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ASIAA

Submillimeter Array Newsletter

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FROM THE DIRECTOR

Dear SMA Newsletter readers,

These are exciting times for millimeter and submillimeter astronomy, and the SMA in particular: the SMA played a key role in capturing an image of M87 with unprecedented sensitivity and resolution as an integral station of the Event Horizon Telescope; the Science with the Submillimeter Array (Present and Future) workshop will be hosted in Taipei later this year; and, the first Submillimeter Array Interferometry School will be hosted at the SMA in Hilo immediately following the January 2020 AAS meeting in Honolulu.

The SMA correlator (SWARM) currently processes 32 GHz of bandwidth stemming from the simultaneous operation of two orthogonally polarized double sideband receivers, each with an IF of 4 – 12 GHz. The digital hardware necessary to enable SWARM to process 48 GHz of bandwidth has been ready for some time, and the SMA receiver IFs have been extended to 4 – 16 GHz. I am happy to announce that tests are proceeding well on the final part of the puzzle, an IF block downconverter assembly, and that we expect to begin shared risk observing with the full 48 GHz bandwidth in the fall.

Finally, a successful critical design review of the wSMA cryostat assembly was held this past March, and preparations are underway in the Cambridge labs to accept delivery of the first prototype cryostats at the end of the year. There will then be a period of extensive lab testing during which components and subsystems will be integrated and performance evaluated before proceeding with on-site commissioning tests at the end of next year.

Ray Blundell

THE SMA'S KEY ROLE IN CAPTURING THE EVENT HORIZON TELESCOPE M87 IMAGE

Jonathan Weintroub & Michael Johnson (CfA | Harvard & Smithsonian)

The Submillimeter Array played an essential role in capturing the M87 image which was published on 10 April 2019 by the Event Horizon Telescope (EHT) Collaboration. See **(https://www.cfa.harvard.edu/news/2019-12)**. The EHT links telescopes around the globe in a high frequency VLBI array, to form an Earth-sized virtual telescope with unprecedented sensitivity and resolution. It offers scientists a new way to study supermassive black holes (SMBH), the most extreme objects in the Universe, predicted by certain solutions to Einstein's theory of general relativity (GR).

About 3.5 petabytes of raw data were gathered across the EHT during the 2017 EHT campaign. It is amusing to note that these 3.5 PB were reduced to a few kilobytes which comprise the final image, the ultimate product of the research. SMA participated with SWARM Correlator running at full sample rate and bandwidth recording at 32 gigabits-per-second to produce 410 TB of phased array EHT data. Including 350 TB of data recorded for an SMA single dish for calibration purposes, and the James Clerk Maxwell Telescope (JCMT), the total data volume produced on

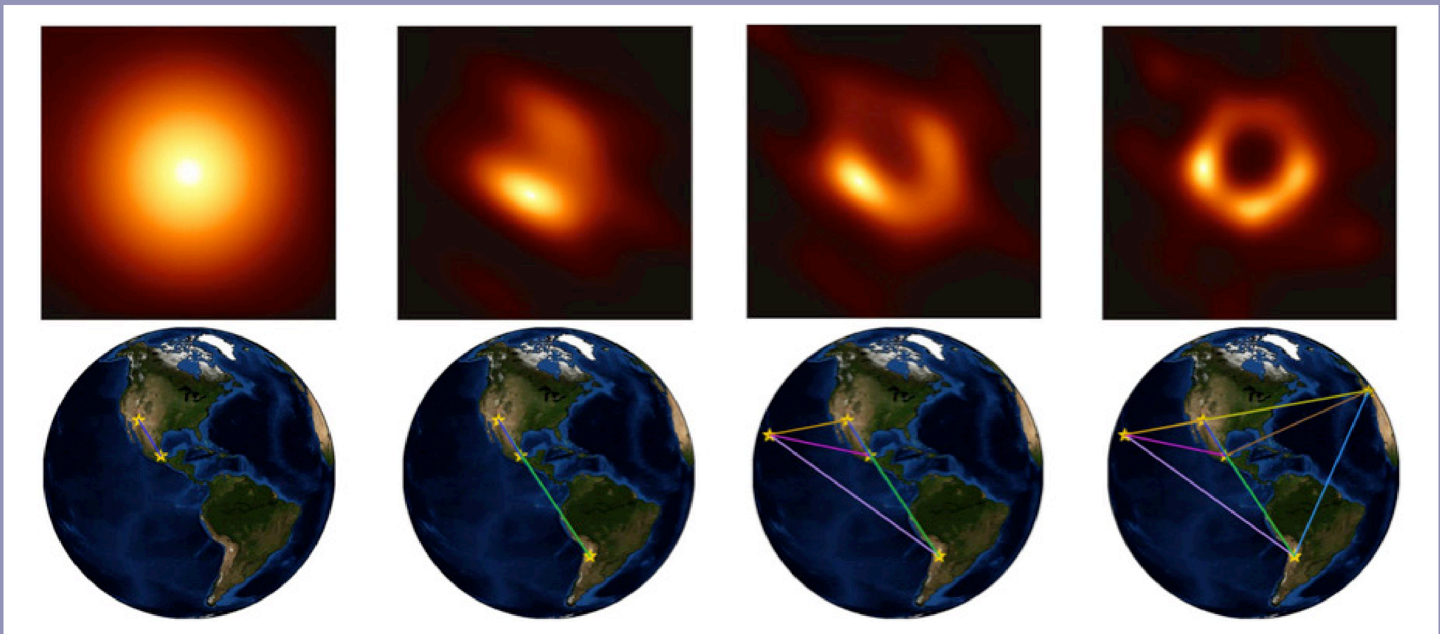

Figure 1: Formation of the M87 image when stations are added one-by-one. The longest EHT baseline is from the SMA and JCMT on Hawai'i to IRAM 30 m in Spain, providing the sharpest information about the black hole structure. The mutual visibility between Hawai'i and Spain on M87 lasted a mere 18 minutes, three scans of six minutes each, at low elevation.

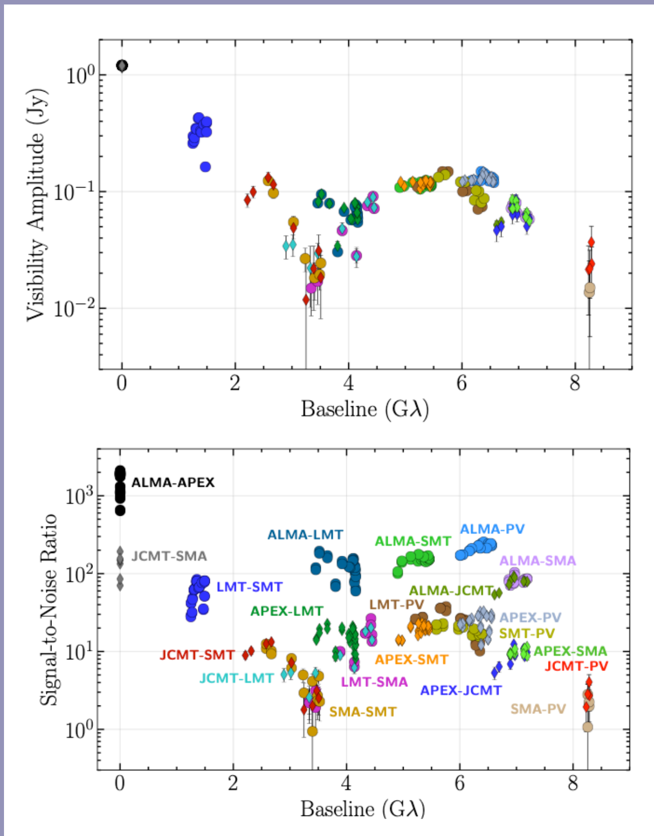

Figure 2: The top panel shows the visibility amplitude as a function of baseline length and the lower panel shows the signal-to-noise ratio and also identifies which colors correspond to which baselines. SMA baselines are critical in locating the nulls in the visibility amplitude at about 3.4 and 8.3 gigalambda. The nulls are the signature of a ring structure. (First M87 Event Horizon Telescope Results. III. Data Processing and Calibration, EHT Collaboration, et al., April 2019, ApJ, 875, L3)

Maunakea was about 750 terabytes. The SMA phased array was reprocessed at CfA with the *Adaptive Phased Array Interpolating Downsampler for SWARM* (APHIDS) system before being sent to the correlation centers at MIT Haystack in Westford, MA, and the Max Planck Institute for Radio Astronomy (MPIfR) in Bonn, Germany, to be combined with data from other VLBI stations.

The six papers documenting the M87 image, all published on April 10, 2019, are open-access and may be downloaded here:

https://iopscience.iop.org/journal/2041-8205/page/Focus_on_EHT

This article describes how the SMA is a crucial station in the EHT array, discusses the significance of the results, the public reaction, and provides some history of the SMA's longstanding contributions to EHT science.

The EHT and many of its key scientists are funded by both public sources such as the US National Science Foundation (NSF) and the Smithsonian Institution (SI), as well as private foundations including the Templeton Foundation and the Gordon and Betty Moore Foundation (GBMF). Because of the international nature of the EHT collaboration funding is received from agencies located around the world. Member organizations make in-kind contributions including the donation of observing time at their facilities.

Effusive thanks are due for the hard work of dedicated and cooperative SMA staff in Hawaii and Cambridge, Massachusetts. The EHT leans very heavily on their support, and we ask for more than our share of favors when installing and testing equipment, and especially for EHT observations. The SMA has an exceedingly strong history for reliability, data quality, and uptime. Technical and operations staff as well as administration and management, are all key contributors to this most enviable track record.

SMA and the IRAM 30 meter telescope constitute the longest baseline for M87

The resolution of the EHT depends on the separation between the telescopes, termed the baseline, as well as the short 1.3 millimeter radio wavelengths observed. The baselines from the two Maunakea observatories, the SMA and the JCMT, to the IRAM 30m on Pico Veleta in Spain are the longest for M87 and predominantly East-West in direction. The SMA, together with JCMT and IRAM 30m produce the highest angular resolution baselines in the image for M87. Because of the large East-West separation, the baselines from Hawaii to Spain allowed very few scans with mutual visibility. However, 18 minutes, typically, of mutual data are key to the fidelity and detail in the final image.

Without the SMA, JCMT and IRAM 30m the shadow would not be nearly as circular, not because of its intrinsic shape, but rather due to elongation of the interferometric beam. The distortion of the image is clearly shown in the leftmost three panels of **Figure 1**. The shape clearly becomes significantly more circular in the rightmost panel when baselines to the IRAM 30m are included. **Figure 2** provides a similar demonstration of the importance of the SMA in plots of visibility amplitude as a function of the baseline length. These figures show how SMA visibilities provide the clearest indication of the deep visibility nulls, characteristic of a thin ring.

Significance of the result

So why do we see a bright ring with a null in the middle? The black hole is bathed in an accretion disk of material heated to billions of degrees and emitting synchrotron radiation from ionized particles in a magnetic field. Radio photons are initially emitted traveling in random directions. In the intense gravity of a black hole, those that approach close to the black hole can

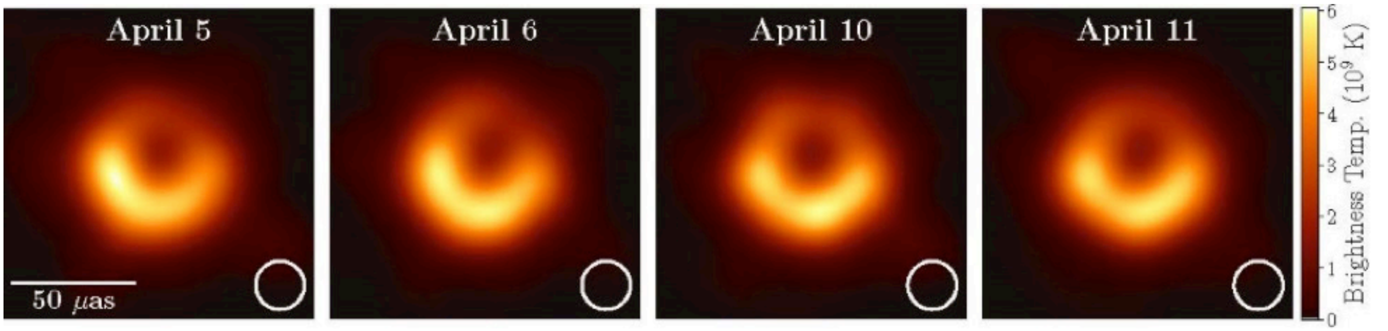

Figure 3: Images of M87 on four nights of the EHT campaign (from EHT Paper IV). In each panel, the white circle shows the resolution of the EHT. All four images are dominated by a bright ring with enhanced emission in the South, and it is interesting to note that the position of the bright part of the ring is very similar between the observations from successive days, but moves slightly between April 6 and 10th. The time scale of variability of M87, whose mass is about 6.5 billion times the mass of our sun, is expected to be about a week.

do a complete U-turn. Those that approach even closer pass through the event horizon and are swallowed up. Because of these effects, an observer, looking from any direction sees a bright ring with a hole in the middle, the "shadow" of the black hole. The observed image is brightened in the South. This is due to relativistic Doppler boosting of the material moving towards the observer, which is moving at nearly light speed.

