Atacama Large Millimeter/submillimeter Array

Mm/submm Astronomy in Latin America: Opportunities and Challenges

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IAR 50 years

In search of our Cosmic Origins

Flow of the talk

- Exploring the Submm/THz wavelength/frequency domain
  - Is late: the last EM range to be explored
  - Atmospheric impacts
  - Submm Generic Science topics

- From ALMA to LLAMA: ALMA and impact on LLAMA

- LLAMA: Opportunities and Challenges

Atacama Large Millimeter/submillimeter Array

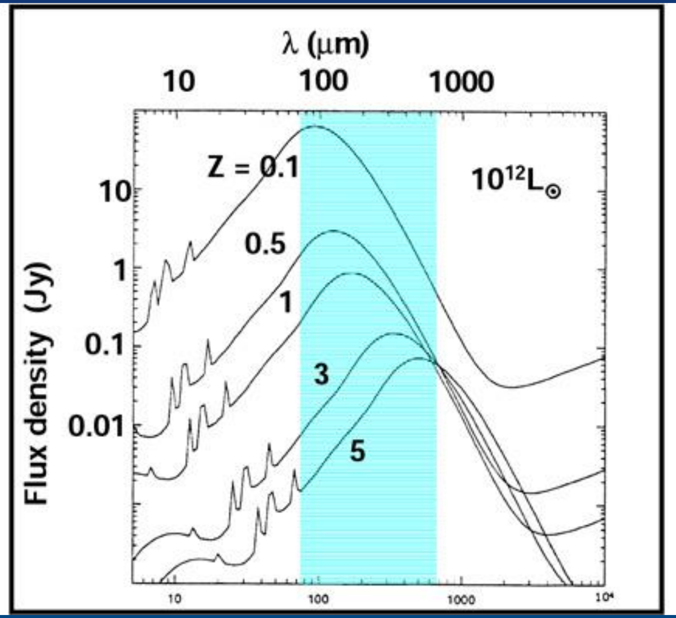
THz Astro-Science: the Cool Universe

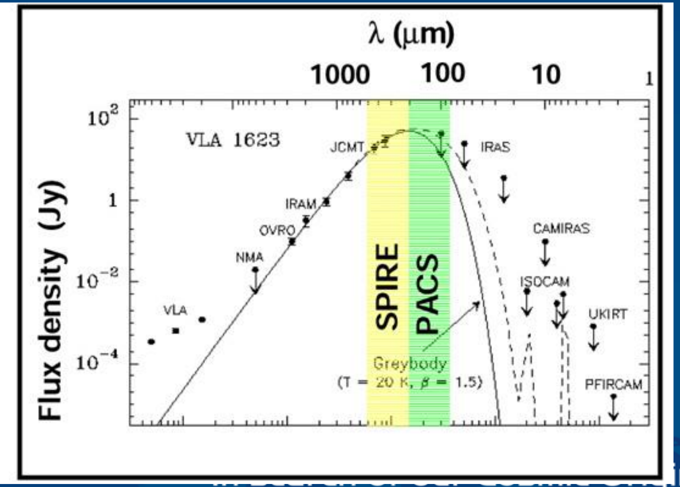
Spectral coverage for:
- Black-bodies 5-100 K
  - continuum radiation
  - dust grains (re-)radiating
- Gasses excitation 10-few100 K
  - Atomic/ionic lines
  - Molecular Universe

    a.o. water lines, CII, etc.
- IR gal & ISM SED peaks, out to high Z and Cosmic Background!

Emphasis:
- Formation and evolution of (first) galaxies & (first) stars/planets
- ISM physics & chemistry
- Solar system bodies

Effectively: **THE MOLECULAR UNIVERSE**

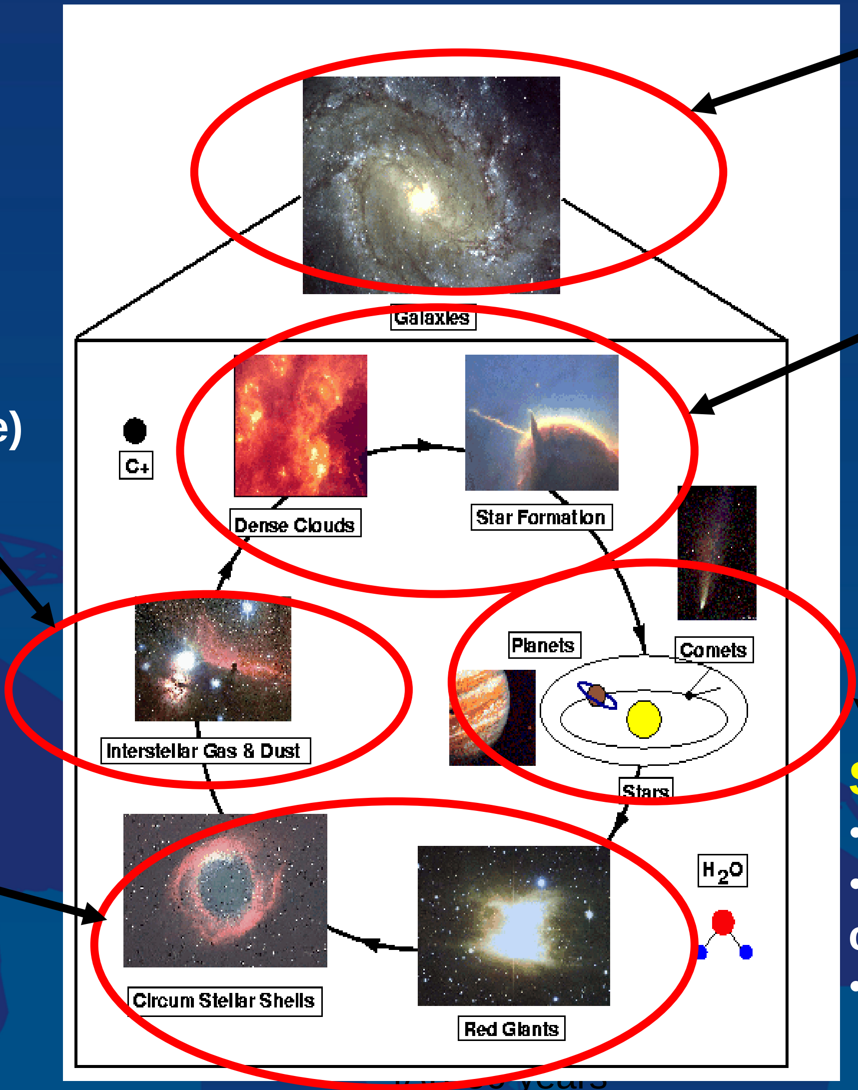




THz Science: Lifecycle of ISM and Stars: Star Formation & Evolution

ISM in the Milky Way:
- Structure
- Dynamics (pressure)
- Composition (gradients)

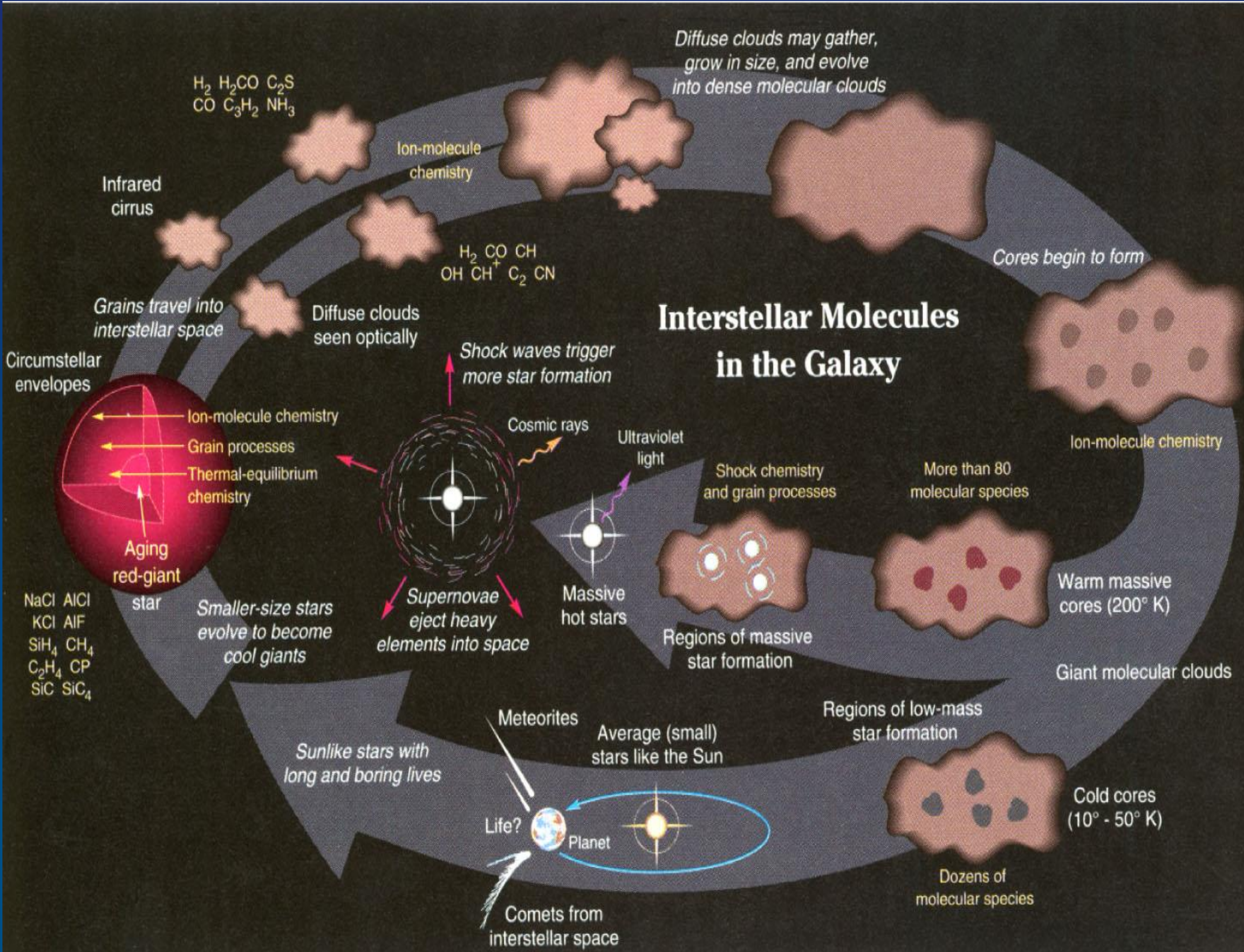
Late stages of stellar evolution:
- Winds
- Shells
- Asymmetries
- Composition



