Evolution of Galaxies and Large Scale Structure at High Redshift

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I present extensive mapping and analysis of large scale structure in the COSMOS survey field with a detailed comparison with the Millennium simulation. The properties of the galaxies – mass, SFR and SED are found to be strongly correlated with the large scale structure environment. Initial results from our ALMA cycle0 projects will also be presented. One project measures the dust continuum in a sample of 60 galaxies to enable estimates of the ISM contents and the evolution of the ISM mass with redshift. The 2nd project provides Band 7 & 9 observation of HCN and H26 Alpha at 0.25 - 0.5 arcsec resolution for Arp 220 and NGC 6240. These low redshift ULIRG galaxies are probably excewllent analogs for understanding evolution in the early universe.

21 cm Cosmology: a Progress Report

TZU-CHING CHANG[1]

[1] ASIAA

Hydrogen is the most abundant baryonic element in the universe, and in its neutral phase (HI) radiates at a wavelength of 21-cm. The redshifted 21-cm line can potentially probe a significant fraction of the universe, shedding light on astrophysical processes and fundamental physics. Recently, two observational redshift windows have emerged in the "intensity mapping" regime: around the epoch of cosmic reionization (EoR), 21-cm line directly traces the distribution and evolution of neutral/ionized regions, probing the reionization history; at redshifts around unity, 21-cm follows large-scale structure and can be used to measure the Baryon Acoustic Oscillation signature, constraining the properties of dark energy. I will describe our current efforts in these two fields, utilizing the Giant Metrewave Radio Telescope (the GMRT-EoR project) and the Green Bank Telescope (GBT), aiming to measure the 21-cm power spectrum at redshifts around nine and one, respectively. Initial results are encouraging.

Detecting Gravitational Waves (and doing other cool physics) with Millisecond Pulsars

SCOTT RANSOM[1]

[1] National Radio Astronomy Observatory

The first millisecond pulsar was discovered in 1982. Since that time their use as highly-accurate celestial clocks has improved continually, so that they are now regularly used to measure a variety of general relativistic effects and probe a variety of topics in basic physics, such as the equation of state of matter at supra-nuclear densities. One of their most exciting uses though, is the current North American (NANOGrav) and international (the International Pulsar Timing Array) efforts to directly detect nanohertz frequency gravitational waves, most likely originating from the ensemble of supermassive black hole binaries scattered throughout the universe. In this talk I'll describe how we are using an ensemble of pulsars to try to make such a measurement, how we could make a detection within the next 5-10 years, and how we get a wide variety of very interesting secondary science from the pulsars in the meantime.

ALMA before re-ionization.

A. BLAIN[1]

[1] University of Leicester, UK.

ALMA is a genuinely transformational facility. Its precision and sensitivity enable quite new things to be done. I will describe the way in which ALMA can be used to investigate the first light and the collapse of the first objects, by combining its great power with the additional tools of gravitational lensing to probe to distances at which lower-resolution instruments are blinded by confusion, and facilities operating at shorter wavelengths are unable to reach. The collapse and processing of metal-free gas, the debris of the first stars, and the fueling of the first blackholes are all accessible to ambitious but practical ALMA observations, using a range of signatures from molecular hydrogen, the Sunyaev–Zel'dovich effect, and conventional molecular tracers. There are several synergies with *JWST*, ELTs and SKA.

The ISM in Nearby Galaxies

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Remarkable progress has been achieved in recent years in quantifying the molecular, atomic and dusty properties of the interstellar medium (ISM) and their relation to star formation in nearby galaxies. This is mainly thanks to a number of dedicated multi-wavelength surveys (infrared [Spitzer, Herschel], optical, UV [Galex], CO [e.g., IRAM], HI [VLA]) that targeted a sample of nearby galaxies. I will highlight some of the recent results emererging from these efforts and review our current understanding of the ISM properties, with a focus on the molecular gas phase, and its relation to star formation in nearby galaxies. I will close by presenting some new high-J CO observations of nearby galaxies from Herschel and some of the early results that ALMA provided in cycle 0 observations.

Observations of high redshift galaxies: from Nobeyama to ALMA

K. KOHNO[1]

[1] The University of Tokyo

Observing facilities operated by Nobeyama Radio Observatory (NRO), including Nobeyama 45 m telescope, Nobeyama Millimeter Array (NMA), and Atacama Submillimeter Telescope Experiment (ASTE)[1], have been played important roles on the study of interstellar medium in high redshift galaxies (e.g., Kawabe et al. 1992; Ohta et al. 1996; Tamura et al. 2009).

In this talk, we will focus on 3 recent follow up studies of confusion-limited deep 1.1 mm surveys conducted with AzTEC camera (Wilson et al. 2008) mounted on ASTE 10 m dish (Ezawa et al. 2008). Emphasis will be also placed on the roles of ALMA on these studies.

1. Dust-obscured star formation in Lyα brobs and emitters in the proto-cluster SSA 22 around $z \sim 3.1$ (Tamura et al. 2012). Relation among submillimeter galaxies, large scale structures (Tamura et al. 2009; Hatsukade et al. 2012), and quasar formation within them (Tamura et al. 2010), will also be discussed.

2. Dust-obscured star formation in the mm/submm bright Hα emitters in the proto-cluster at $z \sim 2.5$ around the radio galaxy 4C23.56 (Suzuki et al. 2012). PdBI imaging studies of bright submillimeter galaxies in this region will also be presented.

3. Ultra-bright mm-selected galaxies and their follow up observations (Ikarashi et al. 2011; Takekoshi et al. 2012). TZ100/SAM45, a newly developed 3-mm band redshift machine for NRO 45 m telescope (Nakajima et al. 2012) will be introduced, along with the early science verification results (Iono et al. 2012).

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[1]ASTE is now operated by Chile Observatory, NAOJ, from FY2012

Detailed Studies of Quasars and their Host Galaxies back to the First Billion Years of Cosmic Time

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Detailed studies of the molecular gas phase in the host galaxies of the highest redshift quasars are important for our understanding of the formation and evolution of quasars and their bulges, since it is the molecular gas out of which stars form. I will highlight a number of key results from our recent studies with the IRAM Interferometer (PdBI), the recently upgraded Jansky Very Large Array (JVLA), and the Atacama Large Millimeter/submillimeter Array (ALMA), which is nearing completion in the coming months. These investigations have substantially improved our understanding of the mass, excitation, composition, morphology, dynamical structure, and environments of the molecular and cold neutral interstellar medium in quasar host galaxies out to $z>6$. Our observations and analysis uniquely constrain the properties of the molecular environments in some of the most active and most massive among the most distant galaxies currently observable, and thus, provide an important foundation for future studies with CCAT and full ALMA.

High-z Galaxies with ALMA

F. COMBES[1]

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ALMA opens a new window on primordial galaxies, and on galaxy formation, up to the reionisation epoch. The detection of dust emission at z=5-10 is as easy than at z=1 due to the negative K-correction, and the high gas excitation in denser star forming regions allows easy detection of high-J CO lines. At least 100 times more sources than with present instruments could be discovered, so that more normal galaxies, with lower luminosities than huge starbursts and quasars will be surveyed. The high spatial resolution will suppress the confusion, which affects single dish bolometer surveys.

The broad-band receivers will allow to determine with CO lines the redshift of objects too obscured to be seen in the optical. With the present instrumentation, only the most masssive and gas rich objects have been detected in CO at high z, most of them being ultra-luminous starbursts with an extremely high star formation efficiency, or highly amplified by gravitational lenses. However, selection biases are omnipresent in this domain, and ALMA will statistically clarify the evolution of star formation efficiency, being fully complementary to JWST and ELTs.

FIR-submm Metallicity Diagnostics for High-z Galaxies

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The chemical properties of galaxies provide important information to constrain galaxy evolutionary scenarios. However, widely-used metallicity diagnostics based on rest-frame optical emission lines are not usable for heavily dust-enshrouded galaxies such as sub-millimeter galaxies (SMGs) and ultraluminous infrared galaxies (ULIRGs) due to serious dust reddening effects. The rest-frame optical emission lines are particularly useless at $z > 3.5$, where those emission lines shift out from the near-infrared atmospheric windows.

Here we report new diagnostics of the gas metallicity based on infrared fine-structure emission lines, which are nearly unaffected by dust extinction even the most obscured systems (Nagao et al. 2011). We then apply our approach to a strongly [CII]-emitting SMG, LESS J033229.4-275619 at z=4.76, whose [NII]205 emission is detected through our ALMA cycle 0 observation. The observed [NII]/[CII] flux ratio and photoionization models suggest that the metallicity in this SMG is consistent with the solar metallicity, implying the chemical evolution has progressed very rapidly in this system even at such high-z (Nagao et al. 2012).

A redshift survey of strongly lensed submm galaxies based on molecular emission lines observed with ALMA

A. Weiss[1], C. de Breuck[2], J. Vieira[3], D. Marrone[4], Y. Hezaveh,[5] S. Chapman[6], & the SPT-SMG team

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[2] ESO, Germany,
[3] Caltech, USA,
[4] Steward Observatory, USA
[5] McGill Uni., USA
[6] Cambridge, UK

Recent ground and space-based multi wavelength (sub)millimeter surveys covering hundreds of square degrees have discovered a large number of strongly lensed, ultra-bright submm galaxies (SMGs). The largest of these, by nearly an order of magnitude at present, is the South Pole Telescope (SPT) survey, which covers 2500 deg^2. Its 1.4 mm detection wavelength ensures a uniform source selection function across $z = 1 - 8$ and makes this survey a perfect repository to study the high redshift tail of the SMGs population. In my talk I will present the results of a blind redshift survey in the 3 mm transmission window in a sample of SPT sources using ALMA. This survey is a large success with 45 detected line features which we identify as redshifted emission lines of ^{12}CO, ^{13}CO, C I, H_2O and H_2O^+. At least 60% of our sample is found to be at $z > 3$ with two sources at $z = 5.7$ placing them among the most distant SMGs known today. Our study suggests that previous SMG redshift survey, which are almost exclusively based on radio identified sources, may have missed a large fraction ($\geq 60\%$) of the SMG population as it resides at redshifts $z > 3$. An alternative interpretation, however, is that the SMG population undergoes a size evolution with decreasing submm emission regions for increasing redshifts. In this case the observed higher redshifts could be a bias due to gravitational lensing.

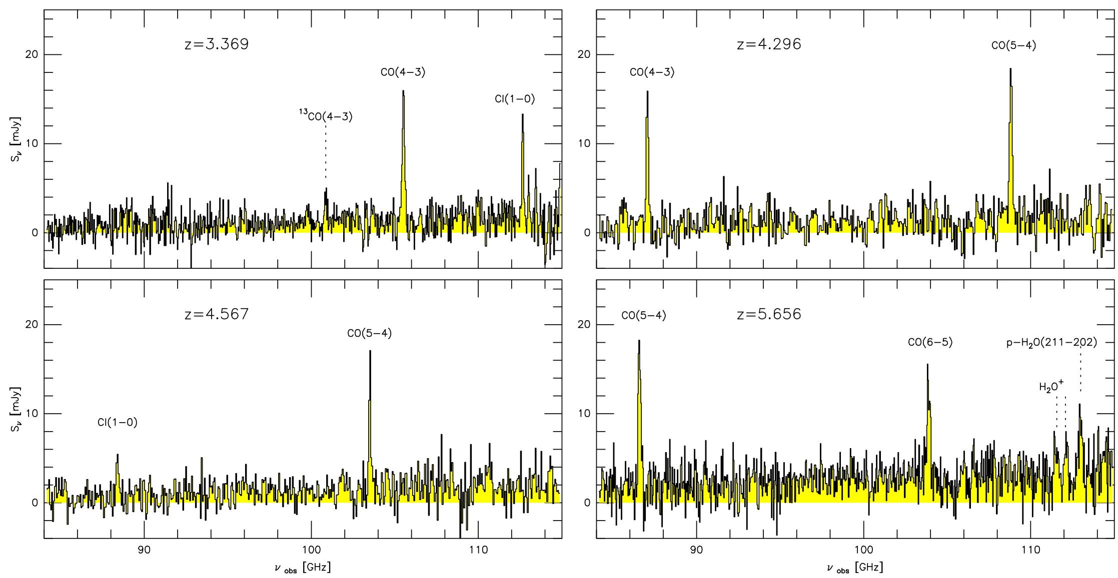


Figure 1: Examples of the ALMA 3 mm spectra obtain by us in cycle 0. The spectra demonstrates the richness of our survey with detections of ^{12}CO, ^{13}CO, C I, H_2O and H_2O^+.

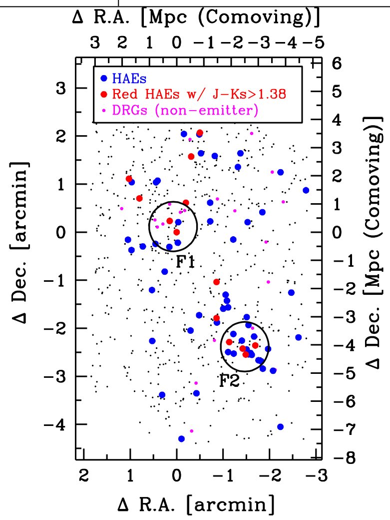
From Mahalo-Subaru to Gracias-ALMA: Resolving Galaxy Formation at Its Peak Epoch

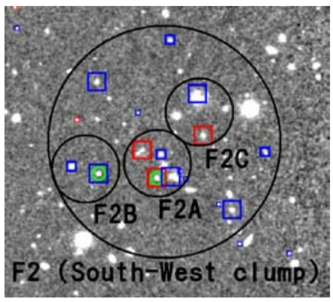
T. Kodama[1], M. Hayashi[2], Y. Koyama[2], K. Tadaki[2], and Gracias-ALMA team
[1] Subaru Telescope [2] Optical-NIR division, NAOJ

The redshift interval of 1.5–2.5 is the critical era for galaxy evolution when the star forming and AGN activities are both highest. Also, galaxy formation and subsequent evolution should be dependent on environment given the clear habitat segregation of different types of galaxies seen today. It is essential therefore to systematically search for star forming galaxies over this critical epoch and across different environments, and investigate their physical properties in detail. For this purpose, we design a fully coordinated program between Subaru and ALMA. The Mahalo-Subaru project has been mapping out star-forming galaxies (eg. Hα emitters) at $1.5 \leq z \leq 2.5$ across various environments by employing the unique set of custom-made narrow-band filters and wide-field cameras. We have discovered large scale structures in and around proto-clusters, complex clumpy structures of individual galaxies, and clear environmental dependence of galaxy properties such as stellar mass and star formation rate. We now propose the Gracias-ALMA project which aims to observe CO lines and dust continua of the star-forming galaxies sampled by Mahalo-Subaru, with great spatial resolution and high sensitivity. We will resolve and scrutinize the physical states and the mode of star formation within galaxies, and identify the physical processes that governs star-forming activities as a function of time and environment. In this talk, we will present the highlights of the Mahalo-Subaru project and describe the prospects for the Gracias-ALMA project.

