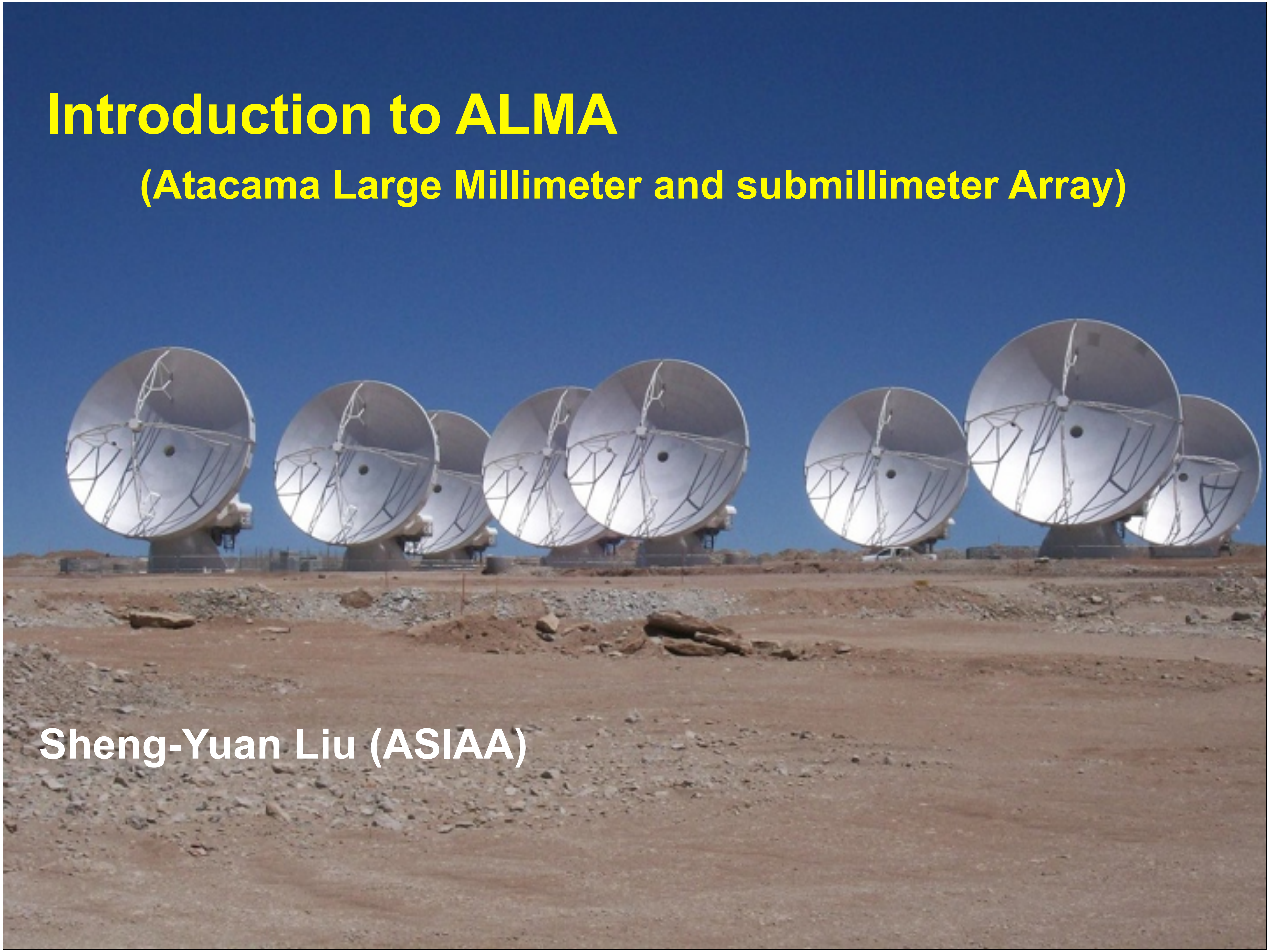
Introduction to ALMA

(Atacama Large Millimeter and submillimeter Array)



Sheng-Yuan Liu (ASIAA)

What is ALMA?

- For REAL novice users, ALMA is just another, perhaps new, (sub)millimeter telescope
  - Why ALMA? or Why (sub)millimeter?
    - Do not worry about the specifications/numbers, think about science first
      - what you can do with (sub)millimeter observations?
      - what (sub)millimeter observations can do for your subject of study?
    - Can you make your observations with existing (sub)millimeter instruments now?
  - Purpose of this Workshop Part I

What is ALMA?

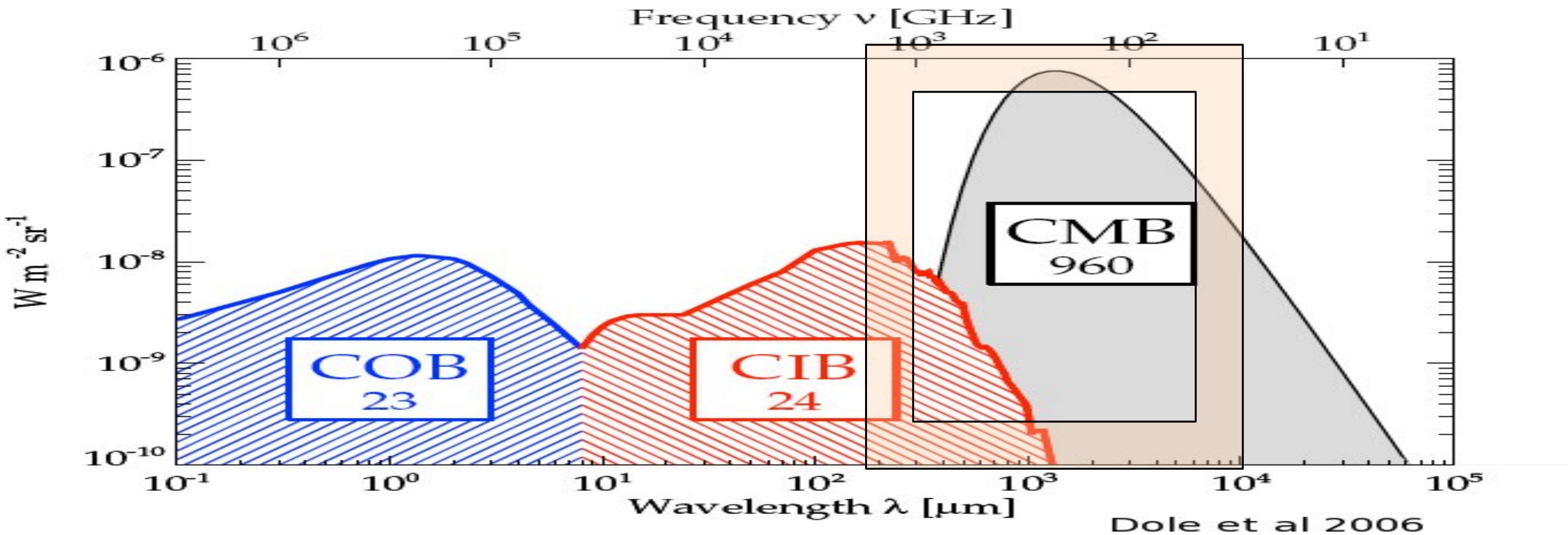
- For users with some experiences, ALMA will be way beyond the current generation of (sub)millimeter telescopes in its
  - sensitivity
  - (spatial) resolution (but do not forget about short/zero spacing)
  - spectral capability (overall wavelength coverage, simultaneous bandwidth, spectral resolution)
  - full scientific service

  - Purpose of this Workshop Part II

The mm/submm Spectrum: Focus of ALMA

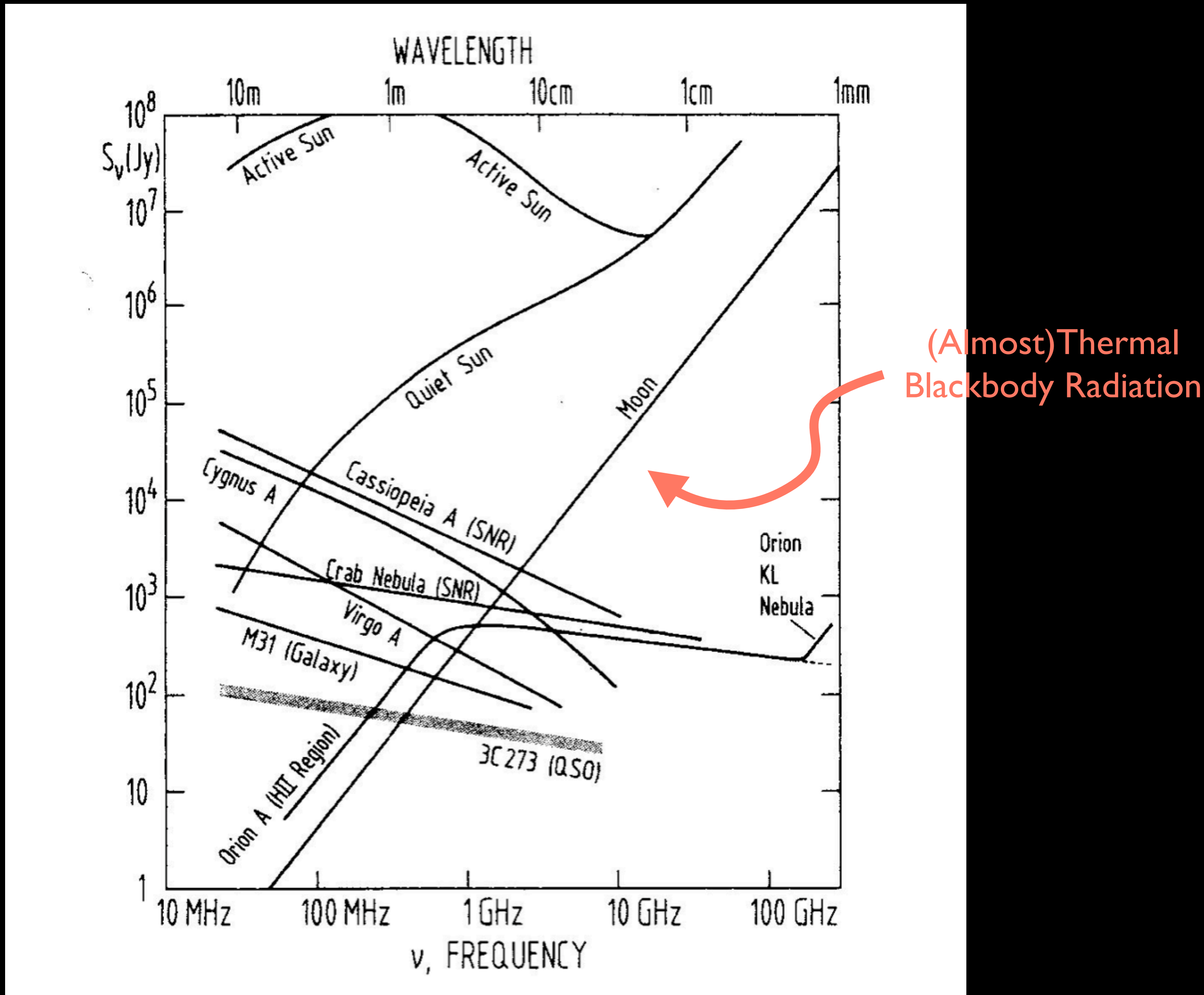
ALMA

slide by Al Wootten



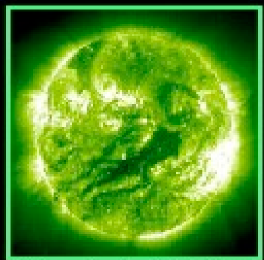
- Millimeter/submillimeter photons are the most abundant photons in the cosmic background, and in the spectrum of the Milky Way and most spiral galaxies.
- ALMA range--wavelengths from 1cm to ~0.3 mm, covers both components to the extent the atmosphere of the Earth allows.

