CCAT Science

Terry Herter and
CCAT Science Steering Committee

CCAT

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.

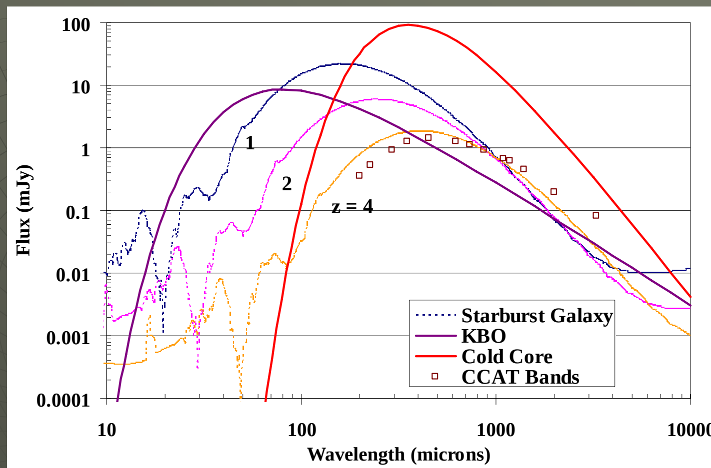
CCAT SSC Membership

- Co-Chairs
  - Terry Herter (Cornell) and Jonas Zmuidzinas (CIT)
- Leads on Science Themes
  - Distant Galaxies – Andrew Blain (CIT)
  - Sunyaev-Zeldovich Effect – Sunil Gowala (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 members
  - Riccardo Giovanelli (Cornell), Simon Radford (CIT)

CCAT Science Strengths

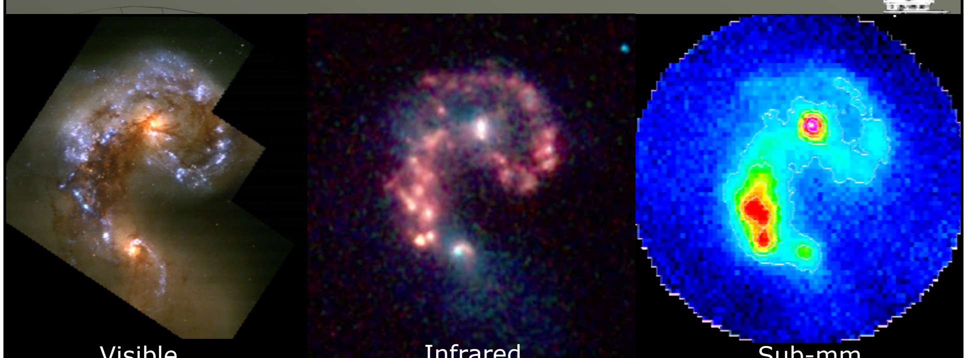
- CCAT will be substantially larger and more sensitive than existing submillimeter telescopes
- It will be the first large submillimeter telescope designed specifically for wide-field imaging
- It will complement ALMA
  - CCAT will be able to map the sky at a rate hundreds of times faster than ALMA
- CCAT will find galaxies by the tens of thousands
- It will map galaxy clusters, Milky Way star-forming regions, and debris disks

Many Sources Peak in the Far-IR/Submillimeter



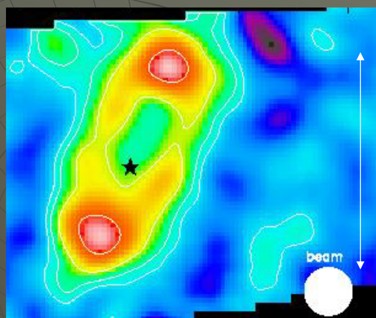
Flux density vs. wavelength for several example sources that peak in the far-infrared/submillimeter – a 10^{12} $L_{\odot}$ starburst galaxy at redshifts of 1, 2, and 4, a T = 8K, 0.03 $M_{\odot}$ cold cloud core located in a nearby (140 pc) star forming region, and a 300 km diameter Kuiper Belt Object located at 40 AU. The CCAT bands are indicated by the open squares (which are the 5-sigma, 30-beams/source confusion limit for CCAT).

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 which 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). Credits: visible (HST), infrared (Spitzer), and submillimeter (Dowell et al.)

