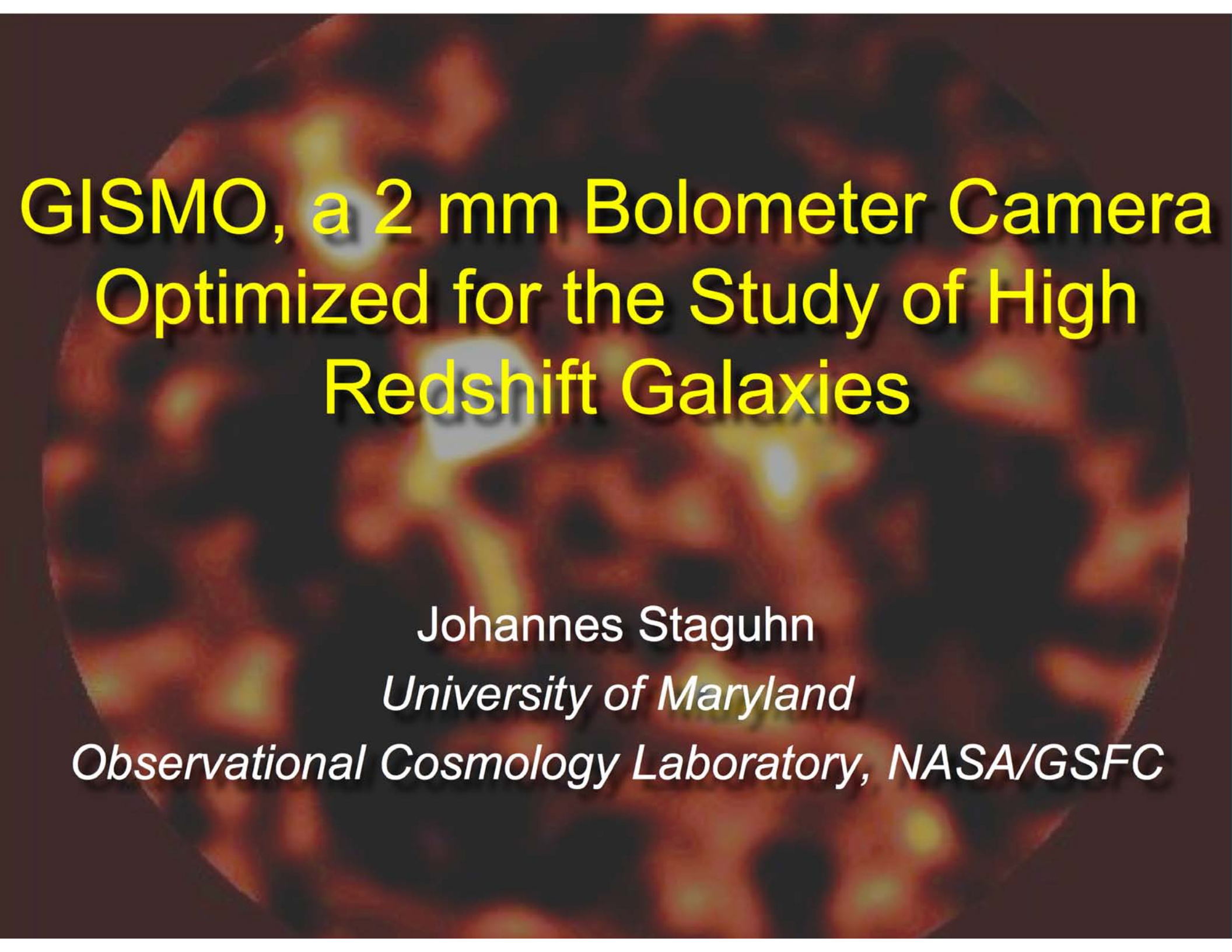


GISMO, a 2 mm Bolometer Camera Optimized for the Study of High Redshift Galaxies

Johannes Staguhn

University of Maryland

Observational Cosmology Laboratory, NASA/GSFC

Outline

Scientific Context

Technology Context

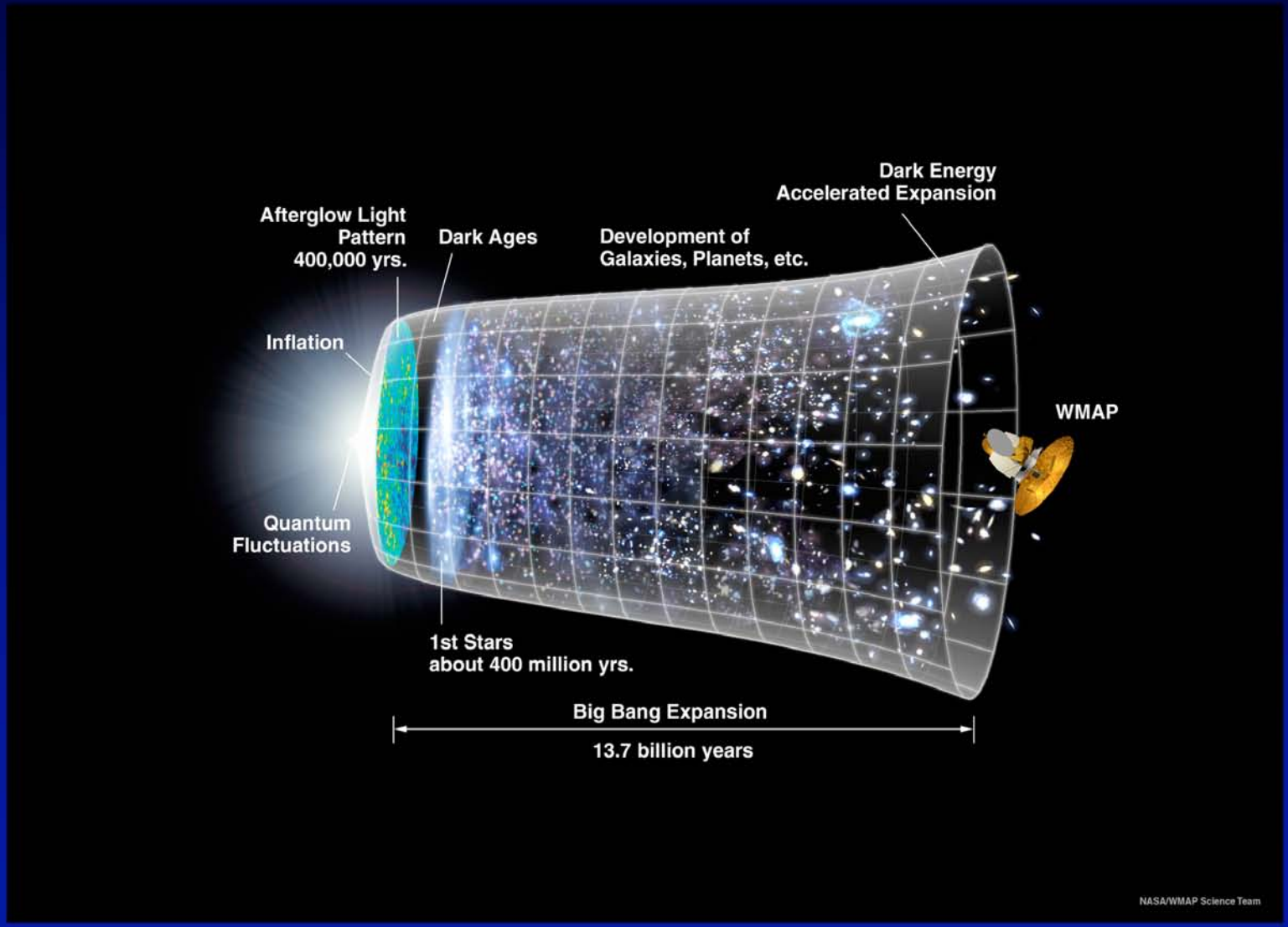
Performance Requirements

Predicted scientific Capabilities

The GISMO Camera, Design & Tests

Examples of High-z Science Projects

Understand the History and Evolution of the Universe



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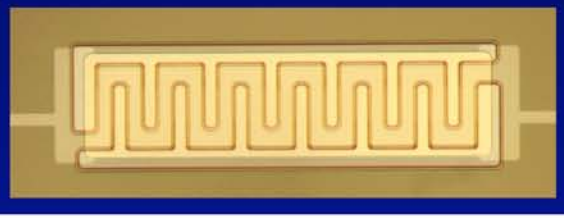
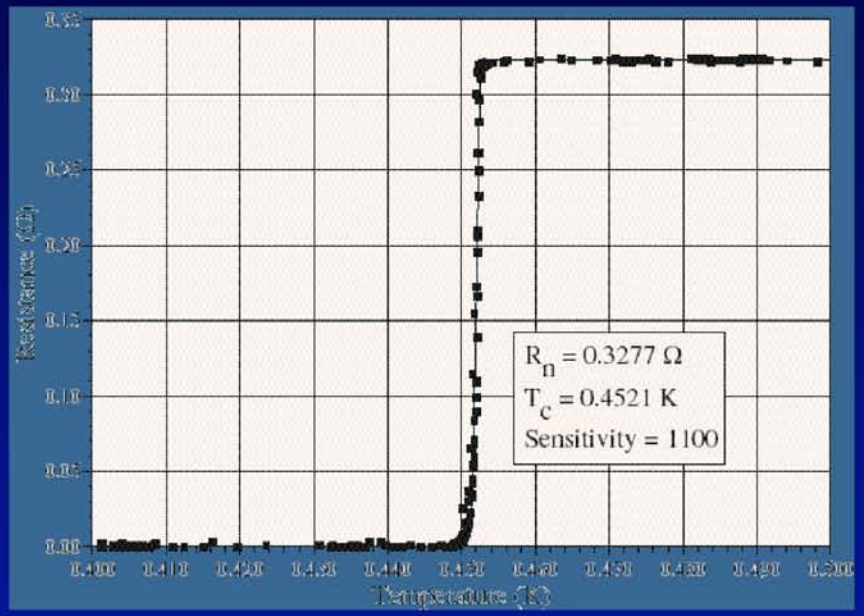
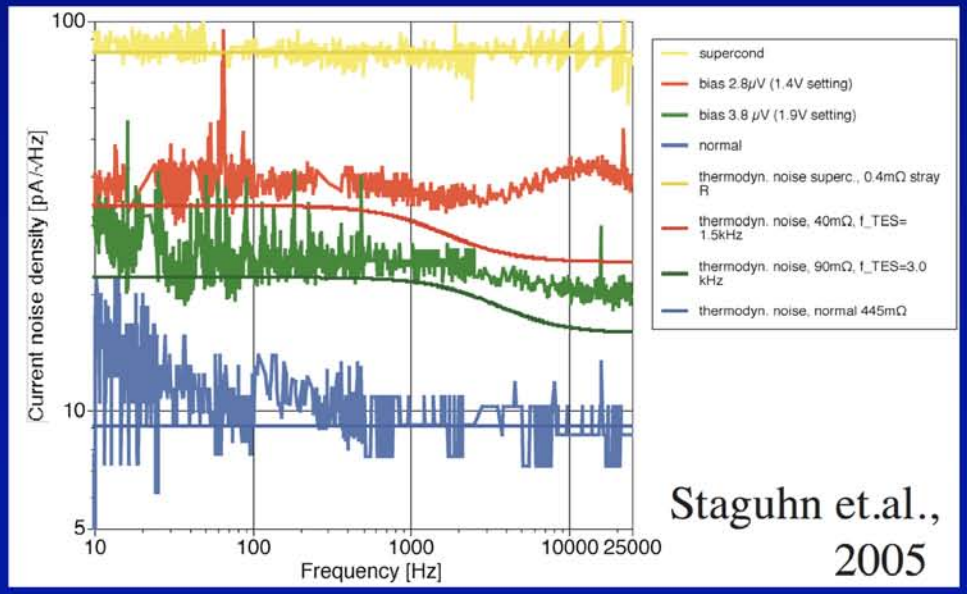
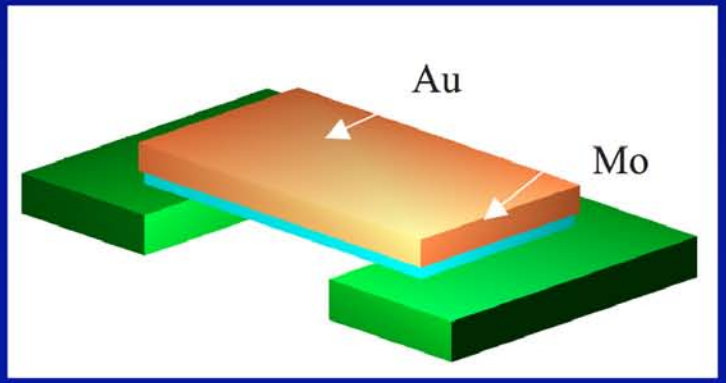
Superconducting Transition Edge Sensors (TES)

- TES bilayers have excellent transitions (sharpness>1000), reproducible T_C and R_N
- TES are low noise devices
- Low R (<1Ω) => match well to SQUIDS





