CCAT: Key Science Goals

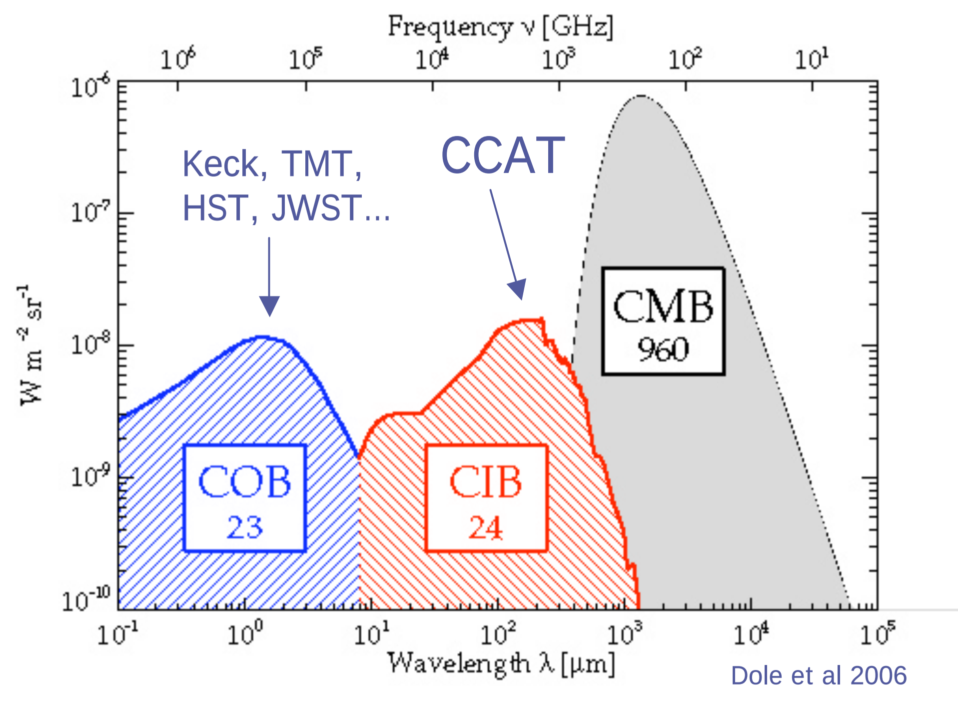
Jonas Zmuidzinas
and
the CCAT Science Steering Committee

Science reports in CCAT Study

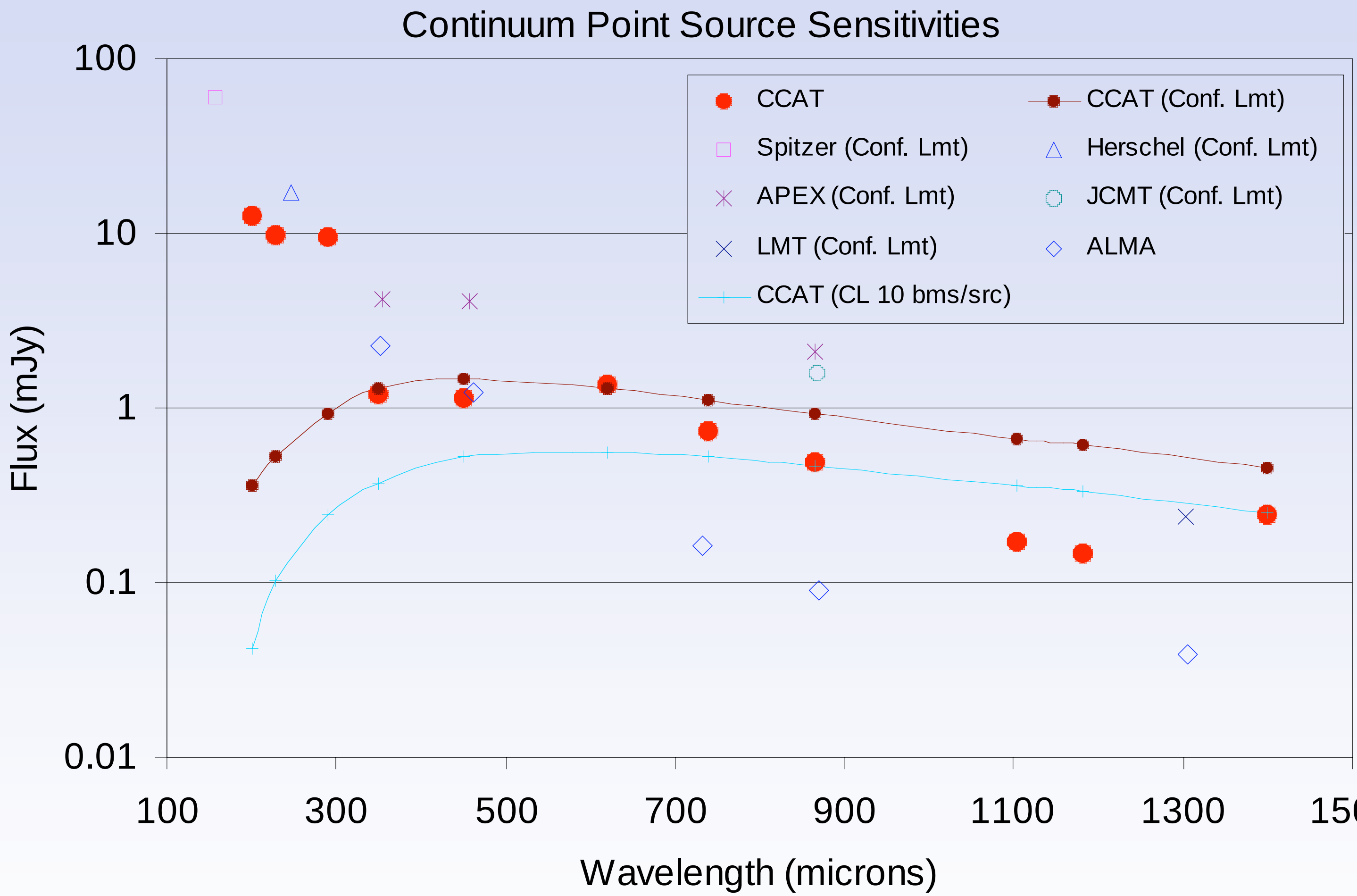
- Co-Chairs
  - Terry Herter (Cornell) and Jonas Zmuidzinas (CIT)
- Science Theme — Lead
  - Distant Galaxies – Andrew Blain (CIT)
  - Sunyaev-Zeldovich Effect – Sunil Gowala (CIT)
  - Local galaxies – Gordon Stacey (Cornell) + Shardha Jogee (UT)
  - Galactic Center – Darren Dowell (JPL/CIT)
  - Cold 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 feasibility study available at: **www.submm.org**

