CCAT Instrumentation: SW-Cam

Gordon Stacey representing the instrumentation group and ATACamera Team

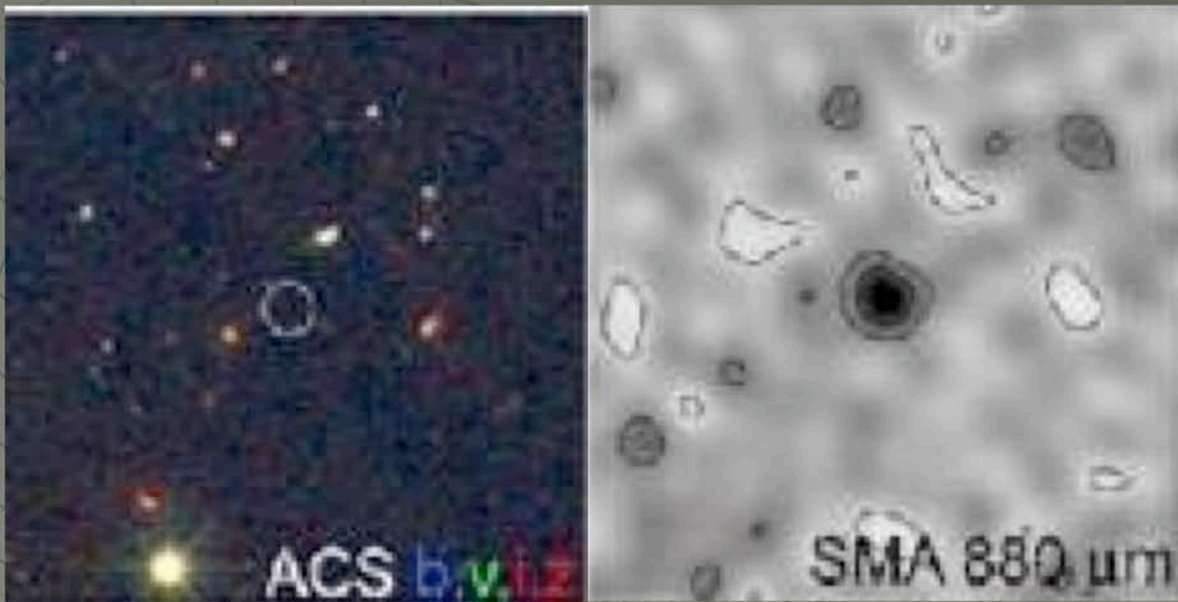
CCAT

Summary

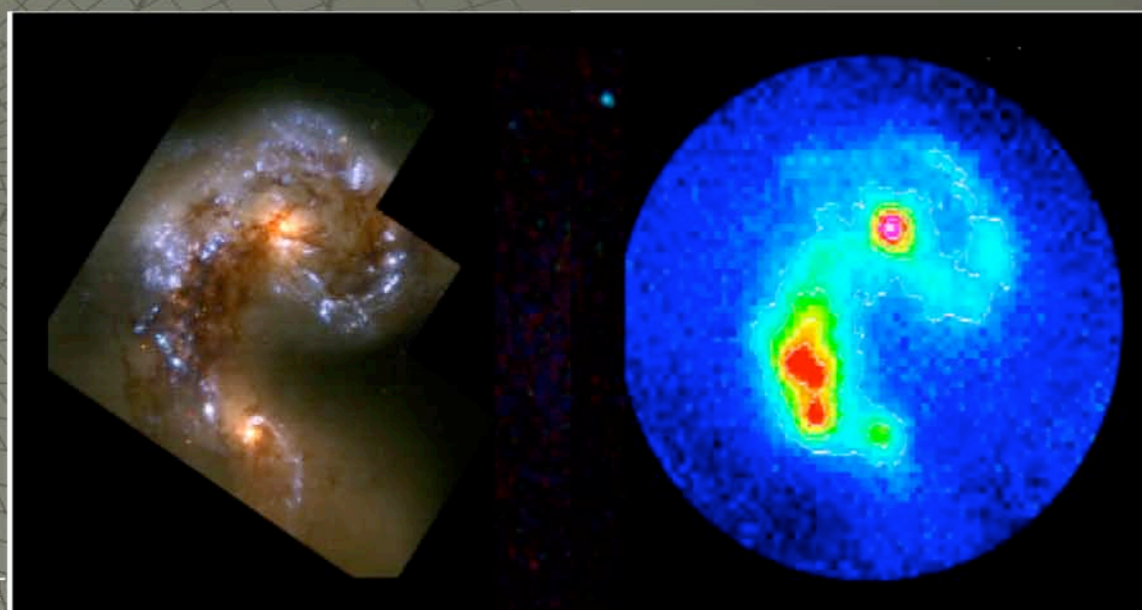
- We envision a > 50,000 pixel first light submm camera at first light
- Primary band is 350 μm ~ 40,000 pixels ⇔ 5' FoV
  - Filter wheel to access 450, 620, (200) μm
- Dichroic splits off a long wavelength 850 μm band
  - Or perhaps more likely, a second camera for 740 and longer wavelengths
  - At least 10,000 pixels
- Advanced Technology Array Camera

ATACamera

The Universe is Dusty

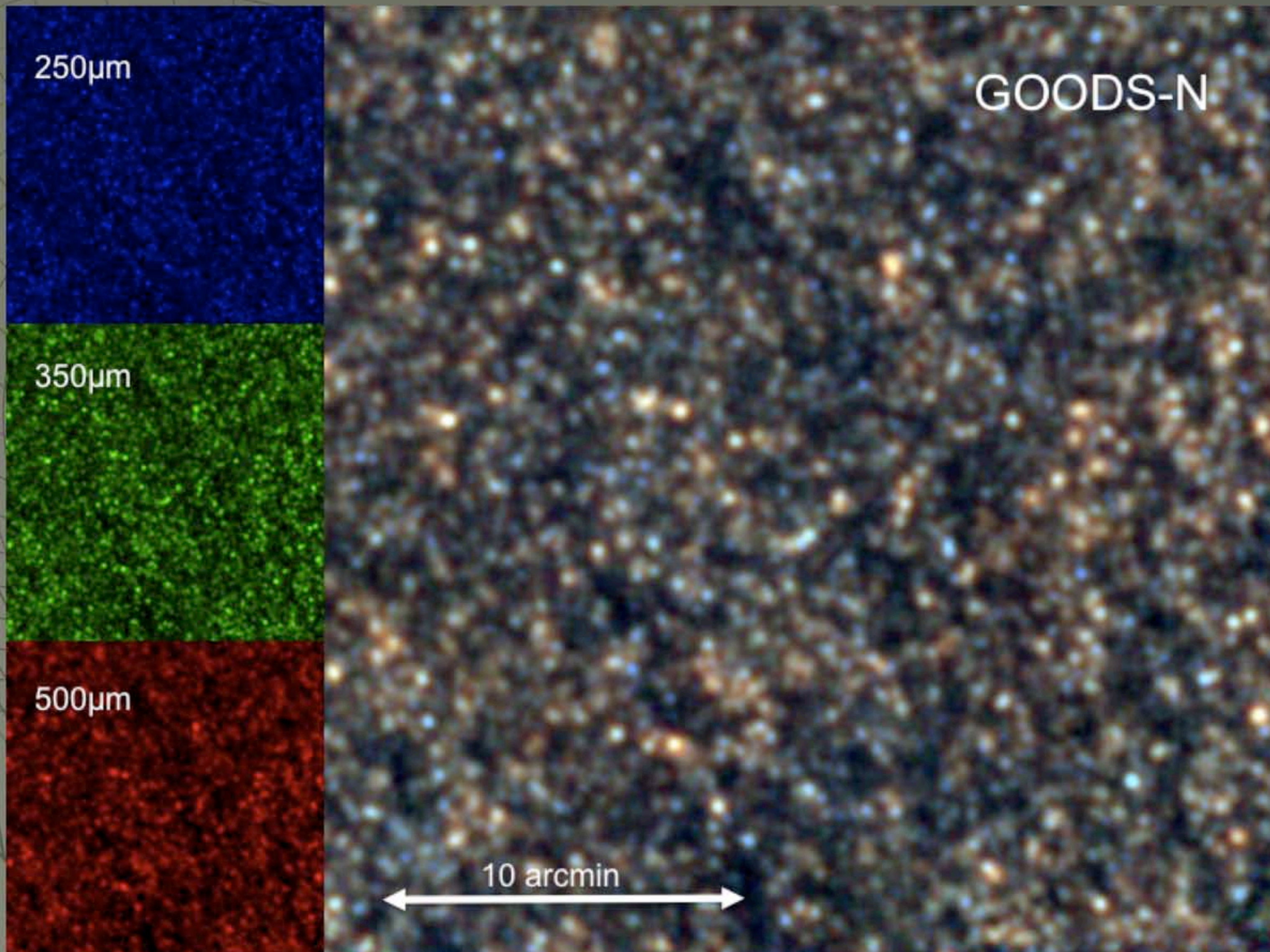


Goods 850-5 (z=4.1) in optical (Hubble, left) and submm (SMA, right)