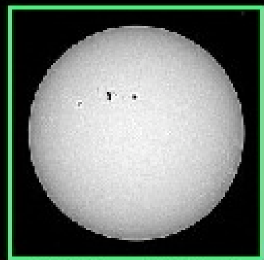
The Power Spectrum of Radiation in Radio

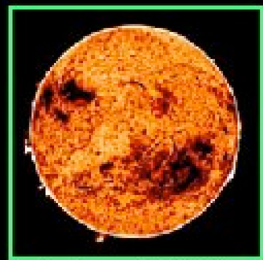


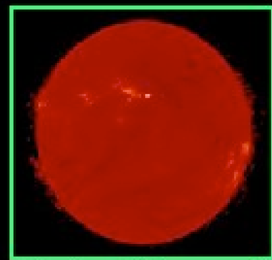
Solar System Objects


X-Ray (Yohkoh)

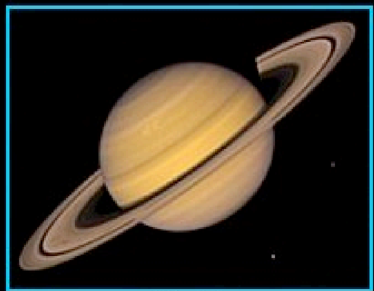

Ultraviolet (SOHO)


Visible (BBSO)


Infrared (NSO)


Radio (Nobeyama)

