

U.S. Radio/Millimeter/Submillimeter Science Futures in the 2020s Abstracts

December 4, 2015

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Cosmology & Cosmic Dawn

Tuesday, December 15, 2015

8:45 AM	Scott Dodelson	Theoretical Perspectives on Cosmology and Cosmic Dawn
9:10 AM	Jamie Bock	Primordial Cosmology and Inflation
9:35 AM	Aaron Parsons	Dark Ages and Reionization
10:00 AM	Abigail Crites	Probing the Epoch of Reionization with CII Tomography: TIME-Pilot and Future Capabilities
10:08 AM	Adrian Liu	Combined Analyses of 21cm Cosmology and Cosmic Microwave Background Data
10:16 AM		Coffee Break
10:45 AM	Suzanne Staggs	Late Time Cosmology
11:10 AM	Sunil Golwala	Using Clustering in the Submillimeter to Trace the Evolution of Dusty, Star-forming Galaxies on the Main Sequence
11:18 AM	Joaquin Vieira	The Redshift Distribution of Submm Galaxies
11:26 AM	Steve Myers	Cosmological Surveys
11:51 AM	Jim Braatz	Direct Probes of H_0
12:16 PM		Discussion
12:45 PM		Lunch/informal discussion

Scott Dodelson (Fermilab UChicago)

Theoretical Perspectives on Cosmology and Cosmic Dawn

Spectacular instruments and observations have enabled us to piece together a coherent, data-driven model of the Universe for the first time in thousands of years. What is next? What are the key questions in cosmology that remain to be answered? How and when will we answer them? Most importantly, what future projects hold the most promise for answering these questions or upending the premises on which they are based?

James Bock (Caltech)

Experimental Searches for Signatures of Inflation

Moments after the Big Bang, our observable universe underwent a violent spurt of inflationary growth. The inflationary expansion flung apart the observable universe from a causally-connected sub-atomic volume, and established a primordial spectrum of scalar perturbations that led to the temperature anisotropies observed in the cosmic microwave background. I will review current searches for inflationary signatures, focusing on measurements of B-mode polarization in the cosmic microwave background, a hallmark of tensor perturbations associated with a background of gravitational waves generated by inflation. However other signatures will be discussed, including prospects for detecting non-Gaussianity. I will also look forward to prospects and experimental challenges for improved measurements in the coming decade.

Aaron Parsons (University of California Berkeley)

HERA Collaboration

The Dark Ages and Reionization with 21cm

The 21cm line of neutral hydrogen provides unique access to the state of the intergalactic medium throughout our Cosmic Dawn, making it an essential tool for understanding the history of structure formation in our universe. Experiments are nearing a first detection of this cosmological signal and will begin characterizing its power spectrum. So far, the most progress has been made with dedicated experiments like PAPER, tailored to this single science application. The partially funded Hydrogen Epoch of Reionization Array (HERA) continues in this vein, competing scientifically with the Square Kilometre Array (SKA) for a small fraction of the cost. The logical next step beyond this involves directly imaging reionization, but unlike for power-spectral measurements, key challenges remain unsolved for building an imaging instrument. Given an uncertain path and timescale for solving these challenges, the US community is faced with a tough decision. Do we join with SKA-low — a leveraged instrument being designed too soon, with many competing science applications — or plan a separate, tailored effort once HERA has delivered more insight?

Abigail Crites (Caltech JPL)

Charles Matt Bradford (Caltech)

Jon Hunacek (Caltech)

Steve Hailey-Dunsheath (Caltech)

Asantha Cooray (UC Irvine)

Bruce Bumble (JPL)

Probing the Epoch of Reionization with [CII] Tomography: TIME-Pilot and Future Capabilities

CII tomography is a promising approach to study the populations of galaxies responsible for reionizing the Universe in the first billion years after the Big Bang. Deep UV dropout surveys in small fields shown that the EoR galaxies are intrinsically faint, even on the scale of the deepest Hubble, JWST, and ALMA surveys. The luminosity functions show steep and/or uncertain faint-end slopes, so that the total integrated light is poorly constrained. We are pursuing wide-field spectroscopic instrumentation for measuring the 3-D clustering via intensity mapping in the 1-mm band, which is sensitive to [CII] at $z=5-9$. With a survey sufficiently wide to measure the 2-halo clustering term on tens of arc minute scales, this technique is sensitive to the luminosity function integral, and thereby measures the total star-formation rate since [CII] broadly traces star-formation activity.

TIME-Pilot is designed for a first measurement of this signal with an experiment that is tractable with existing technology. 32 waveguide spectrometers disperse the 183-326 GHz band at R 100 to arrays totaling 1840 TES bolometers. TIME-Pilot will be deployed to the JCMT, and the survey volume will consist of an on-sky footprint of 1 degree by 1 beam, with depth provided by the spectral coverage. Our models indicate that the raw sensitivity of TIME-Pilot is sufficient to provide a detection of the [CII] clustering signal in a couple of hundred hours on sky. However, the dominant signal in the experiment will be the CO-emitting galaxies at z 0.5 to 3. This signal is interesting in its own right, but will need to be measured and removed to reveal the [CII]; we are developing strategies for this.

Adrian Liu (UC Berkeley)

Jonathan Pritchard (Imperial College London)

Rupert Allison (University of Oxford)

Aaron Parsons (UC Berkeley)

Uros Seljak (UC Berkeley)

Blake Sherwin (UC Berkeley)

Combined Analyses of 21cm Cosmology and Cosmic Microwave Background Data

The 2020s will be an exciting time for observational cosmology, with 21cm cosmology becoming a mature probe of astrophysics and cosmology. At the same time, Stage 4 cosmic microwave background (CMB) experiments will also yield high precision constraints on fundamental parameters. In this talk, I discuss ways in which 21cm cosmology and the CMB can complement one another, leading to improved results as well as ways in which one probe can act as an "insurance policy" for the other in the face of systematics. For example, direct constraints on the epoch of reionization from 21cm experiments can be used to predict—and eliminate—the optical depth nuisance parameter from CMB analyses. This can lead to a 5-sigma detection of the neutrino mass using Stage 4 CMB experiments even if the "reionization bump" polarization feature cannot be measured to high precision. Other possible combinations of 21cm experiments and the CMB include joint analyses of the CMB kinetic Sunyaev-Zel'dovich signal and global 21cm experiments, which are natural complements of one another for constraining the timing of reionization.

Suzanne Staggs (Princeton)

The Future of the (Somewhat) Recent Past: Late-Time Cosmology & Its RMS Probes

In the 50+ years since the background discovery, the microwave in the cosmic microwave background (CMB) has emerged as a term encompassing the radio, millimeter and submillimeter (RMS) bands, with data on the CMB blackbody spectrum, for example, collected at wavelengths extending from 73.5 cm to 470 microns. The satellite CMB anisotropy data from Planck and WMAP at angular scales of tens of arcminutes cap off a gorgeous series of ground-based and balloon-borne experiments and reveal very early conditions in the universe. In fact, those data confirm a surprisingly simple parameterization of the so-called background cosmology. Now high-angular-resolution maps of the CMB across a broad range of RMS bands are providing inventories of more recent events; they are beginning to probe the growth of large-scale structure in the universe under the influence of gravity, and the concomitant development of large scale flows. Of course, the structure and flows depend on not only the properties of matter (dark or not), but on the cosmic expansion history and the nature of the gravitational force over cosmological distances and times. I will describe some aspirations for future revelations from the CMB on late-time cosmology.

Sunil Golwala (Caltech)

Using Clustering in the Submillimeter to Trace the Evolution of Dusty, Star-forming Galaxies on the Main Sequence

With the clear evidence of a main sequence for galaxies in the star formation rate vs. stellar mass plane, it becomes important to understand how galaxies evolve within and along the main sequence with time. Galaxy clustering is a key tool for measuring this evolution: we can measure the dark matter halo mass of classes of galaxies via their observed correlation length, and we know well how dark matter halo masses evolve with time. To date, this tool has been only coarsely applied to the submillimeter-bright, dusty, star-forming galaxy (DSFG) population, recovering the typical halo mass of the Herschel detected galaxies. With the prospect of submillimeter surveys in the next decade covering tens to thousands of square degrees and detecting more typical star-forming galaxies, combined with photometric redshifts from large-area O/IR surveys, clustering measurements will become a precision tool for measuring the evolution of the main sequence in this population.

