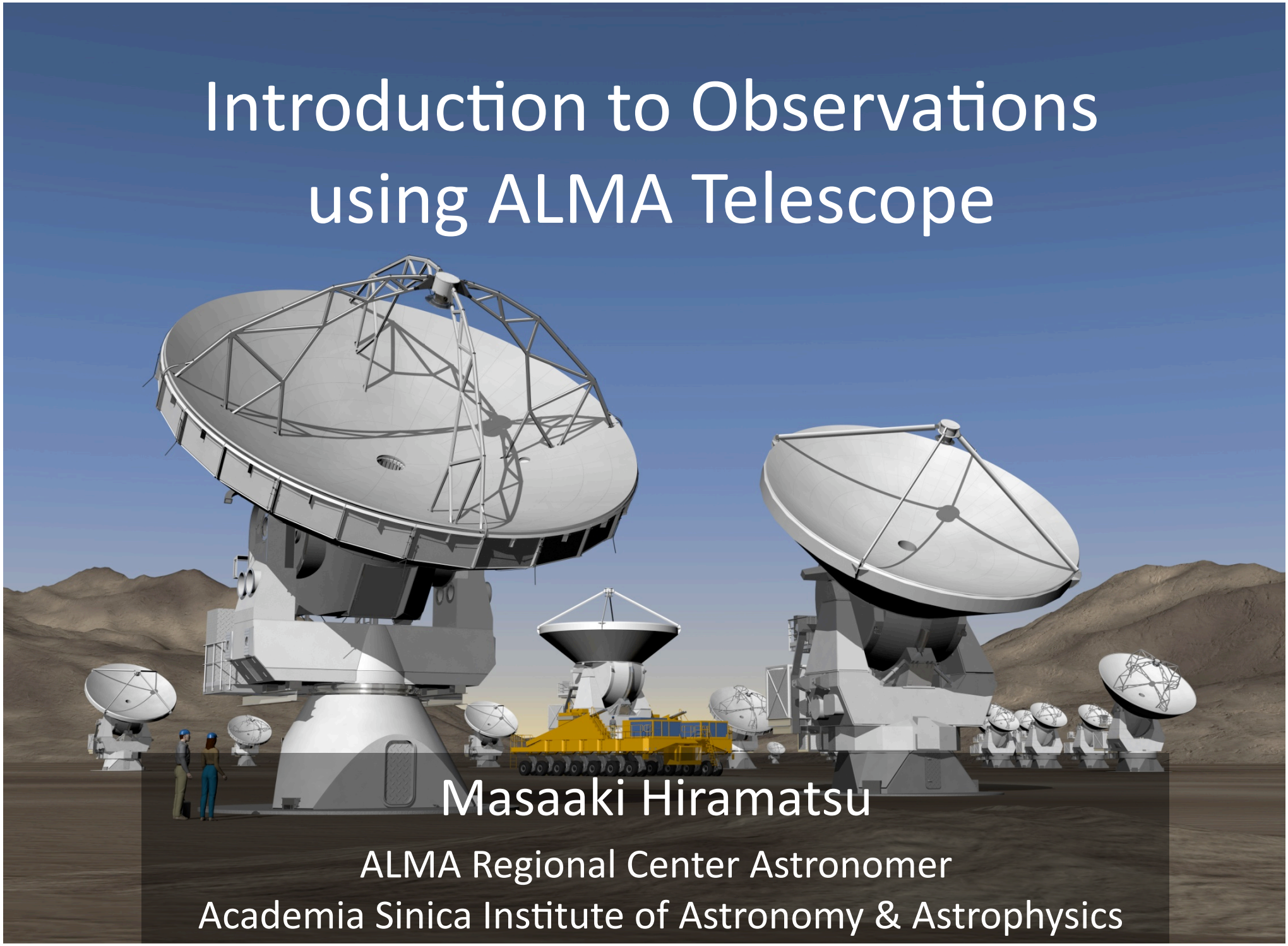
Introduction to Observations using ALMA Telescope



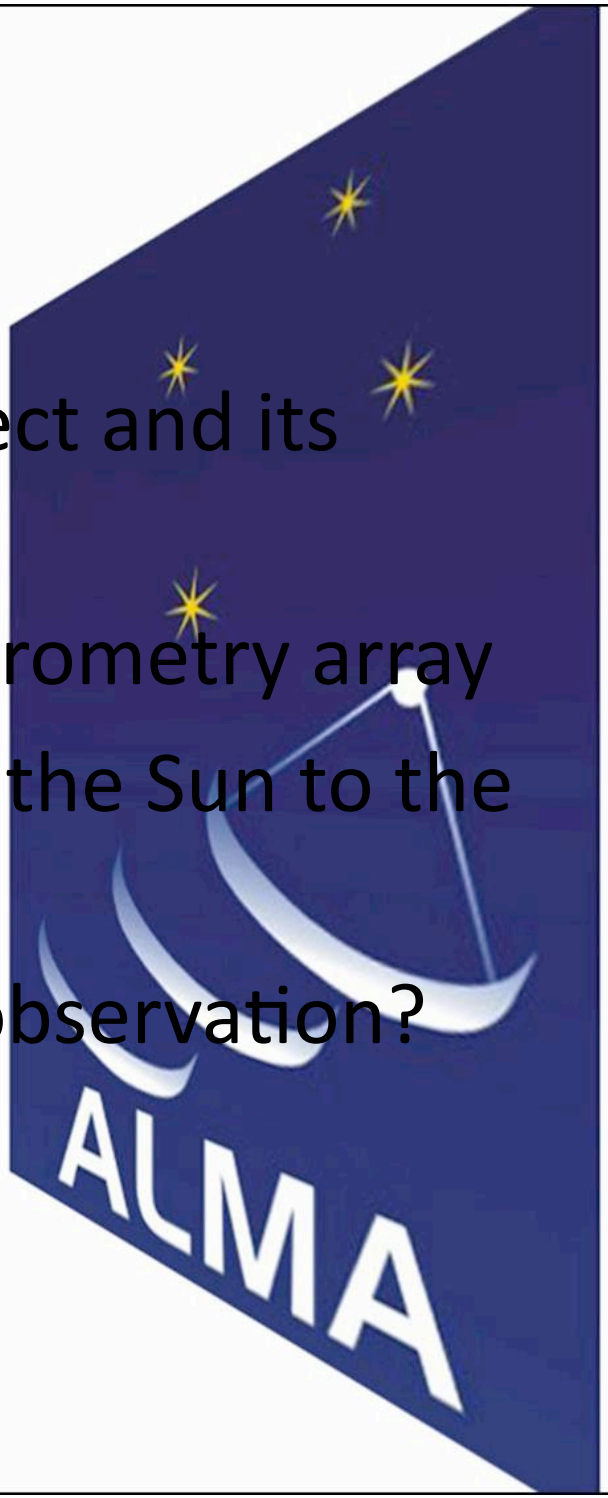
Masaaki Hiramatsu

ALMA Regional Center Astronomer

Academia Sinica Institute of Astronomy & Astrophysics

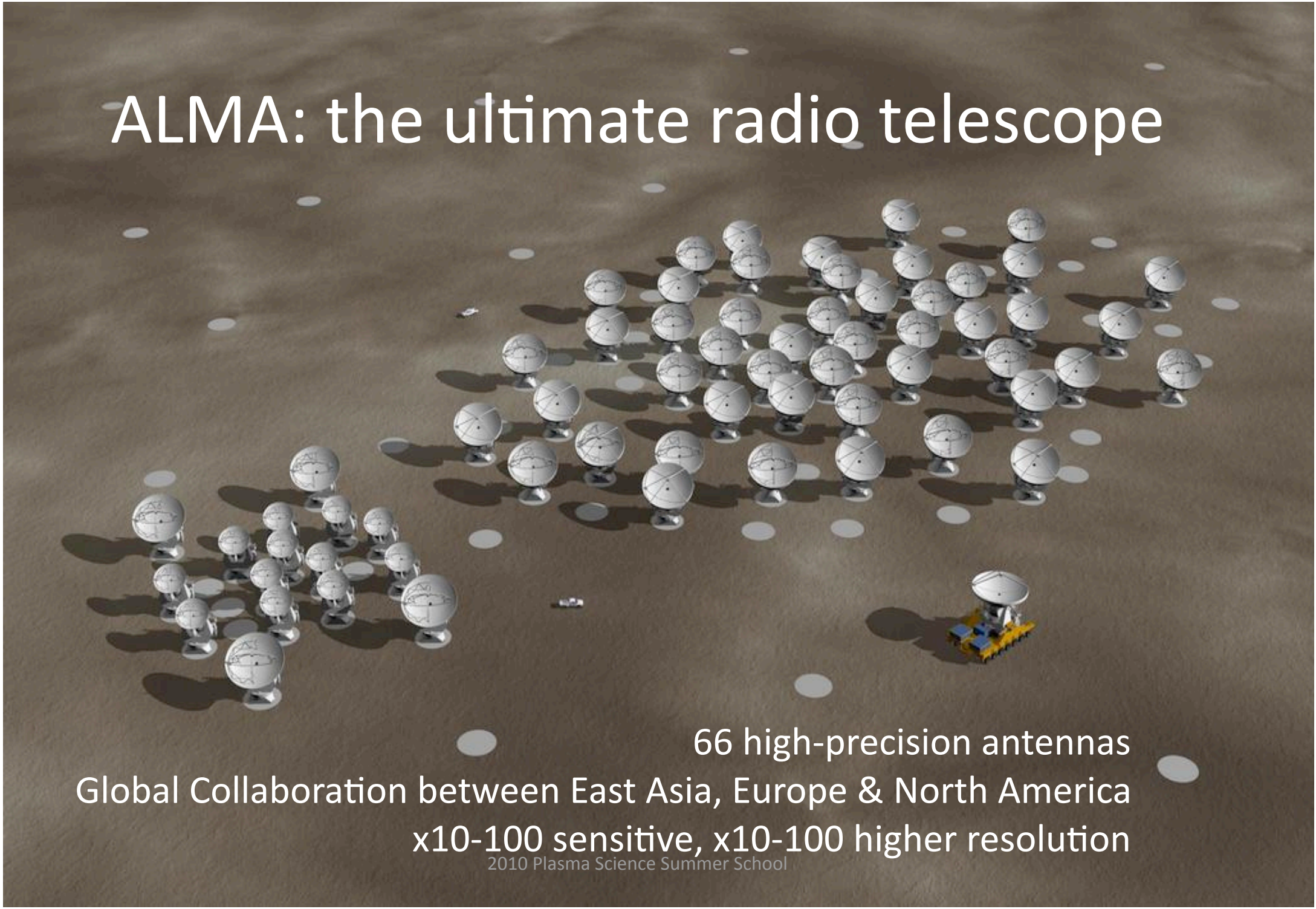
Outline

- Introduction to the ALMA project and its current status
- Observation using radio interferometry array
- ALMA Science Showcase: from the Sun to the most distant universe
- How to access ALMA for your observation?



