SMA Newsletter

Number 7 | Submillimeter Array Newsletter | 21 January 2009

The Submillimeter Array (SMA) is a pioneering radio-interferometer dedicated to a broad range of astronomical studies including protostellar disks and outflows; evolved stars; the Galactic Center and AGN; normal and luminous galaxies; and the solar system. Located on Mauna Kea, Hawaii, the SMA is a collaboration between the Smithsonian Astrophysical Observatory and the Academia Sinica Institute of Astronomy and Astrophysics.

Contents

1 From the Director

Observing time requests to the SMA continue to be significantly greater than the available time and we are always seeking to enhance the throughput of the array. During the past several months we have been testing bandwidth doubler hardware (initial tests were first reported in SMA Newsletter No. 5) and control software that will increase the IF bandpass of the SMA from 4–6 GHz to 4–8 GHz for single receiver operation. Software tools are currently being refined to enable users to construct observations using either the current DSB x 2 GHz bandpass or the upgraded DSB x 4 GHz bandpass. For spectral line observations, this increases the frequency space for line selection and will enable some projects to be completed in half the time, and for continuum observations a factor of $\sqrt{2}$ improvement over the current sensitivity is expected. Eight units have been built and tested, and seven of these have been installed into antennas at the observatory site, the remaining unit will be incorporated into the array during the coming weeks. While some minor teething problems remain, the increase in performance offered by the upgraded system is so significant that we will offer this option in the upcoming call for proposals (semester 2009A: May 16th – November 15th), which will be posted towards the end of January at: http://sma1.sma.hawaii.edu

Ray Blundell

2 Science Highlights

2.1 Probing the Inner Circumstellar Envelope of IRC+10216 with the SMA

Late-type stars in the Asymptotic Giant Branch (AGB) evolutionary stage are the primary source of interstellar dust and perhaps many complex molecules in the ISM. Since these low to intermediate mass (1–8 $M_\odot$) stars are among the most populous and long-lived, they have considerable effect on the chemical evolution of the Galaxy.

Interferometric mapping of such envelopes allows us to check predictions of abundances of specific molecules as a function of radius in the circumstellar envelope. "Parent" molecules, such as CO, C_2H_2, CS, HCN, & SiS, are formed in the stellar atmosphere in thermo-chemical equilibrium (Tsuji 1964, 1973). Once they are expelled to a distance from the star at which the density is too low for chemical reactions, their abundances "freeze out" (McCabe et al. 1979). At about that distance ($\sim$ 20 AU), the temperature has dropped below the dust condensation value ($\sim$ 1200 K) and dust grains begin to form (Monnier et al. 2000). Radiation pressure then accelerates the grains and via collisions, the molecules too, in an outflow which reaches a terminal velocity of $\sim$14 km s^{-1} (Olofsson 2004).

In the outer parts of the expanding envelope, a rich carbon-dominated photo chemistry driven by the ambient ultraviolet field produces species such as CN and C_4H. Their typically optically thin emission can be observed as ring-like distributions with radii, at a few times 10^{16}–10^{17} cm, depending on the chemical reactions at work (see the reviews of Glassgold 1996; Ziurys 2006). The inner envelope at $10^{14} \sim 10^{15}$ cm, where the acceleration of the outflowing material begins, is not well studied, and requires subarcsecond angular resolution observations of highly excited molecular lines.

IRC+10216 (CW Leo) was discovered from an unbiased 2.2 μm survey in the 1960's, and is one of the brightest infrared sources in the sky (Neugebauer & Leighton 1969). This is an archetypal carbon star (relative abundance of carbon is much greater than that of oxygen). At a distance of 150 pc and with a high mass-loss rate ($> 10^{-5}$ M$_\odot$ yr^{-1}), this star is an ideal target for studies of physical and chemical processes in AGB envelopes (e.g. Olofsson et al. 1982). Nearly 60 molecular species have been discovered in the circumstellar shell of IRC+10216, from single-dish spectral-line surveys (Kawaguchi et al. 1995; Avery et al. 1992; Groesbeck et al. 1994; Cernicharo et al. 2000; He et al. 2008).

We have begun a spectral-line survey of IRC+10216 with the SMA to cover a significant fraction of the submm wave spectrum: 300–355 GHz. At submm wavelengths, we can probe the physical conditions in the inner circumstellar envelope with lines requiring higher excitation conditions (temperatures of hundreds to thousands of K and column densities of $10^{22} - 10^{24}$ cm^{-2}) (Keady & Ridgway 1993). The first set of observations were done in early 2007 in the subcompact array configuration, with synthesized beam of $3'' \times 2''$. Observing time has been allocated in the current semester to complete the survey, utilizing the bandwidth-doubling mode of observations. Except for a small range of frequencies near 325 GHz, where the atmosphere becomes opaque due to terrestrial water vapor, we hope to cover the remaining frequency ranges as completely as possible in the 300 GHz band. For technical details of the observations carried out so far, see Patel et al. (2009a).

In the first phase of the SMA line-survey of IRC+10216 a total of 92 lines was detected. Most are from higher rotational transitions of molecules that are well-known in IRC+10216, such as SiCC, SiS and SiO and their isotopic species. The expansion velocity of the circumstellar shell, V_{exp} is one of the fitted line-profile parameters. A distribution of V_{exp} is shown in Figure 2.1. The histogram peaks at 14 km s^{-1}. Also shown in this figure are V_{exp} from published single-dish line-surveys of IRC+10216. The SMA observations shown in grey bars reveal a significant number of narrow lines with velocities around 4 km s^{-1}. Both histograms show a continuous distribution of expansion velocities between these two peaks at 4 and 14 km s^{-1}. To within $\sim$2 km s^{-1}, all the narrow lines detected in the SMA line-survey are centered at the systemic velocity of -26 km s^{-1}. These come from the inner circumstellar envelope where the material is still being accelerated, and has not yet reached the terminal velocity.

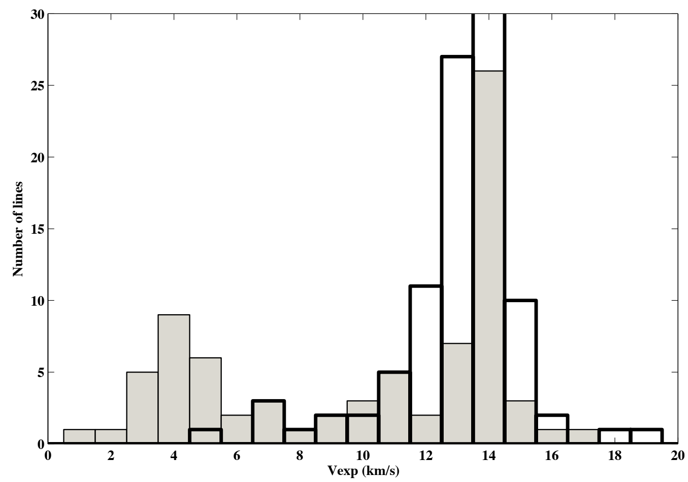

Figure 2.1: Distribution of expansion velocities derived from lines detected in the circumstellar envelope of IRC+10216. The uncertainty in V_{exp} is $\sim$0.2 km s^{-1} (1σ). White bars with bold outlines are from the recent line survey of He et al. (2008) which is representative of all single-dish line surveys toward IRC+10216 at cm to submm wavelengths. The bin at 14 km s^{-1} is shown truncated here; it actually consists of 170 lines. Shaded bars represent SMA observations, showing a new population of narrow lines which peaks at $\sim$4 km s^{-1}.

