ALMA
Recent Progress
Synergies with VLBI

Robert Laing
European ALMA Instrument Scientist

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Outline

- What is ALMA?
- ALMA and VLBI
- ALMA as it will be
- Early Science
- Current status

Atacama Large Millimetre/ Sub-Millimetre Array

- Aperture synthesis array optimised for millimetre and sub-millimetre wavelengths (1cm - 0.3mm/30 – 950 GHz)
- **H**igh, dry site, Chajnantor Plateau, Chile (5000m)
- 50 dishes with 12m diameter (EU/NA).
- Baselines from ~15m to 14.5km.
- ALMA Compact Array (ACA) provided by Japan
  - 12 7m dishes in compact configurations
    - 4 12m dishes primarily for total-power
- Low-noise, wide-band receivers.
- Digital correlator giving wide range of spectral resolutions.
- Software (dynamic scheduling, imaging, pipelines)

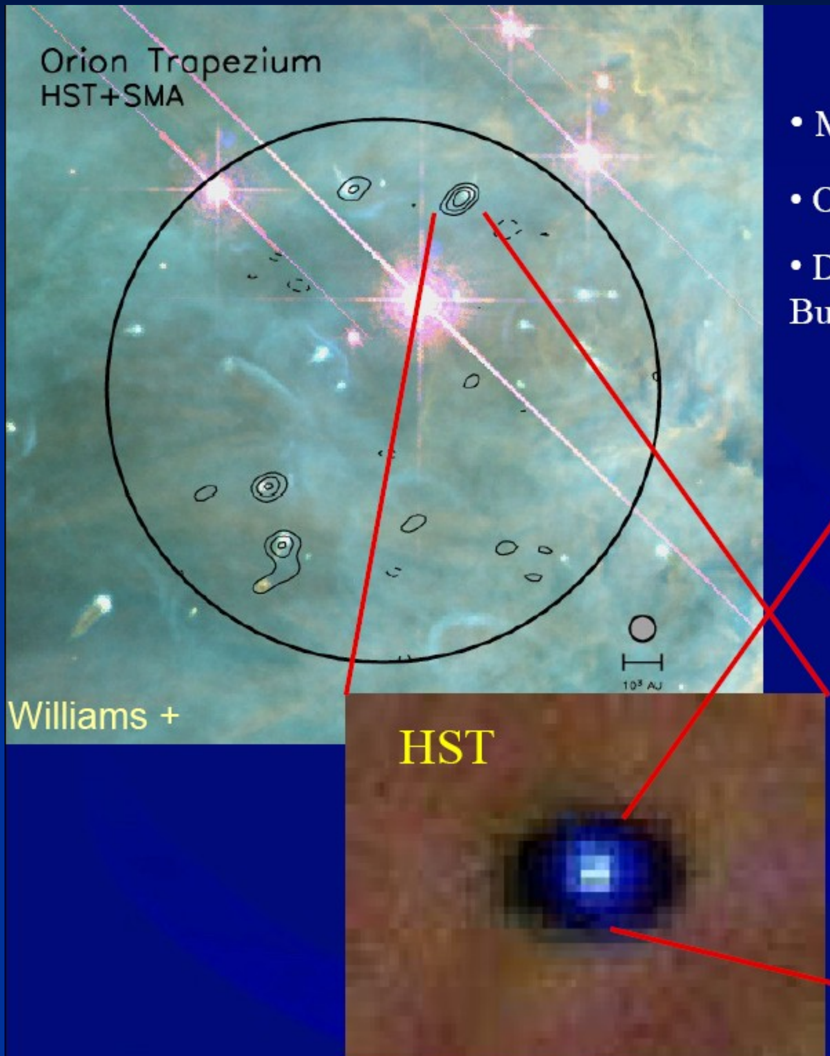
Physical processes

- Aside from non-thermal emission, most of what ALMA will see comes from elements heavier than H and He (except recombination lines, LiH). Therefore probe stellar products.
- Temperatures are < stellar surface – the "Cold Universe"
- Continuum: thermal emission from dust (scattered emission polarized)
- Lines: molecular rotational transitions + redshifted atomic
- Line polarization: Zeeman, Goldreich-Kylafis
- Heating via stellar UV, cosmic rays, hard photons from AGN – hence the link to star and galaxy formation
- Non-thermal mechanisms include synchrotron (lower frequencies; linearly polarized) and Compton scattering (Sunyayev-Zeldovich).

ALMA and VLBI (1)

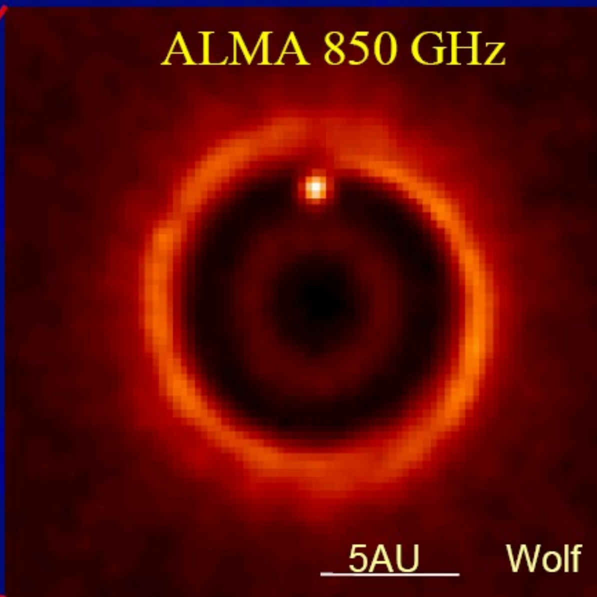
- ALMA probes very similar scales to VLBI arrays
  - 15km at 0.3mm wavelength ↔ 1500km at 3cm
- Emission mechanisms are different e.g.
  - Thermal emission from cold dust, molecular lines, masers ....
  - Synchrotron emission from ultrarelativistic electrons, masers again, HI absorption ....
- Compare the same physical scales in different emission mechanisms

Formation of planets - dust?

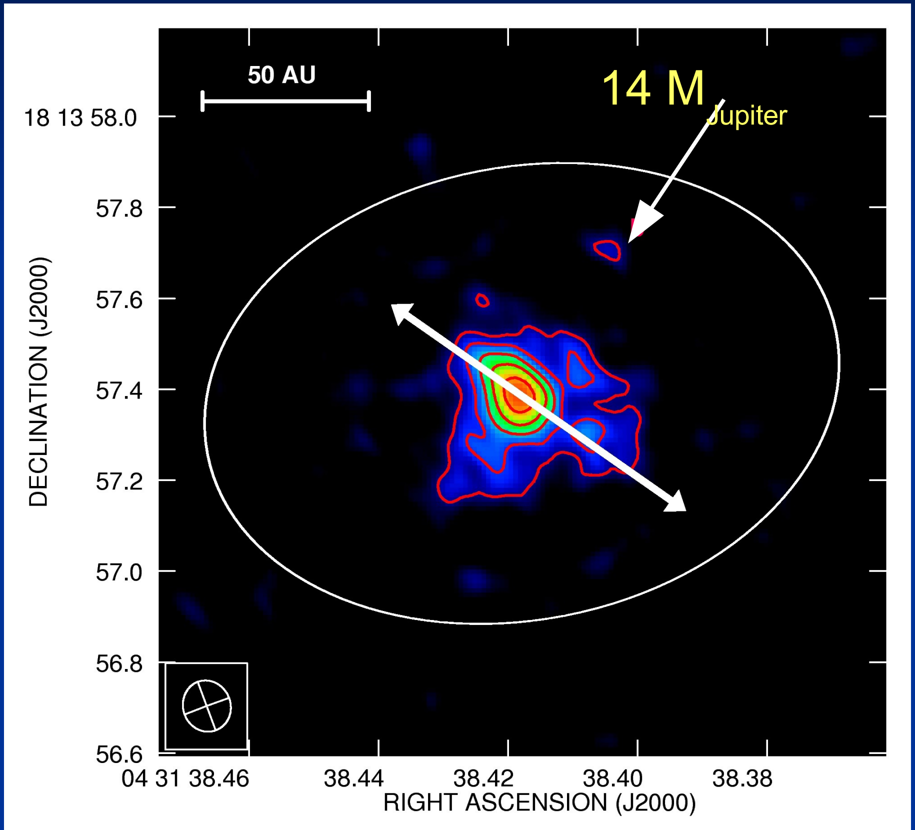


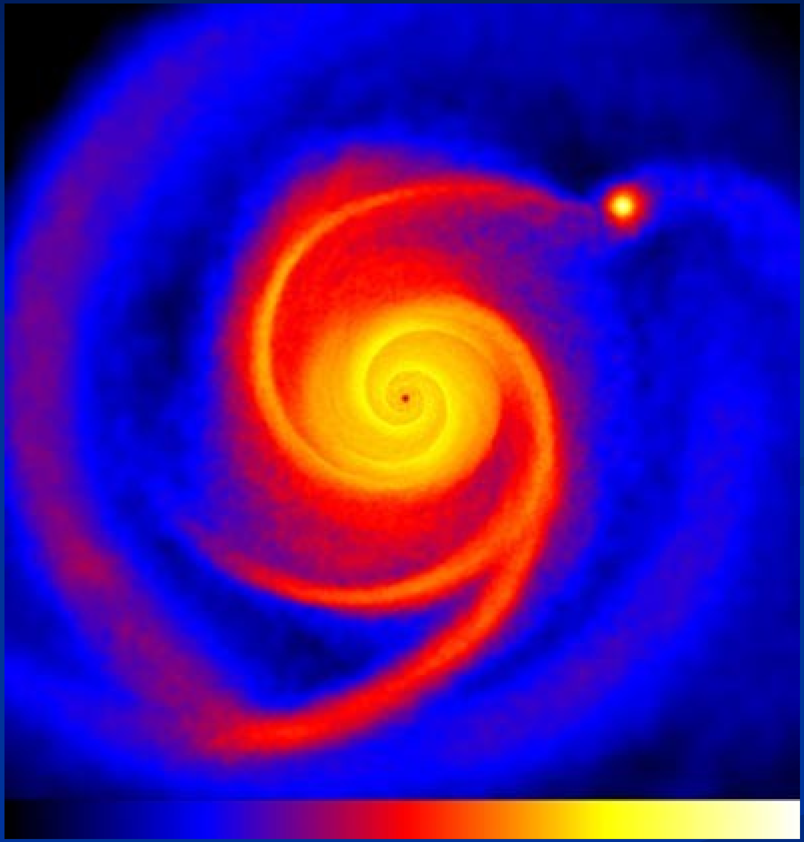
Birth of planets

- M_{planet} / M_{star} = 1.0 M_{Jup} / .5 M_{sun}
- Orbital radius: 5AU at 50pc distance
- Disk mass = circumstellar disk around the Butterfly Star in Taurus



