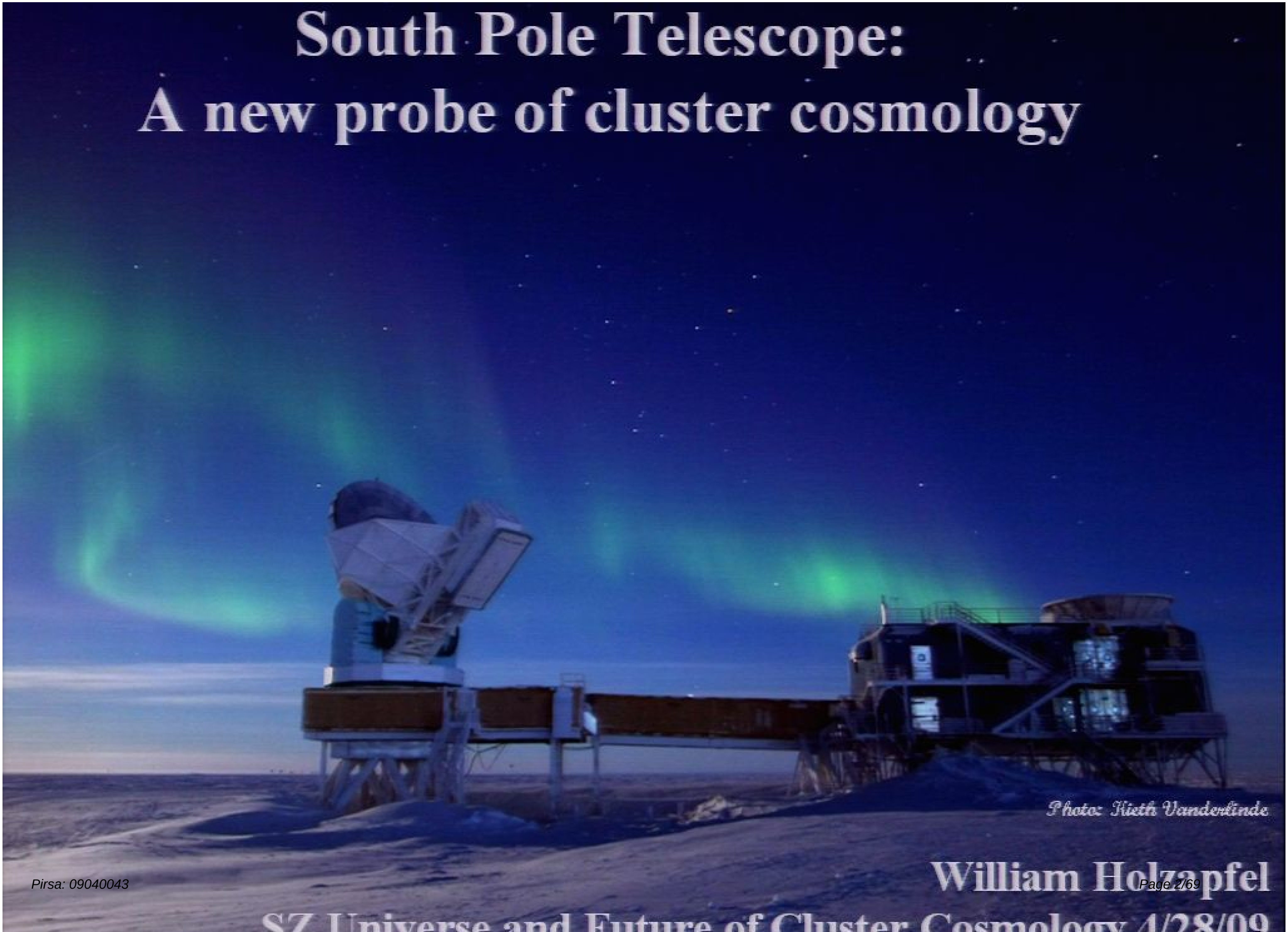
Title: South Pole Telescope: A new probe of cluster cosmology

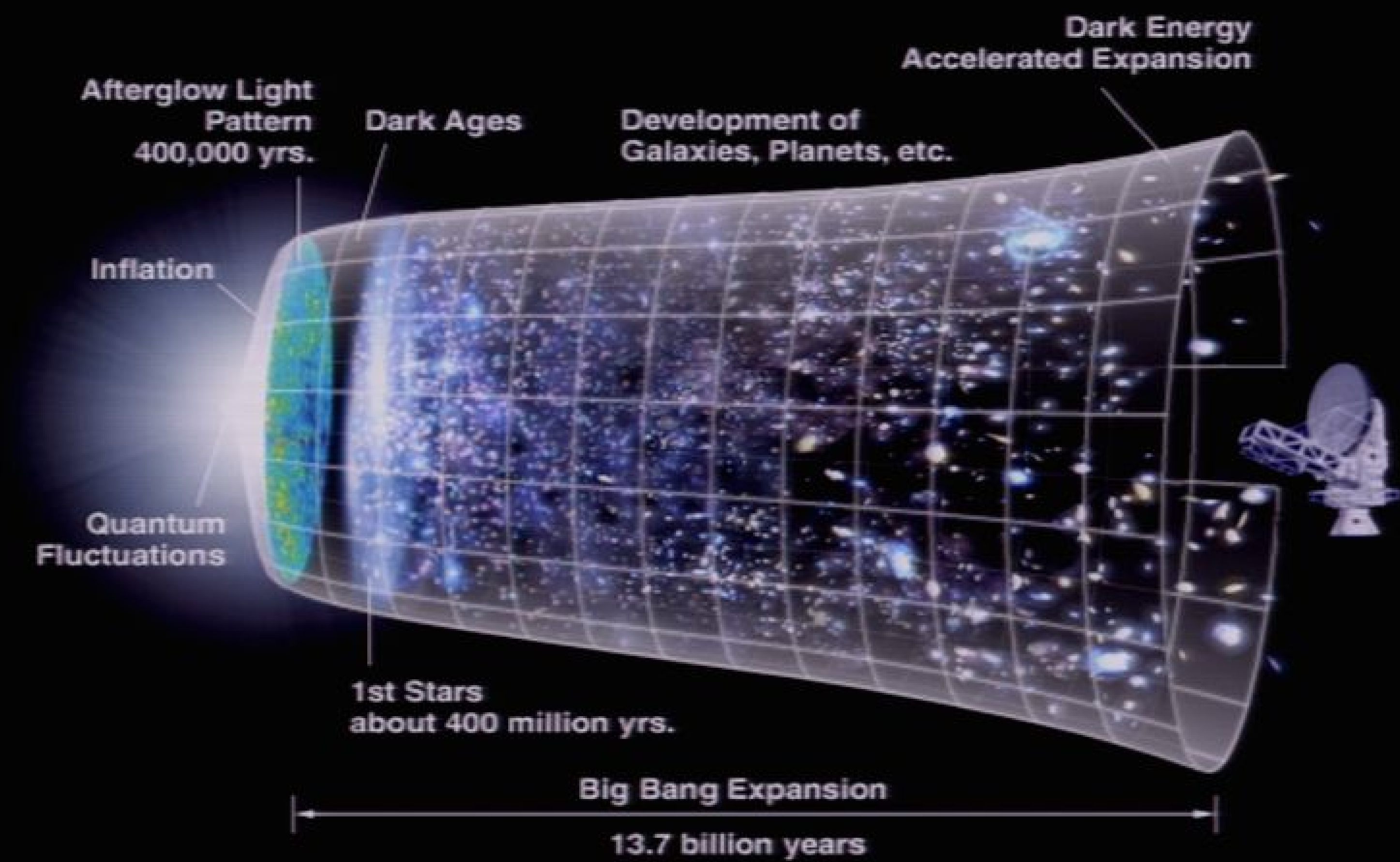
Date: Apr 28, 2009 02:00 PM

URL: http://pirsa.org/09040043

Abstract: The South Pole Telescope (SPT) is a 10-meter diameter telescope with a 960 element millimeter-wavelength bolometric receiver, which is in the midst of its third season of observations at the South Pole. The SPT has been optimized for measurements of the Sunyaev-Zel'dovich (SZ) effect in galaxy clusters. With this instrument, we are surveying the southern sky to create a mass limited catalog of galaxy clusters out to the epoch of their formation. This program of observations will also produce significant detections of the kinetic SZ effect and weak gravitational lensing of the CMB, a multi-band millimeter-wavelength point source catalog, and images of the SZ effect in known galaxy clusters with unprecedented sensitivity. In this talk, I will discuss the design, construction, and deployment of the SPT telescope and receiver, progress of the observations, and conclude with a discussion of future plans.


South Pole Telescope:
A new probe of cluster cosmology
Photo: Kieth Vanderlinde
William Holzapfel
SZ Universe and Future of Cluster Cosmology 4/28/09

he Cosmic Microwave Background is powerful tool for the study of Cosmology



Rapid
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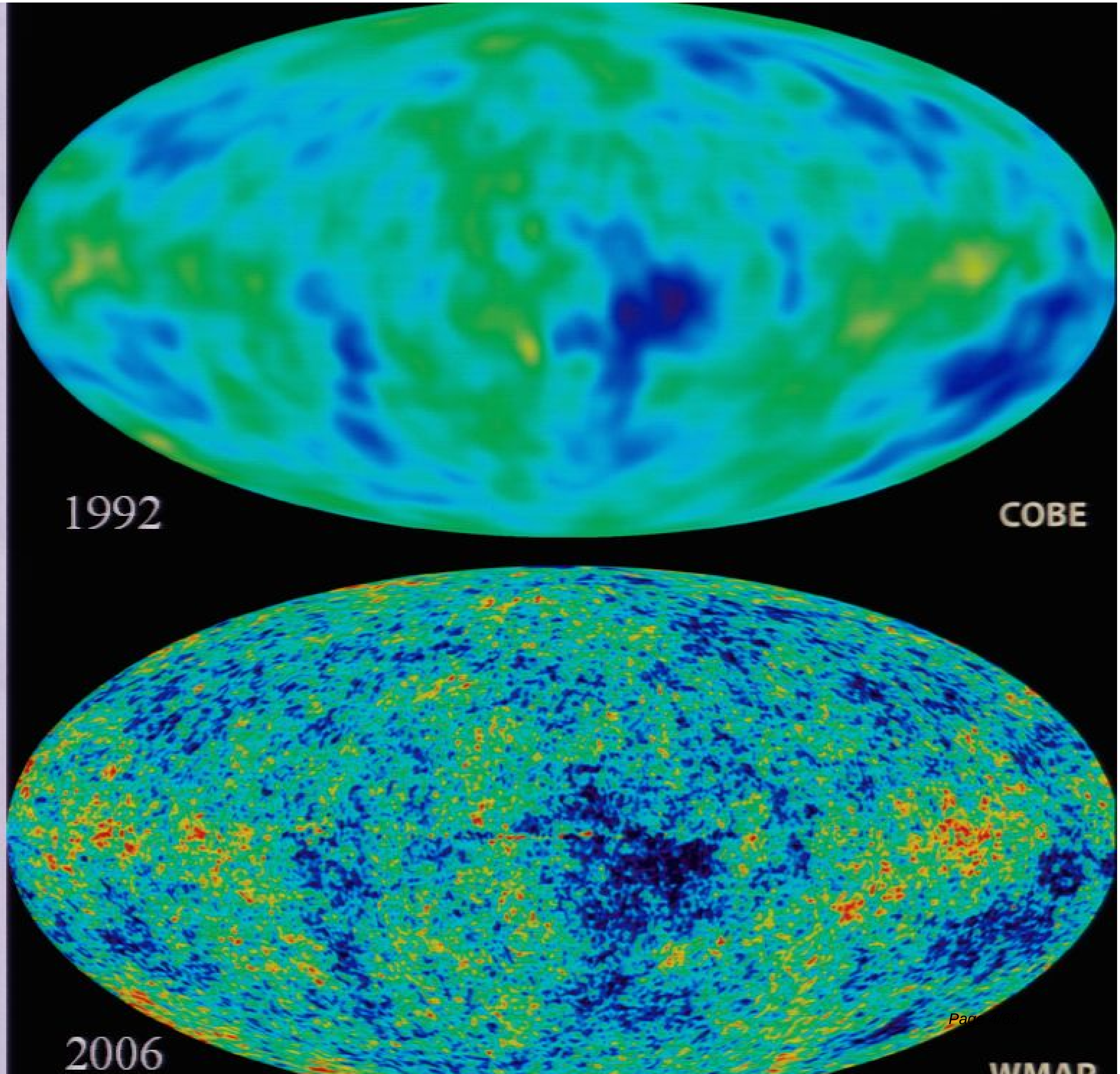
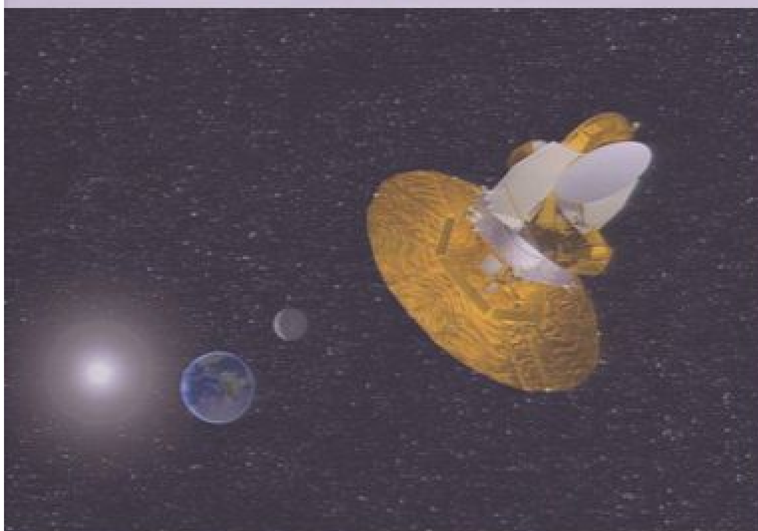


Amazing agreement between diverse experiments.

WMAP



L2

ACBAR

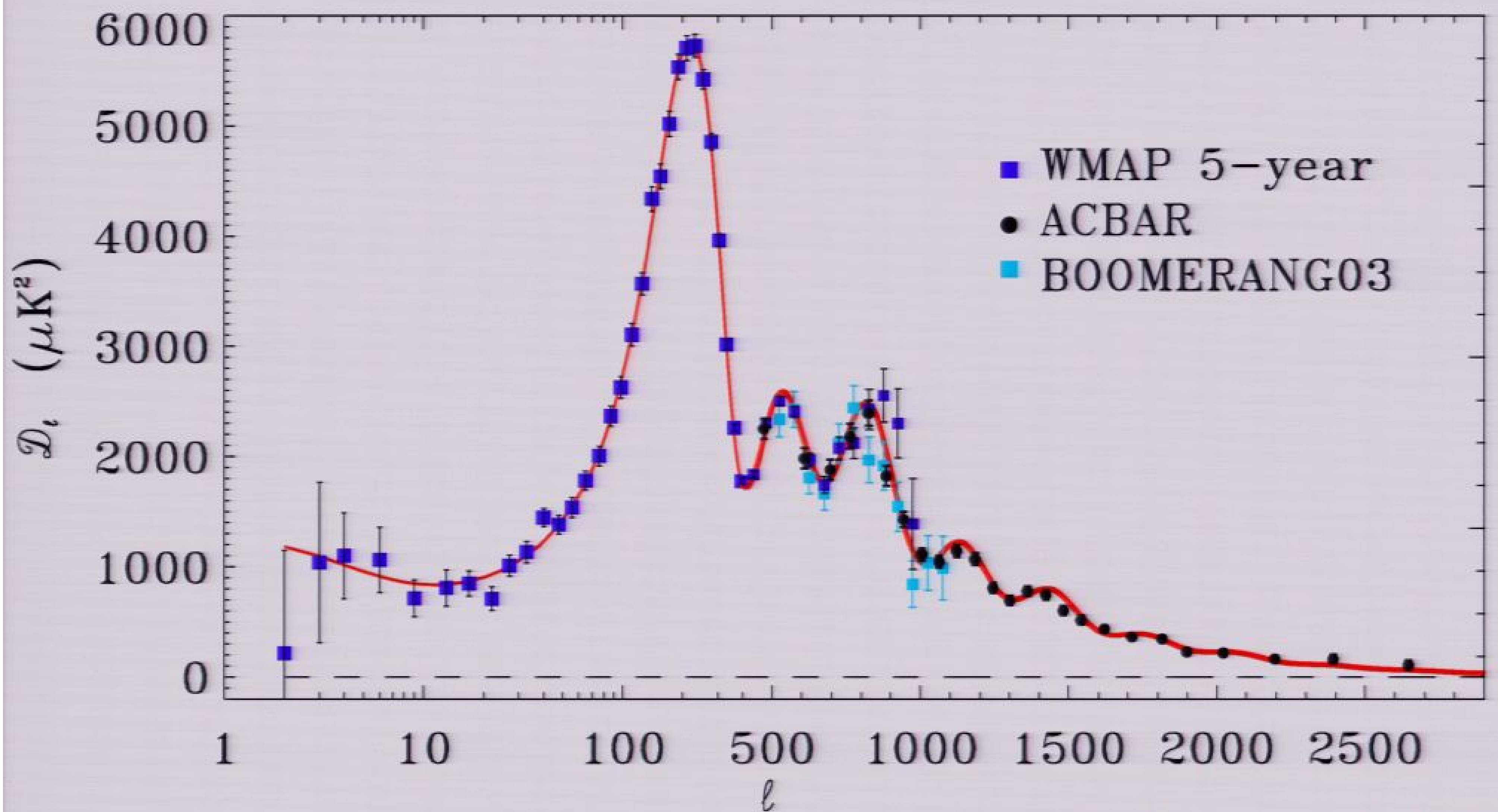
South Pole

BOOMERanG

120,00 ft
Above the
Ross Ice
Shelf

Current CMB Power Spectrum

- Completely consistent with standard Λ-CDM models



Reichardt et al. 2008

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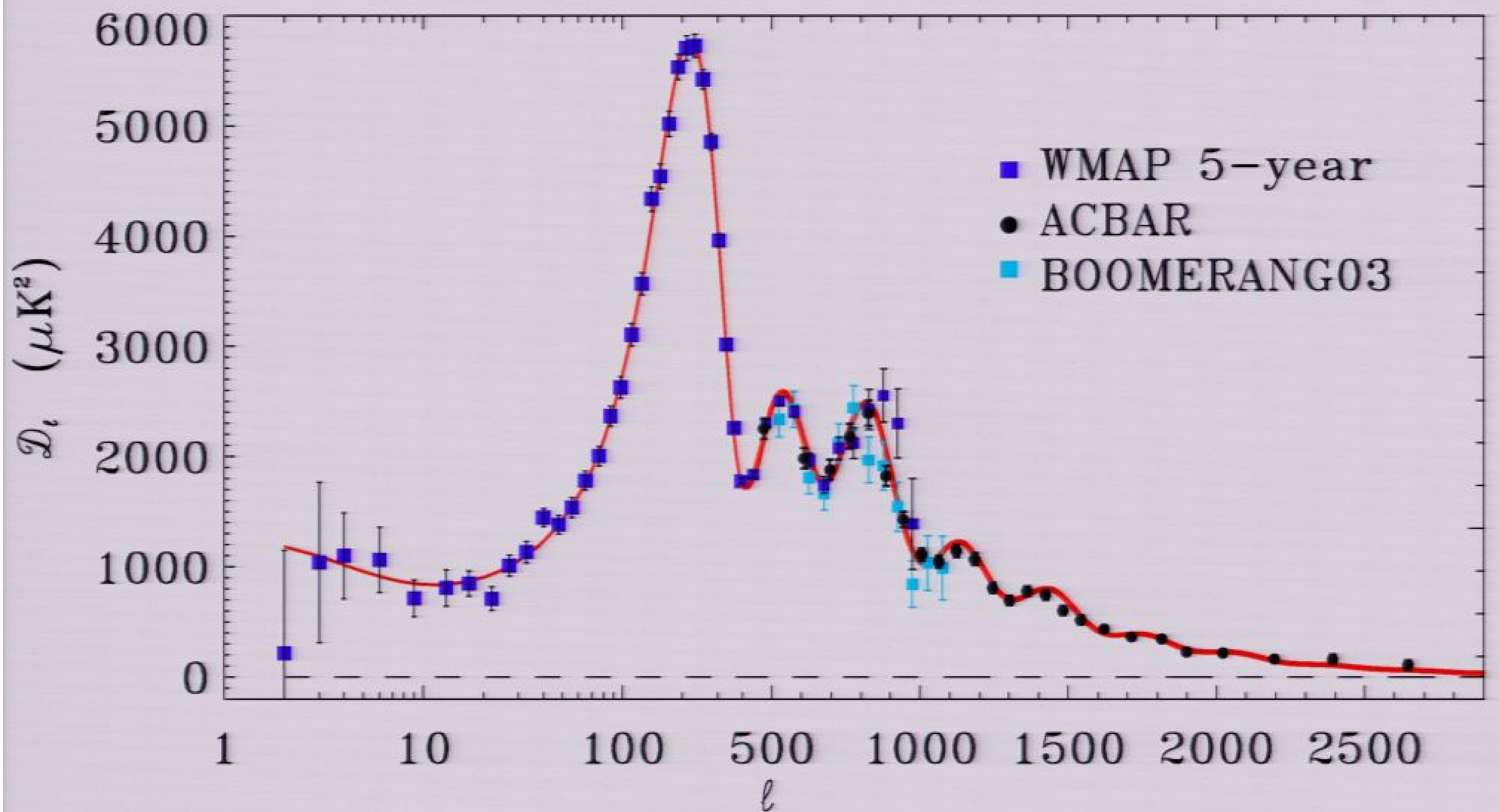

Reichardt et al. 2008

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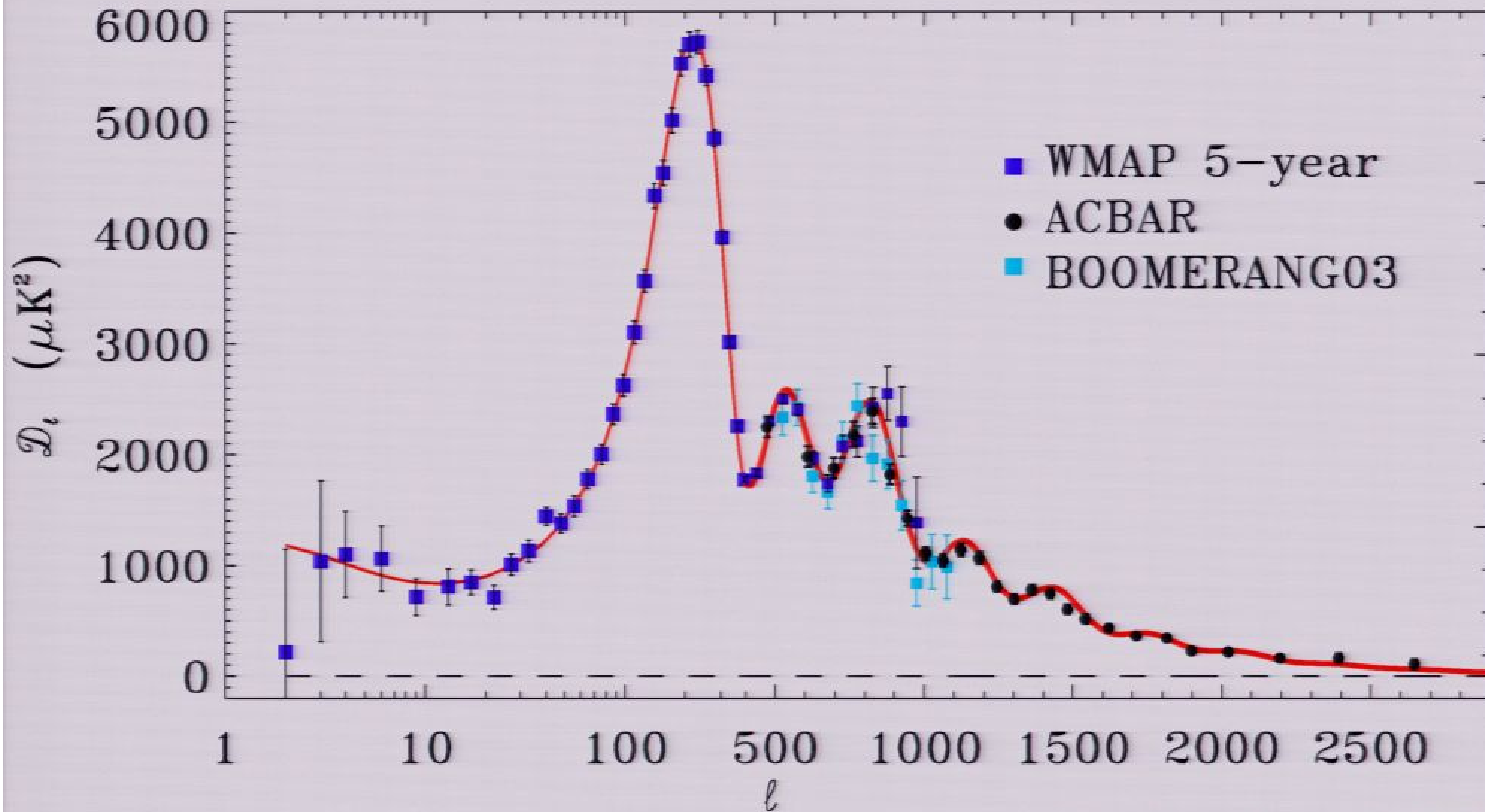
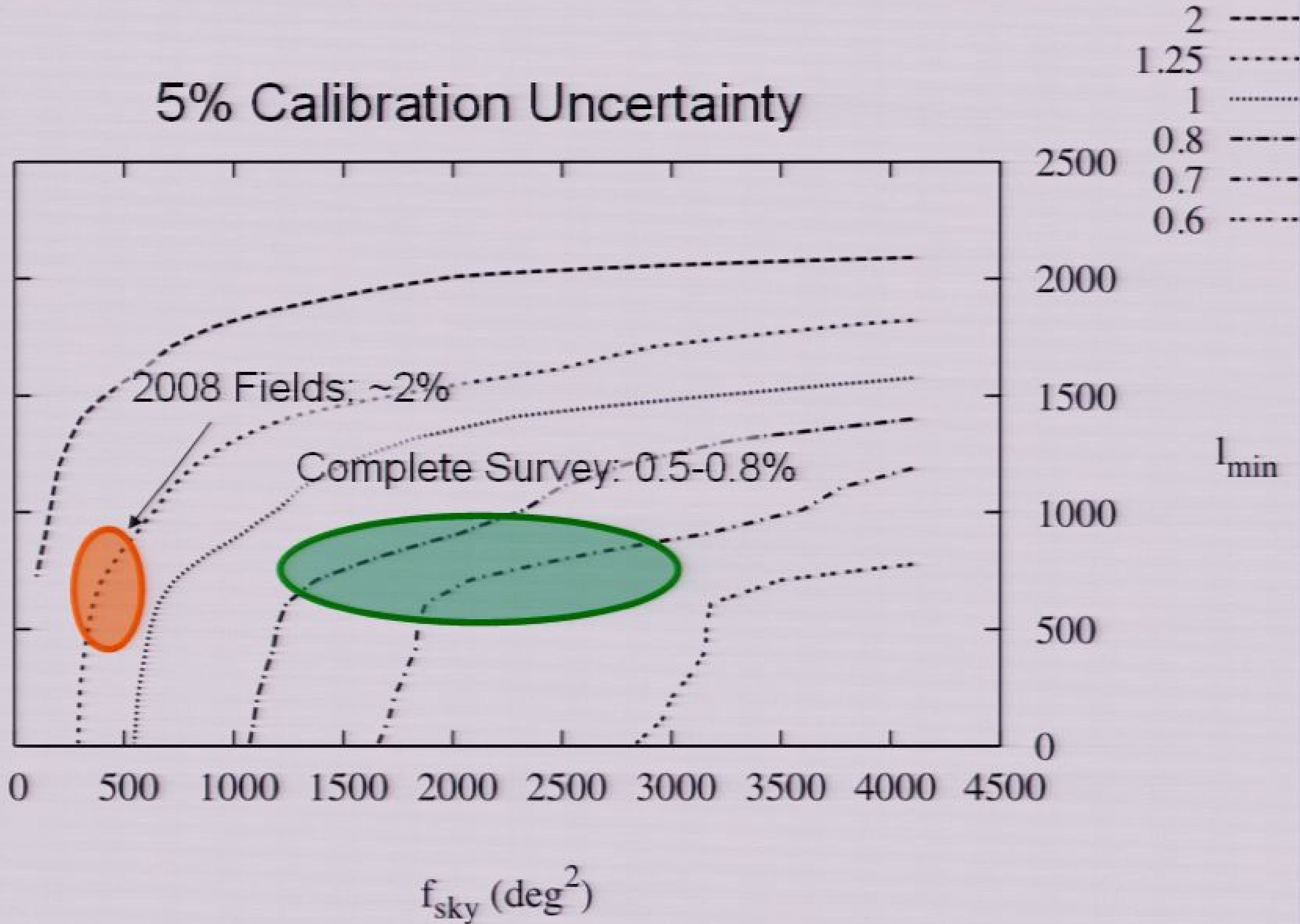


