CCAT

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Gull

CCAT Scientific Inspiration

- Measure the star and characterize the history of star formation in galaxies through cosmic time
  - Photometric surveys to resolve the FIR background
  - Spectroscopic surveys characterizing the energy sources: stellar populations, shocks and AGN activity
- Probe the astrophysics of galaxy clusters through the Sunyaev-Zel’dovich effect (S-Z)
- Characterize the star formation process locally through submm-wave spectroscopy and dust continuum emission
  - Over 10’s of degree scales and through 5 orders of magnitude in scale for in the Milky Way
  - Complete maps over a variety of environments in nearby resolved galaxies

CCAT Implementation

Requirements:

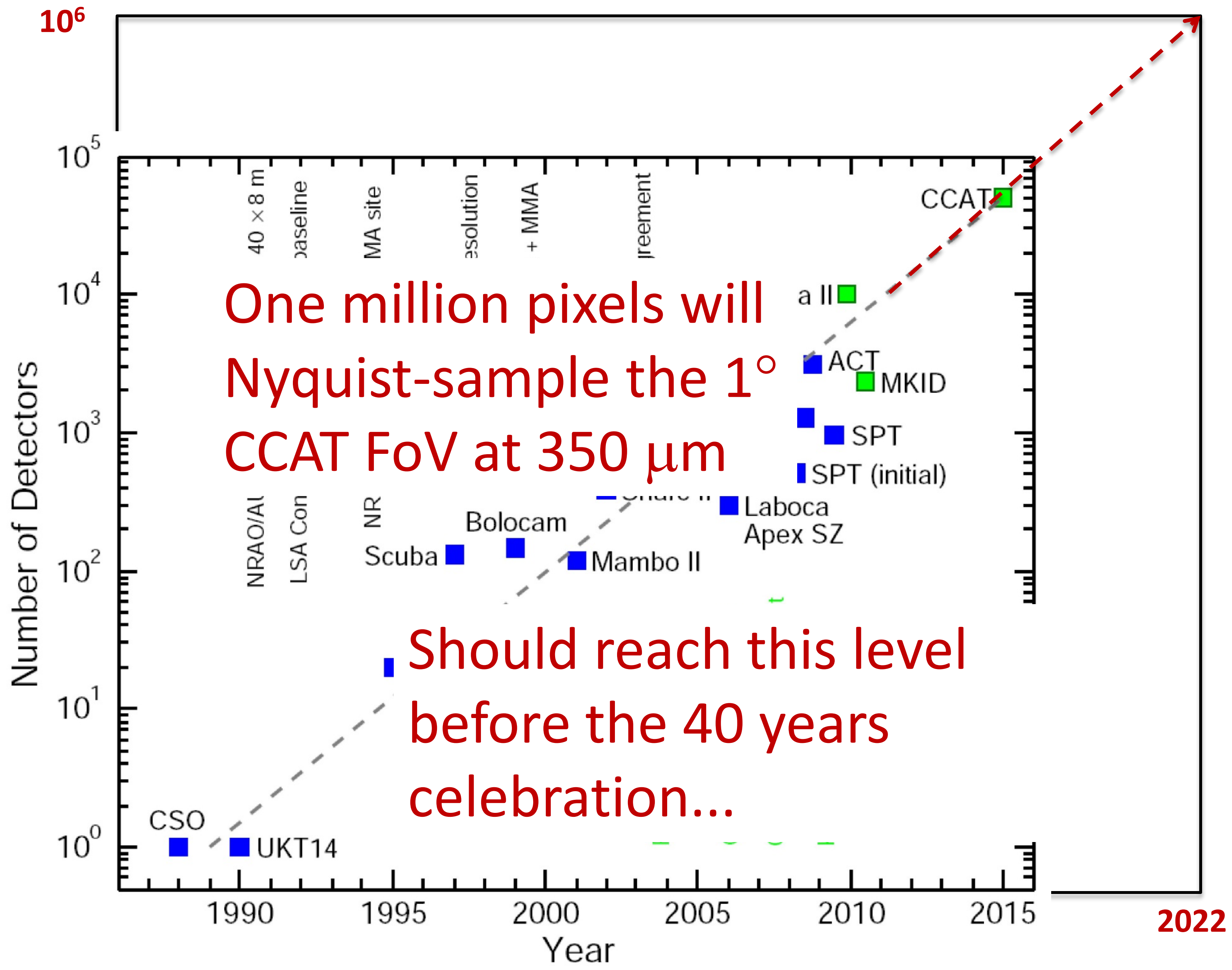
- 25 meter telescope
- high surface accuracy (10 μm RMS goal)
- superb astronomical site: Cerro Chajnantor at 5617 m

  - Resolves the CIRB
  - Beam ~λ(μm/100) (“)
  - Enables accurate astrometry for follow-up
  - Can reach the confusion limit at 350 μm in a few hours
  - Point source sensitivity comparable to ALMA in short submm bands: *discovery and follow-up*

CCAT Implementation

Requirements:

- 25 meter telescope
- high surface accuracy (10 μm RMS goal)
- superb astronomical site: Cerro Chajnantor at 5617 m
  - Highly accessible
  - Takes advantage of technological innovations
  - Look towards future with growth of detector technology
  - Simultaneous mounting and use of instrumentation
- Wide (1°) field of view
- 20 year lifetime



One million pixels will Nyquist-sample the 1° CCAT FoV at 350 μm

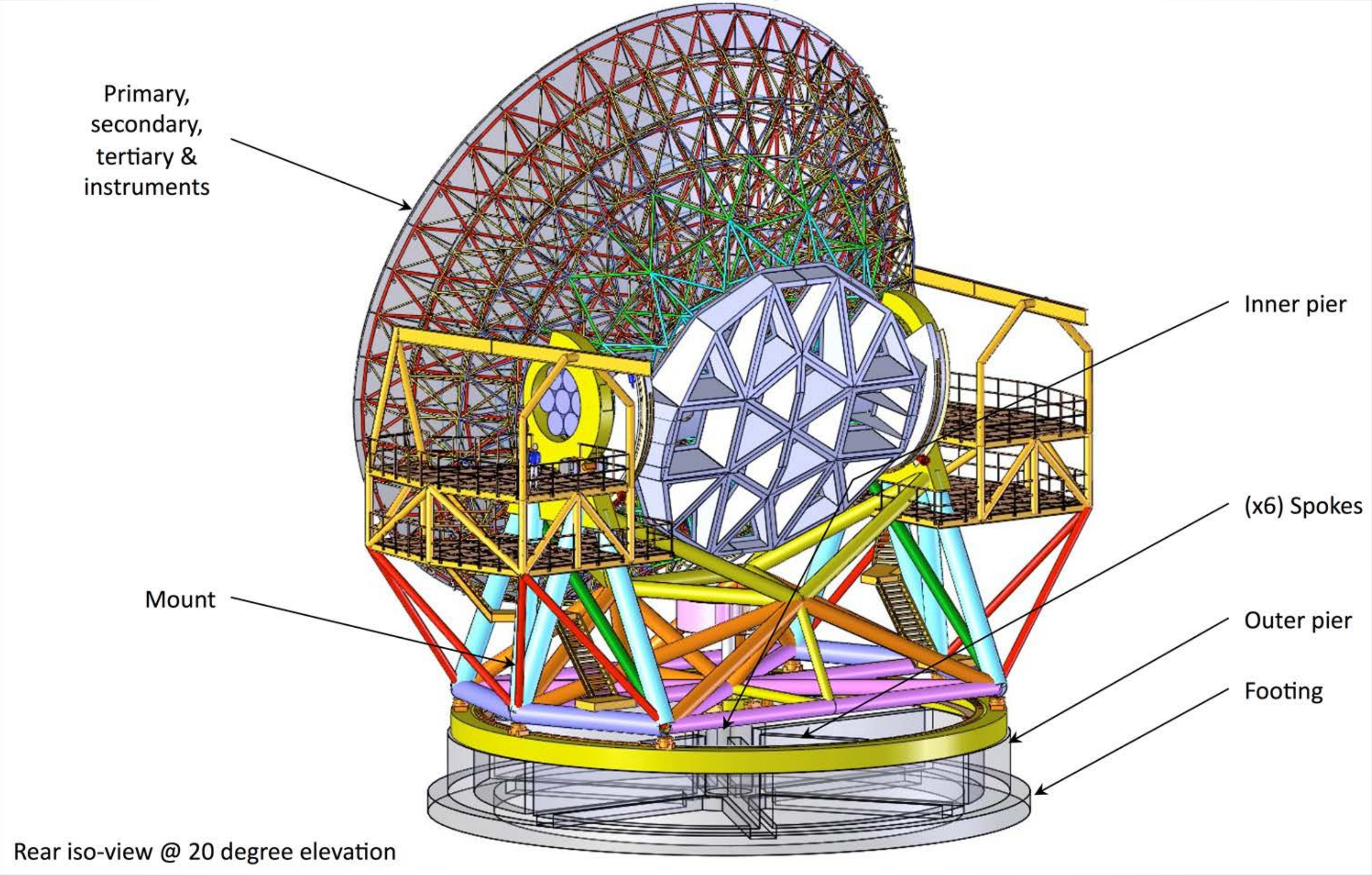
Should reach this level before the 40 years celebration...