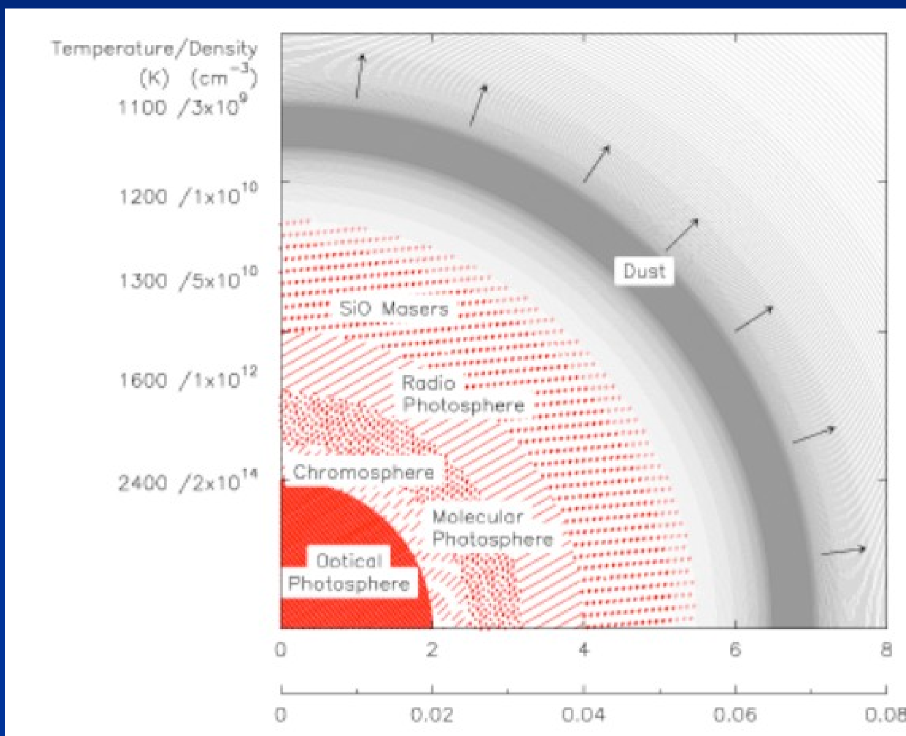
... or pebbles?

