Title: Mustang, the 90 GHz camera on GBT

Date: Apr 29, 2009 04:00 PM

URL: http://pirsa.org/09040059

Abstract:

High Resolution SZE Measurements with MUSTANG on the GBT

(including new results on RXJ1347-1145)

Brian Mason (NRAO)

29apr09

The SZ Universe & The Future of Cluster Cosmology, Perimeter Institute

collaborators:
S. Dicker, M.Devlin, P.Korngut (Upenn)
W. Cotton (NRAO)

H.Moseley, D.Benford, J. Chervenak, J. Staguhn (NASA)
K. Irwin (NIST)
P.Ade (Cardiff)

The Green Bank Telescope

- 100-m off-axis gregorian
  - 7+1 receivers, 300 MHz - 100 GHz
- Surface comprises 2004 individual panels, positioned by ~2000 remotely controlled actuators.
- Surface: 390 (350) um RMS
  - Aeff = 1600 m^2
- Pointing accuracy 5" radial rms (blind), 1.2" RMS (20 min referenced)
- Focus tracking 1.2mm RMS (2 h)
- 2000 hours/year with pwv < 10mm
  - Tsky ~ 30 K
  - Thus far: "paired days" scheduling system
  - Transitioning to automated dynamic scheduling this fall (successful tests 3 months last summer)

Forefront 90 GHz instrument

- Ideal frequency for SZ observations

Science of Long-mm Bolometer Arrays on Large Single Dishes

Point source sensitivity: collecting area

Surface brightness sensitivity
+
Resolution

Long-millimeter regime: high-z thermal, SZ; large dust Grains.

GBT 3mm

also CARMA+SZA, ALMA band 1, EVLA E-array... flexible & clean but hard to compete with bolometers for sheer continuum sensitivity.

The Green Bank Telescope

- 100-m off-axis gregorian
  - 7+1 receivers, 300 MHz - 100 GHz
- Surface comprises 2004 individual panels, positioned by ~2000 remotely controlled actuators.
- Surface: 390 (350) um RMS
  - Aeff = 1600 m^2
- Pointing accuracy 5" radial rms (blind), 1.2" RMS (20 min referenced)
- Focus tracking 1.2mm RMS (2 h)
- 2000 hours/year with pwv < 10mm
  - Tsky ~ 30 K
  - Thus far: "paired days" scheduling system
  - Transitioning to automated dynamic scheduling this fall (successful tests 3 months last summer)

Forefront 90 GHz instrument

- Ideal frequency for SZ observations

Science of Long-mm Bolometer Arrays on Large Single Dishes

Point source sensitivity: collecting area

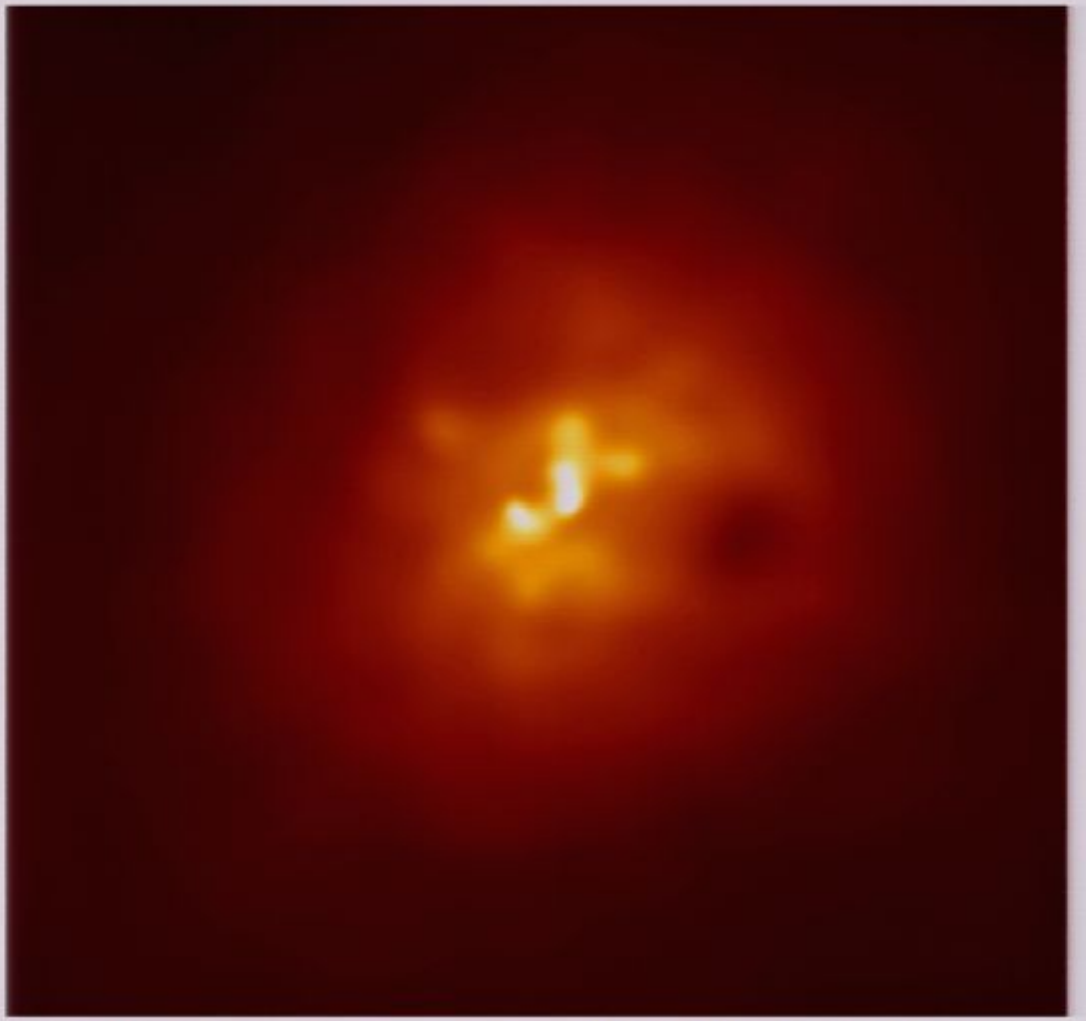
Surface brightness sensitivity
+
Resolution

Long-millimeter regime: high-z thermal, SZ; large dust Grains.

GBT 3mm

also CARMA+SZA, ALMA band 1, EVLA E-array... flexible & clean but hard to compete with bolometers for sheer continuum sensitivity.

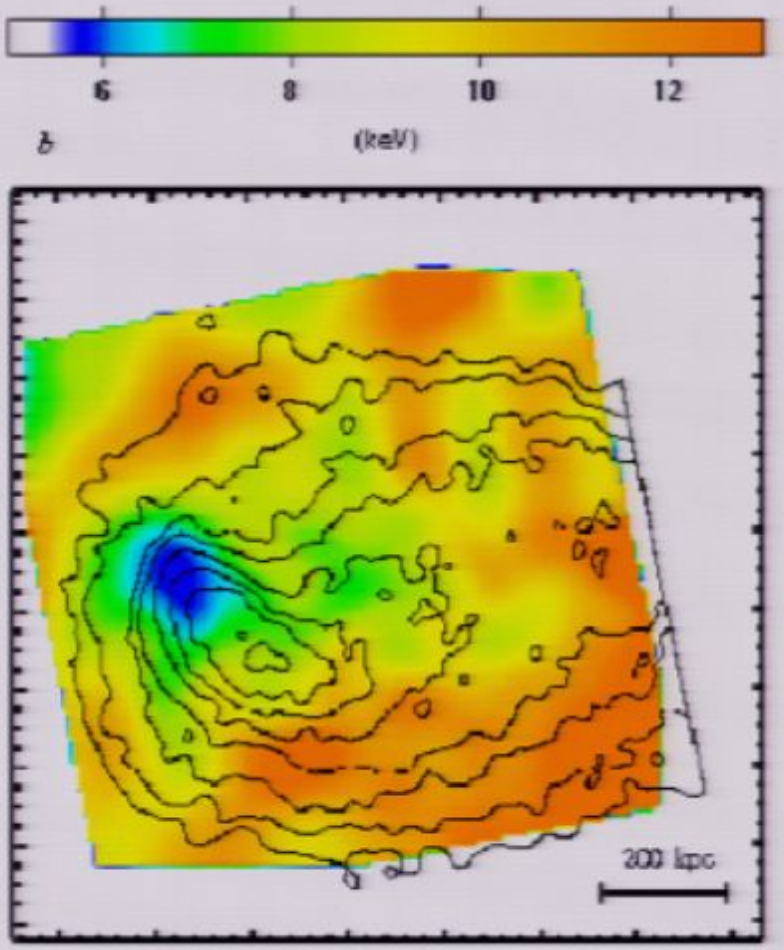
A2597 - Chandra



A2597 Chandra, courtesy NASA/CXC/B.McNamara et al.

A2597 - regular cD cluster with cooling flow.
AGN in center with X-ray shadows in X-ray

A754 - Chandra



Chandra: Govoni et al. astro-ph/0401421

A754 - "prototypical" violent merger, significantly disturbed

The Science of High Resolution SZE

- ICM distribution, Hydrostatic Masses
  - Large R pressure, temp.
- Catalog markers of dynamical state
  - Resolve mergers
  - Hot shocks
- Energetics of cluster core
  - Cooling flows
  - ICM bubbles

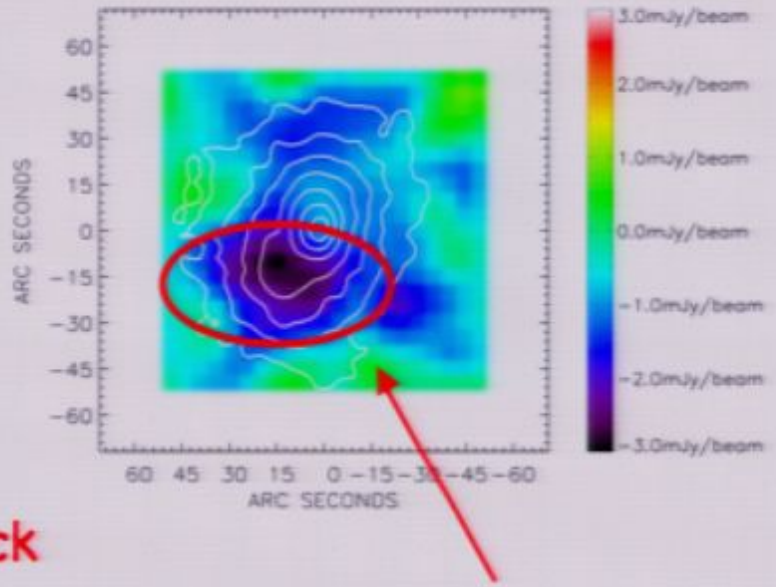
$$M_{tot}(<r) = -\frac{kT(r)}{G\mu m_p}\frac{r^2}{\rho}\frac{d}{dr}(\rho T)$$

Xrays are a poor probe of the ICM outside of the Core

Hi-z, compact -> CMB less problematic

The Science of High Resolution SZE

- ICM distribution, Hydrostatic Masses
  - Large R pressure, temp.
- Catalog markers of dynamical state
  - Resolve mergers
  - Hot shocks
- Energetics of cluster core
  - Cooling flows
  - ICM bubbles



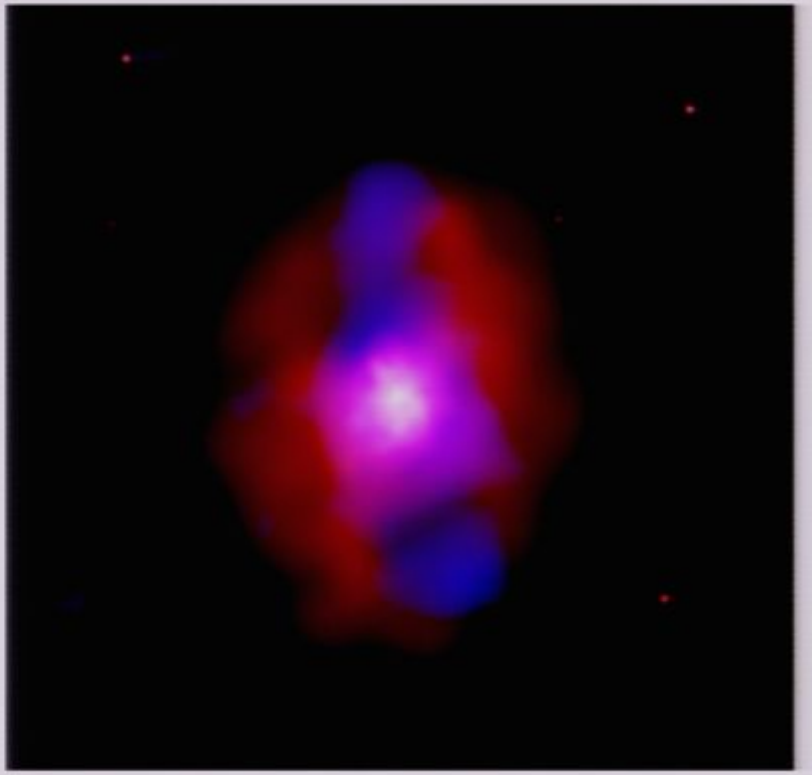
T>20 keV shock

Indicator of recent major merger event!
Out of band for imaging x-ray
Telescopes; very strong in SZE

Kitayama et al. 2004: Nobeyama 45-m, 150 GHz 7 beam rx

The Science of High Resolution SZE

- Hydrostatic Masses
  - Large R pressure, temp.
- Catalog markers of dynamical state
  - Resolve mergers
  - Hot shocks
- Energetics of cluster core
  - Cooling "flows"
  - ICM bubbles



MS0735.6+7421
McNamara et al. 2005, Nature
(Chandra/VLA composite)

The Science of High Resolution SZE

- Hydrostatic Masses
  - Large R pressure, temp.
- Catalog markers of dynamical state
  - Resolve mergers
  - Hot shocks
- Energetics of cluster core
  - Cooling "flows"
  - ICM bubbles

Deep arcminute-scale
SZ contrast

Suitable to be measured with GBT 30 GHz receiver

MKW3s
Mazotta et al. (2004)

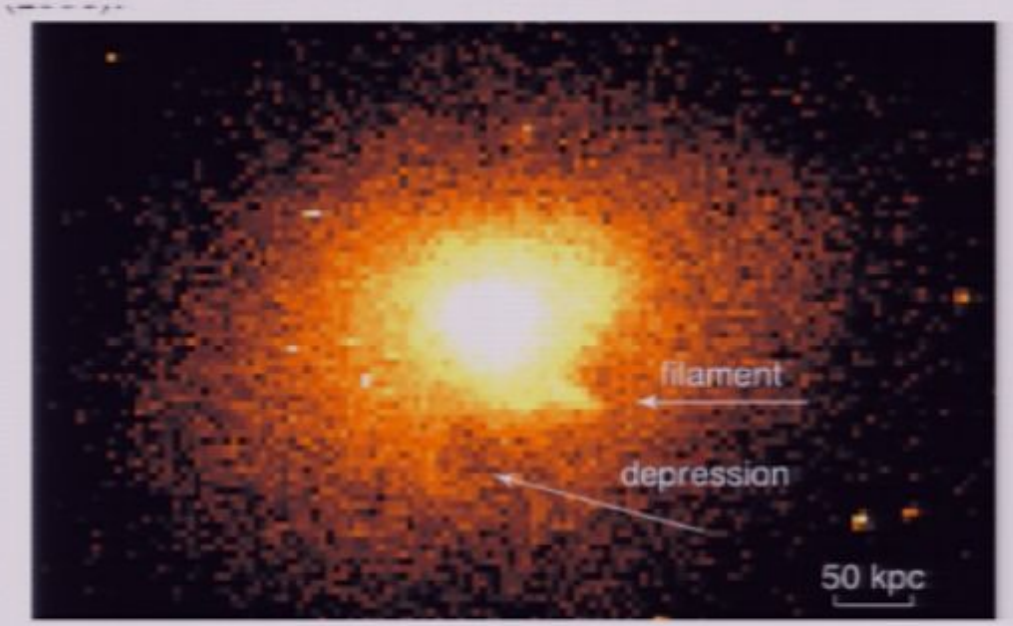
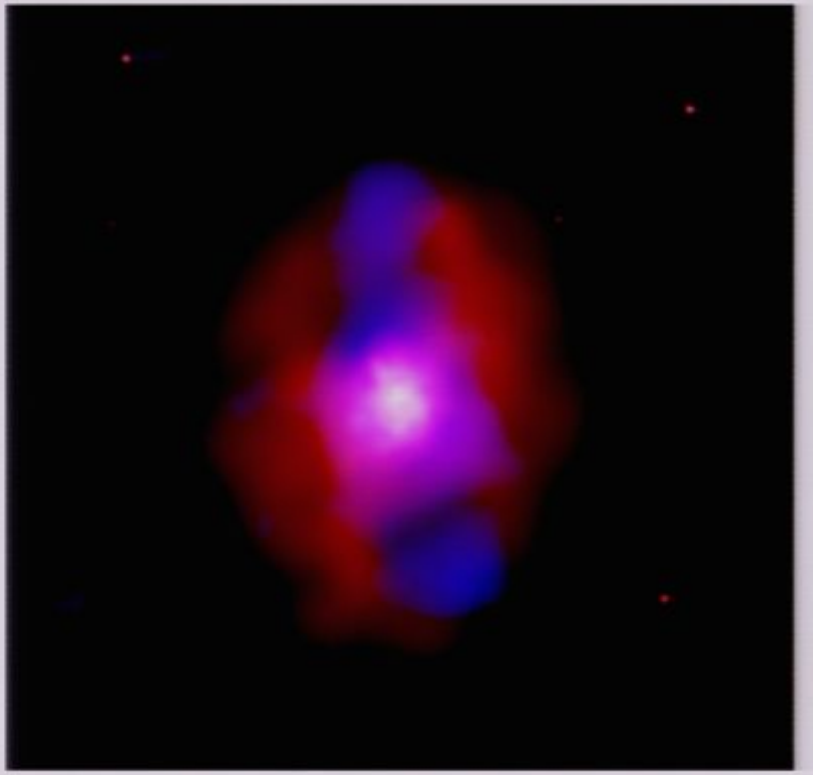


FIG. 1.— *Chandra* image of the central $r = 200$ kpc region of MKW3s in the $0.5 - 8$ keV energy band. Each pixel corresponds to $4'' \times 4''$. The arrows indicate the most prominent features: the filamentary structure and the surface

The Science of High Resolution SZE

- Hydrostatic Masses
  - Large R pressure, temp.
- Catalog markers of dynamical state
  - Resolve mergers
  - Hot shocks
- Energetics of cluster core
  - Cooling "flows"
  - ICM bubbles



MS0735.6+7421
McNamara et al. 2005, Nature
(Chandra/VLA composite)

The Science of High Resolution SZE

- Hydrostatic Masses
  - Large R pressure, temp.
- Catalog markers of dynamical state
  - Resolve mergers
  - Hot shocks
- Energetics of cluster core
  - Cooling "flows"
  - ICM bubbles

Deep arcminute-scale
SZ contrast

Suitable to be measured with GBT 30 GHz receiver

MKW3s
Mazotta et al. (2004)

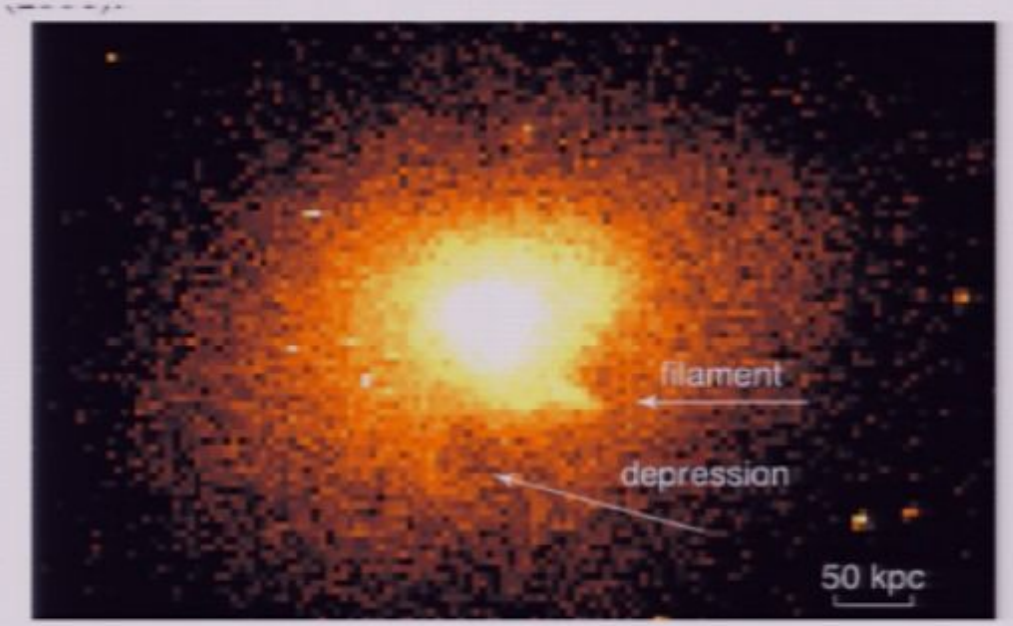
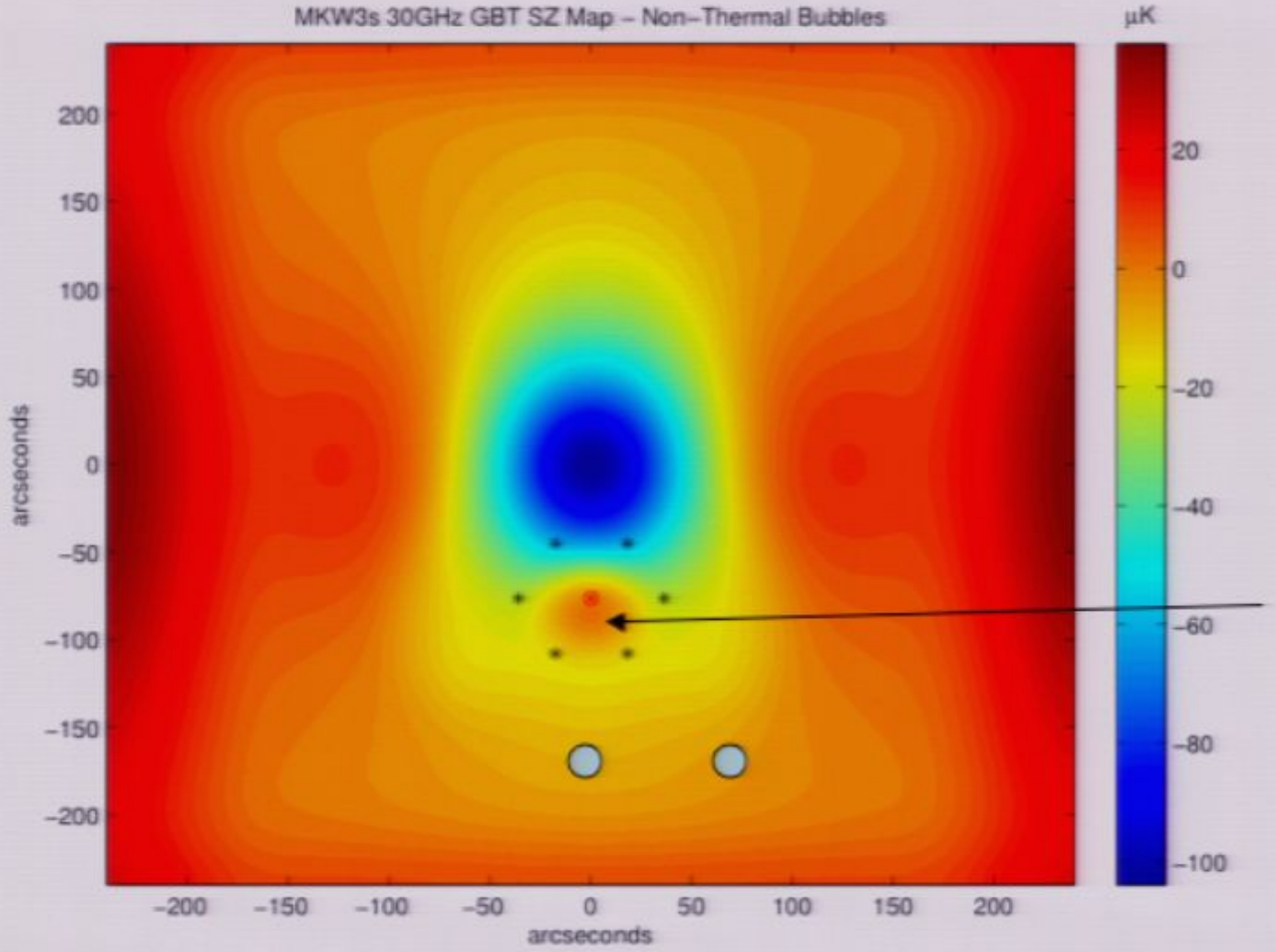


FIG. 1.— *Chandra* image of the central $r = 200$ kpc region of MKW3s in the $0.5 - 8$ keV energy band. Each pixel corresponds to $4'' \times 4''$. The arrows indicate the most prominent features: the filamentary structure and the surface

GBT 30 GHz: Xray bubble Thermal Pressure Constraint

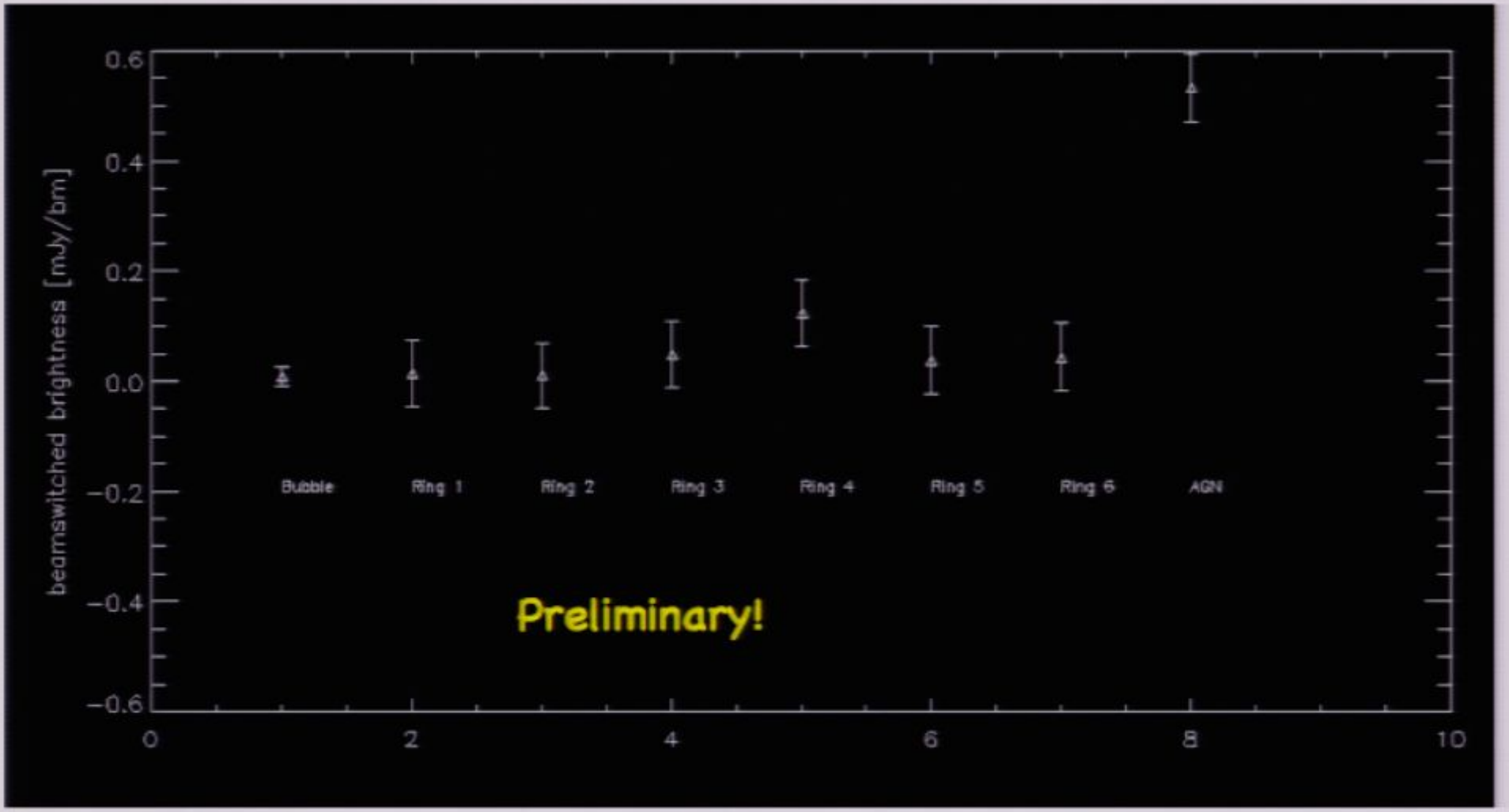


20–30 uK
SZ contrast

Figure 1: Simulation of a GBT 30 GHz beamswitched map of MKW3s. The bubble is visible south of the cluster core; for this simulation, a parallactic-angle averaged beamswitch pattern has been assumed. The central pointing of the 7-point observing pattern described in the text is shown by a red circled-x, and the 6 control pointings are black asterisks.

