Millimeter/submillimeter Instrumentation at ALMA

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ALMA Array Maintenance Group
For the
IUCAF 4th School on Spectrum Management

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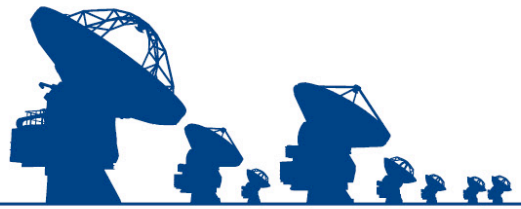
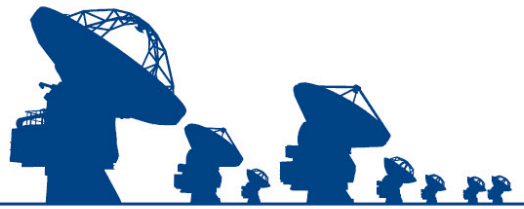


1) Scientific Drivers

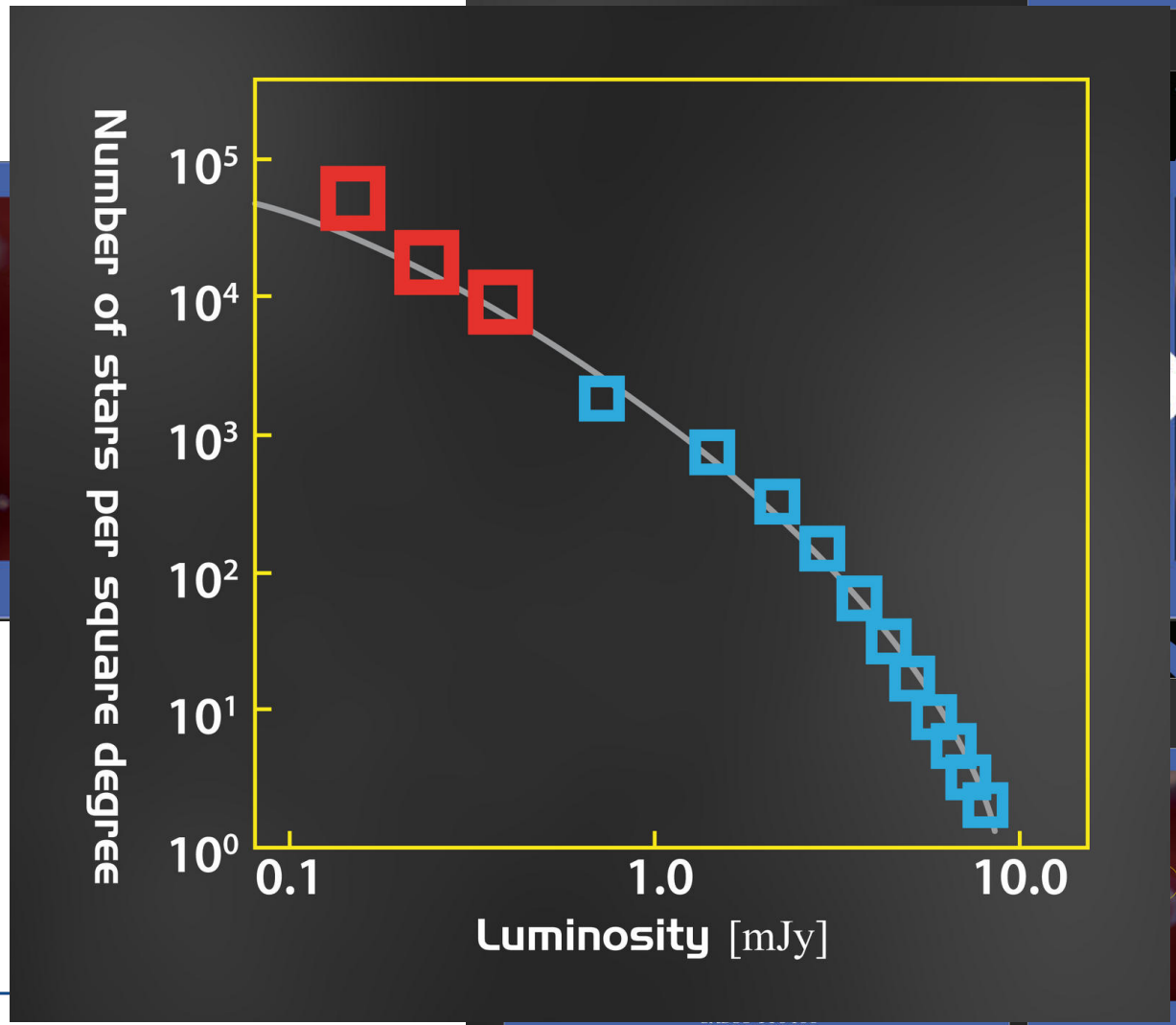
ALMA is a multi purpose facility.

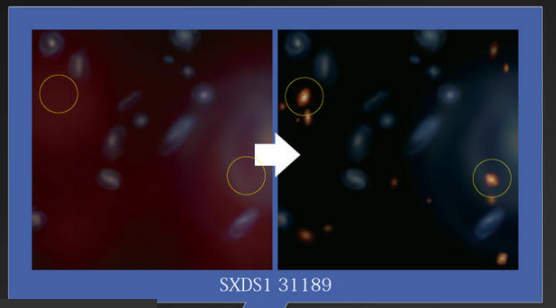
1. Cosmology and Extragalactic
2. Galaxy Evolution
3. Star formation, Molecular Clouds and Astrochemistry
4. Stellar evolution and our Sun
5. Solar System

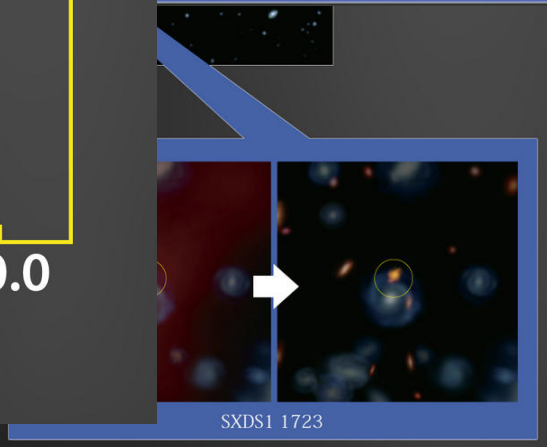


Cosmology and Extragalactic (the high redshift universe)

