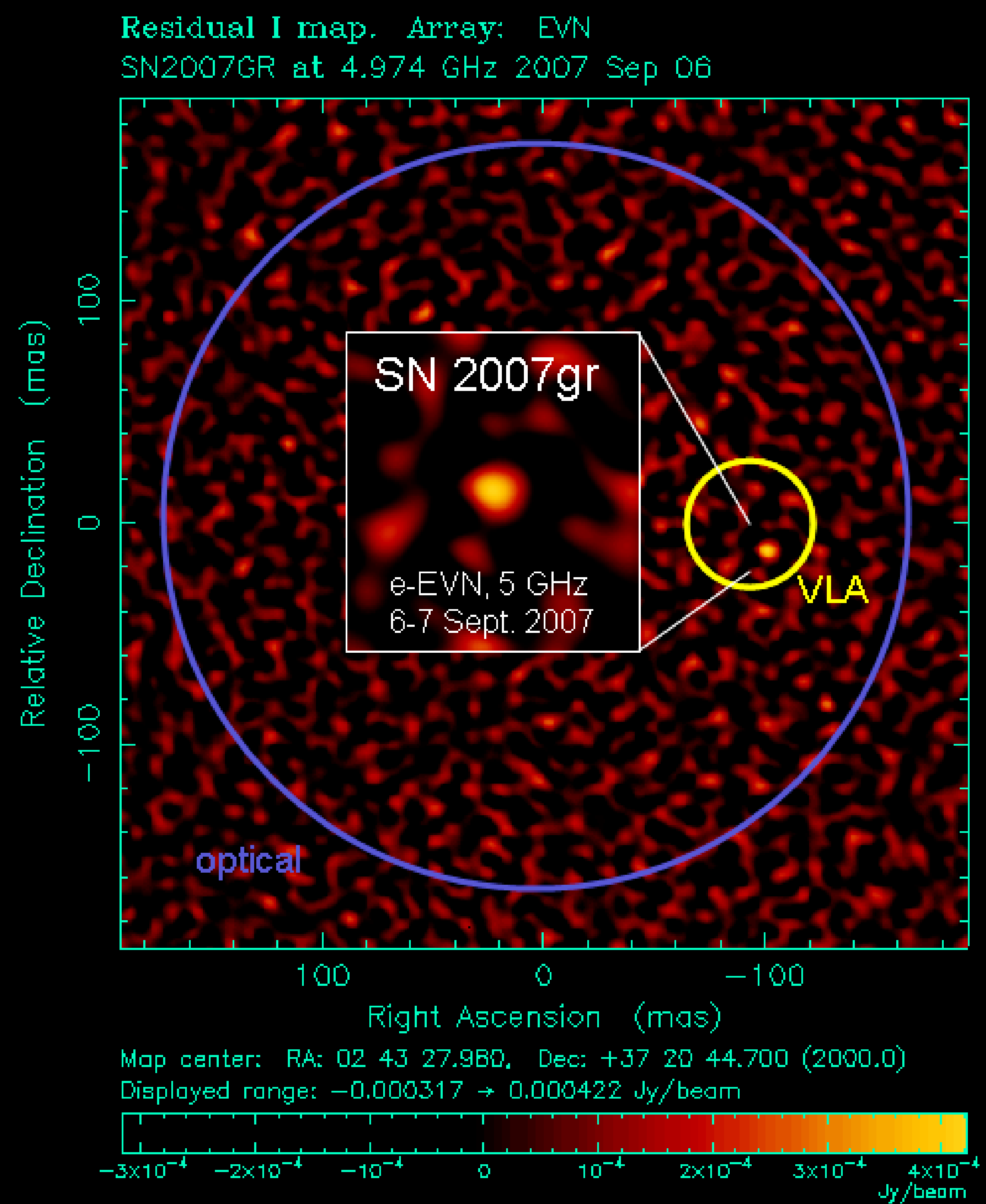

Residual I map. Array: EVN
SN2007GR at 4.974 GHz 2007 Sep 06
SN 2007gr
e-EVN, 5 GHz
6-7 Sept. 2007
VLA
optical
Relative Declination (mas)
100
0
−100
Right Ascension (mas)
Map center: RA: 02 43 27.980, Dec: +37 20 44.700 (2000.0)
Displayed range: −0.000317 → 0.000422 Jy/beam
−3x10^−4 −2x10^−4 −10^−4 0 10^−4 2x10^−4 3x10^−4 4x10^−4
Jy/beam

The Atacama Large Millimeter / Submillimeter Array: ALMA

Huib van Langvelde JIVE

Michiel Hogeheijde

Leiden Observatory

michiel@strw.leidenuniv.nl

Outline

- Millimeter and submillimeter astronomy
- Location requirements
- Existing arrays
- ALMA
  - Specifications
  - Canfigurations and sensitivity
  - Science drivers
  - Calibration issues
  - Operations and data flow
  - Progress and time line
- Concluding remarks

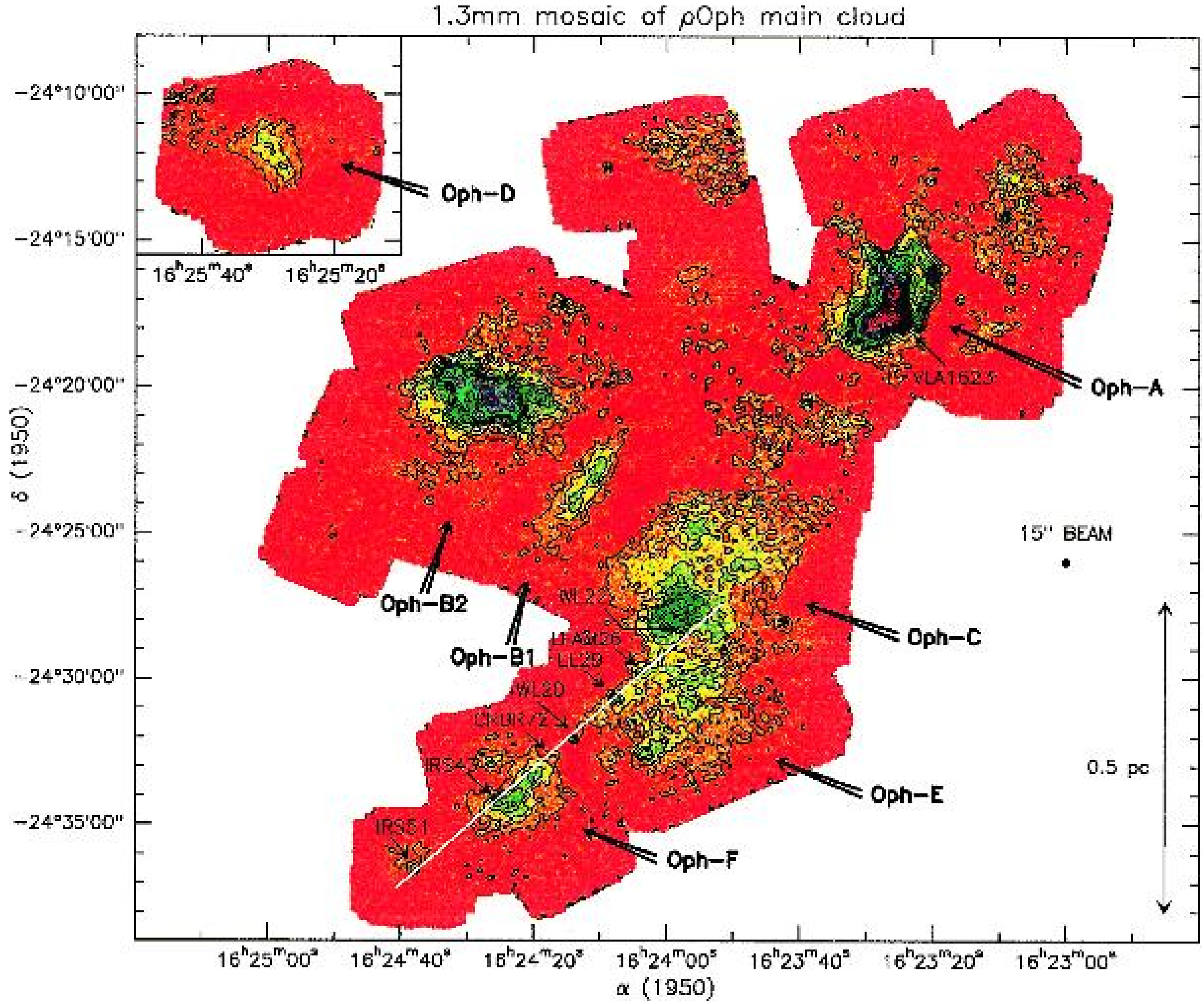
(Sub) millimeter astronomy

- Cold dust (10–100 K) emits at mm/submm
  - But optically thin unlike at infrared and visible wavelengths
- Molecules such as CO emit at mm/submm
  - H_2 does not emit radiation (except weak lines from >200 K gas in infrared)

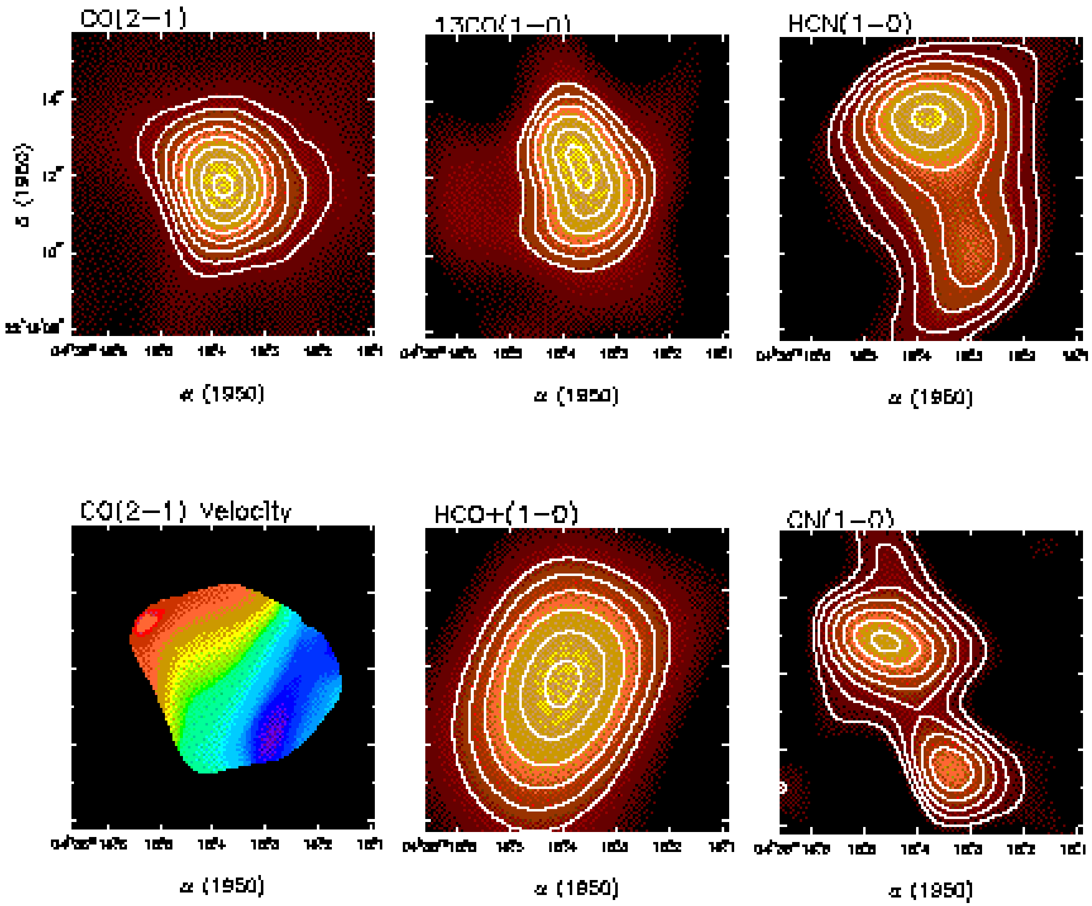
- Study the cold Universe
- Study the dust-enshrouded Universe
- Locations where stars are born and galaxies shaped

A star-forming cloud

IRAM 30m: Motte et al. (1998)