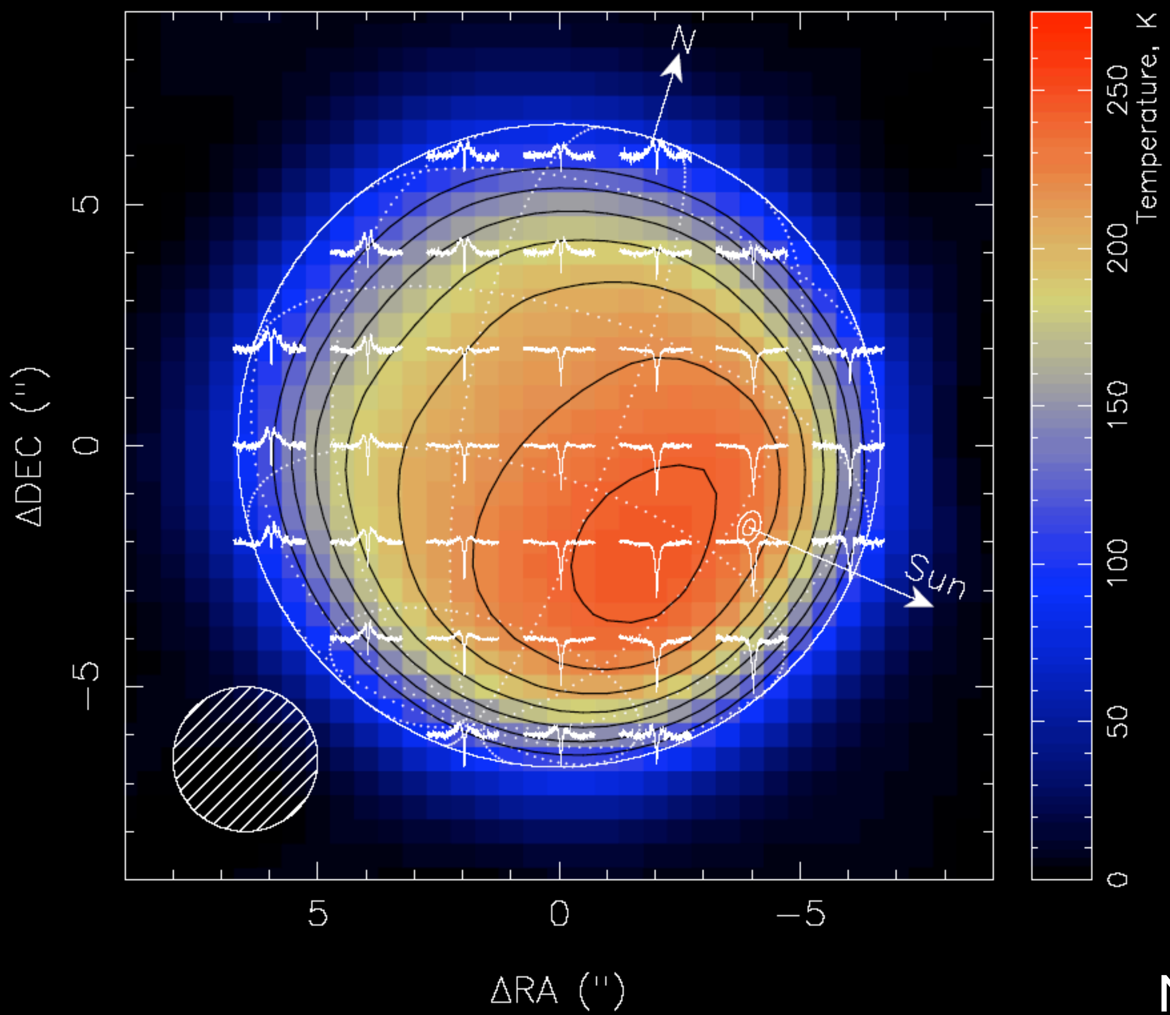

Ultraviolet
J. Trauger JPL/NASA


Visible
NASA/JPL/Voyager


Infrared
E. Karkoschka UA/HST/NASA

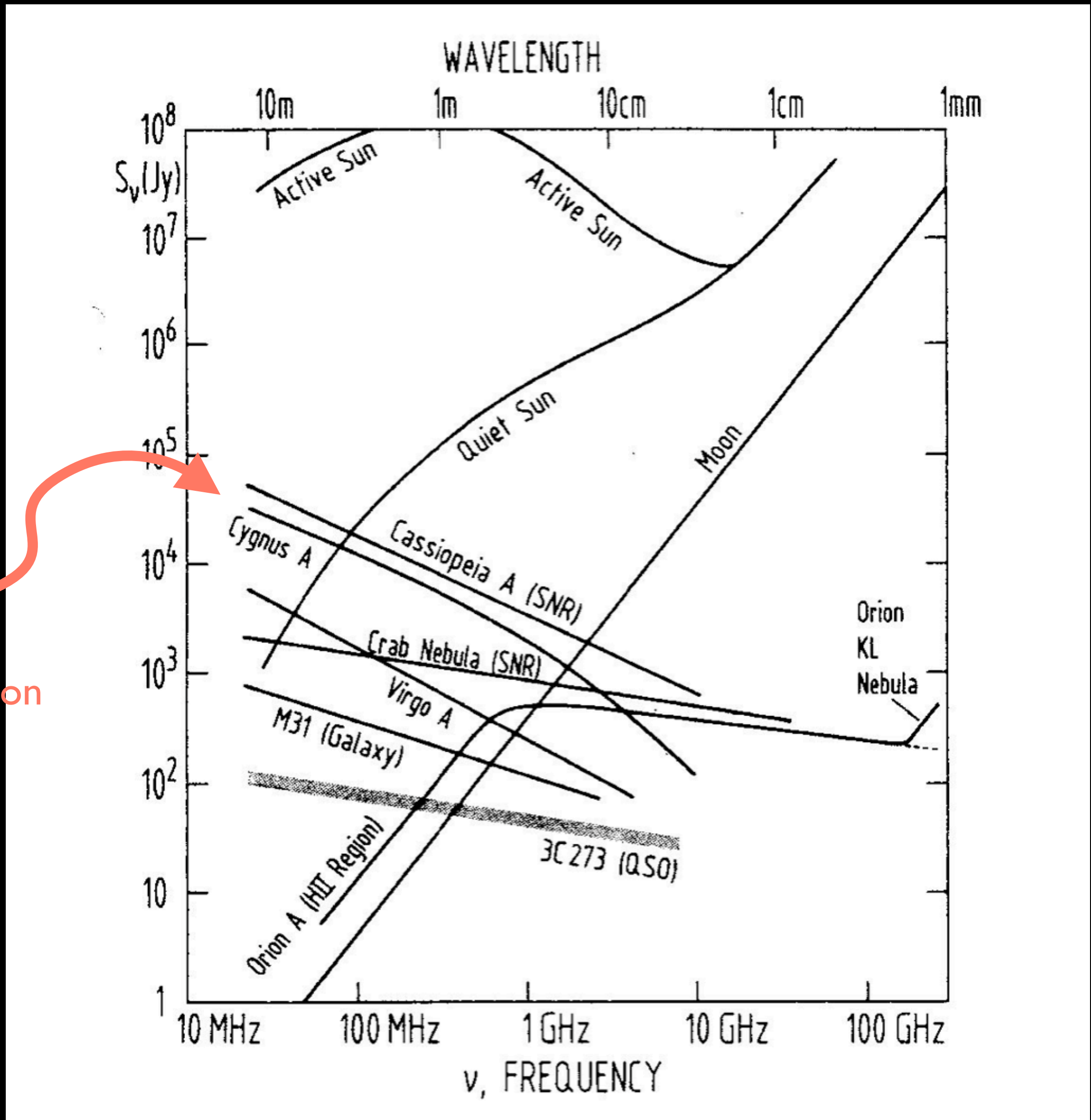

Radio
NRAO

Mars



M. Gurwell

The Power Spectrum of Radiation in Radio

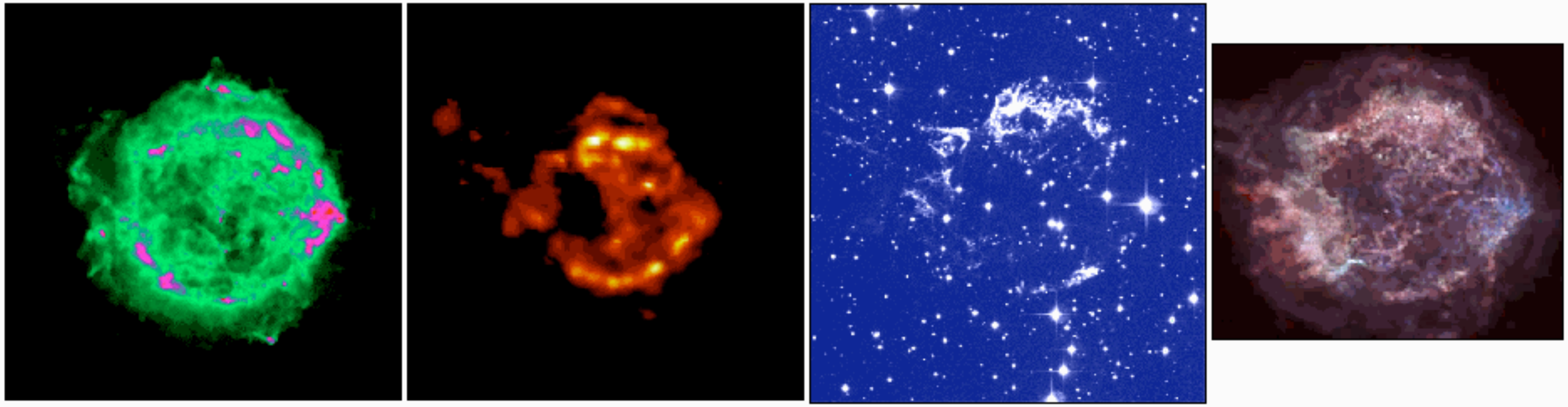


Non-Thermal
Synchrotron Radiation

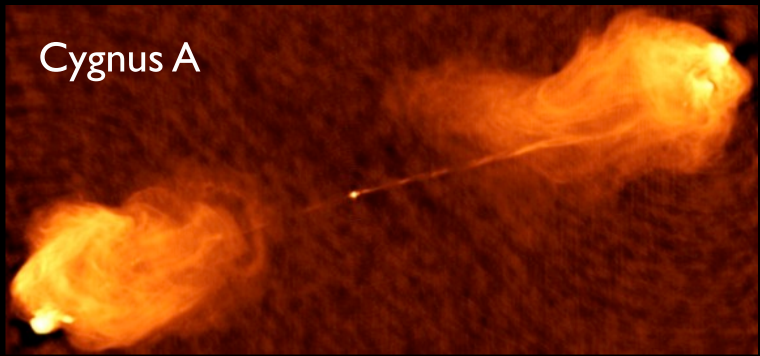
Supernova Remnant Cassiopeia A

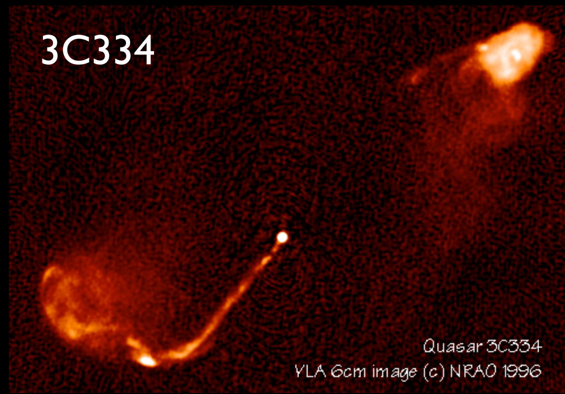
Cassiopeia A: a star that died in ~1700

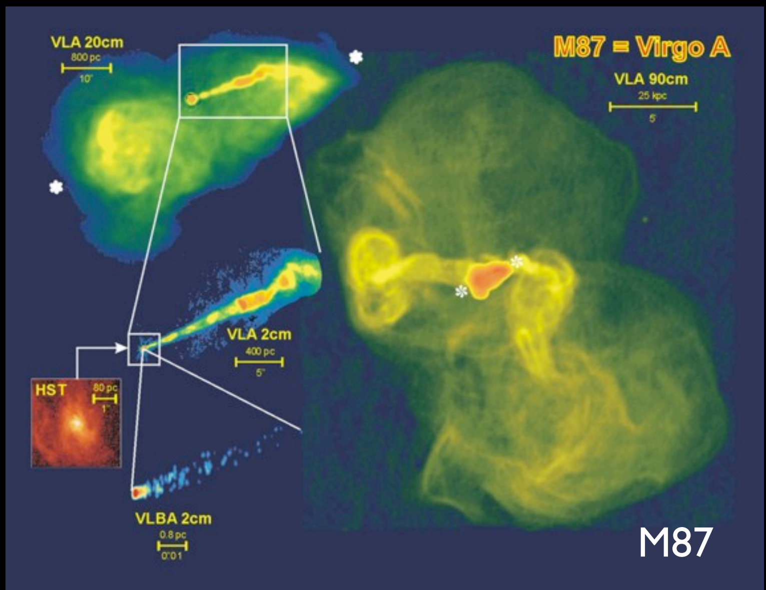
RADIO INFRARED OPTICAL XRAY

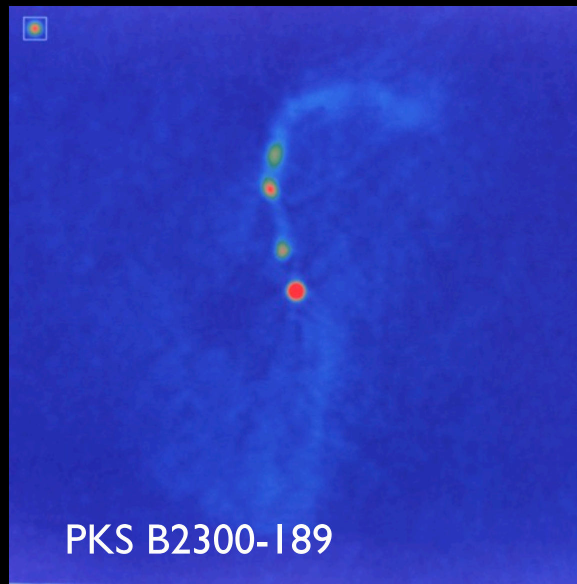


Radio Galaxies and Quasars



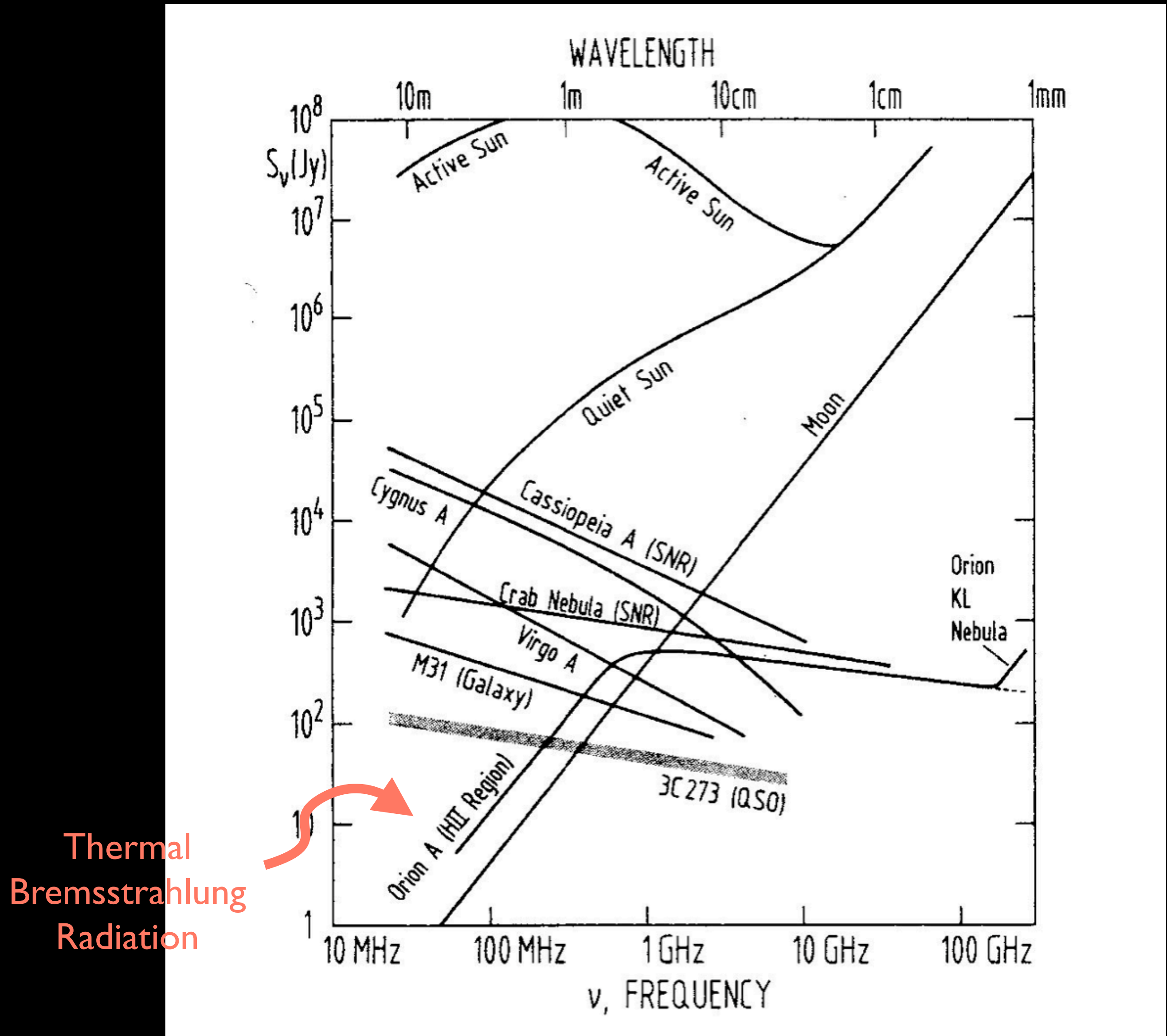






VLA, NRAO

The Power Spectrum of Radiation in Radio



HII Regions in Orion

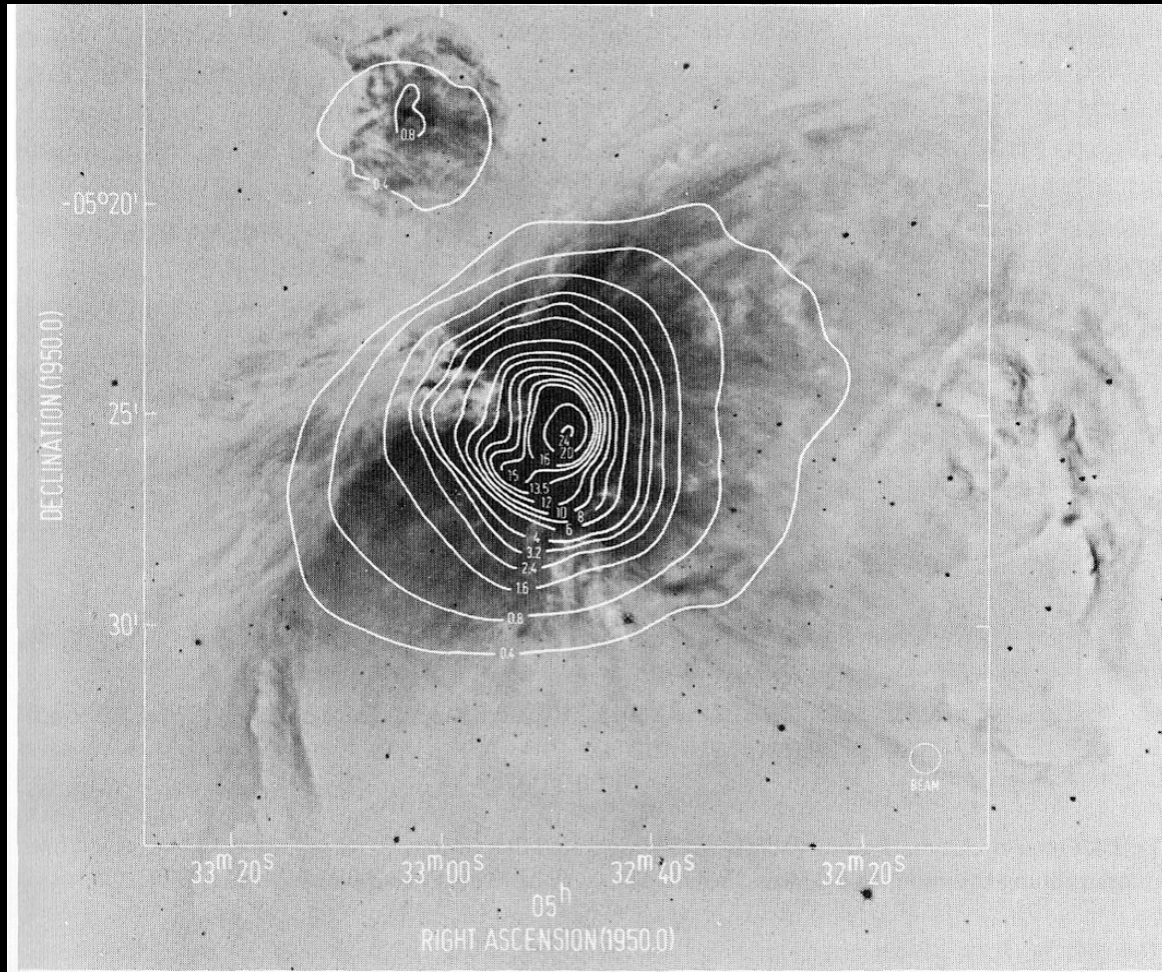
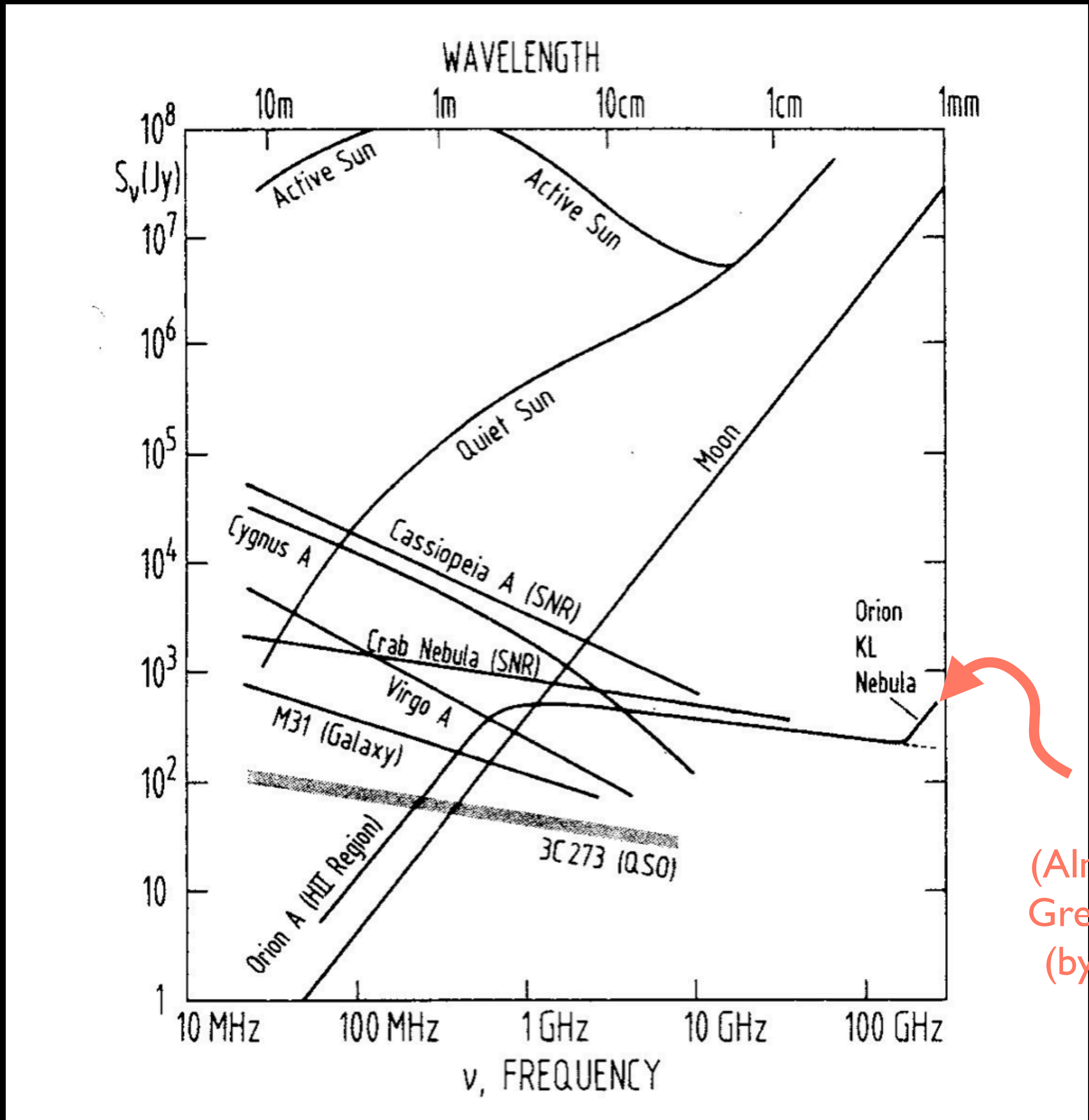


Fig. 2.3. The 23-GHz radio continuum contours, in units of main-beam brightness temperature, on an optical photo in Hα and [NII] of NGC 1976 (Orion A, M42), below, and NGC 1982 (M43), above. The angular resolution is 42″, which at the distance of Orion A, corresponds to a linear resolution of 0.10 pc (Wilson and Pauls, 1984).

