CCAT

A 25-m single aperture telescope operating at submm wavelengths

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With acknowledgements to the CCAT consortium

ROE Submm Workshop, 13 Dec 2011

What is CCAT?

- **Telescope:** A 25-m antenna that will operate at wavelengths as short as 200μm

  → 10× the sensitivity of current single dish telescopes

- **Location:** At very high altitude (5600m) in the Atacama desert

  → More than 50% of the time has PWV < 0.7mm

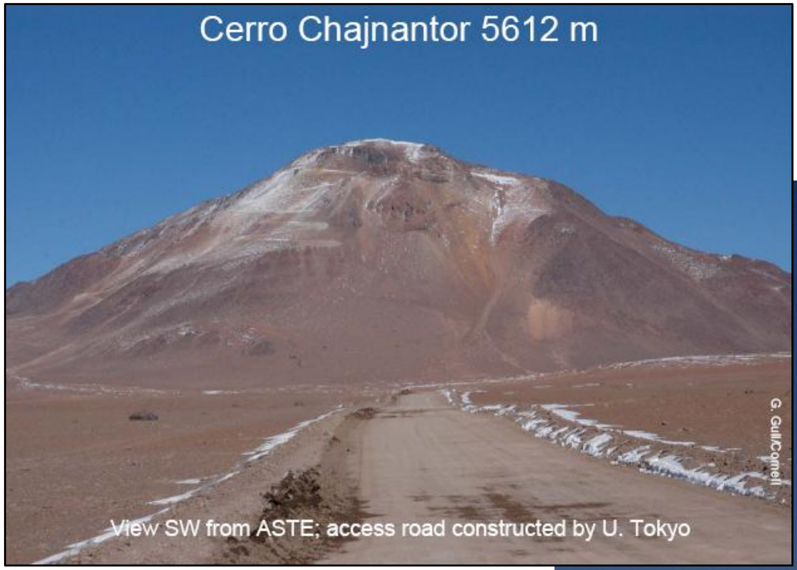
- **Synergy:** Location enables maximum synergy with ALMA

  → Locates sources for ALMA follow-up

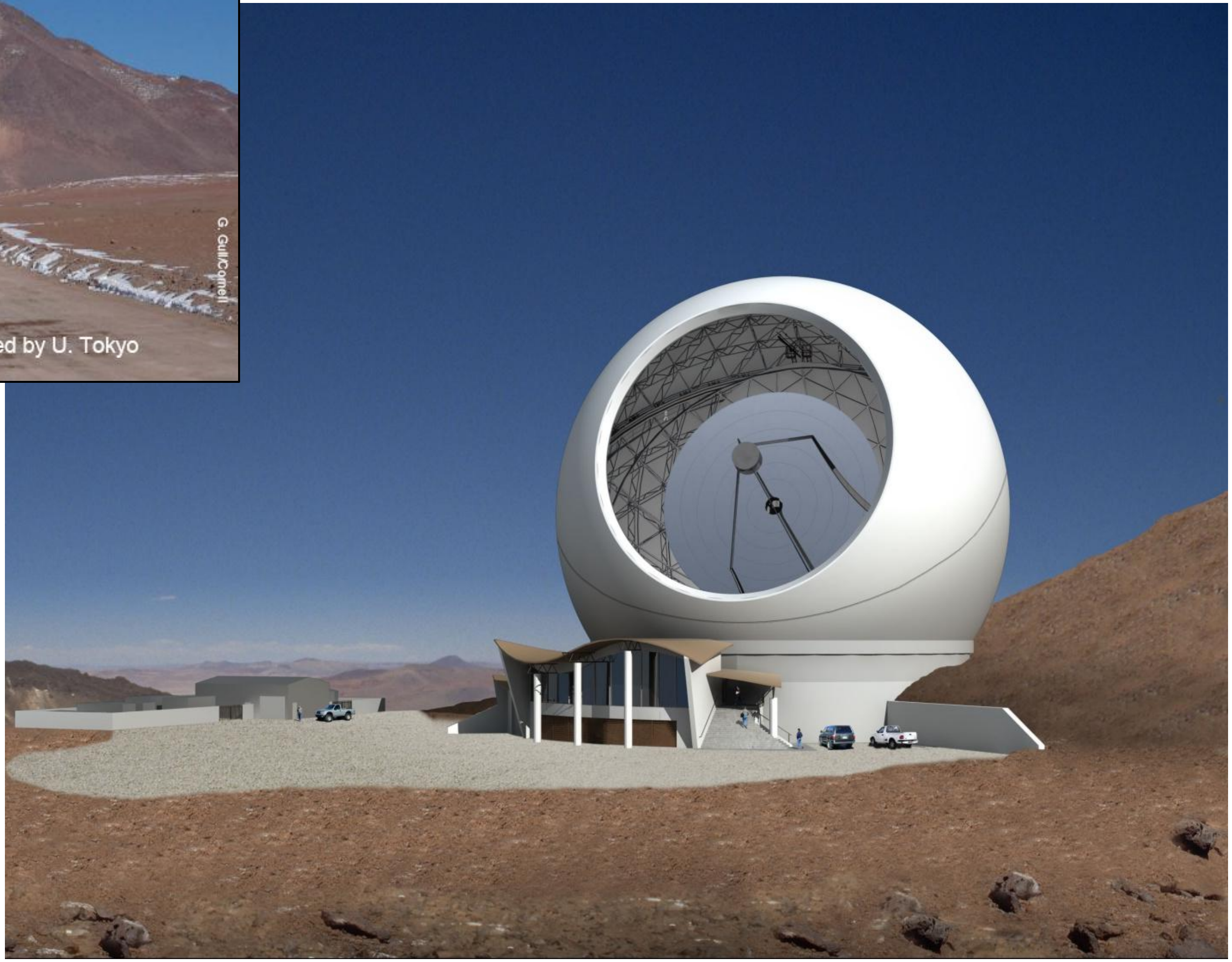
- **Instrumentation:** Take advantage of vast growth in detector technologies

