The Cornell Caltech Atacama Telescope

2007 January 18

NRAO – UVa

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Simon Radford	Deputy Project Manager
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Paul Goldsmith	JPL Group Leader

CCAT Science Committee

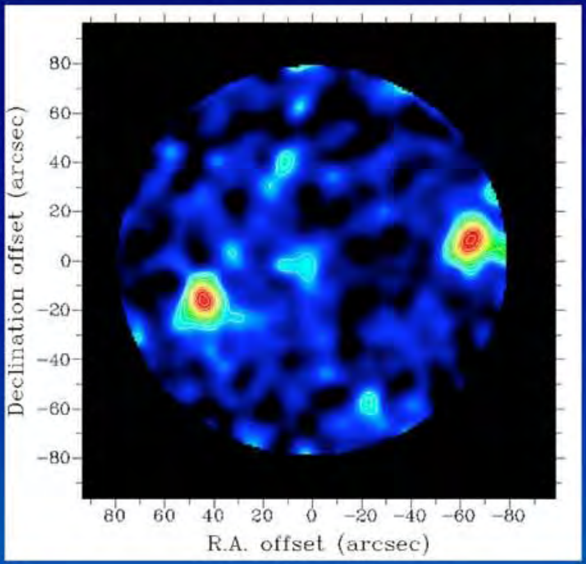
- Co-Chairs
  - Terry Herter (Cornell) and Jonas Zmuidzinas (CIT)

Theme	Lead
Distant Galaxies	Andrew Blain (CIT)
Sunyaev-Zeldovich Effect	Sunil Golwala (CIT)
Local galaxies	Gordon Stacey (Cornell) + Shardha Jogee (UT)
Galactic Center	Darren Dowell (JPL/CIT)
Cold Cloud Cores Survey	Paul Goldsmith (JPL) + Neal Evans (UT)
Interstellar Medium	Jonas Zmuidzinas (CIT)
Circumstellar Disks	Darren Dowell (JPL/CIT)
Kuiper Belt Objects	Jean-Luc Margot (Cornell)

- Ex-officio
  - Riccardo Giovanelli (Cornell), Simon Radford (CIT)
- More details in **CCAT Feasibility Concept Study Report**

www.submm.org

Why CCAT ?



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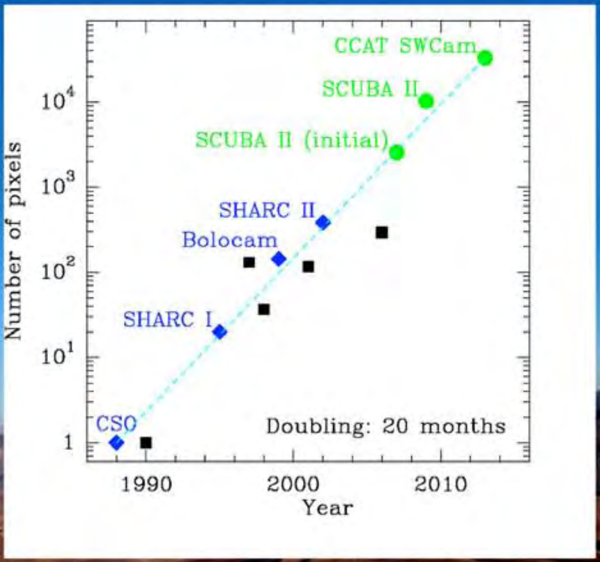

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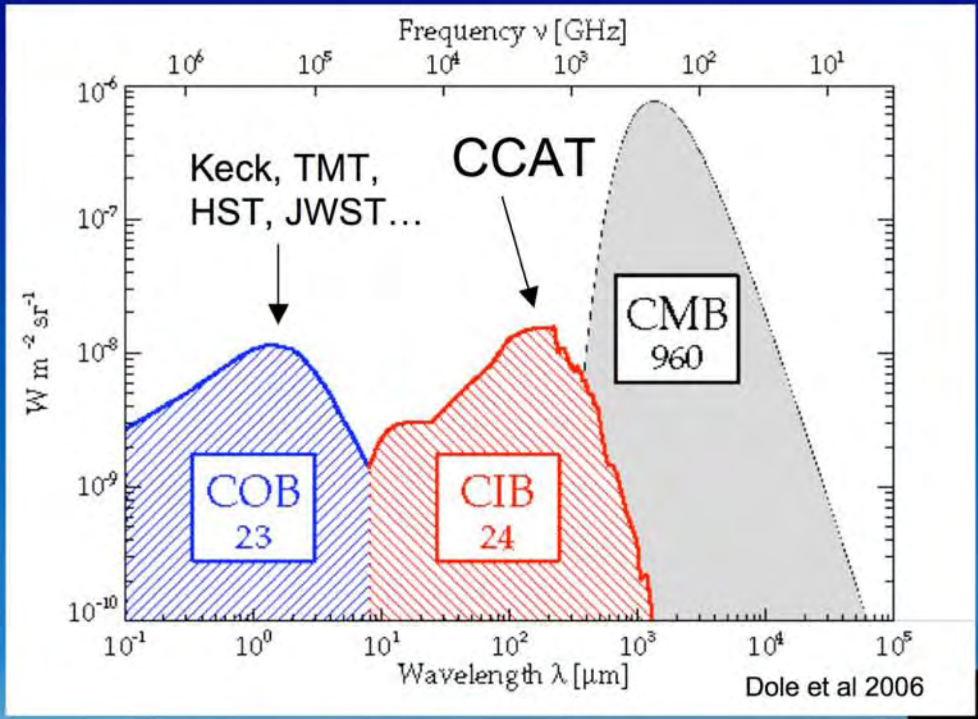
CCAT
25 m, 10 μm rms
Cerro Chajnantor

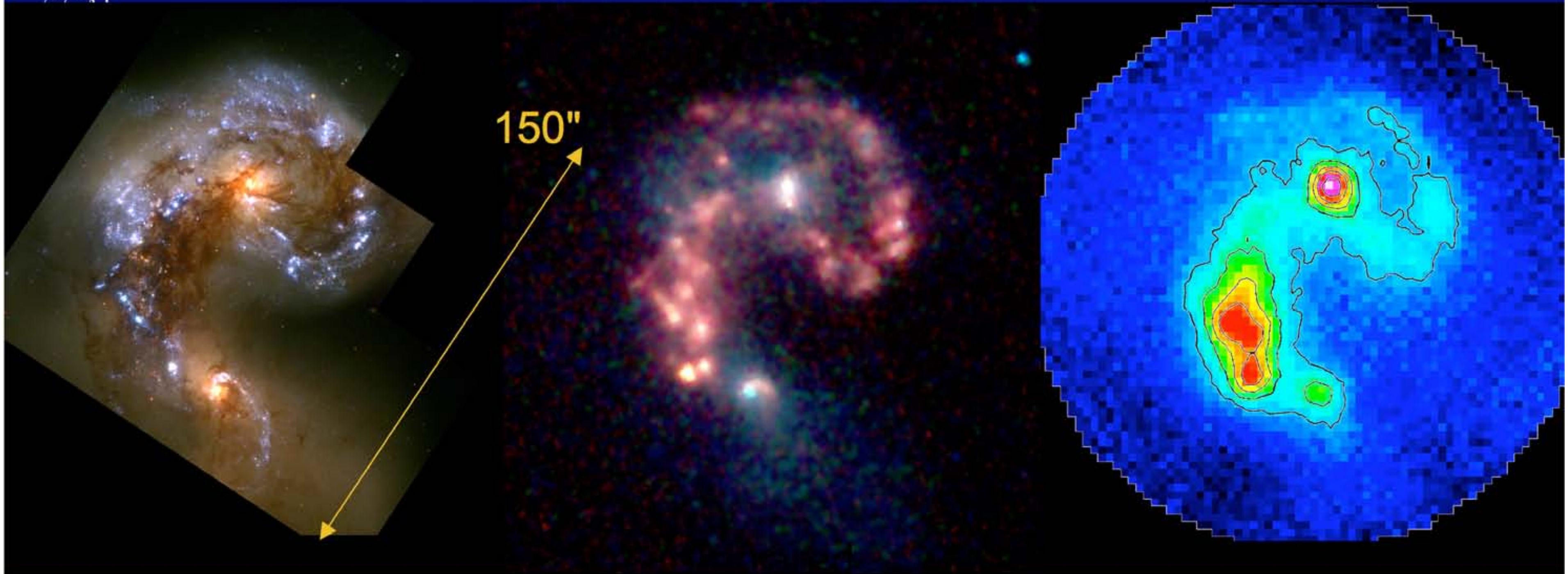
CCAT Science Strengths

- Past decade: submillimeter astronomy is important !!
- CCAT:
  - Is larger, more sensitive
  - Is designed specifically for wide-field imaging
  - Has wide spectral coverage
  - Is *excellent* at 350 μm
    - site, surface
  - Has 4" resolution @ 350 μm
  - Will give multicolor information (SED)
  - Will study high *z* tail of CIB
- CCAT will complement ALMA
  - Fast mapping vs. high angular & spectral resolution
  - Comparable sensitivities: targets for ALMA
- Clusters (SZ), submm galaxies, star-forming regions & cores, debris disks, KBOs



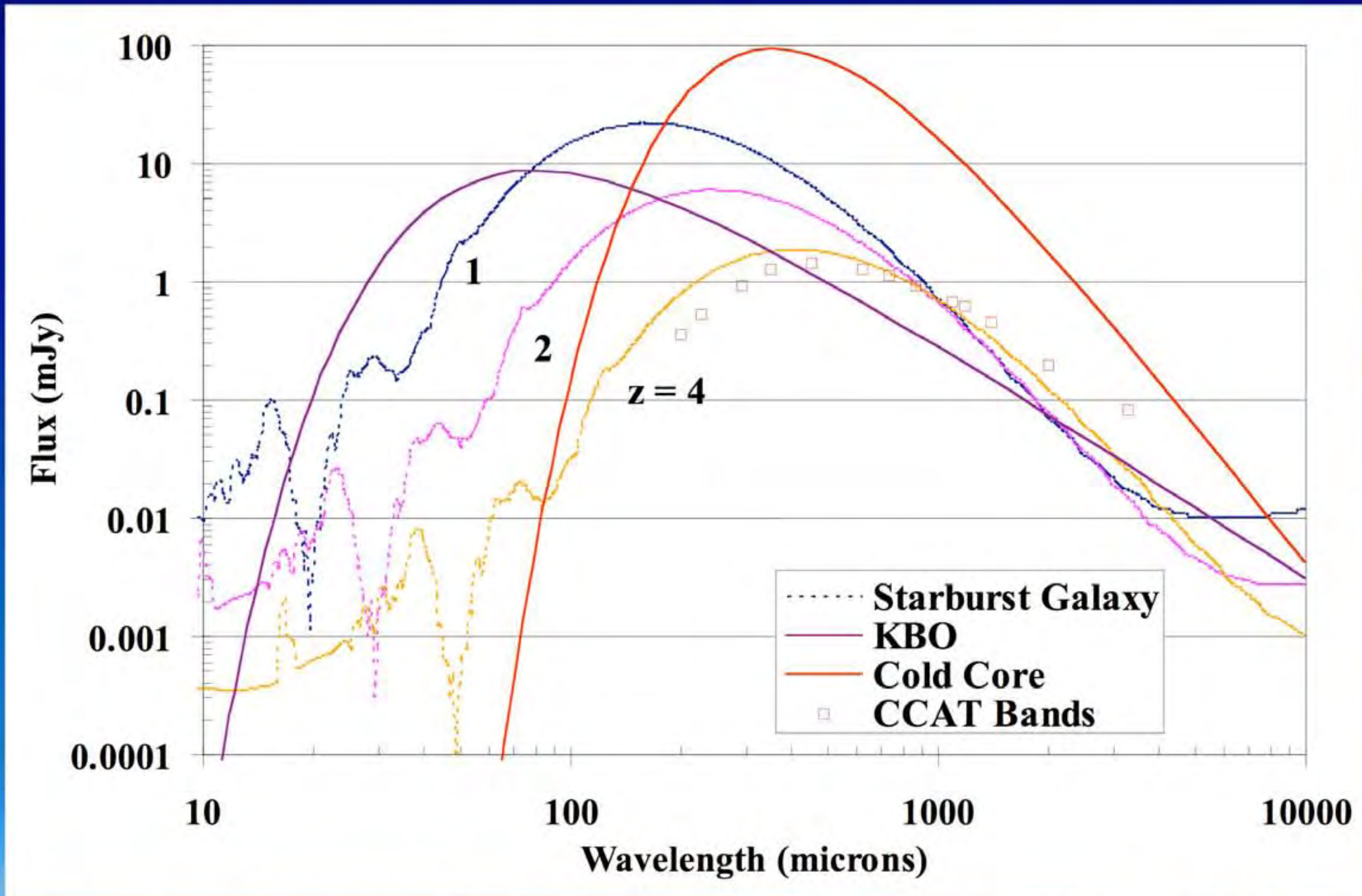
Dole et al 2006

Interacting Galaxies



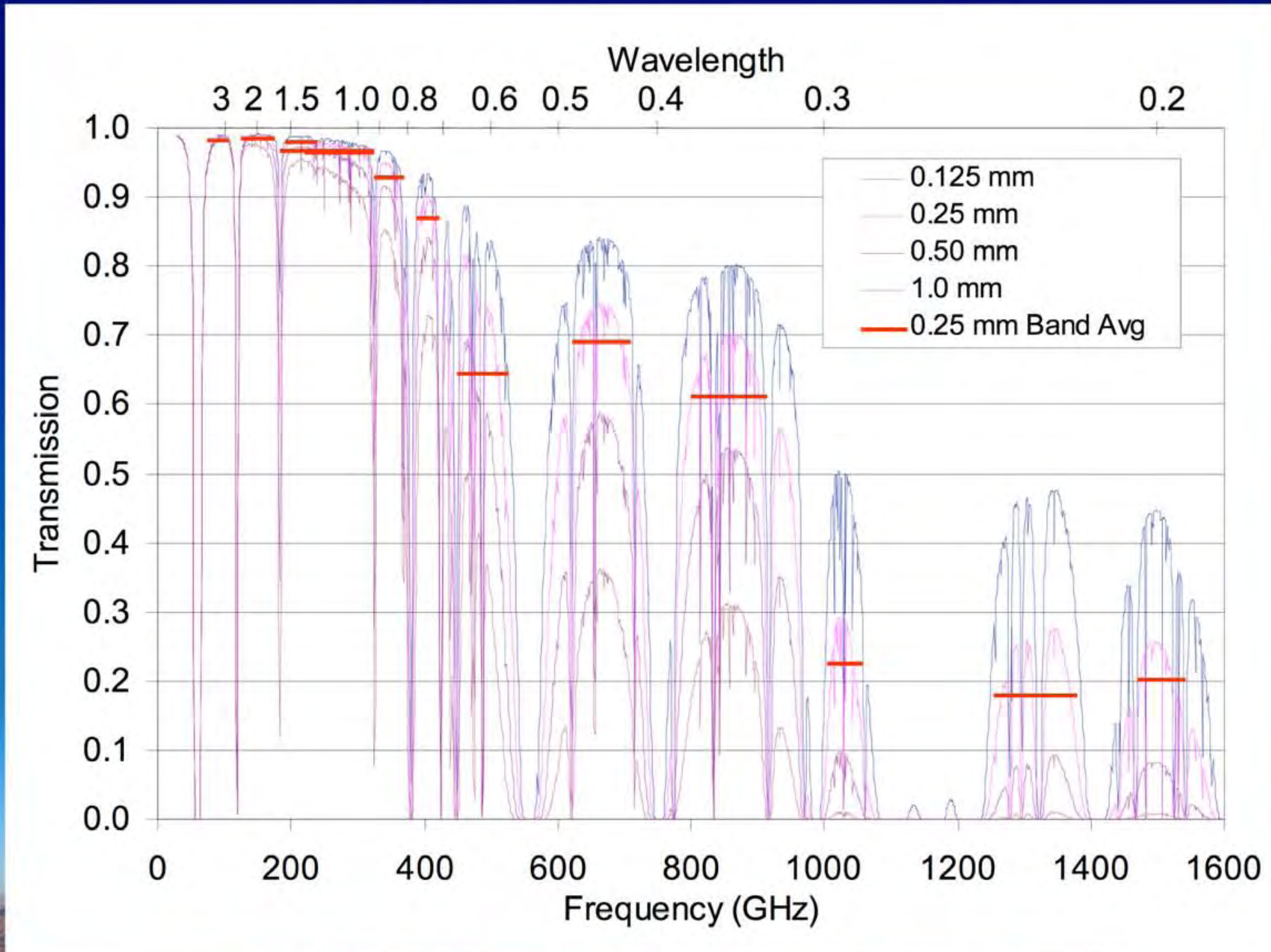
Images of the Antennae (NGC 4038/4039) in the visible (left), infrared (center), and submillimeter (right) showing how the submillimeter reveals regions hidden at shorter wavelengths. For this galaxy and many like it, the submillimeter represents the bulk of the energy output of the galaxy and reveals the real luminosity production regions that are otherwise hidden. CCAT will have 2.5 times better resolution in the submillimeter giving a spatial resolution like that of the infrared image (center). Visible: HST; Infrared: Spitzer; and 350 μm submillimeter: CSO/SHARC II, Dowell et al.

Submillimeter Spectral Peaks



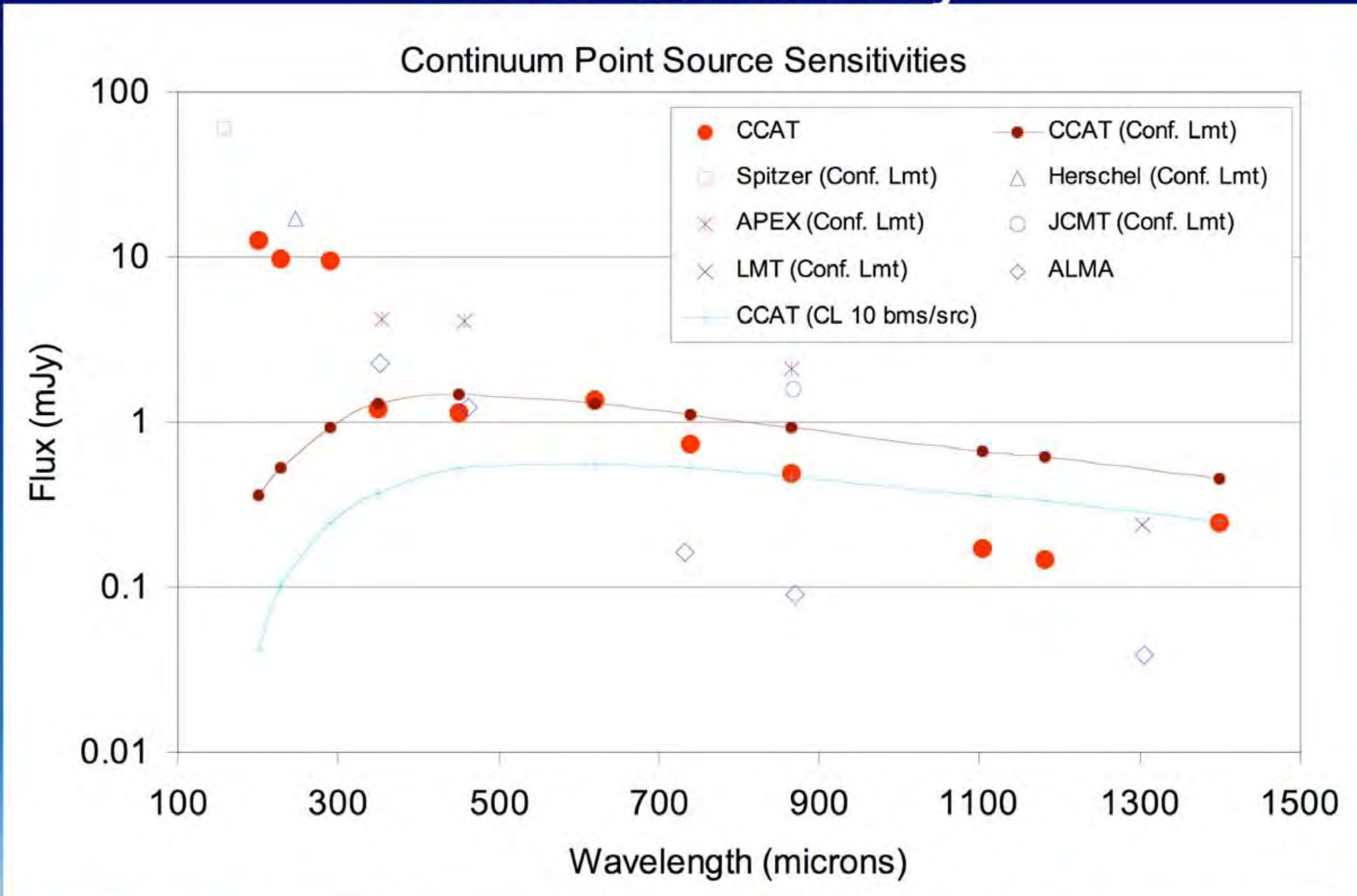
Sources with peak emission in the far-infrared and submillimeter: a $10^{12}\ L_{\odot}$ starburst galaxy at z = 1, 2, and 4; a T = 8 K, 0.03 $M_{\odot}$ cold cloud core in a nearby (140 pc) star forming region; and a 300 km diameter Kuiper Belt Object at 40 AU. The 5 σ, 30 beams source^{-1} confusion limit is shown for CCAT.

Atmospheric Transmission



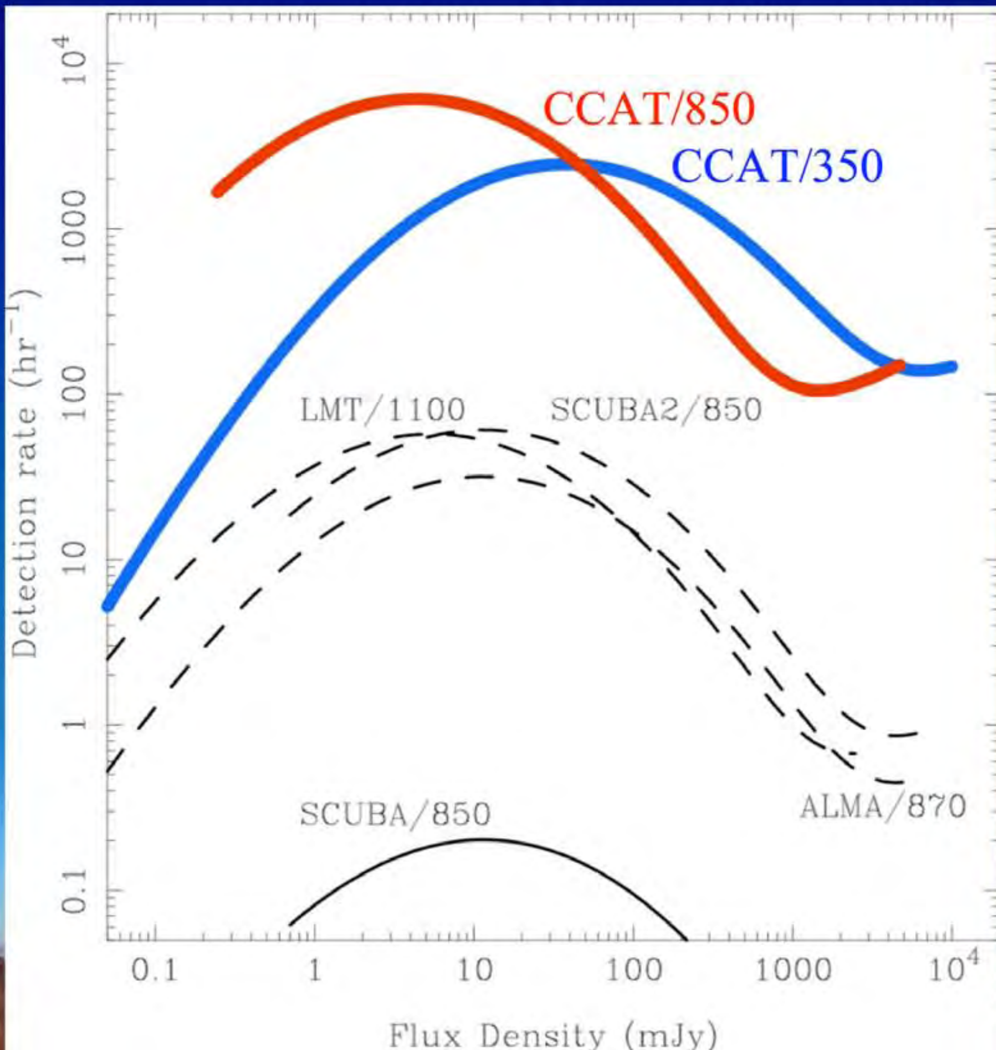
Red bars show bandpass average transmissions for 0.25 mm PWV.

CCAT Sensitivity



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

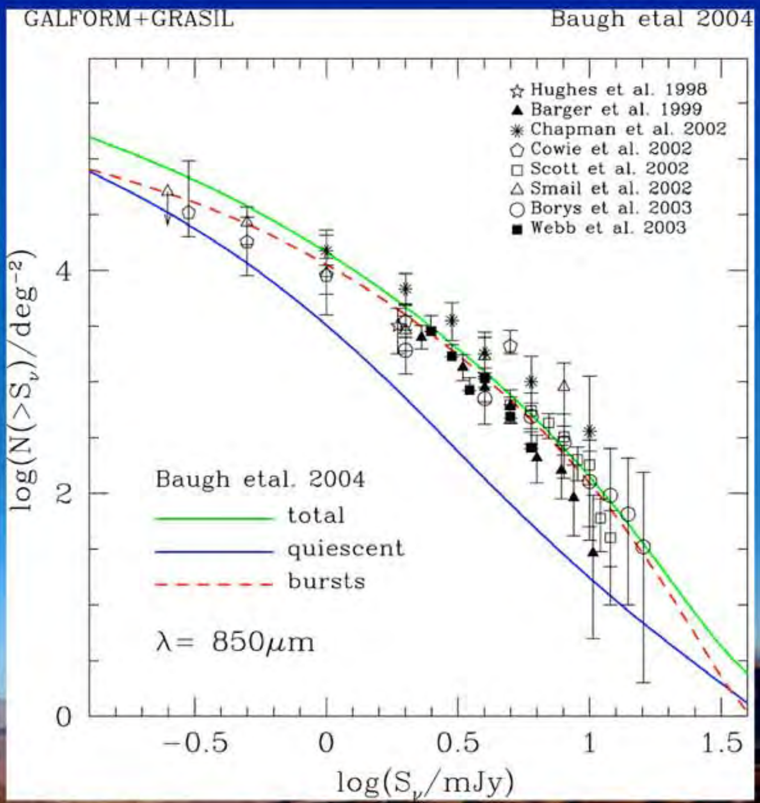


- CCAT is an ultrafast mapper
- Assumptions
  - 32 x 32 (1024) pixel detector, Nyquist sampled, 350 μm & 850 μm
  - Observationally verified counts (good to factor 2)
  - Confusion and all sky limits
- 350 μm & 850 μm detection rates are compatible, but
- Confusion at 350 μm is deeper than at 850 μm
- 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

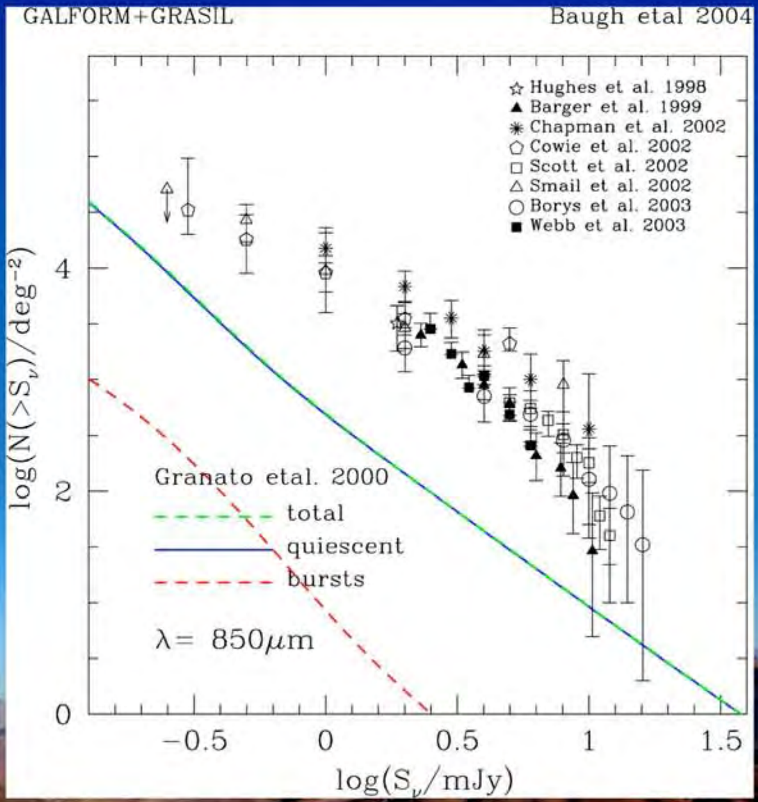
Can the faint sub-mm galaxies be explained in the ΛCDM model? MNRAS 2005

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].