Of the 25 narrow lines ($V_{exp} \leq 7$ km s^{-1}) detected so far, 12 are as yet unassigned. Most of the identified lines are rotational transitions within vibrationally excited states in simple diatomic molecules such as CS, SiS, (and their isotopic species) and notably, CO. Figure 2.2 shows the CO J=3–2 and 2–1 lines in v=1 state which is $\sim$3100 K above the ground state. The rest frequencies of these lines are 342.6 and 228.4 GHz, respectively. Detection of the CO v=1, J=1–0 line in IRC+10216 was claimed by Scoville and Solomon (1978), but this line turned out to be one of C_4H (Cummins et al. 1980). The vibrationally excited CO emission appears to be unresolved in our $3'' \times 2''$ beam, and is coincident with the peak continuum emission from the star (Patel et al. 2009b).

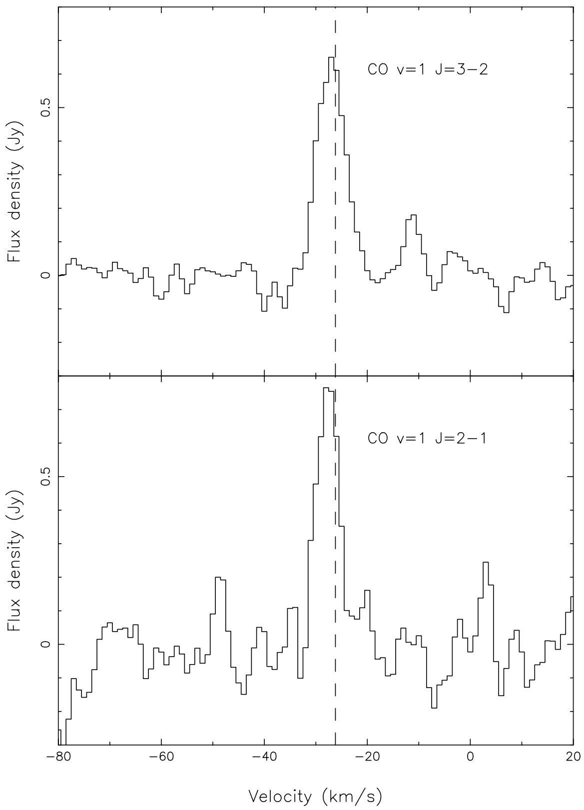

Figure 2.2: The surprisingly strong spectra of vibrationally excited CO emission in $J = 3-2$ (top) and $J = 2-1$ (bottom) toward IRC+10216. The dashed line is the systemic velocity of the source, -26 km s^{-1}.

We obtained higher angular resolution follow-up observations with the SMA, in the extended configuration, of one of the vibrationally excited narrow lines: CS v=2, J=7–6. The emission remains spatially unresolved with our beam of $0.''8 \times 0.''6$, and the deconvolved source size is $\leq 0.''2$ (Patel et al. 2009a). Assuming that these vibrationally excited lines come from a region of size $0.''2$, we obtain a brightness temperature of 200∼400 K. Using the LTE approximation and a kinetic temperature of 1000 K, we find that the gas density required to excite these lines is typically about an order of magnitude higher than 10^8 cm^{-3} for a radius of 2.2×10^{14} cm (corresponding to $0.''1$) deduced from interferometric IR observations by Danchi et al. (1994). This rough estimate suggests that collisional excitation under the LTE assumption is unlikely to explain our observations. Since the A coefficient for the vibrational transition (∼10 s^{-1}) is several orders of magnitude greater than that for rotational transitions, the $v = 1$ levels may be excited via radiation (Carrol and Goldsmith 1981; Menten et al. 2006a). However, to attain such a high radiation temperature, the emission must arise from a region even smaller than $0.''2$.

Since the observations of the CO v=1, J=$3-2$ and $2-1$ lines were carried out at different phases of pulsation of IRC+10216, the relative intensities of these two lines may complicate their interpretation. We calculated the phase, ϕ, for the two epochs of our observations, $T_{\rm obs}$, given by $(T_{\rm obs} - T_{\rm max})/P)$, using 664 d as the period, P. For this we have calculated the time of the last maximum considering the IR minimum date of 1989 Dec 5 given by Danchi et al. (1994). We find $\phi = 0.25(0.99)$ for the 346 (228) GHz observations. These values of ϕ are in good agreement with values obtained using the date of maximum IR flux (at 3.76 μm; Le Bertre 1992) on 1992 May 30 from cm- and IR-monitoring reported by Menten et al. (2006b). Thus it is plausible that the $J = 2-1$ emission is brighter because it is being observed closer to the IR maximum, compared to our $J = 3-2$ observations. Future observations at different epochs may help check the radiative pumping hypothesis while near-simultaneous observations of different J transitions in $v = 1$ will be helpful for detailed radiative transfer modeling of these lines. While our present observations have inadequate angular resolution to definitively rule out maser action to explain the vibrationally excited CO lines, we note that even for a $0.''1$ Gaussian source, the brightness temperature would be 1451 (738) K for the 228.4 (342.6) GHz emission, consistent with thermal emission, implying a gas density $> 10^9$ cm^{-3}. We note that a strict lower limit to the size of the CO emission is given by recent observations by Menten et al. (2009) who derive a (uniform disk) diameter of 84 milliarcseconds for the IRC+10216 radio photosphere from their Very Large Array measurements of the object's 7 mm wavelength continuum emission.

In summary, SMA observations of IRC+10216 have revealed many new lines which appear to be excellent probes of the physical coniditions in the inner circumstellar envelope. Observations of some of these lines in the near future with the eSMA will provide an improvement in angular resolution by nearly a factor of 10 ($0.''2$). In the future, ALMA will have much higher angular resolution and sensitivity, allowing detailed studies of the complex dynamics of the gas close to the stellar surface to be made.

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(CfA)

2.2 Discovery of a Bipolar Molecular Outflow from a Young Brown Dwarf

Studying the earliest stages in the birth of stars is crucial for understanding how they form. Brown dwarfs with masses between those of stars and planets are not massive enough to maintain stable hydrogen-burning fusion reactions during most of their lifetime. It is thought that brown dwarfs (BD) and probably very low-mass stars (0.1–0.2 $M_\odot$) could form the same way as stars (Luhman et al. 2007). However the typical masses of BDs (15–75 M_J) are far below the typical Jeans mass in molecular clouds, and hence it is difficult to make a very low-mass stellar embyro by direct gravitational collapse. Two major models have been proposed for the formation of BDs. In the first senario, they form like stars through gravitational collapse and fragmentation of low-mass cores. In the second one, they form through the ejection process (see Whitworth et al. 2007 and references therein). More observations are needed to find out important clues of the BD formation process and hence to clarify which mechanism dominates.

We present here the detection of a bipolar molecular outflow from the young bona-fide brown dwarf ISO-Oph 102. ISO-Oph 102 (or [GY92] 204), a young M6 dwarf, is located in the ρ Ophiuchi dark cloud at a distance of 125 parsecs. Its estimated mass is 60 M_J (Natta et al. 2002). This value is below the hydrogen-burning limit and in good agreement with the dynamically measured mass of an M6.5 dwarf of 55 M_J at the same age (Stassun et al. 2005). ISO-Oph 102 is therefore a young bona-fide brown dwarf. The presence of the Lithium absorption in its optical spectrum indicates its young nature. Natta et al. (2004) estimated an accretion rate of $10^{-9} M_\odot$ yr^{-1}. The blueshifted optical jet component was discovered by Whelan et al. (2005). The optical visibility of ρ Oph 102 suggests that the source corresponds to a class II object in the star formation phase, with an accreting circumstellar disk and the protostar at this stage is the so-called classical T Tauri star.

