



SMA Newsletter



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.

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1 From the Director

The current status of the SMA was presented to, and reviewed by, the SMA Advisory Committee at its biannual meeting in Cambridge on September 4th and 5th. A brief summary of the Committee's key findings is given below, the full report can be found at: <http://sma-www.harvard.edu/SMA2007.pdf>

Quoting from the report:

"The Committee was very pleased to see that the SMA has hit its scientific stride and is producing a substantial amount of high-quality scientific results. Results at 350 GHz are impressive and unmatched by any other observatory. Star and planet formation is a visible area, with the polarization work in star forming regions and Sgr A* unique

and especially noteworthy. Observations within the Solar System are impressive. The strength of high-z work in combination with Spitzer is exciting and quite unexpected. The SMA's impact, measured by publications (one per week this year) and presence in the field, is high. As part of its success and increase in visibility, the SMA's user base is expanding modestly, a clear sign of relevance to communities inside and outside of the SMA's parent institutions."

"It was clear that there is a strong and mutually beneficial partnership between CfA and ASIAA."

"There are a variety of options for the future of the SMA. In a practical sense they will be viable only if funding is available, and to some degree that depends on exciting science results in the near term. It also depends on a positive view by the community, developed both from publication,

where large data sets carry high impact, and by observing with the SMA. The scientific productivity of the SMA is good and improving, but would be significantly enhanced by interaction with other members of the SAO and particularly theorists. This may naturally occur as papers are published and talks given.”

“The SMA can certainly have a place in the ALMA era if it can exploit its flexibility to compensate for its relatively small collecting area. The Committee endorses the plans to form a task force immediately that will investigate science cases for different possible future courses. Whatever the future path, maintaining strong and vigorous scientific and technical staffs will be key to future plans.”

We are grateful to the committee members for their time and for their recommendations which will help guide the SMA to a future of continued scientific productivity.

Ray Blundell

2 Science Highlights

2.1 Gomez’s Hamburger (IRAS 18059-3211): A pre-main-sequence A-type star

Gomez’s Hamburger (IRAS18059-3211) is a southern nebula with a very striking optical appearance. *HST* images (see *HST* press release 2002/19 and Fig. 2.1) show two bright regions, separated by a dark lane. It appears to be a dramatic example of an edge-on dusty disk. The central star, which is not seen directly, but whose light is scattered in the bright portions of the nebula, has been classified as type A0 (Ruiz et al. 1987). The object’s SED shows two maxima, in the optical and FIR, with some emission excess in the 2–10 μm region. Similar SEDs are typically found both in pre-main sequence, and post-AGB objects. Ruiz et al. proposed that Gomez’s Hamburger is a post-AGB object, mainly due to the similarities with some well-known evolved stars such as the Red Rectangle and M 1-92, and the absence of a clear association with any interstellar clouds.

The Gomez Hamburger was observed with the SMA in the extended configuration on 6 June 2006. Continuum emission and several transitions of CO were detected (Bujarrabal et al. 2008). The receivers were tuned to allow $^{12}\text{CO}(2-1)$ and $^{13}\text{CO}(2-1)$ simultaneously, and the correlator was configured to produce 0.26 km/sec resolution over those spectral lines. Both spectral lines, and the continuum were clearly detected. The synthesized beam had a size of $1.''49 \times 1.''09$, at the $^{12}\text{CO}(2-1)$ frequency. Figure 2.1 shows the $^{12}\text{CO}(2-1)$ emission superposed upon the optical image from *HST*.

The ^{13}CO emission is nearly as strong as the ^{12}CO emis-

sion, indicating that the ^{12}CO emission is very optically thick. The position-velocity (PV) diagram cut along the nebula’s major axis clearly shows the butterfly shape associated with keplerian rotation (see Figure 2.2. A model consisting of a flaring disk in keplerian rotation, similar to those described by Bujarrabal et al. (2003; 2005), was fitted to the data. The best-fit model very accurately reproduces the main features seen in the PV diagram. The model depends primarily on the nebula’s structure, the velocity field, and the temperature distribution. The total density is estimated to range from $1.5 \times 10^7 \text{ cm}^{-3}$ near the central star to $1.5 \times 10^6 \text{ cm}^{-3}$ near the disk’s outer edge. The temperature varies from 65 K near the central star, to 20 K near the cool center of the disk.

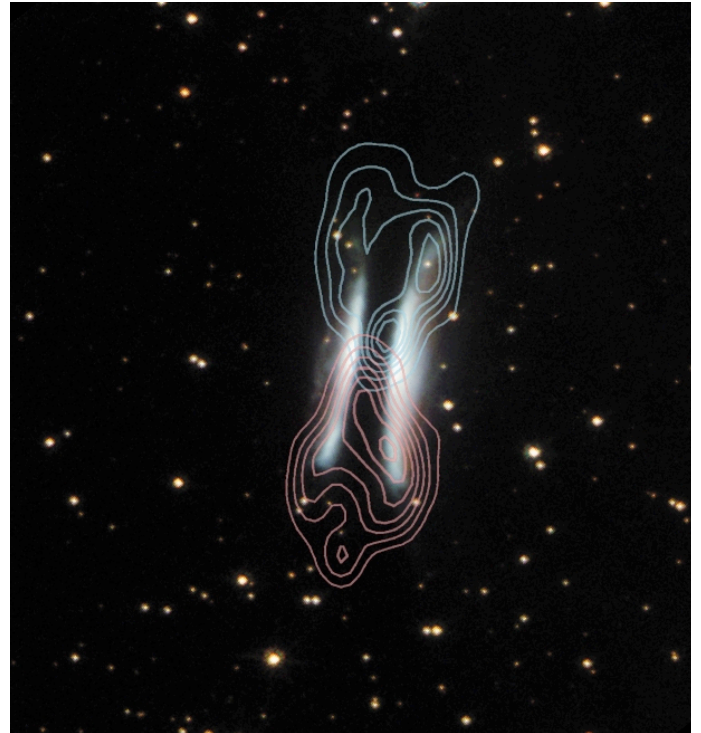


Figure 2.1: The red-shifted and blue-shifted regions of CO(2-1) emission mapped by the SMA are superposed upon an *HST* image of Gomez’s Hamburger.

Since the disk appears to be in keplerian rotation, it is trivial to derive the mass of the central star or stars, once a distance has been chosen. If one chooses a distance of 1 kpc, then the central mass is about $8 M_{\odot}$. As the disk appears to be nearly perfectly edge-on, corrections for disk orientation are negligible. At 1 kpc, the Hamburger’s total luminosity would be $\sim 35 L_{\odot}$. For this assumed distance, the mass is uncomfortably high for a post-AGB object, and the luminosity is too low. Most post-AGB stars are $1 M_{\odot}$ or less, yet they typically have luminosities of several thousand L_{\odot} . There is considerable uncertainty in the Hamburger’s luminosity, because there obviously is obscuring

dust in the disk, and there is probably ~ 0.5 mag of interstellar extinction in the Hamburger’s direction (Dobashi et al. 2005). But no plausible correction would imply that we detect only $\sim 1\%$ of the emitted radiation. The mass can be made more like that of a typical post-AGB object by assuming a smaller distance. But that reduces the luminosity to have an even less likely value for a post-AGB star. Likewise, assuming a distance large enough to imply a luminosity a few thousand L_{\odot} increases the calculated mass to several tens of solar masses – out of the question for a post-AGB star. In addition, many or most post-AGB objects show a high-velocity wind, which is not seen in the Hamburger’s spectra.