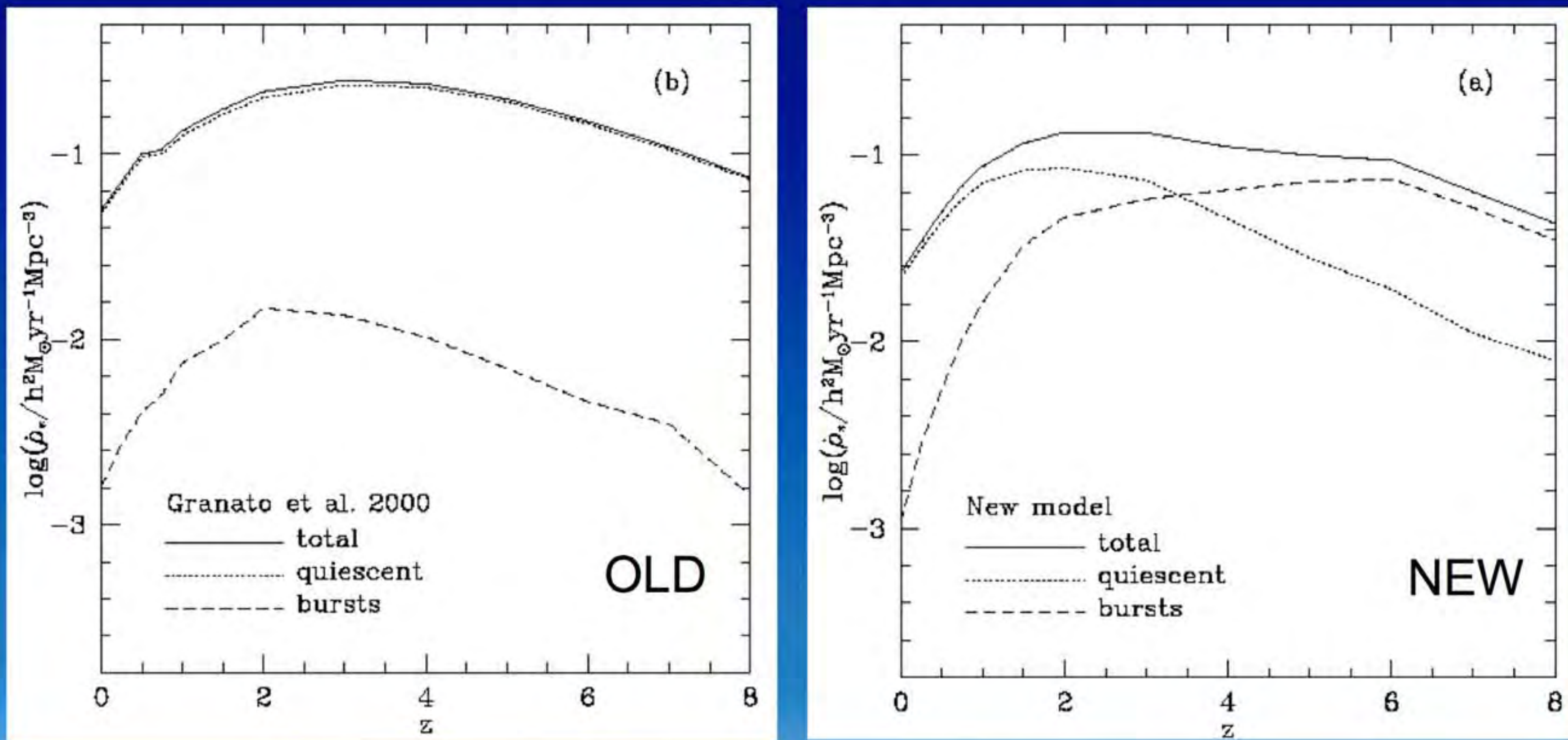
- Semianalytical model
- CDM halo "merger tree"
- Gas cooling, star formation, feedback, …
- Treat chemical evolution, dust production, dust radiative transfer
- Includes galaxy mergers & starbursts
- Number counts OK
- Submm galaxies dominated by mergers

Submm Galaxy Models



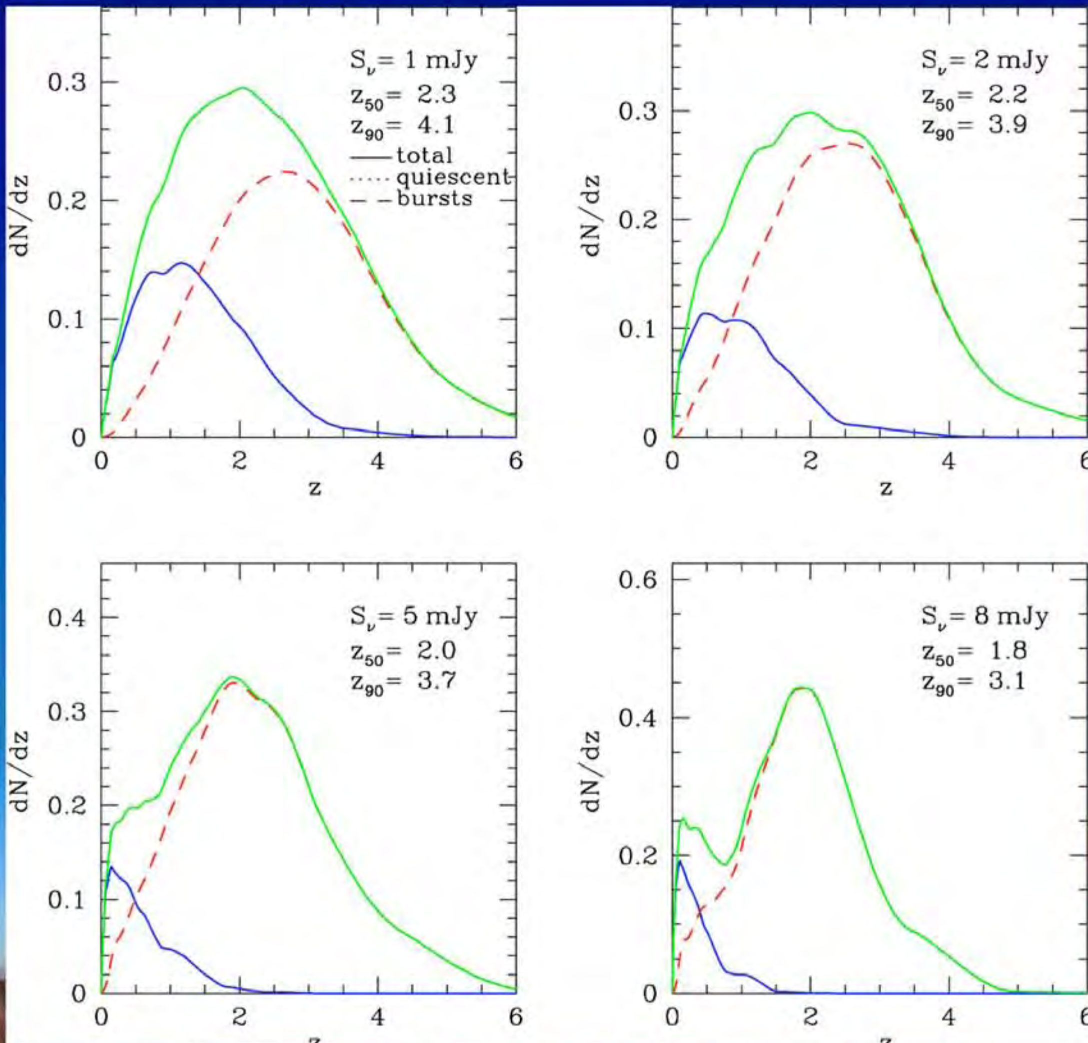
- Original model, pre-submm
- Tuned to match local galaxies…
- …but severely underpredicts submm galaxies!
- Fixes:
  - Slower star formation in disks
  - Minor mergers lead to starbursts
  - Use flat IMF for starbursts (high mass)
- Metallicity OK for cluster gas, ellipticals
  - Nagashima et al., 2005

Submm Galaxy Models

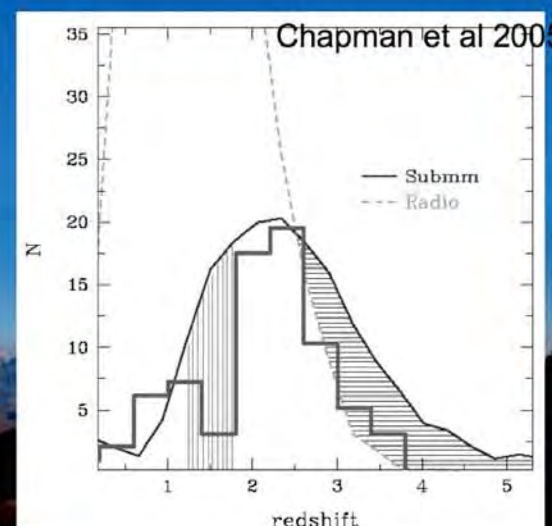


Star formation at z > 3.5 dominated by bursts?

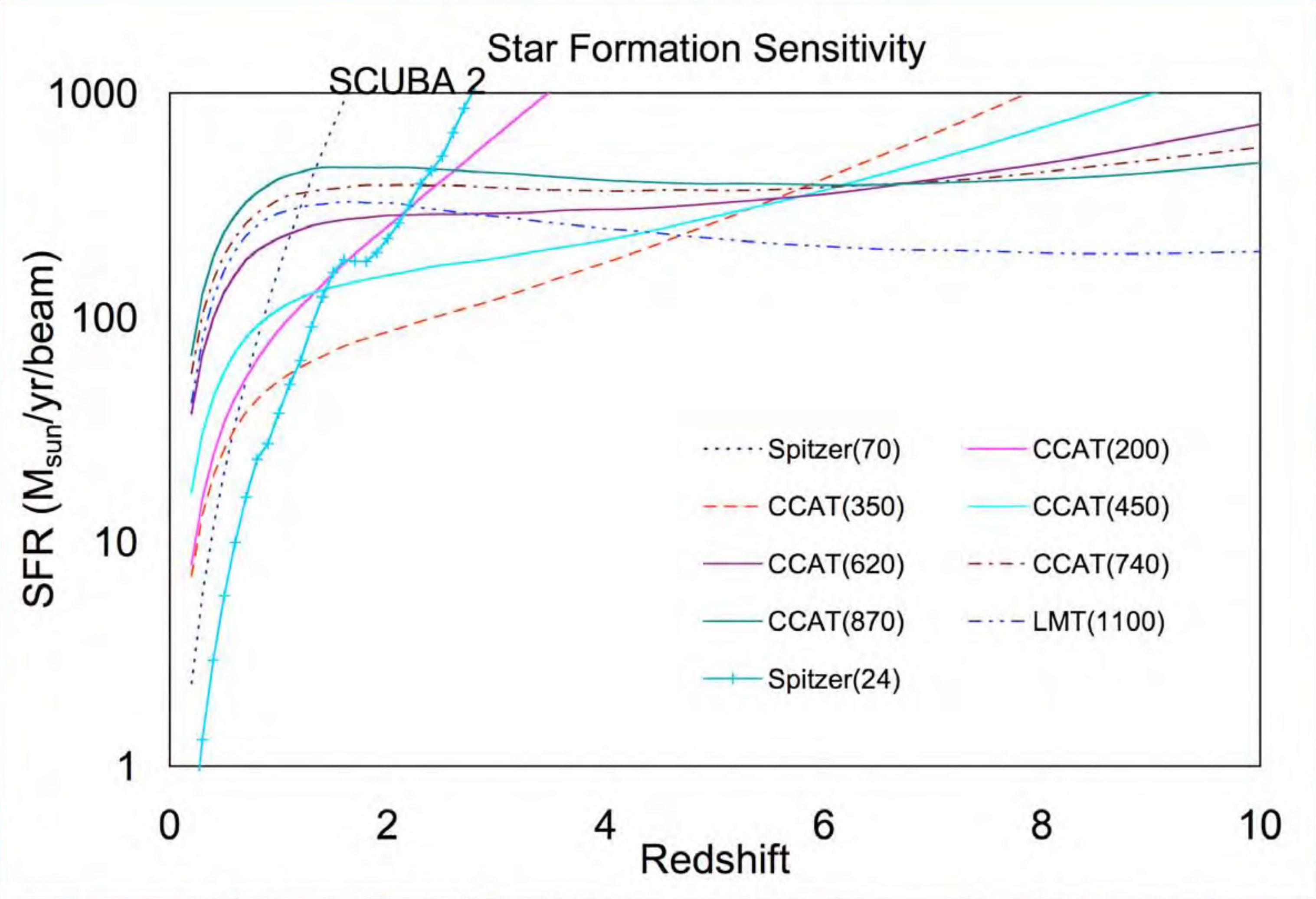
Submm Galaxy Models



- Investigate $z > 4$ tail with CCAT
- Use 850 μm detections that are 350/450 μm dropouts ?

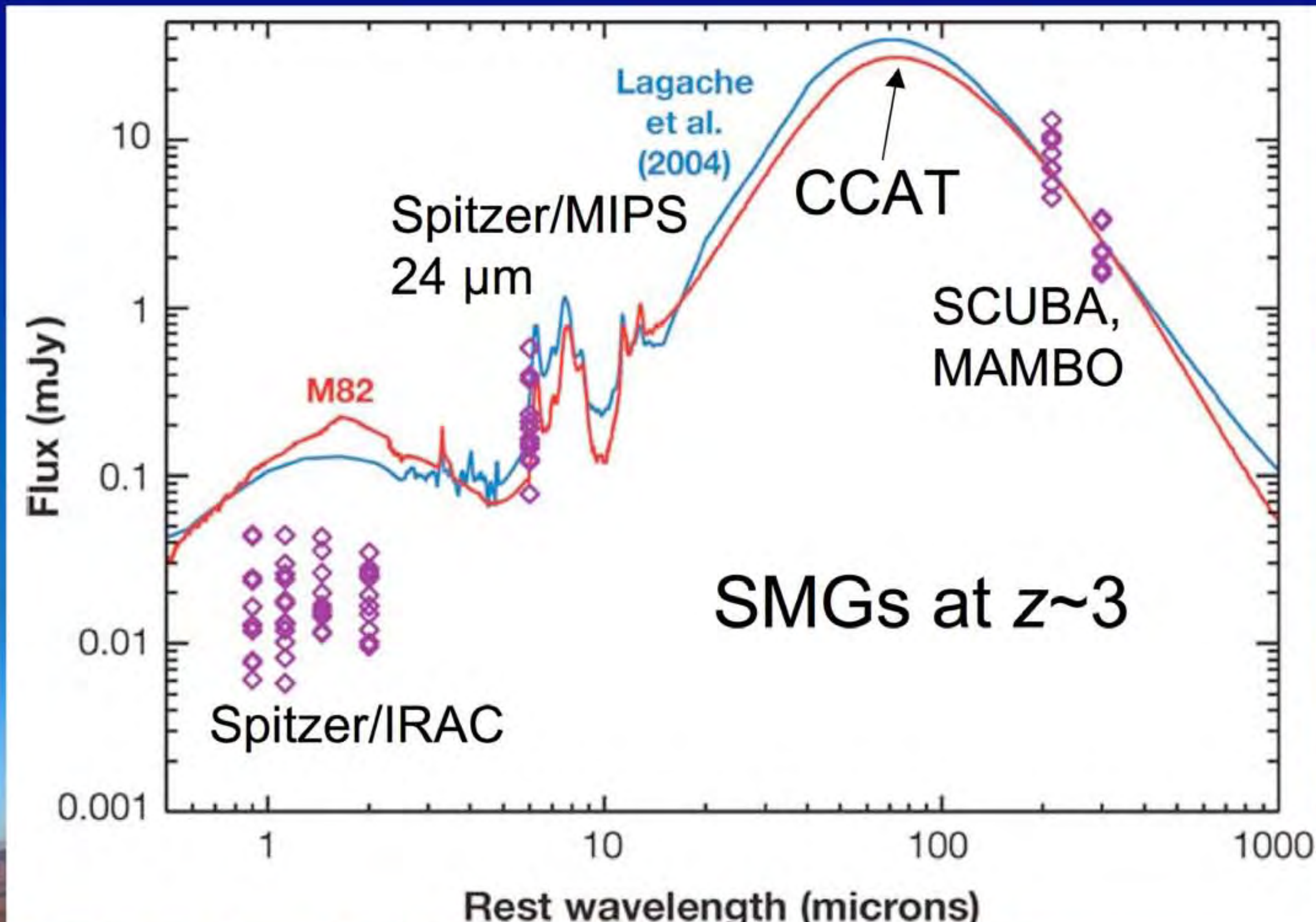


Why 350 µm ?



Sensitivity to star formation rate vs. redshift for an Arp 220 like galaxy. All flux limits are set by the confusion limit except for CCAT(200) which is 5 σ in 10^4 sec. The conversion used is 2 $M_{\odot}$/yr = 10^{10} $L_{\odot}$ & L_{Arp220} = 1.3×10^{12} $L_{\odot}$.

Why 350 µm?


Lagache
et al.
(2004)
CCAT
Spitzer/MIPS
24 µm
SCUBA,
MAMBO
M82
SMGs at z~3
Spitzer/IRAC
Flux (mJy)
Rest wavelength (microns)
10
1
0.1
0.01
0.001
1
10
100
1000

Submm Galaxies with CCAT

- Submm galaxies are mostly mergers ?
  - Black hole growth is due to mergers ? (Malbon 2006)
- Determine number counts to much higher precision and 10x fainter
  - Are faint submm galaxies mostly quiescent ?
- Measure SED from 0.3 to 1 mm
  - Measure luminosity for $z > 2$ (50% or more of SMGs)
  - Look for spectral index variations ?
- Determine luminosity function vs. z
- Clustering vs. z ?
  - Need redshifts
  - 3.5 σ detection by Blain et al. (2004) using Keck redshifts
  - Sensitive to halo mass
    - Also depends on lifetime of submm bright phase ?
    - Need predictions from galaxy formation models (A. Benson)
- Find $z > 5$ objects ? Need model predictions.

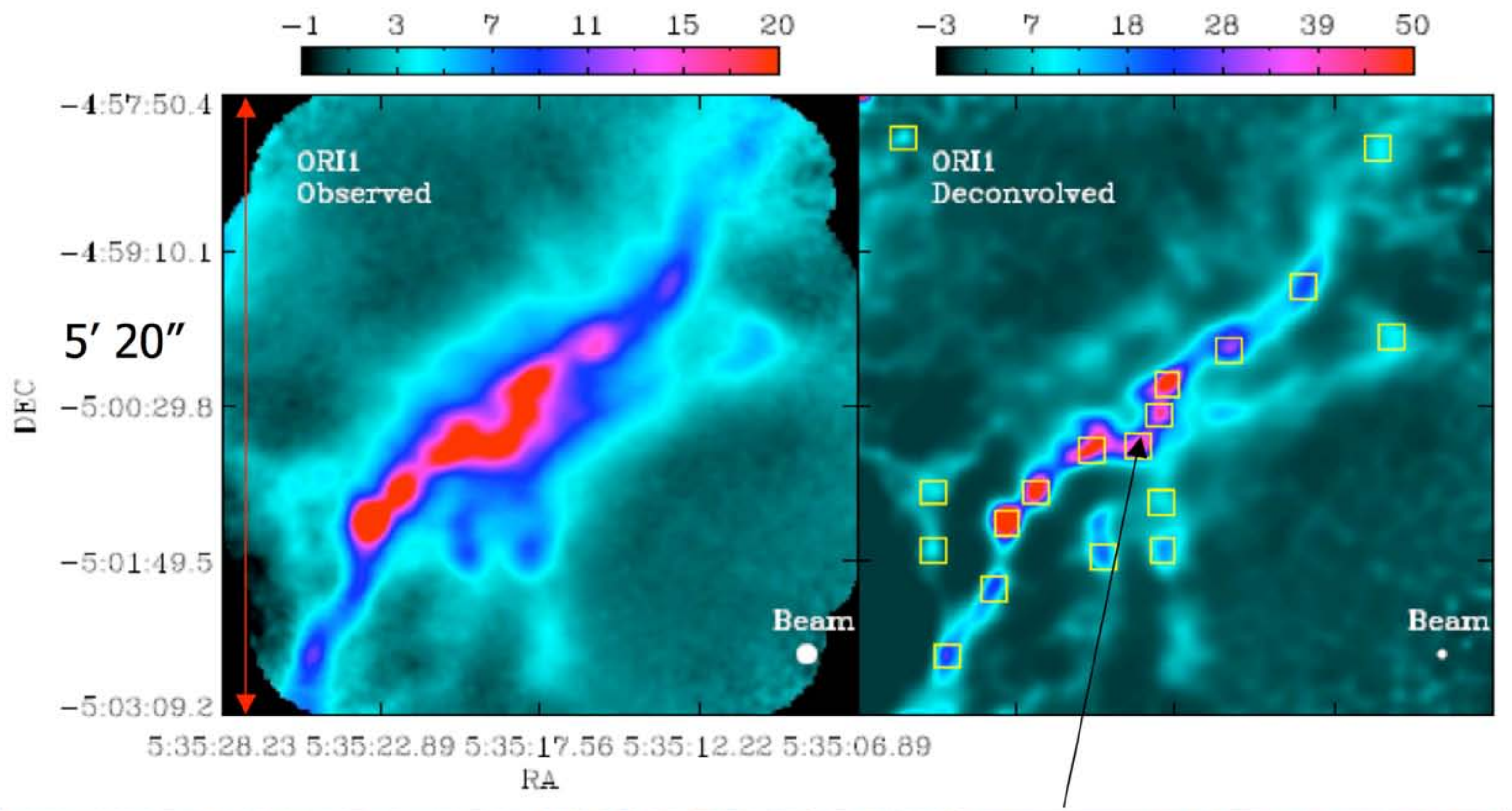
Star Formation:
Prestellar core mass function

(Cold cloud core survey, Evans & Goldsmith)

The Core Mass Function $\quad$ CMF = $N_{\mathrm{core}}(M_{\mathrm{core}})$
is central for a number of key questions in star formation theory

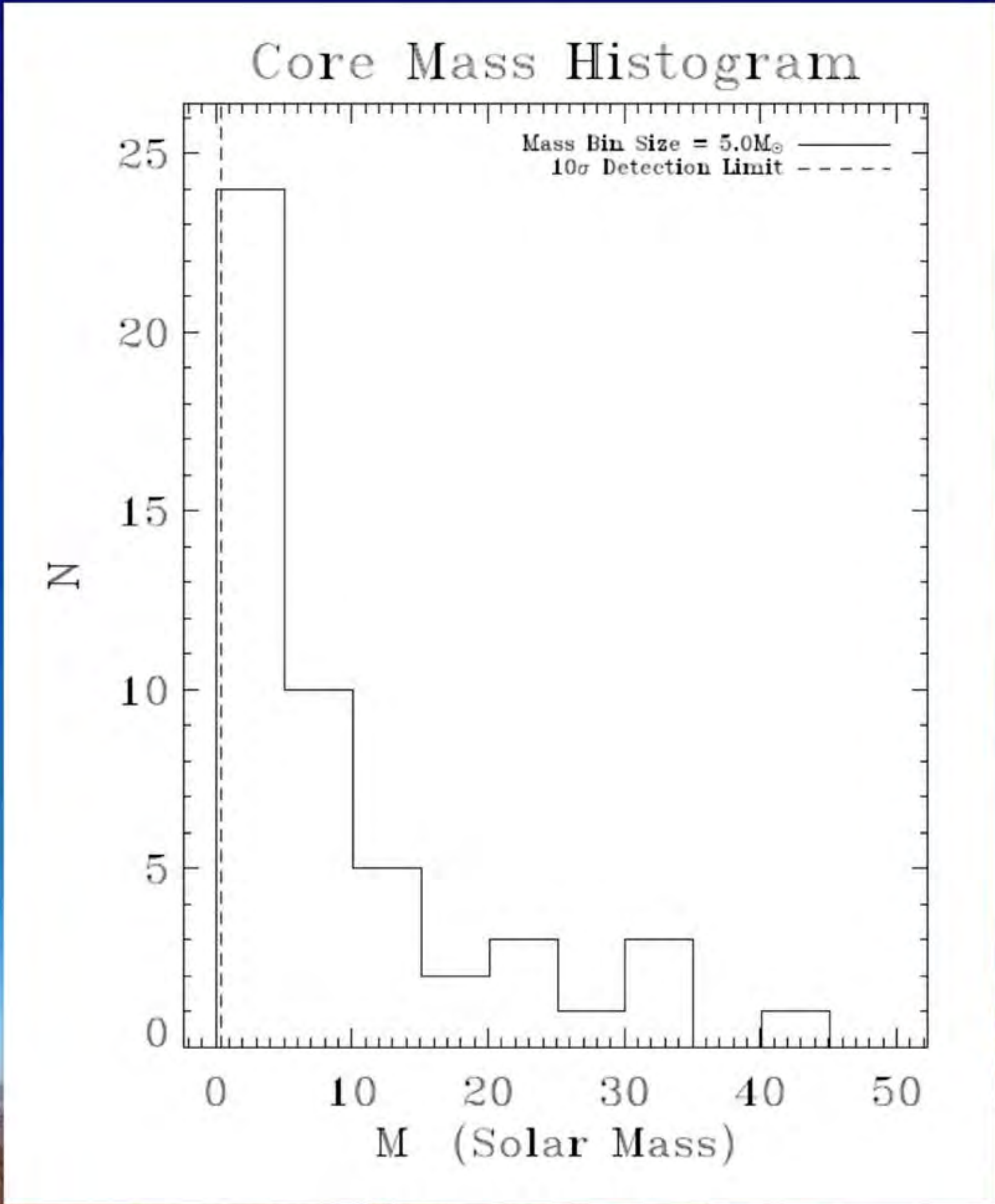
- What is the relationship between the CMF and the stellar IMF?
- Do individual cores collapse to form individual stars?
- What is the role of the environment?
- Where and when does fragmentation take place?