Telescope Design

- Aperture 25 m
- Wavelength 350 µm – 3300 µm (200 µm goal)
  - Beam size 3.5 arcsec @ 350 µm
- Field of view 1° circular
- Half Wave Front Error < 12.5 µm rms

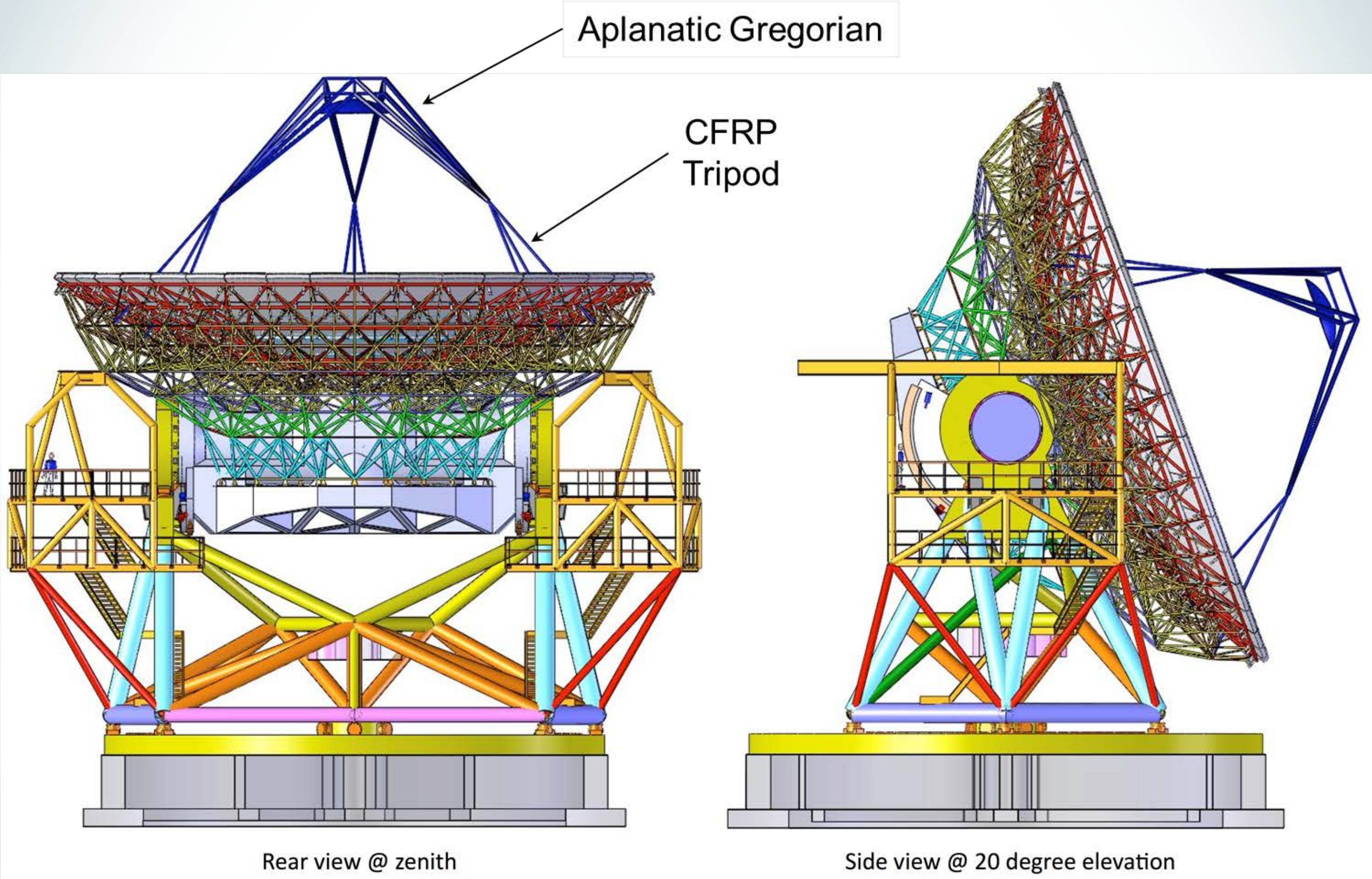
- Gregorian optics, Nasmyth instruments
- Active primary mirror
  - Al tiles on CFRP subframes, CFRP/invar truss
  - Open loop design, provision for closed loop
- Insulated steel Az/El mount, fast scan speed
- Enclosure: protection from wind, Sun

CCAT Rear View



Rear iso-view @ 20 degree elevation

CCAT Side Views



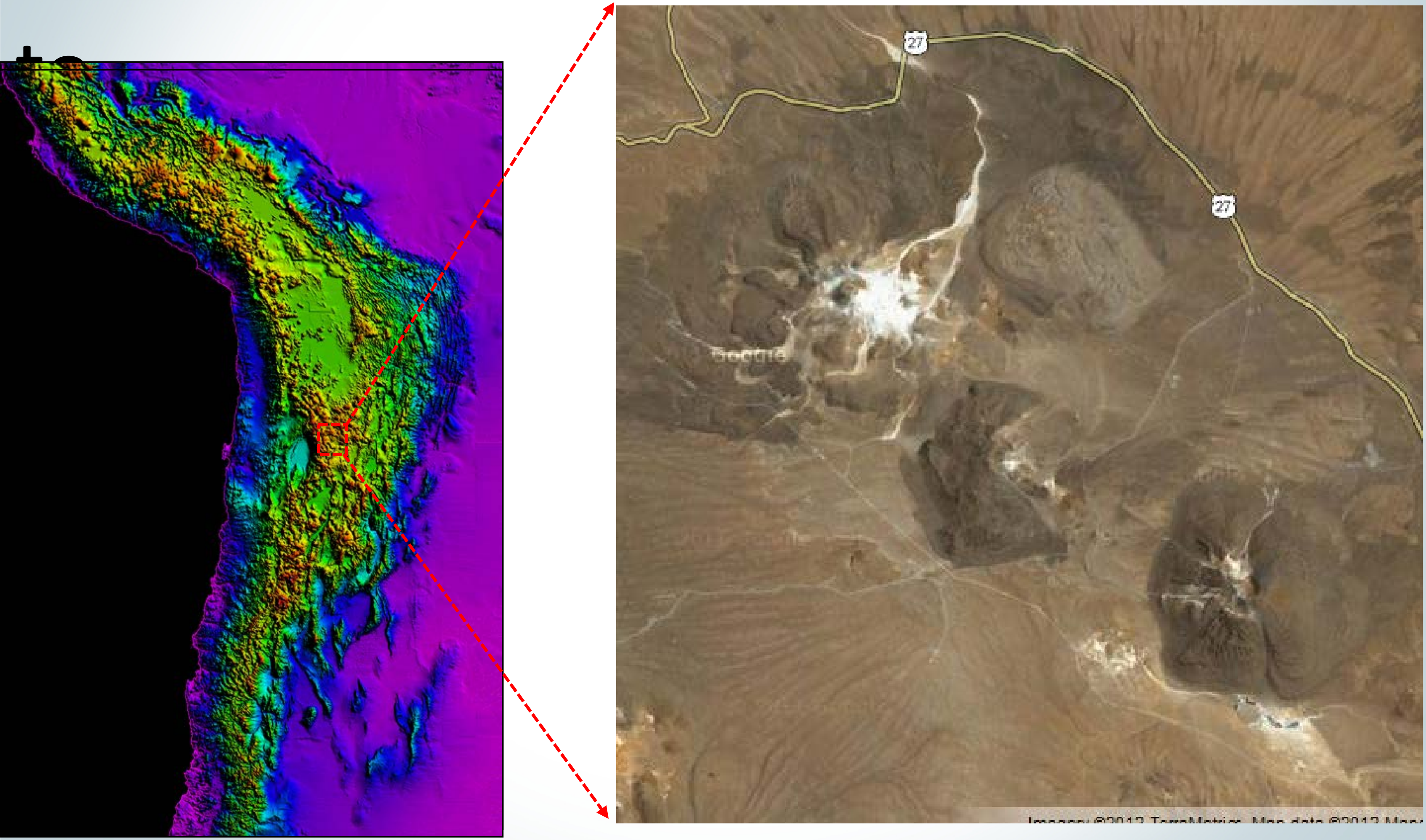
Aplanatic Gregorian

CFRP Tripod

Rear view @ zenith

Side view @ 20 degree elevation

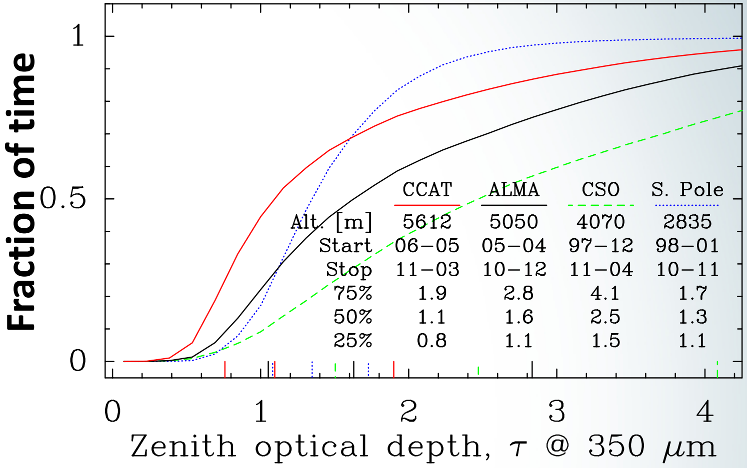
The Site: the driest, high altitude site to which one can drive a truck to