Science Categories

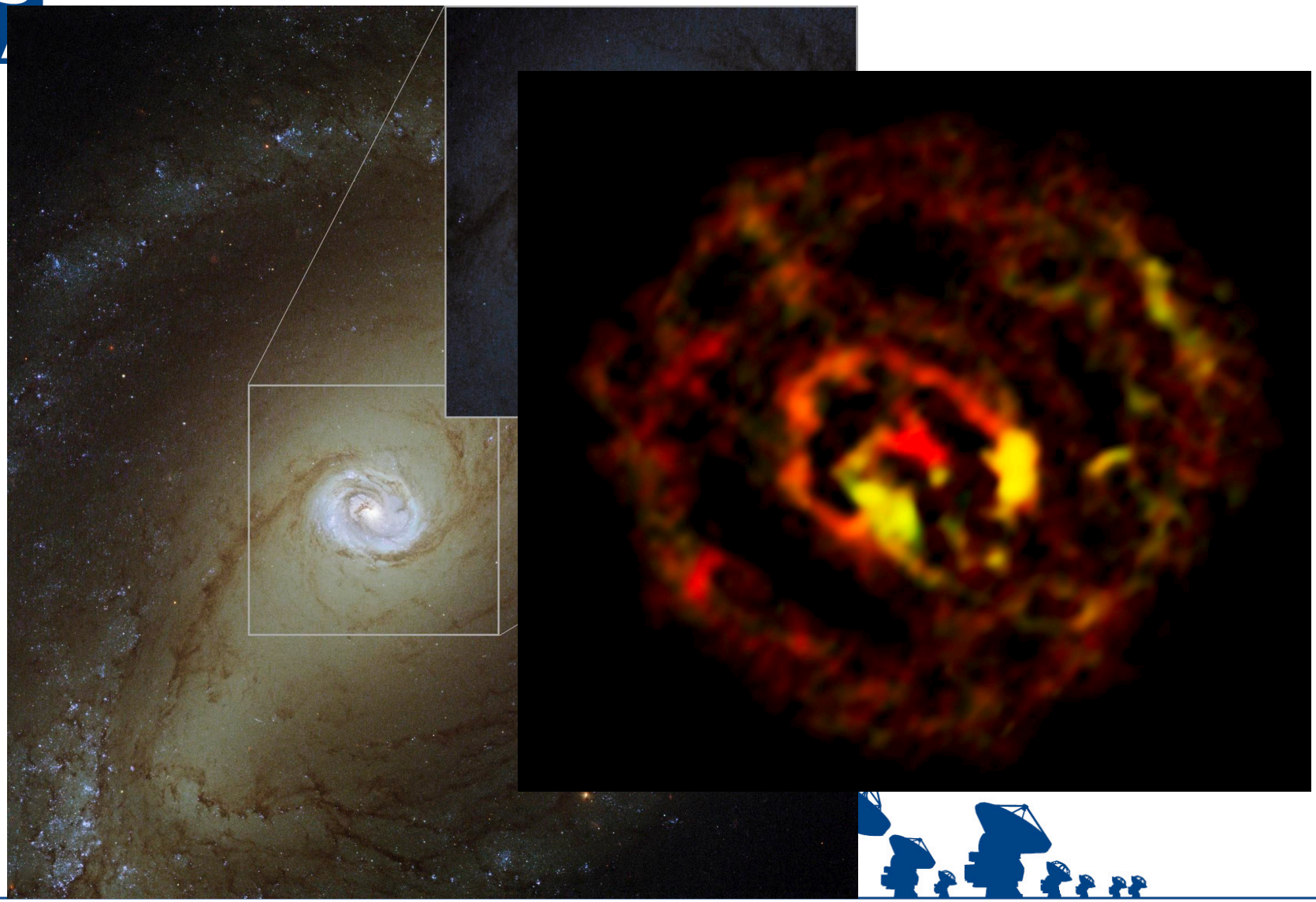






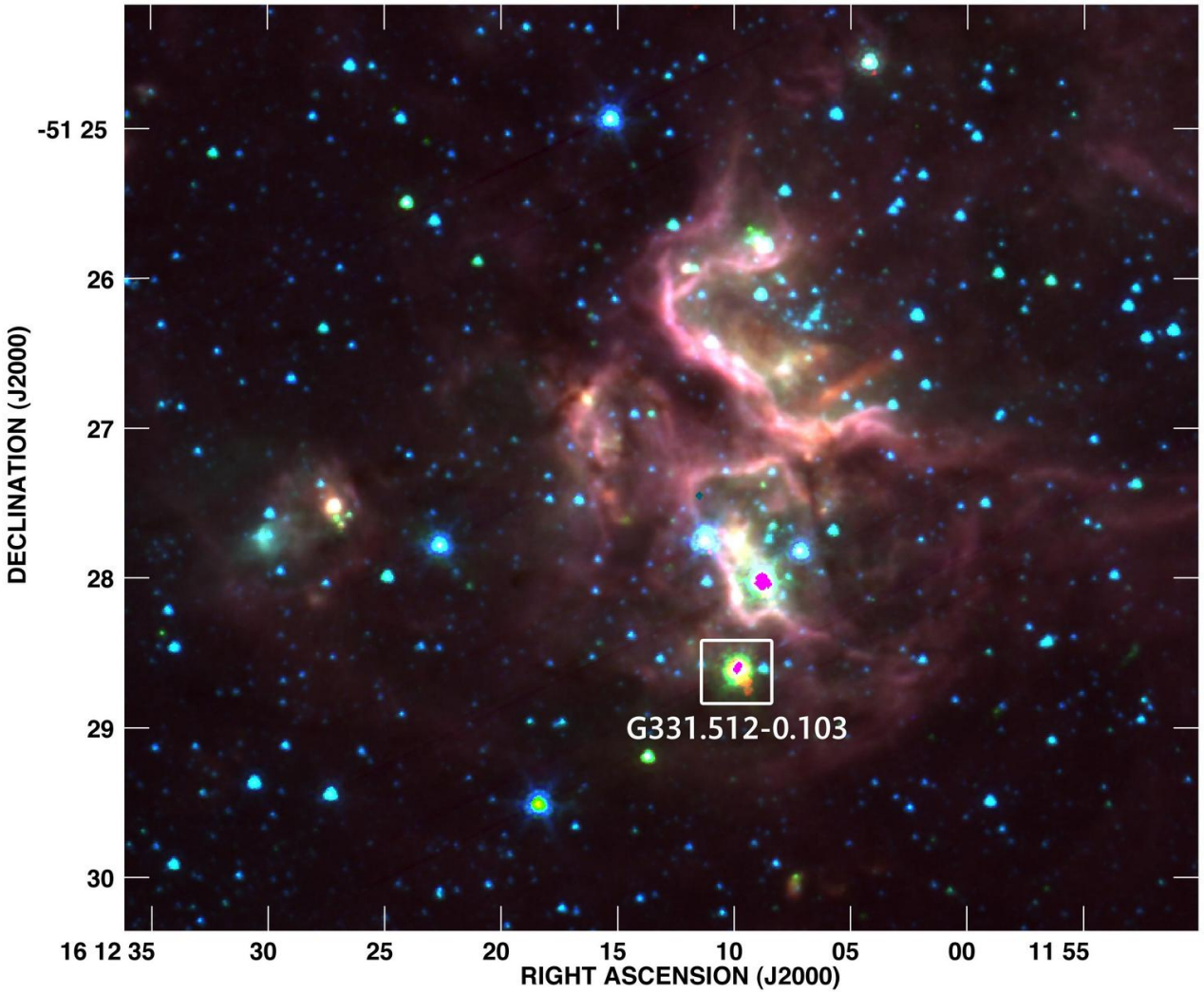
Galaxy evolution

Science Categories



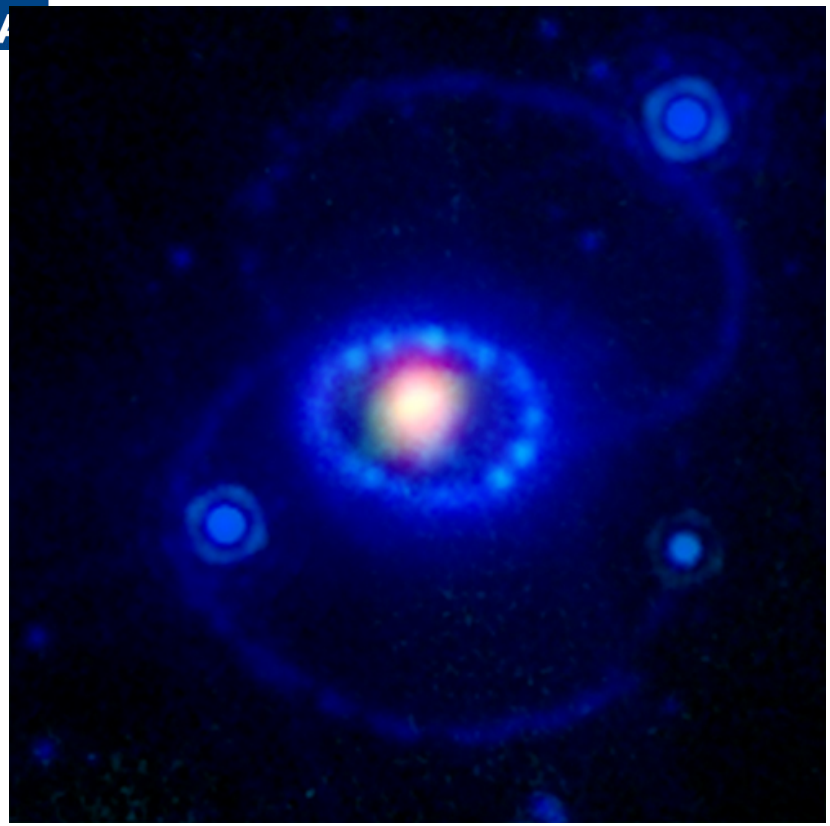
Star Formation

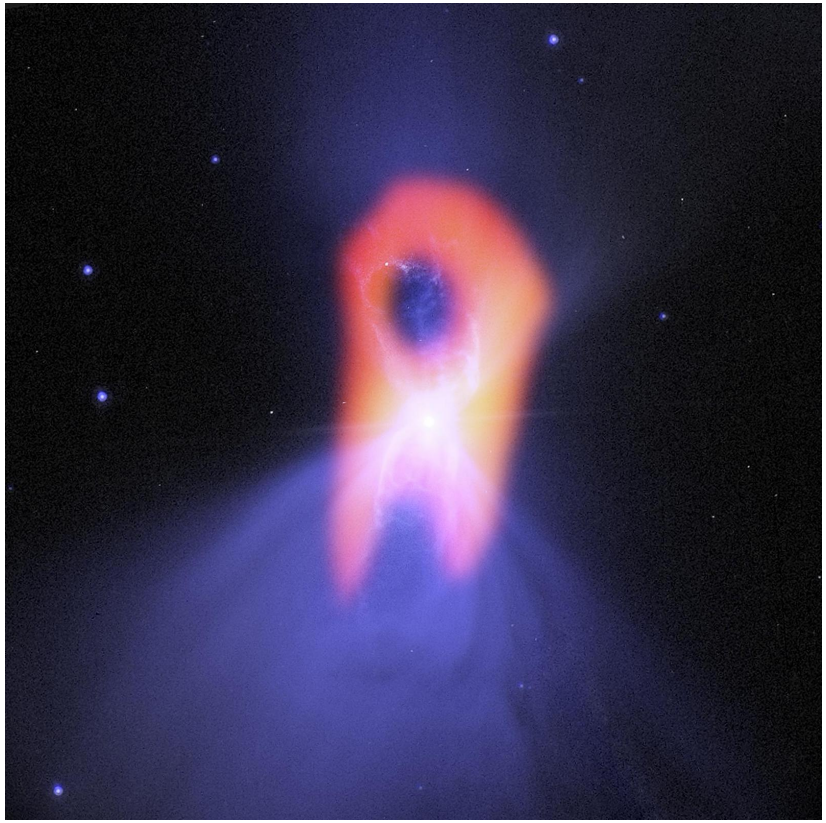
