Smithsonian Astrophysical Observatory
Submillimeter
Array

Report on the Submillimeter Array

Ray Blundell

Mauna Kea Users' Committee Meeting
01 October, 2009

Smithsonian Astrophysical Observatory
Submillimeter Array

The SMA in brief

Collaboration between Smithsonian Astrophysical Observatory and Academia Sinica Institute of Astronomy and Astrophysics

Eight-element interferometer designed to operate from about 200 to 900 GHz

Located on Mauna Kea, close to the JCMT and CSO

6 m diameter antennas with surface accuracy ~ 12 μm

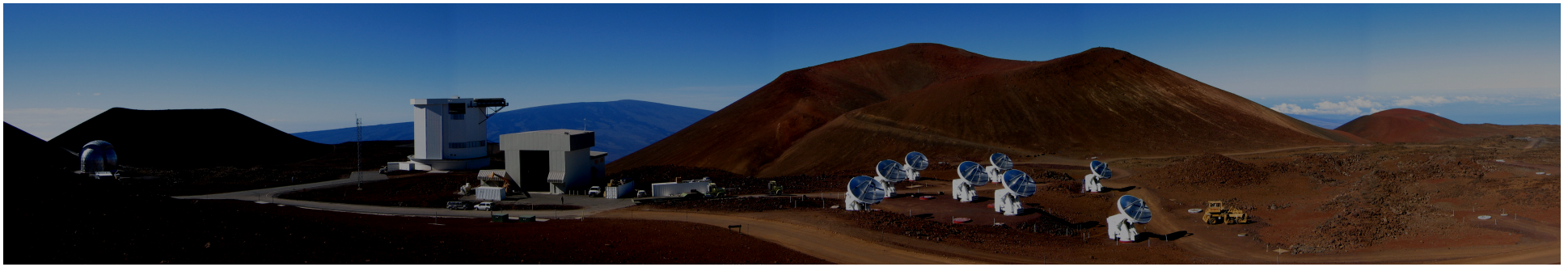
Receivers for 200, 300, 400, and 650 GHz now available on all antennas

IF center frequency 5 GHz, bandwidth 2 GHz

Simultaneous operation of low and high frequency receivers

4 GHz bandwidth now possible for single receiver use

Flexible cross-correlation spectrometer with resolution down to 25 kHz



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Outline

- Look back – upgrades planned for FY 2009
- Current status of planned upgrades
- A few interesting science results
- Proposal statistics, metrics
- Projects planned for FY 2010 and the future

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Upgrades planned for FY 2009

- Install improved 320 – 420 GHz receiver sets
- Improve 650 GHz receiver performance
- Test and field an atmospheric phase monitor
- Incorporate phase correction scheme
- Begin routine science observations with BW doubler
- Build phased array processor for improved VLBI

Ongoing Receiver Upgrades

- Improve performance of 320-420 GHz receivers
  - Difficulties with SIS device fabrication continue at JPL
  - New SIS chip design has been developed and produced at IRAM with good results
  - New mixers currently being installed at the SMA

- Improve performance of 650 GHz receivers
  - New SIS chip design has been developed and produced at U. Cologne
  - Good results ~ 2x more sensitive
  - First of the new mixers installed August 2009, more to follow

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Atmospheric phase monitor

(More efficient observing)

- Rely on CSO for atmospheric opacity data
- Need data on atmospheric stability to improve operations
- Specifically, data may be used to
  - Determine Phase stability trends at the site
  - Choose optimal observing frequency and project for current conditions (Phase stability and τ are only weakly correlated.)
  - Chose optimal time for observing calibrators
- Monitor will run 24/7 and produce uniform data for the Mauna Kea community in real time.
- Uses inexpensive satellite TV components

Two-element interferometer in the lab

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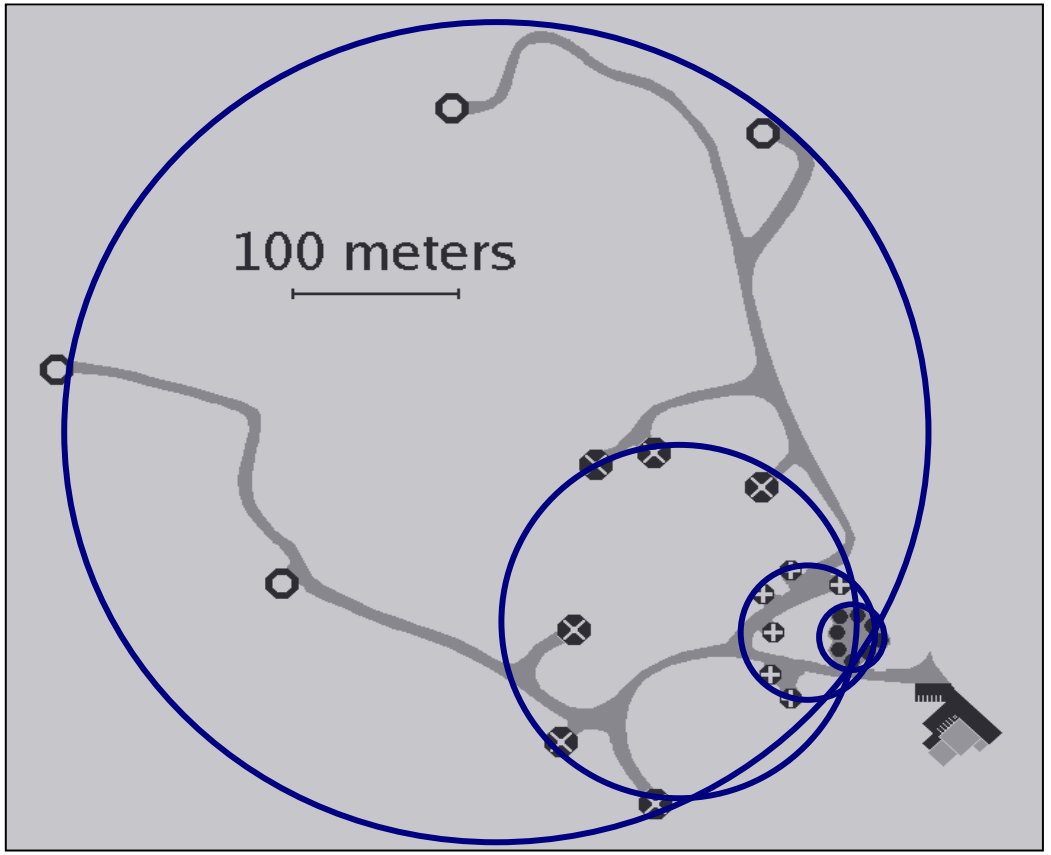
Mauna Kea site - antenna stations



Four nested arrays, Keto (1997)

Subcompact
Compact
Extended
Very extended

Angular resolution at 350 GHz
3.5, 1.8, 0.8, 0.3 arcsec

Phase monitors to be installed in 5 pads so 3 are available independent of configuration