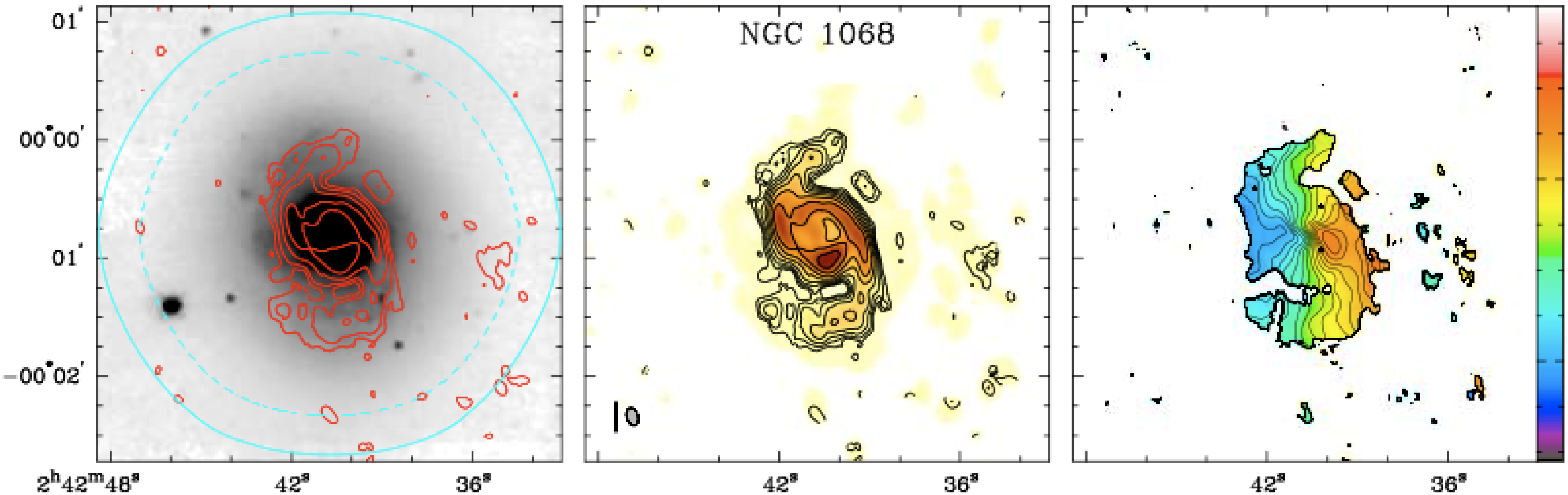


A planet-forming disk



LkC15, OVRO: PhD work Qi and Kessler-Silacci

Nearby galaxies



Helfer et al. (2003) - BIMA SONG

Gas in the early Universe

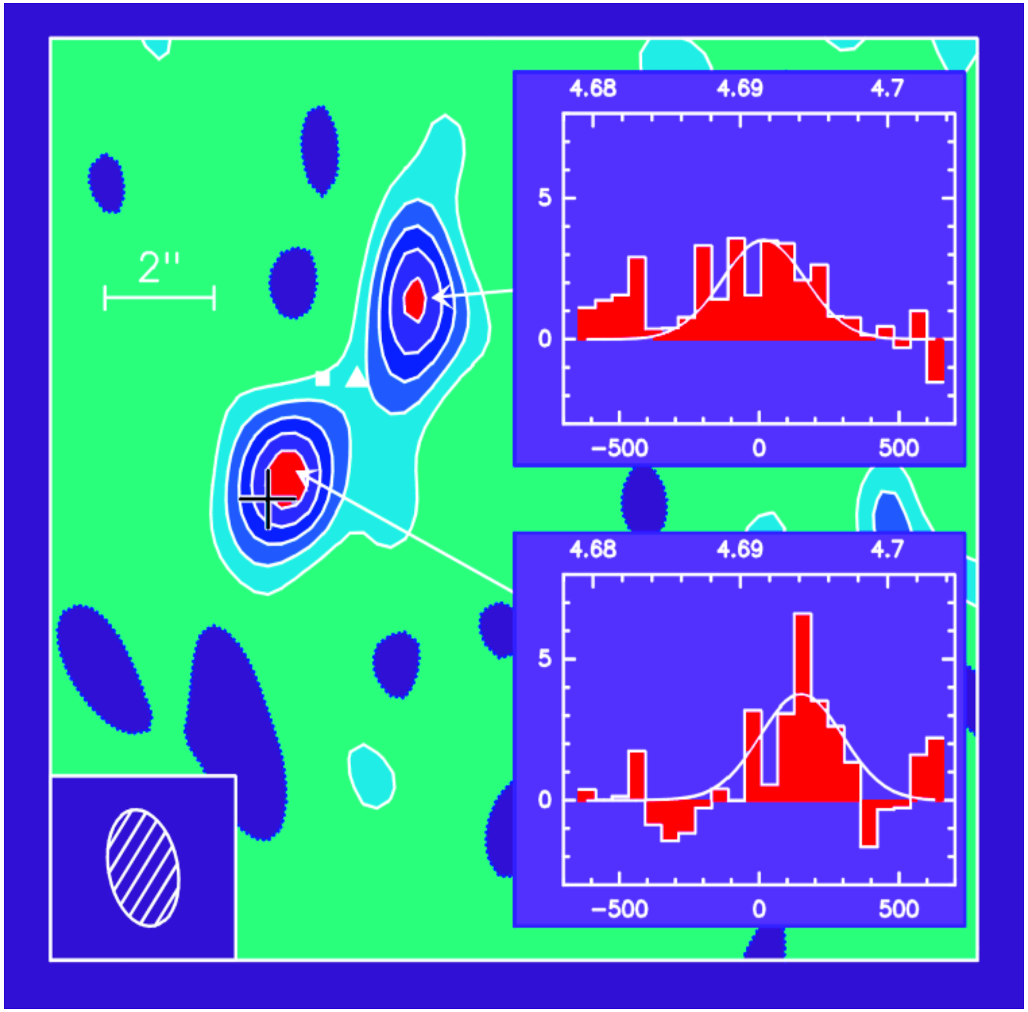
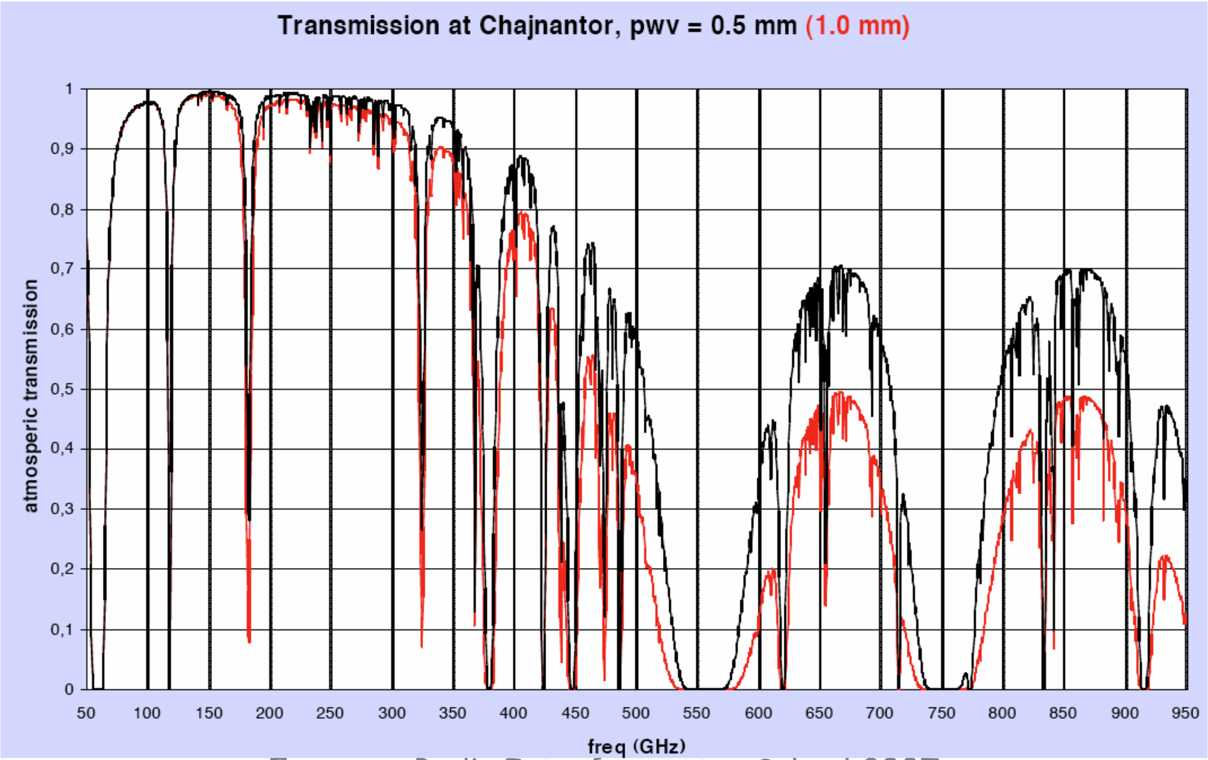


Image courtesy C. de Breuck, ESO

Location Requirements

- Atmosphere is partially transparent in (sub) millimeter wavelengths. Deep absorption by molecules (mostly water) separates various 'windows' or 'bands'.



Location requirements

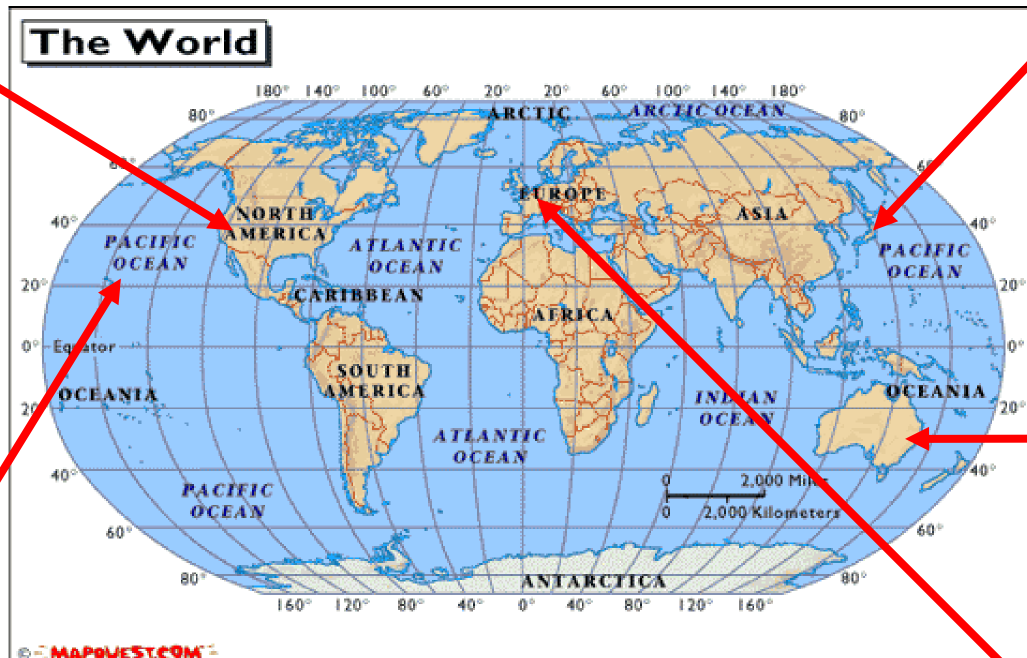
- Need to find
  - A high place (above most atmospheric water)
  - A flat place (need space for baselines)
  - A place without much turbulence in the atmosphere (phase stability)

  - (phase fluctuations are caused by variable path length through the atmosphere. In the case of (sub)mm frequencies, this is due to the passing of 'cells' of humid air over the array.)

Existing Arrays

BIMA + OVRO = CARMA:
Combined Array for Millimeter Astronomy,
Inyo Mountains, Calif.

NMA:
Nobeyama Millimeter
Array, Japan



ATCA:
Australia
Telescope
Compact
Array

SMA: Submillimeter Array, Hawaii

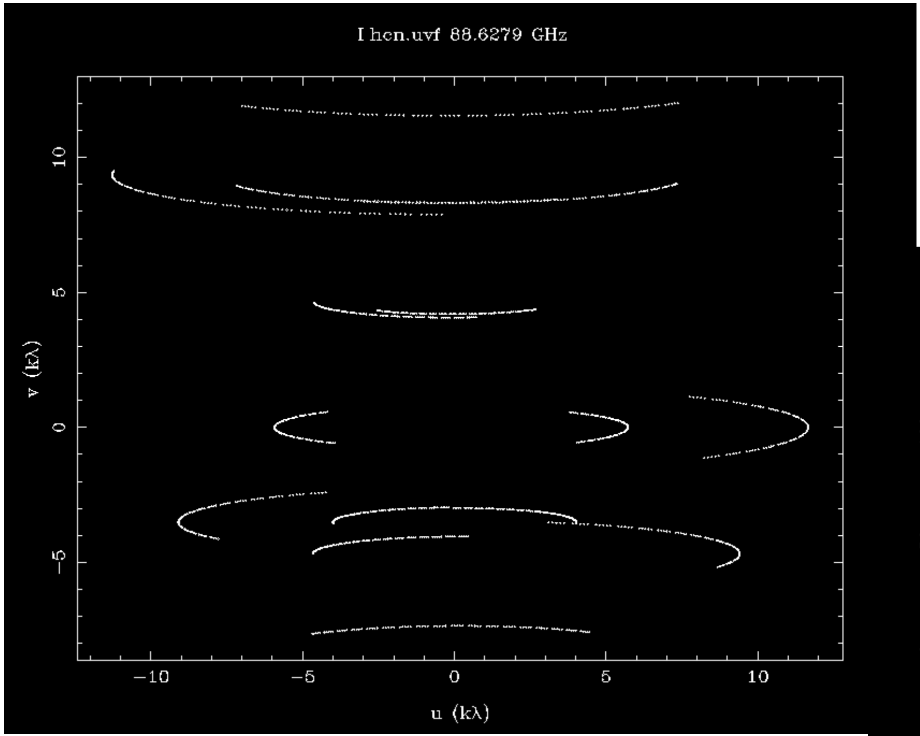
PdBI: Plateau de Bure, France

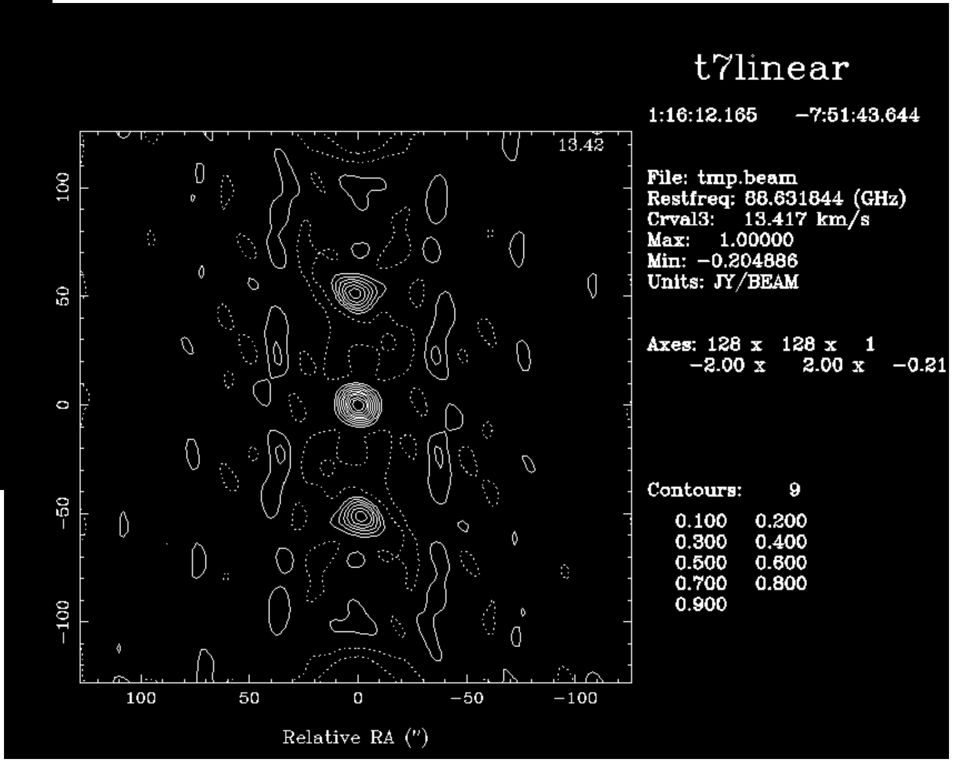
Capabilities and Limitations

Array	Wavelength(s) (mm)	Telescope Diameter	Maximum Resolution
ATCA	3	5×22 m	$2''$
PdBI	3+1	6×15 m	$1.3''$, $0.5''$
OVRO	3+1	6×10.4 m	$2''$, $1''$
BIMA	3+1	10×6.1 m	$0.4''/2''/6''/14''$
CARMA	3+1	6×10.4 m + 9×6.1 m	$0.5''$, $0.2''$
NMA	3+2+1	6×10 m	$1''...5''$
SMA	1.3+0.87+0.44	8×6 m	$0.4''$, $0.3''$, $0.15''$

With the possible exception of CARMA, none of these arrays have many elements -> poor uv filling; multiple tracks required for decent image quality