(Table) The list of Gracias-ALMA core targets. 6 proto-clusters and a general field (SXDF-UDS-CANDELS) are selected from the sample of Mahalo-Subaru narrow-band emitter survey.

		Mahalo-Subaru				**Gracias-ALMA**	
target	z	line	μm	NB-filter	Camera	Continuum	Line@GHz(band)
2215–1738	1.46	[OII]	0.916	NB912	S-Cam	B7,9	CO(2-1)@94 (B3)
0332–2742	1.61	[OII]	0.973	NB973	S-Cam	B7,9	CO(2-1)@89 (B3)
0218.3–0510	1.62	[OII]	0.977	NB973	S-Cam	B7,9	CO(2-1)@88 (B3)
1138–262	2.16	Hα	2.071	NB2071	MOIRCS	B6,7,9	CO(3-2)@110 (B3)
4C23.56	2.48	Hα	2.286	NB2288	MOIRCS	B6,7,9	CO(3-2)@99 (B3)
1558–003	2.53	Hα	2.315	NB2315	MOIRCS	B6,7,9	CO(3-2)@98 (B3)
SXDF-UDS	2.19	Hα	2.094	NB2095	MOIRCS	B6,7,9	CO(3-2)@108 (B3)
-CANDELS	2.53	Hα	2.315	NB2315	MOIRCS	B7,6,9	CO(3-2)@98 (B3)





(left) A 2-D map of the USS1558 proto-cluster at z=2.53, based on Mahalo-Subaru. Red and blue circles indicate red and blue Hα emitters, respectively, and purple filled circles show DRGs (distant red galaxies) without detectable emiss ion. This result is published in Hayashi et al. (2012, ApJ, in press). **(right)** A close-up view of F2. Large circles show the field of view of Band-3 (62″), and the small circles show that of Band-7 (18″). Red and blue squares indicate the red and blue Hα emitters, respectively. Note its extremely high density of strong emitters. Sizes of the squares correspond to 3 classes in star formation rates, separated at 60 and 100 $M_\odot$/yr.

Giant Molecular Clouds in M33 and M83

N. Kuno[1]

[1] Nobeyama Radio Observatory, NAOJ

I will review the results of the NRO legacy project ”M33 All Disk Survey of Giant Molecular Clouds (NRO-MAGiC)”. We mapped the whole disk of M33 in CO(1-0) with NRO 45-m telescope and a large fraction of the disk in CO(3-2) with ASTE 10-m telescope. Furthermore, we obtained 1.1 mm continuum map of M33 with ASTE. Main results of the project are summarized as the followings.

(1) Transition from atomic gas to molecular gas (Tosaki et al. 2011)

We found that the efficiency of molecular gas formation is higher in the inner region (R $<$ 2kpc) than the outer region. Since there is a sharp increase of metallicity in M33, the main cause may be the radial variation of metallicity.

(2) Evolution of Giant Molecular Clouds (Onodera et al. 2012, Miura et al. 2012)

We investigated the relation between CO(3-2)/CO(1-0) ratio and star formation activity. We also investigated the relation between the ratio and GMC mass. As a result, we found that the GMCs with high activity of star formation tend to have higher CO(3-2)/CO(1-0) ratio. Furthermore, the ratio of more massive GMCs tend to be higher. These results imply that the fraction of dense and warm molecular gas increases with star forming activity along with the evolution of GMCs. The results also imply that the fraction of dense gas increases with GMC mass. On the other hand, the GMCs are classified into 4 classes based on the star forming activity. Differences of some properties of the GMCs in those classes are seen.

(3) Relation between molecular gas and star formation (Onodera et al. 2010)

We tested to what scale the Kennicutt-Schmidt law is valid by changing spatial resolution from 1 kpc to 80 pc. We found that the correlation becomes looser with higher resolution and that the K-S law becomes invalid in GMC scale ($\sim$ 80 pc). In this scale we can see the variation of evolutionary stage of the GMCs. It may be the cause of the breakdown of the K-S law in GMC scale.

(4) Temperature variation of cold dust (Komugi et al. 2011)

Using our 1.1 mm data and the Spitzer data, we found a smooth temperature gradient in the Disk of M33. The temperature decreases from the inner to outer region.

Based on the observations of GMCs in nearby galaxies such as M33, IC342 (Hirota et al. 2011) and M83 (Muraoka et al. 2009), we planed a survey of GMCs in M83 with ALMA and the proposal for Cycle 0 was accepted (PI. Hirota). If the data of ALMA cycle 0 is delivered before the conference, I will present the results also.

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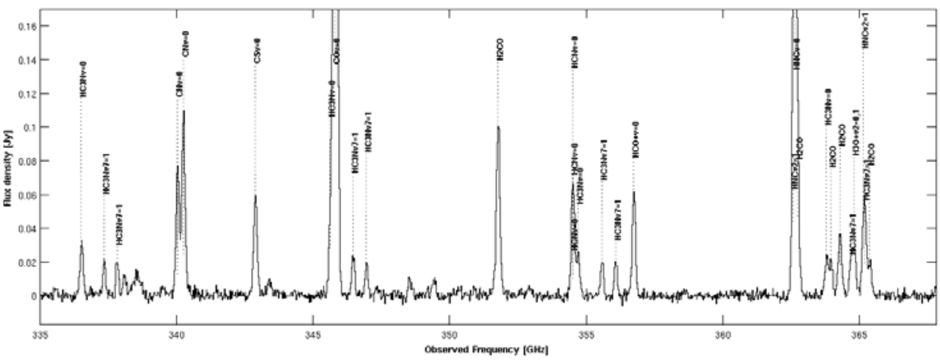
Molecules and Chemistry as Tracers of Galaxy Evolution

S. Aalto[1]

[1] Department of Earth and Space Sciences, Chalmers university of Technology, Sweden.

Intense bursts of star formation and feeding of SMBHs occur when collisions of gas-rich galaxies funnel massive amounts of molecular gas and dust into nuclei of luminous and ultraluminous infrared galaxies (LIRGs/ULIRGs). Much of the ongoing research into initial phases of galaxy building also focuses on the pre-ULIRG phases of super-starbursts, QSOs and assembly of galaxies via major mergers. These phases parallel conditions in lower luminosity starbursts and thus studies of nearby and rapidly evolving LIRGS, ULIRGS, and AGN, are essential both for defining the evolution of present day galaxies and sorting out key astrophysical processes in their more distant predecessors.

I will present methods of studying galaxy evolution through using molecules as observational tools exploiting their ability to trace dynamical, chemical and physical conditions. I will discuss new techniques where the most compact obscured nuclei (CONs), for example, can be studied with radiatively excited molecular emission getting past the optically thick barrier. Furthermore, key molecules in identifying the nature of buried activity and its evolution will be discussed. Finally, I will present recent results on molecular outflows in a selection of nearby LIRGs and ULIRGs.



Simulated 0.8mm spectrum for the CON LIRG NGC4418, T=85 K. (From our successful ALMA Cycle 0 proposal to carry out a spectral scan of NGC4418 (PI:F.Costagliola)).

Giant Molecular Clouds and Star Formation in Nearby Galaxies

JIN KODA[1]

[1] Stony Brook University

The Nobeyama 45m telescope and millimeter array, as well as other mm and submm telescopes in the world, contributed significantly to our understanding of molecular gas and its evolution in galaxies. ALMA is revolutionizing the study of giant molecular cloud (GMC) evolution in nearby galaxies, by not only detecting, but resolving the internal properties of individual GMCs in spiral galaxies down to the ”Taurus” cloud mass – compared to mere detection of ”Orion”s by the existing telescopes. I will summarize recent results and future prospects on the evolution of molecular gas and star formation in nearby galaxies, with a particular emphasis on GMCs and star formation.

SMA High-Resolution Observations of Molecular Gas in Luminous Infrared Galaxies

D. B. SANDERS[1]

[1] University of Hawaii, Institute for Astronomy.

We report new, high-resolution (0.3-0.5 arcsec) observations with the Smithsonian Sub-millimeter Array (SMA) on Mauna Kea, of 10 luminous and ultra-luminous infrared galaxies, (U)LIRGs, selected from the Great Observatories All-Sky LIRG Survey (GOALS). These data are used to determine the total mass and compactness of the molecular gas distributions, and to search for double nuclei, extended spatial structure (e.g. compact disks, bars, rings) and interesting kinematic features such as high-velocity outflows. We highlight the cases of the clear double nucleus sources, NGC 6240 and Mrk 273 – objects which clearly contain two high luminosity active nuclei (AGN), and discuss the relationship of the AGN activity to the surrounding nuclear starburst.

Reformation of Cold Molecular Disks in Merger Remnants

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[1] Univ. of Tokyo, Japan. [2] NAOJ,Japan. [3] Harvard-Smithsonian CfA, US. [4] UMass, US. [5] Univ. of Arizona, US. [6] Kyoto Univ., Japan. [7] Univ. of Tsukuba, Japan. [8] JAO, Chie.

It has been long predicted from numerical simulations that a major merger of two disk galaxies results in a formation of the spheroid-dominated early-type galaxy. Contrary to this classical scenario of galaxy merger evolution, recent simulations with more realistic gas physics have shown that not all of the major mergers will become an early-type galaxy, but some will reemerge as a disk dominated late-type galaxy.

In order to check this scenario and look for observational evidence of a forming molecular disk in merger remnants, we have investigated the CO data of a sample of merger remnants obtained with single-dish telescopes and interferometers, including the NRO 45-m telescope and ALMA (Cycle 0). Our sample is selected based on K-band morphology suggesting advanced stages of the merger. By investigating the interferometric velocity field and fitting with concentric rings, we found that 14 sources (70%) can be modeled by disk rotation. We thus suggest that molecular disk formation is common at the final stages of mergers. In addition, we found that the CO surface brightness profiles of these sources are roughly distributed as exponential disks. The sizes of the molecular disks R_{80} (radius enclosing 80% of the total CO flux) range from 0.5 to 5.0 kpc, and the spatial extent of the largest molecular disk is comparable to the size of the Milky Way disk.

Molecular gas properties of M100 and ALMA Science Verification

C. Vlahakis[1,2], S. Leon[1,2], G. Bendo[3], D. Garcia[1,2], S. Martin[2], M. Zwaan[4]

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[2] European Southern Observatory, Chile.
[3] UK ALMA Regional Centre Node, UK.
[4] European Southern Observatory, Germany.

I will present an overview of Atacama Large Millimetre/submillimetre Array (ALMA) Science Verification results, and will focus on CO J=1-0 ALMA Science Verification observations of M100, a nearby 'grand-design' barred spiral galaxy in the Virgo cluster. M100 has abundant molecular gas in its centre, long spiral arms dominating its optical disk and has a relatively face-on inclination (i$\sim$30 degrees). Due to its proximity ($\sim$16 Mpc) and relatively face-on inclination, M100 is an ideal target for molecular gas studies, and has been the subject of a number of previous interferometric studies in CO with, for example, the Nobeyama mm-wave Array (Sakamoto et al. 1995, 1999), the IRAM interferometer (Garcia-Burillo et al. 1998), and the Berkeley-Illinois-Maryland Association (BIMA) millimeter interferometer array (Regan et al. 2001, Helfer et al. 2003). We compare the ALMA CO data, at a spatial resolution of $\sim$200 pc, with previously unpublished H I data taken with the Very Large Array (VLA). We describe the integrated intensity maps and compare them to other data from the literature to investigate the variation of the molecular gas, atomic gas and star formation properties. Using the velocity field and velocity dispersion maps we also investigate the gas dynamics.

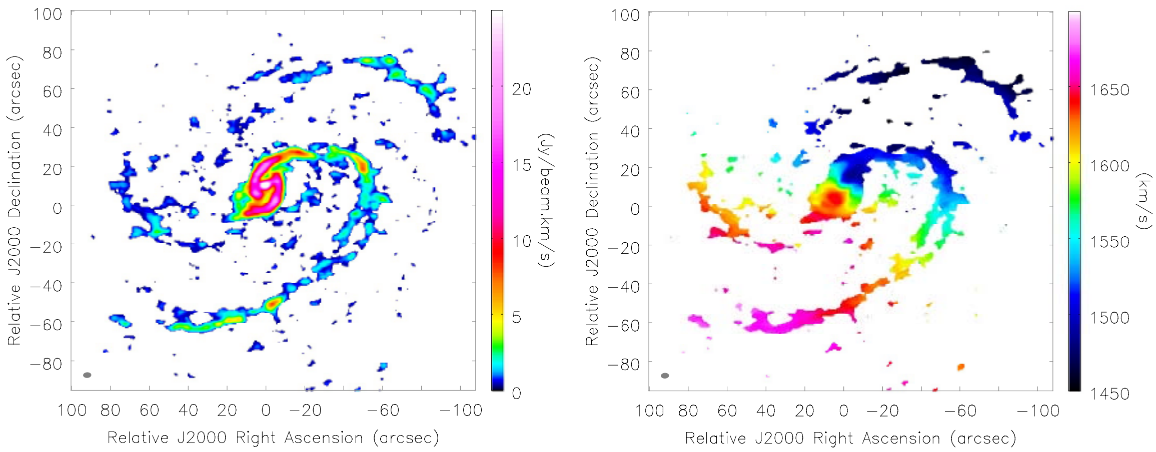

Figure 1: ALMA CO J=1-0 integrated intensity (left) and velocity field (right) images of M100.

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Disentangling the circumnuclear environs of Centaurus A: Gaseous Spiral Arms in a Giant Elliptical Galaxy

D. ESPADA[1]

[1] NAOJ, Japan.

We report the existence of spiral arms in the recently formed gaseous and dusty disk of the closest giant elliptical, NGC 5128 (Centaurus A), using high resolution 12CO(2–1) observations of the central 3 arcmin (3 kpc) obtained with the Submillimeter Array (SMA), and confirmed by ALMA science verification observations. This provides evidence that spiral-like features can develop within ellipticals if enough cold gas exists. The spiral arms extend from the circumnuclear gas at a radius of 200 pc to at least 1 kiloparsec. The general properties of the arms are similar to those in spiral galaxies: they are trailing, the width is $\sim 500 \pm 200$ pc, and the pitch angle is 20 degree. From independent estimates of the time when the HI-rich galaxy merger occurred, we infer that the formation of spiral arms happened on a time scale of less than 10^8 yr. The formation of spiral arms increases the gas density and thus the star formation efficiency in the early stages of the formation of a disk.

