Title: Cosmology with ACT

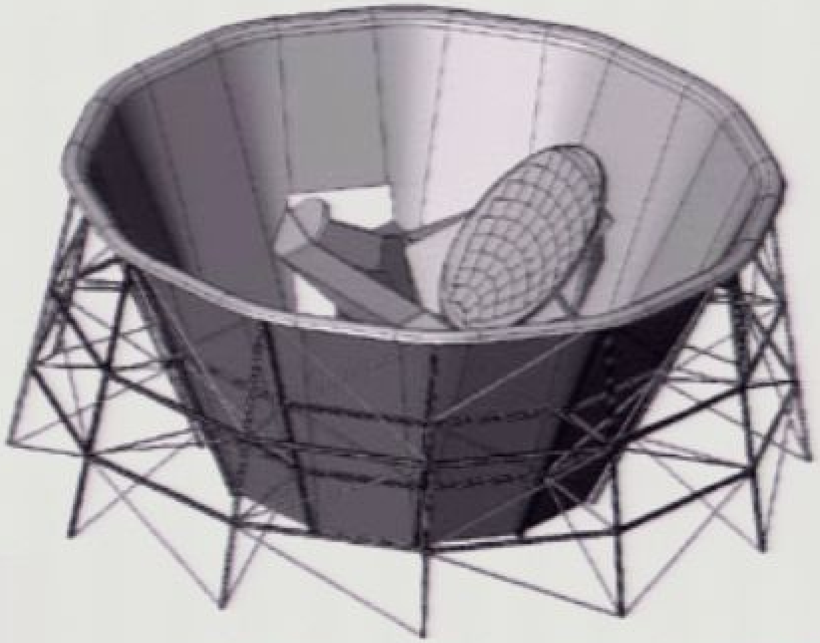
Date: Sep 10, 2007 09:30 AM

URL: http://pirsa.org/07090021

Abstract:

Atacama Cosmology Telescope

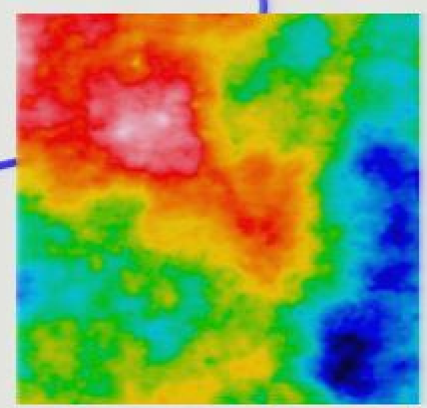
A program designed to measure the high-ℓ features of the CMB



ACT is a 3-color off-axis 6m telescope. Beam sizes are 1-2 arc minutes, corresponding to $400 < \ell < 7000$

X-ray

Optical

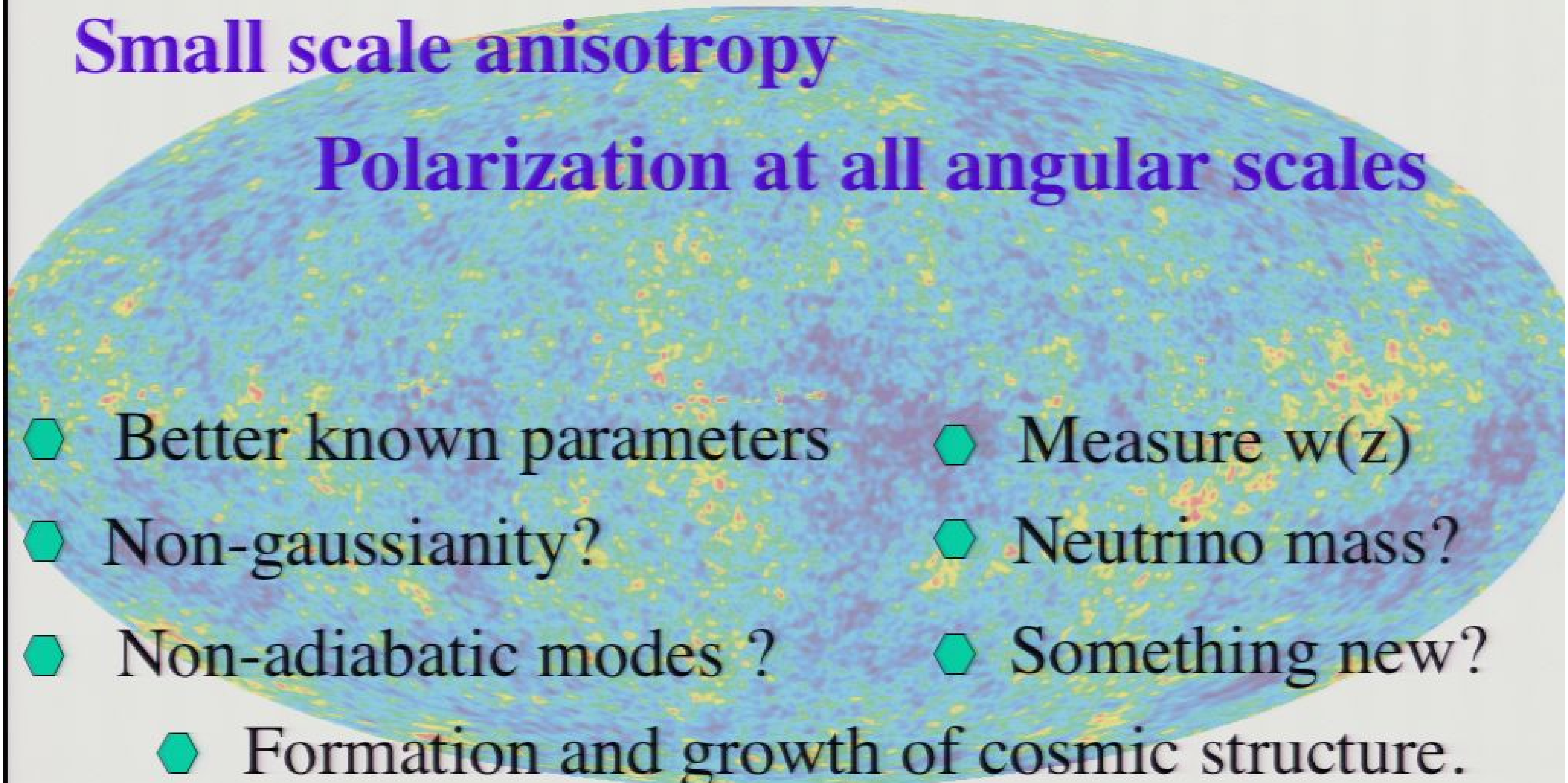


Theory

Collaboration:

Cardiff Columbia CUNY Haverford INAOE NASA/GSFC NIST Princeton

The CMB is still a scientific gold mine.



Small scale anisotropy

Polarization at all angular scales

- Better known parameters
- Measure w(z)
- Non-gaussianity?
- Neutrino mass?
- Non-adiabatic modes ?
- Something new?
- Formation and growth of cosmic structure.
- **Tests of field theories at 10^{-35} s.**

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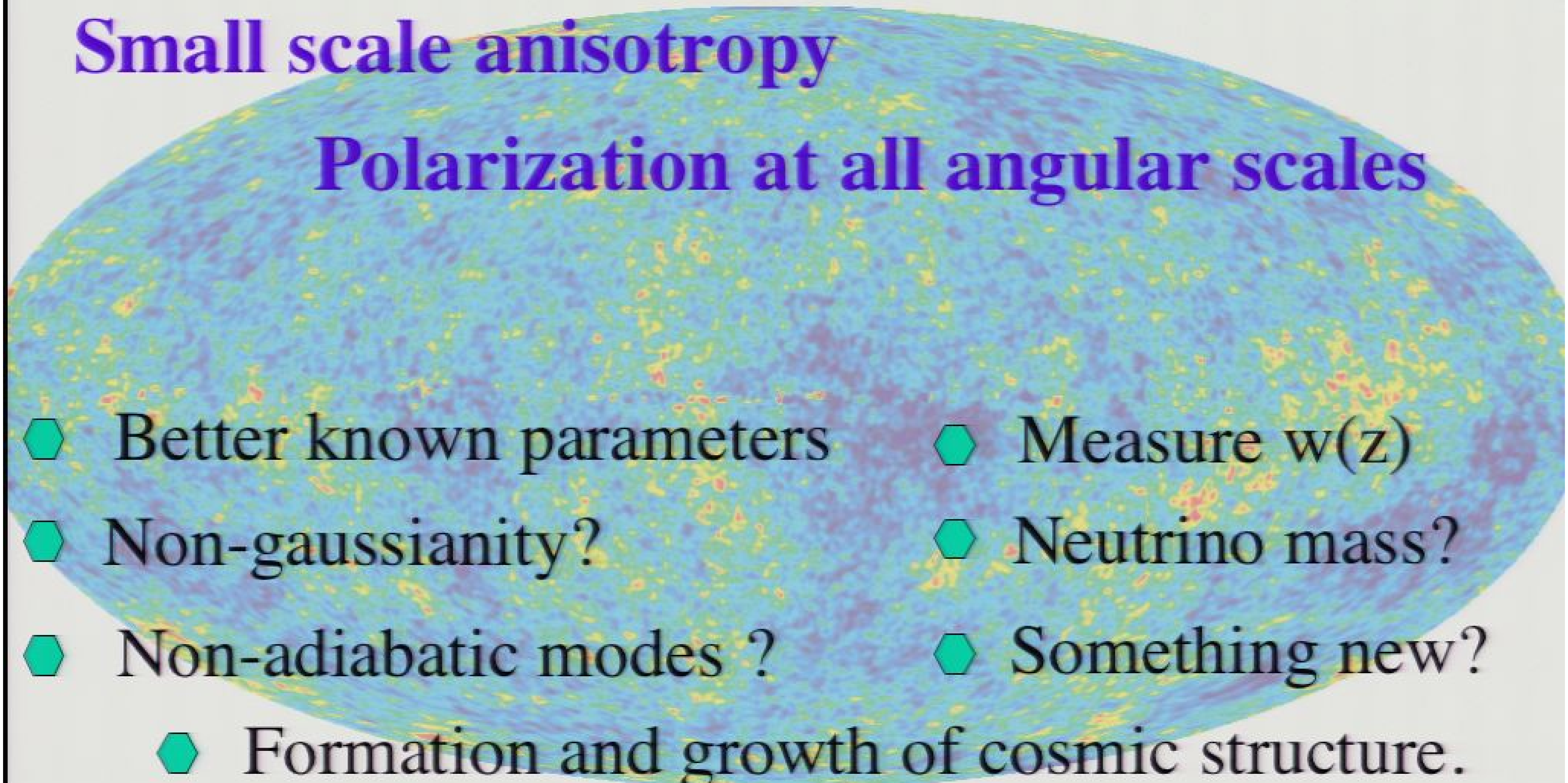

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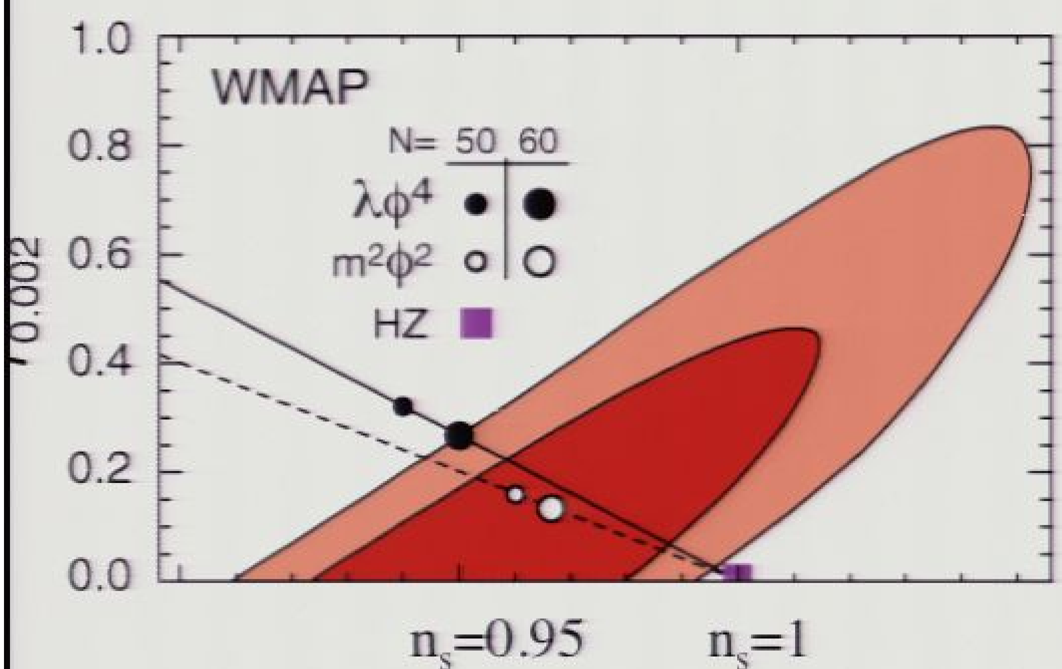
One example…

Tilt of the Angular Power Spectrum.

The overall tilt of the spectrum--- encoded in the "scalar spectral index" n_s--- is a new handle on inflation.

ACT and other small scale measurements will resolve n_s.

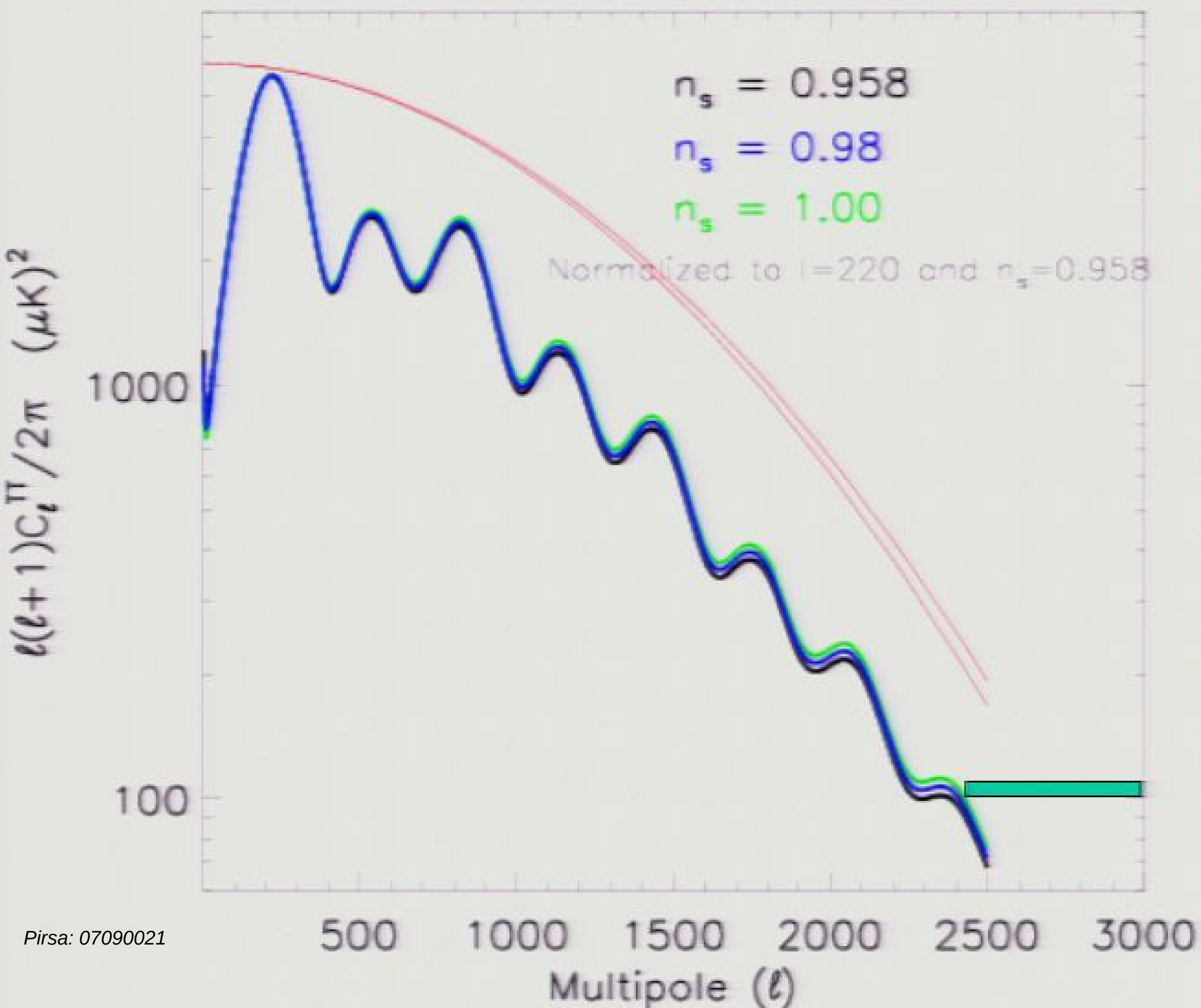


Polarization experiments will help resolve *r*.

Expect results from Planck, Clover, Spider, Ebex, Spud, Bicep, Poincare, bPol, CMB-pol. This is an active field.

Expts in red use UBC TES electronics

Comparison of WMAP and ACT spectra will provide a useful measurement of n_s.



A 2% variation in n_s produces a 5% variation in primary anisotropy at $l = 2500$.

The relative calibration of WMAP and ACT must be known to <1% to provide useful data. This is easier than knowing the WMAP beam shape well enough.

ACT will also probe secondary anisotropies which arise during the epoch of structure formation

Sunyaev Zeldovich effect from clusters	Epoch of cluster formation
Gravitational Lensing of the CMB	Measure w(z)
Vishniac Effect and Kinetic SZ	Measure mass spectrum
Foreground point sources	Star formation history

Photo from Act towards llano de Chajnantor by Michele Limon

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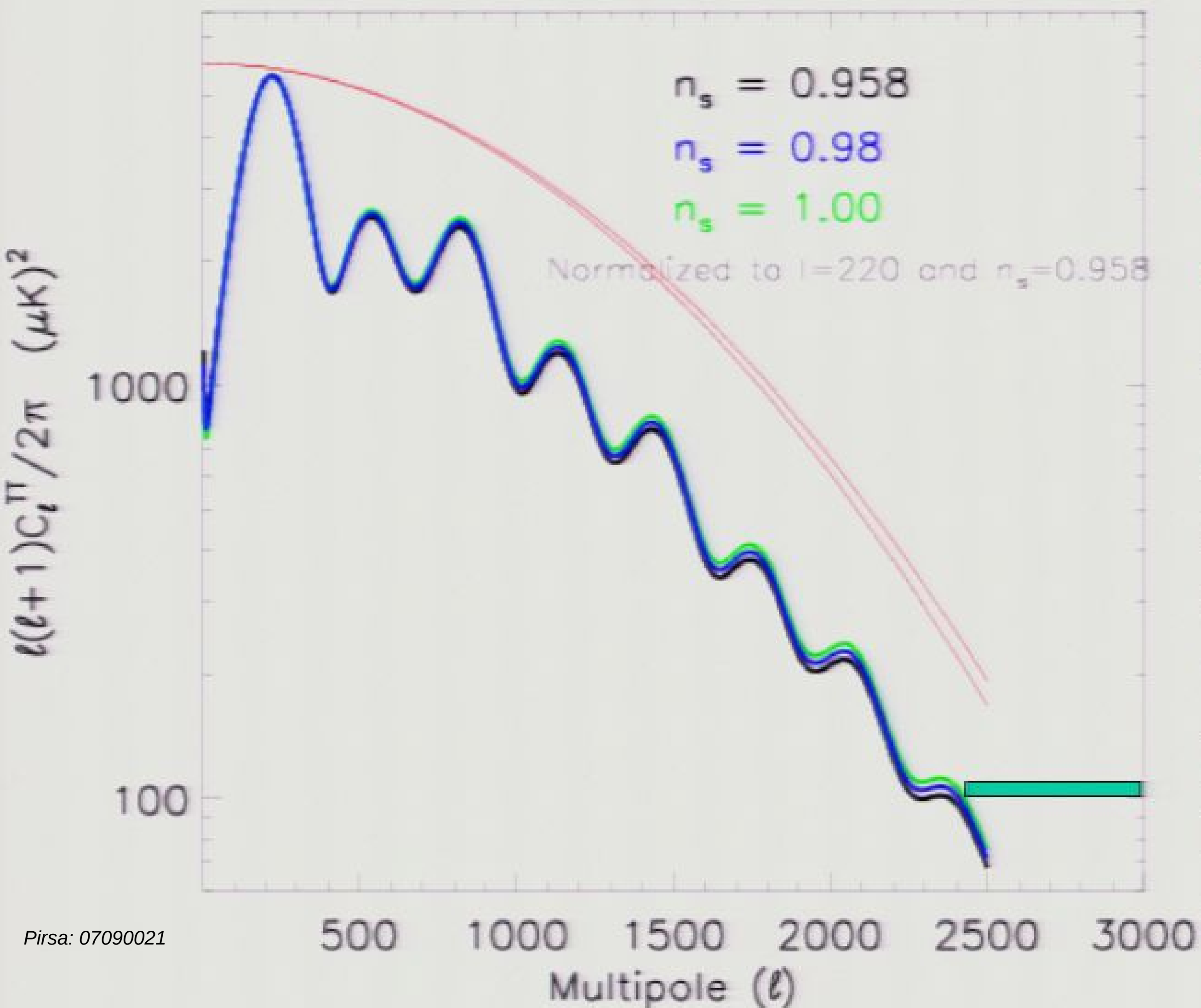

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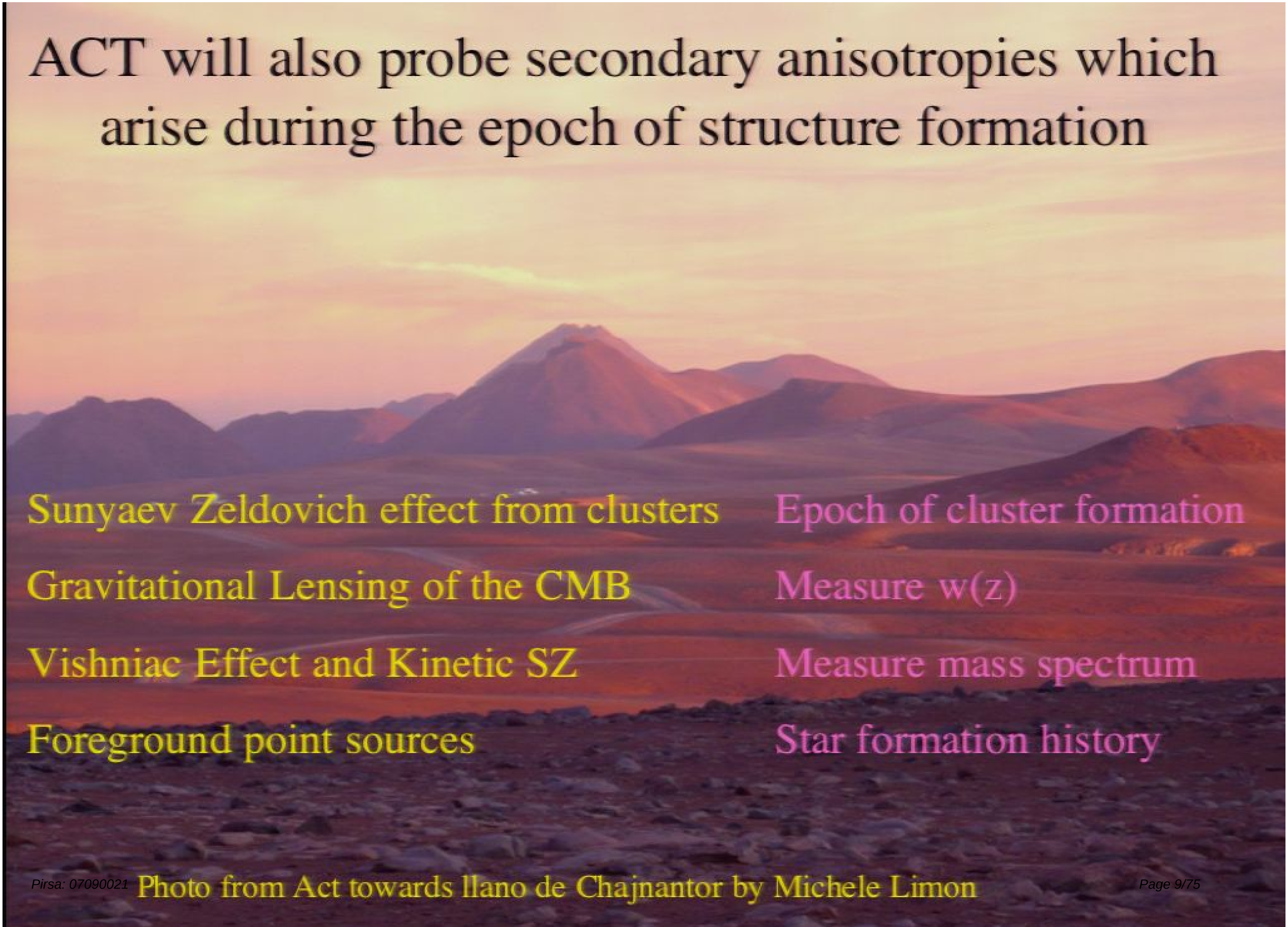
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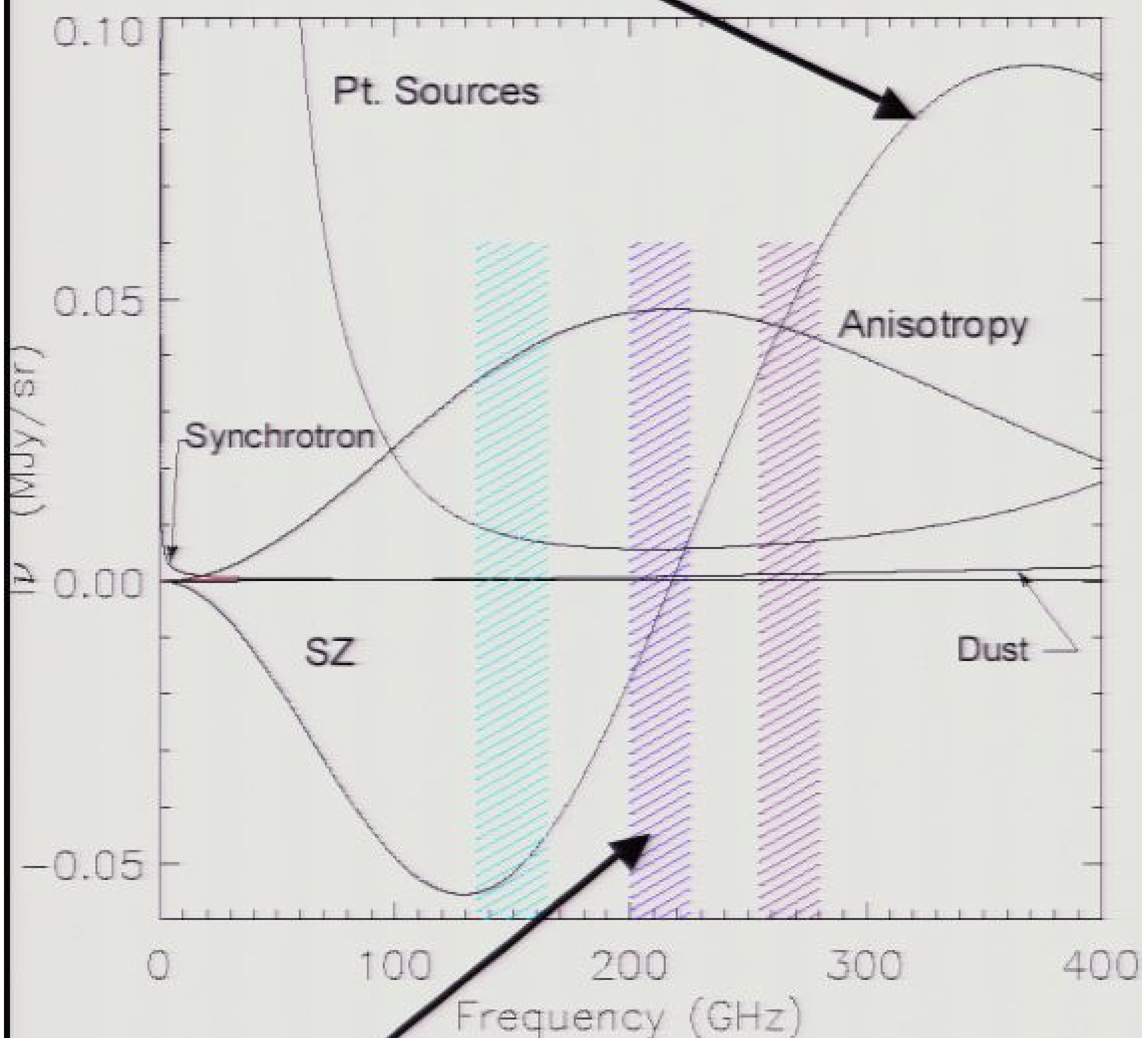
SZ Signature: Non-CMB spectrum

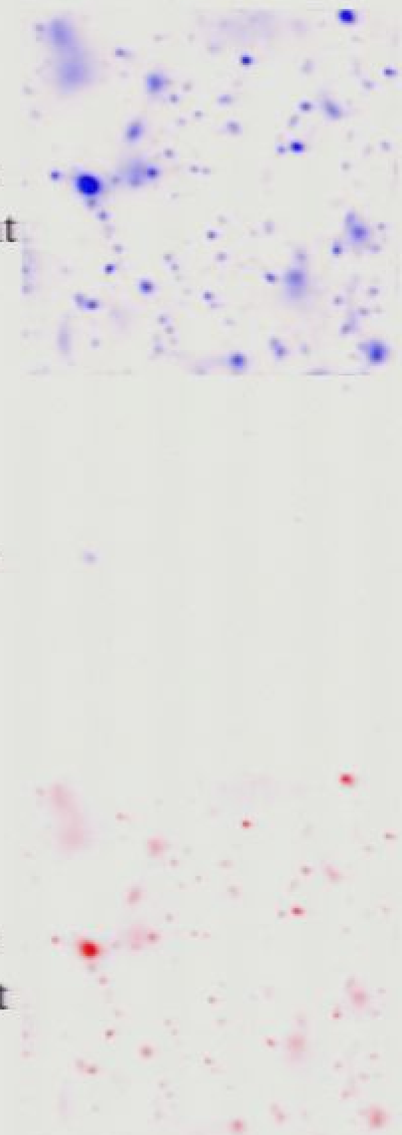
Hot electron gas imposes a unique spectral signature:
photon number is preserved while photons scatter to higher energy



145 GHz
decrement

220 GHz
null

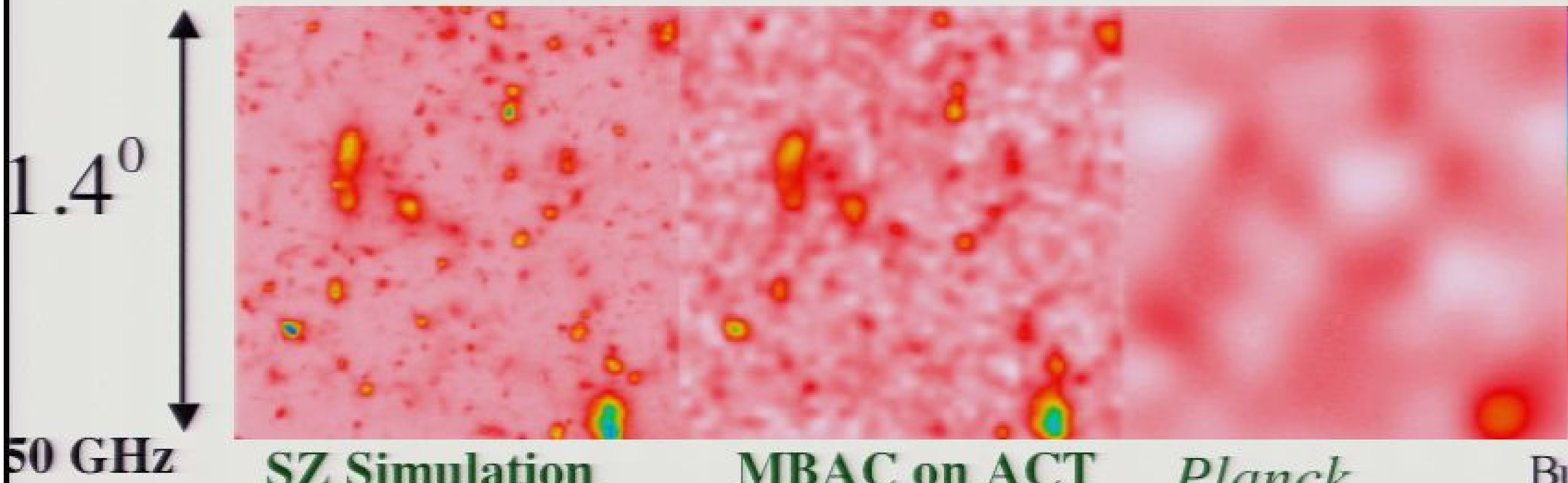
270 GHz
increment



1.4°x 1.4°

NO SZ Contribution in Central Band

The ACT angular resolution is needed to study SZ.



SZ Simulation

MBAC on ACT
2X noise
1.7' beam

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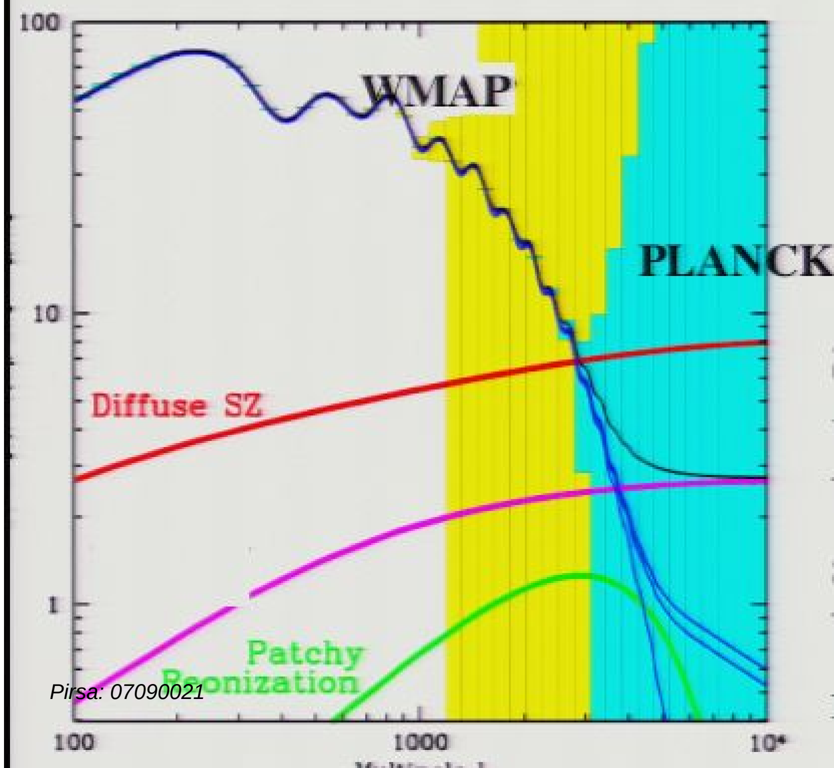

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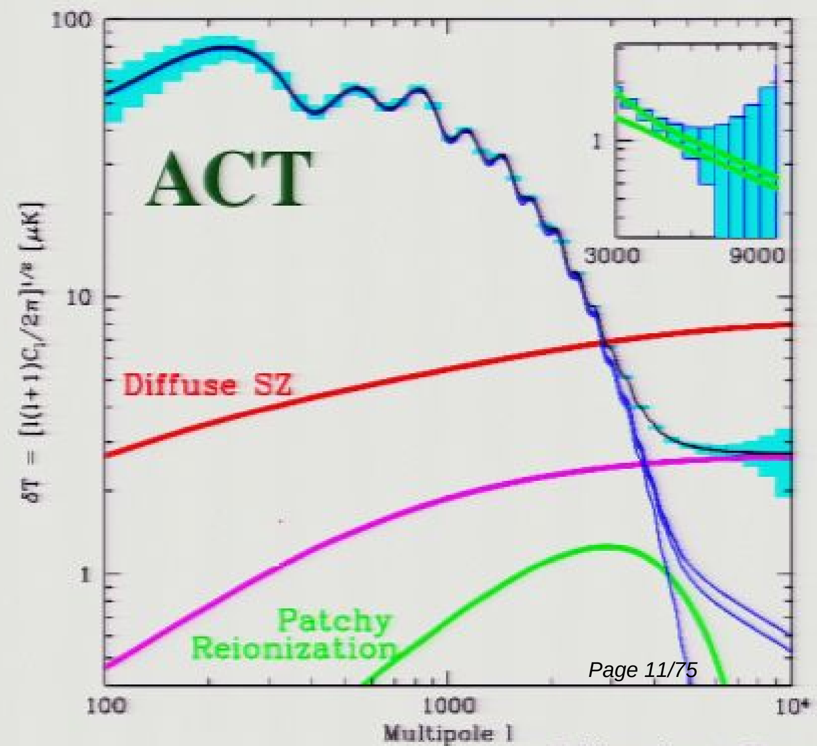

Thomson Scattering and structure in either the velocity or the density of free electrons produce a secondary anisotropy.

