Half a Decade of ALMA:
Cosmic Dawns Transformed

Oral Presentation Abstracts

Half a Decade of ALMA: Cosmic Dawns Transformed
Program Schedule

Tuesday, September 20, 2016

8:45 AM	9:00 AM	Welcome	
9:00 AM	9:30 AM	Pierre Cox (ALMA, JAO)	Half a Decade of Science with ALMA: A Review
Galaxy Formation and Evolution: Gas & Star Formation Properties (Chair: Aeree Chung)			
9:30 AM	10:00 AM	Linda Tacconi (MPIE, Garching)	Review of Galaxy Formation and Evolution: Gas & Star Formation Properties
10:00 AM	10:15 AM	Justin Spilker (University of Arizona)	Resolving the Most Intensely Star-Forming Galaxies in the Universe
10:15 AM	10:30 AM	Jacqueline Hodge (Leiden Observatory)	Discovery of Kiloparsec-Scale Dust Disks in High-Redshift Ultraluminous Galaxies
10:30 AM	10:45 AM	Poster Flash	
10:45 AM	11:15 AM	Break / Poster Viewing	
11:15 AM	11:30 AM	Akio Inoue (Osaka Sangyo University)	Detection of the [OIII] 88 Micron Line at z=7.2
11:30 AM	11:45 AM	Riccardo Pavesi (Cornell University	Significant Variations in the [CII]/[NII] Ratios of Galaxies within the First Billion Years
11:45 AM	12:00 PM	Nanyao Lu (CASSACA NAOC)	ALMA Spectral-Line Survey in CO(7-6) and [NII] at z ~ 5 and a Novel Way to Characterize Star Formation in High-z Galaxies
12:00 PM	12:15 PM	Martin Zwaan (ESO)	Reservoirs Unveiled with Ch+(1-0) Around Starburst Galaxies at Z~2
12:15 PM	12:30 PM	Chelsea Sharon (McMaster University)	Excitation Dependence of the Spatially Resolved Schmidt-Kennicutt Relation in a z~2 Normal UV-bright Disk Galaxy
12:30 PM	2:00 PM	Lunch	

Pierre Cox (Joint ALMA Observatory)

Half a Decade of Science with ALMA: A Review

The Atacama Large Millimeter/submillimeter Array (ALMA) has been conducting science observations for the community since October 2011 with the start of Cycle 0. Today, the fourth cycle (Cycle 3) is being completed and Cycle 4 will begin in October 2016. In its first half decade, ALMA has produced many exciting and fundamental results, enabling transformational science from the solar system to the early universe. I will present a selection of the remarkable ALMA scientific results, emphasizing their evolution with the gradual expansion of the observing capabilities and the ramping up towards full operations. I will also compare the current results with the original fundamental science goals and outline the future evolution of ALMA.

Linda Tacconi (MPE Garching)

Review of Galaxy Formation and Evolution: Gas & Star Formation Properties

I will review how ALMA and other submm observations over the last few years are being used to address some of the key questions in galaxy formation and evolution, and illustrate the important role that cold gas, the fuel for star formation, has played in the assembly of galaxies across cosmic time. In particular, the talk will highlight observations that estimate properties of the cold gas during the epoch of peak star formation (z$\sim$1-3). I will discuss what we know so far about star formation at these redshifts, discuss the evidence for and impact of massive molecular outflows on galaxies in shutting down star formation. Finally, I will show where observations are crucially needed, and where ALMA could play an increasingly important role.

Justin Spilker (University of Arizona)

Daniel Marrone (University of Arizona)
Joaquin Vieira (University of Illinois)
Carlos de Breuck (European Southern Observatories)
Katrina Litke (University of Arizona)
Maria Strandet (MPIfR)

Resolving the Most Intensely Star-Forming Galaxies in the Universe

The South Pole Telescope has discovered one hundred gravitationally lensed dusty, star-forming galaxies at high redshifts, and we are using these systems to amplify the power of ALMA. We have pioneered sophisticated visibility-based modeling techniques which allow us to reconstruct the sources at unprecedented spatial resolution. I will give an overview of our collaboration's detailed, high-resolution (<0.5") observations with ALMA from Cycles 0 to 3, focusing on spatially resolved spectroscopy, allowing us to create 3-dimensional reconstructions of the sources. In particular, I will highlight: 1) studies of the Schmidt-Kennicutt relation on sub-kiloparsec scales in a number of systems, mapping the distribution of star formation and molecular gas in the most extremely star-forming galaxies in the universe; 2) detailed modeling of the FIR fine structure lines at z=5.7, allowing us to create ∼200pc maps of the CII/FIR ratio, gas density and metallicity, in an effort to understand the physical origin of the infamous "CII deficit"; and 3) observations of massive molecular outflows at z∼4, the first evidence that star formation quenching processes act directly on the fuel from which stars form in high-redshift starbursts. These observations showcase the power of ALMA spanning nearly an order of magnitude in wavelength, and in each case would require tens of hours in the most extended ALMA configurations to repeat for equivalent unlensed systems.

Jacqueline Hodge (Leiden Observatory)

Mark Swinbank (Durham University)
James Simpson (University of Edinburgh)
Ian Smail (Durham University)
Fabian Walter (MPIA)
the ALESS collaboration

Discovery of Kiloparsec-Scale Dust Disks in High-Redshift Ultraluminous Galaxies

We present high-resolution (0.16") 870um Atacama Large Millimeter/submillimeter Array (ALMA) imaging of 16 submillimeter galaxies (SMGs) from the ALESS ALMA survey of the Extended Chandra Deep Field South. This rest-frame 250um imaging allows us to clearly resolve the dust-obscured star formation in these z 1-3 galaxies on 1 kpc scales. The dust emission has a median size of 0.42"+/-0.04" (FWHM), corresponding to a typical physical size of 3.0+/-0.4 kpc. Notably, the emission appears remarkably smooth and disk-like at the current resolution and sensitivity, with best-fit Sersic profiles returning a median index of n=0.9+/-0.2 and an effective radius of R_e=1.8±0.2 kpc, significantly more compact than the existing stellar components probed with HST H160-band imaging. We push the resolution of the images to 0.1"(1.0 kpc) in order to search for kpc-scale clumps within the SMGs, but we find no evidence for significant clumping on kpc-scales in the majority of cases. Indeed, we demonstrate that the observed morphologies are generally con-sistent with interferometric maps of smooth exponential disks – in stark contrast to the extended, disturbed stellar morphologies observed in the comparable-resolution HST H160-band images. We suggest that the contrast between the dust and stellar morphologies may have implications for SED fitting routines that assume the dust is co-located with the stellar emission. If the starbursts in these galaxies are major merger driven, as may be suggested by the relative compactness of the obscured star formation, then we are likely observing the result of the gas/dust more rapidly (re-)forming disk structures than the existing stellar components.

Akio Inoue (Osaka Sangyo University)

Y Tamura (U of Tokyo)
H Matsuo (NAOJ)
K Mawatari (Osaka Sangyo U)
I Shimizu (Osaka U)
T Shibuya (U of Tokyo)

Detection of the [OIII] 88 Micron Line at z=7.2

We have detected the [OIII] 88 micron emission line from a $z = 7.2$ Lyα emitter, SXDF-NB1006-2, with ALMA. On the other hand, the [CII] 158 micron emission line was not detected at the position of the Lyα and [OIII] lines. The dust continuum was not detected, either. From the [OIII] line luminosity, an upper limit of dust infrared luminosity, near-infrared spectral energy distribution, we have derived about 10% oxygen abundance in the galaxy compared to that in the Sun. Other physical properties derived are an extremely young age of 1 Myr, a star formation rate of 300 solar mass per year, a stellar mass of $> 3 \times 10^8$ $M_\odot$, and little dust. The velocity shift of the Lyα line relative to the [OIII] line is +100 km s^{-1}, indicating a very low HI column density. The [OIII]-to-[CII] line ratio is > 12 which is consistent with the low HI interpretation. These properties may make this galaxy a prototype of ionizing sources for reionization.

Riccardo Pavesi (Cornell University)

Dominik Riechers (Cornell University)
Chris Carilli (NRAO)
Peter Capak (Caltech)
Nick Scoville (Caltech)
Alexander Karim (University of Bonn)

Significant Variations in the [CII]/[NII] Ratios of Galaxies within the First Billion Years

Thanks to ALMA, observations of atomic fine-structure line emission are a very productive way of measuring physical properties of the interstellar-medium (ISM) in galaxies at high redshift. While the bright [CII] line has been abundantly exploited for dynamical studies of the gas, it needs to be compared to other lines in order to establish its physical origin. [NII] is selectively able to measure the emission coming from the ionized gas component. Thus, we here present ALMA measurements of [NII]205 umfine-structure line emission from a representative sample of galaxies at$z = 5$–6 spanning two orders of magnitude in star-formation rate (SFR). Our results show at least two different regimes of ionized ISM properties for galaxies in the first billion years of cosmic time, separated by their $L_{[CII]}/L_{[NII]}$ratio. While we find extremely low [NII] emission compared to [CII] from a low-SFRt ypical galaxy (LBG-1), likely due to low dust content and reminiscent of local dwarfs; both the dusty Lyman Break Galaxy HZ10 and the extreme starburst AzTEC-3 interestingly show ionized-gas fractions typical of local star-forming galaxies and show hints of spatial variations in their [CII]/[NII] line ratio. These observations of a $z > 5$ sample of faint [NII] detections demonstrate how ALMA's unprecedented sensitivity to faint line emission can best constrain the ionized and neutral gas properties of galaxies over a large range in SFR and dust emission in the first billion years from normal star-forming galaxies, shedding light on some of the ISM properties that are most important to galaxy assembly through star formation.

Nanyao Lu (CASSACA NAOC)

Y Zhao (YNAO)
L Armus (Caltech)
V Charmandaris (U Crete)
T Diaz-Santos (U Diego Portales)
A Evans (NRAO)

An ALMA Spectral-Line Snapshot Survey in CO(7-6) and [NII] 205um at z $\sim$ 5 and a Novel Way to Characterize Star Formation in High-z Galaxies

It remains a challenge to measure the star formation (SF) rates (SFRs) of high-z galaxies in an efficient and accurate way. The conventional full dust SED method requires multiple photometric measurements over a wide wavelength range while the option of using the UV continuum is sensitively subject to dust extinction. The bright [CII] line at 158 um is a popular choice for inferring the SFR in a high-z galaxy, but its luminosity relative to L(IR) (therefore SFR) depends on the effective dust temperature (or equivalently the SF rate surface density) and varies by more than one magnitude even in the local Universe. In view of the superior spectroscopic capability of ALMA, and based on our Herschel and ALMA spectroscopy of the mid-J CO line emission of local luminous galaxies, Lu et al. (2015) proposed a rather simple spectral line approach to characterize the SF in a high-z galaxy, involving only CO(7-6) and the [NII] 205um or [CII] 158um line. This dual-line approach is particularly suited for high-z galaxy studies with ALMA and the observed line fluxes can be used to infer a number of important parameters on SF, including (a) a SFR estimate (from CO(7-6)) that is accurate to 30and independent of the dust temperature (i.e, unlike the [CII] line), (b) the dust mass (from the underlying 370um continuum at CO(7-6)), (c) the gas mass (assuming a reasonable dust-to-gas mass ratio), (d) the SF efficiency (= SFR divided by the gas mass), (e) the dust temperature or the mean SFR surface density (from the [NII]/CO(7-6) or [CII]/CO(7-6) line flux ratio), and (f) the effective size of the star-forming region (= SFR divided by the SFR surface density).

To expand the number of high-z galaxy available for testing and application of this promising method, we conducted an ALMA cycle-3 spectral-line snapshot survey to detect the CO(7-6) and [NII] 205um lines in all the luminous galaxies of $4 < z < 5$ with Dec $< +10$ deg and a prior [CII] 158um detection. Our [NII] line observations also included 4 L*-class galaxies at $5 < z < 5.5$, with the existing [CII] line fluxes and possible sub-solar metallicities. The survey shall produce the largest [NII] 205um line data set at z $\sim$ 5. The pipeline-reduced data are available for most of our targets. We will present observational results on some individual galaxies (e.g., BR1202-0725, ID 141) as well as highlights on the science application of the new ALMA data as prescribed above.

