The Submillimeter Array

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The TL;DR

SMA 2021A Semester Proposal Deadline

4PM EST Thursday March 4, 2021

Proposal Site at SMA Observer Center

http://sma1.sma.hawaii.edu

We are here to help!

sma-propose@cfa.harvard.edu
Outline

• Submillimeter Array Background
• SMA Science
• SMA Specifications
• Proposing
• Q & A
What is the SMA?

The SMA is a pathfinding instrument comprised of eight 6 meter antennas on Mauna Kea, HI, designed for high spatial and spectral resolution imaging in submillimeter atmospheric windows.

The SMA is a collaborative project of the Smithsonian Astrophysical Observatory, part of the Harvard-Smithsonian Center for Astrophysics, and the Academia Sinica Institute of Astronomy and Astrophysics (Taiwan)
What is the SMA?

The SMA is used to study Solar System bodies, protoplanetary disks, star forming regions, evolved star envelopes, the Galactic Center, nearby galaxies, and ultraluminous galaxies at cosmological distances.

The SMA is a collaborative project of the Smithsonian Astrophysical Observatory, part of the Harvard-Smithsonian Center for Astrophysics, and the Academia Sinica Institute of Astronomy and Astrophysics (Taiwan)
Why the Submillimeter?

Cold material is best seen in submillimeter “light”
Many Molecules have Spectral Lines in mm/submm (Orion example)

Easy to excite rotational transitions abound!
Single Aperture vs Interferometry

Resolution ~ wavelength/size
200 meters for 1” at λ=1mm
SMA B=6-508 m (34” to 0.4”)

LMT: \( d = 32 \text{ m (50 m)} \Rightarrow 805 \text{ m}^2 (1965 \text{ m}^2) \)

SMA: \( d = 6 \text{ m (x 8)} \Rightarrow 226 \text{ m}^2 \)

JCMT: \( d = 15 \text{ m} \Rightarrow 177 \text{ m}^2 \)
Antenna Stations

4 Nested Rings
(Keto 1997)

4 Configurations

<table>
<thead>
<tr>
<th></th>
<th>230</th>
<th>345</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcompact</td>
<td>9”</td>
<td>6”</td>
</tr>
<tr>
<td>Compact</td>
<td>3.5”</td>
<td>2.5”</td>
</tr>
<tr>
<td>Extended</td>
<td>1.3”</td>
<td>0.8”</td>
</tr>
<tr>
<td>Very Extended</td>
<td>0.5”</td>
<td>0.3”</td>
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Solar System Spectroscopy

Nitrile redistribution to the southern ('winter') pole has strengthened.
Three year difference between projects; allows measurement of seasonal changes.
Planet Forming Disks

- images of dust and gas around ~1 Myr old stars at scale of our Solar System
- initial conditions for planet building
- significant fraction show inner holes: evidence for infant giant planets

Andrews et al. 2010
Hughes et al. 2009
Brown et al. 2007, 2009

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Star Formation

CO(2-1) Outflows from the MASSES Large Program Stephens et al

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Evolved Stars

Arcs of carbon monoxide emission in the carbon-rich evolved star IRC+10216 (right). Excerpt from the IRC+10216 line survey spectrum is shown below.
Rapid Response/Time Domain Science

Extreme Flaring Activity During the June 2015 Outburst of the Black Hole X-Ray Binary V404 Cygni (Tetarenko et al 2017)
Polarization

- Single receiver, cycling quarter-wave plates (time-sharing to obtain full Stokes coverage)
- Dual receiver, direct full Stokes (no time-sharing, more efficient)

G31.41+0.31 (Girart et al)

PPN OH231.8+4.2 (Sabin et al 2014)
Nearby Galaxies

M51 mosaic, pointings on left, integrated CO(2-1) on right at 3.5” resolution
Nearby Galaxies

CO2-1 focus region at 1.2” resolution

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High Redshift

SMA VEX observations of $z \sim 3$ gravitationally lensed galaxy (orange) overlaid on HST I-band image of foreground $z \sim 1.5$ galaxy (blue).