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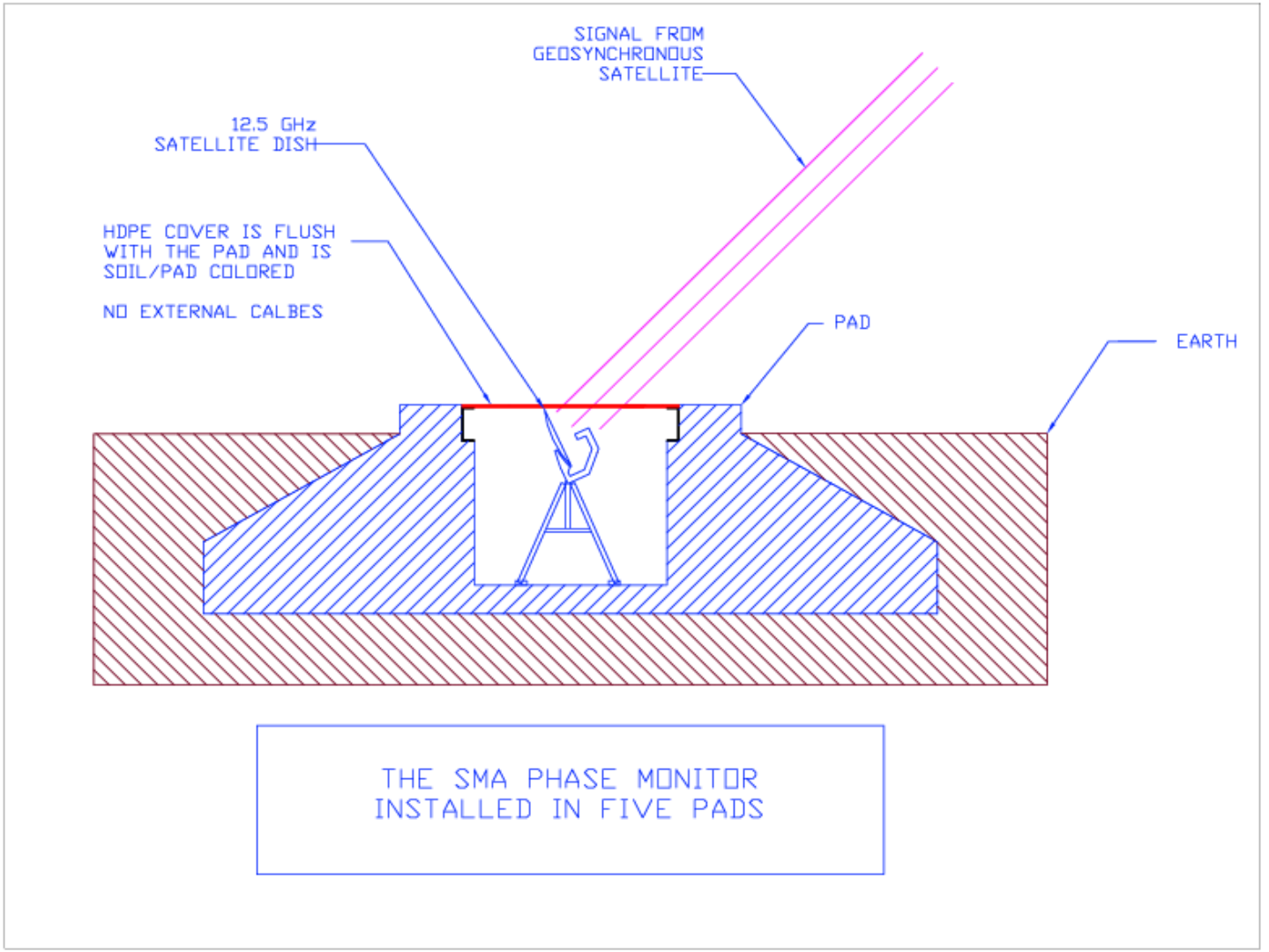
Phase monitor antenna hidden in antenna pad



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Single element buried in antenna Pad

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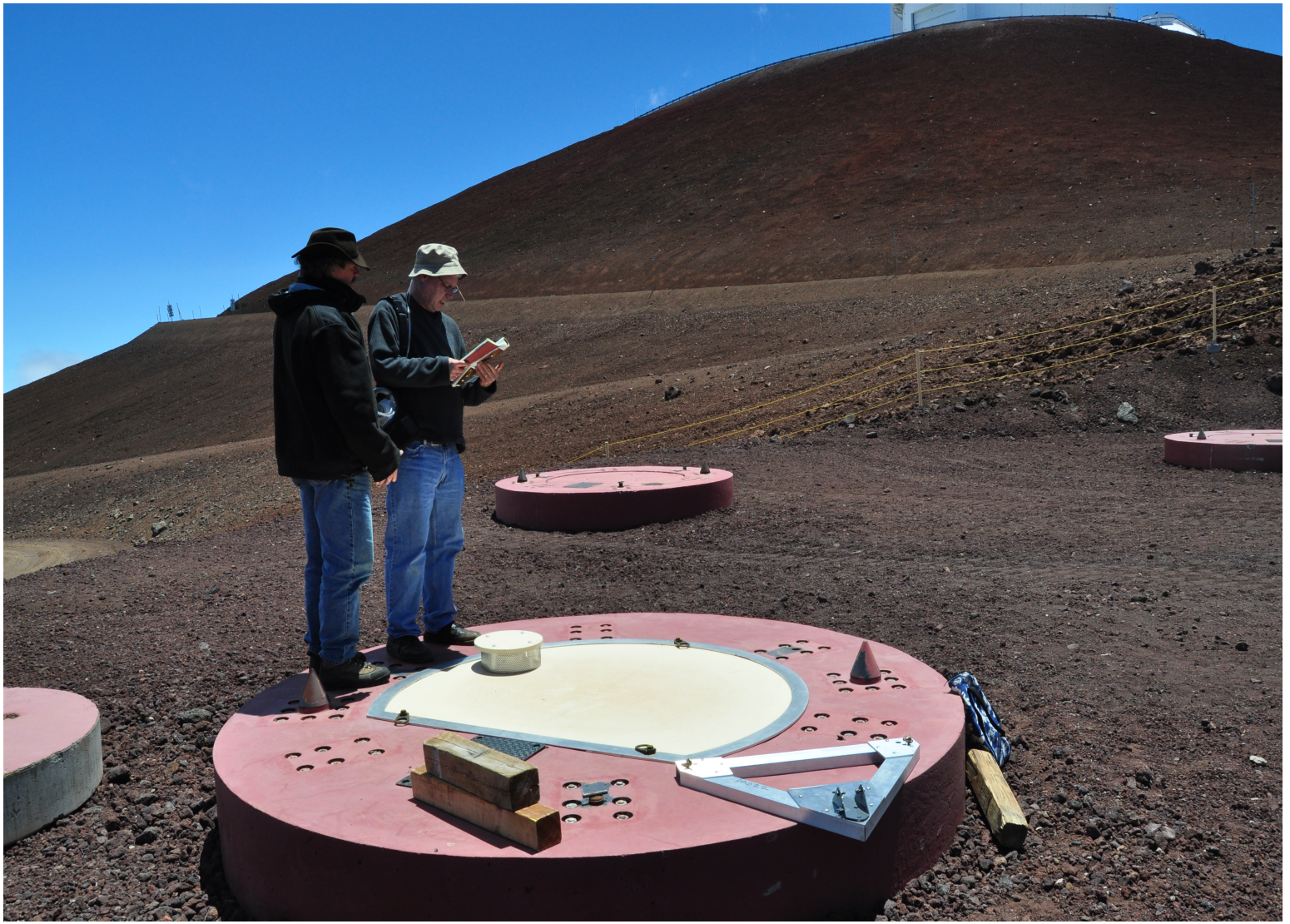
External view of phase monitor installed at the SMA