Joaquin Vieira (University of Illinois)

SPT SMG Collaboration

The Redshift Distribution of Submm Galaxies

In a 2500 square degree cosmological survey, SPT has systematically identified a large number (~ 100) of high-redshift strongly gravitationally lensed sub-millimeter galaxies (SMGs). We are conducting a unique spectroscopic redshift survey with ALMA, targeting carbon monoxide line emission in these sources, across the 3mm spectral window. To date, we have obtained spectroscopic redshifts for 39 sources from $1.8 < z < 5.8$, with a median of $z=3.8$. We are undertaking a comprehensive and systematic followup campaign to use these “cosmic magnifying glasses” to study the infrared background in unprecedented detail, inform the condition of the interstellar medium in starburst galaxies at high redshift, and place limits on dark matter substructure. I will describe our teams method for obtaining and confirming spectroscopic redshifts, detail our current knowledge of the redshifts distribution of SMGs, present a method for selecting the highest redshift SMGs, and discuss future directions for obtaining large samples of mm-wave spectra.

Steven Myers (NRAO)

Radio Astronomical Surveys for Cosmology

In this presentation I describe the range of radio astronomical surveys that are needed to address key problems in cosmology. I focus on topics not covered by other talks, primarily carried out using detailed spectroscopic and spectropolarimetric imaging of large numbers of objects. Examples of these observations include: redshift surveys of galaxies in HI and CO for Baryon Acoustic Oscillation measurements and the mapping of large-scale structure and velocity flows, Faraday Rotation tomography of cosmic magnetic field structure and evolution, and deep high-resolution radio continuum imaging for the measurement of cosmic shear due to weak gravitational lensing distortions of galaxy shapes. These surveys characteristically produce large well-selected samples of galaxies and active galactic nuclei, suitable for detailed astrophysical studies as well as for bread-and-butter cosmology. These in turn can be fed into cosmological applications, such as the study of the formation and evolution of clusters of galaxies through cosmic time, and the use of strong gravitational lensing as a probe of dark matter halos and cosmology. We will also discuss unique opportunities presented by radio astronomy, such as the ultra-high resolution imaging and astrometric capabilities of very long baseline interferometry, allowing direct measurement of distances and motions in the local group and beyond.

James Braatz (NRAO)

MCP team

Direct Measures of the Hubble Constant

The Hubble Constant has been, historically, the most fundamental parameter in observational cosmology. Today, direct measurements of H_0 remain a top priority of the cosmology community. In the context of the standard Λ CDM model, Planck observations of the CMB predict H_0 to be 67.8 km/s/Mpc with 1% precision, while astrophysical measurements using traditional standard candles (Cepheids and SN Ia) measure 74 km/s/Mpc with 3% uncertainty. The tension between these values may indicate new physics, so the measurements require independent confirmation. I will describe ongoing work seeking new measurements of H_0 , including efforts by the Megamaser Cosmology Project (MCP). The MCP combines spectral monitoring of water maser disks in AGN with sensitive VLBI mapping to determine direct geometric distances to the host galaxies. I will also summarize recent work using gravitational lens time delays to measure H_0 . Each of these methods is capable of determining H_0 with a few percent total uncertainty within a couple of years. With new, sensitive telescopes proposed in the coming decade, it may be possible to reach percent-level precision.

Cradle of Life

Tuesday, December 15, 2015

2:00 PM Ted Bergin	Future Challenges Related to Star and Planet Formation
2:25 PM Stella Offner	Star Formation
2:50 PM Crystal Brogan	Revealing the Obscured Hearts of Massive Protostars
2:58 PM Michael Dunham	The Role of Large Surveys in Star Formation
3:06 PM Eric Herbst	Interstellar Chemistry
3:31 PM	Coffee Break / Poster Session
4:00 PM Cornelia Lang	Star Formation in the Galactic Center and Galactic Centers
4:08 PM Meredith Hughes	Protoplanetary and Debris Disks
4:33 PM Andrea Isella	Studying Planet Formation with Future Radio Telescopes
4:41 PM Rebekah Dawson	Planetary Systems and their Evolution
5:06 PM Stefanie Milam	The Solar System
5:31 PM	Discussion

Edwin Bergin (University of Michigan)

Tracing the Elemental Ingredients of Life During the Stage of Planet Formation

Today with ALMA, along with the legacy of Spitzer and Herschel, we are beginning to follow the most abundant elemental carriers of C, H, O, N during the initial stages of planet formation. However, despite its sensitivity and spectral grasp there are several key volatile carriers of these elements that are needed to fully complete our understanding of the chemical composition of icy planet-forming bodies. One important tracer that can be crucial is HD, which can only be observed from space or airbourne observatories. I will discuss the use of HD as a unique tracer of H₂ gas mass. Furthermore it can be used to unlock measurements of chemical abundances from ground-based observatories to trace the implantation of the volatile elements into planetesimals. Another missing piece is ammonia - which may be the most abundant nitrogen carrier. An expansion of the VLA would allow for the improved sensitivity to detect and map the emission of the weaker inversion transitions. Such an expansion would also trace longer wavelength dust thermal emissions as an additional probe of dust evolution towards larger sizes. Thus the combination of observations at far-IR and longer wavelengths is needed to fully understand the origins of terrestrial worlds rich in these key elements such as our own.

Stella Offner (UMass Amherst)

Open Questions in Star Formation

I will present an overview of current outstanding questions in star formation. These include the origin of the stellar initial mass function, the initial conditions of molecular clouds and the role of feedback in regulating star formation. I will discuss how these questions may be resolved through the synergy of numerical simulations and the next generation radio/mm/sub-mm surveys.

Crystal Brogan (NRAO)

Todd Hunter (NRAO)

Claudia Cyganowski (University of St Andrews)

Revealing the Obscured Hearts of Massive Protostars

Wavelengths from 6 cm to 1.3 mm are critical for discerning the nature of massive protostellar objects. In this wavelength range, the dominant continuum emission mechanism transitions from ionized gas to optically-thin dust, both of which can probe the innermost regions of the dense circumstellar material. When combined with high sensitivity and angular resolution to combat confusion problems, data in this regime can be used to completely characterize the obscured inner hearts of massive protostars. I will discuss recent science results from JVLA and ALMA observations toward massive protoclusters and highlight what future telescope advances will be needed to take the next big steps.

Michael Dunham (CfA SAO)

The Role of Large Surveys in Star Formation

Low-mass stars form from the gravitational collapse of dense molecular cloud cores. While a general consensus picture of this collapse process has emerged, many details on how mass is transferred from cores to stars remain poorly understood. Progress in understanding when, why, and how dense cores collapse to form stars requires moving beyond single-object and small-n surveys into the realm of large surveys in order to bring robust statistical measures to the field. I will discuss the role these large surveys will have in the future of star formation research, focusing on results from pilot surveys on protostellar cores with the SMA and starless cores with ALMA.

Eric Herbst (University of Virginia)

Interstellar Chemistry

In the next decade, molecular observations of high spatial resolution obtained from interferometers such as the VLA, extended Plateau de Bure, and ALMA will revolutionize our understanding of the role of chemistry in the study of star and planetary formation. Although the revolution is already beginning, the observation of truly complex molecules (e.g. molecules with 10 or more atoms) is lagging behind, with very few new detections let alone any spatial information. Yet the detection of such molecules has an astrobiological importance as well as allowing astrochemists to better constrain the chemistry that synthesizes molecules in regions of star formation. Given the large moments of inertia of complex species, the low frequency (cm-wave) region of the electromagnetic spectrum will assume more importance in their detection. To observe such molecules, large single dishes such as GBT will continue to be quite useful, but interferometric observations in these low-frequency regions will be needed to understand their environments. The SKA array project promises to represent a huge advance in low-frequency interferometric studies, but its promoters tend to emphasize cosmology rather than star formation, and its upper frequency (14 GHz) will be limiting to molecular detections. Expansion of the VLA leading to a much larger collecting area and improved spatial resolution in the cm-wave and large mm-wave range should be a priority in the next decade for astrochemistry.

Cornelia Lang (University of Iowa)

Star Formation in the Galactic Center and Galactic Centers

The process of star formation in the center of the Galaxy is not well understood and appears to have some major differences than star formation in the Galactic disk. Sensitive, high-resolution imaging capabilities across a wide range of frequencies, including both continuum and spectral line observations, are beginning to provide a complete picture of the scope and energetics of star formation in the dense and unusual core of our Galaxy. Over the next decade, the ability to study an even larger range of individual molecular cloud environments in the Galactic center will be made possible by expanded and upgraded facilities. The addition of sensitivity to polarization will also improve our understanding of star formation in this environment. With the high spatial resolutions of new facilities, similar studies can be made of the cores of the nearest star forming galaxies.