Science Categories



Stellar Evolution

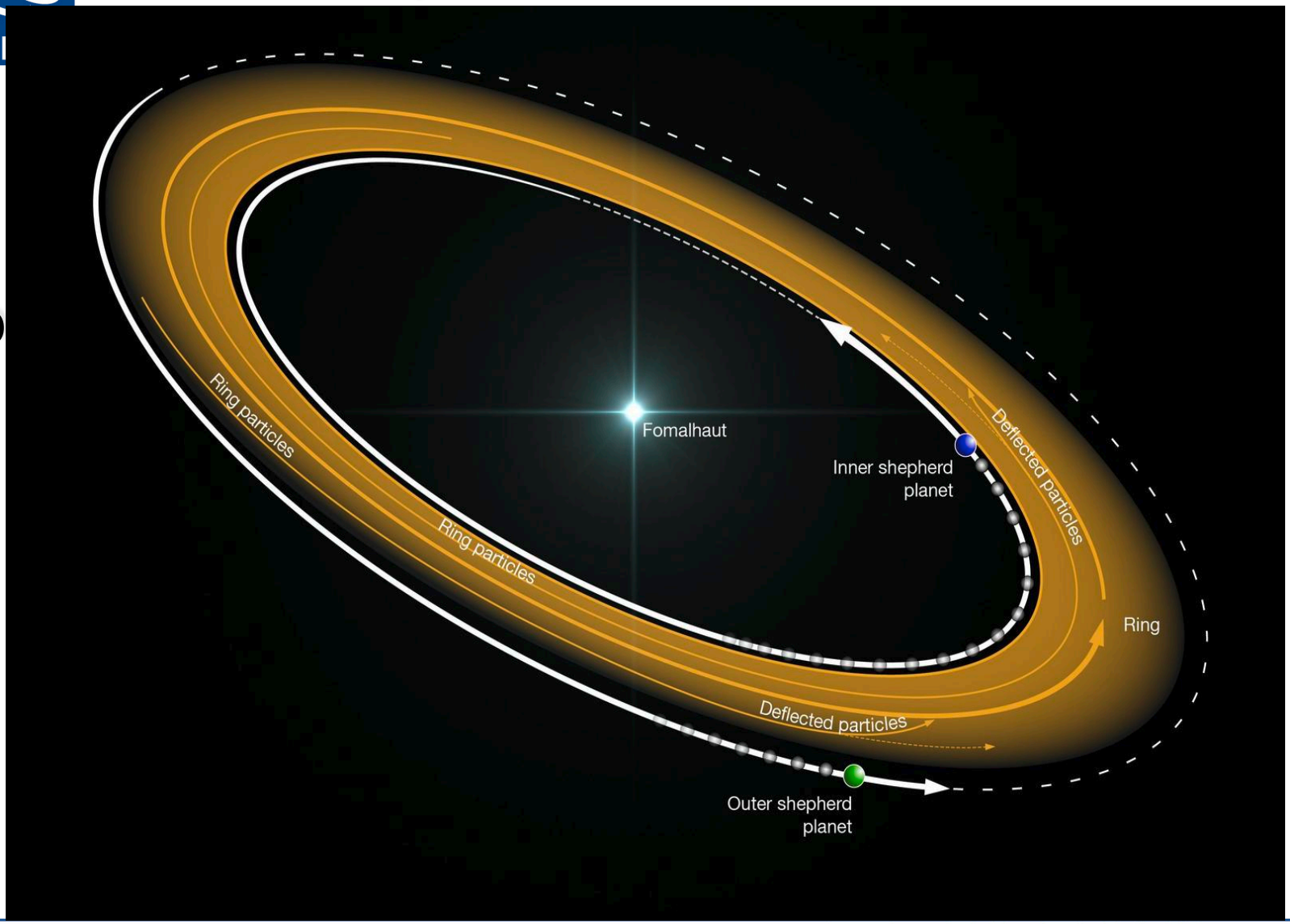
Science Categories





Planetary Science

Science Categories



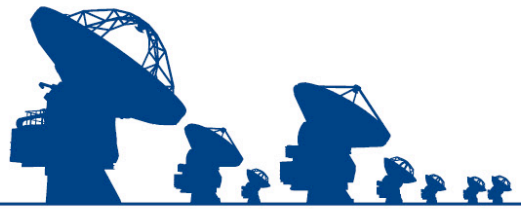
Resulting Requirements (1,2)

