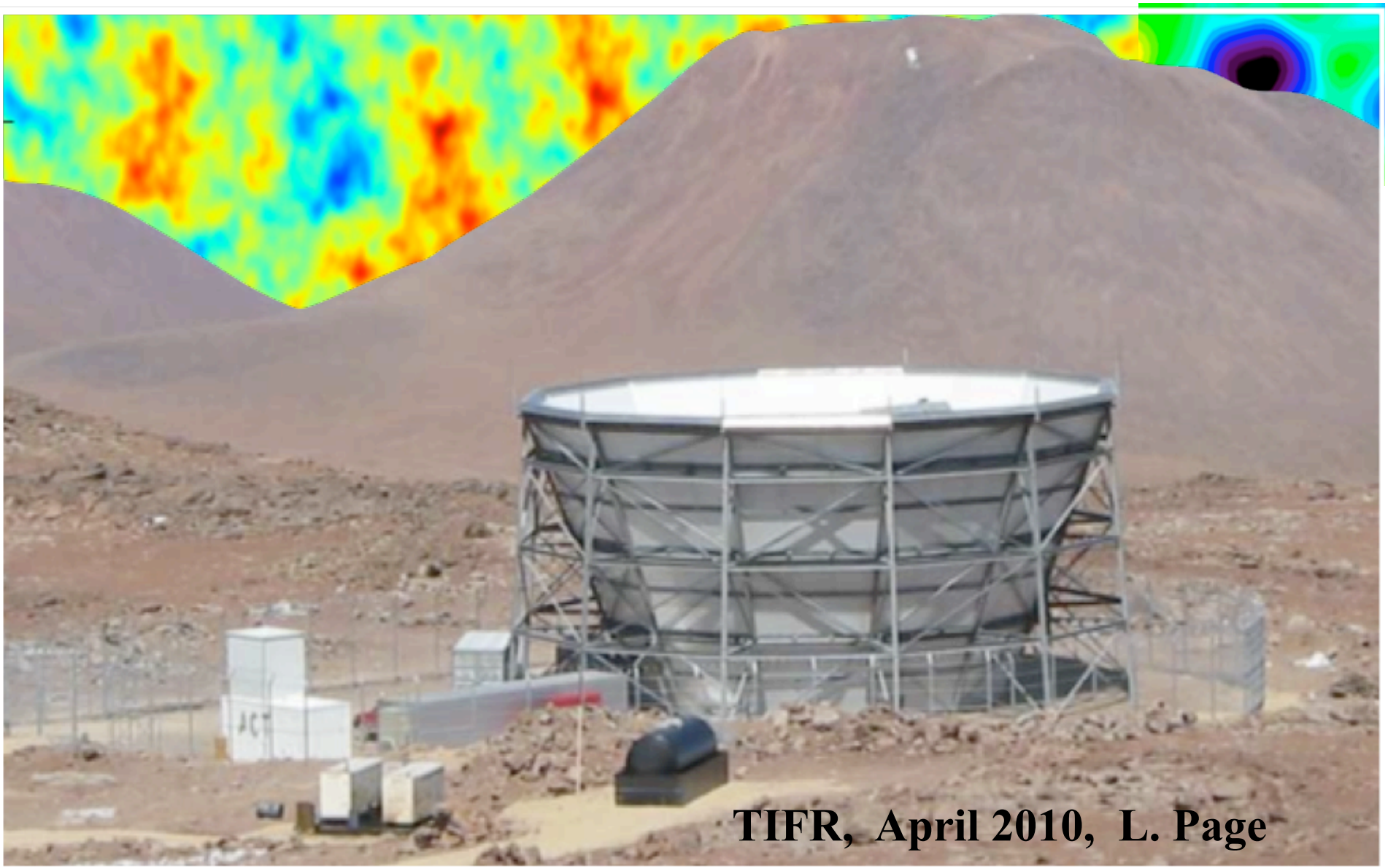
The Atacama Cosmology Telescope



TIFR, April 2010, L. Page

arXiv:0903.0902v1 [astro-ph.CO] 5 Mar 2009

Observing the Evolution of the Universe

Cover page for a white paper in support of fine angular scale CMB probes.[1]

Co-signers in support of the science: James Aguirre, Alexandre Amblard, Amjad Ashoorioon, Carlo Baccigalupi, Amedeo Balbi, James Bartlett, Nicola Bartolo, Dominic Benford, Mark Birkinshaw, Jamie Bock, Dick Bond, Julian Borrill, Franois Bouchet, Michael Bridges, Emory Bunn, Erminia Calabrese, Christopher Cantalupo, Ana Caramete, Carmelita Carbone, Suchetana Chatterjee, Sarah Church, David Chuss, Carlo Contaldi, Asantha Cooray, Sudeep Das, Francesco De Bernardis, Paolo De Bernardis, Gianfranco De Zotti, Jacques Delabrouille, F.-Xavier Dsert, Mark Devlin, Clive Dickinson, Simon Dicker, Matt Dobbs, Scott Dodelson, Olivier Dore, Jessie Dotson, Joanna Dunkley, Maria Cristina Falvella, Dale Fixsen, Pablo Fosalba, Joseph Fowler, Evalyn Gates, Walter Gear, Sunil Golwala, Krzysztof Gorski, Alessandro Gruppuso, Josh Gundersen, Mark Halpern, Shaul Hanany, Masashi Hazumi, Carlos Hernandez-Monteagudo, Mark Hertzberg, Gary Hinshaw, Christopher Hirata, Eric Hivon, Warren Holmes, William Holzapfel, Wayne Hu, Johannes Hubmayr, Kevin Huffenberger, Kent Irwin, Mark Jackson, Andrew Jaffe, Bradley Johnson, William Jones, Manoj Kaplinghat, Brian Keating, Reijo Keskitalo, Justin Khoury, Will Kinney, Theodore Kisner, Lloyd Knox, Alan Kogut, Eiichiro Komatsu, Arthur Kosowsky, John Kovac, Lawrence Krauss, Hannu Kurki-Suonio, Susana Landau, Charles Lawrence, Samuel Leach, Adrian Lee, Erik Leitch, Rodrigo Leonardi, Julien Lesgourgues, Andrew Liddle, Eugene Lim, Michele Limon, Marilena Loverde, Philip Lubin, Antonio Magalhaes, Davide Maino, Tobias Marriage, Victoria Martin, Sabino Matarrese, John Mather, Harsh Mathur, Tomotake Matsumura, Pieter Meerburg, Alessandro Melchiorri, Stephan Meyer, Amber Miller, Michael Milligan, Kavilan Moodley, Michael Neimack, Hogan Nguyen, Ian O'Dwyer, Angiola Orlando, Luca Pagano, Lyman Page, Bruce Partridge, Timothy Pearson, Hiranya Peiris, Francesco Piacentini, Lucio Piccirillo, Elena Pierpaoli, Davide Pietrobon, Giampaolo Pisano, Levon Pogosian, Dmitri Pogosyan, Nicolas Ponthieu, Lucia Popa, Clement Pryke, Christoph Raeth, Subharthi Ray, Christian Reichardt, Sara Ricciardi, Paul Richards, Graca Rocha, Lawrence Rudnick, John Ruhl, Benjamin Rusholme, Claudia Scoccola, Douglas Scott, Carolyn Sealfon, Neelima Sehgal, Michael Seiffert, Leonardo Senatore, Paolo Serra, Sarah Shandera, Meir Shimon, Peter Shirron, Jonathan Sievers, Kris Sigurdson, Joe Silk, Robert Silverberg, Eva Silverstein, Suzanne Staggs, Albert Stebbins, Federico Stivoli, Radek Stompor, Naoshi Sugiyama, Daniel Swetz, Andria Tartari, Max Tegmark, Peter Timbie, Matthieu Tristram, Gregory Tucker, Jon Urrestilla, John Vaillancourt, Marcella Veneziani, Licia Verde, Joaquin Vieira, Scott Watson, Benjamin Wandelt, Grant Wilson, Edward Wollack, Mark Wyman, Amit Yadav, Giraud-Heraud Yannick, Olivier Zahn, Matias Zaldarriaga, Michael Zemcov, Jonathan Zwart

1. What is the dark energy and what are its characteristics? Did the dark energy act differently before $z = 1$?

2. Did neutrinos leave an identifiable imprint on the cosmos and if so what is the sum of their masses? Measurements of neutrino oscillations show that the difference in the square of the masses is ~ 0.002 (eV)^2, indicating that at least one species must have a mass near 0.05 eV. This value can be determined with fine scale anisotropy measurements.

3. Where are the missing baryons? Big Bang nucleosynthesis and CMB derived baryon densities are not in accord with the observational census.

4. How did the first stars turn on and what is their ionization history?

5. Did the early universe have only Gaussian fluctuations or were there phase transitions that perhaps produced cosmic strings? The discovery of primordial non-Gaussianity would revolutionize cosmology.

6. Are the fluctuations solely adiabatic or is there an admixture of isocurvature modes?

Science questions from white paper

astro-ph/0903.0902

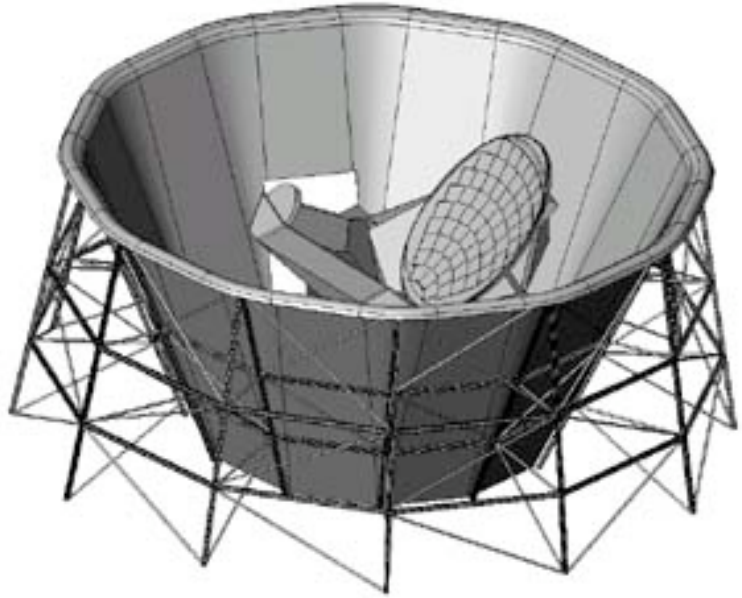
ACT

Science:

- ★Growth of structure
- ★Eqn. of state
- ★Neutrino mass
- ★Inflation
- ★Power spectrum

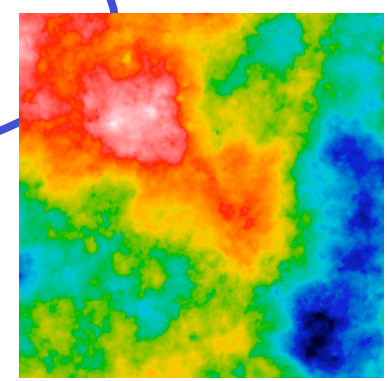
Observations:

- ★CMB: l>1000
- ★ Cluster (SZ, KSZ X-rays, & optical)
- ★ Diffuse SZ
- ★ Lensing



X-ray

Optical (SALT, NTT, SOAR, APO, Gemini, Keck, Hubble)

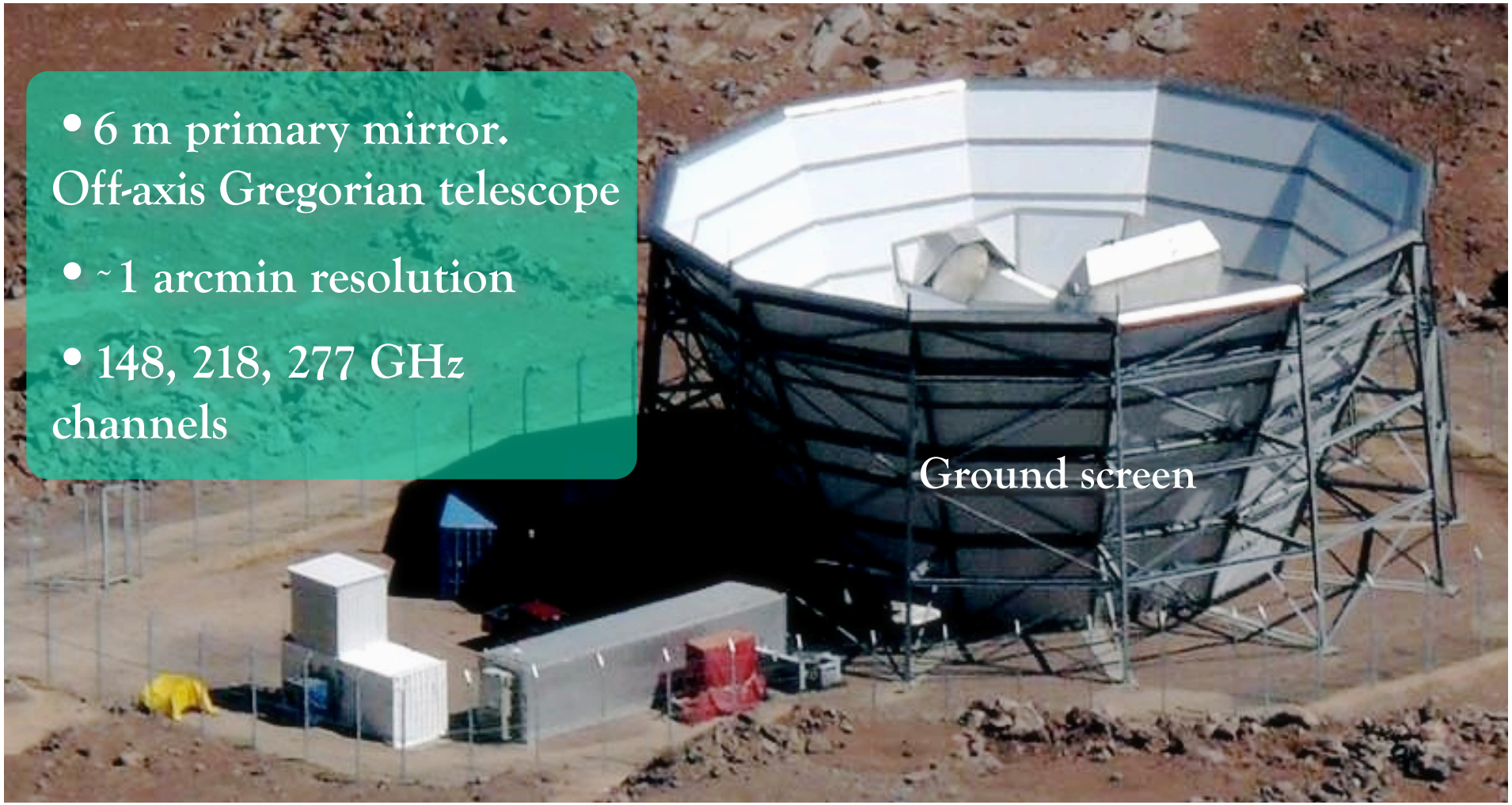


Theory

V. Acquaviva [1,2]
P. Ade [3]
P. Aguirre [4]
M. Amiri [5]
J. Appel [6]
E. Battistelli [7,5]
J. R. Bond [8]
B. Brown [9]
B. Burger [5]
J. Chervenak [10]
S. Das [6,1]
M. Devlin [2]
S. Dicker [2]
W. B. Doriese [11]
J. Dunkley [12,6,1]
R. Dunner [4]
T. Essinger-Hileman [6]
R.P. Fisher [6]
J. W. Fowler [6]
A. Hajian [6]
M. Halpern [5]
M. Hasselfield [5]
C. Hernandez-Monteagudo [13,2]
G. Hilton [11]
M. Hilton [14, 15]
A. D. Hincks [6]
R. Hlozek [12]
K. Huffenberger [16,6]
D. Hughes [17]
J. P. Hughes [18]
L. Infante [4]
K.D. Irwin [11]
N. Jarosik [6]
R. Jimenez [19]
J.B. Juin [4]
M. Kaul [2]
J. Klein [2]
A. Kosowsky [9]
J.M. Lau [20,6]
M. Limon [21]
Y.T. Lin [22,1,4]
R. Lupton [1]
T.A. Marriage [1,6]
D. Marsden [2]
K. Martocci [23,6]
P. Mauskopf [3]
F. Menanteau [18]
K. Moodley [14]
H. Moseley [10]
B. Netterfield [24]
M.D. Niemack [11,6]
M.R. Nolta [8]
L.A. Page (PI) [6]
L. Parker [6]
B. Partridge [25]
H. Quintana [4]
B. Reid [19,1]
N. Sehgal [20,18]
J. Sievers [8]
D. Spergel [1]
S.T. Staggs [6]
O. Stryzak [6]
D. Swetz [2]
E. Switzer [23,6]
R. Thornton [26,2]
H. Trac [27,1]
C. Tucker [3]
L. Verde [19]
R. Warne [14]
G. Wilson [28]
E. Wollack [10]
Y. Zhao [6]

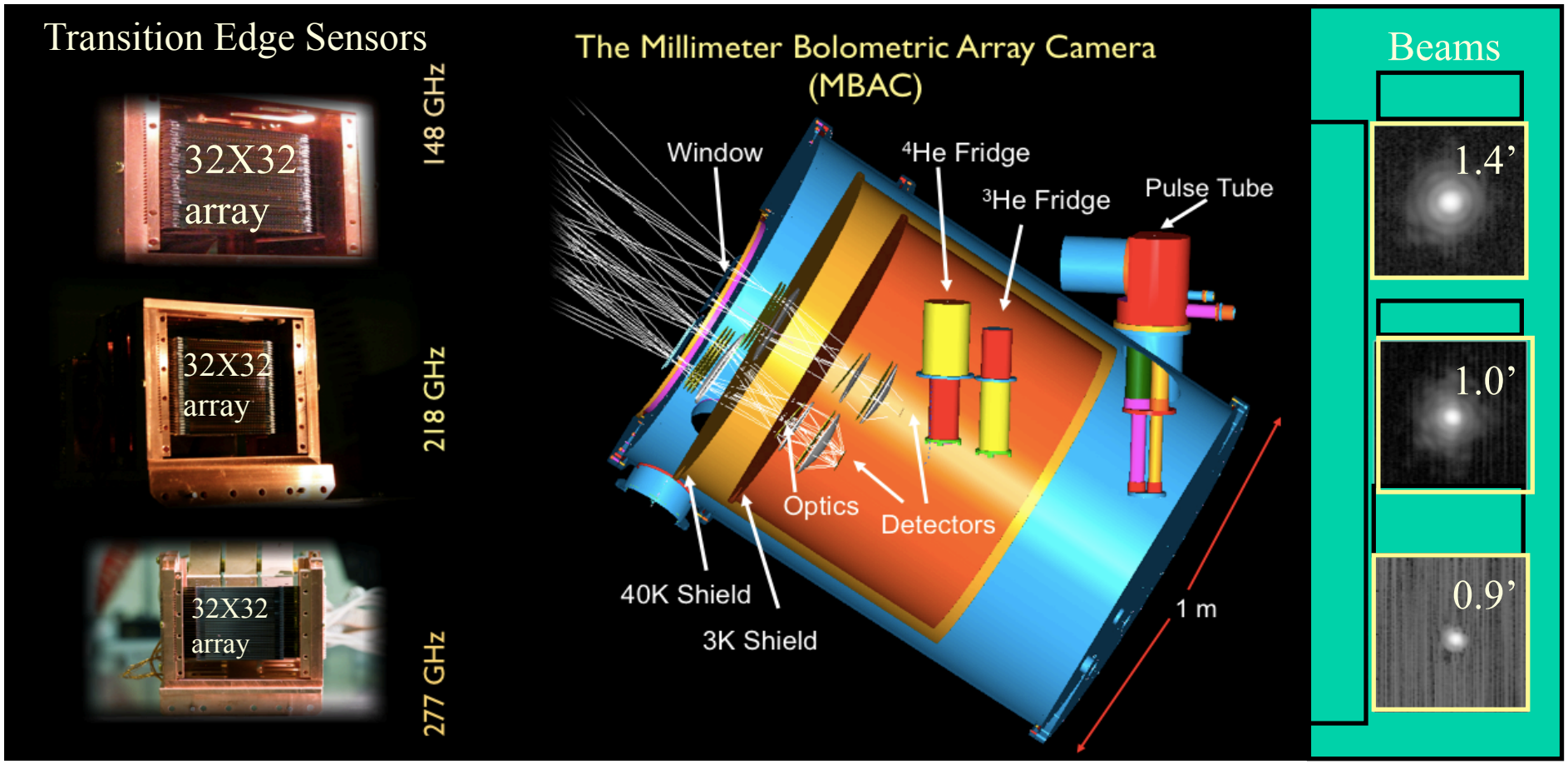
[1] Princeton University Astrophysics (USA)
[2] University of Pennsylvania (USA)
[3] Cardiff University (UK)
[4] Pontifica Universidad Catolica de Chile (Chile)
[5] University of British Columbia (Canada)
[6] Princeton University Physics (USA)
[7] University of Rome "La Sapienza" (Italy)
[8] CITA, University of Toronto (Canada)
[9] University of Pittsburgh (USA)
[10] NASA Goddard Space Flight Center (USA)
[11] NIST Boulder (USA)
[12] Oxford University (UK)
[13] Max Planck Institut fur Astrophysik (Germany)
[14] University of KwaZulu-Natal (South Africa)
[15] South African Astronomical Observatory
[16] University of Miami (USA)
[17] INAOE (Mexico)
[18] Rutgers (USA)
[19] Institute de Ciencies de L'Espai (Spain)
[20] KIPAC, Stanford (USA)
[21] Columbia University (USA)
[22] IPMU (Japan)
[23] KICP, Chicago (USA)
[24] University of Toronto (Canada)
[25] Haverford College (USA)
[26] West Chester University of Pennsylvania (USA)
[27] Harvard-Smithsonian CfA (USA)
[28] University of Massachusetts, Amherst (USA)

