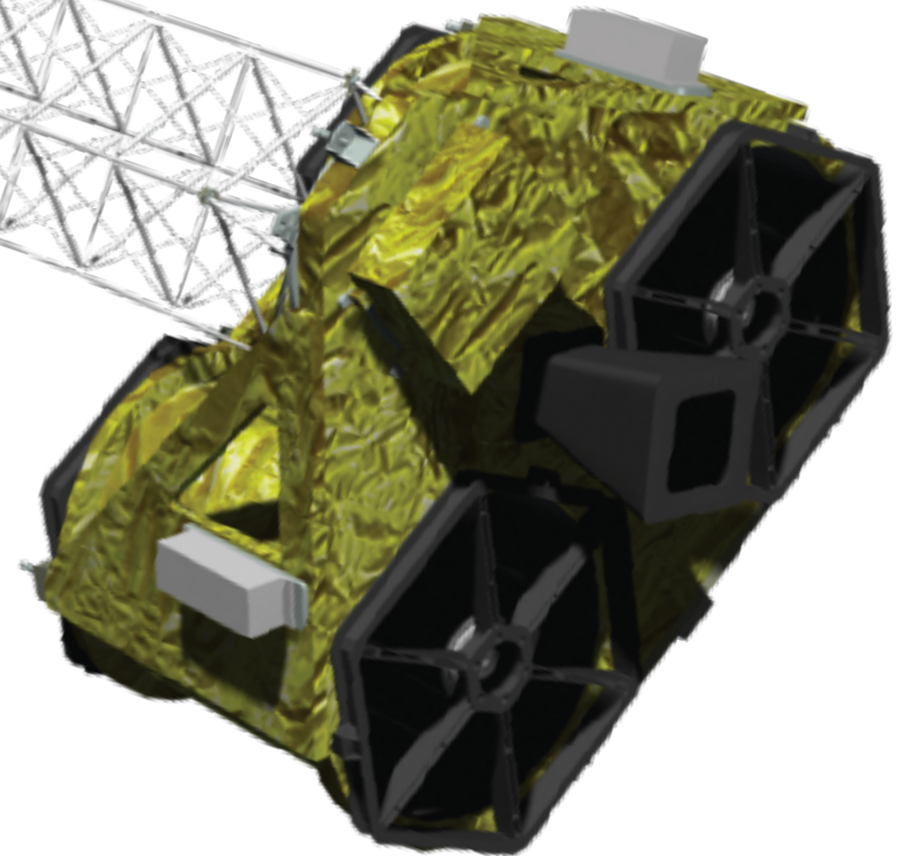




# Inverse Compton Searches at Hard X-ray Energies with *NuSTAR*

Daniel R. Wik  
University of Utah