1) High Fidelity Imaging

- Reconfigurable Array
- Robust Instantaneous uv-coverage, N_{ant} > 60
- Precision Pointing, 6% of the HPBW
- Antenna Surface Accuracy RMS = 20 microns
- Primary Beam Deviations < 7%
- Total Power and Interferometric Capability
- Precise (1%) Amplitude Calibration
- Precise Instrumental Phase Calibration (<10 degrees rms)
- Precise atmospheric phase calibration (<15 degrees rms) with compensation using both fast switching and water vapor radiometry

2) Precise Imaging at 0.1" Resolution

- Interferometric baselines longer than 3 km
- Precise Instrumental Phase Calibration (<10 degrees rms)
- Precise atmospheric phase calibration (<15 degrees rms) with compensation using both fast switching and water vapor radiometry



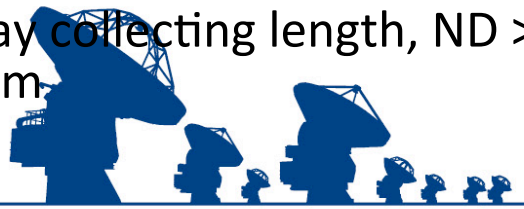
Resulting Requirements (3,4)

3) Routine Sub-Milli-Jansky Continuum Sensitivity

- Array site with median atmospheric transparency < 0.05 at 225 GHz
- Quantum-limited SIS receivers
- Antennas with warm spillover <5K, and aperture blockage <3%
- Antennas of aperture efficiency > 75%
- Wide correlated IF bandwidth, 16 GHz
- Dual polarization receivers
- Array collecting area, ND^2 > 7000 m2

4) Routine Millikelvin Spectral Sensitivity

- Array site with median atmospheric transparency < 0.05 at 225 GHz
- Quantum-limited SIS receivers
- Antennas with warm spillover < 5 K, aperture blockage <3%
- Antennas with aperture efficiency > 0.75
- Wide correlated IF bandwidth, 16 GHz Dual polarization receivers
- Array collecting area, ND^2 > $7000m^2$
- Array collecting length, ND > 700m



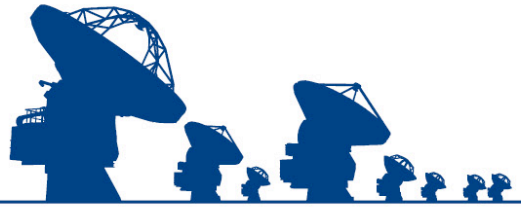
Resulting Requirements (5,6)

5) Wideband Frequency Coverage

- Receiver bandwidths matched to the width of the atmospheric windows
- Tunable local oscillator matched to the bandwidth of the receivers
- Cryogenic capacity >1 W at 4 K

6) Wide Field Imaging, Mosaicking

- Compact array configuration, filling factor > 0.5
- Instantaneous uv-coverage that fills more than half the uv-cells, Nant > 60
- Precision pointing, 6% of HPBW
- Antenna surface accuracy 20 microns
- Total power and interferometric capability
- Precise amplitude calibration, 1%
- Precise Instrumental Phase Calibration (<10 degrees rms)
- Correlator dump time 10 msec
- Capability to handle data rates > 100 Mbyte/sec



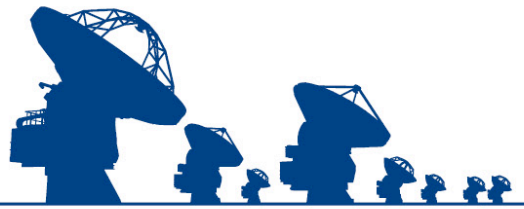
Resulting Requirements (7,8)

7) Submillimeter Receiving System

- Array site with median atmospheric transparency < 0.05 at 225 GHz
- Quantum-limited SIS receivers
- Antennas with warm spillover < 5 K, aperture blockage <3%
- Antennas with aperture efficiency > 0.75
- Precise Instrumental Phase Calibration (<10 degrees rms)
- Precise atmospheric phase calibration (<15 degrees rms) with compensation using both fast switching and water vapor radiometry

8) Full Polarization Capability

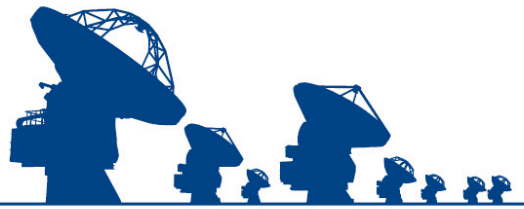
- Measure all Stokes parameters simultaneously
- Cross correlate to determine Stokes V
- Calibration of linear gains to <1%



Resulting Requirements (9)

9) System Flexibility

- Ability to phase the array for VLBI
- Sum port on the correlator for external processing
- Sub-arraying: 4 sub-arrays simultaneously
- Optics designed for solar observations



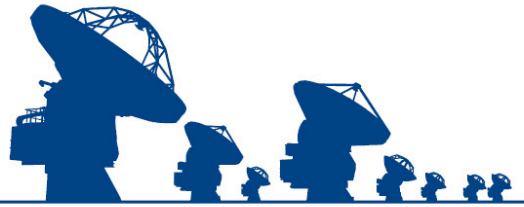
Why driest desert of the World?

Caveat: Atacama is large, and it depends where you look.

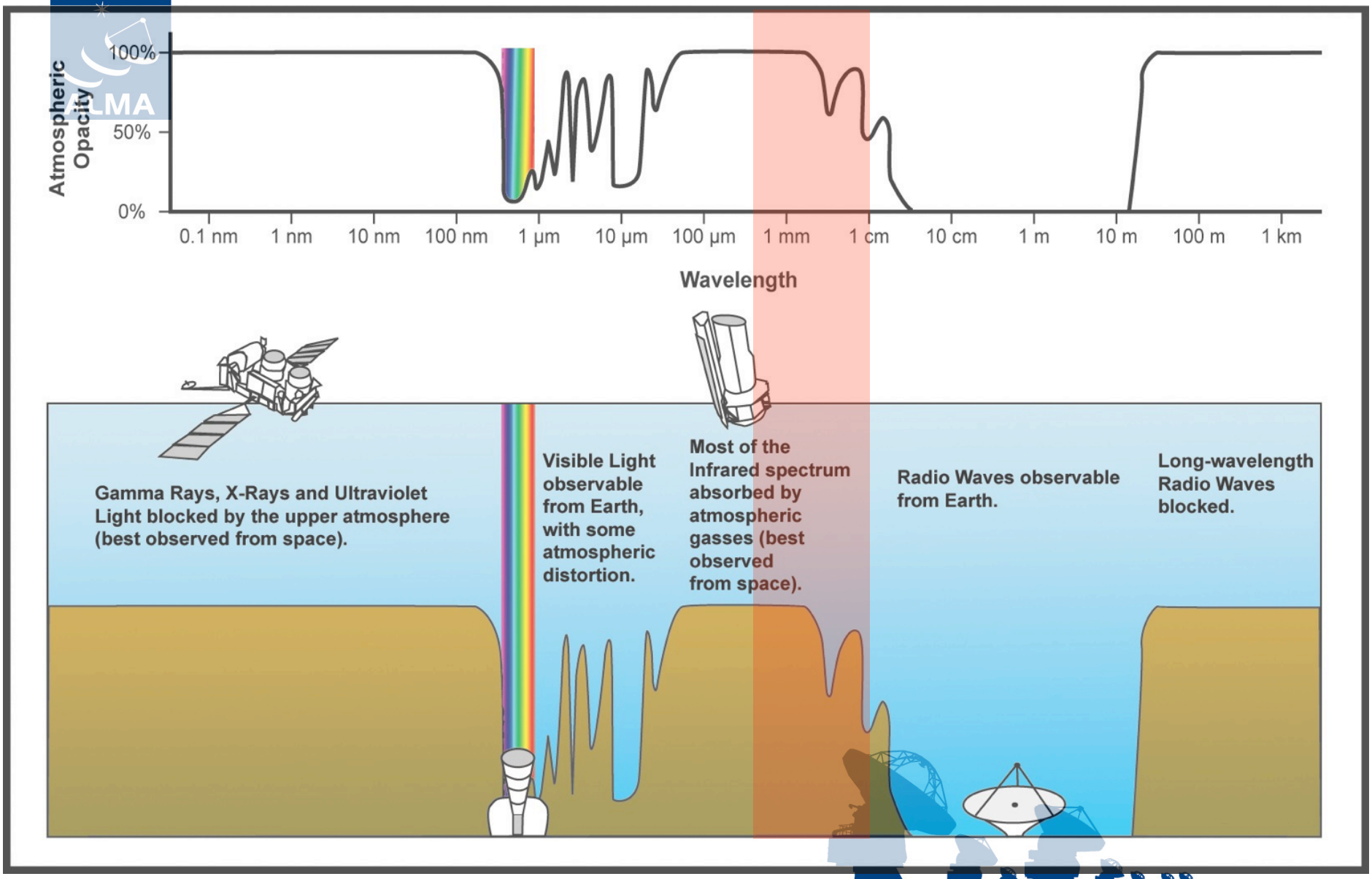
1) By precipitation
   - E.g. Calama: ~1mm rain per year (avg.)