Physical properties of molecular clouds in the Magellanic Clouds revealed by observations in multi-transition CO molecular lines

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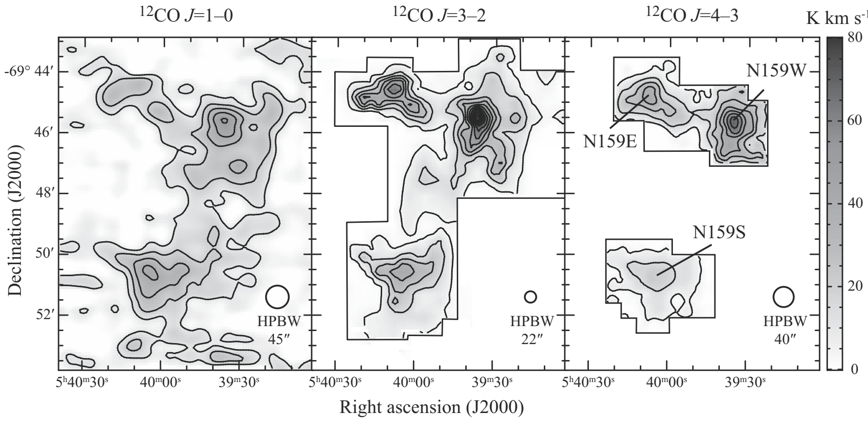
The Magellanic Clouds offer an ideal laboratory to study how the interstellar medium evolves and how stars are formed throughout a galaxy at an unrivaled closeness to us. It is known that young populous clusters like R136 are still being formed, making it possible to study cluster formation and its effects to the surrounding medium as well. We have established a catalog of the molecular clouds through the ^{12}CO $J=$ 1–0 observations by NANTEN, a 4 m telescope at Las Campanas Observatory in Chile (Fukui et al. 2008). This catalog contains about 300 GMCs including those with and without massive star or cluster formation. We find that the molecular clouds are classified into three types according to the associated activities of massive star or cluster formation. If a steady state of massive star and cluster formation is a good approximation, by adopting the time scale of the youngest stellar clusters, 10 Myrs, we roughly estimate a lifetime of a GMC of 20-30 Myrs for those with a mass above the completeness limit, $5 \times 10^5 M_\odot$, in the LMC (Kawamura et al. 2009). We have been extending our observations to higher transition lines of CO in submm by ASTE and NANTEN2 (Minamidani et al. 2008, 2011, Mizuno et al. 2010). More detailed structure and properties of the GMCs are obtained by the Mopra observations. These datasets are combined and compared with LVG calculations to derive the density and temperature of clumps. The derived density and temperature are distributed in wide ranges. We suggest that these differences of clump properties represent an evolutionary sequence of GMCs in terms of density increase leading to star formation. Prospects for ALMA observations will also be presented.



Integrated intensity map of ^{12}CO J =1–0 (left), ^{12}CO J =3–2 (middle) and ^{12}CO J =4–3 (right) of one of the most active on-going massive star forming regions, N159 as an example of multi-transition line observations. Lowest contouar levels are 3σ (11, 5, 5 K km s^{-1} for ^{12}CO J =1–0, ^{12}CO J =3–2 and ^{12}CO J =4–3, respectively) level of each observation and increment is 10 K km s^{-1} (Mizuno et al. 2010).

The ASTE Galactic Center Survey in the 350 and 500 GHz Bands

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The innermost 200 pc region of our Galaxy, or the Central Molecular Zone (CMZ), is the largest molecular gas reservoir in our Galaxy, containing nearly 10 % of the Galactic molecular mass. The region shows burst-like cluster formation activities in the Sgr A, B and C giant molecular cloud (GMC) complexes. To understand the cluster formation in the CMZ and its history is one of the central issues in the study of the Galactic center. The cluster formation is also potentially related to the formation and evolution of the central supermassive black hole (SMBH), since SMBHs may form from intermediate-mass black holes (IMBHs) which are born in supermassive clusters.

The ASTE Galactic Center key-science project started in 2005, in order to investigate the present and past cluster formation in the CMZ with large scale surveys in the 350 and 500 GHz bands. The most important result from the 350 GHz CO J=3–2 and HCN J=4–3 observations is discovery of the 'high velocity compact clouds (HVCCs)[4]'. They are small clumps characterized by (1) very large velocity width (ΔV = 50–$100\ \mathrm{km\,s^{-1}}$ in zero-intensity width) indicative of interaction with shock, and (2) huge kinetic energy of internal motion (up to more than 10^{51} ergs) exceeding typical kinetic energy for a supernova-shocked cloud (10^{49-50} ergs). In addition, several HVCCs are found to be associated to superbubble-like structures by follow-up observations with the Nobeyama Radio Observatory 45 m telescope [1]. One of possible origins of these energetic HVCCs is interaction with a series of multiple supernova explosion which took place in a massive cluster with a mass of $> 10^3\ M_\odot$[1,2]. Investigation of internal structure and kinematics of the HVCCs with ALMA observations may prove this hypothesized link between the HVCCs and past cluster formation activity.

The [CI] $^3P_1$-$^3P_0$ mapping in the 500 GHz band was conducted to detect young GMCs related to cluster formation regions[3]. Since C^0 is abundant in an early phase of the molecular cloud formation from atomic gas, the C^0/CO ratio can be used as an indicator of the ages of GMCs. Although the coverage of the observation is limited to a rather narrow area near the Galactic plane, we found several massive clumps with very high [CI]/^{13}CO intensity ratio ($\gtrsim 1$) indicative of their young ages ($\lesssim$ Myr). These [CI] enhanced regions are mainly found near the on-going cluster formation region. This may imply that infall of molecular gas to these regions are taking place, facilitating active star formation there.

1) Tanaka, K., Kamegai, K., Nagai, M.,& Oka, T. 2007, PASJ, 59, 323
2) Tanaka, K., Oka, T., Nagai, M.,& Kamegai, K. 2009, PASJ, 61, 461
3) Tanaka, K., Oka, T., Matsumura, S., Nagai, M. & Kamegai, K. 2011, ApJL, 743, 39
4) Oka, T., Onodera, Y., Nagai, M., Tanaka, K., Matsumura, S., & Kamegai, K. 2012 ApJS, 201, 14

Maser Astrometry with VERA and the Galaxy's structure

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[1] Mizusawa VLBI Obsevratory, NAOJ, Japan

I will summarize the current status of VERA (VLBI Explortation of Radio Astrometry), a Japanese VLBI array dedicated to maser astrometry. Since 2007, VERA has been conducting astrometric measurements (distances and/or proper motions) for Galactic maser sources within $\sim$10 kpc from the Sun. In this talk I will present the most-updated VERA's results of maser astrometry, covering both individual maser sources and the structure of the Milky Way Galaxy revealed by maser astrometry, and also discuss the future direction of VLBI activity in Japan in the ALMA era.

Star Formation: From Giant Molecular Clouds to Prestellar Cores

T. ONISHI

Osaka Prefecture University, Japan.

Star formation is a complex process that spans many orders of magnitude in mass and linear scale with a wide variety of extreme environments. Giant Molecular Clouds (GMCs), which are believed to be the formation sites of most stars in galaxies, are formed from diffuse HI clouds possibly via effects of large-scale galactic dynamics and/or energetic events with a size scale of 10 pc to 10 kpc. Stars/clusters form from the densest, gravitationally bound, parsec-scale clumps within the GMCs. Once the gravitational collapse occurs, the typical size evolves from sub-parsec to AU scales in the free-fall time. The physical conditions of each process regulate the nature and rate of star formation, with consequences for planet formation and galaxy evolution. In this presentation, I will review current understanding of star formation revealed by the recent observations also with prospects for ALMA, by focusing on the following subjects; the galactic-scale GMC properties, effects of dynamical interaction of molecular clouds/clumps to the star formation efficiencies, and the nature of the most evolved starless cores just prior to protostar formation.

The distribution and nature of GMCs should regulate the evolution of galaxies via star formation process. Unfortunately, the velocity and spatial crowding in the Milky-Way Galaxy seriously limits our resolved view of GMCs only to the solar vicinity, making it impossible to list all the Galactic GMCs as a complete catalog except for a limited portion toward the outer Galaxy, where crowding is less significant. The superb angular resolutions and sensitivities of ALMA, in combination with the ACA that recovers extended emission, enable us to resolve spatially each GMC or even each clump in many nearby galaxies, which will offer a remarkably detailed view and the dynamics of GMCs in the galaxies and a deeper insight into the galactic evolution.

The star formation activities are not only determined by the mass of molecular clouds but also by the dynamical interactions with the environments. Recent studies are revealing the observational evidences for the enhanced star formation activities due to the interactions; cloud-cloud collisions leading to triggering massive star formation and interaction of dense cores with protostar outflows enhancing local star formation efficiency.

The first protostellar core, which will be detected and confirmed by ALMA, is the first milestone of star formation since it is the first quasi-hydrostatic object formed in the course of star formation and it is obviously crucial to find out the object close to this stage and to test theories of evolution from dense cores to protostars. Although the nature of the first protostellar core itself is very important, the mass distribution of the surrounding gas of inner a few 1000 AU, which should regulate the dynamics of the surrounding gas, must be investigated to diagnose the evolutionary status of dense cores. We would like to stress that the ALMA with the ACA 7m array will be the first instrument for us to be able to look into the detailed mass distribution smaller than 1000 AU scale at a distance of $\sim$140 pc, connecting a single dish scale of $\sim 10''$ to interferometer scale of $\sim 1''$, due to the inclusion of extreme short spacings and to the extremely good surface brightness sensitivity.

Star Formation Revealed by Herschel

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[1] Laboratoire AIM Paris-Saclay, CEA Saclay, France

The Herschel Space Observatory has greatly improved our global understanding of the initial conditions and early phases of star formation. I will present an overview of recent results obtained on the structure of molecular clouds as part of the Herschel Gould Belt survey. The role of filaments in the star formation process and their likely connection to interstellar turbulence will be emphasized. Overall, the Herschel results suggest that it may be possible to understand both the IMF and the global rate of star formation in galaxies by studying the physics of how dense structures (e.g. filaments, cores) form and grow in the ISM of our own Galaxy. Despite an apparent complexity, global star formation may be governed by relatively simple universal laws from filament to galactic scales. With very complementary capabilities to Herschel, ALMA will be a unique tool to probe the rotational fragmentation of individual cores into binary protostars and the formation of extreme objects such as brown dwarfs and massive stars.

Magnetic Fields and Star Formation: The Formation of Cores and Disks

SHANTANU BASU[1]

[1] The University of Western Ontario, Canada.

We review recent work that reveals the important role of non-ideal MHD effects to establish a broad core mass distribution in molecular clouds as well as to permit the formation of protostellar disks. Magnetic fields lead to a broad core mass function since regions with transcritical mass-to-flux ratio produce relatively massive cores. Ambipolar diffusion works agains this trend and allows the formation of many low mass cores as well, but does not eliminate the presence of high mass cores. Once a core begins collapse, magnetic fields are initially dragged inward in a near flux-frozen manner. However, intense magnetic pinching and high density near the protostar leads to a dramatic phase of flux-loss driven by Ohmic dissipation. This allows the formation of a centrifugal disk during the earliest phase of protostellar evolution. However, the cumulative effect of magnetic braking may keep the disk size quite small ($<$ 40 AU) during the Class 0 phase.

Hierarchical Fragmentation of the Orion Molecular Filaments

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[2] Institut für Astrophysik, Universtität Wien, Tuerkenschanzstrasse 17, 1180, Wien, Austria,
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We present high angular resolution and wide-field interferometric continuum observations of the Orion Molecular Cloud (OMC) utilizing the Submilllimeter Array and Expanded Very Large Array (covering $25'/3.1$ pc length of the the northern part of the OMC filaments.). We detect more than 50 spatially resolved continuum sources associated with OMC filamentary structures through thermal dust emission. Their estimated masses and sizes range from 0.3 to 5.7 $M_\odot$ and 480 to 4100 AU, respectively, and present a variety of structures. All the detected sources are on the filamentary main ridge ($n_{\rm H_2}\geq 10^6$ cm^{-3}), and analysis based on the Jeans theorem suggests that these sources are most likely gravitationally unstable. Comparison of multi-wavelength datasets indicates that approximately half of the detected continuum sources are associated with outflows, infrared sources, and ionized jets. These sources show the evolutionary stage from prestellar core to Class 0/I phases. We detect quasi-periodical separations between the OMC sources of $\approx$0.05 pc. This spatial distribution is part of a larger hierarchical structure, that also includes fragmentation scales of GMCs ($\approx 5^\circ/37$ pc), large-scale clumps ($\approx$1.3 pc), small-scale clumps (0.3 pc). This suggests that hierarchical fragmentation operates within the Orion A molecular cloud. Fragmentation spacings are roughly consistent with the local thermal fragmentation length in large-scale clumps ($\geq$0.3 pc), while fragmentation spacings in dense cores measured from the SMA observations is smaller than the local fragmentation length. These smaller observed spacings can be explained by either that helical magnetic field or global filament collapse. In this presentation, we will discuss mechanisms that constrain the fragmentation length within the OMC filament, as well as the time-scale of each of the identified substructures.

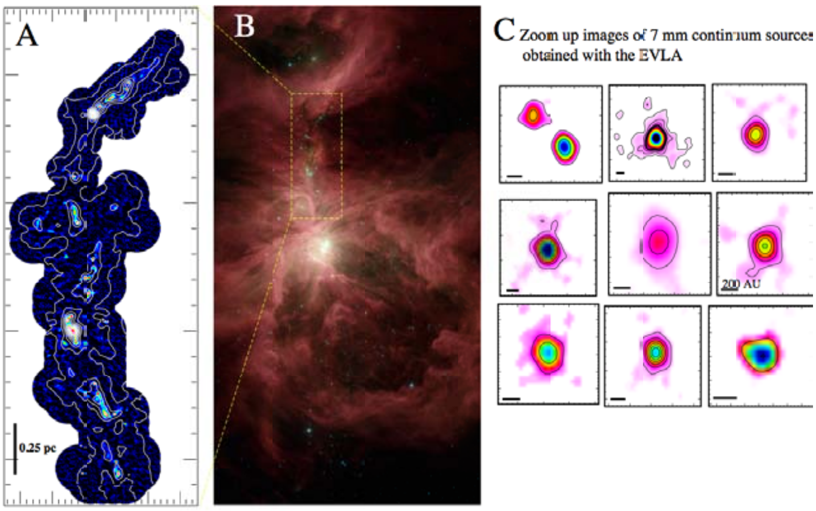

Figure 1: A: The SMA 850 and 1300 μm continuum mosaic image (color) overlaid with the 850 μm continuum image taken with the JCMT/SCUBA (contours referred from Johnstone & Bally 1999). B: The color composite image of OMC cloud obtained with the Spitzer/IRAC bands (Megeath et al.). C: Zoomed up image of the protostellar sources obtained with the EVLA 7 mm continuum.

