ALMA :
results and Cycle 4 capabilities

Rosita Paladino

Italian ALMA Regional Center
INAF-Osservatorio di Radioastronomia (Bologna)

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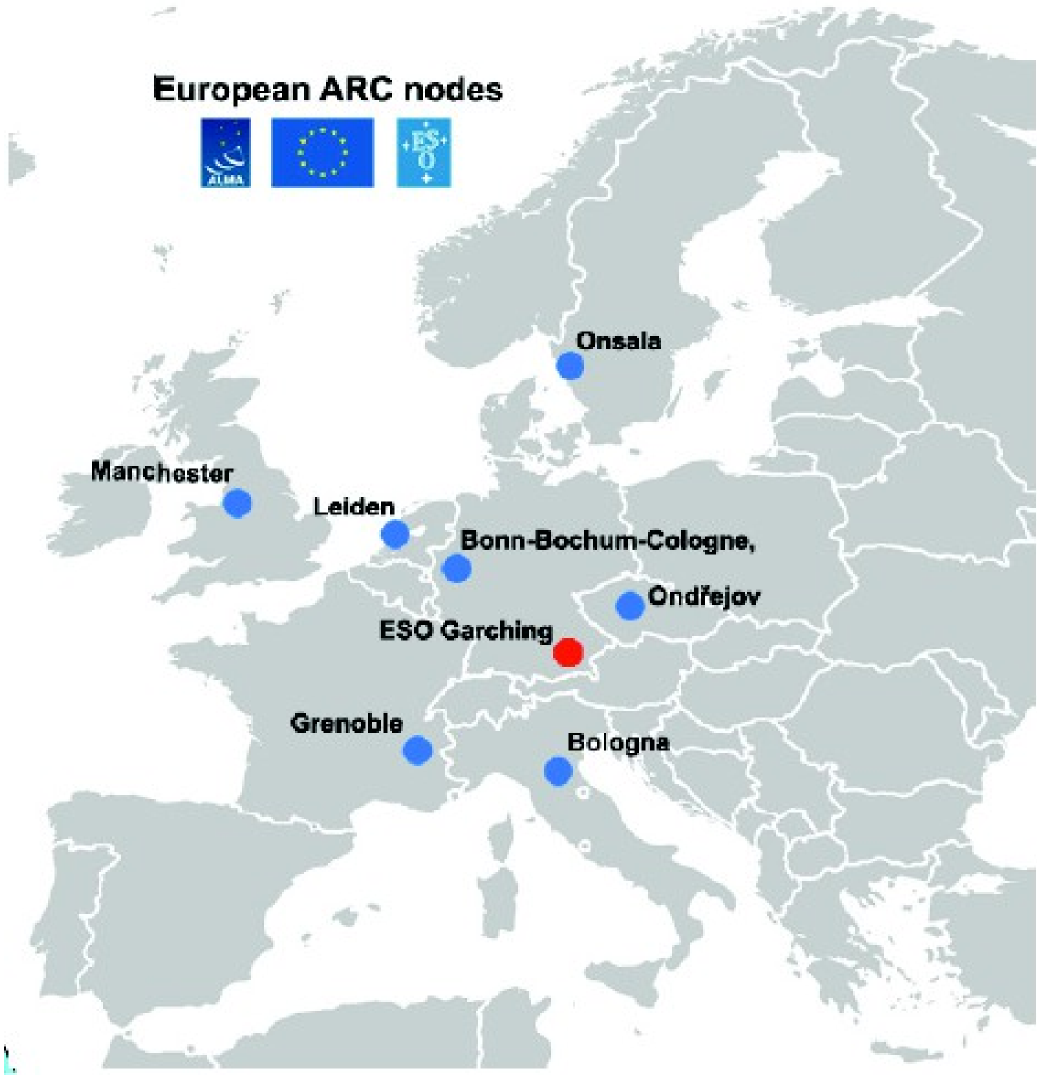
Italian ALMA Regional Center

http://www.alma.inaf.it/

People:

J. Brand
E. Liuzzo
N. Marcelino
M. Massardi
A. Mignano
R. Paladino
K. Rygl



Outline

Basics of Interferometry

ALMA science results:
a very small selection from
http://almaobservatory.org/en/press-room/press-releases

Cycle 4 capabilities

Proposal preparation
- Tools
- Fundamental observational parameters
- Simulation

ALMA archive

Basics of Interferometry

Telescope resolution ~ λ/D
IRAM 30m ~11” @ 1mm

To get higher resolution at mm wavelenghts
--> very large telescopes with very high surface accuracy

Technically difficult!

Aperture Synthesis Technique

• Replacing a single large telescope by a collection of small telescopes “filling” the large one

• Signal received by telescopes are combined by pairs

• Each antenna pair (**baseline**) measures a Fourier component of the source brightness distribution (**visibility**)

• Given sufficient number of measurements the source brightness distribution can be obtained by Fourier inversion

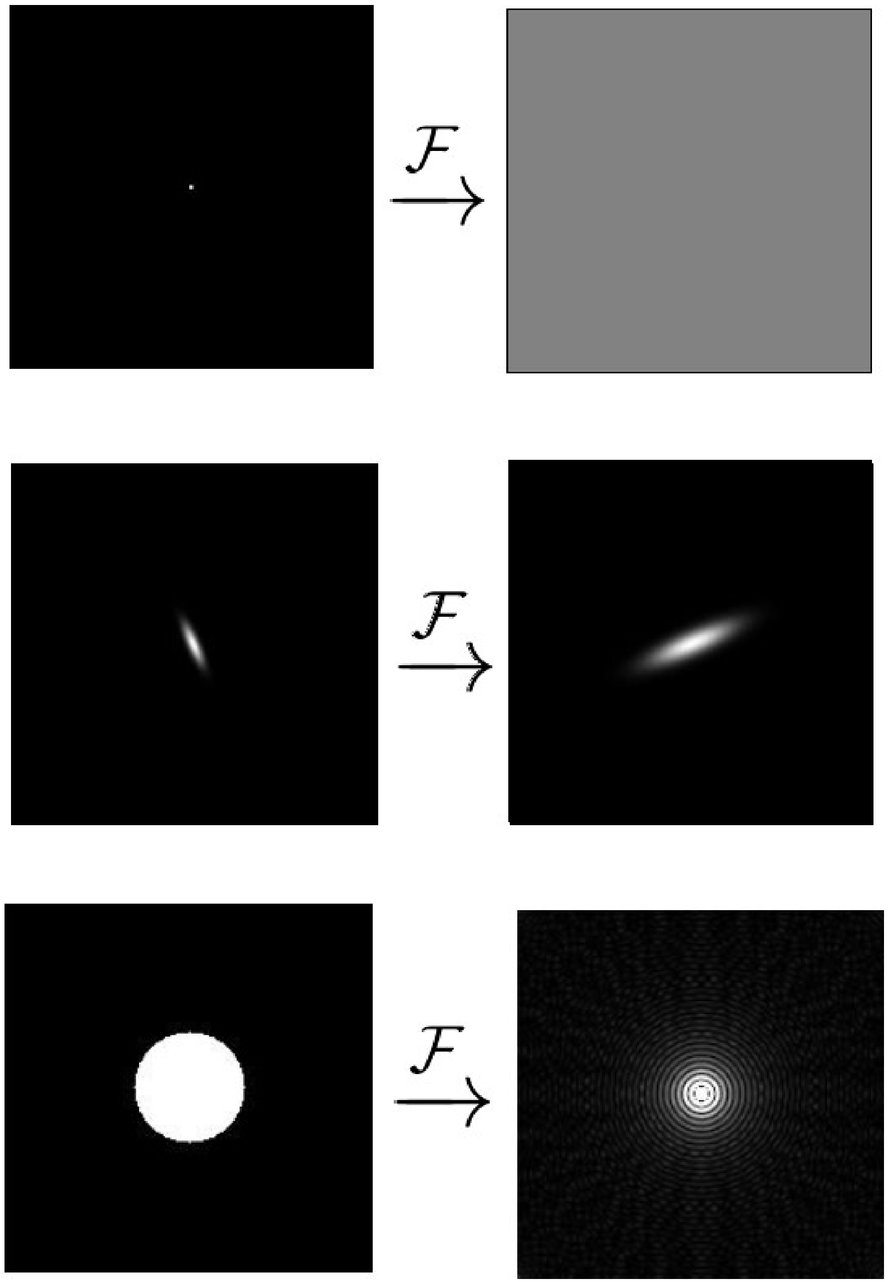
2-D Fourier Transform

$T(l,m)$ $\quad$ $V(u,v)$ *amplitude*

δ function $\xrightarrow{\mathcal{F}}$ constant

elliptical Gaussian $\xrightarrow{\mathcal{F}}$ elliptical Gaussian

uniform disk $\xrightarrow{\mathcal{F}}$ Bessel function



Narrow features

$\downarrow \mathcal{F}$

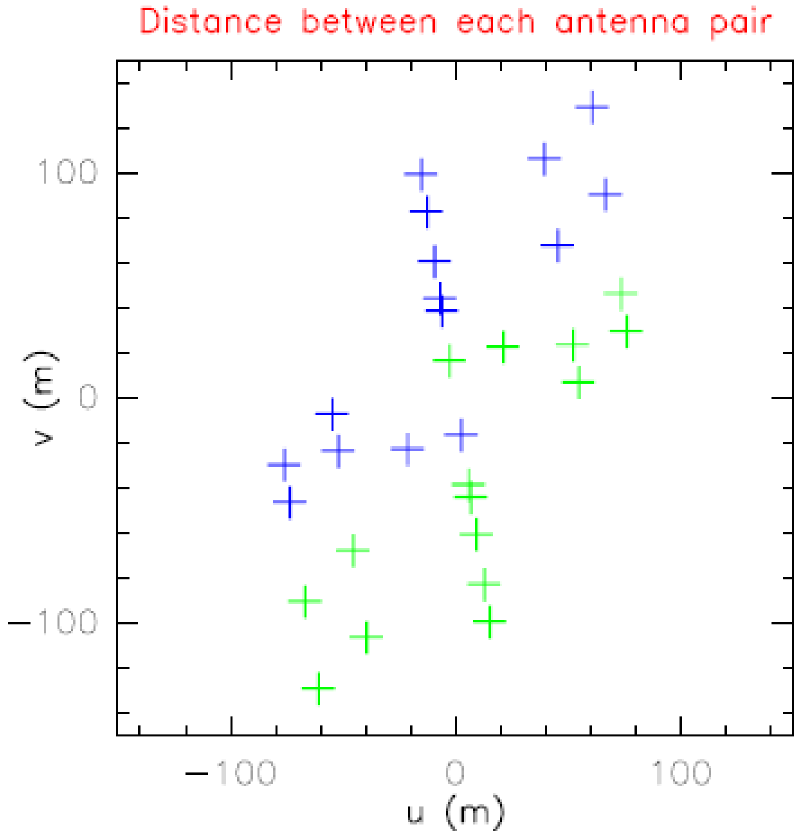
Wide features

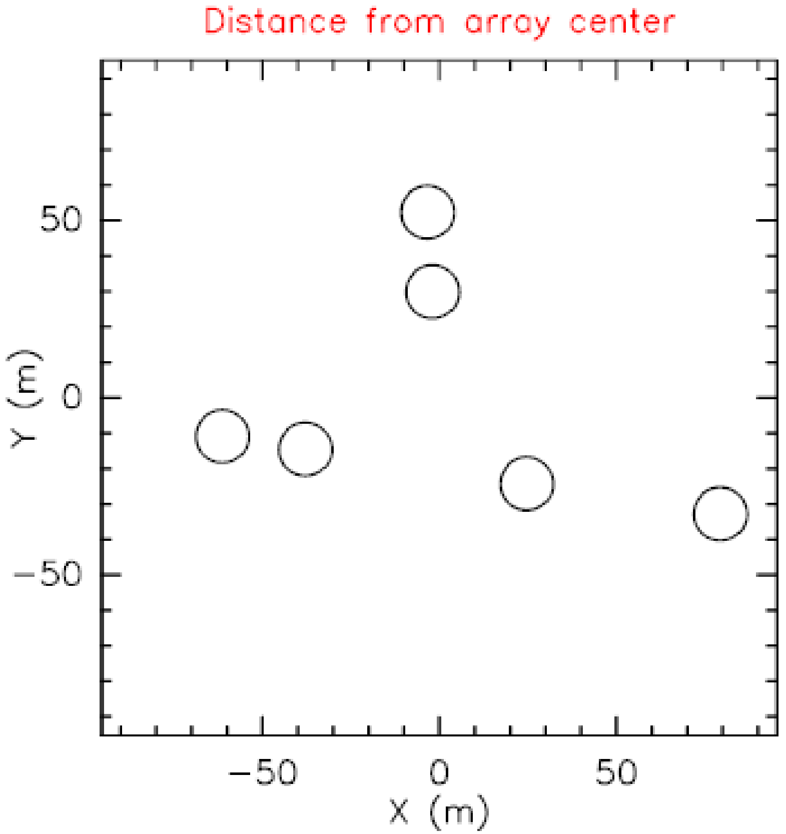
Sharp edges

$\downarrow \mathcal{F}$

High spatial frequencies

uv plane: Fourier transform space.
Each point on this space is related to the distance between each pair of antennas.





J. Pety lecture at 7th IRAM interferometry school 2010

But we actually sample the Fourier domain at discrete points

$$\mathbf{V_{meas}(u,v)=S(u,v\ )V_{ideal}}(\boldsymbol{u,v})$$

where S(u,v) is the sampling function
S= 1 at points where visibilities are measured
and   S = 0 elsewhere

Applying the convolution theorem:

$$\mathbf{FT(V_{meas})=FT(S)*FT(V_{ideal})}$$

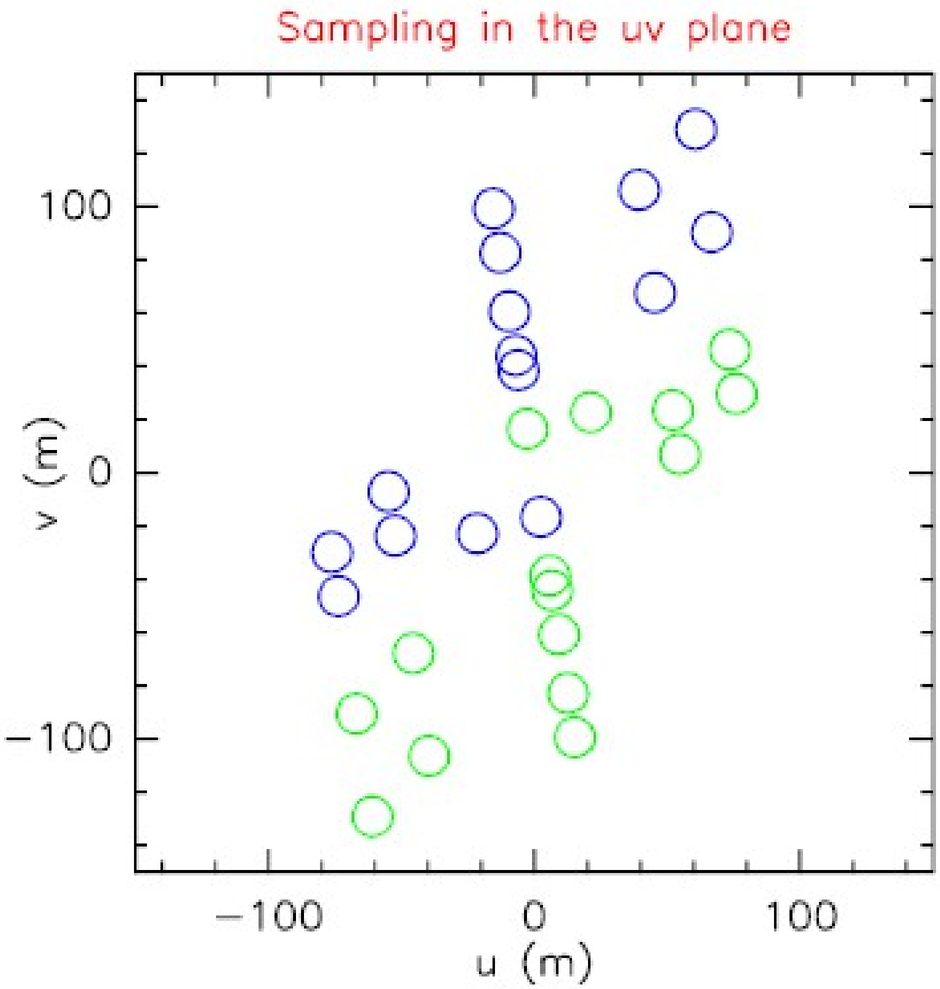
The Fourier transform of the sampled visibilities gives the true sky brightness convolved with the Fourier transform of the sampling function (called **dirty beam**).

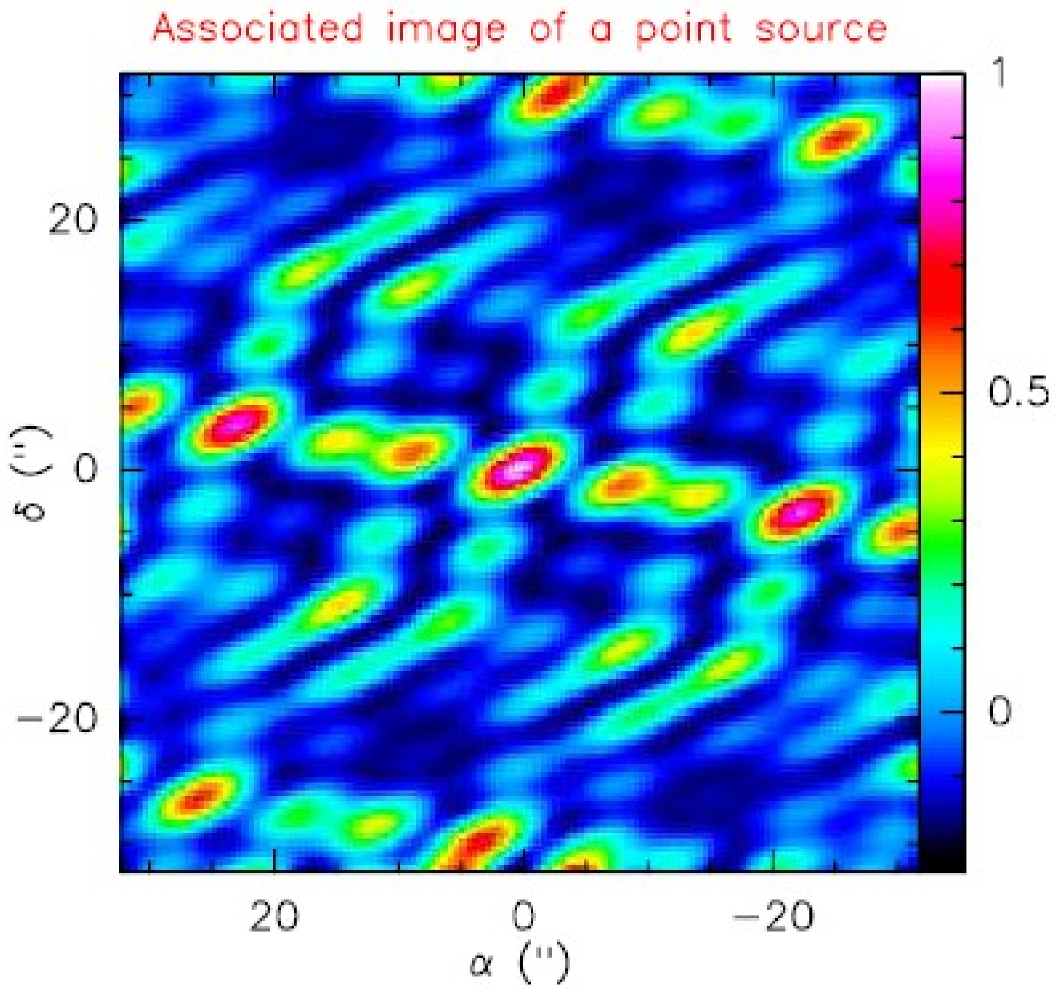
$$T^D(x,y)=D(x,y)\otimes T(x,y)$$

To get an image from interferometric data we need to Fourier transform sampled visibilities, and deconvolve for the dirty beam → **clean**

Earth rotation & Aperture Synthesis

- Possibility to measure different Fourier component without moving antennas
- Increasing the **uv plane coverage** improves images quality





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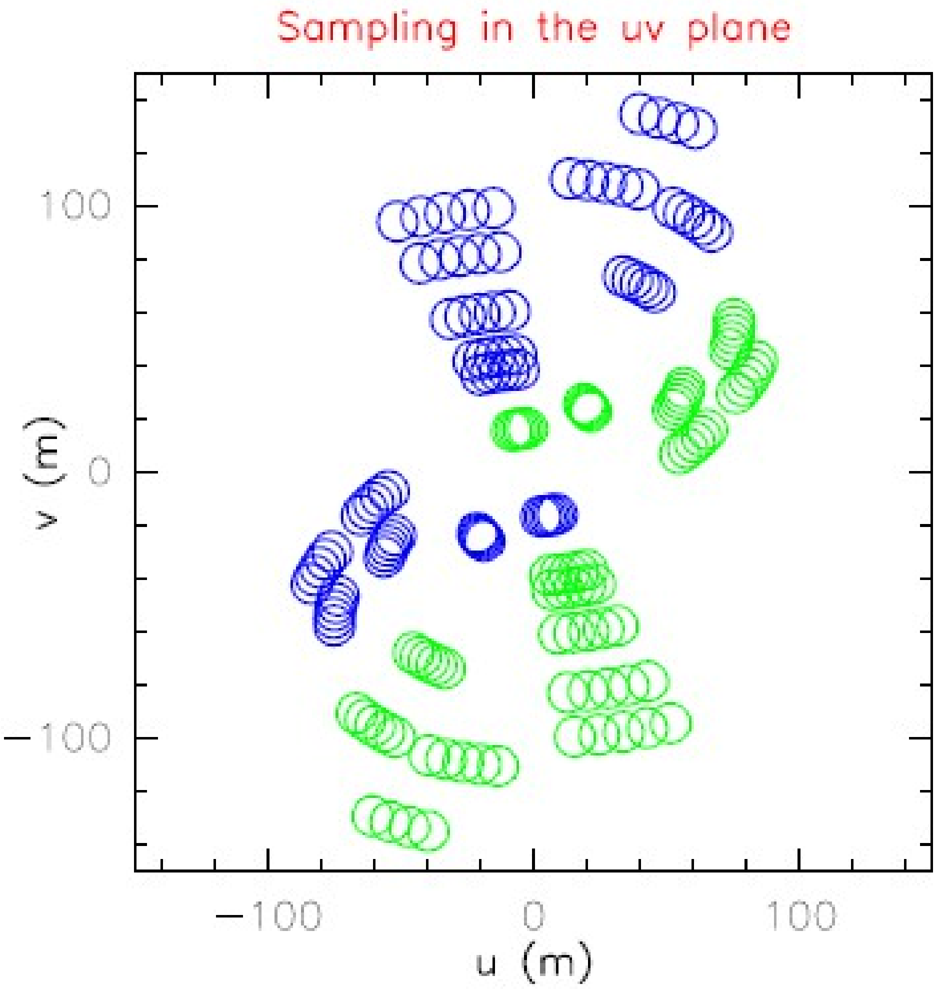