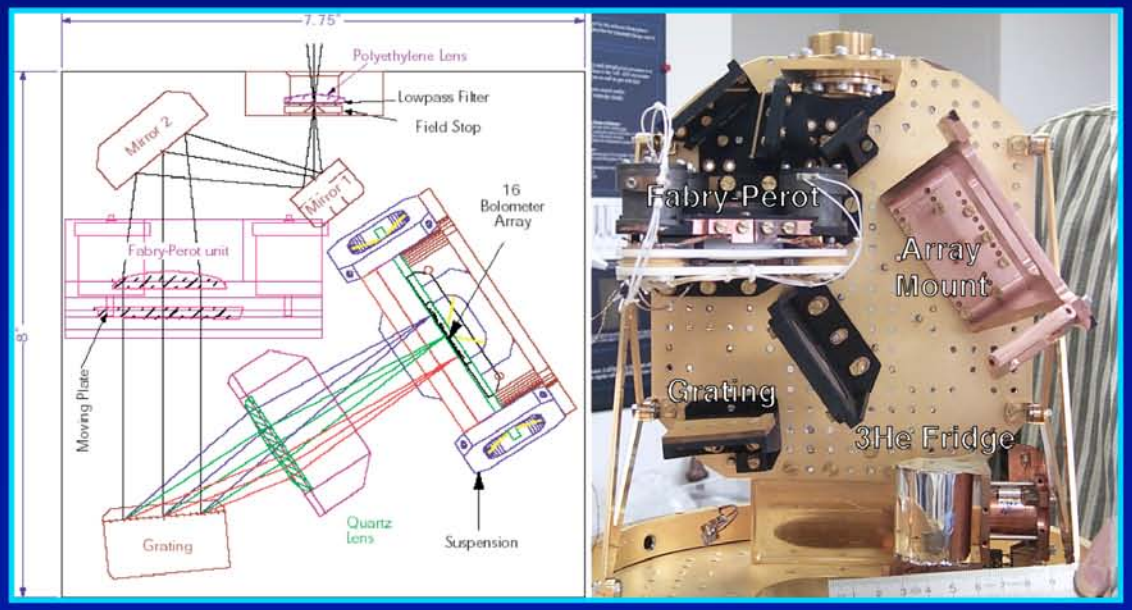


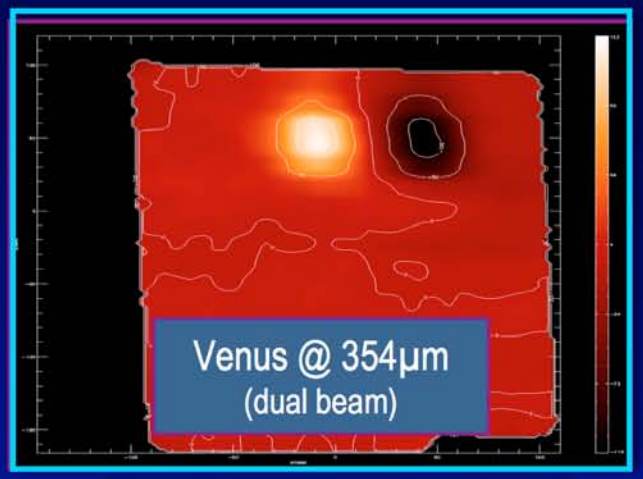


FIBRE

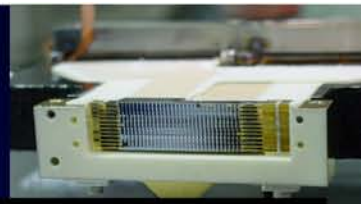
NASA/GSFC, IAS-Paris, Caltech

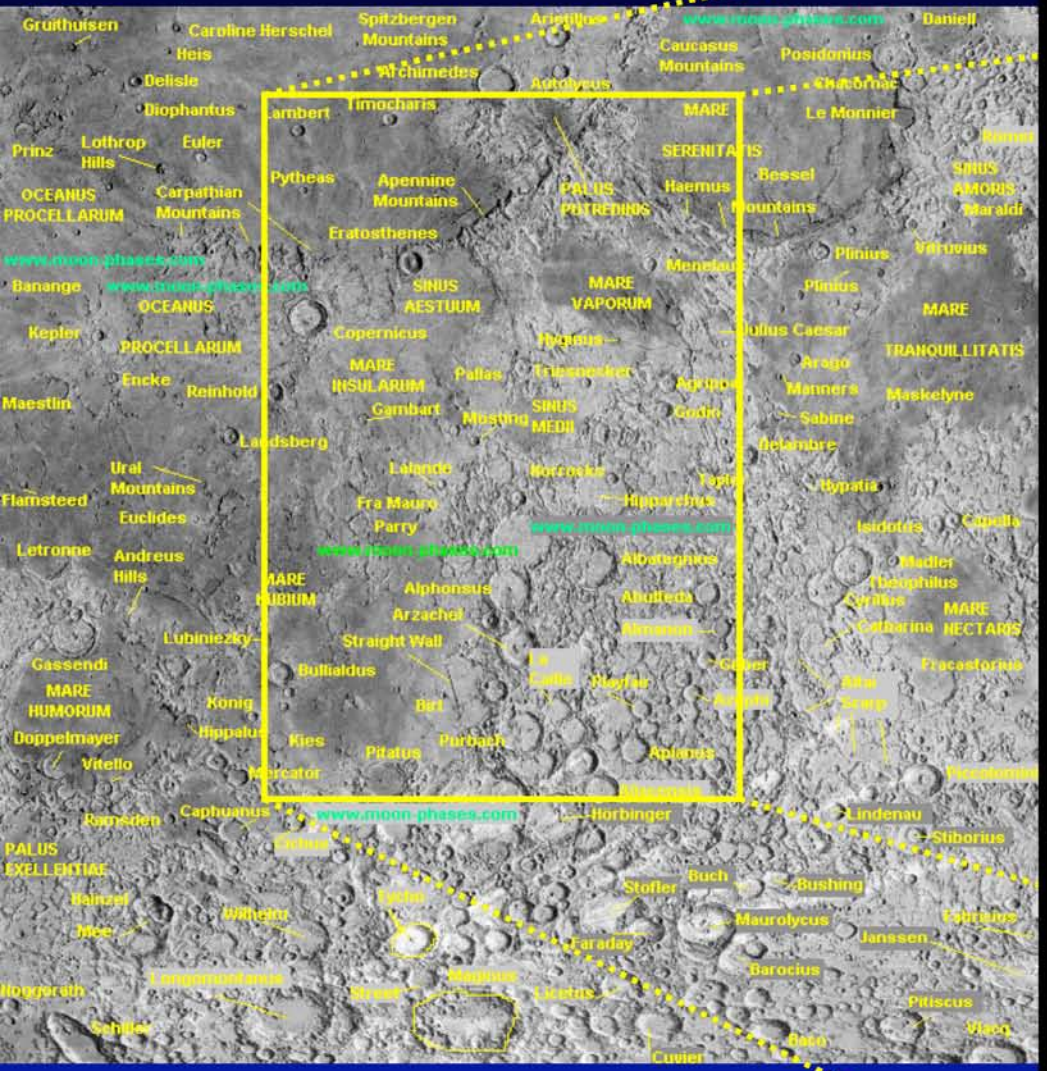
- FIBRE (P.I. Dominic Benford) uses 1x8 TES arrays and multiplexers
- First Astronomical observations with multiplexed Transition Edge Sensors (TES)
- Observing run at CSO yielded images at 5 wavelengths near 350μm,



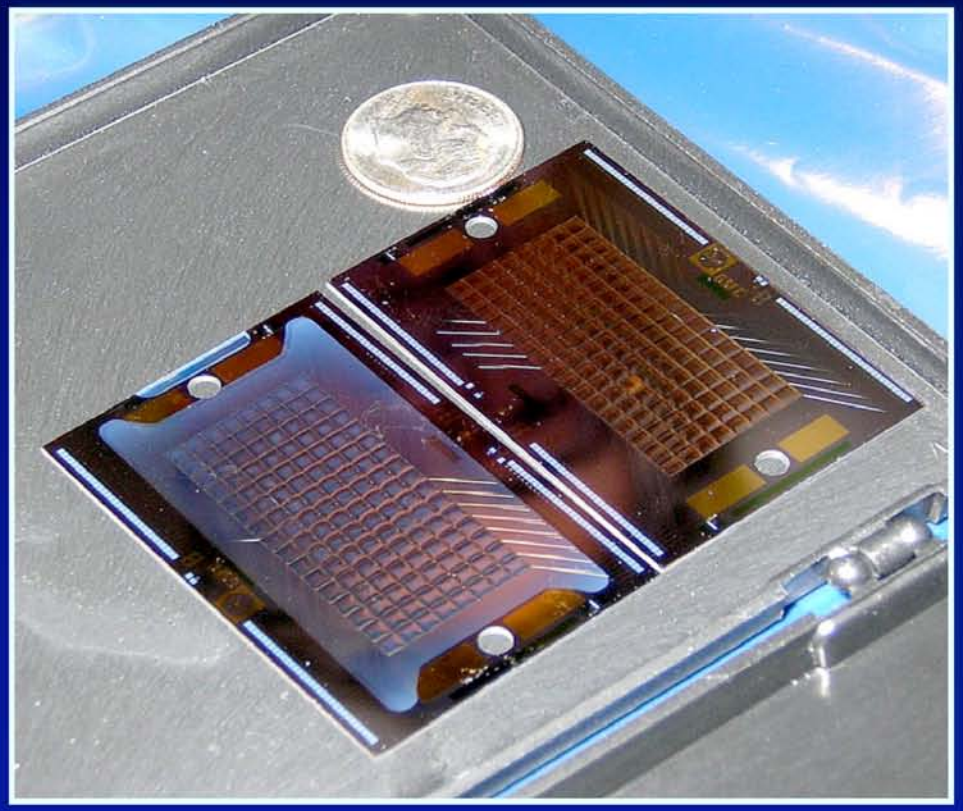


SHARC II: The Moon at 350 μm





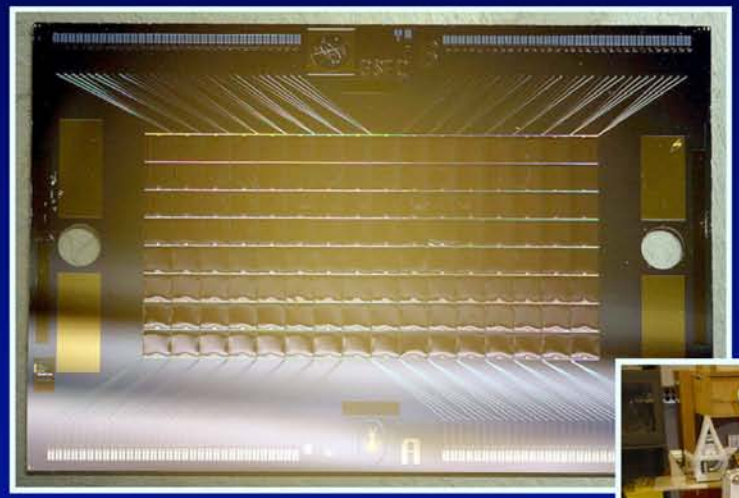
Detector Array Overview



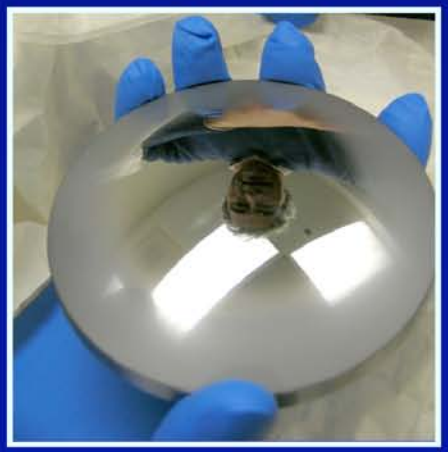
Two 8x16 detector arrays with a dime for scale.

- Detector system for GISMO is a superconducting transition edge sensor (TES) bolometer array and readout electronics
- Made at NASA/GSFC; 128 pixels, close-packed 8x16 for 2'x4' image (nearly beam sampled)
- Operating wavelength of 2.0mm (beam 17")
- Read out by a super-conducting quantum interference device (SQUID) amplifier, produced at NIST/Boulder

Goddard-IRAM Superconducting 2-Millimeter Observer (GISMO)



Backshort under Grid (BUG) TES detector array design



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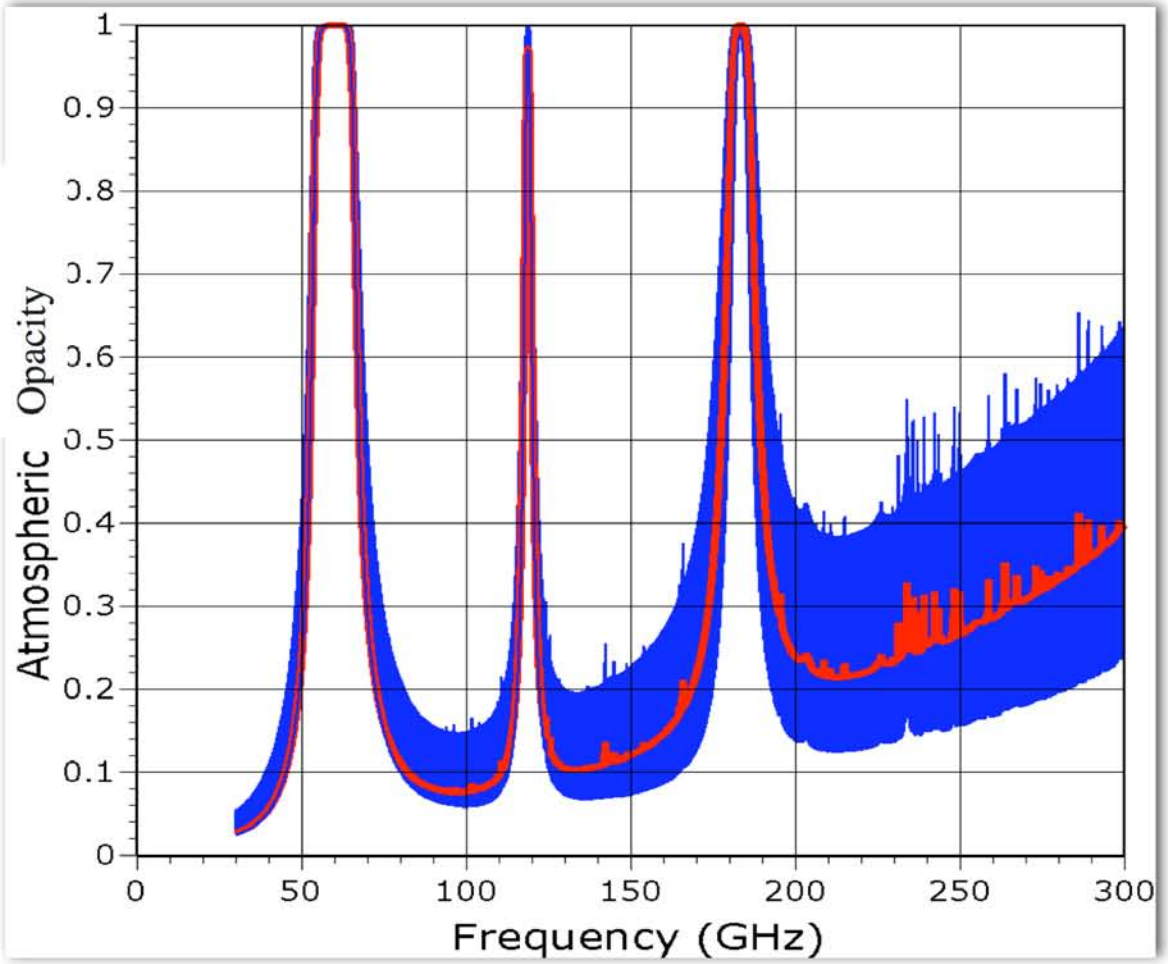
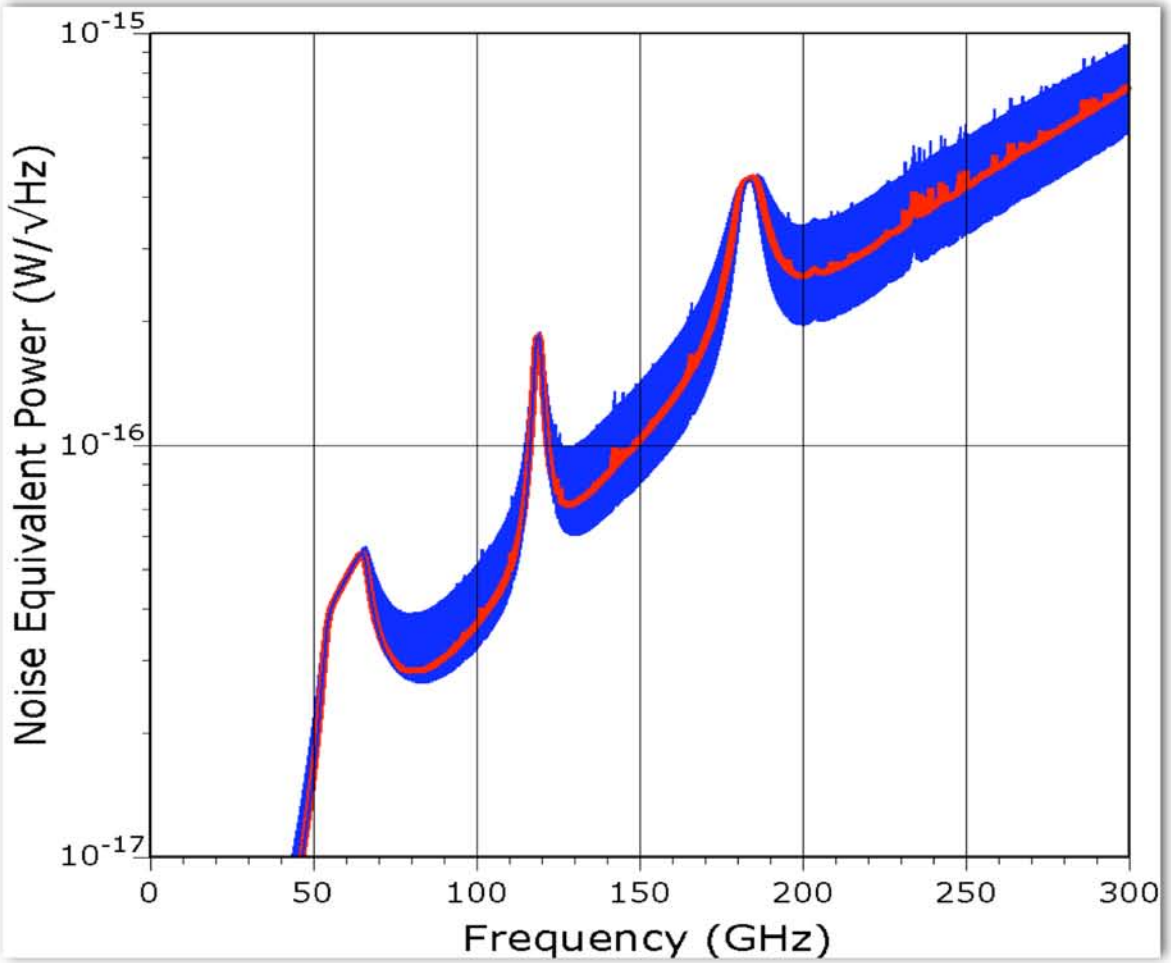
Atmosphere @ Pico Veleta



NEP of Photon Stream



GISMO 2mm Camera Requirements

Sky parameters for Pico Veleta

Average winter atmosphere:
150 GHz: sky emissivity 0.1, sky noise 9×10^{-17} W/$\sqrt{\text{Hz}}$
NEFD: 7 mJy/sqrt(Hz)
250 GHz: sky emissivity 0.2 sky noise 2.2×10^{-16} W/$\sqrt{\text{Hz}}$
NEFD: 20 mJy/sqrt(Hz)

Average summer atmosphere:
150 GHz: sky emissivity 0.2, sky noise 1.6×10^{-16} W/$\sqrt{\text{Hz}}$
NEFD: 12 mJy/sqrt(Hz)
250 GHz: sky emissivity 0.4 sky noise 4.0×10^{-16} W/$\sqrt{\text{Hz}}$
NEFD: 46 mJy/sqrt(Hz)

Typical winter- and summer sky background at Pico Veleta for a λ/D sampling array with 20% bandwidth, observing in on-off mode at 50 degrees elevation.
The following efficiencies were assumed:
Optical throughput 0.5; detector 0.8;
telescope efficiencies are from the 30m users manual.