Debris Disks



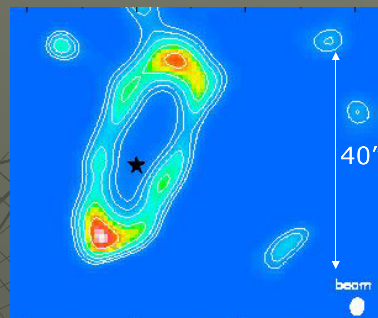
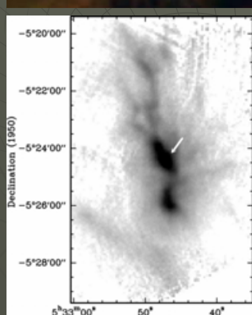
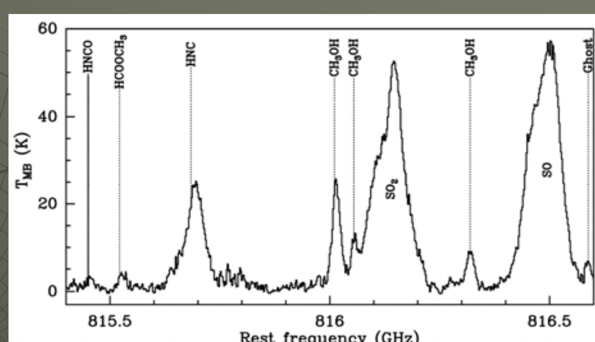


Image of Fomalhaut debris disk acquired with the CSO/SHARC II (Marsh et al. 2005, ApJ, 620, L47). Left: The observed image which has 10″ resolution and shows a complete ring of debris around the star. Right: A resolution enhanced image with 3″ resolution. CCAT will have this resolution intrinsically, 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.

Sub-mm is rich in spectral lines



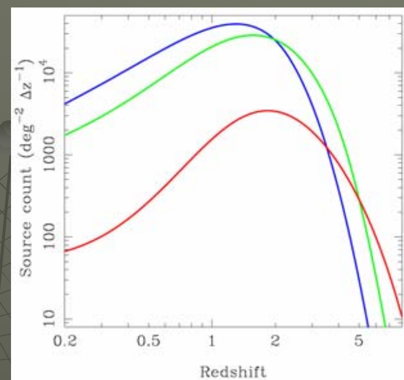


Spectrum Orion KL region in the 350 μm window showing a few of the molecular species accessible in the sub-mm (Comito et al. 2005). This is a very small portion (~1%) of the available window. The spectral resolution is ~ 0.75 km/sec.

Orion Molecular Cloud – Top: Optical image. Bottom: 350 μm map. The arrow points to the location where the spectrum was taken.

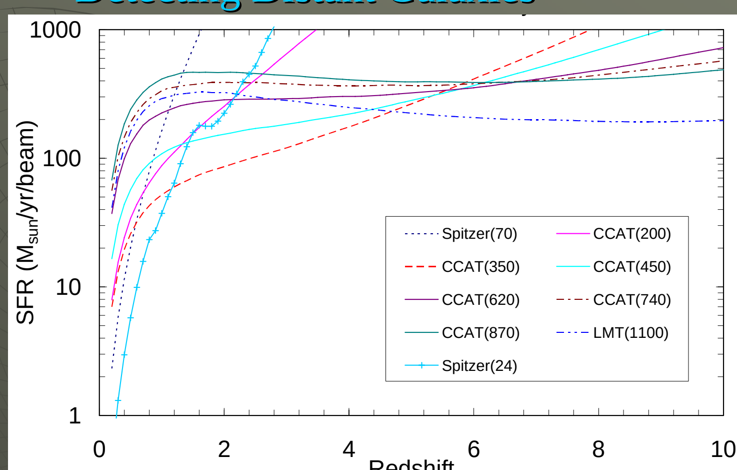
CCAT Science – I

- 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).



Estimated redshift distribution of galaxies that will be detected by CCAT at 1 mJy for 200 (blue), 350 (green), and 850 (red) μm.

Detecting Distant Galaxies



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 5σ in 10^4 sec. The conversion used is 2 M_{sun}/yr = 10^{10} L_{sun} & L_{Arp220} = 1.3x10^{12} L_{sun}.