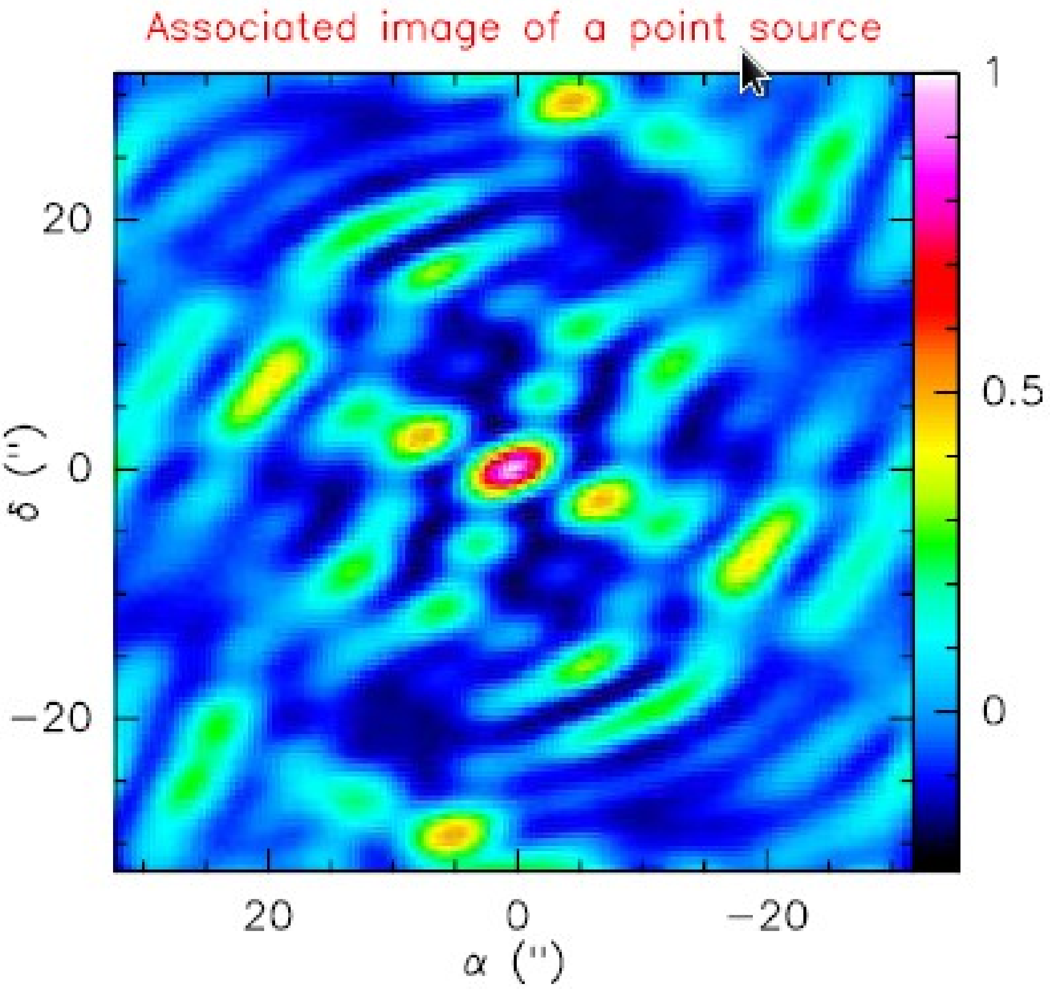

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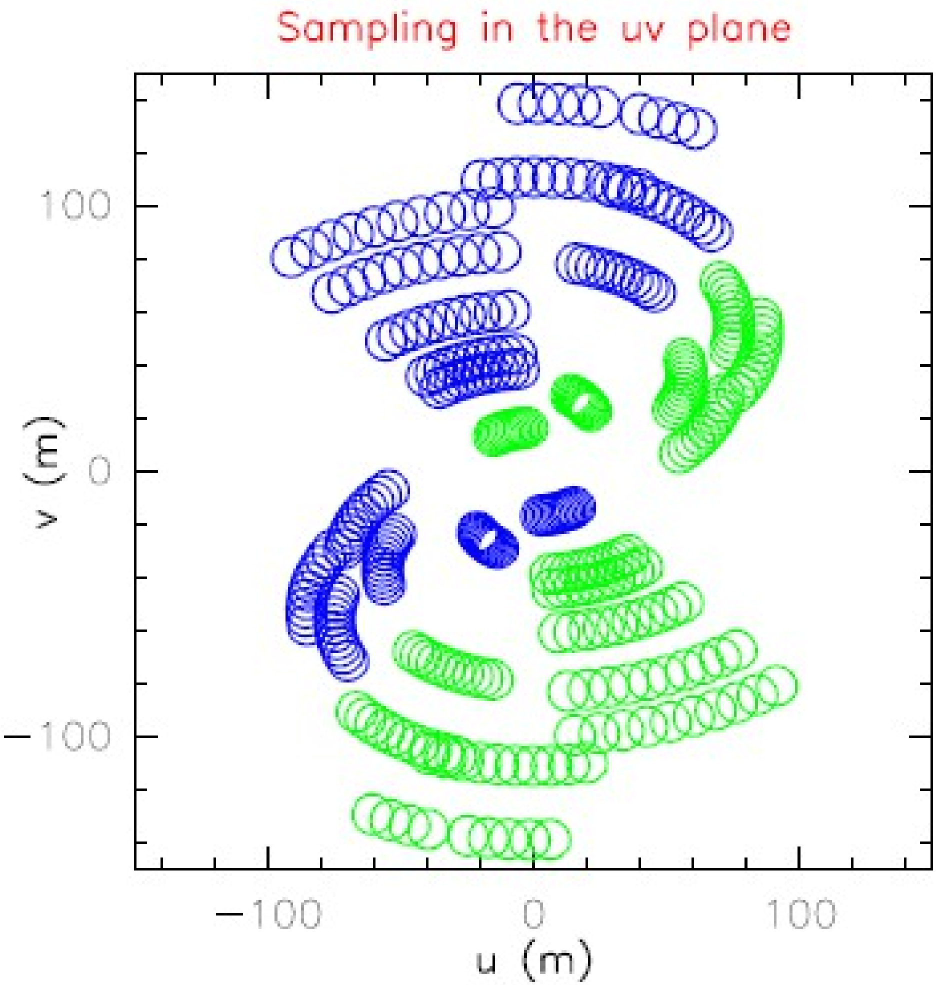

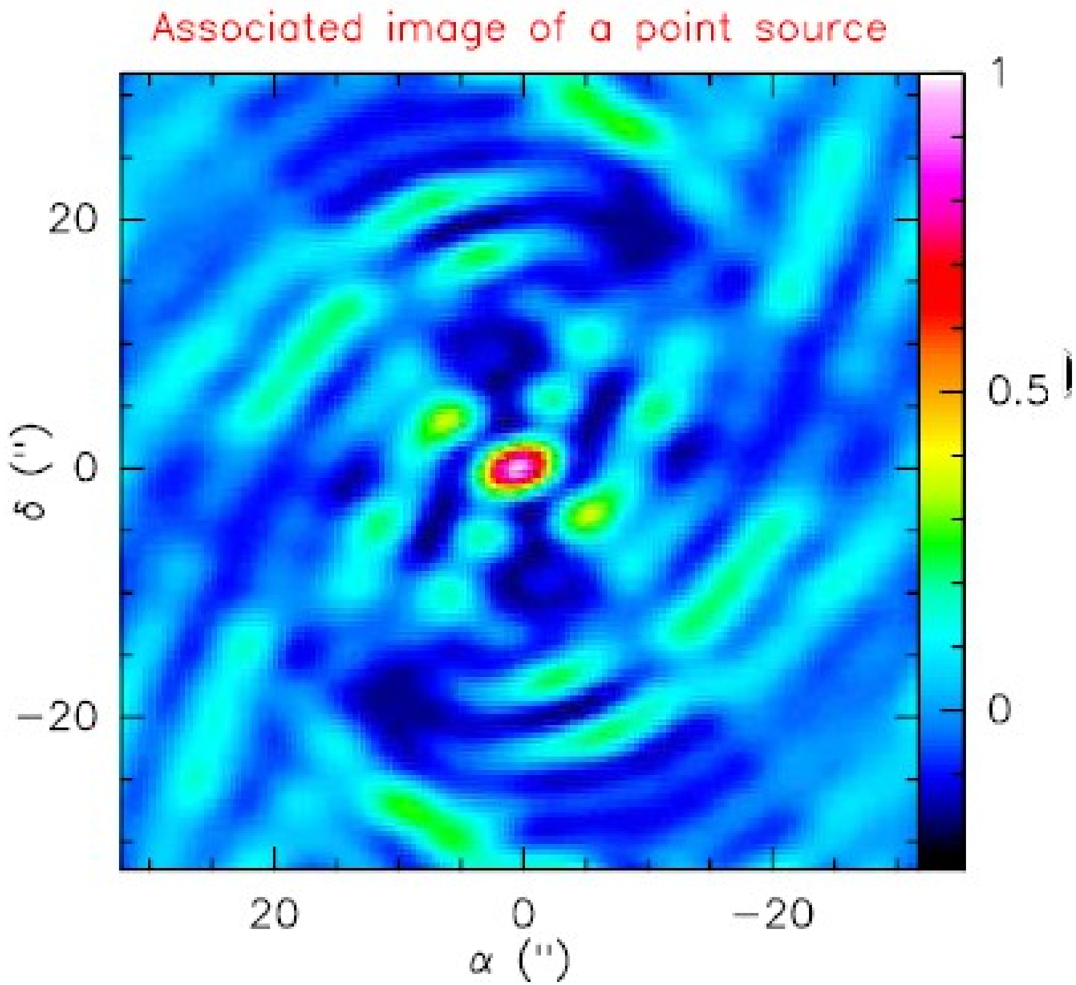

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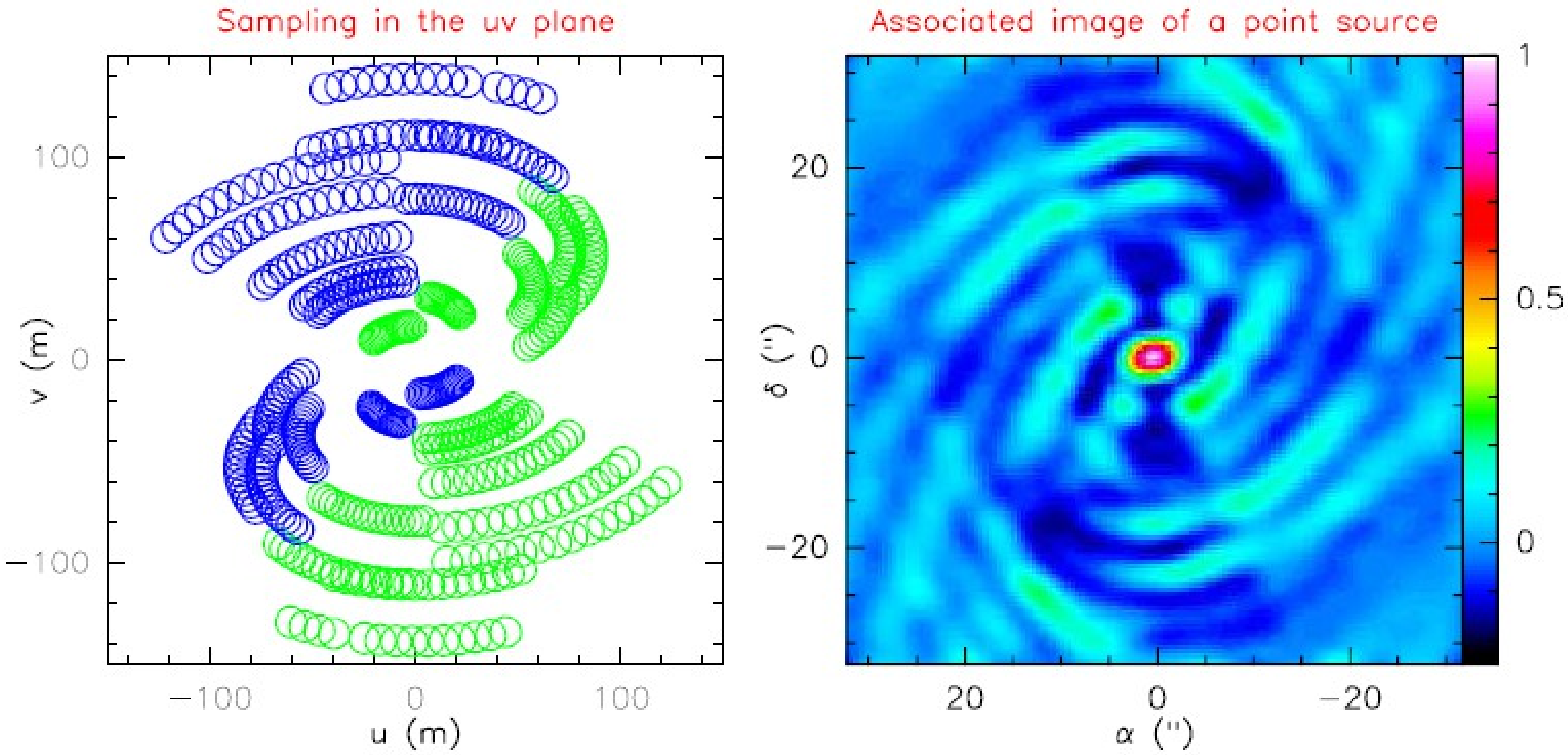

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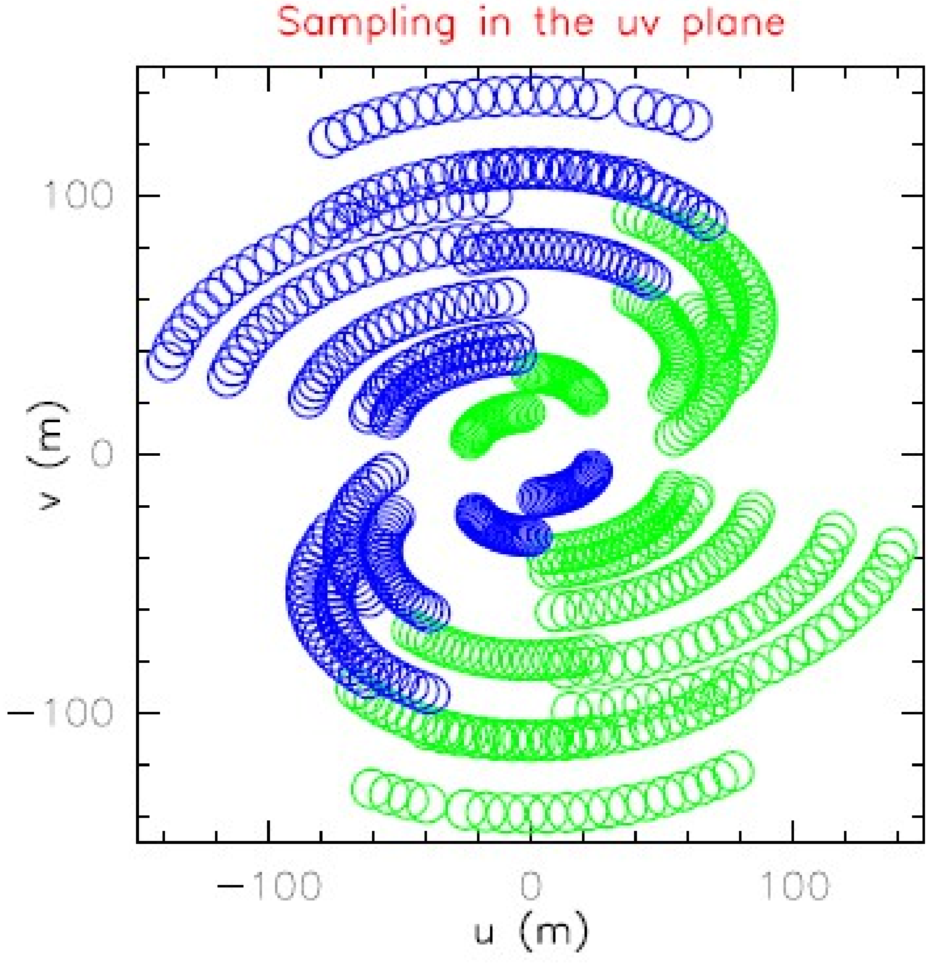

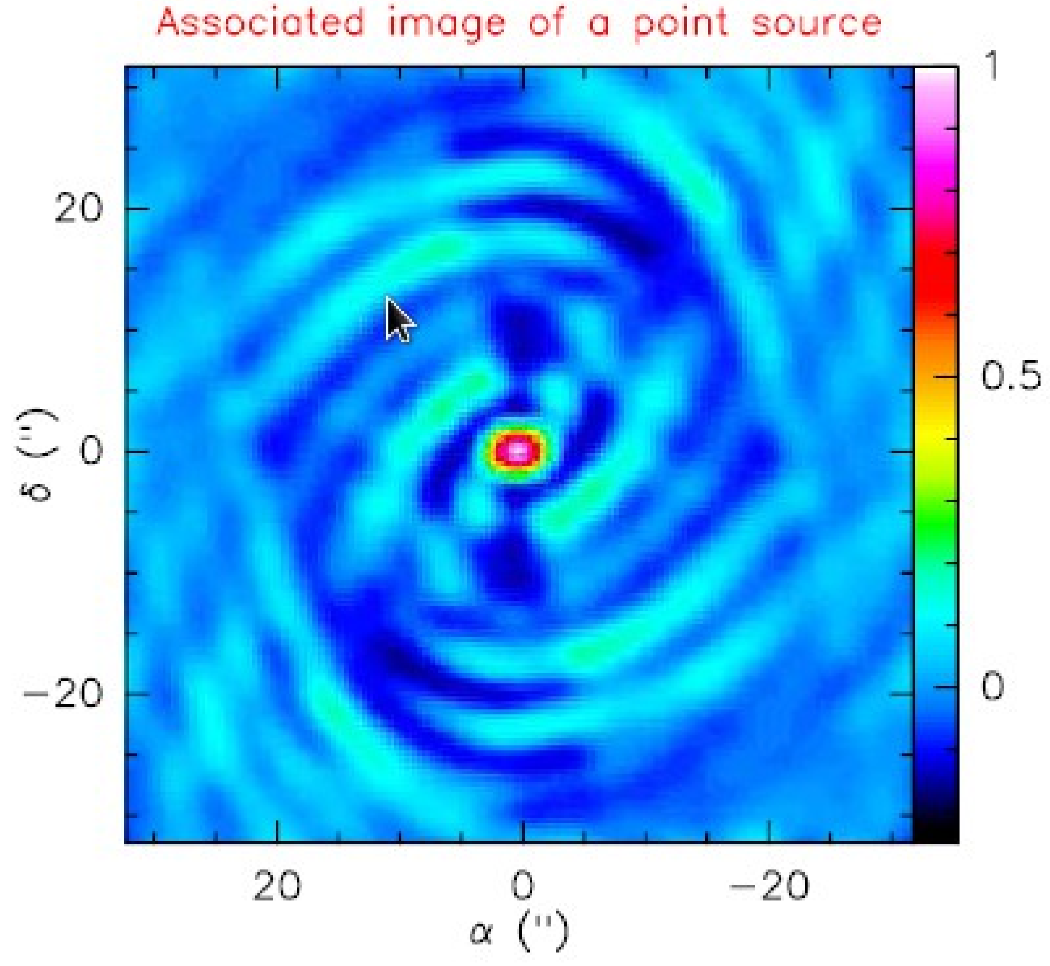

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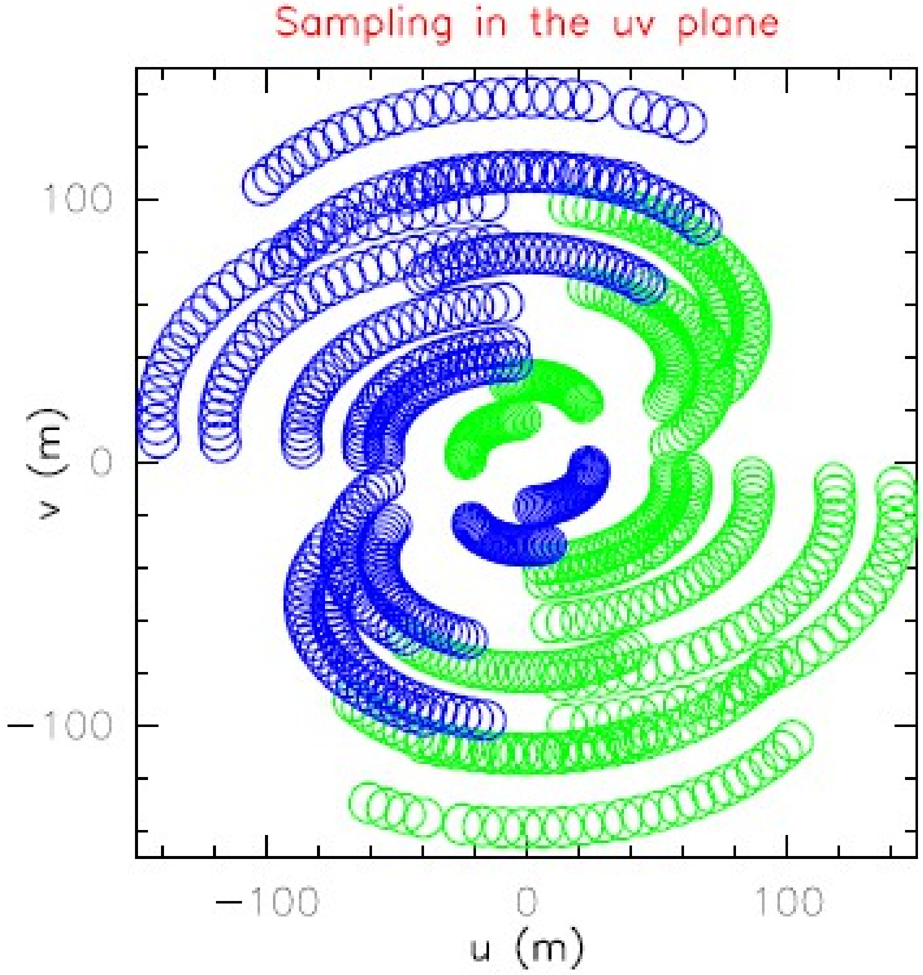

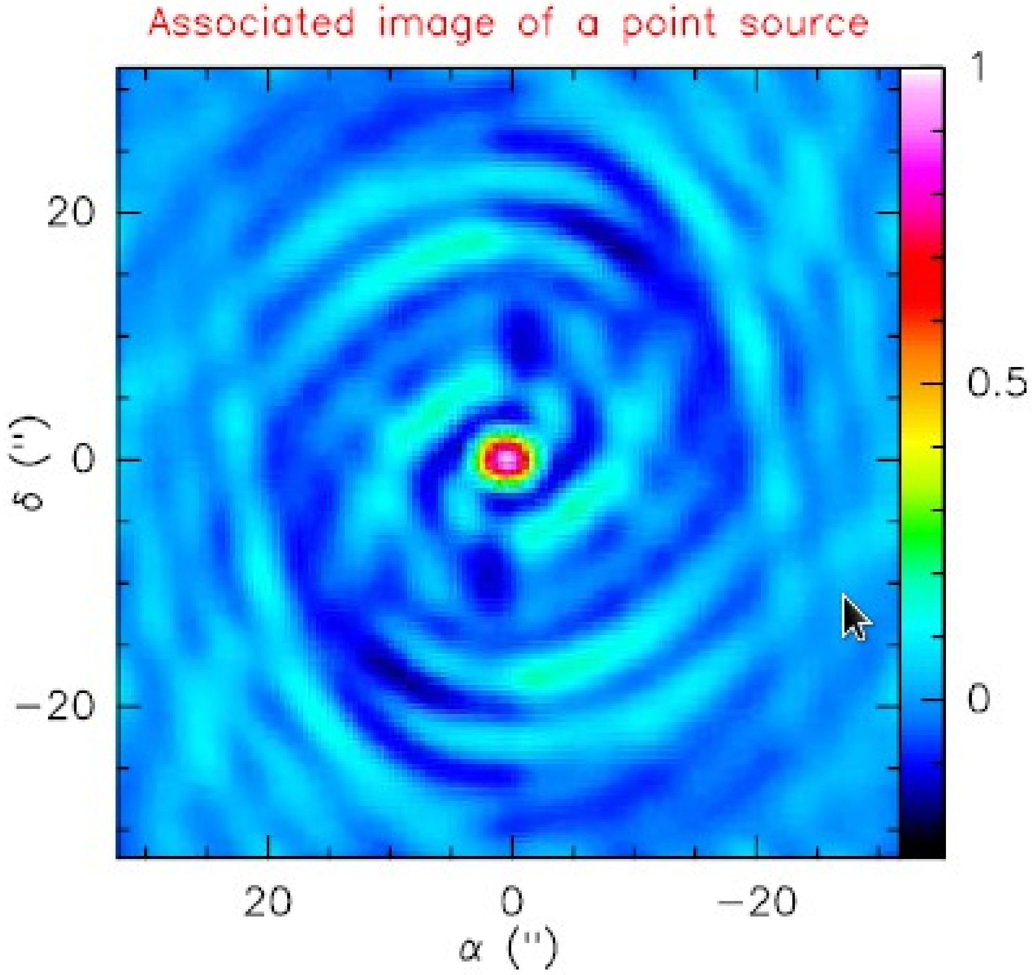

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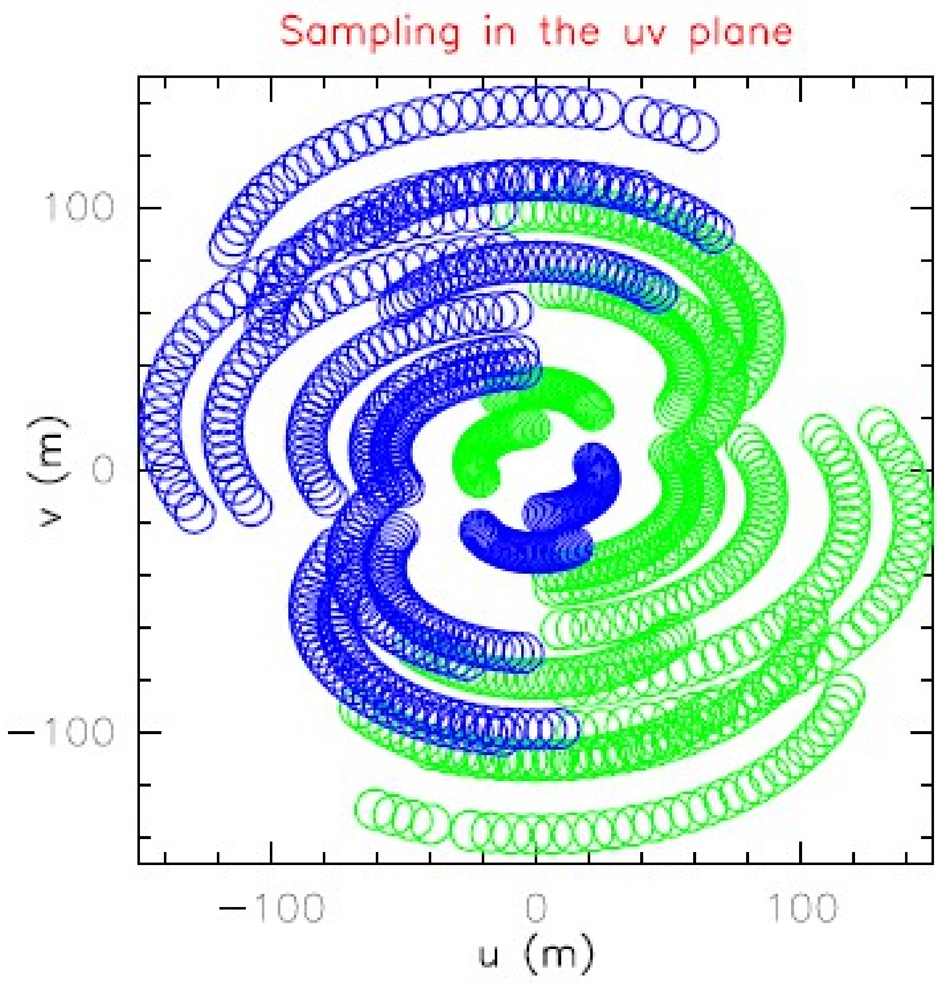