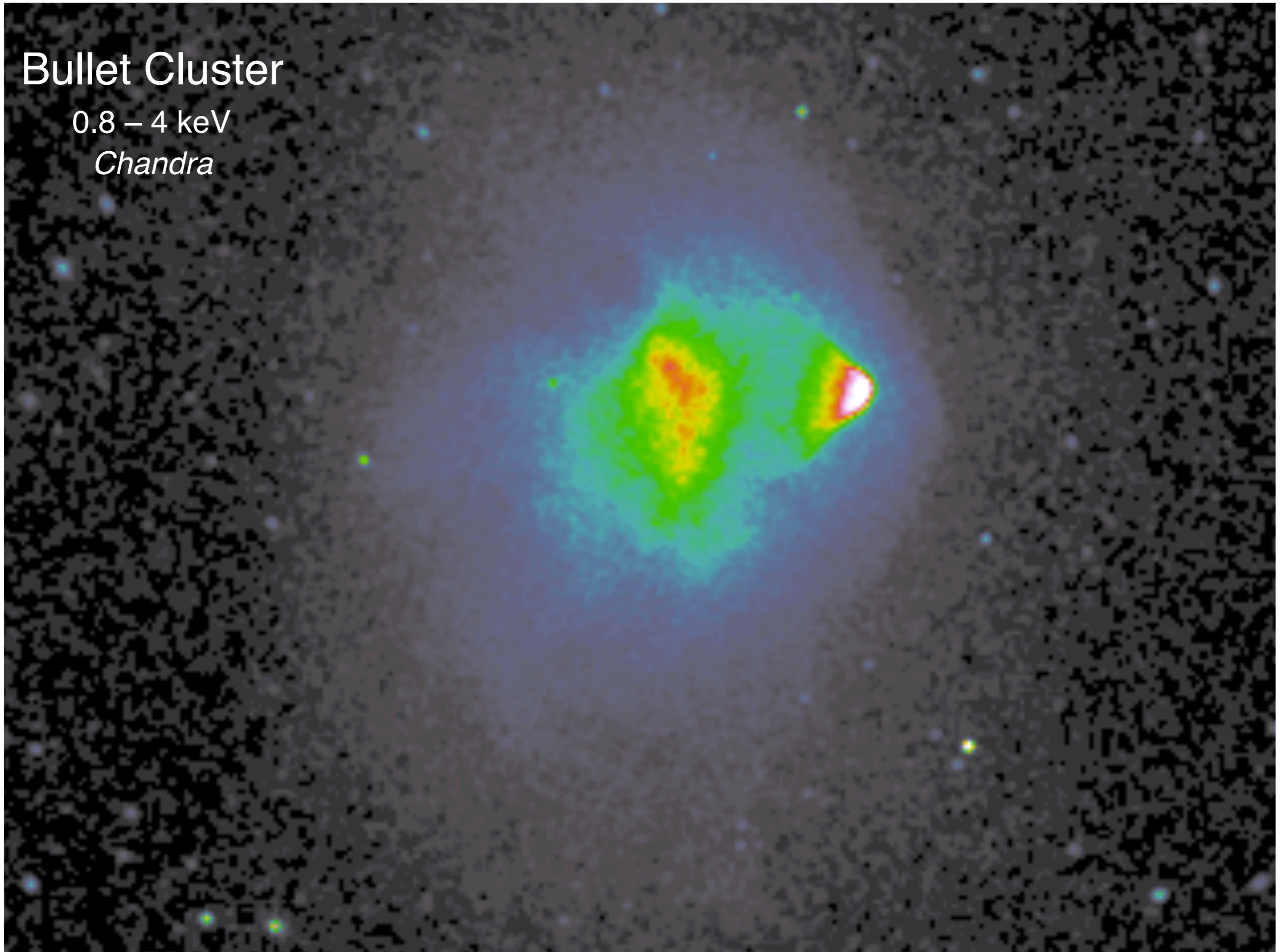
with Fabio Gastaldello, Craig Sarazin,  
Silvano Molendi, Allan Hornstrup, NJ  
Westergaard, Greg Madejski, ++



