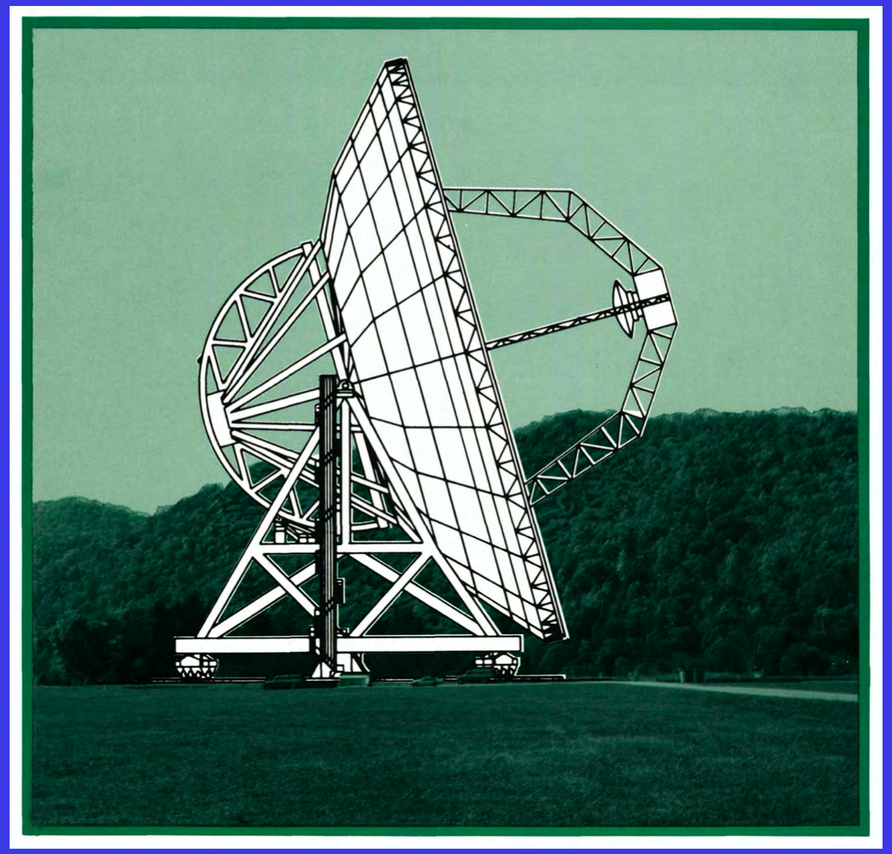
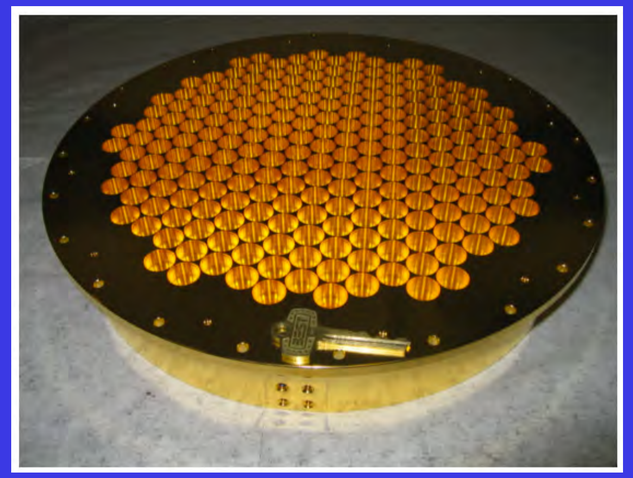