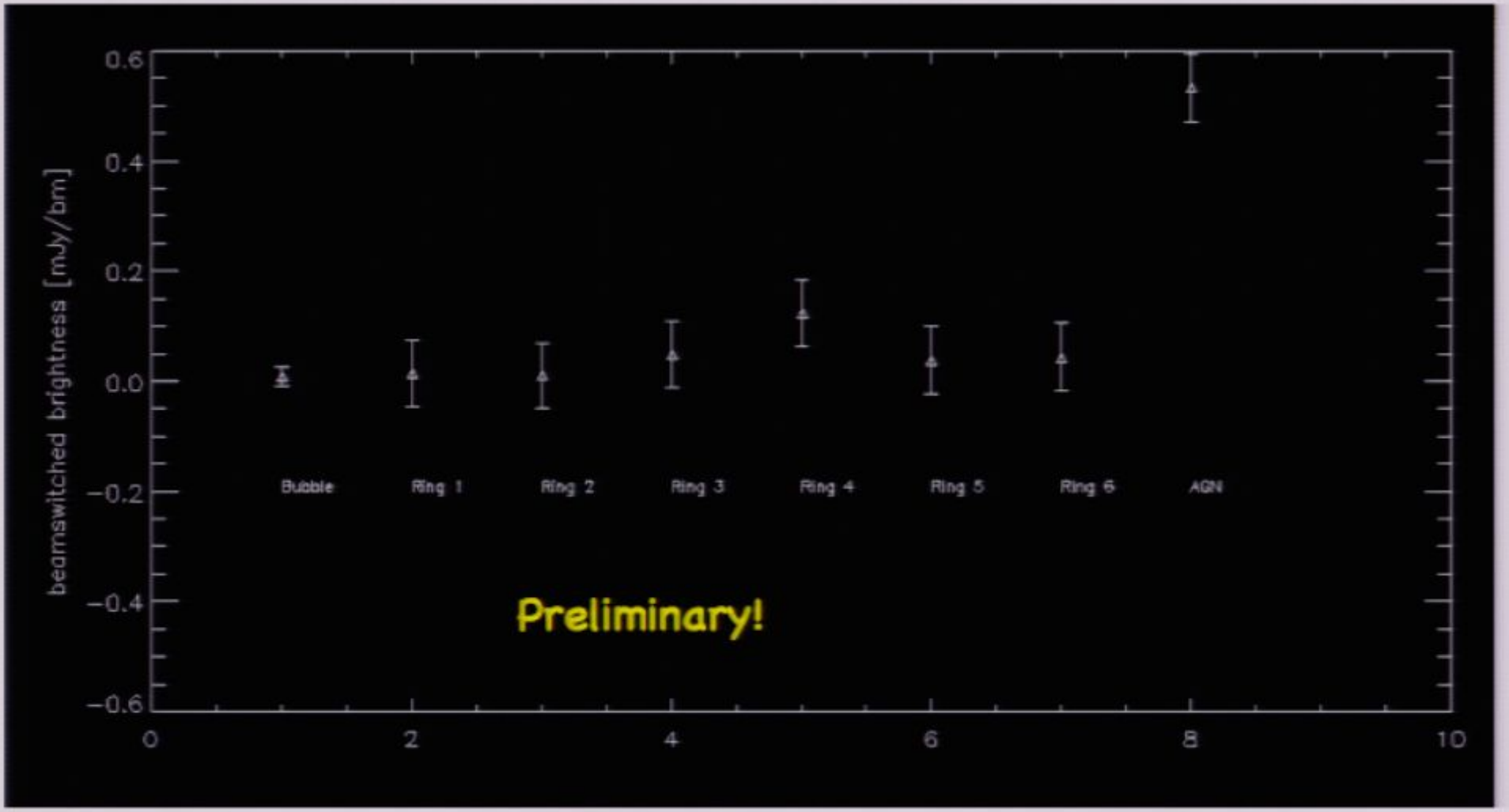
W/C Pfrommer, T. Sievers

GBT 30 GHz: Xray bubble Thermal Pressure Constraint

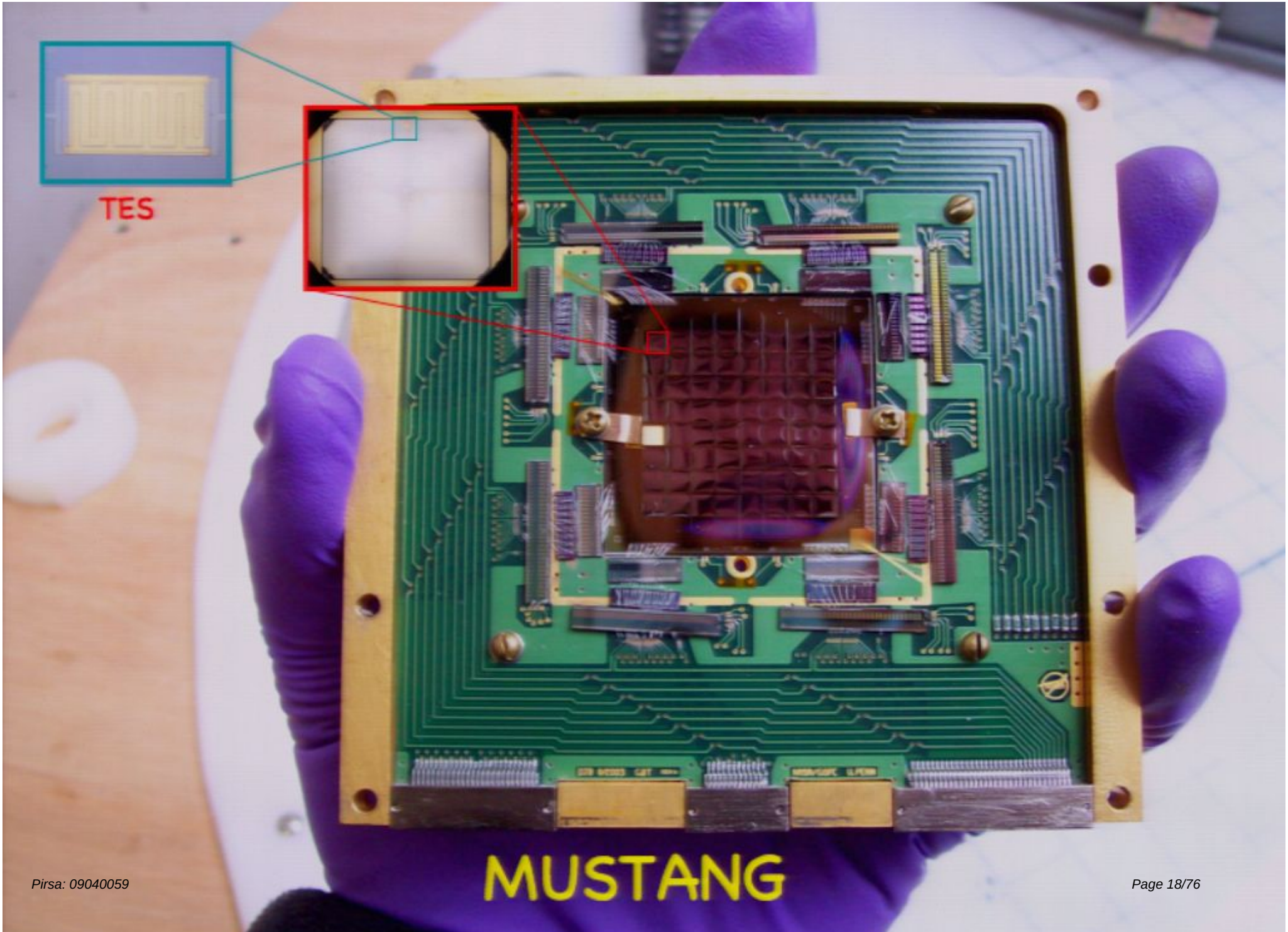


30 uK RMS -- ~1 sigma -- 5 hours of useful data

GBT 30 GHz: Xray bubble Thermal Pressure Constraint



Feasible but laborious!


TES
MUSTANG

MUSTANG

Multiplexed SQUID TES Array at Ninety Gigahertz

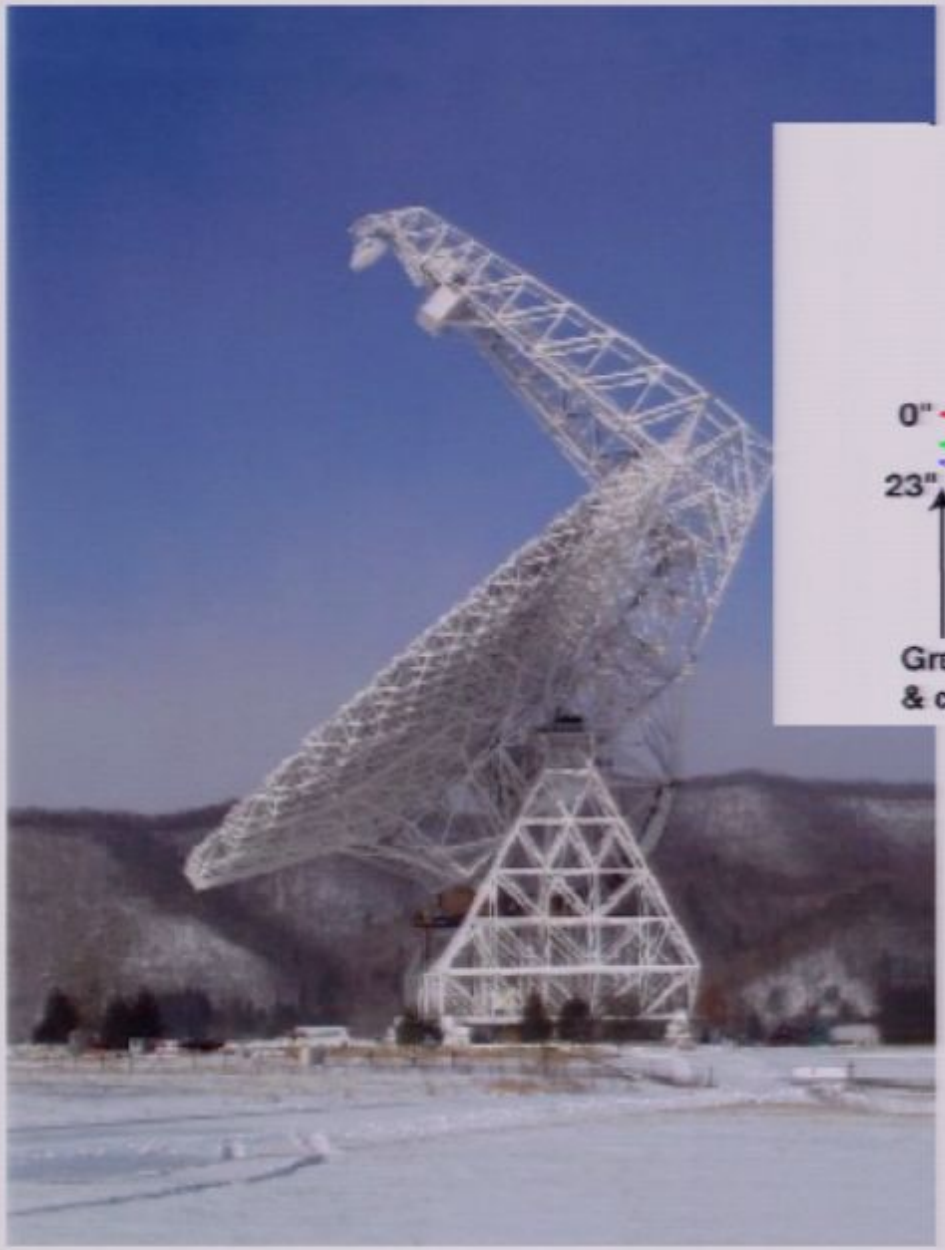
Resolution	9" (fwhm)
Beam Spacing	4"
Npixel	8x8
Target Sensitivity	Tsys = 28 K
Bandwidth	18 GHz

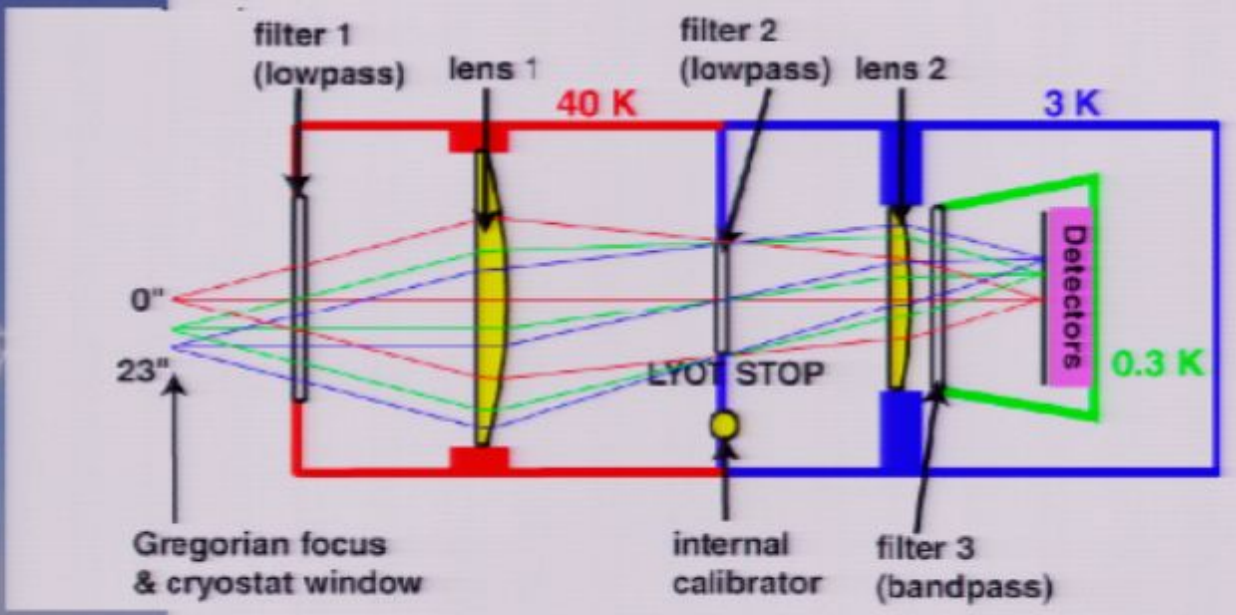
PWV of 10mm
2000 hrs/yr

Bolometers can achieve photon background Limited noise performance (Trx = 0, Tsys = Tsky)

Arrays of 1000s of detectors exist and are not expensive

Optics





- Dicker S.R., & Devlin M.J., "Millimeter wave reimaging optics for the 100 m Green Bank telescope", Applied Optics 44, 5855-5858, 2005
- Dicker, Korngut, Mason et al.,"MUSTANG: Ninety Gigahertz Science with the Green Bank Telescope", Proc. SPIE 7020, 2008

MUSTANG

Multiplexed SQUID TES Array at Ninety Gigahertz

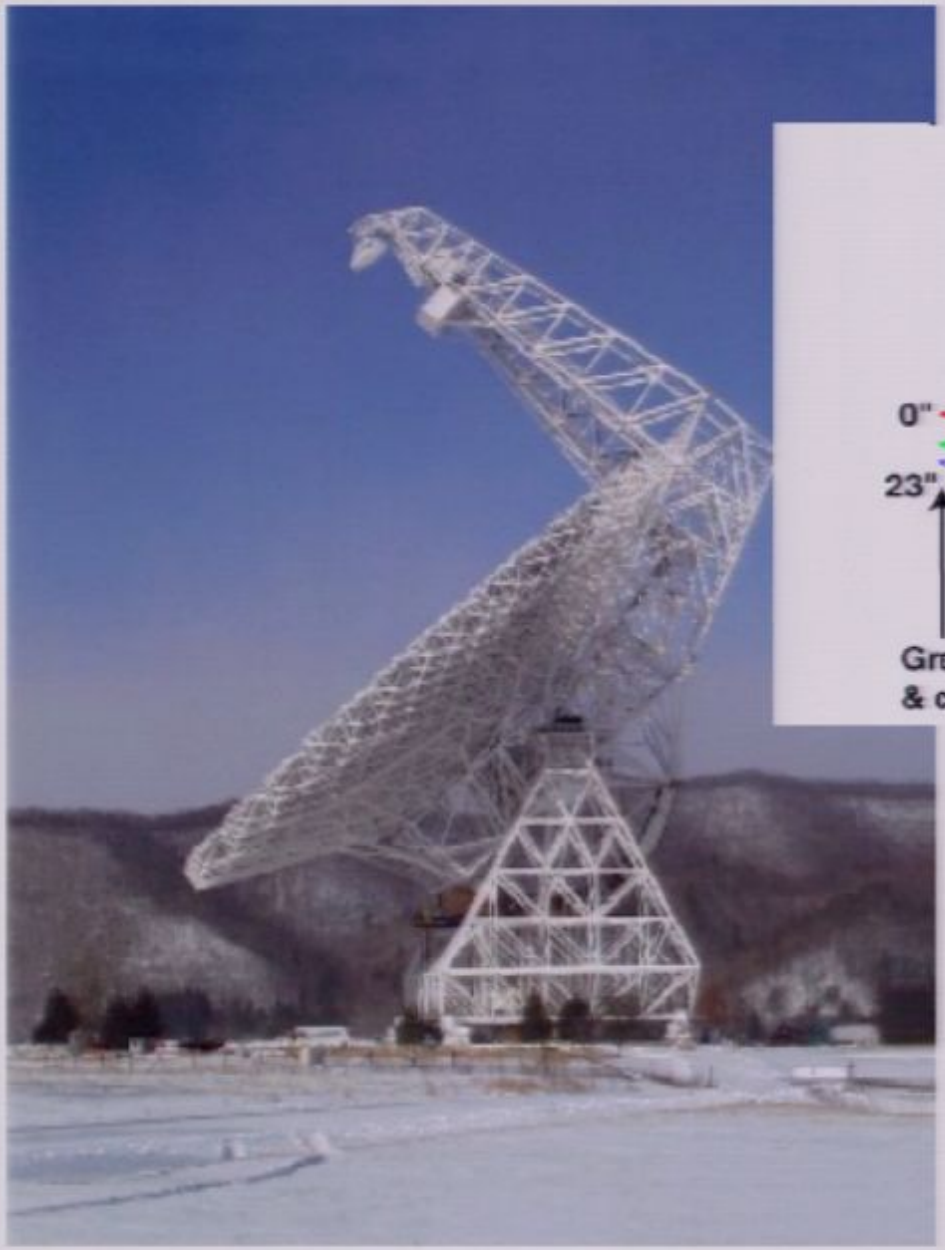
Resolution	9" (fwhm)
Beam Spacing	4"
Npixel	8x8
Target Sensitivity	Tsys = 28 K
Bandwidth	18 GHz

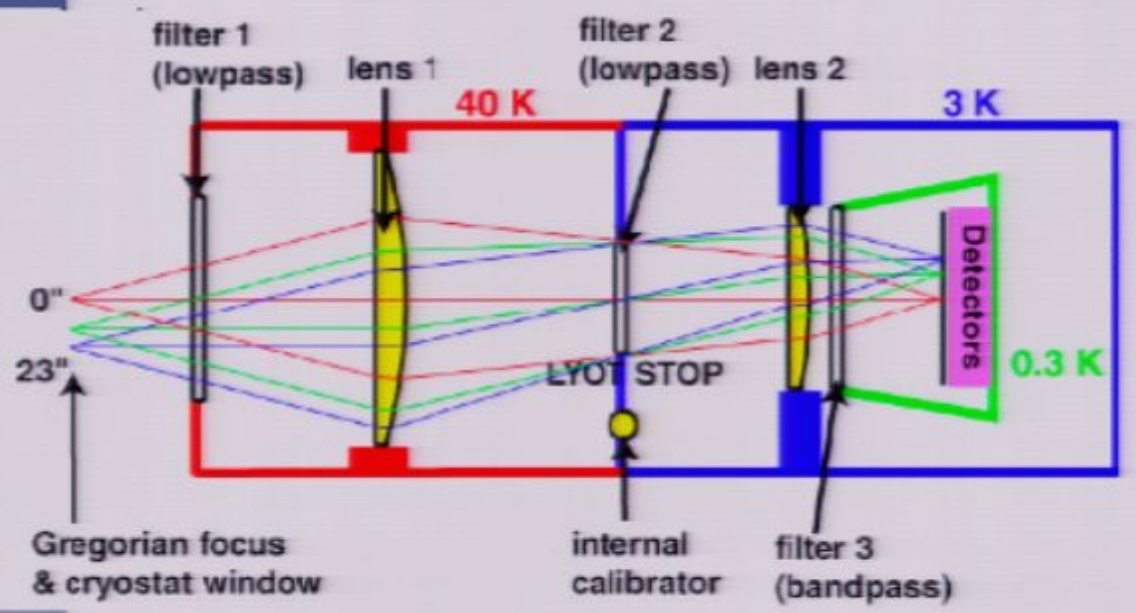
PWV of 10mm
2000 hrs/yr

Bolometers can achieve photon background Limited noise performance (Trx = 0, Tsys = Tsky)

Arrays of 1000s of detectors exist and are not expensive

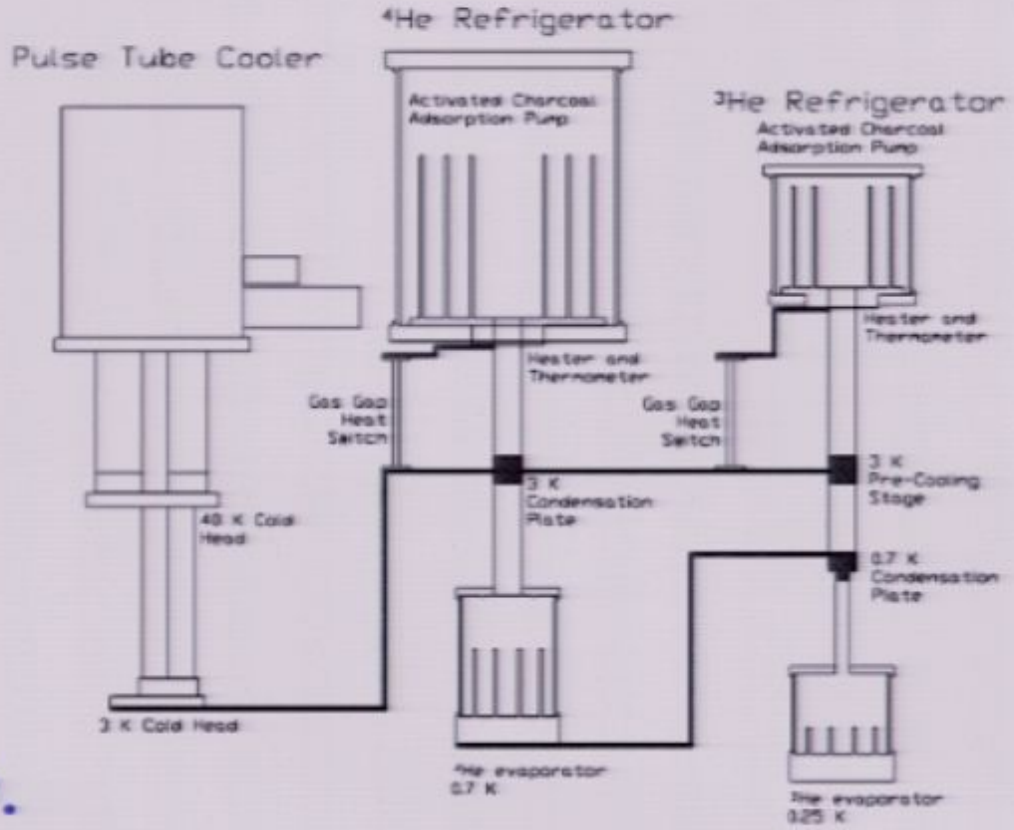
Optics





- Dicker S.R., & Devlin M.J., "Millimeter wave reimaging optics for the 100 m Green Bank telescope", Applied Optics 44, 5855-5858, 2005
- Dicker, Korngut, Mason et al.,"MUSTANG: Ninety Gigahertz Science with the Green Bank Telescope", Proc. SPIE 7020, 2008