SMA resolution is 0.3"

(Nevsbada et al., 2019)
Event Horizon Telescope
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SMA Specifications

Antennas: 8 antennas of 6 m diameter, 12 μm rms surface cost + imaging speed + collecting area

Configurations: 24 pads in four rings
baseline lengths 8 - 508 m,
subarcsecond resolution, best ~0.25” (at 400 GHz)

 Receivers: 4 per antenna; always 2 simultaneously, each single pol.
full frequency coverage of atmospheric windows
dual polarization, “A” & “B” combinations allowed
‘230’ 177-256 GHz (A)
‘345’ 256-360 GHz (A)
‘240’ 205-280 GHz (B)
‘400’ 325-420 GHz (B)

Correlator: Bandwidth: 2 SB x 12 GHz x 2 Rx’s (Pol. too if Rx’s share LO)
Uniform 139 kHz resolution at all times!
Sensitivity and bandwidth to span/resolve extragalactic/galactic lines – excellent for line surveys

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SMA Rx Bands

Rx A: 230 - 345 GHz
Rx B: 240 - 400 GHz

Transmission vs. Frequency (GHz)

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Correlator: Bandwidth: 2 SB x 12 GHz x 2 Rx’s (Pol. too if Rx’s share LO)
Continuum Sensitivity (dual rx, 48 GHz BW, 7 hrs)
1.3mm: 200 μJy for 2.5mm pwv
870μm: 500 μJy for 1.5mm pwv

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SWARM Correlator is Powerful

2 SB x 12 GHz x 2 Rx’s = 48 GHz (dual pol)

All at 139 kHz uniform resolution
SWARM Correlator – Independent Tuning

RxA and RxB orthogonal polarization

Correlator Mode | Application | RX in Use | Comments
--- | --- | --- | ---
12 GHz Dual Rx | Dual Rx | Any RxA + Any RxB | 12 GHz BW per sideband per receiver
12 GHz Full Pol. | Full Polarization | 230+240 or 345+400 | 12 GHz BW per sideband for all pol. states

All at 139 kHz uniform resolution

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SWARM Correlator – 44 GHz

RxA and RxB orthogonal polarization

44 GHz Continuous Frequency Coverage with 4 GHz overlap

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<th>RX in Use</th>
<th>Comments</th>
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<tr>
<td>12 GHz Dual Rx</td>
<td>Dual Rx</td>
<td>Any RxA + Any RxB</td>
<td>12 GHz BW per sideband per receiver</td>
</tr>
<tr>
<td>12 GHz Full Pol.</td>
<td>Full Polarization</td>
<td>230+240 or 345+400</td>
<td>12 GHz BW per sideband for all pol. states</td>
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All at 139 kHz uniform resolution
SWARM Correlator – Dual/Full Pol

RxA and RxB orthogonal polarization

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</tr>
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All at 139 kHz uniform resolution
SMA: practical scientific benefits

every measurement is an imaging spectral line survey

most efficient resolved spectral line mapping facility

nimble, flexible, more responsive for time domain studies

(everything we do now is better and faster, and still improving)
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Observing and Proposal Information

• CfA allocates 72% of SMA Time (UH/ASIAA split rest)
• ‘open skies’ policy…accept proposals from anywhere
• proposal deadlines on 6 month cycle (March/September)
  – next deadline: MARCH 4 2021
• Configuration schedule not preset, driven by highest ranking proposals and Large Scale programs
• dynamic queue scheduling according to weather
• RTDC archive, data in public domain after 15 months
• Calibration and Imaging:
  – MIR/Miriad/CASA + (AIPS)/Miriad/CASA
  – Initial testing of calibration pipeline(s) ongoing

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Many Flexible Observing Modes

- **Standard Projects** (Less than 100 hours requested)
- **Large Scale Projects** (More than 100 hours. Special proposal process)
- **Filler Projects** (Flexible on set-up. Just need “a look”)
- **TOO/Rapid Response** (Typical trigger -> observation time is minutes)
- **Monitoring** (Long term monitoring. Typically a couple hours a week)
- **Coordinated observing** (Simultaneous with other observatories)
Proposal Basics

Proposal Form Initiated on SMA OC

- Cover page forms (PI, Co-I, Abstract, history)
- Time Requests (Source, sensitivity, tuning, configuration)
- 4 page Science and Technical Justification uploaded as PDF

PI can designate authorized users who can access/edit proposal
Proposal Suggestions

Check the SMA Archive!