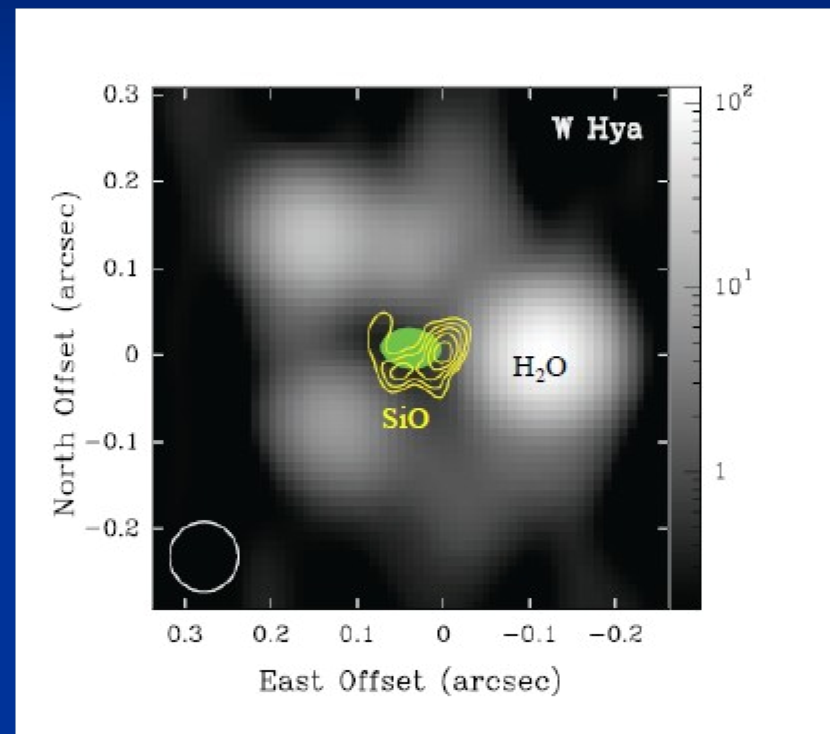




22 GHz observations of the disc around the young star HL Tau (Greaves et al. 2008)

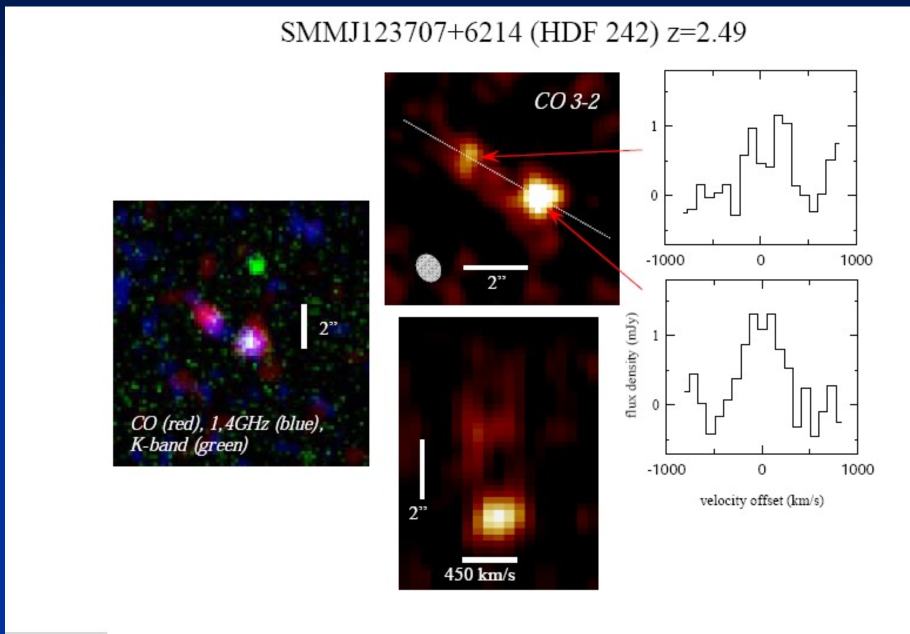
AGB stars

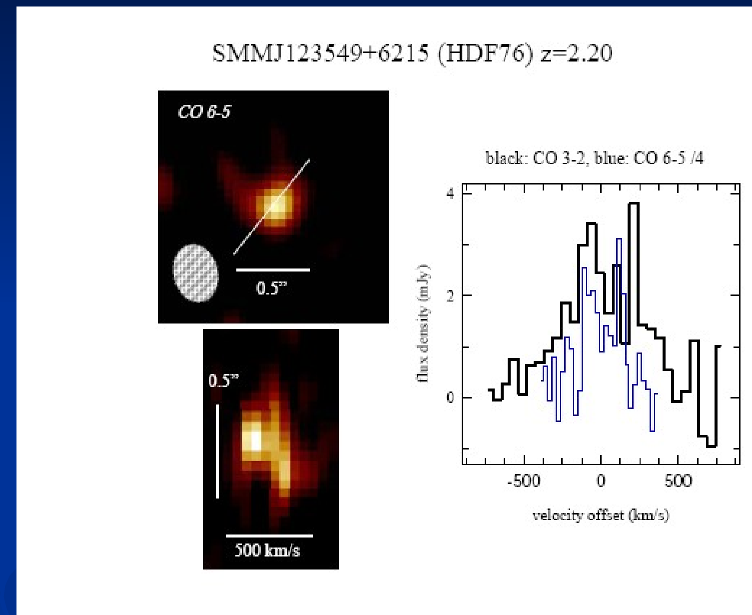




ALMA will probe the chemistry of the molecular photosphere

Mass assembly in galaxies

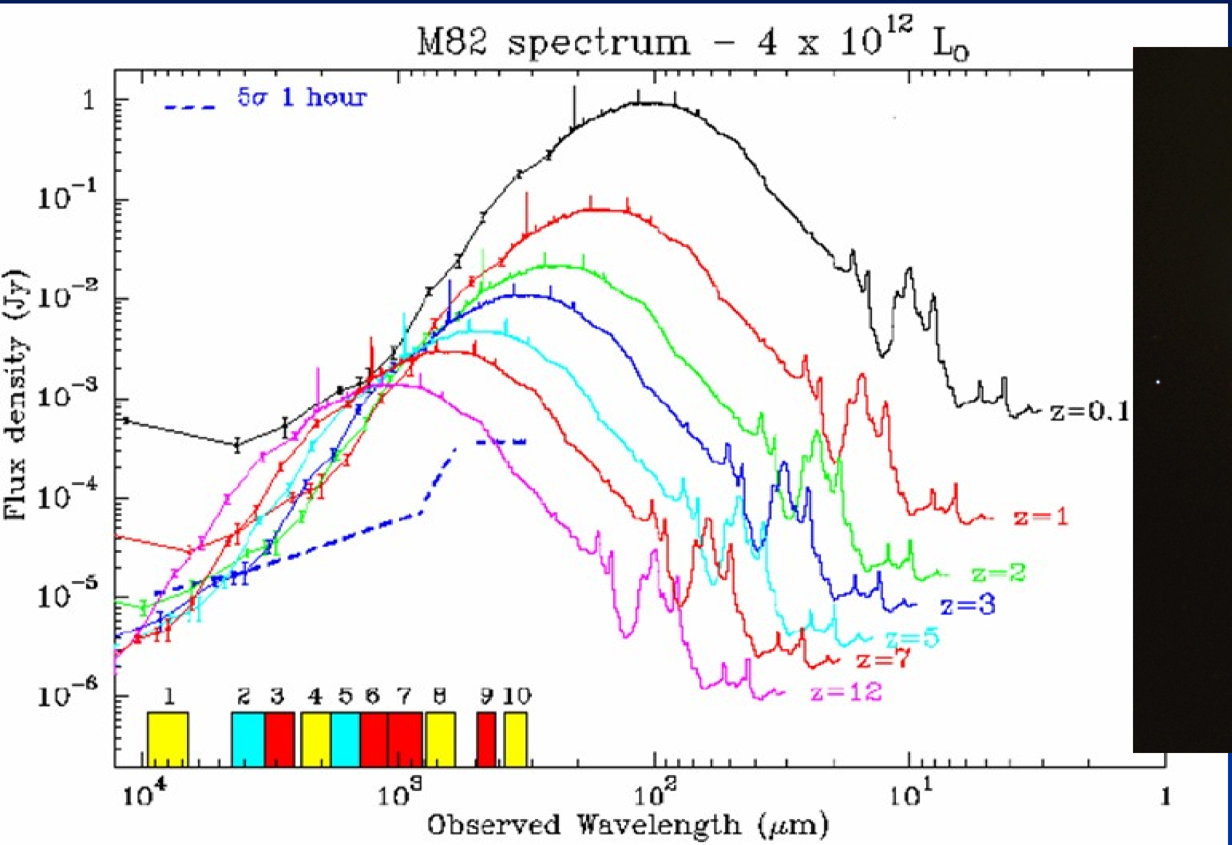




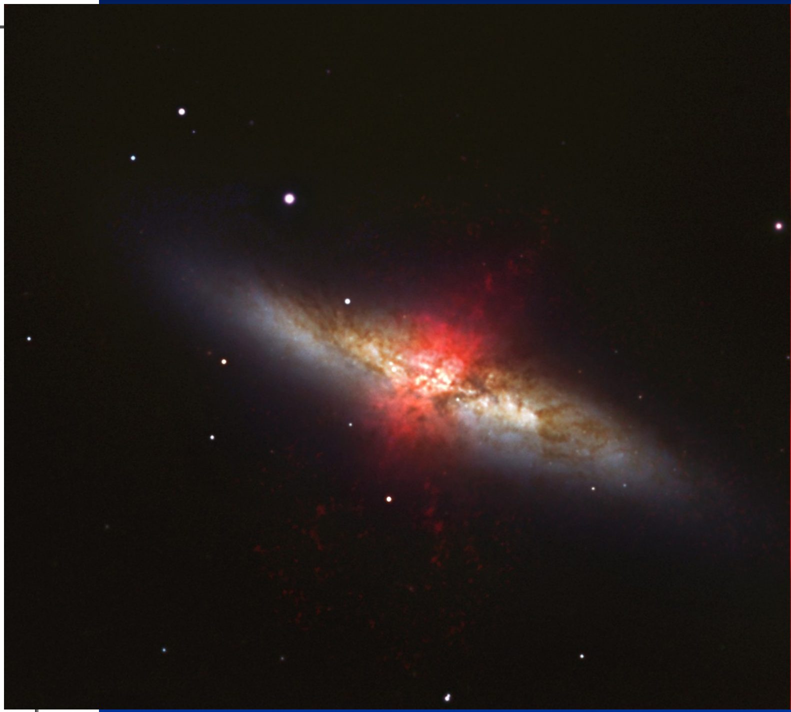
Current observations can resolve only the brightest sub-mm galaxies. These seem to be short-lived examples of maximal star formation in ongoing mergers.

Velocity fields disc-like or irregular.