Martin Zwaan (ESO Garching)

Falgarone E (ENS Observatoire de Paris)
Godard B (Observatoire de Paris)
Bergin E (University of Michigan)
Walter F (MPIA Heidelberg)
Andreani P M (ESO Garching)

Reservoirs Unveiled with Ch$^+$(1-0) Around Starburst Galaxies at $Z \sim 2$

Starburst galaxies at redshift $z \sim 2$–3 are among the most intensely star-forming galaxies in the universe. How do they accrete their gas to form stars at such high rates is still a controversial issue. We report ALMA Cycle 2 detections of CH$^+$(1-0) emission and absorption lines from six gravitationally lensed starburst galaxies at $z \sim 2.5$ with star-formation rates in the range 300–1400 $M_\odot$ yr^{-1}. The unique conjunction of its spectroscopic and chemical properties allows CH$^+$ to highlight the sites of most intense dissipation of mechanical energy. The absorption lines reveal highly turbulent reservoirs of diffuse molecular gas, extending far out of the galaxies. The emission lines, with linewidths, up to 1300 km s^{-1}, much broader than those of CO, arise in myriads of shocks propagating in dense gas and generated in large scale high-speed collisions. The CH$^+$ lines therefore probe the fate of prodigious energy releases, primarily stored in turbulence before being radiated away. The turbulent reservoirs act as sustained mass and energy buffers over timescales up to a few hundreds of Myr. Their ultimate energy supply is more likely to be galaxy mergers and cold stream accretion rather than stellar- or AGN-driven galactic winds.

Chelsea Sharon (McMaster University)

Amitpal Tagore (Jodrell Bank Centre for Astrophysics The University of Manchester)
Jesus Rivera (Rutgers the State University of New Jersey)
Andrew Baker (Rutgers the State University of New Jersey)
Charles Keeton (Rutgers the State University of New Jersey)
Linda Tacconi (Max-Planck-Institut für extraterrestrische Physik)

Excitation Dependence of the Spatially Resolved Schmidt-Kennicutt Relation in a z 2 Normal UV-bright Disk Galaxy

In order to understand the evolution of galaxies, it is important to accurately characterize the molecular gas that fuels galaxy growth near the peak of cosmic star formation (z=2-3). Comparisons to low-redshift galaxies using well-known correlations like the Schmidt-Kennicutt relation have been complicated by several factors, including differences in line excitation for the molecular gas tracer (i.e. CO(1-0) vs. CO(3-2)) and a lack of spatially resolved mapping at high redshift. The latter is particularly important for strongly lensed galaxies where differential magnification and integrated measurements may disguise the true gas conditions. In order to begin addressing these challenges, we will present new high-resolution ALMA CO(7-6), CI, and 380 um (rest frame) maps of a normal UV-bright disk galaxy at z=2.26, SDSS J0901+1814 (J0901). By coupling the ALMA observations with our existing resolved CO(1-0), CO(3-2), and H-alpha maps, we are able to place J0901 on the true surface density version of the Schmidt-Kennicutt relation and evaluate its excitation bias. Since J0901 is strongly lensed, we can also evaluate how characterizations of this source differ when the effects of gravitational lensing are not accounted for. Finally, our resolved multi-line maps can be used to examine the spatial distribution of J0901ś gas physical conditions on sub-galactic scales.

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Low Mass Star Formation (Chair: Vivien Chen)			
2:00 PM	2:30 PM	Adele Plunkett (ESO/ALMA)	Low Mass Star Formation
2:30 PM	2:45 PM	Chat Hull (Harvard / NRAO)	Full-Stokes Observations of Class 0 Protostellar Sources in Serpens: the ALMA Polarization Revolution Has Begun
2:45 PM	3:00 PM	Nuria Marcelino (ICMM, CSIC)	The Young Protostars B1b-N and B1b-S
3:00 PM	3:15 PM	Fumitaka Nakamura (NAOJ)	ALMA Observations of Low-Mass End of A Core Mass Function in Rho Ophiuchus A Region
3:15 PM	3:30 PM	Zsofia Nagy (University of Toledo)	Measuring Rotation in Protostellar Envelopes: ALMA Observations of Edge-On Orion Protostars
3:30 PM	3:45 PM	Poster Flash	
3:45 PM	4:30 PM	Break / Poster Viewing	

Adele Plunkett (ESO Chile)

Low Mass Star Formation

Protostellar regions in nearby molecular clouds provide ALMA ample opportunities for studying how low-mass stars form. Star formation is a multi-component process, and key advances for these studies have been due to ALMAs particular design to optimize multiple observing techniques in a single facility. These capabilities lead us to study the interconnectedness of the disk-envelope-outflow-environment of low-mass protostellar systems, rather than focusing on single components. With respect to various star formation studies, ALMA now offers the sensitivity to probe faint low-mass sources; angular resolution to resolve intricate morphology of the protostar system; spectral setups to study numerous molecular transitions and continuum; velocity resolution to identify rotation, infall and outflow signatures; the ACA to recover extended emission; and polarization measurements. I will feature recent ALMA results that begin to tie together the complex scenario of low-mass star formation, motivating ALMAs potential for advancing this study in the coming years.

Chat Hull (Harvard NRAO)

Full-Stokes Observations of Class 0 Protostellar Sources in Serpens: the ALMA Polarization Revolution Has Begun

The first polarization data from ALMA were delivered to PIs this (northern) spring. The data are already both expanding and confounding our understanding of the role of magnetic fields in low-mass star formation. Here I will show the highest resolution and highest sensitivity polarization images ever made of three Class 0 protostellar sources in the Serpens Main star-forming region. These sources were observed recently with the CARMA polarization system at 1000 AU scales; these new ALMA observations achieve 150 AU resolution, allowing us to probe disk polarization. The ALMA data reveal a number of filamentary structures surrounding the protostars, as well as tantalizing kinks in the magnetic field orientation toward the sourcesíntensity peaks. In one object the magnetic fields are parallel with the filamentsĺong axes, and all lead to the central source, indicating that we may be witnessing magnetized accretion flows onto a protostar for the first time.

Nuria Marcelino (ICMM-CSIC)

A Fuente (OAN)
M Gerin (LERMA)
J Pety (IRAM)
B Commercon (CRAL)
J Cernicharo (ICMM-CSIC)

The Young Protostars B1b-N and B1b-S

The Barnard 1b dense core hosts two very young protostars B1b-N and B1b-S, with bolometric luminosities of 0.15 and 0.31 $L_{\odot}$ and cold SEDs. Using NOEMA, we have clearly shown that these sources drive low velocity outflows, of short dynamical time scales of at most a few thousand years. The properties of the B1b-N SED and the energetics of its outflow are consistent with that of a First Hydrostatic Core, the short-lived phase when the collapse has started but the core is not warm enough for molecular hydrogen to dissociate. 350GHz ALMA observations at 0.05" resolution have revealed the presence of condensed ellipsoidal structures of 40 - 60AU radius, with properties consistent with those of rotationally supported disks formed in MHD simulations of collapsing turbulent and magnetized cores, supporting the theoretical prediction that disks are forming early in the evolution of low mass protostars. We will discuss the ALMA observations and complementary data obtained with NOEMA at lower angular resolution (C18O, NH2D, DCO+, DCN, CH3OH).

Fumitaka Nakamura (NAOJ)

Chihomi Hara (Univ of Tokyo)
Takeshi Kamazaki (NAOJ)
Ryohei Kawabe (NAOJ)
Shigehisa Takakuwa (Kagoshima Univ)
Naomi Hirano (ASIAA)

ALMA Observations of Low-Mass End of A Core Mass Function in Rho Ophiuchus A Region

We carried out ALMA cycle-2 observations toward rho Ophiuchus A Region in 1 arcsecond resolution, corresponding to about 100 AU. Applying clumpfind to the 1.1-m continuum image, we identified more than 100 small prestellar structures in this region. The typical mass of the identified cores is estimated to be about 0.2 Msolar, which is larger than the Jeans mass in this region. Surprisingly, the typical density is estimated to be a few $\times 10^9 cm^{-3}$. If we construct CMF from identified structures, our CMF has a slope similar to the Salpeter IMF at the higher mass and turnover at 0.2 Msolar, which is three times smaller than that of Motte's CMF. The identified small structures may be a basic unit of star formation in this region.

Zsofia Nagy (University of Toledo)

William Fischer (Goddard Space Flight Center)
Thomas Megeath (University of Toledo)
Thomas Stanke (ESO)
Joseph Booker (University of Toledo)
John Tobin (Leiden Observatory)

Measuring Rotation in Protostellar Envelopes: ALMA Observations of Edge-On Orion Protostars

We present ALMA imaging of four class-I edge-on Orion protostars in 12CO, 13CO, and C18O 2-1 transitions at a 1.7” angular resolution. The sources were selected based on an HST NICMOS and WFC3 imaging survey which shows disks visible in near-IR absorption. The edge-on geometry of the sources provides an excellent opportunity to study the gas kinematics in the protostellar envelopes. In addition to their edge-on orientation, the studied protostars are in relative isolation.

We used data from the 12-m and ACA arrays of ALMA in addition to total power observations to recover the extended emission. Due to the high angular resolution, the data directly probe gas acceleration near the protostars down to scales of 700 AU. We identify outflow cavities in the data as well as the kinematic signatures of disk rotation, envelope infall and envelope rotation. However, the data do not show the axial symmetry assumed in standard rotating collapse models. Instead, they suggest a highly asymmetric envelope structure with infall concentrated in streams of gas.

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Chemical Evolution During Star and Planet Formation (Chair: Brett McGuire)			
4:30 PM	5:00 PM	Jeong-Eun Lee (Kyung Hee University)	Chemical Evolution During Star Formation
5:00 PM	5:15 PM	Gary Fuller (Jodrell Bank)	Tracing the Evolution of Massive Protostars
5:15 PM	5:30 PM	Nanase Harada (ASIAA)	Effects of Grain Growth on Chemistry in Protostars
5:30 PM	5:45 PM	Jes Jorgensen (University of Copenhagen)	Protostellar Interferometric Line Survey (PILS): ALMA Insights into the Complex Chemistry of Young Stars
5:45 PM	6:00 PM	James McMillan (The Ohio State University)	Weeding the Astrophysical Garden Using Complete Experimental Spectra
6:30 PM	8:30 PM	Conference Dinner	

Jeong-Eun Lee (Kyung Hee University)

Chemical Evolution During Star Formation

Star formation, which is initiated by the gravitational collapse of cold and dense cores, is associated with energetic activities such as infall, accretion, jets, and outflows. These dynamical processes produce (radiation and/or shock) energy to affect the physical and chemical conditions of associated material. In particular, the accretion of matter to the central protostar has a prime impact on the temperature structures of the disk and the inner envelope in a young stellar object, resulting in inevitable alterations of their chemical distribution. Therefore, depending on the accretion mechanism, the chemical evolution can be very different in the inner structures related to star formation (i.e., disk and inner envelope), which set the initial conditions of planet formation. I will review how the chemistry evolves during star formation, depending on various parameters such as the timescale and temperature of the prestellar cores before collapse, and how the ALMA observations of various chemical species can contribute to our understanding of dynamical processes in star formation.

Gary Fuller (Jodrell Bank Centre for Astrophysics)

Melvin Hoare (Uni of Leeds)
Peter Schilke (Koln)
Adam Avison (JBCA)
Alessio Traficante (IAPS INAF)
Nicolas Peretto (Uni of Cardiff)

Tracing the Evolution of Massive Protostars

Recent surveys of the Galactic plane have identified large populations of candidate young massive protostars. However, we have a very poor understanding of the actual evolutionary status of these sources. The SED based classification schemes used for nearby low mass objects are, alone, inadequate at the large distances of these high mass objects which are embedded in inhomogeneous environments. This presentation will discuss an ALMA Cycle 3 project which has provided the first comprehensive, systematic, high angular resolution survey of the chemical (and physical) properties of a well selected sample of 39 young high mass embedded sources. This survey has observed a single frequency setting in Band 6 at ~ 1" resolution to study a range of organic molecular species which trace the evolution of the circumstellar material as a protostar initially heats its environment. The column density and excitation temperature of these species, together with the dust continuum emission, will be used to study how the properties of the circumstellar molecular gas change with source luminosity, spectral energy distribution and other properties with the goal of identifying evolutionary trends. With the recent delivery of the data for all 39 sources, this presentation will provide an overview of the survey and its initial results.

Nanase Harada (Academia Sinica Institute of Astronomy and Astrophysics)

Yasuhiro Hasegawa (Caltech JPL)
Yuri Aikawa (University of Tsukuba)
Hiroyuki Hirashita (Academia Sinica Institute of Astronomy and Astrophysics)

Effects of Grain Growth on Chemistry in Protostars

Recent observations suggested that the growth of dust particles has already occurred in class 0/I young stellar objects (YSOs). Since chemical reactions on dust grain surfaces are important in determining chemical compositions, the reduced surface area due to the dust size growth may affect chemical compositions in YSOs significantly.

In this work, we aim to determine how much chemical abundances are affected by the grain growth in YSOs.

We use a time-dependent gas-grain chemical model to calculate the gas-phase and grain-surface chemical abundances with variation of surface areas of grains to imitate the grain growth using the physical model of a protostar. We also vary initial abundances and time scales of quiescent time.