Liquid Cryogen Free Cryogenics



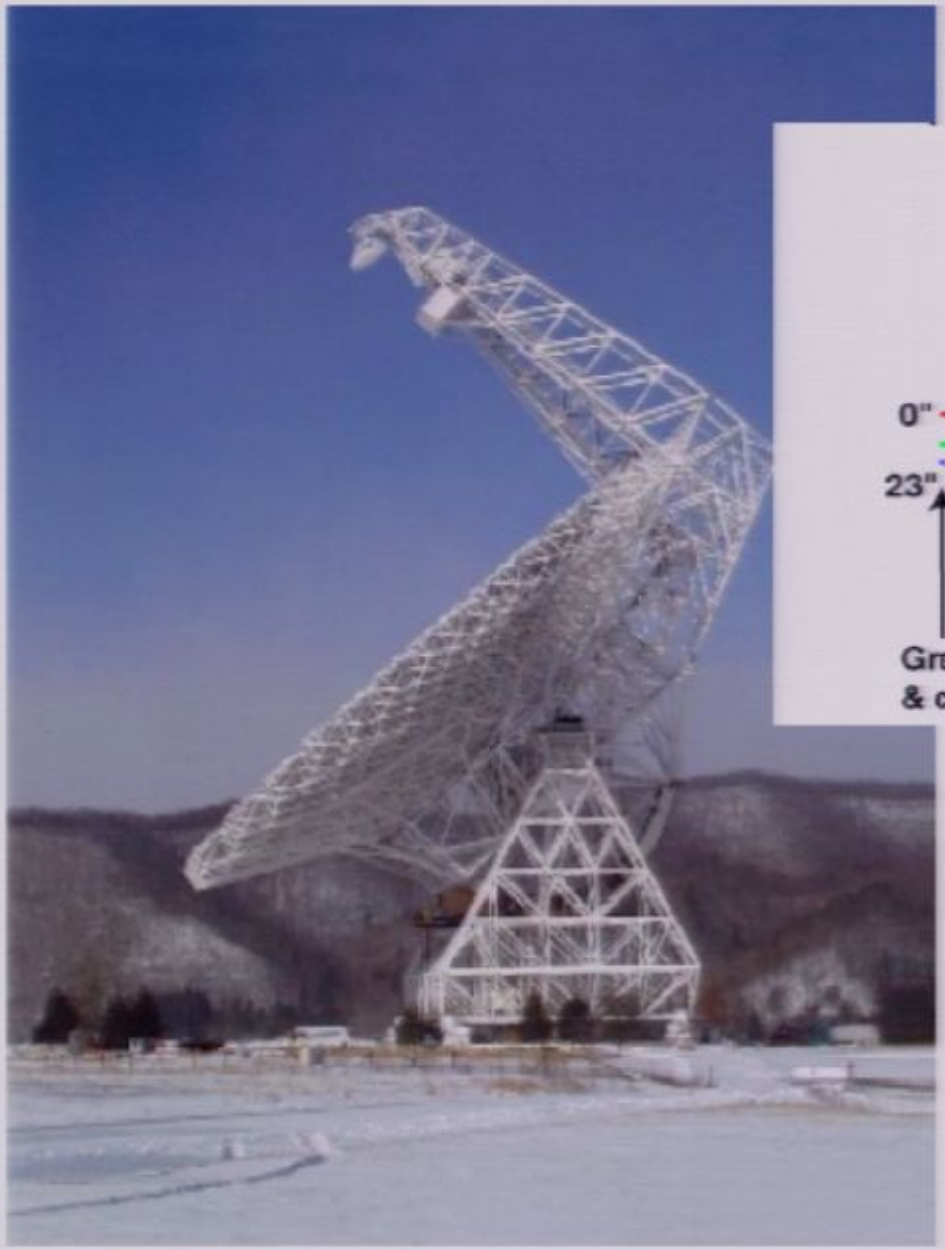
Cycle time: 1.5h

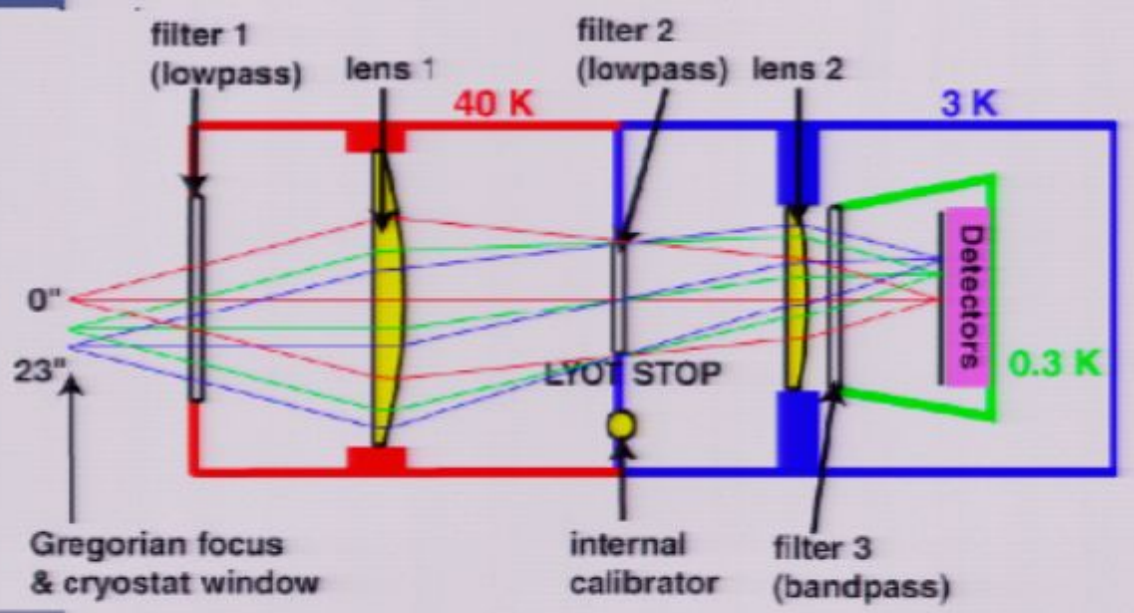
Hold time: >17h

Stays cold to 17 deg elev.

Devlin, Dicker, Klein, & Supanich (2004)

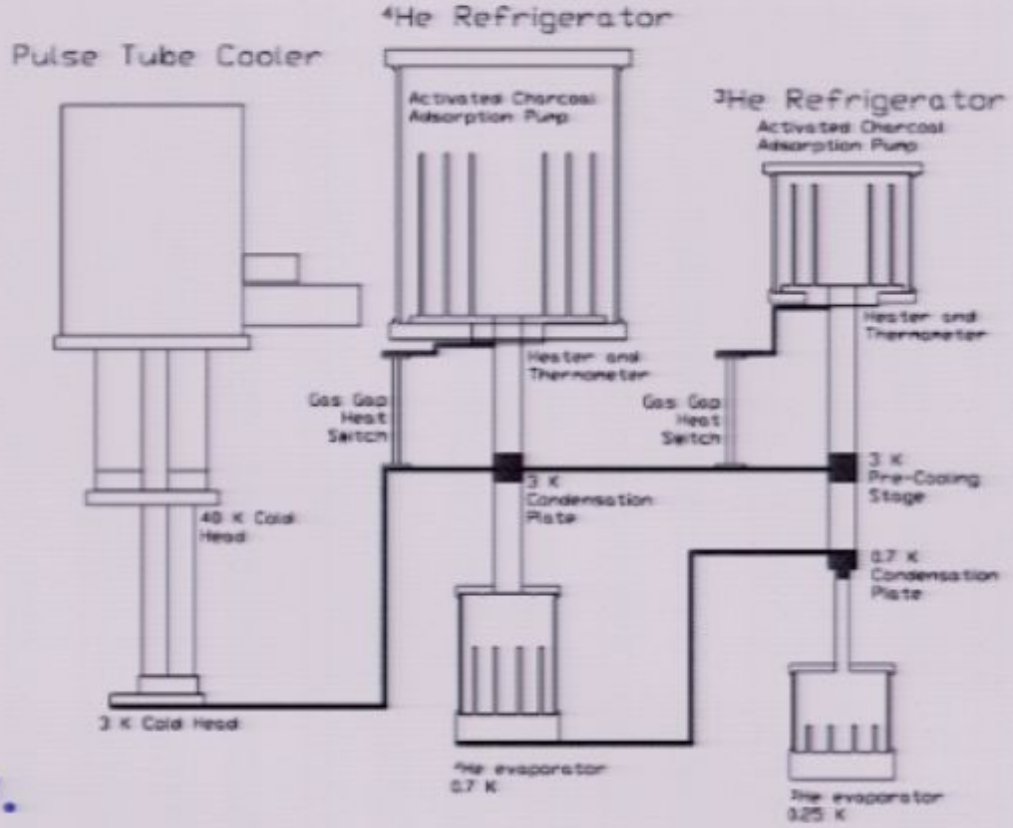
Optics





- Dicker S.R., & Devlin M.J., "Millimeter wave reimaging optics for the 100 m Green Bank telescope", Applied Optics 44, 5855-5858, 2005
- Dicker, Korngut, Mason et al.,"MUSTANG: Ninety Gigahertz Science with the Green Bank Telescope", Proc. SPIE 7020, 2008

Liquid Cryogen Free Cryogenics



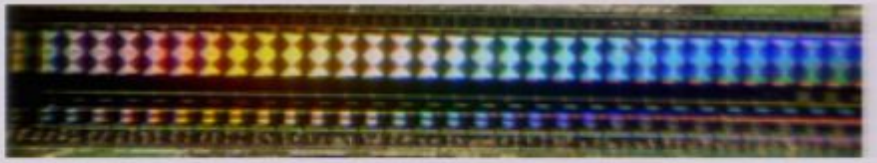
Cycle time: 1.5h

Hold time: >17h

Stays cold to 17 deg elev.

Devlin, Dicker, Klein, & Supanich (2004)

NIST Mark III (Time Domain) SQUID MUX System

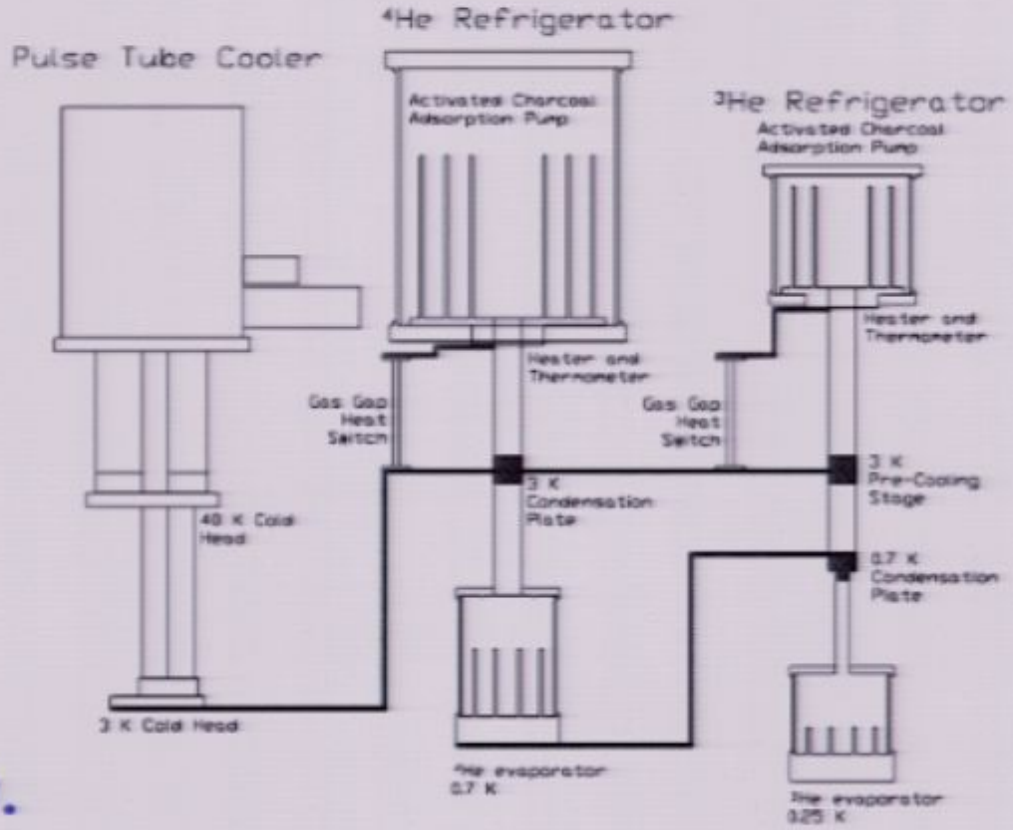


Trivially scalable to 256 Detectors

15 minutes for an expert to Tune & Bias the system.

1 tuning and bias setting sufficient for full nights' observing.

Liquid Cryogen Free Cryogenics



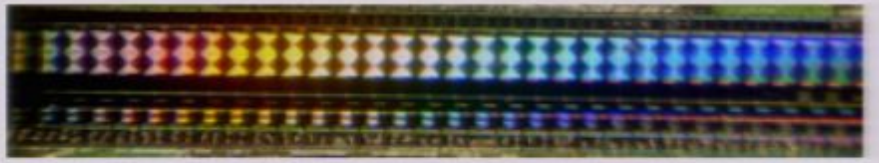
Cycle time: 1.5h

Hold time: >17h

Stays cold to 17 deg elev.

Devlin, Dicker, Klein, & Supanich (2004)

NIST Mark III (Time Domain) SQUID MUX System



Trivially scalable to 256 Detectors

15 minutes for an expert to Tune & Bias the system.

1 tuning and bias setting sufficient for full nights' observing.

History

Fall 2006 Engineering run

- serious 1/f -- traced to microphonics from PTC
    - Uncorrelated between pixels

    Fixed by vibrational isolation of 3K PTC head

Winter 07/08 commissioning + demo science

- bright sources (Orion, nearby AGN etc)

Subsequent improvements

- faster optics (0.5 flambda --> 0.7 flambda)
- Online, near-realtime medium to large scale corrections to the GBT surface
    - out of focus (OOF) holography
- Traditional holography

Total: 2 (surface) * 1.7 (optics) ~ 3.4x in sensitivity

History

Fall 2006 Engineering run

- serious 1/f -- traced to microphonics from PTC

Wi

- b

Sub

- f

- O

the

- out of focus (OOF) holography

- Traditional holography

- Limiting factor is now detector noise (5x BG)

We aim for another 50-100% increase in GBT aperture efficiency

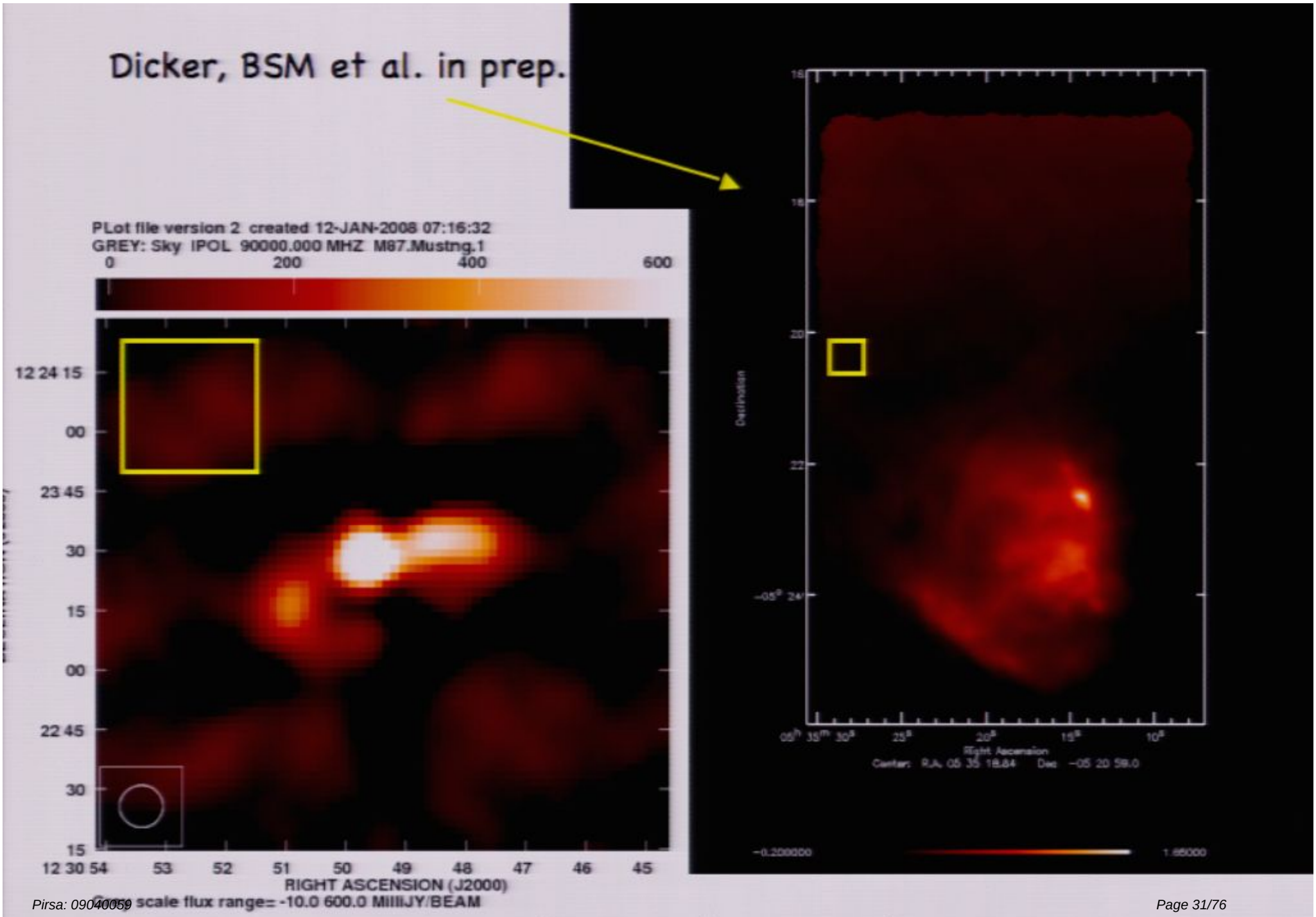
Now a proposable facility instrument

on telescope observing SZ, protostars, debris disks...

large projects (100s of hours) are possible

Total: 2 (surface) * 1.7 (optics) ~ 3.4x in sensitivity

Dicker, BSM et al. in prep.



Cotton, BSM et al. submitted (astro-ph/0902.3149)

History

Fall 2006 Engineering run

- serious 1/f -- traced to microphonics from PTC

Wi

- b

Sub

- f

- O

the

- out of focus (OOF) holography

- Traditional holography

Total: 2 (surface) * 1.7 (optics) ~ 3.4x in sensitivity

- Limiting factor is now detector noise (5x BG)

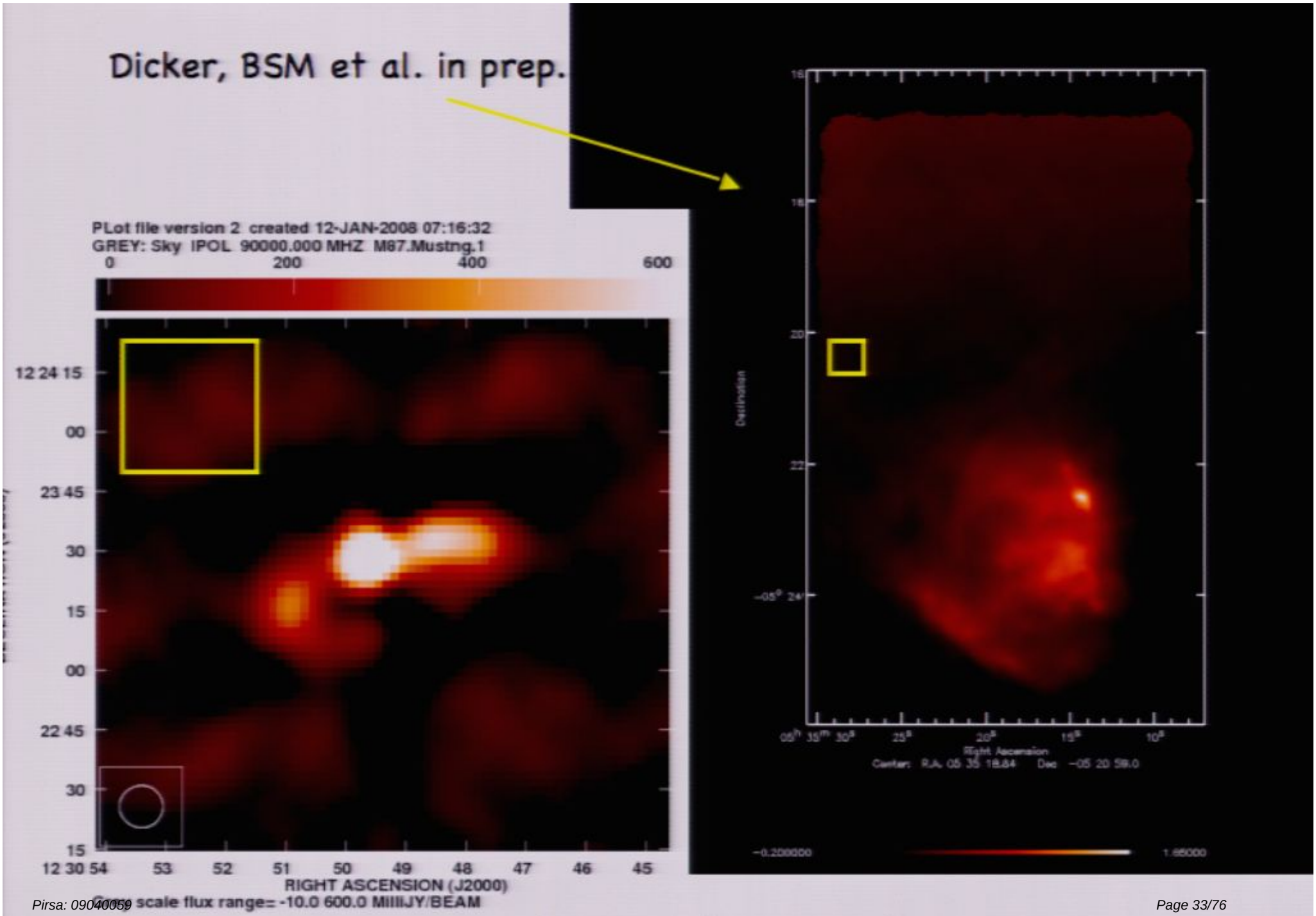
We aim for another 50-100% increase in GBT aperture efficiency

Now a proposable facility instrument

on telescope observing SZ, protostars, debris disks...

large projects (100s of hours) are possible

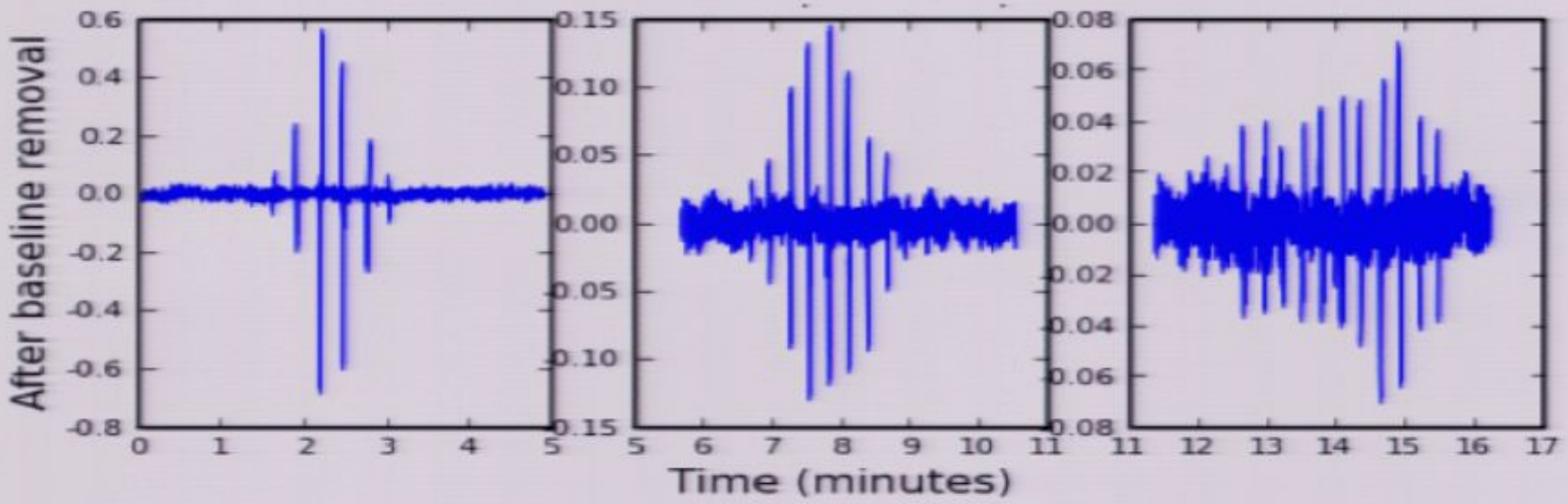
Dicker, BSM et al. in prep.