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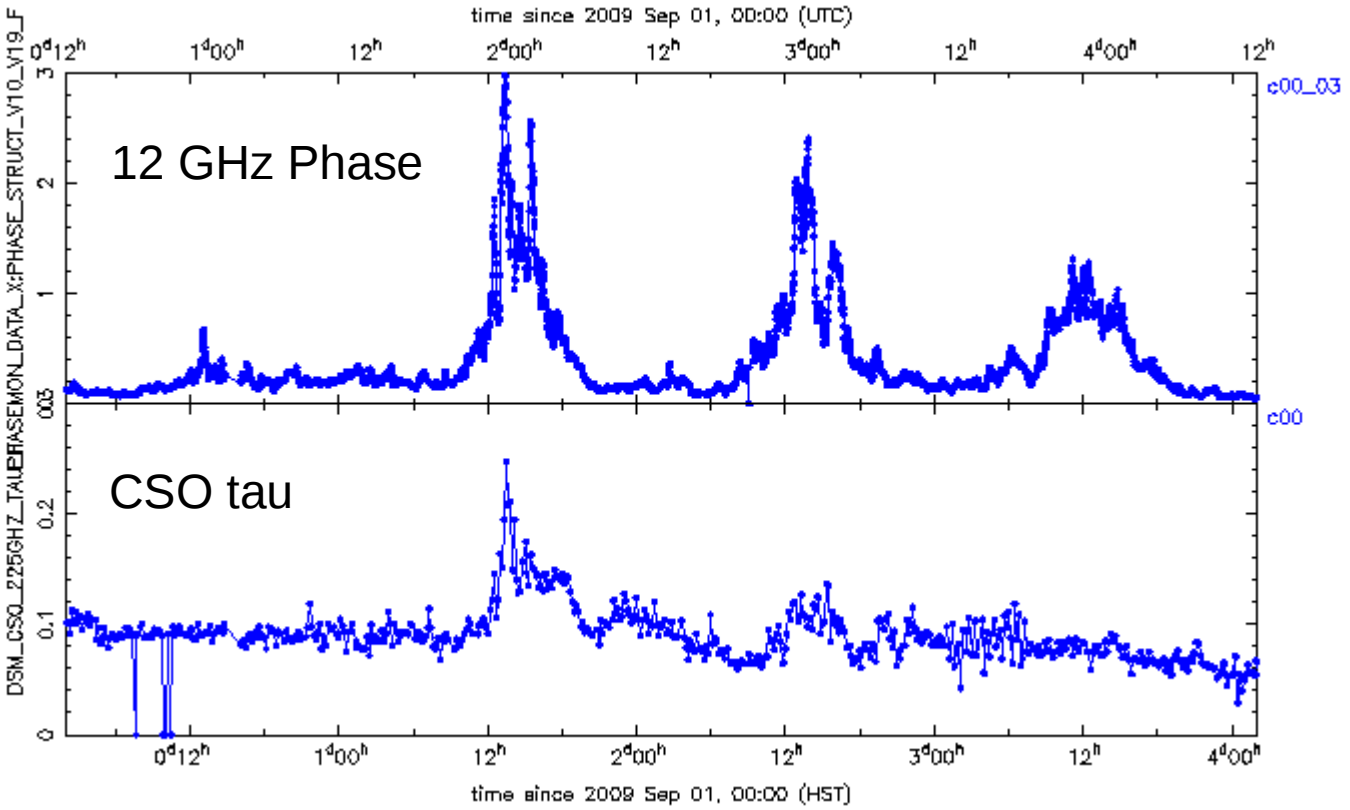
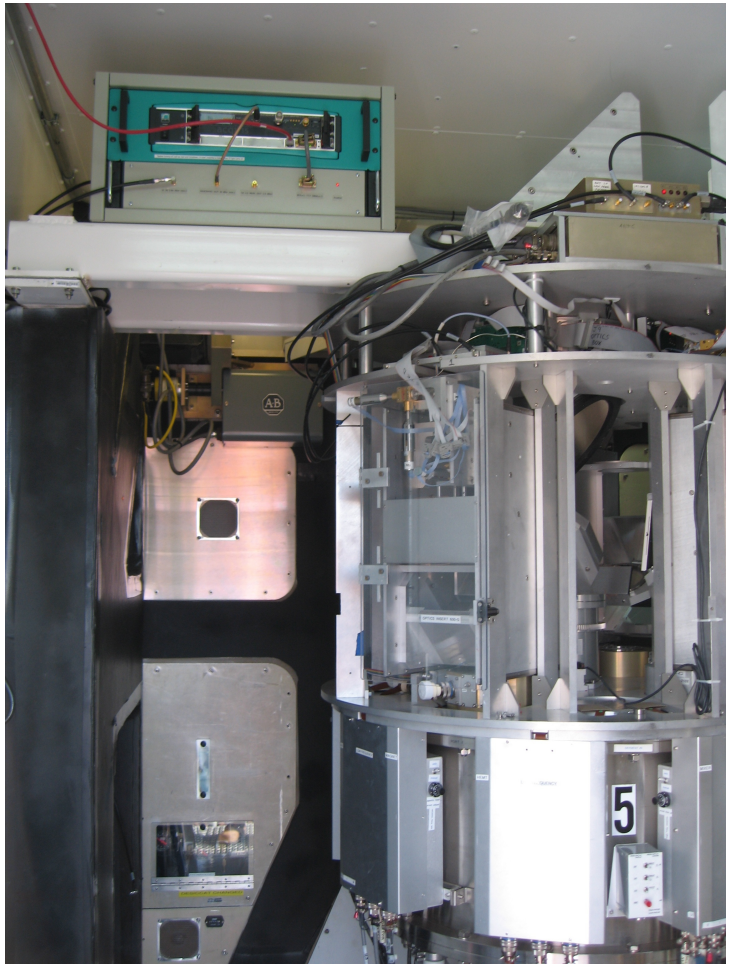
Phase structure function and CSO tau

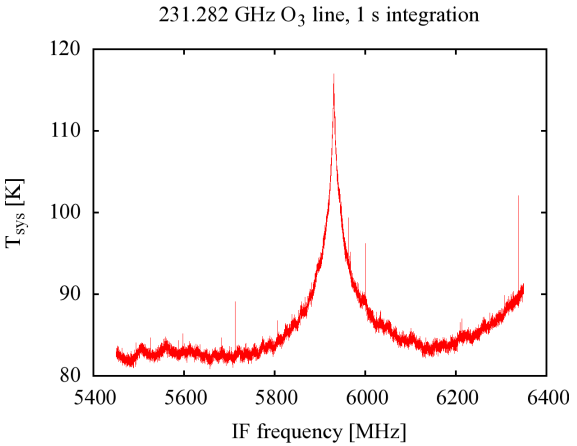


Data from 12 UTC 01 September to 12 UTC 05 September 2009
Atmospheric instabilities during daytime clearly visible
Not well-correlated to atmospheric transmission
Can observe throughout the day from time to time
With phase correction could extend observing more into the daytime

Phase Correction – Cabin Spectrometers



- New FFT spectrometers (1 GHz BW, 16k channels). All complete, four deployed
- Integrated with bandwidth doublers, and tunable across expanded IF
- Required calibration load improvements for absolute radiometry are underway
- Plan is to store H_2O column retrieval as a separate data stream for post-correction of interferometer data.



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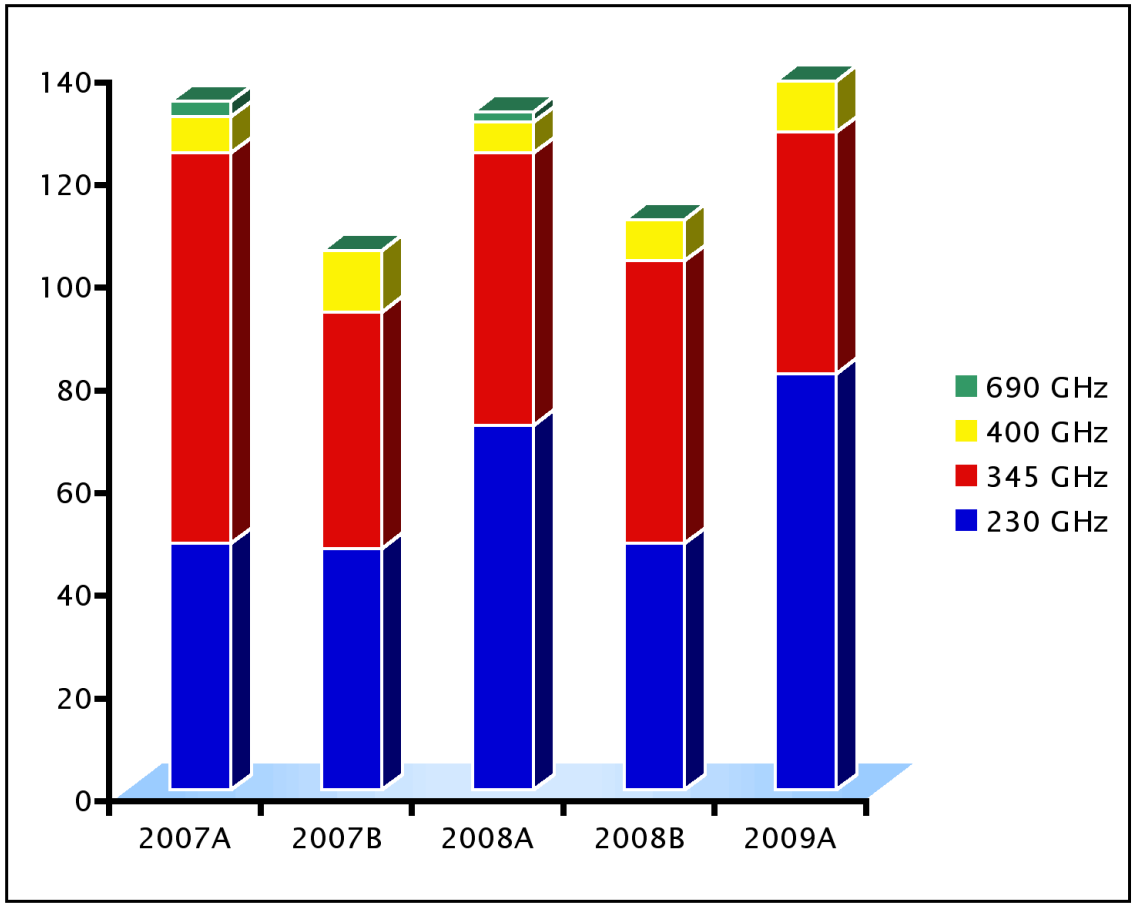
Double bandwidth for single receiver use



Array usage by frequency band

SMA was designed for dual receiver operation with one high and one low frequency receiver at a time

However, Mauna Kea

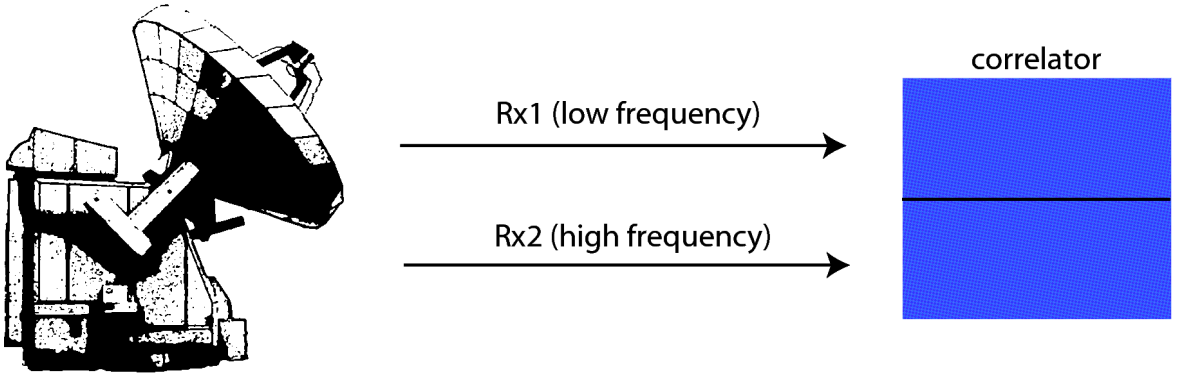
- Really good mm site
- Not so good for submm

