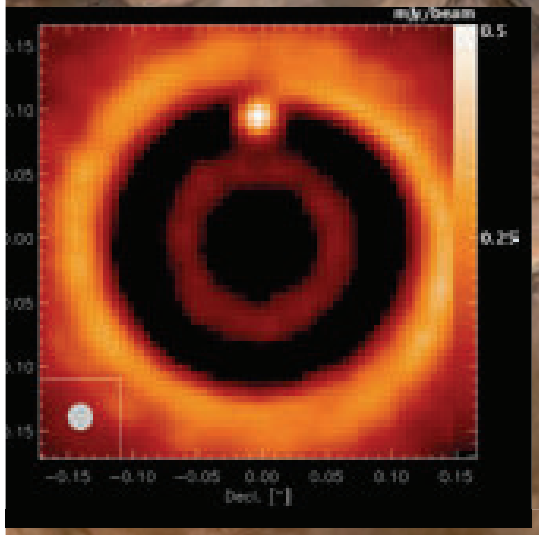
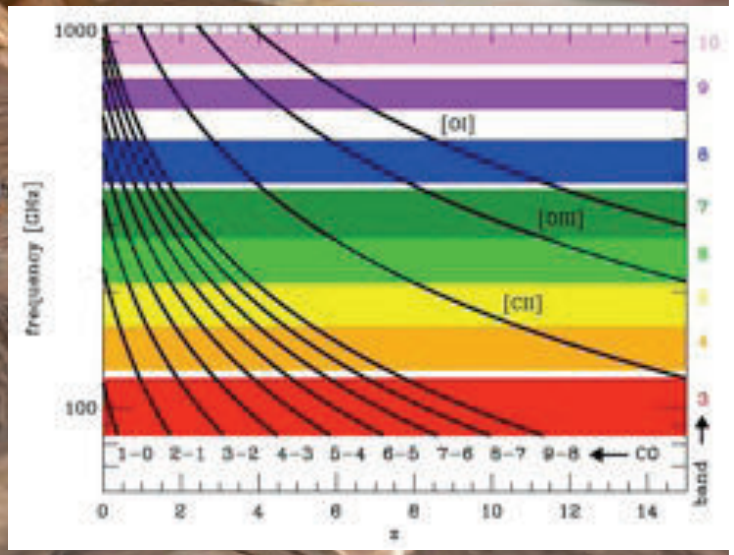
The ALMA Project

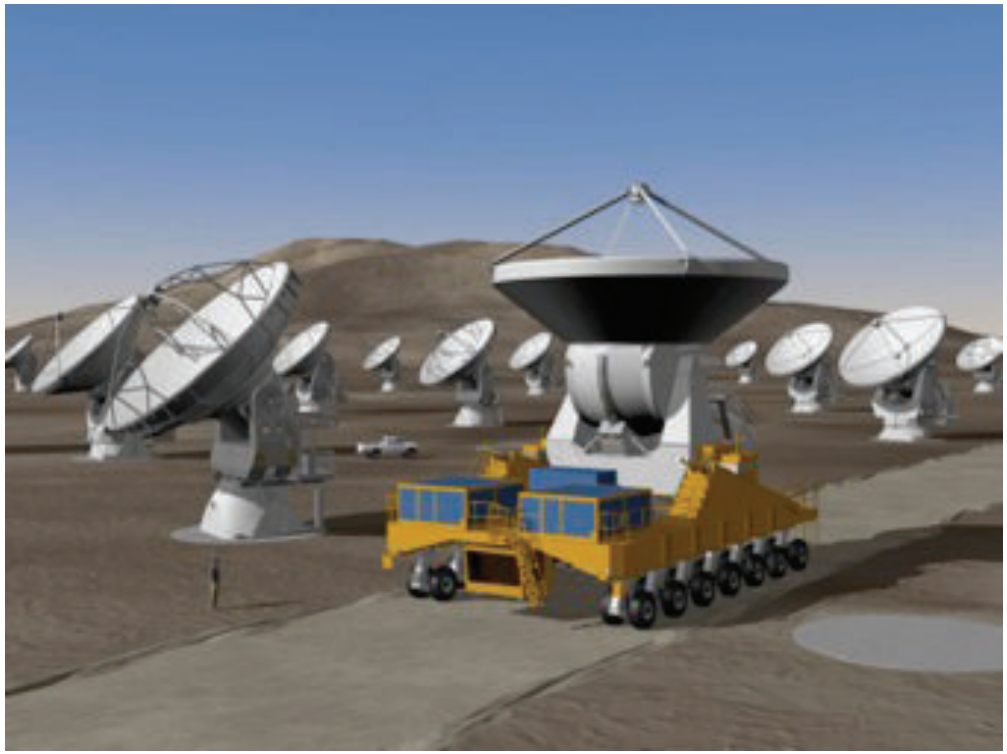
Leonardo Testi
ESO





ALMA and its science goals
ALMA status and timeline
ALMA development plan

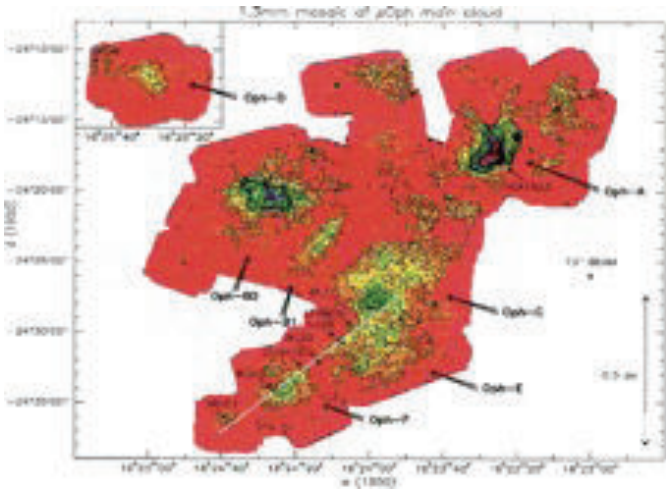
Atacama Large Millimeter Array

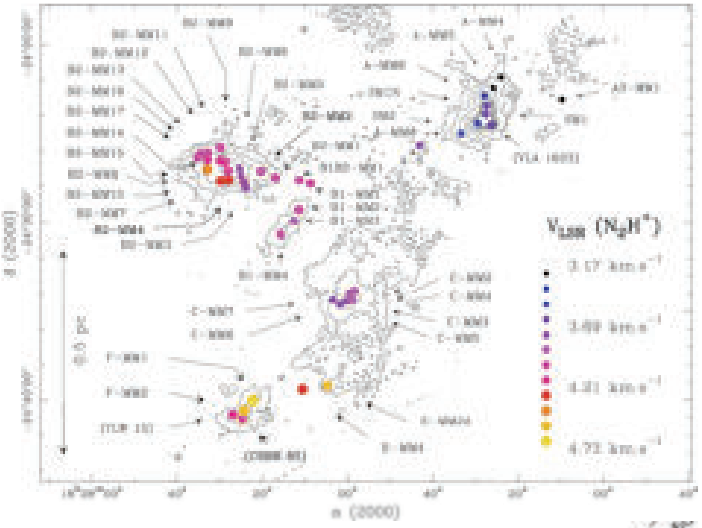


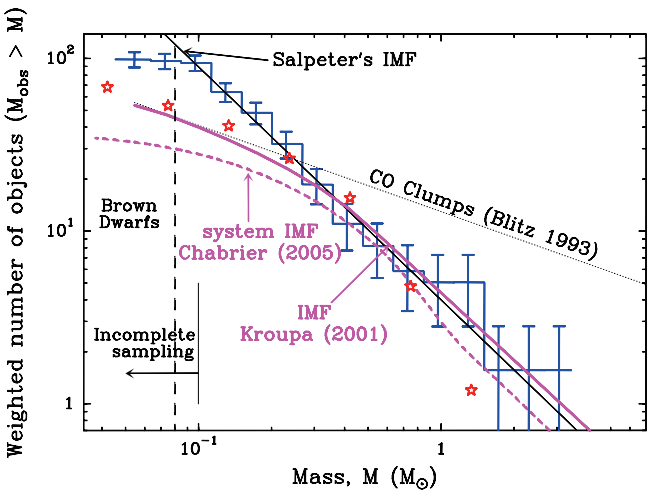
- At least 50x12m Antennas
- Frequency range 30-1000 GHz (0.3-10mm)
- 16km max baseline (<10mas)
- ALMA Compact Array (4x12m and 12x7m)

1. **Detect and map CO and [C II] in a Milky Way galaxy at z=3 in less than 24 hours of observation**
2. **Map dust emission and gas kinematics in protoplanetary disks**
3. **Provide high fidelity imaging in the (sub)millimeter at 0.1 arcsec resolution**

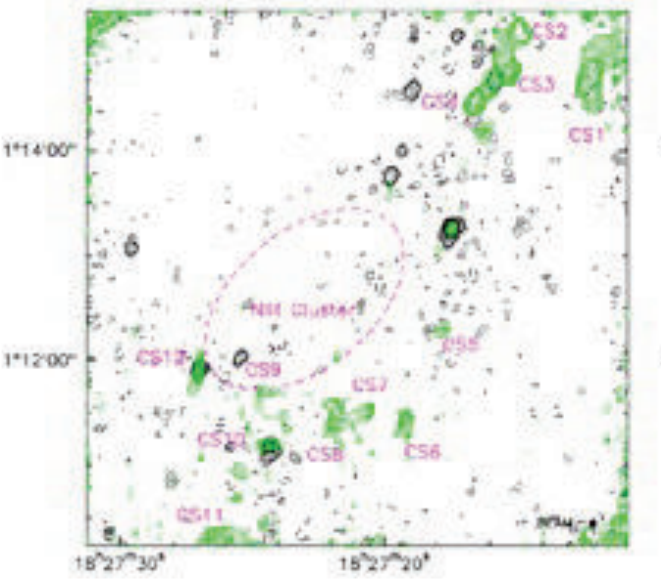
The origin of the stellar IMF

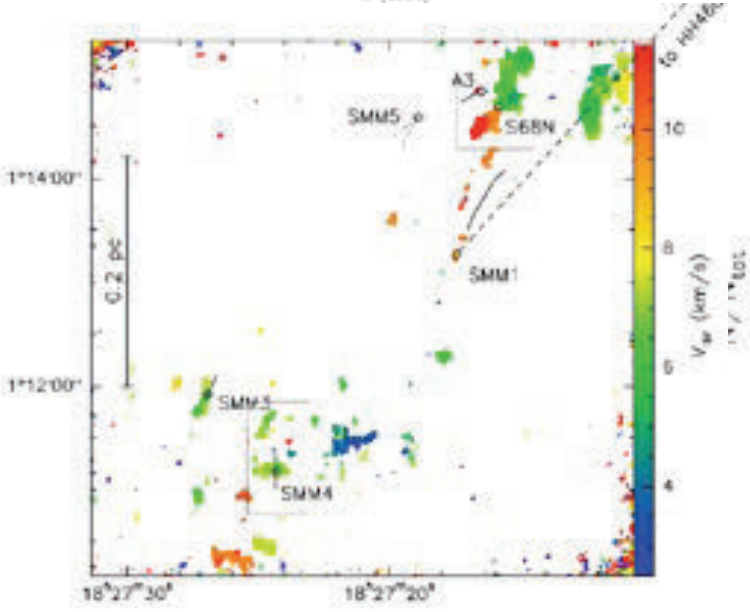


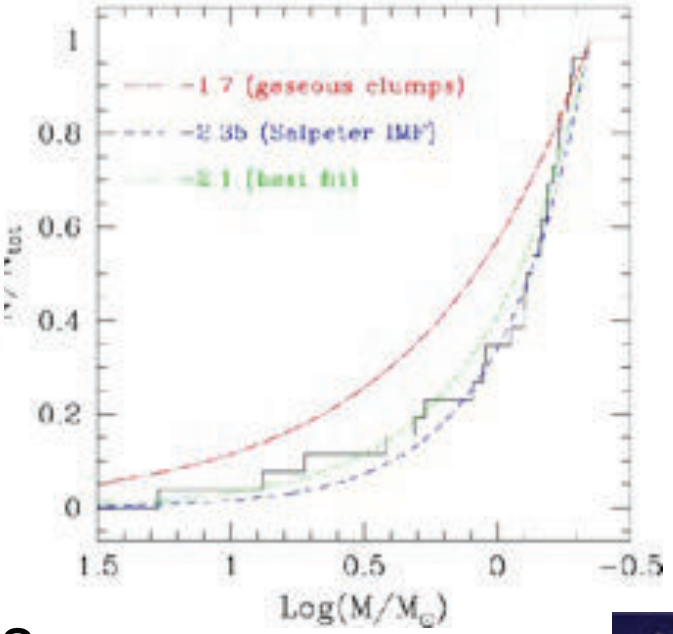




(Motte et al. 1998; André et al. 2007)



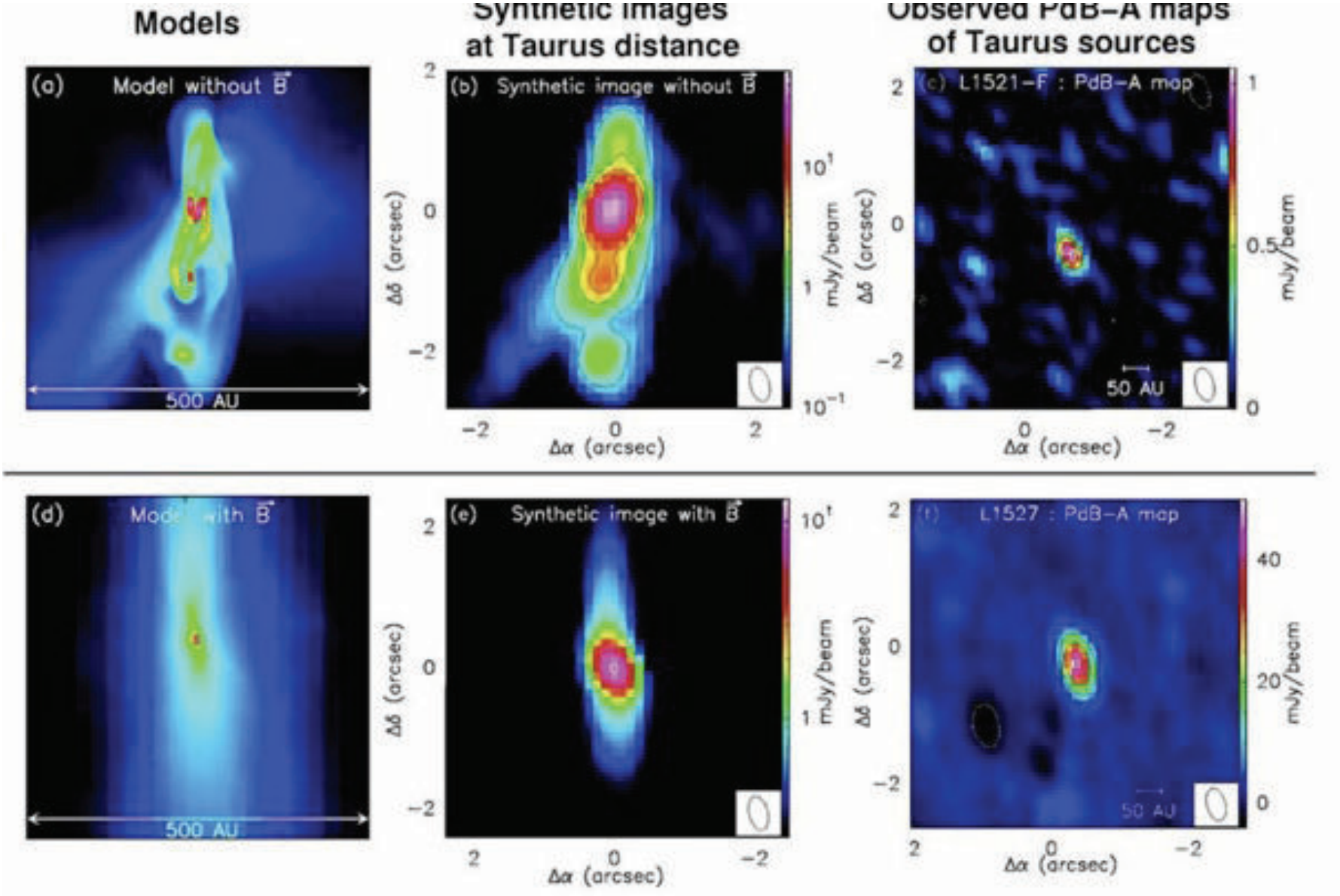




(Testi & Sargent 1998; Testi et al. 2000)

- Physical conditions in individual cores
- Other environments (molecular ring, FOG, ...MC)

Structure of protostars

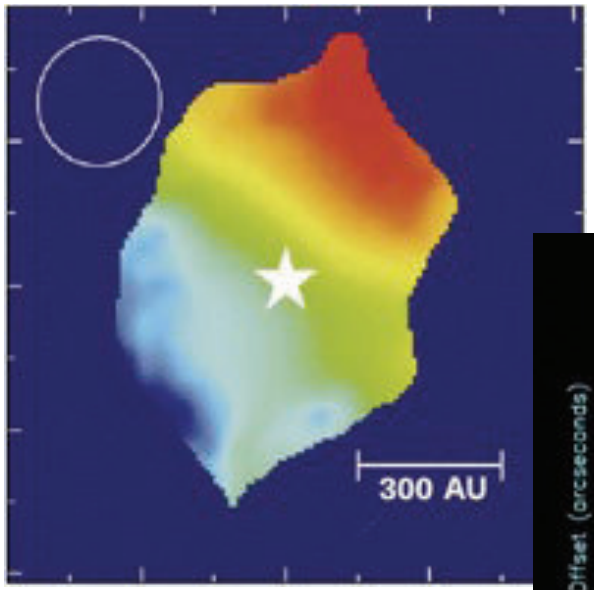


(Maury et al. 2010)

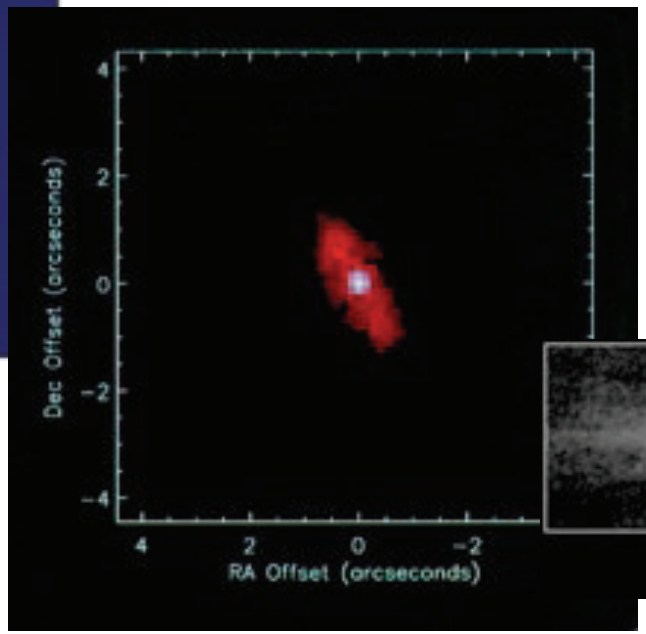
- Multiplicity, disk vs pseudodisk, role of B

Disk Evolution

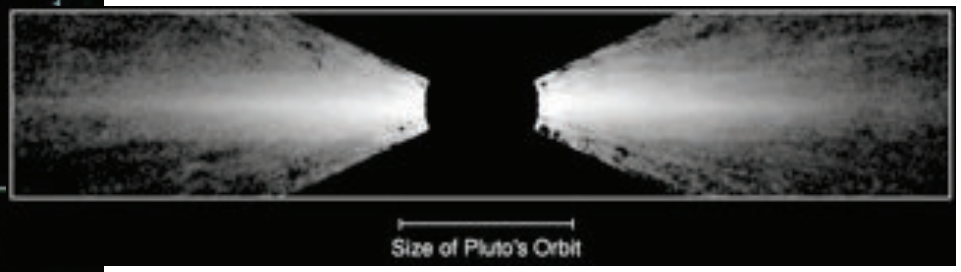
- There is evidence that disk evolution and planet formation systems may occur on timescales of a few million years



MWC 480
Young gaseous disk – 6 Myrs
CO(2-1): Mannings et al 1997

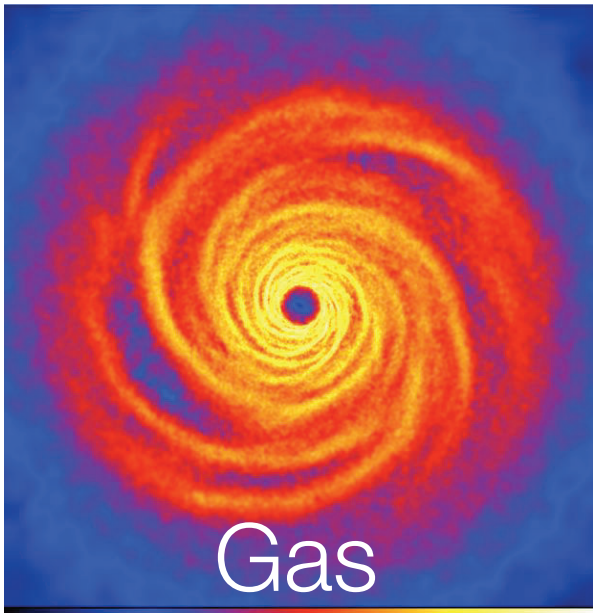


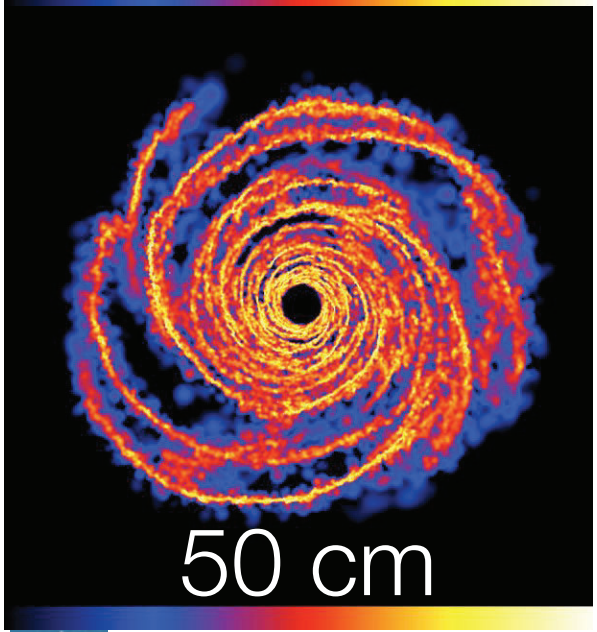
HR 4796 A
Evacuated inner disk – 15Myr
MID-IR: Koerner et al. 1998

