Title: Cluster survey with the Atacama Cosmology Telescope

Date: Apr 28, 2009 04:00 PM

URL: http://www.pirsa.org/09040046

Abstract: In 2008, the Atacama Cosmology Telescope began its first full season observing a strip of the southern sky in three millimeter-wave bands. We present preliminary maps at 145 GHz featuring some SZ clusters.

The Atacama Cosmology Telescope: A Sunyaev-Zel'dovich Cluster Survey

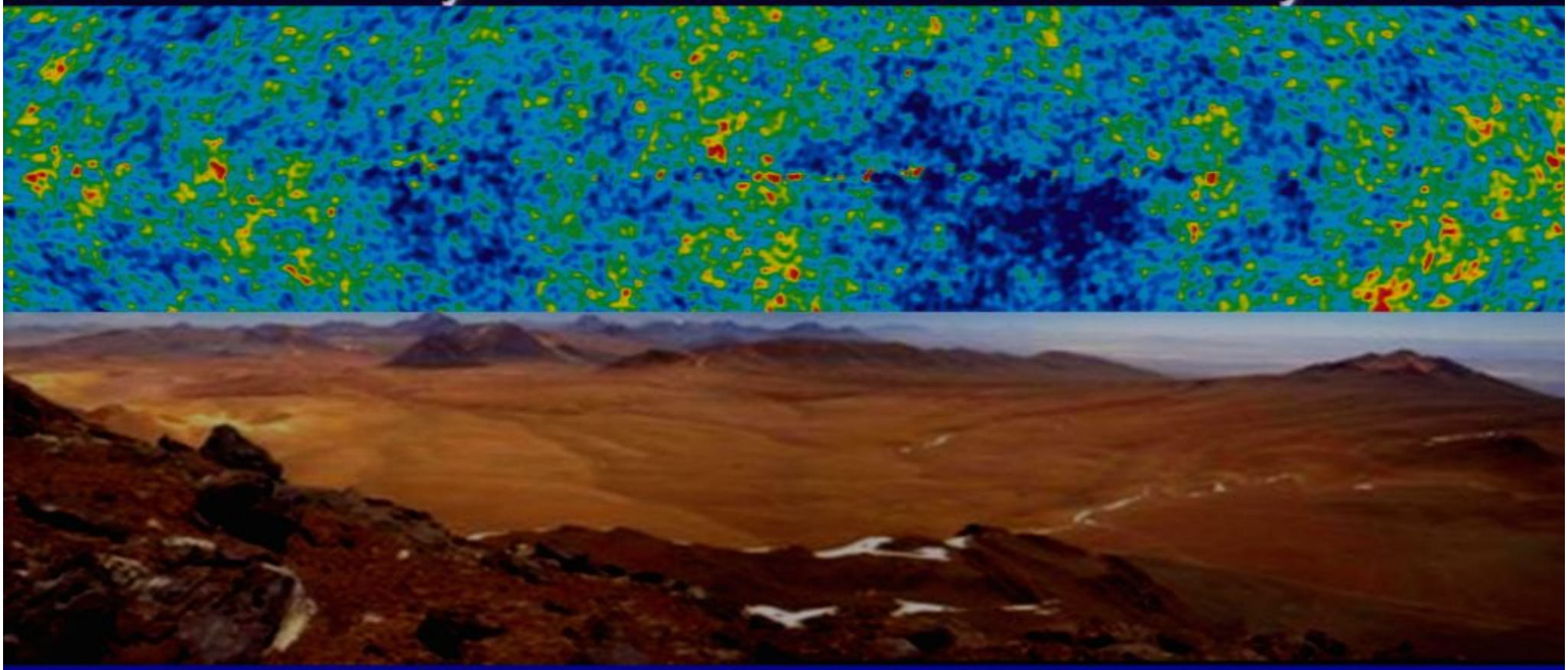
Report at the Perimeter Institute Meeting on Cluster Cosmology

Joe Fowler

Princeton University

April 28, 2009

The Atacama Cosmology Telescope: A Sunyaev-Zel'dovich Cluster Survey



Report at the Perimeter Institute Meeting on Cluster Cosmology

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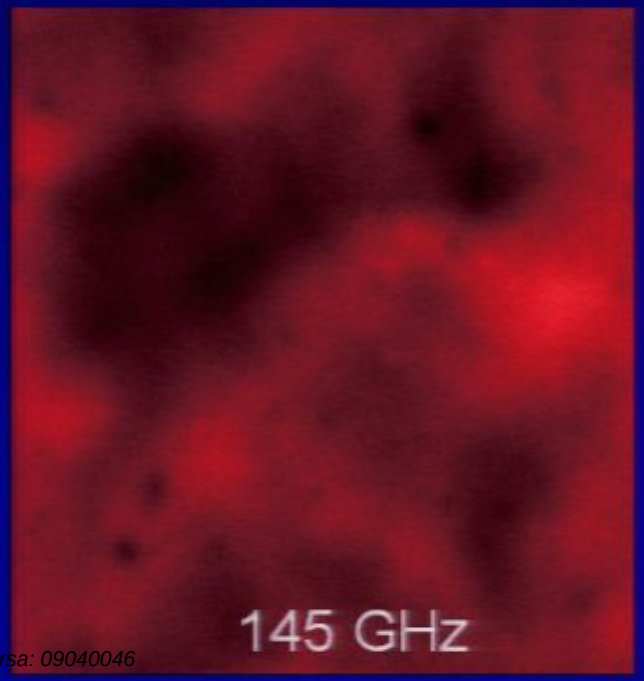
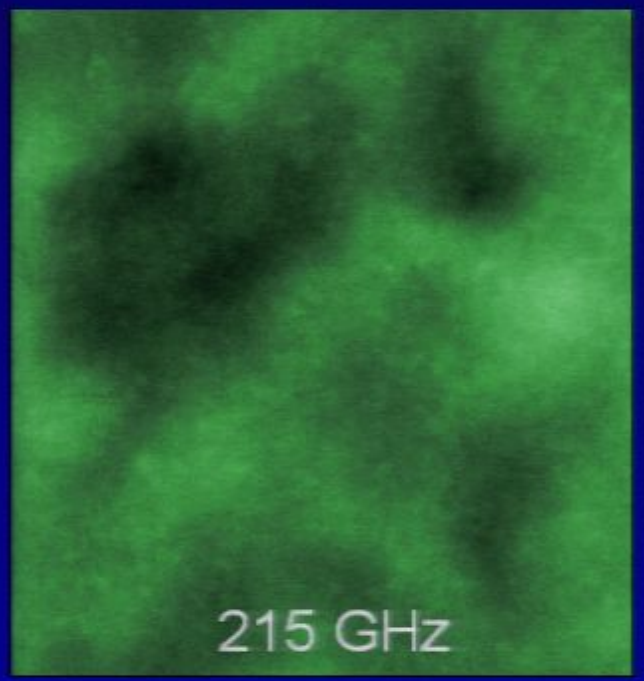
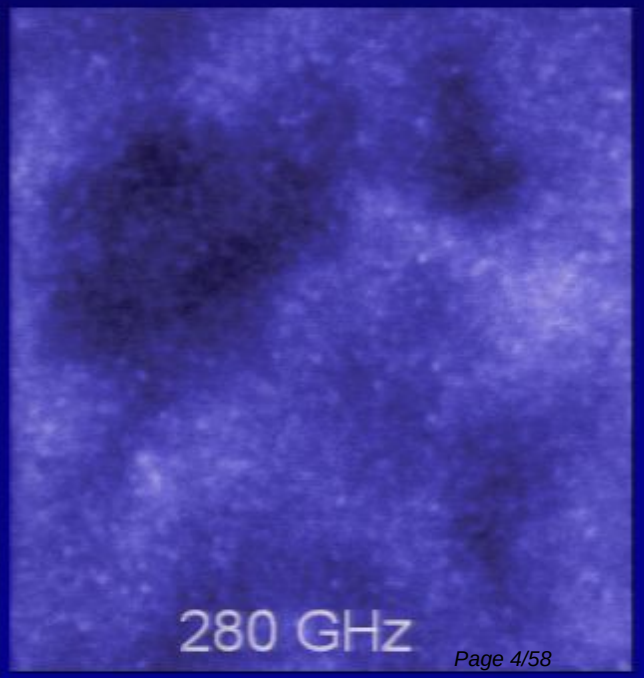
ACT Measurement goal: 3-color sky maps

- Goal: map ℓ>1000 CMB anisotropy in 3 bands (λ = 1-2 mm)
- Survey for S-Z clusters
- Follow clusters in optical & X-ray
- Measure the primary TT power spectrum of the CMB

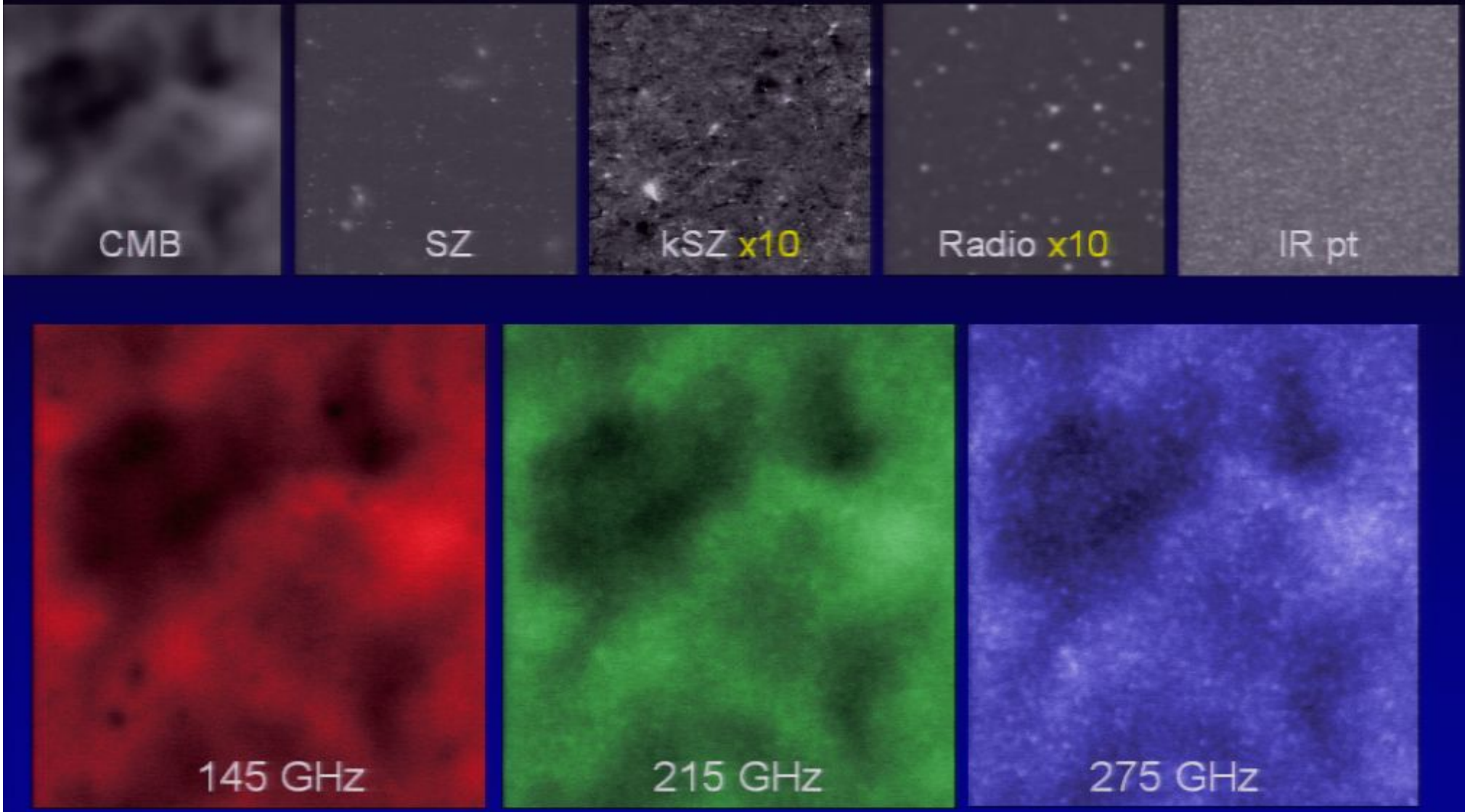
Today: 145 GHz data exclusively







The millimeter-wave sky



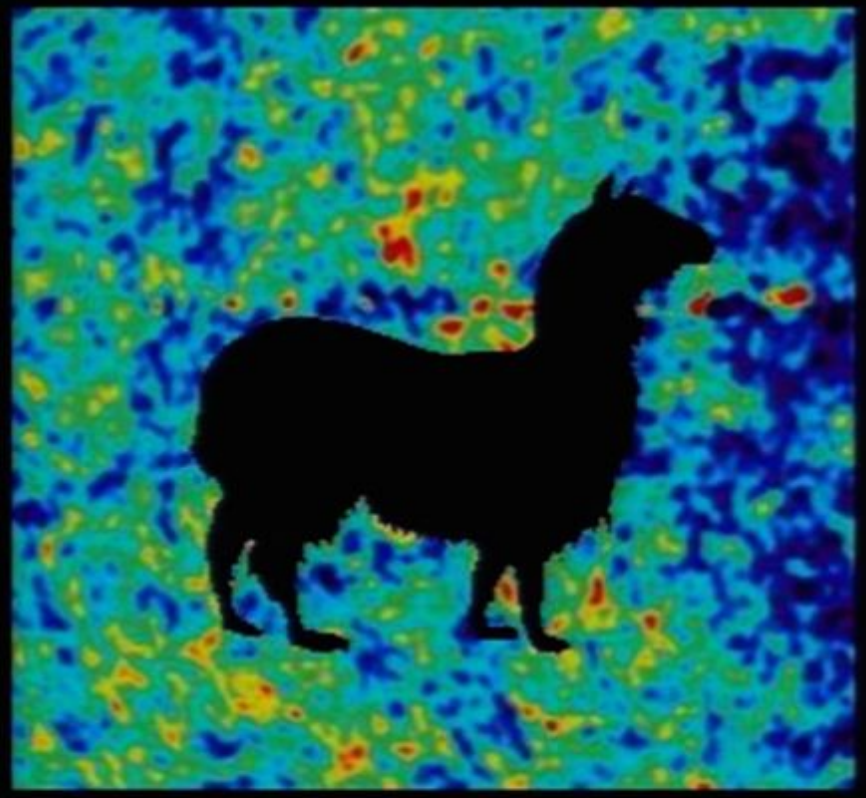
Simulations : Huffenberger, Seghal & Seljak

Atacama Cosmology Telescope Team

ACT with Unfinished Ground Screen

D. Swetz at the site with ACT Receiver

- Cardiff University (UK)
- Columbia University (USA)
- Haverford College (USA)
- INAOE (Mexico)
- LLNL (USA)
- NASA/GSFC (USA)
- NASA/JPL (USA)
- NIST (USA)
- Pontificia Universidad Católica (Chile)
- Princeton University (USA)
- Rutgers University (USA)
- University of British Columbia (Canada)
- University of Cape Town (South Africa)
- University of KwaZulu-Natal (South Africa)
- University of Massachusetts Amherst (USA)
- University of Pennsylvania (USA)
- University of Pittsburgh (USA)
- University of Toronto (Canada)

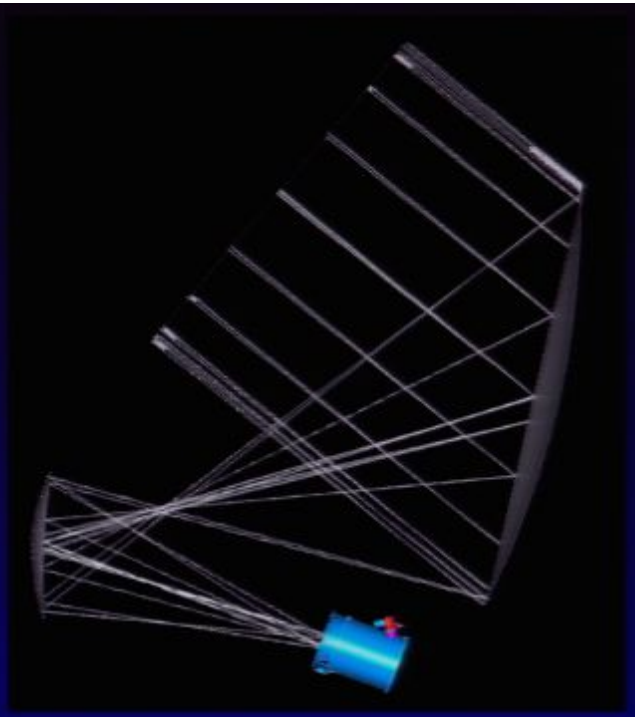


ACT

Atacama Site

5200 meters near peak of Cerro Toco,
in the Atacama Desert in the Andes of Northern Chile

23º south latitude.

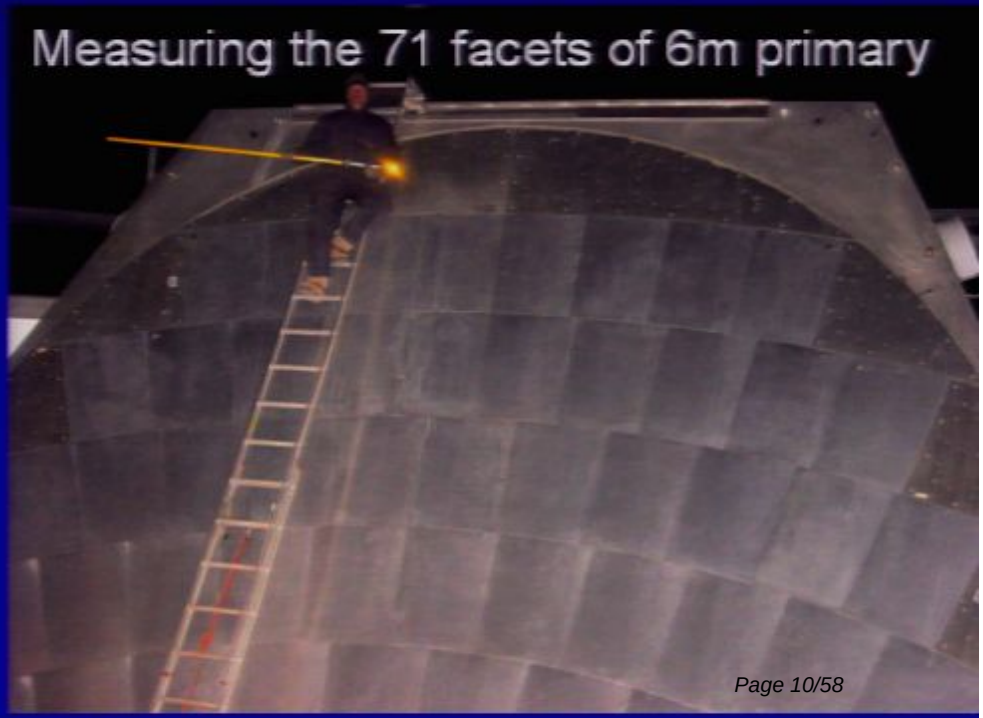


ACT: Telescope & camera

Some constraints:

- Diffraction-limited beams
- 25' fields of view (x3)
- Clear aperture
- 6-meter off-axis primary
- 2-meter secondary
- Fast / compact system

Roughly an aplanatic Gregorian.



Millimeter Bolometric Array Camera (MBAC) internals

Cylindrical, aligned along optical axis

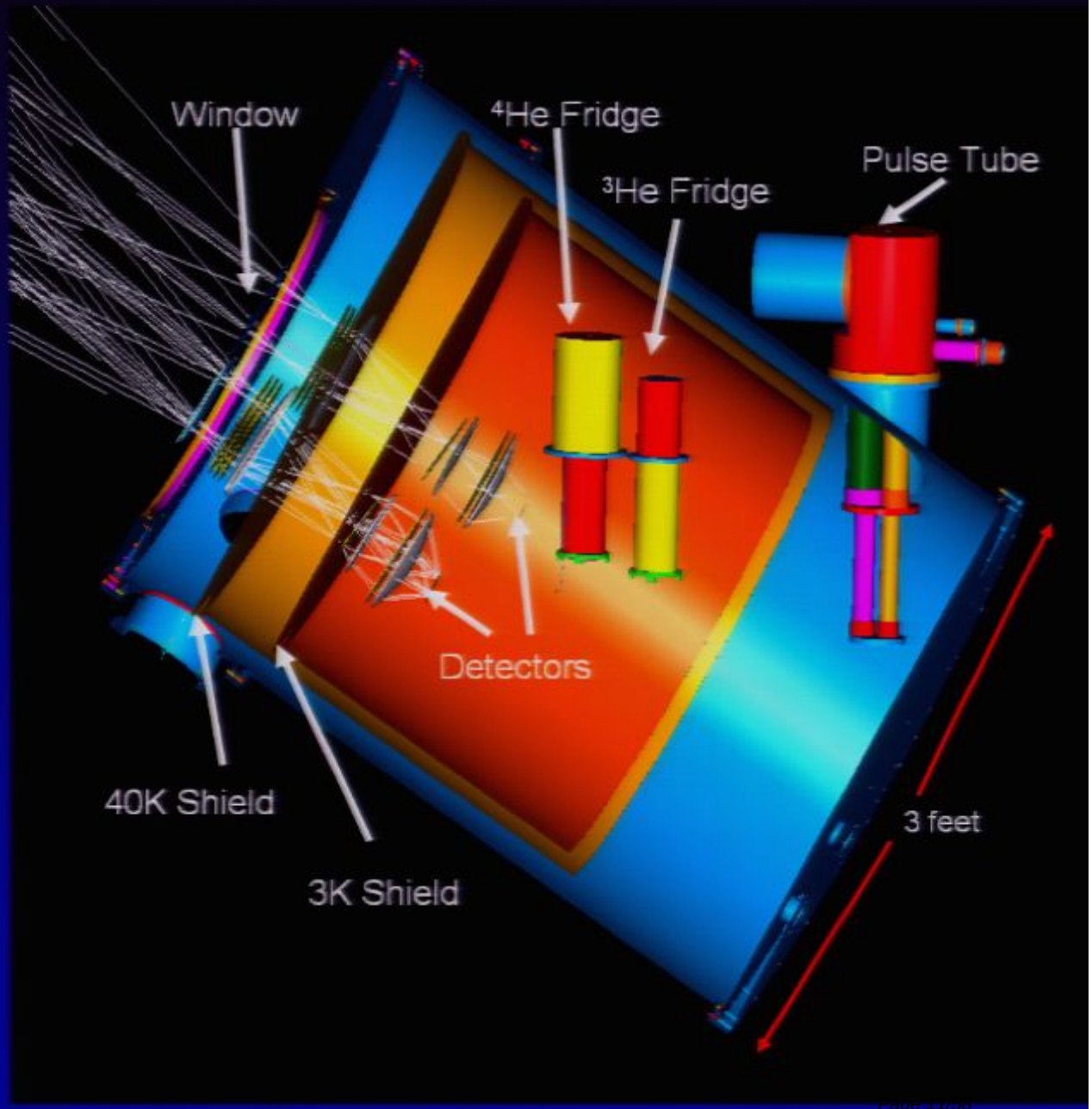
Free of liquid cryogens

Pulse Tube Coolers
- 1st stage: 30W @ 40K
- 2nd stage: 0.2W @ 3K

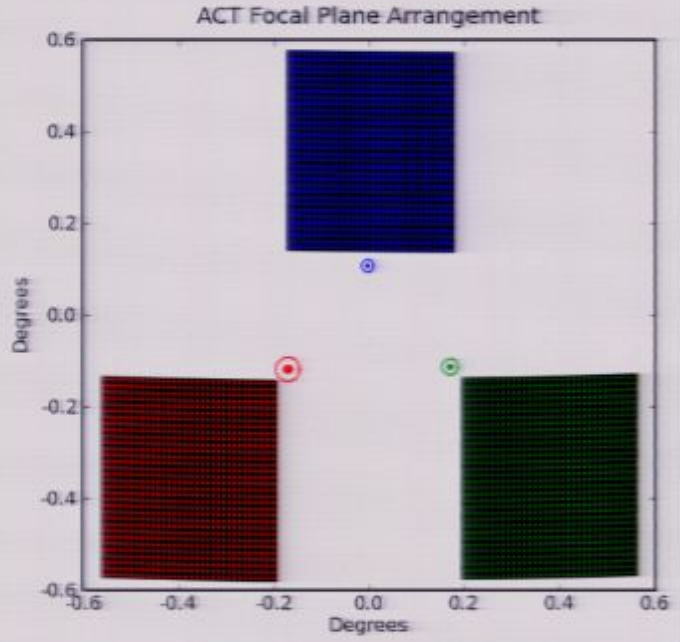
^{4}He+^{3}He sorption fridges
- 270 mK
- 14-hour site hold time