Observations

- 50/50 split 230/345 GHz
- Very little 400 or 650 GHz

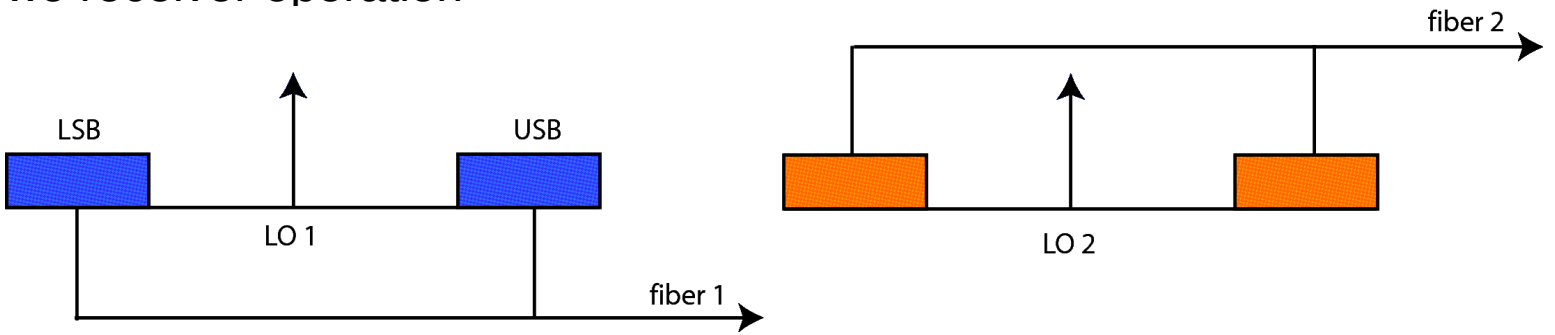
Double bandwidth for single receiver use

- The SMA was originally designed for two receiver operation - one high frequency (>350 GHz), plus one low frequency
- In practice usually use just a single receiver (weather)
- Half of the transmission system and correlator remain idle

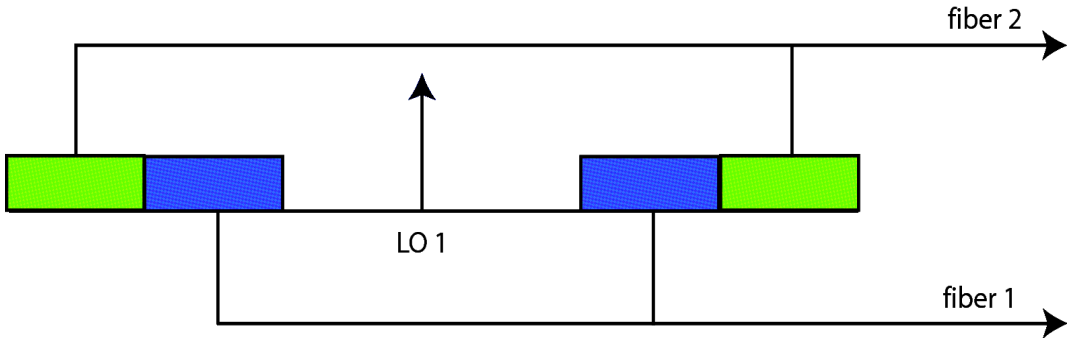


Double bandwidth for single receiver use

Two receiver operation



Single receiver, double bandwidth



Almost all observations over past 2 months have been made in this mode
Seven antennas currently equipped with BW doubler hardware
All will be equipped by November 2009, ahead of semester 2009B

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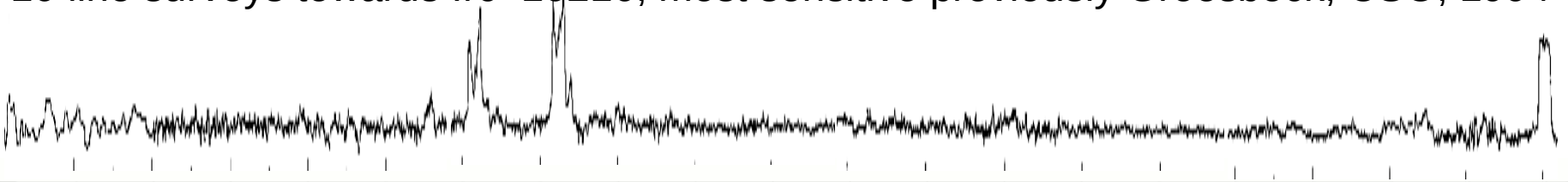
Irc+10216 spectral line surveys

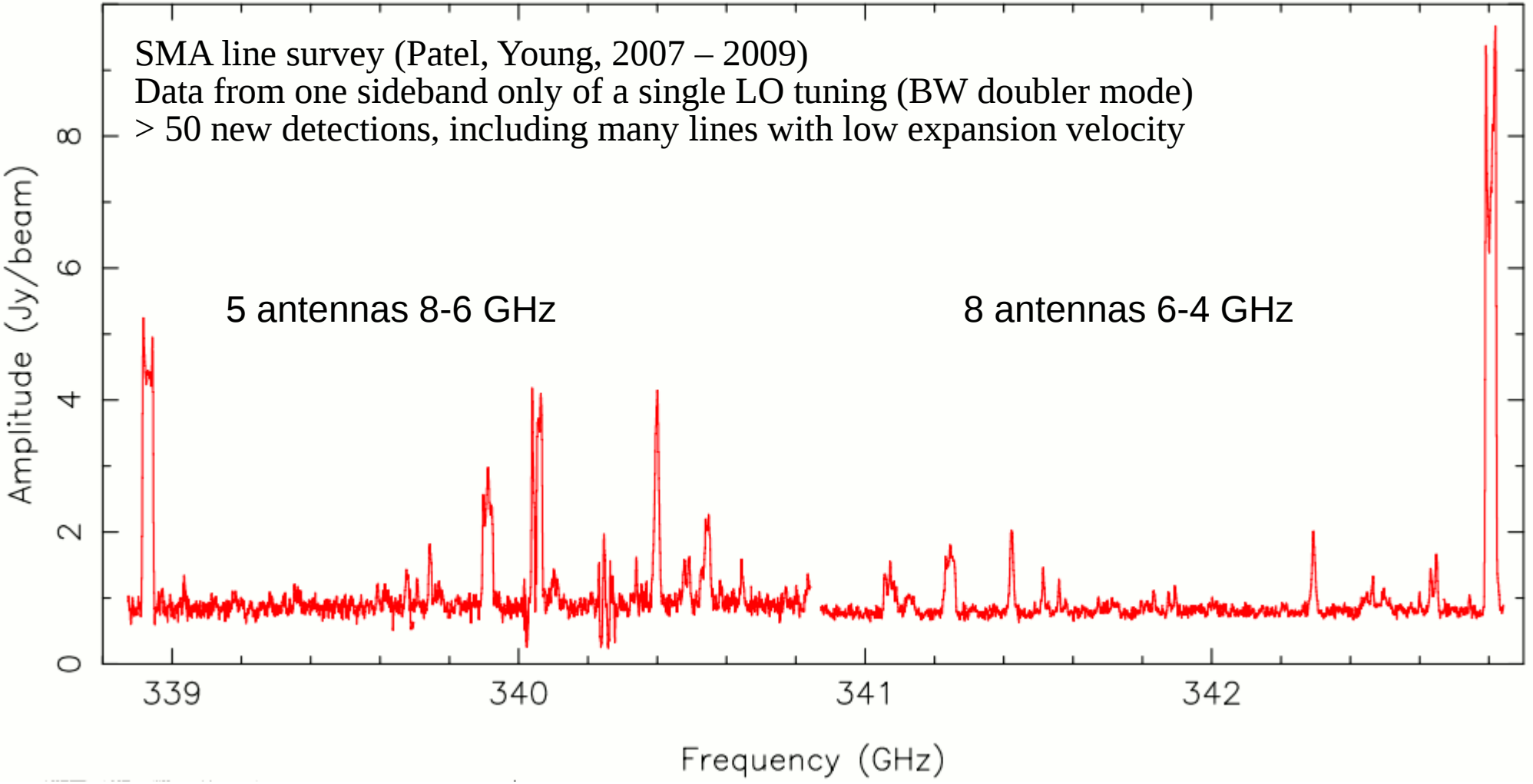
> 10 line surveys towards Irc+10216, most sensitive previously Groesbeck, CSO, 1994