2) By relative humidity
   - Ground level R.H. at ALMA: Oscillating between 0.4% and 20% for weeks, then peaking while precipitation.
   - The oldest meteorites found in the Atacama are 70,000 years old. No corrosion to be found, only thermally driven erosion.

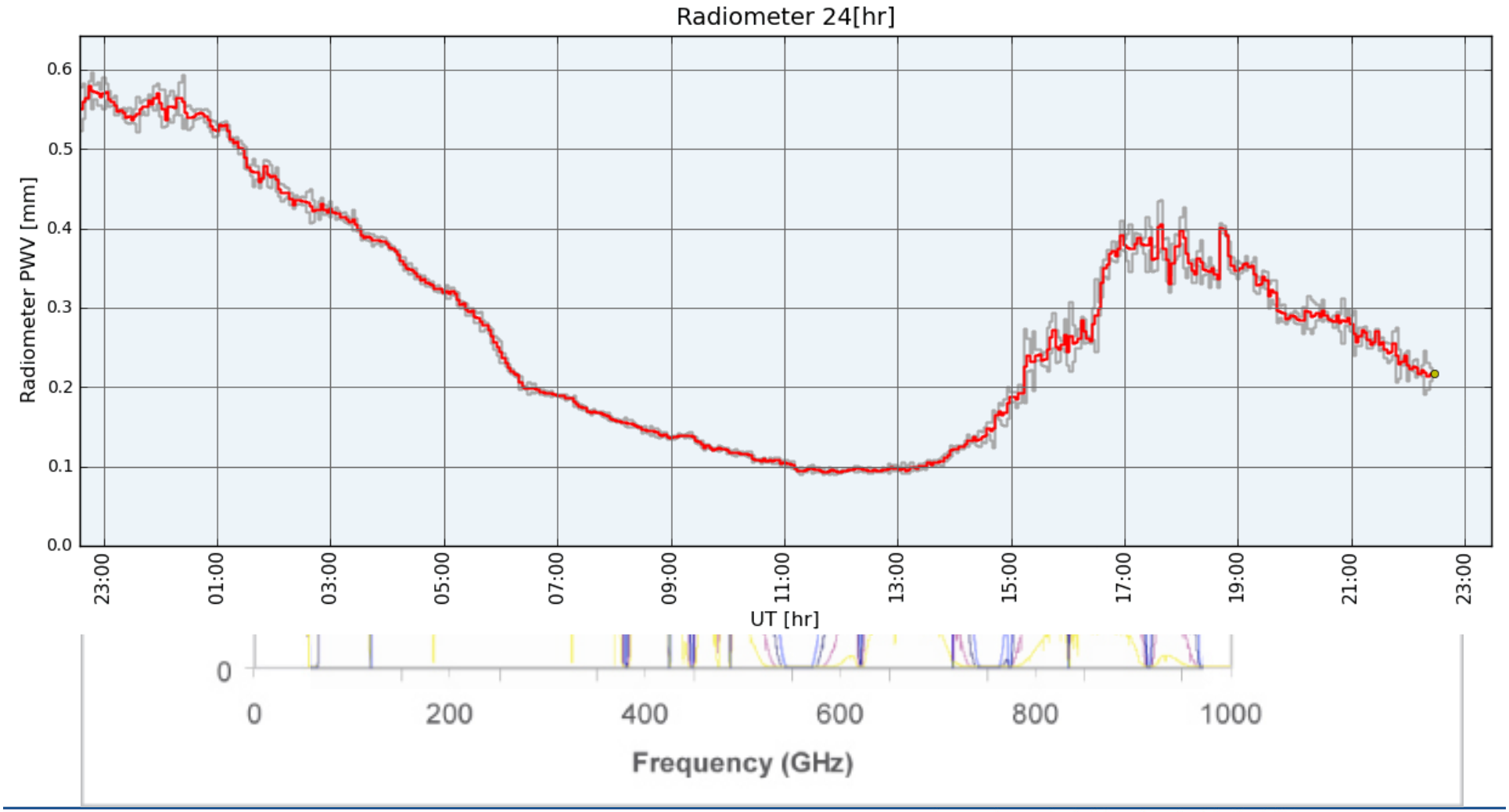
3) By transparency
   - Most of the clouds visible at ALMA site are cirrus, composed of suspended **ice grains.** Their rotational transitions are forbidden ("frozen"), hence there is no absorption.



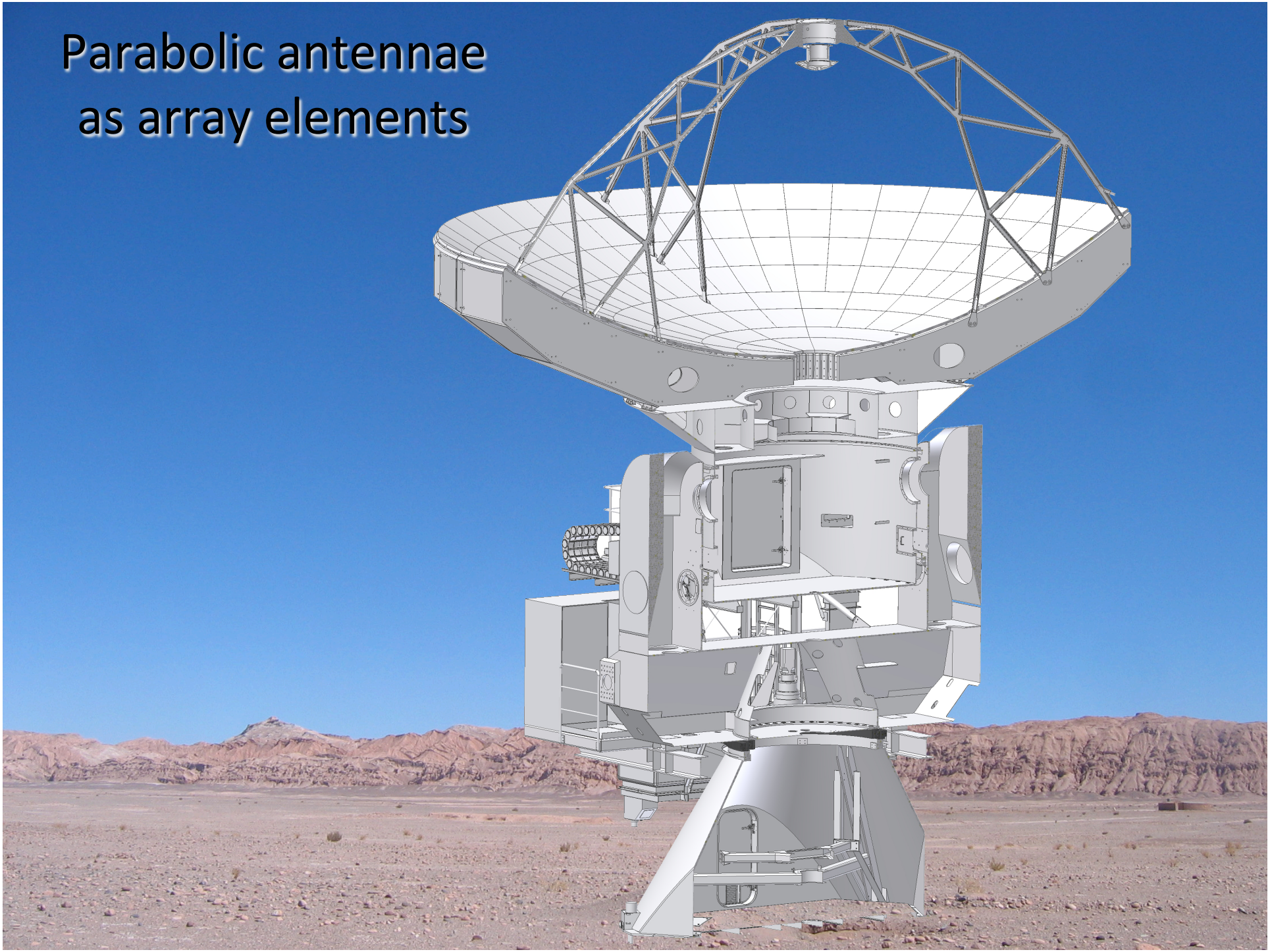
What reaches us? - Opacity of the atmosphere