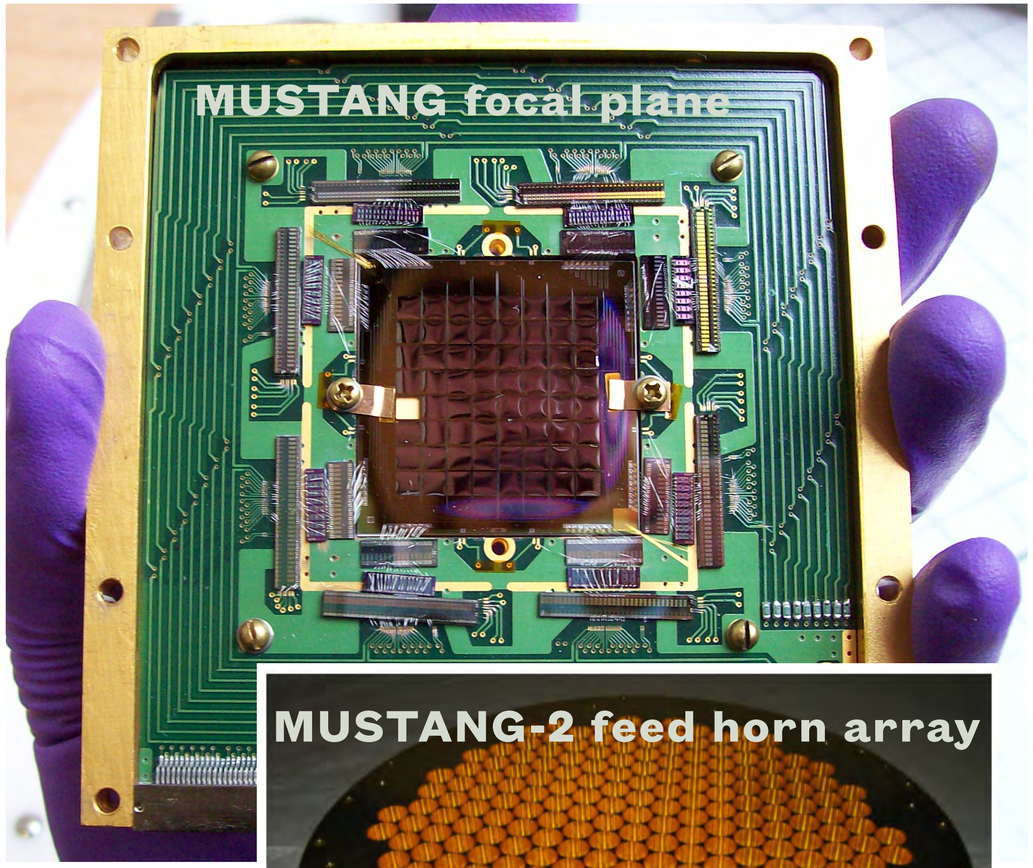


GBT@20: 3mm Continuum Science

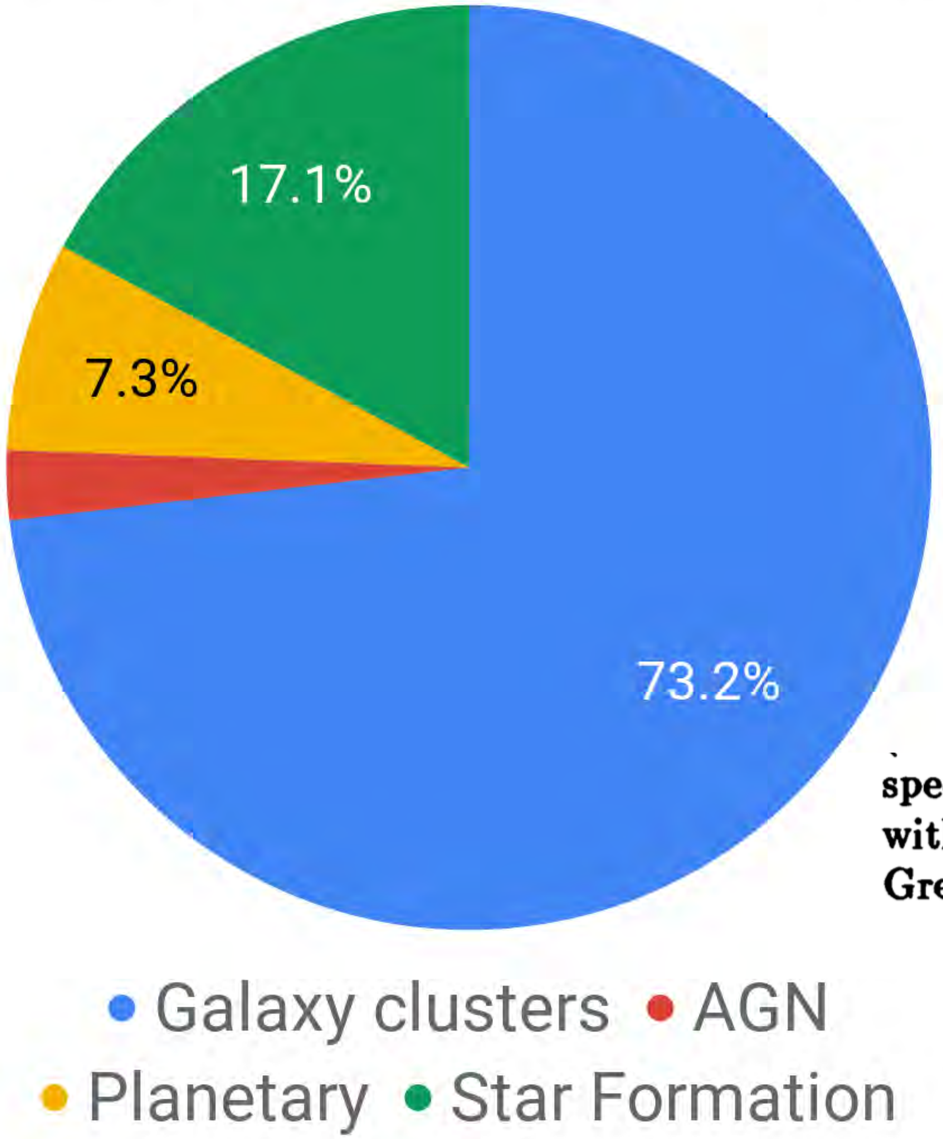
BRIAN MASON (NRAO) – 22 APRIL 2021

MUSTANG & MUSTANG-2

- Broad-band 3mm continuum (bolometer) cameras:
  - ~ 80 - 100 GHz; 9” resolution on the GBT
  - Field of View: 42” (M-1) , 4’ (M_2)
  - Science observing: 2008-2015 (M-1), 2016+ (M-2)
  - 300 mK cryogenics
- Developed in collaboration with ***U.Penn (Mark Devlin, Simon Dicker, +) ; NIST; NASA/GSFC;*** & many others.



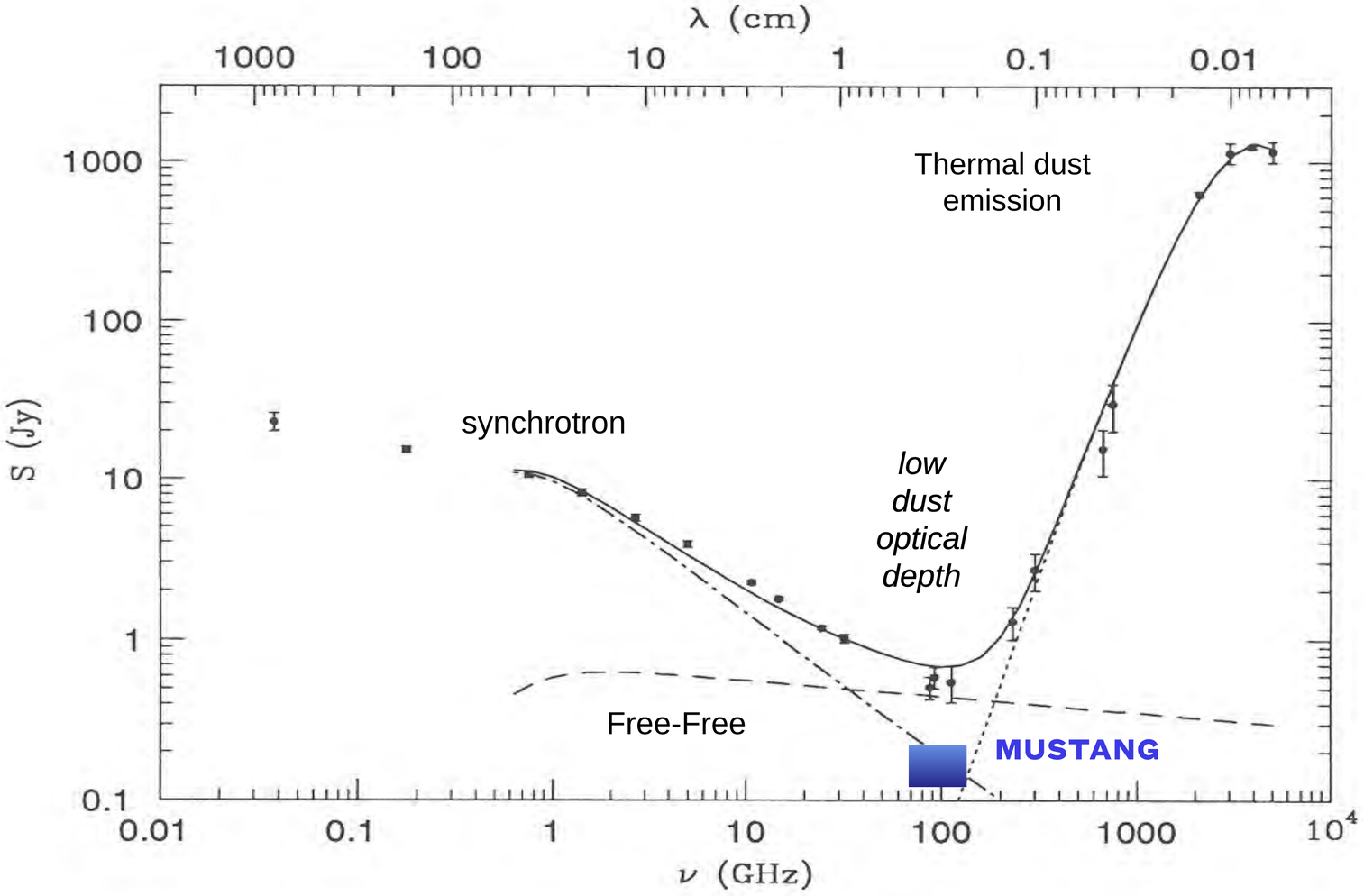
MUSTANG-2 proposals by science category (2018 & 2019)



From the original GBT proposal (1989):

spectra. It will then be necessary to remeasure the Sunyaev–Zel'dovich effect with higher sensitivity and angular resolution, a task perfectly matched to the Green Bank Telescope.