SMA line survey (Patel, Young, 2007 – 2009)
Data from one sideband only of a single LO tuning (BW doubler mode)
> 50 new detections, including many lines with low expansion velocity

5 antennas 8-6 GHz

8 antennas 6-4 GHz



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Phased Array Processor for VLBI

- Began development following VLBI SgrA* observations in 2007
- Uses fast processing and sampling hardware developed by CASPER group at U C Berkeley
- SMA preprocessor handles 2 contiguous 512 MHz bands
- Frequency plan matches Haystack DBE and VLBI Mk 5b+
- Can be used to combine signals from all eight SMA antennas or, more interestingly for VLBI to combine six with the CSO and JCMT for a total collecting area of 424 m^2 compared to 177 m^2 for the JCMT alone
- First on-sky tests November 2008
- First used for science April 2009 – data analysis underway
- Numerous examples of fringes detected on baselines with phased array
- Verification of expected gain with processor underway

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A Few Interesting Science Results

- Spectral line survey towards Irc+10216 completed
- Ionized and molecular gas towards the Galactic Center
- SMA ρ Oph disk survey: inner holes – planets forming
- Arp 220 nuclear winds
- HII regions within star forming galaxy at z~2
- VLBI towards SgrA* and M87

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Patel et. al.

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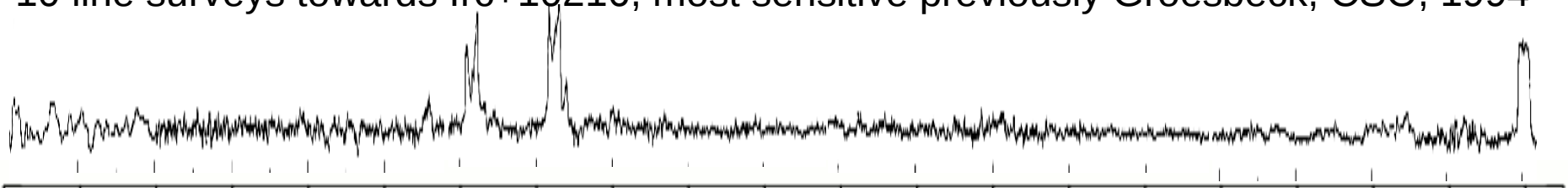

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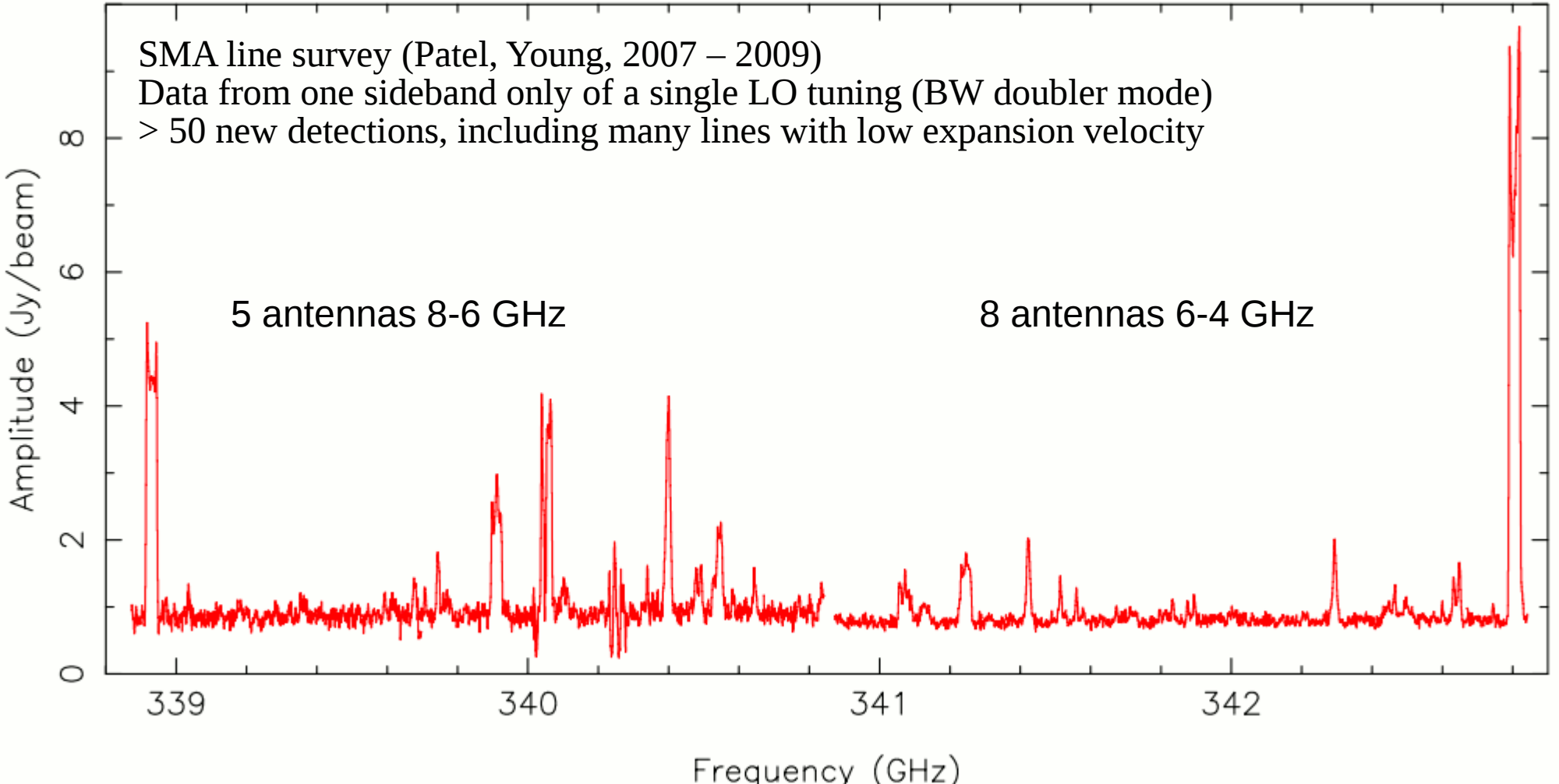

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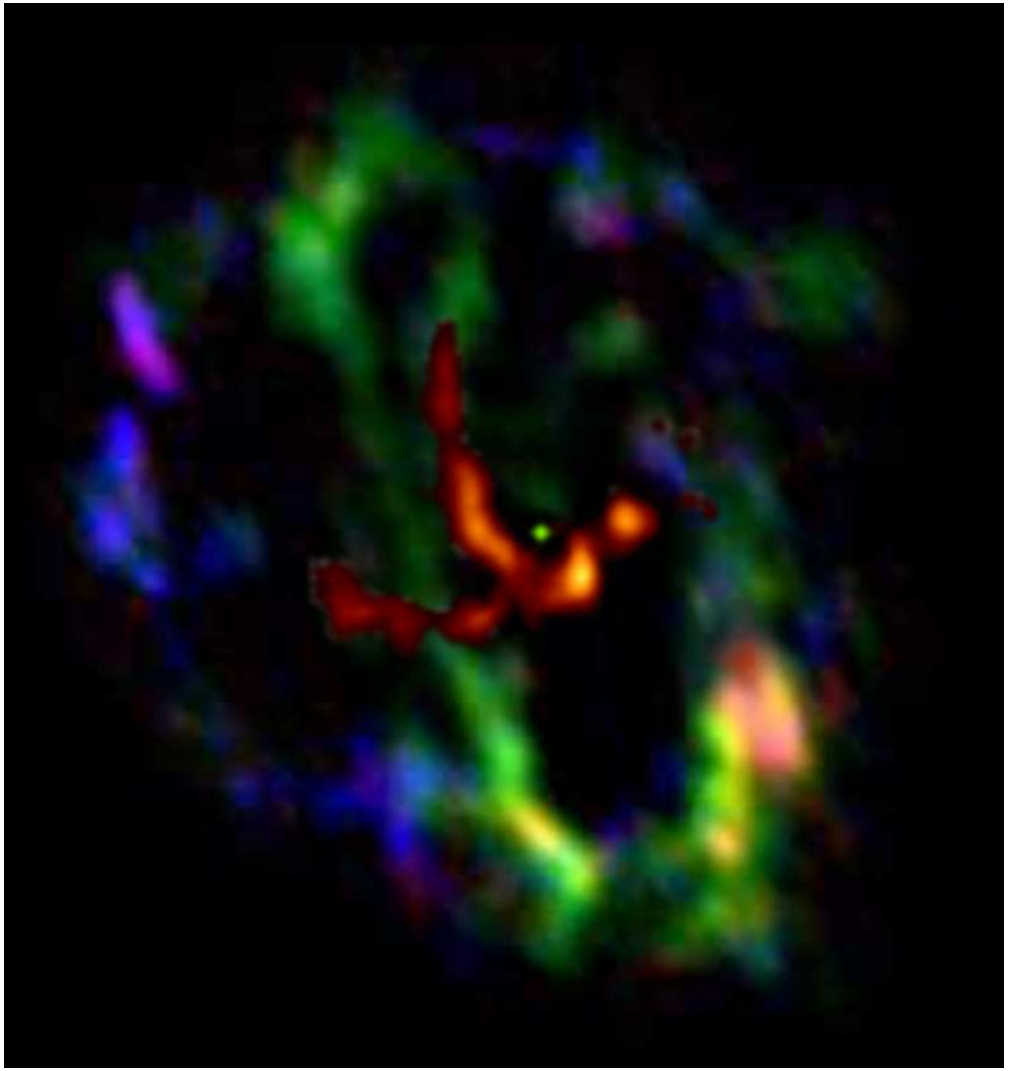
Ionized and molecular gas towards SgrA*



Composite RGB image of SMA observations towards the Galactic Center (9 point mosaic).