- Hosted by Radio Telescope Data Center
- Detailed information available about past observations
- If previous observations exist, can still propose but need to justify

Proposal should be

- Clear on science goals and possible outcomes
- Clear on how observations will satisfy science goals
- Clear justification for: new observations/size of sample/SNR
target/tuning range/array configuration/etc

We Can Help! Contact sma-propose@cfa.harvard.edu
Welcome to the RTDC

The Radio Telescope Data Center (RTDC) archives, and makes available data from the Submillimeter Array (SMA), the CFA Millimeter-wave Telescope, the Antarctic Submillimeter Telescope and Remote Observatory (AST/RO). We also provide hardware, software tools, and necessary support for the analysis of radio interferometric data from the SMA, JVLA, VLBA, and ALMA.

RTDC machines give users access to all raw SMA science data since 2002, and flux and baseline data going back five years. We also maintain a public data archive containing all SMA data from which visitors can download non-proprietary raw datasets. A subset of calibrated and imaged science data is also available.

The CFA Millimeter-wave telescope archive includes the CO (1-0) spectra from the whole-Galaxy survey presented in Dame, Hartmann & Thaddeus (2001), v1-b FITS cubes for each survey listed in Table 1 of that paper, plus larger composite cubes and integrated maps.

Learn more about what the RTDC can offer

News

4 Jan  Remember you can now find data from 2020 in the mir_data.2020 directories.

2 Jan  CASA 5.7.2 is now aliased to casa on the RTDC. You can overwrite this in your .cshrc file if you want to use an older version (see Accessing CASA for a list). For more details on this release see the CASA release notes.

14 Oct  The network between Hawaii and Cambridge is extremely slow at the moment. Expect delays with data being ingested into the archive. This is being investigated. UPDATE (11/12) The network has improved and we have parallelized the archive transfer script. However, to avoid overwhelming the summit network we are not transferring data to Cambridge until observations in Hawaii are complete (~8pm UT).

3 Sep  You can now find a comprehensive list of new SMA antennas files at Complete List of SMA Antennas Files. This list can be checked to see improved antenna positions exist for your data set.

20 Aug  CASA 5.7 is now available on the RTDC. This has been aliased to casa. You can overwrite this in your .cshrc file if you want to use an older version (see Accessing CASA for a list). For more details on this release see the CASA release notes.

15 Aug  CASA 5.6.0 pre-release is now available on the RTDC. Find it at /opt/casa-prerelease-5.6.0-5.el6.
The Submillimeter Array (SMA) is an 8-element radio interferometer located atop Maunakea in Hawaii. Operating at frequencies from 180 GHz to 418 GHz, the 6m dishes may be arranged into configurations with baselines as long as 509m, producing a synthesized beam of sub-arcsecond width. Each element can observe with two receivers simultaneously, with up to 8 GHz bandwidth each per sideband. The digital correlator backend provides a uniform resolution as high as 140 kHz. The Submillimeter Array is a joint venture of the Smithsonian Astrophysical Observatory and the Academia Sinica Institute of Astronomy and Astrophysics.

Call for SMA Science Observing Proposals
### SMA Multi-config Beam Calculator & Sensitivity Estimator

<table>
<thead>
<tr>
<th>Frequency:</th>
<th>GHz</th>
<th><strong>Array Configuration:</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sideband:</td>
<td></td>
<td>SUB</td>
</tr>
<tr>
<td>Declination:</td>
<td>degrees</td>
<td>COM</td>
</tr>
<tr>
<td>Minimum elevation:</td>
<td>degrees</td>
<td>EXT</td>
</tr>
<tr>
<td>HA at start of track:</td>
<td>hours</td>
<td>VEX</td>
</tr>
<tr>
<td>HA at end of track:</td>
<td>hours</td>
<td></td>
</tr>
<tr>
<td>Precipitable water vapor:</td>
<td>2.5 mm</td>
<td></td>
</tr>
</tbody>
</table>

**Notes about and assumptions used in the calculation**

- Minimum elevation and hour angle limits are optional. (elevation limit of 15° assumed if necessary).
- For subcompact configuration, the array elements are physically limited to elevations ≥33°.
- Other fields are required.