CCAT Science Strengths

- Compared to existing telescopes, CCAT:
  - Is larger, more sensitive
  - Is designed specifically for wide-field imaging
  - Has **wide spectral coverage**
    - SED & luminosity
  - Excels at 350 μm (site, surface)
  - Has better angular resolution: 3”.5 @ 350 μm
  - Has fainter confusion limits
- CCAT will complement ALMA
  - Fast mapping vs. high angular & spectral resolution
  - Comparable sensitivities: CCAT provides targets for ALMA
  - 350 μm: ALMA site (observing time), surface accuracy, Rx noise all impose penalties

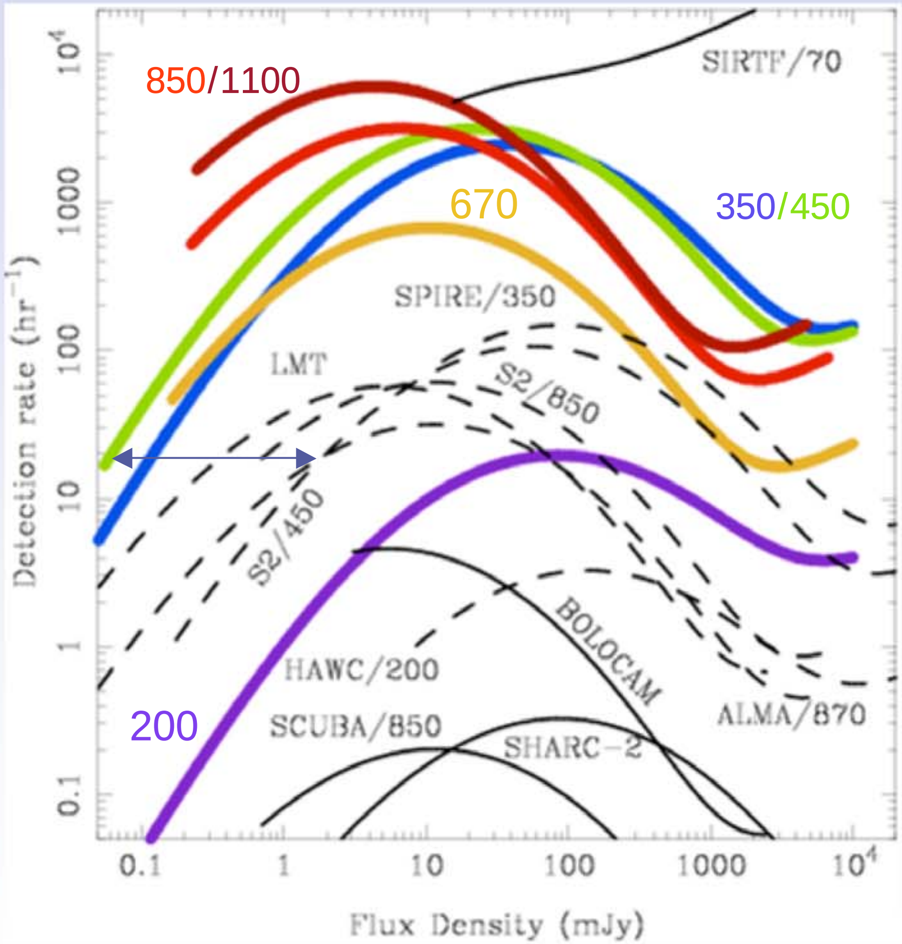


CCAT Sensitivity



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/source 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