Our results show that less surface areas caused by the grain growth change the dominant form of sulfur species by decreasing H_2S abundances and increasing SO and/or SO_2 abundances. As for complex organic molecules, species such as CH_3CN show decreases in abundances with larger grain sizes although other species such as CH_3OCH_3 abundances are also dependent on other parameters such as quiescent time and initial conditions.

Comparisons with observations of a class 0 protostar with our model indicate that observed abundance ratios between sulfur species H_2S, SO, and SO_2 agrees best for models that correspond to grain growth of factors 10 or 100. These species can be used to test the degree of grain growth in YSOs using ALMA with its high spatial resolution.

Jes Jorgensen (Niels Bohr Institute University of Copenhagen)

PILS team

Protostellar Interferometric Line Survey (PILS): ALMA insights into the complex chemistry of young stars

Understanding how, when and where complex organic and potentially prebiotic molecules are formed is a fundamental goal of astrochemistry and an integral part of origins of life studies. For this topic ALMA is providing much needed observational constraints with its high sensitivity for faint lines, high spectral resolution which limits line confusion, and high angular resolution making it possible to study the structure of young protostars on solar-system scales.

We here present the first results from a large unbiased survey P̈rotostellar Interferometric Line Survey (PILS)ẗargeting one of the astrochemical template sources, the low-mass protostellar binary IRAS 16293-2422. The survey is more than an order of magnitude more sensitive than previous surveys of chemical complexity and provide imaging down to 25 AU scales (radius) around each of the two components of the binary. The high sensitivity and spectral resolution that ALMA provides has allowed us to detect a wealth of previously undetected species in this object and the ISM in general, including numerous rare isotopologues of complex organic molecules. The exact measurements of the abundances of these isotopologues shed new light onto the formation of such complex species and link the embedded protostellar stages and the early Solar System.

James McMillan (The Ohio State University)

James P McMillan (The Ohio State University)
Christopher F Neese (The Ohio State University)
Frank C De Lucia (The Ohio State University)

Weeding the Astrophysical Garden Using Complete Experimental Spectra

Recent improvements in both the quality and quantity of the available astrophysical data have increased the strain on the existing quantum mechanical (QM) catalogs. Numerous spectral features and lines have been observed which cannot be accounted for by the current QM catalogs. Our experimentally based approach to this problem allows for the spectrally complete analysis of these data without the need for quantum assignment/numbers. With preliminary science verification data from ALMA, we have shown that our alternative to the QM catalogs allow for species specific temperature and column density measurements. All of the spectral features across the entire frequency band from blended species, including those from isotoplogues, have been successfully modeled. This form of analysis successfully modeled methyl cyanide, ethyl cyanide and vinyl cyanide present in the Hot Core of Orion KL and found them to be in local thermodynamic equilibrium with each other [1]. Methanol, methyl formate, ethyl cyanide, vinyl cyanide and methyl cyanide have all been fully studied in the 210 270 GHz band and our results are ready for their immediate use in astronomy [2] [3] [4] [5]. Acetaldehyde and dimethyl ether have much work done and their results are expected within the next year. In the 550 650 GHz band our results on methanol and ethyl cyanide are ready for immediate use [6] [7]. Weve made the results of our analysis, along with the original spectral scans, available in the electronic archives of The Astrophysical Journal. These archives may be accessed through the online versions of the papers sited in this abstract. We will present: the details of our experimental process, the extent to which we expand upon the existing QM catalogs and our success in modeling the complete spectra of 5 molecular species found in the Hot Core of Orion KL using ALMA's preliminary science verification data.

[1]Fortman, S. M., McMillan, J. P., Neese, C. F., et al. 2012 *JMoSp*, **280**, 11
[2]McMillan, J. P., Fortman, S. M., Neese, C. F. & De Lucia, F. C. 2014, *ApJ*, **795**, 56
[3]McMillan, J. P., Fortman, S. M., Neese, C. F. & De Lucia, F. C. 2016, *ApJ*, **823**, 1
[4]Fortman, S. M., Medvedev, I. R., Neese, C. F. & De Lucia, F. C. 2010, *ApJ*, **725**, 1682
[5]Fortman, S. M., Medvedev, I. R., Neese, C. F. & De Lucia, F. C. 2011, *ApJ*, **737**, 20
[6]Fortman, S. M., Neese, C. F. & De Lucia, F. C. 2014, *ApJ*, **782**, 75
[7]Fortman, S. M., Medvedev, I. R., Neese, C. F. & De Lucia, F. C. 2010, *ApJ*, **714**, 476

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Program Schedule

Wednesday, September 21, 2016

Stars and Stellar Evolution (Chair: Lars-Ake Nyman)			
9:00 AM	9:30 AM	Liz Humphreys (ESO, Garching)	Stars and Stellar Evolution
9:30 AM	9:45 AM	Raghvendra Sahai (JPL)	A Study of High Speed Outflows and Dusty Disks During the AGB to PB Transition
9:45 AM	10:00 AM	Jeonghee Rho (SETI Institute/SOFIA Science Center)	Discovery of Millimeter Shocked Molecular Gas and Molecular Hydrogen from the Supernova Remnant G357.7+0.3
10:00 AM	10:15 AM	Atish Kamble (Harvard-Smithsonian CFA)	Observing the Effects of Cosmic-Ray Acceleration in Young Supernovae
10:15 AM	10:30 AM	Poster Flash	
10:30 AM	11:15 AM	Break / Poster Viewing	

Liz Humphreys (ESO)

Stars and Stellar Evolution

ALMA has been producing stunning images and results for stars across the mass and evolutionary ranges. In this review, I will focus on results for Asymptotic Giant Branch Stars (AGB), Planetary Nebulae, Red Supergiants (RSG) and Supernovae. An area of particular interest is the shaping process by which AGB stars evolve to form often highly axisymmetric Planetary Nebulae - what are the roles of binarity and magnetic fields? As well as the mechanisms by which some of the stars are losing large amounts of mass (10^{-7} to 10^{-4} $M_{\odot}yr^{-1}$) to the interstellar medium. Finally I will discuss how ALMA long baseline and high frequency data are starting to help answer some of the long-standing questions in stellar evolution.

Raghvendra Sahai (Jet Propulsion Laboratory)

Wouter Vlemmings (Space Observatory Chalmers University of Technology Sweden)
Lars-Ake Nyman (Joint ALMA Observatory Chile)

A Study of High-Speed Outflows and Dusty Disks During the AGB to PN Transition

We do not yet understand the physical mechanisms responsible for turning the spherical outflows of AGB stars into extremely aspherical geometries, as AGB stars evolve to planetary nebulae (PNe). It is widely believed that this dramatic transformation is linked to binarity and the associated production of fast jets and central disks. The key to understanding the engines that produce these jets and the jet-shaping mechanisms lies in the study of the structure and kinematics of pre-planetary nebulae (PPNe), objects in transition between the AGB and PN phases.

A comparative high-resolution study of a representative sample of post-AGB objects with outflows and disks is now needed. We have begun this study with ALMA observations of two prominent PPNe, the carbon-rich Boomerang Nebula and the oxygen-rich PPN, IRAS16342-3814. The Boomerang is notable for a massive, high-speed outflow that has cooled below the microwave background temperature, making it the coldest object in the Universe! IRAS16342 is the prime example of the class of water-fountain PPNe (very young, post-AGB objects with high-velocity H2O masers), and shows the signature of a precessing jet in near-IR AO images. We discuss the similarities and differences in the structures of the high-speed outflows and central torii between these objects, that we have now probed with unprecedented detail with ALMA.

Jeonghee Rho (SETI Institute and SOFIA Science Center)

J W Hewitt (U of North Florida)
J Bieging (U of Arizona)
W T Reach (OFIA Science Center USRA)
M Andersen (Gemini Observatory Chile)
R Guesten (MPIfR Germany)

Discovery of Millimeter Shocked Molecular Gas and Molecular Hydrogen from the Supernova Remnant G357.7+0.3: HHSMT, APEX, Spitzer and SOFIA Observations

We report a discovery of shocked gas from the supernova remnant (SNR) G357.7+0.3 using millimeter and infrared observations. Our millimeter observations reveal broad molecular lines of CO(2-1), CO(3-2), CO(4-3), 13CO (2-1) and 13CO (3-2), HCO+ and HCN using Arizona HHSMT and 12-Meter, APEX and MOPRA Telescopes. The widths of the broad lines are 15-30 km/s, caused by strong supernova (SN) shocks passing through dense molecular clouds. The detection of such broad lines is the first, dynamic evidence showing that G357.7+0.3 is the SNR interacting with molecular clouds. We also present detection of H2 lines in mid-infrared using the Spitzer Infrared Spectrograph (IRS) observations to map a few arcmin area. The rotational H2 lines of S(0)-S(5), and S(7) are detected with the IRS. G357.7+0.3 lacks ionic lines compared with other H2 emitting SNRs. The H2 excitation diagram shows a best-fit with a two-temperature LTE model. We observed [C II] at 158um and high-J CO(11-10) with GERAT on SOFIA. The CO(11-10) line is not detected. The GREAT spectrum of [C II] in 3 sigma detection shows a broad line profile with a width of 15.7 km/s that is similar to those of broad CO lines. The line width of [C II] implies that ionic lines can come from a low-velocity C-shock. Comparison of H2 emission with shock models shows that a combination of two C-shock models is favored over a combination of C- and J-shocks or a single shock. We estimate the CO density, column density, and temperature using a RADEX model. The best-fit model with n(H2) = 1.7E4 per cm^3, N(CO) = 5.6E16 per cm^2, and T = 75 K can reproduce the observed CO brightnesses of G357.7+0.3.

ALMA observations of SNRs interacting clouds can spatially resolve shocked CO structures of the prominent broad molecular line regions. ALMA can provide velocity resolved CO spatial structures in sub-arcsec resolution, and resolve shock front, pre-shock and post-shock regions, instability structures and possibly transmitted and reflected shocks.

Atish Kamble (Harvard-Smithsonian Center for Astrophysics)

Maria Petropoulou (Purdue University)
Lorenzo Sironi (Harvard University)

Observing the Effects of Cosmic-Ray Acceleration in Young Supernovae

Cosmic-ray proton acceleration in young supernovae leads to the production of secondary electrons through inelastic proton-proton collisions. We have shown theoretically that the contribution from secondaries electrons may be significant and may even dominate the radiation from shock-accelerated electrons at early times. Self-consistent modeling of multi-band radio observations from interaction-powered SNe of various spectral types enabled us, for the first time, to infer basic parameters of the acceleration process, i.e. the shock acceleration efficiency of protons (ϵ_p) and the electron-to-proton ratio (K_{ep}). We demonstrate that ALMA observations of young supernovae can be decisive for understanding cosmic-ray acceleration in young SNe. We will discuss implications of these results in the context of superluminous SNe and motivate future ALMA observations of supernovae.

Half a Decade of ALMA: Cosmic Dawns Transformed
Program Schedule

Wednesday, September 21, 2016

11:15 AM	12:30 PM	**Future Opportunities**	**(Chair: Stuartt Corder)**
		Klaus Pontoppidan (STScI)	JWST and ALMA: Science Opportunities and Status
		John Carpenter (ALMA/JAO)	ALMA Capabilities in Cycle 4
		Al Wootten (NRAO)	Upcoming Approved ALMA Studies and New Projects
		Neal Evans (UT, Austin)	A Development Vision for ALMA
12:30 PM	12:40 PM	Conference Photo	
12:40 PM	2:00 PM	Lunch	

Klaus Pontoppidan (STScI)

JWST and ALMA: Science Opportunities and Status

The James Webb Space Telescope, scheduled for launch in October 2018 will address many of the key science areas of the ALMA community, including star and planet formation, nearby galaxies, as well as galaxy formation and evolution. We envision that JWST and ALMA data will be highly complementary, and that their combination will enable novel and transformative science. I will give an overview of the capabilities of JWST and some of the science they enable. I will also discuss the current status of the project, as well as the timeline and proposal process for the first cycle of science observations, including coming calls for an Early Release Science Program and the Cycle 1 Program. JWST proposal planning is supported by an extensive set of software tools, such as the JWST exposure time calculator (ETC), Astronomerś Proposal Tool (APT) a new documentation system, and a new set of data analysis tools based on the astropy python library.

John Carpenter (JAO)

ALMA Capabilities in Cycle 4

The Atacama Large Millimeter/submillimeter Array (ALMA) has steadily offered new capabilities since the start of the science operations in October 2011. In this talk, I will highlight the new capabilities offered to the community in Cycle 4, including solar observations, the Very Long Baseline Interferometry (VLBI), and the Morita-san Array (also known as the Atacama Compact Array, or ACA) in "stand-alone" mode. I will also present the anticipated timeline for the roll out of new capabilities as ALMA approaches full operations.