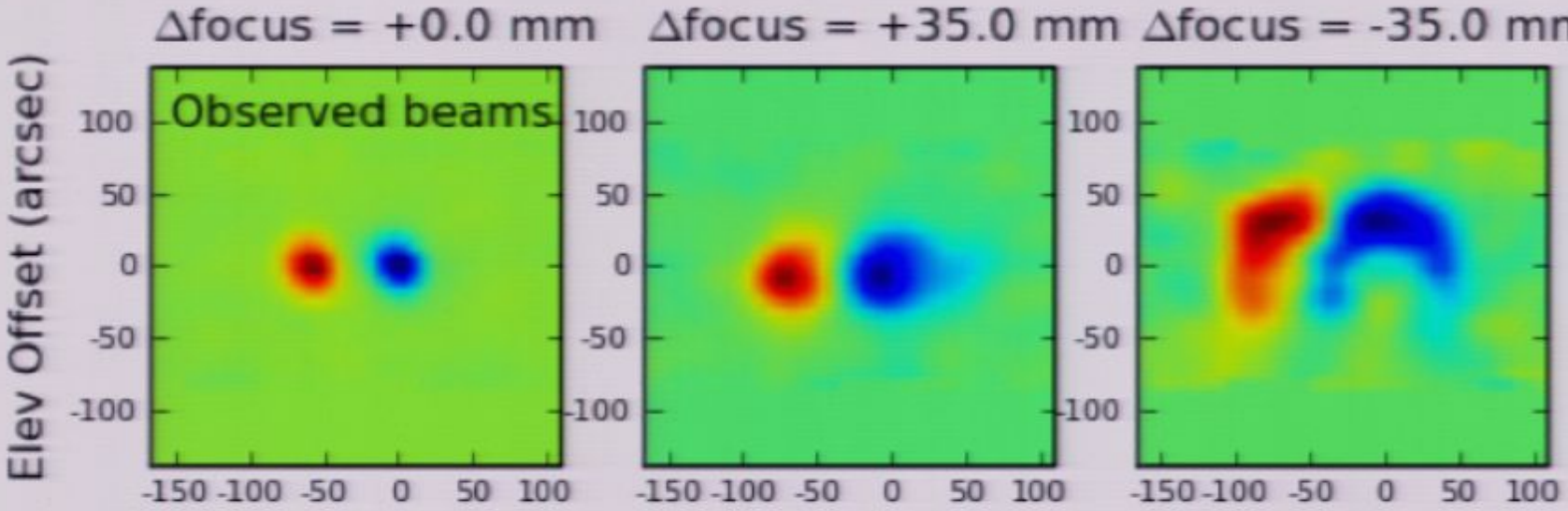


Gray scale flux range= -10.0 600.0 MILLIJY/BEAM

Cotton, BSM et al. submitted (astro-ph/0902.3149)

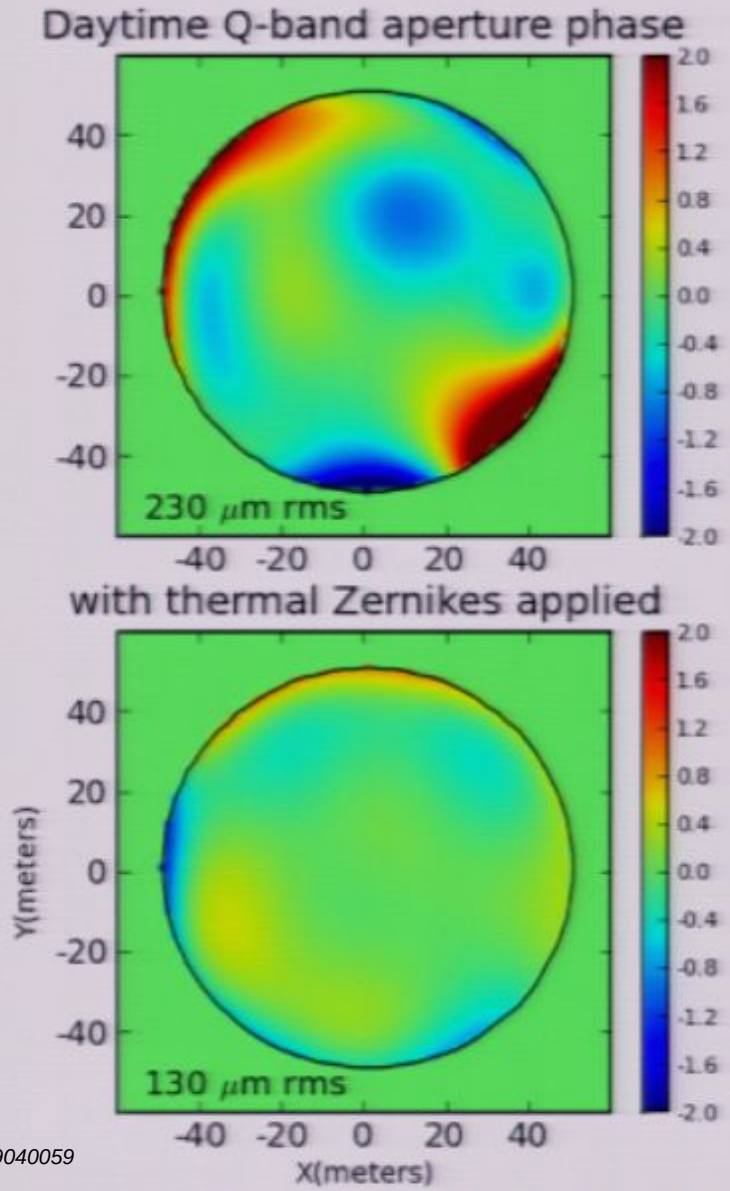
Out-of-Focus (OOF) Holography Technique

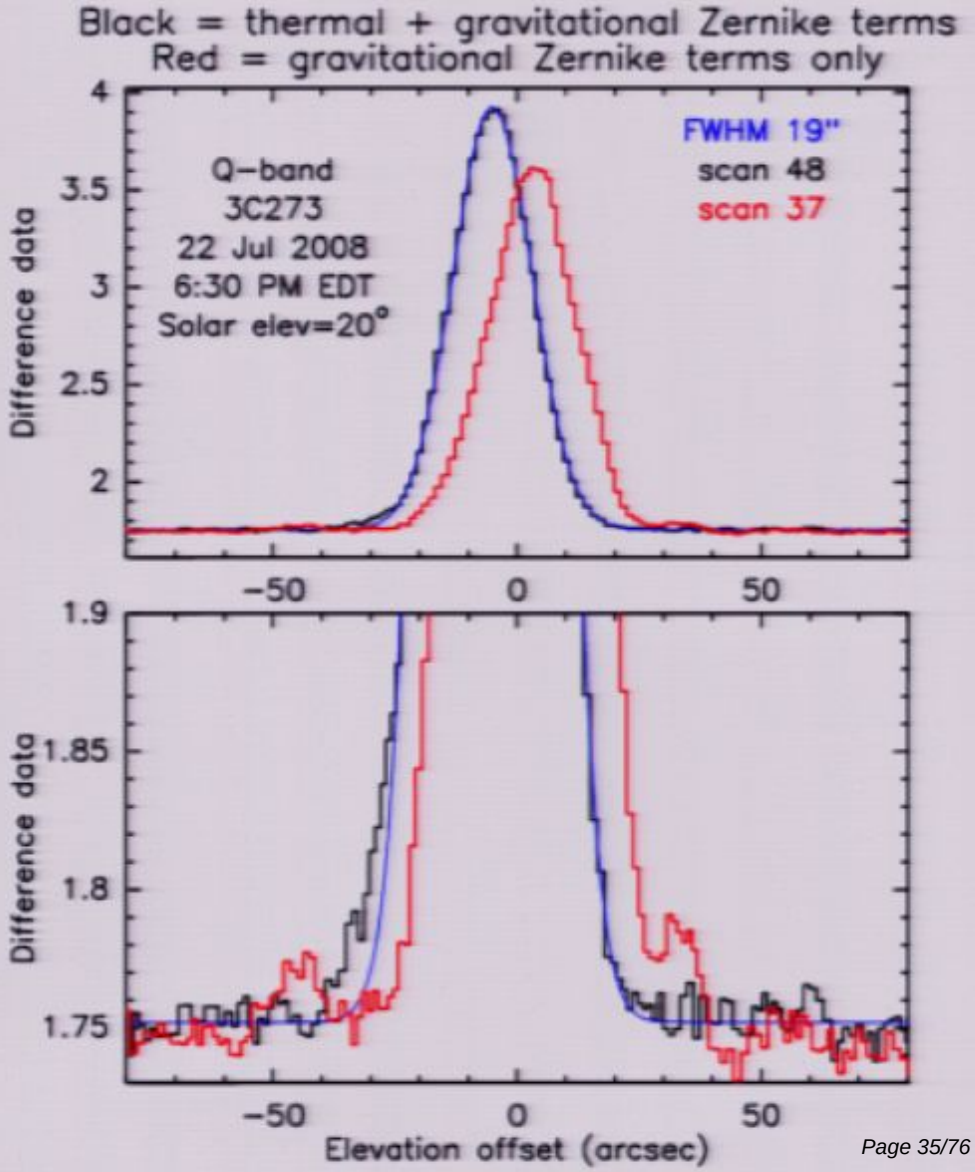


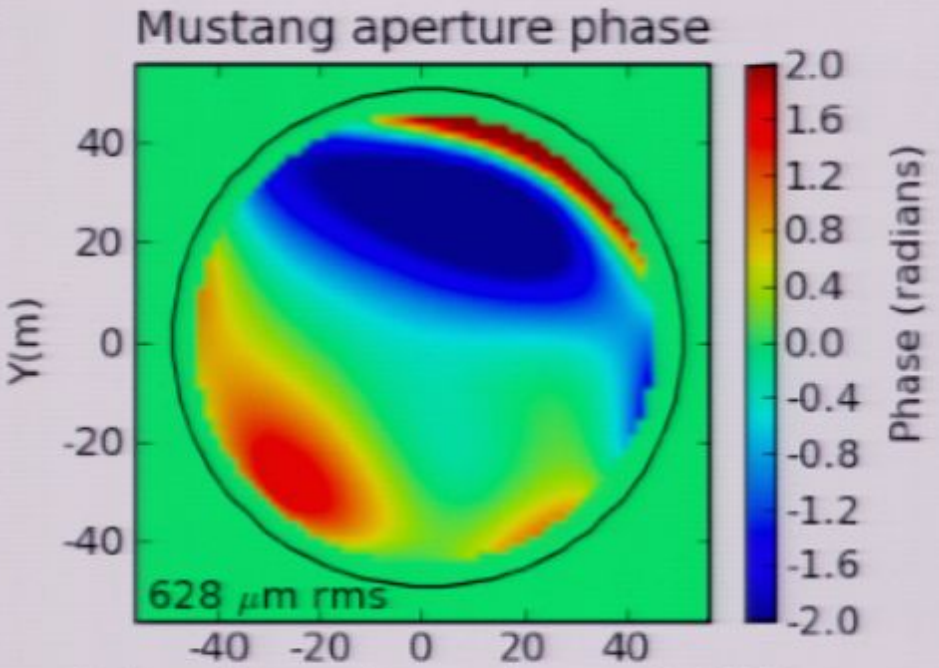


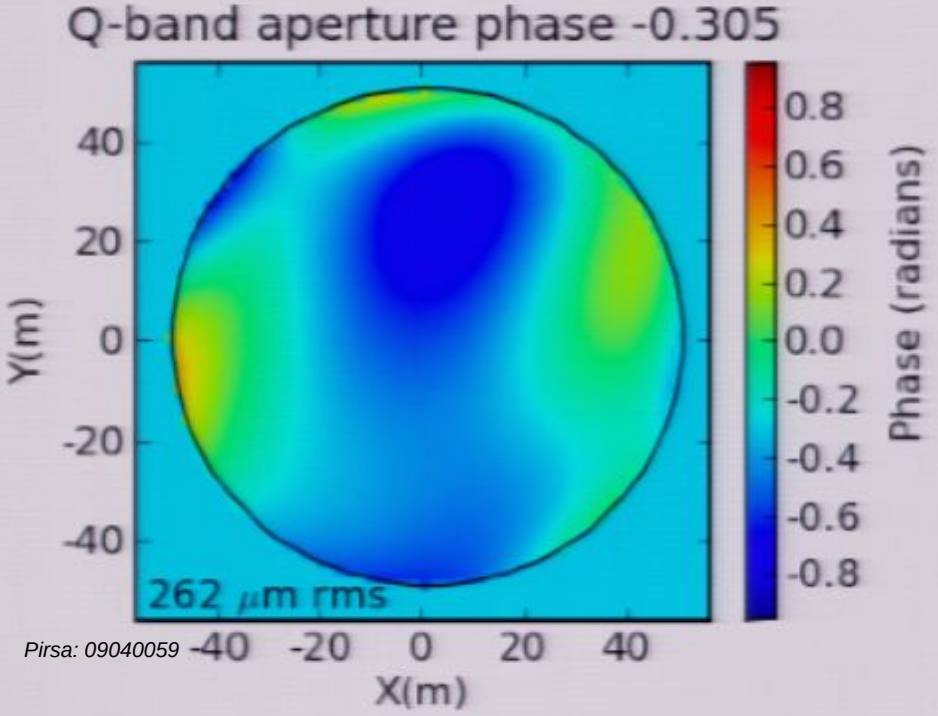
W/Todd Hunter (NRAO), Bojan Nikolic (Cambridge/ALMA)

Out of Focus Holography







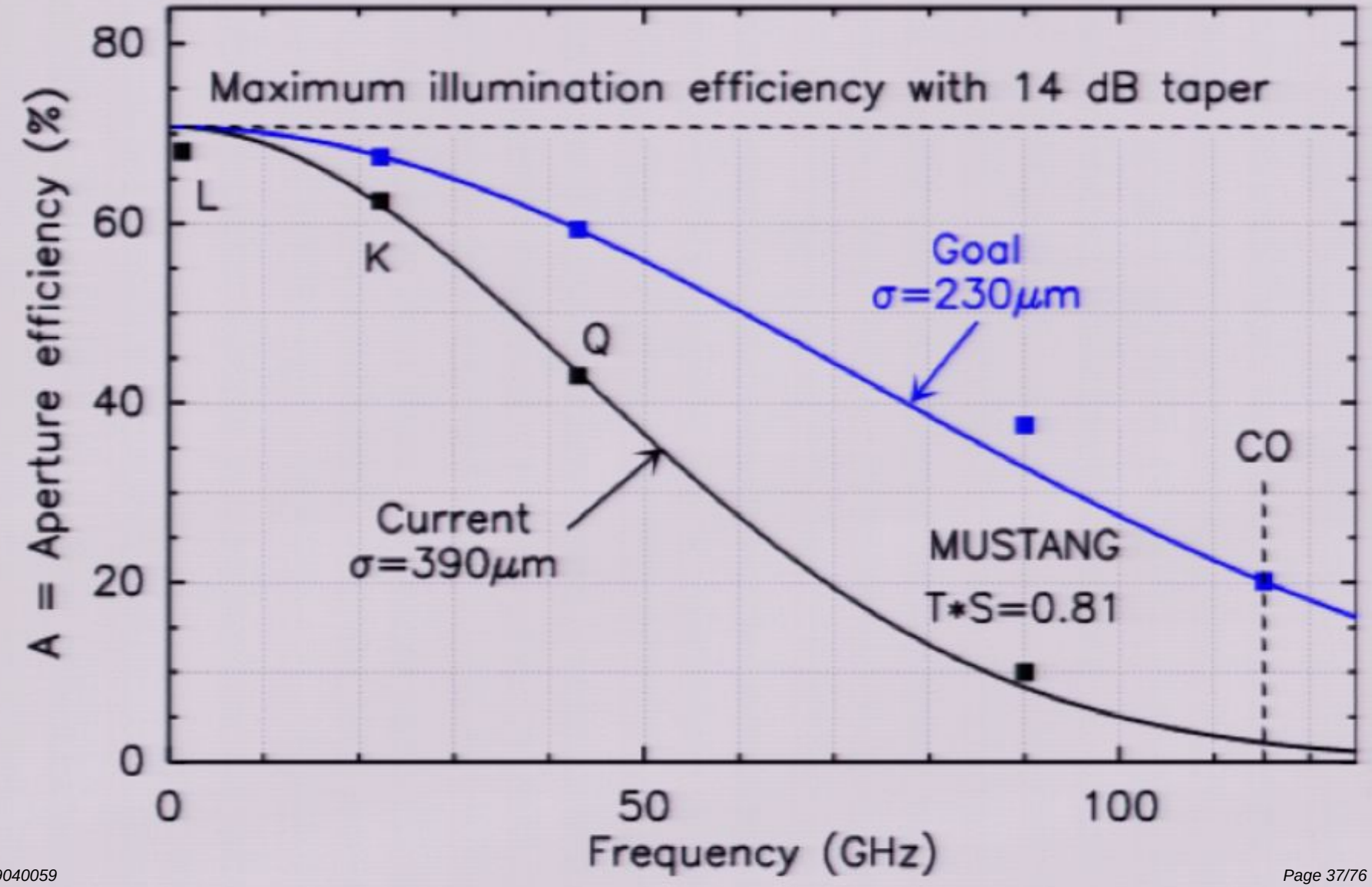


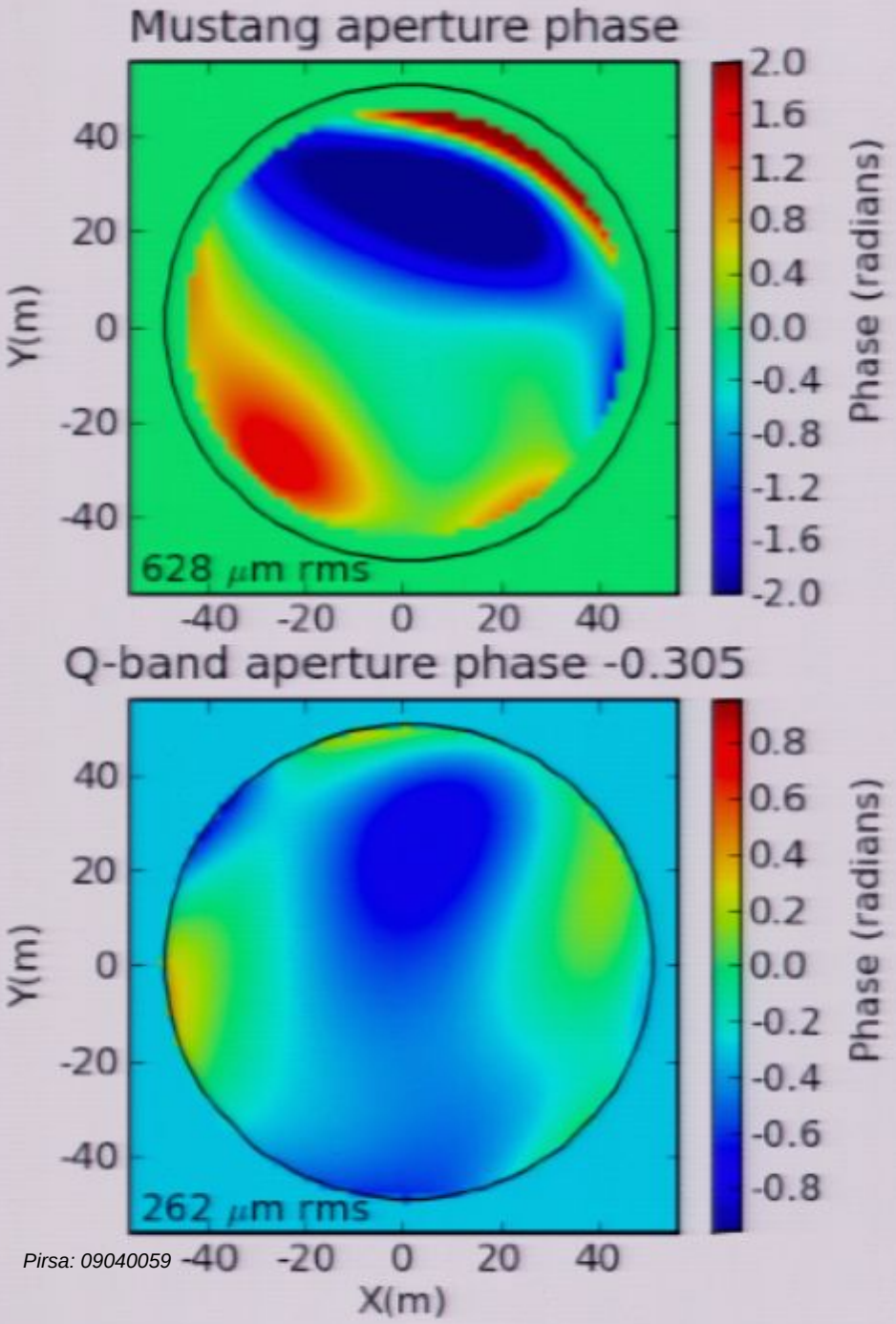
Large scale aperture phase errors can be measured & corrected in under 15 minutes - we do this routinely during observations

Telescope control software:

- Collects the data
- automatically launches OOF analysis
- plots the beammaps & phase corrections
- allows application of corrections

Small-scale Surface Improvements



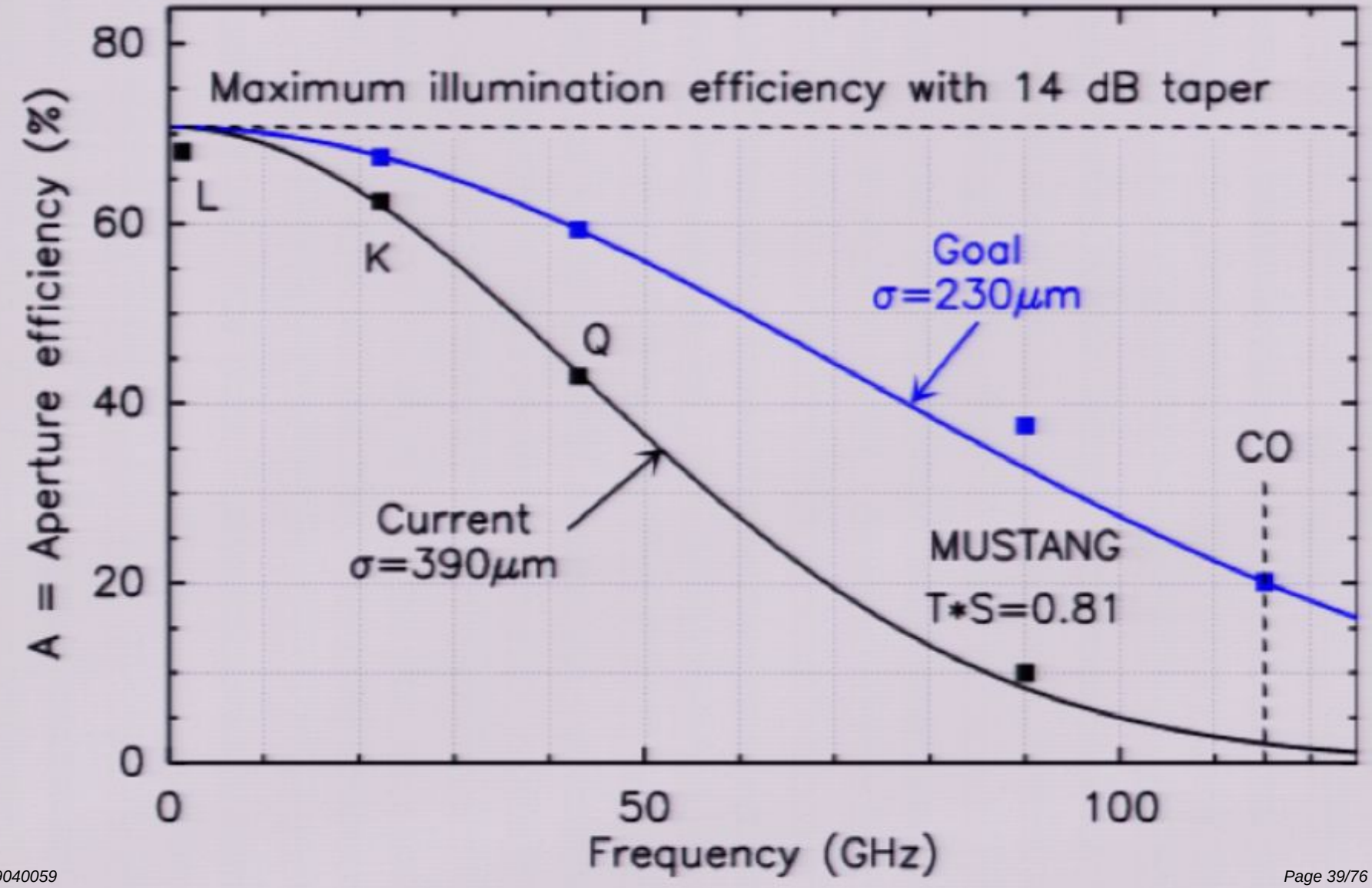


Large scale aperture phase errors can be measured & corrected in under 15 minutes - we do this routinely during observations

Telescope control software:

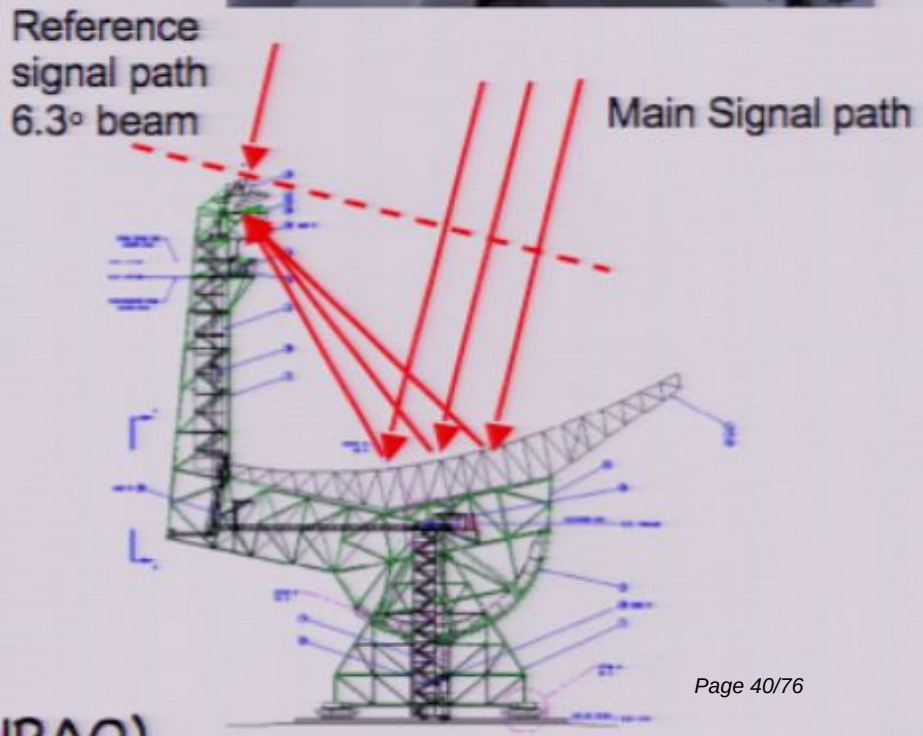
- Collects the data
- automatically launches OOF analysis
- plots the beammaps & phase corrections
- allows application of corrections

Small-scale Surface Improvements



Traditional (with-phase) holography

- Ku-band holography system (2LNBs + correlator) upgraded and re-commissioned in December 2008
  - Sample rate increased to 28 Hz
  - allows 200-column, 2.5° maps in 3hrs
  - New DROs with Digital PLLs, new TECs
- Ku beacons at 11.702 GHz
  - Galaxy 28 at Elev=44°
  - Galaxy 18 at Elev=28°
  - Galaxy 27 at Elev=23°, etc.



