Challenges and Future Directions For Submillimeter Imaging

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(NAASC/NRAO in March)

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URSI, Boulder Co, 2006

Heterogeneous Arrays

<u>eSMA</u>

8 6m

1 15m (JCMT) + 1 10.4m (CSO)

<u>CARMA</u>

6 10.4m

10 6.1m

8 3.5m

1 10.4m for total power

<u>ALMA</u>

50-60 12m antennas in main array (two designs)

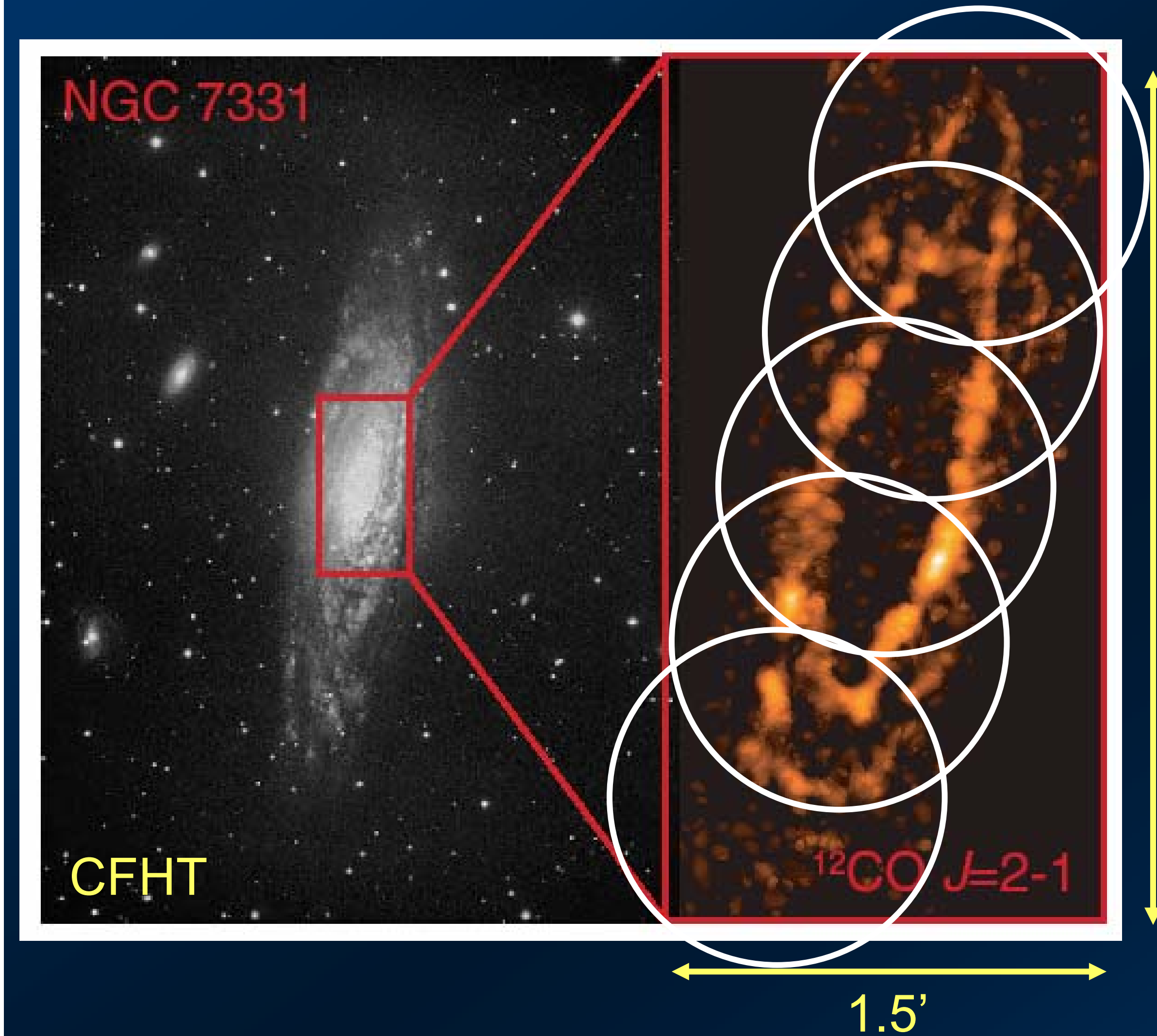
12 7m antennas in ACA (Atacama Compact Array)

4 12m for total power

Challenges

- ❖ Image sources larger than the primary beam (PB)
  - at 1mm a 12m dish has PB~21”
    - ⇨ Mosaic
- ❖ Image sources with structure larger than the largest angular scale
  - For shortest baseline of 15m (1.25*diameter) ~14” at 1mm
    - ⇨ Add total power from single dish
- ❖ Accurate continuum images in presence of copious line emission
    - ⇨ Spectral line mode all the time
- ❖ Sensitive linearly polarized feeds
  - Many quasars are linearly polarized
    - ⇨ Full polarization calibration always