Time Available to Observe

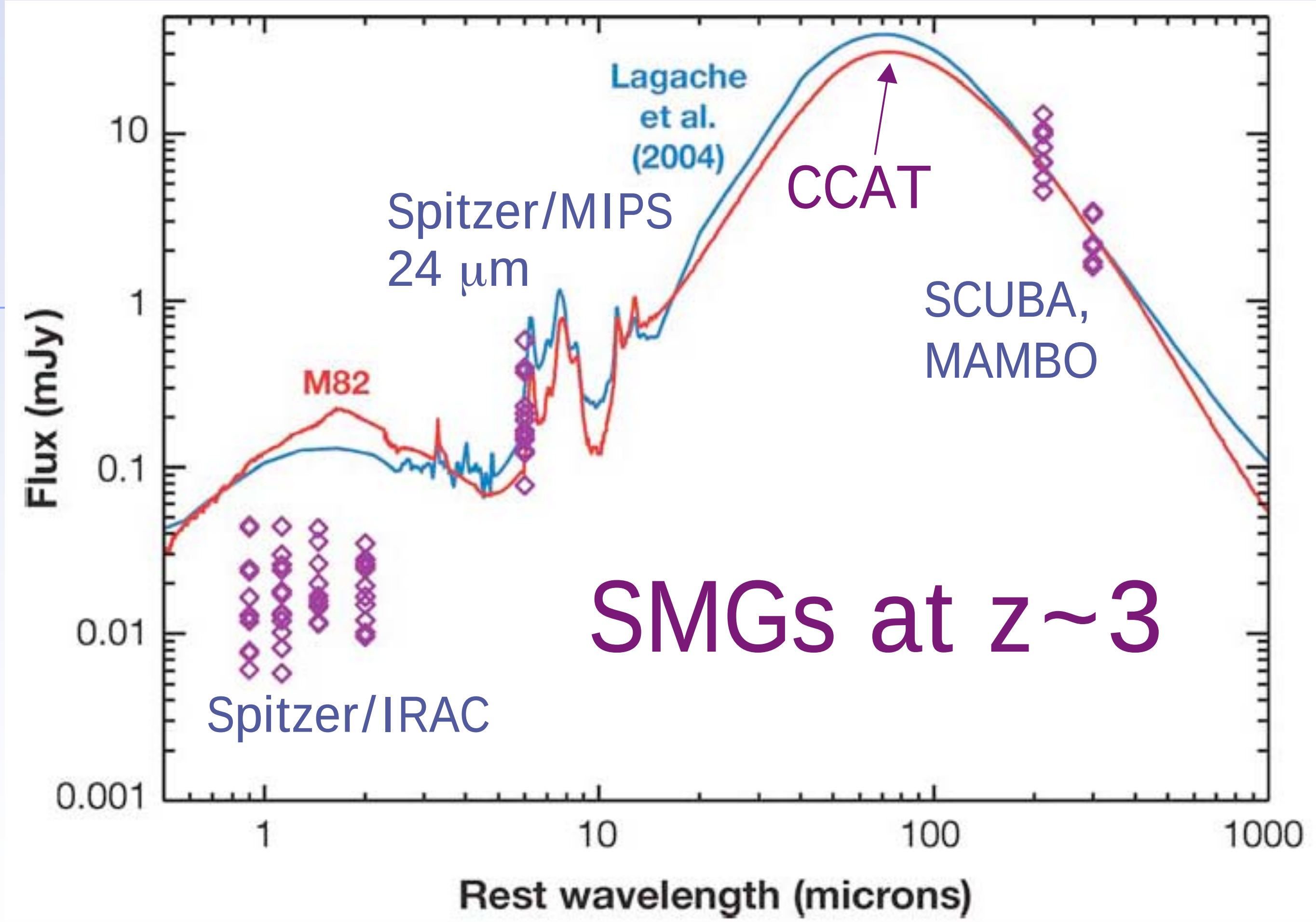
Band λ [μm]	Band ν [GHz]	Time to CL [hr]	Ref. PWV [mm]	Sairecabur (5500 m) Time Available [hr yr^{-1}]	Sairecabur (5500 m) Time Available [%]	Sairecabur (5500 m) CL fields [yr^{-1}]	ALMA (5050 m) Time Available [hr yr^{-1}]	ALMA (5050 m) Time Available [%]	ALMA (5050 m) CL fields [yr^{-1}]
200	1500	1248	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 < 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.