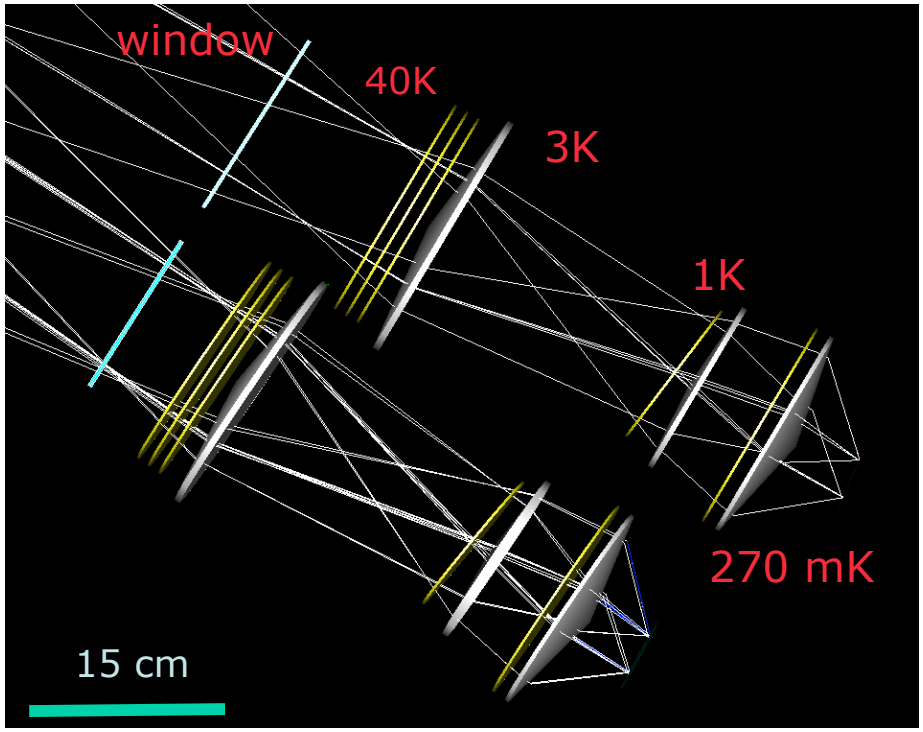
THE TELESCOPE

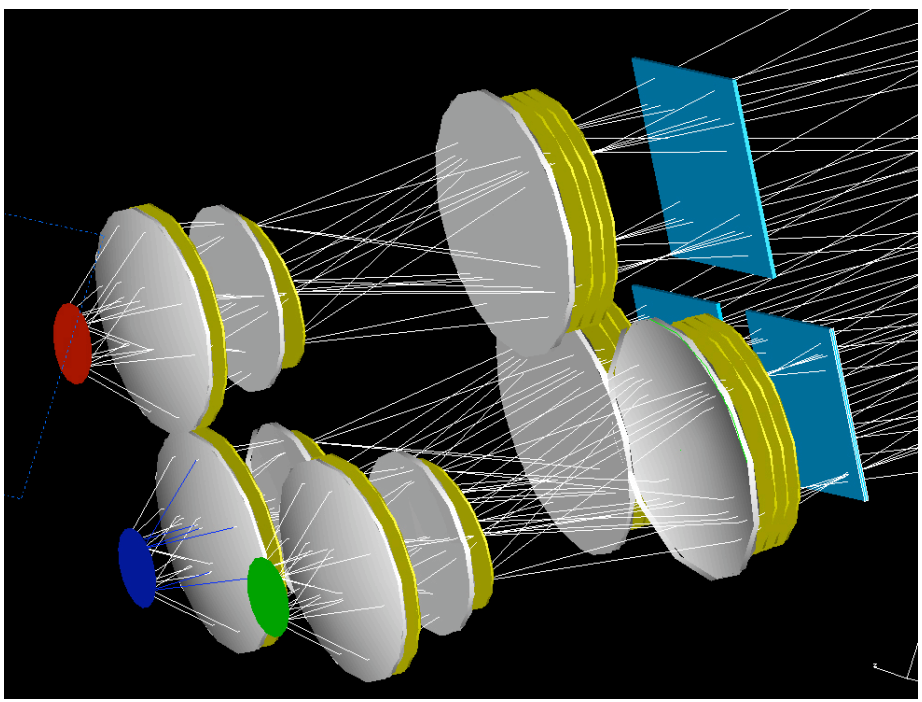


M. Devlin leads the telescope.

THE RECEIVER:
A COMPLETELY NEW KIND OF CAMERA







- Diffraction limited images over a large field of view.

  3 silicon lenses
- Array must be at 0.27K

  IR blocking filters
- Define frequency bandpasses

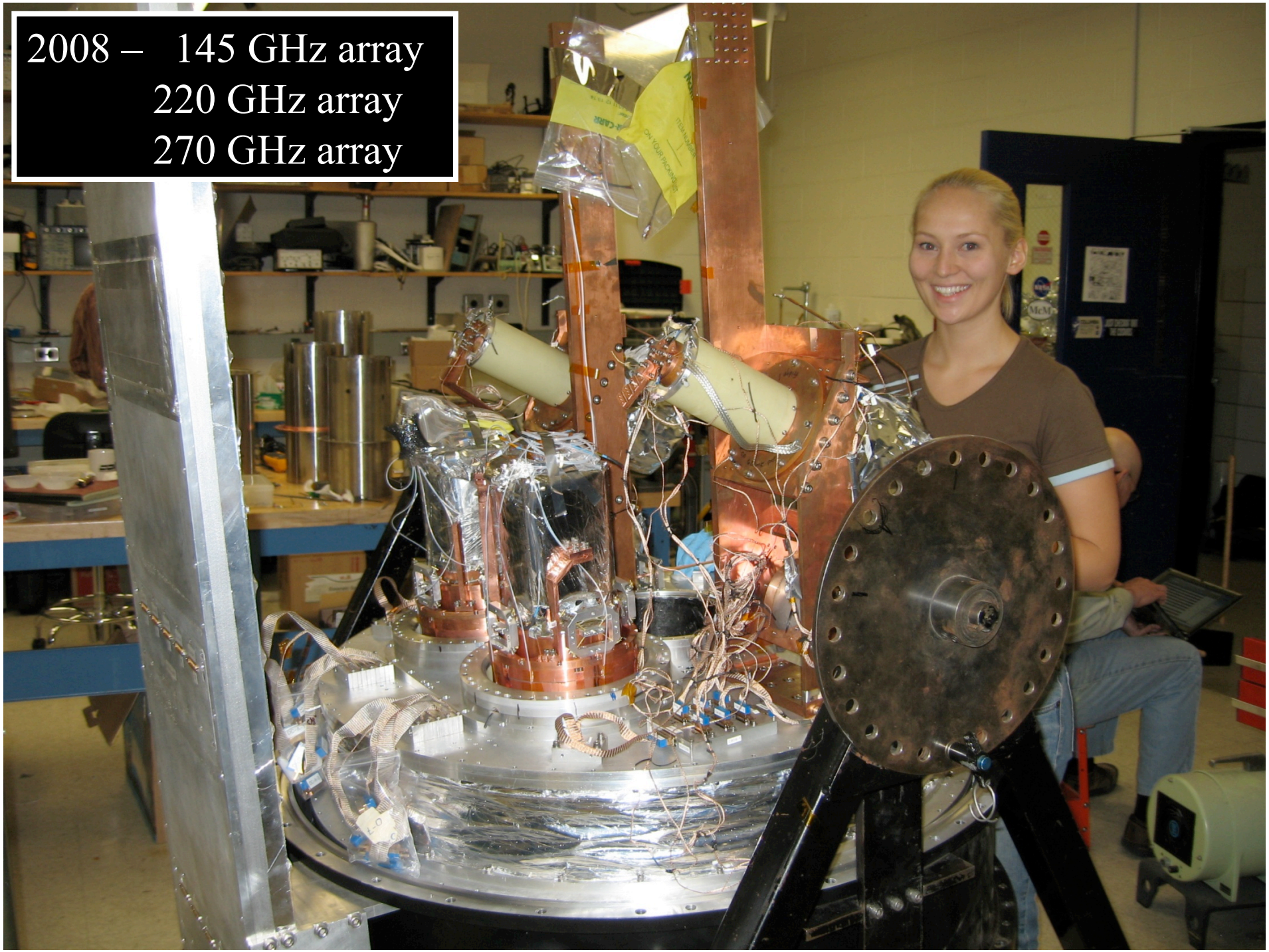
  Bandpass filter
- Illumination control

  Lyot stop
- Low emissivity (<1K of loading)

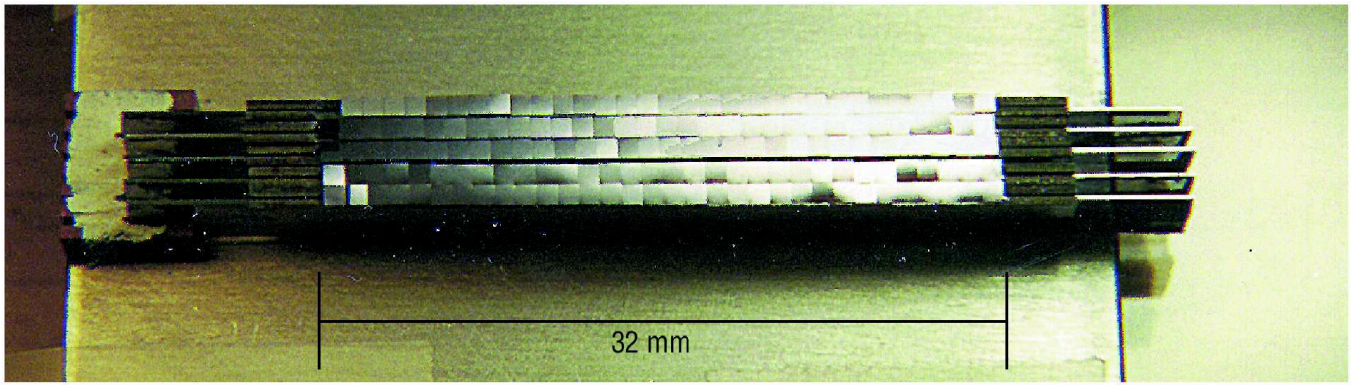
  Cool the lenses
- No “Ghosting”

  AR coatings

  careful modeling


2008 – 145 GHz array
220 GHz array
270 GHz array

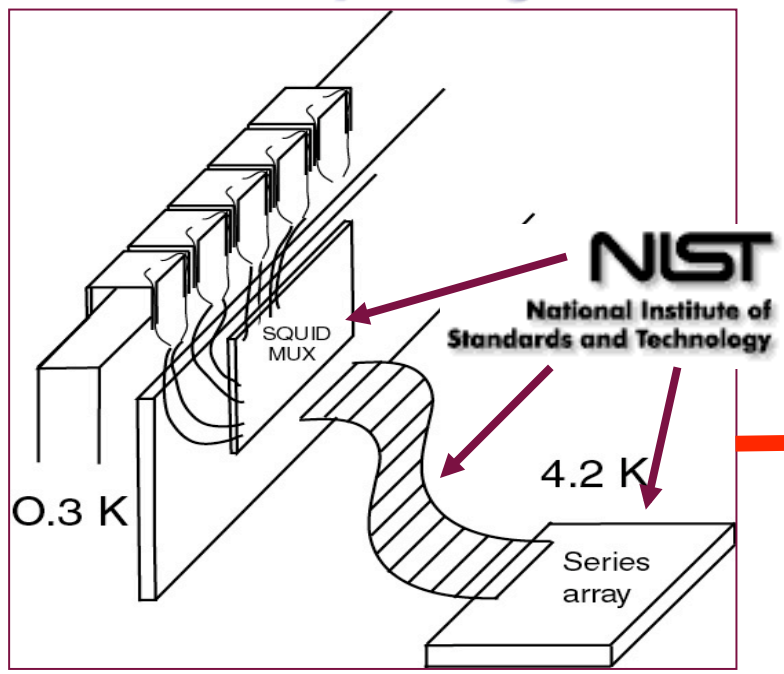
2008 – 145 GHz array
220 GHz array
270 GHz array