The EHT image of the shadow confines the mass of M87 to within its photon orbit, providing the strongest case for the existence of supermassive black holes. The connection between active galactic nuclei and central engines powered by accreting black holes is strengthened. A measurement of the radius of the shadow allowed estimating the mass of this black hole at 6.5 billion solar masses, consistent with prior mass estimates from stellar dynamics, and resolving a systematic uncertainty in black hole mass estimates.

Figure 3 shows that on four successive nights, the image of the ring evolved slightly, with the image from 5 and 6 April matching closely, as does that from 10 and 11 April. Taken as pairs, however, the brightened part of the ring moves slightly in a counter-clockwise direction. The four images from these days are whimsically compared to four donuts donated, with coffee, to the CfA EHT group by Dunkin' Inc., shown in **Figure 4**.

Activities and observations at SMA prior to 2017

In 2006 a small team of 1.3 mm VLBI pioneers attempted an exploratory observation on a single 4,500 kilometer baseline from Hawai'i to Arizona. The Caltech Submillimeter Observatory (CSO) 10 m telescope was used on Maunakea, with hydrogen maser atomic clock, receiver references, and VLBI data recording using SMA equipment and located at the SMA facility. The Arizona Radio Observatory Submillimeter Telescope (ARO/SMT) on Mount Graham was the other station. This first experiment failed.

In 2007 we tried again, using the 15 m James Clerk Maxwell Telescope (JCMT) instead of CSO on Maunakea. The ARO/SMT on Mount Graham was used again, and we added a single dish of the Combined Array for Research in Millimeter Astronomy (CARMA) in Owen's Valley, California thereby enabling three baselines. SMA personnel played a significant role in designing and staffing this observation and in verifying the absolute coherence of the SMA hydrogen maser locked local oscillator system prior to the observation. As in 2006, key VLBI equipment was located on Maunakea at the SMA facility.

To our delight, the 2007 experiment succeeded in making a 1.3 mm detection on SgrA*, measuring 37 microarcseconds as the angular size of the emission, corresponding to less than two Schwartzschild radii. This significant result (Doeleman, Weintroub, Rogers, et al., Nature, 2008) was the very first detection of event-horizon-scale structure in radio astronomy. As a result, we developed confidence that 1.3 mm wavelength interferometric imaging of certain super massive black holes (SMBH) with the largest apparent angular size was indeed possible — given

Figure 4: Fringe benefits include these four donuts donated to the CfA EHT group by Dunkin'. Photo by Jonathan Weintroub.

the enabling of additional stations across the globe for 1.3 mm VLBI, and other technical developments. Of all the SMBH candidates SgrA* has the largest apparent angular size and M87 is only slightly smaller.

The early EH-scale detections, while incontrovertible and scientifically extremely significant, were actually rather marginal in signal-to-noise ratio. In 2007 most of the scans on the Hawai'i to Arizona baseline had no detections, with just four detections out of about 15 scans on SgrA* enabling the size measurement. And no detections at all were made from Hawai'i to California, while detections on the 600km baseline from ARO/SMT to CARMA made clear that the CARMA station was indeed coherent and functional. The conclusion was that greater sensitivity was needed. The work of the CfA DSP group—supporting both the SMA as well as the EHT more broadly over the decade from 2007 to 2017—was focused on designing digital phased array systems to aggregate collecting area, and also bandwidth expansion through faster analog-to-digital conversion and recording.

Initially, the CfA DSP group designed and deployed an early phased array (called PhRInGES for "Phased Array Recording Instrument for Galactic Event Horizon Studies", perhaps our most tortured acronym ever) so that the SMA could contribute its full collecting area to the EHT as if it were a single dish telescope. The sum of the collecting area of eight 6 meter dishes exceeds that of the JCMT's single 15 m dish on which the 2007 detection was obtained. The new phased array was commissioned in 2009 however it had only a 4 Gbps recording rate.

The 2009 observing campaign, with the same 3-baseline array, led to the first detections of event-horizon-scale structure in M87 (Doeleman et al., 2011). Dual polarization observations with the same array in 2013, with PhRInGES recording phased array data from the SMA, led to the detection of event-horizon-scale magnetic field structure and variability in SgrA* (Johnson et al., 2015). All subsequent observations have been dual polarization, and indeed this is an unexploited aspect of the 2017 data set.

PhRInGES was replaced starting in 2015 by the SMA Wideband Astronomical ROACH2 Machine (SWARM, Primiani, et al., 2016), which, in addition to being the new facility wideband correlator for the SMA, also records dual polarization double sideband EHT data in a 16 GHz bandwidth corresponding to a recorded 2-bit data rate of 64 Gbps. This is 16 times the data rate of PhRInGES. Further, the CfA DSP group applied the open source Collaboration for Astronomy Signal Processing and Electronics Research (CASPER) technology used for SWARM, developing an EHT FPGA personality, as the framework of the ROACH2 Digital Back End (R2DBE) systems.

The R2DBE has been deployed to all single dish sites across the EHT, and is a foundational element of all current EHT operations and was critical to observations performed in 2017. **(Figure 5)**.

Figure 5. The SMA played a central role in the development of the wideband EHT back ends used at all single dish telescopes in 2017. The first of the new generation of Digital Back Ends (DBE), the R2DBE, was deployed to the South Pole in October 2014. This photo shows the Digital Back End team with MIT Haystack collaborators at the Westford Radio Telescope. The DBE and signal chain was tested on the sky with the other station at Goddard Space Flight Center, prior to shipment to the South Pole. **Pictured from left to right:** Laura Veratschitsch (CfA), Arthur Neill (MIT-Haystack), Jonathan Weintroub (CfA), Geoff Crew (MIT-Haystack) and Rurik Primiani (CfA). Photo by Mike Poirier, Westford Radio Telescope (Vertatschitsch, et al., 2015).

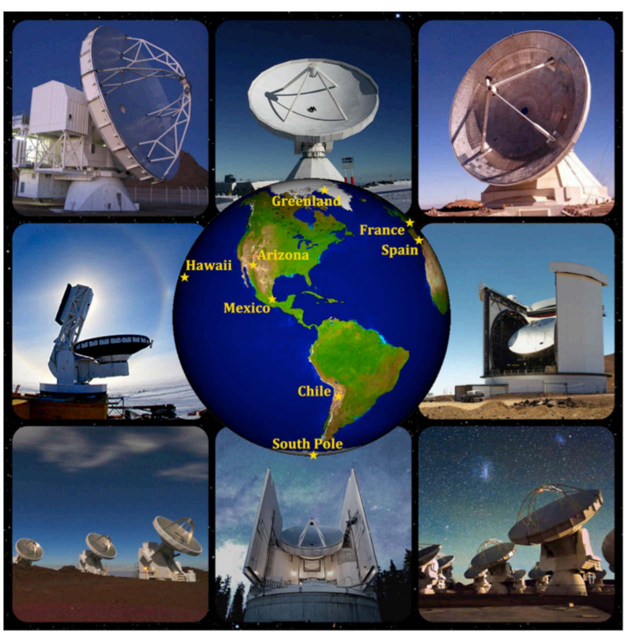

Figure 6: The EHT sites in 2017 included clockwise from top left APEX, IRAM 30m, LMT, JCMT, ALMA, SMTO, SMA, and SPT. Graphic thanks to Kristy Johnson.

Figure 7: This picture was snapped at Washington National Airport on April 11th, the morning after attending the press release party at the Smithsonian Institute's National Air and Space Museum on the Mall. Photo by Robbie Singal.

The CfA and SMA team's contribution to EHT digital back end and recording development and deployment was highly collaborative, working with other members of the EHT Consortium. This work included the logistical elements of equipment production, testing and validation, deployment and commissioning across the globe.

The 2017 EHT campaign

For the EHT campaign run in April 2017, which was written up in the July 2017 SMA newsletter, SWARM was recording at 32 Gbps, and the EHT had commissioned eight facilities, located at six geographic sites, shown in **Figure 6**.

The facilities were the South Pole Telescope (SPT), Atacama Pathfinder Experiment (APEX), Atacama Large Millimeter/submillimeter Array (ALMA), Large Millimeter Telescope (LMT, Mexico), James Clerk Maxwell Telescope (JCMT, Maunakea), Arizona Radio Observatory Submillimeter Telescope (ARO-SMT, Mount Graham, Arizona) and the Institut de Radioastronomie Millimétrique Thirty meter telescope on (IRAM 30m, Pico Veleta, Spain), in addition to the Submillimeter Array. The observed nights were the 5th, 6th, 7th, 10th, and 11th April, 2017, though the night of the 7th did not record data on M87.

The primary EHT targets were M87 and SgrA* though a broader set of AGN science targets including 1055+018, OJ287, and Cen A were observed. In 2017 good luck favored a well prepared EHT team, the weather for these five nights was very good across the array, and technical problems did not occur. Once again the primary EHT targets were M87 and SgrA* and an expanded set of AGN science targets included 3c279, OJ287, NGC1052, and CenA which were selected based on an open call for proposals through ALMA. All the projected allocated observations were completed.

The SMA facility digital back end is designated SWARM and is built to be natively VLBI capable so as to support the EHT. SWARM has features which go beyond correlation, for example, a natively built-in beamformer that enables the SMA to operate in a phased array mode. The beamformer is essential for participation in EHT VLBI observations and combines all antennas to become the equivalent of a single station with a larger collecting area. Phasing the array requires tracking all sources of phase modulation and group delay, including fluctuations in water vapor concentration in the atmosphere. The SWARM phasing system is equipped with a real-time phasing solver that continually updates the beamforming weights to compensate for these variable delays over the course of the observation.

The JCMT for the first time functioned as an independent VLBI station, referenced to the SMA maser but with its own reference generator designed and installed in the SMA vault by Derek Kubo and Paul Yamaguchi. This upgrade provided a maser locked reference signal without using IF/LO equipment used for one of the SMA antennas. Therefore, the JCMT can now be supported without sacrificing the collecting area of a single SMA antenna. We verified fringe coherence to the JCMT each and every night before operations.

Single dish telescopes that employ the EHT-wide standard digital backend process the full frequency bandwidth in blocks that are each 2048 MHz wide, sampling each block at the Nyquist rate of 4096 MSa/s. The SMA processes its full bandwidth in blocks that are 2288 MHz wide, sampled at 4576 MSa/s each. In order to deliver to the EHT correlator an SMA data product that is fully compatible with the rest of the EHT, the SMA data needs to be resampled at a lower rate. Furthermore, the raw beamformer data product recorded at the SMA is a frequency-domain sampling of the signal, and transformation of that signal back to the time-domain is also required prior to correlation with data from other EHT stations. Finally, the output data have to be properly formatted according to the VDIF (VLBI Data Interchange Format) standard.

This interpolation and inversion to time series uses the Adaptive Phased Array Heterogenous Interpolating Downsampler for SWARM (APHIDS) pre-processor. APHIDS runs on a Graphics Processing Unit (GPU). The algorithm uses Fourier-interpolation, transforming between the time- and frequency-domains with windows of the appropriate size to effect a net downsampling rate of 4576/4096 = 143/128.

After APHIDS processing the data were shipped to the VLBI correlators at MIT Haystack Observatory and at Max Planck Institute for Radio Astronomy in Bonn, which processed the low and high bands, respectively. Dr. Alex Raymond joined SAO as a postdoc in 2018 and is developing a FPGA-based real-time version of APHIDS so that this postprocessing step will no longer be needed.

The EHT Collaboration is an international organization with nearly 250 members. The 2018 Collaboration meeting took place in Nijmegen, The Netherlands in November. It was at this meeting where the strategy for releasing the M87 image and the structure for publishing the six science papers was implemented. Photo by D. van Aalst, Radboud.

The announcement

On April 10th, 2019 the EHT presented the image of the M87 supermassive black hole in multiple simultaneous press conferences around the world. Recordings of five of the those press conferences are available on YouTube:

- **Brussels,** hosted by the European Research Council (in English)
- **Santiago**, hosted by the Joint ALMA Observatory (in Spanish and English)
- **Taipei**, hosted by the Academia Sinica (in Chinese)
- **Tokyo**, hosted by the National Astronomical Observatory of Japan (in Japanese)
- **Washington**, hosted by the US National Science Foundation (in English)

The EHT news release was a global event **(Figure 7)**. The press release took place at the National Press Club in Washington DC and hosted by the Director of the NSF, France Córdova. Foundation funders were present and the mood was ebullient.