  → Imaging and spectroscopic cameras

CCAT location and concept

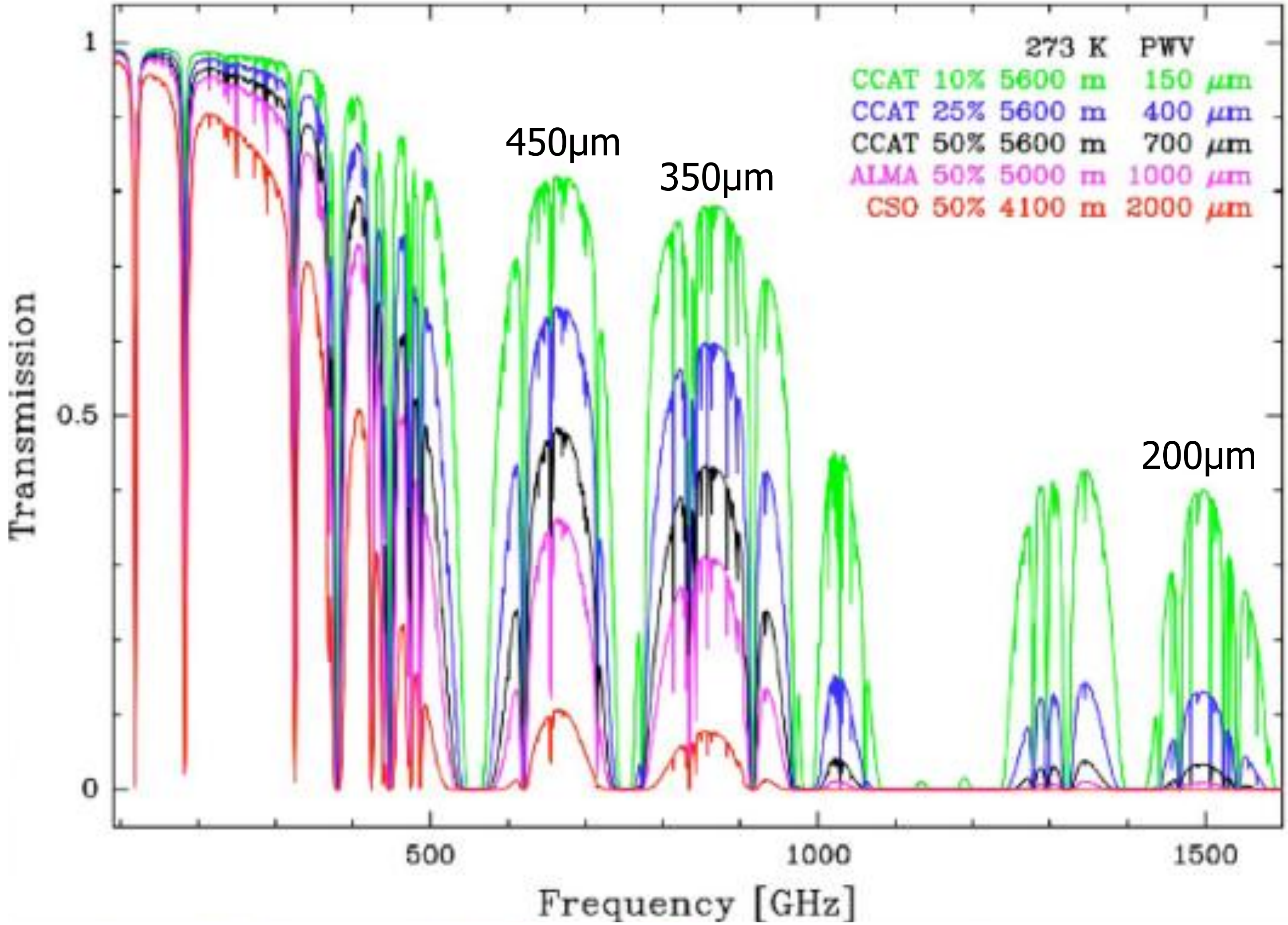


Field-of-view of at least 20′ in diameter



Aiming for large-scale surface error of better than 12.5μm rms

Observing time



For more than 50% of the time the weather is "Band 1" or better!

Project and timeline

- Consortium of US institutes (Cornell, Caltech, JPL, Colorado), German (Bonn and Cologne) and Canada (inc. Waterloo, UBC)
- CCAT was ranked the highest priority among medium scale, ground based projects by the US Astro2010 Decadel survey
- Now: Contracts being awarded; detailed designs underway
- 2013: Completion of engineering design phase
- 2013 – 2017: Scheduled construction phase
- 2018: Estimated start of operations
- UK is not a partner (although we were involved in earlier discussions)

Primary science

Primary science drivers from the CCAT consortium:

- Surveys of star forming galaxies in the early Universe
- Star and planetary system formation
- Cluster astrophysics (Sunyaev-Zeldovich effect)
- Studies of the Kuiper Belt

These necessitate the need for both direct detection cameras and spectrometers

Extragalactic case

Considerations:

1. Ability to cover very wide areas (>100 sq-deg) to overcome cosmic variance

2. Few arcsec resolution to overcome confusion, resolve the FIRB and aid identification of counterparts at other wavelengths

3. Multi-wavelength imaging to identify the highest z candidates

4. Comprehensive spectroscopic follow-up, to measure redshift and characterise the physical conditions within sources

Galactic case

CCAT

Considerations:

1. Sensitivity to reach mass limits <0.01 M_{sun}

2. Ability to cover large fields of 10's of sq-degs to sample a range of different environments

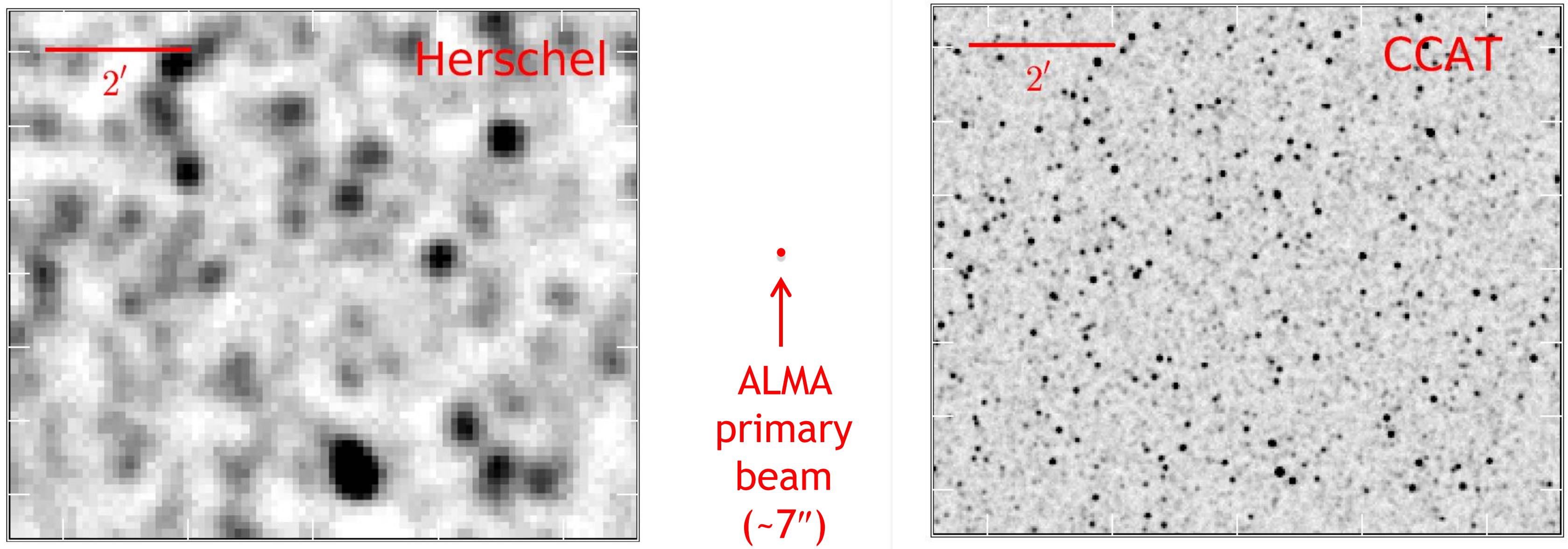
3. Angular resolution of <5" to resolve clumps out to 1kpc

4. Multi-colour imaging (including 200μm) to obtain dust temperatures and masses

5. Spectroscopic follow-up surveys of molecular lines to probe dynamics and evolution

CCAT, Herschel and ALMA

Simulated maps of the same patch of sky at 350μm based on *Herschel* number counts



Approximate F-o-V of first-light camera

- At 450μm ALMA will have approximately twice the mapping speed of CCAT *per beam*

- But with first-light camera and ~1,800 ALMA beams, CCAT's mapping speed will be ~1,000 higher

Baseline instrumentation

The initial instrument suite will likely consist of:

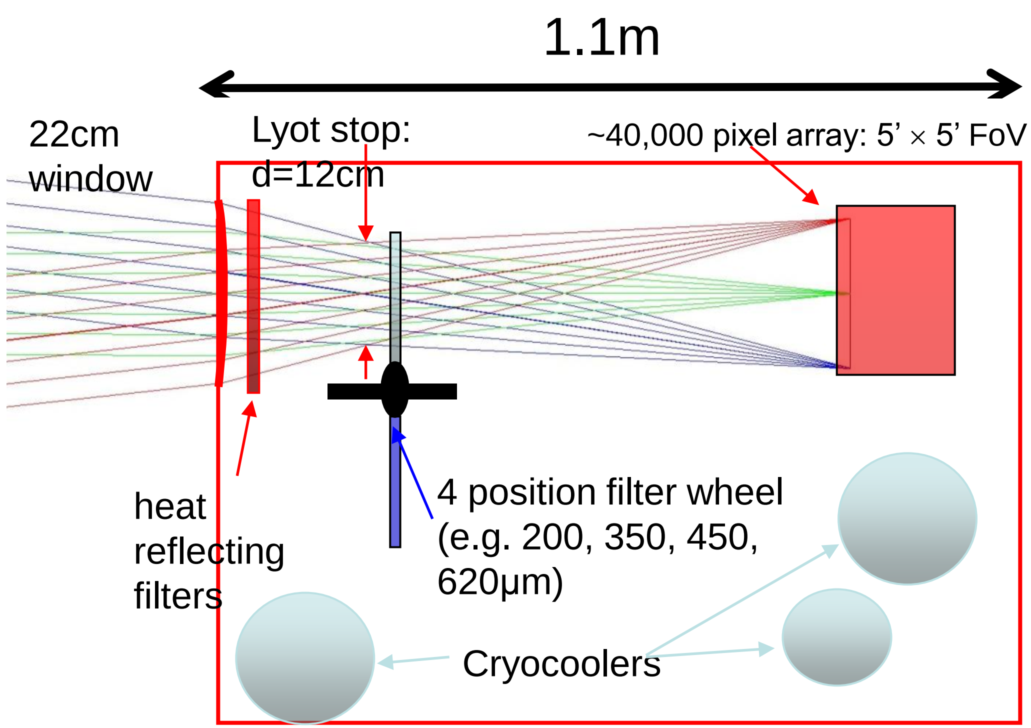
- Submillimetre-wave camera
- Near-millimetre wave camera (demonstrator at first light?)
- Multi-object direct detection spectrometer (maybe +2 years?)

Transferred and/or future instrumentation:

- Full f-o-v camera (“mega-pixel” array)
- Heterodyne spectrometers/arrays (becoming more needed?)
- Polarimeters?

Submillimetre camera (ATA)

- 40,000 pixel camera with a 25 sq-arcmin f-o-v
- Optimised for 350μm (Nyquist sampled pixels), but will work also at 200, 450, and 620μm using a filter wheel
- Current instrument is a transmissive design for compactness and minimising cost



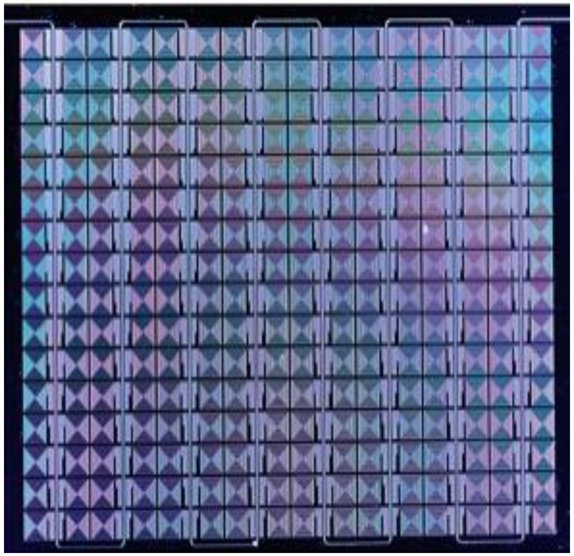
Submillimetre camera (ATA)

- Current thinking is that 40,000 pixels is a reasonable goal on a 2018 timeframe (30′ field would need a million pixels…)

- Submm MKID devices are the preferred detectors – readily scalable to large arrays and less complex readout electronics (and less cost!)

- Per-detector NEFDs at 350μm of around 20 mJy (1-σ, 1 sec)

- Being led by Cornell, JPL and Colorado

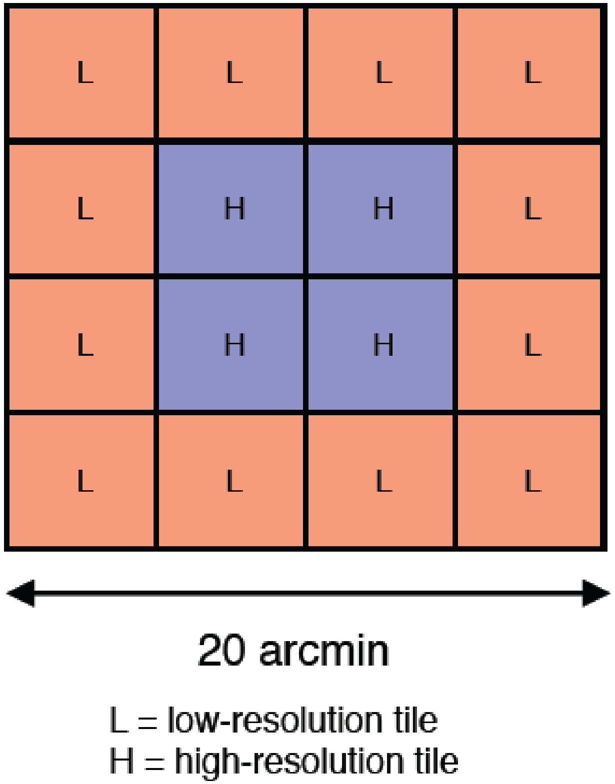


16×16 array of TiN spiral lumped-element pixels 256 pixels coupled to one feedline visible at the top and bottom (courtesy: JPL)

Near-millimetre camera

- 50,000 pixel dual-band camera with a 400-sq-arcmin f-o-v
- 18k pixels for 750μm to 4k at 2mm with varying pixel sizes

- Focal plane layout is split into tiles – with H tiles having 4096 pixels whilst L tiles 256
- 18k pixels for 750μm to 4k at 2mm with varying pixel sizes



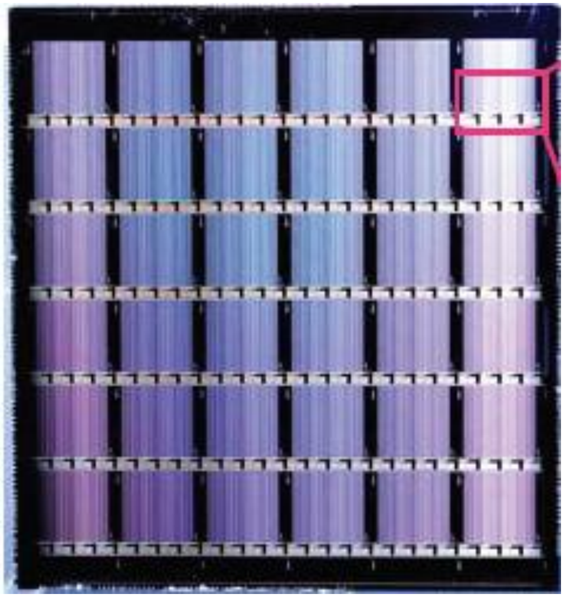
Near-millimetre camera

- Current thinking is that a tile is ~75mm across – compatible with 4” wafer processing

- Antenna coupled bolometers with MKID detectors (although TES not yet ruled out)