Cores in Orion1 Region
(Li, Goldsmith, et al.; CSO/Sharc II)



Enhanced angular resolution ESSENTIAL to determine core size and mass

Cores identified with COREFIND algorithm



51 cores identified

Mass determined from standard dust properties and dust temperatures inferred from NH_3 measurements of gas temperature

Determining core mass function is challenging

Limited sample size makes use of differential mass function *N(M)* difficult

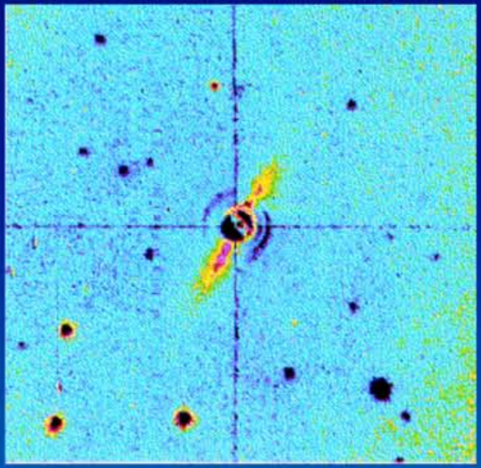
Cumulative mass function *N(>M)* is an attractive approach, but serious errors can result from fitting power laws

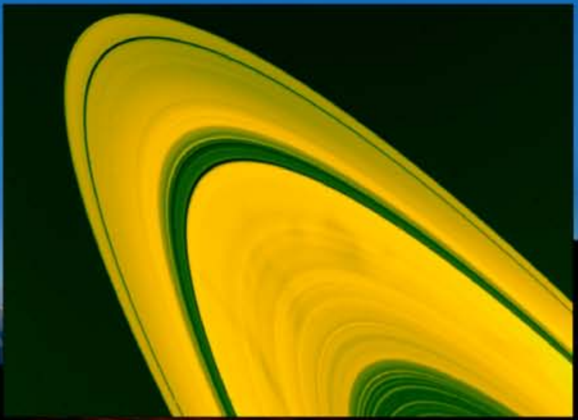
Status and role of CCAT

- Mass range: 0.1 $M_{\odot}$ to 50 $M_{\odot}$
- The core mass function is described by a single power law: $N(M) \sim M^{-0.8}$, very different from stellar IMF
- This type of study requires best possible resolution, and LARGE CORE SAMPLES to determine the effect of environment and the evolutionary steps between cores and stars
- CCAT will be the exemplary facility for this type of study, offering improved angular resolution, larger arrays and coverage, and multiple wavelengths to fit dust temperature distribution directly
- BOLOCAM: Enoch 2005 (Perseus), Young 2006 (Ophiuchus)

Debris Disks with the CCAT

- Debris disks, a.k.a. “Vega phenomenon”, a.k.a. “extra-zodiacal dust”:
  - solid particles surrounding main sequence stars, especially youngish ones (10-100 Myr), after the gas has been absorbed into giant planets or expelled
  - product of collisional grinding of planetesimals in Kuiper belts
  - probably episodic in nature
  - tracer of orbital dynamics (analogous to Saturn’s rings)
- CCAT niches
  - 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)



Debris Disks

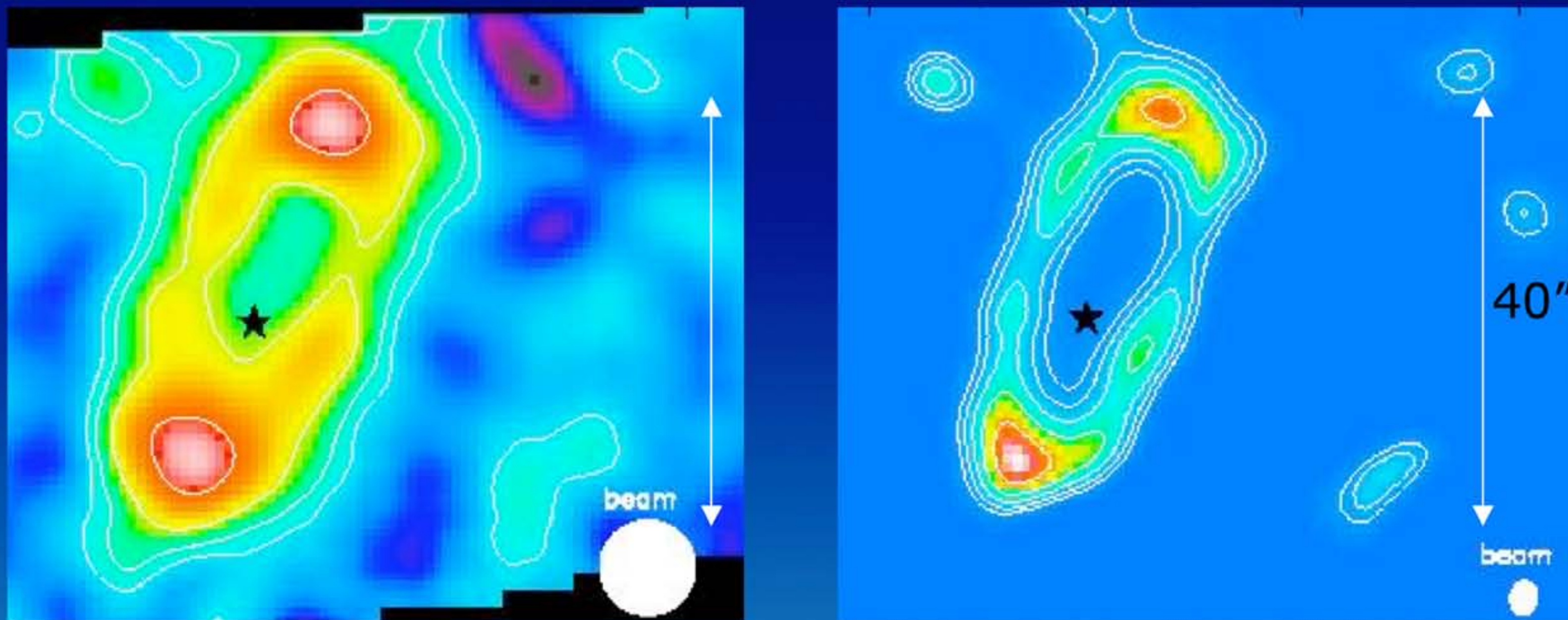
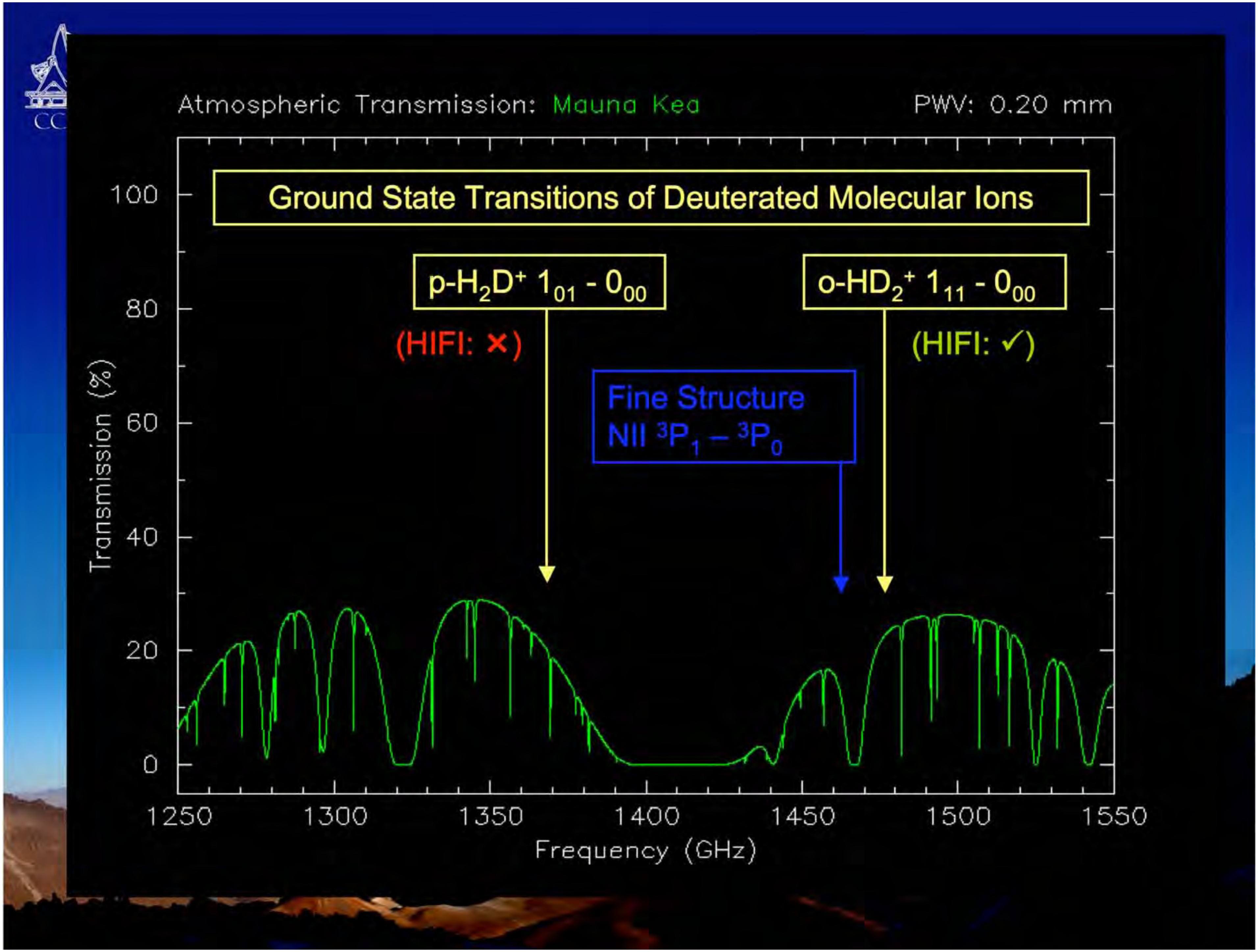


Image of Fomalhaut debris disk acquired at 350 μm with the CSO/SHARC II (Marsh et al. 2005, ApJ, 620, L47). Left: The observed image which has 10″ resolution and shows a complete ring of debris around the star. Right: A resolution enhanced image with 3″ resolution. CCAT will have this resolution intrinsically, with the capability to achieve ~1″ resolution through image enhancement techniques. From the CSO image, we can already infer the presence of a planet due to the asymmetry of the ring. CCAT imaging should show substructure which will pinpoint the location of the planet. The vertical bars in each image are 40″ in length.

CCAT Science – other topics

- Kuiper belt objects (KBO) - solar system formation
  - Determine masses and albedos
  - See Bertoldi et al 2006, Nature, UB313/Eris
- Dark energy: $w(z)$ from galaxy clusters, SZ effect
  - Sunil Golwala's DETF "white paper"
  - Complement 1'-2' SZ surveys from ACT, APEX, SPT, …
  - Higher angular resolution: find lower mass clusters, test survey completeness at low mass, check for submm galaxy contamination, cluster morphology effects, etc.
- THz spectroscopy of the ISM
  - Emphasize 850, 1300, and 1500 GHz windows



Atmospheric Transmission: Mauna Kea
PWV: 0.20 mm
Ground State Transitions of Deuterated Molecular Ions
p-H_2D^+ 1_{01} - 0_{00}
(HIFI: ×)
o-HD_2^+ 1_{11} - 0_{00}
(HIFI: ✓)
Fine Structure
NII $^3P_1 - {}^3P_0$
Transmission (%)
100
80
60
40
20
0
1250
1300
1350
1400
1450
1500
1550
Frequency (GHz)

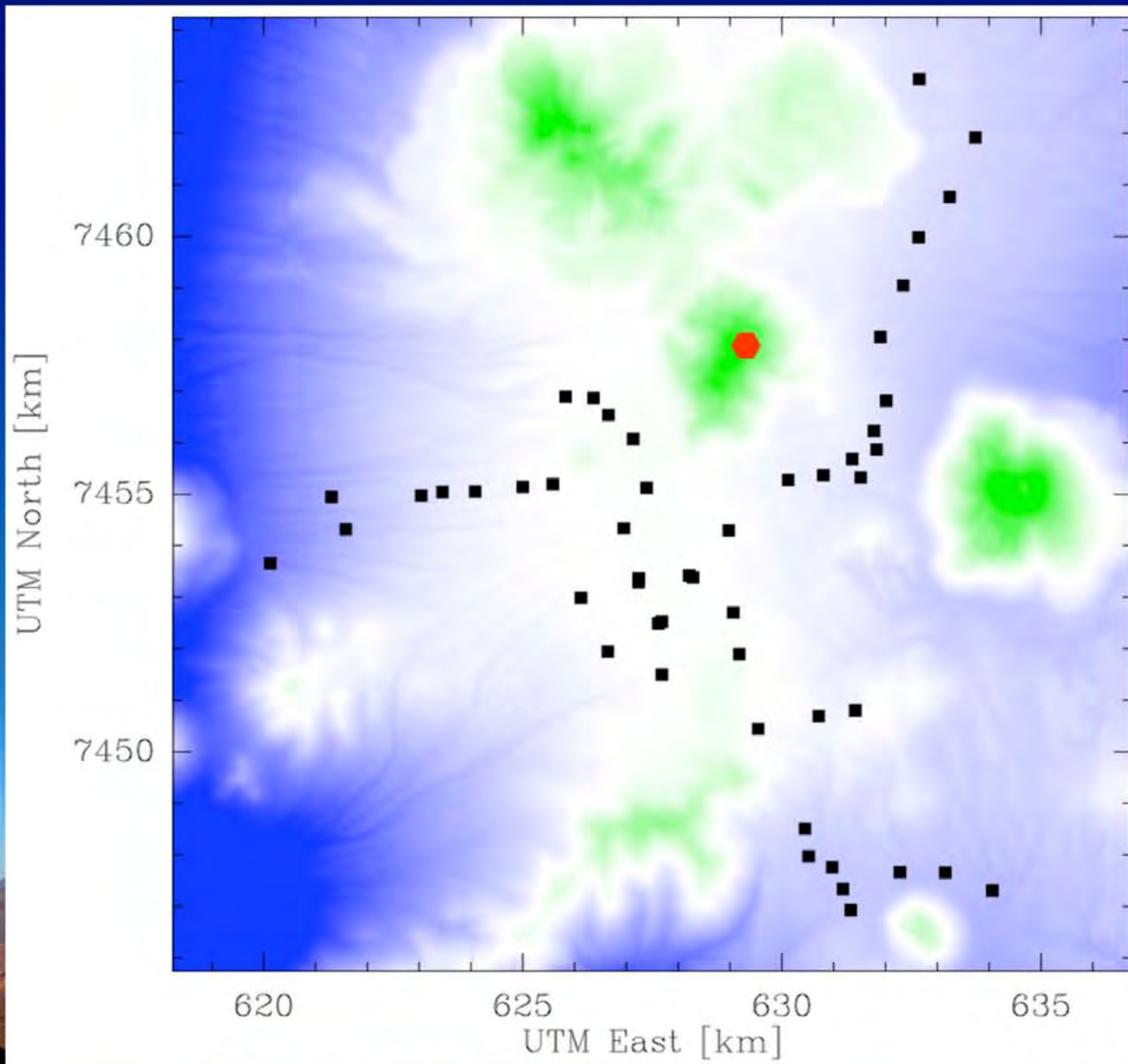
Selected (Key) Facility Drivers

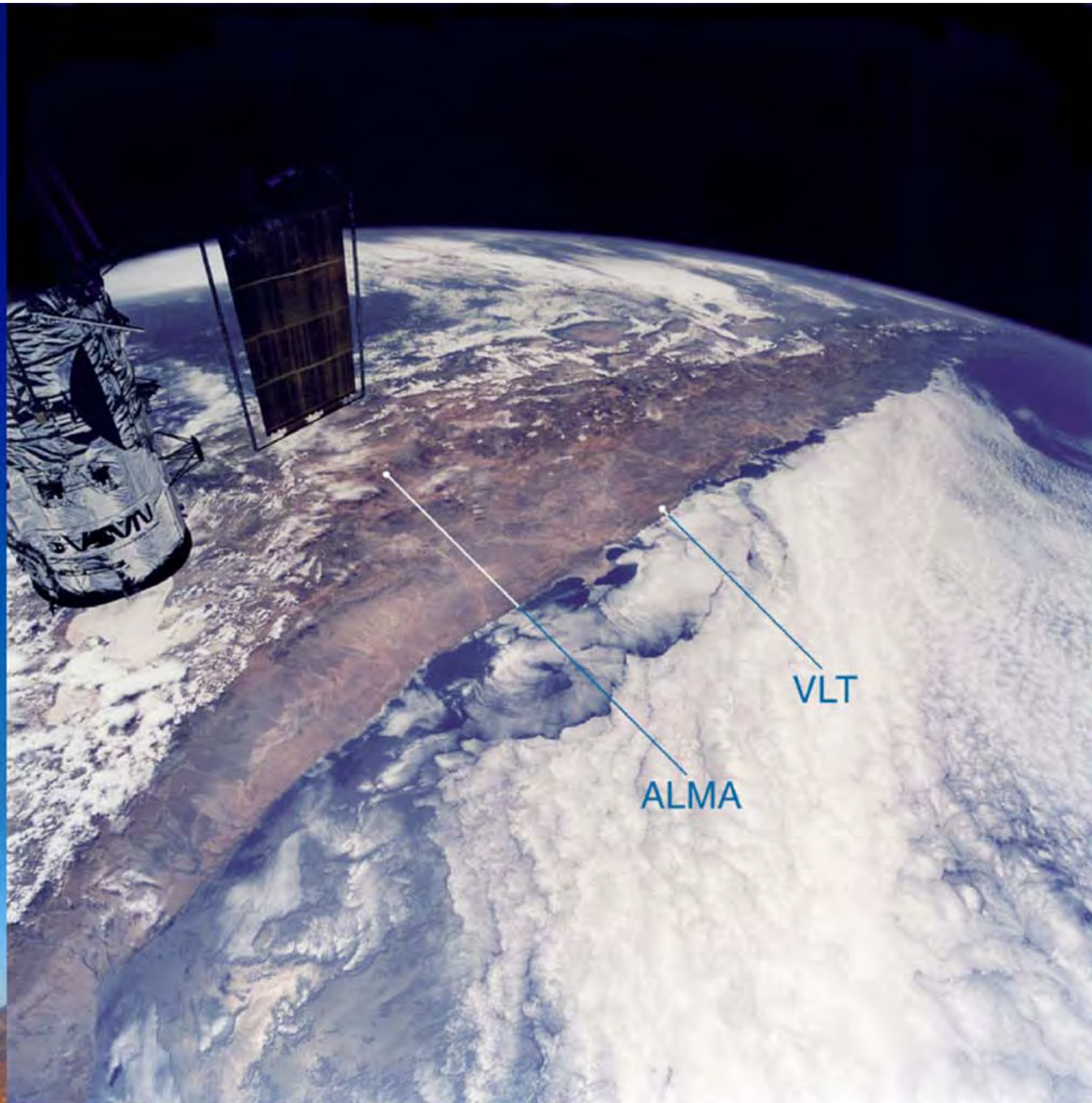
- Aperture: 25 m
  - Sensitivity improves as $\propto D^2$ (hence time to a given S/N $\propto D^{-4}$)
  - Confusion limit $\propto D^{-\alpha}$ ($\alpha \propto 2$ and 1.2 at 350 and 850 μm, respectively)
- Wavelength range
  - 350 – 1400 μm (200 – 2500 μm goal)
  - High efficiency implies 10 μm rms surface precision
- Field of view: 5' x 5' initially, up to 20' across eventually
  - Unchallenged speed for moderate resolution, wide field surveys
- Chopping and Scanning
  - Bolometer arrays require signal modulation by chopping or scanning
  - For chopping, this must be done at the secondary (~ 1' at ~ 1Hz)
  - Scanning requires moderately large accelerations for efficiency (~ 0.2° sec^{-2})
- Pointing and Guiding
  - Spectrographs require placing to a fraction of slit width
  - And guiding to maintain spectrophotometric accuracy
  - => 0.61" and 0.35" pointing and guiding (1D rms)
- Precipitable Water Vapor
  - Provide significant observing time at 350 and 450 μm

CCAT and ALMA

- Complementary Instruments
- ALMA
  - Excels at high resolution spectroscopic imaging
  - Inefficient for wide field surveys
- CCAT
  - Designed for wide field continuum surveys
- CCAT can provide ALMA
  - Source discovery for detailed follow up
  - Anchor dish for long baselines (esp. high freq.)
    - Add 14% to point source sensitivity at 350 μm
    - Improve dirty sidelobe levels (9% $\Rightarrow$ 7%; Holdaway)
  - Zero spacing observations
    - ACA

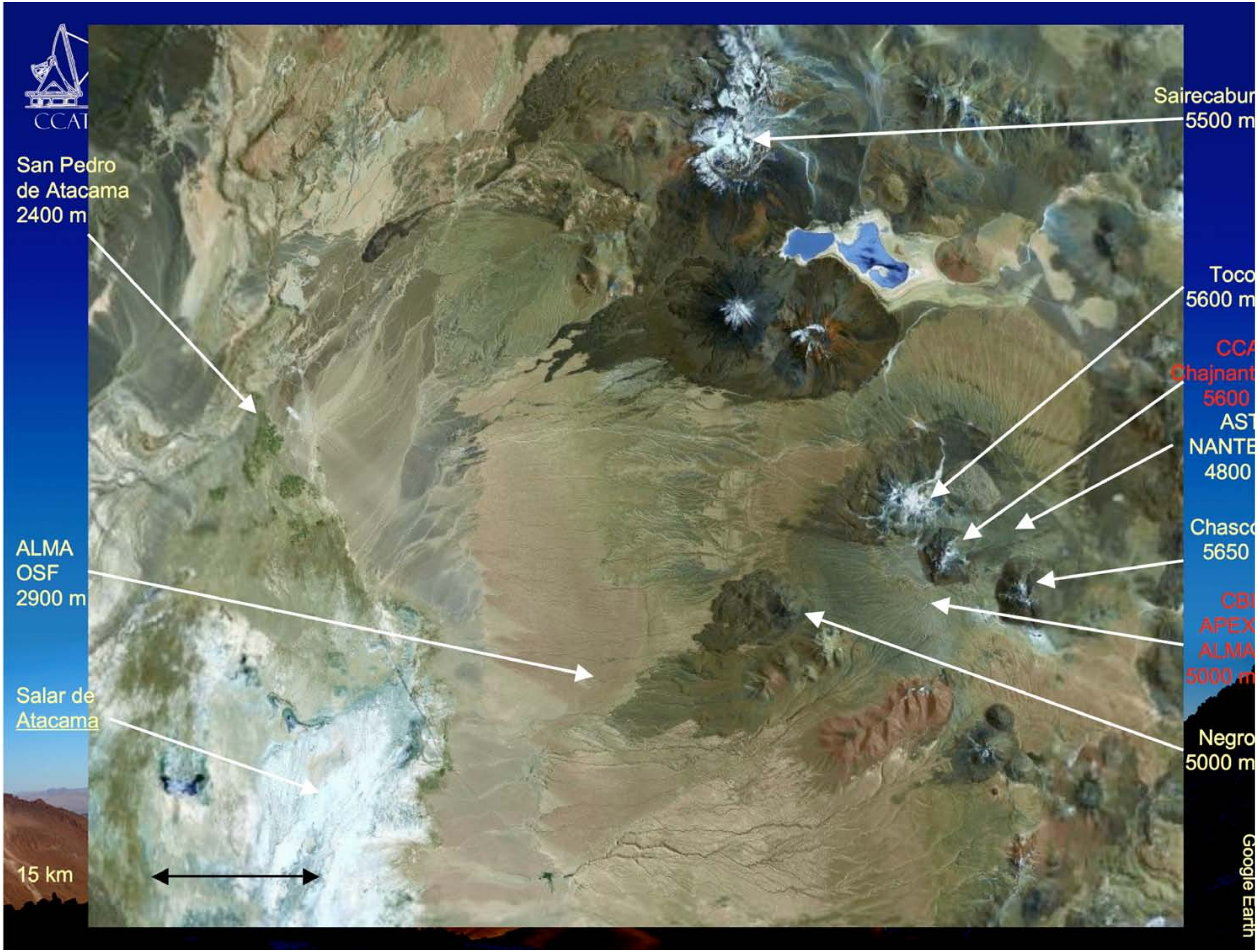
CCAT and ALMA



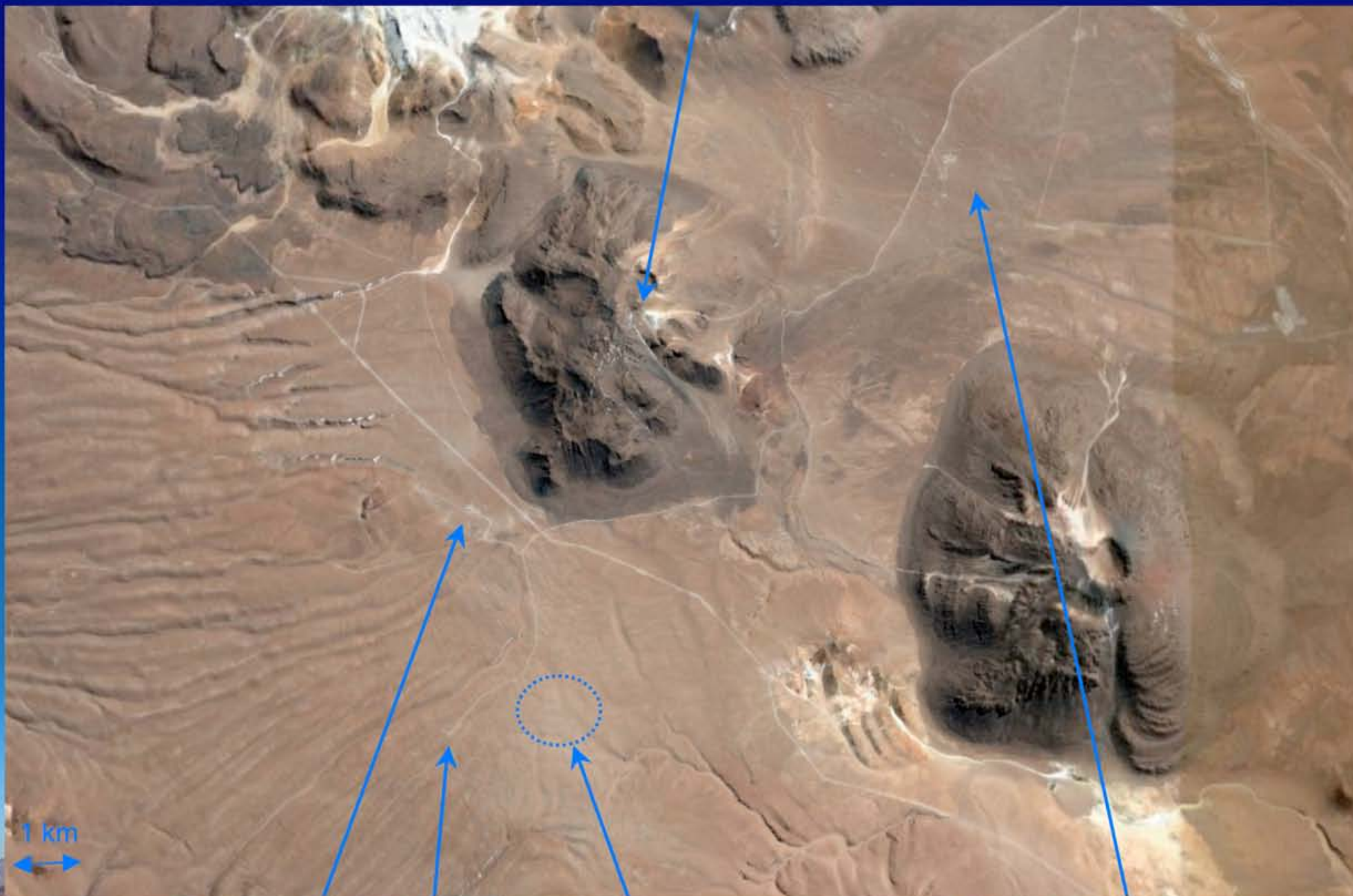


View of Northern Chile (NASA Space Shuttle)

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


CCAT
San Pedro
de Atacama
2400 m
ALMA
OSF
2900 m
Salar de
Atacama
15 km
Sairecabur
5500 m
Toco
5600 m
CCA
Chajnant
5600
AST
NANTE
4800
Chasc
5650
CBI
APEX
ALMA
5000 m
Negro
5000 m
Google Earth

Cerro Chajnantor 5612 m

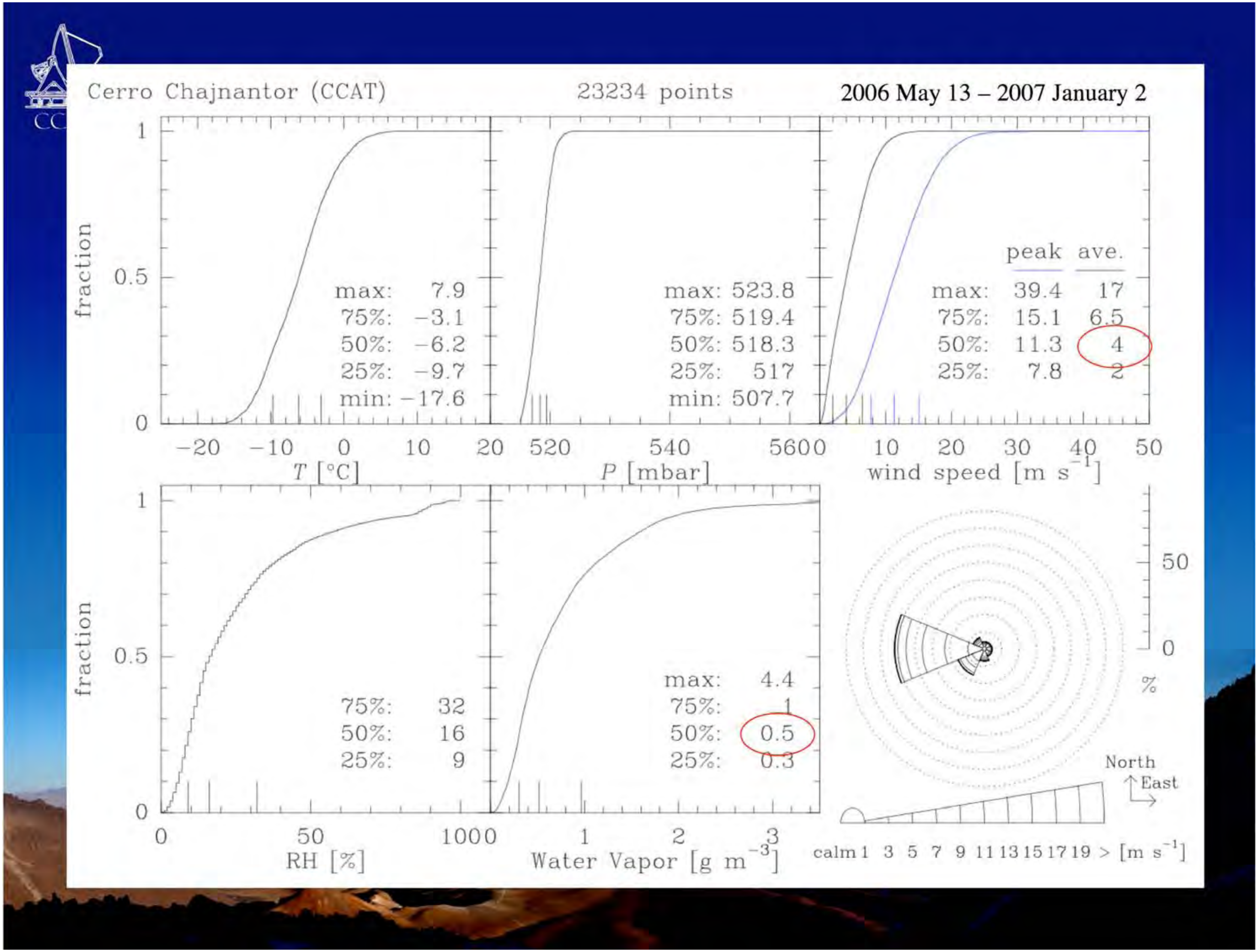



Cerro Chajnantor 5612 m
View SW from ASTE; access road constructed by U. Tokyo
G. Gull/Cornell