The origin of the intersteller turbulence and small scale structures of molecular clouds

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[1] Joint ALMA Observatory, Chile
[2] National Astronomical Observatory of Japan

In order to study the origin of the interstellar turbulence, detailed observations in the CO J = 1–0 and 3–2 lines have been carried out in an interacting region of a molecular cloud with an H II region by the Nobeyama 45m and ASTE telescopes. As a result, several 1,000 to 10,000 AU scale cloudlets with small velocity dispersion ($\Delta V \sim 0.6$ km s^{-1}) are detected, whose systemic velocities have a relatively large scatter of a few km s^{-1}. It is suggested that the cloud is composed of small-scale dense and cold structures and their overlapping effect makes it appear to be a turbulent entity as a whole. This picture strongly supports the two-phase model of turbulent medium driven by thermal instability proposed previously. On the surface of the present cloud, the turbulence is likely to be driven by thermal instability following ionization shock compression and UV irradiation. Those small scale structures have a relatively high CO line ratio of J =3–2 to 1–0, $1 \leq R_{3-2/1-0} \leq 2$. The large velocity gradient analysis implies that the 0.6 km s^{-1} width component cloudlets have an average density of 10^{3-4} cm^{-3}, which is relatively high at cloud edges, but their masses are only $\leq 0.05\ M_\odot$.

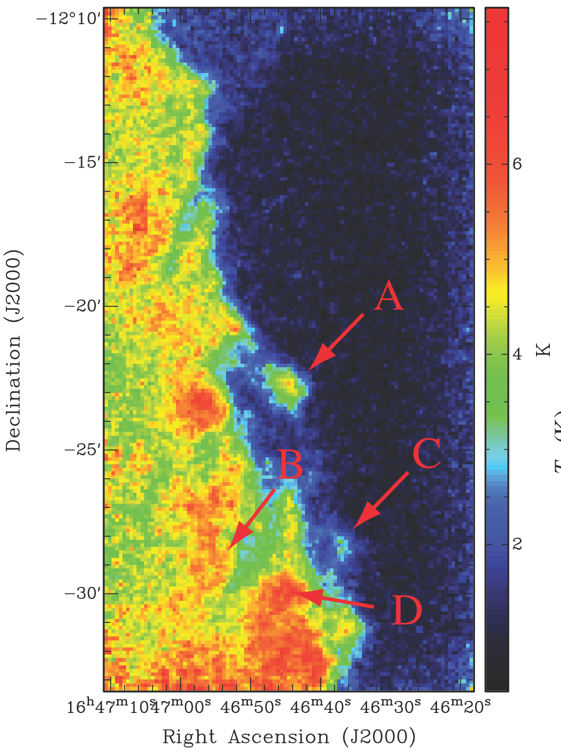

Figure1: Peak T_a map of CO J =1–0 at an interacting cloud surface with an H II region. About several 1,000 to 10,000 AU scale small clumpy (A) and arc-like (C) structures are detected.

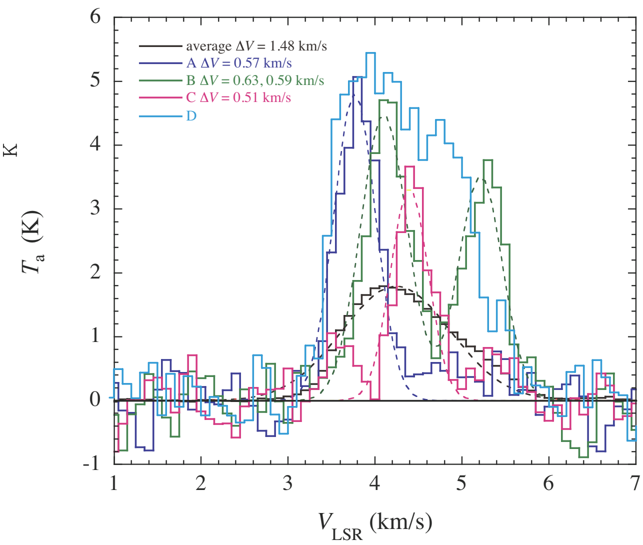

Figure 2: CO J =1–0 spectra obtained at the position designated by the arrows in Fig. 1. The averaged spectrum over the entire observed region are also plotted. The dotted lines denote the best-fit Gaussian profiles.

Tachihara, K., Saigo, K., Higuchi, A. E., Inoue, T., Inutsuka, S., Hackstein, M., Haas, M., Mugrauer, M. 2012, ApJ, 754, 95

Star formation in molecular clouds (theory)

P. HENNEBELLE[1]

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I will review some of the theories and numerical simulations of the star formation within molecular clouds that have been proposed along the years. I will particularly focus on the issue of filament and core formation, the relation between the core mass function and the initial mass function and the collapse which leads to the formation of disks and multiple systems.

The Dynamics and Chemistry of Massive Starless Cores

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[3] Arcetri Observatory, Firenze, Italy

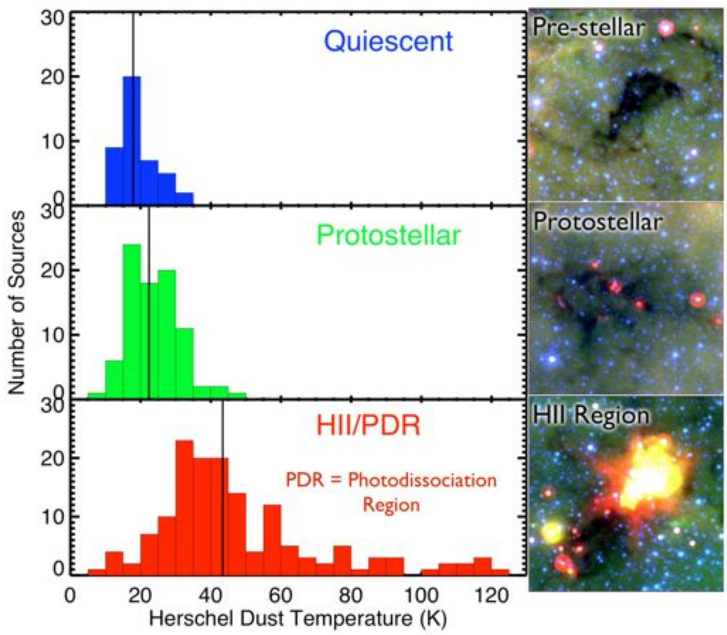
Progress towards resolving a decade-long debate about how massive stars form can be made by determining if massive starless cores exist in a state of near virial equilibrium. These are the initial conditions invoked by the Core Accretion model of McKee & Tan (2003). Alternatively, the Competitive Accretion model of Bonnell et al. (2001) requires sub-virial conditions. We have identified 4 prime examples of massive ($\sim 50 M_\odot$) cores from mid-infrared (MIR) extinction mapping (Butler & Tan 2009, 2012) of Infrared Dark Clouds. We have found spectacularly high deuterated fractions of N_2H^+ of ∼0.5 in these objects with the IRAM 30m telescope (Fontani et al. 2011). Thus N_2D^+ is expected to be an excellent tracer of the kinematics of these cold, dark cores, where most other molecular tracers are thought to be depleted from the gas phase. We report on ALMA Cycle 0 Compact Configuration Band 6 observations of these 4 cores that probe the N_2D^+(3-2) line on scales from 9 arcsec down to 2.3 arcsec, well-matched to the structures we see in MIR extinction and discuss their implications for massive star formation theories. We also present chemical modeling of these cores, which constrains their ages.

The Millimetre Astronomy Legacy Team 90 GHz Survey (MALT90) and ALMA

J.B. Foster[1,2], J.M. Rathborne[3], S.N. Longmore[4], and J.M. Jackson[1]

[1] Boston University
[2] Current Address: Yale University
[3] CSIRO Astronomy and Space Science
[4] ESO

ALMA will revolutionize our understanding of star formation within our galaxy, but before we can use ALMA we need to know where to look. The Millimetre Astronomy Legacy Team 90 GHz (MALT90) Survey is a large international project to make molecular line maps of over 2,000 dense clumps in the Galactic plane. MALT90 serves as a pathfinder mission for ALMA, providing a large public database of dense molecular clumps associated with high-mass star formation. MALT90 provides critical information for planning ALMA observations of these sources, including (1) source velocity, (2) kinematic distance estimates, (3) mass estimates, and (4) chemical/evolutionary stage. A MALT90 source was the basis of a successful ALMA Cycle 0 and the MALT90 source list has been used for several ALMA Cycle 1 proposals. In this talk, I will describe the survey parameters and share early highlights from the survey, including (1) the distribution of high-mass star formation in the Milky Way, (2) a comparison between galactic and extragalactic star-formation relations, and (3) the chemistry of MALT90 clumps. MALT90 will have completed the third year of observations by the date of the conference, and data is publicly available at http://malt90.bu.edu.



MALT90 sources are classified based on their appearance in the mid-infrared. Here, canonical examples of the main classifications (quiescent/prestellar, protostellar, and HII region/photodissociation region) are shown, along with dust temperatures inferred from Herschel Hi-Gal data; the less evolved sources are, on average, colder. MALT90 contains roughly an equal number of sources in each of these three classifications.

A Resolved Keplerian Disk Around One of the Youngest Protostars: Implications for Disk Formation Studies in the ALMA Era

J. Tobin[1]

[1] National Radio Astronomy Observatory, USA.

The formation of proto-planetary disks begins during the earliest phase of the star formation process, while the nascent protostar is still surrounded by a dense envelope of gas and dust. I will present millimeter interferometer observations from CARMA and the SMA at ∼0.3” (42 AU) resolution, revealing an edge-on R ∼ 150 AU proto-planetary disk around the Class 0 protostar L1527 in Taurus. Simultaneous observations of the 13CO (J=2-1) transition are found to trace the disk rotation curve and a protostellar mass of 0.19 +/- 0.04 $M_{\odot}$ is found. The disk structure is constrained through simultaneous radiative transfer modeling of the millimeter data, mid-infrared imaging, and spectral energy distribution, finding properties similar to those of T Tauri disks aside from a large amount of flaring. These observations represent the first direct measurement of protostellar mass from disk rotation and the most definitive evidence for a large disk around a typical Class 0 protostar. This result indicates that large disks can form in the earliest phase of protostellar evolution, contrary to disk formation models which consider magnetic braking. The detection of the disk around L1527 required observations at the highest resolution possible with current interferometers. This lays the ground work for ALMA, which will be needed to make significant gains in the area of disk formation with vastly improved resolution and sensitivity. Most importantly, ALMA’s ability to detect faint molecular lines will enable masses of a large number of Class 0 protostars to be measured for the first time.

Keplerian Circumbinary Disk and Accretion Streams around the Protostellar Binary System L1551 NE

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[2] Joint ALMA Observatory, Chile.
[3] University of Hong Kong, Hong Kong.
[4] National Astronomical Observatory, Japan.
[5] Chiba University, Japan.
[6] Hosei University, Japan.

In the present talk we will show our recent SMA results of L1551 NE, a Class I protostellar binary at a projected separation of ∼73 AU (Source A at the south-east and Source B north-west), in the 0.9-mm dust continuum emission and the ^{13}CO (3–2) and C^{18}O (3–2) line emission at a spatial resolution of ∼120×80 AU. The 0.9-mm dust-continuum image (Fig.1 left) shows three distinct peaks. The brightest component at center is closely coincident with Source A, and exhibits an extension towards B; this component can be decomposed into two unresolved sources, indicating very compact circumstellar disks, coincident with Source A and B. The outer northern and southern continuum components are located almost symmetrically with respect to the central component, and have tilted-U shapes as indicated by the dashed curves, suggestive of a r ∼300 AU circumbinary disk with an inner (r ∼140 AU) clearing. The ^{13}CO and C^{18}O images confirm that the circumbinary continuum feature is indeed a rotating disk (Fig.1 right); furthermore, the C^{18}O channel maps can be well modeled by a geometrically thin disk exhibiting Keplerian rotation with a central stellar mass of 0.8 $M_\odot$. These observational results, *i.e.*, circumstellar disks plus a Keplerian circumbinary disk with an inner clearing, match well our theoretical simulation of accretion onto protostellar binaries from surrounding circumbinary disks. We will discuss the possibility to directly image the theoretically-predicted "spiral accretion streams" that connect the surrounding circumbinary disk to the individual circumstellar disks in L1551 NE with the ALMA observation.

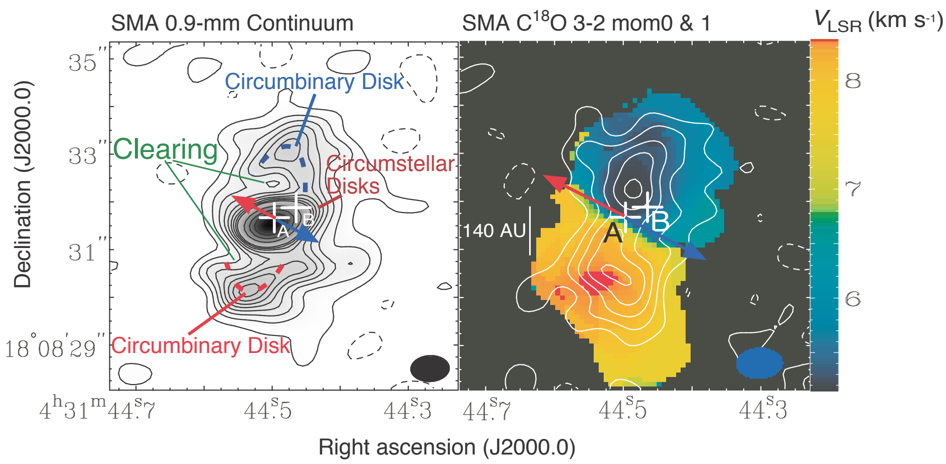

Figure 1: (*Left*) Our (Takakuwa et al. 2012) 0.9-mm continuum image of L1551 NE as observed with the SMA. Contour levels are from 3σ in steps of 4σ until 35σ, and then in steps of 20σ until 115σ (1σ = 3 mJy beam^{-1}). Crosses indicate the positions of the two protostars, named Source A and B, of L1551 NE. A filled ellipse at the bottom-right corner shows the synthesized beam (0.″80 × 0.″54; P.A. = -87°). Dashed curves delineate tilted U-shaped features, and arrows show the direction of the [Fe II] jets driven by Source A. Individual features are labelled as Circumbinary Disk, Circumstellar Disks, or Clearing. (*Right*) Integrated-intensity (white contours) superposed on the intensity-weighted mean-velocity (color scale) maps of the C^{18}O (J = 3–2) emission as observed also with the SMA. Contour levels are from 2σ in steps of 2σ (1σ = 0.17 Jy beam^{-1} km s^{-1}). A filled ellipse at the bottom-right corner indicates the synthesized beam (0.″95 × 0.″66; P.A. = -88°).