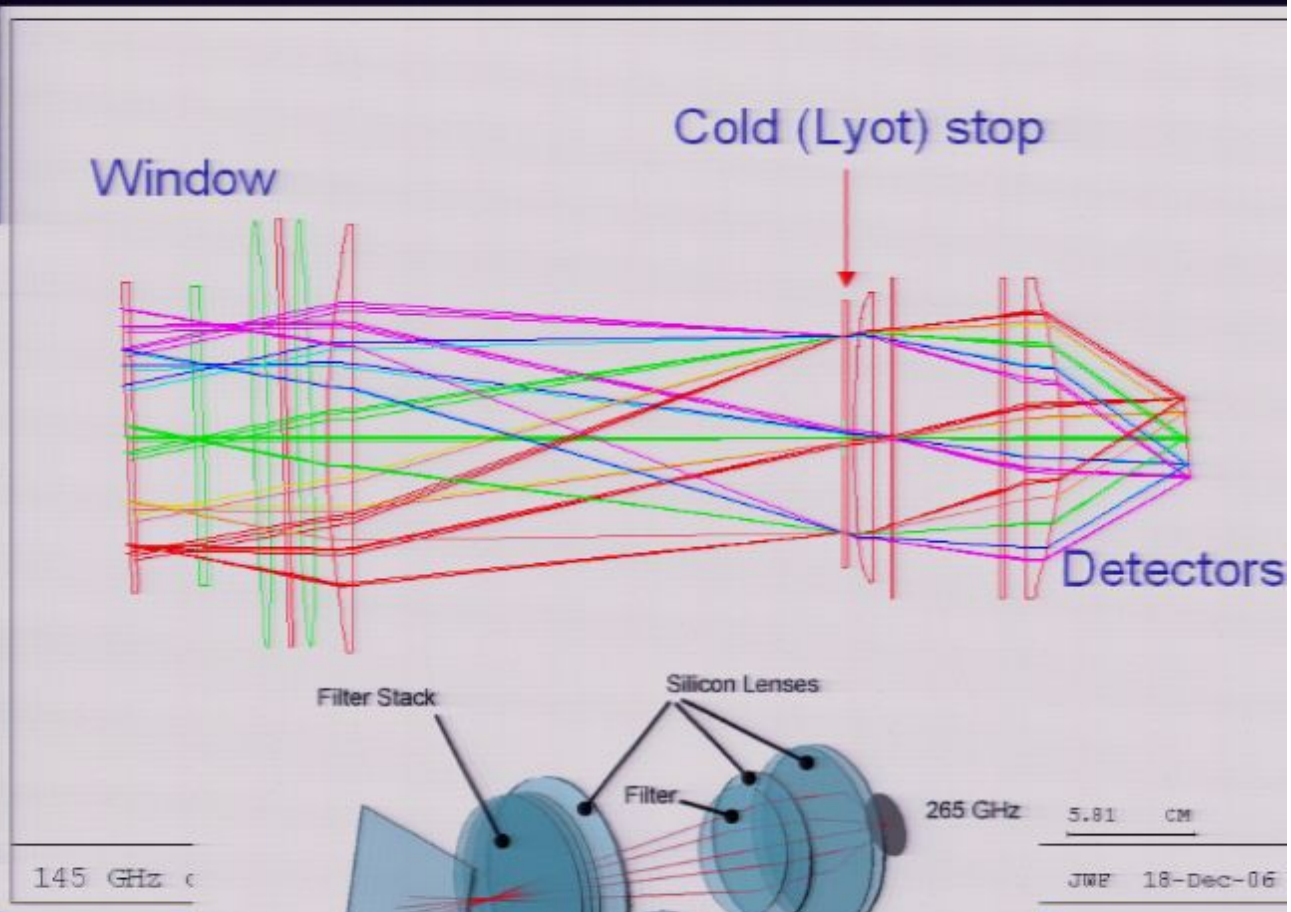
Cold silicon lenses reimage sky

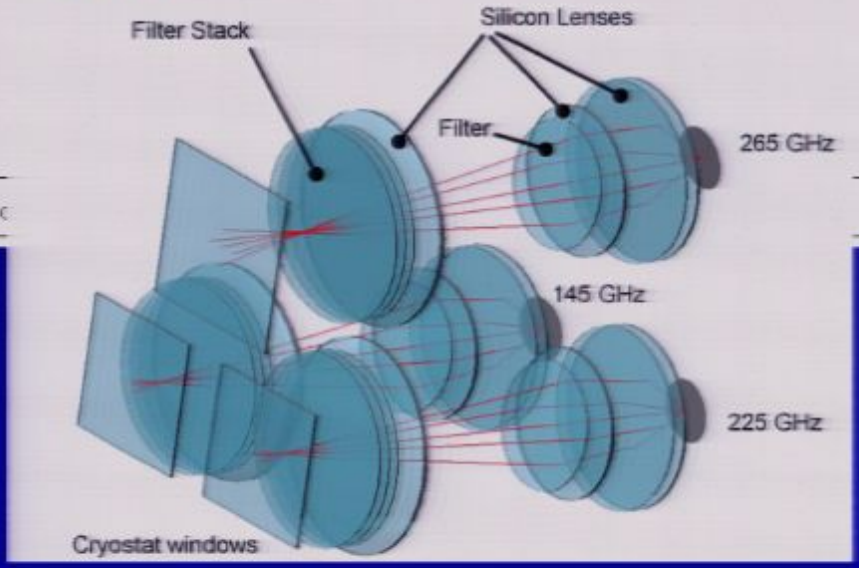
145, 215, 280 GHz filters (Cardiff)



Cold optics

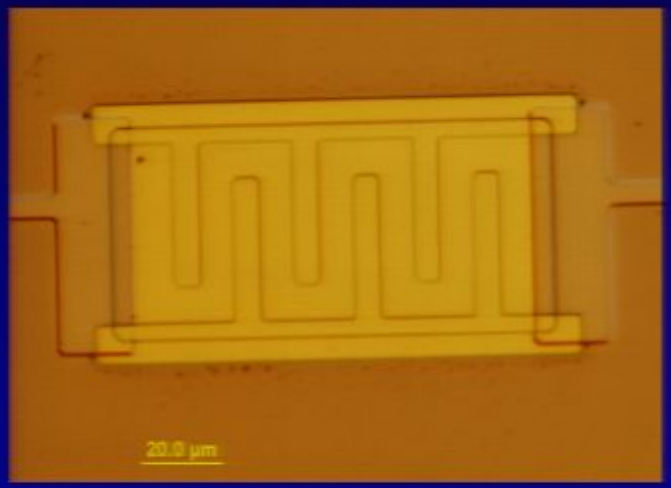

ACT Focal Plane Arrangement
Degrees
Degrees
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6


Window
Cold (Lyot) stop
Detectors
145 GHz
5.81 CM
JWF 18-Dec-06


Filter Stack
Silicon Lenses
Filter
265 GHz
145 GHz
225 GHz
Cryostat windows

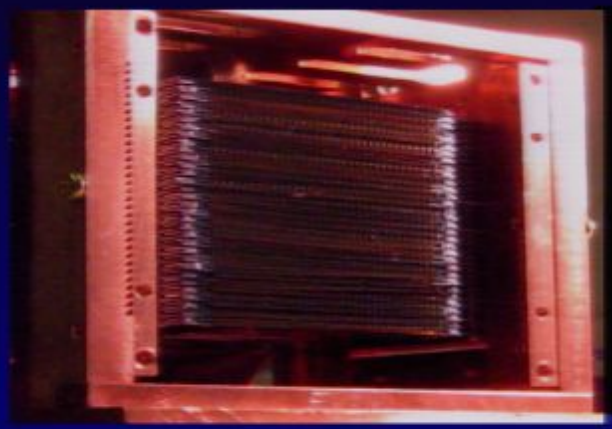
TES Bolometers (NASA/Goddard)

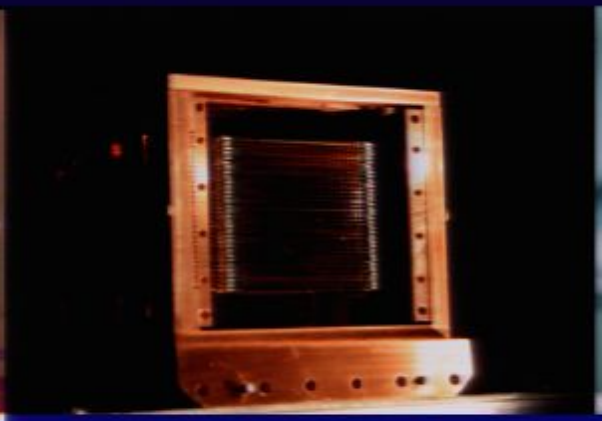
- 1 mm square absorber (silicon with implant).
- No feed horns.
- Pop-up geometry; build focal plane one "column" at a time (32 x 32)
- Transition edge sensor (TES) held on transition at T_c=0.45 K.

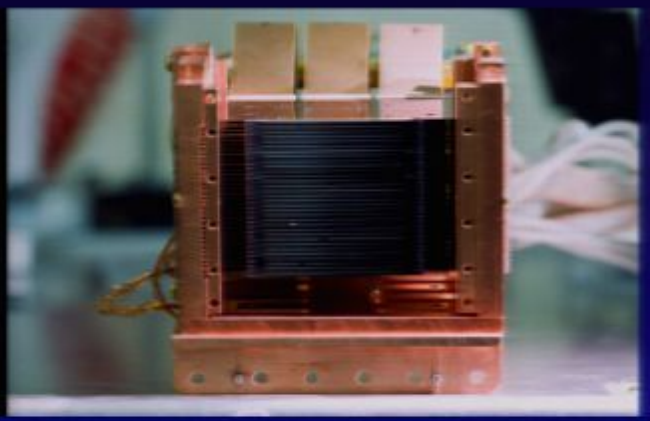


Assembled arrays (3072 detectors)

2007: 1000 x 150 GHz
2008: 1000 x (150 & 220 & 280 GHz)

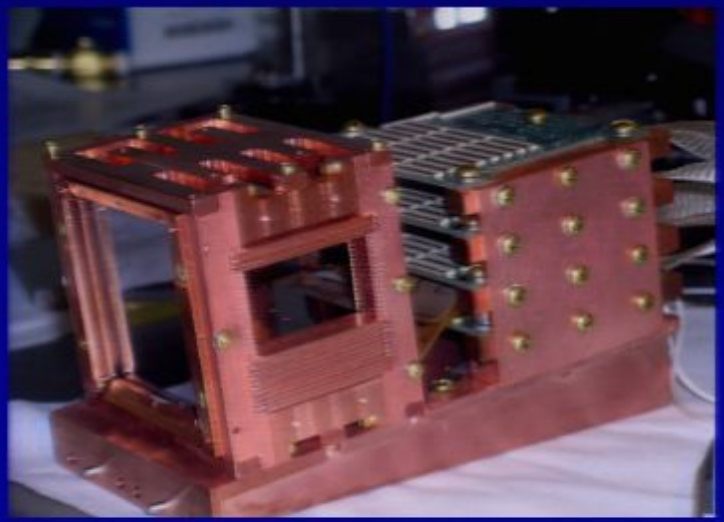


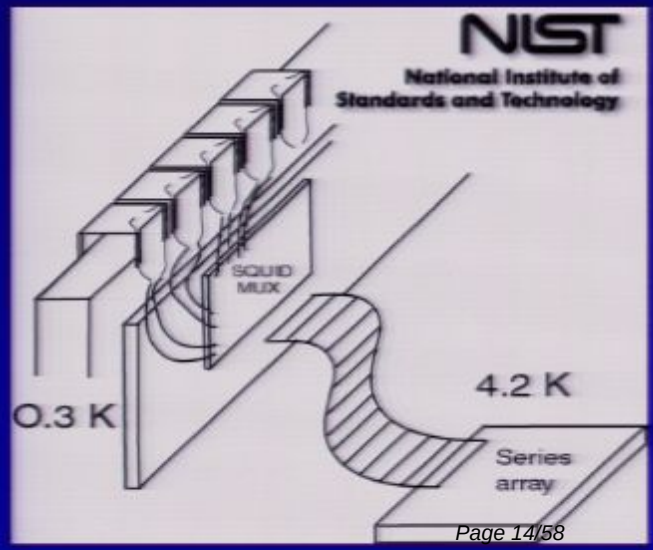




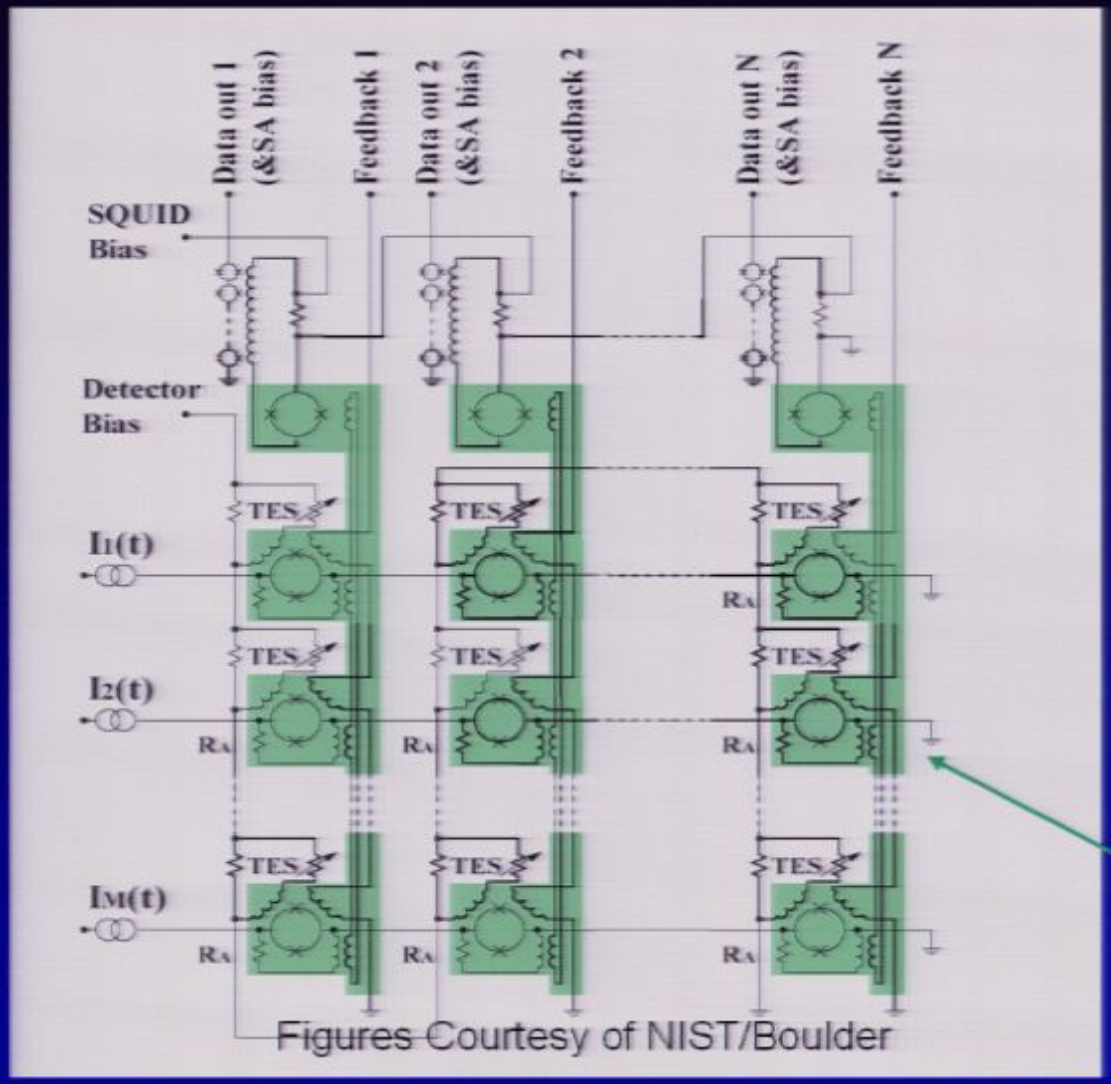
150 GHz **220 GHz** **280 GHz**

High-ρ silicon "coupling layer" is mounted some ~50 μm above absorbers.





Time-domain SQUID-muxed readout (NIST)



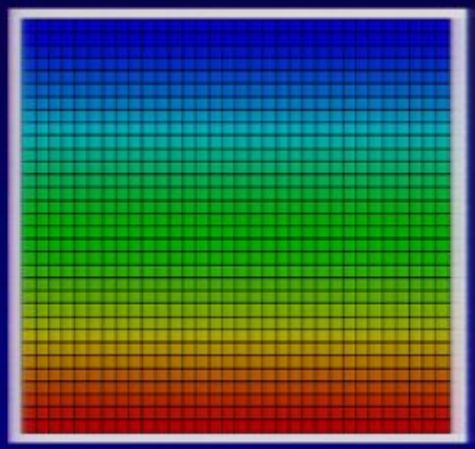
Figures Courtesy of NIST/Boulder

- Feed 1st SQUID output current into a 2nd SQUID many-to-one.
- Turn on only one of the many at a time
- 2 μs on, 64 μs off.
- Cycle the 33 inputs before L/R time.
- UBC readout electronics.

Green parts =
One MUX chip
per TES column.

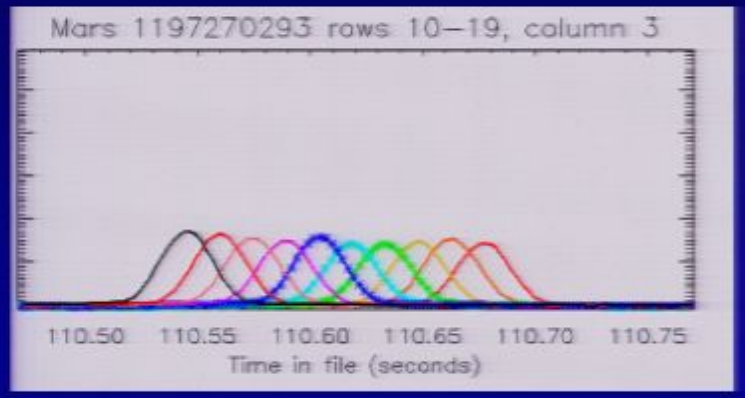
Cross-linked observing

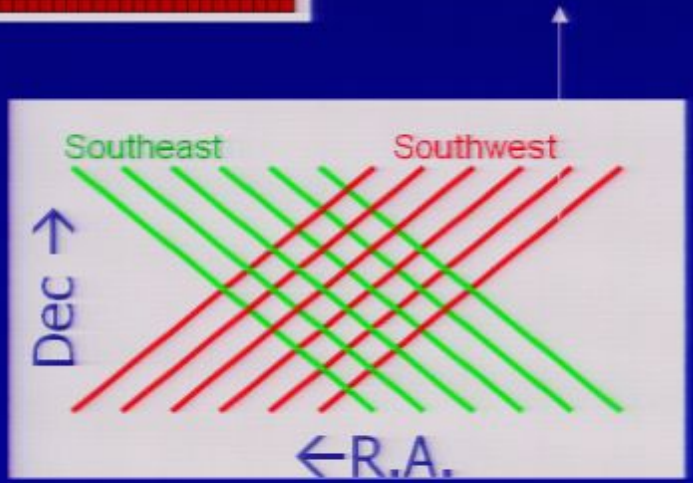
Observe [20:00-09:30 local] =
- Scan ~6° range each 8 sec
- Southeast before mid-night
- Southwest afterwards
- 10 minutes for a planet most nights



Atmosphere causes gradient on the sky ~60-100 mK
(slant depth is 1% bigger at bottom of the field).

ACT approach: Scan at constant elevation





Each spot observed in 2 distinct stripes:
before and after meridian crossing

The raw data set

- The data are the stage1 SQUID feedback values, causally filtered by a DSP to prevent aliasing above f_{Nyq}=200 Hz.

- 3 arrays * (32x32 detectors) * (400 Hz samples) * (4 bytes each) → 19 GB raw data per hour! (6 GB with lossless compression)
- Over 2 TB per month for a single copy of raw data.
- Transport method: HDOA

- Not a lot of good ways to "reduce" the data, short of making maps.

