Filamentary Structure in Clouds in the Galaxy and Nearby: Observational Capabilities

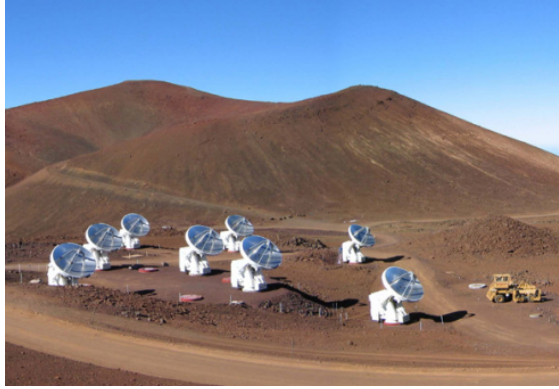
Al Wootten, NRAO

NAASC Workshop 10-11 October 2014

- Dust filaments have been known since ancient times
- To the Andean cultures, they defined the constellations
- Bok, Lynds and others catalogued them much later
- Loren (1989) mapped Rho Oph spatial and velocity structure--kinematic studies
- Herschel revealed they pervade the Milky Way
- A census of available instruments follows

Facilities for Filament Observation

SMA



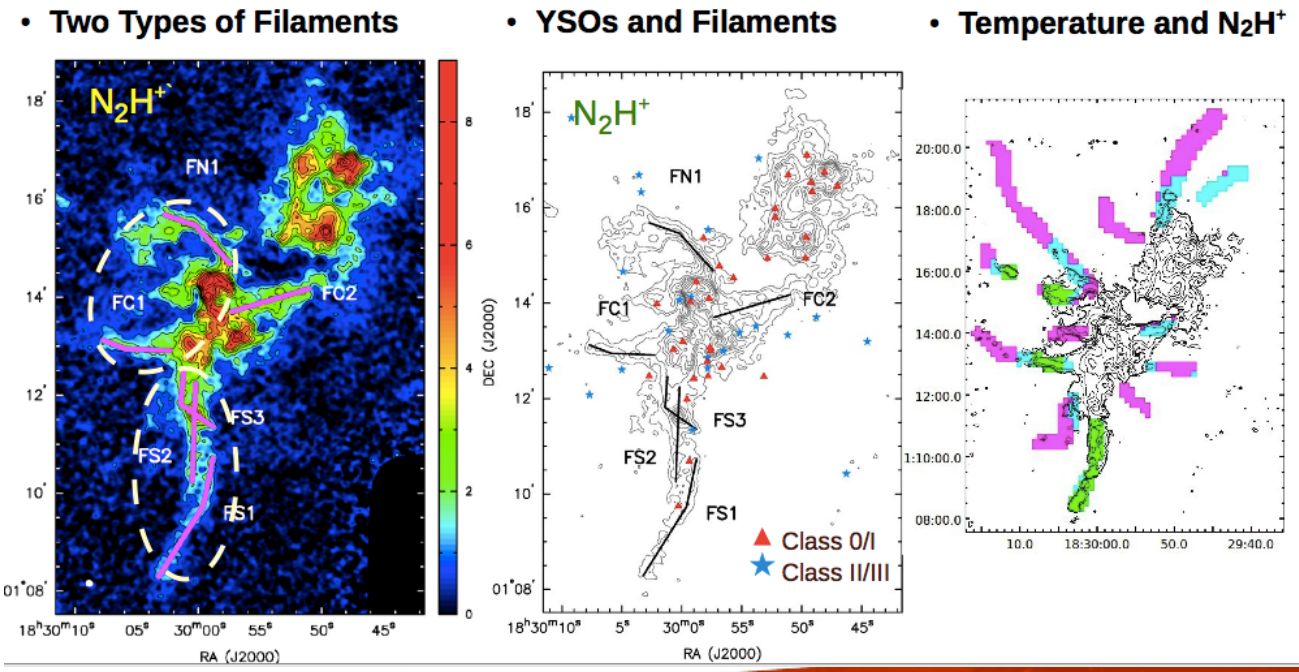
- Mauna Kea at high altitude
  - 8 antennas of 6m diameter, 12 μm rms surface
  - Baselines 8-508m, highest resolution ~0.1”
  - Receivers single pol, 1 or two simultaneously
    - ‘230’: 177-256 GHz (L)
    - ‘345’: 256-360 GHz (L)
    - ‘400’: 320-420 GHz (H)
    - ‘600’: 600-720 GHz (H)
  - Correlator: 2SBx4GHz/receiver

Facilities for Filament Observation

CARMA

- The National Science Foundation has declined CARMA's proposal to support continued operations. If no new funds are identified, CARMA will end operations in 2015.
- See CLASSy