Al Wootten (NRAO)

Upcoming Approved ALMA Studies and New Projects

Science results from the Atacama Large Millimeter/submillimeter Array (ALMA) have been transforming astronomy, and more than 400 papers have been published on a wide range of topics to date, from nearly one thousand delivered datasets. Installation and commissioning of two of the final three of the ten receiver bands defined in the specifications and requirements are in progress. Final installation of its ten bands empower ALMA to operate at wavelengths from 7mm to 0.3mm across a decade of frequency access as enabled by broad bandwidth ALMA receivers, powerful correlators and spectacular site.

The ALMA specifications, contracts and construction began in 2003. The impetus to development of cutting edge technology spurred by ALMA construction has resulted in enormous advances since that time. Having invested $\sim$ \$1.3B USD to realize the largest historical advance in ground-based astronomy, it is vital to maintain and expand ALMA capabilities. The ALMA Development Program provides resources for that; the science community will define the scientific goals to drive that program into the future.

Studies undertaken throughout the ALMA partnership have identified high-impact initiatives providing major advances in ALMA sensitivity, instantaneous bandwidth and spectral coverage, spatial resolution, and imaging speed. An overview of those initiatives will be given to spur further discussion of the science goals they will enable, and to provide further guiding scientific vision.

Neal Evans (Univ of Texas at Austin)

A Development Vision for ALMA

The future development of ALMA is currently being studied. The ALMA2030 document produced by the ALMA Scientific Advisory Committee provides an initial framework for the scientific vision and technical possibilities. However, this plan cannot be implemented in its entirety and therefore it needs to be critically reviewed, prioritized, sequenced and supplemented with costing estimates. The Development Vision Working Group is working on a new document that will prioritize the developments suggested in ALMA2030 and outline a roadmap for development over the next 15 years. This process presents an opportunity for the community to outline a new strategy that will enable ALMA to extend the frontiers of science even further. Long-term development areas receiving the most attention include: i) Receiver improvements, especially increased bandwidth that will improve sensitivity and flexibility; ii) Longer baselines that would allow finer details of many objects, with protoplanetary disks being an obvious example; iii) Multi-beam receivers that would allow faster mapping of extended sources. Of these three, receiver improvements are considered the most achievable on the short term. We will solicit input from the meeting attendees on the above areas and other ideas.

Half a Decade of ALMA: Cosmic Dawns Transformed
Program Schedule

Wednesday, September 21, 2016

Nearby Galaxies: Normal Galaxies (Chair: Linda Watson)			
2:00 PM	2:30 PM	Karin Sandstrom (UC San Diego)	ALMA's View of Molecular Gas and Star Formation in Nearby Galaxies
2:30 PM	2:45 PM	Monica Rubio (Universidad de Chile)	The Lowest Metallicity Molecular Clouds With ALMA
2:45 PM	3:00 PM	Yuri Nishimura (University of Tokyo)	Chemical Composition in Low-Metallicity Dwarfs: the 3 mm Spectral Line Survey Observations toward the LMC and IC10
3:00 PM	3:15 PM	Remy Indebetouw (Uva/NRAO)	Extragalactic Star Formation at <0.1pc Resolution: 30Doradus with ALMA
3:15 PM	3:30 PM	Christine Wilson (McMaster University)	The CN/CO Ratio as a Tracer of UV Heating in Nearby Galaxies
3:30 PM	3:45 PM	Poster Flash	
3:45 PM	4:15 PM	Break / Poster Viewing	

Karin Sandstrom (UC San Diego)

ALMA's View of Molecular Gas and Star Formation in Nearby Galaxies

ALMA observations now routinely provide sensitive, cloud-scale (<50 pc), multi-tracer diagnostics of molecular gas and star formation in nearby galaxies. This wealth of information plus the ability to cover large populations of extragalactic star forming clouds is sharpening our understanding of how star formation is regulated in galaxies. I will review key results in this area from the first five years of ALMA observations as well as several new projects that are currently underway. I will also describe new techniques for synthesizing the wealth of information provided by ALMA on cloud-scale gas and star formation towards to goal of testing models for how galactic environment contributes to regulating star formation in galaxies.

Monica Rubio (Universidad de Chile, Departamento de Astronomia)

Elmegreen B (IBM Research Division T J Watson Research Center)
Hunter D (Lowell Observatory)
Cortes P (Joint ALMA Observatory NRAO)
Brinks E (Centre for Astrophysics Research University of Hertfordshire)
Verdugo C (Joint ALMA Observatory NRAO)

The Lowest Metallicity Molecular Clouds With ALMA

In the standard paradigm stars form out of molecular clouds. These clouds are dense concentrations of H2 that are traditionally traced in external galaxies using transitions of CO or other, more complex molecules. But dwarf irregular (dIm) galaxies seemingly contradict this fundamental picture. Tracers of recent star formation, such as Halfa or far-ultraviolet (FUV) emission, show that most dwarfs contain young stars and star clusters, but CO observations often yield only upper limits. The supposition is that H2 is actually present in star-forming regions in dIm galaxies even when CO is undetected. The structure of star-forming clouds at low metallicity is predicted to be different from that at high metallicity. As the metallicity drops, the cold and dense, CO-emitting part of a cloud where stars form shrinks relative to the warm photo-dissociation region (PDR) around itdue to a corresponding lack of shielding by dust.

We will present CO observations with ALMA of star-forming regions at the lowest metallicities (13% solar) of the dwarf galaxy WLM, revealing tiny CO clouds inside much larger molecular and atomic hydrogen envelopes. The properties of the molecular clouds in low metallicity galaxies along a sequence of decreasing metallicity from the LMC (50% solar), the SMC (20% solar), to WLM (13% solar) will be discussed.

Yuri Nishimura (The University of Tokyo)

Takashi Shimonishi (Tohoku University)
Yoshimasa Watanabe (The University of Tokyo)
Nami Sakai (RIKEN)
Yuri Aikawa (University of Tsukuba)
Akiko Kawamura (NAOJ)

Chemical Composition in Low-metallicity Dwarfs: the 3 mm Spectral Line Survey Observations toward the Large Magellanic Cloud and IC10

We have conducted spectral line survey observations in the 3 mm band toward two low-metallicity dwarf galaxies the Large Magellanic Cloud (LMC) and IC10 to reveal their chemical compositions. Firstly, we have observed seven clouds in the LMC, which have different star-formation activities; two are quiescent molecular clouds without infrared point sources, three are those associated with high-mass star formation, and two are active star-forming regions with the extended HII regions. Spectral lines of fundamental species such as CCH, HCN, HCO^+, HNC, CS, and SO are detected in addition to those of CO and ^{13}CO, while CH_3OH is not detected in any sources. The molecular-cloud scale chemical composition of the seven clouds are found to be similar to each other regardless of different star formation activities, and hence, it represents the chemical composition characteristic to the LMC without significant influences by star formation activities. Following the observation toward the LMC, we have conducted another observation toward IC10. As a result, the lines of CCH, HCN, HCO^+, HNC, CS, SO, ^{13}CO, and CO are detected, while c-C_3H_2, N_2H^+, CH_3OH, $C^{18}O$, and CN lines are not detected. The spectral intensity pattern of IC10 is found to be similar to those observed toward molecular clouds in the LMC. In comparison with chemical compositions of Galactic sources, the characteristic features are (1) deficient N-bearing molecules, (2) abundant CCH, and (3) deficient CH_3OH. Feature (1) is due to a lower elemental abundance of nitrogen in the LMC, whereas features (2) and (3) seem to originate from extended photodissociation regions in cloud peripheries due to a lower abundance of dust grains in the low-metallicity condition.

Remy Indebetouw (U Virginia and NRAO)

Extragalactic Star Formation at ¡0.1pc Resolution: 30Doradus with ALMA

The origin of the stellar initial mass function (IMF) is one of the fundamental unsolved questions in star formation. The mass function of 0.1pc sized dense cores (CMF) in solar neighborhood molecular clouds resembles the stellar IMF, suggesting that its form is imprinted by turbulence prior to star formation. That supersonic turbulence evidently follows fairly universal scaling relations in many environments at >1pc scales. Turbulent motions have only been analyzed at small scales in local clouds, revealing subsonic islands of relative calm at the 0.1pc sonic scale. Thanks to ALMA, these critical properties of molecular clouds (CMF and turbulent motions) have now been analyzed for the first time outside the Milky Way, in a much more extreme environment in the center of 30Doradus. I will present 0.1pc-scale masses and distribution of CO clumps, kinetic temperatures determined from formaldehyde, and how the gas relates to the complete census of sub-solar-mass star formation obtained with HST.

Christine Wilson (McMaster University)

The CN/CO Ratio as a Tracer of UV Heating in Nearby Galaxies

Thanks to ALMA, a wide variety of new molecular species are now accessible in nearby galaxies. Among these molecules, CN is particularly interesting as it relates to the dense gas tracer HCN via photodissociation and should trace the outer UV-heated layers of giant molecular clouds. In addition, the CN J=1-0 line can be measured simultaneously with the 12CO J=1-0 line at no extra cost in observing time. I will present the results of an archival ALMA project investigating the variation of the CN/CO ratio in a sample of 10 nearby galaxies and its correlation with properties such as gas mass fraction, infrared luminosity, and merger phase.

Half a Decade of ALMA: Cosmic Dawns Transformed
Program Schedule

Wednesday, September 21, 2016

Massive Star Formation (Chair: James Chibueze)			
4:15 PM	4:45 PM	Qizhou Zhang (Harvard-Smithsonian CfA)	Massive Star Formation
4:45 PM	5:00 PM	Fabien Louvet (Universidad de Chile)	Origin of the Stellar IMF in the W43-MM1 Mini-Starbust Ridge
5:00 PM	5:15 PM	Todd Hunter (NRAO)	The Massive Protostellar Maelstrom of NGC6334I
5:15 PM	5:30 PM	Adam Ginsburg (ESO)	Feedback and Accretion Toward Proto-O-Stars at ALMA's Highest Resolution
5:30 PM	5:45 PM	Josep M Girart (Institute of Space Sciences IEEC-CSIC)	Scatter-Induced Dust Polarization from an Accretion Disk Around a Massive Protostar
5:45 PM	6:00 PM	Poster Flash	
6:00 PM	7:00 PM	Poster Reception	

Qizhou Zhang (Harvard-Smithsonian Center for Astrophysics)

Massive Star Formation

Massive star formation begins in cold and dense molecular clouds that undergo significant physical and chemical change during protostellar evolution. As the mass of the protostar grows, the stellar radiation heats and ionizes material in its immediate surroundings. Massive stars are also born predominately in dense clustered environments together with stars of lower stellar masses. These unique characteristics, coupled with strong feedback that massive young stars impart on their environment present a rich laboratory for astrophysics, as well as present challenges in unlocking these complex phenomena. In this presentation, I will review the progress that ALMA has brought to this field during its past 5 years of discovery. I'll highlight some questions that ALMA will (hopefully) tackle in the next 5 years.

Fabien Louvet (Universidad de Chile)

F Motte (IPAG Grenoble CEA Saclay)
T Nony (IPAG Grenoble)
Q Nguyen Luong (NAOJ Tokyo)
et (al)

Origin of the Stellar IMF in the W43-MM1 Mini-Starbust Ridge

Studying extreme protoclusters is necessary to test if the IMF origin can be independent of cloud local characteristics. The W43-MM1 ridge, being extreme in terms of cloud concentration and star formation activity, is a case-study to confront models up to their limits. In Cycle 2, ALMA performed a deep, large mosaic of the 5 pc^2 ridge. The 1mm image reveals an exquisite hub of spiraling filaments and a rich cluster of about 300 cores with 2000 AU sizes. A temperature model was built from the knowledge of the main hot core characteristics and the heating of protostars identified with ALMA. The resulting core mass function (CMF) definitively is 'top-heavy', for both the low- and high-mass regimes. For the first time, one can question the origin of stellar masses for solar-type to O-type (1-100 Msun) stars in a single cloud. I will present various interpretations for this ‘top-heavyĆMF in the framework of mini-starburst events.