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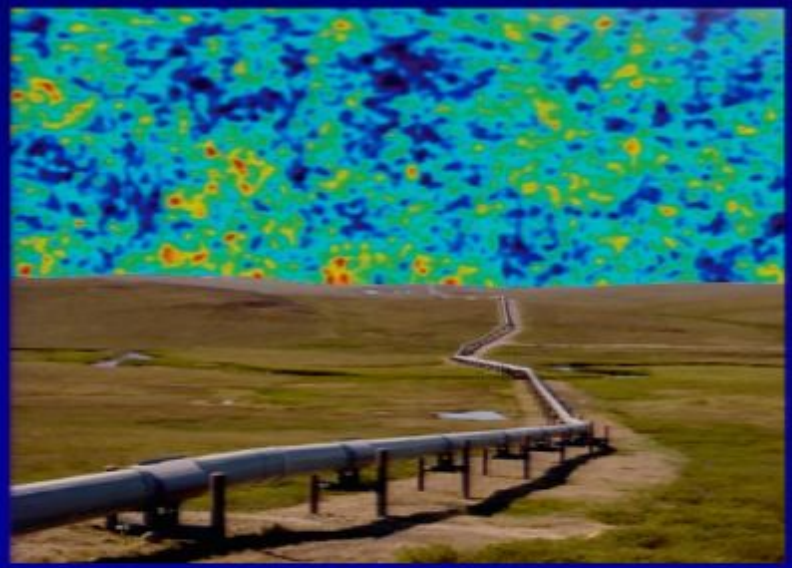
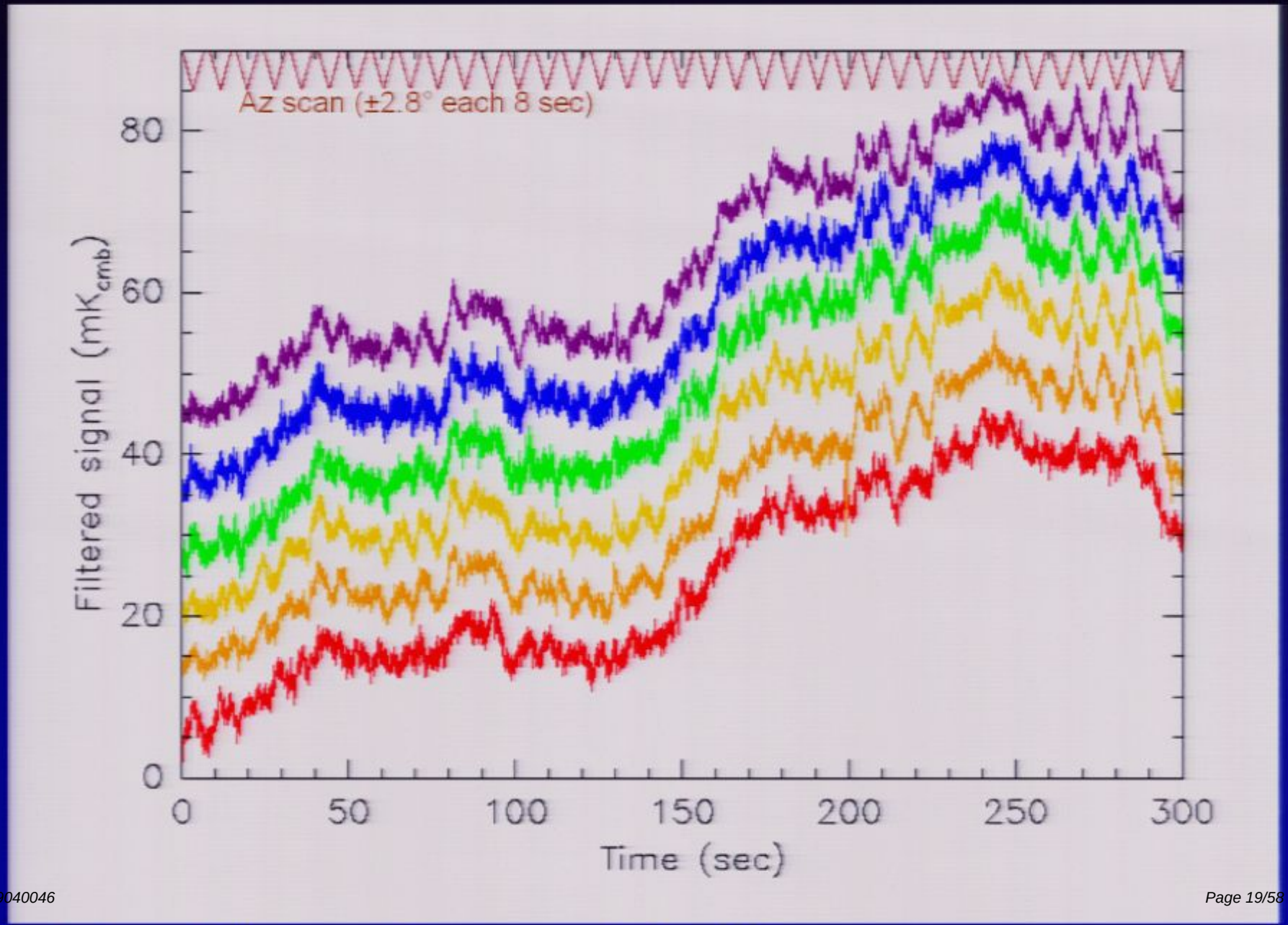
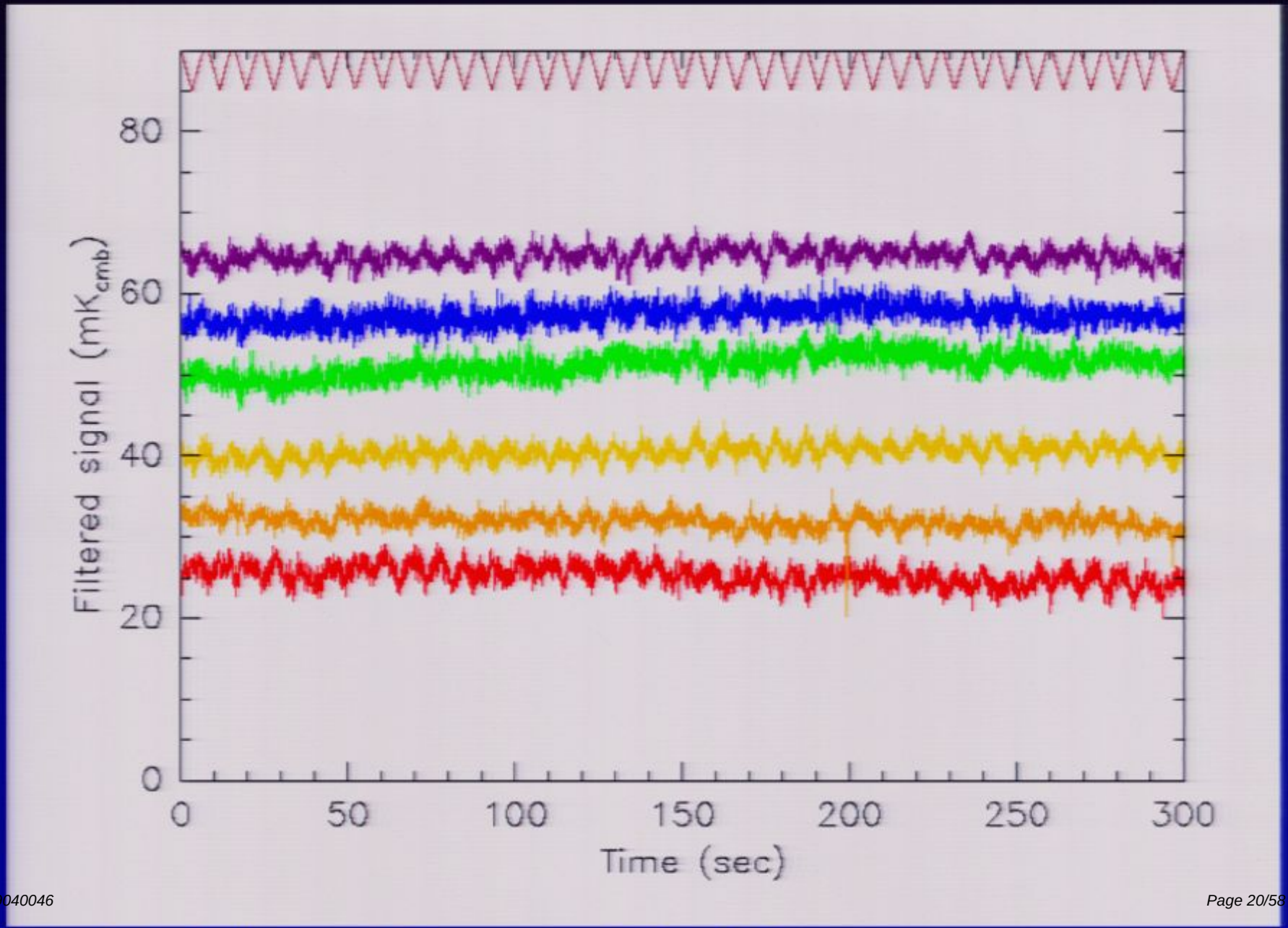


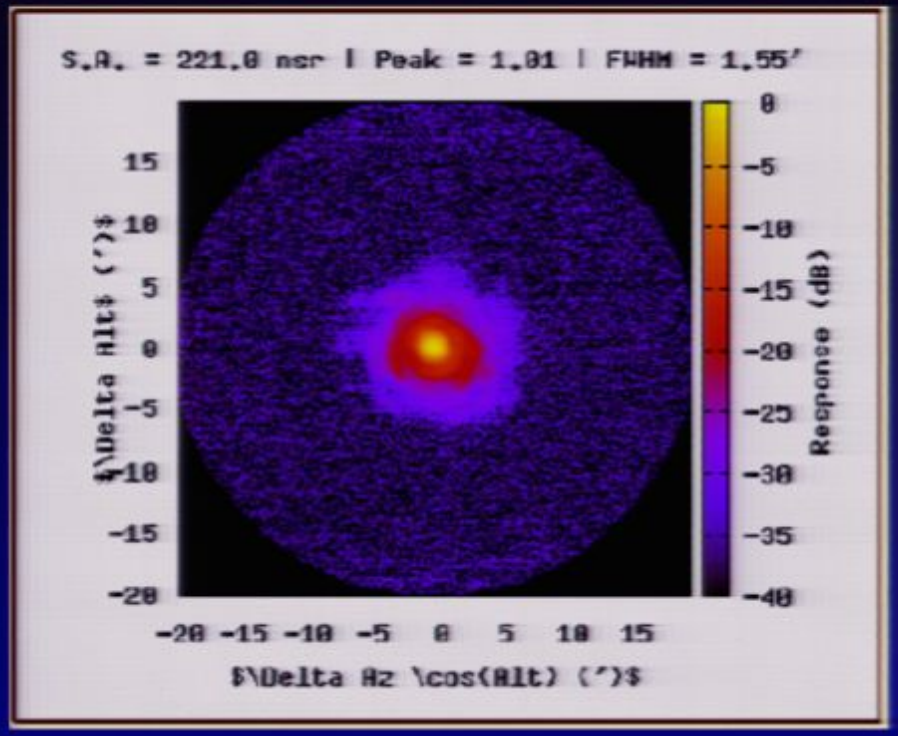
6 detectors, 5 minutes



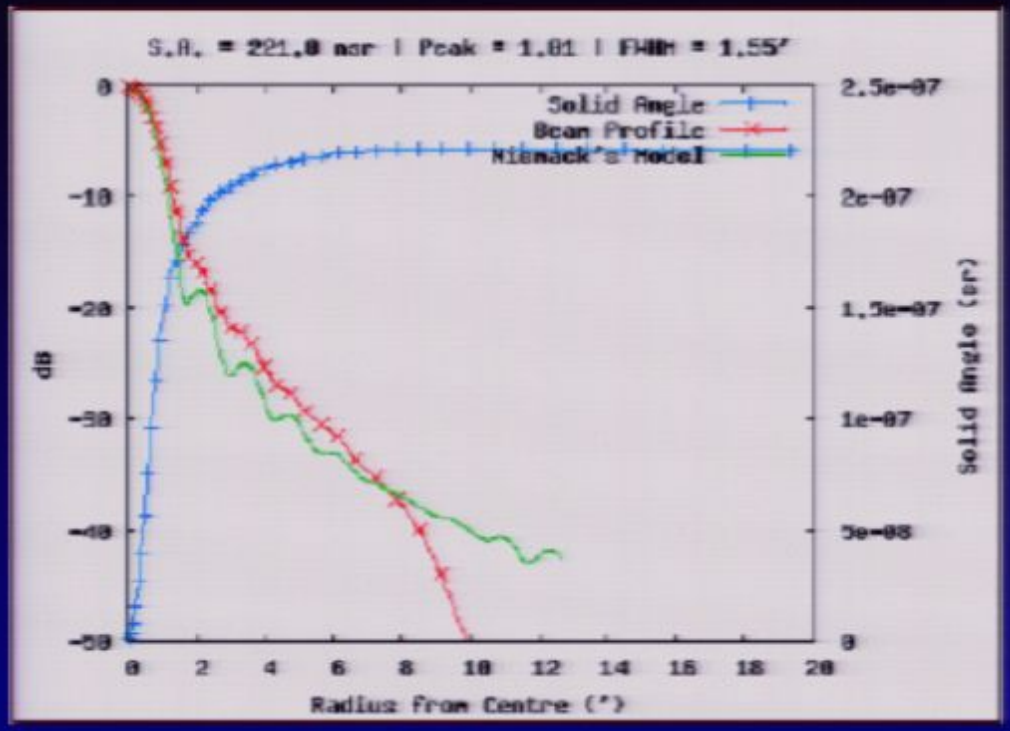
Same detectors, "common-mode" removed



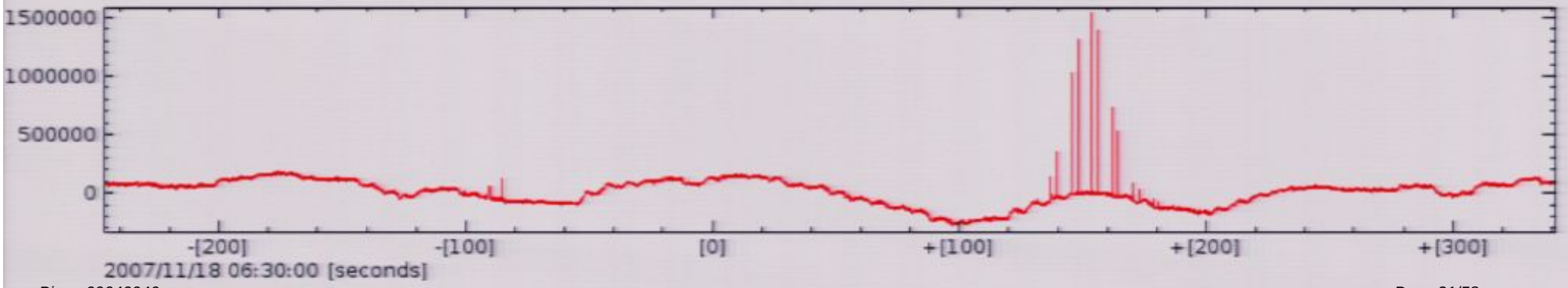
Planets: beam / PSF (preliminary)



One 6-minute stare at Saturn



Az-avg beam profile (red), model (green)



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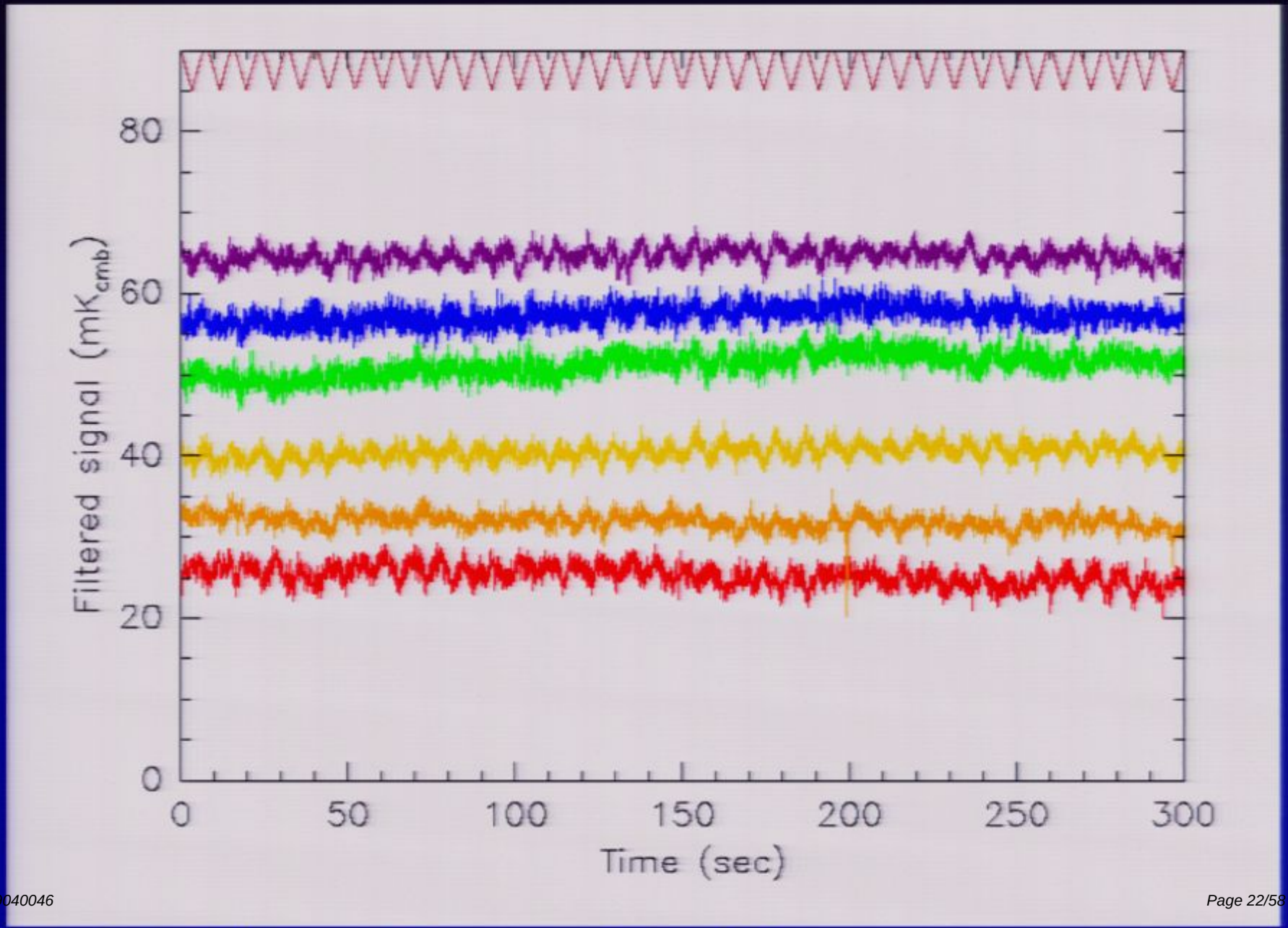

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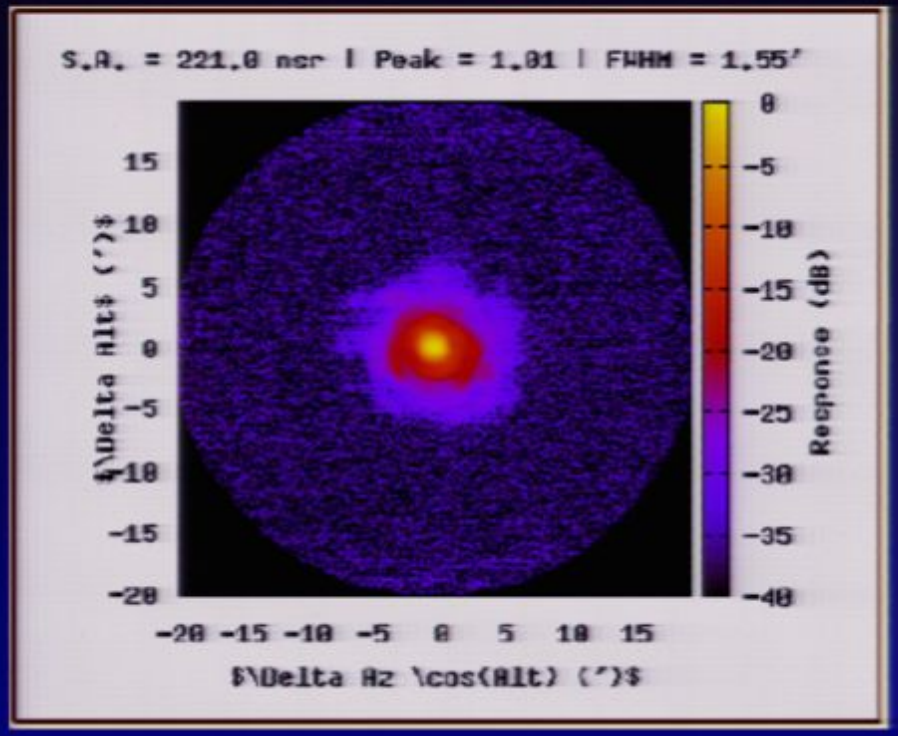

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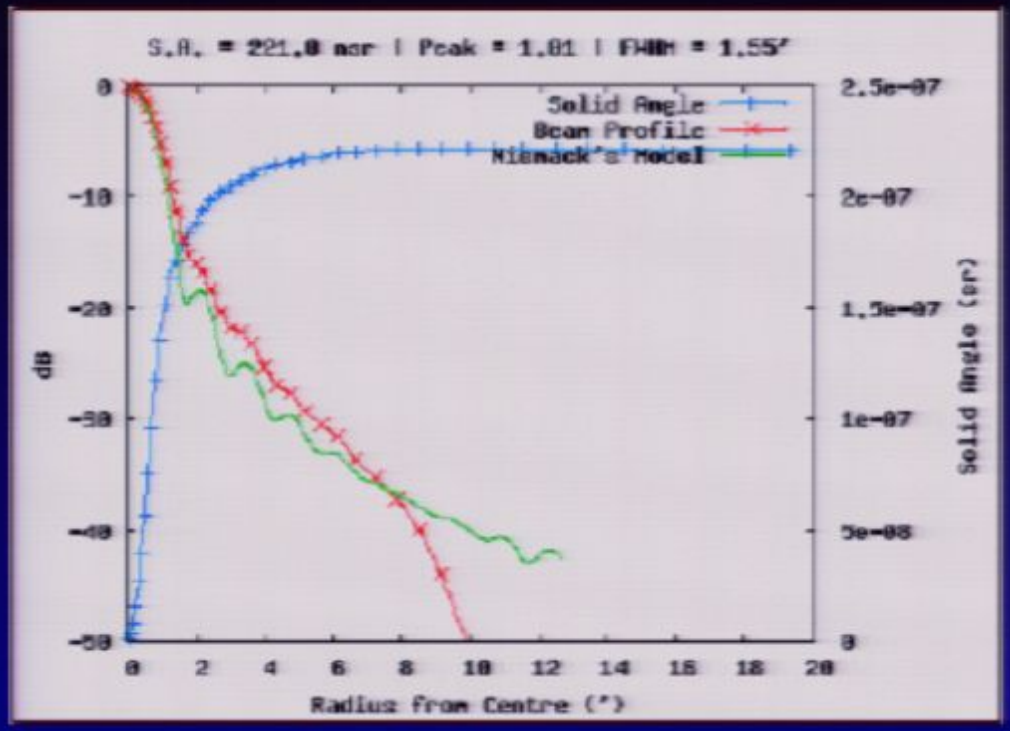

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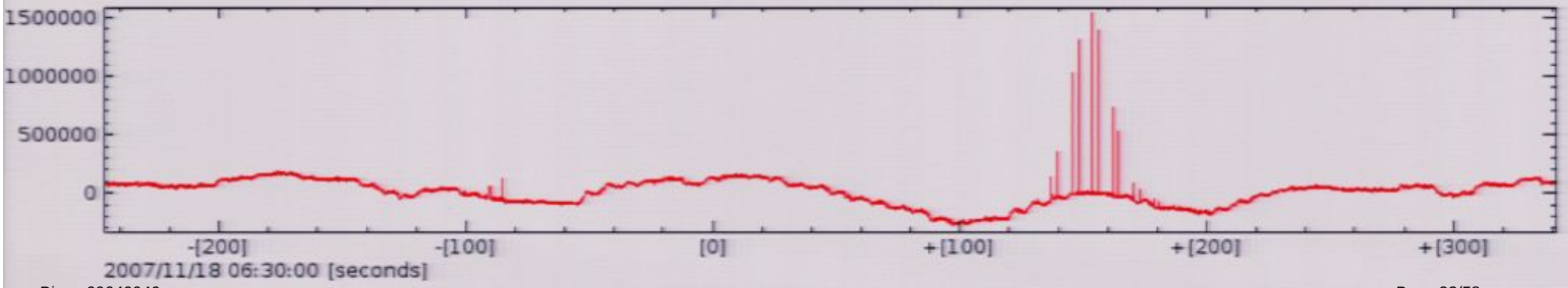


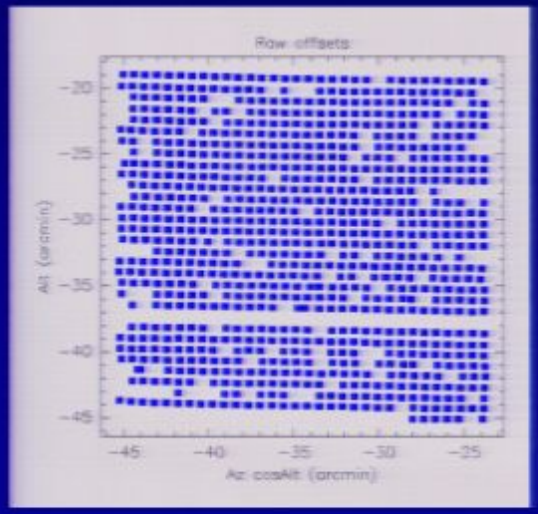
Elements of ACT calibration

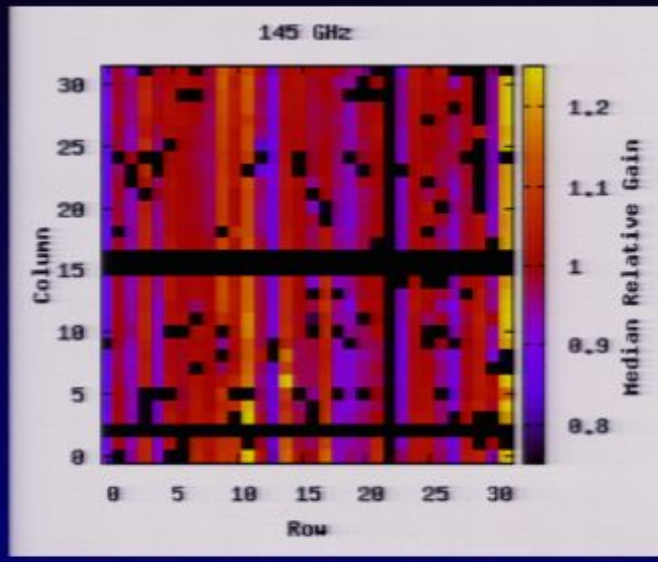
Gain:

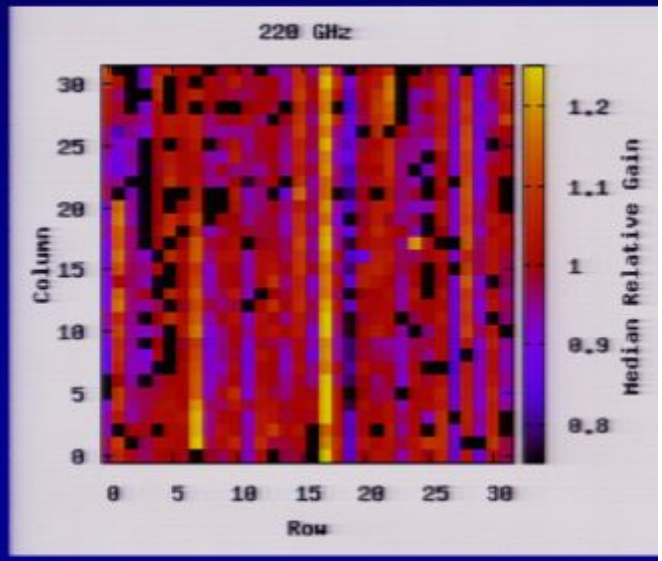
- Flat field = response to atmosphere
- Time variation = TES modeling + opacity (APEX)
- Cross-check with internal pulsed source
- Absolute = response to Uranus (Saturn agrees to 2%)