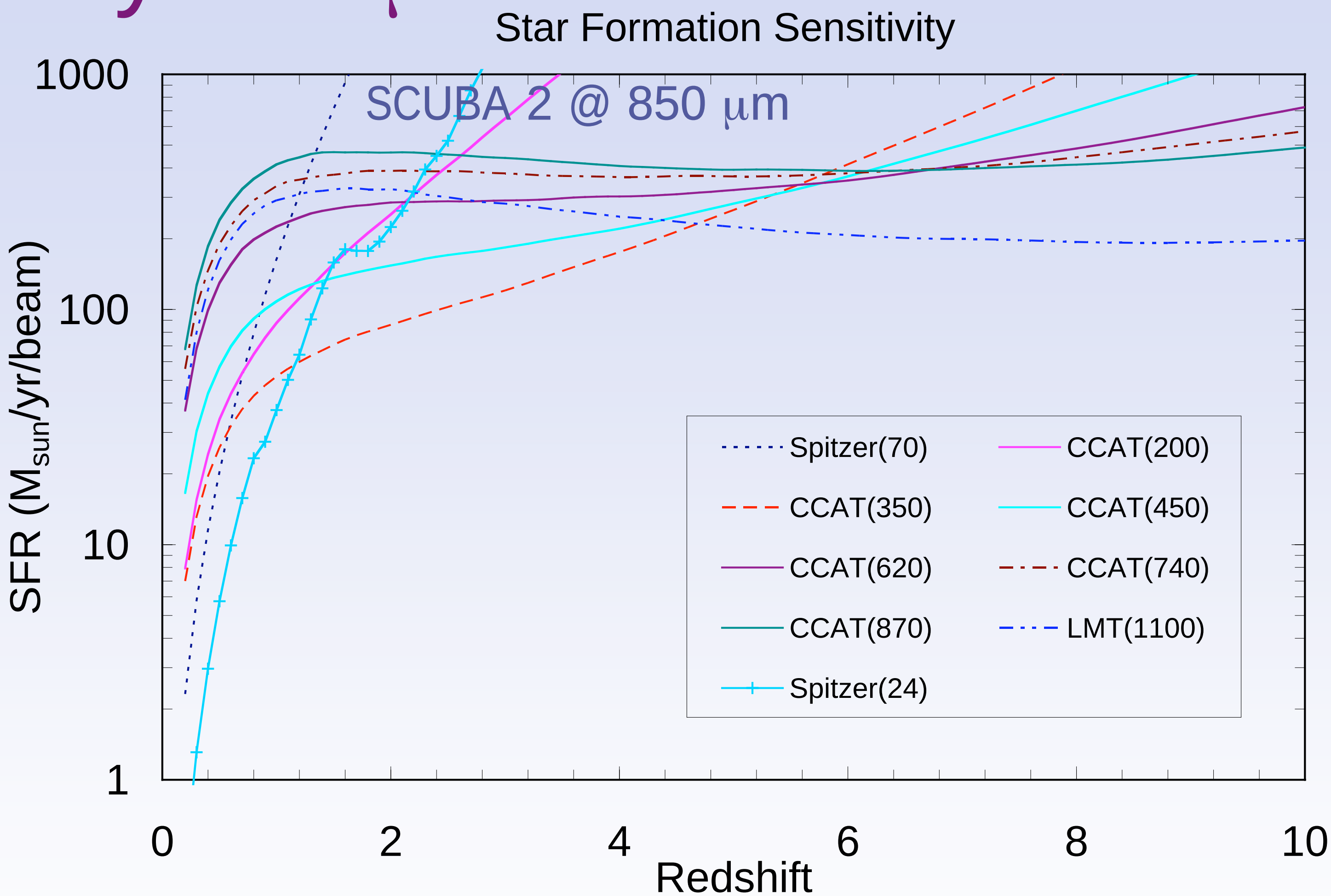
SMG science goals with CCAT

- Measure number counts to much higher precision, deeper by factors of several, at multiple wavelengths
- Investigate z>4 universe
  - Use submm color selection, e.g. 350 vs 850 μm
  - Select out brightest high-z candidates, feed to ALMA
  - SFR at high z dominated by mergers ?
- Measure SED from 0.3 to 1 mm
  - Look for beta variations ? Photometric redshifts ??
  - Feed "unusual" candidates to ALMA
- With redshifts, we can provide the complete picture:
  - Only CCAT SED can give L, T_d (for $z>2$; 50% or more of SMGs)...
  - ...so CCAT can determine luminosity function vs. *z*
  - Study clustering vs. *z*, luminosity, ...