Lee et al

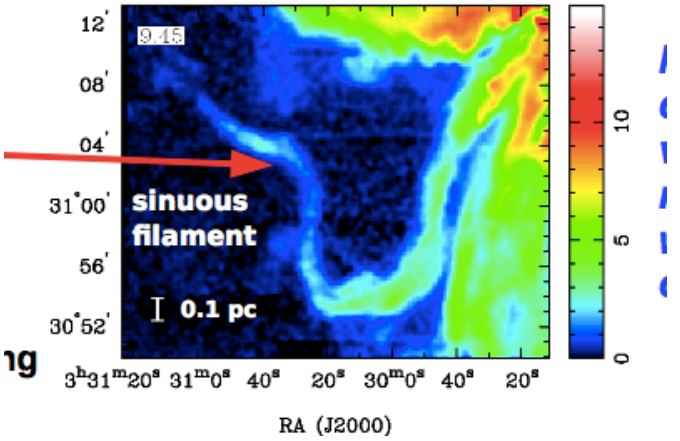


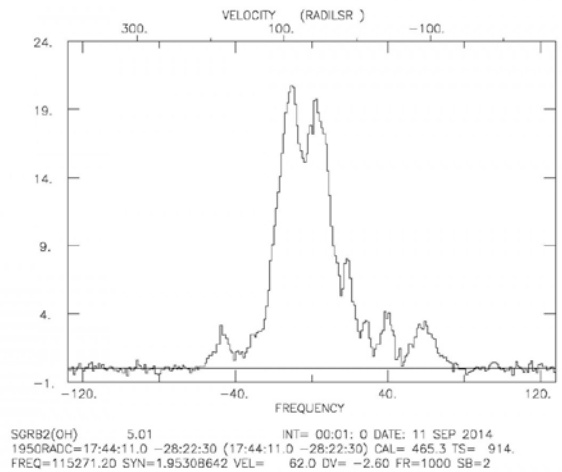
Facilities for Filament Observation

Arizona Radio Observatories

- SMT
  - High altitude on Mt Graham
  - Receivers
    - 1.3mm: ALMA-type 2SB, 4 Ifs
    - 0.8mm (315-365 GHz)
    - 0.6mm ALMA-type 2SB
    - 0.4mm (600-720 GHz) as in ALMA B9, IF 4-6 GHz
    - 64 beam Supercam (0.8mm) has been used
  - Backends:
    - 2048 x 1 MHz, 512 x 250 kHz filterbanks
    - 2 - 1 GHz BW AOS, resolution ~930 kHz.
- ALMA Prototype 12m (Alcatel design)
  - At Kitt Peak in former NRAO 12m dome
  - Spectra—operational soon.

Bieging





Facilities for Filament Observation

JCMT

- Observatory status in flux
- SCUBA-2
  - 32x40 arrays at 850 and 450 microns
    - Currently about 3500 (of 5120) bolometers are working at each wavelength band.
    - Dedicated surveys, including the Gould Belt Survey
- HARP
  - 16 (14 operational) pixels 14" with 30" separation
  - 325-375 GHz

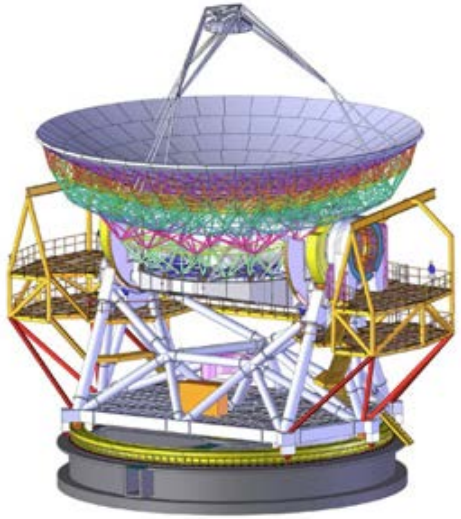
Facilities for Filament Observation

LMT

- 50m telescope at high altitude at low latitude (currently 32m operational).
- AZTEC: 1.1m, 144 pixel continuum array camera
  - The field-of-view of AzTEC on the 50m-LMT is 2.4 sq. arcmin and, with a per pixel sensitivity of ~3 mJy $Hz^{-1/2}$ and FWHM beam-size of 6 arcsecs at 1.1 mm, AzTEC will have an extremely fast mapping-speed of ~0.36 $deg^2/hr/mJy^2$.
- SEQUOIA: (Future) 16 pixels in single-polarized 4x4 array that operates in the range 85-116GHz, T_{rx}~55K rising to 90K at 116 GHz.

Facilities for Filament Observation

CCAT



Chajnantor, operation into superTHz
Operational date uncertain

- CHAI: Heterodyne Array to observe in 350, 650 and 850 micron bands
- SWCam: continuum camera to observe 200-450 micron bands
- LWCam: continuum camera to observe in 6 bands between 750 and 3300 microns.
- X-Spec: wide-band multi-object spectrometer (85 elements, 6 bands)

SOFIA

- Science Instrument Suite
- EXES *Echelon-Cross -Echelle Spectrograph*
- FIFI-LS *Field Imaging Far-Infrared Line Spectrometer*
- FLITECAM *First Light Infrared Test Experiment CAMera*
- FORCAST *Faint Object InfraRed CAmera for the SOFIA Telescope*
- GREAT *German Receiver for Astronomy at Terahertz Frequencies*
- HAWC *High-resolution Airborne Wideband Camera*
- HIPO *High-speed Imaging Photometer for Occultations*

Facilities for Filament Observation

IRAM

- 30m: Heterodyne
  - Emir
    - 86-370 GHz, 2SB
    - 8 GHz of instantaneous bandwidth per sideband and per polarization
    - 32GHz IF transport system allows 8 sub-bands of 4GHz BW, some limitations.
  - Hera
    - heterodyne receiver array consisting of two orthogonally polarized arrays of 3x3 pixels with 24" spacing.
    - SSB, 1 GHz BW, 215-272 GHz, T_{rx} 110-380
    - Can accommodate simultaneous observations of CO, ^{13}CO, $C^{18}O$

IRAM 30m

- Continuum
  - NIKA: a prototype in constant evolution
    - 1mm
      - (220-270 GHz BW), 136 valid KIDs
      - NEFD~35 mJy*$s^{1/2}$
      - 12" HPBW, foV 1.8', spacing 6.8"
    - 2mm
      - (137-172 GHz BW), 114 valid KIDs
      - NEFD~14 mJy*$s^{1/2}$
      - 17.5" HPBW, foV 2.0', spacing 9.6"
  - GISMO
    - 2mm
    - 8x16 TES pixels (140-162 GHz BW)
      - NEFD~14 mJy*$s^{1/2}$
      - 16.7" HPBW, foV 1.8'x3.7', spacing 13.75"
      - Lissajous curves and on-the-fly scans