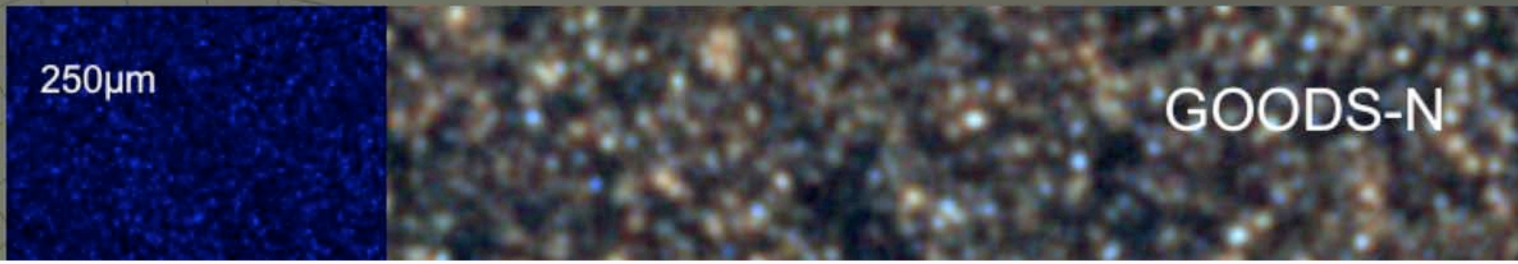


Antenna Optical (Hubble, left) and submm (SHARC/CSO, right)

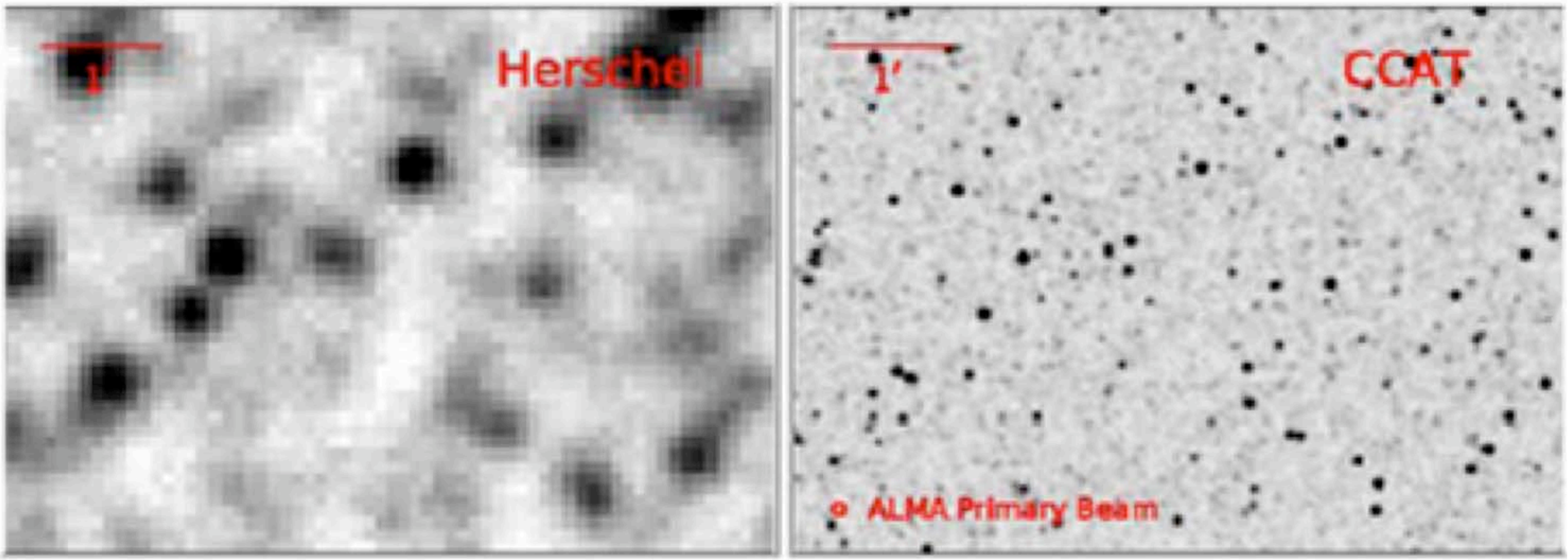
The Universe is Confused

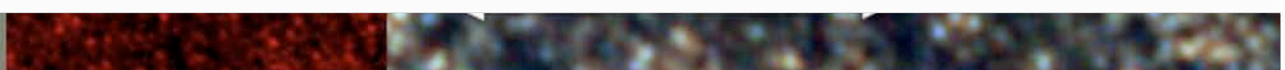


The Universe is Confused



350 μm





P. Maloney

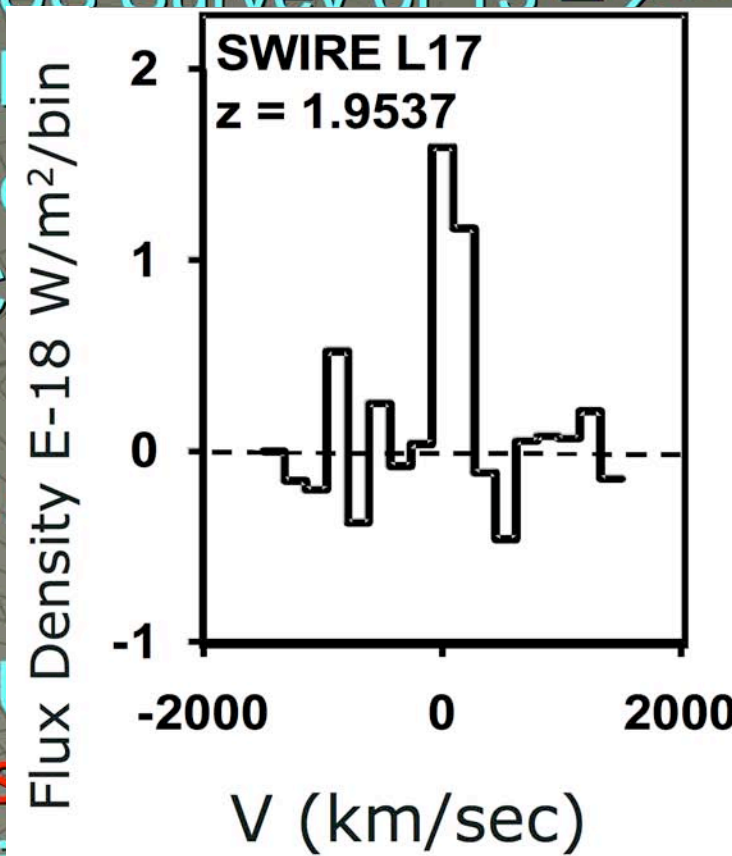
Confusion ⇒ [CII] = FIR Continuum Detection Limits

- ZEUS Survey of 13 – z ~ 1 to 2 galaxies shows [CII]/FIR continuum ~ 0.2%
- Line/continuum ~ 10:1
- CCAT: 1 mJy ⇒ 10 mJy in line × 1.9 THz/1000

  or 1.9×10^{-19} W/m^2 – easily detectable (10σ /4hrs) with ZEUS – like spectrometers on CCAT
- ZEUS NOW on CSO/APEX can detect (*and has detected*) > 10 or 20 σ/4 hrs **confusion** limited Herschel sources
- See talk by T. Nikola – 1:40 Saturday

Confusion ⇒ [CII] = FIR Continuum Detection Limits

- ZEUS Survey of 13 – z ~ 1 to 2 galaxies shows [CI… %
- Lin…
- CC… n line × 1.9 THz/1000
  or…