Reichardt et al. 2008

SPT n_s Projections

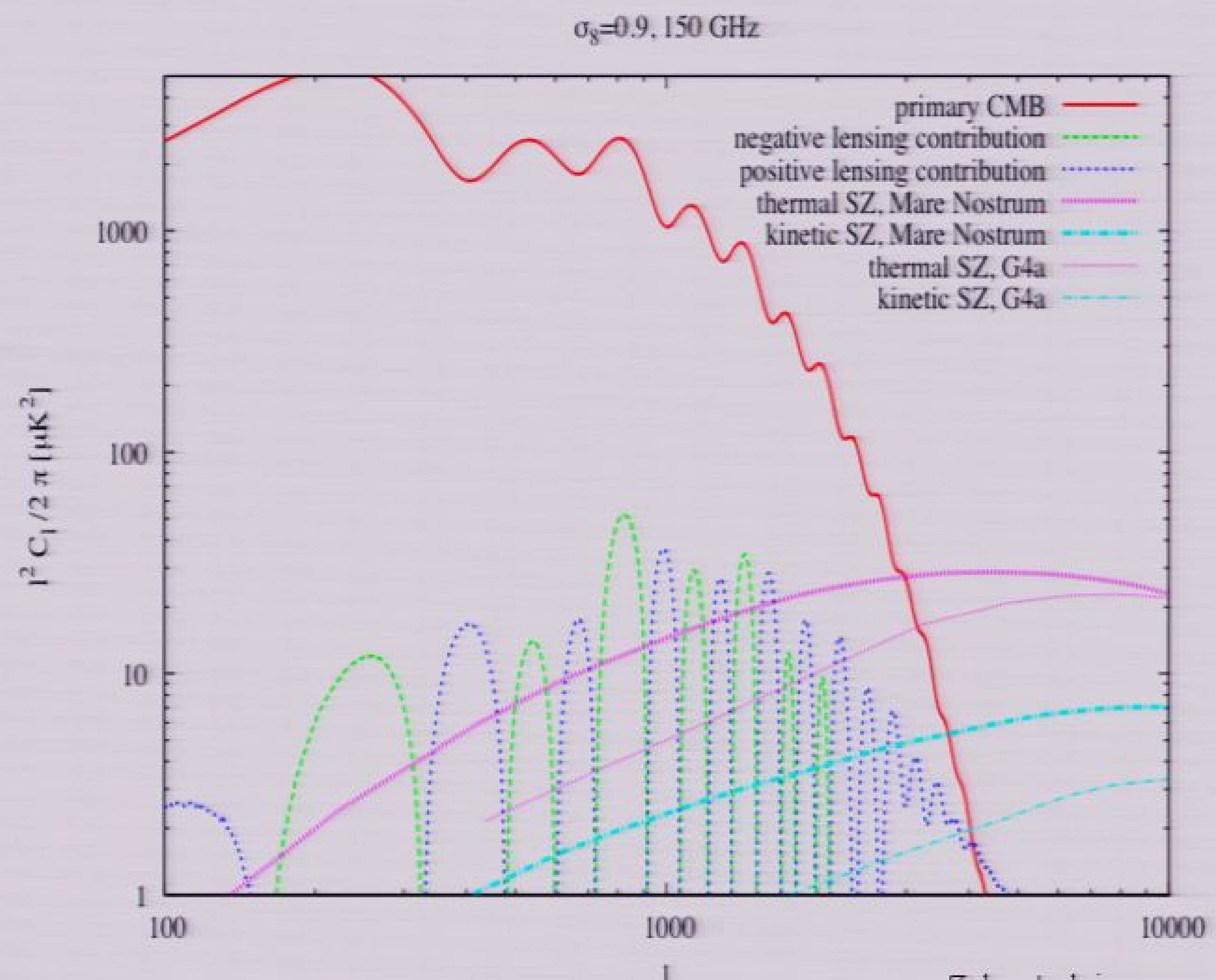


CMB interacts with intervening structure

• Secondary Anisotropies of the CMB become significant on smaller scales

▪everal Effects:

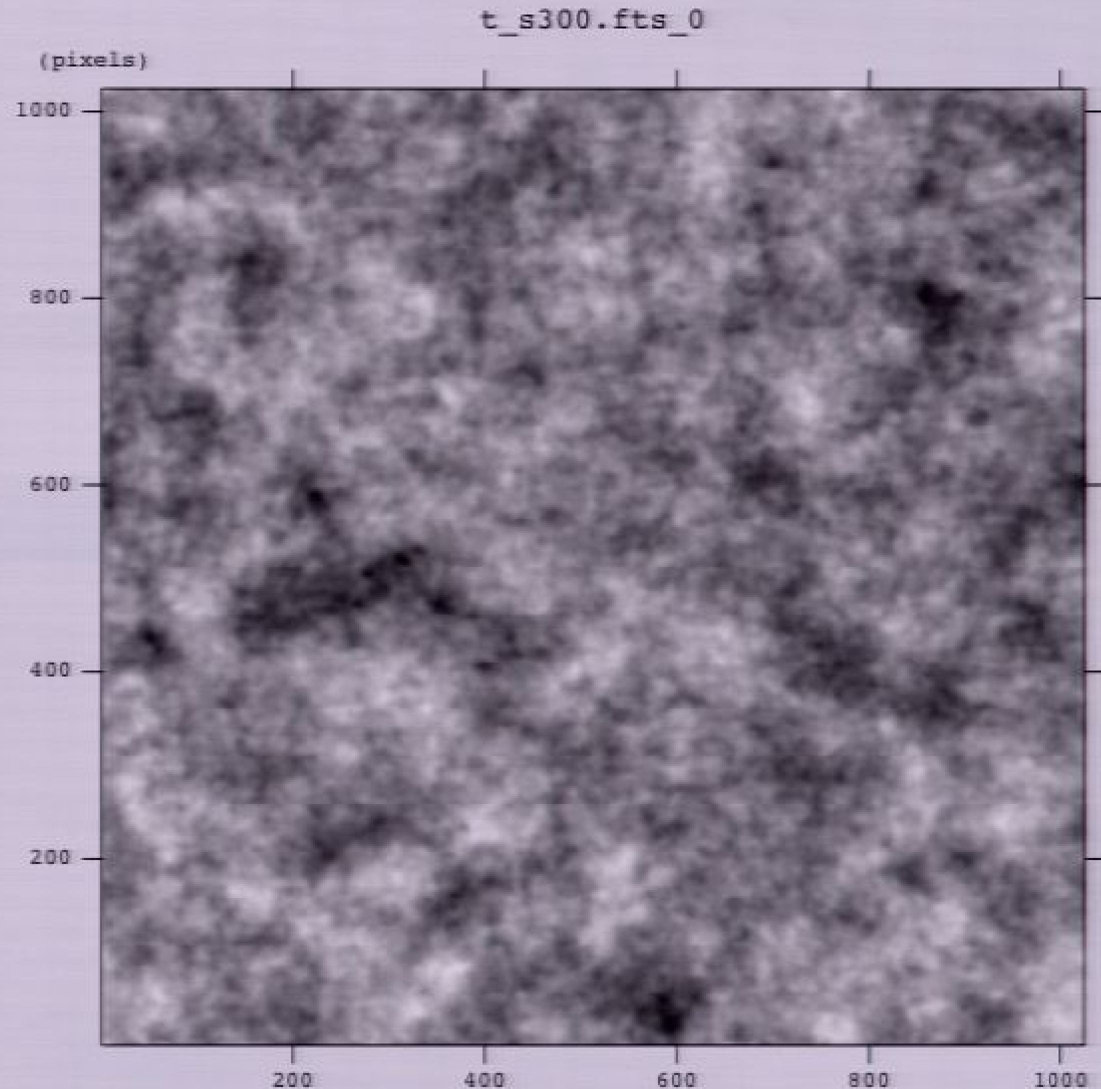
- Gravitational Lensing f CMB ▪mooths wiggles)
- Thermal SZ effect
- Kinetic SZ effect



Zahn et al. in prep

.ensing introduces a non-Gaussianity to the observed CMB

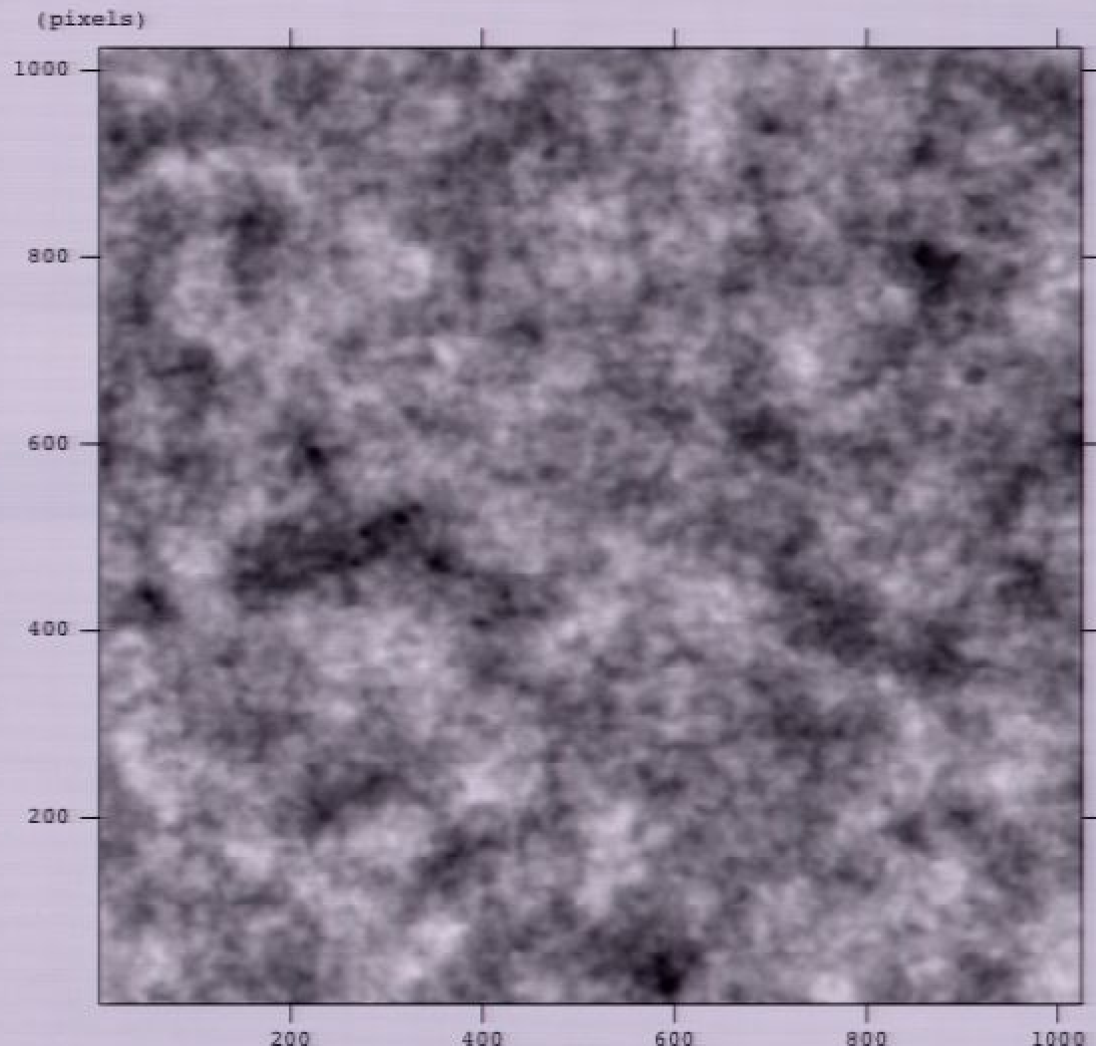
Unlensed temperature map



15X15 deg

Lensing introduces a non-Gaussianity to the observed CMB

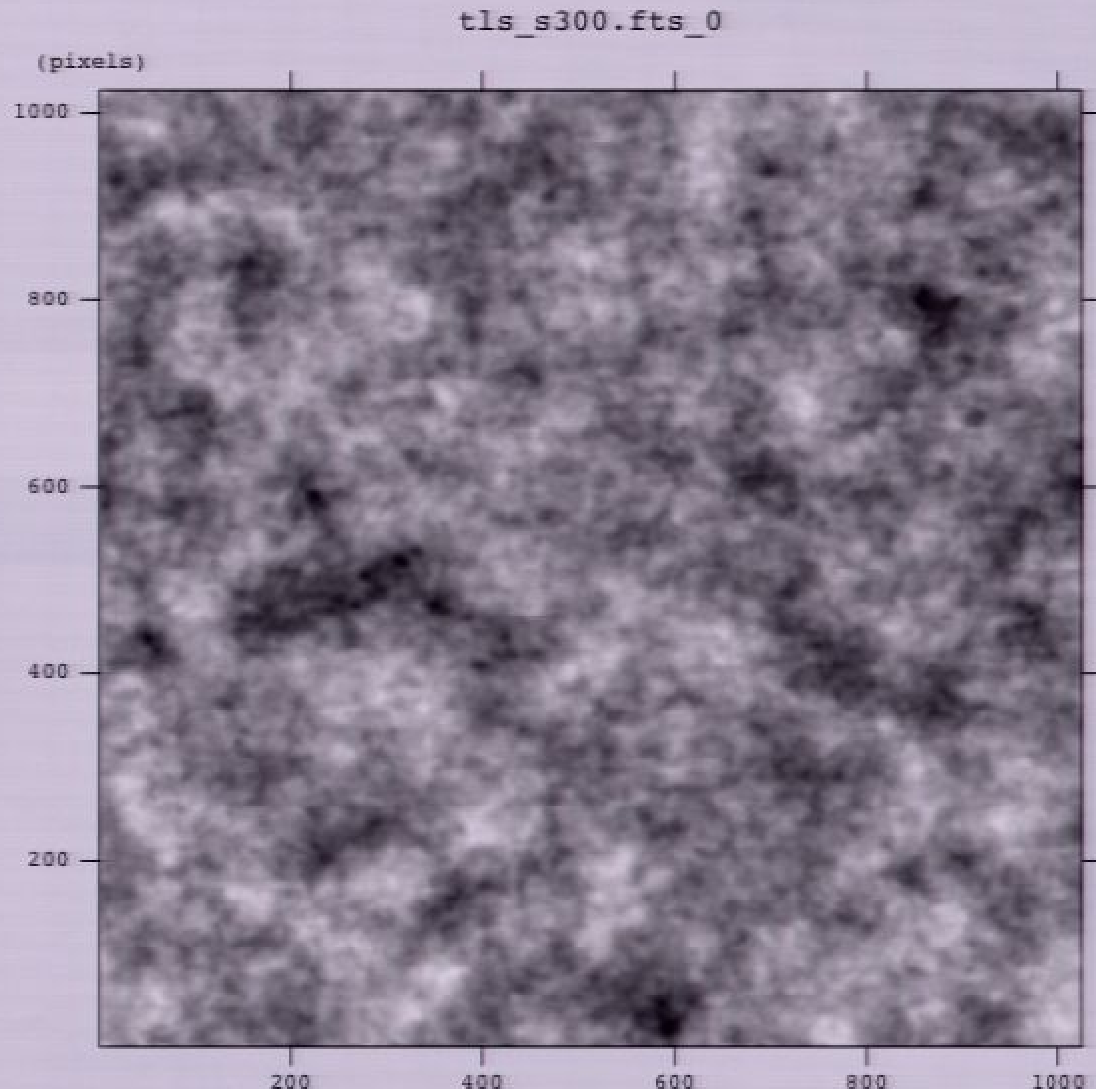
Lensed temperature map



15X15 deg

.ensing introduces a non-Gaussianity to the observed CMB

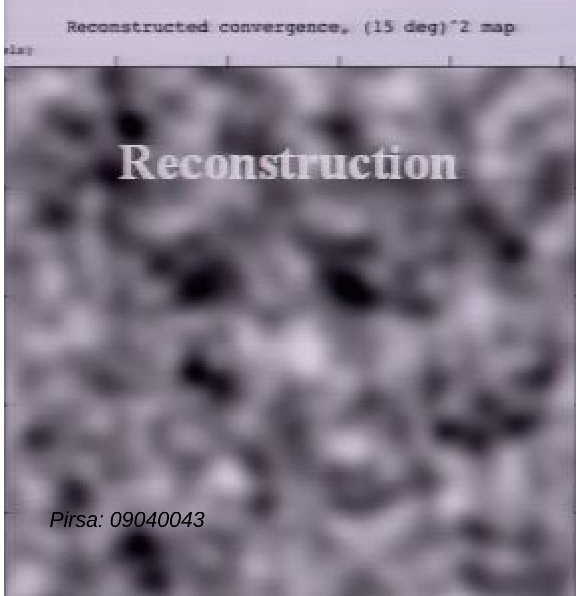
Lensed temperature map

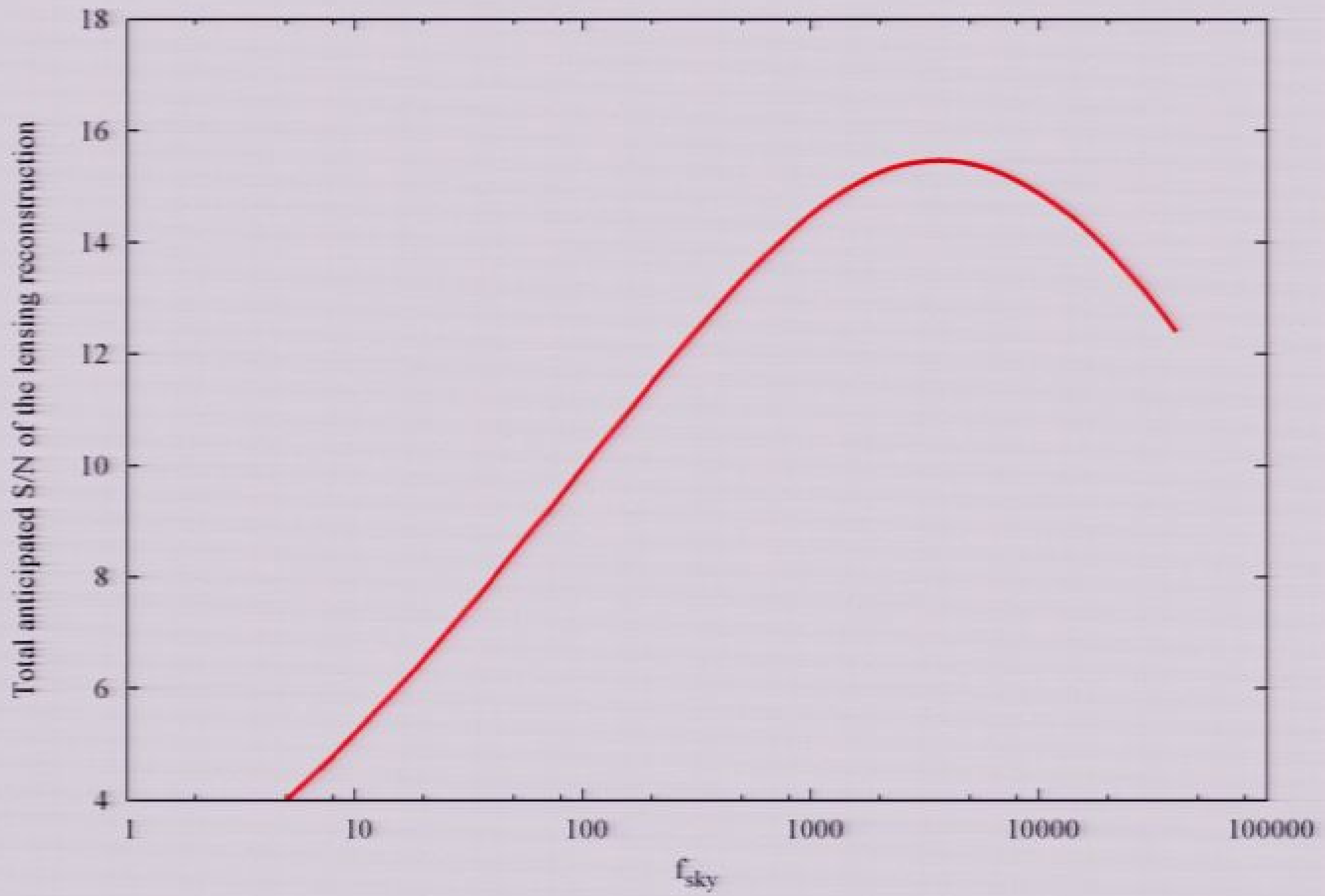


15X15 deg

SPT potential to reconstruct the lensing convergence with this years SPT survey data

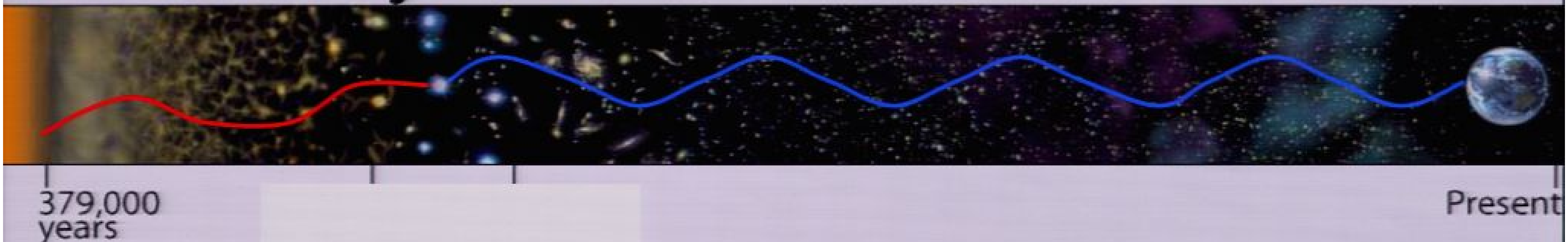
Input





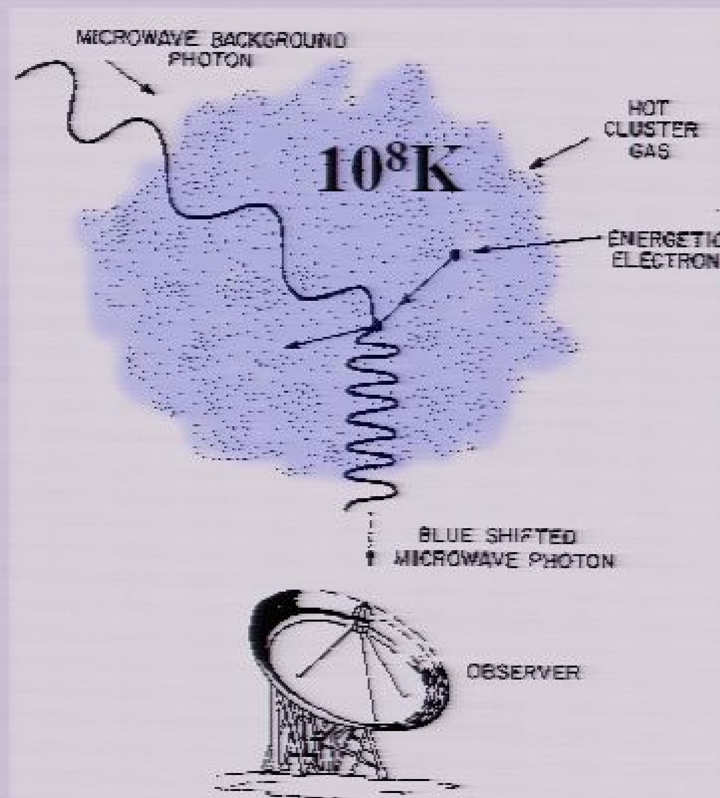
Oliver Zahn

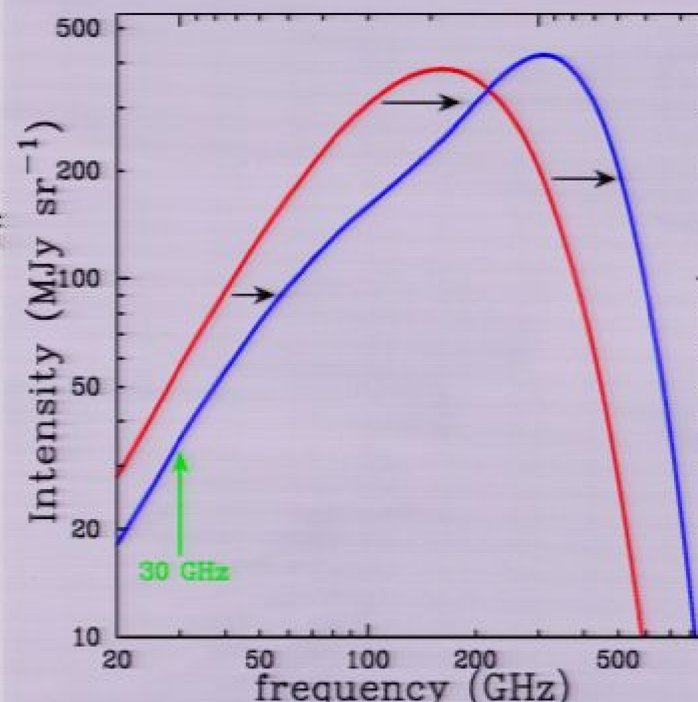
Sunyaev-Zel'dovich Effect



MB photons provide a backlight for structure in the universe.