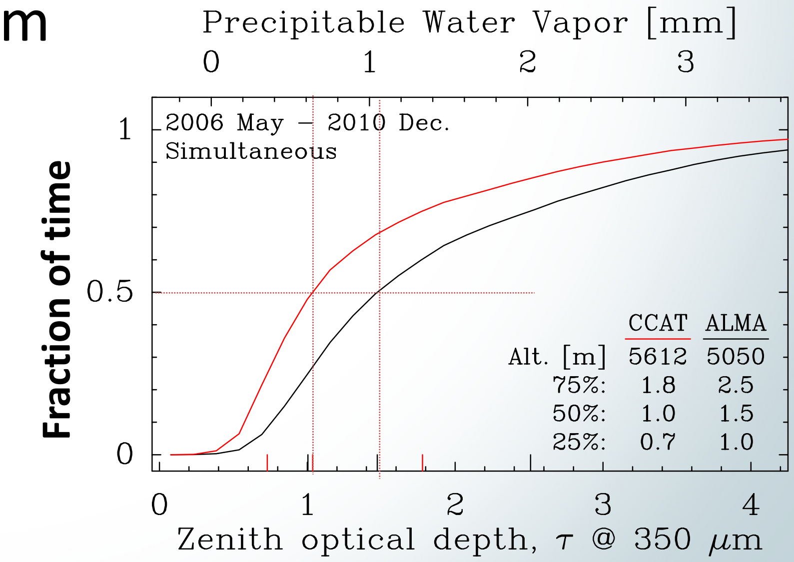


Looking *Down* on the ALMA Site

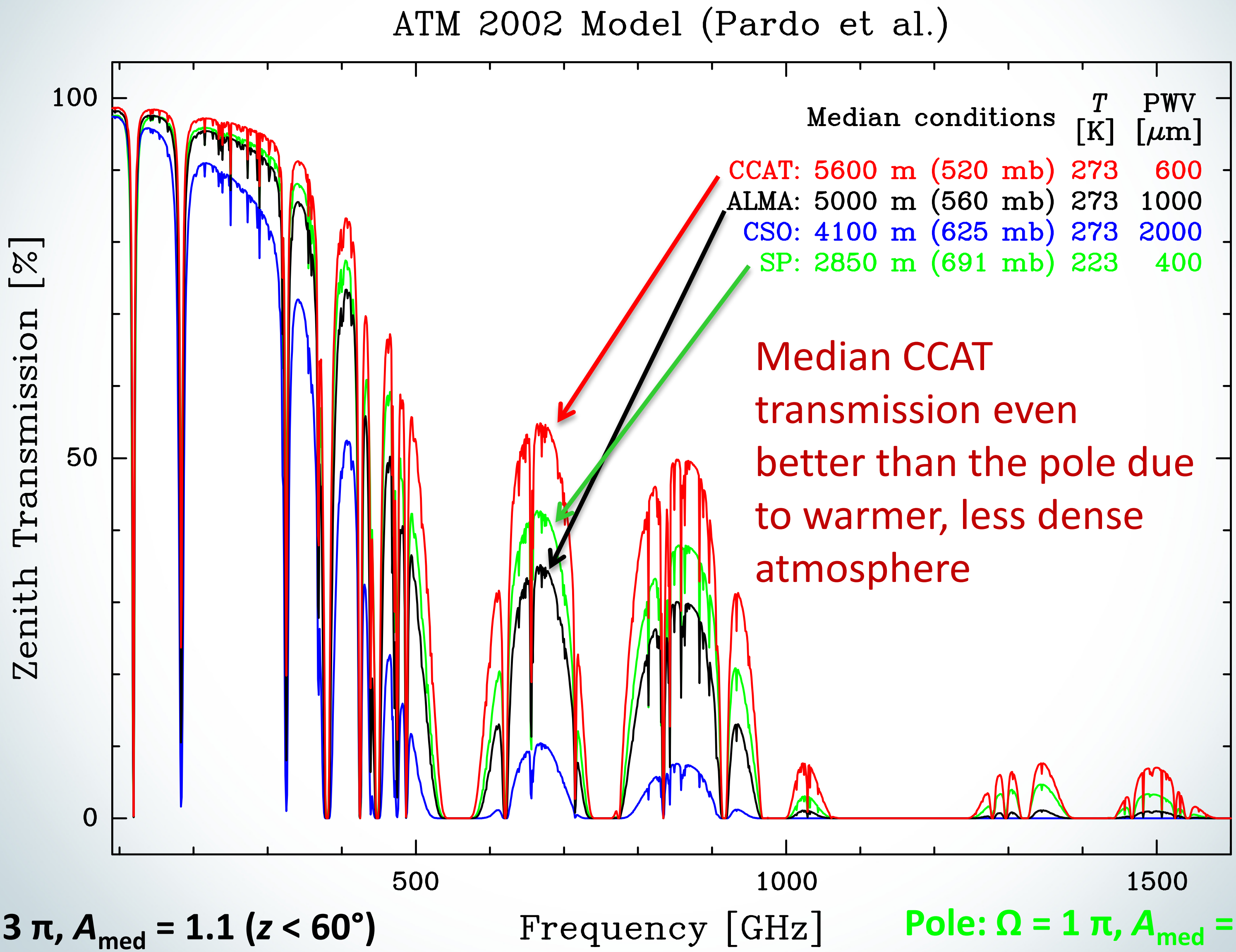
Why the Extra 600 Meters?

- Submillimeter sensitivity is all about telluric transmission
- Simon Radford has been running tipping radiometers at primary sites for more than a decade –
- Simultaneous period for CCAT vs. ALMA site: median is 0.6 vs. 1.0 mm $H_2O \Rightarrow$ *factor of 1.4 in sensitivity*





Median Conditions

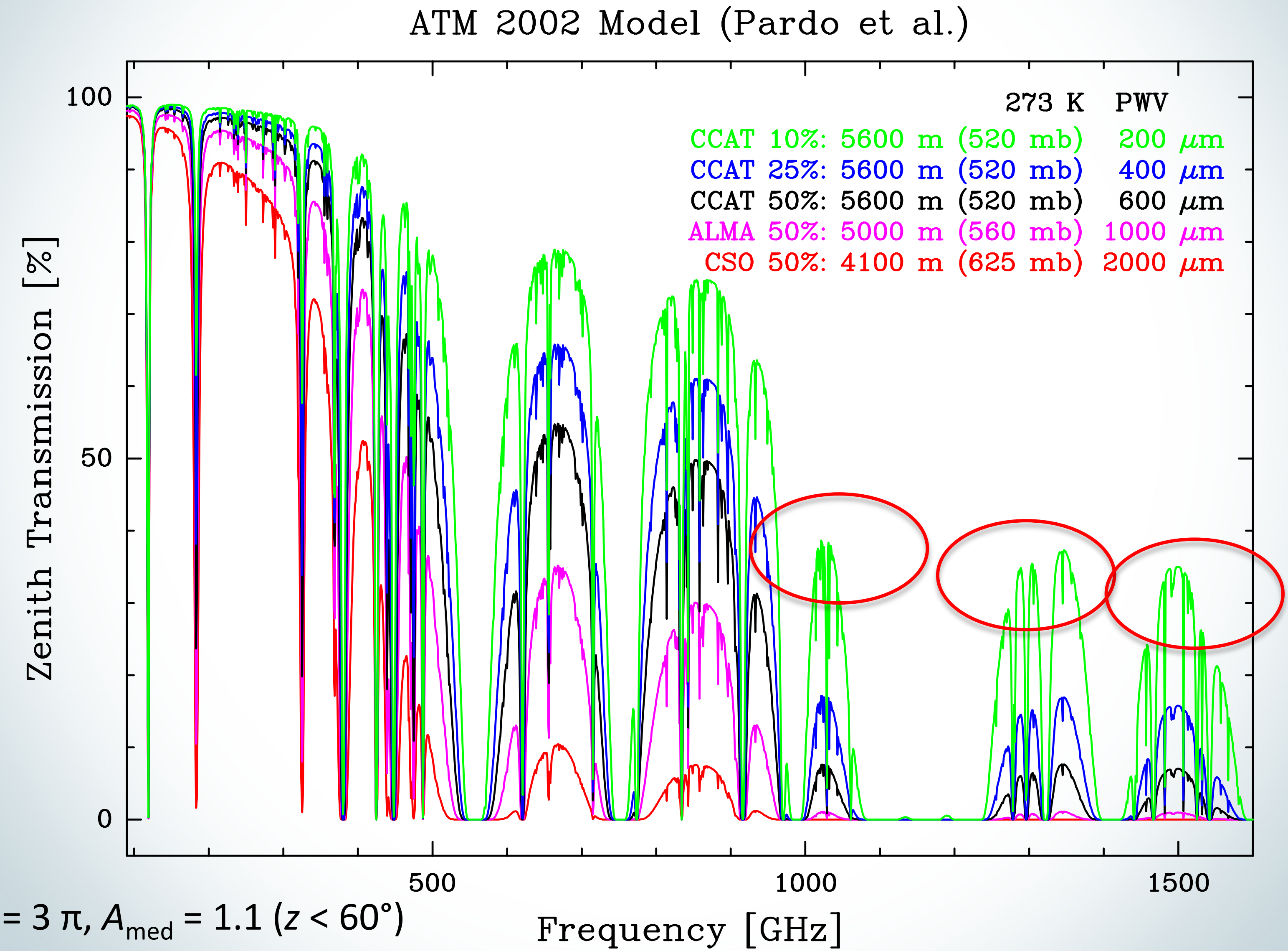


Median CCAT transmission even better than the pole due to warmer, less dense atmosphere

$\Omega = 3\pi$, $A_{\mathrm{med}} = 1.1$ ($z < 60°$)

Pole: $\Omega = 1\pi$, $A_{\mathrm{med}} = 1.4$ ($z < 60°$)

Top 10% Opens up THz Windows


ATM 2002 Model (Pardo et al.)