Todd Hunter & Fred Schwab (NRAO)

First holography results

412 microns rms

10% -> 15% -> 20%
Aperture efficiency!

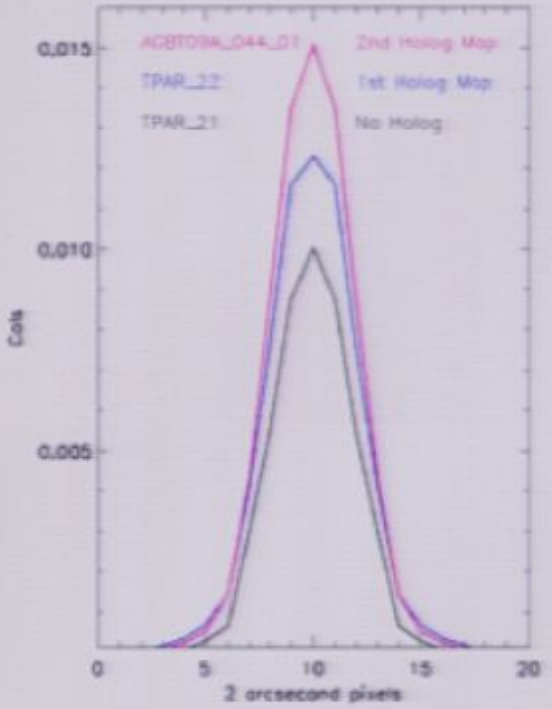
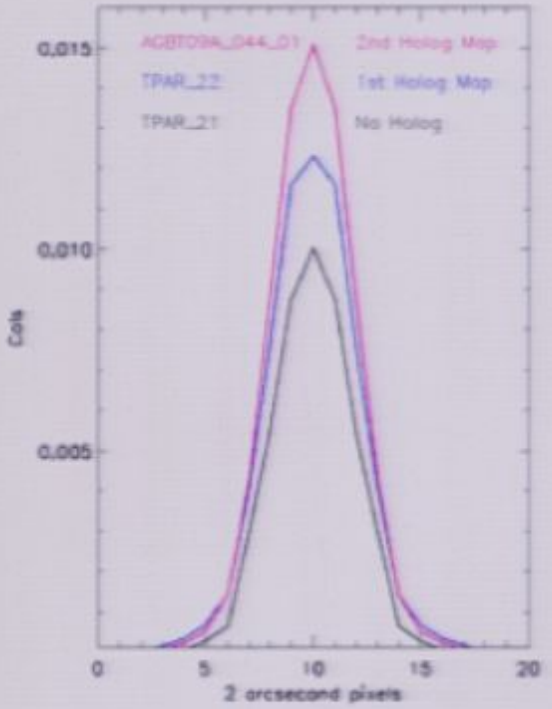


Image credit: Todd Hunter & Fred Schwab (NRAO)

First holography results

412 microns rms

10% -> 15% -> 20%
Aperture efficiency!



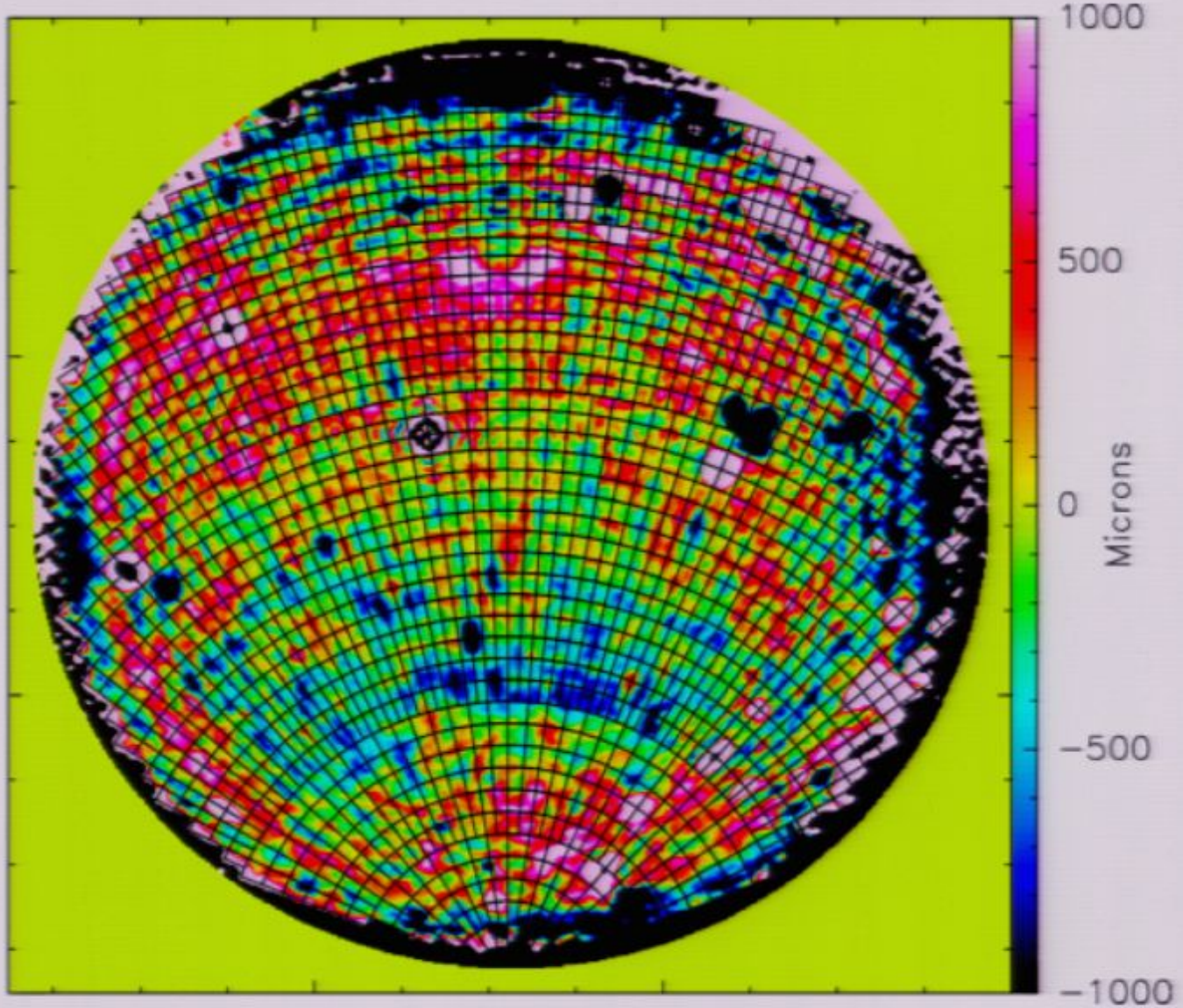
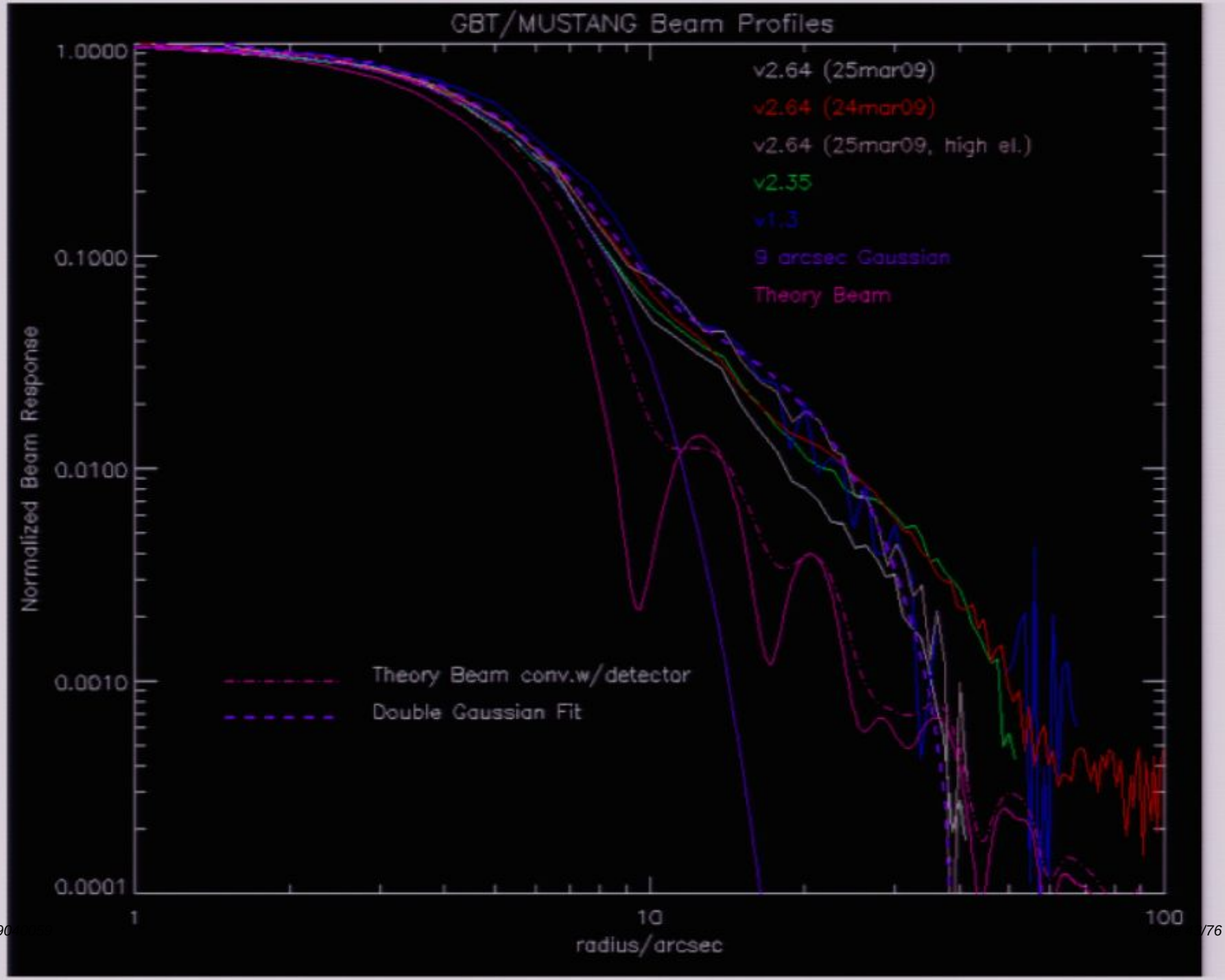
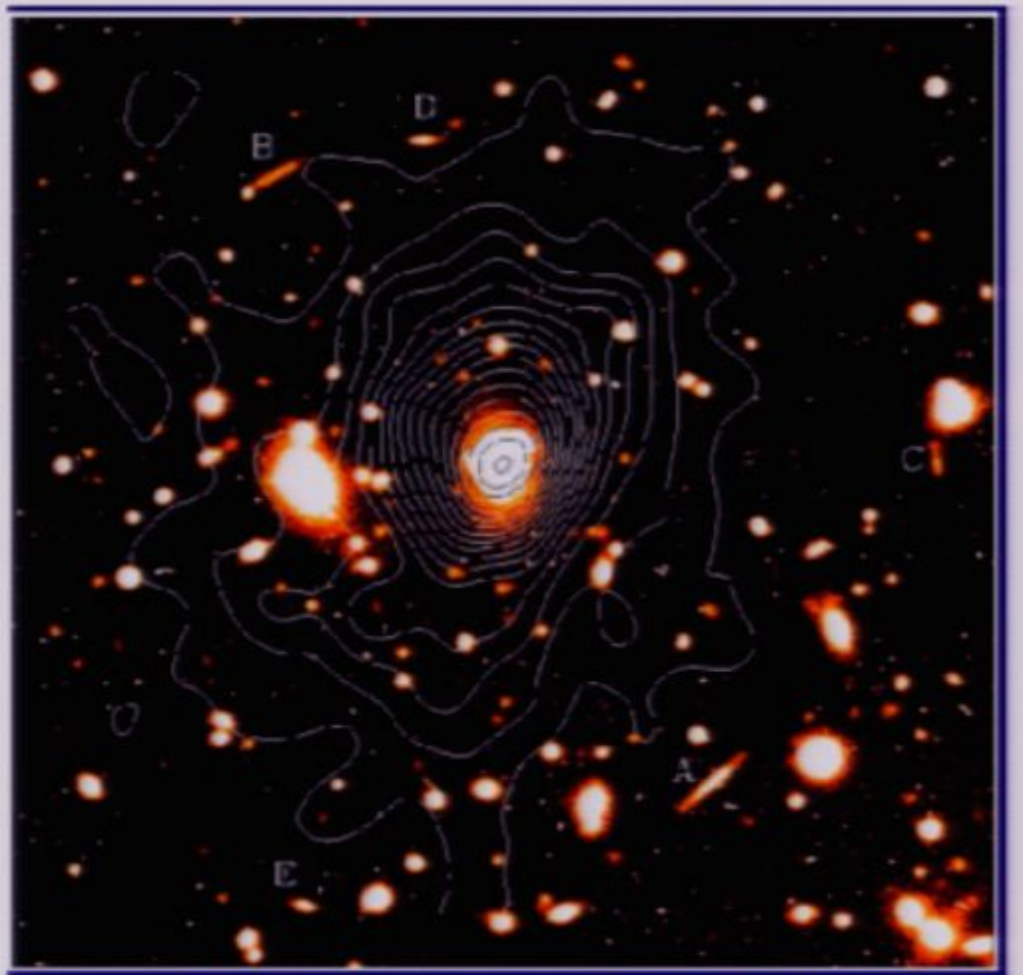


Image credit: Todd Hunter & Fred Schwab (NRAO)


GBT/MUSTANG Beam Profiles
v2.64 (25mar09)
v2.64 (24mar09)
v2.64 (25mar09, high el.)
v2.35
v1.3
9 arcsec Gaussian
Theory Beam
Theory Beam conv.w/detector
Double Gaussian Fit
Normalized Beam Response
1.0000
0.1000
0.0100
0.0010
0.0001
1
10
100
radius/arcsec

First SZ Observations: RXJ1347-1145



Schindler et al. (1997)

The most luminous known X-ray cluster

$L_X = 2 \times 10^{46}$ erg/s

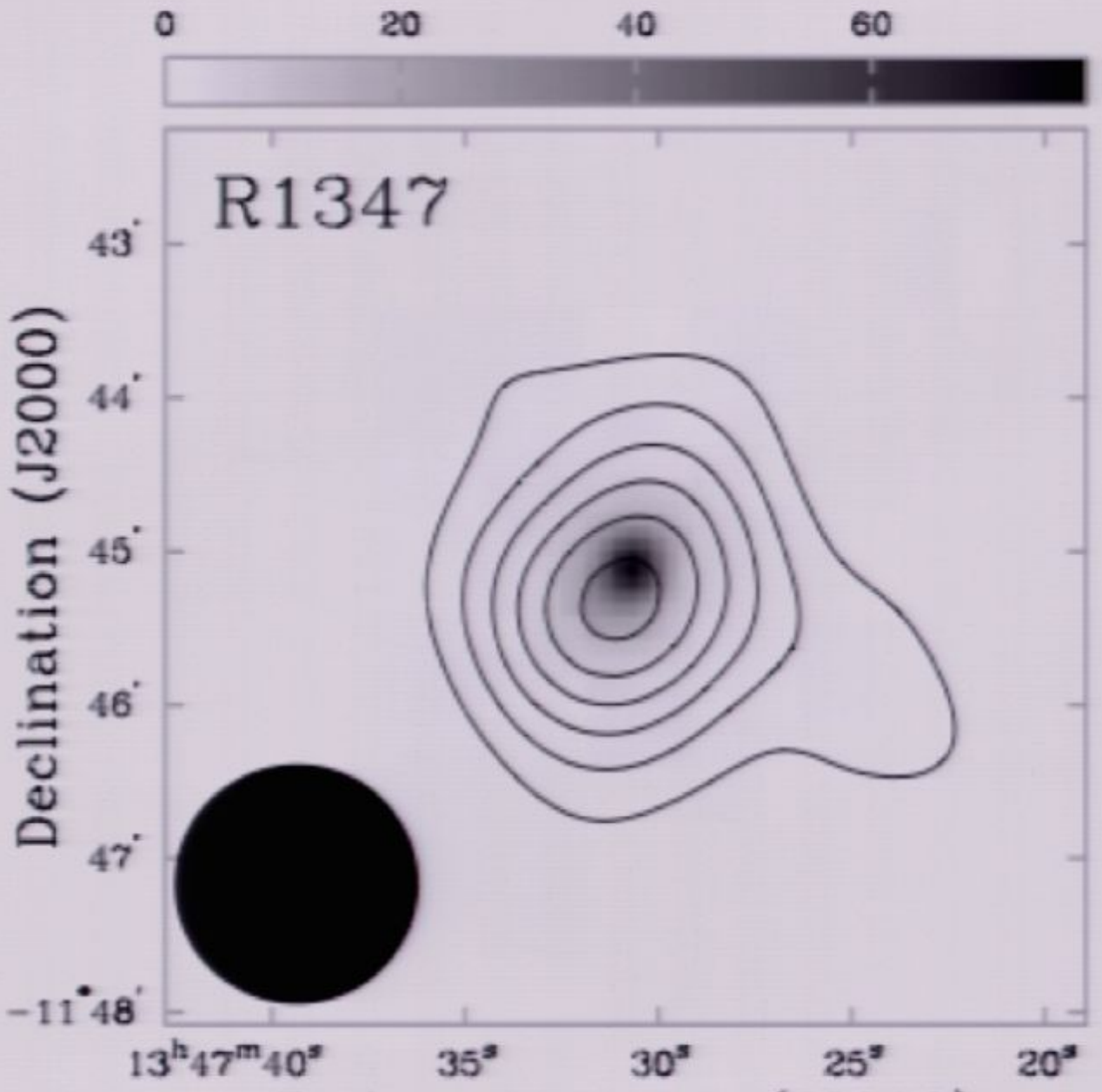
$\langle kT \rangle = 12$ keV

$N_{eo} = 2 \times 10^{-2}$ cm

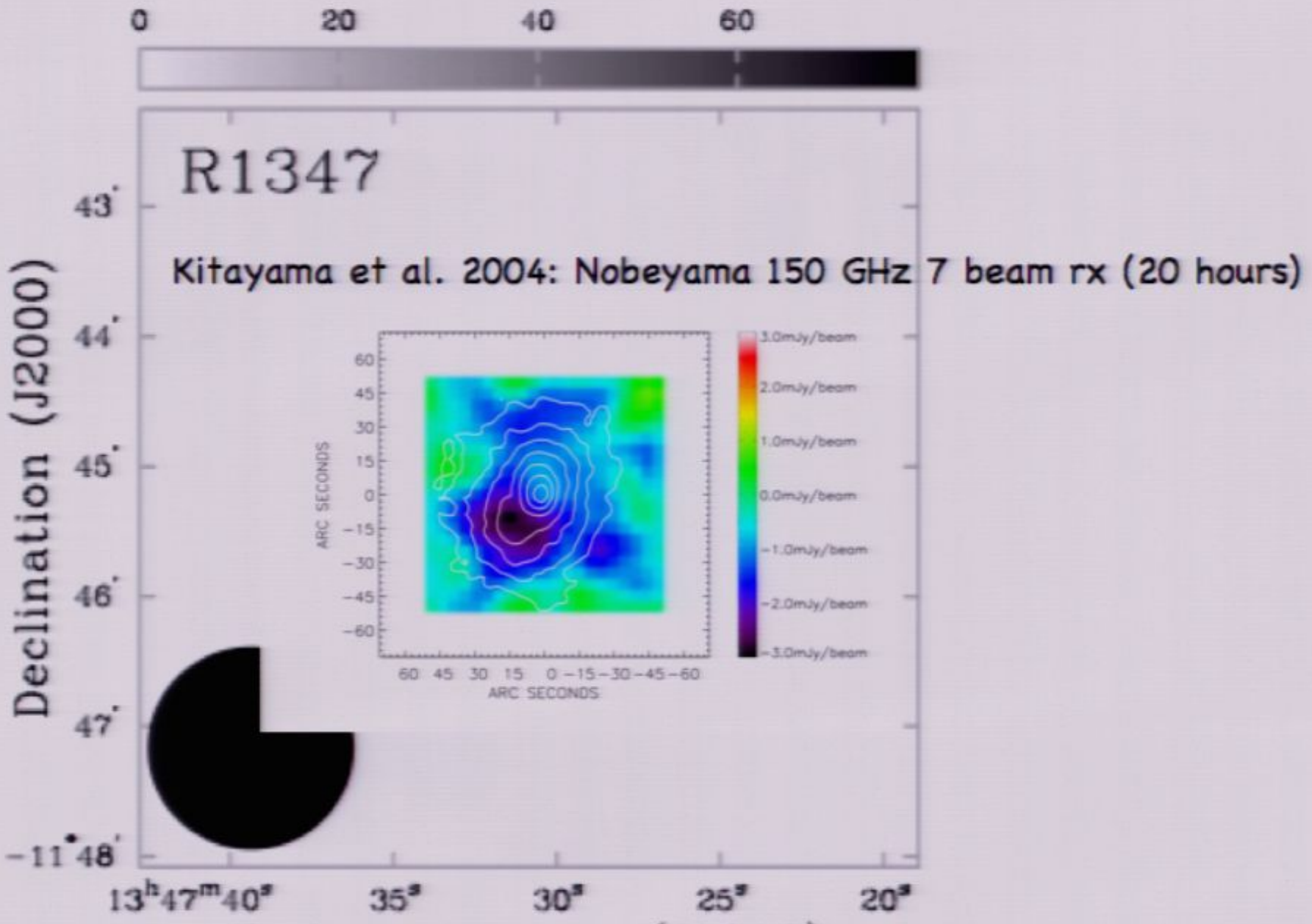
Central Decrement

$y = 10^{-3}$

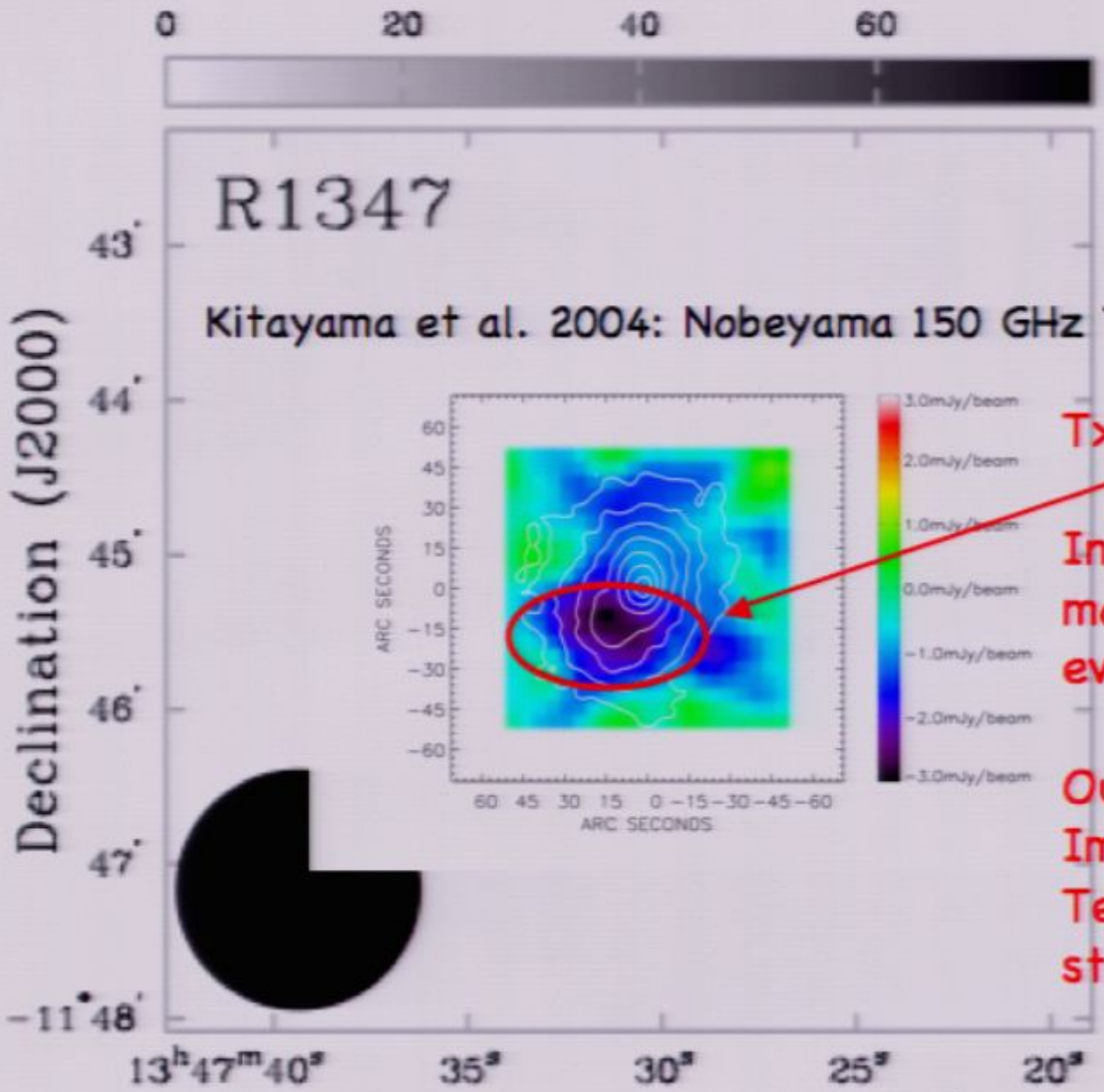
2 mJy/bm @ 8", 90 GHz



Reese et al. 2002: BIMA 30 GHz (20 hours)



Reese et al. 2002: BIMA 30 GHz (20 hours)


