CCAT

2008 April 23

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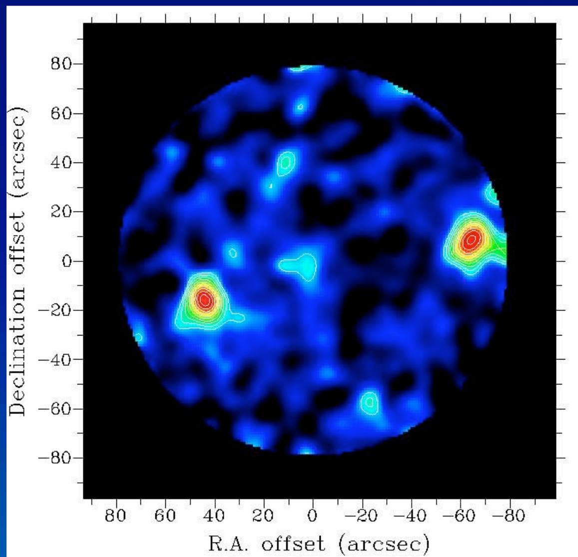
Why CCAT ?


Declination offset (arcsec)
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80
60
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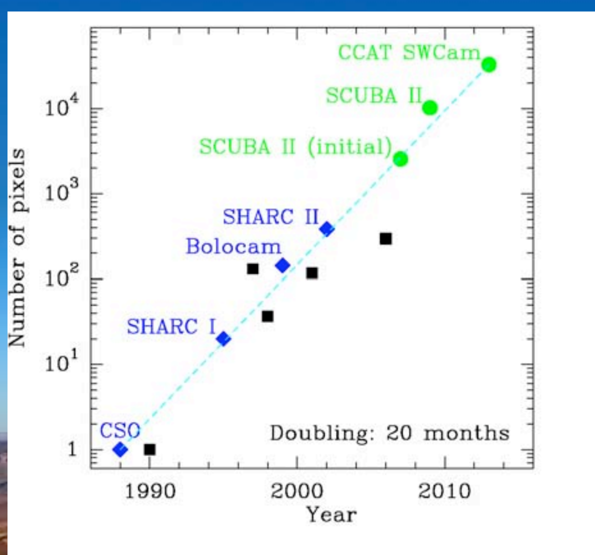

CCAT SWCam
SCUBA II
SCUBA II (initial)
SHARC II
Bolocam
SHARC I
CSO
Doubling: 20 months
Number of pixels
Year
1990
2000
2010

=

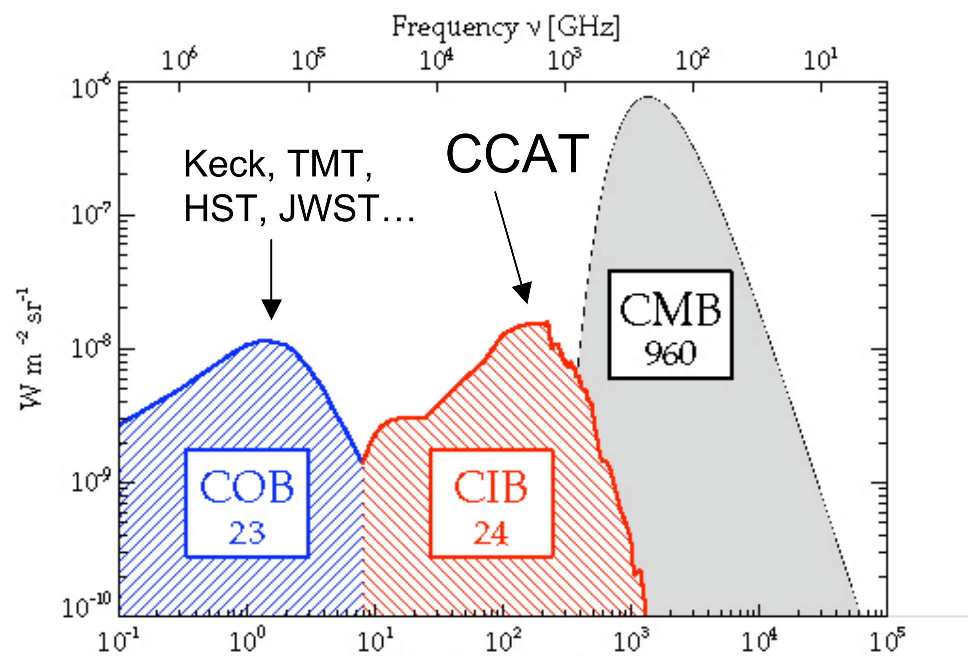

CCAT
25 m, 10 μm rms
Cerro Chajnantor

CCAT Overview

- Big: 25 m diameter submm telescope
  - high aperture efficiency at 200 μm
- Wide: Field of View > 15′
  - large format bolometer array cameras
- High: dry, tropical mountain site
  - 5600 m, median PVW < 1 mm
  - wide sky coverage
- Complement ALMA

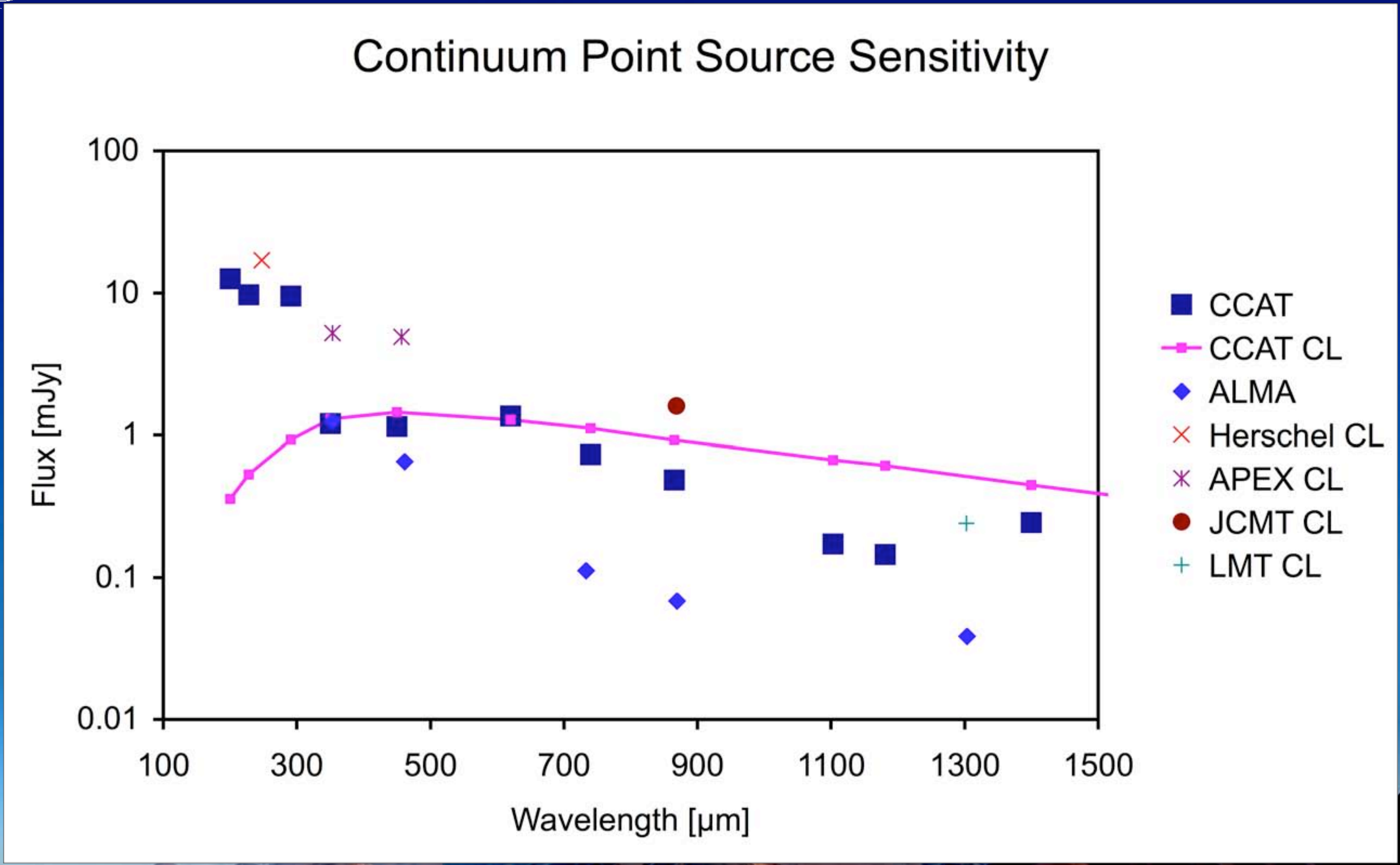
CCAT Science Strengths

- Past decade: submillimeter astronomy is important !!
- CCAT:
  - Large and sensitive
  - Designed for wide-field imaging
  - Wide spectral coverage
  - *Excellent* performance at 350 µm
    - site, surface
  - 3.5" resolution @ 350 µm
  - Multicolor information (SED)
  - Study high *z* tail of CIB sources
- CCAT will complement ALMA
  - Fast continuum mapping vs. high angular & spectral resolution
  - Comparable sensitivities: identify targets for ALMA
- Clusters (SZ), submm galaxies, star-forming regions & cores, debris disks, KBOs



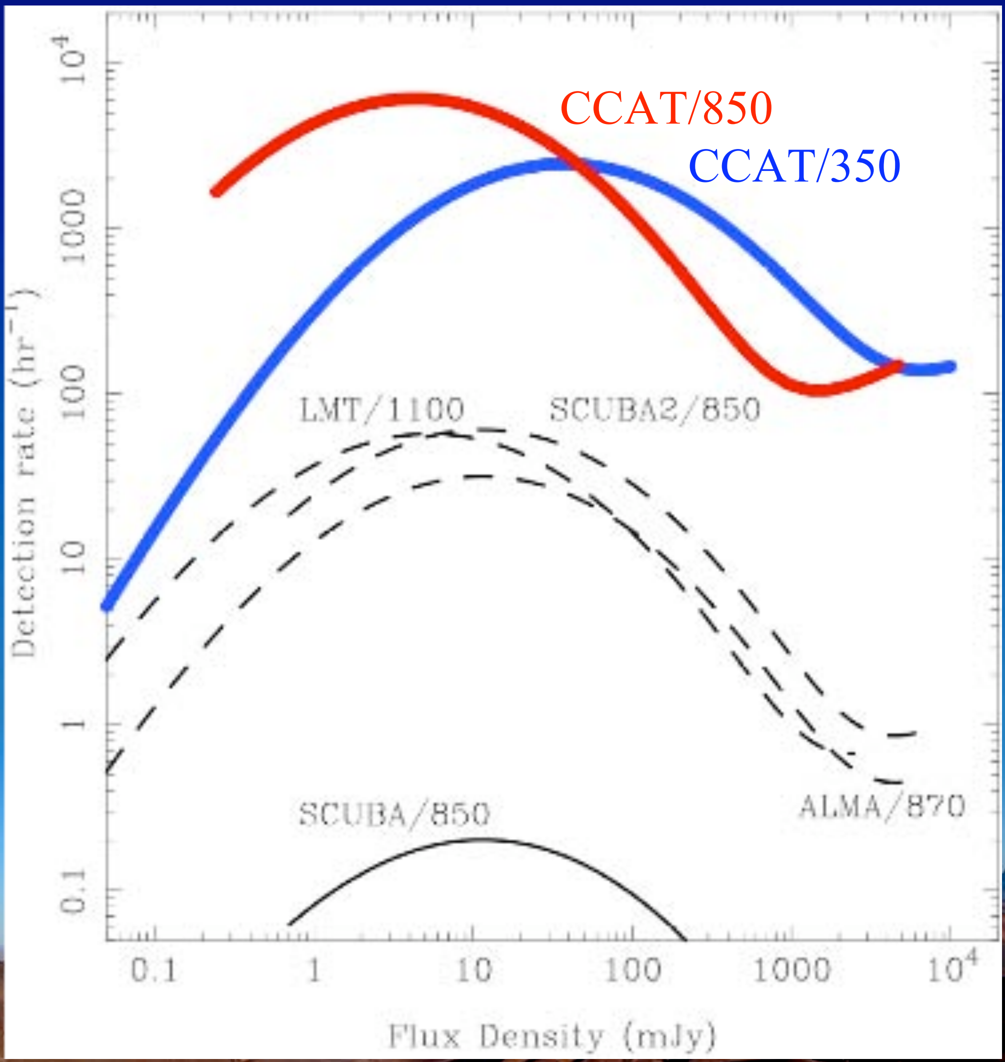
Dole et al 2006

CCAT Sensitivity



Continuum sensitivities of CCAT and other instruments (5 σ in 1 hour) with confusion limits (30 beams source^{-1}). CCAT sensitivities computed for precipitable water vapor appropriate to that band.

Submm Galaxy Detection Rate



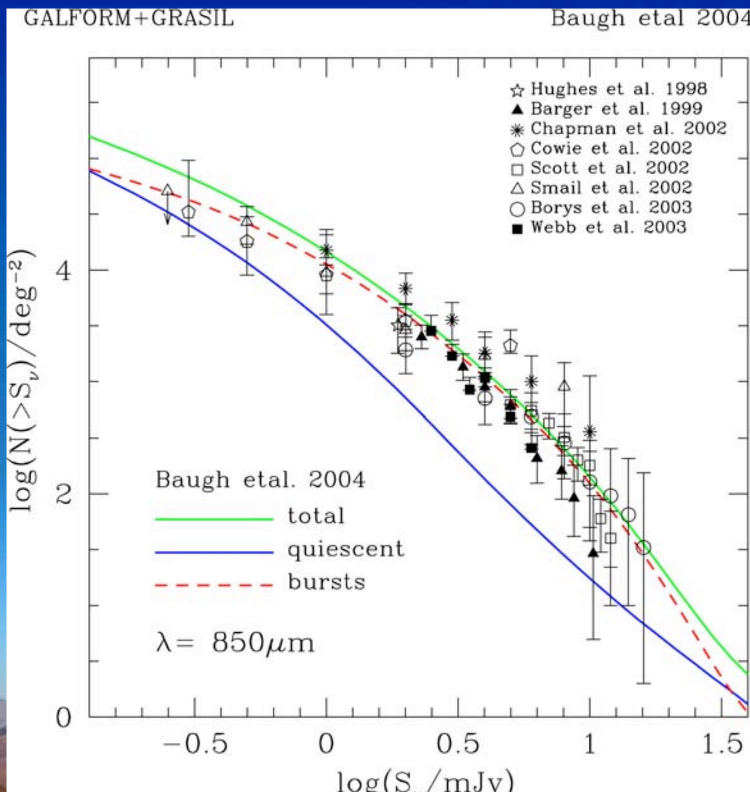
- CCAT is an ultrafast mapper
- Assumptions
  - 32 x 32 (1024) pixel detector, Nyquist sampled, 350 µm & 850 µm
  - Observationally verified counts (good to factor 2)
  - Confusion and all sky limits
- 350 µm & 850 µm detection rates are compatible, but
- Confusion at 350 µm is deeper than at 850 µm
- Detection rates:
  - ~150 × SCUBA2; ~300 × ALMA
  - About 100-6000 per hour
  - Lifetime detection of order 10^{7-8} galaxies: ~1% of ALL galaxies!
- '1/3 sky survey': ~1000 deg^2 at 3 deg^2 hr^{-1} in 5000 hr

Submm Galaxy Models

Can the faint sub-mm galaxies be explained in the ΛCDM model?