Cerro Chajnantor 5612 m

Cerro Chajnantor 5612 m

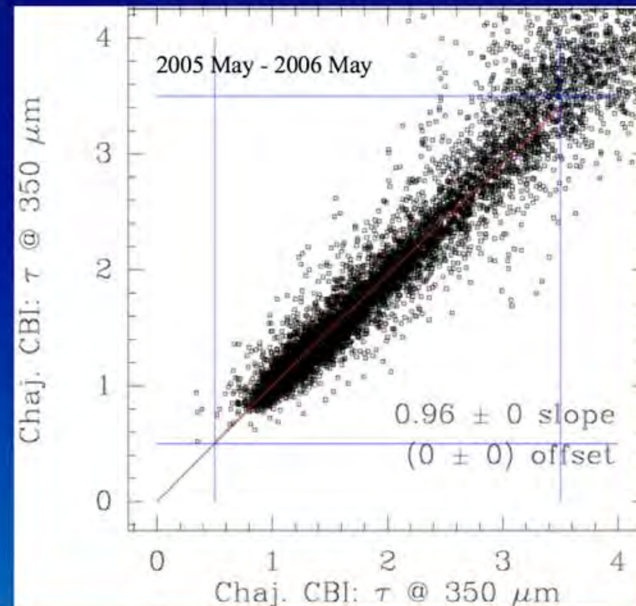
CCAT equipment: weather station and 350 µm tipper

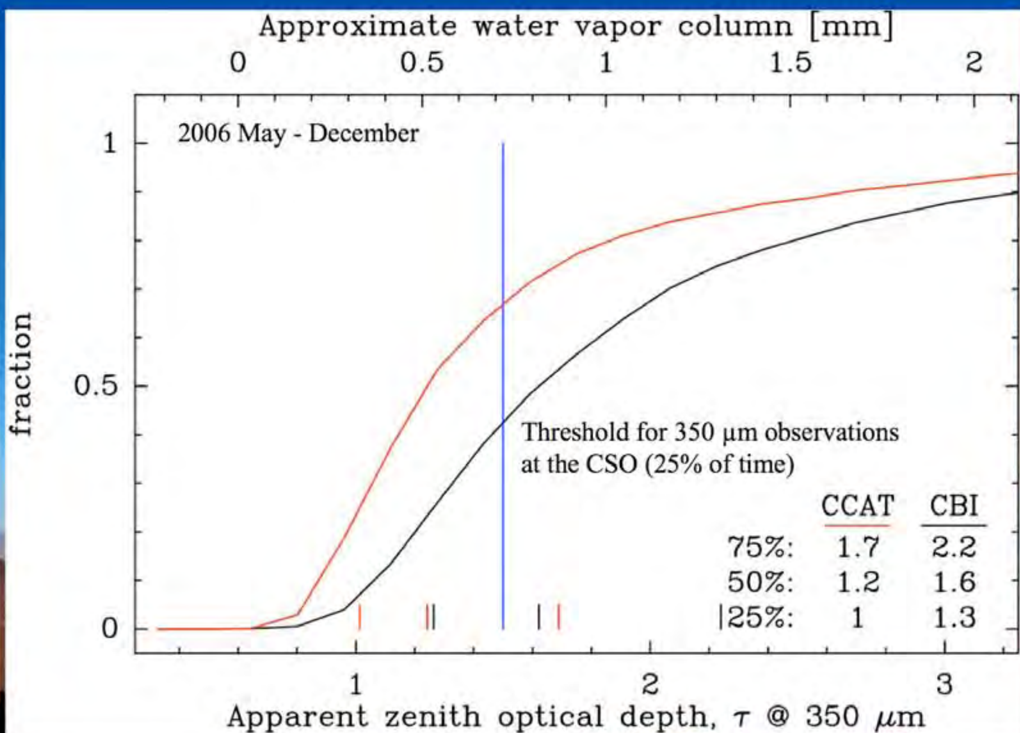


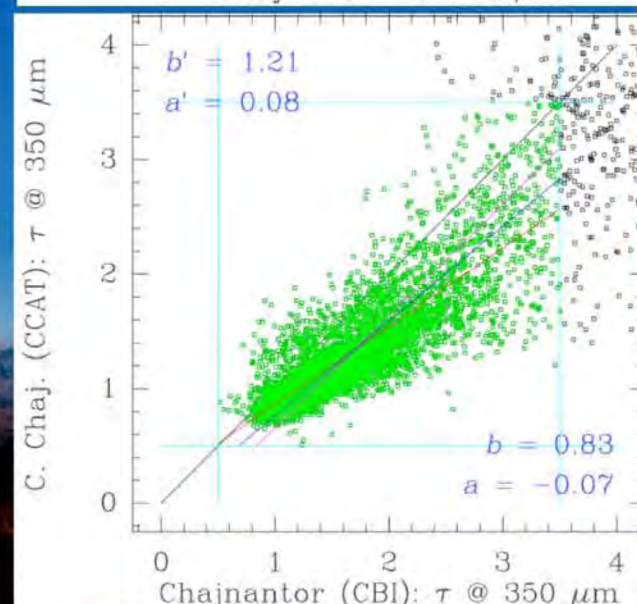
Cerro Chajnantor (CCAT)
23234 points
2006 May 13 – 2007 January 2
fraction
max: 7.9
75%: −3.1
50%: −6.2
25%: −9.7
min: −17.6
T [°C]
max: 523.8
75%: 519.4
50%: 518.3
25%: 517
min: 507.7
P [mbar]
peak ave.
max: 39.4 17
75%: 15.1 6.5
50%: 11.3 4
25%: 7.8 2
wind speed [m s−1]
75%: 32
50%: 16
25%: 9
RH [%]
max: 4.4
75%: 1
50%: 0.5
25%: 0.3
Water Vapor [g m−3]
50
0
%
North
East
calm 1 3 5 7 9 11 13 15 17 19 > [m s−1]

350 µm Transparency

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

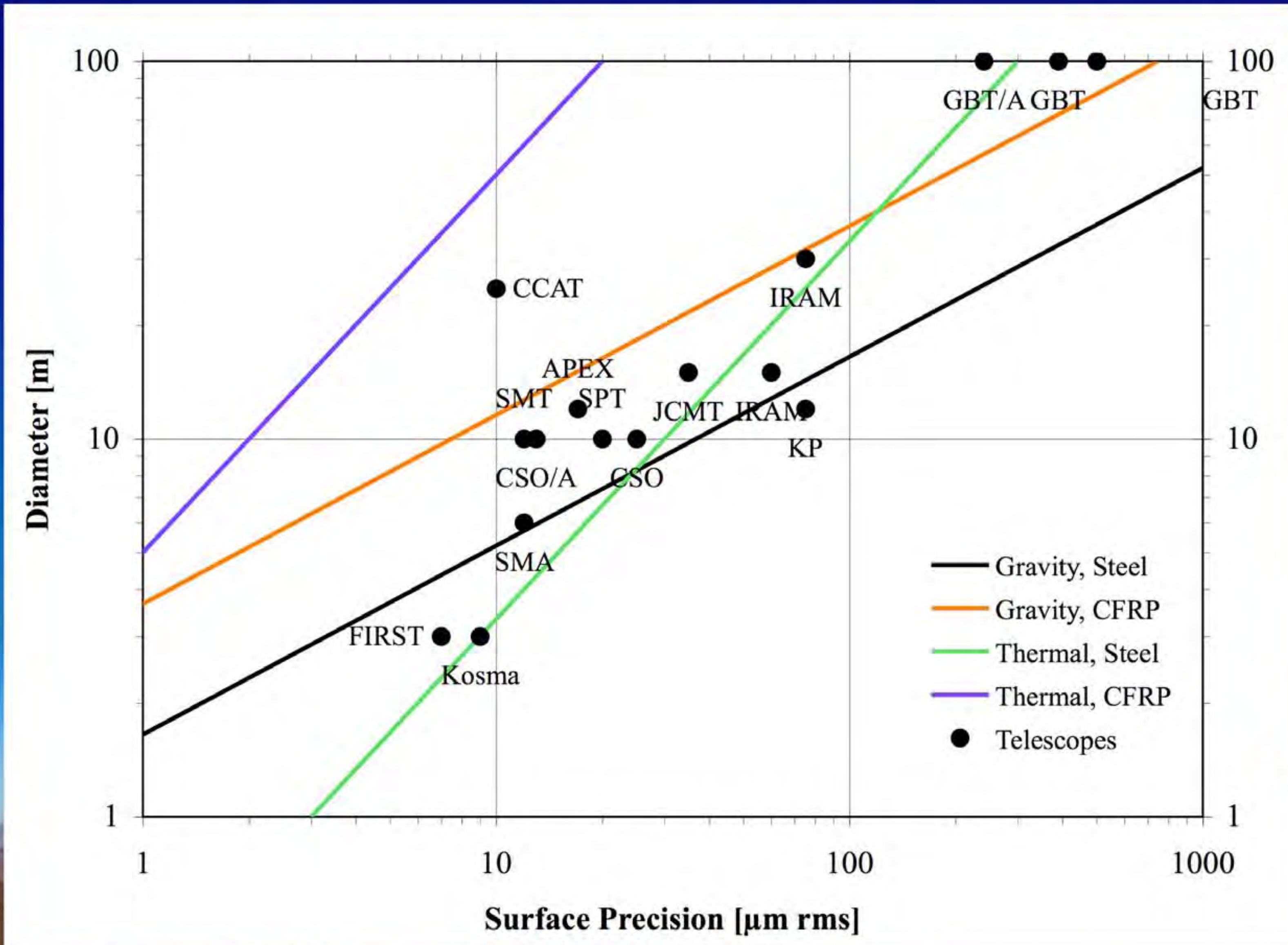






Cerro Chajnantor 5612 m

Passive Telescope Limits



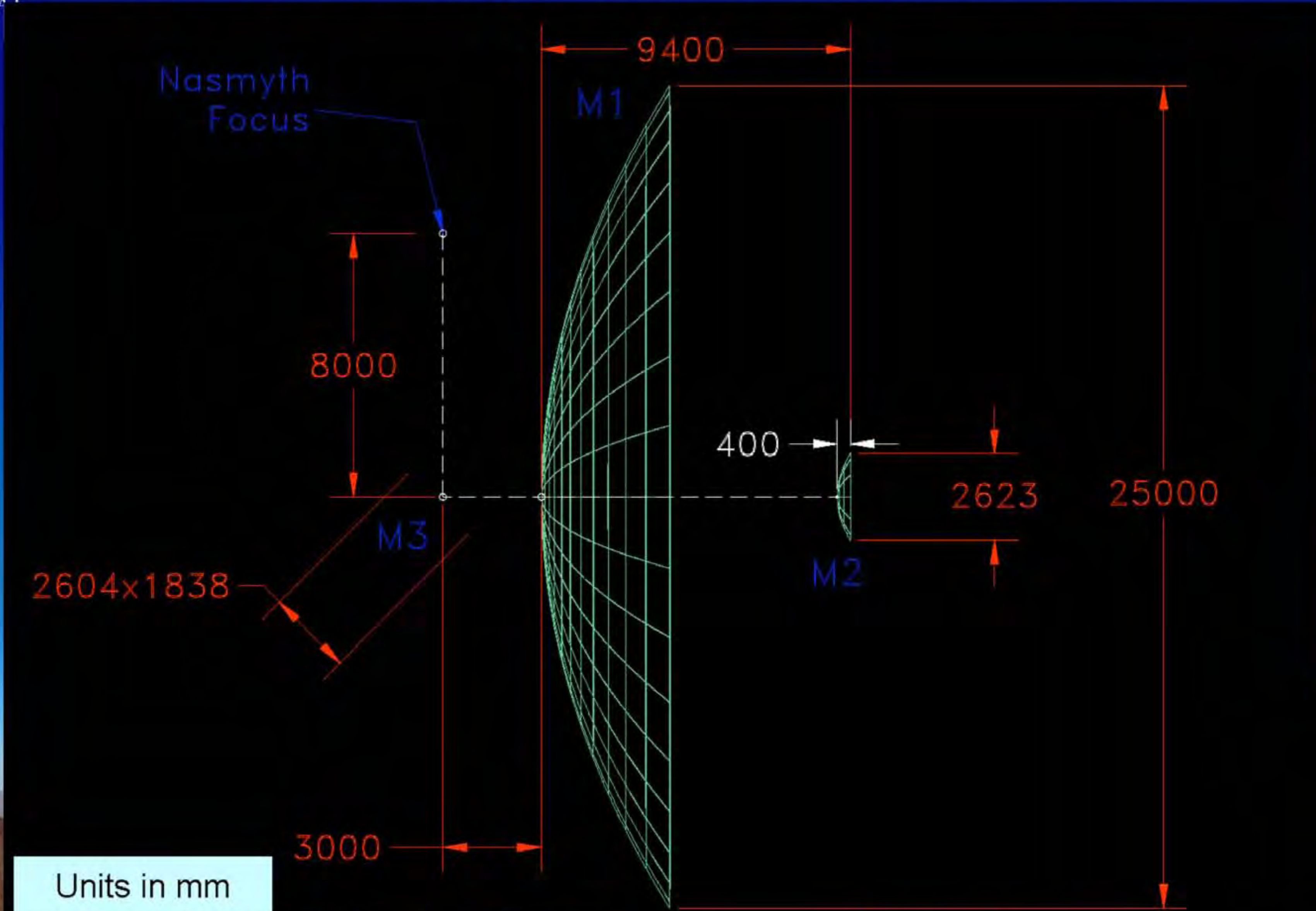
CCAT Requirements

	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
Polarization	0.2%	0.05%	after cal.
Emissivity	<10% @ >300 µm <20% @ 200 µm	< 5% @ >800 µm	

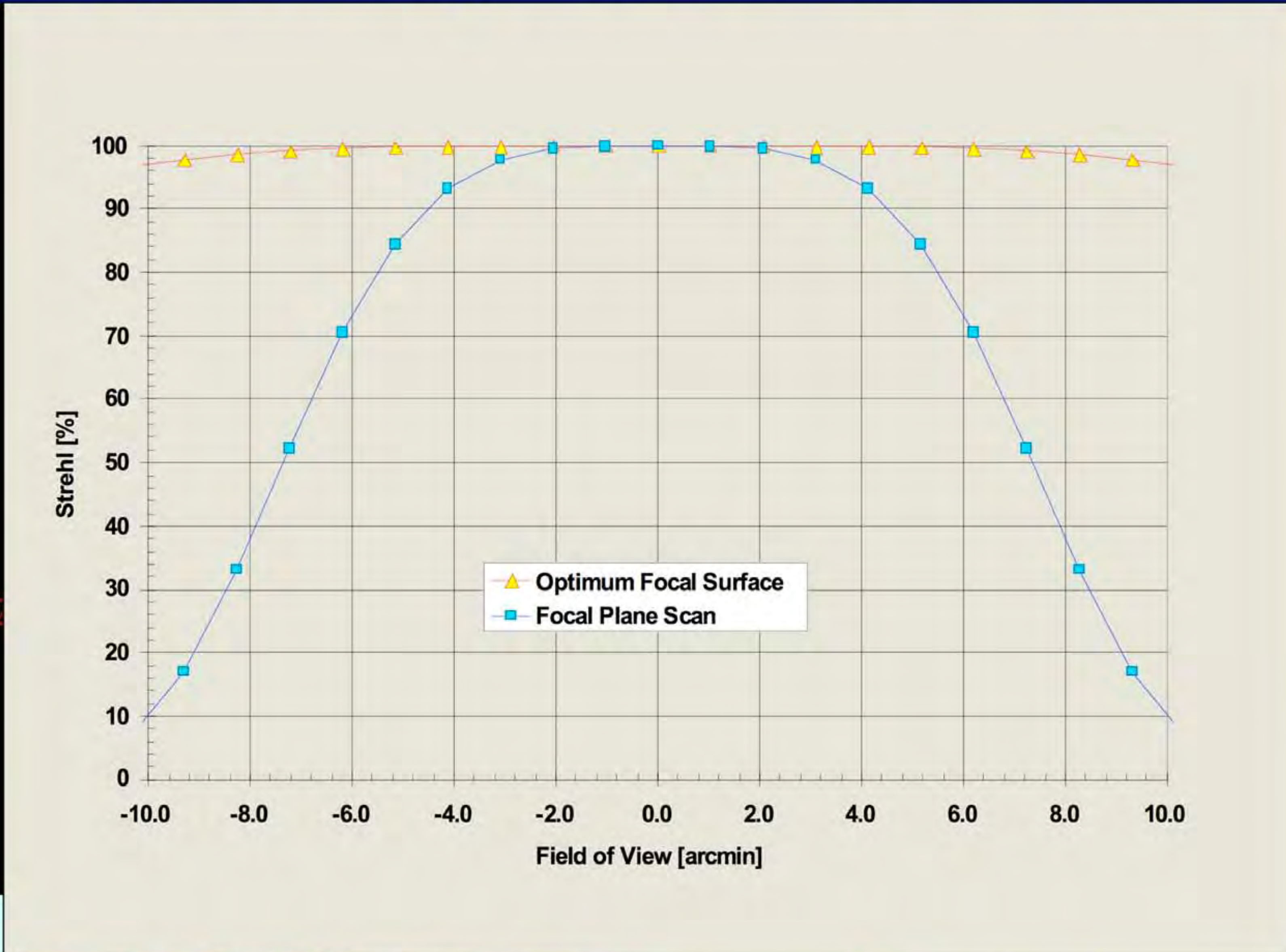
Pointing and Scanning

	Requirement	Goal	remark
Pntg, blind	2"	0.5"	rms
Pntg, offset	0.3"	0.2"	within 1°
Pntg, repeat.	0.3"	0.2"	rms, 1 hour
Scanning rate	$0.2° \, s^{-1}$	$1° \, s^{-1}$	slow/fast
Scan. accel.	$0.4° \, s^{-2}$	$2° \, s^{-2}$	short/long λ
Pointing knowledge	0.2"	0.1"	rms
M2 nutation	±2.5' @ 1 Hz		azimuth only

Optical Design: German Cortes NAIC



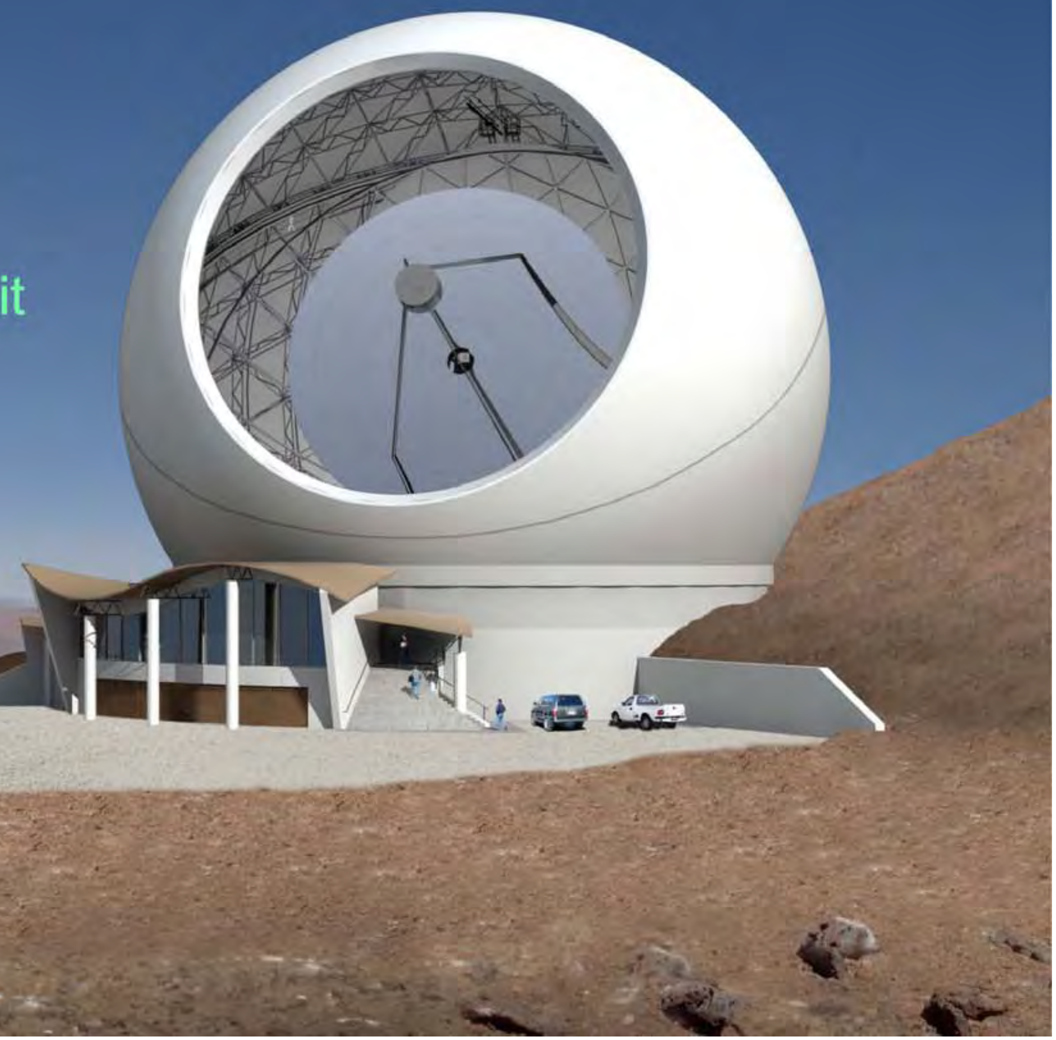
Optical Design: German Cortes NAIC



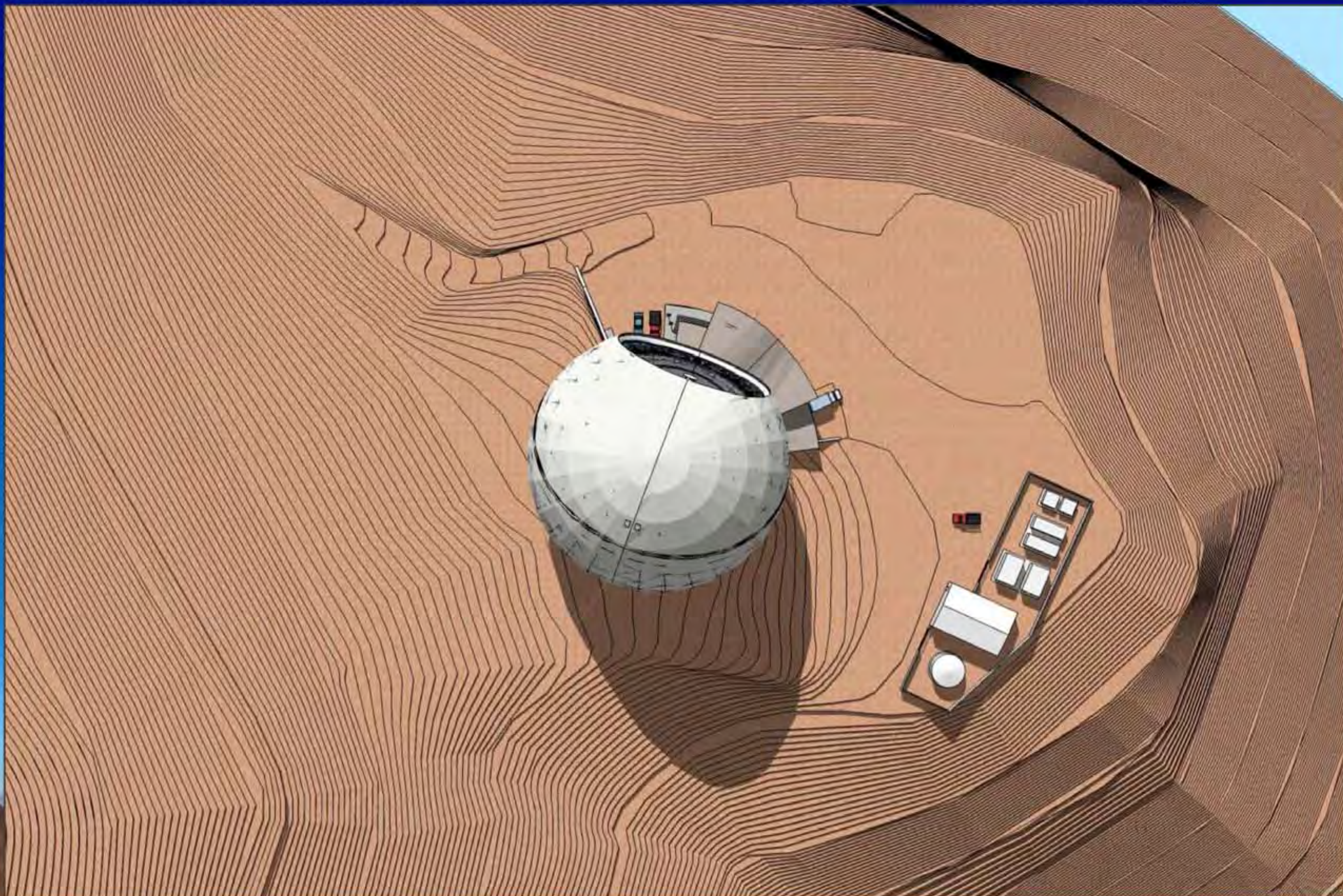
Facility Concept Design
M3 Engineering & Technology