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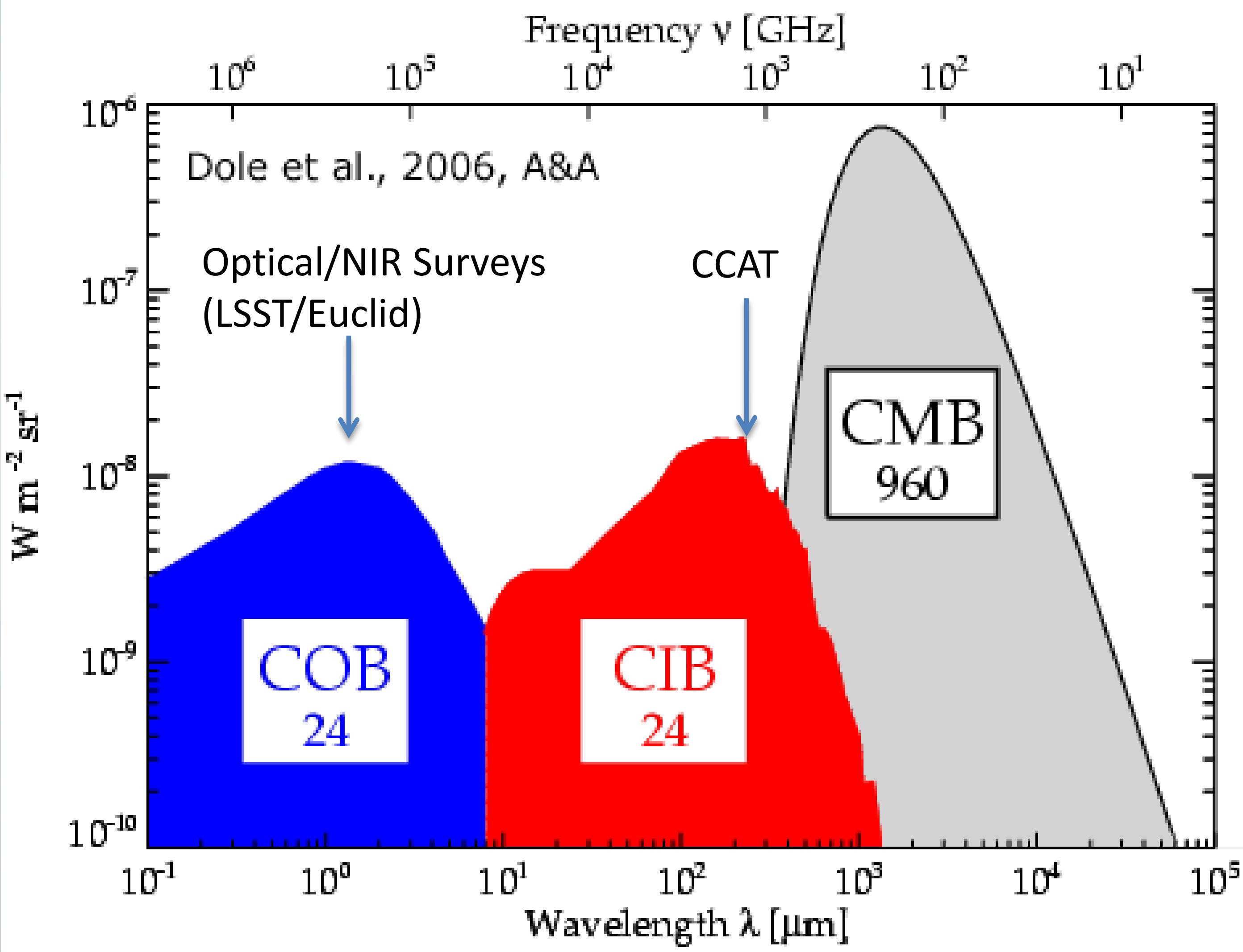
Photon Energy Density of the Universe

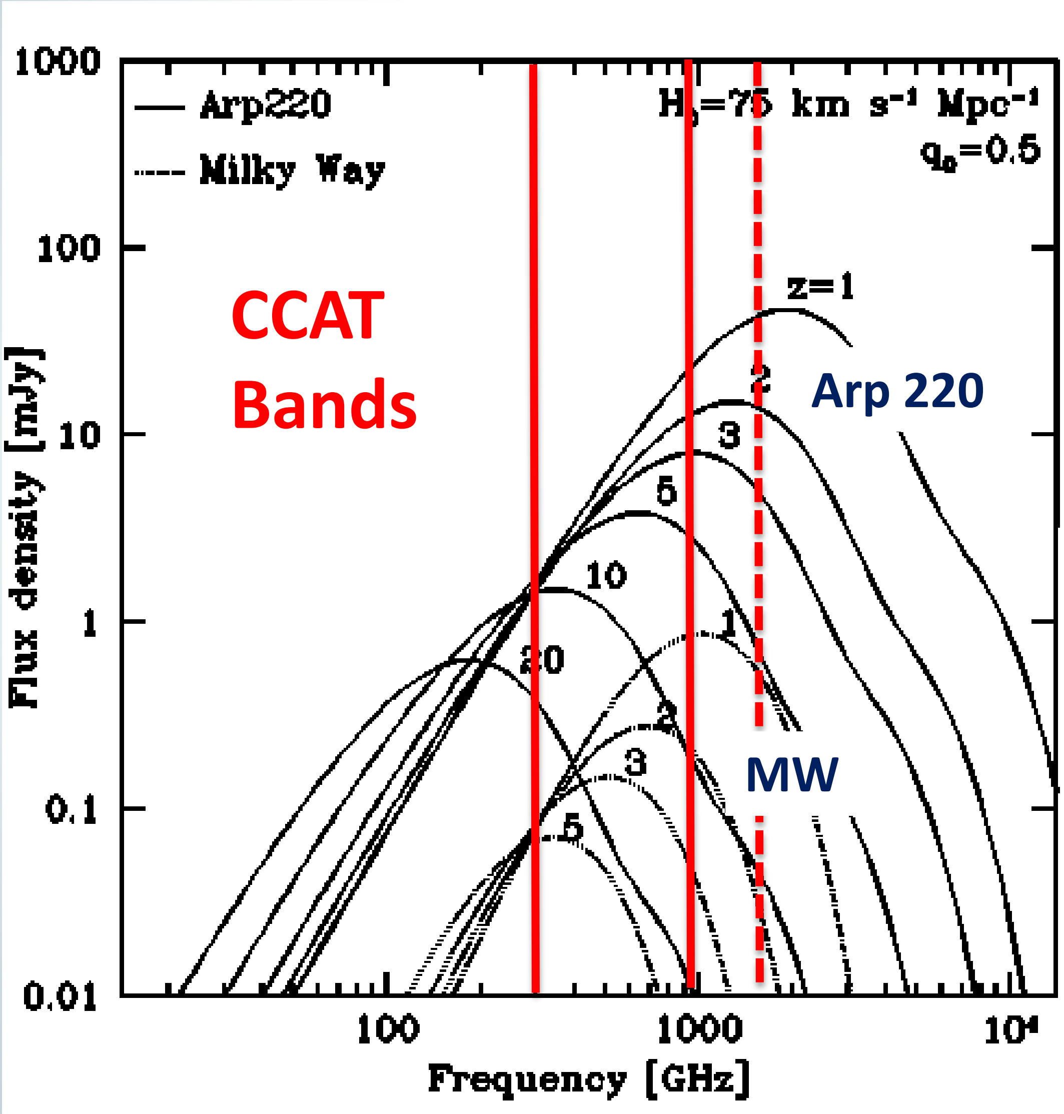

Dole et al., 2006, A&A

Optical/NIR Surveys (LSST/Euclid)

CCAT

Half the optical light of stars and AGN produced over the history of the Universe is absorbed by dust and re-radiated in the FIR band

CCAT Characterizes Luminosity

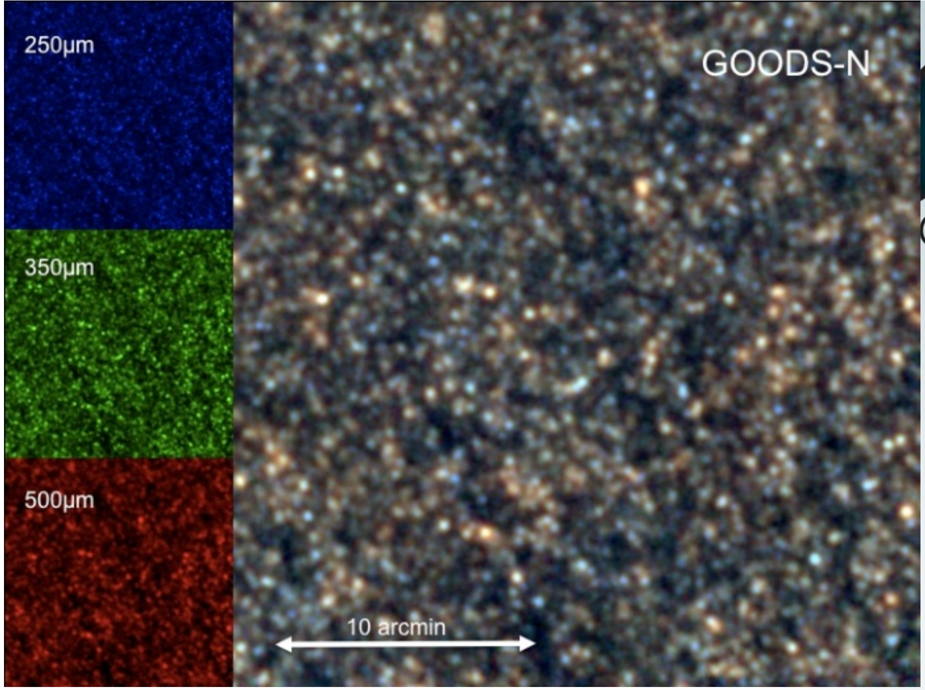


- CCAT measures the L_{FIR} for star forming galaxies at $z > 1$
- For most cases this is:
  - Nearly the bolometric luminosity
  - Good estimate for star formation rates
  - Note that 850 μm flux is insensitive to z, whilst 350 μm flux is quite sensitive

Red-shifted SEDs from Paul van der Werf’s web-page

Confusion

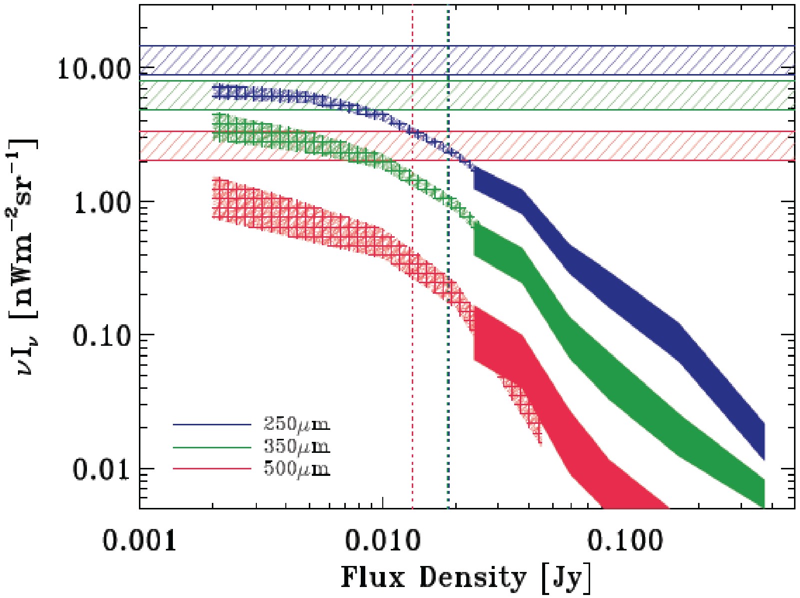
- The large CCAT aperture breaks the confusion limit
- Herschel surveys limited to ~ 25 mJy confusion limit ⇒ resolve the CIRB at 10% level
- Statistically inferred at 50% level to 2 mJy/beam
- 25 m CCAT resolves directly sources at ~0.5 to 1 mJy level in few hours at 350 μm
- → large (10-40$^{(\circ)2}$)/yr) surveys into the most active epoch of assembly of galaxies and large scale structures in the Universe
- ~ million sources/year