Green (CN) traces material mostly affected by XDR radiation
Red (SiO) traces shock interfaces
Blue (H_2CO) traces the densest molecular components.

Overlaid in orange is the minispiral traced by H30α emission.

This image shows how the different molecular species trace different gas components in the nuclear region of the Galaxy.

The overlap in projection between the ionized and molecular gas suggests a possible interaction between them.

More to follow – other species, kinematics ...
Project well-suited to capabilities of the SMA

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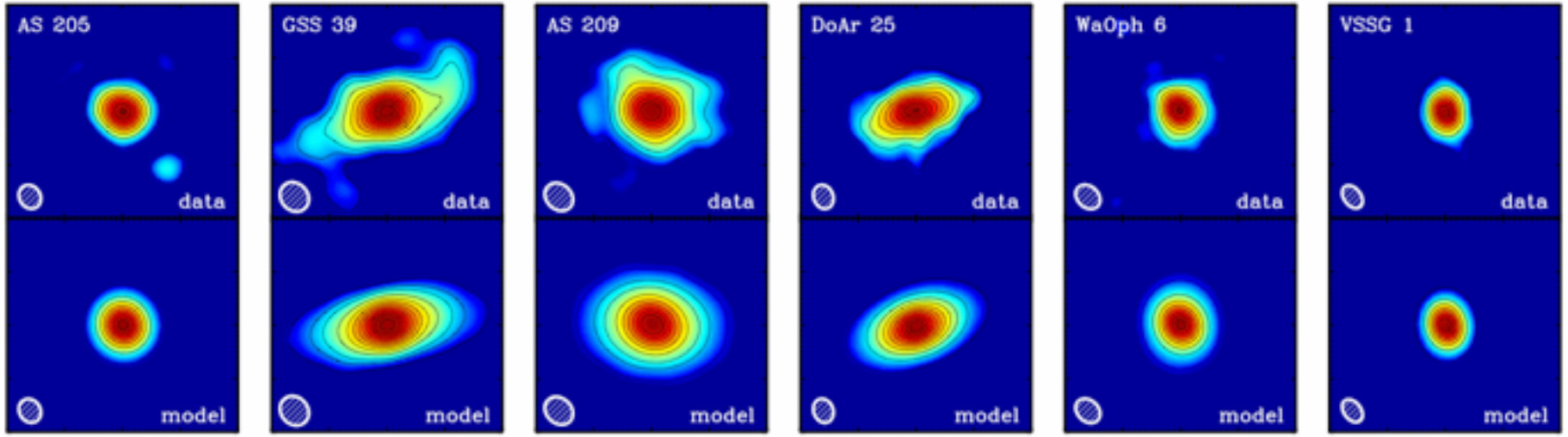
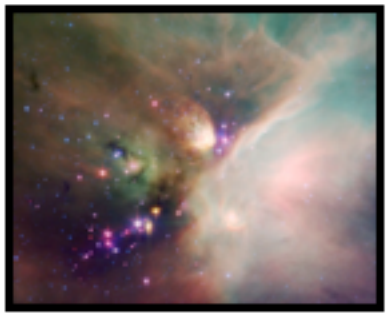
Andrews et al.

SMA ρ Oph Disk Survey

Andrews et al. 2009

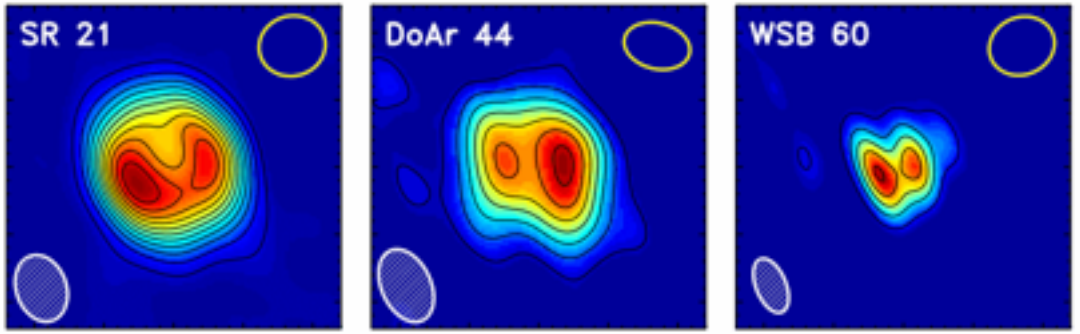




870 μm , 0.3" = 40 AU

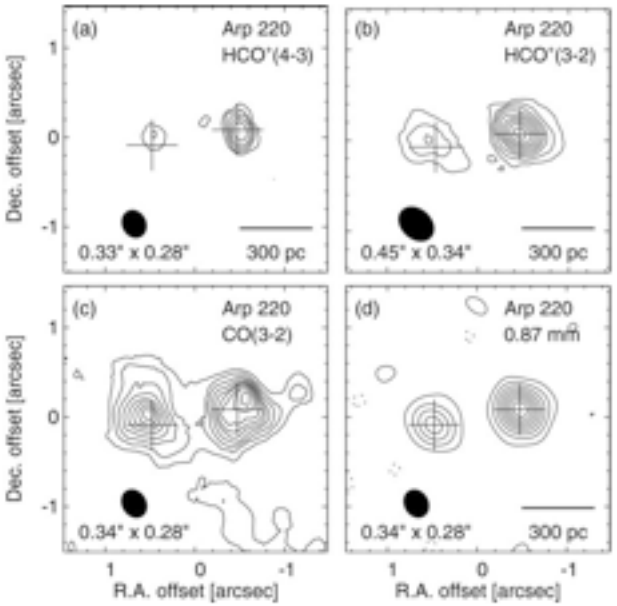
"flux limited" survey

significant fraction show large inner holes: 3/9
evidence for giant planets in formation

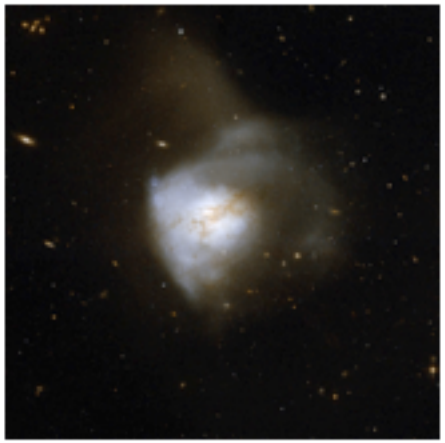


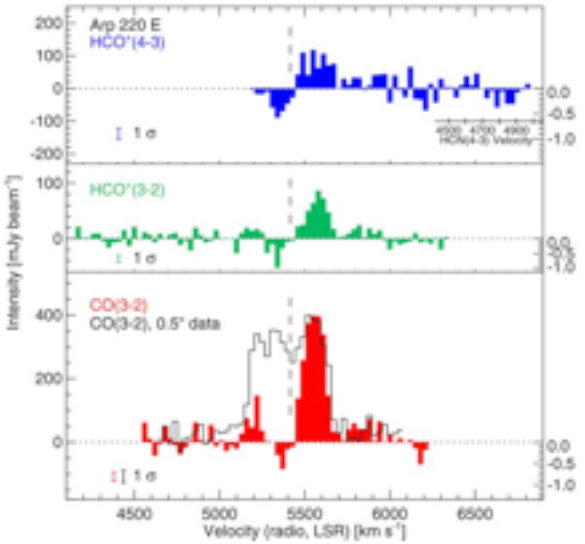
Arp 220 Nuclear Winds

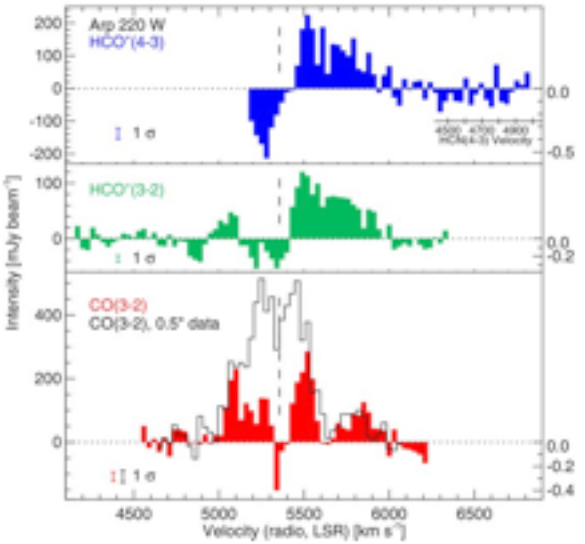
Sakamoto et al. 2009



- prototype ULIRG, advanced merger
- nuclei: 870 μm dust size & T_B → L > 2x10^{11} $L_\odot$
- dense molecular gas concentrations
- blueshifted HCO^+ absorption → nuclear winds (100 km/s outward motion of molecular gas)