1. INTRODUCTION TO THE ALMA PROJECT & ITS CURRENT STATUS

ALMA: the ultimate radio telescope



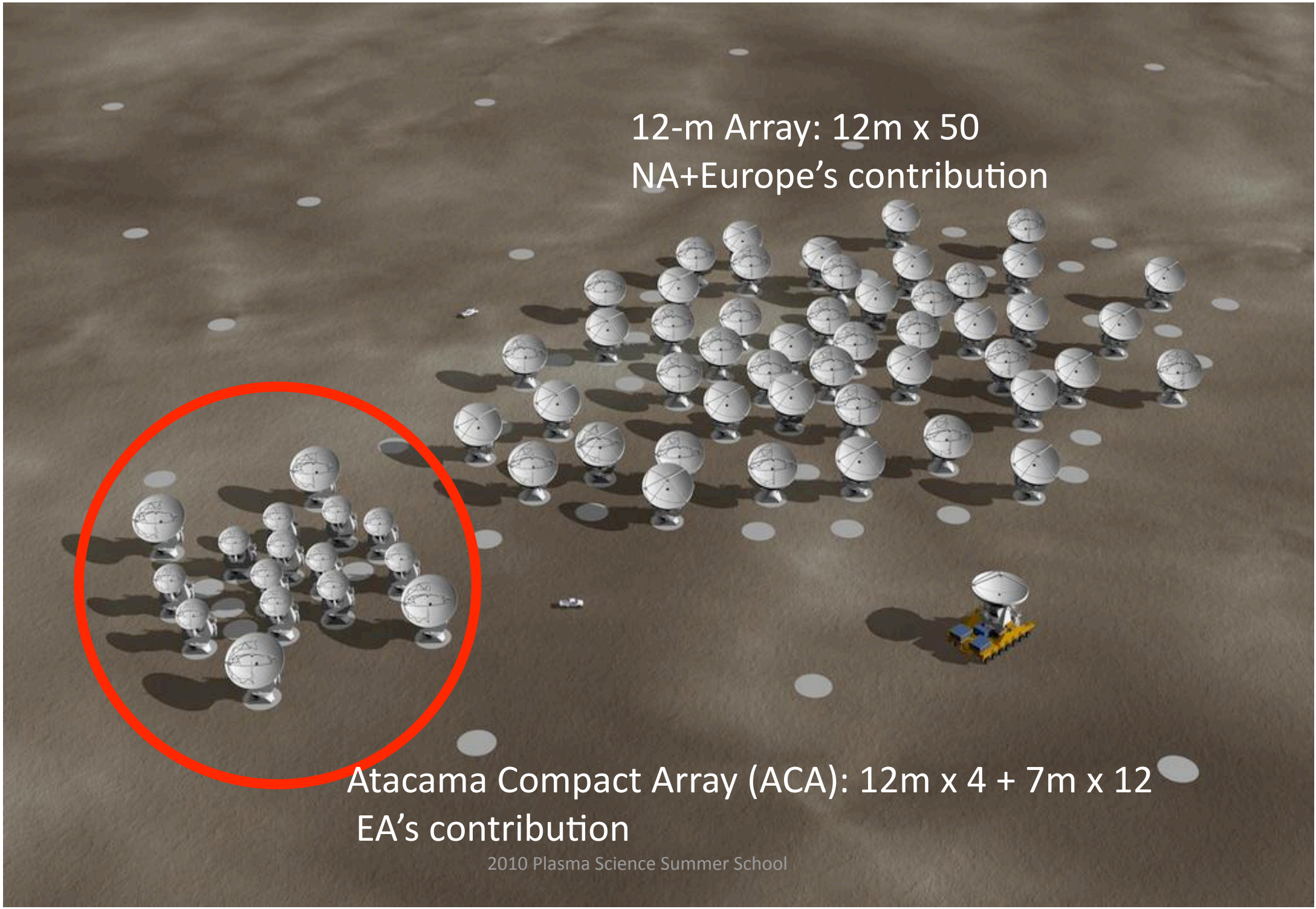
66 high-precision antennas

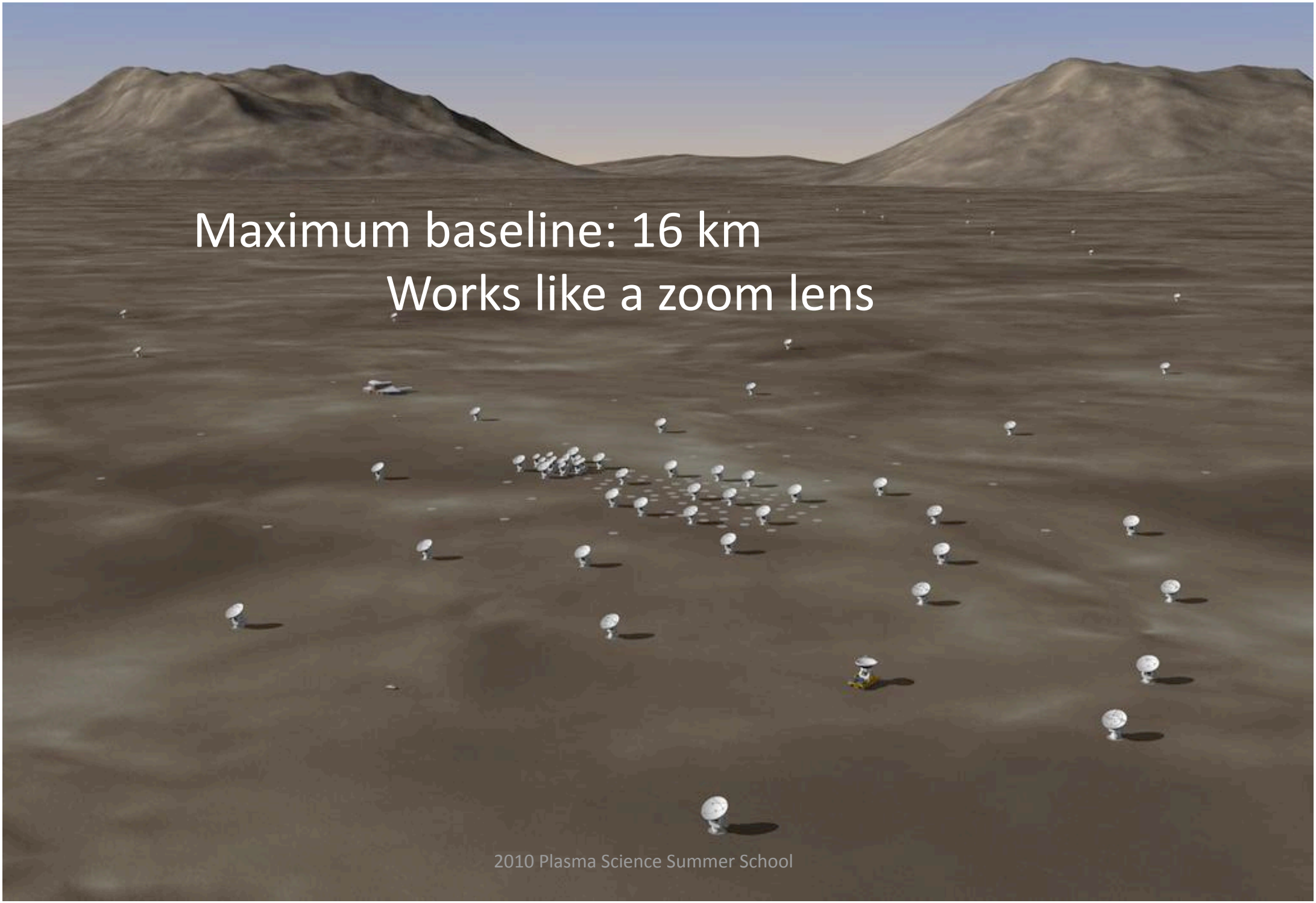
Global Collaboration between East Asia, Europe & North America

x10-100 sensitive, x10-100 higher resolution

ALMA: Basics

- Atacama Large Millimeter/submillimeter Array
- Largest ground-based telescope ever built
- Under construction at Atacama Desert, northern Chile
- 12m x 54 + 7m x 12 antennas
- 10 frequency bands (30 – 950 GHz)
- Highest angular resolution: 0.01 arcsec
- Great tool for all fields in astronomy/planetary science
- Observations start from ***2011*** !


12-m Array: 12m x 50
NA+Europe's contribution
Atacama Compact Array (ACA): 12m x 4 + 7m x 12
EA's contribution


Maximum baseline: 16 km
Works like a zoom lens

Receiver Bands

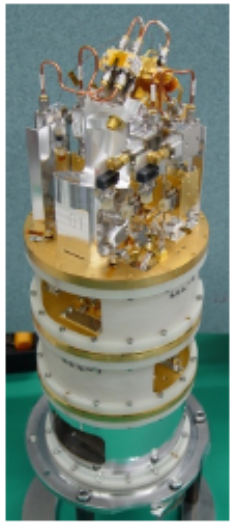
	Freq. (GHz)	Noise Temp.	Type	Who
Band 1	31.3 – 45.0	17 K	SSB	--

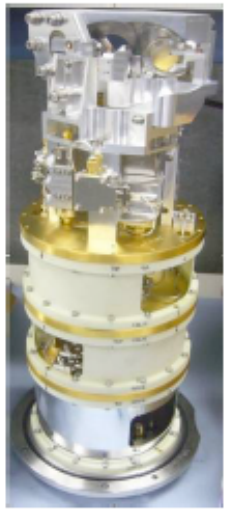

Band 3


Band 4


Band 6


Band 7


Band 8


Band 9


Band 10

Band 8	385 – 500	196 K	2SB	NAOJ
Band 9	602 – 720	175 K	DSB	SRON
Band 10	787 – 950	230 K	DSB	NAOJ

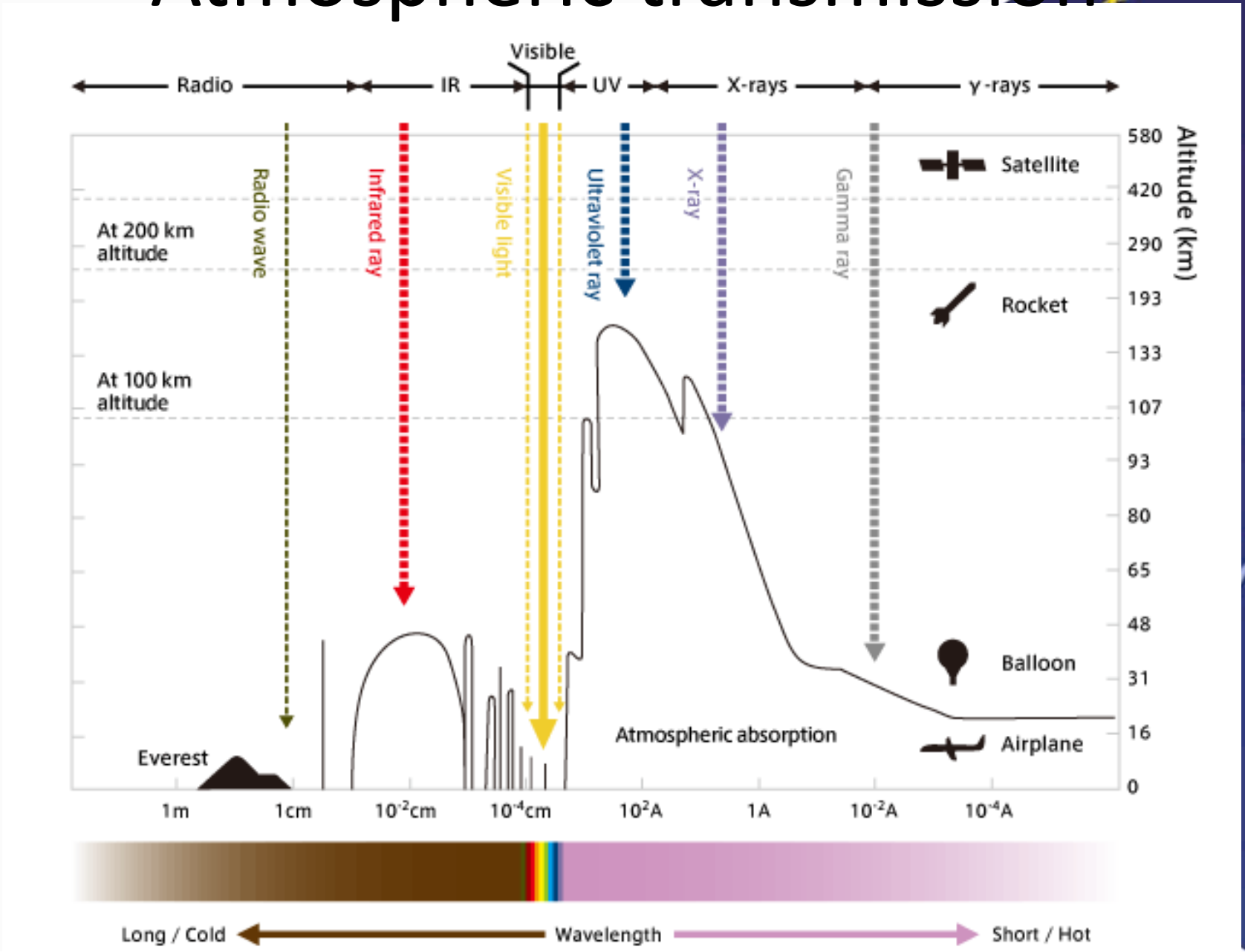
The ALMA site

Array Operation Site (AOS)