1-2% of CMB photons traversing galaxy clusters are inverse Compton scattered to higher energy



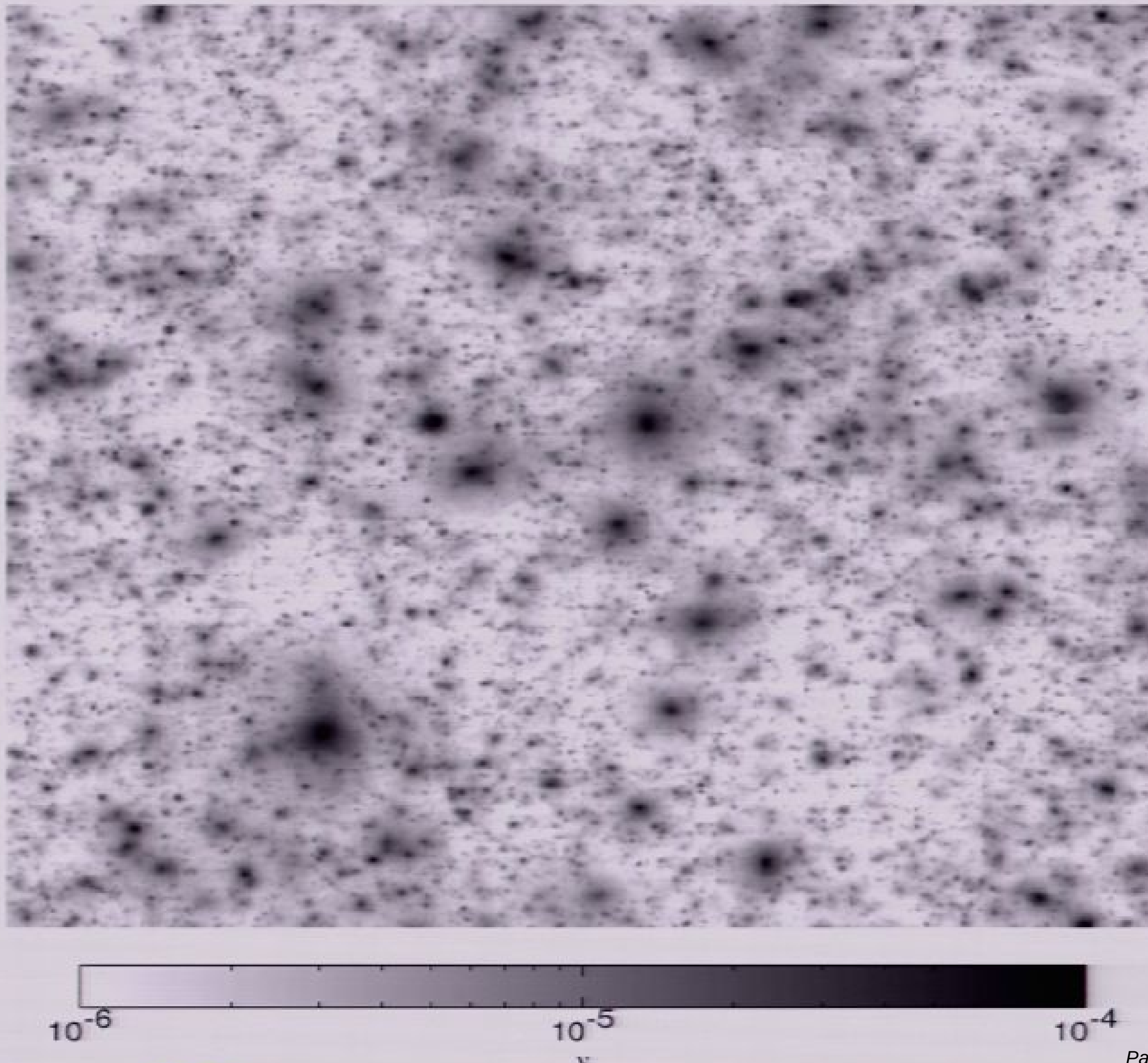


Kinetic Effect for cluster moving wrt CMB

Surface Brightness of the effect independent of redshift

SZ as a probe of Structure formation

Through the SZ effect we can study Galaxy Clusters out to the epoch of their formation



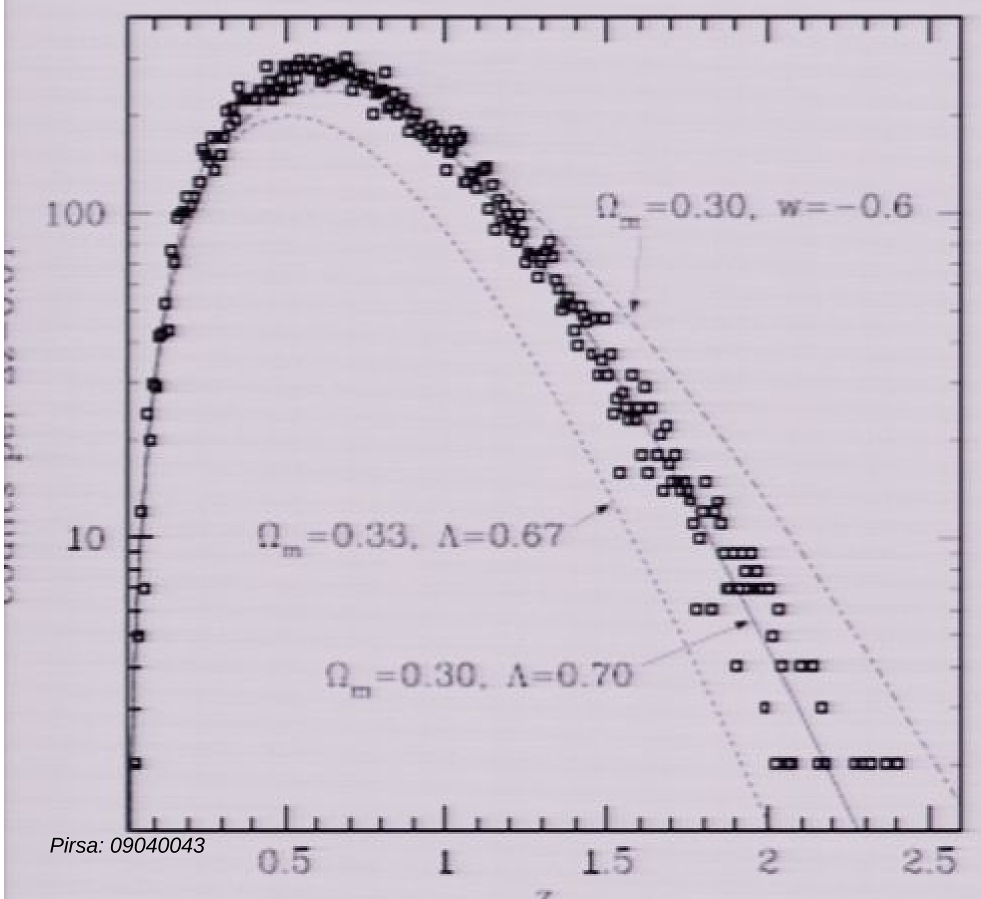
1 deg² of sky @ 150 GHz

Springel, White, Hernquist 2000

SPT Survey:

- ~2000 square degrees (by end of 2010)
- 90, 150, 220 GHz
- 15μK/arcmin pixel
- hundreds - thousands of clusters
- Mass limited down to ~ few x 10^{14} solar masses

Self-calibration plus 100 clusters with 30% mass determinations



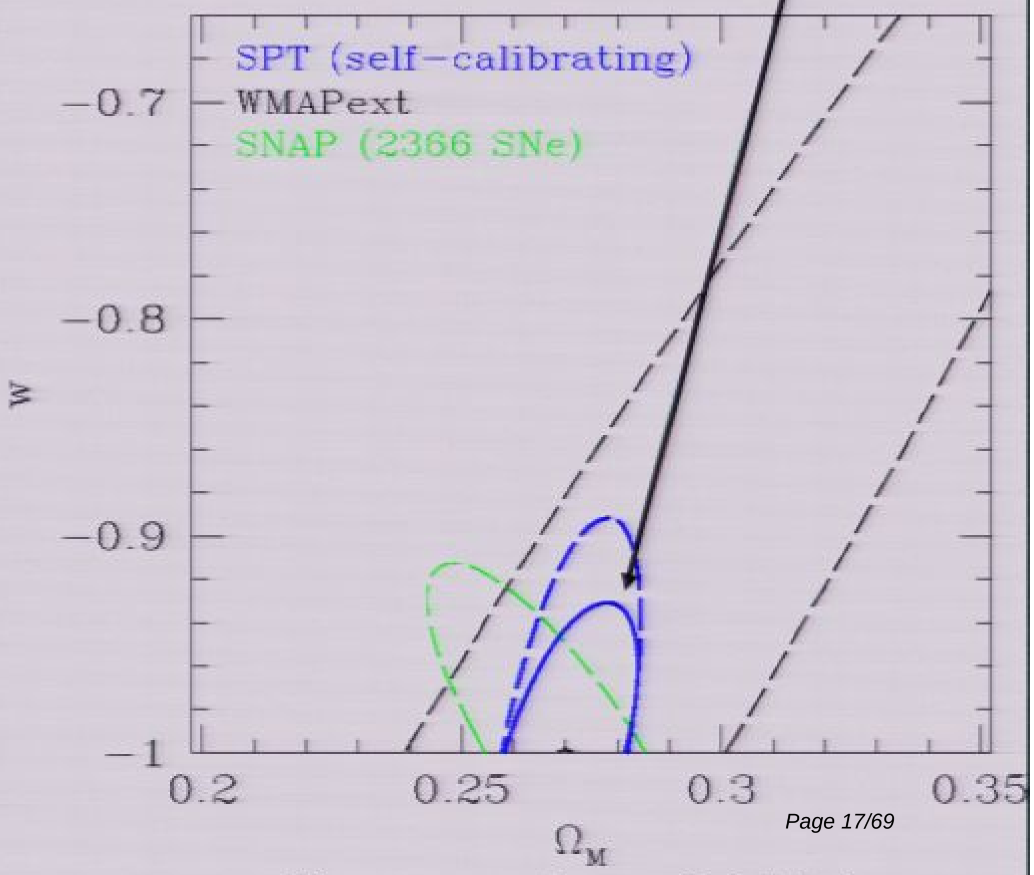
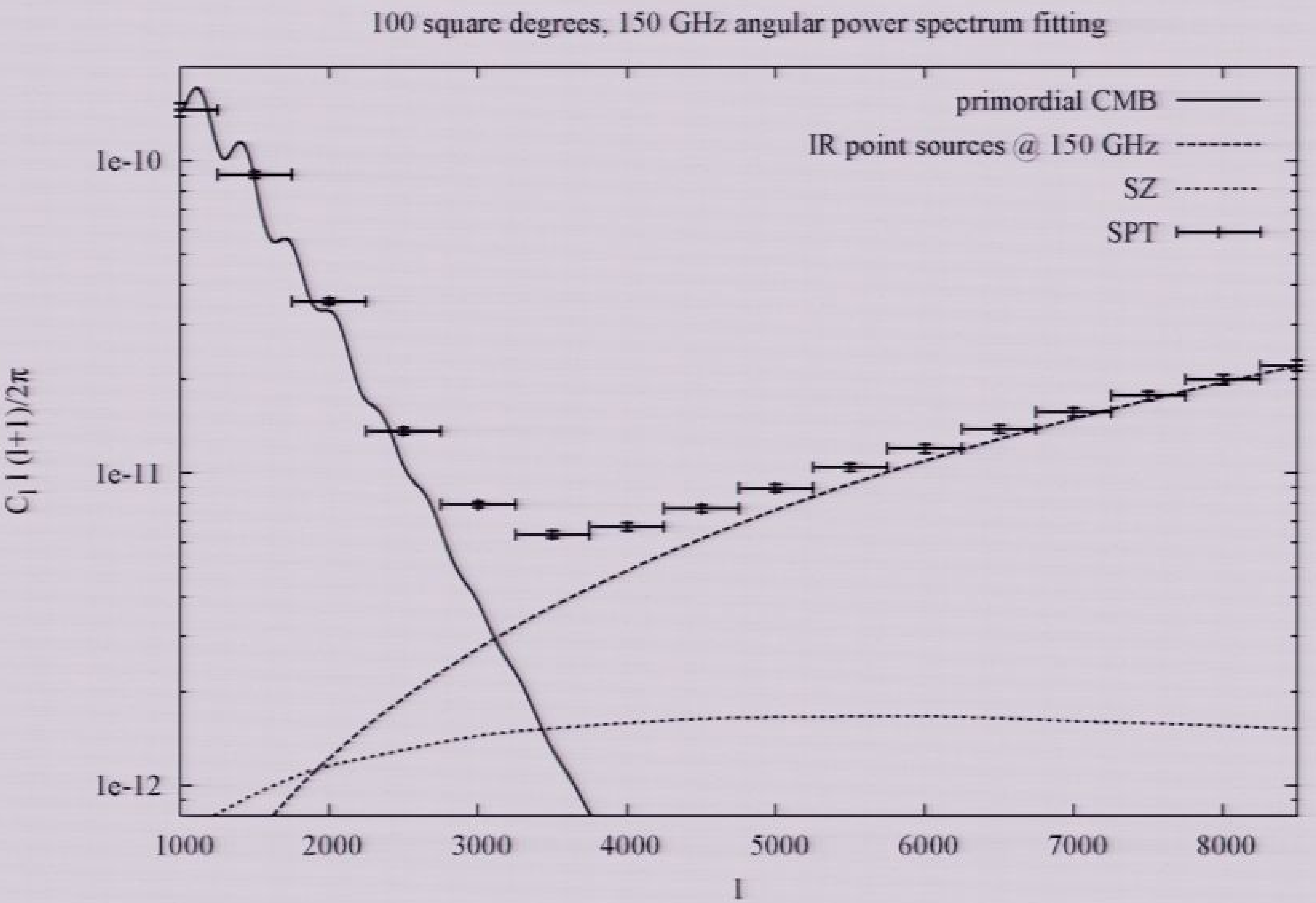


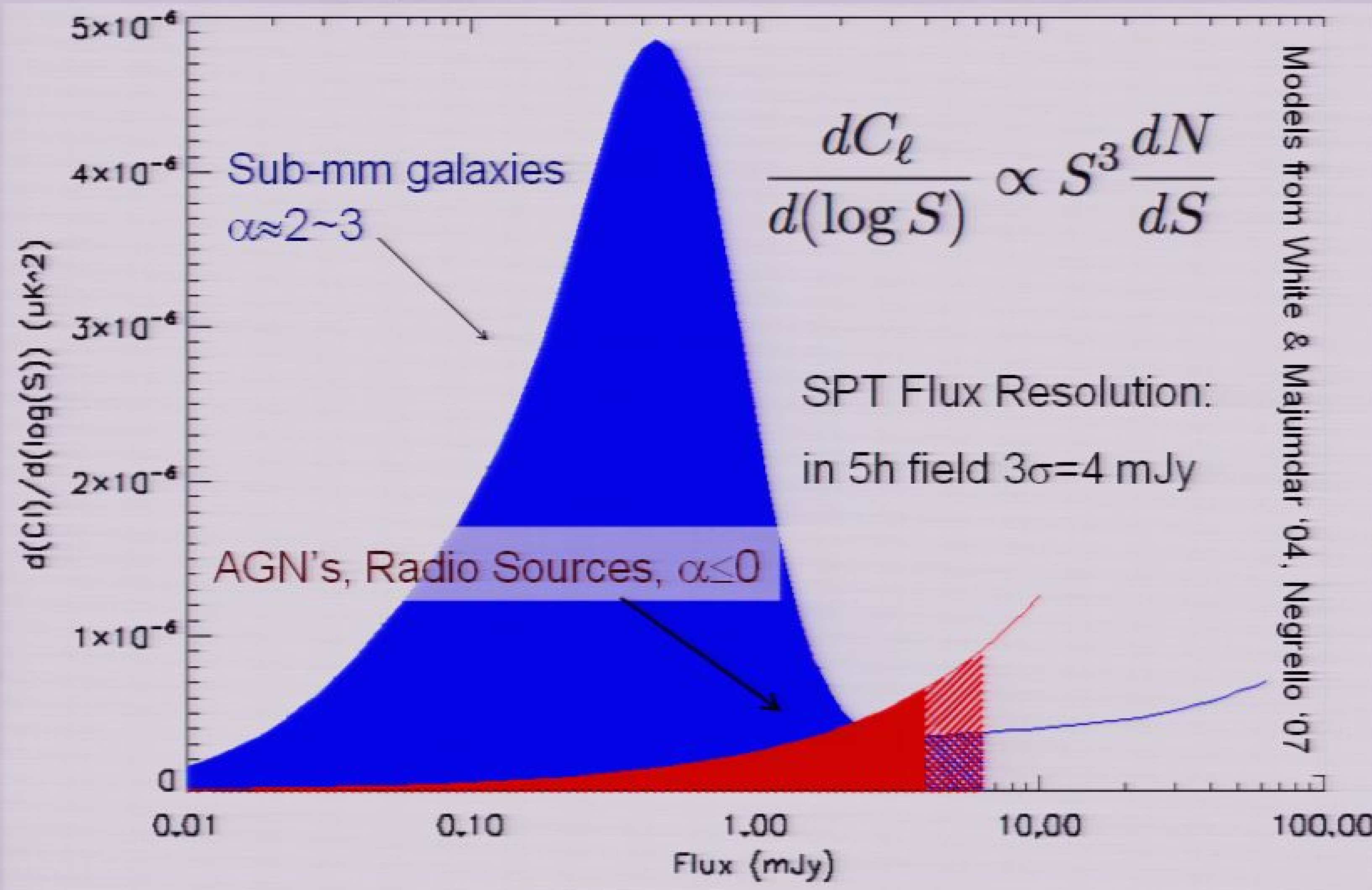
Figure courtesy of J. Mohr

SPT has the sensitivity to measure this signal but Dusty Galaxies are a significant contaminant



Simulation of SPT observation by Oliver Zahn

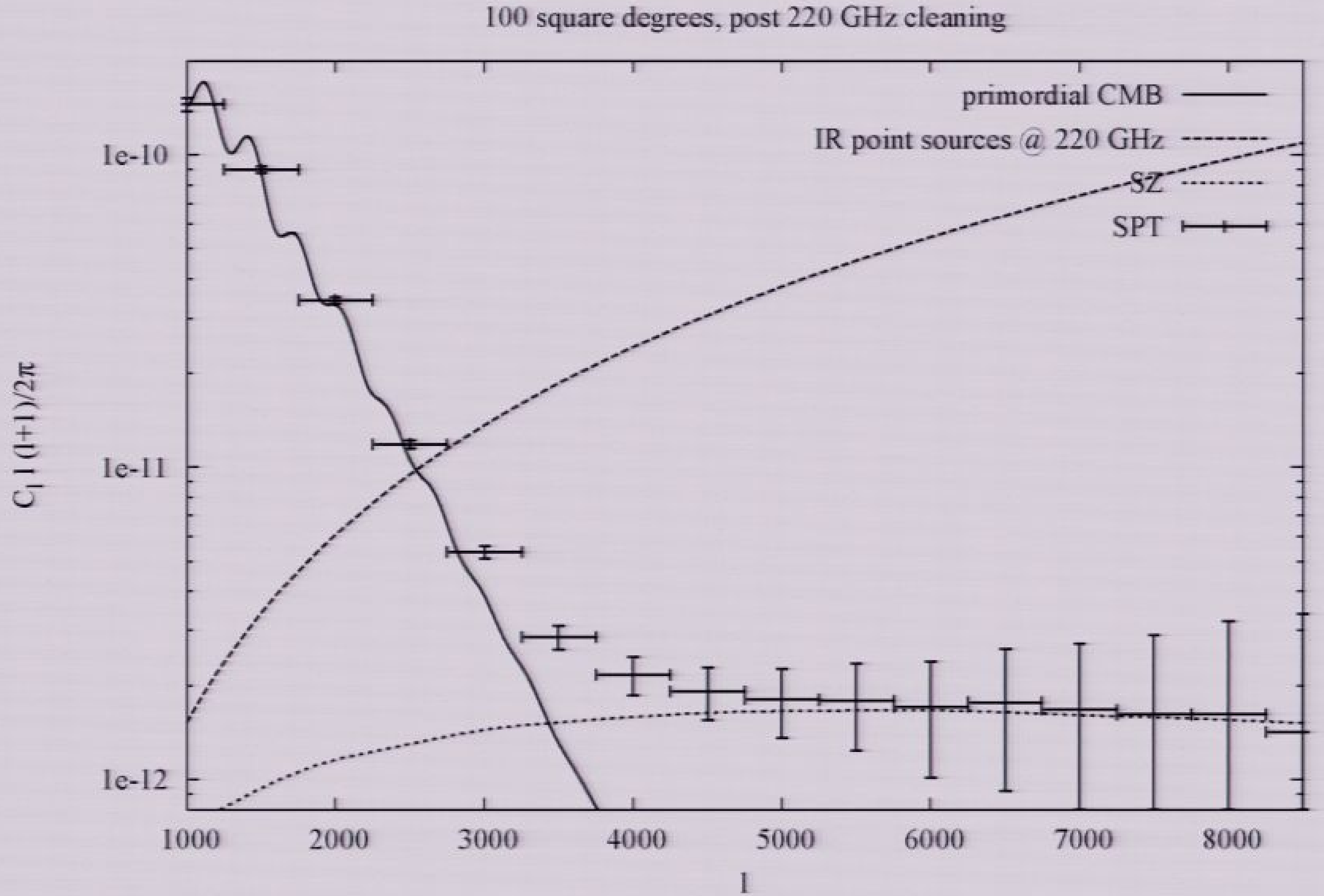
Point Source Contributions
(Scaled to 150 GHz)



Low flux IR sources add significant power to our maps.

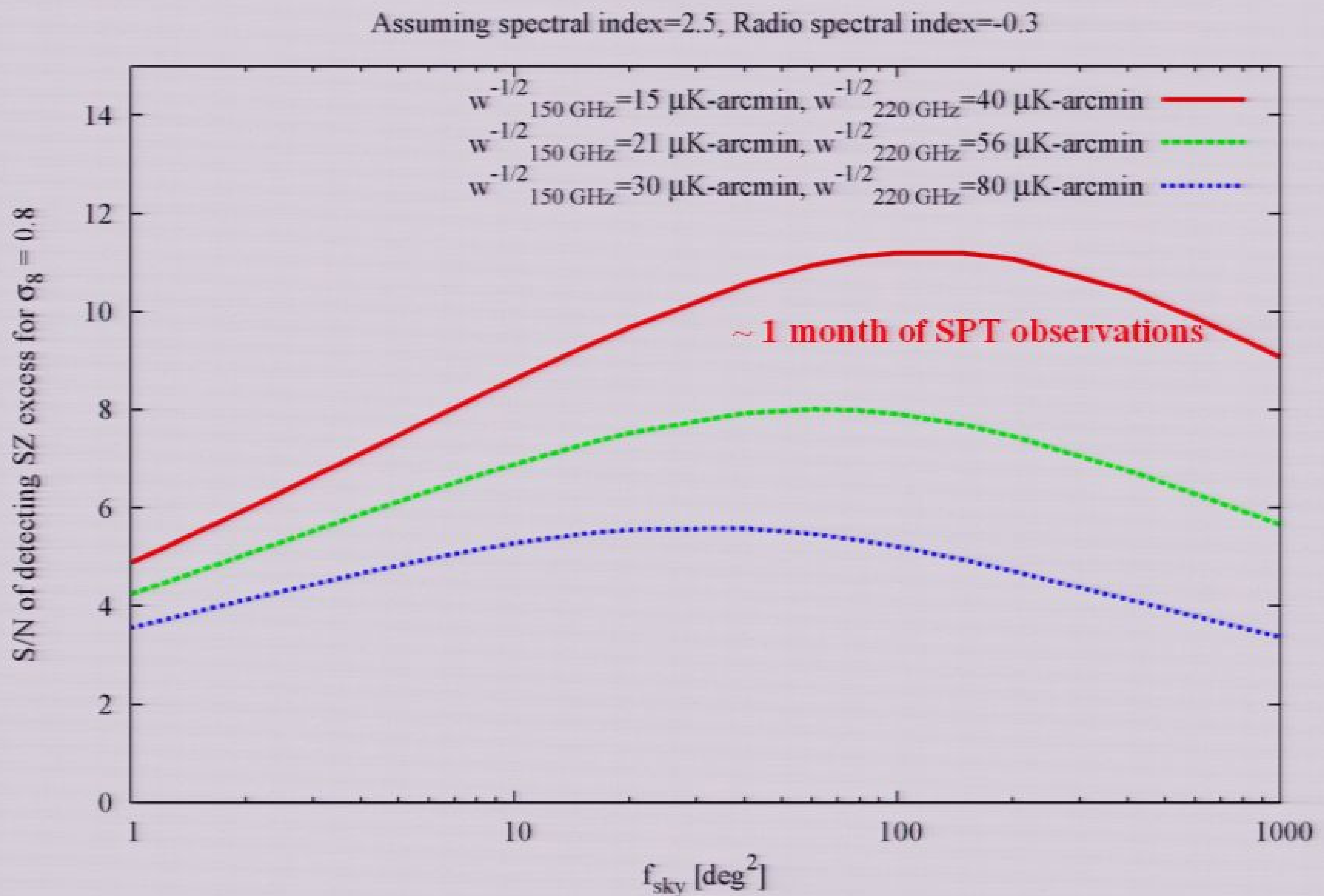
How can we remove them?