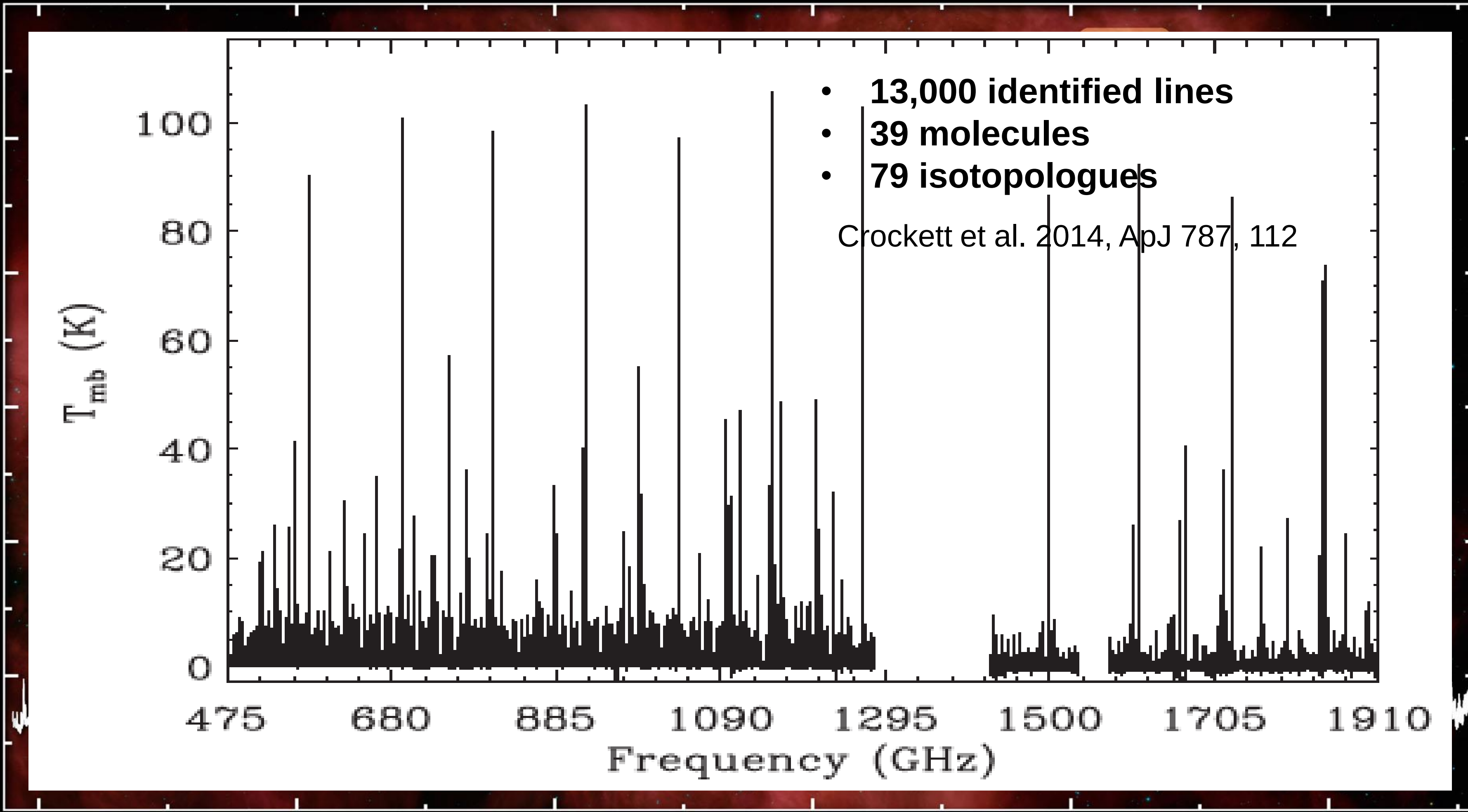
ISM in Galaxies:
- Normal galaxies
- Physical properties of star-forming ISM

Dense cores and star-formation:
- Temperature, density structure
- Dust properties
- Stellar IMF

Solar System:
- Water in Giant Planets
- Atmospheric chemistry
- Water activity and composition of comets



Interstellar Molecules in the Galaxy
Diffuse clouds may gather, grow in size, and evolve into dense molecular clouds
H_2 H_2CO C_2S CO C_3H_2 NH_3
Ion-molecule chemistry
Infrared cirrus
H_2 CO CH OH CH^+ C_2 CN
Cores begin to form
Grains travel into interstellar space
Diffuse clouds seen optically
Shock waves trigger more star formation
Circumstellar envelopes
Ion-molecule chemistry
Grain processes
Thermal-equilibrium chemistry
Aging red-giant star
Cosmic rays
Ultraviolet light
Shock chemistry and grain processes
More than 80 molecular species
Ion-molecule chemistry
$NaCl$ $AlCl$ KCl AlF SiH_4 CH_4 C_2H_4 CP SiC SiC_4
Smaller-size stars evolve to become cool giants
Supernovae eject heavy elements into space
Massive hot stars
Regions of massive star formation
Warm massive cores (200° K)
Giant molecular clouds
Meteorites
Average (small) stars like the Sun
Regions of low-mass star formation
Sunlike stars with long and boring lives
Life?
Planet
Cold cores (10° - 50° K)
Dozens of molecular species
Comets from interstellar space



HIFI Spectrum of Water and Organics in the Orion Nebula

E. Bergin

Why Submm/THz is behind w.r.t. Visible/NIR

1) Advances in THz Astronomy strongly coupled to progress in THz technology development

2) THz technology was/is behind as compared to visible, infrared, radio, x-ray.

Reasons:

- Low energy photons; **deep cooling needed**
- λ/D requires large apertures (factor 1000)
- Atmospheric transmission problematic (water vapour)

- No defense development, radar, ir vision,
- Little medical research support (now a bit)
- Not much consumer technology (like ccd) (now phone stuff)
- <u>BUT::: quantum computing needs!!!</u>

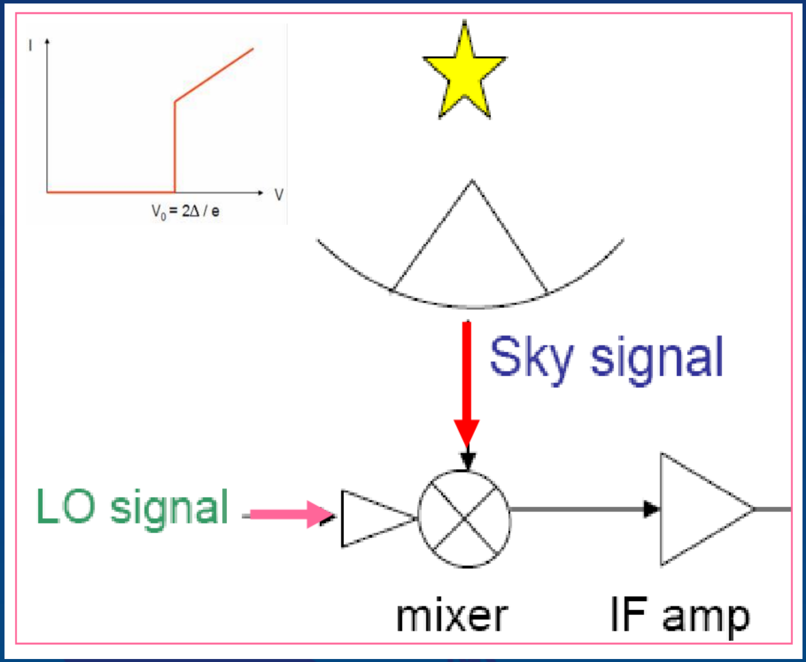
cont.