Continuum Emission from a Typical Galaxy (M82)



Condon (1992, ARA&A)

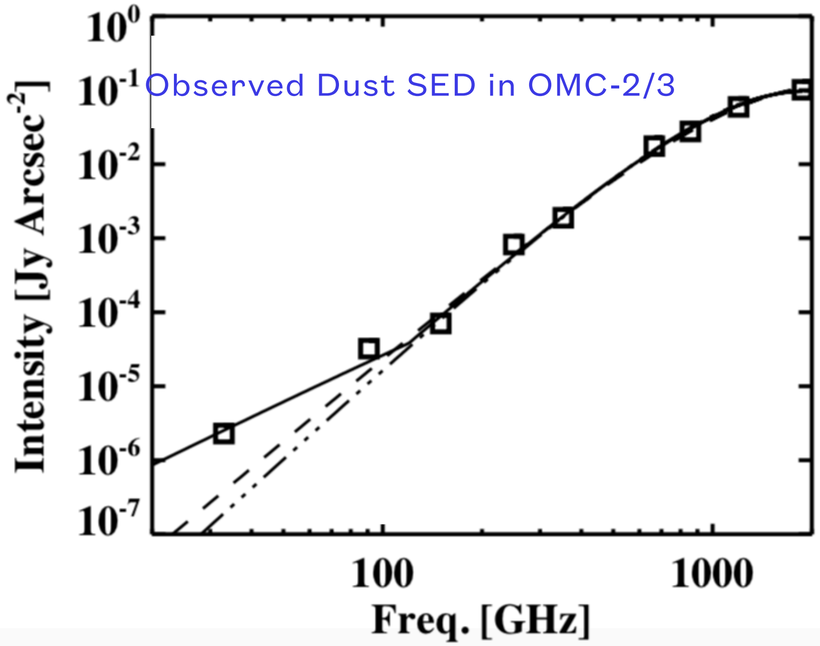
3mm Dust Emission in the Integral Shaped Filament

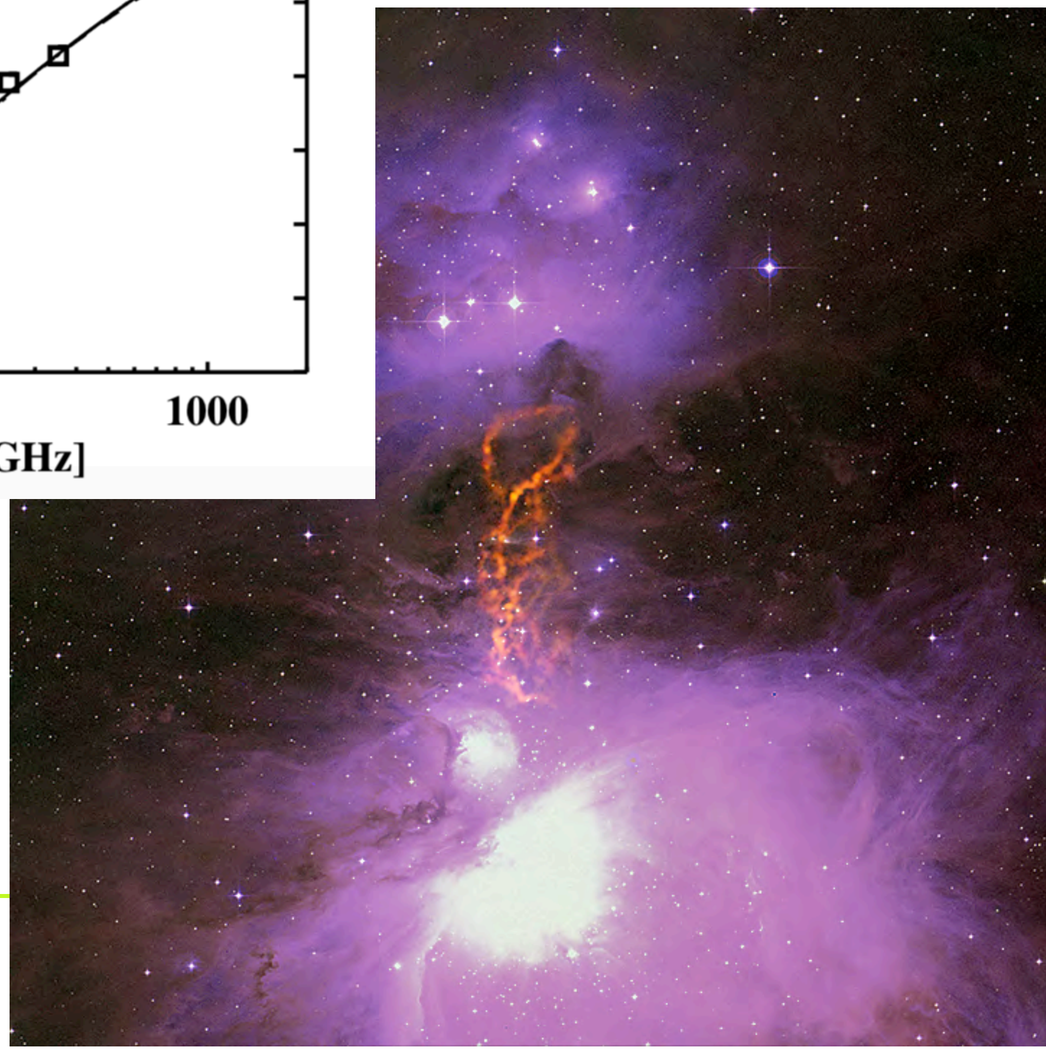
Schnee+2014; Sadavoy+ (2016):
Mason+ (2020):

Distinct break in the spectrum of thermal dust emission which continues to 1cm

IMPLICATIONS:

- dust models
- Inferences from 1cm~3mm continuum (dynamical stability estimates)





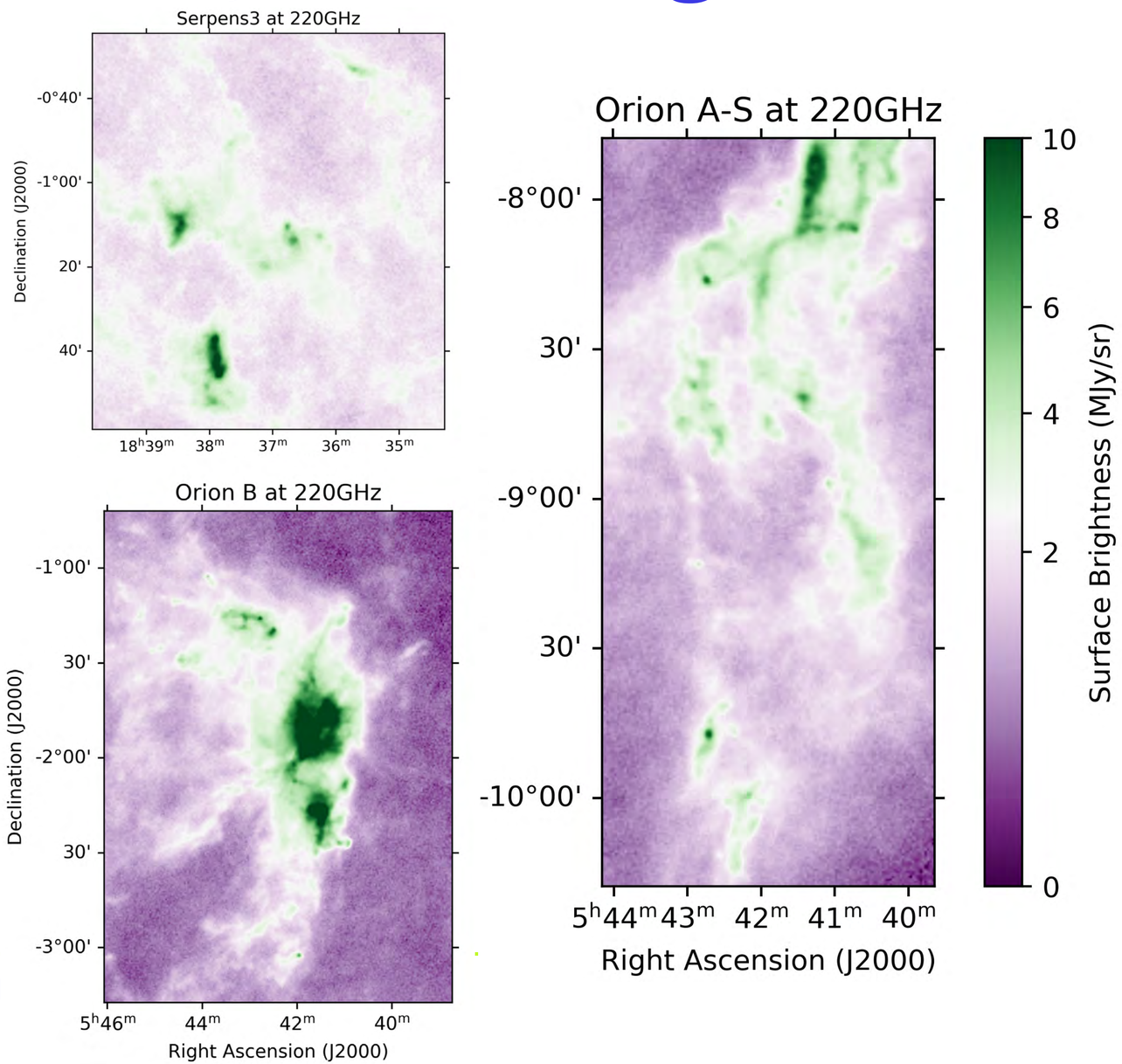
3mm dust emission in other dense, star forming filaments