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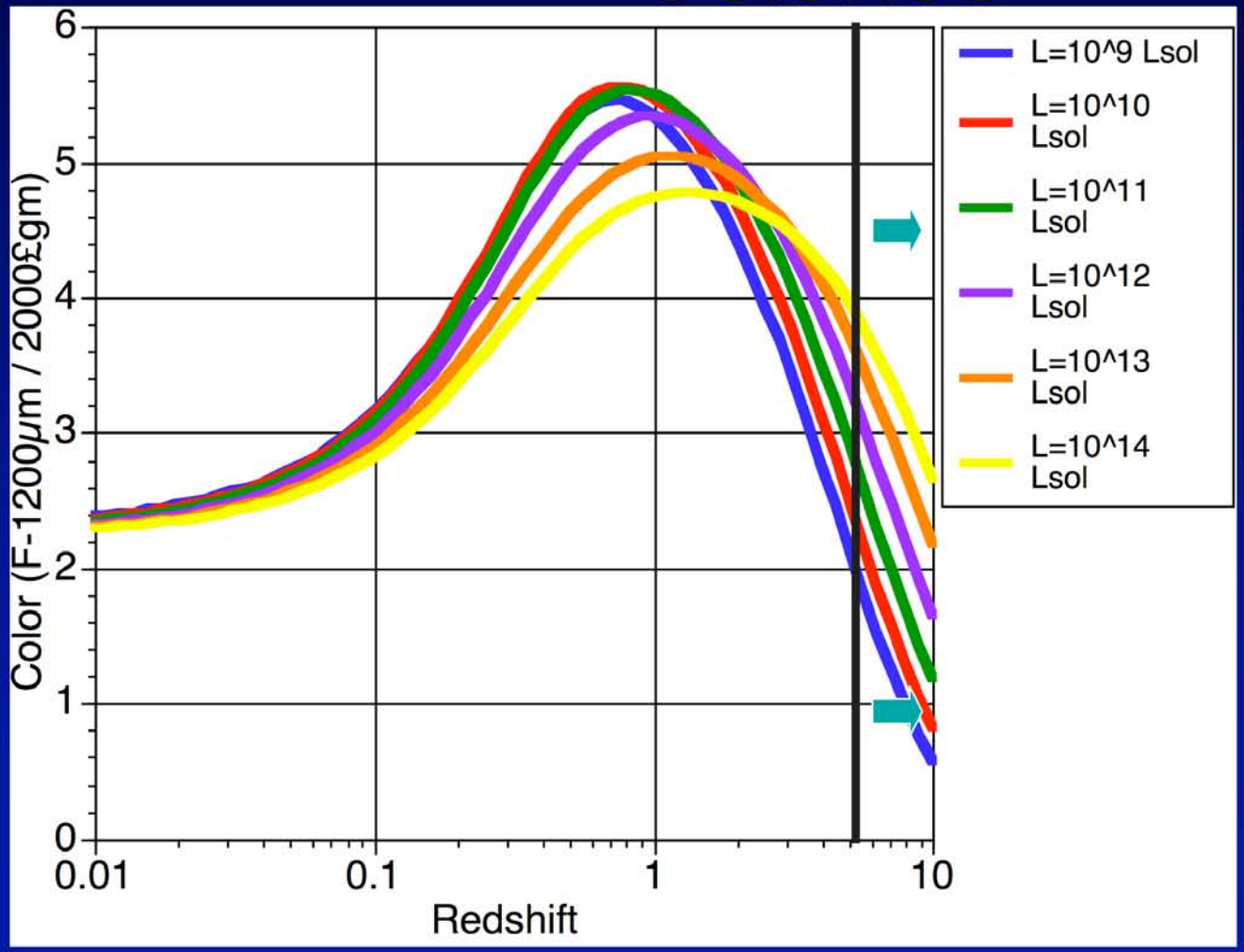
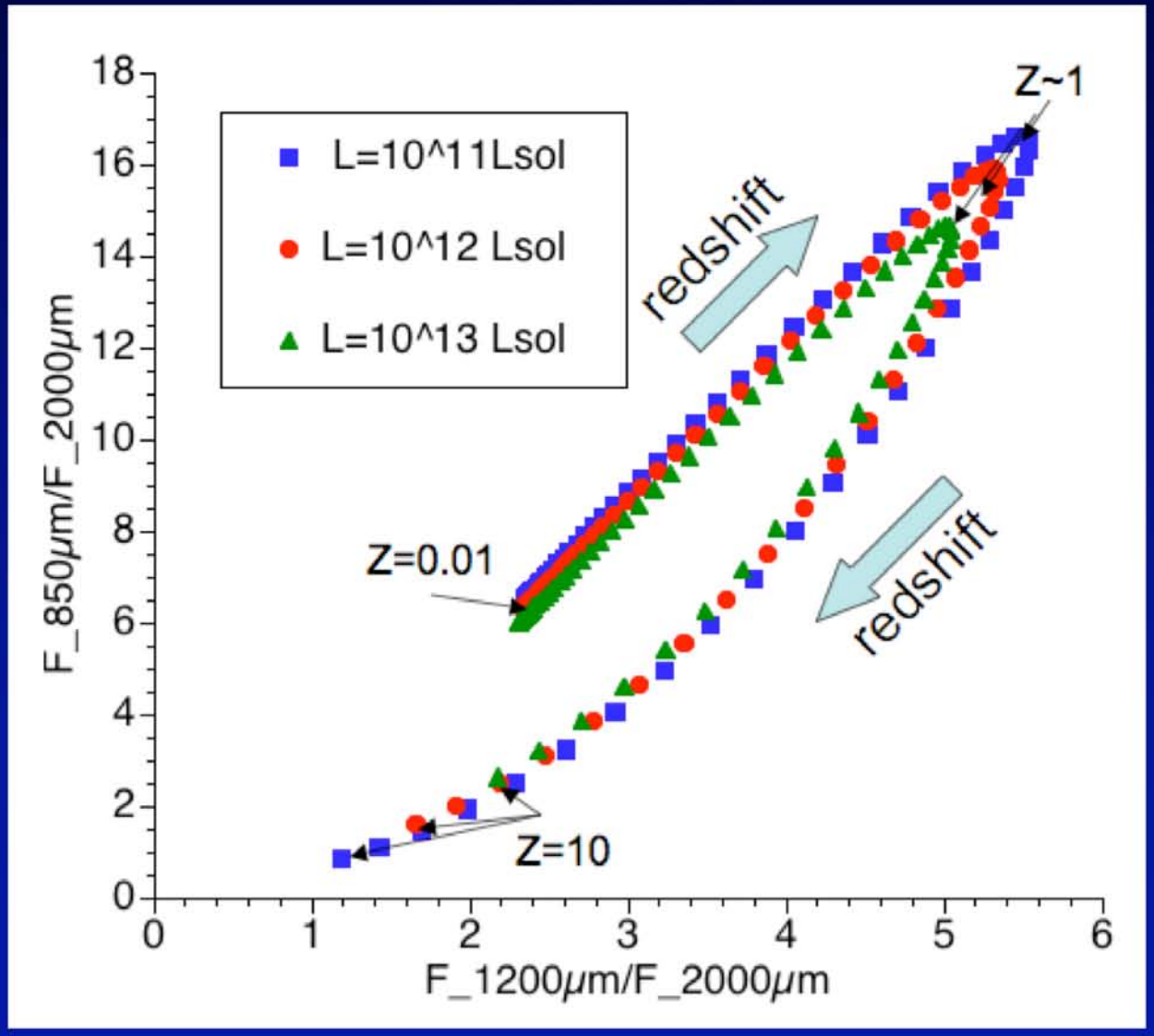
GISMO 2mm Camera Science



detection speed/pixel of high-z galaxies for $z \geq 5$ is better than at 1.2 mm

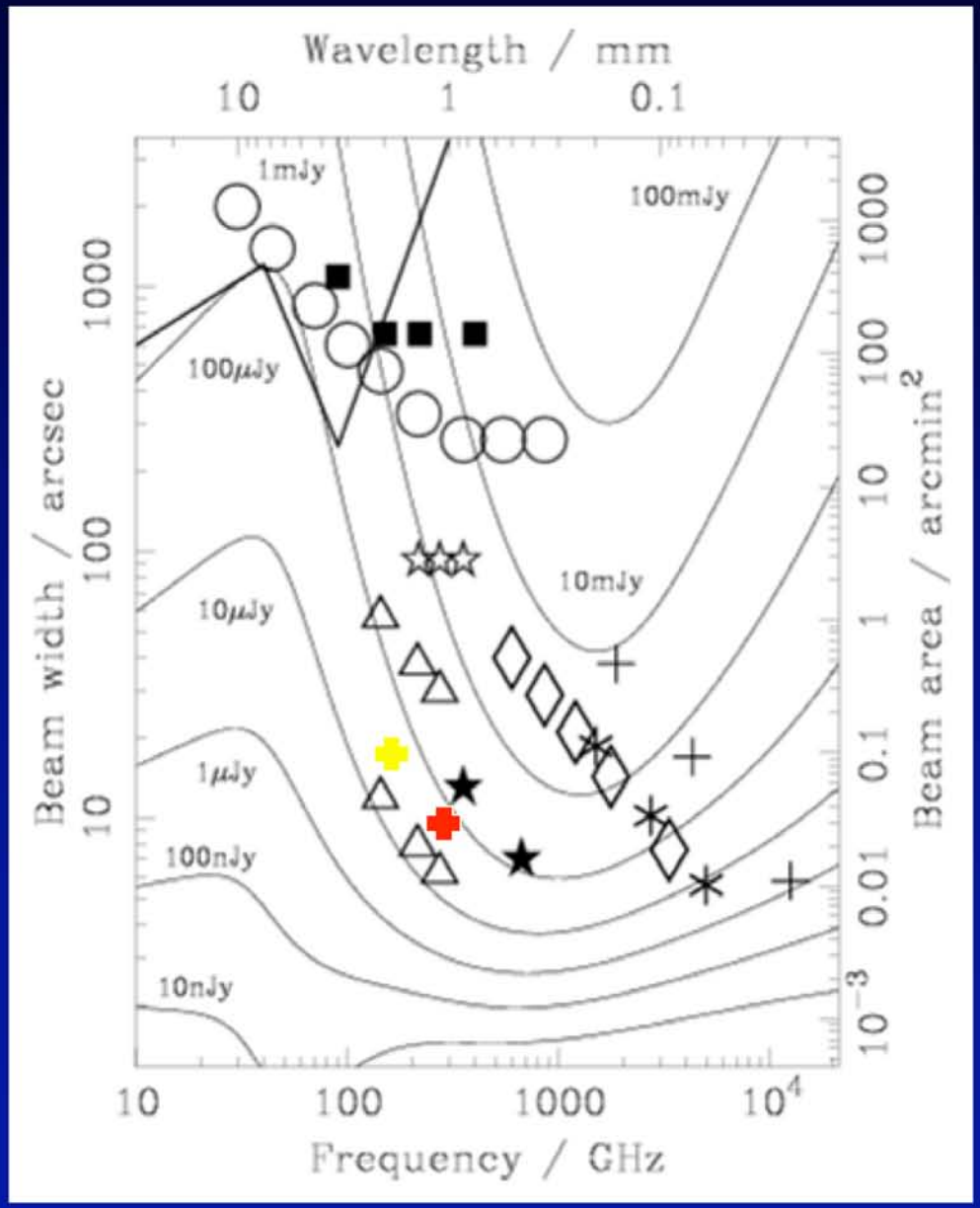
GISMO 2mm Camera Science



Plot of Confusion Limit

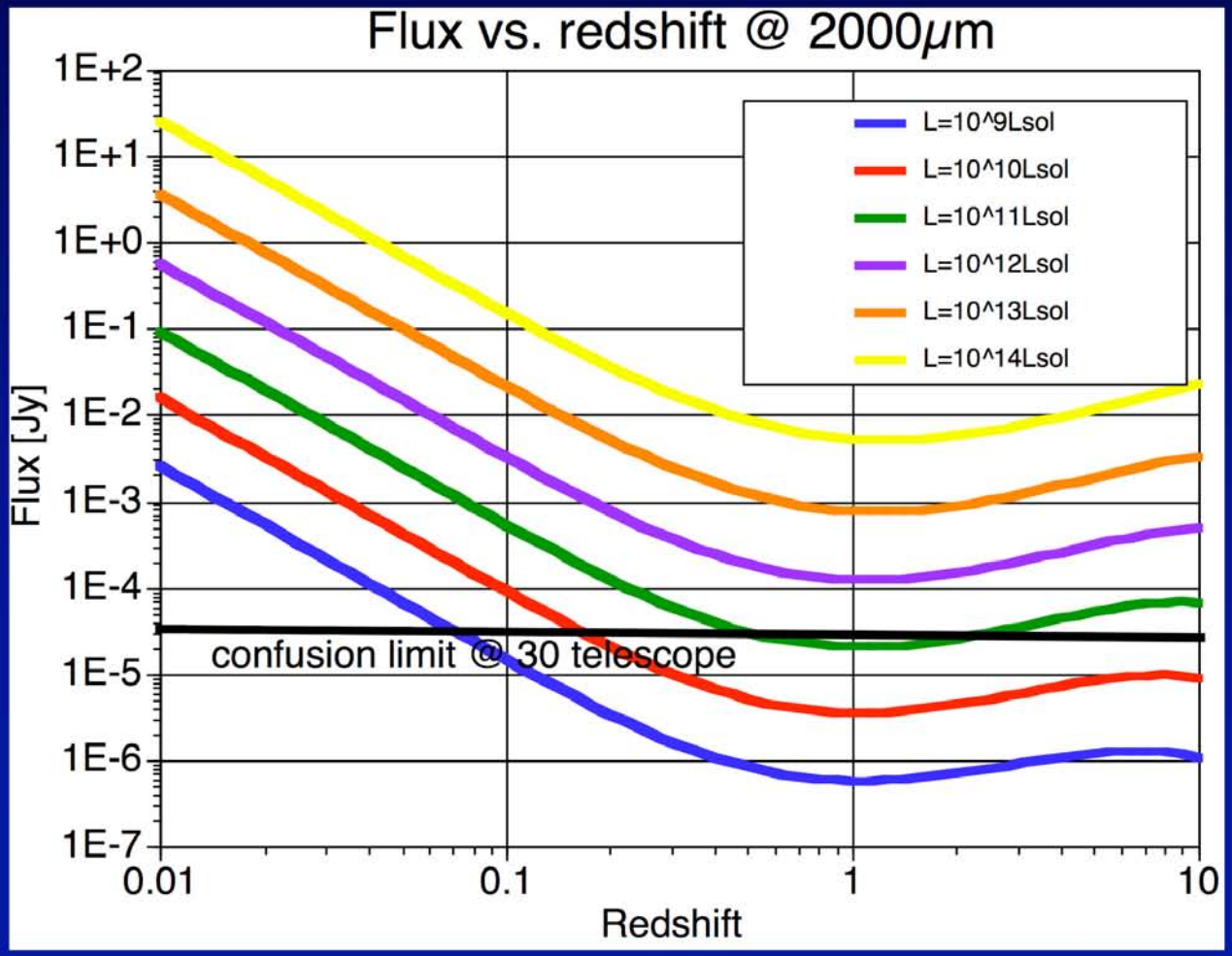
30 m Telescope:

- : 1.2 mm
- : 2 mm

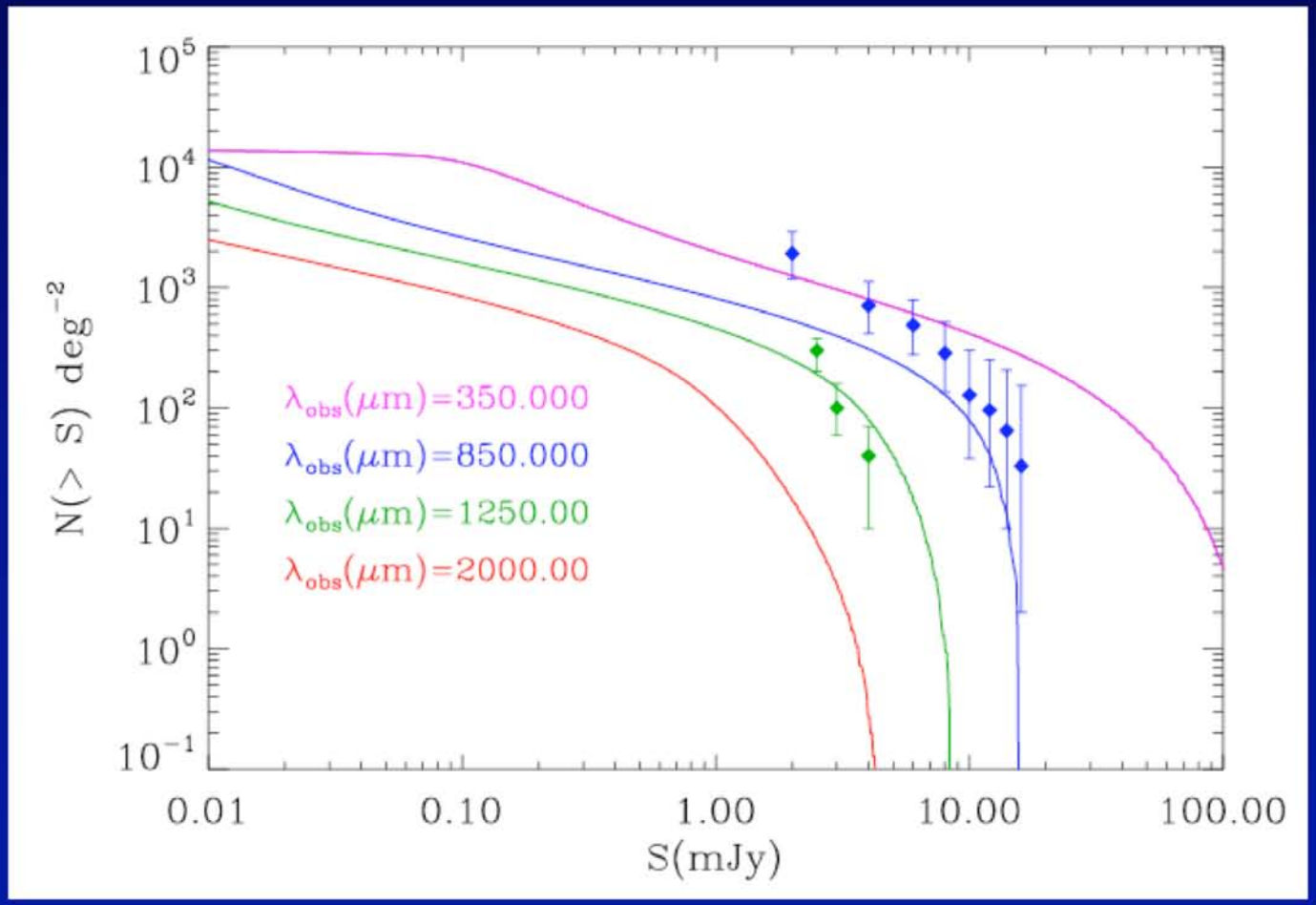


Plot: A. Blain

GISMO 2mm Camera Science

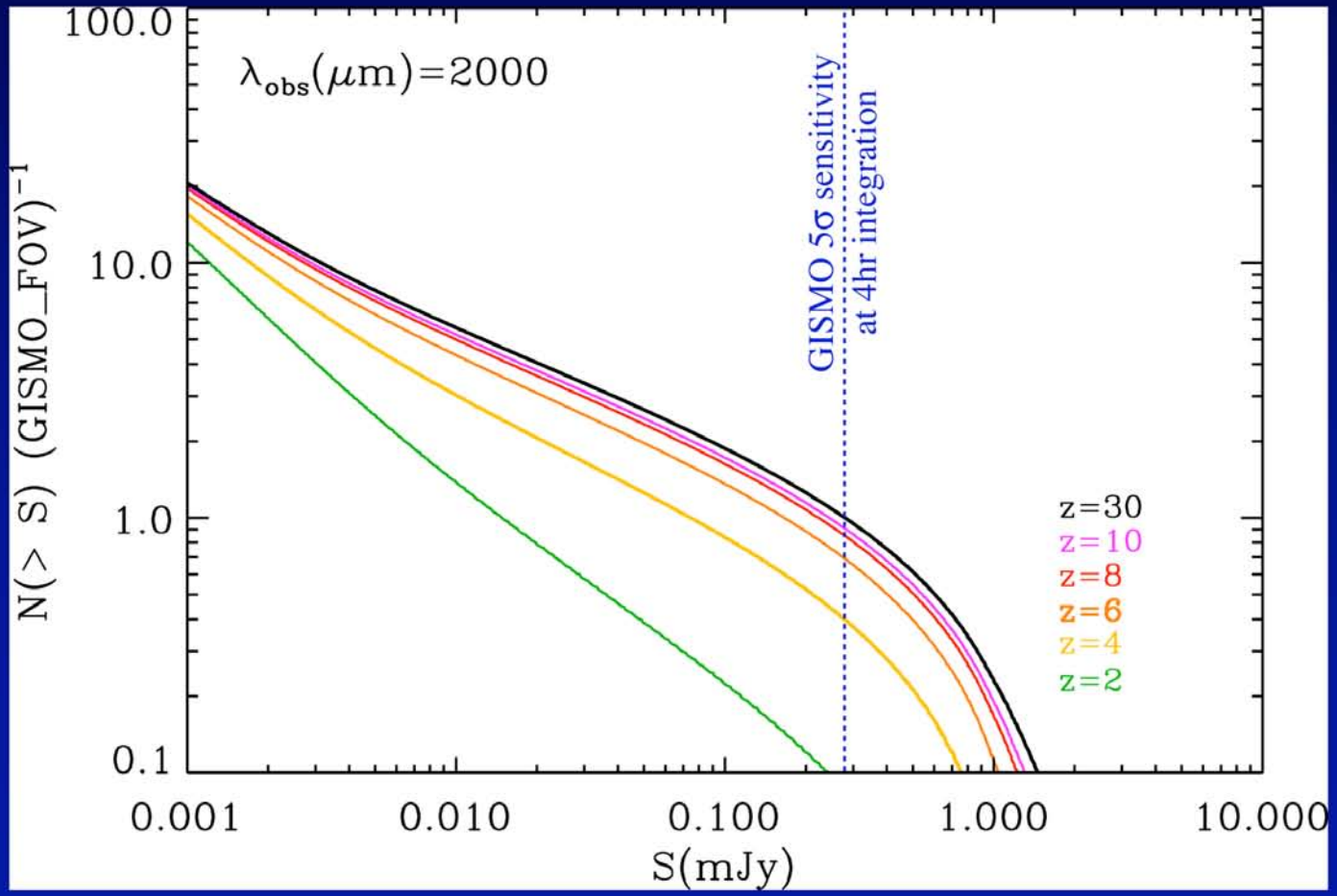


GISMO 2mm Camera Science



N(>S) versus flux. The data points are from *blue:* SCUBA (Borys et al., 2003), and *green:* 1.25mm SEST (Franceschini et al., 1998)

GISMO 2mm Camera Science



The plot demonstrates that one serendipitous source will be detected during this segment of integration time with the probability of one in three that the source is at $z > 6$.

***With a > 25%* probability that $z > 6.42$, this translates to the prediction that every 15 hours we will detect a galaxy that is farther away than the current redshift record for quasars**

Cumulative redshift dependent N(>S) @ 2 mm for GISMO instantaneous sky coverage versus flux

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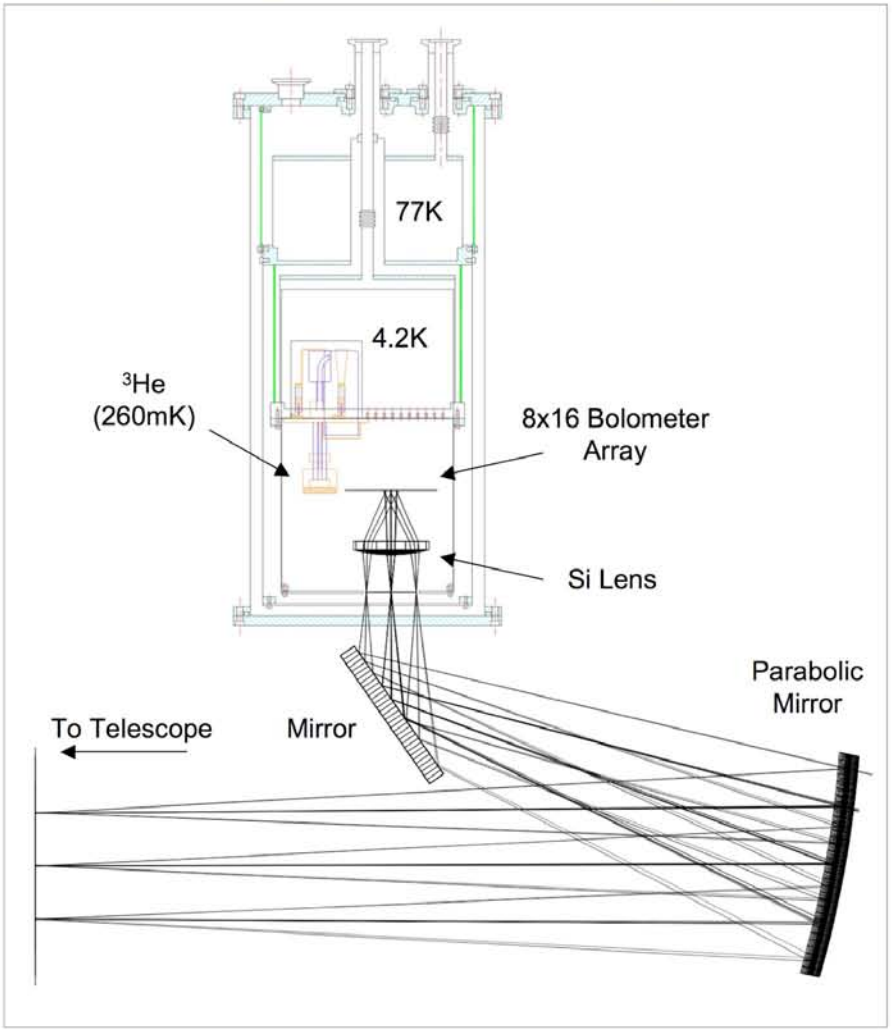
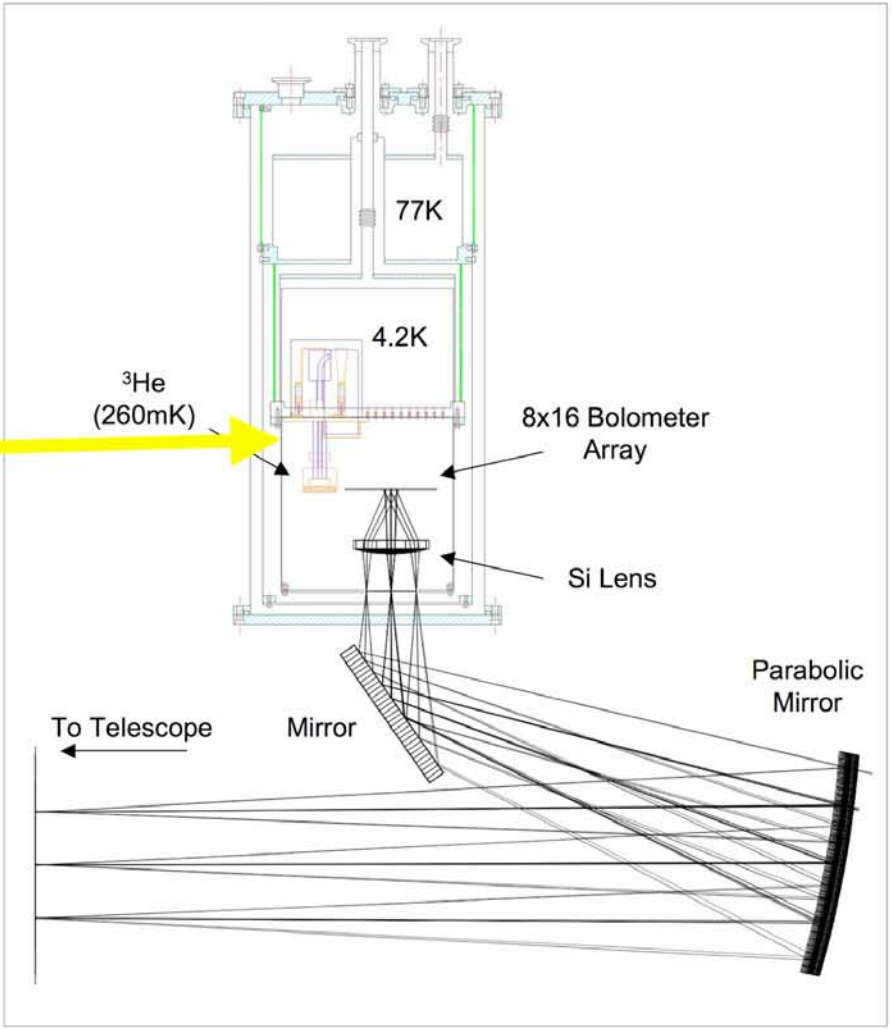
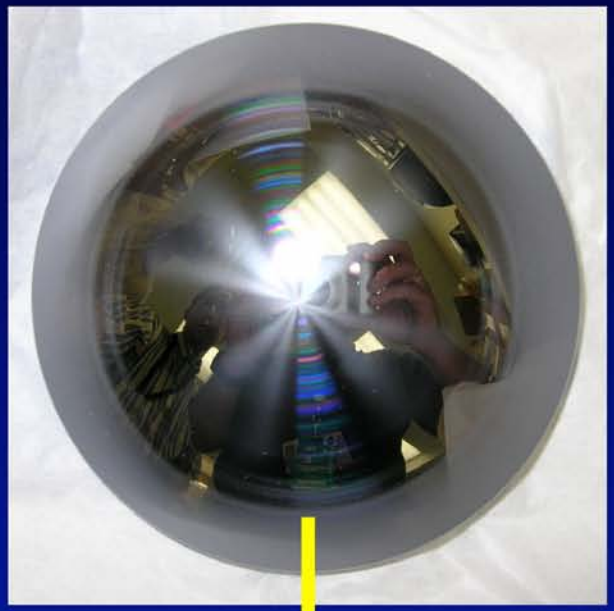
Goddard-Iram Superconducting Millimeter Observer (GISMO)

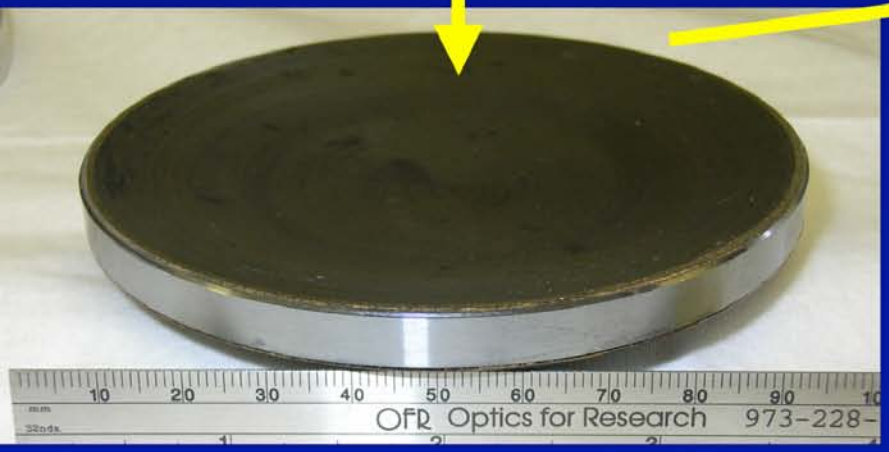


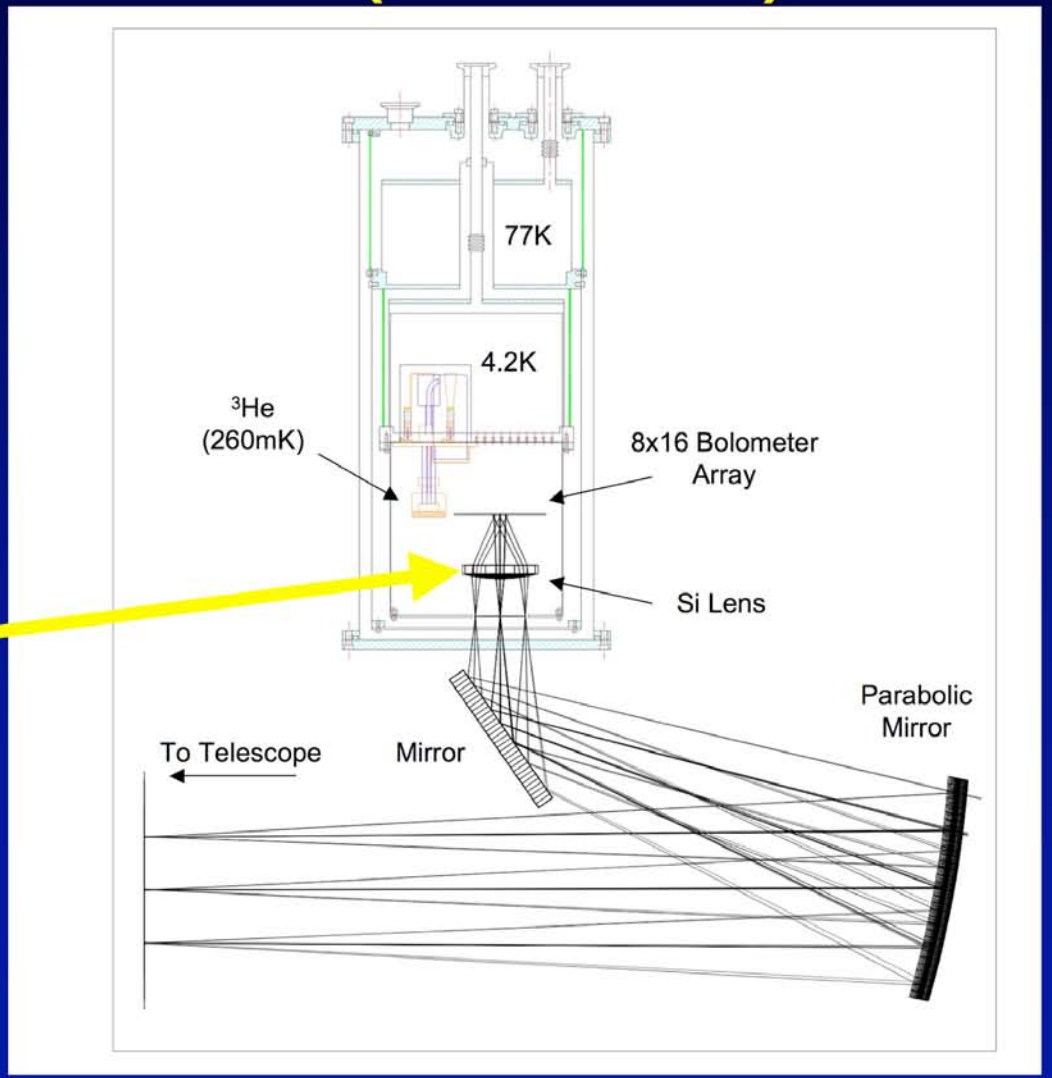
Goddard-Iram Superconducting Millimeter Observer (GISMO)