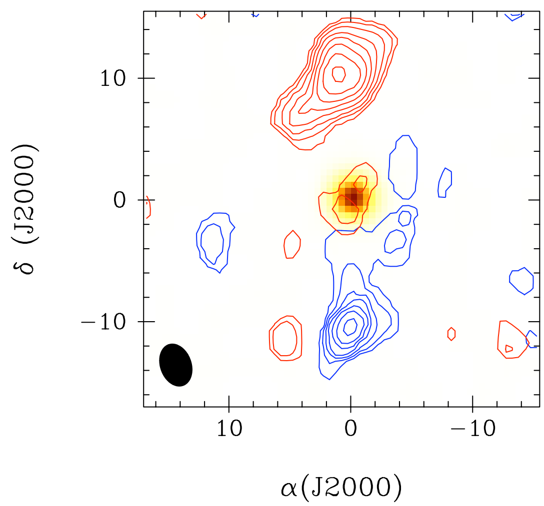

Figure 2.3: Overlay of the J-band (1.25 μm) near-infrared *Two Micron All Sky Survey* (2MASS) image and the integrated intensity in the carbon monoxide (CO $J = 2-1$) line emission from 3.8 to 7.7 km s^{-1} line-of-sight velocities. The blue and red contours represent the blueshifted (integrated over 3.8 and 5.9 km s^{-1}) and redshifted (integrated over 5.9 and 7.7 km s^{-1}) emissions, respectively. The contours are 3, 6, 9,...times the rms of 0.15 Jy beam^{-1} km s^{-1}. The BD is visible in the J-band image. The position angle of the outflow is about 3°. The peaks of the blue- and redshifted components are symmetric to the center of the BD with an offset of 10″. The synthesized beam is shown in the bottom left corner.

[1]Other members of the SMA IRC+10216 line survey team are: Sandra Brünken, Robert W. Wilson, Karl M. Menten, Mark Reid, Michael McCarthy, Dinh-Van-Trung and Jinhua He

We have observed ISO-Oph 102 with the receiver band at 230 GHz of the SMA. The SMA correlator was configured with high spectral resolution bands of 512 channels per chunk of 104 MHz for the ^{12}CO, ^{13}CO, and C^{18}O $J = 2 \rightarrow 1$ lines, giving a channel spacing of 0.27 km s^{-1}. A lower resolution of 3.25 MHz per channel was set up for the remainder of each sideband. The compact configuration was used, resulting a synthesized beam of $3''.60 \times 2''.43$ with a position angle of 8.5°. The integrated flux density from the dust continuum emission was 7±3 mJy measured at the brown dwarf position.

An overlay of a near-infrared image and the integrated intensity in the carbon monoxide (CO $J = 2-1$) line emission is shown in Figure 2.3. Two spatially resolved blue- and redshifted CO components are symmetrically displaced on opposite sides of the brown dwarf position, with each lobe of about $8''$ in size, corresponding to 1000 AU in length. This is similar to the typical pattern of bipolar molecular outflows as seen in young stars. The two outflow components with a wide range of velocity (Fig. 2.4) suggest a bow shock structure, an effect of the interaction between the jet propagation and the ambient material, which appears very similar to the bow shock phenomena as seen in young stars (Lee et al. 2000). Such a CO outflow morphology suggests that the jet-driven bow shock model (Masson & Chernin 1993) may be at work in ISO-Oph 102. However, more observations are clearly needed to confirm this structure.

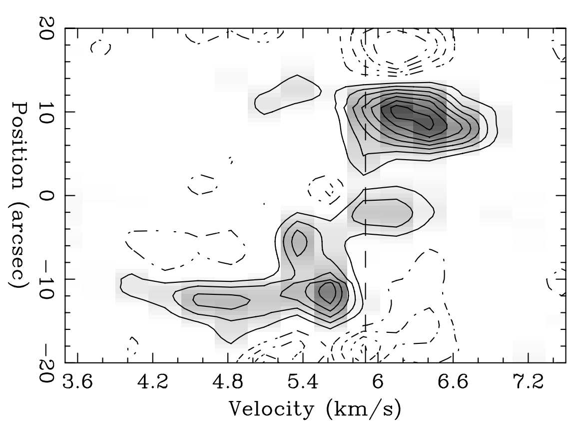

Figure 2.4: Position-velocity (PV) cut diagram for CO $J = 2 \rightarrow 1$ emission at a position angle of 3°. The contours are −12, −9, −6, −3, 3, 6, 9, 12,...times the rms of 0.2 Jy beam^{-1}. The systemic velocity of 5.9±0.27 km s^{-1} of the BD, which is estimated by an average of the velocities of red- and blue-shifted components, is indicated by the dashed line. Both blue- and red-shifted components show a wide range of velocity in their structure, which appears to be the bow-shock surfaces as observed in young stars (Lee et al. 2000). These surfaces are formed at the head of the jet and accelerate the material in the bow-shock sideways (e.g., Masson & Chernin 1993).

Following the standard manner, we estimate an outflow mass of $1.6 \times 10^{-4} M_\odot$ and a mass-loss rate of $1.4 \times 10^{-9} M_\odot$. These values are over 2 orders of magnitude smaller than the typical ones for T Tauri stars. From our millimiter continuum data and our own analysis of *Spitzer* infrared photometry, our disk modeling indicates that the brown dwarf has a disk with a mass of $8 \times 10^{-3} M_\odot$, an inclination angle between 63° and 66°, and an outer disk radius of 80±10 AU. The disk radius value is significantly greater than the maximum one of truncated disks (∼20 AU) if the brown dwarf would form through an ejection (Bate & Bonnell 2005).

The IRS infrared spectra of ISO-Oph 102 exhibit strong crystalline silicate features (enstatite at 9.3 μm and forsterite at 11.3 μm). Using the method in van Boekel et al. (2003), we estimate a mass fraction of the crystalline silicates of 32±2 % in the BD. The high crystalline mass fraction provides a direct evidence of grain growth and dust settling, indicating ISO-Oph 102 is in the transition phase between classes II and III (a class with an optically thin disk) and the BD is reaching the final mass.

Our results indicate that the bipolar molecular outflow in BDs is very similar to outflows as seen in young stars but scaled down by three and two orders of magnitude for the outflow mass and the mass-loss rate, respectively. This strongly supports the idea that BDs share the same formation mechanism with the low-mass stars, through gravitational collapse and fragmentation of low-mass cores (Padoan & Nordlund 2004, Bonnell et al. 2008).

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Ngoc Phan-Bao (ASIAA)

3 Engineering Highlights

eSMA Complex Gain Calibration Test

On Nov. 7, 2008 (UT), an experiment was performed to see if we have good enough baseline solutions to the JCMT and CSO, and a good enough interferometer model, to allow us to use a quasar for complex gain calibration of an astronomical source. To make the test as realistic as possible, we ran an observing script for an SMA-only project which had been approved through the normal TAC process. This was turned into an eSMA test by adding the CSO and JCMT into the array, and adding two additional quasar gain calibrators to the script. The program source was MWC480, and the quasars 0428+329, 3C111 and 3C84 (7.3, 11.7 and 23.1 degrees away from the program source, respectively) were used as gain calibrators. The array was tuned to 267.6 GHz, which is a frequency at which all eSMA stations can be locked to a single reference signal. The data were corrected offline for the CSO's 4.4 mm axis non-intersection term, which is the only eSMA-specific term in our interferometer model.

For an initial test, the 3C111 data was calibrated with the 3C84 data. An antenna-based complex gain calibration was derived using a 0.8 hour smoothing window. During the nine hours when good data were acquired, the CSO's phase drifted relative to an SMA reference antenna by about 100 degrees. The JCMT's phase drifted by about 450 degrees during the same period, but the gain calibrators where observed frequently enough (once every 30 minutes) to track the phase with no wrap ambiguities. The amplitude was nearly constant on both the CSO and JCMT baselines, indicating that the rotation of waveplates on the CSO and JCMT worked well in matching their polarizations to that of the SMA antennas. After calibration, maps of the 3C111 data were made for the upper and lower sidebands. The images were point-like, and were displaced 0.07 arc seconds from the expected location. The synthesized beam had a size of 1.14 x 0.43 arc seconds. Imaging 3C84 using 3C111 as a calibrator gave similar results. Data for the program source, MWC480, was also calibrated and imaged. Maps made with and without the CSO and JCMT data showed the intensity peaking at the same position.

