizon Telescope and New Directions

The Event Horizon Telescope project links mm and submm wavelength facilities around the globe into a VLBI array capable of spatially resolving the nearest supermassive black holes. Towards SgrA*, the 4 million solar mass black hole at the Galactic Center, and the ~6 billion solar mass black hole in Virgo A, EHT observations at 1.3mm can resolve the 'silhouette' of the event horizon. First EHT observations in April 2017 achieved have been correlated and are now being processed and analyzed, with VLBI detections to all sites. This talk will provide an update on progress and describe new directions for this ultra-high angular resolution work over the coming years, including exploration of space-VLBI opportunities, new sites, and extension to shorter wavelengths.

Black Holes and Transient Phenomena

Friday, June 29, 2018

Start	End	Session	Speaker
9:00 AM	10:00 AM	**Plenary: Connecting Interstellar Gas and Star Formation in Nearby Galaxies**	**Karin Sandstrom** (Aaron Evans, Chair)
10:00 AM	10:40 AM	Break and Posters	
Black Holes & Transient Phenomena - Kristina Nyland, Chair			
10:40 AM	11:10 AM	**Tidal Disruption of Single and Binary Stars by Supermassive Black Holes**	**Elena Rossi**
11:10 AM	11:40 AM	**Growth of Black Hole Seeds**	**Rich Plotkin**
11:40 AM	12:00 PM	Multimessenger Signatures from Massive Black Holes in Dwarf Galaxies	Jillian Bellovary
12:00 PM	1:40 PM	Lunch	
Black Holes & Transient Phenomena - Rich Plotkin, Chair			
1:40 PM	2:00 PM	*Signatures of Supermassive Black Hole Seed Formation over Cosmic Time*	*Colin DeGraf*
2:00 PM	2:20 PM	*Taking a Census of Supermassive Binary Black Holes*	*Karishma Bansal*
2:20 PM	2:40 PM	A Search for Recoiling Super Massive Black Holes and its Implications to Changing-Look AGN	Dongchan Kim
2:40 PM	3:00 PM	Finding Unresolved Dual AGNs at High Redshift Using Astrometry	Yu-Ching Chen
3:00 PM	3:20 PM	LSST Contributions to the Black Hole Census	Eric Bellm
3:20 PM	4:00 PM	Break & Posters	
4:00 PM	5:00 PM	Summary and Final Remarks	

Bold = Invited Speaker

Italics = ngVLA Community Studies Talk

Karin Sandstrom (University of California, San Diego)

Topic: Galaxy Evolution Mechanisms

Connecting Interstellar Gas and Star Formation in Nearby Galaxies

Star formation on galactic scales is governed by the need to collect interstellar gas into successively denser and colder phases, beginning with the accretion of low density gas from the circumgalactic medium all the way through the collapse of dense protostellar cores in molecular clouds. How effectively gas can proceed through these changes in its chemical and physical state depends on the local environment and therefore can vary within and between galaxies. Nearby galaxies are our best laboratory for studying these processes, providing an external, galaxy-wide perspective on the structure and properties of ISM gas. I will discuss our current observational constraints on the key phase transitions that govern the state of gas in nearby galaxies. In particular, I will discuss the properties of the cold neutral gas, the balance between neutral and molecular gas phases, and the density structure of molecular clouds and its relation to star formation. Key aspects of the physics of ISM gas in nearby galaxies remain out of the reach of current observational facilities and I will outline how future observations with the ngVLA, the SKA, and the Origins Space Telescope will revolutionize our understanding of the physics of ISM gas and star formation in nearby galaxies.

Elena Maria Rossi (Leiden Observatory, The Netherlands)

Topic: Black Holes and Transient Phenomena

Tidal Disruption of Single and Binary Stars by Supermassive Black Holes

Tidal disruption of stars by supermassive black holes (SMBHs) in galactic nuclei are both fascinating (hydro)-dynamical phenomena and tools to study galaxies and their connection with SMBHs in novel way. In this talk, I will first review my efforts to unveil the hydrodynamics underlying the production of visible flares, when either a single star or a binary star gets disrupted. Then, to exemplify the power of tidal disruption events as galactic probes, I will review a comprehensive program I am leading that exploits tidal break-ups of binaries to constrain the dark matter content of our Galaxy.