Future plans

The 2017 data set, in which the weather was so unusually favorable, has excellent SgrA* data, as well as on other science targets. The data set supports full Stokes polarimetry which the M87 published results have not yet exploited. With polarimetry additional work will be focused on looking at magnetic fields in both M87 and SgrA*. Another as yet untapped product of this same data set is time variability. Group efforts are directed to fuller exploitation of the 2017 data, with publications coming soon.

Also in the short term, the EHT looks forward to welcoming new stations including NOEMA on Plateau de Bure in a phased array mode, a single dish from the ALMA Test Facility on Kitt Peak in Arizona, and science data from The Greenland Telescope, now in Thule. It is hoped that in the future The Greenland Telescope will be moved to the Greenland ice sheet's summit. We are also looking to activate a 10m dish which is unused in Owen's Valley, California, which would fill in the UV information lost when CARMA shut down in 2015. Additional ground-based sites are being investigated, including one in Gamsberg in Namibia, and the deployment of small dishes across North America is also being explored.

Continued emphasis on supporting polarimetry to map magnetic fields on horizon scales is a priority. Improving temporal resolution is also crucial. M87 is expected to vary in time on about a one week time scale, and SgrA* on about 20 minute scales. Increased resolution through shorter wavelength observations in the context of the Earth EHT array is also in the cards. The ongoing pursuit of greater sensitivity needed for small dishes and 345 GHz observations, is driving an effort to design entirely new generations of wider band receivers, digital back ends, and recording systems.

Efforts are being directed at putting an EHT station into space. In low Earth orbit (LEO) the rapidly evolving array geometry quickly fills the UV plane and thus improves the time resolution of the EHT. The 2017 campaign included excellent data taken on SgrA* but because the characteristic time variability of SgrA* is only about 20 minutes, earth rotation aperture synthesis breaks down, and that black hole is harder to image than M87. However, a LEO space station will help that immensely. Extending the array into space would allow for improved angular resolution, higher observing frequencies, and faster coverage of the Fourier plane. These improvements would enable the study of rapid horizon-scale variability and new tests of general relativity.

For continuum sources such as Sgr A*, the sensitivity of an interferometric baseline depends on the geometric mean of the two telescope sensitivities, the averaged bandwidth, and the coherent integration time. The first property allows small telescopes (e.g., an orbiter) to form sensitive baselines when paired with a large telescope (e.g., ALMA). The second allows digital enhancements (e.g., wider recorded bandwidths) to offset limitations in telescope sensitivity. The third ties sensitivity to phase stability, which is limited by the atmosphere, and the reference frequency. In addition to sensitivity, the imaging quality of an interferometric array depends on the baseline coverage. Together, these factors broadly determine the tradeoffs available when considering mission concepts for space-VLBI.

Technical projects for space VLBI include the need to design a deployable antenna with precise millimeter wavelength surface, low noise cryogenic receivers, space qualified digital back ends and buffer memory, and ultrafast downlinks. A LEO constellation may need a GEO relay station for downlink, which will most probably need to be implemented with the new breed of free space optical communications technologies known as LaserCom.

With a larger array, and wider bandwidths, the processing load on the VLBI correlator becomes immense, and the logistics of media management onerous. With a view to simplifying this process, and leveraging industry developments supporting data processing, we are looking at porting the correlation of EHT data to the Google Cloud. A paper by summer intern Ajay Gill on the prospects for VLBI correlation in the Cloud is currently under review by PASP.

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MASS ASSEMBLY OF STELLAR SYSTEMS AND THEIR EVOLUTION WITH THE SMA (MASSES)

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INTRODUCTION

The formation of stars is a complex process that consists of many interrelated phenomena. Rather than only considering a simple gravitational collapse to a compact structure, other processes must be considered, such as turbulence, angular momentum conservation, magnetic field strength, radiation pressure, and feedback from bipolar outflows. Together, these processes govern the star formation time scale, the fragmentation of the system, and the formation of the protoplanetary disk. Studies that address this complex process typically focus on

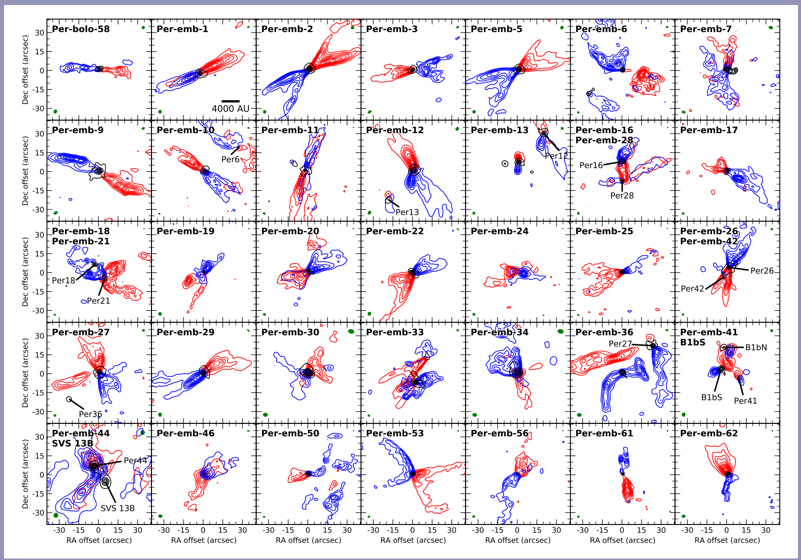

Figure 1: Sample of protostellar outflows from the MASSES survey (adapted from Stephens et al. 2018 and Stephens et al. in prep). Red and blue contours show the red- and blue-shifted CO(2–1) emission, while the black contours show the continuum emission. Each panel is approximately 0.1 pc on a side.

small pieces of the puzzle, and frequently target already well-known sources throughout different star-forming clouds. Small number statistics combined with selection bias may greatly obscure our understanding of the interplay of these processes.

To overcome these issues, we used the SMA to observe the 74 known young protostars (the so-called Class 0 and I systems) within the Perseus molecular cloud (~300 pc from the sun; Zucker et al. 2018). This large-scale observing program is called the **Mass Assembly of Stellar Systems and Their Evolution with the SMA (MASSES).** Considerable biases are alleviated since we target the complete sample of protostars (i.e., not just the brightest) within a single cloud. With observations of 74 protostars, we have the statistical leverage to come to meaningful conclusions about the star formation process. We observed both spectral lines and continuum for each protostar. In particular, MASSES probes each protostar's bipolar outflow and disk/envelope system. From the bolometric temperatures of each protostars (Enoch et al. 2009; Tobin et al. 2016), we can infer their relative ages. As such, MASSES can help statistically constrain protostellar evolution with regards to, e.g., kinematics, multiplicity, chemistry, outflows, and envelopes.

DATA SUMMARY

At ~230GHz, we observed each of the 74 protostars in both the subcompact and extended configurations, providing resolutions up to ~1˝ (~300 au). Additionally for the subcompact tracks, we simultaneously observed at ~350 GHz. The spectral setup is shown in **Table 1**. More details can be found in the subcompact data release (Stephens et al. 2018) and the forthcoming full data release (Stephens et al. in prep).

Tracer	Transition	Frequency (GHz)	Spectral Resolution ($km\ s^{-1}$)
1.3 mm cont		231.29	
CO	$J = 2 - 1$	230.53796	0.26
13CO	$J = 2 - 1$	220.39868	0.28
C18O	$J = 2 - 1$	219.56036	0.14
N_2D^+	$J = 3 - 2$	231.32183	0.13
850 um cont		356.72	
CO	$J = 3 - 2$	345.79599	0.088
HCO^+	$J = 4 - 3$	356.73424	0.085
$H^{13}CO^+$	$J = 4 - 3$	346.99835	0.088

NOTE: The table shows typical parameters for the ASIC correlator; tracks observed with SWARM correlator are different. See Stephens et al. (2018) and the final data release (Stephens et al. in prep) for details.

The continuum observations provide information about the compact envelope structure and the unresolved protostellar disk. The CO(2-1), ^{13}CO(2-1), CO(3-2), and HCO^+(4-3) transitions typically provide information about the outflows, while the $C^{18}O$(2-1), N_2D^+(3-2), and $H^{13}CO^+$(4-3) lines typically provide information about the protostellar envelopes. In **Figure 1** we show some of the well-defined outflows of the MASSES survey.

For each protostellar system, the MASSES survey has information of the underlying multiplicity from the Very Large Array (VLA) via the VLA Nascent Disk and Multiplicity (VANDAM) survey (Tobin et al. 2016). This survey revealed the multiplicity of each source at resolutions up to ~20 au resolution.

Science Highlights

Here, we briefly discuss recent publications that specifically highlight the statistical power of the MASSES survey.

Misalignment of Outflows in Multiple Protostellar Systems

In the first study to use the statistical power of the MASSES survey, Lee et al. (2016) examined the alignment of outflows driven by protostars in multiple systems with separations >~1000 au. The orientations of outflows in multiple systems can be used to distinguish between different theoretical scenarios for the origins of multiplicity. **Figure 2** shows maps of the outflows driven by these systems. Lee et al. (2016) showed that the distribution of outflow orientations in the multiple systems are most consistent with either randomly aligned or anti-aligned outflows, and inconsistent with aligned outflows. As discussed by Lee et al.

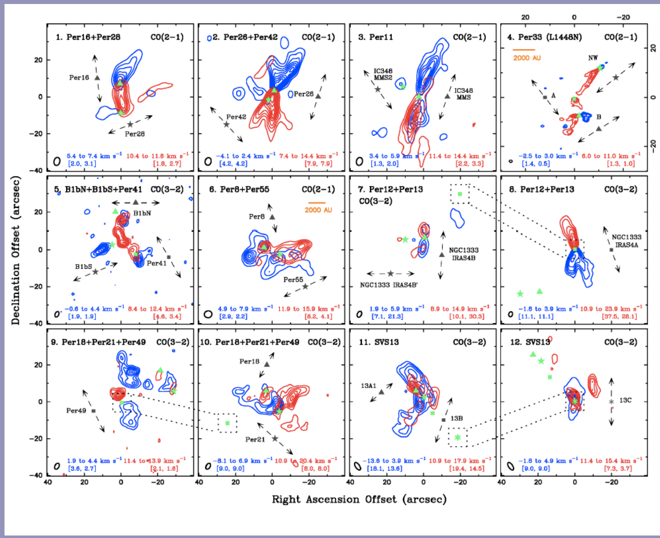

Figure 2: CO(2–1) contours showing outflows driven by multiple protostellar systems. The green symbols show the positions of the individual protostars. Statistics show that wide-binary outflows are not parallel. Each panel is approximately 0.1 pc on a side. Figure adapted from Lee et al. (2016).

(2016), these results are broadly consistent with those expected for multiple systems forming via the turbulent fragmentation scenario (e.g. Offner et al. 2010, 2016), but inconsistent with fragmentation scenarios where the angular momentum direction is conserved from core to protostar scales.

Investigating Alignment Between Filaments and Outflows

Within molecular clouds, most stars are expected to form within filaments. As mass falls into its gravitational potential, the material is expected to both flow onto filaments or through the filaments. This flow could potentially induce a vorticity, imparting angular momentum to the protostar.

In Stephens et al. (2017) we mapped the filamentary structure in Perseus based on *Herschel*-derived column density maps (Zari et al. 2016). We then compared this to the outflow direction, which is a proxy for the angular momentum axis. **Figure 3** shows these results. Specifically, we find with over 99% confidence that the angles between the filament directions and the protostars' angular momentum axes are inconsistent with angles that are always parallel or perpendicular. However, we cannot significantly distinguish the observed distribution from a random distribution. This may imply that at smaller scales, complex processes (e.g., turbulence) can cause a protostar to `lose memory' of the large-scale collapse.

Hierarchical Fragmentation in Perseus

Fragmentation in molecular clouds takes place in a hierarchical process over multiple size scales. Pokhrel et al. (2018) studied this hierarchical process in Perseus, showing that the Perseus Molecular Cloud fragments into parsec-scale clumps, the clumps fragment into 0.1 pc-scale cores, the cores fragment into 1000 au-scale envelopes, and the envelopes fragment into individual protostars or multiple protostellar systems. A cartoon schematic showing this hierarchical fragmentation is shown in **Figure 4**, which is reproduced from Pokhrel et al. (2018).