Atacama Cosmology Telescope (ACT) 90 GHz + 150 GHz data + Herschel: ~8 square degrees

Work led by Ian Lowe (U.Penn) with the MUSTANG-2 and ACT collaborations

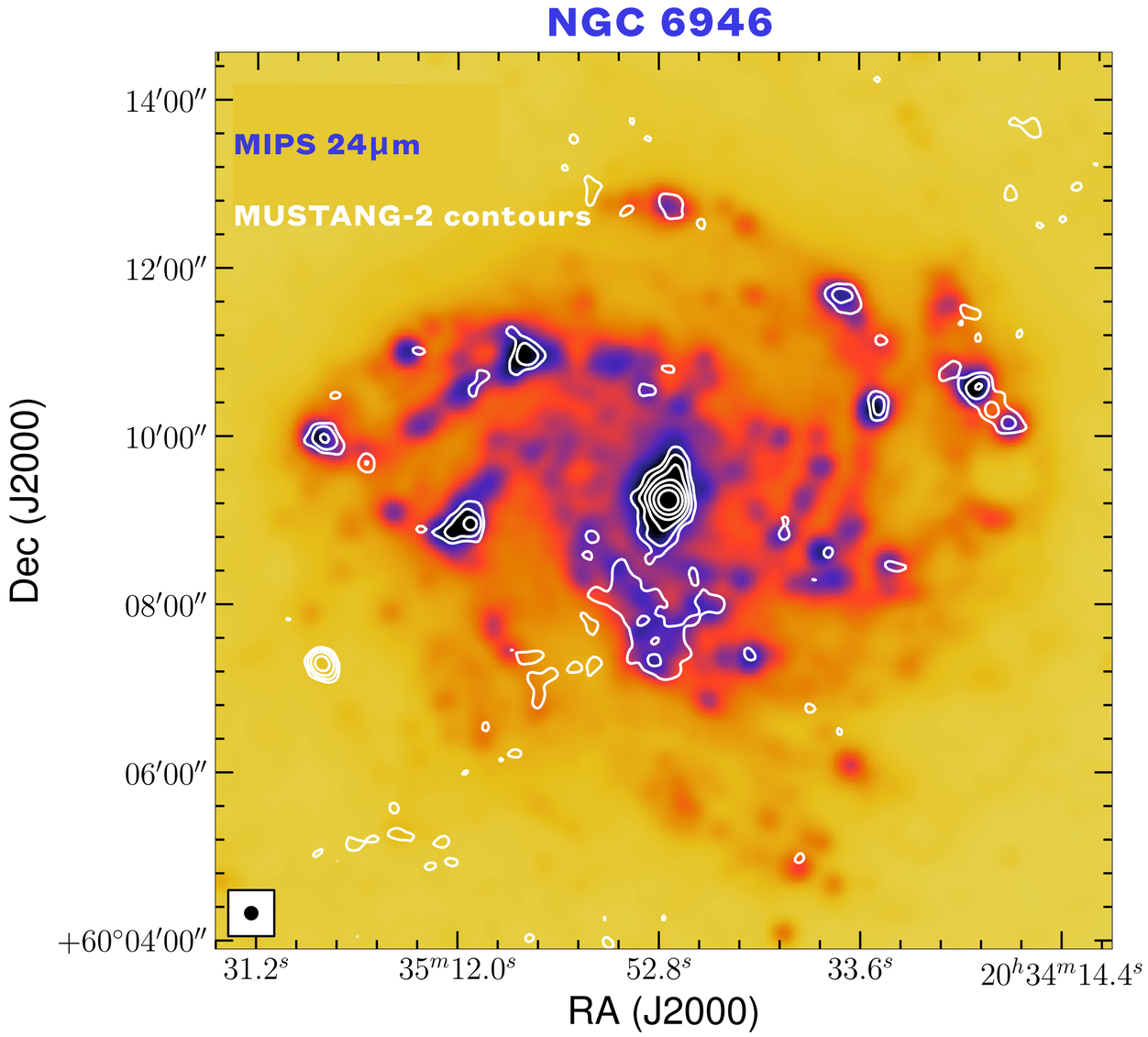
Similar behavior is seen in 5 other dense, star-forming filaments

MUSTANG-2+ALMA+ACT: GBT21A-376



Star Formation Radio Survey (SFRS)

- Multi-wavelength survey aiming to provide a ***better-calibrated, better understood relationship between high mass SF and radio continuum brightness*** (PI Eric Murphy)
  - >60 nearby galaxies (SINGS/KINGFISH/GOALS): Spitzer, VLA, ALMA, ATCA …
- ***GBT+MUSTANG-2 3.3mm continuum imaging for 18 galaxies & counting*** (GBT19A-284, 19B-012, 21A-250)
  - Emission at 3.3mm is mostly dominated by free-free, with some scatter (including sources that are dust-dominated at 3.3mm)