[Calculate] [Clear Values]
NOISE ESTIMATE -- Natural Weights
Assumes requested frequency placed at 10 GHz in IF

LO Freq = 220.5 GHz  \( \tau_{\text{LO}} = 0.775 \)
\( T_{\text{LO}}(\text{DSB}) = 66.4 \text{ K} \)  \( \tau_{\text{NSB}} = 0.920 \)
PWV: 2.50 mm  \( \tau_{\text{PWV}} = 0.134 \)
\( \tau_{\text{inc}} = 0.120 \)  \( \tau_{\text{vis}} = 0.145 \)

On-source = 13.97 hr  \( \text{Beam}_{\text{LO}} = 1.96'' \times 1.52'' \)

**RMS NOISE/BEAM**

<table>
<thead>
<tr>
<th>BANDWIDTH</th>
<th>LSB (210.5 GHz)</th>
<th>USB (230.5 GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FLUX (mJy)</td>
<td>FLUX (mJy)</td>
</tr>
<tr>
<td></td>
<td>T(RU)</td>
<td>T(RU)</td>
</tr>
<tr>
<td>12 GHz</td>
<td>0.25 mJy</td>
<td>0.27 mJy</td>
</tr>
<tr>
<td>2 GHz</td>
<td>0.61 mJy</td>
<td>0.63 mJy</td>
</tr>
<tr>
<td>100 km/s</td>
<td>3.3 mJy</td>
<td>3.2 mJy</td>
</tr>
<tr>
<td>1 km/s</td>
<td>32.3 mJy</td>
<td>32.2 mJy</td>
</tr>
</tbody>
</table>

SINGLE RX USB = LSB SENSITIVITY 0.13 mJy/beam
DUAL RX OPERATION: divide above sensitivities by \( \sqrt{2} \)

1 Assumes 20% noise penalty in upper 4 GHz of IF
2 Assumes same LO and spectral response for both RX

220.5 GHz LO Config: COM EXT

DEG = 33.0°, \( E_{\text{min}} = 20.0° \)

Beam (Full SMA Primary Field)  \( B_{\text{max}} = 1.96'' \)
\( B_{\text{min}} = 1.62'' \)
PA = 92.7°

Beam (Center of Field)

10% Contours, Normalized Beam

Natural Weighting
SMA Passband Visualizer

Note: Sections 5 and 6 of the correlator are known to be less sensitive. Details here.

Cursor frequency (GHz): 302.042.

See below for instructions.

Use the following information for the tuning setup in the time request section of your proposal.
(Note that the target velocity is specified along with the source coordinates, and is not part of the receiver tuning setup).

tuning: 230.538, sideband: usb, band: s1, offset: 0.0000

tuning: 238.538, sideband: usb, band: s1, offset: 0.0000

(dopplerTrack -r 230.538 -u -s1 -f 0.0000 -h 10 -R h -r 238.538 -u -s1 -f 0.0000 -h 10)
Special Cases: ToO Proposals

• SMA is *very* quick to respond, if a proposal is already accepted (e.g. GRB event)

• Propose for (n) events, describe trigger criteria

• If accepted, when your group triggers, send position information to designated contact, and we will observe at next possible opportunity
  – 9 minutes is current ‘record’ from contact to on-sky

• 12 hr response window in case of multiple PI triggers

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The Take Away

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Landscape of mm/submm Telescopes

SMT  APEX  JCMT

SMA

IRAM

IRAM/NOEMA

LMT

ALMA

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Orion BNKL
SWARM
Demonstration

obtained when SWARM covered 8 GHz IF band
current coverage is 12 GHz IF band

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Time Oversubscription

Majority of time requests come at 345 GHz
Proposal Statistics

No. of Proposals

- Stellar, 60, 7%
- Star Formation, 500, 55%
- Galactic Center, 34, 4%
- Other, 13, 1%
- Planetary, 18, 2%

Time request

- Stellar, 7%
- Star Formation, 46%
- Extragalac., 41%
- Galactic Center, 7%
- Planetary, 1%
- Other, 1%

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Spatial Frequencies

Short baselines – large spatial scales

Long baselines – small spatial scales

SPATIAL DOMAIN

(Spatial) FREQUENCY DOMAIN
Spatial Frequencies

Short baselines – large spatial scales

Long baselines – small spatial scales

For high spatial dynamic range but small number of sampling points (antennas) need multiple configurations

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