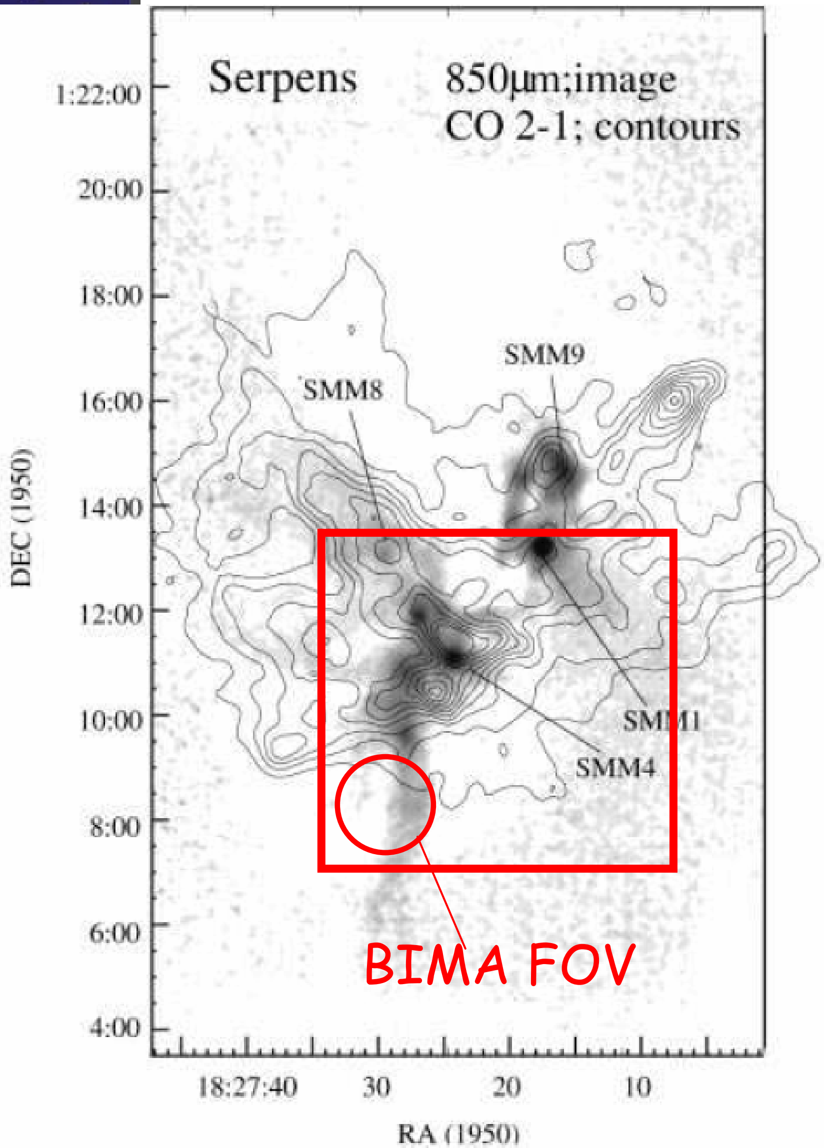
(u,v) positions and beam shape

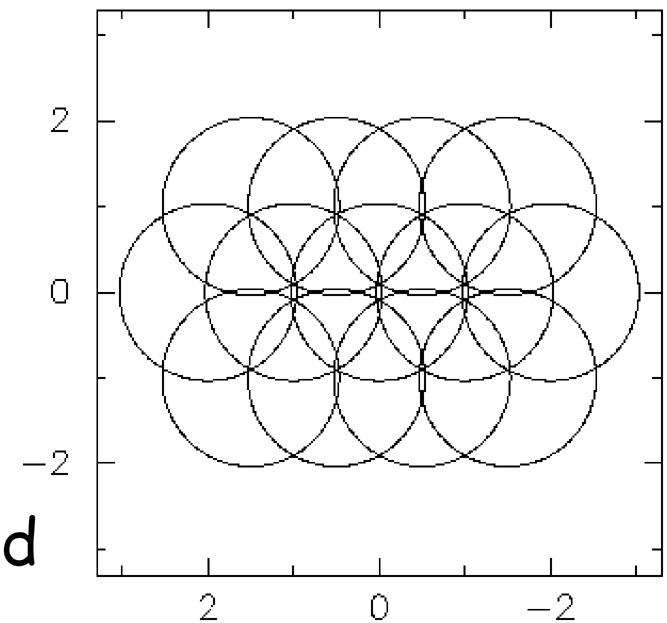




Mosaicing

- What if emission extends beyond the array's primary field of view? -> mosaic

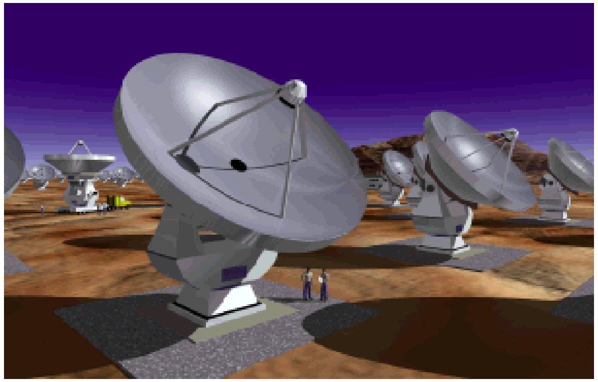




Fields need to be Nyquist spaced

Atacama Large Millimeter Array

- Need to bring (sub) millimeter interferometry at the same level as cutting edge facilities like HST and JWST: sensitivity and resolution
  - Large collecting area
  - Many baselines: imaging quality
  - Excellent site: access highest submm frequencies
- Europe + North-America + Japan, in cooperation with Chile



Existing Arrays & ALMA

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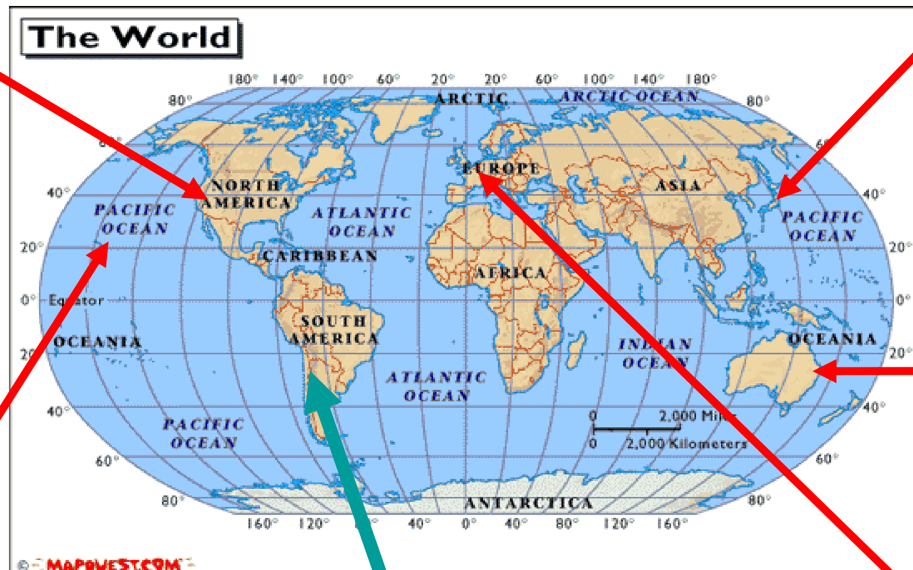

ATCA:
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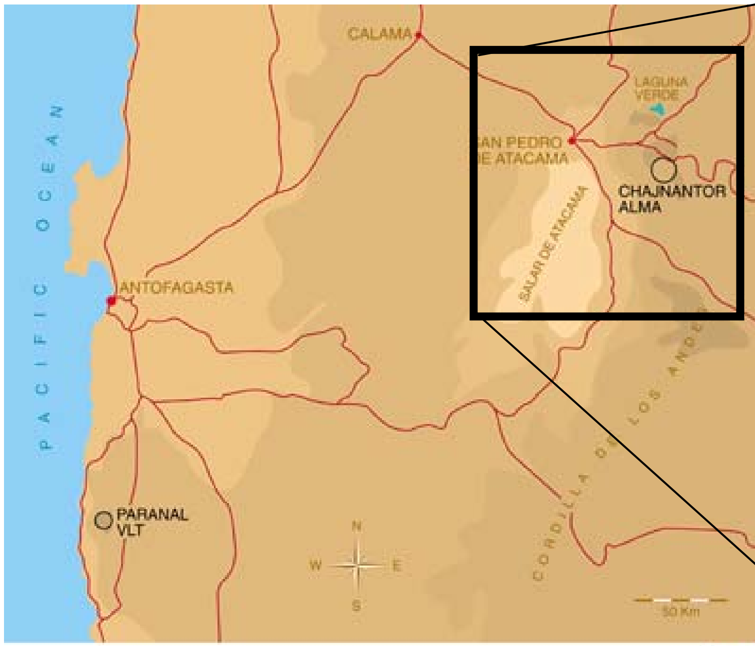
Compact
Array

SMA: Submillimeter Array, Hawaii

PdBI: Plateau de Bure, France

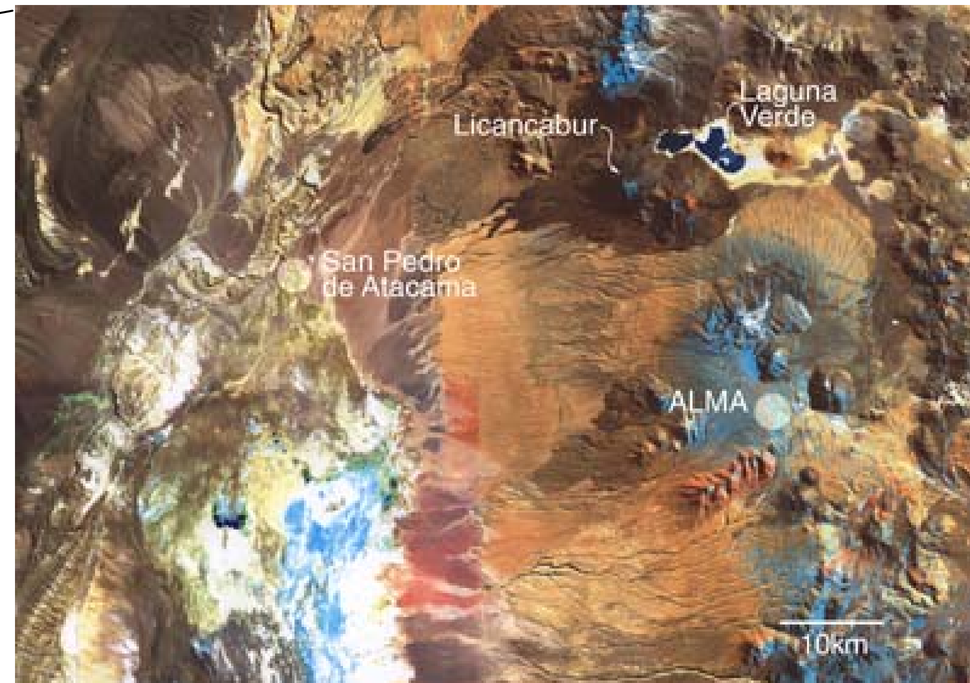
ALMA: Cajnantor, Chile

Chajnantor



Geographical Map with VLT and ALMA Locations

ESO PR Photo 24d/99 (8 June 1999)



Location of the Compact Configuration of ALMA

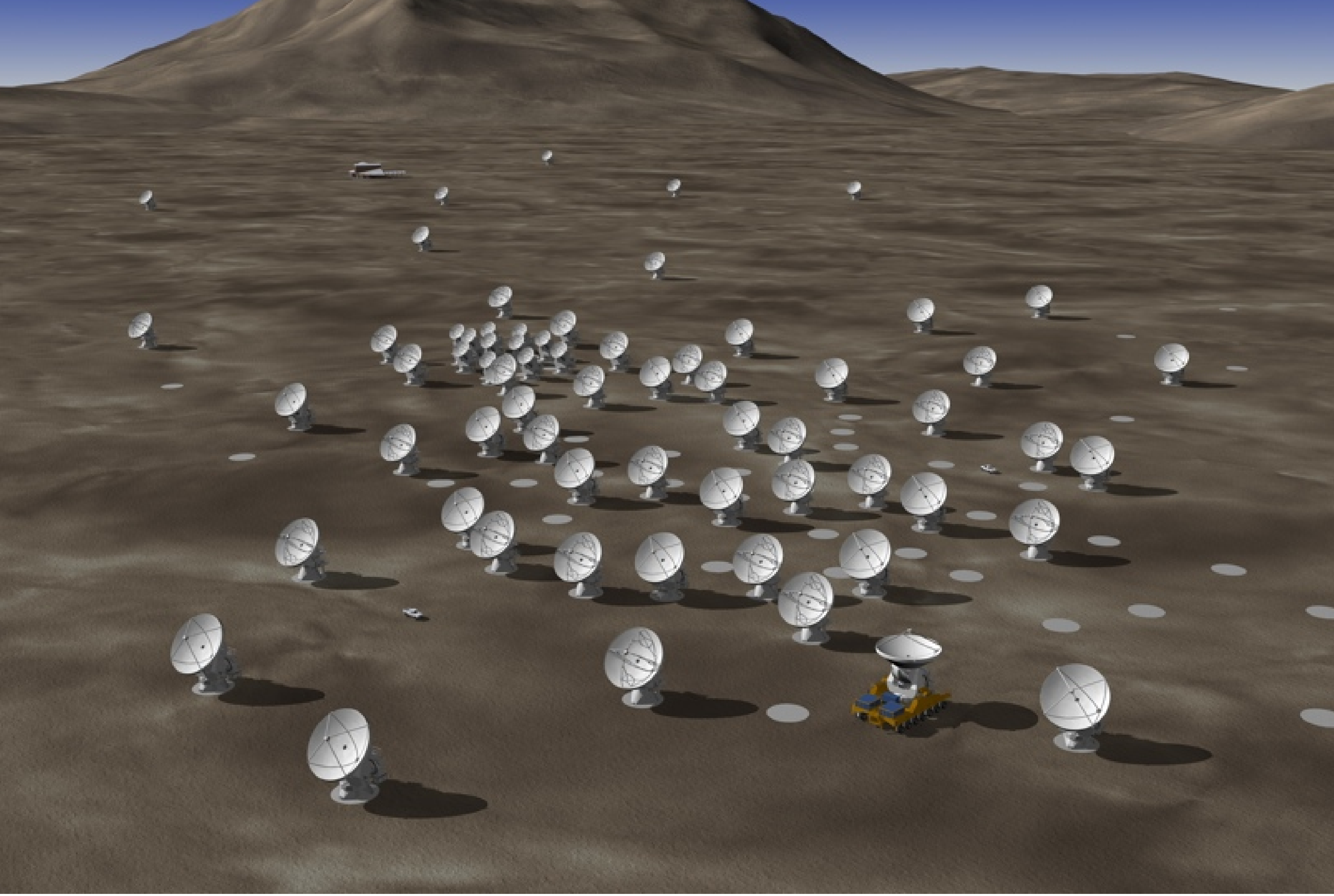
ESO PR Photo 24c/99 (8 June 1999)

ALMA: Science Drivers

1. The ability to detect spectral line emission from CO or CII in a normal galaxy like the Milky Way at a redshift of z = 3, in less than 24 hours of observation.
2. The ability to image the gas kinematics in protostars and in protoplanetary disks around young Sun-like stars at a distance of 150 pc (roughly the distance of the star-forming clouds in Ophiuchus or Corona Australis), enabling the study of their physical, chemical and magnetic field structures and to detect the tidal gaps created by planets undergoing formation in the disks.
3. The ability to provide precise images at an angular resolution of 0.1 arcsec. Here the term "precise image" means being able to represent, within the noise level, the sky brightness at all points where the brightness is greater than 0.1% of the peak image brightness.