3 cm

Pop-up detectors (PUDs) from H. Moseley

NASA Goddard Space Flight Center



NIST
National Institute of Standards and Technology

UBC electronics

S. Staggs leads the detectors.

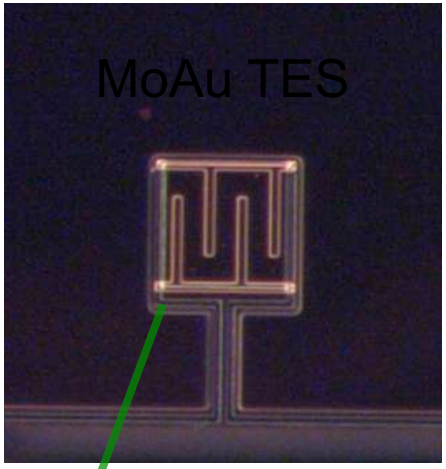
MBAC Detectors and Readout

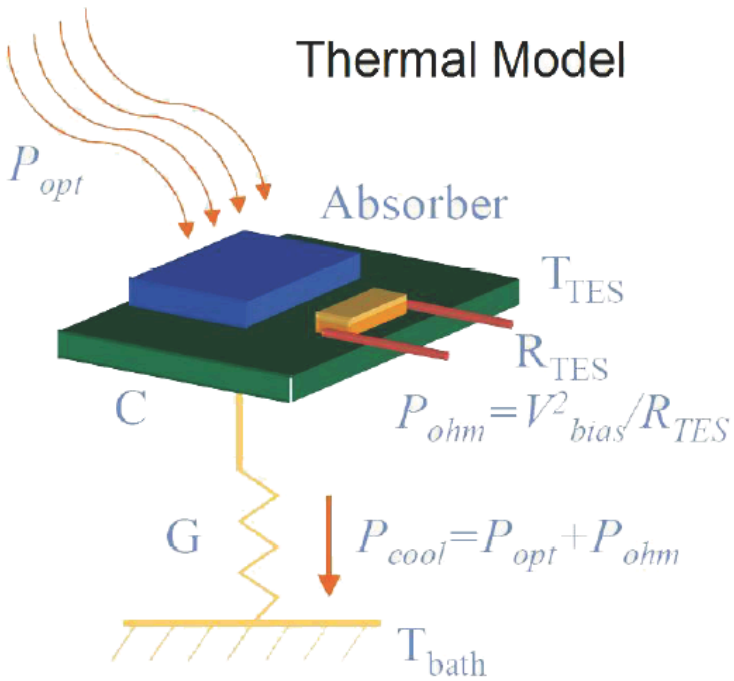
TES PUDs: detect fluctuations

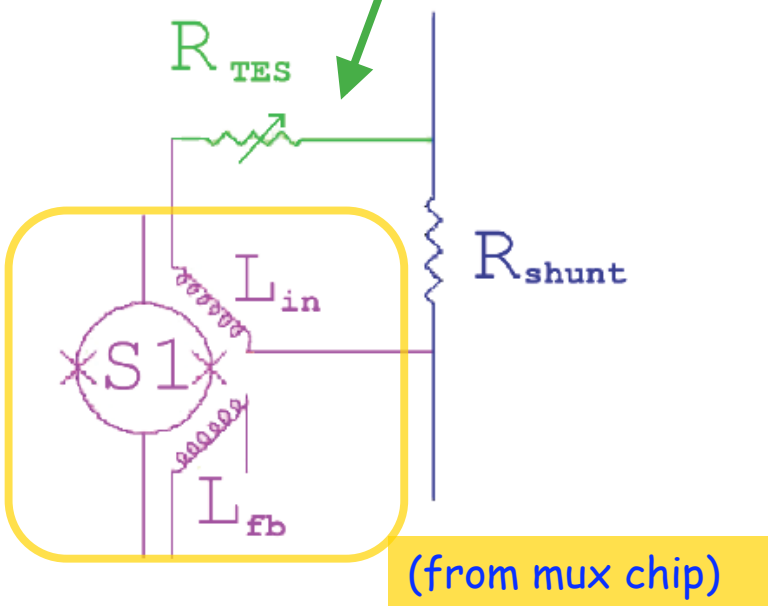
Shunts: provide voltage bias

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

Nyquist inductors: provide L/R signal bandwidth limit

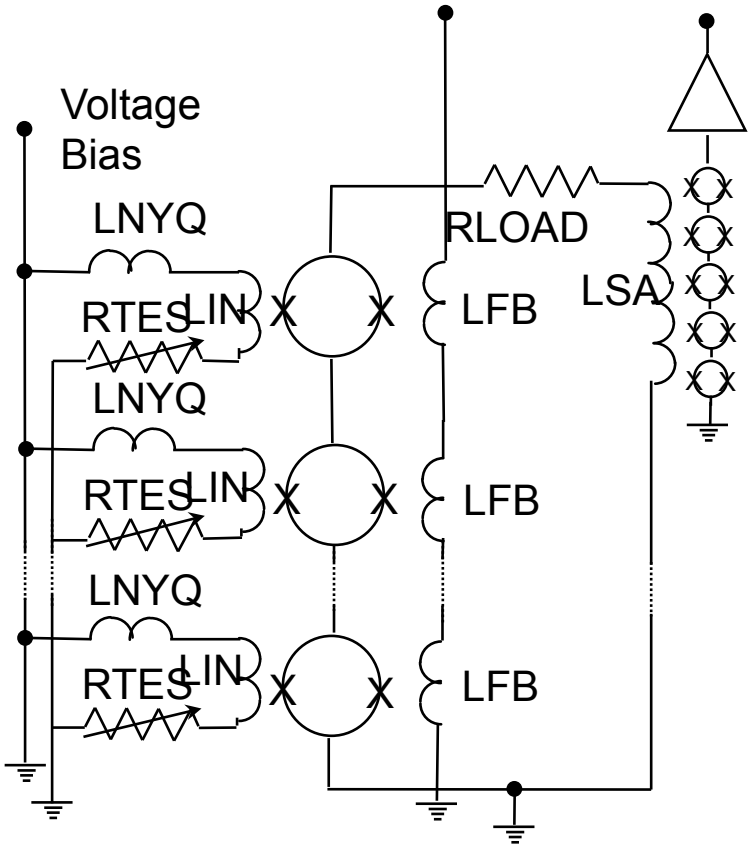




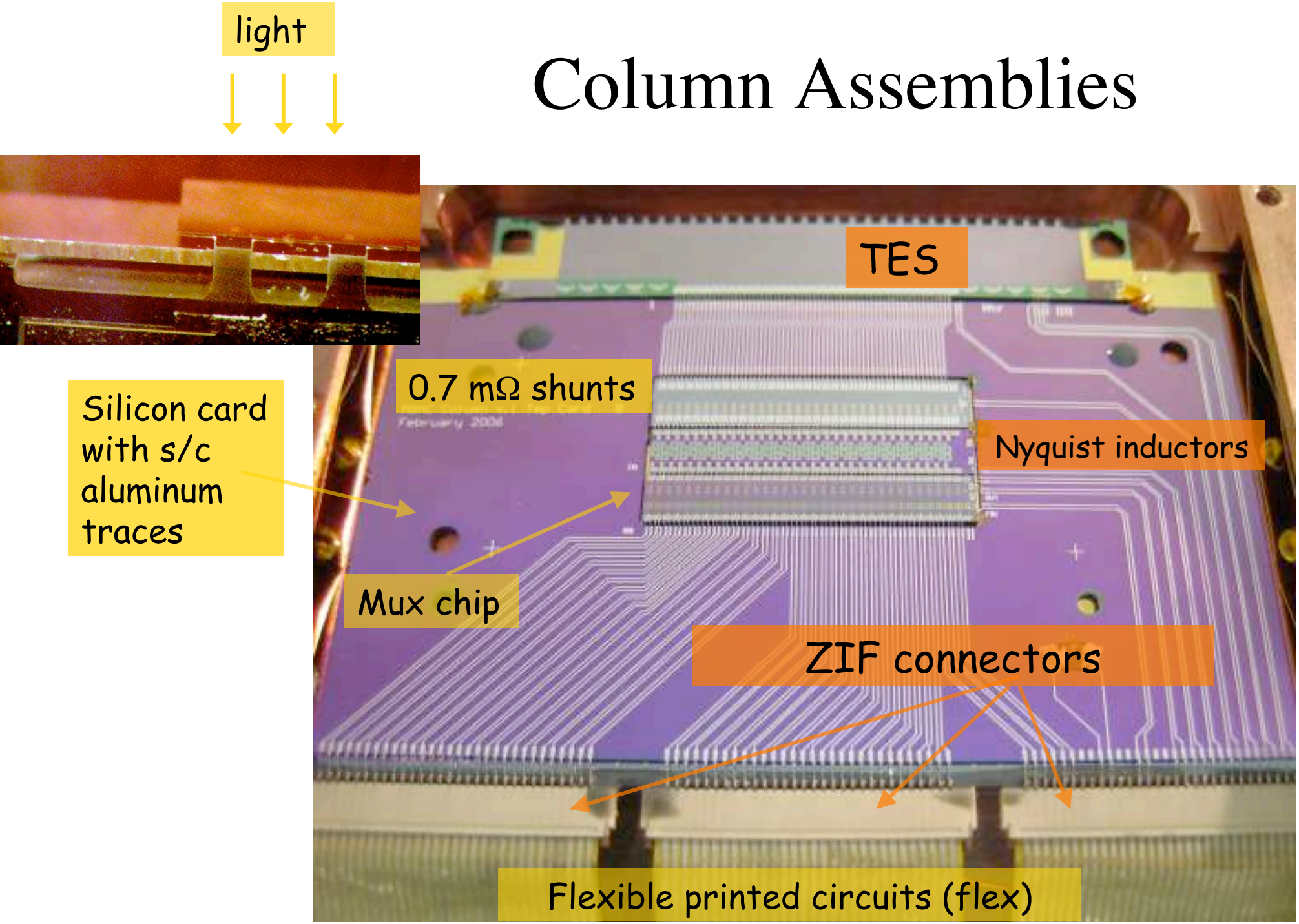


Multiplexing Concept

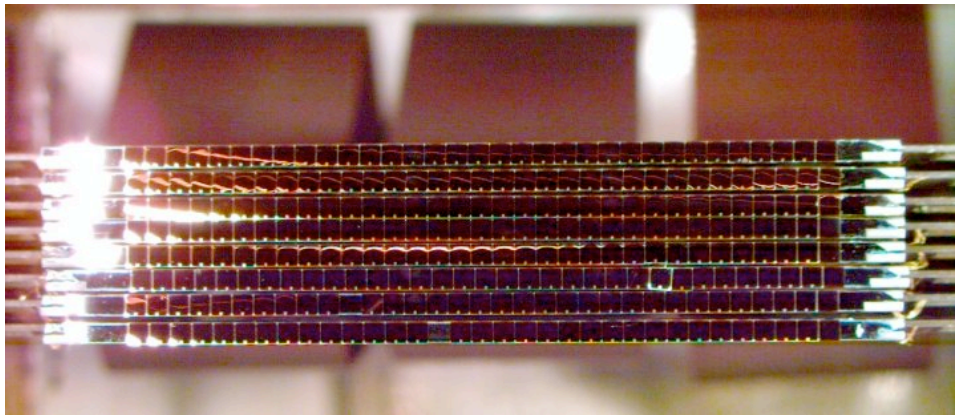
- Multiplexing is effected by sequential sampling of individual input SQUIDS

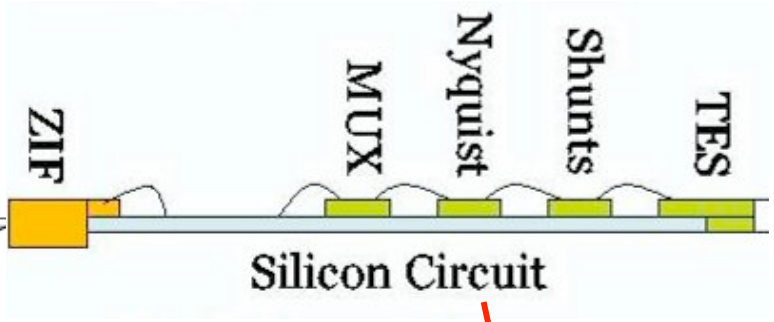


Column Assemblies

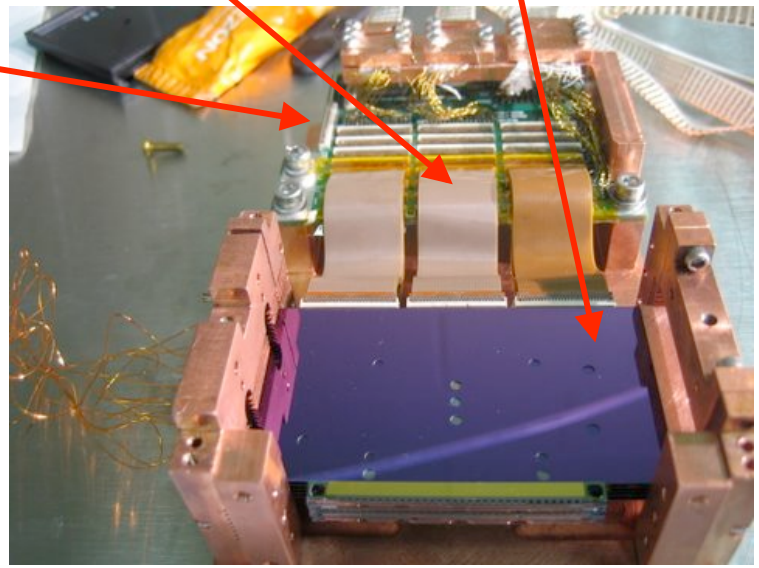


Assembly



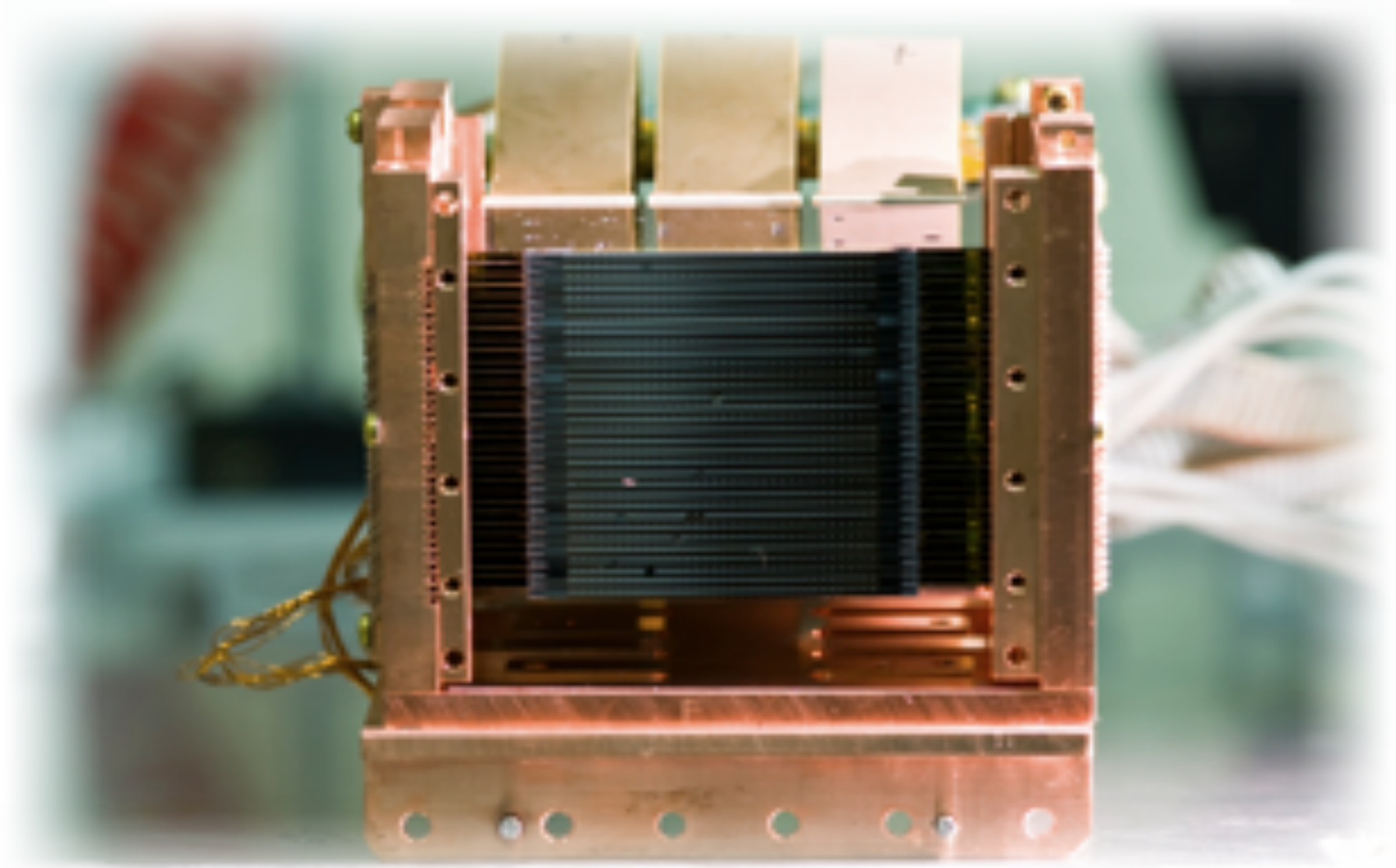


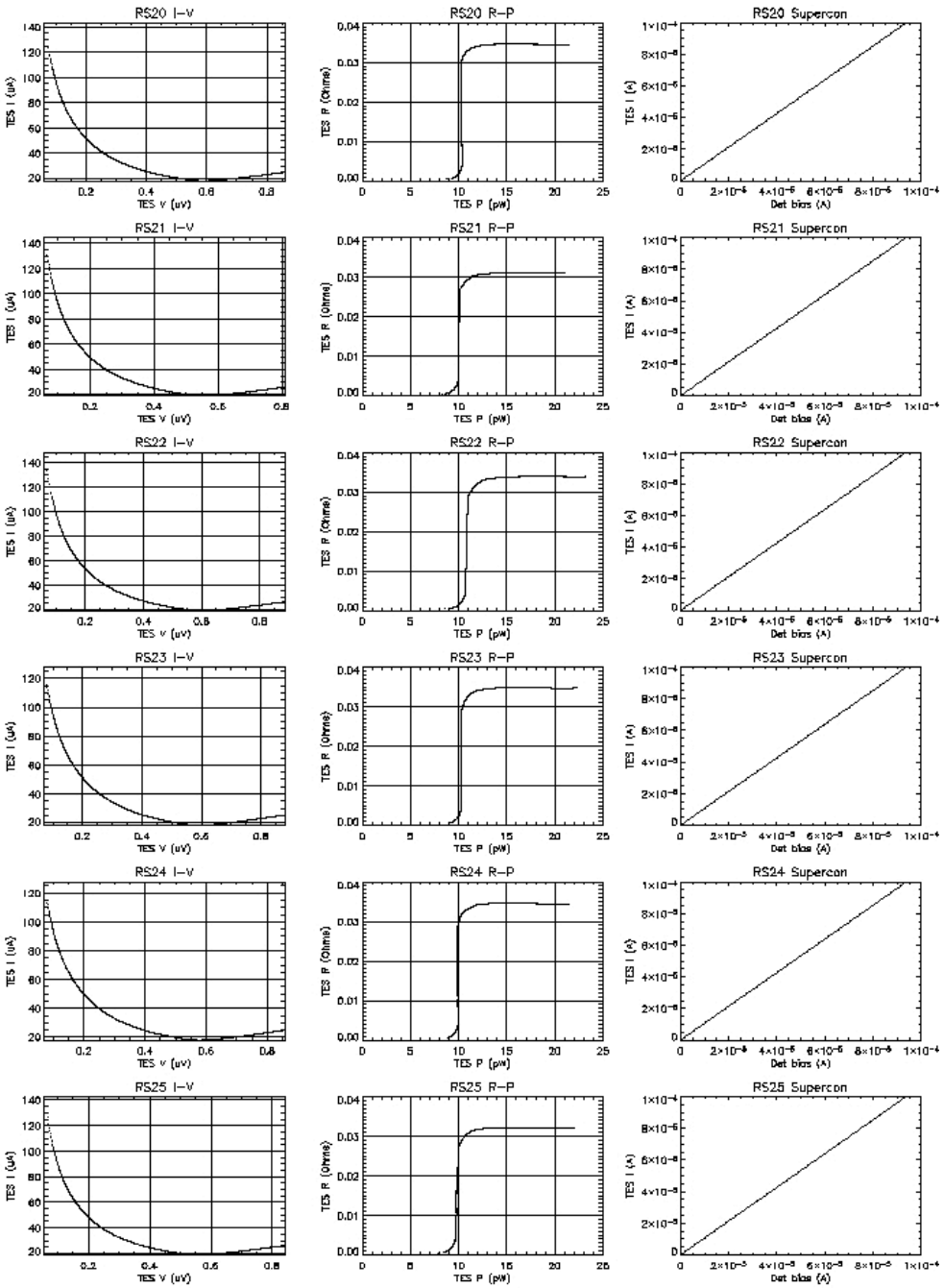
300 mK backplane



4K breakout & SA

(not shown in photo)





UBC Warm Electronics

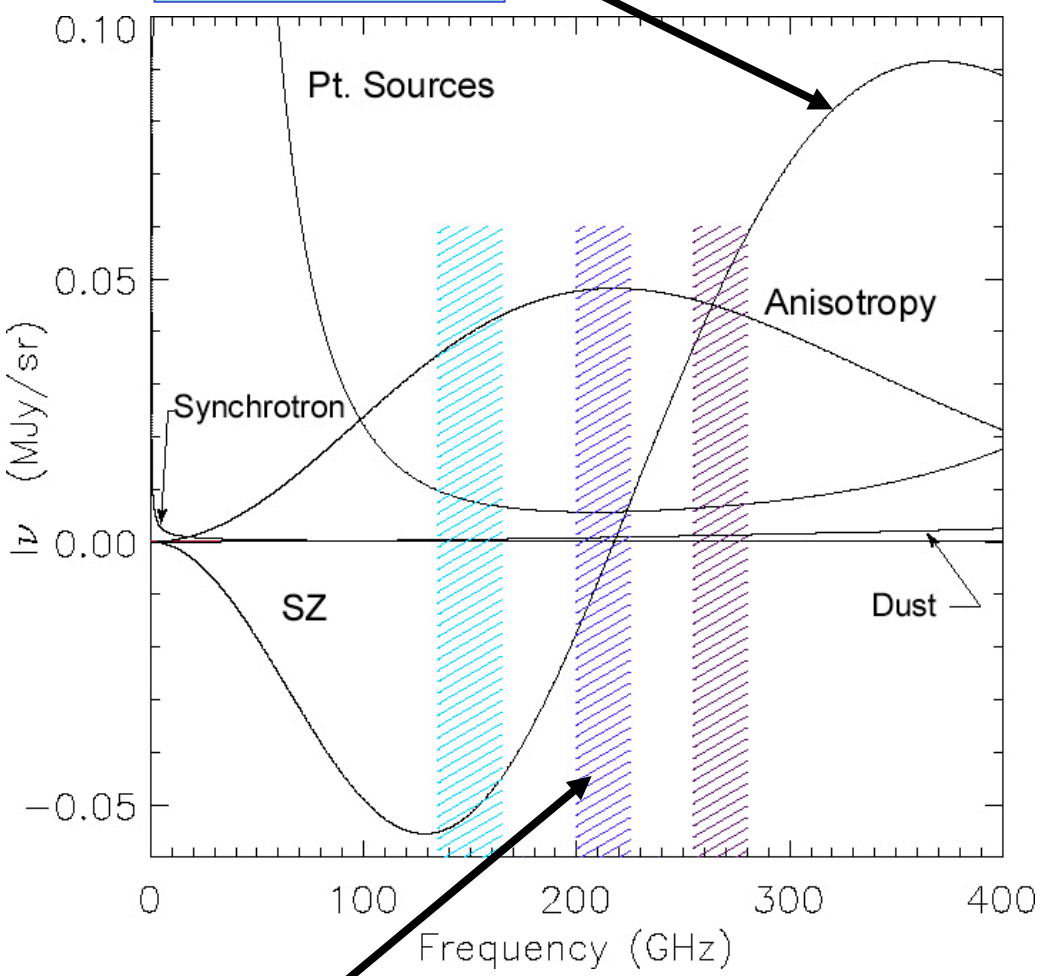
(<u>designed</u> for arrays)

Automatically tunes and biases 1000 detectors.