Using mean IR source Spectral index to remove these sources



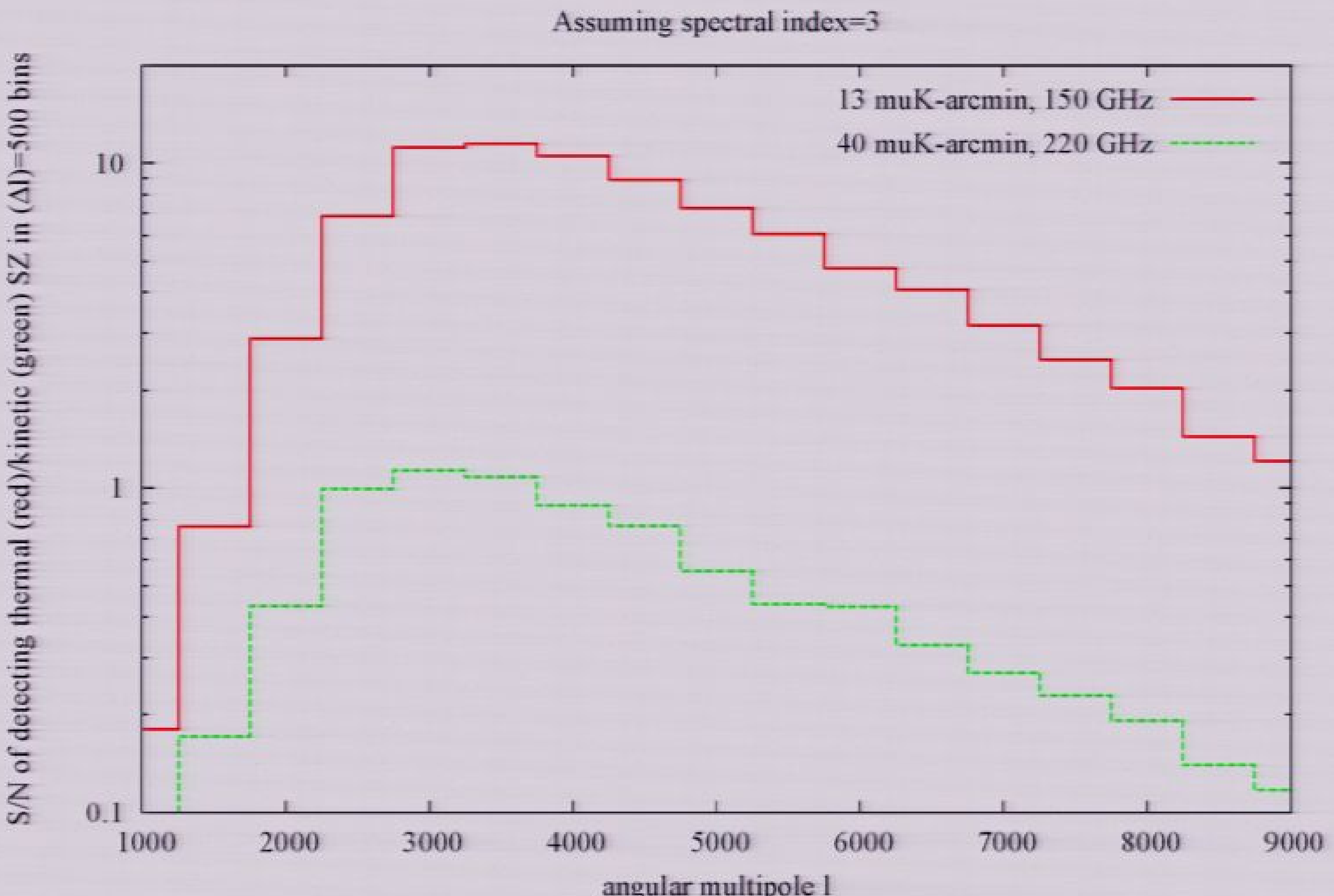
Simulation of SPT observation by Oliver Zahn

Significance of SZ as a function of sky coverage

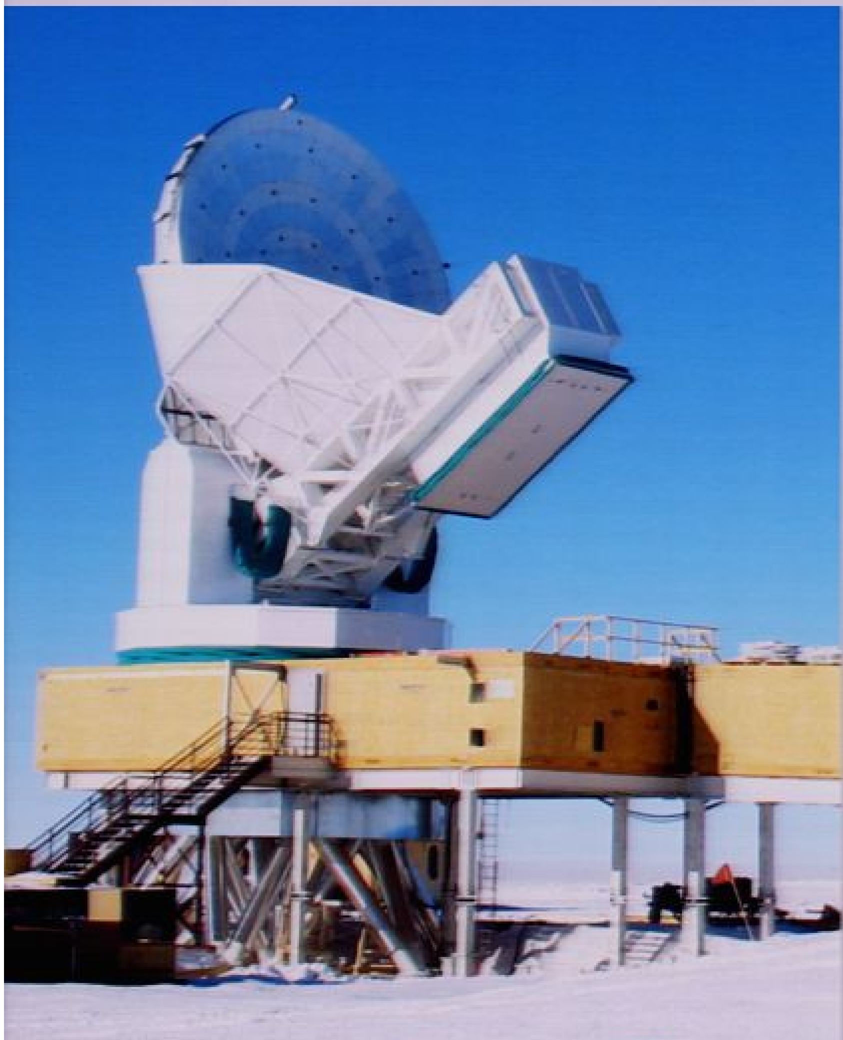


Oliver Zahn

**It is also possible to detect the kinetic SZ effect.
However this signal (and treatment of systematics) will be greatly enhanced through correlation with a tracer of LSS.**



The South Pole Telescope (SPT)



Sub-millimeter Wavelength Telescope:

- 10 meter telescope (1' FWHM beam at 150 GHz)
- Off-axis Gregorian optics design
- 20 microns RMS surface accuracy
- 1 arc-second pointing
- Fast scanning (up to 4 deg/sec in azimuth)

SZ receiver:

- 1 sq. deg FOV
- ~960 background limited pixels
- Observe in 3+ bands between 90-220 GHz simultaneously with a modular focal plane

Funded by NSF

merica is now spending huge sums
 deploy the massive The **South**
ole Telescope (SPT) in Antarctica.
he final installation will be the size
f a mini-mall and will require a
assive C-130 airlift effort to
ansport pre-assembled modules
nd a large staff to the most
esolate, inhospitable and
accessible region of the world.
/hy? Because **Planet X / Nibiru**
as first sighted in 1983 and this
iscovery spurred the USA to build
e SPT — humanity's new **Planet X**
acker. **Their resulting multi-**
pectrum observations will
anslate into life-saving data.

leed to know more?

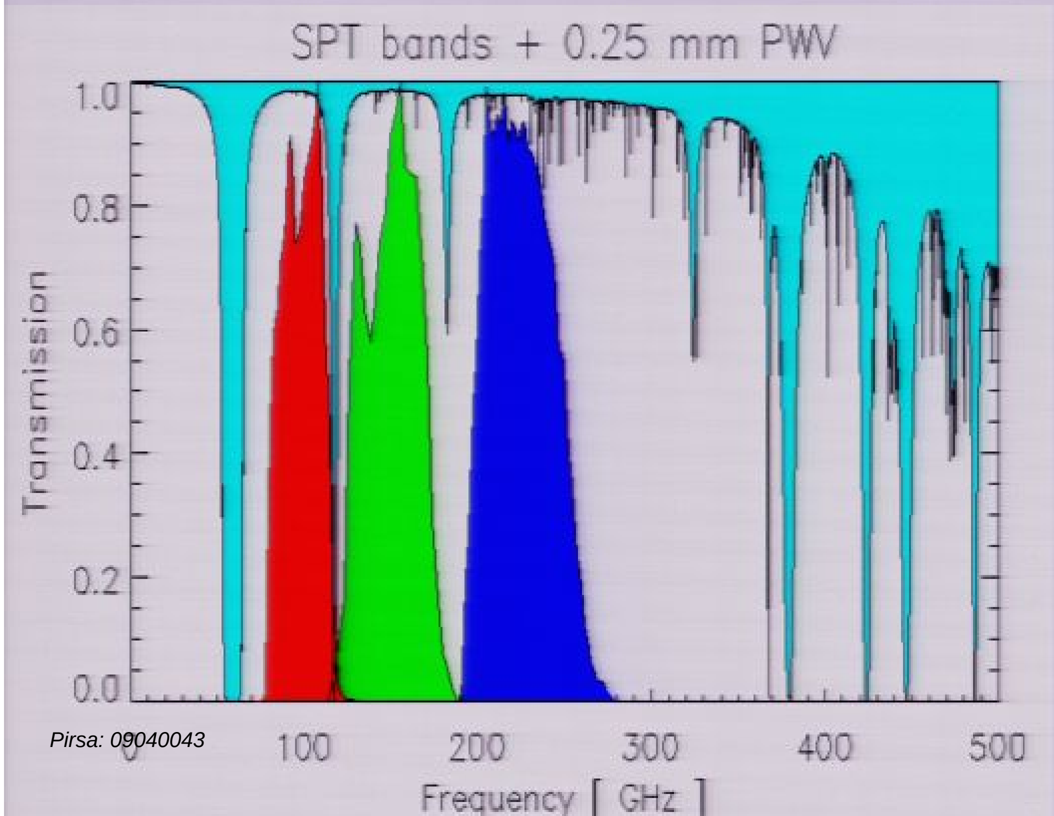
lear the 4-hour podcast at http://yowusa.com/planetx/

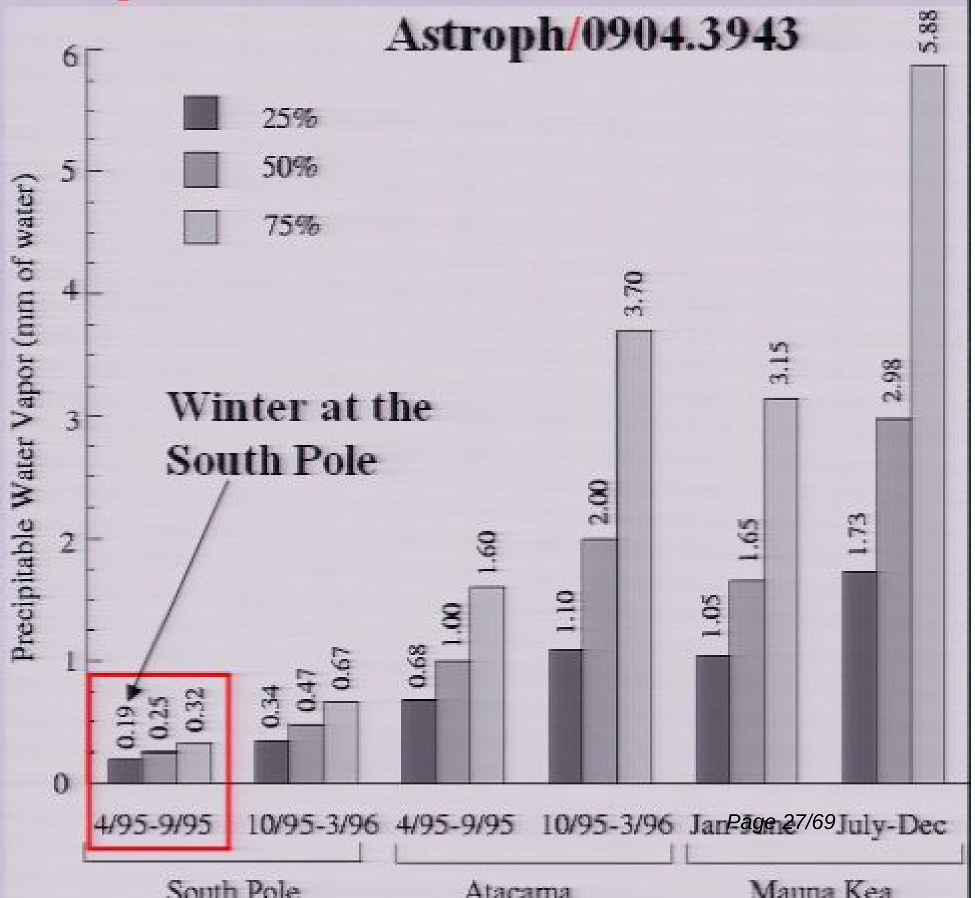
SPT Collaboration

Why the South Pole?

- **High Elevation** (comparable overall transmission to Atacama)
- **Extremely Dry** (very little water vapor at -70C)
- **Stable** (no diurnal variations and low turbulence)
- **Low peak wind speed**

Fluctuation power at Mauna Kea 120X worse than SP





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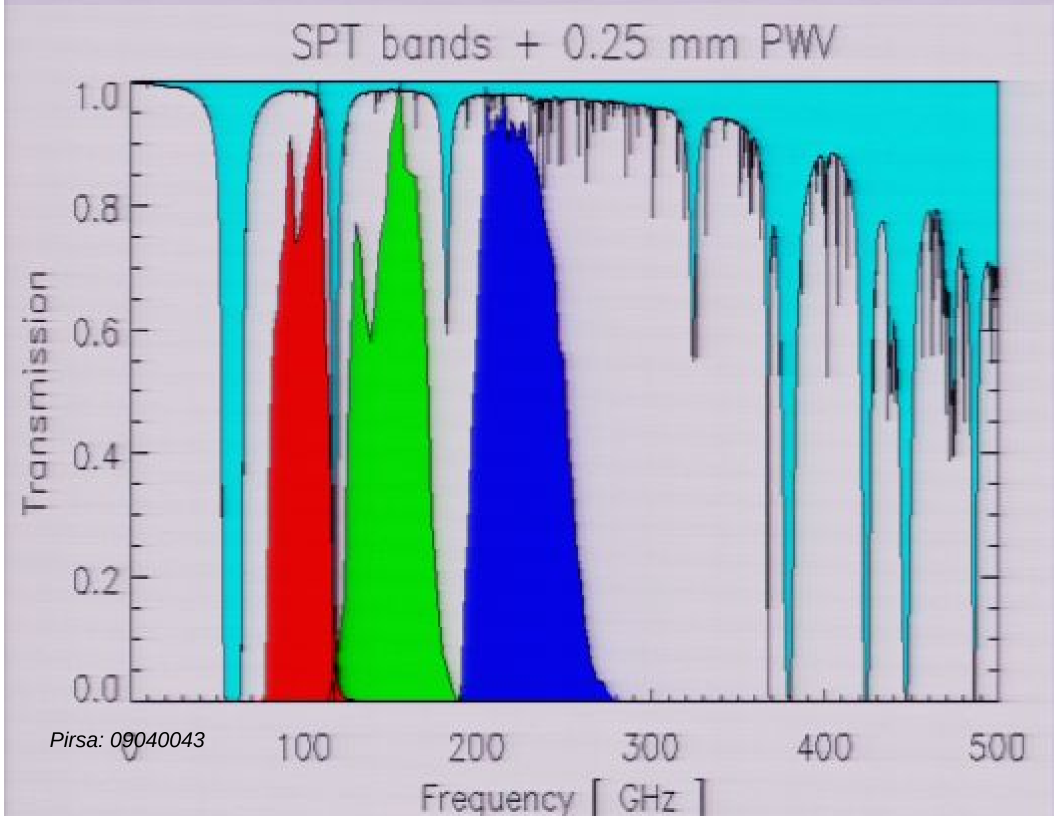
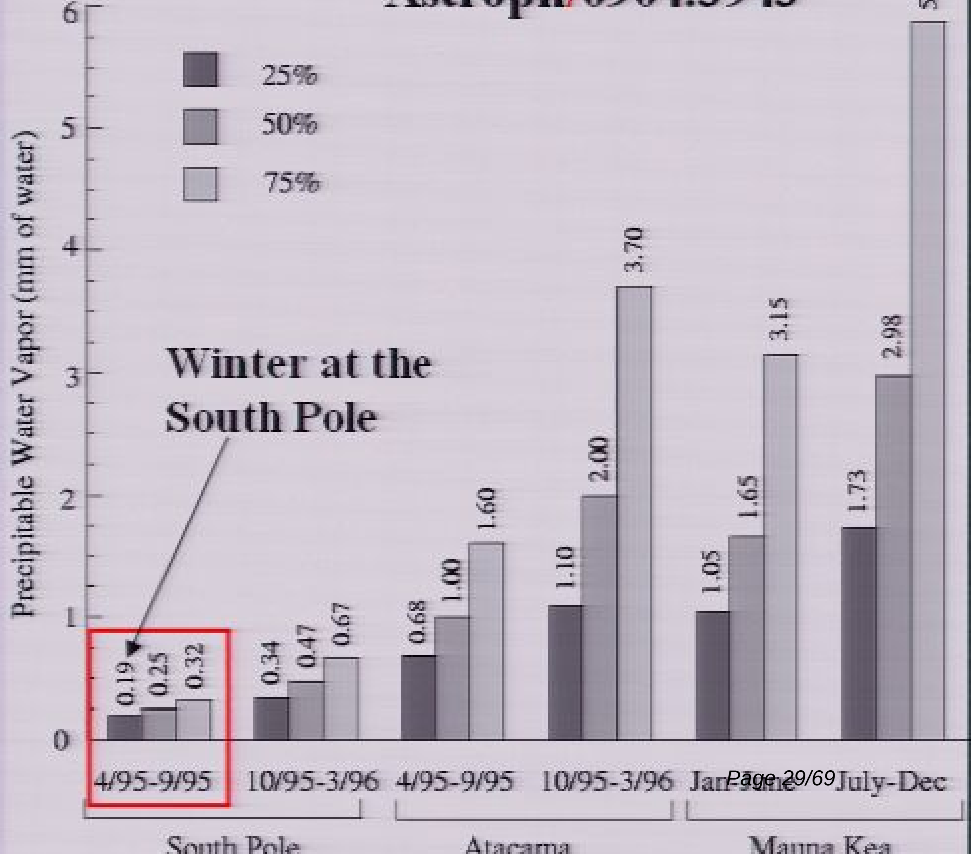


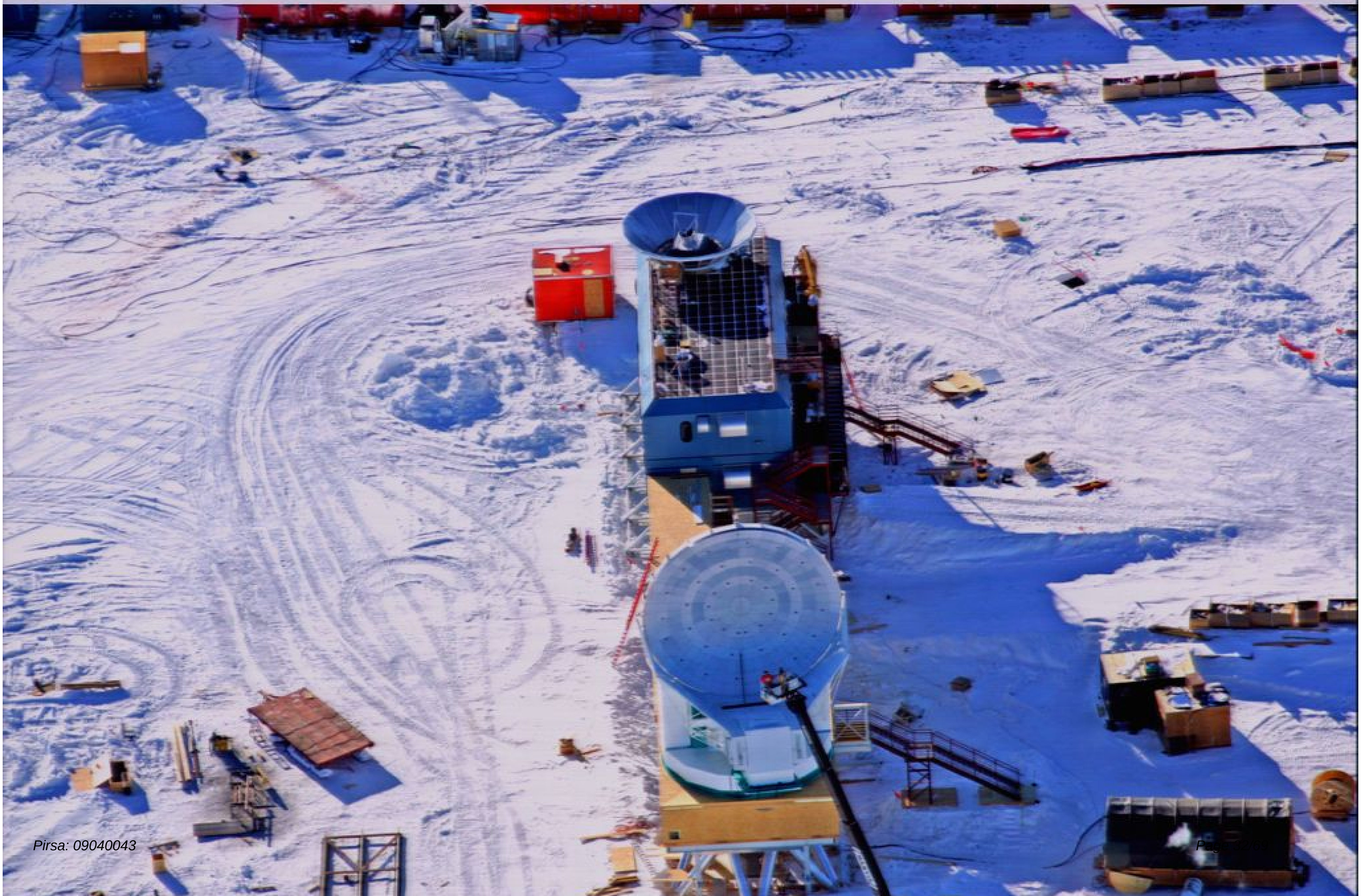
Astroph/0904.3943



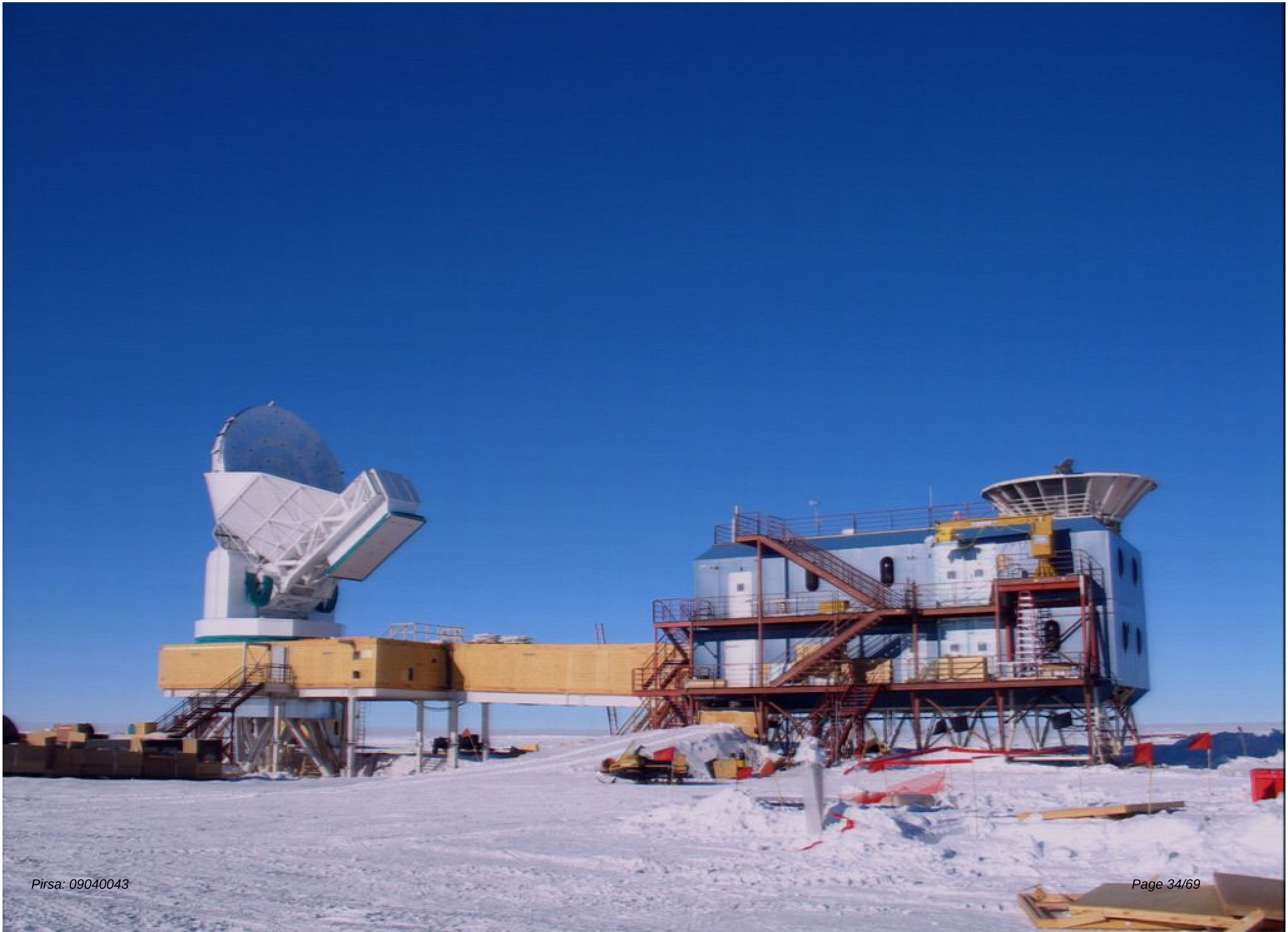
Only 10,500 lbs per LC-130 flight and 600,000 lbs of telescope.

Installing reflector panels

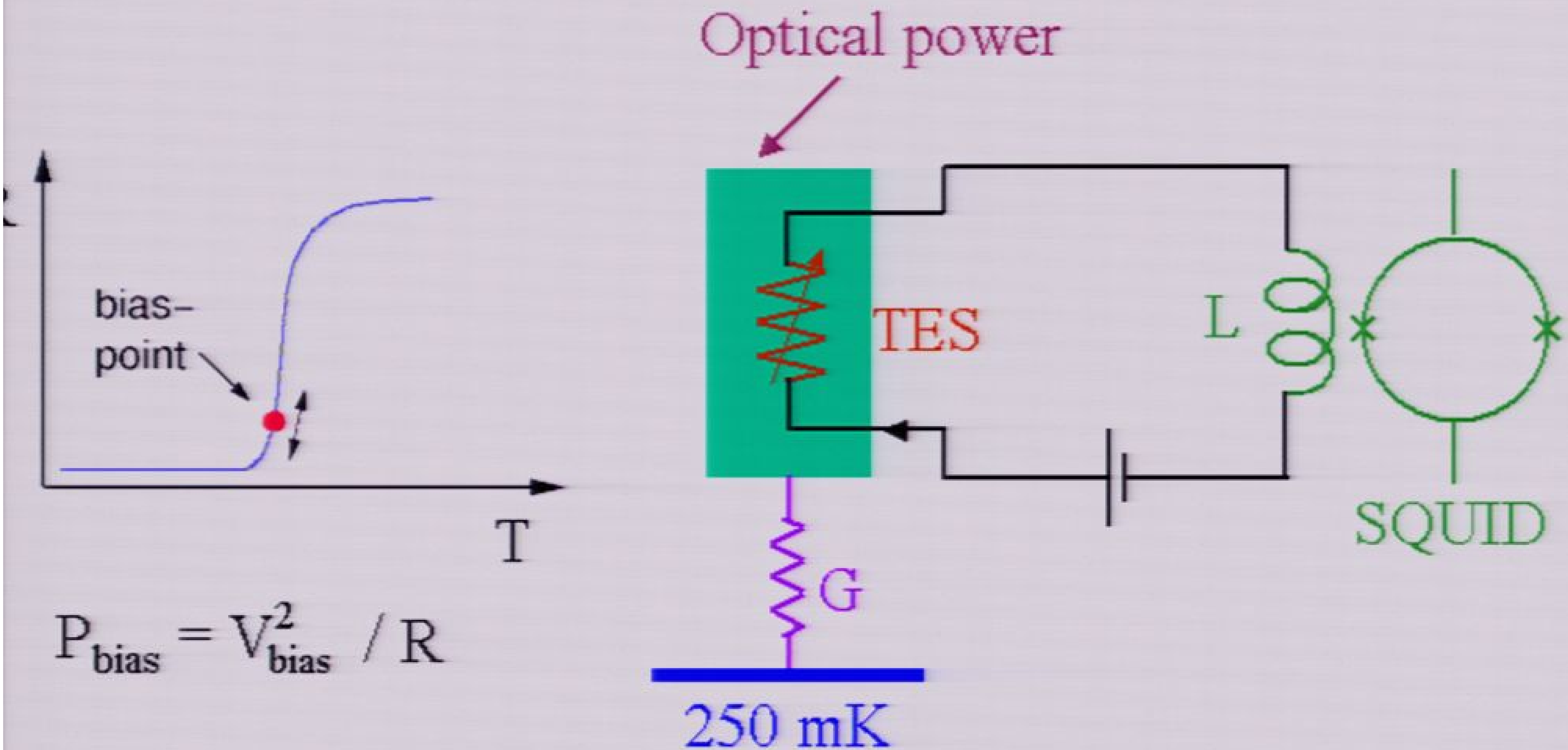
Hundreds of photographs. Thousands of screws




BICEP



Transition-Edge Sensor (TES) Bolometers



$$P_{bias} = V_{bias}^2 \; / \; R$$

$$P_{total} = P_{bias} + P_{photon} \approx \text{constant}$$

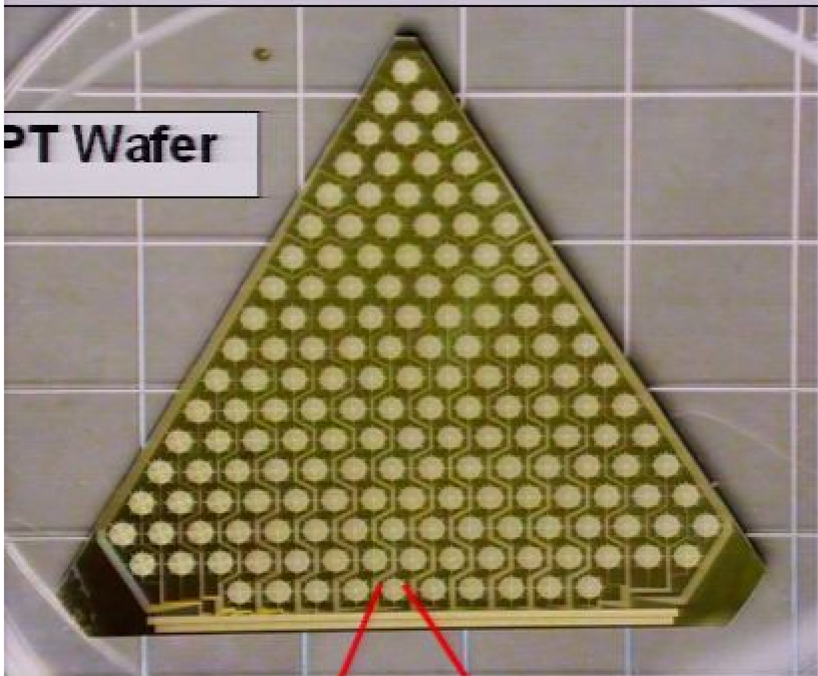
We are the photometers, we the irritable goldleaf and tinfoil that measure the ccumulations of the subtle element. We know the authentic effects of the true fire hrough every one of its million disguises.