Keplerian Disks around Protostars: from NMA to SMA and ALMA

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Keplerian disks have been considered to be formed as by-products of star formation. It is, indeed, true that Keplerian disks are ubiquitous around pre-main-sequence stars. Since they are the most probable site of planet formation, they are called protoplanetary disks, and have been observationally and theoretically studied in the last two decades. Nevertheless, the formation and evolution process of these Keplerian disks is still poorly understood. Some theoretical simulations suggest even pictures where it is difficult for Keplerian disks to be formed around protostars because of magnetic fields. In order to understand the formation and evolution process of Keplerian disks around protostars observationally, the key is to unambiguously identify Keplerian disks around protostars deeply embedded in dynamically infalling and slowly rotating envelopes.

We have been observing protostars deeply embedded in infalling envelopes with NMA and SMA, suggesting possible transition from infalling motions to Keplerian motions In the inner regions of infalling envelopes. In this talk, we will briefly review NMA observations of infalling envelopes around protostars, and will present recent SMA observations demonstrating possible formation and evolution of Kepelrian disks in these infalling envelopes. In addition, results of approved cycle 0 ALMA observations of the innermost envelopes will be also discussed if they are available, including a possibility to derive dynamical masses of protostars using Kepler motions of their disks.

The Structure of Protoplanetary Disks as inferred from mm/submm Interferometry

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In the early nineties, mm/submm arrays begun to routinely image gas and dust disks orbiting low-mass TTauri and young intermediate-mass stars. The first images were strongly limited in sensitivity and angular resolution and did not allow observers to perform detailed comparisons with models. Moreover one key parameter for planet formation, the disk mass distribution, remains difficult to measure because it relies on indirect tracers such as the dust thermal emission or the molecular lines. The interpretation of these data suffer from different uncertainties. However, thanks to recent upgrades of mm/submm interferometers associated to the heterodyne detection which provides very high spectral resolutions (of the order of 0.2 km/s or better), the first quantitative studies of the physical structure (temperature, density, turbulence...) and kinematics of gas-rich protoplanetary disks have been made possible. One can consider that the thermal and density structures are basically understood even if there are several discrepancies between model predictions and observations which must be solved before constraining models of planet formation. The most recent observations performed at high angular resolution also reveal that the geometry is more complex than that of a simple flaring disk, as usually assumed by most disk models. Several images show the presence of inner cavities and inhomogeneities in the gas and dust distributions. In a few cases, departure to pure Keplerian rotation has also been observed.

In this review, I will summarize our current understanding of the physical structure of disks as inferred from recent dust continuum maps and molecular spectro-imaging obtained at high angular resolution ($\sim 0.5''$) on a few proto-typical objects such as AB Auriga, GG Tau or DM Tau... I will then discuss these results in light with the advent of ALMA.

The Structures of Protoplanetary Disks

S. M. Andrews[1]

[1] Harvard-Smithsonian Center for Astrophysics, USA.

Direct observations of the reservoirs of planet-building material – the disks around young stars – play a critical role in developing theoretical models of the planet formation process. For more than 30 years, radio/mm/sub-mm interferometry measurements have held the most promise for groundbreaking work in this field: they provide high-resolution access to a wealth of molecular emission lines and an optically thin dust continuum that serve as unique probes of disk structures (the spatial distributions of densities, temperatures, etc.). After a brief overview of the methodology, I review some key aspects of what we have learned about disk structures and comment on their implications for models of disk evolution and planet formation. Building on those results, I will highlight some of the current (and future) directions being pursued in this field, including the potential signatures of planet-disk interactions (the so-called "transition" disks) and some tentative evidence for the growth and migration (radial drift) of solid particles.

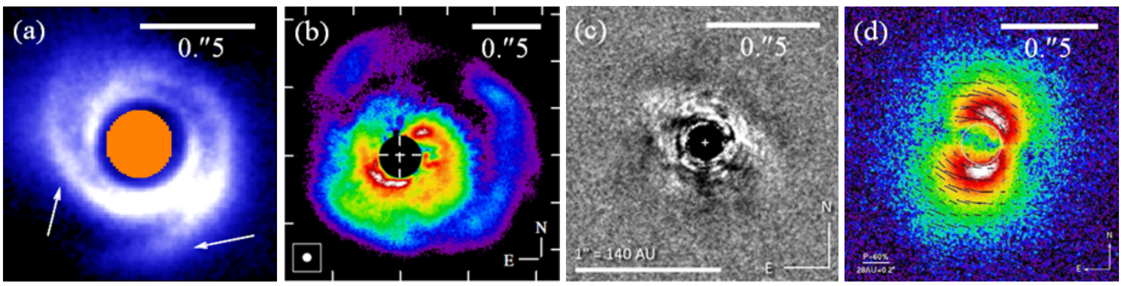
High Angular Resolution Infrared Observations of Protoplanetary Disks

M. Fukagawa[1], J. Hashimoto[2], M. Tamura[2], SEEDS/HiCIAO/AO188 teams

[1] Osaka University, Japan.
[2] National Astronomical Observatory, Japan

Observations of protoplanetary disks are essential to understand planet building process since they provide realistic initial conditions as well as insights into new-born planets through disk-planet dynamical interaction. We present the recent effort to directly image those disks in scattered light with high angular resolution, focusing on the near-infrared results obtained with Subaru. Scattered-light observations are complementary with longer-wavelength studies as they can provide the information on smaller grains in disks, thus useful to discuss such as grain growth and dust transport that can be either the basic step toward or the consequence of planet-forming activity. In fact, the comparable angular resolution will be achieved in submillimeter soon with ALMA, and multi-wavelength study will become more important for comprehensive understanding of disks.

As a part of Strategic Exploration of Exoplanets and Disks with Subaru (SEEDS), we have observed more than 40 T Tauri and Herbig Ae/Fe stars. Our targets include transitional systems showing the dips in the mid-infrared SEDs and/or the resolved cavities in submillimeter. We have primarily employed the technique of polarization differential imaging (PDI) combined with adaptive optics, which is powerful to achieve high contrast by extracting the scattered light from the disk while suppressing the unpolarized stellar light. The PDI observations indeed enabled us to look at the inner region, as close as 10 AU in radius, with the typical angular resolution of 0.06 arcsec, corresponding to less than 10 AU in nearby star-forming regions (e.g., Hashimoto et al. 2011, Kusakabe et al. 2012, Tanii et al. 2012). Consequently, the SEEDS imaging has newly uncovered rich structures such as spiral arms, inner holes, and gaps for transitional systems. One of the highlights is the discovery of two spiral arms in the submillimeter cavity for SAO 206462, which can be explained by presence of possible planets (Muto et al. 2012). We will overview the results of scattered-light imaging and discuss how to exploit the synergy with submillimeter/millimeter observations.



Images of protoplanetary disks at 1.6 micron obtained with Subaru/HiCIAO+AO188. (a) SAO 206462 (Muto et al. 2012), (b) AB Aur (Hashimoto et al. 2011), (c) LkCa 15 (Thalmann et al. 2010), (d) UX Tau A (Tanii et al. 2012). Note that the images show the *polarized* intensity except for LkCa 15.

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Thalmann, C., Grady, C. A., Goto, M., et al. 2010, ApJL, 718, L87

SEEDS: Direct Imaging of Exoplanets and Their Forming Disks with the Subaru Telescope

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SEEDS (Strategic Explorations of Exoplanets and Disks with Subaru) is the first Subaru Strategic Program, whose aim is to conduct a direct imaging survey for giant planets as well as protoplanetary/debris disks at a few to a few tens of AU region around 500 nearby solar-type or more massive young stars devoting 120 Subaru nights for 5 years. The survey employs the new high-contrast NIR instrument HiCIAO, a successor of the previous NIR coronagraph camera CIAO for the Subaru Telescope. We describe the outline of this survey and present its first 2 years results including detection of the most unequivocal and low-mass planet via direct imaging and discovery of unprecedentedly detailed structures of protoplanetary disks.

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Observational constraints on disk evolution and the initial steps towards planet formation

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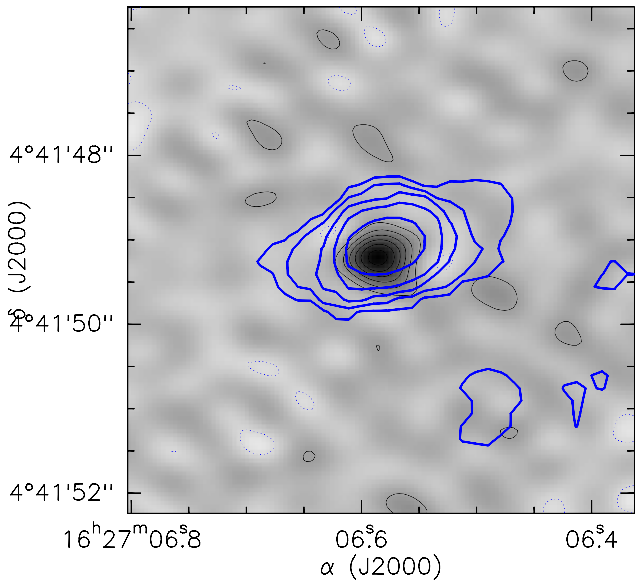
Planet formation is expected to occur in circumstellar disks during the first few Myrs of the stellar pre main sequence evolution. In the core accretion paradigm of planet formation, the solid component of the disks (the dust) grows and coagulate to form planetesimals and rocky cores of planets. We have been studying extensively the grain growth process in nearby star forming regions protoplanetary disks. As a tool we use submillimetre and centimeter wave emission from the dust in the disk midplane, that depends on the opacity per gram of dust, which in turn is related to the composition and size of dust grains. We find evidence for an early growth of dust and a relatively long survival time for large grains in disks. Our results are at odds with simple model expectations that predict rapid migration and depletion of the large grains population in disks: observations show that large grains are retained in the outer disks for relatively long timescales (few to several Myrs). We discuss possible mechanisms to solve the discrepancies between models and observations. We present also the results of new observational tests with ALMA and other millimetre arrays that provide critical constraints on the model assumptions and on the initial conditions for planet formation. In particular we will report on the results of an ALMA Cycle 0 project aimed at constraining dust evolution in disks around young Brown Dwarfs. Young BDs systems offer the opportunity to test disk evolution models in an environment that is significantly different than around solar-mass stars and thus provide critical tests of the validity of dust evolution models. At the time of writing of this abstract, we have just received the first LMA dataset on one of our brown dwarfs disks. We measure with high reliability the disk mass and constrain the grain properties with continuum measurements at 850um and 3mm with ALMA. In addition, we confirm the detection of a molecular outflow from our target (which was previously observed with the SMA) and serendipitously detect molecular gas from the disk. While the analysis is ongoing at the moment, we can already confirm that the disk around this object is relatively large and massive with strong evidence for grain growth. These results impose strong constraints on the formation theories of BDs and disk/dust evolution models.



ALMA-Cycle 0 observations of the bright disk around the young BD ρ–Oph 102. The greyscale and thin black contour show the 340 GHz continuum emission, the thick blue contours show the CO(3-2) integrated line emission. These data has just received at the time of writing the present abstract and, while the analysis is still ongoing, we confirm the continuum detection of the disk, derive an estimate of the continuum spectral index (which was the scientific goal of the Cycle 0 proposal) and serendipitously detect, for the first time, molecular gas emission in a disk associated with a young BD.

Sub-mm studies of debris disks

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Several hundred nearby main sequence stars are known to be surrounded by dusty debris disks that are usually considered to be extrasolar analogues to the Kuiper belt. Sub-mm studies play a crucial role in understanding the disks, since they trace large (mm-sized) dust that is much less affected by radiation and stellar wind forces than the smaller (micron-sized) dust that is traced by far-IR and optical observations. Thus sub-mm observations are crucial to provide a more accurate measure of the mass of parent planetesimals in the disk, and to trace the location of those planetesimals, as well as giving a constraint on the size distribution of the dust. Here I will review the current status of knowledge of the debris disk population resulting from two complementary surveys: DEBRIS, a key programme on Herschel that searched for far-IR emission from dust around the nearest $\sim$100 stars of each spectral type A, F, G, K and M, and SONS, a legacy survey on JCMT using SCUBA2 to search for sub-mm emission from known debris disks. This will be used to place the most recent ALMA observations of debris disks into context, and to outline what we can expect to learn from ALMA observations of these disks about their planetary systems in the coming few years.

Resolved Millimeter Emission Belts in the β Pictoris and AU Microscopii Debris Disks

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Debris disks around young main-sequence stars provide a window into formation of planetary systems. Imaging at millimeter wavelengths plays a key role because emission at these long wavelengths is dominated by large grains that are minimally affected by non-gravitational forces and therefore trace best the underlying population of dust-producing planetesimals. We SMA observations that resolve the millimeter emission from the debris disks surrounding the nearby ~ 10 Myr-old stars β Pictoris and AU Microscopii. For both systems, which are viewed nearly edge-on, the observations reveal a belt of emission surrounding the star with the same geometry as the more extended scattered light imaged at optical wavelengths. Simple models show the locations of these millimeter belts are consistent with reservoirs of planetesimals ("birth rings") previously invoked to explain the detailed shape of the scattered light surface brightness profiles through size-dependent dust dynamics. We have an ALMA Cycle 0 program in the queue to image the AU Microscopii system at substantially better sensitivity and higher angular resolution than the SMA, and we will present these results, if available. While the SMA shows the global disk structure, ALMA has the potential to reveal asymmetries and substructure indicative of perturbations from unseen planets.