ZEUS/CSO

$F_{[CII]} \sim 2\times10^{-18}$ W/m²
$F_{350\ um} \sim 30$ mJy

- ZE… EX can detect (*and has*… σ/4 hrs **confusion** limited Herschel sources
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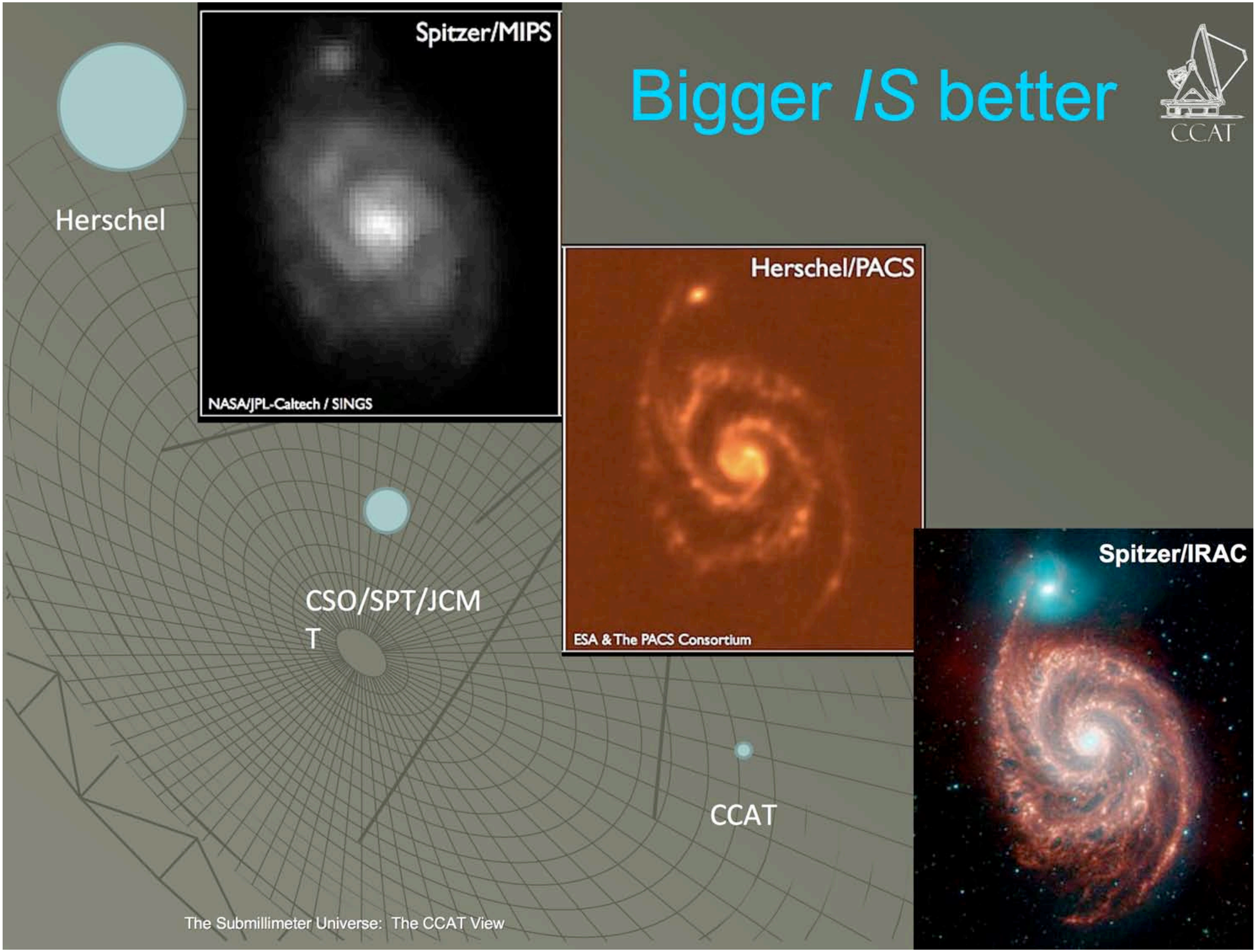
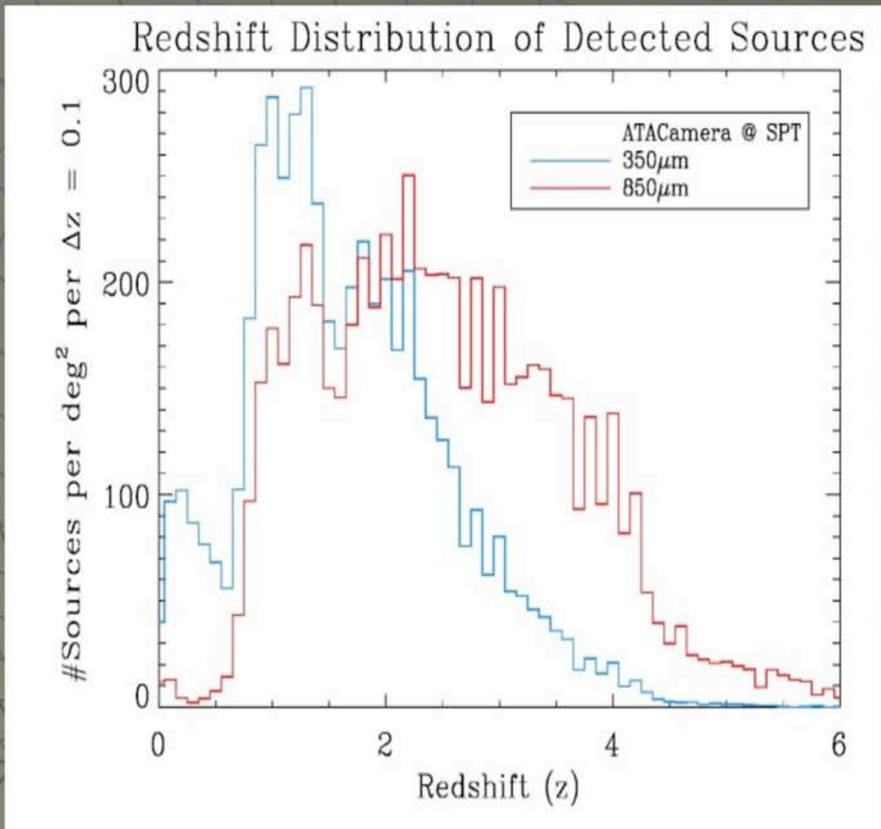
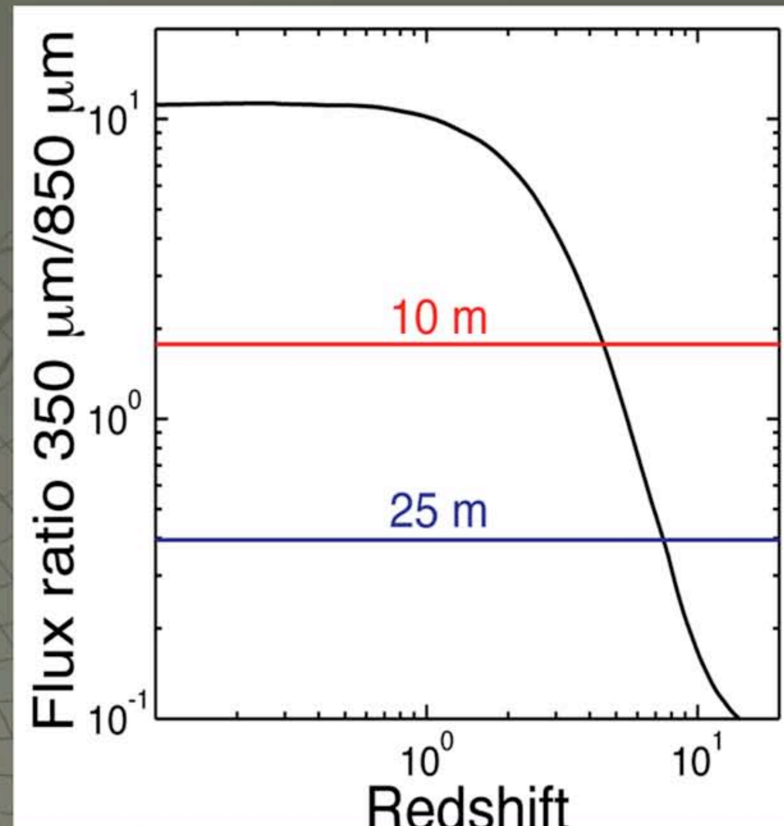

Bigger *IS* better
CCAT
Herschel
Spitzer/MIPS
NASA/JPL-Caltech / SINGS
Herschel/PACS
ESA & The PACS Consortium
Spitzer/IRAC
CSO/SPT/JCM
T
CCAT
The Submillimeter Universe: The CCAT View

Most Distant is Better Still...