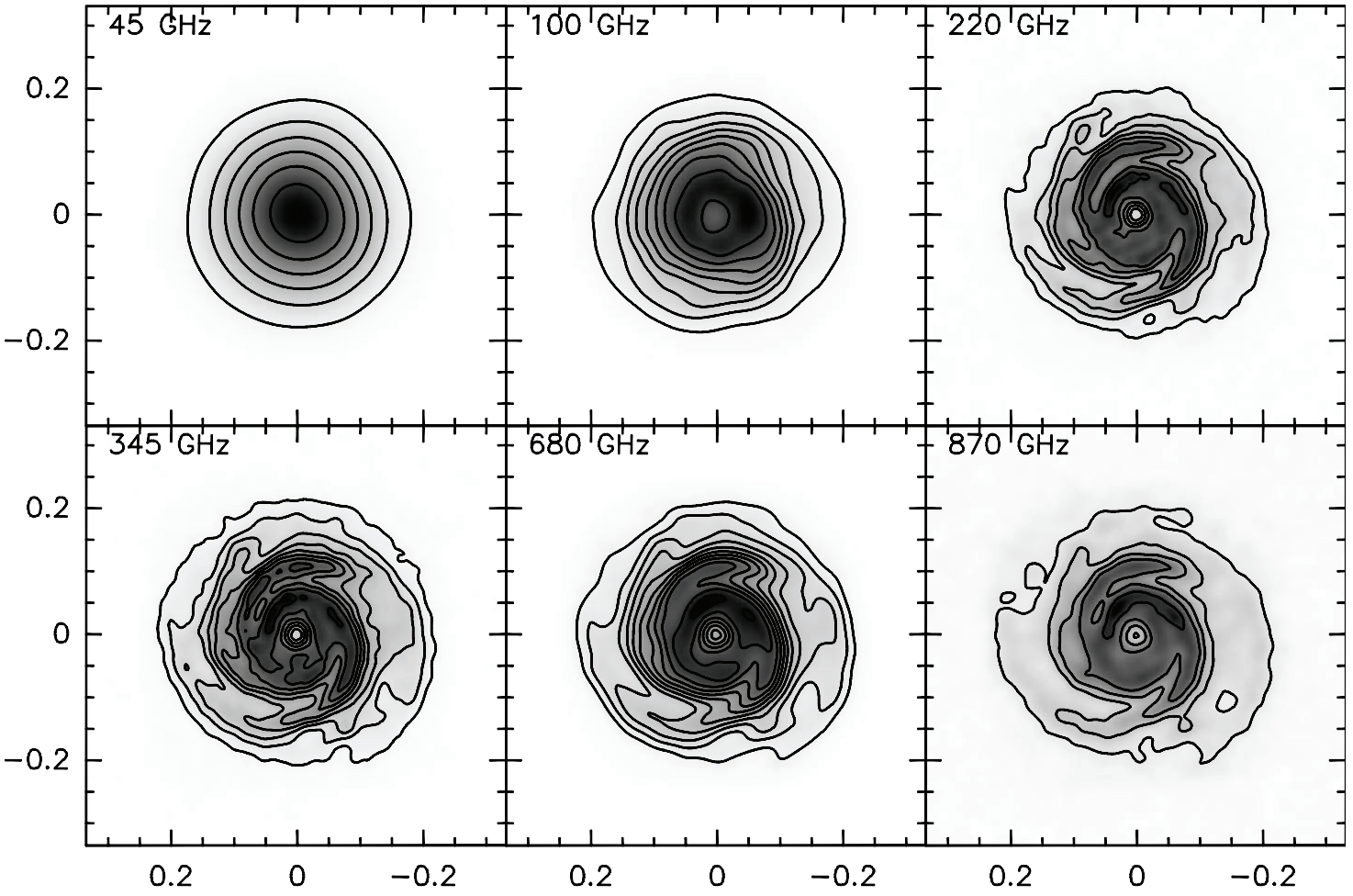


ß Pic
Debris disk – 100 Myrs
Scattered light: Burrows et al. 1995

Gas density maxima and grain trapping

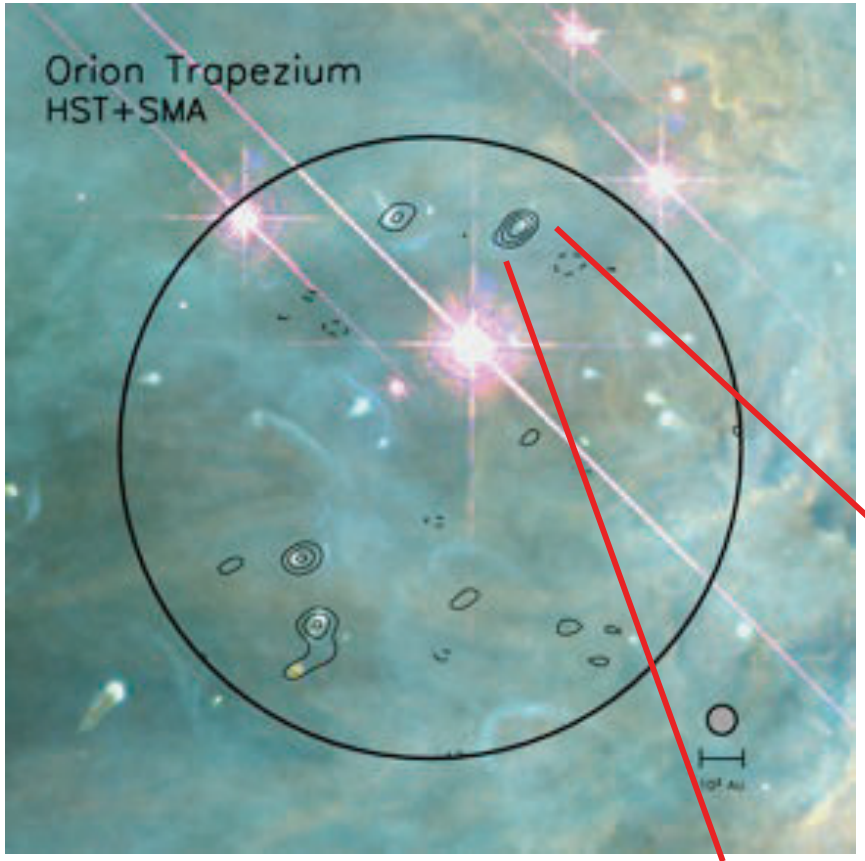






- Resolving disk structures with ALMA (simul from Cossins, Lodato & Testi 2010)

Birth of Planets

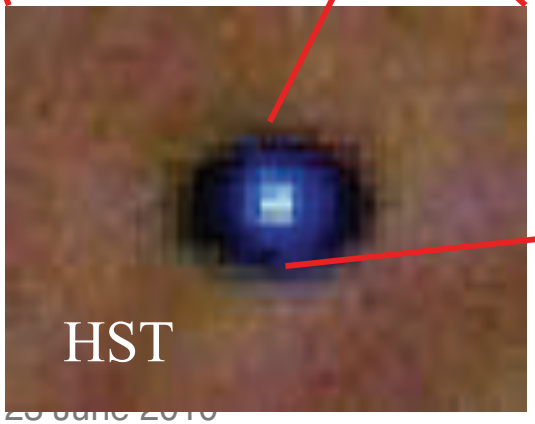


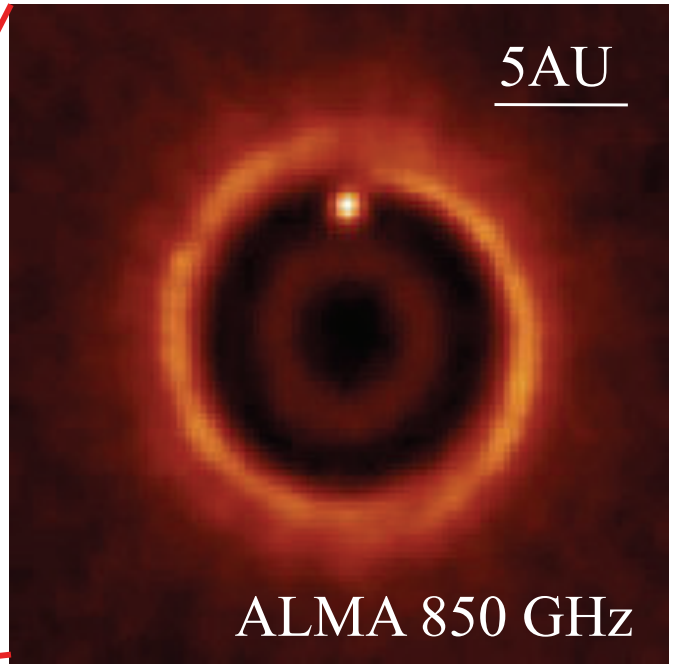
$M_{planet} = M_{Jup}$

$M_{star} = 0.5\ M_{sun}$

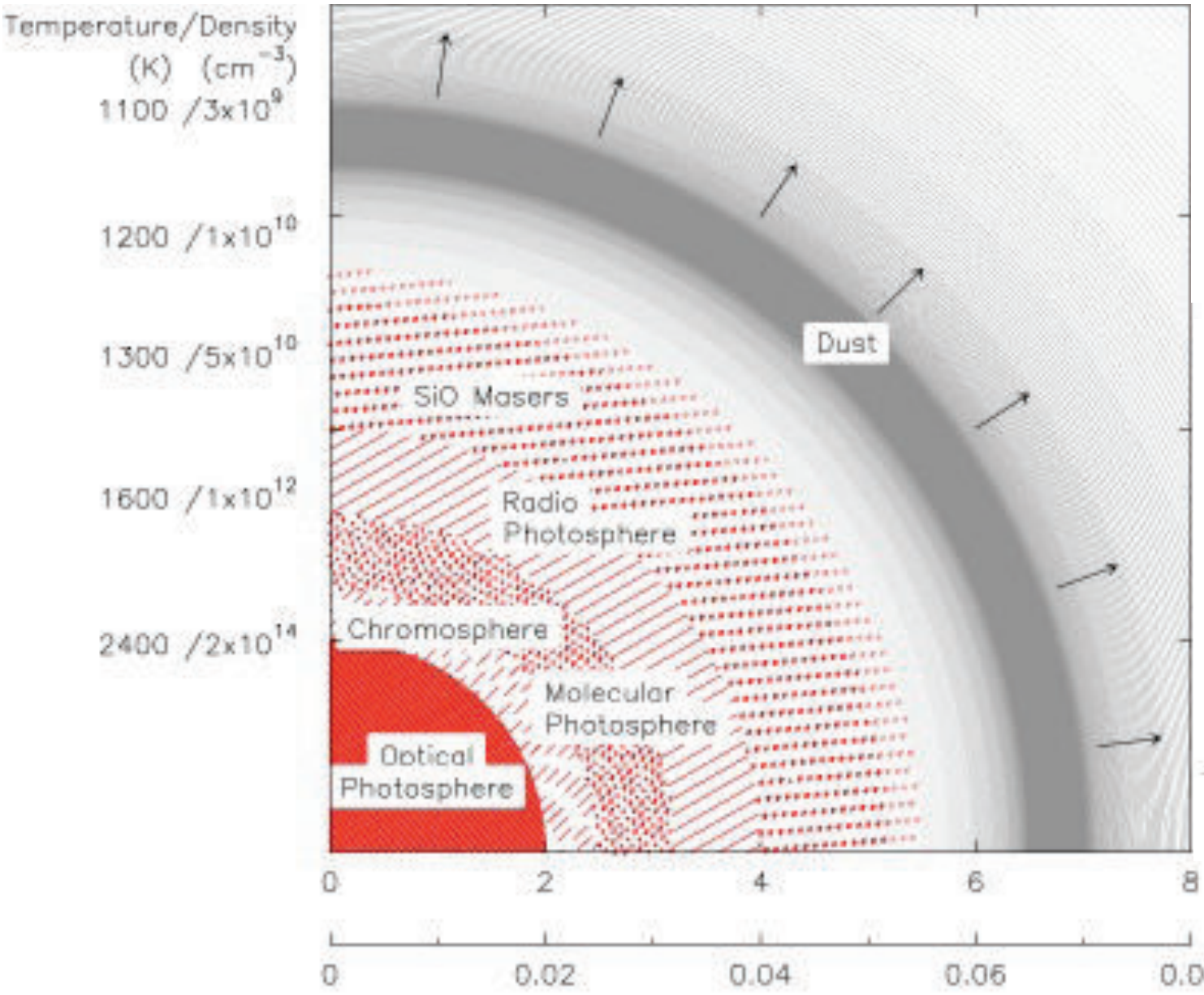
Orbiting at 5AU

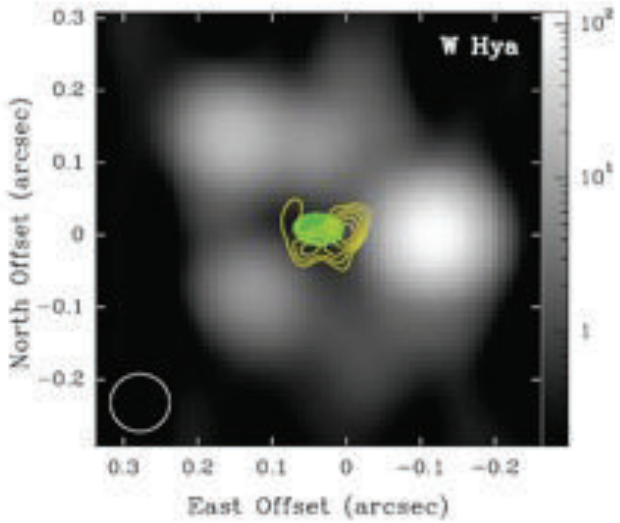
Distance 50pc

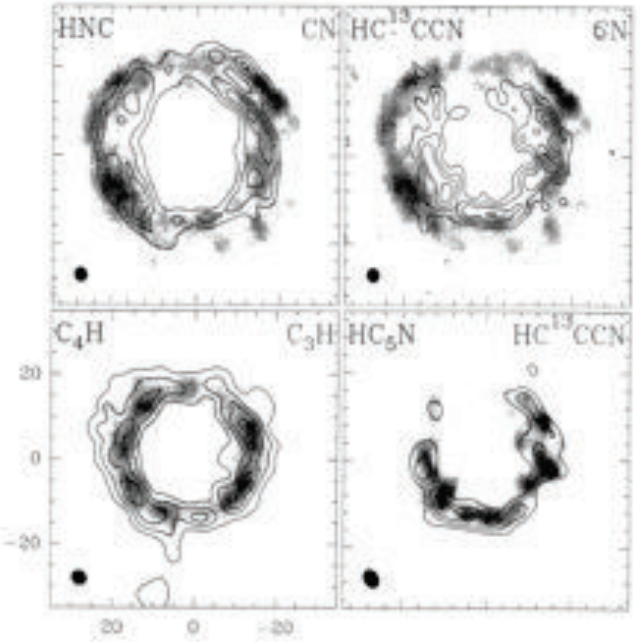




AGB Stars

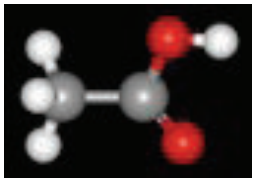

Temperature/Density
(K) (cm^{-3})
1100 /3x10^{9}
1200 /1x10^{10}
1300 /5x10^{10}
1600 /1x10^{12}
2400 /2x10^{14}
Dust
SiO Masers
Radio Photosphere
Chromosphere
Molecular Photosphere
Optical Photosphere
0 2 4 6 8
Radius (AU)
0 0.02 0.04 0.06 0.08
Radius (arcsec)
(at D=100 pc)


W Hya
North Offset (arcsec)
East Offset (arcsec)
0.3
0.2
0.1
0
−0.1
−0.2

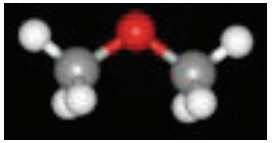

HNC
CN
HC^{13}CCN
6N
C$_4$H
C$_3$H
HC$_5$N
HC^{13}CCN
20
0
−20

Complex Organic Molecules

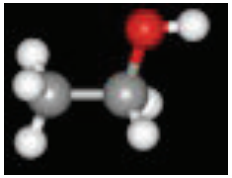
Detected



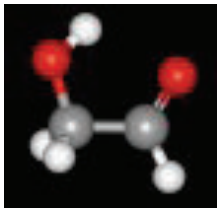
Acetic acid



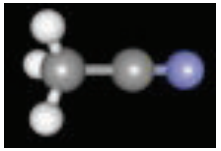
Di-methyl ether



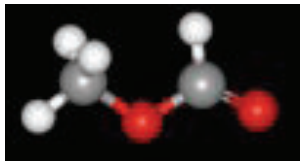
Ethanol



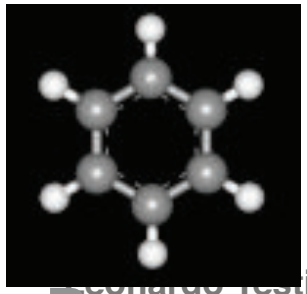
Sugar



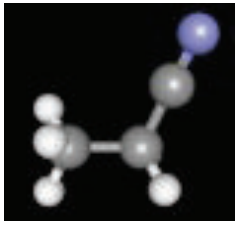
Methyl cyanide



Methyl formate

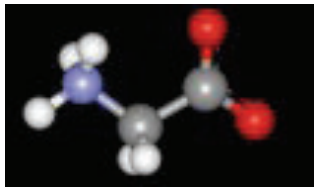


Benzene

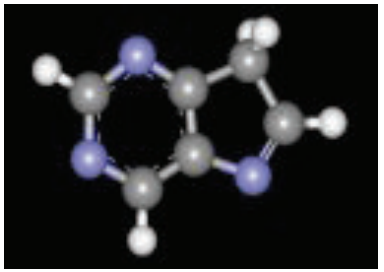


Ethyl cyanide

Not (yet) detected

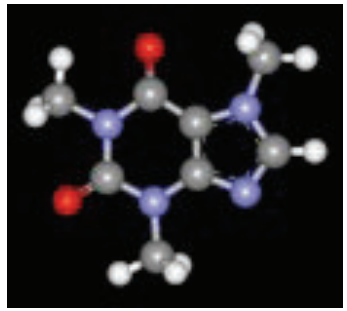


Glycine



Purine

Pyrimidine

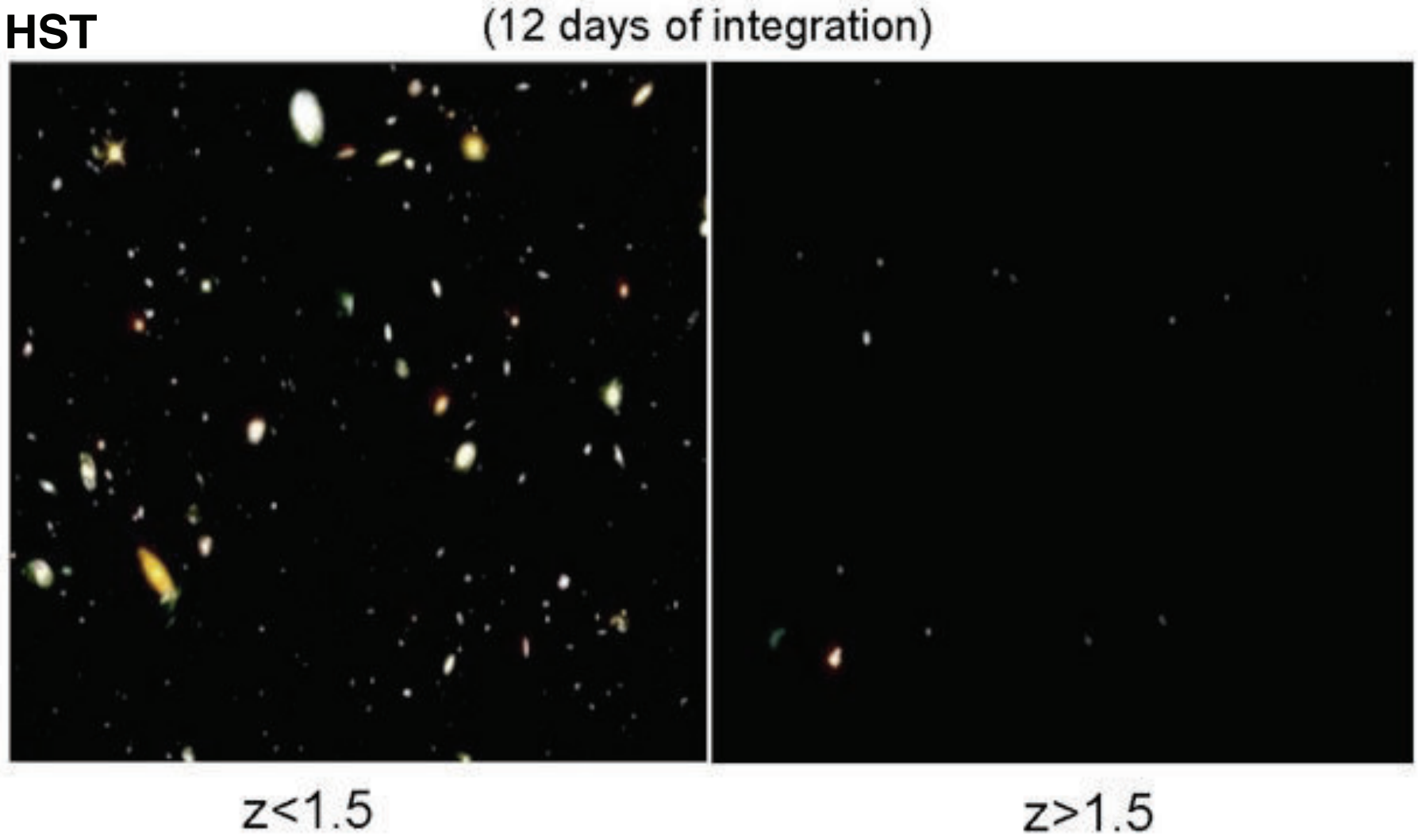


Caffeine

How far does chemical complexity go?
Can we find pre-biotic molecules in Disks?