A. Meredith Hughes (Wesleyan University)

Protoplanetary and Debris Disks

Protoplanetary disks provide the raw materials and initial conditions for the planet formation process, while debris disks give us glimpses of planetary systems that have already formed. These fields have been advancing rapidly thanks to ALMA, the JVLA, and new direct imaging instruments in the OIR, and we now have more insight than ever before into the planet formation process. I will briefly review frontiers in this field and discuss future directions, including prospects for taking advantage of greater sensitivity, resolution, and wavelength coverage offered by upcoming radio facilities and upgrades to existing instruments.

Andrea Isella (Rice University)

Studying Planet Formation with Future Radio Telescopes

ALMA observations of nearby protoplanetary disks allow us to study the formation of giant planets orbiting at more than 10 AU from the central star. In my talk, I will show that unveiling planet formation inside this orbital radius requires observations at wavelengths longer than those covered by ALMA. In particular, I will argue that a long baseline (>300km) cm-wave telescope would enable us to observe the formation of super-Earths and giant planets down to an orbital radius of about 1 AU.

Rebekah Dawson (UC Berkeley)

Planetary Systems and their Evolution

A complete theory for how planetary systems form and evolve must start with the initial conditions for planet formation, identify the physical processes triggered by these conditions, and detail how the physical processes driving the formation and evolution of planetary systems give rise to the observed diversity of exoplanet properties. I will describe recent work on how the variety of exoplanet orbits and compositions observed today are rooted in conditions in the proto-planetary disk that determine planetary systems' early evolution. I will lay out how the next generation of radio/mm/sub-mm observations will enable us to test the theories that link proto-planetary disk conditions to the young directly imaged planetary systems to the mature planetary systems observed with transits, radial-velocity, and microlensing.

Stefanie Milam (NASA GSFC)

Solar System Observations with Radio/Millimeter/Submillimeter Assets in the 2020s

Solar system objects are some of the brightest and fastest moving objects in the sky, requiring of sensitive and modern facilities to study their highly dynamic and seasonal changes. Radio/millimeter/submillimeter continuum and spectral line observations provide a unique spectroscopic window to study these bodies. At these wavelengths details of the bulk physical composition of icy surfaces, the size and albedo of small objects, the composition/dynamics/physics of planetary atmospheres can be measured, as well as monitoring of time variable phenomena for extended periods. Long standing questions in solar system science can be addressed by observations in the millimeter/sub-millimeter regime, such as the origin of the solar system (isotope ratios, composition) and the evolution of solar system objects (dynamics, atmospheric constituents, etc). Small bodies are considered to contain the most primitive material remaining from the formation of our solar system, with cometary ices providing an important source of information about the physical and chemical conditions of the early Solar Nebula. Comparing abundances and cosmogonic values (isotope and ortho:para ratios) of cometary parent volatiles to those found in the interstellar medium, in disks around young stars, and in other bodies across the solar system, we can better understand planetary system formation and the processing history experienced by organic matter. Advances in radio/millimeter/submillimeter technologies now allow for broad-band surveys to search for multiple molecules simultaneously during short lived events (e.g. comet outburst, storms on gas giants), while advances in interferometry can now map different species in the outer planets and conduct sensitive searches for new species and follow seasonal effects.

Formation and Evolution of Galaxies

Wednesday, December 16, 2015

8:30 AM	Dusan Keres	Theories of Gas Flows In and Out of Galaxies
8:55 AM	Sylvain Veilleux	Observations of Gas Flows In and Out of Galaxies
9:20 AM	Christopher Hayward	Constraining the Importance of Stellar Feedback-driven Outflows in Galaxy Formation
9:28 AM	Andrew Baker	Observations of the Interstellar Medium of Galaxies
9:53 AM	Nick Scoville	ISM masses and Star Formation at High z using Dust Continuum
10:01 AM		Coffee Break / Poster Session
10:30 AM	Desika Narayanan	Theory of Interstellar Matter in Galaxies
10:55 AM	Brant Robertson	Theories of Star Formation and AGN Activity over Cosmic Time
11:20 AM	Caitlin Casey	Observations of Star Formation and AGN Activity over Cosmic Time
11:45 AM	Elisabeth Mills	Characterizing the Environment of Deeply Buried AGN with the NGVLA
11:53 AM	Alexandra Pope	Taking Census of Dust-obscured Star Formation in All Galaxies Over Cosmic Time
12:01 PM		Discussion
12:30 PM		Lunch/informal discussion

Dusan Keres (University of California San Diego)

Theories of Gas Flows In and Out of Galaxies

Our understanding of the gas infall into galaxies evolved over the past decade and is now believed to be driven by a mixture of cold filamentary infall and cooling of the hot gas. Addition of galactic outflows makes the picture more complex where outflowing gas can interact with the infall and can also recycle back into galaxies. Modeling of realistic feedback that produces outflows from galaxies is therefore crucial for understanding of both infall and outflow processes. I will briefly review these processes and discuss gaseous flows and their consequences in FIRE suite of simulations that includes explicit stellar feedback model.

Sylvain Veilleux (University of Maryland)

Observations of Gas Flows In and Out of Galaxies

Galaxies are not isolated and static Island Universes. Material flows into, within, and out of them via accretion and large-scale fountains and outflows powered by intense star formation episodes (starbursts) and nuclear activity driven by supermassive black holes (AGN). I will summarize the current observational evidence for this galactic ecosystem in and around nearby and distant galaxies. Then I will look to the future and discuss how the new radio/millimeter/sub-millimeter-wave facilities planned for the 2020s and beyond should allow us to make significant progress in this area of research.

Christopher Hayward (Caltech)

Constraining the Importance of Stellar Feedback-Driven Outflows in Galaxy Formation

Modern large-volume cosmological simulations rely on stellar feedback-driven outflows to solve the 'overcooling' problem, but they must incorporate such outflows via highly uncertain sub-resolution prescriptions. In contrast, state-of-the-art simulations with resolved stellar feedback generate outflows self-consistently. I will discuss the underlying physics of such outflows and describe how simulations and theoretical models for outflows can be tested using future radio/(sub)mm facilities.

Andrew Baker (Rutgers The State University of NJ)

Observations of the Interstellar Medium of Galaxies

New radio, millimeter, and submillimeter facilities offer powerful capabilities for studying the cold (neutral atomic and molecular) phases of the interstellar medium in galaxies at low and high redshift. I will discuss the use of spectral line observations of these phases as tools for understanding how galaxies grow in mass, how their masses are internally distributed, and how they turn their gas reservoirs into stars.

Nick Scoville (Caltech)

ISM masses and Star Formation at High z using Dust Continuum

I will describe our development of a new technique using the RJ dust continuum to measure ISM masses of galaxies at high redshift. We now have continuum measurements with ALMA of over 300 galaxies at $z = 1$ to 6 yielding mass estimates independent of the conversion factor issues associated with CO. We find a linear correlation of SFRs with derived ISM masses both on and above the galaxy main sequence. This technique can enable massive samples of galaxies using future large submm telescopes.

Desika Narayanan (Haverford College)

Theory of Interstellar Matter in Galaxies

Observable measures of the interstellar medium in galaxies, CO, CI and [CII], depend sensitively on the physical properties of the gas and background radiation field. I will discuss how the chemical and physical structure of clouds in a turbulent interstellar medium change with average galaxy properties, and discuss how we may utilize proposed radio facilities to detect the neutral interstellar medium during the first billion years of the Universe.

Brant Robertson (UC Santa Cruz)

Theory of Star Formation and AGN Activity over Cosmic Time

Radio/mm/sub-mm (RMS) astronomy provides a unique view of the universe, and helps us to understand star formation and AGN activity in galaxies over cosmic time by probing cold star-forming gas, synchrotron emission, and radio bright activity fueled by supermassive black hole accretion. I review the theory of star formation and AGN activity over cosmic time, emphasizing the connection of RMS astronomy to the physical processes involved. The bright future of RMS astronomy will allow us to make huge gains in our understanding of the star formation and AGN activity histories of the universe, and I highlight some particularly interesting theoretical issues where future RMS observations will greatly contribute.