Facilities for Filament Observation

NRO

- 45m:
- Spectroscopy (see webpage for details)
  - S40 35-50 GHz ;Tsys~150-300K;AOS Backend1.075-1.675 GHz
  - S80 72-116. GHz;Tsys~250-900K;AOS, may be used simultaneously with S100
  - S100 77-116. GHz;Tsys~250-500K;AOS
  - T70 (V,H): 71.5-92. GHz;Tsys~130-250; SAM45 4-8 GHz 2SB
  - TZ1 (V,H): 80-116 GHz;Tsys~100-250; SAM45 4-8 GHz 2SB
  - TZ2 (V,H): 71.5-92. GHz;Tsys~135-240; SAM45 4-8 GHz 2SB
    - TZ1/TZ2 used simultaneously as 2-beam receiver, 46" separation
  - FOREST multibeam receiver undergoing commissioning
    - 4 beams x 2 pol x 2SB, 3mm, 4-12 GHz IF (Nishimura et al poster)

Facilities for Filament Observation

ASTE

- Chajnantor site, ALMA 10m prototype

Table 1. Current status of ASTE receivers. (Jun. 27, 2014)

Instrument	Type	Frequency (GHz)	HPBW (arcsec)	N_{pix}	Band width (GHz)	Back-end Option	Status	Note
CATS345	Heterodyne	324-372	22	1	IF=4.5-7.0	MAC/WHSF	Open	
ALMA B8QM	Heterodyne	400-500	17	1	IF=4.5-7.0	MAC	N/A	
TES Camera	Bolometer	270	28	169	~50	None.	N/A	The status is for Phase I.
		350	22	271	~30			

Facilities for Filament Observation

APEX

APEX instrumentation

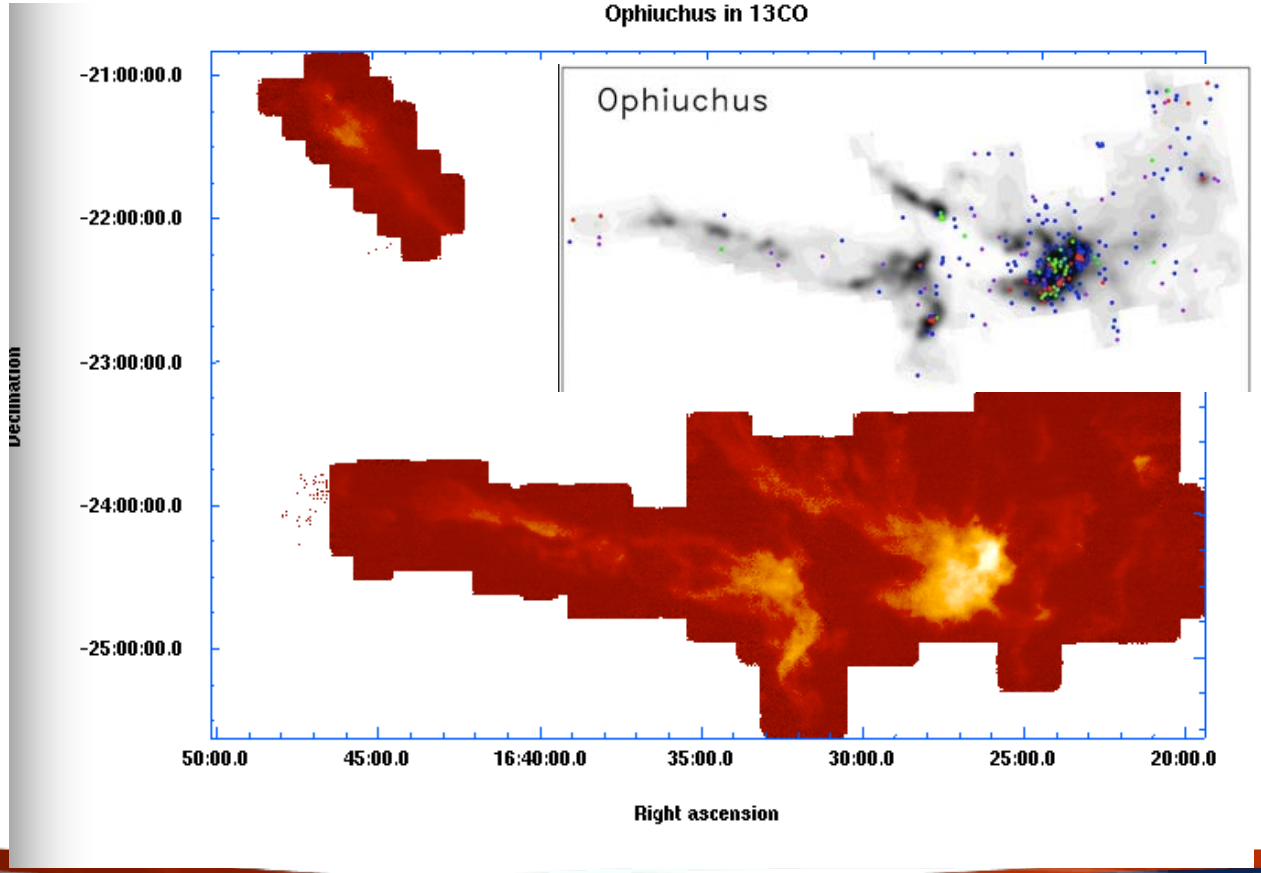
Facility instruments

Instrument	Type	Mode	Frequency [GHz]	HPBW [arcsec]	IF range [GHz]	# of beams	Location	Status	Comment
APEX-1 *(SHeFI)*	Heterodyne SIS	SSB	214 - 275	30 - 25	4 - 8	1	Nasmyth-A	✓	
APEX-2 *(SHeFI)*	Heterodyne SIS	SSB	267 - 378	23 - 17	4 - 8	1	Nasmyth-A	✓	
APEX-3 *(SHeFI)*	Heterodyne SIS	DSB	385 - 500	17 - 13	4 - 8	1	Nasmyth-A	✓	
APEX-T2 *(SHeFI)*	Heterodyne HEB	DSB	1250 - 1390	5	2 - 4	1	Nasmyth-A	✗	Science Verification pending
LABOCA	Bolometer array		345	19		295	Cassegrain	✓	
SABOCA	Bolometer array		850	8		39	Cassegrain	✗	warmed up