If we assume a distance of 500 pc, we get a mass of $\sim 4 M_{\odot}$ and a luminosity $\sim 18 L_{\odot}$. A model with two $2 M_{\odot}$ stars just approaching the main sequence, in a binary system, matches these mass and luminosity values fairly well. So we do not believe the Hamburger is a highly evolved star, but rather a pair of young A-type stars just settling onto the main sequence, surrounded by a rotating dusty disk.

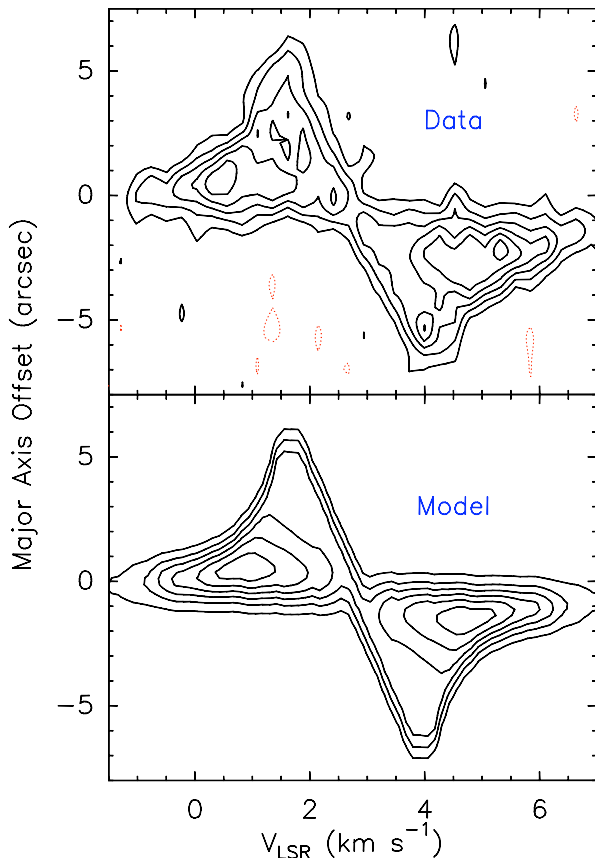


Figure 2.2: Velocity-position diagram of the CO(2-1) line emission from Gomez’s Hamburger along the nebula’s major axis (P.A. = -5°). The upper panel shows the data, and the lower panel shows the best-fit keplerian model. The continuum has not been subtracted from these diagrams, but its contribution is very small.

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 & D. Fong (CfA)

2.2 Radially-Inflowing Molecular Gas from an X-ray Cooling Flow

Rich groups and clusters of galaxies are immersed in hot ($\sim 10^7$ – 10^8 K) X-ray-emitting gas. Radiative cooling of this gas, by virtue of its X-ray emission, should result in an inflow of relatively cool gas to the cluster center; i.e., a X-ray cooling flow (Cowie & Binney 1977; Fabian & Nulsen 1977). This flow is predicted to have mass-deposition rates ranging from $\sim 10 M_{\odot} \text{ yr}^{-1}$ to $\sim 1000 M_{\odot} \text{ yr}^{-1}$ depending on the given cluster, and over a Hubble time ($\sim 10^{10}$ yr) deposit $\sim 10^{11} M_{\odot}$ to $\sim 10^{13} M_{\odot}$ of relatively cool gas in the central cD (giant elliptical) galaxy (see reviews by Fabian 1994; Allen 2000).

Numerous searches, however, either fail or find much lower quantities of relatively cool gas in putative cooling-flow clusters than those predicted (see review by Mathews & Brighenti 2003). In addition, recent observations with *XMM-Newton* and *Chandra* have radically altered the traditional concept of X-ray cooling flows. *XMM-Newton* spectra of putative cooling-flow clusters show no detectable gas below about one-third the bulk ambient temperature (see review by Peterson & Fabian 2006), implying that any cooling flow must have a mass-deposition rate at least ten times lower than that previously predicted. *Chandra* images show that the X-ray gas at the centers of putative cooling-flow clusters is usually disturbed (e.g., Mazzotta et al. 2002), and commonly exhibit cavities inflated by radio jets (where detectable) from the central AGN. The energy input from these radio jets is more than sufficient to balance radiative losses from the X-ray gas (Churazov et al. 2002; Birzan et al. 2004).

With X-ray observations no longer offering any evidence for a cooling flow, the only indication that such flows may occur, albeit at a greatly reduced rate, comes from the presence of relatively cool gas in the central cD galaxies of putative cooling-flow clusters. Where molecular gas (as traced in CO) is detectable (Edge 2001; Salomé & Combes 2003), it far outweighs all other gas components below X-ray temperatures combined. A cooling flow, however, is not

the only possible source of relatively cool gas in cD galaxies. Ram-pressure stripping of the interstellar medium of gas-rich galaxies by the hot intracluster medium, or cannibalisms of gas-rich galaxies by the cD galaxy, provide plausible if not more attractive alternatives (e.g., reviews by Mathews & Brighenti 2003; Bregman 2004).

Gas deposited by a X-ray cooling flow should simply flow radially inwards along the gravitational potential of the cD galaxy, whereas that captured from a gas-rich galaxy should normally orbit the cD galaxy. Our SMA observations of Perseus A (Per A, NGC 1275), the central cD galaxy in the Perseus Cluster, reveals for the first time an ordered spatial-kinematic pattern in its molecular gas. Located at a comparatively close distance of ~ 74 Mpc, the Perseus Cluster is the X-ray-brightest cluster in the sky: the radiative cooling time in its inner few tens of kpc is less than $\sim 10^9$ yr, which in the absence of any reheating leads to a predicted mass-deposition rate of a few $100 M_{\odot} \text{ yr}^{-1}$.

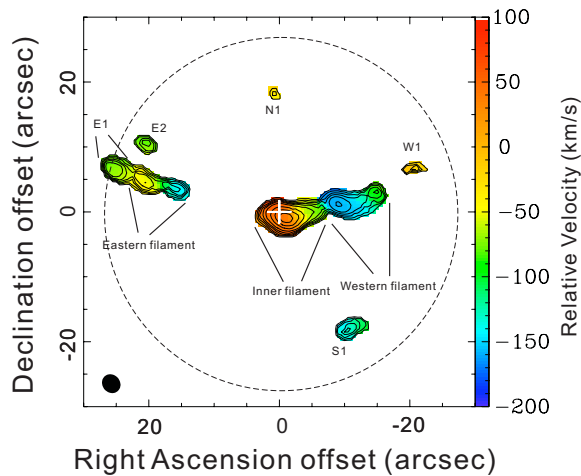


Figure 2.4: Contours of the integrated CO(2-1) intensity (after correction for the primary beam response of the telescope) and color-coded map of its intensity-weighted mean velocity measured with respect to the systemic heliocentric velocity for Per A of $5264 \pm 11 \text{ km s}^{-1}$ (Huchra, Vogeley, & Geller 1999). The full-width half-maximum of the SMA primary beam ($55''$) is indicated by the dotted circle. The cross marks the location of the AGN in Per A as detected in the continuum. The synthesized beam is shown as a filled ellipse at the lower left corner.