Large Nearby Galaxies

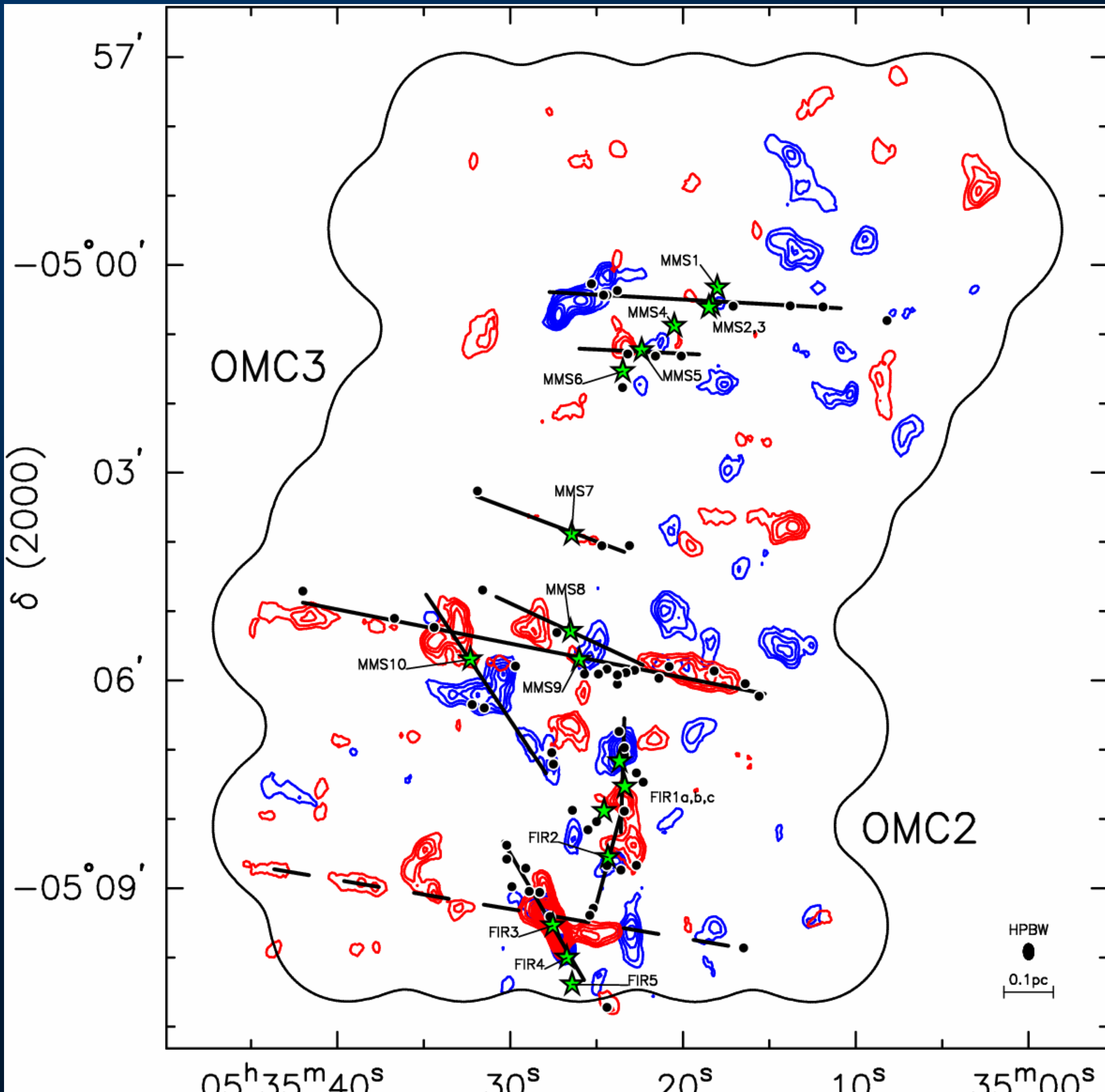


SMA ~1.3 mm observations

- Primary beam ~1'
- Resolution ~3"

Petitpas et al. 2006, in prep.

Galactic Star Formation



Williams et al. (2003)

BIMA 46 pointing mosaic covering 10’ x 15’

CO(1-0) at ~115 GHz

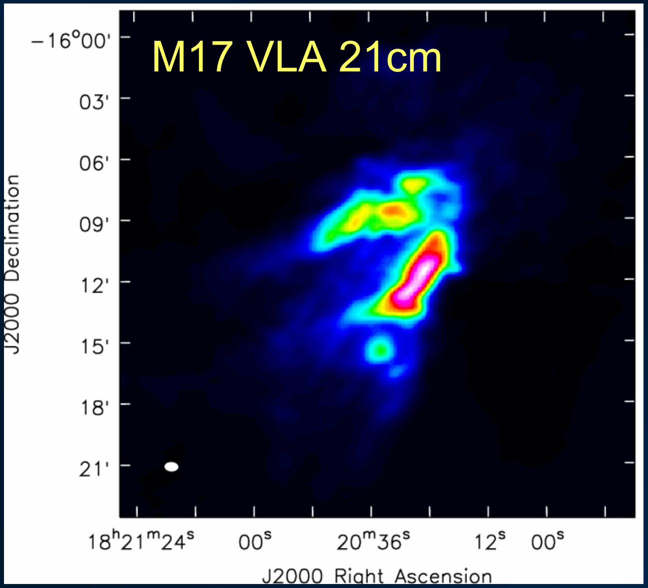
~10” resolution

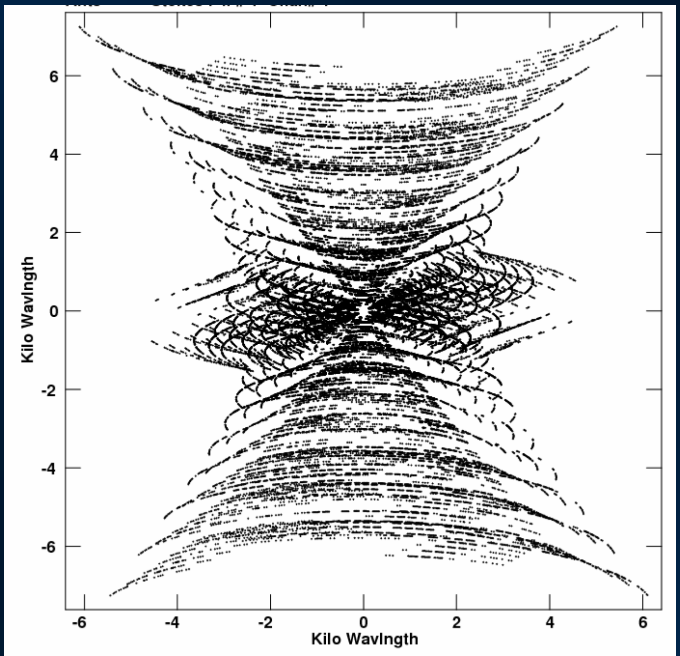
○ ALMA 0.85mm PB

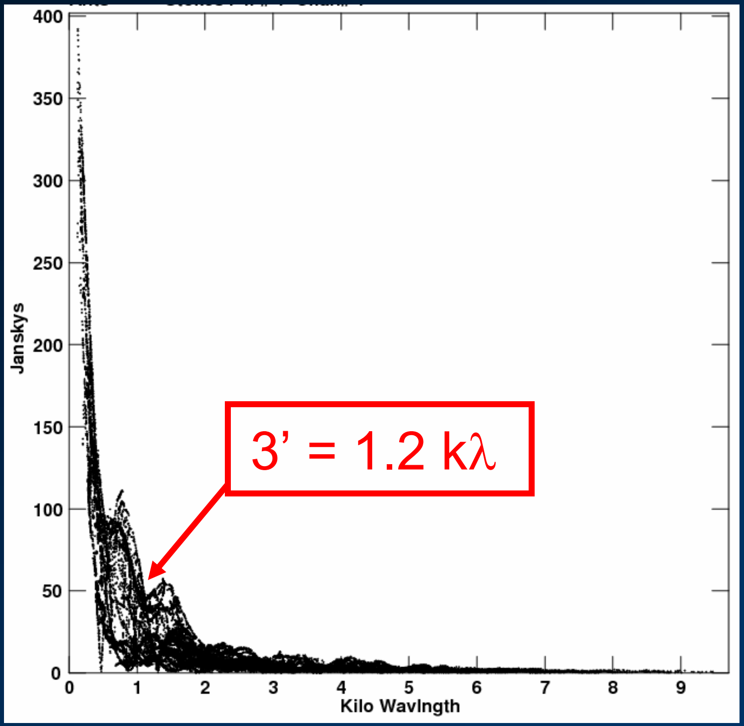
Image Quality

Image quality depends on:

- *U-V* coverage
- Density of *U-V* samples
  - Image fidelity is improved when high density regions are well matched to source brightness distribution
  - *U-V* coverage isn't enough





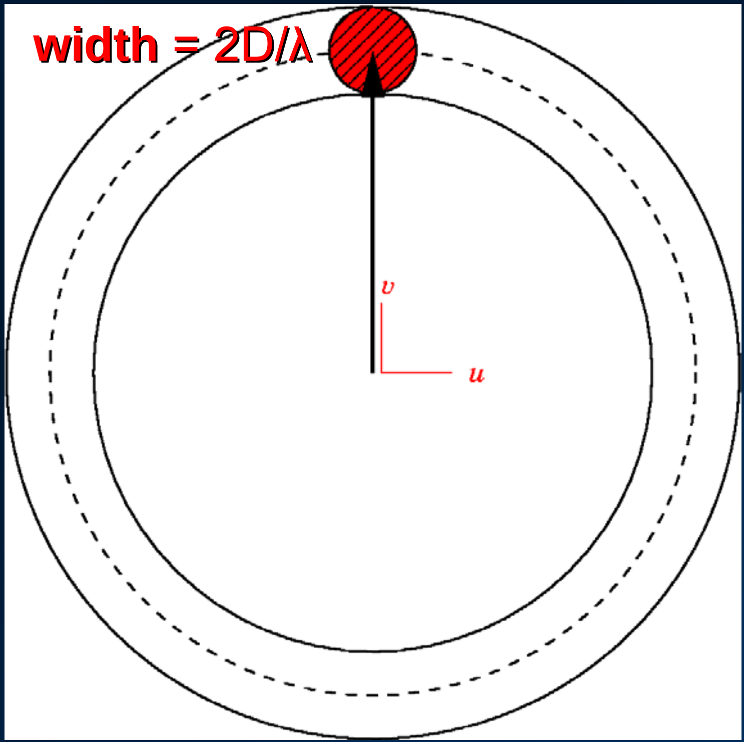


Mapping and the Fourier Plane

A visibility is constructed by cross-correlating signals from two apertures (of diameter D), a given visibility fills out uv modes between all surface elements of each aperture

Information in uv-plane is smeared by radius D/λ

Fourier transform of sky is convolved by aperture cross-correlation



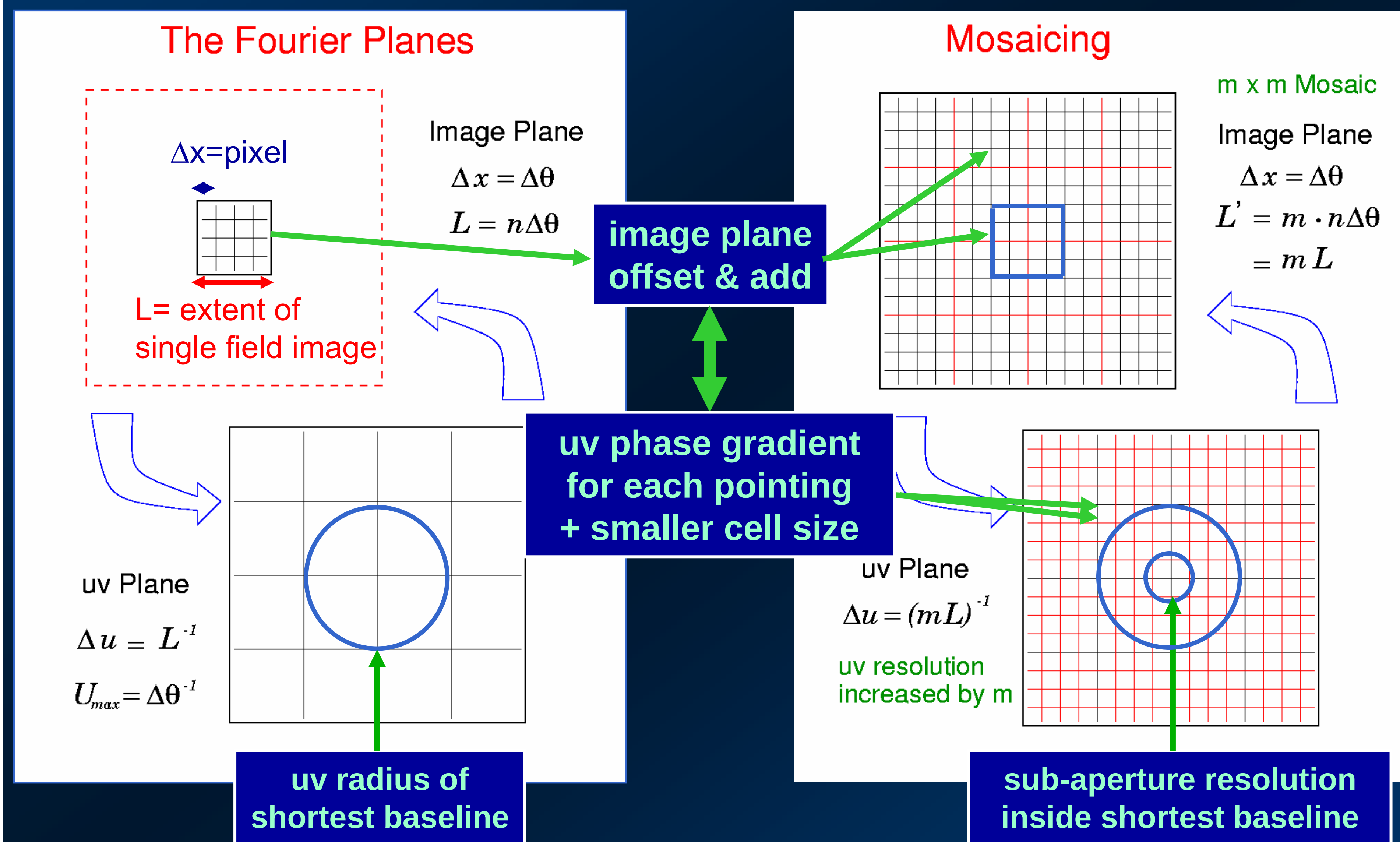
visibility centroid at **B**/λ for baseline vector **B**