Richard Plotkin (ICRAR-Curtin University)

Topic: Black Holes and Transients

Growth of Black Hole Seeds

The co-evolution of black holes and galaxies is one of the most important and high-priority topics in extragalactic astrophysics. A crucial part in understanding black hole evolution is to understand what types of black holes `seeded' the initial growth of supermassive black holes (i.e., 'heavy' seeds from direct collapse vs. 'light' seeds from population III stars). Understanding the seed black hole population has implications ranging from black hole feedback, to galaxy evolution, to the gravitational wave background expected from space-based gravitational wave observatories and/or pulsar timing arrays. Some of our best observational constraints on black hole seeds will come from clues embedded in local black hole populations found in nearby galaxies, and the largest lever arm for constraining different seed black hole formation scenarios will come from examining black hole populations in low-mass galaxies. Over the last decade there has been an ever-growing population of low-mass black holes (10^4-10^6 M_{Sun}) discovered in nearby dwarf galaxies ($M_* < 10^9$ M_{Sun}), and radio facilities like the Very Large Array have played a crucial role in confirming the nature of these objects. In this review talk I will discuss how a next generation Very Large Array (ngVLA) can help switch the landscape. With its order of magnitude improvement in sensitivity and its exquisite spatial resolution from ~10^3 km baselines, an ngVLA can become a powerful machine for economically deriving large samples of black hole candidates in dwarf galaxies. I will conclude by discussing how black hole seeds might have grown to supermassive sizes through accretion processes; I will also describe applications of large radio-selected black hole samples toward unraveling the initial black hole seed population, including synergies between an ngVLA and other current and upcoming facilities at other wavebands.

Jillian Bellovary (CUNY – Queensborough Community College)

Ferah Munshi (University of Oklahoma / Vanderbilt University)
Michael Tremmel (Yale University)
Colleen Cleary (CUNY – Hunter College)
Topic: Black Holes & Transient Phenomena

Multimessenger Signatures from Massive Black Holes in Dwarf Galaxies

Inspired by the recent discovery of several nearby dwarf galaxies hosting active galactic nuclei, I will present results from a series of cosmological hydrodynamic simulations focusing on dwarf galaxies which host supermassive black holes (SMBHs). Cosmological simulations are a vital tool for predicting SMBH populations and merger events which will eventually be observed by LISA. Dwarf galaxies are the most numerous in the universe, so even though the occupation fraction of SMBHs in dwarfs is less than unity, their contribution to the gravitational wave background could be non-negligible. I find that electromagnetic signatures from SMBH accretion are not common among most SMBH-hosting dwarfs, but the gravitational wave signatures can be substantial. The most common mass ratio for SMBH mergers in low-mass galaxy environments is ~1:20, which is an unexplored region of gravitational waveform parameter space. I will discuss the occupation fraction of SMBHs in low-mass galaxies as well as differences in field and satellite populations, providing clues to search for and characterize these elusive giants lurking in the dwarfs.

Colin DeGraf (University of Cambridge)

Debora Sijacki (University of Cambridge)

Topic: Black Holes and Transient Phenomena

Signatures of Supermassive Black Hole Seed Formation over Cosmic Time

It is well understood that supermassive black holes are found in essentially all galaxies. However the mechanisms by which their seeds originally form remain highly uncertain, despite the importance the formation pathway can have on AGN and quasar behavior at all redshifts. Using a combination of cosmological simulations and analytic modeling, I will discuss how varying the conditions under which supermassive black hole seeds form leads to changes in AGN populations. In particular, we find a moderate impact on the black hole mass function and the mid- and faint-end of the luminosity functions, and a strong impact on both AGN accretion efficiencies and BH merger rates. I will discuss both the importance of initial seed formation on our understanding of long-term black hole behavior, and also how the signatures of seed formation suggest multiple means by which upcoming observational surveys (at both high- and low-redshifts) can provide the data required to constrain the way in which supermassive black hole seeds initially form.

Karishma Bansal & Greg Taylor (UNM)

Topic: Black Holes and Transient Phenomena

Taking a Census of Supermassive Binary Black Holes

Supermassive black holes reside at the heart of most of the major galax-ies. They affect the growth and dynamics of their host galaxy. When such two galaxies collide, they are expected to form a supermassive binary black hole (SMBBH) system. Surprisingly, very few systems have been detected to date. This raises questions such as how often do galaxies collide? Does a collision give rise to a binary system, and how quickly do these black holes merge after binary formation? Understanding these systems is important to understanding fundamental astrophysical problems ranging from galaxy evolution to active galactic nuclei (AGN) to black hole growth.