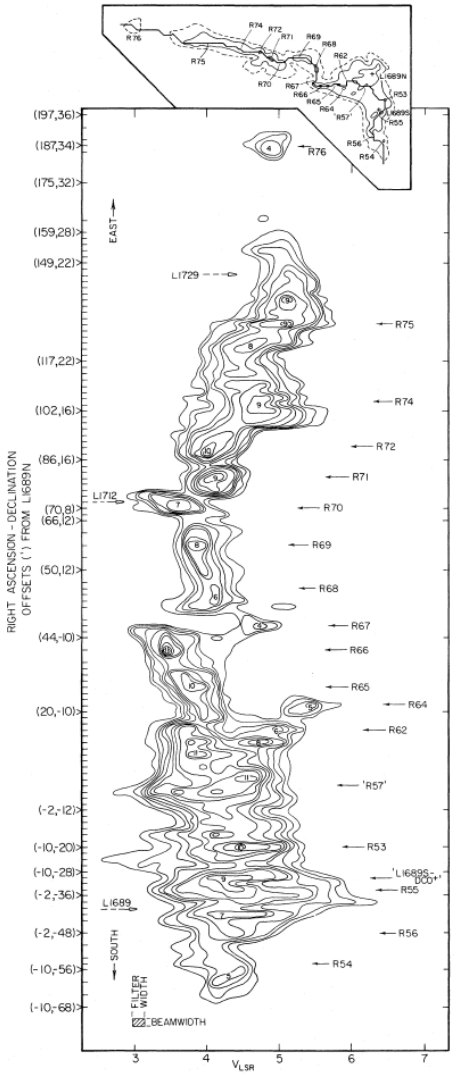
Various PI instruments (incl. Artemis)

Ophiuchus:

- Higher resolution ^{13}CO COMPLETE data is available



Loren 89 Survey



Facilities for Filament Observation

GBT: See talks and posters adjacent to this talk

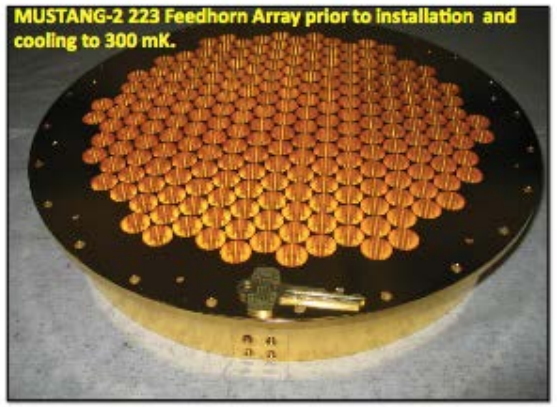
Table 1: GBT Receivers

Receiver	Frequency Range
Prime Focus 1	290-920 MHz
Prime Focus 2	910-1230 MHz
L-band	1.15-1.73 GHz
S-band	1.73-2.60 GHz
C-band (shared risk)	3.8-8.0 GHz
X-band	8.0-11.6 GHz
Ku-band	12.0-15.4 GHz
K-band Focal Plane Array (7 pixels)	18.0-26.0 GHz
Ka-band	26.0-39.5 GHz
Q-band	38.2-49.8 GHz
W-band	67-93.3 GHz
MUSTANG 1.5 bolometer array (shared risk)	80-100 GHz
ARGUS (shared risk)	75-115.3 GHz, Private PI instrument

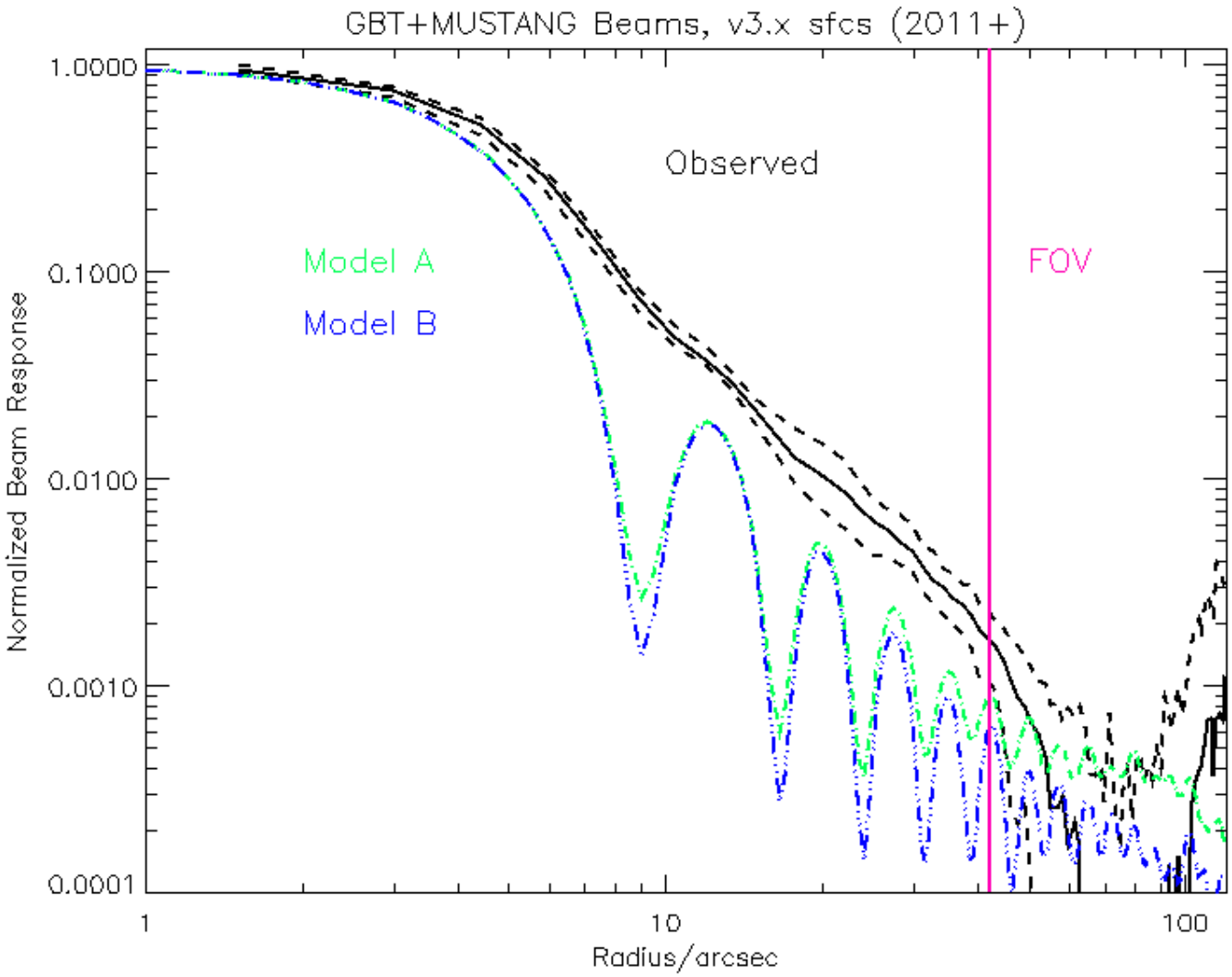
Table 2: GBT Backends and Observing Modes