0
20
40
60
R1347
Kitayama et al. 2004: Nobeyama 150 GHz 7 beam rx (20 hours)
Declination (J2000)
43'
44'
45'
46'
47'
-11°48'
13h47m40s
35s
30s
25s
20s
Right Ascension (J2000)
ARC SECONDS
60 45 30 15 0 -15 -30 -45 -60
3.0mJy/beam
2.0mJy/beam
1.0mJy/beam
0.0mJy/beam
-1.0mJy/beam
-2.0mJy/beam
-3.0mJy/beam
T>20 keV shock
Indicator of recent major merger event!
Out of band for Imaging x-ray Telescopes; very strong in SZE
Reese et al. 2002: BIMA 30 GHz (20 hours)

Observations

- Regular GBT proposal (24 (12) h)
- 4 hour run 21feb09 (1.5h on source)
- 4 hour run 25feb09 (1.5h on source)
- Aperture phase measured with OOF holography & corrections to the GBT surface made at the start of each run and checked each 0.5h (pointing/focus check)

- Primary flux calibrator: Ceres

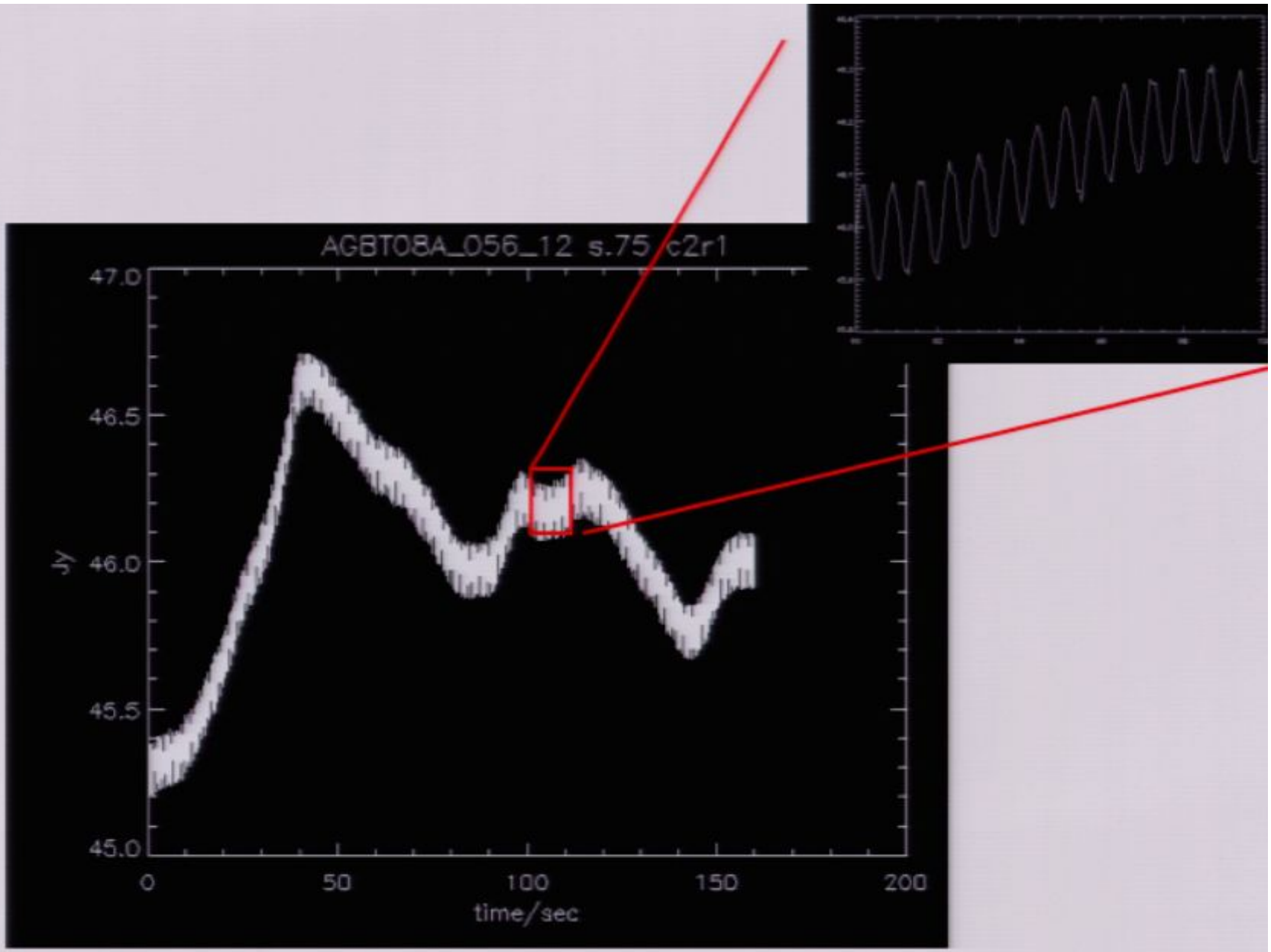
Data reduction

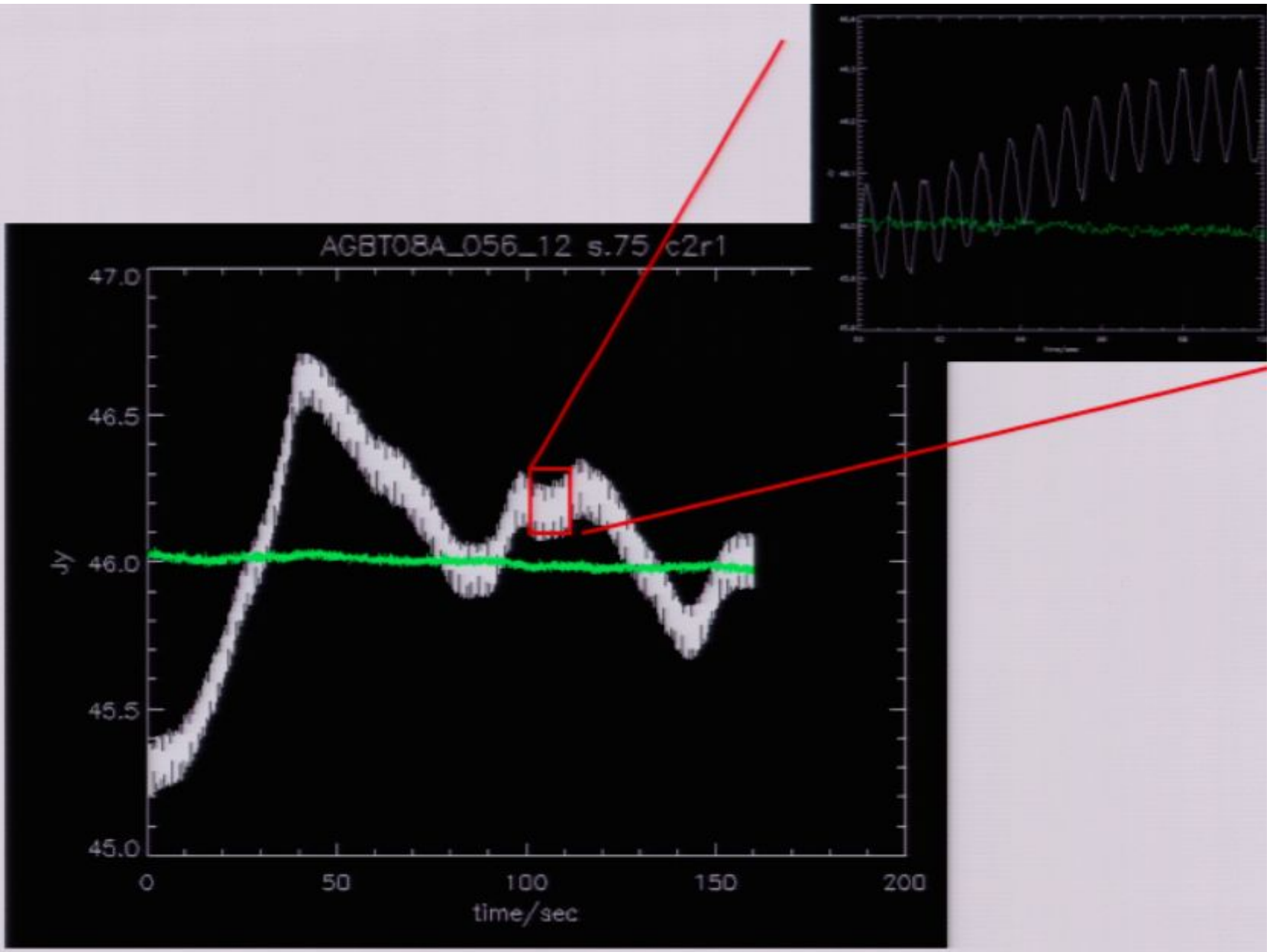
SYSTEMATICS

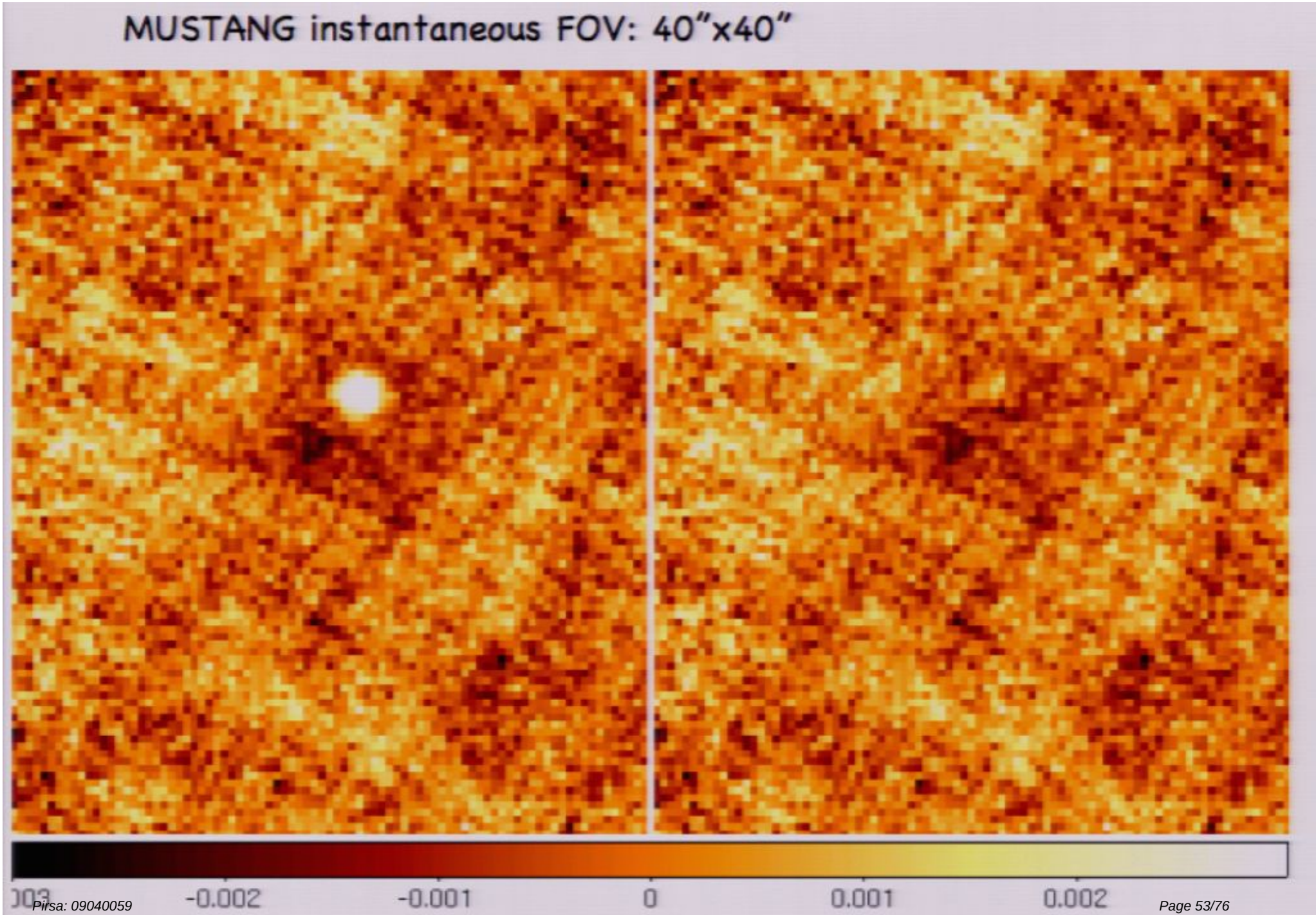
- Atmospheric emission
  - few seconds or longer
- Pulse Tube Cooler
  - 1.4 Hz (very stable)

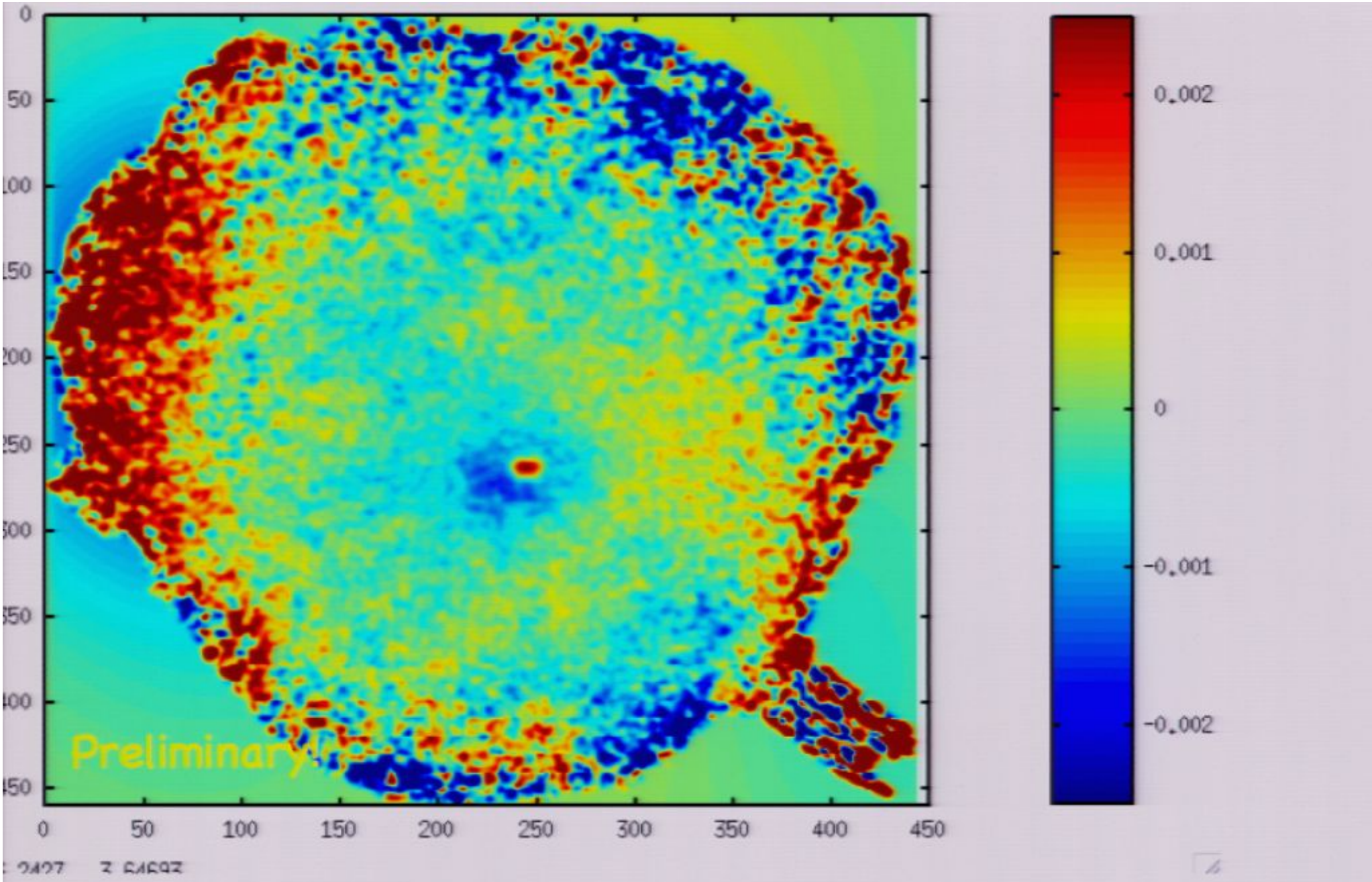
Common Mode

100m telescope, 40" FOV
Beams fully diverge
500 km from the telescope


AGBT08A_056_12 s.75 c2r1
47.0
46.5
46.0
45.5
45.0
Jy
0
50
100
150
200
time/sec


AGBT08A_056_12 s.75 c2r1
47.0
46.5
46.0
45.5
45.0
Jy
0
50
100
150
200
time/sec


MUSTANG instantaneous FOV: 40"x40"
-0.002
-0.001
0
0.001
0.002



T. Sievers – Noise eigenvector approach – 2 nights data with NO pointing Corrections

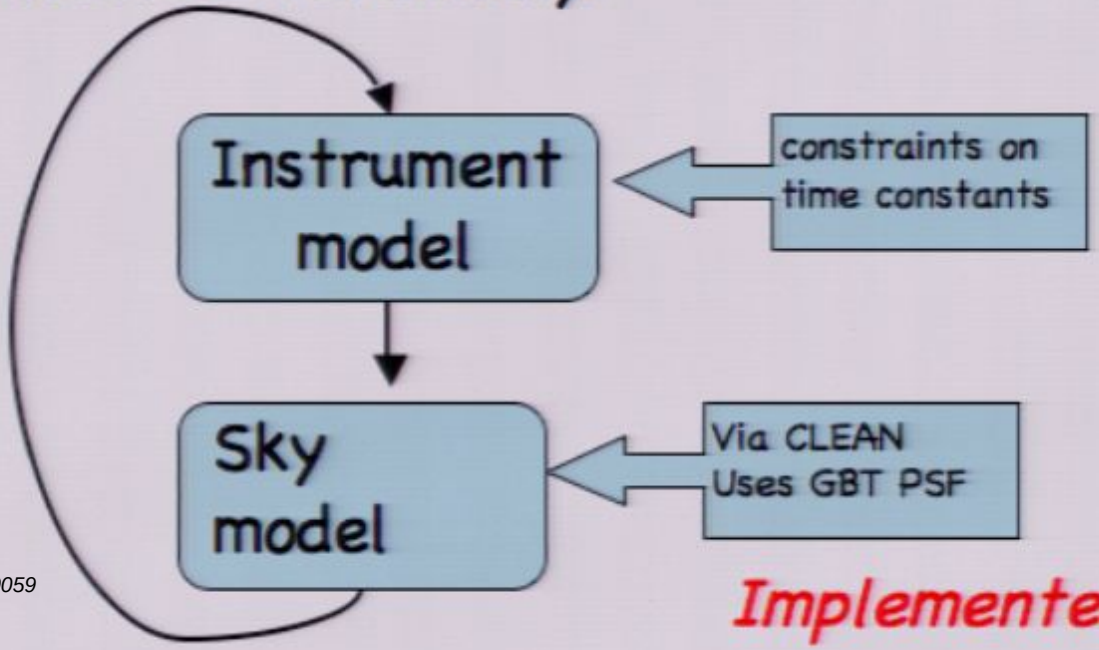
Data reduction

SYSTEMATICS

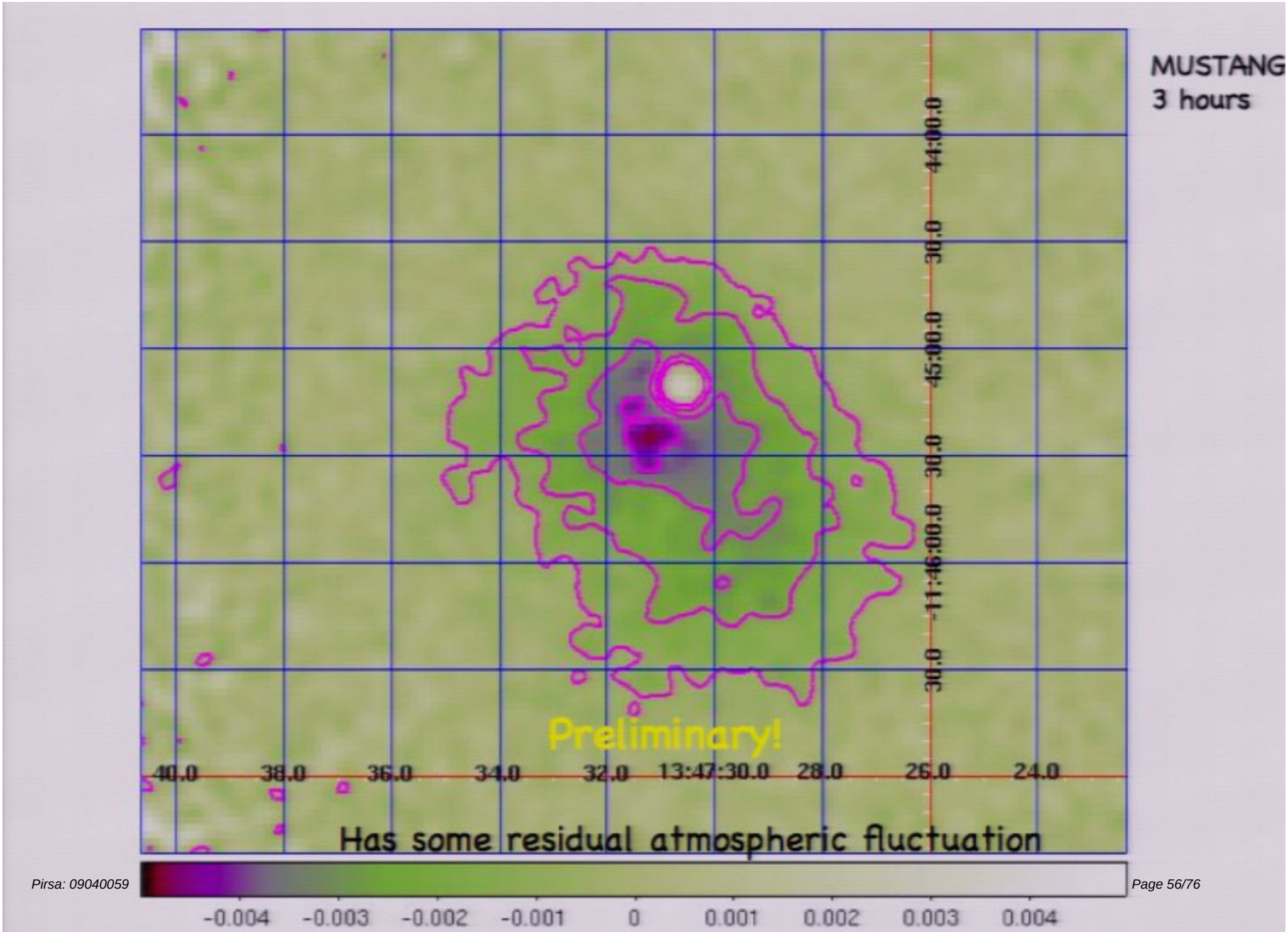
- Atmospheric emission
  - few seconds or longer
- Pulse Tube Cooler
  - 1.4 Hz (very stable)

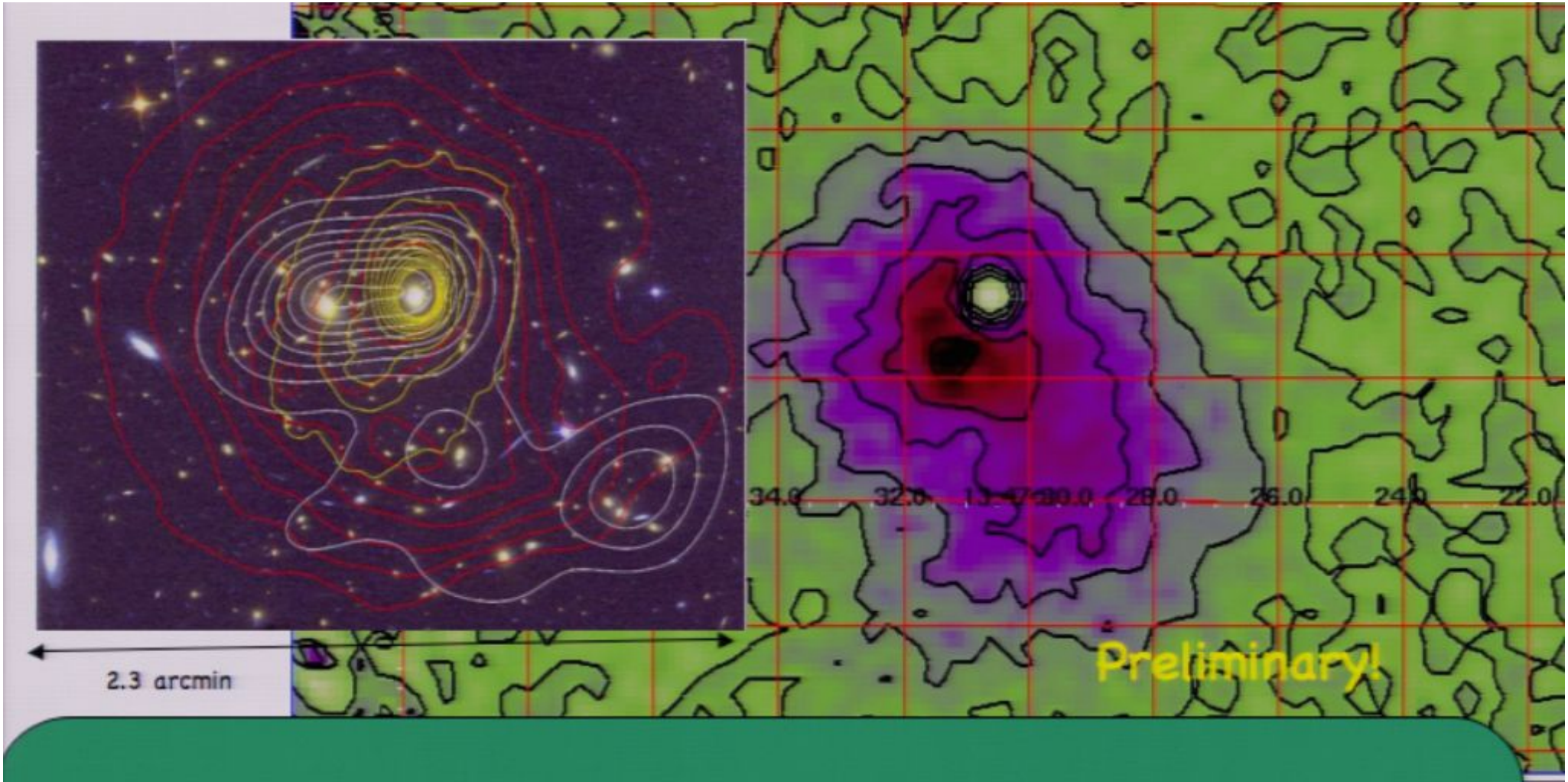
Common Mode...
But some sky signals are also common mode