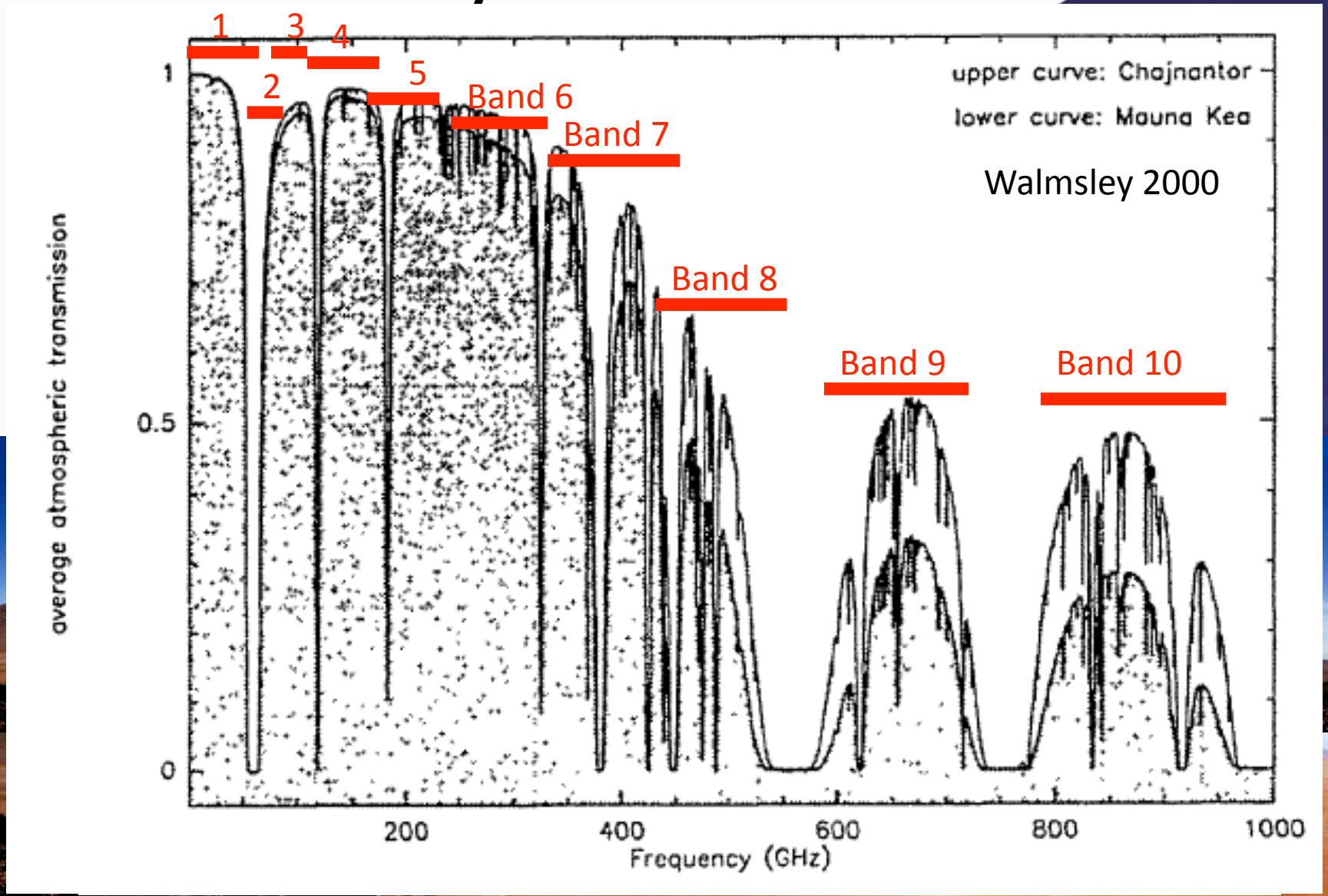
Current Status of ALMA

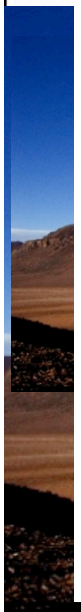
- 5 antennas at AOS
- >10 antennas at OSF under test/construction
- 10 receiver systems will be ready in 2010.
- Software: Under testing

Atmospheric transmission



Why Chilean Andes?



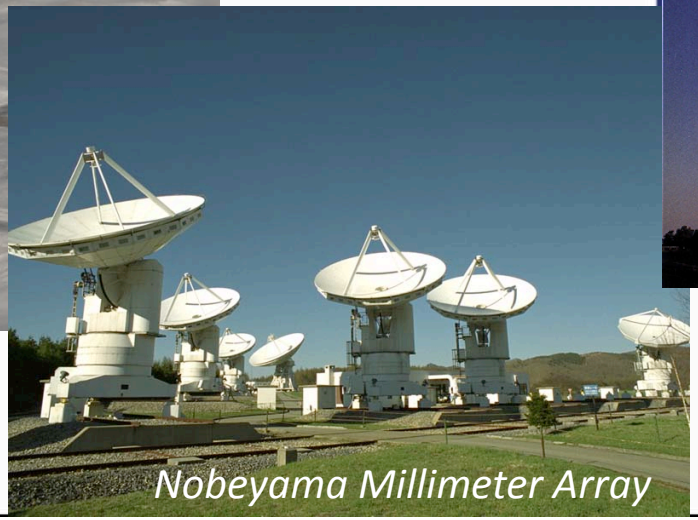


Before ALMA


Submillimeter Array (SMA)


Combined Array for Research in Millimeter-wave Astronomy (CARMA)


Plateau de Bure Interferometer (PdBI)


Nobeyama Millimeter Array

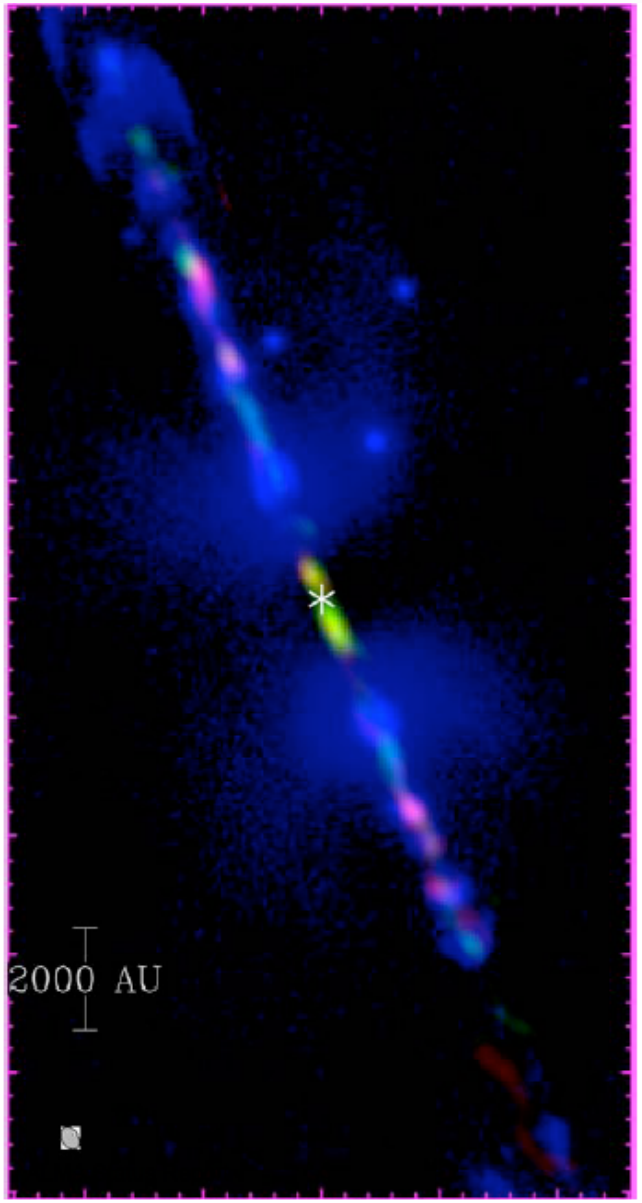

Australia Telescope Compact Array (ATCA)

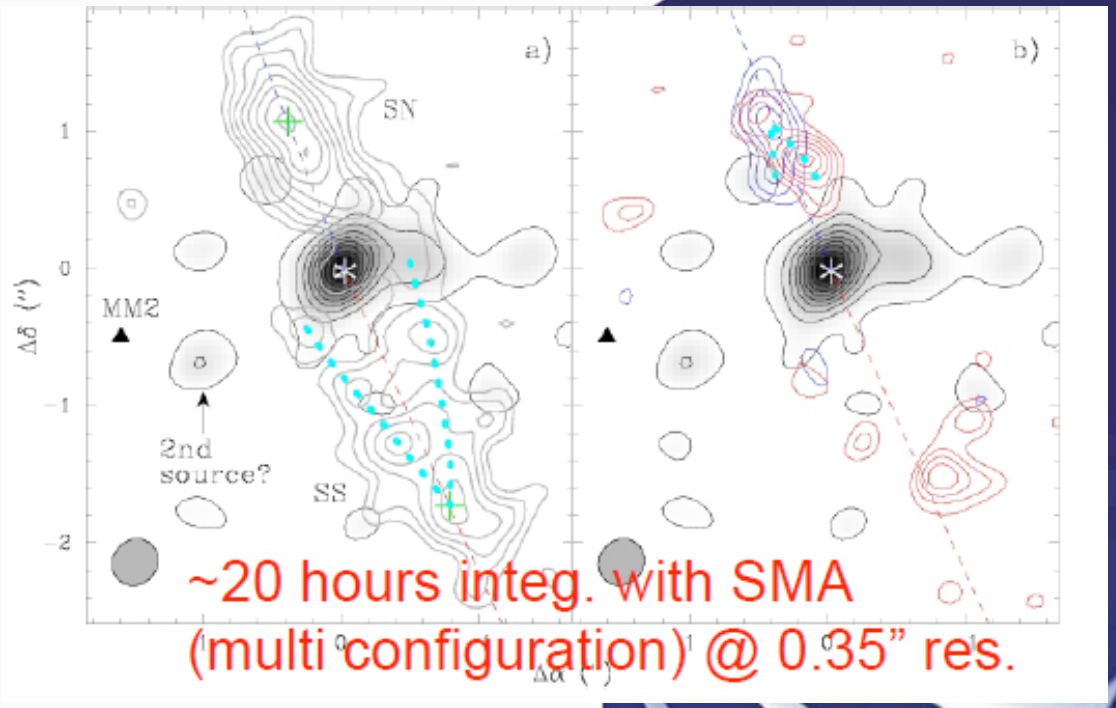
ALMA: How powerful?