Abigail Harden (NRAO REU, incoming UVA astro), Eric Jimenez-Andrade, Eric Murphy

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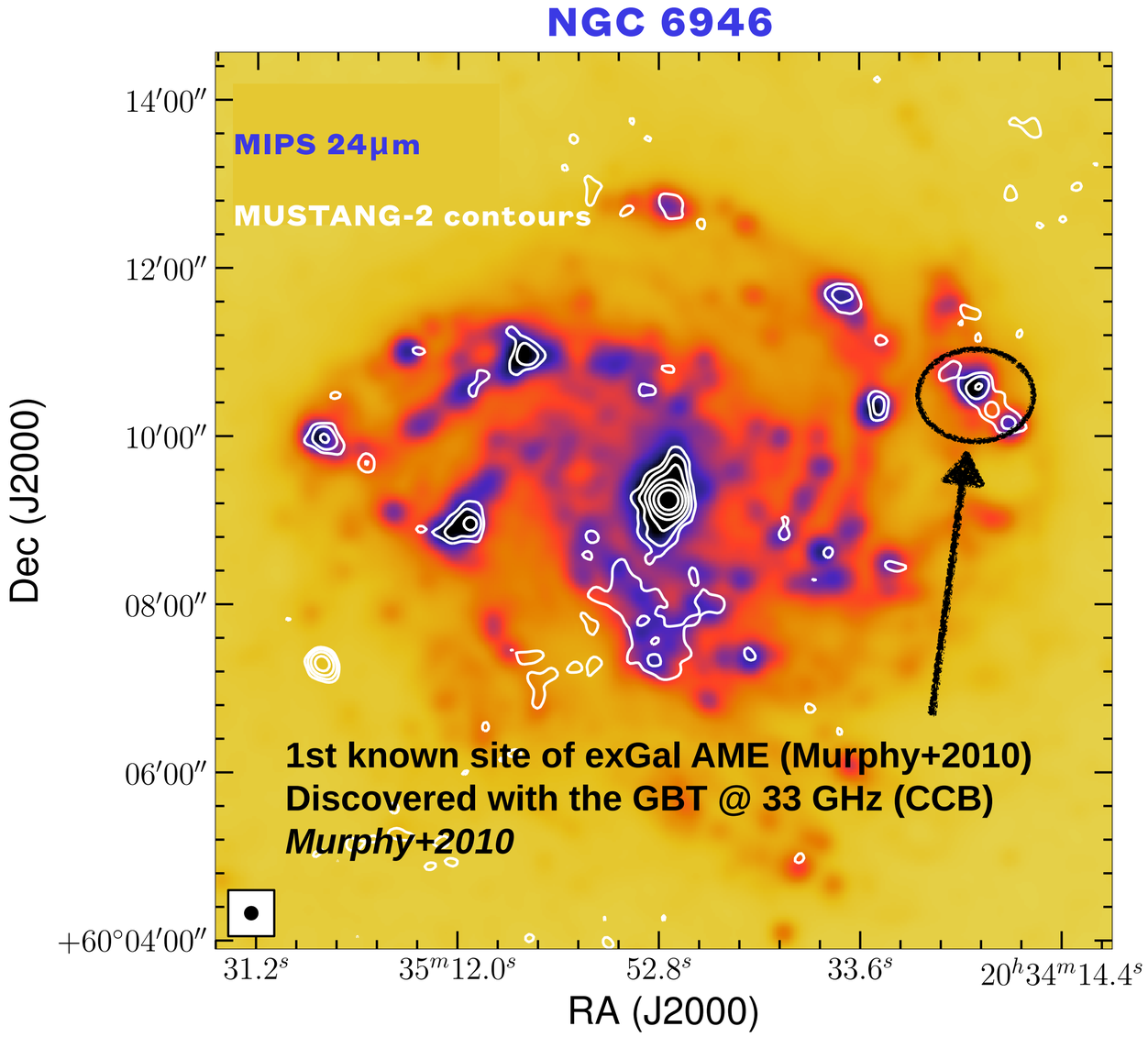

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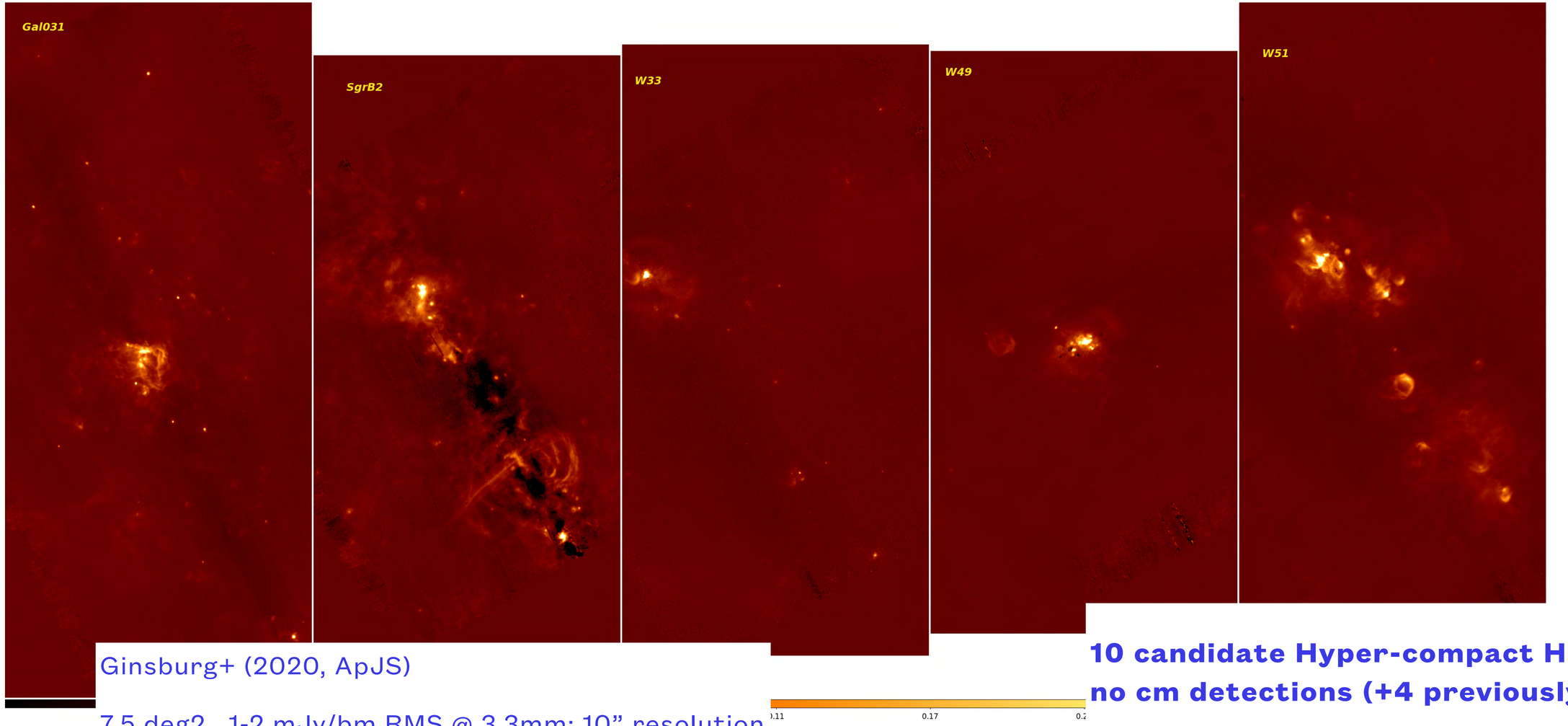
MUSTANG Galactic Plane Survey



Ginsburg+ (2020, ApJS)

7.5 deg2 , 1-2 mJy/bm RMS @ 3.3mm; 10” resolution

18 hours of GBT time in total

Maps available at doi:10.7910/DVN/HPATJB

10 candidate Hyper-compact HII regions with no cm detections (+4 previously known)

Comparing HCHII count with UCHII count yields an estimate of HC HII lifetime:

16% < THCHII/TUCHII < 46%

Galaxy Clusters

Galaxies

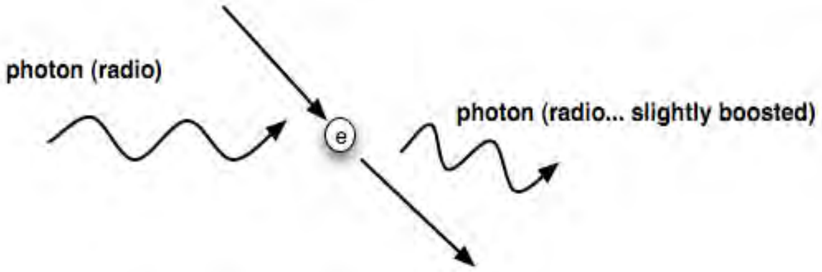
+

Hot Intra-Cluster Plasma

+

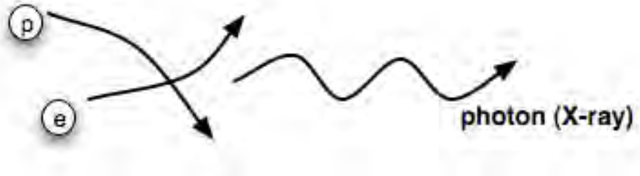
Dark Matter

Sunyaev-Zel'Dovich Effect (SZE)