ALMA: Specifications

- All atmospheric bands between 30 and 950 GHz
- 0.01 km/s resolution at 100 GHz: thermal line widths
- Spectral dynamic range 1:10,000; imaging dynamic range: 1:50,000
- Detect <1 mJy in 10 min under median atmospheric conditions: 8 GHz bandwidth x 2 polarizations
- 50 antennas of 12m diameter
- 0.01" scales high fidelity imaging
- Baselines 150 m – 18.5 km
- Total power: 4 ants have nutating subreflectors
  - Additional array with 7m antennas for intermediate scales
- Phase correction better than 1 rad at 950 GHz, amplitudes better than 3% at 300 GHz and 5% at higher freqs
- Full polarization capability (<0.1% polarized intensity, <6 deg PA)
- Can look at Sun at all freqs
- Software for proposal and observations preparation
- Software for pipeline calibration and reduction



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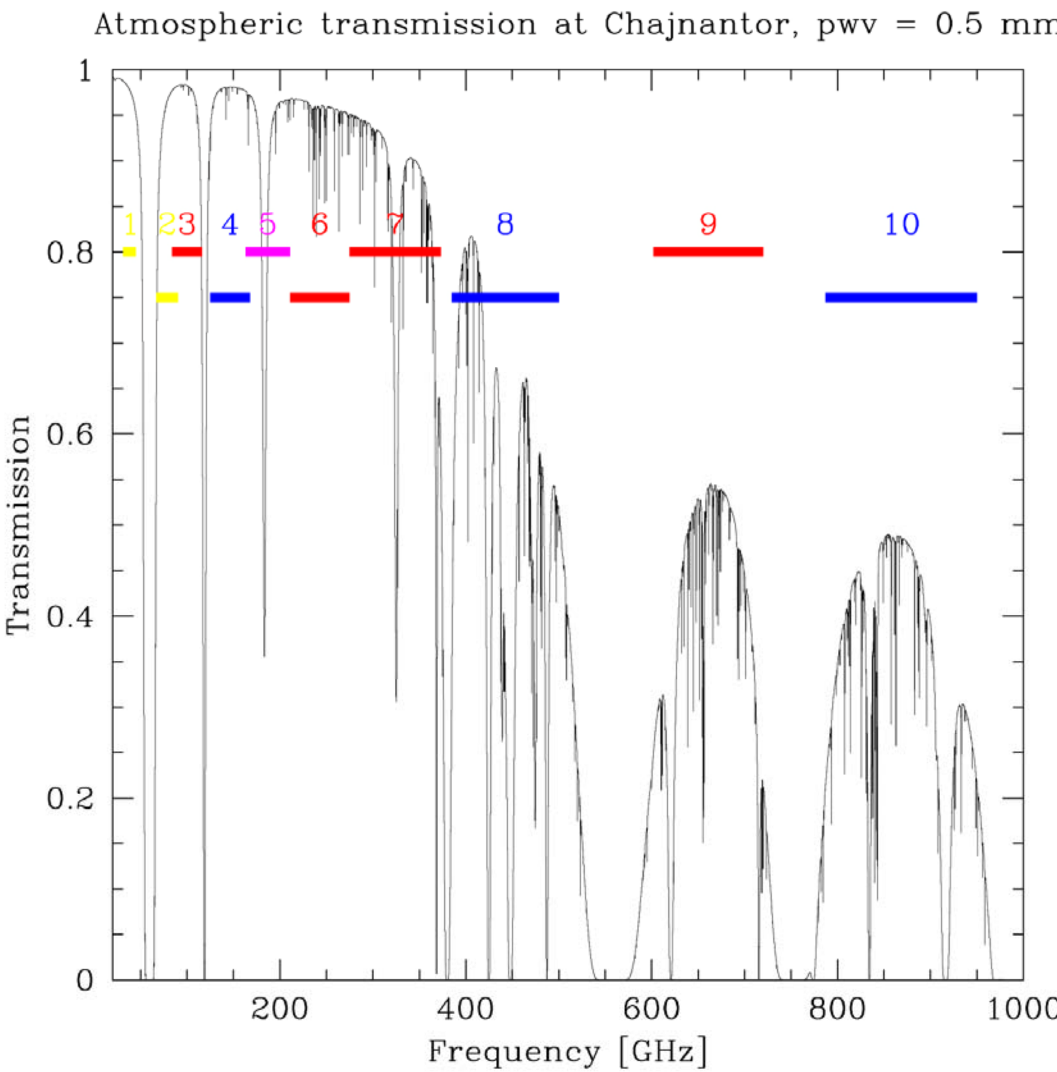
ALMA bands

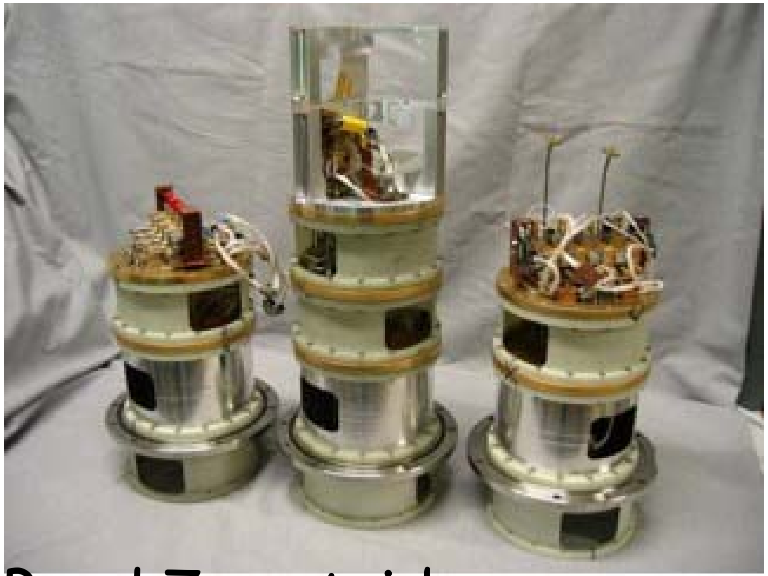


Construction:
3,4,(5),6,7,8,9,(10)