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

- Base Facility
- Road and Site



Site and Facility Design



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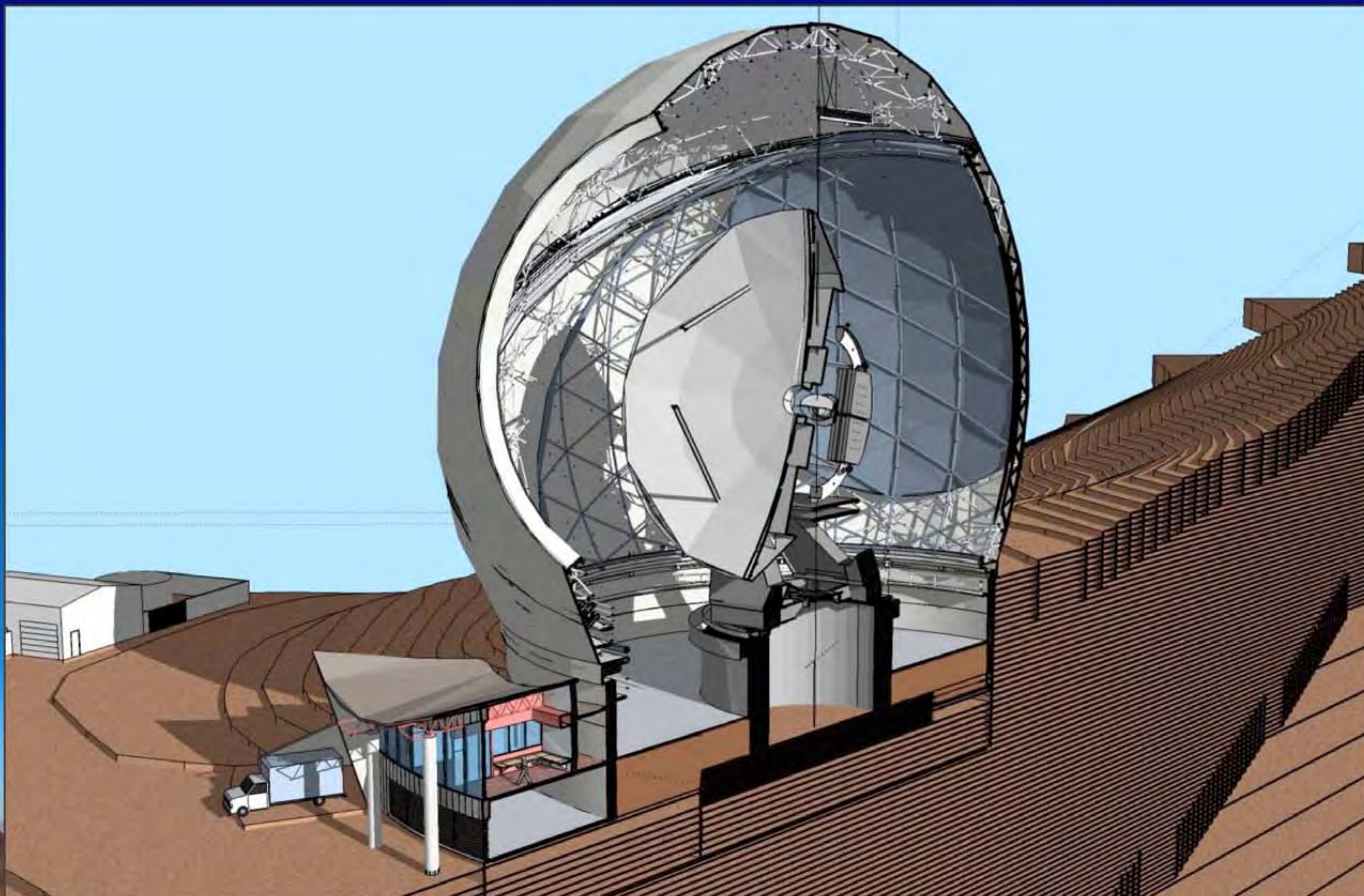
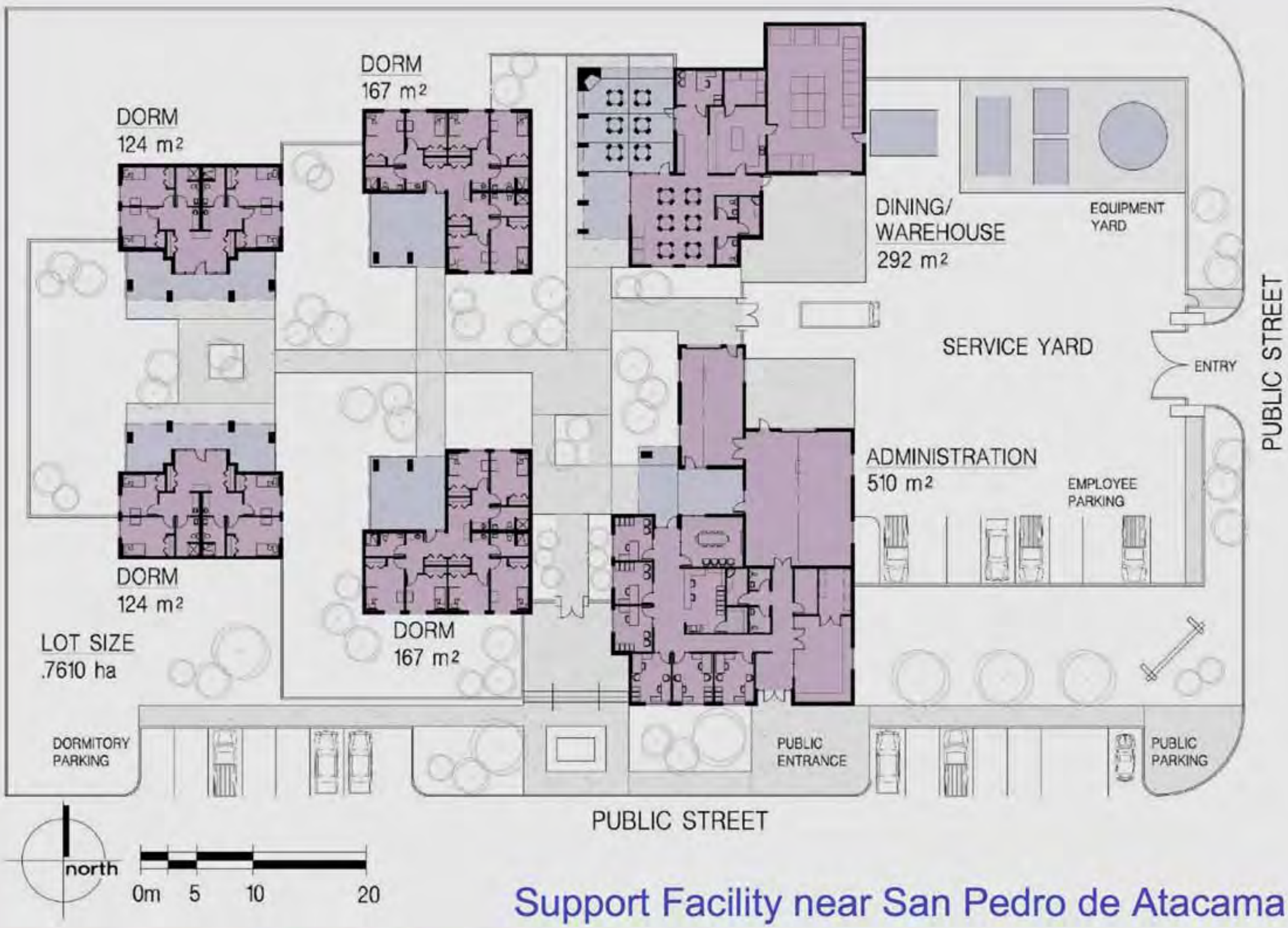


Site and Facility Design



Support Facility near San Pedro de Atacama

Dome Design Study
AMEC Dynamic Structures

- Various enclosure types considered
  - Formal trade studies carried out for CCAT, TMT, VLOT, GSMT

Dome-Shutter

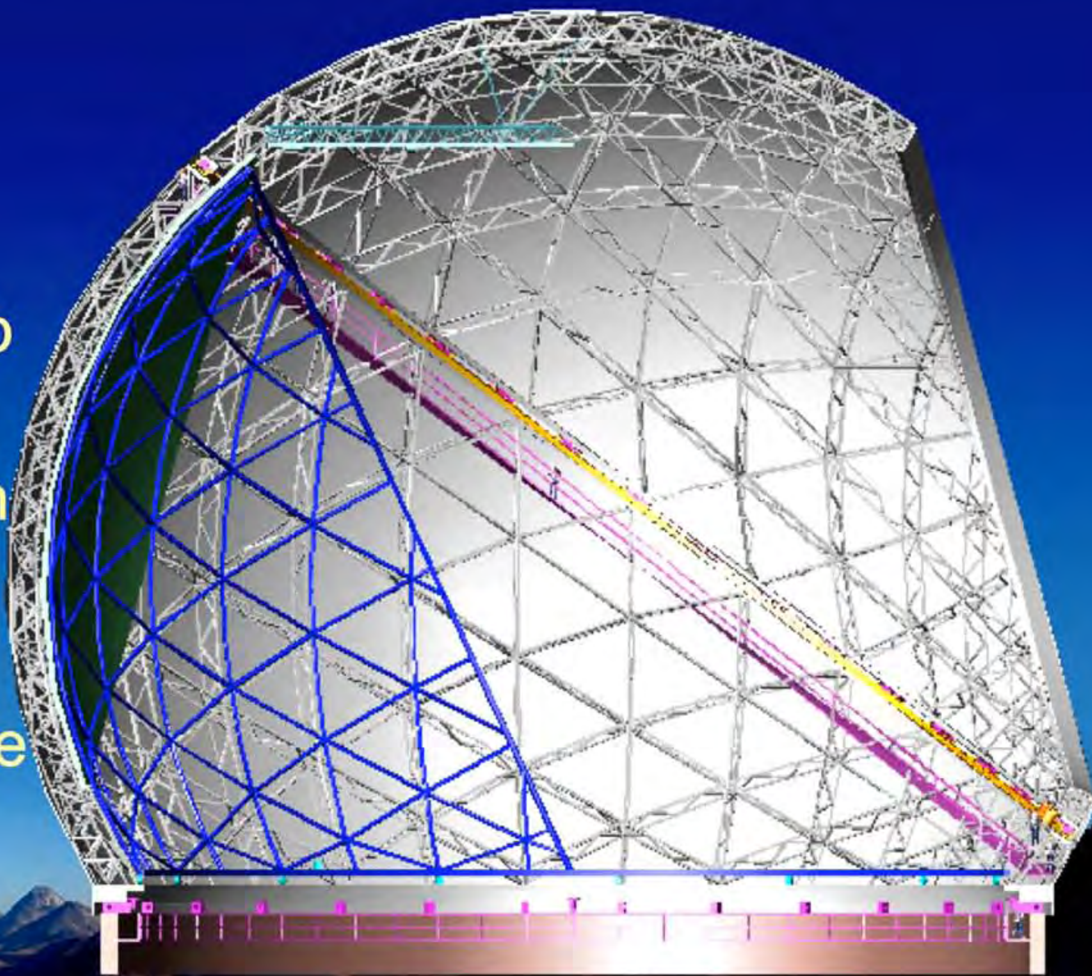
Carousel

Calotte

- “Calotte” selected as baseline design
  - Structurally More Efficient: Lighter, Stronger, Stiffer
  - Amenable to “Geodesic” Type Structural Design: High Efficiency
  - No Large Clear Spans or Concentrated Loads
  - Completely Balanced in Operation
    - Smaller Power Requirements and Mechanical Stresses
  - Minimum Aperture: Good Wind Protection without Windscreens

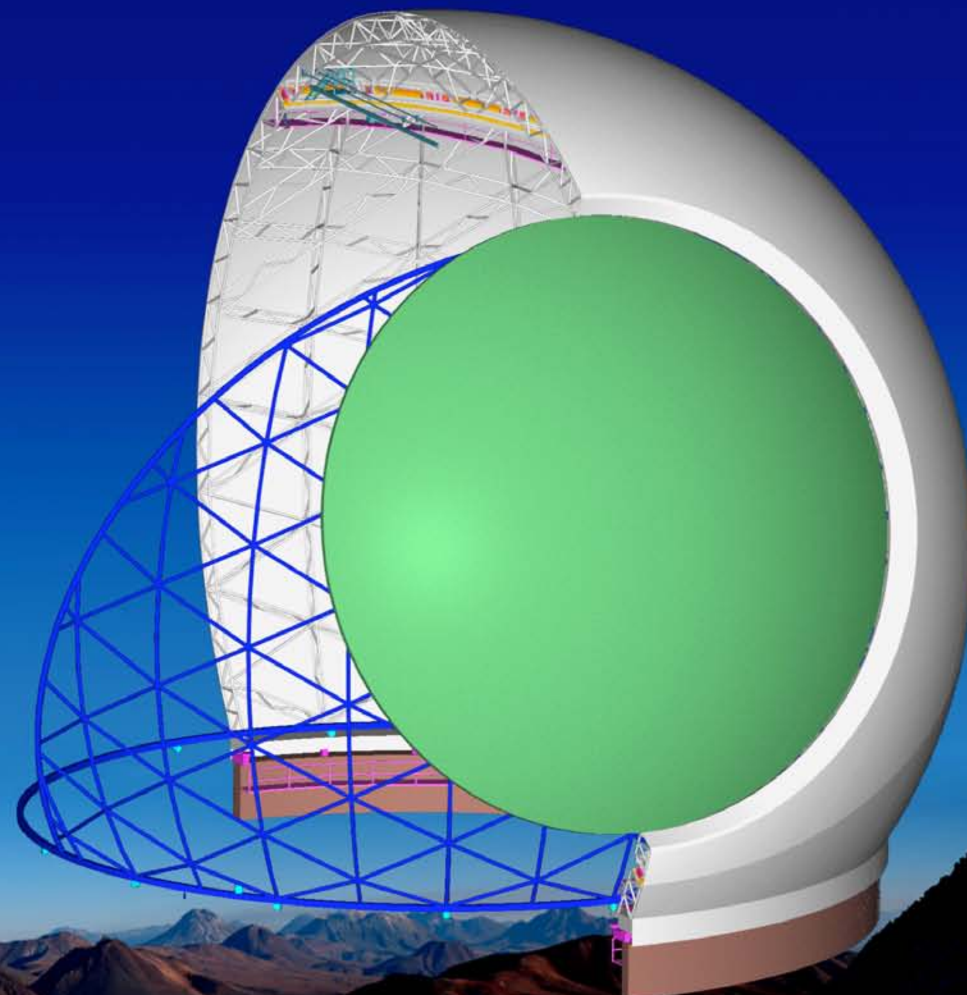
Telescope Dome Concept

- 42 m Diameter at Equator
- 30 m Aperture
- Highly Repetitive Rib and Tie Structure
- Two Similar Rotation Stages
- Diameter Keeps secondary 2 m Inside Dome



Shutter Approach

- Rotates Independently or with Dome
- Pneumatic Seal to Dome Surface
- Heated for Ice and Snow Protection

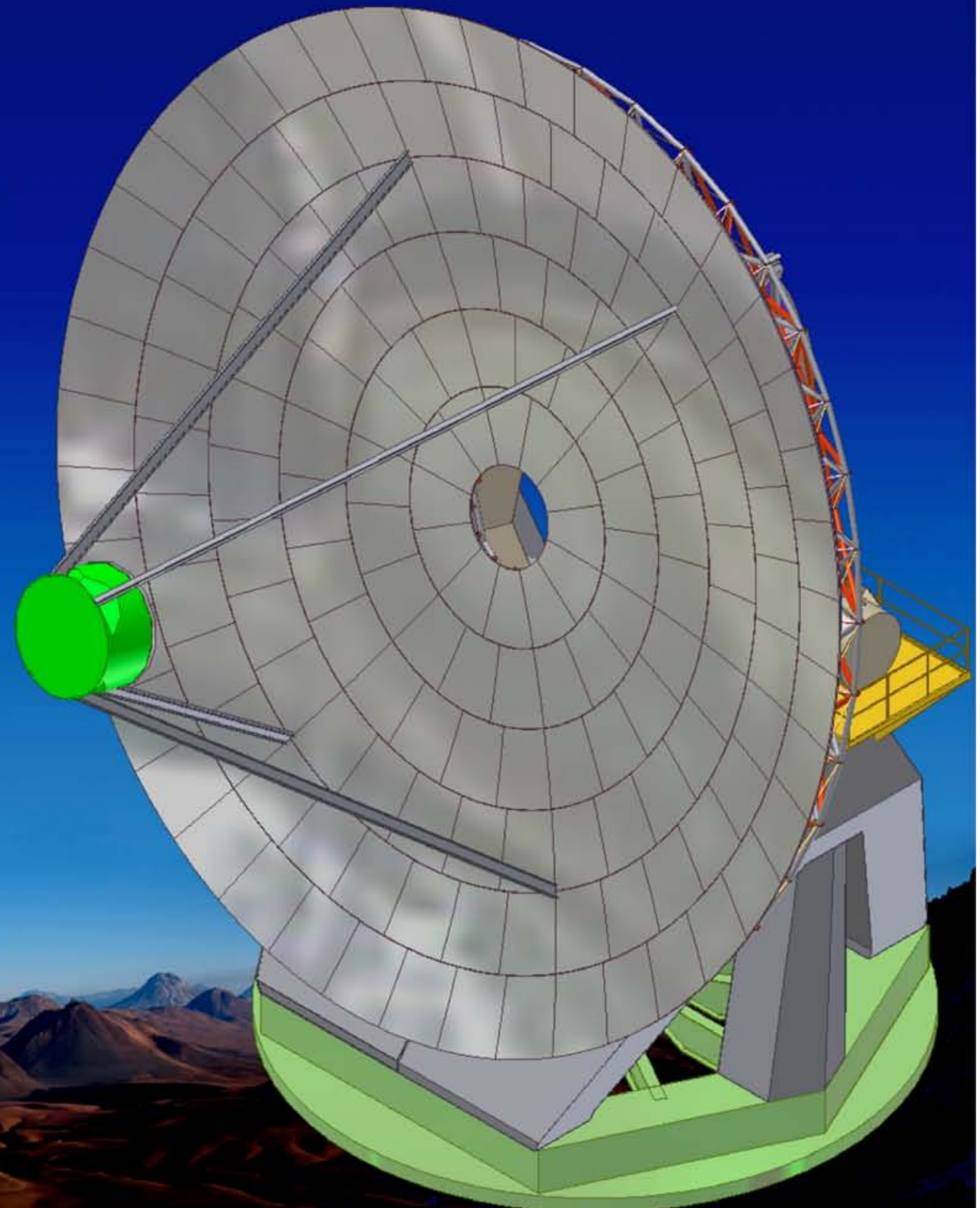


CCAT

CCAT Mount

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

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



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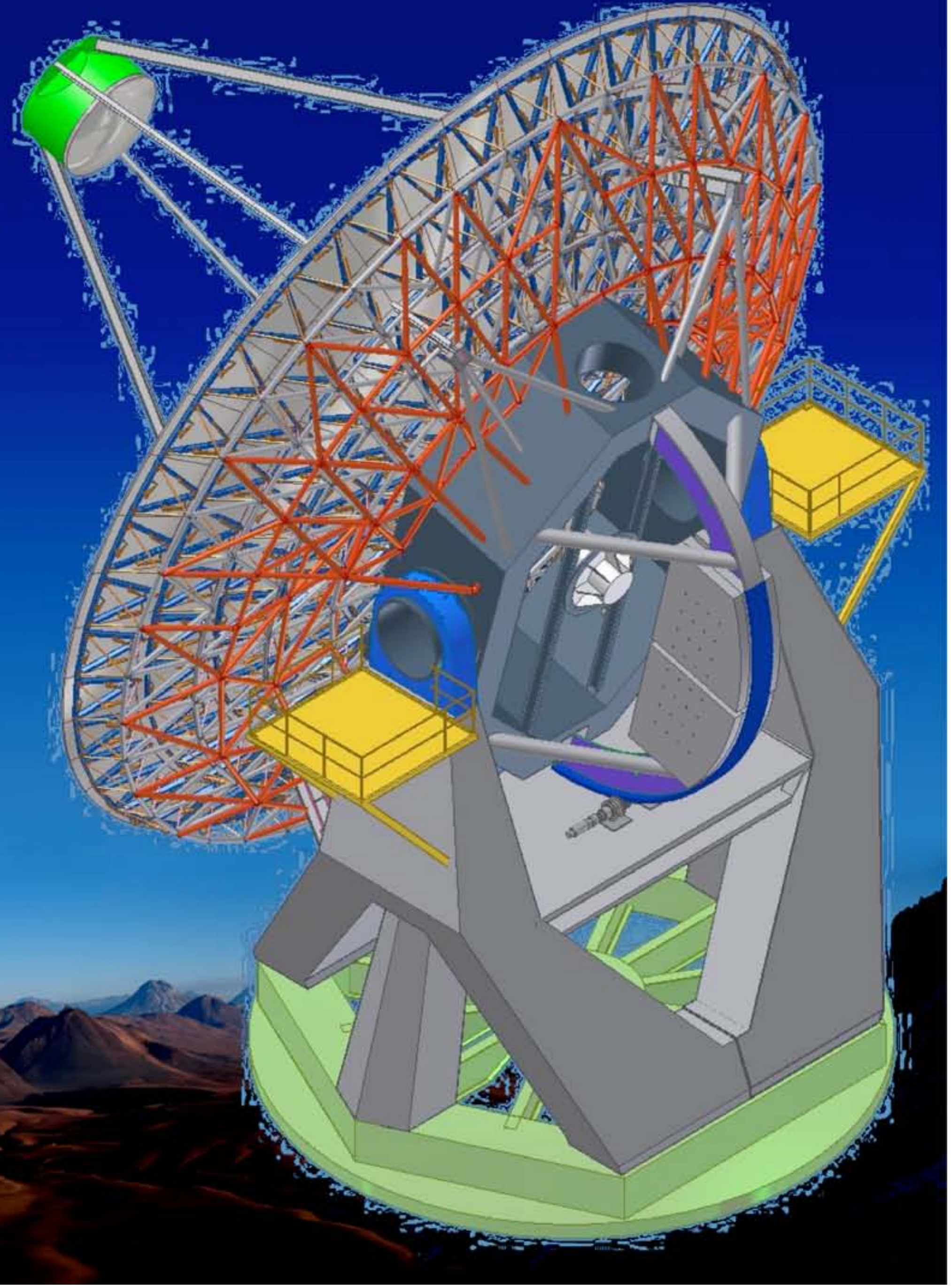
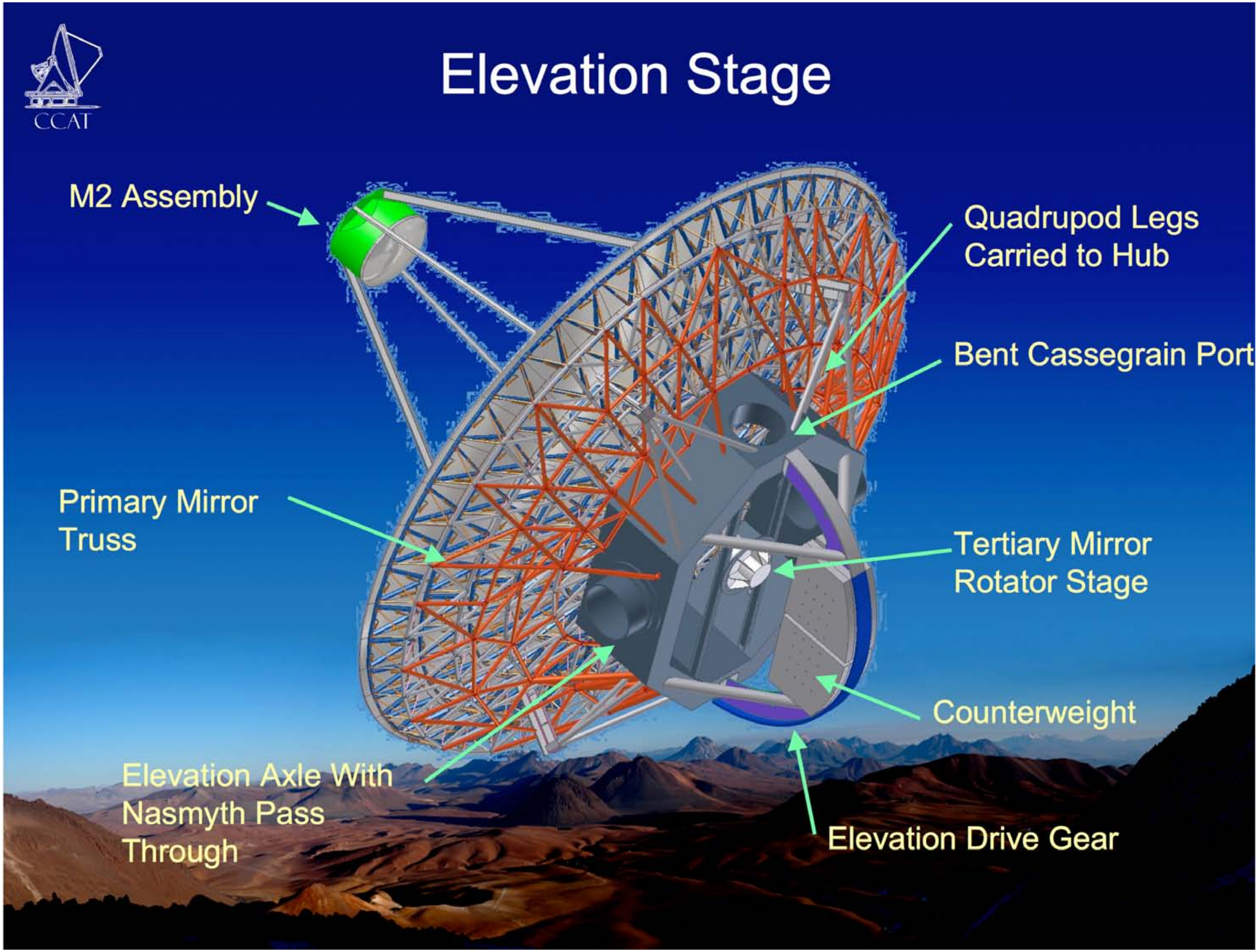
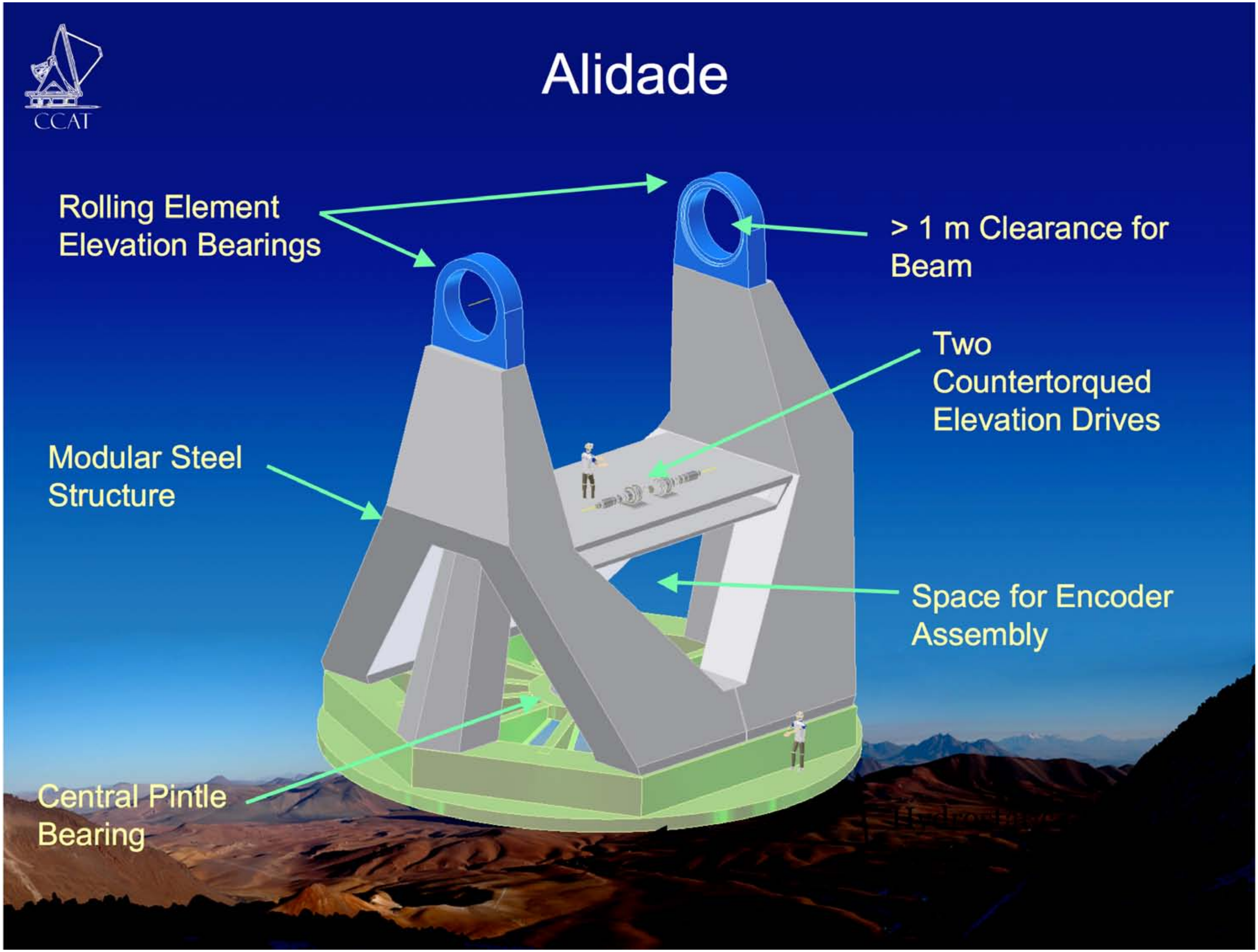


Elevation Stage

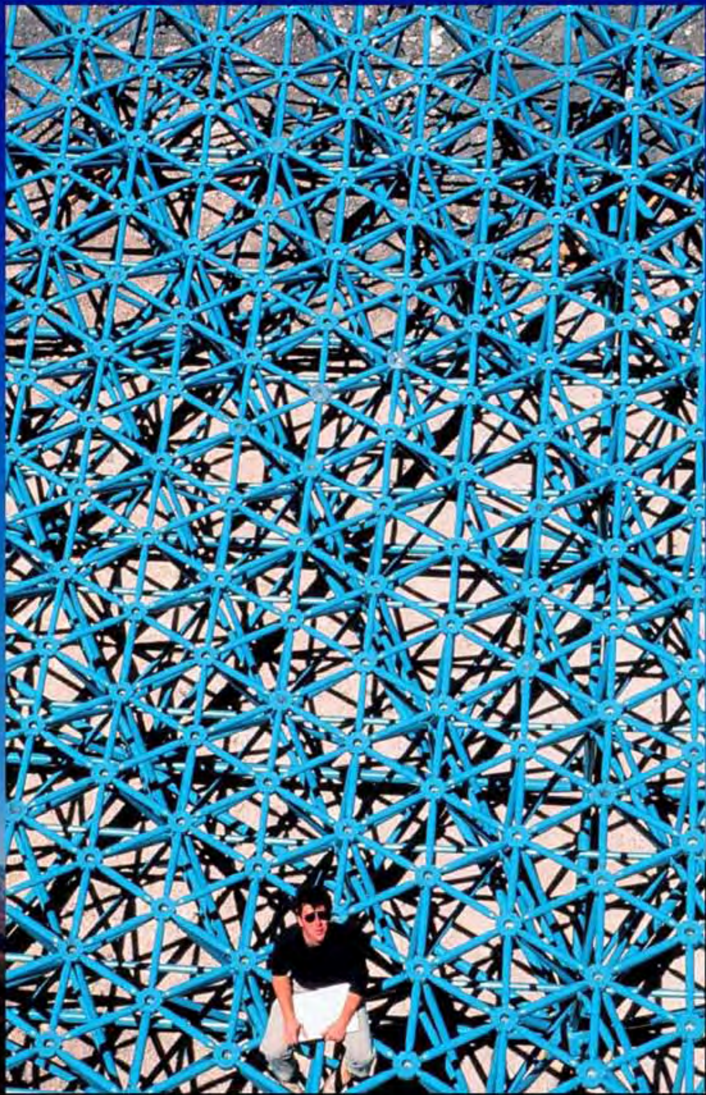




Alidade
CCAT
Rolling Element Elevation Bearings
> 1 m Clearance for Beam
Two Countertorqued Elevation Drives
Modular Steel Structure
Space for Encoder Assembly
Central Pintle Bearing