- **Proportional to integrated thermal electron pressure**
- **Appears as a decrement at λ< 1.4mm**

X-ray Bremmstrahlung

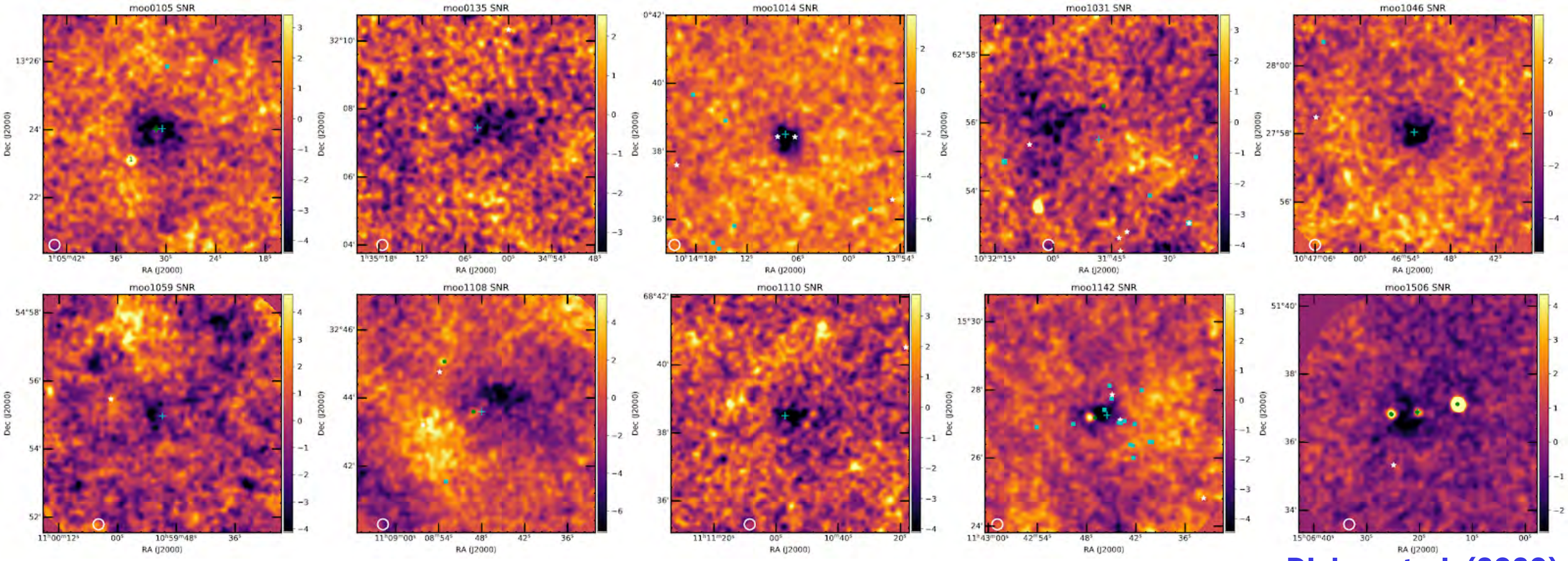


- **Outstanding sensitivity to hot gas**
- **Redshift-independent: effective tool at high-z**
- **requires sensitive detectors**

*** Excellent view of density variations**

*** Some Spectral Information — but less useful in low-density regions (outside cluster core) , at hi-z, or for very hot gas**

Routine 9” resolution SZE Imaging!

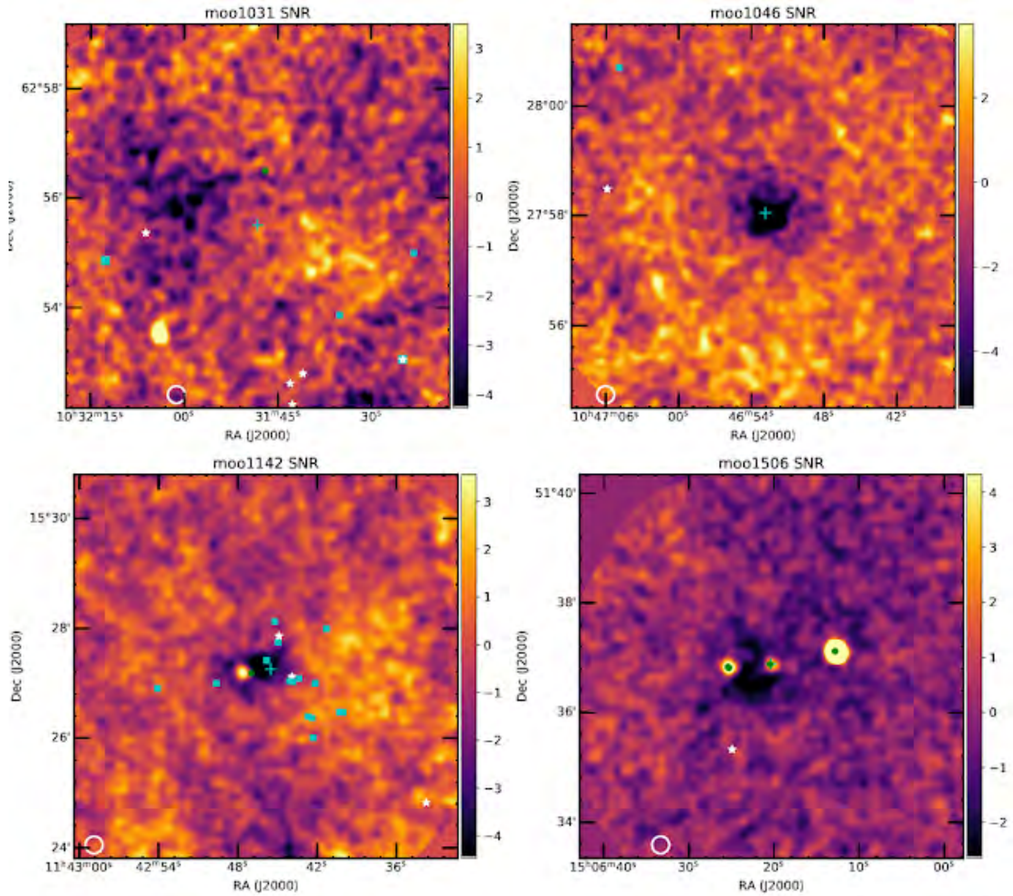


Dicker et al. (2020)

MUSTANG-2 SZE Images of MADCOWs clusters (PI: Mark Brodwin)

Routine 9” resolution SZE Imaging!