Todd Hunter (NRAO)

Crystal Brogan (NRAO)
Claudia Cyganowski (St Andrews University)
Claire Chandler (NRAO)
Rachel Friesen (University of Toronto)
Remy Indebetouw (NRAO UVa)

The Massive Protostellar Maelstrom of NGC6334I

NGC6334I is a nearby (1.3 kpc) example of a deeply-embedded massive protostellar cluster. At the center is a Trapezium-like arrangement of four millimeter sources, two of which are prolific hot cores (MM1 and MM2). We will present our initial ALMA observations in Band 6 with 220 AU resolution, which have resolved the dominant millimeter source MM1 into at least six continuum components separated by 1000 AU. This configuration suggests a ḧot multi-coreïn which several seeds appear to be accreting from a common gas reservoir at the core of the protocluster, possibly leading to a proto-multiple system. Two of them show compact line emission in CH3CN J=12-11, K=10 (782K above ground) while three of them appear in absorption in the low K lines. We also resolve the two other previously known massive protostars in the region and detect 5 new fainter millimeter sources. In conjunction with sensitive VLA 1.3 cm and 7 mm images of comparable resolution, we will also present the results from our modeling of the SEDs of the individual protostars. We find a diverse range of circumstellar properties including hypercompact HII regions, jets, and massive cores lacking any free-free component – one of which appears to be a variable millimeter dust source.

Adam Ginsburg (European Southern Observatory)

Ciriaco Goddi (Radboud University)

Feedback and Accretion Toward Proto-O-Stars at ALMA's Highest Resolution

I will present ALMA observations of the high-mass star-forming complex W51 in which dozens of O-stars have already formed and many more OB stars are vigorously accreting. We have used ALMA to probe scales from 200 AU to 0.5 pc both toward the known proto-O-stars and in the surrounding protocluster cloud. These data have allowed us to compare the impact of different feedback mechanisms on the formation of both low- and high-mass stars. We detect dozens of collimated outflows with lengths 0.03-0.5 pc, many of which originate in barely resolved or even unresolved sources at 200 AU resolution, which identify the accreting massive stars. Where the central source is resolved in the dust continuum, it is elongated orthogonal to the outflow. Observations of temperature probes reveal that regions within about 0.1 parsecs of these high-mass protostars are significantly warmer than their surroundings, reaching temperatures of 100-200 K. The enhanced temperature only occurs around the accreting proto-massive-stars, not around their main sequence colleagues or nearby compact HII regions. These high-mass stars are able to maintain their food source by heating their surroundings, suppressing the fragmentation of infalling and orbiting gas, thereby keeping it available for future accretion.

Josep M Girart (Institute of Space Sciences IEEC-CSIC)

C Carrasco-Gonzalez (IRyA)
G Anglada (IAA-CSIC)
S Curiel (IAA-UNAM)
M Osorio (IAA-CSIC)
M Fernandez-Lopez (IAR)

Scatter-Induced Dust Polarization from an Accretion Disk Around a Massive Protostar

HH80-81 represents a clean case of high-mass star formation through an accreting disk in the presence of magnetic fields. The protostellar system includes a magnetized highly collimated jet; a disk perpendicular to the jet; and possible rotating motions in the molecular gas around the massive protostar. There are very few massive protostars known to show all these signatures. Here we present very sensitive (1 σ rms of 20 μJy), 40 milliarcsecond angular resolution polarimetric observations toward the driving source of the powerful jet. The superb sensitivity, angular resolution and image fidelity allow us to well resolve the accretion disk around the massive young star with a dynamic range of more than 5000. The disk has a radius of $\sim$300 AU, surrounded by a tenuous, flattened halo of dust emission with a radius of 1000 AU. The majority of the disk exhibits linear polarization of the dust emission at a level of 0.5–5%. The polarization pattern is suggestive of scattering produced on the surface of the disk facing the observer. The detail of the polarization pattern makes this disk possibly a textbook example of scattering. In addition, we detected two dozen of compact continuum sources that most likely trace the disk emission of a cluster of low/intermediate-mass young stellar objects within 20,000 AU of the massive protostar. Half of these disks are partially resolved with a radius between 30 and 100 AU.

Half a Decade of ALMA: Cosmic Dawns Transformed
Program Schedule

Thursday, September 22, 2016

Galaxy Formation and Evolution: Cosmic Evolution (Chair: Catherine Vlahakis)			
9:00 AM	9:30 AM	Caitlin Casey (UT Austin)	ALMA's View of Molecular Gas and Star Formation in Nearby Galaxies
9:30 AM	9:45 AM	Fabian Walter (MPIA Heidelberg)	CO Emission in ASPECS, the ALMA Spectroscopic Survey in the Hubble Ultra Deep Field
9:45 AM	10:00 AM	Manuel Aravena (Universidad Diego Portales)	Continuum and [CII] line emission from ASPECS: The The ALMA SPECtroscopic Survey in the Hubble Ultra Deep Field
10:00 AM	10:15 AM	Hideki Umehata (University of Tokyo)	ALMA Deep Field in SSA22
10:15 AM	10:30 AM	Yiping Ao (NAOJ)	Deep Submm and Radio Observations Towards LABs
10:30 AM	10:45 AM	Poster Flash	
10:45 AM	11:15 AM	Break / Poster Viewing	
11:15 AM	11:30 AM	Marcel Neeleman (UC Santa Cruz)	Lighting Up Shadows: CO and [CII] Detections of Absorption-Selected Galaxies
11:30 AM	11:45 AM	Nick Scoville (Caltech)	Evolution of ISMs and Star Formation at z = 1 to 4
11:45 AM	12:00 PM	Helen Russell (University of Cambridge)	Massive Molecular Gas Flows and AGN Feedback in Galaxy Clusters
12:00 PM	12:15 PM	Yashar Hezaveh (Stanford University)	Detecting the Missing Dark Matter Subhalos with ALMA Observations of Gravitationally Lensed Galaxies
12:15 PM	12:30 PM	James Geach (University of Hertfordshire)	ALMA Solves the Mystery of Lyman-alpha Blob 1: Halo Substructure Illuminated from Within
12:30 PM	2:00 PM	Lunch	

Caitlin Casey (UT Austin)

ALMA's View of the Obscured Universe at High-Redshift

I will discuss results from the first five years of ALMA on studying galaxies in the distant Universe. I will focus on the bulk characteristics of both DSFGs and more normal-type galaxies, from z$\sim$1 towards the epoch of reionization. While results have been quite rich to-date, I will also discuss some thoughts on the future of ALMA large programs and aims over the next five years in high-z galaxy evolution.

Fabian Walter (MPIA Heidelberg)

Roberto Decarli (MPIA Heidelberg)
Manuel Aravena (Universidad Diego Portales)
Chris Carilli (NRAO)
Rychard Bouwens (Leiden Observatory)
Elisabete da Cunha (ANU)

CO Emission in ASPECS, the ALMA Spectroscopic Survey in the Hubble Ultra Deep Field

We present first results emerging from ASPECS: The ALMA SPECtroscopic Survey in the Hubble Ultra-Deep Field (UDF). The overarching goal of ASPECS is to obtain an unbiased census of molecular gas and dust continuum emission in high-redshift galaxies through full frequency scans in the ALMA bands 3 and 6 at approximately uniform line sensitivity. The molecular surveys in both bands cover the different rotational transitions of the CO molecule, leading to essentially full redshift coverage. We discuss some of the individually CO-detected galaxies in our field in the context of previous molecular gas observations at high redshift (star formation law, gas depletion times, gas mass fractions): The CO-detected galaxies in the UDF tend to reside on the low-L_{IR} envelope of the scatter in the L_{IR} - L_{CO} relation, but exceptions exist. For the CO-detected sources, we find an average depletion time of 1Gyr, although significant scatter is in place. From our blind CO detections, we derive first constraints on the CO luminosity function in a number redshift bins. The resulting cosmic molecular gas density as a function of redshift shows a factor 3-10 rise from z=0 to z=2, possibly followed by a decline at z¿3. This is similar to the observed evolution of the cosmic star formation rate density. The latter therefore appears to be at least partly driven by the increased availability of molecular gas reservoirs at the peak of cosmic star formation (z 2).

Manuel Aravena (Universidad Diego Portales)

Roberto Decarli (MPIA)
Fabian Walter (MPIA)
Rychard Bouwens (Leiden)
Chris Carilli (NRAO)

Millimeter Continuum and [CII] Line Emission from ASPECS: The ALMA Spectroscopic Survey in the Hubble Ultra Deep Field

We present first results emerging from ASPECS: The ALMA SPECtroscopic Survey in the Hubble UltraDeep Field (UDF), the cosmological deep field that has the deepest multi-wavelength data available. Our survey reaches an unprecedented depth over a 1 arcmin^2 area in the millimeter continuum, and our band-6 scan covers the fine-structure [CII] line over the redshift range $6 < z < 8$, thus probing well into the the reionization epoch. In this talk, we will discuss the physical properties of the individual continuum detections (redshift, stellar masses and SFRs) and the stringent constraints obtained by our survey on average dust obscuration properties of galaxies, based on the measured IRX-beta relation at $z > 3$. Finally, we also present our results on our deep, systematic search for [CII] line emission from optical dropouts at $z > 6$.

Hideki Umehata (University of Tokyo)

Yoichi Tamura (University of Tokyo)
Kotaro Kohno (University of Tokyo)
Rob Ivison (Royal Observatory)
Ian Smail (Durham University)
Bunyo Hatsukade (NAOJ)

ALMA Deep Field in SSA22

We present the results of a $2' \times 3'$ (3.7 Mpc$\times$ 5.5 Mpc at $z = 3$, in a comoving scale) deep survey at 1.1 mm taken with ALMA in the SSA22 field (ALMA deep field in SSA22 or ADF22). Using a mosaic of 103 ALMA pointings, we observed the core region of a $z = 3.09$ proto-cluster, achieving an typical rms sensitivity of 60 μJy beam^{-1} at a resolution of 0.7 arcsec. We obtained 18 robustly detected ALMA sources (here after submillimeter galaxies, SMGs) with a signal-to-noise ratio (SNR) > 5. At least 10 ALMA SMGs have spectroscopic redshifts of $z = 3.09$. We find that multiple $z = 3.09$ ALMA SMGs contribute to two AzTEC sources, supporting that interaction may be responsible for a significant fraction of multiplicity in single-dish sources. Not only are these SMGs members of the proto-cluster but they in fact reside within the node at the junction of the 50 Mpc-scale filamentary three-dimensional structure traced by Lyman-*alpha* emitters (LAEs) in this field. We also find that six of the 10 ALMA SMGs host a X-ray luminous active galactic nuclei (AGN). Our results suggest that the vigorous star formation activity and the growth of super massive black holes (SMBHs) occurred simultaneously in the densest regions at $z \sim 3$, which is likely to correspond to the most active historical phase of the massive galaxy population found in the core of the clusters in the present universe.

Yiping Ao (NAOJ)

Deep Submm and Radio Observations Towards LABs

Lyman alpha blobs at high redshift are characterised by their huge lyman alpha luminosities and large physical sizes over several tens kpc. However, the heating mechanism of the LABs is still unclear and under debate. We will present our recent work about lyman alpha blobs (LABs). Using the Herschel PACS and SPIRE, SCUBA-2, ALMA, ATCA and JVLA data, we study the LABs in J2143-4423 at z=2.38 and SSA22 at z=3.1. We found that the many LABs are associated with submm sources with high SFRs, suggesting active SF may be the powering source for the extended lyman alpha emission in some LABs. Our preliminary ALMA results in some LABs show that multiple submm counterparts are associated with many LABs, may suggesting the LABs are the site forming galaxy protoclusters in their early stage. Deep radio observations to be completed soon will help us to distinguish the heating mechanisms between AGN and SF activity.

Marcel Neeleman (UC Santa Cruz)

J Xavier Prochaska (UC Santa Cruz)
Nissim Kanekar (TIFR)
Marc Rafelski (NASA Goddard)

Lighting Up Shadows: CO and [CII] Detections of Absorption-Selected Galaxies

In this talk, I will present the first ever detections of molecular and atomic-fine structure line emission from absorption-selected galaxies. One of the key science goals of ALMA is to detect CO or [CII] from a normal galaxy at high redshift. However, typical selection strategies are based on emission measurements which introduces a variety of different selection biases. By selecting galaxies from their absorption profiles in background quasars, we circumvent these biases allowing us to better probe the true galaxy distribution function at high redshift. Our initial study of high-metallicity absorption-selected galaxies has resulted in the detection of CO emission in two z$\sim$0.5 absorbers and two detections of [CII] in z$\sim$4 absorbers. These detections indicate that the high-metallicity absorption-selected galaxies probe a population of galaxies marked by moderate star formation (SFR $\sim$20 - 80 Msol/year) and relatively large dust obscuration. The large impact parameter of the [CII] emission compared to the quasar sightline ($\sim$40 kpc) further suggest that these high redshift systems have a large envelope of neutral gas surrounding them, which they are effectively enriching with metals.