	SMA	CARMA	PdBI	ATCA	ALMA ES	ALMA full
Antenna	6m x 8	10.4m x 6 6.1m x 9	15m x 6	22m x 6	12m x 16	12m x 54 + 7m x 12
Collecting Area (m^2)	230	770	1060	2280	> 1800	6500
Frequency (GHz)	230, 350 400, 690	100, 230	100, 230	1.2 - 100	100, 230, 350, 650	+ 150, 450, 800
resolution	0.15”	0.4”	0.5”	0.4”	0.15”	0.01”

More than 10 times powerful!

ALMA: How powerful?





ALMA needs only ***10 sec*** on-source time to achieve same sensitivity and same resolution.

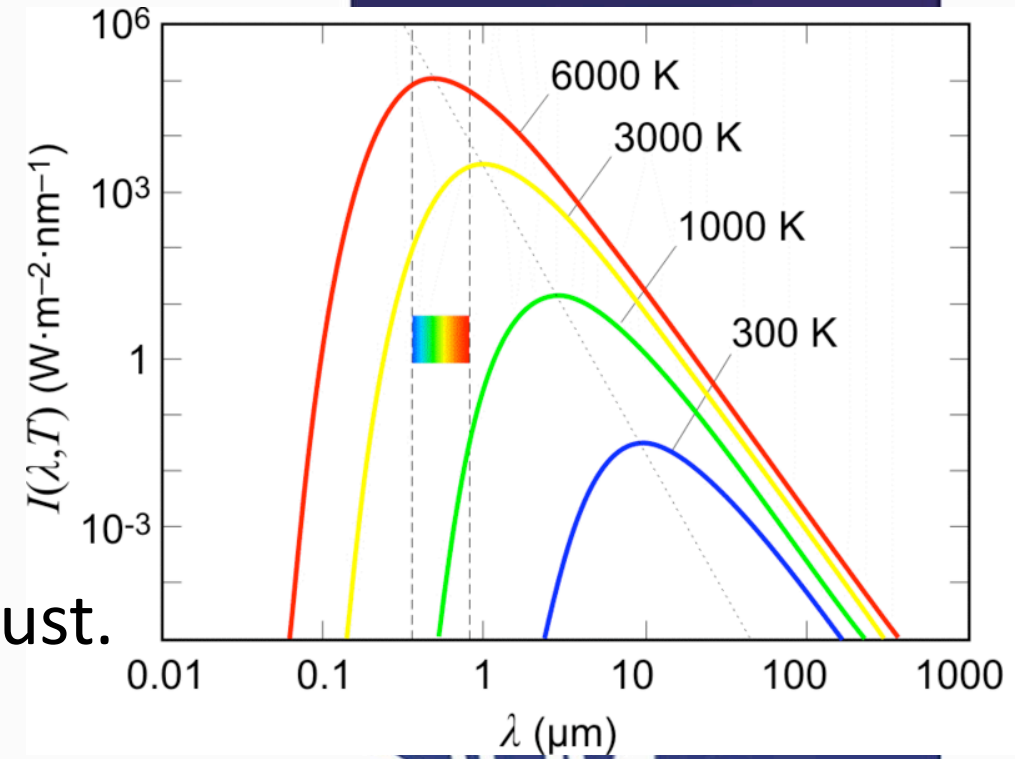
2. OBSERVATION USING RADIO INTERFEROMETRY ARRAY

What can we see in mm/submm wave?

- Blackbody radiation from the cool universe

Wien's displacement law

$$\lambda_{\max} = \frac{2.9 \times 10^{-3}}{T}\,\mathrm{m \cdot K} = 290\mu\mathrm{m} \quad (T\text{=}10\ \mathrm{K}) \simeq 1000\mathrm{GHz}$$

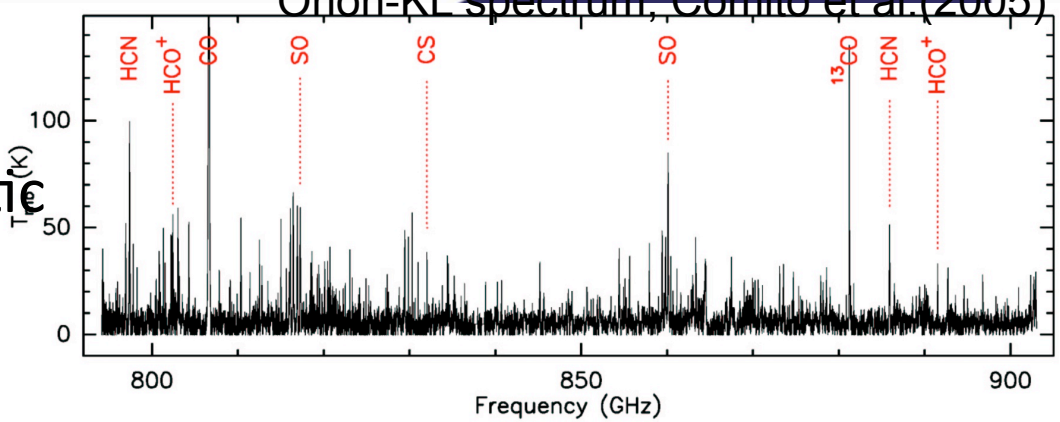


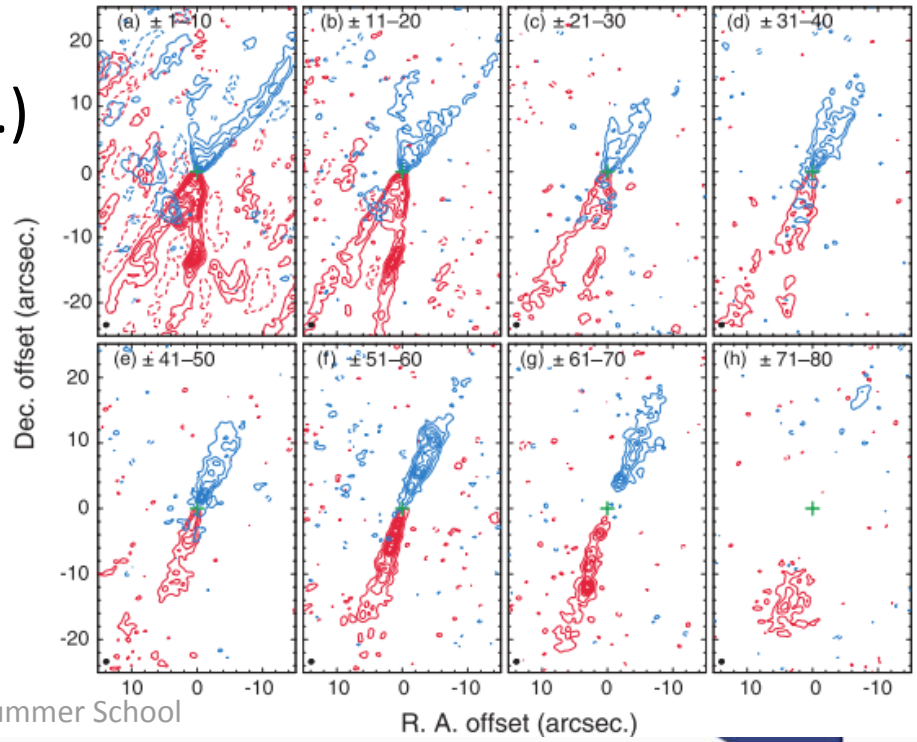
- Efficient in detecting emissions from cosmic dust.

What can we see in mm/submm wave?

- Molecular line forest:
  physical/chemical diagnostic
- Excitation
  -> temperature, density
- Doppler broadening
  -> kinematics (jet, rotating disk…)
- Molecule species
  -> chemistry, timescale, shock...

Orion-KL spectrum, Comito et al.(2005)

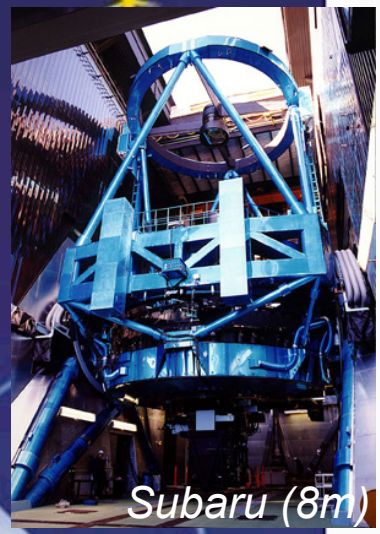




L1448 Jet, Hirano et al. (2010)

Why need 66 antennas?: Interferometer

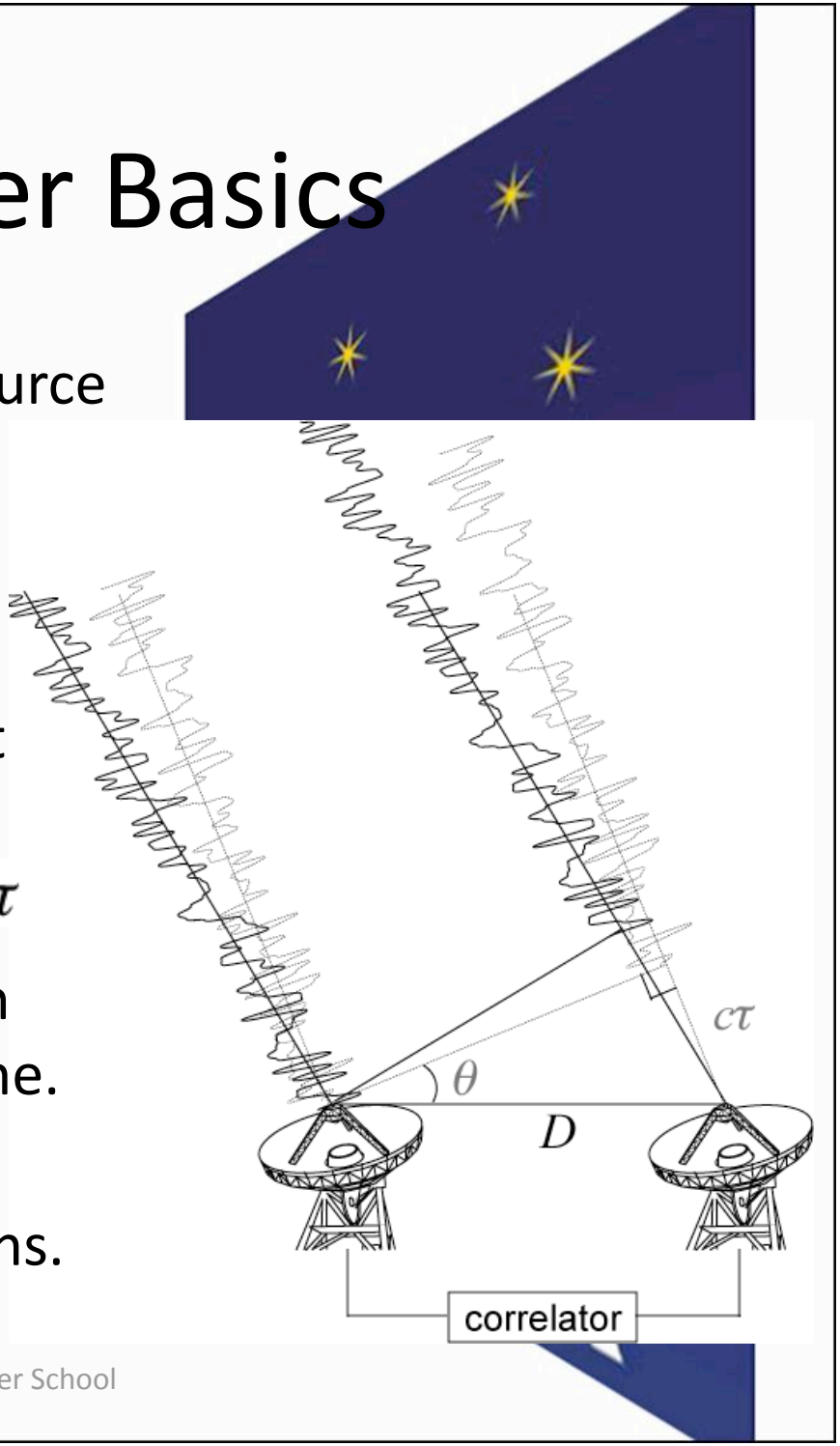
- Angular resolution: $R \propto \frac{\lambda}{D}$ Wavelength / Telescope diameter