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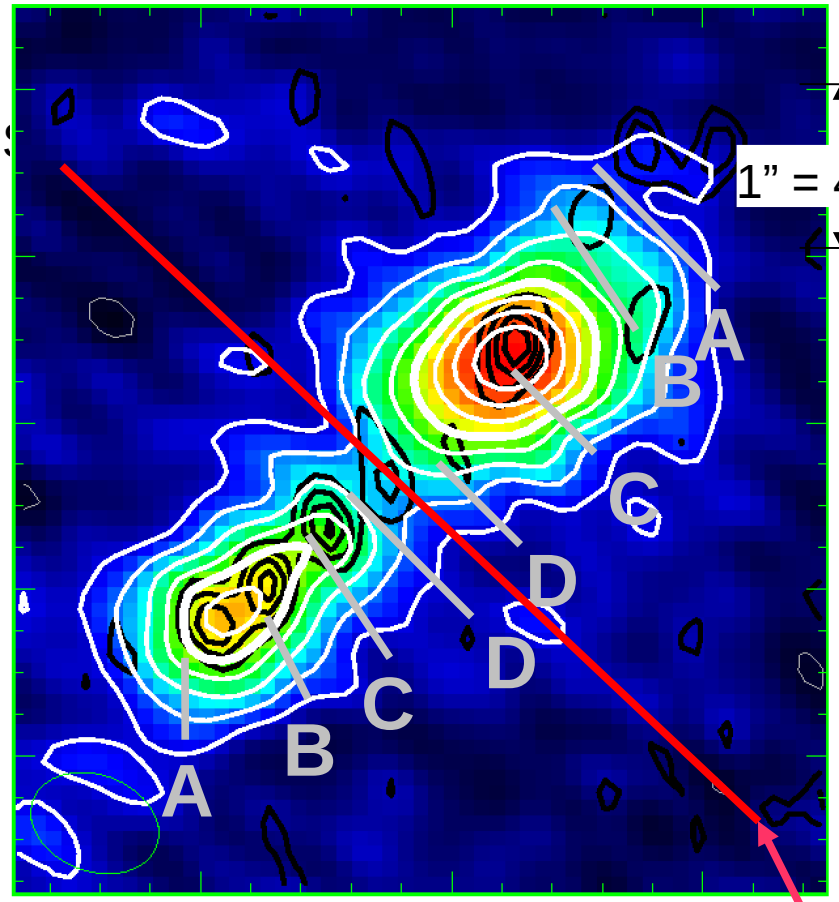
Swinbank et al.

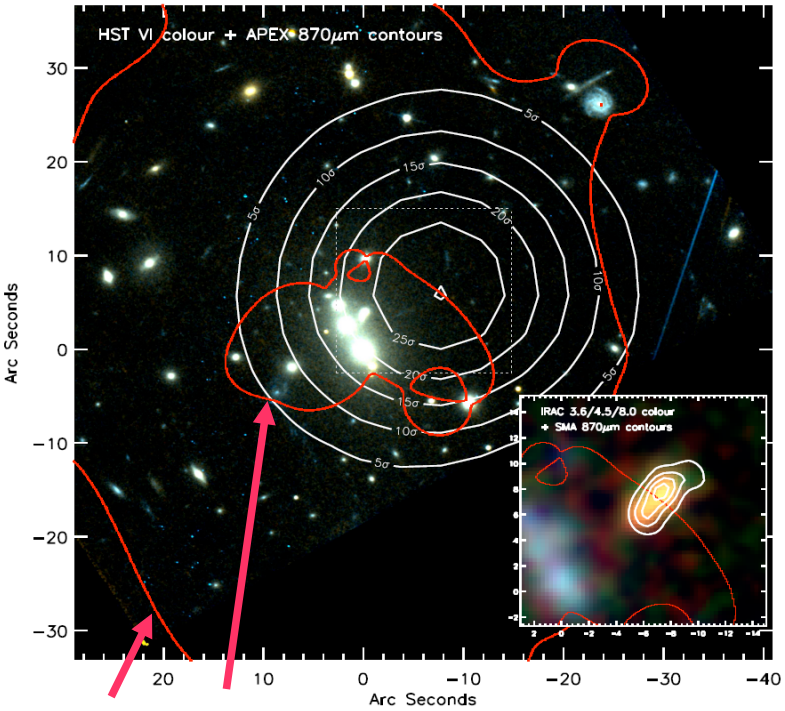
The first direct size and luminosity measurement of HII regions within a star forming galaxy at z~2



White contours = SMA all configs.
Black contours = SMA VEX

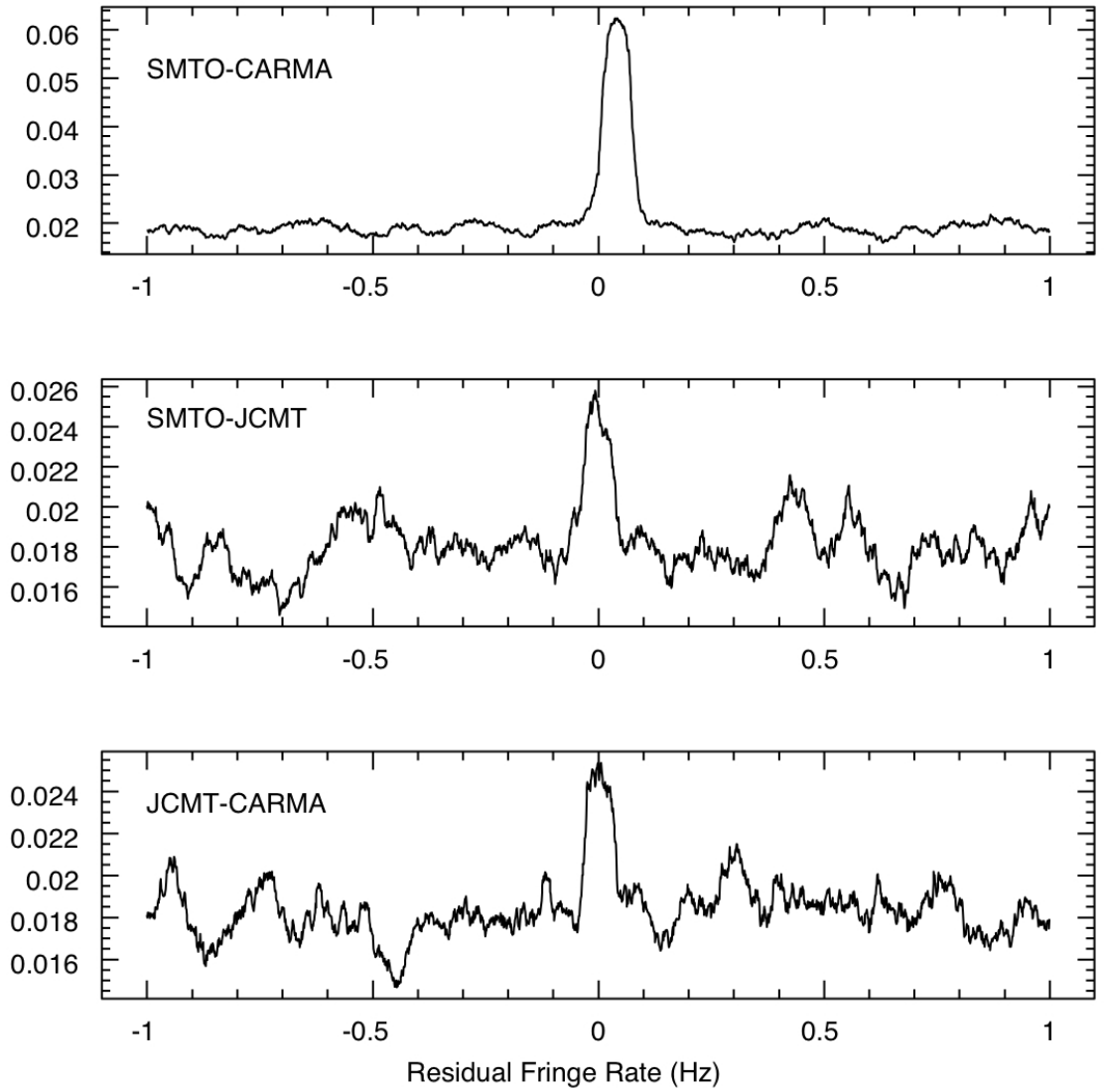
- $L_{SMA\ clouds} \sim 100 \times L_{local\ GMCs}$
  - Efficient star formation?
  - Top-heavy IMF?