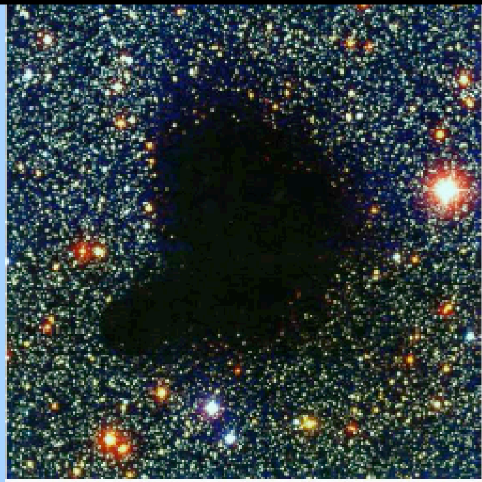
The Power Spectrum of Radiation in Radio

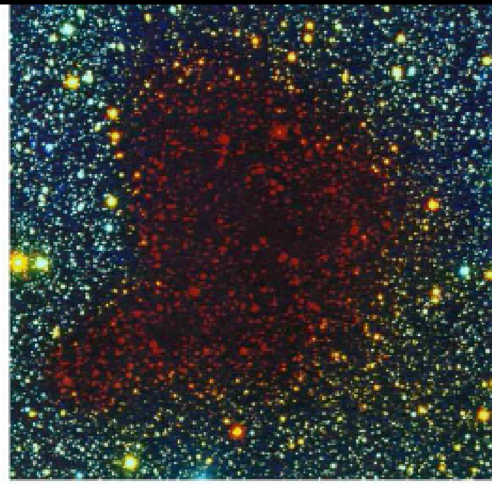


Thermal
(Almost Blackbody)
Greybody Radiation
(by dust particles)