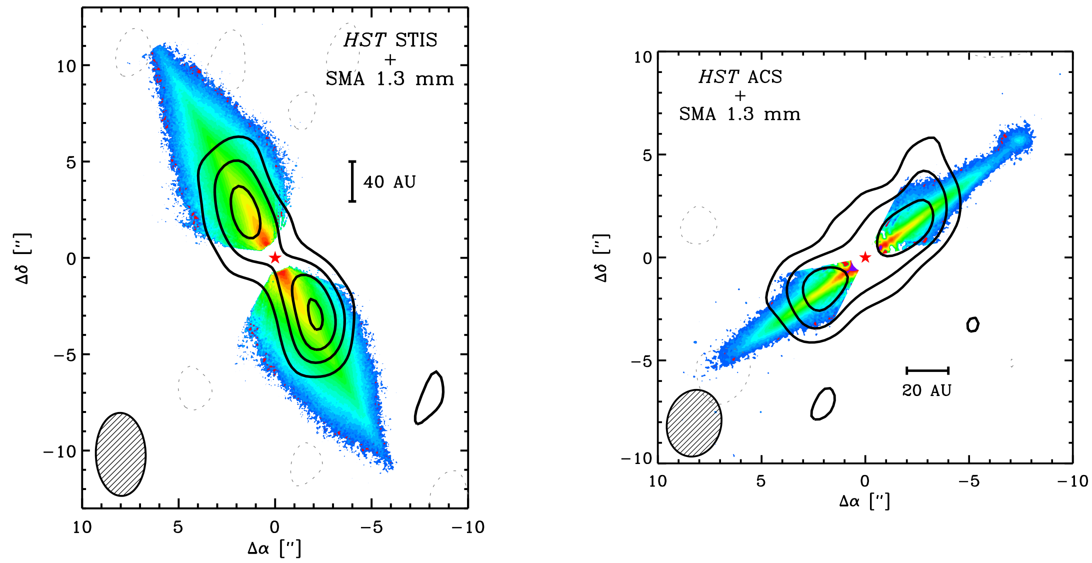

Figure 1: SMA images of the 1.3 millimeter emission in contours overlayed on images of optical scattered light from the Hubble Space Telescope for the debris disks around *(left)* β Pic (Wilner et al. 2011) and *(right)* AU Mic (Wilner et al. 2012). The contour levels are $-2, 2, 4, 6, \ldots \times$ the rms noise of 0.6 mJy and 0.4 mJy, respectively. The ellipses in the lower left corners represent the $\sim 3''$ synthesized beams. The star symbols show the locations of the stars.

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New trends in astrochemistry in the ALMA era

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Astrochemistry is entering a golden age, with new powerful telescopes from radio to infrared wavelengths opening up studies of molecules from the smallest < 1 AU scales in protoplanetary disks to the largest kpc scales in high redshift star-forming galaxies. In this talk, an overview will be given of recent developments in the field, including the wealth of data on water and other molecules from Herschel and the surprisingly rich near- and mid-infrared spectra of disks. Recent results from single dish and millimeter interferometers on simple and complex molecules will be summarized in the context of models of the physical and chemical evolution of star- and planet-forming regions. The promise of ALMA in revolutionizing the field will be illustrated with early results, and the need for further laboratory work emphasized.

Pre-stellar Cores and Infrared Dark Clouds

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The initial conditions in the process of star and planet formation are to be found in pre-stellar cores, which are dense ($n_H > 10^5$ cm^{-3}), cold ($T \leq 10$ K), centrally concentrated $\simeq$0.1 pc regions of molecular clouds, undergoing gravitational contraction. A good knowledge of the physical structure and kinematics of pre-stellar cores is needed to put constraints on theories of star and planet formation. This implies a good understanding of the pre-stellar core chemical structure, as spectral line profiles provide the best diagnostics of the physical properties across the core and the only diagnostics of the dynamics. Because of their simple structure and quiescent nature, pre-stellar cores are also ideal laboratories where to measure key astrophysical processes and parameters. In this talk I will review our current understanding of pre-stellar cores in low-mass star forming regions, show recent Herschel observations and describe how ALMA will soon unveil the still unexplored central few hundreds AU of pre-stellar cores, the future stellar cradles. I'll then move to Infrared Dark Clouds (IRDCs), which host the earliest stages in the process of high-mass star and stellar cluster formation. I will show that the molecular tools used to study nearby pre-stellar cores have provided a way to unveil starless massive cores within IRDCs and test star formation theories. The crucial role of ALMA in this study will be highlighted.

Molecules in Bipolar Outflows from Young Stellar Objects

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Bipolar outflows from young stellar objects represent some of the best laboratories to study shock chemistry in the interstellar medium. Recent observations show that a number of molecular species suffer order-of-magnitude abundance enhancements in the outflow gas, likely due to a combination of dust-mantle disruption and high-temperature gas chemistry. The study of these enhanced species is of great interest to characterize shock chemistry. It also offers a highly selective tool to trace the interaction between the outflow and the cloud, which is necessary to elucidate the still mysterious nature of the outflow driving wind. Here we will review some of the recent progress in the study of the molecular composition of bipolar outflows, with emphasis on the tracers most relevant for shock chemistry and on the new data from the Herschel Space Observatory.

Chemical Diversity of Low-Mass Star-Forming Cores: Class 0 to Class I

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In formation of a solar-type star by gravitational collapse of a dense core, molecules and dust particles contained in a parent core are processed through various chemical reactions both in the gas and solid phases, a part of which would be delivered to a protoplanetary disk and eventually to planets. They may be related to presolar materials found in meteorites. Thus, tracing chemical evolution of a prestellar/protostellar core along formation and evolution of a solar-type protostar is of fundamental importance in order to explore a relation between interstellar chemistry and chemistry of our solar system.

So far, chemical composition of prestellar cores and Class 0 sources has been studied in detail by radioastronomical observations. In these studies, chemical diversity has clearly been established for the Class 0 sources. One distinct case is the hot corino chemistry characterized by rich existence of ′saturated′ complex organic molecules (COMs) such as $HCOOCH_3$ and C_2H_5CN, whereas the other is the warm carbon-chain chemistry (WCCC) characterized by extraordinary richness of ′unsaturated′ complex organic molecules such as carbon-chain molecules. We proposed that such chemical diversity would originate from the difference of the duration time of a starless-core phase (Sakai et al. 2009; 2011).

Then, an apparent question is whether the diversity is seen in more evolved (i.e.Class I and II) stages. Although the relation between hot corinos and protostellar disks is still unknown, saturated COMs are acturally distributed within a few 100 AU region around the protostar. Furthermore, Pineda et al. (2012) have recently found the inverse P Cygni profile of the $HCOOCH_3$ lines toward the hot corino IRAS16293-2422, by using the ALMA SV data. This is a clear evidence that saturated COMs exist in the infalling material near the Class 0 protostar. On the other hand, we recently found that carbon-chain molecules also exist in the closest vicinity of the protostar (¡ 500 AU) in the WCCC sources. Thus, the chemical variation should be delivered to the protoplanetary disks. Its detailed processes are needed to be clarified.

With this motivation, we have extensively searched for Class I sources showing the WCCC feature, and have finally found a potential candidate. It is IRAS04365+2535 in TMC-1A. Strong high excitation lines of carbon-chain molecules with a peculiar velocity structure have been found toward this source. The lines appear at 5.9 km/s, which is different from the systemic velocity of the parent cloud core (6.4 km/s). The lines show central condensation around the protostar, and can better be seen in higher excitation lines. It seems most likely that the 5.9 km/s component traces a warm and dense part near the protostar, where the carbon-chain molecules are abundant. The velocity shift of the 5.9 km/s component would be explained as a remnant of the rotating envelope structure or a part of the inverse P Cygni profile originating from the infalling motion. By high spatial resolution observations toward the Class 0 and Class I WCCC sources with ALMA, we would like to explore how the two distinct chemistry in the Class 0 stage evolve into the Class I stage. This will provide us an important clue for a thorough understanding of chemical evolution from protostellar cores to protoplanetary disks. In the presentation, I would like to discuss the evolution of the WCCC sources from Class 0 to Class I, hopefully with the ALMA cycle 0 data.

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Chemistry in Star-Forming Regions: Herschel Looking towards ALMA

E. BERGIN[1]

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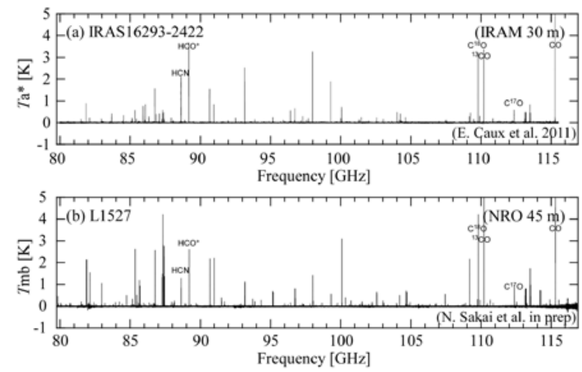
In this talk I will present a census of results from the Herschel Space Observatory regarding molecules in space. With ALMA coming online I will frame the talk as a discussion of what the Herschel results are telling us about chemsitry in space and how we can use ALMA to look deeper. Key aspects to be discussed include the chemistry of organics in hot cores, simple molecules in the interstellar medium and dense cores, to hot gas in photodissociation i regions and protostars. A part of this talk will be directed towards presenting some of the near complete spectral scans obtained by Herschel covering from 460 GHz to 1.9 THz with 1 MHz resolution. The plethora of data available in the Herchel data sets presents challenges in analysis. I will discuss the techniques applied to model the entire spectrum at once and how these may change when confronting ALMA data.

Nobeyama 45 m telescope legacy project: Line survey

TAKANO, S. (NRO/GUAS), AIKAWA, Y. (KOBE U.), CHEN, V. (NTHU), HIRANO, N. (ASIAA), HIROTA, T. (NAO), KAMEGAI, K. (TOKYO U. SCI.), KOBAYASHI, K. (TOYAMA U.), KOHNO, K. (U. TOKYO), KUAN, Y-J. (NTNU), LIU, S.-Y. (ASIAA), NAKAJIMA, T. (NAGOYA U.), OHASHI, N. (NAO), OHISHI, M. (NAO), OZEKI, H. (TOHO U.), SAKAI, N. (U. TOKYO), SAKAI, T. (U. TOKYO), SHIBA, S. (U. TOKYO), SU, Y.-N. (ASIAA), SUGIMURA, M. (U. TOKYO), TAKAKUWA, S. (ASIAA), UMEMOTO, T. (NAO), WANG, K.-S. (U. LEIDEN), WATANABE, Y. (U. TOKYO), YAMADA, M. (ASIAA), YAMAGUCHI, T. (U. TOKYO), YAMAMOTO, S. (U. TOKYO), ZHANG, Q.-Z. (CFA)

Line surveys are of fundamental importance in astronomy not only for complete understanding of molecular abundances, but also for finding out new observational tools (spectral lines) probing interstellar medium. We carried out a new line survey project at the 3 mm region. The target sources are the low-mass star-forming region in L1527, the shocked region in L1157 B1, the infrared dark clouds G28.34+0.06, and the external galaxies NGC 1068, NGC 253, and IC 342.

The preliminary main results are as follows. (1) L1527: This is an interesting star-forming region with high abundances of carbon-chain molecules (Sakai et al. 2008). The survey was done from 80 to 117 GHz. We detected many lines from 39 species including various carbon-chain molecules, isotopic species (D, ^{13}C) of some carbon-chain molecules, and unidentified species (see Figure). (2) L1157 B1: This is a prominent region of interactions between a molecular outflow from the protostar and ambient clouds (Umemoto et al. 1992 and Mikami et al. 1992). This is an ideal region to study shock chemistry. The survey was finished from 78.1 to 115.5 GHz. We detected 130 lines from 44 species including CH_3CHO, CH_2DOH, carbon-chains, and PN (Sugimura et al. 2011, Yamaguchi et al. 2011, 2012). (3) G28.34+0.06 (possible high-mass star-forming regions): Three interesting positions called MM1, MM4, and MM9 were selected, and the survey almost covered from 80 to 110 GHz. Toward MM1 and MM4 line wings were found in SiO and so on. These wings indicate outflow activities. In addition, CH_3CHO is detected only in MM1 and MM4, though N_2D^+ was detected only in MM9. Based on these results, MM1 and MM4 are thought to be active and more evolved objects. (4) NGC 1068 is a nearby galaxy with X-ray radiation from AGN, and NGC 253 and IC 342 are also nearby galaxies with prototypical starbursts. The survey was finished from 85 to 116 GHz. We detected 21-23 species depending on the galaxies including several new detections (e.g. cyclic-C_3H_2 and C_2H in NGC 1068, Nakajima et al. 2011). The intensities of HCN and CN relative to ^{13}CO are significantly strong in NGC 1068 compared to those in NGC 253 and IC 342.



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Shocks in Low-Mass Protostellar Environments: Present Lessons and Future Observations

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Herschel and the large ground-based millimeter radiotelescopes have revealed the important role of shocks in the chemical evolution of star forming regions. This is well illustrated by the spectral survey of the protostellar shock L1157-B1 from $672\mu m$ up to $55\mu m$, carried out with Herschel, as part of the CHESS key project, and from 80 to 350 GHz with the IRAM 30m telescope. The unprecedented sensitivity of these instruments brings new insight both on the molecular content and the physical conditions of this long studied region, thanks to the detection of hydrides (H_2O, HCl,) and of the high-excitation lines of heavy molecules (CO, CS, HCO^+, HCN,...). With the help of complementary molecular emission maps from the Plateau de Bure interferometer, multi-transition analysis of the line profiles reveals the presence of multiple emission components [1,5,6,7] of differing excitation conditions and constrains the formation/destruction scenarios of various molecular species [2,3,4] including water, in relation with shock models, while unveiling the chemical history of the cloud. I will discuss the new view on the physical and chemical structure of protostellar bowshocks which emerges from these observations, the role of ALMA and NOEMA as well as the need for future complementary instruments to get a coherent picture of protostellar shocks.

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Chemical Models of Star Forming Cores

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[1] Kobe University, Japan

In this talk, I will review chemical models of low-mass star forming cores including our own work. Chemistry in molecular clouds are not in equilibrium. Molecular abundances in star forming cores change not only with physical conditions in cores but also with time.