    - 3.5 σ detection by Blain et al., 2004, using Keck redshifts
    - Sensitive to halo mass
    - Need predictions from galaxy formation models (A. Benson)
  - Will need very large samples, 10^5 or more
- *Can we get redshifts* ?

Why 350/450 μm?



Why 350 μm ?

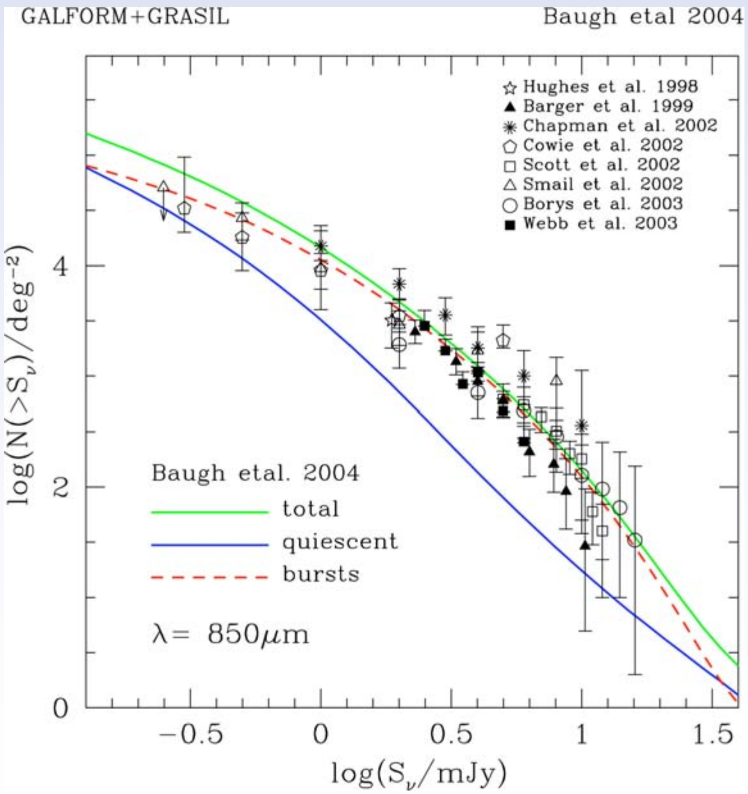


Sensitivity to star formation rate vs. redshift for an Arp 220-like galaxy. All flux limits are set by the confusion limit except for CCAT(200) which is 5σ in 10^4 sec. The conversion used is 2 M_{sun}/yr = 10^{10} L_{sun} & L_{Arp220} = 1.3x10^{12} L_{sun}.

Submm galaxies

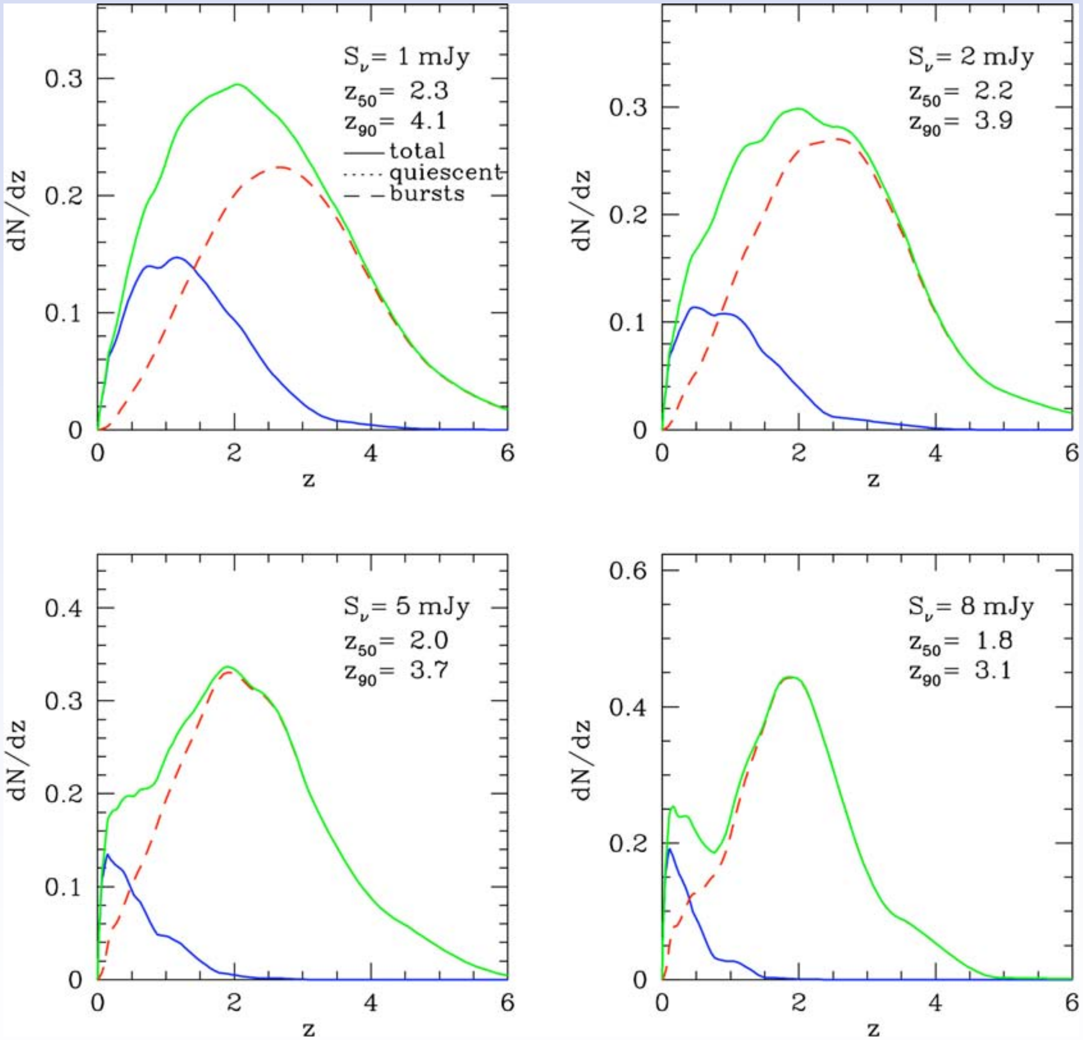
Can the faint sub-mm galaxies be explained in the ΛCDM model? MNRAS 2005