Using a combination of new MASSES data and previously published archival data from several different facilities, Pokhrel, et al. (2018) showed that, at all levels of the hierarchy, the number of fragments correlates better with the thermal Jeans number[1] of the parent structure than it does with the non-thermal Jeans number. While this suggests a simple picture where thermal Jeans fragmentation determines the outcome of fragmentation in each structure, Pokhrel, et al. (2018) also found that the number of fragments in a parent structure is always *less* than that predicted by the thermal Jeans number, by a factor that increases as the size scale of the parent structure increases. In other words, there are far fewer clumps than predicted by thermal Jeans fragmentation of the entire cloud, but only slightly fewer protostars than predicted by thermal Jeans fragmentation of the envelopes. These unexpected results led Pokhrel, et al. (2018) to describe fragmentation in Perseus as an "inefficient

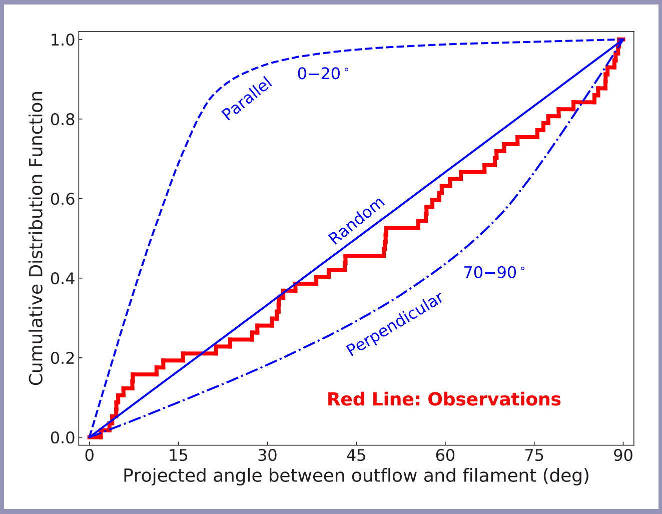

Figure 3: Cumulative distribution functions of the projected angles between outflows and filaments. Blue curves show the expected projected distributions for parallel, random, and perpendicular outflows and filaments. The red line shows the measurement based on observations. Figure adapted from Stephens et al. (2017).

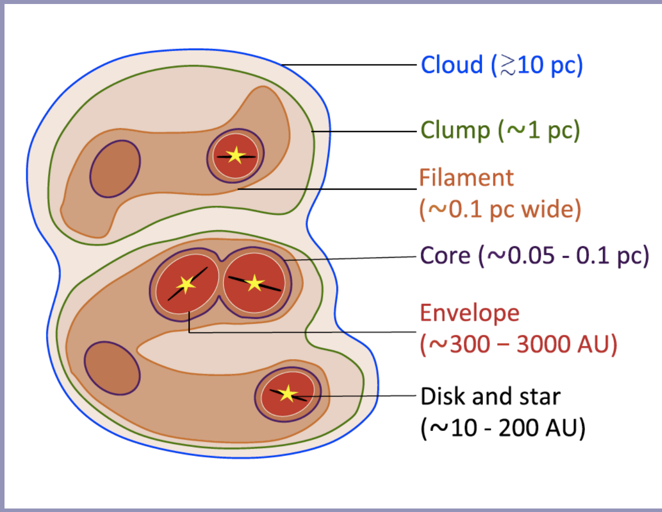

Figure 4: A cartoon schematic (not to scale) showing the hierarchical fragmentation in the Perseus Molecular Cloud. Figure adapted from Pokhrel et al. (2018).

[1]The ratio of the observed mass of an object to its thermal Jeans mass. A structure with a thermal Jeans number of ***n*** is expected to form, on average, ***n*** fragments.}

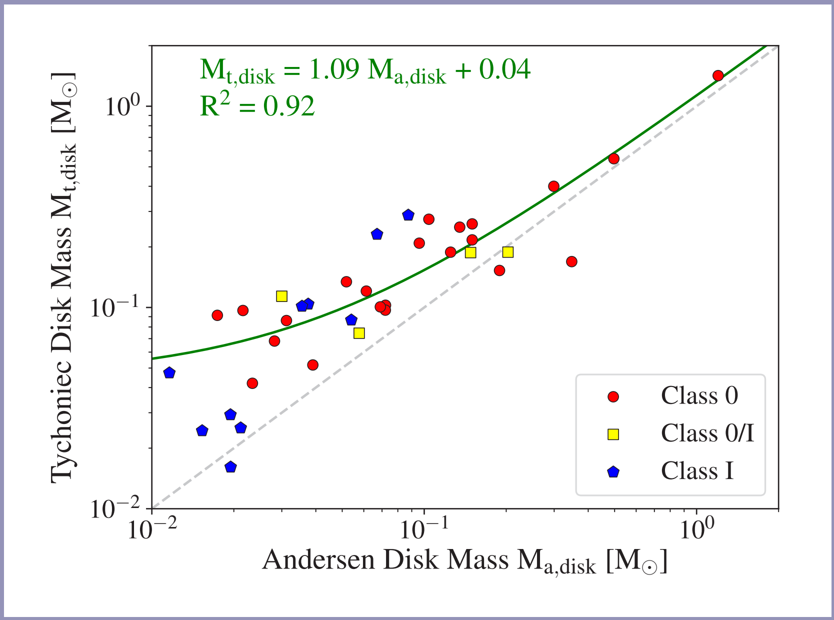

Figure 5: Comparison of disk mass measurements estimated at high resolution (~20 au) by Tychoniec et al. (2018) and via the MASSES survey. Adapted from Andersen et al. (2019).

thermal Jeans fragmentation" process, although the exact physical explanation for this inefficiency remains under investigation.

Measuring Embedded Disk Masses via Unresolved Observations

Estimating a disk mass from dust emission usually requires resolving the disk (usually <100 au in size). Given their small size, resolving disks can require time intensive observations, particularly in clouds that are far away. Jørgensen, et al. (2009) suggested a method of which disks can be estimated from unresolved observations by using a combination of interferometric and single disk observations. Essentially, by assuming a simple model, one can derive the disk and envelope mass from a measurement of the protostar's peak flux as taken by a single dish (several 1000 au resolution), and the flux at scales of ~1000 au as taken by the interferometer.

As previously mentioned, the VANDAM survey has observed all these MASSES protostars at ~20 au resolution, which have been used to estimate disk masses toward these sources (Segura-Cox, et al. 2018; Tychoniec et al. 2018). Therefore, we can test the Jørgensen, et al. (2009) model by using MASSES and single-dish data and compare to disk masses measured at high resolution. In Andersen et al. (2019) we made these comparisons, as shown for the Tychoniec et al. (2018) estimates in **Figure 5**. The method matches masses measured by high resolution observations remarkably well, suggesting that Jørgensen, et al. (2009) model is accurate, especially for a statistical sample.

Since we can estimate disk masses for most sources in MASSES, we can also estimate how disk masses evolve with time. By assuming the bolometric temperature of a protostar is a good indicator of its age, Andersen et al. (2019) found that disk masses remain at a relatively constant mass, as established at the early Class 0 stage. However, Andersen et al. (2019) noted that there is a subsample of several Class 0 protostars that have extremely low masses (<10^{-2} $M_\odot$), indicating that not all disks have their mass established at the early Class 0 stage.

Future Work and Legacy

Several additional studies leveraging the full statistical power of MASSES are currently in progress. These include projects aimed at studying (1) the evolution of outflow morphologies (specifically their opening angles, and thus the extent to which they remove mass from the system), (2) the relationship between outflow and envelope morphology (which indicates how outflow feedback regulates accretion onto stars), and (3) the relationships between the kinematics of dense cores (specifically, their levels of rotation and turbulence) and the level of fragmentation within each core. All of these published and in-progress studies are made possible by the statistical power provided by a survey of approximately 70 protostars in a single molecular cloud.

Beyond our own studies, one of the most important parts of the MASSES survey is its legacy value. All data products will be made publicly available, and indeed the first MASSES data release has already been provided (Stephens et al. 2018)[2]. The community will have access to these data products to use as ancillary data in their own studies, with two such examples already published (Lee et al. 2015; Agurto-Gangas et al. 2019).

[2]Data products are available at https://www.cfa.harvard.edu/sma/LargeScale/MASSES/.

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STAR FORMATION RATES OF MASSIVE MOLECULAR CLOUDS IN THE CENTRAL MOLECULAR ZONE

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One of the fundamental observational results in star formation studies is a linear correlation between the star formation rate (SFR) and the amount of dense ($\gtrsim 10^4$ cm^{-3}) molecular gas found in both Galactic sources and external galaxies (Gao & Solomon 2004; Wu et al. 2005, 2010; Lada et al. 2010, 2012; Kennicutt & Evans 2012), sometimes referred to as the dense gas star formation relation. This linear correlation is suggested to be a result of constant star formation efficiency (SFE) in molecular gas of densities $\gtrsim 10^4$ cm^{-3} (Lada et al. 2012).

The Central Molecular Zone (CMZ, Figure 1), the inner 500 pc of our Galaxy, does not fit into this correlation. It contains molecular gas of several times 10^7 M$_\odot$ with mean densities of $\sim 10^4$ cm^{-3} (Morris & Serabyn 1996; Ferrière et al. 2007), but the SFR is lower by at least an order of magnitude than expectation from the

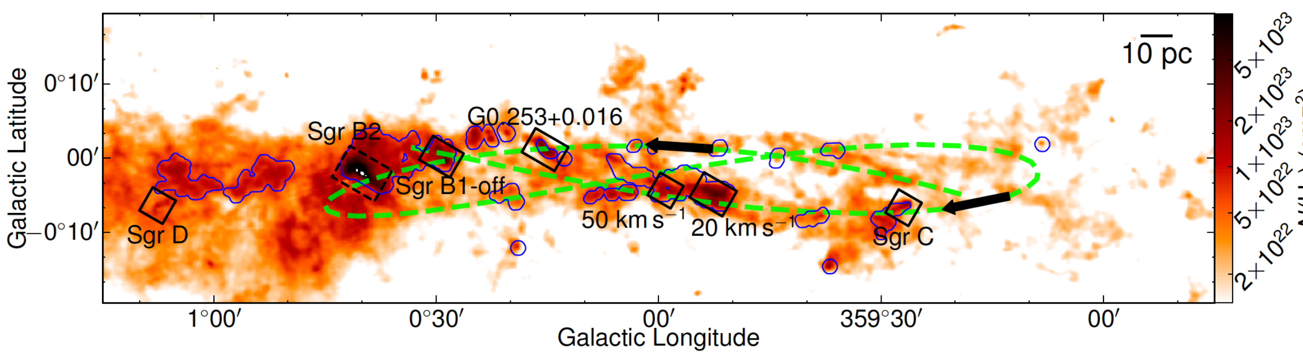

Figure 1: Overview of the CMZ and the six clouds in our observations. The background image shows column densities derived from the Herschel data (Battersby et al. 2011). The black boxes mark the location of the six clouds. Sgr B2 is not included in our observations but is discussed in the paper, and is marked by a dashed box. Covered area in the CMZoom survey (see text) is shown by the blue contour. The orbital model for the gas streams in the CMZ proposed by Kruijssen et al. (2015) is shown by the green dashed curve, with two black arrows indicating the direction of the proposed orbital motion.

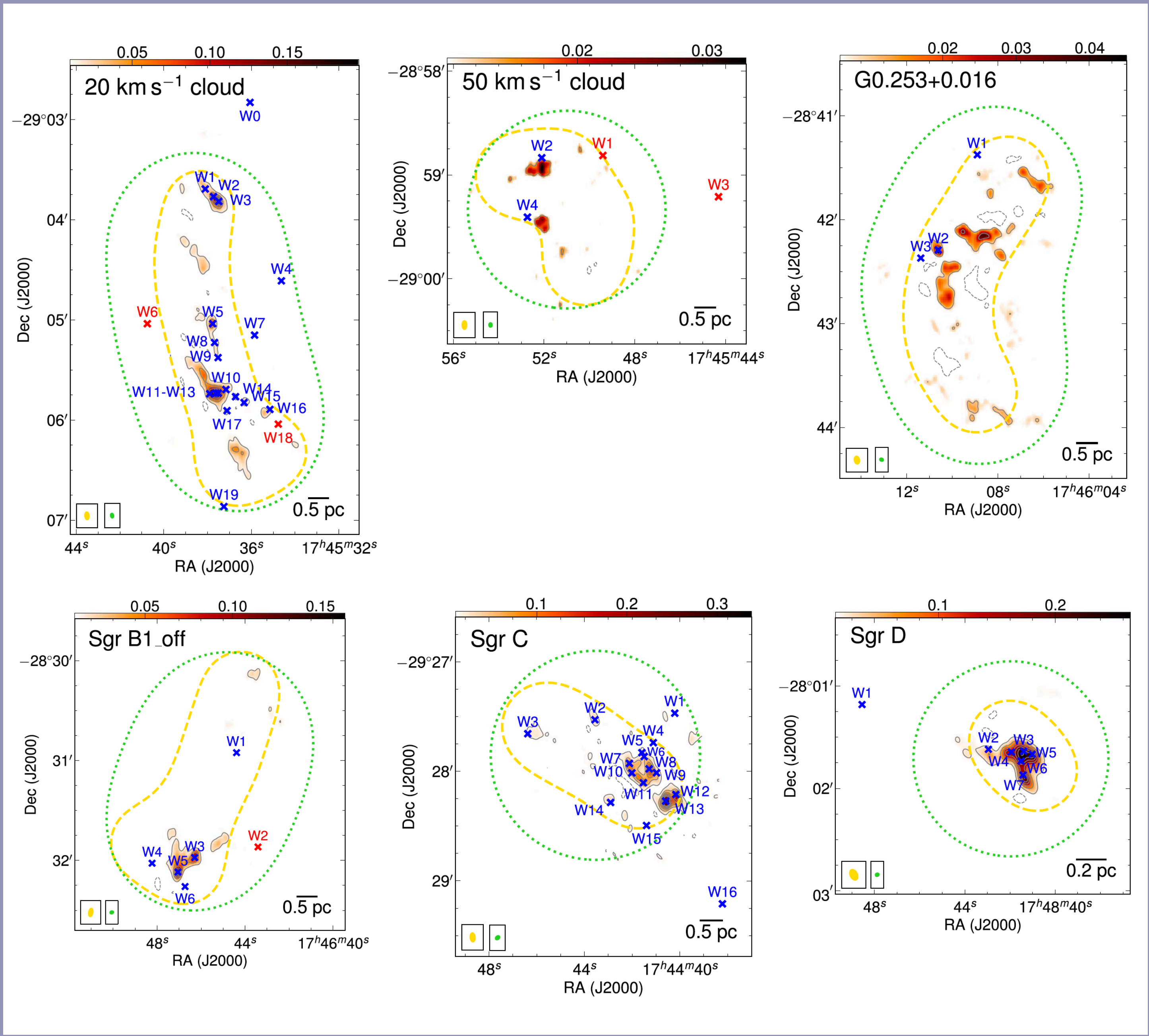

Figure 2: A summary of the SMA and VLA observations of the six clouds. The background images and contours show the SMA 1.3 mm continuum emission. VLA H_2O masers are marked by crosses, among which red ones are those with AGB star counterparts and have been excluded in the analysis of star formation. The dashed and dotted loops show the mosaic field of the SMA and VLA, respectively.