Starbursts are easy with ALMA

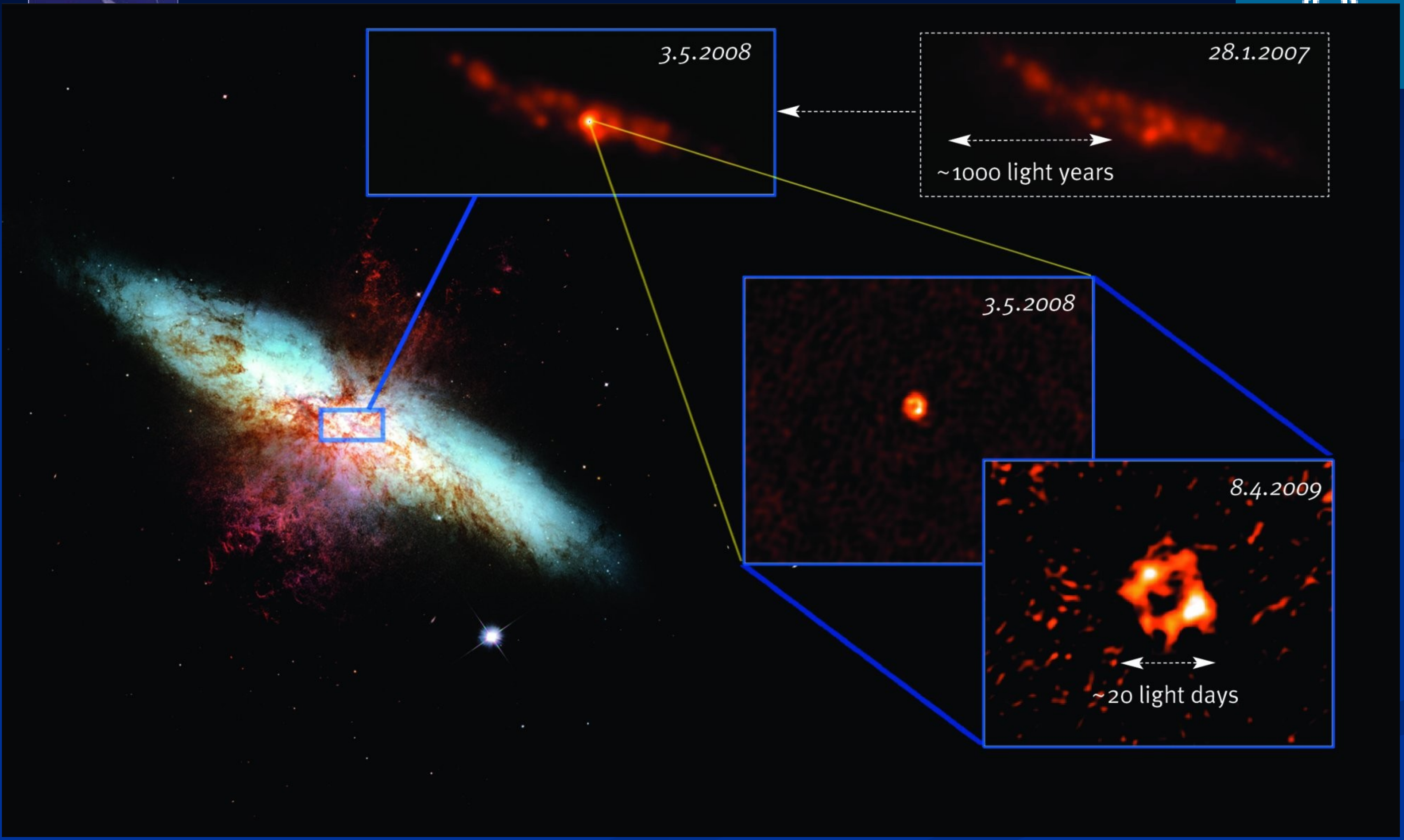


Spectral energy distribution of the nearby starburst galaxy M82

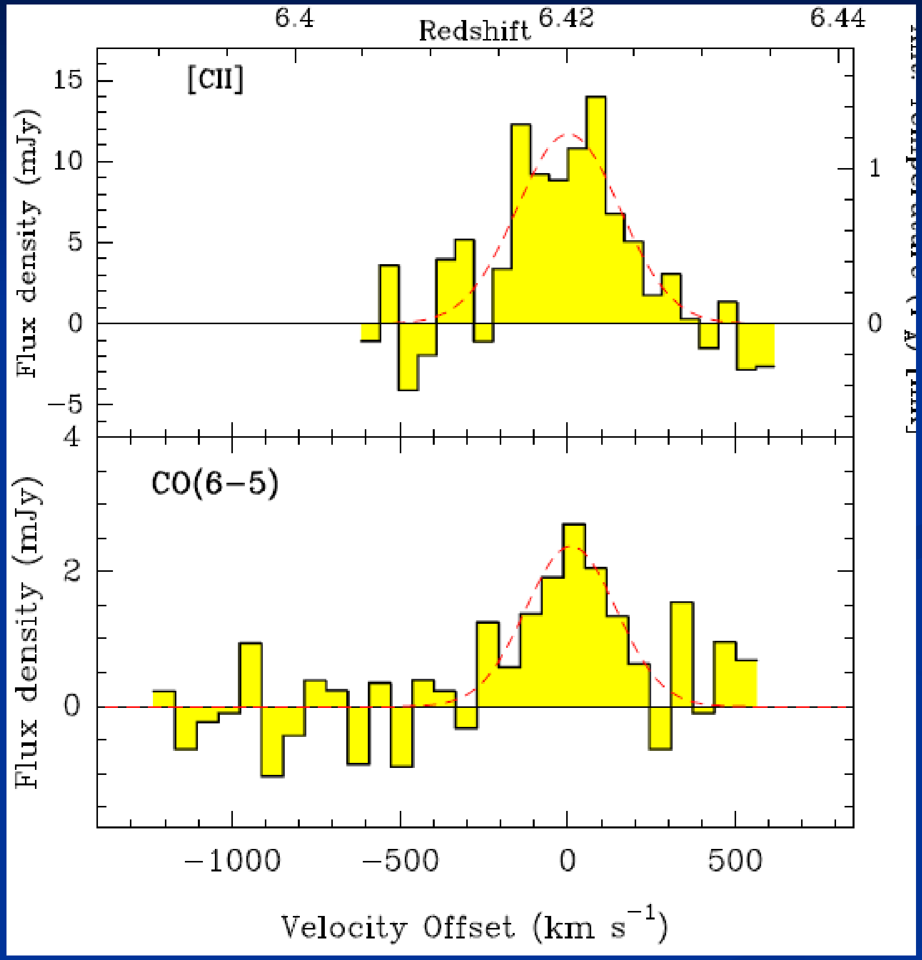


The effect of redshift on the SED: dusty galaxies are easily detected at high z

M82: from arcmin to mas



The first galaxies

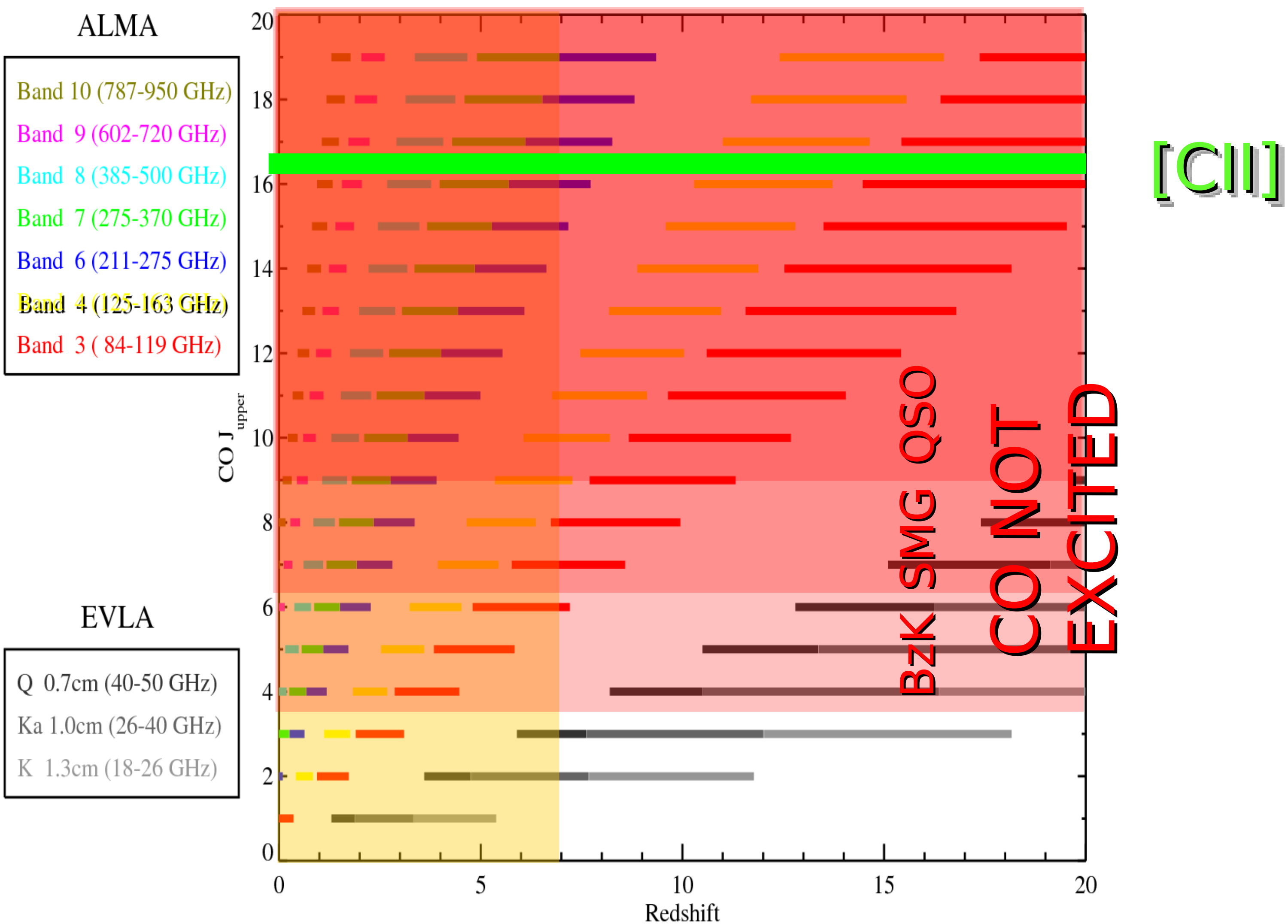


CII – Main coolant in the Milky Way

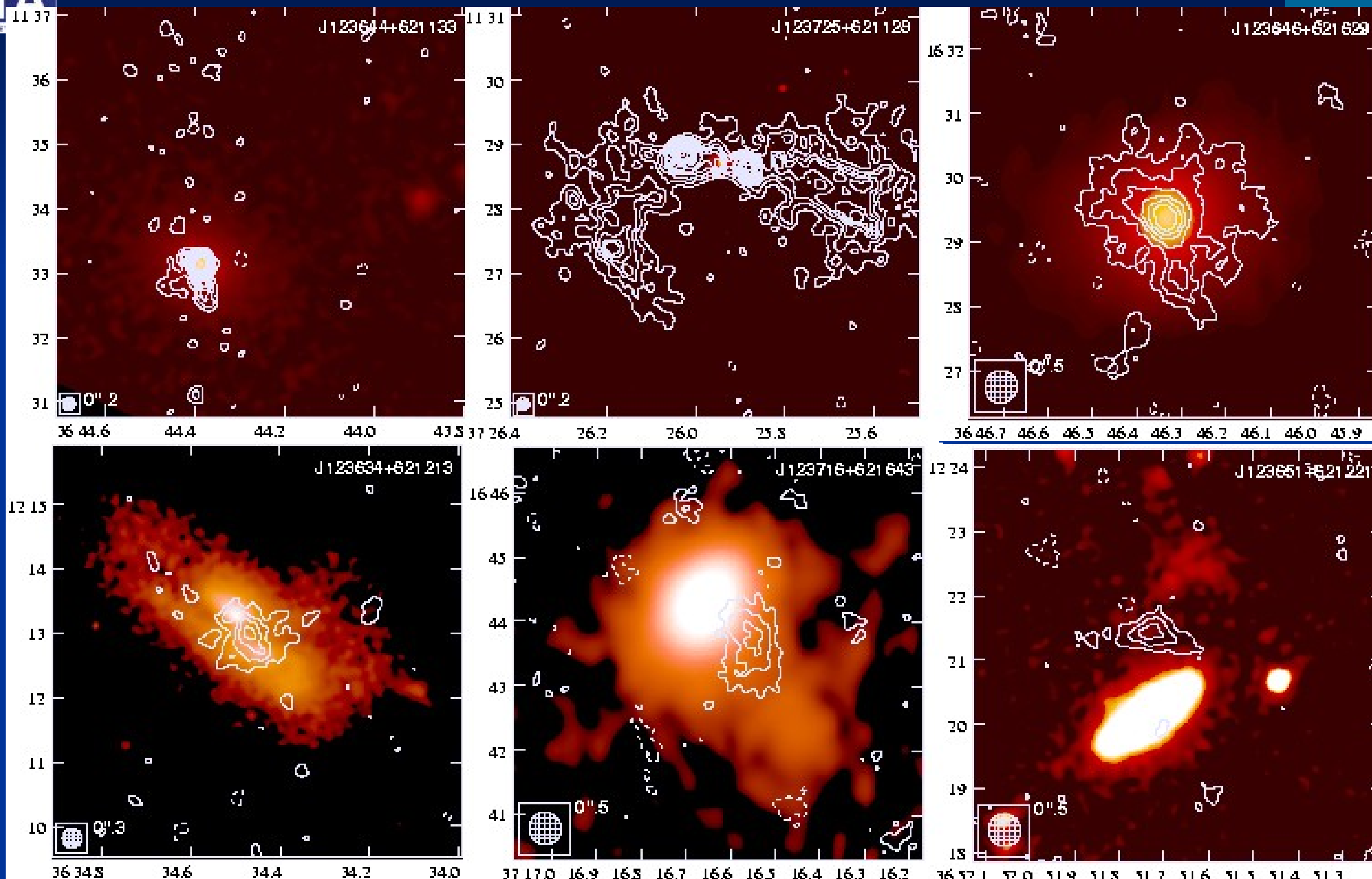
Line of choice for EoR studies

Quasar, z = 6.4

[CII] in the EoR



HDF mJy radio source classification



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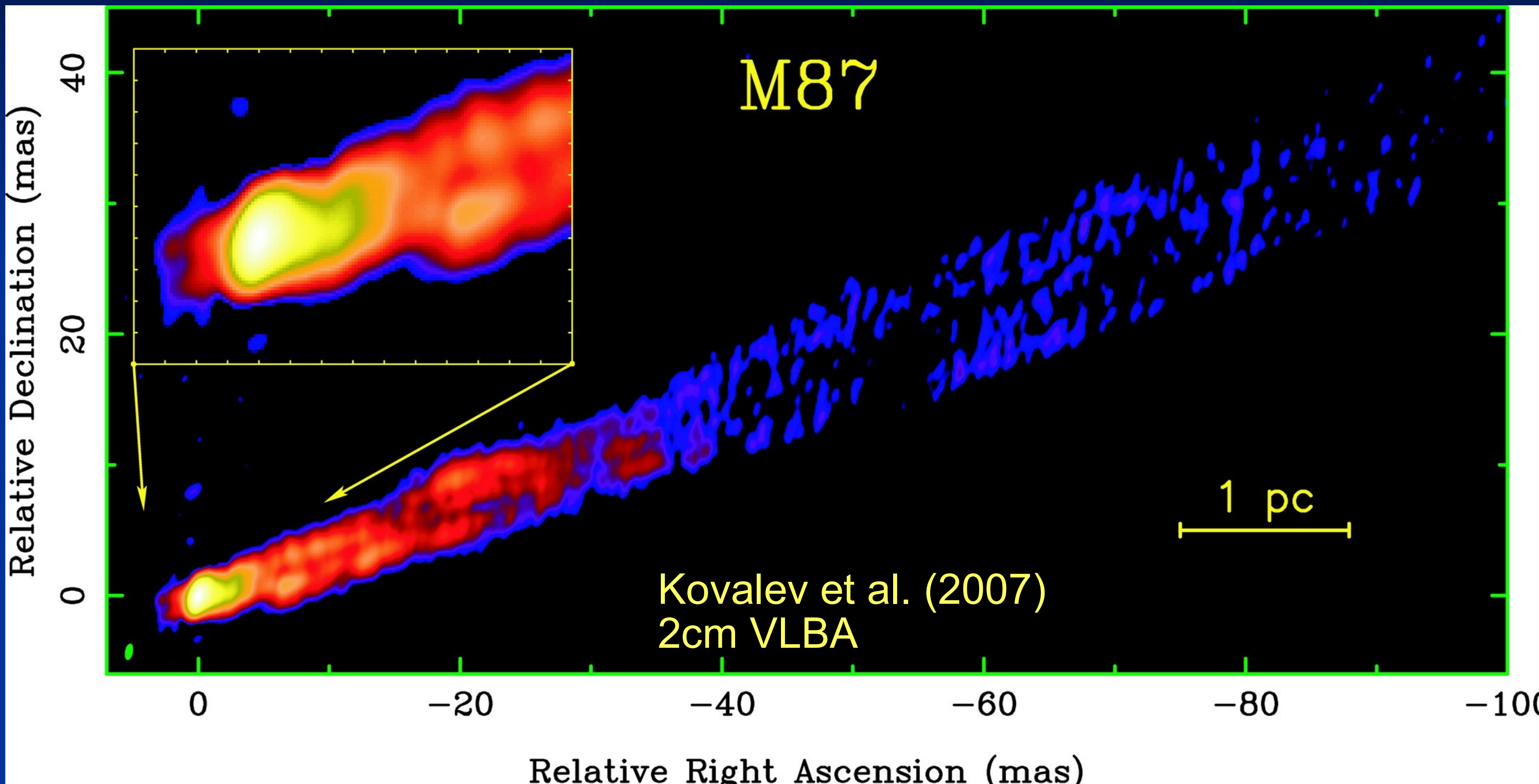
More ALMA science areas