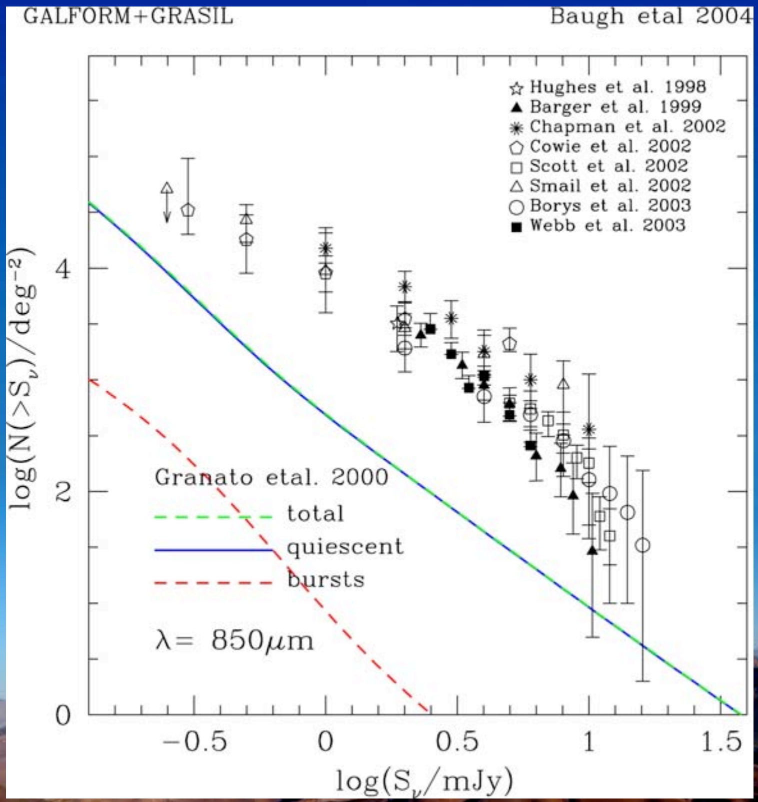
MNRAS 2005

C. M. Baugh[1], C. G. Lacey[1], C. S. Frenk[1], G. L. Granato[2], L. Silva[3], A. Bressan[2], A. J. Benson[4], S. Cole[1].



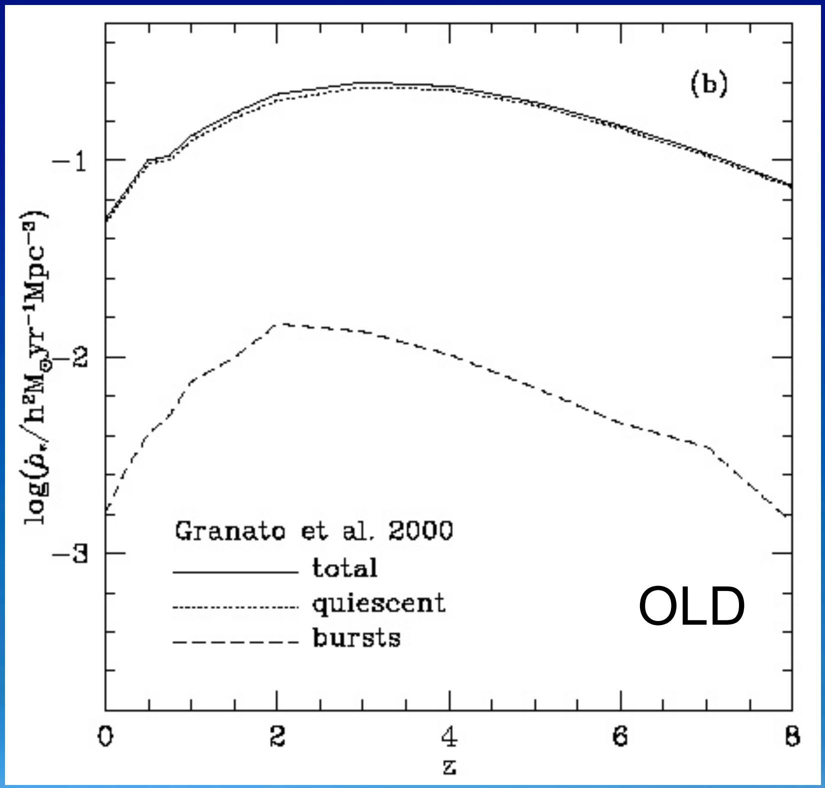
- Semianalytical model
- CDM halo "merger tree"
- Gas cooling, star formation, feedback, …
- Treat chemical evolution, dust production, dust radiative transfer
- Includes galaxy mergers & starbursts
- Number counts OK
- Submm galaxies dominated by mergers

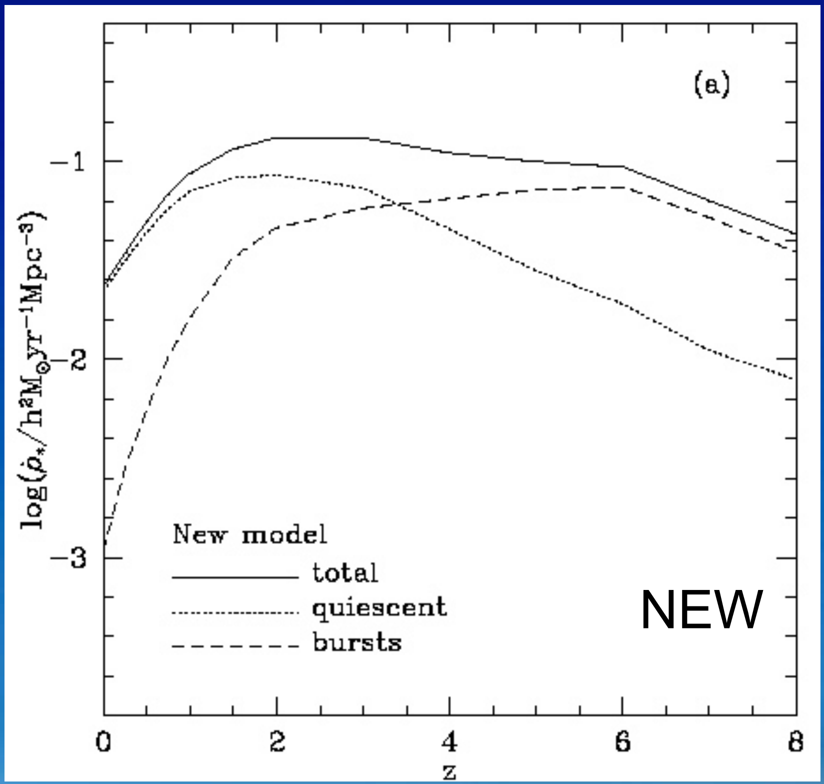
Submm Galaxy Models



- Original model, pre-submm
- Tuned to match local galaxies…
- …but severely underpredicts submm galaxies!
- Fixes:
  - Slower star formation in disks
  - Minor mergers lead to starbursts
  - Use flat IMF for starbursts (high mass)
- Metallicity OK for cluster gas, ellipticals
  - Nagashima et al., 2005

Submm Galaxy Models



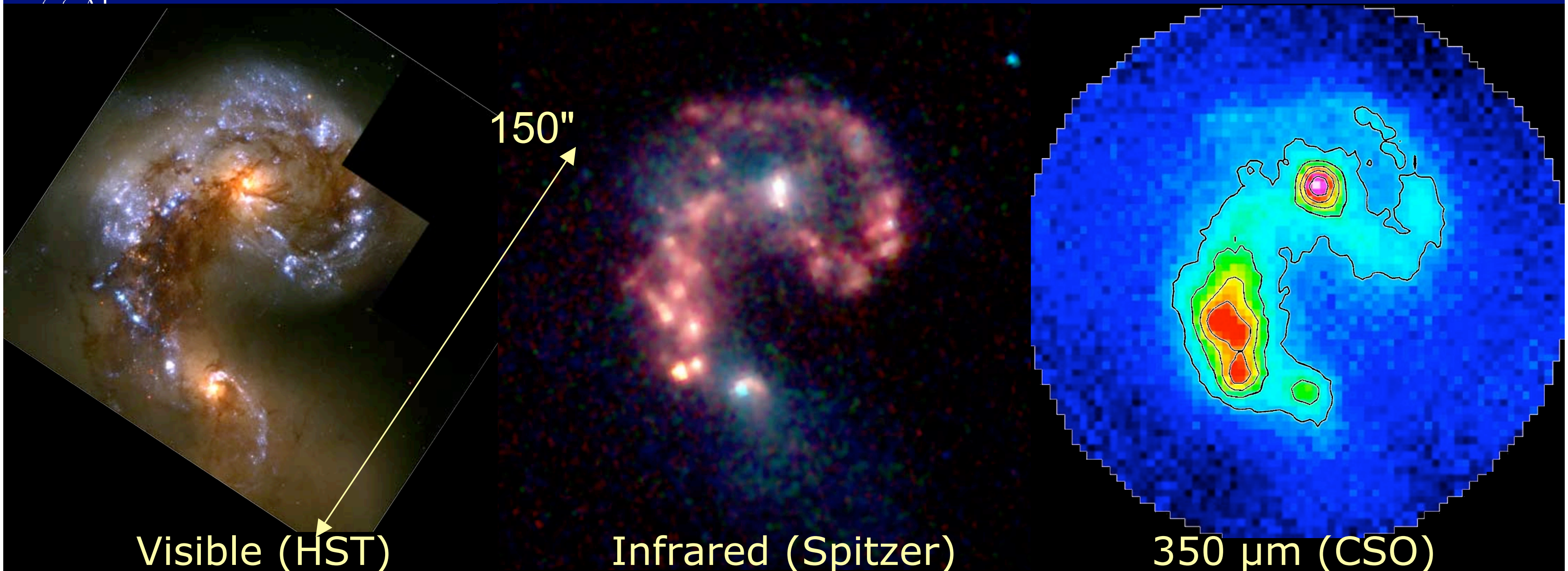


Star formation at z > 3.5 dominated by bursts?

Distant Submm Galaxy Surveys

- CCAT Detection Rate Will Provides Huge Samples
  - Find rare distant red objects; i. e., opt/IR (or 350 μm) dropouts
  - Address clustering properties of submm galaxies
  - Map large scale structure, high density regions
  - Measure submm galaxy luminosity function
- CCAT Confusion Limit Fainter than Other Surveys
  - Higher precision number counts
  - Are faint submm galaxies more quiescent ?
- Surveys Guide Detailed Follow-on Studies with ALMA
  - CCAT will provide accurate positions

Nearby Interacting Galaxies



Images of the Antennae show the submillimeter reveals active star formation regions hidden at shorter wavelengths. The bulk of the luminosity emerges in the submillimeter. CCAT will provide a submillimeter image with a spatial resolution similar to the infrared image. Mapping this galaxy would require hundreds of pointings with ALMA. With CCAT's high mapping speed and sensitivity, a complete survey of all galaxies in the local volume would be practical.

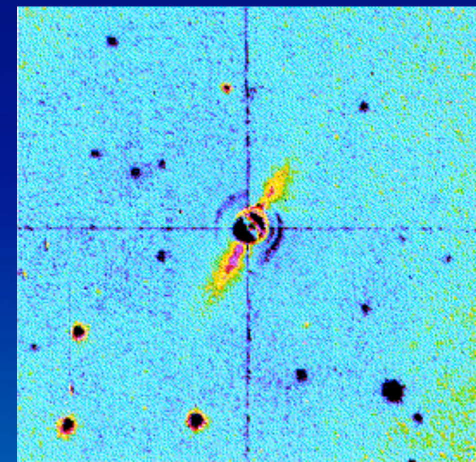
CCAT Galactic Plane Survey

- Measure the Galaxy-wide star formation rate and history
- Obtain the complete inventory of cold dust in the Galactic Plane
- Determine the relative importance of global and local triggers for star formation
- Provide templates, recipes and prescriptions for Xgal science

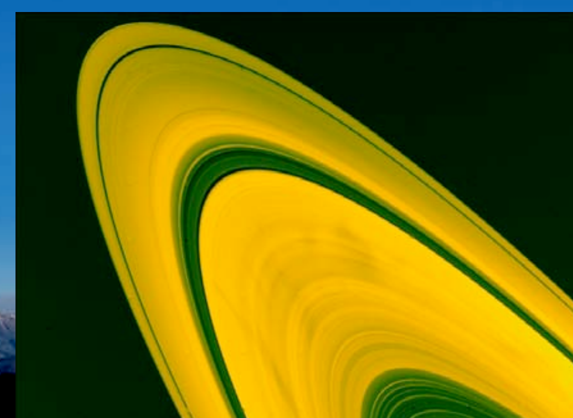
- CCAT mapping speed (0.9 deg^2 hr^{-1}) and sensitivity (8.5 mJy) enable:
  - a complete survey of the “inner” Galactic Plane
  - detect *all* star forming regions (i. e., cool dust)
  - not just massive star regions (i. e., warm or hot dust)

Debris Disks with CCAT

- Debris disks, a.k.a. “Vega phenomenon”, a.k.a. “extra-zodiacal dust”:
  - solid particles around main sequence stars, especially younger ones (10-100 Myr); gas has been absorbed into giant planets or expelled
  - Produced by collisional grinding of planetesimals in Kuiper belts; probably episodic
  - trace orbital dynamics (analogous to Saturn’s rings)
- CCAT objectives
  - high-quality images of statistical sample of nearby disk systems
  - surveys for undiscovered cold disks (T < 40 K) around nearby stars
  - important data points on spectral energy distribution
    - characteristics of particles ⇒ evolutionary clues?
    - much better measurement of mass than is possible with scattered light images
  - unbiased surveys for disks in stellar clusters



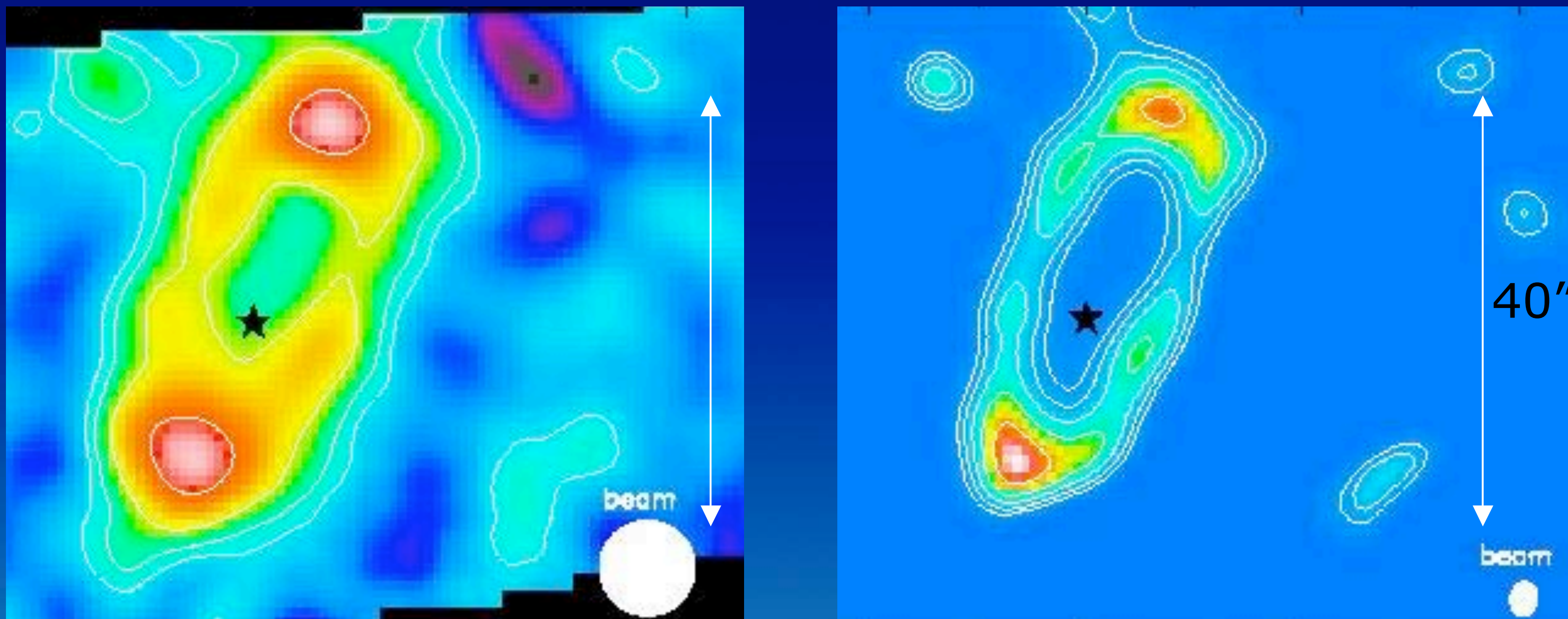
β Pictoris: debris disk discovery image
Smith & Terrile (1984)