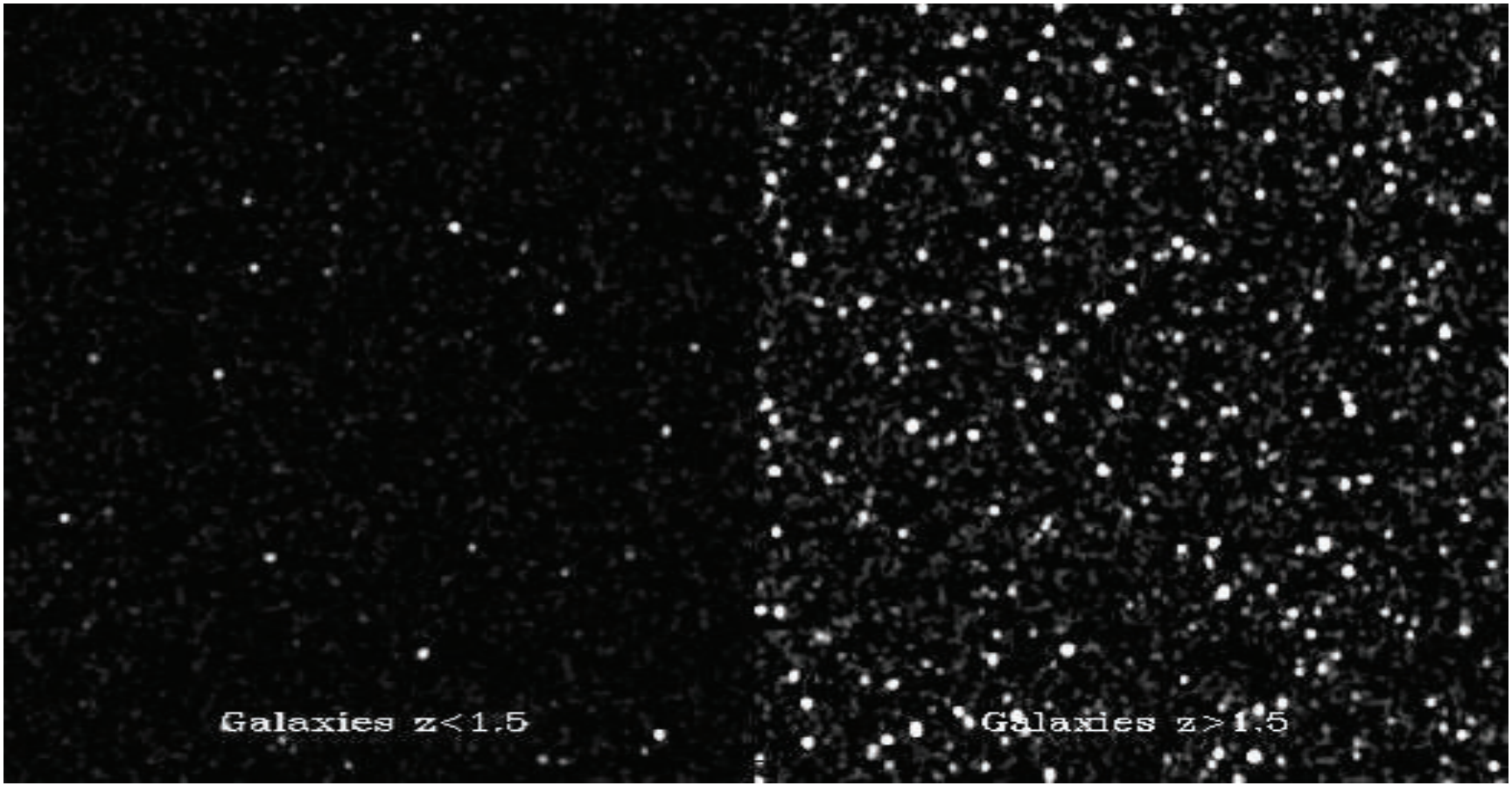
Based on Ehrenfreund 2003

History of Galaxies



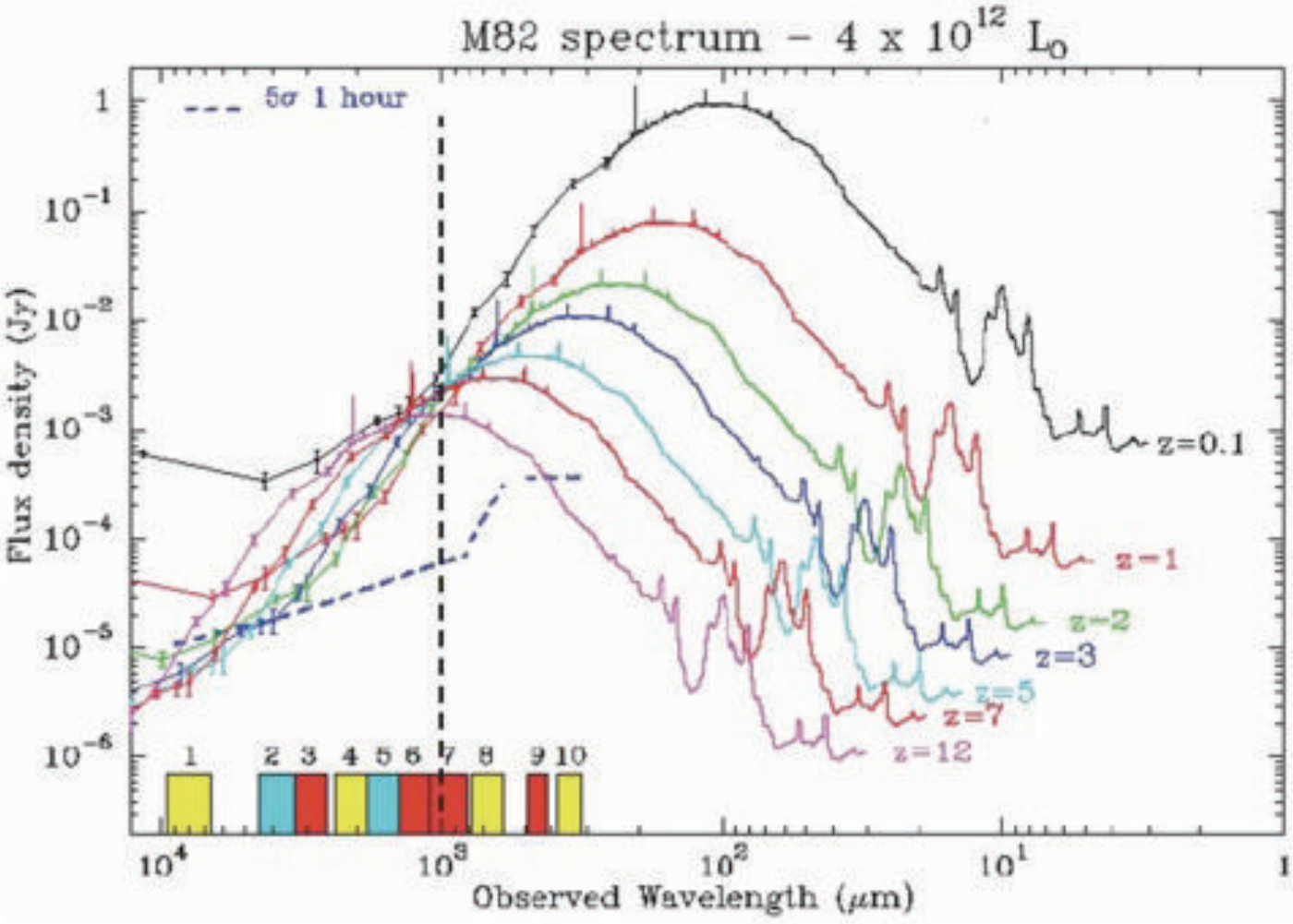
History of Galaxies

ALMA



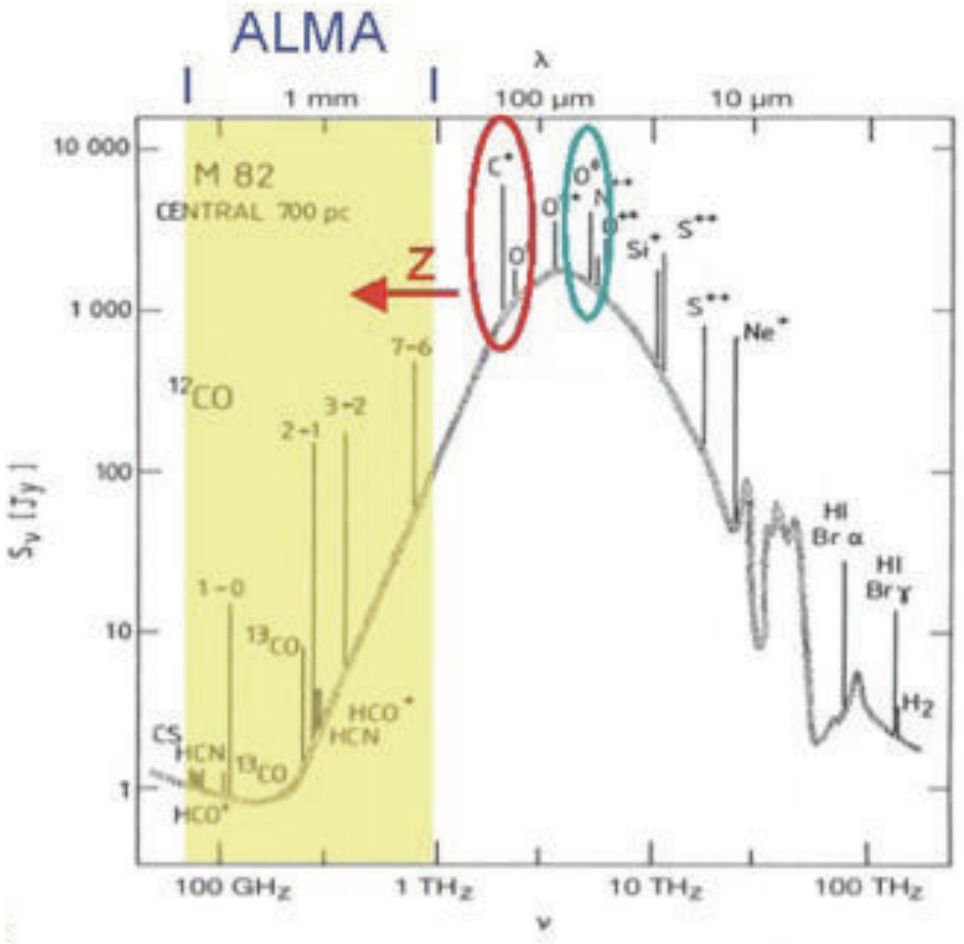
- ALMA will resolve the far infrared background seen by DIRBE and FIRAS

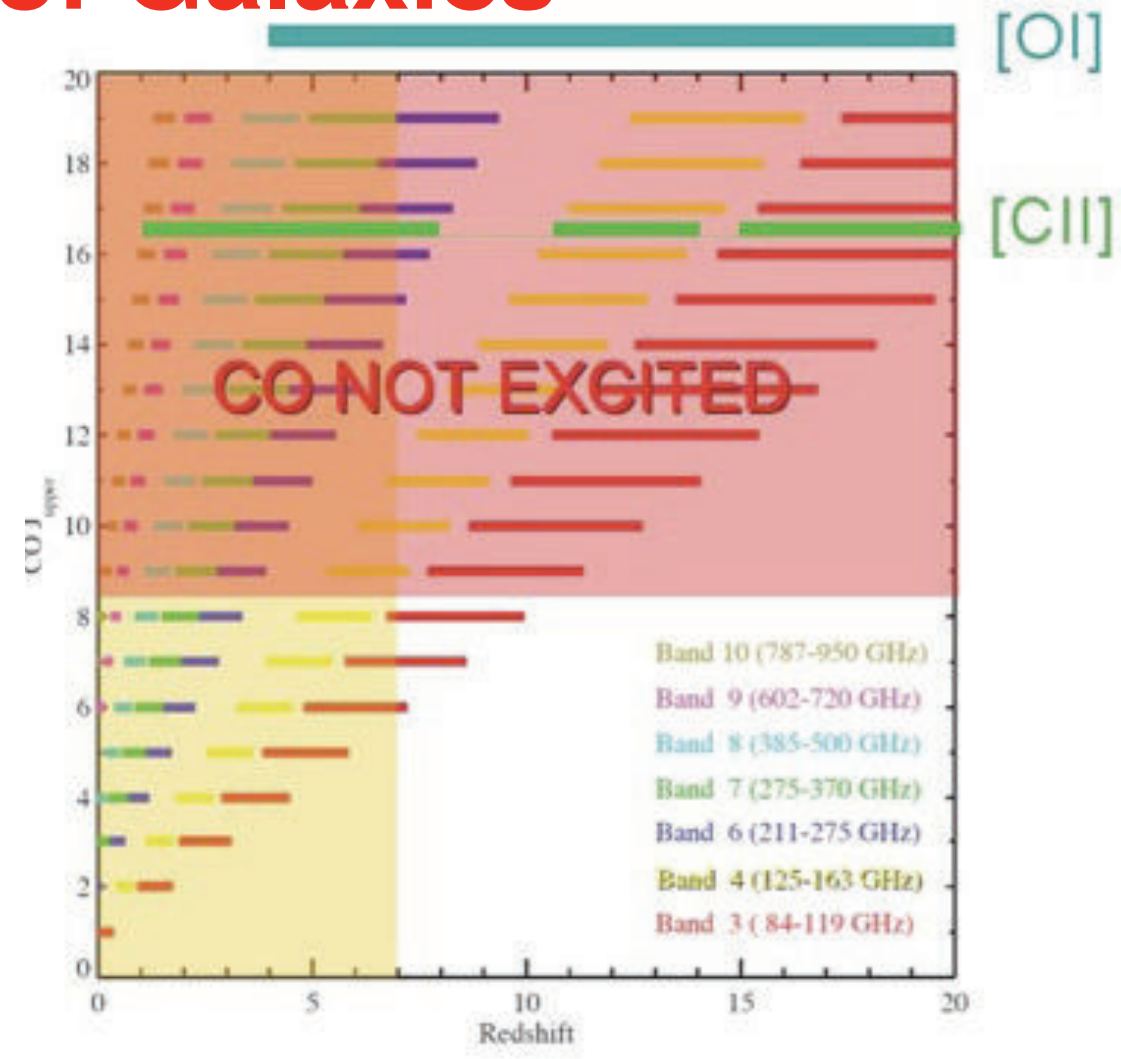
History of Galaxies



- In the (sub-)millimeter the inverse K-correction compensates for the distance as z increases

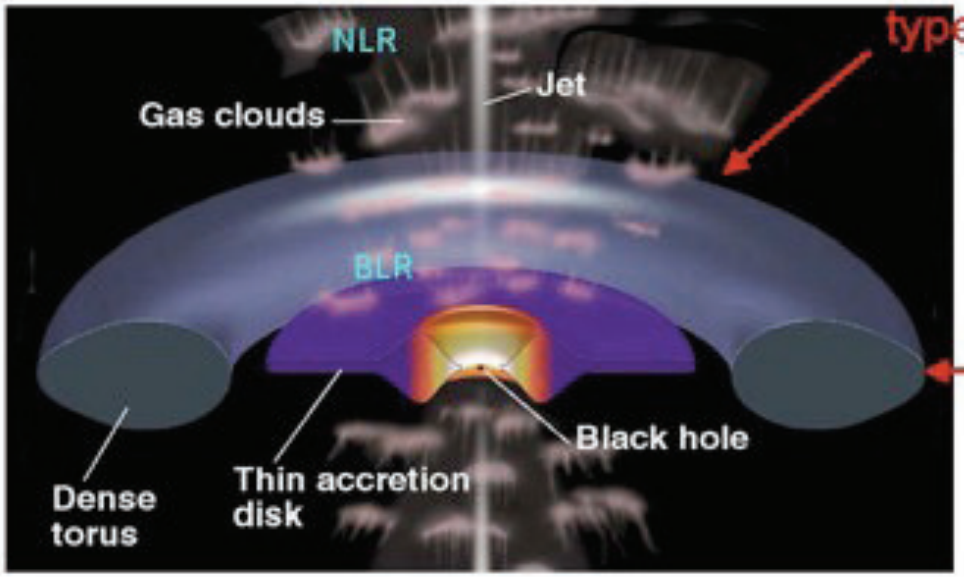
History of Galaxies

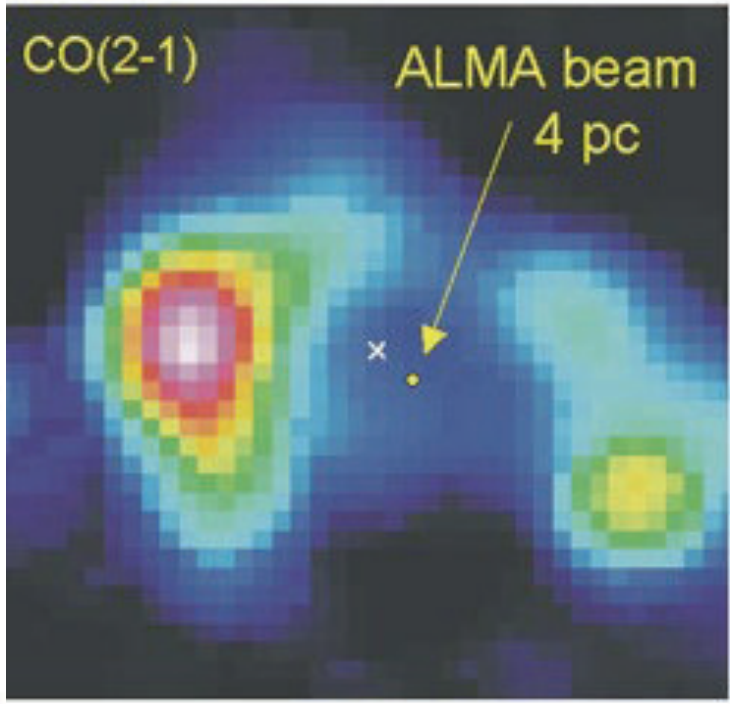




- Measuring redshift (and more) using CO, [CII] or [OI]

The Engine of nearby AGNs



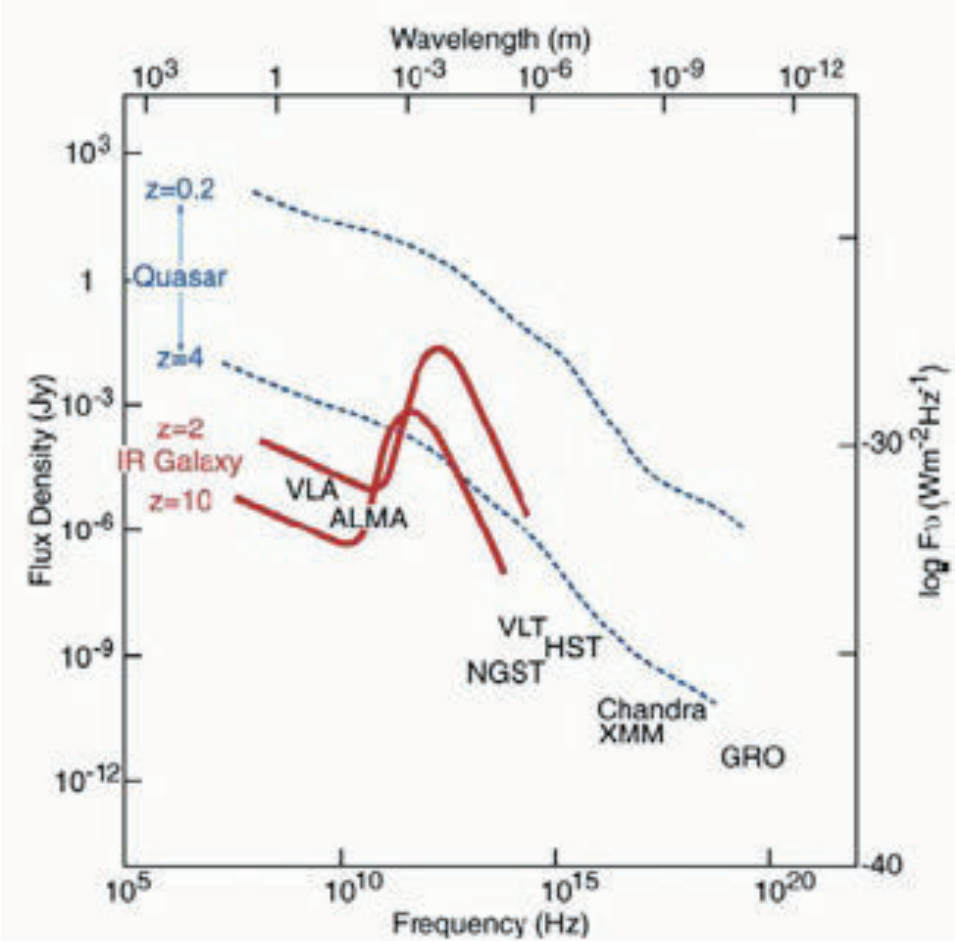


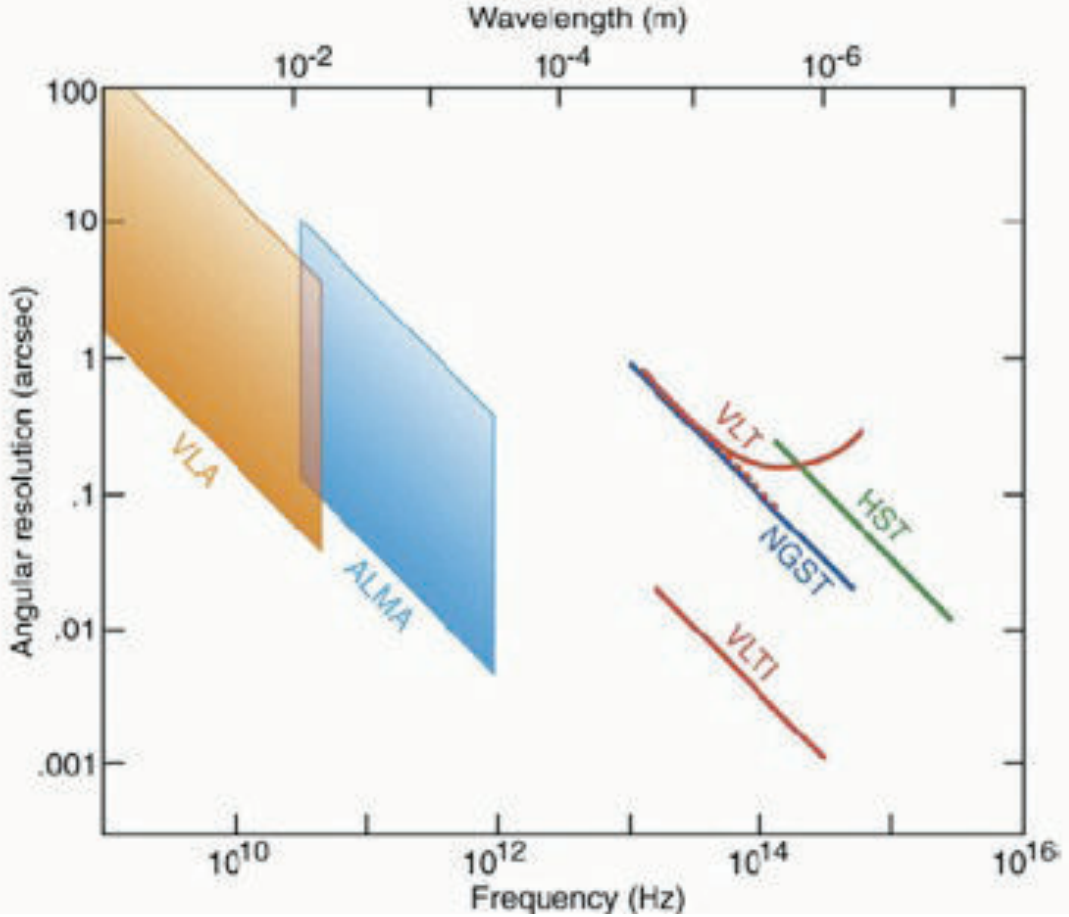
Several (competing) models:

Geometry		Dynamics		Structure	
large ~100 pc	small ~1 pc	rotation	rotation and outflow	cont./diff. medium	clumpy medium
(observed)	(ALMA)	(ALMA)		(ALMA)	

- ALMA will resolve the molecular gas structure and dynamics around nearby AGNs

Sensitivity and Resolution





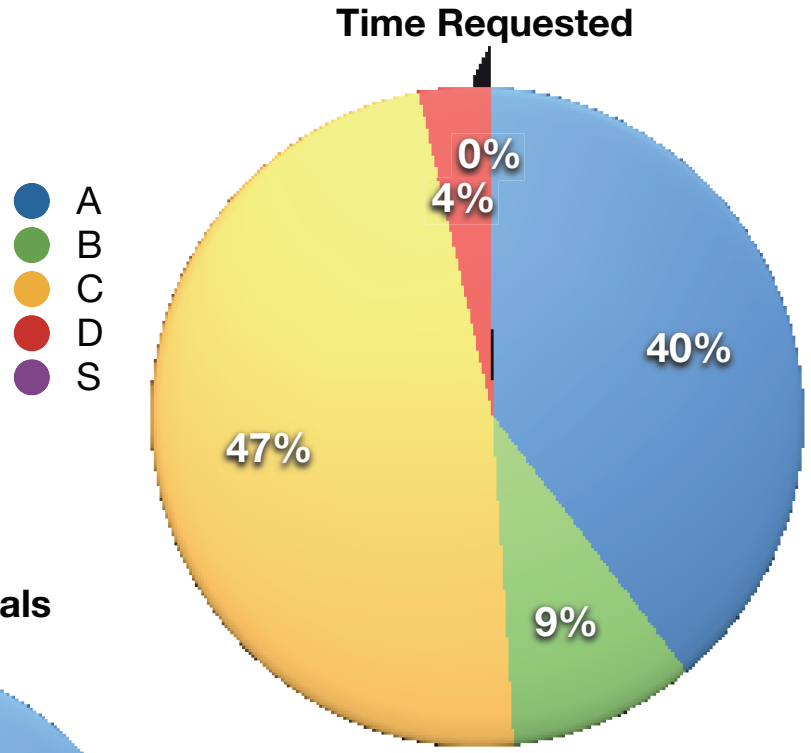
ALMA Science

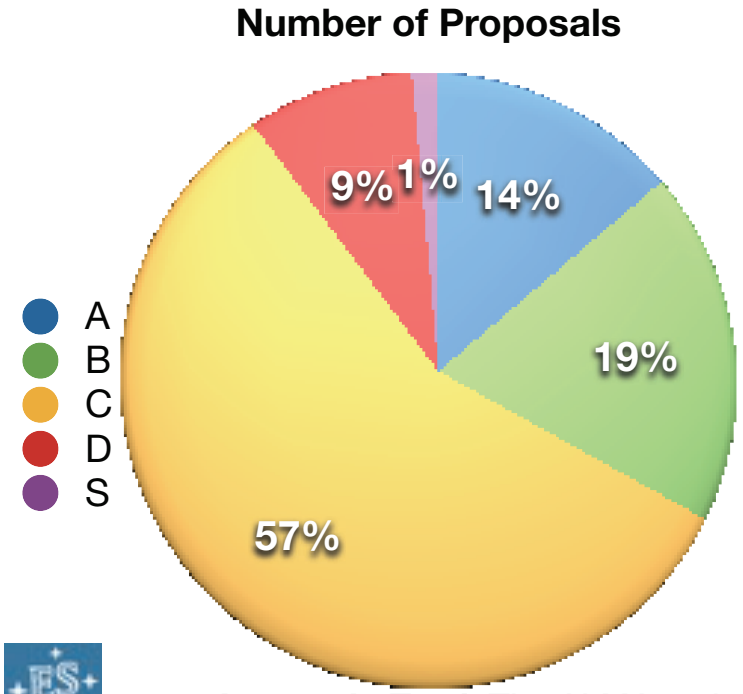
- Star Formation, Proto-planets in nearby disks
- Astrochemistry
- Interstellar medium (Galaxy, Local Group)
- High-redshift deep fields

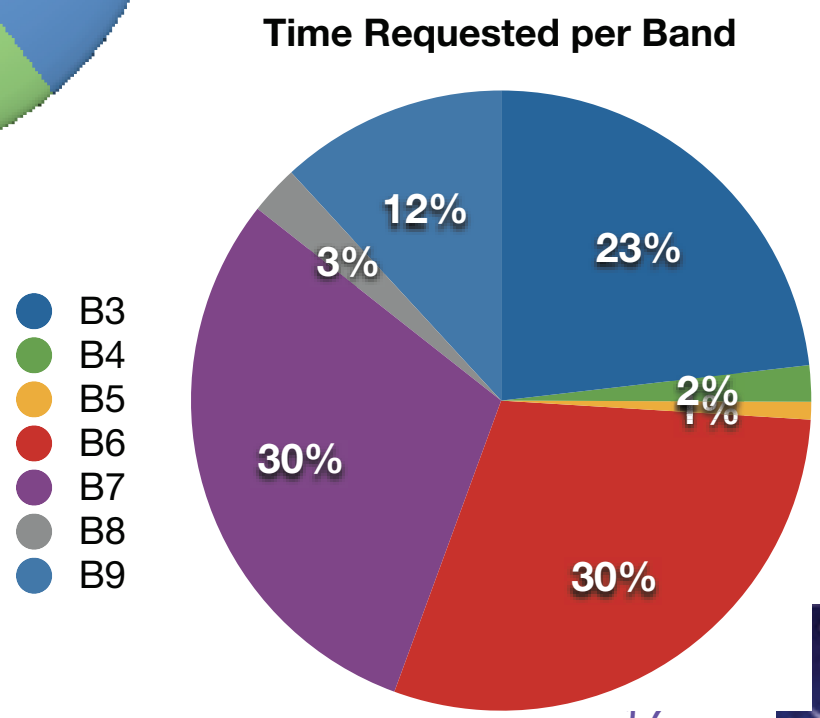
- *+130 projects in first 3yrs – DRSP 2.0*
  - http://www.eso.org/sci/facilities/alma/science/drsp/

- **ALMA Science is for everyone**
  - High resolution/sensitivity 3D instrument at mm-wl
  - 100% service observing with full dynamic scheduling
  - Complete e2e data flow system
  - Science quality images (cubes) delivered to the users
  - Raw, calibrations, pipeline processed data and recipes in archive
  - Friendly and widespread User Support through ARCs

The ALMA DRSP 2.0







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ALMA Science Requirements

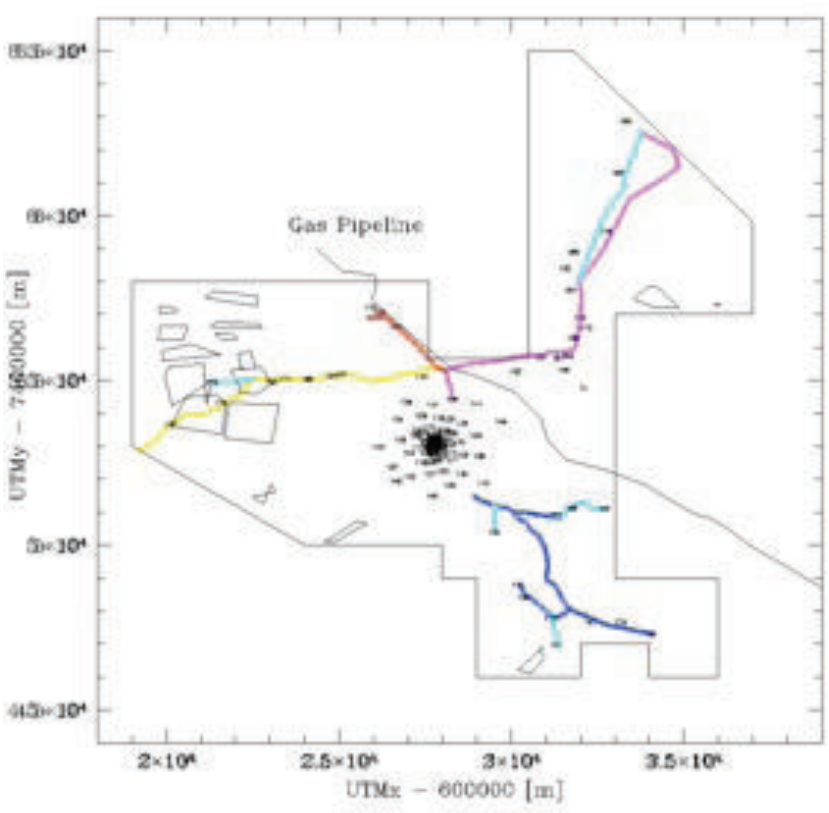
- High Fidelity Imaging.
- Precise Imaging at 0.1” Resolution.
- Routine sub-mJy Continuum Sensitivity.
- Routine mK Spectral Sensitivity.
- Wideband Frequency Coverage.
- Wide Field Imaging Mosaicing.
- Submillimeter Receiver System.
- Full Polarization Capability.
- System Flexibility.

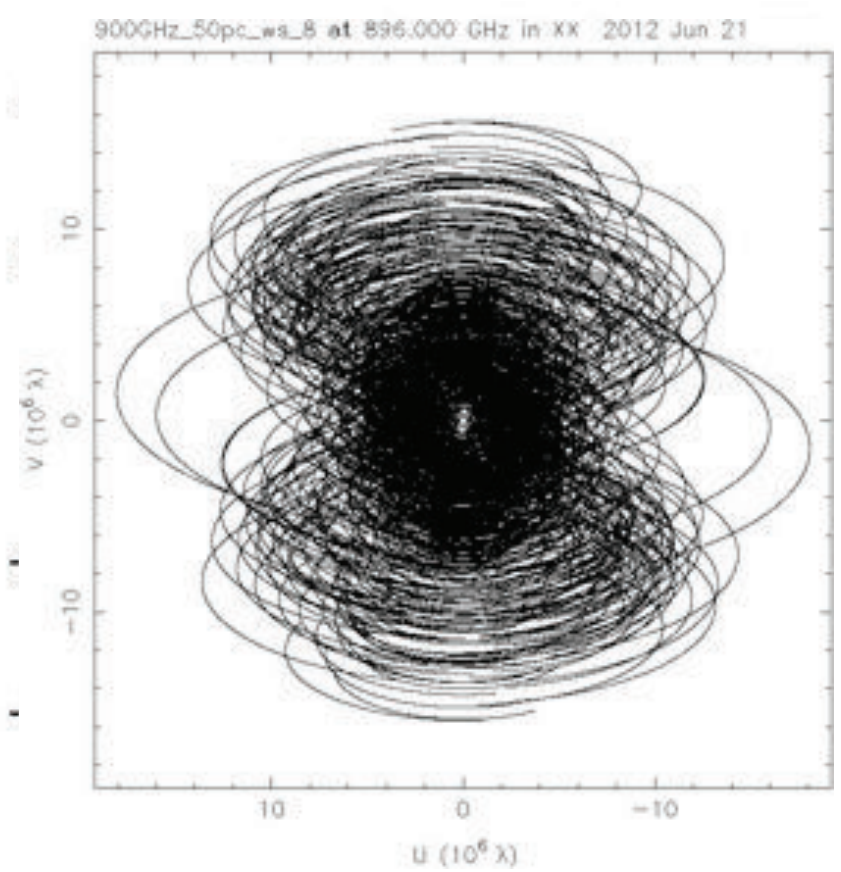
Technical Specifications

- 54 12-m antennas, 12 7-m antennas, at 5000 m site
- Surface accuracy ±25 μm, 0.6” reference pointing in 9m/s wind, 2” absolute pointing all-sky.
- Array configurations between 150m to ~16km.
- 10 bands in 31-950 GHz + 183 GHz WVR.
- 8 GHz BW, dual polarization.
- Flux sens. 0.2 mJy in 1 min at 345 GHz (median cond.).
- Interferometry, mosaicing & total-power observing.
- Correlator: 4096 channels/IF (multi-IF), full Stokes.
- Data rate: 6MB/s average; peak 60-150 MB/s.
- All data archived (raw + images), pipeline processing.

mm Interferometers (u,v) coverage

- Current mm interferometers offer typically ~10^4 visibility measurements in several hours, the VLA delivers ~10^5 visibilities per hour
- ALMA will improve by almost two orders of magnitude

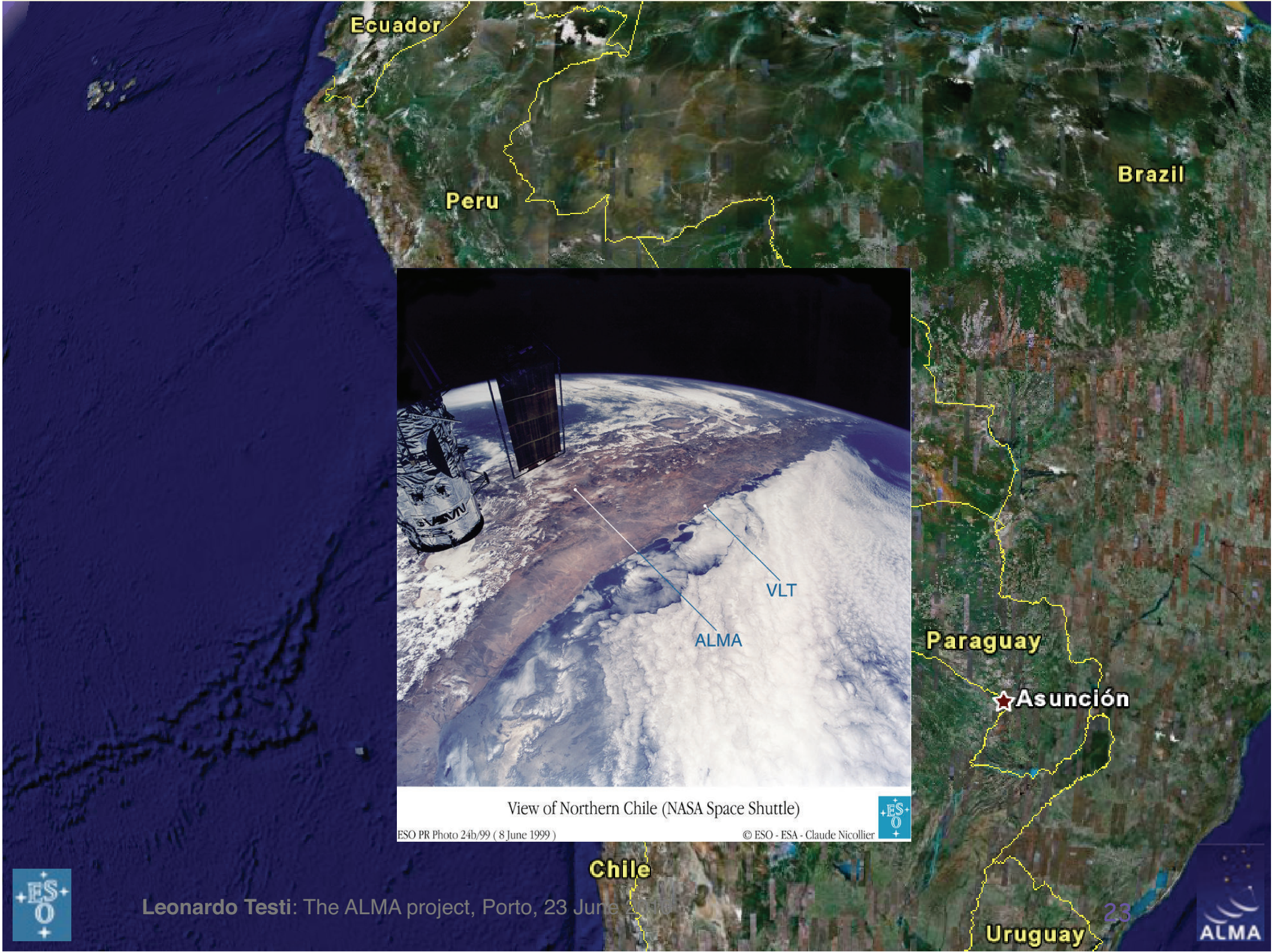




ALMA

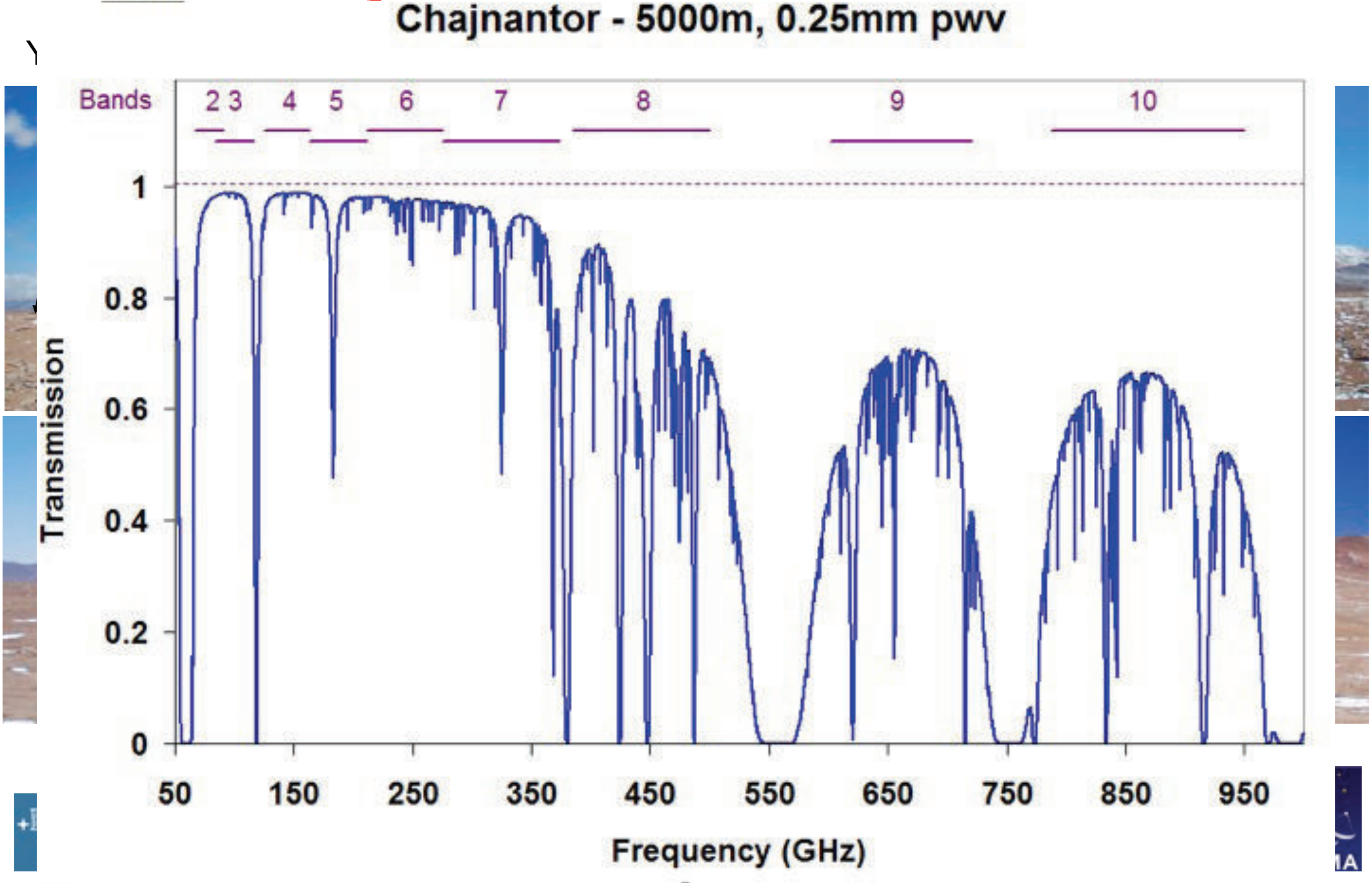
In Search of our Cosmic Origins

Construction Status
June 2010


Ecuador
Peru
Brazil
VLT
ALMA
Paraguay
Asunción
Chile
Uruguay
View of Northern Chile (NASA Space Shuttle)
ESO PR Photo 24b/99 (8 June 1999)
© ESO - ESA - Claude Nicollier


San Pedro de Atacama
Operations Support Facilities
OSF (2900m altitude)
ALMA Operations Site
AOS (5000m altitude)
Toconao