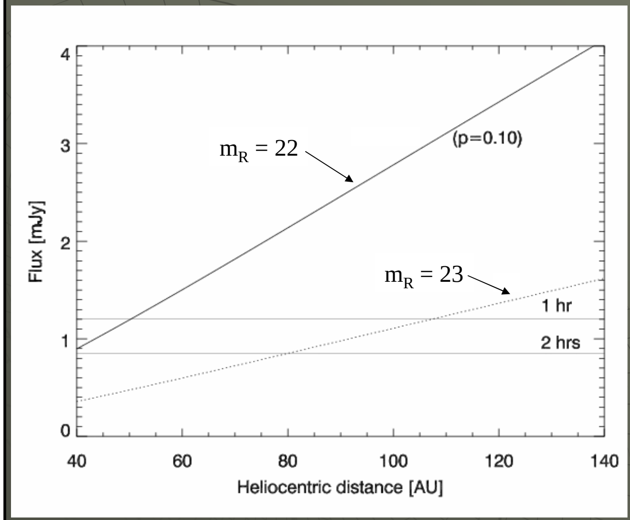
CCAT Science – II

- What is the nature of the dark matter and dark energy?
  - CCAT will image hundreds of clusters of galaxies selected from current and planned southern-hemisphere cluster searches (via the Sunyaev-Zeldovich Effect).
  - CCAT imaging will be important in understanding how clusters form and evolve, and in interpretation and calibration of the survey data to constrain crucial cosmological parameters (Ω_M, Ω_Λ, dark energy equation of state) independently of other techniques (Type Ia supernova and (direct) CMB measurements).
- How do stars form?
  - CCAT will survey molecular clouds in our Galaxy to detect the (cold) cores that collapse to form stars, providing for the first time a complete survey of the star formation process down to very low masses.
  - In nearby molecular clouds, CCAT will be able to detect cold cores down to masses well below that of the lowest mass stars (0.08 $M_\odot$).

CCAT Science – III

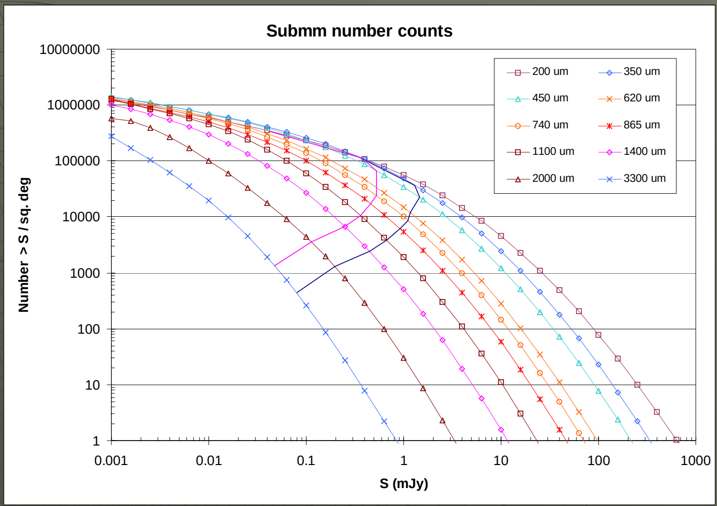
- How do conditions in circumstellar disks determine the nature of planetary systems and the possibilities for life?
  - In concert with ALMA, CCAT will study disk evolution from early (Class I) to late (debris disks) stages.
  - CCAT will image the dust resulting from the collisional grinding of planetesimals in planetary systems around other stars allowing determination of the (dynamical) effects of planets on the dust distribution, and hence the properties of the orbits of the planets.
- How did the Solar System form?
  - The trans-Neptunian region (Kuiper Belt) is a remnant disk that contains a record of fundamental processes that operated in the early solar system (accretion, migration, and clearing phases).
  - CCAT will determine sizes and albedos for hundreds of Kuiper belt objects, thereby providing information to anchor models of the planetary accretion process that occurred in the early solar system.

KBO sub-mm advantage



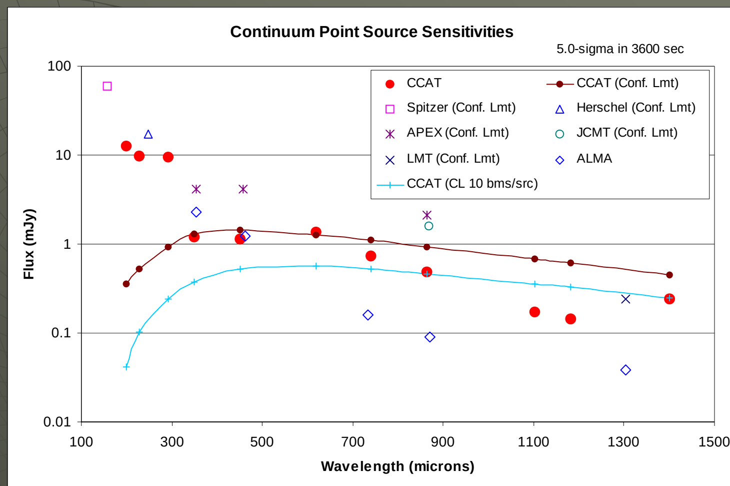
Predicted 350 um flux for KBOs with 10% albedo (m_R=22, solid and m_R=23, dotted) or 4% albedo (m_R=23, solid and m_R=24, dotted). Horizontal lines show 5-sigma detection in 1 and 2 hours, respectively for CCAT.