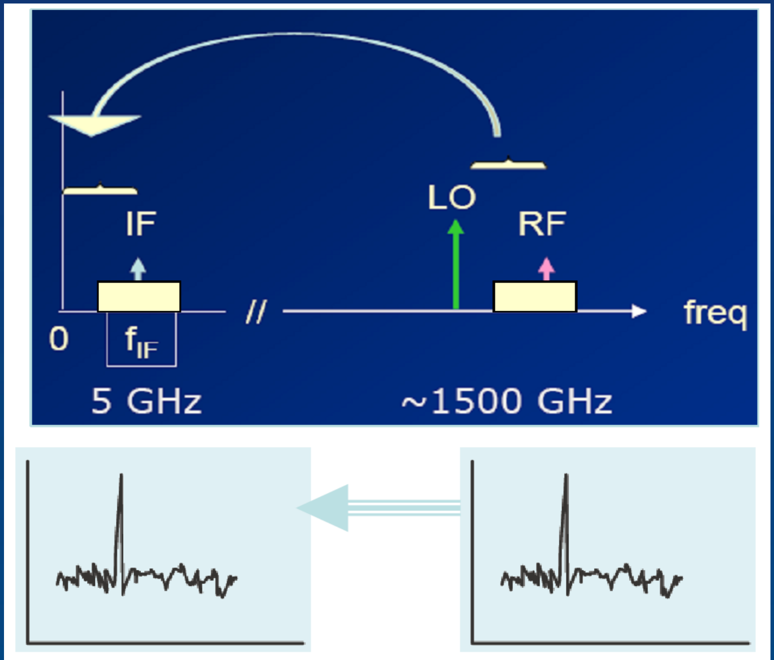
- THz regime in between Optical and Radio ranges >>> Quasi-optical techniques
- In general THz receiver equipment is complex and involves wide diversity of techniques: Optical, RF and Microwave techniques, Nano tyechnology, Fine Micro-Mechanical, Superconductivity, Semiconductors, Cryo-cooling, Thermal stability, High speed digital, Unusual materials
- So: a paradise for those who love technology science
- It took a while to go from:

    - From single pixel bolometers to arrays

    - From video (bolometer) detection to sensitive heterodyne receivers for high frequencies (quantum optics was late)

Hetrodyne detection: signal frequency range translation





The heterodyne principle in action. In the left panel the sky signal is combined with the LO signal in a non-linear mixing element (with IV-curve given in the top left). The output signal is down converted and can be amplified electronically. In the right panel it is shown that the down converted signal has the original information content, but now at much lower frequency.

- The SIS revolution: In 1977-78:
  - For 100 GHz-1200 GHz

with T.G. Phillips, P. Richards, J. Tucker, etc

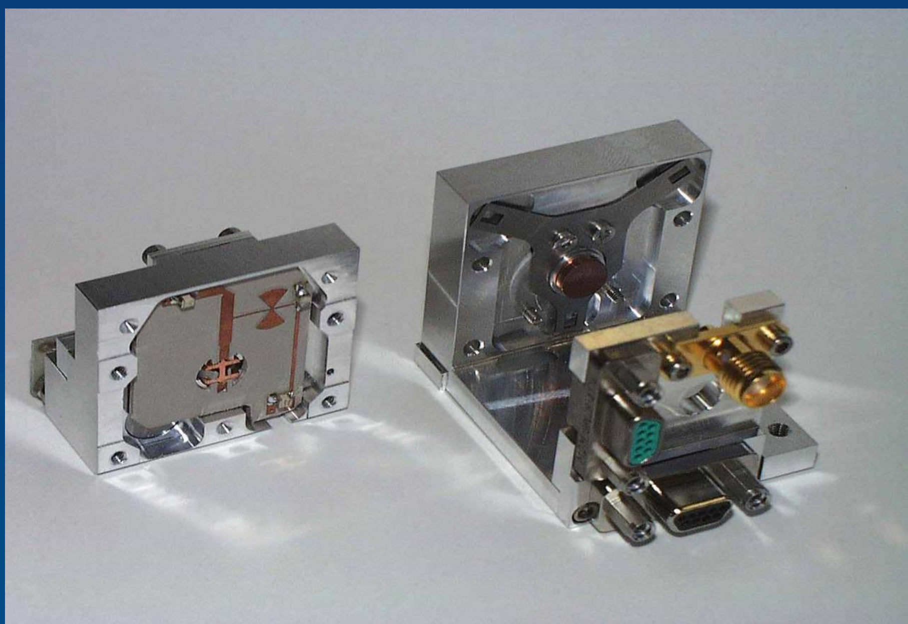
- The HEB revolution,In 1980:

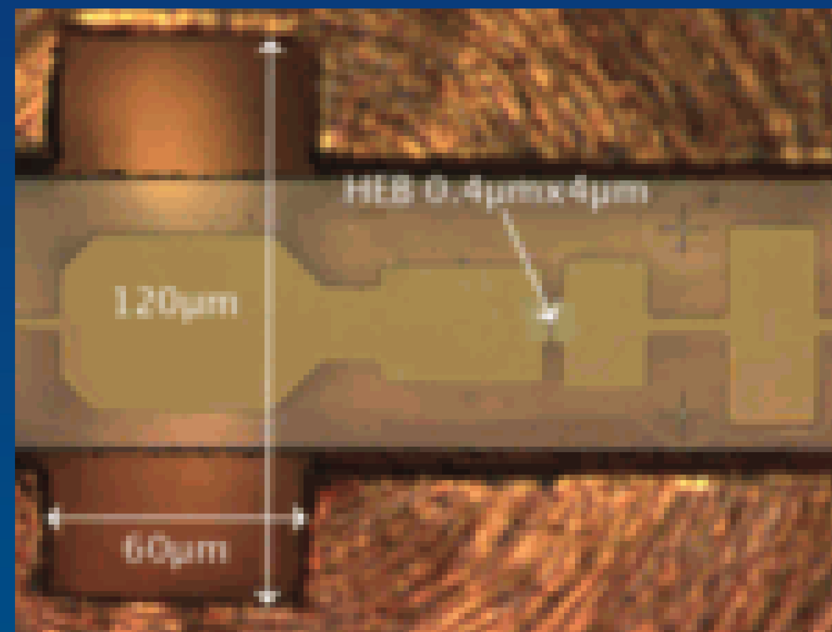
For 1000 GHz – 6000 GHz,

E. Kollberg, Yngvison, Goltschman, etc..

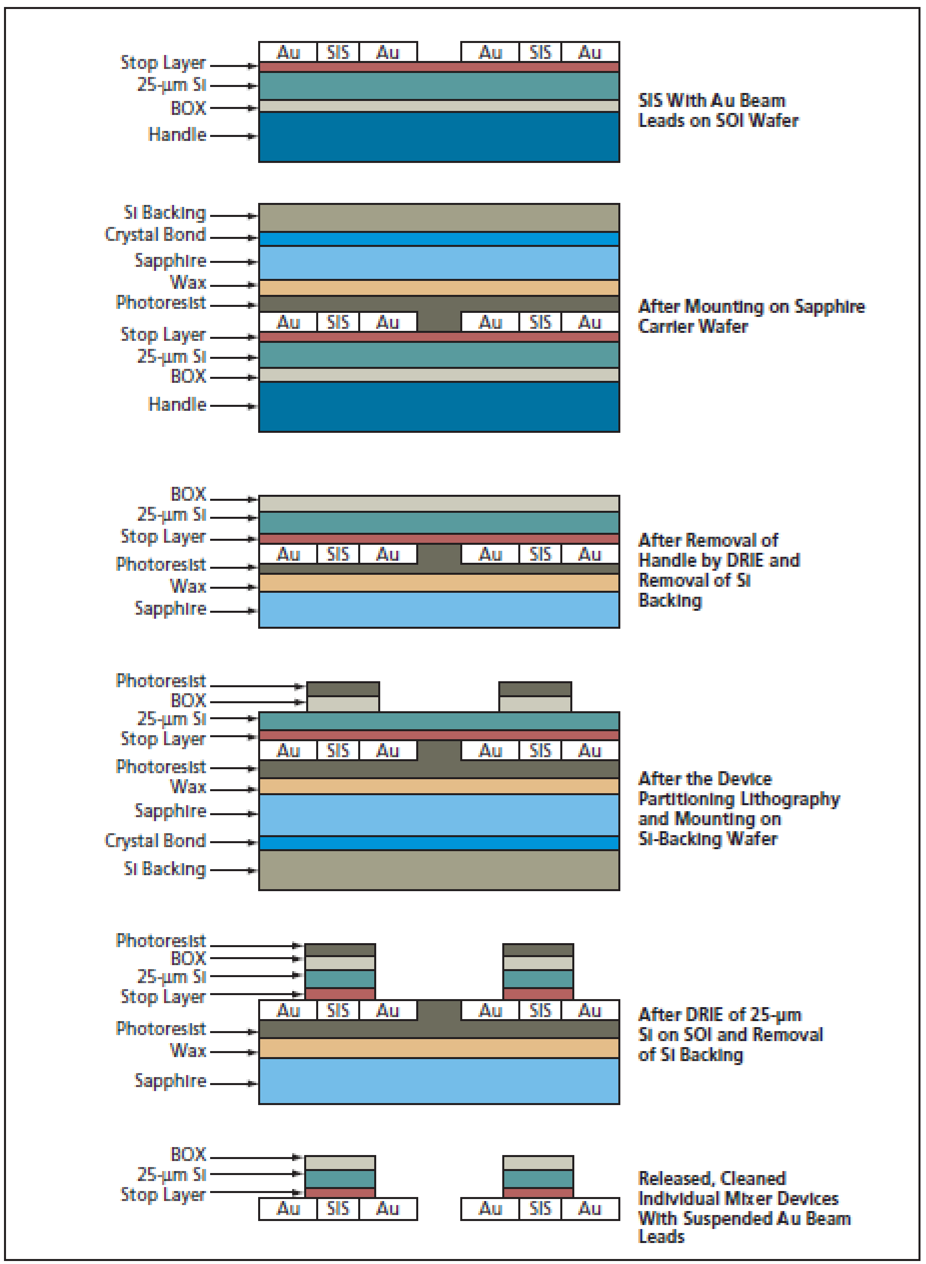
Sensitive Heterodyne detection/mixer components

Mixers: SIS (100 GHz – 1200 GHz and HEB (>1 THz)





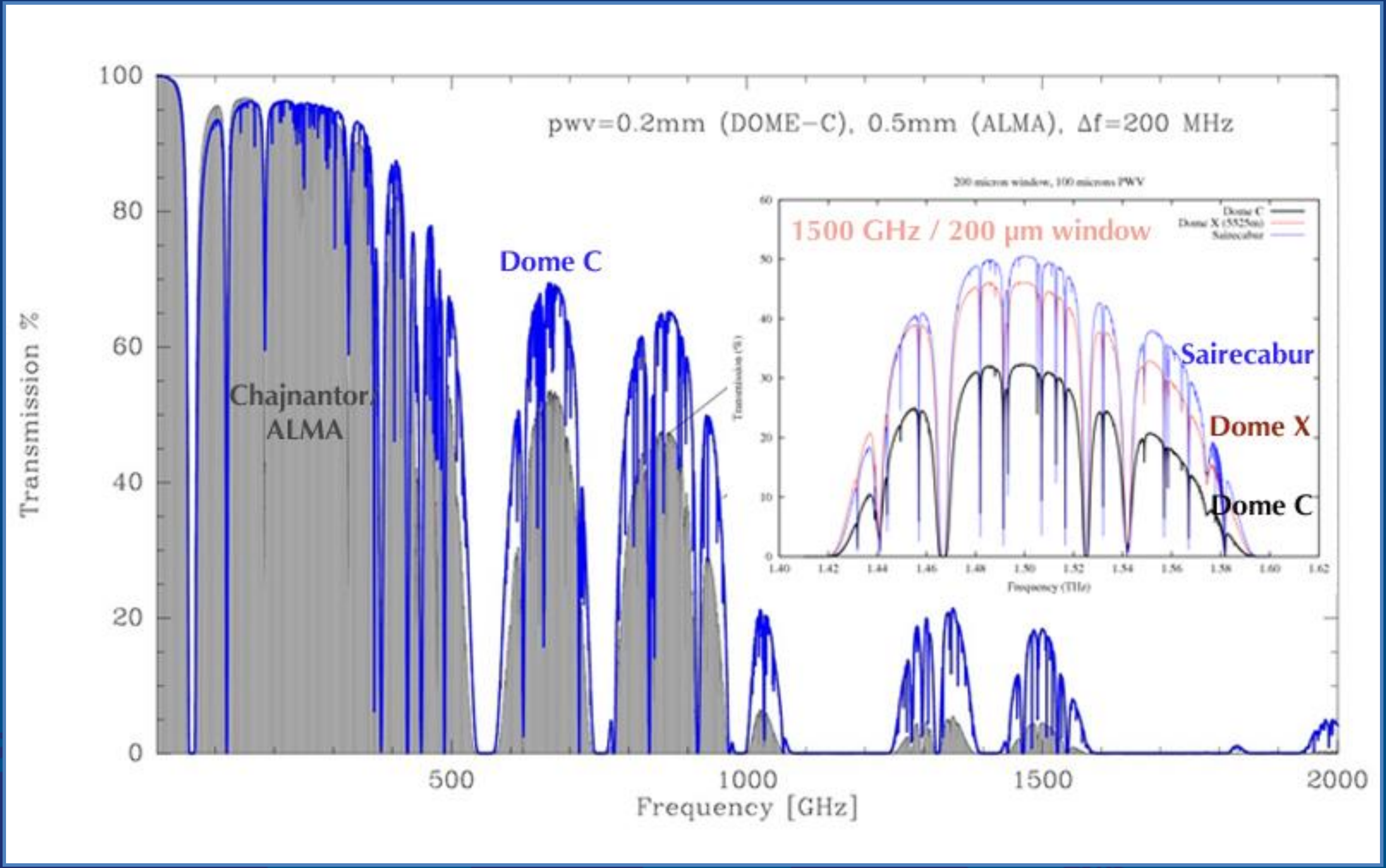
(SRON and JPL



Complicated SIS fabrication process with nano technology

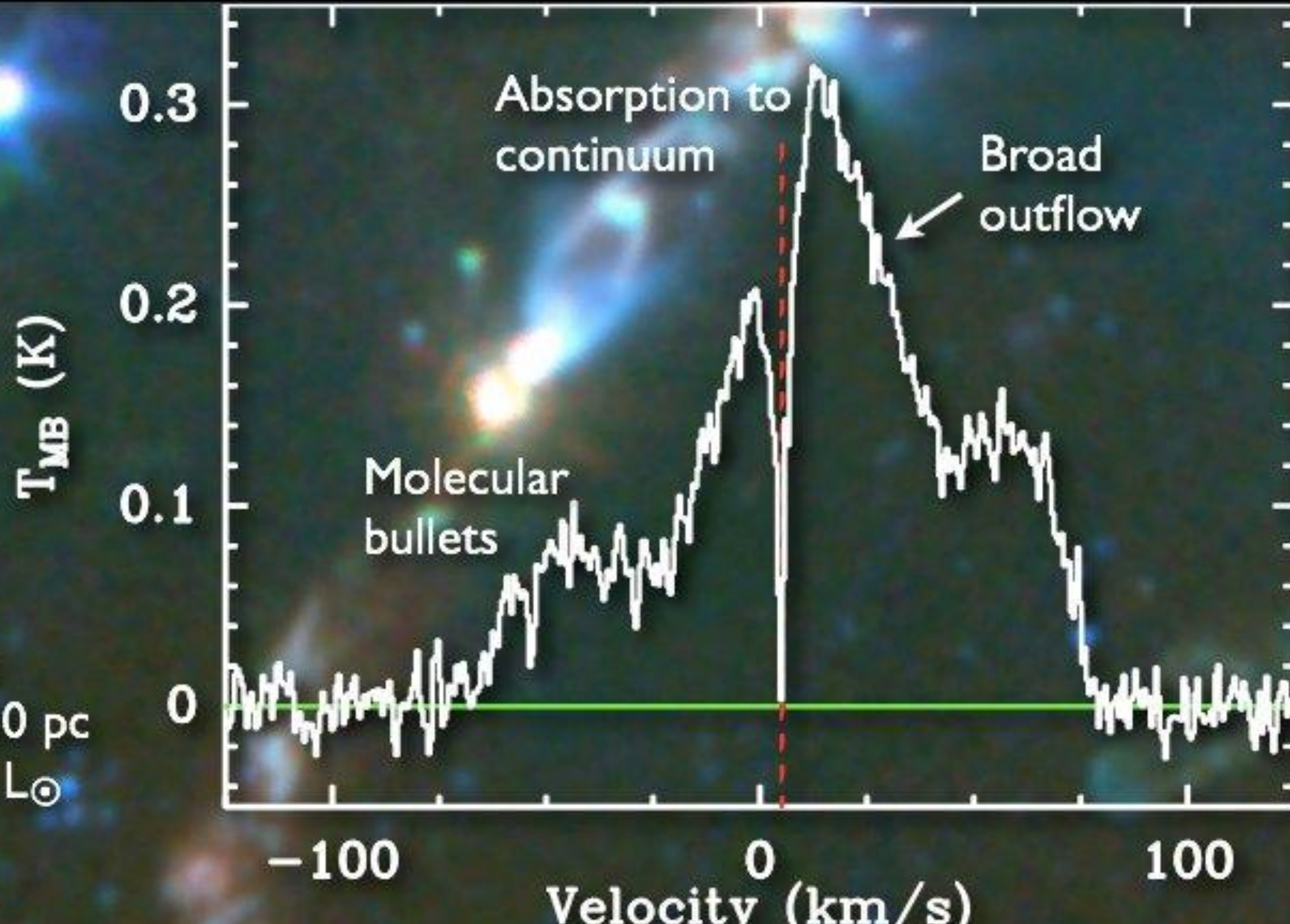
(JPL)