In prestellar cores, temperature stays almost constant while the gas density increases. Three chemical phenomena are observed in this cold phase: molecular depletion, chemical fractionation, and deuterium enrichment. As the gas density increases at the core center, collisional timescale of gaseous species and grains shortens and molecules are frozen onto grain surfaces. While CO depletion is often observed towards prestellar cores, depletion of N-bearing species are less frequently found, which is called chemical fractionation. Since the conversion of N atom to N_2 and NH_3 is slower than the CO formation, N-bearing species are more resilient against depletion. Molecular D/H ratio, XD/XH, becomes larger than the elemental D/H ratio in prestellar cores. Since the zero-point energy of deuterated species are smaller than their normal isotope counter parts, exchange reactions such as H_3^+ + HD $\rightarrow$ H_2D^+ + H_2 are exothermic. The high D/H ratios achieved by the exchange reactions propagate to other molecules via chemical reactions. CO depletion further enhances the deuterium enrichment, because CO is the dominant reactant with H_2D^+.[1][2]

The collapse timescale of prestellar cores depends on the initial ratios of thermal/turbulent/magnetic pressure to gravitational energy. Since chemical timescales, such as adsorption timescale of gas particle onto grains, are comparable to the collapse timescale, molecular abundances in cores vary depending on the collapse timescale. So far, a variety of molecular abundances are found in cores with similar central densities; it could originate in the pressure to gravity ratio in the cores.[2][3]

As the core contraction proceeds, compressional heating eventually overwhelms radiative cooling, and the core starts to warm up. The first core is formed when the contraction in the central region is temporally halted by the pressure gradient. As the temperature exceeds 2000 K at the core center, H_2 is dissociated, and the center of the first core collapses again to form a protostar.[4] Temperature of the infalling gas from the envelope increases as it approaches the central region. Grain-surface reactions of adsorbed molecules occur in this warm-up phase as well as in prestellar phase. Hydrogenation is efficient at $T \leq 20$ K, whereas radicals can react with each other to form complex organic molecules (COMs) at $T \geq 30$ K. Grain-surface species are sublimated to the gas phase and re-start gas-phase reactions; i.e. unsaturated carbon chains are from sublimated methane. Our model calculation predicts that both COMs and unsaturated carbon chains increases as the warm region extends outwards. These newly formed molecules in protostellar phase inherit high D/H ratio of their mother molecule, which originates in cold prestellar phase.[5][6]

3D hydrodynamics simulations show that the first core is oblate. While the central region collapse to form a protostar, the rest of the first core will evolve to be the protoplanetary disks. I will present molecular abundances in the core harboring the first core and briefly discuss how the molecules accreted from the envelope evolve in the protoplanetary disks.[7][8]

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Observations of chemistry in protoplanetary surrounding low-mass stars

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Understanding the structure and evolution of disks surrounding young low-mass stars is one of the key issues to study the process of planet formation. Nevertheless the overall properties of those disks are not yet well constrained by observations. Several other molecules than CO and its isotopologues have been detected in the outer part of the disks in the millimeter domain : HCO^+, $H^{13}CO^+$, DCO^+, H_2CO, H_2O, CS, C_2H, N_2H^+, HCN, HNC, CN, DCN, and very recently HC_3N. This molecular tracers bring some constraints on the disk physical structure since they sample different physical conditions.

In this talk I will present recent results obtained thanks to molecular line observations (including some ALMA results if available), and confront them to models of proto-planetary disks, in particular to the the layered structure that is predictied by all chemical models so far.

Diagnosing gas dispersal processes in protoplanetary disks

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Thanks to the recent development of (sub)mm and infrared instruments, it has become possible to detect transition lines of various kinds of molecular species in protoplanetary disks. ALMA will be able to detect molecular lines from the inner disks, which will reveal detailed physical and chemical structure of planet-forming region in the disks.

In this work we have studied the chemical structure of protoplanetary disks using a comprehensive astrochemical reaction network extracted from UMIST Rate06, based on a detailed model for the gas and dust temperature and density profiles, which takes into account UV and X-ray irradiation from stars. Here we especially focus on molecular lines which could useful to diagnose physical processes related to gas dispersal from the disks; molecular line tracers of (i) ionization degree near the midplane and (ii) gas temperature profiles in the surface layer. The former is related to magnetorotationally unstable regions and gas accretion towards the central star, and the latter is connected to photoevaporation process; keys to understanding planet-formation in the disks. Our results indicate that HCO^+ 1-0/$C^{18}O$ 1-0 line ratio will be useful to measure ionization degree near the disk midplane, and our model suggests that the disk surface is magnetorotationally unstable due to ionization by UV and X-ray irradiation, while disk midplane is stabilized due to Ohmic dissipation ($<$20AU) and ambipolar diffusion/ Hall effect ($<$200AU). Also, we find that multi-line observations of CN and HCN will reveal gas temperature gradient in the disk surface, and CN lines will trace the gas temperature of photoevaporating region of an externally irradiated disk, where thermal energy dominates the gravitational energy of the central star. Observations of these simple molecular lines by ALMA will be useful to diagnose gas dispersal processes in the disks.

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Planetary Atmospheres at High Resolution

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The long millimeter through submillimeter bands are particularly well suited for studying the wide variety of planetary atmospheres in our solar system. Temperatures ranging from a few 10s to hundreds of degrees, coupled with typically high densities (relative to the ISM) mean that thermal 'continuum' emission can be strong and molecular rotational transitions can be well-populated. Large bodies (Jovian and terrestrial planets) can be reasonably well studied by current interferometers, yet many smaller bodies with atmospheres can only be crudely studied, primarily due to lack of sensitivity. Figure 1 presents roughly the current 'dynamic scale' available for studying atmospheres in our solar system (∼50 in the mm/submm). Newly powerful interferometers such as the EVLA and ALMA will usher in a new era of planetary atmospheric exploration. The vast sensitivity and spatial resolution of these arrays, especially with ALMA, will increase this dynamic scale substantially. New science allowed will range from detailed mapping of HDO, ClO, and sulfur species in the mesosphere of Venus and PH3 and H2S in the upper tropospheres of the gas and ice giants, high SNR mapping of winds on Mars, Neptune and Titan, down to spectroscopic imaging of volcanic eruptions within the tenuous atmosphere on Io, resolved imaging of CO and other species in the atmosphere of Pluto, and even potentially detection of the plumes of Enceladus.

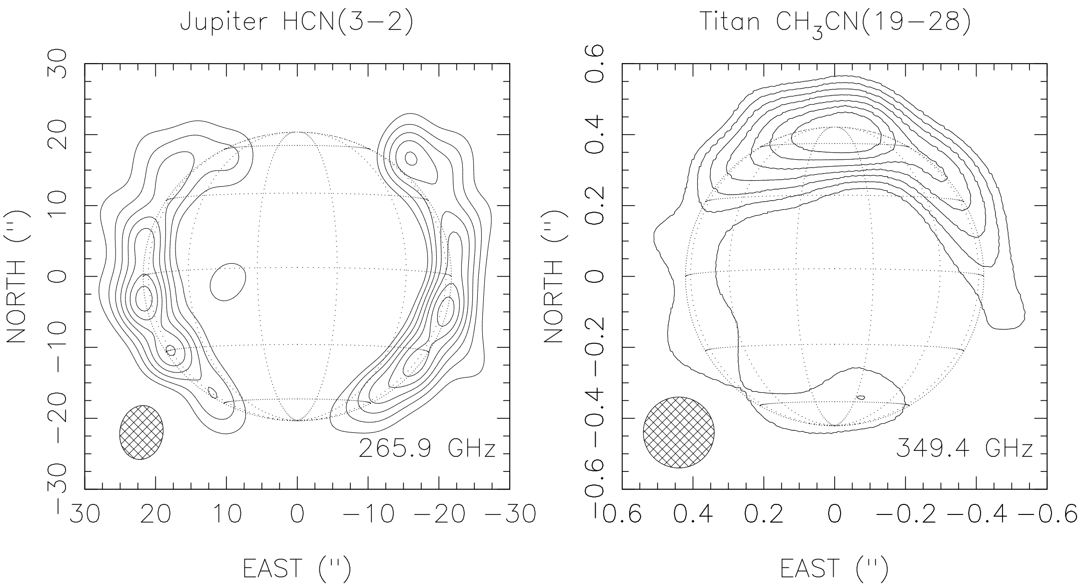

Fig. 1. Demonstration of the range of spatial scales currently available in planetary astronomy at mm/submm frequencies. These images differ in apparent spatial scale by ~ 50. (*left*) Submillimeter Array (SMA) imaging of stratospheric HCN on Jupiter (eq. diameter $43''$, resolution $\sim 7''$; 27 April 2007). The HCN is a relic of the Comet Shoemake-Levy 9 impacts in July 1995. The broad mid- to low-latitude distribution implies latitudinal mixing, but the distinct lack of HCN in the polar regions is suggestive of a polar vortex, which entrains HCN and transports it downward where it is destroyed (courtesy R. Moreno). (*right*) SMA imaging of stratospheric CH_3CN on Titan (eq. diameter $0.84''$, resolution $\sim 0.21''$; 23 March 2009). Methyl cyanide, like many nitriles and hydrocarbons on Titan, shows a strong latitudinal gradient. It is expected that these gradients will vary seasonally over the 30-year Titanian 'year'.

Small Solar System Bodies

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Understanding of the small bodies in the solar system is critical to our understanding of solar system formation and evolution. This class of bodies includes dwarf planets, moons, asteroids, comets, and Trans-Neptunian Objects (TNOs). Observations at longer wavelengths (submm to cm) are important because they allow us to probe into the subsurfaces of the bodies, something unique to those wavelengths. Such a probe yields information on composition and physical structure of that region of the subsurface. The smaller of these bodies have been difficult to observe in this wavelength range in the past due to the limited sensitivity of available telescopes, and even the larger bodies have been limited to unresolved observations. With the advent of ALMA and the upgrade to the VLA, it is now possible to make high-resolution, high-sensitivity observations at these wavelengths, allowing us to study them in detail in this heretofore unavailable range. We will present recent VLA observations of the Pluto/Charon system (see Figure 1 below) and several TNOs (Butler et al. 2011), discuss the prospects for observations of these bodies with ALMA (Moullet et al. 2011), present recent VLA observations of Near Earth Asteroid 2005 (YU55) (Busch et al. 2012), and discuss several other potential areas of growth in observations of small bodies with new or upcoming telescopes.

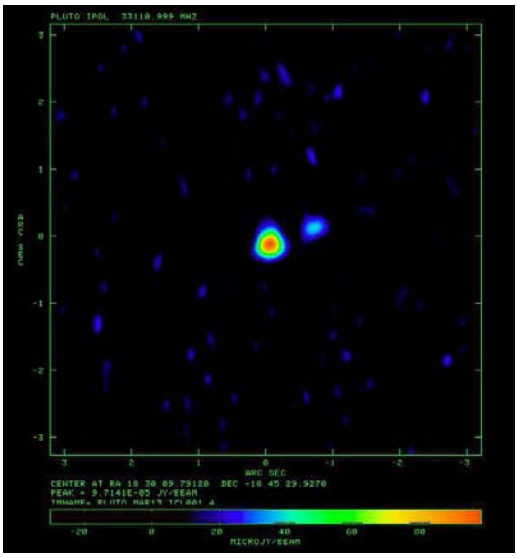

Figure 1: Image of Pluto and Charon at 1 cm wavelength from data obtained on March 13, 2010 with the Very Large Array. The separation of the two is obvious, and allows us to determine the brightness temperature of each of them individually.

References:

Busch, M.W., et al., 2012, ACM Conference Proceedings, number 1667 Butler, B.J., M.A. Gurwell, & A. Moullet, 2011, EPSC-DPS meeting, 1670
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The Chemistry of Carbon and Oxygen-rich Evolved Stars

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Herschel's view on late stages of stellar evolution – New enigmas to be solved with ALMA

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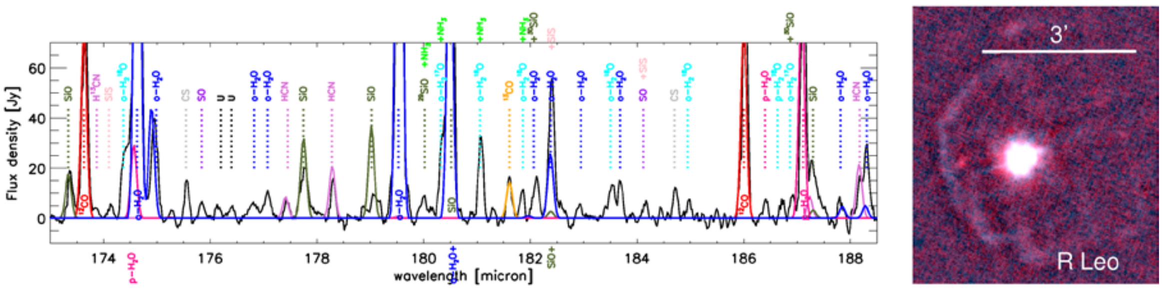
Mass loss is the dominating factor in the post-main sequence evolution of most stars but many aspects of the mass loss mechanism(s) are still not understood. The Herschel Space Observatory offers the astronomers some unique instruments (HIFI, PACS and SPIRE) to study circumstellar environments around evolved stars. We present the latest results obtained with Herschel in the field of low and intermediate mass evolved stars. The main focus of this talk will be on the chemistry occuring in the envelope of evolved oxygen-rich, carbon-rich and S-type Asymptotic Giant Branch (AGB) stars. Detailed analyses of the very rich infrared and sub-millimeter spectra show that various chemical processes, as shock-induced non-thermal equilibrium chemistry, ion-ion processes, photodissociation, etc. determine the chemical fractional abundances in the circumstellar environments around these evolved stars (see, e.g., left panel in the figure). In addition, recent images obtained with the PACS and SPIRE photometers show that the energetic encounter between the circumstellar material and ISM (see, e.g., right panel in the figure) is a very important player in establishing the exact chemical composition of the circumstellar material which is injected into the ISM. Using recent Herschel spectra and images, the different chemical processes will be discussed. I will show how the Herschel observations can answer some historical questions on these late stages of stellar evolution, but also add some new enigmas which potentially can be solved using ALMA.



Left panel: The continuum-subtracted PACS spectrum (black) of the red supergiant VY CMa between 173 and 188.5 μm (Royer et al. 2010). The main contributing molecules and isotopes are identified. Features not yet identified are indicated with a 'U'. The first modeling results are shown in different colors, corresponding to the different molecular species. *Right panel:* PACS 70 μm image of R Leo showing the interaction between the circumstellar and interstellar material.

Outflows in Late-type Stars

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The biggest challenge in the study of the final stage of low to intermediate mass (1–8 $M_{\odot}$) stars is the metamorphosis of a spherically symmetric asymptotic giant branch (AGB) star into a planetary nebula (PN) with highly asymmetric shape (such as bipolar or point symmetric shapes). During the AGB phase, stars loose their mass in slow ($V_{\rm exp}$∼15 km s^{-1}) spherical winds. Then, stars change their morphology and kinematics drastically in a subsequent very short (∼1000 yr) phase called proto-PN or post-AGB. In this transition phase, high-velocity (>100 km s^{-1}) outflows from the central stars (or star systems) are considered to be playing crucial roles in forming highly asymmetric structures. However, the origin of high-velocity outflows from evolved stars (PNe and proto-PNe) is still an open question. In this talk, I will review the recent observations of high-velocity outflows from evolved stars. I also compare the properties of high-velocity outflows from evolved stars with those of the outflows from young stellar objects.

From large scale surveys to ALMA observations of massive star forming regions.