We believe that we can now phase calibrate eSMA data, and we expect to begin test science observations in the 345 GHz band in March 2009.

Ken Young

4 Proposal Statistics (16 November 2008 – 15 May 2009)

The SMA received a total of 96 proposals (SAO: 59, ASIAA: 23, UH: 14) requesting 226 nights of observing time in the 2008B semester.

Of the 59 proposals received by the SAO TAC, there are 32 internal proposals (PIs affiliated with CfA) requesting a total of 93 tracks, and 27 external proposals requesting a total of 61 tracks. In science categories, star formation makes up of 35 proposals, followed by Extragalactic (19 proposals), Galactic Center (1), Stellar (3) and Planetary (1).

The overall over subscription rate for the semester is 2:1, but the over subscription is not uniformly distributed in terms of weather or source RA requests. The demand for good weather (<2.5 mm PWV) and higher frequency bands (345 GHz and 690 GHz) is higher, with an oversubscription of 3:1.

Track allocations by weather requirement (all partners[1]):

PWV[2]	SAO	ASIAA	UH[1]
<4 mm	2A + 33B	10B	15
<2.5 mm	26A + 17B	7A	11
<1 mm	2A + 8B	2A	4
	30A + 58B	9A + 10B	30

(1) UH does not list As and Bs. (2) Precipitable water vapor required for the observations.

The following is the listing of all SAO & ASIAA proposals with at least partial A ranking with the names and affiliations of the principal investigators.

Star Formation

Sean Andrews (CfA)
2008B-S005
Protoplanetary Disk Structures in Ophiuchus

Henrik Beuther (MPIA)
2008B-S018
Sequential massive star formation between S255 and S257: SMA in concert with VLT-SINFONI and Subaru

Catherine Espailla (University of Michigan)
2008B-S012
Measuring Transitional Disk Masses in IC 348

Jan Forbrich (CfA)
2008B-S048
HH 211 pre-shock chemistry at submillimeter wavelengths

Jes Jorgensen (University of Bonn)
2008B-S015
Origin of Water in Low-Mass Protostars

Meredith Hughes (CfA)
2008B-S013
Millimeter-Wavelength Signatures of Accretion in Circumstellar Disks

Joel Kastner (Rochester Institute of Technology)

2008B-S001
Imaging the molecular disk orbiting the twin (proto)Suns of V4046 Sgr

Sakamoto Kazushi (ASIAA)
2008B-A024
Diagnostics of Hot Cores in Galactic Nucleus

Roberto Galvan-Madrid (CfA)
2008B-S040
G5.89-0.39: a Highly-Excited Outflow Powered by an HII Region or a Cluster of Dust Cores?

Sergio Martin (CfA)
2008B-S036
The 400 GHz line survey of Orion

Gina Santangelo (Universita' di Bologna)
2008B-S043
The molecular environment of Super Star Clusters in He 2-10

Lai Shih-Ping (NTHU)
2008B-A018
Exploring the Magnetic Structure of NGC 1333 IRAS 4A in Detail

David Wilner (CfA)
2008B-S011
Structure of the HD 107146 Debris Disk

Tang Ya-Wen (NTU/ASIAA)
2008B-A009
Magnetic field in the star forming regions: Linking the individual cores to large scale structures

Kuan Yi-Jehng (NTNU/ASIAA)
2008B-A013
A Search for Interstellar Pyrimidine in Orion KL

Qizhou Zhang (CfA)
2008B-S026
Bridging the Disk Gap

Qizhou Zhang (CfA)
2008B-S031
Role of Turbulence and Magnetic Fields in the Early Phase of Cluster Formation

Extragalactic

Leo Blitz (UC Berkeley)
2008B-S044
High Resolution Observations of the Galaxy NGC1266

Giovanni G. Fazio (CfA)
2008B-S028
SMA/MAMBO Observations of High-Redshift Galaxies in the COSMOS Field

Dan Marrone (University of Chicago)
2008B-S042
Polarimetry of M81*: Constraining LLAGN Accretion

Wang Wei-Hao (ASIAA)
2008B-A021
SMA Identification of a Large Submillimeter Galaxy Sample in the GOODS-N

Min Yun (University of Massachusetts)
2008B-S034
Tracing Cosmic Down-sizing at z>3 using the Brightest AzTEC 1100 μm Sources

Galactic Center

Sheperd Doeleman (MIT Haystack)
2008B-S038
Getting to the Event Horizon: VLBI with the SMA

Planetary

Hideo Sagawa
2008B-S051
Measurement of the 3-D structure of Venus mesosphere
Max Planck Institute for Solar System Research

Stellar

Nimesh A. Patel (CfA)
2008B-S035
A Submillimeter Wavelength Line Survey of IRC+10216

5 Recent SMA publications

High-resolution HNC 3-2 SMA observations of Arp220

S. Aalto[1], D. Wilner[2], M. Spaans[3], M. C. Wiedner[4], K. Sakamoto[2,5,6], J. H. Black[1], M. Caldas[1]
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We present high resolution (0.″4) observations of HNC J=3–2 with the SubMillimeter Array (SMA). We find luminous HNC 3–2 line emission in the western part of Arp220, centered on the western nucleus, while the eastern side of the merger shows relatively faint emission. A bright (36 K), narrow (60 km s^{-1}) emission feature emerges from the western nucleus, superposed on a broader spectral component. A possible explanation is weak maser emission through line-of-sight amplification of the background continuum source. There is also a more extended HNC 3–2 emission feature north and south of the nucleus. This feature resembles the bipolar OH maser morphology around the western nucleus. Substantial HNC abundances are required to explain the bright line emission from this warm environment. We

discuss this briefly in the context of an X-ray chemistry and radiative excitation. We conclude that the luminous and possibly amplified HNC emission of the western nucleus of the Arp220 merger reflects the unusual, and perhaps transient, environment of the starburst/AGN activity there. The faint HNC line emission towards Arp220-east reveals a real difference in physical conditions between the two merger nuclei.

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Chemical Diversity in High-Mass Star Formation

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Massive star formation exhibits an extremely rich chemistry. However, not much evolutionary details are known yet, especially at high spatial resolution. Therefore, we synthesize previously published Submillimeter Array high-spatial-resolution spectral line observations toward four regions of high-mass star formation that are in various evolutionary stages with a range of luminosities. Estimating column densities and comparing the spatially resolved molecular emission allows us to characterize the chemical evolution in more detail. Furthermore, we model the chemical evolution of massive warm molecular cores to be directly compared with the data. The four regions reveal many different characteristics. While some of them, e.g., the detection rate of CH_3OH, can be explained by variations of the average gas temperatures, other features are attributed to chemical effects. For example, $C^{34}S$ is observed mainly at the core-edges and not toward their centers because of temperature-selective desorption and successive gas-phase chemistry reactions. Most nitrogen-bearing molecules are only found toward the hot molecular cores and not the earlier evolutionary stages, indicating that the formation and excitation of such complex nitrogen-bearing molecules needs significant heating and time to be fully developed. Furthermore, we discuss the observational difficulties to study massive accretion disks in the young deeply embedded phase of massive star formation. The general potential and limitations of such kind of dataset are discussed, and future directions are outlined. The analysis and modeling of this source sample reveals many interesting features toward a chemical evolutionary sequence. However, it is only an early step, and many observational and theoretical challenges in that field lie ahead.