-Ralph Waldo Emerson
Spiritual Laws

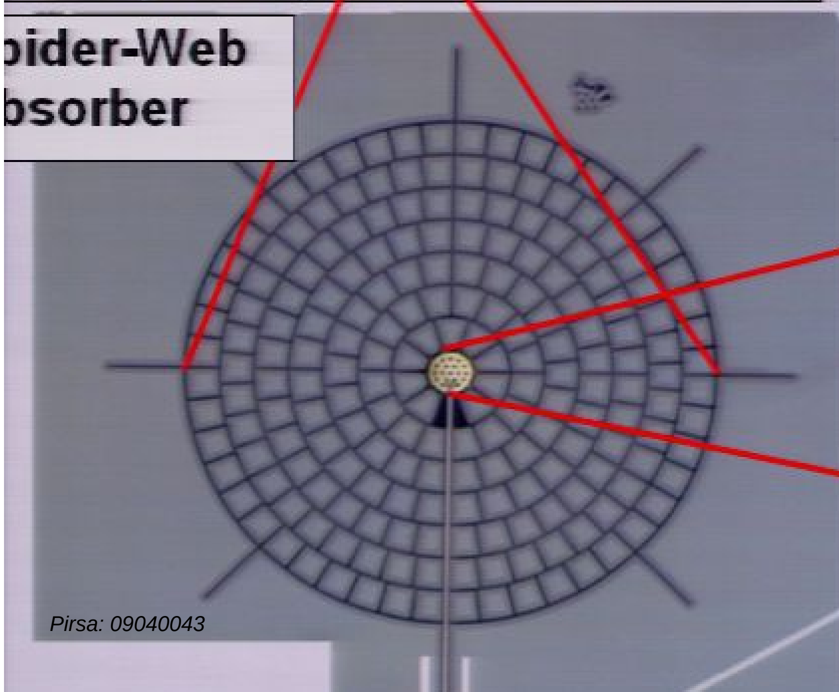
Physics Graduate Student and South Pole winterover Erik Shirokoff

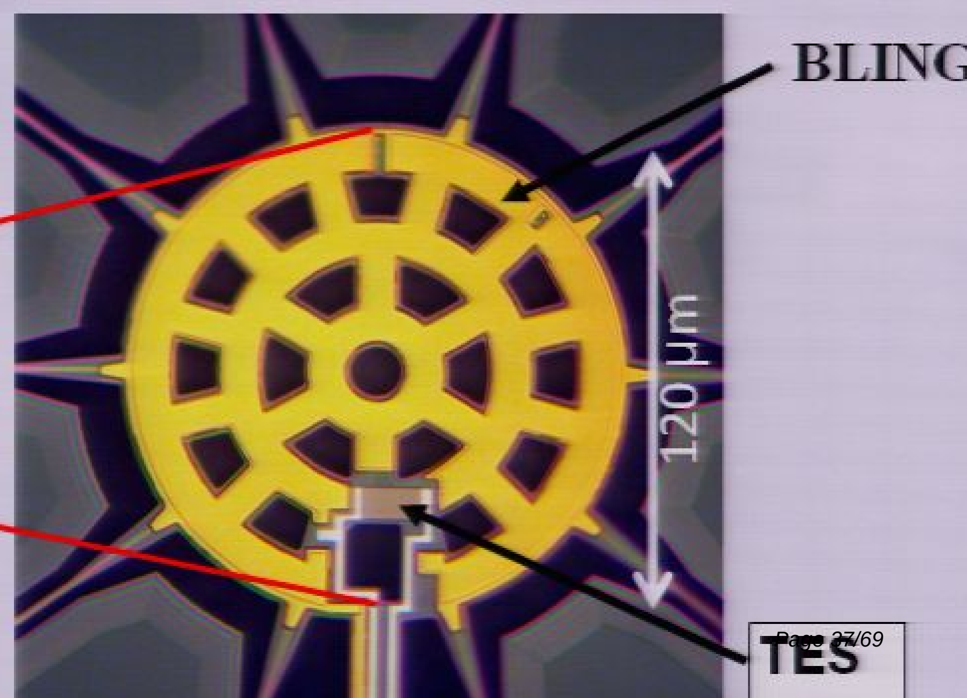
Berkeley Microlab

SPT Detector Wafer

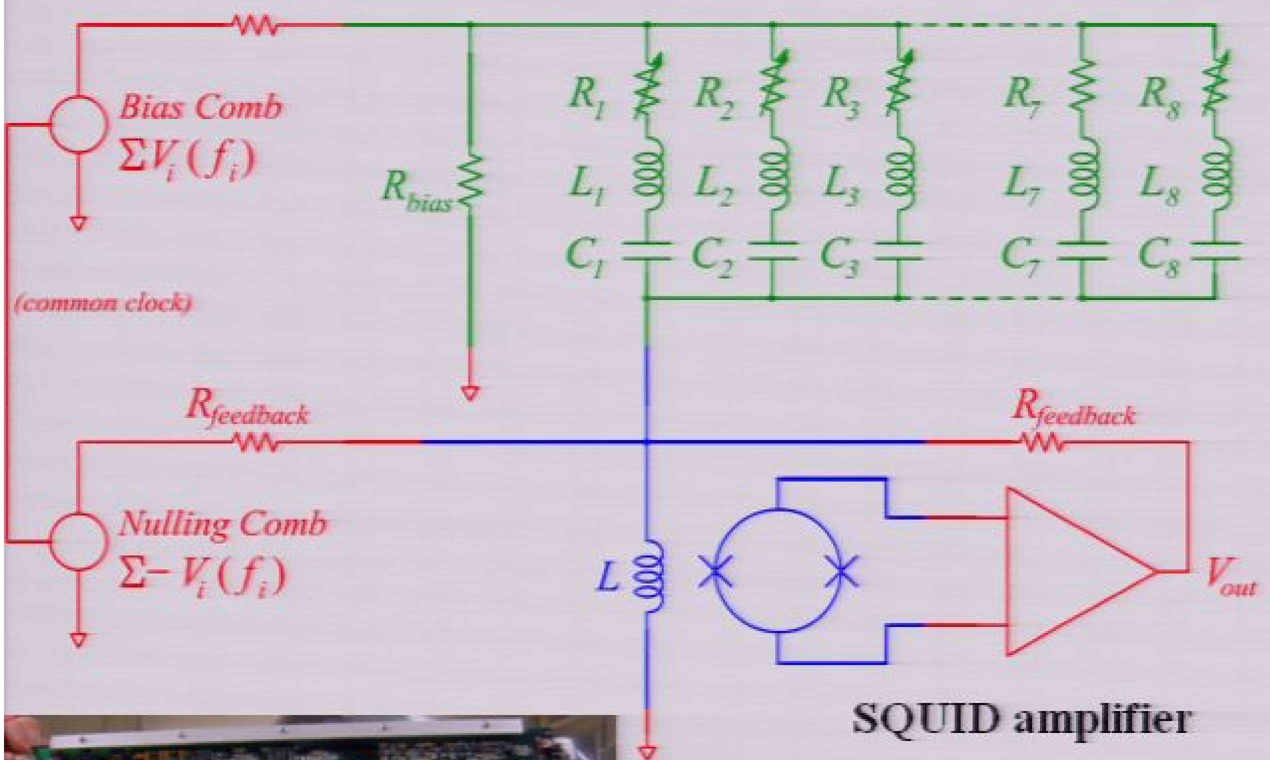


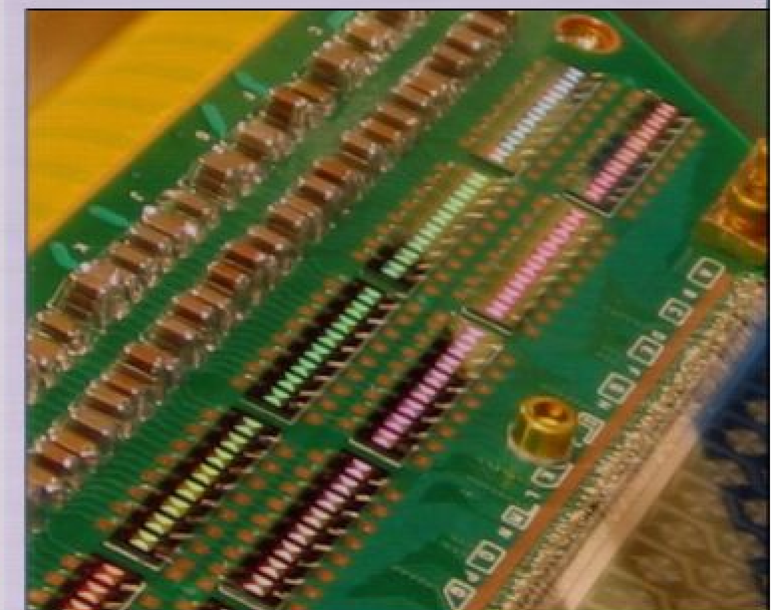
- 160 bolometers per wafer
- Al-Ti bi-layer Transition Edge Sensor (TES) with Tc = 0.55 K attached to spider-web shaped absorbing substrate
- Optical time constant of 10 ms
- Electrical time constant in transition of 1 ms
- Wafer thickness tuned to frequency bands

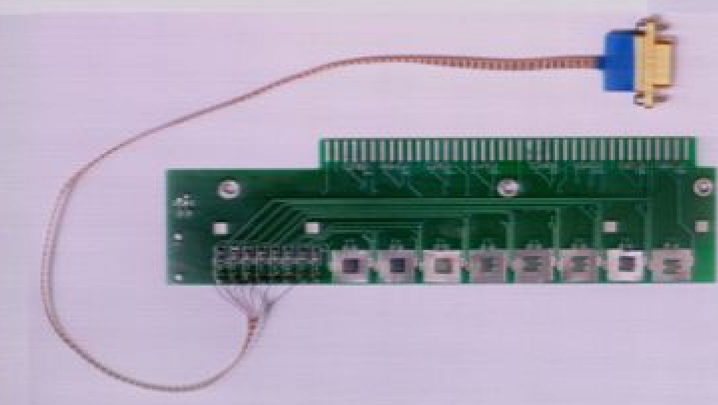




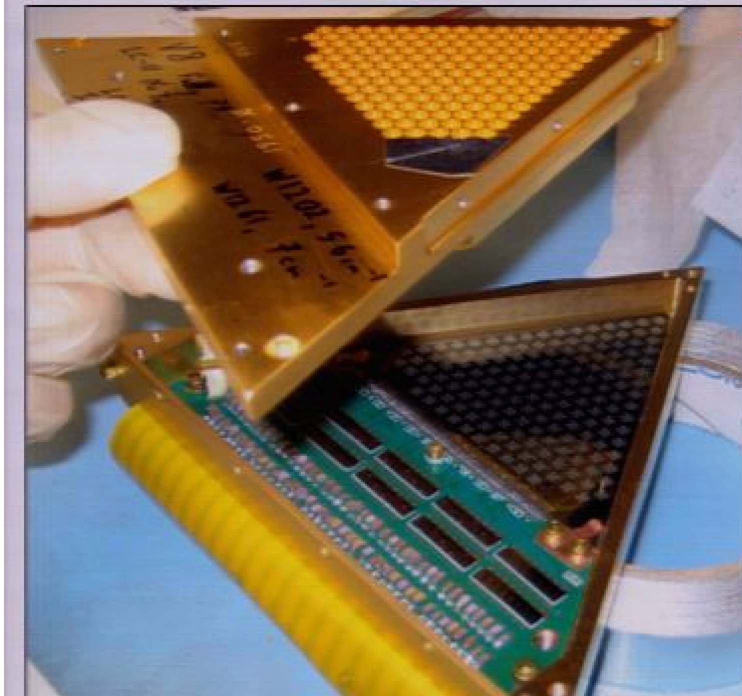
Frequency-domain multiplexer



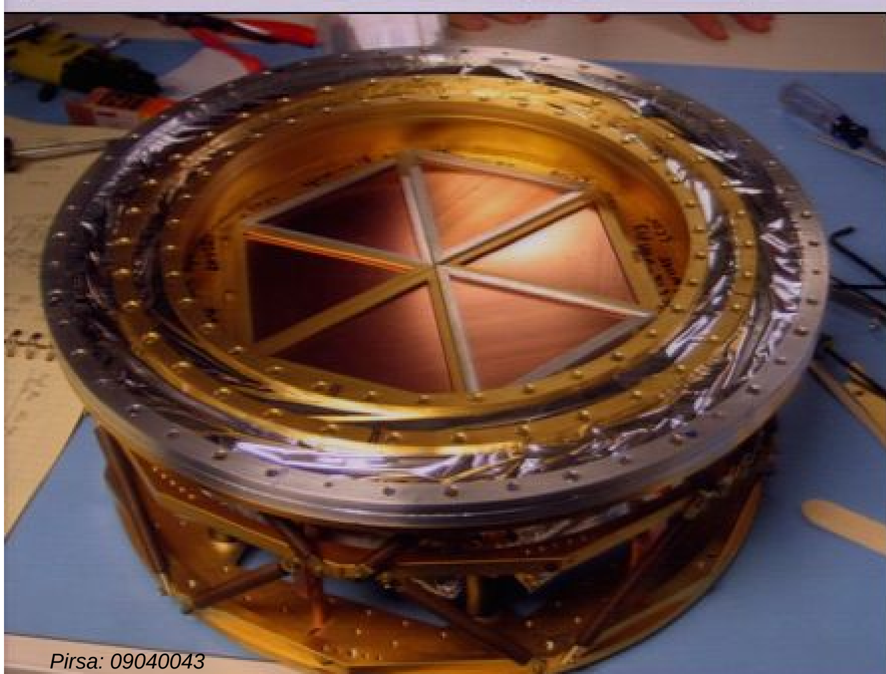


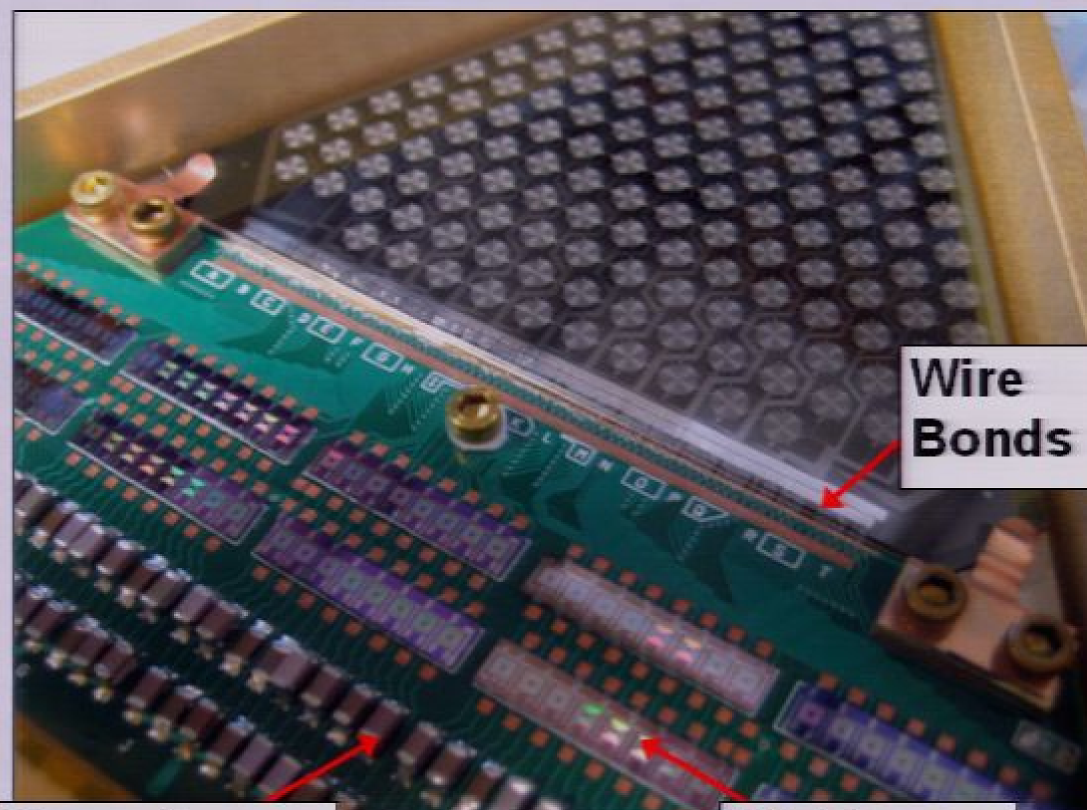


Wedge Assembly and LC Board

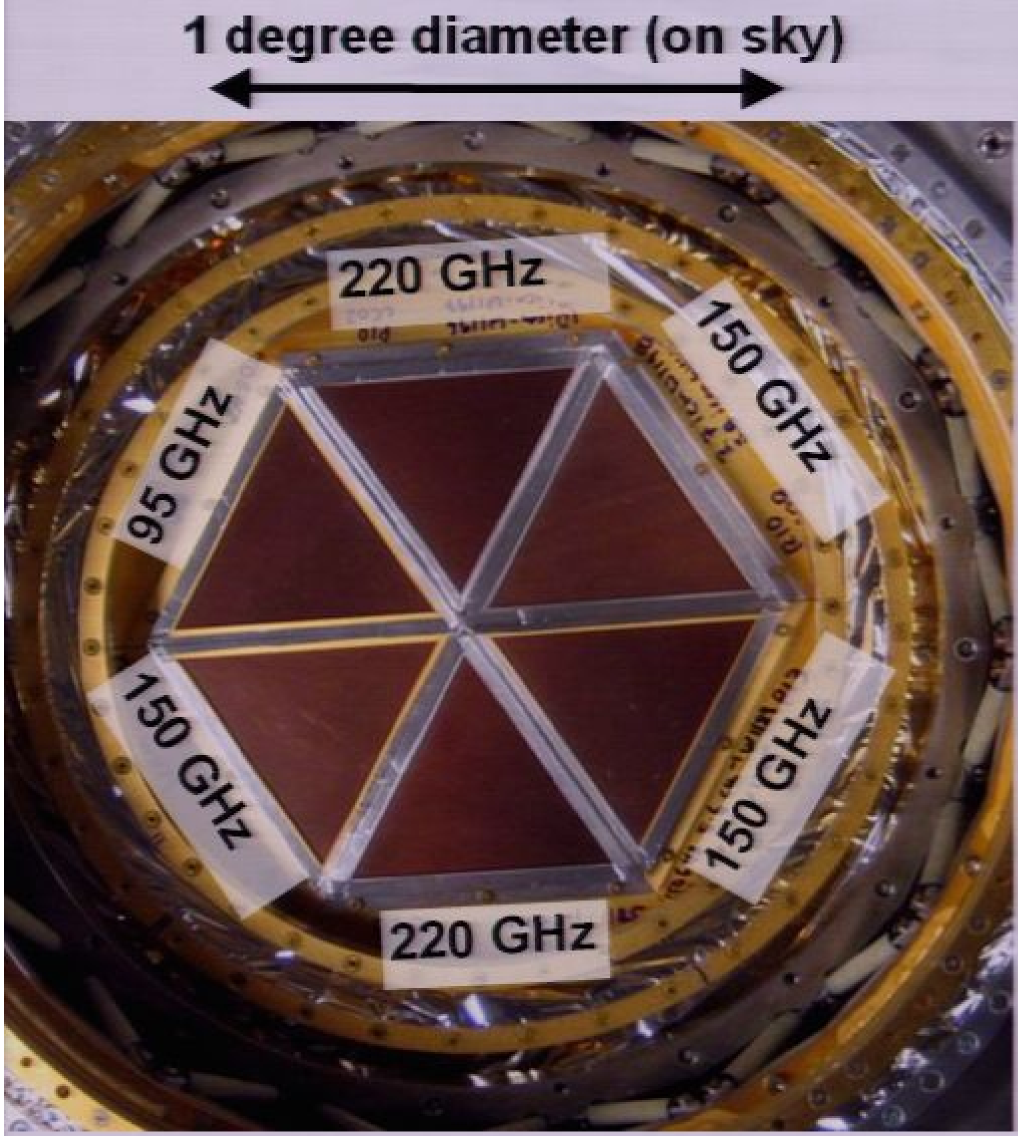


- Wafer wire-bonded to circuit board with LC circuit, which sets each bolometer's resonant frequency for frequency Multi-plexing (fMUX)





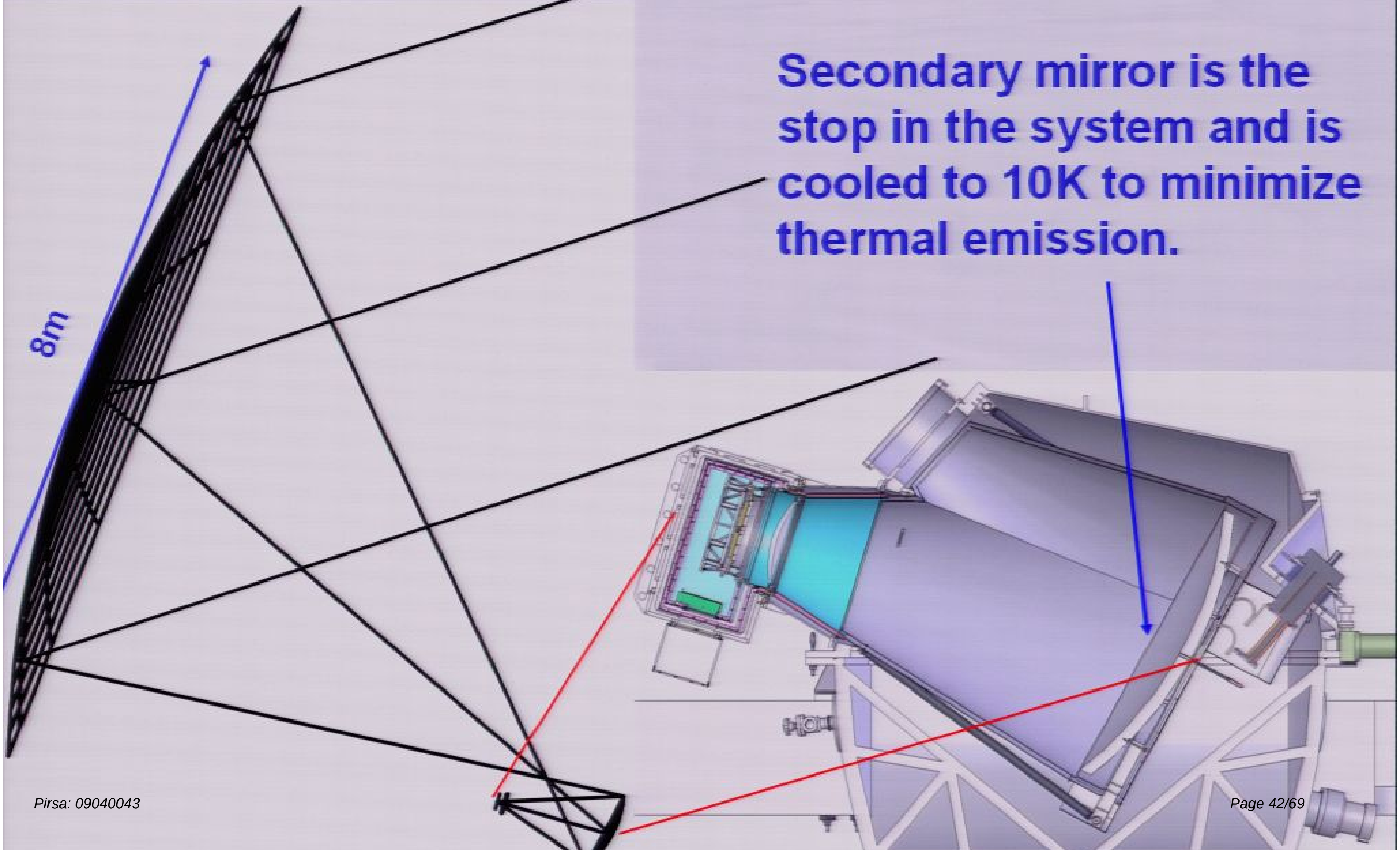
SPT Focal Plane

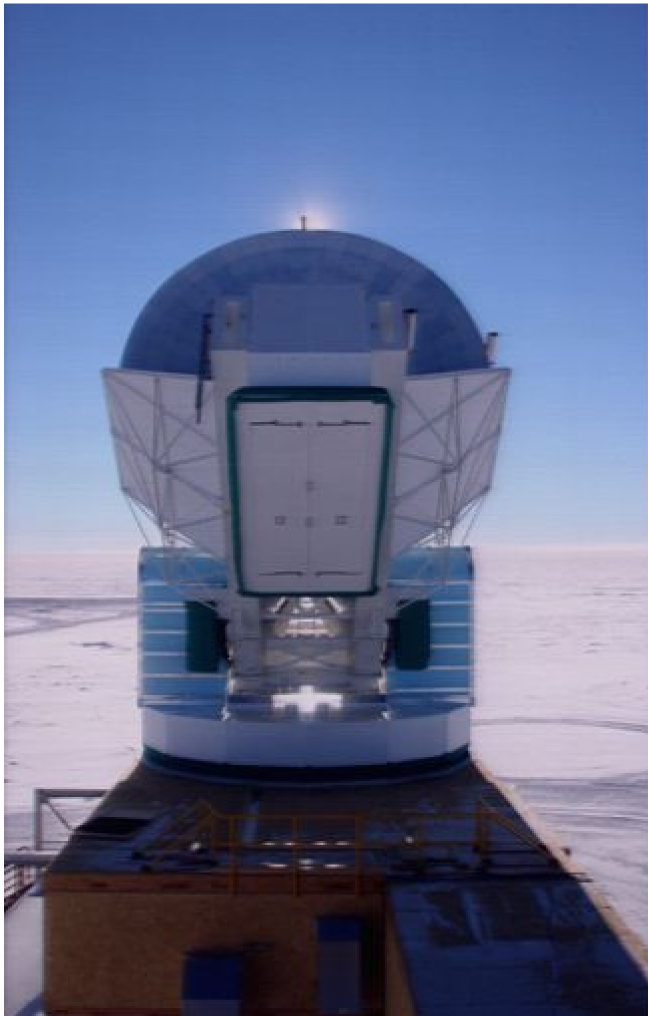


- Modular design of SPT focal plane into 6 wedges is useful to allow multiple frequencies
- First season: **2x 95 GHz**, **3x 150 GHz**, and **1x 220 GHz** wedges – Sensitivity/yield not great.
- Second season: **1x 95 GHz**, **3x 150 GHz**, and **2x 220 GHz** wedges – 150 and 220 GHz excellent
- Third season: **1x 95 GHz**, **4x150 GHz**, and **1x 220 GHz** wedges – All bands near background limit

SPT optics: off-axis Gregorian

Secondary mirror is the stop in the system and is cooled to 10K to minimize thermal emission.