Bok Globule B68

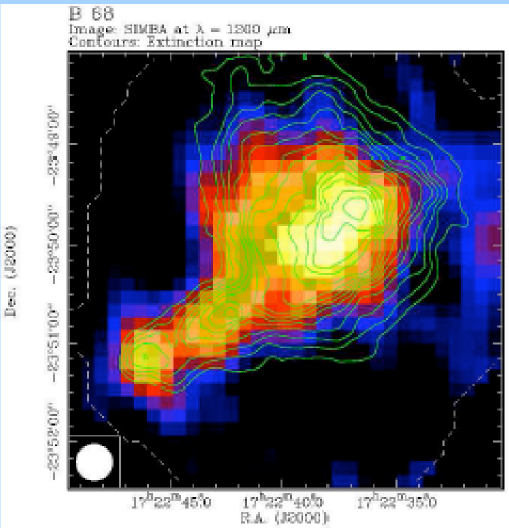
Visual



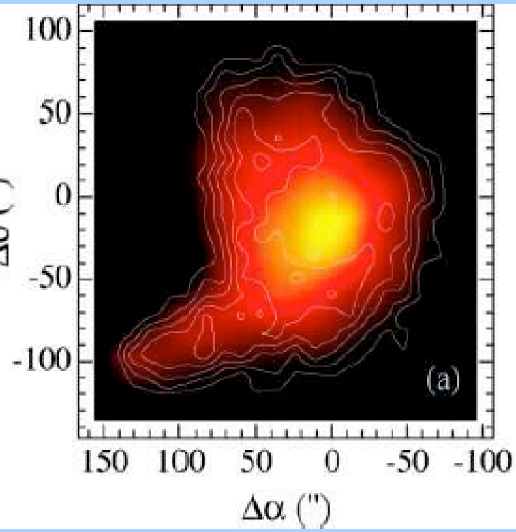


Near Infrared

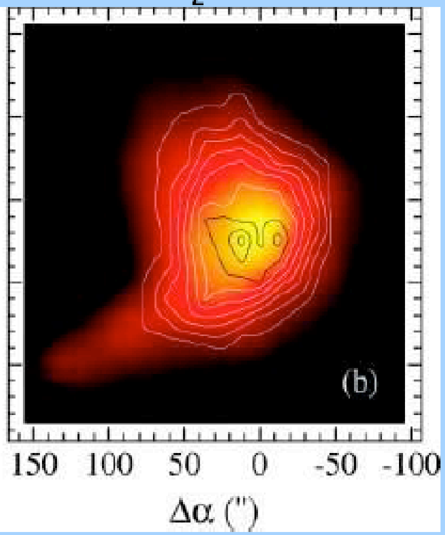
1.2 mm dust continuum



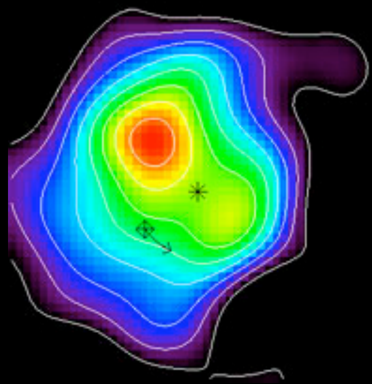
$C^{18}O$

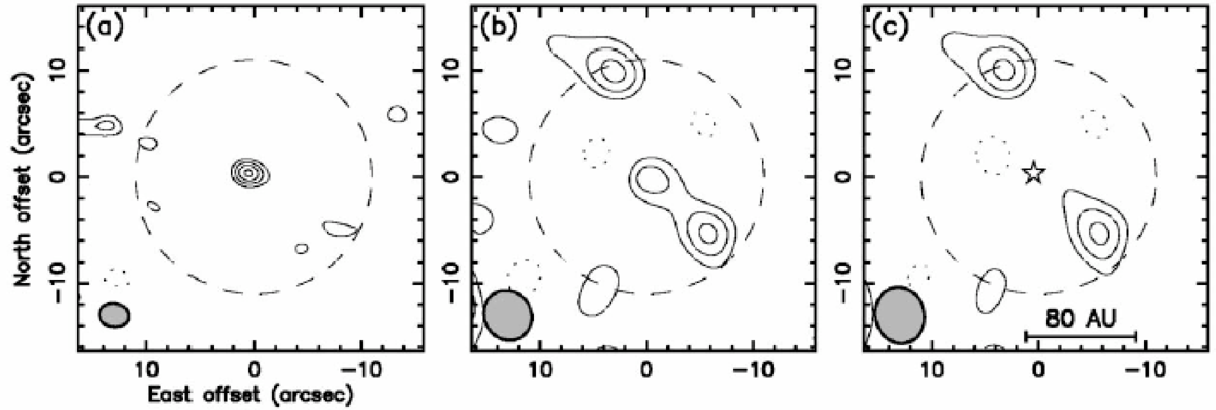


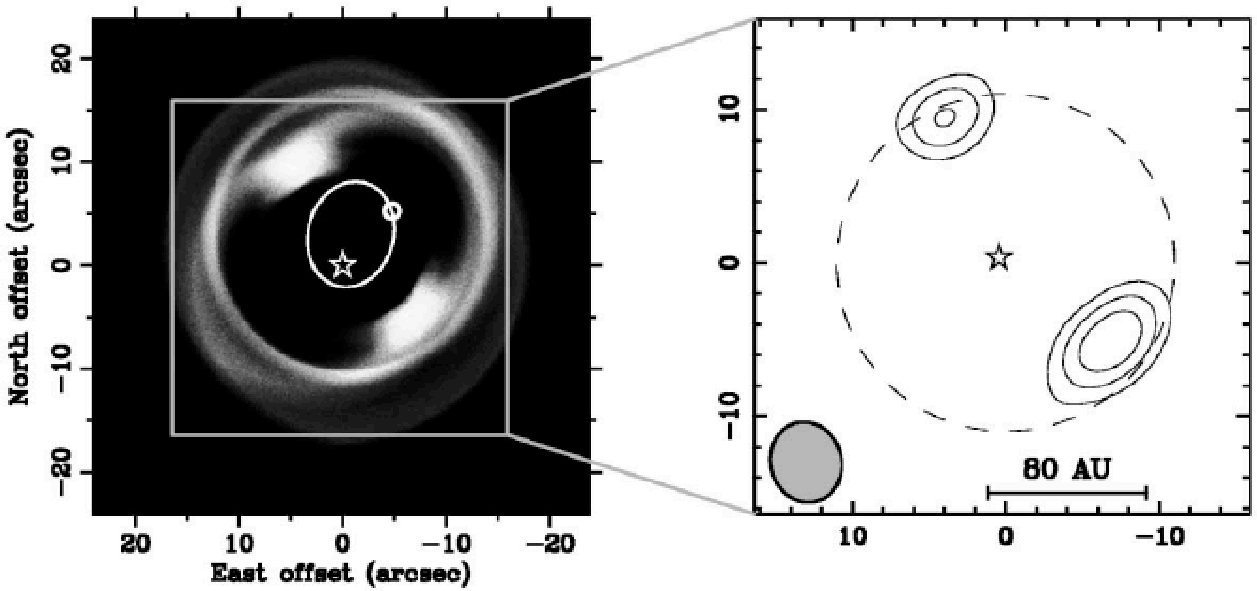
N_2H^+

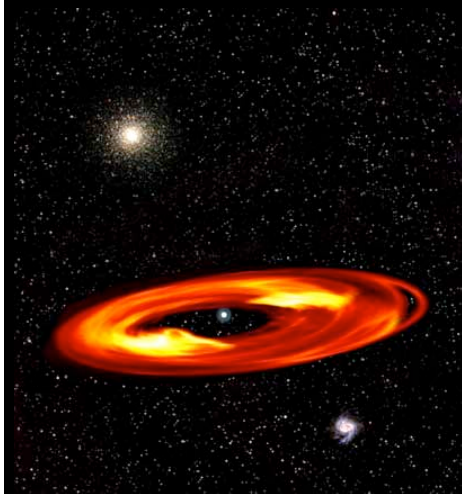


Debris Disk Vega



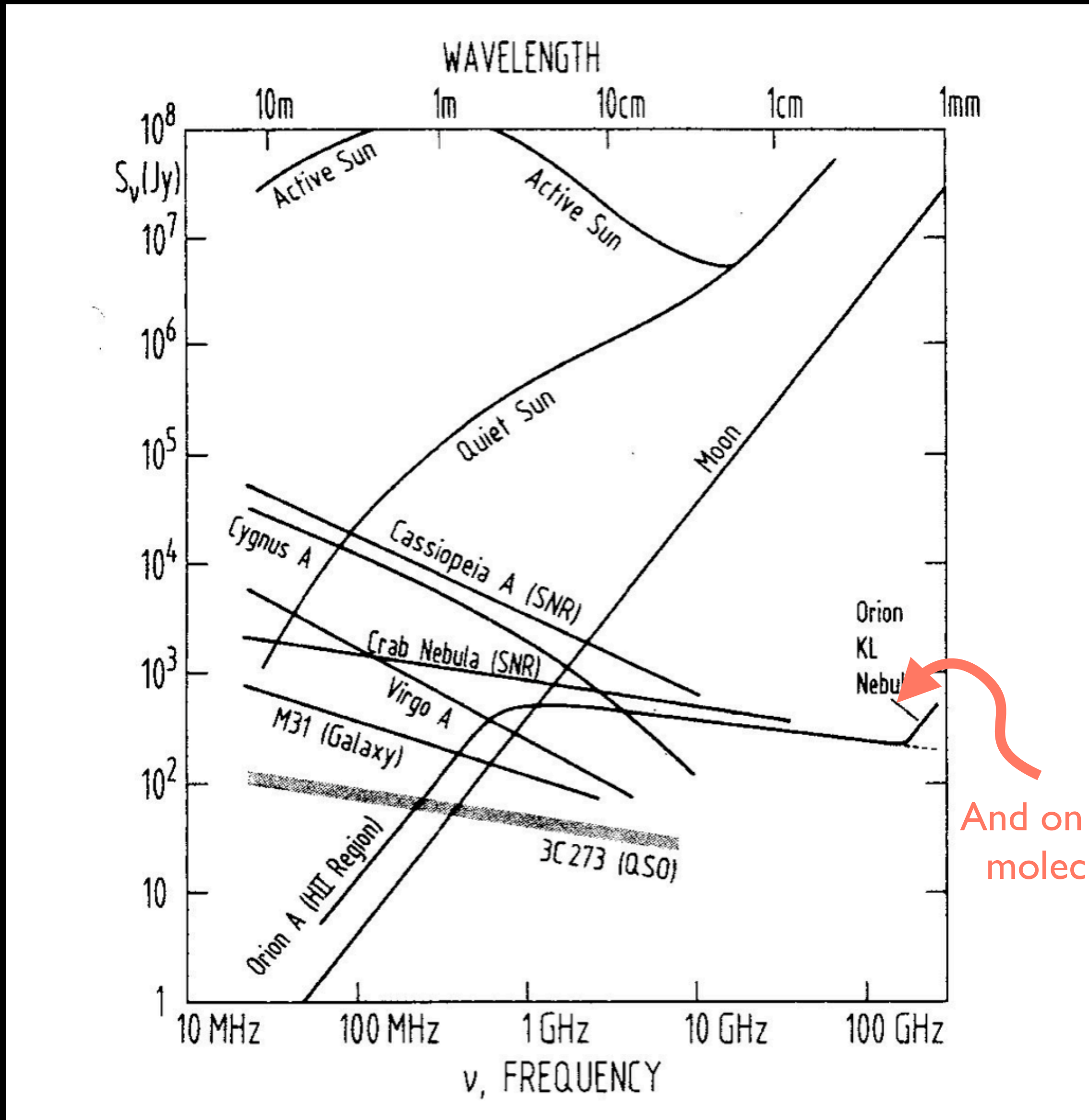






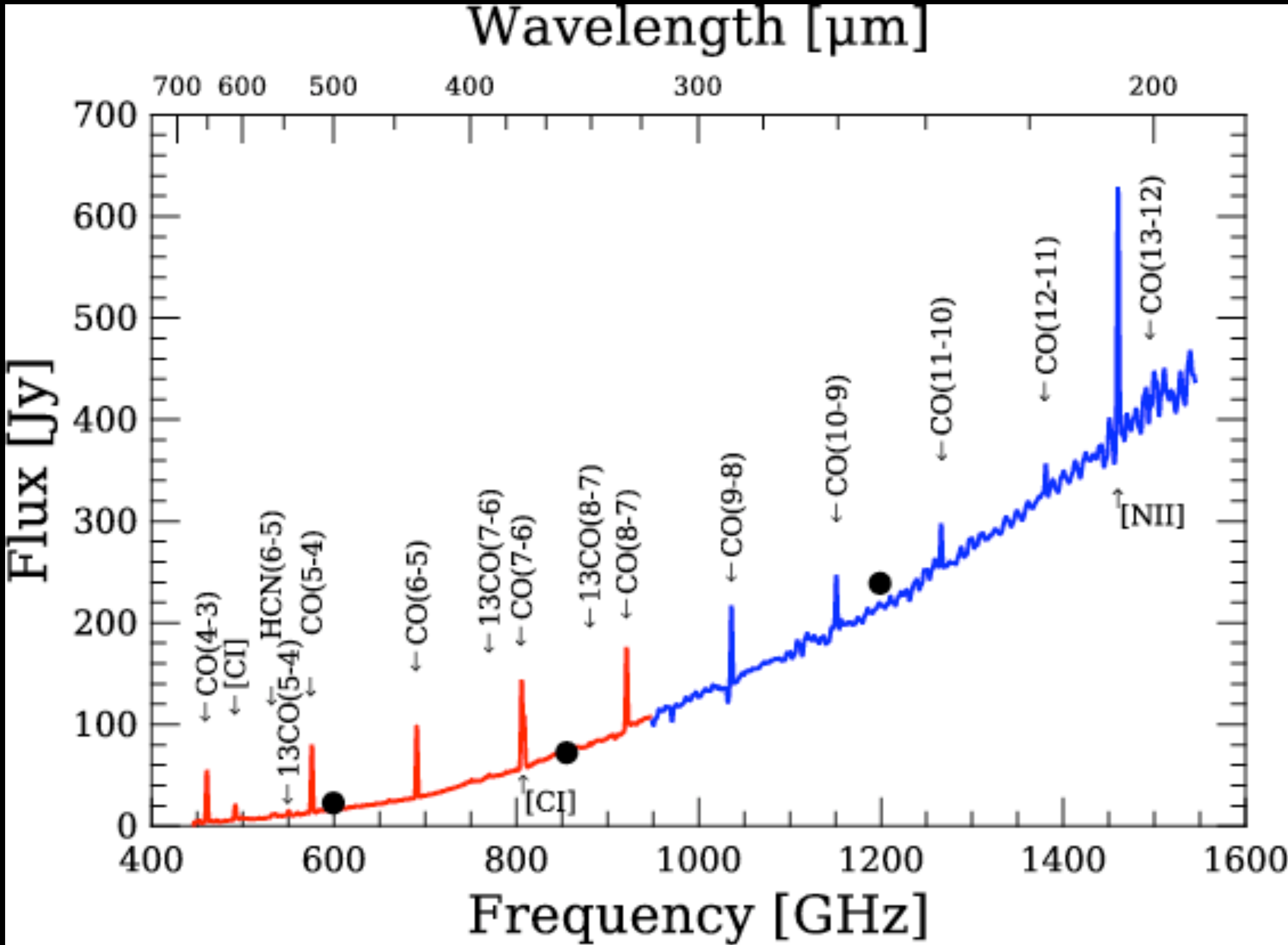
Wilner et al. (2002)

The Power Spectrum of Radiation in Radio



And on top of continuum, molecular line features

Starburst Galaxy M82



Panuzzo et al. (2010)

Interaction Galaxies Antennae Galaxies

Fig. 4.— Contours of CO(1–0) emission in two colliding galaxies, NGC4038/4039 (the Antennae) overlaid on an HST image. Massive concentrations of molecular gas are located at the nucleus of each galaxy and in the interaction region.

ALMA -General Science Goals

A General Purpose Instrument

General Science Requirements, from ALMA Project Plan v2.0:

"ALMA should provide astronomers with a general purpose telescope which they can use to study at a range of angular resolutions millimeter and submillimeter wavelength emission fron … pres … to:

- Ima … f forr …
- Tra … con …
- Rev … atial sca …
- Ima … ets and …
- Rev … reflect the chronology of invisible stellar nuclear processing;
- Obtain unobscured, sub-arcsecond images of cometary nuclei, hundreds of asteroids, Centaurs, and Kuiper Belt Objects in the solar system along with images of the planets and their satellites;
- Image solar active regions and investigate the physics of particle acceleration on the surface of the sun.

Understanding the origin and evolution of
The Universe
(galaxies, stars, the Solar system and alike)

via continuum and (mostly) molecular line

DRSP Review

- DRSP - Design Reference Science Plan
  - http://www.eso.org/sci/facilities/alma/science/drsp/
  - prototype suite of high priority ALMA projects to be carried out in 3-4 years
  - a quantitative reference for developing ALMA science operation
  - not real/approved proposals, but very good example/ starting point for new users

The Era before ALMA

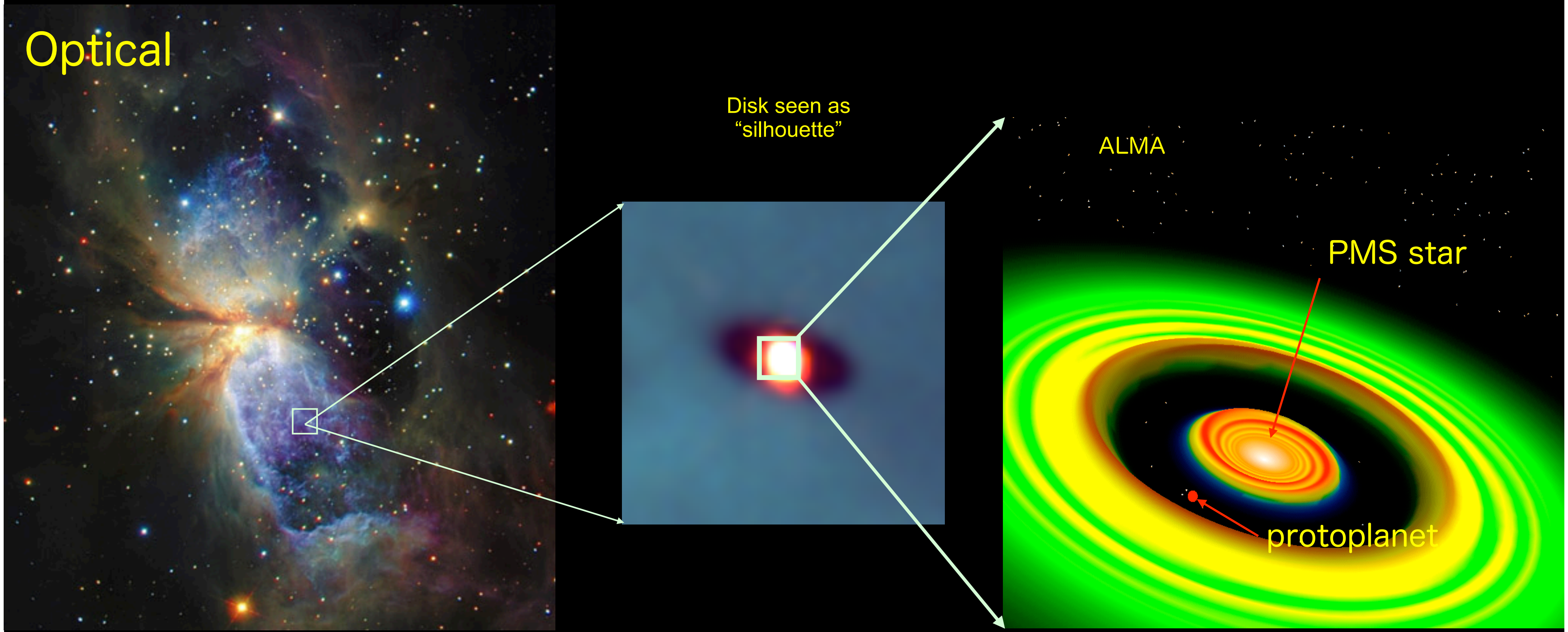
- Millimeter Array (MMA) of NRAO
  - envisioned in the 1980’s as a new frontier after the VLA
  - top priority ground-based radio facility in U.S.
  - search of international partners started in 1995
- Large Millimeter Array (LSA) of ESO
  - envisioned in 1991 for complementing VLA, HST
  - collaboration established in 1995 between ESO, IRAM, OSO, NFRA top
- Large Millimeter and Submillimeter Array (LMSA) of NAOJ
  - envisioned after the completion of Nobeyama MMA and site survey started in 1990
  - a high sensitivity corresponding to a 70m dish
  - top priority ground-based facility in Japan

ALMA Key Science Goals

- Key science goal includes
  - Image protoplanetary disks to detect tidal gaps created by planets undergoing formation in the disks;
  - Image normal galaxies like the Milky Way (in CO or CII line, for example) out to Z=3
  - Precision imaging at high angular resolution(0.1”)