In Figure 2.4, we show our CO(2-1) image spanning a radius ~ 10 kpc centered on the AGN in Per A. Confirming what was previously known from single-dish observations (e.g., Salomé et al. 2006), the molecular gas is elongated roughly east-west and exhibits no ordered global (e.g., orbital) motion, but instead blueshifted velocities both sides of center. For the first time, our SMA map reveals that the molecular gas is concentrated primarily in three radial filaments, referred to as the inner, western, and eastern filaments in order of increasing projected radii from the

nucleus. Both the eastern and western filaments exhibit increasingly blueshifted velocities with decreasing radii. By contrast, the inner filament exhibits increasingly redshifted velocities with decreasing radii.

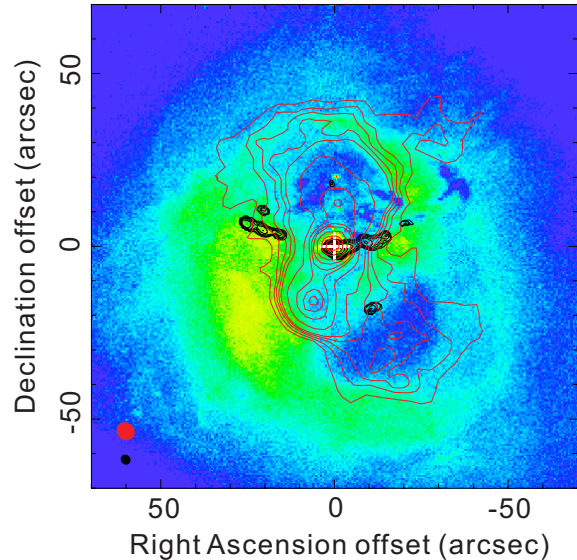


Figure 2.5: Black contours of the integrated CO(2-1) intensity and red contours of the continuum emission at 90 cm from Pedlar et al. (1990) showing radio jets from the AGN in Per A, both overlaid on a false-color X-ray image from Fabian et al. (2006). The synthesized beams of the CO(2-1) and 90 cm images are shown as the black and red ellipses, respectively, at the lower left corner.

In Figure 2.5, we compare the CO(2-1) map with a 90 cm image showing radio jets from Per A and the *Chandra* X-ray map. The molecular gas lies between two X-ray cavities located north and south of center, both of which have been inflated by the radio jets. The *HST* optical image of Per A shows dust in silhouette against starlight from the galaxy, as well as many blue star clusters. Much of this dust, as well as many (but not all) of the blue star clusters, is known to be associated with a foreground infalling galaxy. The two outer (eastern and western) filaments do not coincide with the visible dust, suggesting that they are located at a high inclination on the far side of the galaxy. Their blueshifted velocities therefore imply inflow. The inner filament lies close to the center of the galaxy where the dust distribution is complicated, making uncertain interpretations of its orientation. Both the eastern and western filaments exhibit a simple linear change in velocity with radius from the center of the galaxy (Lim et al. 2008). The inner filament, on the other hand, exhibits different velocity gradients on either sides of the systemic velocity; this filament may actually comprise two separate structures that are poorly resolved spatially in our map. To determine whether the behavior of the eastern and western filaments are consistent with radial free-fall, we assume a gravitational potential for Per A

based on a simple analytical model proposed by Hernquist (1990) for elliptical galaxies. Beyond a distance of ~ 1 kpc from which the object is dropped, its velocity increases approximately linearly with decreasing radius. The PV-diagrams of the western and eastern filaments, deprojected in both velocity and radius for the best-fit inclinations, are also shown in Figure 2.6. We can only find satisfactory fits for a galaxy mass smaller than that inferred from optical measurements of $\sim 8.3 \times 10^{11} M_{\odot}$.

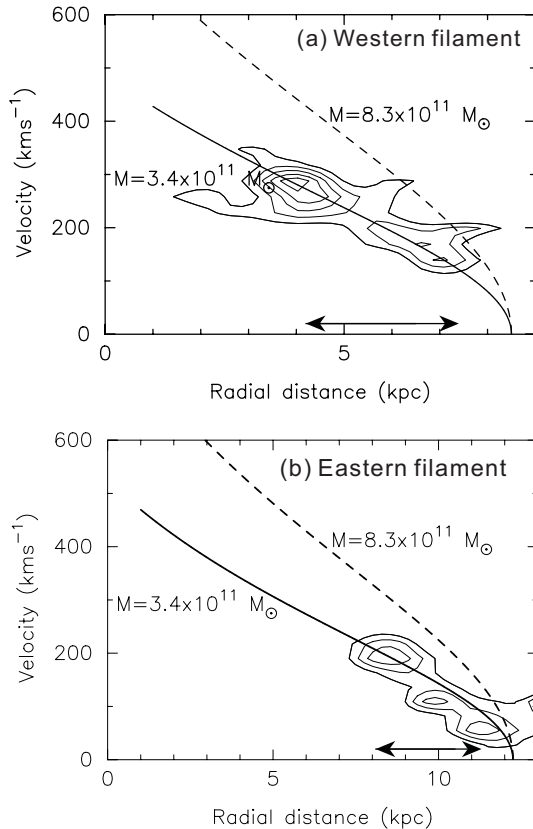


Figure 2.6: Velocity of an object in free-fall along the gravitational potential of Per A as a function of radial distance from center, computed for two different galaxy masses as indicated by the solid and dashed curves. Superposed in contours are PV-diagrams for the western filament deprojected by an inclination of $\sim 40^\circ$ so that it spans 4.2-7.4 kpc (double-headed arrow in upper panel), and the eastern filament deprojected by an inclination of $\sim 47^\circ$ so that it spans 8.1-11.3 kpc (arrow in lower panel). The computed velocity profile better matches the observed PV-diagrams for a lower galaxy mass of $3.4 \times 10^{11} M_{\odot}$ (solid curve) than the nominal galaxy mass of $8.3 \times 10^{11} M_{\odot}$ (dashed curves).

For a galaxy mass of $\sim 3.4 \times 10^{11} M_{\odot}$ (solid curves), the western filament has an inclination of $\sim 40^\circ$ and the eastern filament $\sim 47^\circ$; smaller inclinations require even lower galaxy masses to provide a good fit. For the nominal galaxy mass, the filaments lie where the velocity increases non-

linearly with decreasing radius (dashed curves). We have ignored the outward pressure the X-ray gas exerts on the infalling molecular gas, which should cause a slower than predicted increase in velocity and therefore a larger galaxy mass than that assumed to fit our observations.

The properties of the eastern and western filaments are therefore consistent with their being deposited by a X-ray cooling flow in the Perseus Cluster. Our model implies a dynamical age for both these filaments of about 20 Myrs, and hence a combined mass-deposition rate into these filaments of $\sim 75 M_{\odot} \text{ yr}^{-1}$. This value is probably accurate to only a factor of a few given the various uncertainties, but is roughly comparable with the upper limit from X-ray observations for a cooling flow in the Perseus Cluster. Despite the observed disturbances in the X-ray gas, a cooling flow is able to continue operating in the Perseus Cluster, but along just those directions where the gas is presumably not being reheated by the radio jets. In turn, this cooling flow can provide a nearly continuous supply of molecular gas to fuel the central AGN.