Atmospheric Transmission: Groundbased--Space Observatories Interaction



Herschel and Planck launched with Ariane-5, May 2009

Water bullets in a low-mass protostar



L1448:
D ~ 250 pc
L ~ 11 $L_\odot$

H_2O bullets in protostellar jet vs. broad, shocked gas along outflow walls

Kristensen et al. in prep.

Ortho- to Para- Ratio in Water Molecules Towards 3 Sources Studied in Absorption with Herschel HIFI

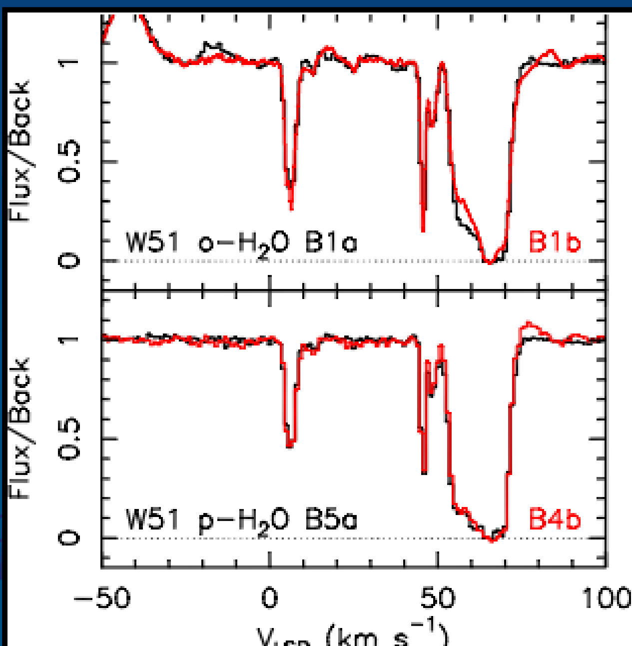
Paul Goldsmith, Darek Lis, Raquel Monje, David Neufeld, Tom Phillips, and Maryvonne Gerin

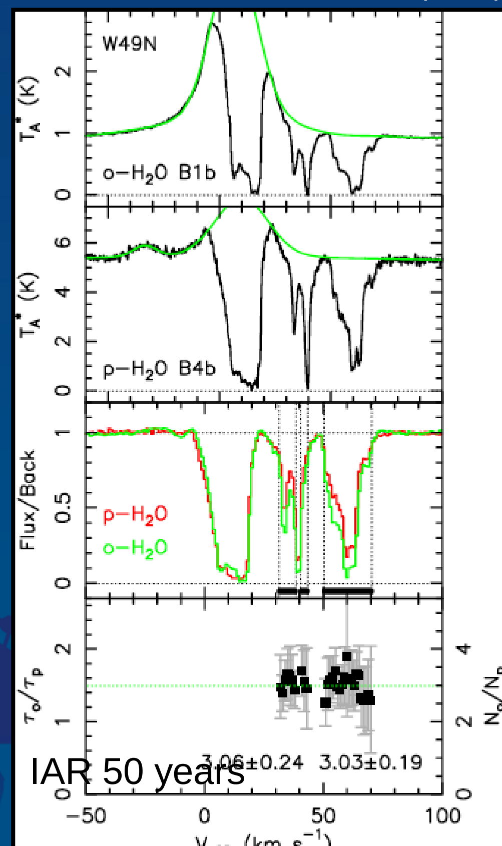
The biggest challenge in determining OPR is to fix the background level, which may include emission from known and unknown lines as well as dust.

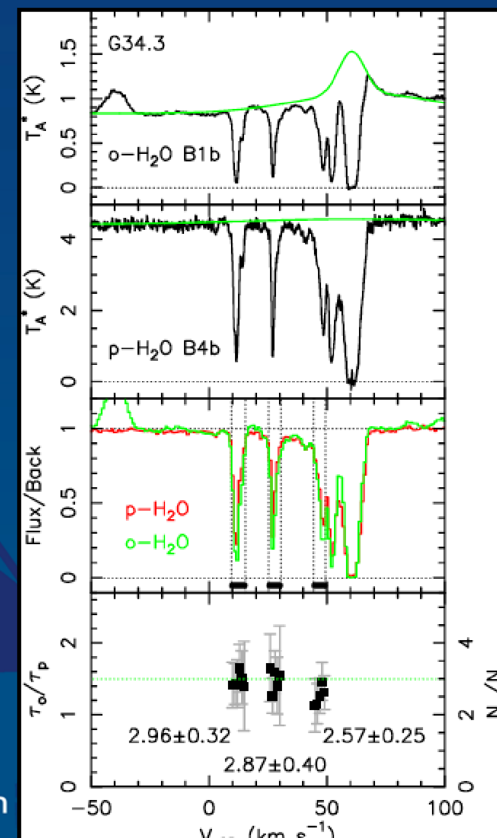
We are comparing results from 1669 GHz 1_{01}-2_{12} as well as 557 GHz 1_{01} to 1_{10} o-H_2O lines. Higher frequency data have higher noise but stronger dust continuum and lower line density.

OPR ~ 3 within uncertainties (TBC)

-H_2O 557 GHz line observed with band 1a and with band 1b show excellent agreement. So do p-H_2O 1113 GHz line observed with band 4b and with band 5a.







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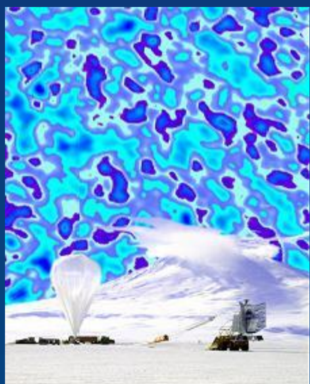
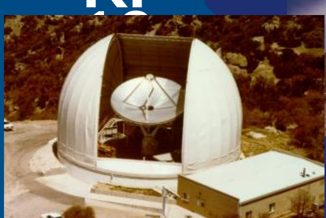
Evolution in Single Dish Ground Based Submm/mm Observatories



Submm/Mm
Balloon experiments

KP



CSO

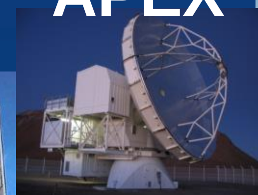
JCMT

PdV

SEST

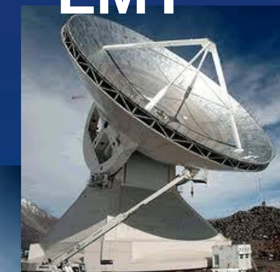
HH

APEX



SPT

LMT



LLAMA

PM: NANTEN, ASTE, etc.