Mosaicing and Fourier Resolution

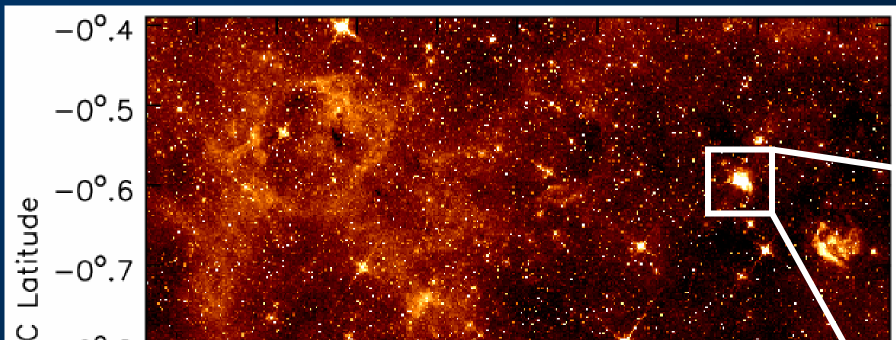
- The aperture (antenna) size restricts response
  - Convolution in uv plane = loss of Fourier resolution
  - Same as multiplication on sky = limited field-of-view
  - Smaller apertures = wider field-of-view = higher intrinsic Fourier resolution

- Synthesize wider field of view by scanning interferometer across sky
  - Mosaicing does <u>not</u> generate extra U-V coverage!
  - But what it does do is increase Fourier resolution
  - In innermost part of uv-plane (shortest baselines, typically at shadowing limit), this increased resolution allows us to separate out <u>short spacings</u> that were convolved with single-pointing response