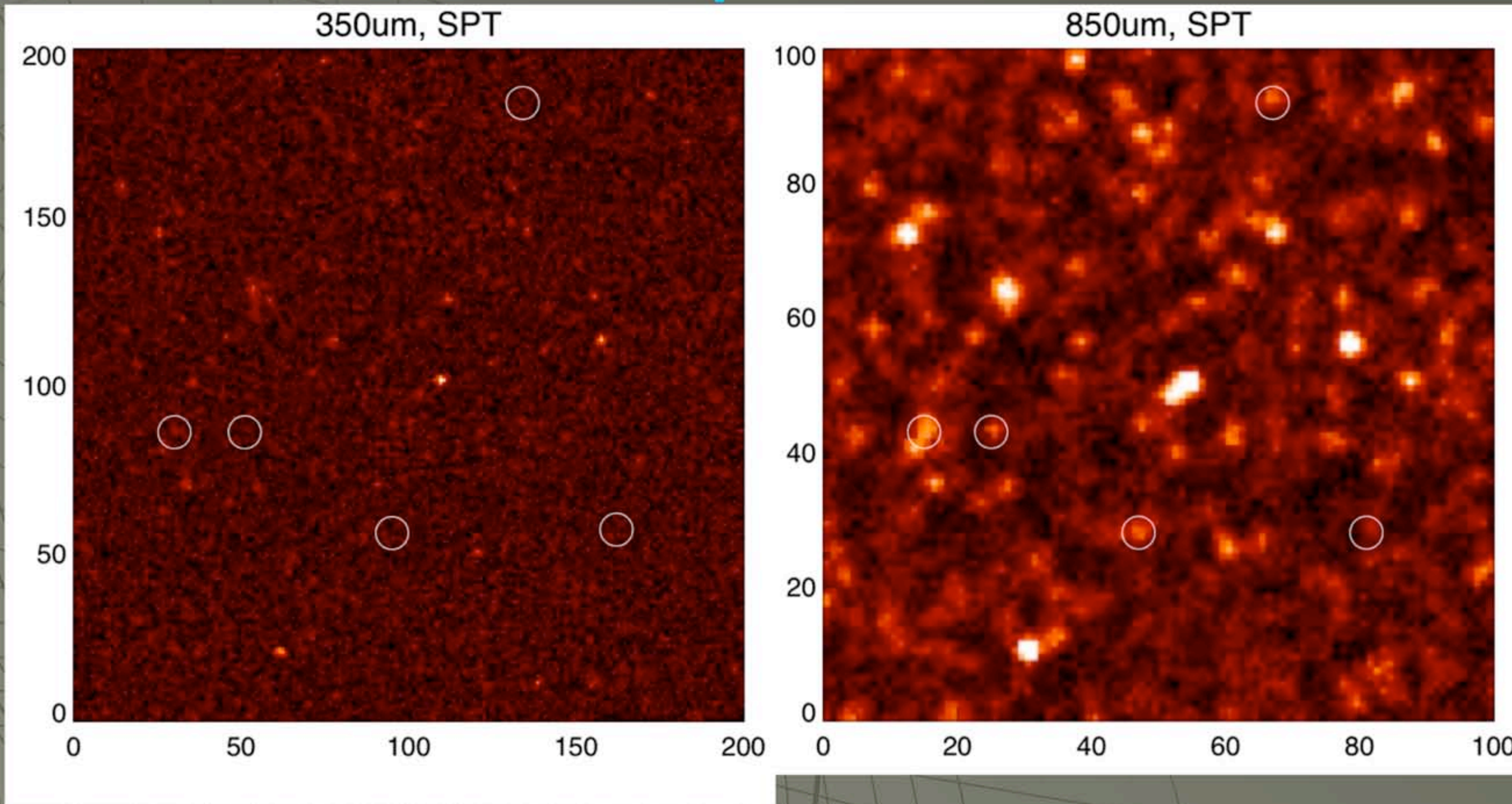




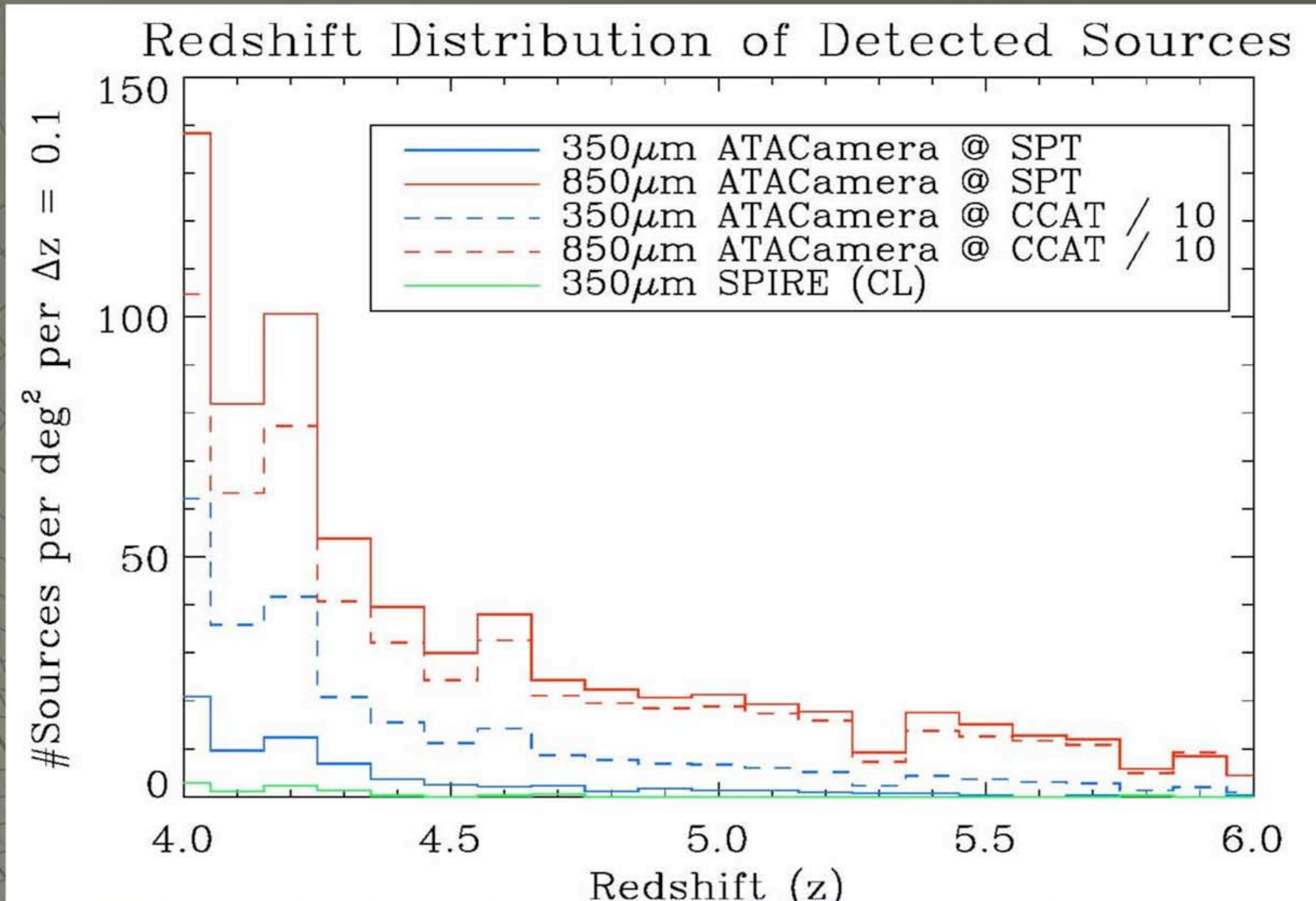
Redshift distribution of sources for ATACamera on SPT at 350 and 850 μm.

350/850 μm flux density ratio for a $10^{12} L_{\odot}$ galaxy as a function of redshift.