Pointing:

- Focal plane arrangement: Planets
- Global pointing model: Radio point sources in CMB fields





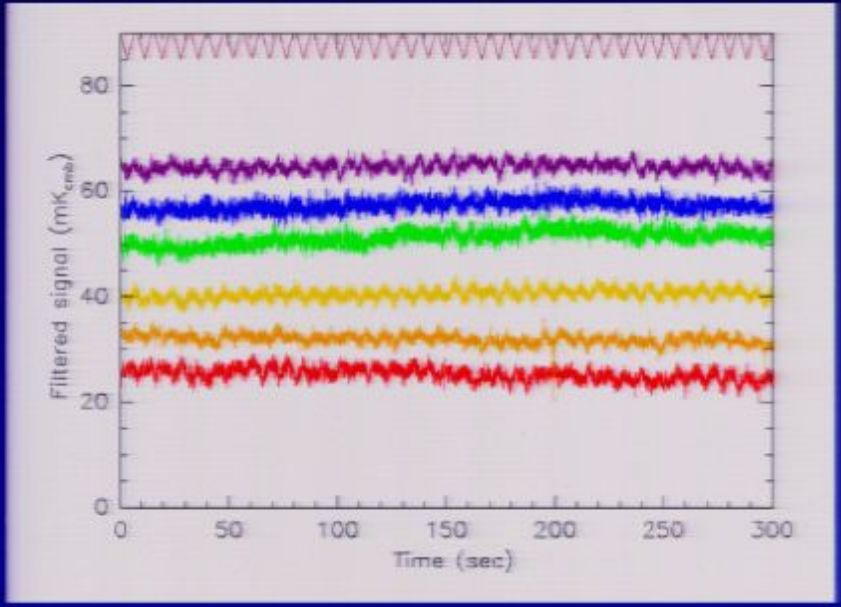


Sample flat-field result (4 nights)

2007-08 camera performance

- 600-800 working detectors per array (~500 in 280 GHz camera)
- Sensitivity: ~700 μK_{CMB} $\sqrt{s}$ per 150 GHz detector.
- Drift ("1/*f* noise"): below 0.2 to 3 Hz (predominantly atmosphere)

- 1600 hours total [cut / equator / south]



Nov-Dec 2007: 35 nights, 1 array

Aug-Dec 2008: 140 nights, 3 arrays

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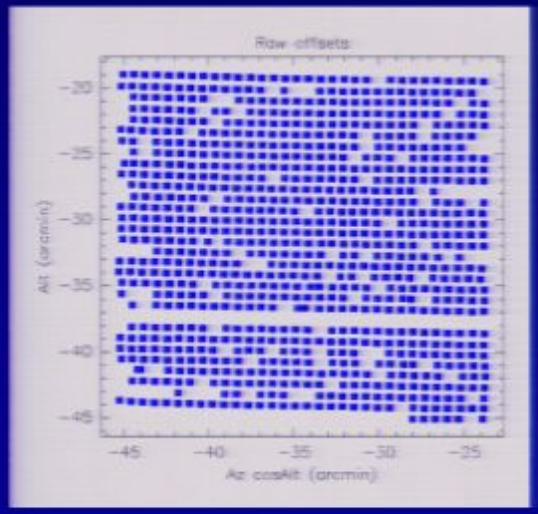

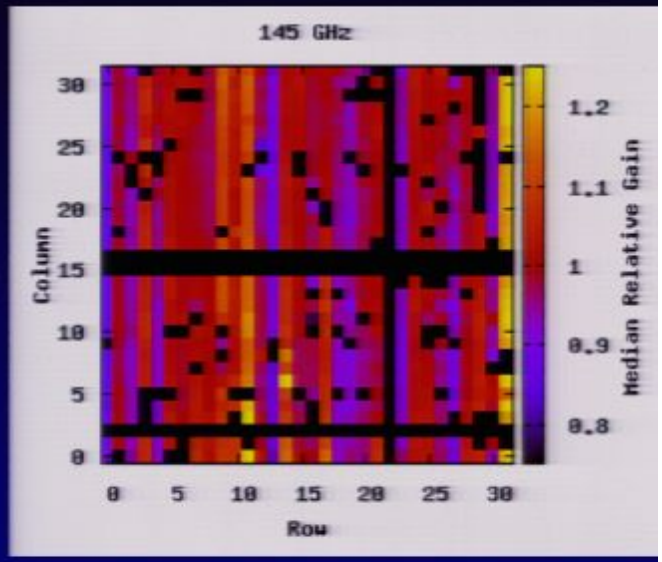

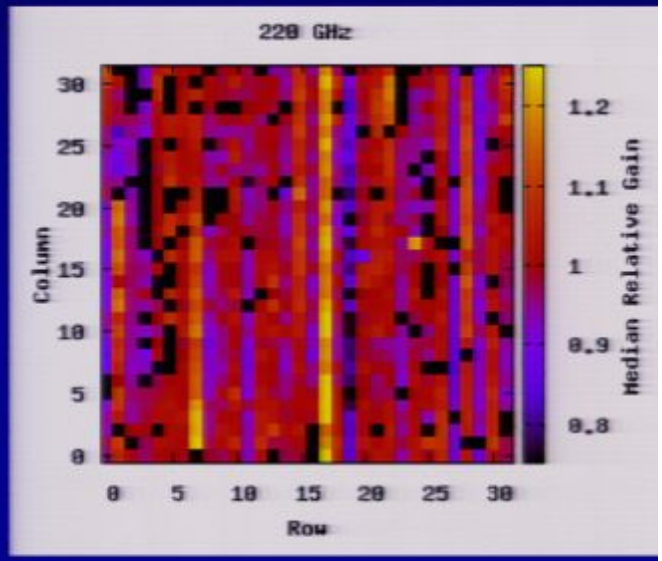

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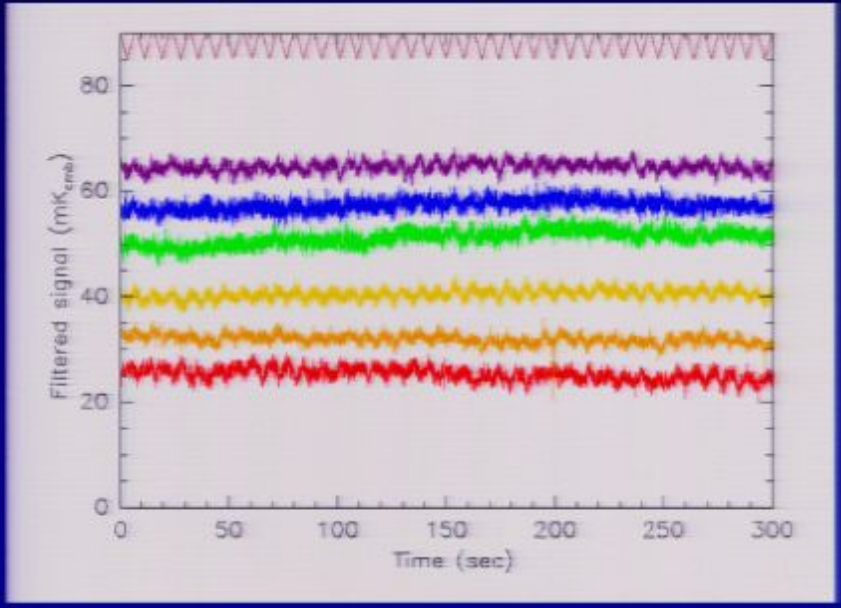

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ACT approach to the mapmaking problem

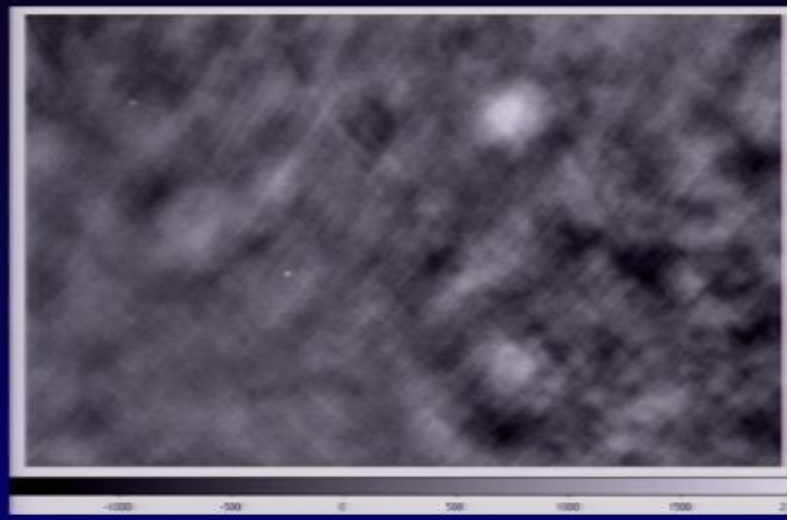
- Our goal: converge to a maximum likelihood map.

Mapmaking equation:

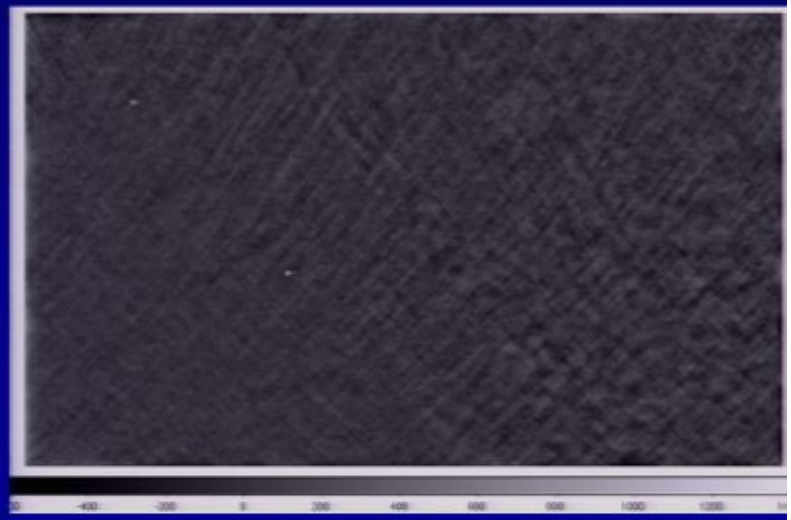
$$A^T N^{-1} A\, m = A^T N^{-1} d$$

- Accounts for arbitrary (known) noise covariance in data.
- Analogous to using weighted means in place of straight.
- Solution is just linear algebra, but involves $(10^9 \times 10^9)^{-1}$ per hour of observing.

How to approximate *m* without losing information?

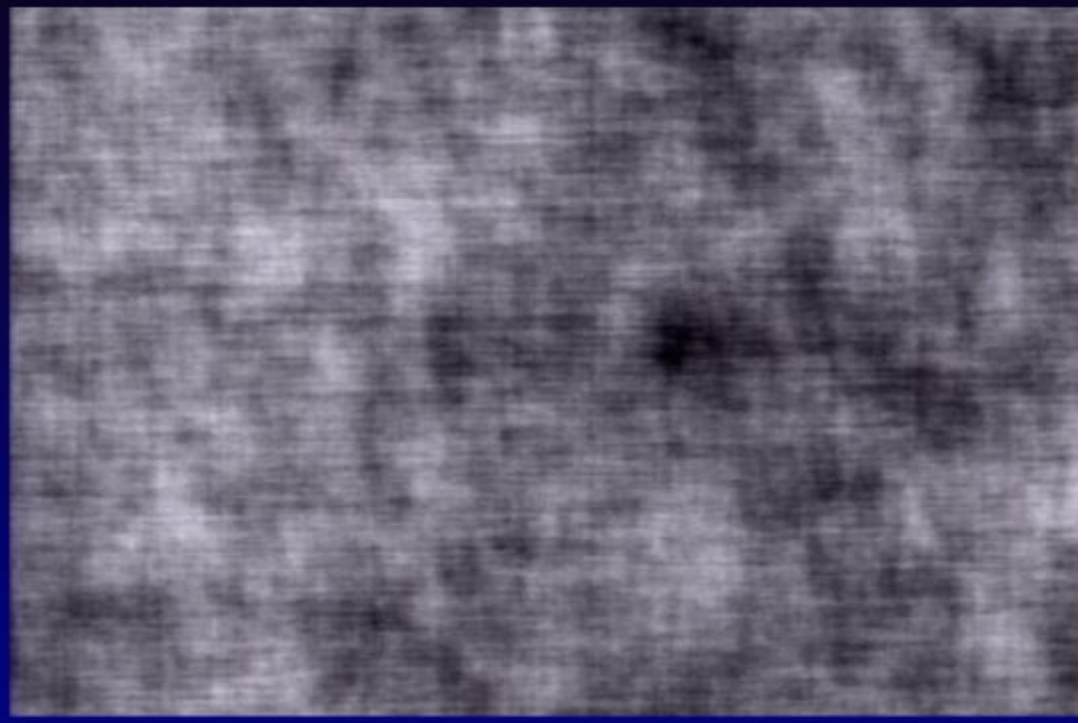


(SIM) Made map, then filtered (high-pass) at 6'



- Separate analysis for small clusters images.
- High-pass filter each detector at 0.5 Hz.
- Find noisy modes (common mode+others).
- Recover low-ℓ sky modes iteratively.
- *k*-space noise-weighting for cross-linked maps.

The one map + power spectrum that my group will let me show



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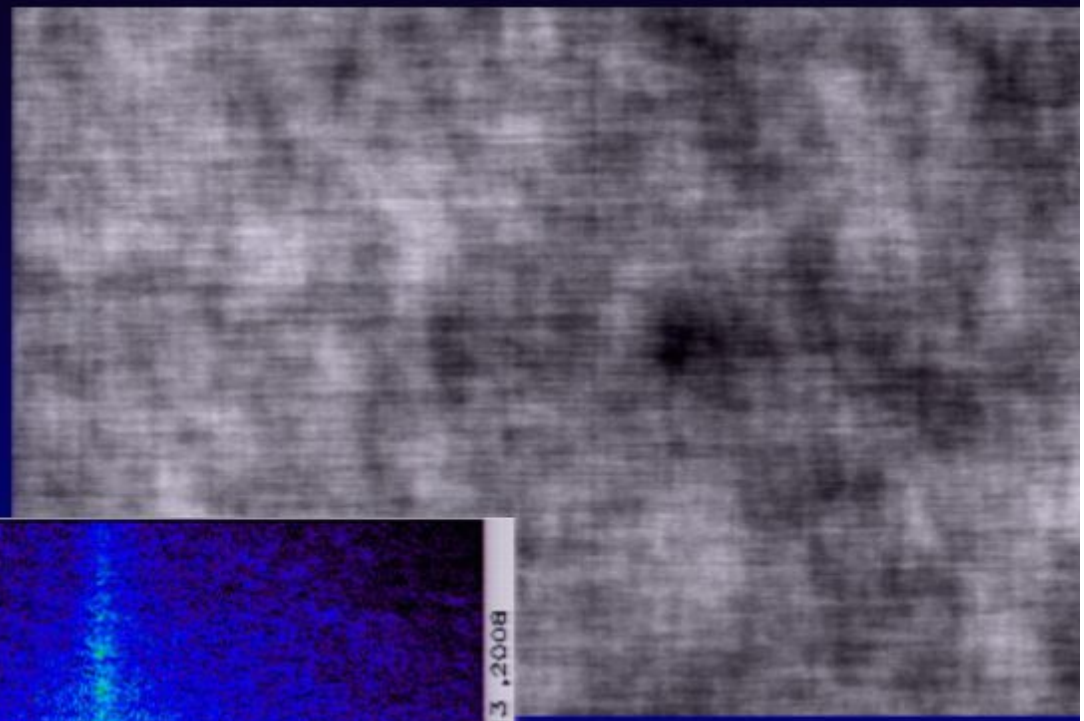
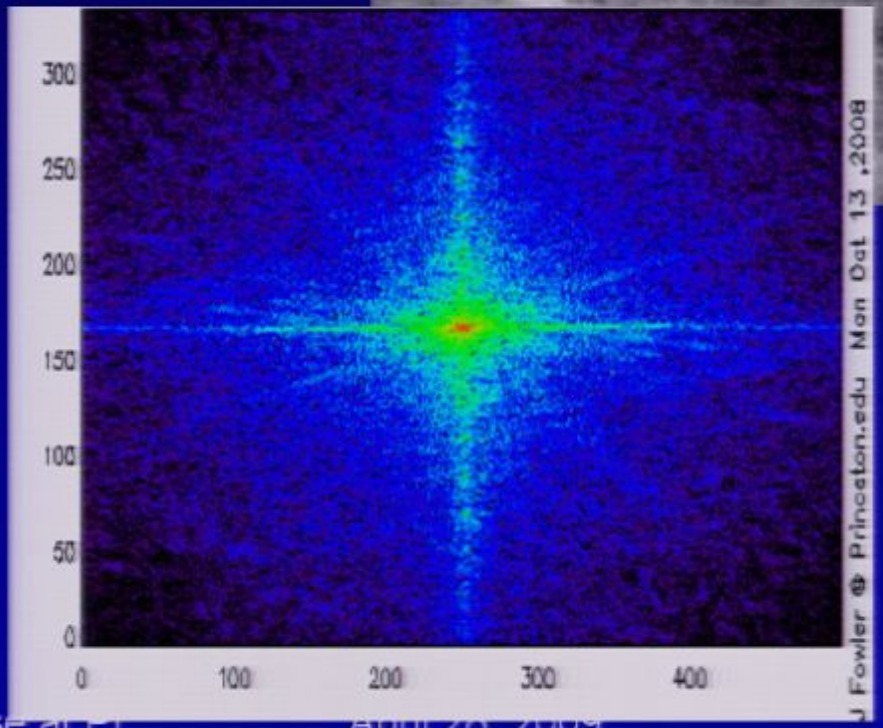
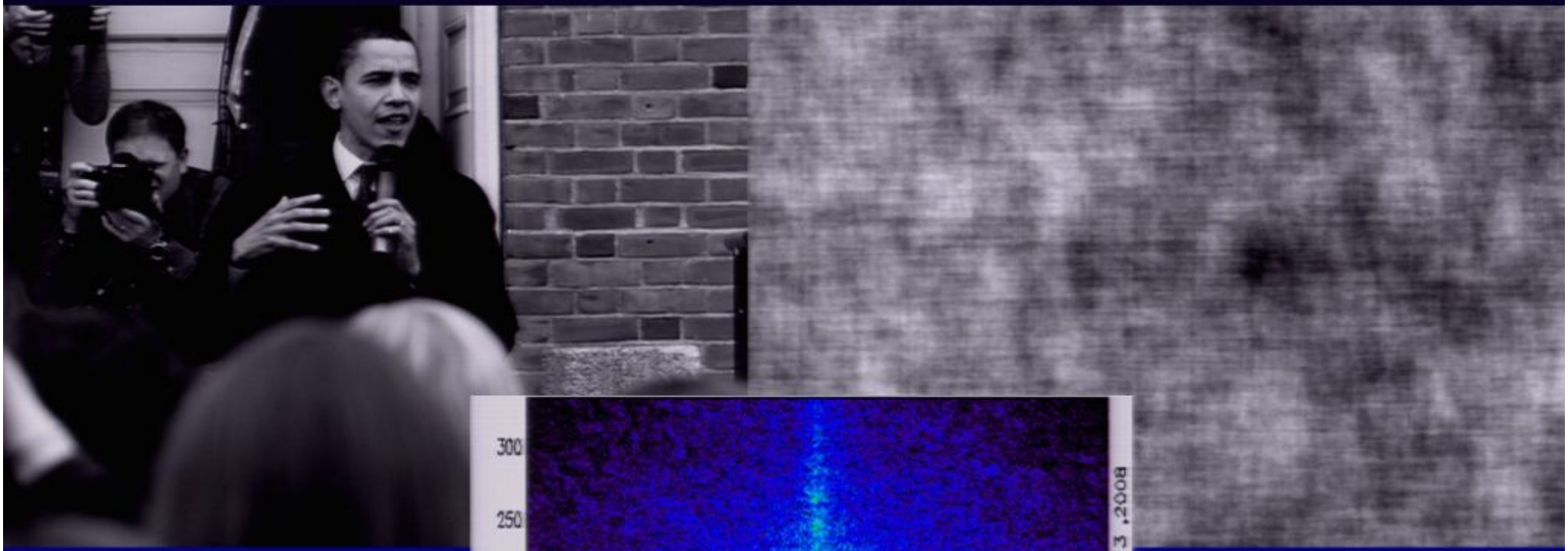
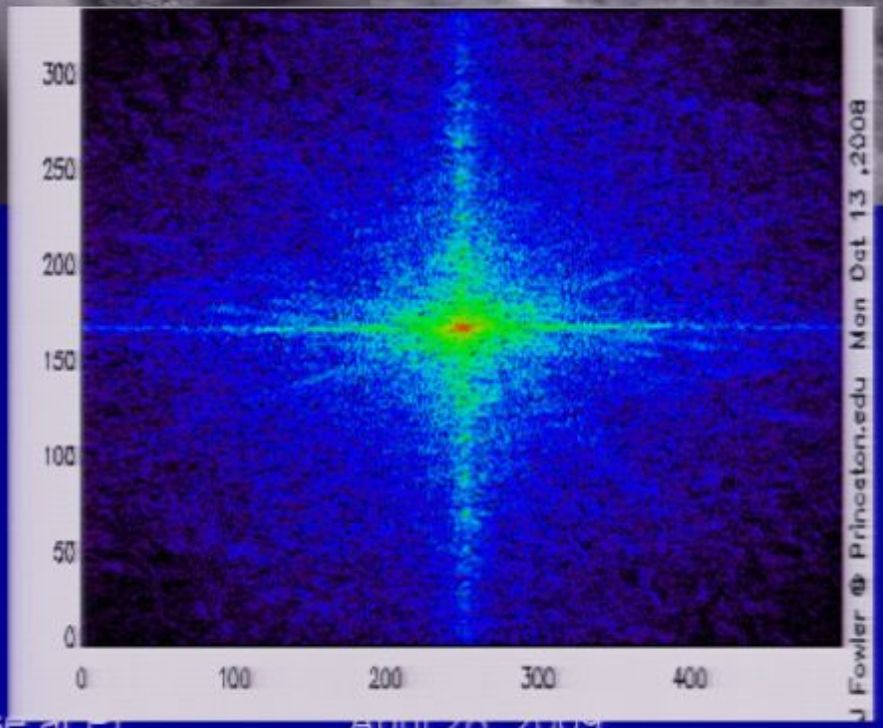




The one map + power spectrum that my group will let me show

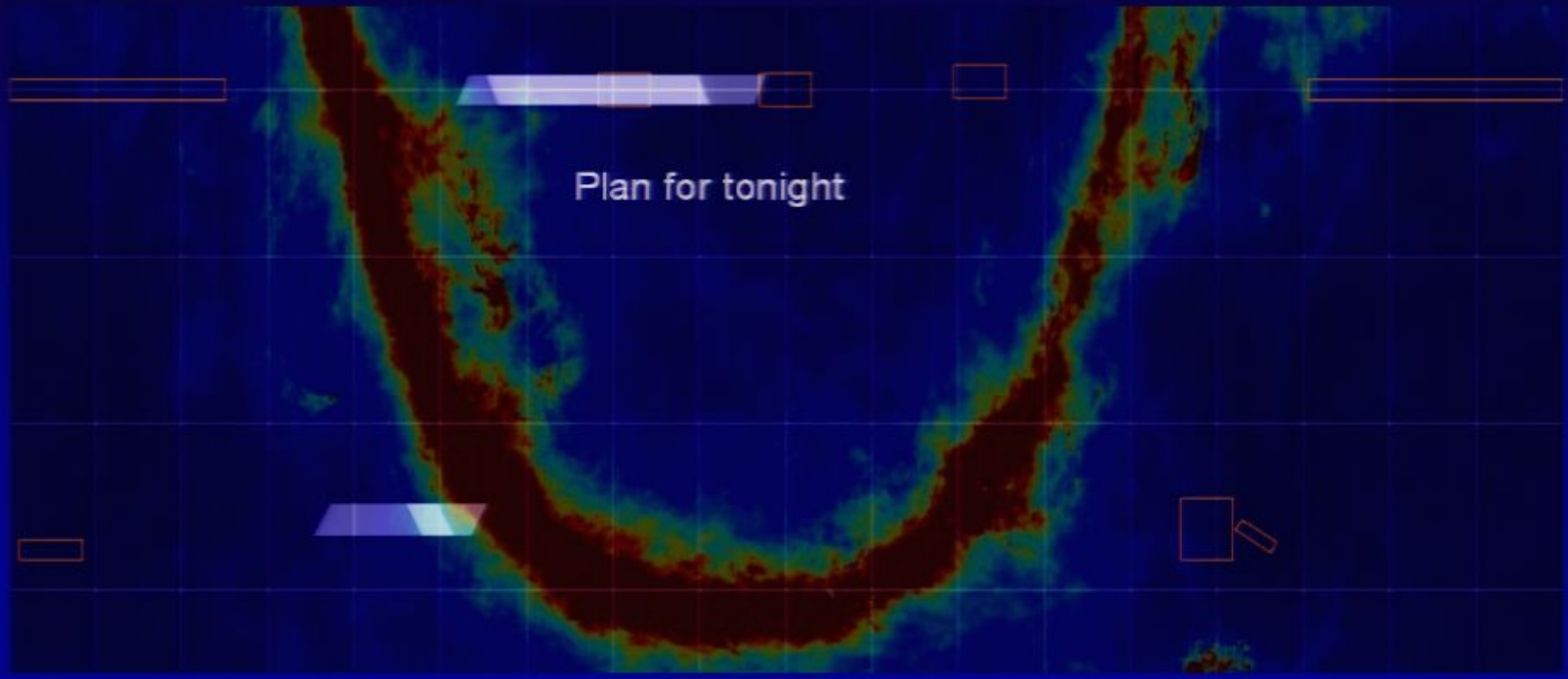




Another realization of the same power spectrum.