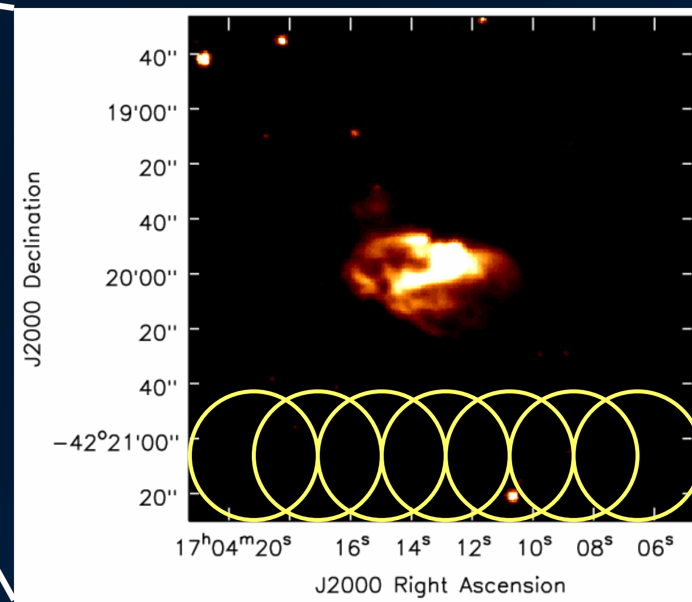
Mosaicing Graphics

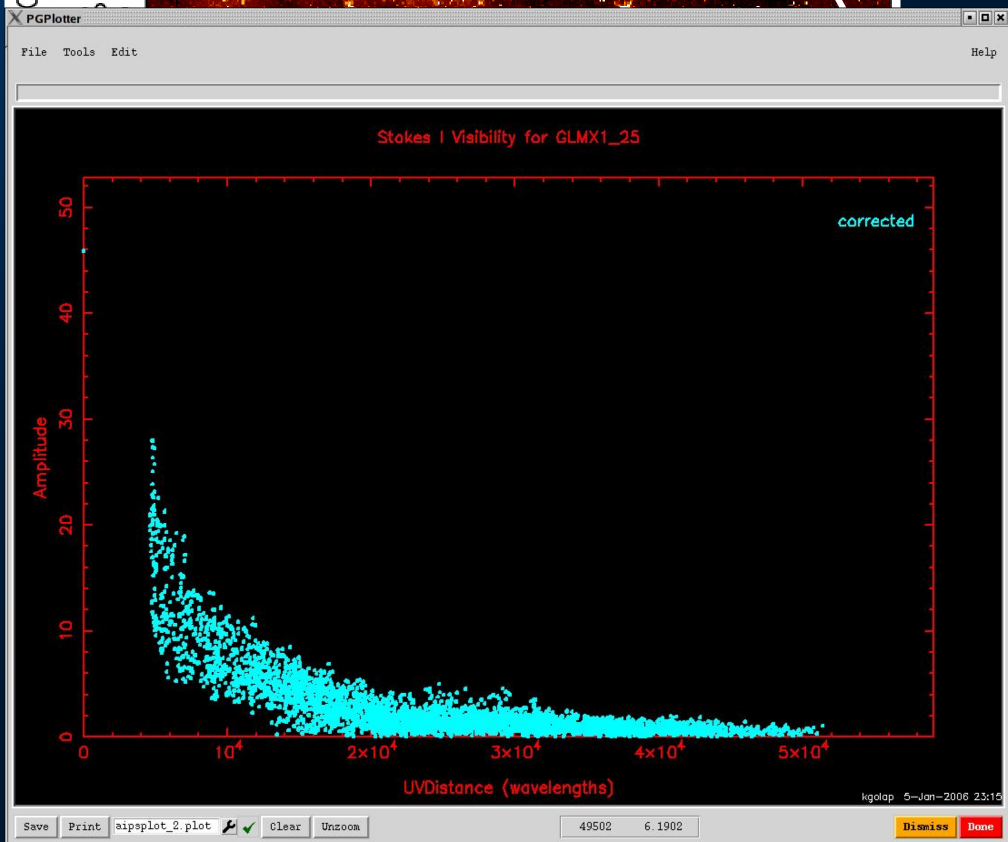


Model Image



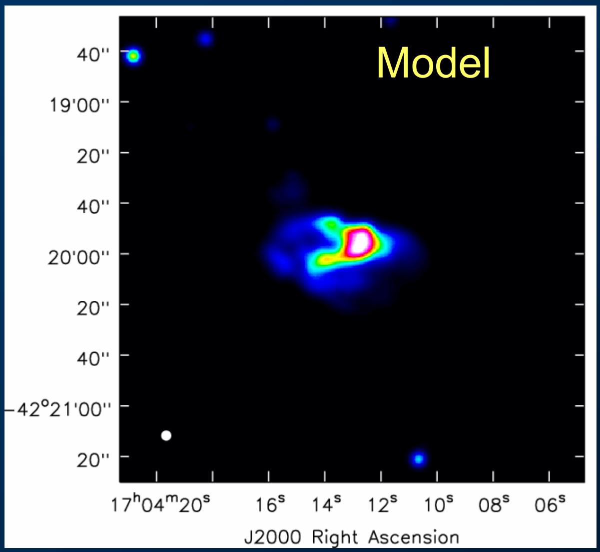
Spitzer GLIMPSE 5.8 μm image

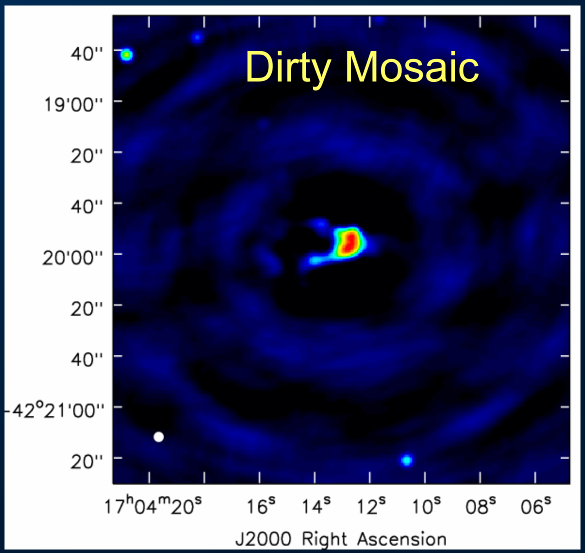


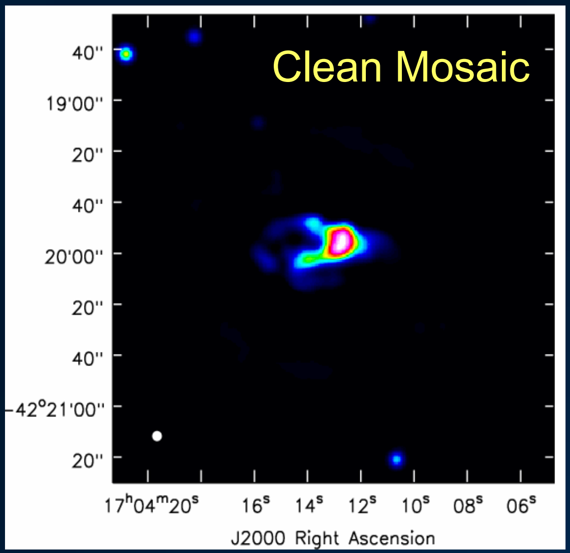


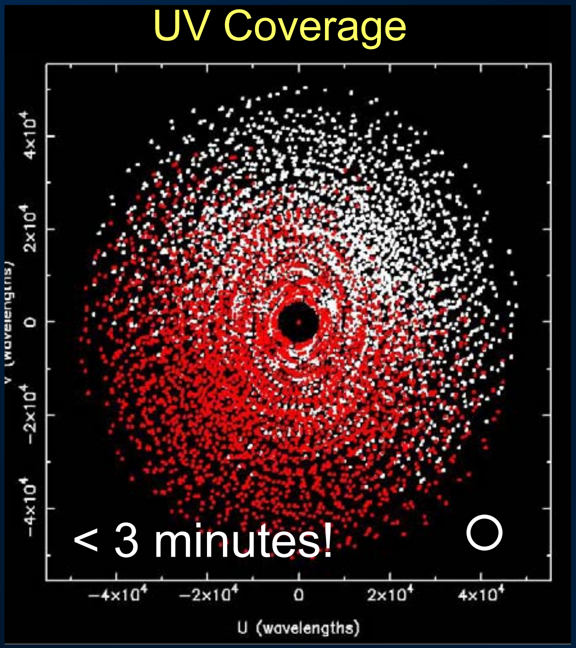
- Aips++/CASA simulation of ALMA with 50 antennas in the compact configuration (< 100 m)
- 100 GHz 7 x 7 pointing mosaic
- +/- 2hrs