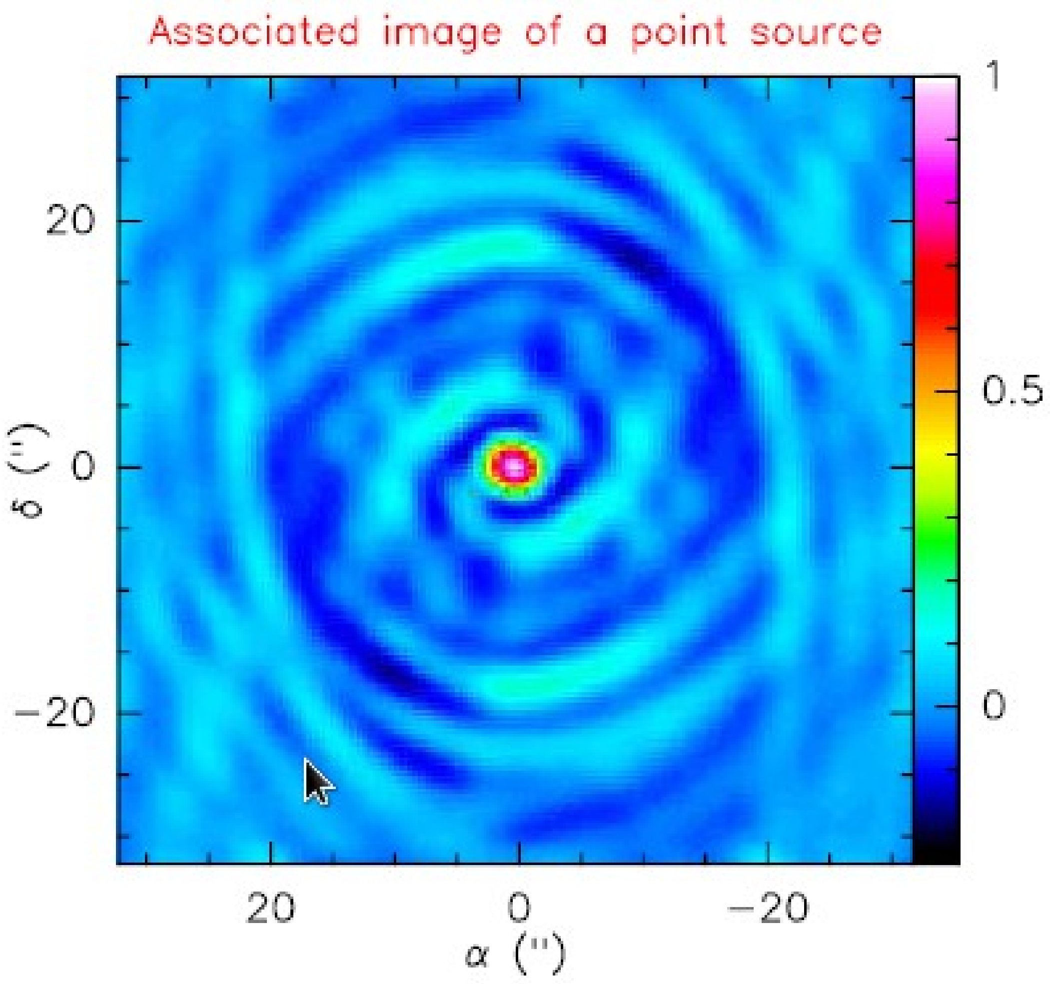

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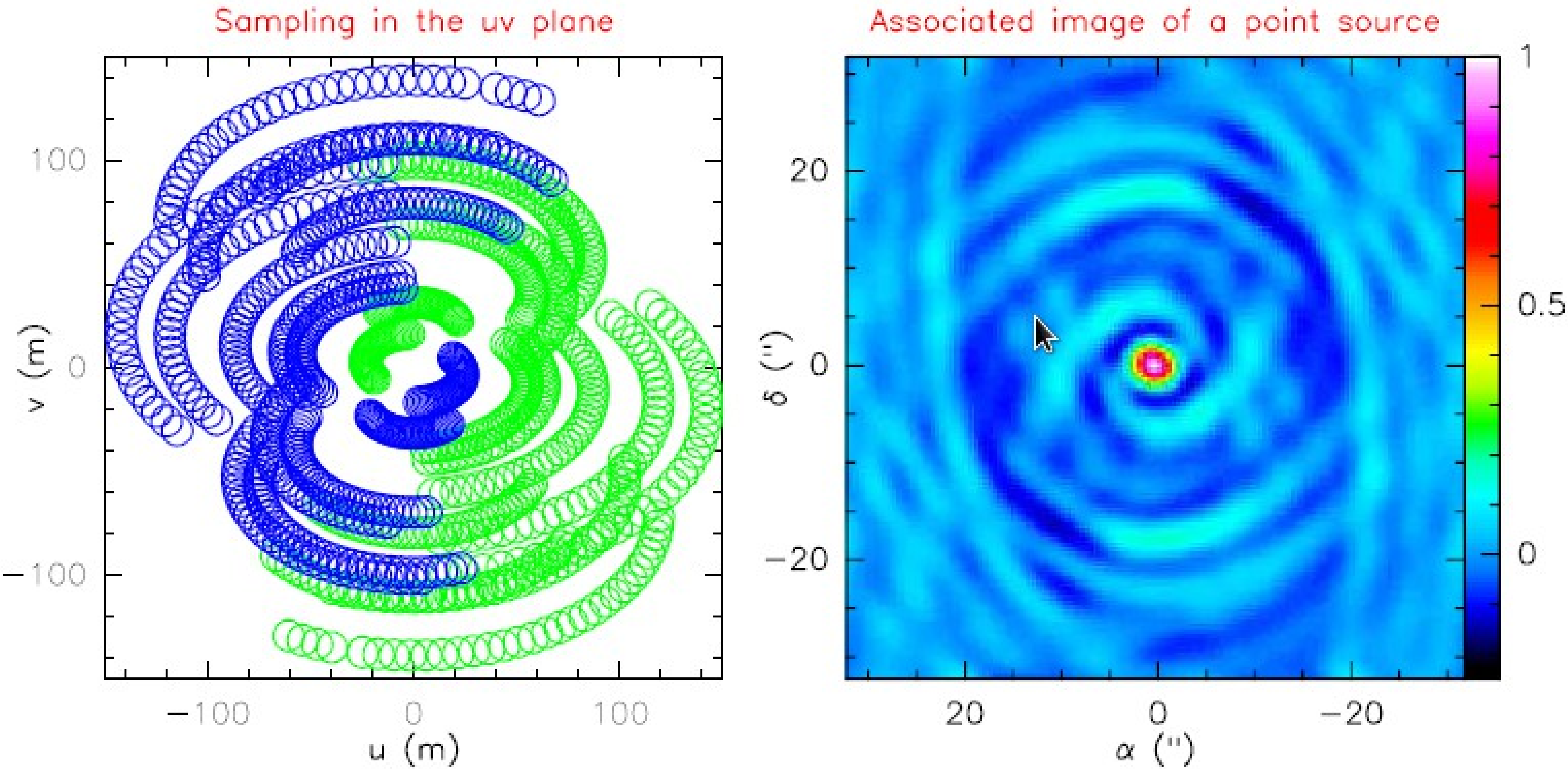

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Synthesis array is `blind' to structures on angular scales both smaller and larger than the range of fringe spacings given by the antenna distribution.

FOV

$$FOV \propto \frac{\lambda}{D}$$

Resolution

$$\theta_{res} \propto \frac{\lambda}{b_{max}}$$

Maximum scale observable

$$\theta_{max} \propto \frac{\lambda}{b_{min}}$$

Sensitivity

$$\sigma \propto \frac{T_{sys}}{A_{eff}\sqrt{N(N-1)\Delta\nu\tau}}$$

T_{sys} System temperature

A_{eff} Effective area

N Number of Antennas

$\Delta\nu$ Bandwidth

τ Observing time

That's Why ALMA !

- Dry site (low pwv)
- low Tsys
- >6500sqm of effective area
- 1225 baselines for the main array
- Short spacings with ACA

Excellent instantaneous uv coverage
& high sensitivity
< 0.05mJy @100 GHz in 1 hr

- Up to 16km baselines

subarcsec resolution
40 mas @ 100 GHz,
5 mas @ 900 GHz

- 10 spectral bands
- 70 correlator modes

Flexibility in spectral studies

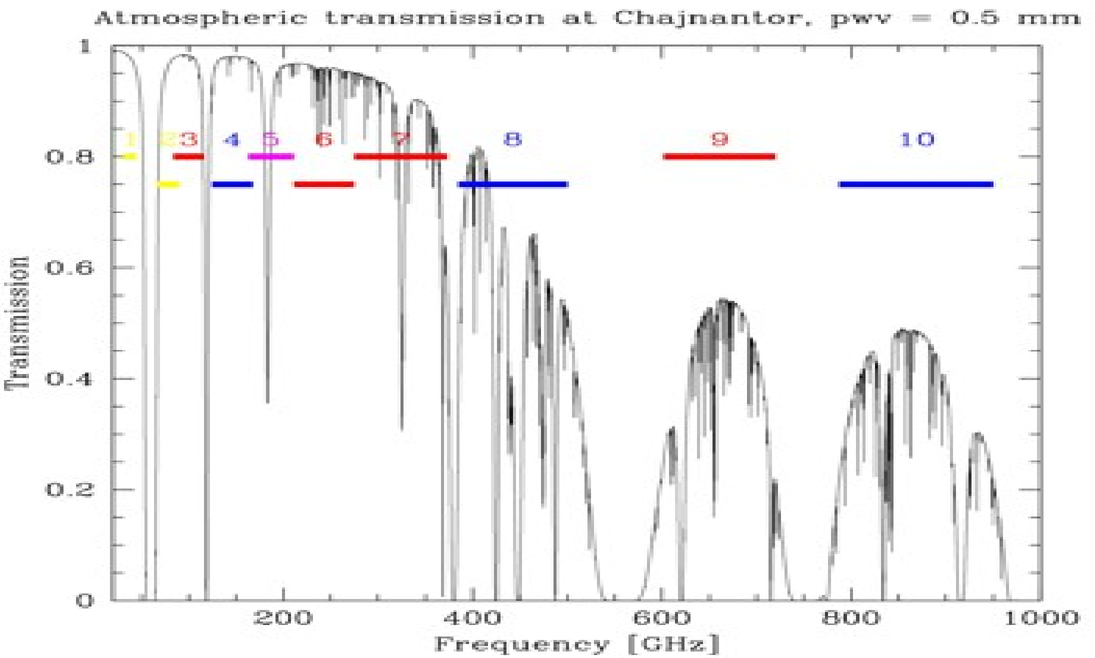
ALMA full array capabilities

Antennas: 50 x 12m
+ 12 x 7m & 4 TP (ACA)

10 bands 84-950 GHz
(possible extension to ~ 30 GHz)

Total Bandwidth: 16 GHz
(dual pol, 2 GHz/ baseband)

Spectral resolution::
0.008 km/s @ 300 GHz



Baselines : 150 m – 16 km

Spatial resolution: ~ 0.2” @ 300 GHz x 1km baseline

Polarization: full Stokes parameters

ALMA science drivers

Detect spectral line emission from C+ in a normal galaxy like the Milky Way at z=3 in less than 24 hrs

Image the gas kinematics in protostars and proto-planetary disks around young Sun-like stars in the nearest molecular clouds (at 150 pc)

Provide precise high dynamic range (~1000) images at an angular resolution of 0.1 arcsec.