dense gas star formation relation, both on the scale of the entire CMZ (e.g., Yusef-Zadeh et al. 2009; An et al. 2011; Immer et al. 2012; Longmore et al. 2013; Barnes et al. 2017) and of individual clouds (e.g., Kauffmann et al. 2013, 2017; Barnes et al. 2017). Studying the peculiar star formation in the CMZ is crucial for understanding similar variations of star formation between nuclei and disks in external galaxies (Saintonge et al. 2012; Leroy et al. 2013) and origins of the scatter in the dense gas star formation relation (Burkhart 2018).

A possible explanation for the low SFR in the CMZ clouds is that these clouds are at very early evolutionary phases and active star formation has not emerged yet (Kruijssen et al. 2014; Krumholz & Kruijssen 2015; Krumholz et al. 2017). Previous studies using infrared luminosities (e.g., Barnes et al. 2017) or free-free emission from H II regions (e.g., Longmore et al. 2013; Kauffmann et al. 2017) generally characterize star formation in a timescale of a few Myr. A very young generation of star formation deeply embedded in dense gas that is invisible in infrared or

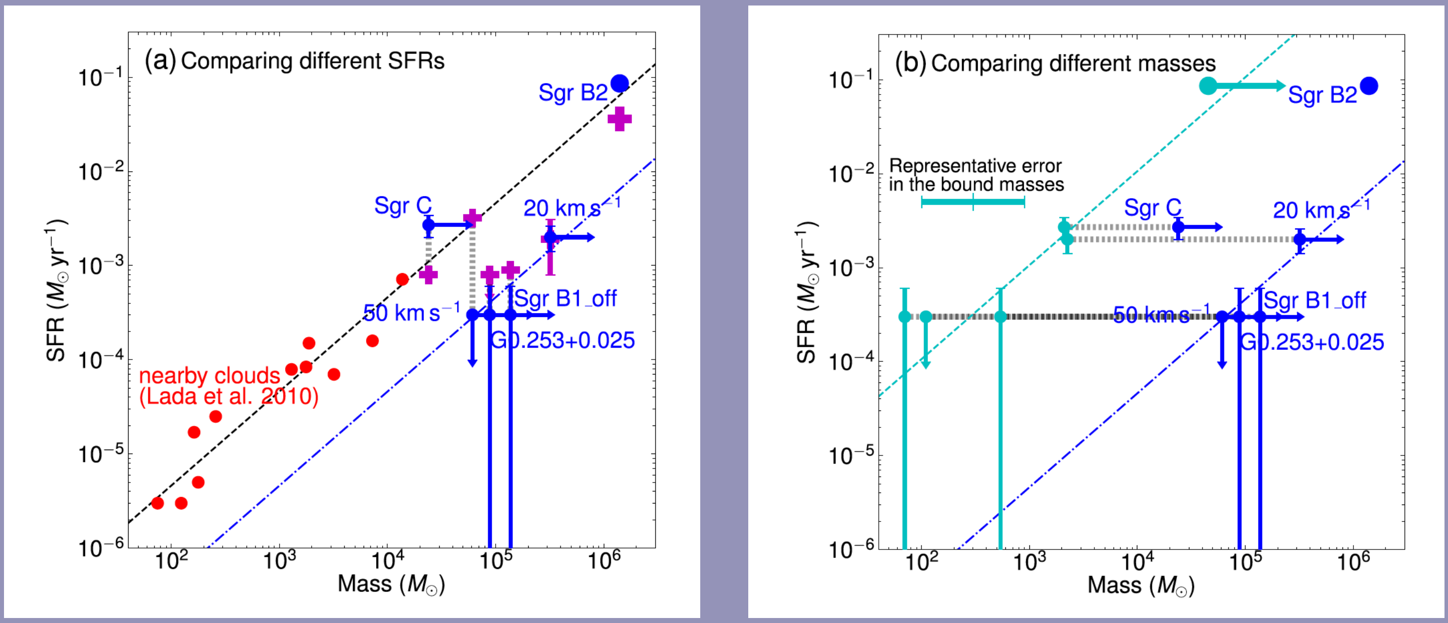

Figure 3: SFRs and masses of dense gas in the five CMZ clouds and in a sample of nearby clouds from Lada et al. (2010). Data of Sgr B2 compiled from the literature are also shown. (a) The blue dots mark the masses and SFRs of the five CMZ clouds in our observations plus Sgr B2. Each blue dot is connected to a magenta cross through a vertical line, which shows the SFR derived in Kauffmann et al. (2017). The black dashed diagonal line marks the linear correlation in Lada et al. (2010), with red dots showing masses and SFRs of the nearby clouds, based on which the correlation is derived. The blue dashed–dotted diagonal line marks the expected relation when the SFR is 10 times lower. (b) The blue dots, error bars, and blue diagonal line are identical to those in (a). In addition, each blue dot is connected to a cyan dot through a horizontal line, which marks the gravitationally bound masses. The horizontal cyan error bar represents the uncertainty in the gravitationally bound masses. The cyan dashed diagonal line is a linear fit to the cyan dots of the five CMZ clouds in our observations.

free-free emission could have been missed. Another compelling reason to investigate star formation at very early evolutionary phases is the evolutionary cycling–that is, the potential time delay between the star formation indicated by observations and the observed gas (Kruijssen & Longmore 2014). The turbulent crossing timescale of the CMZ clouds is ≳0.3 Myr (Kruijssen et al. 2014; Federrath et al. 2016; Kauffmann et al. 2013, 2017). Over a timescale of much longer than 0.3Myr, the feedback from star formation may have altered the environment therefore the observed gas reservoir is not directly related to the observed star formation.

In a recently published work (Lu et al. 2019), we investigate star formation at very early evolutionary phases in a sample of six CMZ clouds using the SMA 1.3 mm and the VLA K-band observations **(Figures 1 & 2)**. The SMA observations are from pilot projects to the SMA Legacy Survey *CMZoom* (website: https://www.cfa.harvard.edu/sma/LargeScale/CMZ/), which is led by Cara Battersby and Eric Keto and has mapped all major clouds above a column density threshold of 10^{23} cm^{-2} in the inner 5° longitude times 1° latitude of the CMZ over a period of three years (see the blue contour in **Figure 1**).

Five of the clouds have high column densities (>10^{23} cm^{-2}, see **Figure 1**) and therefore are potential sites of star formation. One cloud, Sgr D, has been suggested to reside outside of the CMZ and is included as a control object. In addition, Sgr B2 is one of the most active star-forming regions in the Galaxy, we compile published data from the literature and include it in the analysis.

Results of the SMA and VLA observations are presented in **Figure 2**. The angular resolution of both observations is about 3 arcsec, equivalent to ~0.1 pc linear scale. The SMA 1.3 mm continuum emission is mainly from thermal dust emission, which is used to trace gas in cores of 0.1 pc scale. H_2O masers and compact free-free emission from ultra-compact (UC) H II regions from the VLA observations, which are usually associated with star formation occurred in the last <1 Myr, are used to trace early phase star formation in the clouds.

In two clouds, the 20 km s^{-1} cloud and Sgr C, we find a large population of H_2O masers, many of which are new detections. Several UC H II region candidates are also found in the two clouds. These masers and UC HII regions are often associated with cores traced by the dust continuum emission from the SMA. In the other three CMZ clouds, including the 50 km s^{-1} cloud, G0.253+0.016, and Sgr B1-off, fewer cores and masers are detected.

We estimate SFRs and SFEs of the clouds based on the SMA and VLA observations. We assume each bright H_2O maser ($\gtrsim 10^{-6}\ L_\odot$) or UC H II region is associated with a high-mass ($>8\ M_\odot$) protostar, and count their numbers in each cloud. Then we estimate masses of the star clusters to be formed, by extrapolating to the full stellar mass range using the canonical multiple-power-law IMF of Kroupa (2001). Dividing the masses by a characteristic time scale of 0.3 Myr, we obtain the SFRs of the clouds. We also apply the same procedures to Sgr B2 using data from Ginsburg et al. (2018) and estimate its SFR. In the end, we have six clouds in the sample (excluding Sgr D and including Sgr B2) with results displayed in **Figure 3(a)**.

It is clear from **Figure 3(a)** that four CMZ clouds, including the 20 km s^{-1} cloud, the 50 km s^{-1} cloud, G0.253+0.016, and Sgr B1-off, have ~10 times lower SFRs than expected by the dense gas star formation relation given their cloud masses. The two known star formation clouds, Sgr B2 and Sgr C, on the other hand, are consistent with the dense gas star formation relation. It is also interesting to note that the 20 km s^{-1} cloud and Sgr C have similar SFRs, as already qualitatively evidenced from the numbers of H_2O masers in **Figure 2**, but the 20 km s^{-1} cloud falls below the linear relation because of the much larger cloud mass. The other interesting case is the 50 km s^{-1} cloud, which seems to be controversial given four prominent H II regions but little dense gas at <0.1 pc scale (Kauffmann et al. 2017). Our observations suggest that there is no signature of recent active star formation in the last <1 Myr in the 50 km s^{-1} cloud, which agrees with its dearth of dense gas.

Our new approach of quantifying SFRs strengthens the conclusion that star formation in the CMZ clouds (apart from a few cases like Sgr B2 and Sgr C) is suppressed as compared to the dense gas star formation relation, even after taking the very early phases of star formation traced by masers and UC H II regions into account.

In addition, we compare with the orbital model of Kruijssen et al. (2015), which suggests that all major clouds in the CMZ are subject to the gravitational potential around the Galactic Center and move in several gas streams (see the green curve in **Figure 1**), and that star formation in clouds could be triggered by tidal compression during a close passage to the bottom of the gravitational well near Sgr A*. While three of the clouds, G0.253+0.016, Sgr B1-off, and Sgr B2, can be well described by the orbital model, the other three clouds, including the 20/50 km s-1 clouds and Sgr C, do not fit into this model. This may suggest that local effects such as impact of supernova remnants or H II regions are responsible for triggering star formation in the latter three clouds.

Finally, as we have the SMA dust emission data, we are also able to estimate the gas masses confined in gravitationally bound cores in each cloud, and obtain the SFE at the core scale (<0.2 pc). The results are shown in **Figure 3(b)**. When plotting the SFRs again masses in bound cores, we find that the six clouds are well fit by a linear relation. It suggests an SFE of 30% in the cores, which is comparable to those at the same scale in nearby clouds (Alves et al. 2007; Könyves et al. 2015). These results suggest that star formation at the core scale in the CMZ clouds is not different from that in Galactic disk clouds in terms of the core to star-formation efficiency, but at the cloud scale the star formation is ~10 times less efficient because less than 1% of the gas is confined in gravitationally bound cores. This may be the result of the strong turbulence in the CMZ, and/or because the clouds are dynamically young and have not had the time to populate their high-density component. Future analysis in a similar manner of the CMZoom data toward all major CMZ clouds will be the key to solving the mystery of inactive star formation in the CMZ.