Saturn's rings

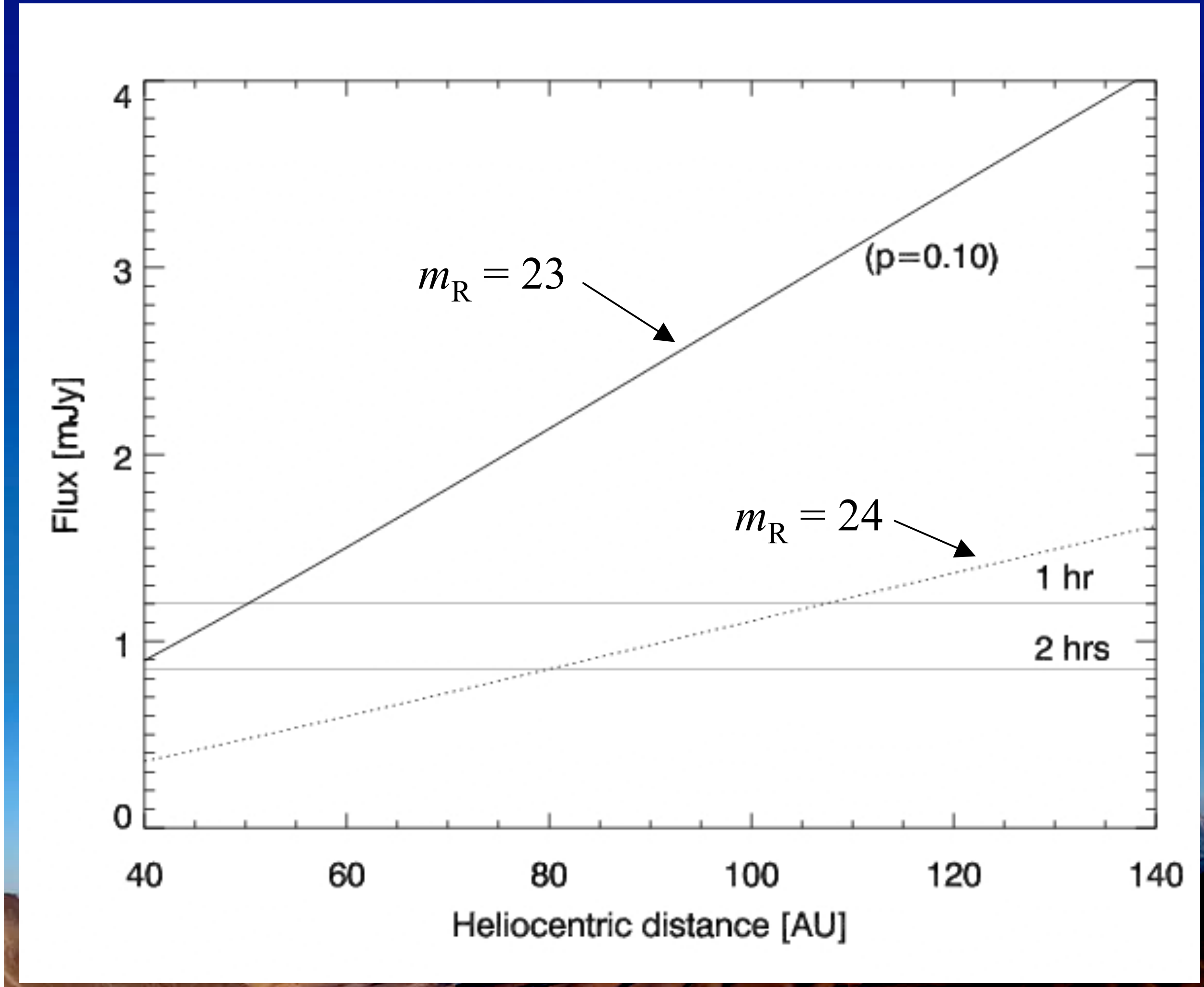
Debris Disks

CSO/SHARC II Marsh et al. 2005



Images of Fomalhaut debris disk at 350 µm. The observed image (*left*), with 10″ resolution, shows a complete debris ring encircling the star. With enhanced (3″) resolution (*right*), we can infer the presence of a planet due to the asymmetry of the ring. CCAT will achieve this resolution intrinsically and be capable of 1″ resolution with image enhancement techniques. CCAT imaging will measure the entire flux and should show substructure pinpointing the location of the planet. Imaging this system would require dozens of ACA pointings.

KBO submm advantage



Optical brightness (refl.)

$$B \propto R^{-4}$$

Submm flux (thermal)

$$S \propto R^{-5/2}$$

Submm advantage

$$\propto R^{+3/2}$$

Predicted 350 µm flux for KBOs with 4% albedo (m_R = 23, solid, and m_R = 24, dotted). Horizontal lines show the 5 σ detection limits for one and two hour observations, respectively, with CCAT.

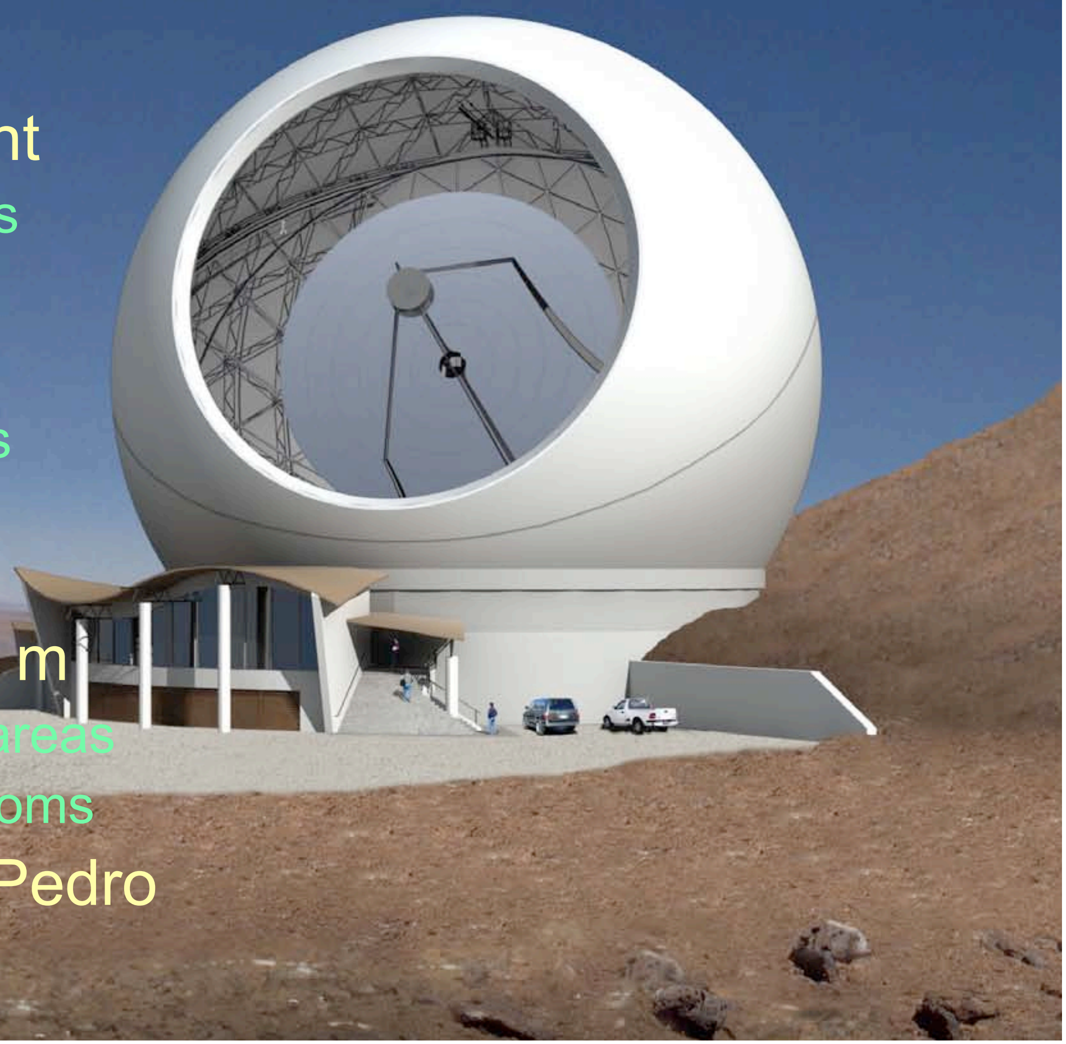
CCAT Technical Goals

	Requirement	Goal	remark
Wavelength	350 – 1400	200 – 2500	μm
Aperture	25 m		
Field of view	10'	20'	
Half WFE	< 12.5 μm	< 9.5 μm	rms
Site condns.	< 1.0 mm	< 0.7 mm	median pwv

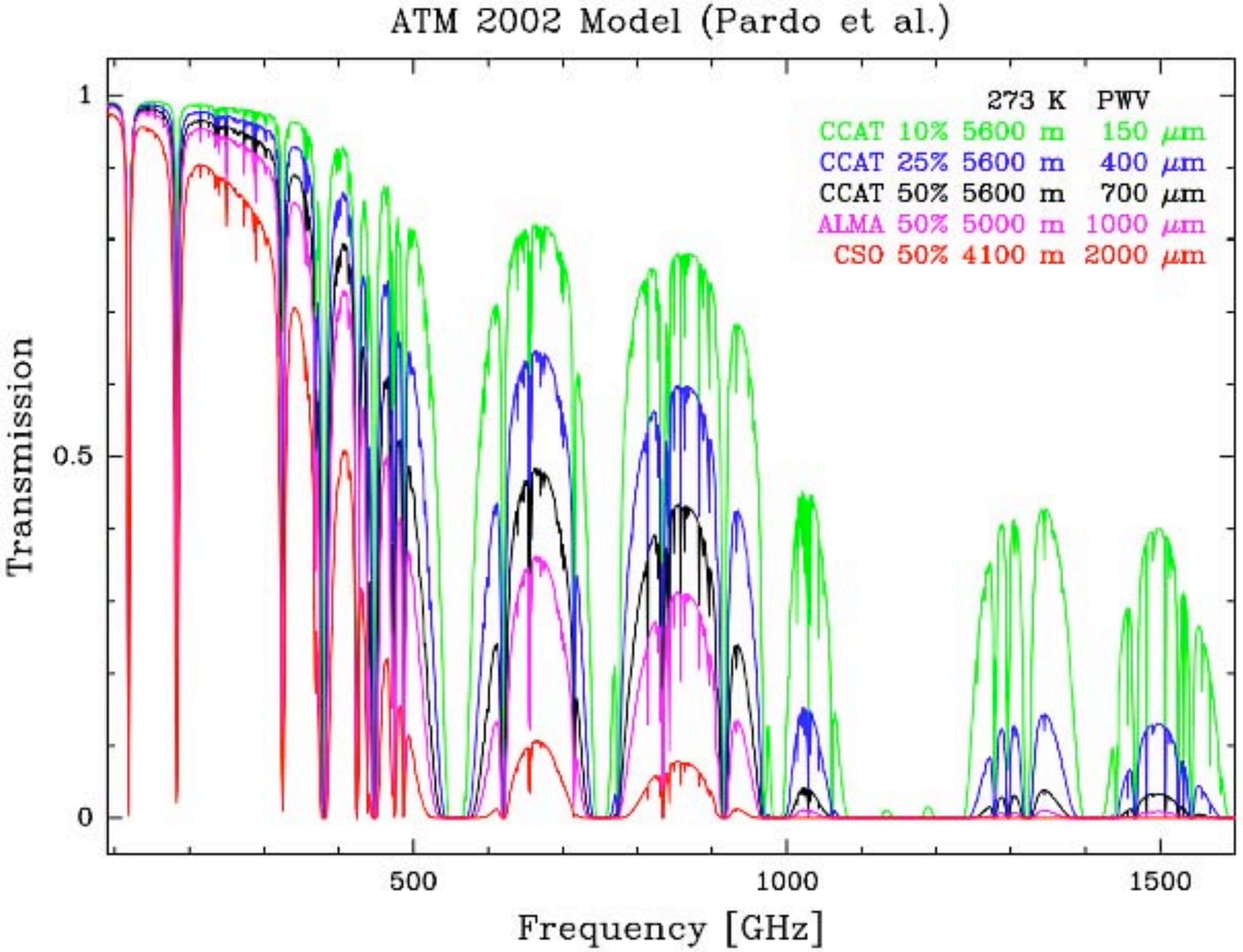
These Goals and Advanced Bolometer Arrays Will Make CCAT a Revolutionary New Observatory

CCAT Concept Design

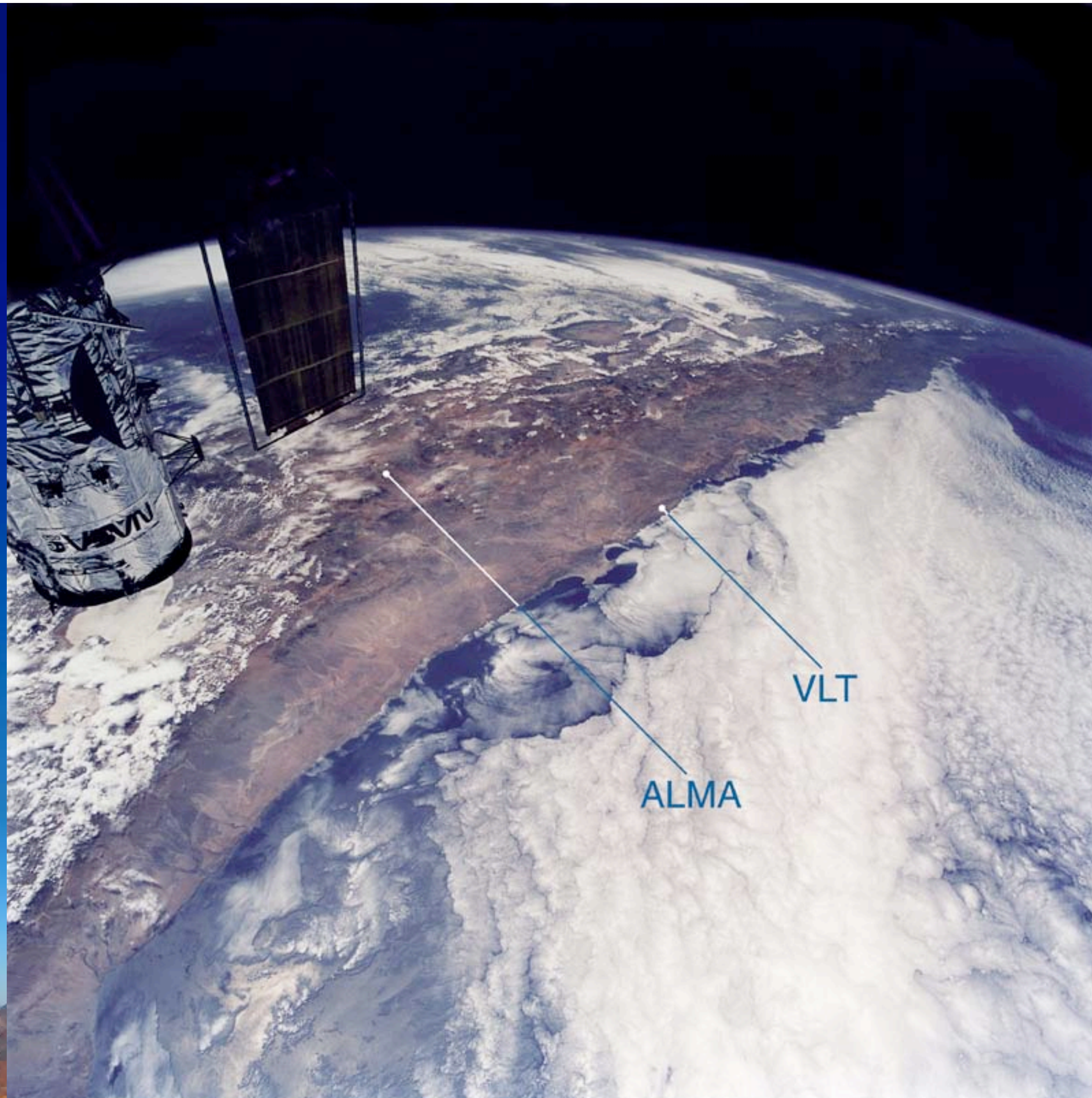
- RC Optics, Nasmyth Foci
- Calotte Dome
  - Internal storm shutter
- High Performance Mount
  - Precise pointing, 0.3" rms
  - Agile scanning motions
- Active Primary Surface
  - Kinematic panel supports
  - Closed loop control
  - Holography alignment
- Cerro Chajnantor, 5612 m
  - Instrument prep. & ops. areas
  - Oxygen enrichment in rooms
- Base Facility near San Pedro