To find the distant ones, look for drop-outs



- Simulated ATACamera on SPT at 350 and 850 μm – 4 hours/pixel
- Circled sources: >5 σ detections at 850 μm that drop out at 350 μm
- There are the 85 ~350 μm drop-outs in the image.



- Predicted high z galaxies (4 hr/field)
- Confusion severely limits the Herschel/SPIRE
- CCAT ~ $200/(°)^2$ -- thousands/Δz/year

Baselined CCAT Instrumentation

- Three Primary Science Instruments
  - Submillimeter wave camera
  - Near millimeter wave camera –Sunil Golwala
  - Multi-object direct detection spectrometer
    - Z-spec – Matt Bradford
    - ZEUS/ZEUS-2 – Thomas Nikola
  - Transferred, and future instrumentation
    - Full FoV cameras
    - Heterodyne spectrometers/arrays

Submm Camera Decision Tree – Field of View

- The telescope delivers up to 1º FOV – why are we designing to a 5' FOV?
  - Science: Initial science deliverable with 5' FOV cameras
  - Image Scale: The telescope delivers a ~3 m image for a 1º FOV – this is quite challenging to couple into a background limited camera ⇒ smaller sub-systems
  - Technology: Current/near future technology suggests 32,000 pixels is a reasonable goal – this delivers Nyquist sampled images over a 5' × 5' FOV at 350 μm
    - tiling a 30' FOV requires ***one million pixels*** at 350 um, -- extremely expensive using today's technologies
    - Future developments will greatly reduce the costs – therefore mega pixel cameras are postponed

Two Designs Considered

- All reflective design
  - Maximizes throughput
  - Minimizes emissivity
  - Off-axis approach leads to BIG (3-4 m class) optics -- but 5' FoV design not too bad…
- Transmissive design
  - Nice, compact design
  - Throughput and emissivity quite good
- Direct imaging
  - Would be fine at 200 um, over-sampled at longer wavelengths
  - Problems with stray light…

Transmissive Optics

- System is much more compact
  - Instrument is then only ~0.7 × 1.1 m in size, with a 25 cm dewar window
  - However, selection of lens material is an issue – bulk absorption hurts both with transmission, and emission
- A variety of materials that will work (e.g. PE, Quartz, Sapphire, Silicon, Germanium)
- Selected Silicon primarily due to its small extinction coefficient

Lens Materials Considered

CCAT

Material	Index	Extinction Coefficient	Radius of Curvature (cm)	Thick-ness (cm)	Trans-mission
Polyethylene	1.506	0.126	50.6	10.3	69%
Sapphire	3.2	0.91	220	2.13	38%
Fused silica	1.81	0.179	81	6.0	59%
Quartz	2.113	0.089	111	4.28	83%
Germanium	4.006	0.073	300	1.56	**93%**
Silicon	3.416	0.040	242	1.94	**96%**

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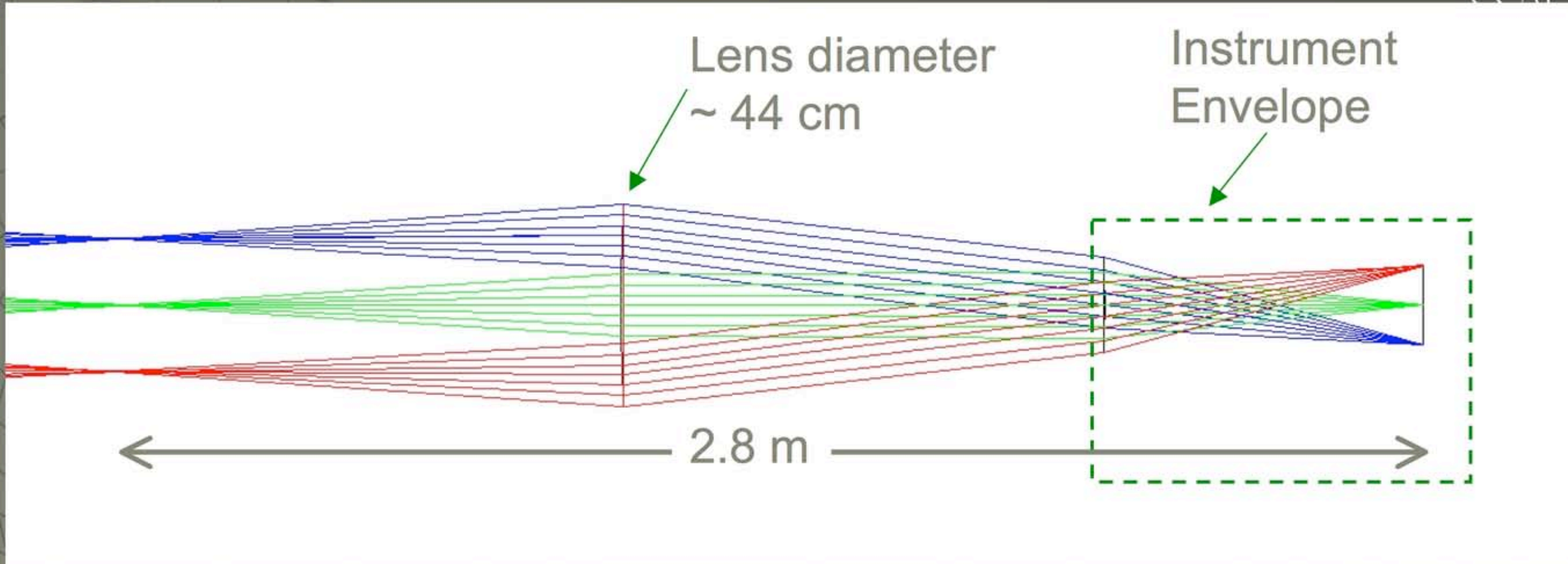
Next Generation likely lenses made from meta-materials – tunable for low loss, high transmission

Cardiff

Transmissive Optics

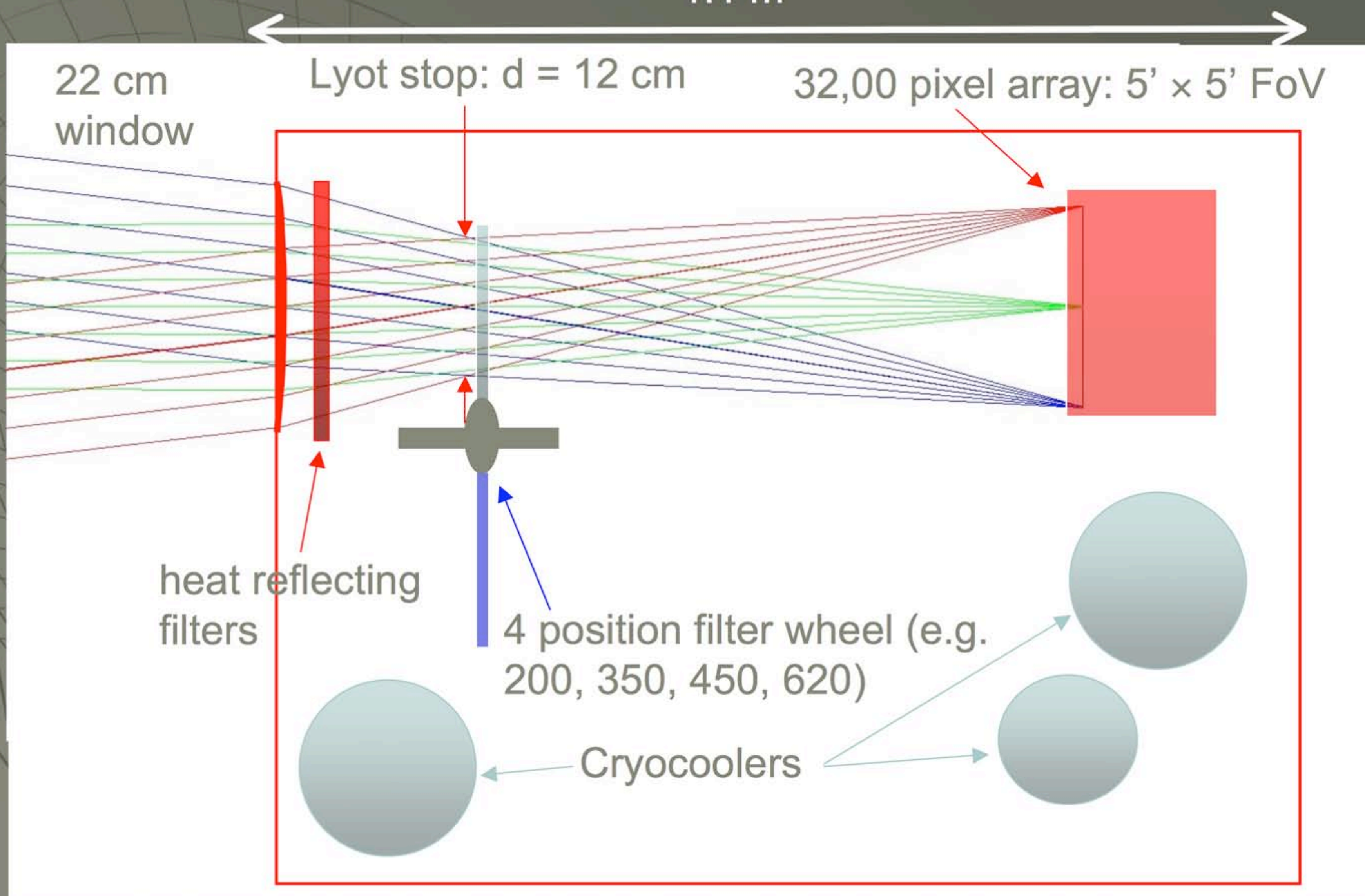
- Other important selection criteria
  - Material properties – environmental (H_2O), structural (window)
  - Cost and availability
  - AR coating
- Design is based on Silicon lenses.
  - Broad band (200 to 650 um) A/R coating achieved by tapering the index of the surface
    - Micro-machine pyramid-like structures
    - Under investigation at Caltech/JPL (Golwala)
  - These A/R coatings ⇒ transmissions > 90%