)07

Front ends

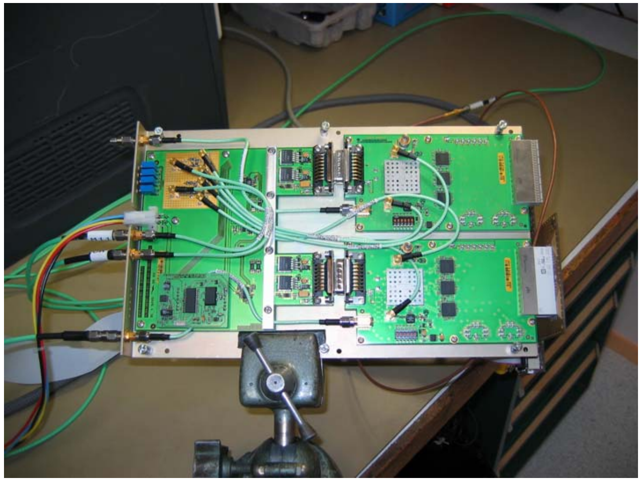
Band 9 cartridge

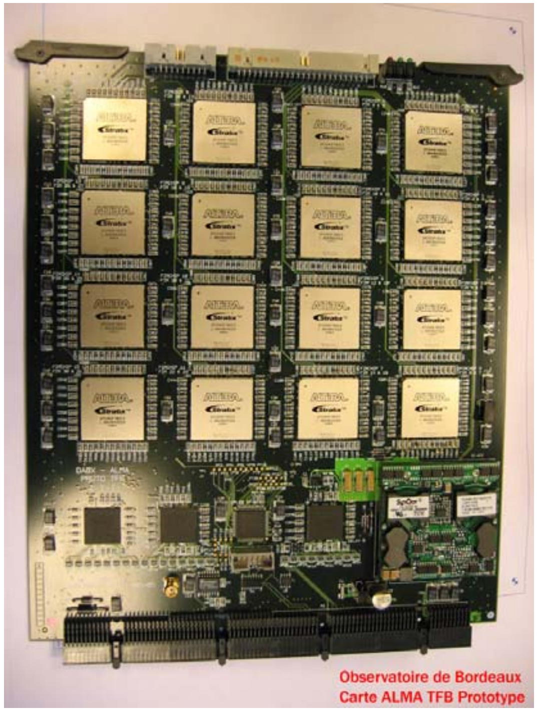


Band 7 cartridge

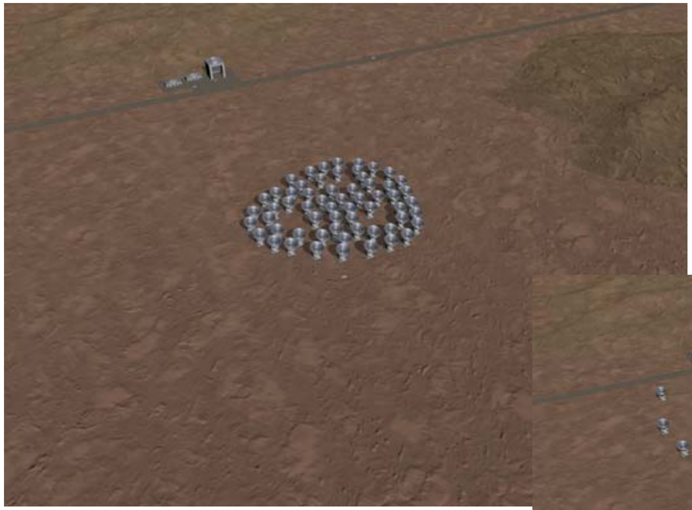
Cryostat

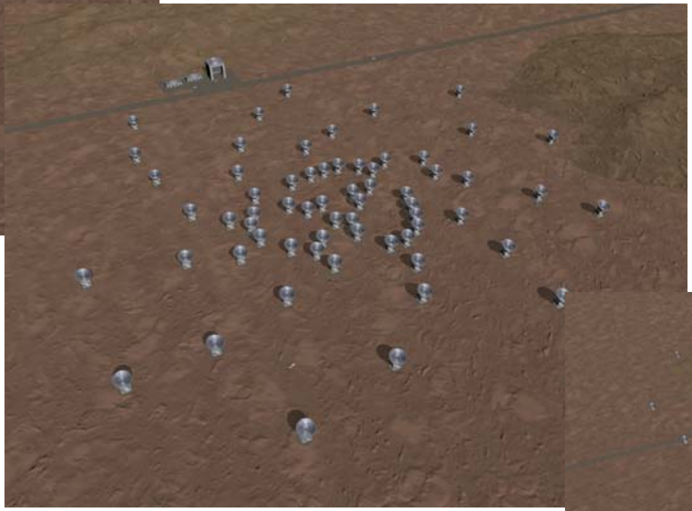
...and backends

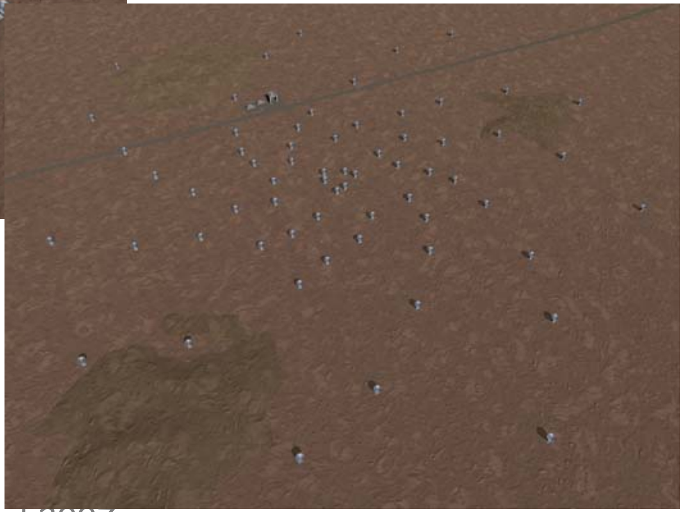




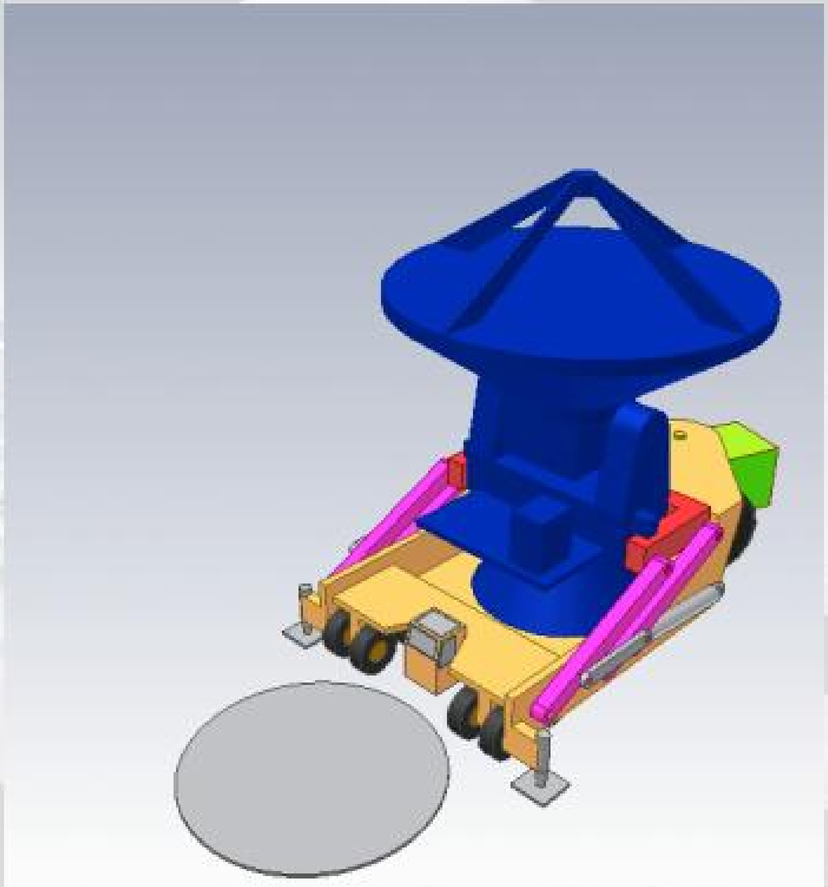
ALMA: Configurations

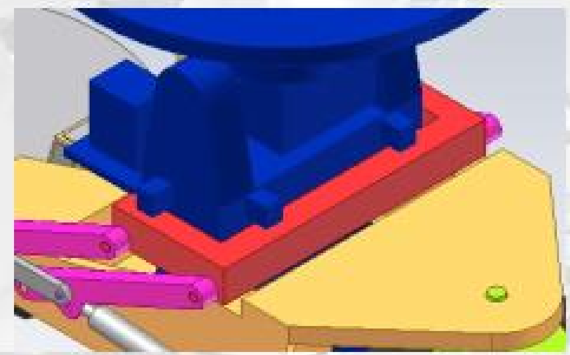


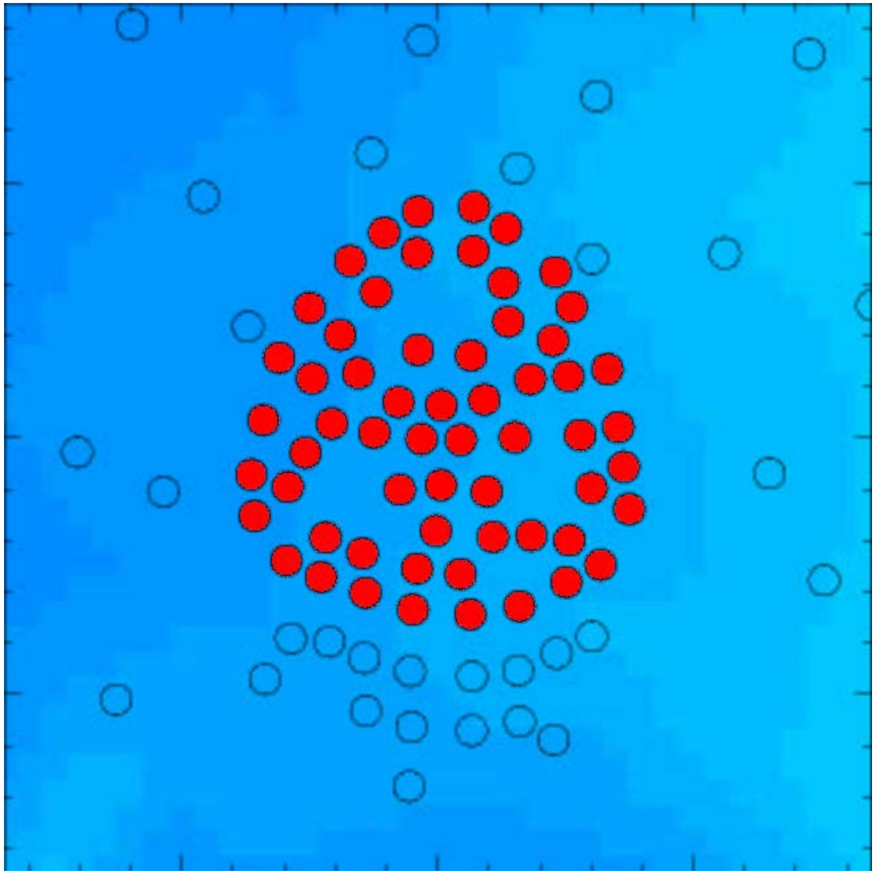


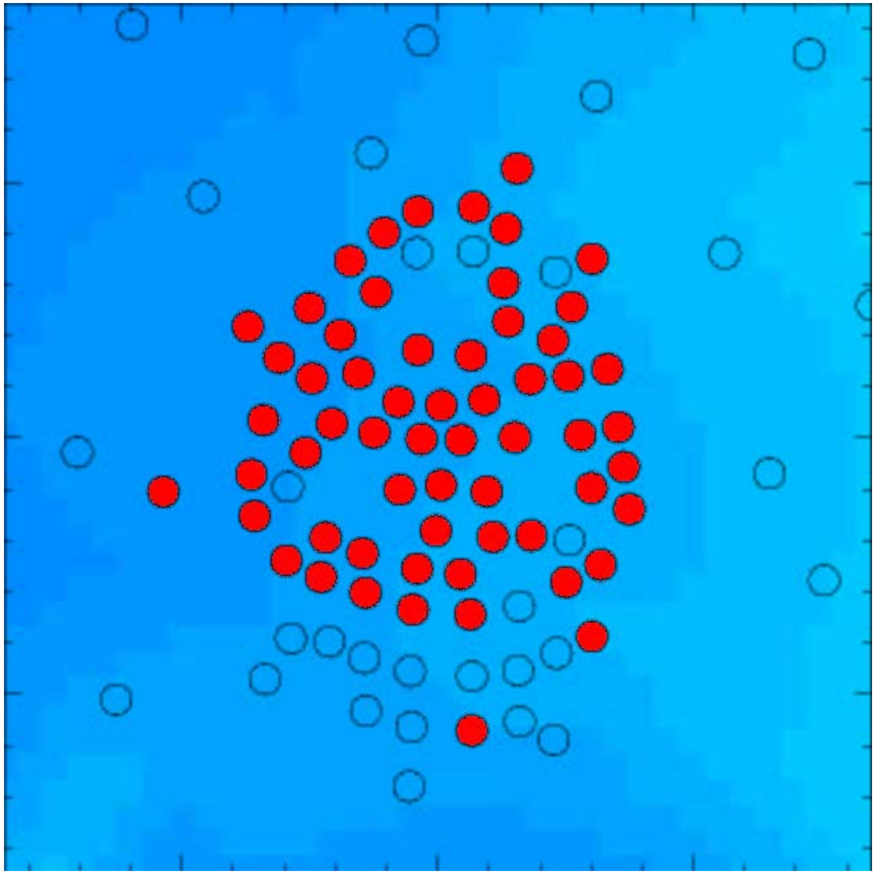


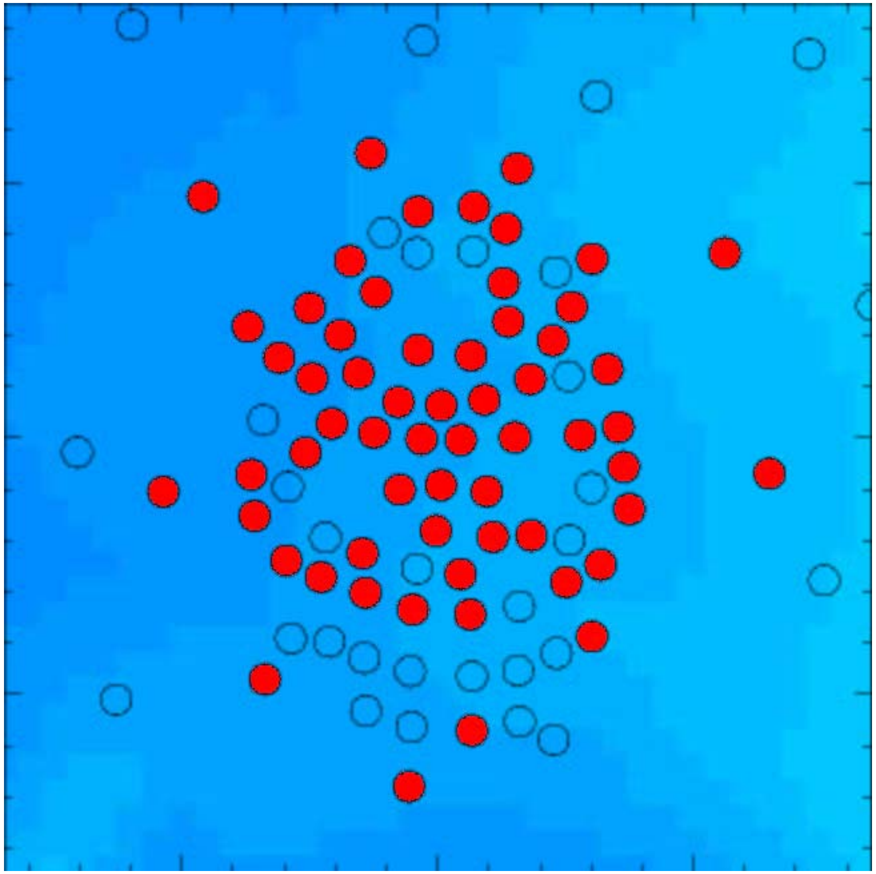
Current Transporter Concepts

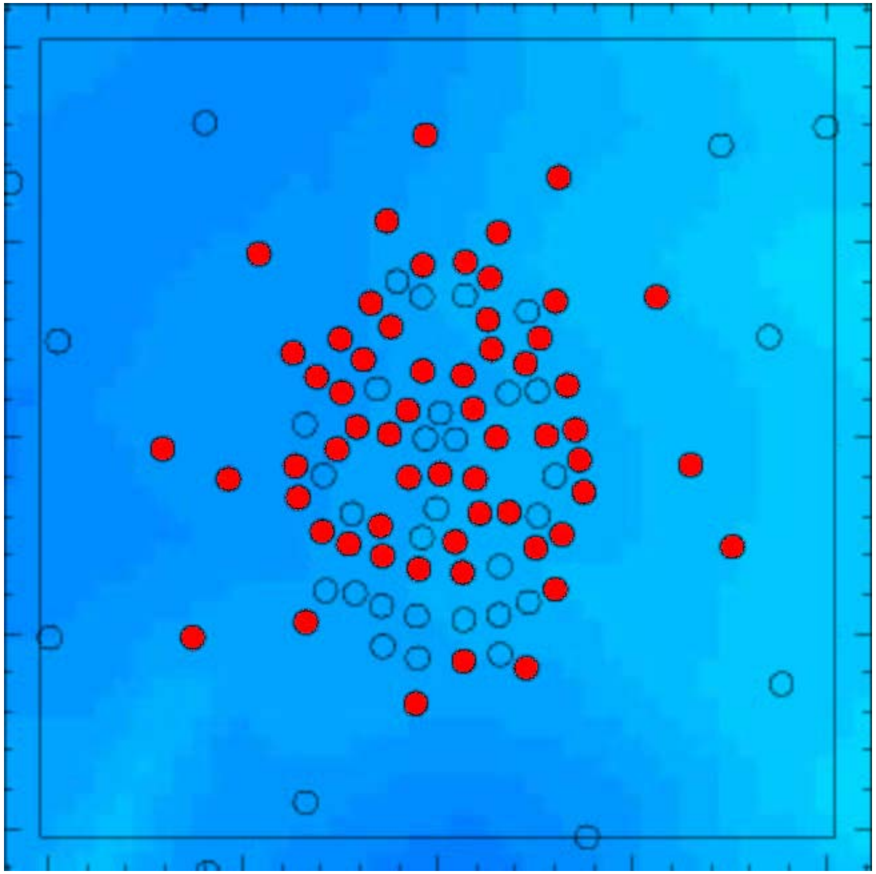


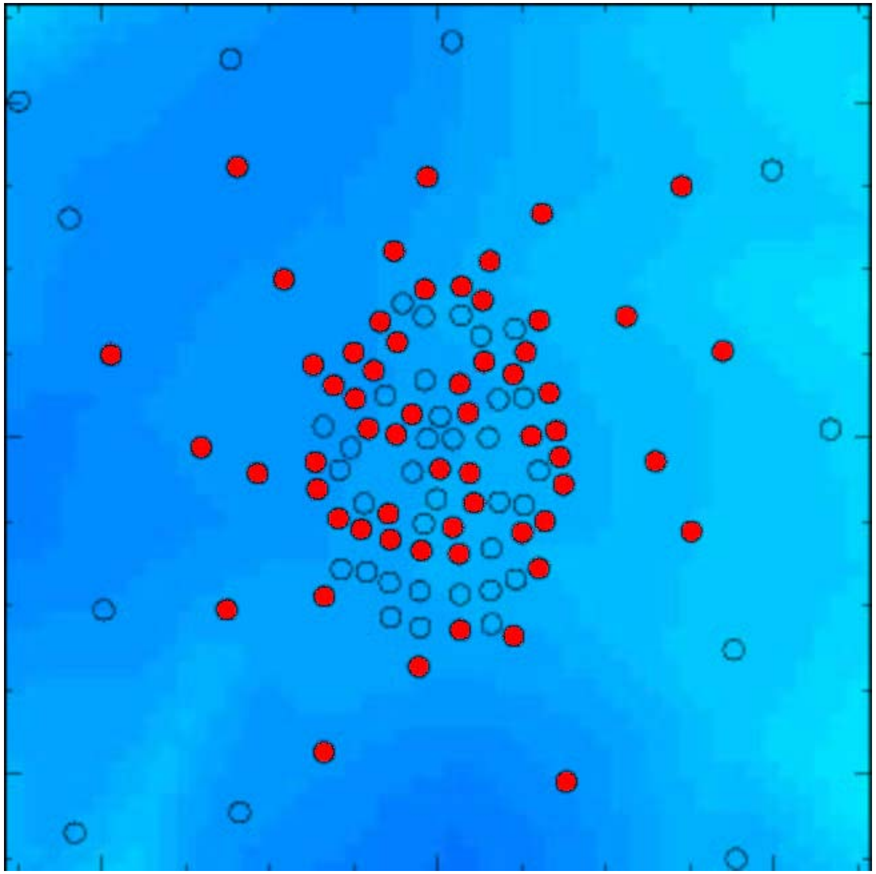


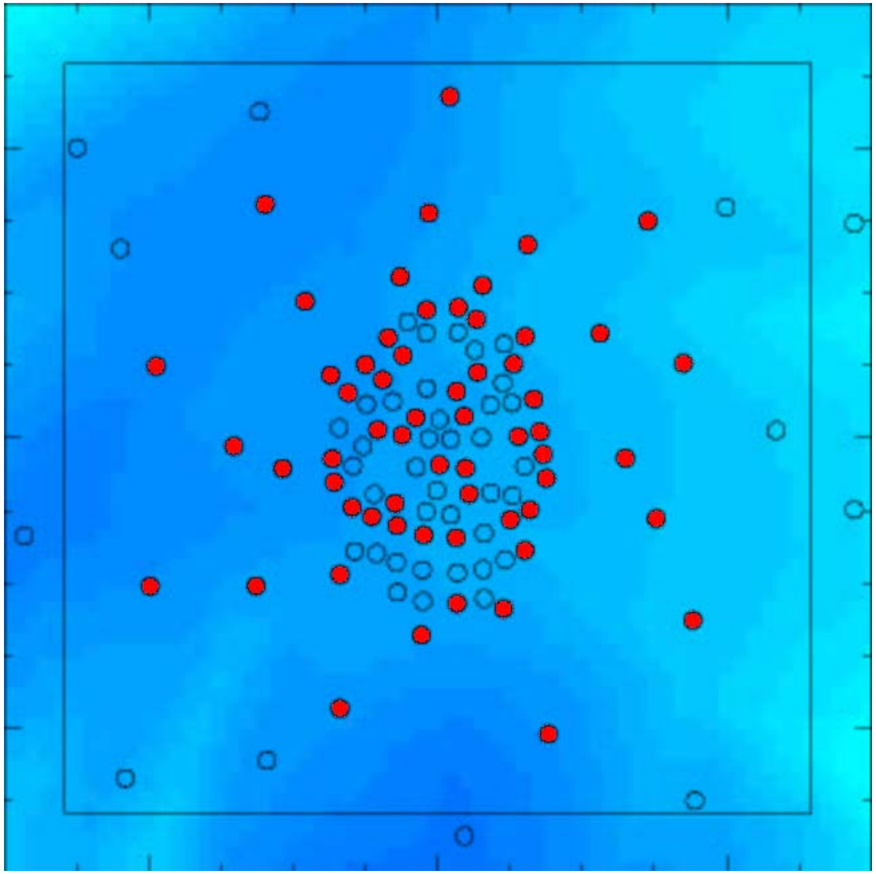


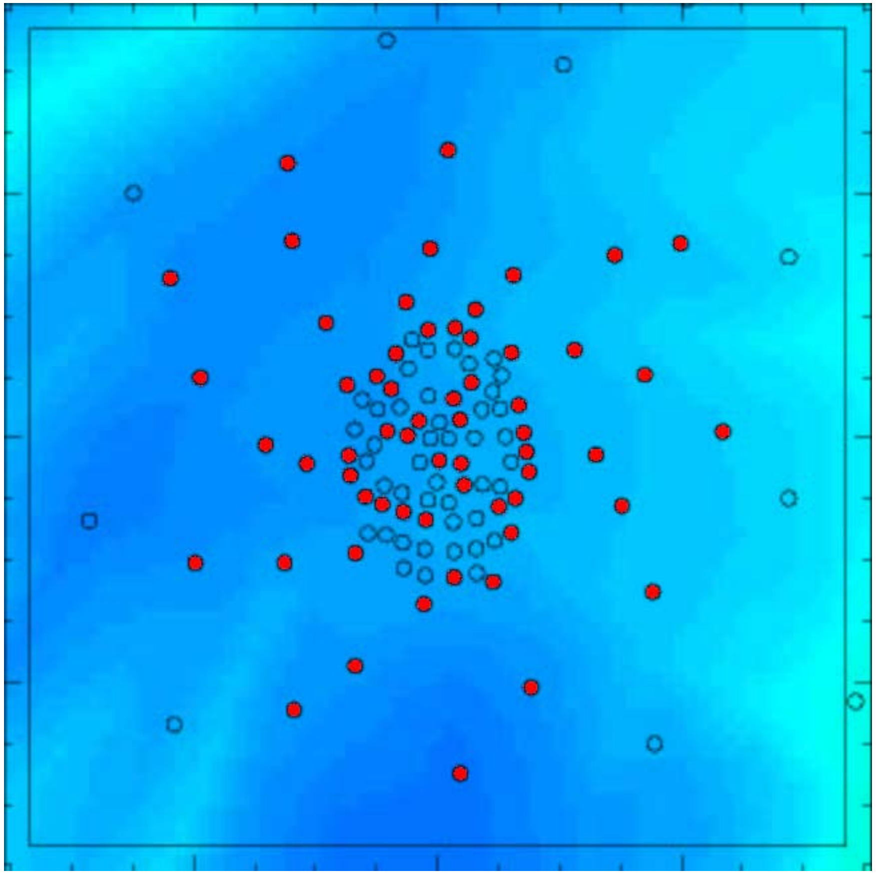


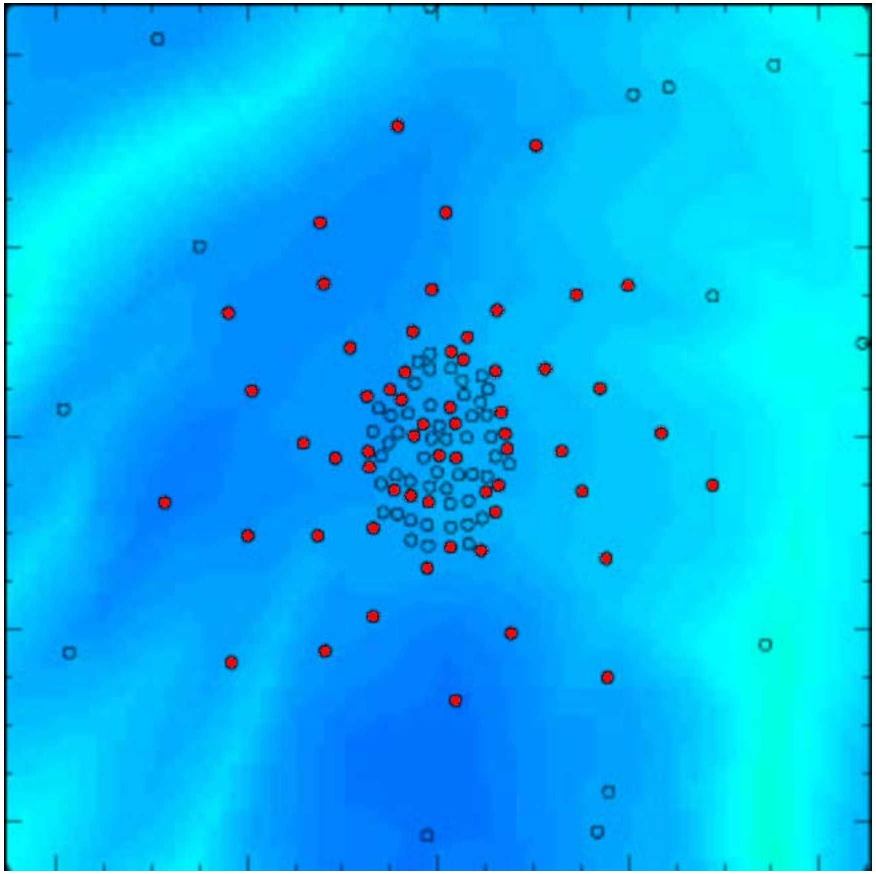


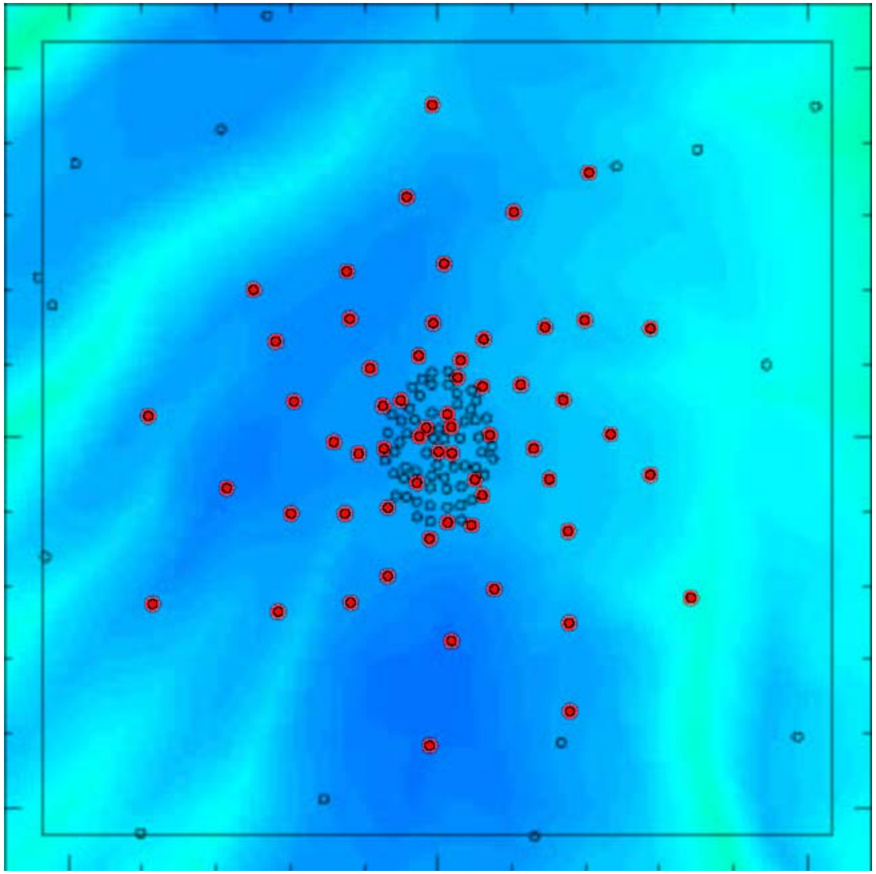