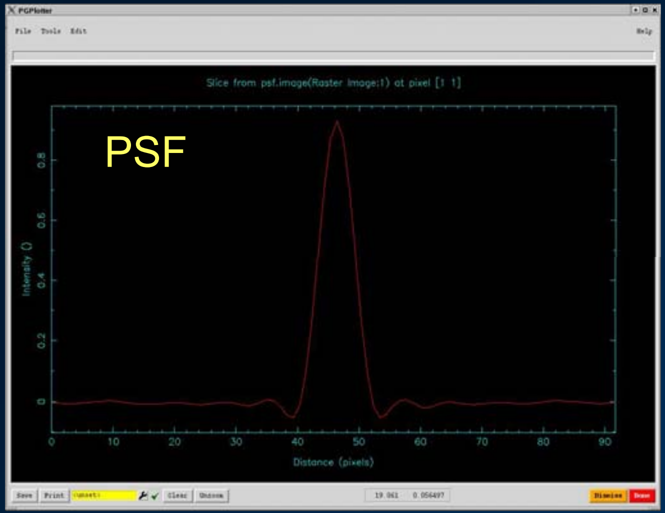
50 Antenna ALMA CLEAN results

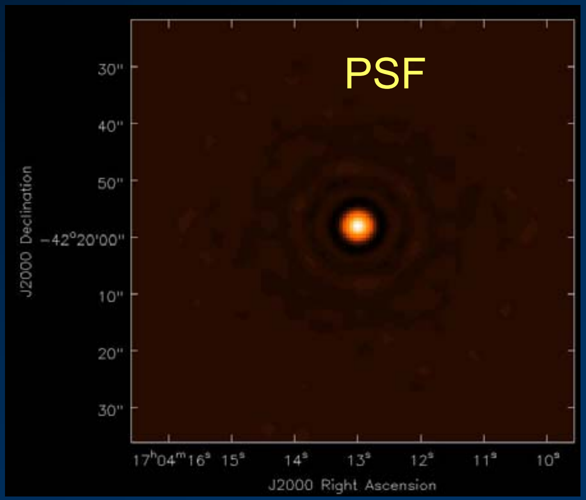












Missing Short Spacings

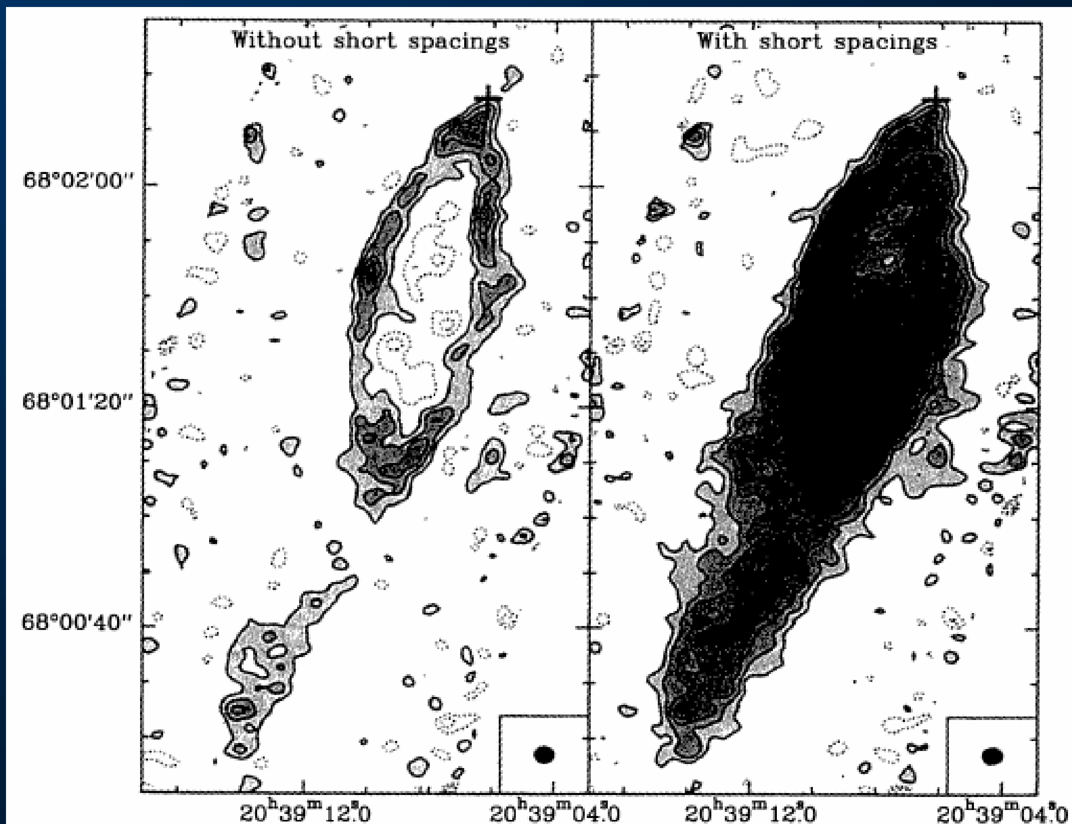
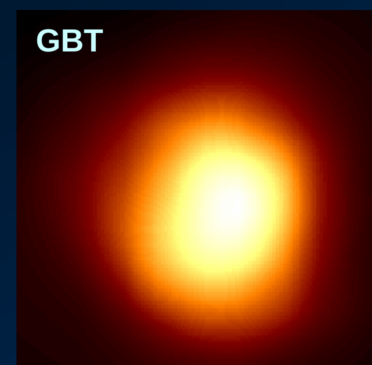
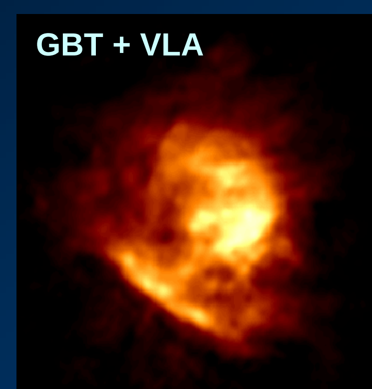
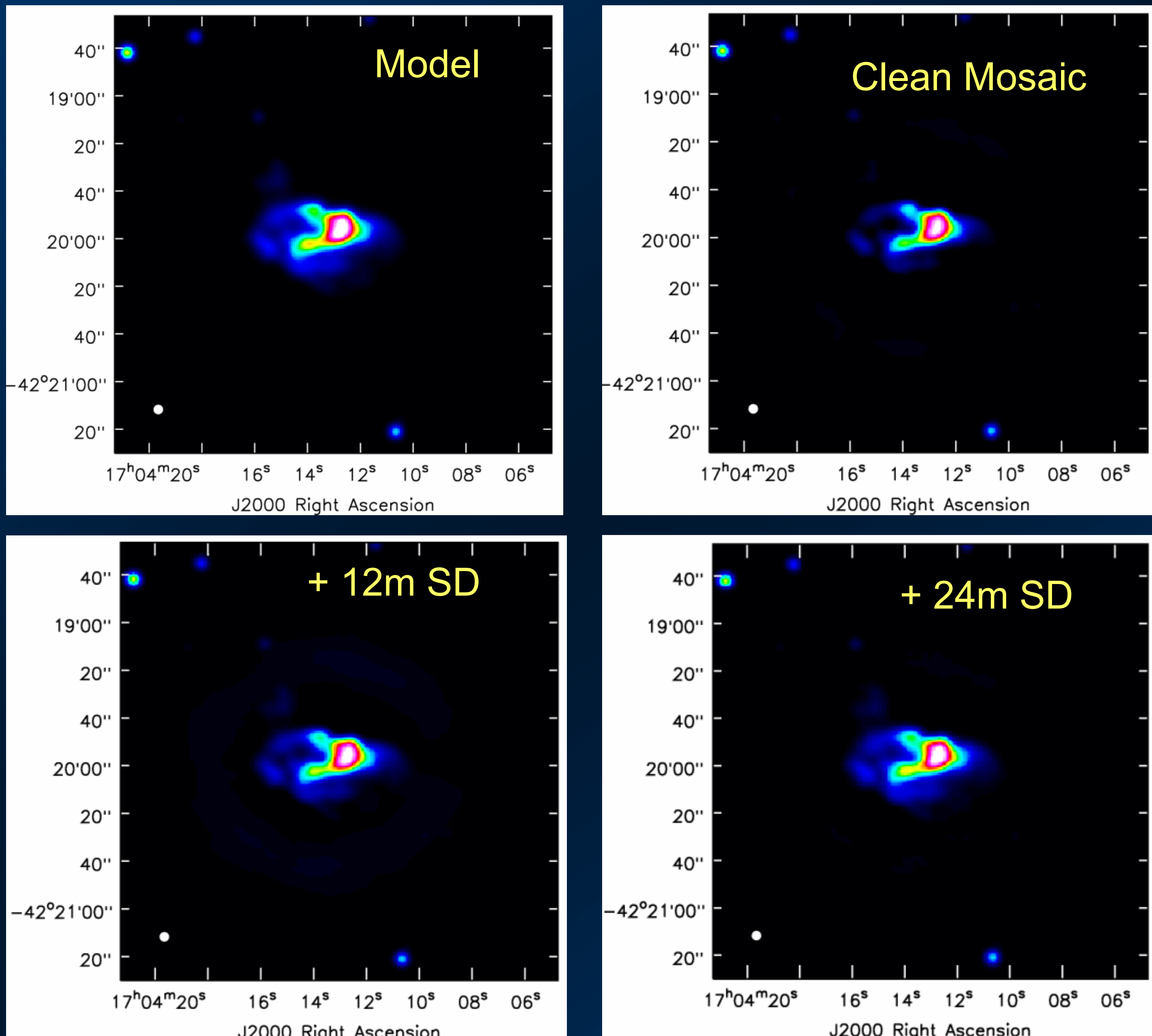