HerMES Lockman Hole North

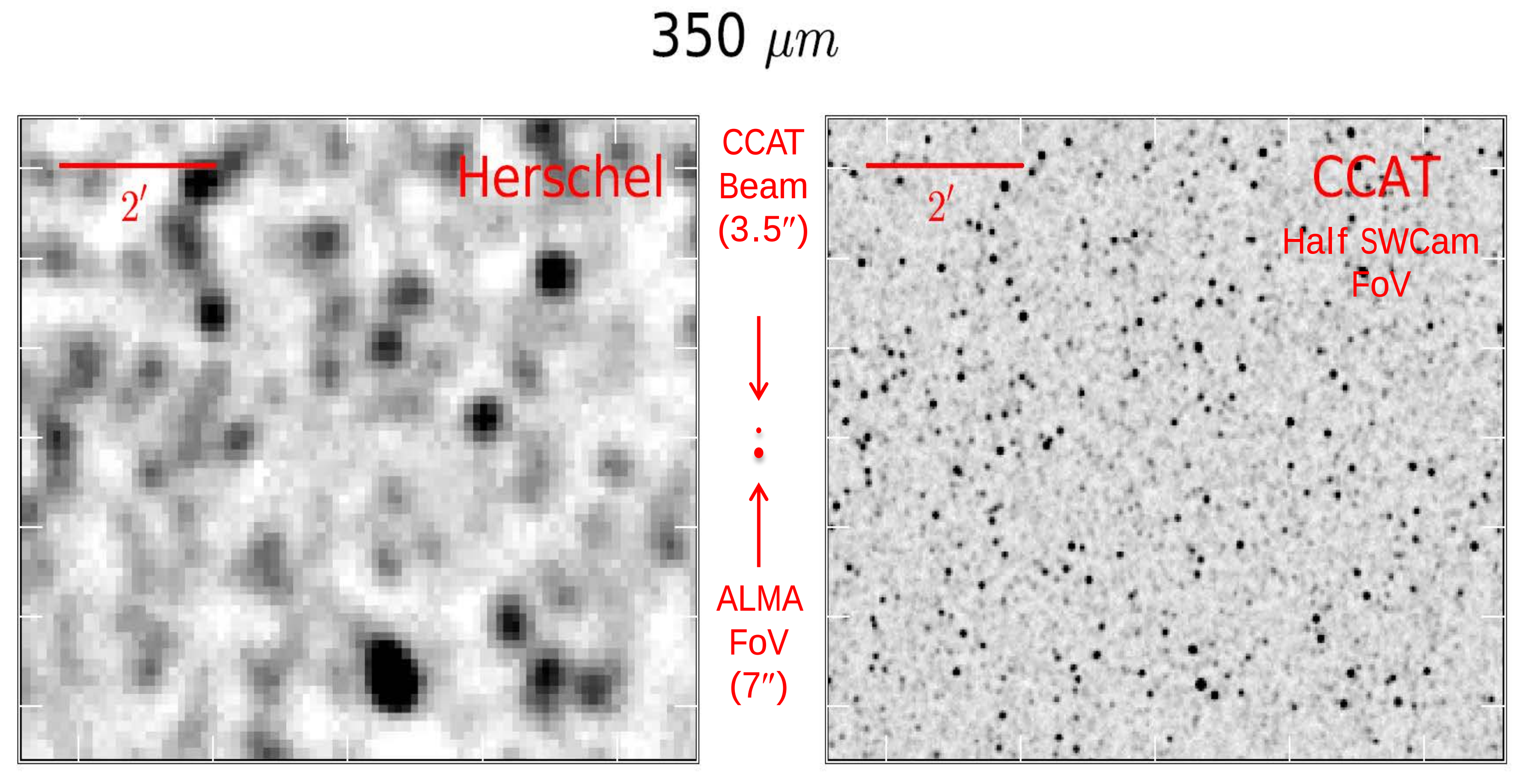
Oliver et al. (2010, 2011)

See Patanchon et al. (2010), Glenn et al. (2011)



60%
60%
45%

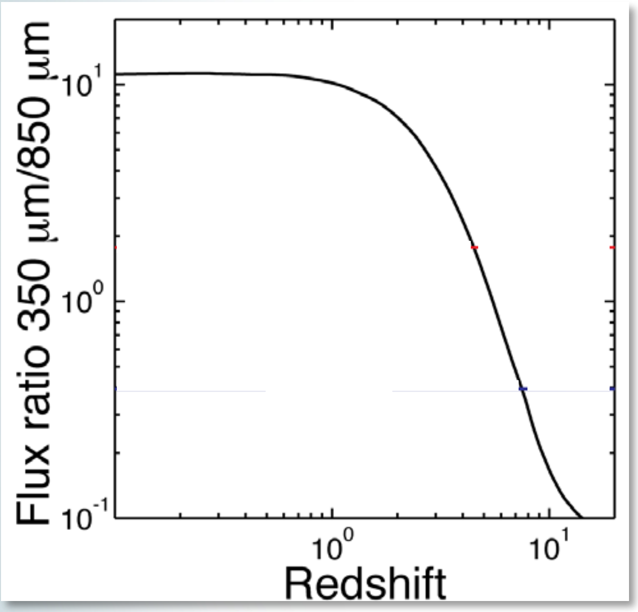
Confusion: 25 m vs. 3.5 m telescopes

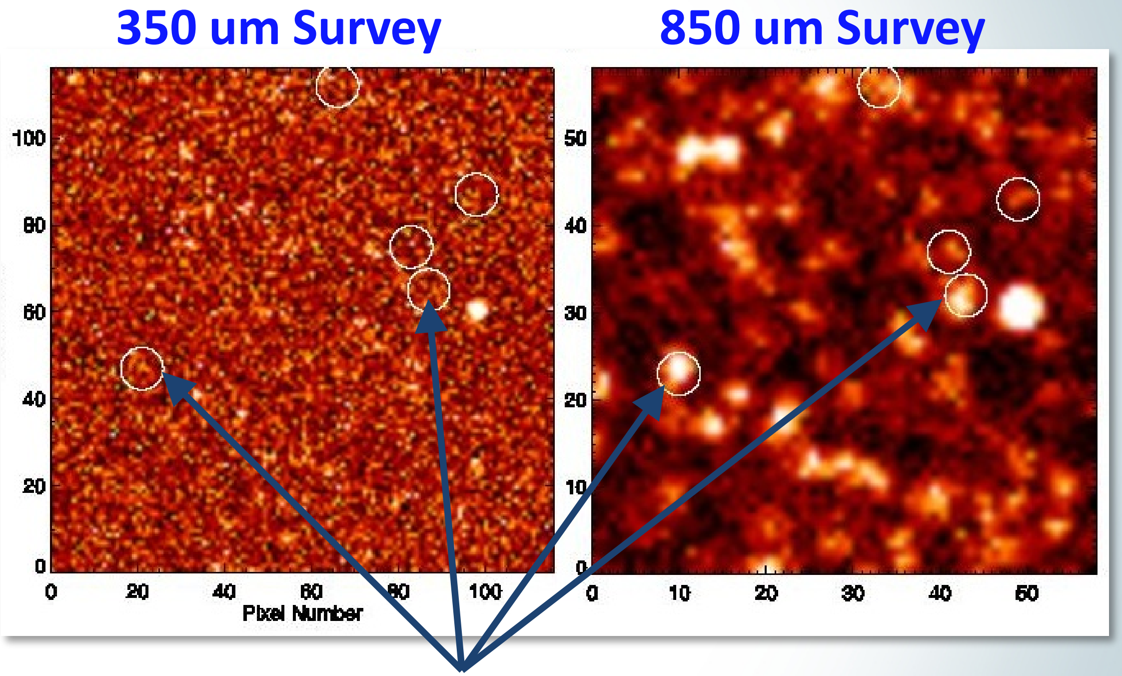


CCAT Beam (3.5″)

ALMA FoV (7″)