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3 Engineering Highlights

Preliminary tests of bandwidth doubling

At present, the SMA offers observers the possibility of using a high frequency receiver (400 or 600 GHz) at the same time as a low frequency receiver (200 or 300 GHz). This configuration provides the highest data rate of the array, with the SMA correlator processing a bandwidth of 2×1.92 GHz in real time. A number of observers have taken advantage of this feature of the array. In particular, there is a rising demand of dual-band polarization measurements, using either a combination of 200/600 GHz, 200/400 GHz or 300/400 GHz receivers. Nevertheless, the majority of SMA observations are made solely using the low frequency receivers. As a result the part of the correlator dedicated to the high frequency receivers is often left idling. In order to further increase the efficiency of the array, we have begun to explore ways to harness the full power of the correlator for observations using a single receiver.

The SMA was designed to operate with a first intermediate frequency (IF) of 4–6 GHz. This was an advanced design at the time of the array’s conception, when nearly all millimeter and submillimeter radio-telescopes were operating with an IF near 1.5 GHz. Recently, components covering a wider bandwidth of 4–8 GHz have become widely available, and some have been incorporated into SMA receivers. An obvious upgrade to the SMA that takes advantage of this is to extend the SMA IF output to cover 4–8 GHz. A simple down-conversion of the additional 6–8 GHz part of the IF to 4–6 GHz could then be implemented and the additional IF bandwidth from the receiver in use could be transmitted to the sections of the correlator usually dedicated to the second receiver in dual frequency operation. This would effectively double the available instantaneous bandwidth of the array for single receiver operation.

In order to test the feasibility of such an arrangement, we have designed a simple frequency shifting circuit. This circuit utilizes the 6–8 GHz IF extracted from the SMA cryostat. Frequency shifting is achieved by beating this higher IF signal with either a 2 GHz or 12 GHz Local Oscillator source. To maintain coherence, the 2 GHz or 12 GHz Local Oscillator sources are locked to the 200 MHz reference signal which is currently used to lock other reference frequency oscillators in each antenna. Minor modifications to the correlator software are also required to accommodate this experimental module.

In November, we installed two frequency shifting units in the array, in antennas 1 and 4, for a system test. The receiver packages in these two antennas were fully upgraded so as to be able to accommodate the increased IF band-

width. For initial tests, we used the 230 GHz receiver sets and observed 3C273. Following an adjustment of the phase delays to the IF system, fringes were clearly seen in the correlator output from both the regular 4–6 GHz IF and the frequency shifted 4–6 GHz IF. During this experiment, the system noise temperatures, shown in figure 3.1, for both receiver sets and all four IF’s remained comparable to within 5–10%. In other words, the sensitivity of the down-converted 6–8 GHz output is essentially equivalent to that of the regular 4–6 GHz output, so a factor of $\sqrt{2}$ improvement in continuum sensitivity should be obtained once this scheme is implemented on all antennas of the array. Similarly, for spectral line survey work, the bandwidth of single receiver observations would be doubled at the original line sensitivity.

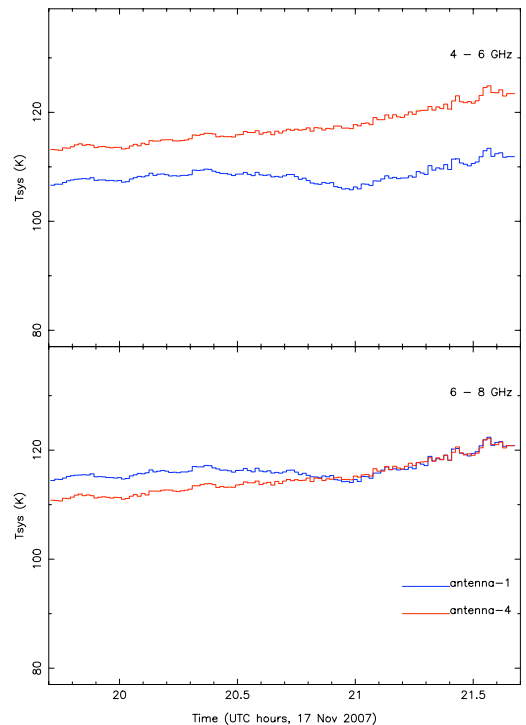


Figure 3.1: Tsys values are plotted vs time for antennas 1 and 4, showing similar values for the 4–6 GHz band and the new 6–8 GHz band.

To confirm the spectral response of the extended bandwidth, we used the SMA to observe H30 α emission towards MWC 349. The Local Oscillator frequency was first set to place the line in the center of the standard 4–6 GHz IF, and then shifted by 2 GHz so as to move the line to the center of the 6–8 GHz IF. The results are shown in figure 3.2. As expected, an almost identical line emission spectrum appeared at the center of the band.

The above experiments demonstrate that, with a minimum

change in hardware and software, we can double the instantaneous bandwidth of the SMA for single receiver operation without loss of sensitivity. Plans are currently underway to further develop the hardware and software to enable implementation of bandwidth doubling in each antenna during 2008.

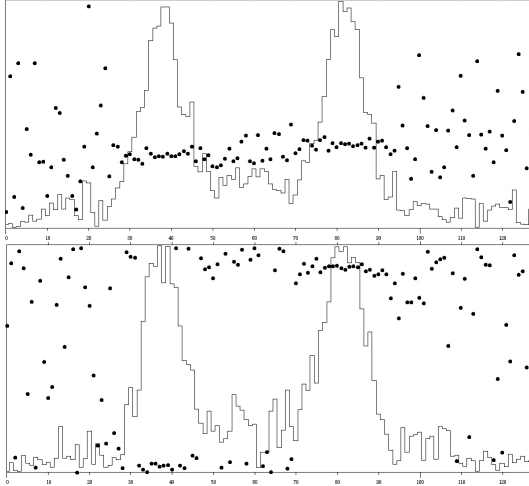


Figure 3.2: H30 α maser line observations toward MWC 349. Integration time is 300 seconds. The dots show the phase and continuous lines show the amplitude. The top panel shows the line in chunk S12 (82 MHz) in our normal 4–6 GHz bandpass. The bottom panel shows the same line seen with the new chunk S36 (82 MHz) available from the new 6–8 GHz bandpass.

Edward Tong, John Test, Ken Young & Rob Christensen

4 Proposal Statistics (November 2007 - April 2008)

The following tables summarize the proposal statistics for semester 2007B. The proposals are ranked and grouped into three categories: A (best effort to execute), B (may be executed as conditions permit), and C (will not be executed). At SAO, the SMA received a total of 58 proposals for the observing period from 2007 November to 2008 April. The overall over subscription was about 2.7:1, but the oversubscription was not uniformly distributed in terms of weather or source RA requests. For proposals requiring PWV(H₂O) < 2.5mm, the oversubscription factor was over 4:1, and over subscription was higher for targets in the RA range 9-12 hours.