ACT target regions

- 2007 season:
  30 days with 1000-element 145 GHz detector array. ~50% time each on Equator, 55° South
- 2008 season started in mid-2008 for 4.5 months with 145, 215, and 280 GHz arrays.
  Most time at 55° South



- 2009 season: Another 6-9 months with three arrays. Starts this week.

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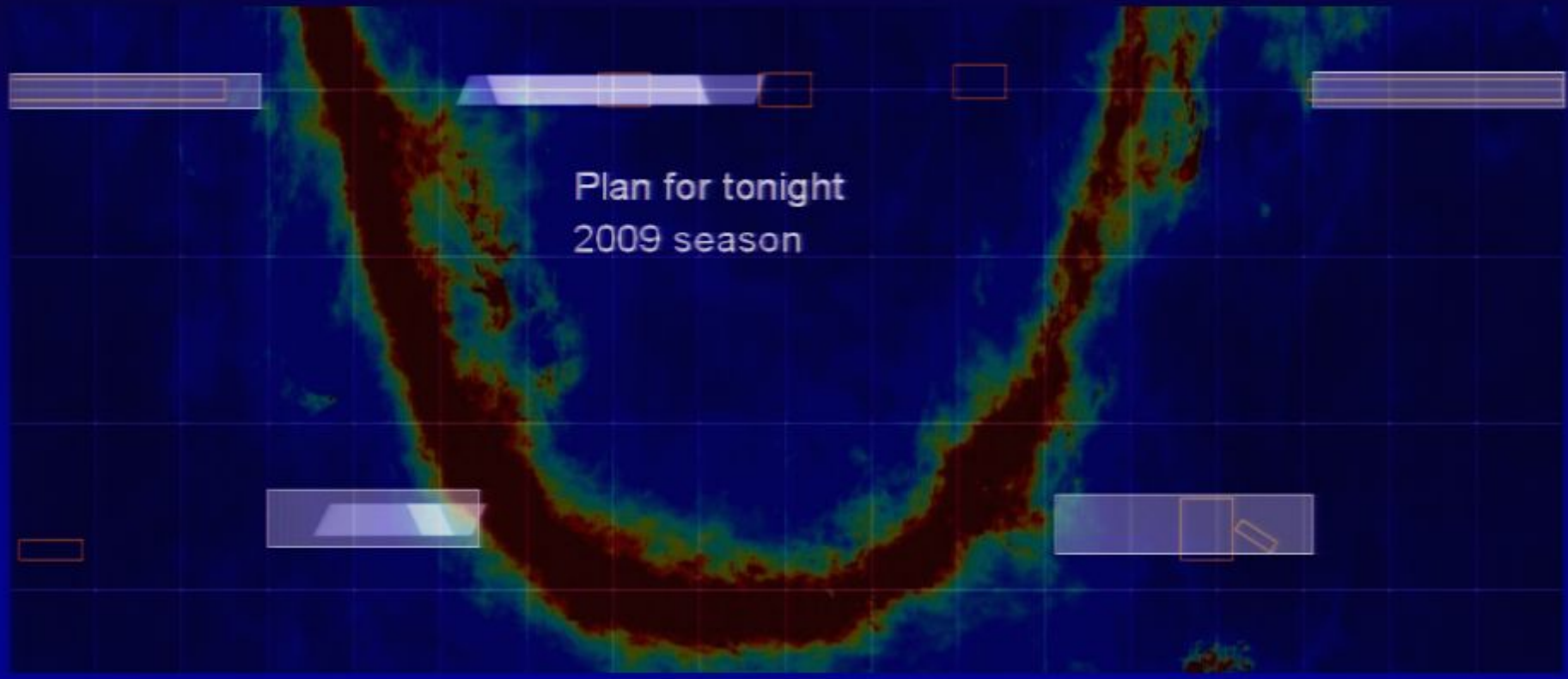
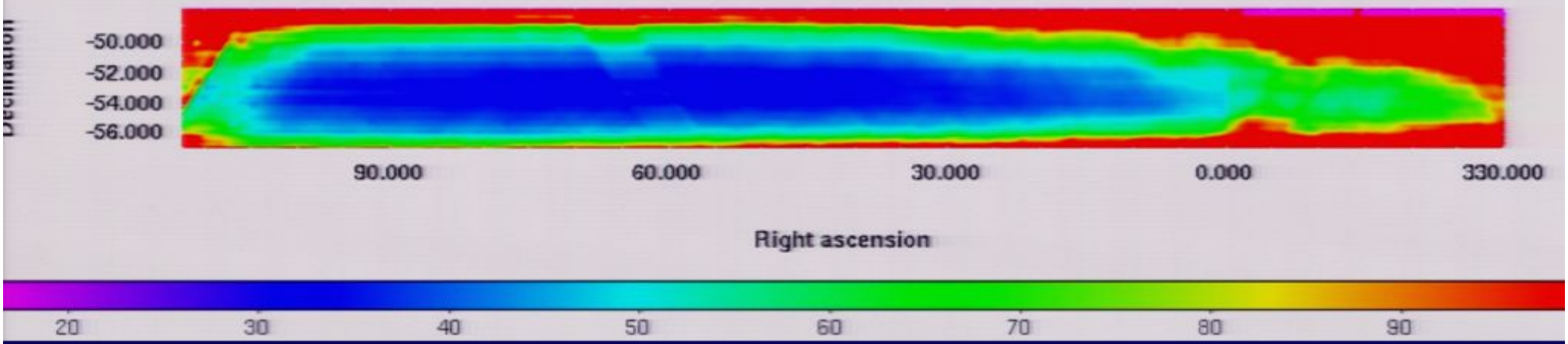


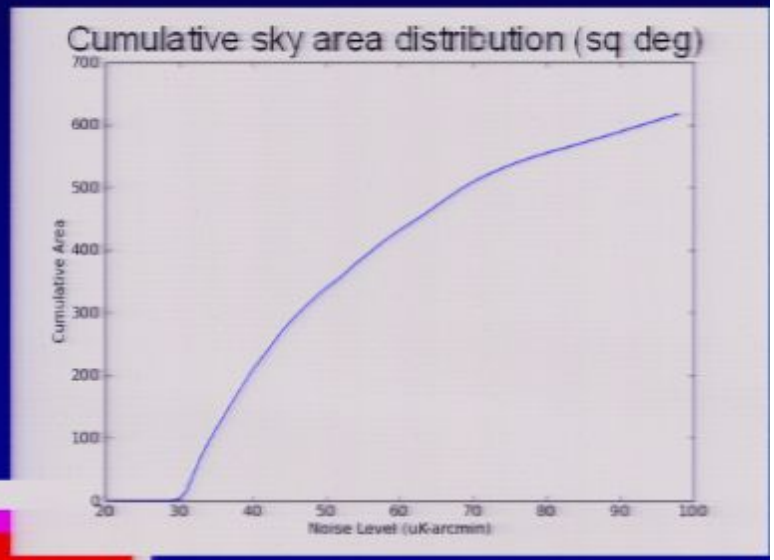
- 2009 season: Another 6-9 months with three arrays. Starts this week.

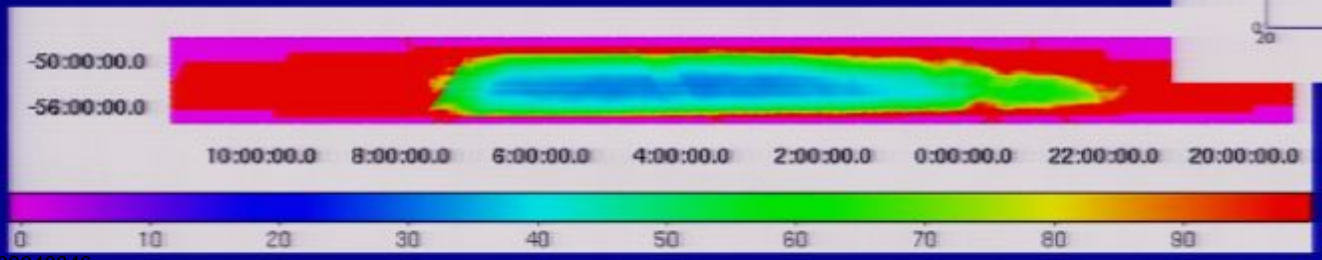
2008 ACT map sensitivity at 145 GHz



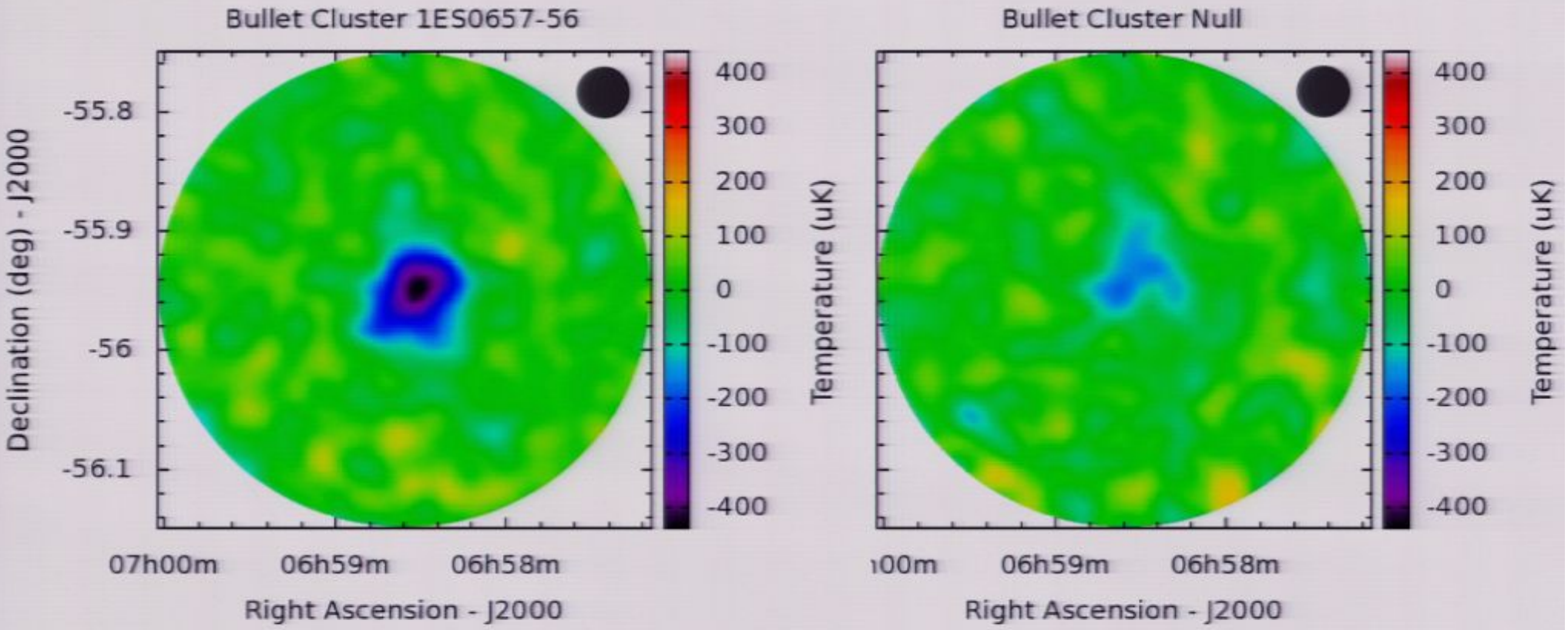
- 140 nights: ~900 hours this region
- ~200 hours from 2007 not included
- ~500 hours at δ=0° not included

- 500 sq deg equivalent at 40 μK_{cmb}-arcmin.





ACT Bullet Cluster (with null)

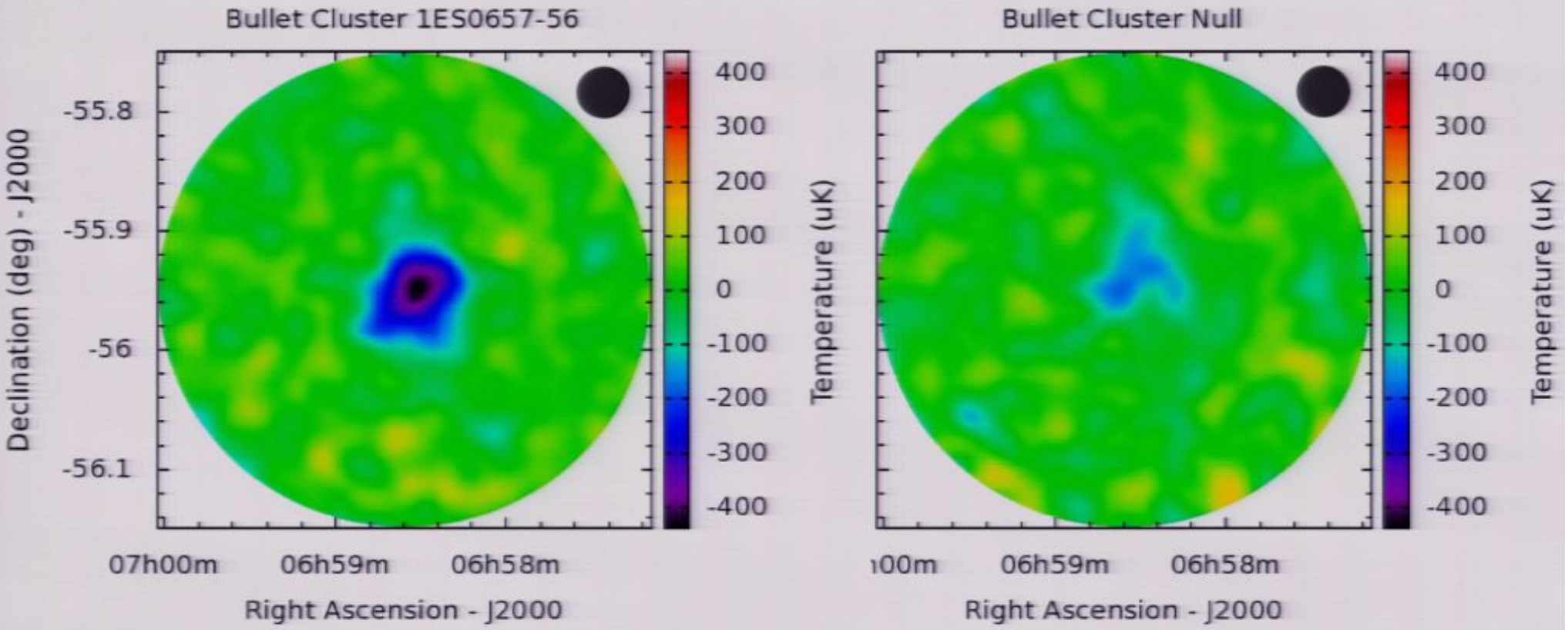


Smoothed to 95" (~1 beam); 12" pixels; 40' diam

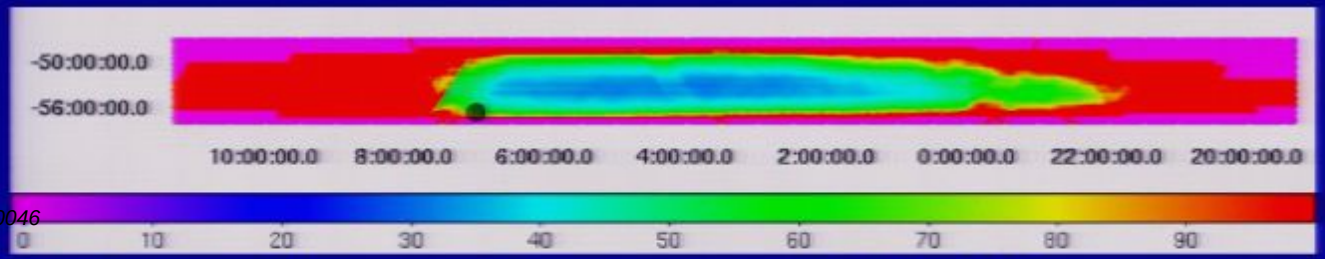
NULL =
(first – second)
half of season

z=0.296 (Tucker et al 1999);

ACT Bullet Cluster (with null)



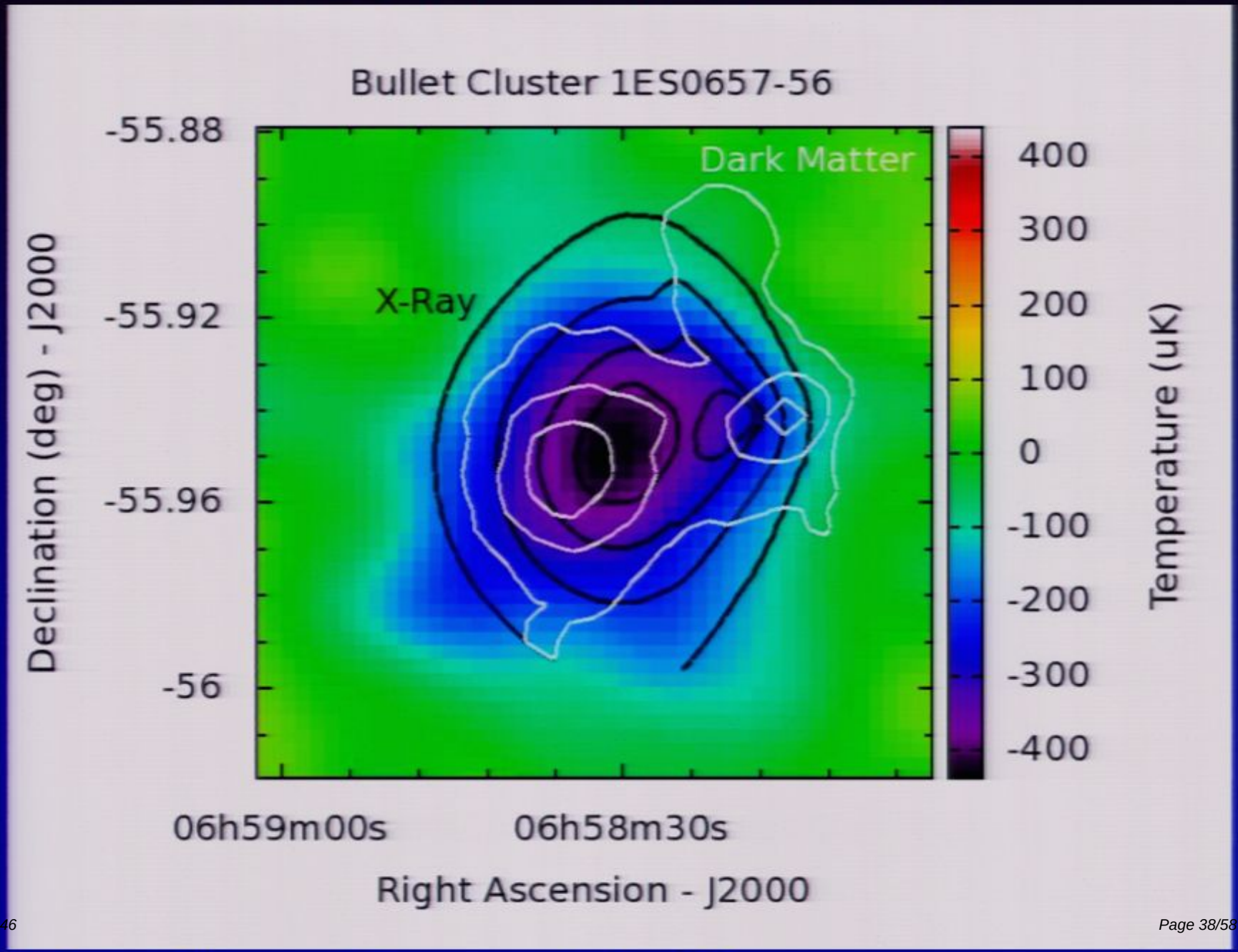
Smoothed to 95" (~1 beam); 12" pixels; 40' diam



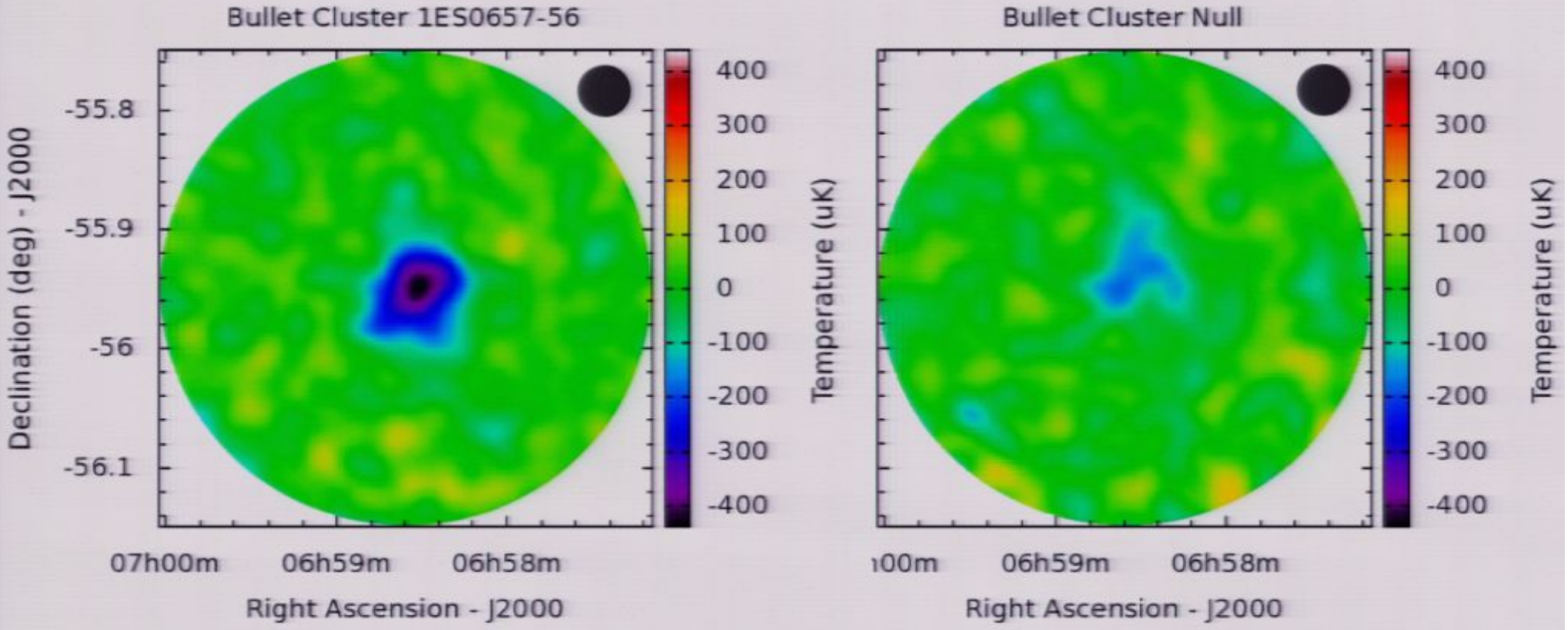
NULL =
(first – second)
half of season

Bullet Cluster from other bands

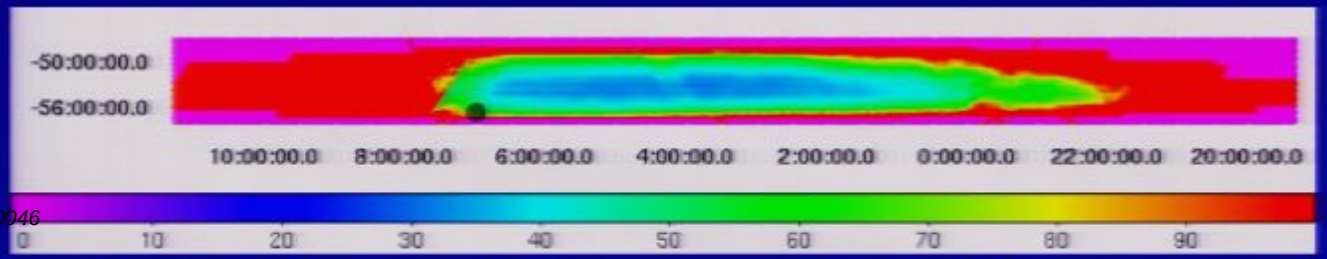
Bullet Cluster from other bands



ACT Bullet Cluster (with null)