Identifying the Highest Redshift Sources: 350 μm Drop-outs





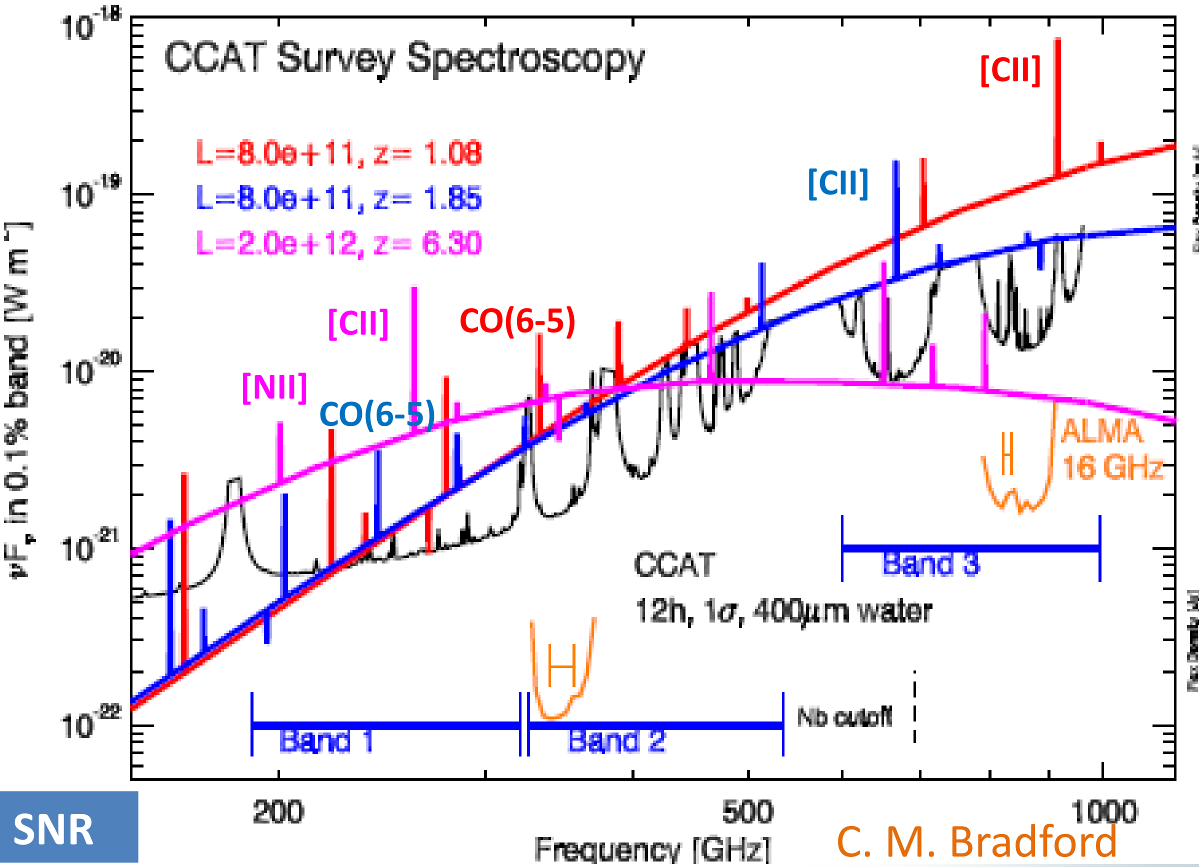
>5σ 850 μm detection, 350 μm non-detections, or "drop-outs"

Spectroscopic Redshifts

- Determined with multi-object, large bandwidth, direct detection spectrometers
  - Spacing of CO lines: 115 GHz/(1+z)
  - FIR fine structure lines, especially [CII]
- Most sources detectable in the continuum are detectable in the [CII] line (if transmitted):
  - For $L_{[CII]}/L_{FIR} = 10^{-3}$; [CII]/158 μm continuum ~ 10:1
  - Photometric BW/Spectroscopic BW ~ 1000/10
  - $\Rightarrow$ sensitivity ratio ~ sqrt(1000/10) = 10:1
  - $\Rightarrow$ line is as detectable as the continuum
- CO lines roughly 5 times harder to detect, but the detection of multiple lines helps significantly

Spectroscopy

- X-Spec: a very broad (50%) BW spectrometer
- [CII] much easier to detect…
- Multiple CO lines help, and uniquely determine the redshift



C. M. Bradford

Redshift	L(FIR)	Line	SNR
1.15	8×10^{11}	[CII]	75
		CO(6-5)	12
1.85	8×10^{11}	[CII]	18
		CO(6-5)	4
6.3	2×10^{12}	[CII]	30
		[NII] 205 μm	6

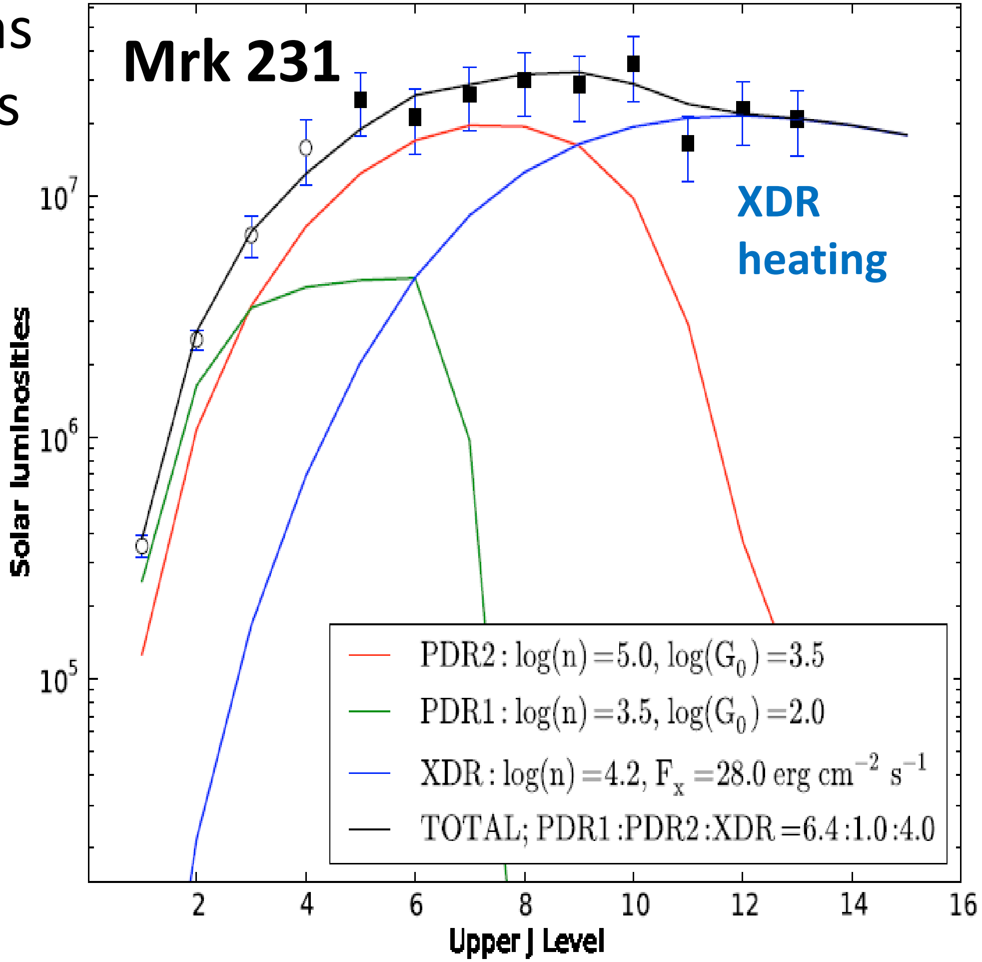
ALMA 5 to 10 times more sensitive per spectral tuning, but:

- Several tunings necessary
- CCAT spectrometer is multi-object

⇒ *Can be more efficient with CCAT* spectrometer

Physical Properties

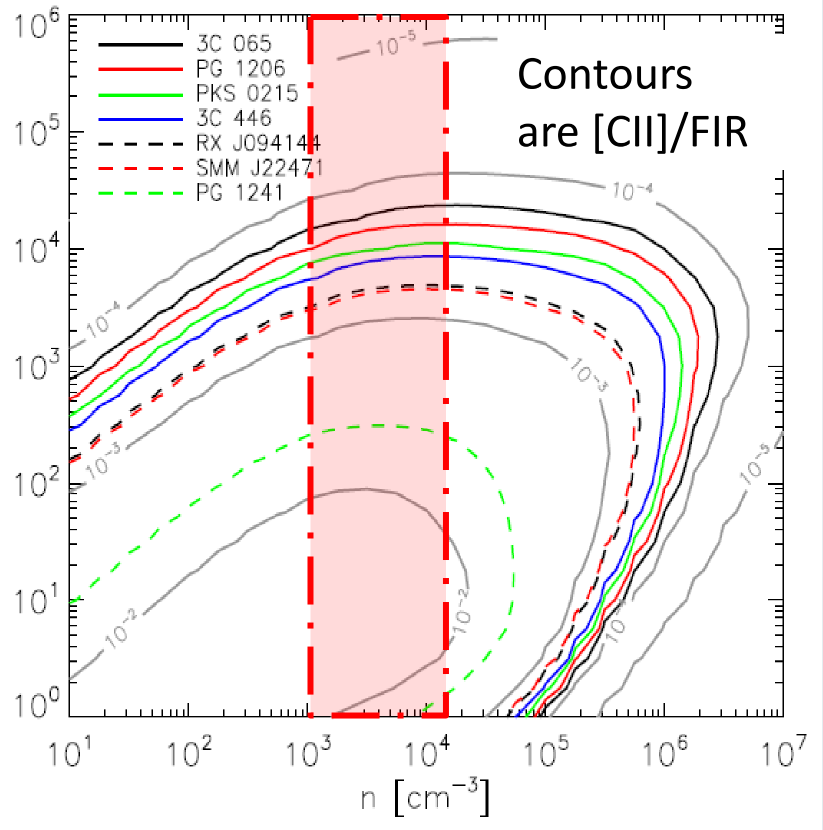
- CO SED constrain molecular gas mass reservoir and the sources of gas heating
  - PDR heating
  - Cosmic rays
  - Micro-turbulent shocks: mid-J
  - XDR heating: high-J
- FIR fine-structure lines constrain physical parameters of the gas and the stellar radiation fields



van der Werf et al. 2010

Fine-Structure Line Science

- [CII] mostly arises in PDRs on neutral clouds exposed to stellar FUV
- [CII]/FIR yields the *intensity* of the ambient FUV radiation field, G_o
- Observed FIR intensity is connected to the modeled G_o by the beam filling factor⇒ the [CII]/FIR ratio indirectly yields the *size* of star formation regions
- Survey found star formation occurs on several kpc scales enveloping redshift 1-2 star forming galaxies