Silicon Lens Design: 5' FOV

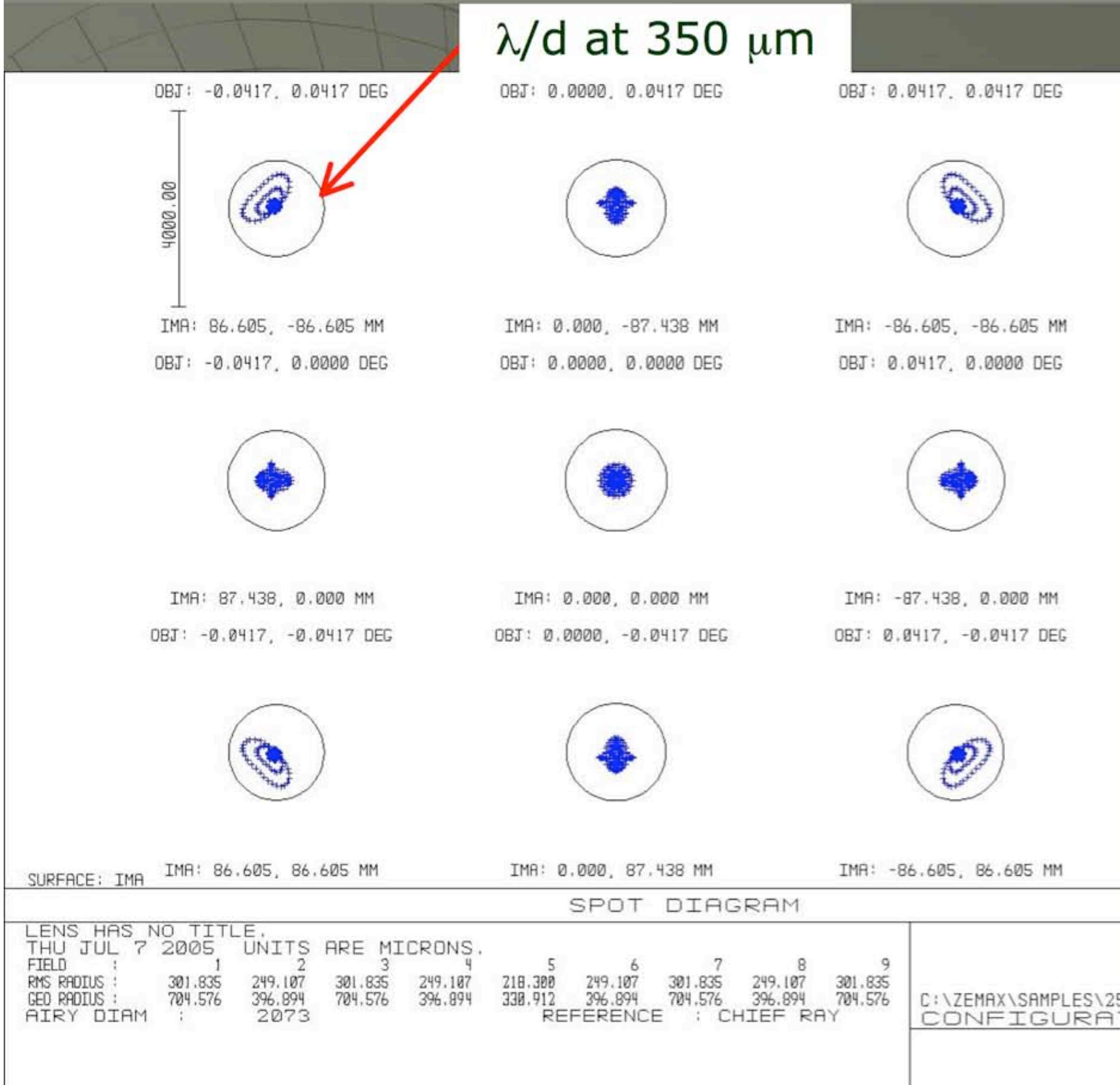


- 44 cm diameter first lens collimates telescopes f/8 beam at 13.5 cm
- Beam is transferred to a 22 cm diameter lens near the pupil which reimages to f/4.8 onto 1 mm square pixels (Nyquist sampled at 350 μm)
- Second lens serves as the dewar window (>1 cm thick)

The Dewar


1.1 m
22 cm window
Lyot stop: d = 12 cm
32,00 pixel array: 5’ × 5’ FoV
heat reflecting filters
4 position filter wheel (e.g. 200, 350, 450, 620)
Cryocoolers