Category	CfA P.I.	CfA Co.I.
Star-formation	8	17
Extragalactic	15	13
Stellar	1	1
Planetary	1	0
Galactic center	1	1
Polarization	0	0
	26	32

Track allocations by weather requirement (all partners¹):

PWV ²	SAO	ASIAA	UH ¹
<4 mm	12A + 22B	2A + 5B	2
<2.5 mm	24A + 19B	6A + 5B	16
<1 mm	3A + 3B		2
	39A + 44B	8A + 10B	20

(1) UH does not list As and Bs. (2) Precipitable water vapor required for the observations. In general, 230 GHz band requires PWV<4 mm, the 345 GHz and 400 GHz bands require PWV<2.5 mm or PWV<1mm. The 690 GHz band requires PWV<1 mm.

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)

2007B-S018

Circumstellar Disk Structure and the Origins of Planetary Systems

Henrik Beuther (MPIA)

2007B-S030

Investigating the earliest stages of (massive) star formation with Ethynyl (C₂H)

Tyler Bourke (CfA)

2007B-S002

The Initial Conditions for Star Formation in Clusters

Jonathan Foster (CfA)

2007B-S031

L1448: Multiplicity and Outflows in a Goldilocks Cluster

Josep Miquel Girart (Univ. of Barcelona)

2007B-S045

On the magnetic structure in the NGC 2024 region

Silvia Leurini (ESO)

2007B-S023

Probing the initial conditions of massive star formation: the starless core in IRAS 05358+3543

Dave Lommen (Leiden Observatory)

2007B-S033

A multi-wavelength study of grain growth in protoplanetary disks

Nagayoshi Ohashi (ASIAA)

2007B-A023

High Resolution Observations of the transition disk system of HD 135344

Charlie Qi (CfA)

2007B-S027

Deuterium Fractionation in Circumstellar Disks

Keping Qiu (CfA)

2007B-S044

Testing the Evolutionary Scenario for Massive Molecular Outflows

Ramprasad Rao (ASIAA)

2007B-A022

Observations of the Magnetic Field Structure in OMC1 and NGC 1333 IRAS2A

Javier A. Rodon (MPIA)

2007B-S035

Massive star formation from mm to near-infrared wavelengths: a SMA and VLT-SINFONI concert

Rainer Roloffs (MPIfR)

2007B-S032

The structure of High Mass Star Forming Regions at 690 GHz

Ya-Wen Tang (NTU/ASIAA)

2007B-A021

High-resolution Observations of Dust Polarization and Molecular Lines in Two Massive Star Forming Clusters

Jingwen Wu (CfA)

2007B-S054

Studying Infall at Cluster Forming Scale with the SMA

Luis Zapata (MPIfR)

2007B-S028

A Large Scale Millimeter Study of the OMC1 Region and its Dusty Filaments

Luis Zapata (MPIfR)

2007B-S019

Revealing the structure at submillimeter wavelengths of two very young circumbinary rings

Extragalactic

Daniel Espada (ASIAA)

2007B-A010

Disentangling the Circumnuclear Environs of Centaurus A

Giovanni G. Fazio (CfA)

2007B-S041

The SMA/AzTEC Legacy Survey of the High-Redshift Submillimeter Galaxies in the COSMOS Field

Melanie Krips (CfA)

2007B-S020

Gas chemistry in the prototypical SB galaxy M82: HCN and HCO+(J=3-2)

Jeremy Lim (ASIAA)

2007B-A016

The X-ray Cooling Flow in the Perseus Cluster

Dan Marrone (Univ. of Chicago)

2007B-S013

Polarimetry of M81*: Constraining LLAGN Accretion

Sergio Martin (CfA)

2007B-S005

Unveiling the heating/chemistry of ULIRGs: The Arp220 line survey

Satoki Matsushita (ASIAA)

2007B-A017

Dense Gas Around the Seyfert 2 Nucleus of M51: Is There Any Circumnuclear Disk or Torus ?

Glen Petitpas (CfA)

2007B-S057

Warm and Dense Gas in the Antennae Galaxy

Kazushi Sakamoto (NOAJ)

2007B-S016

Southern Starbursts 2007

Galactic Center

James Moran (CfA)

2007B-S058

Tracking Accretion Events in the Galactic Black Hole, Sgr A*

Planetary

Mark Gurwell (CfA)

2007B-S050

Winds in the Venus Mesosphere

5 Recent SMA publications

ENERGETIC RADIATION AND THE SULFUR CHEMISTRY OF PROTOSTELLAR ENVELOPES: SUBMILLIMETER INTERFEROMETRY OF AFGL 2591

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CONTEXT: The chemistry in the inner few thousand AU of accreting envelopes around young stellar objects is pre-

dicted to vary greatly with far-UV and X-ray irradiation by the central star. Aim We search for molecular tracers of high-energy irradiation by the protostar in the hot inner envelope. METHODS: The Submillimeter Array (SMA) has observed the high-mass star forming region AFGL 2591 in lines of CS, SO, HCN, HCN(v2=1), and HC15N with 0."6 resolution at 350 GHz probing radial scales of 600-3500 AU for an assumed distance of 1 kpc. The SMA observations are compared with the predictions of a chemical model fitted to previous single-dish observations. RESULTS: The CS and SO main peaks are extended in space at the FWHM level, as predicted in the model assuming protostellar X-rays. However, the main peak sizes are found smaller than modeled by nearly a factor of 2. On the other hand, the lines of CS, HCN, and HC15N, but not SO and HCN(v2=1), show pedestal emissions at radii of about 3500 AU that are not predicted. All lines except SO show a secondary peak within the approaching outflow cone. A dip or null in the visibilities caused by a sharp decrease in abundance with increasing radius is not observed in CS and only tentatively in SO. CONCLUSIONS: The emission of protostellar X-rays is supported by the good fit of the modeled SO and CS amplitude visibilities including an extended main peak in CS. The broad pedestals can be interpreted by far-UV irradiation in a spherically non-symmetric geometry, possibly comprising outflow walls on scales of 3500 – 7000 AU. The extended CS and SO main peaks suggest sulfur evaporation near the 100 K temperature radius.

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A DEEPLY EMBEDDED YOUNG PROTOPLANETARY DISK AROUND L1489 IRS OBSERVED BY THE SUBMILLIMETER ARRAY

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Circumstellar disks are expected to form early in the process that leads to the formation of a young star, during the collapse of the dense molecular cloud core. It is currently not well understood at what stage of the collapse the disk is formed or how it subsequently evolves. We aim to identify whether an embedded Keplerian protoplanetary disk resides in the L1489 IRS system. Given the amount of envelope material still present, such a disk would represent a very young example of a protoplanetary disk. Using the Submillimeter Array (SMA) we have observed the HCO⁺ J = 3-2 line with a resolution of about 1". At this resolution a protoplanetary disk with a radius of a few hundred AUs should be detectable, if present. Radiative transfer tools are used to model the emission from both continuum and line data. We find that these data are consistent with theoretical models of a collapsing envelope and Keplerian circumstellar disk. Models reproducing both the SED and

the interferometric continuum observations reveal that the disk is inclined by 40° which is significantly different to the surrounding envelope (74°). This misalignment of the angular momentum axes may be caused by a gradient within the angular momentum in the parental cloud or if L1489 IRS is a binary system rather than just a single star. In the latter case, future observations looking for variability at sub-arcsecond scales may be able to constrain these dynamical variations directly. However, if stars form from turbulent cores, the accreting material will not have a constant angular momentum axis (although the average is well defined and conserved) in which case it is more likely to have a misalignment of the angular momentum axes of the disk and the envelope.