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We have compiled a large molecular line data base of massive star forming regions in the southern Milky Way. These regions are confined within giant molecular, identified from our large scale CO survey, that trace the galactic spiral structure. The molecular gas radial distribution peaks midway between the Sun and the galactic center, corresponding in the IV quadrant to the location of the Norma Spiral arm. We study in some detail one of the foremost regions of massive star formation, G331.5, in the tangent region of Norma arm, using single dish millimeter continuum and line emission maps, as well as recent observations with ALMA.

Progress of ALMA Construction and Operations

T. Hasegawa[1], S. Iguchi[1], K. Tatematsu[1], D. Iono[1] and the East Asian ALMA team

[1] NAOJ Chile Observatory, National Astronomical Observatory of Japan.

The Atacama Large Millimeter/submillimeter Array (ALMA), an international astronomy facility, is a partnership of Europe, North America and East Asia in cooperation with the Republic of Chile. ALMA is approaching its end of construction and start of full operations expected in 2013, while its Early Science Operations since 2011 September is producing exciting results as we see in this conference. In this paper, we review the status of the ALMA construction and operations with an emphasis on the contribution from East Asia (EA), i.e., the Atacama Compact Array (ACA) and the receiver Bands 4, 8 and 10.

ACA has been designed and built to collect the spatially extended (i.e., low spatial frequency) components of the observed objects and to improve the fidelity of the resultant image. It consists of eleven 7-m antennas and four 12-m antennas. The commissioning observations of the ACA system on the galaxy M100 have demonstrated that it can indeed recover the spatially extended component of the object. The Band 4, 8 and 10 receiver cartridges are being delivered for installation at the Front End Integration Centers and at the ALMA Operations Support Facility.

ALMA: the Challenges of Construction and Operations

THIJS DE GRAAUW[1]

[1] Joint ALMA Observatory, Santiago, Chile

The Atacama Large Millimeter/submillimeter Array (ALMA) is an international radio observatory under construction in the Atacama region of northern Chile. ALMA is a combination of two arrays of high-precision submm antennas: one made of fifty 12-meter antennas which can be arranged in configurations with diameters ranging from about 150 meters to 16 km. The other, the ALMA compact Array (ACA), consists of twelve 7-meter diameter antennas operating in closely-packed configurations of about 50m in diameter. In addition there will be four more 12-meter antennas to provide the zero-spacing information. The total collecting area will be 6600 m2. The antennas will be equipped with receivers covering most of the frequency range from 35 to 950 GHz.

The construction is progressing well and by now 50 (of the 66) antennas have been installed at the ALMA Observing Site (5000m). Operations started with Early Science observations. Cycle-0 observations are almost completed and the cycle-1 highest ranked proposals have been selected. These parallel activities show an interesting synergy between the activities for construction (hardware acceptance, site infrastructure works, AIV, CSV, software upgrades) and for operations (hardware and software maintenance, observing, data reduction,etc) but present at the same time a challenge to the joint observatory in transition phase from Construction-to-Operations.

As the first data show very interesting scientific results, that build up pressure for more observations, and construction needs to be completed with first priority (budget) an interesting balancing act is taking place.

Future Development of ALMA

Daisuke Iono[1], Satoru Iguchi[1], Norikazu Mizuno[1], Masao Saito[2], EA ALMA team members

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[2] Joint ALMA Observatory, Santiago, Chile

The Atacama Large Millimeter/submillimeter Array (ALMA) is already producing a growing number of impressive and scientifically compelling results during its first year of operation as the most powerful mm/submm interferometer in the world. In order to maintain ALMA as the state-of-the-art facility over the course of its projected life of 30+ years, continuing technical upgrades and development of new capabilities are essential. Here we present progress of the development studies/projects for the next 5 years with particular emphasis on our recent discussion and developments in the East Asian region. Specifically, we will focus our discussion on the recent progress and the scientific importance of band 1 (40 GHz). In addition, we will summarize our study of the development of the 1.3 - 1.5 THz band (Band 11) and briefly mention the status of the updated photonic LO system, and the development of the high-site artificial noise for the improvement of calibration accuracy which is led by the NAOJ. We also provide a status update of the other new receiver bands.

IRAM: Present and Future

PIERRE COX[1]

[1] IRAM, Grenoble

In recent years, major changes were successfully done at the IRAM Plateau de Bure interferometer and the 30-meter telescope, in particular in the areas of receivers and back-ends. These enhancements increased in significant ways the sensitivity and the efficiency of both IRAM facilities. I will present results obtained on a variety of topics, emphasizing the studies of the high-redshift ($1 < z < 7.3$) sub-millimeter galaxies and quasars, that will illustrate the recent progress that has been made.

The talk will also describe the NOrthern Extended Millimeter Array (NOEMA), a project that will further enhance the IRAM interferometer in the ALMA era.

The Large Millimeter and Sub-millimeter Telescope Project, "ALMA SPICA Synergy Telescope (ASTe)"

RYOHEI KAWABE[1], KOTARO KOHNO[2], SATOSHI YAMAMOTO[2], YOICHI TAMURA[2], & TAI OSHIMA[3]

[1] Joint ALMA Observatory
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Here we report on the new medium-scale plan in Japan to construct a 30 - 50 m class millimeter (mm) and sub-mm single dish telescope. The main observing frequency of the telescope is 70 to 400 GHz, which just covers main atmospheric windows in good observing sites at mm and sub-mm wavelengths such as the ALMA site. We are also aiming at observations at higher frequency up to 1 THz with the limited use of the antenna surface, e.g., under-illumination of the telescope. One of important science goals in this new telescope project is unveiling the large scale structure of the high-z universe and cosmic star formation history by spectroscopic surveys of high-z galaxies in CO and [CII] lines. With exploiting synergy with ALMA this telescope can contribute to the breadth of astronomy and astrophysics, e.g, astrochemistry, star formation in the galaxy and external galaxies, cosmology, and sub-mm VLBI.

The CCAT Project

Gordon J. Stacey[1]

[1] Cornell University

The CCAT telescope is a 25 m submillimeter telescope envisioned for a site near the summit of Cerra Chajnantor, in the Atacama desert in northern Chile. The large CCAT aperture with its high surface accuracy (~ 10 μm rms) and wide (1 deg) field of view, at the excellent Chajnantor site (less than 0.7 mm precipitable water, 50% of the time), together with the large format array cameras and spectrometers envisioned for the facility promise to deliver superb point source sensitivity and unrivaled mapping speed in the submillimeter telluric windows. I will discuss the characteristics of the CCAT facility including telescope and first light instrumentation, the primary science goals for the project, its current status and timeline, and finish with a discussion of the scientific synergies between CCAT and other contemporary faciliites. The CCAT project is a collaboration between Cornell University, Caltech, the University of Colorado, a consortium of Canadian Unversities (Dalhousie, McGill, McMaster, British Columbia, Calgary, Toronto, Waterloo, Western Ontario), the Universities of Cologne and Bonn, and Associated Universities, Incorporated, and the work is supported in part by the US National Science Foundation.

The LMT in the ALMA Era

MIN S. YUN[1]

[1] University of Massachusetts, USA.

The Large Millimeter Telescope (LMT) is a 50-m diameter radio telescope designed to operate at the wavelength range between 1 and 4 mm. Taking advantage of its large collecting area (about 1/3 of ALMA) and high angular resolution (5” at 1.1mm), the main emphasis of the LMT instrumentation program is large format cameras with a wide wavelength coverage, exploiting the parameter space distinct from that of the ALMA: rapid large area mapping and ultra-wide spectral coverage. As a single aperture system, another distinct advantage of the LMT is that a unique instrument employing state-of-art technology can be deployed rapidly, unlike an interferometer. I will review the current suite of LMT instruments and those planned in the near future and the science goals these instruments aim to achieve during the next decade. I will also describe how the LMT will play an important complementary role to the ALMA in addressing a broad range of questions in different scientific areas.

The CCS 45 GHz Zeeman Project: Magnetic Field Measurements Towards Prestellar Cores

F. Nakamura[1], H. Ogawa[2], S. Kameno[3], K. Kimura[2], I. Mizuno[3], K. Tokuda[2], M. Takatsu[2], D. Iono[1], S. Takano[4], K. Dobashi[5], T. Matsumoto[6], N. Kuno[4], R. Kawabe[7], T. Onishi[2], M. Momose[8], H. Shinnaga[1], T. Tanaka[2], S. Yamamoto[9], H. Maezawa[2], and T. Hirota[1]

[1] National Astronomical Observatory of Japan.
[2] Osaka Prefecture University.
[3] Kagoshima University.
[4] Nobeyama Radio Observatory.
[5] Tokyo Gakugei University.
[6] Hosei University.
[7] JAO.
[8] Ibaraki University.
[9] University of Tokyo.

Stars are believed to form via gravitational collapse of dense cores. According to the standard scenario of star formation, the gravitational collapse is significantly influenced by magnetic fields. However, the role of magnetic fields in the gravitational collapse phase remains poorly understoond because of the difficulty of direct measurements of the core magnetic field strengths. Recent numerical simulations have revealed that the strong magnetic fields reduce the core angular momenta efficiently, resulting in the retardation or suppression of circumstellar disks (so-called magnetic braking catastrophe). Therefore, measuring the core magnetic field strengths is crucial to understand how star and planet formation takes place in the cource of the gravitational collapse of the dense cores. Until now, the magnetic field strengths in star forming regions have been measured mainly by the Zeeman obsevations using the HI and OH thermal and OH maser lines (see, however, the recent CN Zeeman observations towards massive star forming regions). Since these emission lines are generally not associated with the dense cores, it is difficult to estimate the core magnetic field strengths from these observations. To elucidate the role of magnetic fields in the gravitational collapse phase, we have started a project of the Zeeman measurements towards prestellar dense cores, using the CCS ($J_N = 4_3 - 3_2$) line by developing a new 45GHz band, dual polarization reciever for the NRO 45m telescope. The CCS molecule is known to be abundant in the prestellar cores in nearby star forming regions such as Taurus. In addition, CCS ($J_N = 4_3 - 3_2$) has a large magnetic dipole moment. Therefore, it is suitable to measure the core magnetic field strengths. In this presentation, we present the details of our CCS Zeeman project and the current status of the development of our new 45GHz band reciever.

The Next-Generation Infrared Astronomy Mission SPICA

TAKAO NAKAGAWA[1]

[1] ISAS/JAXA

We present the overview and the current status of SPICA (Space Infrared Telescope for Cosmology and Astrophysics), which is a mission optimized for mid- and far-infrared astronomy with a cryogenically cooled 3.2 m telescope. SPICA has high spatial resolution and unprecedented sensitivity in the mid- and far-infrared, which will enable us to address a number of key problems in present-day astronomy, ranging from the star-formation history of the universe to the formation of planets. To reduce the mass of the whole mission, SPICA will be launched at ambient temperature and cooled down on orbit by mechanical coolers on board with an efficient radiative cooling system, a combination of which allows us to have a 3-m class cooled (6 K) telescope in space with moderate total weight (3.7t). SPICA is proposed as a Japanese-led mission together with extensive international collaboration. ESA's contribution to SPICA has been studied under the framework of the ESA Cosmic Vision. The consortium led by SRON is in charge of a key focal plane instrument SAFARI (SPICA Far-Infrared Instrument). Korea and Taiwan are also important partners for SPICA. US participation to SPICA is under discussion. The SPICA project is now in the "risk mitigation phase". The target launch year of SPICA is 2022.

The Event Horizon Telescope: Observing Black Holes with Schwarzschild Radius Resolution

S. DOELEMAN[1]

[1] MIT Haystack Observatory, USA.

It is now almost certain that at the center of our Milky Way Galaxy lies a super massive black hole - 4 million times more massive than our Sun. Because of its proximity to Earth, this object, known as Sagittarius A*, presents astronomers with the best opportunity in the Universe to spatially resolve and image a black hole Event Horizon. To do this requires using Very Long Baseline Interferometry (VLBI), the technique whereby radio telescopes around the world are linked together in a Global phased array. Very short wavelength VLBI observations have now confirmed structure on $\sim$4 Schwarzschild radius scales within SgrA*, and have revealed time variability in this source on the same spatial scales. For the much more massive (6 billion solar mass) black hole powering the relativistic jet in M87, similarly compact structures have been detected. I will describe the instrumentation efforts that enable these observations, discuss what current and future VLBI observations can tell us about these super-massive black holes, and describe plans for assembling a Global submm-VLBI Event Horizon Telescope that will incorporate ALMA as a beam formed single aperture.

The Greenland Telescope (GLT) Project

K. Asada[1], M. Inoue[2], S. Matsushita[3] and the GLT team[4,5,6,7]

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[2] AS Institute of Astronomy and Astrophysics, Taiwan R.O.C.
[3] AS Institute of Astronomy and Astrophysics, Taiwan R.O.C.
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[5] Smithsonian Astrophysical Observatory, USA [6] MIT Haystack Observatory, USA [7] NRAO, USA

We report the latest overview of Greenland Telescope Project.

Imaging the shadow of the black hole is one of the ultimate goals for modern astrophysics. By imaging the super massive black holes (SMBHs) with its mass at the center of active galaxies, we can prove their existence directly, and determine their mass and spin parameters. Strong lensing effect is expected, which is crucial for testing general relativity in regime of strong gravitational field. In addition, imaging the vicinity of the black holes is important to investigate the launching mechanisms of the ultra-relativistic jets and the accretion process onto SMBHs. Even for the SMBHs, their expected angular sizes of the shadows are very small (40 - 50 micro arcseconds at largest). VLBI observations at submillimeter wavelength is one of the most effective methods to achieve sufficient angular resolution for imaging the shadow; VLBI observation at 345 GHz with 9,000 km baseline can provide an angular resolution of $\sim$ 20 micro arcseconds, about one order of magnitude better than current best angular resolution.

In order to realize the imaging of the shadow of SMBHs, one of our primary efforts is establishing a new submillimeter VLBI station in order to improve the angular resolution and image quality. In addition to VLBI usage, we plan to use the telescope in single dish mode as a pathfinder for THz astronomy. We plan to realize it by redeploying the ALMA-NA prototype antenna. Based on the atmospheric condition and geometrical configuration with other existing telescopes, we select the Summit Camp on Greenland as the possible new site for the prototype antenna.

We have already started a site-testing to measure the atmospheric transparency at submillimeter wavelength since August of 2011 for further studies of atmospheric condition at the site. In the meantime, we have started works on retrofitting the ALMA-NA prototype antenna to understand current status after its shut down and to adapt to the new environment.

Detailed on the project will be presented by M. Inoue in this conference.

(left) ALMA-NA prototype antenna at VLA site. (right) Working on the panel adjustment for photogrametry measurement.