ALMA Proposal categories

Cosmology and the high redshift universe

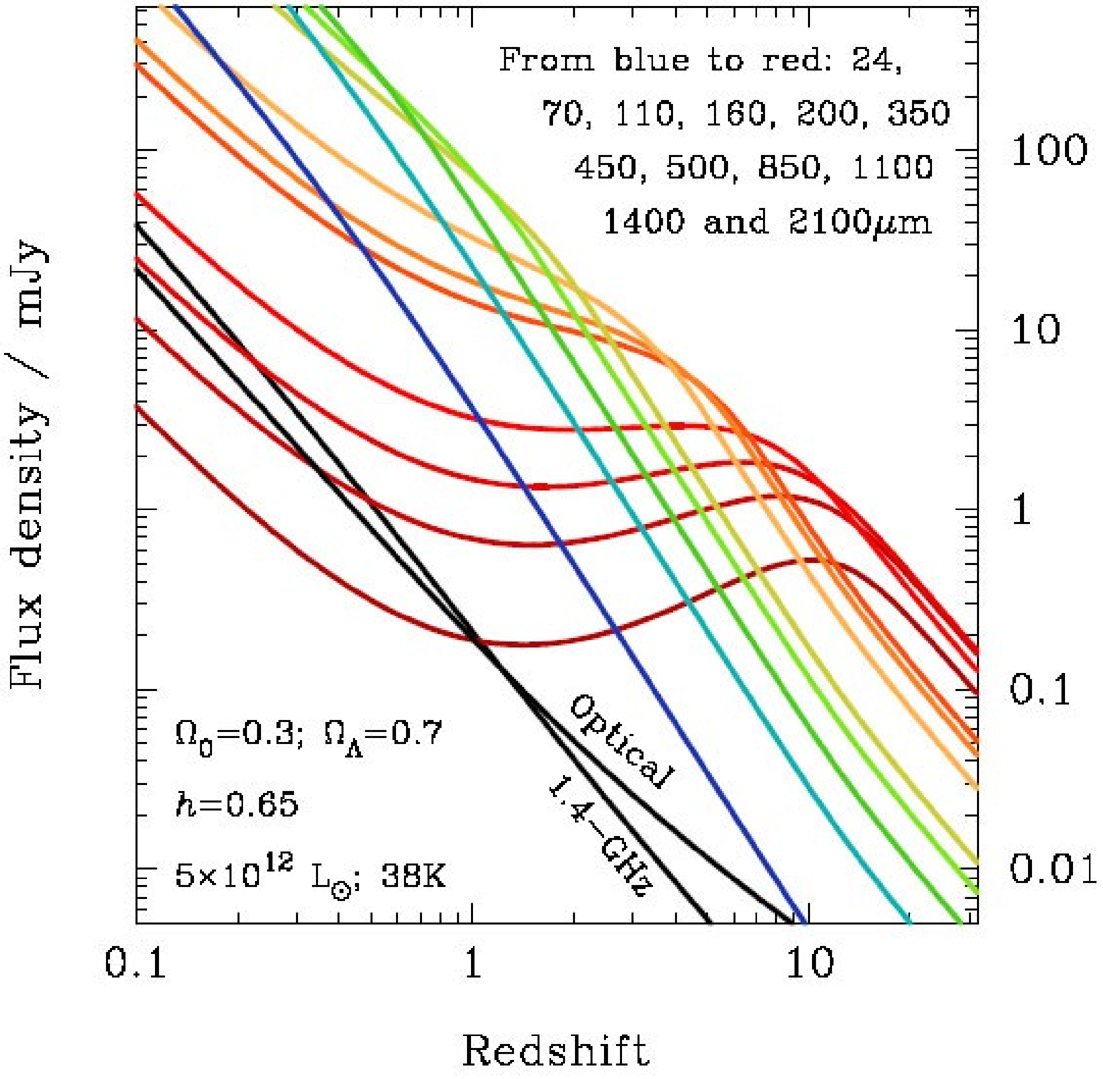
Galaxies and galactic nuclei

ISM, star formation and astrochemistry

Circumstellar disks, exoplanets and the solar system

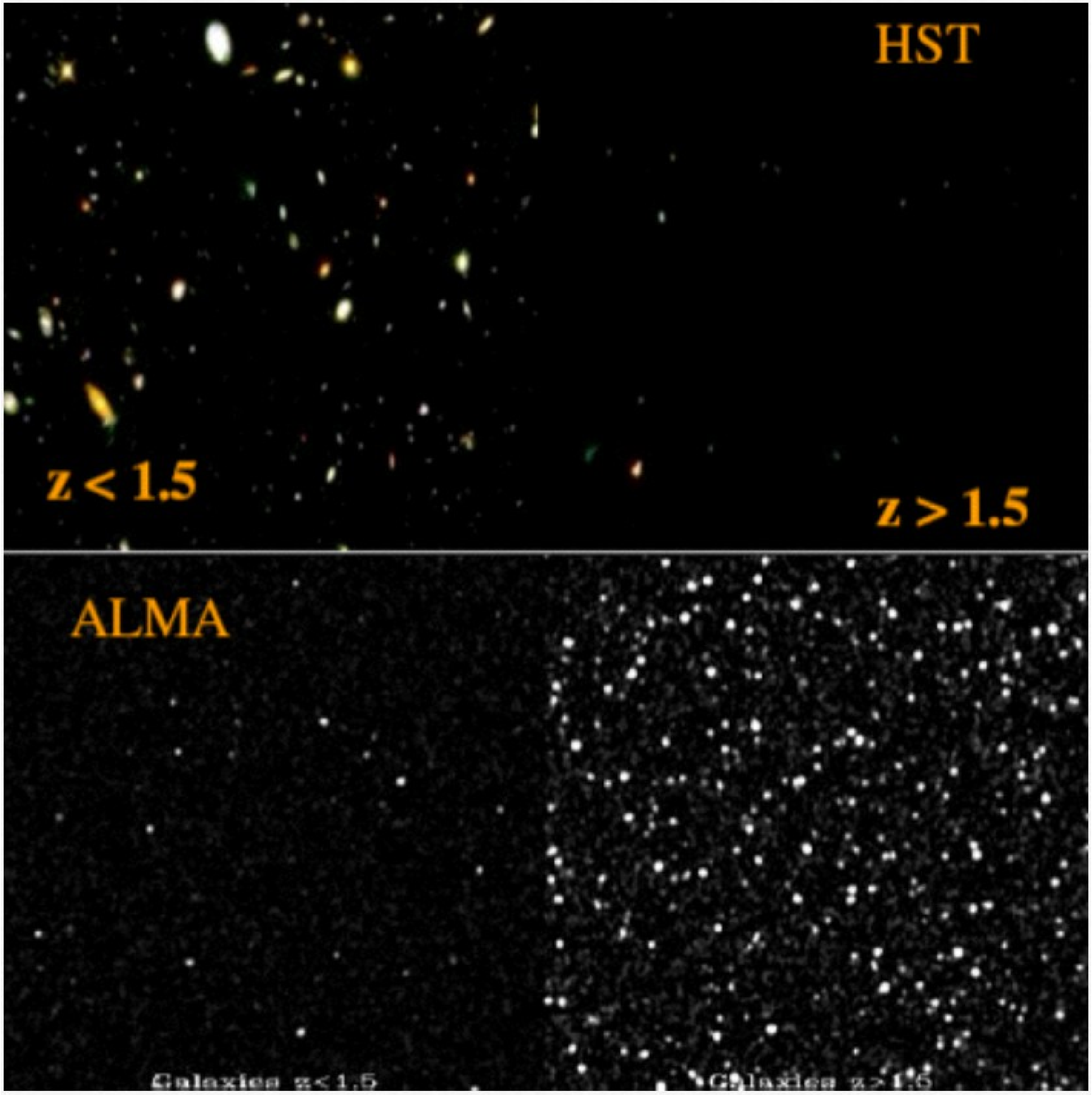
Stellar evolution and the Sun

Cosmology and high redshift Universe



- **Negative K- correction**
- **Flux is z independent in mm and sub mm**

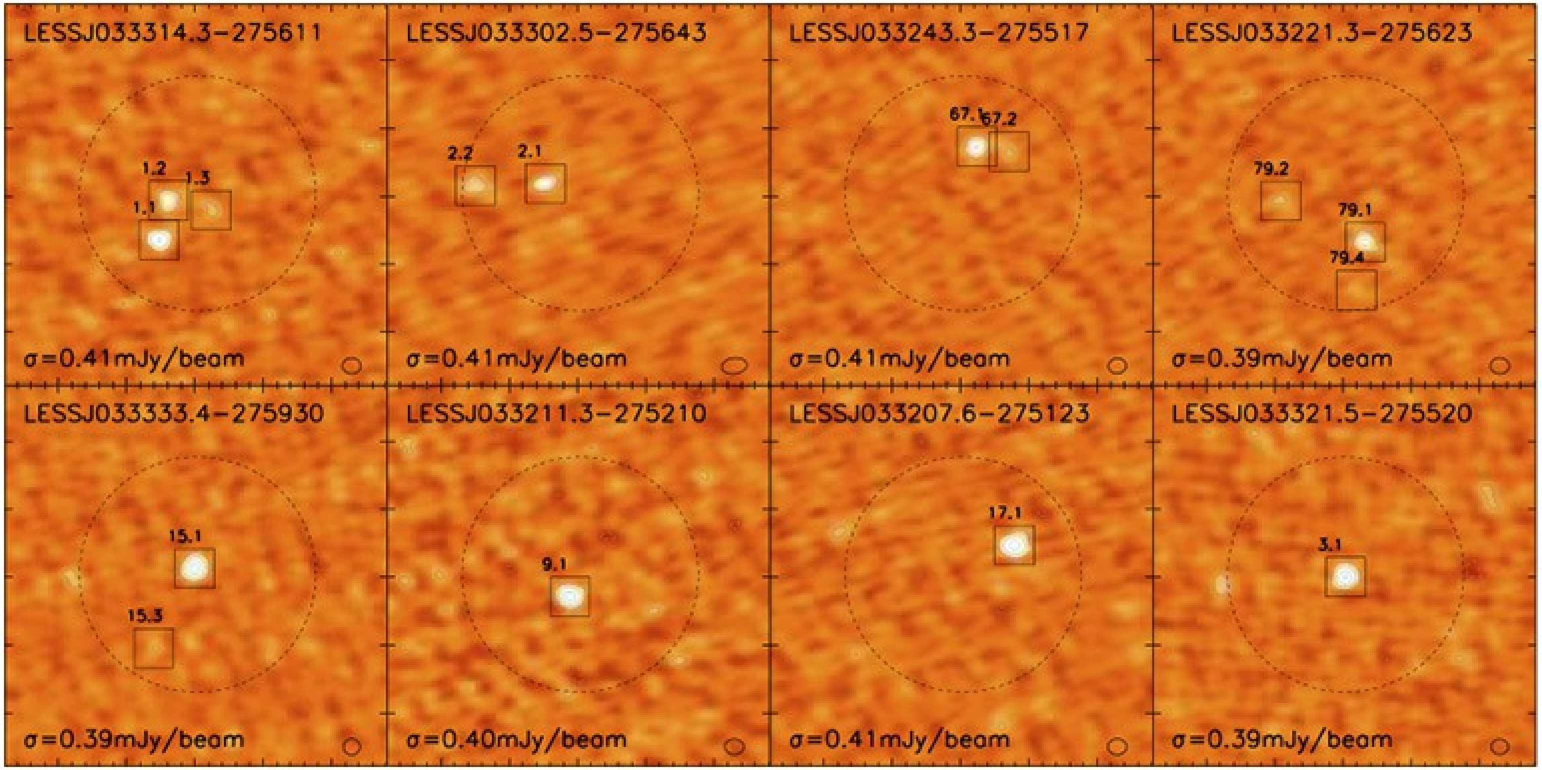
Cosmology and high redshift Universe



- **Galaxies at high redshift**

Cosmology and high redshift Universe

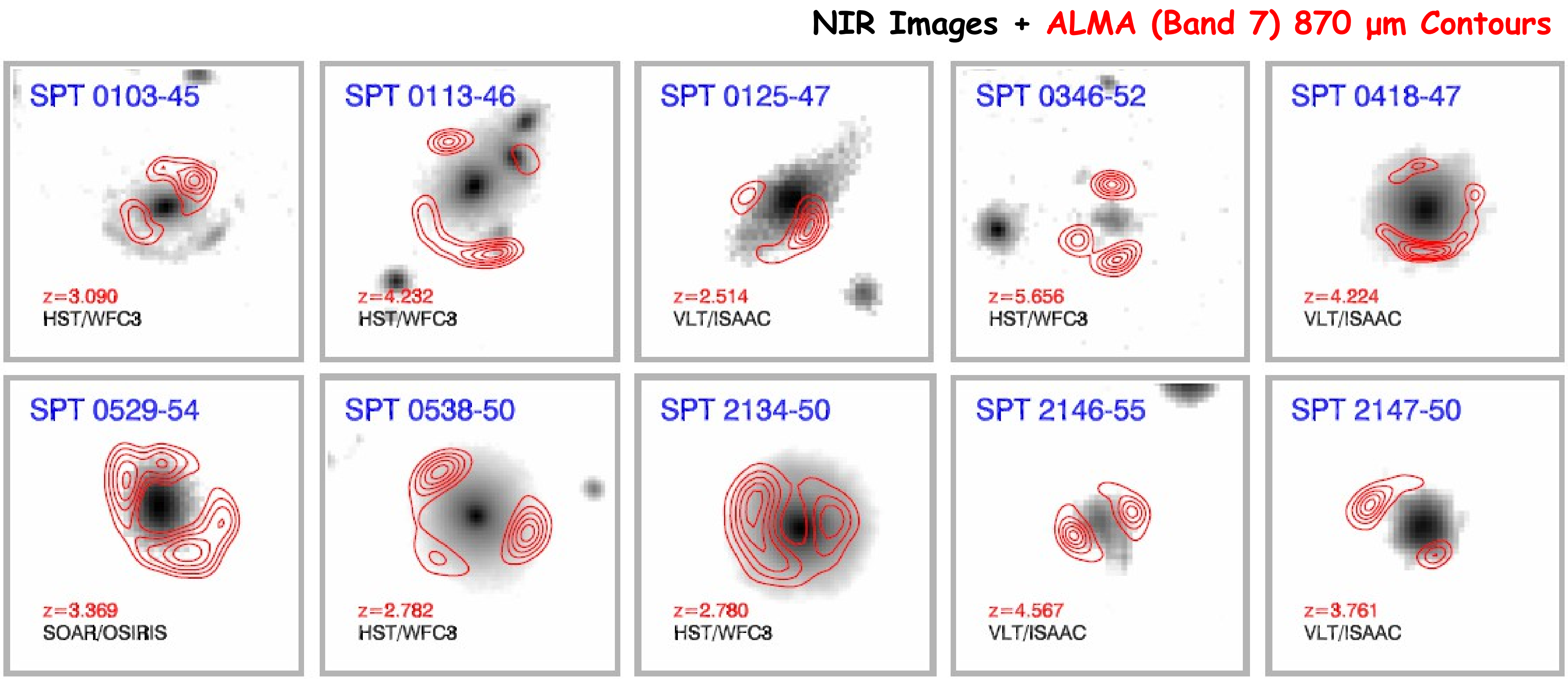
- **Cycle0 results**: Hodge et al. 2013; Karim et al. 2013; Simpson et al. 2013, Swinbank et al. 2014 and many other papers



Follow-up of LABOCA LESS survey: 122 submm sources.
ALMA Band7 observations reveal that ~35% of the LABOCA sources are resolved in multiple SMGs.
Serendipitous detections of bright emission lines in two SMGs which are likely CII emission @ z~4.4.

Cosmology and high redshift Universe

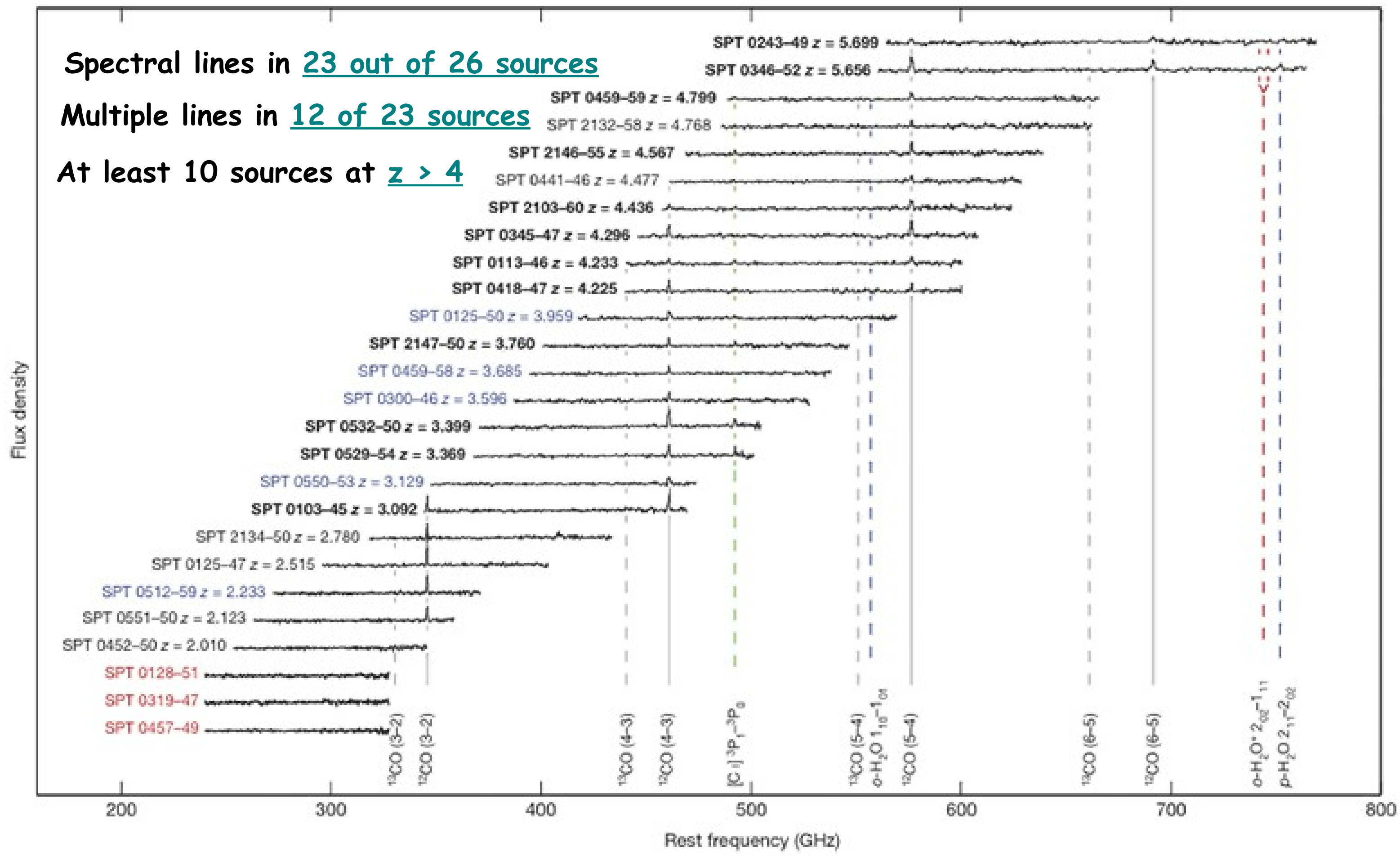
- **Cycle0 results**: Vieira et al. 2013; Weiss et al. 2013; Hesaveh et al. 2013



ALMA Band3 and Band7 observations of strongly gravitationally lensed sources.

Cosmology and high redshift Universe

- **Cycle0 results**: Vieira et al. 2013; Weiss et al. 2013; Hesaveh et al. 2013

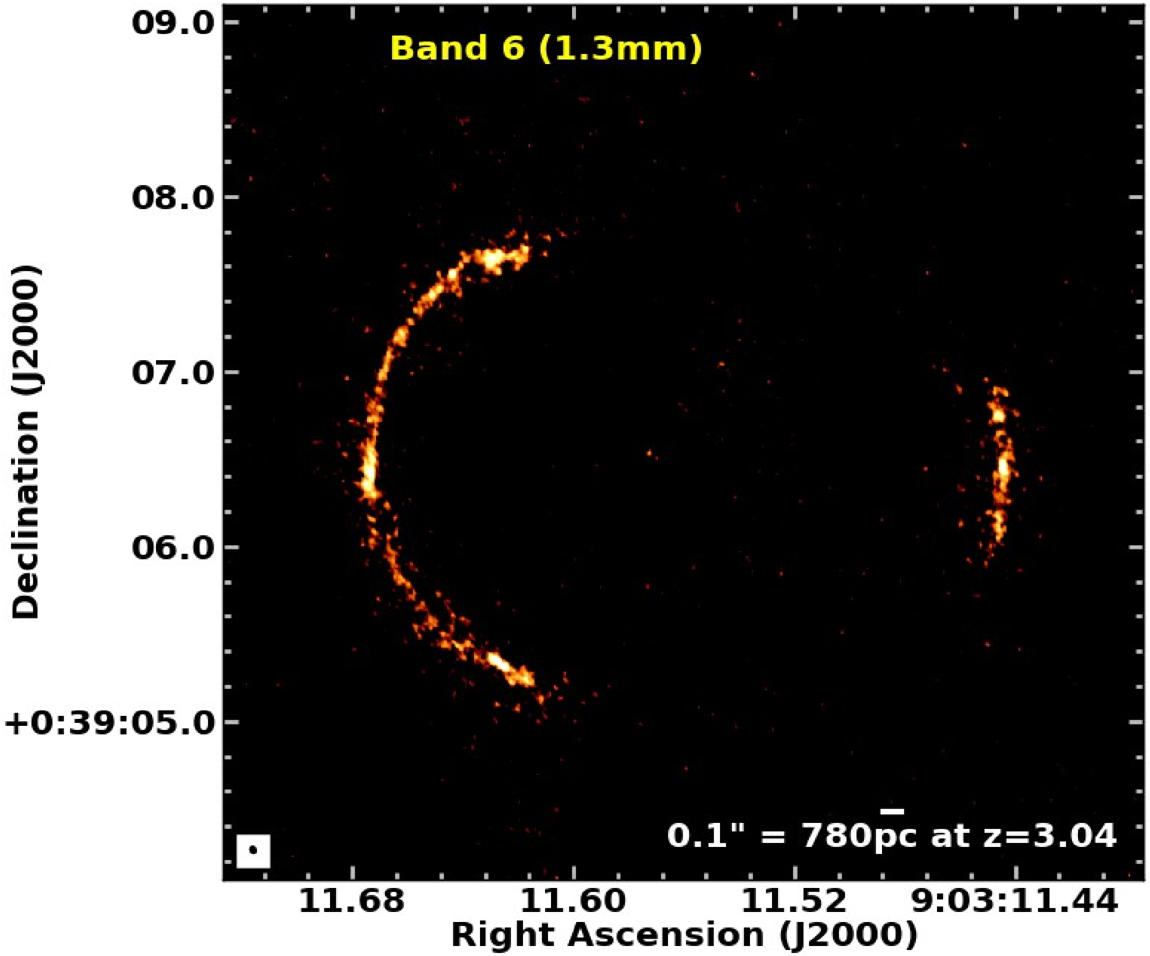


ALMA Band 3 first spectroscopic redshift survey
In some cases unambiguous z determination from ALMA only.

Cosmology and high redshift Universe

- **The Einstein Ring SDP8.1 seen with ALMA:**

ALMA partnership 2015, Hatsukade 2015, Wong 2015, Swinbank 2015, Dye 2015, Tamura 2015 and many more

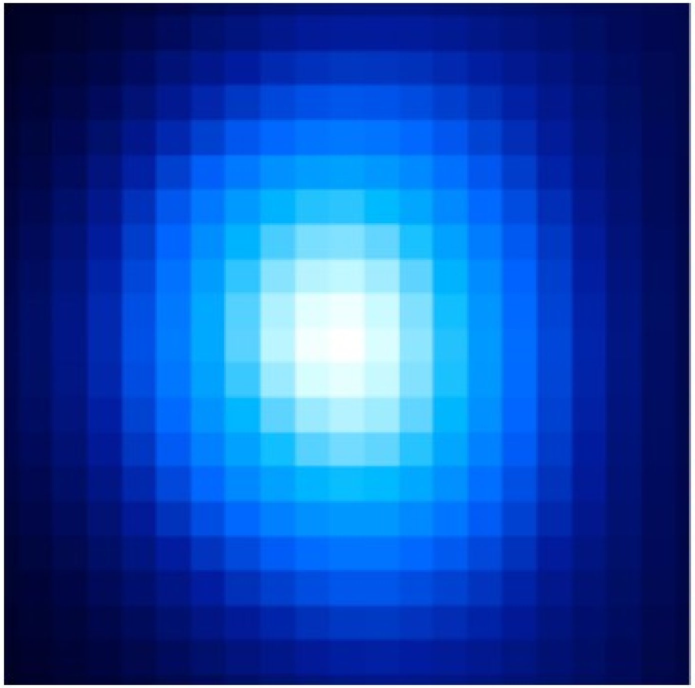


ALMA long baselines (up to 15 km) campaign

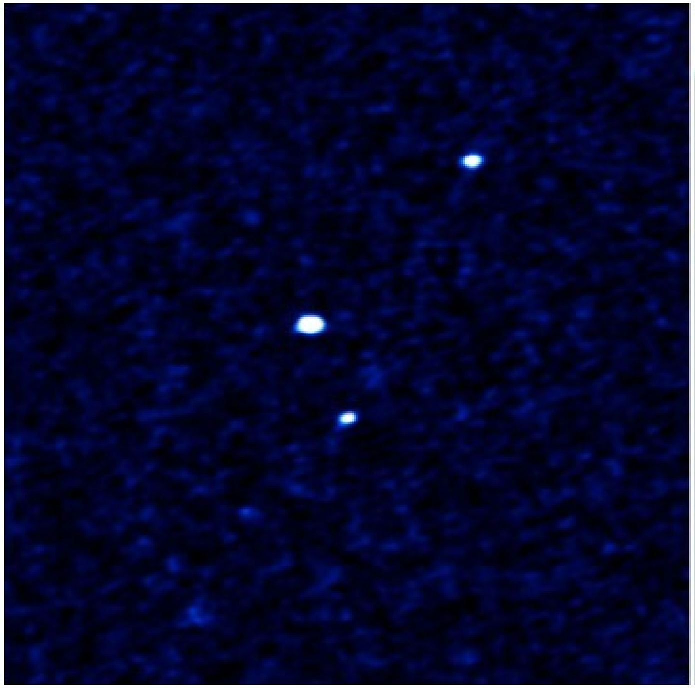
the number of papers shows how ALMA will enable astronomers to make more discoveries in the years to come

Cosmology and high redshift Universe

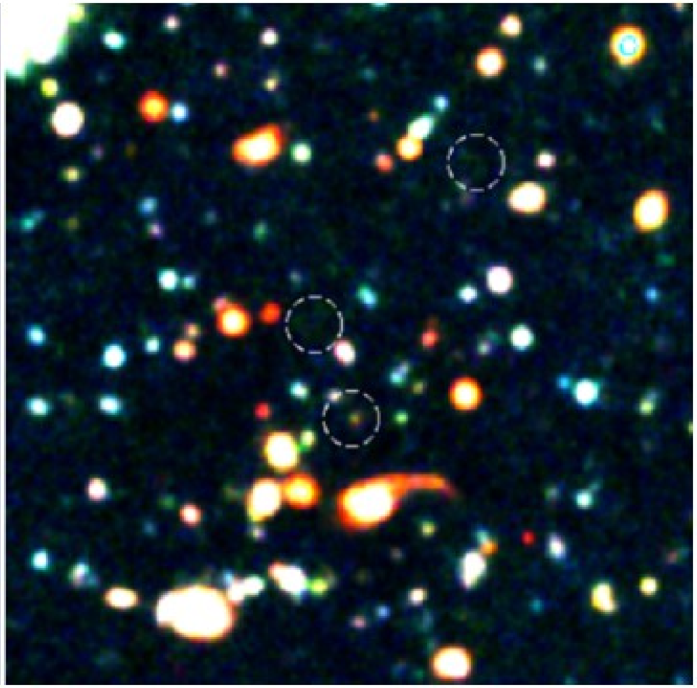
- **ALMA deep field in SSA22: concentration of dusty starbursts in a z=3.09 protocluster core**



ASTE observations
there might be a cluster of monstrous galaxies



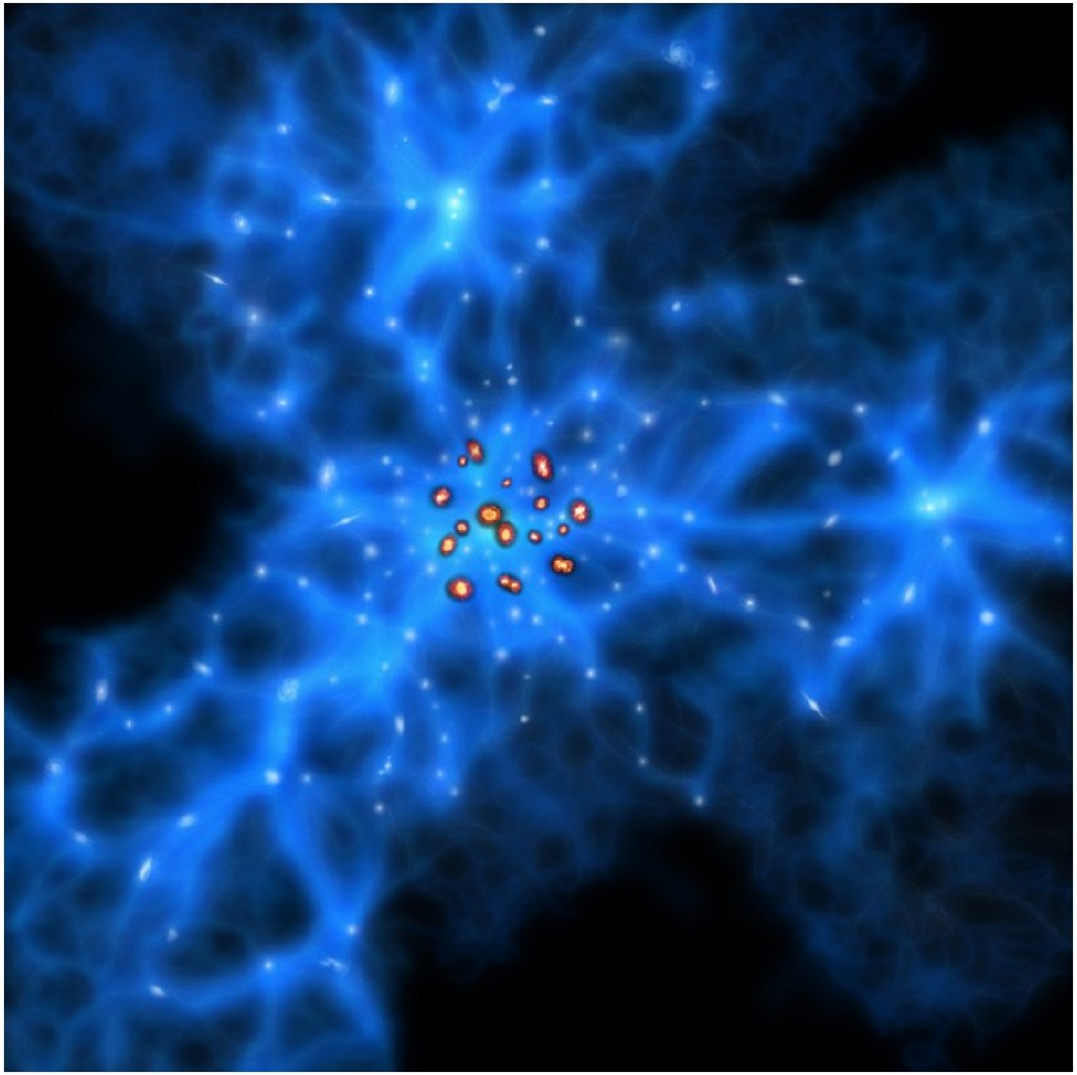
ALMA observations
nine monstrous galaxies can be identified



Subaru observations
not all the galaxies are visible.

Cosmology and high redshift Universe

- **ALMA deep field in SSA22: concentration of dusty starbursts in a z=3.09 protocluster core**

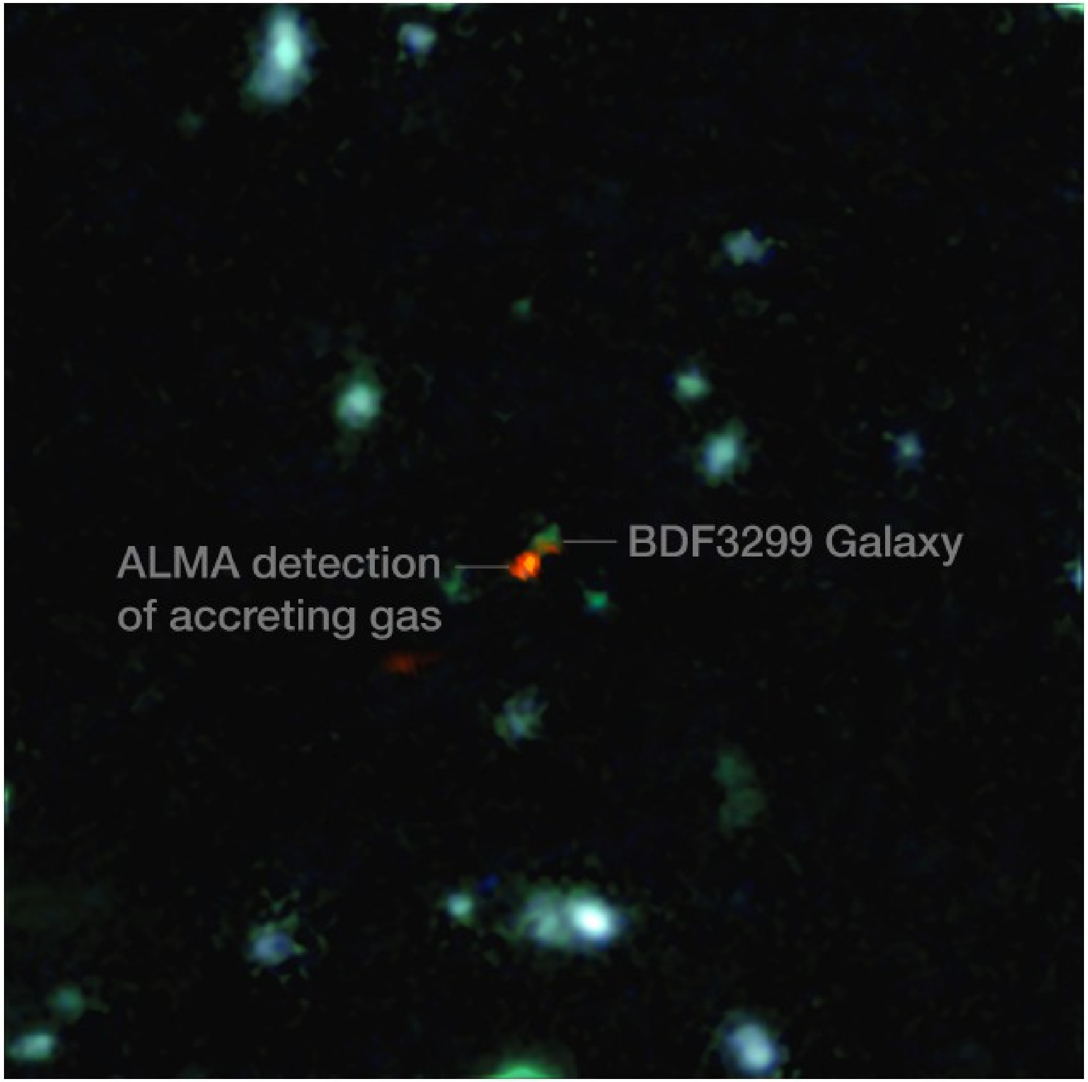


The shape of the cluster indicates the presence of a huge 3D web of invisible dark matter. Monstrous galaxies seem to be located in the intersections of dark matter filaments.