Tidal Gap Due to (Proto)Planets

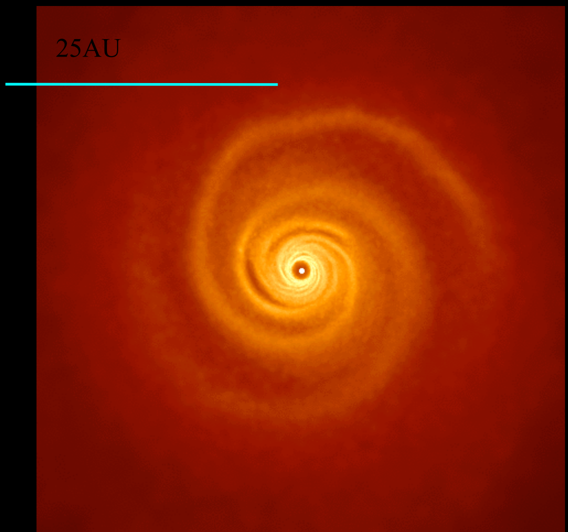
slide by Al Wootten



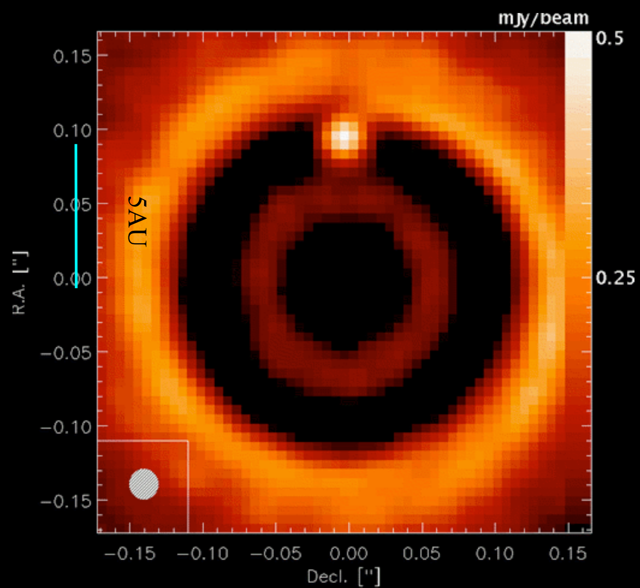
Birth of Stars and Planets

Evolutionary Sequence—
Molecular Cloud Core to Protostar (10^4 yrs) to
Protoplanetary Disk (to ~10^6 yrs) to
Debris Disk (to 10^9 yrs)

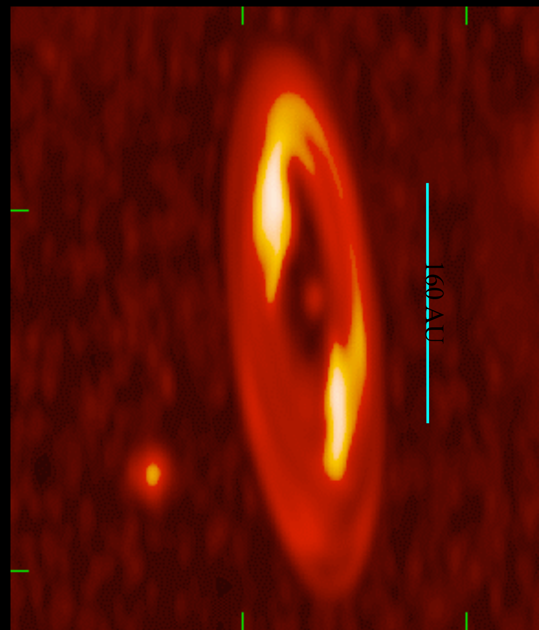
Lodato and Rice 2005



Wolf and D'Angelo 2005



Wilner et al. 2002



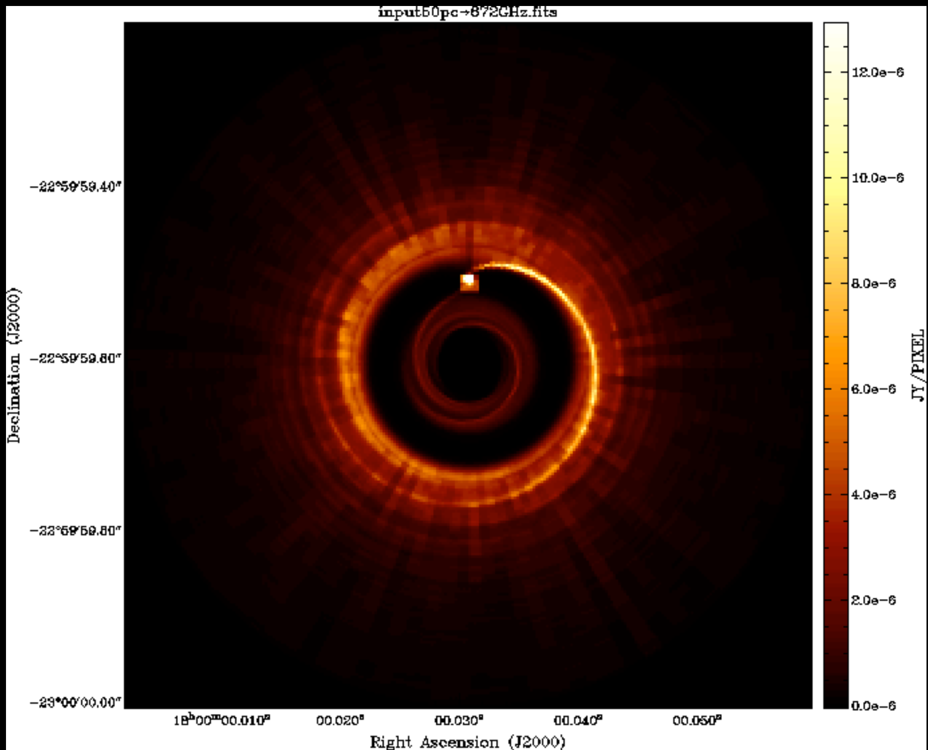
Model and Simulation Observations of Proplyds Emission

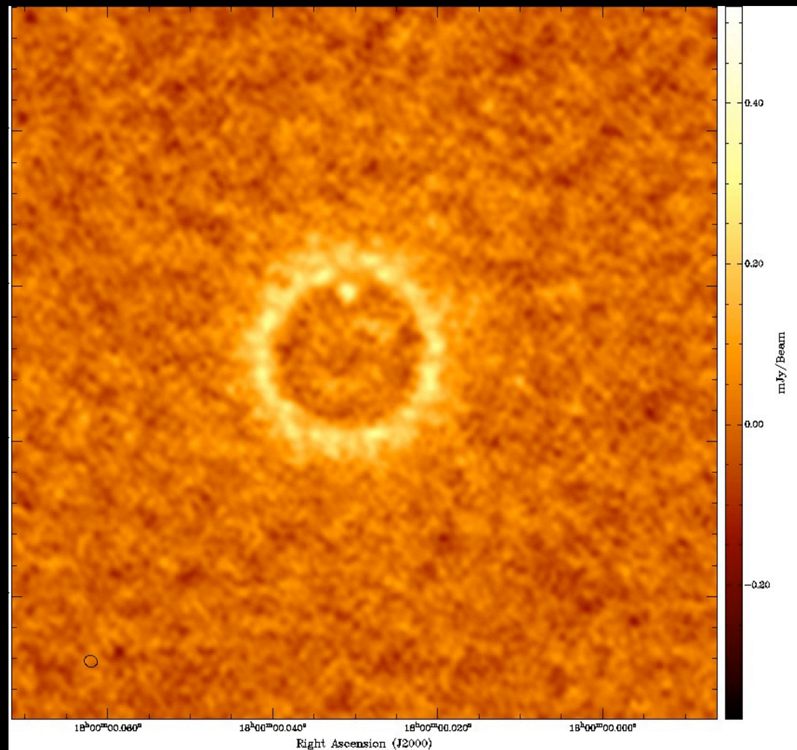
Protoplanetary disks

M_{planet} / M_{star} = $0.5M_{Jup}$ / $1.0\ M_{sun}$

Orbital Radius: 5 AU

R. Reid

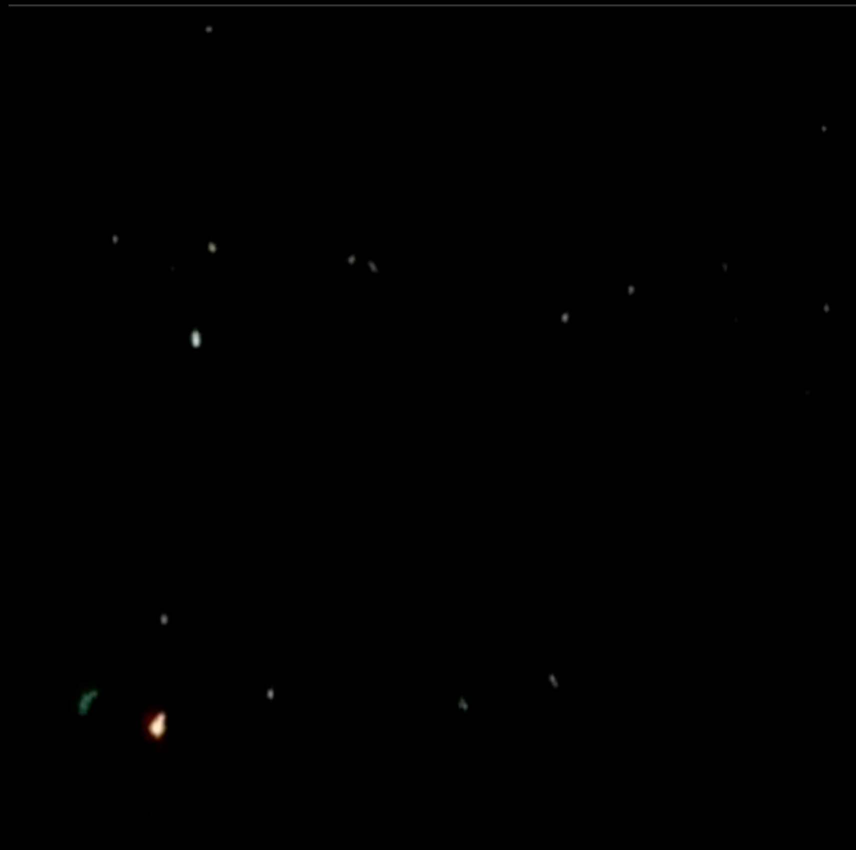




Hubble Deep Field

Rich in Nearby Galaxies, Poor in Distant Galaxies

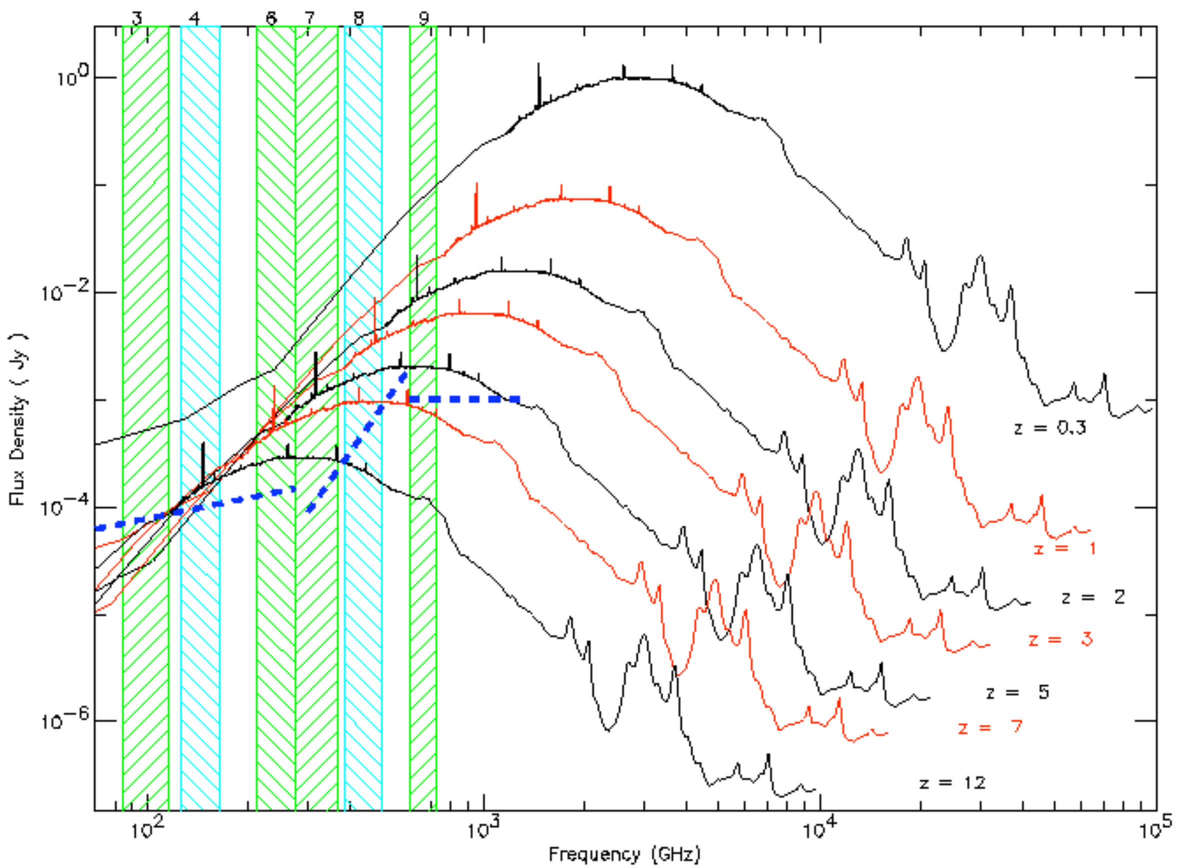
Source: K. Lanzetta, SUNY-SB



Infrared Luminous Galaxies

- As galaxies get redshifted into the ALMA bands, dimming due to distance is offset by the brighter part of the spectrum being redshifted in. Hence, galaxies remain at relatively similar brightness out to high distances.