Silicon Lens Design: 5’ FOV

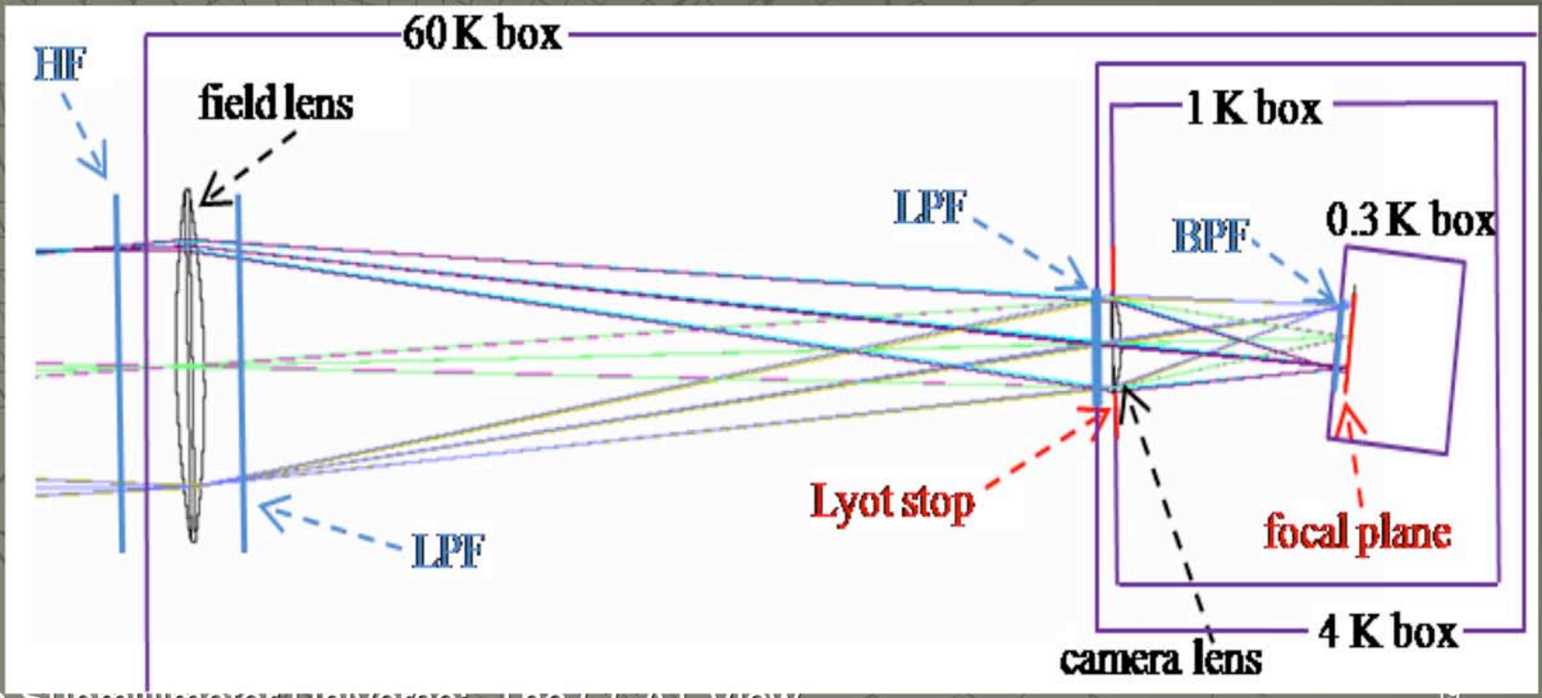


CCAT

- Spot diagram is *excellent* – circle is λ /d at 350 μm
- Image plane is curved so can do better with curved focal plane
- *ISSUE* with this system is the large collimating lens
  - Availability
  - Warm?

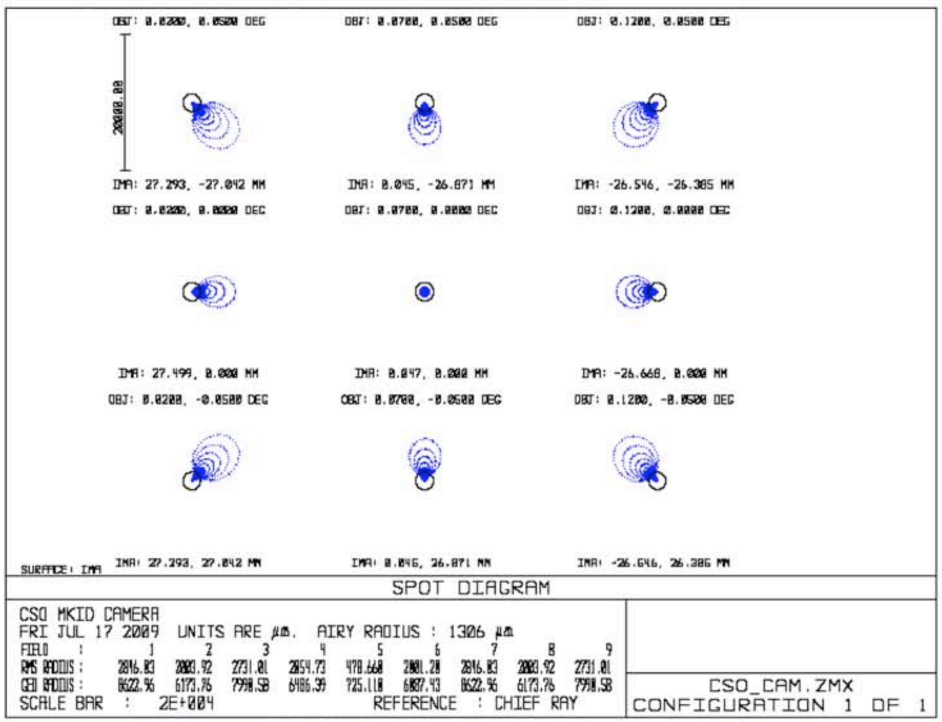
ATACamera

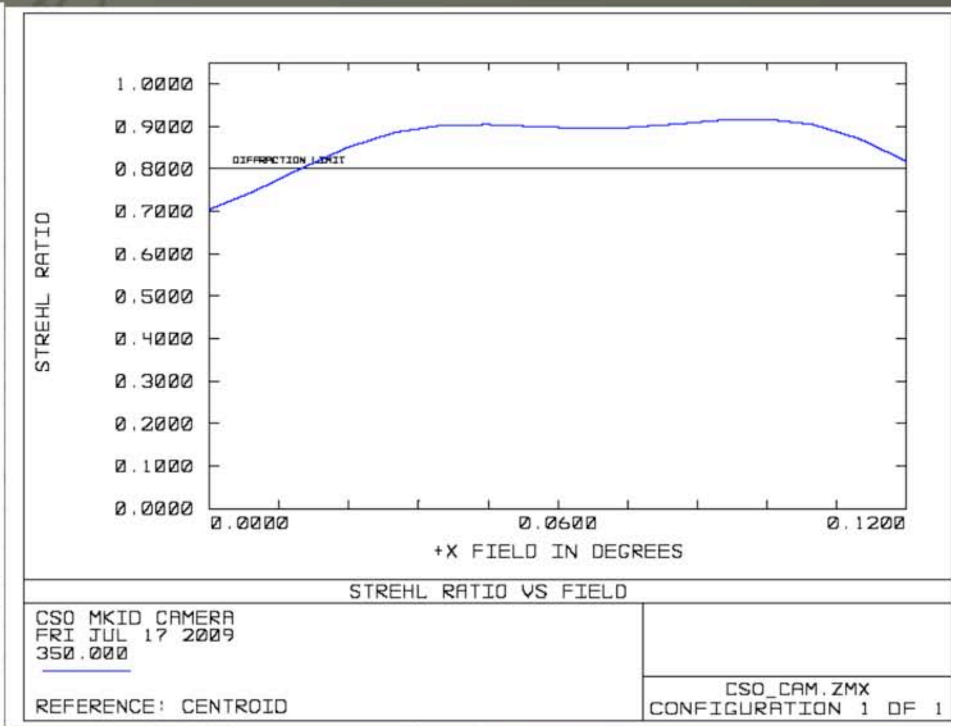
- Cornell – Caltech – Colorado collaboration
- First light camera composed of sub-cameras
- Dichroic 5' field of view on CCAT
  - 40,000 pixel at 350 μm and 10,000 pixels at 850 μm
- FoV broken into 3 – 3' "sub" fields (128×128): aberrations, window
-



Ray-trace

- Spot sizes quite good – circles are Airy disk
- Sub-cameras have Strehl ratios > 90 over nearly entire FoV (centered at angle of 0.07°)





Detectors

- Preliminary Design baselined TES sensed SQUID multiplexed arrays (SCUBA-2)
- Workable, within budgets for 40,000 pixel camera
- Submm MKID devices are now preferred option
  - Considerably less complex architecture
  - Considerably less complex read-out electronics