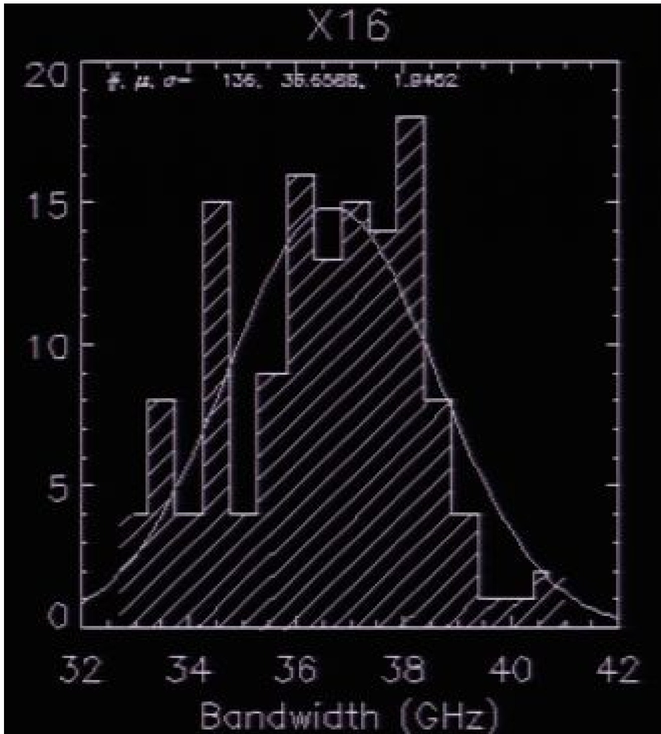


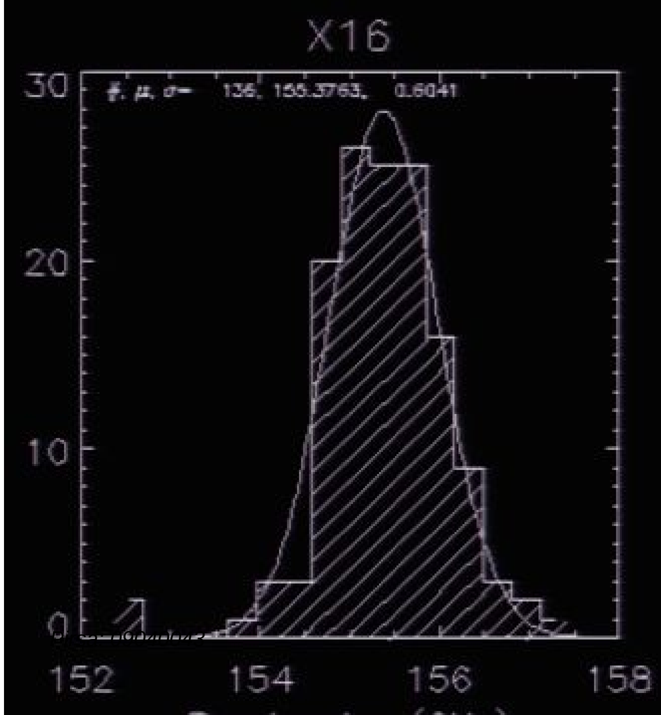


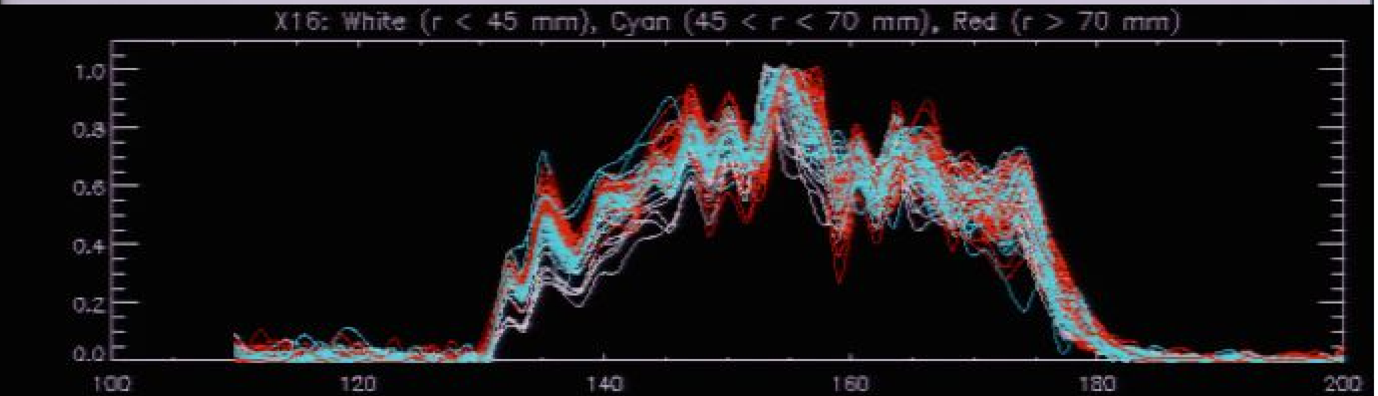


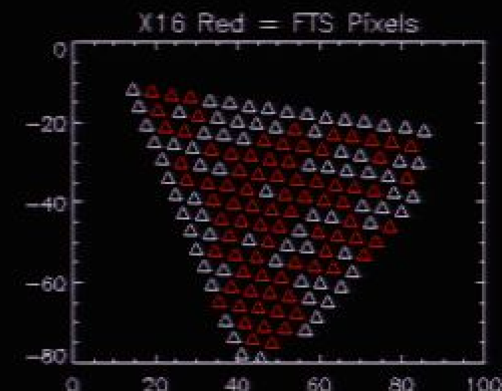
2007 2 23

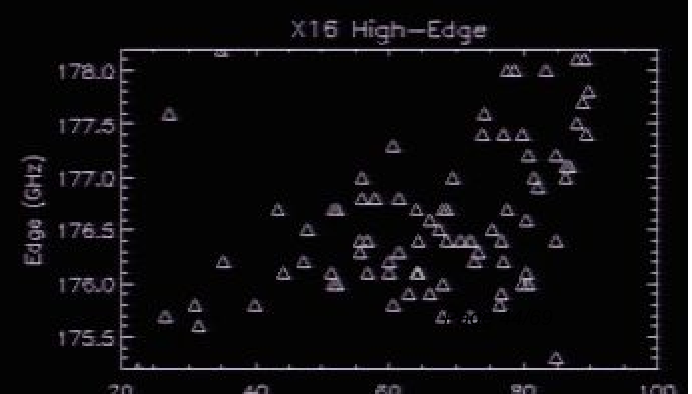
Spectroscopy for one 150 GHz Wedge

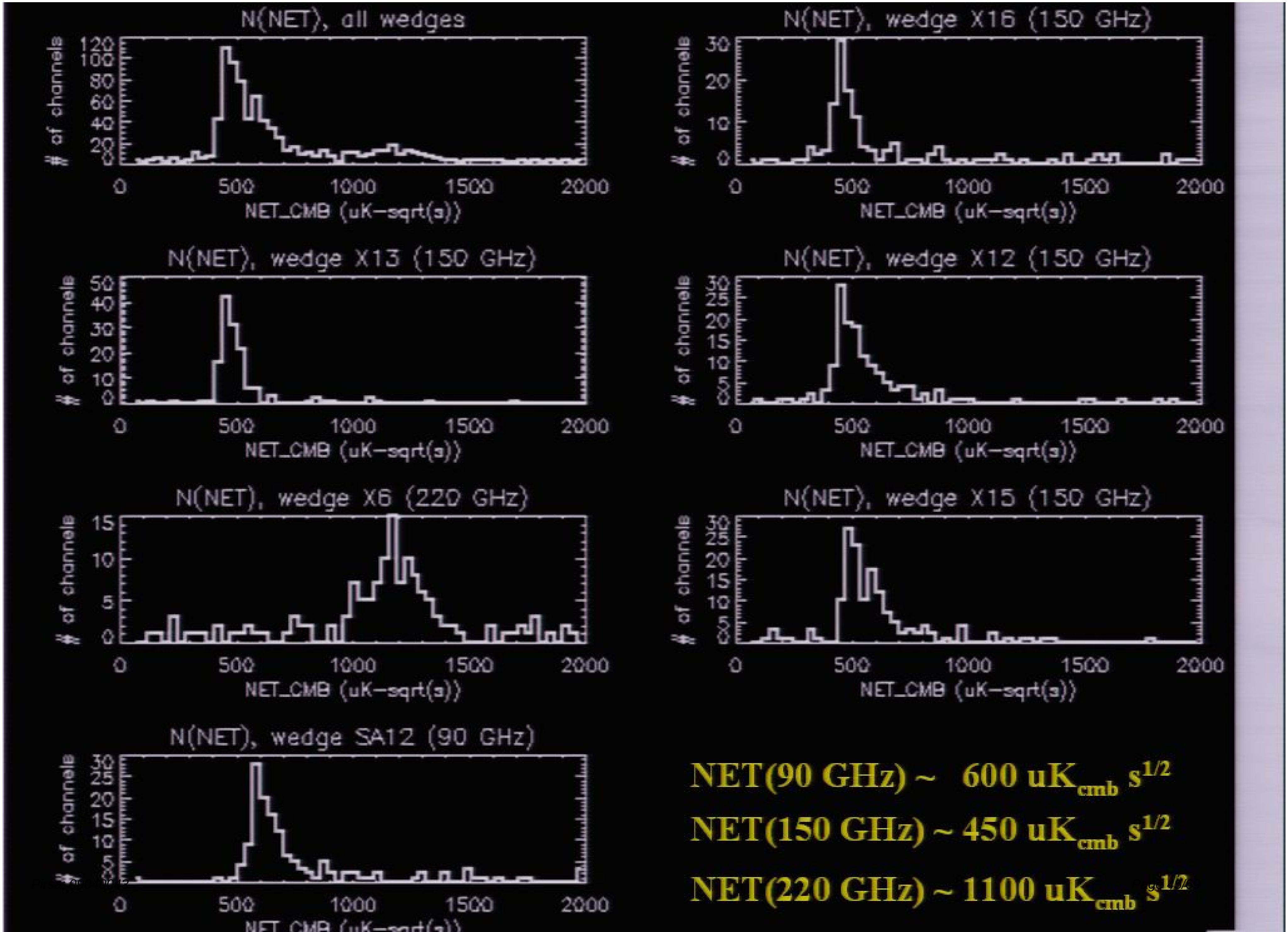






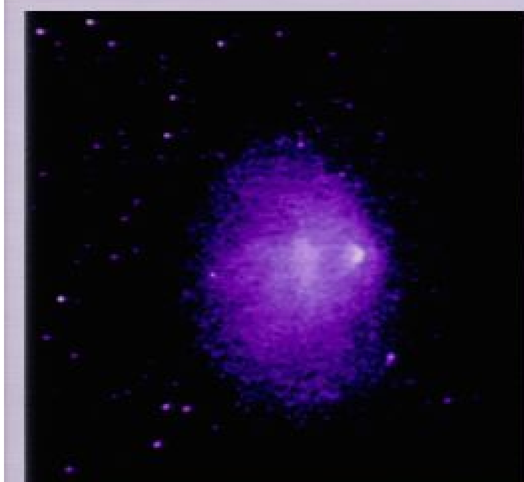





N(NET), all wedges
N(NET), wedge X16 (150 GHz)
N(NET), wedge X13 (150 GHz)
N(NET), wedge X12 (150 GHz)
N(NET), wedge X6 (220 GHz)
N(NET), wedge X15 (150 GHz)
N(NET), wedge SA12 (90 GHz)
# of channels
NET_CMB (uK-sqrt(s))
NET(90 GHz) ~ 600 uK$_{cmb}$ s$^{1/2}$
NET(150 GHz) ~ 450 uK$_{cmb}$ s$^{1/2}$
NET(220 GHz) ~ 1100 uK$_{cmb}$ s$^{1/2}$

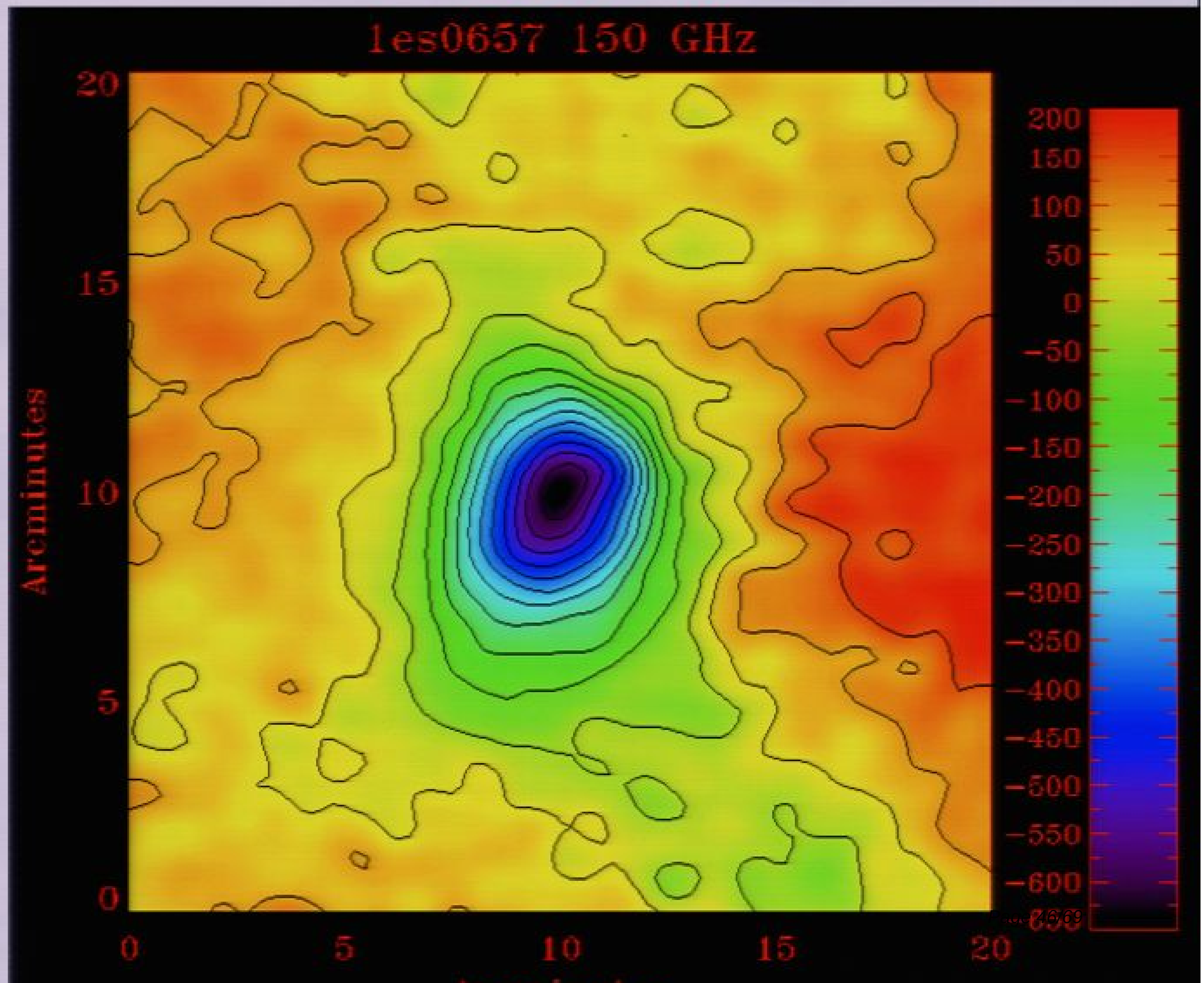
ointed Cluster SZ Maps

Chandra X-ray Image
140 hour observation
0.5 Ms)



SZ Image of Bullet Cluster

- $z = .297$
- 7 hours of observation
- ~ 20 μK RMS per 60” pixel



Brad Benson and Tom Plagge

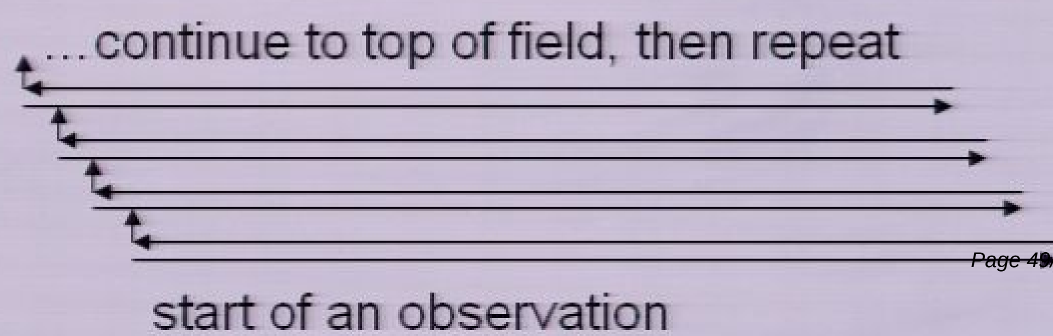
SPT Heroes Gallery

Mechanical Requirements of the Observing Strategy

The problem: want to prevent "1/f noise" and atmospheric fluctuations from contaminating the interesting sky signal.

One solution: fast scanning – noise at low *temporal* frequencies contaminates only low *spatial* frequencies in the data

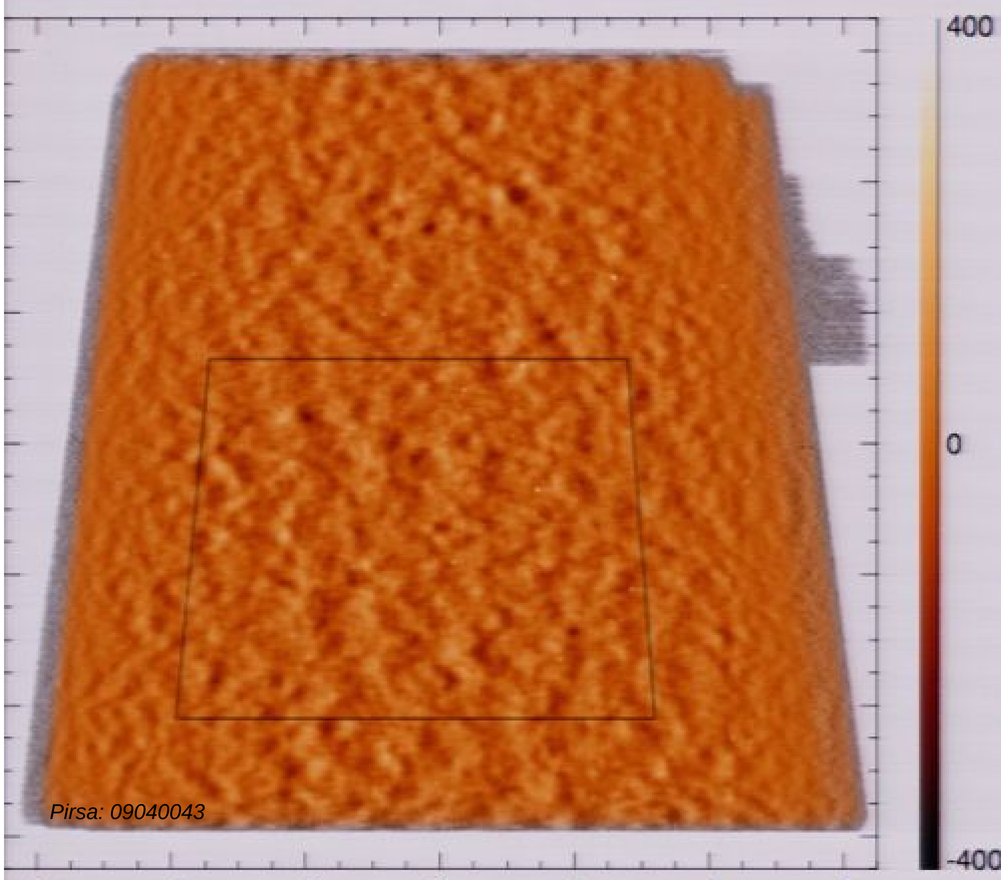
SPT design: 4 degrees/s maximum scan speed
Typical observations: scan back and forth in azimuth at 0.25 degrees/s, step in elevation



First Survey Field RA~ 5 Hours

- Mapped with interleaved azimuth raster scans
- ~800 hours of observation
- 100 deg^2 ~17 uK/arcmin pixel
- 60 deg^2 overlap with BCS

150 GHz L+R map

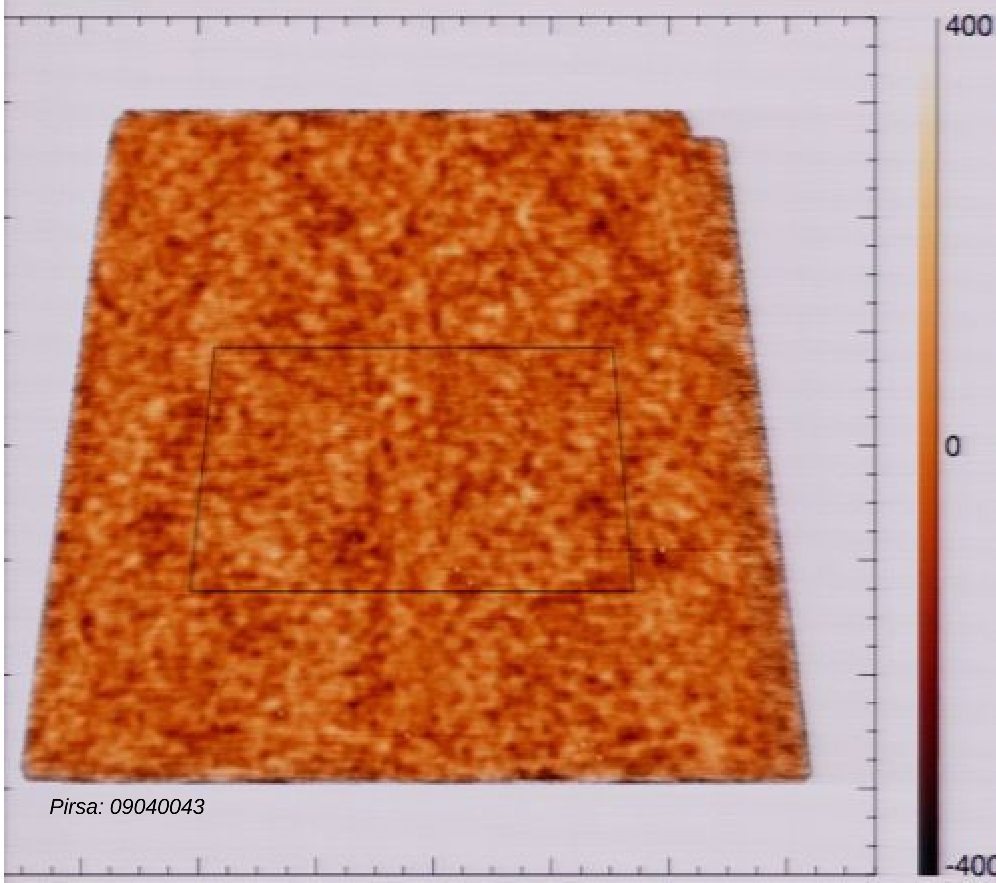


150 GHz L-R map

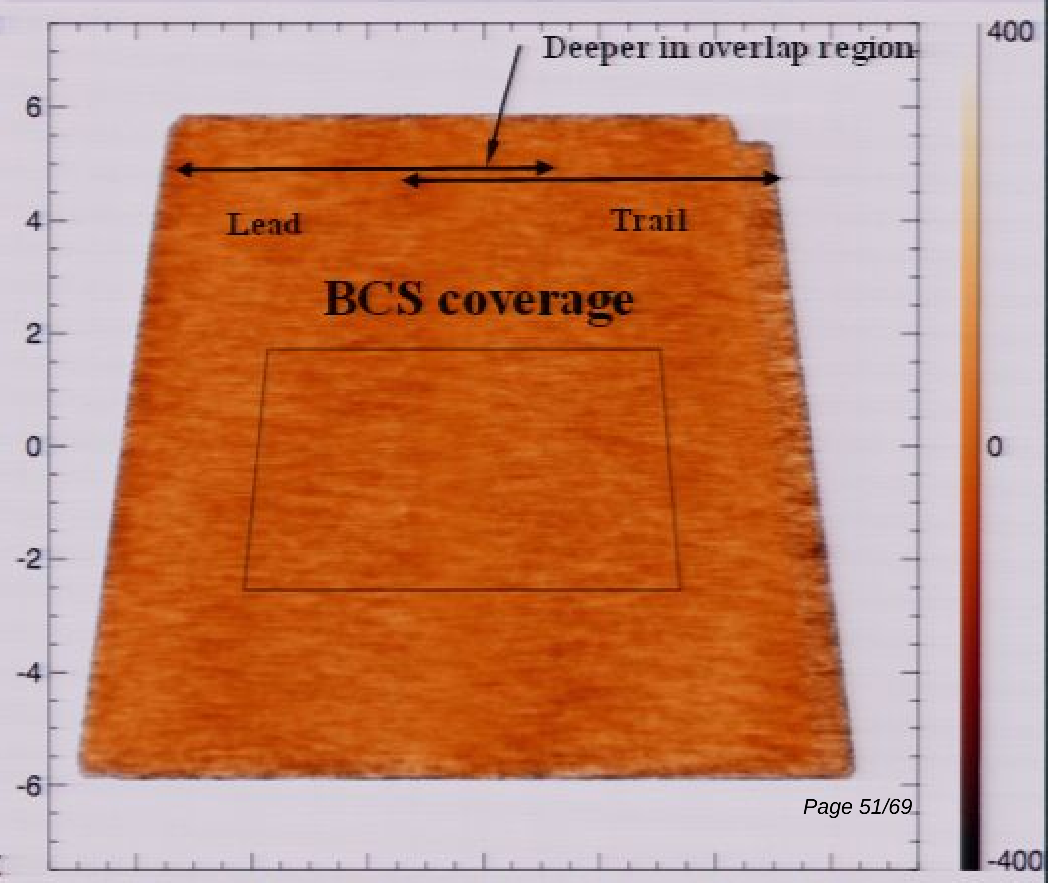
Second Survey Field RA~ 23 Hours

- Mapped with alternating Lead/Trail azimuth raster scans
- ~1000 hours of observation
- 100 deg^2 ~15 uK/arcmin pixel
- 40 deg^2 overlap with BCS