Atmospheric Transmission



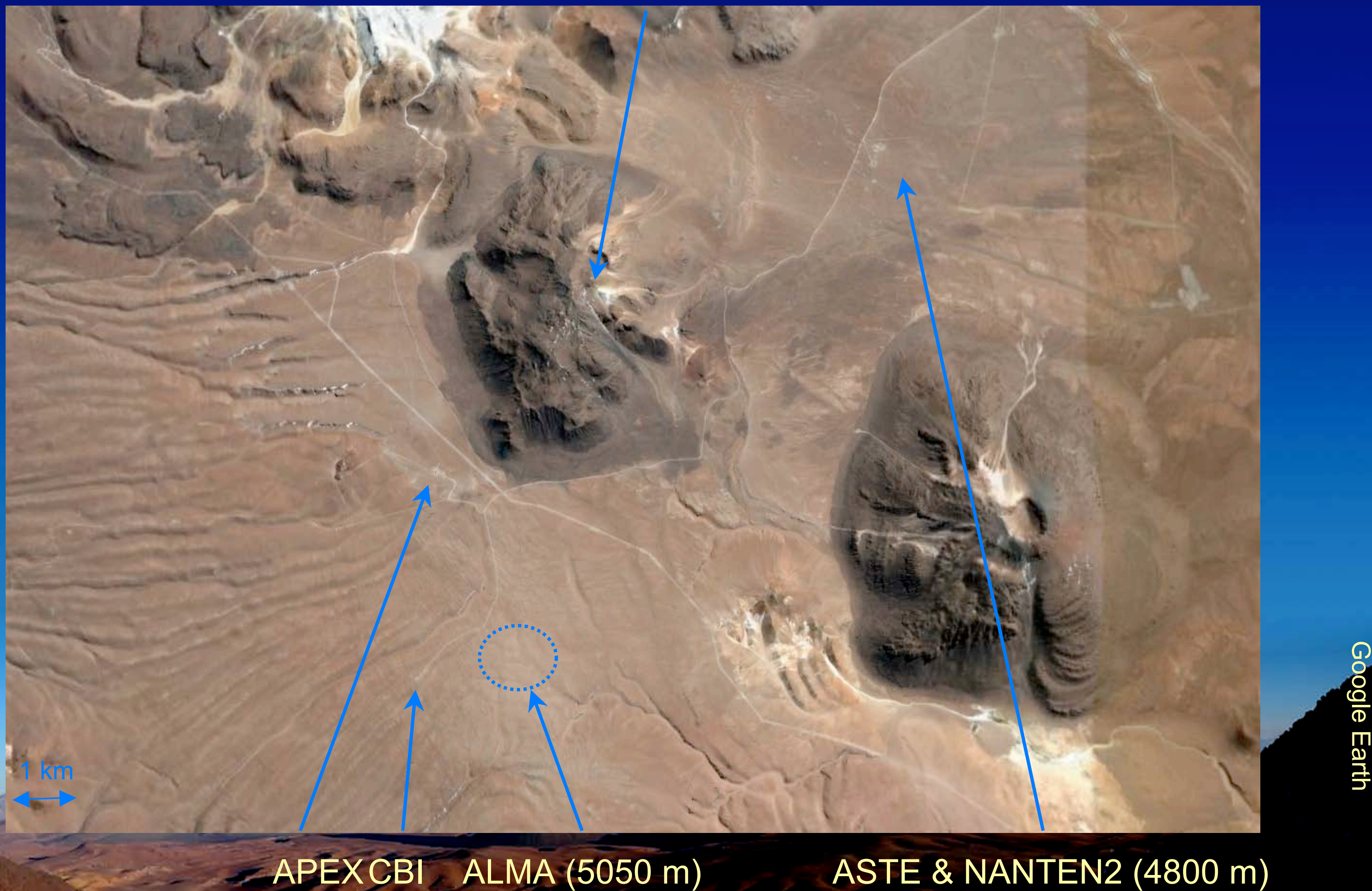
CCAT



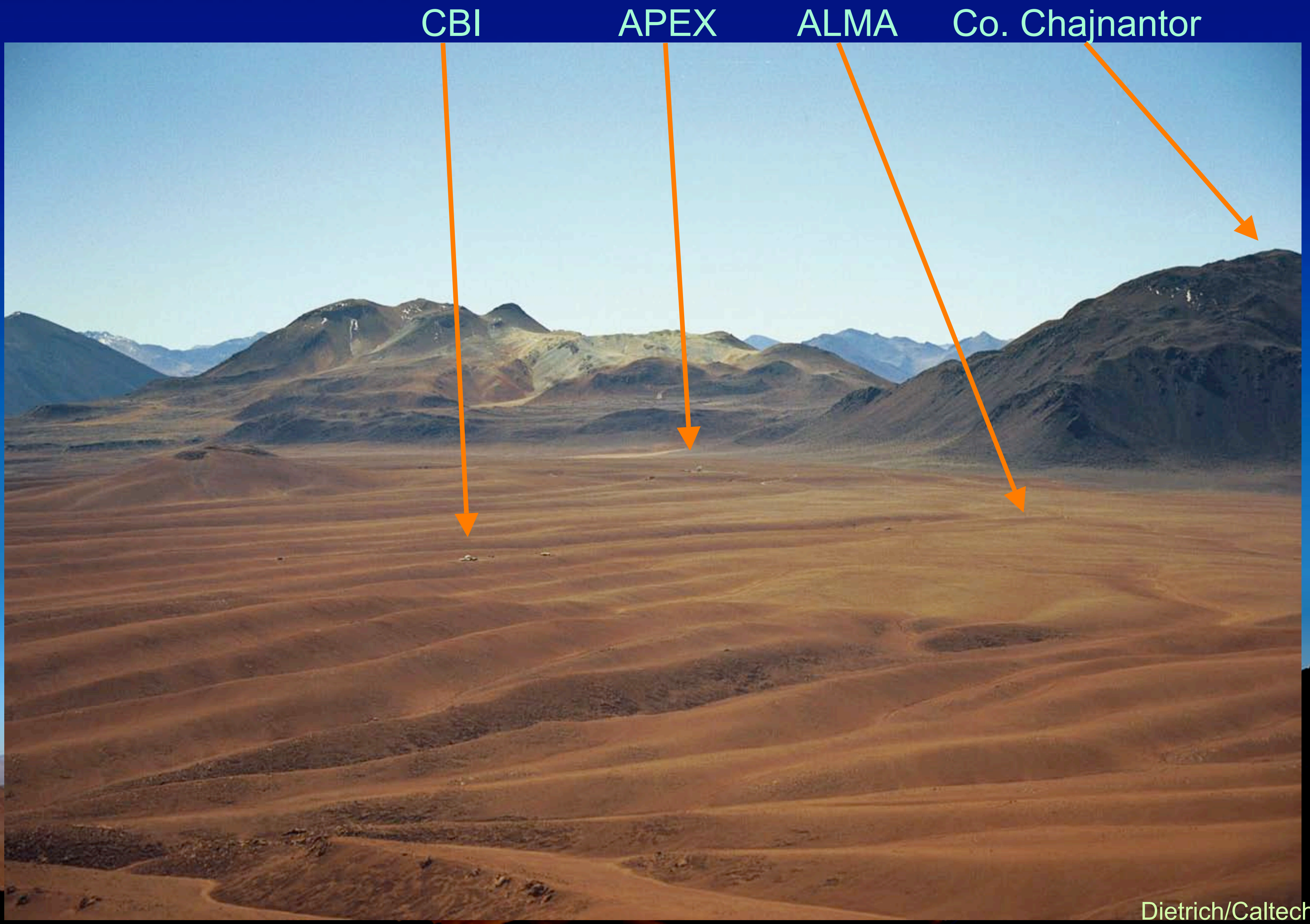
View of Northern Chile (NASA Space Shuttle)

ESO PR Photo 24b/99 (8 June 1999)

Cerro Chajnantor 5612 m

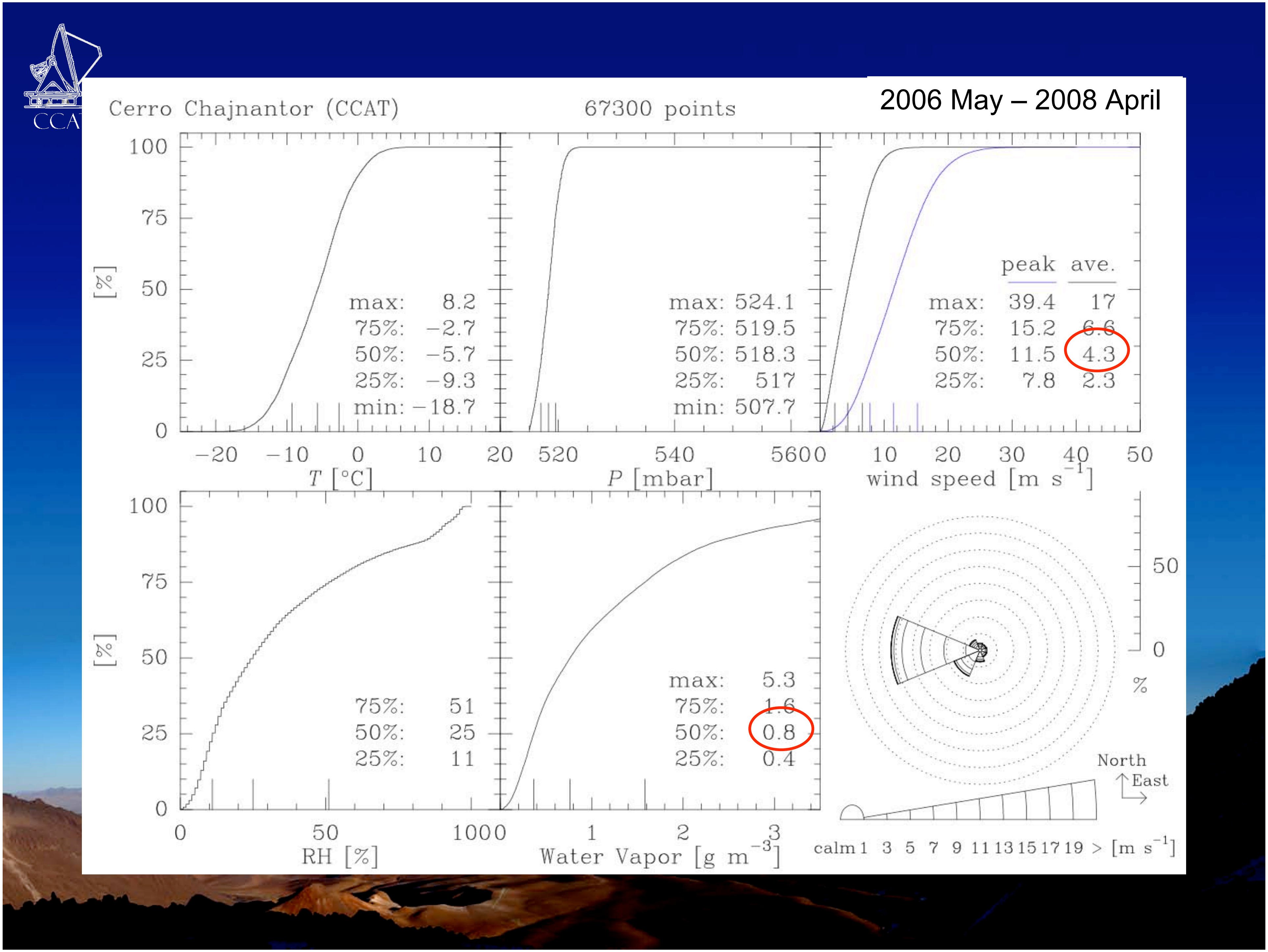


Chajnantor Plateau (5000 m)



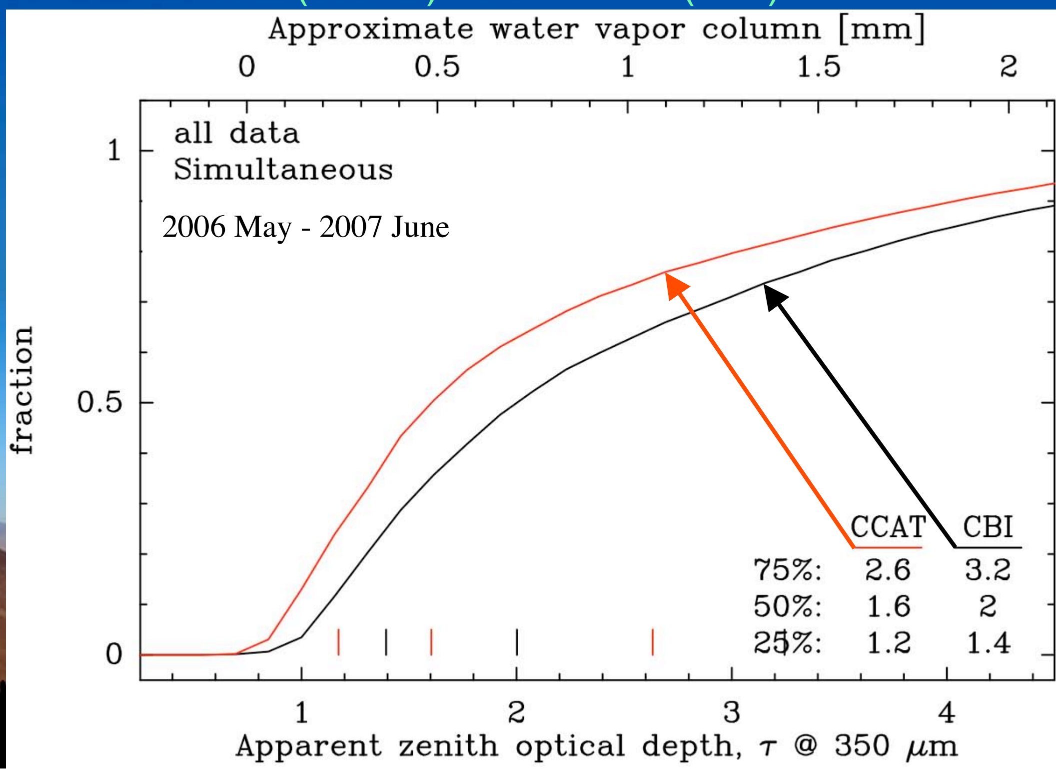
Cerro Chajnantor 5612 m

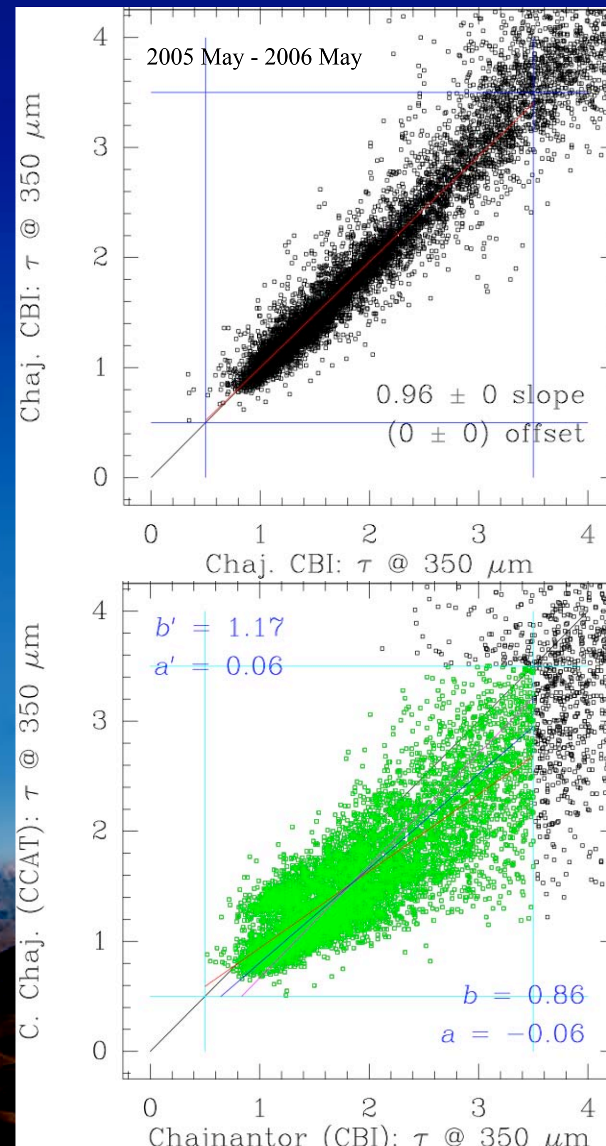
Cerro Chajnantor 5612 m


2006 May – 2008 April
Cerro Chajnantor (CCAT)
67300 points
[%]
max: 8.2
75%: −2.7
50%: −5.7
25%: −9.3
min: −18.7
T [°C]
max: 524.1
75%: 519.5
50%: 518.3
25%: 517
min: 507.7
P [mbar]
peak ave.
max: 39.4 17
75%: 15.2 6.6
50%: 11.5 4.3
25%: 7.8 2.3
wind speed [m s⁻¹]
75%: 51
50%: 25
25%: 11
RH [%]
max: 5.3
75%: 1.6
50%: 0.8
25%: 0.4
Water Vapor [g m⁻³]
North
East
%
calm 1 3 5 7 9 11 13 15 17 19 > [m s⁻¹]