Umehata et al. 2015

Cosmology and high redshift Universe

- **The assembly of "normal" galaxies at z~7 probed by ALMA**



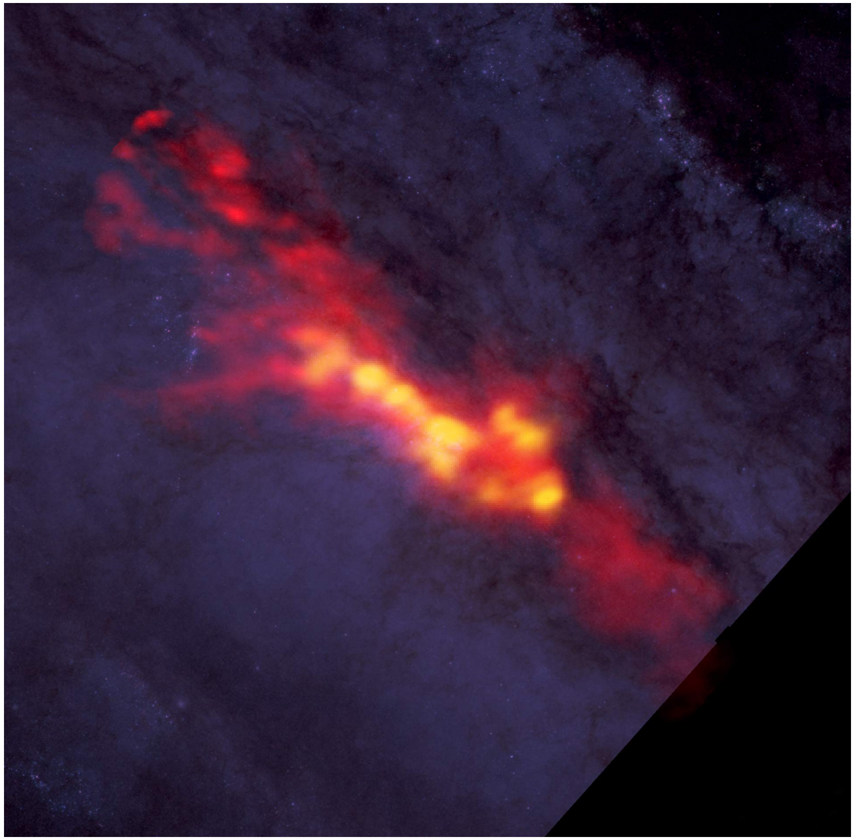
Detection of the CII emission at z=7.107 but spatially offset from the optical emission. This suggests that molecular clouds in the central parts of primordial galaxies are rapidly disrupted by stellar feedback.

Maiolino et al. 2015

Galaxies and galactic nuclei

Star forming clouds have
been identified in the closeby
starburst galaxy NGC253
in different molecular emissions.

These clouds are much more
massive, ten times denser,
and far more turbulent than
similar clouds in the Milky Way.



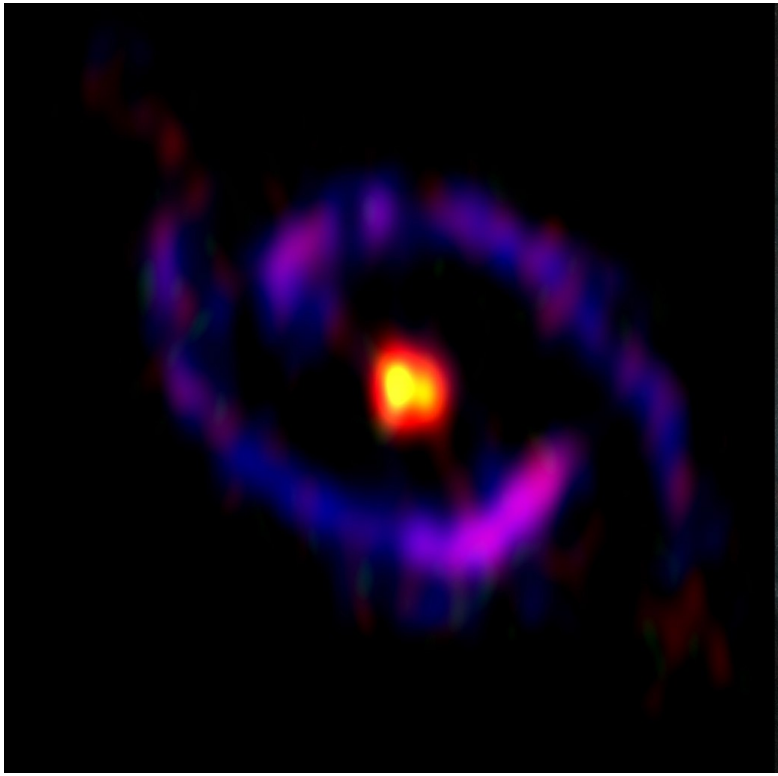
NGC253
Leroy et al., 2015

Galaxies and galactic nuclei

The distribution around the AGN of a variety of molecules has been revealed.

Unexpected molecules (HC_3N and CH_3CN) have been detected in the circumnuclear disk.

ALMA images
yellow =HC_3N
red = CS
blue = CO



NGC1068
Takano et al., 2014; Nakajima et al. 2015; Garcia-Burillo et al., 2014;

Galaxies and galactic nuclei

- **A measurement of the black-hole mass in NGC1097 using ALMA**

Measuring the distribution and motion of two molecules (HCN and HCO+) near the center of the galaxy, it has been possible to estimate the black hole mass: 140×10^6 solar masses.

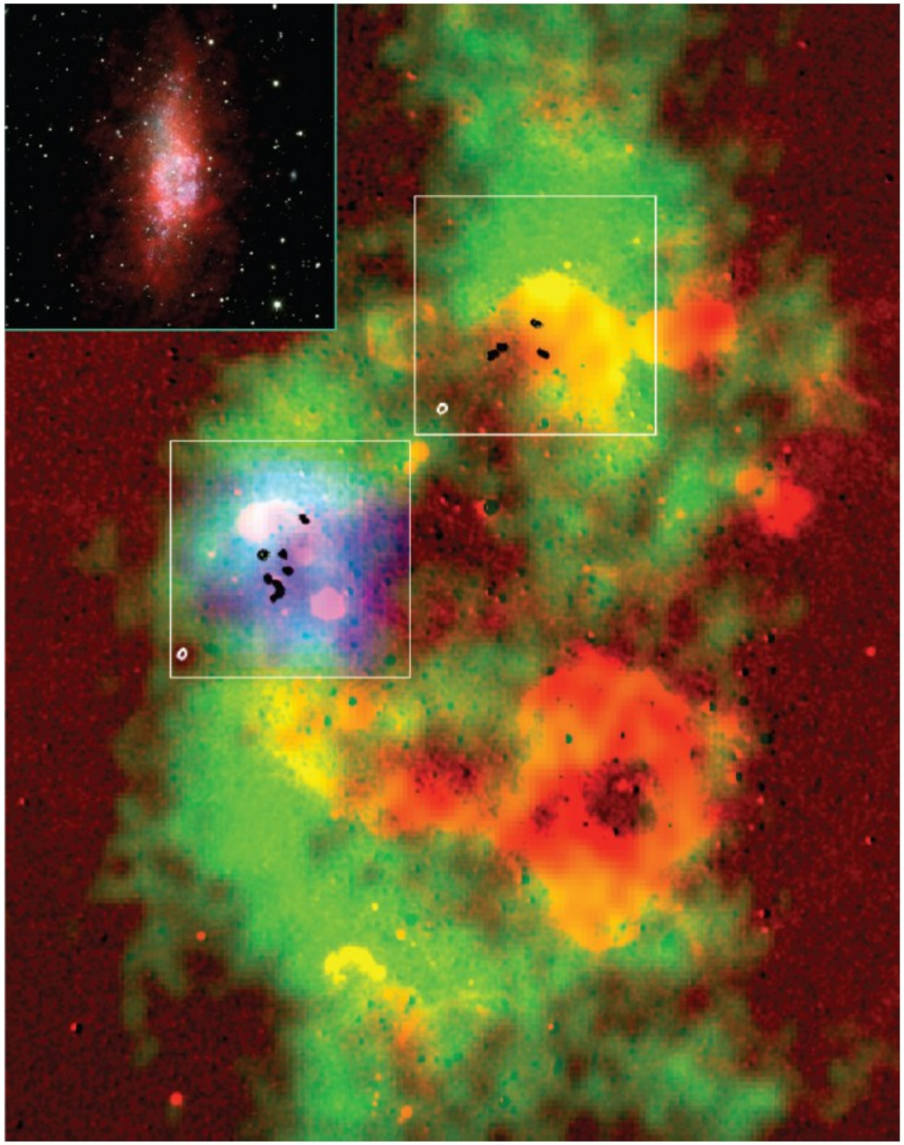
A new measuring technique

red: ALMA HCO+
green/orange: ALMA HCN
optical image from Hubble

Onishi et al., 2015

Galaxies and galactic nuclei

- **Dense cloud cores revealed by CO in the low metallicity dwarf galaxy WLM**



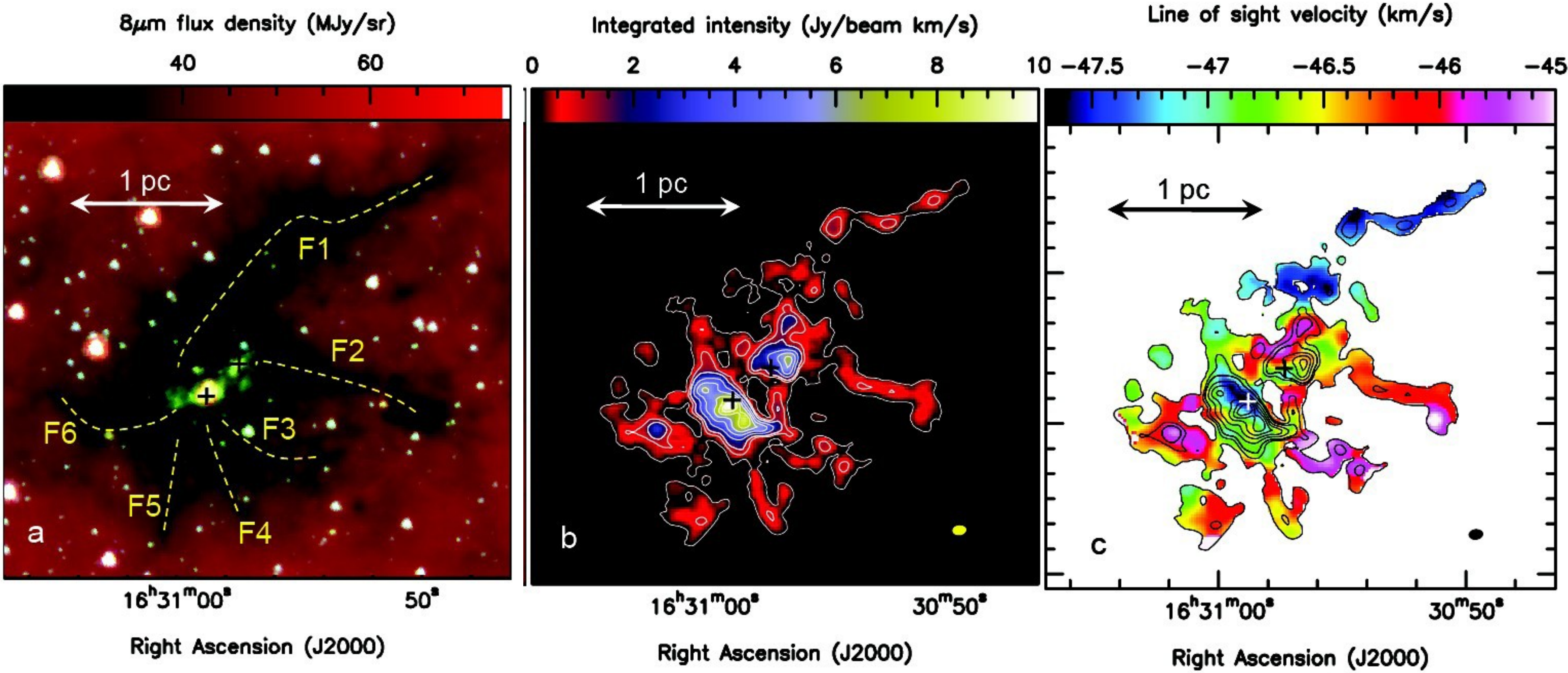
An unexpected population of compact interstellar clouds hidden within the nearby dwarf irregular galaxy WLM. These clouds nested within a heavy blanket of interstellar material help explain how dense star cluster are able to form in the tenuous environs of a galaxy thousands of times smaller and far more diffuse than our MW.

Rubio et al. 2015

green:HI
red: Halpha
blu: CII
black contours: CO observed with ALMA

ISM, star formation and astrochemistry

First observations of a network of cold, dense filamentary structure in a massive IR dark cloud. **Peretto et al. 2013**



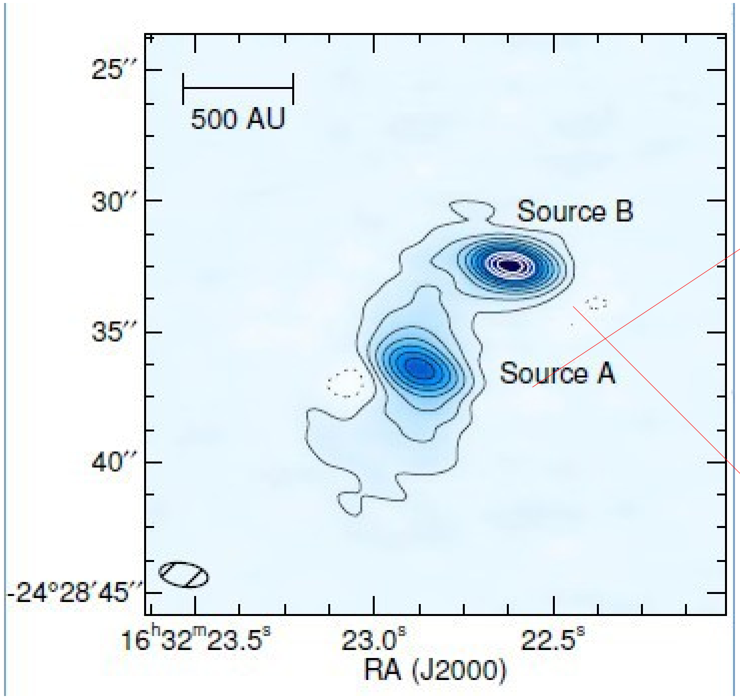
Spitzer composite:
8(red) 4.5(green)
3.6 μm (blue)

ALMA N_2H^+(1-0)
Integrated intensity

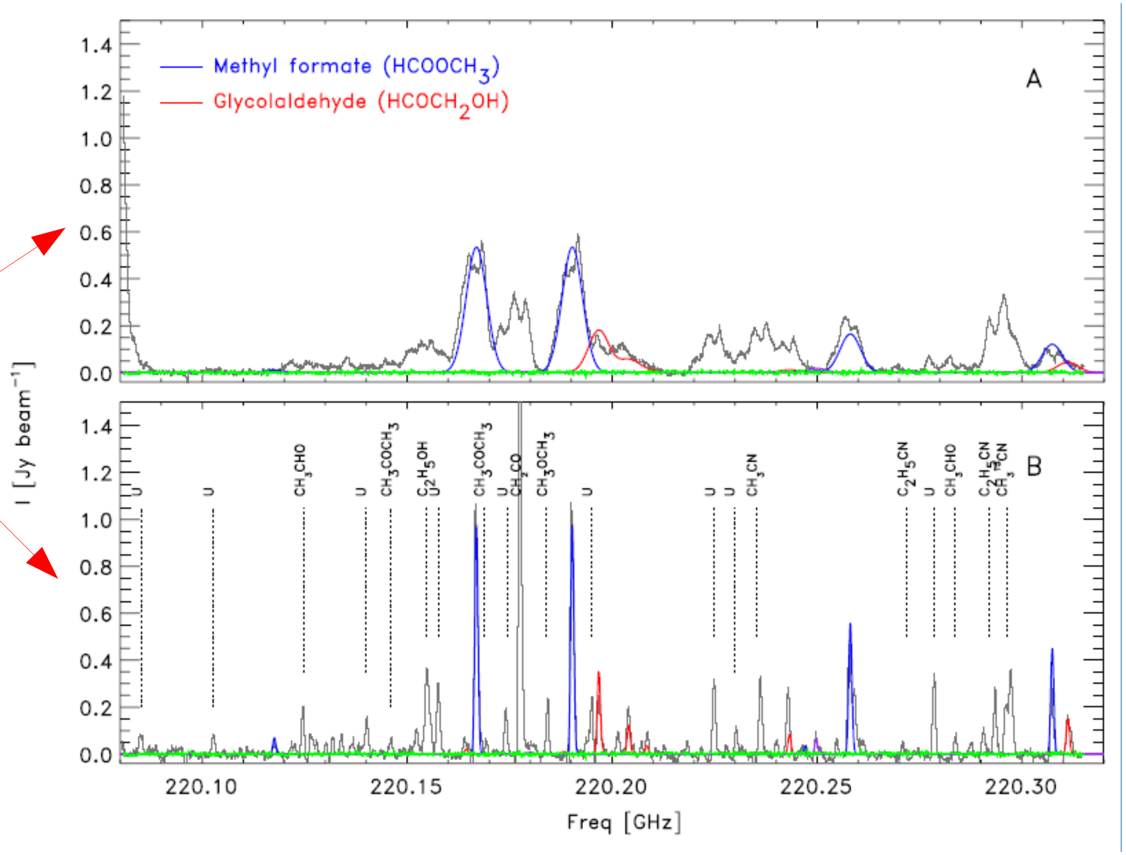
ALMA N_2H^+(1-0):
velocity field

ISM, star formation and astrochemistry

The proto-binary IRAS 16293-2422



ALMA Continuum map

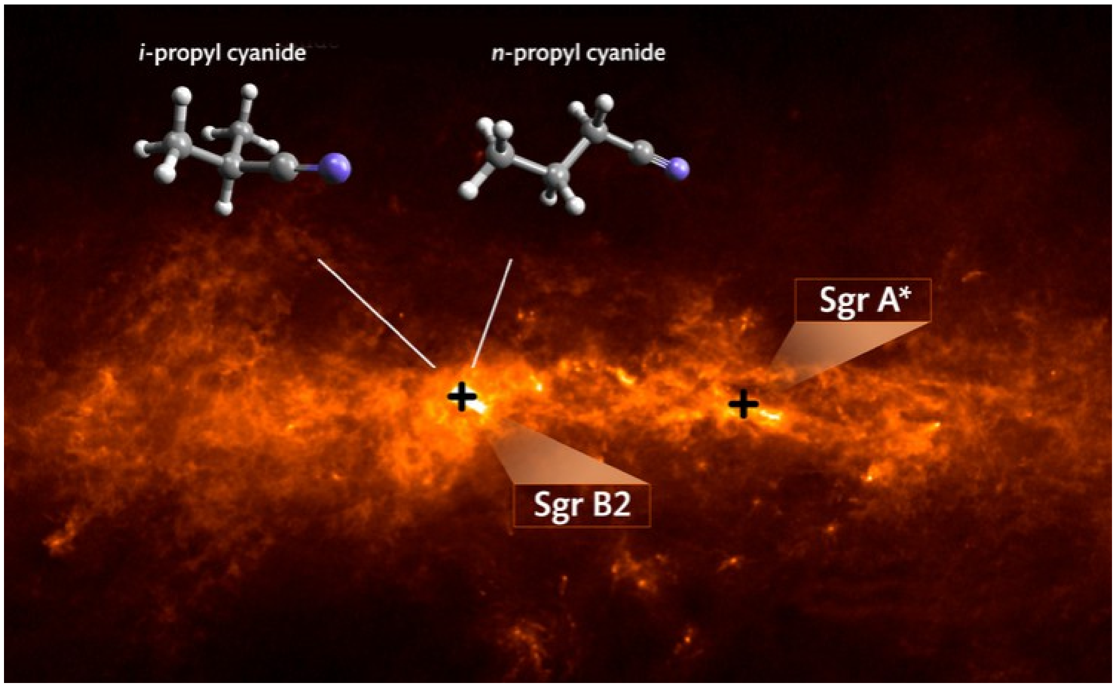


6 lines of glycolaldehyde detected

Jorgensen et al. 2013

ISM, star formation and astrochemistry

The star forming region Sgr B2

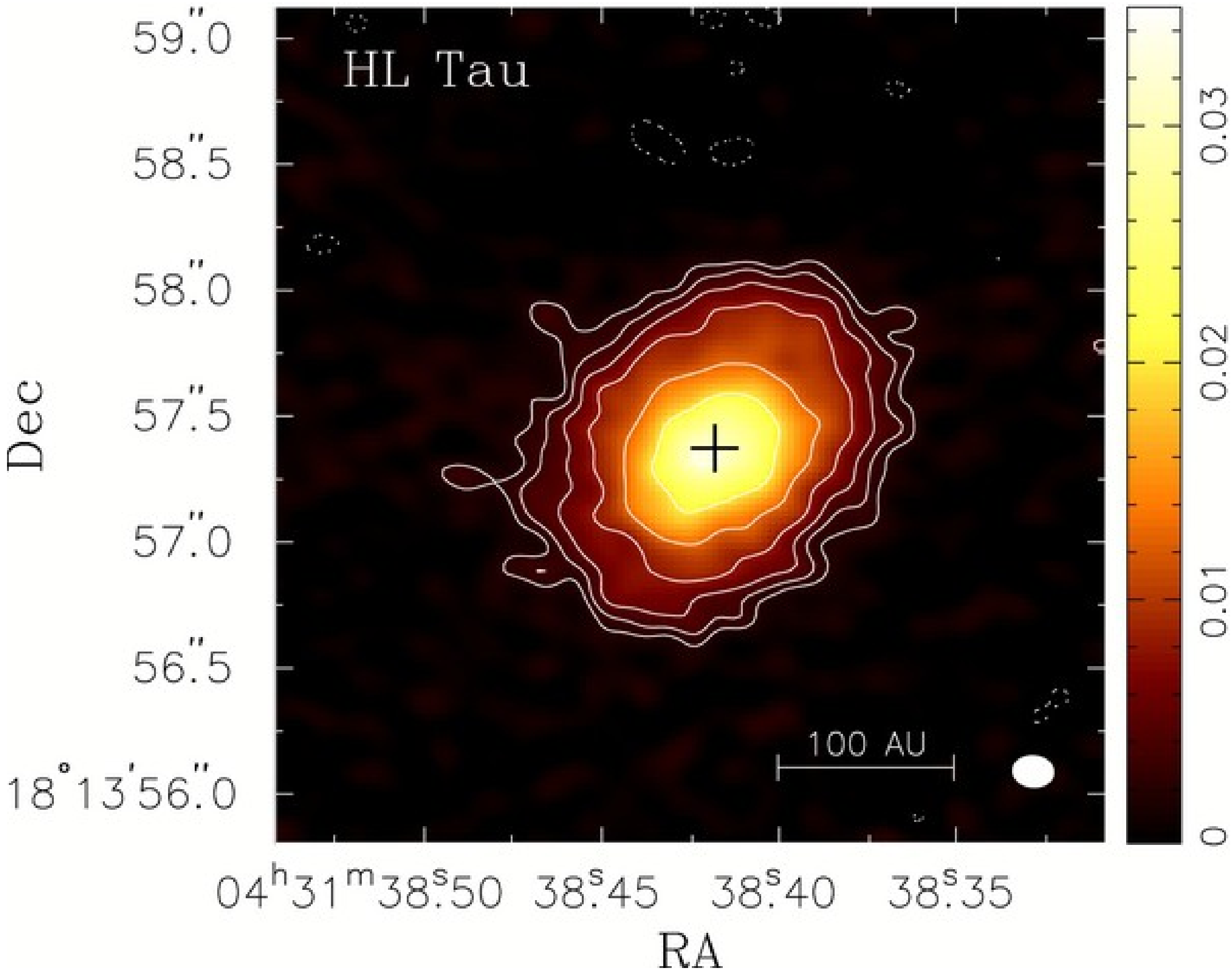


New organic molecules
Iso-propyl cyanide
have been detected by ALMA
in the star forming region Sgr B2.
Other telescopes to do that
would have need days, while
ALMA needed minutes.