The frequency spectrum (color) of the anisotropy matches the CMB.

$$\Delta_T(\hat{\gamma}) = -\int \mathrm{d}\mathbf{l}.\frac{\mathbf{v}}{c}\,\sigma_T n_{e,\mathrm{f}} e^{-\tau} = -\frac{\sigma_T c}{H_0}\int \frac{\mathrm{d}\chi}{1+z}\,\frac{\hat{\gamma}.\mathbf{v}}{c} n_{e,\mathrm{f}} \qquad (1)$$

where σ_T is the Thomson cross-section, $n_{e,\mathrm{f}}$ the number density of free electrons, $\mathbf{v}$ the peculiar velocity and l the coordinate along the line of sight, all in physical units.

Valageas, Balbi &Silk Astro-ph 0009040

ACT will measure the matter power spectrum in both linear (Ostriker-Vishniac) and non-linear (kinetic Sunyaev-Zel'dovich) regimes.

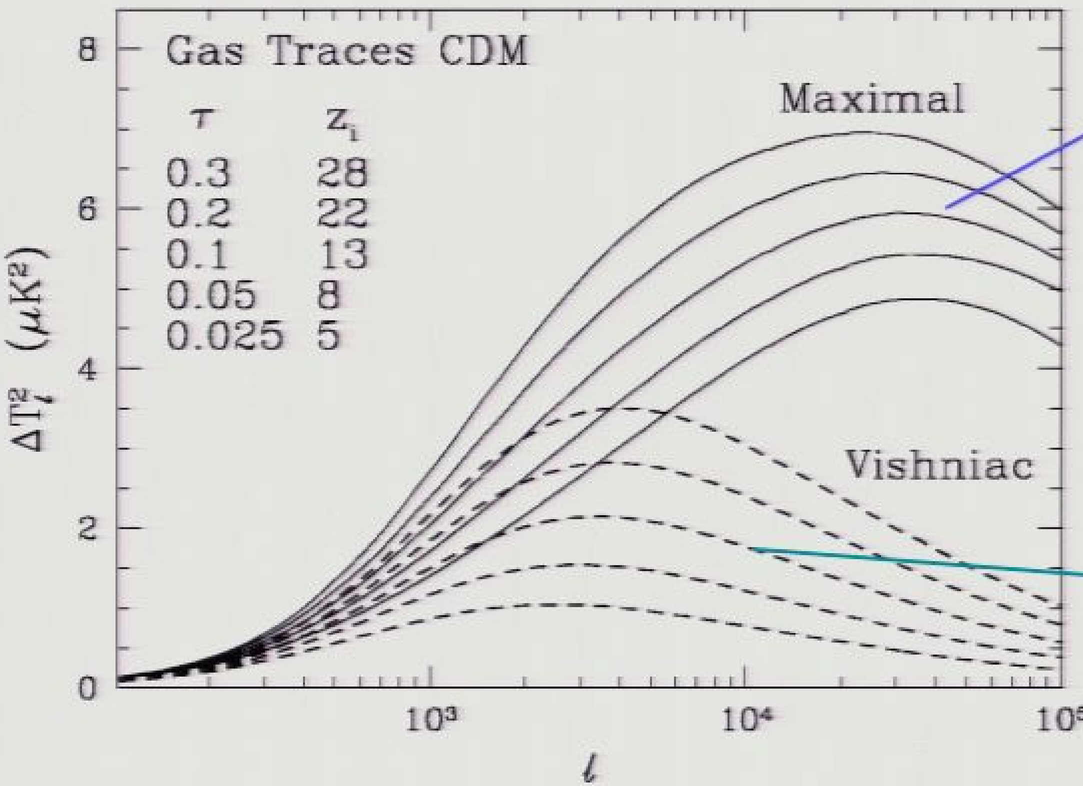

FIG. 5.— Maximal nonlinear enhancement of the Vishniac effect. Under the assumption that the gas density traces the dark matter density into the deeply nonlinear regime the Vishniac effect is significantly enhanced by nonlinearities at $\ell \gtrsim 1000$ especially in the late reionization scenarios.

Non-linear: kSZ

Clusters have formed. Cluster velocity produces signal

Linear Effects: OV

Structure in n_e not correlated with bulk **v**.

From Wayne Hu, Astro-ph 9907103

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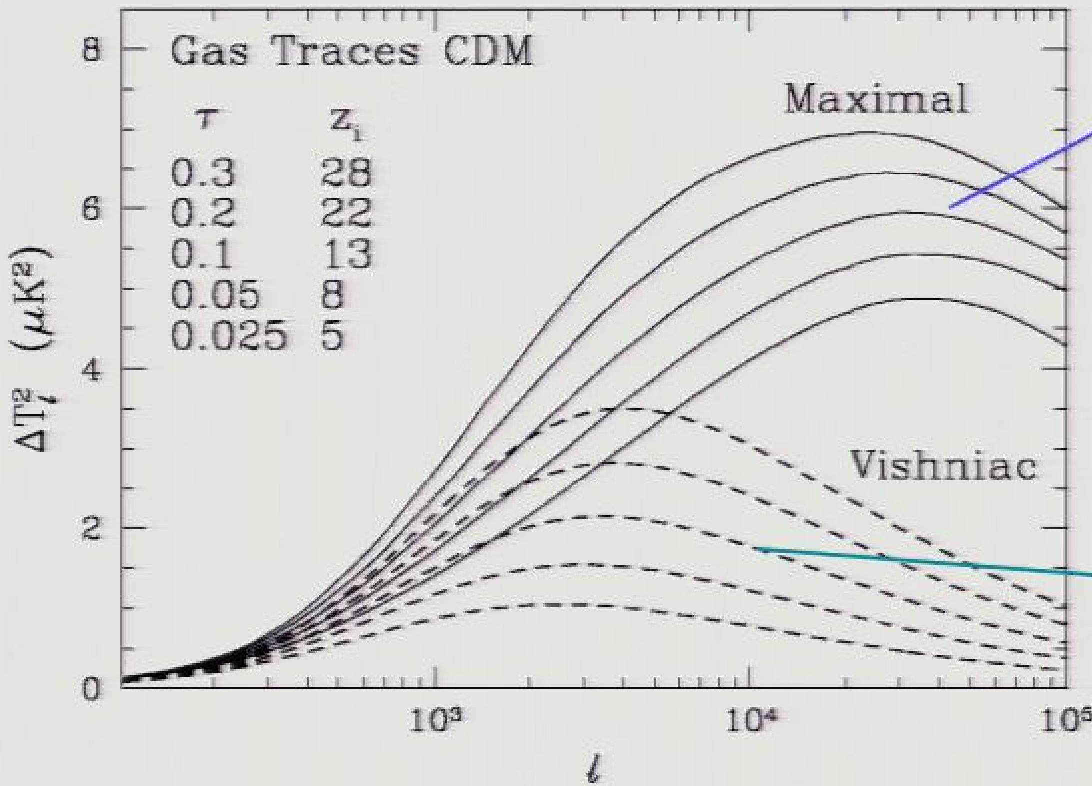

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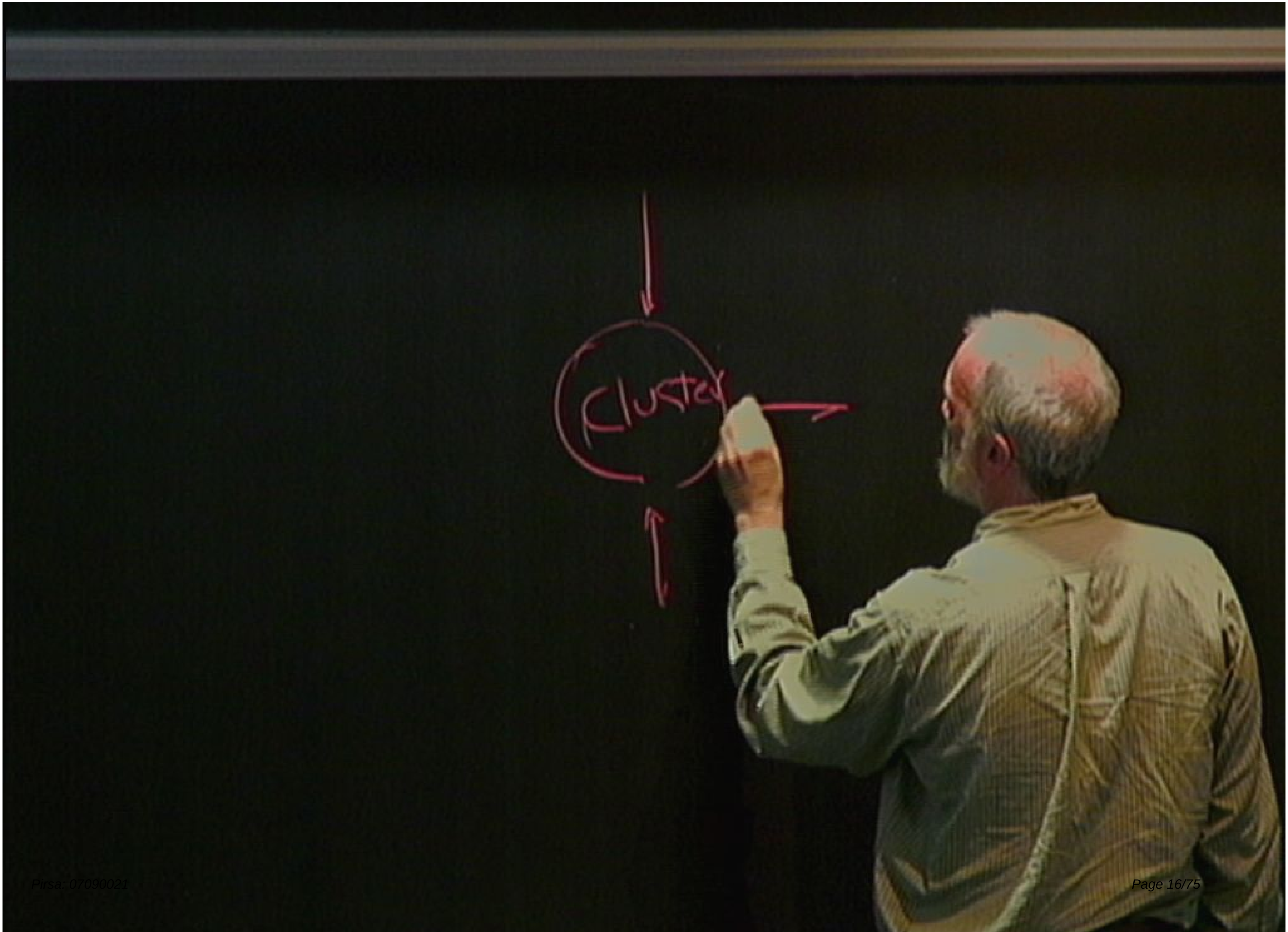
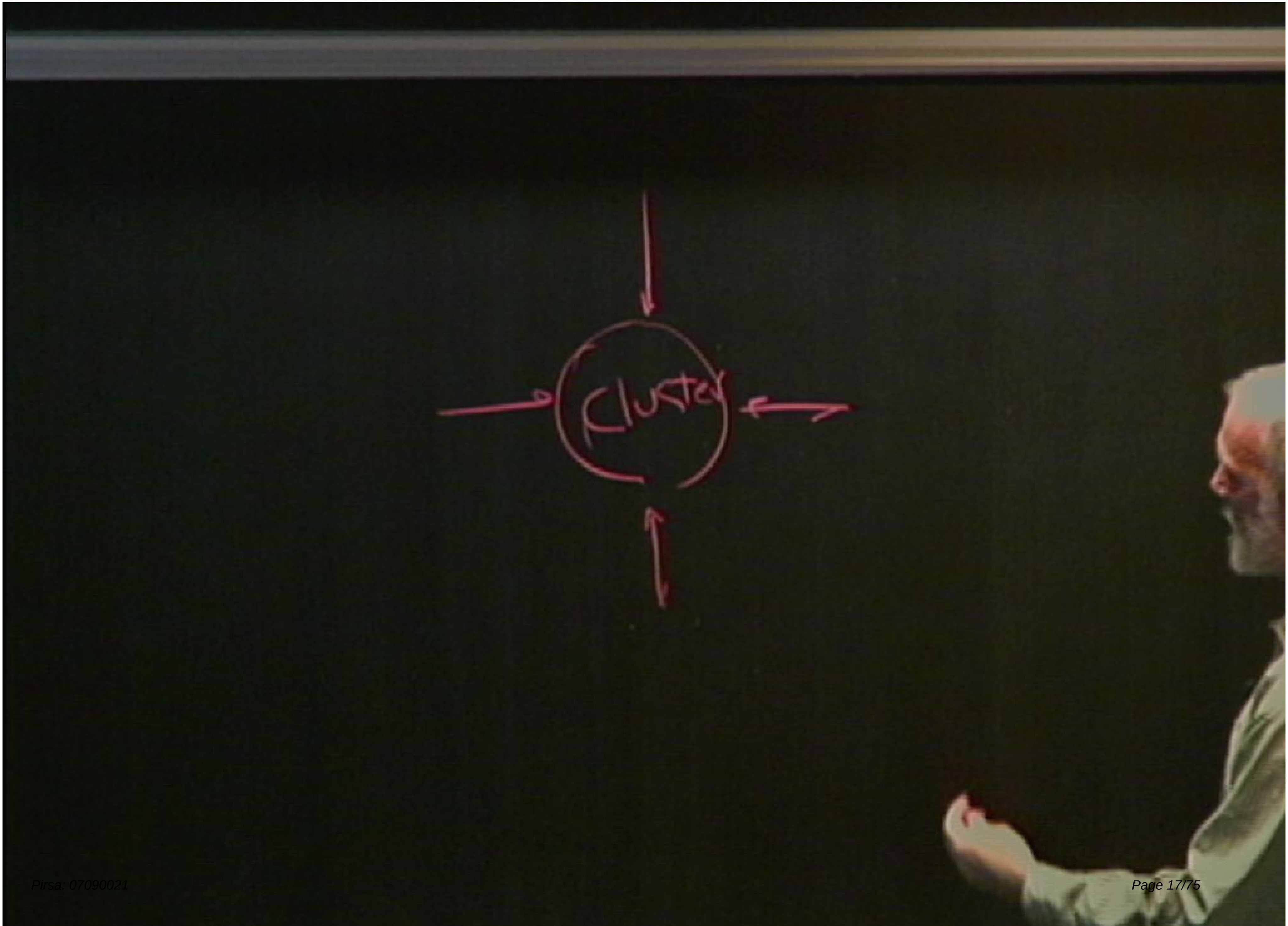

Cluster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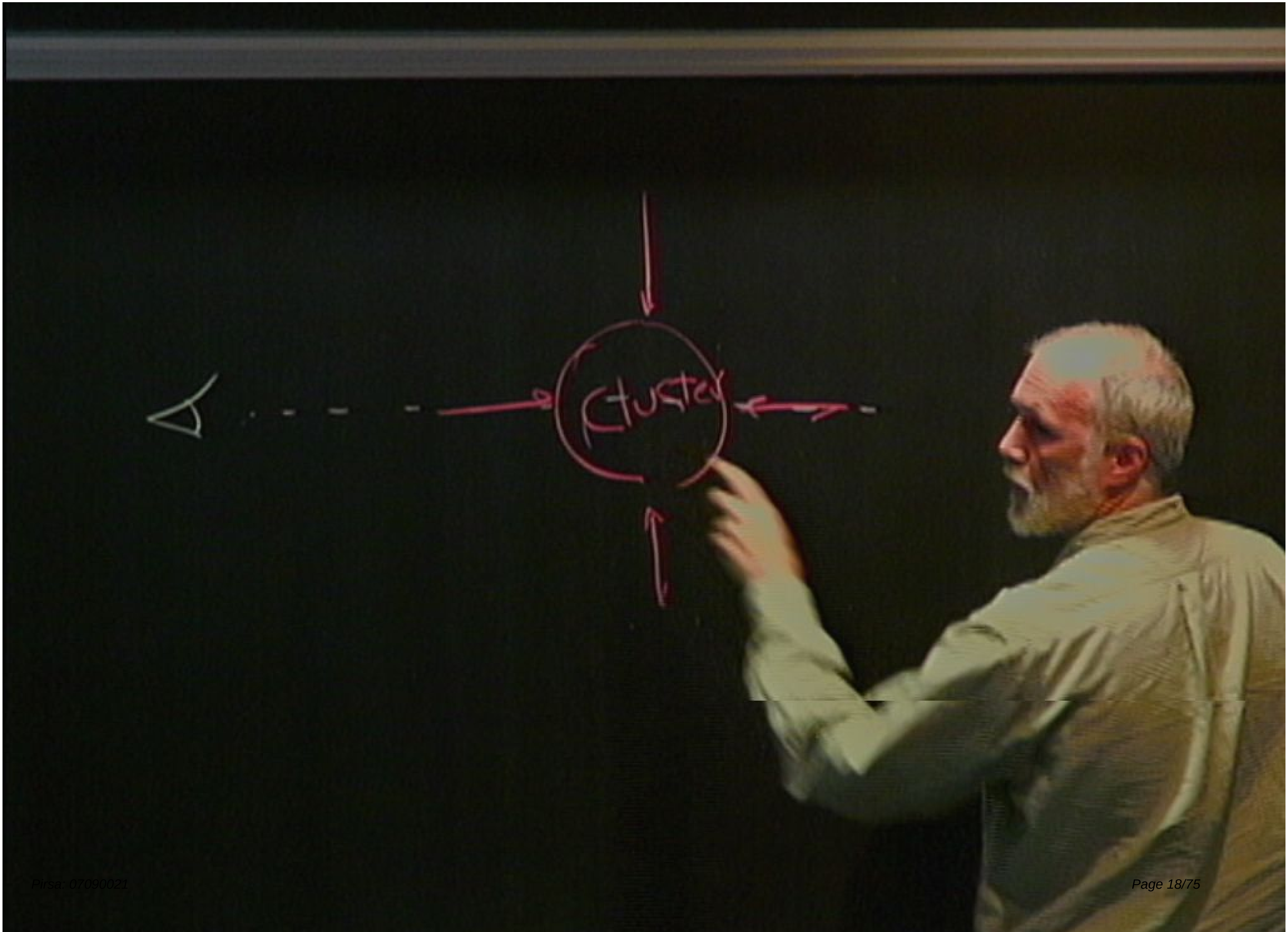
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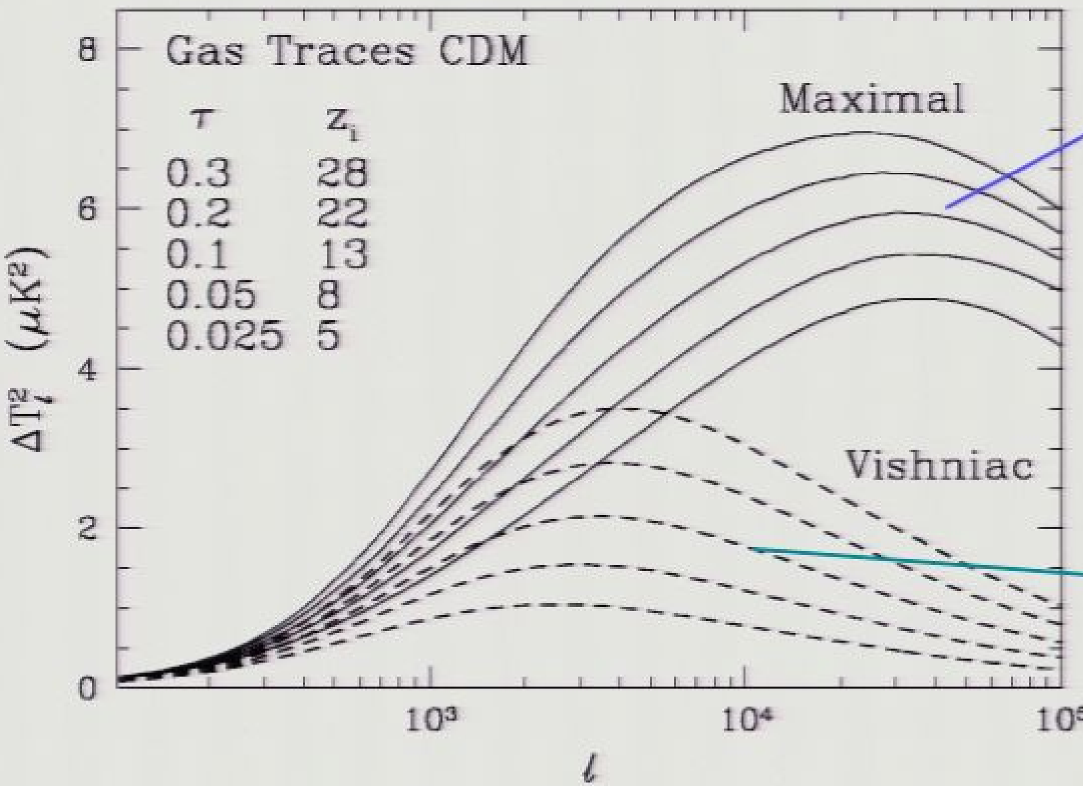

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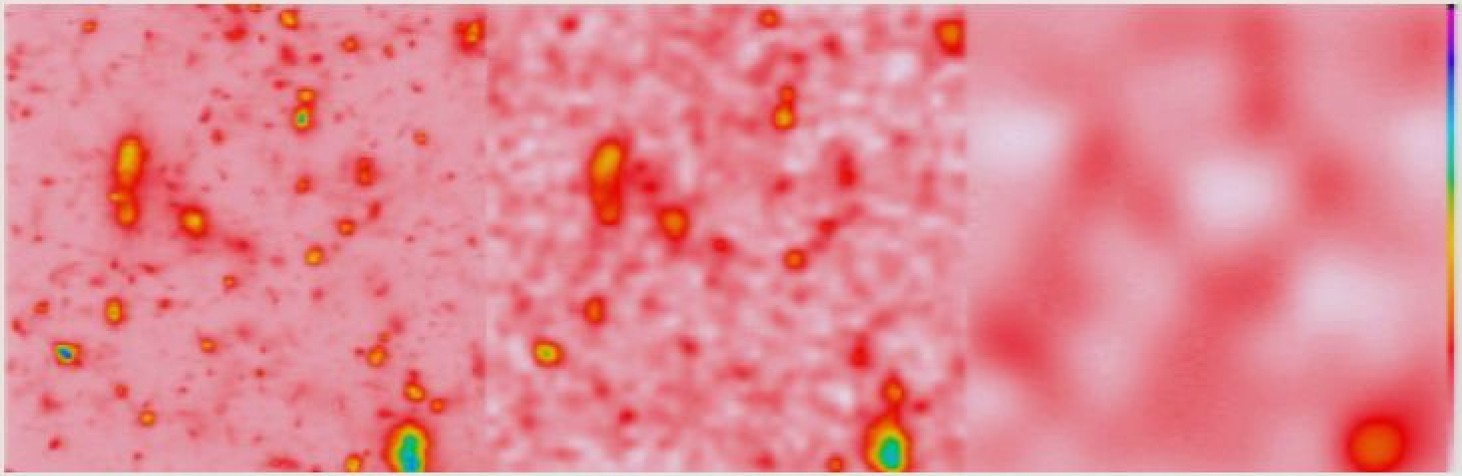

50 GHz

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2X noise
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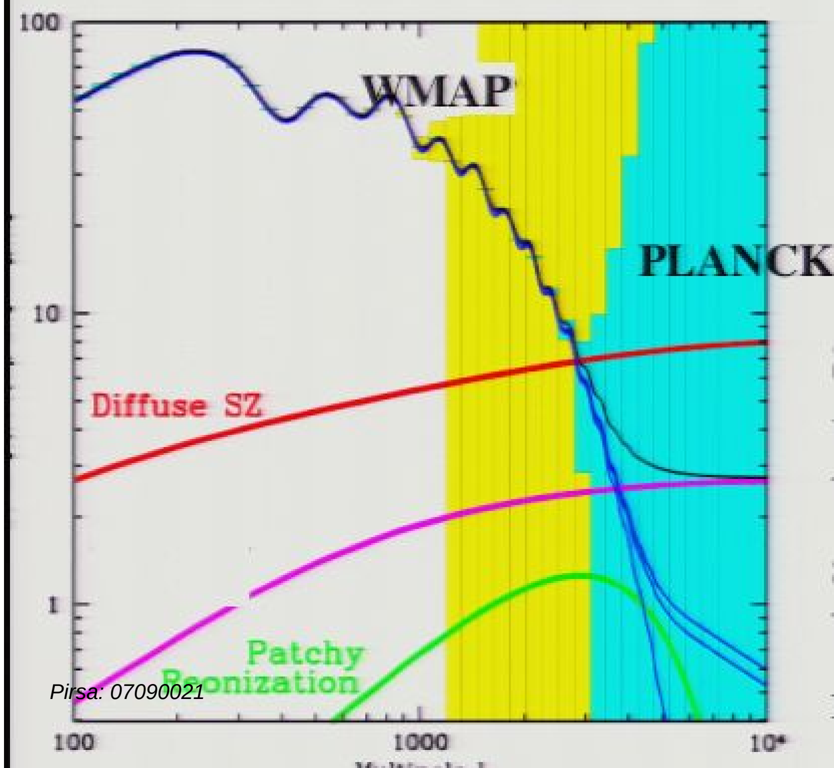

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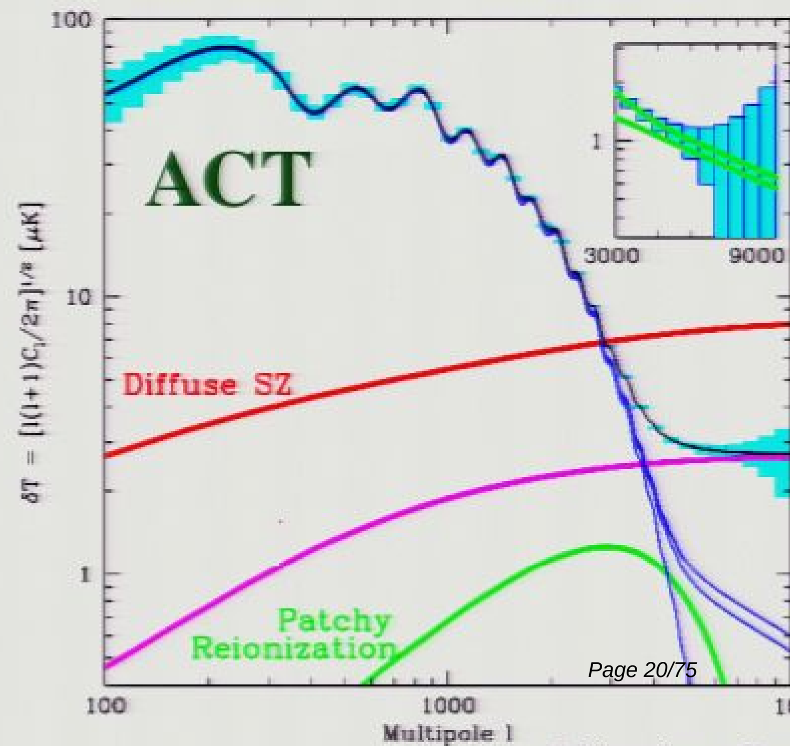

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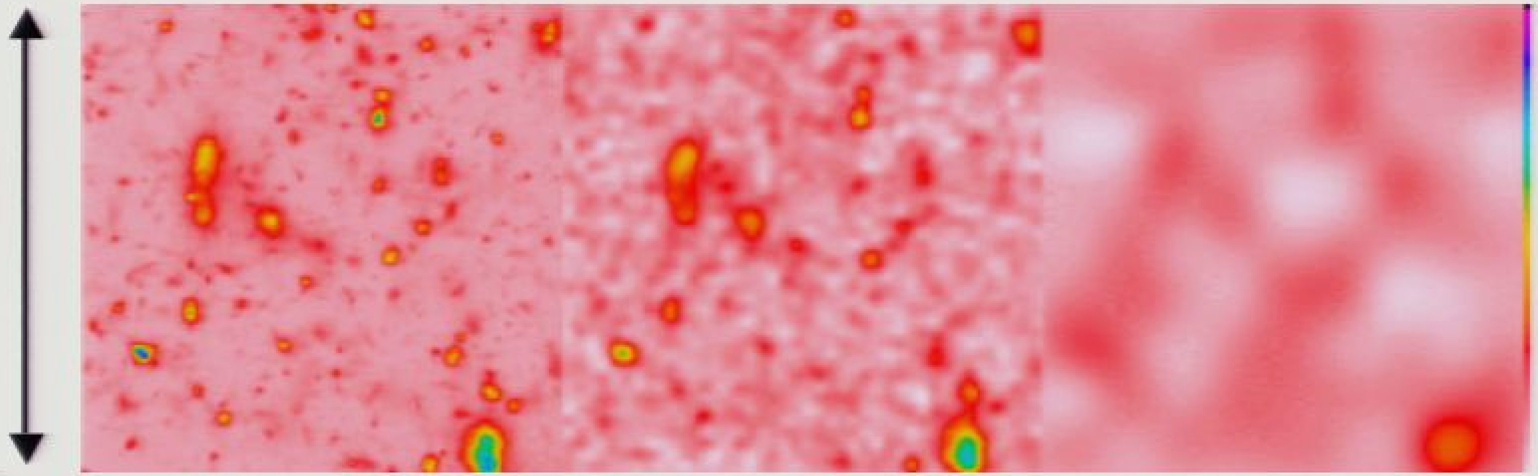

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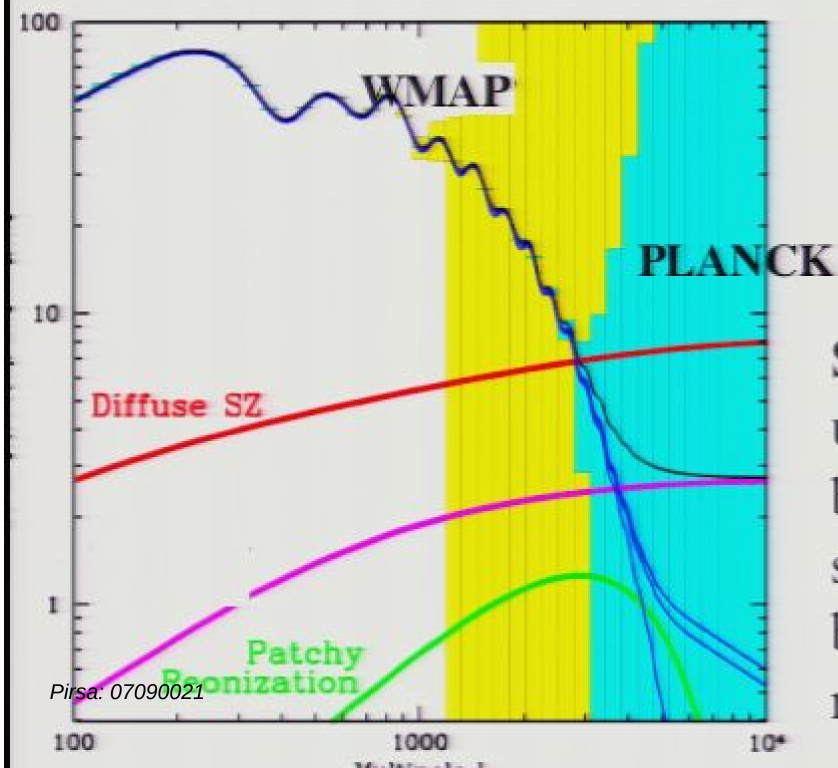

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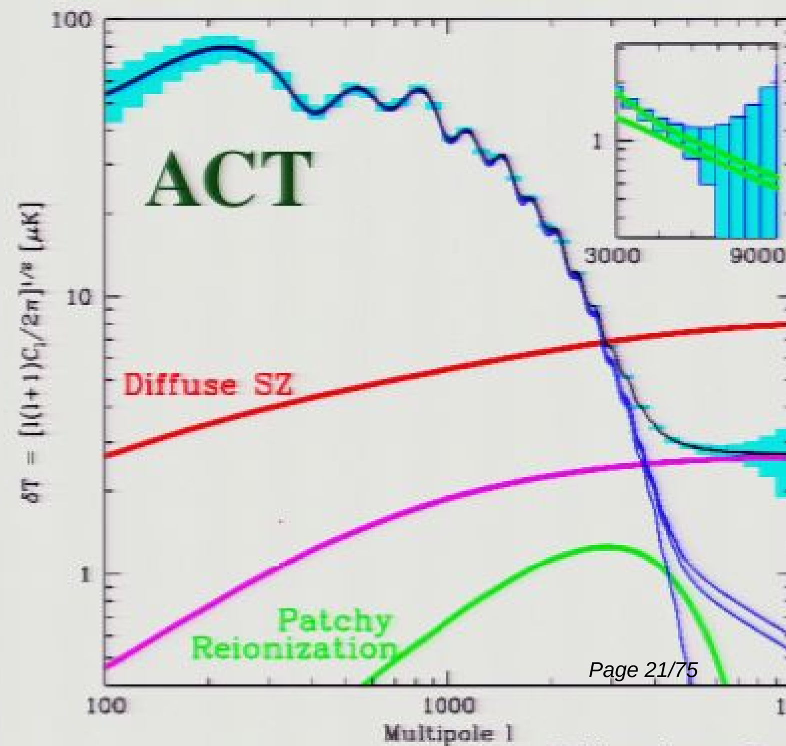