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].



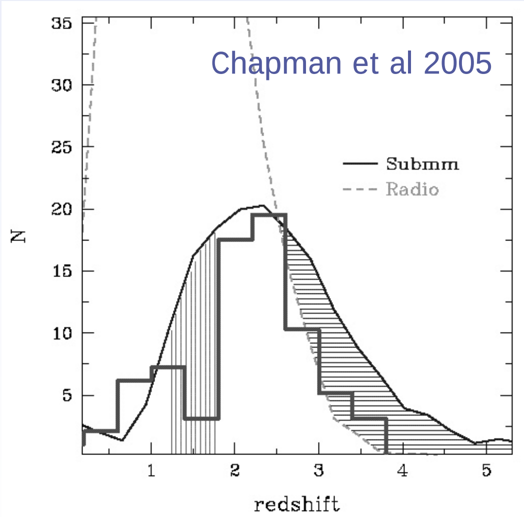
- Semianalytical model
- CDM halo "merger tree"
- Gas cooling, star formation, feedback, ...
- Treat chemical evolution, dust production, dust radiative transfer
- Includes galaxy mergers & starbursts
- Number counts OK
- Submm galaxies dominated by mergers

Submm galaxies

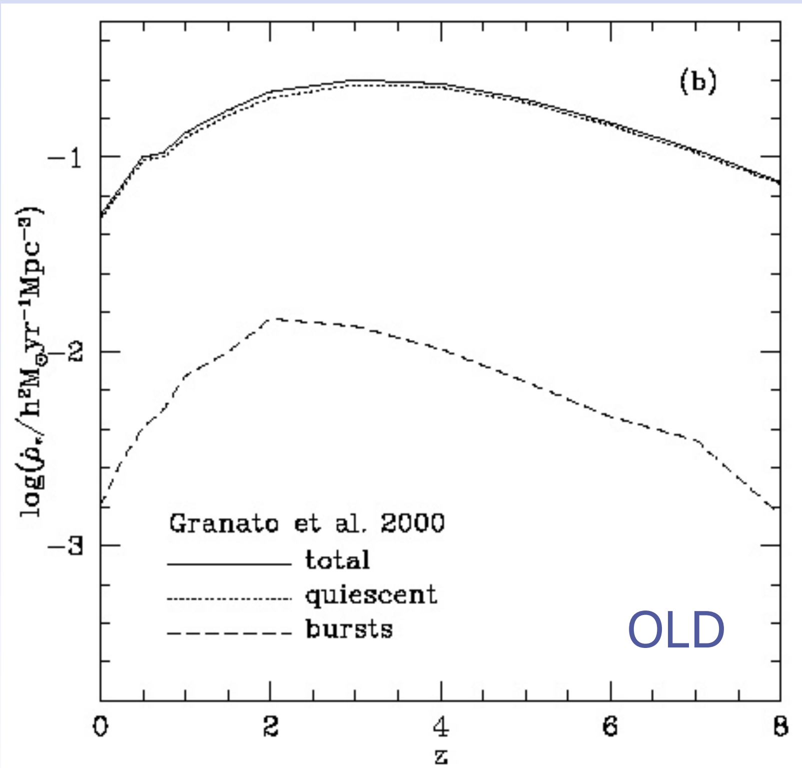


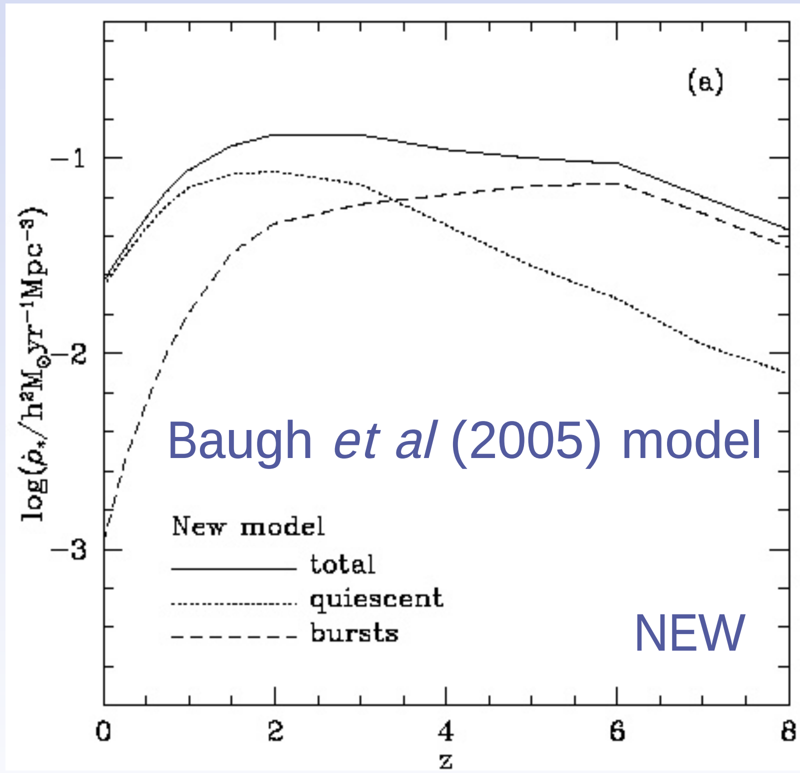
Baugh *et al* (2005) model

- CCAT can investigate z>4 tail
- **Use 850 μm detections that are 350/450 μm dropouts ?**



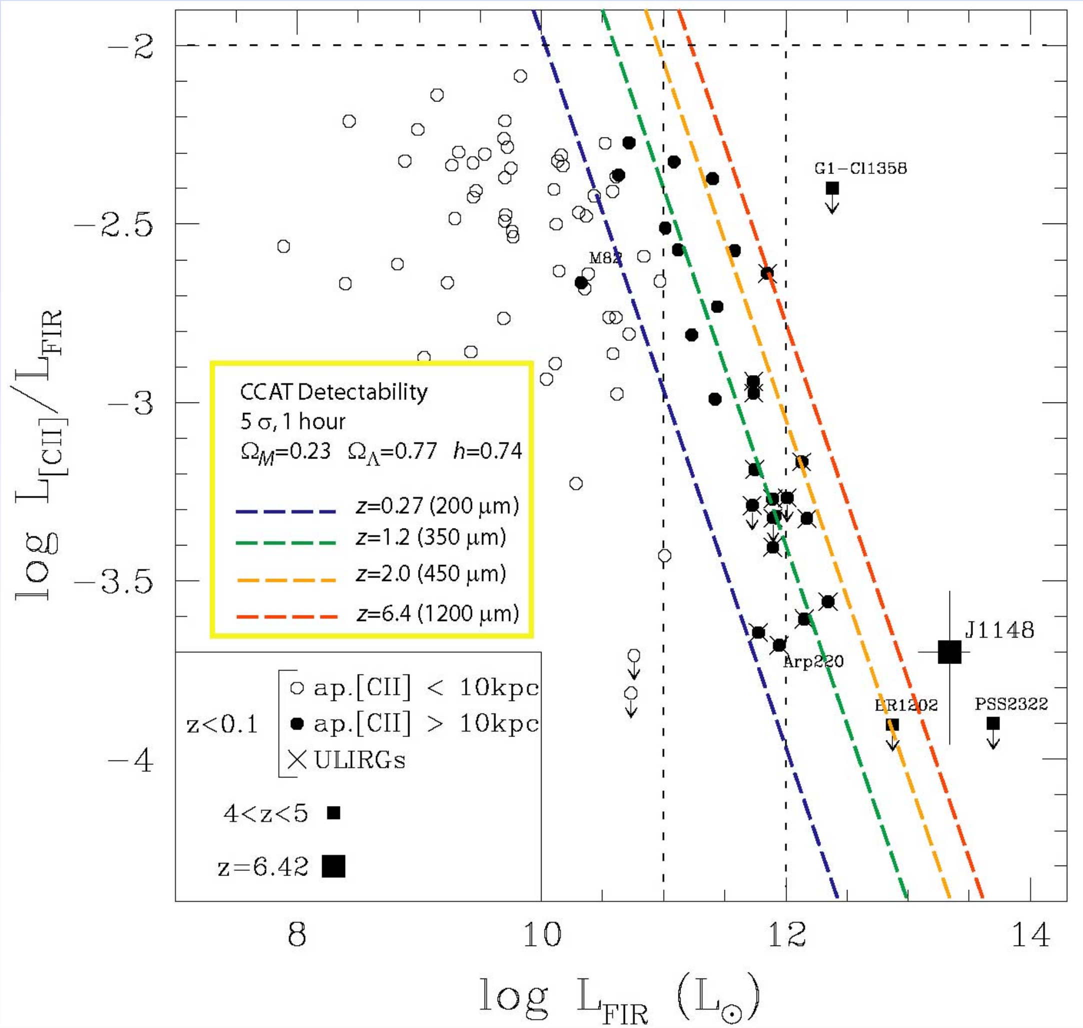
What will we learn at high z ?





- Star formation dominated by bursts/mergers for z > 3.5 ?
- Use submm colors to select high-z candidates for ALMA follow-up

Redshifts: a 350/450 μm MOS ?



- C+ readily detectable with CCAT
- About 1/3 of SMGs have C+ in 350 & 450 μm windows
- 200 μm window provides access to “local” population
- A 50-object MOS on CCAT would be very powerful