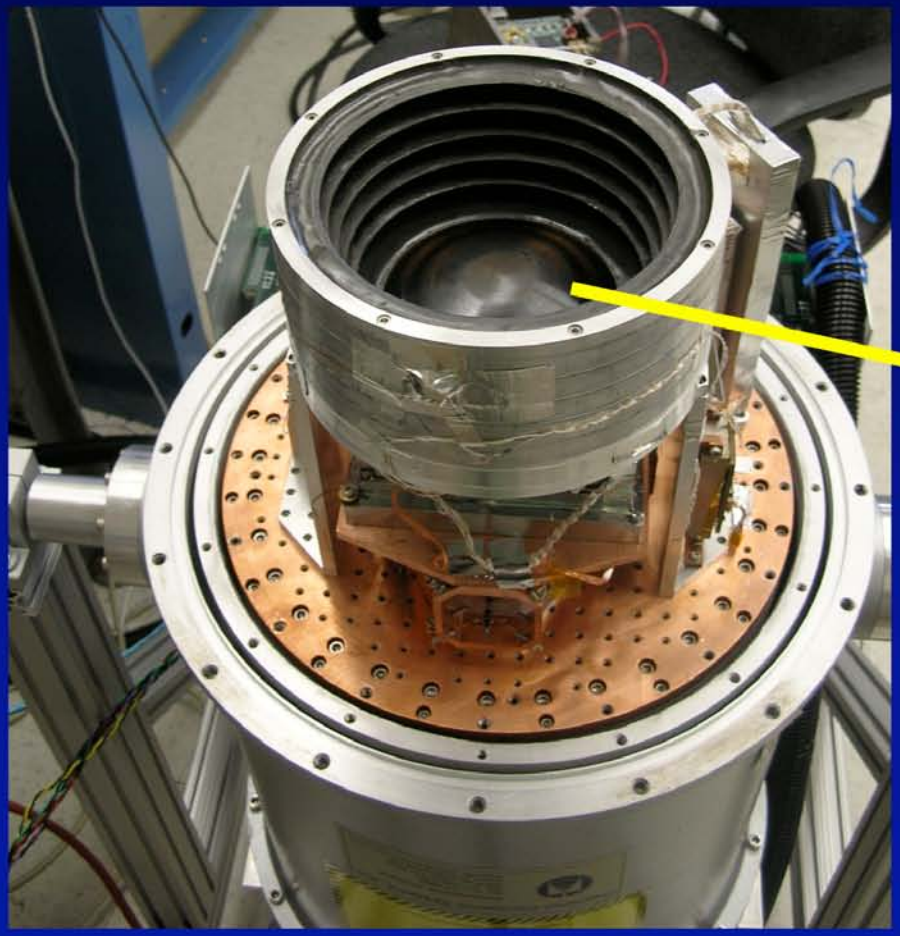
Goddard-Iram Superconducting Millimeter Observer (GISMO)

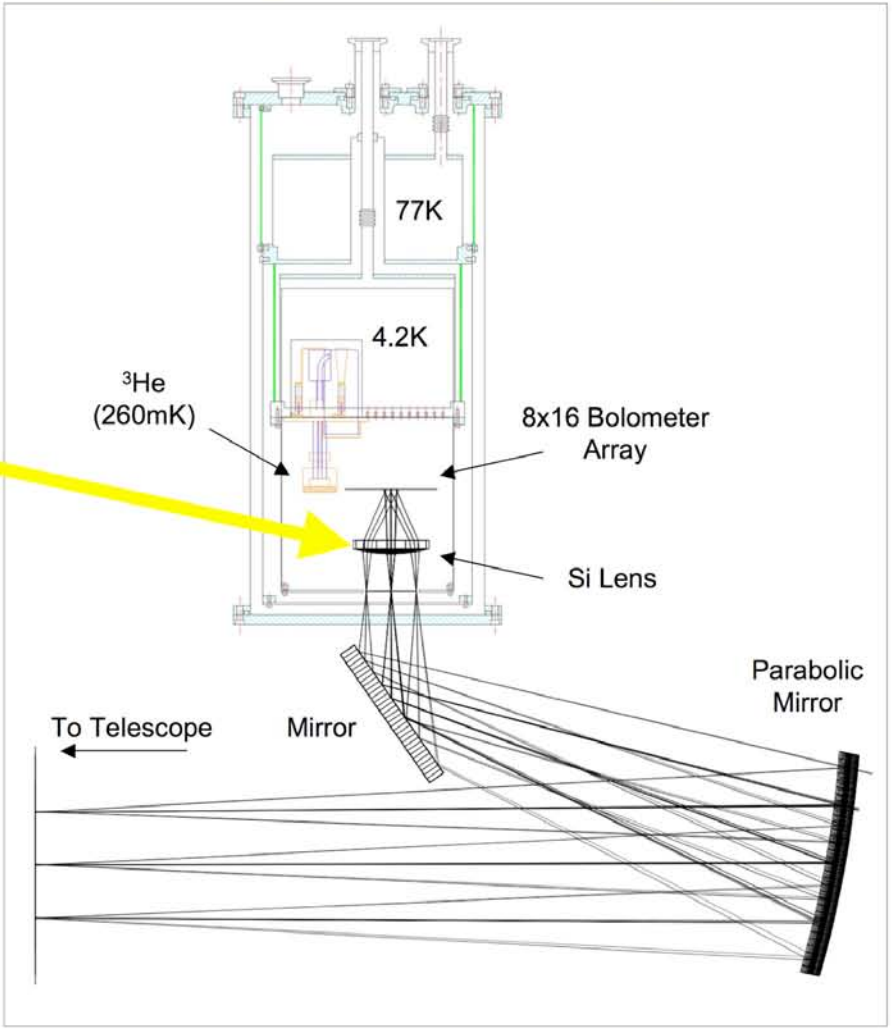




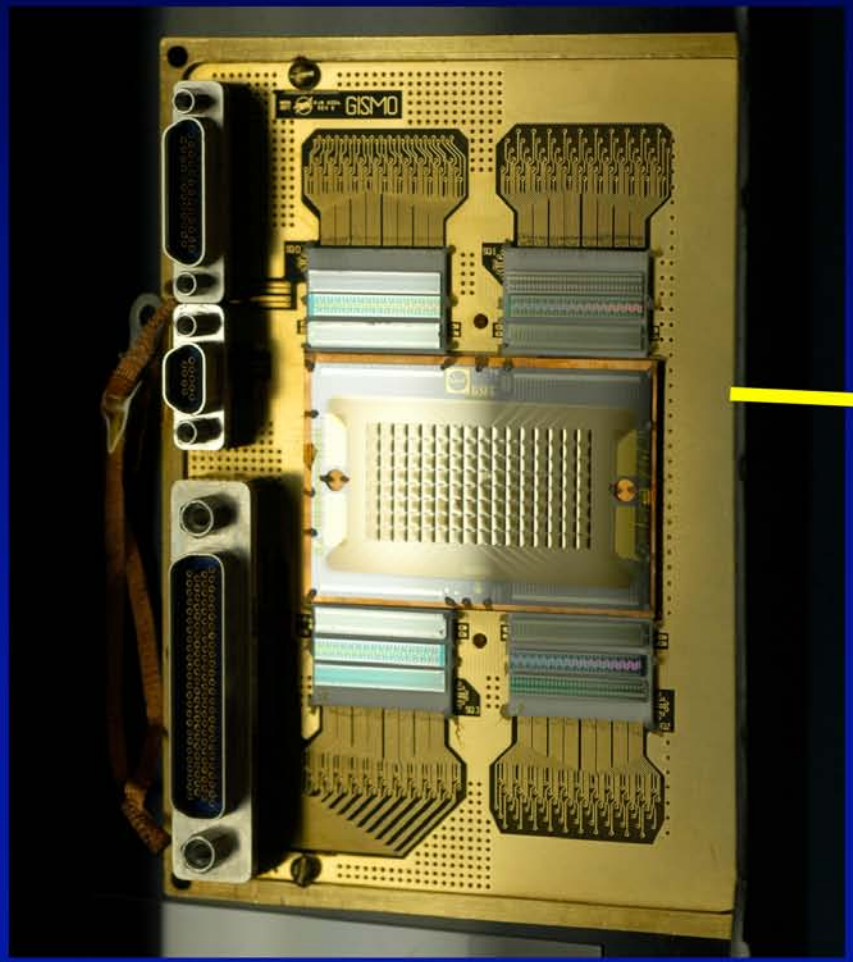


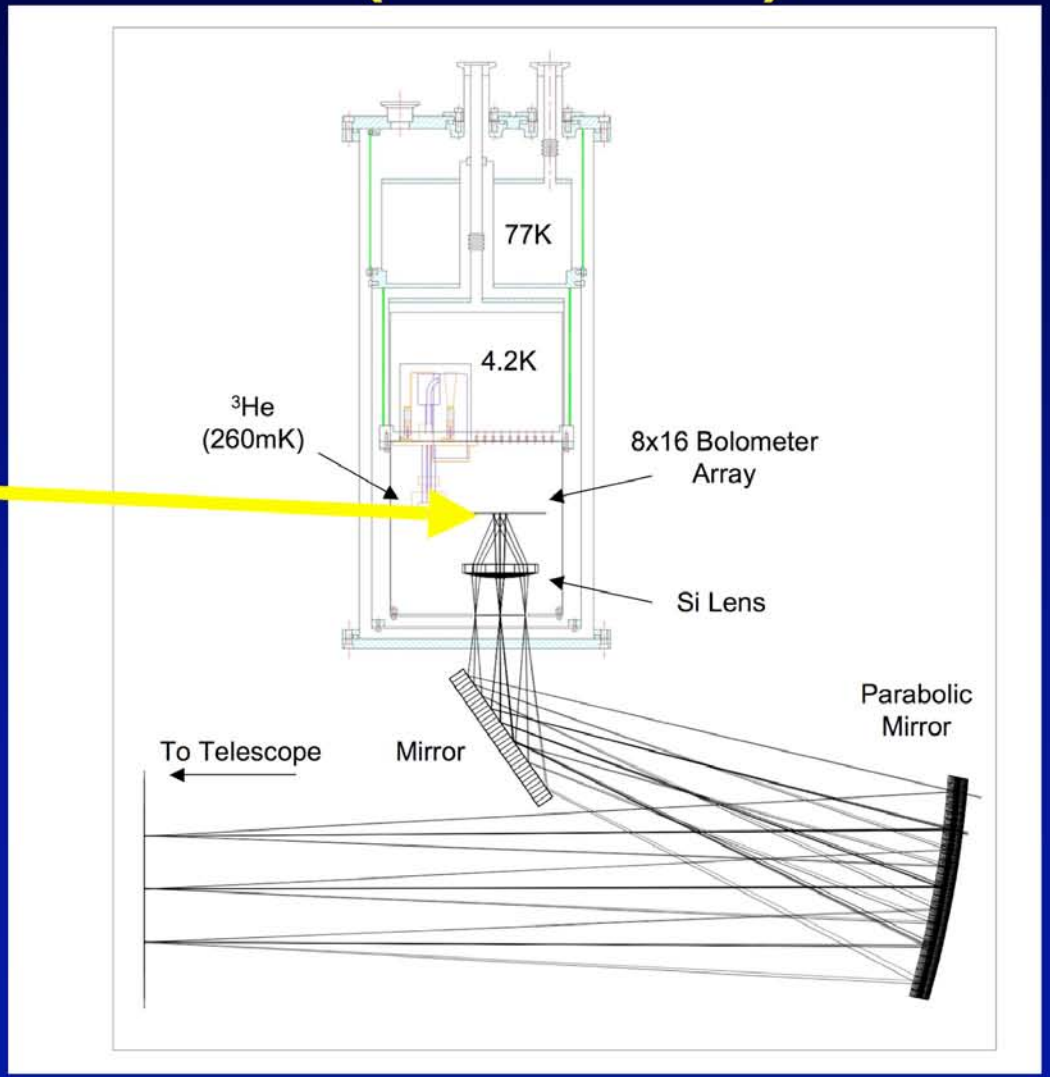
Goddard-Iram Superconducting Millimeter Observer (GISMO)





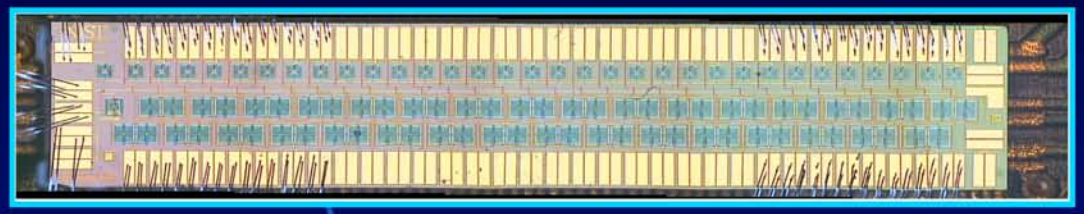
Goddard-Iram Superconducting Millimeter Observer (GISMO)