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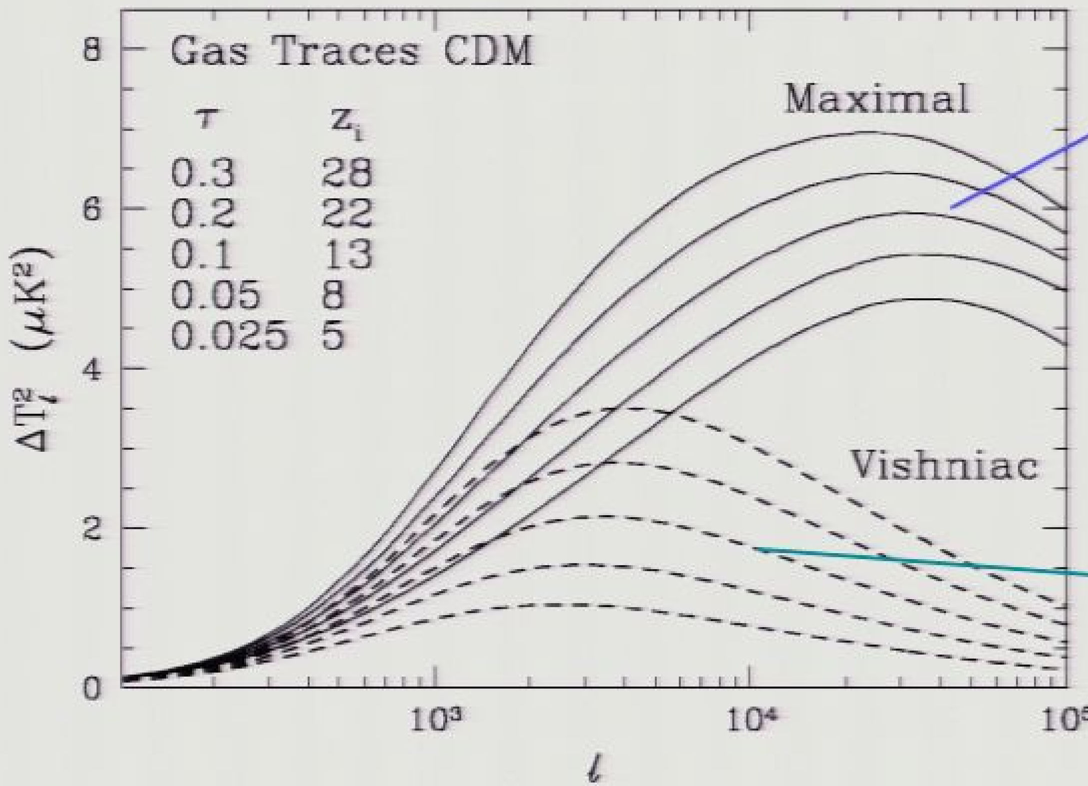

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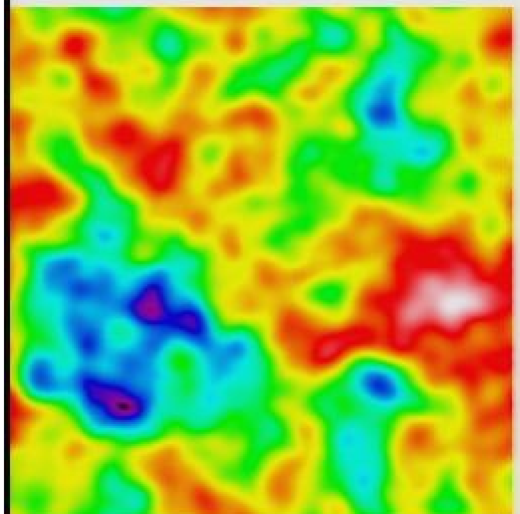
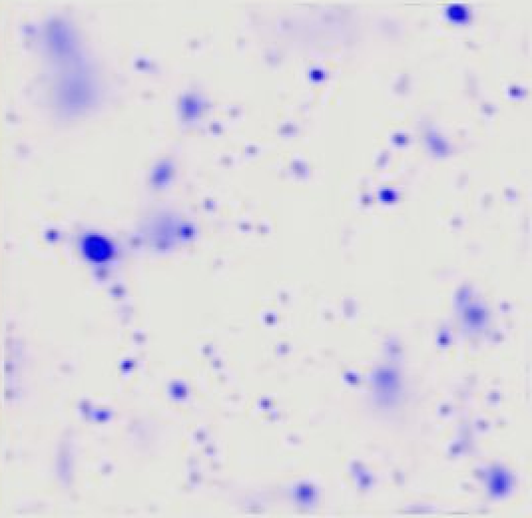
145 GHz Maps

Map Components



CMB



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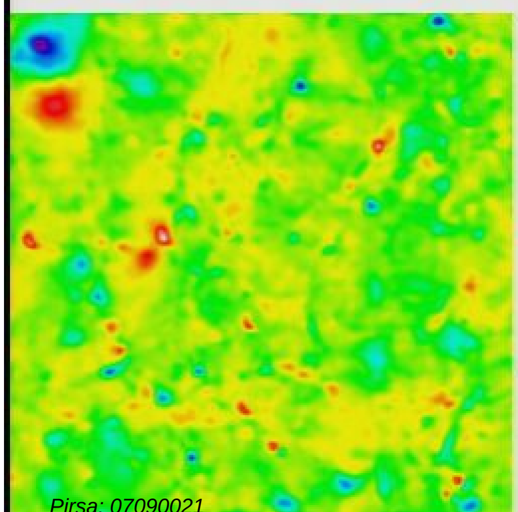
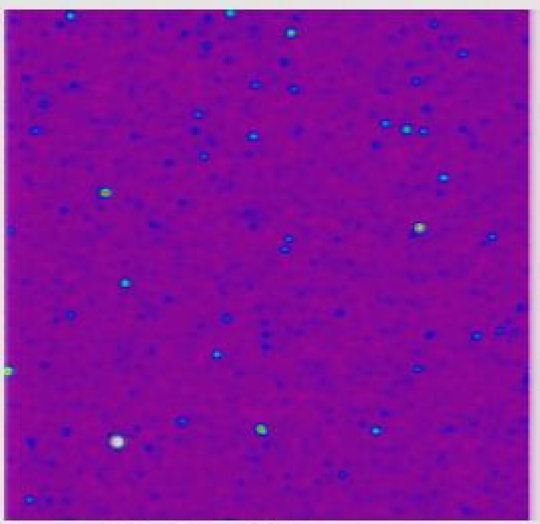
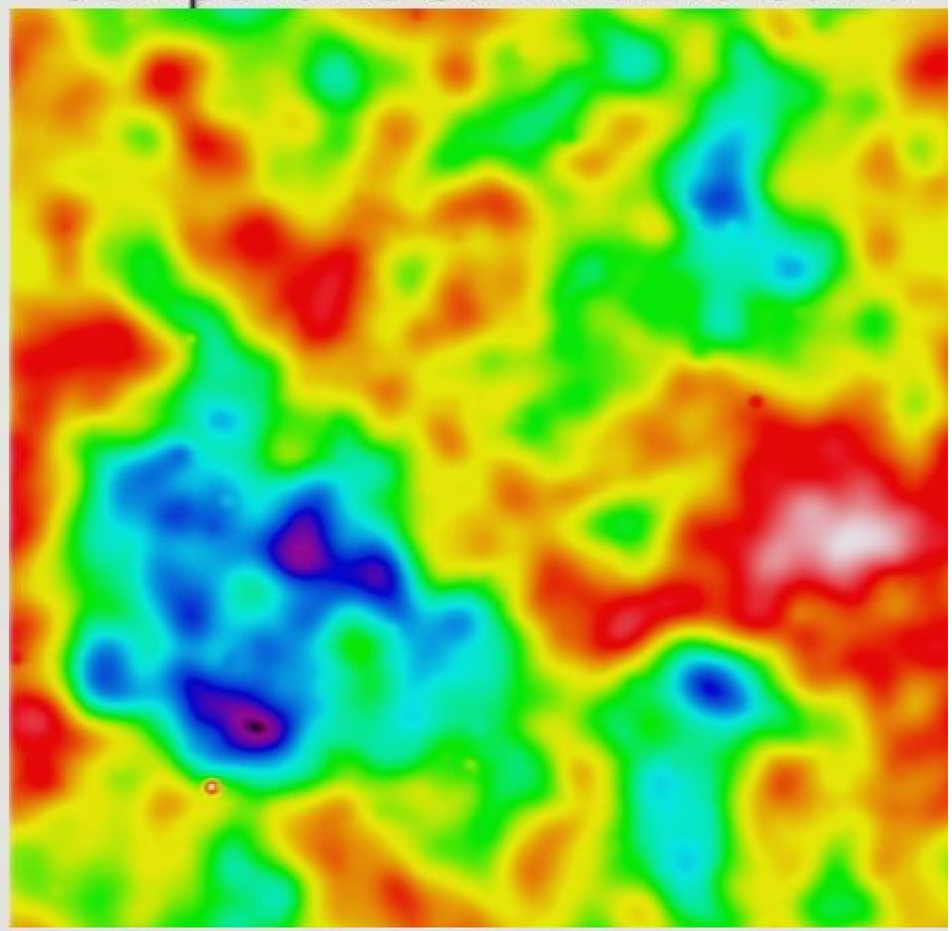


KSZ/OV



Point Sources

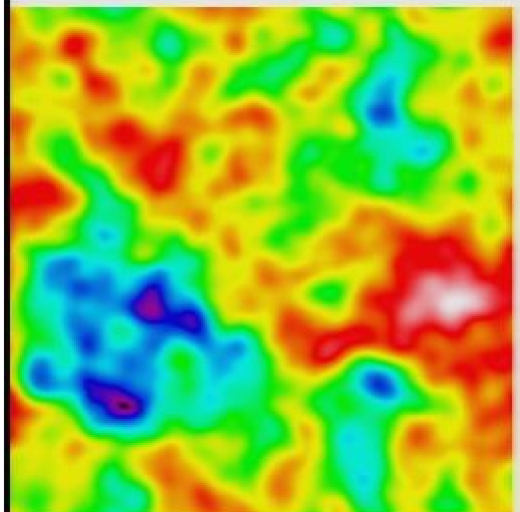
Components Summed to Scale



1.4°x 1.4°

220 GHz Maps

Map Components



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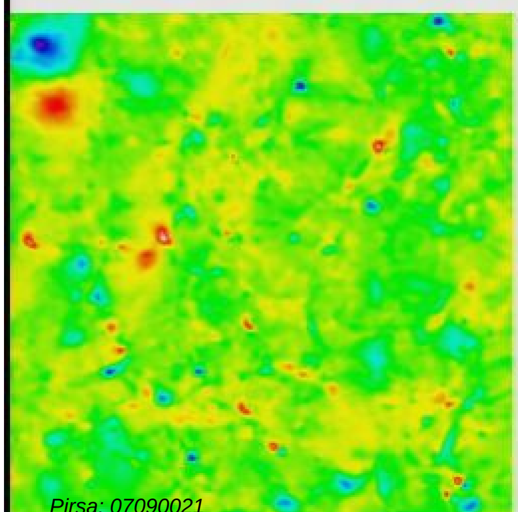

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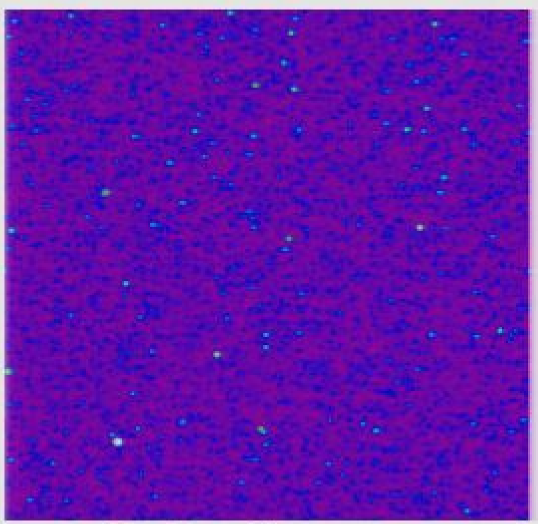

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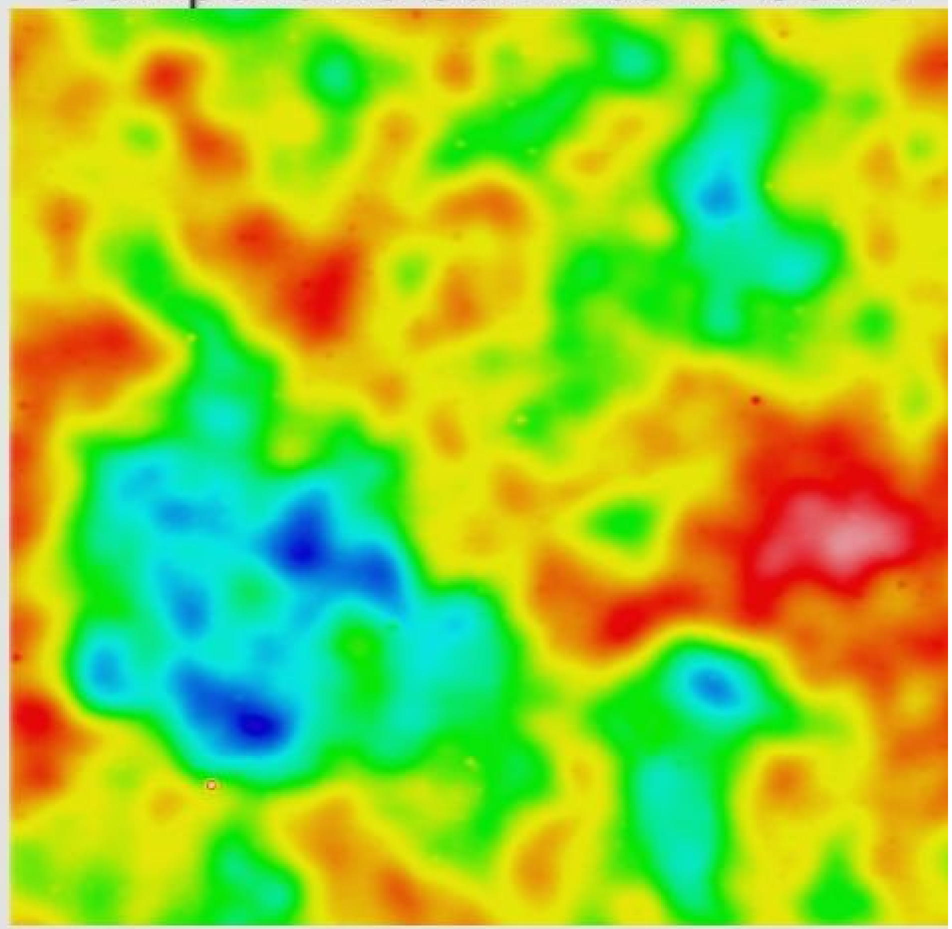
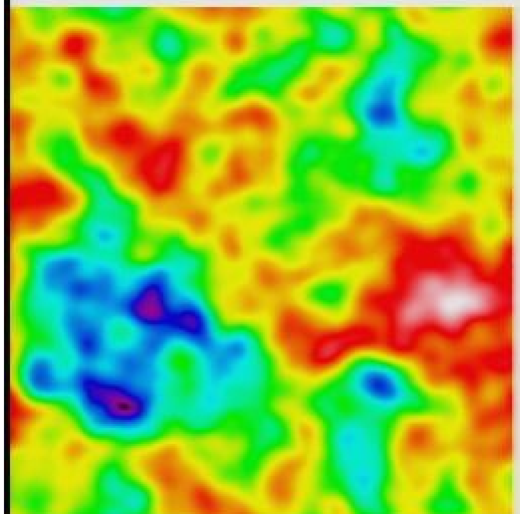


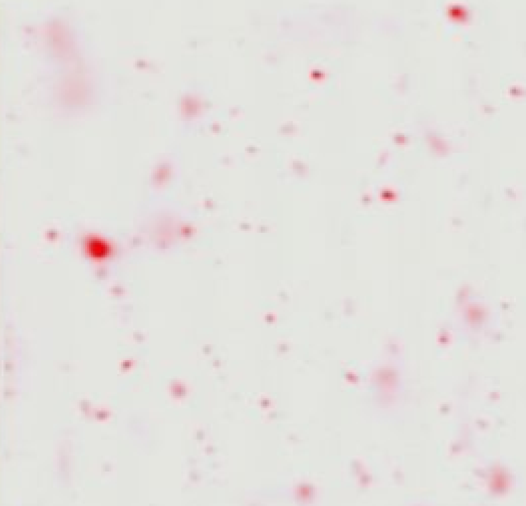
1.4°x 1.4°

270 GHz Maps

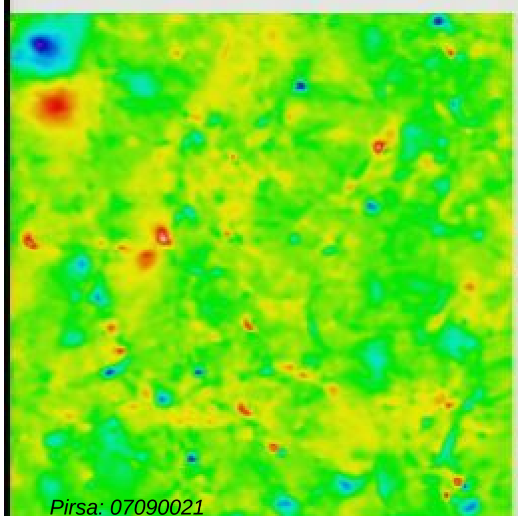
Map Components



CMB



SZ



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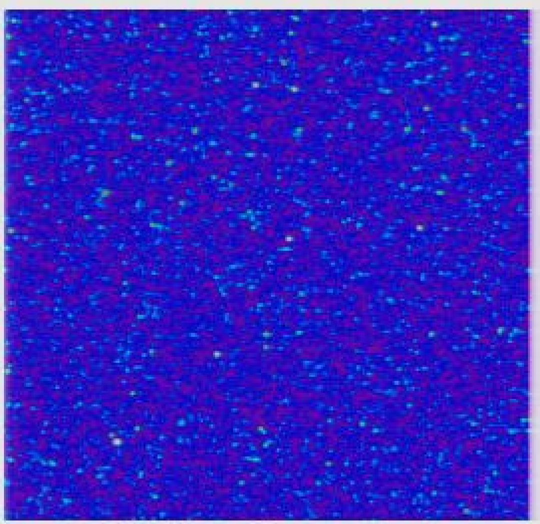

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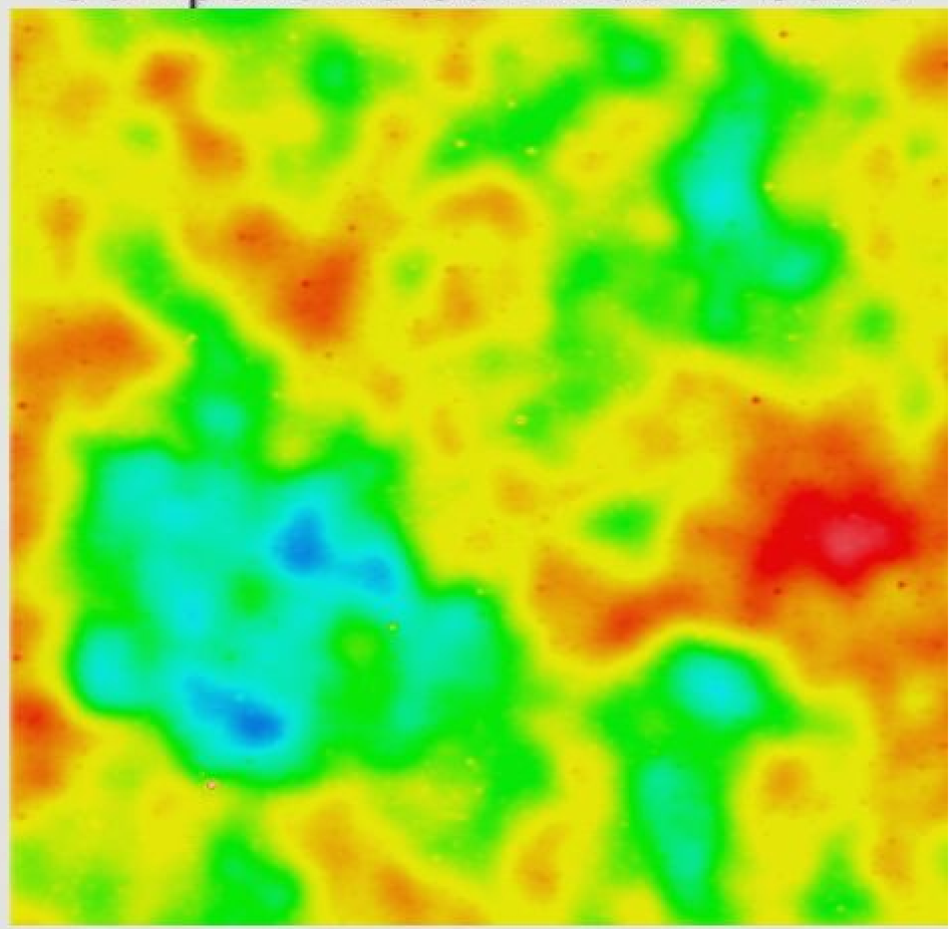

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145 GHz Maps

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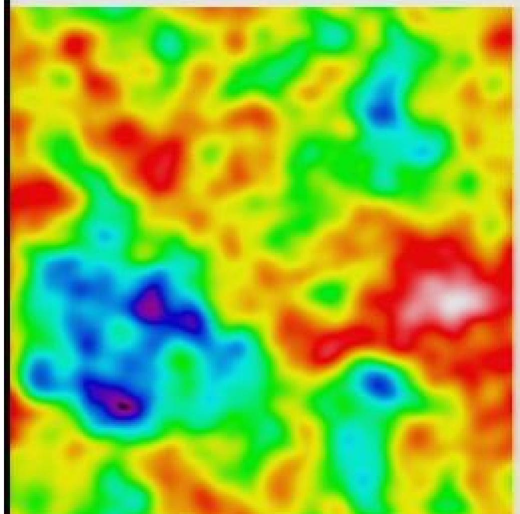

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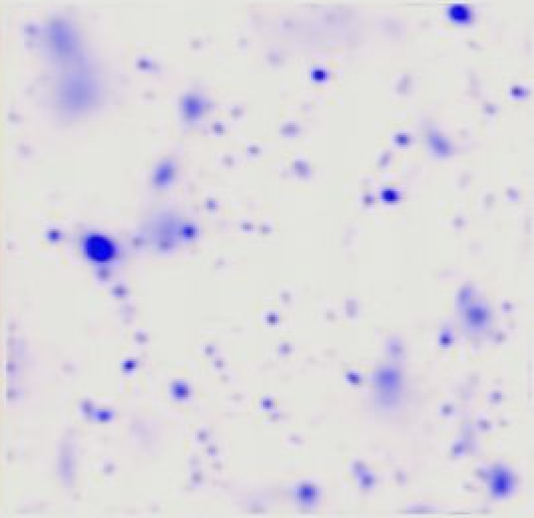

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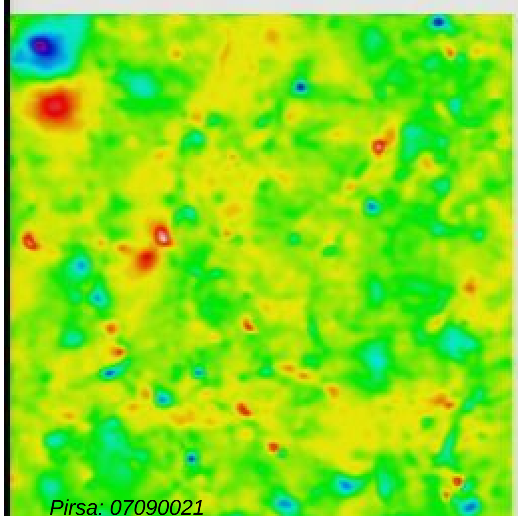

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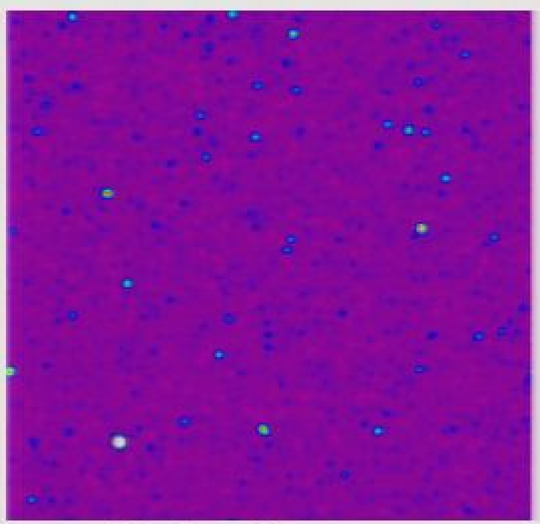

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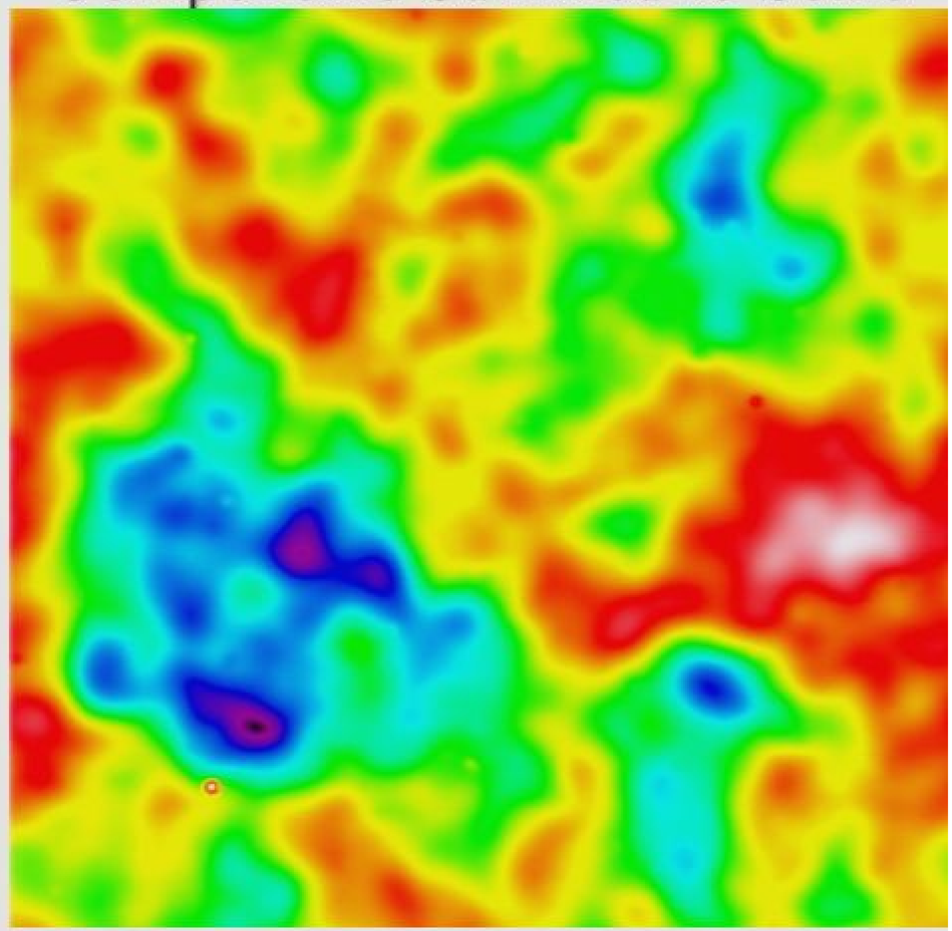

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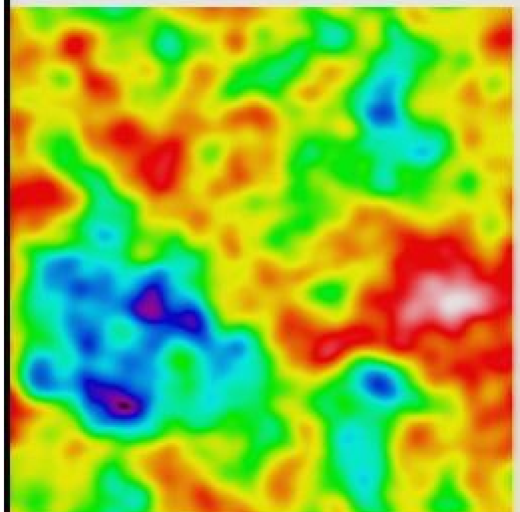

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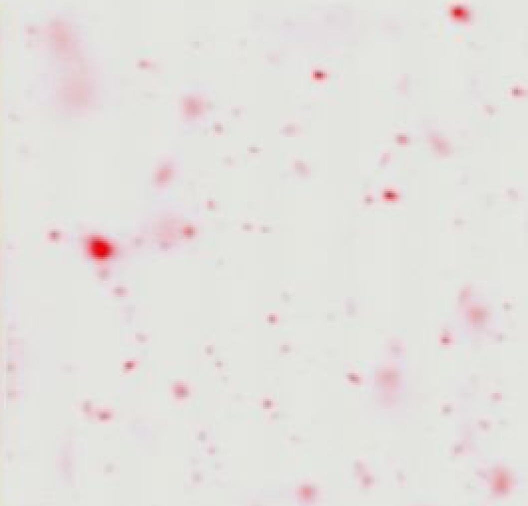

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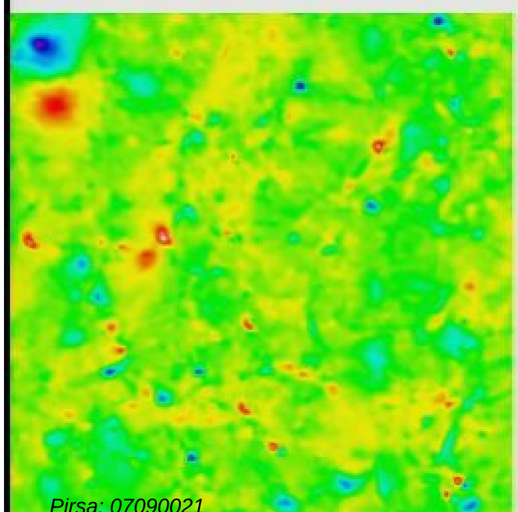

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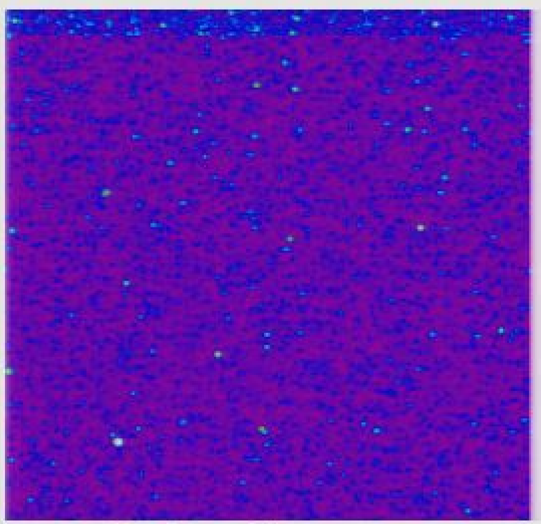

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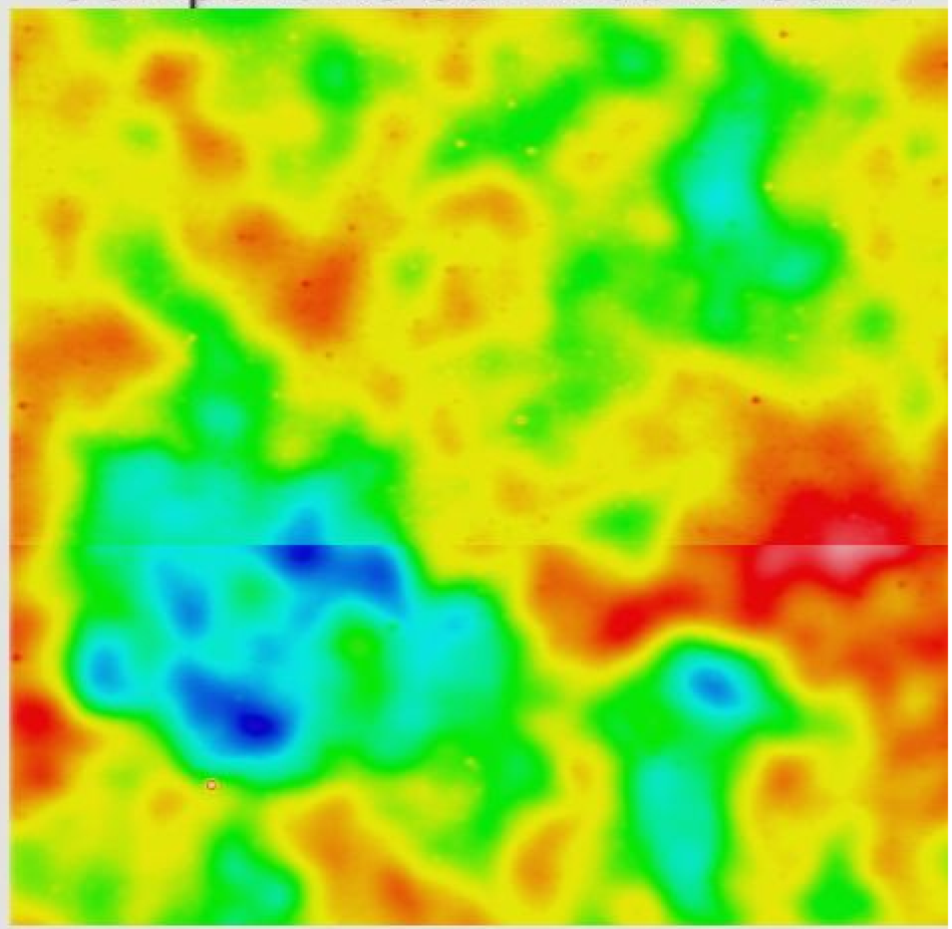

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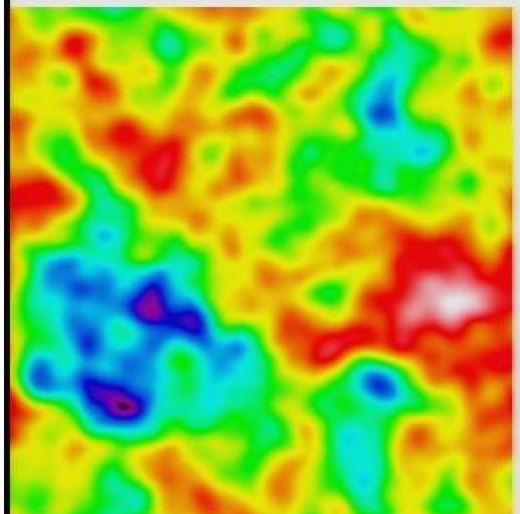

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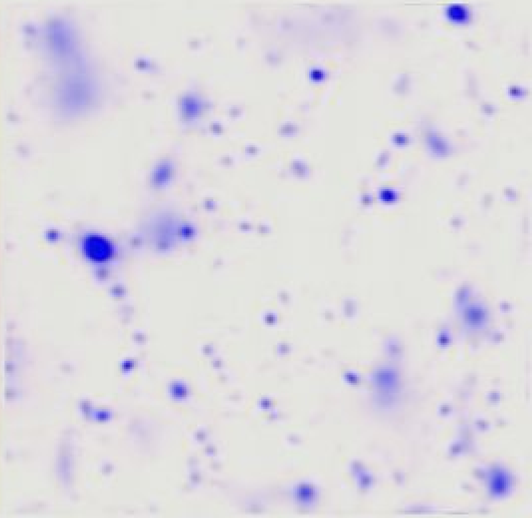