Figure 3. 10 field mosaic of the CO J = 1→0 emission in the southern lobe of the L 1157 molecular outflow. The two panels represent





50 antenna + SD ALMA Clean results



Mosaicing Considerations

❖ Each pointing ideally should have similar U-V coverage and hence synthesized beams – similar S/N is more important

❖ Nyquist sampling of pointings

- ➢ On-the-fly mosaicing can be more efficient at lower frequencies

❖ Small beams imply many pointings

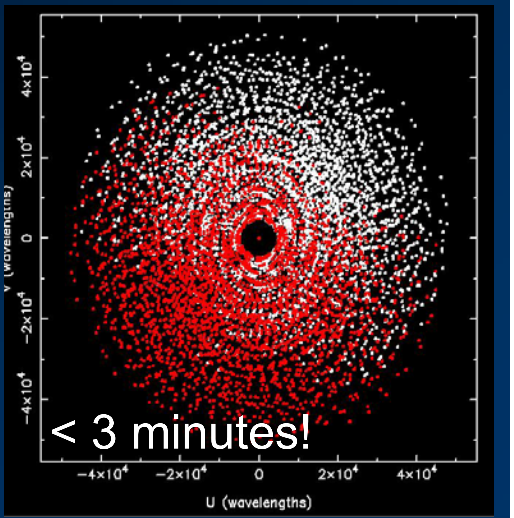
❖ At higher frequencies weather conditions can change rapidly

- ➢ Push to have very good instantaneous snapshot U-V coverage

❖ Polarimetry even more demanding for control of systematics due to rotation of polarization beam on sky

❖ Accurate primary beam characterization

- ➢ Account for heterogeneous array properties



Total Power Considerations

- Getting Single Dish (SD) zero-spacing tricky because it requires
  - Large degree of overlap in order to calibrate with interferometric data
  - Excellent pointing accuracy which is more difficult with increasing dish size
  - On-the-fly mapping requires rapid telescope movement
  - SD Continuum calibration – stable, accurate, large throws

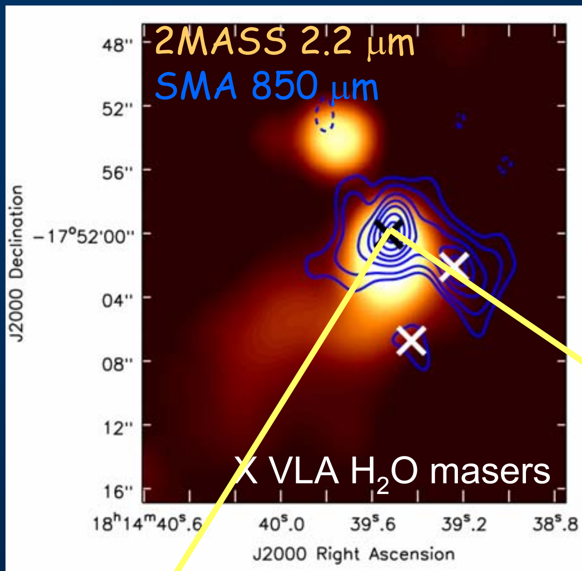
New Algorithm Development: Gridding Convolution

- Traditional mosaicing done in image plane by co-adding weighted images made by transforming individual pointings (e.g. as facets)

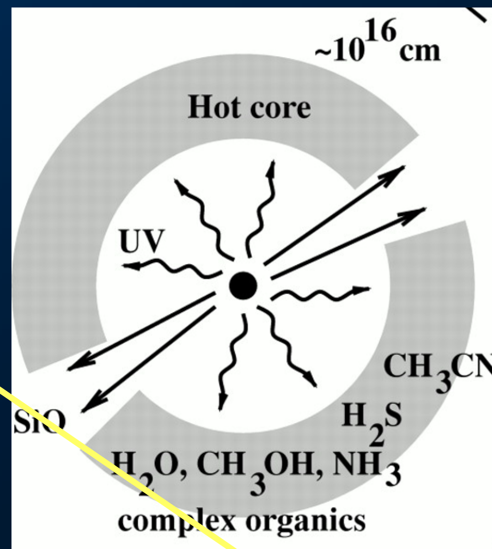
- But can grid all the data onto a large over-sampled uv grid (with sub-aperture resolution) using gridding convolution function given by the aperture cross-correlation function (the transform of a single-pointing primary beam) and then transforming to image plane (e.g. Myers et al. 2003, see Pearson's talk this afternoon)
  - approximate primary beam(s) incorporated into gridding
    - accurate primary beam needed for model/residual calculation
  - optimal weighting built in (mosaic pointings weighted by PB)
  - already doing gridding convolution anyway!