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Detection of CI in absorption towards PKS 1830-211 with the eSMA

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We report the first science observations and results obtained with the "extended" SMA (eSMA), which is composed of the SMA (Submillimeter Array), JCMT (James Clerk Maxwell Telescope) and CSO (Caltech Submillimeter Observatory). Redshifted absorptions at z=0.886 of CI ($^3P_1$–$^3P_0$) were observed with the eSMA with an angular resolution of $0.''55 \times 0.''22$ at 1.1 mm toward the southwestern image of the remarkable lensed quasar PKS 1830-211, but not toward the northeastern component at a separation of $\sim 1''$. Additionally, SMA observations of CO, ^{13}CO and $C^{18}O$ (all J=4–3) were obtained toward this object: CO was also detected toward the SW component, but none of the isotopologues were. This is the first time [CI] is detected in this object, allowing the first direct determination of relative abundances of neutral atomic carbon to CO in the molecular clouds of a spiral galaxy at z>0.1. The [CI] and CO profiles can be decomposed into two and three velocity components respectively. We derive C/CO column density ratios ranging from <0.5 (representative of dense cores) to ∼2.5 (close to translucent clouds values). This could indicate that we are seeing environments with different physical conditions or that we are witnessing chemical evolution of regions where C has not completely been converted into CO.

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SMA CO(2-1) Observations of CG30: A Protostellar Binary System with a High-Velocity Quadrupolar Molecular Outflow

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We present interferometric observations in the ^{12}CO (2–1) line and at 1.3 mm dust continuum of the low-mass protostellar binary system in the cometary globule CG30, using the Submillimeter Array. The dust continuum images resolve two compact sources (CG30N and CG30S), with a linear separation of ∼8700 AU and total gas masses of ∼1.4 and ∼0.6 $M_\odot$, respectively. With the CO images, we discover two high-velocity bipolar molecular outflows, driven by the two sources. The two outflows are nearly perpendicular to each other, showing a quadrupolar morphology. The northern bipolar outflow extends along the southeast (redshifted, with a velocity up to ∼23 km s^{-1}) and northwest (blueshifted, velocity up to ∼30 km s^{-1}) directions, while the southern pair has an orientation from southwest (blueshifted, velocity up to 13 km s^{-1}) to northeast (redshifted, velocity up to ∼41 km s^{-1}). The outflow mass of the northern pair, driven by the higher mass source CG30N, is ∼9 times larger than that of the southern pair. The discovery of the quadrupolar molecular outflow in the CG30 protobinary system, as well as the presence of other quadrupolar outflows associated with binary systems, demonstrate that the disks in (wide) binary systems are not necessarily co-aligned after fragmentation.

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The Masses of Transition Circumstellar Disks: Observational Support for Photoevaporation Models

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We report deep Sub-Millimeter Array observations of 26 pre-main-sequence (PMS) stars with evolved inner disks. These observations measure the mass of the outer disk (r ∼20-100 AU) across every stage of the dissipation of the inner disk (r < 10 AU) as determined by the IR spectral energy distributions (SEDs). We find that only targets with high mid-IR excesses are detected and have disk masses in the 1-5 M_{Jup} range, while most of our objects remain undetected to sensitivity levels of M_{DISK} ∼0.2-1.5 M_{Jup}. To put these results in a more general context, we collected publicly available data to construct the optical to millimeter wavelength SEDs of over 120 additional PMS stars. We find that the near-IR and mid-IR emission remain optically thick in objects whose disk masses span 2 orders of magnitude ($\sim 0.5 - 50 M_{Jup}$). Taken together, these results imply that, in general, inner disks start to dissipate only after the outer disk has been significantly depleted of mass. This provides strong support for photoevaporation being one of the dominant processes driving disk evolution.

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Event-horizon-scale structure in the supermassive black hole candidate at the Galactic Centre

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The cores of most galaxies are thought to harbour supermassive black holes, which power galactic nuclei by converting the gravitational energy of accreting matter into radiation. Sagittarius A*, the compact source of radio, infrared and X-ray emission at the centre of the Milky Way, is the closest example of this phenomenon, with an estimated black hole mass that is 4 million times that of the Sun. A long-standing astronomical goal is to resolve structures in the innermost accretion flow surrounding Sgr A* where strong gravitational fields will distort the appearance of radiation emitted near the black hole. Radio observations at wavelengths of 3.5 mm and 7 mm have detected intrinsic structure in Sgr A*, but the spatial resolution of observations at these wavelengths is limited by interstellar scattering. Here we report observations at a wavelength of 1.3 mm that set a size of 37 (+16, -10; 3-σ) microarcseconds on the intrinsic diameter of Sgr A*. This is less than the expected apparent size of the event horizon of the presumed black hole, suggesting that the bulk of SgrA* emission may not be not centred on the black hole, but arises in the surrounding accretion flow.

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Disentangling the circumnuclear environs of Centaurus A: I. High resolution molecular gas imaging

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We present high resolution images of the ^{12}CO(2–1) emission in the central 1′ (1 kpc) of NGC 5128 (Centaurus A), observed using the Submillimeter Array. We elucidate for the first time the distribution and kinematics of the molecular gas in this region with a resolution of 6″0 × 2″4 (100 pc × 40 pc). We spatially resolve the circumnuclear molecular gas in the inner 24″ × 12″ (400 pc × 200 pc), which is elongated along a position angle P.A. ≃ 155° and perpendicular to the radio/X-ray jet. The SE and NW components of the circumnuclear gas are connecte d to molecular gas found at larger radii. This gas appears as two parallel filaments at P.A. = 120°, which are coextensive with the long sidesof the 3 kiloparsec parallelogram shape of the previously observed d ust continuum, as well as ionized and pure rotational H_2 lines. Spatial and kinematical asymmetries are apparent in both the circumnuclear and outer gas, suggesting non-coplanar and/or non-circular motions. We extend to inner radii ($r < 200$ pc) previously studied warped disk models built to reproduce the central parallelogram-shaped structure. Adopting the warped disk model we would confirm a gap in emission between the radii $r = 200 - 800$ pc (12"– 50"), as has been suggested previously. Although this model explains this prominent feature, however, our ^{12}CO($2 - -1$) observations show relevant deviations from this model. Namely, the physical connection between the circumnuclear gas and that at larger radii, brighter SE and NW sides on the parallelogram-shaped feature, and an outer curvature of its long sides. Overall it resembles more closely an S-shaped morphology, a trend that is also found in other molecular species. Hence, we explore qualitatively the possible contribution of a weak bi-symmetric potential which would naturally explain these peculiarities.

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Modeling the magnetic field in the protostellar source NGC 1333 IRAS 4A

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Magnetic fields are believed to play a crucial role in the process of star formation. We compare high-angular resolution observations of the submillimeter polarized emission of NGC 1333 IRAS 4A, tracing the magnetic field around a low-mass protostar, with models of the collapse of magnetized molecular cloud cores. Assuming a uniform dust alignment efficiency, we computed the Stokes parameters and synthetic polarization maps from the model density and magnetic field distribution by integrations along the line-of-sight and convolution with the interferometric response. The synthetic maps are in good agreement with the data. The best-fitting models were obtained for a protostellar mass of 0.8 solar masses, of age 9×10^4 yr, formed in a cloud with an initial mass-to-flux ratio ~2 times the critical value. The magnetic field morphology in NGC 1333 IRAS 4A is consistent with the standard theoretical scenario for the formation of solar-type stars, where well-ordered, large-scale, rather than turbulent, magnetic fields control the evolution and collapse of the molecular cloud cores from which stars form.

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The L723 low mass star forming protostellar system: resolving a double core

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We present 1.35 mm SMA observations around the low-mass Class 0 source IRAS 19156+1906, at the the center of the L723 dark cloud. We detected emission from dust as well as emission from H_2CO, DCN and CN, which arise from two cores, SMA 1 and SMA 2, separated by 2.″9 (880 AU). SMA 2 is associated with VLA 2. SiO 5–4 emission is detected, possibly tracing a region of interaction between the dense envelope and the outflow. We modeled the dust and the H_2CO emission from the two cores: they have similar physical properties but SMA 2 has a larger p-H_2CO abundance than SMA 1. The p-H_2CO abundances found are compatible with the value of the outer part of the circumstellar envelopes associated with Class 0 sources. SMA 2 is likely more evolved than SMA 1. The kinematics of the two sources show marginal evidence of infall and rotation motions. The mass detected by the SMA observation, which trace scales of ~1000 AU, is only a small fraction of the mass contained in the large scale molecular envelope, which suggests that L723 is still in a very early phase of star formation. Despite the apparent quiescent nature of the L723, fragmentation is occurring at the center of the cloud at different scales. Thus, at 1000 AU the cloud has fragmented in two cores, SMA 1 and SMA 2. At the same time, at least one of these cores, SMA 2, has undergone additional fragmentation at scales of 150 AU, forming a multiple stellar system.