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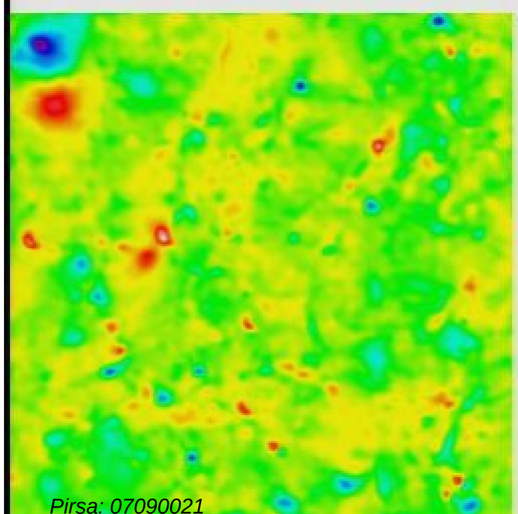
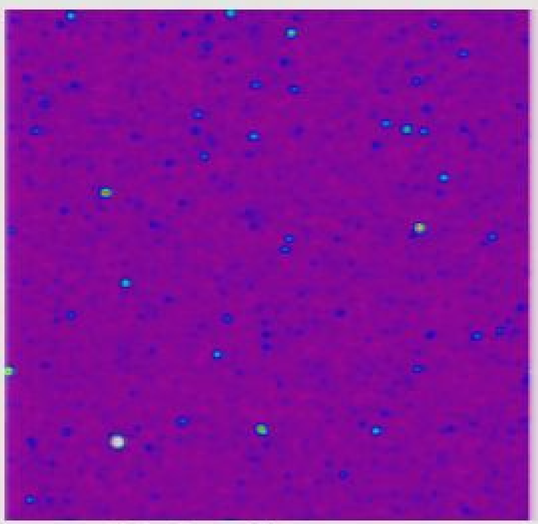
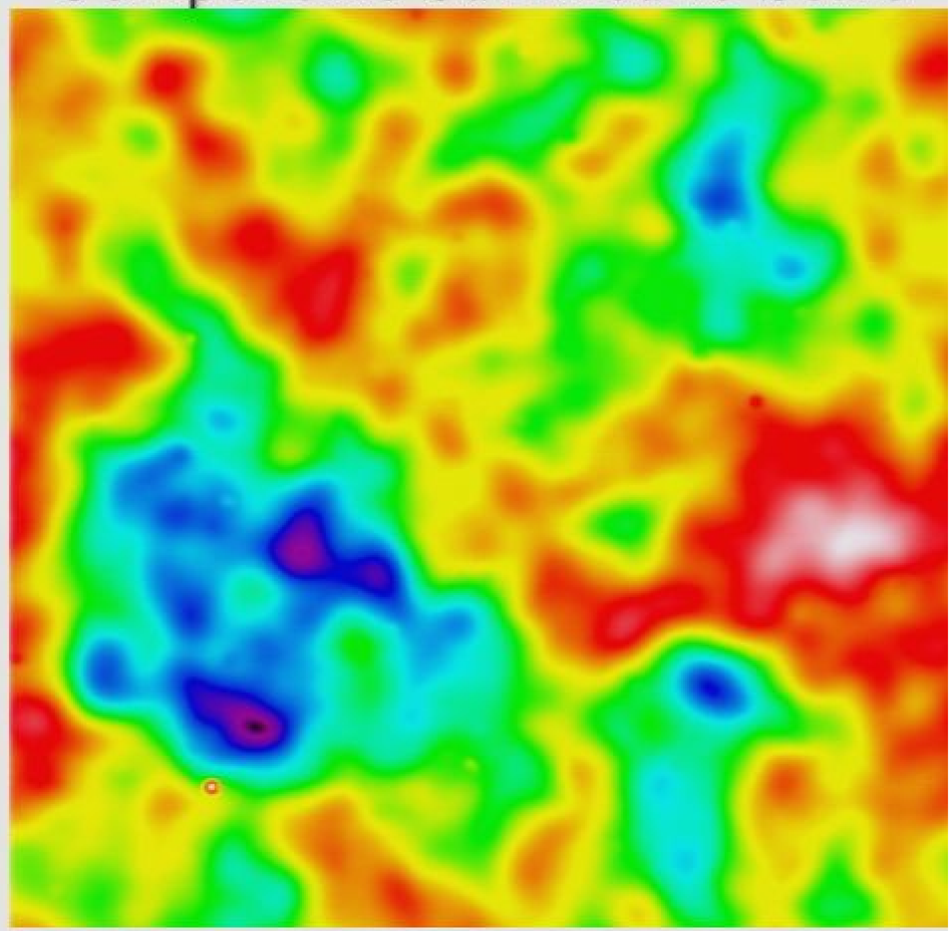


KSZ/OV



Point Sources

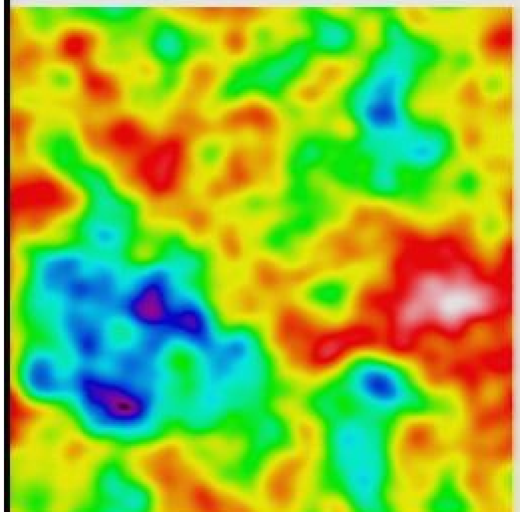
Components Summed to Scale



1.4°x 1.4°

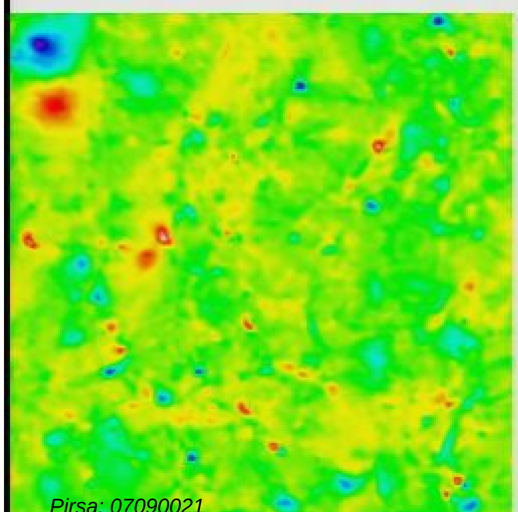
220 GHz Maps

Map Components

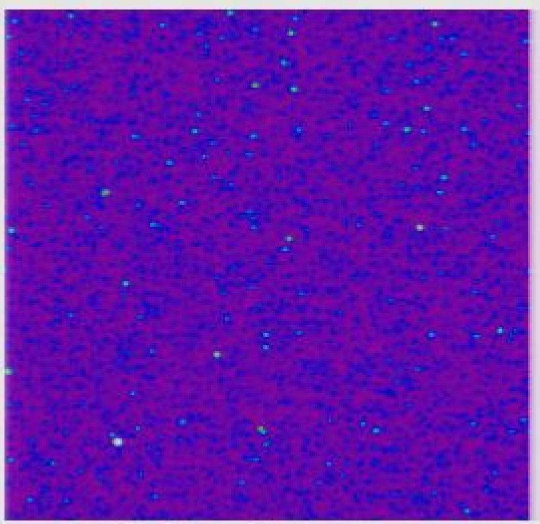


CMB

SZ

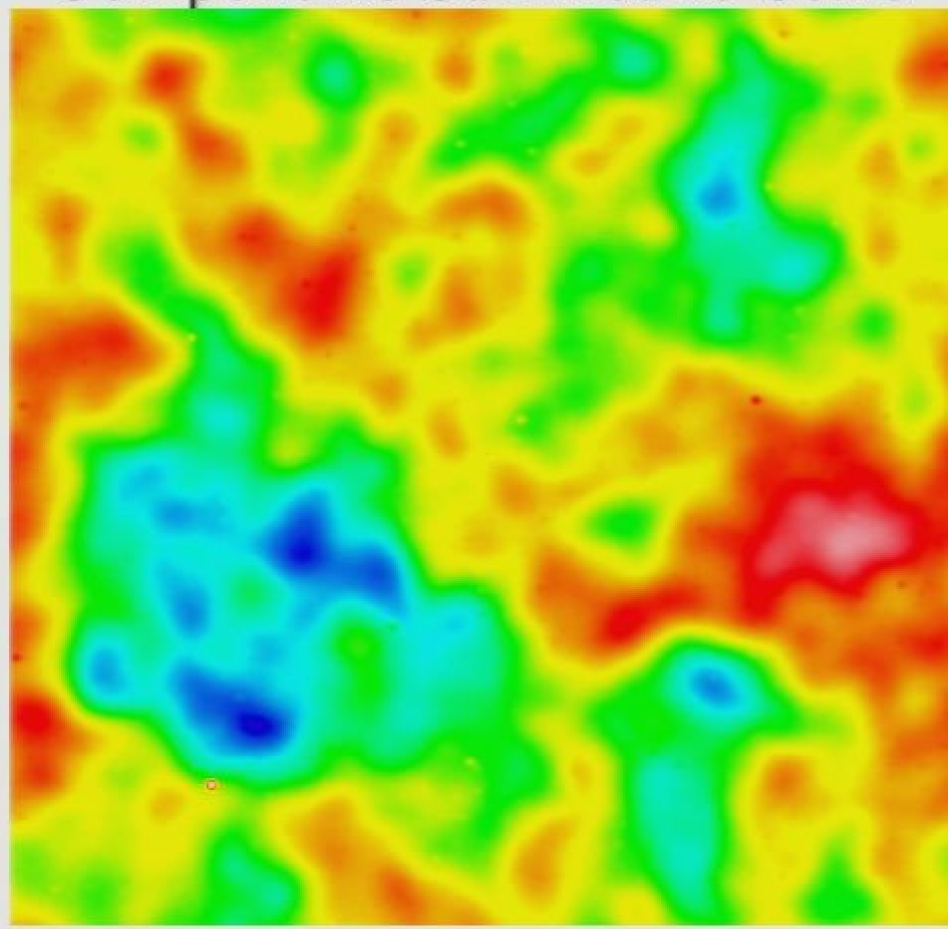


KSZ/OV



Point Sources

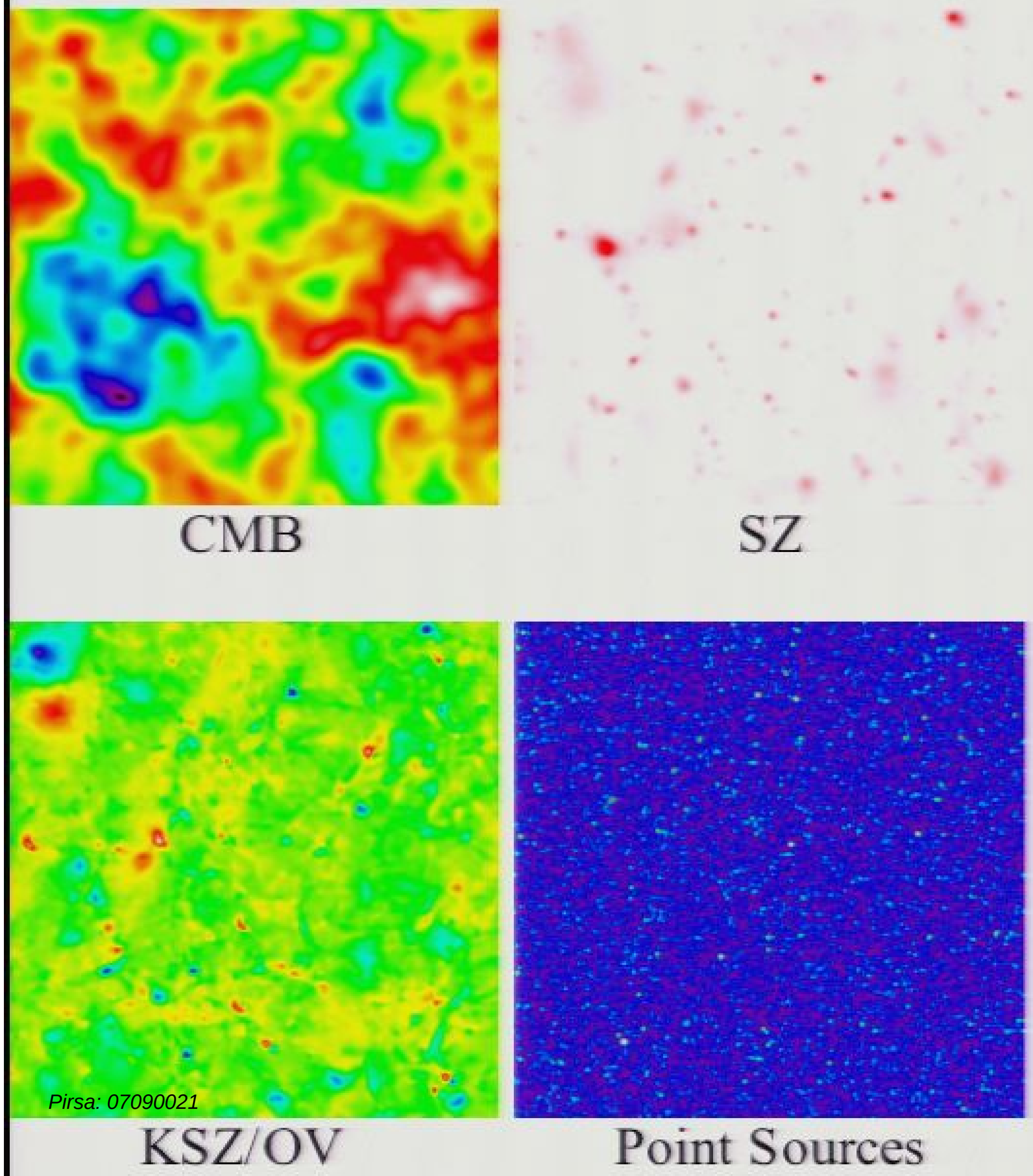
Components Summed to Scale



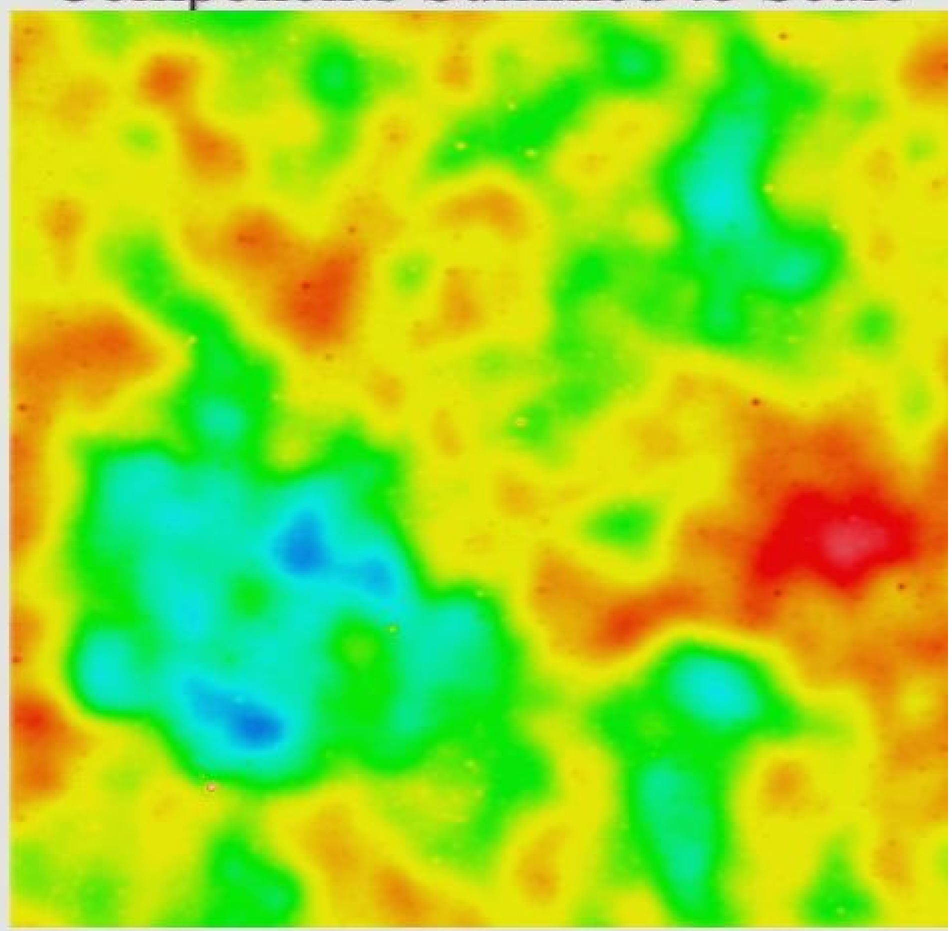
1.4°x 1.4°

270 GHz Maps

Map Components



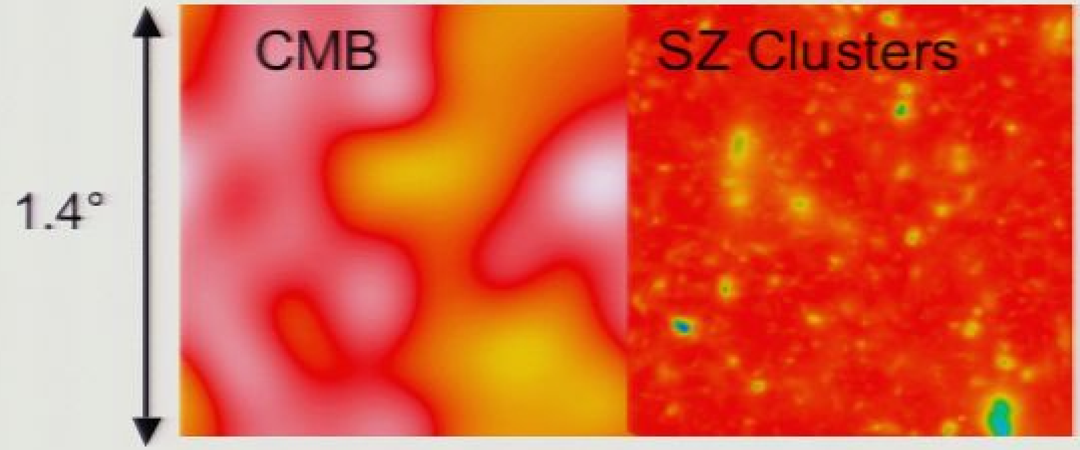
Components Summed to Scale



1.4°x 1.4°

ACT Simulations: SZ Survey

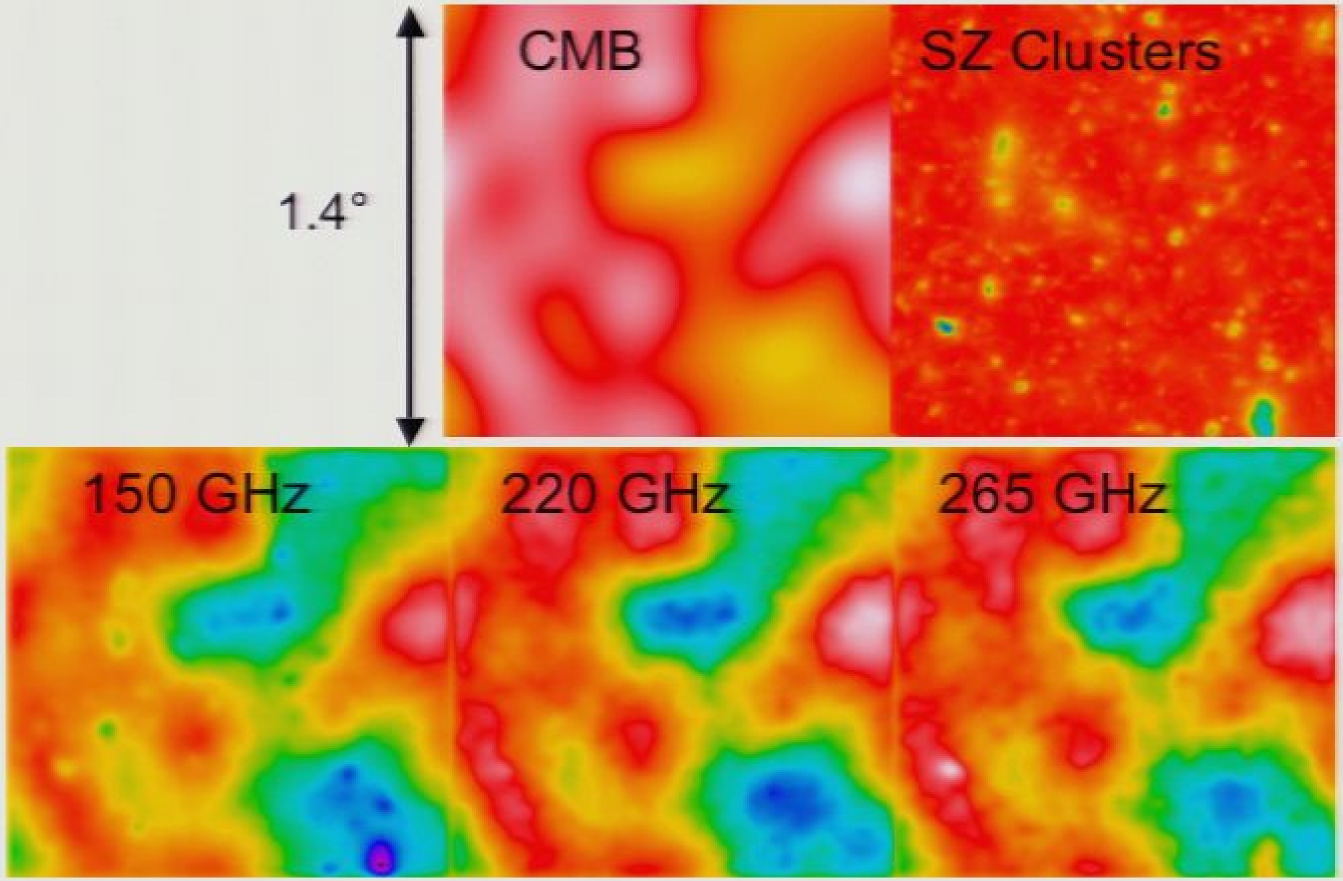
Ideal (no noise,
~0.5' resolution):



ACT Simulations: SZ Survey

Ideal (no noise, ~0.5’ resolution):

3-color maps with instrument noise and 1.7’ beam:

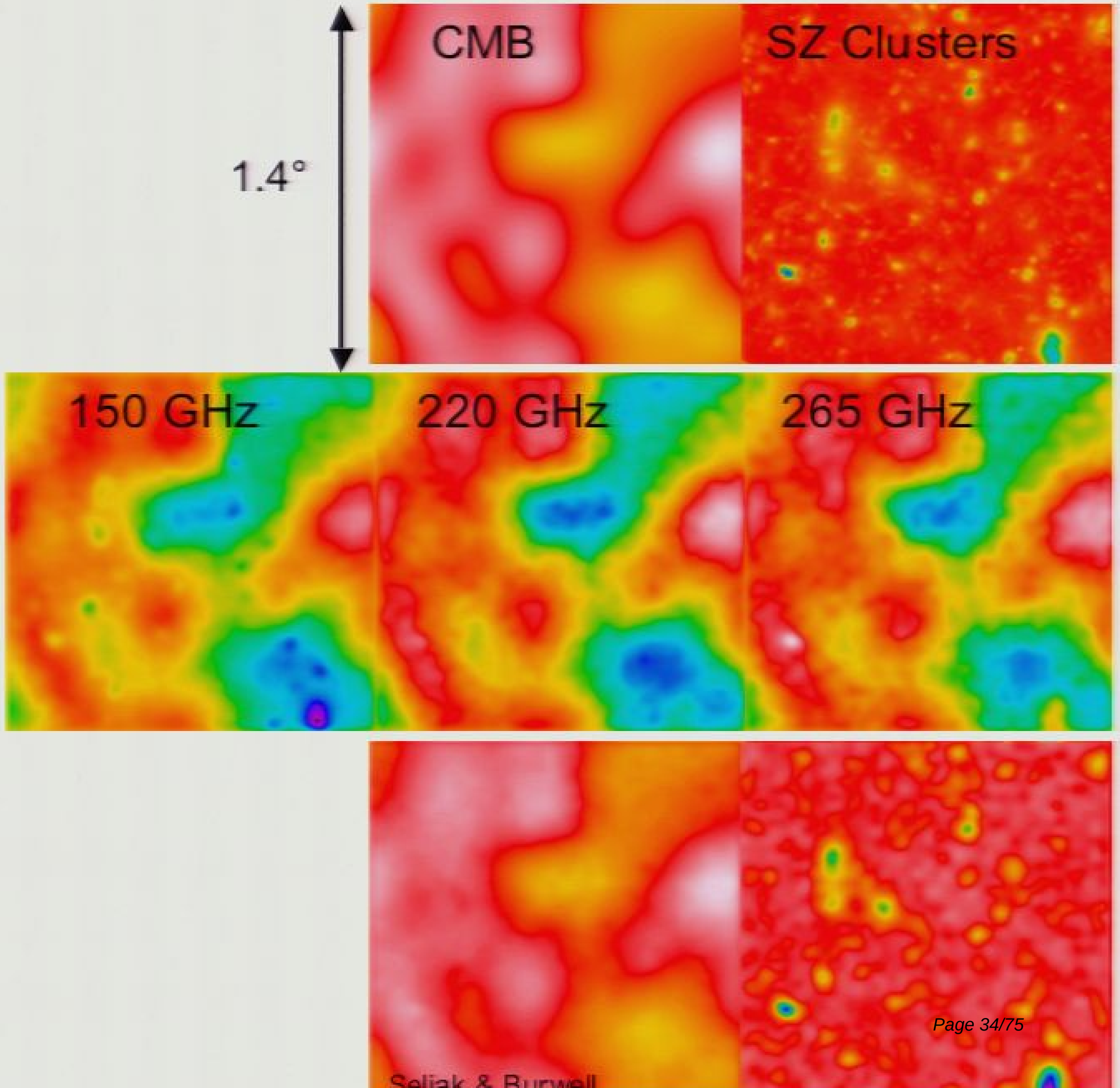


ACT Simulations: SZ Survey

Ideal (no noise, ~0.5' resolution):

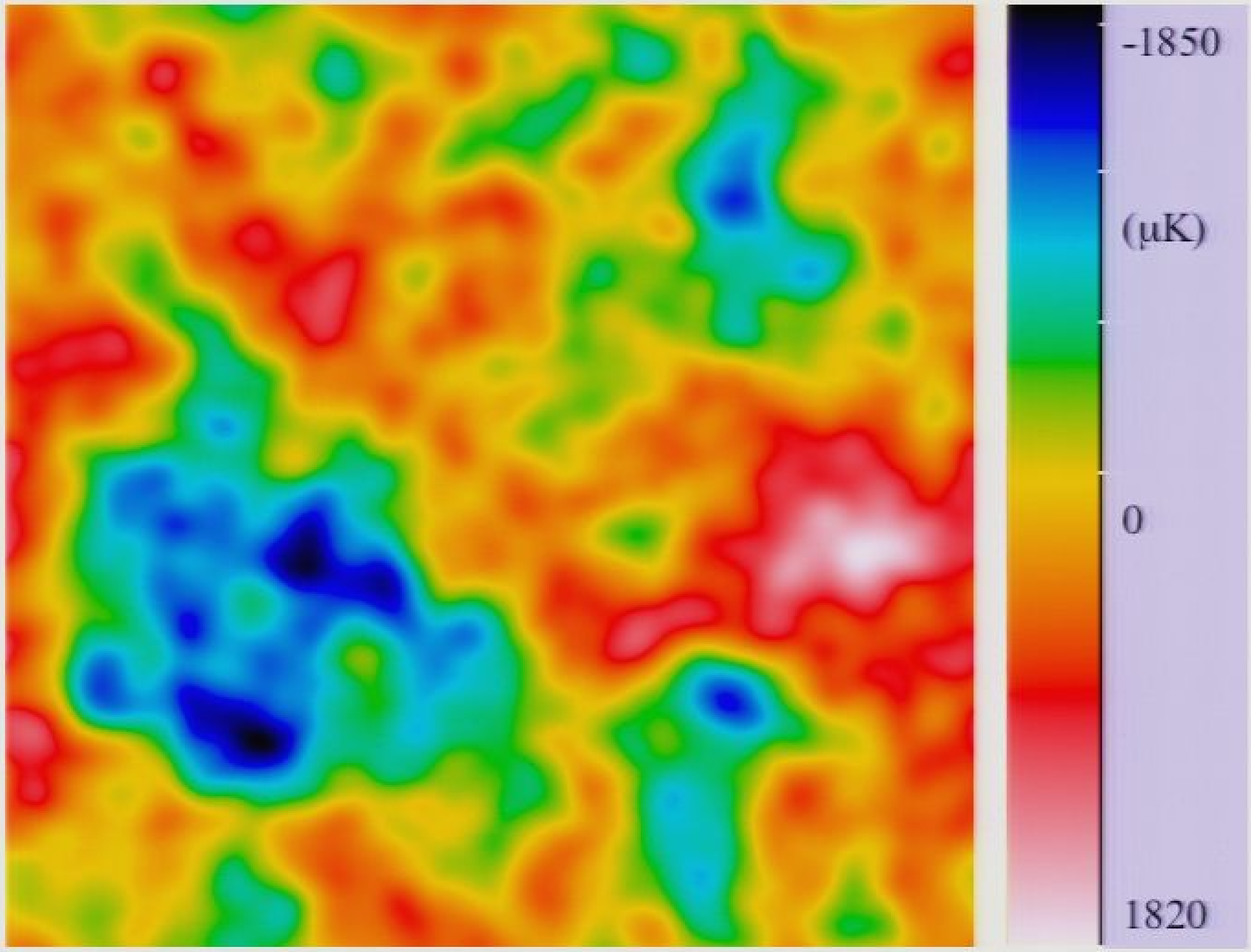
3-color maps with instrument noise and 1.7' beam:

Recovered CMB and SZ from simple analysis:



Lensing of the CMB

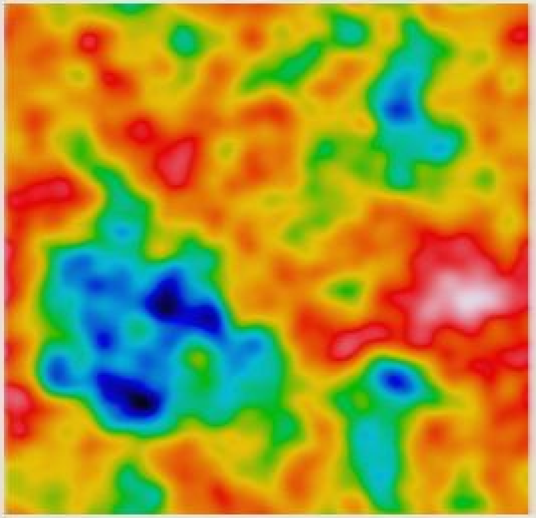
- Lensing arises from integrated nass fluctuations along the line f sight.
- The CMB acts as a fixed listance source, removing the legeneracy inherent to other ensing measurements.
- Signal at $l = 1000\text{-}3000$
- Image distortion – only a ninor effect in the power pectrum.
- *Must* have a deep, high idelity map to detect this ffect.



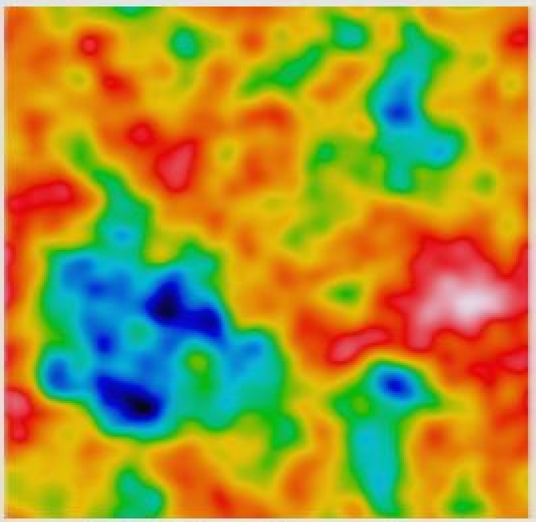
CMB

1.4°x 1.4°

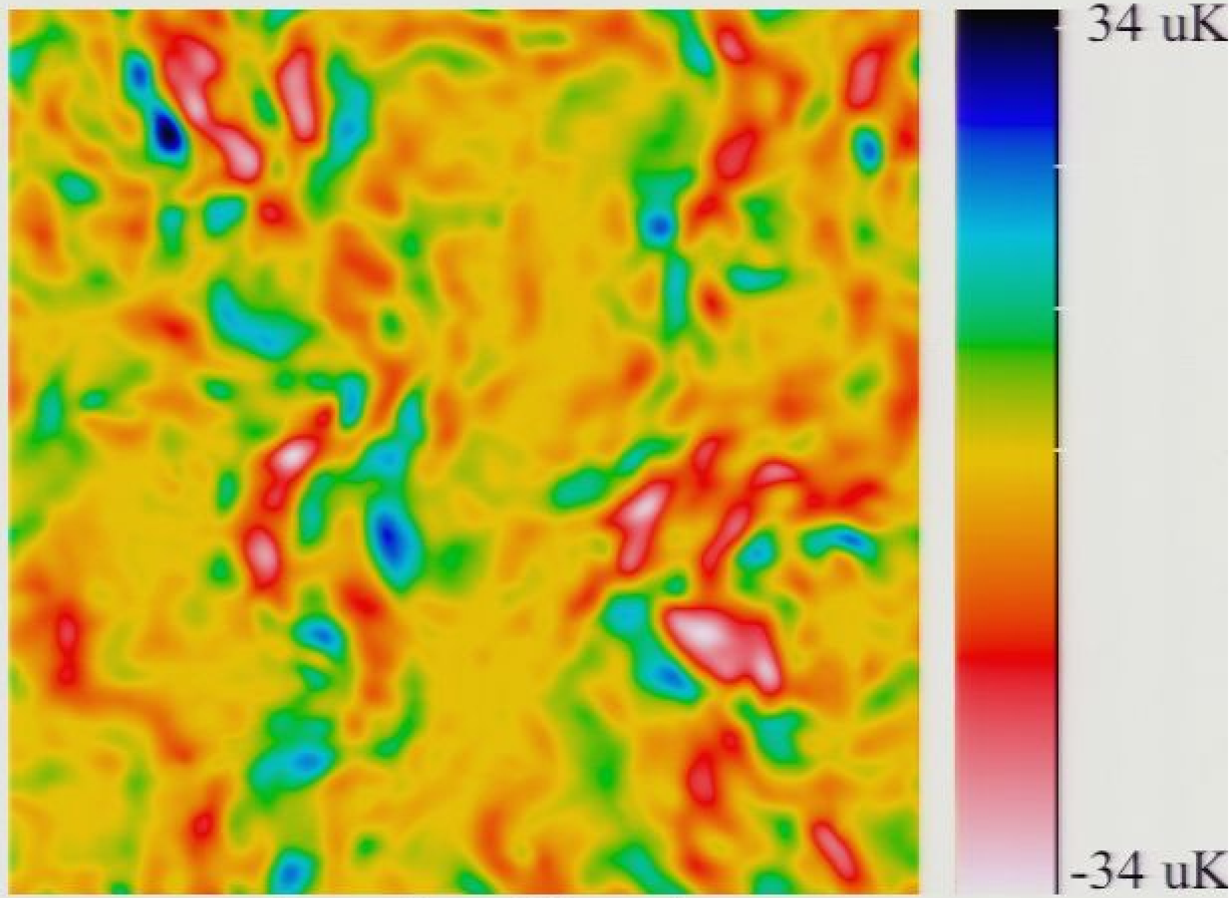
Lensing of the CMB



CMB



CMB + Lensing



Lensing Signal
1.4°x 1.4°

2% of CMB RMS

- RMS signal well above noise floor.
- Isolate from SZ and point sources spectrally.
- Identify with distinctive 4-point function.