Backend	Observing Modes
Versatile Green Bank Astronomical Spectrometer (VEGAS)	Continuum, pulsar, spectral line
Digital Continuum Receiver (DCR)	Continuum

Lunar Eclipse over



GBT Beam


GBT+MUSTANG Beams, v3.x sfcs (2011+)
Observed
Model A
Model B
FOV
Normalized Beam Response
1.0000
0.1000
0.0100
0.0010
0.0001
1
10
100
Radius/arcsec

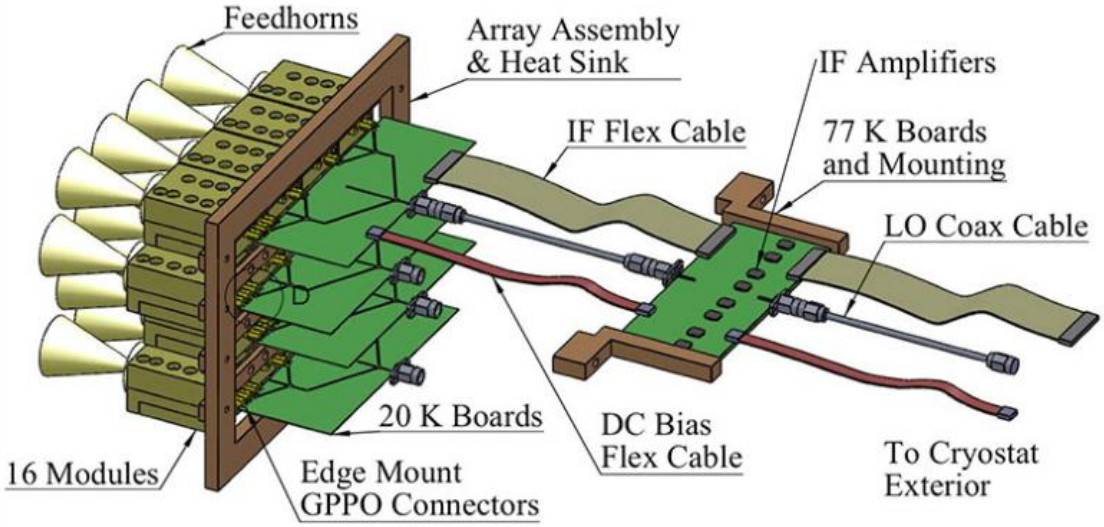
16 element scalable W-band FPA for the GBT

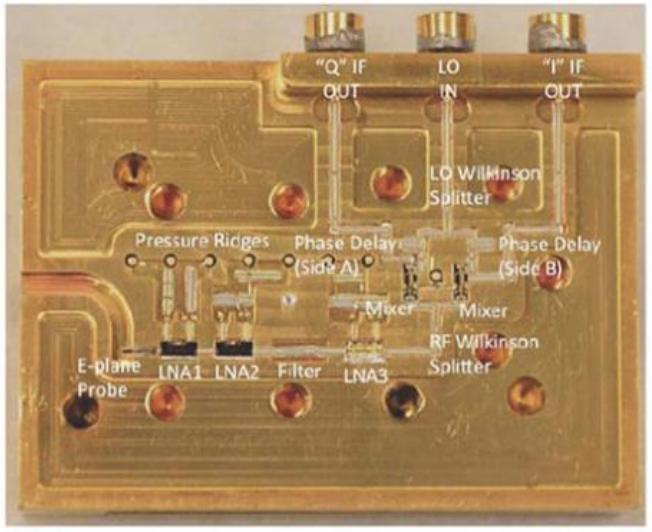
Stanford (PI Sarah Church), Caltech, JPL, Univ. Maryland, Univ. Miami, and NRAO.

First light on the GBT November 2014

Frequency operation range: 75-115.3 GHz

Tsys~75K





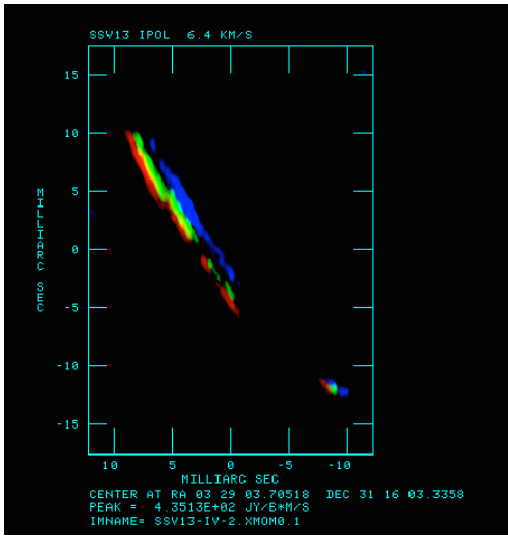
Slide courtesy of D.Frayer (NRAO)