- Optical telescope:
  2 um / 8m -> 0.06 arcsec
- Radio telescope:
  3 mm / 45m -> 15 arcsec
- A ***10 km*** telescope can achieve 0.06arcsec resolution.
- Technically very difficult to build a huge telescope.
- *Divide to smaller pieces!*

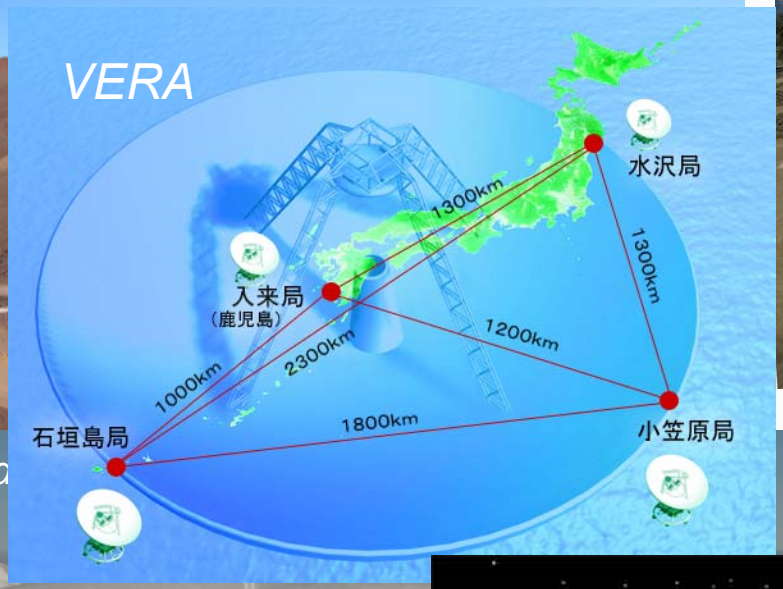
Interferometer Basics

- Coherent signal from the target source
- Difference in the path length: $c\tau$
- Correlator seeks the delay τ, then you get θ : position of the source.
- The other source (or, different part of a source) has different τ .
- Large D: easy to measure small $\Delta c\tau$
- Interferometer has its resolution in the direction parallel to the baseline.
- Earth rotation + multiple antenna provide baselines in many directions.



Interferometers

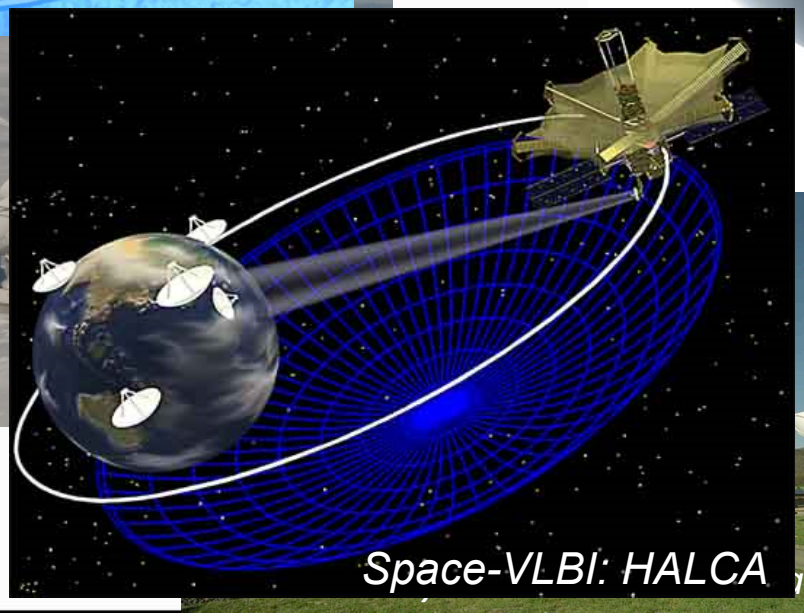
Submillimeter Array (SMA)



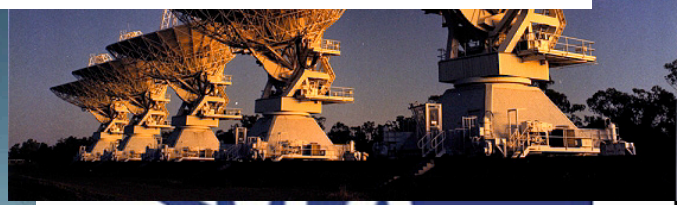
Combined Ar
(CARMA)

VLBA

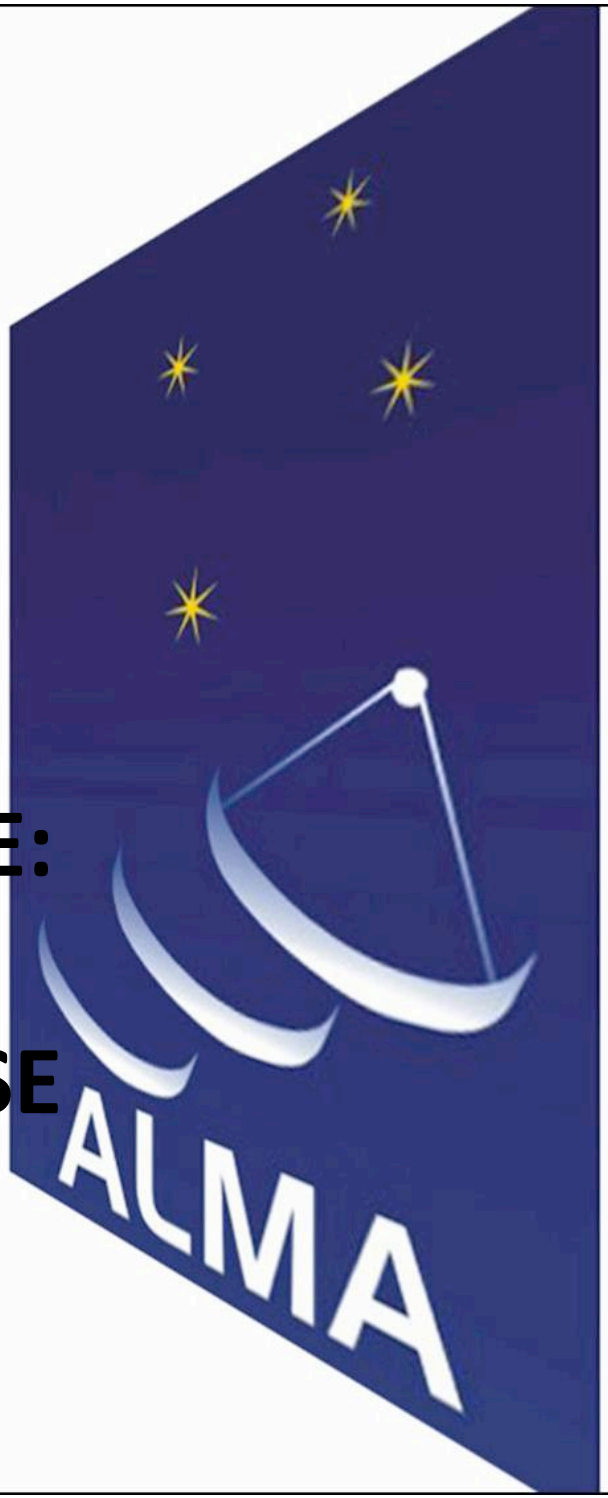
Pla



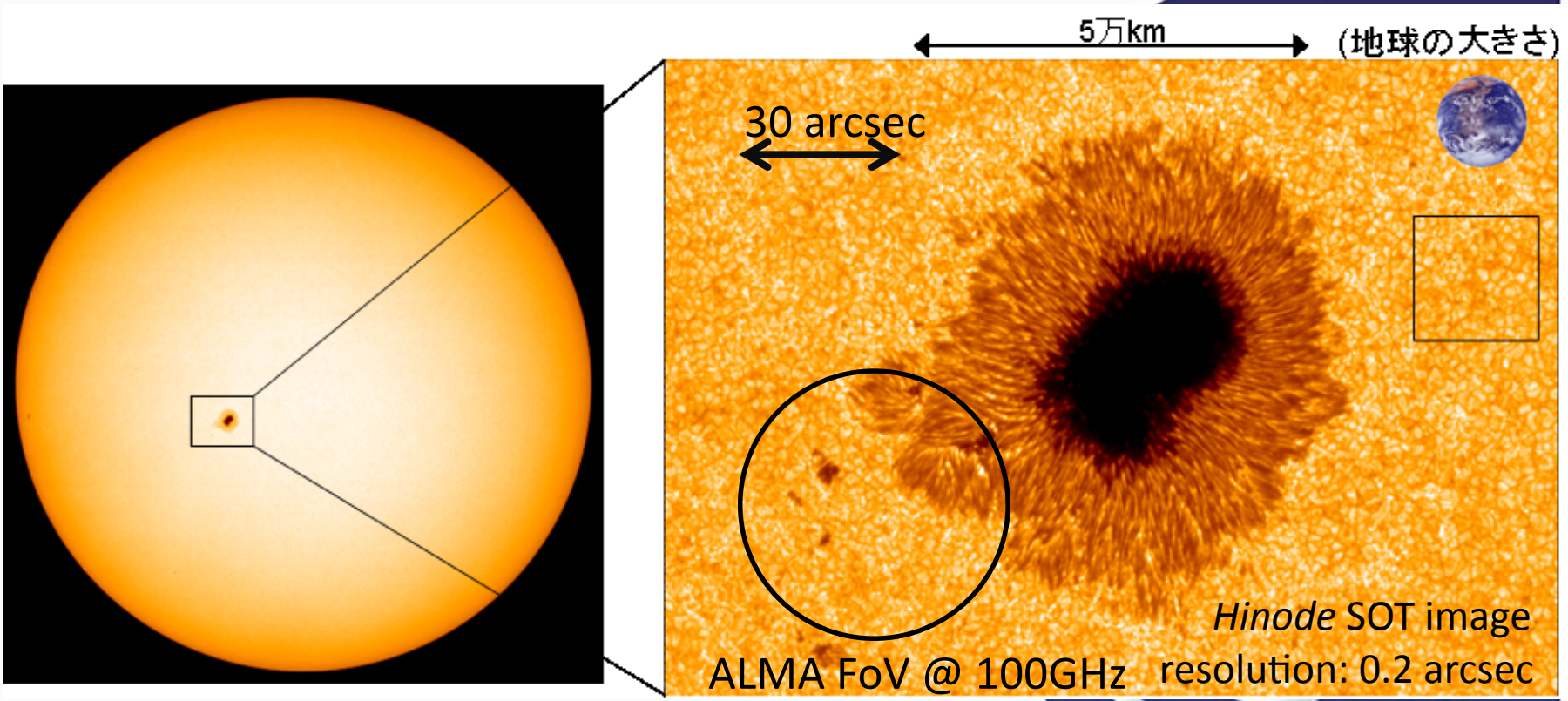
ray



3. ALMA SCIENCE SHOWCASE: FROM THE SUN TO THE MOST DISTANT UNIVERSE



ALMA Science: The Sun

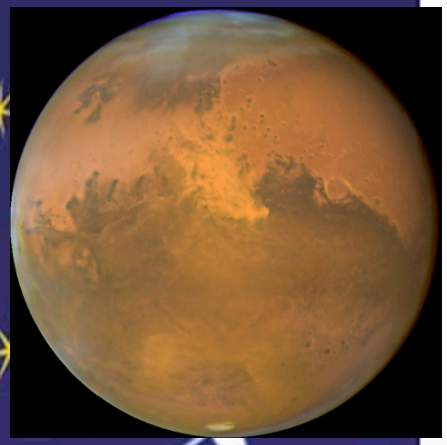


Imaging Flares, Filaments, dynamic processes in the chromosphere.
Recombination lines(?), Zeeman effect..