Lensing of the CMB

- Lensing arises from integrated nass fluctuations along the line f sight.
- The CMB acts as a fixed listance source, removing the legeneracy inherent to other ensing measurements.
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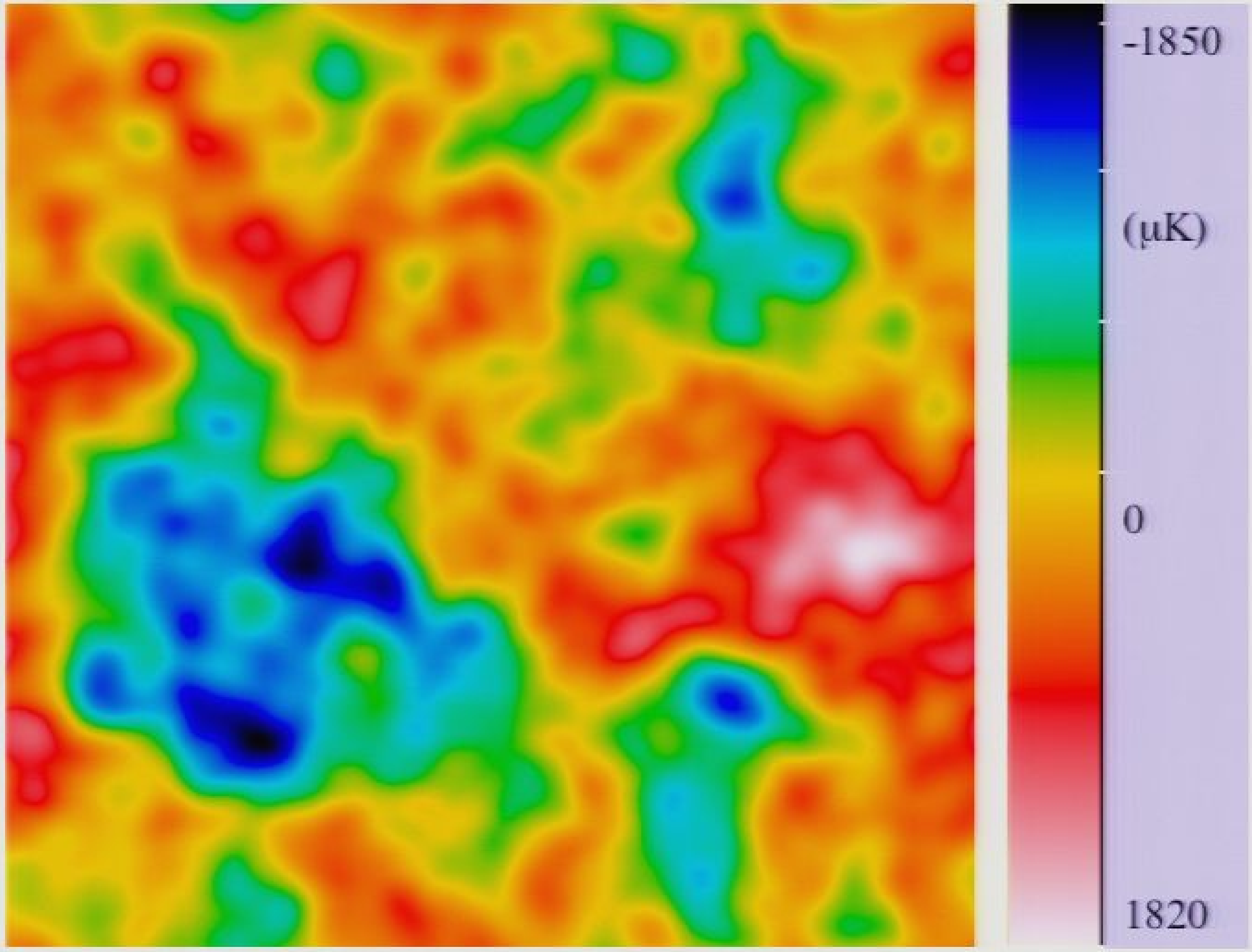


CMB

1.4°x 1.4°

Coordinated Observations

I. Australian Telescope 20 GHz Survey. PI: Ron Ekers. For ACT: Bruce Partridge & Yen-Ting Lin. In progress.

II. AzTex on ASTE: PIs Grant Wilson and David Hughes. Observations start in 2007.

III. BLAST PI: Mark Devlin. Observations made.

IV. SALT: PI for ACT: Ted Williams.

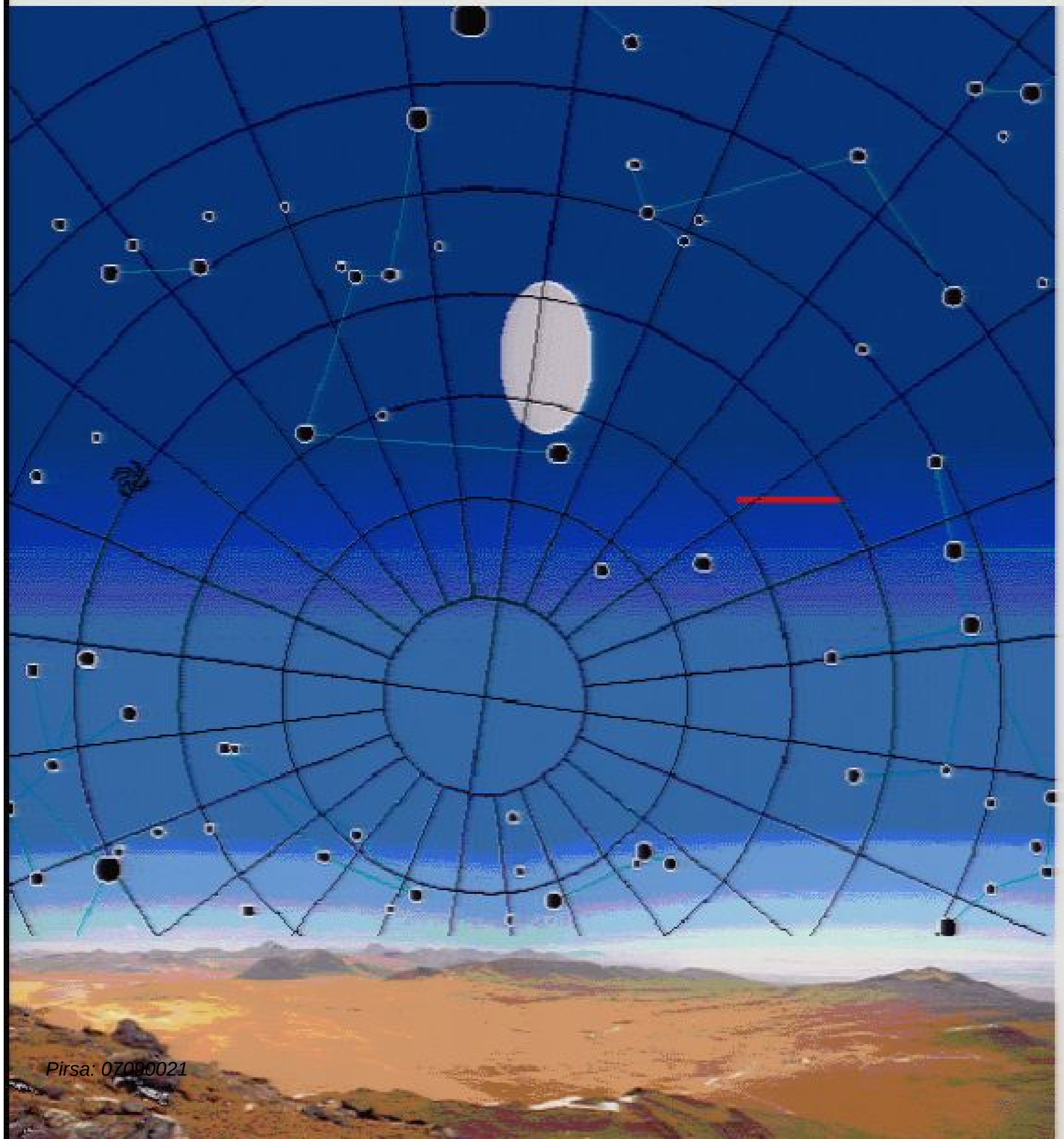
V. BCS: Funded in progress. PI: Joe Mohr. ACT people: Raul Jimenez, Jack Hughes, Arthur Kosowsky.

VI. Galex: Funded. PI: Raul Jimenez. Observations start May 2007.

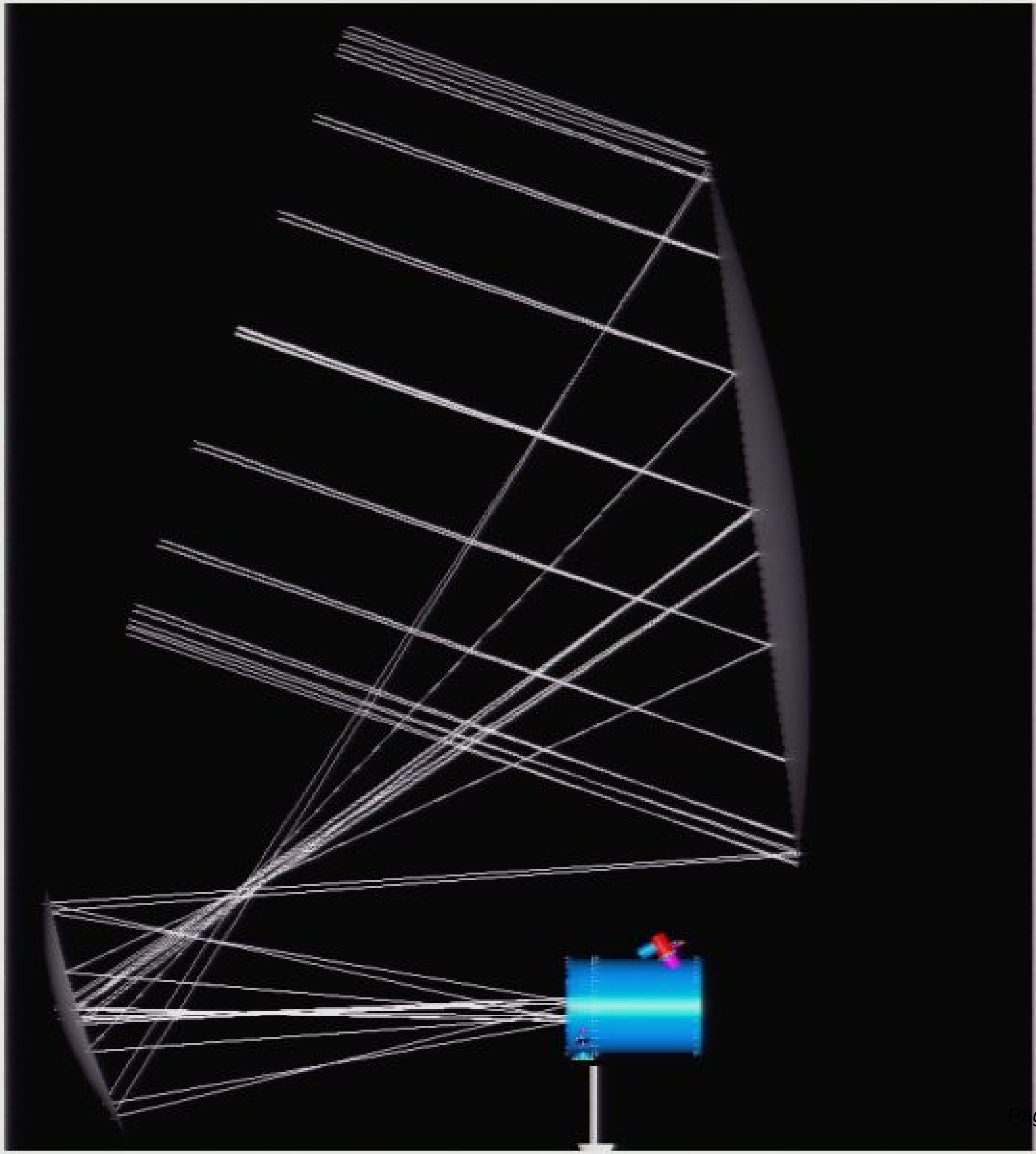
VII. X-Ray Funded. PI: Hans Bohringer . For ACT, Jack Hughes. Observations start April 2007.

- 240 square degrees in circle
- 100 square degrees for CMB

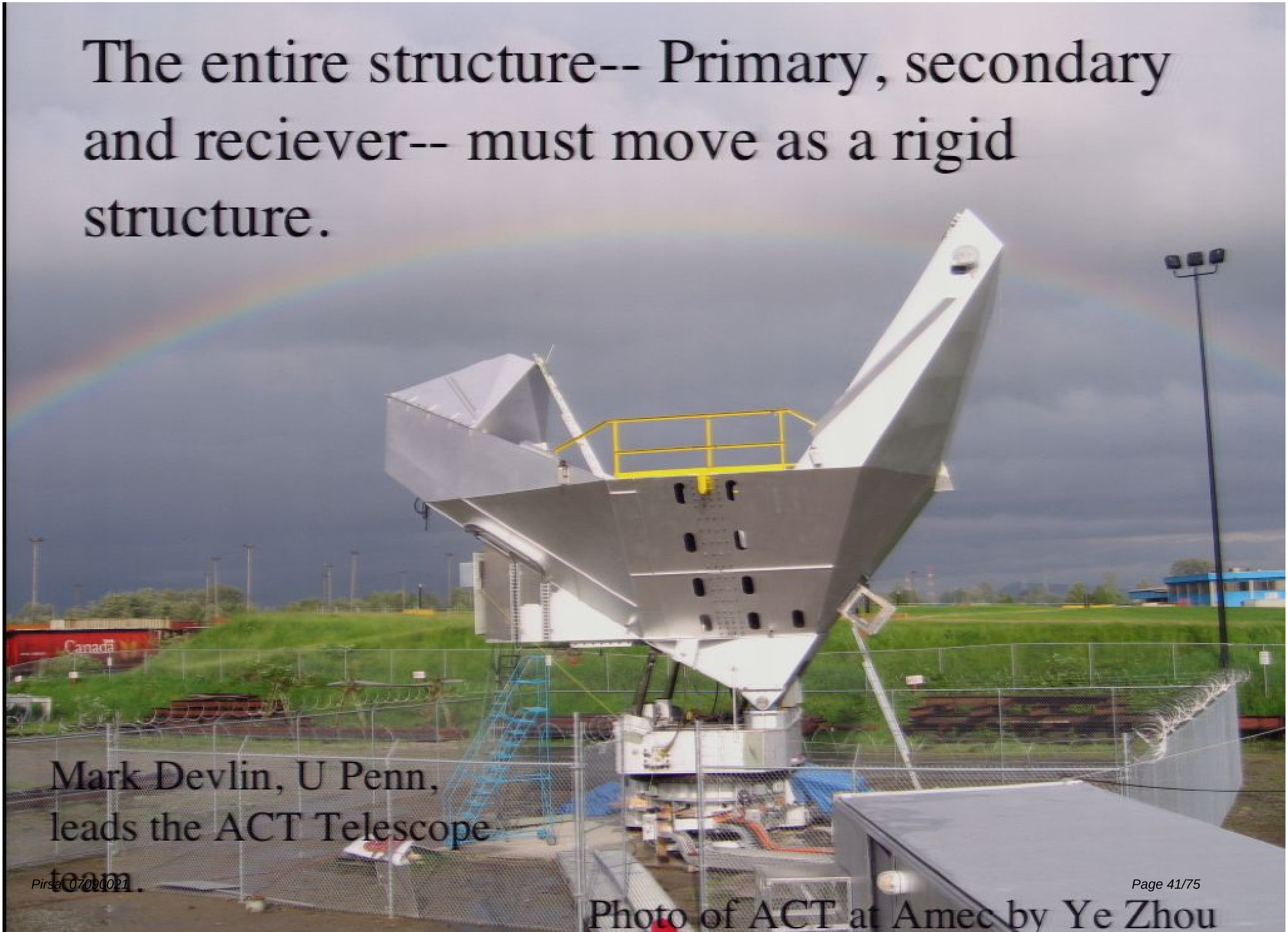
Cross Linked Scan Strategy is Crucial to Making Maps on Degree Angular Scales



Scanning is performed by rotating the entire structure about a vertical axis passing through the cryostat.



The entire structure-- Primary, secondary and reciever-- must move as a rigid structure.



Mark Devlin, U Penn, leads the ACT Telescope team.

Photo of ACT at Amec by Ye Zhou

- 240 square degrees in circle
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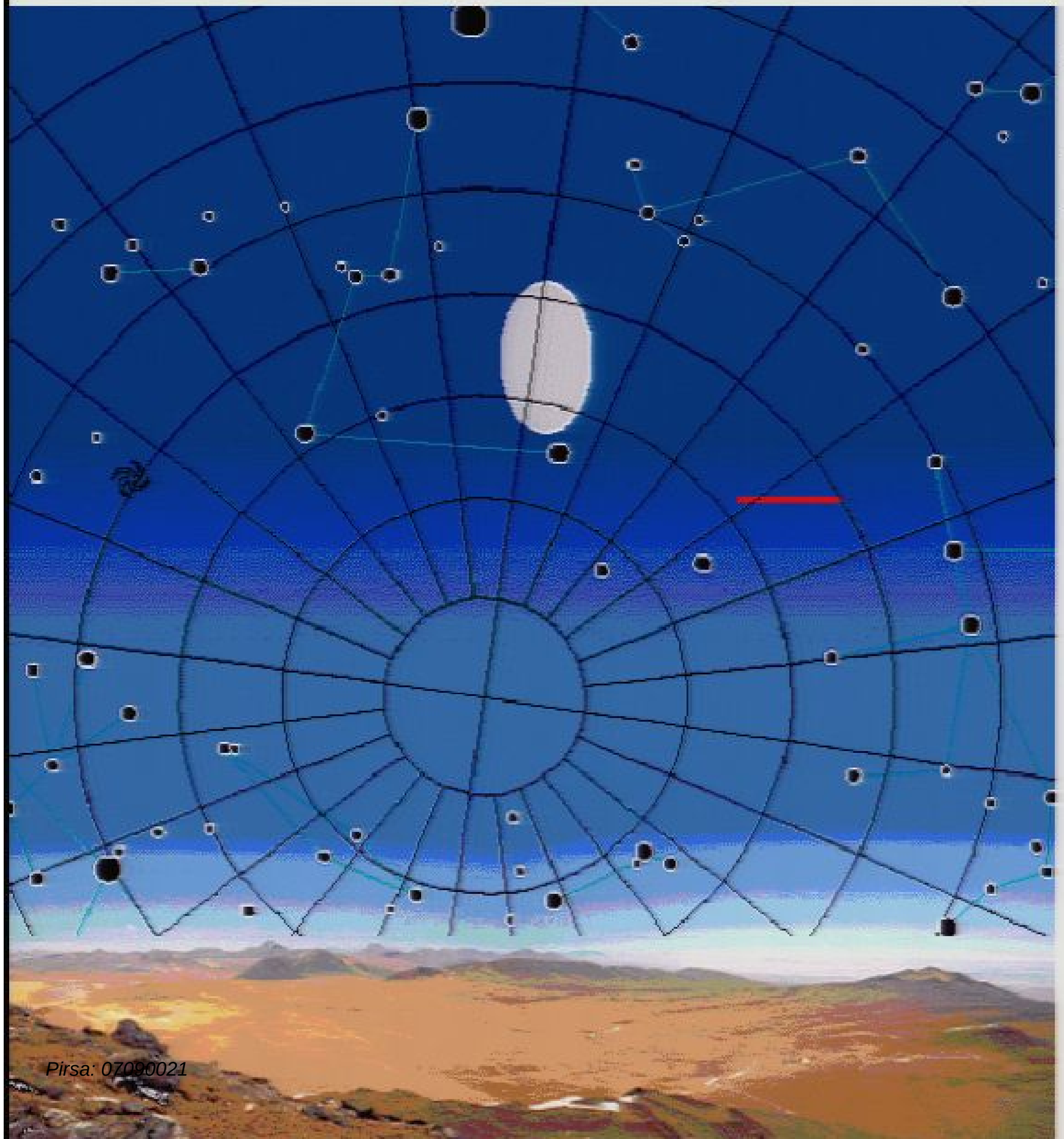
Cross Linked Scan Strategy is Crucial to Making Maps on Degree Angular Scales



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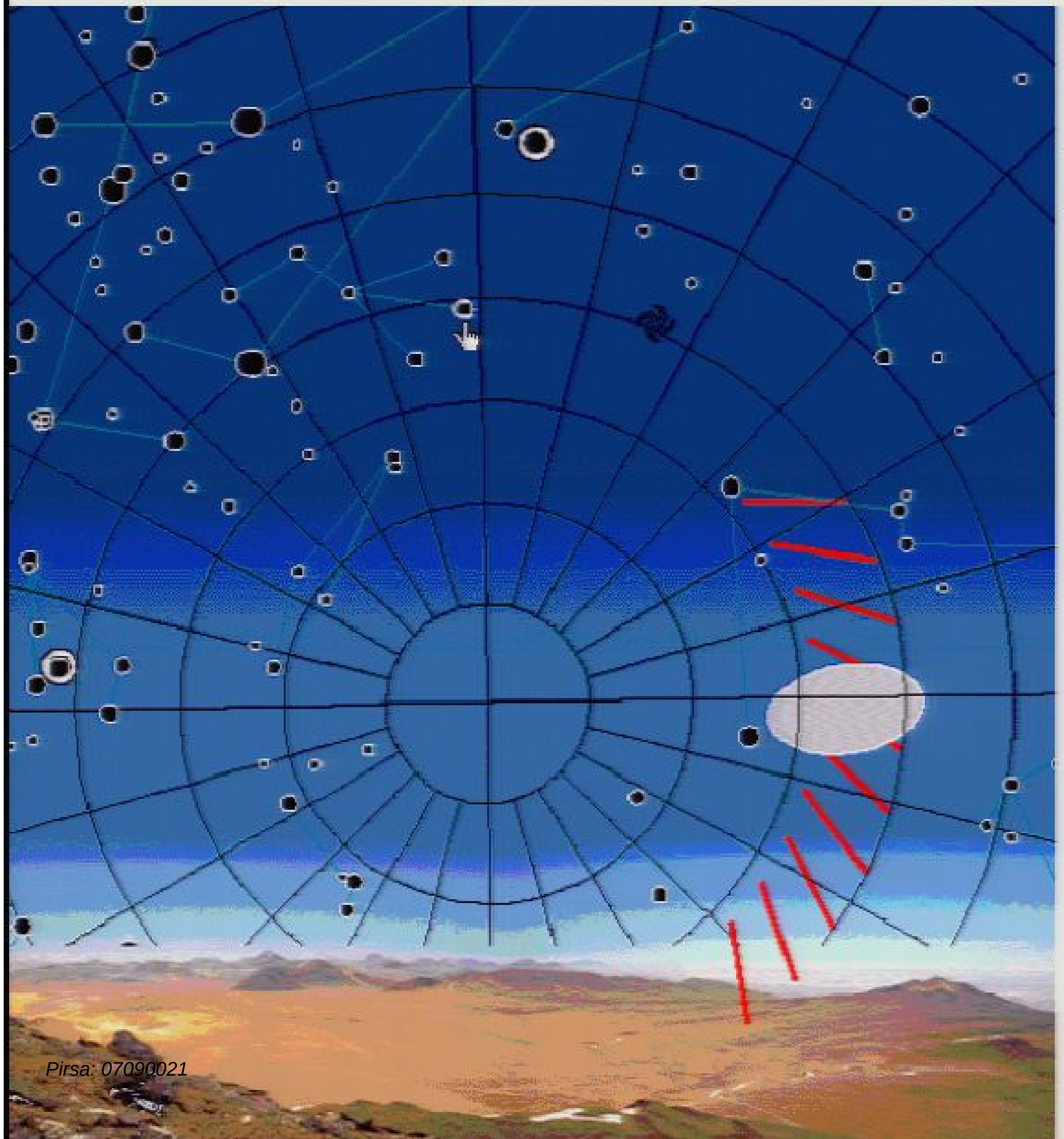
Cross Linked Scan Strategy is Crucial to Making Maps on Degree Angular Scales



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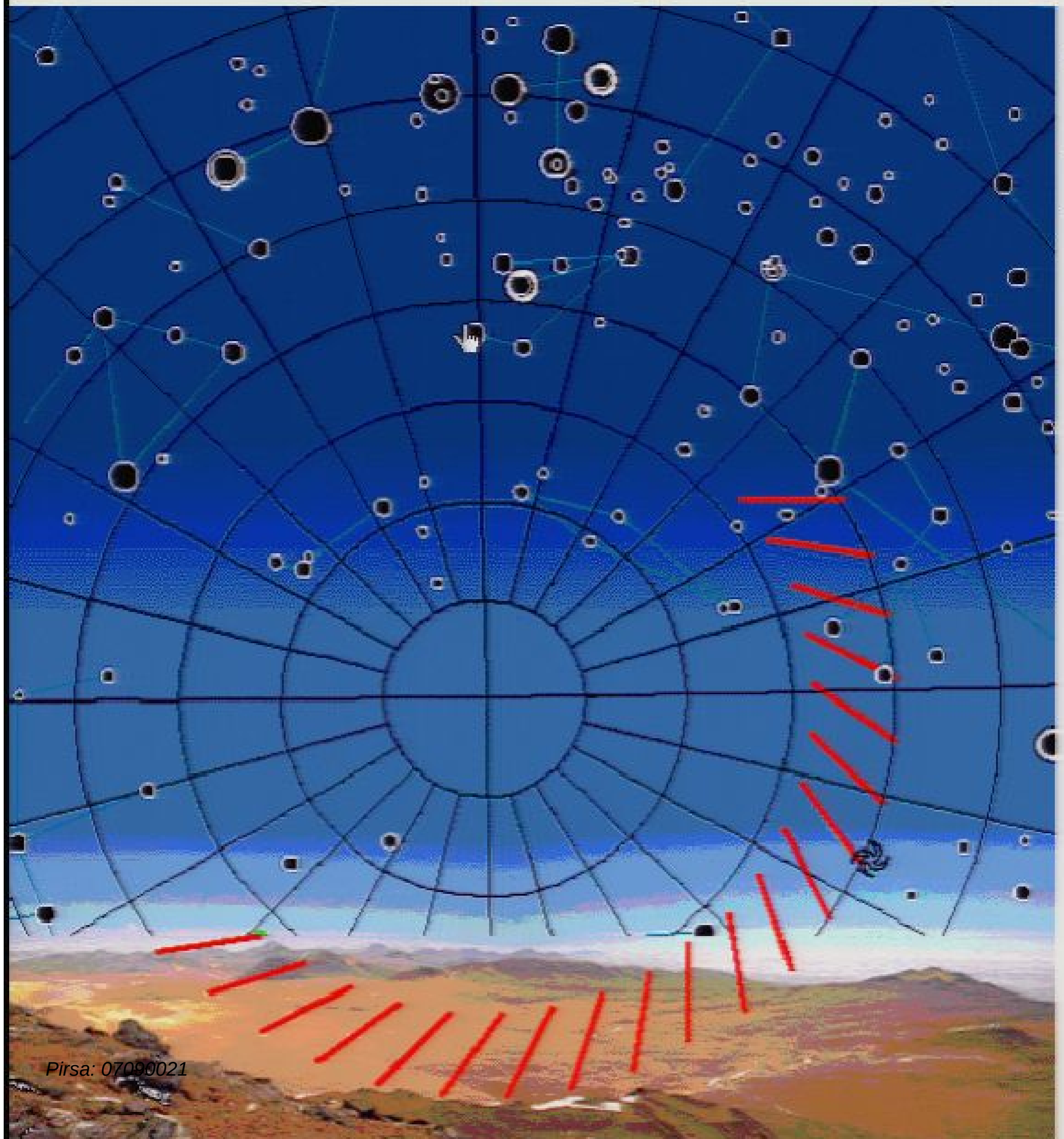
Cross Linked Scan Strategy is Crucial to Making Maps on Degree Angular Scales



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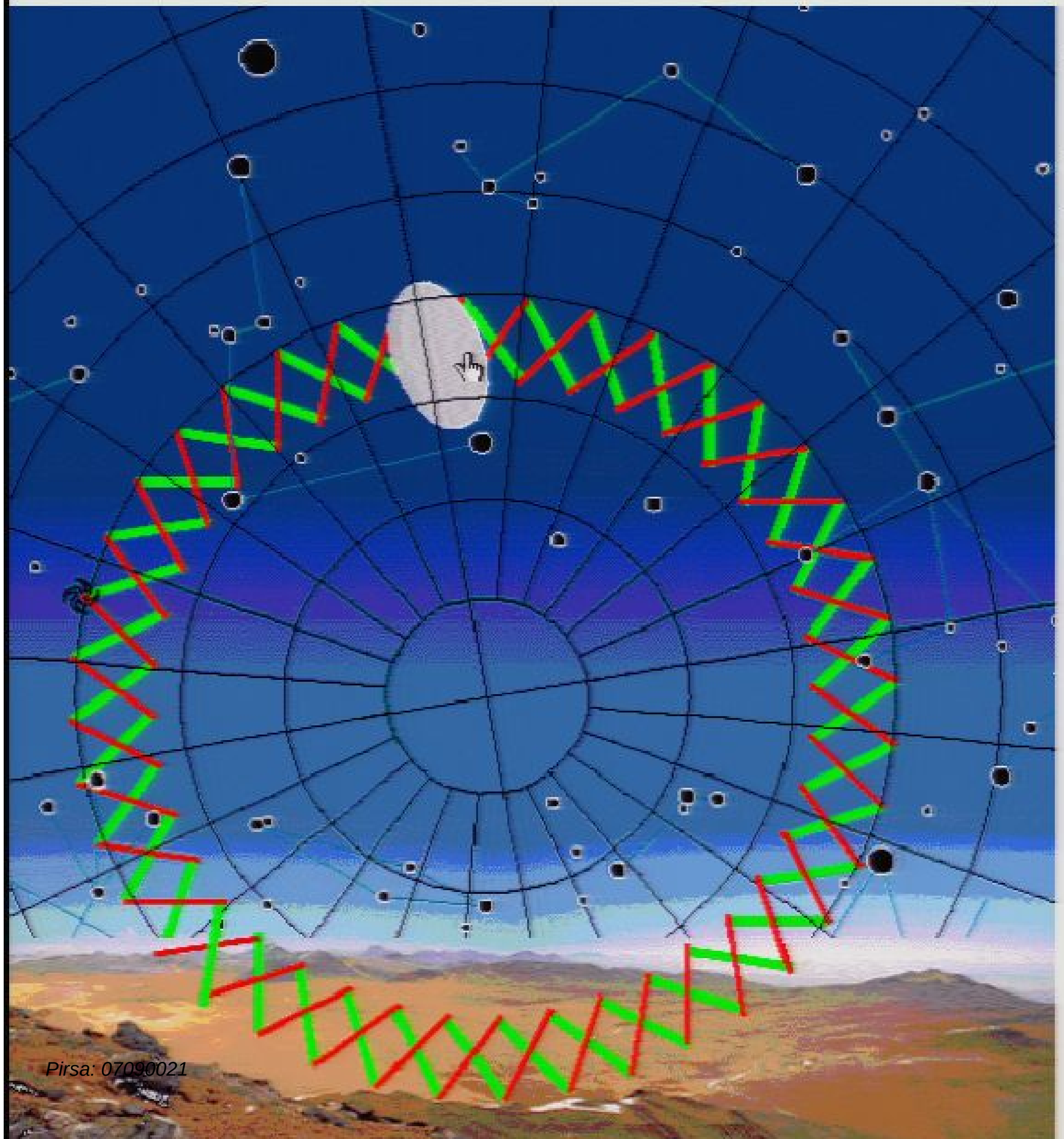
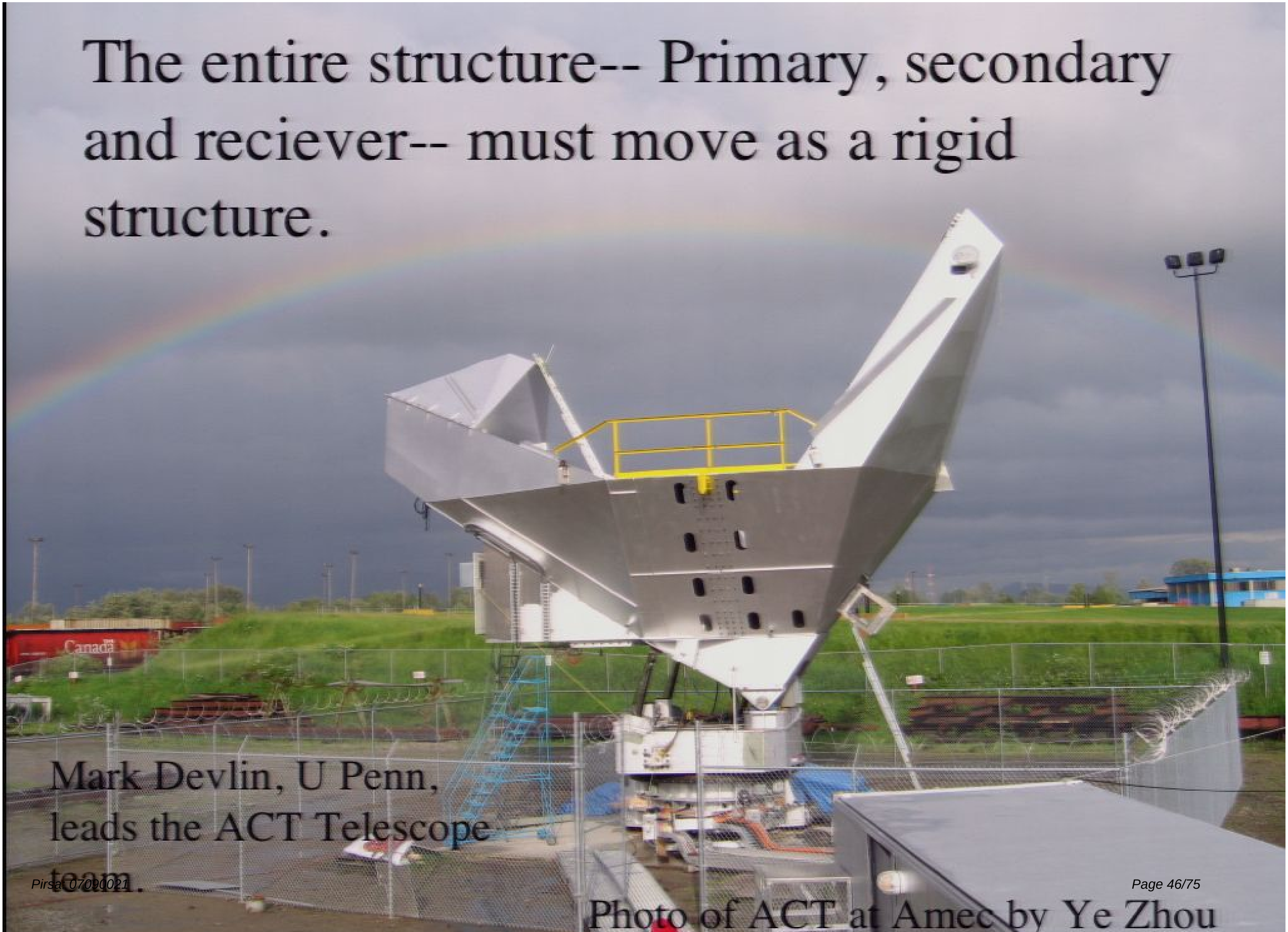
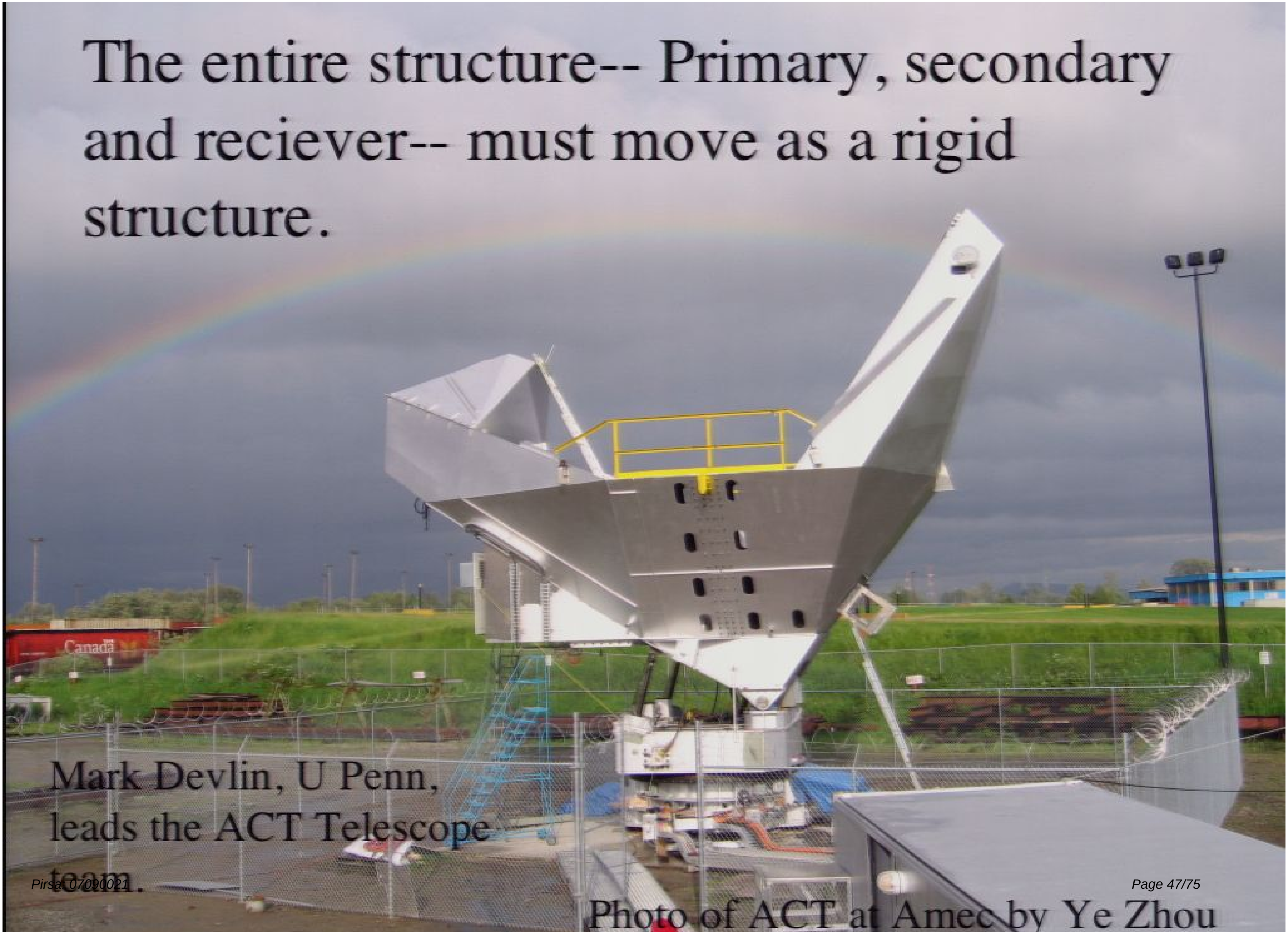
Cross Linked Scan Strategy is Crucial to Making Maps on Degree Angular Scales