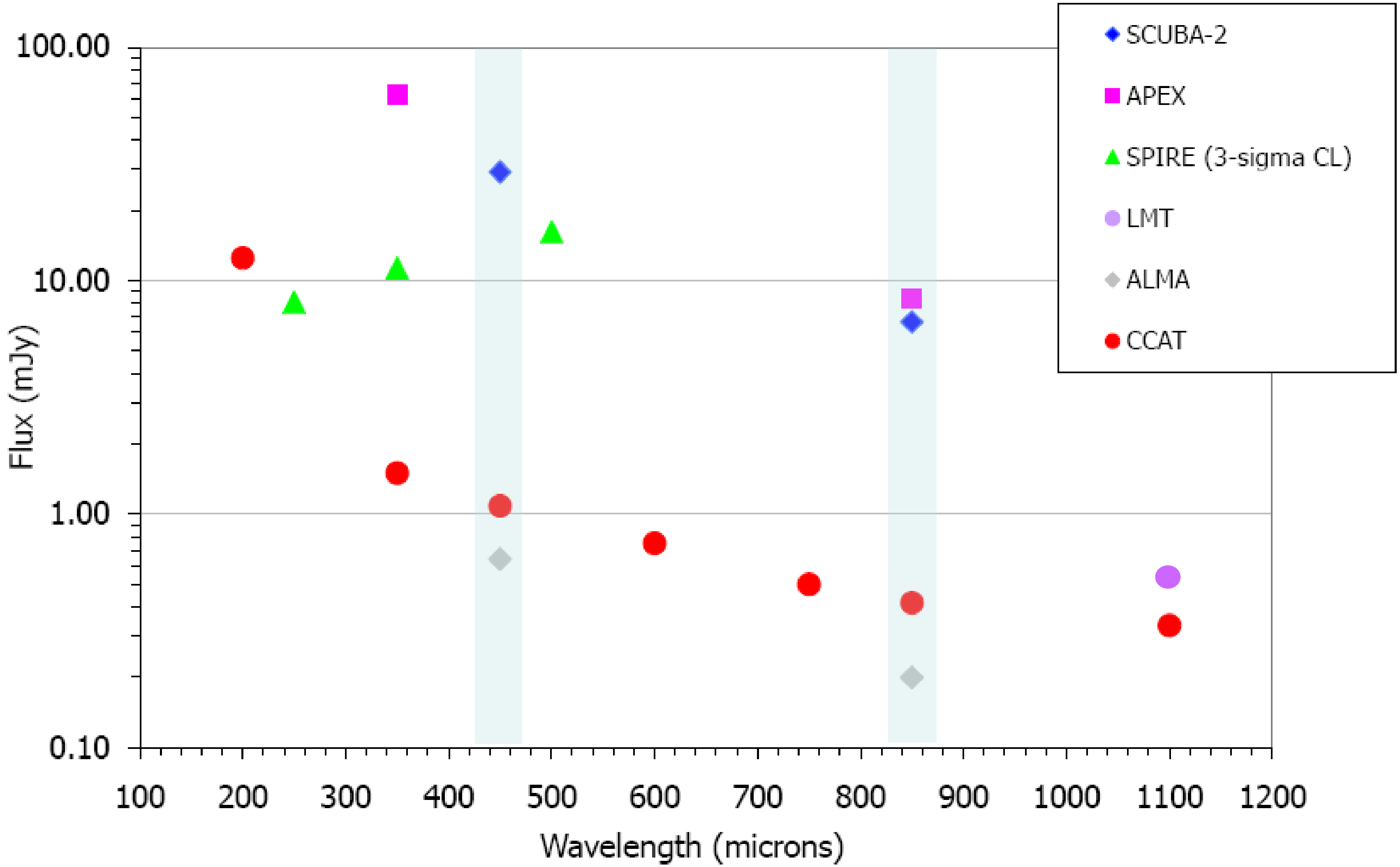
- Per-detector NEFDs at 850μm of around 7 mJy (1-σ, 1 sec)

- Being led by Caltech based on MUSIC “demonstrator” (to be tested on CSO early next year?)



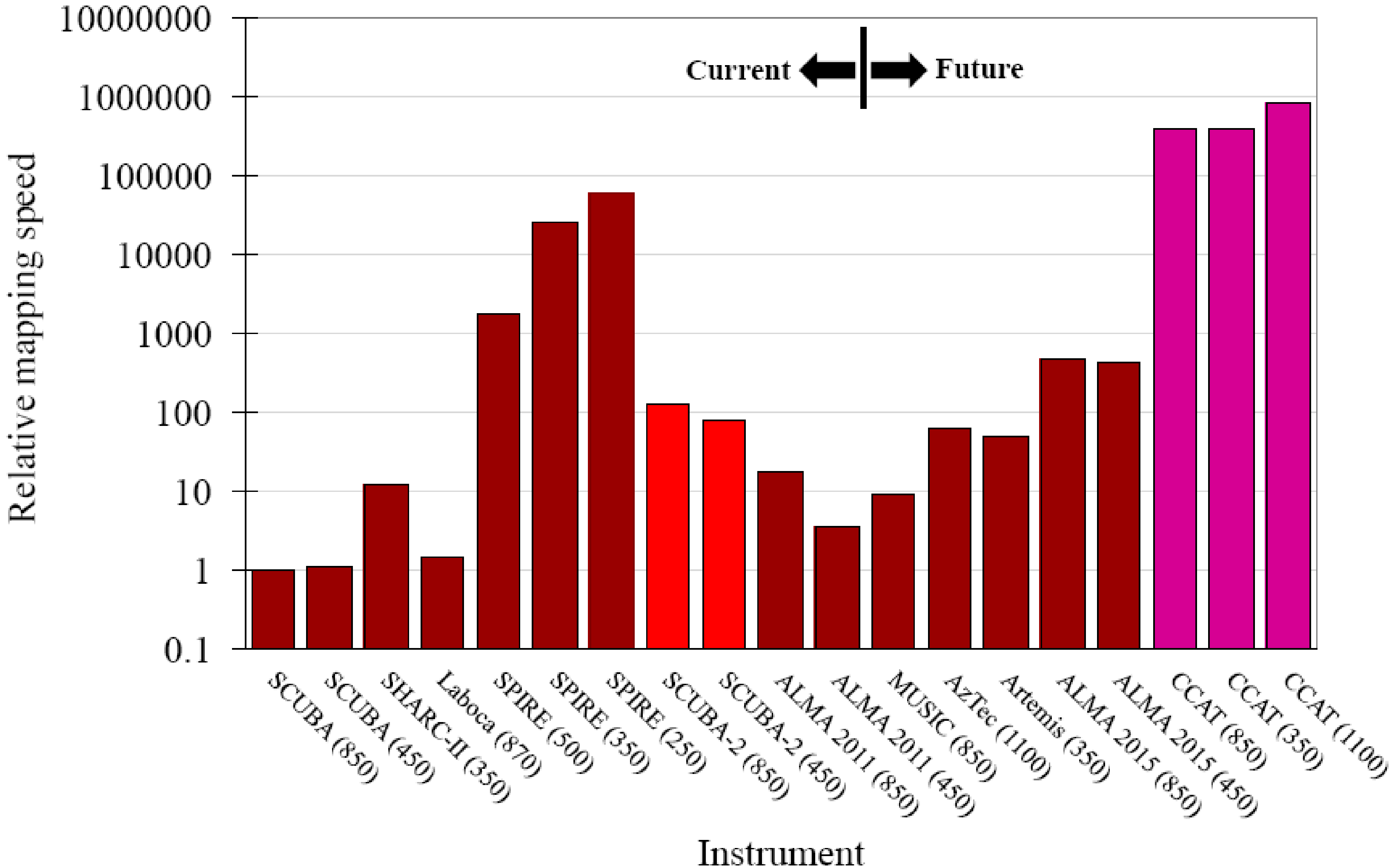
6×6 spatial pixel array as part of development of multi-pixel antenna-coupled MKIDs (courtesy: Caltech)

Sensitivity (per pixel)



5-σ, 1-hour sensitivities for various instruments

Mapping performance



- In terms of large-area mapping speed out-performs everything except space (Herschel) by factors of 1000+

Imaging cameras summary

What does this give us?