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HIGHLY DEUTERATED PRE-STELLAR CORES IN A HIGH-MASS STAR FORMATION REGION

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We have observed the deuterated gas in the high-mass star formation region IRAS 05345+3157 at high-angular resolution, in order to determine the morphology and the nature of such gas. We have mapped the N₂H⁺ (1-0) line with the Plateau de Bure Interferometer, and the N₂D⁺ (3-2) and N₂H⁺ (3-2) lines with the Submillimeter Array. The N₂D⁺ (3-2) integrated emission is concentrated in two condensations, with masses of 2-3 and 9 M_⊙ and diameters of 0.05 and 0.09 pc, respectively. The high deuterium fractionation (0.1) and the line parameters in the N₂D⁺ condensations indicate that they are likely low- to intermediate-mass pre-stellar cores, even though other scenarios are possible.

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THE EARLY EVOLUTION OF MASSIVE STARS: RADIO RECOMBINATION LINE SPECTRA

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Velocity shifts and differential broadening of radio recombination lines are used to estimate the densities and velocities of the ionized gas in several hypercompact and ultracompact HII regions. These small HII regions are thought to be at their earliest evolutionary phase and associated with the youngest massive stars. The observations suggest that these HII regions are characterized by high densities, supersonic flows and steep density gradients, consistent with accretion and outflows that would be associated with the formation of massive stars.

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SMA HIGH ANGULAR RESOLUTION IMAGING OF THE LENSED QUASAR APM08279+5255

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We present Submillimeter Array observations of the $z=3.91$ gravitationally lensed broad absorption line quasar APM08279+5255 which spatially resolve the 1.0mm (0.2mm rest-frame) dust continuum emission. At 0."4 resolution, the emission is separated into two components, a stronger, extended one to the northeast (46 ± 5 mJy) and a weaker, compact one to the southwest (15 ± 2 mJy). We have carried out simulations of the gravitational lensing effect responsible for the two submm components in order to constrain the intrinsic size of the submm continuum emission. Using an elliptical lens potential, the best fit lensing model yields an intrinsic (projected) diameter of 80pc, which is not as compact as the optical/near-infrared (NIR) emission and agrees with previous size estimates of the gas and dust emission in APM08279+5255. Based on our estimate, we favor a scenario in which the 0.2mm (rest-frame) emission originates from a warm dust component ($T_d=150-220$ K) that is mainly heated by the AGN rather than by a starburst (SB). The flux is boosted by a factor of ~ 90 in our model, consistent with recent estimates for APM08279+5255.

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SUBMILLIMETER ARCSECOND-RESOLUTION MAPPING OF THE HIGHLY COLLIMATED PROTOSTELLAR JET HH 211

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We have mapped the protostellar jet HH 211 in 342 GHz continuum, SiO ($J = 8 - 7$), and CO ($J = 3 - 2$) emission at $\sim 1''$ resolution with the Submillimeter Array (SMA). Thermal dust emission is seen in continuum at the center of the jet, tracing an envelope and a possible optically thick compact disk (with a size < 130 AU) around the protostar. A knotty jet is seen in CO and SiO as in H₂, but extending closer to the protostar. It consists of a chain of knots on each side of the protostar, with an interknot spacing of $\sim 2'' - 3''$ or 600–900 AU and the innermost pair of knots at only $\sim 1.''7$ or 535 AU from the protostar. These knots likely trace unresolved internal (bow) shocks (i.e., working surfaces) in the jet, with a velocity range up to ~ 25 km s⁻¹. The two-sided mass-loss rate of the jet is estimated to be $\sim (0.7 - 2.8) \times 10^{-6} M_{\odot} \text{ yr}^{-1}$. The jet is episodic, precessing, and bending. A velocity gradient is seen consistently across two bright SiO knots (BK3 and RK2) perpendicular to the jet axis, with $\sim 1.5\pm 0.8$ km s⁻¹ at $\sim 30\pm 15$ AU, suggesting a presence of a jet rotation. The launching radius of the jet, derived from the potential

jet rotation, is $\sim 0.15-0.06$ AU in the inner disk.

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MOLECULAR LINE OBSERVATIONS OF THE SMALL PROTOSTELLAR GROUP L1251B

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We present molecular line observations of L1251B, a small group of pre- and protostellar objects, and its immediate environment in the dense C¹⁸O core L1251E. These data are complementary to near-infrared, submillimeter and millimeter continuum observations reported by Lee et al. (2006, ApJ, 648, 491; Paper I). The single-dish data of L1251B described here show very complex kinematics including infall, rotation and outflow motions, and the interferometer data reveal these in greater detail. Interferometer data of N₂H⁺ 1-0 suggest a very rapidly rotating flattened envelope between two young stellar objects, IRS1 and IRS2. Also, interferometer data of CO 2-1 resolve the outflow associated with L1251B seen in single-dish maps into a few narrow and compact components. Furthermore, the high resolution data support recent theoretical studies of molecular depletions and enhancements that accompany the formation of protostars within dense cores. Beyond L1251B, single-dish data are also presented of a dense core located $\sim 150''$ to the east that, in Paper I, was detected at 850 μm but has no associated point sources at near- and mid-infrared wavelengths. The relative brightness between molecules, which have different chemical timescales, suggests it is less chemically evolved than L1251B. This core may be a site for future star formation, however, since line profiles of HCO⁺, CS, and HCN show asymmetry with a stronger blue peak, which is interpreted as an infall signature.

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MULTI-LINE (SUB)MILLIMETRE OBSERVATIONS OF THE HIGH-MASS PROTO CLUSTER IRAS 05358+3543

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Since most high- and intermediate-mass protostars are at great distance and form in clusters, high linear resolution observations are needed to investigate their physical properties. To study the gas in the innermost region around the protostars in the proto-cluster IRAS 05358+3543, we observed the source in several transitions of methanol and other molecular species with the Plateau de Bure Interferometer and the Submillimeter Array, reaching a linear resolution of 1100 AU. We determine the kinetic temperature of the gas around the protostars through an LVG and LTE

analysis of their molecular emission; the column densities of CH₃OH, CH₃CN and SO₂ are also derived. Constraints on the density of the gas are estimated for two of the protostellar cores. We find that the dust condensations are in various evolutionary stages. The powerhouse of the cluster, mm1a, harbours a hot core with T~220 (75<T<330) K. A double-peaked profile is detected in several transitions toward mm1a, and we found a velocity gradient along a linear structure which could be perpendicular to one of the outflows from the vicinity of mm1a. Since the size of the double-peaked emission is less than 1100 AU, we suggest that mm1a might host a massive circumstellar disk. The other sources are in earlier stages of star formation. The least active source, mm3, could be a starless massive core, since it is cold (T<20 K), with a large reservoir of accreting material (M ~ 19 M_⊙), but no molecular emission peaks on it.