The entire structure-- Primary, secondary and reciever-- must move as a rigid structure.
Canada
Mark Devlin, U Penn, leads the ACT Telescope team.
Photo of ACT at Amec by Ye Zhou


The entire structure-- Primary, secondary and reciever-- must move as a rigid structure.
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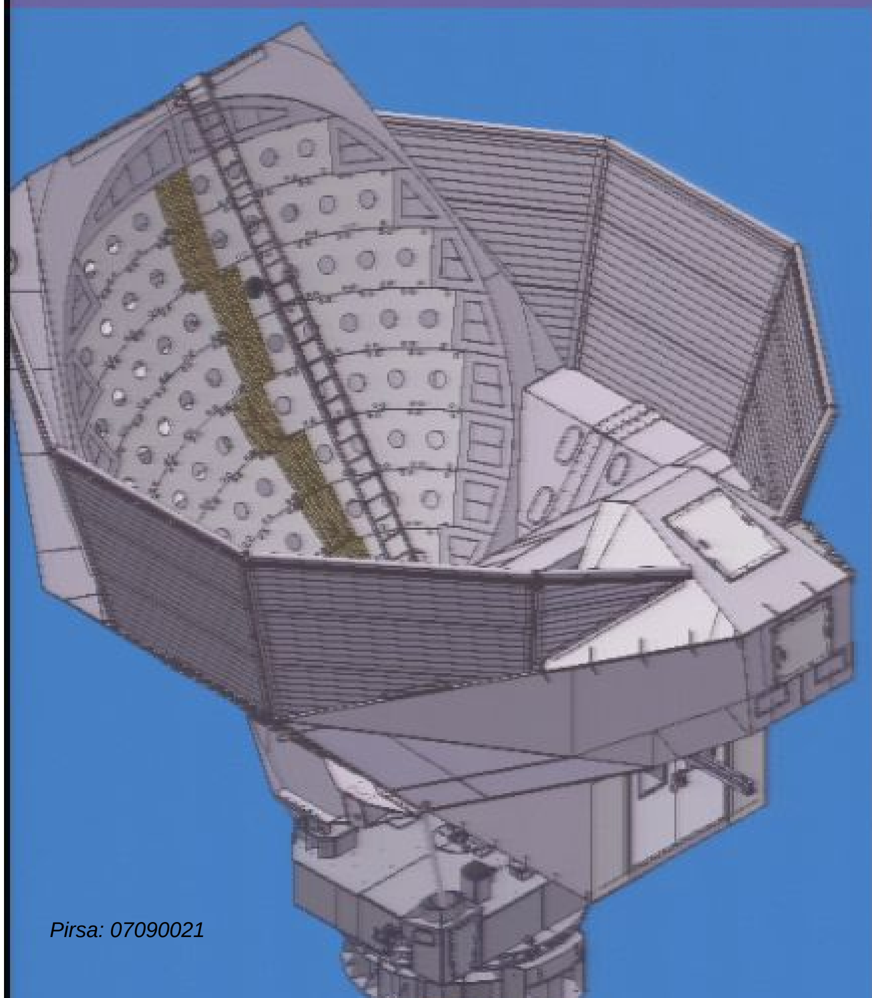
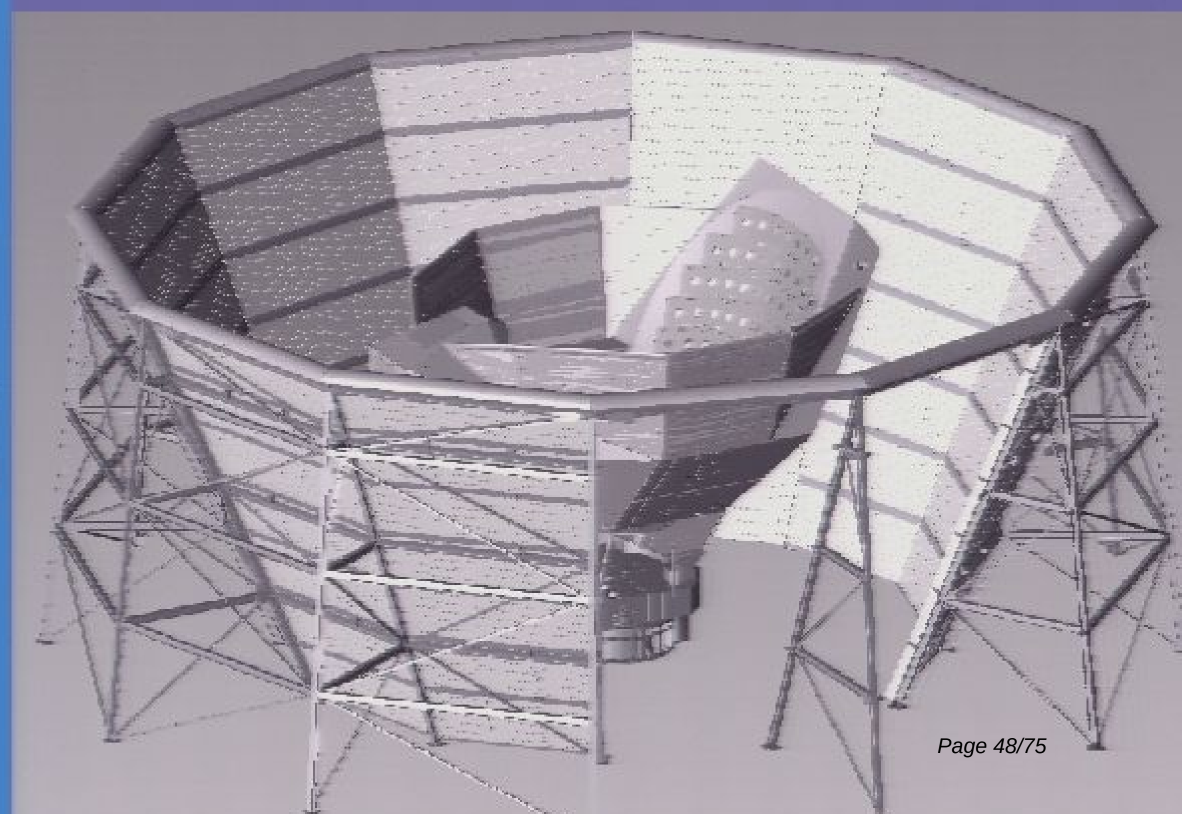
Low Ground Pickup is crucial for ACT

Off-axis design,

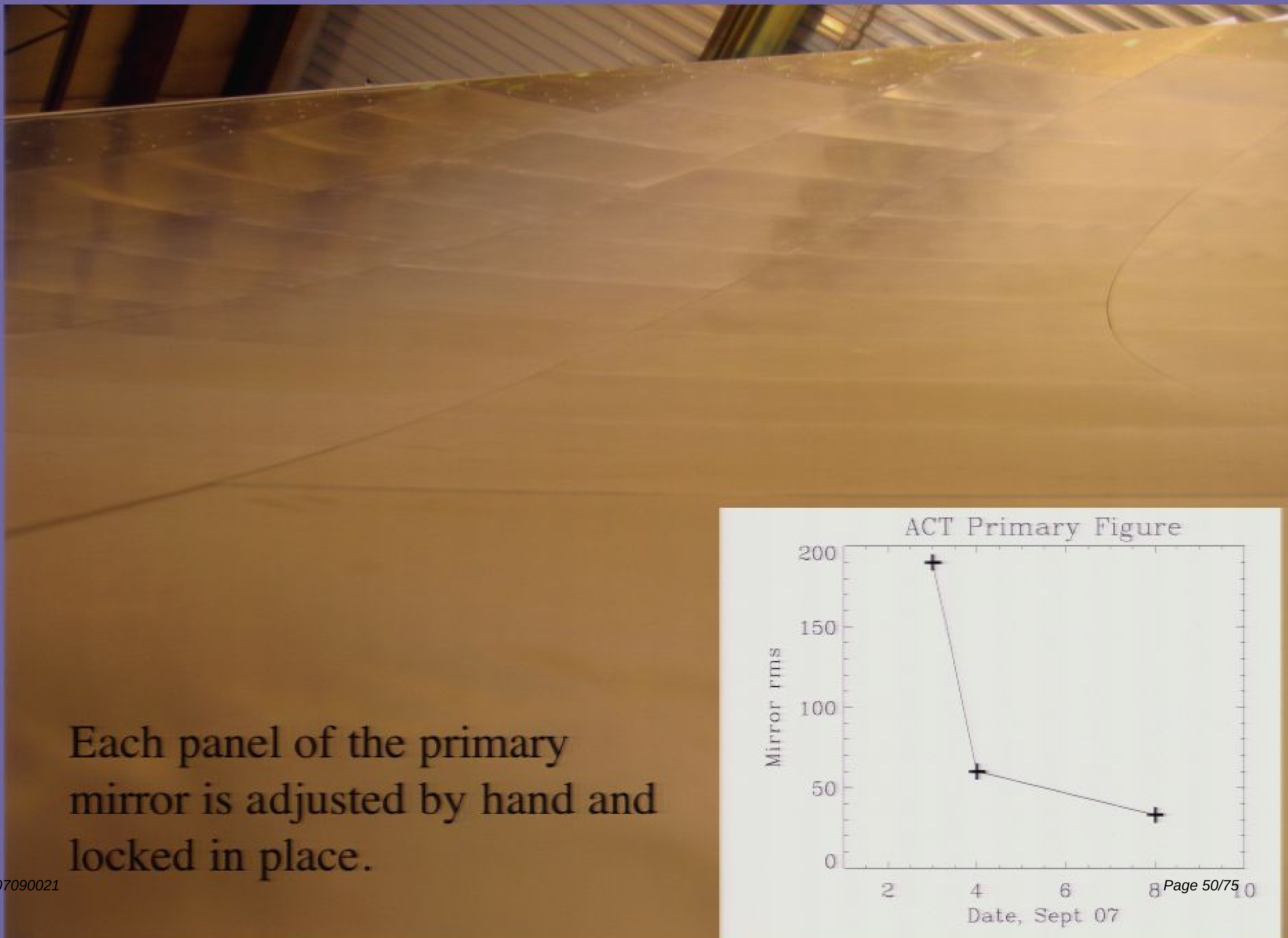


surrounded by a complete ground screen.




A view looking down the face of the
primary, before the panels were installed

Panels Installed



Each panel of the primary mirror is adjusted by hand and locked in place.

The ground screen is bigger than the telescope.

Photo by Michele Limon

Large sensitive arrays of superconducting Transition Edge Sensor bolometers are at the heart of ACT.

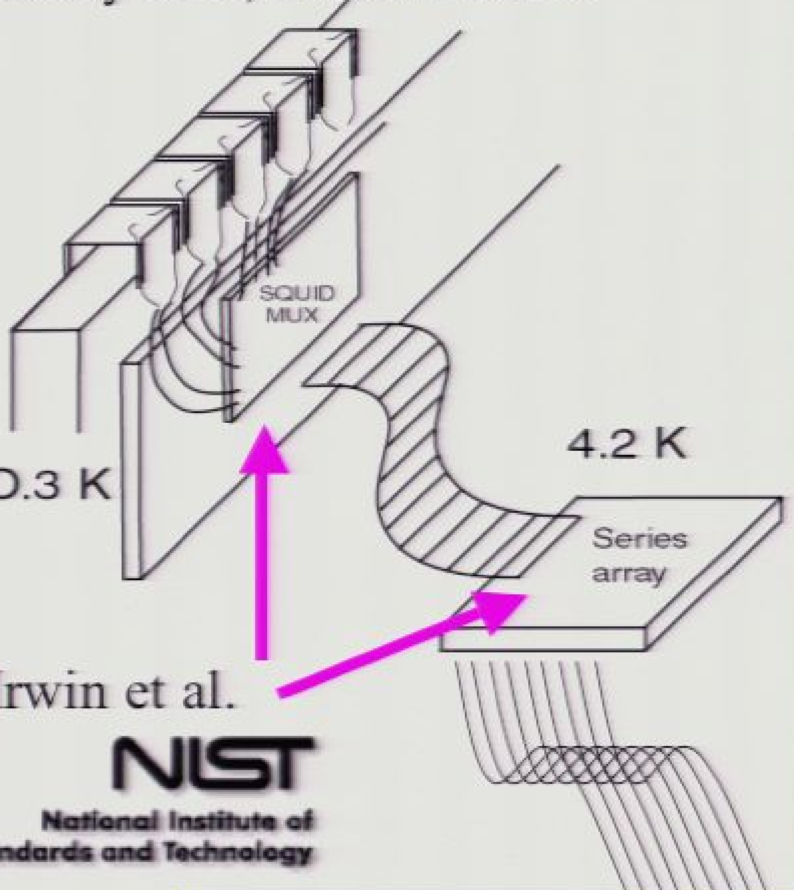
I'll say a few words about how they work because so many new experiments use similar detectors.

(ACT, ASTE, Bicep, CCAT, Clover, Ebex, Gismo, bPol, Poincare, SCUBA2, Spider, SPT, Spud, …)

Arrays of bolometers

S. Staggs is lead

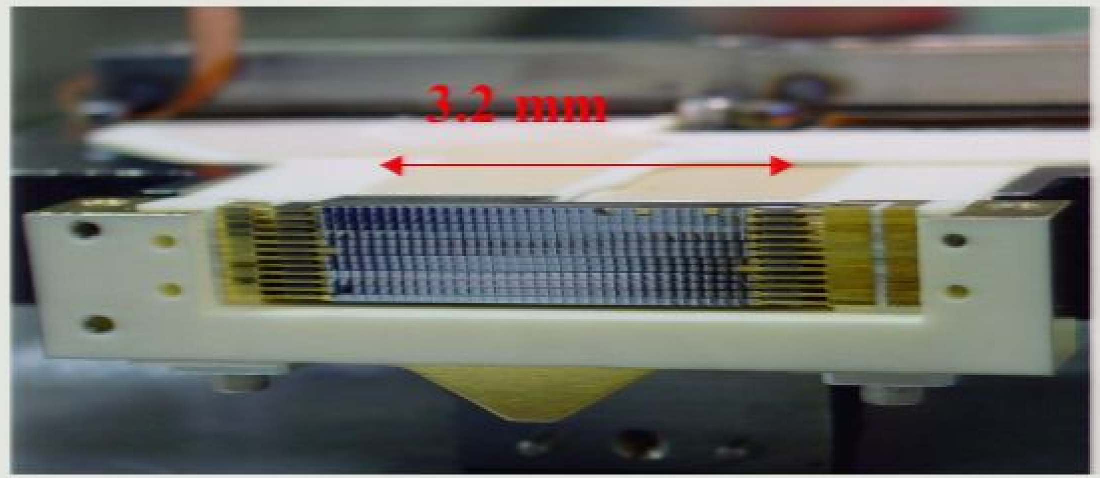
Moseley et al, NASA/GSFC



Irwin et al.

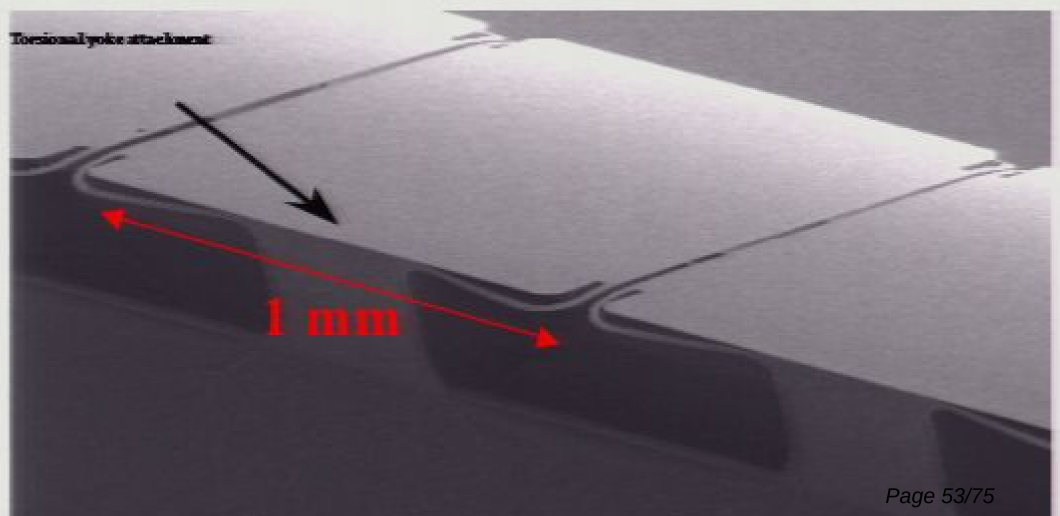
National Institute of Standards and Technology

Warm electronics based on SCUBA2



SHARC II 12x32 Popup Array

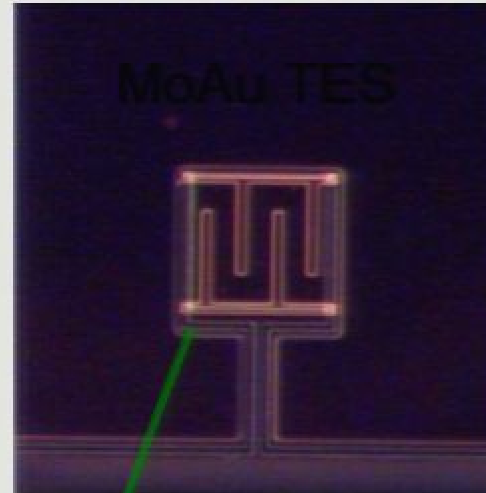
PI D. Dowell



One element of array

Halpern et al. UBC

MBAC Detectors and Readout



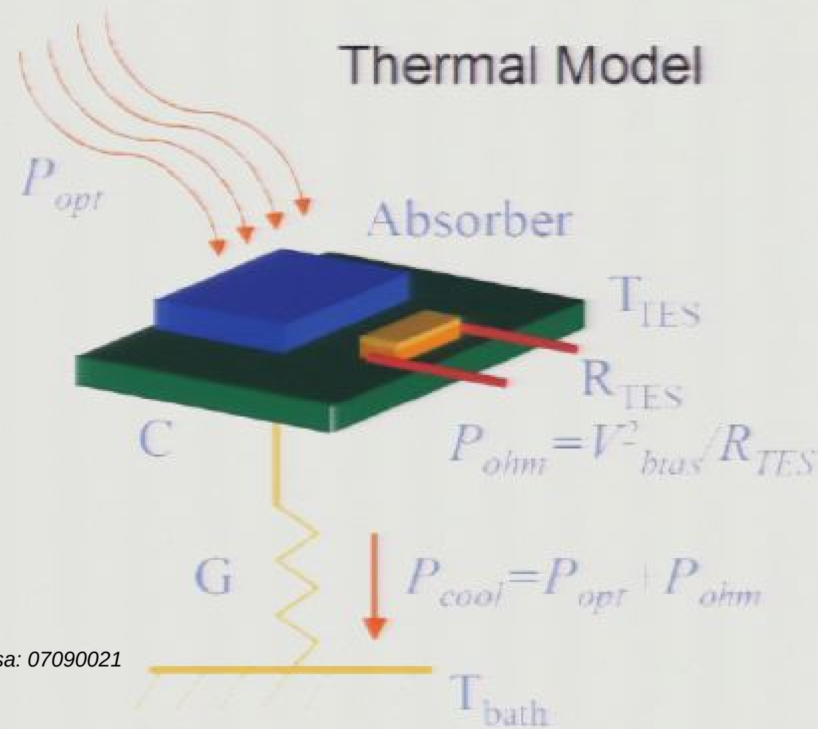
TES PUDs: detect fluctuations

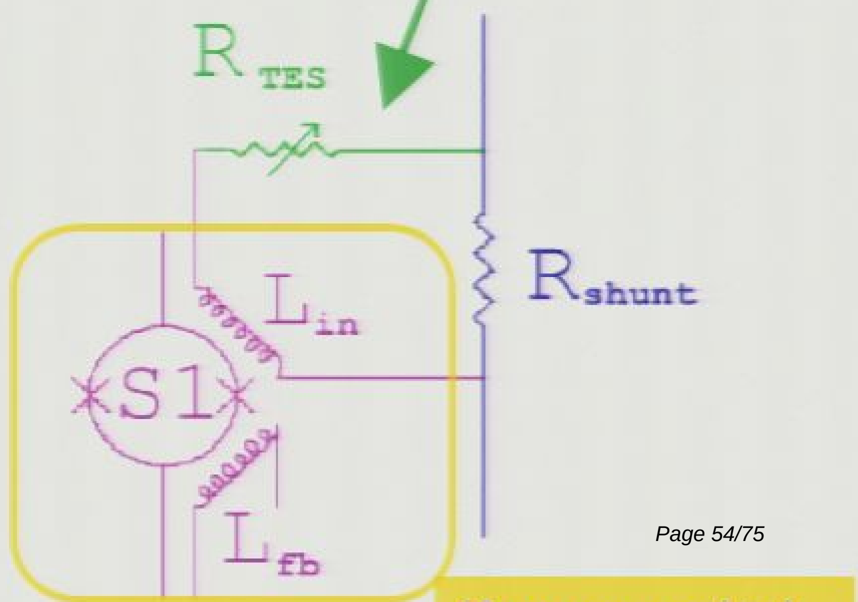
Shunts: provide voltage bias

Mux chips: provide multiplexing & current readout through flux-feedback

Nyquist inductors: provide L/R signal bandwidth limit

Thermal Model





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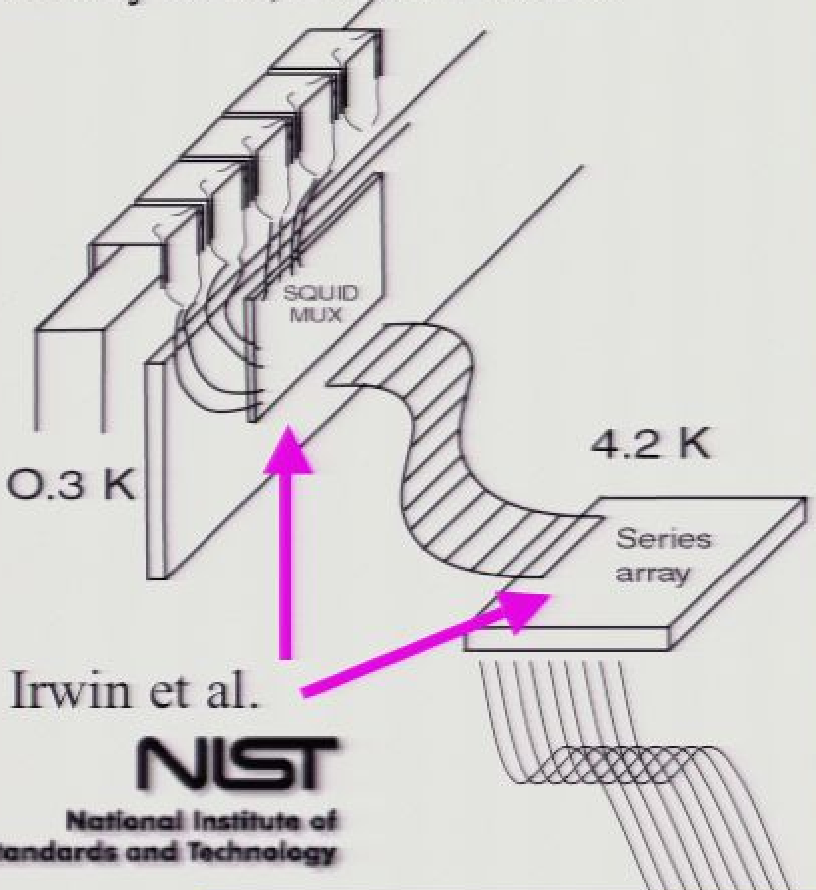
Moseley et al, NASA/GSFC



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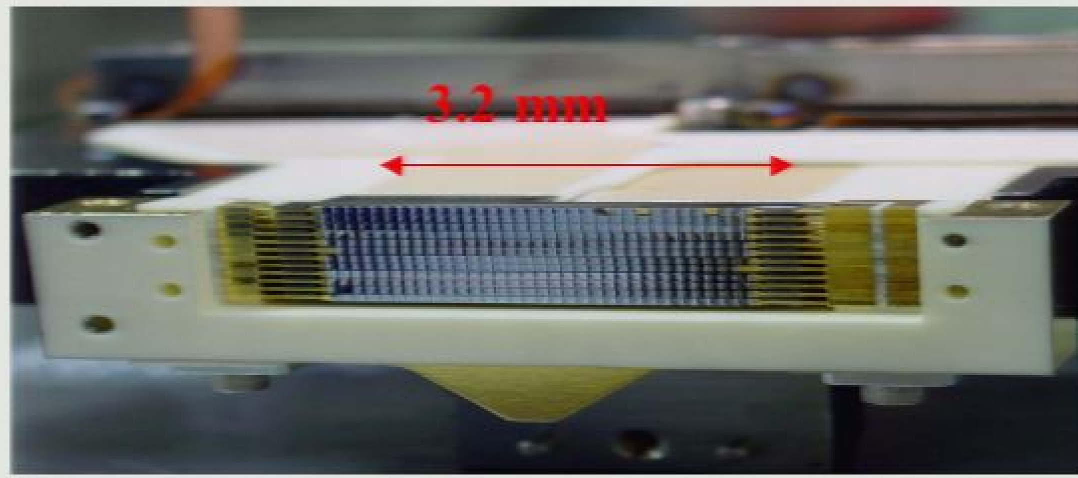

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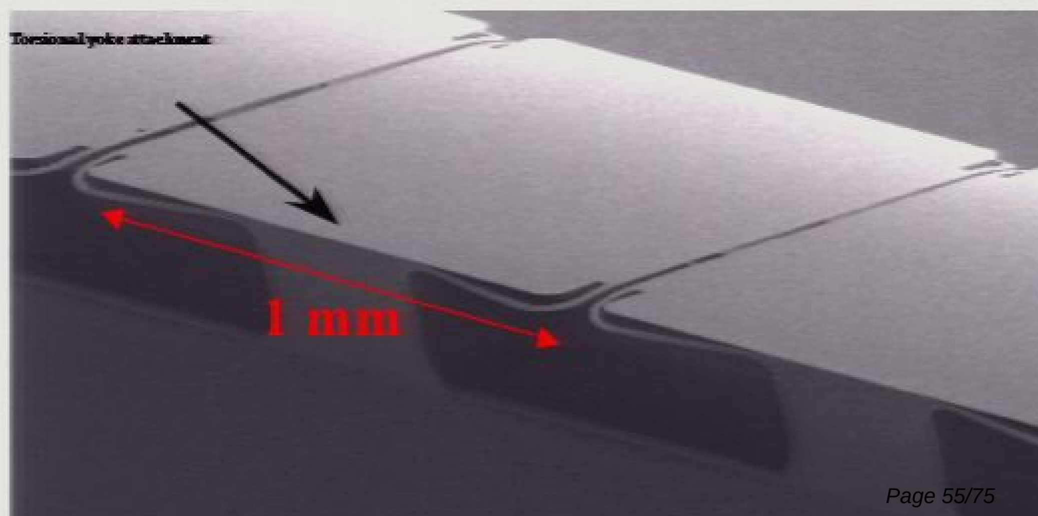

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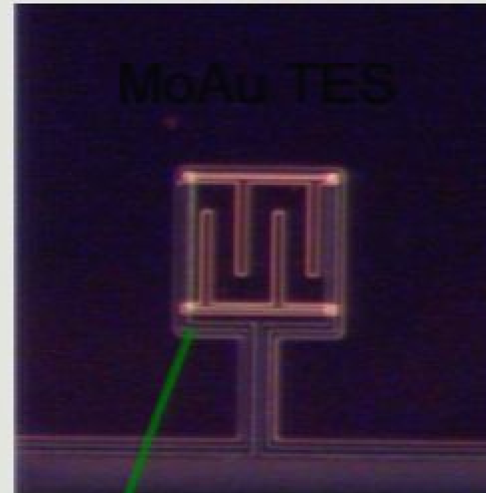