- 0.2” resolution with 3km baseline @ 100 GHz
- temporal resolution < 1 second

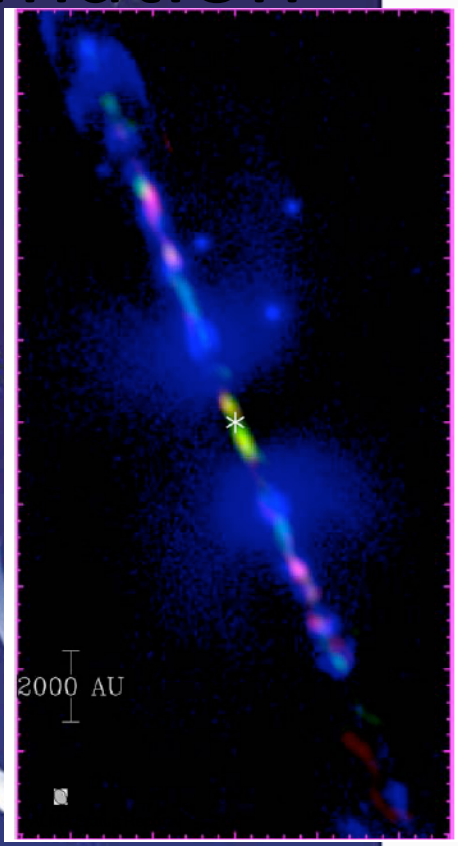
ALMA Science: Solar System

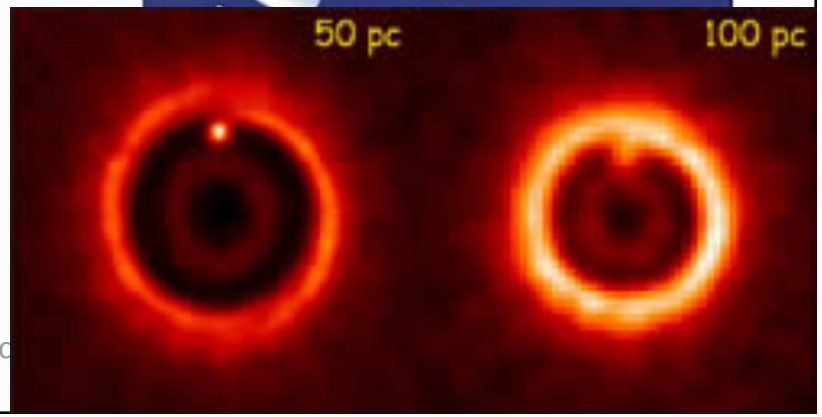
- Dynamics of Mars/Venus atmosphere
  - Local CO abundance, thermal field, wind
- Io's volcano
  - Map the spatial/temporal variation
  - Interaction with plasma torus
- Size/albedo determination of transneptunian objects
  - Records of the ancient solar system



ALMA Science: Star/planet formation

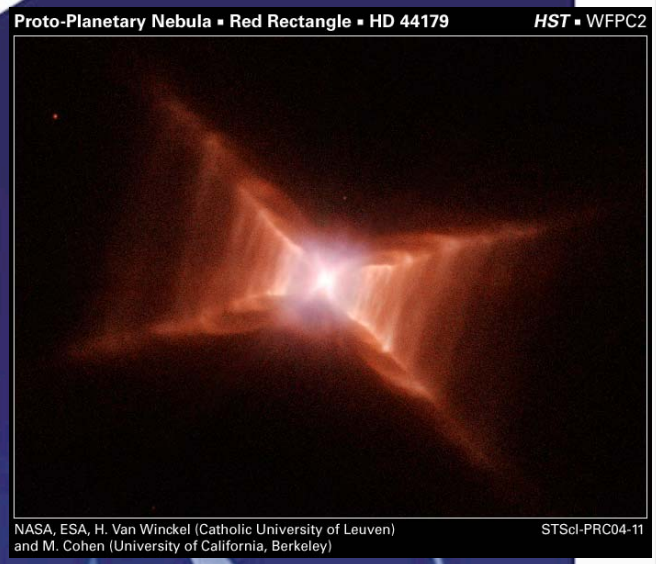
- Kinematics at the most inner part of protostellar cores: When do disks form?
- Exploring the launching point of the jets.
- Direct imaging of the planet formation.
  - When & how are the disks cleared up?
  - What kind of planetary systems are forming?
  - Earth-like planes: how common?

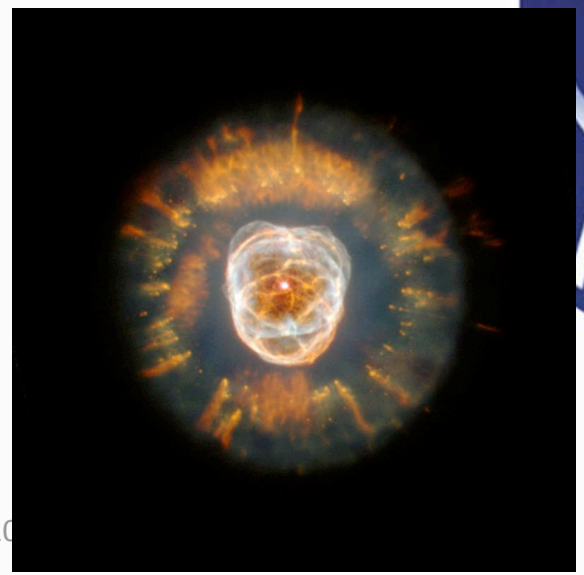




ALMA Science: Dying stars

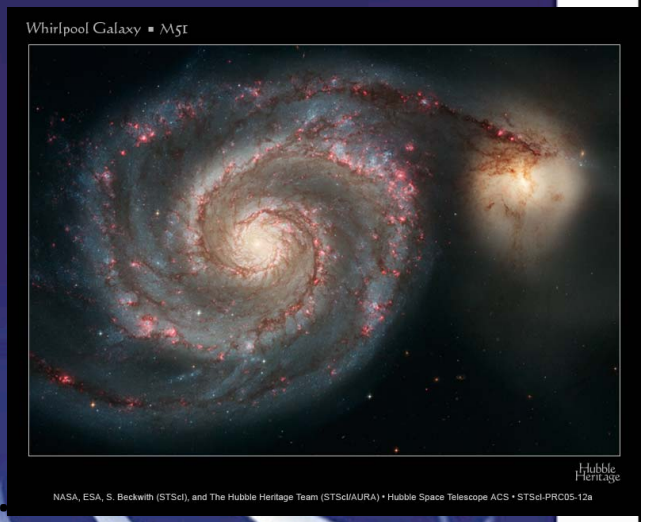
- What makes asymmetric nebula?
- Probe the high velocity stellar winds & investigate the mass-loss process.
- Physical/chemical condition of tiny structures in planetary nebulae

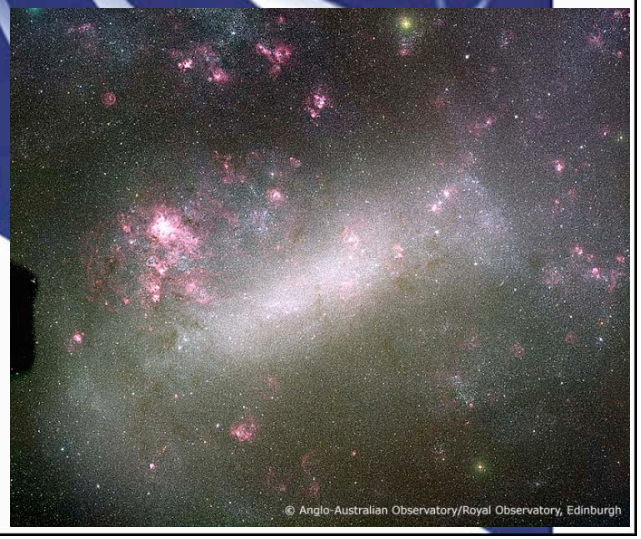




ALMA Science: Galaxies

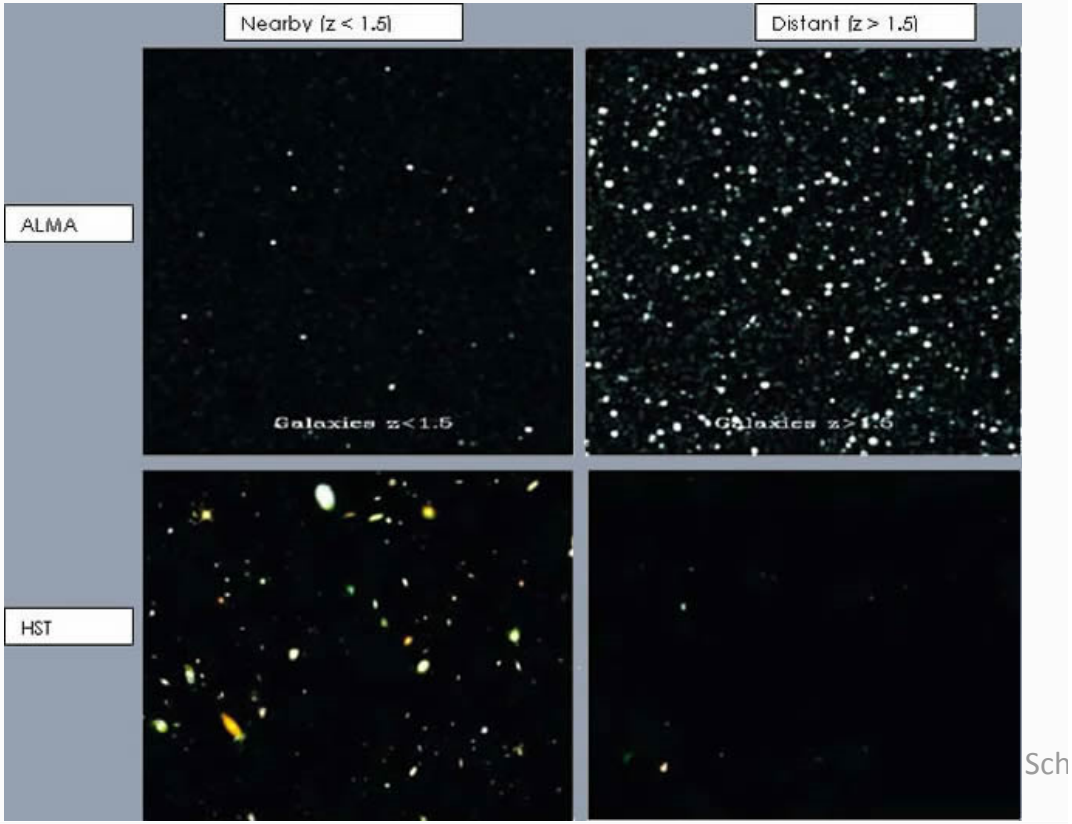
- Galactic-scale chemistry:
  - Ionization fraction variation?
  - Shocks and galactic dynamics?
- Gas mass & Star formation efficiency
- Magellanic Cloud
  - Structure & star-formation in LMC/SMC.
  - Low metallicity than Milky Way
    Early universe analogous