- Point source sensitivities close to ALMA and more than 10× better than SCUBA-2
- Mapping speeds some 1000–5000× faster than ALMA and SCUBA-2 to the same S/N
- Spectral coverage over 9 bands from 200μm to 2mm
- 4″ angular resolution at 350μm (up to 10″ at 1mm)
- Confusion limits more than 10× lower than Herschel/SPIRE and a few times lower than JCMT/SCUBA-2

Wide area galaxy surveys

What kind of survey is scientifically interesting?

- Let's say we need half-a-million galaxies over a range of redshifts to fully characterise the submm galaxy population
- Expect ~50,000 sources per square degree (350μm) based on 10-beam/source confusion limit, so need 10 sq-deg survey to the C-L.
- Needs ~1 hour/pixel to reach 3-σ C-L of 0.3mJy (350μm)
- 1400 hours survey or just over 100 nights to achieve (based on 12-hr night)

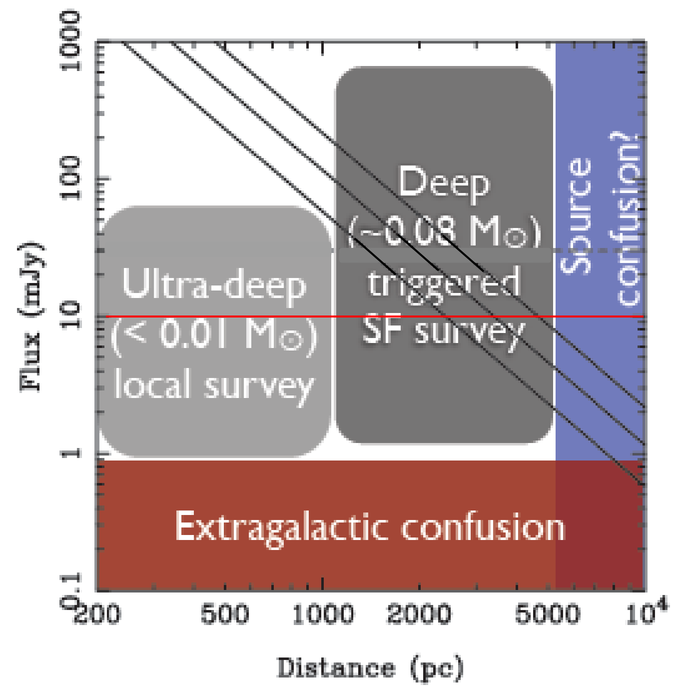
Is CCAT the only facility that can do this?

Galactic surveys

What is the parameter space for galactic surveys with CCAT?

- Let's say capitalise on the lower C-L and mass sensitivity by carrying out an ultra-deep survey of local clouds to 0.01 M_{sun}
- Assume same area of GBS (24 sq-deg to 3-σ of ~10mJy at 850) but go down to C-L of 0.7mJy – about 14× deeper…
- 70 hours survey (6 nights) would be needed (c.f. ~300 hours for imaging part of GBS)

Is CCAT the only facility that can do this?



CCAT survey parameter space as function of mass limit for 0.04, 0.08 and 0.15 solar mass core. Red line is 3-σ detection limit for JCMT Gould Belt survey (adapted from plot by M. Thompson)

Direct detection spectrometer

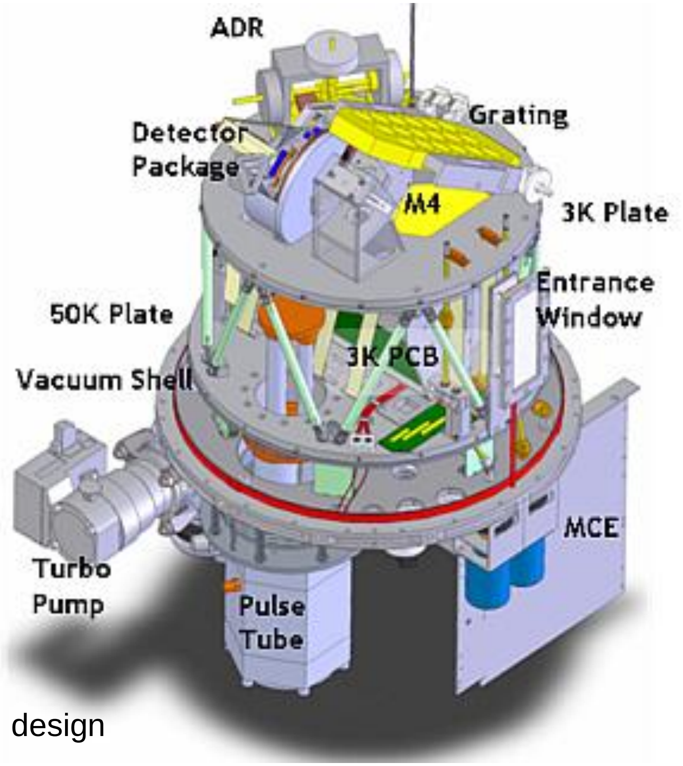
- Low order grating spectrometer being investigated to maximise point-source sensitivity (based on ZEUS-2 "free space" design)

- Other options available including FTS and Fabry-Perot designs as well as more advanced "spectrometer-on-a-chip" concepts

- Likely 4 bands between 200 and 620μm

- Spectral resolution $\lambda/\Delta\lambda \sim 1000$ optimised for detection of extragalactic lines

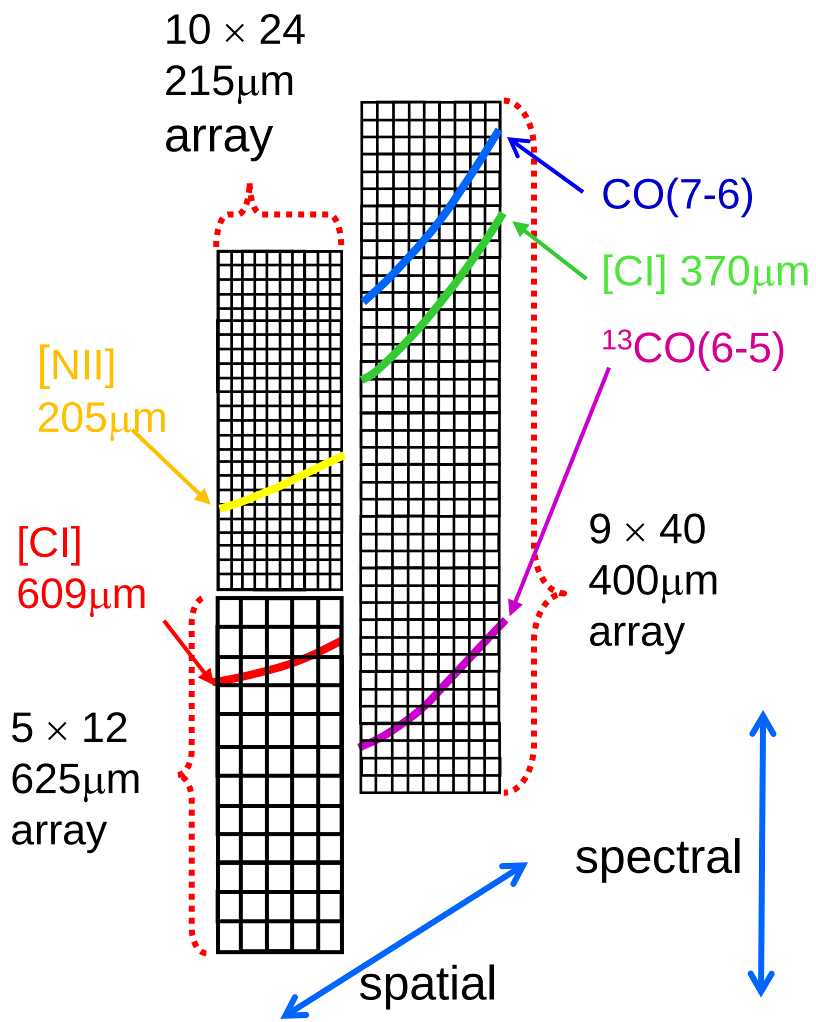
- Bandwidth of 40GHz with equivalent T_{rec} < 40K (SSB)