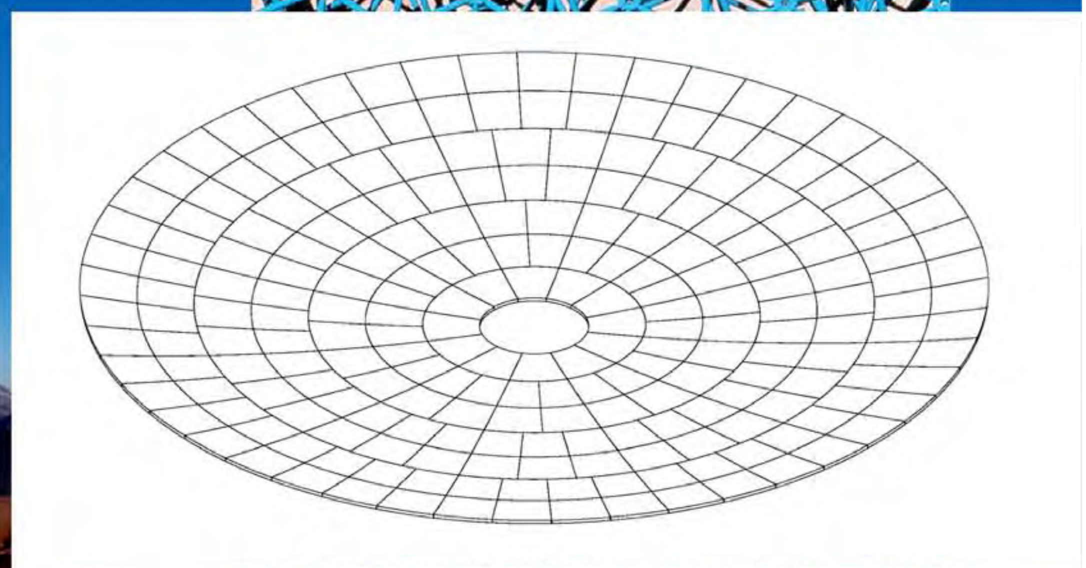
Primary Mirror Concept

- Steel Truss: ~5x Lower Cost than CFRP



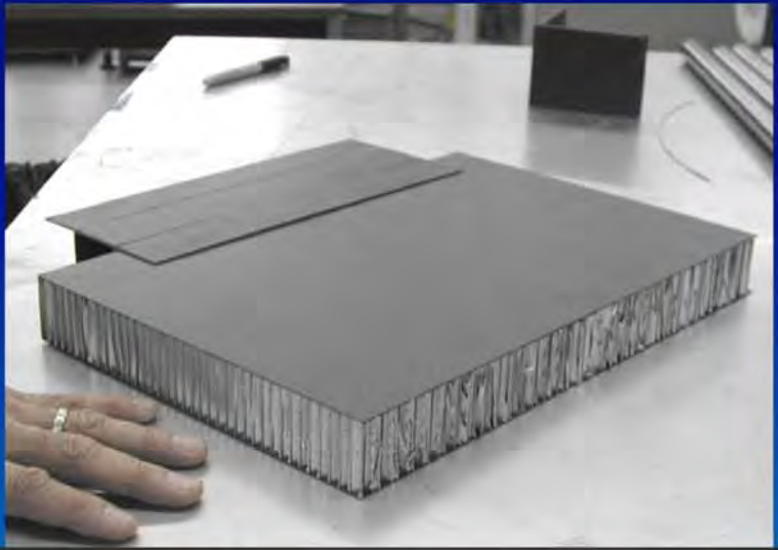
Primary Mirror Concept

- Steel Truss: ~5x Lower Cost than CFRP
- Commercial Actuators Support Axial and Lateral Loads
- 7 Ring Panel Layout
- 7 Sets of Identical Panels
- Total ~ 210 Panels @ ~1.7 m Major Dim.



Primary Mirror

- Two Current Panel Approaches Considered
  - Replicated CFRP/Al Sandwich (CMA)
  - Precision Molded Lightweight Borosilicate (ITT)
- Panels Kinematically Supported on 3 Points by Bipod Flexures
- ~8 kg m^{-2} Areal Density



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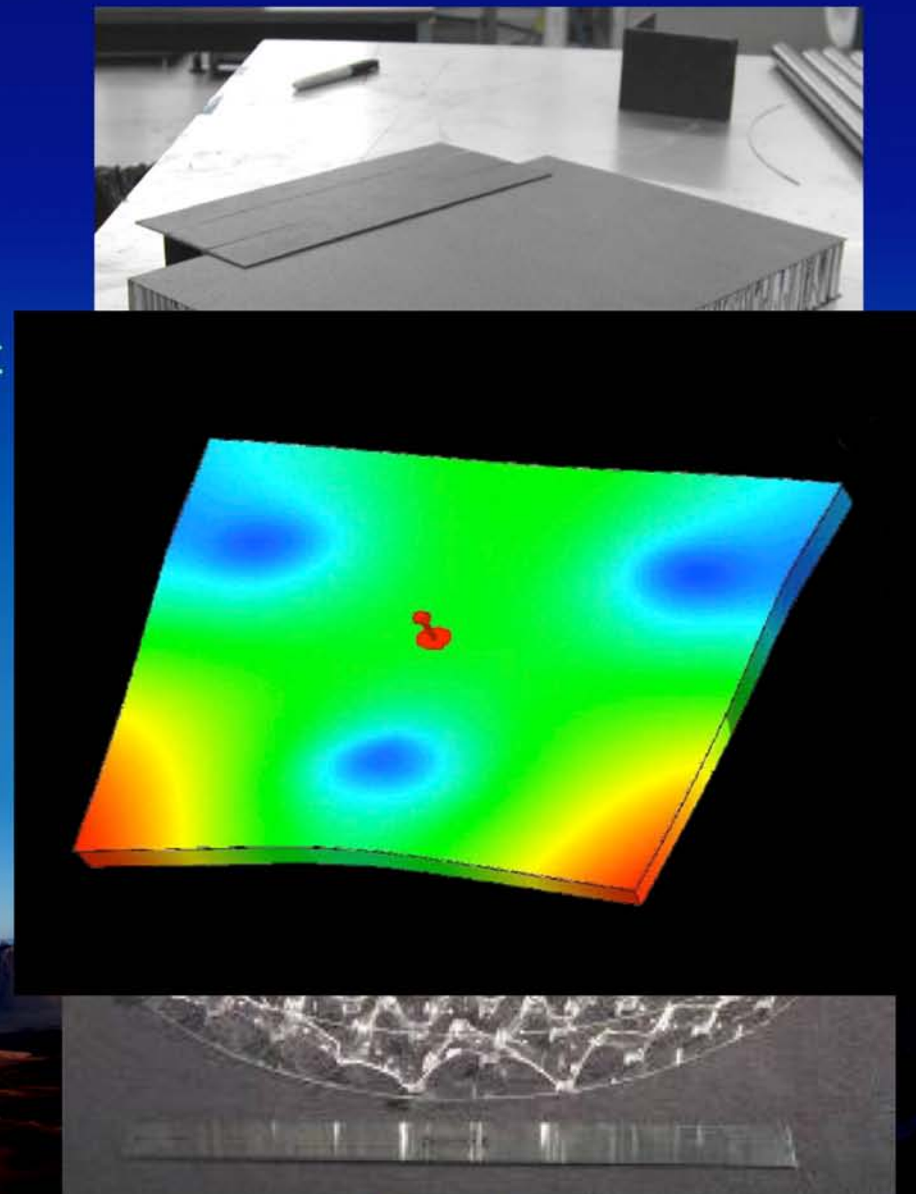
- ~5 μm rms Panel Figure <u>Total</u> Error



Primary Mirror Truss

- Bolted Truss Preferred
  - Easily Test Assembled, Disassembled, Shipped
  - Easy On-Site Assembly
  - Top Surface Precision Results from Component Accuracy
- Ground Assembled in Modules & Lifted via Crane

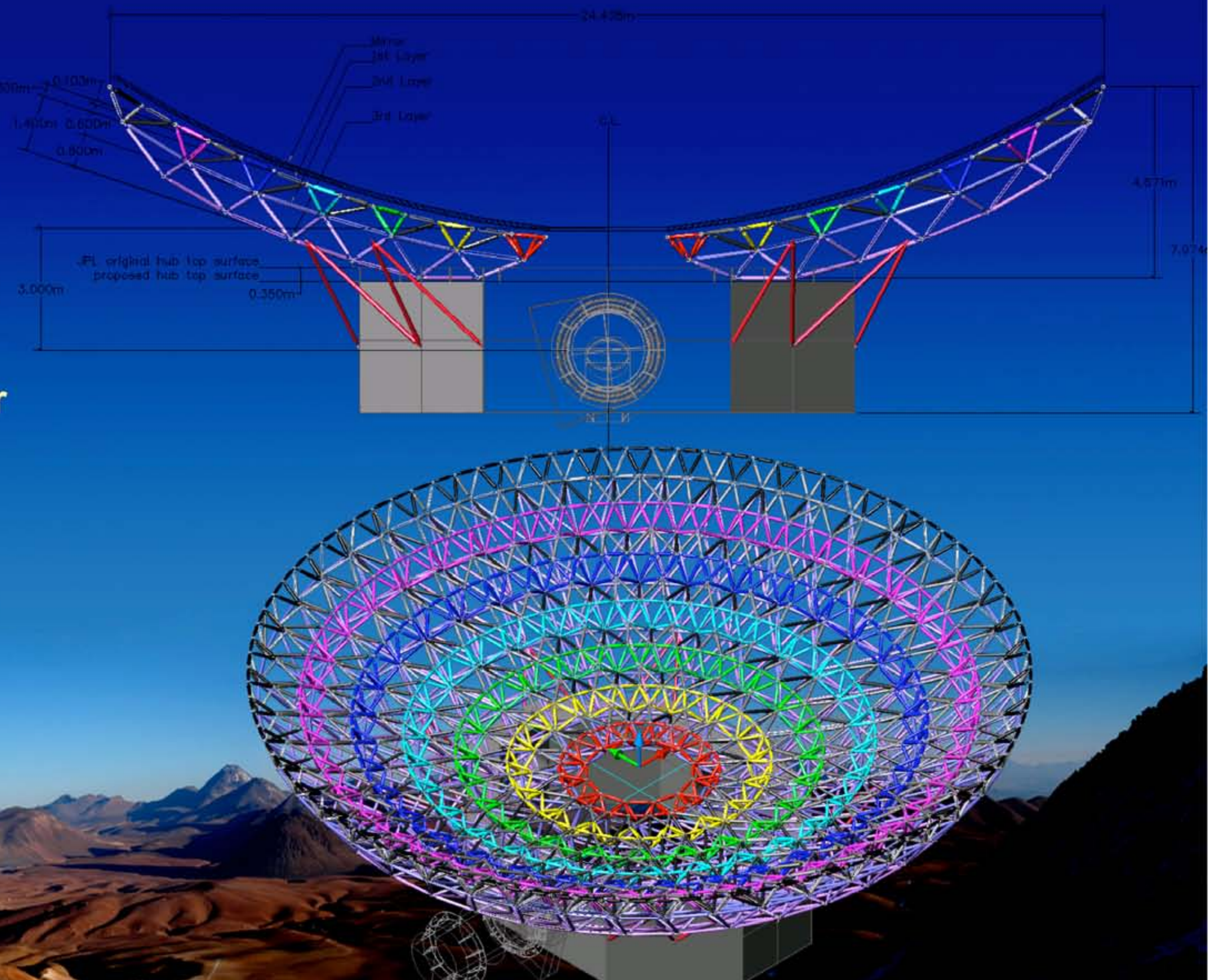
HET Truss

Mero Bolted Truss

Mero Bolted Truss

Primary Mirror Truss Concept Design

- Funded by JPL
- Stutzki Engr.
- Objective: First Order Design to Assess Deformation and Modes
- Provide Basis for Initial Estimates of Cost
- Identify any Significant Risks of Cost or Performance
- Discussed with Mero Structures, Wurzburg, Germany



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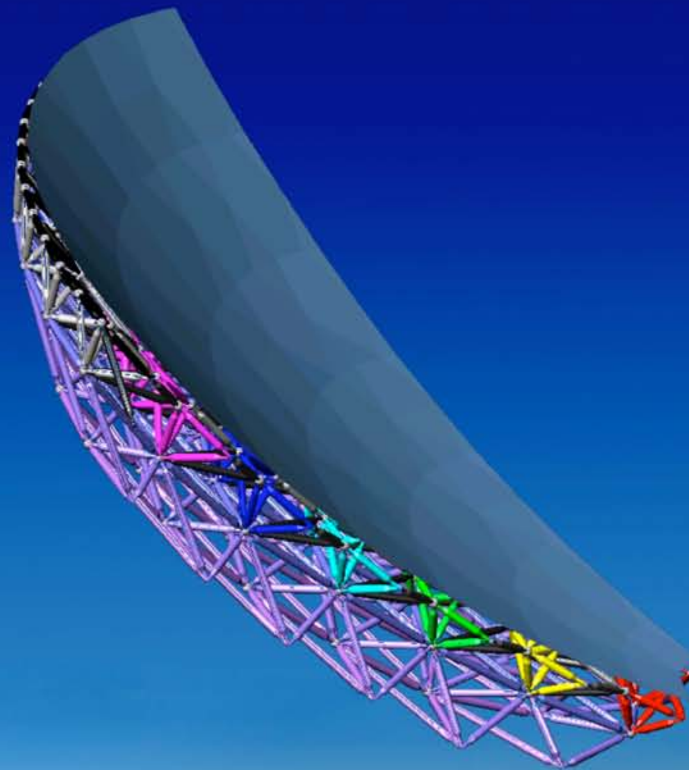

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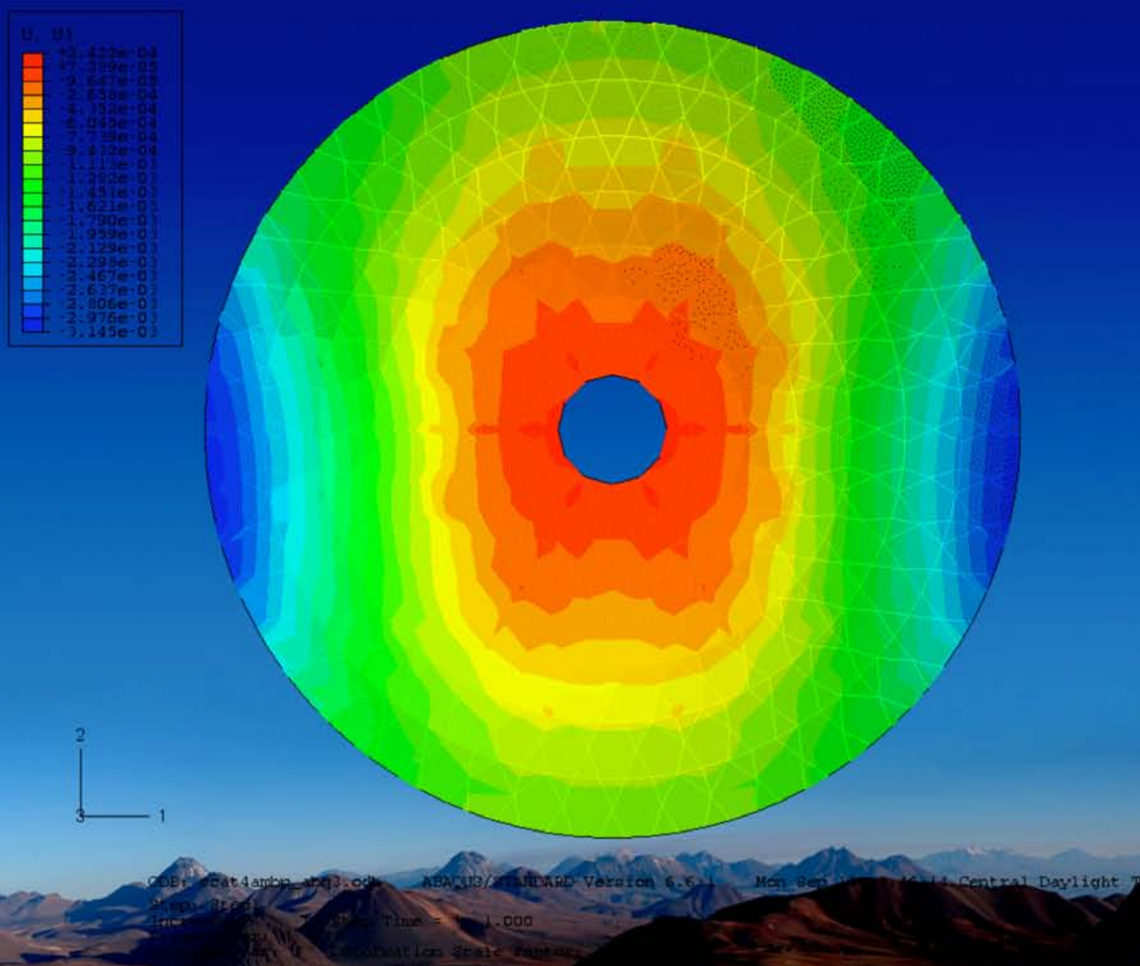
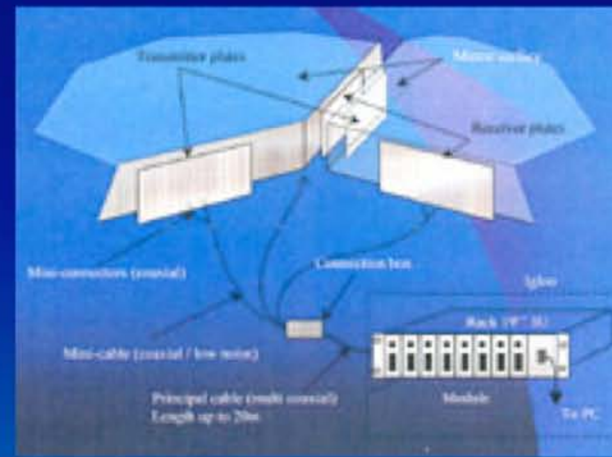
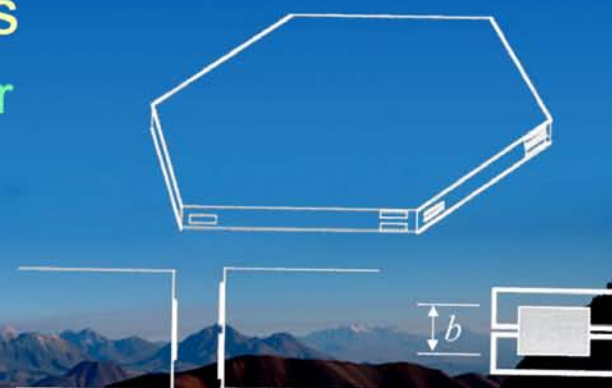


Panel Alignment and Control

- Edge Sensors: Baseline Solution
  - Fogale Nanotech (SALT)
  - Blue Line Engineering (HET)
  - Commercial Solutions…~$1000-1500/sensor
  - TMT Developing Mark II Keck Edge Sensor
- Possible Edge Sensor Shortcomings
  - Error Magnification of Low Spatial Order Modes of Primary Mirror
  - Dihedral Angle Helps
  - Supplementary Sensors Under Consideration
    - Laser Distance Measurement (JPL)
    - Hartmann Panel Angle (AOA)



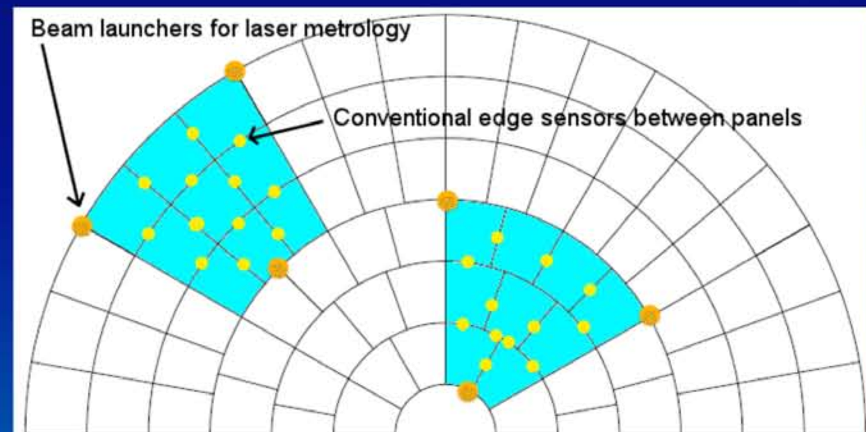
Fogale SALT Sensor

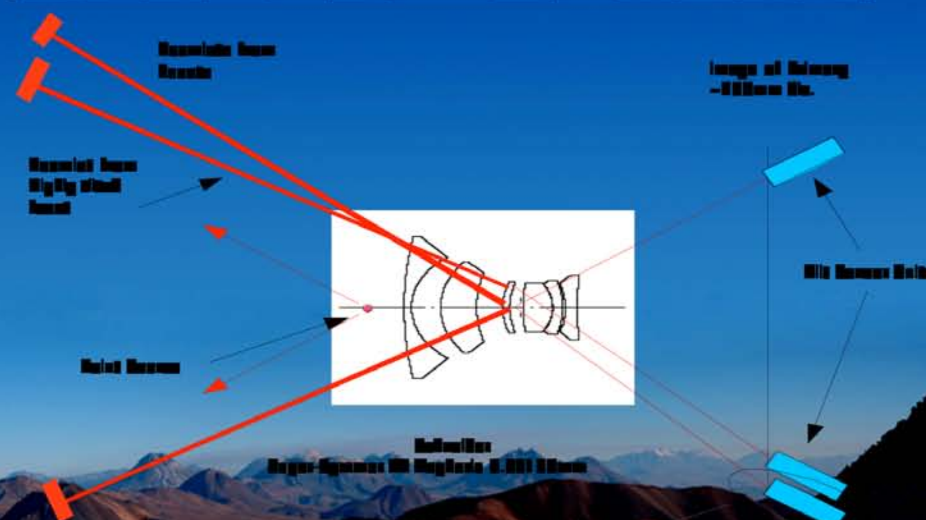


Proposed TMT Edge Sensor

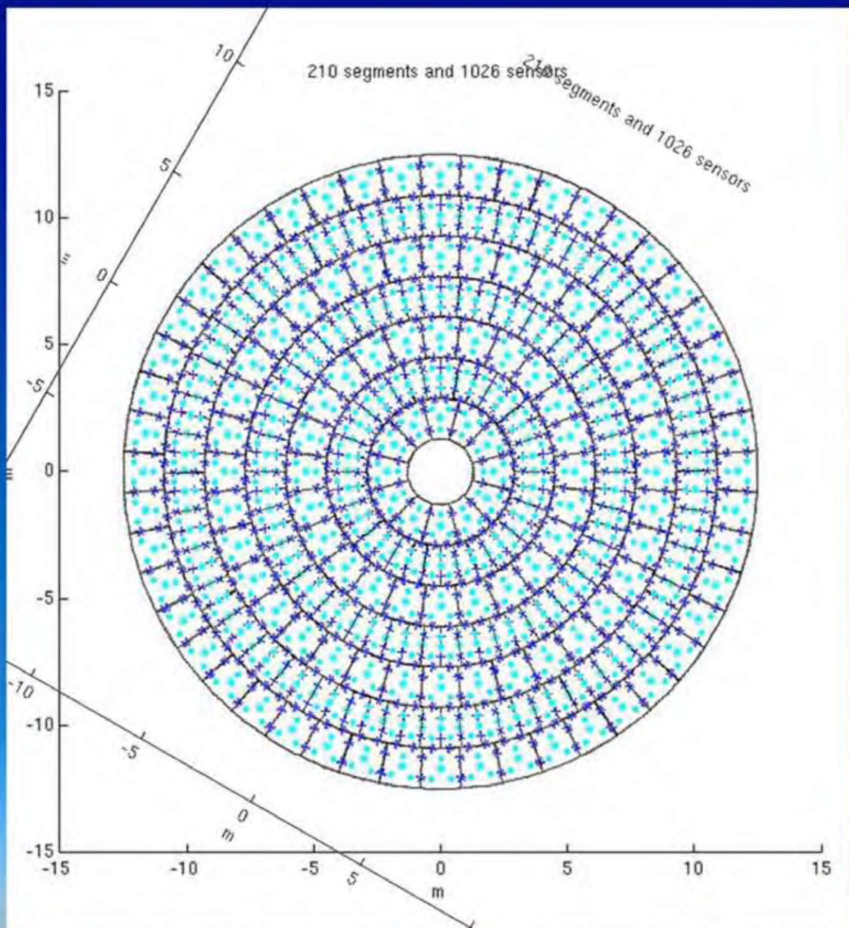
Possible Supplementary Sensors

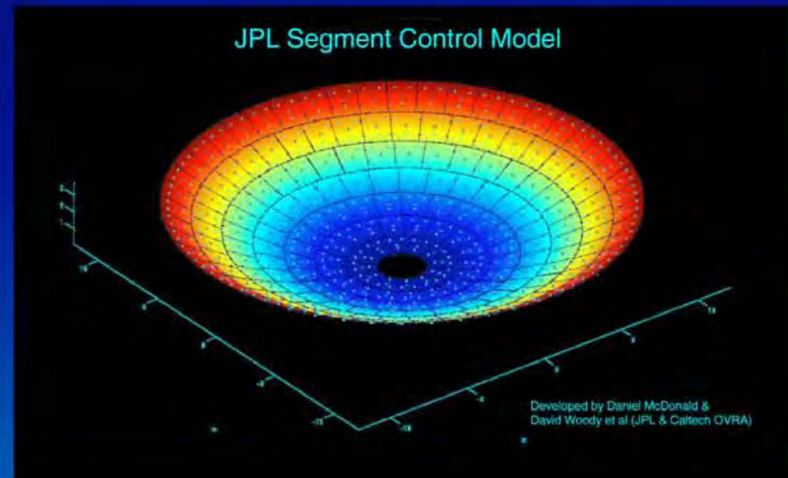
- Laser Absolute Distance Measuring Interferometry: JPL
  - Sparsely Distributed
  - Measure to M2
- Hartman Type Panel Angle Sensor: AOA
  - Point Source near M2
  - Returns from Small Flats on Segments
- IR Wavefront Sensing Guiding
  - Solves Guiding and Sensing
  - Requires Specular Panels at Operating Wavelength





Segmented Mirror Control Modeling

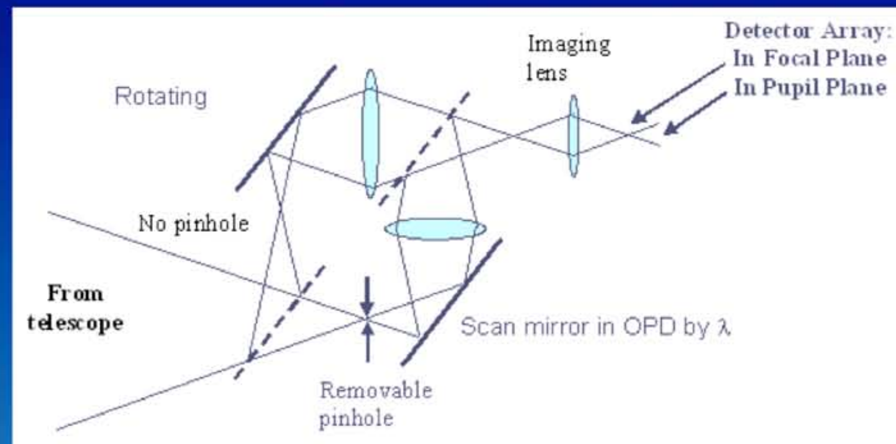




- D. MacDonald, D. Woody, et al. @ JPL and Caltech
- Model Incorporates
  - Segmentation
  - Sensor Properties
  - Edge Sensor Distribution
  - Error Propagation
  - Control Law