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A 1.3 mm SUPERCONDUCTOR INSULATOR SUPERCONDUCTOR MIXER RECEIVER WITH 40 GHz WIDE INSTANTANEOUS BANDWIDTH

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The majority of SIS mixers at millimeter and submillimeter wavelengths have been designed for radio astronomy receiver applications, where low noise and high sensitivity are of paramount importance. During the early development phase, these receivers incorporated mechanical tuners to tune out the large SIS junction capacitance, thus enabling low-noise operation across a wide input tuning range. However, the available instantaneous bandwidth was ultimately limited by the mixer IF and the availability of low-noise cryogenic IF amplifiers, which typically offered ~ 500 MHz bandwidth. The first fixed-tuned waveguide SIS mixer, which was pioneered at the SMA, had an input frequency range of 176 – 256 GHz.[1] However, the available instantaneous bandwidth was still limited by the availability of low-noise cryogenic IF amplifiers and the mixer IF to about 2 GHz. During the past decade, advances in low-noise IF amplifier technology have enabled operation across wider bandwidths. For example, many of the receivers incorporated into the Atacama Large Millimeter Array provide IF output from either 4 – 8

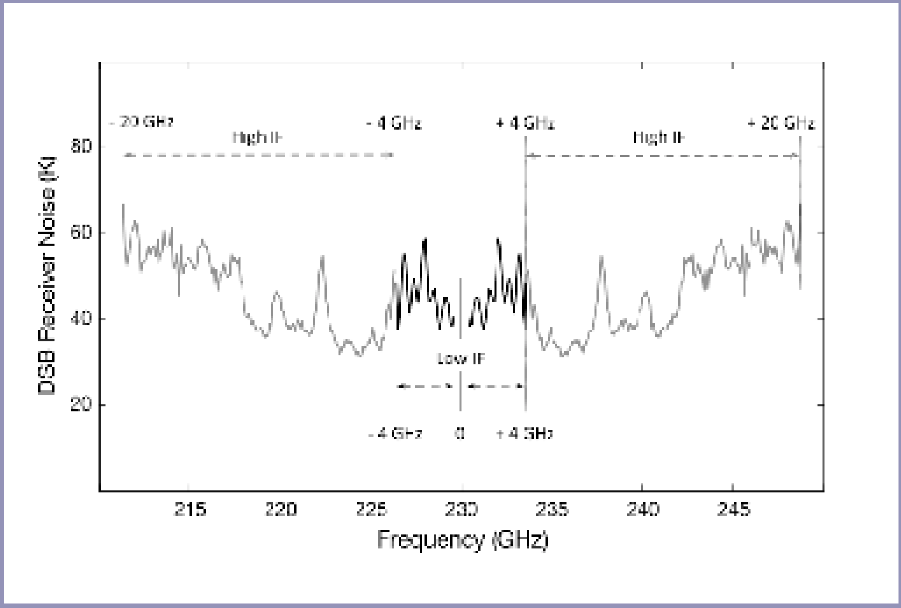


Figure 1: Double Side Band receiver noise as a function of input frequency measured at an LO frequency of 230 GHz.

GHz in the case of 2SB mixer receivers, or 4 – 12 GHz for DSB mixer receivers, which is similar to that of receivers operating at the IRAM 30 m radio telescope and those at the SMA.

For a DSB mixer with wide available instantaneous input bandwidth, full band and continuous sky frequency coverage is most efficiently achieved using an IF stretching from DC to half of the instantaneous RF input bandwidth, with the LO set at band center. However, impedance matching places limits on the bandwidth of low noise IF amplifiers that go to high IF, 1/f noise limits the performance of amplifiers close to DC, and the finite line width of the local oscillator precludes the use of mixers down to DC. Furthermore, IF amplifier noise tends to increase with increasing frequency, so it is not currently feasible to produce a receiver with wide available instantaneous bandwidth (~ 80 GHz) with the lowest noise. In order to process such a wide bandwidth, multiple LO tunings are therefore required. Continuous frequency coverage is then best achieved for wideband IF's with center frequency equal to the IF bandwidth. For example, in the case of a DSB mixer receiver with a 4 – 12 GHz IF, 2 LO tunings, each separated by 12 GHz, would provide continuous frequency coverage over a band 32 GHz – wide. Furthermore, using 2 orthogonally polarized mixers, each with a separate LO, the 32 GHz wide band could be recovered in a single observation. Similarly, in order to process an 80 GHz wide band efficiently with two DSB receivers, an IF of 10 – 30 GHz would be required. In each of these cases, the LO from one receiver appears as a huge signal at the center of the passband of the other (one in LSB, the other in USB) which is not ideal. In addition, output from the mixer at IF's below the lower end of the IF band are not processed, and since mixer losses and IF amplifier noise generally increase with frequency, extending the IF to 30 GHz again results in poorer noise performance.

Here we present an SIS mixer receiver with an IF bandwidth of 20 GHz, which also makes use of the frequency range below 4 GHz with low noise. This provides an available instantaneous frequency response for the double side band mixer receiver of almost 40 GHz, with only a small gap, about 100 MHz wide, centered at the local oscillator frequency. To achieve this, we use a standard SMA waveguide mixer coupled to a commercially available IF diplexer with two output ports, the first is used to couple the mixer IF output from ~ 100 MHz to 4 GHz directly to a commercially available low-noise SiGe amplifier, and the second to couple the mixer IF from 4 GHz to 20 GHz to a separate commercially available low-noise amplifier via a wideband circulator produced in-house[2].

Referring to **Figure 1**, when coupled to an ortho-mode transducer two such receivers could be used to perform wide band dual polarization observations. Alternatively, incorporating 2 independent local oscillators (40 GHz apart) to feed the two mixers, an 80 GHz instantaneous bandwidth could be recovered in a single observation. This would facilitate spectral line surveys, enable accurate determination of the redshift of high-z targets without the need for multiple frequency tunings, and could be used to better enable multi-frequency synthesis imaging.

Finally, the data presented here were measured using a receiver assembled from components at hand. We expect that a dedicated effort to further develop this concept will result in even better performance, and that further upgrades to the SMA would include such receivers.

REFERENCES

- 1. Raymond Blundell, C-Yu E Tong, D. Cosmo Papa, R. Louie Leombruno, Xiaolei Zhang, Scott Paine, Jeffrey A. Stern, Henry G. Leduc, and Bruce Bumble, "A wideband fixed-tuned SIS receiver for 200-GHz operation," IEEE Trans. Microwave Theory and Techniques vol. 43, no. 4, pp.933-937, April 1995.
- 2. L. Zeng, C. E. Tong, R. Blundell, P. K. Grimes and S. N. Paine, "A Low-Loss Edge-Mode Isolator with Improved Bandwidth for Cryogenic Operation," IEEE Trans. Microwave Theory and Techniques vol. 66, no. 5, pp. 2154-2160, May 2018. 10.1109/TMTT.2018.2799574.

DOPPLER TRACKING ERROR AFFECTING SMA NARROW-LINE OBSERVATIONS

The SMA discovered a software error affecting Doppler tracking during science observations from 2011 April 4 to 2019 April 3. This error has a negligible effect on observations of continuum and broad spectral lines. However, this error may impact observations of narrow spectral lines by a blurring of up to 0.8 km/s (with a blue-shifted bias of 0.3 km/s).

A software tool to fix this problem is available in the MIR/IDL package. This fix should be run on calibrated visibilities, just prior to export to MIRIAD or CASA for imaging. Further details can be found on the RTDC website at

https://www.cfa.harvard.edu/rtdc/SMAdata/process/mir/.

If you need assistance in applying the MIR/IDL-based solution above, or have any additional questions, please contact the SMA help desk at **sma-help@cfa.harvard.edu.**

RTDC UPDATE

By sharing user validation information, PIs and authorized users can now follow a link on their SMAOC project page straight to their data in the Radio Telescope Data Center (RTDC) archive without the need to log in and provide project details separately through the RTDC website.

For more information:

RTDC: **https://www.cfa.harvard.edu/rtdc/**

SMAOC: **http://sma1.sma.hawaii.edu/smaoc.html**

SCIENCE WITH THE SUBMILLIMETER ARRAY: PRESENT AND FUTURE, NOVEMBER 4-5, 2019, ASIAA, TAIPEI

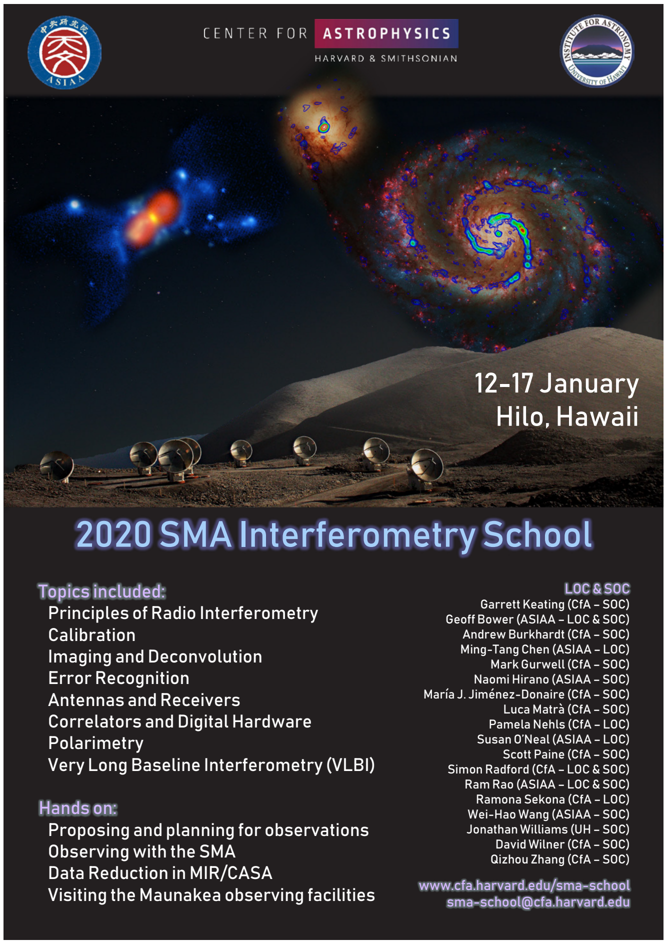
We are pleased to announce the workshop Science with the Submillimeter Array: Present and Future co-organized by Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) and the Center for Astrophysics | Harvard & Smithsonian. The registration is now open. Please visit the workshop website **https://events.asiaa.sinica.edu.tw/workshop/20191104** for more information.

In coordination with the Eastern Asian Observatory, the SMA Science Workshop and the JCMT annual Users Meeting will be held back to back during the week of November 4. This presents opportunities for interested parties to attend both meetings. Please visit **www.eaobservatory.org/jcmt/science/um-asiaa-2019/** for more information on the JCMT meeting.

We look forward to seeing you in Taipei.

Qizhou Zhang and Patrick Koch on behalf of the SOC.

2020 SUBMILLIMETER ARRAY INTERFEROMETRY SCHOOL



The Center for Astrophysics, in conjunction with the Academia Sinica Institute of Astronomy and Astrophysics and the University of Hawaii, is organizing the first Submillimeter Array Interferometry School.

The school will be held from 12-17 January 2020 at the facilities of the Smithsonian Astrophysical Observatory located in Hilo, conveniently following the Winter AAS Meeting in Honolulu. The main goals of the school are to provide graduate students, post-docs and scientists outside the field with a broad knowledge of interferometry and data reduction techniques at (sub)millimeter wavelengths.

The workshop will provide a series of lectures focusing on fundamentals of radio interferometry, with a special emphasis on the Submillimeter Array (SMA) interferometer and its new capabilities. The school will also extensively utilize the SMA, located on Maunakea, providing hands-on experience of actively performing observations and data reduction for projects proposed by school participants.

Website: www.cfa.harvard.edu/sma-school

Contact: sma-school@cfa.harvard.edu

CALL FOR STANDARD OBSERVING PROPOSALS - 2019B SEMESTER

We wish to draw your attention to the latest Call for Standard Observing Proposals for observations with the Submillimeter Array (SMA). This call is for the 2019B semester with observing period **16 Nov 2019 – 15 May 2020.**

Standard Observing Proposals

Submission deadline: **05 September 2019 (US)/06 September 2019 (Taiwan)**

Proposal Information and Submission **http://sma1.sma.hawaii.edu/proposing.html**

The SMA is a reconfigurable interferometric array of eight 6-m antennas on Maunakea jointly built and operated by the Smithsonian Astrophysical Observatory and the Academia Sinica Institute of Astronomy and Astrophysics. The array operates in the 230, 345 and 400 GHz bands, observing simultaneously with two orthogonally polarized receivers, one in the 230 GHz or 345 GHz band and the other in the 240 GHz or 400 GHz band (with full polarimetric observations available using the 230+240 or 345+400 band combinations). The SWARM correlator processes 8 GHz bandwidth for each receiver in each sideband, for a total of 32 GHz, at a uniform 140 kHz resolution. This 32 GHz frequency coverage can be continuous where the tuning ranges overlap for the two orthogonally polarized receivers. The SMA provides flexible, wide band frequency coverage that delivers high continuum sensitivity and excellent spectral line capabilities. A full transit observation offers continuum sensitivity of 250 or 600 micro-Jy (1 sigma) at 230 or 345 GHz in good weather conditions (precipitable water vapor 2.5mm and 1.0mm, respectively). The corresponding line sensitivities at 1 km/s resolution are 35 and 80 mJy. The small antennas allow access to low spatial frequencies in the sub-compact configuration, and at the other extreme, the finest angular resolution with the very extended configuration at 345 GHz is ~ 0.25". The compact and extended configurations complete the range. The characteristics and performance of the SMA are both similar and complementary to those of the stand-alone Atacama Compact Array (ACA) component of ALMA.