0402+379 is a well established SMBBH. It contains two core components at a separation of about 7 pc, which are compact and have flat spectra. Recently, Bansal et al (2017) studied the relative motion of binary black holes in this system and estimated the period of the orbit ~ 30000 years. As a result of Einstein's General Theory of Relativity, binary black hole mergers are expected to emit Gravitational waves. We aim to search for more SMBBH candidates to better understand the population of the precursors to the systems that will eventually become strong gravitational wave sources prior to coalescence. For this purpose, we would look for more compact and nearby sources. A compact system will have a shorter orbital period, and a nearby system will be easier to resolve.

We plan to present the results of orbital motion of 0402+379 along with our recent study using the ongoing VLASS, being conducted by NRAO, to search for more candidates. We cross match these sources with SDSS to obtain their redshift, and NVSS to obtain spectral index information. We use various criteria such as brightness, redshift, and source size to obtain a census of SMBBH candidates. With the ngVLA, it would be possible to confirm SMBBH candidates and, provided the appropriate configuration, study the orbital dynamics.

Dongchan Kim (NRAO)

Ilsang Yoon (NRAO), Aaron Evans (University of Virginia/NRAO), Jihoon Kim (NAOJ)
Minjin Kim (KASI)

Topic: Black Holes and Transient Phenomena

A Search for Recoiling Super Massive Black Holes and its Implications to Changing-Look AGN

We report on a search for recoiling super massive black holes (rSMBHs) and discuss its implications to black hole and galaxy co-evolution. We have identified 26 rSMBH candidates from the SDSS spectroscopic survey. We also have identified one potential rSMBH from imaging and spectroscopic survey of all sources in CSC-SDSS Cross-match Catalog. We have demonstrated that the rSMBH scenario can explain changes in the AGN luminosity and kinematics of the broad line region of the changing-look AGN Mrk 1018. Sub-arcsec spatial offsets between the AGN and host galaxy nucleus can easily be identified with ngVLA. Multi-epoch LSST data for the rSMBHs will provide important insight how the SMBHs form and grow together with their host galaxies.

Yu-Ching Chen (University of Illinois at Urbana-Champaign)

Xin Liu (University of Illinois at Urbana-Champaign)
Robert Gruendl (University of Illinois at Urbana-Champaign)
Eric Morganson (National Center for Supercomputing Applications)
Hengxiao Guo (National Center for Supercomputing Applications)
Yue Shen (University of Illinois at Urbana-Champaign)
Robert Brunner (University of Illinois at Urbana-Champaign)
Matias Carrasco Kind (National Center for Supercomputing Applications)
and the DES collaboration

Topic: Black Holes & Transient Phenomena

Title: Finding unresolved dual AGNs at high redshift using astrometry.

Dual AGNs with sub-kpc separations are hard to find with ground-based telescopes due to the limited angular resolution, but they are crucial for understanding the merging history of supermassive black holes and AGN triggering. In recent years, spectroscopic searches such as those using the Sloan Digital Sky Survey have made significance progress in identifying dual AGNs at $z < 0.5$, but rest-frame optical spectroscopy is still too expensive for large samples of AGNs at high redshift, where galaxy mergers are thought to be more common. We employ a new astrometric technique to find unresolved dual AGNs at high redshift in time-domain imaging surveys. The technique includes two complimentary methods: variability, which detects the centroid shift because of the non-synchronous variation of two AGNs, and color, which measures the centroid shift between two different filters due to the color difference of two AGNs. The technique is suitable for time-domain imaging surveys such as the ongoing Dark Energy Survey (DES) and the Large Survey Synoptic Telescope in future. We will present our preliminary results based on DES 4-year data including some dual AGN candidates identified from astrometry.

Eric Bellm (University of Washington/LSST)

LSST Data Management

Topic: Black Holes & Transient Phenomena

LSST Contributions to the Black Hole Census

Beginning in 2022, the Large Synoptic Survey Telescope (LSST) will conduct a ten-year survey of the Southern Hemisphere Sky. Thanks to its wide survey area, depth, and cadence, LSST will enable major advances in the study of black hole systems at all mass scales.

I will present an overview of LSST with a view towards its contributions to studies of Galactic black hole binaries, Active Galactic Nuclei, Tidal Disruption Events, and Gravitational Wave sources.

I will describe the baselined survey cadences and forthcoming opportunities for community input. I will review the LSST data products and services most relevant to time-domain studies. LSST will produce both a nightly alert stream of 10 million difference image sources as well as high-precision annual Data Releases. The former will be accessible to all through community brokers and the latter to data rights holders through the LSST Science Platform; I will describe the features of each.

I will discuss expectations for the performance of LSST's data reduction pipelines in crowded stellar fields such as the Galactic Plane. Finally, I will point out opportunities for science users to preview these tools and pipelines on precursor datasets.