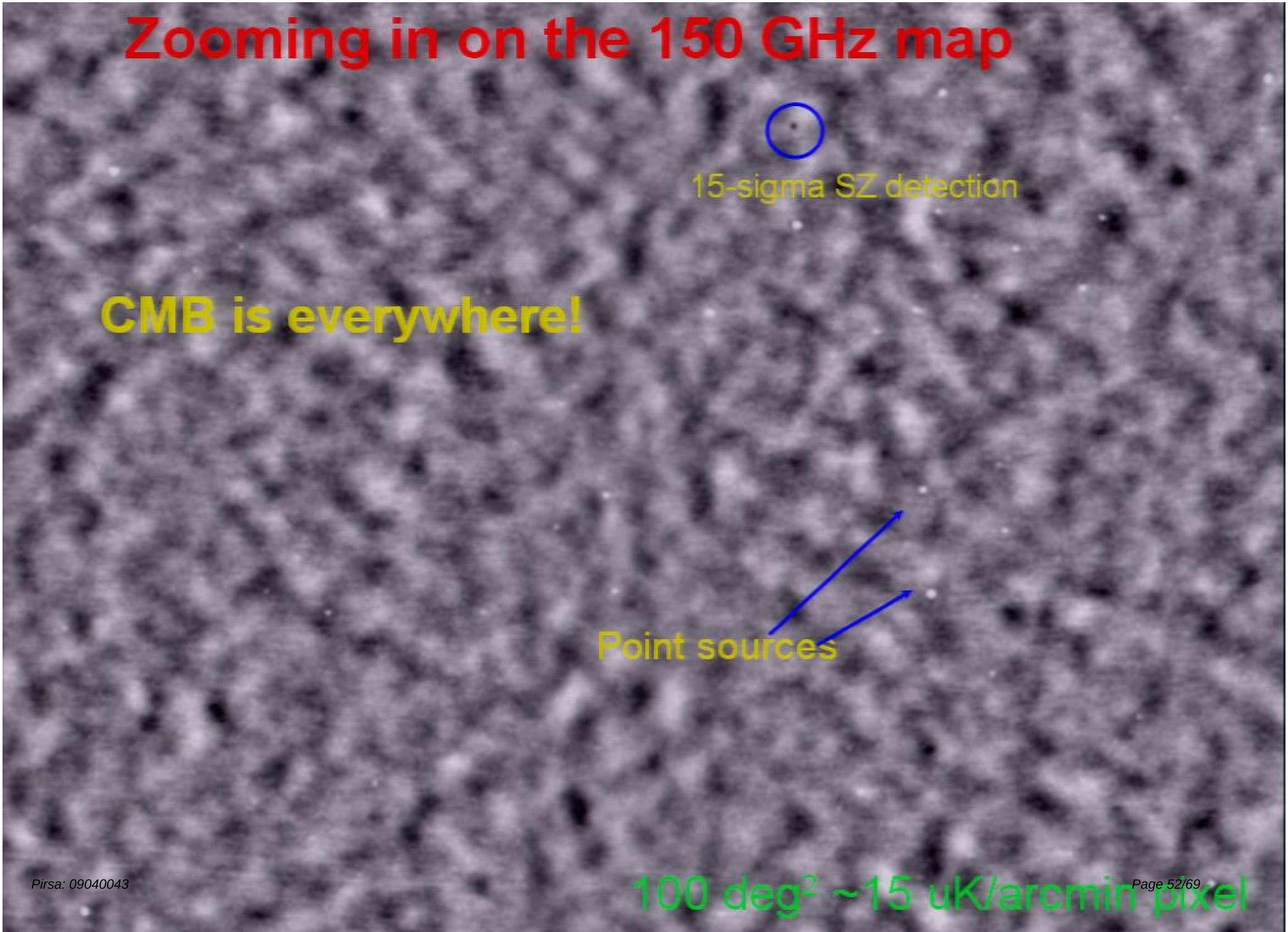
150 GHz L+R map



150 GHz L-R map



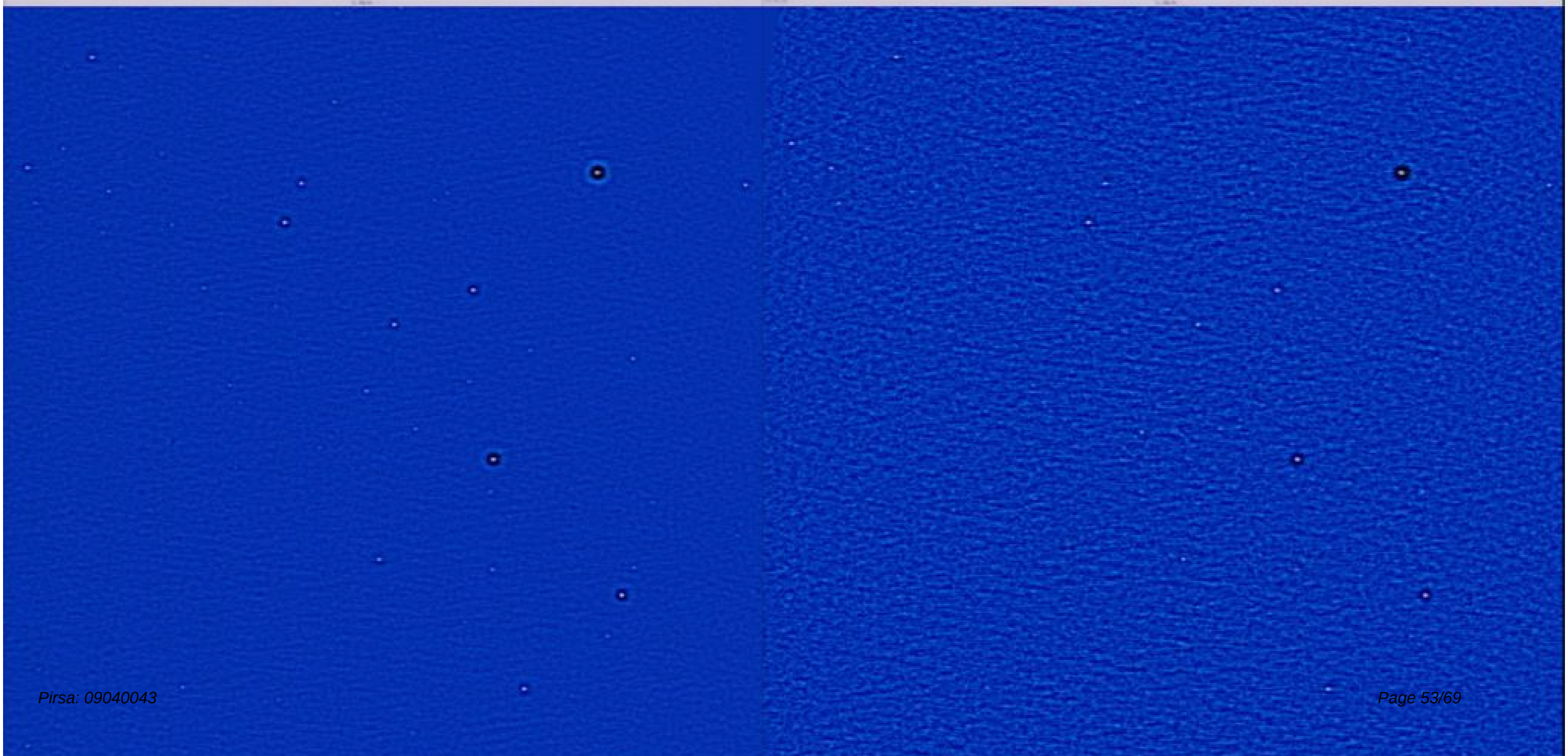
Zooming in on the 150 GHz map

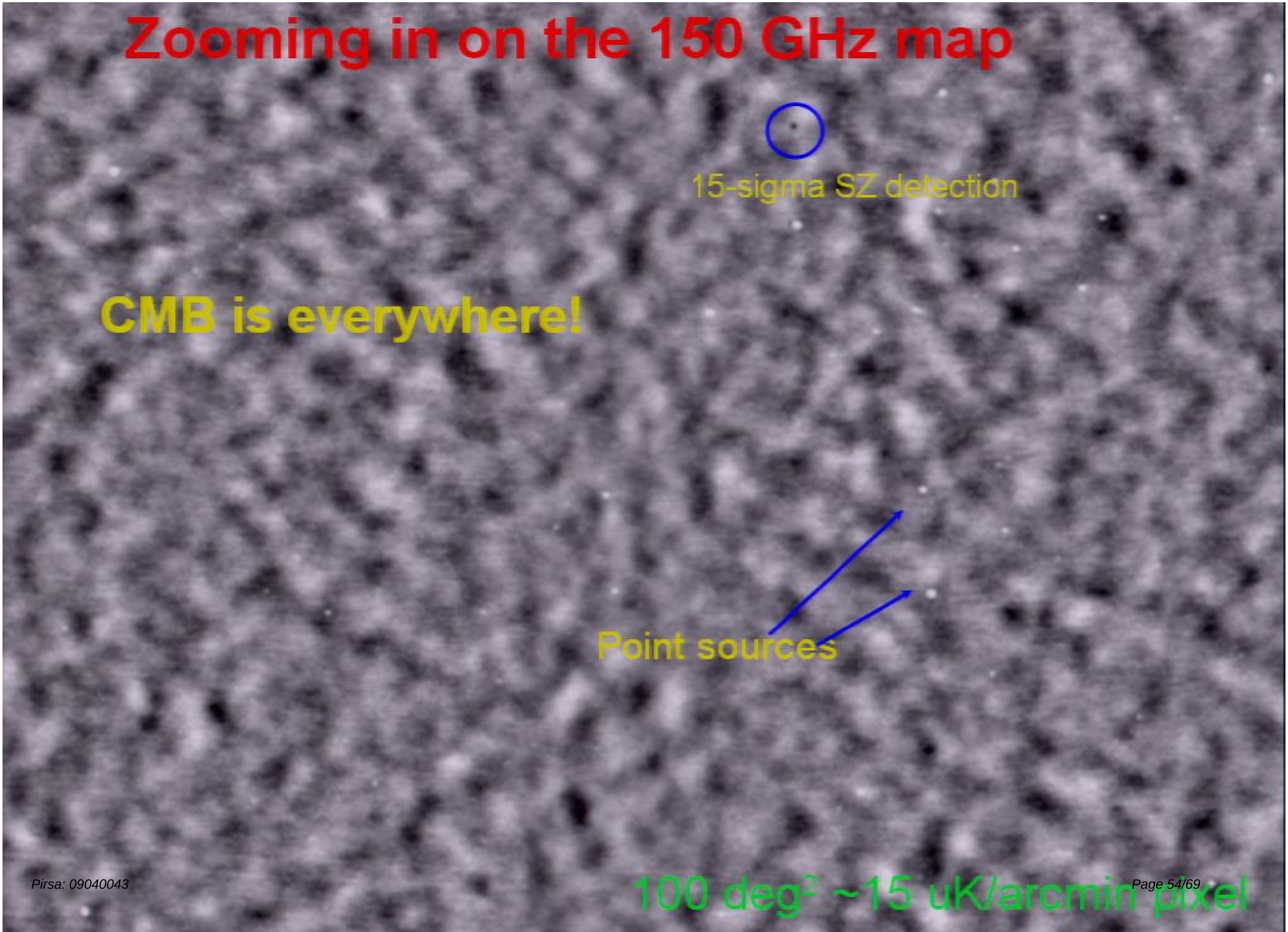


Point Source Number and Spectra

- High pass filter to enhance point source significance
- Preliminary results from 23 Hour field

Filtered 150 GHz Filtered 220 GHz




Zooming in on the 150 GHz map
15-sigma SZ detection
CMB is everywhere!
Point sources
100 deg² ~15 uK/arcmin pixel

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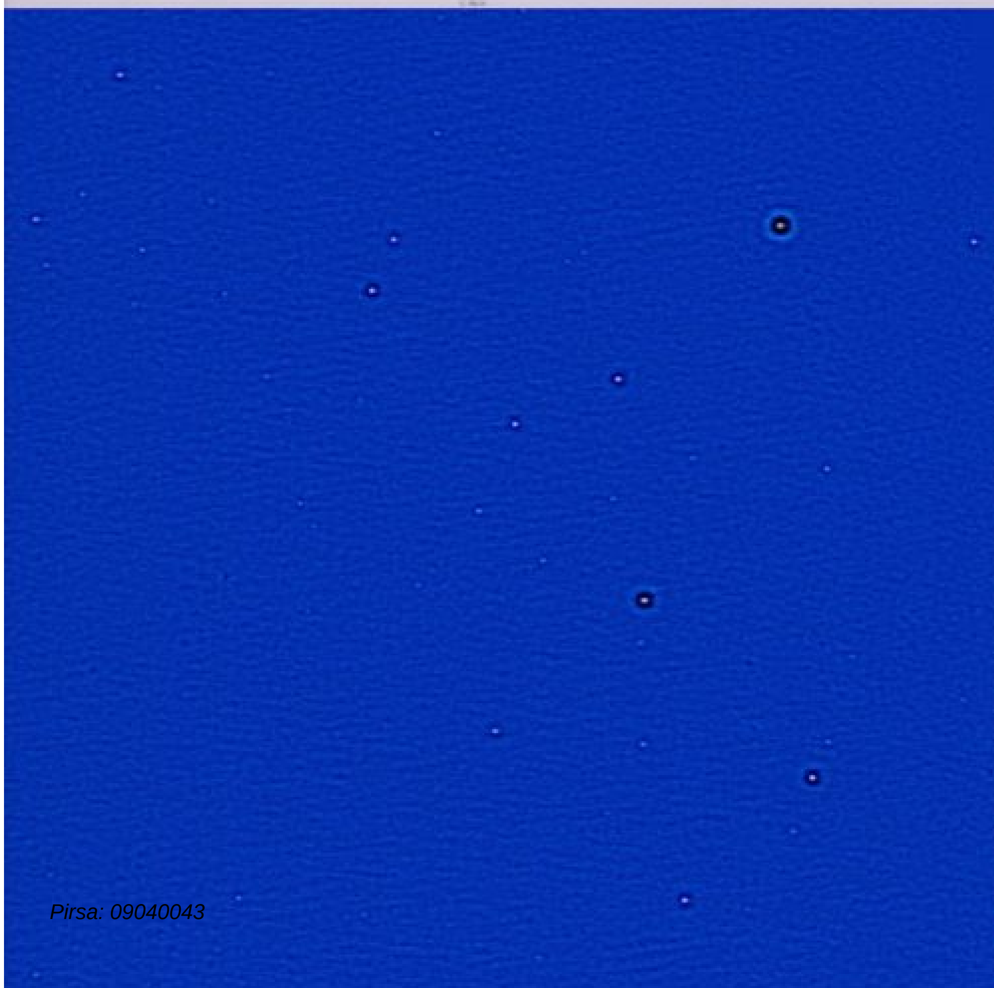
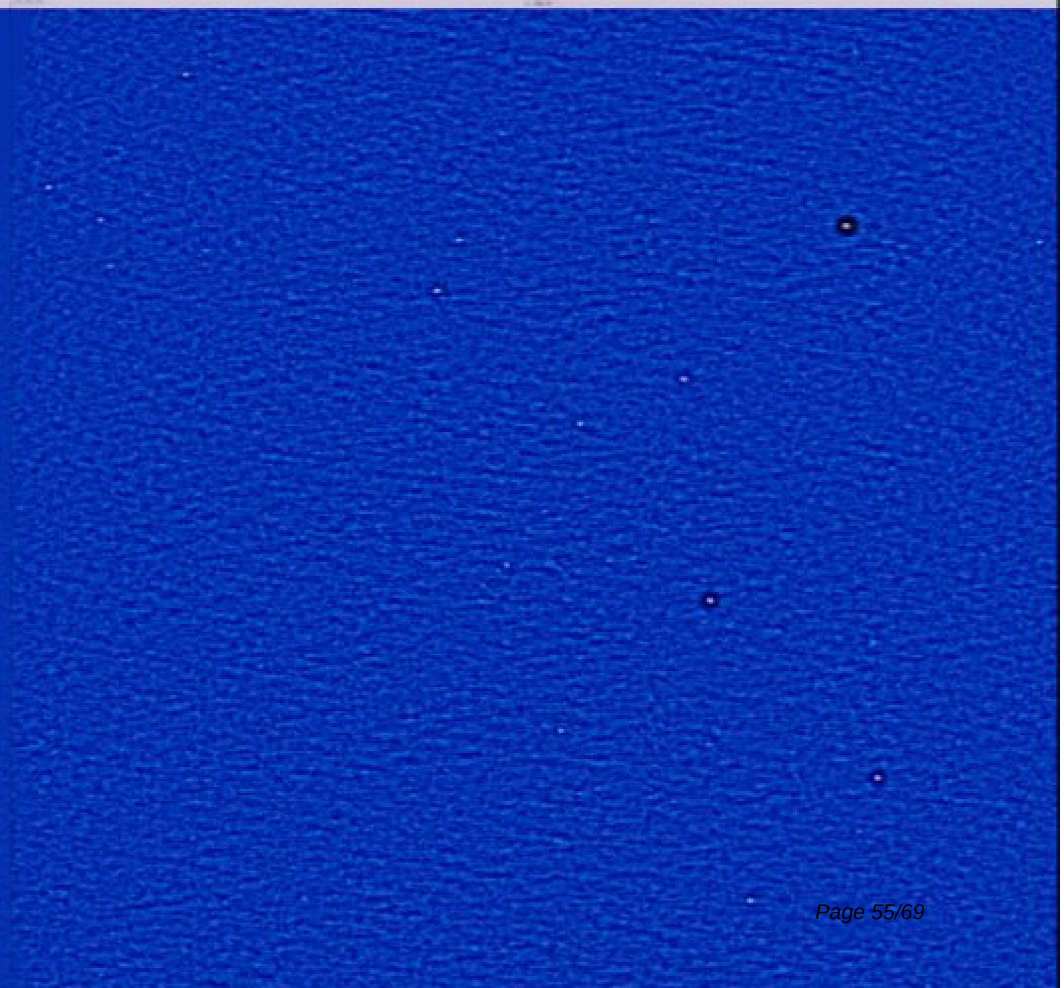
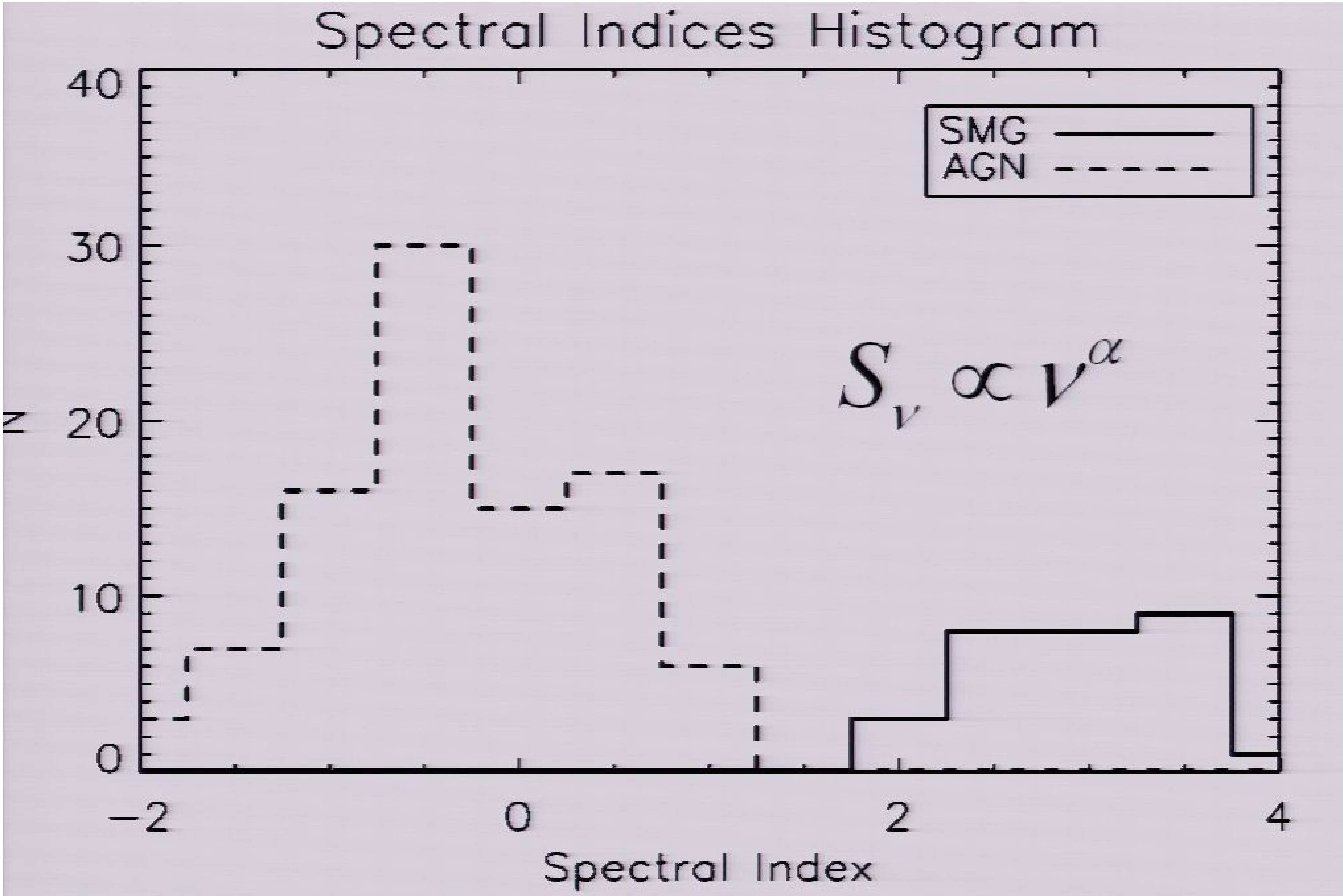


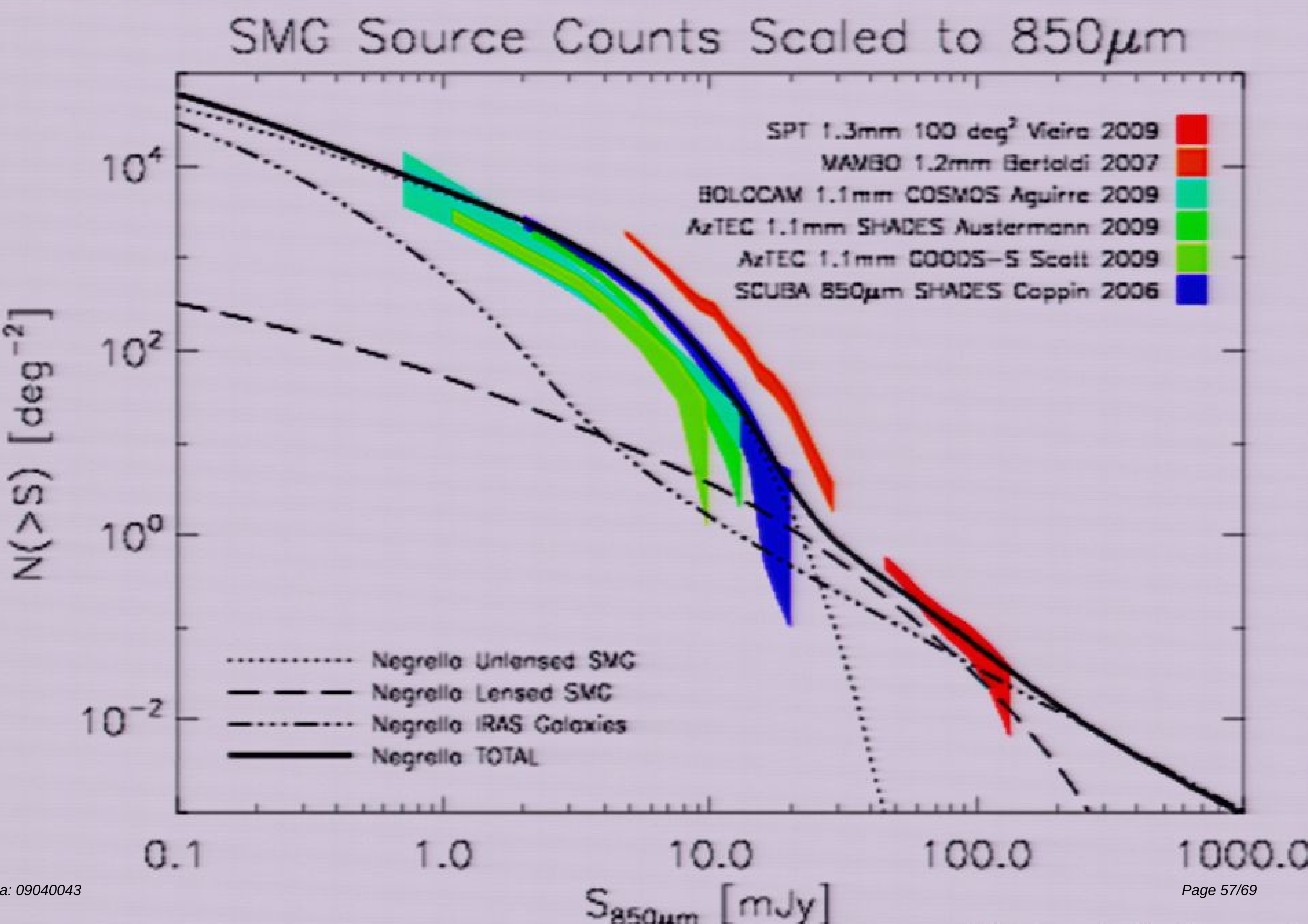
Filtered 220 GHz



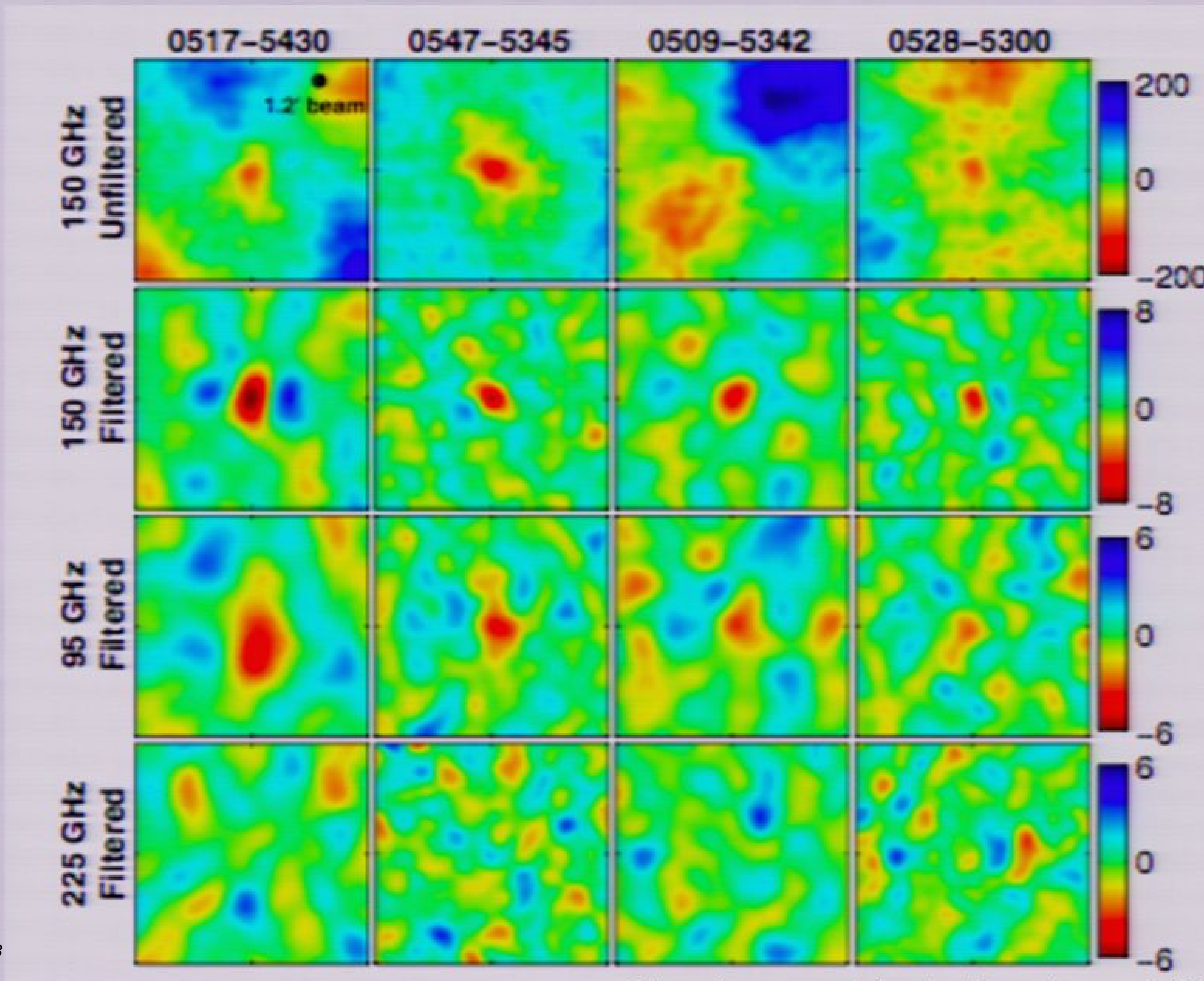


Vieira *et al* 2009 in prep

New Population of Lensed Distant Dusty Galaxies



The four most significant SPT 150 GHz detections in region overlapping 40 deg^2 BCS5h30m field



Staniszewski et al. astro-ph/0810.1578

South Pole Telescope Photometric Survey

Stage I: Blanco Cosmology Survey (BCS)