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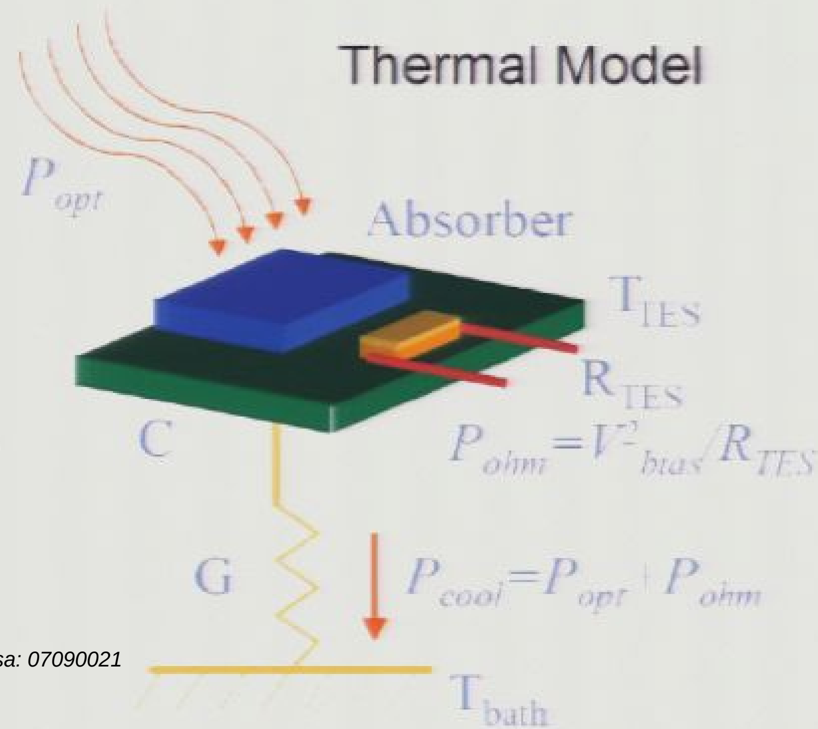
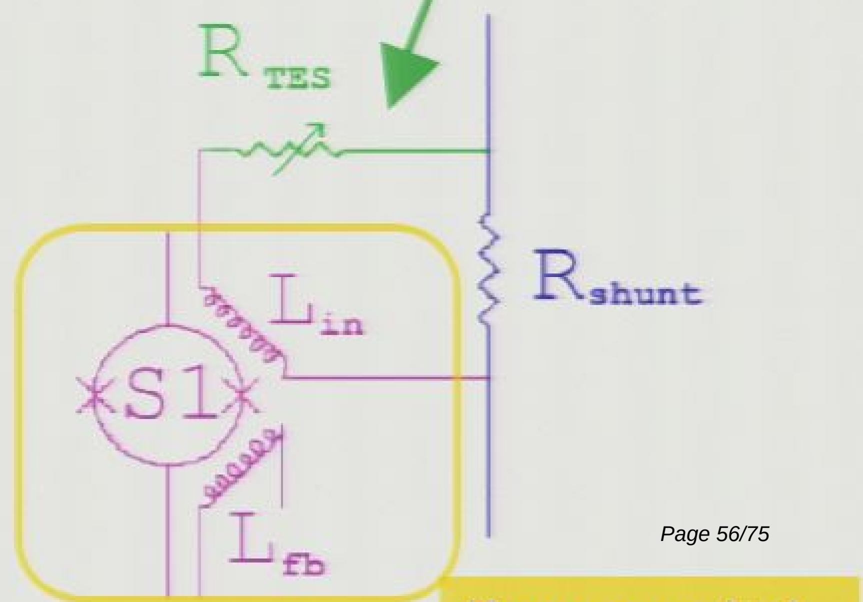
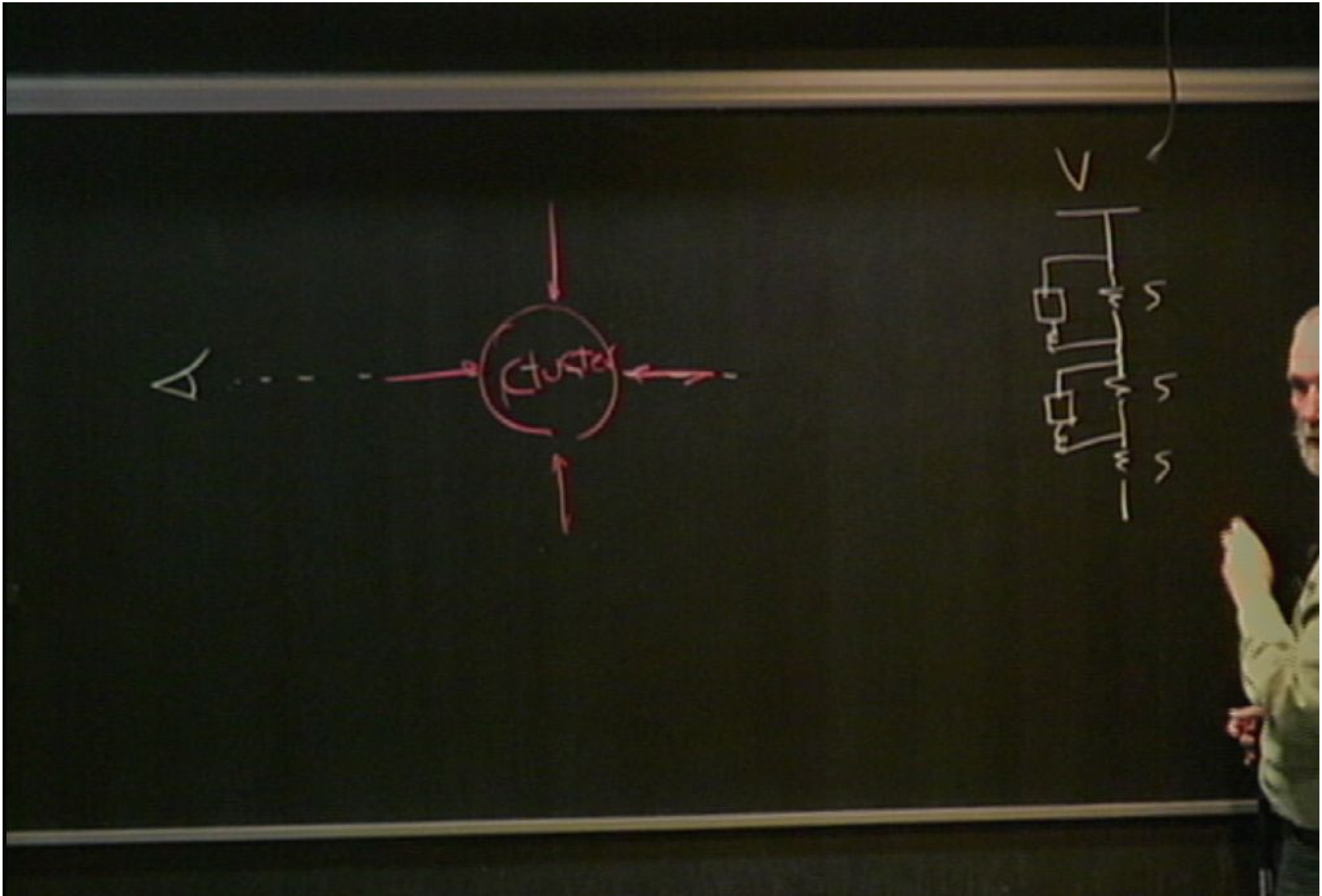
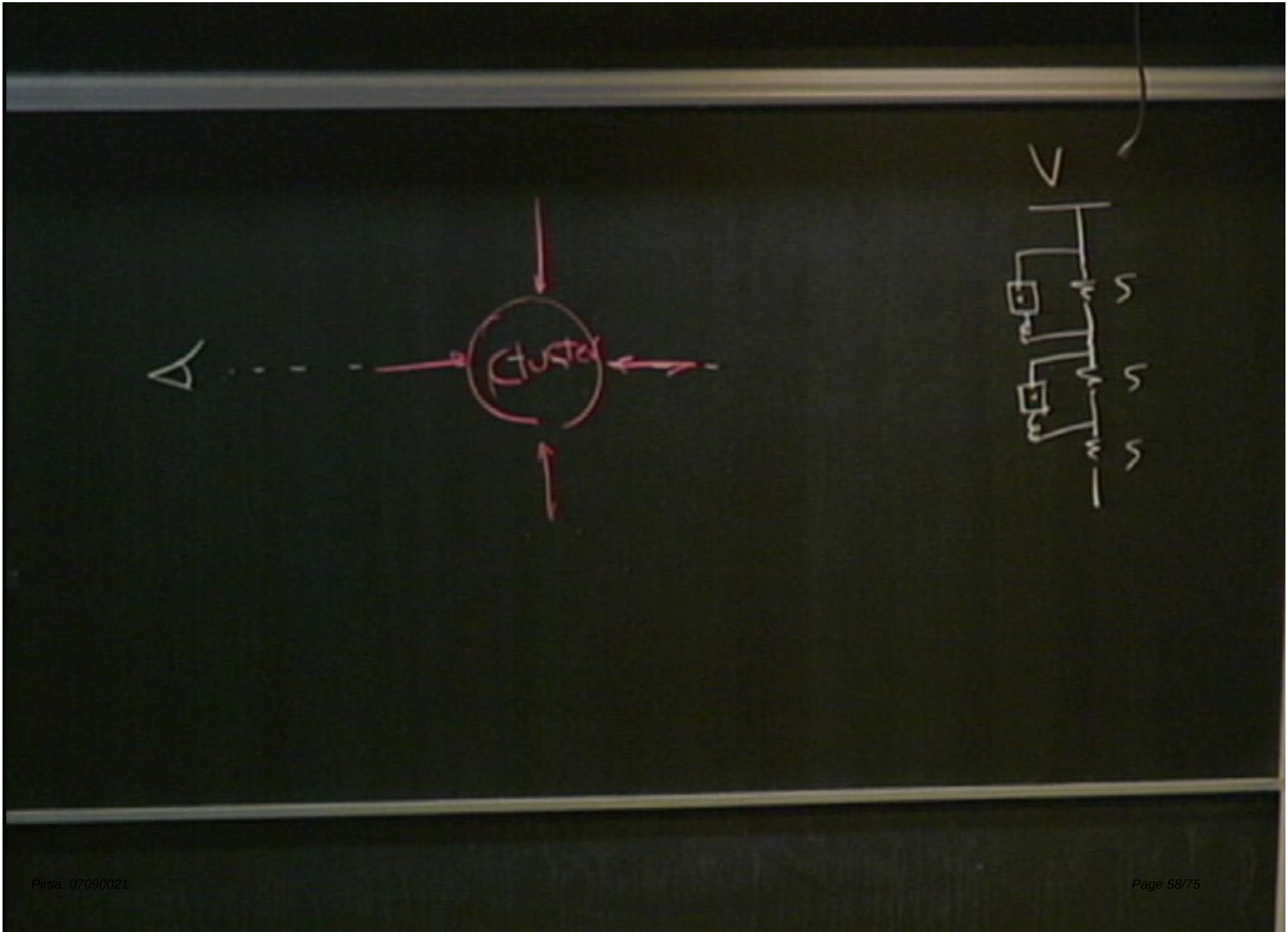


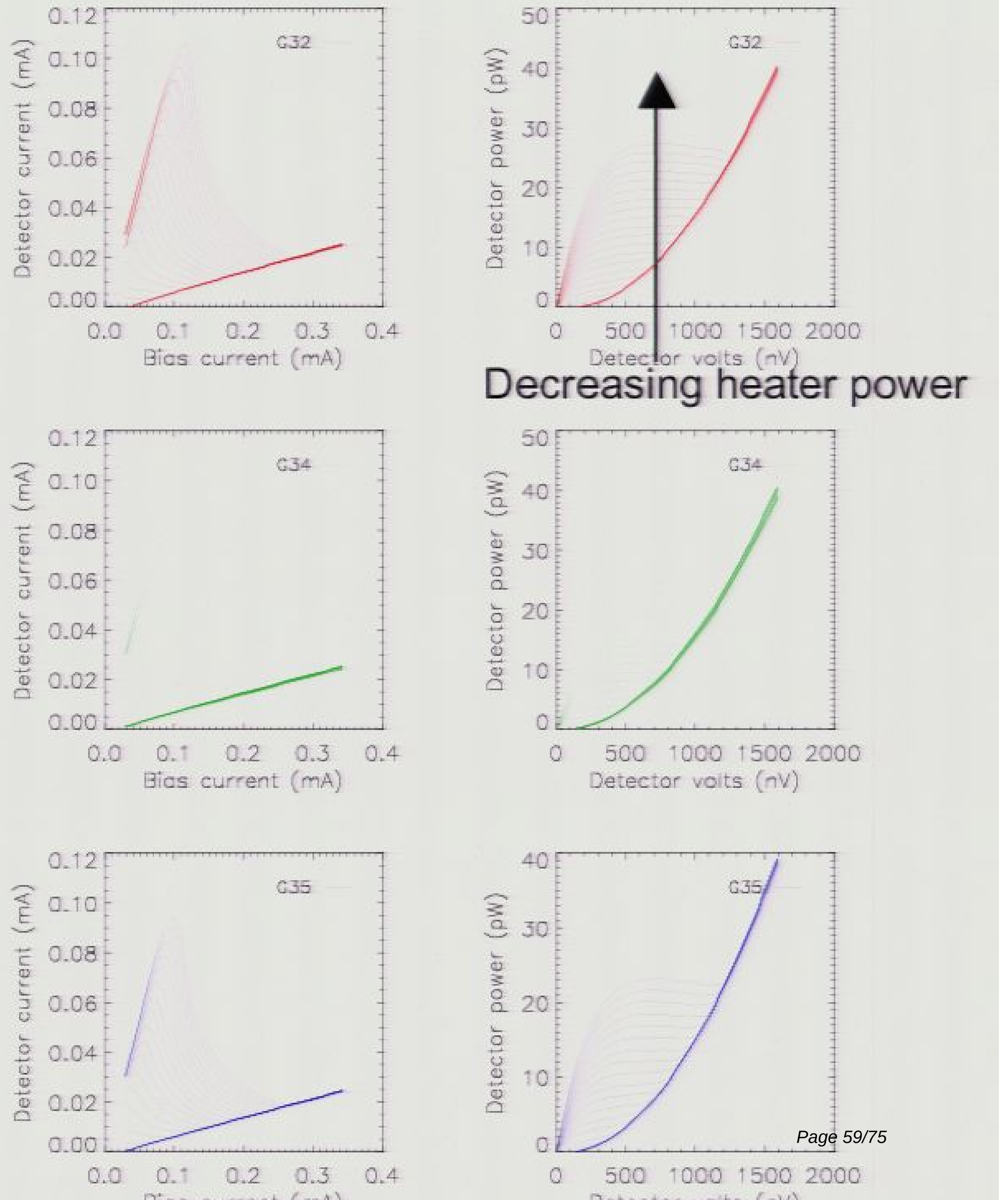


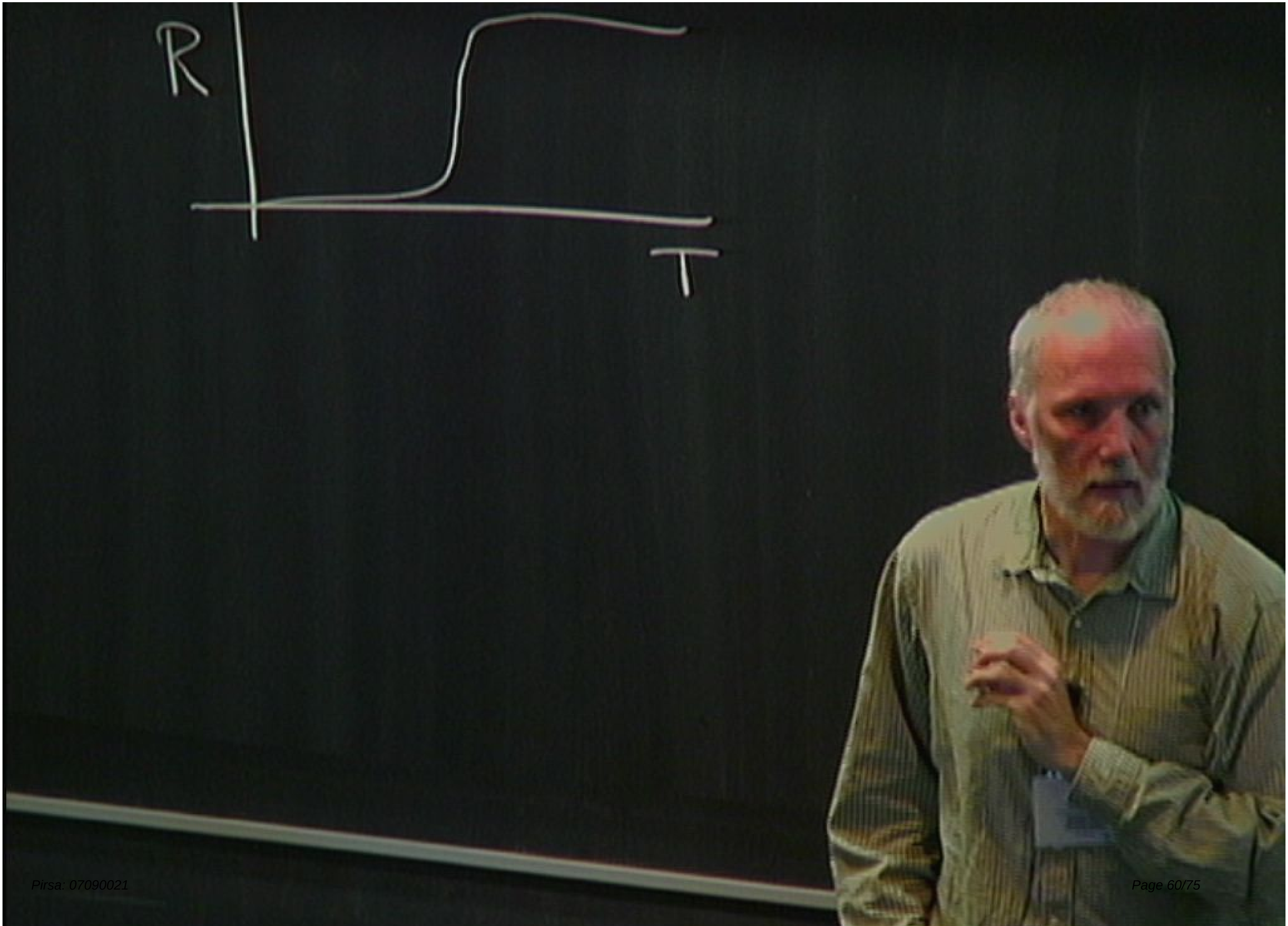

Cluster
V
5
5
5

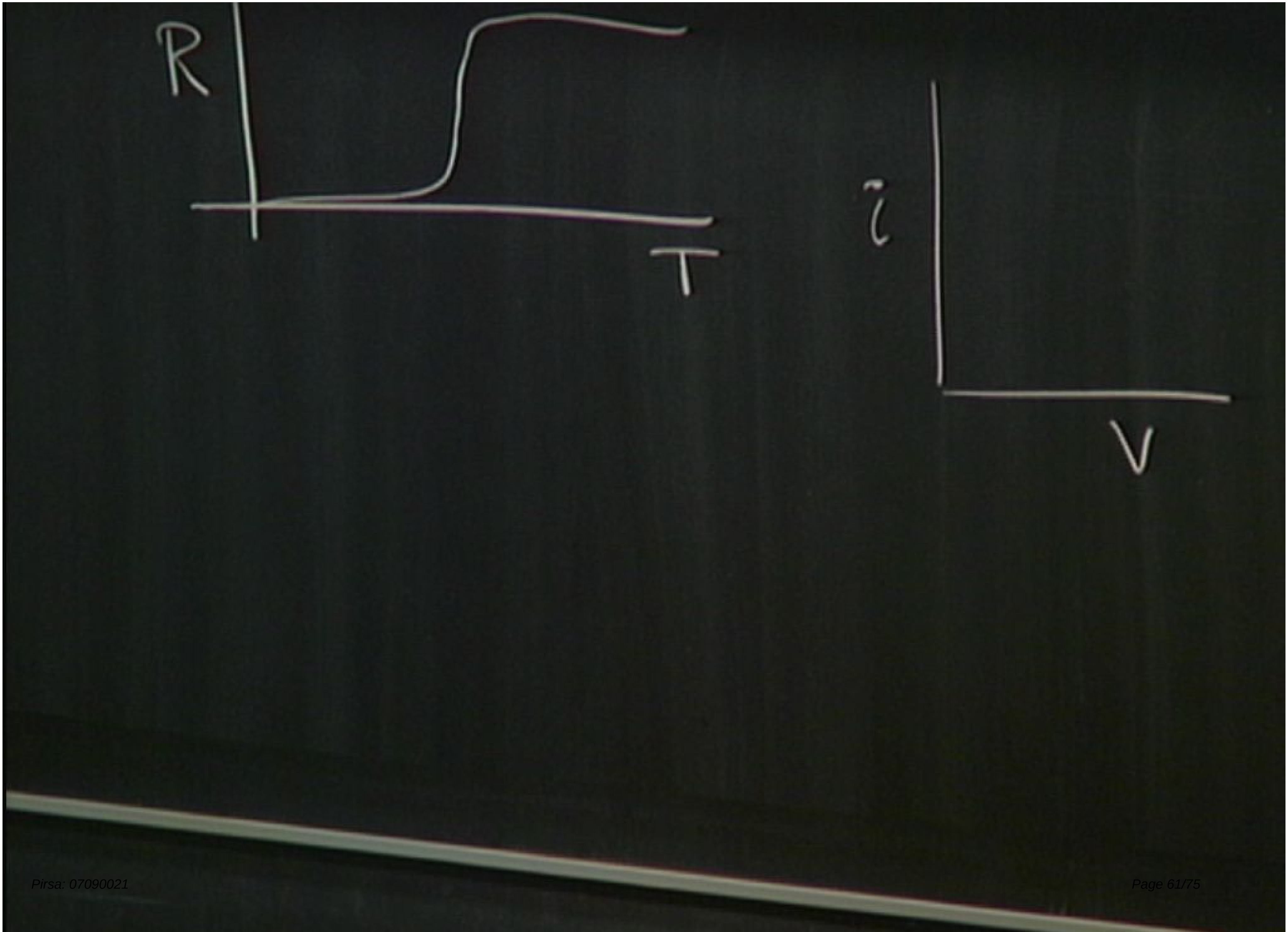

cluster
V
S
S
S

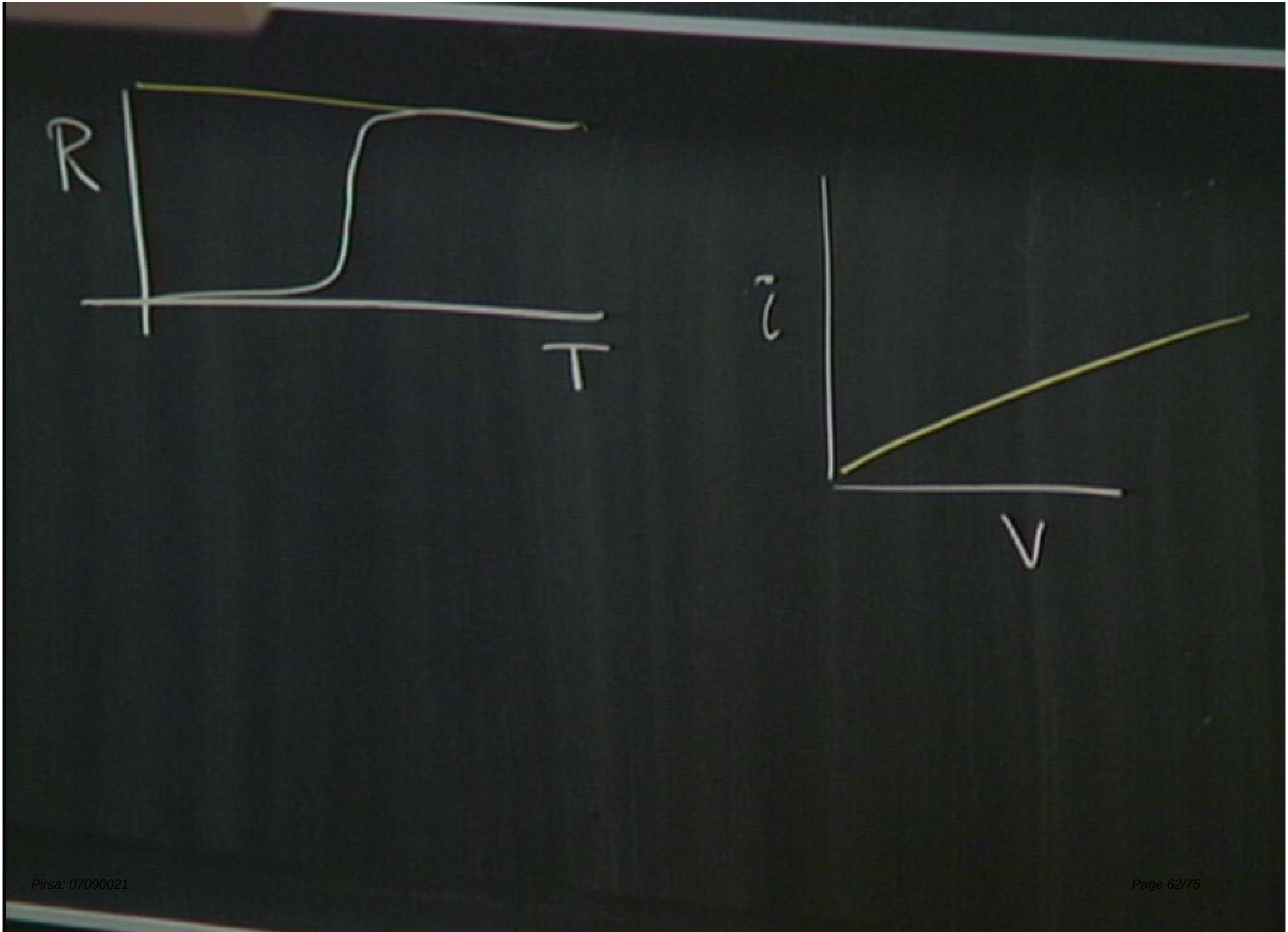
Load curves

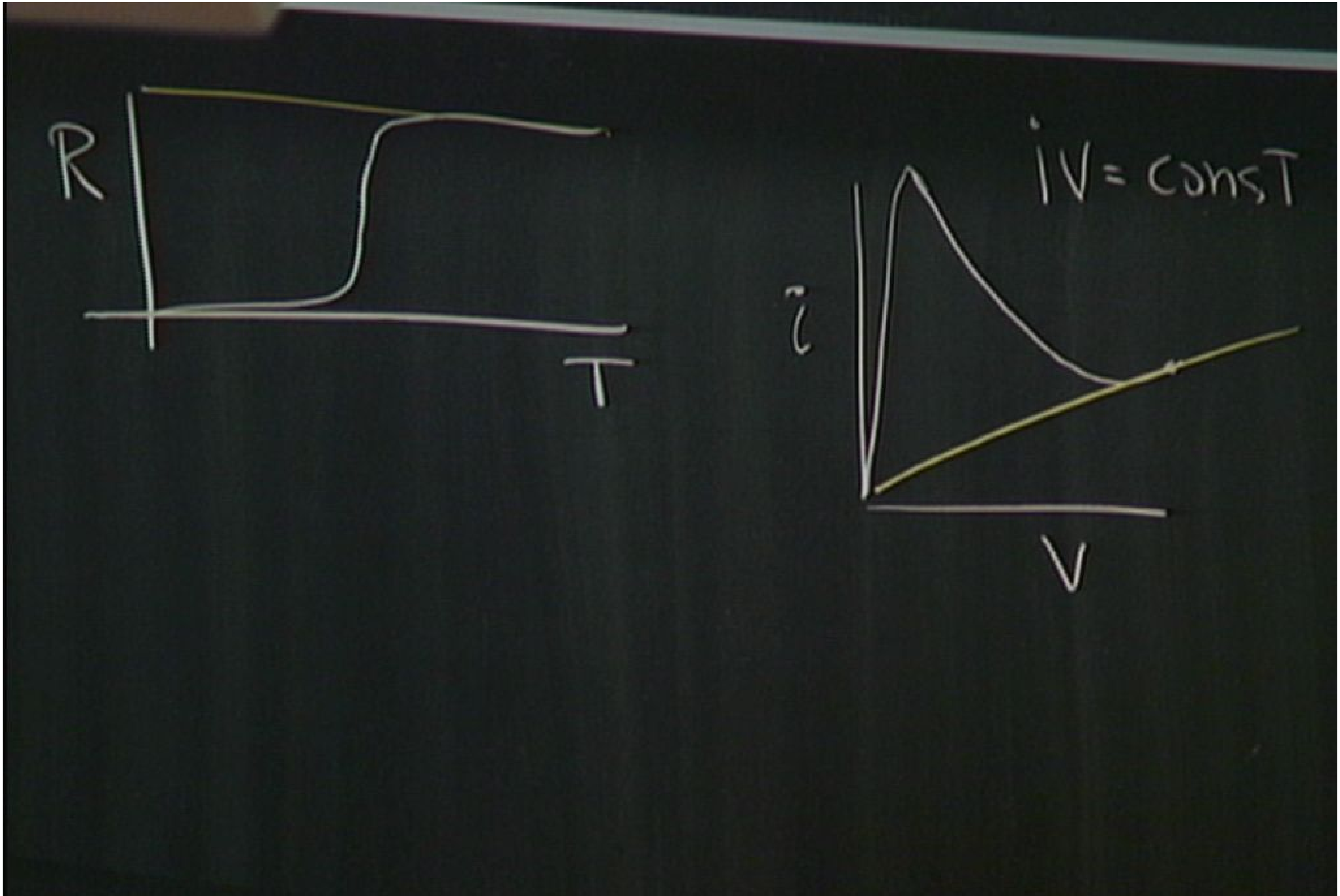
- Also plot as power in detector vs voltage
- Power constant in superconducting transition
- Power proportional to V^2 in normal state
- Responsivity (S) in transition proportional to 1/V

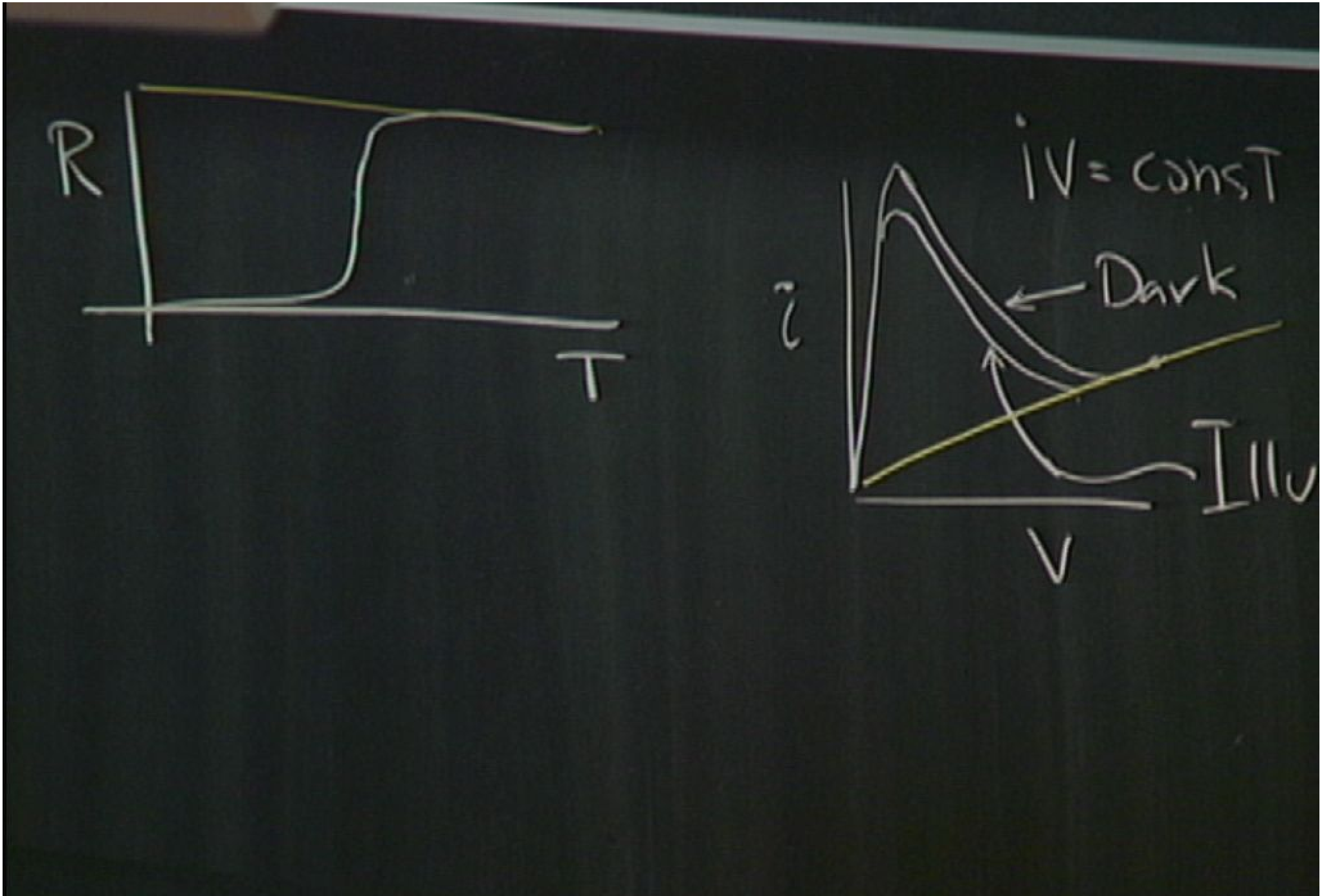


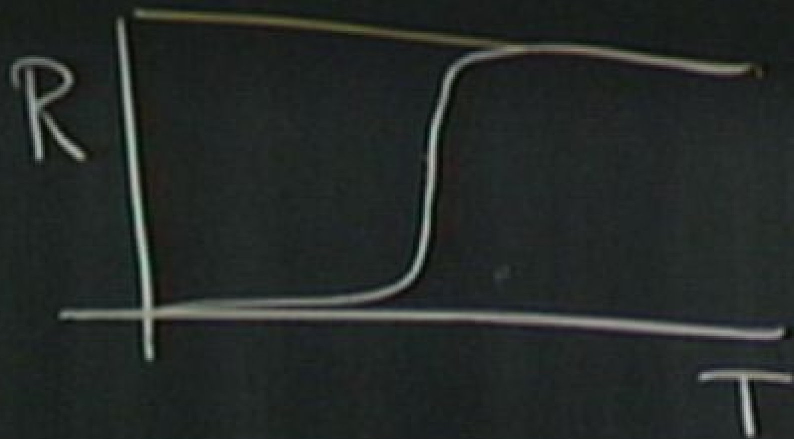

R
T

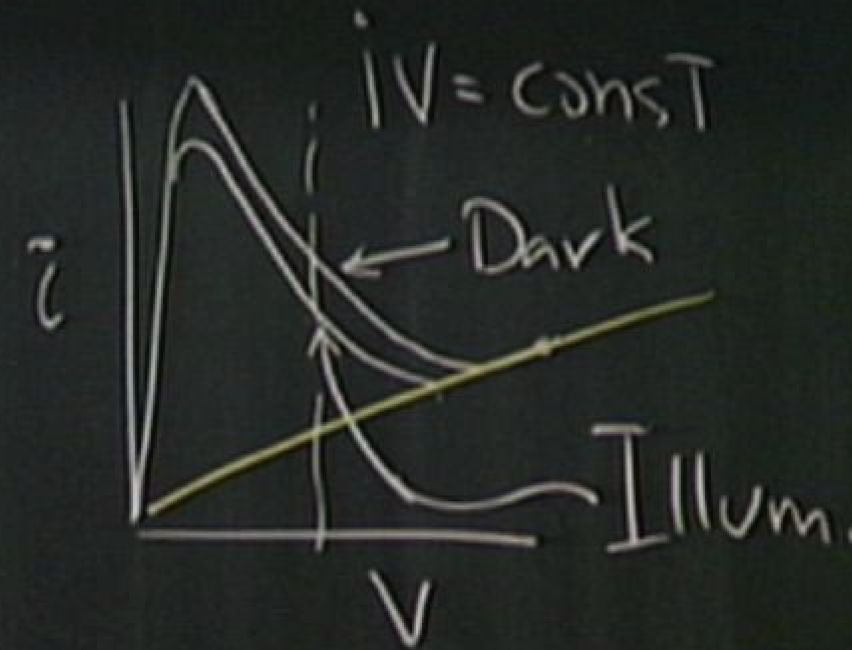

R
T
i
V


R
T
i
V


R
T
iV = const
i
V


R
T
i
iV = const
Dark
Illu
V


R
T


iV = const
i
Dark
Illum.
V

Load curves

- Also plot as power in detector vs voltage
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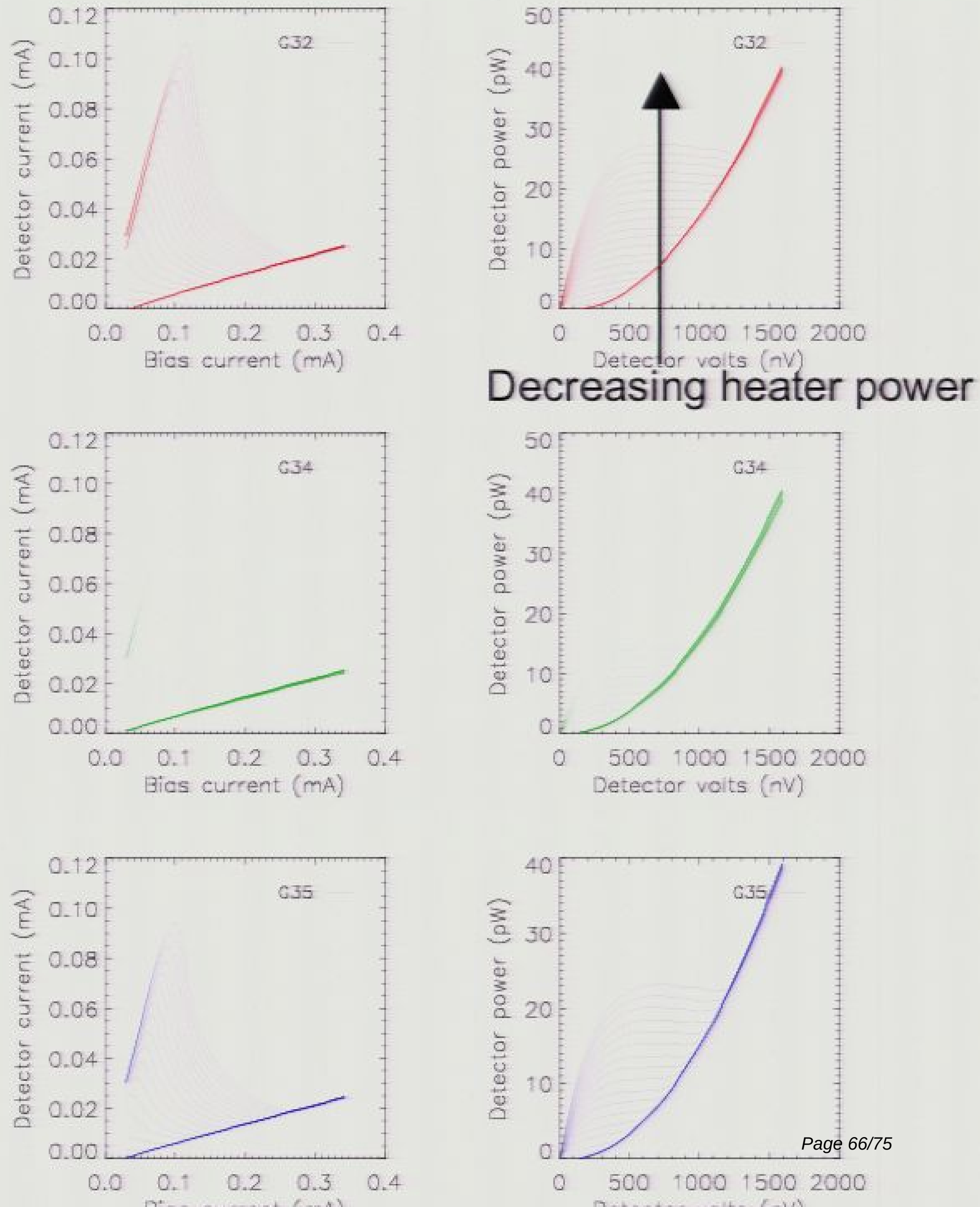
- Power proportional to V^2 in normal state
- Responsivity (S) in transition proportional to 1/V