Alignment Calibration

- Initial Panel Alignment
  - Optomecahnical
  - 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

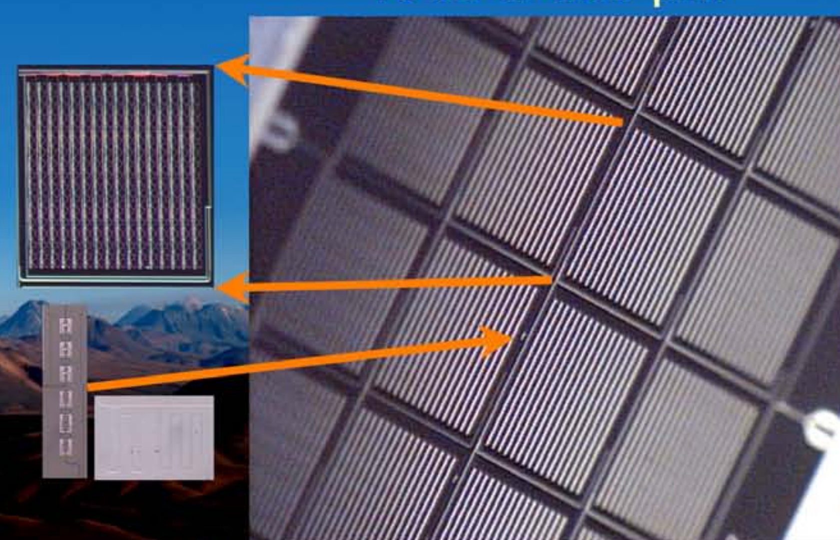
Hybrid Interferometer Combines Three Types in One Instrument

G. Serabyn, JPL

Instruments

- Short Wavelength Camera: SWCam
  - 200–620 µm; Mesh Filters on Wheel
  - Direct Illumination; 32,000 pixel; 5' x 5' Field of View
  - NIST SCUBA2 Silicon TES Bolometer Arrays
- Long Wavelength Camera: LWCam
  - 750–2000 µm; Microstrip Filters; Slot Dipole Antennae
  - MKID Bolometers 20' x 20' Field of View
    - Wavelength Dependent FOV
- SCUBA2 (?)
  - Proven First Light Instrument
- Spectrometers
  - Multiobject, direct detection
- Heterodyne Arrays
  - 10^2 pixels @ 650 or 850 GHz

Antenna coupled array
1300 & 850 µm



Project Phases and Schedule

- Feasibility/Concept Design Study
  - October 2005–January 2006
  - Cornell, Caltech, & JPL: Develop Baseline Concept, Assess Feasibility, Initial Cost Estimate
- Partnership Development Phase
  - June 2006–January 2008
  - Complete Partnership, Identify & Secure Funding
  - Address Key Technical Issues
- Technical Development Phase
  - June 2008–June 2011
  - Detailed Design, Manufacture, Integration
- Commissioning Phase
  - June 2011–June 2012
  - Optimize Performance & Handover to Operations

CCAT

Project Phases and Schedule

- Feasibility/Concept Design Study
  - October 2005–January 2006
  - Cornell, Caltech, & JPL: Develop Baseline Concept, Assess Feasibility, Initial Cost Estimate

> *"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)*

ure Funding

  - Detailed Design, Manufacture, Integration
- Commissioning Phase
  - June 2011–June 2012
  - Optimize Performance & Handover to Operations

Partnership Status

- Caltech 20% +?
  - Proposal Submitted to Moore Foundation
  - Additional JPL involvement, i. e., instruments?
- Cornell University 25-30%
  - Donor Identified for $10 M
  - University and NY State Support for Remainder
- University of Colorado Boulder 5-10%
  - Prospective Donor Identified for Major Share
- UK (ATC/ROE) 25%
  - Statement of Intent Submitted to PPARC
- Canada (Us. of BC & Waterloo) 20%
  - Canadian Government Funding

Interim Consortium Agreement: Signature Pending
Full Project Agreement by 2008 January

Project Organization

- Final Structure to be Decided by Partners
  - Observing Shares, Investment Levels, Operations Obligations
- Non Profit Corporation (NY State)
  - Partners Share Ownership, Rely on Cornell for Admin. Support
  - Legal Presence in Chile, Obtain Necessary Status and Site
  - Project Management Reports to Board
- Technical Project Team
  - Oversee Technical Design, Industrial Fabrication, & Construction
  - Lead Commissioning Effort in Chile with Operations Team
- Instruments
  - Develop at Institutions (SWCam @ Cornell, LWCam @ Caltech)
  - Leverage Specialized Talent and Facilities, i. e., MDL @ JPL

CCAT Operations

- Observations Mostly Remote or Service Mode
- Operations Base near San Pedro
  - Reduced Staff at Telescope, Daily Commute
  - Most Chilean hires, 20-25 Operations Staff
  - Weekly Commuting (*Turno*)
  - Other Telescopes in Chile Provide Examples
- Annual Cost $ 5 M
  - Telescope Operations Only, Science Analysis Additional
  - NSF Support? Redirect from CSO; Community Access
  - Other Partners Provide Proportional Shares

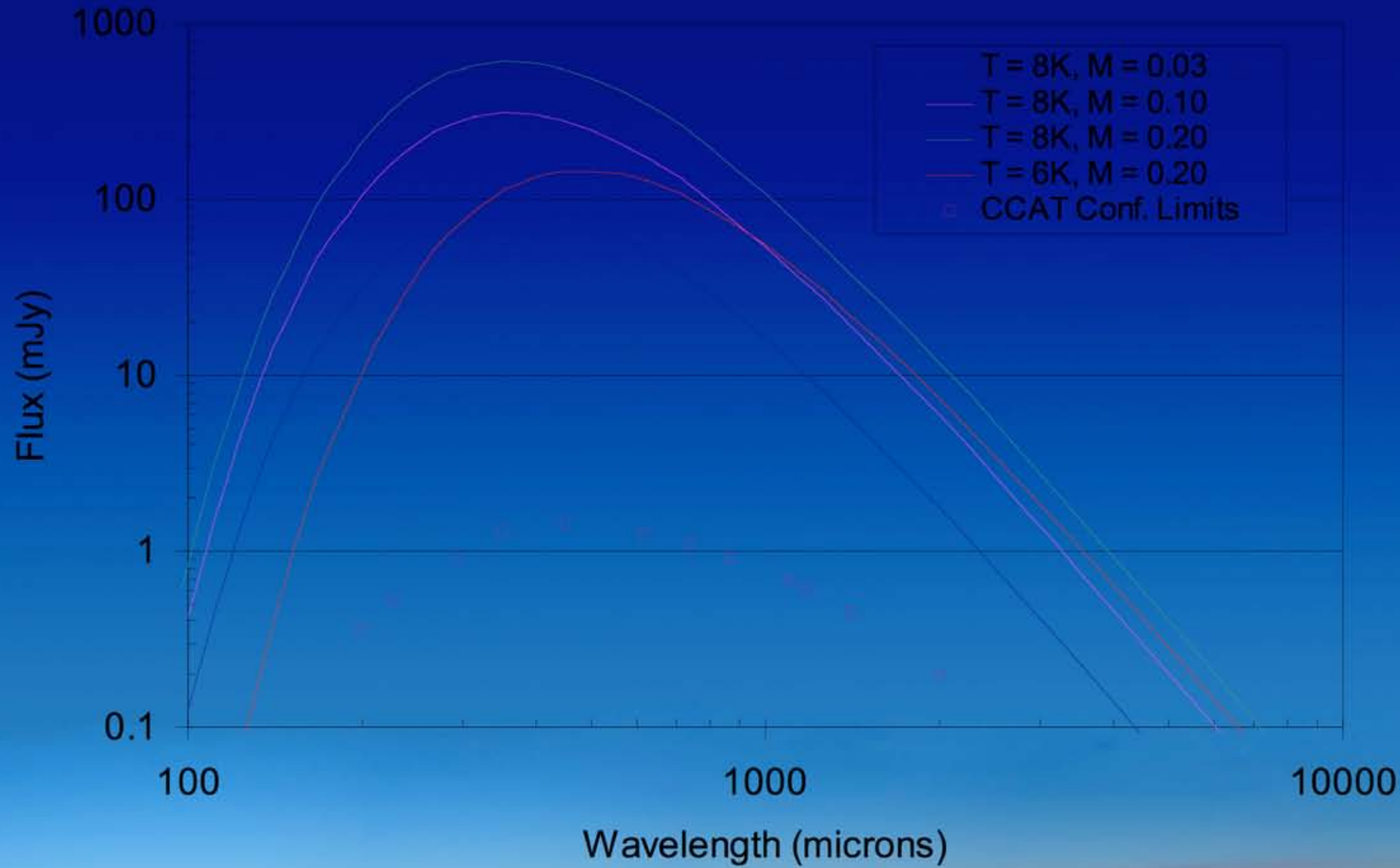
Next Steps

- Additional Consortium Development
- Interim Consortium Agreement: Signature Pending
- Engineering Work on Critical Systems
- Focus on:
  - Change from f/0.6 to f/0.4 Primary…More Compact Telescope
  - System Analysis of Optimal Segmentation, Sensor Deployment, Control Law for Mirror and Telescope Alignment (JPL Modeling)
  - Additional Investigation of Calibration WFS, Supplemental Panel Position Sensing, Edge Sensing
  - Further Development of Science Instrument Concepts
- Full Project Agreements by Early 2008

Cerro Chajnantor 5612 m

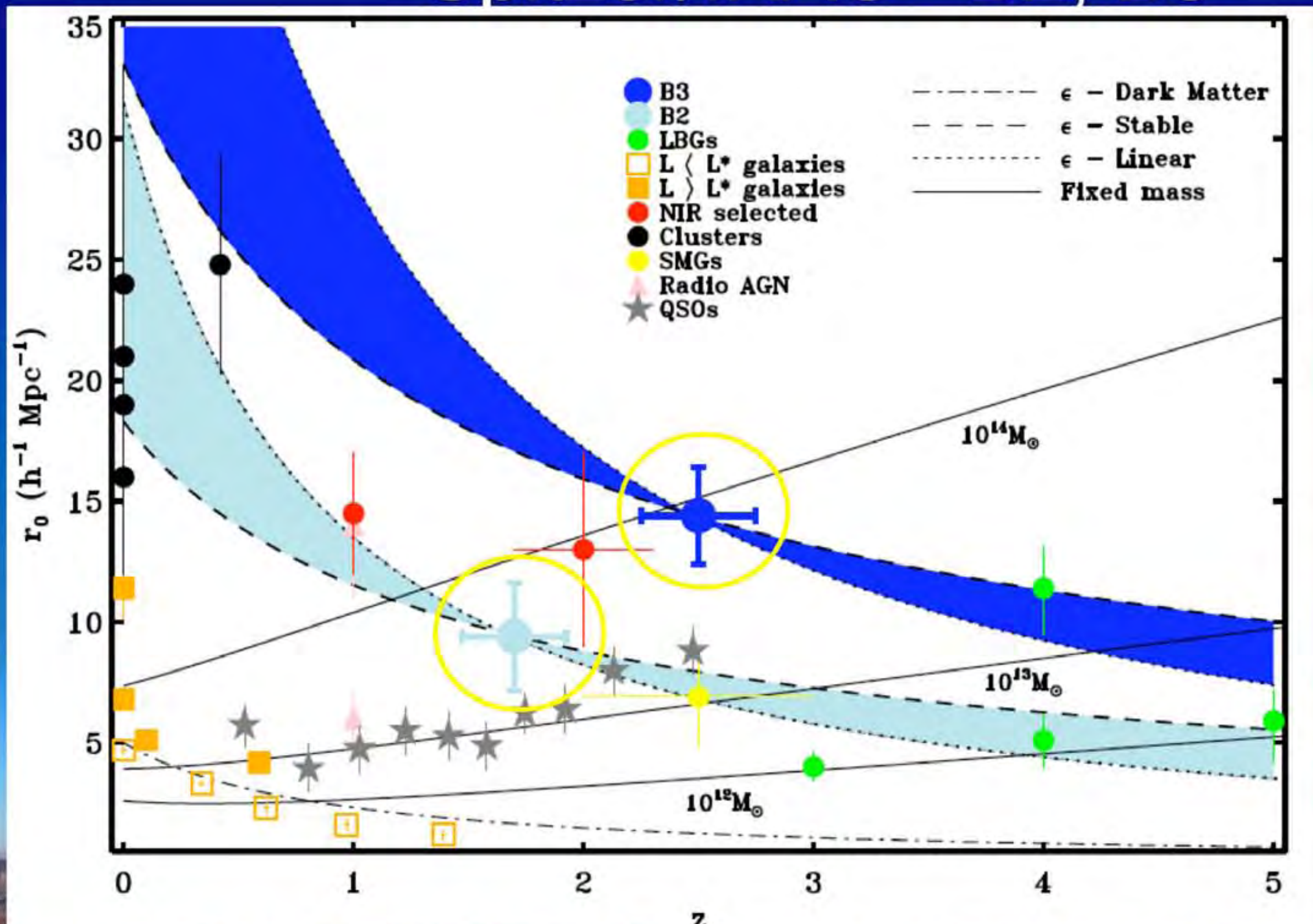
End of Presentation

Cold Cloud Core Survey



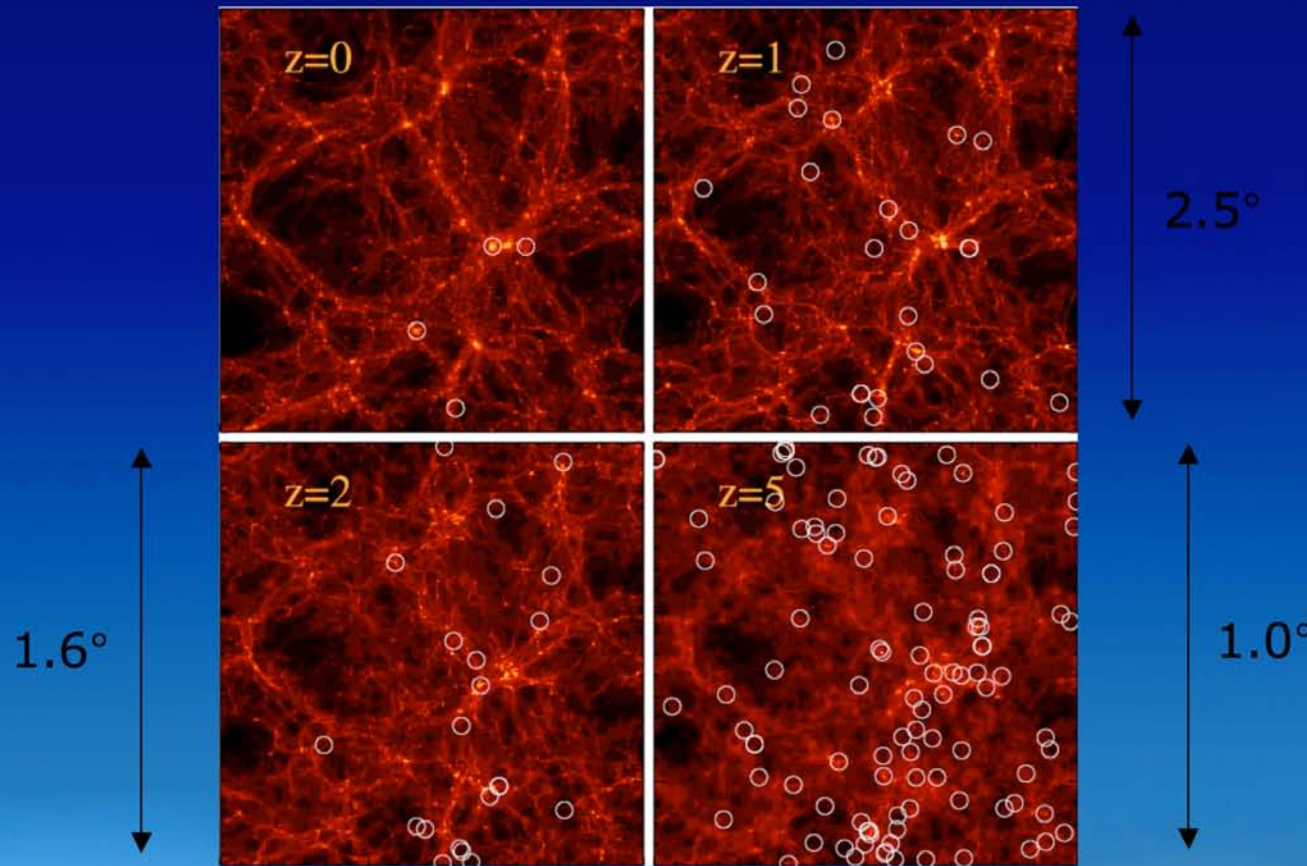
Expected flux for several low mass (and low temperature) cold cloud cores located at 140 pc. This survey is limited by the field of view of the [illegible] and how fast we can move the telescope.

ULIRG Clustering: Spitzer/IRAC - B2, B3



Farrah et al (2006), ApJL 641: 10^{12} $L_\odot$, 200 $M_\odot$/yr

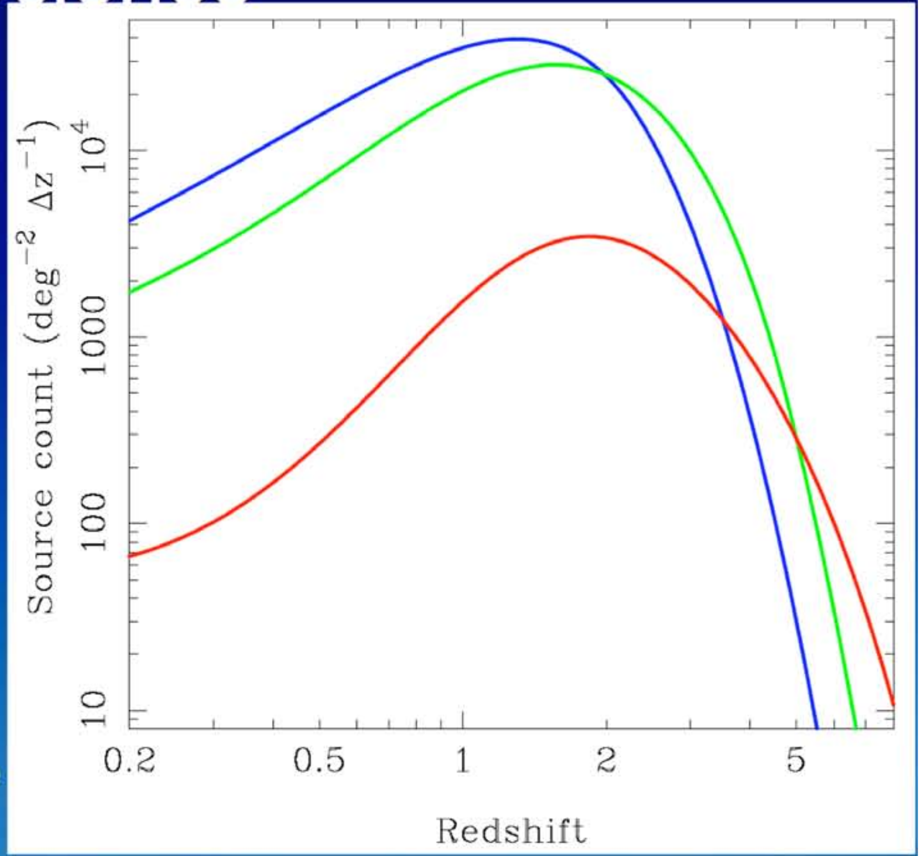
Large-scale structure



An example of modern cosmological hydrodynamic simulations (Nagamine et al 2005). Each panel has a comoving size of 143 Mpc on a side, and th star forming galaxies with instantaneous star form 100 $M_{\odot}$/yr at each epoch are indicated Duncan Farrah).

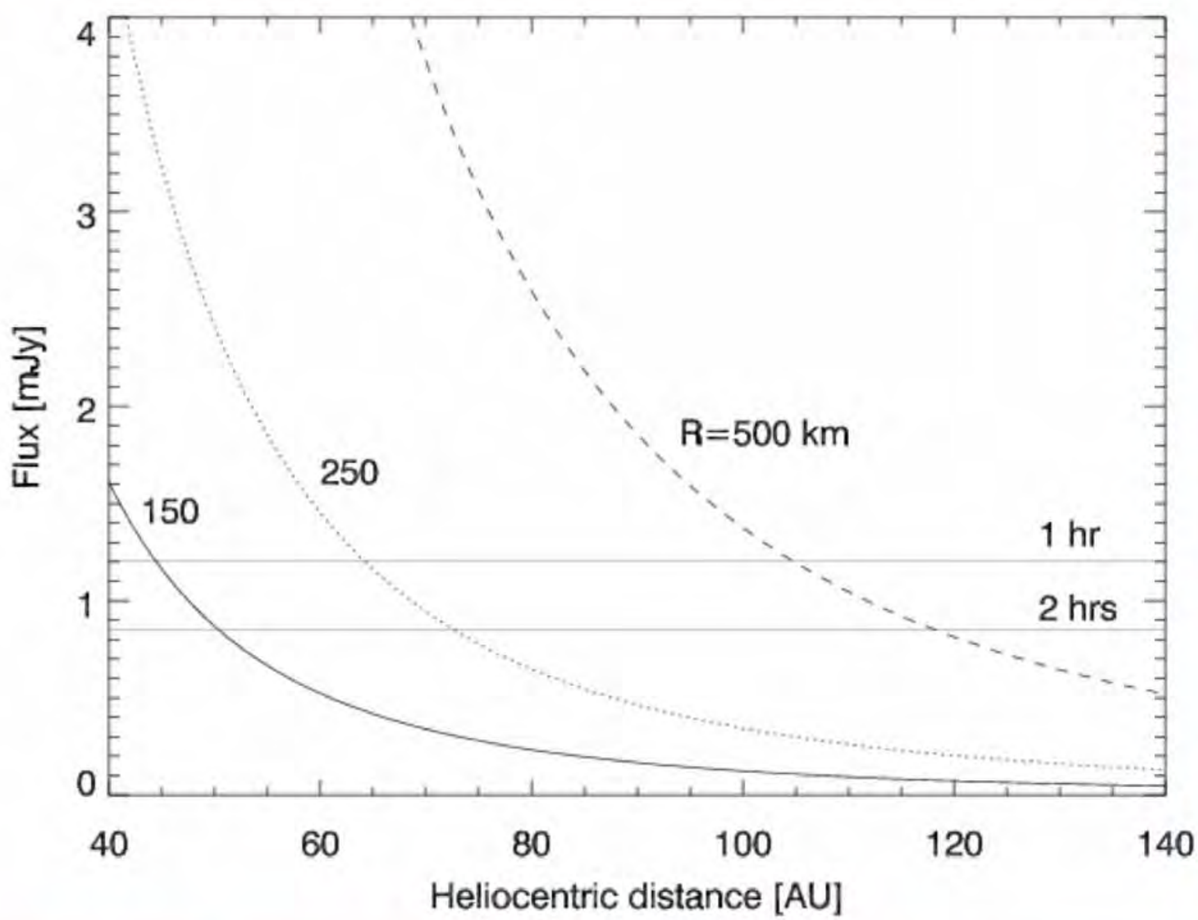
CCAT Science

- How did the first galaxies form?
  - CCAT will detect hundreds of thousands of primeval galaxies from the era of galaxy formation and assembly (z = 2 – 4 or about 10-12 billion years ago) providing for the first time a complete picture of this process.
  - CCAT will probe the earliest bursts of dusty star formation as far back as z ~ 10 (less than 500 million years after the Big Bang or when the Universe was ~ 4% of its current age).
  - More detail: presentations by Robson, Soifer, Borys



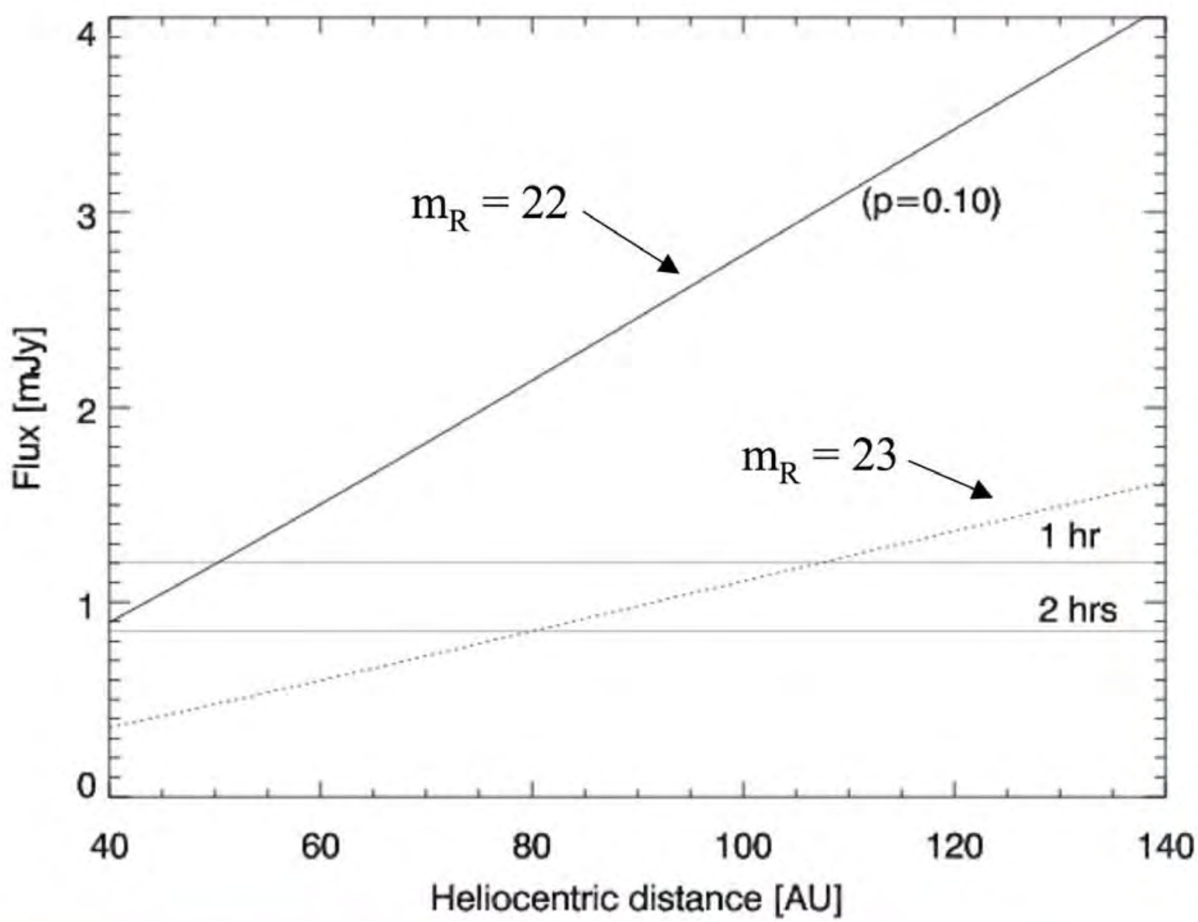
Estimated redshift distribution of galaxies that will be detected b
CCAT at 1 mJy for 200 (blue
350 (green), an