- APEX discovery, $z_{CO} = 2.32$
- 106 mJy @ 850 microns, no HST optical counterpart, faint Spitzer infrared counterpart
- Strongly lensed (x32)



Critical curves from lensing model

April 2009 M87 1.3 mm VLBI Detections (M87)



A Close-up of M87

Mass of M87 Black Hole = 6.4×10^9 M_{sol}

The angular size of the Schwarzschild radius is similar to SgrA*'s: 8μas.

Apparent size of Black Hole 'Shadow' is 40μas (5.2 R_{sch} for non spinning BH).

Apparent Size of the Innermost Stable Circular Orbit (ISCO) is 60μas.

These are the relevant size scales for modelsof TeV photon generation and jet formation.

* 1.3mm VLBI is now detecting compact structure on these size scales.

* With higher sensitivity, more VLBI sites, and the phased array at SMA, this technique can image a radio loud AGN on R_{sch} scales.

Proposed 'Event Horizon Telescope' needs station on Mauna Kea

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Proposal Statistics by Science Category

Semester	2007A	2007B	2008A	2008B	2009A	2009B
Extragalactic	19	28	23	19	19	27
Star formation	51	25	54	33	50	33
Stellar	5	2	6	4	5	8
Planetary	2	1	2	1	1	1
Galactic Center	8	2	6	2	4	4
Other	3	0	2	0	3	0
Total	88	58	93	59	80	73

Proposals submitted through SAO only, ~ 72% Time Allocation
Proposal statistics do not tell the whole story
Need to look at time requests – requests for individual tracks

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Time Requests by Science Category

Semester	2007A	2007B	2008A	2008B	2009A	2009B
Extragalactic	42	99	59	70	172	160
Star formation	143	92	163	96	158	151
Stellar	24	3	7	13	16	26
Planetary	4	2	3	2	2	1
Galactic Center	20	6	19	2	14	17
Other	6	0	3	0	3	0
Total	239	202	254	183	365	355

Time requests submitted through SAO only, ~ 72% Time Allocation
Maximum available time to SAO ~ 120 nights (0.72 x 365/2 - 18) per semester
Includes down time for reconfiguration, excludes other tests and bad weather
SMA is very heavily oversubscribed ~3:1
Even more than for some hour angles and frequency bands

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SMA observing success rate

Observing statistics during last 5 semesters

	Number of observations			Time share	
	Attempted	Satisfactory	Unsatisfactory	Target	Actual
ASIAA	118	84	34	15%	15%
SAO	562	152	152	72%	72%
UH	104	77	27	13%	13%
Totals	784	571	213	100%	100%

Includes current semester, ie ~ 825 nights total including bad weather nights
Have attempted 784 observations, > 1 on average per available night
Since 3 nights per reconfiguration are for testing and calibration and about 1 night every two weeks are used for other tests
Observing success rate ~ 73%
Could be higher with better prediction of conditions via atmospheric phase monitor
Even better with atmospheric phase correction (akin to adaptive optics)

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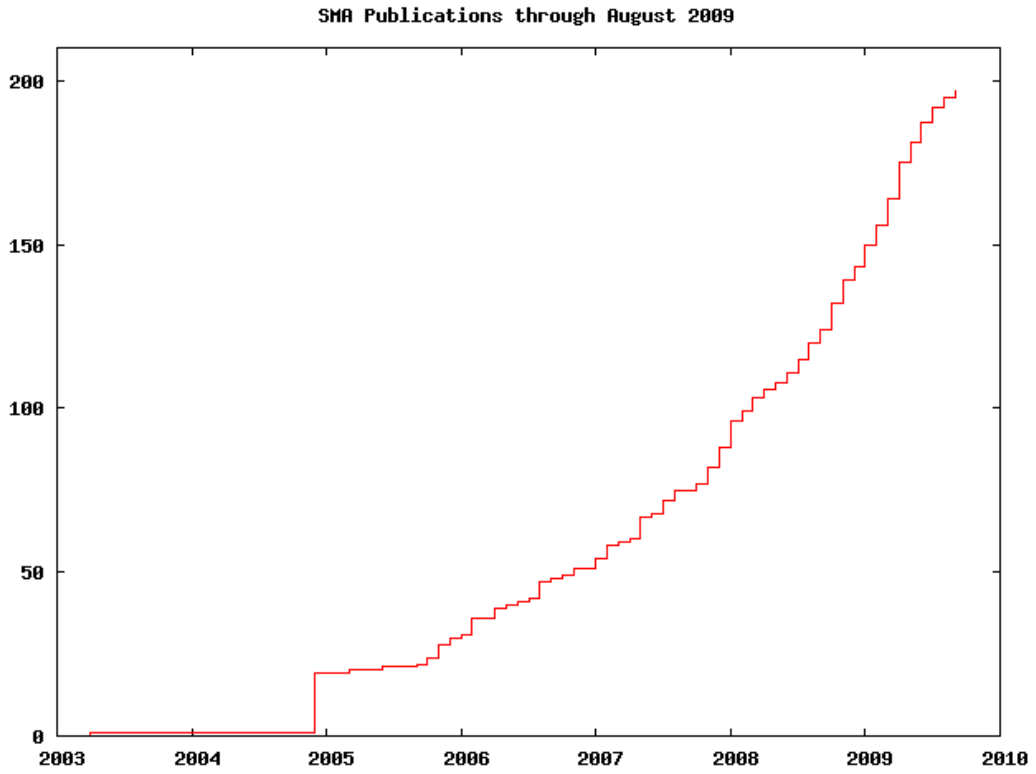
SMA refereed publications (Aug 2009)



Distribution of published papers in various fields

Star Formation	60%	Galactic Center	4%
Extragalactic	19%	Solar System	3%
Stellar	11%	Other	3%

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Ongoing and Possible Upgrades to the SMA

Recall the SMA is:

Eight-element interferometer designed to operate from about 200 to 900 GHz

6 m diameter antennas with surface accuracy ~ 12 μm

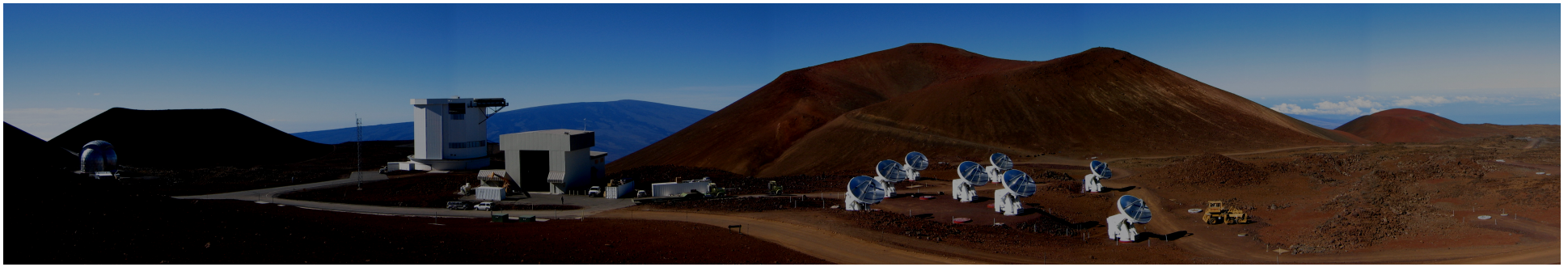
Receivers for 200, 300, 400, and 650 GHz now available on all antennas

IF center frequency 5 GHz, bandwidth 2 GHz

Simultaneous operation of low and high frequency receivers

4 GHz bandwidth now possible for single receiver use

Flexible cross-correlation spectrometer with resolution down to 25 kHz



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Ongoing and Possible Upgrades to the SMA

- Improve sensitivity
  - reflecting optics, better mixers, SSB, dual polarization
- Increase bandwidth*
  - relatively easy to test performance to 14 GHz
  - eventually move to > 30 GHz wide IF
- Increase collecting area
  - increase antenna diameter from 6m to 7 m
  - more antennas (up to ten?)
- Increase mapping speed*
  - more pixels (up to nine x 2 polarizations)

* Need new correlator and lots of money