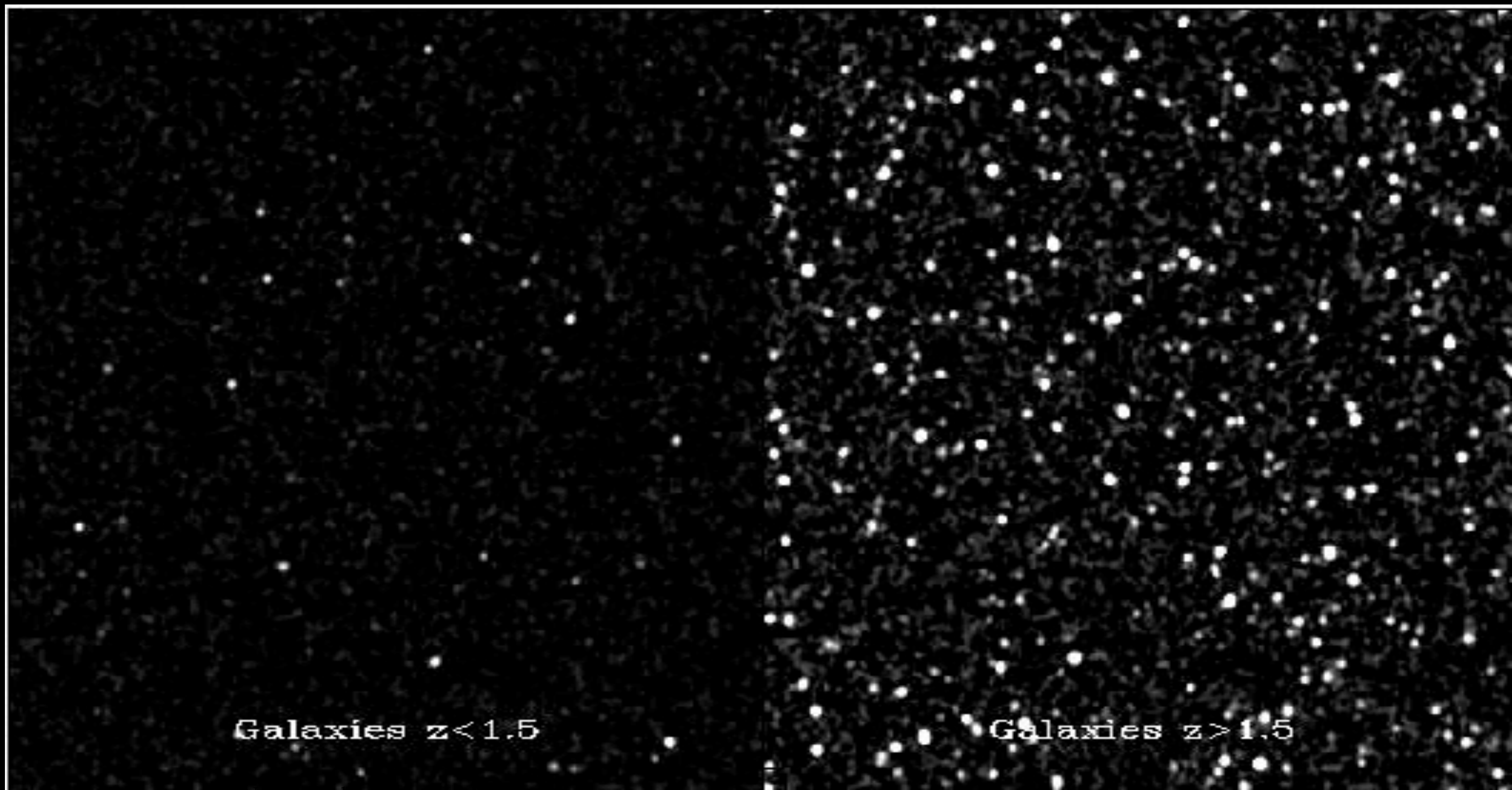
M82 from ISO, Beelen and Cox



ALMA Deep Field

Poor in Nearby Galaxies, Rich in Distant Galaxies

Source: Wootten and Gallimore, NRAO



ALMA Science Specification in a Nutshell

Sensitivity- and Resolution- Driven

What is ALMA?

- For users with some experiences, ALMA will be way beyond the current generation of (sub)millimeter telescopes in its
  - sensitivity
  - (spatial) resolution (but do not forget about short/zero spacing)
  - spectral capability (overall wavelength coverage, simultaneous bandwidth, spectral resolution)
  - full scientific service

Radio Telescope Sensitivity

system temperature

new generation of receivers and high (Atacama site)

noise level
(point source sensitivity)

$$\Delta S \propto \frac{2k}{A} \frac{T_{sys}}{\sqrt{\tau_{int} \Delta\nu}}$$

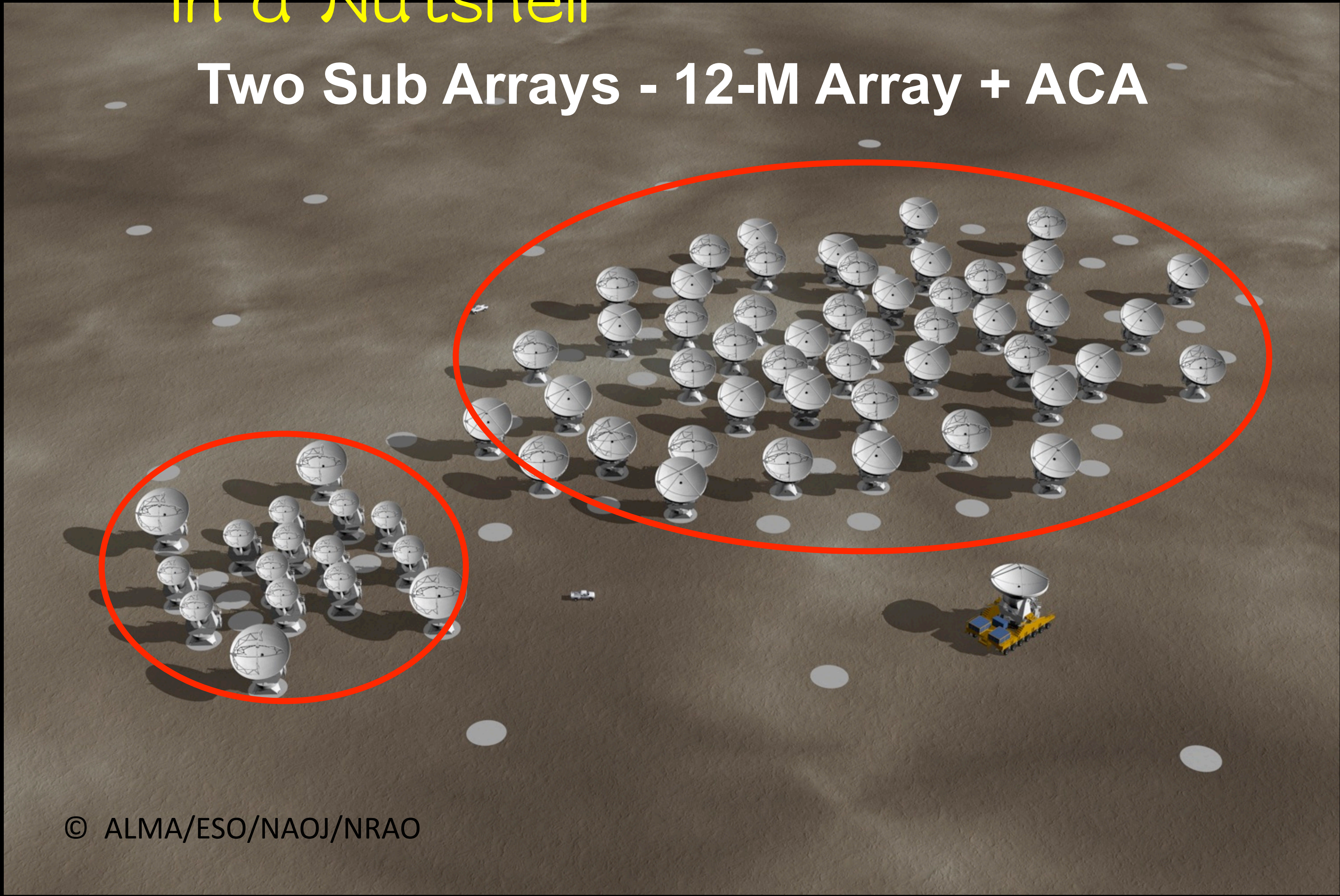
(roughly) total collecting area

large number of big antennas, 66 in total

continuum bandwidth or spectral line resolution

new correlator for wide continuum bandwidth (8 GHz, dual polarization) and high/flexible spectral line resolution

ALMA Science Specification in a Nutshell



Comparign the power of (sub)mm telescopes

	ATCA	CARMA	SMA	PdBI	ALMA ES	ALMA full
Antennas	6	15	8	6	16	66
Freq range	20, 100	100, 230	230, 345, 690	100, 230	100, 230, 345, 650	+ 150, 450, 800
collecting area	2280	772	226	1060	> 1350	6500
max resolution	0.4″	0.4″	0.15″	0.5″	0.15″	0.01″
Tsys (freq)	350 K (100)	200 K (230)	140 K, 2640 K (230) (650)	200 K (230)	30 K, 70 K, 430 K (100) (230) (650)	

by Tachihara

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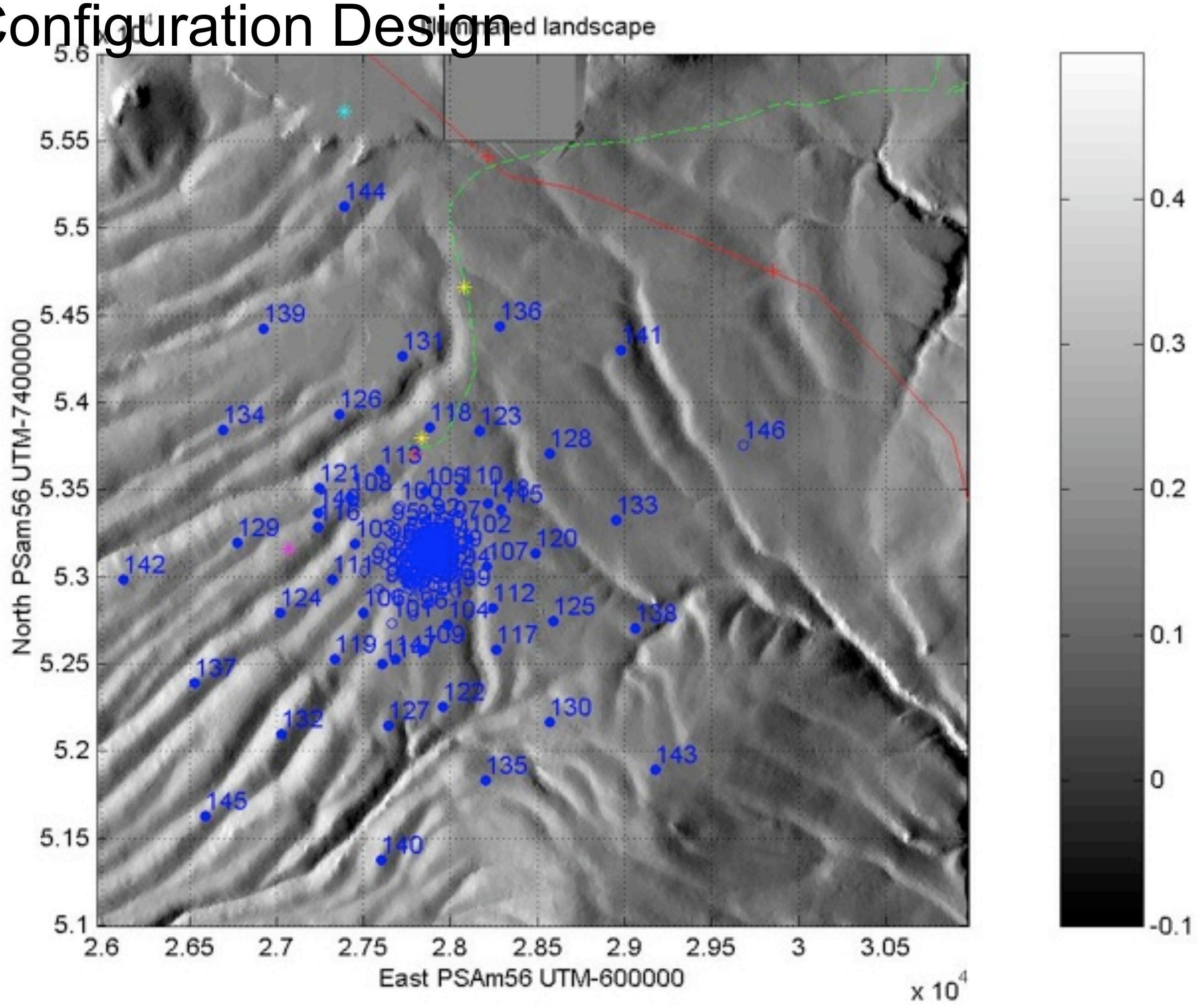
  - full scientific service