It is a fundamental discovery for
interstellar chemistry is evidence
of the advances that ALMA can
contribute to astronomy.

Belloche et al. 2015; Muller et al., 2015; Higuchi et al., 2015

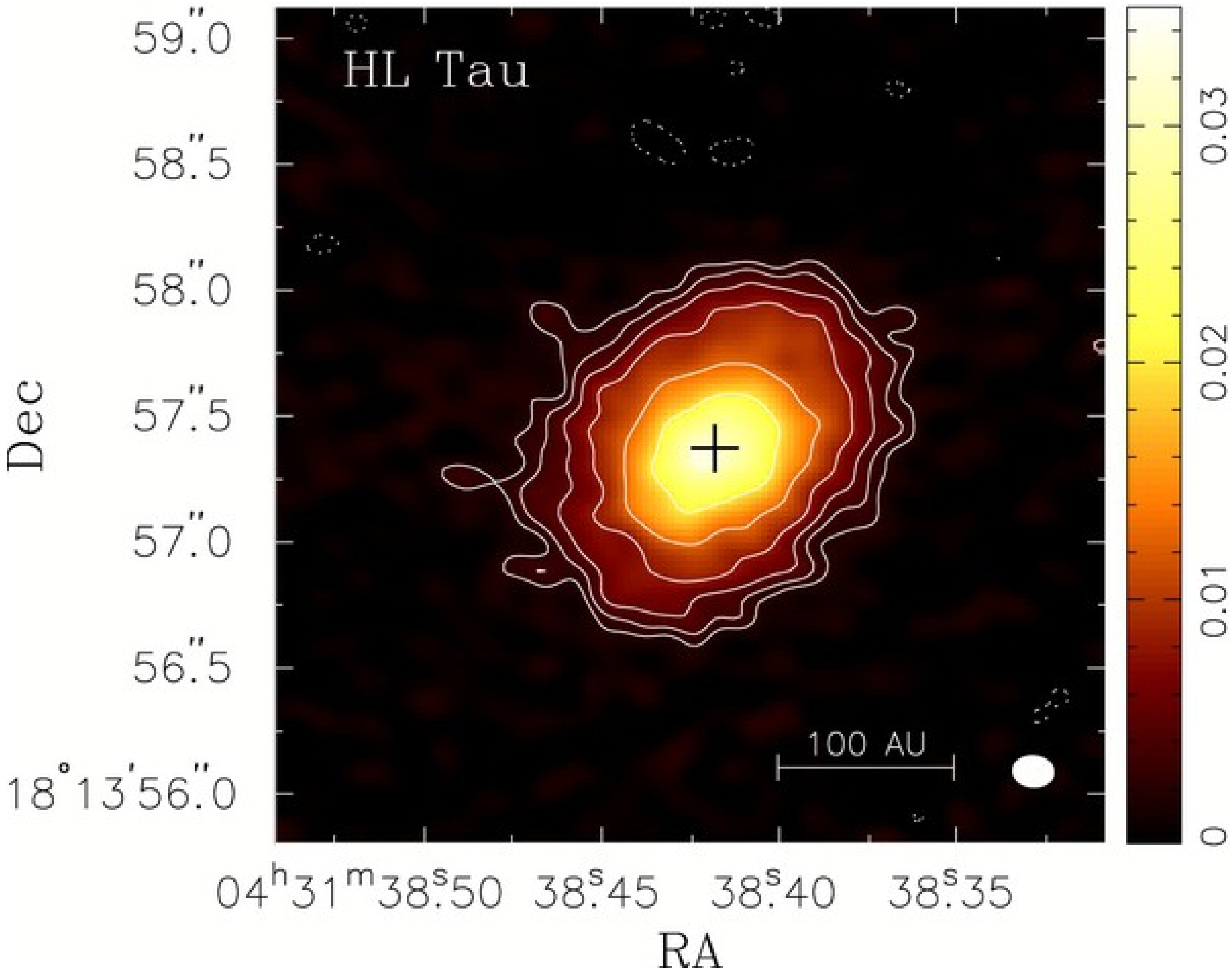
Circumstellar disks....



The proto-planetary disc around the HL Tau star as seen by CARMA.

CARMA observations : 0.17'' x 0.13'' ~18 AU
Kwon et al. 2011

Circumstellar disks....



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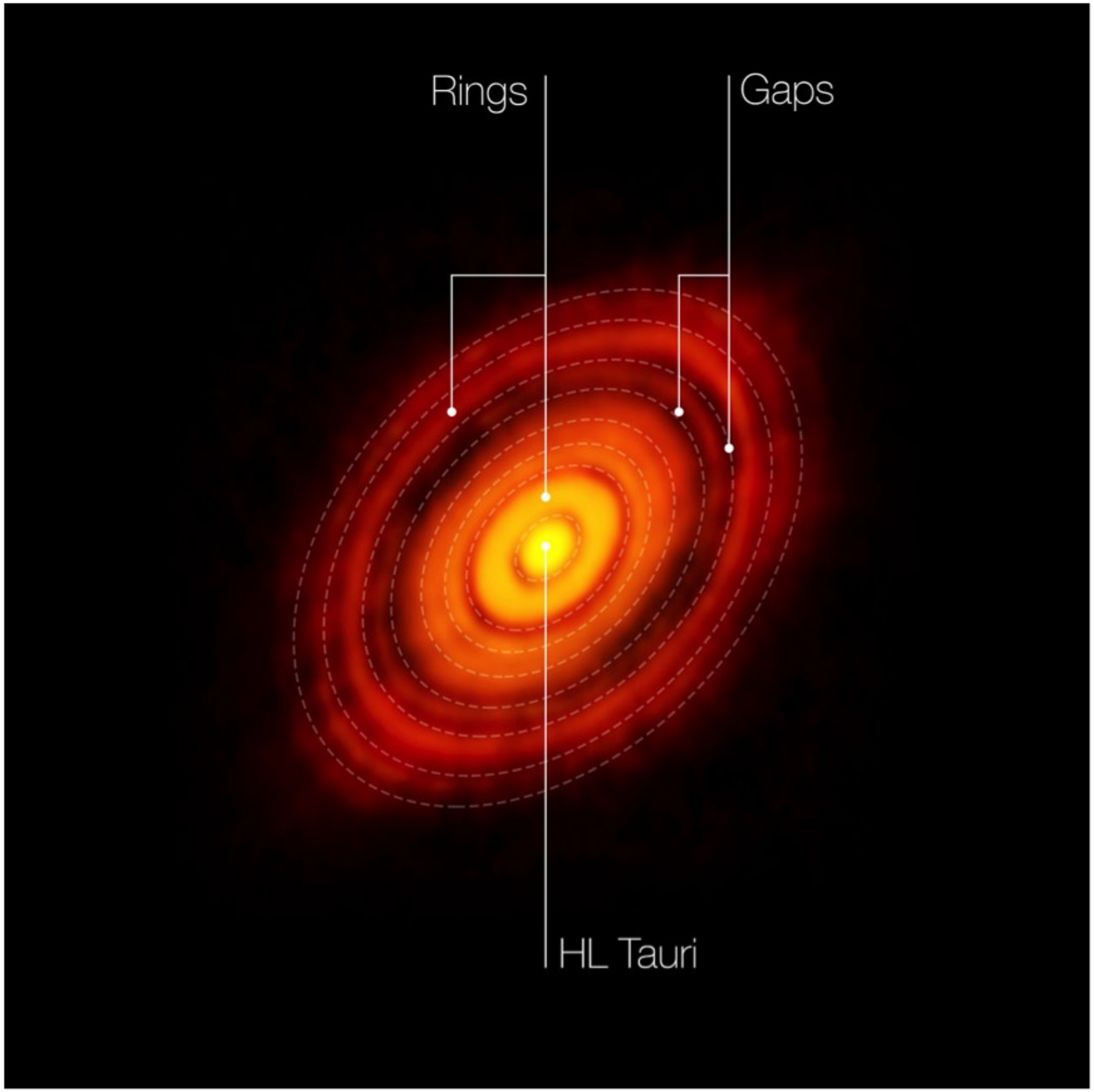
Circumstellar disks....

Long baselines (15 km) science verification

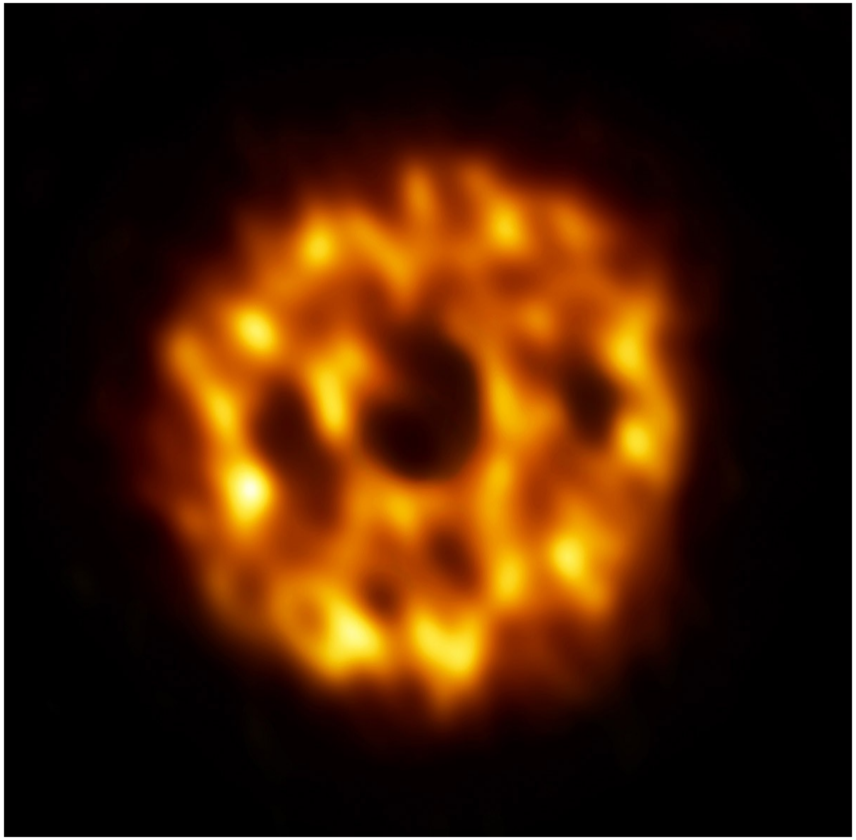


ALMA observations : 0.035''
Partnership ALMA, 2015

ALMA observations of HL Tau reveal substructures within the disc that have never been seen before and even show the possible positions of planets forming.

Resolution to see a penny from ~100 km!

Circumstellar disks....

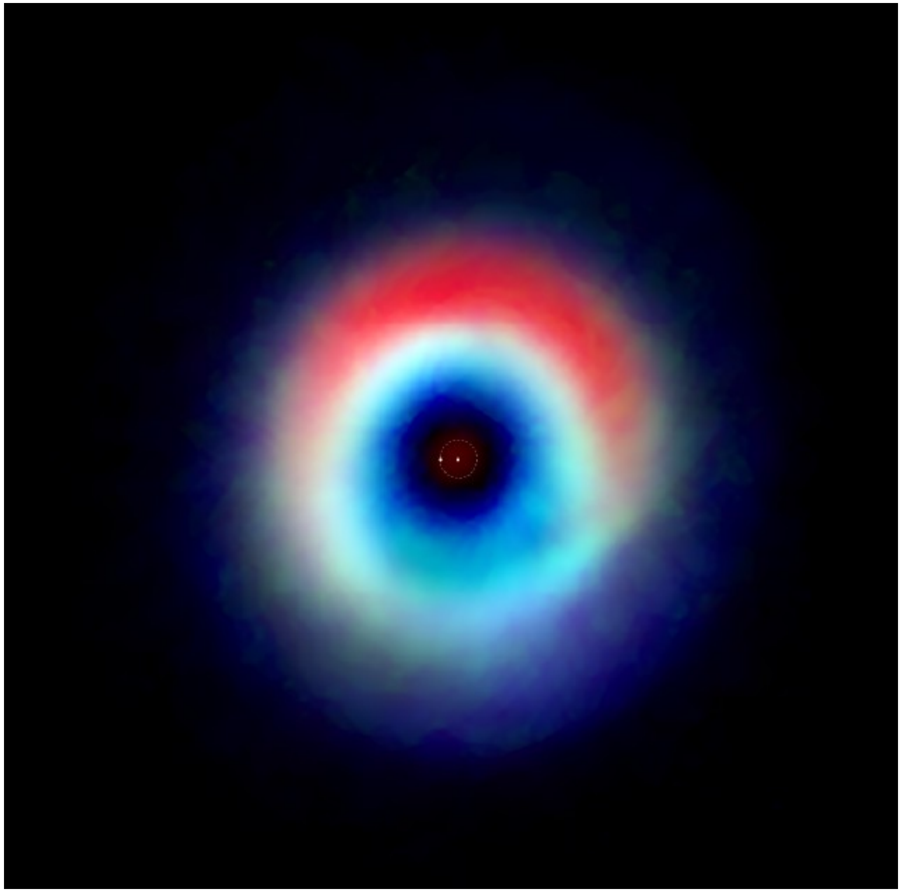


The dust surrounding the star HD 107146, a younger version of our Sun, is thicker in the outer reaches of the disk, and thinner in the inner regions.
This suggests that Pluto-size planetesimals cause smaller grains to smash together.

The dark ring-like structure in the middle may indicate a gap where a planet is sweeping its orbit clear of dust.

1.25 mm continuum, res=1”.15x0”.84
HD 107146
Ricci et al., 2015

Circumstellar disks....

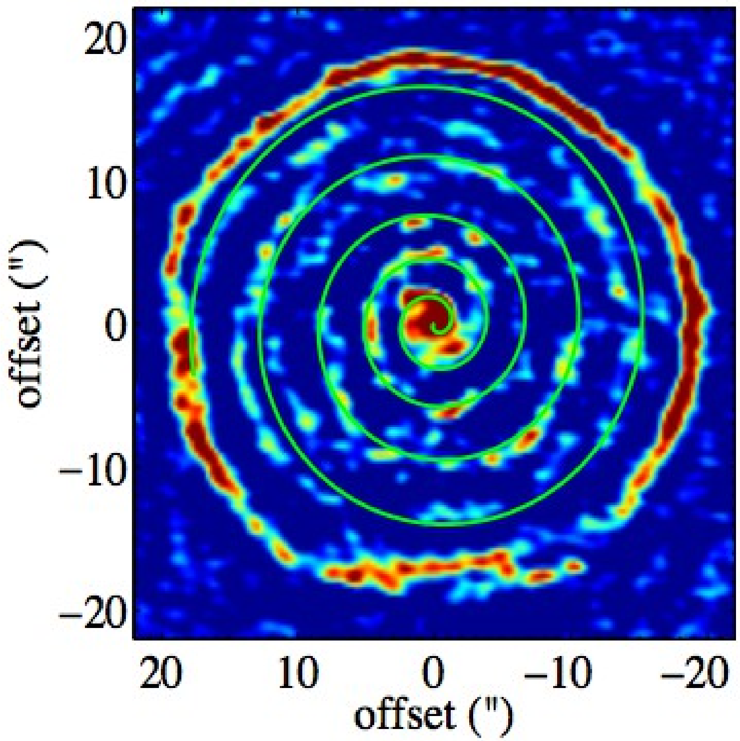


Broad elliptical ring around the double star. The disk begins about 50 times the Sun-Hearth distance.
Most of it consists of gases (^{13}CO and $C^{18}O$, green and blue), but there is a noticeable arc free of gas (red).
In this arc the temperature is so low that the gas turns into ice and sticks to the grains.
This process is thought to act as a strong catalyst for the formation of planetesimals, and planets.

Composite image from ALMA data
HD 142527

Credit: Andrea Isella/Rice University; B. Saxton (NRAO/AUI/NSF);
ALMA (NRAO/ESO/NAOJ

Stellar evolution and Sun

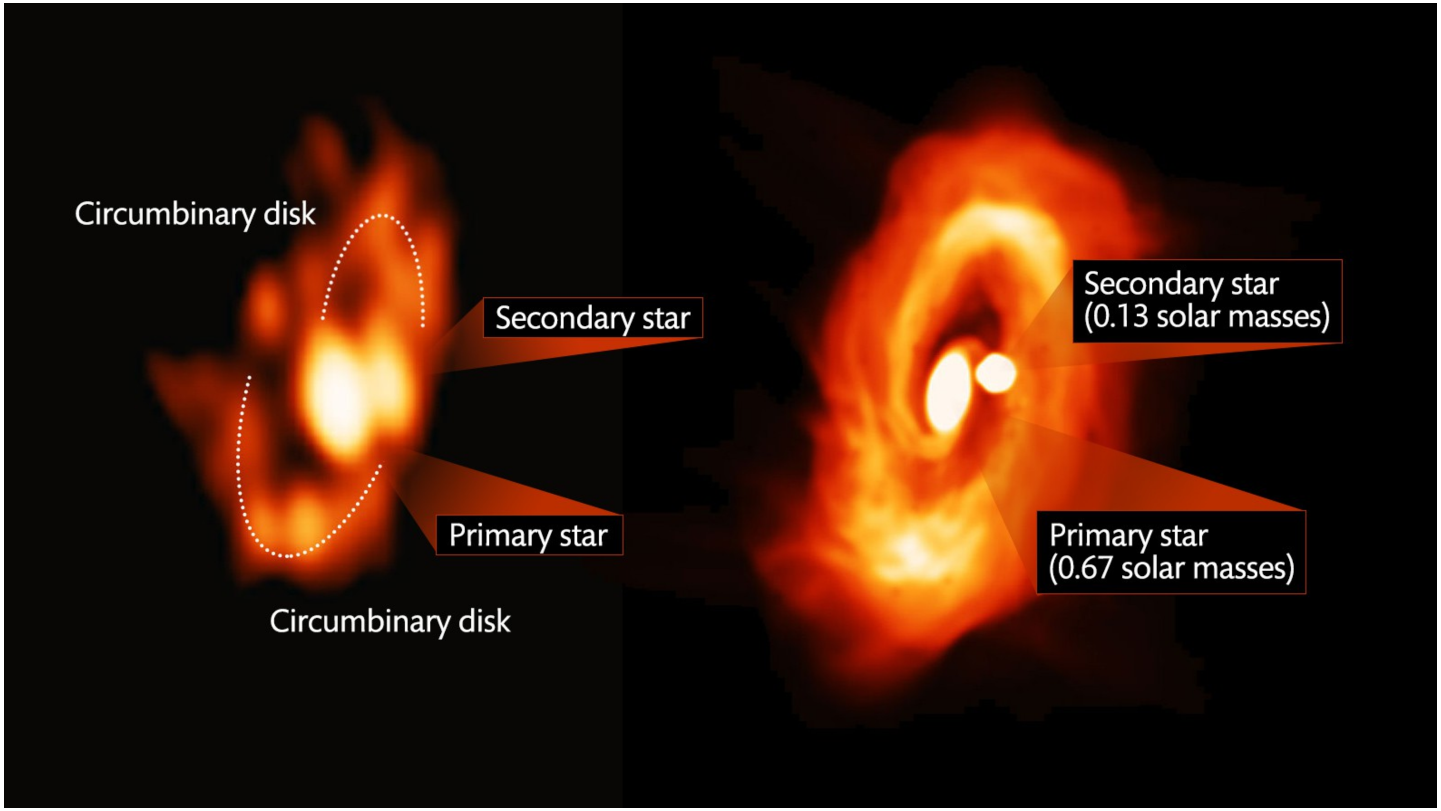


Spiral structures in shell.
An unseen companion
modulates the loss of mass
from the AGB star.

Maerker et al., 2012
Vlemmings et al., 2013

Stellar evolution and Sun

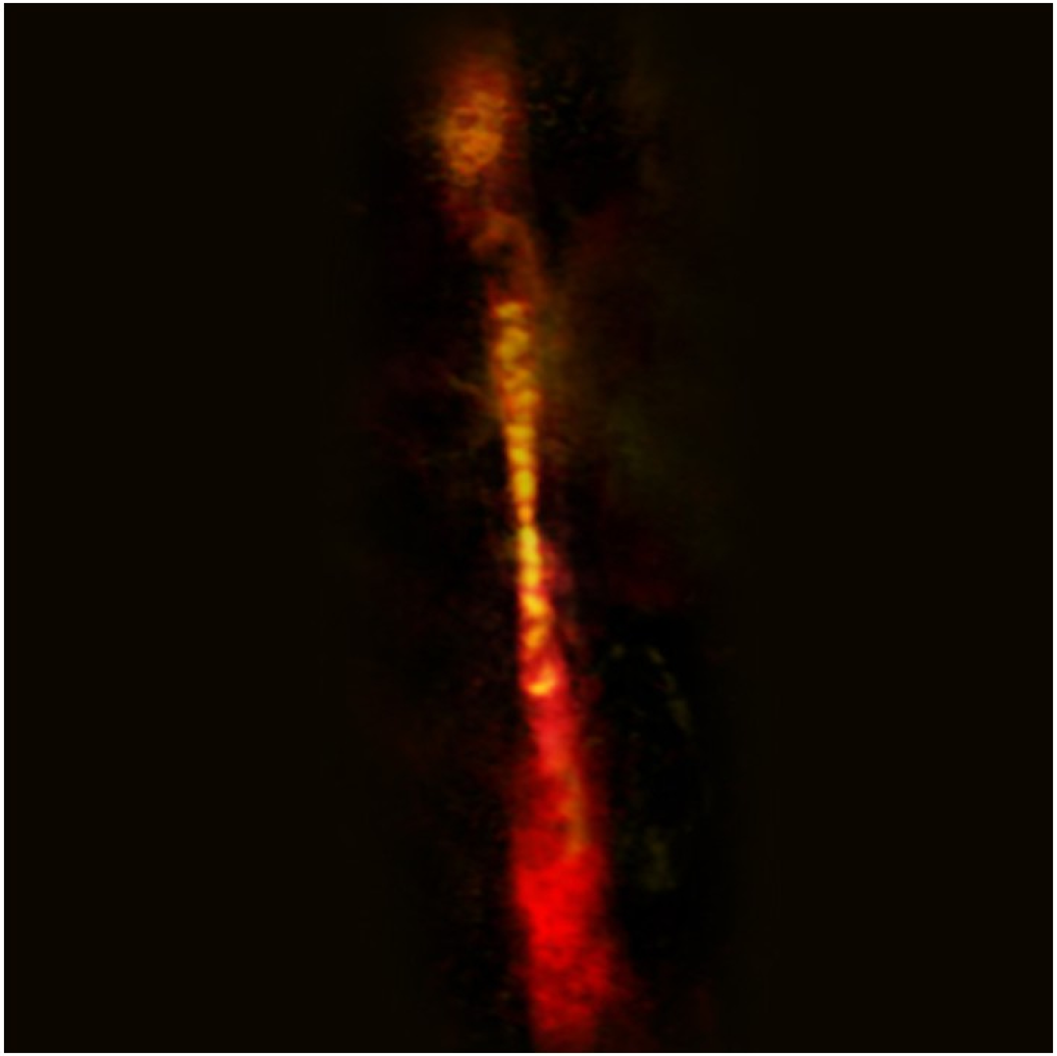
Dust continuum and CO observations of a young binary system reveal the presence of spiral arms around the stars.
These results unveil for the first time the mechanisms of the birth and growth of binary systems.