Figure from M. Niemack

SZ Signature

Hot electron gas imposes a unique spectral signature



145 GHz decrement

220 GHz null

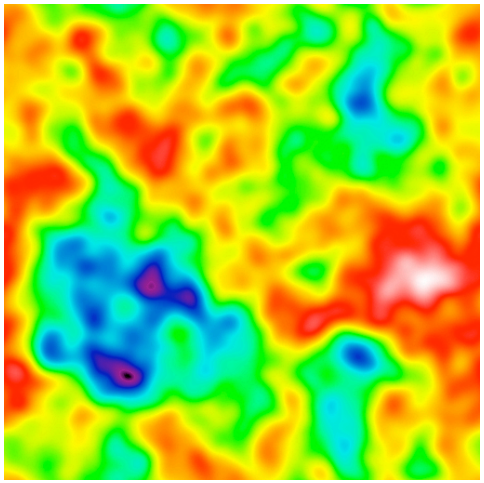
270 GHz increment

1.4°x 1.4°

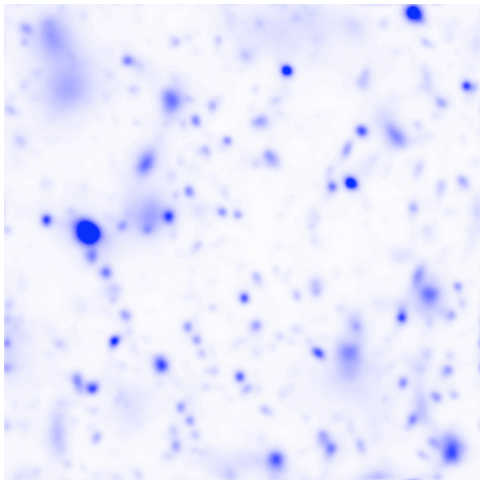
NO SZ Contribution in Central Band

145 GHz Maps

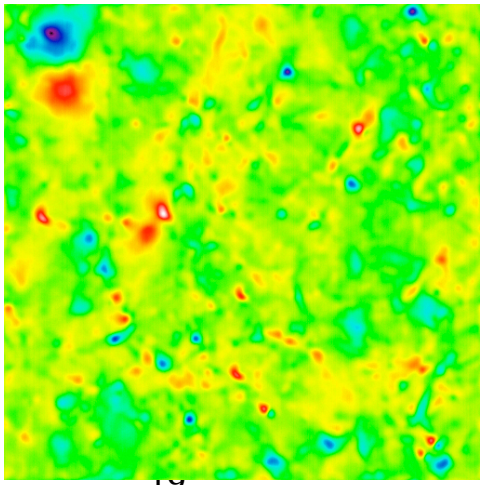
Map Components



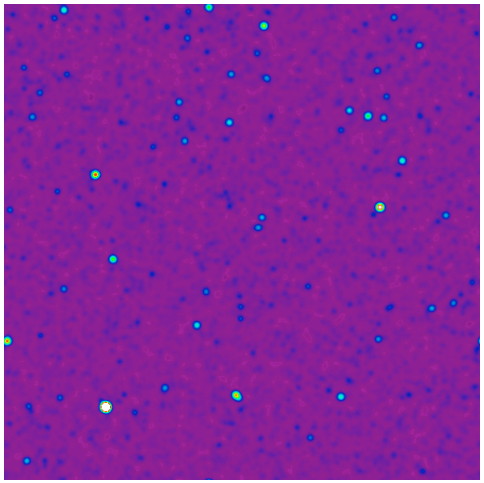
CMB



SZ

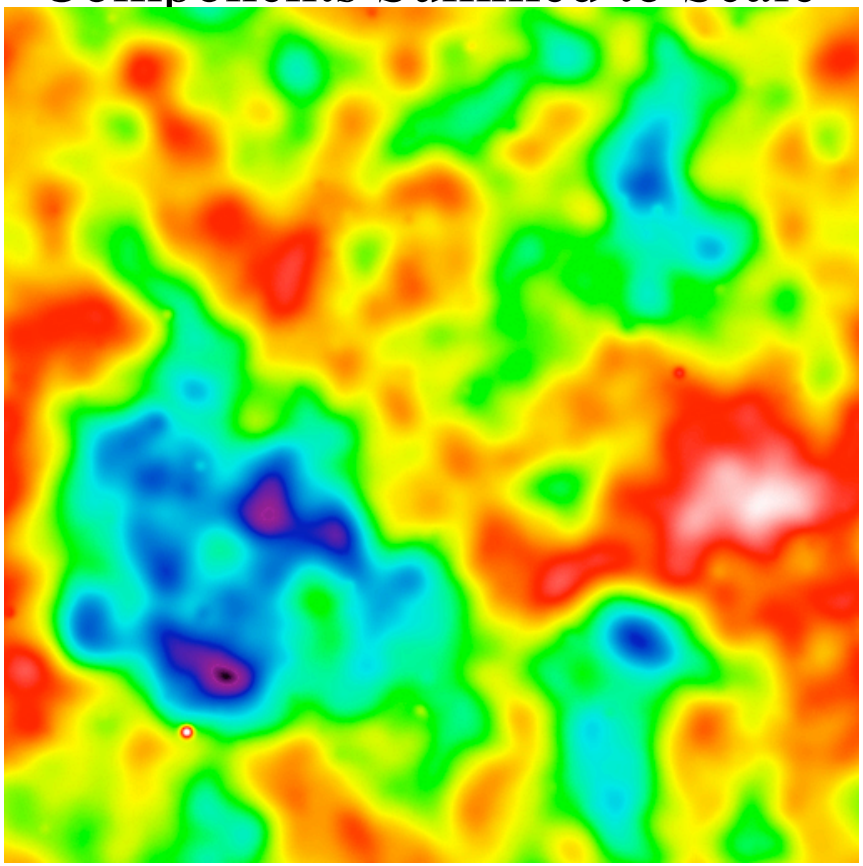


KSZ/OV



Point Sources

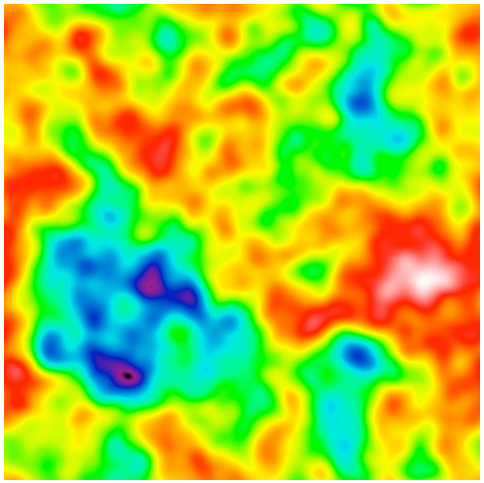
Components Summed to Scale



1.4°x 1.4°

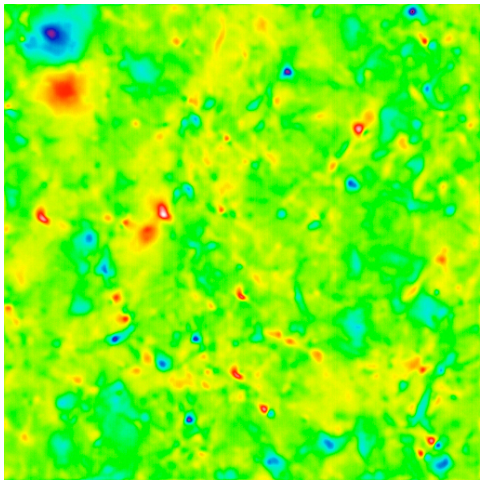
220 GHz Maps

Map Components

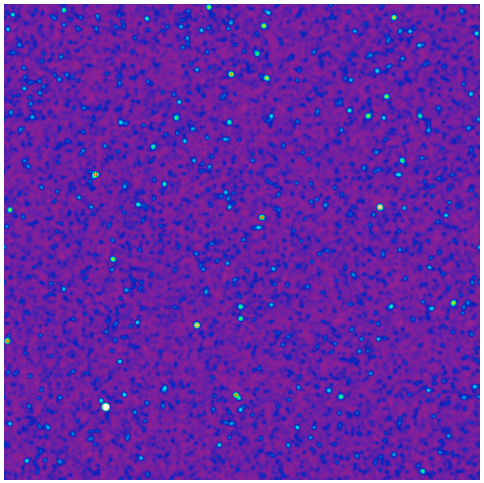


CMB

SZ

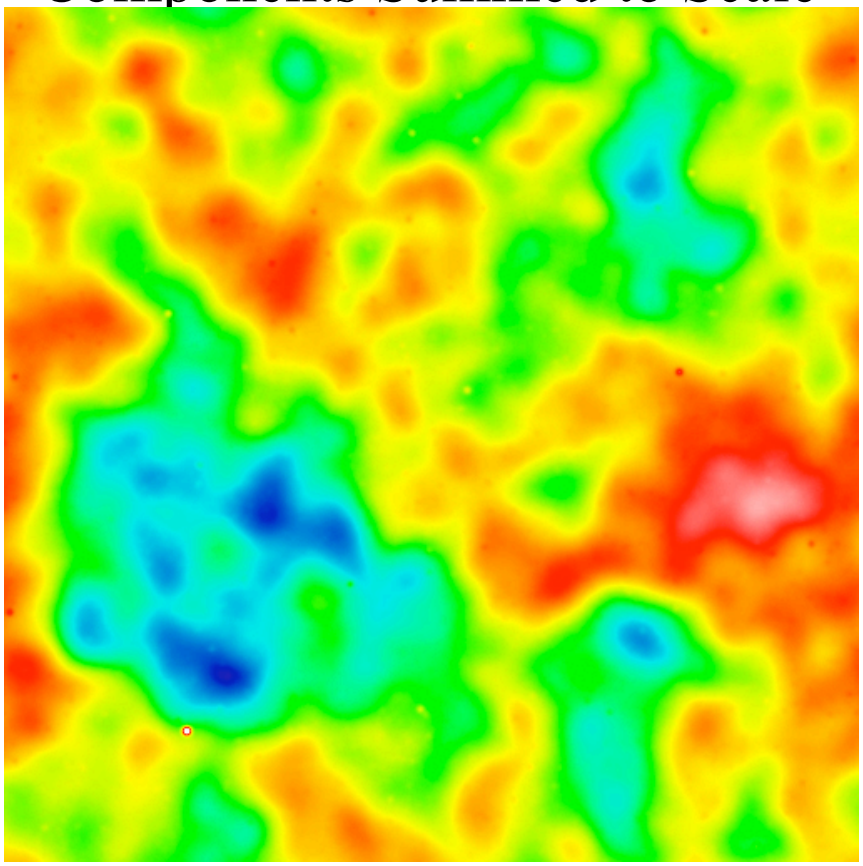


KSZ/OV



Point Sources