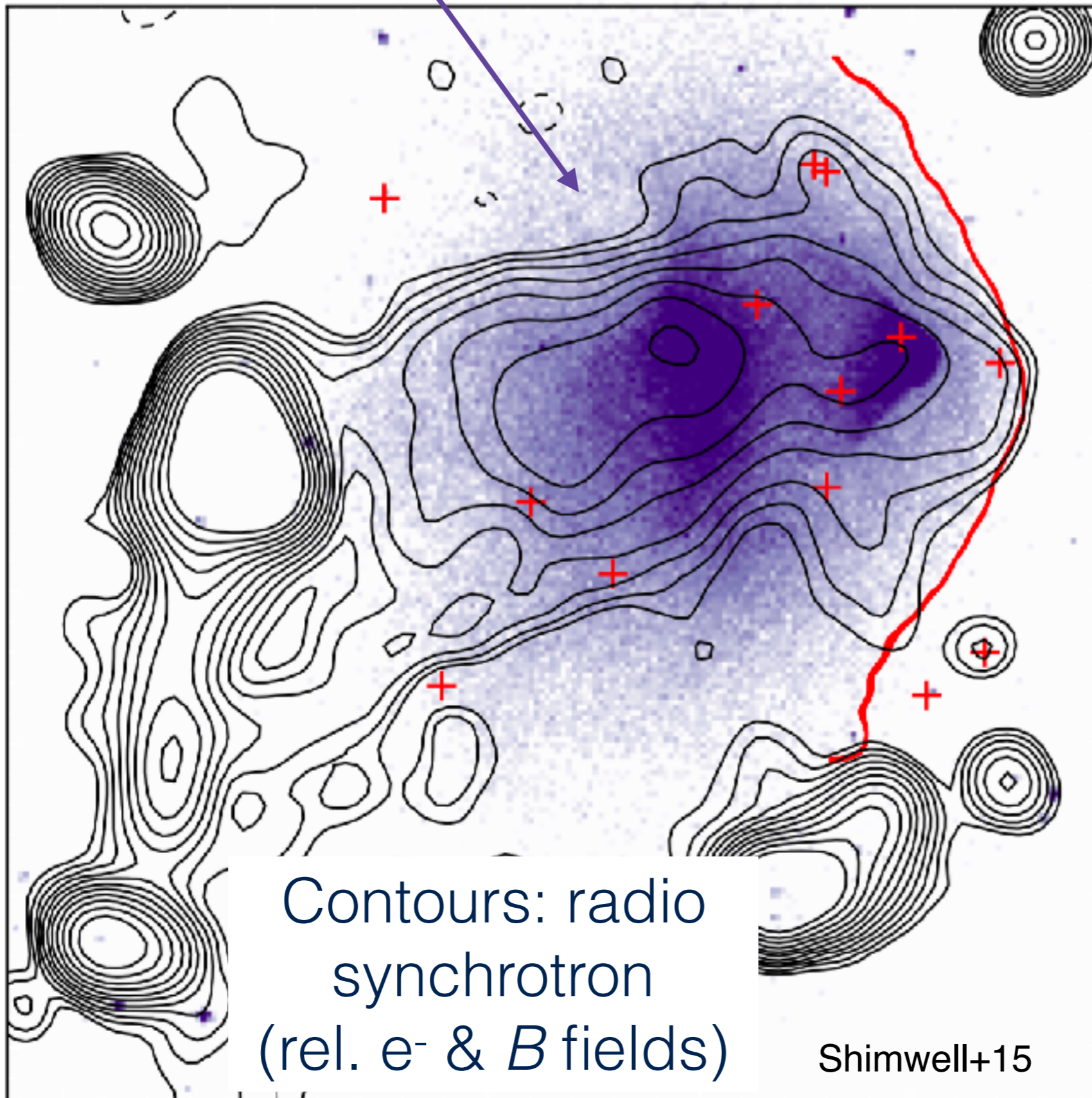
# Bullet Cluster

0.8 – 4 keV

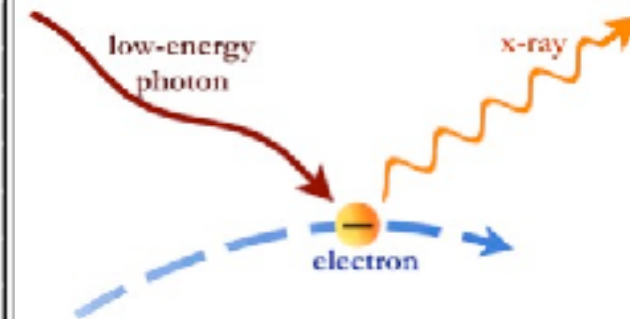
*Chandra*



X-ray emission  
(hot gas)