For more information about SMA capabilities, visit the **SMA Observer Center website (http://sma1.sma.hawaii.edu/status.html)** and explore the set of **SMA proposing tools (http://sma1.sma.hawaii.edu/tools.html).** Current and archived **SMA Newsletters (https://www.cfa.harvard.edu/sma/Newsletters/)** provide a sampling of the wide variety of science possible with the SMA.

For more details visit the SMA Observer Center Proposal Information Page at **http://sma1.sma.hawaii.edu/proposing.html**

IMPORTANT DATES FOR STANDARD OBSERVING PROPOSALS

Submissions open: **08 August 2019 (on or before)**
Submissions close: **05 September 2019 (US)/06 September 2019 (Taiwain)**

Due to current and expected investment in further upgrades to the SMA capabilities, as well as obligations to previous approved programs, the Large Scale Projects program (for projects requesting 100 to 1000 hours) will not be accepting proposals at this time.

Questions or comments regarding the Standard Observing Proposals can be addressed to **sma-proposal@cfa.harvard.edu**.

Mark Gurwell
Chair, Submillimeter Array Time Allocation Committee

SMA POSTDOCTORAL FELLOWS: COMINGS AND GOINGS

The Submillimeter Array Postdoctoral Fellowship program supports early career scientists active in a variety of astronomical research fields involving submillimeter astronomy. The SMA Fellowship is competitive, and a high percentage of our past Fellows have gone on to permanent faculty and research staff positions located around the world.

The SMA welcomes our newest Fellows:

John Garrett received his Ph.D. from University of Oxford, UK, in 2018, with the thesis ‘A 230 GHz Focal Plane Array Using a Wide IF Bandwidth SIS Receiver' (advisor: Ghassan Yassin). He is currently a postdoctoral fellow in University of Oxford. John’s expertise is in SIS mixer with wide IF bandwidth, focal plane array of SIS receivers, simulating SIS mixer operation and performance, and observing star formation in intermediate redshift galaxies.

Feng Long is finishing her Ph.D. work at Peking University, China, with the thesis ‘ALMA Surveys of Protoplanetary Disks' (adviser: Gregory J. Herczeg). Feng's research is in observational astronomy related to star and planet formation. She has a particular interest in protoplanetary disks, including disk formation, disk physical and chemical evolution, and their implications to planet formation.

Richard Teague received his Ph.D. from Max-Planck-Institute for Astronomy, Heidelberg, Germany in 2017, with the thesis ‘Tracing the Earliest Stages of Planet Formation through Modelling and Sub-mm Observations' (advisors: Thomas Henning and Dmitry Semenov). He is currently a postdoctoral fellow in University of Michigan. Richard’s research is focused on using spatially and spectrally resolved observations of molecular line emission to trace the physical and kinematical structure of the planet formation environment, the protoplanetary disk.

Drs. Garrett, Long and Teague will take up their fellowship in fall 2019. They join continuing SMA Fellows Luca Matrà, Maria Jesus Jiménez-Donaire and Andrew Burkhardt.

As new Fellows arrive, we also take the time to thank those Fellows who are moving on to even bigger things:

- Tomek Kamiński is moving to Toruń, Poland, to assume an assistant professorship at the Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences. He is awarded a grant to build a new group to study stellar mergers and common-envelope systems using interferometric techniques at infrared and submillimeter wavelengths. Tomek will be leaving the SMA in September 2019. we wish him (and all our current and former Fellowship holders) continued success!

A list of current and former SMA Fellows is provided at **https://www.cfa.harvard.edu/opportunities/fellowships/sma/smafellows.html** along with further information on the SMA Fellowship program. We anticipate the deadline for the 2020 SMA Fellowship opportunities will be in October 2019.

Mark A. Gurwell and Qizhou Zhang
Current and incoming Chair, SMA Fellowship Selection Committee

STAFF CHANGES IN HILO

Pamela Nehls, Administrative Staff Assistant, joined SMA in April, reporting to Simon Radford. Previously she worked for the USFS Institute of Pacific Islands Forestry in Hilo.

POSTDOCTORAL OPPORTUNITIES WITH THE SMA

Applications for the 2020 Submillimeter Array (SMA) Postdoctoral Fellowship program will be due in fall 2019. We anticipate offering one or more SMA Postdoctoral Fellowships starting Summer/Fall 2020.

The SMA is a pioneering radio interferometer designed for arc-second imaging in the submillimeter spectrum. SMA science spans an impressive array of fields, ranging from our solar system, through imaging of gas and dust and tracing magnetic fields in stellar nurseries and planet-forming disks, to exploration of nearby galaxies and imaging of dusty star-forming galaxies at high redshift. In addition to its outstanding record in astronomical research, the SMA is a world leader in the design of wide-bandwidth, high-frequency radio receivers for astronomy. The SMA recently commissioned a next generation correlator which vastly increases total bandwidth (to 8 GHz/sideband per polarization) while retaining high spectral resolution (140 kHz) across the entire processed spectral range, providing significantly enhanced science capability, and further expansion to 12 GHz/sideband per polarization is underway.

These positions are aimed chiefly at research, both observational and theoretical, in submillimeter astronomy. Successful candidates will participate in remote and on-site observations with the SMA, research in their interpretation, and/or instrument development. While the SMA fellowships are intended primarily for research associated with the SMA, our main offices at the Center for Astrophysics provide Fellows with unique opportunities to develop collaborations within the broader CfA community of 250 Ph.D. staff researchers and with extraordinary freedom in structuring their research activities. Applicants must have a recent Ph.D. in astronomy or a related field.

The SMA is a collaboration between the Smithsonian Astrophysical Observatory and the Academia Sinica Institute of Astronomy and Astrophysics in Taipei, Taiwan. The Smithsonian Astrophysical Observatory is an Equal Opportunity/Affirmative Action Employer where all qualified applicants receive equal consideration without regard to race, color, creed, national origin or gender.

Application information and instructions can be found at

http://www.cfa.harvard.edu/opportunities/fellowships/sma

The deadline for applications is October 10, 2019. The website is expected to be open for application submission on August 15, 2019. Please check the above link for up to date information and application procedure.

Questions: **smapostdoc@cfa.harvard.edu**

PROPOSAL STATISTICS 2019A (16 MAY 2019 – 15 NOV 2019)

The SMA received a total of 83 proposals (SAO 62) requesting observing time in the 2019A semester. The proposals received by the joint SAO and ASIAA Time Allocation Committee are divided among science categories as follows:

CATEGORY	PROPOSALS
high mass (OB) star formation, cores	24
low/intermediate mass star formation, cores	14
submm/hi-z galaxies	13
local galaxies, starbursts, AGN	7
protoplanetary, transition, debris disks	7
GRB, SN, high energy	5
evolved stars, AGB, PPN	3
other	3
solar system	3
UH	3
Galactic center	1

TRACK ALLOCATIONS BY WEATHER REQUIREMENT (ALL PARTNERS):

PWV[1]	SAO	ASIAA	UH[2]
< 4.0mm	26A + 56B	4A + 73B	0
< 2.5mm	14A + 31B	4A + 6B	4
< 1.0mm	0A + 0B	2A + 0B	2
Total	**40A + 87B**	**10A + 13B**	**6**

(1) Precipitable water vapor required for the observations.

(2) UH does not list As and Bs.

TOP-RANKED SAO AND ASIAA PROPOSALS – 2019A SEMESTER

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

GALACTIC CENTER

Howard Smith, CfA
SMA Continued Participation in Simultaneous Monitoring of Flaring from the Galactic Center's Supermassive Black Hole

GRB, SN, HIGH ENERGY

Alexandra Tetarenko, East Asian Observatory
Constraining Jet Formation and Evolution with Transient X-ray Binaries

Anna Ho, Caltech
The death throes of massive stars, revealed through early millimeter observations

Yuji Urata, NCU
Search for Bright submm GRB afterglows Toward Radio Polarimetry

HIGH MASS (OB) STAR FORMATION, CORES

Henrik Beuther, Max-Planck-Institute for Astronomy
The importance of magnetic fields for the fragmentation of high-mass star-forming regions (the summer targets)

Jia-Wei Wang, National Tsing-Hua University, Taiwan
Resolve the polarization morphology from the envelope to the Keplerian disk at 200 AU scale in the massive protostar Cepheus A HW2

Todd Hunter, NRAO
Accretion outbursts in massive protostars: Monitoring of dust continuum and excited methanol masers in the third known source - G358.931-0.030

LOW/INTERMEDIATE MASS STAR FORMATION, CORES

Andrew Burkhardt, CfA
A Deep, Broadband Interferometric Chemical Survey of L1157

Chia-Lin Ko, National Tsing Hua University
Abundance ratios of S-bearing molecules as an alternative probe of grain growth

Nacho Añez, Institut de Ciències de l'Espai (ICE, IEEC-CSIC)
What is controlling the fragmentation process?

Yusuke Aso, ASIAA
Pilot Survey of Deuterated Molecules in Class 0 Protostars (resubmission)

OTHER

Meredith MacGregor, Carnegie DTM
The Origin and Impact of Flares in M Dwarf Systems

PROTOPLANETARY, TRANSITION, DEBRIS DISKS

Hau-Yu Baobab Liu, ASIAA
Millimeter Flux Variability/Stability of FU Orionis Objects and EXors

SOLAR SYSTEM

David Jewitt, UCLA
Extraordinary Distant Comet C/2017 K2

Mark Gurwell, CfA
Full Polarization Thermal Mapping of Ganymede and Callisto

SUBMM/HI-Z GALAXIES

David Clements, Imperial College London
A Rosetta Stone for Distant Dusty Star-Forming Galaxies: SERVS, Herschel and the SMA

Justin Spilker, University of Texas at Austin
A Complete Inventory of the Molecular ISM in a Starburst Galaxy at the Peak Epoch of Cosmic Star Formation

ALL SAO PROPOSALS – 2018B SEMESTER

The following is the listing of all SAO proposals observed in the 2018B semester (16 Nov 2018 – 15 May 2019).

Dana Anderson, Caltech
An Exploration of Nitrogen Gas Content in Protoplanetary Disks

Ashley Bemis, McMaster University
Investigating Dense Gas and Star Formation in the Antennae

Henrik Beuther, Max-Planck-Institute for Astronomy
The importance of magnetic fields for the fragmentation of high-mass star-forming regions (completing the sample)

Cheng Cheng, Chinese Academy of Sciences
Exploring molecular gas content in low mass galaxies

Elizabeth Cooke, Durham University
The nature of the ULIRG population in massive clusters at z=1-1.5

Decker French, Carnegie Observatories
Evolution of the resolved Kennicutt-Schmidt relation through the Post-Starburst Phase

Anna Ho, Caltech
A new frontier in cosmic explosions

Yun-Hsin Hsu, ASIAA
Determination of the HyLIRG Fraction among Herschel Bright Sources

Jane Huang, CfA
A pilot wideband chemical survey of Class I protostellar disks

Todd Hunter, NRAO
Accretion Outburst in a Massive Protostar

Sigurd Jensen, University of Copenhagen
Quantifying water deuteration toward the densely clustered Serpens SMM1 source.