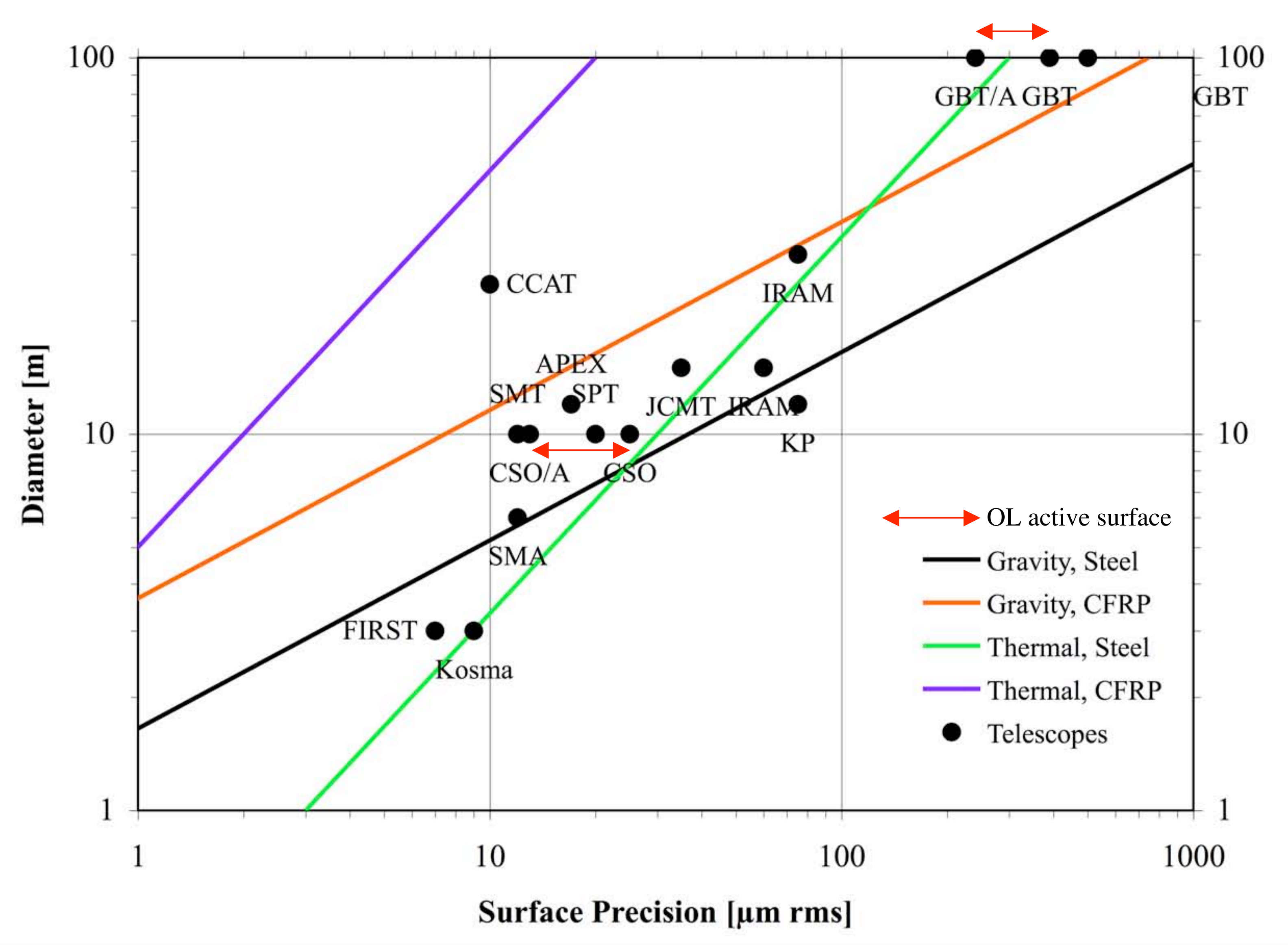
Better 350 µm Transparency

- Two Tippers: CCAT (5600 m) & CBI (5050 m)
- Side-by-Side at CBI: Same Values
- Better Transparency at CCAT
- Less Water Vapor at CCAT
  - $\tau_{off} \approx 0.5$
  - Slope ∝ PVW
  - PWV(CCAT) ≤ 70% PWV(CBI)



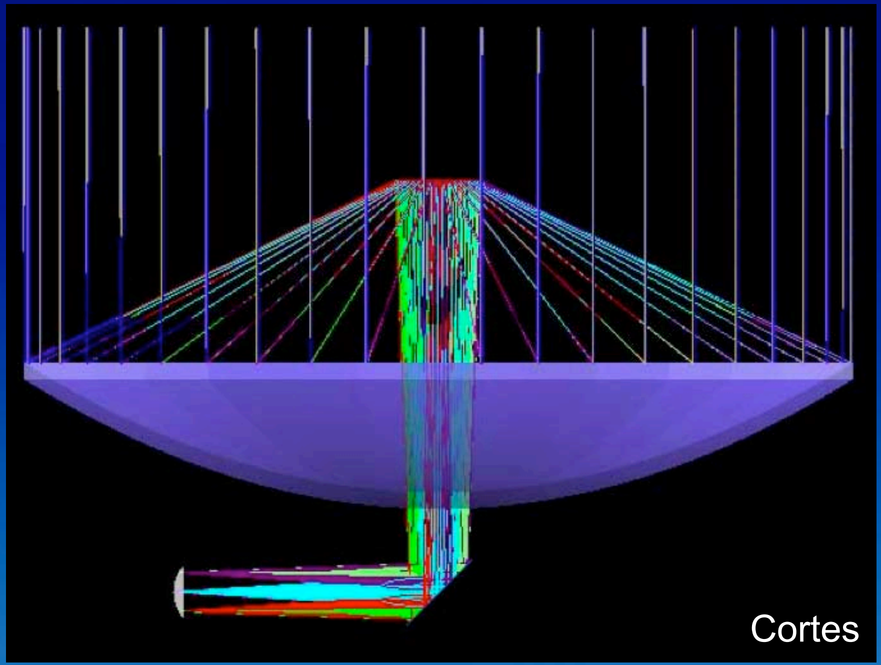


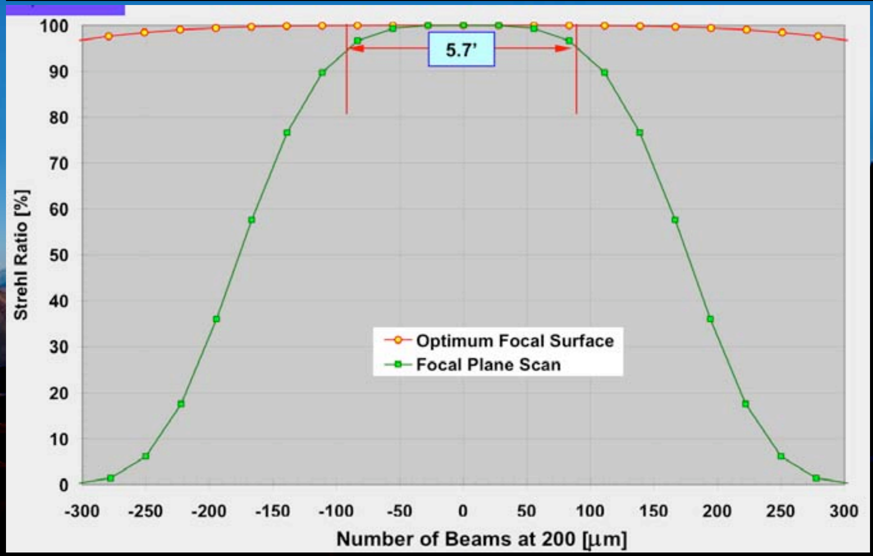
Passive Telescope Limits



Optical Design

- Ritchey Chretién Layout
  - Wide field of view
  - High Strehl ratio
  - High aperture efficiency
- *f* 0.4 Primary Focus
  - Compact telescope
  - Minimum dome
  - Monolithic secondary mirror
- *f* 8 Secondary Focus
  - Match instruments
- Nasmyth Foci
  - Rapid instrument changes
  - Large cameras
- Bent Cassegrain Foci
  - Diagnostic instruments
  - Small instruments

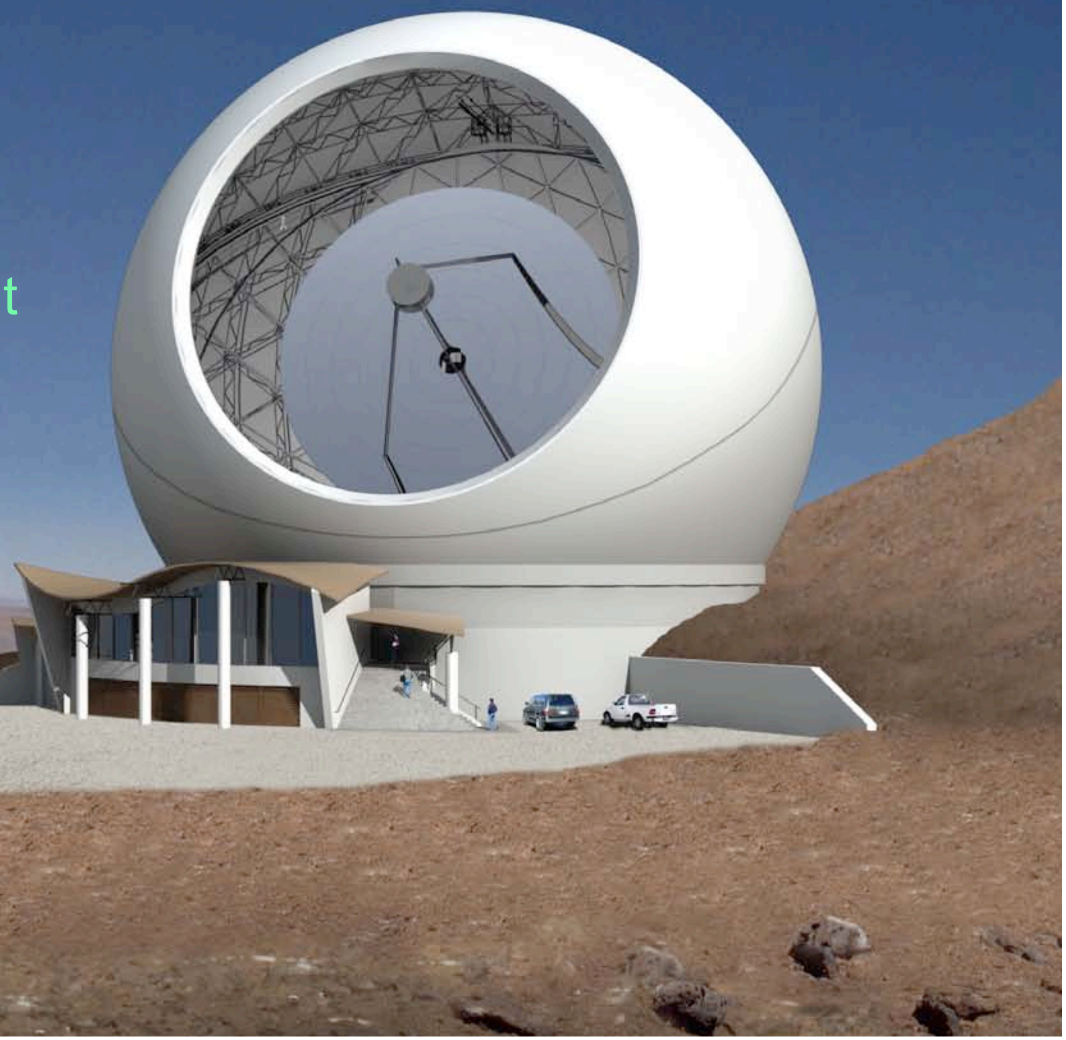




Facility Concept Design
M3 Engineering & Technology

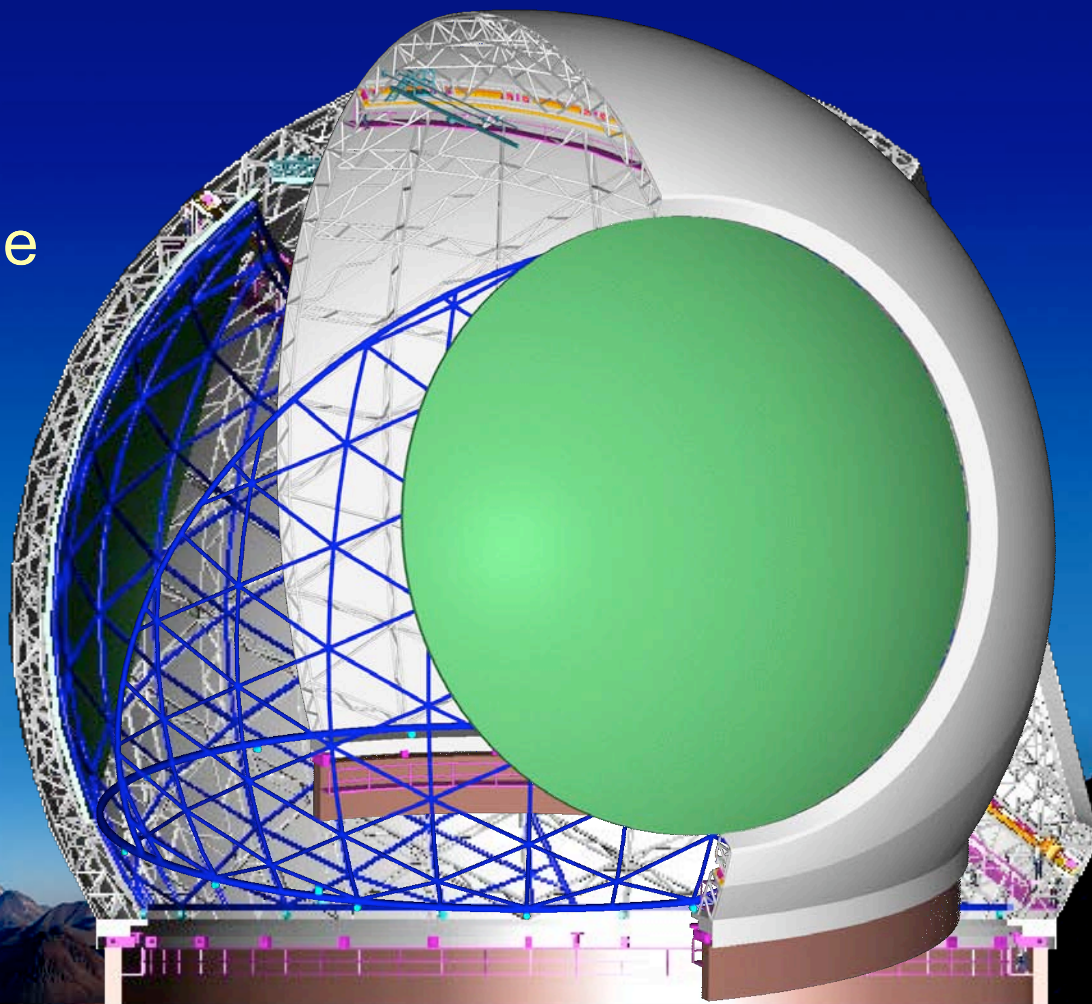
- Summit Facility
- Minimum Size
  - Support Operations
- Oxygen Enrichment
  - Working Areas at Summit