Evolution in Submm/mm Interferometres; before 2012

IRAM PdB (NOEMA)
6 **(12)** antennas,
each 15 m in diameter

ATCA : 6 antennas each 22 m in diameter

SMA
8 antennas each 6 meters in diameter

CARMA

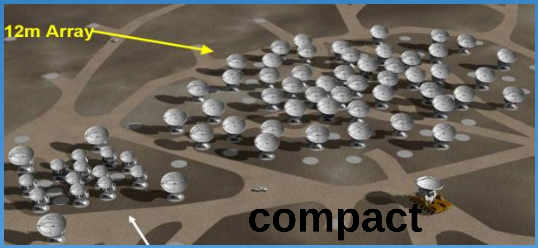
- 6 Antennas each 10.4 m. in diameter. (OVRO)
- 9 Antennas each 6.1 m. (Hat Creek)
- 8 Antennas each 3.5 m. in diameter. (SZA)

NRO: 6 antennas each 10 metres in diameter

Atacama Large Millimeter/submillimeter Array

ALMA:

A partnership among Europe, North America and East Asia (in cooperation with the Republic of Chile) to build and operate:



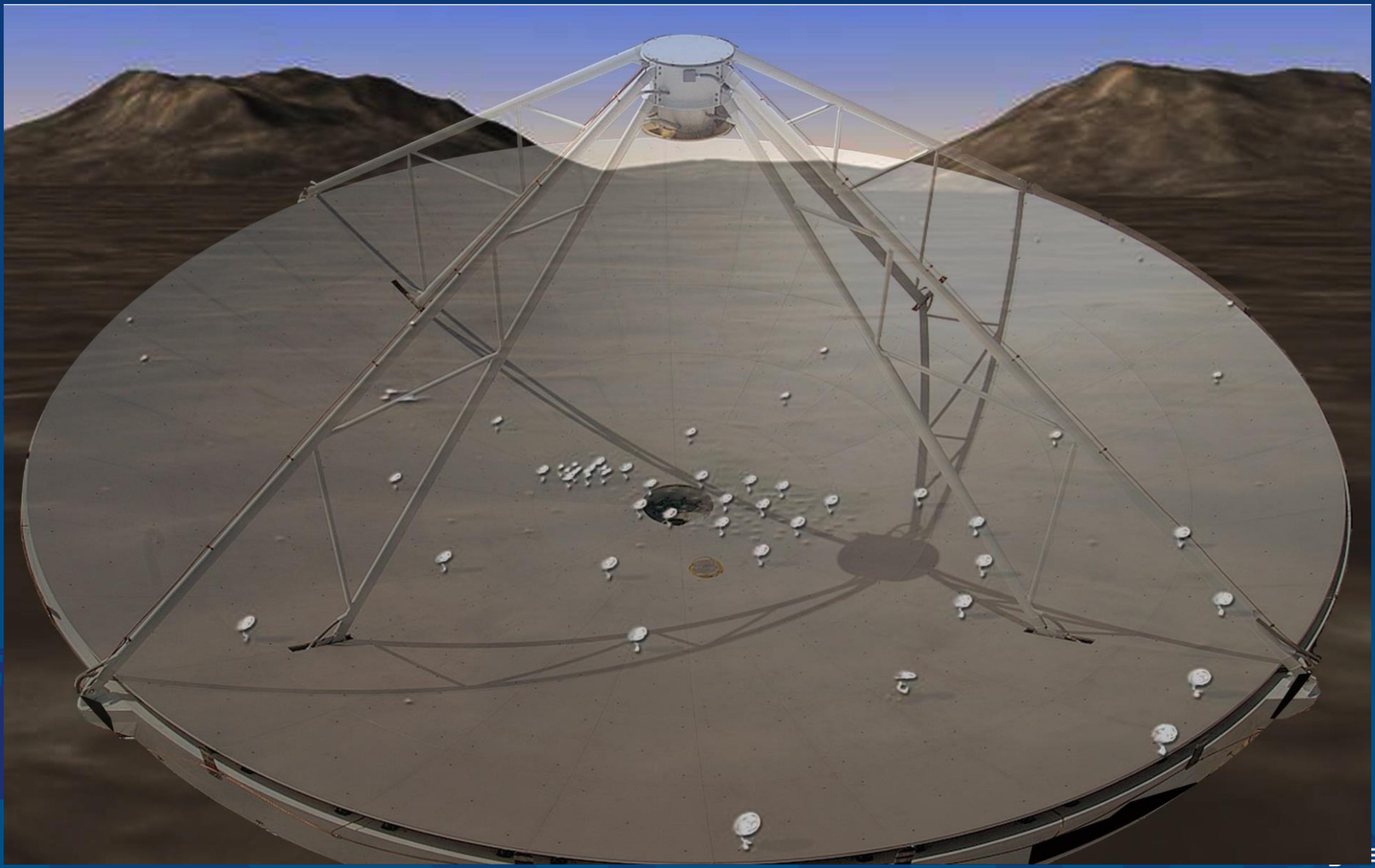
An array of **66 antennas, in *aperture synthesis*** *,as a* “zoom telescope”

At 5000m

Remotely operated from OSFControl room

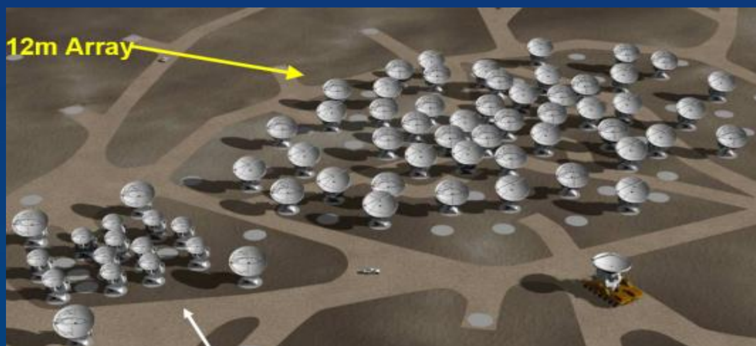
ALMA is presently the largest astronomical ground-based project
It started Early Science 30 September 2011, Inauguration March 2013,
Now in full operations.

ALMA synthesized beam



ALMA: some characteristics

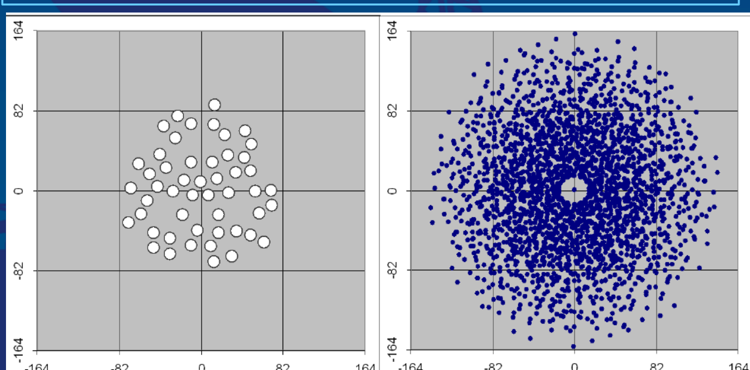
Speed and Configurations



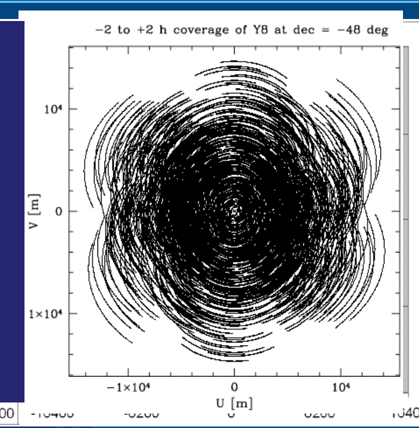
Most extended configuration –
Note that scale is 100 x larger than on previous slide

ACA

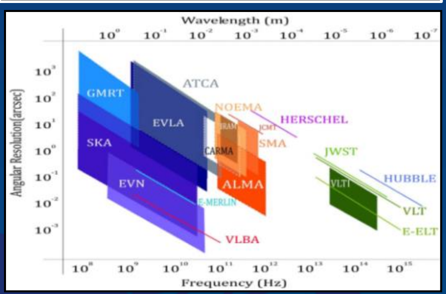
Most compact configuration –
Left: Antennas,
Right: snapshot UV coverage

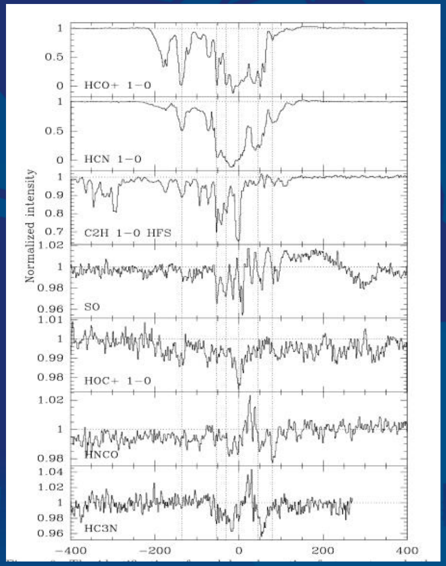


UV coverage of most extended configuration, <u>including</u> earth rotation: 4 hours of observation



What makes ALMA in demand
ALMA Science Capabilities:



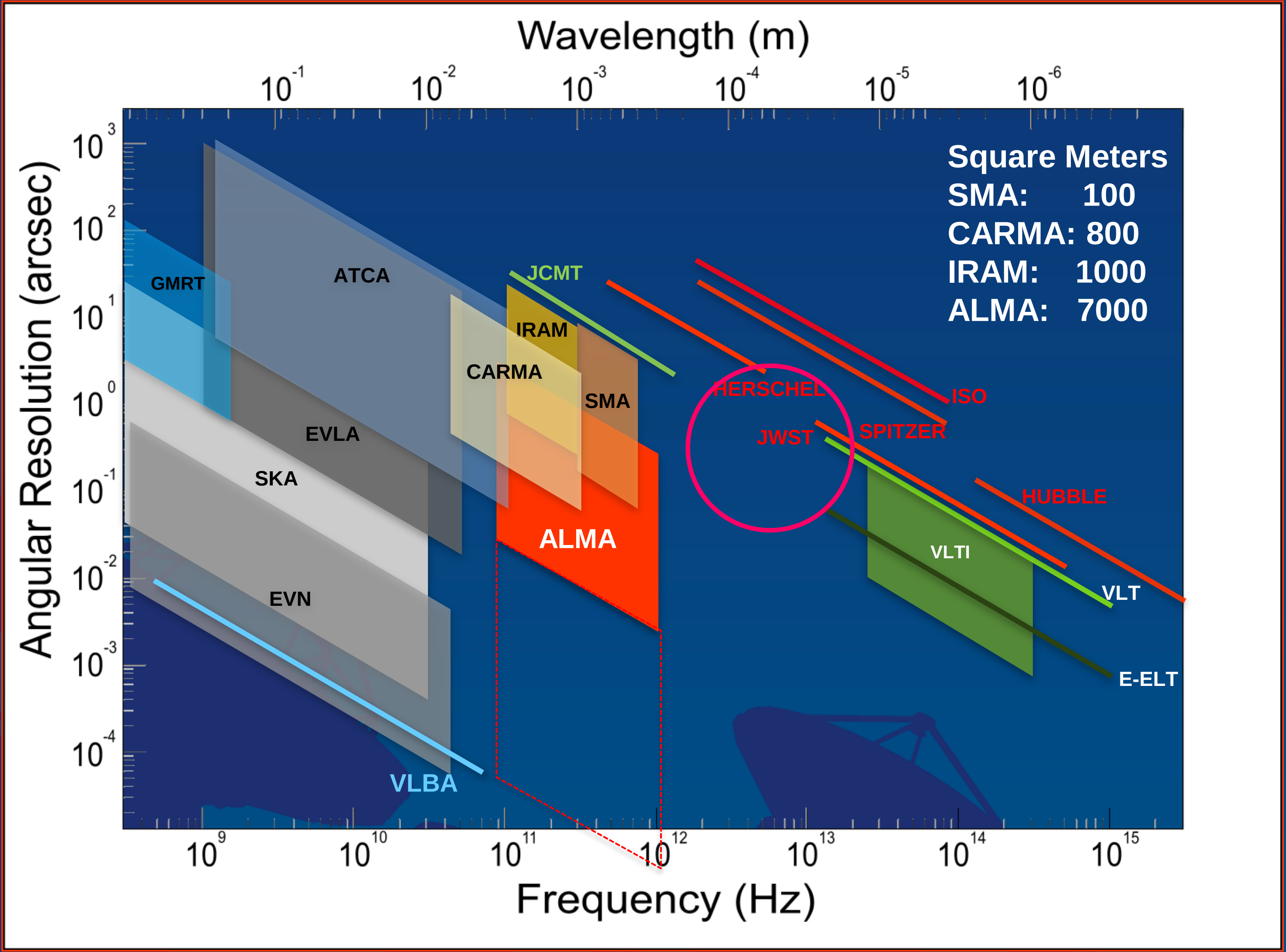


Angular Resolution:

- ~8 times better that Hubble ST
- ~10-100 times better than current mm interferometers
- *Spectral resolution:* sub-Km/s (heterodyne techniques)
- *Sensitivity (Speed)*
- : large increase surface: 10 -100 times
  - 7000m^2 collecting area; receivers
  - 6 *μ Jy/beam in 1 hour;*
  - *1.1 m Jy/beam in10 hours. spectral:*

IAR 50 years

Filling the FIR/Submm angular resolution gap



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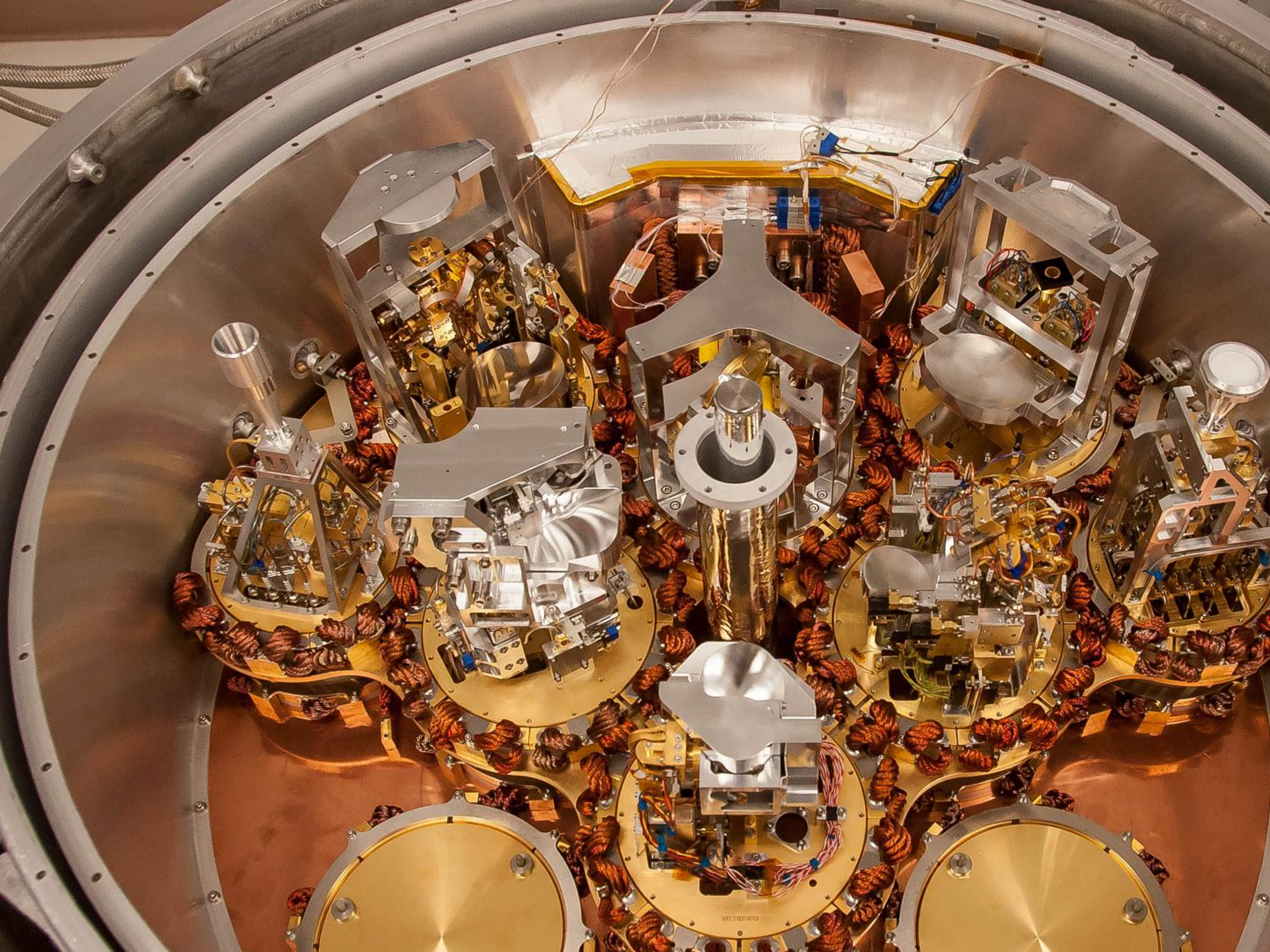
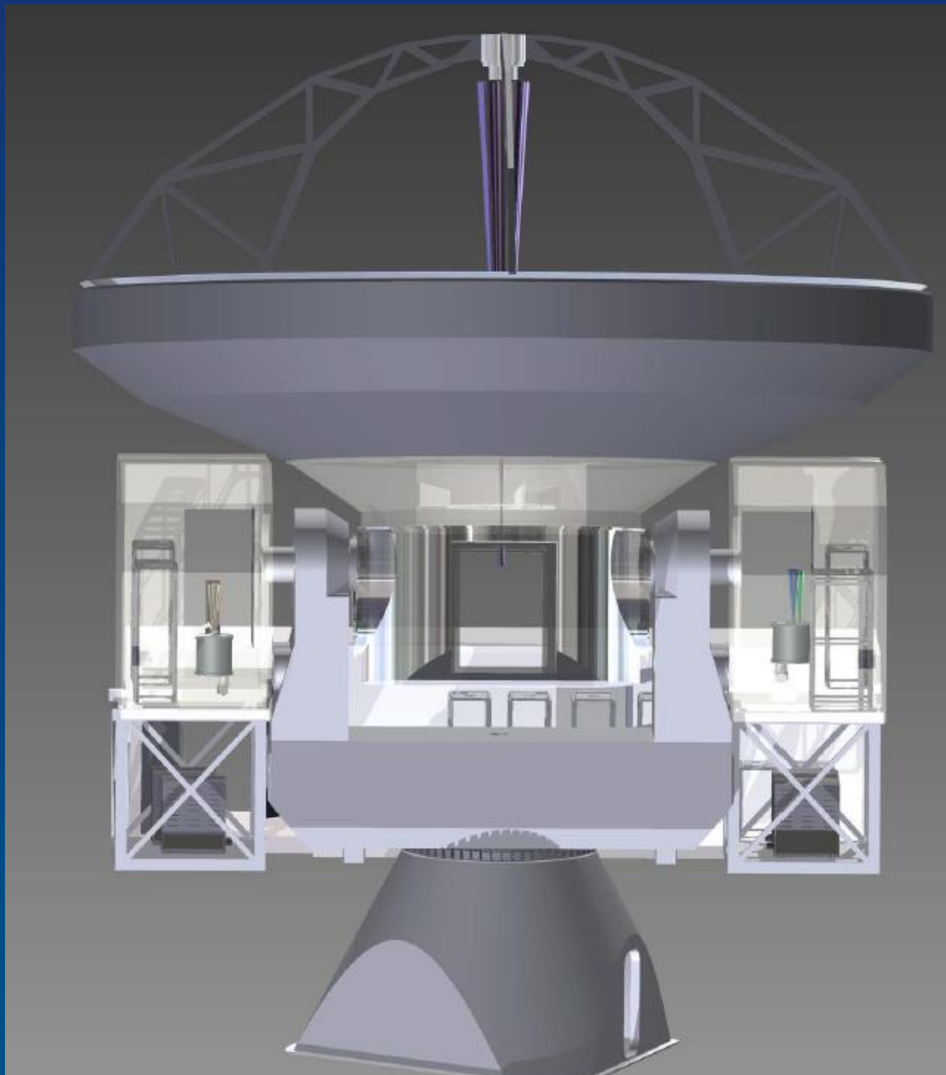
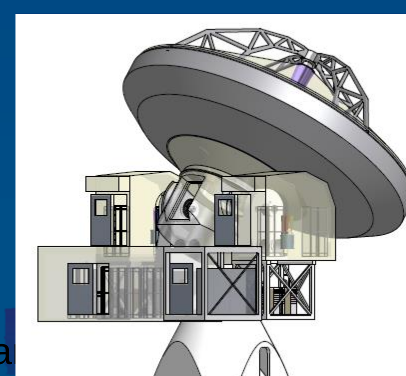