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Interferometric imaging of the high-redshift radio galaxy, 4C60.07: An SMA, Spitzer and VLA study reveals a binary AGN/starburst

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High-resolution submm imaging of the HzRG, 4C60.07, at z=3.8, has revealed two dusty components. Spitzer imaging shows that one of these components (B) is coincident with an extremely red AGN, offset by $\sim 4''$ (~30 kpc) from the HzRG core. The other submm component (A) - resolved by our beam and devoid of emission at 3.6-8.0μm - lies between B and the HzRG core. Since the HzRG was discovered via its young, steep-spectrum lobes and their creation was likely triggered by the interaction, we argue that we are witnessing an early-stage merger, prior to its eventual equilibrium state. The interaction is between the host galaxy of an actively-fueled BH, and a gas-rich starburst/AGN (B) marked by the compact submm component and coincident with broad CO emission. 'A' is a plume of cold, dusty gas, associated with a narrow (~150 km s^{-1}) CO feature, and may represent a short-lived tidal structure. It has been claimed that HzRGs and SMGs differ only in the activity of their AGNs, but such complex submm morphologies are seen only rarely amongst SMGs. Our study has important implications: where a galaxy's gas is not aligned with its central BH, CO may be an unreliable probe of dynamical mass, affecting work on the co-assembly of BHs and spheroids. Our data support the picture wherein close binary AGN are induced by mergers. They also raise the possibility that some supposedly jet-induced starbursts may have formed co-evally with (yet independently of) the radio jets, both triggered by the same interaction. We note that the HzRG host would have gone unnoticed without its jets/companion, so there may be many other unseen BHs at high redshift, lost in the sea of $\sim 5 \times 10^8$ similarly bright IRAC sources - sufficiently massive to drive a $> 10^{27}$ -W radio source, yet practically invisible unless actively fueled (abridged).

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Results of WEBT, VLBA and RXTE monitoring of 3C 279 during 2006-2007

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We present radio-to-optical data taken by the WEBT, supplemented by VLBA and RXTE observations, of 3C 279. Our goal is to use this extensive database to draw inferences regarding the physics of the relativistic jet. We assemble multifrequency light curves with data from 30 ground-based observatories and the space-based instruments, along with linear polarization vs. time in the optical R band. In addition, we present a sequence of 22 images (with polarization vectors) at 43 GHz at resolution 0.15 milliarcsec, obtained with the VLBA. We analyse the light curves and polarization, as well as the spectral energy distributions at different epochs, corresponding to different brightness states. The IR-optical-UV continuum spectrum of the variable component corresponds to a power law with a constant slope of -1.6, while in the 2.4-10 keV X-ray band it varies in slope from -1.1 to -1.6. The steepest X-ray spectrum occurs at a flux minimum. During a decline in flux from maximum in late 2006, the optical and 43 GHz core polarization vectors rotate by ∼300 degrees. The continuum spectrum agrees with steady injection of relativistic electrons with a power-law energy distribution of slope -3.2 that is steepened to -4.2 at high energies by radiative losses. The X-ray emission at flux minimum comes most likely from a new component that starts in an upstream section of the jet where inverse Compton scattering of seed photons from outside the jet is important. The rotation of the polarization vector implies that the jet contains a helical magnetic field that extends ∼20 pc past the 43 GHz core.

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Infall and rotation motions in the HH 111 protostellar system: A flattened envelope in transition to a disk?

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We have mapped the central region of the HH 111 protostellar system in 1.33 mm continuum, $C^{18}O$ (J=2-1), ^{13}CO (J=2-1), and SO ($N_J = 5_6 - 4_5$) emission at $\sim 3''$ resolution with the Submillimeter Array. There are two sources, VLA 1 (=IRAS 05491+0247) and VLA 2, with the VLA 1 source driving the HH 111 jet. Thermal emission is seen in 1.33 mm continuum tracing the dust in the envelope and the putative disks around the sources. A flattened, torus-like envelope is seen in $C^{18}O$ and ^{13}CO around the VLA 1 source surrounding the dust lane perpendicular to the jet axis, with an inner radius of $\sim$ 400 AU ($1''$), an outer radius of $\sim$ 3200 AU ($8''$), and a thickness of $\sim$ 1000 AU ($2\farcs5$). It seems to be infalling toward the center with conservation of specific angular momentum rather than with a Keplerian rotation as assumed by **?**. An inner envelope is seen in SO, with a radius of $\sim$ 500 AU ($1\farcs3$). The inner part of this inner envelope, which is spatially coincident with the dust lane, seems to have a differential rotation and thus may have formed a rotationally supported disk. The outer part of this inner envelope, however, may have a rotation velocity decreasing toward the center and thus represent a region where an infalling envelope is in transition to a rotationally supported disk. A brief comparison with a collapsing model suggests that the flattened, torus-like envelope seen in $C^{18}O$ and ^{13}CO could result from a collapse of a magnetized rotating toroid.

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SMA CO (J=6–5) and 435 micron interferometric imaging of the nuclear region of Arp 220

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We have used the Submillimeter Array (SMA) to make the first interferometric observations (beam size $\sim 1''$) of the ^{12}CO J=6–5 line and 435 micron (690 GHz) continuum emission toward the central region of the nearby ULIRG Arp 220. These observations resolve the eastern and western nuclei from each other, in both the molecular line and dust continuum emission. At 435 micron, the peak intensity of the western nucleus is stronger than the eastern nucleus, and the difference in peak intensities is less than at longer wavelengths. Fitting a simple model to the dust emission observed between 1.3 mm and 435 micron suggests that dust emissivity power law index in the western nucleus is near unity and steeper in the eastern nucleus, about 2, and that the dust emission is optically thick at the shorter wavelength. Comparison with single dish measurements indicate that the interferometer observations are missing ∼60% of the dust emission, most likely from a spatially extended component to which these observations are not sensitive. The ^{12}CO J=6–5 line observations clearly resolve kinematically the two nuclei. The distribution and kinematics of the ^{12}CO J=6–5 line appear to be very similar to lower J CO lies observed at similar resolution. Analysis of multiple ^{12}CO line intensities indicates that the molecular gas in both nuclei have similar excitation conditions, although the western nucleus is warmer and denser. The excitation conditions are similar to those found in other extreme environments, including M82, Mrk 231, and BR 1202-0725. Simultaneous lower resolution observations of the ^{12}CO, ^{13}CO, and $C^{18}O$ J=2–1 lines show that the ^{13}CO and $C^{18}O$ lines have similar intensities, which suggests that both of these lines are optically thick, or possibly that extreme high mass star formation has produced in an overabundance of $C^{18}O$.

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Distribution and Kinematics of the HCN (3-2) Emission Down to the Innermost Region in the Envelope of the O-rich Star W Hydrae

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We report high angular resolution observations of the HCN (3–2) line emission in the circumstellar envelope of the O-rich star W Hya with the Submillimeter Array. The proximity of this star allows us to image its molecular envelope with a spatial resolution of just ∼40 AU, corresponding to about 10 times the stellar diameter. We resolve the HCN (3–2) emission and find that it is centrally peaked and has a roughly spherically symmetrical distribution. This shows that HCN is formed in the innermost region of the envelope (within ∼10 stellar radii), which is consistent with predictions from pulsation-driven shock chemistry models, and rules out the scenario in which HCN forms through photochemical reactions in the outer envelope. Our model suggests that the envelope decreases steeply in temperature and increases smoothly in velocity with radius, inconsistent with the standard model for mass-loss driven by radiative pressure on dust grains. We detect a velocity gradient of ~ 5 km s^{-1} in the northwest-southeast direction over the central 40 AU. This velocity gradient is reminiscent of that seen in OH maser lines, and could be caused by the rotation of the envelope or by a weak bipolar outflow.