Modeled iteratively:



Implemented in OBIT


MUSTANG
3 hours
44:00.0
30.0
45:00.0
30.0
-11:46:00.0
30.0
40.0
38.0
36.0
34.0
32.0
13:47:30.0
28.0
26.0
24.0
Preliminary!
Has some residual atmospheric fluctuation
-0.004
-0.003
-0.002
-0.001
0
0.001
0.002
0.003
0.004



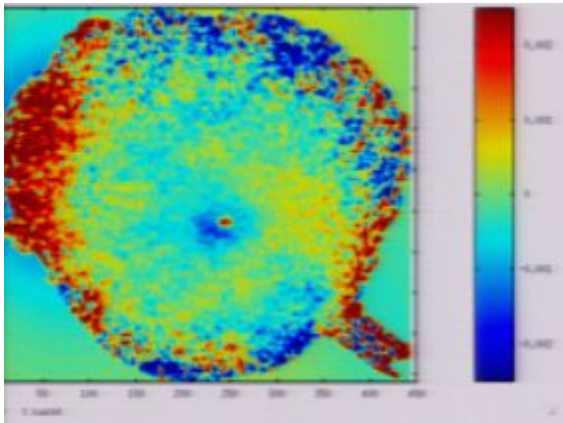
Lensing Mass Map
Galaxy Density
Xray Surface Brightness

Optical + Xray (Left)
Bradac et al 2008

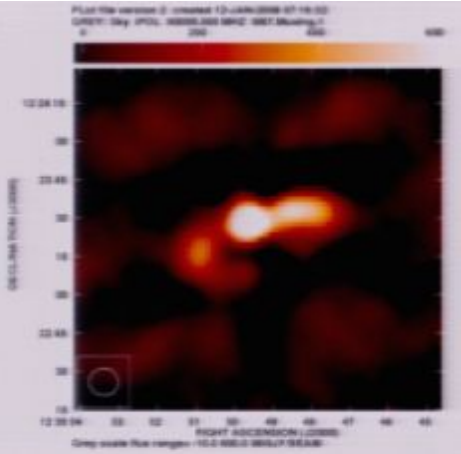
MUSTANG SZ (Right)
Similar angular scales

Current Work

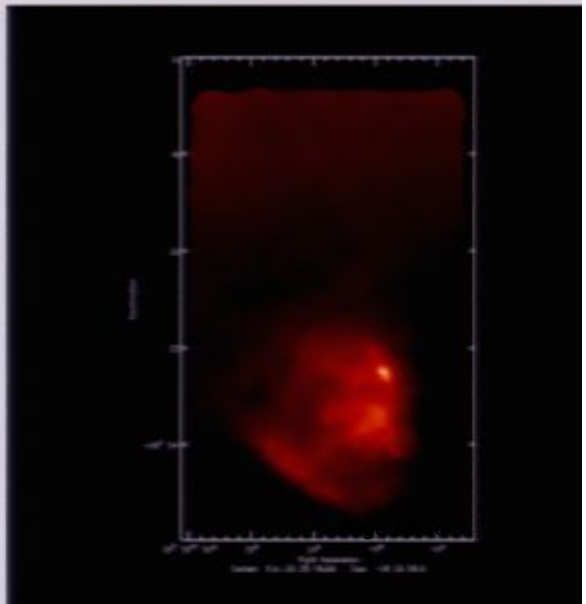
- Assess image fidelity: some large-scale decrement certainly being lost to common-mode subtraction.
  - simulations
  - ACT pipeline
- Interpretation
  - X-ray data: azimuthal variations in temperature
  - distance (Reese et al.: 1221 +/- 350 MPc)
  - Geometry & merger model (mass, speed)
- Data on two more clusters
  - A1835: relaxed, strong "cooling flow" system
  - CL1226+3332: luminous z~1 system

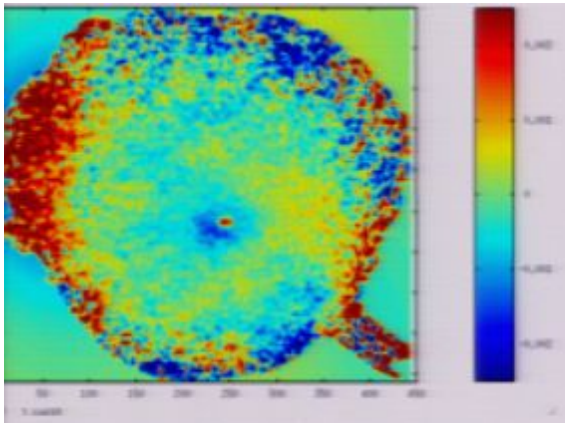


What's next?

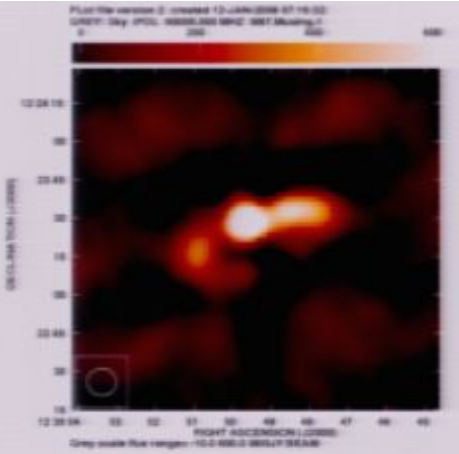


- GBT surface: 20% -> 35%
- Our detector array is 5x from the photon noise limit -- 1x arrays exist
  - Other major technical risks conqured: magnetic fields, saturation, operation of SQUIDs & TESs; data analysis & observing procedures developed; etc.
- 5h realtime for RXJ1347-1145
  - Less pathological clusters, large samples require 3-4x more sensitivity
- 10x10 2mm detector array (NIST) under test in the lab
  - Larger FOV
  - Higher per-pixel sensitivity (root(2)?)
  - Aiming for Oct 2009 on GBT





What's next?

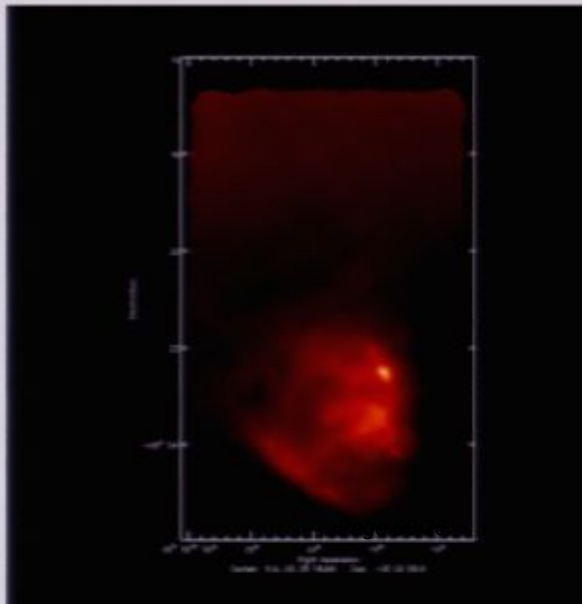


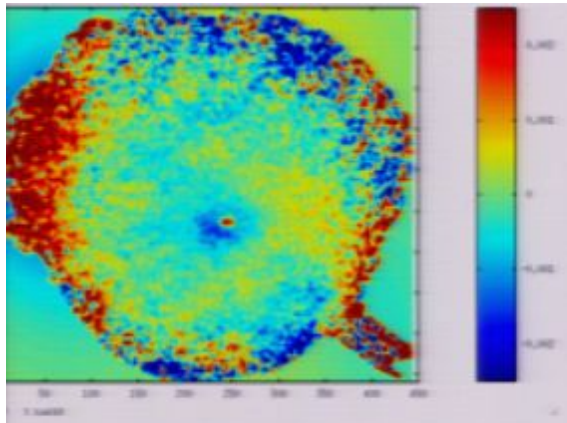
- 4x increase in Npixels: cheap ($300K) and easy
  - Proposal submitted to MRI
  - 100 mK focal plane? (NIS coolers)
- 16x increase (1024 pixels): $3M project
  - MKID camera: Large format, robust, simple.
  - Microstrip coupling

arge FOV breaks atmosphere/low-k degeneracy
9", microKevlin RMS imaging (4'x4') in under an hour!

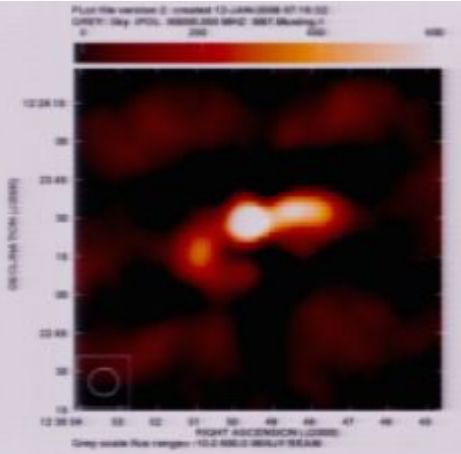
egrees squared imaging to micro-Kelvin sensitivity
- hi-z galaxies (COSMOS, etc.)
- Large area surveys at submJy sensitivity (eg:

GPS sources, Galactic Plane surveys, ALMA calibrators)

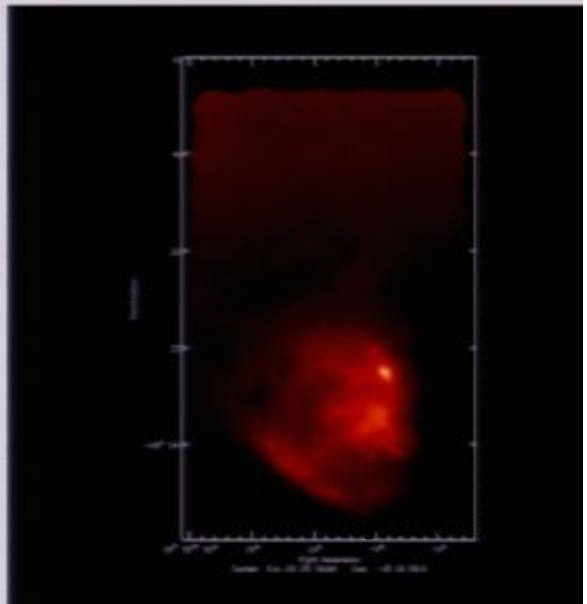


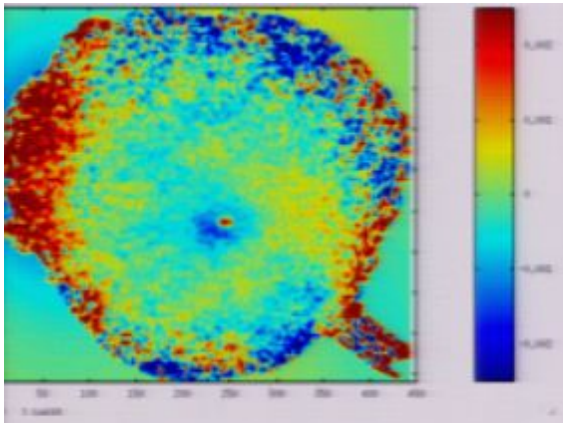


What's next?

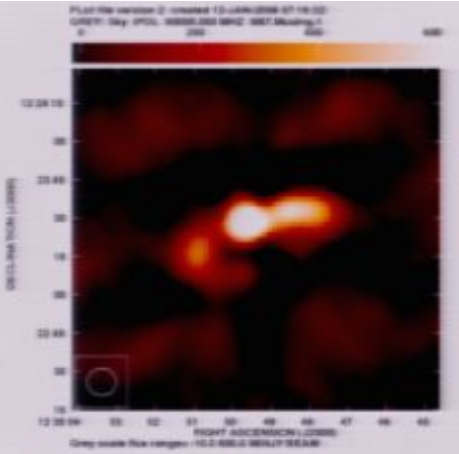


- GBT surface: 20% -> 35%
- Our detector array is 5x from the photon noise limit -- 1x arrays exist
  - Other major technical risks conqured: magnetic fields, saturation, operation of SQUIDs & TESs; data analysis & observing procedures developed; etc.
- 5h realtime for RXJ1347-1145
  - Less pathological clusters, large samples require 3-4x more sensitivity
- 10x10 2mm detector array (NIST) under test in the lab
  - Larger FOV
  - Higher per-pixel sensitivity (root(2)?)
  - Aiming for Oct 2009 on GBT





What's next?

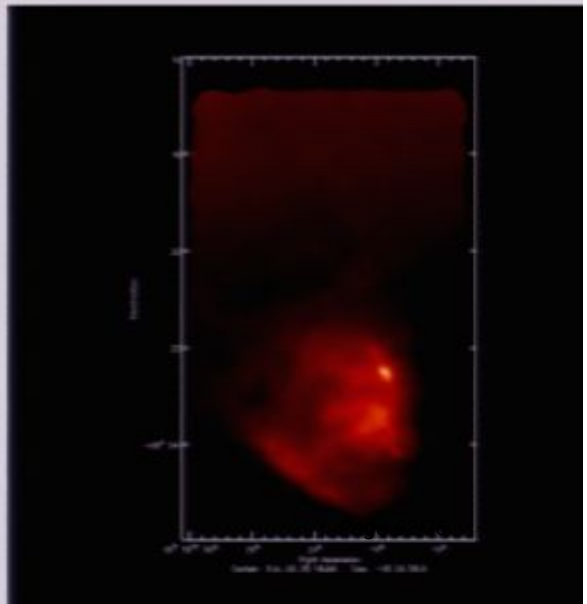


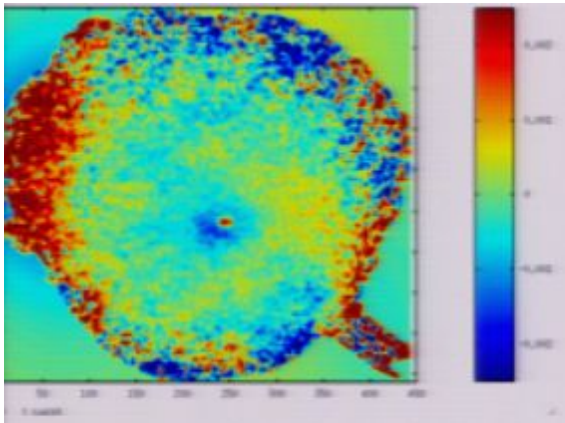
- 4x increase in Npixels: cheap ($300K) and easy
  - Proposal submitted to MRI
  - 100 mK focal plane? (NIS coolers)
- 16x increase (1024 pixels): $3M project
  - MKID camera: Large format, robust, simple.
  - Microstrip coupling

arge FOV breaks atmosphere/low-k degeneracy
9", microKevlin RMS imaging (4'x4') in under an hour!

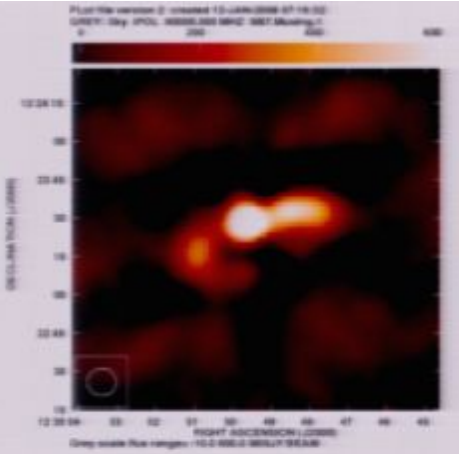
egrees squared imaging to micro-Kelvin sensitivity
- hi-z galaxies (COSMOS, etc.)
- Large area surveys at submJy sensitivity (eg:

GPS sources, Galactic Plane surveys, ALMA calibrators)

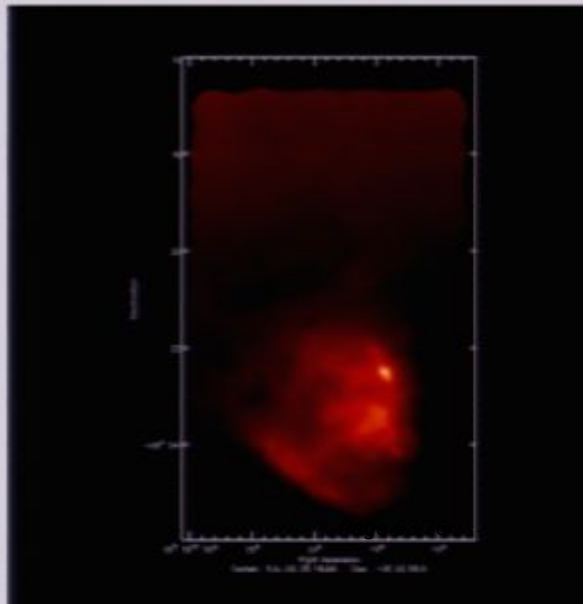


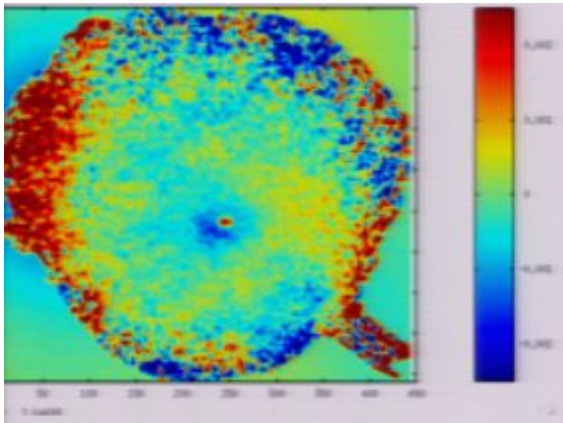


What's next?

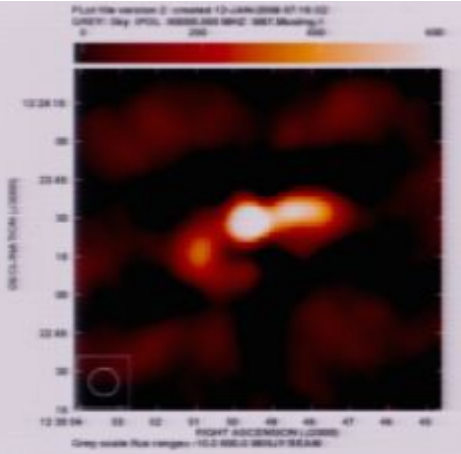


- GBT surface: 20% -> 35%
- Our detector array is 5x from the photon noise limit -- 1x arrays exist
  - Other major technical risks conqured: magnetic fields, saturation, operation of SQUIDs & TESs; data analysis & observing procedures developed; etc.
- 5h realtime for RXJ1347-1145
  - Less pathological clusters, large samples require 3-4x more sensitivity
- 10x10 2mm detector array (NIST) under test in the lab
  - Larger FOV
  - Higher per-pixel sensitivity (root(2)?)
  - Aiming for Oct 2009 on GBT





What's next?

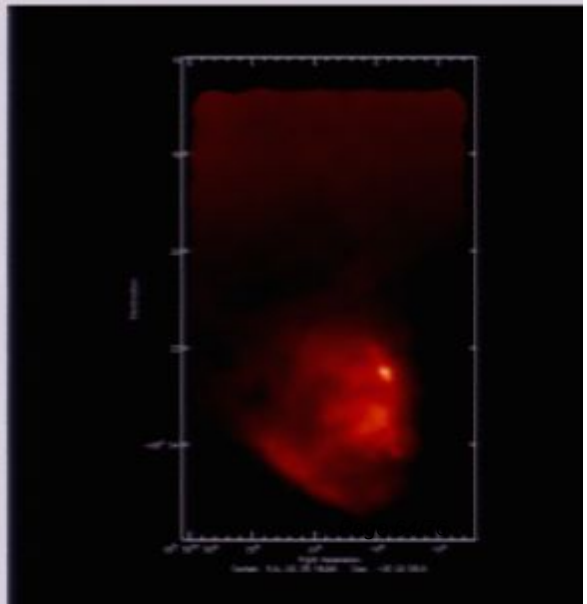


- 4x increase in Npixels: cheap ($300K) and easy
  - Proposal submitted to MRI
  - 100 mK focal plane? (NIS coolers)
- 16x increase (1024 pixels): $3M project
  - MKID camera: Large format, robust, simple.
  - Microstrip coupling

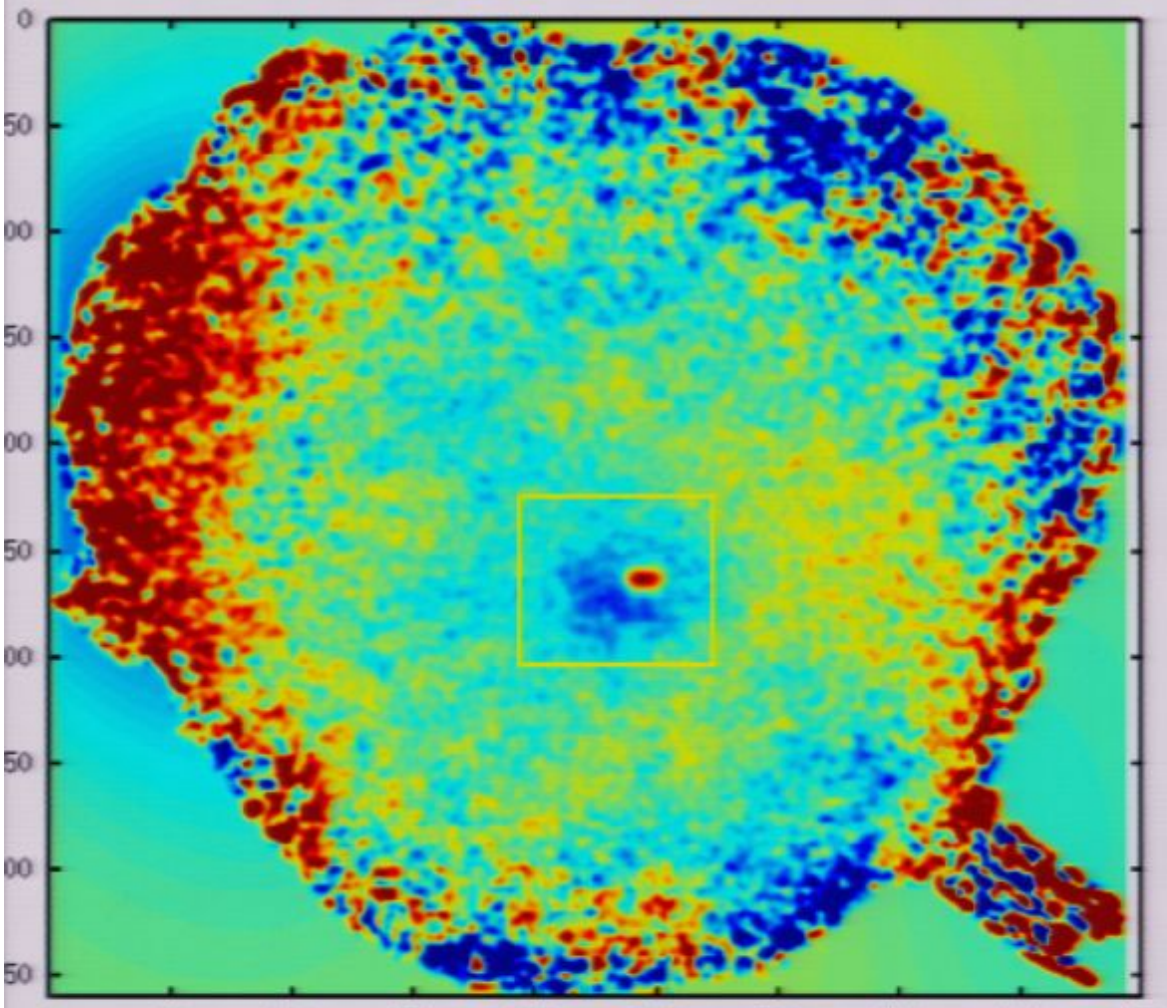
arge FOV breaks atmosphere/low-k degeneracy
9", microKevlin RMS imaging (4'x4') in under an hour!

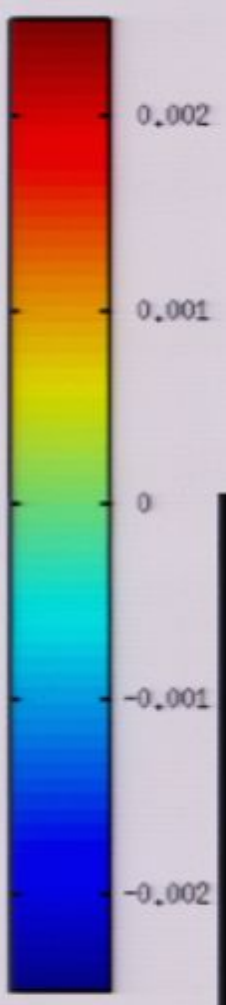
egrees squared imaging to micro-Kelvin sensitivity
- hi-z galaxies (COSMOS, etc.)
- Large area surveys at submJy sensitivity (eg:

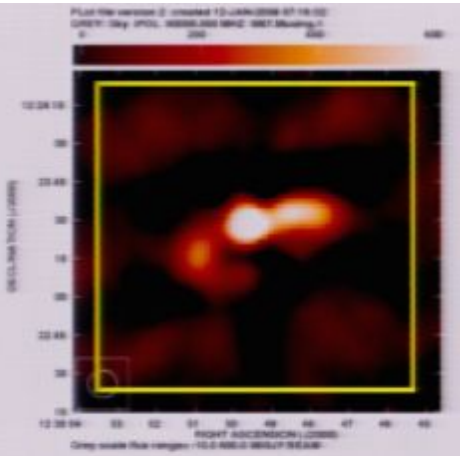
GPS sources, Galactic Plane surveys, ALMA calibrators)

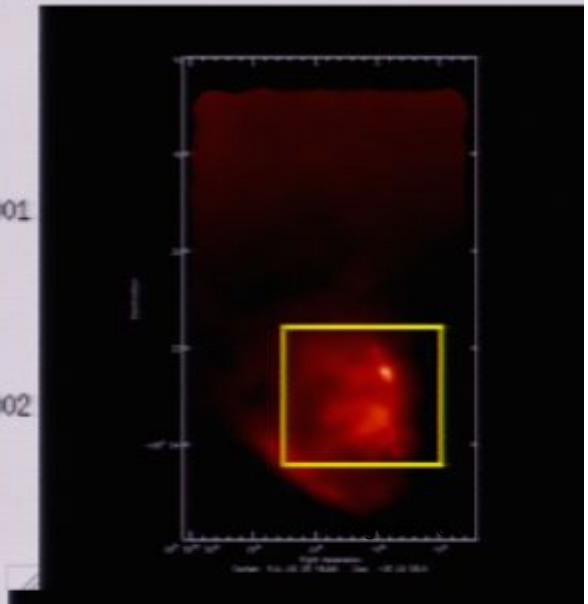


What's next?