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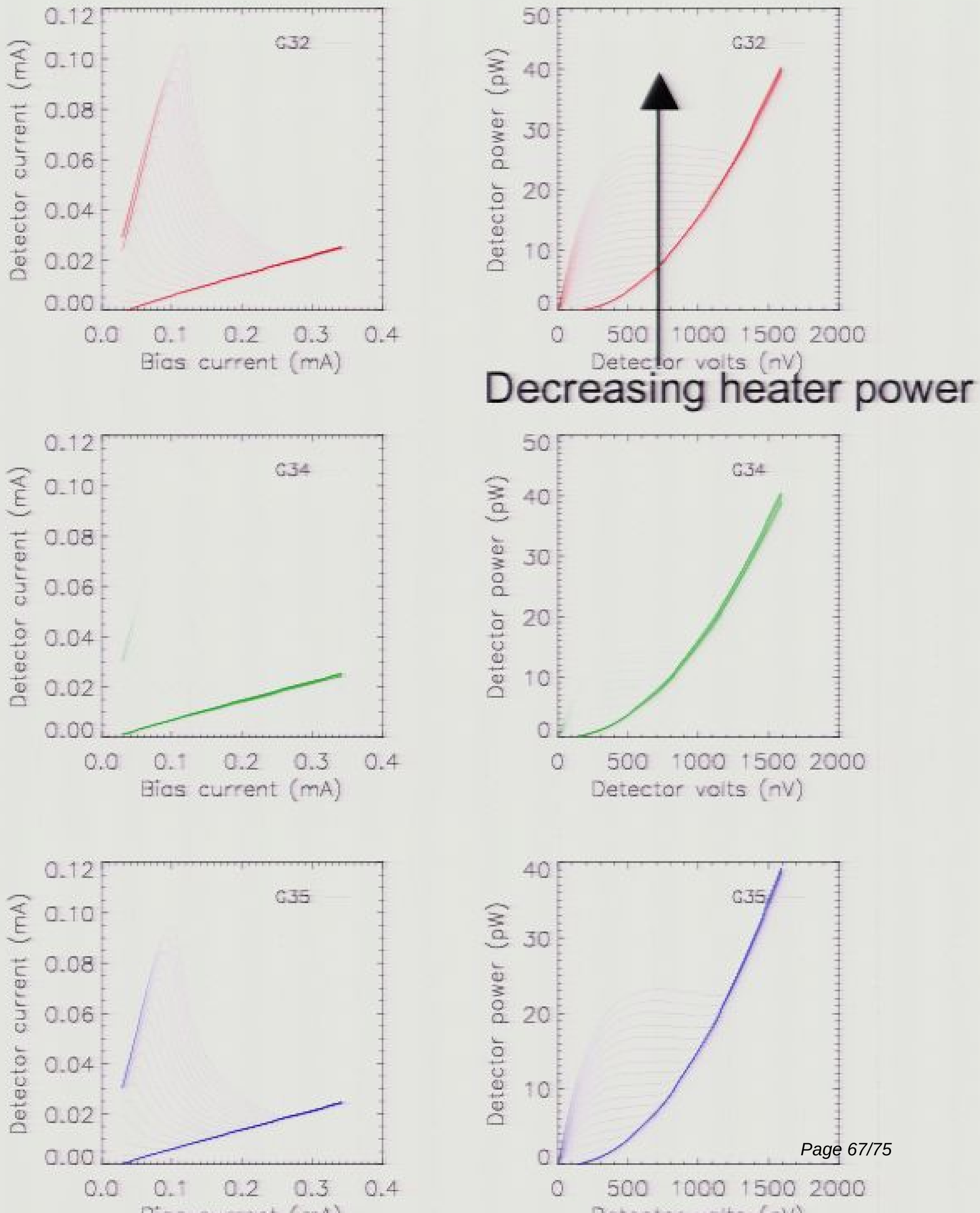
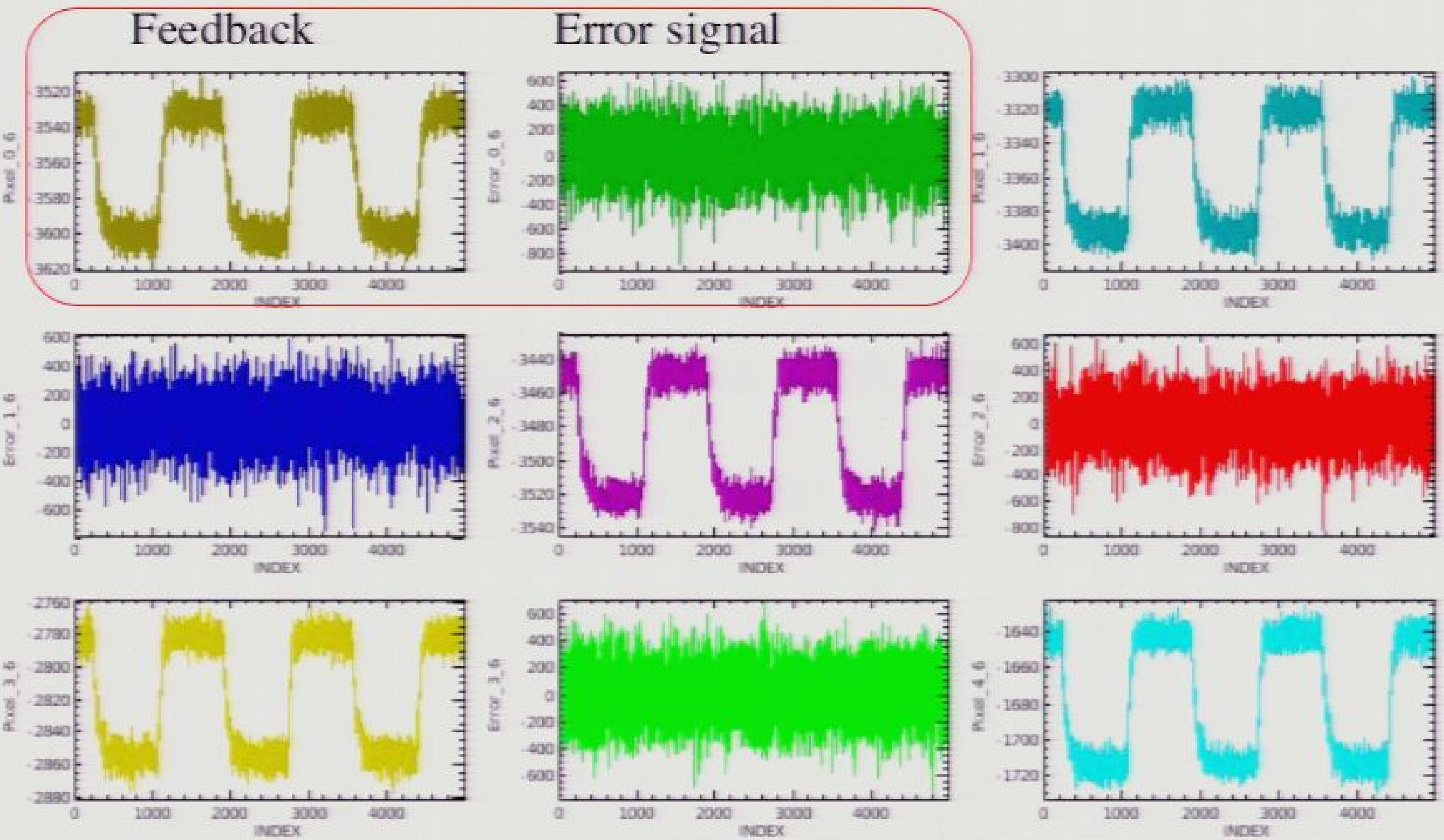
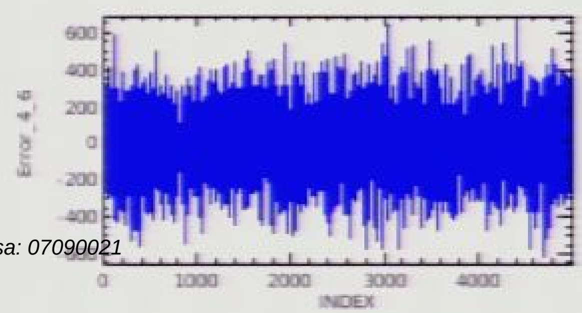


Optical response of five bolometers:





This is 10 kHz readout of a sub-pW optical signal. SCUBA2 data will be filtered to 100 Hz in the electronics.

(Data collected at UBC on a cryostat in New Jersey. by Elia Batastelli.)

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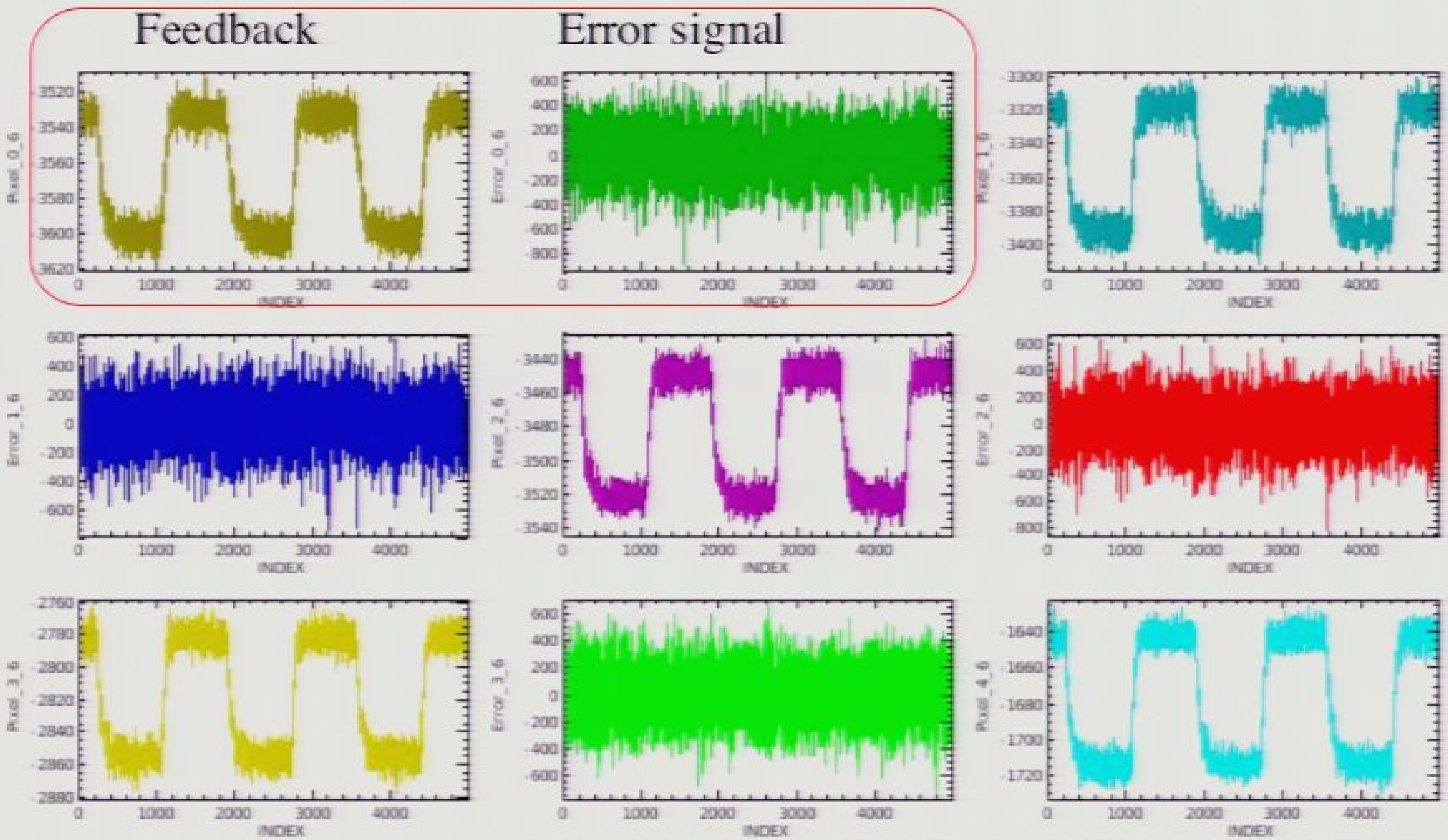

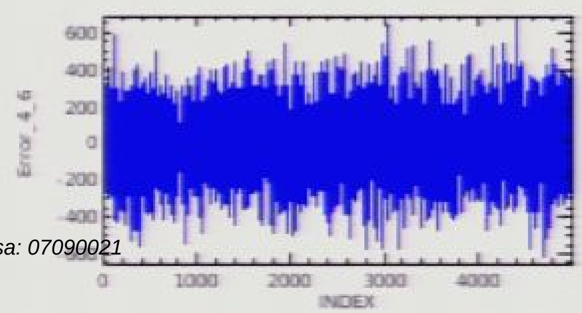

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The ACT 145 GHz array, fully assembled.

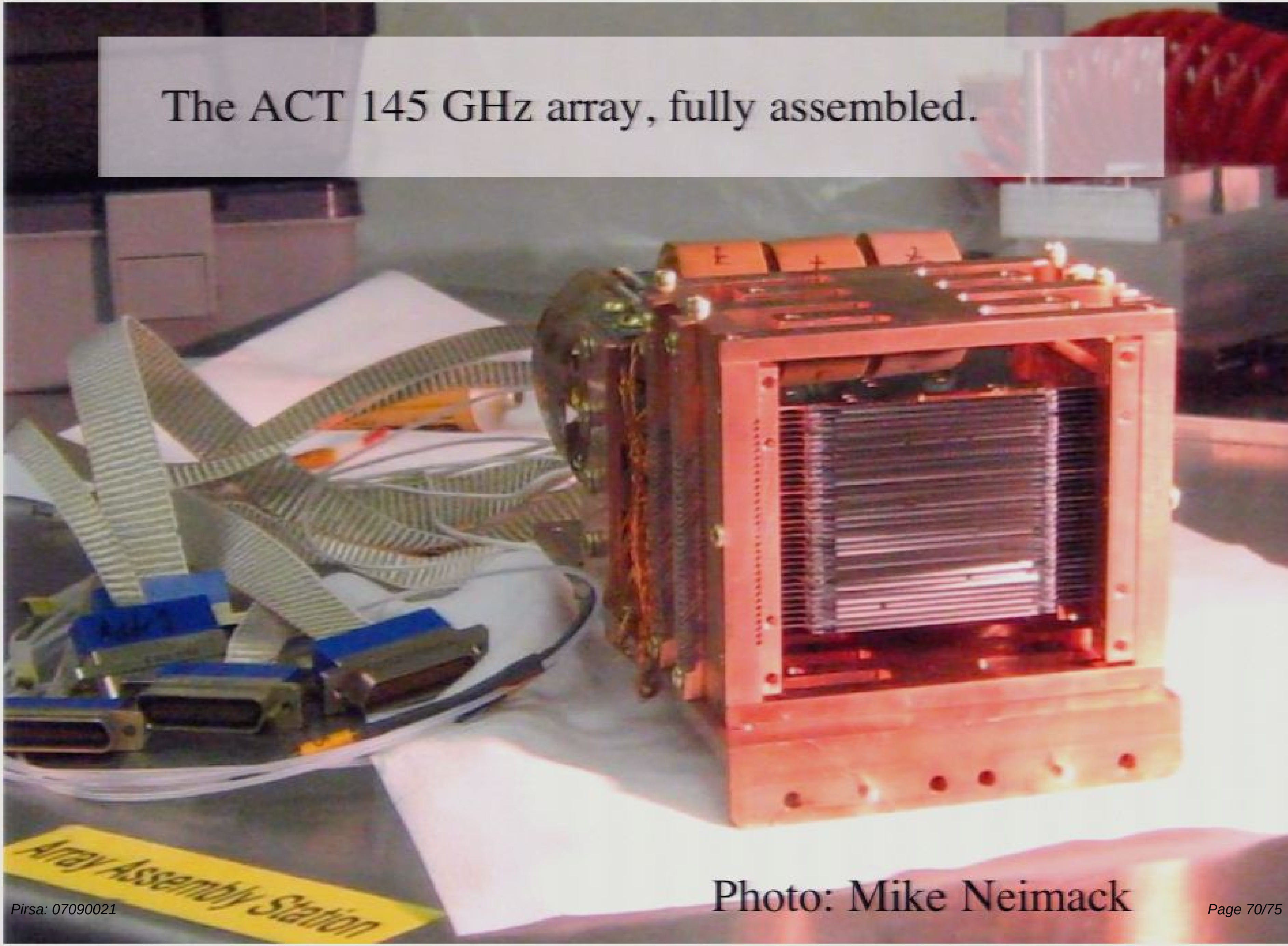
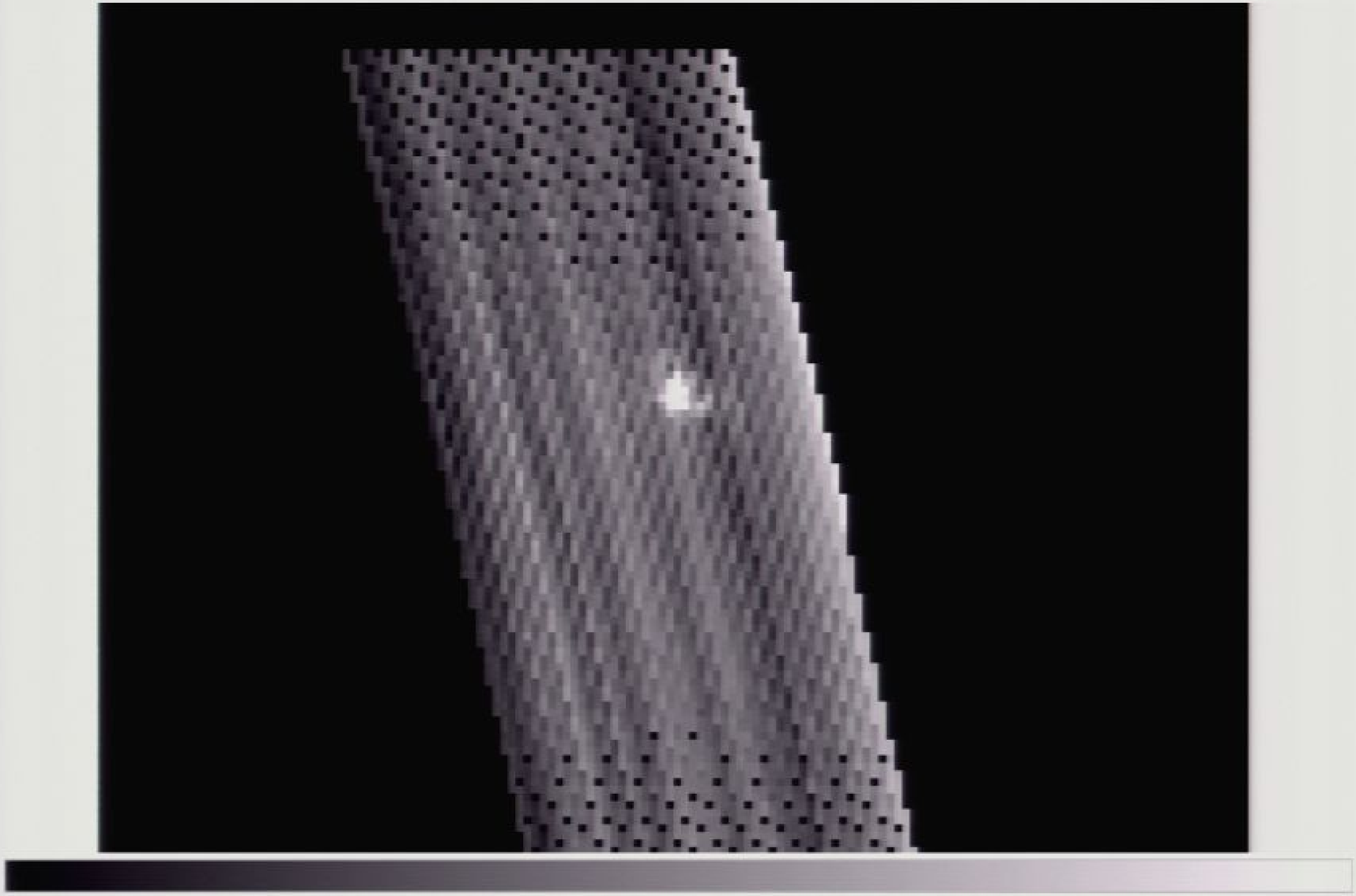
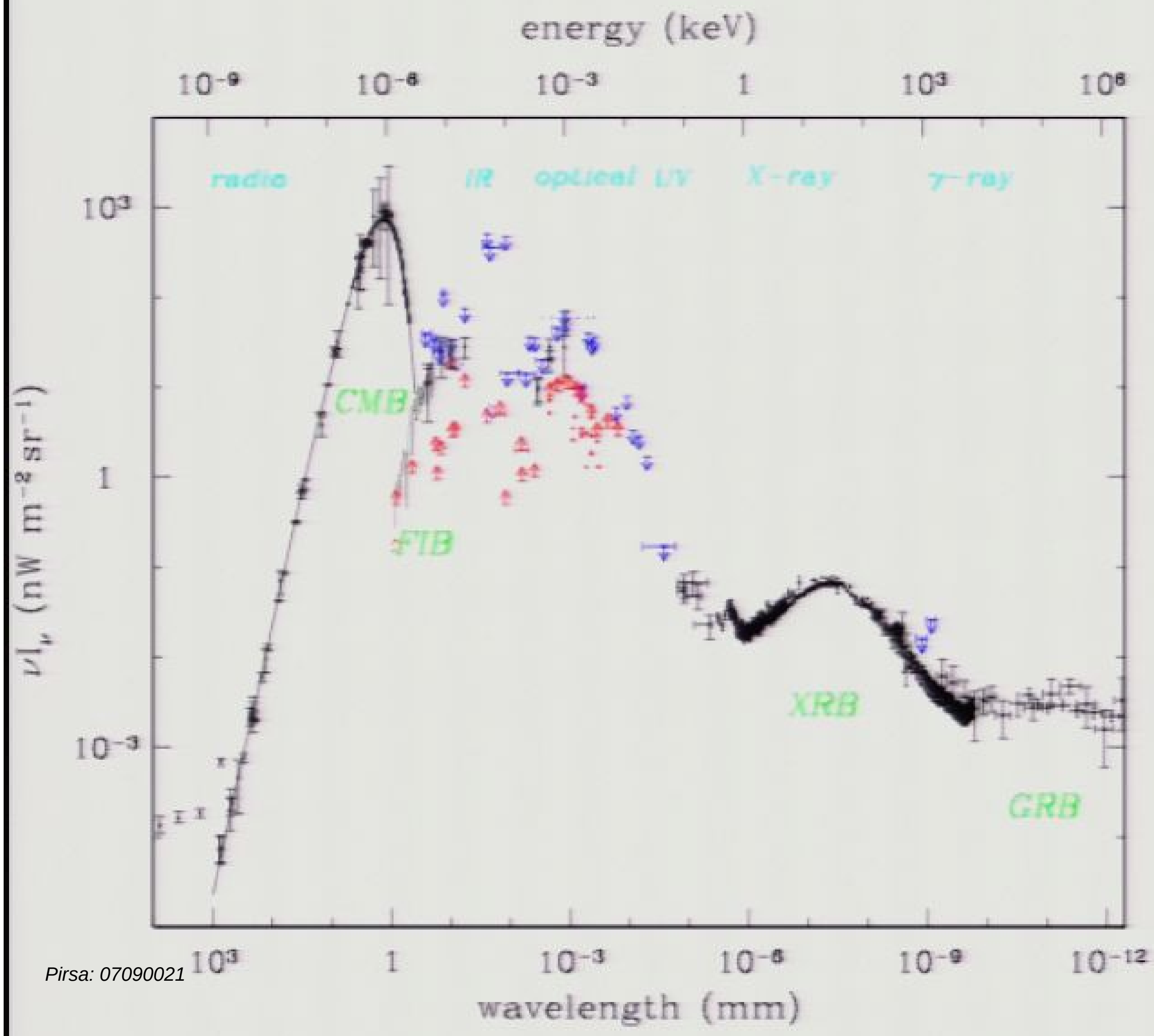


Photo: Mike Neimack



An image of Jupiter taken in drift scan with an 8x32 camera, taken before primary surface alignment, in fact taken before the ladder was removed from in front of the primary!

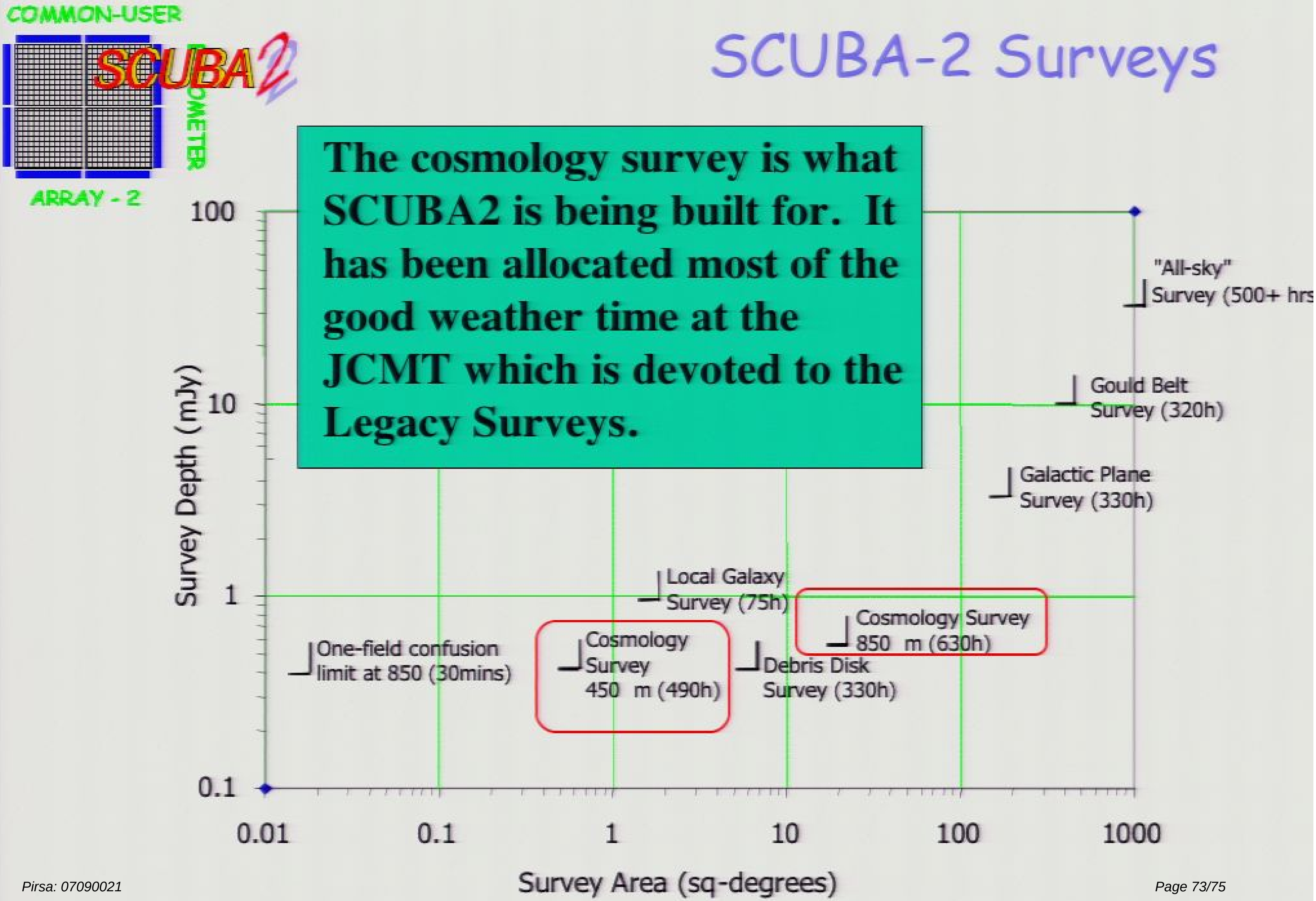
Point sources and SCUBA2

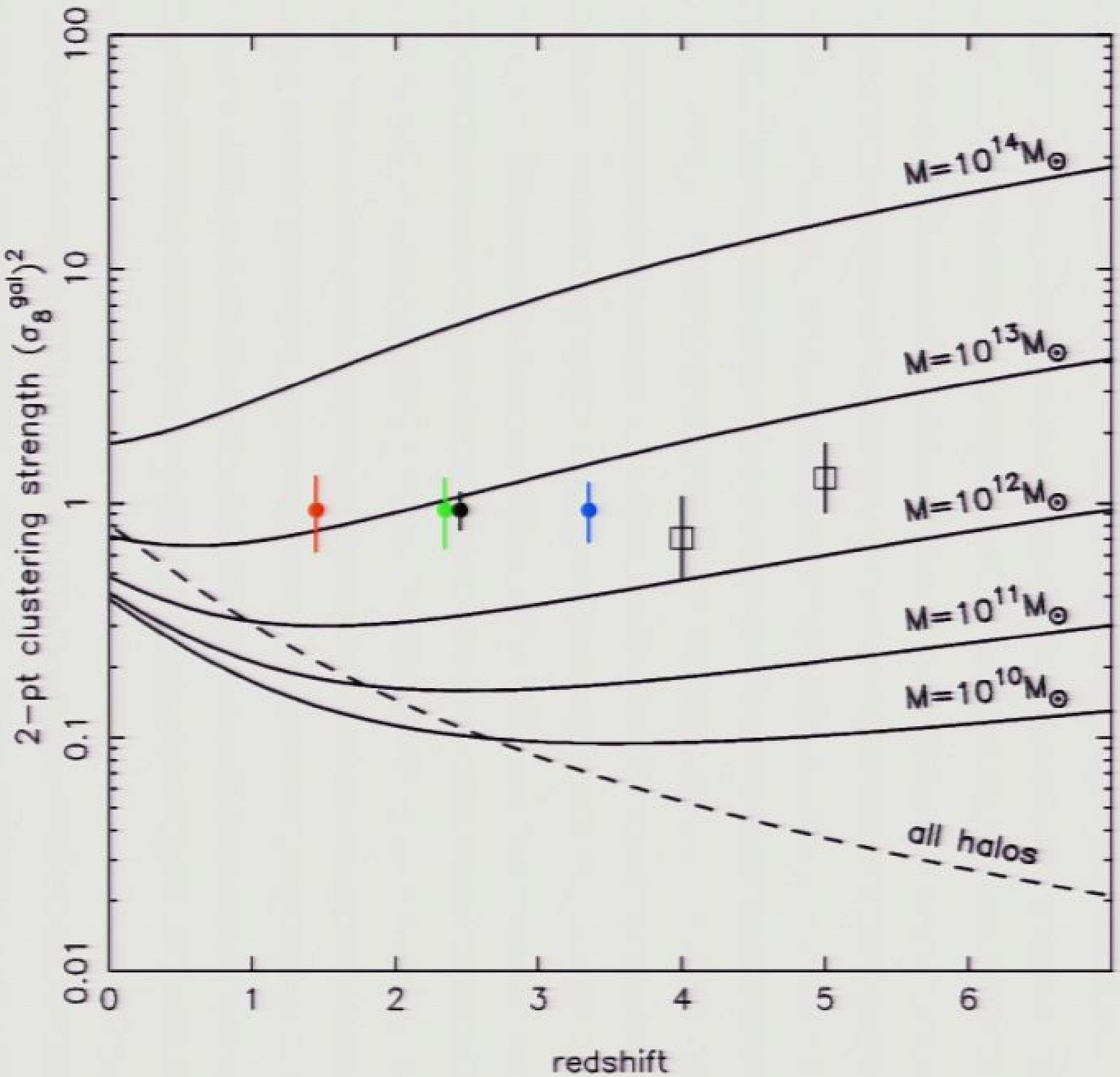


After the Cosmic Microwave Background, the far IR background (FIB) comprises a large fraction of the light in the universe.

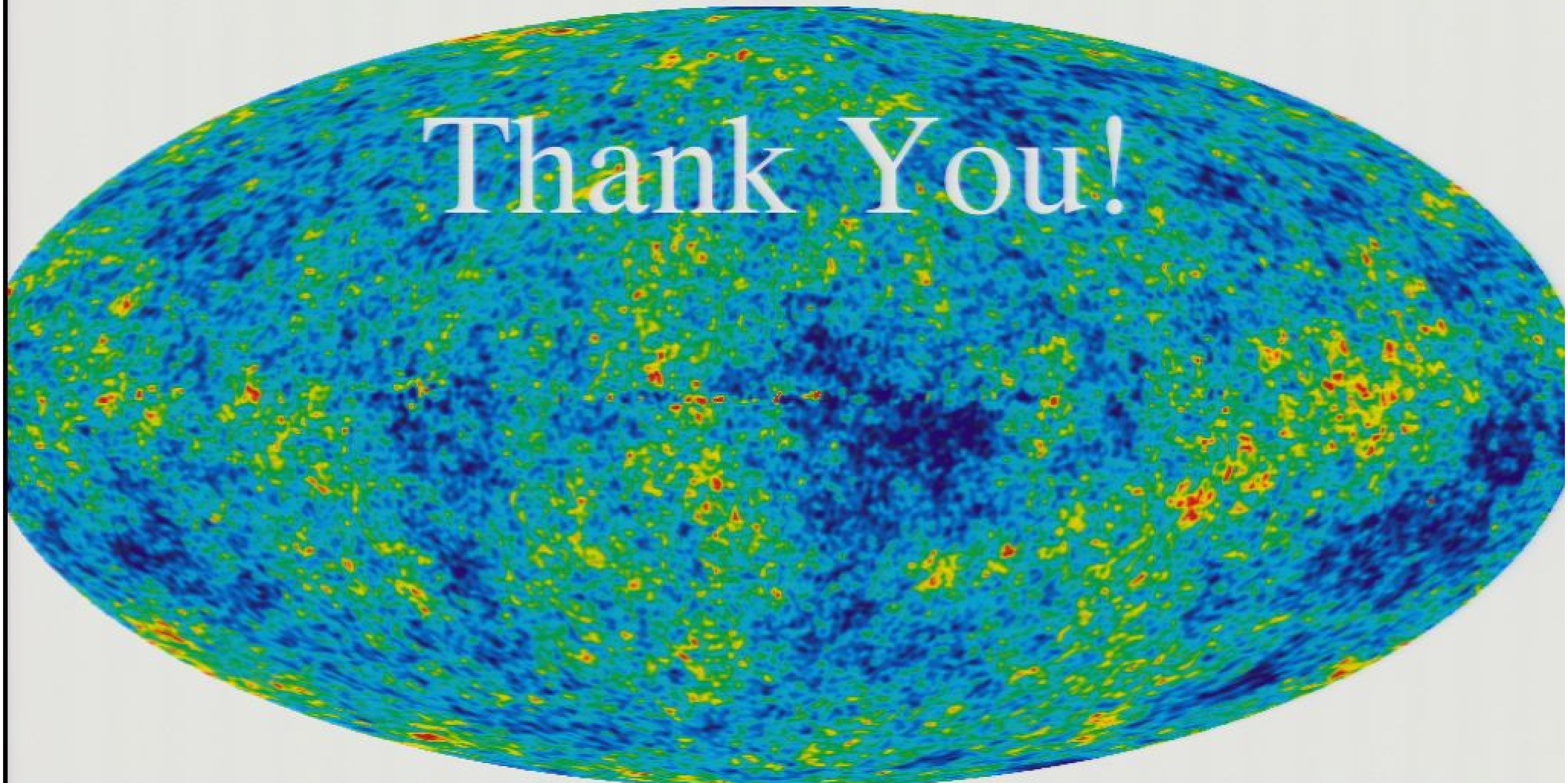
SCUBA-2 Surveys

The cosmology survey is what SCUBA2 is being built for. It has been allocated most of the good weather time at the JCMT which is devoted to the Legacy Surveys.





2−pt clustering strength $(\sigma_8^{gal})^2$
100
10
1
0.1
0.01
0
1
2
3
4
5
6
redshift
$M=10^{14}M_\odot$
$M=10^{13}M_\odot$
$M=10^{12}M_\odot$
$M=10^{11}M_\odot$
$M=10^{10}M_\odot$
all halos


Thank You!