- Dust emission from star-forming galaxies at z ~ 10
- Blind surveys for CO in star-forming galaxies at all epochs
- Detailed studies of cold gas and dust in nearby galaxies; AGN torus structure
- Dynamics of molecular gas around the Galactic Centre
- Star formation: physics and chemistry of collapse, accretion, outflows and disks.
- Complex organic (including prebiotic) molecules
- Molecules and dust around evolved stars
- Planetary atmospheres, cometary nuclei, asteroids
- ……………

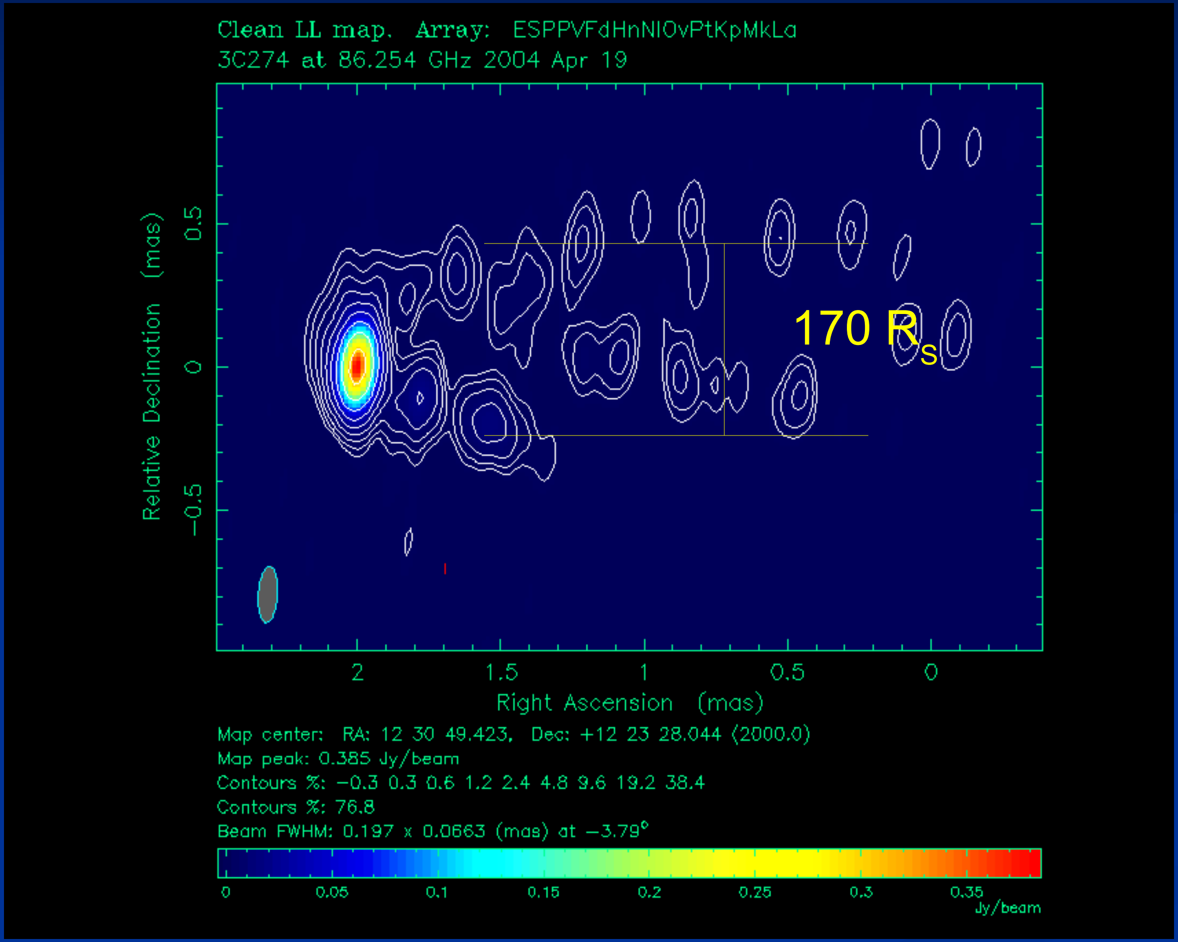
ALMA and VLBI (2)

- ALMA as part of a mm/sub-mm VLBI array
  - Galactic Centre (Fish, Doelman)
  - Jet formation
  - Masers
  - ....
- ALMA needs VLBI techniques