Facilities for Filament Observation

EVLA, VLBA

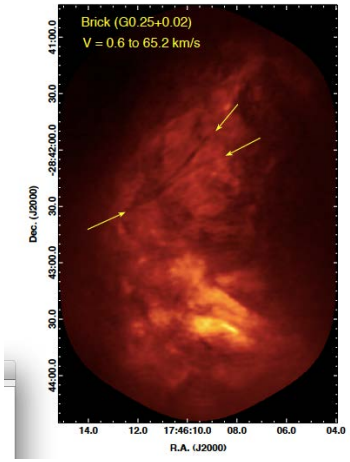
Table 7: Default frequencies for "continuum" applications with 8-bit sampling

Band	Range[1] (GHz)	Default frequencies for continuum applications (GHz) IF pair A0/C0	IF pair B0/D0
4 m (4)	0.058-0.084	N.A.	.054 -- .086
90 cm (P)	0.23-0.47[2]	0.236 -- 0.492	N.A.
20 cm (L)	1.0-2.0[3]	1.0 -- 1.5[2]	1.5 -- 2.0[2]
13 cm (S)	2.0-4.0	2.0 -- 3.0	3.0 -- 4.0
6 cm (C)	4.0-8.0	4.5 -- 5.5	5.5 -- 6.5
3 cm (X)	8.0-12.0	8.0 -- 9.0	9.0 -- 10.0
2 cm (Ku)	12.0-18.0	13.0 -- 14.0	14.0 -- 15.0
1.3 cm (K)	18.0-26.5	20.2 -- 21.2	21.2 -- 22.2
1 cm (Ka)	26.5-40.0	32.0 -- 33.0	31.0 -- 32.0
0.7 cm (Q)	40.0-50.0	40.0 -- 41.0	41.0 -- 42.0



Facilities for Filament Observation: ALMA

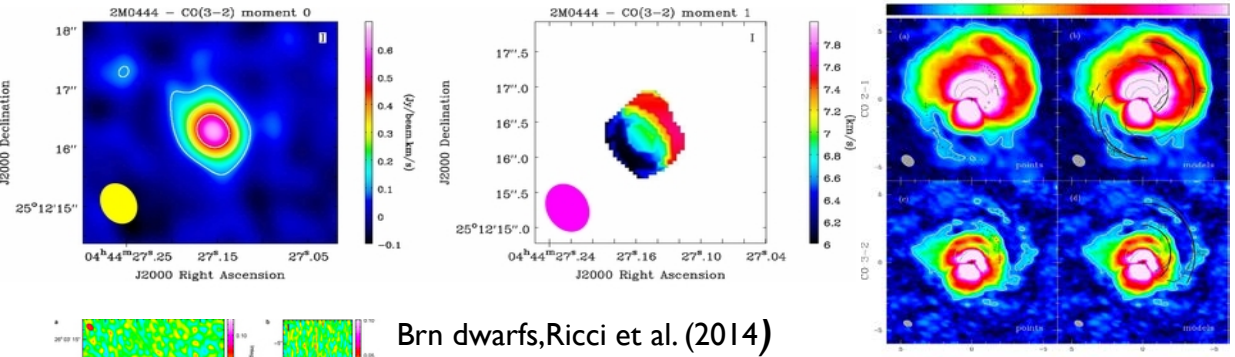
Brick, Bally et al (2014)arXiv:1409.3640



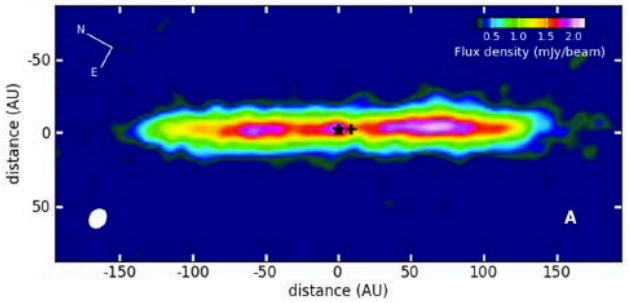
About 70 ISM/SF papers overall (39 Cyc 0) with over 400 citations

- Results on low mass star formation, high mass star formation, disks and their chemistry, outflows, filaments

H142527V. Christiaens et al. 2014 ApJ 785 L12

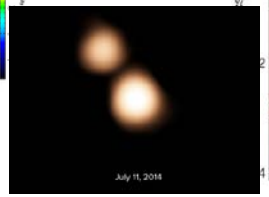


B Pic,W. Dent et al. Science, 2014

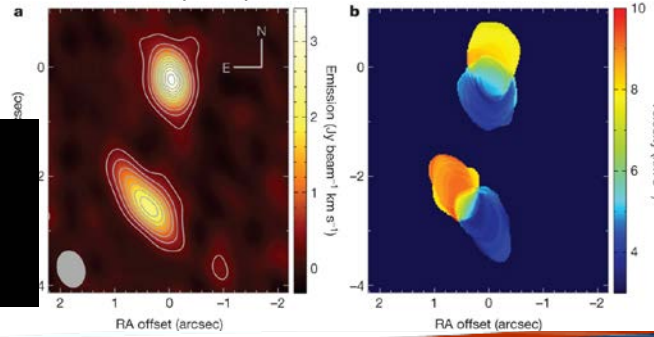


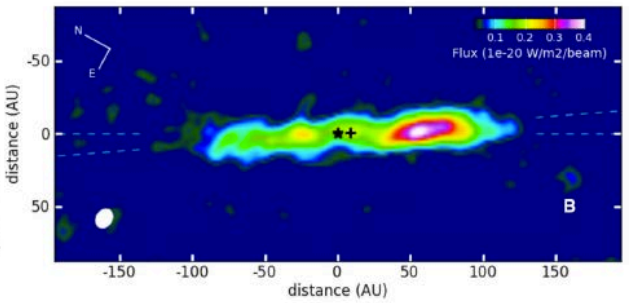
Brn dwarfs,Ricci et al. (2014)