L1551
Takakuwa et al., 2014

Stellar evolution and Sun

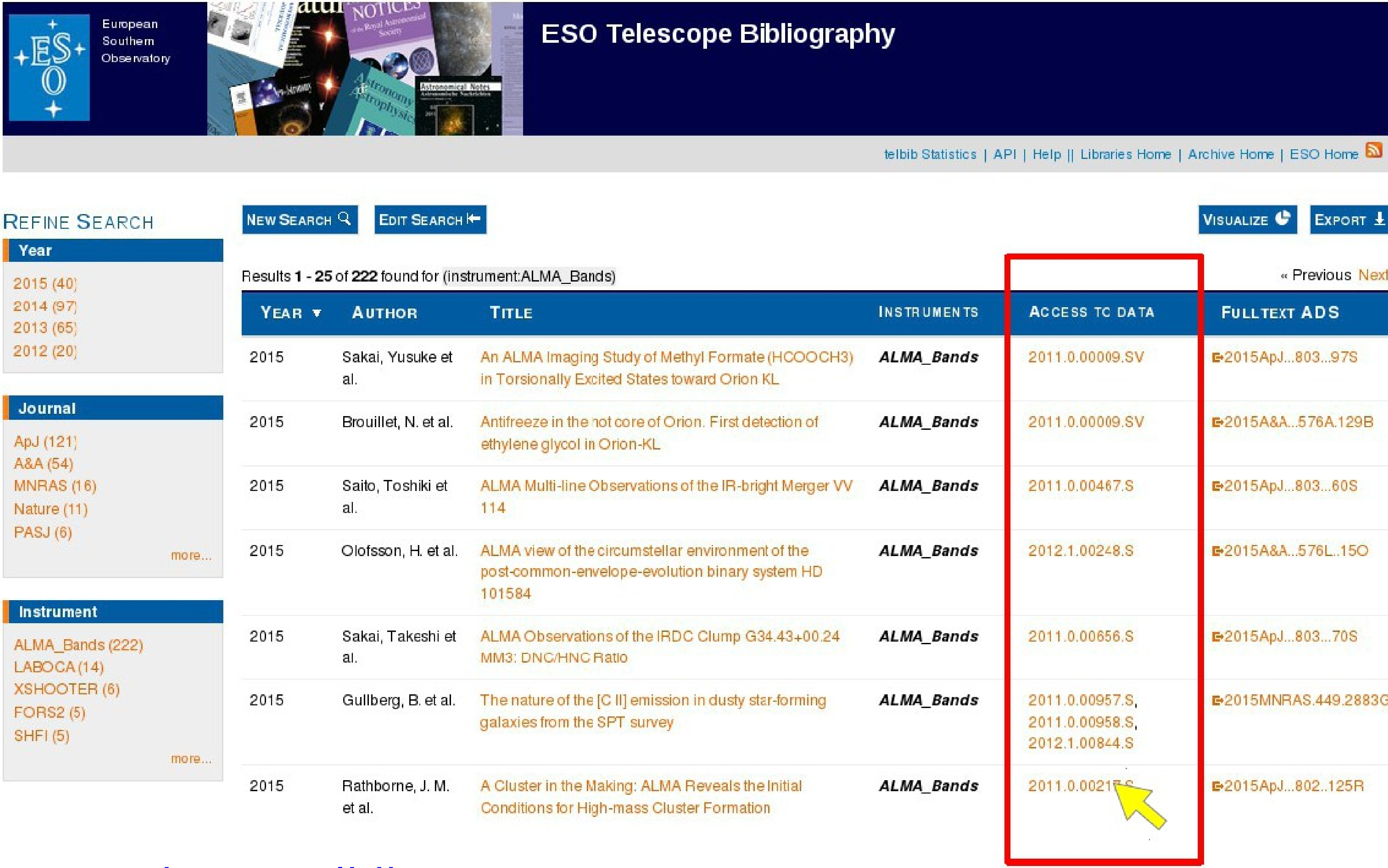
- **The episodic molecular outflow in the very young cluster Serpens South**



Well defined jets have been observed in a protostar.
They seem to turn on and off with startling regularity, alternating from one to the other in ~100 years.
This jets offer an otherwise hidden insight into the environment of the accretion disk surrounding the protostar.

Plunkett et al., 2015

The ESO telbib



European Southern Observatory

ESO Telescope Bibliography

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REFINE SEARCH

Year

2015 (40)
2014 (97)
2013 (65)
2012 (20)

Journal

ApJ (121)
A&A (54)
MNRAS (16)
Nature (11)
PASJ (6)
more...

Instrument

ALMA_Bands (222)
LABOCA (14)
XSHOOTER (6)
FORS2 (5)
SHFI (5)
more...

NEW SEARCH | EDIT SEARCH | VISUALIZE | EXPORT

Results **1** - **25** of **222** found for (instrument:ALMA_Bands)

« Previous Next »

YEAR ▼	AUTHOR	TITLE	INSTRUMENTS	ACCESS TO DATA	FULLTEXT ADS
2015	Sakai, Yusuke et al.	An ALMA Imaging Study of Methyl Formate (HCOOCH3) in Torsionally Excited States toward Orion KL	***ALMA_Bands***	2011.0.00009.SV	2015ApJ...803...97S
2015	Brouillet, N. et al.	Antifreeze in the hot core of Orion. First detection of ethylene glycol in Orion-KL	***ALMA_Bands***	2011.0.00009.SV	2015A&A...576A.129B
2015	Saito, Toshiki et al.	ALMA Multi-line Observations of the IR-bright Merger VV 114	***ALMA_Bands***	2011.0.00467.S	2015ApJ...803...60S
2015	Olofsson, H. et al.	ALMA view of the circumstellar environment of the post-common-envelope-evolution binary system HD 101584	***ALMA_Bands***	2012.1.00248.S	2015A&A...576L..15O
2015	Sakai, Takeshi et al.	ALMA Observations of the IRDC Clump G34.43+00.24 MM3: DNC/HNC Ratio	***ALMA_Bands***	2011.0.00656.S	2015ApJ...803...70S
2015	Gullberg, B. et al.	The nature of the [C II] emission in dusty star-forming galaxies from the SPT survey	***ALMA_Bands***	2011.0.00957.S, 2011.0.00958.S, 2012.1.00844.S	2015MNRAS.449.2883G
2015	Rathborne, J. M. et al.	A Cluster in the Making: ALMA Reveals the Initial Conditions for High-mass Cluster Formation	***ALMA_Bands***	2011.0.0021	2015ApJ...802..125R

http://telbib.eso.org/

Direct link to the ALMA Archive

ALMA Cycle 4 pre-announcement

Antennas	at least 40 x 12m + 10 ACA + 3TP		
Bands	3,4,6,	7,	8,9,10
Max baselines	12.8	5.3	2.7 Km
Polarization	full on-axis	no	no

ACA stand-alon
Solar
Mm VLBI

Observing time 3000 hrs for 12m and 1800 for ACA

- **22 March: call for proposals and ALMA Science Portal opening**
- **21 April: proposal submission deadline**
- **August: outcome of the proposal review process**
- **1 October: Start of Cycle 4 Science Observations**
- **30 September 2017: End of Cycle 4**
  hrs available for scientific projects will be announced in the call

ALMA Cycle 4

Observing bands

Band	Frequency (GHz)	Wavelength (mm)	FOV (arcsec)	Cont Sens (mJy/beam)
3	84 – 116	2.6 – 3.6	73 – 53	0.084
4	125 – 163	1.8 – 2.4	49 – 38	0.097
6	211 – 275	1.1 – 1.4	29 – 22	0.11
7	275 – 373	0.8 – 1.1	22 – 16	0.18
8	385 – 500	0.6 – 0.8	16 – 12	0.35
9	602 – 720	0.4 – 0.5	10 – 8.5	1.41
10	787 – 950	0.3 – 0.4	7.8 – 6.5	3.44

ALMA Cycle 4

Non standard observing modes

Cycle 4 includes

- **standard** modes: those already used in previous cycles, and for which the data can be reduced by the pipeline

- **non-standard** observing modes

are less well characterized and the data need to be processed manually by ALMA staff. Up to **20%** of the total observing time will be assigned to such projects.

- Bands 8,9, and 10
- Band 7 Long baselines (>2.7 km)
- Polarization
- Spectral Scan
- Solar observations
- VLBI observations
- Non standard calibrations

ALMA Cycle 4

Large programs

Cycle 4 includes

- > 50 hours with the 12-m array or ACA stand-alone or both if needed for short spacing

- Only standard observing modes

- Proposal format different from regular proposals

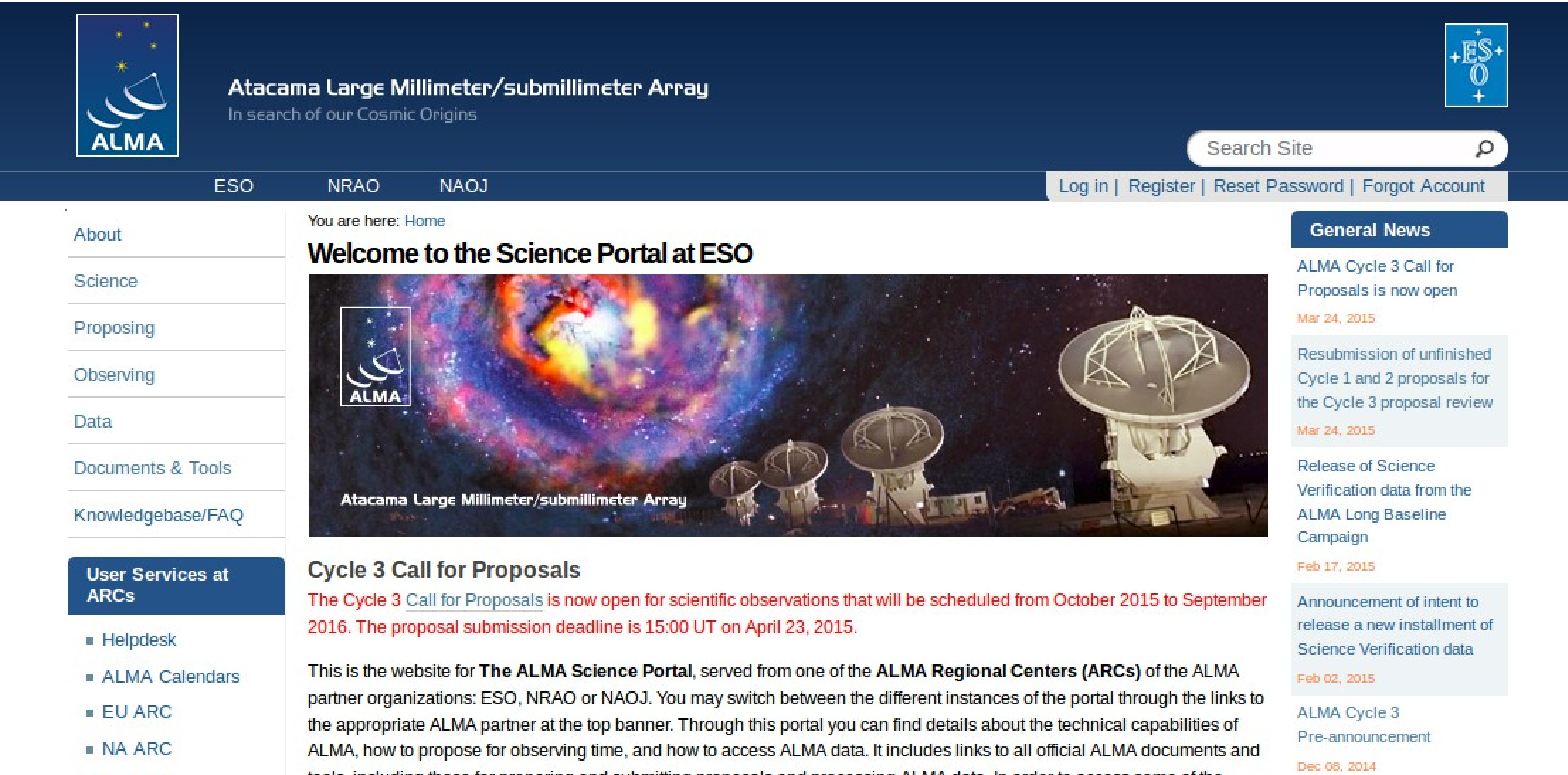
- In addition to PI and co-I, any number of co-PIs can be designated

- 15% of the time will be allocated to Large Programs (~450 hrs for 12 m array and 270 for ACA stand-alone)

ALMA Cycle 4

How to submit a proposal

- Register to the ALMA Science Portal
  http://almascience.eso.org

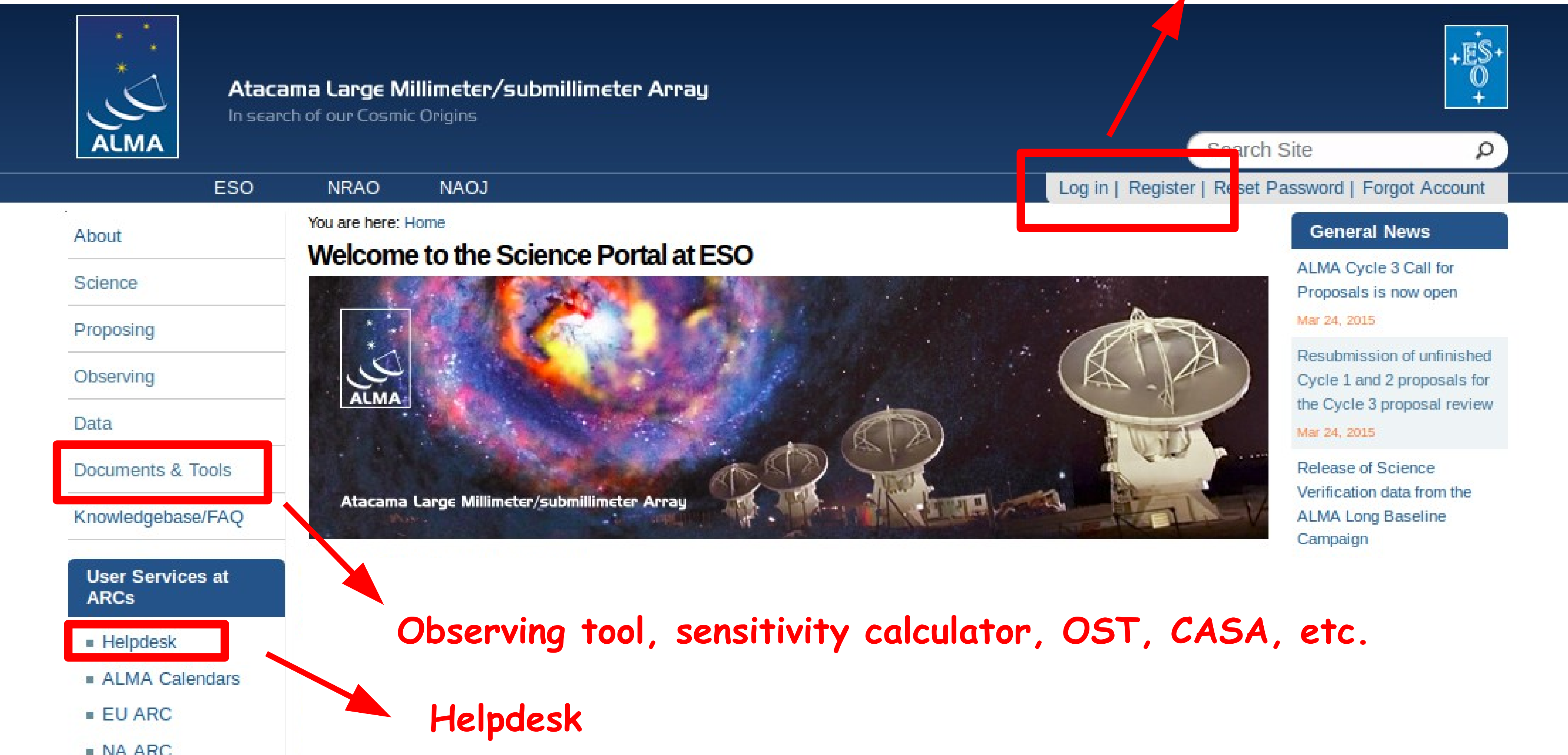


ALMA Cycle 3

How to submit a proposal

- Register to the ALMA Science Portal **http://almascience.eso.org**

Login & Registration

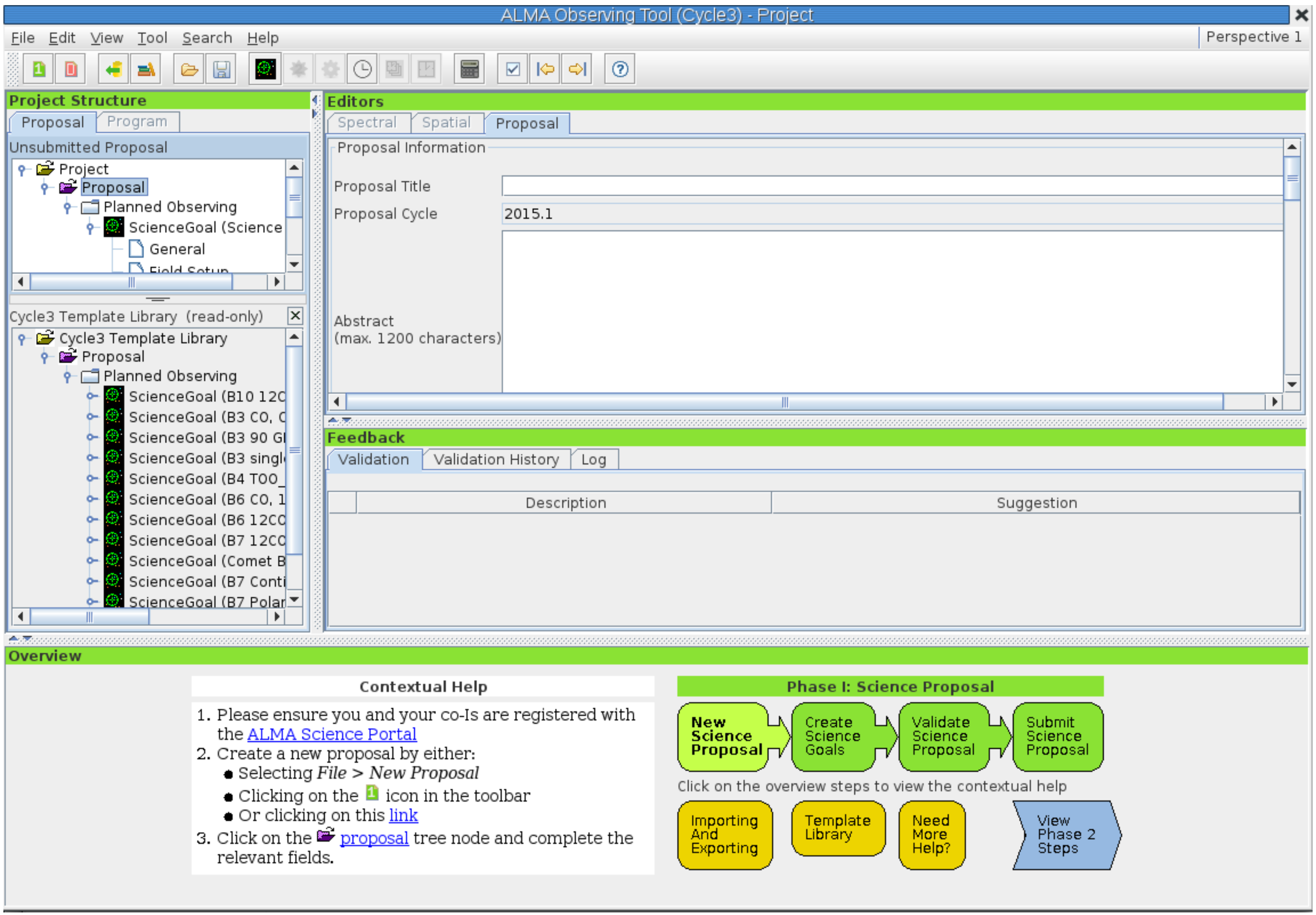


Observing tool, sensitivity calculator, OST, CASA, etc.

Helpdesk

Proposal preparation

✯ The observing tool (OT) is a Java application used for the preparation and submission of ALMA proposals, and for phase II materials.



Proposal preparation

- The OT to be used for cycle 4 observations will be released with the call for proposals.
  It includes a sensitivity calculator and viewers to assist with correlator setup and mapping parameters

  For details on the OT:

- Observing tool documentation is available

- You can ask questions through the helpdesk

Proposal preparation
fundamental observational parameters

ALMA is a very flexible instrument, data can be obtained over a wide range of observational parameters, which must be defined and justified in the proposal. Careful choises are required to ensure that the project's scientific aim can be met.

Angular resolution and maximum recoverable scale

Due to the nature of interferometers only a descrete set of angular scales is observed. Consider that some emission can be filtered out in a given baseline distribution.

$$\theta_{res} \propto \frac{\lambda}{b_{max}}$$

$$\theta_{max} \propto \frac{\lambda}{b_{min}}$$

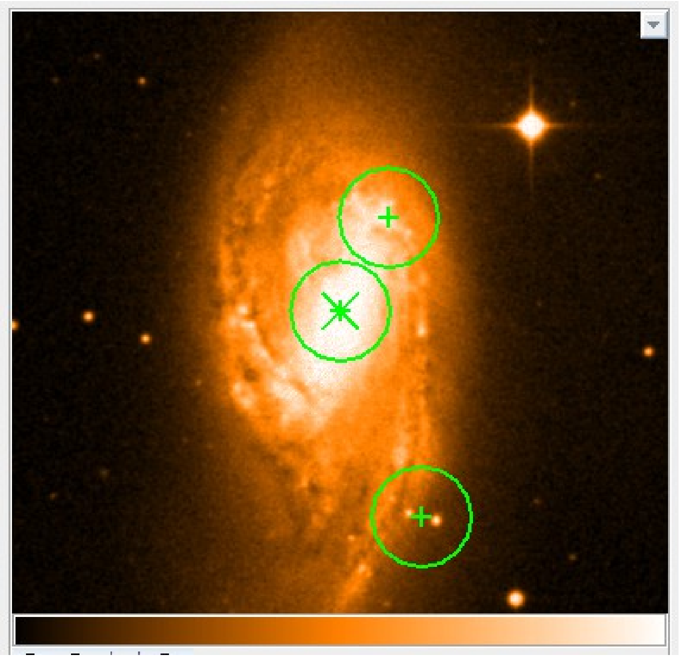
Proposal preparation
fundamental observational parameters

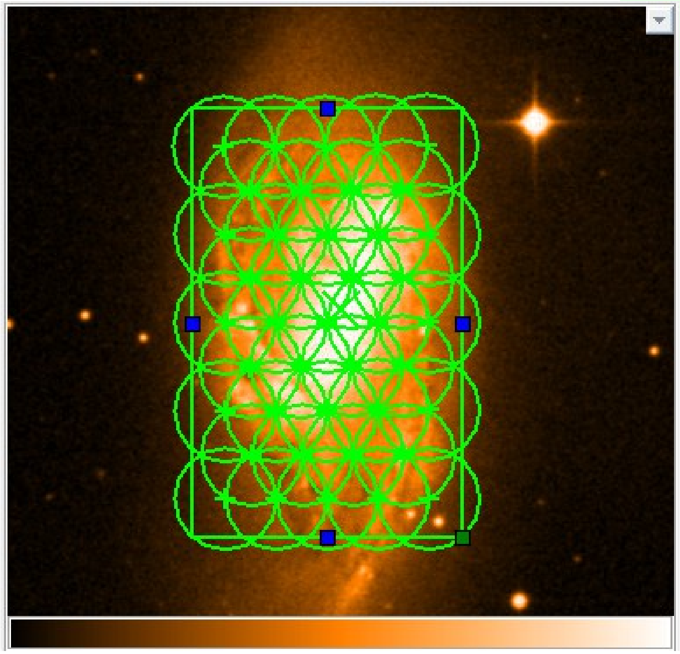
Field of view

To get images larger than the interferometer FOV with flat sensitivity, observations can be obtained observing in series many adjacent locations on the sky. Mosaics can be costly in terms of observing time.