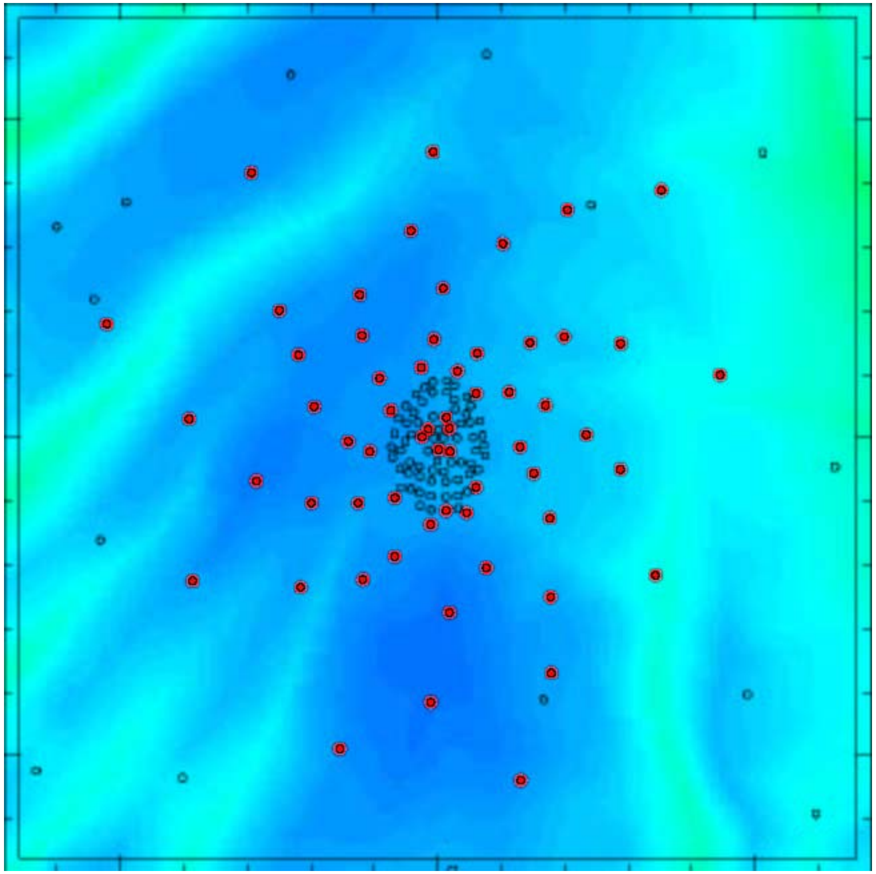


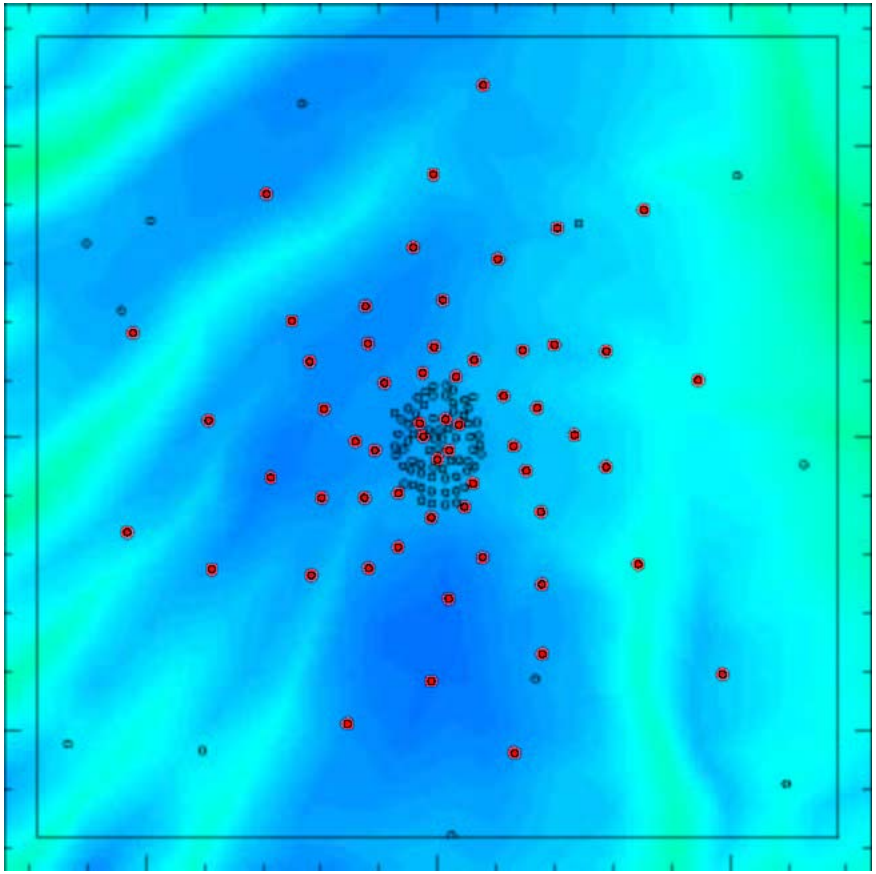


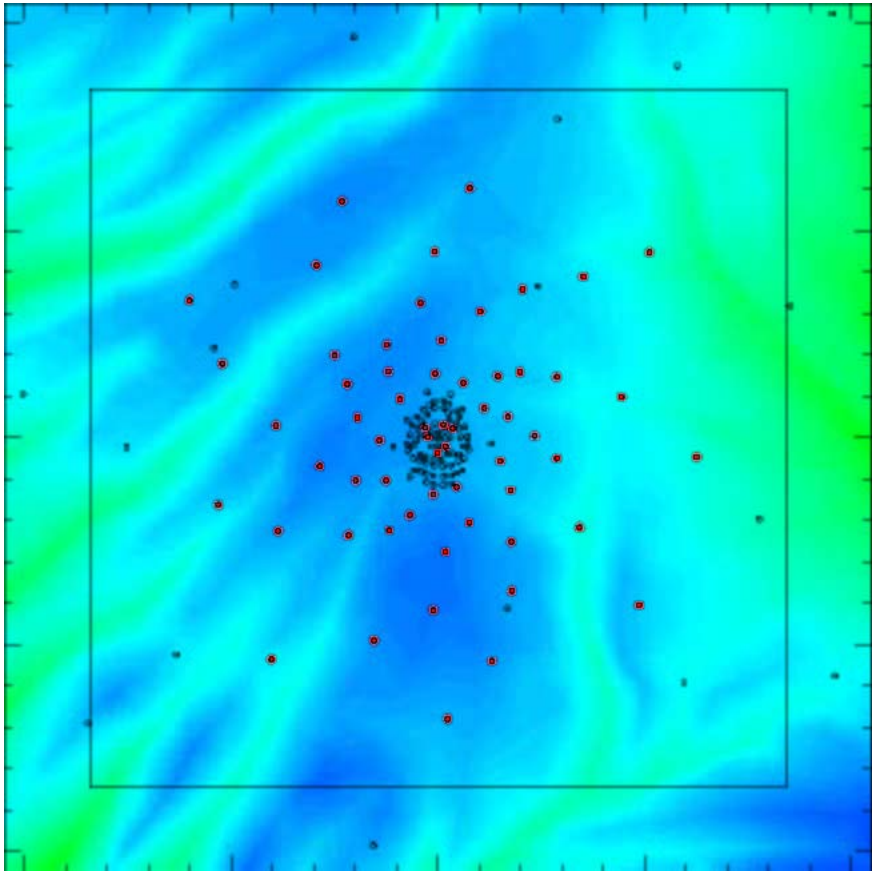


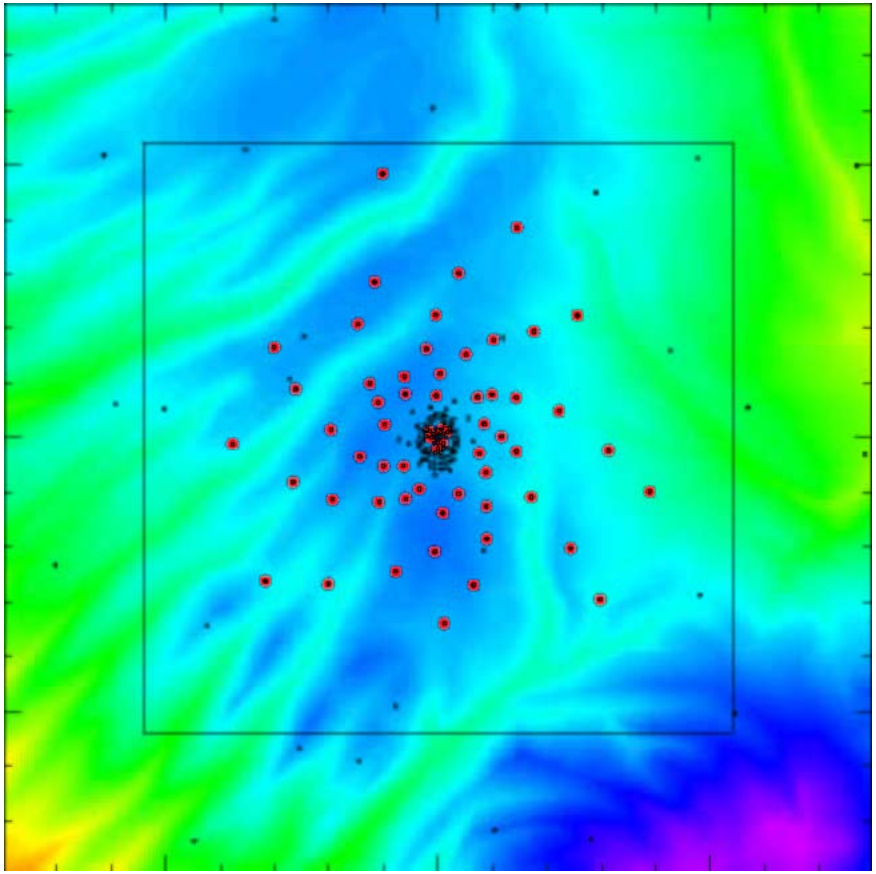


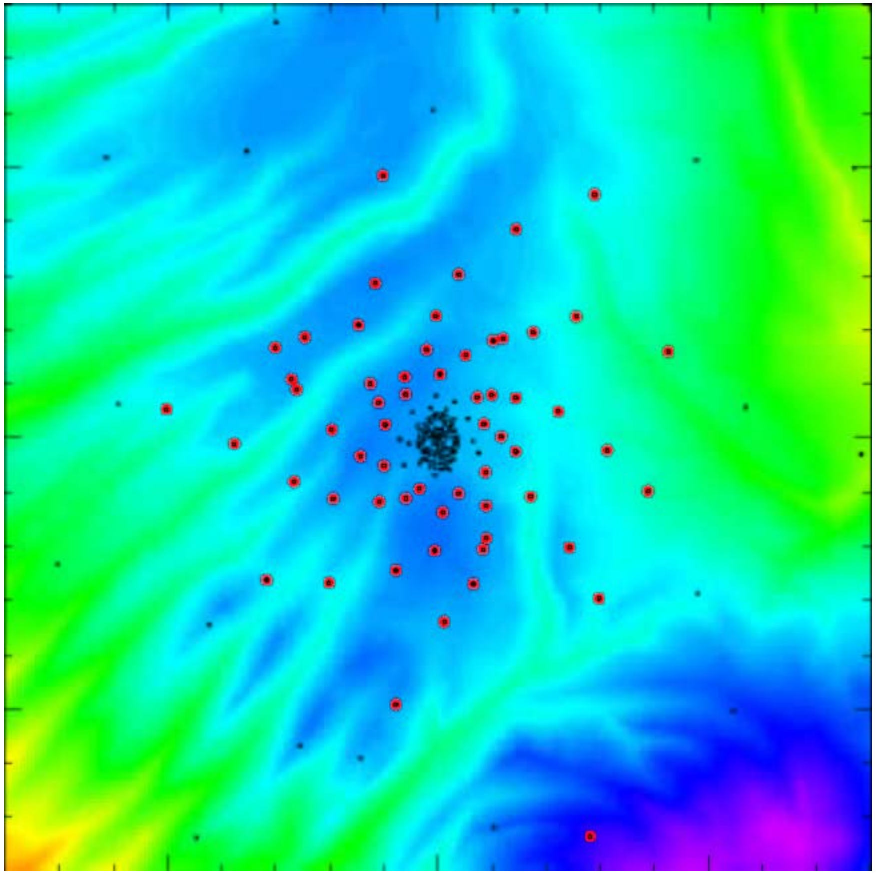


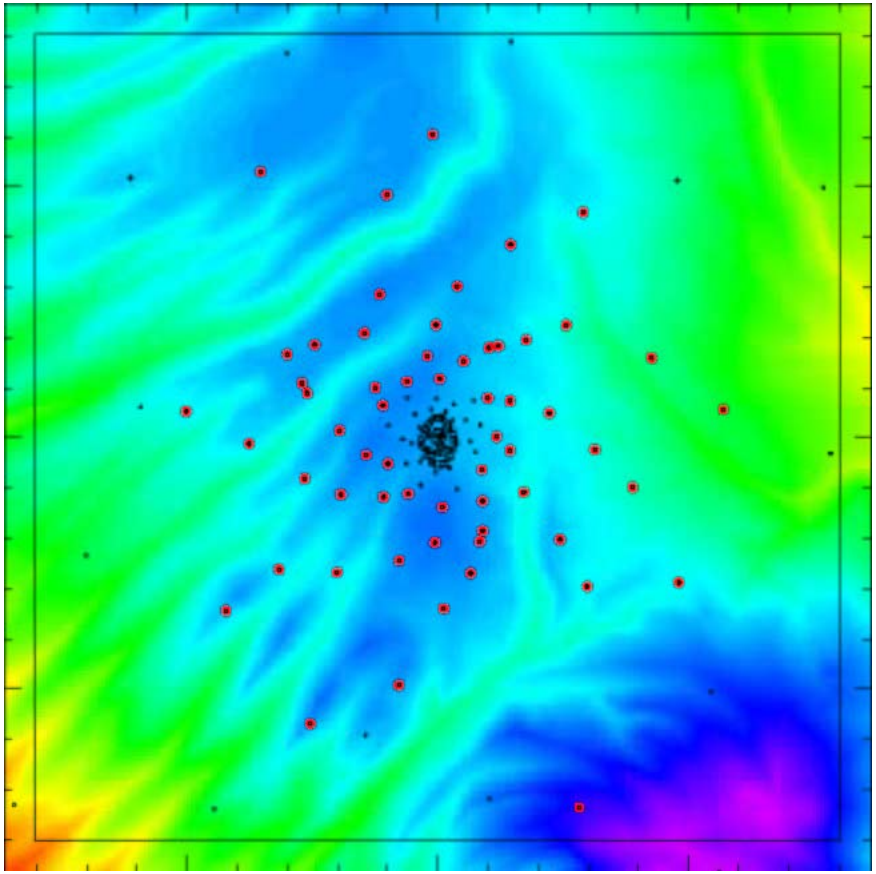


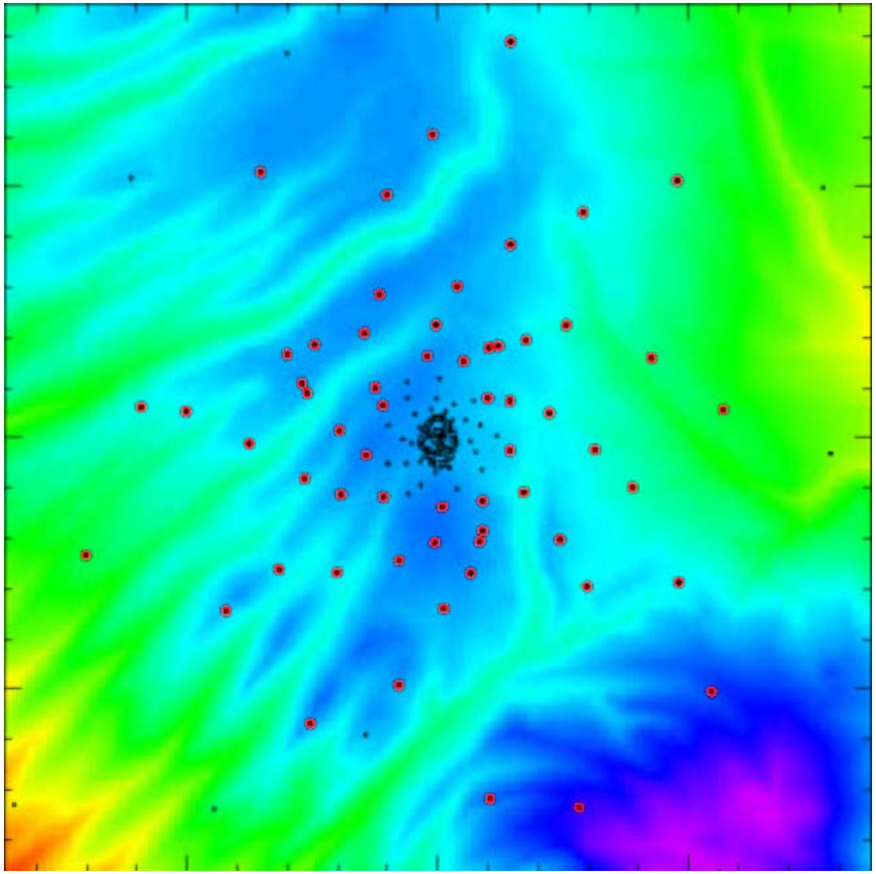


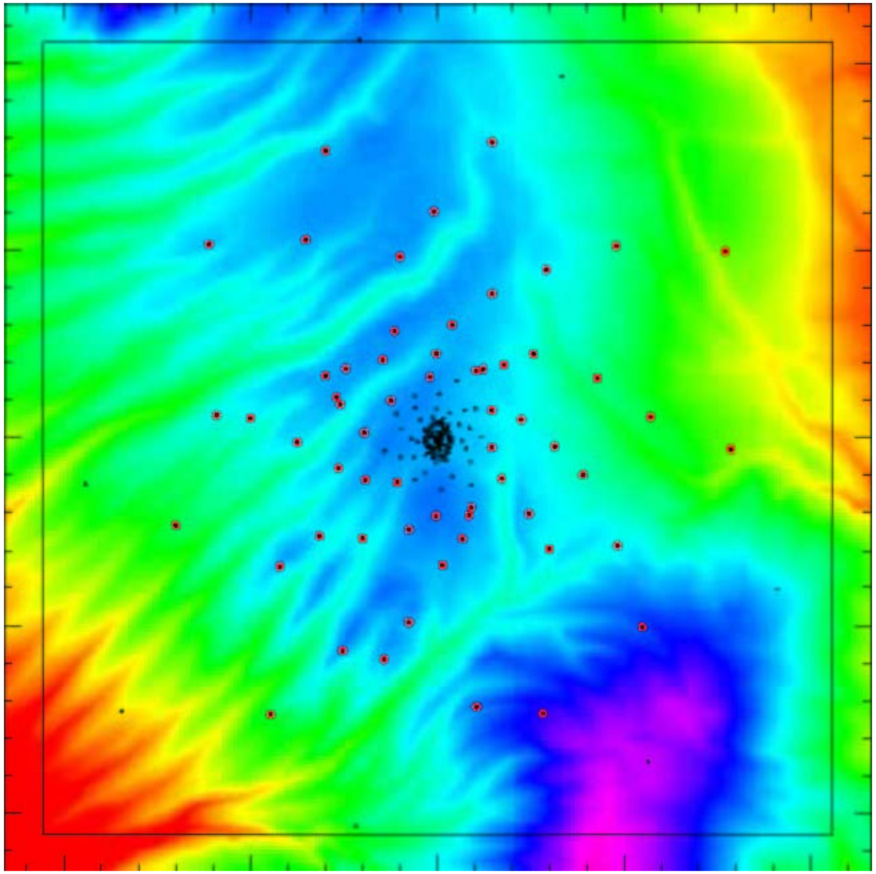


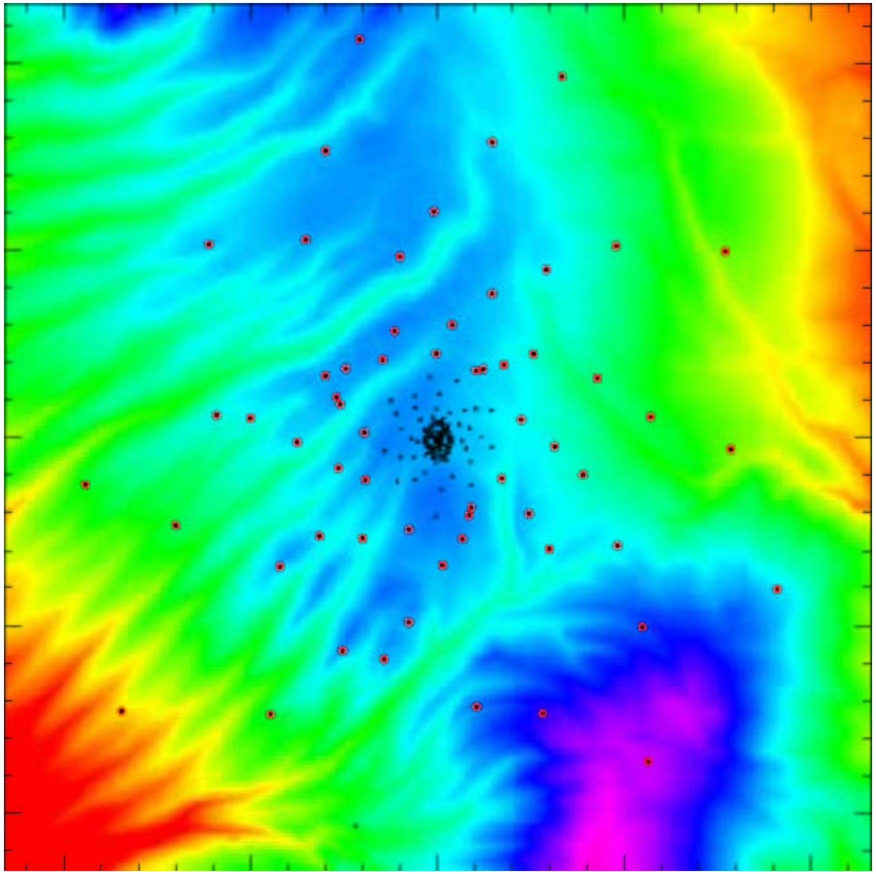


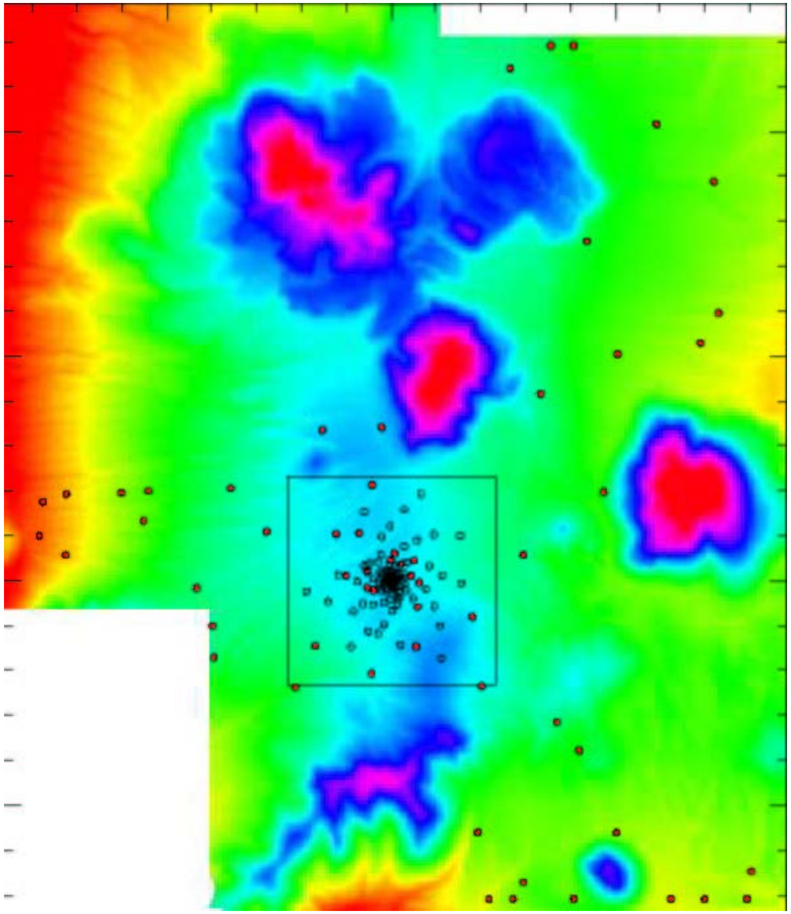










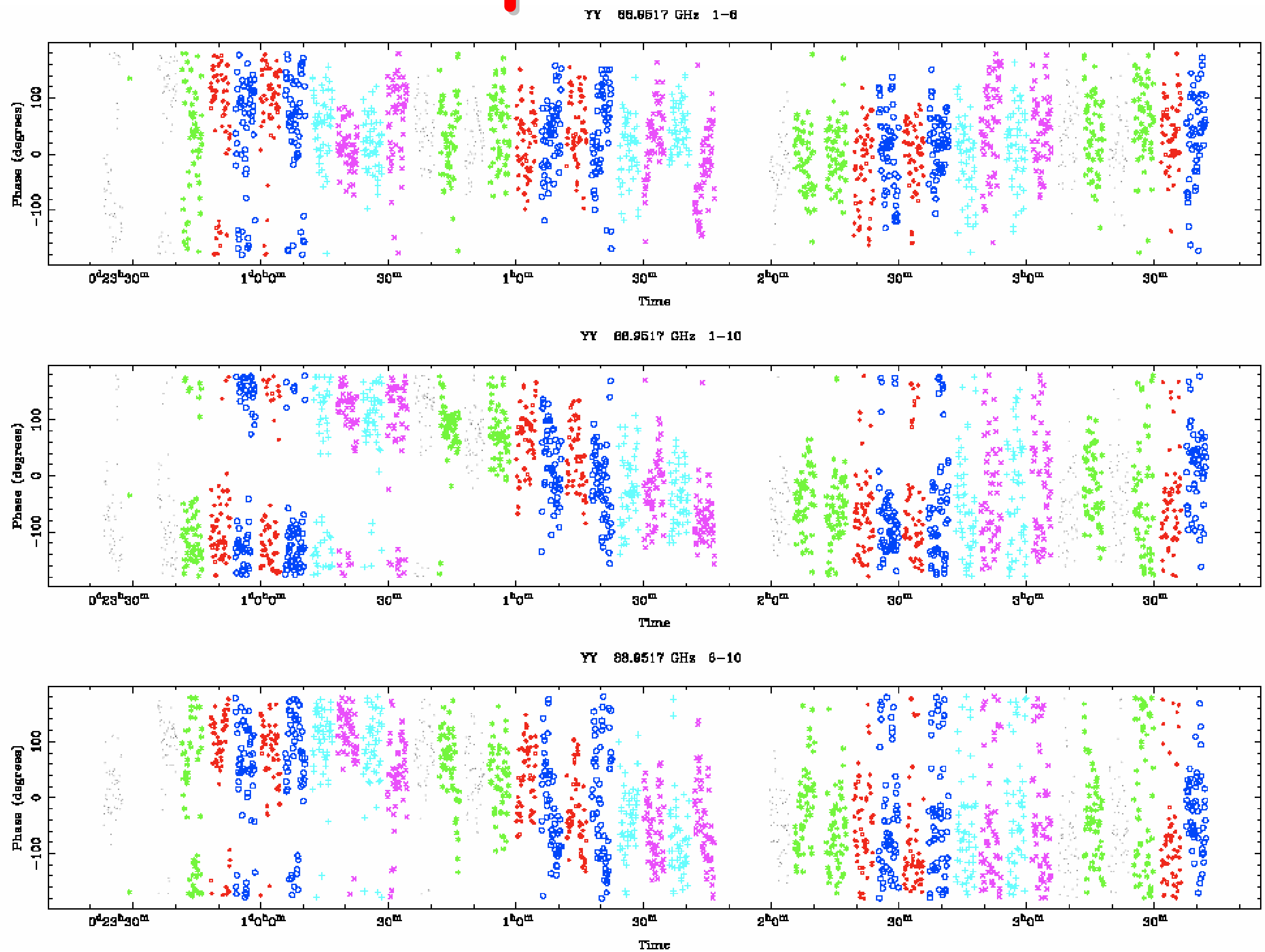


ALMA: Calibration

- Calibration strategy under development
- Hot & cold loads
- Suitable astrophysical calibrators
- Phase calibration may/will require continuous monitoring of the phases
  - Track water vapor at 22 GHz or 183 GHz
  - Derive path length variations -> phase correction
  - Developed for BIMA, OVRO, SMA