L1527, Sakai et al Nature 507, 78 (2014)



HK Tau, Jensen & Akeson *Nature* **511**, 567-569 (2014)

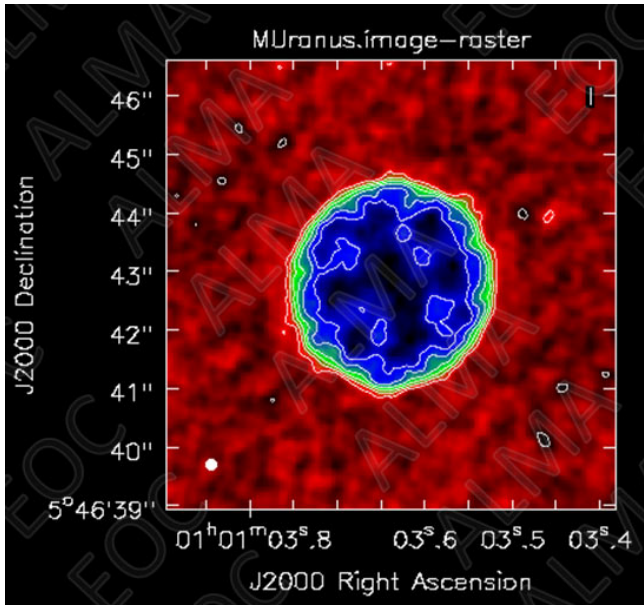




Facilities for Filament Observation

ALMA

- ALMA: For a reasonably lengthy filament, mosaicking, perhaps with ACA, TP (currently completely integrated with 12m array)
  - Cycle 3: Proposal deadline Spring 2015
    - 12 months, begins 1 Oct 2015
- Proposed capabilities:
  - Proviso
    - Software deadlines passed (i.e. OT updates)
    - Now being commissioned
    - Downselect based on testing 1 December
  - >40 12m array elements
  - B3 (3mm), B4 (2mm), B6 (1mm), B7 (.85mm), B8 (.6mm), B9 (.45mm), B10 (.35mm)

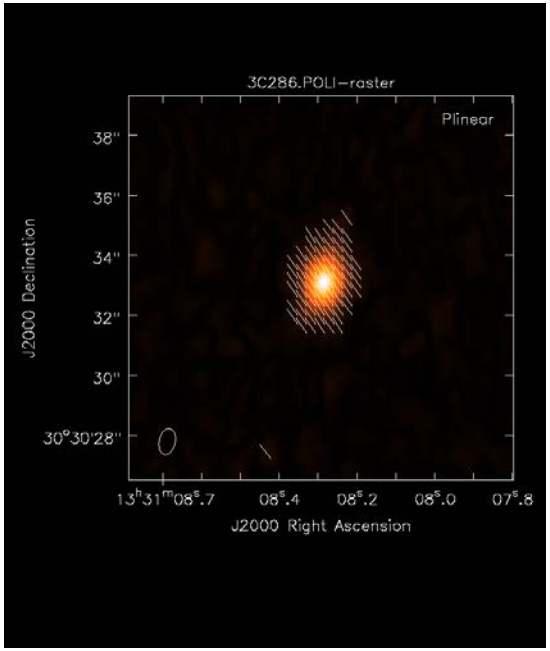


Uranus, 350 microns

ALMA, cont

Cycle 3 prognostication

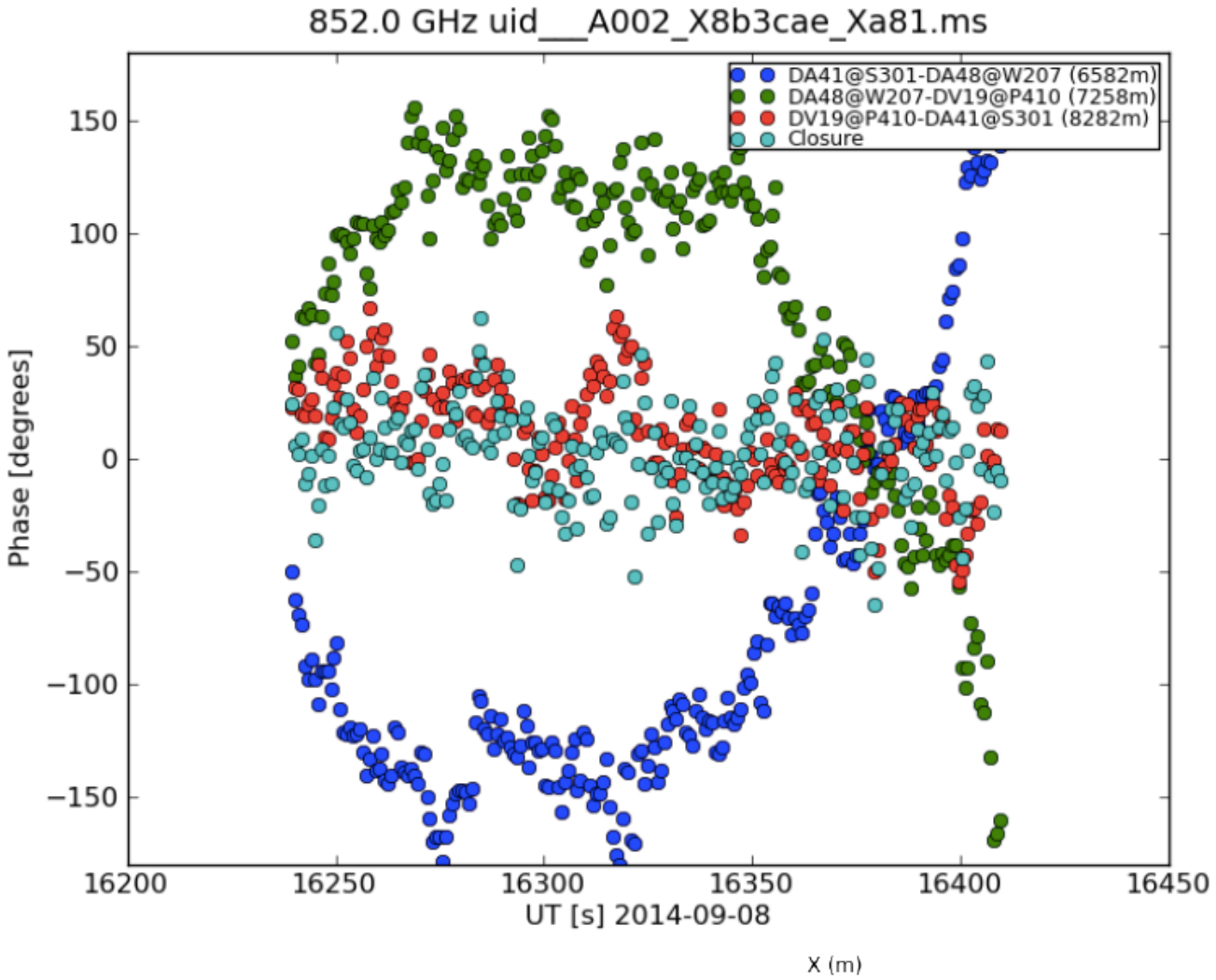
- Baselines:
  - Depends on outcome of current long baseline campaign but MAY include:
    - B3, B4, B6 perhaps out to 10km
    - B7, B8 to 5km
    - B9, B10 to 2km
    - Cycle 2: Beyond 2km, no ACA
- Polarization
  - As in Cycle 2
    - Linear at fixed frequencies continuum mode
  - New: high resolution modes, aim for frequency freedom
    - May restrict bandwidth to wide filters (for calibration)