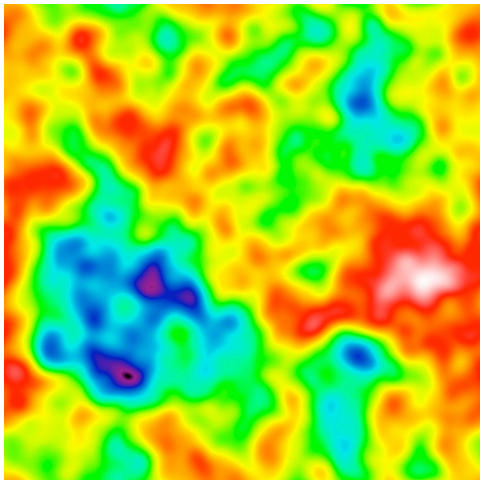
Components Summed to Scale



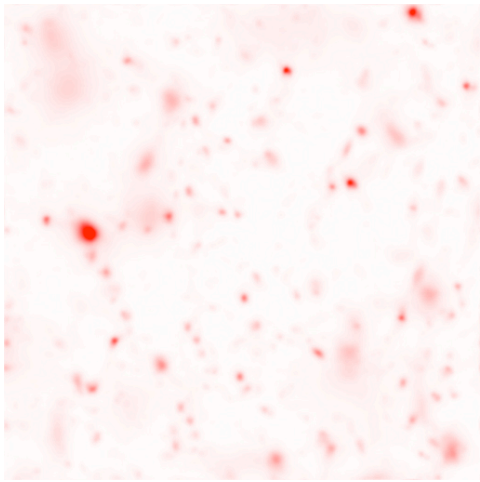
1.4°x 1.4°

270 GHz Maps

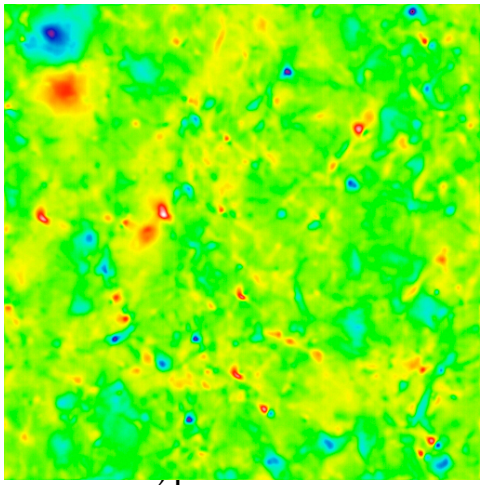
Map Components



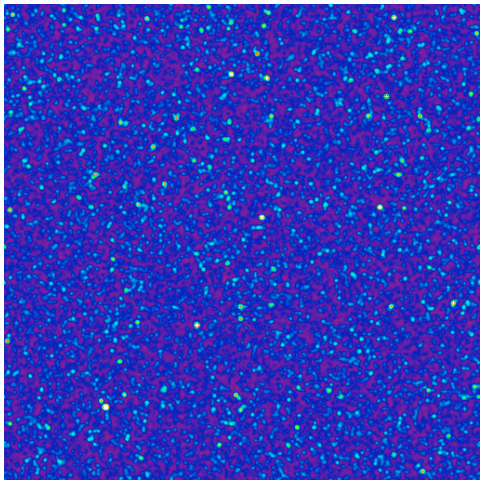
CMB



SZ

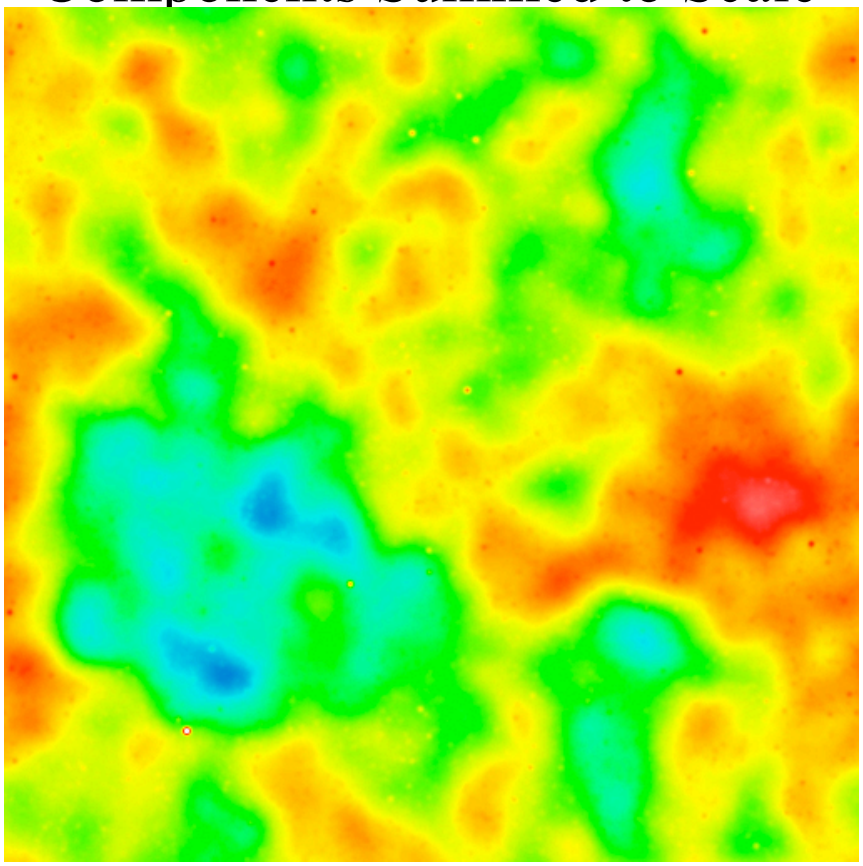


KSZ/OV



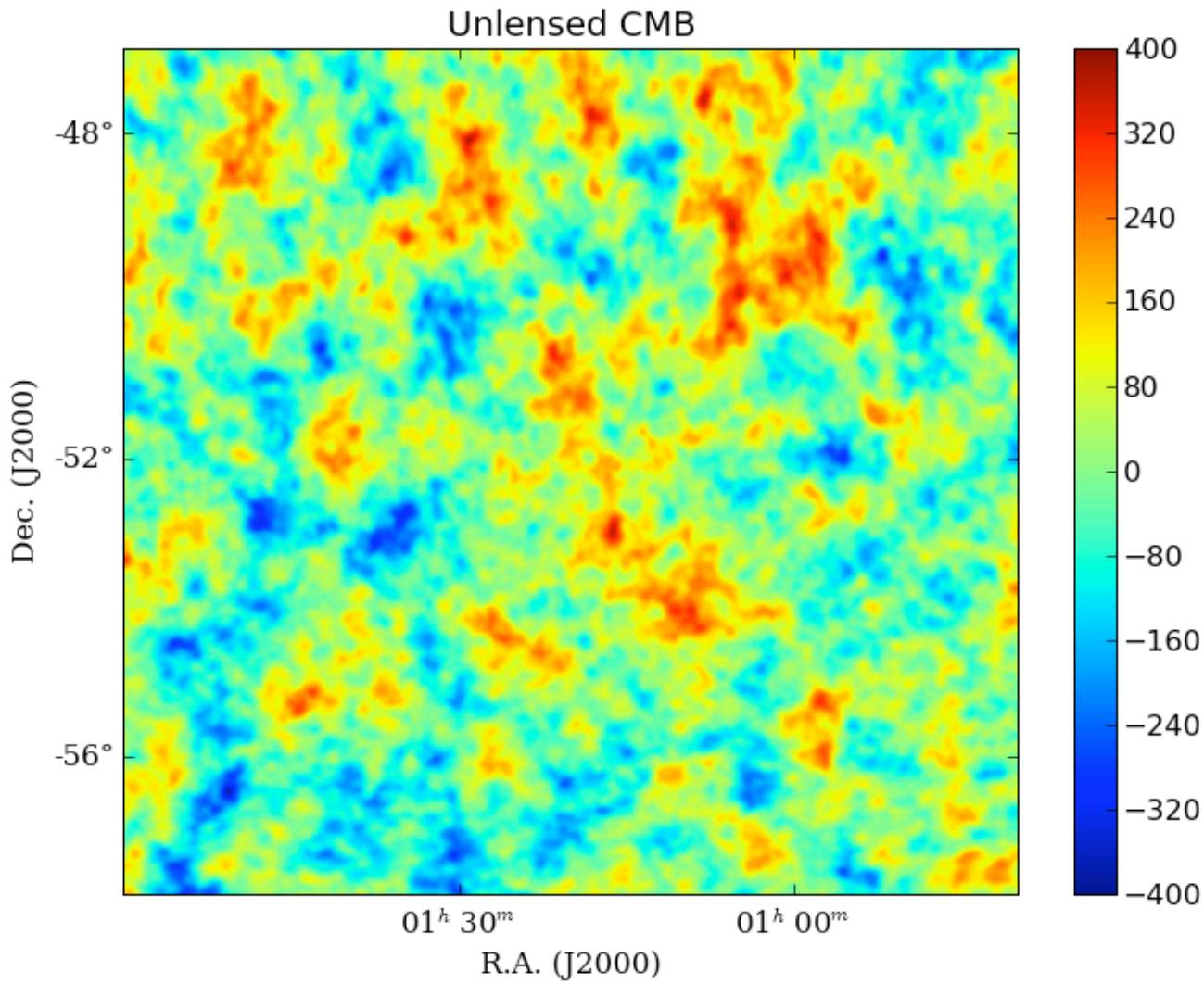
Point Sources

Components Summed to Scale



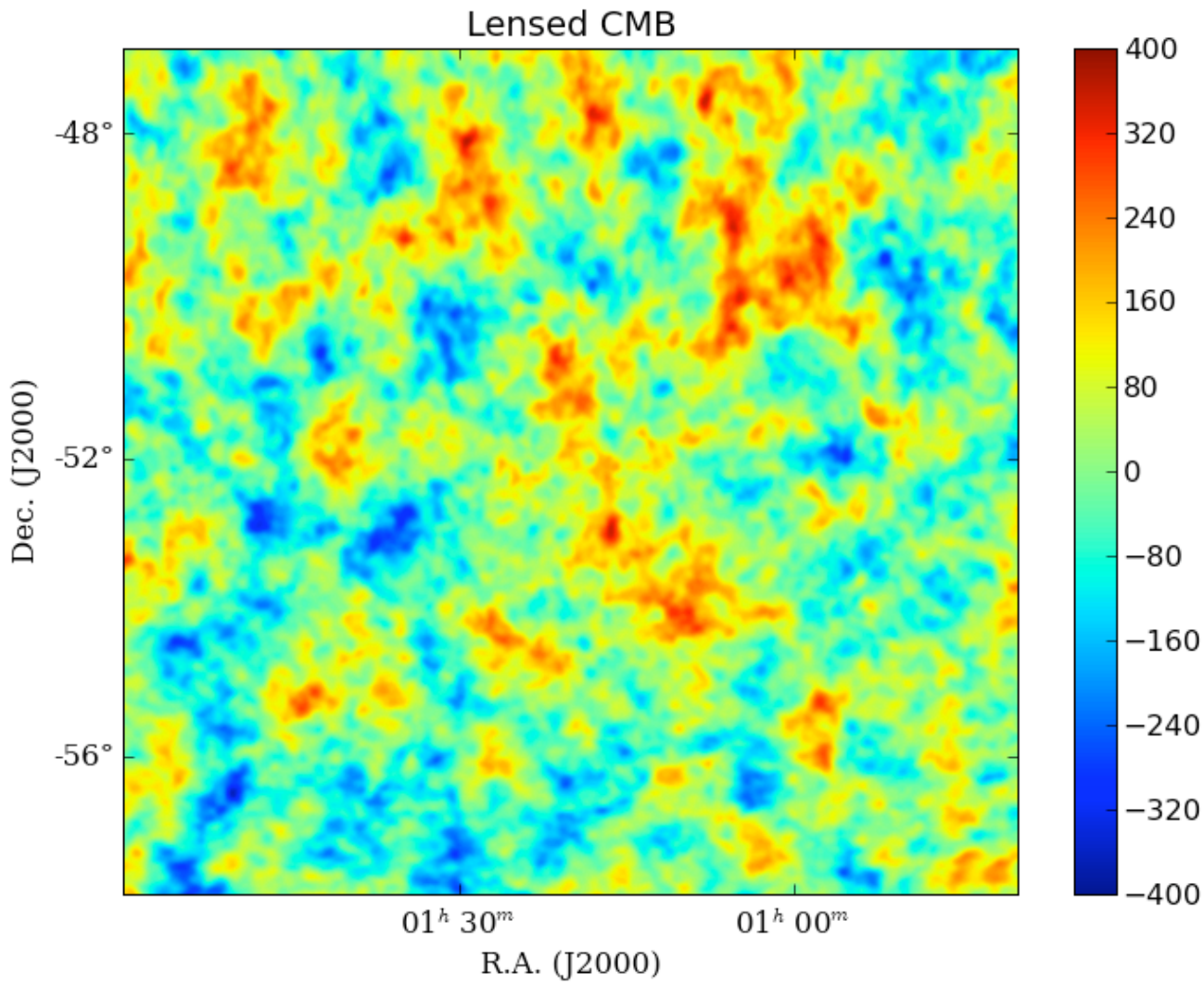
1.4°x 1.4°

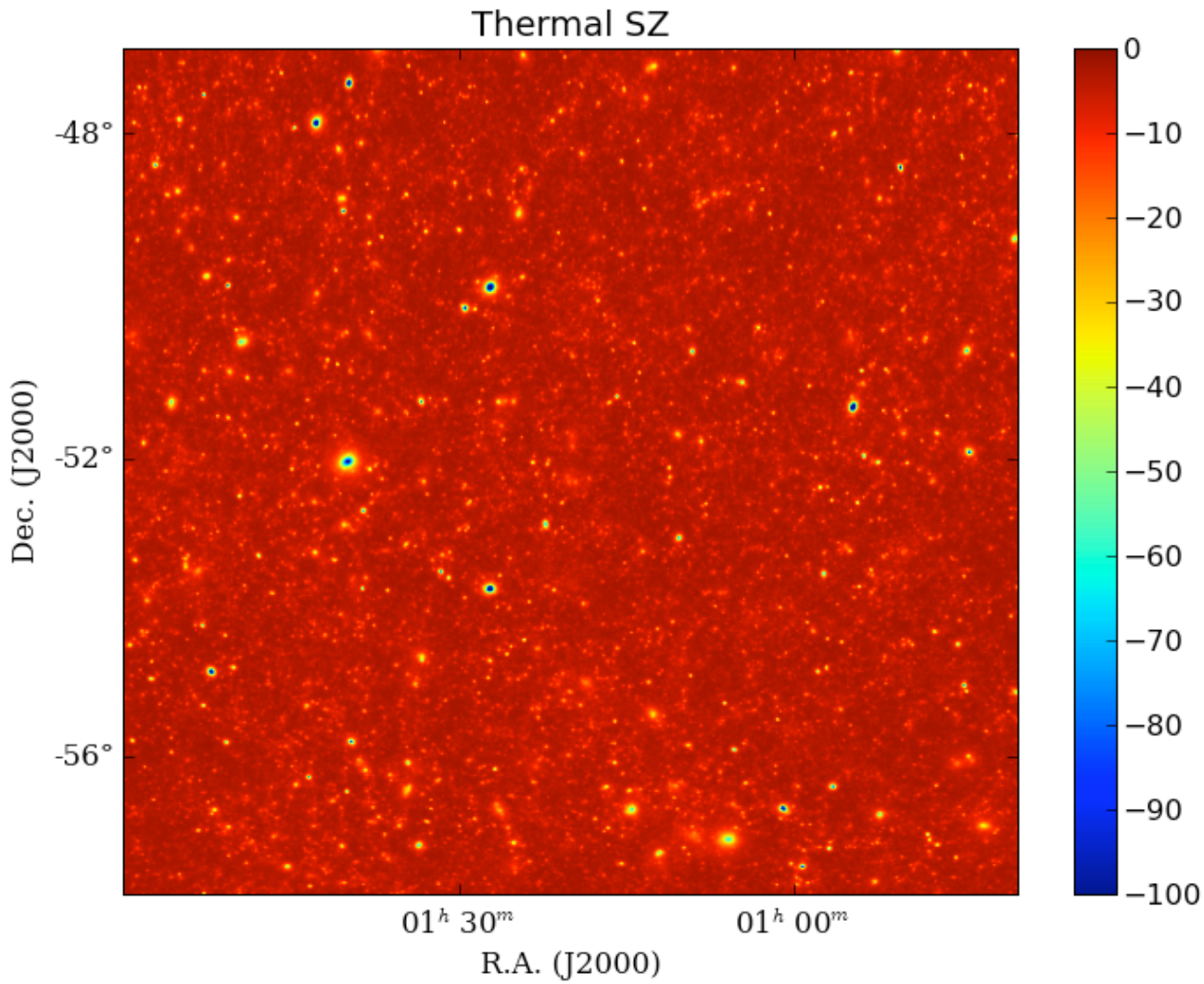
Simulations

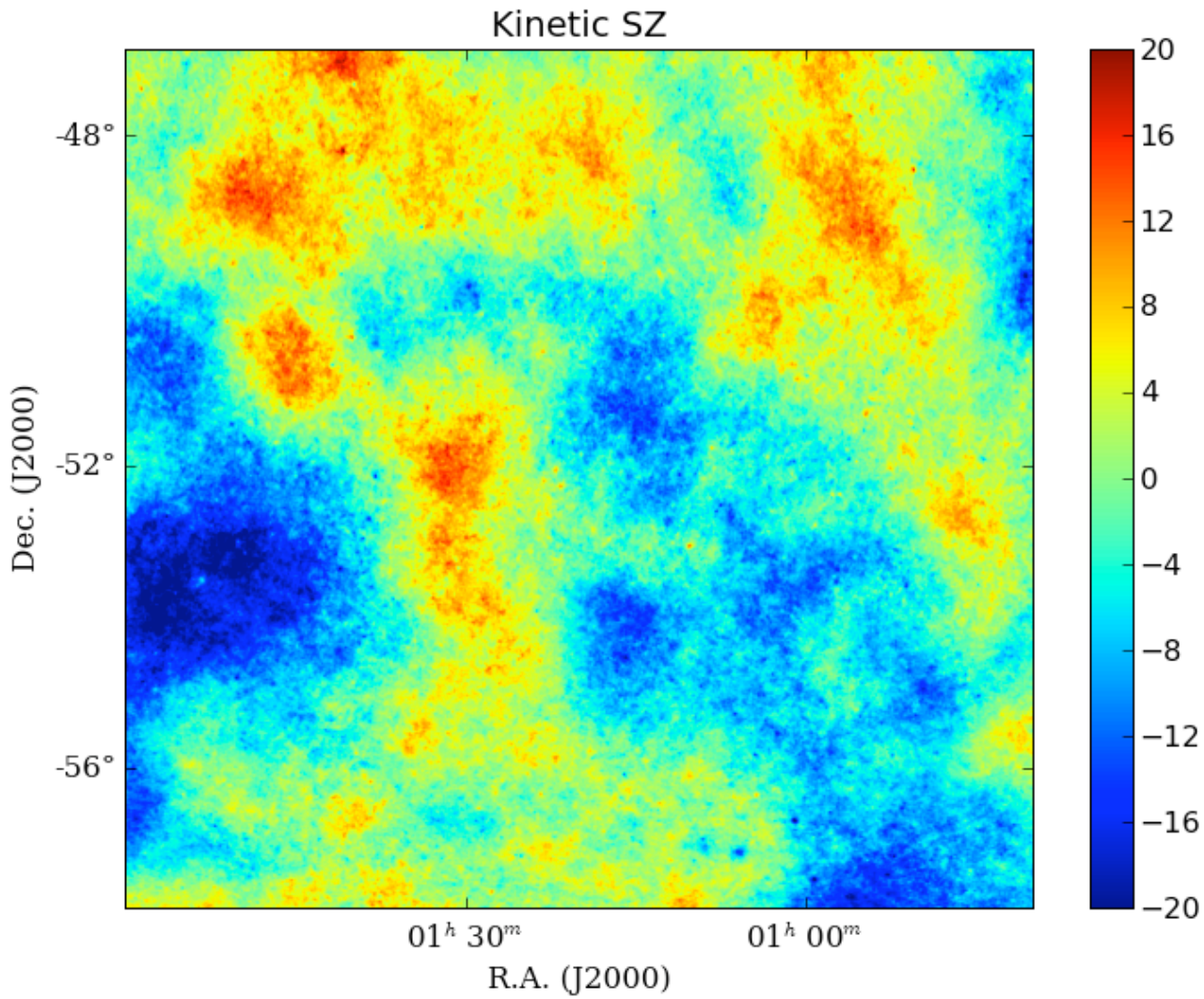


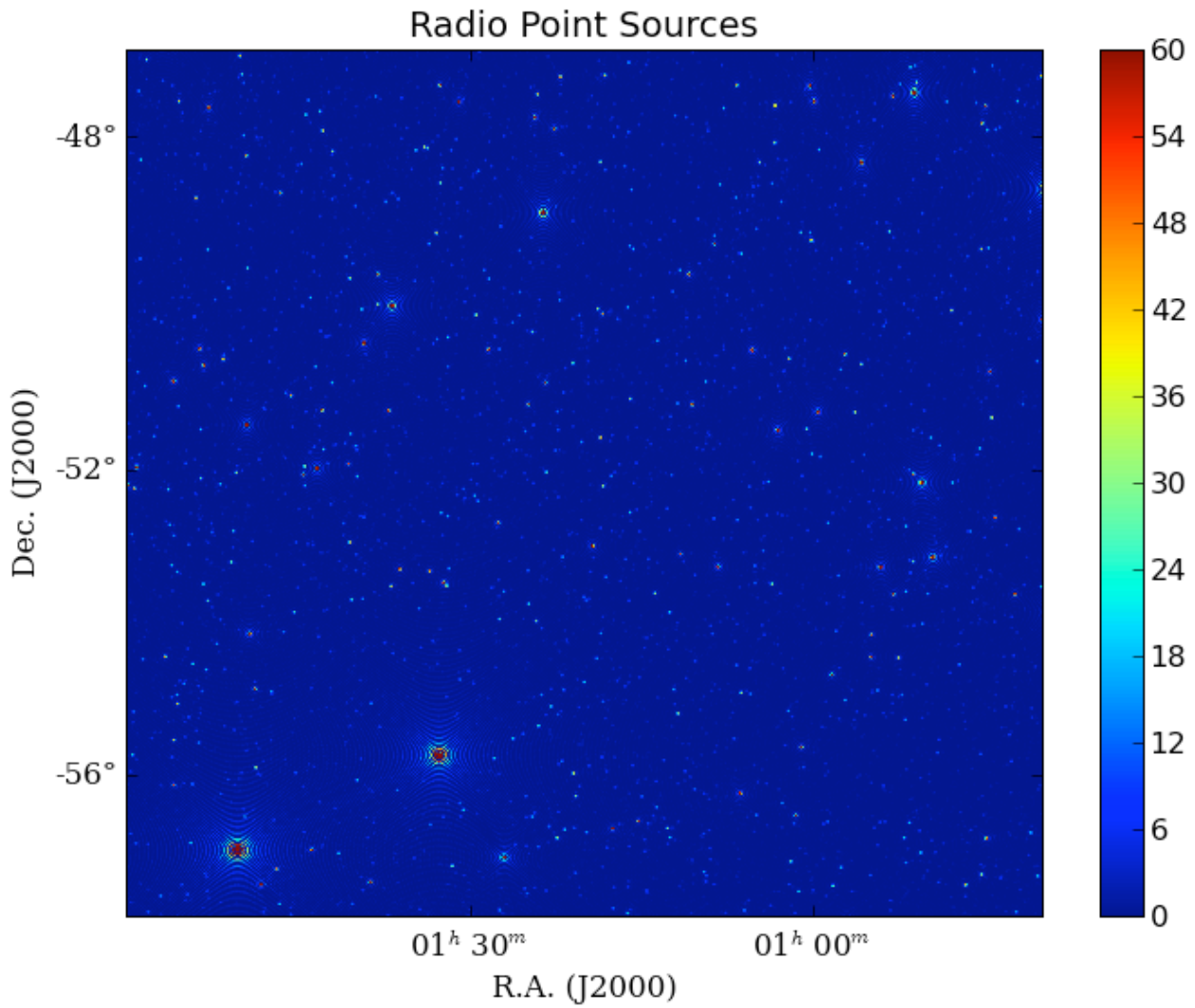
uK

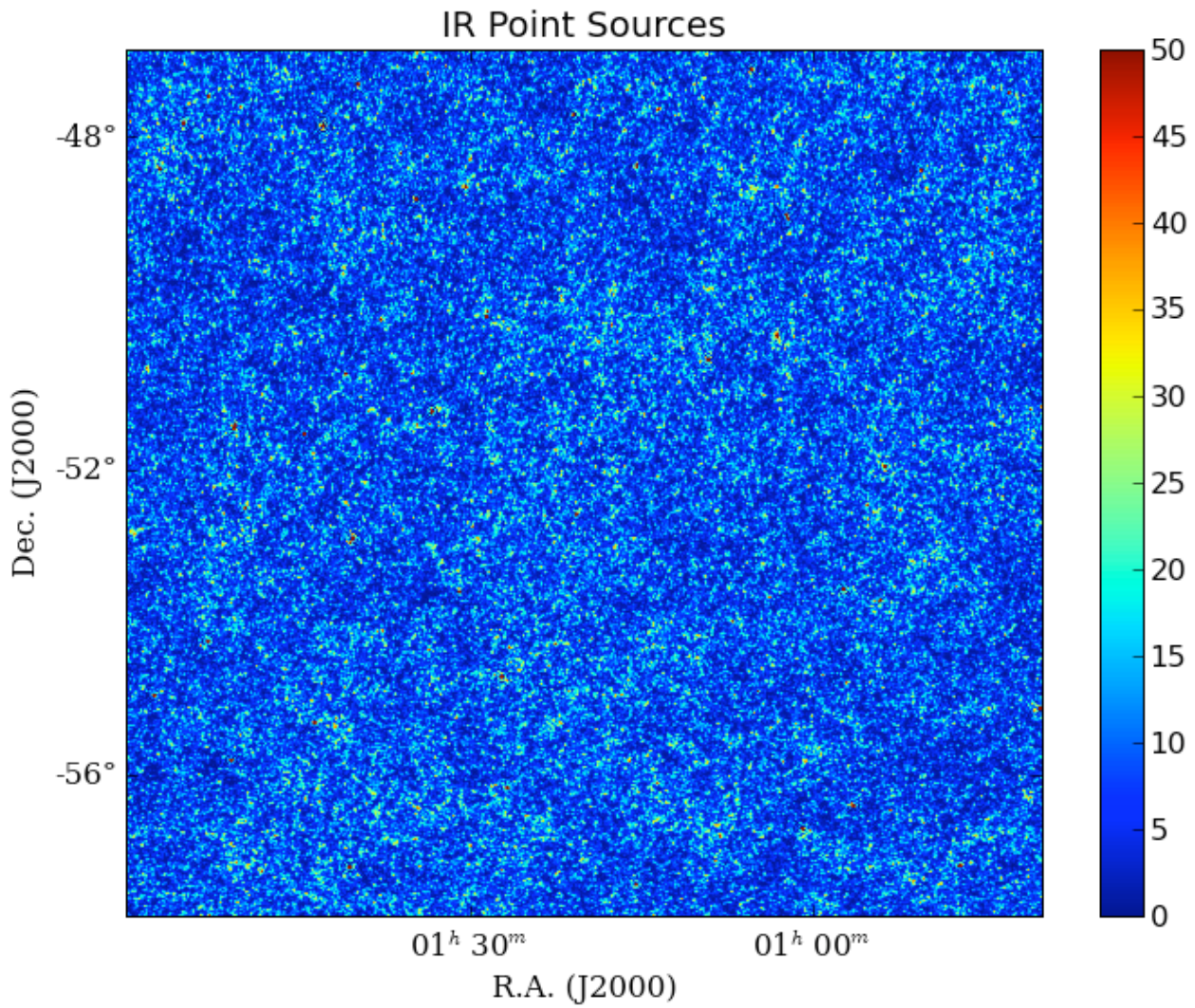
100 deg^2


Lensed CMB
-48°
-52°
-56°
Dec. (J2000)
01h 30m
01h 00m
R.A. (J2000)
400
320
240
160
80
0
−80
−160
−240
−320
−400