Chajnantor Plateau - 5000m



ALMA Receivers

ALMA Band	Frequency Range	Receiver noise temperature		Mixing scheme	Receiver technology
		T_{Rx} over 80% of the RF band	T_{Rx} at any RF frequency		
1	31.3 – 45 GHz	17 K	28 K	USB	HEMT
2	67 – 90 GHz	30 K	50 K	LSB	HEMT
3	84 – 116 GHz	37 K	62 K	2SB	SIS
4	125 – 169 GHz	51 K	85 K	2SB	SIS
5	163 - 211 GHz	65 K	108 K	2SB	SIS
6	211 – 275 GHz	83 K	138 K	2SB	SIS
7	275 – 373 GHz*	147 K	221 K	2SB	SIS
8	385 – 500 GHz	98 K	147 K	DSB	SIS
9	602 – 720 GHz	175 K	263 K	DSB	SIS
10	787 – 950 GHz	230 K	345 K	DSB	SIS

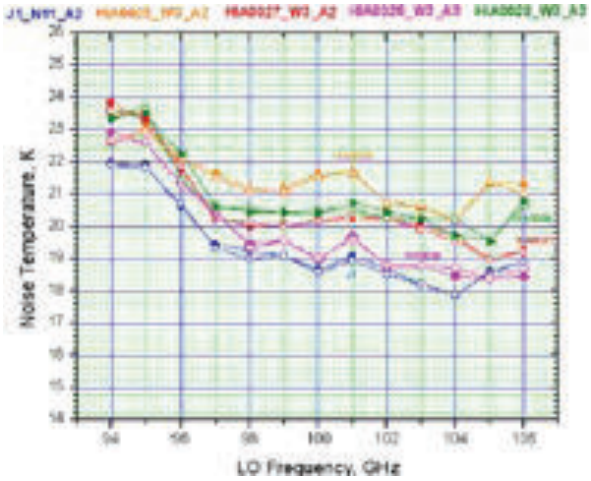
* - between 370 – 373 GHz T_{rx} is less then 300 K

- Dual, linear polarization channels:
  - Increased sensitivity
  - Measurement of 4 Stokes parameters
- 183 GHz water vapour radiometer:
  - Used for atmospheric path length correction

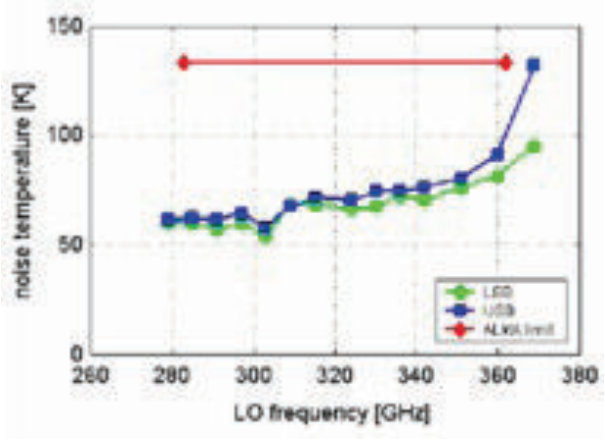
★ Japanese contribution all telescopes plus ACA

★ EC funded 6 receivers ALMA–Herschel sinergy

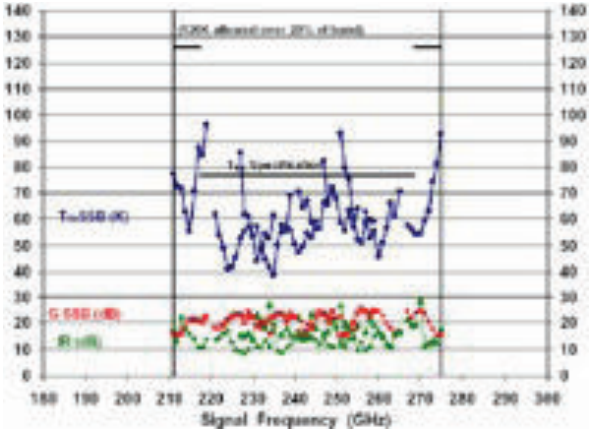
ALMA Receivers



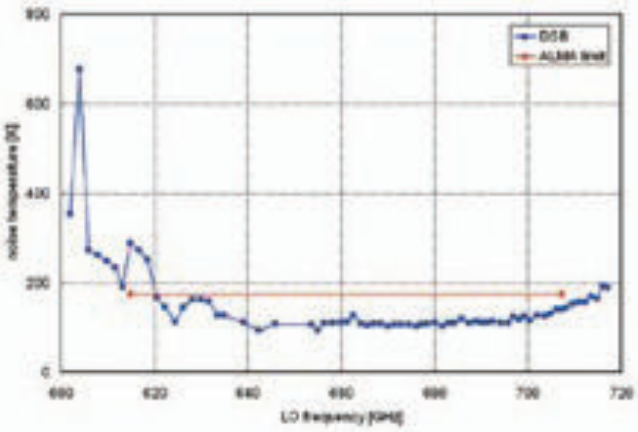
Band 3 ("3mm")



Band 7 ("850μm")

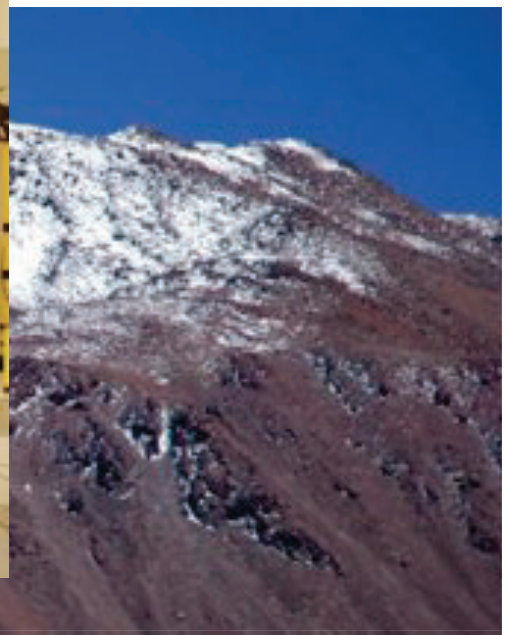


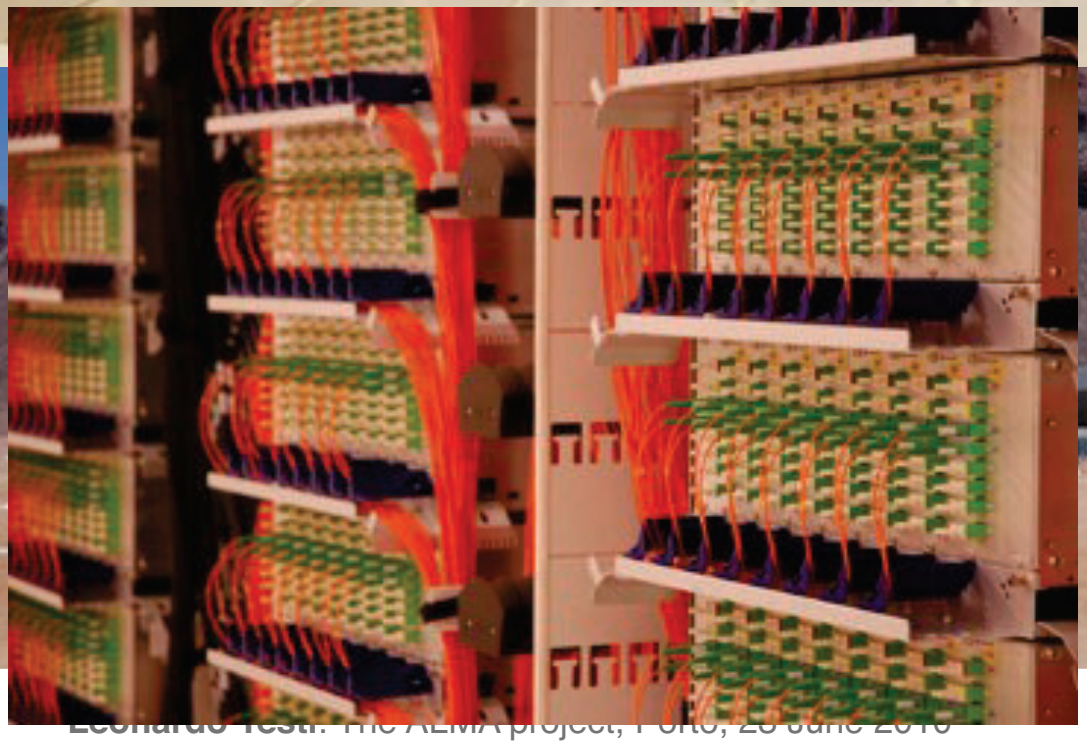
Band 6 ("1mm")



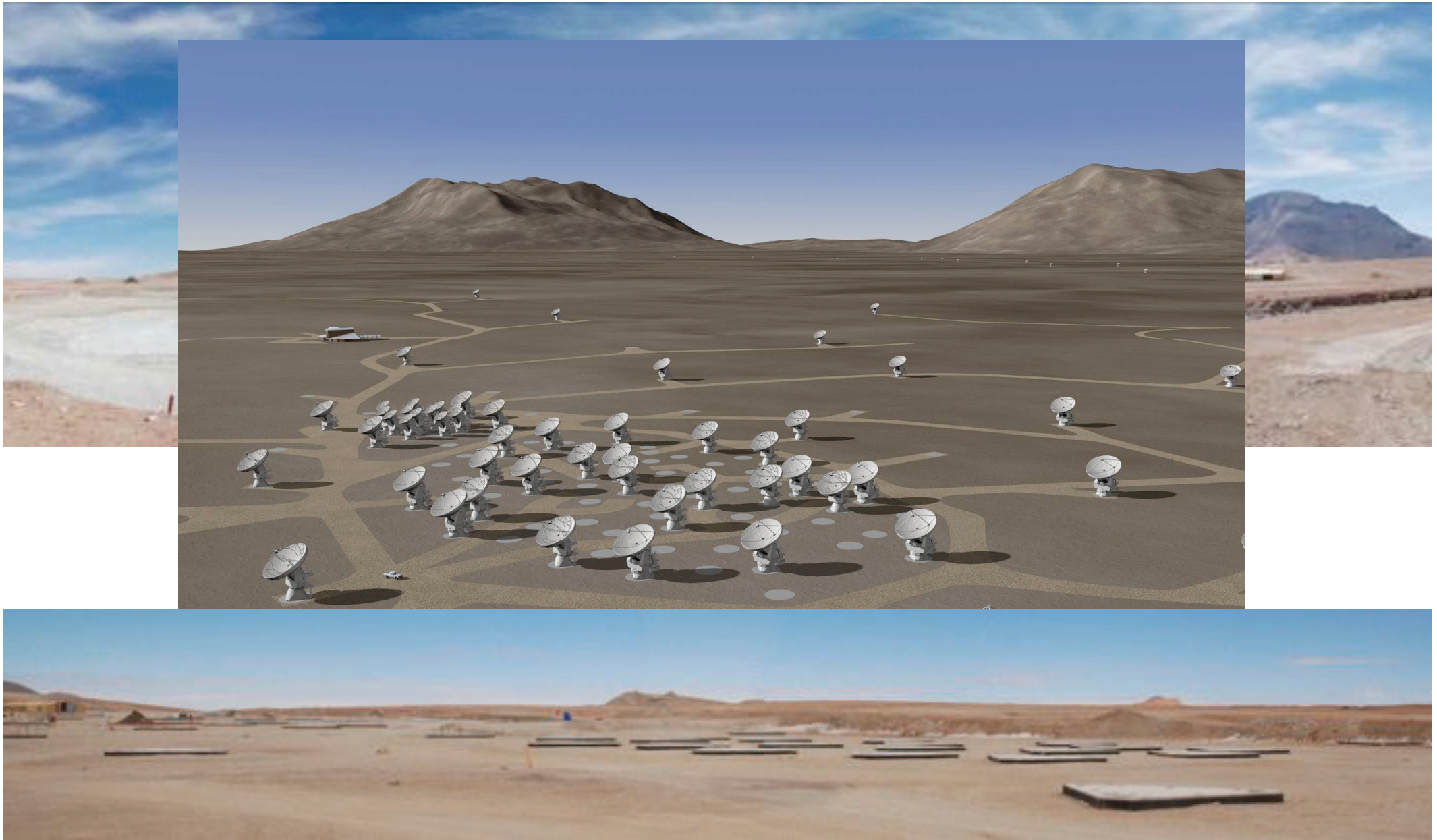
Band 9 ("450μm")

Array Operations Site

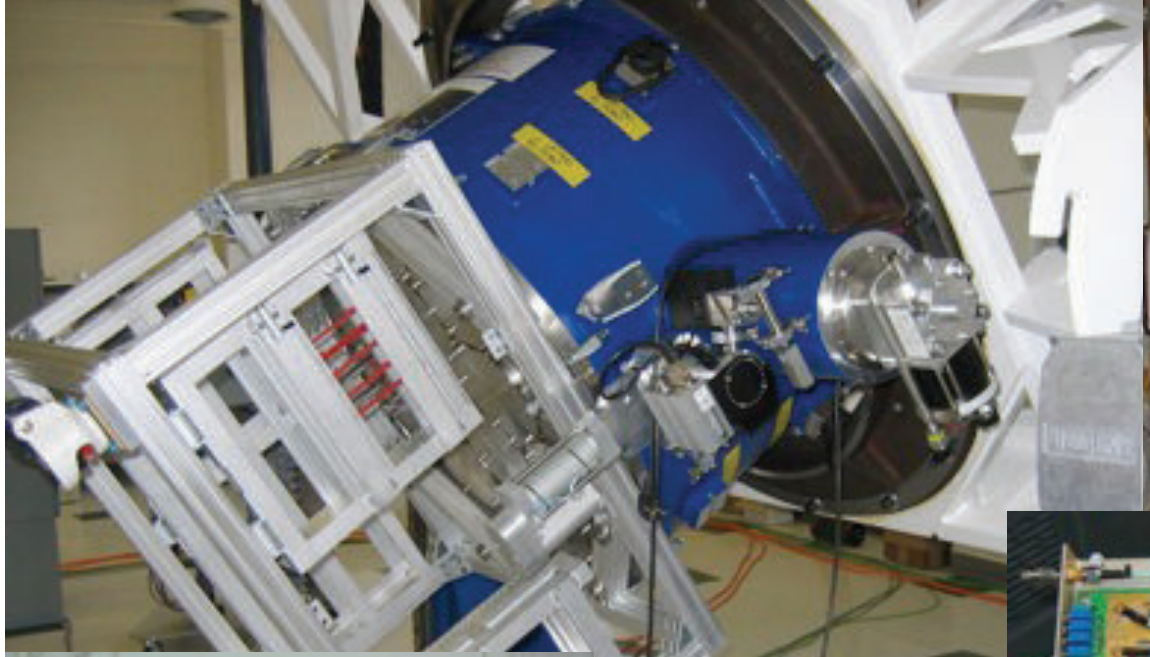


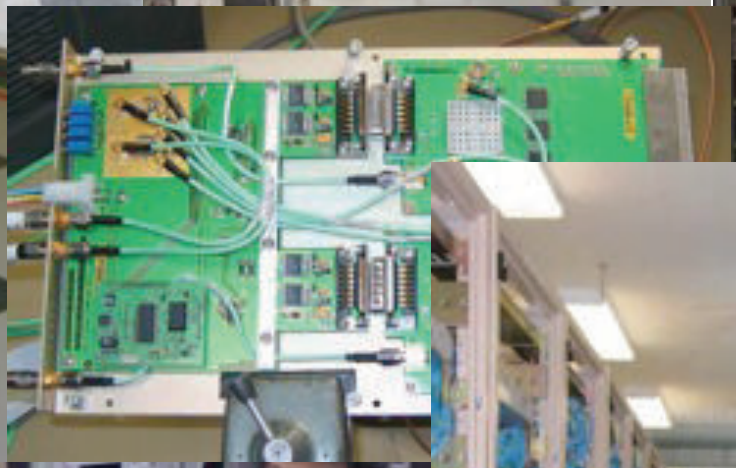


Array Operations Site



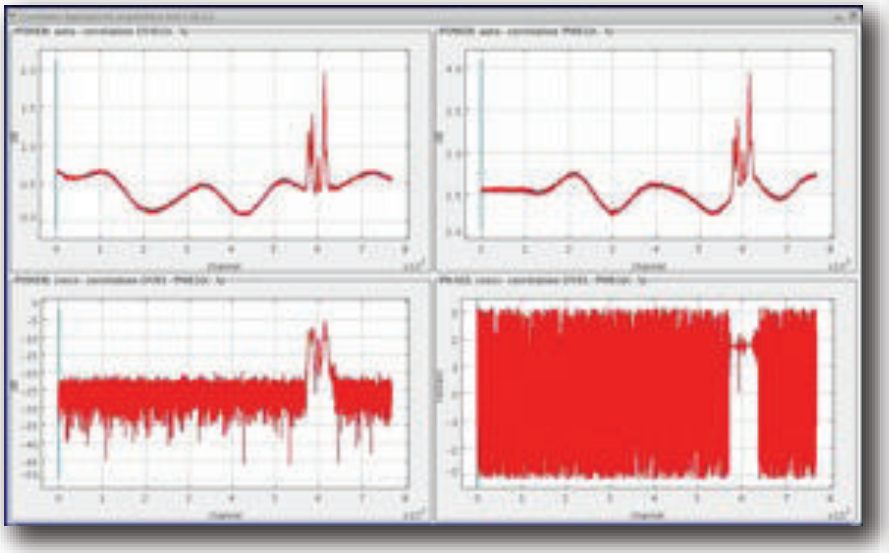
Operations Support Facility - 2900m



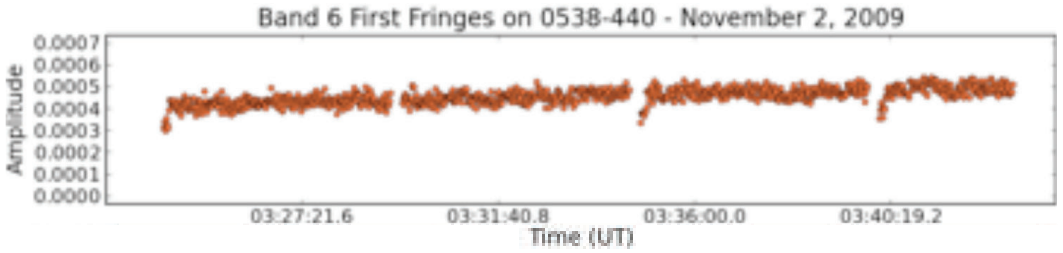



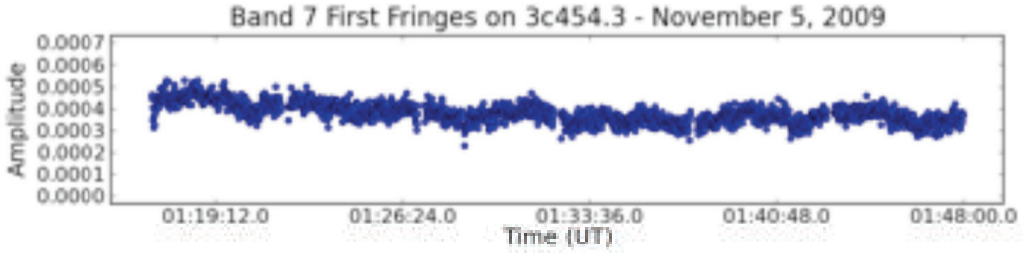


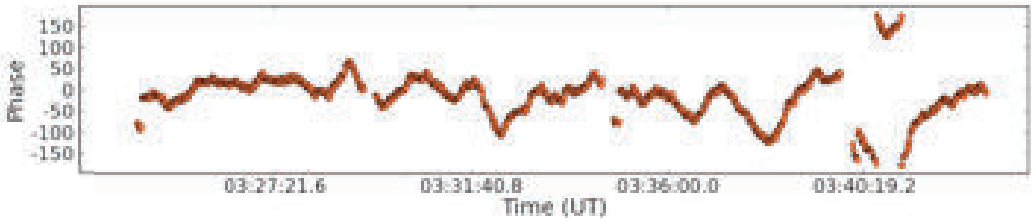
First Fringes at OSF

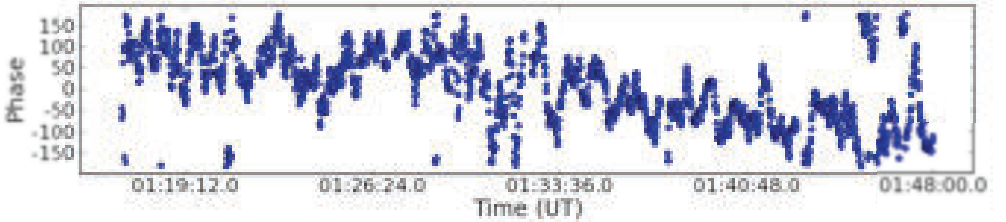


First antenna at 5000m

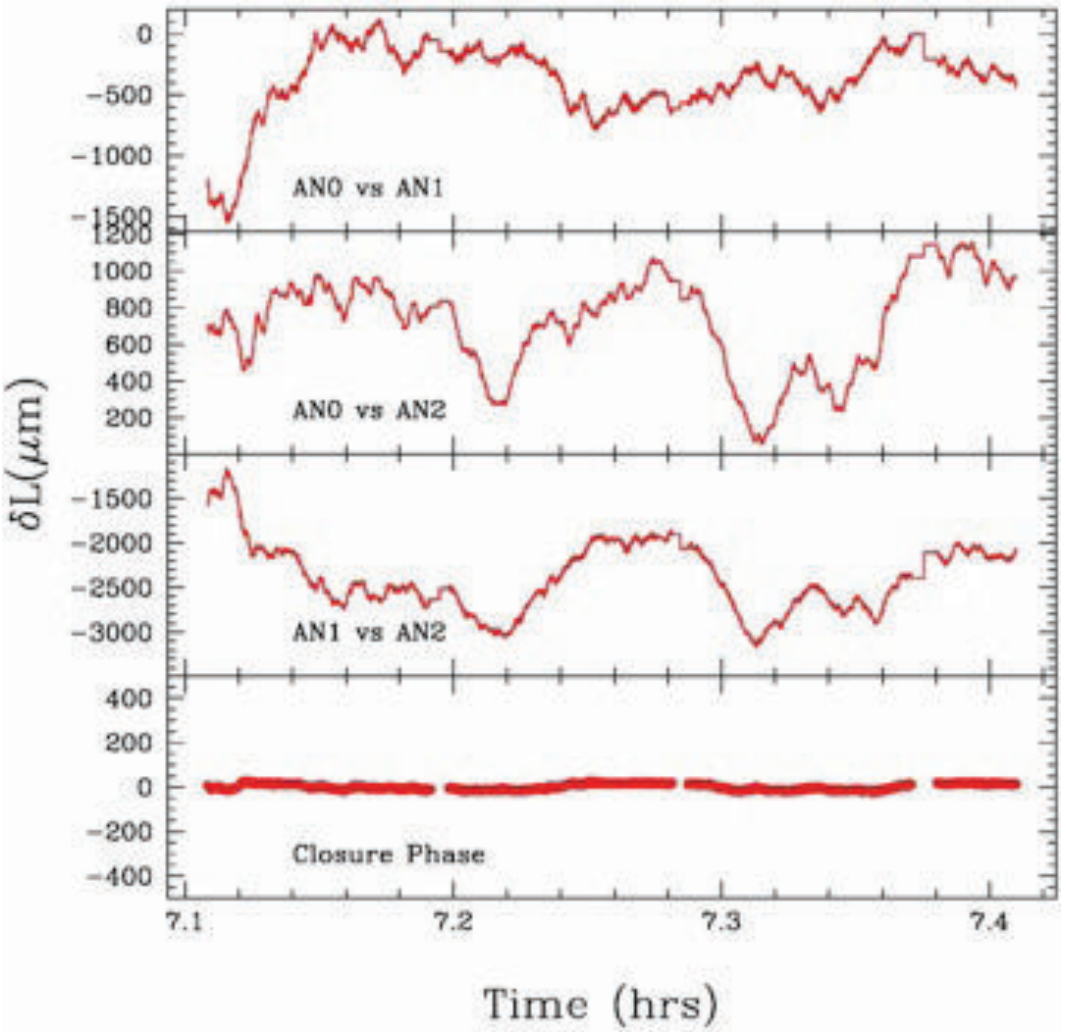

Band 6 First Fringes on 0538-440 - November 2, 2009
Amplitude
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
03:27:21.6
03:31:40.8
03:36:00.0
03:40:19.2
Time (UT)