Nick Scoville (Caltech)

P Vanden Bout
L Murchikova
D Sanders
C Vlahakis
others

Evolution of ISMs and Star Formation at z = 1 to 4

Observations of the ISM content as a function of redshift and galaxy mass is critical to understanding the factor 20 increase in star formation from z = 0 back to z =2. Over 3 ALMA cycles, we have obtain long wavelength dust continuum measures for 800 galaxies at z = 1 to 4 and stellar masses above $2{\times}10^{10}$ solar masses. We calibrate the dust continuum emission relative to CO(1-0) emission and find a single constant of proportionality and hence validate the dust emission as a probe of ISM masses. We see strong increase in the ISM masses by a factor 10-20 out to z = 2 and increases as one moves above the galaxy main sequence. We propose a new star formation law, approximately linear with ISM mass but with a larger proportionality constant than for low z galaxies (i.e. a shorter gas depletion time). The bulk of the SF in the early universe is likely dynamically driven like that in low z ULIRGs.

Helen Russell (Institute of Astronomy Cambridge)

Brian McNamara (University of Waterloo)
Andy Fabian (Institute of Astronomy Cambridge)
Michael McDonald (MIT Kavli Institute)
Paul Nulsen (Harvard-Smithsonian Center for Astrophysics)
Alastair Edge (Durham University)

Massive Molecular Gas Flows and AGN Feedback in Galaxy Clusters

Powerful radio jets launched by a central supermassive black hole pump a substantial amount of energy into their host galaxies and cluster environment. This feedback from the central AGN is thought to regulate galaxy growth and cooling of the surrounding hot atmosphere. Our ALMA Early Science observations of brightest cluster galaxies in cooling clusters revealed molecular gas filaments extending 5-15 kpc with masses of 10^9 to a few 10^{10} solar masses, which likely formed from gas cooling out of the clusters' hot atmospheres. I will present new ALMA observations of extended molecular filaments in the Phoenix and PKS0745-191 brightest cluster galaxies, which are drawn up around radio bubbles and show that radio jets interact with cold, dense molecular gas as well as the hot, diffuse intracluster medium.

Yashar Hezaveh (Stanford University)

Detecting the Missing Dark Matter Subhalos with ALMA Observations of Gravitationally Lensed Galaxies

The number of observed dwarf satellites of the Milky Way is about three orders of magnitude lower than what cold dark matter (CDM) simulations predict, an issue that is referred to as the "Missing Satellite Problem". In this talk, I will discuss how in strong lensing systems we can detect low-mass dark matter subhalos in the lensing galaxies by measuring the gravitationally-induced distortions that they induce in the lensed images of background sources. Measuring the abundance of dark matter subhalos with strong lensing allows us to determine their mass function and to compare it with the predictions of CDM and other dark matter models. I will present our first detection of a subhalo using ALMA data and show how we can place constraints on the abundance of subhalos down to 2×10^7 solar masses with these observations. I will also give a brief overview of our ongoing observational campaign to place stronger constraints at lower masses.

James Geach (University of Hertfordshire)

ALMA Solves the Mystery of Lyman-alpha Blob 1: Halo Substructure Illuminated from Within

We present new ALMA 850μm continuum observations of the original Lyman-α Blob (LAB) in the SSA22 field at $z = 3.1$ (SSA22-LAB01). The ALMA map resolves the previously identified submillimeter source into three components with obscured star formation rates of $\sim$200 $M_{\odot}$ yr^{-1}. The ALMA sources are associated with several faint rest-frame ultraviolet sources identified in *Hubble Space Telescope* Imaging Spectrograph (STIS) imaging, at least one of which is spectroscopically confirmed with Keck MOSFIRE to lie within 20 pkpc and 250 km s^{-1} of one of the ALMA components. We postulate that some of these STIS sources represent a population of low-mass star-forming satellites surrounding the central submillimeter sources, potentially contributing to their growth and activity through accretion. Using a high resolution cosmological zoom simulation of a $10^{13} M_{\odot}$ halo at $z = 3$, including stellar, dust and Lyα radiative transfer, we can accurately model the ALMA+STIS observations and demonstrate that Lyα photons escaping from the central submillimeter sources are expected to resonantly scatter in neutral hydrogen associated with the surrounding satellites: the ALMA sources are effectively íllumination´the halo substructure from within.

Half a Decade of ALMA: Cosmic Dawns Transformed
Program Schedule

Thursday, September 22, 2016

Protostellar Disks & Planet Formation (Chair: Ken Tatematsu)			
2:00 PM	2:30 PM	Laura Perez (MPIfR, Bonn)	Planet Formation in Protostellar Disks: New Insights from ALMA Observations
2:30 PM	2:45 PM	Yusuke Aso (University of Tokyo)	ALMA Observations of Keplerian Disks Around Protostars
2:45 PM	3:00 PM	Dominique Segura-Cox (University of Illinois)	Has Planet Formation Already Begun in the Class I Protostellar Phase?
3:00 PM	3:15 PM	Dmitry Semenov (MPIA, Heidelberg)	Molecular Diagnostics of Protoplanetary Disk Gaps
3:15 PM	3:30 PM	Kamber Schwarz (University of Michigan)	Resolved CO and H2 Abundance Structure in the Protoplanetary Disk TW Hya
3:30 PM	3:45 PM	Andrea Isella (Rice University)	Ringed Structure of the HD 163296 Disk Revealed by ALMA
3:45 PM	4:00 PM	Ryan Loomis (Harvard University)	AA Tau: A Surprise Multi-Ringed Transition Disk
4:00 PM	4:30 PM	Arielle Moullet (NRAO)	Planet Formation in Protostellar Disks: New Insights from ALMA Observations
5:30 PM	10:30 PM	Palm Springs Village Fest Excusion	

Laura Perez (MPIfR)

Planet Formation in Protostellar Disks: New Insights from ALMA Observations

Planet formation takes place in the disks of gas and dust that surround young stars, generally referred to as protostellar disks. With the advent of ALMA, and together with new developments in theory, we are making rapid progress in understanding how the reservoir of material in these disks is transformed into new planetary systems. In this review, I will describe how observations of the dust and gas components in disks trace their evolution. I will also highlight recent observational results that provide new insight into key aspects of the planet formation process. Finally, I will conclude with new avenues of observational work that can be carried out with ALMA, aimed at directly witnessing the process of planet formation in protostellar disks.

Yusuke Aso (The University of Tokyo)

Nagayoshi Ohashi (NAOJ)
Yuri Aikawa (Kobe University)
Msahiro Machida (Kyushu University)
Kazuya Saigo (Osaka Prefecture University)
Masao Saito (NAOJ)

ALMA Observations of Keplerian Disks Around Protostars

Keplerian disks around young stars play essential roles in star and planet formation. Compared with disks around T Tauri stars, the disk formation process prior to the T Tauri phase is still not well understood because their observations are quite limited. There has been, however, a dramatic transformation in the study of the disk formation around protostar in the ALMA era. To study the disk formation, we have observed 8 protostars (6 Class 0 and 2 Class I) with ALMA in C18O (J=2-1) line and 1.3 mm continuum emissions at sub-arcsec resolutions. Keplerian disks were identified toward 4 of 8 protostars. Class 0 protostars tend to have less detectable disks with lower specific angular momenta as compared with those for detectable disks, suggesting a scenario of the disk formation that disks grow by accumulating larger angular momenta as time goes on. We will also report a latest study of L1527 IRS using its continuum visibility, which suggests its disk structure in hydrostatic equilibrium and density enhancement in the disk as compared with the surrounding envelope.

Dominique Segura-Cox (University of Illinois)

Leslie Looney (University of Illinois)
Ian Stephens (Harvard-Smithsonian Center for Astrophysics)
Lee Mundy (University of Maryland)
Manuel Ferna ndez-Lo pez (Instituto Argentino de Radioastronom a)
Robert Harris (University of Illinois)

Has Planet Formation Already Begun in the Class I Protostellar Phase?

How early can disk substructures, and hence signs of early planet formation, be found in young disks? The long-baseline observations of gaps in HL Taus disk has been a watershed event in empirically constraining planet formation in protostellar disks, strongly suggesting that planets are already forming by early Class II or late Class I phase. While disks around Class II objects have been studied systematically, their less evolved Class I counterparts, which are still embedded in dense envelopes, have only begun to be characterized. We have conducted ALMA continuum Band 6 long-baseline observations of the disk of Class I source IRS 63 to search for gaps in an even younger protostellar disk than HL Tau. IRS 63 is considered significantly less evolved than the famous HL Tau due to an obvious envelope detected at mm/submm wavelengths not found in HL Tau. The long-baseline observations allow for sub-arcsec resolution (¡10 AU at the distance of IRS 63), key to studying any fine substructure that may be present in the disk due to early planet formation. The implications of the IRS 63 high-resolution observations for disk and planet formation are far-reaching because these data are the highest resolution available in a protostellar disk at such an early stage of evolution. We compare disk parametersmodeled in both the image and u,v-planesto HL Tau and other disk observations.

Dmitry Semenov (MPIA Heidelberg Germany)

Molecular Diagnostics of Protoplanetary Disk Gaps

The new stunning high-resolution images of protoplanetary disks with ALMA reveal the common presence of rings and gaps in both dust continuum and, since recently, in molecular emission lines. There is a variety of theoretical ideas about physical mechanisms that can create such features in accretion disks, e.g. due to perturbation of the disk gas by a planet or (magneto)hydrodynamical instability. These various mechanisms act differently on the gas and dust distributions across the gap.

Unfortunately, one cannot easily distinguish between gap-opening mechanisms by measuring the locations and widths of these features in dust (sub-)mm continuum emission or via dust near-IR scattered-light images. We will demonstrate that additional observations of molecular lines of different chemical tracers could help to resolve this deficiency and provide constraints on the gap-opening mechanisms.

Kamber Schwarz (University of Michigan)

Edwin Bergin (University of Michigan)
L Ilsedore Cleeves (Harvard-Smithsonian Center for Astrophysics)
Geoffrey Blake (California Institute of Technology)
Ke Zhang (University of Michigan)
Karin Oberg (Harvard-Smithsonian Center for Astrophysics)

Resolved CO and H2 Abundance Structure in the Protoplanetary Disk TW Hya

We present spectrally and specially resolved ALMA observations of 13CO and C18O 3-2 and 6-5 in the protoplanetary disk TW Hya. These observations provide a measurement of the surface CO snowline at 30 AU and constrain the likely location of the midplane CO snowline to 17-23 AU. Additionally, the 3-2 maps show evidence for an outer ring of CO centered at 53 AU. Using these observations, combined with previous observations, we have estimated the azimuthally averaged gas temperature, CO, and H2 gas surface density profiles. These represent the first resolved estimates of the abundance of a major volatile in a young planet forming disk. We find that the abundance of CO is depleted in the gas by two orders of magnitude relative to the expected value, based on abundance in the interstellar medium. This depletion is observed from our resolution limit of 10 AU out to the edge of the detected emission at 60 AU. Furthermore, we will present additional lines of evidence which demonstrate the missing carbon is likely locked up in the midplane as ices coating pebbles and perhaps even cometesimals. This traces the beginnings of the implantation of key volatiles into the solids.

Andrea Isella (Rice University)

Ringed Structure of the HD 163296 Disk Revealed by ALMA

I will present ALMA observations of the protoplanetary disk around the Herbig Ae star HD 163296 that trace the spatial distribution of millimeter-sized particles and cold molecular gas on spatial scales as small as 25 astronomical units (au). The image of the disk recorded in the 1.3 mm continuum emission reveals three pairs of bright and dark concentric annuli similar to those observed toward HL Tau. By modeling the dark annuli with partially dust depleted circular gaps, we derive gap radii of 60 au, 100 au, and 160 au. The observations of the 12CO, 13CO, and C18O J=2-1 emission indicate that the middle and outer gaps are also partially depleted in gas, while we do not find evidence of gas depletion inside the inner gap. I will argue that the favored explanation for the formation of the two outermost gas and dust depleted gaps is the clearing caused by two Saturn-mass planets orbiting at 100 au and 160 au from the central star, while other processes, such as the dust accumulation at the edge of a Magneto-Rotational instability (MRI) dead zone, or the dust opacity variation at the edge of the CO frost line, might be required to explain the width and gas-to-dust ratio of the inner gap.