Star Formation: Prestellar core mass function

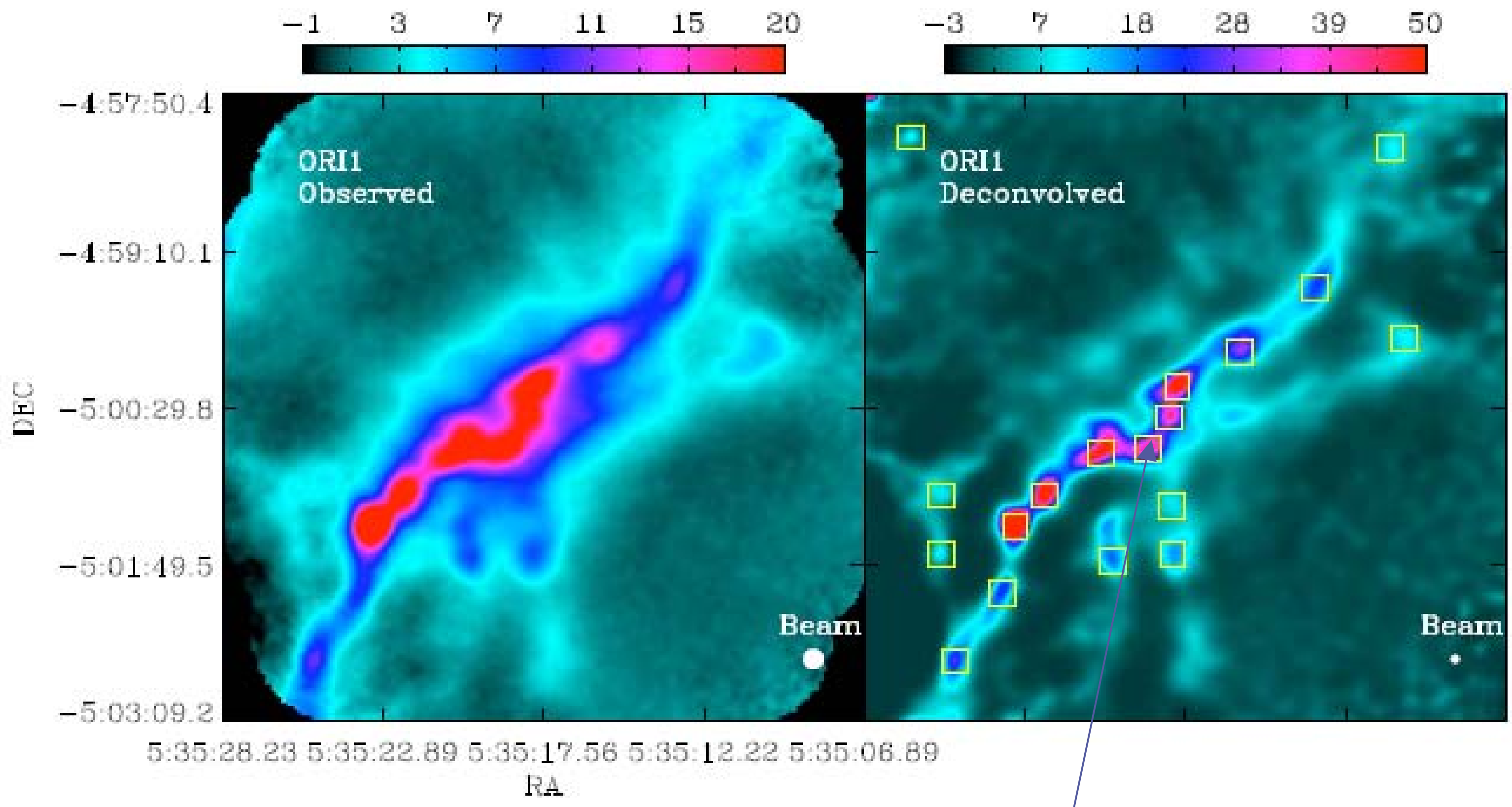
Evans & Goldsmith Cold Cloud Core Survey, in CCAT report

The Core Mass Function $CMF = N_{core}(M_{core})$

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?

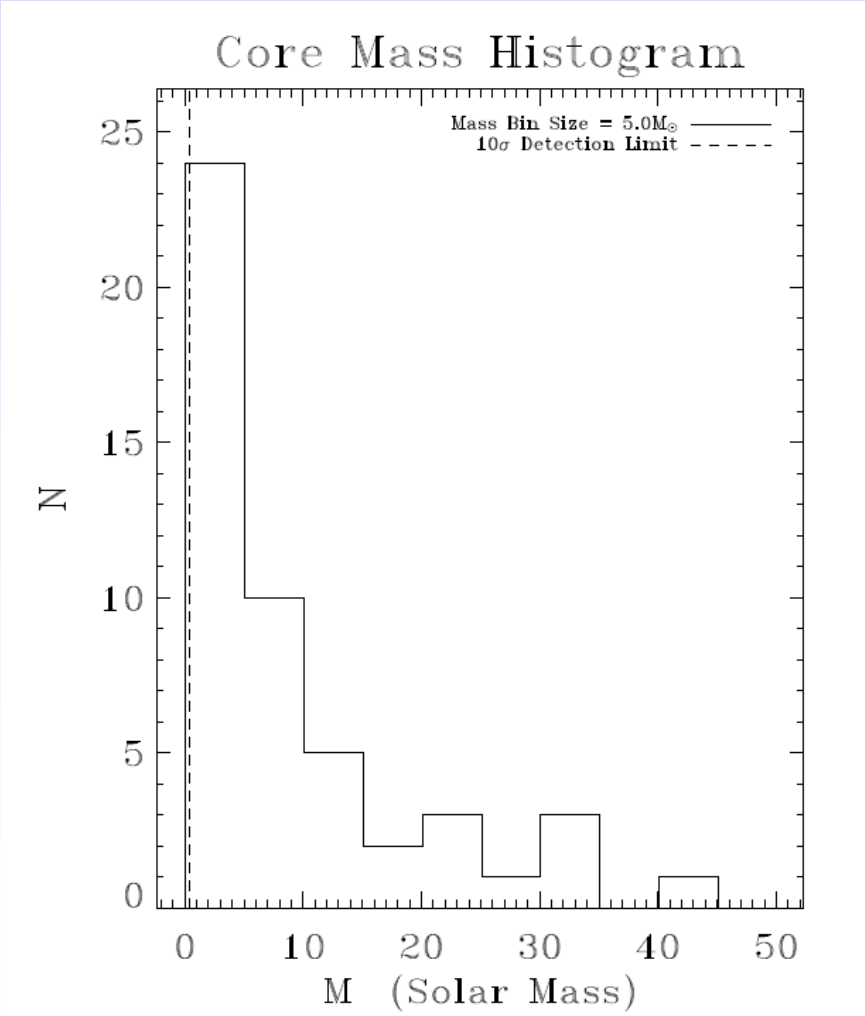
CORES IN ORION1 REGION (Li, Goldsmith, et al.; CSO/Sharc2)