Band 7 First Fringes on 3c454.3 - November 5, 2009
Amplitude
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0.0000
01:19:12.0
01:26:24.0
01:33:36.0
01:40:48.0
01:48:00.0
Time (UT)


Phase
150
100
50
0
-50
-100
-150
03:27:21.6
03:31:40.8
03:36:00.0
03:40:19.2
Time (UT)


Phase
150
100
50
0
-50
-100
-150
01:19:12.0
01:26:24.0
01:33:36.0
01:40:48.0
01:48:00.0
Time (UT)

Closure phase

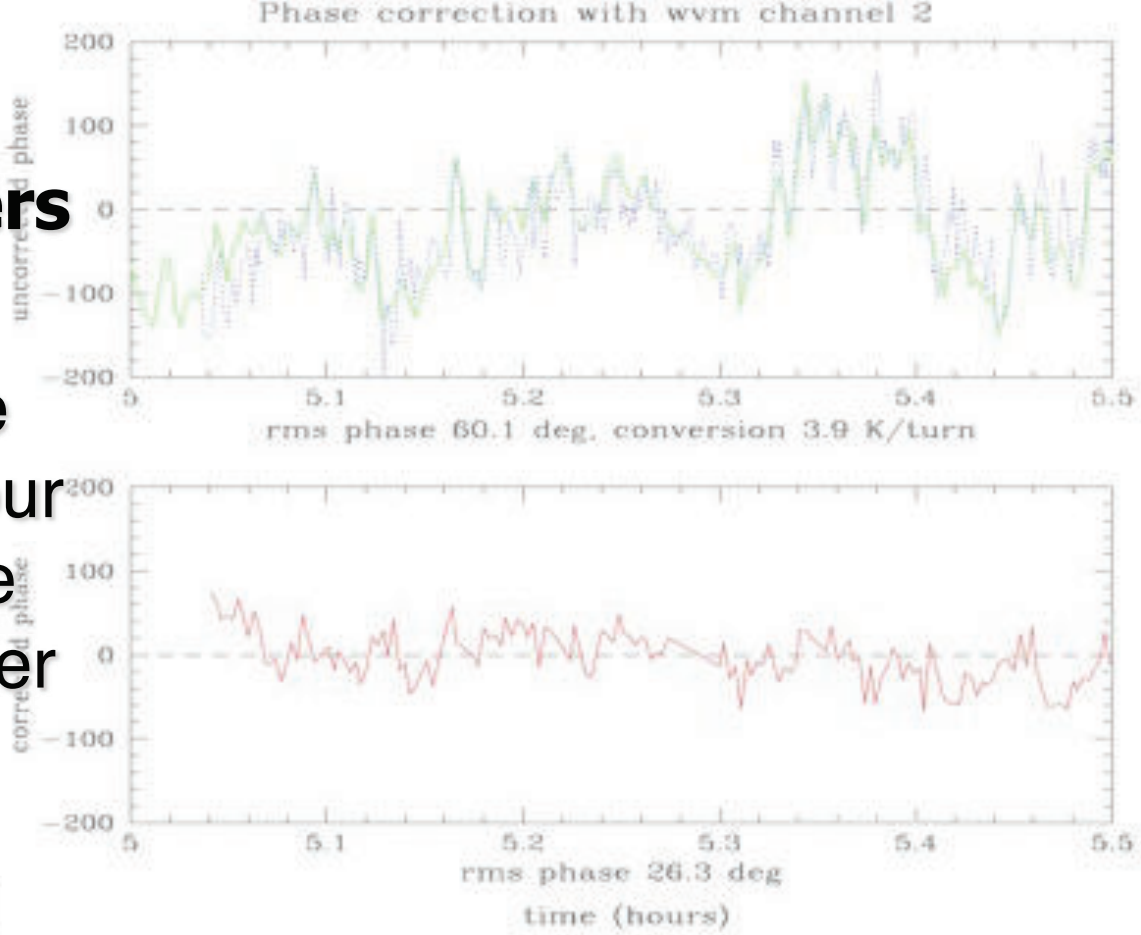


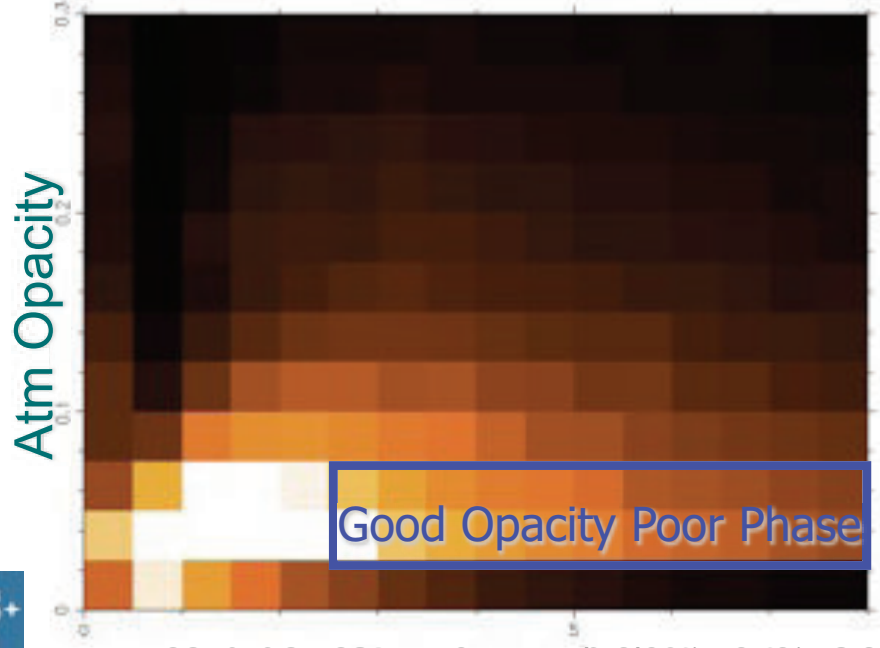
- Closure phase achieved at the end of 2009
- CSV started on Jan 22, 2010

Five antennas interferometer

✦ Water Vapour Radiometers

- All ALMA antennas will be equipped with water vapour radiometers observing the 183GHz atmospheric water line.



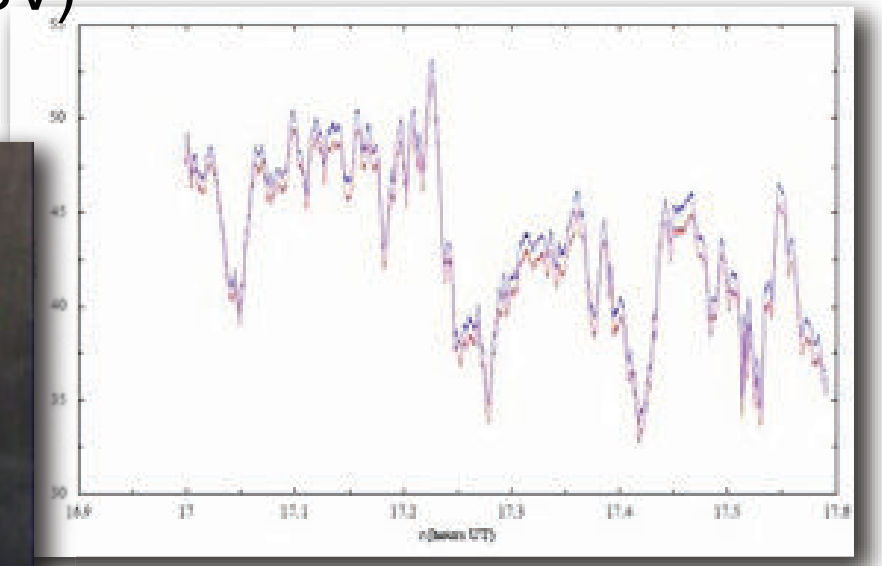


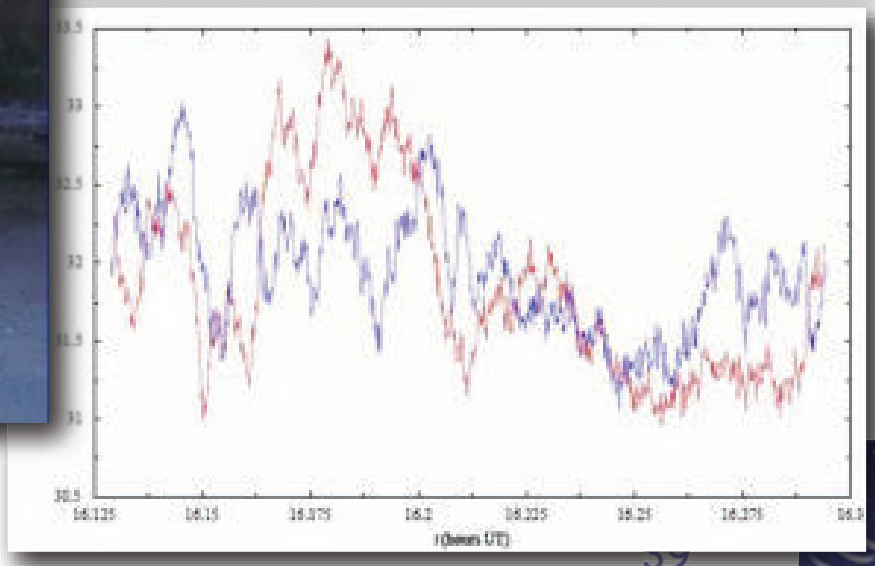
WVRs track phase on 1s timescales along the same path (within 3-10 arcmin) as the astronomical signal from the source (complementary to fastswitching: ≥10s and few degs)

-Improve Sensitivity and Fidelity
-Allow to increase switch time

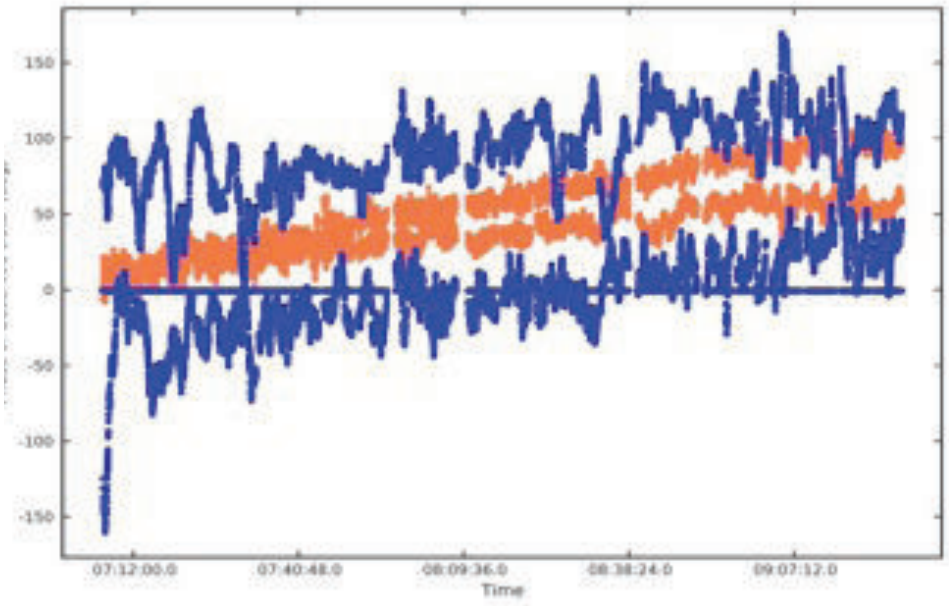
WVR progress

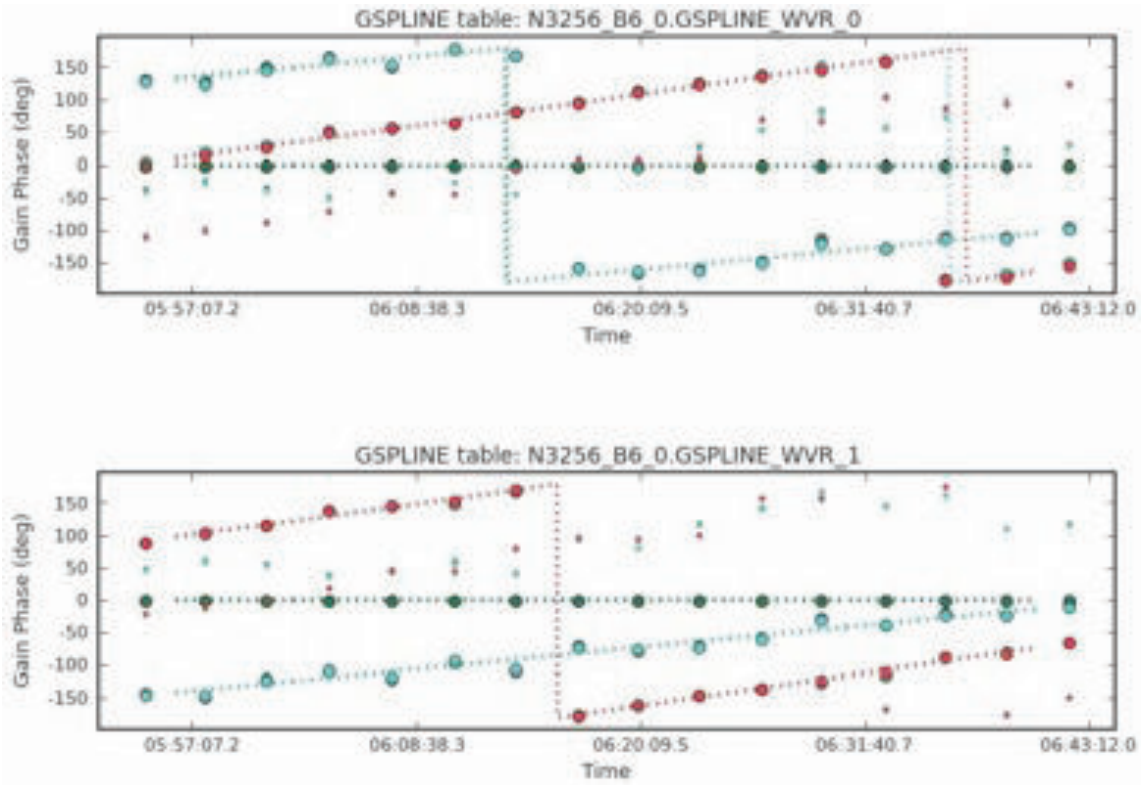
- Successful testing at Onsala, OSF and AOS
- Correction very promising (part of CSV)





WVR Phase correction





Blue: uncorrected interferometer phase

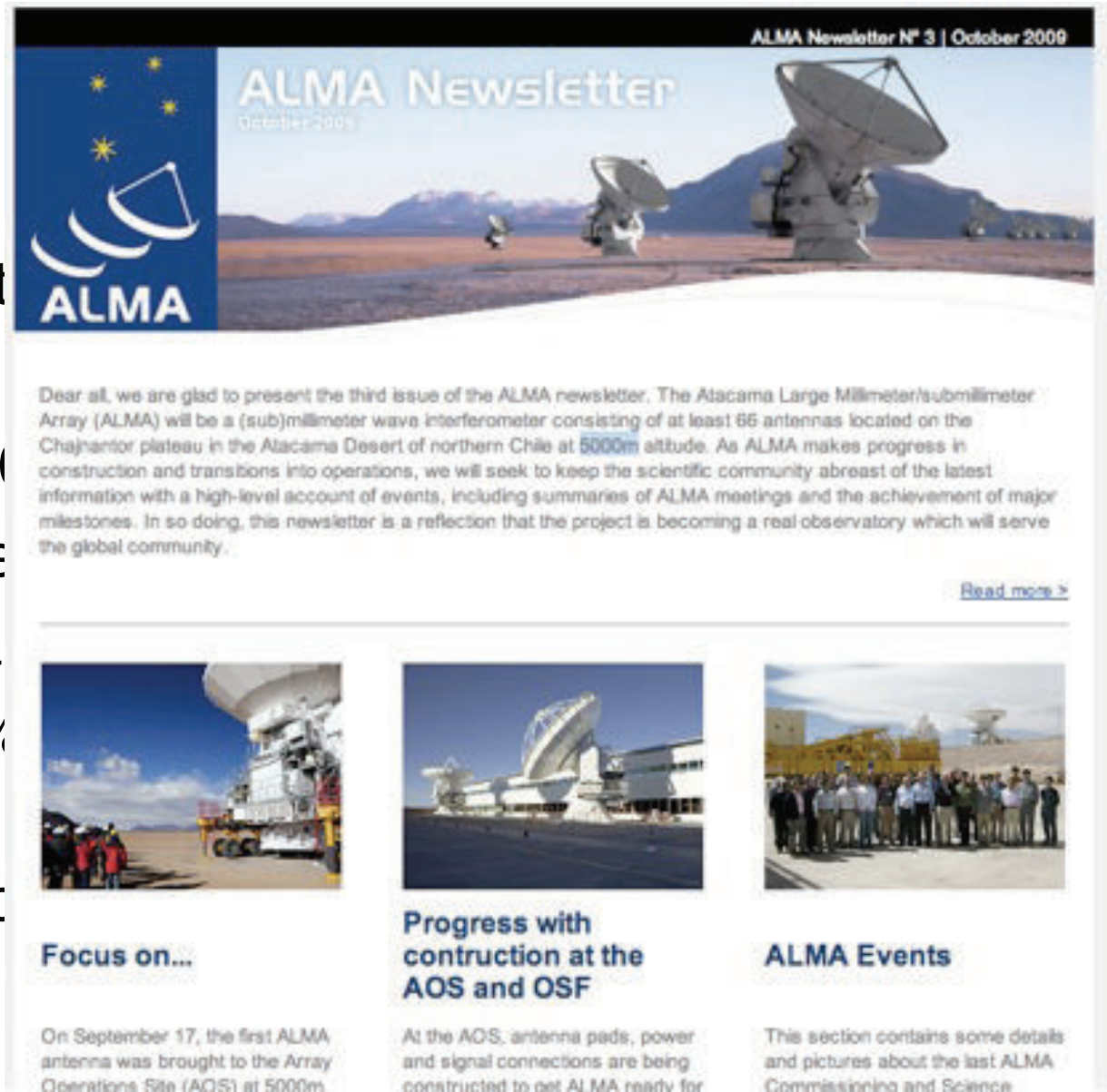
Orange: phase after correction using water-vapour radiometers

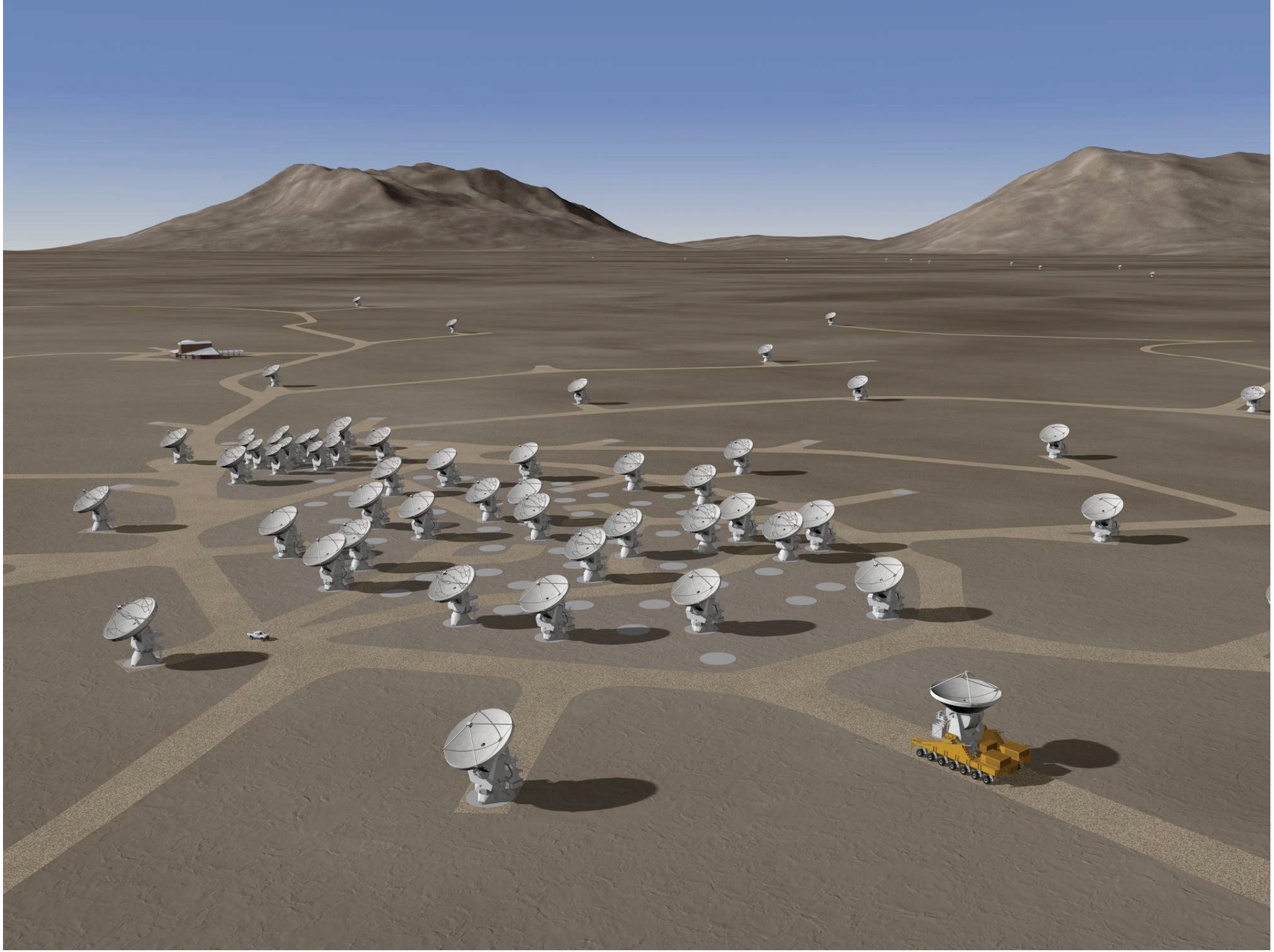
Full calibration test in CASA

Small dots: raw measurements
Large circles: WVR corrected

ALMA CSV, Early and Full Science

- CSV Team
  - Sci IPT plus Ops Astr.
  - Community involveme
- Early Science: 16 ants, at
  - Configurations probab
  - Bands: 3mm, 1.3mm, (
  - We expect to issue the
  - Demonstration/Tutoria
- Science Operations >75%
  expected in 2012
- Endo of construction/full c