- Base Facility
- Road and Site

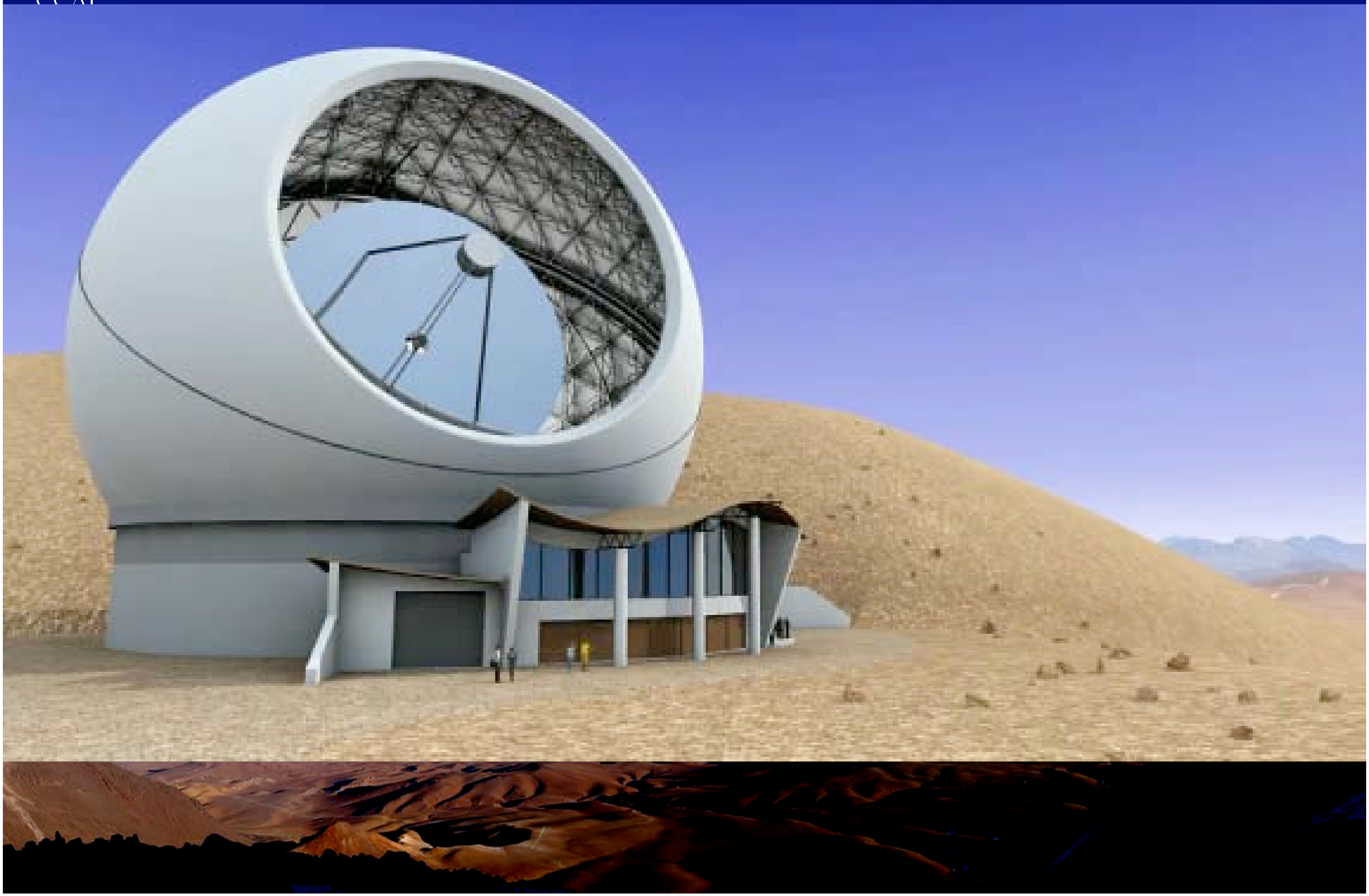


Calotte Dome Concept

- 42 m Diameter
- 28 m Aperture
- Secondary Mirror Inside
- Two Rotation Stages
  - Tilted stage: tech. chall.
- Better Wind Protection
- Less Drive Power
- Internal Closure
- Similar to TMT design
- Emp. Dynamic Struct.



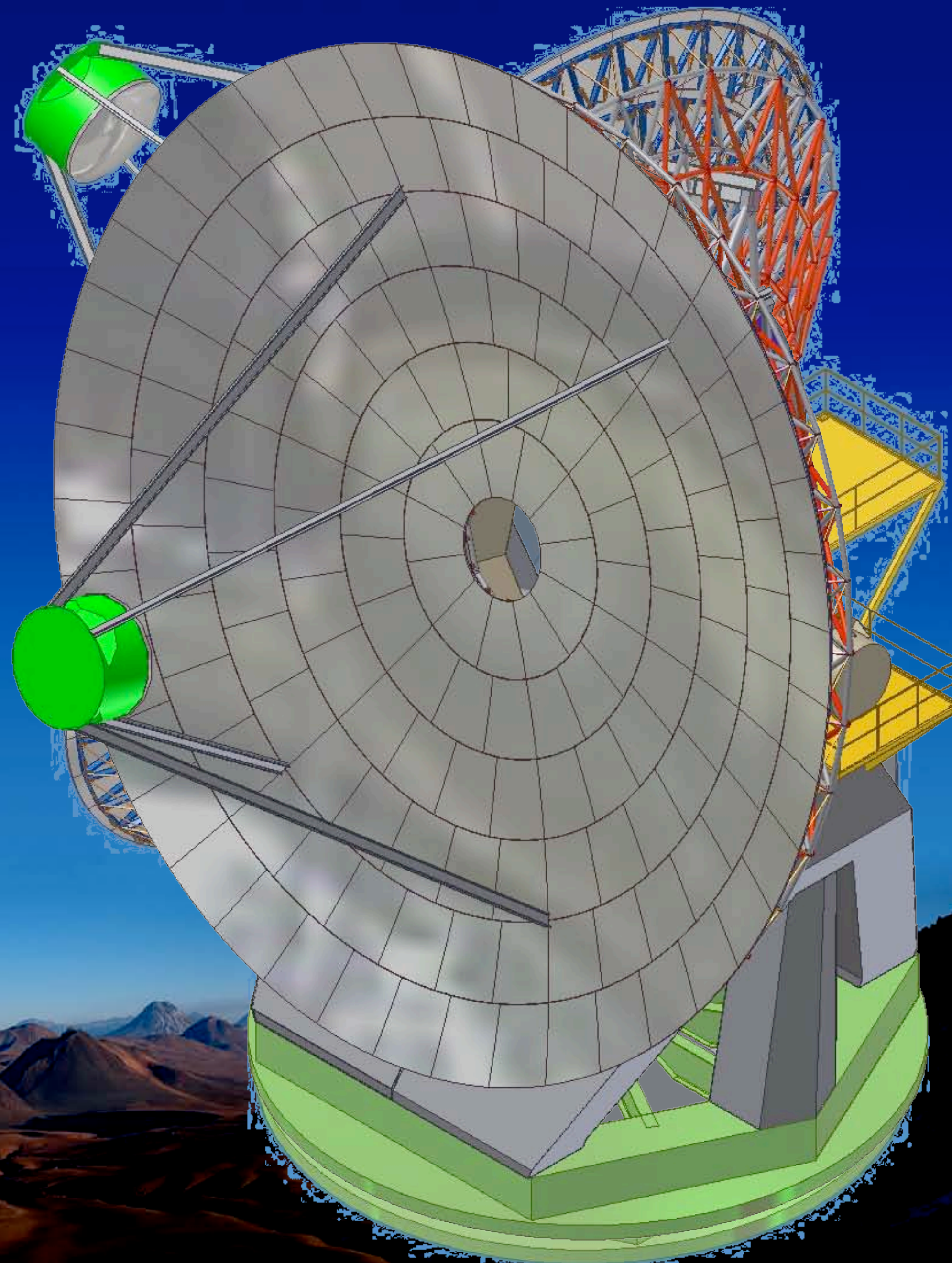
CCAT



CCAT Mount

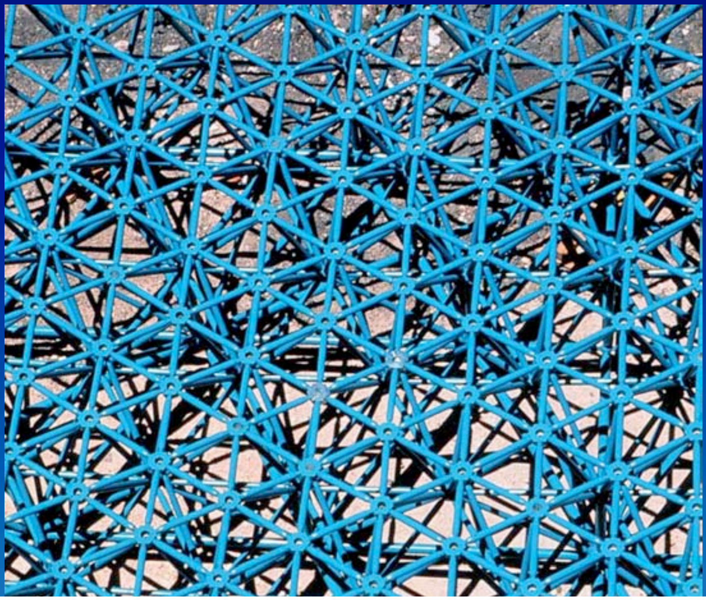
- Combines Radio and Optical Telescopes Approaches
- Hydrostatic (Az) & Rolling Element (El) Bearings
- Vertex RSI Dallas (GD)

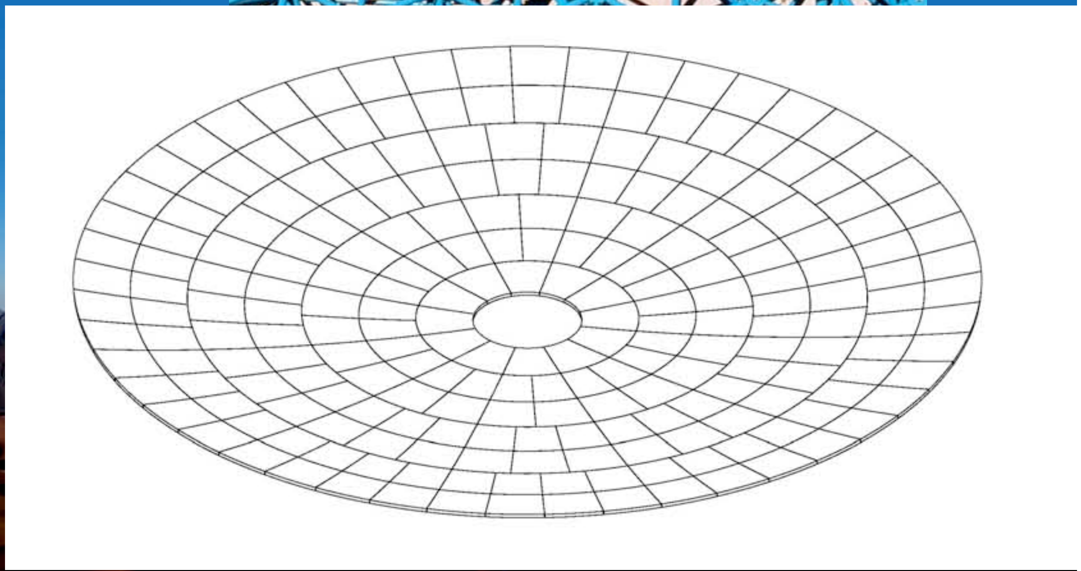
Pointing	2 arcsec RMS
Offset Pointing	0.2 arcsec RMS
Dynamics	0.25 deg/sec
	0.01 deg/sec^2
Unguided Jitter	<0.1 arcsec
Open Loop Drift	0.1 arcsec/min
Max Accel.	2 deg/sec^2
Axis Velocity	1 deg/sec



Primary Mirror Concept

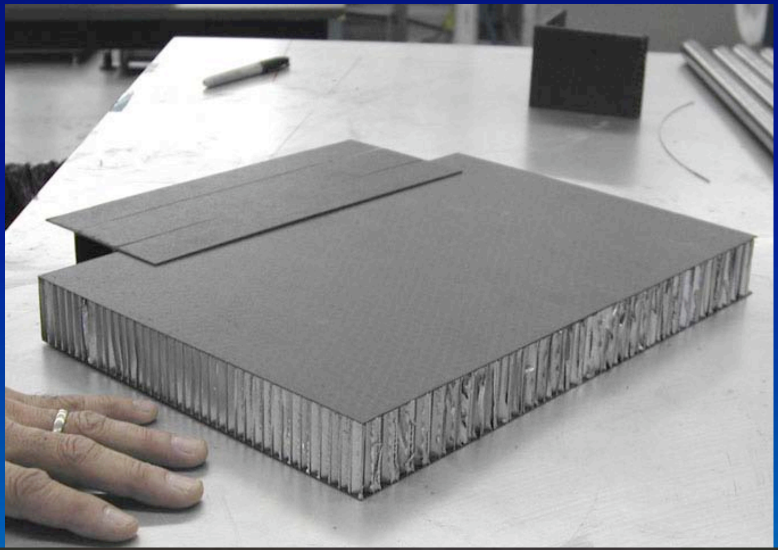
- Closed Loop Active Surface
- Bolted Steel Truss
  - CFRP possible if low cost
- 7 Rings of Panels
  - 210 Panels @ 1.7 m
- 3 Actuators per Panel
  - Kinematic bipod flexures

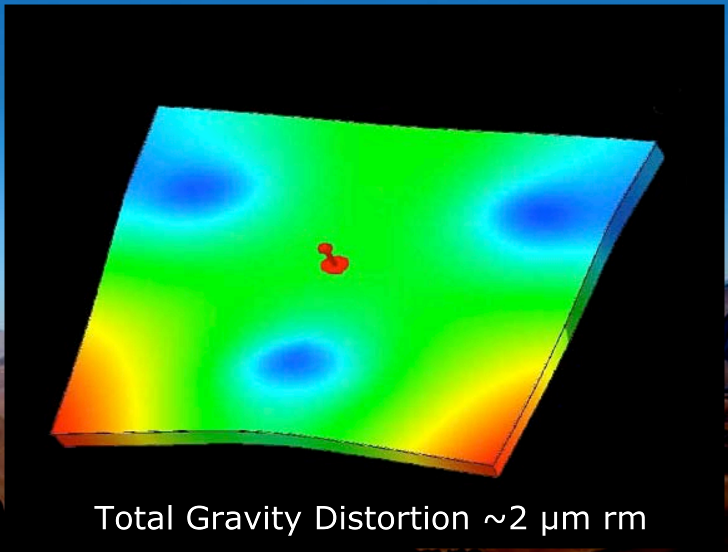


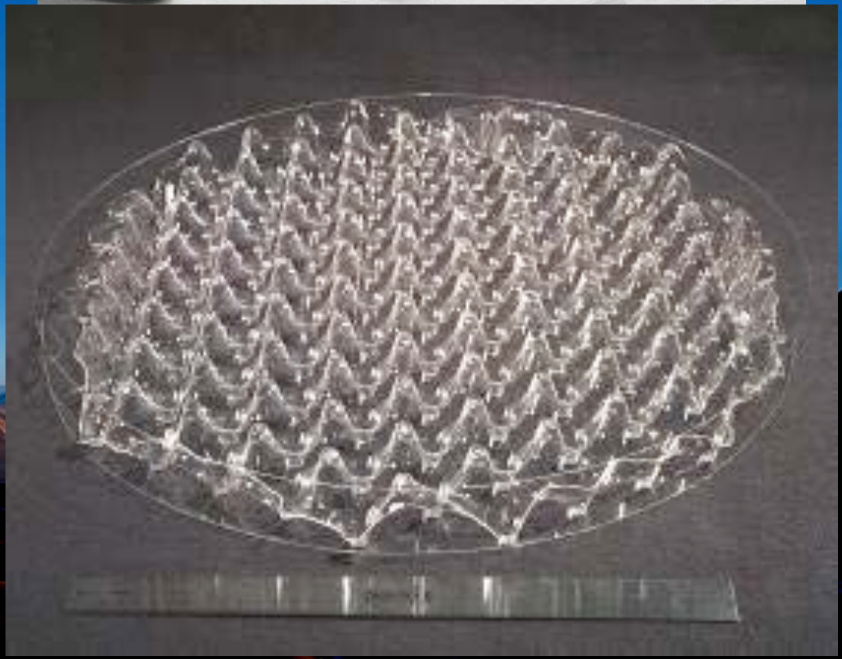


Primary Mirror Panels

- Possible Panel Techs.
  - CFRP/Al Sandwich
  - Lightweight Borosilicate
  - Ni/Al Sandwich
  - Al/Al Sandwich
- ~8 kg m^{-2} Areal Density
- ~5 μm rms <u>Total</u> Error