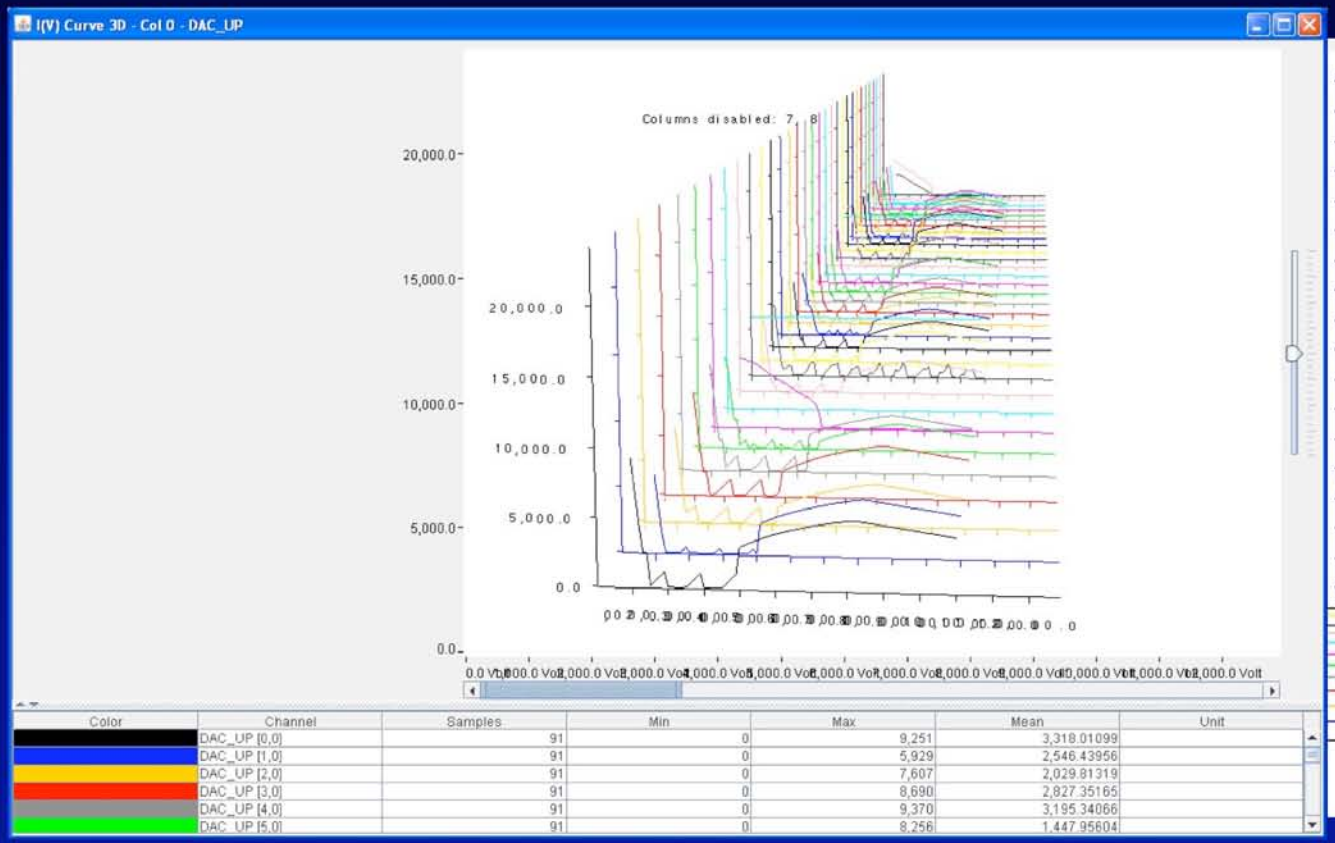


Electronics Photos

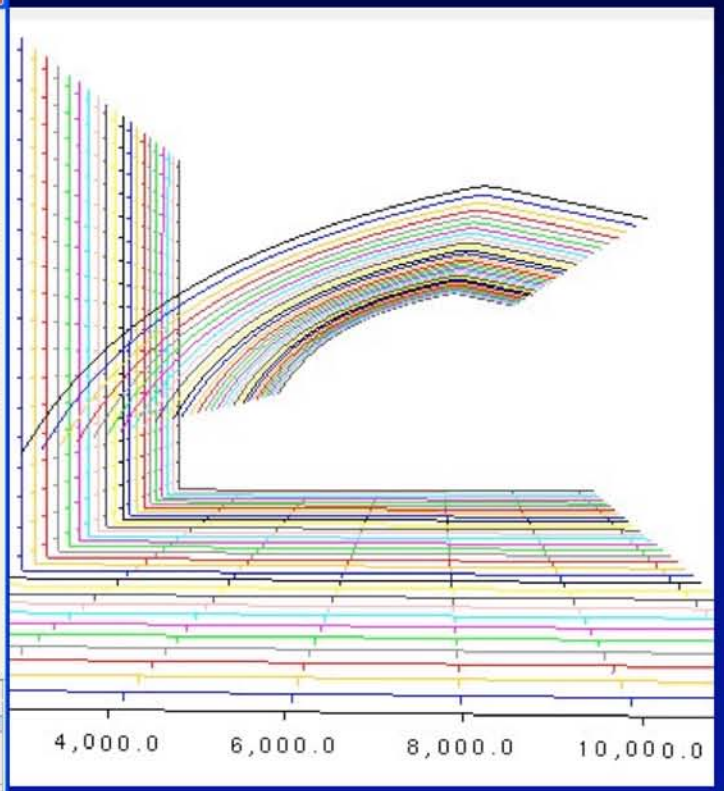
Below: Mark III Tower prepared for operation.



Lab Tests

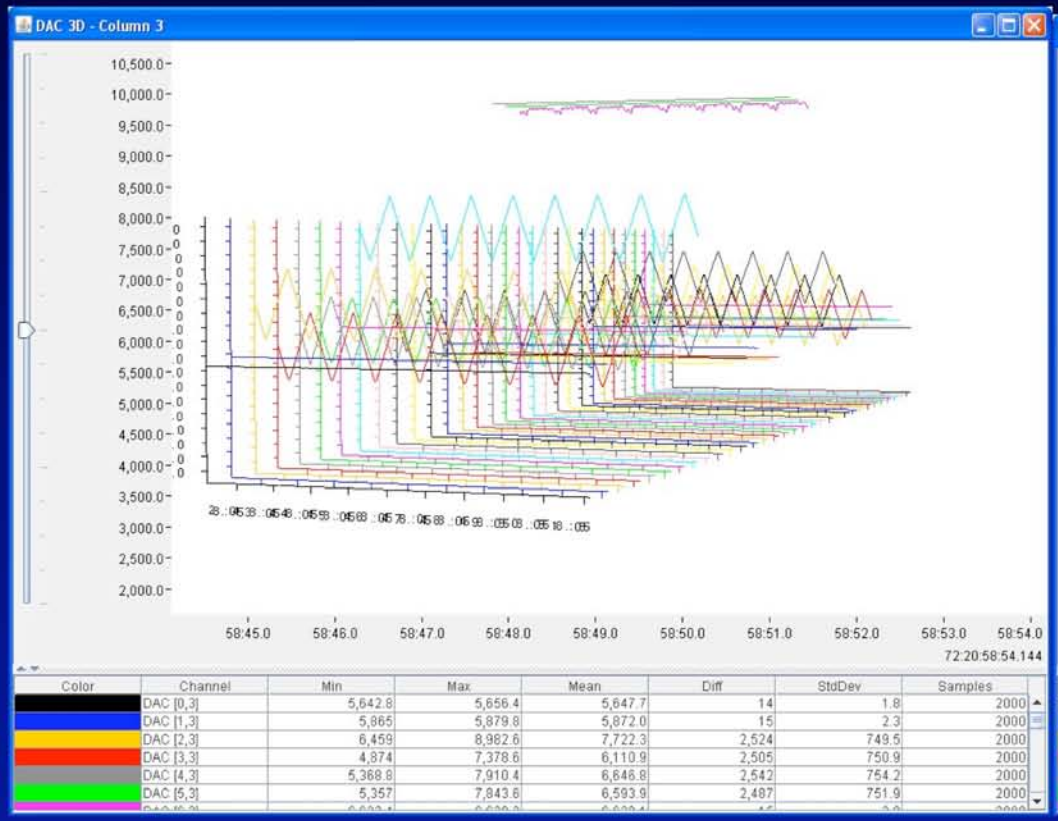


Color	Channel	Samples	Min	Max	Mean	Unit
	DAC_UP [0,0]	91	0	9,251	3,318.01099	
	DAC_UP [1,0]	91	0	5,929	2,546.43956	
	DAC_UP [2,0]	91	0	7,607	2,029.81319	
	DAC_UP [3,0]	91	0	8,690	2,827.35165	
	DAC_UP [4,0]	91	0	9,370	3,195.34066	
	DAC_UP [5,0]	91	0	8,256	1,447.95604	

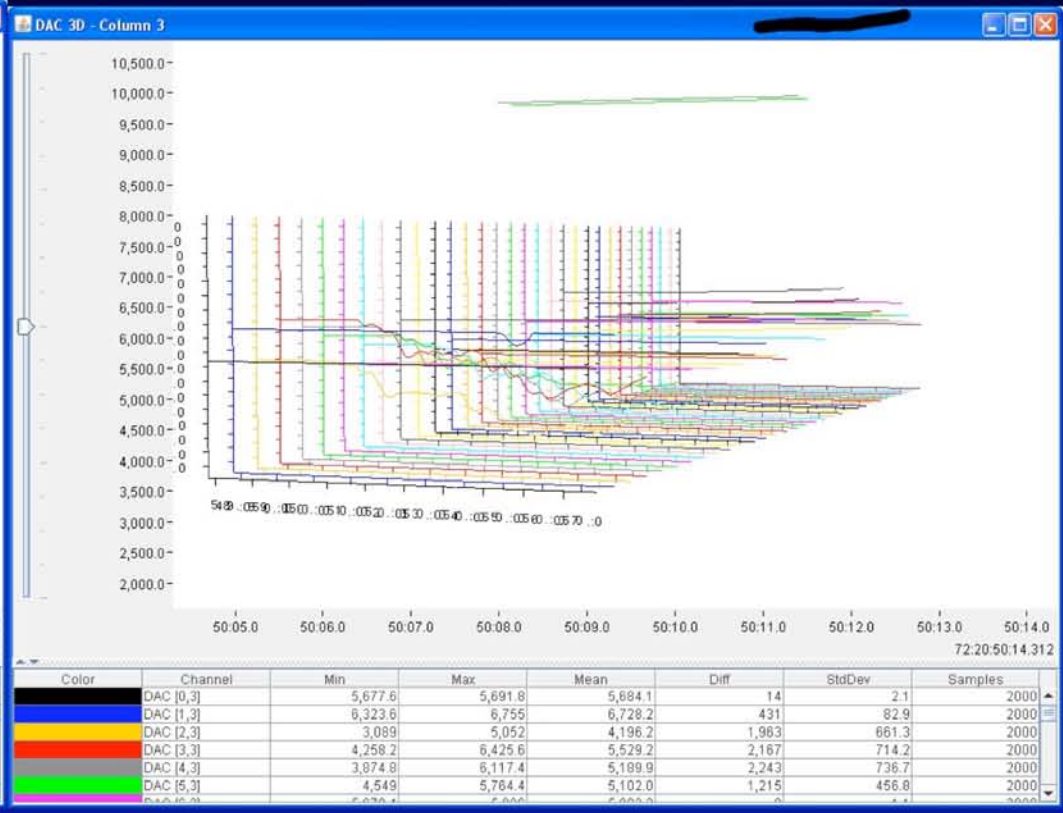


IV Curves of one colums (left), in dwell mode (right)

Lab Tests



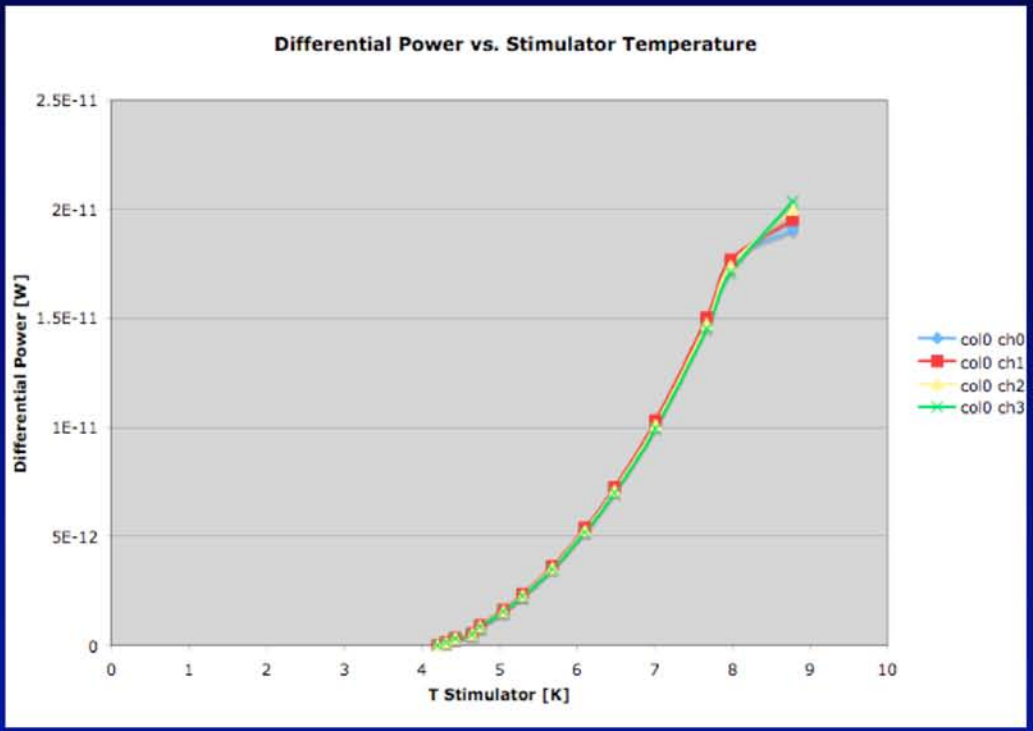
Color	Channel	Min	Max	Mean	Diff	StdDev	Samples
	DAC [0,3]	5,642.8	5,656.4	5,647.7	14	1.8	2000
	DAC [1,3]	5,865	5,879.8	5,872.0	15	2.3	2000
	DAC [2,3]	6,459	8,982.6	7,722.3	2,524	749.5	2000
	DAC [3,3]	4,874	7,378.6	6,110.9	2,505	750.9	2000
	DAC [4,3]	5,368.8	7,910.4	6,646.8	2,542	754.2	2000
	DAC [5,3]	5,357	7,843.6	6,593.9	2,487	751.9	2000

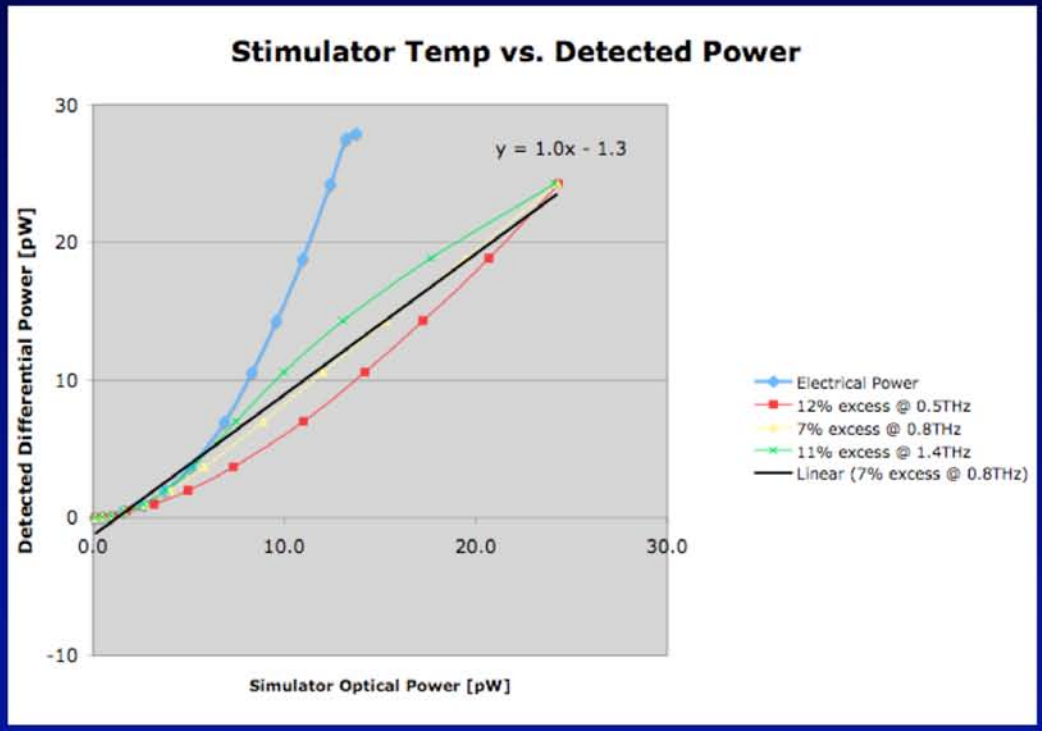


Color	Channel	Min	Max	Mean	Diff	StdDev	Samples
	DAC [0,3]	5,677.6	5,691.8	5,684.1	14	2.1	2000
	DAC [1,3]	6,323.6	6,755	6,728.2	431	82.9	2000
	DAC [2,3]	3,089	5,052	4,196.2	1,963	661.3	2000
	DAC [3,3]	4,258.2	6,425.6	5,529.2	2,167	714.2	2000
	DAC [4,3]	3,874.8	6,117.4	5,199.9	2,243	736.7	2000
	DAC [5,3]	4,549	5,764.4	5,102.0	1,215	456.8	2000

- (left) Detectors (both Bi-coated and uncoated) show response to bias ramp
- (right) Bi-coated detectors detect blackbody radiation from stimulator