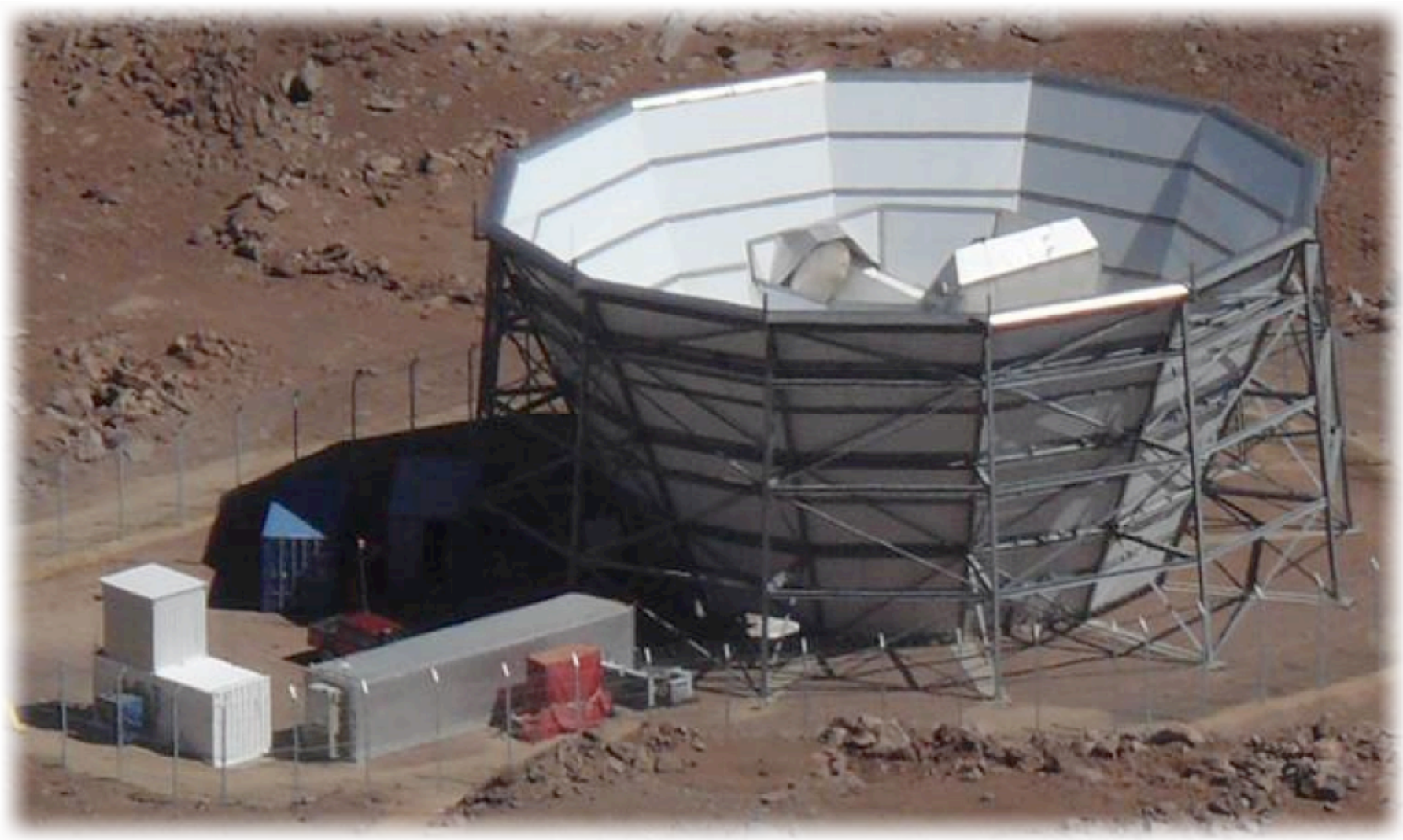

Thermal SZ
-48°
-52°
-56°
Dec. (J2000)
01^h 30^m
01^h 00^m
R.A. (J2000)
0
−10
−20
−30
−40
−50
−60
−70
−80
−90
−100


Kinetic SZ
-48°
-52°
-56°
Dec. (J2000)
01^h 30^m
01^h 00^m
R.A. (J2000)
20
16
12
8
4
0
−4
−8
−12
−16
−20

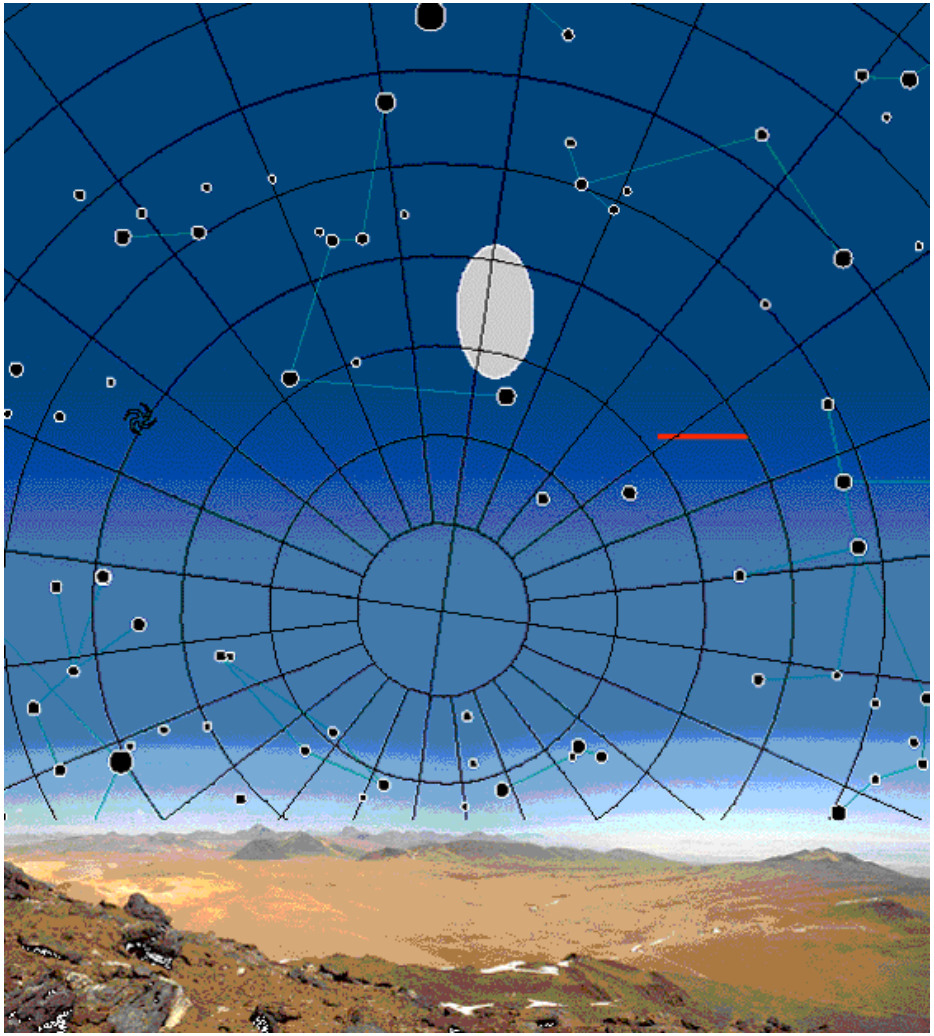

Radio Point Sources
-48°
-52°
-56°
Dec. (J2000)
01^h 30^m
01^h 00^m
R.A. (J2000)
60
54
48
42
36
30
24
18
12
6
0


IR Point Sources
-48°
-52°
-56°
Dec. (J2000)
01^h 30^m
01^h 00^m
R.A. (J2000)
50
45
40
35
30
25
20
15
10
5
0

Whole 40t telescope moves to observe



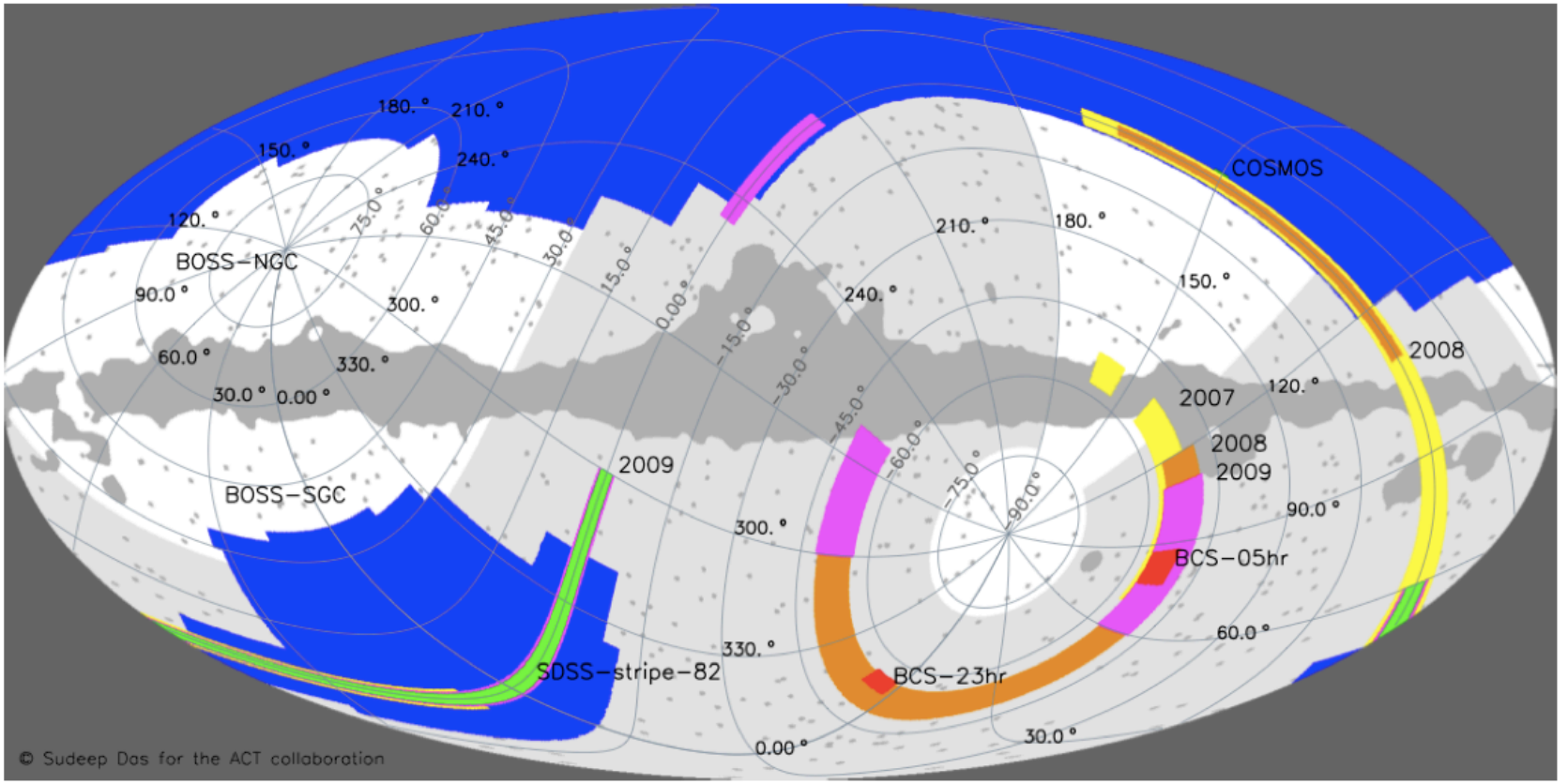
Cross Linked Scan Strategy is Crucial to Making Maps on Degree Angular Scales



Scan in azimuth to maintain constant elevation with respect to the ground and atmosphere.

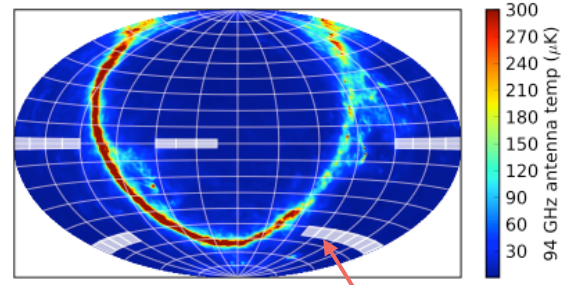
THE OBSERVATIONS:

ACT has taken 12 months of data at 3 frequencies already, over ~1300 deg^2. !