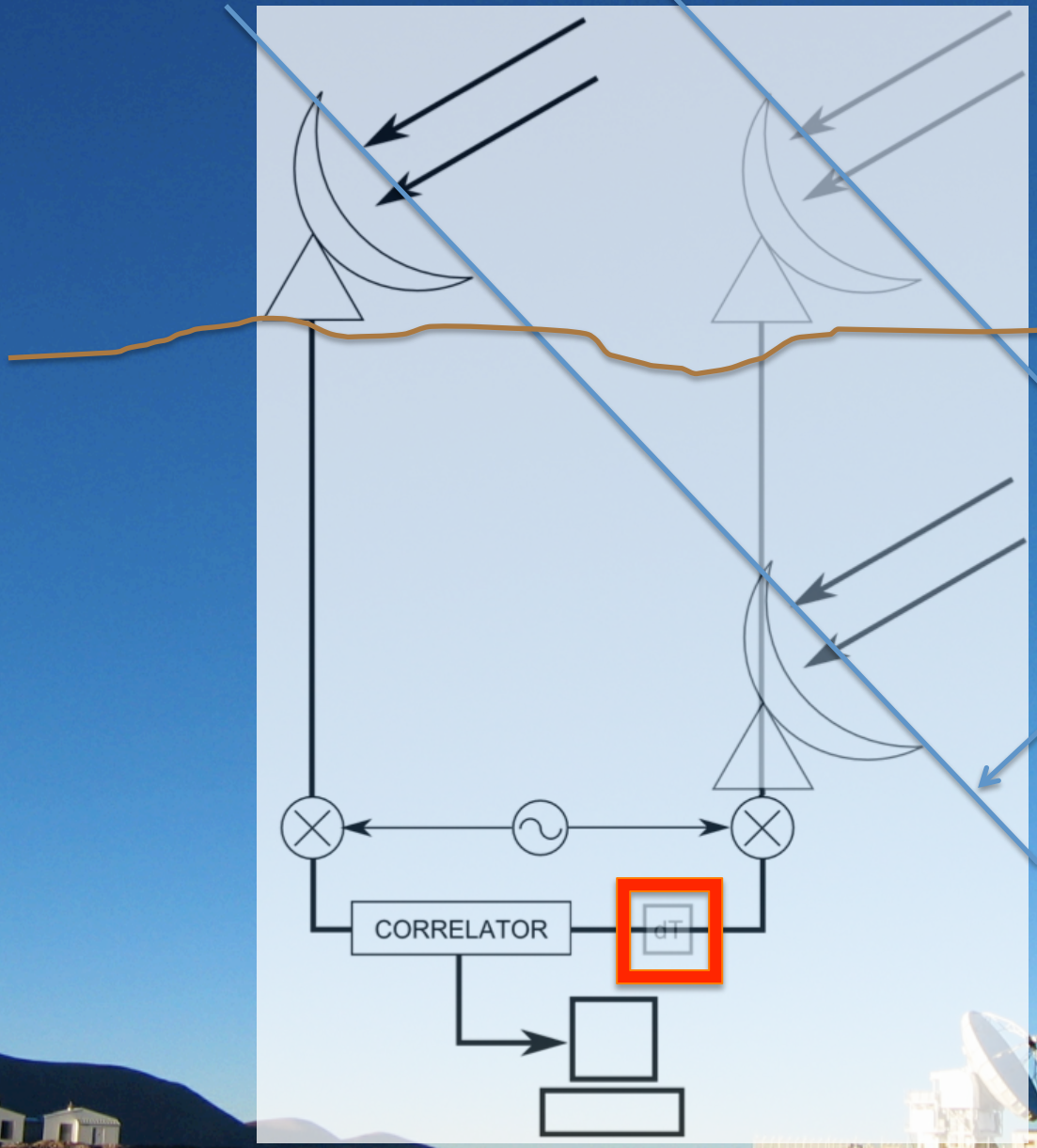
Atmospheric Transmission



Parabolic antennae as array elements



Simulation of a plane



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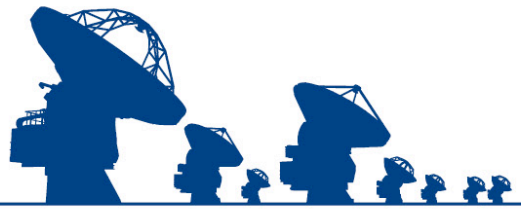
ALMA Technological Details

Antennae:

- Acc. to Ruze-Formula: 15µm rms deviation from perfect paraboloid
- Exposed to harsh weather: wind; diurnal, annual cycles
- Pointing accuracy ~1” rms

Phase stability:

- Central Local Oscillator: Timing stability: ~2.5 fs
- Amplitude stability



Central Local Oscillator

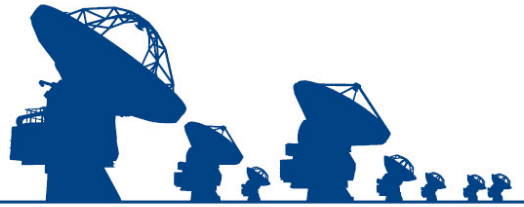
Line Length Correction

Why?