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RADIALLY INFALLING MOLECULAR GAS FROM A X-RAY COOLING FLOW

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We have imaged in CO(2-1) the molecular gas in NGC 1275 (Perseus A), the cD galaxy at the center of the Perseus Cluster, at a spatial resolution of ~1 kpc over a central region of radius ~ 10 kpc. Per A is known to contain ~1.3x10¹⁰ M_⊙ of molecular gas, which has been proposed to be captured from mergers with or ram-pressure stripping of gas-rich galaxies, or accreted from a X-ray cooling flow. The molecular gas detected in our image has a total mass of ~4x10⁹ M_⊙, and for the first time can be seen to be concentrated in three radial filaments with lengths ranging from at least 1.1-2.4 kpc all lying in the east-west directions spanning the center of the galaxy to radii of ~8 kpc. The eastern and outer western filaments exhibit larger blueshifted velocities with decreasing radii, whereas the inner western filament spans the systemic velocity of the galaxy. The molecular gas shows no signature of orbital motion, and is therefore unlikely to have been captured from gas-rich galaxies. Instead, we are able to reproduce the observed kinematics of the two outer filaments as free-fall in the gravitational potential of Per A, as would be expected if they originate from a X-ray cooling flow. Indeed, all three filaments lie between two prominent X-ray cavities carved out by radio jets from Per A, and closely resembles the spatial distribution of the coolest X-ray gas in the cluster core. The inferred mass-deposition rate into the two outermost filaments alone is roughly 75 M_⊙ yr⁻¹. This cooling flow can provide a nearly continuous supply of molecular gas to fuel the active nucleus in Per A.

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AN EVOLVED DISK SURROUNDING THE MASSIVE MAIN SEQUENCE STAR MWC 297?

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We present the results of the interferometric observations of the circumstellar disk surrounding MWC 297 in the continuum at 230 GHz (1.3 mm) and in the (J=2-1) rotational transitions of ¹²CO, ¹³CO and C¹⁸O using the Submillimeter Array. At a distance of 250 pc, MWC 297 is one of the closest, young massive stars (M_{*} ~10 M_⊙) to us. Compact continuum emission is detected towards MWC 297 from which we estimate a disk mass (gas+dust) of 0.07 M_⊙ and a disk radius of ≤ 80 AU. Our result demonstrates that circumstellar disks can survive around massive stars well into their main sequence phase even after they have become optically visible. Complementing our observations with the data compiled from the literature, we find the submm dust opacity index β to be between 0.1 and 0.3. If the emission is optically thin, the low value of β indicates the presence of relatively large grains in the disk, possibly because of grain growth. We do not detect any CO emission associated with the continuum source. We argue that the ¹³CO emission from the disk is likely optically thin, in which case, we derive an upper limit to the gas mass which implies significant depletion of molecular gas in the disk. The mass of this disk and the evolutionary trends observed are similar to those found for intermediate mass Herbig Ae stars and low mass T Tauri stars.

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UNVEILING THE NATURE AND INTERACTION OF THE INTERMEDIATE/HIGH-MASS YSOs IN IRAS 20343+4129

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In order to elucidate the nature of the brightest infrared sources associated with IRAS 20343+4129, IRS1 and IRS3, we observed with the Submillimeter Array (SMA) the 1.3 mm continuum and CO(2-1) emission of the region. Faint millimeter dust continuum emission was detected toward IRS1, and we derived an associated gas mass of 0.8 Msun. The IRS1 spectral energy distribution agrees with IRS1 being an intermediate-mass Class I source of about 1000 Lsun, whose circumstellar material is producing the observed large infrared excess. We have discovered a high-velocity CO bipolar outflow in the east-west direction, which is clearly associated with IRS1, and the outflow parameters are similar to those of intermediate-mass young stellar objects. Associated with the blue large scale CO

outflow lobe, detected with single-dish observations, we only found two elongated low-velocity structures on either side of IRS3. The large-scale outflow lobe is almost completely resolved out by the SMA. Our detected low-velocity CO structures are coincident with elongated H₂ emission features. The strongest millimeter continuum condensations in the region are found on either side of IRS3, where the infrared emission is extremely weak, and the CO and H₂ elongated structures follow the border of the millimeter continuum emission that is facing IRS3. All these results suggest that the dust is associated with the walls of an expanding cavity driven by IRS3, estimated to be a B2 star. Within and beyond the expanding cavity, the millimeter continuum sources can be sites of future low-mass star formation.

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A DENSE MICRO-CLUSTER OF CLASS 0 PROTOSTARS IN NGC 2264 D-MM1

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We present sensitive and high angular resolution ($\sim 1''$) 1.3 mm continuum observations of the dusty core D-MM1 in the Spokes cluster in NGC 2264 using the Submillimeter Array. A dense micro-cluster of seven Class 0 sources was detected in a $20'' \times 20''$ region with masses between 0.4 to 1.2 solar masses and deconvolved sizes of about 600 AU. We interpret the 1.3 mm emission as arising from the envelopes of the Class 0 protostellar sources. The mean separation of the 11 known sources (SMA Class 0 and previously known infrared sources) within D-MM1 is considerably smaller than the characteristic spacing between sources in the larger Spokes cluster and is consistent with hierarchical thermal fragmentation of the dense molecular gas in this region.

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MASSIVE EXPANDING TORUS AND FAST OUTFLOW IN PLANETARY NEBULA NGC 6302

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We present interferometric observations of ¹²CO and ¹³CO $J=2-1$ emission from the butterfly-shaped, young planetary nebula NGC 6302. The high angular resolution and high sensitivity achieved in our observations allow us to resolve the nebula into two distinct kinematic components: (1) a massive expanding torus seen almost edge-on and oriented in the North-South direction, roughly perpendicular to the optical nebula axis. The torus exhibits very complex and fragmented structure; (2) high velocity molecular knots moving at high velocity, higher than 20 km s⁻¹, and

located in the optical bipolar lobes. These knots show a linear position-velocity gradient (Hubble-like flow), which is characteristic of fast molecular outflow in young planetary nebulae. From the low but variable ¹²CO/¹³CO $J=2-1$ line intensity ratio we conclude that the ¹²CO $J=2-1$ emission is optically thick over much of the nebula. Using the optically thinner line ¹³CO $J=2-1$ we estimate a total molecular gas mass of $\sim 0.1 M_{\odot}$, comparable to the ionized gas mass; the total gas mass of the NGC 6302 nebula, including the massive ionized gas from photon dominated region, is found to be $\sim 0.5 M_{\odot}$. From radiative transfer modelling we infer that the torus is seen at inclination angle of 75° with respect to the plane of the sky and expanding at velocity of 15 km s⁻¹. Comparison with recent observations of molecular gas in NGC 6302 is also discussed.

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GOODS 850-5 – A z>4 GALAXY DISCOVERED IN THE SUBMILLIMETER?