ZEUS-2 system design

Direct detection spectrometer

- Natural spatial multiplexing is achieved using 2-D arrays of detectors
- ZEUS-2 will use NIST TES arrays (at least to start with)
- Cornell led design (ZEUS-2 on CSO at 400μm in early 2012 and APEX later in 2012)



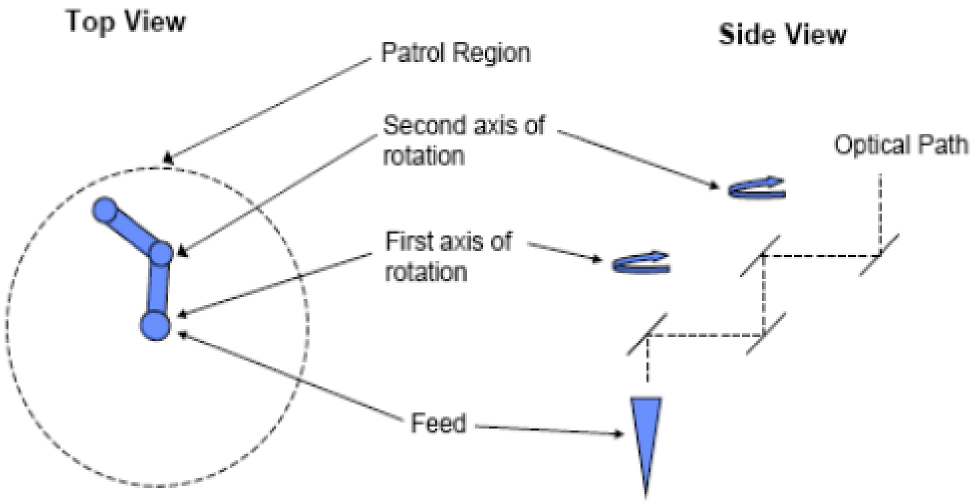
Multi-object spectrometer

- To be competitive with ALMA, CCAT needs a multi-object capability

- For example, if configure ZEUS-2 into one band (350/450μm) then useable f-o-v is ~20 beams (long slit)

- Could configure with 10 beams using a quasi-optical light pipe arrangement at the front end (other options possible)

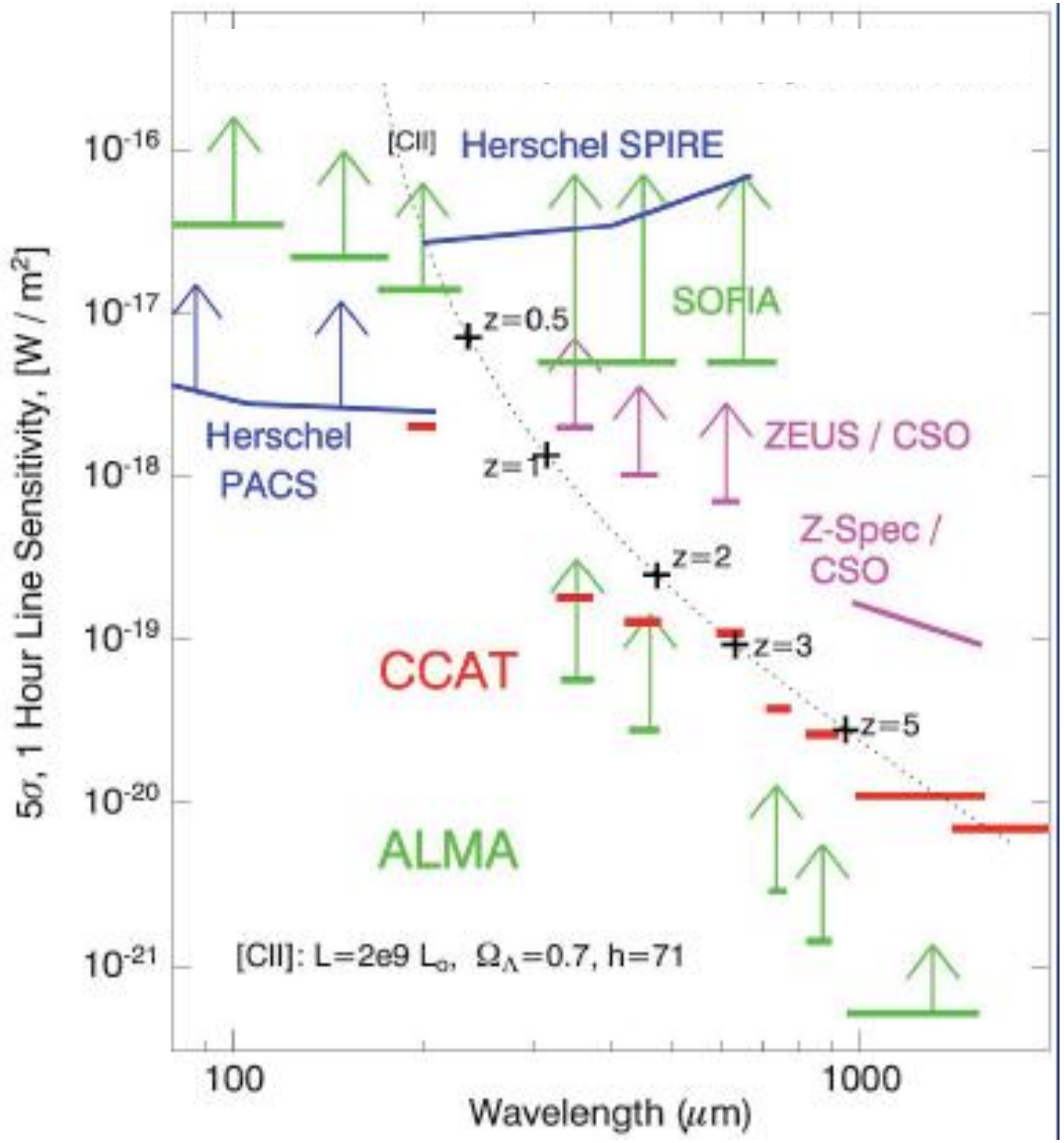
- Patrol regions over the focal plane assigned to particular arrays of detectors



Quasi-optical light pipe arrangement (Goldsmith & Seiffert)

Spectroscopic sensitivity

- CCAT is less sensitive than ALMA per spectral resolution element
- With full window bandwidth can carry out surveys with comparable speed
- Multi-object capability is the **only** way to give CCAT an advantage