AGN jet collimation



AGN jet collimation

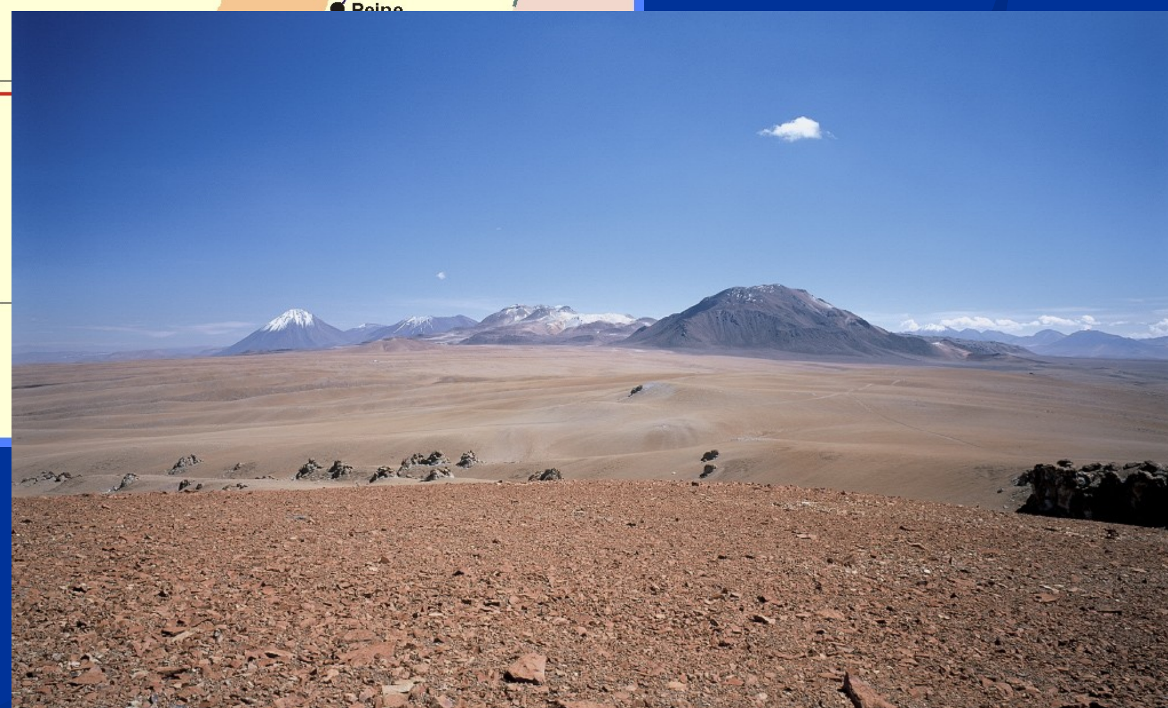


M87 VLBI 86GHz

(Krichbaum

Collimation region
<70 x 20 R_s

ALMA as it will be



Key performance numbers

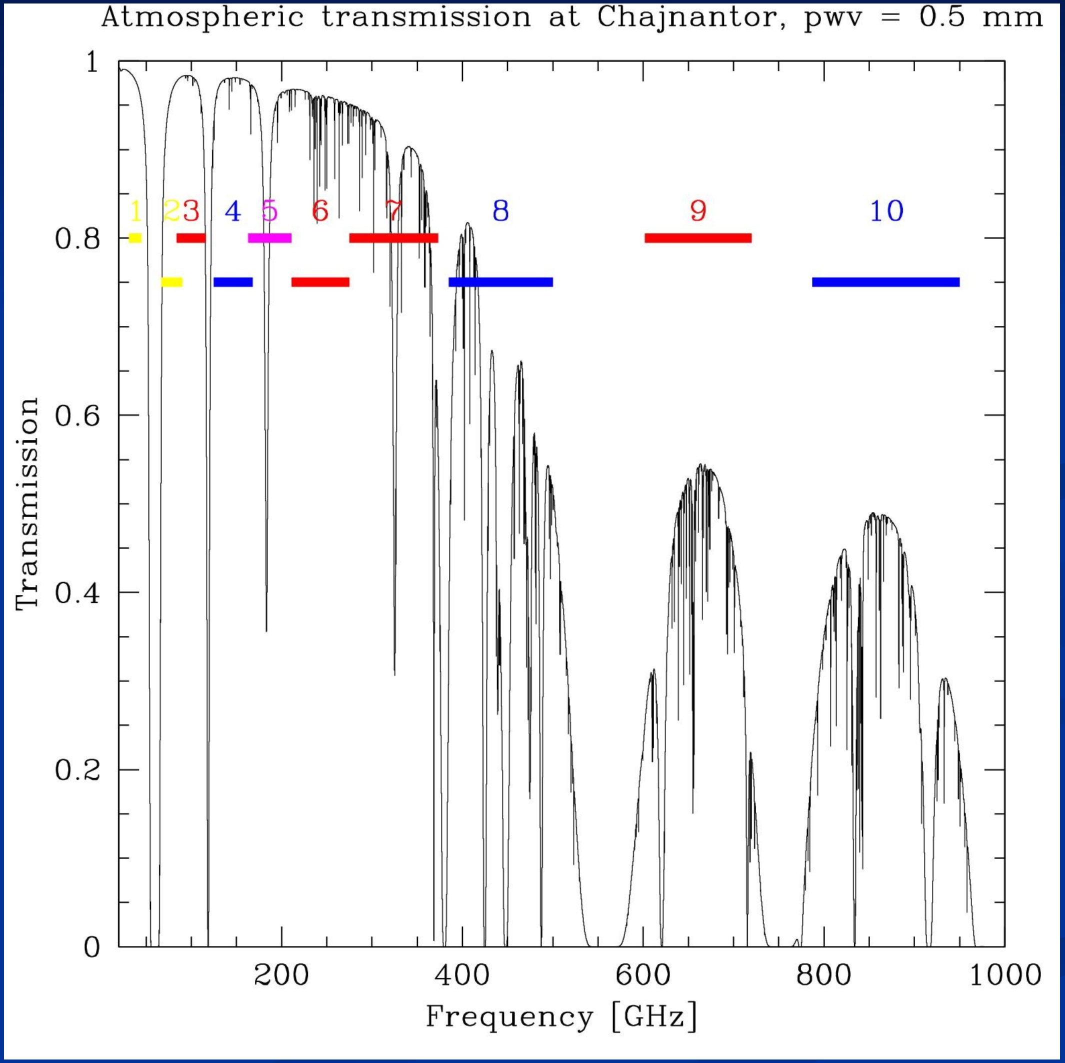
- Baseline range 15m – 14.5 km + ACA + single dish
- Field of view / arcsec ≈ 17 (λ/mm) [12m dish]

  29 (λ/mm) [7m dish]
- Resolution/ arcsec ≈ 0.2(λ/mm)/(max baseline/km)

  0.04 arcsec at 100 GHz, 14.5 km baseline

  0.005 arcsec at 900 GHz, 14.5 km baseline
- Wide bandwidth (8 GHz/polarization), low noise temperatures, good site and antennas, … → sub-mJy continuum sensitivity and wide spectral coverage
- Full polarization

Transparent site allows full spectral coverage



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Basic numbers

Continuum sensitivities for 8 GHz bandwidth,
Lines 1 km/s; 2 polarizations, 50 antennas, 60s

Band	Frequency	Primary Beam (FOV; ")	Largest Scale (")	Continuum Sensitivity (mJy)	Compact Angular Resolution (")	Compact ΔT_{line} (K)	Most Extended Angular Resolution (")	Most Extended ΔT_{line} (K)
Band 1	31.3 - 45 GHz							
Band 2	67 -90 GHz							
Band 3	84 - 116 GHz	56	37	0.05	3.18	0.07	0.038	482
Band 4	125 - 163 GHz	48	32	0.06	2.5	0.071	0.03	495
Band 5	163 - 211 GHz	35	23					
Band 6	211 - 275 GHz	27	18	0.10	1.52	0.104	0.018	709
Band 7	275 - 373 GHz	18	12	0.20	1.01	0.167	0.012	1128
Band 8	385 - 500 GHz	12	9	0.40	0.86	0.234	0.01	1569
Band 9	602 - 720 GHz	9	6	0.69	0.52	0.641	0.006	4305
Band 10	787 - 950 GHz	7	5	1.1	0.38	0.940	0.005	

To be developed in the future. Available for early science.

Spectral modes

- Channel bandwidth 31.25 MHz – 2 GHz (x4 baseband channels)
- Maximum 4096 x (4/N) x (2/P) spectral points/channel, where N = 1, 2 or 4 is the number of channels and P=2 for full polarization; 1 for parallel hands only.
- Maximum spectral resolution 3.8 kHz.
- Tunable FIR filter bank to subdivide 2 GHz baseband into 32 (possibly overlapping) sub-channels, each 62.5 or 31.25 MHz wide
- Flexible combinations of centre frequency and resolution

Phase calibration

- **Requirements**
  - Reduce atmospheric and electronic phase fluctuations to as low a level as possible
  - Required by imaging and flux scale (decorrelation)
- **Techniques**
  - Fast switching (interleave with observations of a nearby calibrator, perhaps at a lower frequency). 20 – 300s cycle times. Requires calibrator within ~2^{o}.
  - Water-vapour radiometry (measure emission from 183 GHz atmospheric line; deduce phase fluctuations on 1s timescales).
  - Self-calibration

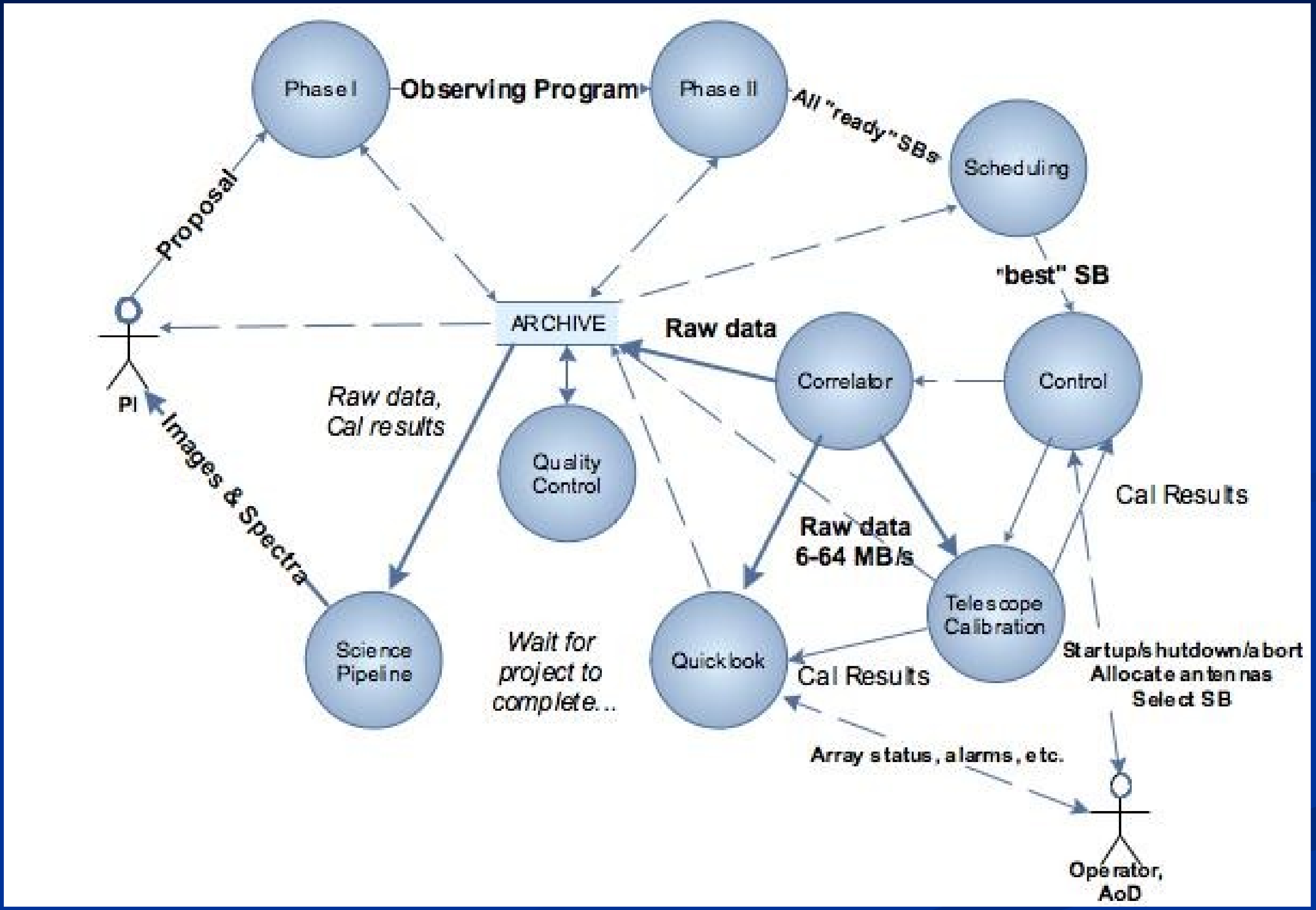
ALMA Operations

- Basic concepts
  - Service mode, scheduled dynamically (weather)
  - All observations executed as scheduling blocks, which contain all of the information required to schedule and run the observations (calibration)
  - Primary data products are image cube; raw, calibrated visibility data also available.
  - Everything is archived.
- Support
  - Software for proposal preparation, reduction, pipeline
  - Documentation
  - Face-to-face support

ALMA Projects

Data-cubes will be primary product

uv data also archived



ALMA Regional Centres

- Three ALMA Regional Centres
  - Europe
  - North America
  - East Asia
- Primary interfaces to their respective user communities
  - Assist users in proposal/programme preparation and data reduction
  - Manage the time allocation process
  - Run archive mirrors and deliver data
  - Provide AOD and commissioning personnel

The European ARC

- Central Node at ESO
  - Archive and data delivery
  - Proposals
  - e-mail helpdesk
  - VLT support model
  - Funded by ESO/ALMA
- Regional nodes
  - Face-to-face user support
  - Regional users
  - Specialised expertise
  - Local/EU funds