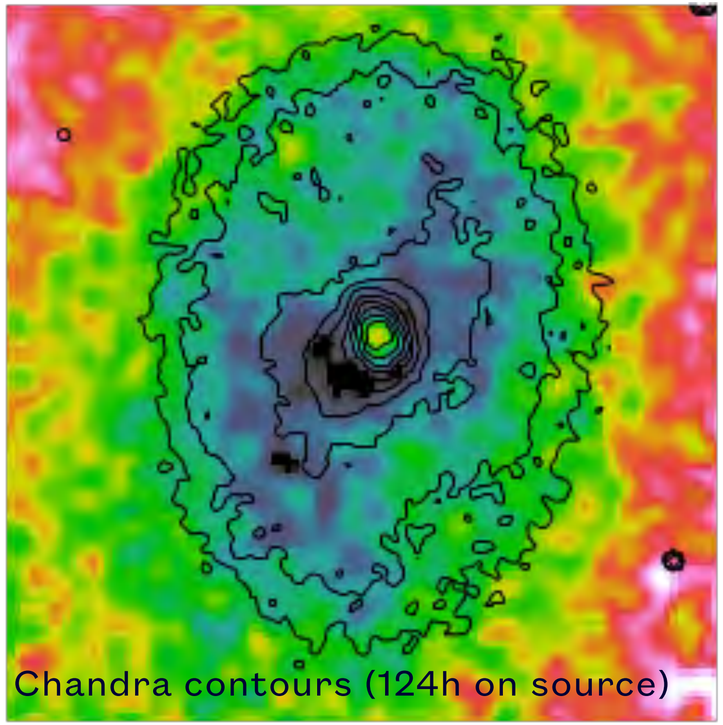
- > 30 high quality, high-resolution SZ images
- Samples:
  - MaDCOWS
  - Hyper-Suprime Cam (weak lensing)
  - Hubble Frontier clusters
  - Individually interesting targets (high-z, merging)
- Science:
  - Measure pressure profiles
  - Assess dynamical state
  - Look for shocks & other difficult to study ICM features



Dicker et al. (2020)

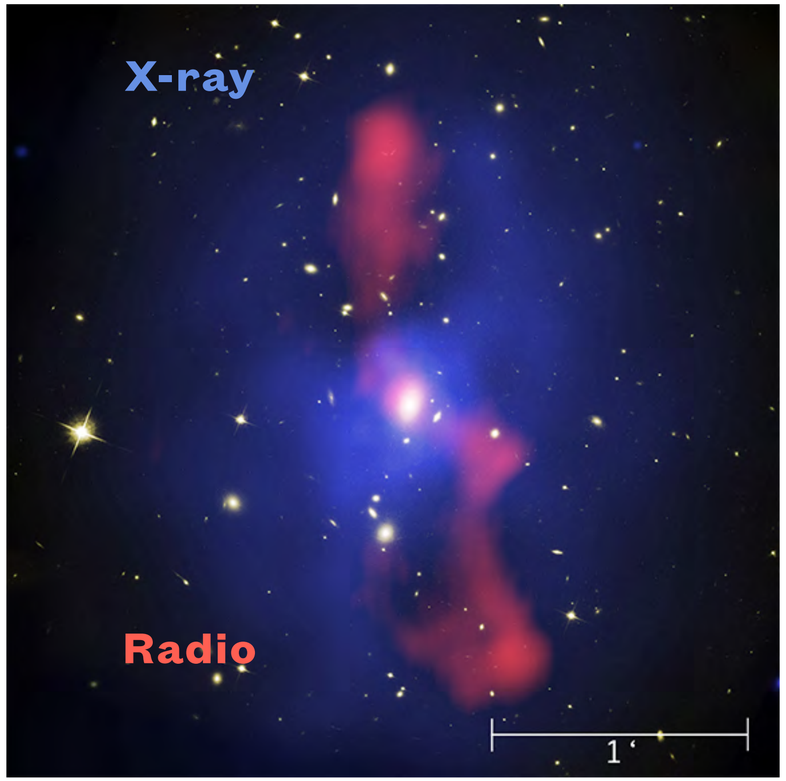
AGN-inflated X-ray Bubbles

MS0735+7421



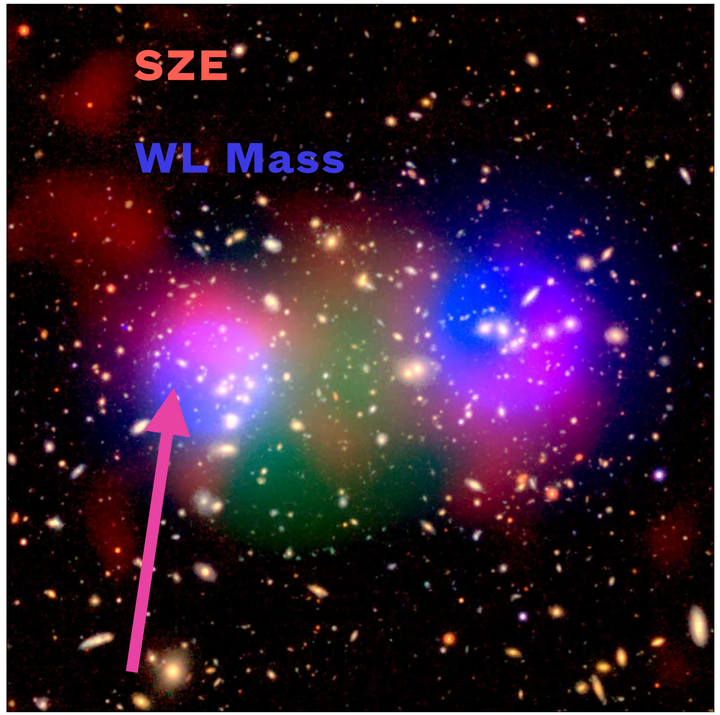
MUSTANG-2 SZE image (16h on source)

PI: Tony Mroczkowski (GBT21A-123 +)



Suppression of SZE decrement suggests the jet does not primarily comprise very hot, thermal electrons.