Lab Tests

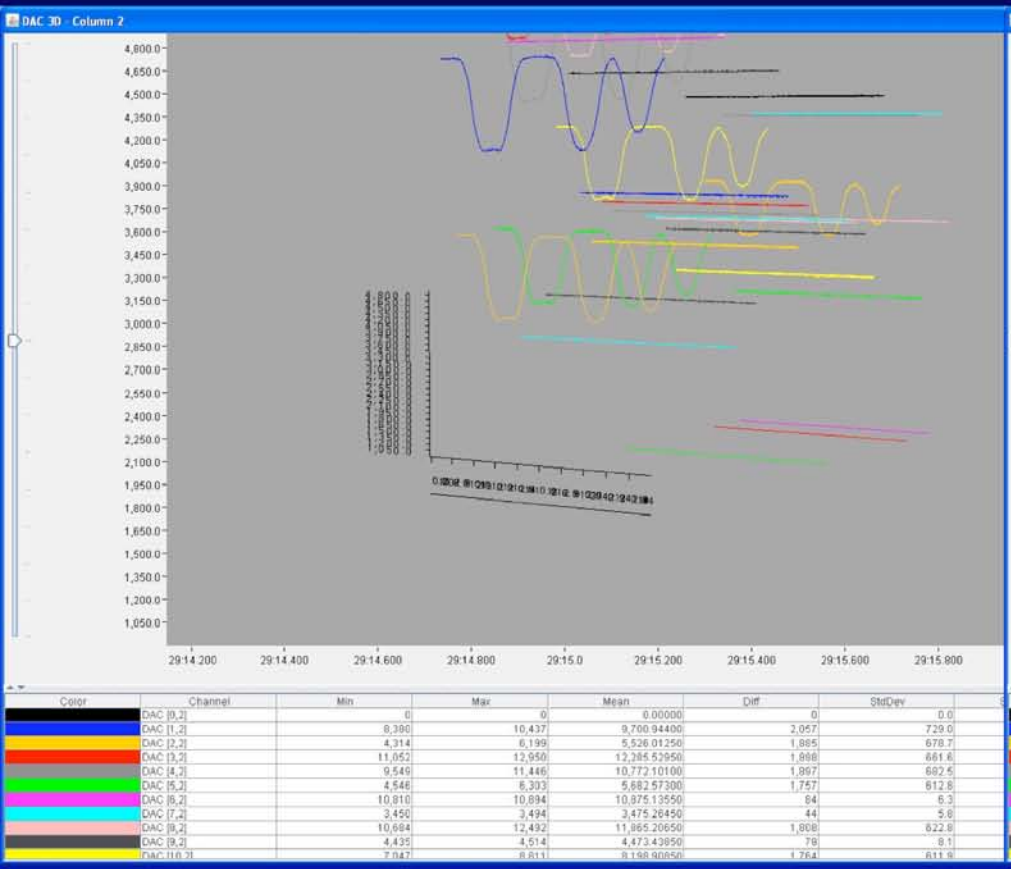




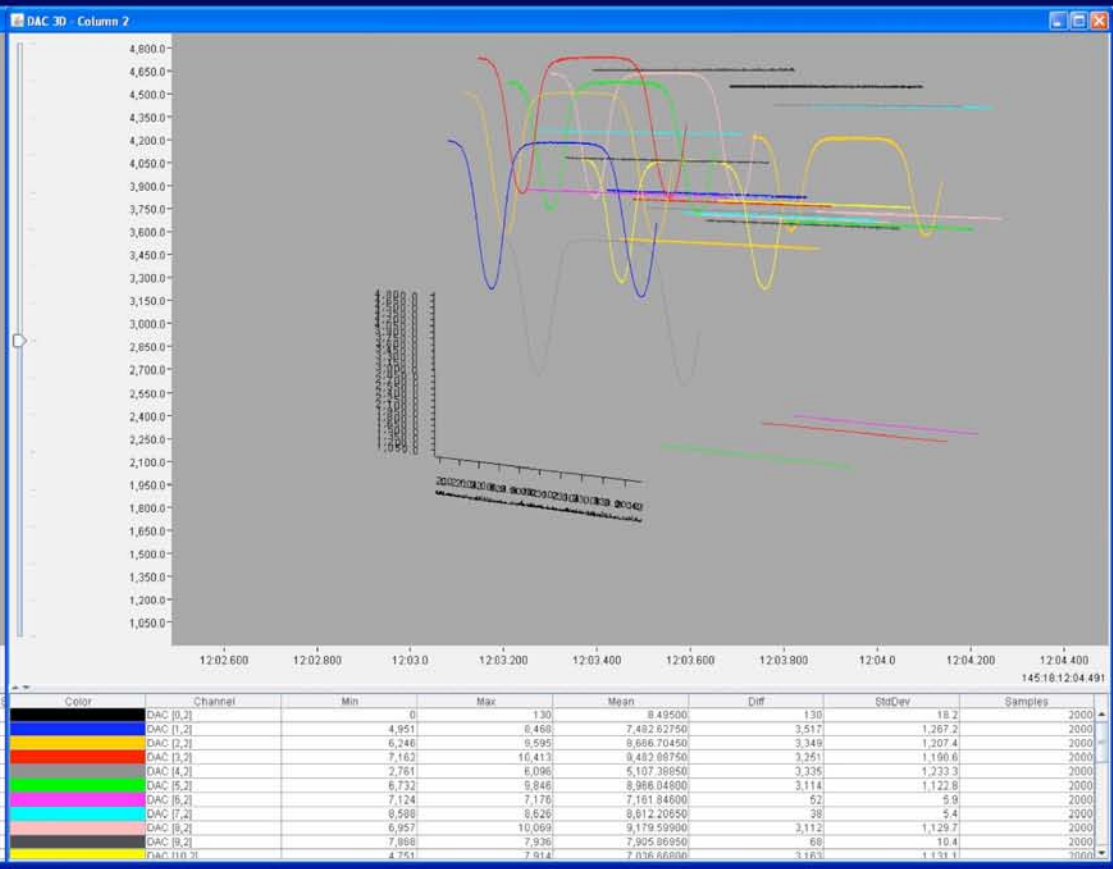
- Bi-coated detectors detect blackbody radiation from stimulator
- Radiometric measurement helps model detector response/filter properties

Lab Tests

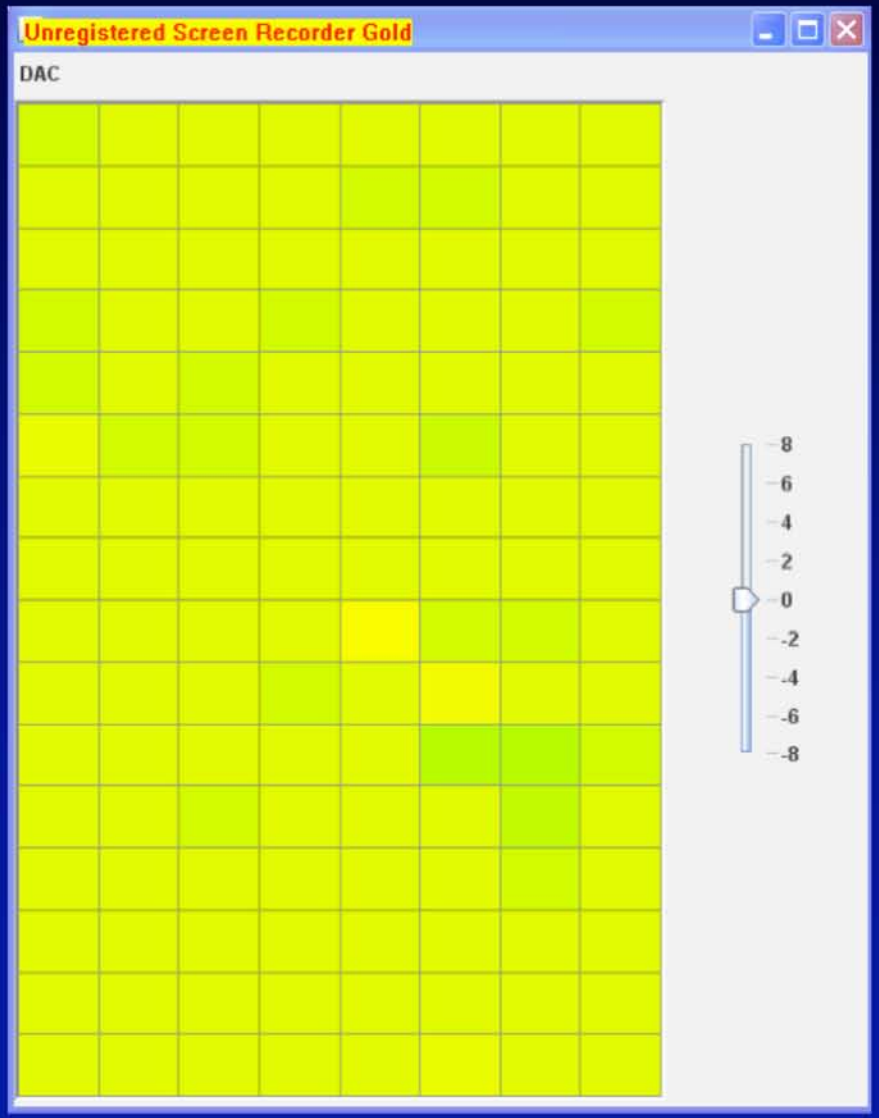
PI's hand waving



Technician's hand waving

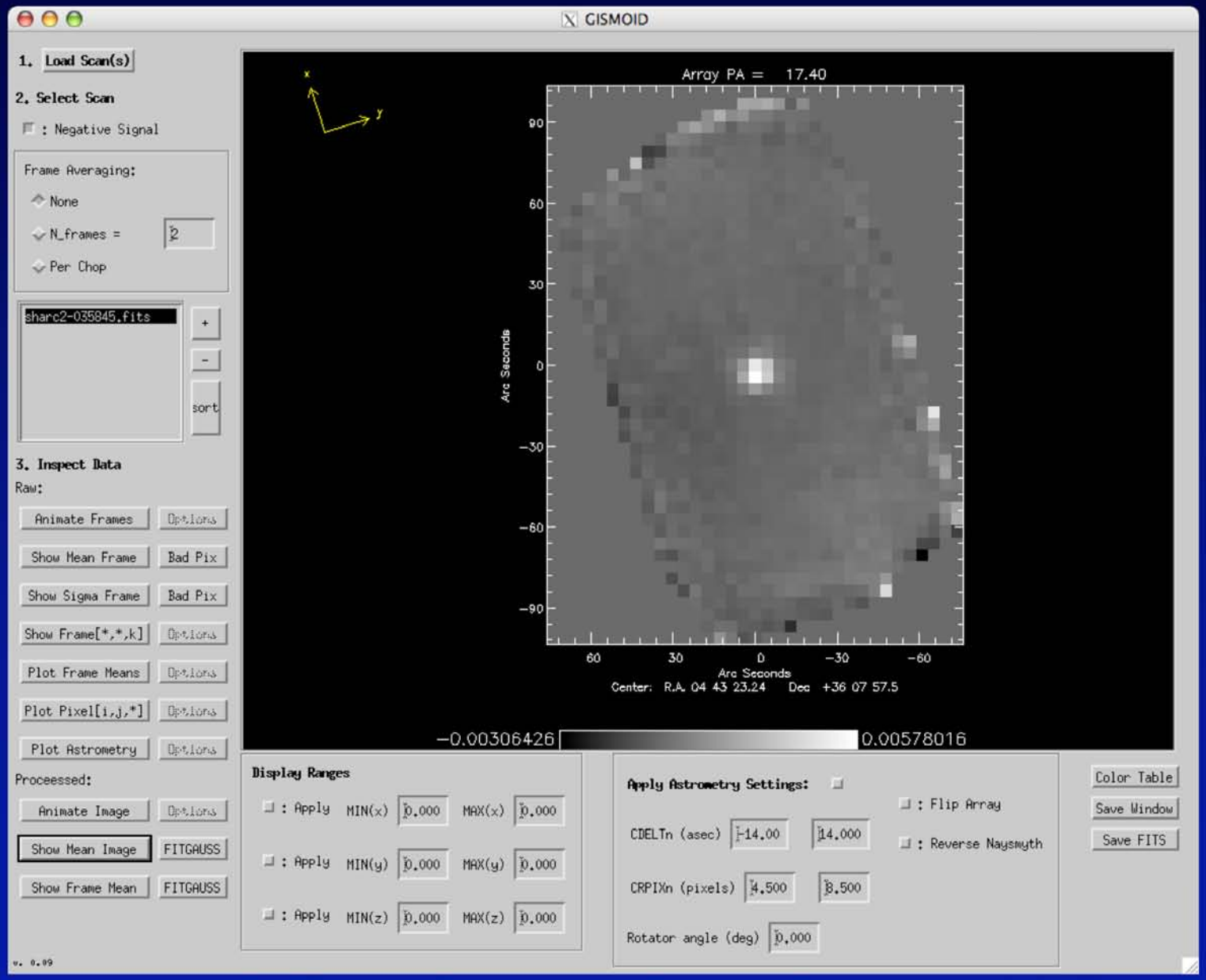


Lab Tests



GISMO detects blackbody radiation from heated baffles

Data Reduction Software



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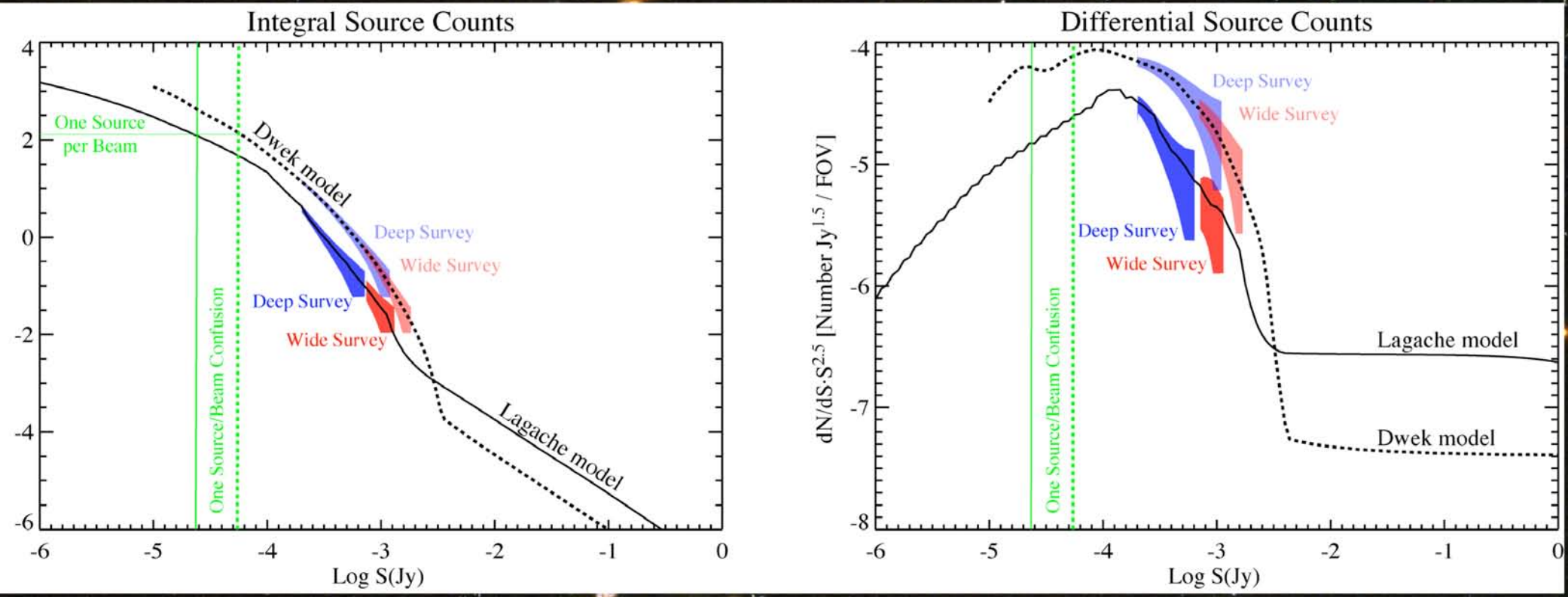
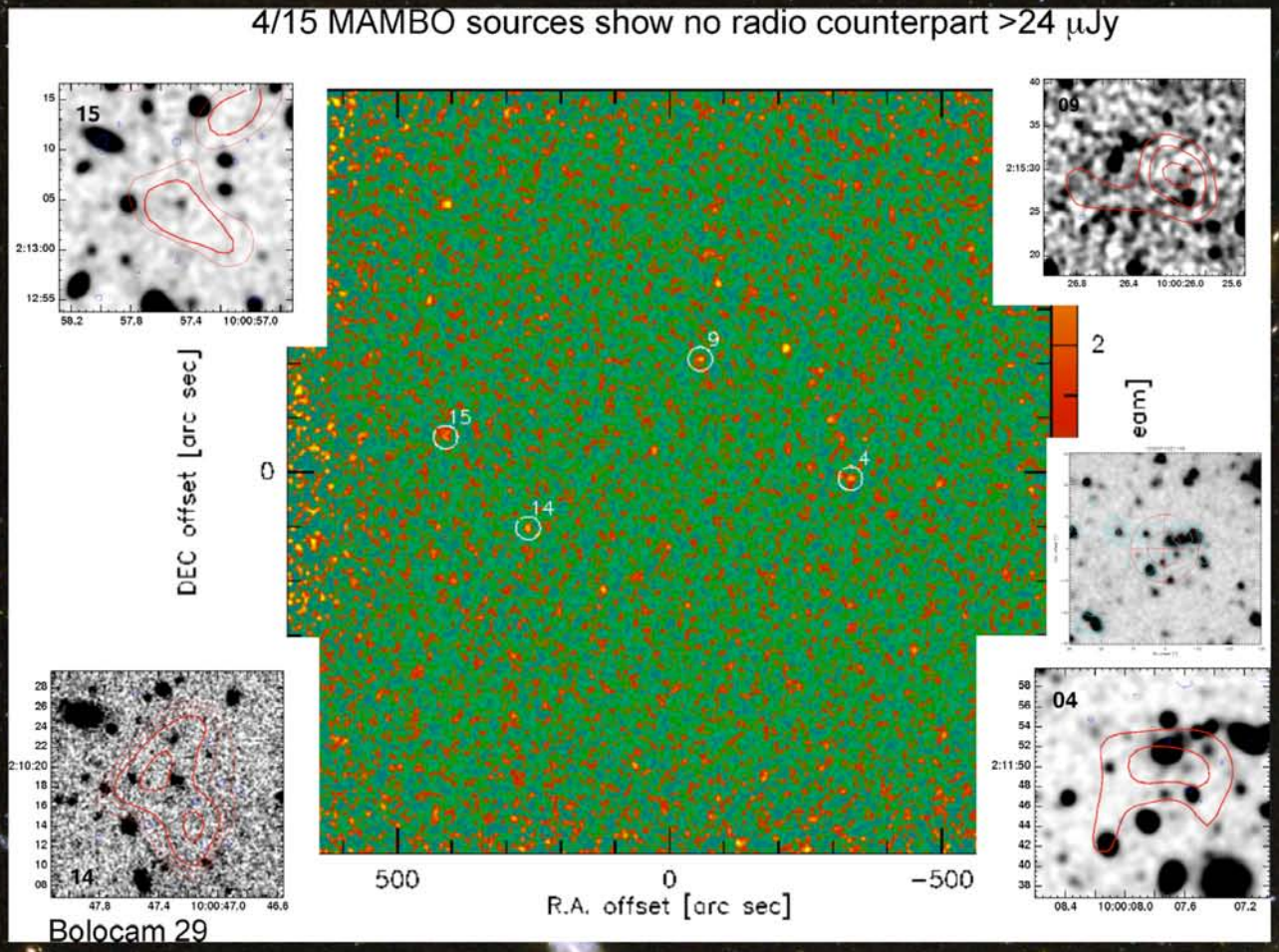
Probing the Evolution of Galaxies via Source Counts at 2 mm wavelength



. The blind survey limits for the integral (left) and differential (right) galaxy number counts show GISMO can effectively discriminate between two models of galaxy evolution (shown here Lagache et al., 2004, and Dwek, priv. comm.)