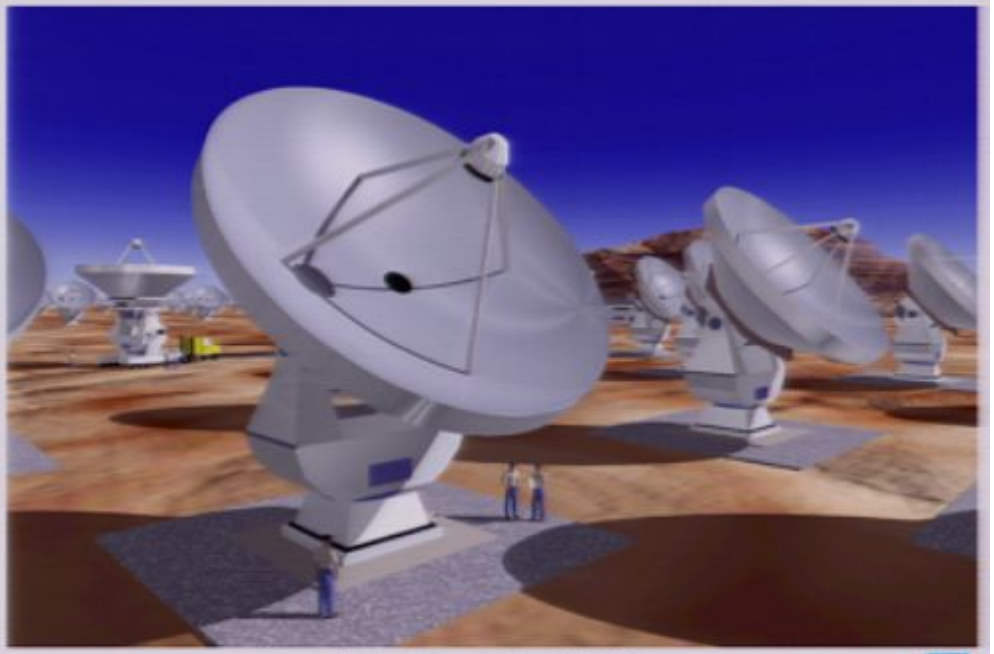
ALMA Band 1 SZE

Atacama Large Millimeter Array

- 64 (probably 50) 12m antennas
- sub-mm grade surfaces (good to THz)
- wide-band correlator (8 GHz bandwidth)
- compact configuration (100-m)
- also ACA 10 x 7m (NAOJ)

ALMA at Chajnantor
(Courtesy NAOJ)

ESO PR Photo 14/01 (5 April 2001)



Artist's Impression of ALMA
(Atacama Large Millimetre Array)

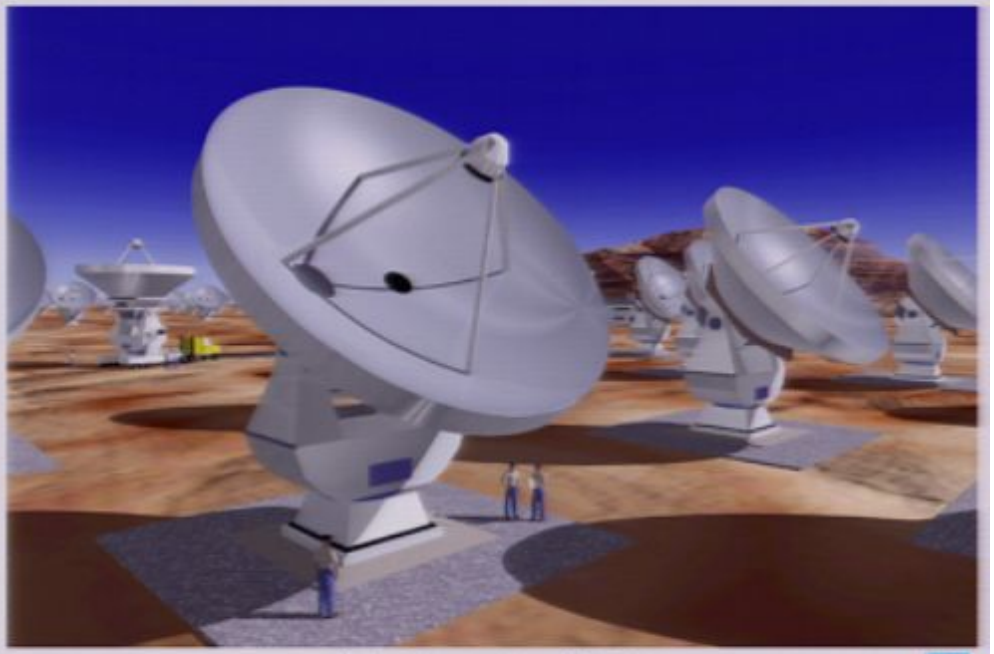
ESO PR Photo 24a/99 (8 June 1999)

Atacama Large Millimeter Array

- 64 (probably 50) 12m antennas
- sub-mm grade surfaces (good to THz)
- wide-band correlator (8 GHz bandwidth)
- compact configuration (100-m)
- also ACA 10 x 7m (NAOJ)

ALMA at Chajnantor
(Courtesy NAOJ)

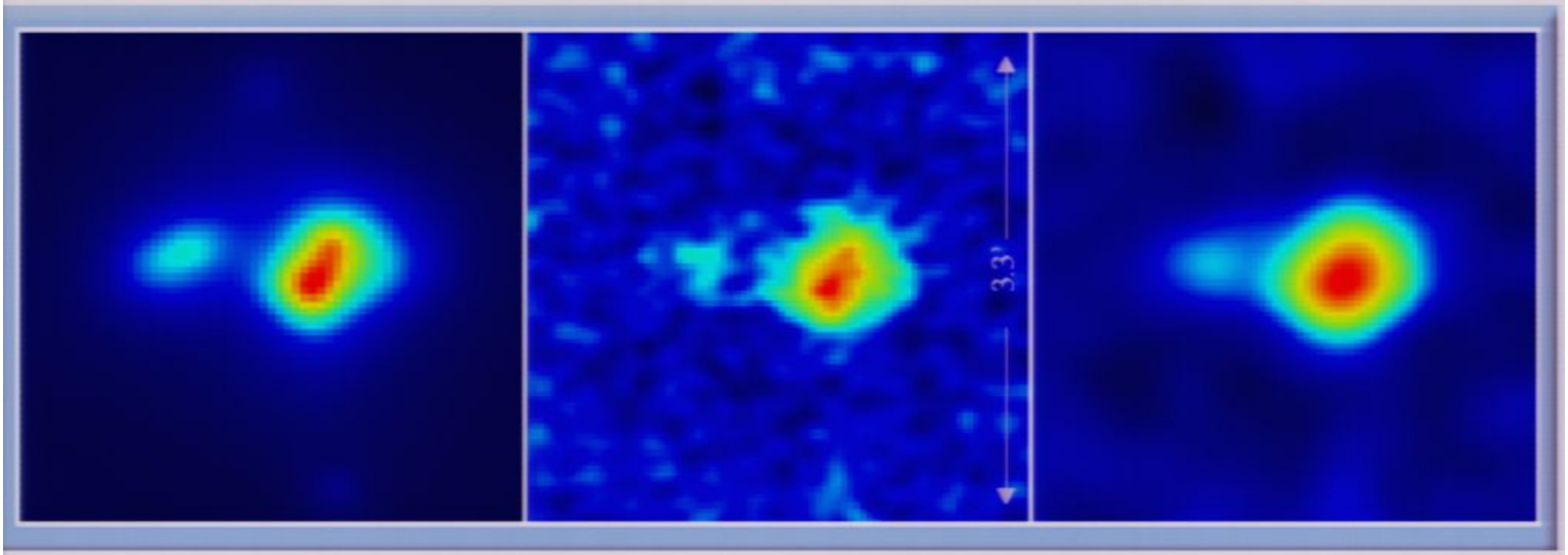
ESO PR Photo 14/01 (6 April 2001)



ESO PR Photo 24a/99 (8 June 1999)

Artist's Impression of ALMA
(Atacama Large Millimetre Array)

SPT/ACT CLUSTER SAMPLES: Are in the Southern Hemisphere!



ALMA SZ Observations

SZE simulation (left) 4 hours ALMA (center) after 4kl taper (right)

2.5×10^{14} Msun z=1

34 GHz in compact config. equiv. 22" FWHM

arge collecting area + compact (in wavelength) configuration = high SB sens + angular
esolution

SPT/ACT CLUSTER SAMPLES: Are in the Southern Hemisphere!

Band 1 not currently funded but of scientific interest
To a broad ALMA user community (galactic, hi-z CO, SZ)

Cost ~ $7-10M
cheaper if built in collaboration w/university instrument community?

EVLA E-array (compact configuration) matches ALMA Band-1 resolution at 15 GHz

ALMA SZ Observations

SZE simulation (left) 4 hours ALMA (center) after 4kl taper (right)

2.5×10^{14} Msun z=1

34 GHz in compact config. equiv. 22" FWHM

arge collecting area + compact (in wavelength) configuration = high SB sens + angular esolution

Bolometer arrays on ALMA

mage courtesy of NRAO/AUI and ALMA/ESO/NRAO/NAOJ

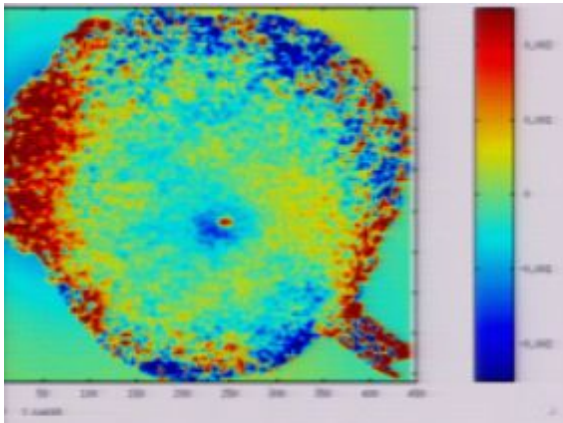
Bolometer Array on each (50) ALMA Antenna:

- 3x more collecting area than LMT
- 12x more than CCAT
- many times the total focal plane area

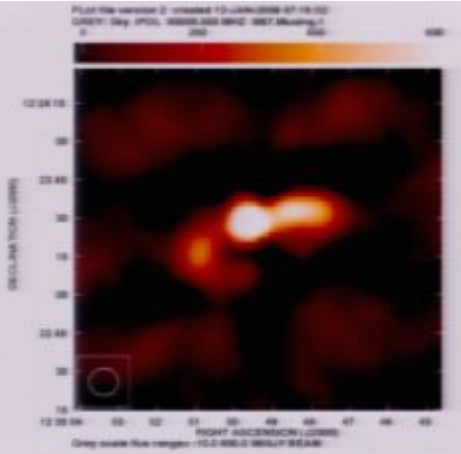
From long-mm through submm

SCIENCE

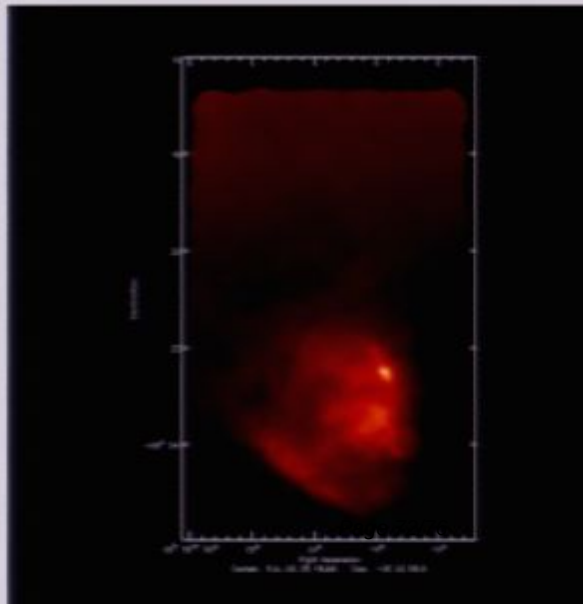
- small scale CMB (lensing, strings) & SZ Polarization
  - quadrupole meas't
- large area/synoptic mm&submm surveys

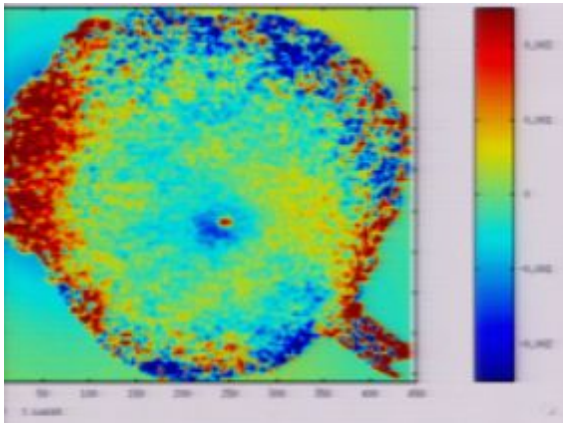


Conclusions

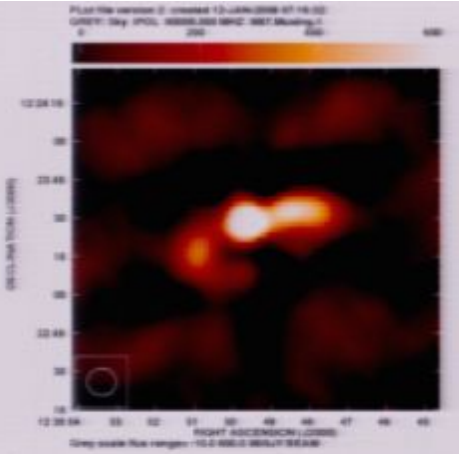


- First sub-10" SZ Image -- good prospects for future imaging studies
  - Large samples of clusters
  - Substructure, ICM/mass profiles, core energetics...
- Clear path to much greater sensitivity
  - 1.5 - 2 x higher GBT surface efficiency
  - 10x10 array for upcoming season
  - 256 pixel upgrade proposal under review
  - Technical issues for kilopixel array under control (not only for the receiver, but also the telescope)
- Degrees squared 9" imaging to micro-Kelvin sensitivity
  - SZE
  - hi-z galaxies (COSMOS, etc.)
  - Large area surveys at submJy sensitivity (eg: GPS sources, Galactic Plane surveys, ALMA calibrators)

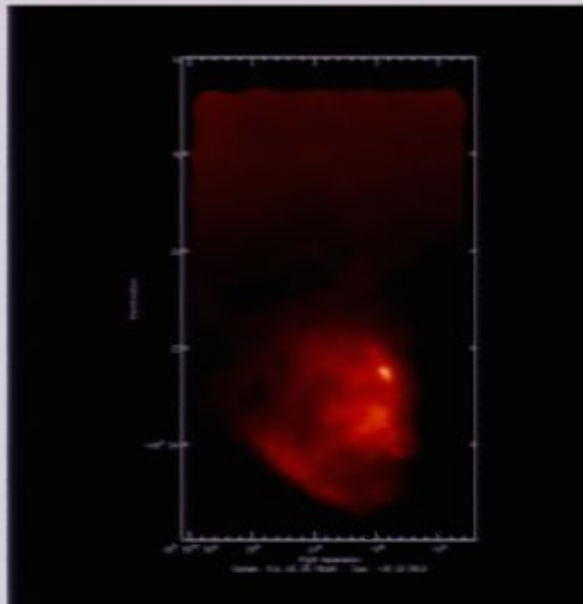


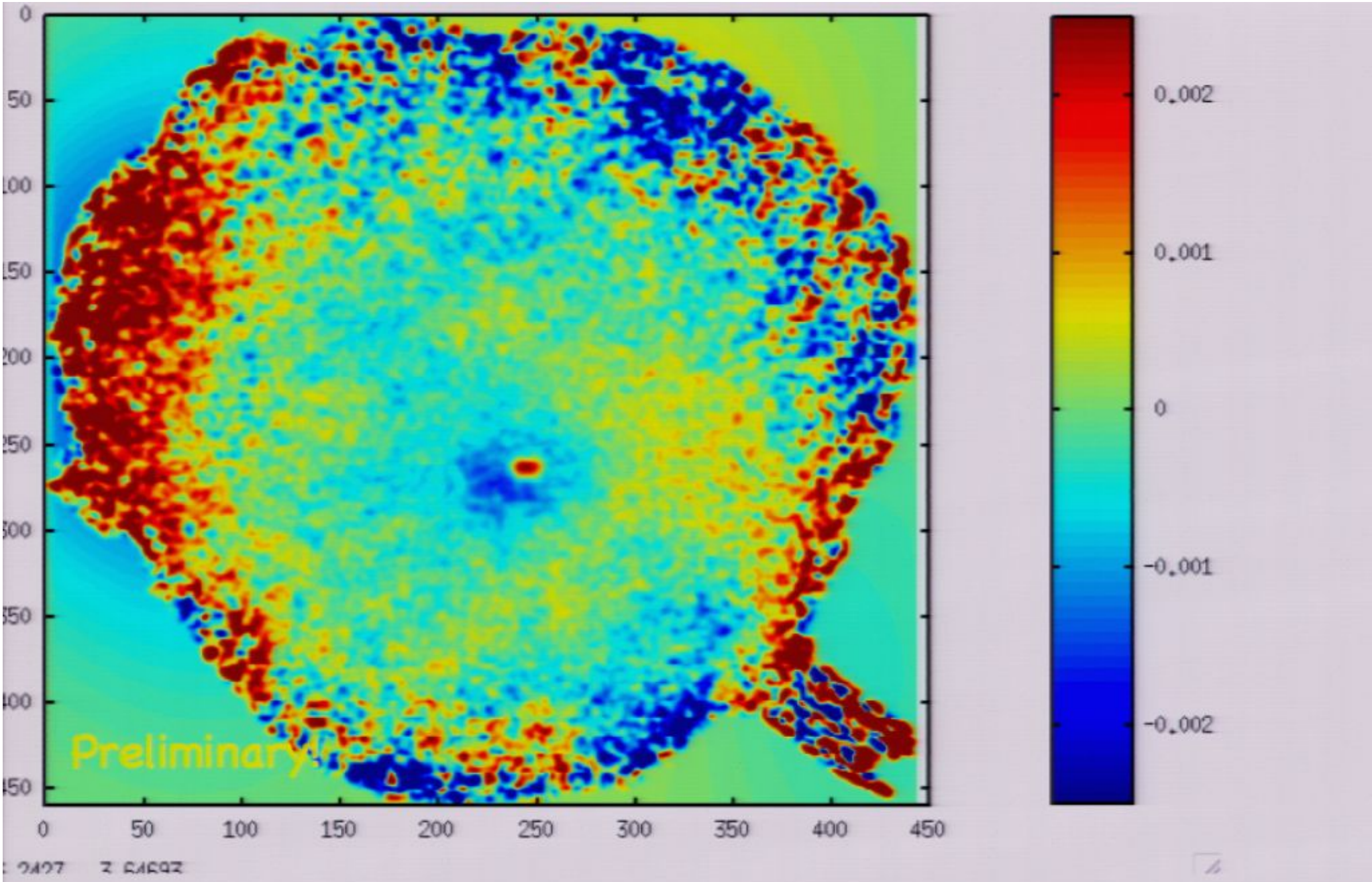


What's next?



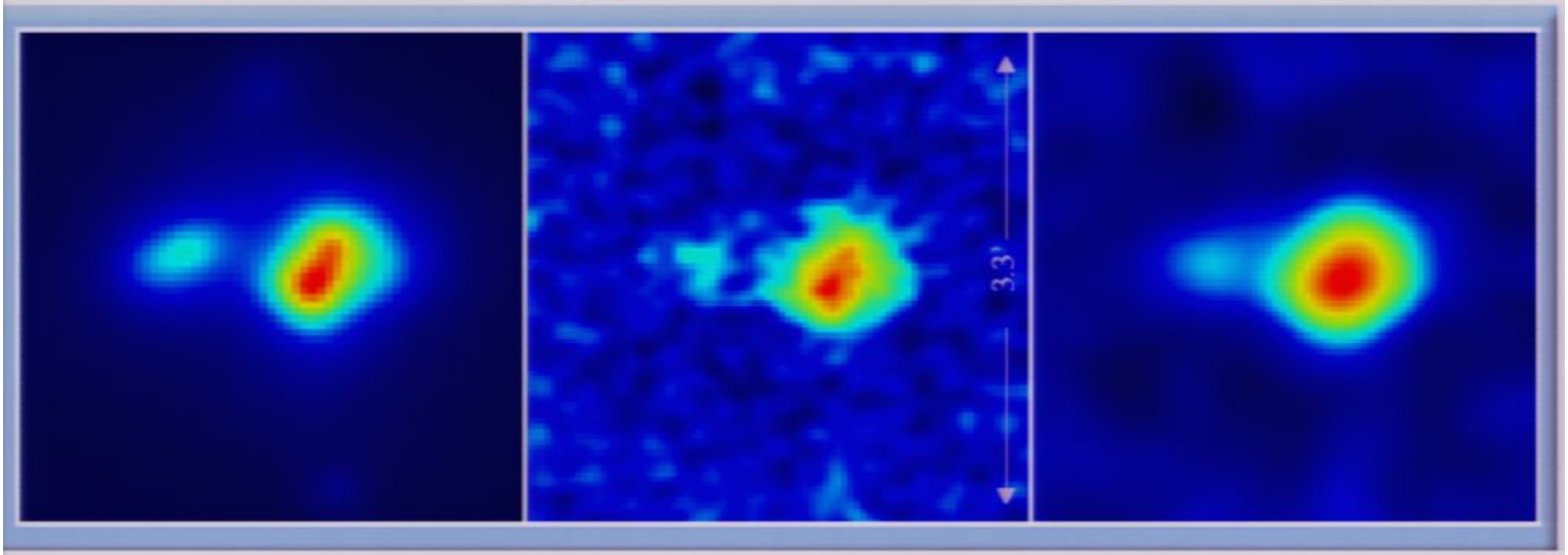
- GBT surface: 20% -> 35%
- Our detector array is 5x from the photon noise limit -- 1x arrays exist
  - Other major technical risks conqured: magnetic fields, saturation, operation of SQUIDs & TESs; data analysis & observing procedures developed; etc.
- 5h realtime for RXJ1347-1145
  - Less pathological clusters, large samples require 3-4x more sensitivity
- 10x10 2mm detector array (NIST) under test in the lab
  - Larger FOV
  - Higher per-pixel sensitivity (root(2)?)
  - Aiming for Oct 2009 on GBT





T. Sievers – Noise eigenvector approach – 2 nights data with NO pointing Corrections

SPT/ACT CLUSTER SAMPLES: Are in the Southern Hemisphere!



ALMA SZ Observations

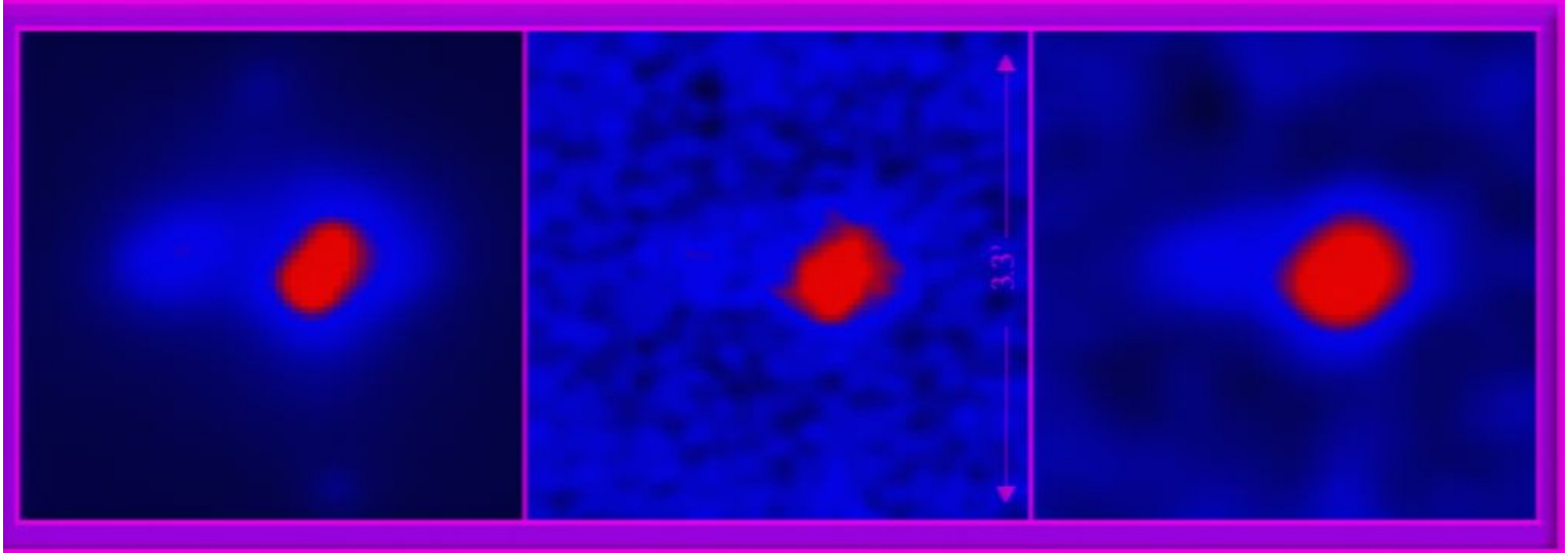
SZE simulation (left) 4 hours ALMA (center) after 4kl taper (right)

2.5×10^{14} Msun $z=1$

34 GHz in compact config. equiv. 22" FWHM

arge collecting area + compact (in wavelength) configuration = high SB sens + angular esolution

SPT/ACT CLUSTER SAMPLES: Are in the Southern Hemisphere!



ALMA SZ Observations

SZE simulation (left) 4 hours ALMA (center) after 4kl taper (right)

2.5×10^{14} Msun $z=1$

34 GHz in compact config. equiv. 22" FWHM

arge collecting area + compact (in wavelength) configuration = high SB sens + angular
esolution