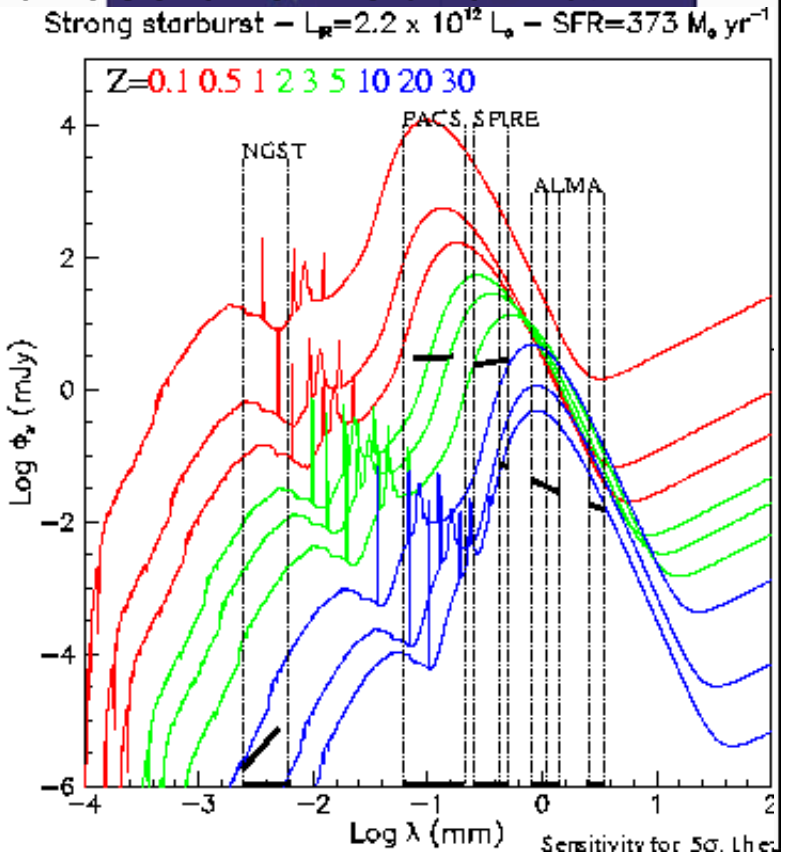




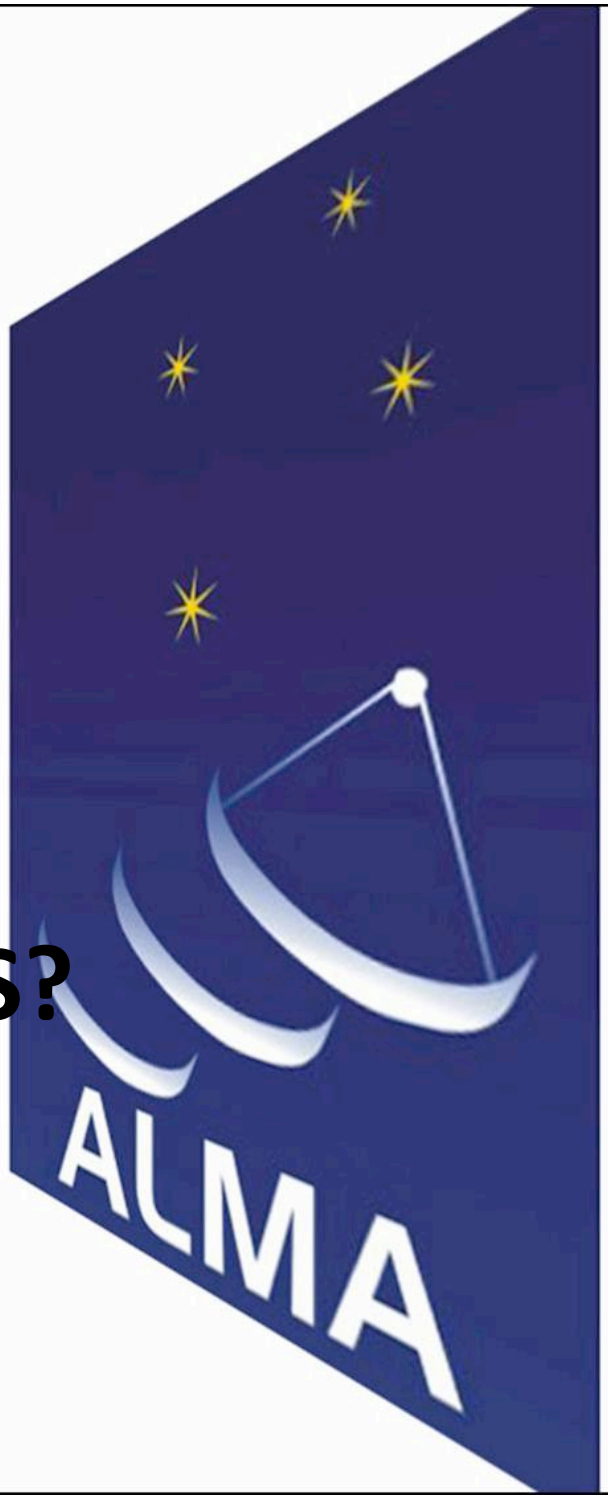
ALMA Science: Deepest universe

- Unbiased survey of submm galaxies to investigate the formation and evolution of galaxies
- Negative *K*-correction: distant sources are not faint!





4. HOW TO ACCESS ALMA FOR YOUR OBSERVATIONS?

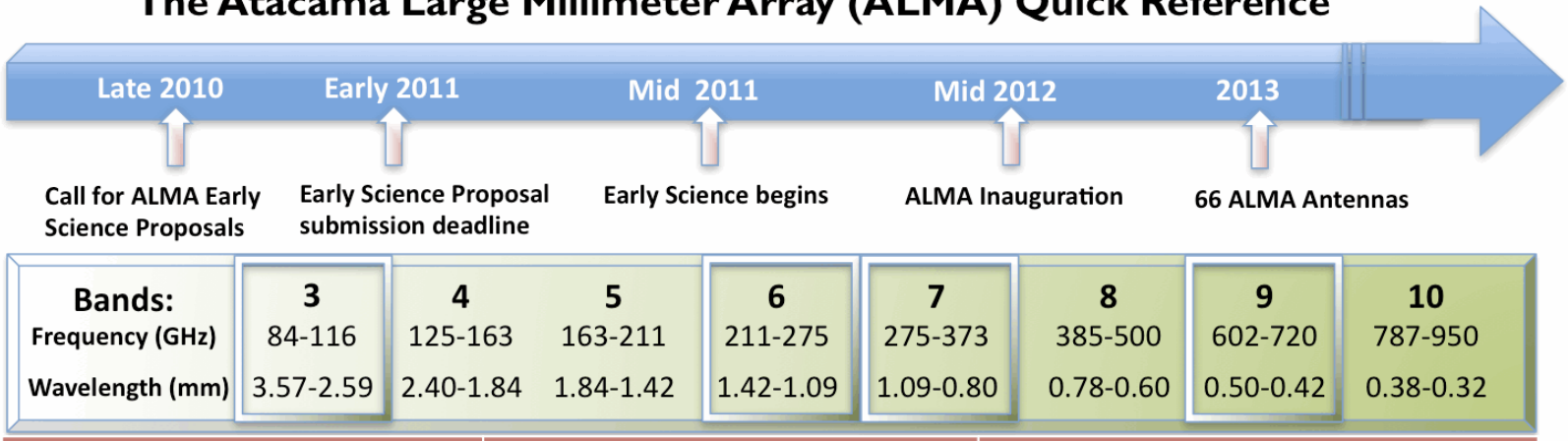


ALMA timeline

- Sep. 2009: First antenna moved to AOS
- Nov. 2009: First fringe with 3 antennas at AOS
- Jan. 2010:
  Start the Commissioning & Science Verification (CSV)
- Jan. 2011: ***First Call for Proposal***
- Sep. 2011: Start “Early Science”
- Sep. 2012: Inauguration
- Apr. 2013: 66 antennas in service

ALMA Early Science

The Atacama Large Millimeter Array (ALMA) Quick Reference



Bands:	3	4	5	6	7	8	9	10
Frequency (GHz)	84-116	125-163	163-211	211-275	275-373	385-500	602-720	787-950
Wavelength (mm)	3.57-2.59	2.40-1.84	1.84-1.42	1.42-1.09	1.09-0.80	0.78-0.60	0.50-0.42	0.38-0.32

	Early Science	ALMA Inauguration
Antennas	≥ 16 x 12m	≥ 50 (12m & 7m)
Bands	≥ 3 bands (Bands 3,6,7,9 likely)	Bands 3,6,7,9 (+ 4,8 & 10 on some)
Maximum Bandwidth	16 GHz (2 polarizations × 8 GHz)	
Correlator Configurations	≥ 5	0.01 - 40 km/sec, 71 configurations
Maximum Angular Resolution	$0.02'' \left(\frac{\lambda}{1\ \text{mm}}\right)$	$\left(\frac{10\ \text{km}}{\text{max baseline}}\right)$
Maximum Baseline	At least 250m (may reach 1km)	15.3 km
Continuum Sensitivity (60 sec, Bands 3—9)	~0.2 — 4.2 mJy	~0.05 — 1 mJy
Spectral Line Sensitivity (60 sec, 1 km/sec, Bands 3—9)	~30 — 250 mJy	~ 7 — 62 mJy