Enhanced angular resolution ESSENTIAL to determine core size and mass

Cores identified with COREFIND algorithm

Results



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

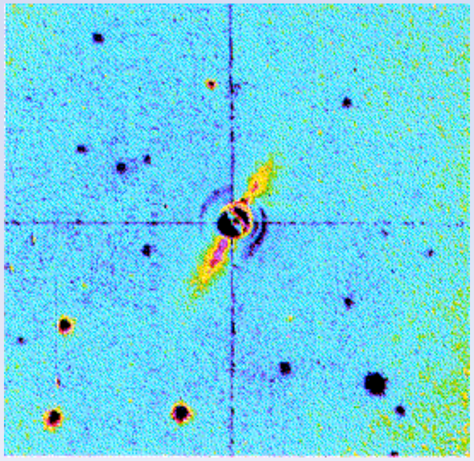
Limited sample size makes use of differential mass function N(M) difficult

Status & role of CCAT

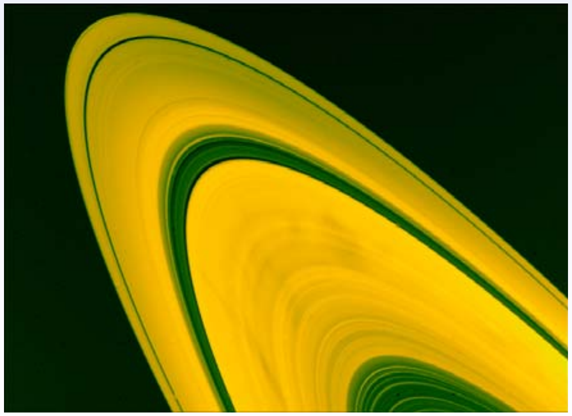
- Mass range: 0.1 M_{solar} to 50 M_{solar}
- The core mass function is described by a single power law: $N(M) \sim M^{-0.8}$, very different from stellar IMF
- This type of study requires best possible resolution, and LARGE CORE SAMPLES to determine the effect of environment and the evolutionary steps 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 determine T_d and β directly
- BOLOCAM: Enoch 2005 (Perseus), Young 2006 (Ophiucus)

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)



Saturn's rings: result of the interaction of moons and dust

Debris Disks

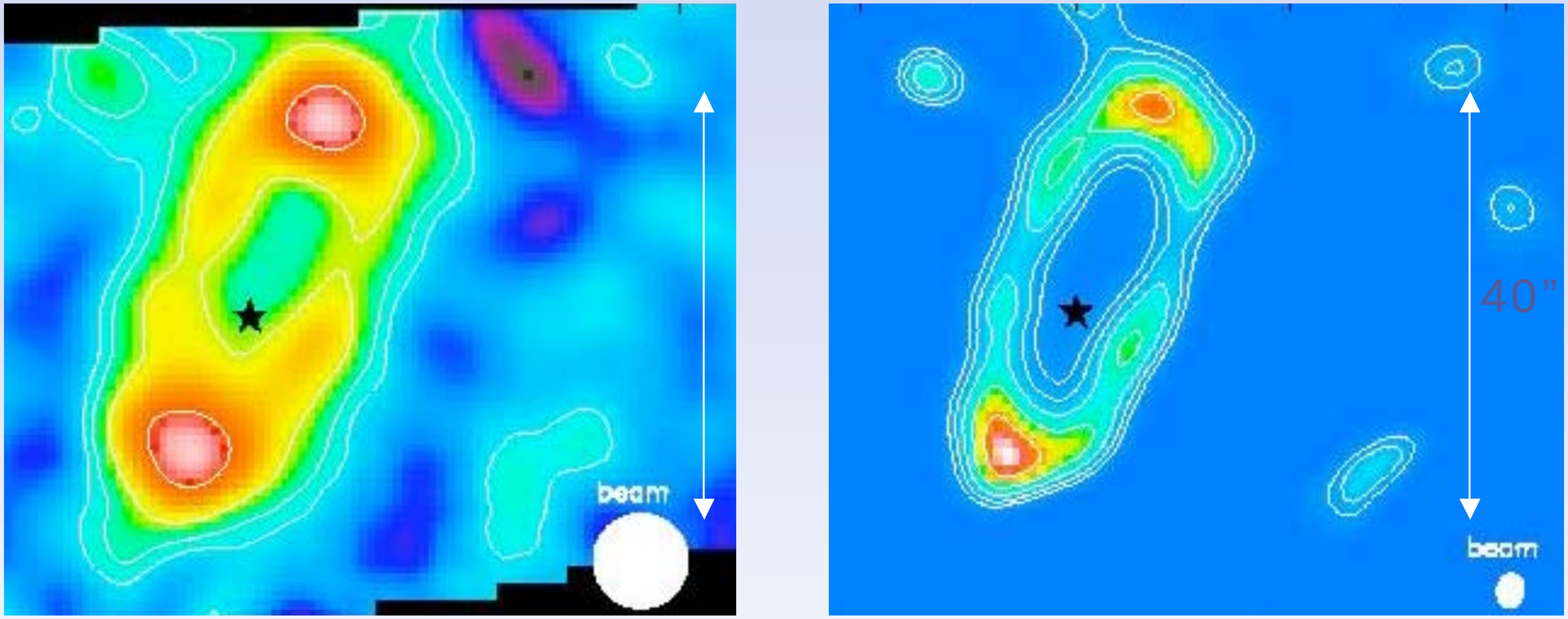


Image of Fomalhaut debris disk acquired with the CSO/SHARC II (Marsh et al. 2005, ApJ, 620, L47). Left: The observed image which has 10″ resolution and shows a complete ring of debris around the star. Right: A resolution enhanced image with 3″ resolution. CCAT will have this resolution intrinsically,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

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