Caitlin Casey (University of Texas Austin)

Observations of Galaxy Evolution over Cosmic Time

Half of all starlight in the Universe is absorbed and re-radiated in the far-infrared and submillimeter, yet much of what we have learned about the early Universe to-date comes from surveys carried out at optical wavelengths. The significant advances in far-infrared and submillimeter technology of the past decade including the arrival of the Atacama Large Millimeter Array, the Herschel Space Observatory, and the next-generation of single-dish submm/mm bolometer arrays has finally shifted focus from the optical regime to longer wavelengths where dust and gas emit. For the first time, we are able to scrutinize the physics of the obscured Universe and piece together the ingredients governing its evolution, and the state of galaxies in the Universe today. I will discuss the most recent submillimeter/radio observatories impact on the study of galaxy evolution across cosmic time, in particular looking back to the earliest epochs, $\sim 1-2$ billion years after the Big Bang to the peak of cosmic star-formation (at $z \sim 2$), 10 billion years ago. I will also review our community's priorities moving forward into the next few decades and discuss the potential contribution of future facilities, including the possibility of a space-based 5m-class FIR Surveyor, ground-based 30m single-dish designs for the submm/mm, and the next-generation Very Large Array, all of which will have tremendous impact on our understanding of hierarchical galaxy formation if completed. This wavelength regime has become fundamental in contributing benchmark studies of how galaxies form, grow, and enrich the underlying composition of the cosmic web, and most likely will continue to do so well into the future.

Characterizing the Environment of Deeply Buried AGN with the NGVLA

The growth of supermassive black holes is intimately tied to the structure and evolution of their host galaxies. However, the mechanisms that fuel active black holes, and the scales upon which they operate, remain debated. A significant fraction of black hole growth is suggested to occur in a stage in which the active nucleus is highly obscured by and potentially fed by a 'torus' of cool gas and dust. However, the nature of this circumnuclear gas, including its geometry, filling factor, and spatial extent, remains largely unexplored. A Next-Generation Very Large Array or NGVLA will have the ability to characterize the molecular circumnuclear gas (determining its kinematics, size scale, and structure) for a significant sample of active galactic nuclei in the local universe. The spectral lines that are accessible in the 10-100 GHz range can also offer diagnostics of the physical conditions in this gas. The increased sensitivity of the NGVLA compared to existing instruments will further enable observations of a larger suite of diagnostic lines (e.g., rovibrational lines, isotopologues) with the potential to identify the presence of deeply buried AGNs via anomalous excitation and chemistry of the surrounding gas. The NGVLA will offer a a unique window into the some of the most deeply buried AGN in the local universe that will complement the sample of AGNs that can be probed with existing and future optical, infrared, and x-ray facilities.

Alexandra Pope (University of Massachusetts Amherst)

Taking Census of Dust-obscured Star Formation in all Galaxies over Cosmic Time

While we know that the majority of star formation occurs behind dust, we have yet to directly detect this dust-obscured activity in large numbers of the normal galaxies that dominated the cosmic history star formation. Building on the success of the first (sub)millimeter surveys of high redshift galaxies 10-15 years ago, I will present new results from the Large Millimeter Telescope including our survey program of the Frontier Fields. Thanks to this large telescope and the magnification from foreground clusters, this millimeter survey is able to detect dust in galaxies with star formation rates as low as $\lesssim 10$ solar masses per year. I will discuss the synergy between these large surveys and targeted programs with ALMA. I will argue that the future of radio/millimeter/submillimeter astronomy needs large single-dish (sub)millimeter facilities in order to take a complete census of dust-obscured activity in the Universe.

Fundamental Physics

Wednesday, December 16, 2015

1:30 PM	Tracy Slatyer	Dark Matter
1:55 PM	Shep Doeleman	Imaging the Event Horizon of Supermassive Black Holes
2:20 PM	Mansour Karami	Directly Imaging Gravitational Microlensing Events
2:28 PM	Xavier Siemens	Detecting Gravity Waves
2:53 PM	Michael Rupen	Radio Imaging of Galactic Explosions
3:01 PM		Coffee Break / Poster Session
3:30 PM	Scott Ransom	The Physics of Pulsars
3:55 PM	Paul Demorest	Testing GR with Pulsars
4:20 PM	Duncan Lorimer	Fast Transients
4:36 PM	Laura Chomiuk	Slow Transients
4:52 PM	Tanmoy Laskar	Fundamental Physics with Gamma-ray Bursts
5:00 PM		Discussion

Tracy Slatyer (Massachusetts Institute of Technology)

Dark Matter

Dark matter annihilation or decay may produce striking signatures in millimeter, sub-millimeter and radio frequencies – for example, via electrons that produce synchrotron radiation in galactic/cluster magnetic fields, heating of the intergalactic medium during the epoch of reionization, or distortions to the spectrum of the cosmic microwave background. The small-scale structure of dark matter may be probed by improved lensing observations, in turn constraining new physics in the dark matter sector. Finally, searches for dark matter signatures at all wavelengths are complicated by astrophysical backgrounds that radio/mm/sub-mm searches could help address. I will discuss the current status and future prospects of these various directions.

Shep Doeleman (SAO MIT)

Observing Supermassive Black Holes with Event Horizon Resolution

A convergence of high bandwidth radio instrumentation and Global mm and submm wavelength facilities are enabling assembly of the Event Horizon Telescope (EHT): a short-wavelength Very Long Baseline Interferometry (VLBI) array, which can observe the nearest supermassive black holes with Schwarzschild Radius resolution. Initial observations with the EHT have revealed event horizon scale structure in SgrA*, 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, testing GR, and modeling black hole accretion, outflow and jet production. This talk will describe the technology that underpins the project, the planned timeline, and the latest EHT results.

Mansour Karami (University of Waterloo)

Directly Imaging Gravitational Microlensing Events

Gravitational microlensing is one of a handful of tools with which to study stellar remnants, and the way to probe inactive stellar mass black holes. Unfortunately, it suffers from the considerable limitation of a near complete degeneracy between many of the lens and source parameters. Imaging microlensing events would provide a means to break this degeneracy directly, enabling the full reconstruction of the lens parameters. This can be accomplished in practice using the existing optical microlensing surveys to long-duration events involving radio bright stars (e.g. Mira variables) and triggering follow up VLBA. In practice, an optical/infrared microlensing survey of Galactic bulge and disk comparable to existing efforts is expected to result in black hole detection at a rate of 1.3 per year. Future radio microlensing surveys can push this rate to 10 detections per year, hence doubling the number of confirmed stellar holes in a couple years. I will describe how these rate estimates are obtained and what capabilities are required to achieve them

Xavier Siemens (University of Wisconsin – Milwaukee)

Detecting Gravitational Waves

For the last decade, the North American Nanohertz Observatory for Gravitational Waves (NANOGrav) has been using the Green Bank and Arecibo radio telescopes to monitor millisecond pulsars. NANOGrav aims to directly detect low-frequency gravitational waves which cause small changes to the times of arrival of radio pulses. In this talk I will discuss the work of the NANOGrav collaboration and our sensitivity to gravitational waves from astrophysical sources. I will show that a detection is possible in the next few years.

Michael Rupen (NRC Herzberg Astronomy and Astrophysics)

Radio Imaging of Galactic Explosions

I explore the use of a next-generation radio interferometer for imaging accretion-powered outbursts in our Galaxy. An array with resolution of order milliarcseconds and the sensitivity to image thermal ($<10^4$ K) sources would have an enormous impact. I illustrate the possibilities with examples of both thermal (novae) and non-thermal (X-ray binaries) transients, with source ages ranging from days to decades.

Scott Ransom (NRAO)

Physics of and from Radio Pulsars

The extreme nature of neutron stars and their regular clock-like pulsations allow unique probes into a wide variety of physics. This past decade has seen huge steps forward in our understanding of the equation of state of dense matter with the discovery of two-solar-mass neutron stars, and in the physics of the pulsar magnetosphere and emission mechanism(s) with advanced computer simulations and high-quality radio and gamma-ray observations. Wideband and high time resolution radio observations, particularly when using very-long baselines, are also allowing new and truly unique probes of the ionized interstellar medium. Future progress in these fields requires much improved sensitivity at decimeter wavelengths and a Galactic census of the radio pulsar population. MeerKAT and FAST will begin to provide both of these in the coming few years, and SKA Phase I should be revolutionary. The US needs to be part of these projects in some way and/or should ensure that a next-generation US-based radio array can address some of the same science topics.