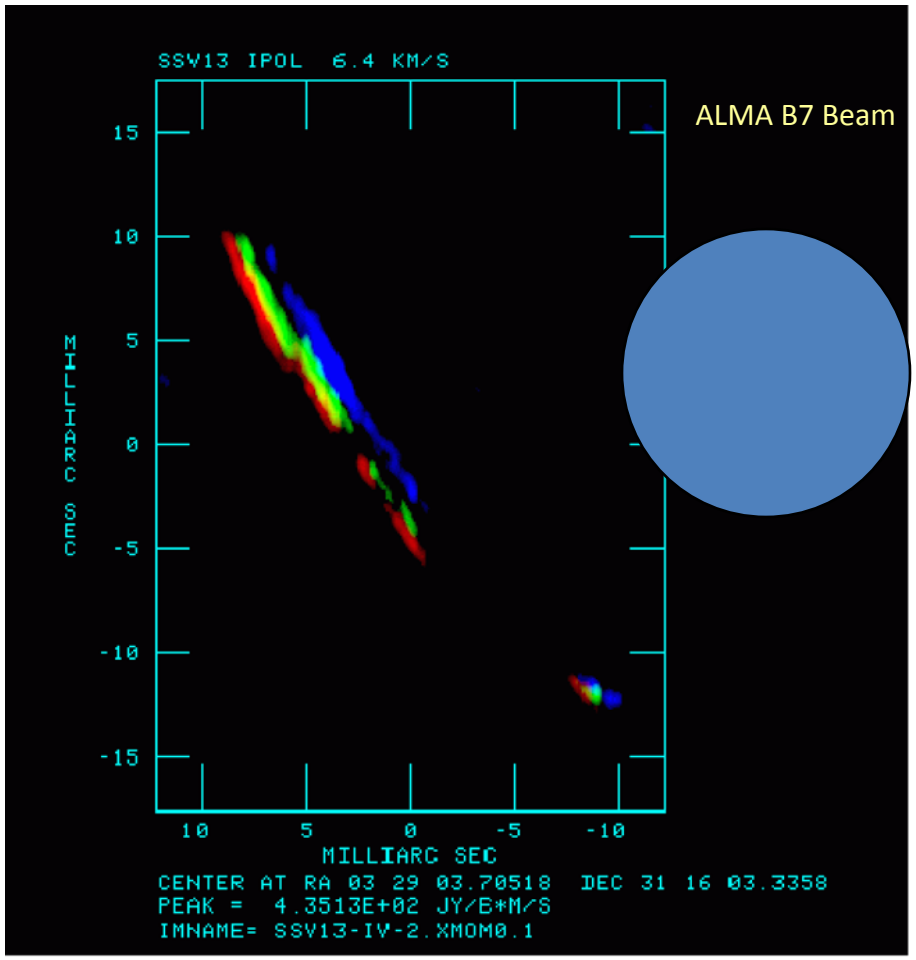
Extension of Capabilities Campaign

Continues th[illegible] Cycle 2

- Antenna mc
  most distant
  arms, 14km
  testing.
- Band-to-ban
  works well b
  testing
- Science obse
  array to resu
  December
- Future—54
  antennas an[illegible]



Resolution: Proper Motion, Shock Structure in Dense Clouds



Masers near SVS13; 1mas=0.34AU
Blue Epoch I, Green Epoch III, Blue Epoch IV
Wootten, Marvel, Claussen and Wilking

Winds, jets and outflows interact with local media at shocks; masers can trace these.
Water masers observed over four epochs encompassing 50 days (22 GHz, VLBA).
Several of the masers define an arc structure about 5AU in length. This consistently moved at a rate of 0.023 mas/day, or 13.6 km/s.
Including the radial velocity offset, a space velocity of 13.7 km/s is calculated at an inclination of 6 degrees from the plane of the sky.
These structures apparently represent water emission from interstellar shocks driven by the outflow from SVS13.

ALMA, VLBA, JVLA can provide images of chemistry in action in shocks such as this.

Archive: Nearly All Cycle 0 data available

Almascience.nrao.edu science portal links to archive

- An interesting alternative: Japanese Virtual Archive (jvo.nao.ac.jp)

www.nrao.edu
science.nrao.edu

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