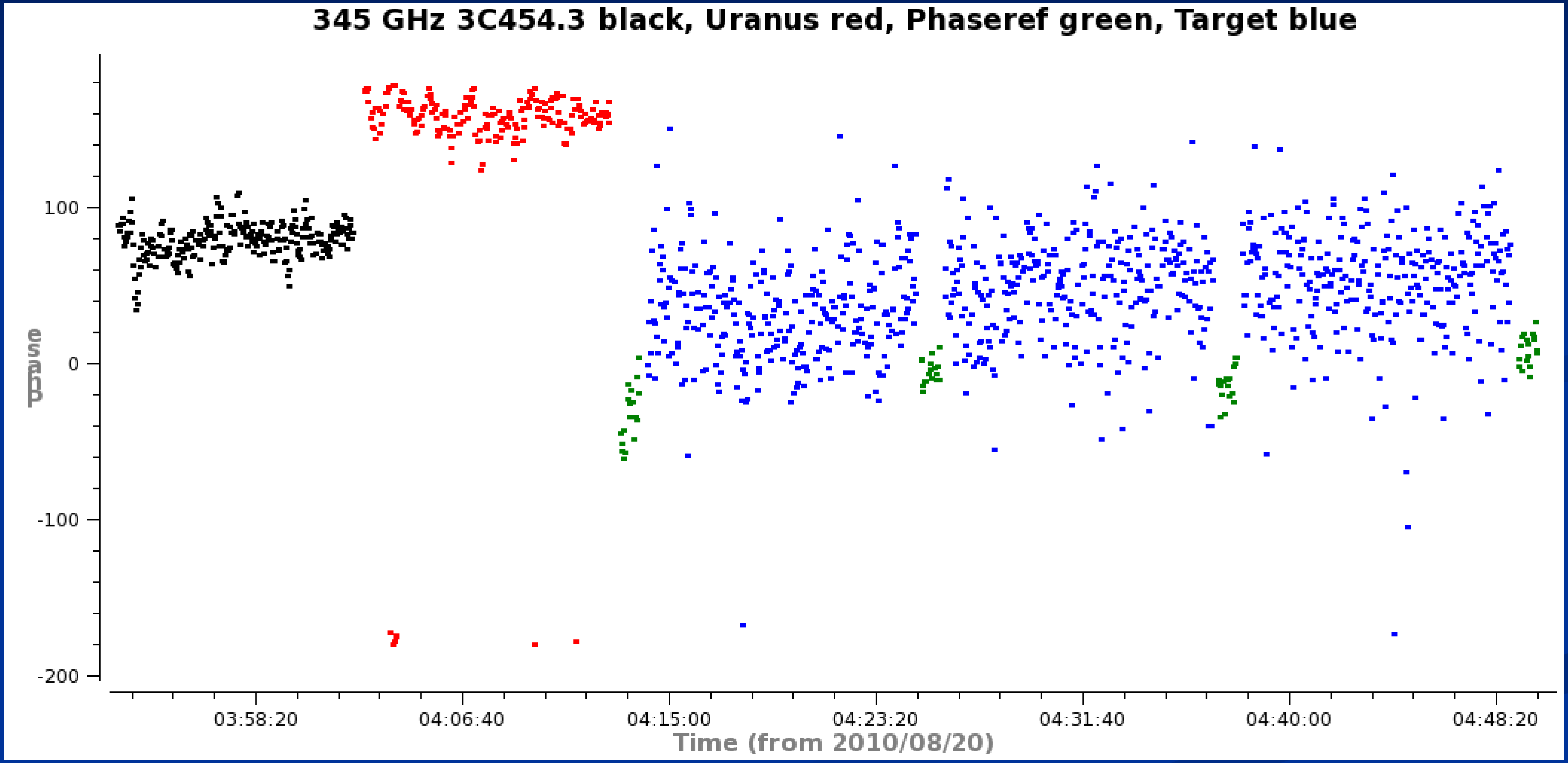
IRAM (France, Spain, MPG)
Jodrell Bank (UK)
Leiden (Netherlands)
Bonn/Koeln/Bochum (Germany)
Onsala (Nordic countries)
IRA Bologna (Italy)
Czech Republic (Ondrejov)

Current Status
European Antennas assembled

Infrastructure

Seven Antennas (close-packed)

Raw Phase Stability



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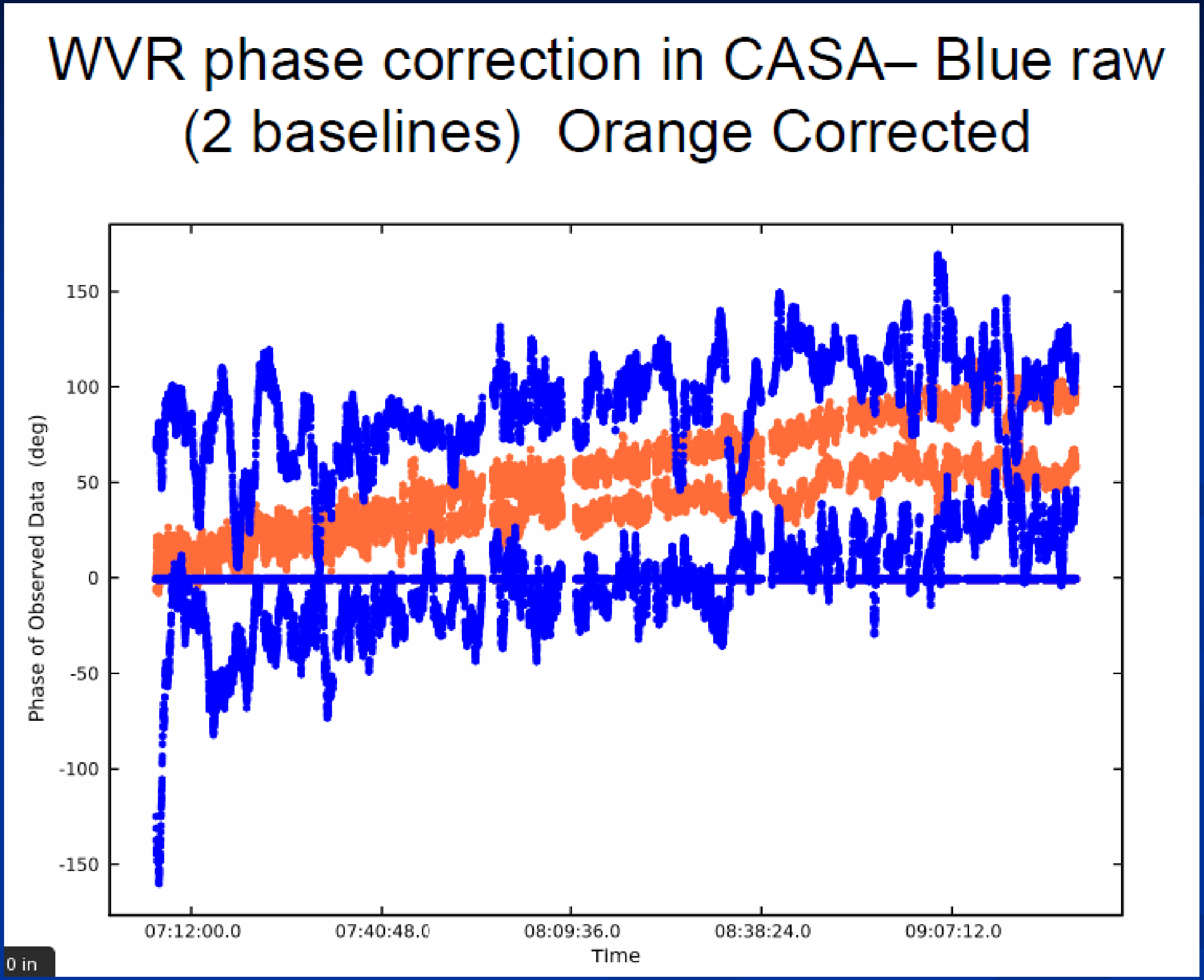
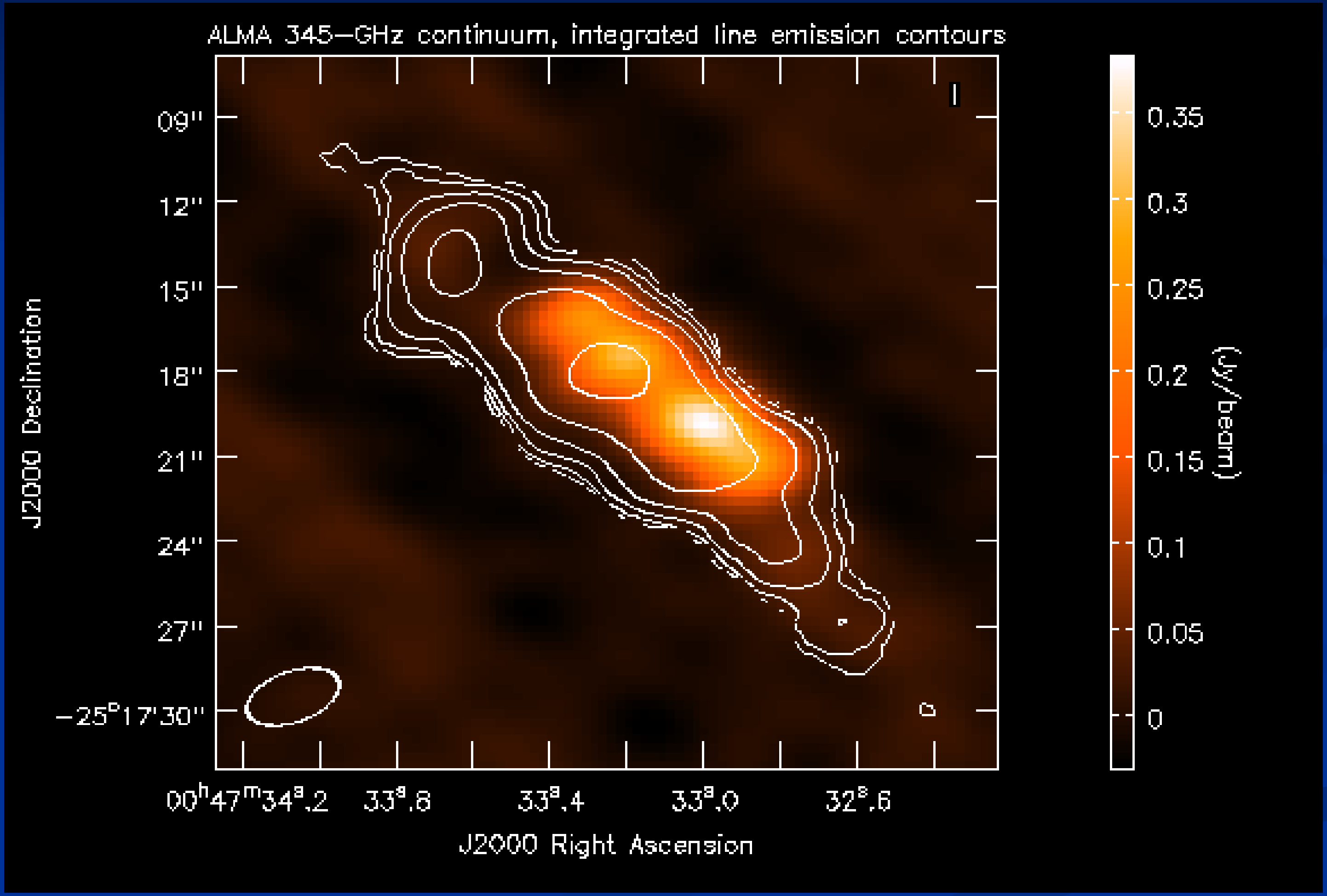
WVR correction in action