Paul Demorest (NRAO)

Testing General Relativity with Pulsars

Radio pulsars in binary systems act as nearly ideal astronomical laboratories for testing gravity and general relativity in regimes inaccessible to local experimentation. The regular pulsed radio signal acts as a high-precision clock with which to measure orbital and space-time properties in the system, while the neutron star and its generally compact binary companion provide both a dynamically clean environment and strong gravitational fields. Timing of double-NS binaries, unequal mass NS-WD binaries, and a recently discovered triple system all have already given unique tests of GR. Current or future telescopes are expected to discover pulsar-black hole systems, which would result in unprecedented probes of the spacetime around a black hole. These may include pulsars bound to Sgr A* or those in orbit with a stellar-mass BH. I will review the dramatically different instrumentation and observing strategy required for these searches, as well as current and future prospects for finding these elusive objects.

Duncan Lorimer (WVU)

Fast Radio Bursts in the 20s

I will review what is known and what is unknown about the emerging phenomenon of Fast Radio Bursts since their discovery almost a decade ago. Our understanding of this population is likely to be solidified over the coming few years as the prospects for identification of counterparts at other wavelengths improve. Looking ahead to the next decade, if they are cosmological, Fast Radio Bursts have great potential as cosmological probes. If they are something else, that's interesting too! In any event, current theoretical development based on these preconceived notions is stimulating the design of next generation transient instruments which in my humble opinion is a very good thing.

Laura Chomiuk (Michigan State University)

Slow Transients

I will review recent progress on both Galactic and extragalactic incoherent transients at radio wavelengths, touching on novae, X-ray binaries, stellar flares, supernovae, tidal disruption events, and gamma-ray bursts. I will then discuss specifications for future facilities that can enable exciting discoveries and deeper physical insight into these explosions and outbursts.

Tanmoy Laskar (National Radio Astronomy Observatory)

Fundamental Physics with Gamma-ray Bursts

Gamma-ray bursts, the most energetic explosions in the Universe, are ideal probes of extreme relativistic astrophysics. Thanks to their great luminosities, they illuminate our understanding of the emergence of the first light in the Universe, while providing a unique laboratory for the study of relativistic shock physics. Observing and modelling their radiation provides crucial clues to our understanding of particle acceleration in relativistic shocks, explosion and jet launching mechanisms, and the characteristics of GRB progenitors, which together inform our ability to use GRBs as probes of the cosmic dawn to the highest redshifts. I argue how multi-wavelength follow-up observations are beginning to yield a wealth of information about each of these aspects, and present results of our on-going campaign to obtain unprecedented spectral and temporal coverage of GRB afterglows with the VLA. I conclude by demonstrating the power of radio observations in uncovering unexpected phenomena, and present the detection of multiple relativistic shocks in GRB radio afterglows.

Facilities Under Construction

Thursday, December 17, 2015

8:30 AM	Guseppina Fabbiano	Next Generation X-ray Telescopes
8:55 AM	Beth Willman	LSST
9:20 AM	Phil Diamond	Square Kilometer Array
9:45 AM	Gregg Hallinan	The Owens Valley LWA: Next-generation All-Sky Imaging at Radio Frequencies
9:53 AM	Charles Romero	NIKA2: Millimeter observations with KIDs
10:01 AM		Coffee Break / Poster Session
10:30 AM	Rachel Osten	James Webb Space Telescope
10:55 AM	Jeff Kruk	WFIRST
11:20 AM	Dan Werthimer	Advanced Radio Instrumentation
11:45 AM	Gordon Stacey	The CCAT Observatory
11:53 AM	F.P. Schloerb	Status of the Large Millimeter Telescope

Future X-ray Telescopes

In the last two decades X-ray astronomy has been dominated by two major telescopes, both operating in the 0.1-10 keV energy band: the ESA telescope XMM-Newton and NASA's great observatory Chandra. While XMM-Newton has a larger collecting area, and therefore provides in some cases better spectral data, Chandra is unique in having sub-arcsecond spatial resolution. With this resolution, and matched spectral capabilities, Chandra has revealed ubiquitous and complex X-ray emission in the universe, and has provided a good match to HST, Spitzer and ground-based telescopes for multi-wavelength studies. Other telescopes, both operational and planned, cover selected, yet important regions of discovery space, the harder X-ray energies (NuSTAR), high spectral resolution micro-calorimeters at the 6.4keV FeK line (Suzaku, ASTRO-H), and all-sky shallow survey coverage (eROSITA). However, a deep sky coverage that will be compatible with the next generation space and ground radio and optical telescopes, requires significantly larger X-ray telescopes. ESA has responded to this challenge with ATHENA, a much larger version of XMM-Newton, with comparable angular resolution. In the US, NASA has called for a study of the X-Ray Surveyor concept, as part of the preparations for the next Decadal Review. The X-Ray Surveyor will have a collecting area at least as large as that of ATHENA, but an angular resolution comparable with Chandra, over a larger field of view than Chandra, optimized for large-area and deep surveys. The high angular resolution of the X-Ray Surveyor also enables dispersive spectroscopy with much higher spectral resolution than on Chandra, at energies complementary to micro-calorimeters. This telescope, made possible by recent advances in X-ray optics, will provide a unique facility for studying the cosmic evolution of black-holes and hot baryons, and for exploring the cycle of stellar birth and death; it will bring the study of the X-ray sky to an entirely new level, and allow the next generation of truly multi-wavelength astrophysical investigations.

Beth Willman (LSST Steward Observatory)

The Large Synoptic Survey Telescope

The Large Synoptic Survey Telescope (LSST) started construction in 2014, will begin commissioning in 2019, and will enter full survey operations in 2022. Over a ten year period, LSST will image the southern sky hundreds of times in 6 broad-band, optical filters. The wide-field, time domain, and deep co-added images of LSST will yield a dataset that enables investigations from star formation to galaxy evolution to dark energy. Many community-LSST connections are already underway, including a community-based study of LSST's observing strategy and publicly available software and simulations.

Philip Diamond (SKA Organisation)

Square Kilometre Array

SKA is the next-generation radio telescope, a science facility for the 21st Century. I shall summarise the scientific motivation for the SKA, the current status of its design and outline the project's workplan for the coming year.

Gregg Hallinan (California Institute of Technology)

The Owens Valley LWA: Next-generation All-sky Imaging at Radio Frequencies

The Owens Valley LWA (LWA-OVRO) is a new array of 256 dual polarization antennas spaced over a 1.7 km diameter area at Caltech's Owens Valley Radio Observatory that targets the sub-100 MHz radio sky. The array is serviced by custom low-cost fiber links to enable signal transport via optical fiber over km baselines and makes use of the LEDA correlator to allow full cross-correlation of all 256 dual polarization inputs delivering 58 MHz bandwidth with 2400 channels. Together, this enables instantaneous imaging of the entire viewable sky every few seconds with a spatial resolution of 10 arcminutes, delivering a survey speed 50 times greater than any other array operational in this band. The primary science goals are i) searching for low frequency radio transients, particularly radio bursts caused by coronal mass ejections on nearby stars and the associated auroral radio emission from extrasolar planets ii) probing the Cosmic Dawn era by measuring the HI signature at $z \approx 20$ iii) dynamic imaging spectroscopy of the Sun and iv) continuous monitoring of the ionosphere. I will discuss the science motivation for the Owens Valley LWA and the power of all-sky imaging as a distinct and complementary tool at low frequencies in the SKA-era.

Charles Romero (IRAM)

NIKA2 consortium (IRAM Institut N el IN IPAG OSUG LPSC IAS CEA Cardiff Univers)

NIKA2: Millimeter Observations with KIDs.

NIKA2 is the successor to the New IRAM KID Array (NIKA), which saw first light in 2008 and improvements throughout its lifetime. NIKA2 is a continuum camera consisting of Kinetic Inductance Detectors (KIDs) which detect incident photons via a change in the (kinetic) inductance of the detectors. This method of detection is well suited to frequency multiplexing and allows for many detectors to be read out. NIKA2 has 1000 detectors at 150 GHz and 4000 detectors at 260 GHz with an instantaneous field of view of 6.5 arcminutes. NIKA2 observes with both bands simultaneously, and at 260 GHz the NIKA2 arrays are dual polarization sensitive.

NIKA2 has recently been installed on the IRAM 30-m telescope at the Pico Veleta in Spain and is intended for observations of clusters of galaxies via the Sunyaev-Zeldovich (SZ) effect, deep surveys of the high redshift universe, measuring the SED of nearby galaxies, and mapping dusty molecular clouds and their magnetic fields, providing insights into stellar formation and the stellar IMF.