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Morpho-Kinematic Properties of the 21-Micron Source IRAS 07134+1005

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We report the results of a Submillimeter Array (SMA) interferometric observation of 21-micron source IRAS 07134+1005 in the CO J=3–2 line. In order to determine the morpho-kinematic properties of the molecular envelope of the object, we constructed a model using the Shape software to model the observed CO map. We find that the molecular gas component of the envelopes can be interpreted as a geometrically thick expanding torus with an expanding velocity of 8 km s^{-1}. The inner and outer radii of the torus determined by fitting Shape models are 1.″2 and 3.″0, respectively. The inner radius is consistent with the previous values determined by radiative transfer modeling of the spectral energy distribution and mid-infrared imaging of the dust component. The radii and expansion velocity of the torus suggest that the central star has left the asymptotic giant branch about 1140-1710 years ago, and that the duration of the equatorial enhanced mass loss is about 2560-3130 years. From the absence of an observed jet, we suggest that the formation of a bipolar outflow may lag behind in time from the creation of the equatorial torus.

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Gas and dust mass in the disc around the Herbig Ae star HD 169142

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Context: Spatially resolved observations of circumstellar discs at millimetre wavelengths allow detailed comparisons with theoretical models for the radial and vertical distribution of the material. Aims: We investigate the physical structure of the gas component of the disc around the pre-main-sequence star HD 169142 and test the disc model derived from the spectral energy distribution. Methods: The ^{13}CO and C^{18}O J = 2–1 line emission was observed from the disc with 1.″4 resolution using the Submillimeter Array. We adopted the disc physical structure derived from a model that fits the spectral energy distribution of HD 169142. We obtained the full three-dimensional information on the CO emission with the aid of a molecular excitation and radiative transfer code. This information was used for the analysis of our observations and previous ^{12}CO J = 2–1 and 1.3 mm continuum data. Results: The spatially resolved ^{13}CO and C^{18}O emission shows a Keplerian velocity pattern. The disc is seen at an inclination close to 13° from face-on. We conclude that the regions traced by different CO isotopologues are distinct in terms of their vertical location within the disc, their temperature, and their column densities. With the given disc structure, we find that freeze-out is not efficient enough to remove a significant amount of CO from the gas phase. Both observed lines match the model prediction both in flux and in the spatial structure of the emission. Therefore we use our data to derive the ^{13}CO and C^{18}O mass and consequently the ^{12}CO mass with standard isotopic ratios. We constrain the total disc gas mass to $(0.6 - 3.0) \times 10^{-2}$ $M_{\odot}$. Adopting a maximum dust opacity of 2 cm^2 g^{-1}_{dust} we derive a minimum dust mass of 2.16×10^{-4} $M_{\odot}$ from the fit to the 1.3 mm data. Comparison of the derived gas and dust mass shows that the gas-to-dust mass ratio of 100 is only possible under the assumption of a dust opacity of 2 cm^2 g^{-1} and ^{12}CO abundance of 10^{-4} with respect to H_2. However, our data are also compatible with a gas-to-dust ratio of 25, with a dust opacity of 1 cm^2 g^{-1} and ^{12}CO abundance of 2×10^{-4}.

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Detection of Vibrationally Excited CO in IRC+10216

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Using the Submillimeter Array we have detected the J=3–2 and 2–1 rotational transitions from within the first vibrationally excited state of CO toward the extreme carbon star IRC+10216 (CW Leo). The emission remains spatially unresolved with an angular resolution of $\sim 2''$ and, given that the lines originate from energy levels that are ∼3100 K above the ground state, almost certainly originates from a much smaller ($\sim 10^{14}$ cm) sized region close to the stellar photosphere. Thermal excitation of the lines requires a gas density of $\sim 10^9$ cm^{-3}, about an order of magnitude higher than the expected gas density based on previous infrared observations and models of the inner dust shell of IRC+10216.

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Submillimeter narrow emission lines from the inner envelope of IRC+10216

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A spectral-line survey of IRC+10216 in the 345 GHz band has been undertaken with the Submillimeter Array. Although not yet completed, it has already yielded a fairly large sample of narrow molecular emission lines with linewidths indicating expansion velocities of ∼4 km s^{-1}, less than 3 times the well-known value of the terminal expansion velocity (14.5 km s^{-1}) of the outer envelope. Five of these narrow lines have now been identified as rotational transitions in vibrationally excited states of previously detected molecules: the v=1, J=17–16 and J=19–18 lines of $Si^{34}S$ and ^{29}SiS and the v=2, J=7–6 line of CS. Maps of these lines show that the emission is confined to a region within ∼60 AU of the star, indicating that the narrow-line emission is probing the region of dust-formation where the stellar wind is still being accelerated.

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First Confirmed Detection of a Bipolar Molecular Outflow from a Young Brown Dwarf

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Studying the earliest stages in the birth of stars is crucial for understanding how they form. Brown dwarfs with masses between that of stars and planets are not massive enough to maintain stable hydrogen-burning fusion reactions during most of their lifetime. Their origins are subject to much debate in recent literature because their masses are far below the typical mass where core collapse is expected to occur. We present the first confirmed evidence that brown dwarfs undergo a phase of molecular outflow that is typical of young stars. Using the Submillimeter Array, we have obtained a map of a bipolar molecular outflow from a young brown dwarf. We estimate an outflow mass of 1.6×10^{-4} $M_\odot$ and a mass-loss rate of 1.4×10^{-9} $M_\odot$. These values are over two orders of magnitude smaller than the typical ones for T Tauri stars. From our millimiter continuum data and our own analysis of Spitzer infrared photometry, we estimate that the brown dwarf has a disk with a mass of 8×10^{-3} $M_\odot$ and an outer disk radius of 80 AU. Our results demonstrate that the bipolar molecular outflow operates down to planetary masses, occurring in brown dwarfs as a scaled-down version of the universal process seen in young stars.

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Probing dust grain evolution in IM Lupi's circumstellar disc

Multi-wavelength observations and modelling of the dust disc

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We present a panchromatic study, involving a multiple technique approach, of the circumstellar disc surrounding the T Tauri star IM Lupi (Sz 82). We have undertaken a comprehensive observational study of IM Lupi using photometry, spectroscopy, millimetre interferometry and multi-wavelength imaging. For the first time, the disc is resolved from optical and near-infrared wavelengths in scattered light, to the millimetre regime in thermal emission. Our data-set, in conjunction with existing photometric data, provides an extensive coverage of the spectral energy distribution, including a detailed spectrum of the silicate emission bands. We have performed a simultaneous modelling of the various observations, using the radiative transfer code MCFOST, and analysed a grid of models over a large fraction of the parameter space via Bayesian inference. We have constructed a model that can reproduce all of the observations of the disc. Our analysis illustrates the importance of combining a wide range of observations in order to fully constrain the disc model, with each observation providing a strong constraint only on some aspects of the disc structure and dust content. Quantitative evidence of dust evolution in the disc is obtained: grain growth up to millimetre-sized particles, vertical stratification of dust grains with micrometric grains close to the disc surface and larger grains which have settled towards the disc midplane, and possibly the formation of fluffy aggregates and/or ice mantles around grains.

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High-Resolution Observations of Molecular Lines toward the Hot Core G28.20-0.04N

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We present the results from arcsecond resolution observations of various line transitions at 1.3 mm toward hypercompact HII region G28.20-0.04N. With the SMA data, we have detected and mapped the transitions in the CH_3CN, CO, ^{13}CO, SO_2, OCS, and CH_3OH molecular lines as well as the radio recombination line H30α. The observations and analysis indicate a hot core associated with G28.20-0.04N. The outflow and possible rotation are detected in this region.