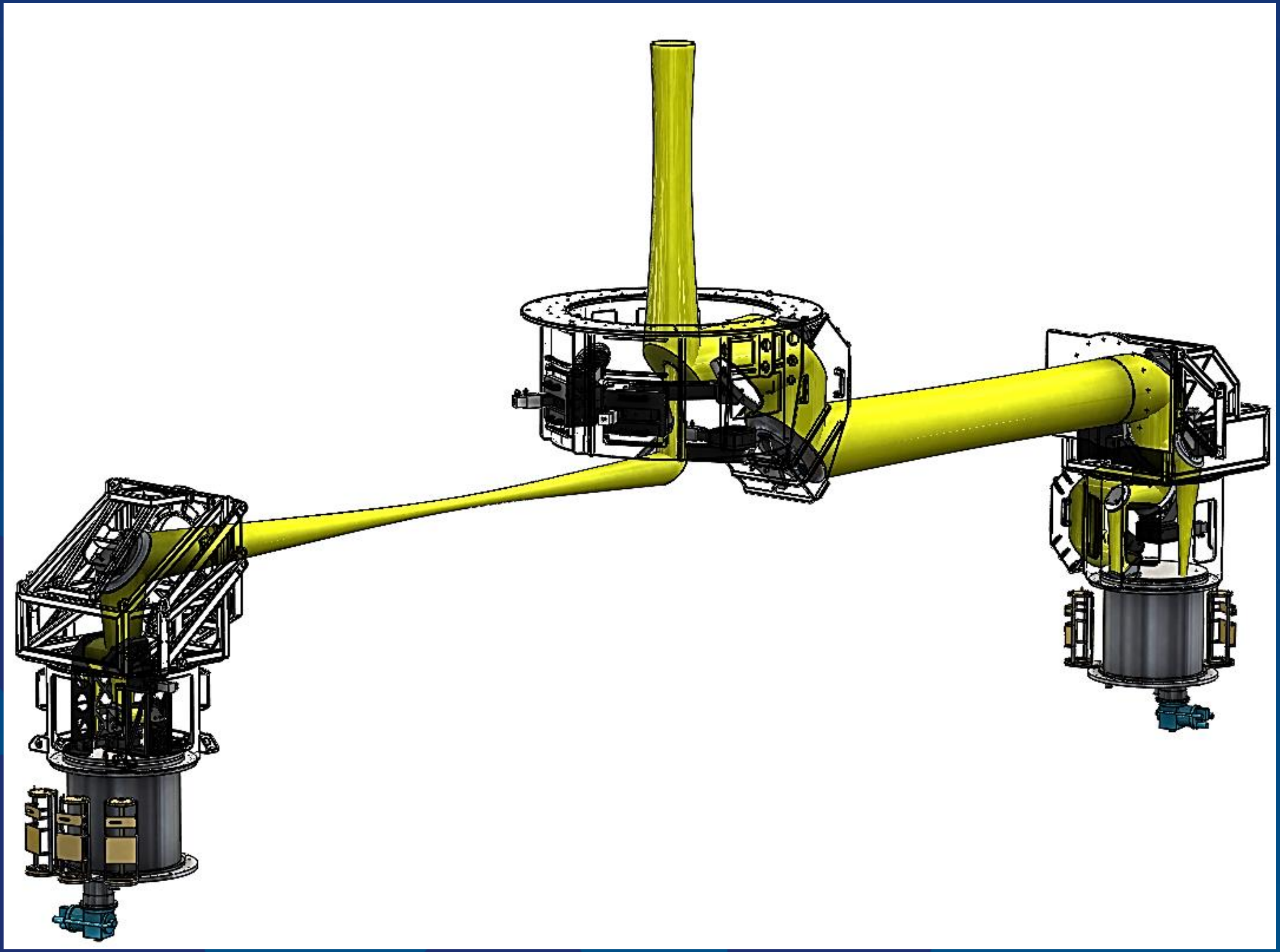

LLAMA



LLAMA: ALMA type antenna
but
with two Nasmyth Foci/Cabins (APEX)

- First Light Receivers:Bands 5, 9
- Routine Receivers 1st generation:
  a) Band 6 (EHT)
  b) Bands 3, 1, etc
- Bolometer arrays: various possible "second generation"





IAR 50 years

LLAMA Schedule

- Heavily dictated by start site works (road,foundation,power,etc.
- Antenna acceptance at factory in May (VERTEX)
- Agreements/purchases for Bands-5 and 9 in place; + training (NOVA)
- Cryostat (1) agreements/purchase ready (NAOJ)
- Plan for additional electronics ready; order is waiting
- Plan for Spectrometer ready; order is waiting
- Plans for calibration and WVR ready. order is waiting (U.Conc.)

In optimistic case (personal guesses):
Start site bidding and works: 15 April
Start integration antenna: 1 October
Start antenna slew 1 Jan. 2017
Start Pointing and Holography 1 Febr. 2017
Start Commisioning Observations: 1 June 2017
Start “Routine” Observationss

ALMA ⟷ LLAMA
Science

Science programs:

1) EHT participation

2) More Mm VLBI in Latin America
   More LA antenna's: LLAMA with 3 more antenna's
   CAT for band-1?; CSO?; ??

3) ALMA Pilot programs: LLAMA beam is ALMA's field

4) ALMA archive for LLAMA scientists

A fiber between LLAMA and ALMA very feasible

ALMA ⟷ LLAMA Technique

Technical Heritage provided by ALMA:

- ACS= ALMA Common Software
- CCA and WCA = Cartridges = Frequency bands as in ALMA
- M&C = Monitoir and Control H/W and F/W
- Use of ASTE (test) cryostat
- VERTEX/APEX experience in antenna, instrumentation, documentation,etc
- ALMA experience in antenna, instrumentation, documentation and people
- Connection with UdChile that is already using the ALMA-tech bandwagon

Opportunities and challenges

- There is a genuine interest in the astro-community for LLAMA
  - Test antenna
  - As camera for S-Z work, etc..
  - No other new mm antenna's planned

- ALMA is and can be more as a flywheel for technology/science
  - With ALMA a flying start for LLAMA possible
  - Connecting to EHT is stimulating

- Can we create a young(er) technology team for LLAMA?
- Can we expand LLAMA with more antennas?

ALMA

Best wishes to IAR
For next 50 years

Atacama Large Millimeter/submillimeter Array

IAR 50 years

In search of our Cosmic Origins

IAR 50 years