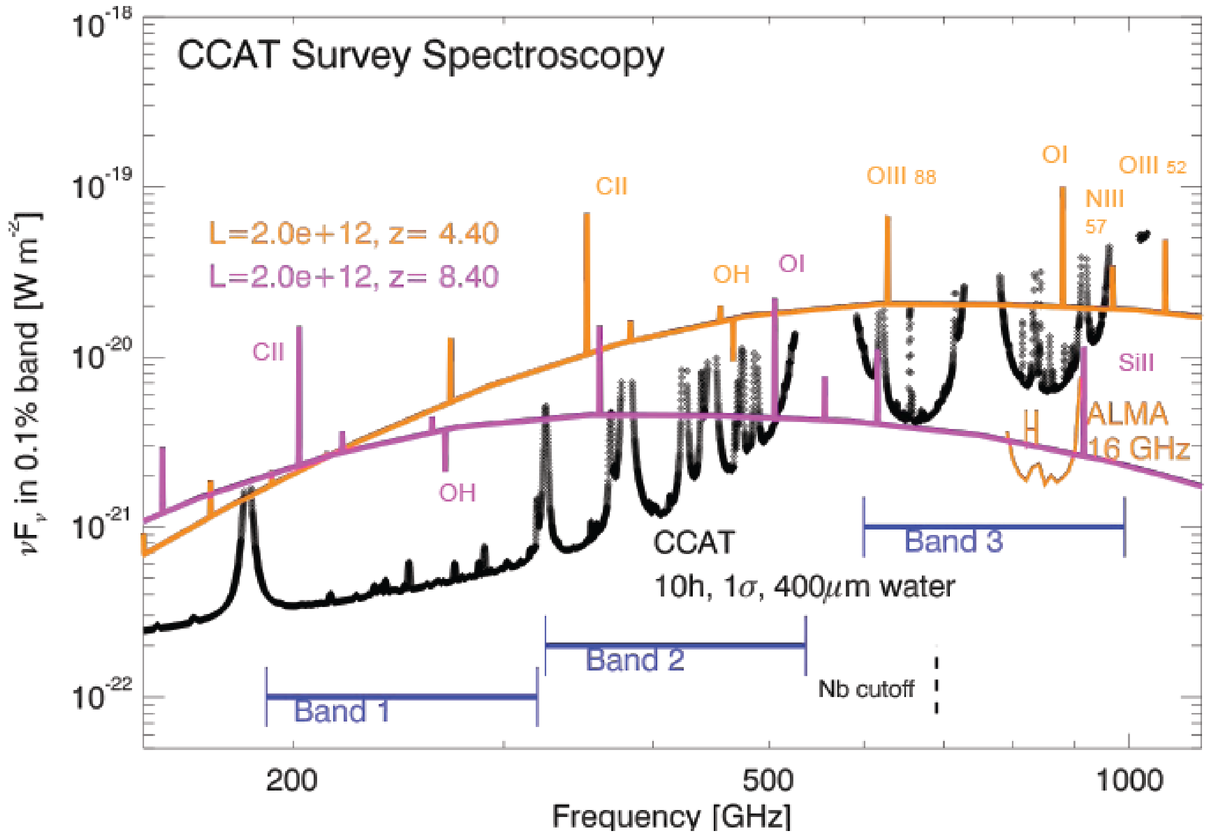
Spectroscopic applications

Why do we need a multi-object capability?

- Speed in obtaining spectroscopic red-shifts
  - capitalises on broad bandwidth to observe red-shifted spacings between CO lines (e.g. like the Z-spec instrument)
- Spectral line surveys to new sensitivity levels e.g.
  - CI line ratios → strong constraints on temperature
  - $^{13}CO(6-5)$ → strong constraints on CO opacity
  - NII → probes cooling of ionised gas
  - 158μm CII → dominant coolant of neutral ISM

Spectral line surveys

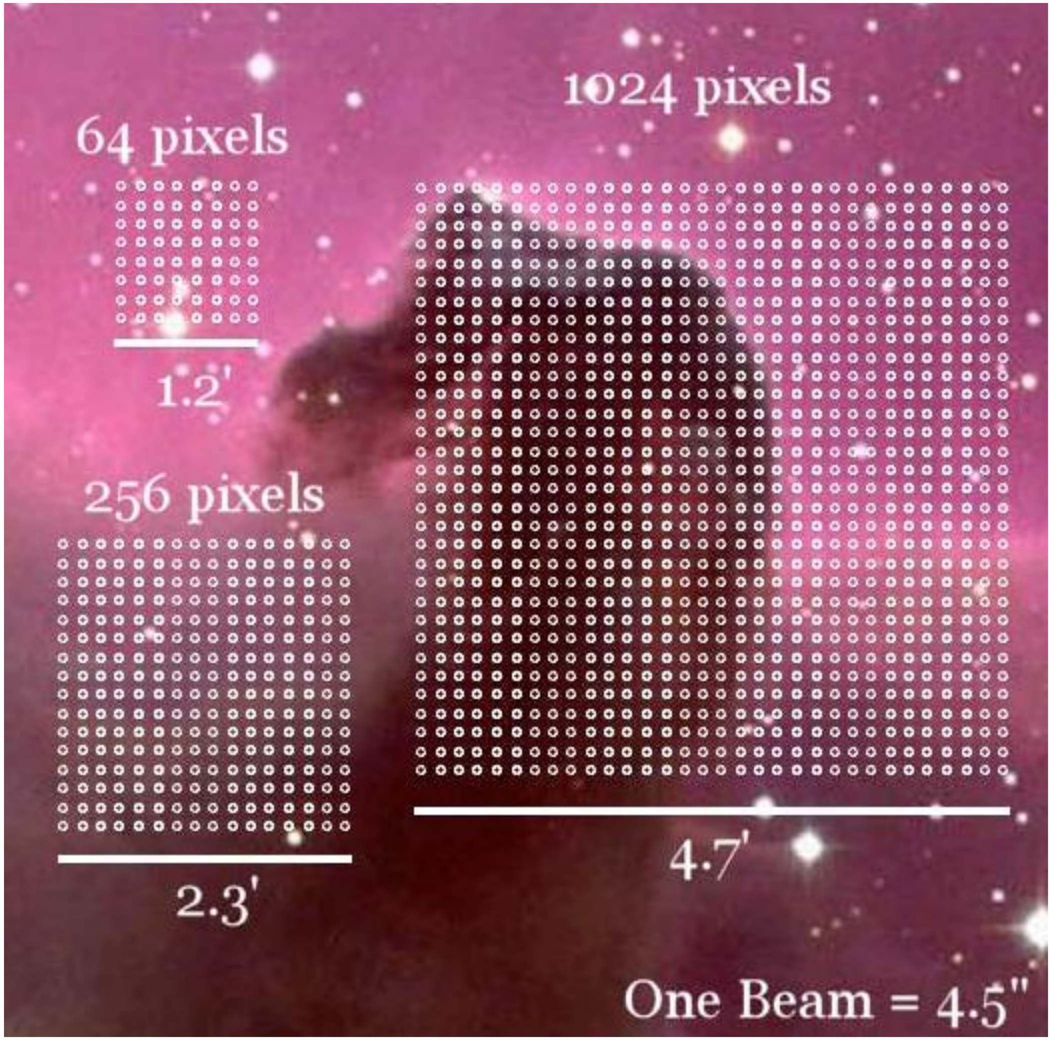
- Example wide-field survey across the submm band
- Submm fine structure lines more luminous than CO!
- Diagnostics of physical conditions of gas and radiation fields



Could have smaller, less complex separate instruments covering each of the three bands? – What really drives the complexity of submm MOS designs?