Rachel Osten (STScI)

Exploring the Universe with the James Webb Space Telescope

The James Webb Space Telescope was the primary large mission to be advocated as a result of the 2000 Decadal Survey, and the 2010 Decadal Survey affirmed the role of JWST in shaping the astrophysics questions in the next decade, with a launch date in 2018. It is often labelled as a successor to the Hubble Space Telescope, although working at near- and mid-infrared wavelengths. The combination of sensitivity and resolution make JWST a formidable facility to tackle the most pressing scientific problems in astrophysics, from studying the Universe's first stars and galaxies, mapping the evolution of galaxies across cosmic time, performing detailed characterization of exoplanet atmospheres, and studying the formation of Solar Systems. JWST contains a new generation of complex instrumentation to ensure diverse modes of operation without servicing, including new science modes flown in space for the first time. In this talk I will describe the instruments and observing modes on JWST, and lay the groundwork for expected science discoveries with JWST. I will describe current elements of the mission timeline that lead up to a scheduled launch in October 2018, as well as steps being taken by both NASA and ESA to prepare the astronomy community to use JWST and maximize its full potential for science. I will describe synergies with current and planned telescopes in the radio, mm and sub-mm wavelength range, and discuss how to best utilize investments in these areas to maximize science.

Jeffrey Kruk (NASA-GSFC)

The WFIRST Mission

The Wide-Field Infrared Survey Telescope (WFIRST) mission, the top-priority in the 2010 Astronomy & Astrophysics Decadal Survey, is now planned to use an already-built 2.4m telescope obtained from the National Reconnaissance Organization. This telescope provides image clarity similar to HST, but with an optical design and array of new-generation H4RG infrared detectors that enables imaging of 100 times the area of HST in a single exposure. This wide-field IR instrument will provide galaxy surveys and supernova monitoring for dark energy studies that are significantly deeper than those planned by other observatories. A coronagraph instrument will directly image ice and gas giant planets, and circumstellar disks. The talk will summarize the mission and its capabilities for joint observations with future radio telescopes.

Dan Werthimer (UC Berkeley)

Future Digital Instrumentation for Radio Astronomy

I will present architectures and technologies for next generation digital instruments, including correlators, beamformers, spectrometers, pulsar, VLBI, and SETI. I will discuss how to develop flexible general purpose heterogeneous instruments that are scalable, upgradeable, and fault tolerant, using ethernet switches and industry standard protocols. I'll also speculate on what kind of instruments the radio astronomy community could build in 10 and 20 years.

I will also present some of the new open source heterogeneous radio astronomy instruments, hardware, gateware, GPUware, and software developed by the CASPER collaboration, including new ADC and FPGA boards, as well plans for next generation CASPER tools and libraries. CASPER collaborators at hundreds of universities, government labs and observatories have used these techniques to rapidly develop and deploy a variety of instrumentation. CASPER instrumentation is also utilized in physics, medicine, genomics and engineering. Open source hardware, software, libraries, tools, tutorials, training videos, reference designs, and information on how to join the collaboration are available at <http://casper.berkeley.edu>

Gordon Stacey (Cornell University)

R Giovanelli (Cornell University)

J Stutzki (University of Cologne)

F Bertoldi (University of Bonn)

M Fich (University of Waterloo)

S Chapman (Dalhousie University)

The CCAT Observatory

The CCAT telescope is a 25 meter-class submillimeter telescope envisioned for the Cerro Chajnantor site at 5600 meters – 600 meters above the high Atacama plain in northern Chile. CCAT will have an exceptionally small overall wave front error ~ 17 rms, and with its large aperture at the exceptional Chajnantor site CCAT promises to have very high mapping speed (several tens of square degrees/yr) at high spatial resolution (down to $\sim 3.5''$) in the short submm to mm wave bands (350 μm to 2 mm). CCAT's primary science goals are to: (1) Measure and characterize the history of dusty star formation in galaxies through cosmic time through multi-band photometric surveys that will nearly fully resolve the FIR background into its constituent sources, and spectroscopic surveys to reveal sources of energy in these galaxies be it the stellar radiation, shocks, or AGN activity; (2) Characterize the star formation process in the local Universe through submm wave spectroscopy and dust continuum emission. CCAT will obtain complete maps of many nearby galaxies in the submm spectral lines and continuum and easily map several submm/mm colors the Milky Way galaxy over several tens of square degrees/year, tracing the cycles of star formation at high spatial resolution, large scales, and in many different environments; (3) Probe the astrophysics of galaxy clusters through multiband, high spatial resolution studies of the Sunyaev-Zel'dovich effect (S-Z). We will discuss the science drivers, the facility, briefly describe the first generation instruments envisioned for CCAT and give an update on the status of the project. CCAT is a consortium that consists of Cornell University, the University of Colorado, the Universities of Cologne and Bonn, and a consortium of Canadian Universities. CCAT activities in Chile are managed through AUI.

F P Schloerb (University of Massachusetts at Amherst)

Status of the Large Millimeter Telescope

The Large Millimeter Telescope (LMT) is a 50m-diameter millimeter-wave radio-telescope designed to operate at wavelengths between 1 and 4 millimeters. The large aperture and collecting area provide resolutions (5-18 arcsecs) and mapping speeds that make LMT an ideal single-dish complement to ALMA at its operational wavelengths. The LMT has also established itself as an important station for millimeter-wave VLBI networks. The telescope system was completed with the inner 32.5m diameter of its reflector surface in 2011, and it is entering its fourth season of early science observations using the 32.5m-diameter surface. The telescope's effective rms is approximately 86 microns, and the active control of the antenna surface maintains the antenna gain constant within about 5

Posters

Sara Beck (Tel Aviv University)

3-D Views of Ion/Molecule Interactions in Starbursts from High Resolution Spectra

The SMA and ALMA have shown the molecular component of starburst galaxies in amazing detail. Now we ask how the molecular clouds interact with the ionized gas excited by the young stars: how do HII regions break out of embedding clouds, and how do they affect the development of the starburst? To combine the ionic and molecular components into one picture we need to measure ions with spatial and spectral resolution comparable to the molecules. HI lines are limited to $\sim 20 \text{ km s}^{-1}$ resolution, much worse than molecular spectra, by thermal broadening;

heavy elements, which gain momentum

in thermal effects, must be used. We show detailed

comparisons of the molecular and ionized kinematics in nearby starbursts from SMA data and the MIR lines of [NeII] and [SIV], and suggest candidate ions for high resolution spectroscopy in the FIR to mm range.

David Blank (James Cook University)

Glenn Langston (NSF)

Joe Lazio (JPL)

MASER Searches of Young Exoplanets From TESS and PLATO

MASER emission from exoplanets have the potential to give much information about their evolution and habitability. Searches for such emission from nearby systems, primarily the 22 GHz water line have not been successful. Those searches though have been of mature exoplanets because the majority were discovered using the radial velocity method. Discovering young exoplanets is easier with the transit method. This is important because star-planet interactions which can lead to MASER emission are much stronger when the system is young. The upcoming TESS and PLATO space mission will discover nearby young exoplanets which will be excellent targets for MASER searches.

James Bock (Caltech)

SPHEREx: An All-Sky Spectral Survey?

SPHEREx, a mission in NASA's Small Explorer (SMEX) program that was selected for Phase A, is an all-sky survey satellite designed to address all three science goals in NASA's astrophysics division, in a single survey, with a single instrument. We will probe the physics of inflation by measuring non-Gaussianity by studying large-scale structure, surveying a large cosmological volume at low redshifts, complementing high-z surveys optimized to constrain dark energy. The origin of water and biogenic molecules will be investigated in all phases of planetary system formation - from molecular clouds to young stellar systems with protoplanetary disks - by measuring ice absorption spectra. We will chart the origin and history of galaxy formation through a deep survey mapping large-scale spatial power. Finally, SPHEREx will be the first all-sky near-infrared spectral survey, creating a legacy archive of spectra (0.75 - 4.8 μm at $R = 41.5$ and 150) with high sensitivity using a cooled telescope with large mapping speed.

SPHEREx will observe from a sun-synchronous low-earth orbit, covering the entire sky in a manner similar to IRAS, COBE and WISE. During its two-year mission, SPHEREx will produce four complete all-sky maps for constraining the physics of inflation. These same maps contain numerous high signal-to-noise absorption spectra to study water and biogenic ices. The orbit naturally covers two deep regions at the celestial poles, which we use for studying galaxy evolution. All aspects of the SPHEREx instrument and spacecraft have high heritage. SPHEREx requires no new technologies and carries large technical and resource margins on every aspect of the design. The projected instrument sensitivity, based on conservative performance estimates, meets the driving point source sensitivity requirement with 300

SPHEREx is a partnership between Caltech and JPL, following the successful management structure of the NuSTAR and GALEX SMEX missions. The spacecraft will be supplied by Ball Aerospace, based on the demonstrated low-cost BCP 100 bus. The Korea Astronomy and Space Science Institute will contribute hardware and scientific analysis based on two similar space infrared astronomy instruments.