Ryan Loomis (Harvard University)

Karin Oberg (Harvard University)
Meredith MacGregor (Harvard University)
Sean Andrews (Harvard-Smithsonian CfA)
David Wilner (Harvard-Smithsonian CfA)
Ilse Cleeves (Harvard University)

AA Tau: A Surprise Multi-Ringed Transition Disk

ALMA's high spatial resolution and sensitivity have recently begun to reveal previously unresolved sub-structure in protoplanetary disks, simultaneously shedding light and posing new questions on disk evolution. AA Tau hosts a highly inclined protoplanetary disk, and is the prototypical source for a class of stars with a peculiar periodic photometric variability thought to be dependent on viewing geometry. We present high resolution (∼0.2") ALMA observations of the 1.3mm dust continuum, which surprisingly reveal a multi-ringed transition disk at an inclination of ∼60 degrees. In addition to the ringed sub-structure, we find non-axisymmetric features, including a 'bridge' of flux across the inner-most gap. Observations of HCO^+ 2-1 show bright emission from within the inner-most gap, suggesting that large quantities of molecular gas still reside within the hole. The kinematics of this emission are indicative of a radial flow, possibly associating the gas with gap-crossing streamers. AA Tau may therefore offer a rare glimpse into the dynamical processes governing accretion in planet-forming transition disks. We additionally discuss how resolving the disk geometry and substructure may affect interpretations of the mechanism behind AA Tau's variability, and speculate on the nature of the continuum 'flux bridge'.

Arielle Moullet (NRAO)

Arielle Moullet (NRAO)

Solar System Science with ALMA

The most recent developments of ALMAś capabilities have enabled an unprecedented range of possibilities for Solar System (sub)mm observations, already resulting in significant scientific achievements. The large total collective area available now allows for searches of atmospheric compounds in the thin atmospheres of Kuiper Belt Objects and icy moons, and the deployment of long baselines configurations opened the way to detailed thermal surface studies of asteroids and moons. Improvements in scheduling flexibility have enabled observations of time-sensitive phenomena as well as rotational mapping. The unique measurements offered by ALMA are highly complementary of observations from recent or upcoming planetary missions (Cassini, Dawn, New Horizons, Juno), and contribute in a unique way to the understanding of the composition and structure of planetary atmospheres and surfaces. Models of Solar System formation are also informed by the tremendous progress made in the knowledge of gas and dust distribution in protoplanetary and debris disks, while white dwarf disks observations can help to place constraints on the asteroid and cometary reservoirs. I will present the most recent and scientifically compelling results obtained by ALMA on Solar System objects, as well as ambitious projects that will be carried out in Cycle 4. I will also present the case for ALMAś role in the characterization of exoplanets.

Half a Decade of ALMA: Cosmic Dawns Transformed
Program Schedule

Friday, September 23, 2016

Transition and Debris Disks (Chair: Antonio Hales)			
9:00 AM	9:30 AM	Brenda Matthews (NRC Herzberg Astronomy)	ALMA Observations of Debris Disks: A Window into the Diversity of Planetary Systems
9:30 AM	9:45 AM	Scott Barenfeld (Caltech)	The End of Primordial Disk Evolution: An ALMA Survey of Upper Sco
9:45 AM	10:00 AM	Luca Matra (University of Cambridge)	Gas in Debris Disks and the Dawn of Exocometary Science with ALMA
10:00 AM	10:15 AM	Jacob White (University of British Columbia)	ALMA 1.3 mm Observations of the Fomalhaut System
10:15 AM	10:30 AM	Poster Flash	
10:30 AM	11:15 AM	Break / Poster Viewing	

Brenda Matthews (NRC Herzberg)

ALMA Observations of Debris Disks: A Window into the Diversity of Planetary Systems

ALMA has now observed a significant number of debris disks, ranging from those well-studied by earlier facilities to those recently identified. An interesting characteristic of this class of circumstellar disks, those collisionally-generated around young and old stars, is their striking diversity. While the mechanism which generates debris disks is most commonly a collisional cascade acting to return large solid bodies to small dust grains, debris disks are not easily classified into categories by their morphology. ALMA has revealed disks which appear very broad in radial distribution and also many that show confined narrow rings of emission. Most interestingly, ALMA has finally begun to reveal significant numbers of debris disks with evidence of molecular gas emission, including several which are so young that the origin of the molecular gas is difficult to discern: is the gas leftover from a protoplanetary disk or is it, like the dust, second-generation, i.e., the product of collisional processes? These disks essentially bridge the gap between transition and debris disks, revealing the latter to be very much along the continuum of circumstellar disk evolution rather than a class by themselves.

Scott Barenfeld (Caltech)

John Carpenter (Joint ALMA Observatory)
Anneila Sargent (Caltech)
Andrea Isella (Rice University)
Luca Ricci (Harvard-Smithsonian Center for Astrophysics)

The End of Primordial Disk Evolution: An ALMA Survey of Upper Sco

We present results of an ALMA survey to study the evolution of disks around low mass stars. Our goals are to measure the spatial distributions of gas and dust in primordial disks approaching the final stages of their evolution and to compare the dust masses of these disks to those of younger systems. To this end, we have obtained ALMA 0.88 mm continuum and ^{12}CO (3-2) observations of over 100 sources with suspected circumstellar disks in the Upper Scorpius OB Association (Upper Sco). The 5-11 Myr age of Upper Sco suggests that any such disks will be quite evolved, making this association an ideal target for such a study. With ALMA, we achieve an order of magnitude improvement in sensitivity over previous (sub)millimeter surveys of Upper Sco and detect 58 disks in the continuum. Of these, 24 are also seen in CO, along with two disks detected in CO but not in the continuum. We present a comparison of the the radial extent of the dust and CO in these disks and constrain the extent to which dust traces CO. In addition, we calculate the total dust masses of these disks and compare their masses to those of younger disks in Taurus and Lupus. We find strong evidence for a decline in disk dust mass between an age of 1-3 Myr and 5-11 Myr. Our results represent the first large census of the spatial distributions of gas and dust in disks at an age of 5-11 Myr and the first definitive measurement of a decline in disk dust mass with age.

Luca Matra (Institute of Astronomy University of Cambridge UK)

S Marino (Institute of Astronomy University of Cambridge UK)
M Wyatt (Institute of Astronomy University of Cambridge UK)
W Dent (ALMA Santiago Chile)
Q Kral (Institute of Astronomy University of Cambridge UK)
C Stark (Space Telescope Science Institute Baltimore USA)

Gas in Debris Disks and the Dawn of Exocometary Science with ALMA

The unprecedented sensitivity of ALMA is revolutionising the very definition of debris disks around main-sequence stars. Previously considered gas-free, detections of CO + atomic gas and the power to spatially resolve them is showing that this is not necessarily the case. The trend with youth for these systems has brought forward a dichotomy in the origin of this gas: is it a remnant from the protoplanetary disk (primordial) or is it released from exocometary ices (secondary)? In this talk, I will present new ALMA observations of the first two gas disks of confirmed exocometary origin, around debris disk stars beta Pictoris and HD181327. I will discuss the nature and evolution of these secondary gas disks and connect the observables to their cometary composition. Finally, I will present a new method using ALMA observations of NLTE CO line ratios to probe for the H2 content and hence solve the primordial vs secondary dichotomy in other gas-bearing debris disks.

Jacob White (University of British Columbia)

Aaron Boley (University of British Columbia)
Eric Ford (Pennsylvania State University)
Stuart Corder (ALMA Science Center)
Bill Dent (ALMA Science Center)
Matthew Payne (Harvard Center for Astrophysics)

ALMA 1.3 mm Observations of the Fomalhaut System

We present ALMA Band 6 (1.3 mm) observations of Fomalhaut and its debris disk. Since the system is relatively close at 7.7 pc, it has been the target of numerous studies at multiple wavelengths, and can serve as a test-bed for debris disk evolution models and planet-disk interactions. Outstanding issues that need to be resolved to properly characterize the debris include tightening constraints on the spectral index in the submm/mm regime and determining whether there is indeed excess over the stellar emission, indicating the presence of an inner debris disk or ring.

These ALMA 1.3 mm observations provide the highest resolution observations to date of the mm grains the outer ring. Tight constraints are placed on the geometry of the disk and on the mm-wavelength spectral index. We explore fitting the debris disk model in the image plane in addition to the standard method of fitting the visibilities. The results are compared and potential advantages/disadvantages of each approach are discussed.

The central emission detected is indistinguishable from a point source, with 0.89 mJy being the best fit flux of the host star for Fomalhaut itself. This implies that any inner debris component must contribute little to the total central emission. Moreover, the stellar flux is less than 70% of that predicted by extrapolating a blackbody from the constrained photosphere temperature and just over 70% of the flux if extrapolating from the far infrared. This behavior is similar to that seen in the Sun for submm/mm wavelengths, but more pronounced. Currently, insufficient data exists to properly constrain the degree to which stellar atmospheres affect the observed flux in the submm/mm regime. This result is part of an ongoing larger project focused on measuring the emission from stellar atmospheres at submm/mm wavelengths which directly impact inferred excesses for debris disk studies.

Half a Decade of ALMA: Cosmic Dawns Transformed
Program Schedule

Friday, September 23, 2016

Nearby Galaxies: Starbursts & Super Star Clusters (Chair: Amanda Kepley)			
11:15 AM	11:45 AM	Kazushi Sakamoto (ASIAA)	Starburst and Super Star Clusters with ALMA
11:45 AM	12:00 PM	Kazimierz Sliwa (MPIA)	A Tale of Woe for 13CO in Luminous Infrared Galaxies
12:00 PM	12:15 PM	Kelsey Johnson (Uva)	The Relationship Between Super Star Clusters and Molecular Gas
12:15 PM	12:30 PM	Ryo Ando (University of Tokyo)	Five Parsec View of the Diverse Starburst Activities in the Heart of NGC253
12:30 PM	12:45 PM	Poster Flash	
12:45 PM	2:15 PM	Lunch	

Kazushi Sakamoto (ASIAA)

Starburst and Super Star Clusters with ALMA

As of 2016 August 1st, 87 refereed papers from ALMA contain a term starburst, super star cluster, or their variants (SSC, YMC, etc.) in their title, abstract, or keywords. They comprise slightly above 20% of all ALMA publications, indicating the importance of these subjects. Concentrating on starburst and SSCs in nearby galaxies (z<1), I will try to describe the current status of ALMA research on these subjects, open questions, and some possible future directions.

Kazimierz Sliwa (Max Planck Institute for Astronomy)

Christine Wilson (McMaster University)

A Tale of Woe for ^{13}CO in Luminous Infrared Galaxies

Major mergers such as Luminous Infrared Galaxies (LIRGs) are extremely bright in ^{12}CO; however, to get a better understanding of the molecular gas physical conditions, an optically thin tracer such as ^{13}CO is required. Unfortunately, ^{13}CO is unusually weak relative to ^{12}CO (>20 times weaker) in LIRGs which made observations difficult. Now with ALMA, these observations are more routine. We present new ALMA observations of ^{13}CO (and C^{18}O) for four major mergers: VV 114, Arp 240, NGC 2623 and the second closest ULIRG, IRAS 13120-5453 (nickednamed "The Yo-Yo"). In addition to the four sources, we analyzed three other major mergers and we find that an enhanced abundance of ^{12}CO to ^{13}CO ([^{12}CO]/[^{13}CO] ¿90) is the most likely explanation for the advanced mergers. For relatively younger mergers, we find the most likely [^{12}CO]/[^{13}CO] value to be similar to the value near the Galactic center (30). We suggest that stellar nucleosynthesis the culprit in the enhanced abundance value in advanced. This is evident in the Yo-Yo, as a hole is observed in ^{13}CO emission but not in ^{12}CO and C^{18}O.

Kelsey Johnson (UVa)

The Relationship Between Super Star Clusters and Molecular Gas

Observationally constraining the physical conditions that give rise to massive star clusters has been a long-standing challenge. Now with the ALMA Observatory, we can probe the birth environments of massive clusters in a variety of galaxies with sufficient angular resolution. ALMA observations enable an assessment of the molecular cloud chemical abundances in the regions surrounding super star clusters. For example, based on our ALMA observations of Henize 2-10, molecular clouds associated with existing super star clusters are strongly correlated with HCO+ emission, but appear to have relatively low ratio of CO/HCO+ emission compared to other clouds, indicating that the super star clusters are impacting the molecular abundances in their vicinity. Thus, these line ratios could potentially provide a mechanism for identifying newly formed massive clusters.