Heterodyne array camera

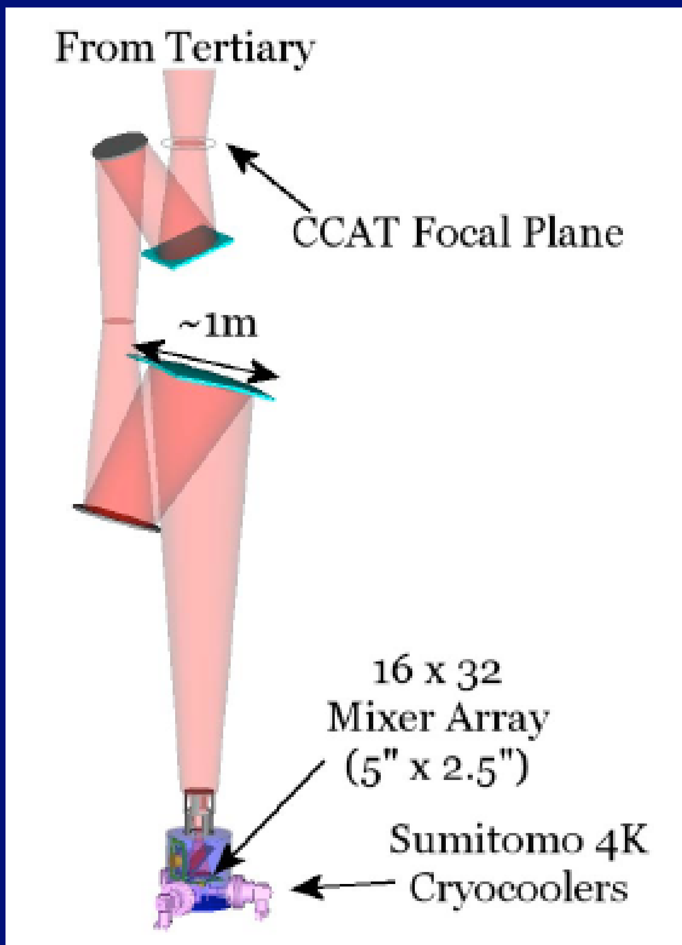
- Based on 8 × 8 channel SuperCAM for the HHT operating at 870μm
- Current 64-channel is two orders of magnitude faster than single-pixel receivers
- Key project is to obtain a fully-sampled survey of the GP in ^{12}CO(3-2) and ^{13}CO(3-2) over 500 sq-degs



Courtesy: Chris Walker

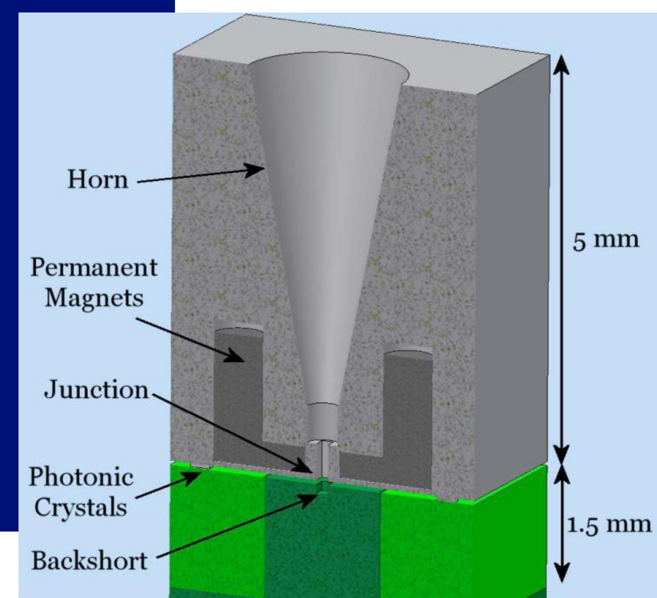
Heterodyne camera

Kilo-Pixel Heterodyne Camera for CCAT: KCAM

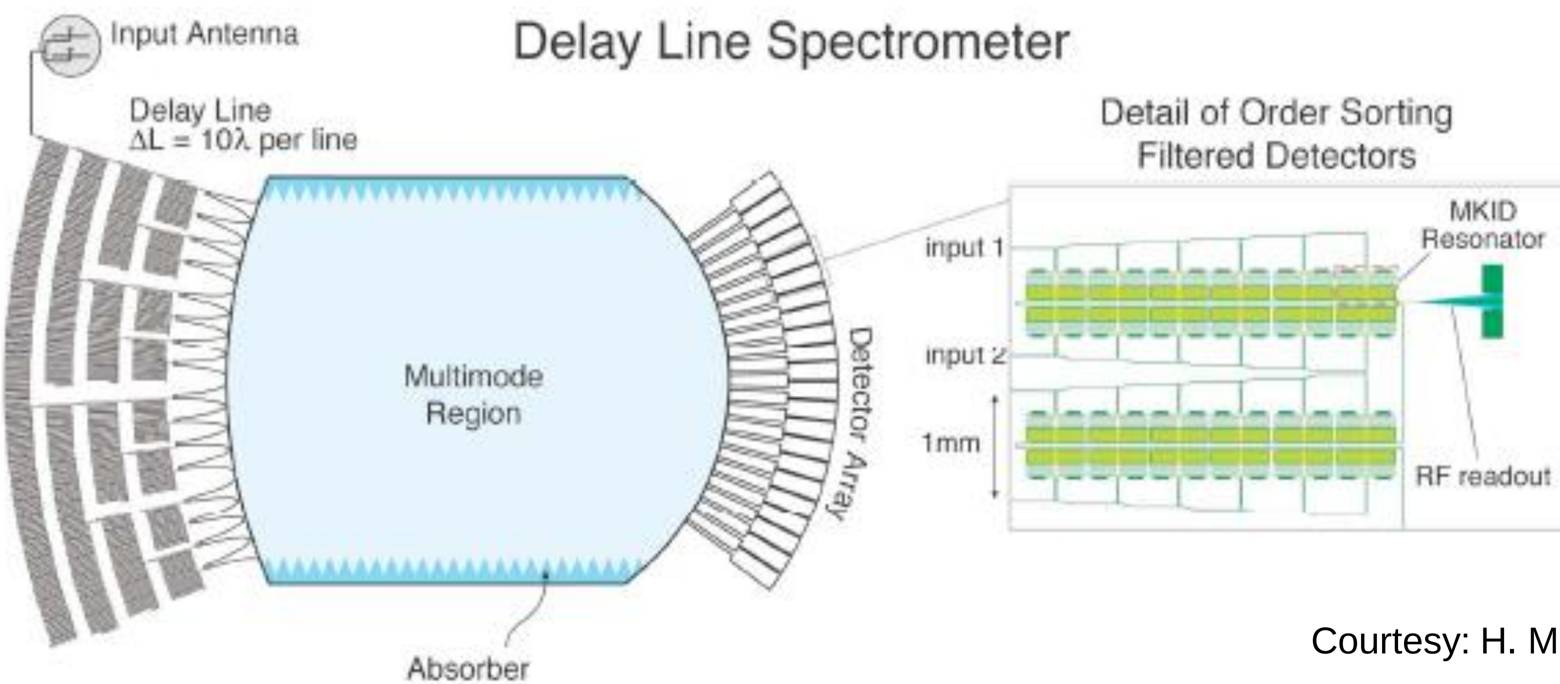


- Stacked,16x8 arrays
- MMIC IF modules
- On-board IF processor
- Solid-State LOs (~5mW)
- >2 GHz/per pixel
- Cryo-Coolers

- Stacked pixel concept



Compact integrated spectrometers



Courtesy: H. Moseley

- μ-spec design uses delay lines to give phase delay for R~1000 spectroscopy
- Can be fabricated on a single 10cm wafer and can produce diffraction-limited images across the focal plane
- Synthetic grating operates in high order (~10) and compact filter banks (right) separate the orders and direct them to individual detectors

Some possible (random) questions…

CCAT

- Should 350μm be the workhorse wavelength? Does the case for 200μm (is there a strong one?) drive the dish surface or is it a bonus?

- How many sources do we need for extragalactic science goals? Drives the f-o-v and sensitivity of the submm camera.

- Is mapping galactic SF regions with 4″ angular resolution in the era post Herschel (and after 3-4 years of full ALMA) useful?

- Case for spectroscopy? Case may be strong but technical feasibility of a MOS with >20 channels? Grating versus FTS – still not a clear choice?

- Would an image slicing IFU be better in crowded (galactic) fields be more use? (has to have a big f-o-v though and diffraction effects?!…)

- Galactic plane surveys not worthwhile since all science has (or will have) been done?! But note much lower confusion – heterodyne array?