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A new activity phase of the blazar 3C 454.3. Multifrequency observations by the WEBT and XMM-Newton in 2007-2008

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We present and analyse the WEBT multifrequency observations of 3C 454.3 in the 2007-2008 observing season, including XMM-Newton observations and near-IR spectroscopic monitoring, and compare the recent emission behaviour with the past one. In the optical band we observed a multi-peak outburst in July-August 2007, and other faster events in November 2007 - February 2008. During these outburst phases, several episodes of intranight variability were detected. A mm outburst was observed starting from mid 2007, whose rising phase was contemporaneous to the optical brightening. A slower flux increase also affected the higher radio frequencies, the flux enhancement disappearing below 8 GHz. The analysis of the optical-radio correlation and time delays, as well as the behaviour of the mm light curve, confirm our previous predictions, suggesting that changes in the jet orientation likely occurred in the last few years. The historical multiwavelength behaviour indicates that a significant variation in the viewing angle may have happened around year 2000. Colour analysis reveals a complex spectral behaviour, which is due to the interplay of different emission components. All the near-IR spectra show a prominent Halpha emission line, whose flux appears nearly constant. The analysis of the XMM-Newton data indicates a correlation between the UV excess and the soft-X-ray excess, which may represent the head and the tail of the big blue bump, respectively. The X-ray flux correlates with the optical flux, suggesting that in the inverse-Compton process either the seed photons are synchrotron photons at IR-optical frequencies or the relativistic electrons are those that produce the optical synchrotron emission. The X-ray radiation would thus be produced in the jet region from where the IR-optical emission comes.

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SMA observations of Infrared Dark Clouds: A tale of two cores

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We present high-angular resolution sub-millimeter continuum images and molecular line spectra obtained with the SMA toward two massive cores that lie within Infrared Dark Clouds; one actively star-forming (G034.43+00.24 MM1) and the other more quiescent (G028.53-00.25 MM1). The high-angular resolution sub-mm continuum image of G034.43+00.24 MM1 reveals a compact (∼0.03 pc) and massive ($\sim 29 M_\odot$) structure while the molecular line spectrum shows emission from numerous complex molecules. Such a rich molecular line spectrum from a compact region indicates that G034.43+00.24 MM1 contains a hot molecular core, an early stage in the formation of a high-mass protostar. Moreover, the velocity structure of its ^{13}CO(3-2) emission indicates that this B0 protostar may be surrounded by a rotating circumstellar envelope. In contrast, the sub-mm continuum image of G028.53-00.25 MM1 reveals three compact (<0.06 pc), massive (9-21 Msun) condensations but with no lines detected in its spectrum. We suggest that the core G028.53-00.25 MM1 is in a very early stage in the high-mass star-formation process; its size and mass are sufficient to form at least one high-mass star, yet it shows no signs of localized heating. Because the combination of high velocity line wings with a large IR-mm bolometric luminosity ($\sim 100 L_\odot$) indicates that this core has already begun to form accreting protostars, we speculate that the condensations may be in the early phase of accretion and may eventually become high-mass protostars. We, therefore, have found the possible existence of two high-mass star-forming cores; one in a very early phase of star-formation and one in the later hot core phase. Together the properties of these two cores support the idea that the earliest stages of high-mass star-formation occur within IRDCs.

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A Search for Molecular Gas in the Nucleus of M87 and Implications for the Fueling of Supermassive Black Holes

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Supermassive black holes in giant elliptical galaxies are remarkably faint given their expected accretion rates. This motivates models of radiatively inefficient accretion, due to either ion-electron thermal decoupling, generation of outflows that inhibit accretion, or settling of gas to a gravitationally unstable disk that forms stars in preference to feeding the black hole. The latter model predicts the presence of cold molecular gas in a thin disk around the black hole. Here we report Submillimeter Array observations of the nucleus of the giant elliptical galaxy M87 that probe 230 GHz continuum and CO(J=2–1) line emission. Continuum emission is detected from the nucleus and several knots in the jet, including one that has been undergoing flaring behavior. We estimate a conservative upper limit on the mass of molecular gas within ∼100 pc and ±400 km s^{-1} line of sight velocity of the central black hole of $\sim 8 \times 10^6$ $M_\odot$, which includes an allowance for possible systematic errors associated with subtraction of the continuum. Ignoring such errors, we have a 3 σ sensitivity to about 3×10^6 $M_\odot$. In fact, the continuum-subtracted spectrum shows weak emission features extending up to 4 σ above the RMS dispersion of the line-free channels. These may be artifacts of the continuum subtraction process. Alternatively, if they are interpreted as CO emission, then the implied molecular gas mass is $\sim 5 \times 10^6$ $M_\odot$ spread out over a velocity range of 700 km s^{-1}. These constraints on molecular gas mass are close to the predictions of the model of self-gravitating, star-forming accretion disks fed by Bondi accretion (Tan & Blackman 2005).

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Evolution of Magnetic Fields in High Mass Star Formation: SMA dust polarization image of the UCHII region G5.89-0.39

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We report high angular resolution (3″) Submillimeter Array (SMA) observations of the molecular cloud associated with the Ultra-Compact HII region G5.89-0.39. Imaged dust continuum emission at 870 μm reveals significant linear polarization. The position angles (PAs) of the polarization vary enormously but smoothly in a region of 2×10^4 AU. Based on the distribution of the PAs and the associated structures, the polarized emission can be separated roughly into two components. The component "x" is associated with a well defined dust ridge at 870 μm, and is likely tracing a compressed B field. The component "" is located at the periphery of the dust ridge and is probably from the original B field associated with a pre-existing extended structure. The global B field morphology in G5.89, as inferred from the PAs, is clearly disturbed by the expansion of the HII region and the molecular outflows. Using the Chandrasekhar-Fermi method, we estimate from the smoothness of the field structures that the B field strength in the plane of sky can be no more than 2–3 mG. We then compare the energy densities in the radiation, the B field, and the mechanical motions as deduced from the $C^{17}O$ 3–2 line emission. We conclude that the B field structures are already overwhelmed and dominated by the radiation, outflows, and turbulence from the newly formed massive stars.

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The peculiar envelope around the post-AGB star IRAS 08544-4431

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Circumbinary disks have been hypothesized to exist around a number of binary post-AGB stars. Although most of the circumbinary disks have been inferred through the near IR excess, a few of them are strong emitters of molecular emission. Here we present high angular resolution observations of the emission of ^{12}CO and its isotopomer ^{13}CO J=2–1 line from the circumstellar envelope around the binary post-AGB star IRAS 08544−4431, which is one of the most prominent members of this class of objects. We find that the envelope is resolved in our observations and two separate components can be identified: (a) a central extended and strong component with very narrow linewidth between 2 - 6 km s^{-1}; (b) a weak bipolar outflow with expansion velocity up to 8 km s^{-1}. The central compact component possesses low and variable $^{12}CO/^{13}CO$ J=2–1 line ratio, indicating optically thick emission of the main isotope. We estimate a molecular gas mass of 0.0047 $M_\odot$ for this component based on the optically thinner ^{13}CO J=2–1 line. We discuss the relation of the molecular envelope and the circumbinary disk inferred from near IR excess and compare with other known cases where the distribution of molecular gas has been imaged at high angular resolution.

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6 Other news

Call for proposals

A call for proposals for the 16 May – 15 November 2009 period will be issued towards the end of January 2009. Please watch the SMA Observer Center website http://sma1.sma.hawaii.edu for the announcement.

The SMA newsletter is edited by Nimesh A. Patel (npatel@cfa.harvard.edu). This issue includes contributions from Ray Blundell, Tatsuhiko Hasegawa, Nimesh Patel, Ngoc Phan-Bao, Patrick Thaddeus, David Wilner, Ken Young, and Qizhou Zhang.

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