ALMA Science Specification in a Nutshell

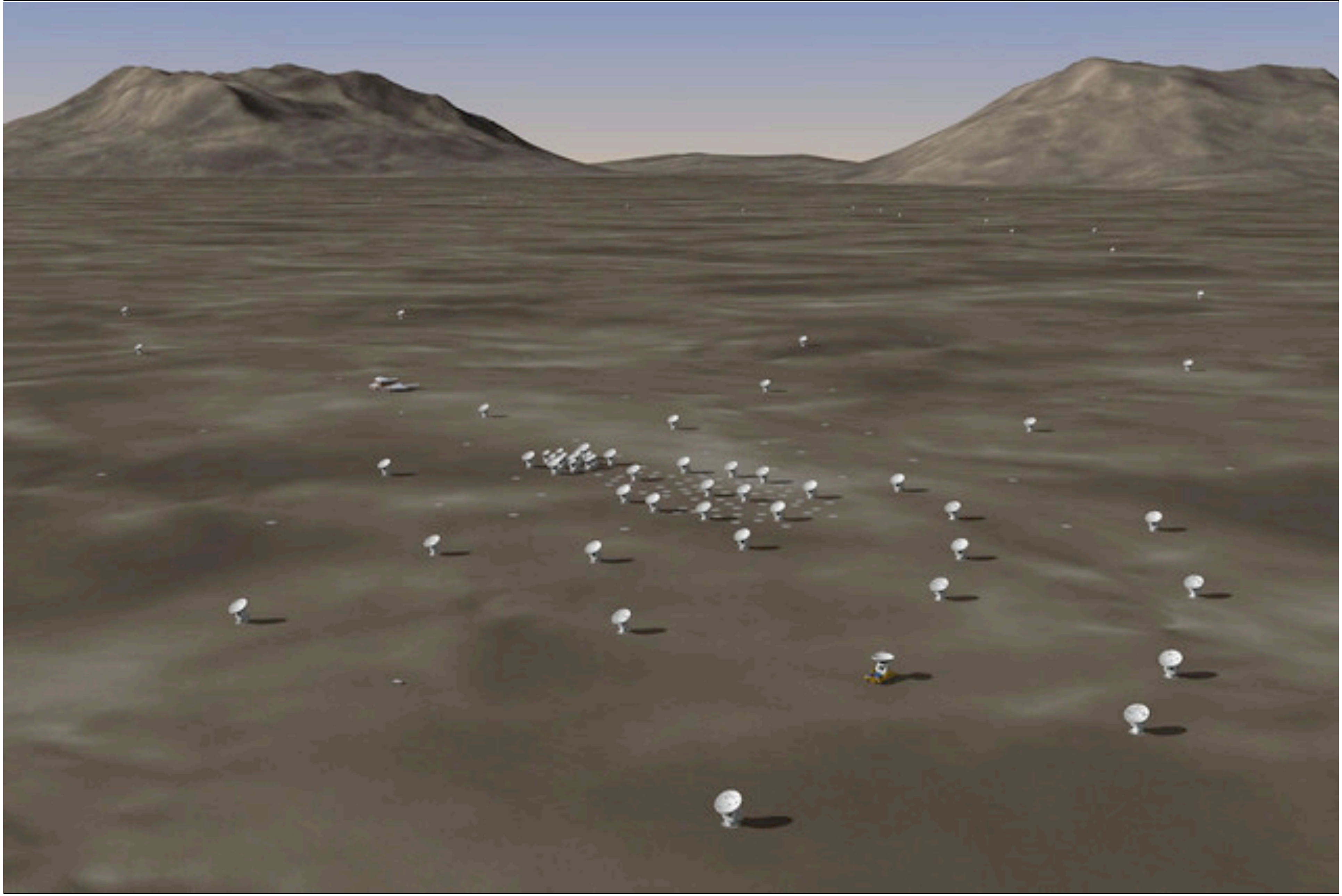
- Why two sub-arrays?
  - 12-m Array (50 x 12-m)
    - more collecting area to provide high sensitivity
    - reconfigurable to achieve an angular resolution of ~0.01”.
    - more baselines to provide better uv-coverage.
  - Atacama Compact Array (4 x 12-m + 12 x 7-m)
    - recover short spacing data, including single-dish (zero spacing) flux, to provide images with high fidelity, full-synthesis imaging.
    - (nearly) fixed configuration.

Antenna Pads at AOS

Configuration Design



Maximum Baseline 18km



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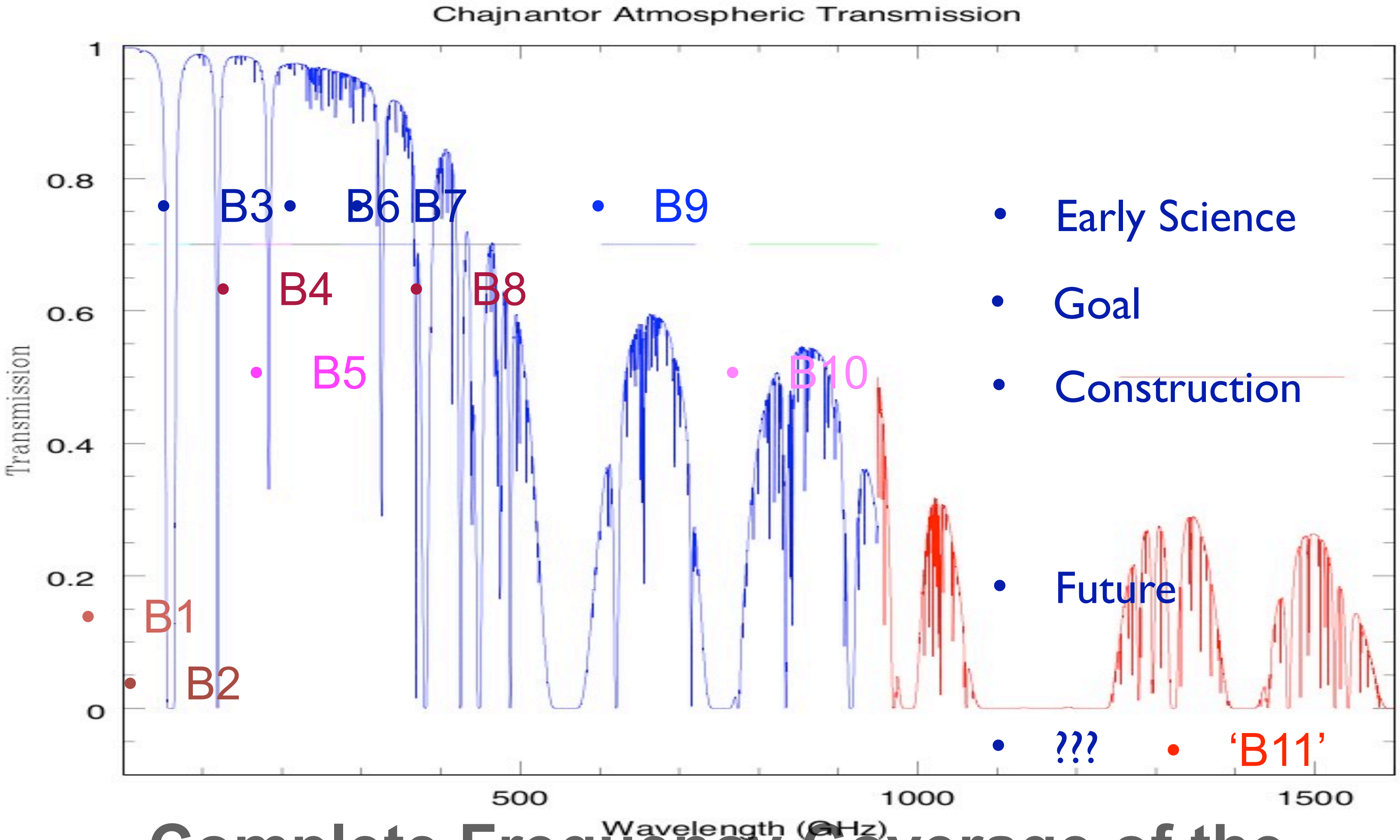
ALMA Bands and Transparency

slide by Al Wootten



Complete Frequency Coverage of the mm/submm atmospheric window

What is ALMA?

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  - sensitivity
  - (spatial) resolution (but do not forget about short/zero spacing)
  - spectral capability (overall wavelength coverage, simultaneous bandwidth, spectral resolution)
  - full scientific service, provided by Joint ALMA Observatory (JAO) and ALMA Regional Centers (ARCs) such as helpdesk, scientific pipeline, etc

ALMA Operation Service Facility (OSF)

(at 3000 m)

ALMA Operation Site (AOS) (5000 m)

ALMA Antenna Transporter

ALAM Timeline and Science Preparation

- Future Milestone
  - Start of CSV - beginning of 2010
  - Call for Early Science - spring/first half of 2011
  - Start of Early Science - fall/second half of 2011
  - Inauguration - late 2012
  - End of construction - 2013

ALAM Timeline and Science Preparation

- Minimum Requirements for the Start of Early Science
  - At least 16 12-m antennas with at least 3 bands
  - Synthesis Mapping of single fields
  - Antenna stations to cover the shortest spacings and out to at least 250 m
  - 5 correlator modes selected by ASAC
  - Calibration to a level comparable with existing mm-wave arrays
  - Software to support user's applications, preparation and execution of observations, and off-line data reduction
  - more than 1/3 of the usable time is available for Early Science observations

Transformational Performance

- ALMA improves
  - Sensitivity: 100x
  - Spatial Resolution: up to 100x
  - Wavelength Coverage: ~2x
  - Bandwidth: ~2x
    - Scientific discovery parameter space is greatly expanded!
- ***ALMA Early Science*** begins the transformation
  - Sensitivity: ~10% full ALMA
  - Resolution: up to ~0.4" (0.1" goal)

Science Opportunities!

ALMA
ATACAMA LARGE MILLIMETER ARRAY

- Dual-path collaborations in the ALMA project:
  – ALMA-J/T collaboration (since 2005)
  – ALMA-NA/T collaboration (since 2008)

- Observation time up to 55% every year!
  – Compete internationally and get whatever time you can!
  – It is a unique open-sky opportunity!!!
  – Our Advantage: Submillimeter Array…….

Comparign the power of (sub)mm telescopes

	ATCA	CARMA	SMA	PdBI	ALMA ES	ALMA full
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Tsys (freq)	350 K (100)	200 K (230)	140 K, 2640 K (230) (650)	200 K (230)	30 K, 70 K, 430 K (100) (230) (650)	

ALMA Early Science capability already surpasses other existing instruments!

Too good to pass!

by Tachihara

Final Remark

- ALMA is a powerful, complicated, and expensive machine, for a great purpose.
- While ALMA will provide great sensitivity and resolution, the science goals will also become much more demanding than now! Competition will be severe.
- It is important to conduct exercises in advance (NOW!) for formulating sensible and workable combination of sensitivity/resolution and observing strategy.

Thank you for your attention!