ALMA beyond ALMA

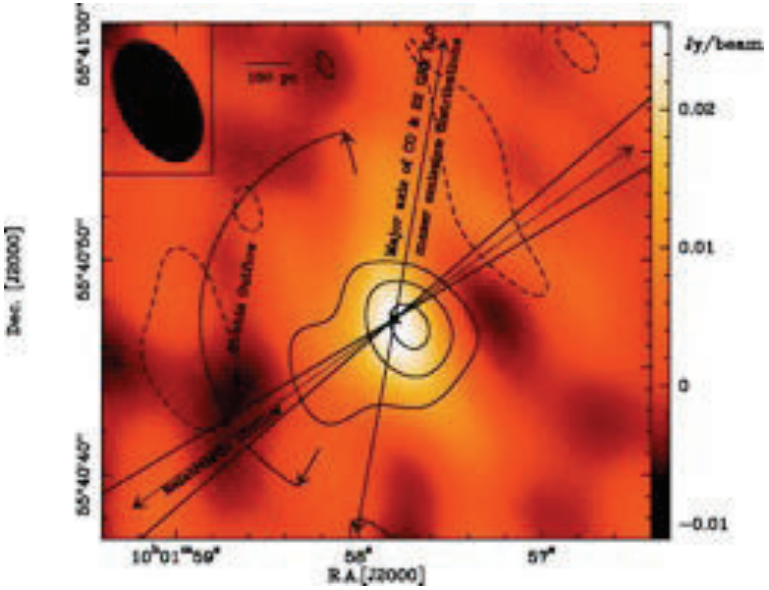
- ALMA will allow transformational science thanks to the sensitivity, angular resolution, spectral coverage and image fidelity, but...

- The baseline ALMA project will only achieve a fraction of the full potential of the site and instrument

- Incomplete Receiver Complement
- Limited Wide Field Capabilities
- Limited Correlator and Data Rate Capabilities
- Extended baselines (30-50km), VLBI (200-10000km)
- Advanced Calibration, Software, Science Tools....

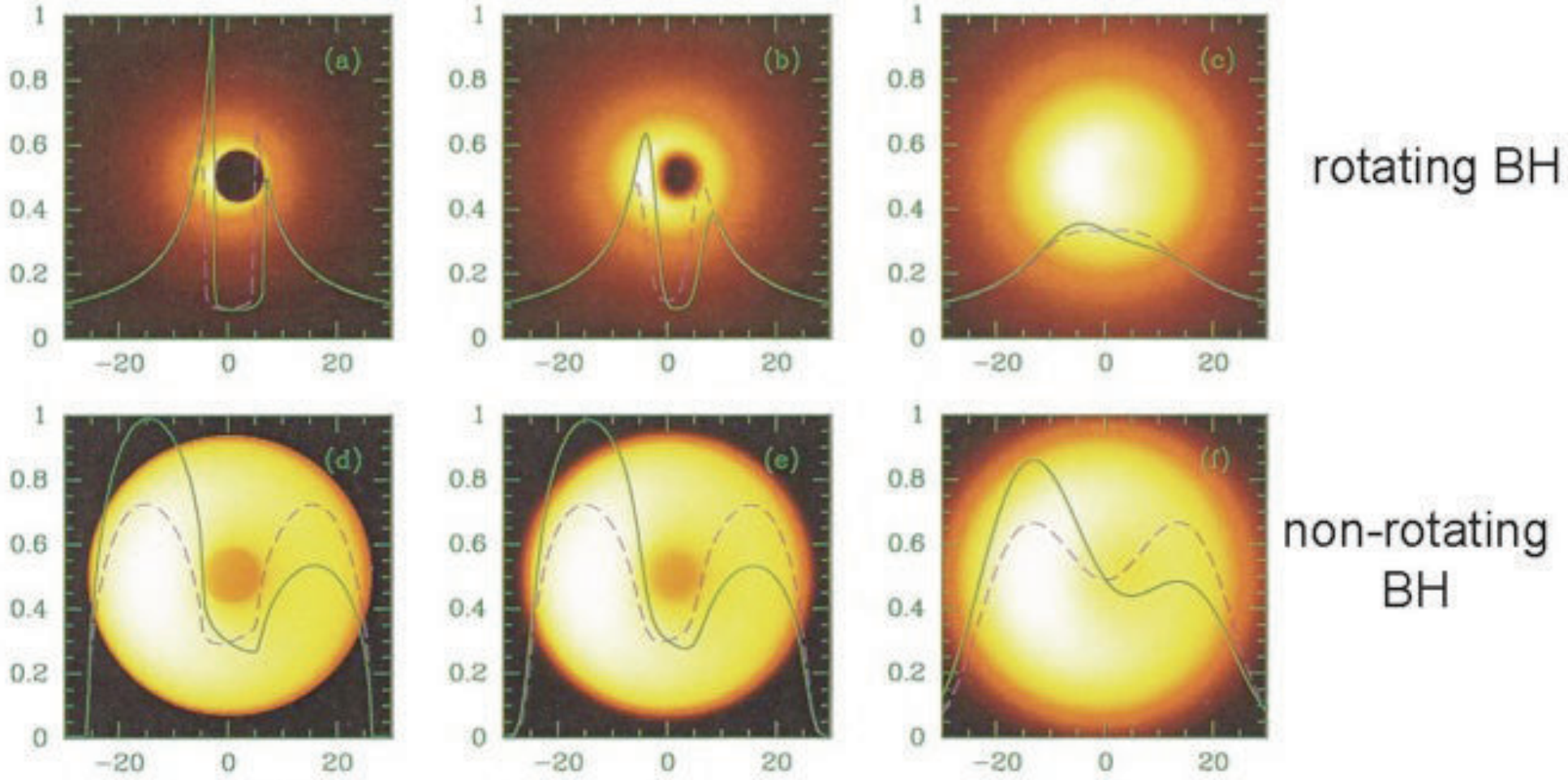
Examples of Scientific Limitations

- Limited Band 5 Complement
  - Eu FP6 6 B5: just a glimpse at B5
  - Water in the Universe
  - [CII] in the range 8 < z < 11
- No Band 1 & 2
  - High-z low excitation CO
  - Sunyaev-Zeld'ovich effect
  - Dust Evolution in Protoplanetary Disks
- Limited correlator capabilities
  - Line surveys, chemistry studies very time consuming
- Continuum Wide Field Mapping Efficiency
  - SZ and Molecular Clouds applications very time consuming
  - Instantaneous wide field of view for solar physics



183 GHz H2O maser in NGC3079
(SMA, Humphreys et al 2005)

Galactic Center Black Hole

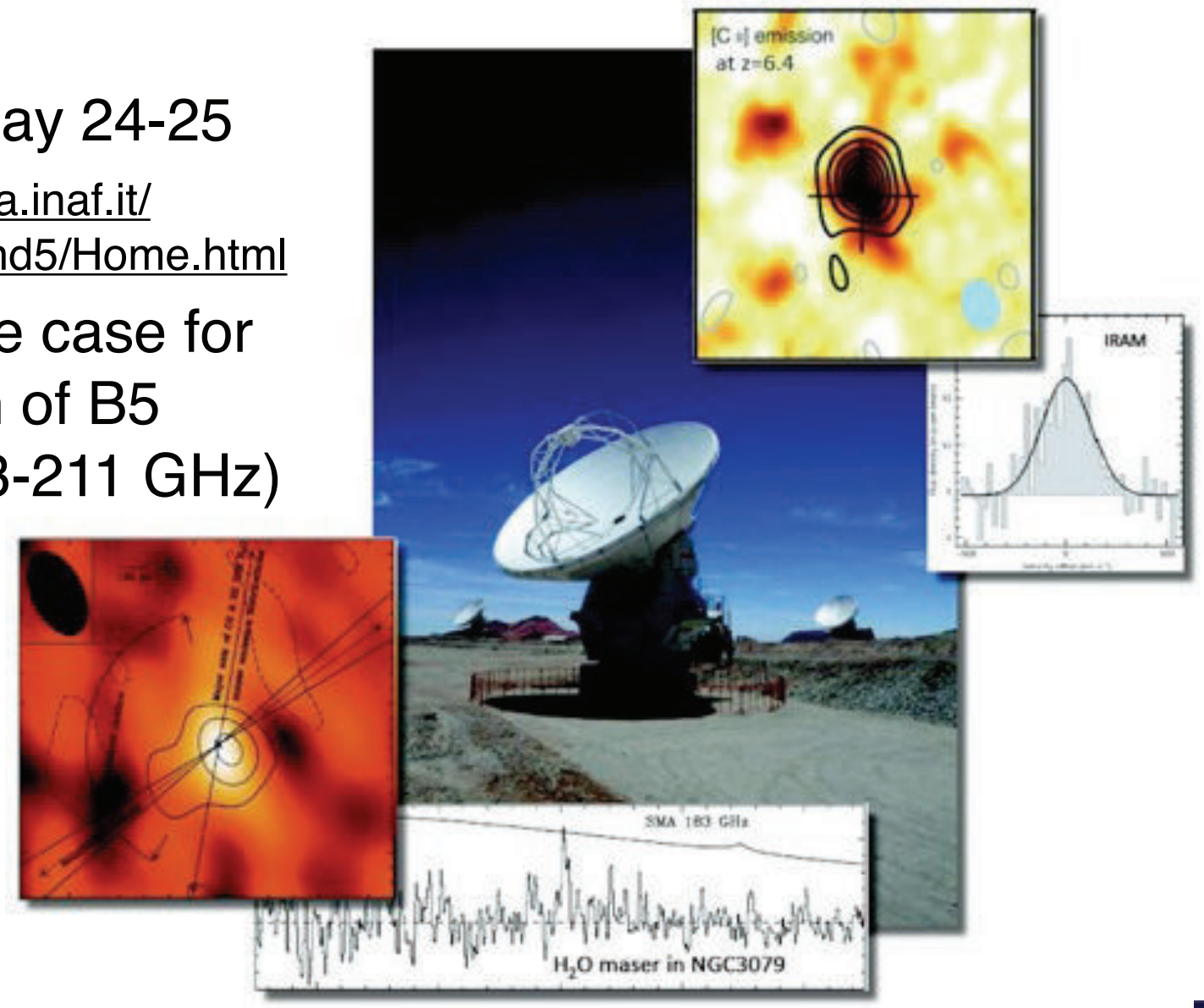


Falcke+2000

- ALMA + mmVLBI

Science with ALMA Band 5

- INAF-OAR, May 24-25
- http://www.oa-roma.inaf.it/meetings/AlmaBand5/Home.html
- Define science case for full production of B5 receivers (163-211 GHz)



The ALMA Development Program

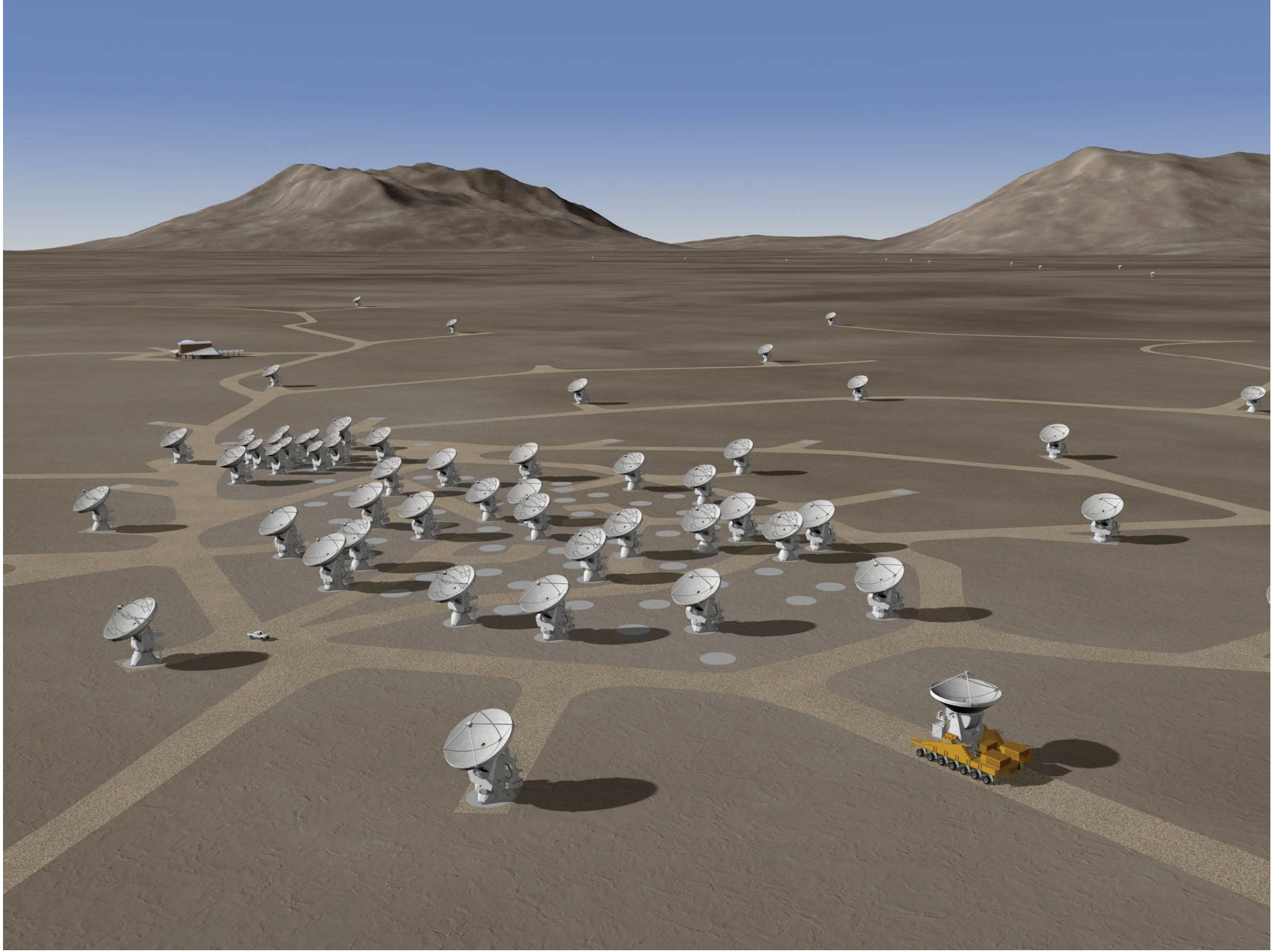
- ALMA development budget is proposed to ramp up starting in 2013 to reach ~12M$/yr from ~2015
- The ALMA Board has initiated a process to plan the development program

- Working Group has prepared a preliminary report, this has been integrated with other ideas from project and community

- Next steps:
  - Feasibility and order of magnitude cost/effort estimate
  - Evaluation of technical readiness
  - Possible impacts on other aspects of the project
- ESO is about to issue a call for studies to fund these activities

Development Items (not prioritized)

- Phasing-up for VLBI
- Solar Widget for wider field of view
- Six sub-arrays.
- Building-in expansion capability to longer baselines
- More antennas
- Additional receiver bands:
- (Band 0 20-30 GHz)
- Band 1 31 to 45 GHz
- Band 2 67 to 90 GHz (band 3 covers 84 to 116 GHz)
- Band 5 163 to 211 GHz
- Band 11 ~1500 GHz ???
- Multi-beam feeds
- Multi-band operation
- Improved phase correction
- Improved Calibration accuracy
- Upgrading the backend and correlator
- Improved FE's more sensitivity.
- Additional correlator for serendipity
- More accurate polarization systems
- Software developments:
- Better scheduling and setup tools
- More advanced reduction and visualization
- New algorithms



ALMA Operations and the ALMA Regional Centers

interaction with and support to the users

ALMA Science

- Star Formation, Proto-planets in nearby disks
- Astrochemistry
- Interstellar medium (Galaxy, Local Group)
- High-redshift deep fields

- *+130 projects in first 3yrs – DRSP 2.1*
  - http://www.eso.org/sci/facilities/alma/science/drsp/

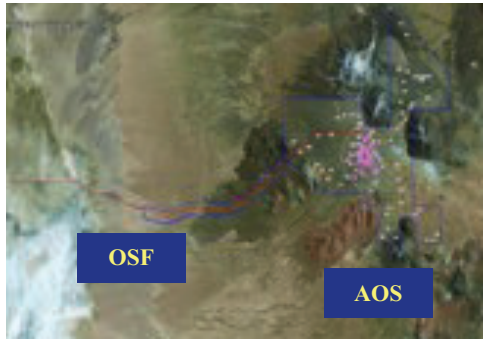
Science Operations Astronomer's

Principles:

* Non-experts should be able to use ALMA
♣ Dynamic scheduler to match observing conditions
♠ Reliable and consistent calibration
♦Data public in timely fashion

ALMA in operations

San Pedro (OSF) Operations Support Facilities

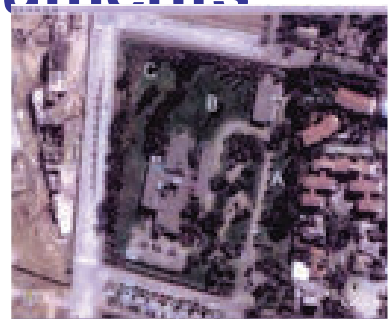


array scheduling + operations

quick-look reduction

maintenance and repair antennas + instruments

Santiago (SCO) Santiago Central Office



issues of calls

TAC (Time Allocating Committee) process

SB (Scheduling Block) checks

pipeline data reduction

quality assessment

production of archive

High-level concepts for Science Operations

(from the ALMA Project and Operations Plans)

- Observations will be done in service observing mode with flexible (dynamic) scheduling.
- Observations 24h/day interrupted by maintenance periods.
- All observations are executed in the form of scheduling blocks (SBs), each of which contains all information necessary to schedule and execute the observations.
- The default output to the astronomer are reliable images, calibrated according to the calibration plan.
- The Joint ALMA Observatory (JAO) is responsible for the data product quality.
- All science and calibration raw data are captured and archived.

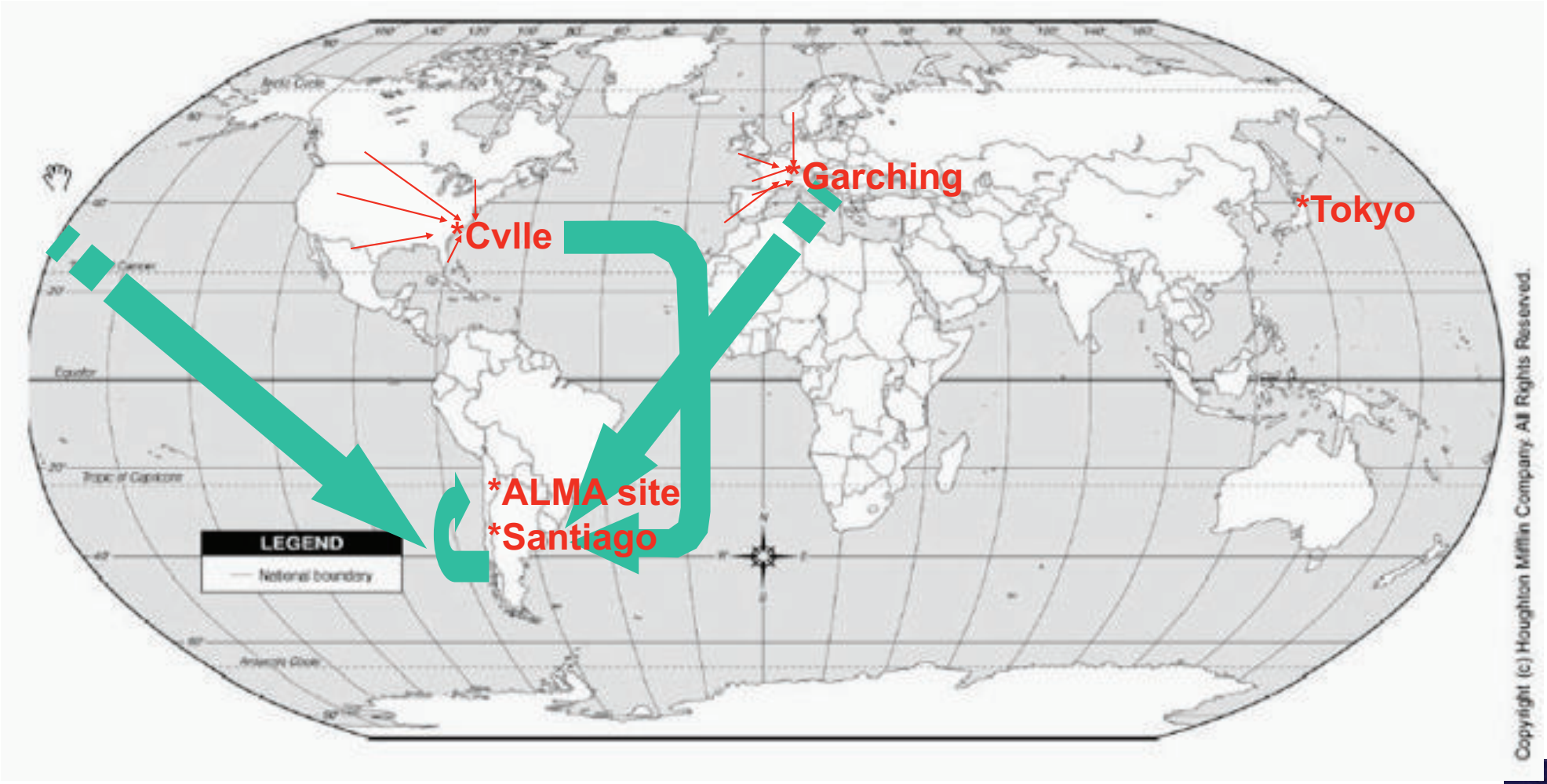
Science Deliverables:

- uv-plane astronomical source and calibration data.
- Processed images, with supporting information on the data processing and quality assurance.
- Off-line data reduction software, including user support for installation and basic usage.
- Software tools for proposal and observation preparation, including user documentation.
- ALMA users manual.