Ryo Ando (The University of Tokyo)

Kotaro Kohno (The University of Tokyo)
Koichiro Nakanishi (National Astronomical Observatory of Japan)

Five Parsec View of the Diverse Starburst Activities in the Heart of NGC253

We perform ALMA Band 7 (850 μm) observation of the nearby starburst galaxy NGC253 with unprecedentedly high spatial resolution, and its nuclear starburst is resolved into 10 pc scale star-forming regions having markedly diverse nature. The achieved spatial resolution is 0".3 (corresponding to 5 pc), which is five times higher than that of previous ALMA observations. By virtue of it, we resolve the central 200 pc region of NGC253 into eight dust-obscured star-forming regions for the first time. These regions appear to be aligned in two parallel ridges, while they have been mixed up and indistinguishable even in previous ALMA studies. In each region, we detect various kinds of molecular lines such as H_3O^+, H_2CO, HNCO, and H_2CS. Molecular line properties, such as line intensity ratios, drastically vary from region to region, even though they are apart just by $\sim$ 10 pc. Unexpectedly, the distribution of vibrationally excited line of HNC ($J = 4-3, v_2 = 1f$) and hydrogen recombination line H26α strikingly differ, and their relative intensity ratio has a large variance, ranging from 0.1 to 8. Furthermore, several star-forming regions in NGC253 exhibit prominent chemical features, such as the enhancement of HNC and the suppression of SO, in comparison with Galactic star-forming regions. These diverse star-forming activities in the midst of NGC253 could be attributed to the individualities of each 10 pc scale region, such as evolutionary stages of starbursts and dominant radiative heating sources. In terms of the latter factor, there suggested to be not only typical HII regions irradiated by large number of massive stars, but also a star-forming region dominantly heated by an O-star deficient cluster. High resolution observation with ALMA reveals the picture that the heart of the prototypical starburst galaxy NGC253 consists of various types of star-forming regions, which cannot be explained just as the summation of their Galactic analogues.

Half a Decade of ALMA: Cosmic Dawns Transformed
Program Schedule

Friday, September 23, 2016

Galactic Centers (<1 kpc): Star Formation, AGN, Black Holes & ULIRGs (Chair: Daisuke Iono)			
2:15 PM	2:45 PM	Masatoshi Imanishi (NAOJ)	ALMA Molecular Line Observations of the Nuclei of Ultraluminous Infrared Galaxies and Optical Seyfert Galaxies
2:45 PM	3:00 PM	Masato Tsuboi (ISAS)	ALMA View of the Galactic Center Mini-Spiral
3:00 PM	3:15 PM	Alvaro Sanchez-Monge (University of Cologne)	An ALMA View of SgrB2: Continuum Characterization and Spectral Line Survey
3:15 PM	3:30 PM	Akio Taniguchi (University of Tokyo)	ALMA Study of the Shocked Gas Around the Nucleus of NGC 1068 By the Observations of Multi-transition SiO Lines
3:30 PM	3:45 PM	Loreto Barcos-Munoz (ALMA)	ALMA's View of the Arp 220 Disks From New Extended Configuration Observations of Dense Gas Tracers
3:45 PM	4:00 PM	Aaron Barth (UC Irvine)	Measuring Black Hole Masses in Early-Type Galaxies with ALMA
4:00 PM	4:30 PM	Break / Poster Viewing	
4:30 PM	5:30 PM	Anneila Sargent (Caltech)	Summary and Final Remarks
5:30 PM		Closing Cocktails in Stir (Cash Bar)	

Masa Imanishi (National Astronomical Observatory of Japan)

ALMA Molecular Line Observations of the Nuclei of Ultraluminous Infrared Galaxies and Optical Seyfert Galaxies

We present our own and related recent results of ALMA molecular line observations of the nuclear regions of ultraluminous infrared galaxies (ULIRGs) and optical Seyfert galaxies. Thanks to the high sensitivity of ALMA, we can observe multiple molecular emission lines for ULIRGs, and investigate their hidden elusive energy sources, based on molecular line flux ratios. We have obtained an indication that our ALMA (sub)millimeter molecular line observations may be sensitive to extremely deeply buried AGNs which were missed with conventional infrared and X-ray spectroscopic methods, due to reduced effects of dust extinction in the (sub)millimeter wavelength range. Next, thanks to ALMAś high spatial resolution, we were able to observationally investigate the properties of the putative compact dusty molecular torus around a central AGN engine. I will review exciting ALMA results in these topics.

Masato Tsuboi (Institute of Space and Astronautical Science)

Yoshimi Kitamura (Institute of Space and Astronautical Science)
Kenta Uehara (The University of Tokyo)
Atsushi Miyazaki (Japan Space Forum)
Ryosuke Miyawaki (Oberlin University)
Takahiro Tsutsumi (NRAO)

ALMA View of the Galactic Center Mini-Spiral

We have performed the observation of the "Galactic Center Mini-spiral(GCMS)ïn H42α recombination line as a part of the first large-scale mosaic observation in the Sagittarius A complex using Atacama Millimeter/sub-millimeter Array (ALMA). We made clear the kinematics of ionized gas streamers of the GCMS. Especially we found that the streamer corresponding to the Bar of the GCMS has a Keplerian orbit with high eccentricity which is independent from Keplerian orbits of other substructures of the GCMS. The periastron is probably located within the Bondi accretion radius derived from X-ray observation. We estimated the LTE electron temperature in the substructures of the GCMS from the line-continuum flux density ratio. The electron temperatures are in the range of $T_{\rm e}^* = 6 - 13 \times 10^3$ K. We confirmed the previously claimed tendency that the electron temperatures increase according as approaching to Sgr A*. We also found that the electron temperature at the positive velocity end of the Bar is twice higher than that at the negative velocity end.

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An ALMA View of SgrB2: Continuum Characterization and Spectral Line Survey

The giant molecular cloud complex SgrB2 is the most massive region with ongoing star formation in the Galaxy. It is located at a projected distance of about 100 pc along the plane to the Galactic center and at 8.5 kpc from the Sun. The whole complex contains a total gas mass of $10^7\,M_\odot$, with the main sites of active star formation corresponding to the hot molecular cores SgrB2-N and SgrB2-M that are located at the center of the complex. They contain more than 50 high-mass stars with spectral types ranging from O5 to B0, and constitute one of the best laboratories for the search of new chemical species in the Universe.

We have conducted a high-spatial resolution, spectral line survey of the two hot cores SgrB2-M and SgrB2-N with ALMA. Despite their similar masses ($3\text{-}7\text{x}10^4\,M_\odot$) and luminosities ($1\text{-}6\times10^5\,L_\odot$), the ALMA observations reveal clear differences between the two objects. A study of the continuum emission reveals a clearly fragmented structure in SgrB2-M, while SgrB2-N remains monolithic and contains one of the, probably, most massive, not fragmented condensations in the Galaxy. Furthermore, SgrB2-M and SgrB2-N have a very different chemical composition, with M being rich in sulphur-bearing molecules and N in organics. The observational results are compared with 3D radiative transfer models.

Here we present the first results of the ALMA project as well as some new tools to characterise the continuum emission in line-rich sources, as well as the spectral line properties.

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ALMA Study of the Shocked Gas Property Around the Nucleus of Seyfert 2 Galaxy NGC 1068 By the Observations of Multi-transition SiO Lines

Investigating the molecular gas composition in interstellar medium (ISM) by observations of molecular emission lines is a unique diagnostic tool for nuclear activity in galaxies with active galactic nucleus (AGN) and/or starburst (SB). It has been proposed that high HCN/HCO^+ and/or HCN/CO ratios are characteristic of AGNs rather than SB (Usero et al. 2004; Krips et al. 2008; Kohno et al. 2008; Izumi et al. 2016a), however the explanation of such HCN enhancement is still far from well understood. There are several possible origins such as X-ray dominated region (XDR) formed by the strong X-ray emission and mechanical heating (MH) caused by the shock of jet and/or outflow from AGNs (Izumi et al. 2016a). The observations at higher sensitivity and spatial resolution are still necessary for the confirmation of such origins.

In the ALMA Cycle 2 program, we therefore investigated the spatially resolved ($\sim$ 40 pc) shocked gas property in the gas disk around the nucleus (circumnuclear disk; CND) of nearby Seyfert 2 galaxy NGC 1068. We obtained SiO $J = 2-1$, $3-2$, $5-4$ and $6-5$, and also obtained other molecular lines such as CS $J = 2-1$, $J = 5-4$, $H^{13}CN$ $J = 1-0$, and $H^{13}CO^+$ $J = 1-0$ as references. SiO, one of the shocked gas tracers, seems to be unevenly distributed at the eastern knot (hereafter E-knot) in the CND and has an elongated shape (especially visible in SiO $J = 3-2$, which has the highest spatial resolution of $\sim$ 30 pc), which partially overlaps with the edge of the ionized outflow cone traced by [Fe II] (Barbosa et al. 2014).

For revealing the origin of SiO, we conducted an LTE analysis by the rotational (Boltzmann) diagrams of SiO and CS at the E-knot. We found that SiO has two different gas components: one is composed of lower-J SiO lines ($J = 2-1$, $3-2$) which is cooler ($T_{\rm rot} = 5.4$ K) and more abundant ($N = 2.6 \times 10^{14}$ cm^{-2}), and the other is composed of higher-J SiO lines ($J = 5-4$, $6-5$) which is warmer ($T_{\rm rot} = 30.2$ K) and less abundant ($N = 5.1 \times 10^{13}$ cm^{-2}). As the sum of these components, the fractional abundance of SiO over CS is enhanced at the E-knot of NGC 1068 ([SiO]/[CS] ~ 0.3) compared to those of typical starburst galaxies and ULIRGs ([SiO]/[CS] < 0.1; Aladro et al. 2015). We also found high $H^{13}CN/H^{13}CO^+$ and SiO/$H^{13}CO^+$ integrated intensity ratios at the E-knot (both greater than unity), which suggests some energy input from the AGN to the ISM in the CND.

Taking these evidences together, it is suggested that SiO is originated from the strongly shocked gas in the CND interacting with the outflow from the AGN, which may reflect the feedback of AGN activity onto the ISM through the shock. We further speculate that the two gas components of SiO mentioned above may reflect the different time phases of the shocked process: while the lower-J SiO arises from more abundant and cooler post-shocked gas ($\sim 10^{3-4}$ yr), the higher-J SiO arises from less abundant but hot just-after-shocked gas ($\sim 10^{1-2}$ yr). This is what is expected from the outflow model, where there is some chemical delay to the conversion of Si into SiO in C-type shock waves (Gusdorf et al. 2008a).

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ALMA's View of the Arp 220 Disks From New Extended Configuration Observations of Dense Gas Tracers

We present new continuum and line observations of the proto-typical (and closest) ULIRG, Arp 220. Physically, Arp 220 is often invoked as the most extreme local star-forming system and often used as a template for starbursts at high redshift. It is evident that understanding its ISM conditions is crucial for star formation and galaxy evolution. Using the most extended configuration available at Cycle 3, we achieve resolution of 0.08≐ 30 pc targeting the mm-wave continuum and the high critical density tracers HCN, HCO+, their isotopologues, and the shock tracer SiO. This resolution is sufficient to resolve both disks and ideal to compare to our 33 GHz VLA continuum images at the same resolution (Barcos-Muoz et al. 2015). We combine the two data sets to construct resolved spectral energy distributions maps of the two nuclear disks hosting the main activity in the galaxy. From their SED, the two nuclei show distinct behaviors, with the west showing a rising spectral index through the 90 GHz regime, indicative of opaque free-free or dust emission. The eastern nucleus shows a flatter spectrum implying thermal emission is still an important component at this high frequencies. Using the line emission, which traces the high density gas pervasive in the system, we present gas and kinematic profiles for both disks. For the well-resolved eastern nucleus, we use these data to compare the structure of the disk to predictions for models of self-regulated star formation (including the Eddington limited model of Thompson et al. 2005), which pivot on knowing the disk mass, gas mass fraction, and local velocity dispersion, all available in a resolved way for the first time from ALMA. Finally, we present the integrated 8 GHz-wide mm-wave spectrum of each nucleus near 90 GHz, highlighting potential differences in the ISM conditions between the two and shedding light on the nature of their powering source.

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Measuring Black Hole Masses in Early-Type Galaxies with ALMA

Taking an accurate census of black hole masses in nearby galaxies is essential to understanding the growth and evolutionary history of supermassive black holes over cosmic time. ALMA now offers a powerful new method for carrying out precise measurements of black hole masses, by mapping and modeling the kinematics of cold molecular gas disks in galaxy nuclei. In Cycle 2, we initiated an ALMA program to determine black hole masses in nearby elliptical and lenticular galaxies. We start by using HST imaging data to select galaxies that contain arcsecond-scale circumnuclear dust disks. Initial ALMA CO(2-1) observations at 0.3 arcsec resolution are then used to search for gas orbiting within the black holeś gravitational sphere of influence. Five galaxies from our Cycle 2 program show rotation-dominated CO kinematics, with CO emission tracing the same structure as the dust disks. NGC 1332 is the first of our dust-disk targets to show evidence of central high-velocity rotation, and we will describe new Cycle 3 observations of NGC 1332 at 0.044 arcsec resolution and dynamical modeling of the data. This is the first ALMA observation that has resolved the gravitational sphere of influence of a supermassive black hole, and the data allow us to measure the black hole mass in NGC 1332 to 10% precision. We will describe the dynamical modeling methodology and results, emphasizing the critical importance of resolving the black hole's sphere of influence in order to minimize systematic uncertainty and determine black hole masses accurately, and discuss the prospects for ALMA to make major contributions to the study of black hole demographics.