Commissioning images: Starburst Galaxy NGC253



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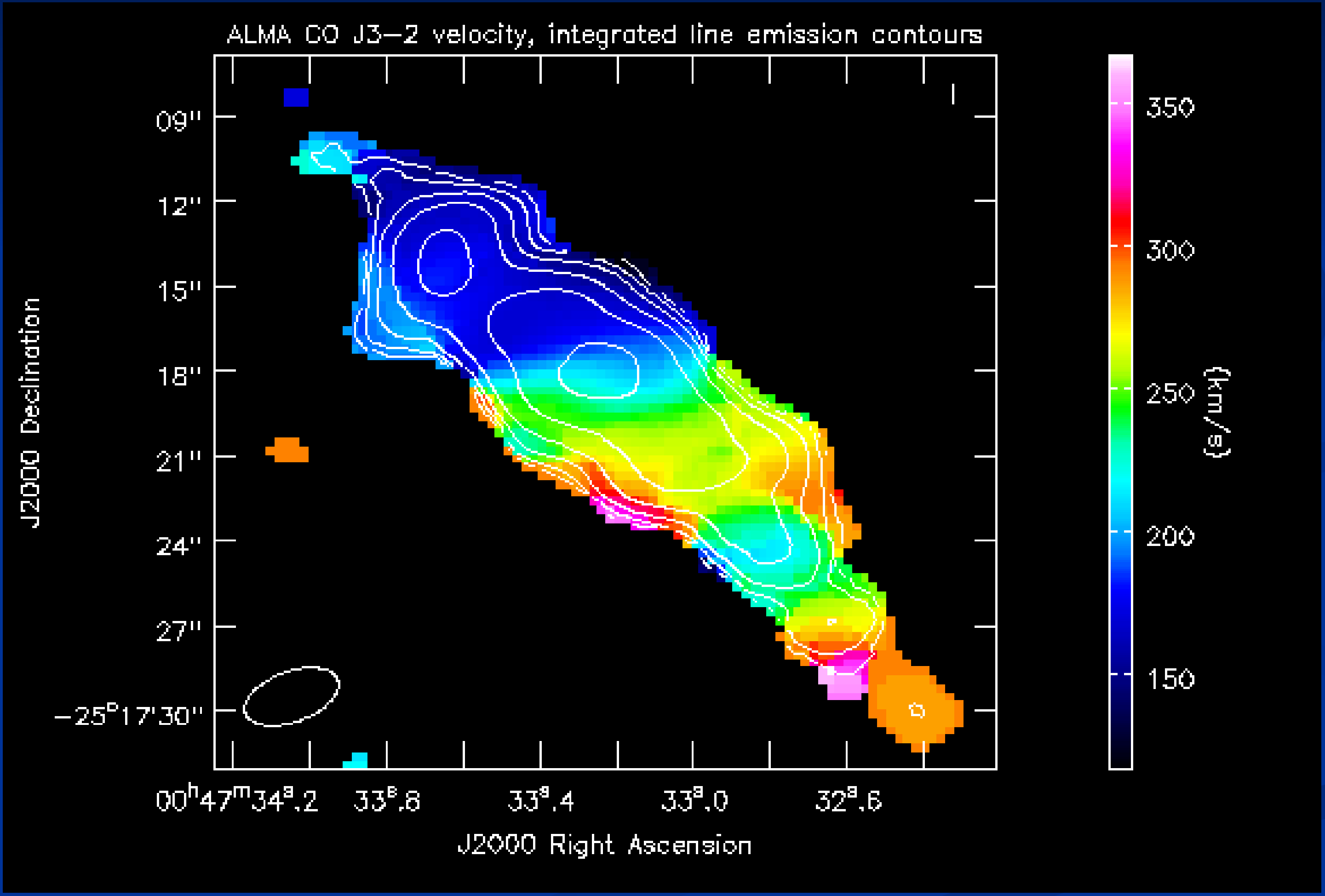
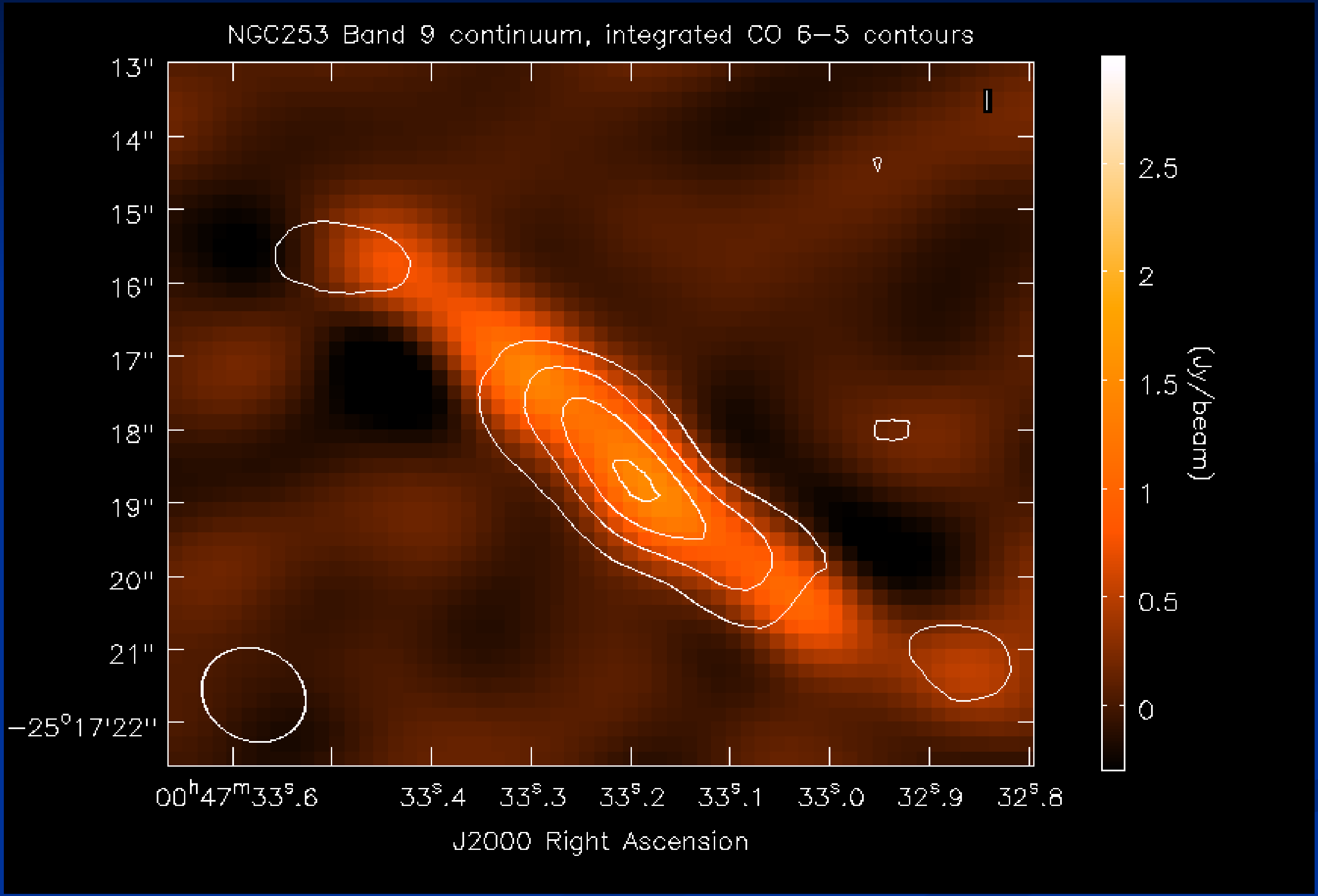
NGC253: CO



ALMA CO J3–2 velocity, integrated line emission contours
J2000 Declination
09''
12''
15''
18''
21''
24''
27''
−25°17'30''
00h47m34s.2
33s.8
33s.4
33s.0
32s.6
J2000 Right Ascension
350
300
250
200
150
(km/s)

NGC253: 690 GHz



What is Early Science?

- Minimum
  - 16 antennas with at least 3 bands out of 3, 6, 7, 9
  - Single-field synthesis imaging
  - Antenna stations to provide good coverage out to 250m
  - Calibration equivalent to current mm arrays (loads + WVR)
  - Software
  - At least 33% of time available (1 year scheduling period)
- Goals
  - Bands 3, 6, 7 and 9 on all antennas; 4 and 8 on some
  - Pointed mosaics
  - Baselines out to at least 1 km
  - Linear and circular polarization
  - Single-dish mapping (including OTF)
  - Calibration better than existing arrays

Current Schedule

- First fringes at AOS 2009 April 30
- Three antennas at high site, closure phase, 2009 Nov 26
- Start of Commissioning and Science Verification 2010 Jan 22
- Early Science Decision Point Nov 2010
- Call for Proposals end 2010+
- Proposal deadline early 2011+
- Start of Early Science with 16+ antennas Autumn 2011+
- Full operation early 2013

Outlook

- No show-stoppers
  - All main subsystems basically work
  - Key technical risks (phase correction, local oscillator distribution) addressed
  - Construction budget adequate for completion
- Schedule
  - Still very tight (especially front ends)
  - EU antennas
- Reliability and efficiency
  - Much work needed to make system fully reliable (antenna control; correlator)
  - Sofware test and optimization

Not without problems

... but ALMA is coming soon