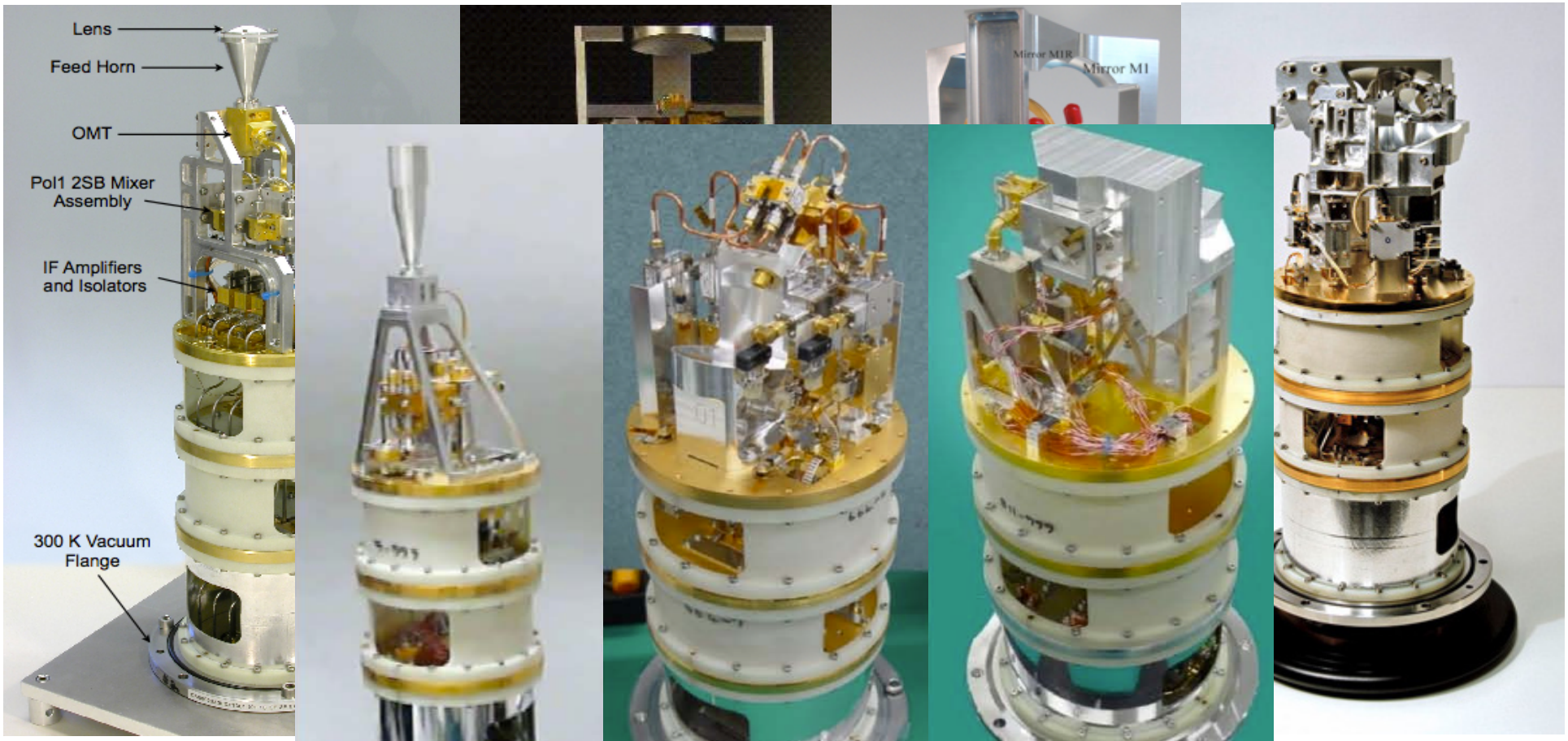
- Fluctuations of refractive index in optical fibers
- Varying absolute lengths of fibers to the many antenna pads

How?

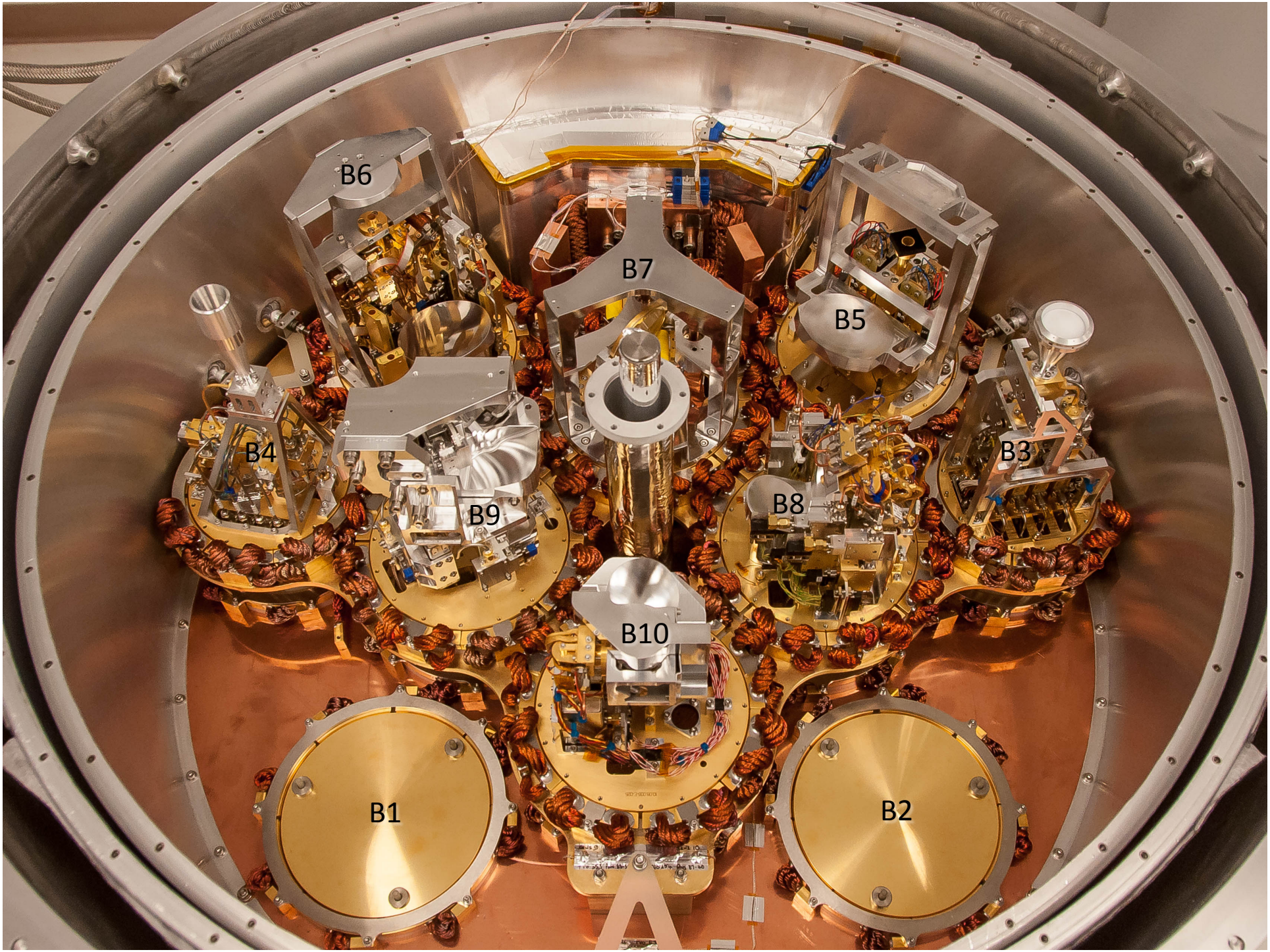
- Measure round-trip phase with Michelson interferometer on each fiber in use
- Lock on an interference fringe and stretch mechanically the fiber to a **constant number of wavelengths in the fiber**