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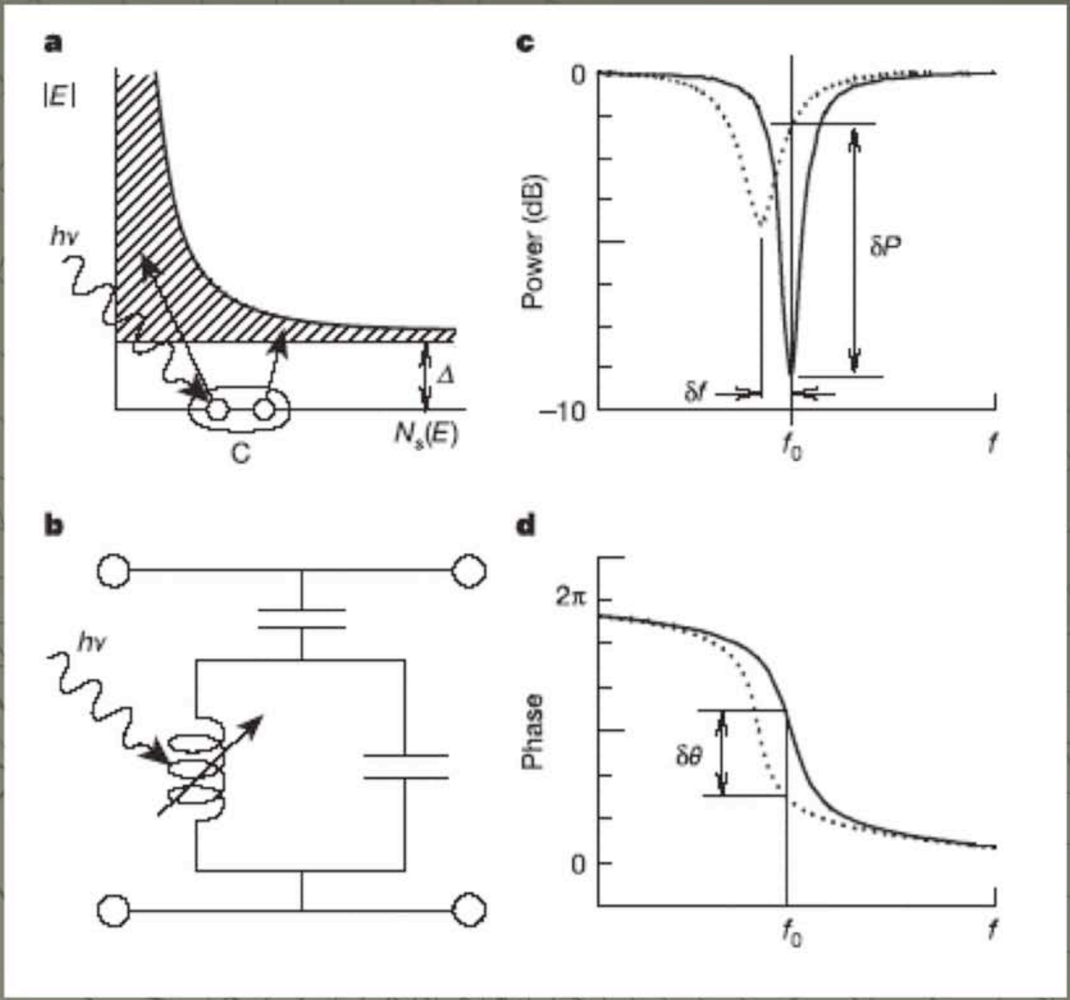
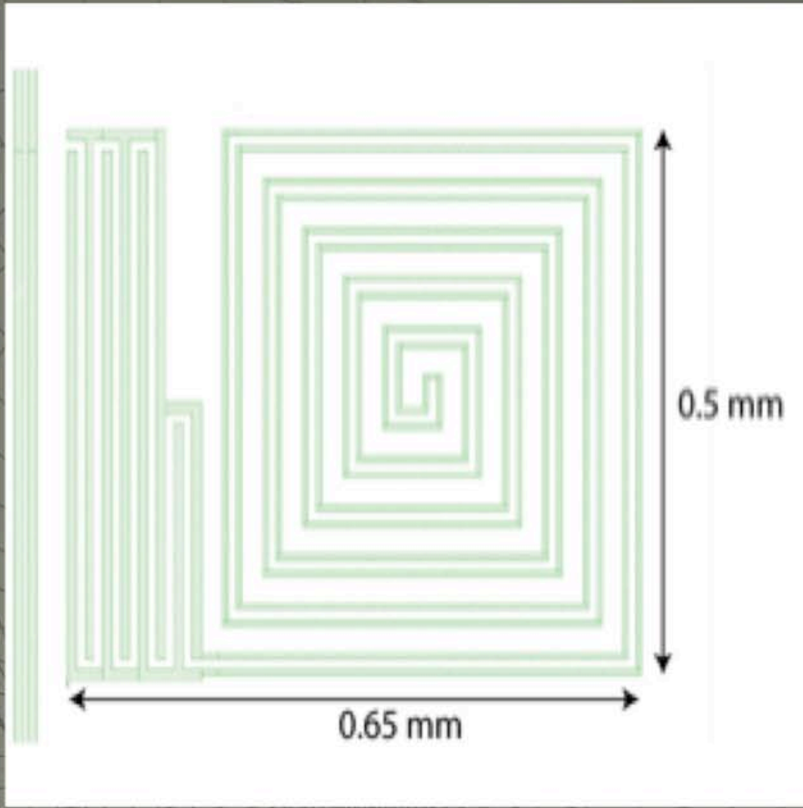
$\Rightarrow$ Considerably less cost

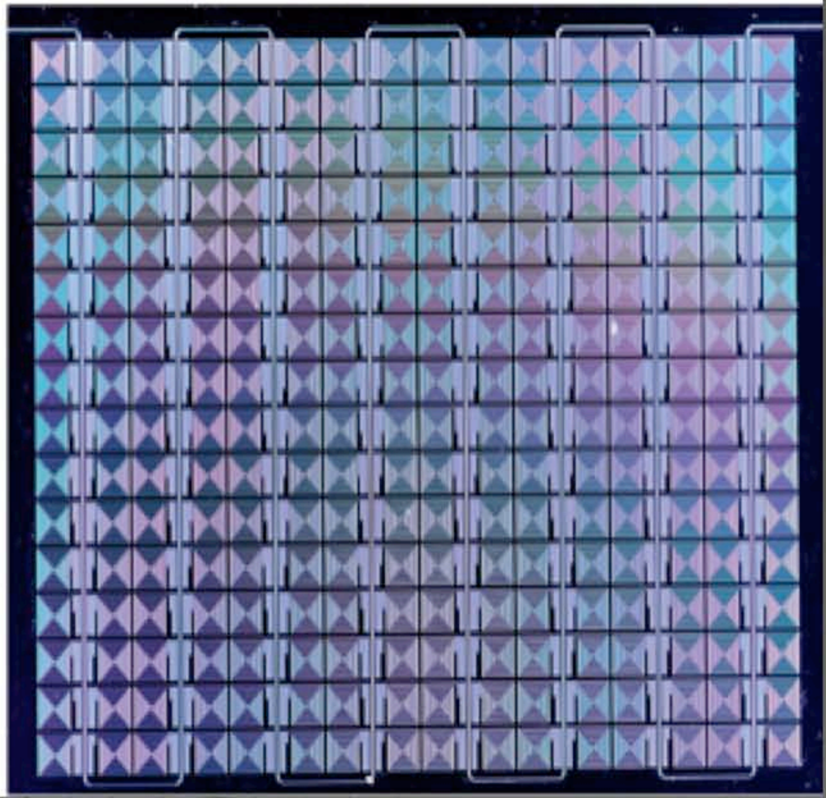
MKID Principles



- Photon detector is incorporated into a superconducting resonator circuit
- This causes the frequency and line-width of the resonator to change
- Frequency domain multiplexing achieved by designing resonators with slightly different resonant frequencies and using a broadband low noise microwave amplifier to read out the array

Array Development at JPL





Lumped-element 350 μm direct absorption MKID pixel spiral inductor/absorber and an inter-digitated capacitor

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

200 μm MKID Device

Demonstration of TiN far-IR MKID device at 200 μm illustrating the inductive (frequency shift) and dissipative (resonance width) response to temperature (Peter Day et al.)

Predicted Sensitivity

CCAT

Table 5: Detector Noise Requirements and System Sensitivity						
Telescope/Site	350 μm Band			850 μm Band		
	NEP	NEFD	MDF	NEP	NEFD	MDF
CSO/Mauna Kea	1.E-16	870	29	4.6E-17	72	2.4
ASTE/Atacama	1.3E-16	406	13.5	3.5E-17	57	1.9
SPT/South Pole	1.1E-16	249	8.5	3.0E-17	48	1.55
CCAT/Chajnantor	1.1E-16	22.8	0.78	3.0E-17	7.1	0.23
Values for Q1 transparency. NEP is W $Hz^{-1/2}$ NEFD is mJy, 1 σ, 1 sec. MDF is mJy, 4σ, 4 hours						

Can detect Milky Way at z ~ 1 to 2!

How Many Sources

Table 2: Sources per Square Degree				
Band	CSO	ASTE	SPT	CCAT
350 µm	340	2060	5180	55600
4 σ (mJy)	29	13.5	8.5	0.78
C.L.	3.5	3.5	3.5	0.3
850 µm	2430	4150	6290	52000
4 σ (mJy)	2.4	1.9	1.55	0.23
C.L.	2.0	2.0	2.0	0.7
Confusion limit (C.L.) is 10 beams/source				

- 4 hours/pixel, 2000 hour survey – 14° survey in 2 years

  Approaches a million sources/year

Summary

- We can build a 50,000 pixel camera with today's technology
- The MKID technology a preferred due to simplicity and costs
- A 40,000/10,000 pixel camera is achievable with total costs < 8.5 M$
- MKID technology scalable – expect 20' FoV to be reached in not too distant future.