Sub-mm Number Counts & Confusion Limits



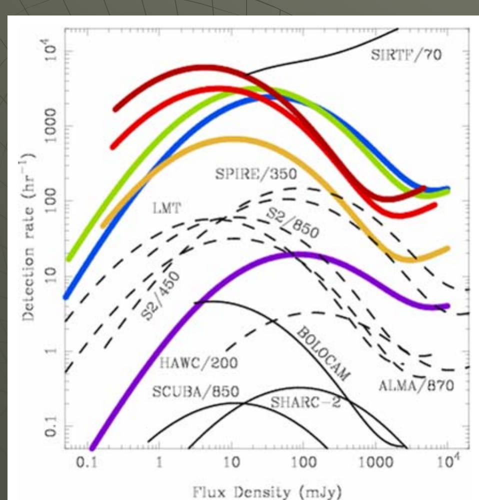
Sub-mm galaxy counts vs. flux density (number of sources with flux greater than S vs. S) for different wavelengths (after Blain et al.). Crossing lines show 30 (lower) and 10 (upper) beams/source confusion limits for D = 25 m.

CCAT Sensitivity



5σ, 1-hour CCAT and ALMA sensitivities. CCAT sensitivities computed for precipitable water vapor appropriate to that band. Confusion limits shown are 30 beams/source except for 10 beams/src case shown for CCAT.

Mapping speed comparing other facilities



- CCAT is an ultrafast mapper
- Assumptions
  - 10000 pixel detector, Nyquist sampled at all bands 0.2, 0.35, 0.45, 0.67, 0.85,1.1mm (in order from violet-red)
  - Observationally verified counts (good to factor 2)
  - Confusion and all sky limits
- 1.2/0.85/0.35mm imaging speeds are compatible
  - To reach confusion at 0.35mm go several times deeper at 0.85mm
- Detection rates are
  - ~150×SCUBA-2; ~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} for 3 $deg^2 hr^{-1}$ gives 5000 hr

Selected (Key) Facility Drivers

- Aperture
  - 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)
- Field-of-view (5' x 5' initially, up to 20' across eventually)
  - The major role of CCAT will be its unchallenged speed for moderate-resolution wide-field surveys
  - CCAT strongly complements ALMA (which will do follow-up)
- Chopping/Scanning
  - Bolometer arrays require modulating the signal through chopping and/or scanning the telescope
  - For chopping, this must be done at the secondary (~ 1' at ~ 1Hz)
  - Scanning requires moderately large accelerations for reasonable efficiency (~ 0.2 deg/sec^2) [R];
- Pointing & Guiding
  - For spectrographs require placing to a fraction of slit width
  - And guiding to maintain spectrophotometric accuracy
  - => 0.61” [R] and 0.35” [G] arcsec pointing/guiding (1D rms)
- Precipitable Water Vapor
  - Provide significant observing time at 350/450 μm

Time Available to Observe

Band		Time to CL	Ref. PWV	Sairecabur (5500 m)			ALMA (5050 m)		
λ	ν			Time Available		CL fields	Time Available		CL fields
[μm]	[GHz]	[hr]	[mm]	[hr yr^{-1}]	[%]	[yr^{-1}]	[hr yr^{-1}]	[%]	[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 < 1.1 mm. Because observations at some wavelengths require similar conditions, i.e., 350 μm and 450 μm, they share a common range. Note that at CSO, 350 μm observations are done when PWV < 0.9 mm.

Time to Complete Programs

Band		PWV	Time Available		Science	Time to Complete	
λ	ν		Sairecabur (5500 m)	ALMA (5050 m)	Program Time	Sairecabur (5500 m)	ALMA (5050 m)
(μm)	(GHz)	(mm)	(hr yr^{-1})	(hr yr^{-1})	(hr)	(yrs)	(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.

Next Phase

- Refinements
  - What have we left out?
  - Parametric trade analysis, e.g. when surface roughness changes, how do program time change.
- Detailed survey planning
  - Teaming – bring together necessary expertise
  - Selection of fields and/or objects
  - Institute critical precursor surveys (e.g. Spitzer) or other observations
- Data reduction requirements
  - Establish requirements:
    - Quicklook tools, pipelines, etc.
    - Calibration
- Data analysis
  - Identifying steps to produce science from calibrated data
- Archiving
  - Scope out problem in more detail – storage, access requirements, processing/reduction level, etc.