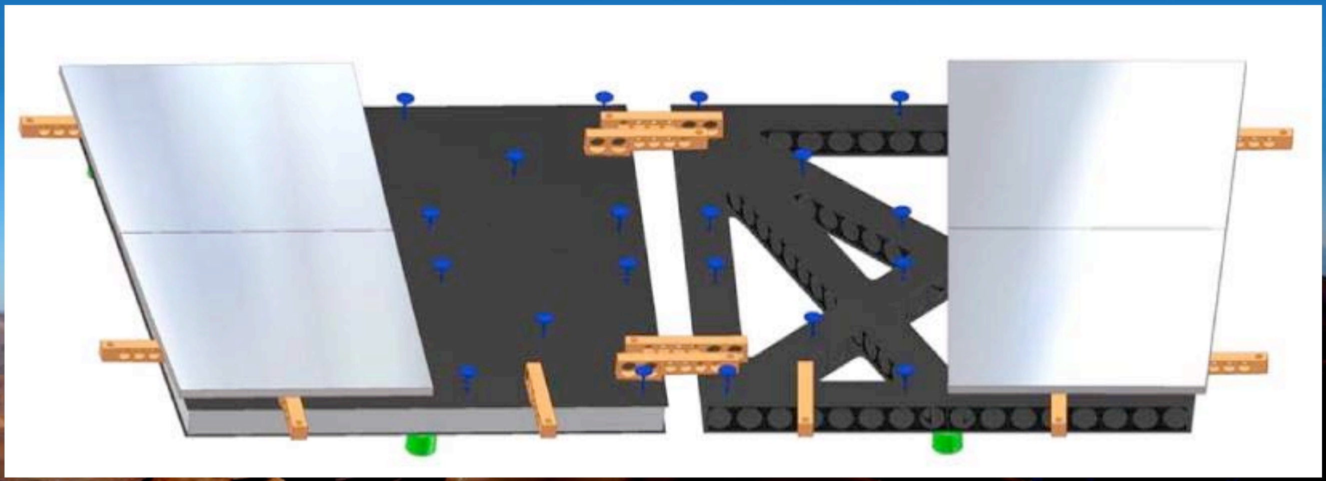






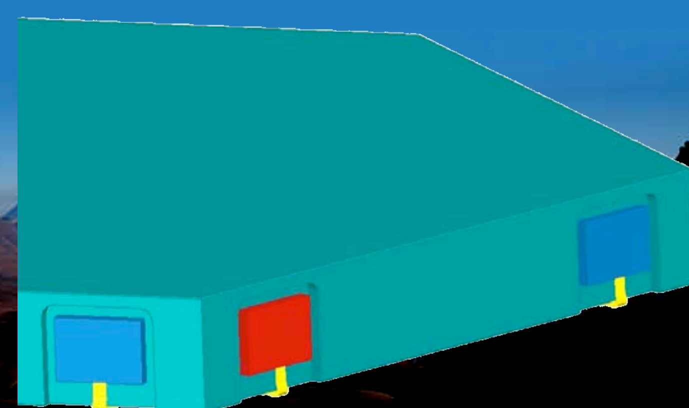
Hybrid Panels

- Separate functions: support and optical surface
- CFRP sub-frames provide stiff, thermally stable platform
  - Exploit excellent thermal & structural properties of CFRP
  - Sensors mounted to frames
- Precision reflecting tiles mounted on sub frame (similar to LMT)
  - Better manufacturing and performance of small panels
  - Tiles aligned with high precision measuring machine
- Extra layer of structure
  - Weight, complexity

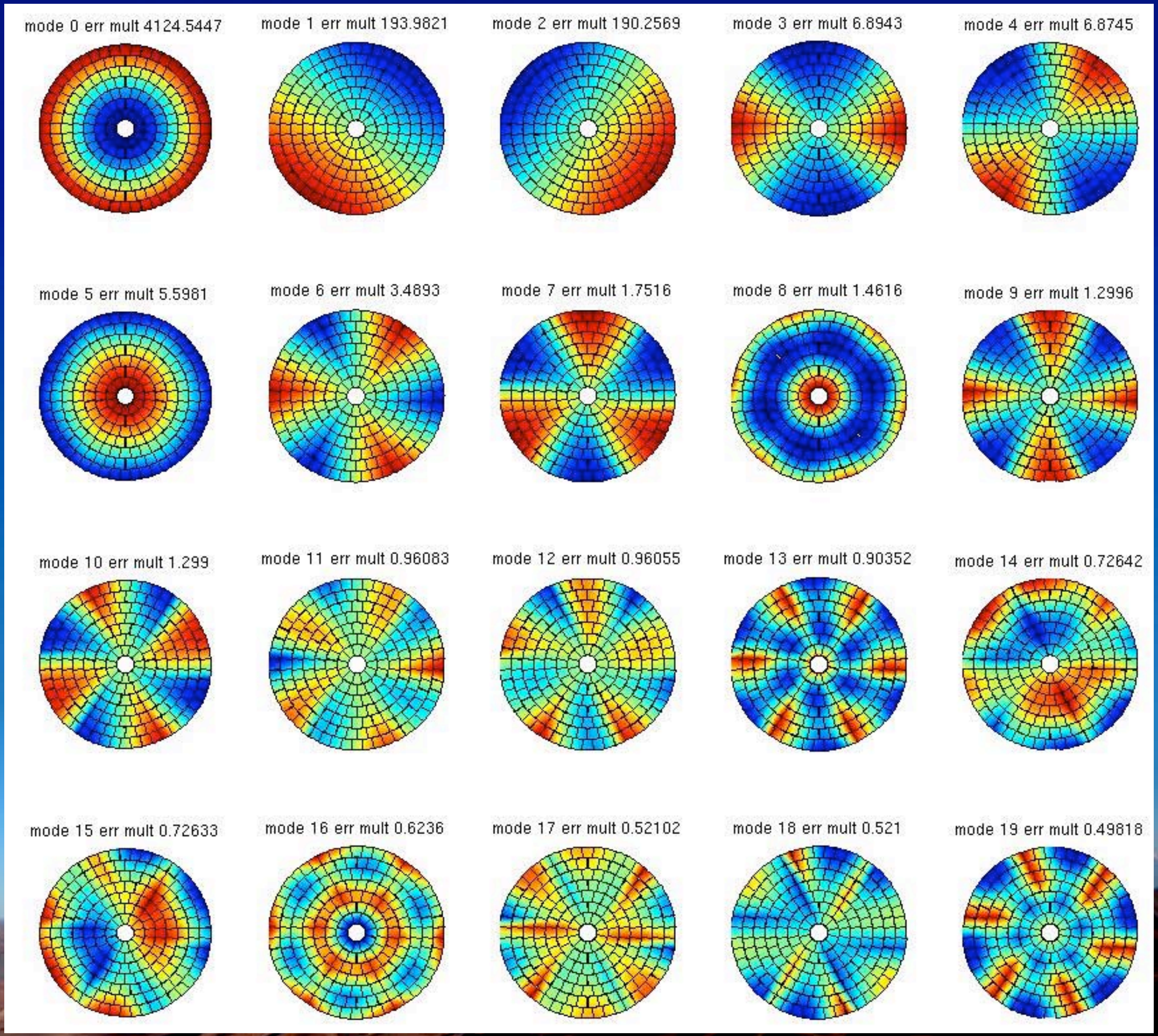


Active Surface Alignment

- Sensing and Control Model
  - D. MacDonald (JPL), D. Woody (OVRO)
  - Sensor response to segment motions, modal analysis
  - Closed loop control to maintain surface
  - Low sensor sensitivity to global modes, i. e., focus, tilt, astig.
  - Thermal and gravity segment distortions disrupt control
- “Edge” Sensors
  - Displacement and dihedral information at segment borders
  - Necessary but not sufficient



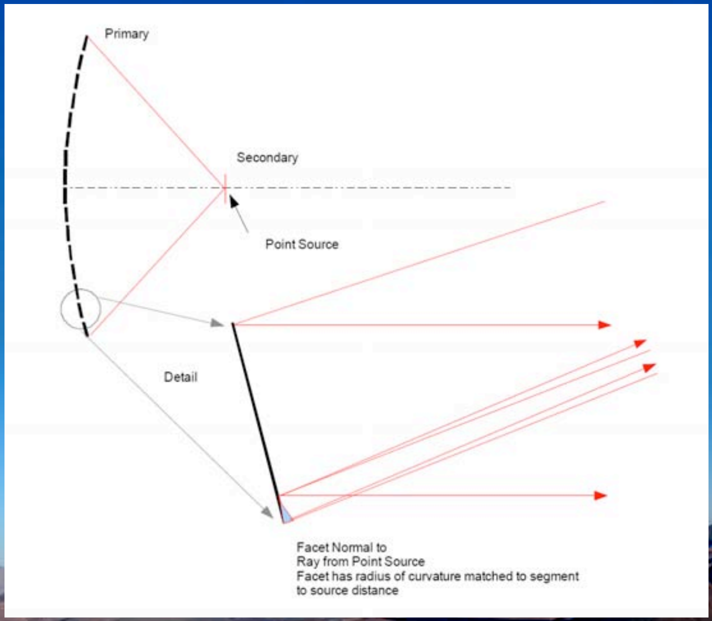
CCAT *f* = 0.4 Mirror Modes

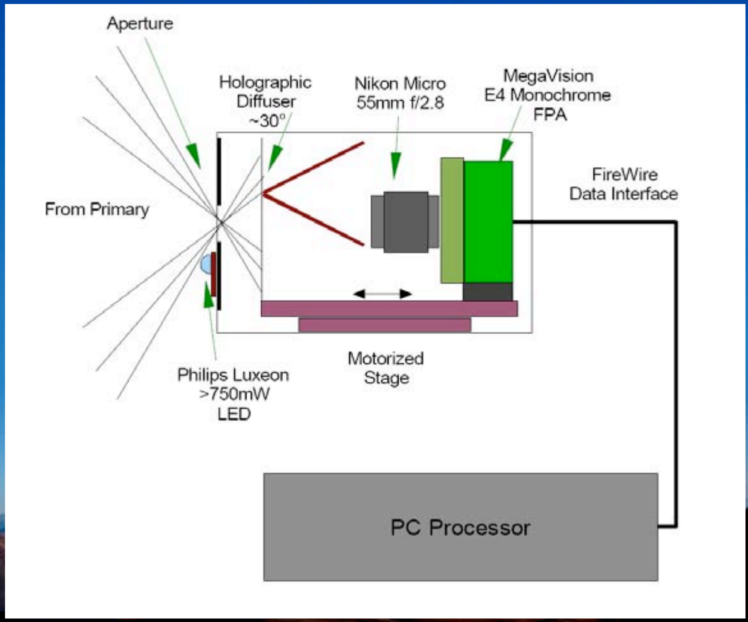


Displacement sensors on 55 mm fingers

Segment Tilt Sensor

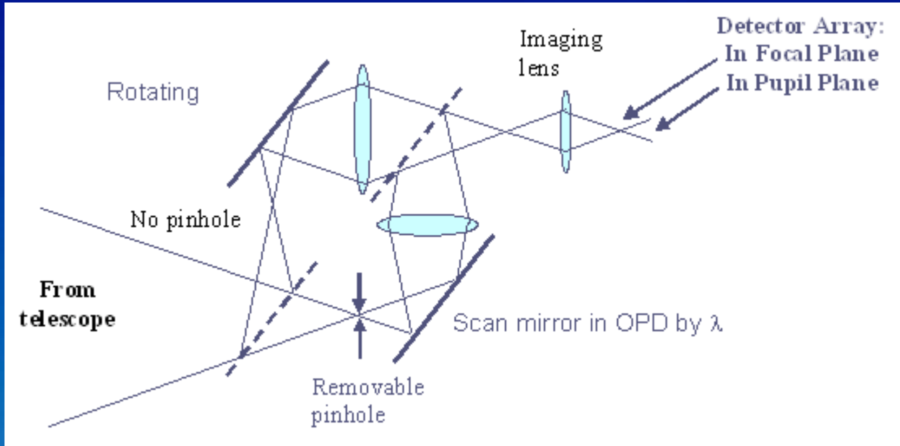
- Optical system measures segment tilts
- Complements edge sensors
- Improves mirror control
- Concept design by Adaptive Optics Associates





Surface Alignment Calibration

- Initial Panel Alignment
  - Optomechanical
  - Photogrammetry
- Submm Interferometry
  - Uses Distant Planets
    - Mars, Uranus, & Neptune
  - Three Techniques Proposed
    - Shearing with Single Detector
    - Shearing with Extended FPA
    - Point Diffraction Interferometer
  - Single Detector Used at CSO
  - Arrays Improve Systematics?