Shocks & other interesting ICM features



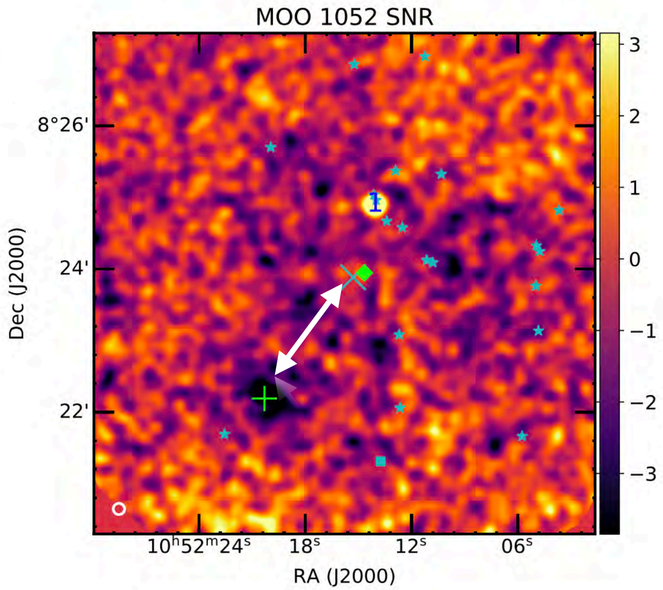
HSC J023336-053022

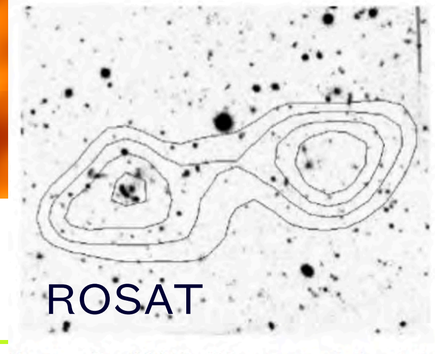
20 - 30 keV gas

Okabe+ 2020

Significant (> 2’) offset between SZE and BCG / optical centroid

Dicker+2020



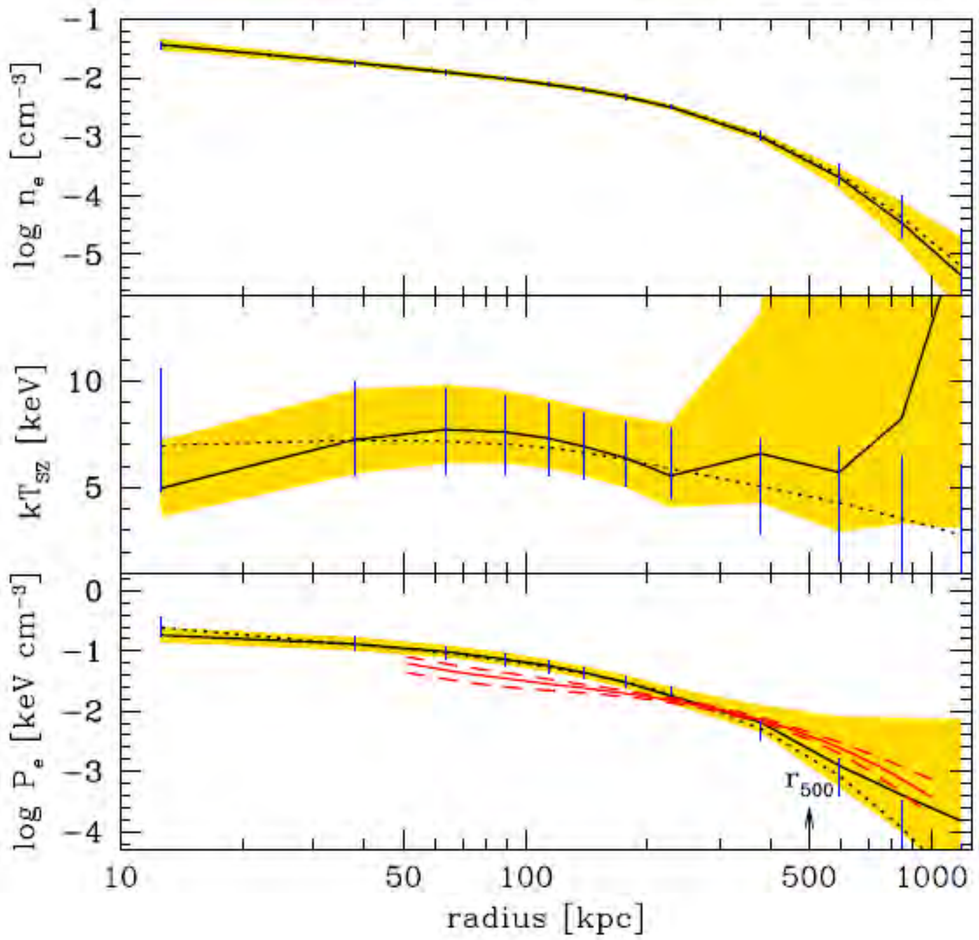


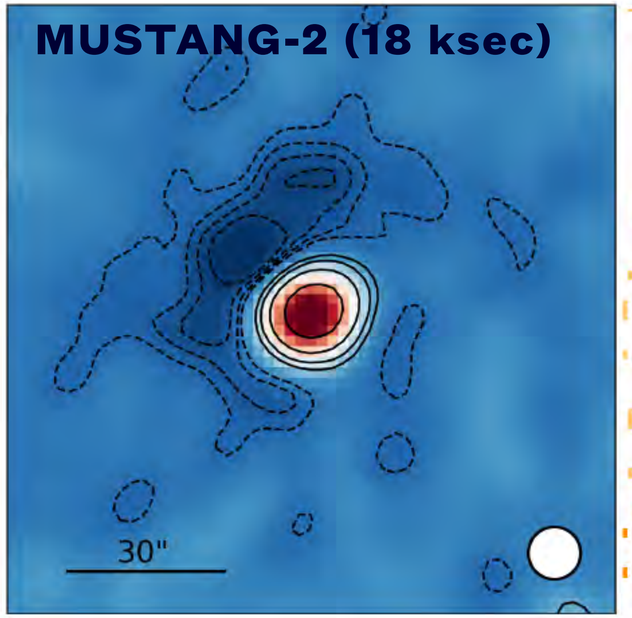
(Hashimoto+2002)

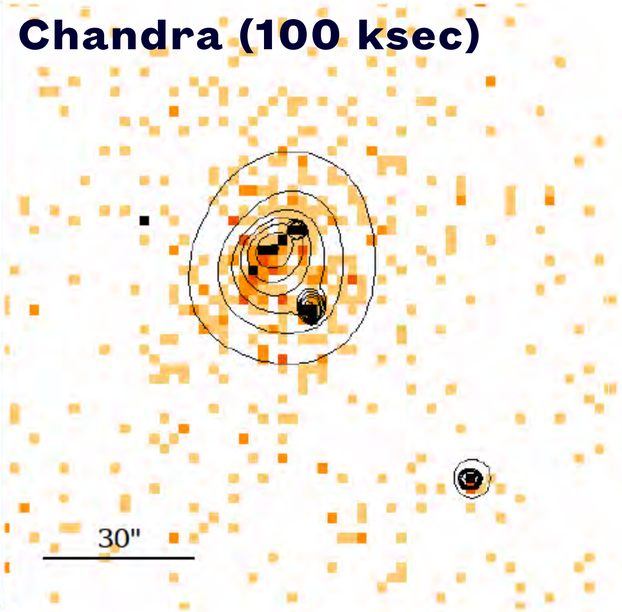
RXJ1053+5725 (z=1.14)

Ongoing high-z merger

IDCS J1426.5+3508 (z=1.75)





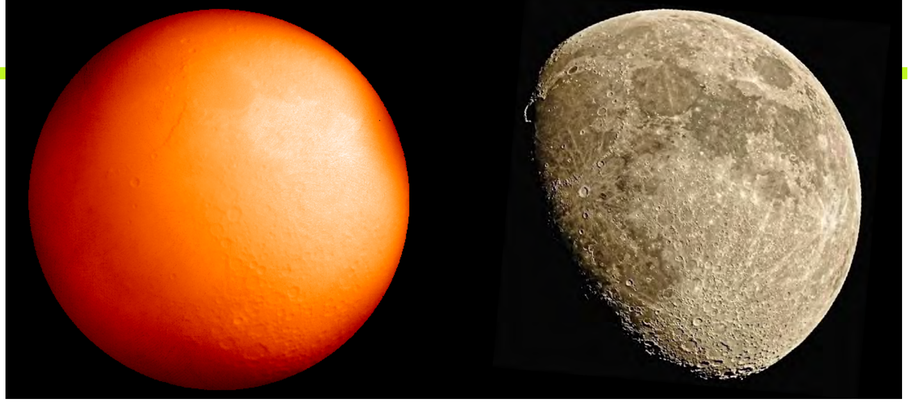


MUSTANG-2 + Chandra pressure profile fit

Pressure profile at r > 400 kpc flatter than "Universal" pressure profile, suggesting non-thermal pressure support in outskirts (bulk motion & turbulence)

Andreon et al. (submitted)

Summary



MUSTANG-2 & Optical

May 15, 2019

GBT19A-427 (PI: Paul Hayne)

- Multi-pixel continuum cameras on the GBT provide a powerful, flexible capability to address a wide range of science topics, some foreseen, and some not:
  - High-angular resolution SZE
  - Star formation (Galactic and extragalactic)
  - Dust physics
  - Even lunar physics!
- ***These capabilities, and the underlying flexibility of the GBT to readily deploy new instrumentation, will remain valuable in the era of NGVLA, SKA, and ALMA 2030.***

Thank you to: the organizers,

Everyone who helped imagine & build the GBT,

Everyone who helps keep it running,

MUSTANG co-I's,

And the MUSTANG instrument collaboration.