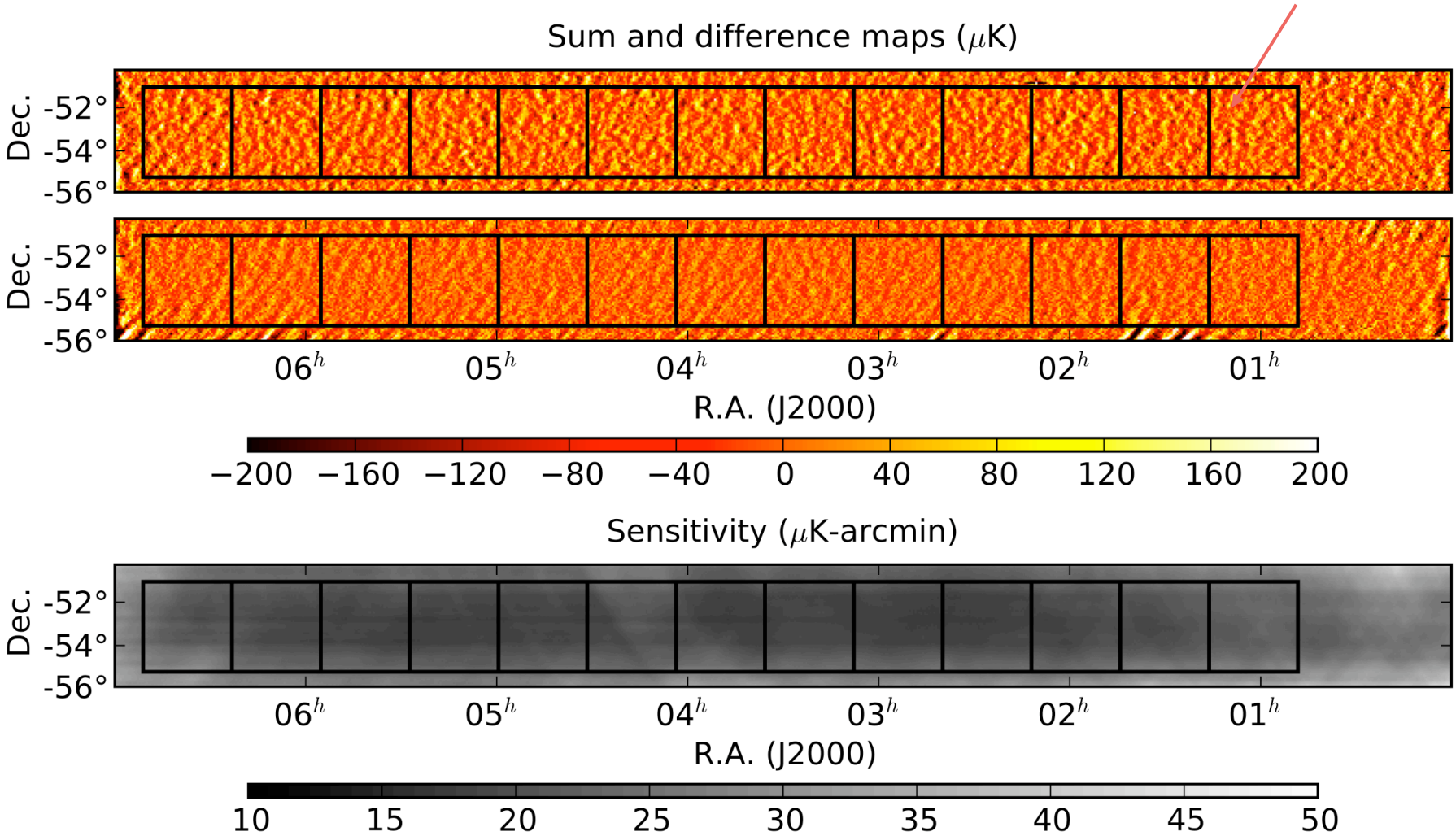


2007	2009	Stripe 82	BCS
2008	ACT Range	BOSS	Masked

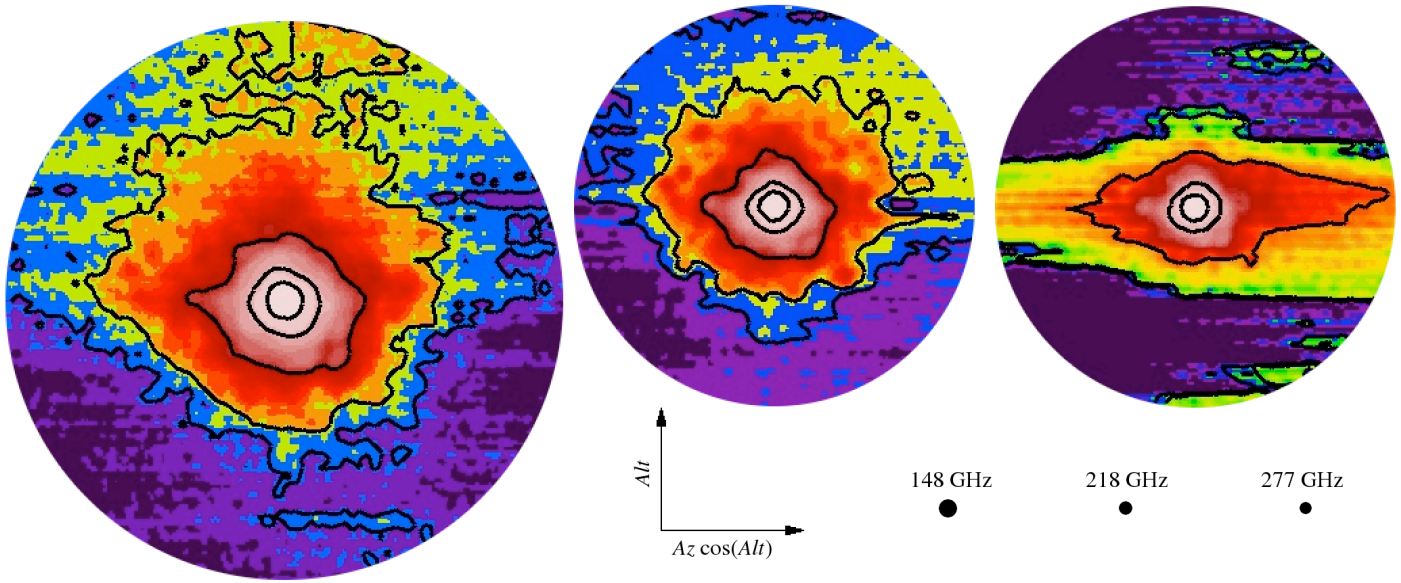
Southern Field Sievers solution



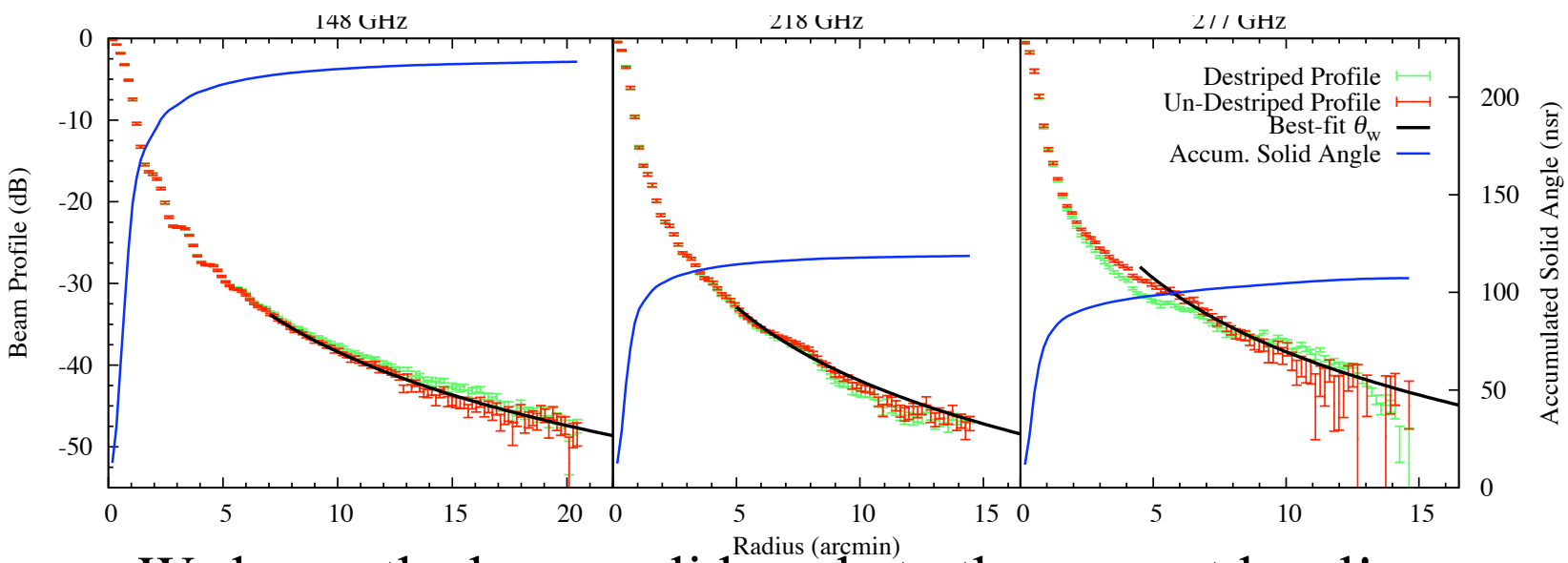
228 deg^2



ACT Optics Work VERY Well

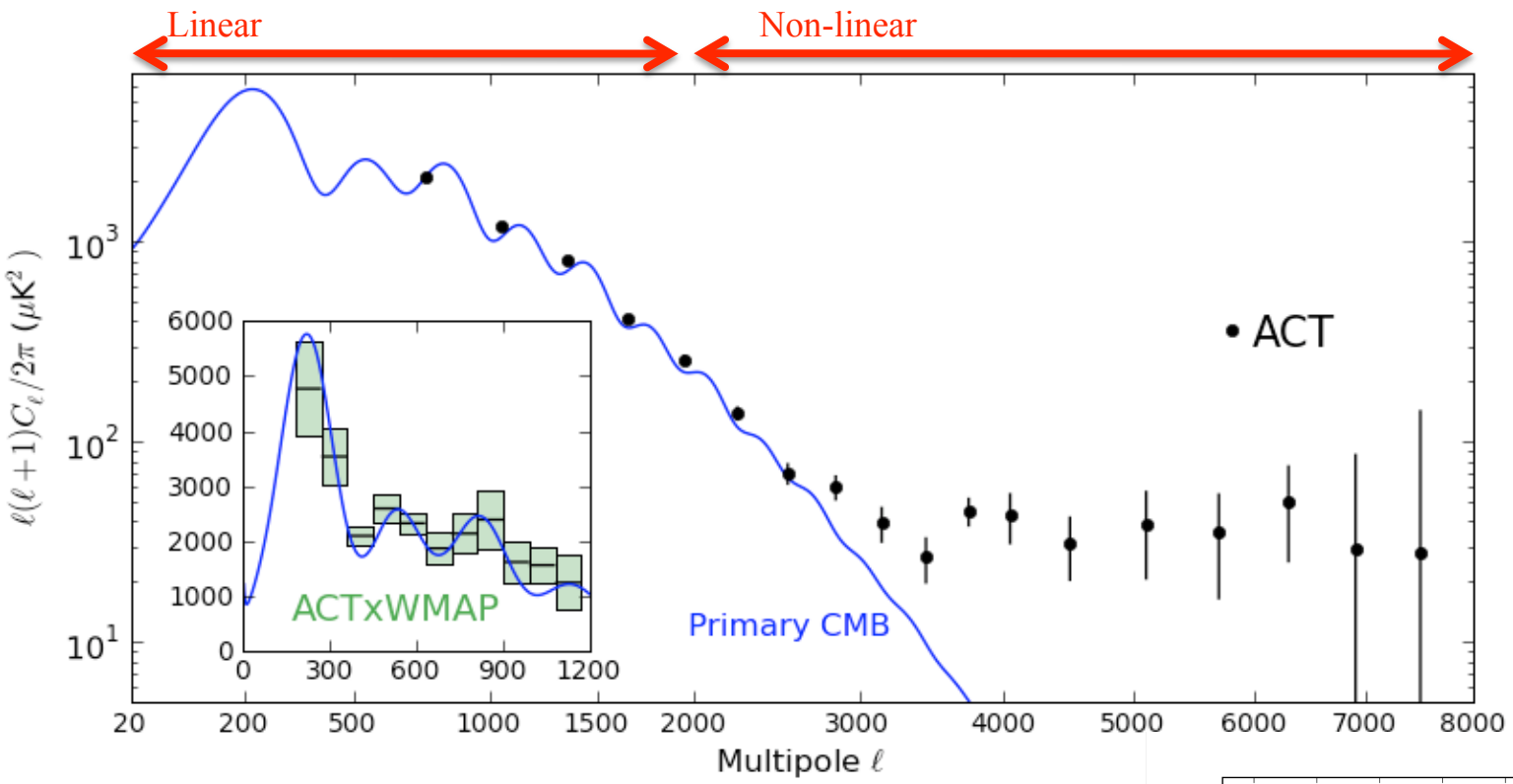


Hincks et al.



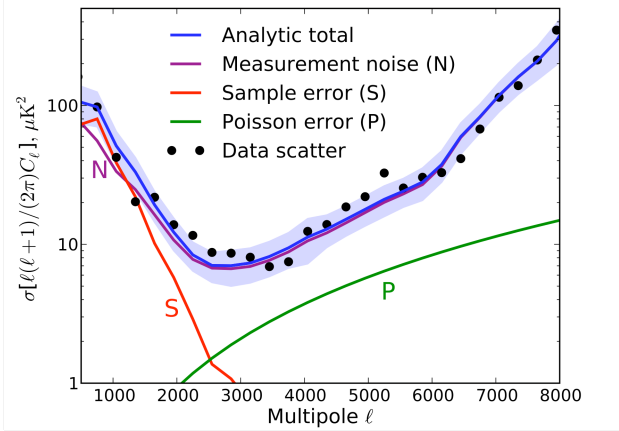
We know the beam solid angle to the percent level!

Power spectrum

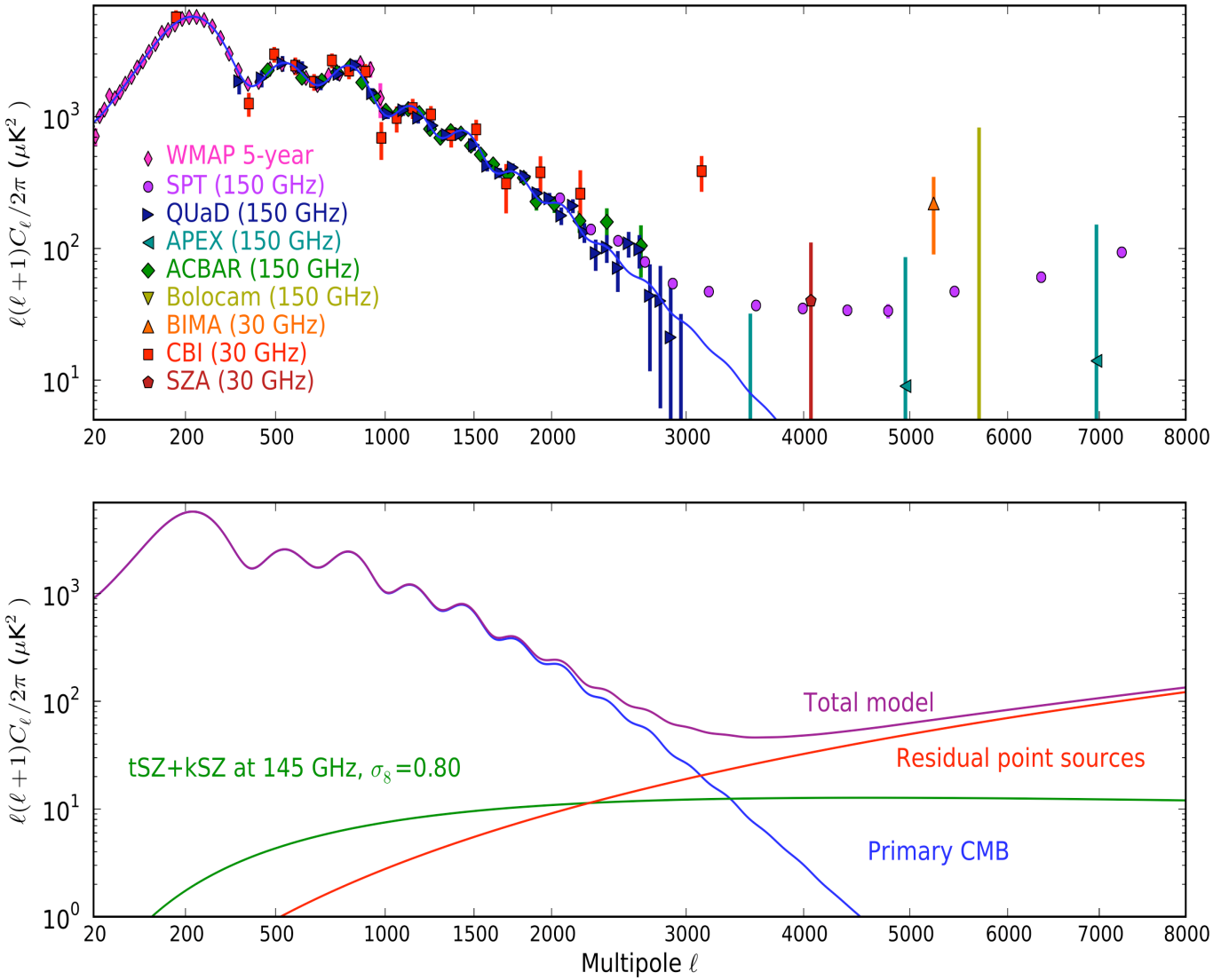


Cross-power with WMAP agrees with WMAP spectrum!

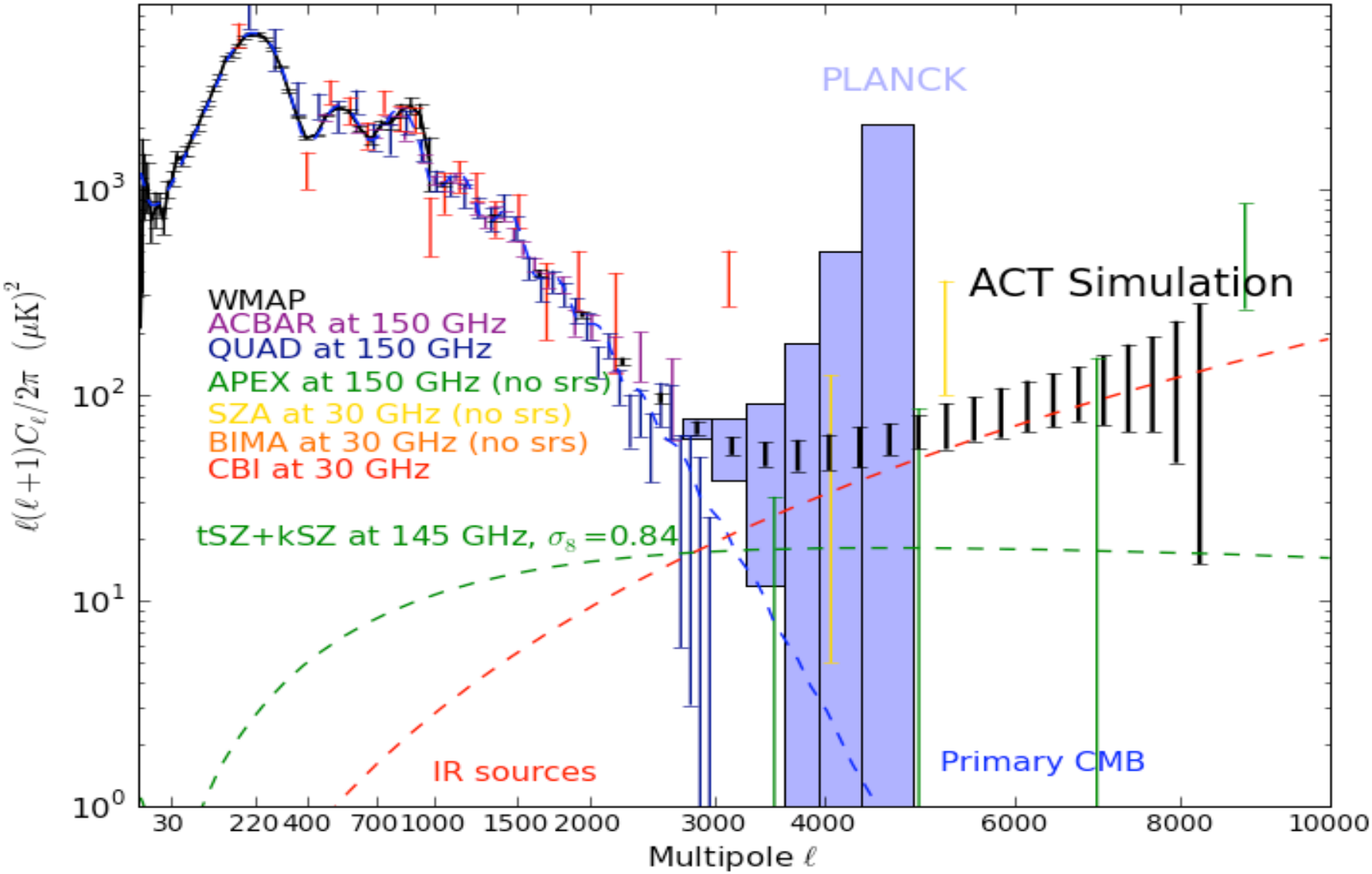
Analytic formulation of error bars



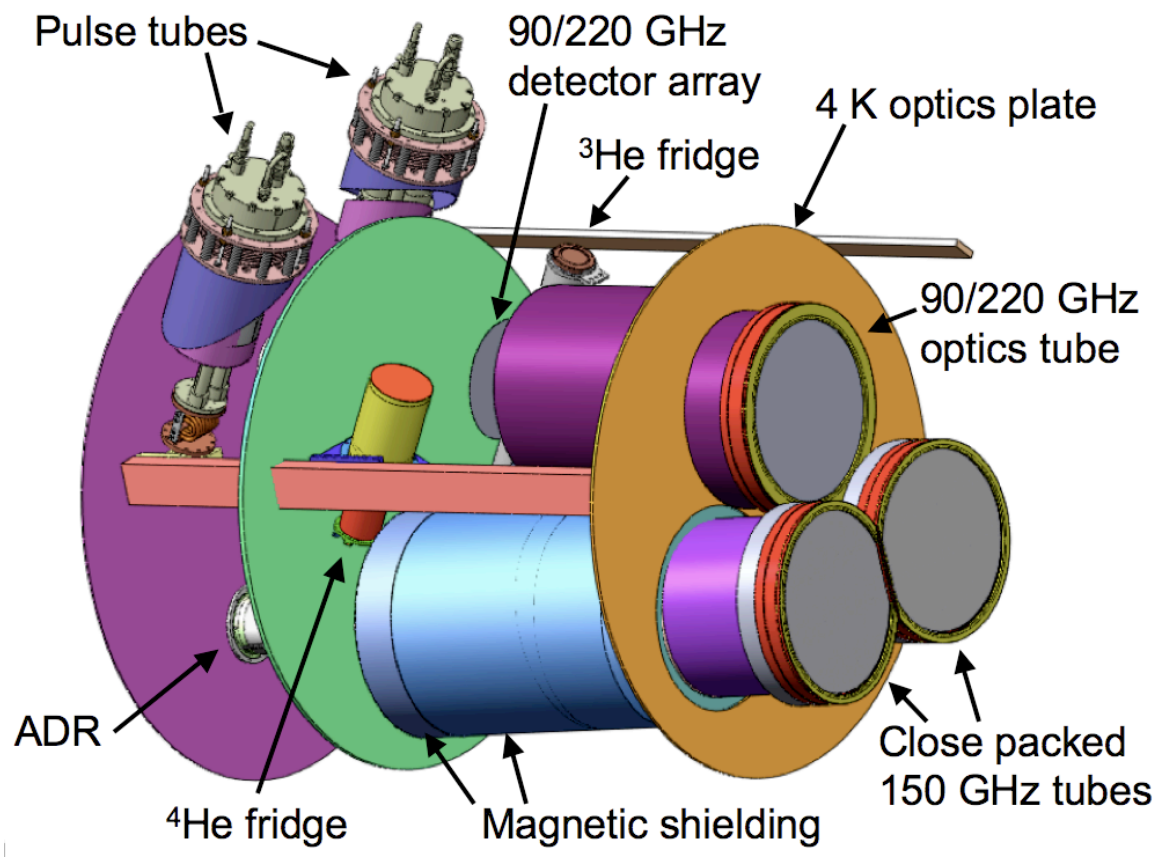
Recent data & the model



Power Spectrum Analysis

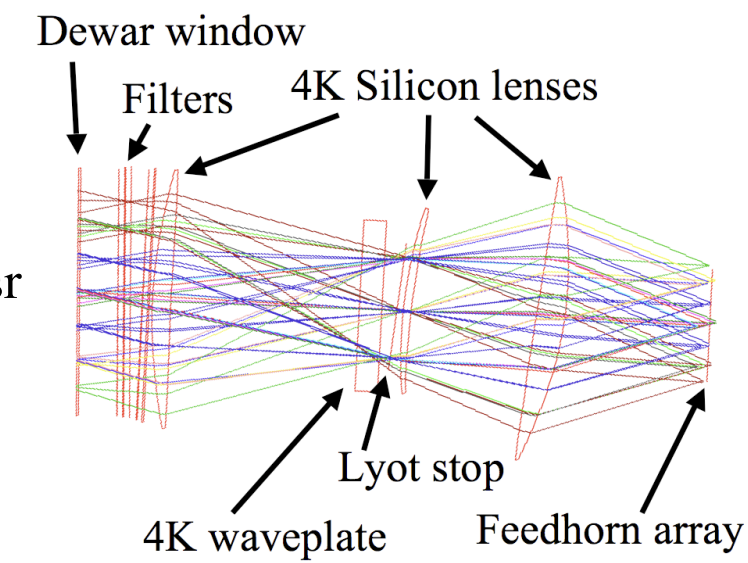


ACTpol: A Polarization Sensitive Receiver

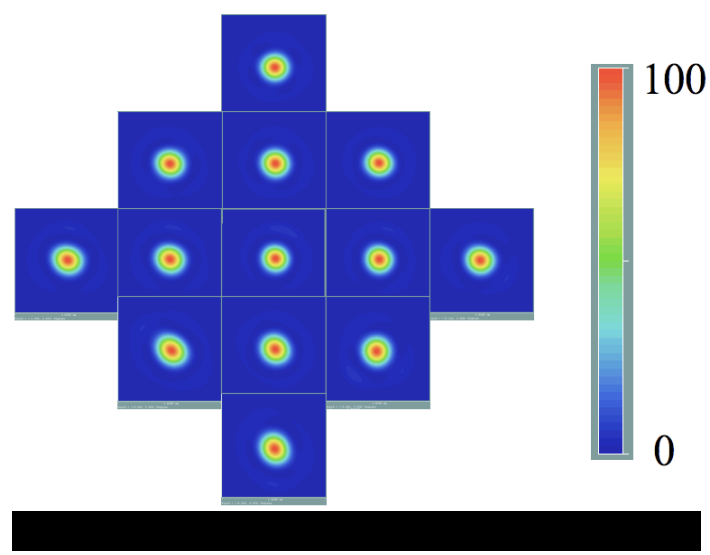


ACTpol Optics

- Three independent optical paths
  - ~5x FOV of MBAC (~ 1° dia./array)
  - $A\Omega = 4.3 \times 10^{-6}\ m^2sr \times 1280\ pix = 5.5 \times 10^{-3}\ m^2sr$
  - Two 150 GHz optical paths
  - Third path 220 GHz (could swap to 90 GHz)
  - Lyot stop => ~ 5.8 m primary illumination