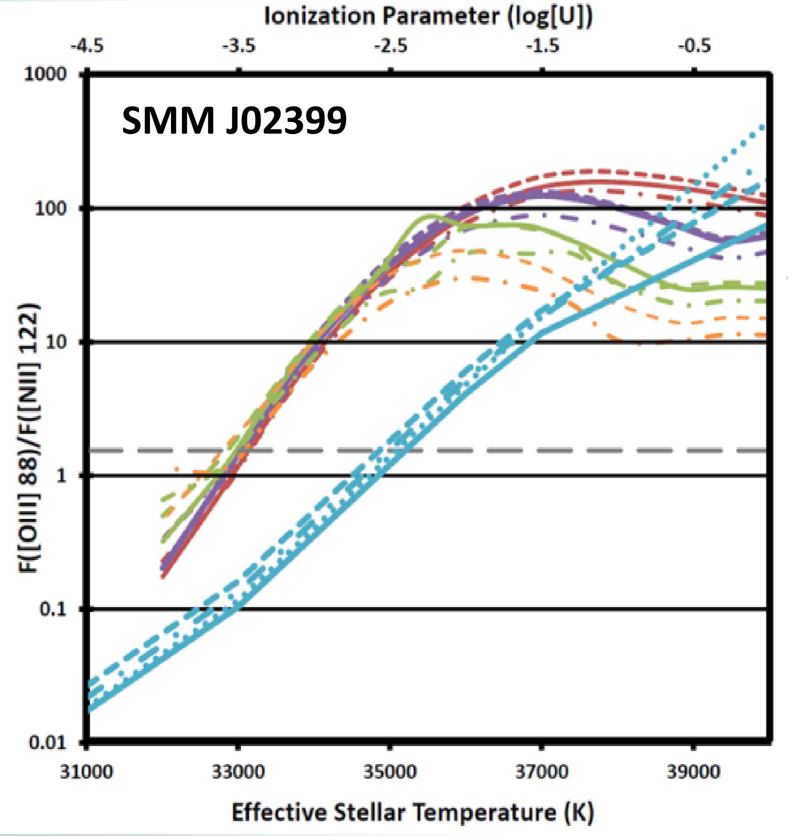


Contours are [CII]/FIR

Hailey-Dunsheath et al. 2010, Stacey et al. 2010

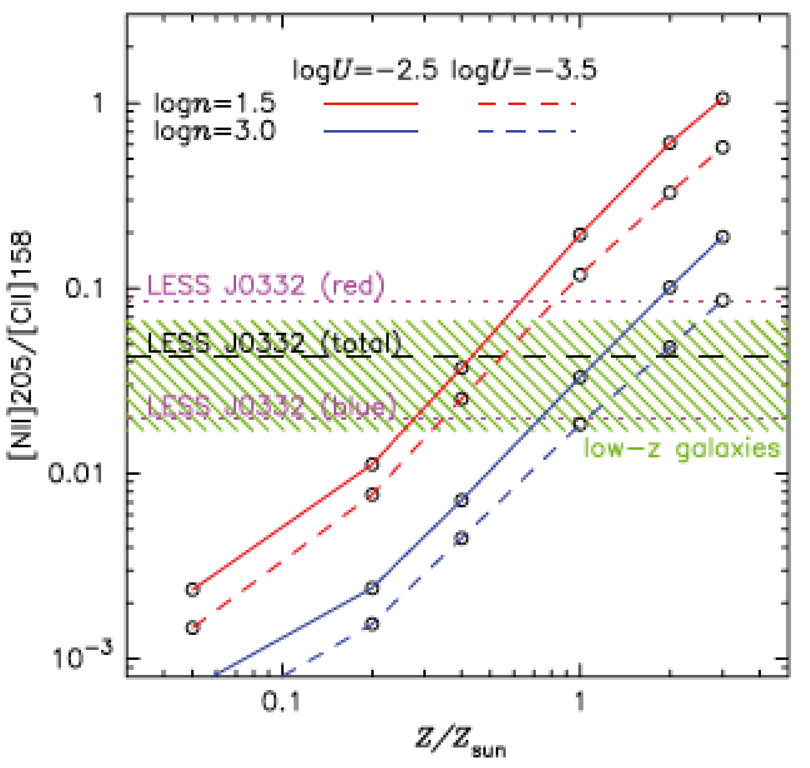
Fine-Structure Line Science

[OIII]/[NII] yields hardness of the radiation field ⇒ Age of starburst



Ferkinhoff et al. 2011

[NII]/[CII] yields fraction of [CII] from HII regions (Oberst et al. 2006), or with other F-S lines and FIR, metalicity



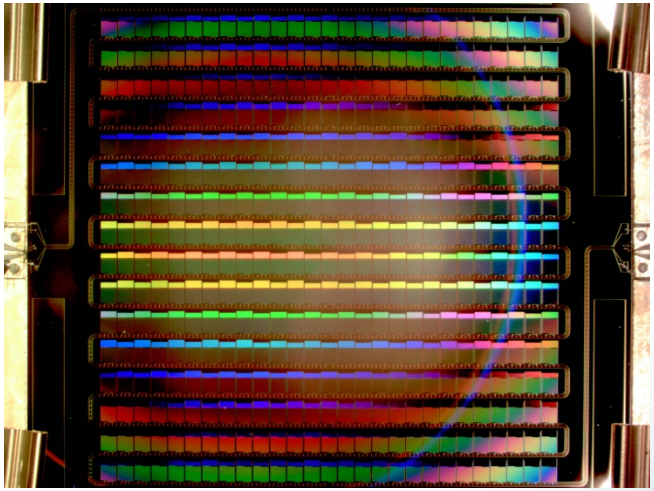
Nagao et al. 2012

Instrumentation Plans

Four instruments are in preliminary design phase, all multi-institutional :

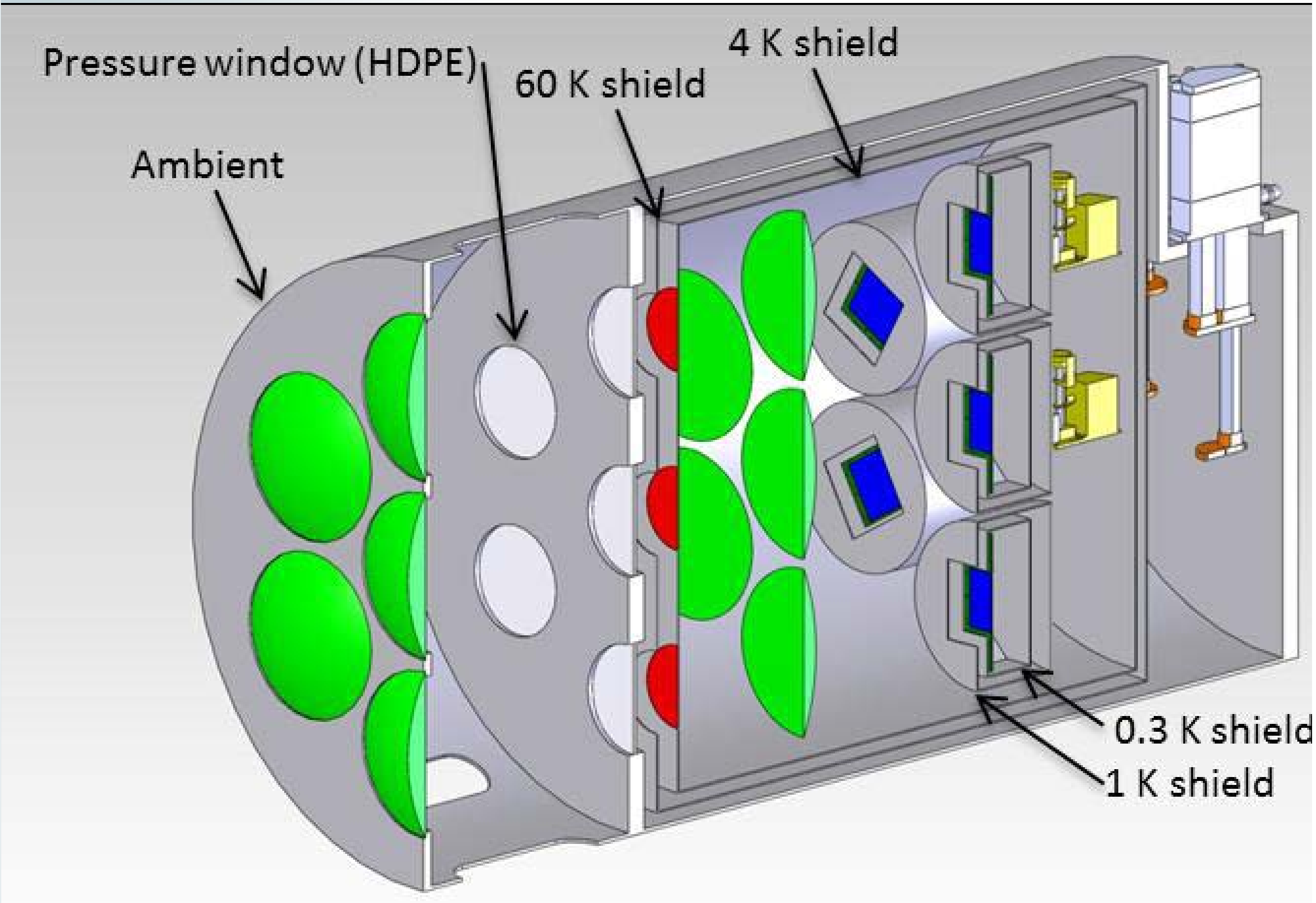
- Short Wavelength Camera (PI: G. Stacey, Cornell) (*)
- Long Wavelength Camera (PI: S. Golwala, Caltech) (*)
- Direct Detection MOS (PI: M. Bradford, JPL) (*)
- Heterodyne Feed Array (PI: J. Stützki, Köln)

(*) Direct detection instruments MKIDs are technology of choice: they are intrinsically multiplexable, and can be implemented into large format arrays with relatively simple readout electronics.