Cold Cartridge Assemblies

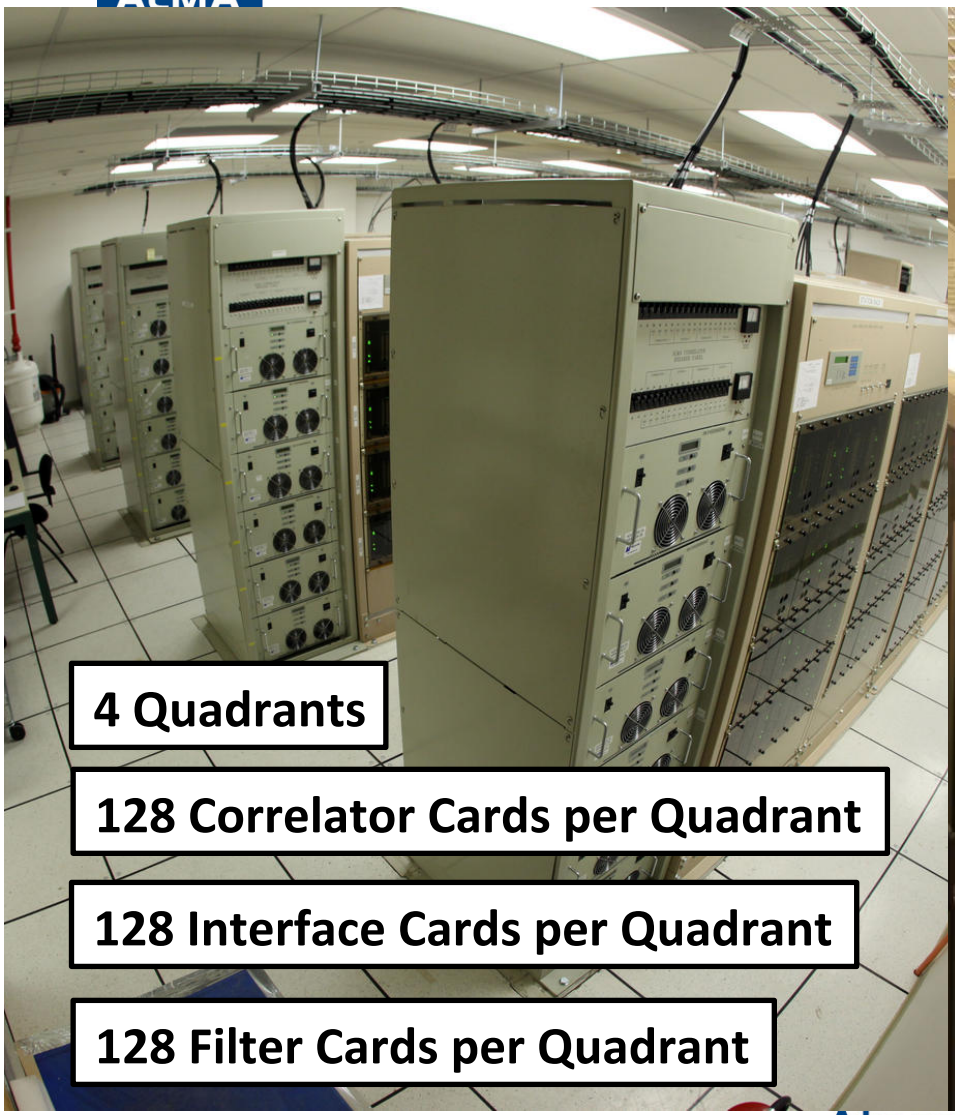


Band 4 Band 8 Band 10 Band 9


B6
B7
B5
B4
B3
B9
B8
B10
B1
B2

Correlators

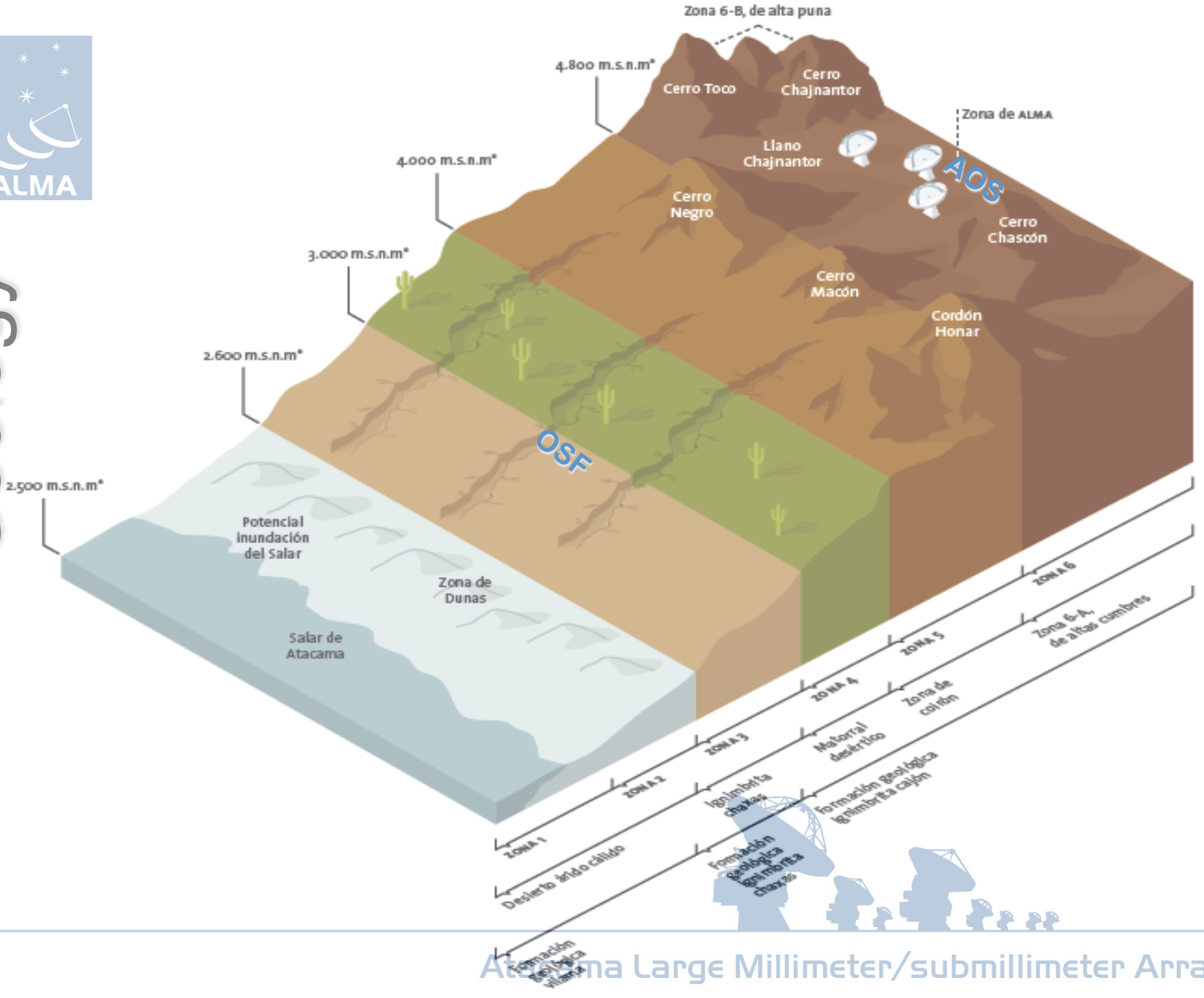
Base Line



- 4 Quadrants
- 128 Correlator Cards per Quadrant
- 128 Interface Cards per Quadrant
- 128 Filter Cards per Quadrant

ACA

Geology


Zona 6-B, de alta puna
4.800 m.s.n.m*
Cerro Toco
Cerro Chajnantor
Zona de ALMA
Llano Chajnantor
AOS
4.000 m.s.n.m*
Cerro Negro
Cerro Chascón
3.000 m.s.n.m*
Cerro Macón
Cordón Honar
2.600 m.s.n.m*
OSF
2.500 m.s.n.m*
Potencial inundación del Salar
Zona de Dunas
Salar de Atacama
ZONA 1
ZONA 2
ZONA 3
ZONA 4
ZONA 5
ZONA 6
Desierto árido cálido
Ignimbrita chaxas
Matorral desértico
Zona de cañón
Formación geológica ignimbrita cajón
Formación geológica ignimbrita chaxas
Zona 6-A, de altas cumbres
Formación geológica volcánica

Atacama Large Millimeter/submillimeter Array