Smoothed to 95" (~1 beam); 12" pixels; 40' diam



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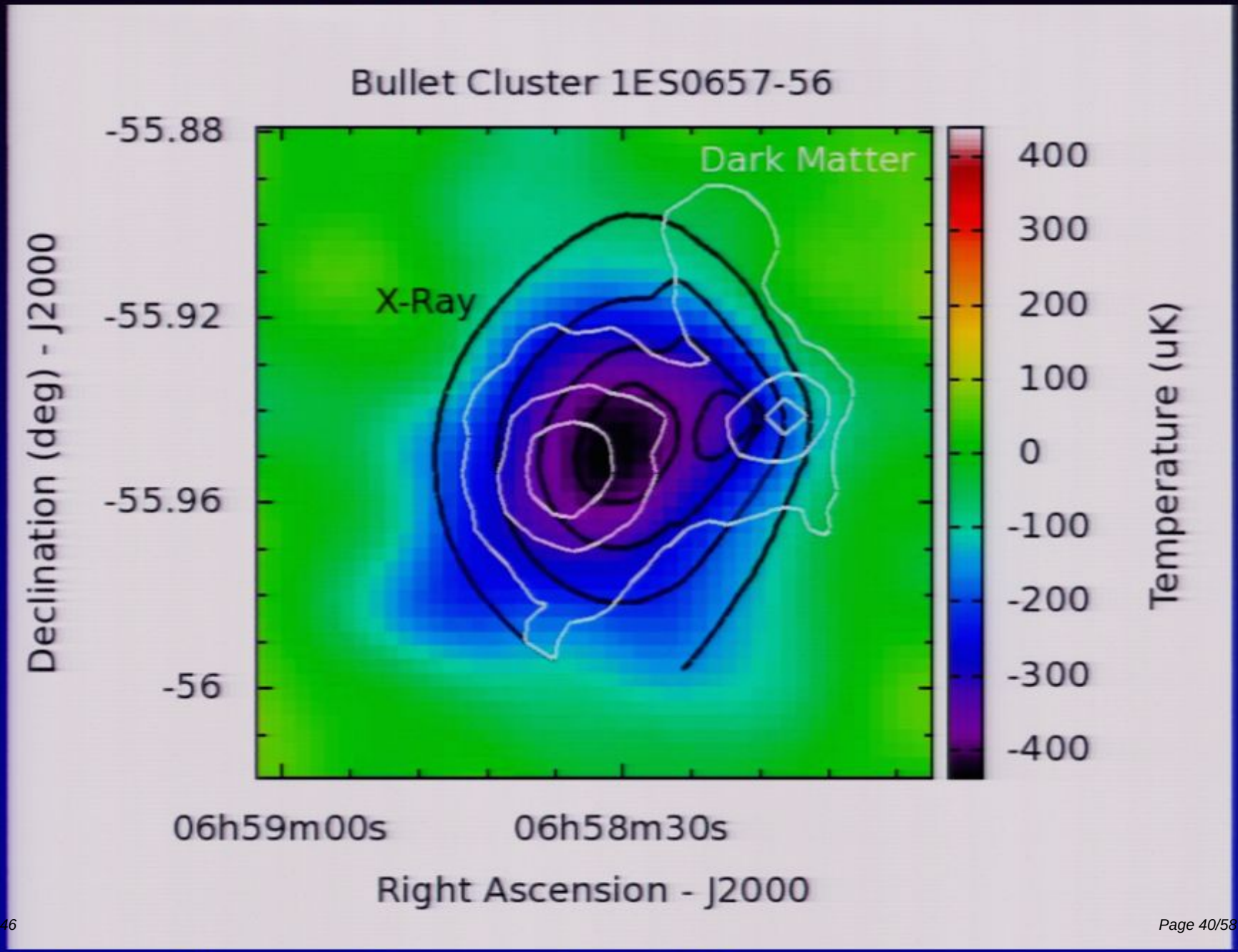
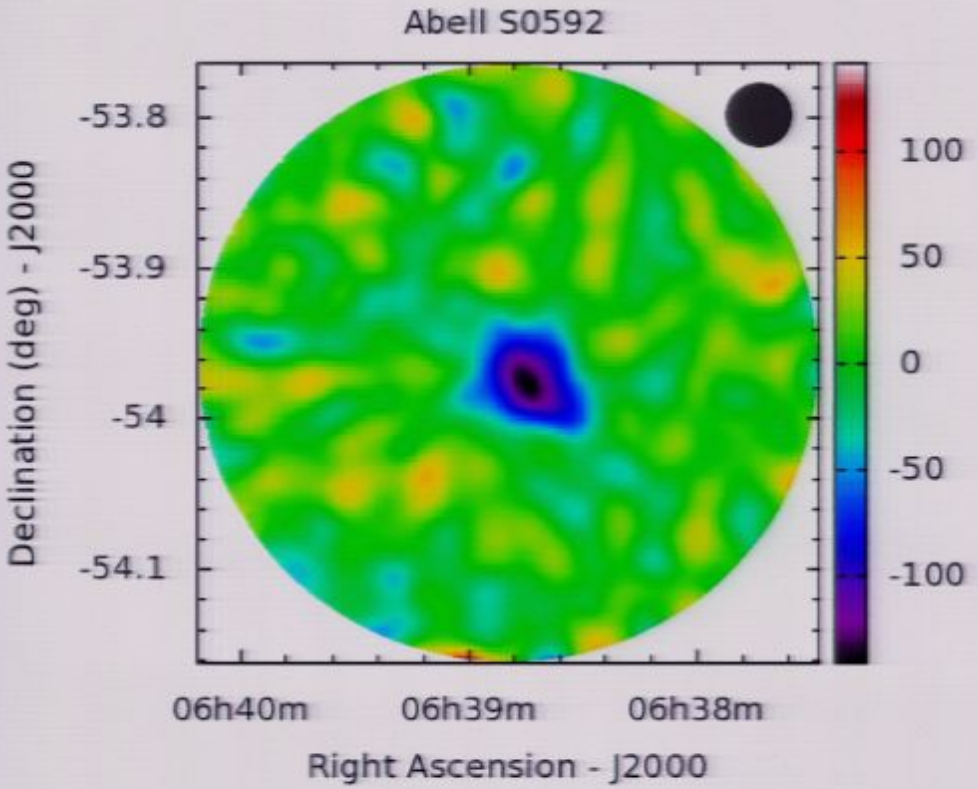
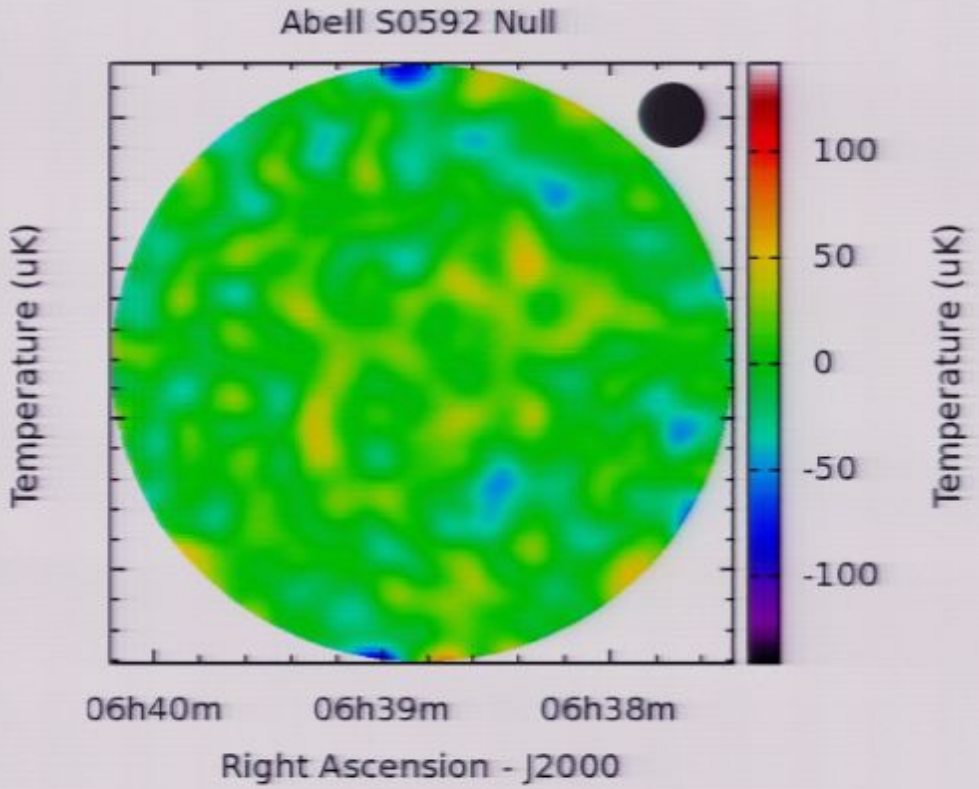
Bullet Cluster from other bands