432 pixel TiN MKID array for MAKO/SWCam (Caltech/JPL)

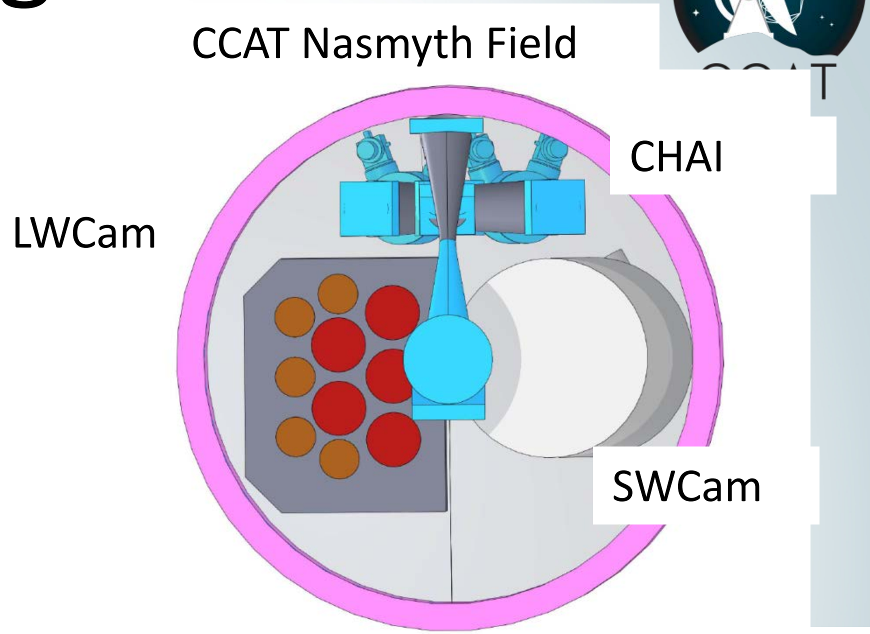
Short Wavelength Camera (SWCam)



- 7 planar subarrays ~ 8000 pixels each @ 2.9” p.s. ⇒ 56,000 pixel submm camera w/ 13’ FoV
- Primary band 350 μm; secondary access to 450, 200 μm bands
- Meandering inductor coupled direct absorption MKID arrays

Long-Wavelength Camera

- PI: Sunil Golwala
- Primary Observing Bands
  - Between 750 μm and 3.3 mm
  - 6 sub-arrays
  - 20’ FoV
  - ~ 40,000 pixels
- Technology
  - Antenna coupled MKID detectors
  - TES/feed-horn coupled backup



λ [μm]	ν [GHz]	$\Delta\nu$ [GHz]	Per-Pixel Sensitivity [mJy $s^{1/2}$]	Number of Pixels
750	400	30	18	16384
850	350	34	10	16384
1100	275	95	2.4	4096
1300	230	62	2.2	4096
2000	150	47	2.3	1024
3300	90	35	2.7	1024

X-S bject Spectrometer
CCAT

- PI:
- Spe – 520
  GH
- Rec ~ 0 to
  3, f 3 to 10
- Res
- Sim een 20
  and ikely
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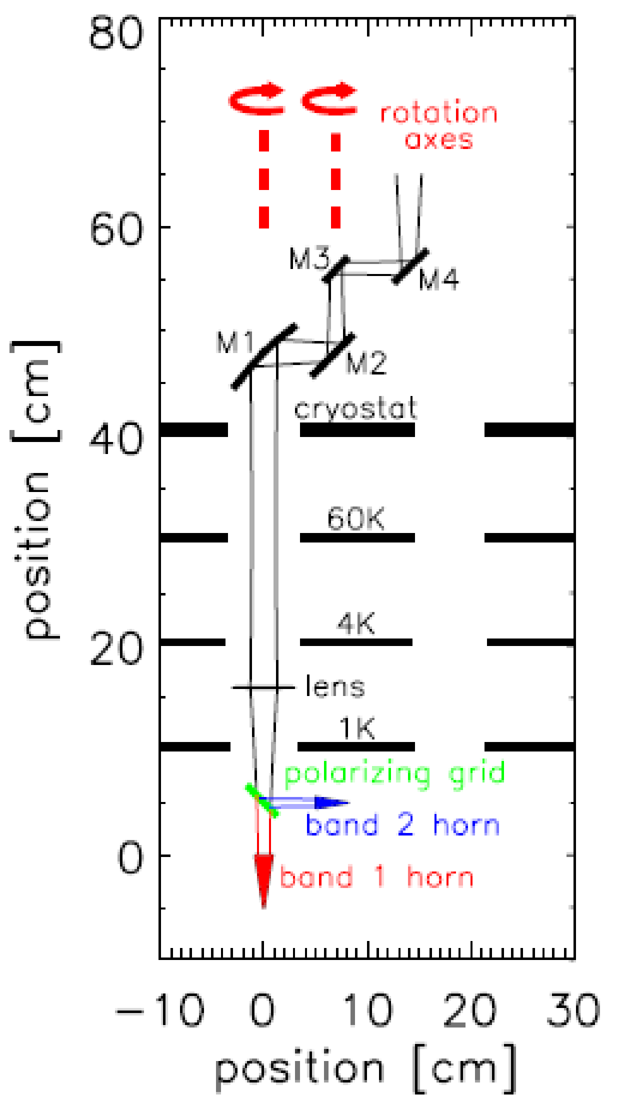
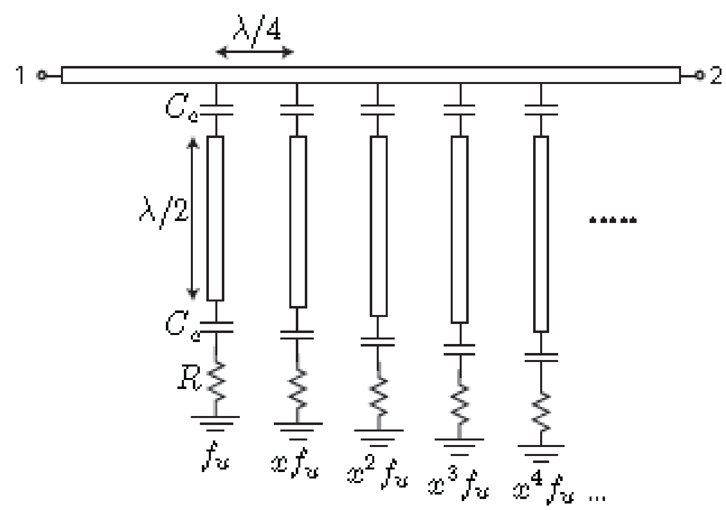
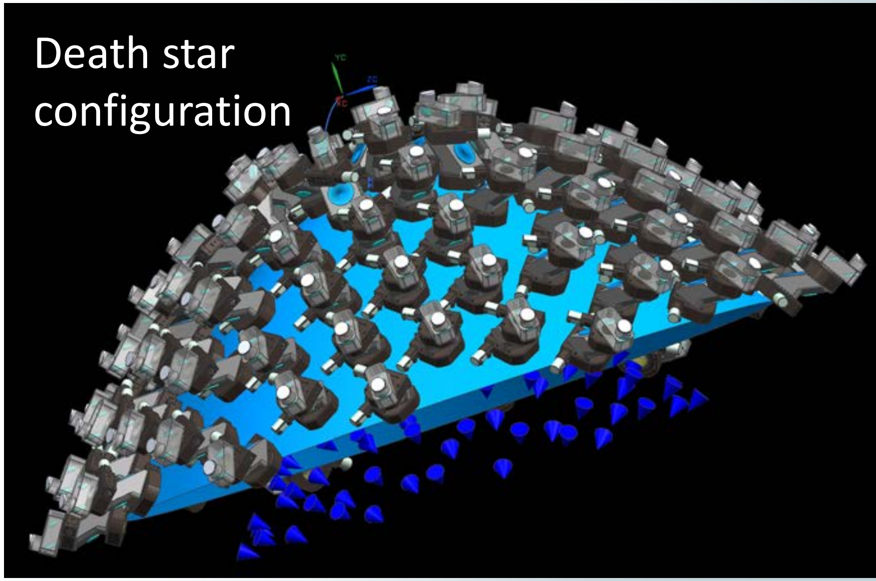
  for
- Tec bank
  arc douts
- Fed with swinging arm twin periscopes






Death star configuration

CHAI: CCAT Heterodyne Array Instrument

- PI: Jürgen Stutzki
- Heterodyne, dual frequency array
- Operating bands: 500 GHz (600 μm) and 850 GHz (350 μm)
  - 2’ × 2’, 14” spacing at 600 μm
  - 1’ × 1’, 8” spacing at 370 μm
  - Mid-J CO; ^{13}CO, and [CI] F-S lines in Galactic star formation regions and nearby galaxies
  - Comets in the HDO 1_{10}-1_{01} 509 GHz line
- 64 (baseline), 128 (goal) pixels in each band

CCAT Consortium Members

- Cornell University (*)
- California Institute of Technology(*)/Jet Propulsion Laboratory
- University of Colorado(*)
- University of Cologne(*) + University of Bonn
- Canadian consortium(**):
    - U. of Waterloo, U. of British Columbia, U. of Toronto, Dalhousie U., McGill U., of Western Ontario, McMaster U. and U. of Calgary
- Associated Universities, Inc.
- U.S. National Science Foundation

(*) Signers of CCAT Consortium Agreement and members of CCAT Corp.
(**) Members of Canada Corp., which is in process of joining CCAT Corp.

Project Timeline

- October 2003: Partnership Workshop in Pasadena
- Feb 2004: MOU signed by Caltech, JPL and Cornell
- 2005: Project Office established
- 2006: Feasibility Study Review
- 2007-2010: Consortium consolidation, design development.
  Site selection completed
- 2010: First-ranked mid-scale project by Astro2010
- 2010 Nov: $11M donation by F. Young
- 2011 Feb:
- 2011 Jun:
- 2011 Nov nan Foundation
- 2011-201) underway
($12.7M)
- mid-2013
- 2013-201

Jason Koski/University Photography

Provost Kent Fuchs, left, introduces benefactor Fred Young '64, who committed $11 million to support the CCAT telescope, at a workshop for CCAT scientists.

CCAT