S Michelle Consiglio (UCLA)

Jean Turner (UCLA)

A Newly Observed Type of Star Formation

Recent SMA results of CO(3-2) in a nearby dwarf galaxy, host to a young, actively forming super star cluster with $106 M_{\odot}$, reveal record star formation efficiency of more than 60

James Di Francesco (National Research Council of Canada)

Kinematic Studies of Filamentary Structure in Molecular Clouds

Recent continuum observations by the Herschel Space Observatory have shown that nearby molecular clouds are rife with filamentary structure. These filaments are intimately related to the star formation process, in that the vast majority of gravitationally bound starless cores and the youngest protostars in clouds are associated with filaments of larger column density. Indeed, a column density threshold for star formation in filaments at $A_v \gtrsim 7$ is apparent, one possibly related to the criteria for gravitational stability of cylindrical morphologies. Filaments also appear to produce cores that populate the mass functions that resemble the stellar Initial Mass Function in overall shape. Higher-mass stars and clusters may originate in those filaments of the highest column densities ($A_v \sim 100$) that arise from filaments that have merged. Though turbulence has been implicated as being the source of the filamentary structure in clouds, kinematic studies are needed to determine how such filaments assemble mass into star-forming units, particularly in the higher-mass regime. Preliminary studies into filament kinematics will be performed with existing or imminently available instrumentation at the NRAO Green Bank Telescope and the NRAO Jansky Very Large Array. By 2025, however, larger focal plane arrays and more sensitive high resolution instruments will be needed to probe filaments in all clouds within 1 kpc and obtain a general picture of filament formation and evolution.

Simon Dicker (University of Pennsylvania)

The MUSTANG collaboration

A survey of Galaxy Clusters using the Green Bank Telescope.

Observations of the intra-cluster medium (ICM) of galaxy clusters has long provided a powerful set of cosmological constraints. In addition, the ICM displays a wealth of astrophysical phenomena such as shocks, radio bubbles, and non-thermal radio emission. Although nearby clusters have been extensively studied using X-ray and optical techniques, cosmic dimming makes observations of high redshift clusters extremely challenging. The dynamical state and physical conditions of these high redshift systems is only weakly constrained by observations. Radio observations of the Sunyaev-Zel'dovich (SZ) effect offer a highly complementary probe to other wavelengths. The SZ effect is the scattering of photons from the cosmic microwave background so its magnitude does not depend on distance and high redshift clusters can be imaged. In addition because of the SZs different dependence on temperature and density it is possible to detect very hot gas which emits weakly in the X-ray and to measure the cluster profiles out to a larger radius where densities are low.

Due to its large collecting area the Green Bank Telescope combines high surface brightness sensitivity with 9 resolution. With its wide (4.3 arcminute) field-of-view the new focal plane array MUSTANG 2, will be able to image extended emission in clusters that would be resolved out by interferometers. We describe a program to observe a cosmologically representative sample of clusters which if successful could be extended to map a significant fraction of clusters visible in the northern sky.

Todd Hunter (NRAO)

Crystal Brogan (NRAO)

Claudia Cyganowski (University of St Andrews)

Measuring the Luminosity of Massive Protostars via their Millimeter Brightness Temperature

A significant hurdle to our understanding the process of massive star formation is the inability to determine the luminosity of individual massive protostars in deeply-embedded protoclusters. The problem is caused by the persistent lack of high-resolution ($\lesssim 0.1$ arcsec) telescopes in the mid- to far-infrared that cover the peak of the Planck curve. Without being able to apportion the total luminosity among the cluster members, it is impossible to construct luminosity functions which might shed light on how clusters evolve. The high dust column density around a massive protostar means it will become optically thick to radiation shortward of about 1-3 mm wavelength. The advent of ALMA's long baseline capability offers a new technique for measuring the luminosity of these compact dust sources. By measuring their angular size and brightness temperature at several wavelengths near unity opacity, one can compute a luminosity estimate from the Stefan-Boltzmann law. I will describe a proof-of-concept experiment using matched resolution observations in ALMA bands 4, 6 and 8 (approved for Cycle 3), and how this technique could be extended with future capabilities such as the ngVLA.

Namir Kassim (NRL)

C J Law (UCB)

P S Ray (NRL)

S Burke-Spolaor (NRAO)

T E Clarke (NRL)

P Demorest (NRAO)

Doing More with Less: Leveraging Existing and Planned Investments in Radio Astronomy Infrastructure through Commensal, Lower-frequency Observing.

The relentless drive towards transformational science is increasingly corralling scarce radio astronomy resources towards a limited number of instruments developed on a grand scale. At higher frequencies the expenses are naturally quite high, driven by cryogenics, expansive bandwidths, and stringent mechanical tolerances. While costs are often lower at longer wavelengths, tight budgets have nonetheless left the pursuit of large projects at lower frequencies lagging. Commensal observations can break this paradigm, by leveraging existing radio astronomy capital investments to pursue compelling lower frequency science for what can amount to pennies on the dollar. Past and current examples include Arecibo feeds scanning the sky in opposing directions, GMRT and WSRT dual frequency nested feed systems, V-FASTR on the VLBA, and the legacy VLA accommodating concurrent primary- and Cassegrain-focus observations.

Kenneth Kellermann (NRAO)

Radio Loud and Radio Quiet Quasars

Quasars and AGN are the most powerful long lived phenomena in the Universe. Although, it has been a half a century since their discovery, and even longer since the recognition of radio galaxies, many questions remain unanswered. These include:

a) Although all quasars probably contain a super massive black hole to supply the power needed to support their extraordinary optical and infrared luminosity, why are only a small fraction of quasars strong radio sources?

b) What is the radio emission mechanism in radio quiet quasars?

c) Do the radio loud and radio quiet quasar luminosity functions evolve differently?

d) What is the role of quasars and AGN in the formation and evolution of galaxies? Do radio quiet and radio loud quasars play the same role in galaxy evolution.

e) What is the role of relativistic jets in producing the apparent excessive radio as well as OIR and gamma-ray luminosity? How are relativistic jets formed; how are they collimated, and how do they evolve? What causes the apparent rotation of ejection position angle in some quasars? What is the relation between the presumably beamed radio and gamma-ray emission?

f) Are other radiation processes beside incoherent synchrotron radiation important?

g) What is the contribution, if any, of discrete radio sources to the observed apparent excess non thermal cosmic radio background radiation?

Amanda Kepley (NRAO)

Understanding Galaxy Evolution Requires Sensitive, Wide-Field Spectral Line Observations of Nearby Galaxies

The evolution of a galaxy is driven by the state of its interstellar medium. Dense molecular gas serves as the site for the formation of young massive stars, which in turn heat the gas and may drive outflows of material. Understanding the evolution of galaxies, therefore, requires quantitative measurements of the interstellar medium in wide range of galaxies from puny dwarf galaxies to mighty LIRGs. In this talk, I argue that developing wide-field, moderately high resolution, spectral line capabilities are key to this understanding using recent GBT 4mm observations of dense molecular gas as an example. These, and other observations, are already uncovering differences in the relationship of dense molecular gas to star formation in other nearby galaxies.

Justin Linford (Michigan State University)

Laura Chomiuk (MSU)

Jeno Sokoloski (Columbia)

Tommy Nelson (Minnesota)

Michael Rupen (NRC of Canada)

Amy Mioduszewski (NRAO)

Thermal and Non-thermal Imaging of Stellar Outflows

Stellar outflows are complicated events, rich with opportunities for studying fundamental physics. Imaging the thermal outflows allows us to study their complicated evolutions, the mass loss mechanism, dust formation, and the shaping of the outflows. In binary systems, angular momentum transfer and common envelope ejection can also be studied. The ability to image non-thermal emission in stellar outflows provides information about the location and nature of shocks, which can lead to high-energy emission in the hard x-ray and gamma-ray regimes. In addition, these shocks may both create and destroy dust. We present observations of novae utilizing multiple modern radio instruments at several resolutions and frequencies as examples of what the next generation of radio telescope will be able to accomplish with a single instrument.