Sensitivity Calculator: http://science.nrao.edu/alma/tools.shtml

NRAO ALMA ES O NAOJ

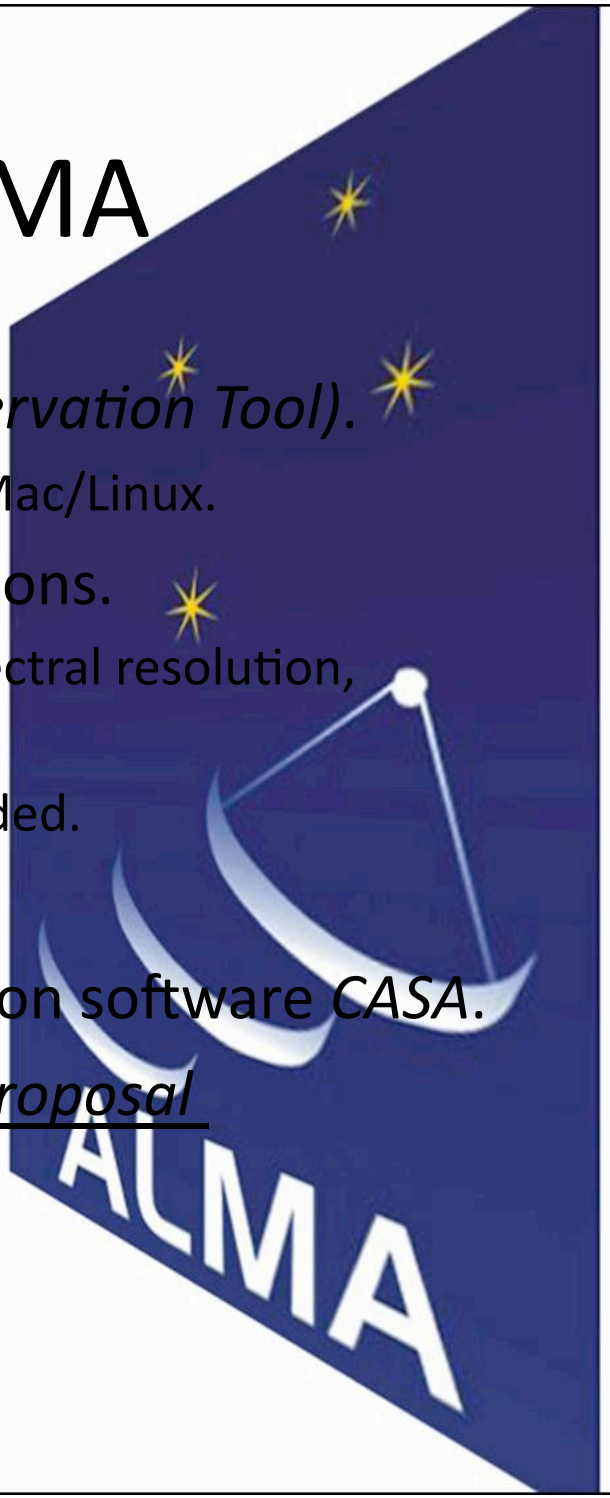
ALMA Specifications

ALMA Sensitivities, FOV, and Resolutions

Band	Frequency Range (GHz)	Wavelength Range (mm)	angular resolution (")	line sensitivity (mJy)	Continuum sensitivity (mJy)	Field of View (")	Largest scale (")
Band 1	31.3 - 45						
Band 2	67 - 90						
Band 3	84 - 116	3.6 - 2.6	3.18 - 0.038	8.9	0.05	56	37
Band 4	125 - 163	2.4 - 1.8	2.5 - 0.03	9.1	0.06	48	32
Band 5	163 - 211	1.8 - 1.4				35	23
Band 6	211 - 275	1.4 - 1.1	1.52 - 0.018	13	0.10	27	18
Band 7	275 - 373	1.1 - 0.8	1.01 - 0.012	21	0.20	18	12
Band 8	385 - 500	0.8 - 0.6	0.86 - 0.01	63	0.40	12	9
Band 9	602 - 720	0.5 - 0.4	0.52 - 0.006	80	0.69	9	6
Band 10	787 - 950	0.4 - 0.3	0.38 - 0.005		1.1	7	5

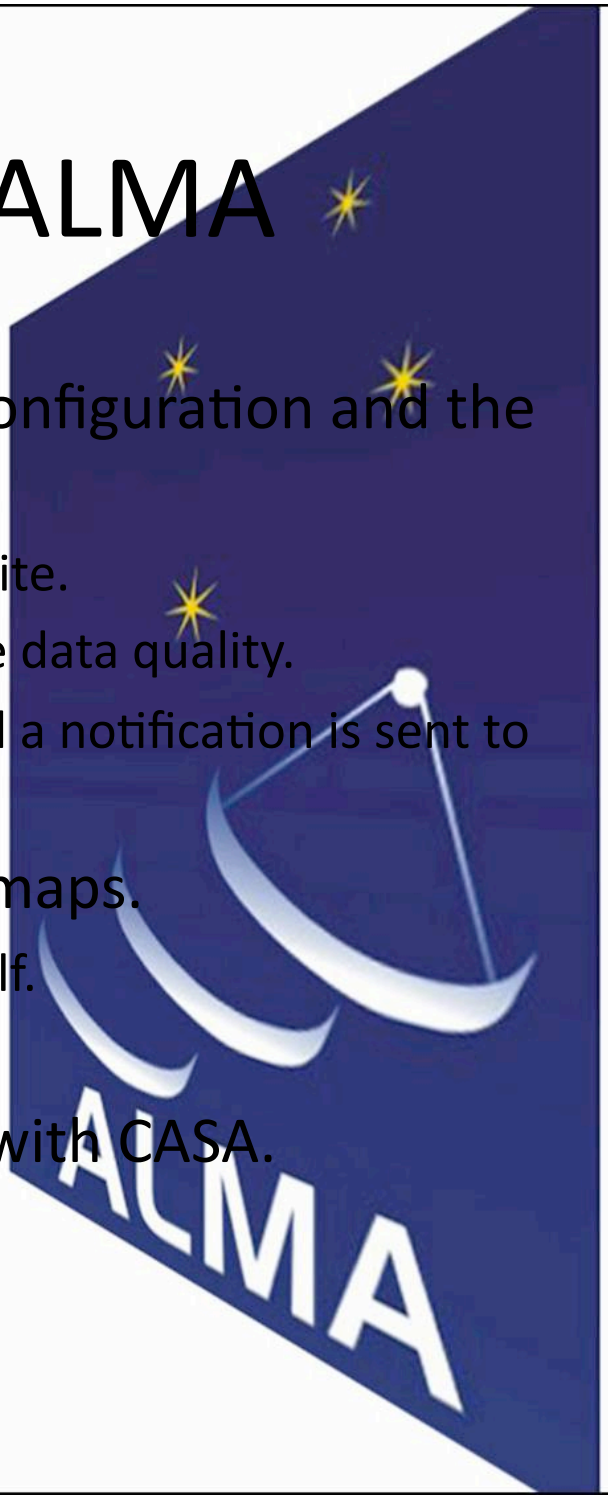
Proposal for ALMA

- Make proposals with a software *OT (Observation Tool)*.
  - Java-based program. Available on Windows/Mac/Linux.
- Set various parameters for your observations.
  - names of Co.I., target position, frequency, spectral resolution, desired spatial resolution, desired noise level
  - Molecular line list/Sensitivity Calculator included.
- Submit (upload) proposals with *OT*
- Simulation can be done with data reduction software *CASA*.
- *Tutorial for OT will be held after Call for Proposal*



Observation with ALMA

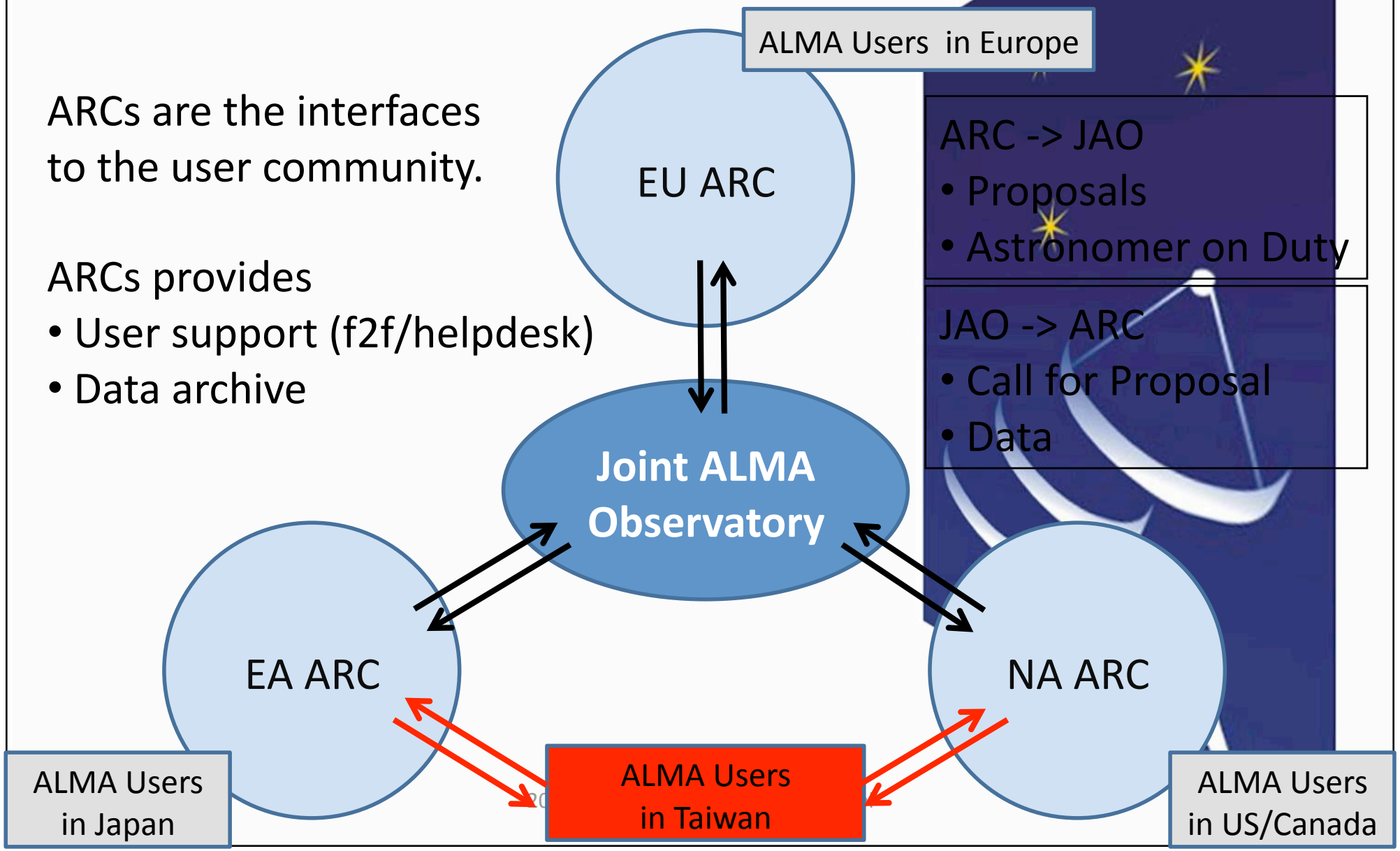
- *Dynamic scheduling* based on the array configuration and the weather condition
  - You don't need to go to the harsh, O_2-deficit site.
  - After the observation, Observatory checks the data quality.
  - Then, data will be stored in ALMA Archive and a notification is sent to the P.I..
- *Data reduction pipeline* will produce the maps.
  - You don't need to reduce your data by yourself.
  - NOT ready in the Early Science
- Raw data also provided. Can be reduced with CASA.



User Support: ALMA Regional Centers

ARCs are the interfaces to the user community.

ARCs provides
- User support (f2f/helpdesk)
- Data archive



EA-ARC Taiwan node

- Manager: Dr. Chin-Fei Lee
- Member: Dr. Yu-Nung Su, Dr. Shige Takakuwa & myself
- Missions
  - Provide user support (f2f, email, website..)
  - Organize tutorials (Proposal preparation, data reduction..)
  - Promote ALMA science in Taiwan
  - Send people to ALMA as Astronomer on Duty.
- Facilities
  - Computers (Data reduction computer/ Data archive)

ALMA-T website

Summary

- ALMA is the very powerful telescope for all fields in astrophysics, astrochemistry, planetary science, and maybe astrobiology.
- First Call for Proposal will be issued in Jan.2011.
- Please consider what you can do with ALMA.

- Any comments/questions about ALMA
  - send e-mail to *arc@asiaa.sinica.edu.tw*