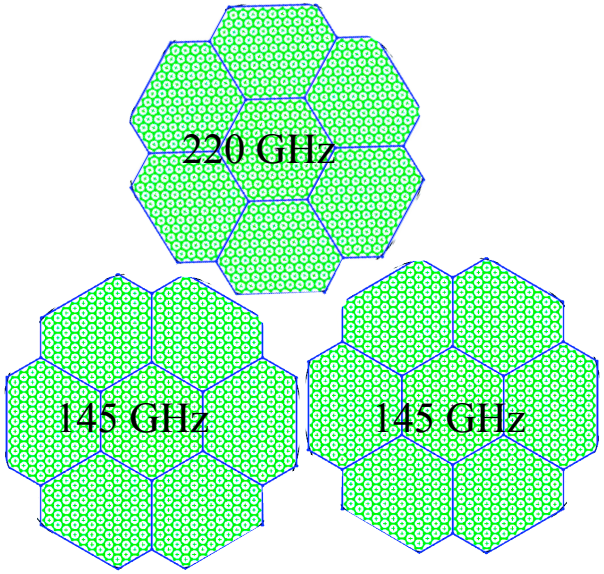


- Large aspheric silicon lenses (n ~ 3.4)
  - Up to 395 mm diameter
  - Anti-reflection coating Cirlex used in MBAC
    - Laser machining

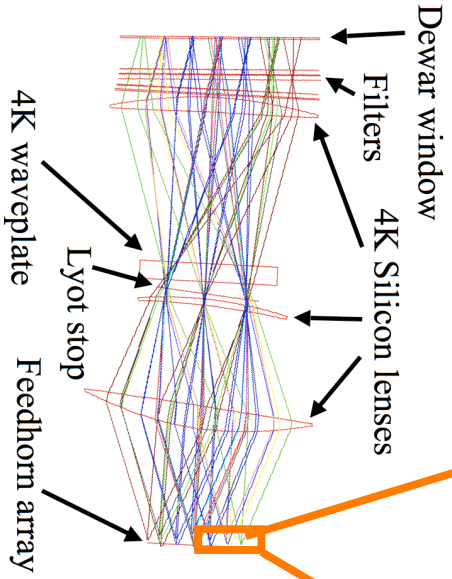


- Telecentric focal plane
- Symmetric PSFs (Strehls > 0.95)

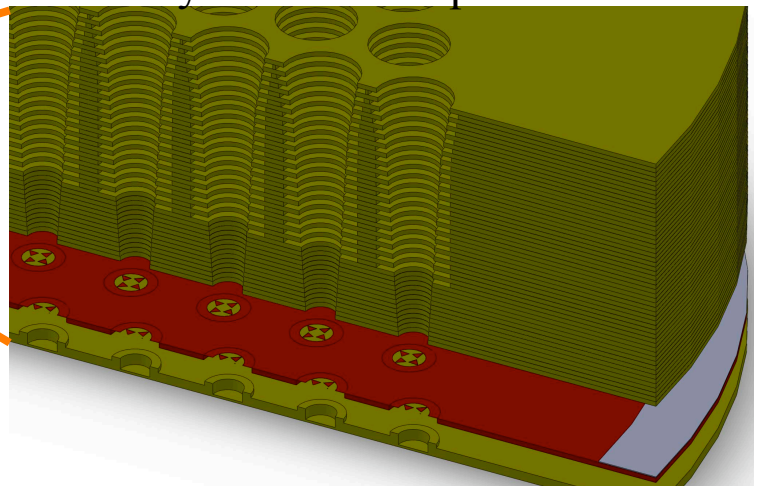
640 corrugated feeds/array



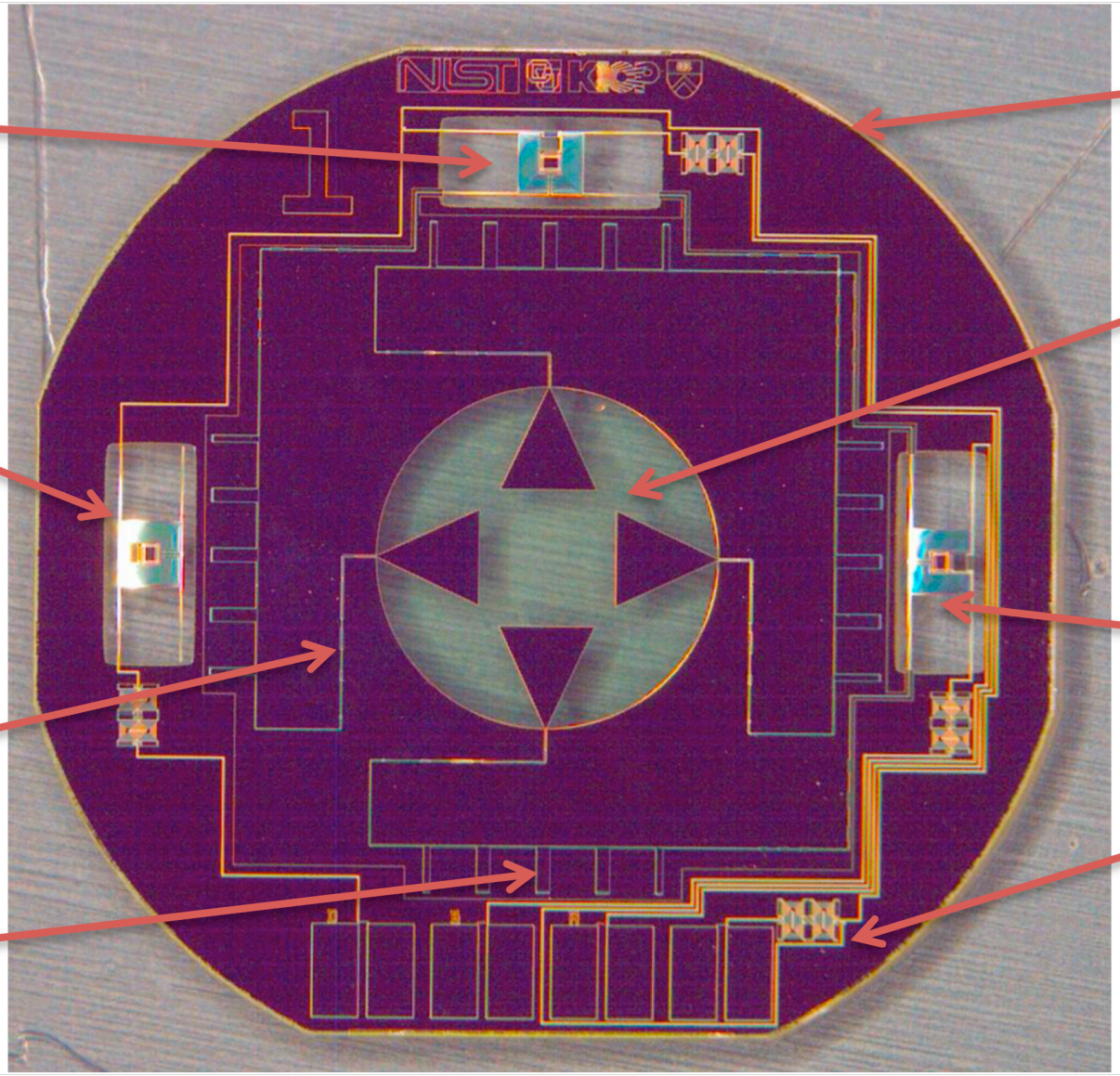
- Gold-plated silicon feedhorns
- New detectors measure the CMB polarization and intensity
- Testing results
- Sensitivity
- Systematics



Each optics tube reimages the sky onto a Si platelet feedhorn array mated to an array of OMT-coupled detectors

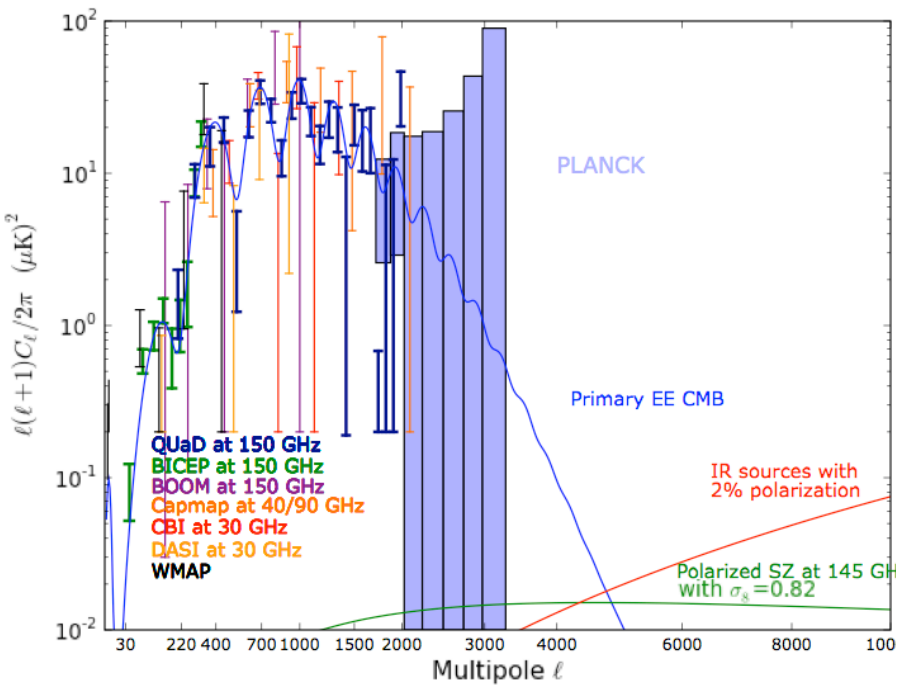


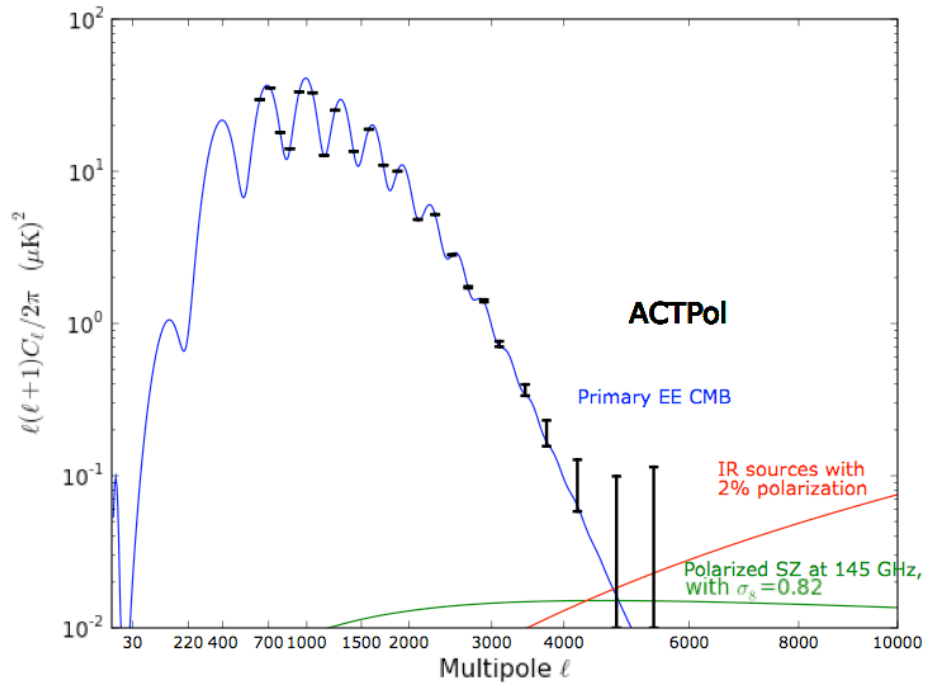
NIST Detectors



ACTPol

Planck: sensitive to l=2000 in polarization



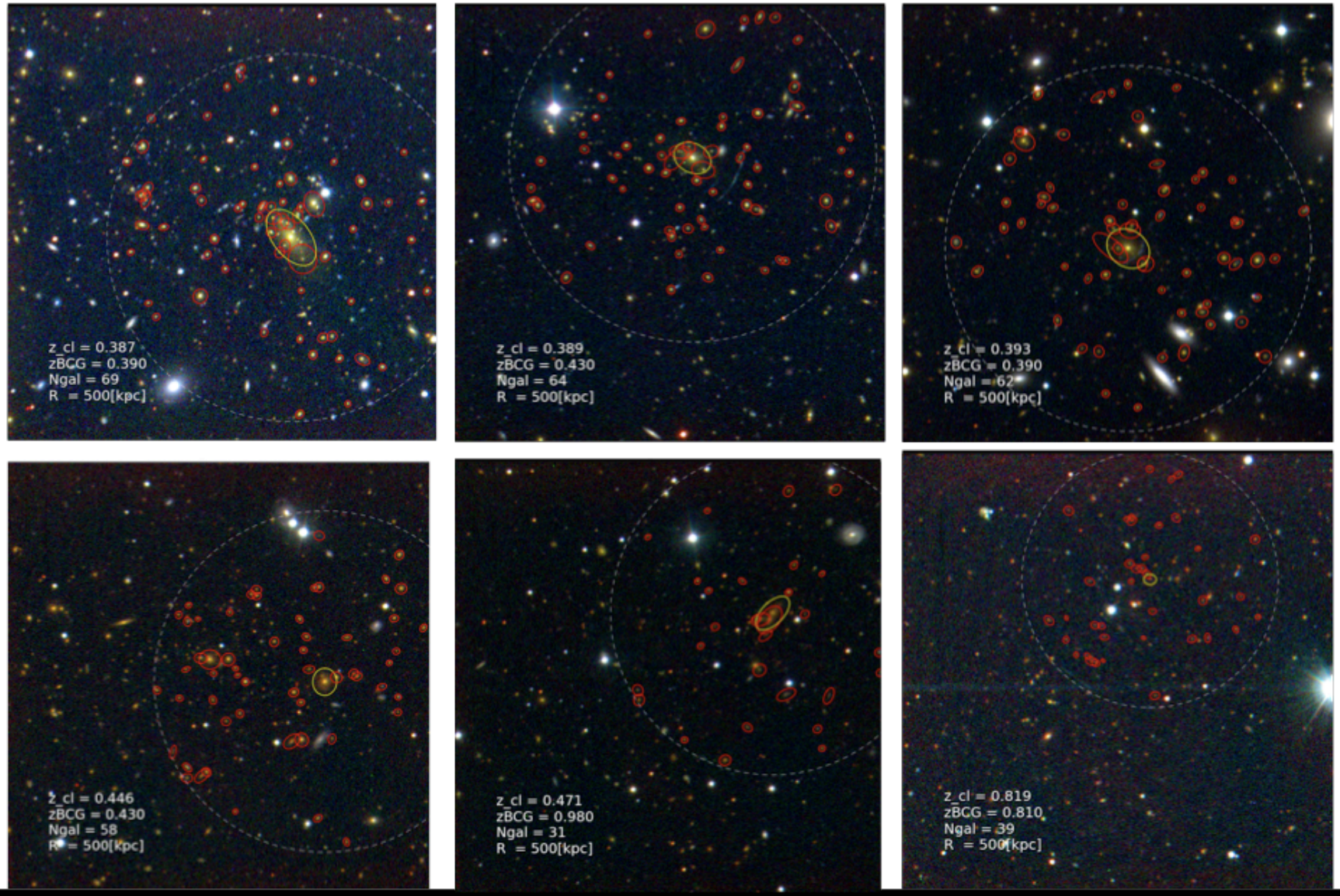


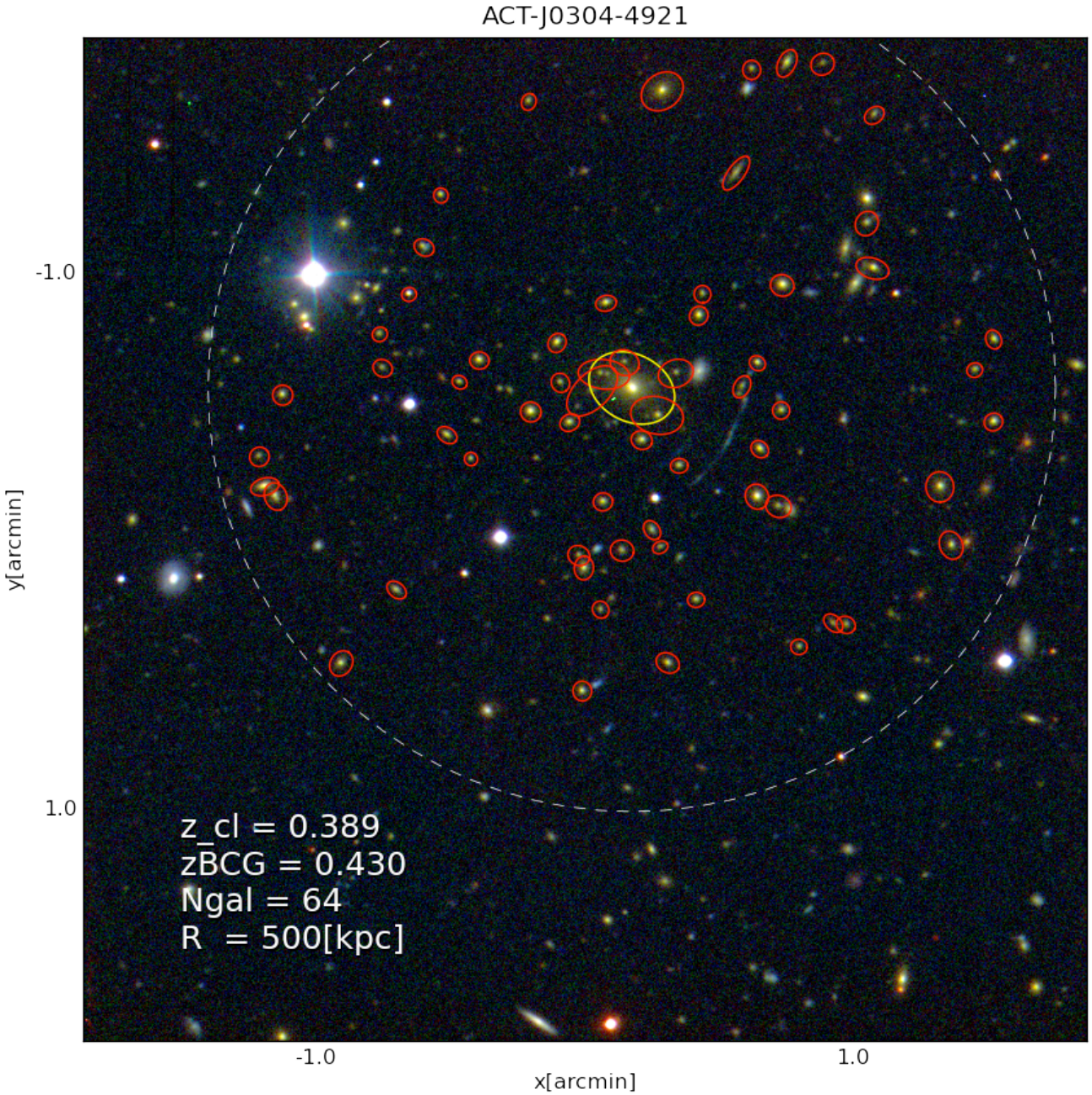
- ACTPol looks through foregrounds in EE at l>2000 to get at n_s
- Measure lensing B-modes to get sum of m_nu to ~0.05 eV.

Clusters

- Anticipate detecting ~200-500 clusters in ACT Wide I and an additional ~1000-2000 clusters in ACT Wide II. This is more than an order-of-magnitude increase over the samples from the current ACT and SPT observations.
- The key to using clusters for cosmology will be calibrating SZ mass/temperature relation and understanding selection effects. Essential to have optically and X-ray selected samples as well as extensive numerical simulations to understand issues such as lensing of backgrounds sources, etc.
- Clusters will serve as tracers of the large scale velocity field
- Clusters survey will reveal enormous amount about cluster physics and has the potential to provide insights into dark energy and "fundamental" cosmology

New Clusters from NTT Run




ACT-J0304-4921
-1.0
1.0
y[arcmin]
-1.0
1.0
x[arcmin]
z_cl = 0.389
zBCG = 0.430
Ngal = 64
R = 500[kpc]

Thank You