Detecting Trans-Neptunian Objects



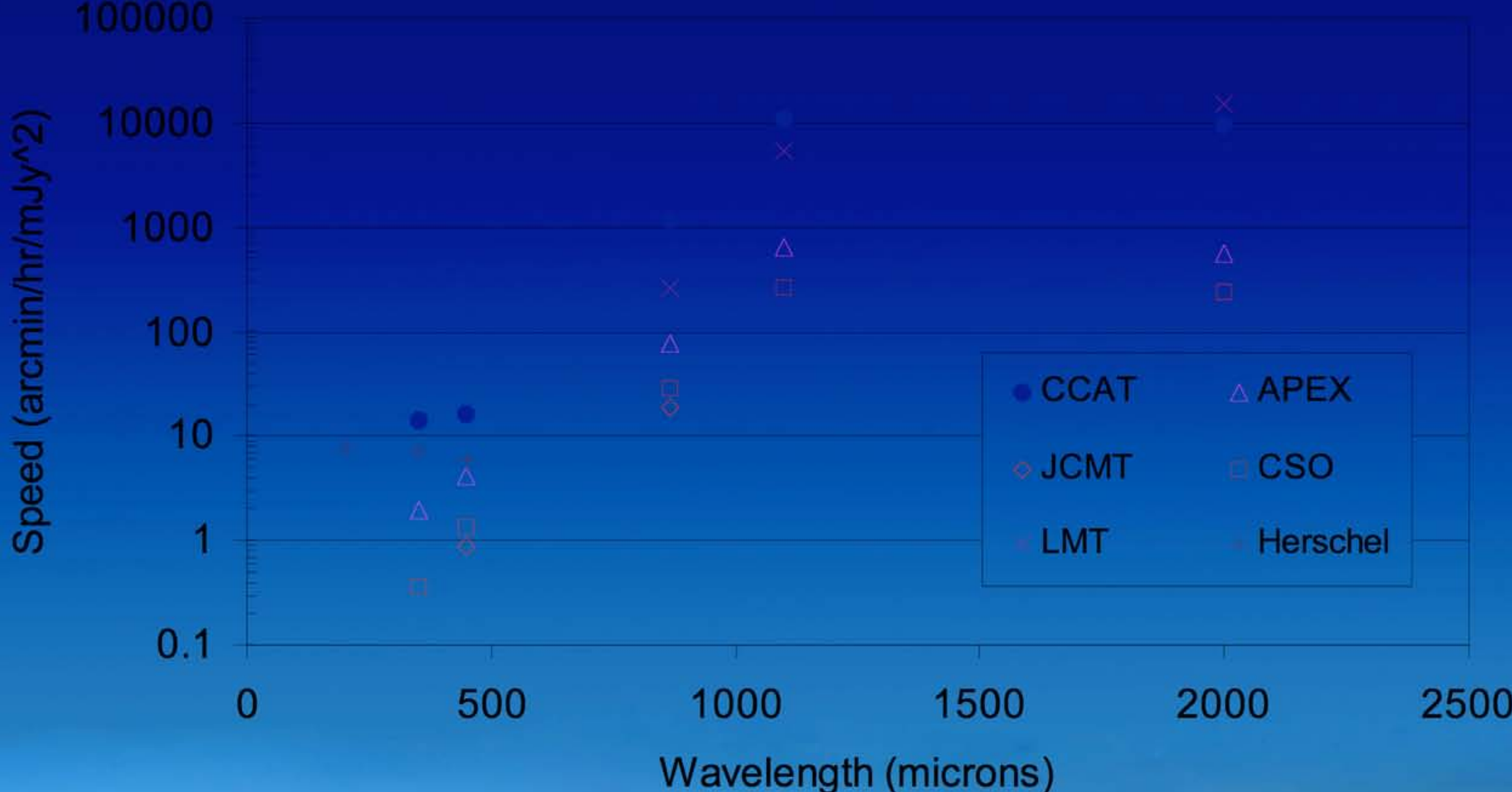
Predicted 350 μm submm flux for TNOs assuming the standard thermal model, i.e. non-rotating. Bodies with radii of 150 km, 250 km, and 500 km are shown with the solid, dotted, and dashed lines, respectively. Curves assume a geometric albedo p = 10%, phase integral q = 0.45, bolometric and submillimeter emissivity $\varepsilon = \varepsilon_\nu = 0.9$. The horizontal lines show the CCAT 5-sigma detection limits for one hour and two hours of on-source

TNO sub-mm advantage



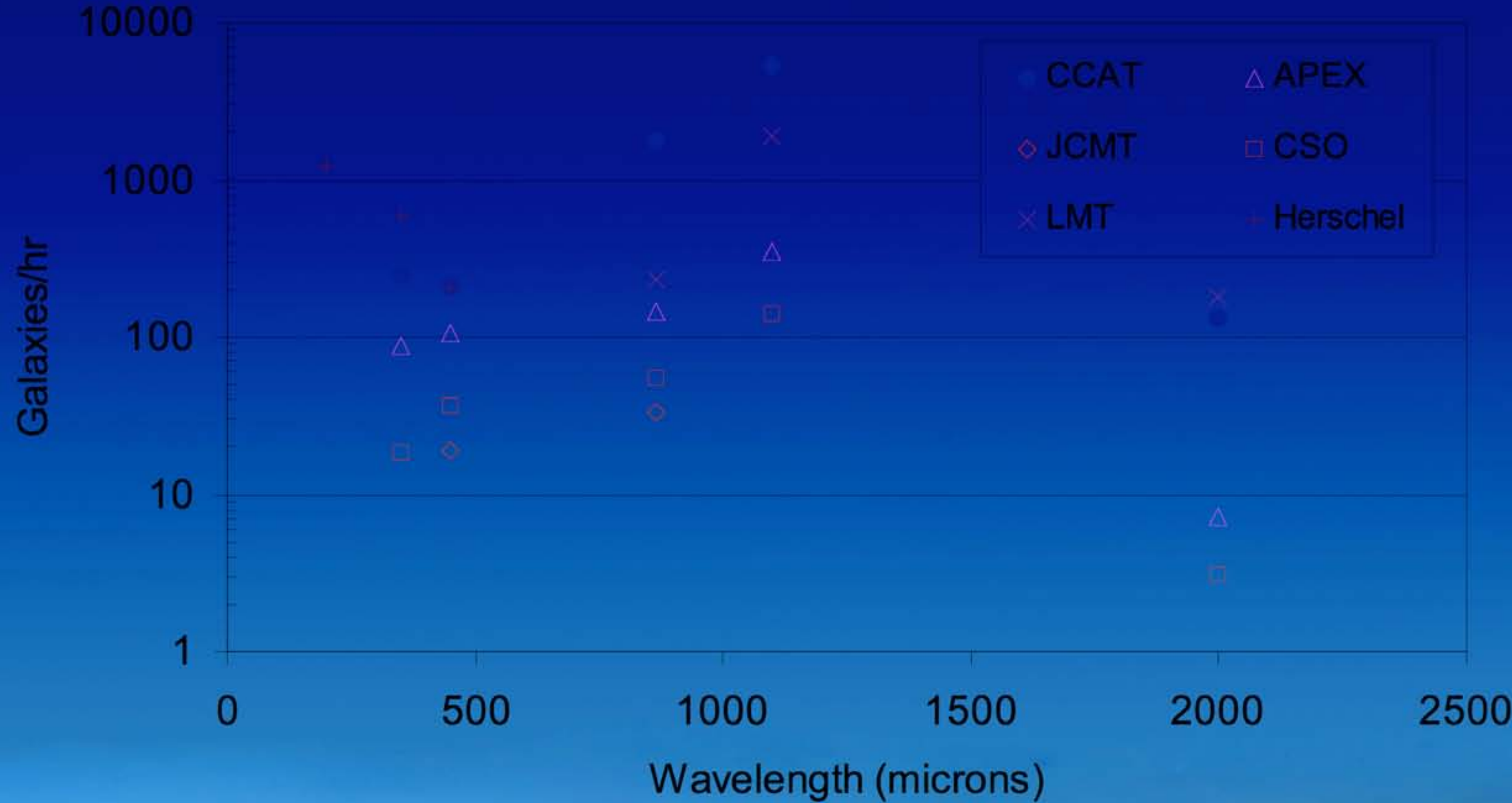
Predicted 350 um flux for Trans-Neptunian Objects (TNOs) with 10% albedo (m_R=22, solid and m_R=23, dotted) or 4% albedo (m_R=23, solid and m_R=24, dotted). Horizontal lines show 5-sigma detection in 1 and 2 hours, respectively for CCAT.

Mapping Speed



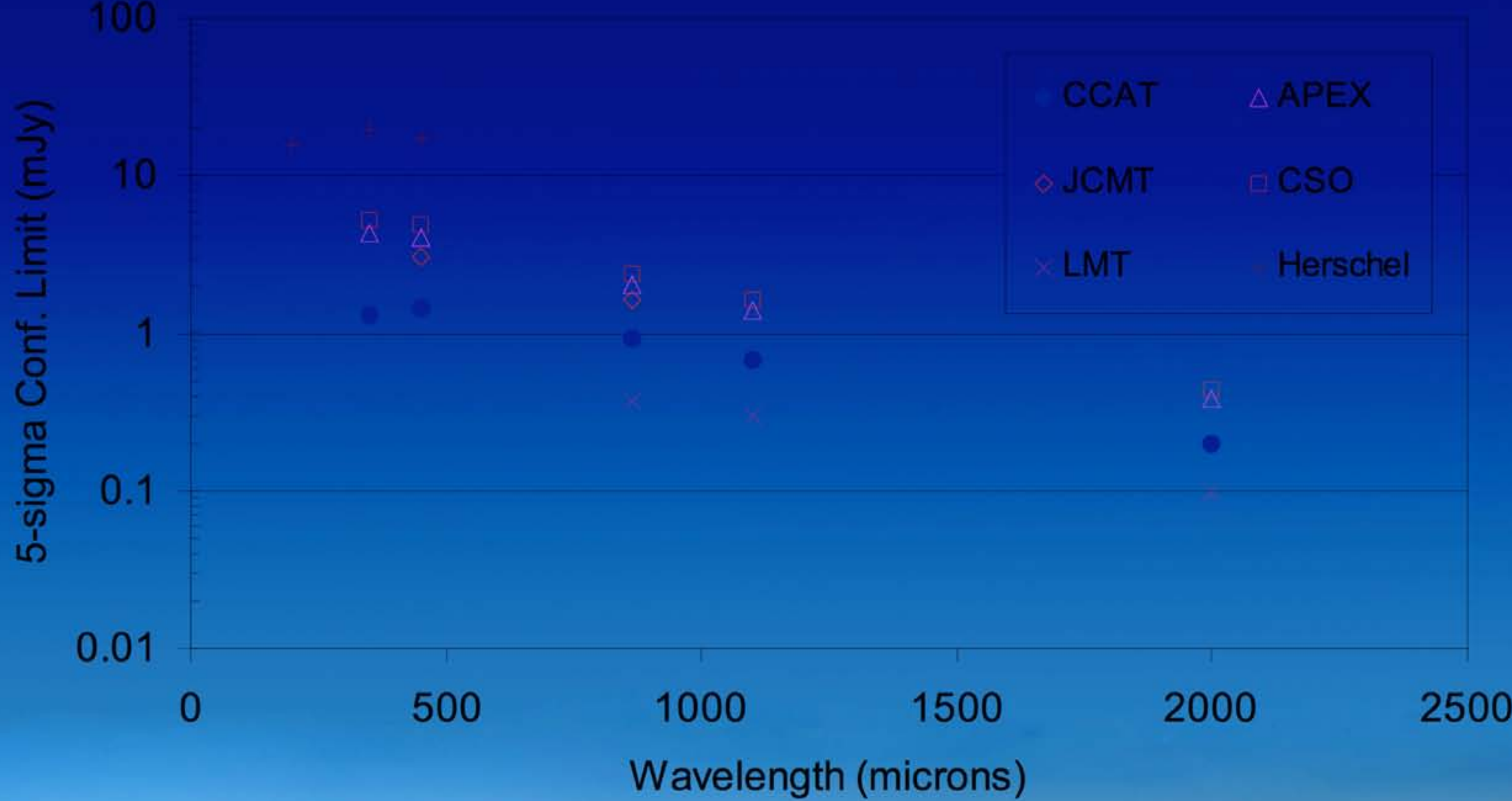
Rate at which sky can be mapped ($\Omega_{array}/NEFD^2$). This is a measure of how quickly sky can be covered to a give flux level providing the confusion limit is not reached. Calculation [illegible] with 2 pixels/res. element with max 20' [illegible] is 8' FoV for JCMT & LMT and 4' [illegible]

Galaxy Detection Rate at Confusion Limit



Rate at which galaxies are detected down to the confusion limit for each telescope. Note that the confusion limit varies for each tele[illegible] (and with wavelength). Calculation [illegible] 150x150 [illegible] element with max 20' FoV for [illegible] for JCMT & [illegible] and 4' FoV [illegible]

Confusion Limits



Confusion limits for various telescopes assume confusion at 30-beams/source. Note that the confusion limit for C[illegible] times fainter than Apex and Hersch[illegible]

CCAT Science Steering Committee Charter

- Establish top-level science requirements
  - Determine and document major science themes
- Flow down science requirements to facility requirements
  - Telescope, instrumentation, site selection criteria, operations, etc.

- Outputs
  - Science document
    - Write-ups on major science themes using uniform format (science goals, motivation/background, techniques, CCAT requirements, uniqueness and synergies)
  - Requirements document
    - Specifies requirements for aperture, image quality, pointing, tracking, scanning, chopping, etc.

Time Available to Observe

CCAT

Band λ [µm]	Band ν [GHz]	Time to CL [hr]	Ref. PWV [mm]	Sairecabur (5500 m) Time Available [hr yr^{-1}]	Sairecabur (5500 m) Time Available [%]	Sairecabur (5500 m) CL fields [yr^{-1}]	ALMA (5050 m) Time Available [hr yr^{-1}]	ALMA (5050 m) Time Available [%]	ALMA (5050 m) CL fields [yr^{-1}]
200	1500	1248	0.26	281	3		84	1	
350	857	0.86	0.47	1936	22	2244	1084	12	1257
620	484	1.14	0.64	716	8	629	723	8	634
740	405	0.43	0.75	639	7	1488	690	8	1607
865	347	0.28	0.86	1223	14	4413	1205	14	4348
1400	214	0.30	1.00	1517	17	5093	1299	15	4361
Time (PWV < 1.1 mm)				6312	72		5084	58	

Number of hours/year (round the clock) available for observing at a given λ (PWV) for Sairecabur (5500 m) vs. the ALMA region (5050 m). "CL fields" is the number of fields that can be observed to the confusion limit over a year. The "Total Time" is the sum of available hours and represents all time (day or night) with PWV [illegible] mm. Because observations at some wavelengths re[illegible] 350 µm and 450 µm, they sha[illegible] a common [illegible] observations are done when PWV [illegible]

CCAT

Time to Complete Programs

Band λ (μm)	Band ν (GHz)	PWV (mm)	Time Available: Sairecabur (5500 m) (hr yr^{-1})	Time Available: ALMA (5050 m) (hr yr^{-1})	Science Program Time (hr)	Time to Complete: Sairecabur (5500 m) (yrs)	Time to Complete: ALMA (5050 m) (yrs)
200	1500	0.26	281	84	204	0.7	2.4
350	857	0.47	1936	1084	4881	2.5	4.5
620	484	0.64	716	723	5832	8.1	8.1
740	405	0.75	639	690	256	0.4	0.4
865	347	0.86	1223	1205	1128	0.9	0.9
1400	214	1.00	1517	1299	350	0.2	0.3

"Science program time" is the total time to perform the baseline science for camera observations only – this does not include spectroscopic follow-up. This is the on-sky integration time needed according to best estimates of the sensitivity and does not include observing overhead or other inefficiencies. With overheads and "real" sensitivities [illegible] are likely to increase by a factor of two.

Time to Complete Programs

PWV	Observing Bands	Distant Gals	S-Z Effect	Nearby Gals	Cold Cores Survey	C-S Disks	KBOs	Total Hours
0.30	200	0	0	5	0	199	0	204
0.40	350	2312	0	181	885	749	753	4881
0.50	450, 620	2173	3400	260	0	0	0	5832
0.70	740	256	0	0	0	0	0	256
1.00	865 - 1200	121	460	82	221	243	0	1128
1.50	> 1400	0	350	0	0	0	0	350
Total		4862	4210	529	1106	1192	753	12652

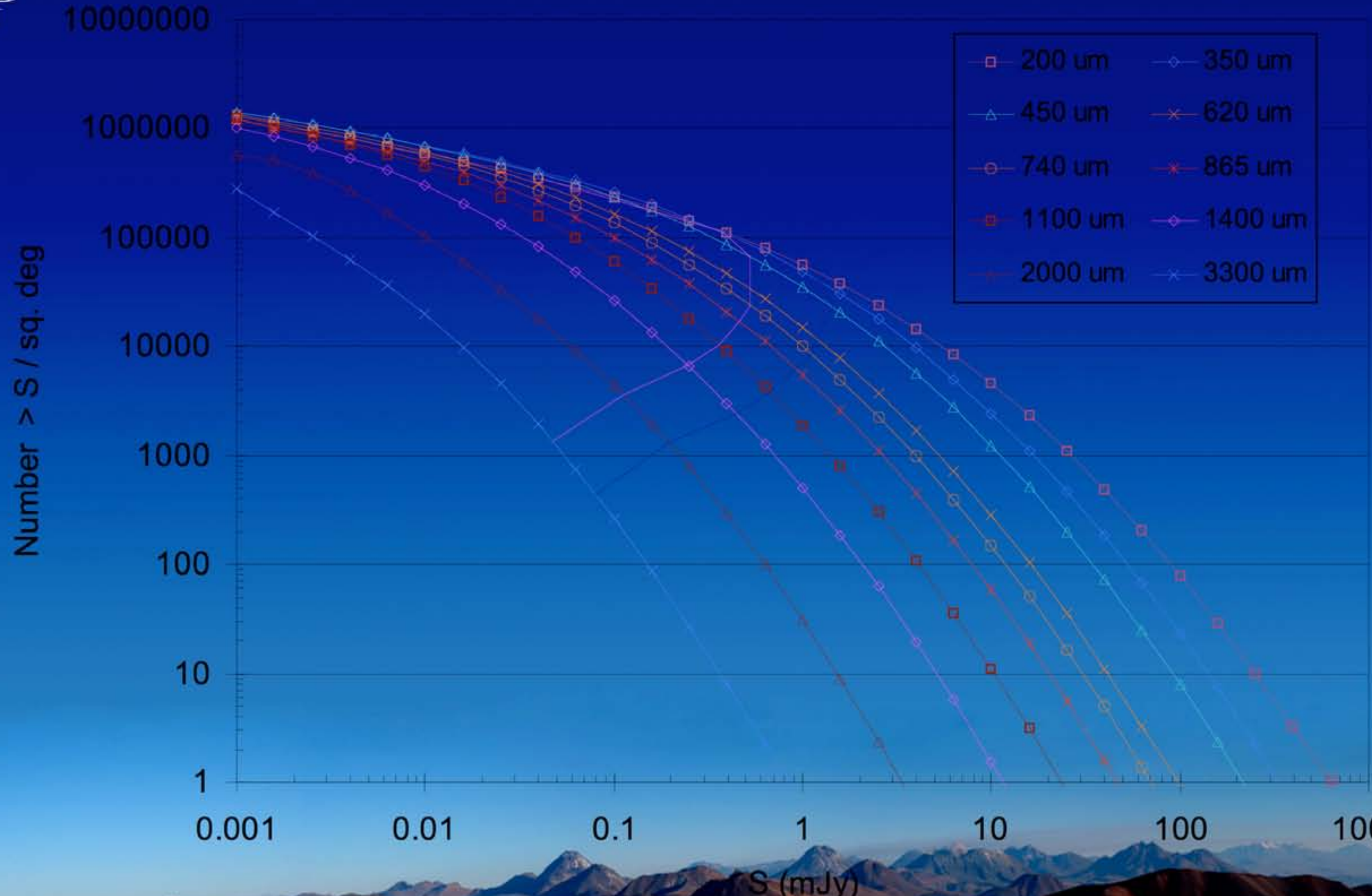
"Science program time" is the total time to perform the baseline science for camera observations only – this does not include spectroscopic follow-up. This is the on-sky integration time needed according to best estimates of the sensitivity and does not include observing overhead or other inefficiencies. With overheads and "real" sensitivities [illegible] are likely to increase by a factor of two.

CCAT vs. Other Facilities

Facility	Lambda (microns)	Freq. (GHz)	Beam Diam. (arcsec)	Array FoV (arcmin)	f_ν (mJy)	Conf. Limit (mJy)	Time to Conf. Limit (sec)	Conf. Limit src density (#/sq-deg)	Survey Speed (arcmin/ hr/mJy^2)	Gals/hr to CL	Gals on Array f >= CL	Gals on Array f >= f_ν
CCAT	350	857	3.81	4.76	1.25	1.29	3384	37856	14	251	236	243
	450	667	4.90	4.75	1.18	1.45	2392	22901	16	213	142	180
	865	347	9.42	19.6	0.57	0.92	1357	6198	1202	1772	668	1384
	1100	273	11.2	20.0	0.19	0.67	290	3833	11030	5325	429	2950
	2000	150	21.8	19.6	0.20	0.20	3730	1159	9684	134	139	134
APEX	350	857	7.94	9.93	7.03	4.27	9767	8722	2.0	89	242	117
	450	667	10.2	12.8	6.25	4.09	8413	5276	4.2	106	249	127
	865	347	19.6	19.8	2.27	2.06	4375	1428	76	144	175	146
	1100	273	25.0	19.8	0.78	1.41	1100	883	647	354	108	325
	2000	150	45.4	19.9	0.85	0.39	17217	267	549	7.1	34.2	5.2
JCMT	450	667	8.17	7.94	8.55	3.05	28325	8244	0.9	19	149	27
	865	347	15.7	7.96	1.83	1.63	4578	2231	19	34	43	35
	1100	273	20.0	7.99	0.61	1.13	1060	1380	169	91	27	80
	2000	150	36.3	7.87	0.61	0.32	13349	417	166	2.2	8.3	1.8
CSO	350	857	9.16	11.5	19.0	5.21	47733	6551	0.4	18	243	29
	450	667	11.8	14.7	12.8	4.90	24705	3963	1.3	36	250	47
	865	347	22.6	20.0	3.73	2.39	8768	1073	29	56	135	57
	1100	273	28.8	19.9	1.24	1.62	2111	663	258	148	83	140
	2000	150	52.4	19.6	1.26	0.44	29283	201	243	3.1	25	1.8
LMT	865	347	4.71	8.01	0.49	0.38	6173	24791	266	235	403	282
	1100	273	5.99	7.99	0.11	0.30	465	15330	5482	1914	247	974
	2000	150	10.9	7.99	.065	.096	1651	4637	15072	181	83	155
Herschel	200	1500	15.6	3.89	1.42	15.9	29	2272	7.5	1212	9.6	174
	350	857	27.2	4.08	1.50	19.6	21	742	7.4	588	3.5	148
	450	667	35.0	4.08	1.71	17.1	36	449	5.7	206	2.1	86

confusion limits (CL)

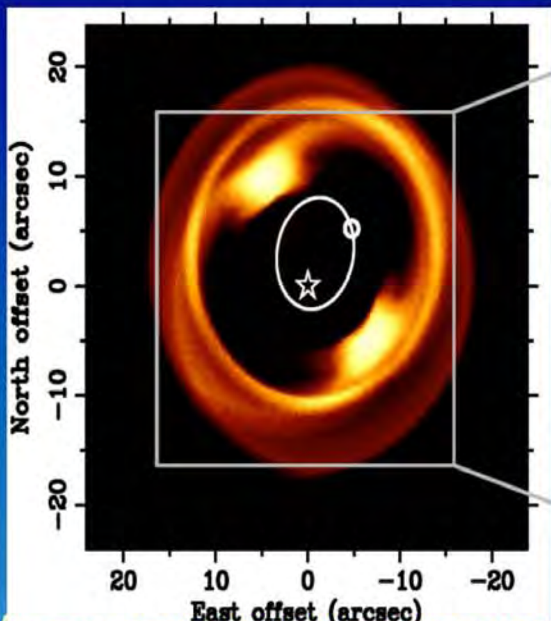
Sub-mm Number Counts & Confusion Limits



Sub-mm galaxy counts vs. flux density (number of ... with ... than S vs. S) for different wavelengths ... show 30 (lower) and 10 (upper) beam...

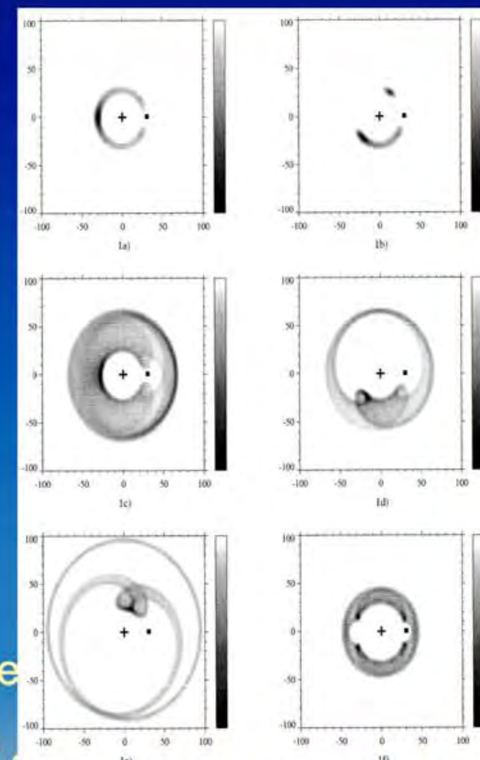
Debris disks trace the underlying distribution of planets.

- The distribution of dust indicates where planets are and what their mass is. Theoretical simulations:



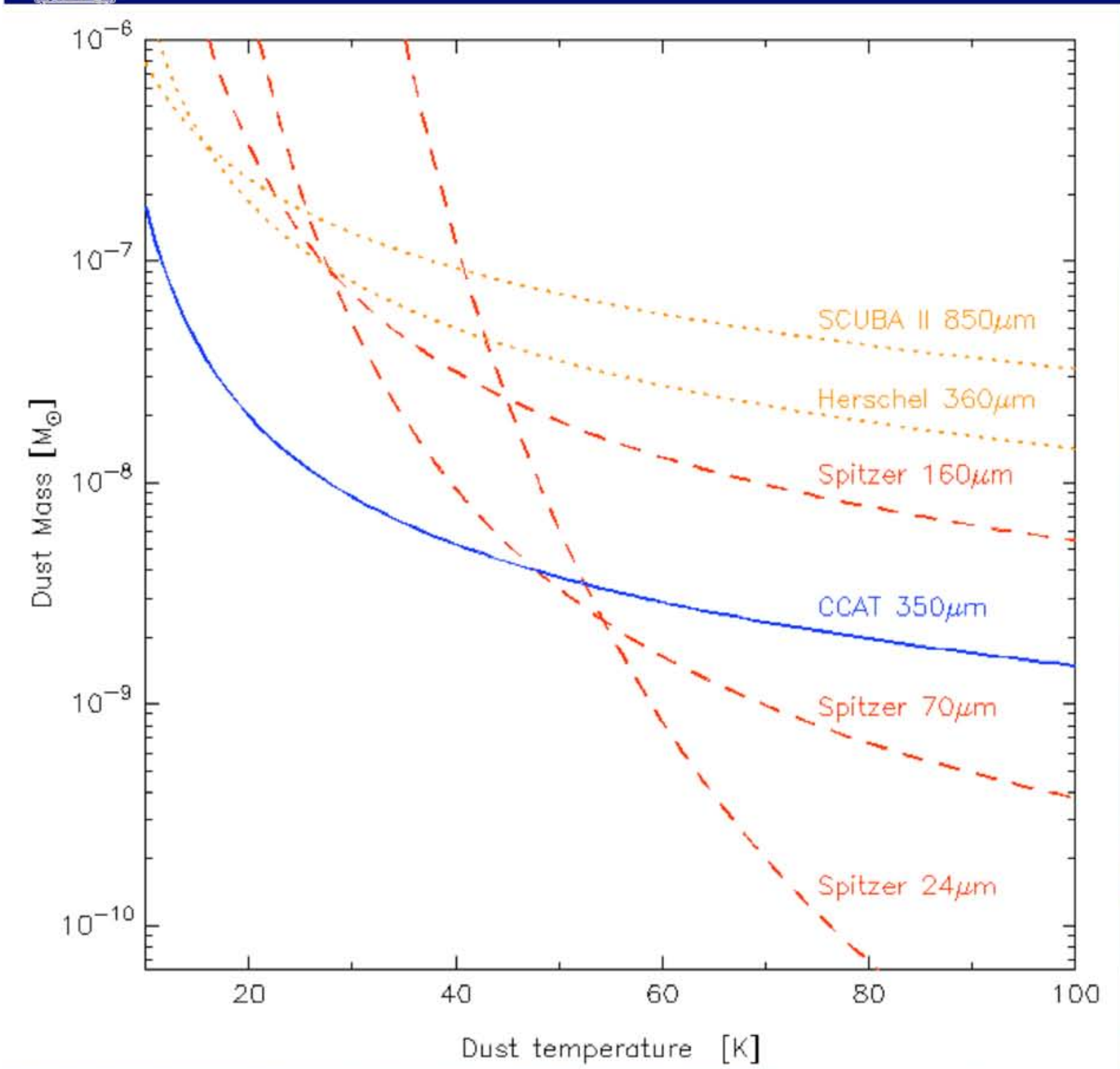
Wilner et al. (2002)

Ozernoy et al. (2000)



- We are currently in a situation where better images are ne[eded to see] structures in more than a handful of sources.
- The nearby debris disk systems to be imaged with CCAT are the ones which have the best chance for direct detection of both the dust and the planets (the latter with other facilities).

Searching for Debris Disks



Sensitivity of various telescopes to tenuous disk emission. Although typical far-infrared-selected disks have characteristic temperatures of 80 K, selection is biased towards warmer disks. Disks with temperatures as low as 40 K are known (Liu et al. 2004, ApJ, 608, 526; Chen et al. 2005, ApJ, accepted), and especially around lower mass stars and brown dwarfs we can expect d of yet lower temperat discover