- A 45 night program that began fall 2005 to survey 100 square deg (2.5 pct of SZ survey size) at Blanco 4m on Cerro Tololo
- http://cosmology.uiuc.edu/BCS

Stage II: Dark Energy Survey (DES)

- 5000 square deg G, R, I, and Z bands
- 2005-2010: Construction of a new 3 square deg camera for the Blanco 4m
- 2010-2015: Survey Operations
- https://www.darkenergysurvey.org/

Blanco 4m on Cerro Tololo

Image credit: Roger Smith/NOAO/AURA/NSF

John Peoples, Director

Collaboration of: Fermilab, U Illinois, U Chicago, LBNL, CTIO/NOAO, Barcelona, UCL, Cambridge, Edinburgh, U Michigan, UPenn, Brazil

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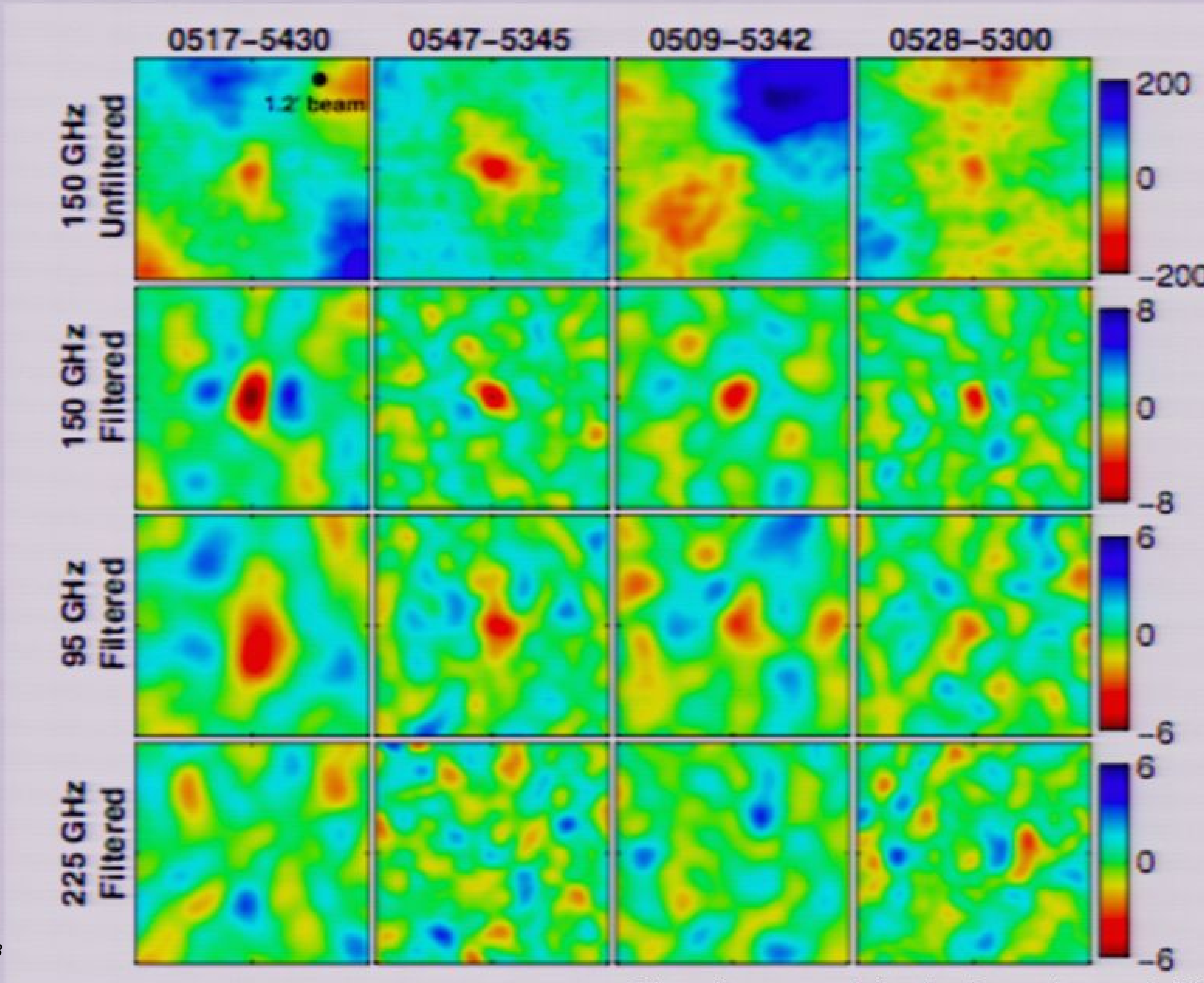

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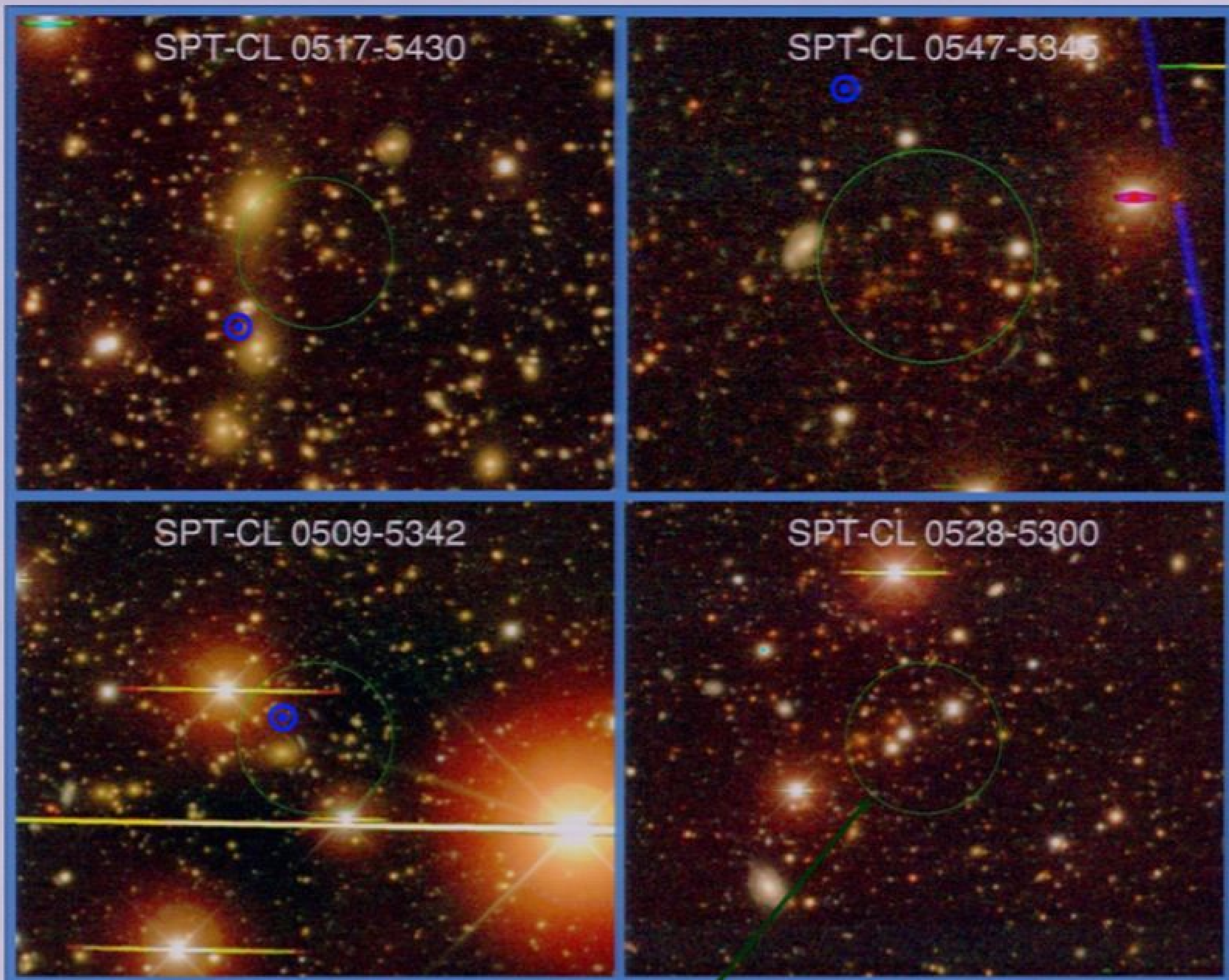
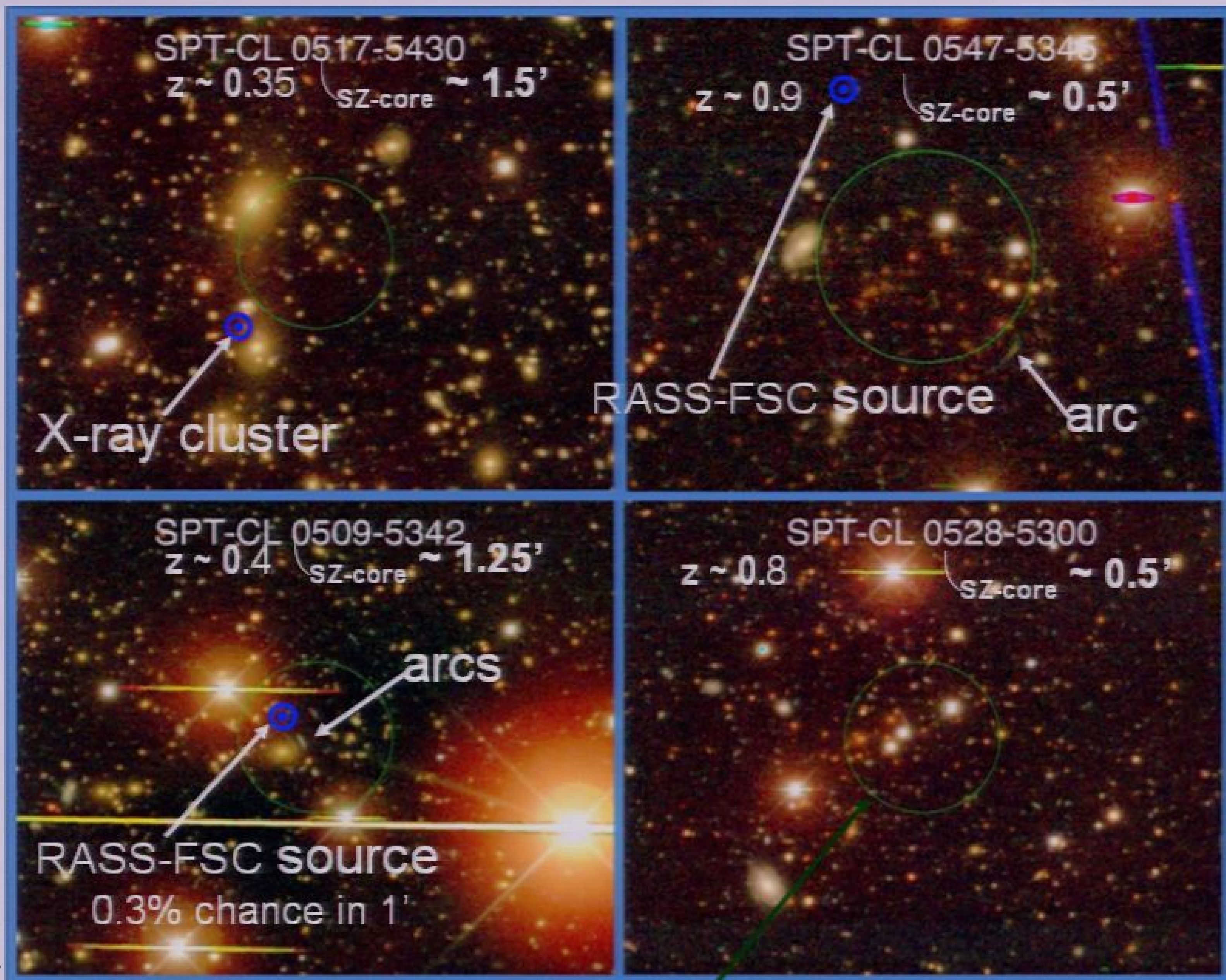
BCS *gri* pseudo color images of the SPT detection fields



Green circles mark 1' diameter centered on SPT location

BCS *gri* pseudo color images of the SPT detection fields



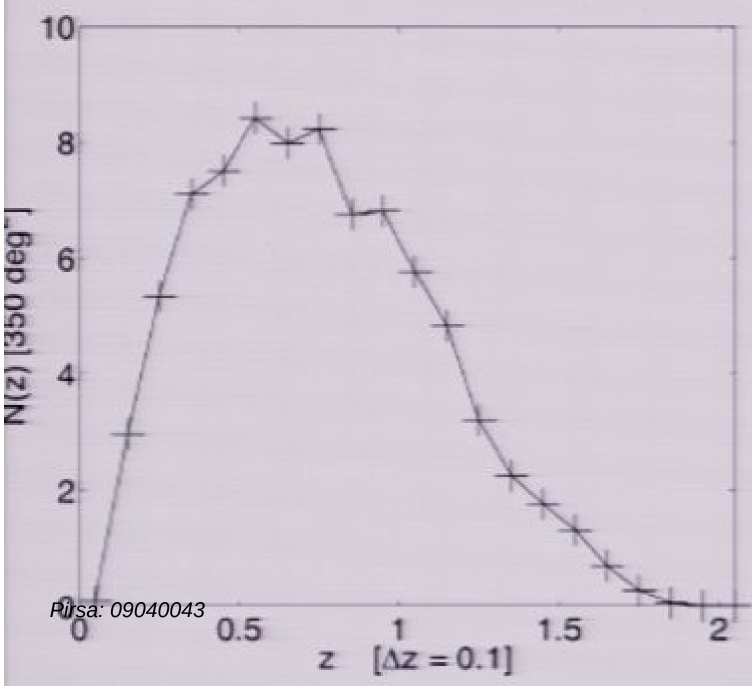
Green circles mark 1' diameter centered on SPT location

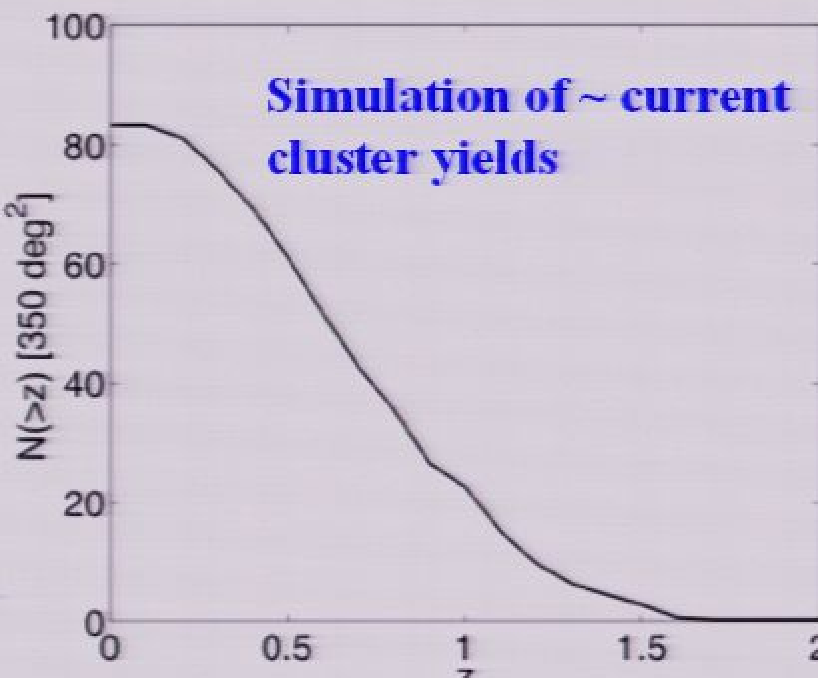
2008 season:

- 200 deg^2 surveyed
- 48 clusters above 4.5σ (20% expected due to noise/foregrounds)
- 16 candidates in BCS region, 10 with Magellan data (so far)
- >20 photo/spectroscopic redshifts (so far)

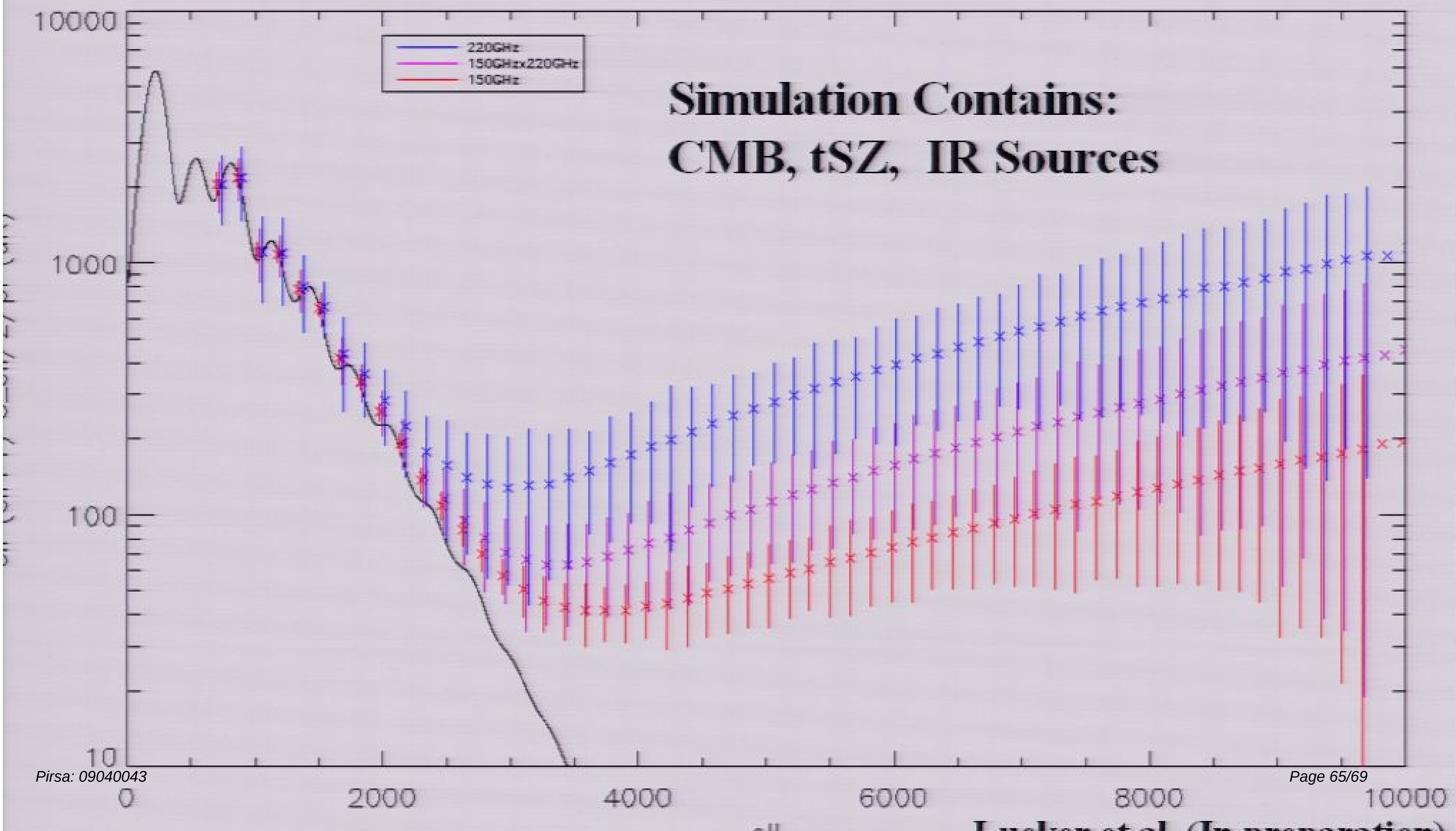
By December 2009:

- ~1000 deg^2 to similar depth
- Catalog of >200 massive clusters (mean z~0.7, tail to very high z)





Realistic Expectations for PS from first SPT 100 deg^2 field



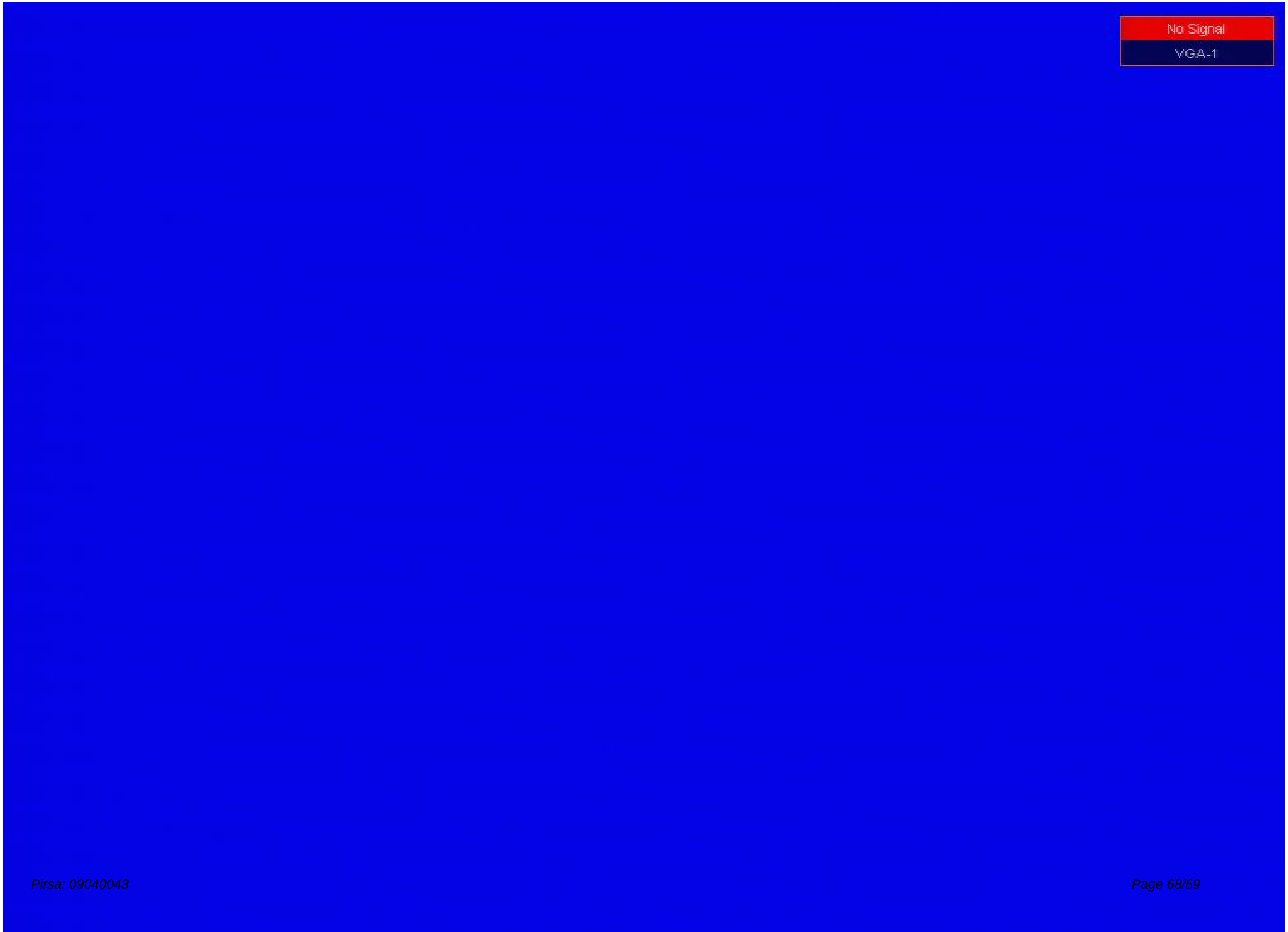
Summary

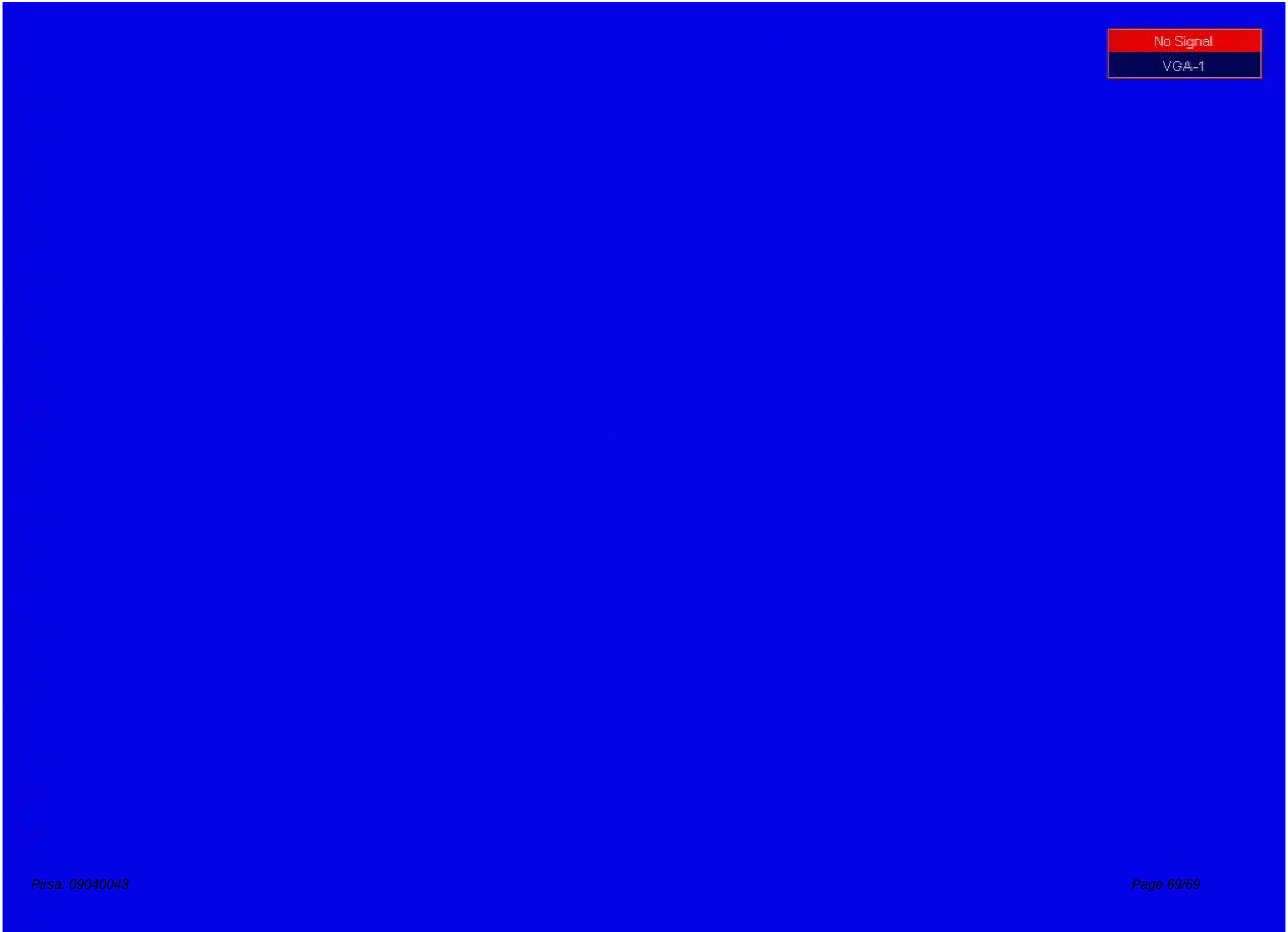
- SPT is online and producing the first SZ selected cluster catalog.
  - Cluster X-ray, IR, and Optical follow-up is underway.

- Catalog of bright point sources including AGN and what are likely high-redshift lensed galaxies.
- CMB power spectrum analysis proceeding, new constraints on σ_8 forthcoming.
- High signal to noise wide-field cluster imaging

- Observe until at least December 2010 (end of season 4), and likely December 2011 with current receiver.

- During this period, will cover >2000 deg^2 of sky and produce a catalog of hundreds of massive clusters.


No Signal
VGA-1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