  - Still experimental, but essential for operations at higher frequencies

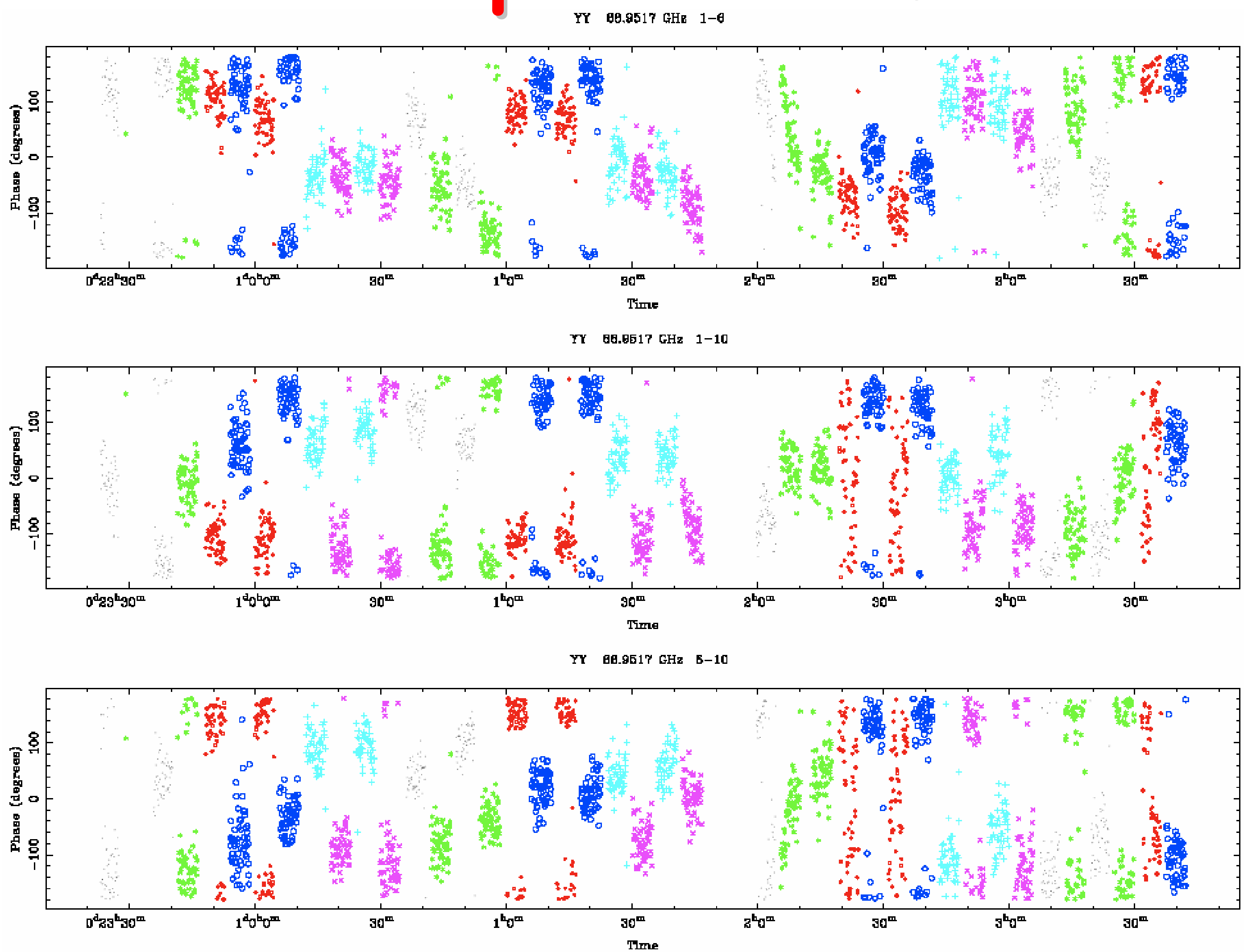
Water Vapor Radiometers

Source: BIMA Memo 78 by Mel Wright



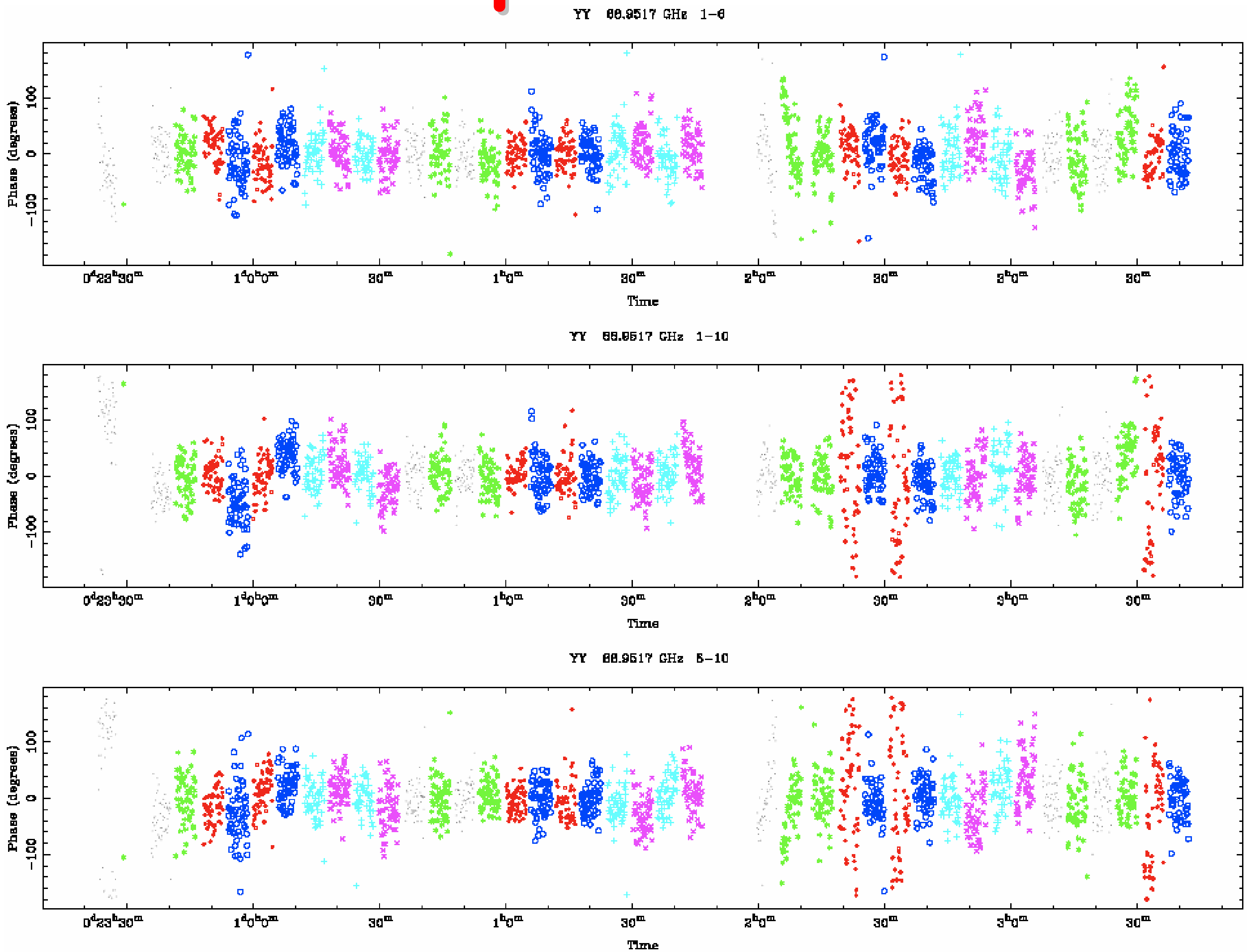
Observed phases of calibrators

Water Vapor Radiometers



After WVR phase corrections have been applied

Water Vapor Radiometers



+ apply selfcal to correct intermittent offsets

From proposal to observations

user

Phase I proposal

NRAO

NAOJ

Science case
Source(s)
Lines/freqs
Sensitivity
Resolution

TAC

Phase II proposal

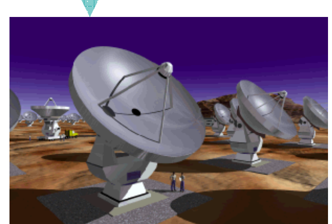
JAO-Santiago

Integration times
Configurations
Total power?
-> script

OSF-San Pedro

AOS-Chajnantor

Minimally schedulable blocks
Weather conditions



From observations to images

user

Science quality image + raw visibilities

European ALMA Regional Center
Archive copy

NAASC
Archive copy

NAOJ
Archive copy

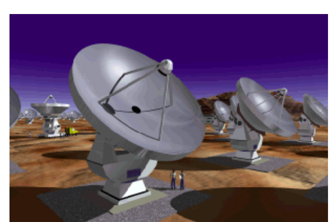
JAO-Santiago

Archive

OSF-San Pedro
Data quality control

Pipeline calibration
& reduction

AOS-Chajnantor



Time line

- 2005 antenna contracts signed
- 2007 first antennas arrive in Chile
- 2008 assembly, integration, verification
- 2009 AIV, commissioning, science verification
- 2010 commissioning and early science (~16 ants)
- 2011 early science and commissioning
- 2012 fully operational

Concluding Remarks

- Interferometry at (sub) millimeter wavelengths has progressed
  - ~3 element arrays operating at 3 mm
  - 6-10 element arrays operating at 3 and 1 mm
  - Submillimeter arrays of 10-15 elements

- *ALMA*: quantum leap to 50 element array that will make submillimeter interferometry a standard tools for all astronomers.