User support:

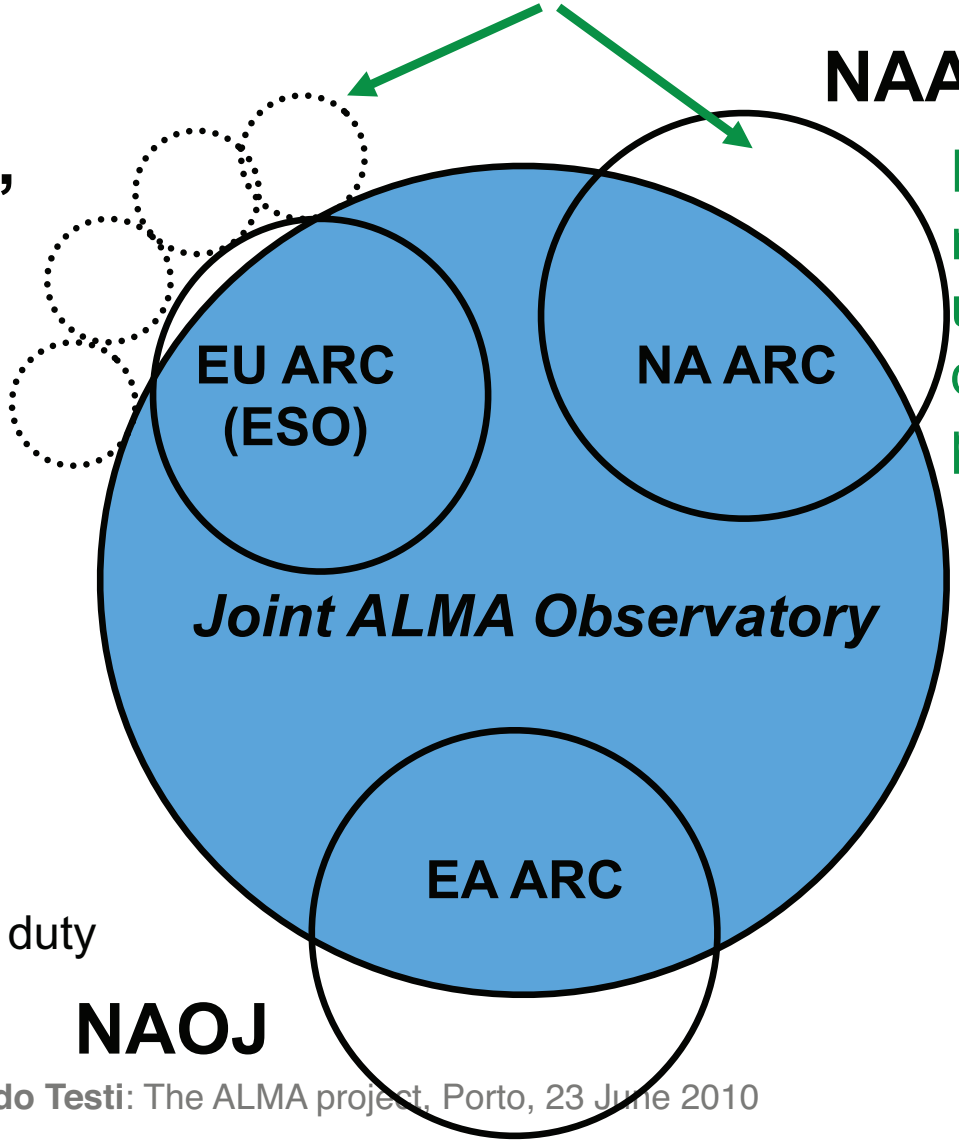
- Web pages
- Phase I and phase II support
- Helpdesk
- f2f support

ALMA Science Operations sites
OSF, Santiago and the ARCs



ALMA Operations: Three ALMA Regional Centres - ARCs

Enhanced User Services



Enhanced services are needed to provide advanced user support, algorithm development, student programs, EPO, grants

ARCs provide
user interface,
archive,
software tools
data delivery

Astronomers on duty

DSO provides:
- Array operations
- Scheduling of projects
- Execution of observations
- Data quality assurance and trend analysis
- Calibration plan maintenance
- Delivery of data to the archives
- Archive operations
- Pipeline operations

The ALMA Regional Centres

- Core functions

Scientific support services

  - Proposal & observation preparation user support
  - Basic data analysis
  - ALMA Archive operations: host copy, data package delivery
  - OSF AoD shifts (CSV)
  - Science community development

- Additional functions

Extended archive & data reduction support

  - f2f help
  - Advanced pipeline
  - Archival research projects

Support for special projects

Science community development

- basic training, schools, workshops

Core functions include:

+ f2f help during first years
+ archival research help

What does science Operations mean?

- **Phase I + II proposals through ARCs**
  (time estimator, end-to-end data simulator)
- **Create project (scheduling blocks) to OSF**
- **Data taken in service mode, dynamic scheduler selects programmes according to science rating weather conditions, array configuration, consistent calibration**
- **Pipeline data reduction, quality control, archive**
- **Advanced data reduction at ARCs**

Getting ALMA time

Phase I

- Joint ALMA Observatory issues calls for proposals
- Reg
- Prep
- user
  - ➢
- A
  coo
  - ➢
- Executives approval

MAKE A PROPOSAL!

Scientific case

Instrument setup: **frequency**

rms

S/

sc

sp

Getting ALMA time

Phase II

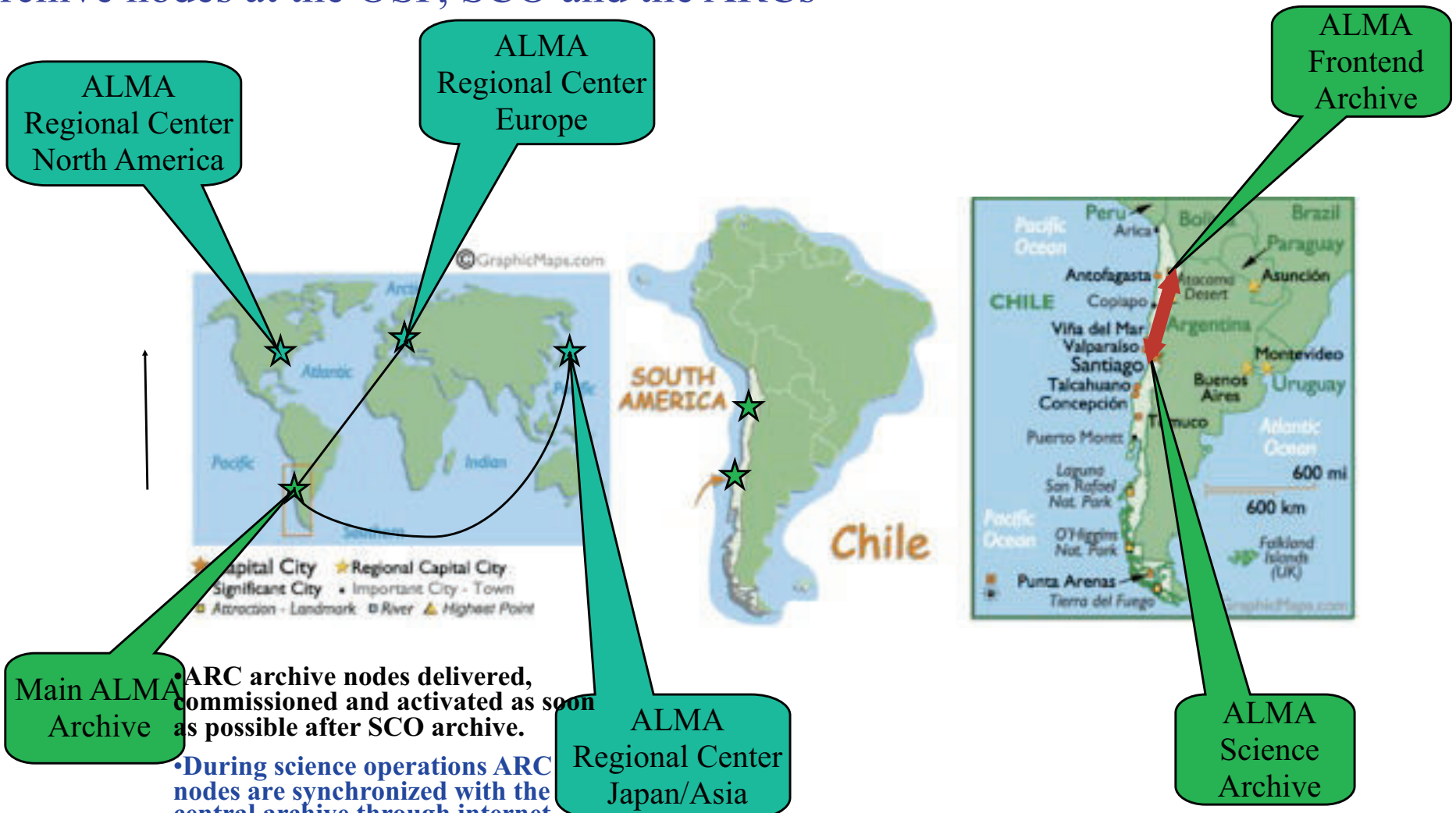
- Phase I: Proposals are submitted using ALMA Observing Tool
  - Phase II: Successful PIs submit observing programme using the Observing Tool
  - Preparation of the scheduling blocks
  - European ARC helps with observation planning and validates observing schedule

Getting ALMA data

- Queue based dynamic scheduling
  - Programs are composed of 30-60 min scheduling blocks
- Raw data pass through multi-tiered quality assurance
  - Combination of on-site duty astronomer, ARC staff, and automated checks
- Data proceeds to pipeline and archiving
  - Data available from ARC (ESO) within ~2 weeks (TBD, quicker if internet available)
  - Pipeline products (images and calibrated u-v data), raw data, off-line data processing software made available to Pis
  - Expert hands-on data reduction help from ARC nodes staff provided on request, helpdesk also available at ESO

The ALMA archives and data distribution

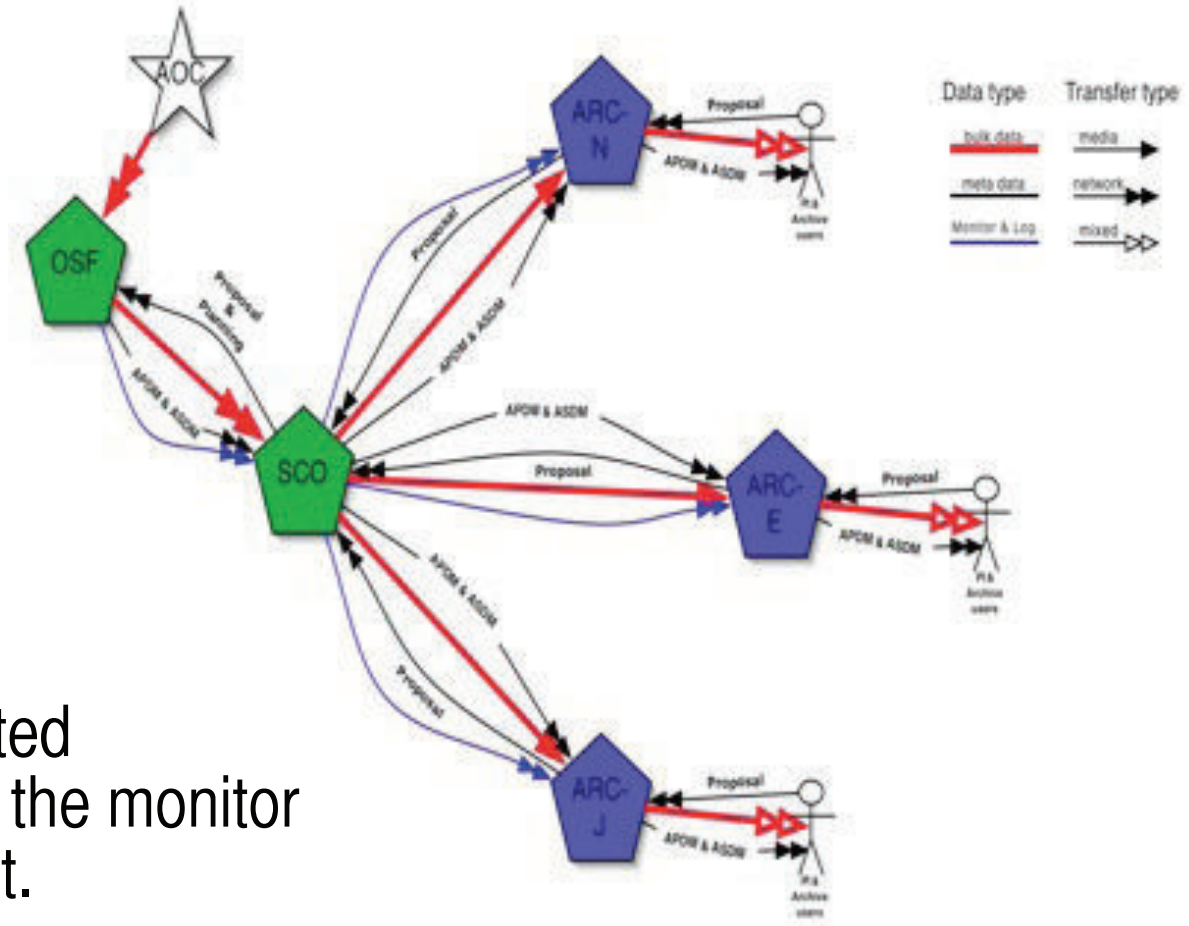
Archive nodes at the OSF, SCO and the ARCs



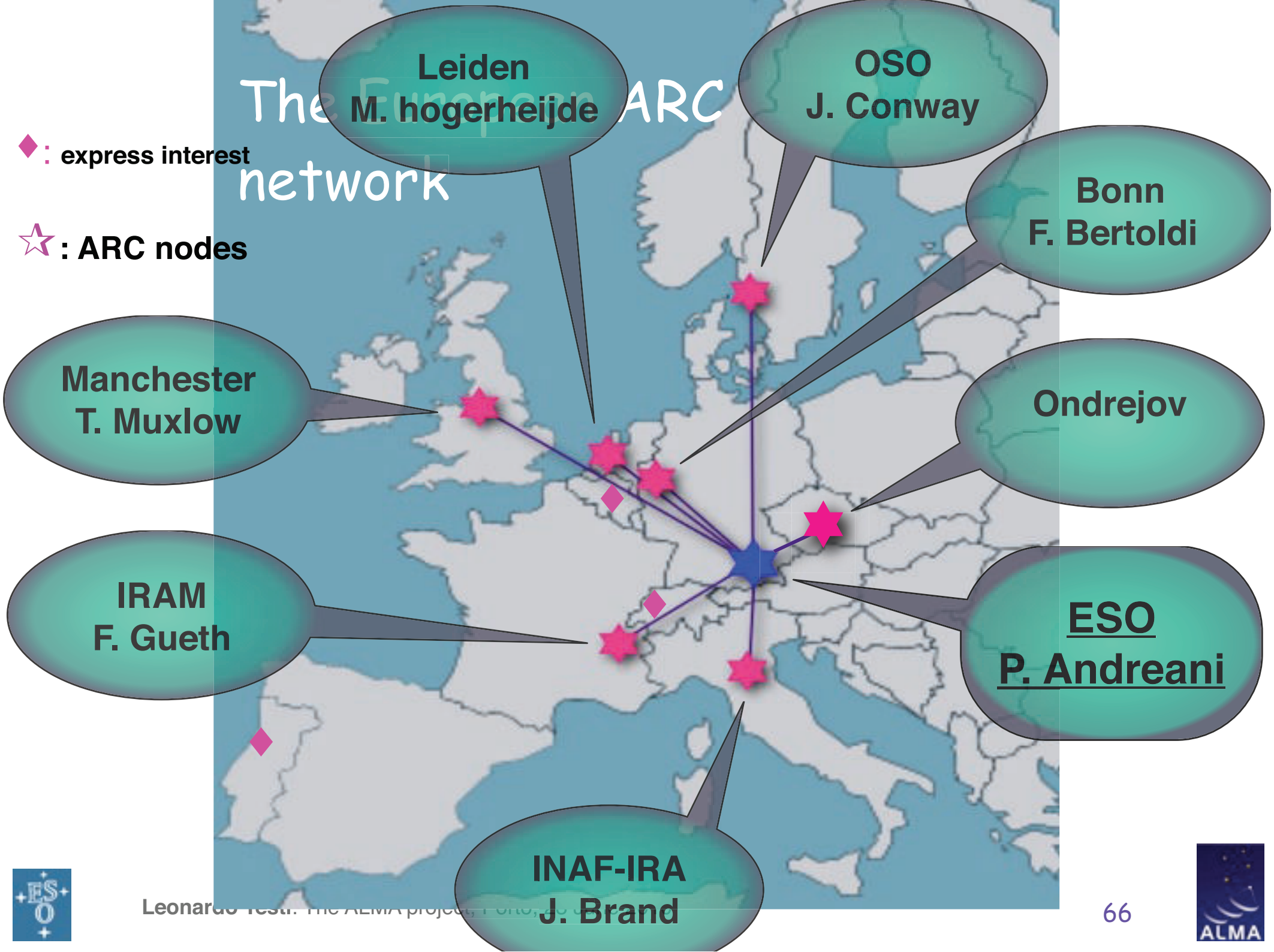
- **ARC archive nodes delivered, commissioned and activated as soon as possible after SCO archive.**
- **During science operations ARC nodes are synchronized with the central archive through internet (small data sets) or via physical media.**

OSF connected to SCO via high-bandwidth. It MUST be always possible to operate ALMA even if the internet link does not work

High level concepts



- SCO is hub for bulk and meta-data.
- OSF archive is hidden. Data are first replicated to SCO and from there to the ARCs.
- In general everything is replicated to the ARCs; in practice part of the monitor and log data might be irrelevant.
- Proposals are submitted to the SCO and replicated to the ARCs. OT submission interface talks to SCO.


The European ARC network
♦: express interest
☆: ARC nodes
Leiden
M. hogerheijde
OSO
J. Conway
Bonn
F. Bertoldi
Manchester
T. Muxlow
Ondrejov
IRAM
F. Gueth
ESO
P. Andreani
INAF-IRA
J. Brand

The European ARC

- Core functions
  - Scientific support:

  Proposal & observation preparation

  user support
  - Archive Operations:

  host a copy, data delivery
  - Astronomer on duty at OSF
  - Science community activity
  - User support:

ESO: ARC Department

ARC nodes

- Non-core functions

  Data reduction
  - Advanced pipeline
  - Extended archive support
  - Support for special projects
  - Science community activity:

  training, schools, workshops

ARC nodes

ALMA simulators

ESO ARC + nodes

ARC nodes: location and expertise

Bonn-Cologne-Bochum (F.Bertoldi) Bonn

expertise: Infrastructure for advanced data analysis and modeling (incl. Cologne Database for Molecular Spectroscopy), Polarimetry, Astrometry, Pipeline heuristics, Automatic data calibration

IRAM (F. Gueth) Grenoble

expertise: millimeter interferometry (PdBI), calibration, imaging, phase correction, polarimetry, imaging simulator, schools

Italy (J. Brand) Bologna

expertise: Data handling/GRID-technology, Mosaicing, Coordinating surveys/key-projects, Polarimetry

Netherlands (M. Hogerheijde) Leiden

expertise: High-frequency, Wide field imaging, Data analysis tools

Nordic node (J. Conway) Onsala

expertise: Multi-Frequency Synthesis, Phase modeling, Self-calibration, Astrometry, Deconvolution, GRID computing, Astrochemical modelling and radiation transfer

UK (T. Muxlow) Manchester

expertise: Data analysis, Archive, Data reduction heuristics, Proposal preparation

Application for a new node sent by the **Czech Republic. Portugal, Switzerland and Belgium** may put man power and join one of the existing node

What ARCs are going to do

- **Participating in software pre-release tests**
- **Commissioning** (as a means of pre-AoD training)

} **Pre-Ops**

- **PST submission support (Phase I support)**
- **Phase II support**
  - **helpdesk**
  - **SB verification**
- **Offline & data reduction help-desk support**
- **Documentation** (End-user doc + web content)
- **Astronomer on Duty**
- **Coordination meetings between ARCs, JAO**
- **Science Verification**
- **TAC Support** (technical feasibility assessment)

} **Full Ops**

What ARC nodes are going to do

- Participating in offline software tests
- Commissioning?

} **Pre-Ops**

- Face to face help for Phase I and II
- Offline & data reduction face-to-face support
- Advanced data reduction
- Training of students, schools
- Science Verification?
- Special Projects

} **Full Ops**

Community Input

into the operations of the Global ALMA project and the EU ARC

- International community input into the ALMA project (via the ALMA Board) is through the ALMA Science Advisory Committee (**ASAC**)

  http://www.alma.nrao.edu/committees/ASAC/

- European community input into the ALMA project and operation of the EU ARC is through the European ALMA Science Advisory Committee (**ESAC**) and the ESO Users Committee (**UC**)

http://www.eso.org/public/about-eso/committees/stc-esac/index.html

http://www.eso.org/public/about-eso/committees/uc/uc2010.html


Your proposal here
2011