Maria Jesus Jimenez-Donaire, CfA
Searching for Embedded Super Star Clusters in M82

Attila Kovacs, CfA
Actively growing Sunyaev-Zel'dovich clusters: sub-structure and the galaxies they feed or magnify

Shih-Ping Lai, National Tsing Hua University
Pilot mosaic polarization observations towards W51 and Orion BN/KL

Charles Law, CfA
Searching for Ionized Accretion Flows around 0.1 pc Scale Clusters with O-Type Stars

Sheng-Yuan Liu, ASIAA
The Excitation and Variation of A Newly Discovered Methanol Maser in the Massive YSO S255~IR (copied from 2017B-A017)

Sheng-Yuan Liu, ASIAA
The Interplay between Magnetic Fields and Stellar Feedback in the Sequential Massive Star Forming Complex G9.62+0.19

Hau-Yu Baobab Liu, ASIAA
Millimeter Flux Variability/Stability of FU Orionis Objects and EXors

Meredith MacGregor, Carnegie Institution for Science
The Origin and Impact of Flares in M Dwarf Systems

Luca Matrà, CfA
REsolved ALMA and SMA Observations of Nearby Stars (REASONS): a legacy population study of the formation location of planetesimal belts (part 3)

Luca Matrà, CfA
The First Millimeter Image of the Herbig Ae/Be Disk around the Multiple Stellar System HD34700

Anaelle Maury, Paris Saclay University
Evidence of magnetic braking in Class 0 protostars : towards a statistical view

Mattia Negrello, Carnegie Institution for Science
SMA imaging of Herschel-ATLAS candidate lensed galaxies

Charlie Qi, CfA
Close-up Imaging of Comet 46P/Wirtanen

Aneta Siemiginowska, CfA
SMA Observations of Compact Radio Sources (copied from 2018A-S042)

Yuji Urata, NCU
Search for Bright submm GRB afterglows Toward Radio Polarimetry

Wei-Hao Wang, ASIAA
SMA Pilot STUDIES: Imaging the Brightest SCUBA-2 450 micron Sources

Yoshimasa Watanabe, University of Tsukuba
Spectral Line Survey toward Ultraluminous X-ray (ULX) Source in M51 with SMA

Jonathan Williams, University of Hawaii
Resolved Observations of Nearby Debris Disks

RECENT PUBLICATIONS

TITLE: G5.89: an explosive outflow powered by a proto-stellar merger?
AUTHORS: Zapata, Luis A.; Ho, Paul T. P.; Guzmán Ccolque, Estrella; Fernández-Lopéz, Manuel; Rodríguez, Luis F.; Bally, John; Sanhueza, Patricio; Palau, Aina; Saito, Masao
ABSTRACT: https://ui.adsabs.harvard.edu/abs/2019MNRAS.486L..15Z/abstract
PUBLICATION: *Monthly Notices of the Royal Astronomical Society: Letters, Volume 486, Issue 1, p.L15-L19*
PUBLICATION DATE: June 2019

TITLE: Revealing the chemical structure of the Class I disc Oph-IRS 67
AUTHORS: de la Villarmois, E. Artur; Kristensen, L. E.; Jørgensen, J. K.
ABSTRACT: https://ui.adsabs.harvard.edu/abs/2019arXiv190600685D/abstract
PUBLICATION: *eprint arXiv:1906.00685*
PUBLICATION DATE: June 2019

TITLE: Resolved Molecular Gas and Star Formation Properties of the Strongly Lensed z=2.26 Galaxy SDSS J0901+1814
AUTHORS: Sharon, Chelsea E.; Tagore, Amitpal S.; Baker, Andrew J.; Rivera, Jesus; Keeton, Charles R.; Lutz, Dieter; Genzel, Reinhard; Wilner, David J.; Hicks, Erin K. S.; Allam, Sahar S.; Tucker, Douglas L.
ABSTRACT: https://ui.adsabs.harvard.edu/abs/2019arXiv190509845S/abstract
PUBLICATION: *eprint arXiv:1905.09845*
PUBLICATION DATE: May 2019

TITLE: Massive Young Stellar Objects and Outflow in the Infrared Dark Cloud G79.3+0.3
AUTHORS: Laws, Anna S. E.; Hora, Joseph L.; Zhang, Qizhou
ABSTRACT: http://ui.adsabs.harvard.edu/abs/2019ApJ...876...70L
PUBLICATION: *The Astrophysical Journal, Volume 876, Issue 1, article id. 70, 10 pp.*
PUBLICATION DATE: May 2019

TITLE: A Survey of C_2H, HCN, and $C^{18}O$ in Protoplanetary Disks
AUTHORS: Bergner, Jennifer B.; Öberg, Karin I.; Bergin, Edwin A.; Loomis, Ryan A.; Pegues, Jamila; Qi, Chunhua
ABSTRACT: http://ui.adsabs.harvard.edu/abs/2019ApJ...876...25B
PUBLICATION: *The Astrophysical Journal, Volume 876, Issue 1, article id. 70, 10 pp.*
PUBLICATION DATE: May 2019

TITLE: First Detection of Radio Linear Polarization of GRB Afterglow
AUTHORS: Urata, Y.; Toma, K.; Huang, K.; Asada, K.; Nagai, H.; Takahashi, S.; Petitpas, G.; Tashiro, M.; Yamaoka, K.
ABSTRACT: https://ui.adsabs.harvard.edu/abs/2019arXiv190408111U/abstract
PUBLICATION: *eprint arXiv:1904.08111*
PUBLICATION DATE: April 2019

TITLE: Molecular Bullets in A High-mass Protostar
AUTHORS: Cheng, Yu; Qiu, Keping; Zhang, Qizhou; Wyrowski, Friedrich; Menten, Karl; Guesten, Rolf
ABSTRACT: https://ui.adsabs.harvard.edu/abs/2019arXiv190401429C/abstract
PUBLICATION: *eprint arXiv:1904.01429*
PUBLICATION DATE: April 2019

TITLE: First M87 Event Horizon Telescope Results. VI. The Shadow and Mass of the Central Black Hole
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TITLE: First M87 Event Horizon Telescope Results. I. The Shadow of the Supermassive Black Hole

AUTHORS: Event Horizon Telescope Collaboration; Akiyama, Kazunori; Alberdi, Antxon; Alef, Walter; Asada, Keiichi; Azulay, Rebecca; Baczko, Anne-Kathrin; Ball, David; Baloković, Mislav; Barrett, John; Bintley, Dan; Blackburn, Lindy; Boland, Wilfred; Bouman, Katherine L.; Bower, Geoffrey C.; Bremer, Michael; Brinkerink, Christiaan D.; Brissenden, Roger; Britzen, Silke; Broderick, Avery E. 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PUBLICATION: *The Astrophysical Journal Letters, Volume 875, Issue 1, article id. L1, 17 pp. (2019).*

PUBLICATION DATE: April 2019

TITLE: A submillimeter polarization analysis of Frosty Leo

AUTHORS: Sabin, L.; Zhang, Q.; Vázquez, R.; Steffen, W.

ABSTRACT: https://ui.adsabs.harvard.edu/abs/2019MNRAS.484.2966S/abstract

PUBLICATION: *Monthly Notices of the Royal Astronomical Society, Volume 484, Issue 3, p.2966-2973*

PUBLICATION DATE: April 2019

TITLE: The Mass Evolution of Protostellar Disks and Envelopes in the Perseus Molecular Cloud

AUTHORS: Andersen, Bridget C.; Stephens, Ian W.; Dunham, Michael M.; Pokhrel, Riwaj; Jørgensen, Jes K.; Frimann, Søren; Segura-Cox, Dominique; Myers, Philip C.; Bourke, Tyler L.; Tobin, John J.; Tychoniec, Łukasz

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PUBLICATION: *The Astrophysical Journal, Volume 873, Issue 1, article id. 54, 11 pp. (2019).*

PUBLICATION DATE: March 2019

TITLE: Revealing the dust grain size in the inner envelope of the Class I protostar Per-emb-50

AUTHORS: Agurto-Gangas, C.; Pineda, J. E.; Szűcs, L.; Testi, L.; Tazzari, M.; Miotello, A.; Caselli, P.; Dunham, M.; Stephens, I. W.; Bourke, T. L.

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PUBLICATION: *Astronomy & Astrophysics, Volume 623, id.A147, 17 pp.*

PUBLICATION DATE: March 2019

TITLE: Massive and low-mass protostars in massive "starless" cores

AUTHORS: Pillai, Thushara; Kauffmann, Jens; Zhang, Qizhou; Sanhueza, Patricio; Leurini, Silvia; Wang, Ke; Sridharan, T. K.; König, Carsten

ABSTRACT: https://ui.adsabs.harvard.edu/abs/2019A%26A...622A..54P/abstract

PUBLICATION: *Astronomy & Astrophysics, Volume 622, id.A54, 11 pp.*

PUBLICATION DATE: February 2019

TITLE: Star Formation Rates of Massive Molecular Clouds in the Central Molecular Zone

AUTHORS: Lu, Xing; Zhang, Qizhou; Kauffmann, Jens; Pillai, Thushara; Ginsburg, Adam; Mills, Elisabeth A. C.; Kruijssen, J. M. Diederik; Longmore, Steven N.; Battersby, Cara; Liu, Hauyu Baobab; Gu, Qiusheng

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PUBLICATION: *The Astrophysical Journal, Volume 872, Issue 2, article id. 171, 34 pp. (2019).*

PUBLICATION DATE: February 2019

TITLE: Multi-wavelength characterization of the blazar S5 0716+714 during an unprecedented outburst phase

AUTHORS: MAGIC Collaboration; Ahnen, M. L.; Ansoldi, S.; Antonelli, L. A.; Arcaro, C.; Baack, D.; Babić, A.; Banerjee, B.; Bangale, P.; Barres de Almeida, U.; Barrio, J. A.; Becerra González, J.; Bednarek, W.; Bernardini, E.; Ch Berse, R.; Berti, A.; Bhattacharyya, W.; Biland, A.; Blanch, O.; Bonnoli, G.; Carosi, R.; Carosi, A.; Ceribella, G.; Chatterjee, A.; Colak, S. M.; Colin, P.; Colombo, E.; Contreras, J. L.; Cortina, J.; Covino, S.; Cumani, P.; da Vela, P.; Dazzi, F.; de Angelis, A.; de Lotto, B.; Delfino, M.; Delgado, J.; di Pierro, F.; Domínguez, A.; Dominis Prester, D.; Dorner, D.; Doro, M.; Einecke, S.; Elsaesser, D.; Fallah Ramazani, V.; Fernández-Barral, A.; Fidalgo, D.; Fonseca, M. V.; Font, L.; Fruck, C.; Galindo, D.; Gallozzi, S.; García López, R. J.; Garczarczyk, M.; Gaug, M.; Giammaria, P.; Godinović, N.; Gora, D.; Guberman, D.; Hadasch, D.; Hahn, A.; Hassan, T.; Hayashida, M.; Herrera, J.; Hose, J.; Hrupec, D.; Ishio, K.; Konno, Y.; Kubo, H.; Kushida, J.; Kuveždić, D.; Lelas, D.; Lindfors, E.; Lombardi, S.; Longo, F.; López, M.; Maggio, C.; Majumdar, P.; Makariev, M.; Maneva, G.; Manganaro, M.; Mannheim, K.; Maraschi, L.; Mariotti, M.; Martínez, M.; Masuda, S.; Mazin, D.; Mielke, K.; Minev, M.; Miranda, J. M.; Mirzoyan, R.; Moralejo, A.; Moreno, V.; Moretti, E.; Nagayoshi, T.; Neustroev, V.; Niedzwiecki, A.; Nievas Rosillo, M.; Nigro, C.; Nilsson, K.; Ninci, D.; Nishijima, K.; Noda, K.; Nogués, L.; Paiano, S.; Palacio, J.; Paneque, D.; Paoletti, R.; Paredes, J. M.; Pedaletti, G.; Peresano, M.; Persic, M.; Prada Moroni, P. G.; Prandini, E.; Puljak, I.; Garcia, J. R.; Reichardt, I.; Rhode, W.; Ribó, M.; Rico, J.; Righi, C.; Rugliancich, A.; Saito, T.; Satalecka, K.; Schweizer, T.; Sitarek, J.; Šnidarić, I.; Sobczynska, D.; Stamerra, A.; Strzys, M.; Surić, T.; Takahashi, M.; Takalo, L.; Tavecchio, F.; Temnikov, P.; Terzić, T.; Teshima, M.; Torres-Albà, N.; Treves, A.; Tsujimoto, S.; Vanzo, G.; Vazquez Acosta, M.; Vovk, I.; Ward, J. E.; Will, M.; Zarić, D.; Fermi-Lat Collaboration; Bastieri, D.; Gasparrini, D.; Lott, B.; Rani, B.; Thompson, D. J.; MWL Collaborators; Agudo, I.; Angelakis, E.; Borman, G. A.; Casadio, C.; Grishina, T. S.; Gurwell, M.; Hovatta, T.; Itoh, R.; Järvelä, E.; Jermak, H.; Jorstad, S.; Kopatskaya, E. N.; Kraus, A.; Krichbaum, T. P.; Kuin, N. P. M.; Lähteenmäki, A.; Larionov, V. M.; Larionova, L. V.; Lien, A. Y.; Madejski, G.; Marscher, A.; Myserlis, I.; Max-Moerbeck, W.; Molina, S. N.; Morozova, D. A.; Nalewajko, K.; Pearson, T. J.; Ramakrishnan, V.; Readhead, A. C. S.; Reeves, R. A.; Savchenko, S. S.; Steele, I. A.; Tornikoski, M.; Troitskaya, Yu. V.; Troitsky, I.; Vasilyev, A. A.; Zensus, J. Anton

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

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