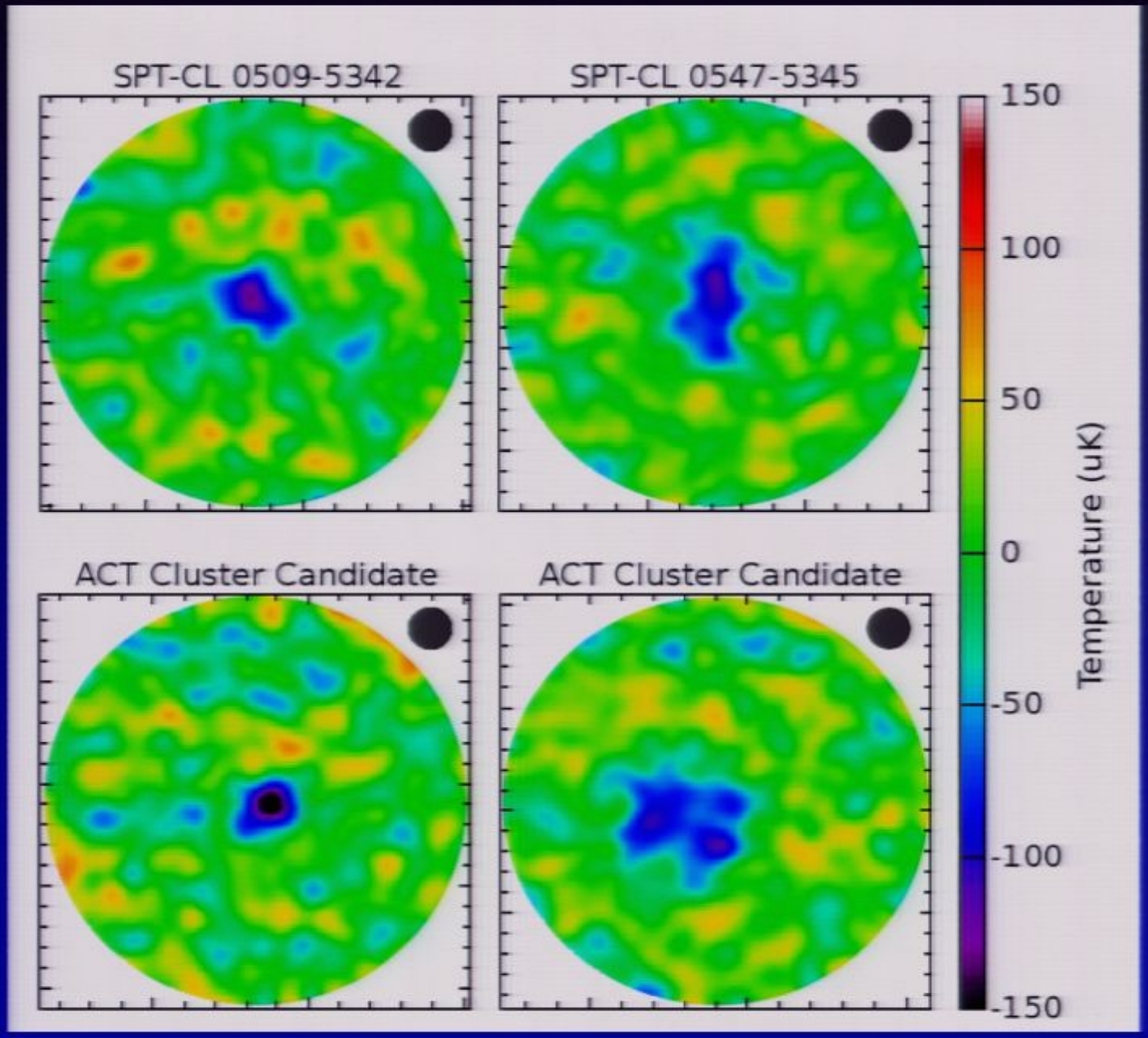


Another known cluster: Abell S0592

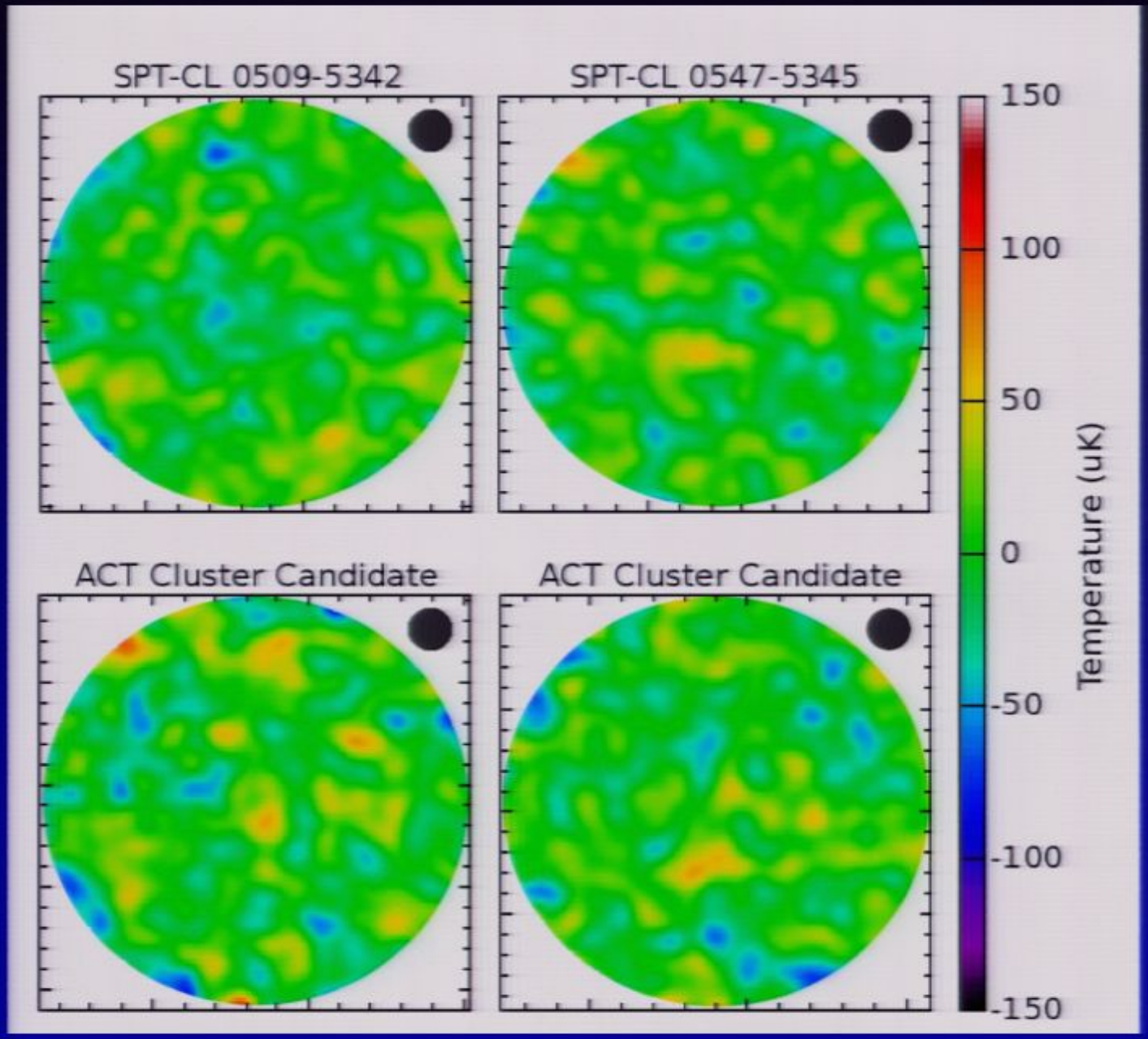




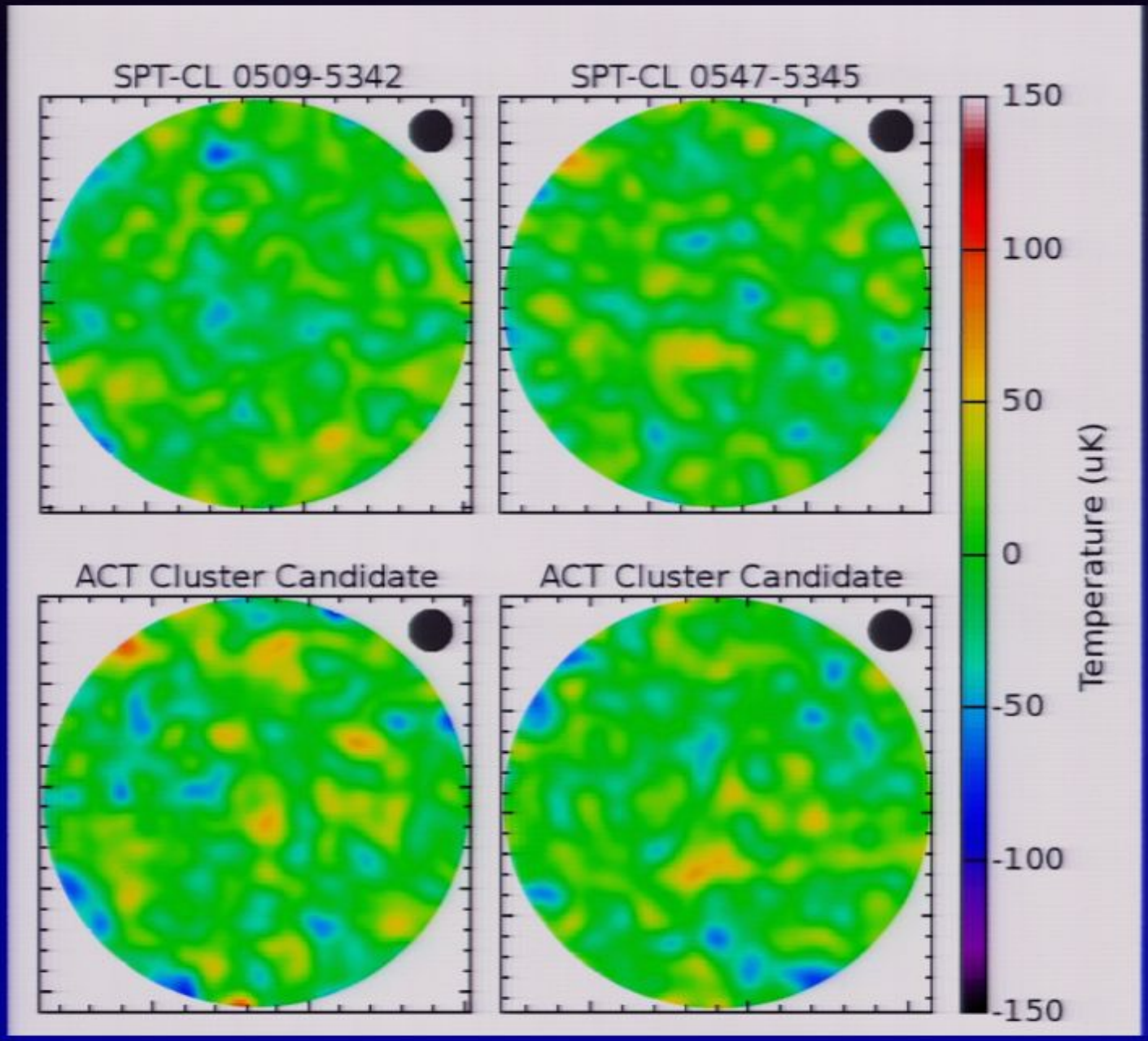
Four other clusters



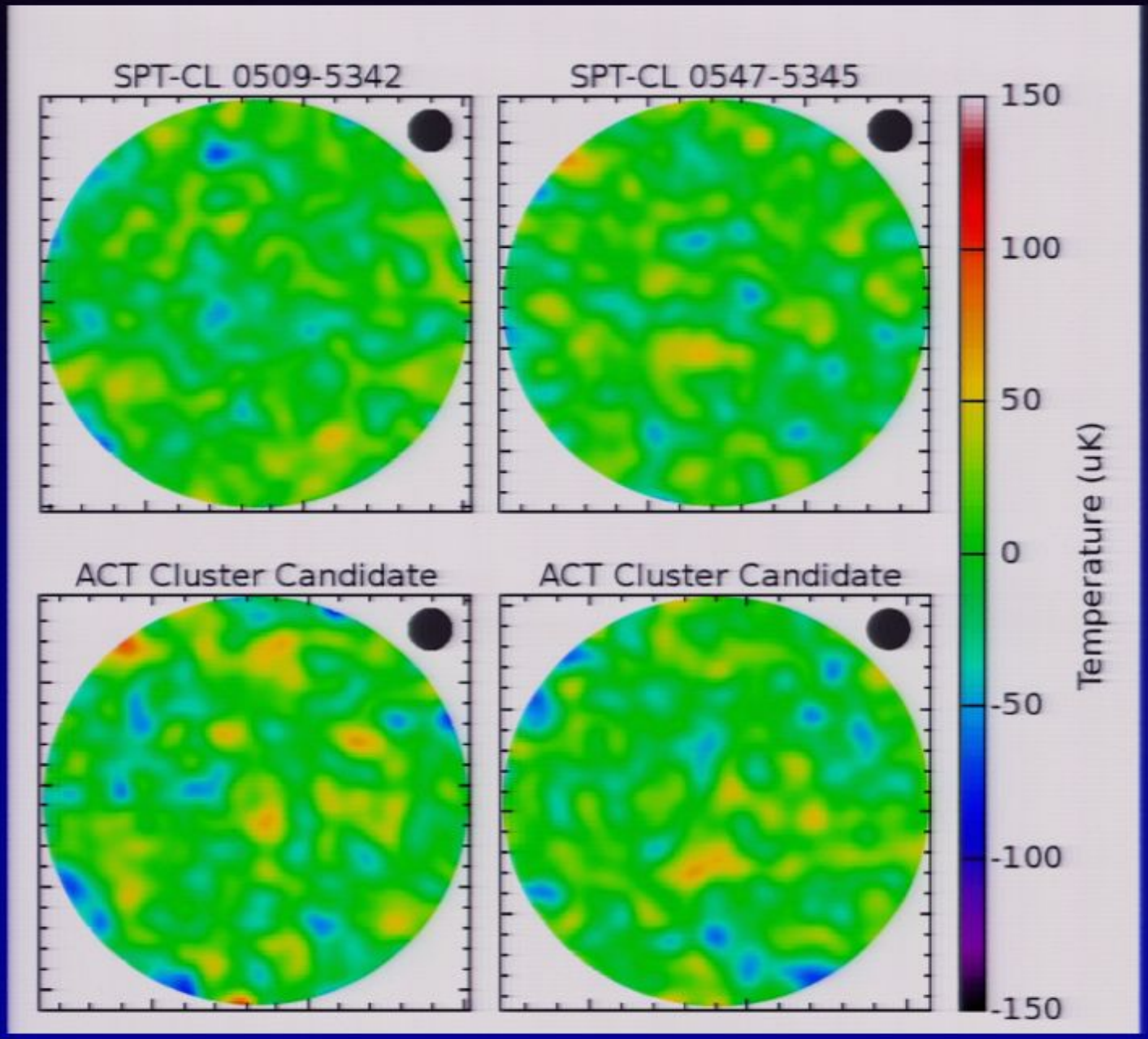
Null maps of 4 previous fields



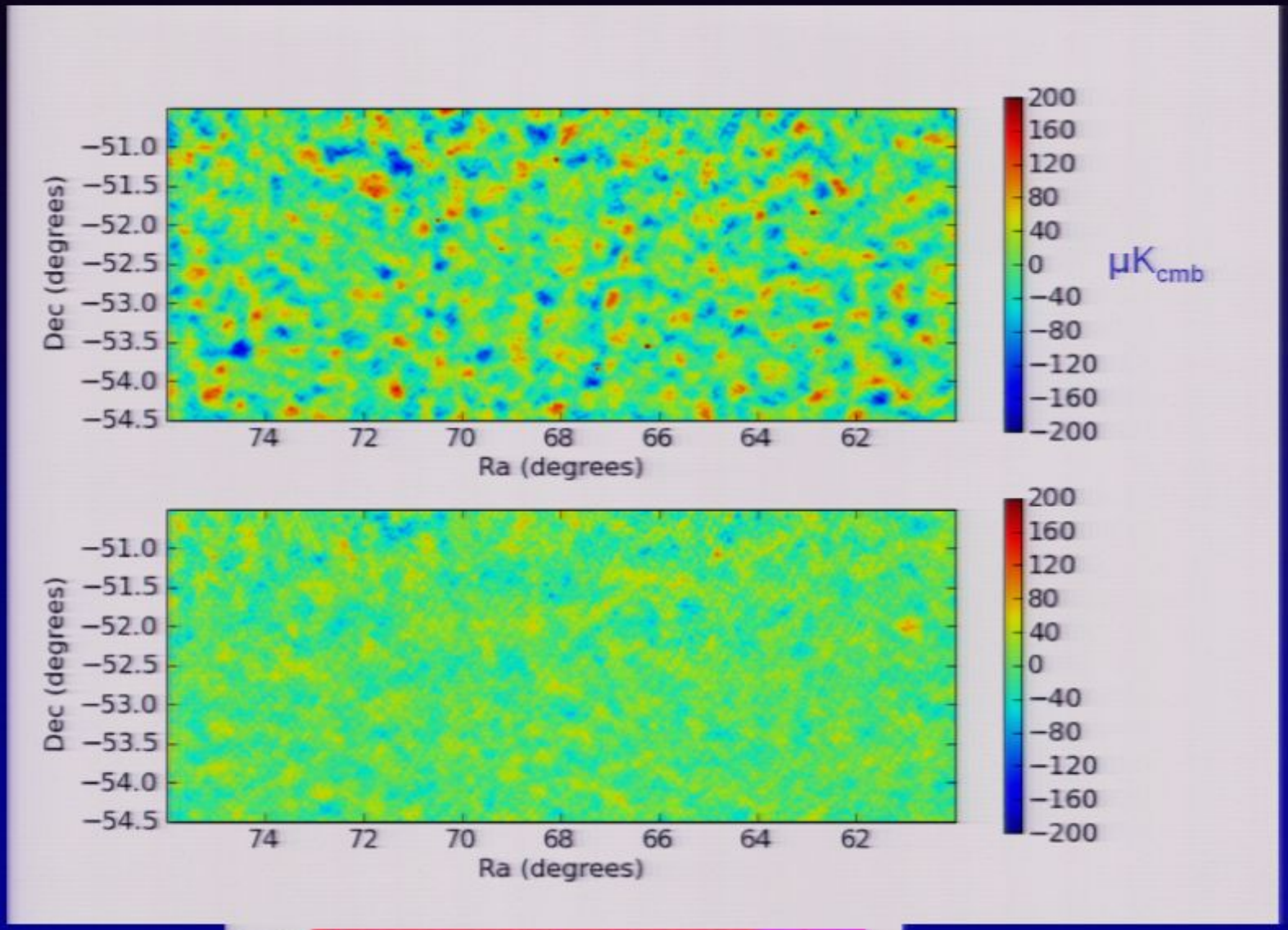
Null maps of 4 previous fields

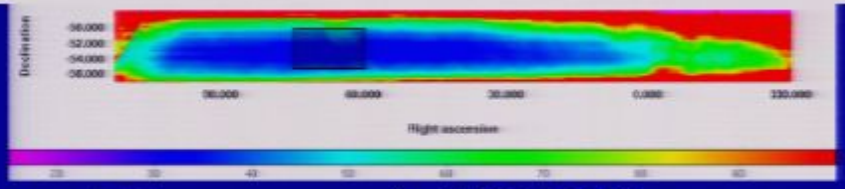


Null maps of 4 previous fields



Sample from full ACT Map





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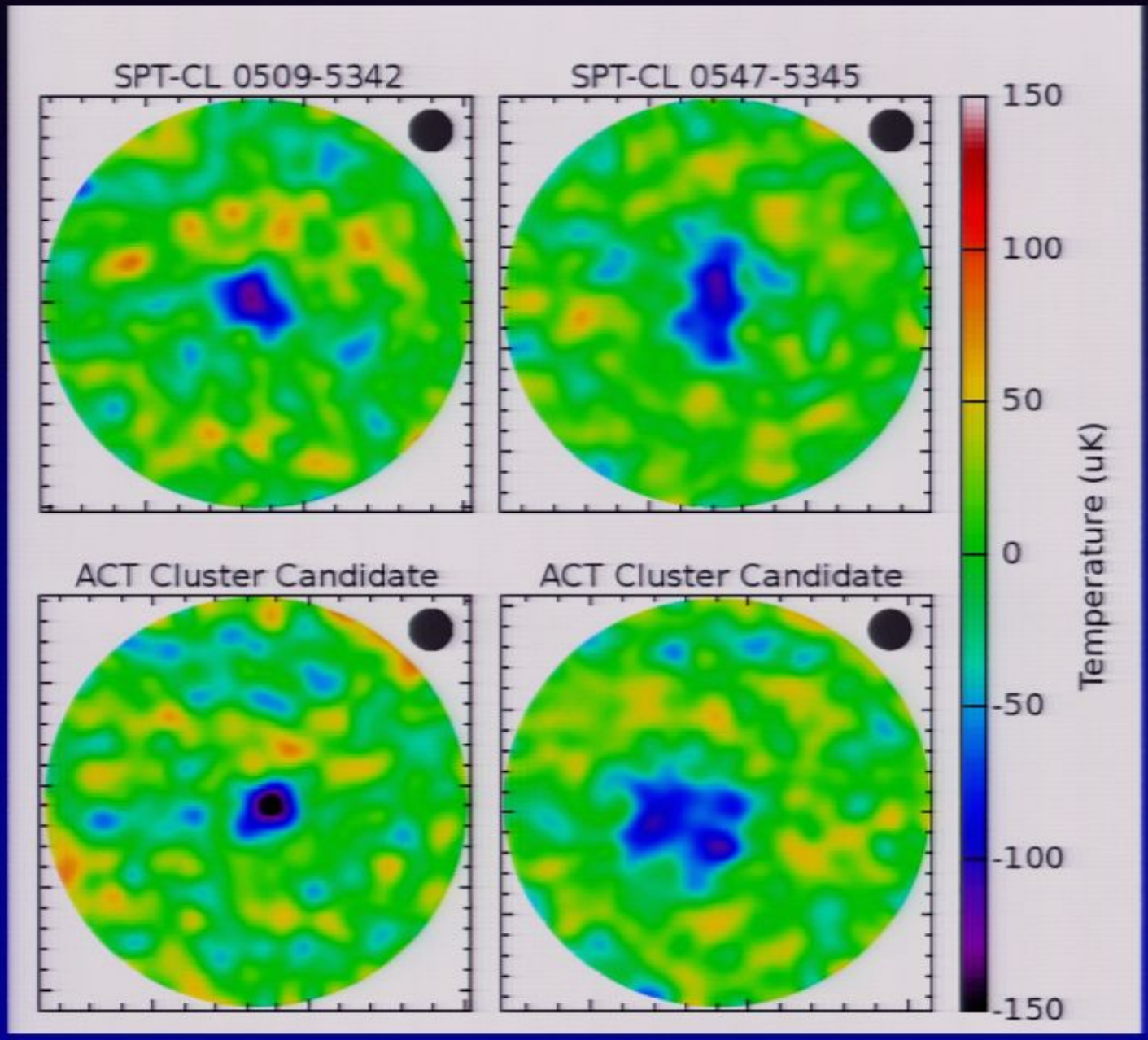

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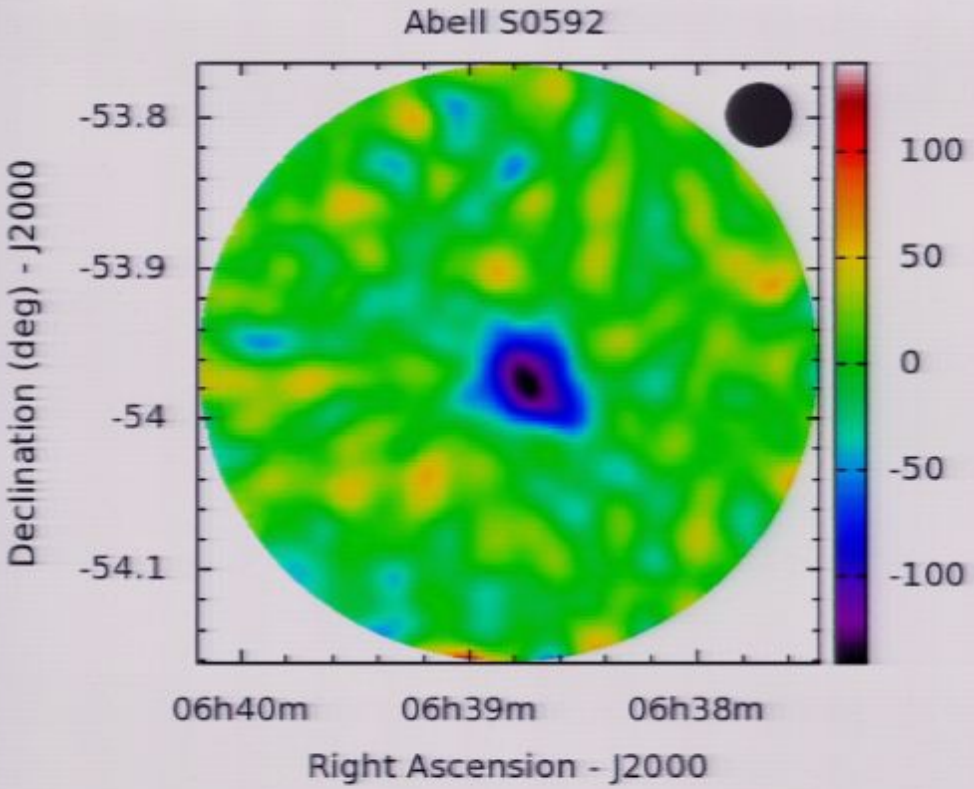
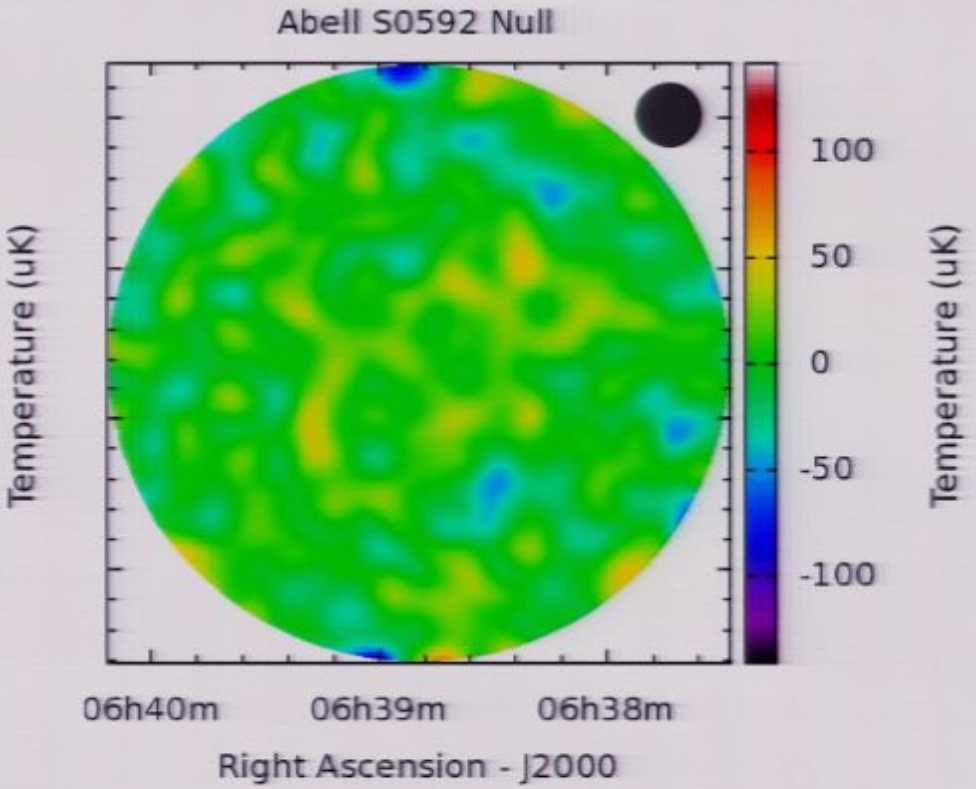
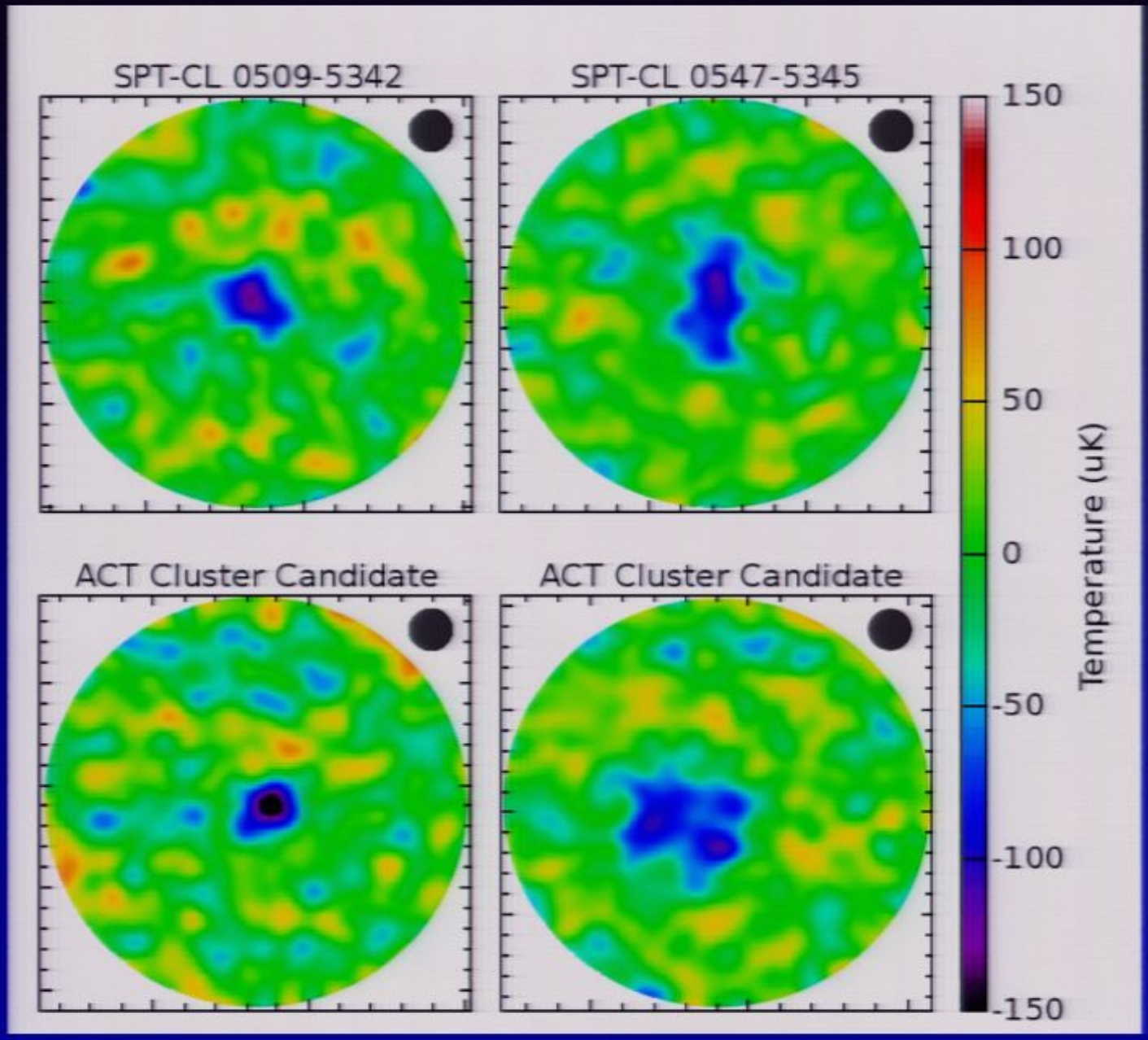
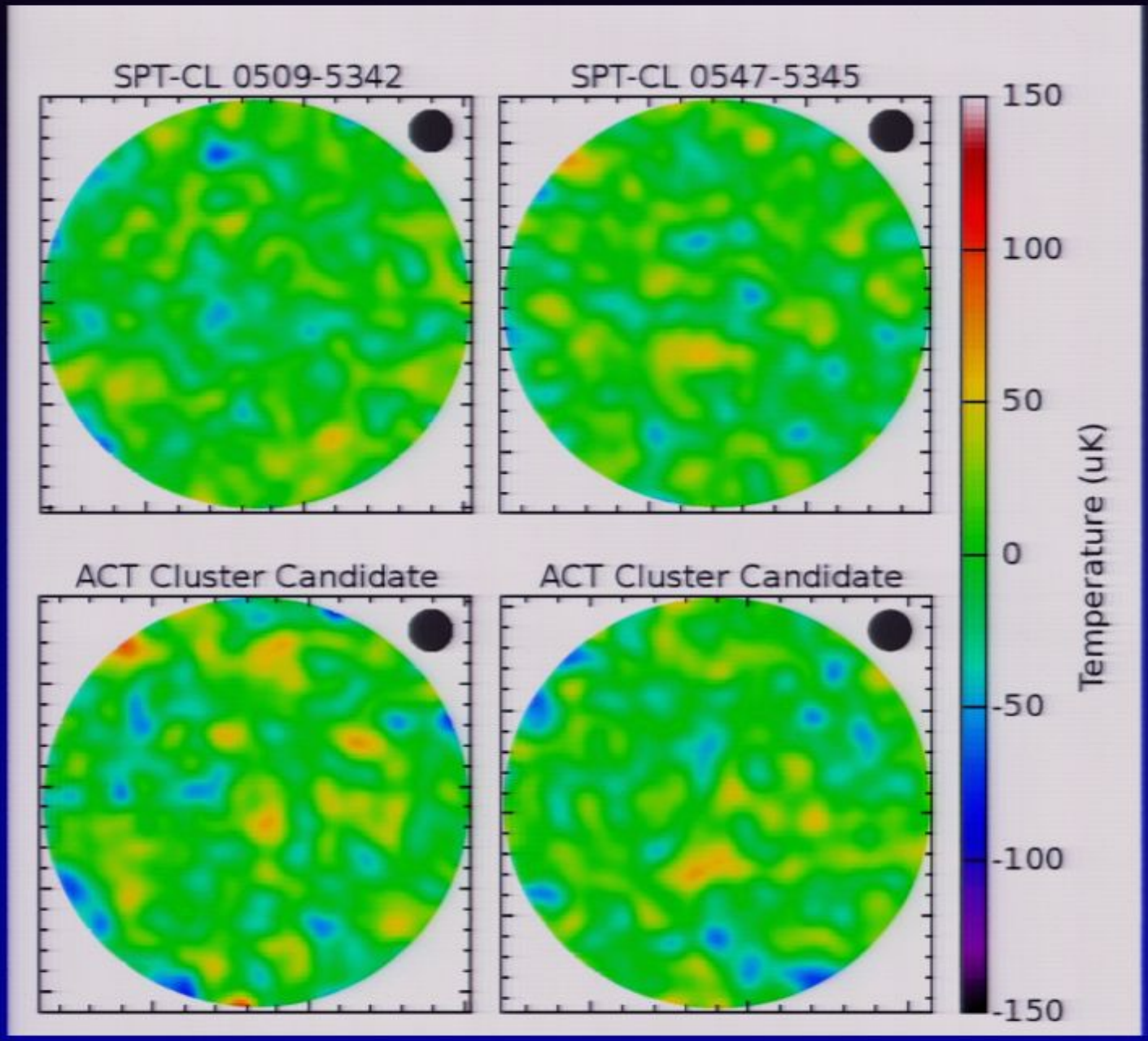