- Need to combine with deconvolution and calibration

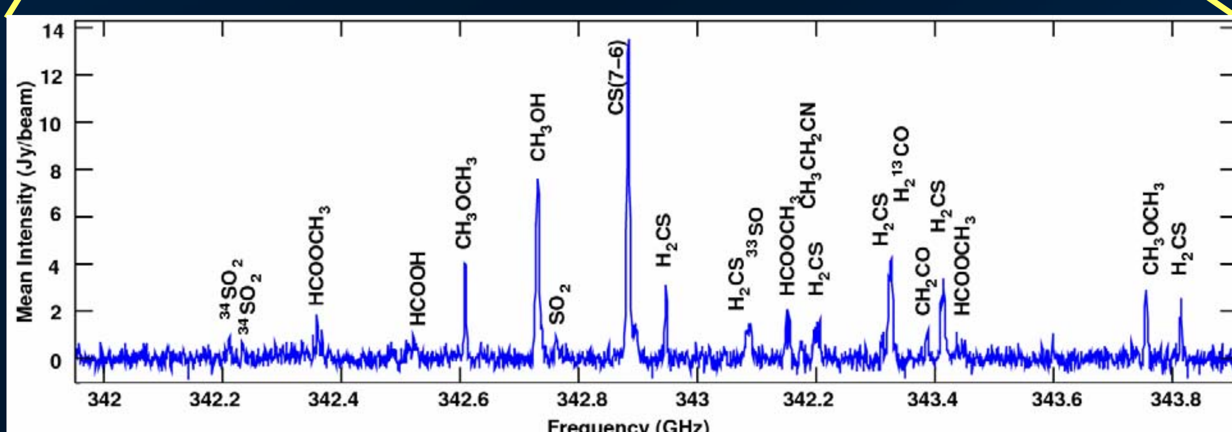
Massive Star Birth in W33A



At 4kpc 2" = 8,000 AU



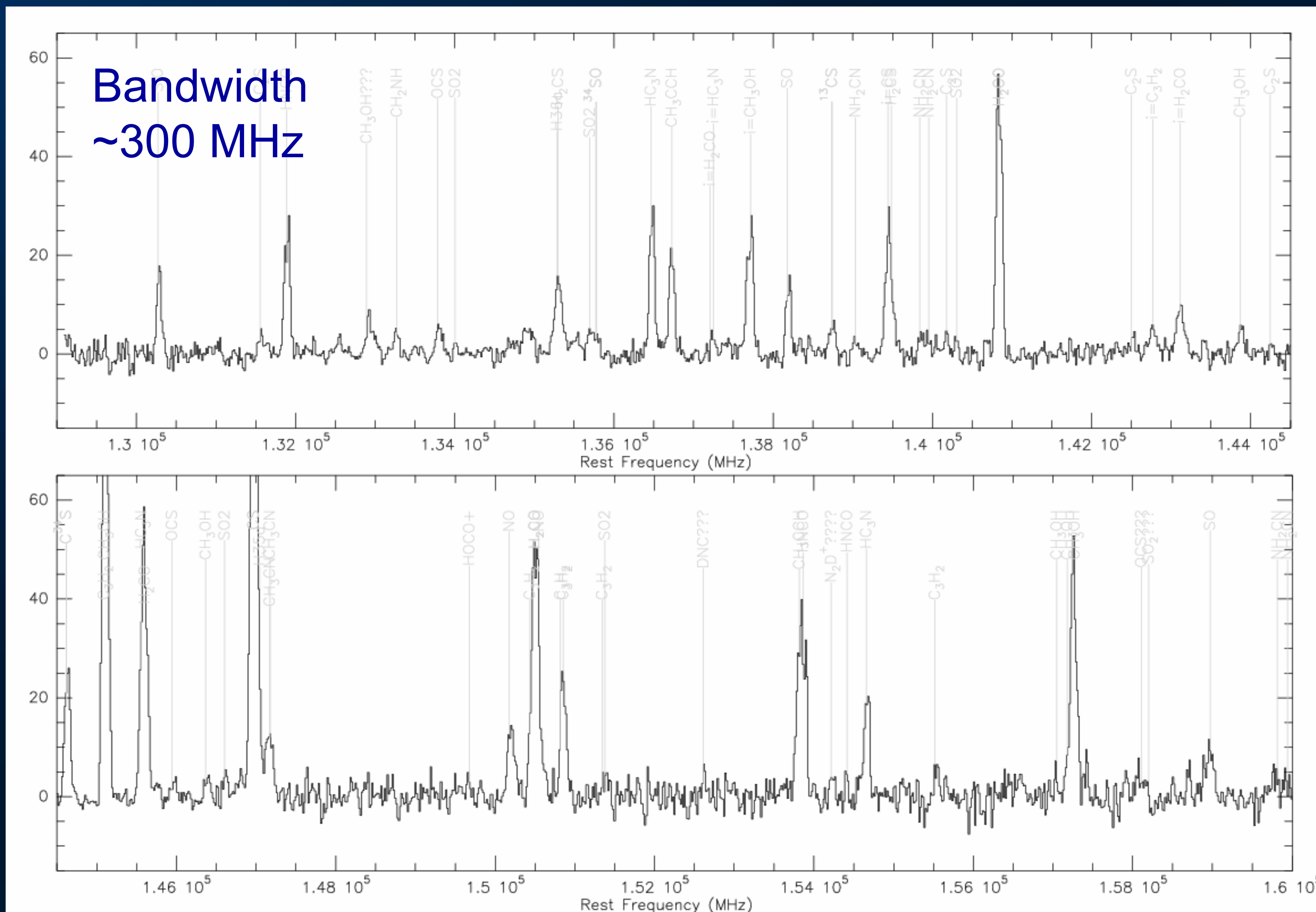
- Line to continuum ratio in regions of high mass star formation (at high angular resolution) can easily be 20-40%
- Difficult in wideband to isolate all the lines manually
- Need automated line "finding" algorithms for continuum subtraction



Brogan et al. (2006)

Extragalactic Line Forest

Starburst NGC 253 (d = 2.5 Mpc)



Martin et al. (2005)

Summary

❖ Image sources larger than the primary beam (PB)

- ALMA science will rely heavily on mosacing

  ⇨ Algorithms are maturing, new techniques under development

❖ Image sources with structure larger than the largest angular scale

- ALMA science will also rely heavily on SD addition

  ⇨ As anticipated 12m SD addition not optimal but ACA will fill the gap. A 24m dish (i.e. CCAT) near ALMA would be fabulous

❖ Sensitive linearly polarized feeds

- Much more development needed

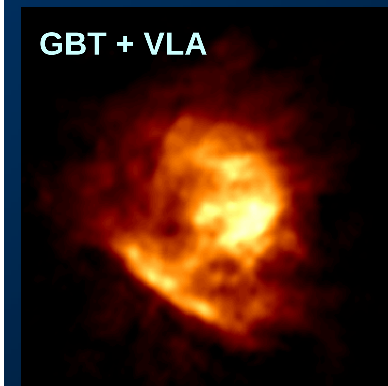
❖ Accurate continuum images in presence of copious line emission

  ⇨ Automated line finding algorithms needed

Pipeline and Off-line Data Reduction Software

CASA (Common Astronomy Software Applications)

- ❖ CASA has subsumed AIPS++
- ❖ CASA is written in C++, Java, and Python



- ➢ Conversion of AIPS++ Glish user interface to Python ongoing
- ➢ Internal & External testing ongoing
- ➢ Completed tests (1) Basic imaging, (2) Mosaicing, and (3) Single dish + interferometric data combination using VLA, BIMA, and PdBI datasets.

- ❖ CASA demos planned for Calgary, AAS (June 2006)
- ❖ CASA release early 2007
- ❖ Pipeline testing and development underway