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We report an SMA interferometric identification of a bright submillimeter source, GOODS 850-5. This source is one of the brightest 850 um sources in the GOODS-N but is extremely faint at all other wavelengths. It is not detected in the GOODS HST ACS images and only shows a weak 2 sigma signal at 1.4 GHz. It is detected in the Spitzer IRAC bands and the MIPS 24 um band, however, with very low fluxes. We present evidence in the radio, submillimeter, mid-IR, near-IR, and optical that suggest GOODS 850-5 may be a z>4 galaxy.

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THE CO MOLECULAR OUTFLOWS OF IRAS 16293-2422 PROBED BY THE SUBMILLIMETER ARRAY

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We have mapped the proto-binary source IRAS 16293-2422 in CO 2-1, ¹³CO 2-1, and CO 3-2 with the Submillimeter Array (SMA). The maps with resolution of $1''.5 - 5''$ reveal a single small scale (~ 3000 AU) bipolar molecular outflow along the east-west direction. We found that the blueshifted emission of this small scale outflow mainly extends to the east and the redshifted emission to the west from the position of IRAS 16293A. A comparison with the morphology of the large scale outflows previously observed by single-dish telescopes at millimeter wavelengths suggests that the small scale outflow may be the inner part of the large scale (~ 15000 AU) E-W outflow. On the other hand,

there is no clear counterpart of the large scale NE-SW outflow in our SMA maps. Comparing analytical models to the data suggests that the morphology and kinematics of the small scale outflow can be explained by a wide-angle wind with an inclination angle of $\sim 30 - 40^\circ$ with respect to the plane of the sky. The high resolution CO maps show that there are two compact, bright spots in the blueshifted velocity range. An LVG analysis shows that the one located $1''$ to the east of source A is extremely dense, $n(\text{H}_2) \sim 10^7 \text{ cm}^{-3}$, and warm, $T_{\text{kin}} > 55 \text{ K}$. The other one located $1''$ southeast of source B has a higher temperature of $T_{\text{kin}} > 65 \text{ K}$ but slightly lower density of $n(\text{H}_2) \sim 10^6 \text{ cm}^{-3}$. It is likely that these bright spots are associated with the hot core-like emission observed toward IRAS 16293. Since both two bright spots are blueshifted from the systemic velocity and are offset from the protostellar positions, they are likely formed by shocks.

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FORMING AN EARLY O-TYPE STAR THROUGH GAS ACCRETION?

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We present high angular resolution ($\sim 3''$) and sensitive 1.3 mm continuum, cyanogen (CN) and vinyl cyanide ($\text{C}_2\text{H}_3\text{CN}$) line observations made with the Submillimeter Array (SMA) toward one of most highly obscured objects of the W51 IRS2 region, W51 North. We find that the CN line exhibits a pronounced inverse P-Cygni profile indicating that the molecular gas is infalling inwards this object with a mass accretion rate between 4 and $7 \times 10^{-2} M_\odot \text{ yr}^{-1}$. The $\text{C}_2\text{H}_3\text{CN}$ traces an east-west rotating molecular envelope that surrounds either a single obscured (proto)star with a kinematic mass of $40 M_\odot$ or a small central cluster of B-type stars and that is associated with a compact high velocity bipolar outflow traced by H_2O masers and SiO molecular emission. We thus confirm that the W51 North region is part of the growing list of young massive star forming regions that have been associated with infalling motions and with large mass accretion rates ($\sim 10^{-2} - 10^{-4}$), strengthening the evidence for massive stars forming with very high accretion rates sufficient to quench the formation of an UCHII region.

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THE OUTFLOW FROM THE LUMINOUS YOUNG STELLAR OBJECT IRAS 20126+4104: FROM 4000 AU TO 0.4 PC

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We have imaged the outflow from the luminous young stel-

lar object IRAS 20126+4104 (I20126) with the Submillimeter Array in CO (3-2), HCN (4-3), and SiO (5-4) at $1'' - 2''$ resolutions within a radius of $\sim 20''$ from the central driving source. Our observations reveal at least three different components of the outflowing gas: (1) A compact ($\sim 4000 \text{ AU}$) bipolar outflow toward the central young stellar object. With a dynamical timescale of $\sim 120 \text{ yr}$, this component represents a very new jet/outflow activity in I20126. (2) A collimated outflow with an extent of $\sim 0.2 \text{ pc}$ previously detected in SiO (2-1). Both morphology and kinematics favor this component being a jet-driven bow shock system. (3) An S-shaped CO outflow with an extent of $\sim 0.4 \text{ pc}$. This component records the precession history very well. Its kinematic feature, where the velocity increases with distance from the YSO, indicates, independently of other evidence, that the outflow axis is moving toward the plane of the sky. The three outflow components record the history of the primary jet precession over scales ranging from a few hundred AU to approximately 0.4 pc . Our results indicate that CO (3-2) emission is a good tracer to probe the primary jet. The gas densities and SiO relative abundances in I20126 shocks are estimated using the large velocity gradient calculations. The inferred SiO abundances of $(1 - 5) \times 10^{-8}$ in I20126 outflow lobes are comparable to the expected enhancement at shocked regions.

ApJ, 2007, 671, 571 <http://adsabs.harvard.edu/abs/2007ApJ...671..571S>

6 Other news

6.1 Frequency labeling error

We have recently detected a problem that affects the frequency setup for all SMA data obtained before 26 November 2007. When observing strong spectral lines in the overlap region between chunks in SMA spectra, it was noted that sometimes the spectral feature would appear shifted in one chunk relative to another. The apparent shift varied depending upon which neighboring pair of chunks were considered. Specific test data obtained in November 2007 finally allowed complete diagnosis of the problem, which stems from subtly incorrect frequency labeling when completing Fourier transformations from lag to frequency. The effect of this error is to introduce a $\frac{1}{2}$ channel error in frequency for all chunks, but the sign of the error depends upon the chunk position in the IF. Thus, all frequencies are in error by $\frac{1}{2}$ channel, but that the relative error between spectral features observed simultaneously with the SMA can be either -1 , 0 , or $+1$ channels (for uniform spectral resolution). Note that this also means that the magnitude of the error in frequency or velocity is dependent upon the spectral resolution that was used: the finer the spectral resolution, the smaller the error.

Data obtained after 26 November 2007 are free of this error. Data obtained prior to this date can be easily corrected, since the effect of the mishandled FFT can be countered by a simple relabeling of the frequency and velocity header information. For correction of this problem using the MIR reduction package, please see section 6.8 of the MIR Cookbook (<http://www.cfa.harvard.edu/~cqi/mircook.html>). A utility for Miriad users is also available; see the section *Correction for Sky Frequencies* under *UV Data Loading, Display, Flagging and Corrections* in the SMA Miriad Users Guide

(<http://sma-www.cfa.harvard.edu/miriadWWW/manuals/SMAguide/smauserhtml/index.html>) for further information.

Mark Gurwell & Ken Young

6.2 Call for proposals

A call for proposals for the 2008A semester (May – November 2008) period will be issued in February 2008. Please watch the SMA website <http://sma-www.harvard.edu> for the announcement.

The SMA newsletter is edited by Nimesh Patel (npatel@cfa.harvard.edu). This issue includes contributions from Ray Blundell, V. Bujarrabal, Rob Christensen, David Fong, Mark Gurwell, Jeremy Lim, Edward Tong, David Wilner, Ken Young and Qizhou Zhang.

Submillimeter Array

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