Identification and Characterization of Submillimeter Galaxies at the the Highest Redshifts



1mm-detected sources without radio counterparts are likely very high redshift candidates. (Bertoldi et al., ApJ, submitted)

Search for High-Redshift Galaxy Clusters: Tracing the Primordial Distribution of Massive Dark Matter Halos

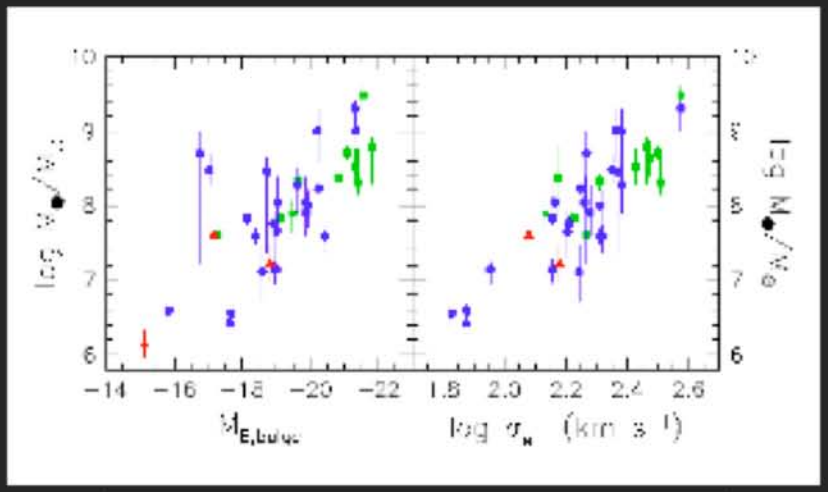
- Rare, luminous high redshift quasars provide a powerful probe of structure formation and biasing in the early universe, as they can be found out to the largest distances
- The formation of elliptical galaxies and massive bulges is accompanied by an early QSO phase (e.g. Kauffmann & Haehnelt, 2000), linking high-z quasars to early formation of massive galaxies.
- At high redshifts, luminous quasars are expected to reside within some of the most massive halos at those epochs. Hence they are found near high peaks (4-5 σ or more) of the large scale density field (e.g. Efstathiou & Rees 1988, Nusser & Silk 1993) that collapsed sufficiently early

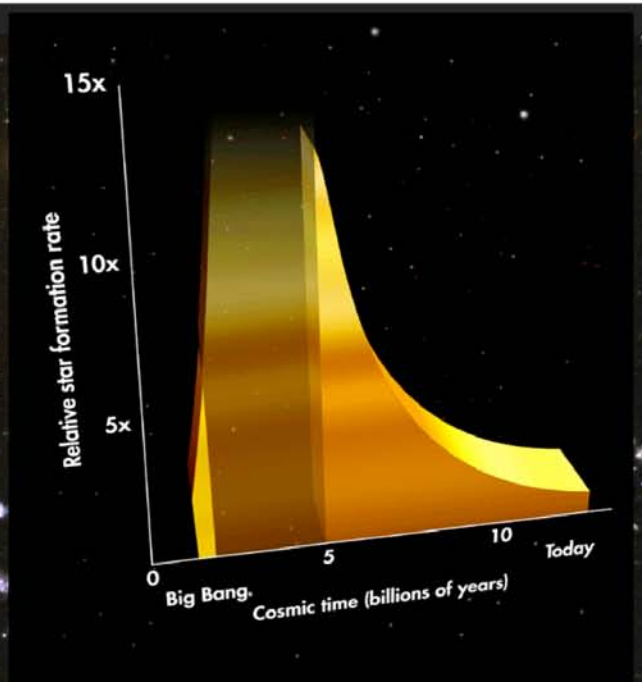
GISMO's Primary Science

- Galaxy formation: feedback, environment
- Correlation between mass of bulges and central black hole
- Star formation history
- Complement existing surveys and provide Target Lists for NGST, Herschel, ALMA

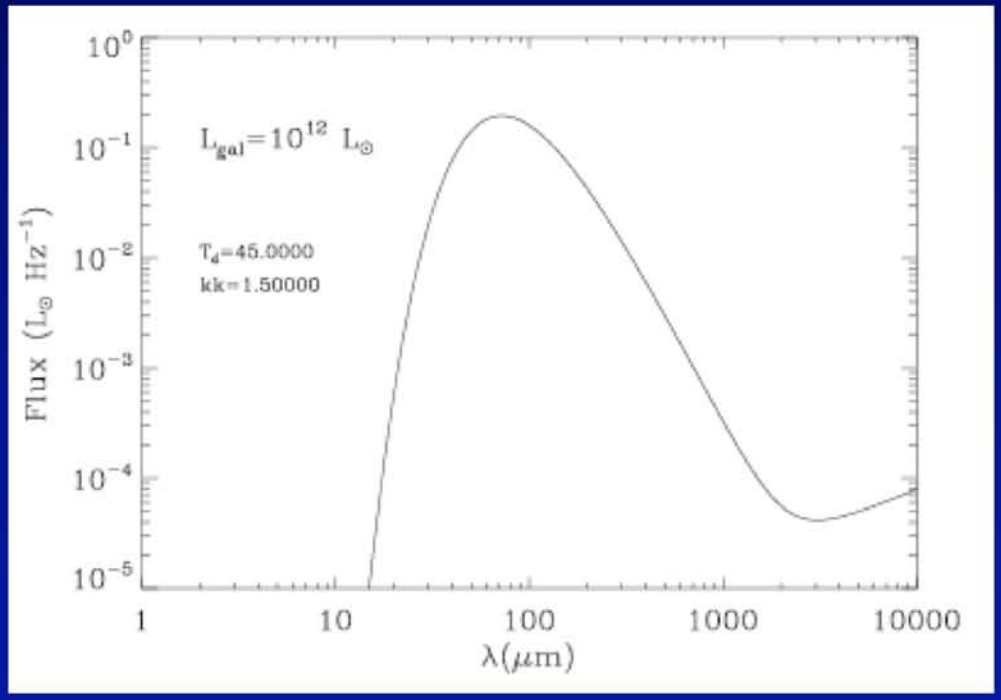
Lilly-Madau Diagramm

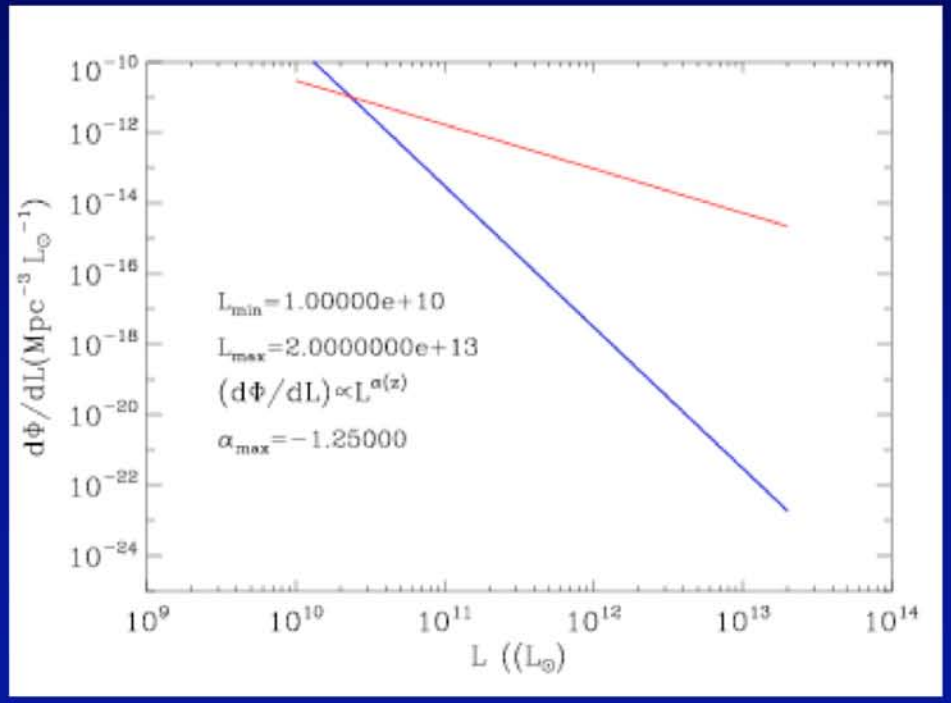
+





GISMO 2mm Camera Science





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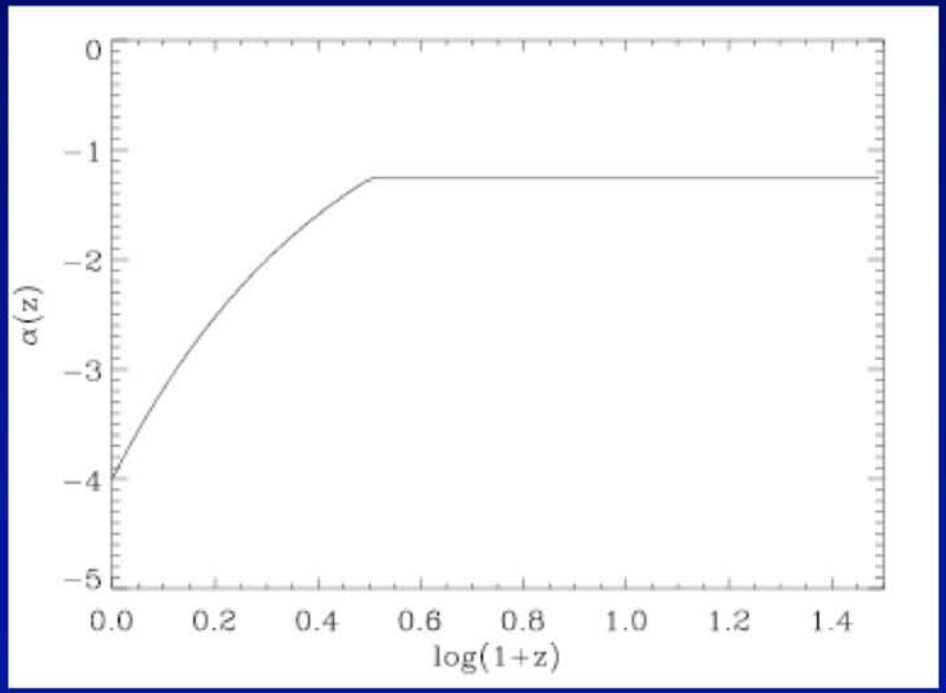
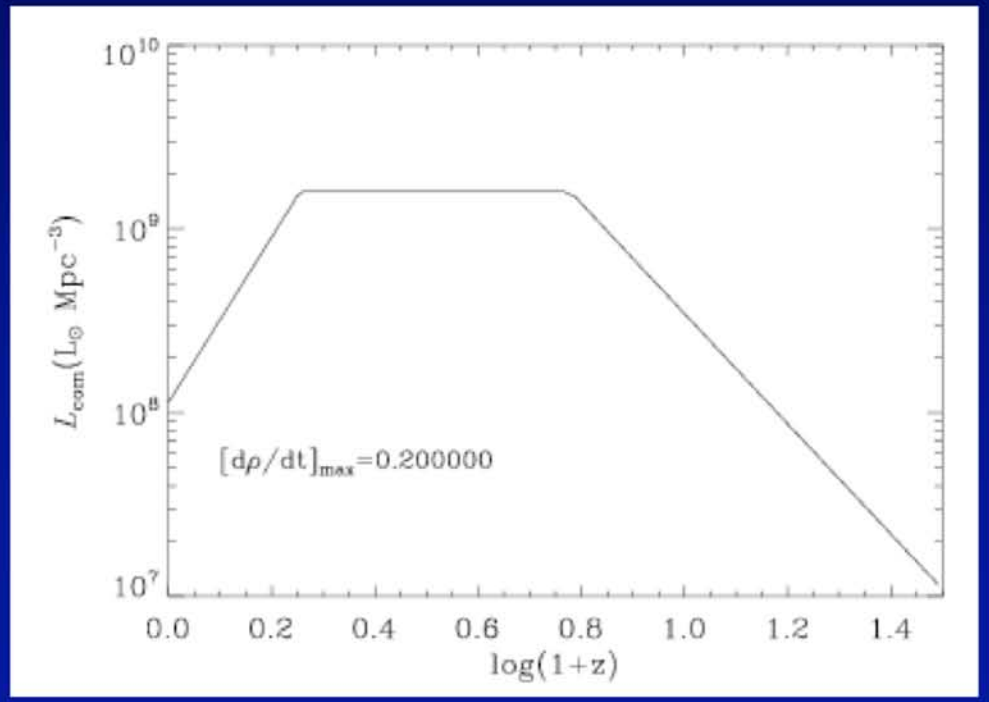
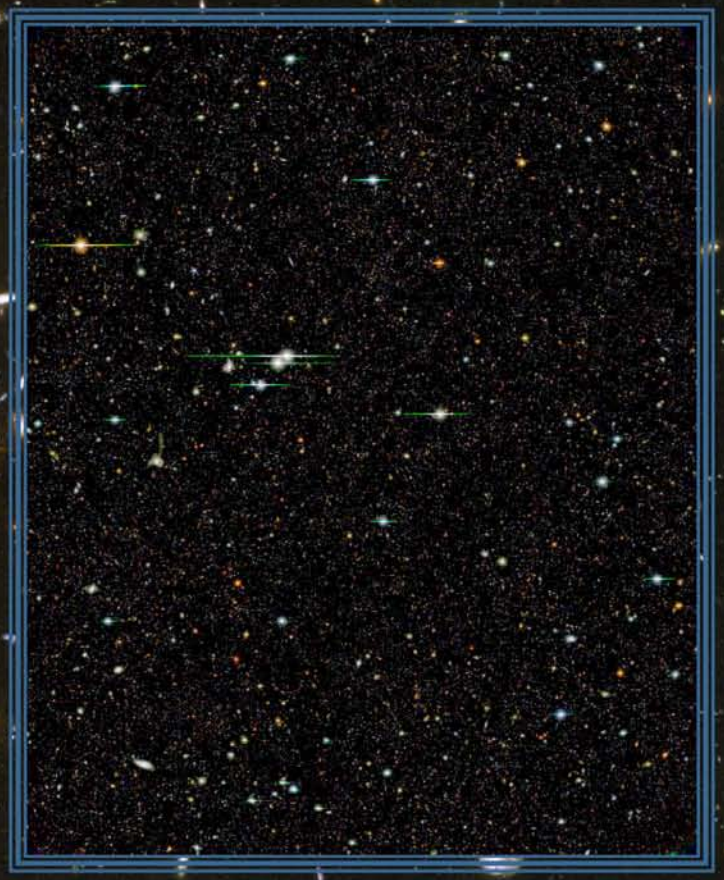




Probing the Star Formation Rates in High-z Lyα Galaxies

• Among the known kinds of high redshift galaxies, Lyman-α Emitters (LAEs) are ubiquitous (e.g. Fynbo et al. 2001, Kodaira et al. 2003) and poor in nuclear activity (e.g. Malhotra et al. 2003, Wang et al. 2004).
• they possess impressive line equivalent widths (EWs > 240Å are observed, Malhotra & Rhoads 2002),), indicating that they are young galaxies undergoing a strong burst of star formation.
• The Lyα line, however, is a poor indicator of star formation rate (SFR) as it is susceptible to both scattering by neutral hydrogen and absorption by dust and therefore uncertain corrections have to be applied to derive, e.g., global star formation rates.



. Subaru Deep Field provides candidate LAEs for GISMO (from the SDF Project web site, http://step.mtk.nao.ac.jp/sdf/project/)