The OT spatial visualizer allows to define pointings and mosaic regions

$$FOV \propto \frac{\lambda}{D}$$





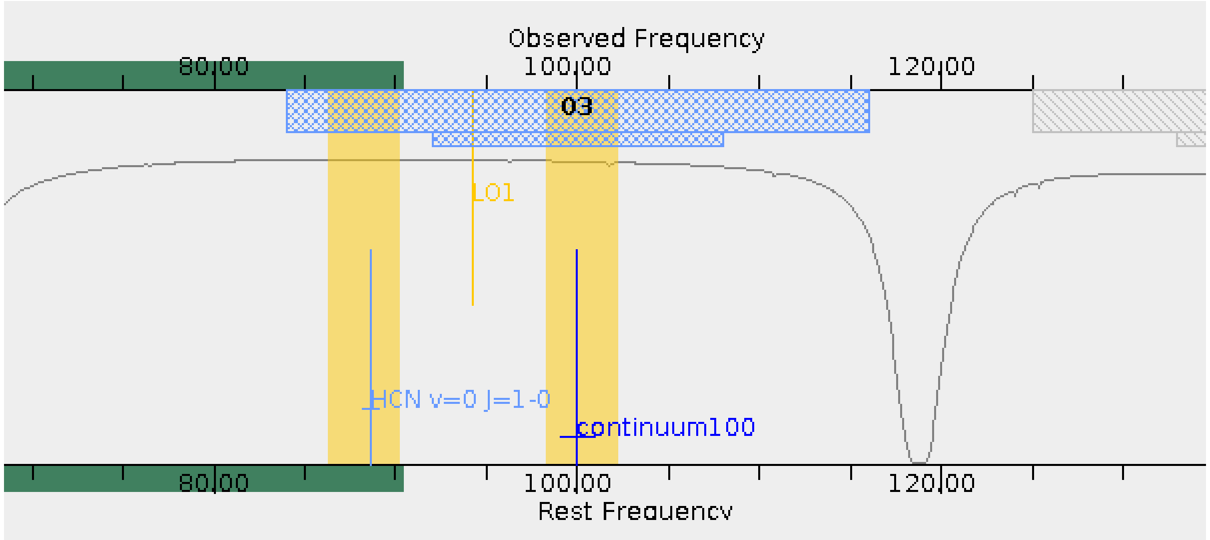
Proposal preparation
fundamental observational parameters

$$\sigma \propto \frac{T_{sys}}{A_{eff}\sqrt{N(N-1)\Delta\nu\tau}}$$

Spectral resolution

minimum separation in frequency whereby adjacent independent features can be distinguished.
For continuum observations or very broad spectral lines, wide bandwidths and low spectral resolution are used. Maximum bandwidth: 7.5 GHz.
For spectral lines, narrower bandwidths with higher spectral resolution channels may be required. Sensitivity will decrease.
A combination of high and low resolution spw can be chosen.

- The OT spectral viewer helps in setting the spectral choises.

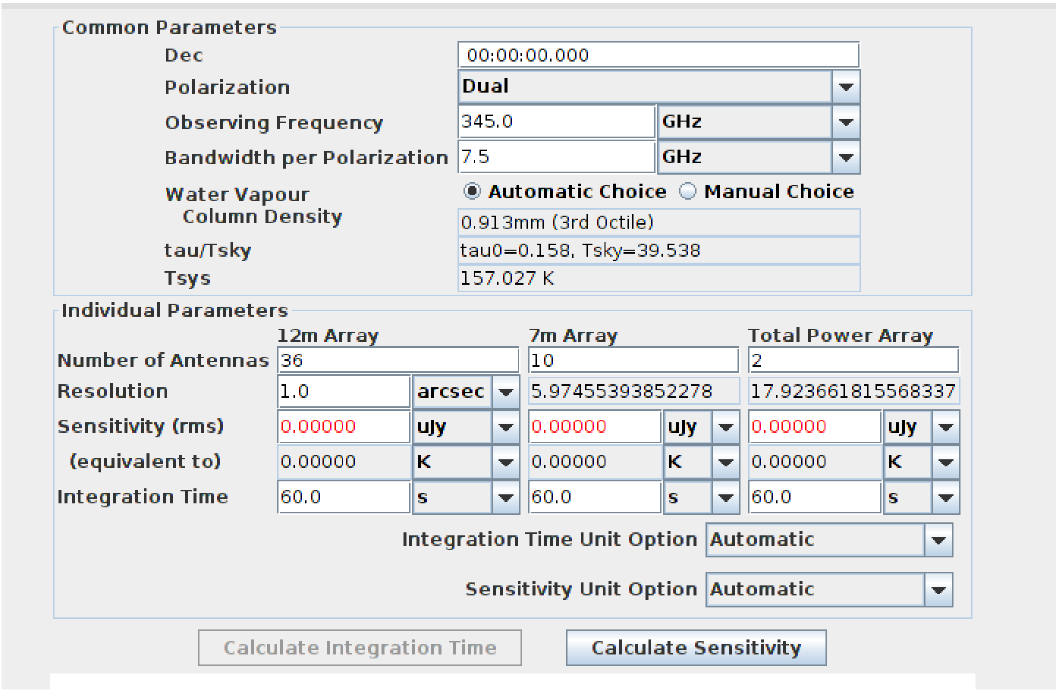


Proposal preparation
fundamental observational parameters

Sensitivity

https://almascience.eso.org/proposing/sensitivity-calculator

$$\sigma \propto \frac{T_{sys}}{A_{eff}\sqrt{N(N-1)\Delta\nu\,\tau}}$$



ALMA proposals ask for sensitivity not observing time. Ideally S/N ~ 5, S/N < 3 must be fully justified

Some a priori knowledge of source size and emission distribution are important when estimating the required sensitivity of an ALMA observation starting from previous measures.

A source bright in 30” beam, maybe difficult to detect in a 1” beam if the emission is spread over a few arcseconds. If smoothly spread over 30” it may have a flux density only $(1/30)^2$ as bright.

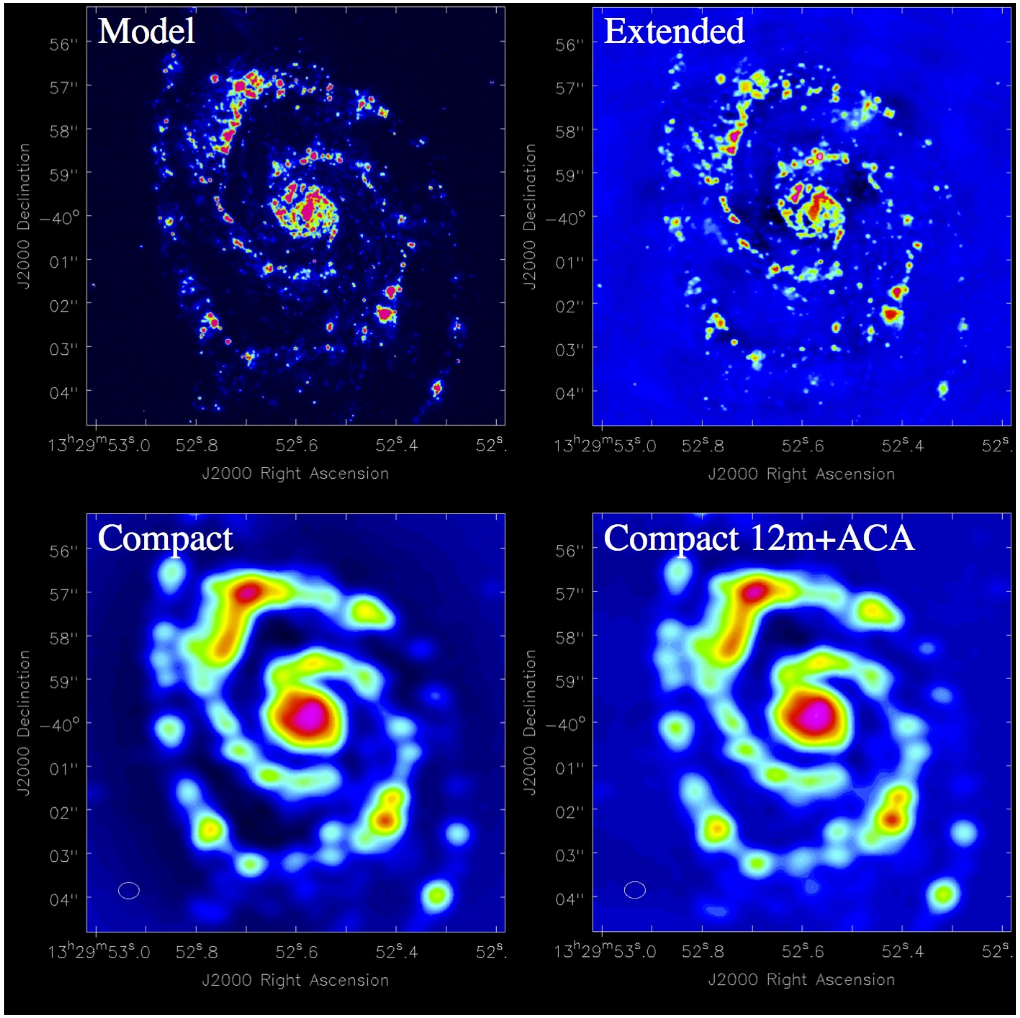
Proposal preparation
ALMA simulation tools

In planning observations of complex fields uv-coverage can be as important to consider as sensitivity. Having a reasonable model for the source structure simulations of ALMA observations can be done.

- **CASA (Common Astronomy Software Application)**
  tasks simalma, simobserve, simanalyze

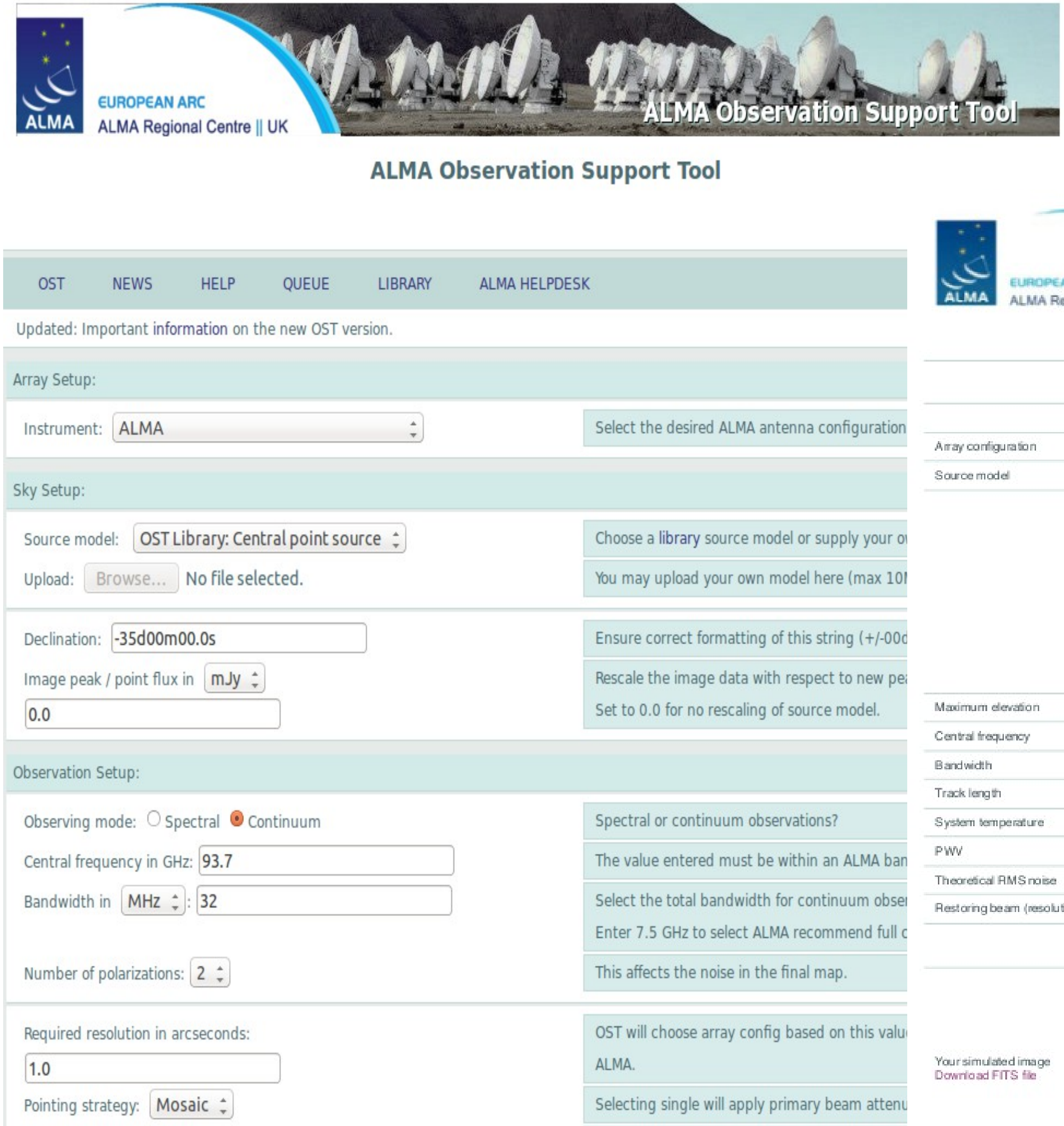
- **Observation Support tool**
  web-based interface
  Less control on the simulation and imaging process than simalma

  In both noise values determined can be different from those calculated with the exposure calculator, and **should not be used in the proposal**

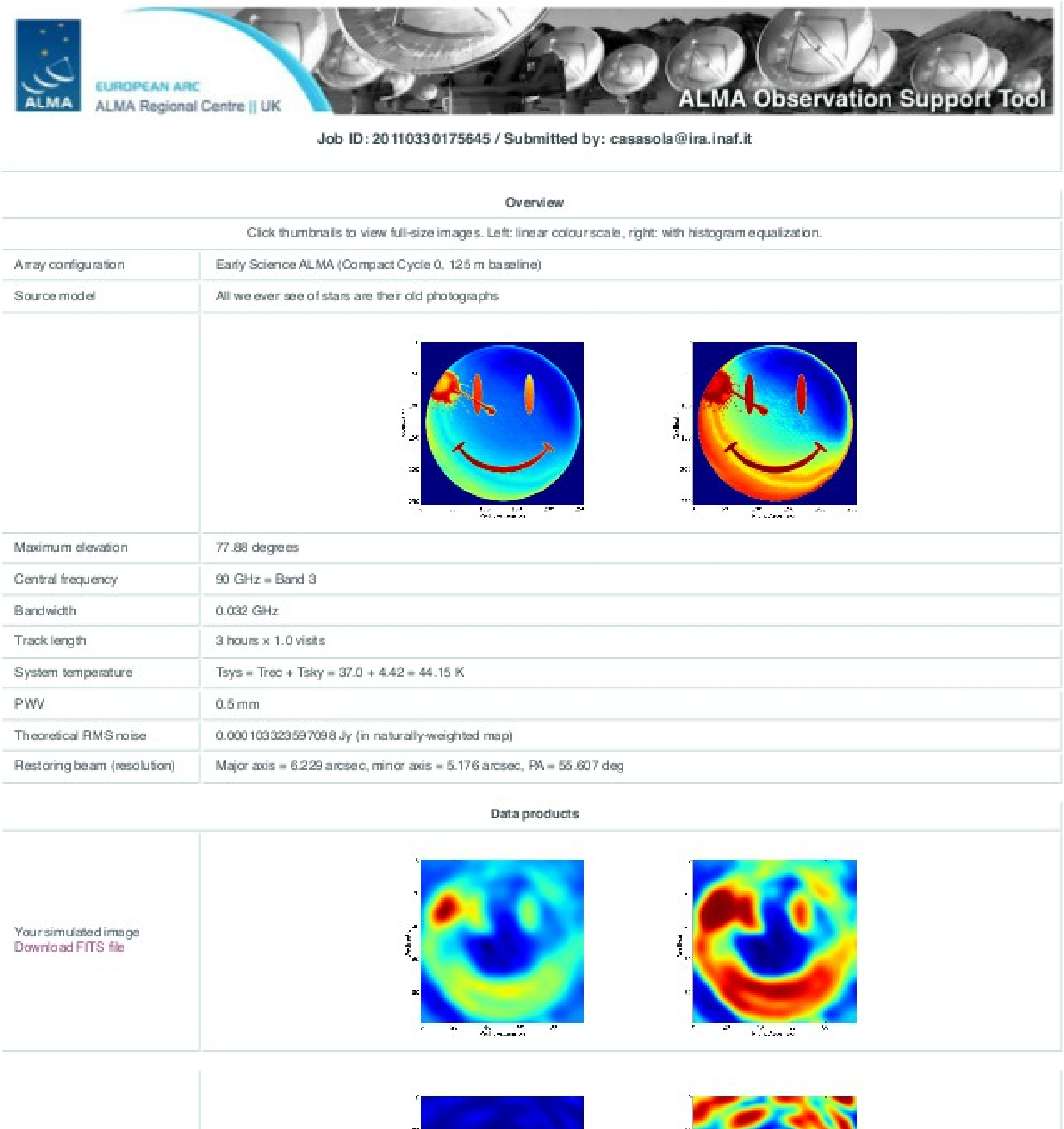


ALMA simulations (Observation Support Tool)

http://almaost.jb.man.ac.uk/



Submit a request for a full simulation of ALMA capabilities for your target
Receive the results via e-mail

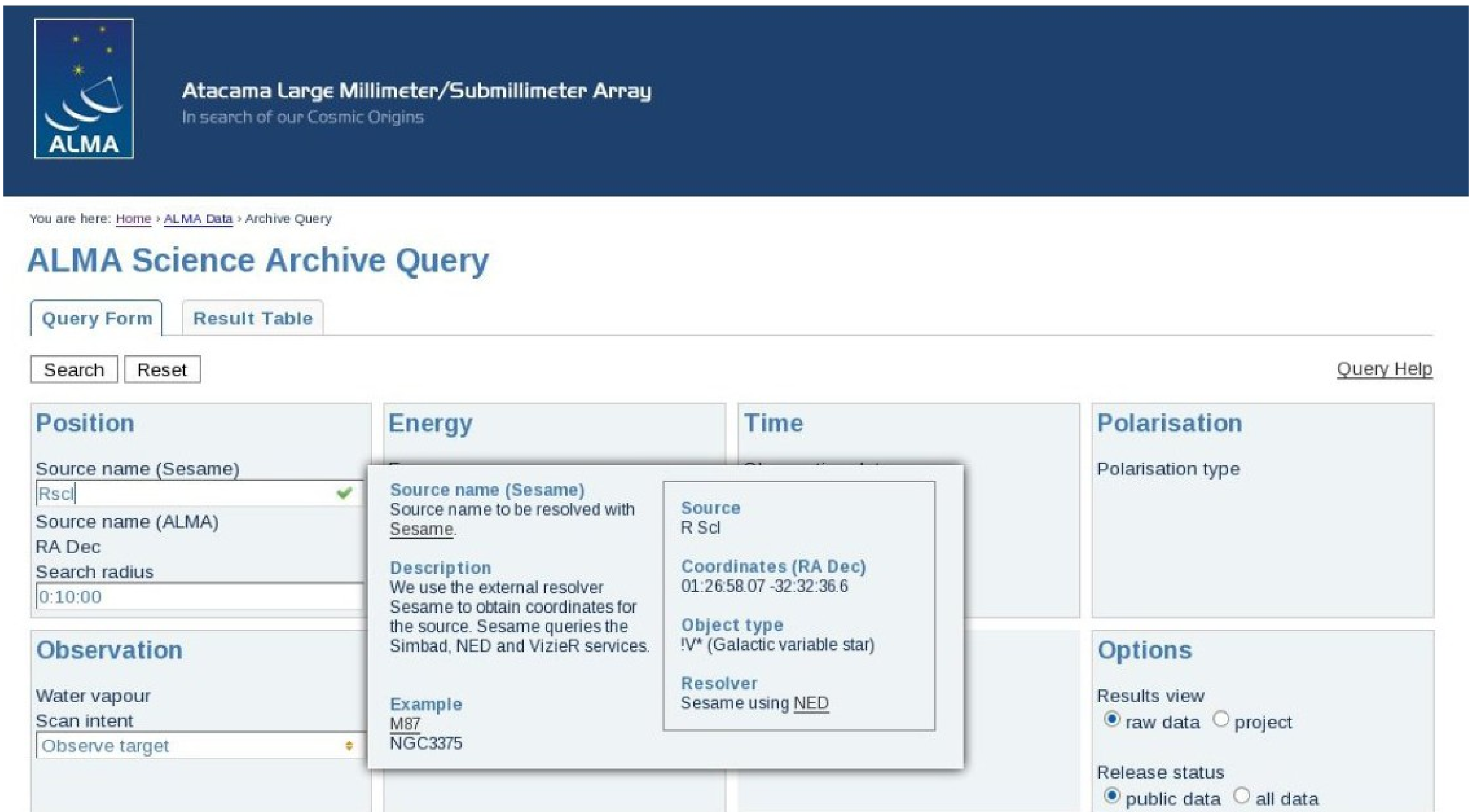


ALMA Archive

A high level principle of ALMA is that identical data should not be taken twice unless scientifically necessary.
Duplication criteria are given in the Call for Proposal.

Check the ALMA archive

http://almascience.org/alma-data/archive



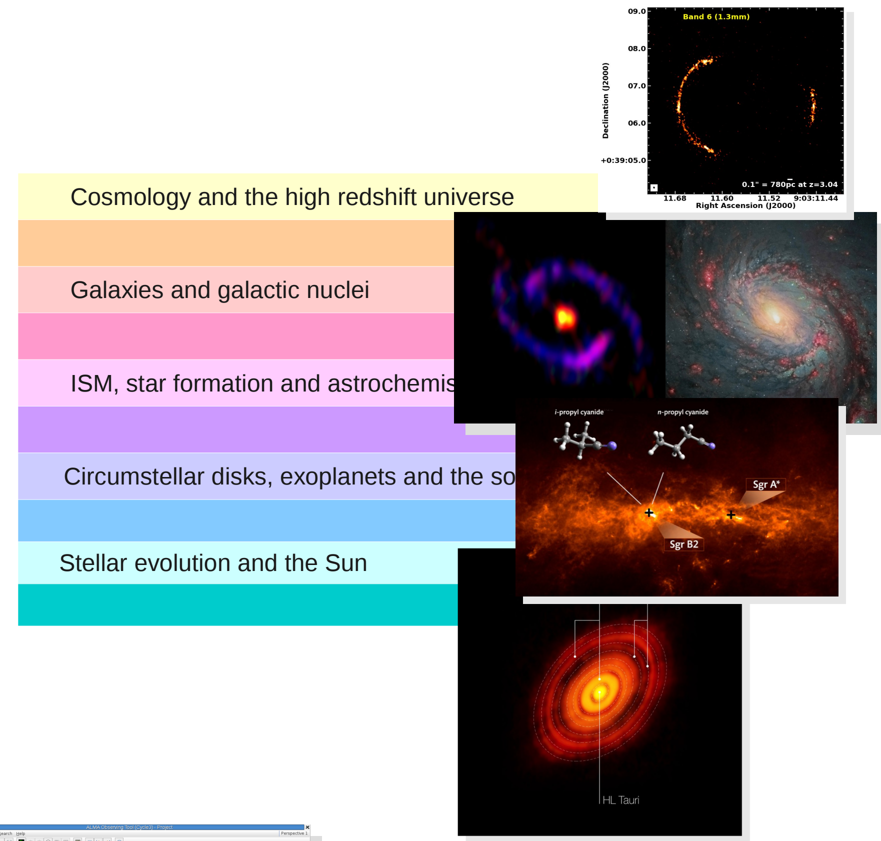
To get help during proposal preparation
or archival data reduction
you can contact us:

help-desk@alma.inaf.it

or book a face-to-face visit @:
Istituto di Radioastronomia Bologna

or contact me:
paladino@ira.inaf.it

Summary

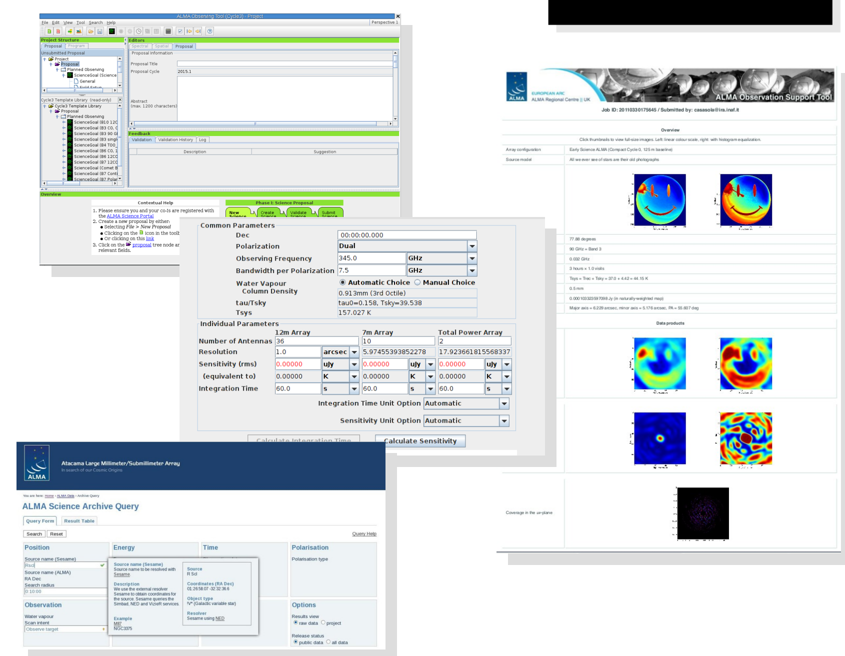


ALMA has already obtained unexpected scientific results

In Cycle 4 ALMA capabilities will furtherly improve

Proposal preparation tools available

Many public data are already available trough the ALMA archive



Grazie