Felix Lockman (NRAO)

Radio Studies of the Low Surface-brightness Universe

Many objects have very weak radio emission, not because they are of small angular size but rather because they have intrinsically low surface brightness. Examples include cluster SZE, the circum-galactic medium of large spiral galaxies, some molecular lines, and intra-cluster gas. I will describe new studies of extremely faint 21cm HI emission lines. This emission may be a very important tracer of accretion onto galaxies but it presents interesting observational challenges. Care will be needed in the design of future instrumentation so as not to preclude this type of research unintentionally.

Brett McGuire (NRAO)

Anthony J Remijan (NRAO)

Chemistry Matters: The Importance of Radio Astronomy

The inauguration of higher-sensitivity and spatial-resolution facilities has sparked a gold rush of studies of processes and phenomena on ever smaller scales, from high-redshift galaxies to planetary systems. As we move to more localized systems, standard assumptions of homogenous, equilibrium-based chemistry, which governs the populations and behavior of molecules we use as probes of these environments, begin to break down. I will present several examples, from our work and the literature, of how modern facilities are beginning to give us insight into the formation, destruction, and evolution of these chemical probes in various environments. These observations only scratch the surface of this complexity, however, and uncovering the full picture is a process that will require the continuing use of, and advances in, radio astronomical observations in the decades to come.

Eric Murphy (Caltech IPAC)

Adam Leroy (OSU)
ngVLA Ecosystem Science Working Group

Baryon Cycling on the Scales of Individual Star-Forming Regions within Nearby Galaxies

Objects in the nearby universe provide the best means to obtain a complete picture of baryon cycling for a heterogenous set of astrophysical conditions. This includes the inflow of atomic gas into galaxies, the formation of molecular structures, the birth of stars, and the expulsion of gas from galaxies due to associated feedback processes. Moving into the next decade, this will continue to remain true and our knowledge of galaxy formation and evolution will be fundamentally improved by having higher resolution/sensitivity observations of nearby galaxies to better interpret high- z observations of sources that were rapidly evolving at epochs soon after the Big Bang. The radio-to-mm part of the spectrum provides critical diagnostics for each of these processes and access to almost all phases of gas in galaxies: cool and cold gas (via emission and absorption lines), ionized gas (via free-free continuum and recombination lines), cosmic rays and hot gas (via synchrotron emission and the Sunyaev-Zeldovich effect) each of these is free from dust extinction, which plagues shorter wavelengths. In this talk we highlight a number key science problems that will remain relevant going into the next decade and are best answered by a next-generation radio-mm interferometer.

David Nice (Lafayette College)

Neutron Star Distribution and Kinematics

Neutron stars offer powerful tools for probing nuclear matter and stellar evolution. Analysis of pulsar motion and distribution through the Galaxy yields insight on such diverse topics as dynamics of supernova explosions, evolution of compact binary systems, and the pulsar radio emission mechanism. Today a majority of known Galactic canonical (young) pulsars are within 5 kpc of the Sun and most known Galactic millisecond (recycled) pulsars are within 2 kpc of the Sun. Ongoing and future pulsar surveys will greatly expand coverage through the Galaxy. Radio telescope observations are essential both for discovering pulsars and for measuring their velocities (proper motion) and distances (parallax). Proper motion and parallax measurements are achieved by high-precision pulsar timing and by long-baseline interferometry.

Giles Novak (Northwestern University)

The BLAST-TNG team

Submillimeter Polarimetry with BLAST-TNG: Constraining Magnetic Field Strength in Star Forming Clouds

A key question concerning star formation is whether magnetic fields are strong enough to provide support against gravitational collapse of clouds and cloud cores, thereby regulating the star formation process. Direct measurement of magnetic field strength in molecular clouds is very challenging, but observations of polarized submillimeter thermal emission from magnetically aligned dust grains can be used to make highly detailed maps of magnetic field morphology. Here I will discuss BLAST-TNG, the Next Generation Balloon-borne Large Aperture Submillimeter Telescope, that observes simultaneously at 250, 350, and 500 microns, with a diffraction-limited angular resolution of 22 arcseconds for our shortest waveband. BLAST-TNG is on track for a first Antarctic flight in December 2016. This highly sensitive polarimeter will map the magnetic fields of dozens of star-forming clouds, with approximately 500,000 individual measurements of magnetic field orientation expected from our first flight. Using results from the predecessor BLASTPol experiment (Fissel et al. 2015) I will show how BLAST-TNG can place important constraints on magnetic field strength and thus illuminate the role of magnetic fields in star formation.

Masao Saito (NRO National Astronomical Observatory of Japan)

Satoru Iguchi (National Astronomical Observatory of Japan)

Future (Sub)Millimeter Development in Japan

National Astronomical Observatory of Japan started discussion on the direction of future radio astronomy in the next decade or so in Japan or East Asia. NAOJ Chile observatory hosted a series of ALMA development workshop annually in the last several years covering antennas, receivers, spectrometers, and so on. Summary of technological development activities related to ALMA and future radio telescope projects will be presented in the conference.

Jr Wei Tsai (Virginia Tech)

John Simonetti (Virginia Tech) Michael
Kavic (Long Island University) Cregg
Yancey (University of Maryland) Peter
Shawhan (University of Maryland)

Searches for Radio Transients using the Long Wavelength Array

We report a null detection of searching for radio transients with dispersion measure trials from 1.0 to 5000 pc cm^{-3} at 40 and 74 MHz. We are considering various possible observing strategies in the cooperation between radio and gravitational wave observatory.

Joaquin Vieira (University of Illinois)

SPT SMG Collaboration

High Redshift Star Formation under the Cosmic Microscope

Recent facilities such as the South Pole Telescope (SPT), the Herschel Space Observatory, and the Atacama Large Millimeter Array (ALMA) have opened a window to the millimeter (mm) sky and revealed a unique and unprecedented view of the Universe. In a 2500 square degree cosmological survey, SPT has systematically identified a large number (~ 100) of high-redshift strongly gravitationally lensed starburst galaxies. We are conducting a unique spectroscopic redshift survey with ALMA, targeting carbon monoxide line emission in these sources, across the 3mm spectral window. To date, we have obtained spectroscopic redshifts for 39 sources from $1.8 < z < 5.8$, with a median of $z=3.8$. We are systematically measuring low-J CO and [CII] for these sources with ATCA and APEX, making this the largest and most well-studied samples of high-redshift starburst galaxies. We are undertaking a comprehensive and systematic followup campaign to use these “cosmic magnifying glasses” to study the infrared background in unprecedented detail, inform the condition of the interstellar medium in starburst galaxies at high redshift, and place limits on dark matter substructure. I will describe our teams latest science results and discuss the scientific potential of these strongly lensed starburst galaxies within the context of future instruments and facilities.

Al Wootten (NRAO)

A Vision of ALMA in the Next Decade

ALMA has been producing science since Early Science began in 2011. Nearly 300 papers have been produced, garnering over 3000 citations. The ALMA Development Program is fully embarked on a program of upgrades to the baseline mission, with a focus on equipping the array with a full complement of receivers. New ALMA Development Studies suggest a variety of pathways to an even more productive instrument. ALMA scientists recently completed a survey of future needs to guide further development initiatives. From these, a path to ALMA in 2030 can be forged. I detail a personal vision of ALMA in the next decade.

J Anton Zensus (Max-Planck-Institut für Radioastronomie)

Eduardo Ros (Max-Planck-Institut für Radioastronomie)

Andrei Lobanov (Max-Planck-Institut für Radioastronomie)

The Sharpest View of High Brightness Temperature Objects: mm & Space VLBI in the 2020s

Recent developments have pushed the limits of resolution in astrophysics to new frontiers. Millimetre-wavelength radio interferometric observations with very-long-baseline interferometry (VLBI) and centimetre-wavelength observations with baselines to a radio telescope in orbit in the framework of the RadioAstron mission have brought resolutions down to tens of microarcseconds. At these resolutions, the objects with the highest brightness temperature are probed.

New enterprises such as the coming inclusion of ALMA in millimeter VLBI arrays (both for the 3-mm Global Millimeter VLBI Array and the 1-mm Event Horizon Telescope) or plans for a new space mission at short wavelengths, Millimetron, will revolutionize the field of radio interferometry at high frequencies. Additionally, new techniques such as source-frequency phase referencing at 3 mm and shorter wavelengths will enhance dramatically the signal-to-noise ratio of those challenging observations. These developments will open a new window for hundreds to thousands of sources, addressing, among other questions, the nature of the acceleration and collimation regions in AGN jets and the role of magnetic fields in the immediate neighbourhood of their central engines.