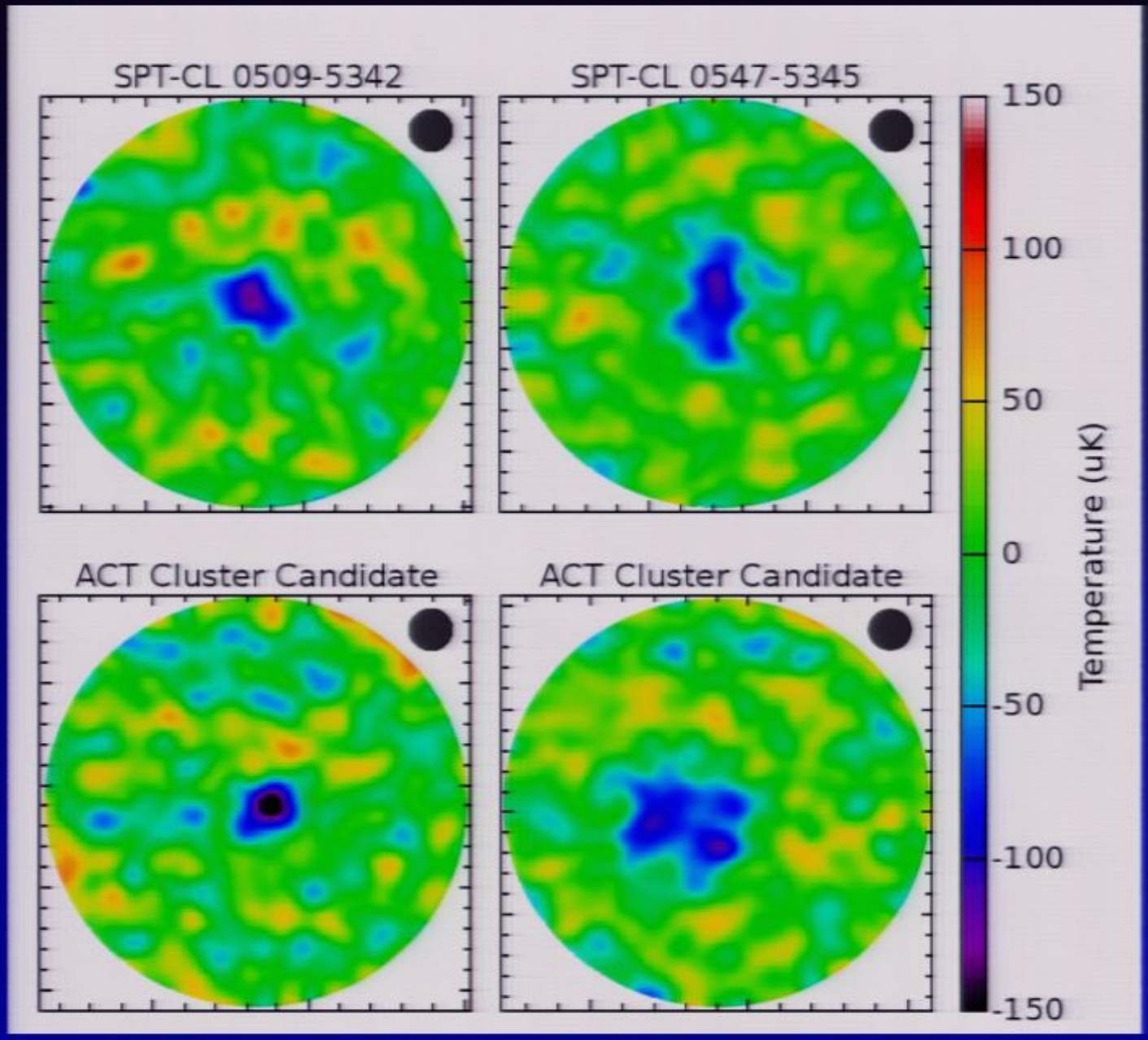
Four other clusters



Null maps of 4 previous fields



Four other clusters



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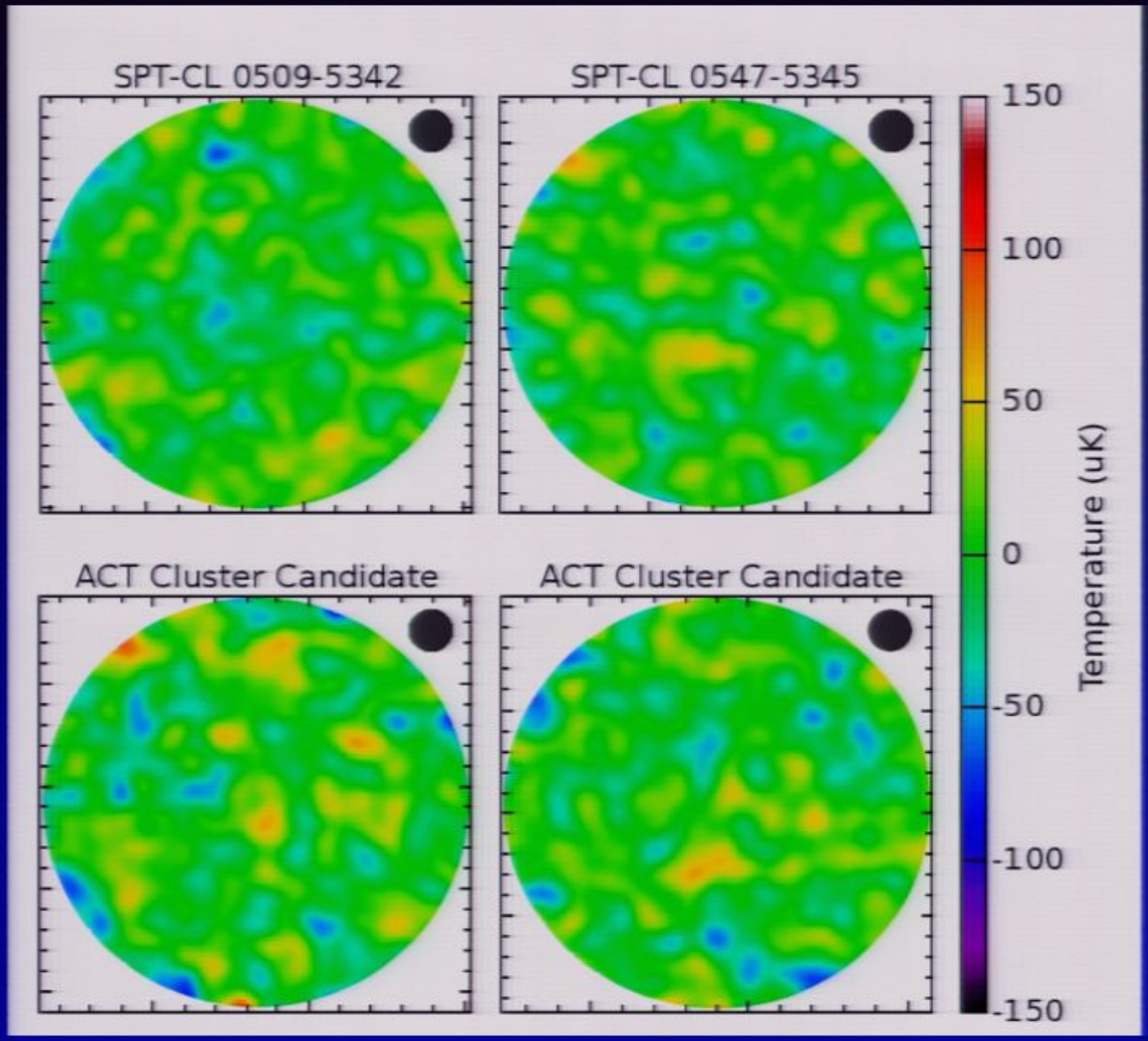

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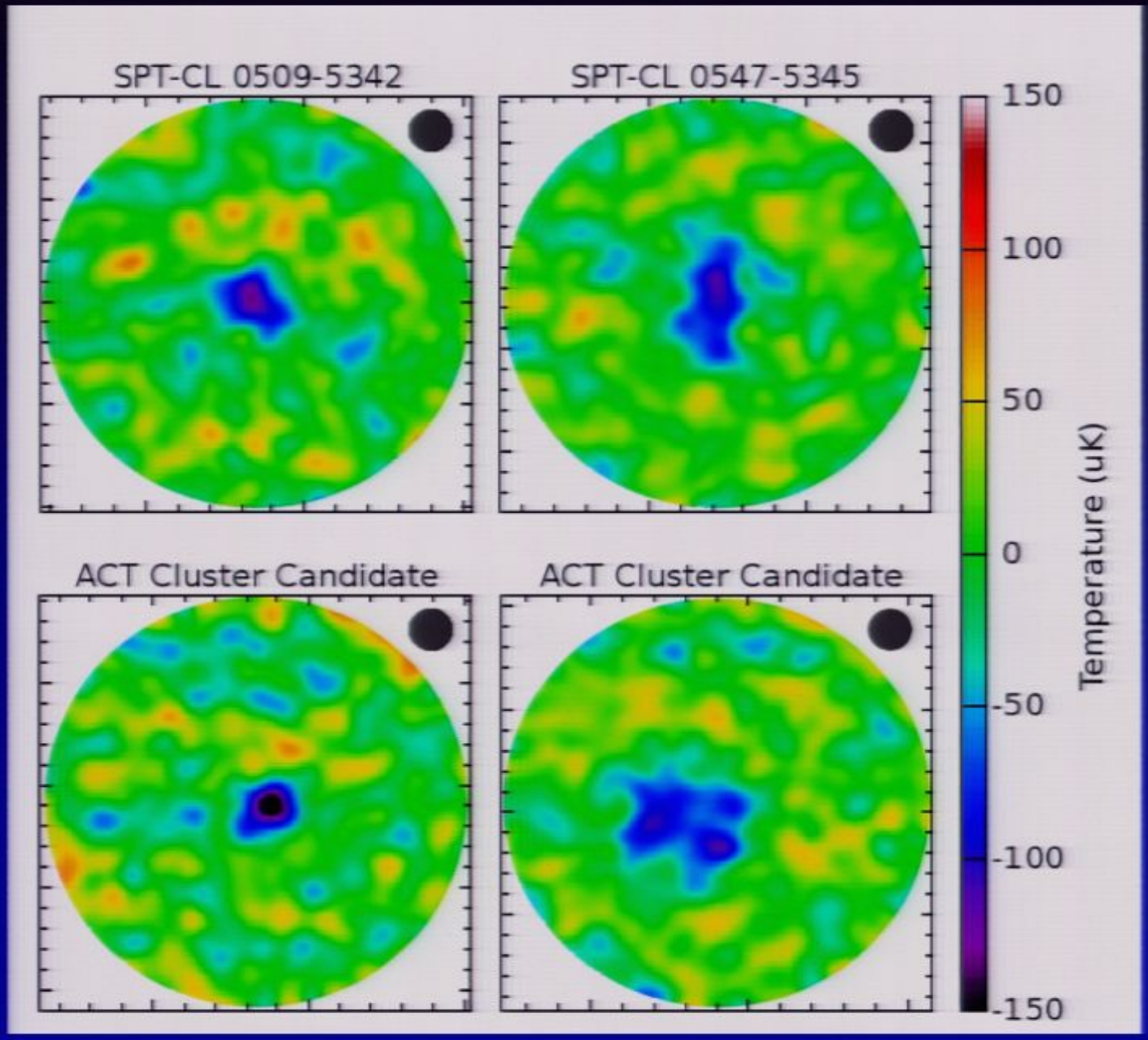
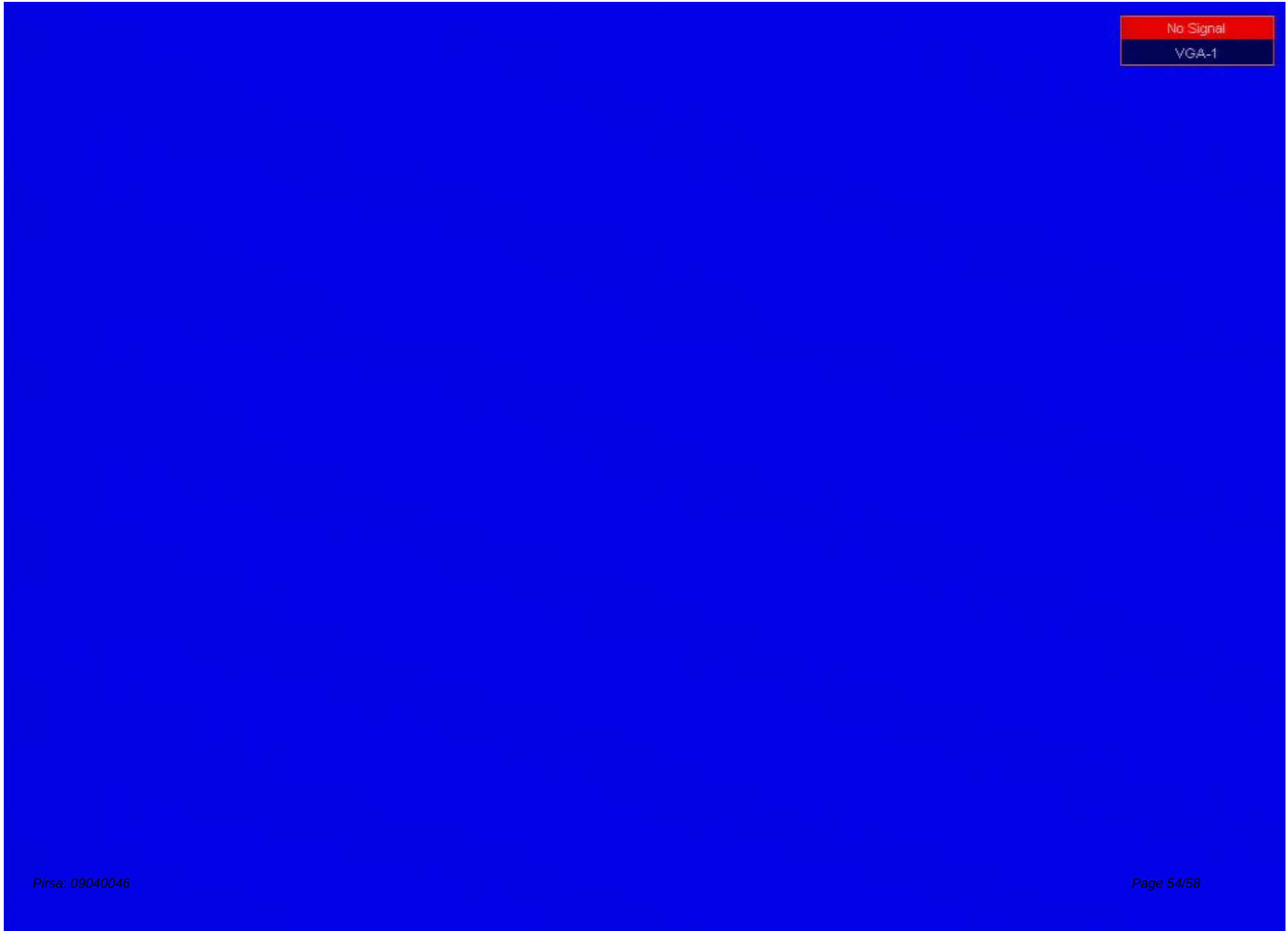
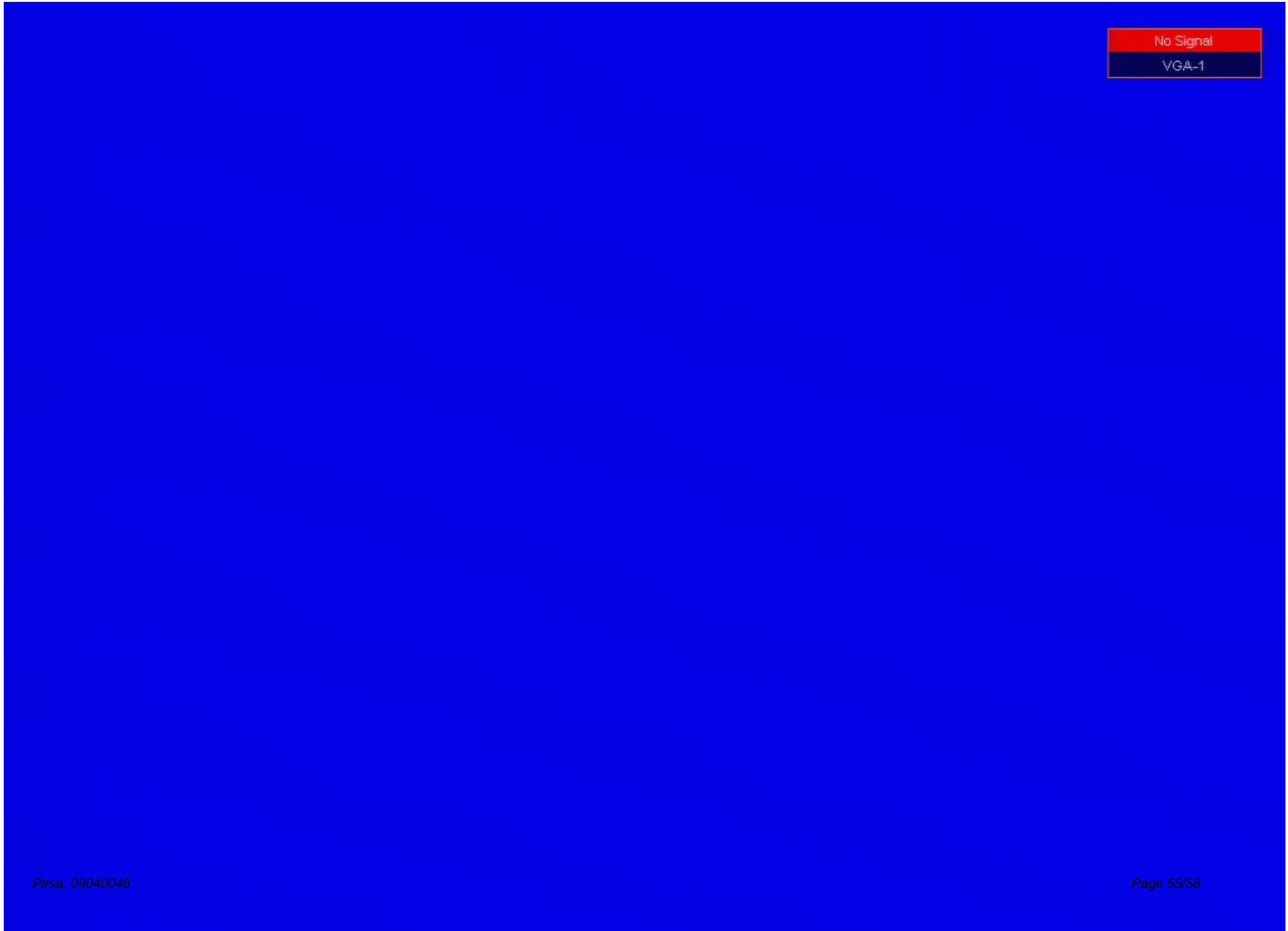



No Signal
VGA-1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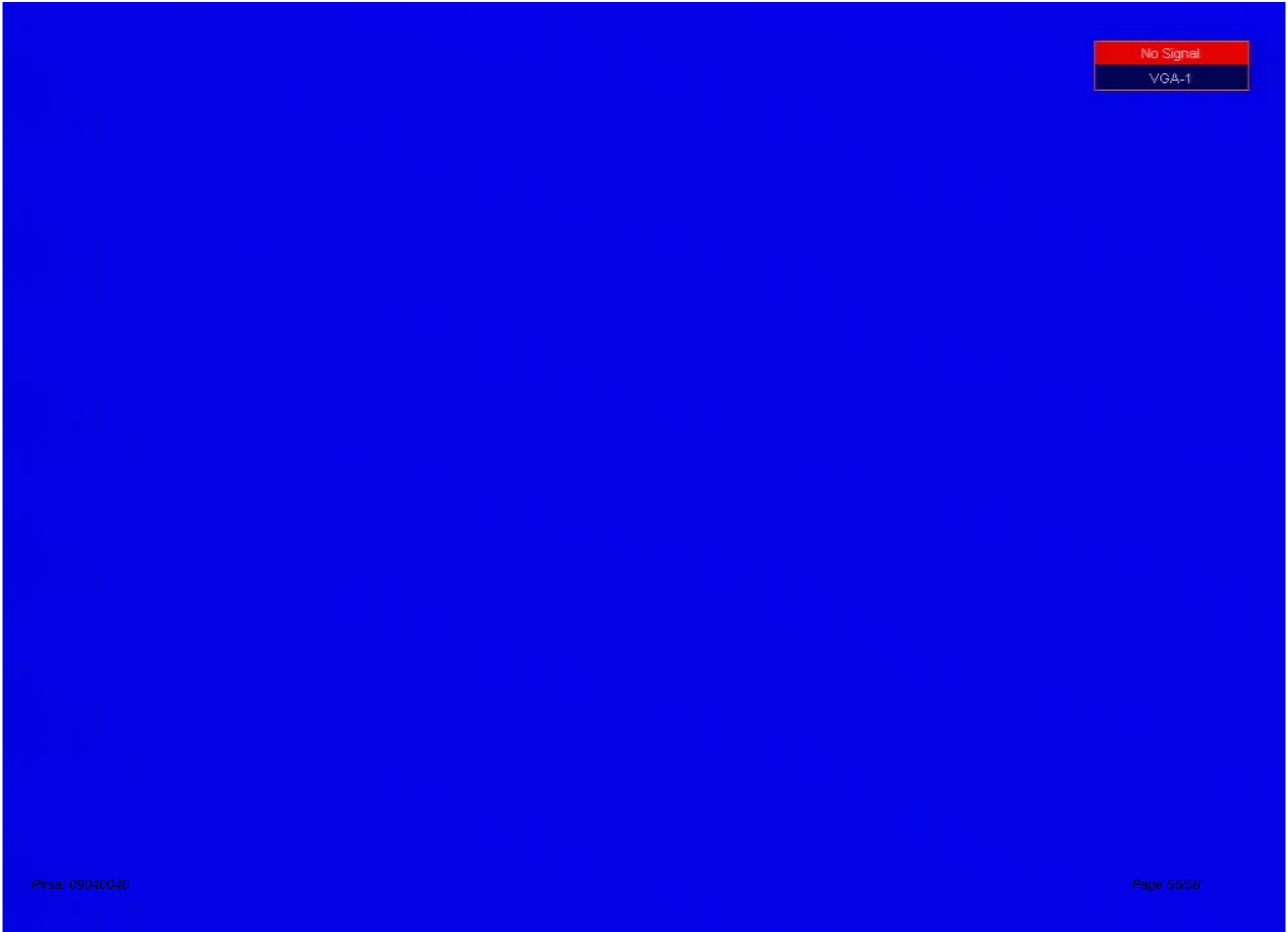
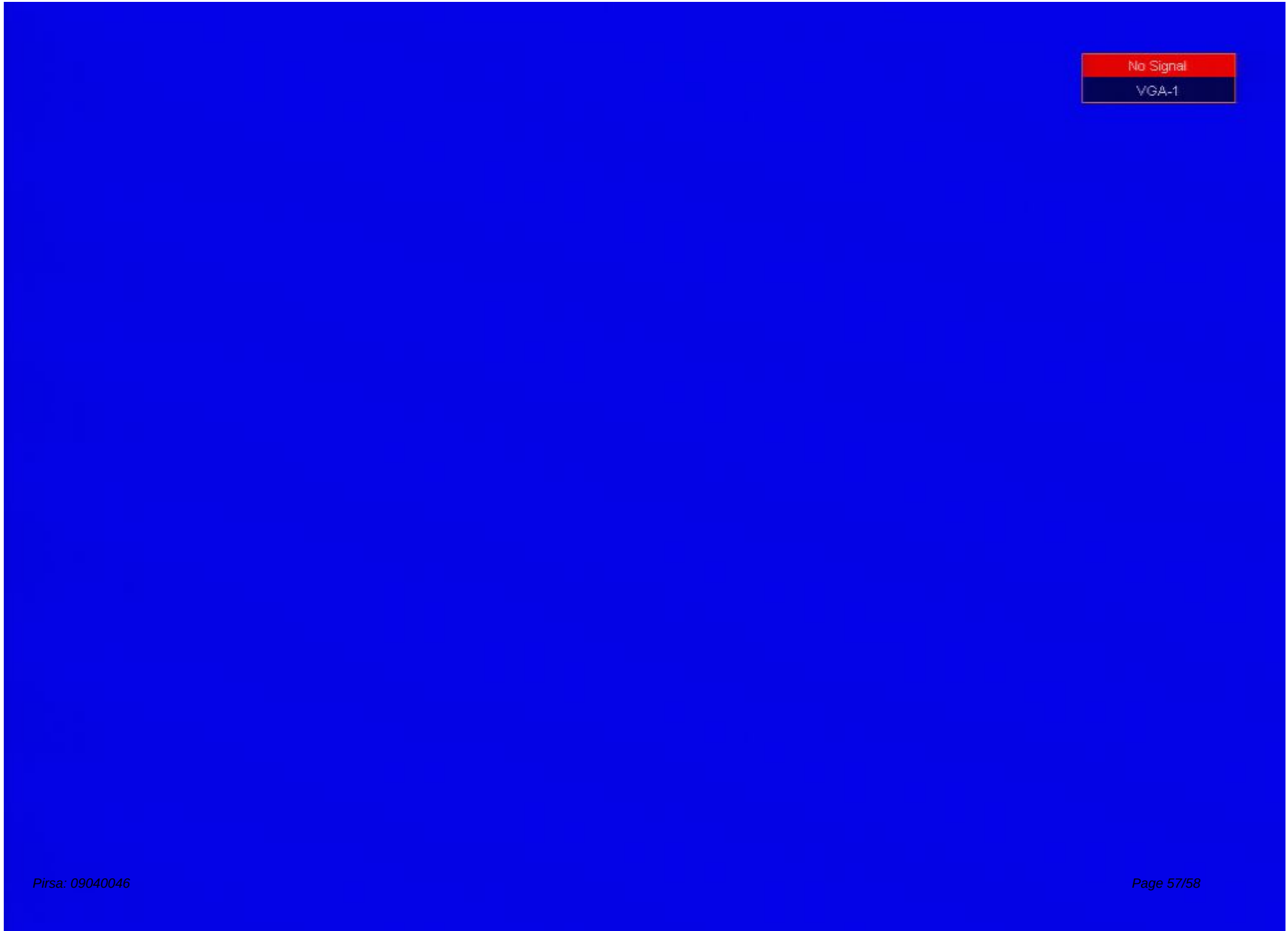

No Signal
VGA-1


No Signal
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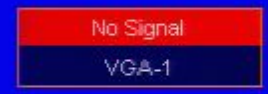
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