Hybrid Interferometer

Hybrid Interferometer Combines Three Types in One Instrument

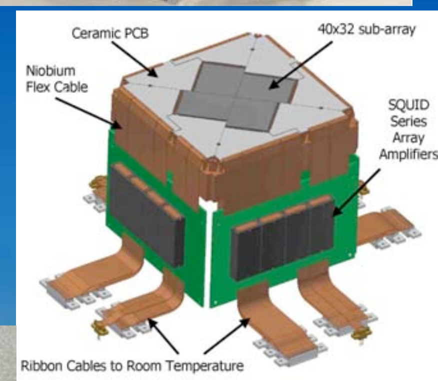
G. Serabyn, JPL

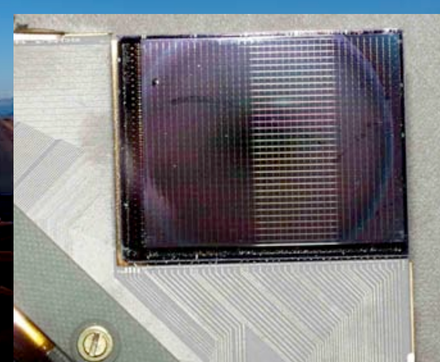
CCAT Instruments

- Direct Illumination Cameras
  - SCUBA2: 450 & 850 μm
  - SWCam: 200–620 μm
- Antenna Coupled Camera
  - LWCam: 700–2000 μm
- Spectrometers
  - Multiobject gratings
- Heterodyne Receivers
  - Array cameras
  - ALMA receiver, connect to ALMA, VLBI
- Legacy Instrumentation

Direct Illumination Cameras

- SCUBA2 (UK ATC, Canada)
  - To JCMT in 2007
  - On CCAT, would be:
    Proven first light instrument
    2.7' at 450 μm, 5' at 850 μm
- CCAT SW Camera (concept)
  - 200 μm, 350 μm, 450 μm, 620 μm
  - Single color with filter wheel
  - NIST TES silicon bolometers
  - Total: 32 000 pixels
  - 5' field of view @ 350 μm

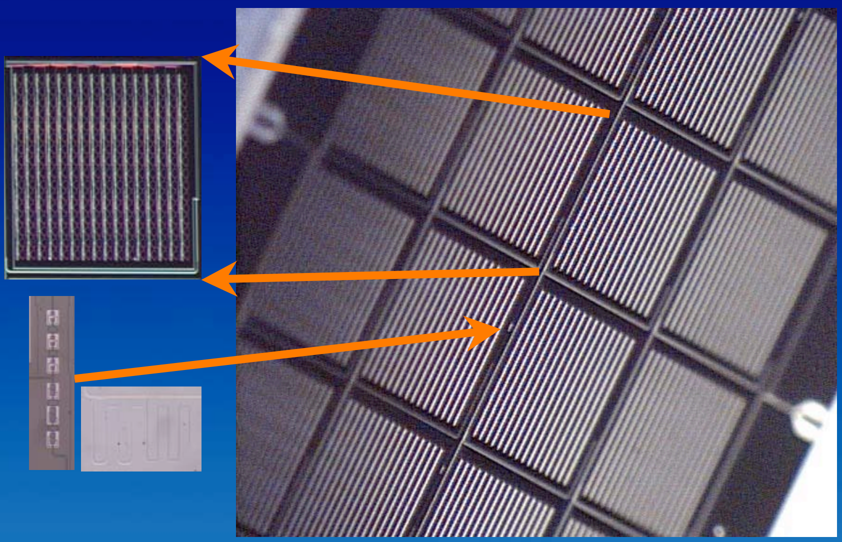


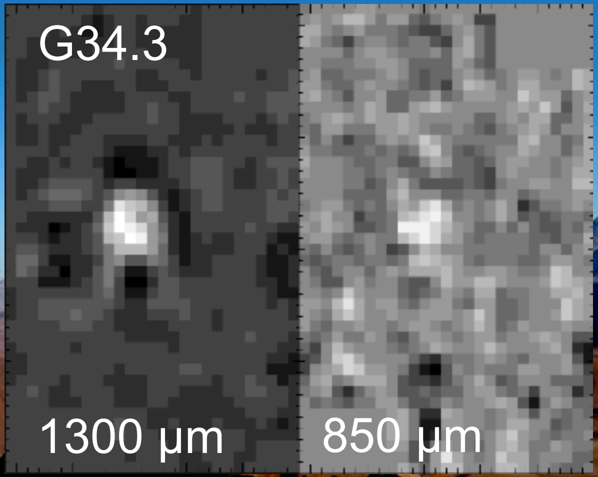


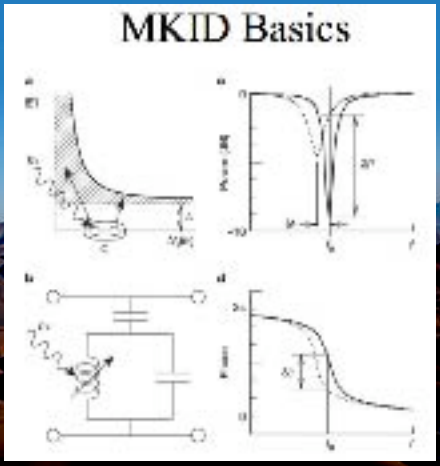
Antenna Coupled MKID Camera

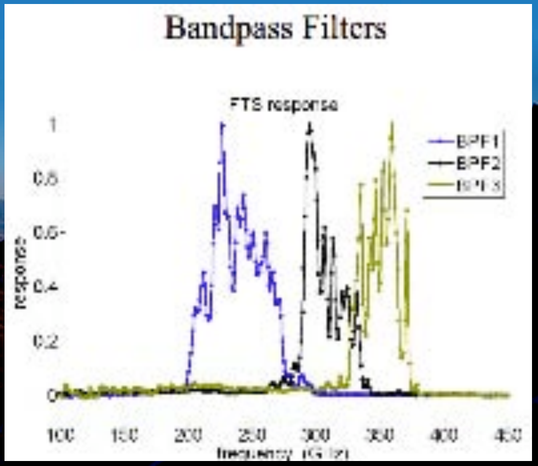
- CSO camera (CIT, Colorado)
  - DemoCam, 4x4 pixels, two colors
  - CSO observations in 2007 April
  - Successor funded, NSF ATI
  - 24x24 pix, 4 color 750-1300 µm
- CCAT LW Camera (concept)
  - 750–2000 µm, 45 000 pixels
  - Up to 20' x 20' Field of View

Antenna coupled array
1300 & 850 µm



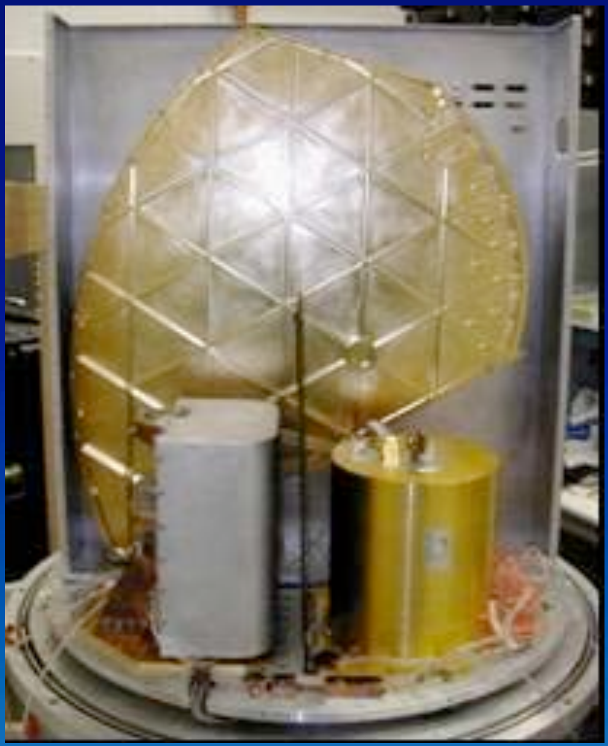


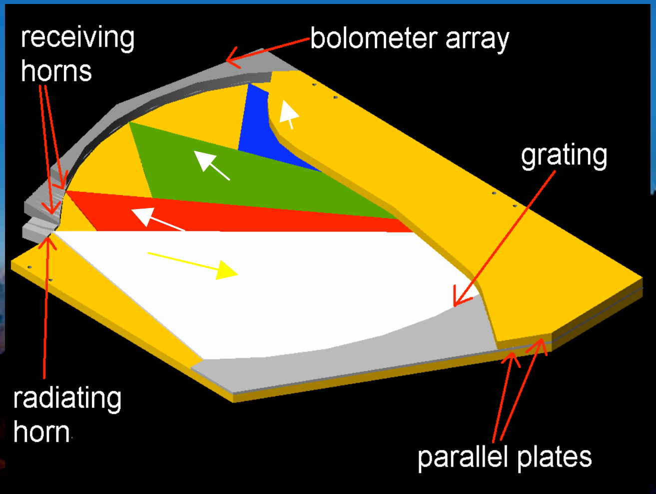




Spectrometers

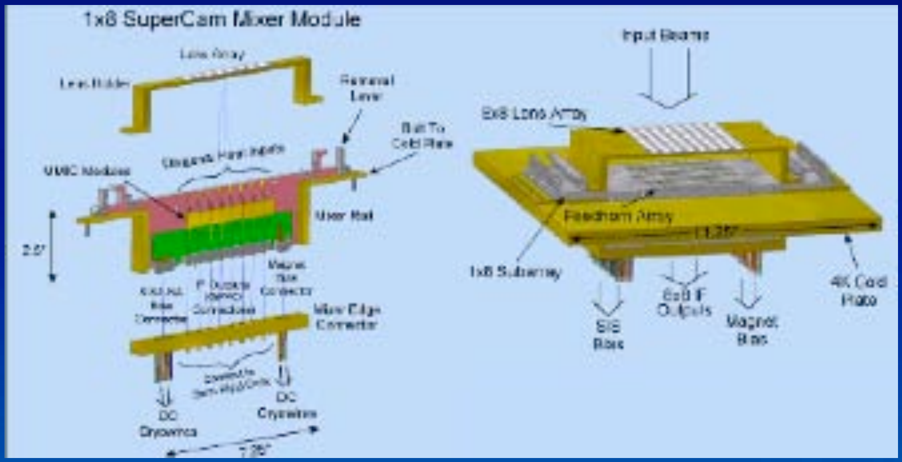
- Zeus (Cornell)
  - Long slit echelle grating
  - 350, 450, 610 μm, R ~ 1000
  - Already to CSO
- Z-Spec (CIT, JPL, Colorado)
  - Parallel plate grating cavity
  - 190–310 GHz, R ~ 250 to 400
  - Already to CSO (2005 June)
- Multiobject
  - Flexible dielectric waveguide
  - Optical relays
  - Laboratory studies

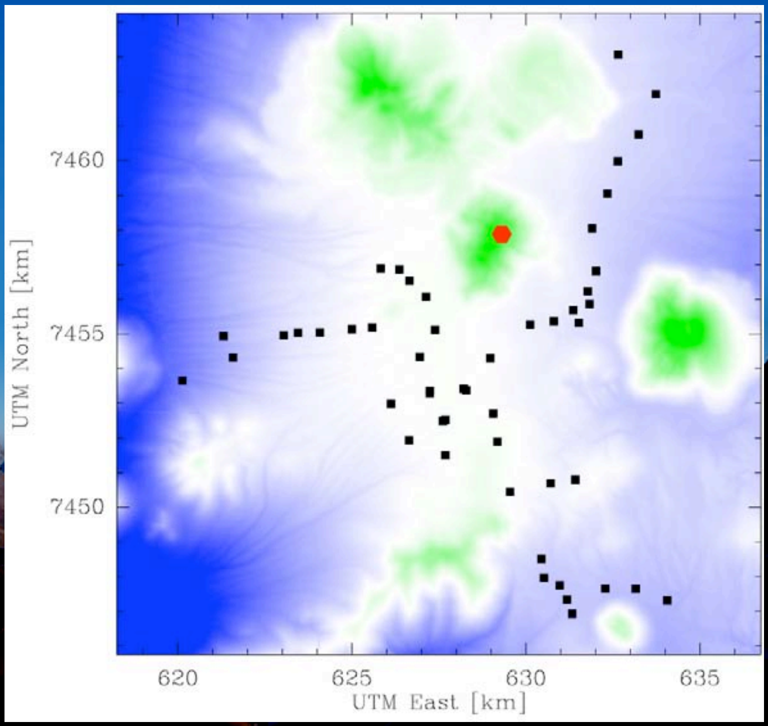




Heterodyne Receivers

- Super Cam (Arizona)
  - 64 pixels, 330–360 GHz
  - FPGA spectrometers
  - 1 GHz IF BW
  - Under development
- CHARM (concept)
  - 64–128 pixels, 650–700 GHz
  - 2–4 GHz IF BW
  - Digital spectrometers
- ALMA Receivers
  - Anchor for long baselines
  - At 350 μm, add 14% sens.
  - Improve dirty sidelobe levels
    - 9% ⇒ 7% (Holdaway)
  - Also VLBI





Consortium

- Caltech
  - Includes JPL involvement
- Cornell University
- University of Colorado Boulder
- UK Astronomy Technology Centre (STFC)
- Canada (Univs. of BC & Waterloo)
- Germany (Univs. Cologne & Bonn)
- Other Institutions Interested

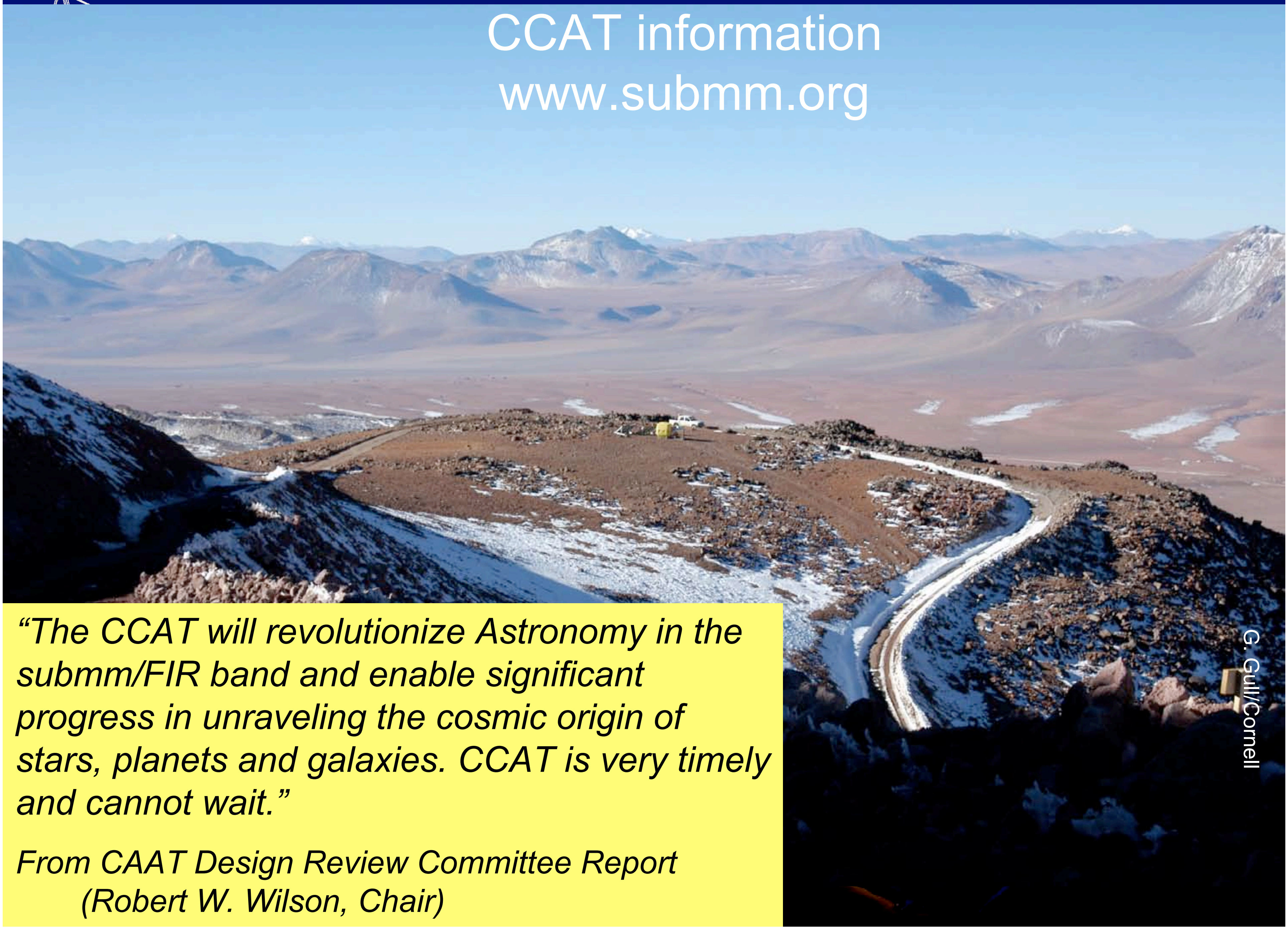
Interim Consortium Agreement Signed in 2007

Full Project Agreement Planned in 2008

Project Phases and Schedule

- Feasibility/Concept Design Study
  - 2004 – 2006
  - Cornell, Caltech, & JPL: Develop Baseline Concept, Assess Feasibility, Initial Cost Estimate
- Consortium Development Phase
  - 2006 – 2008
  - Complete Consortium, Identify & Secure Funding
  - Address Key Technical Issues
- Technical Development Phase
  - 2008 – 2012
  - Detailed Design, Manufacture, Integration
- Commissioning Phase
  - 2013
  - Optimize Performance & Handover to Operations

CCAT information
www.submm.org



“The CCAT will revolutionize Astronomy in the submm/FIR band and enable significant progress in unraveling the cosmic origin of stars, planets and galaxies. CCAT is very timely and cannot wait.”

From CAAT Design Review Committee Report
(Robert W. Wilson, Chair)