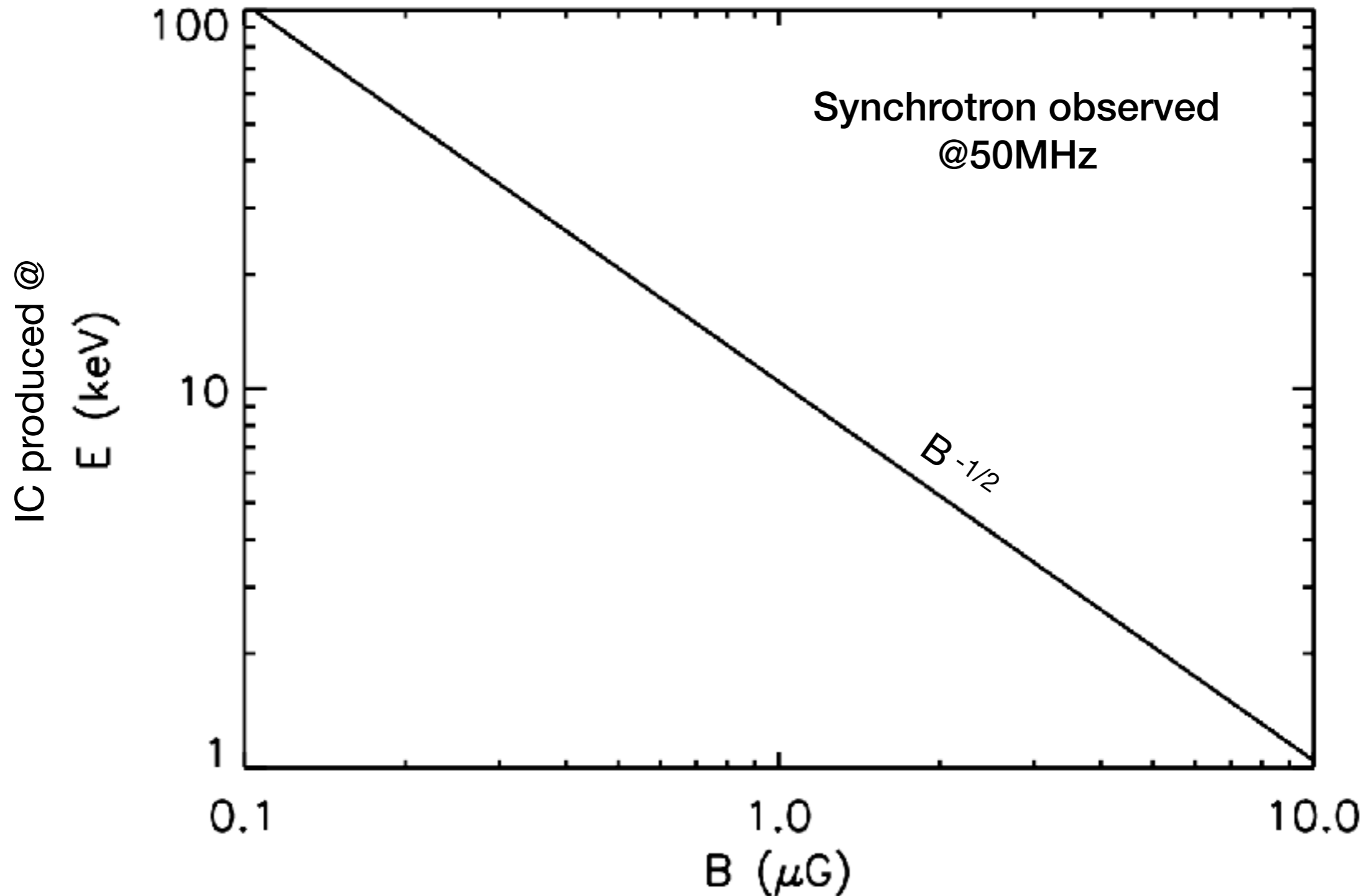


Inverse Compton  
(IC) Scattering

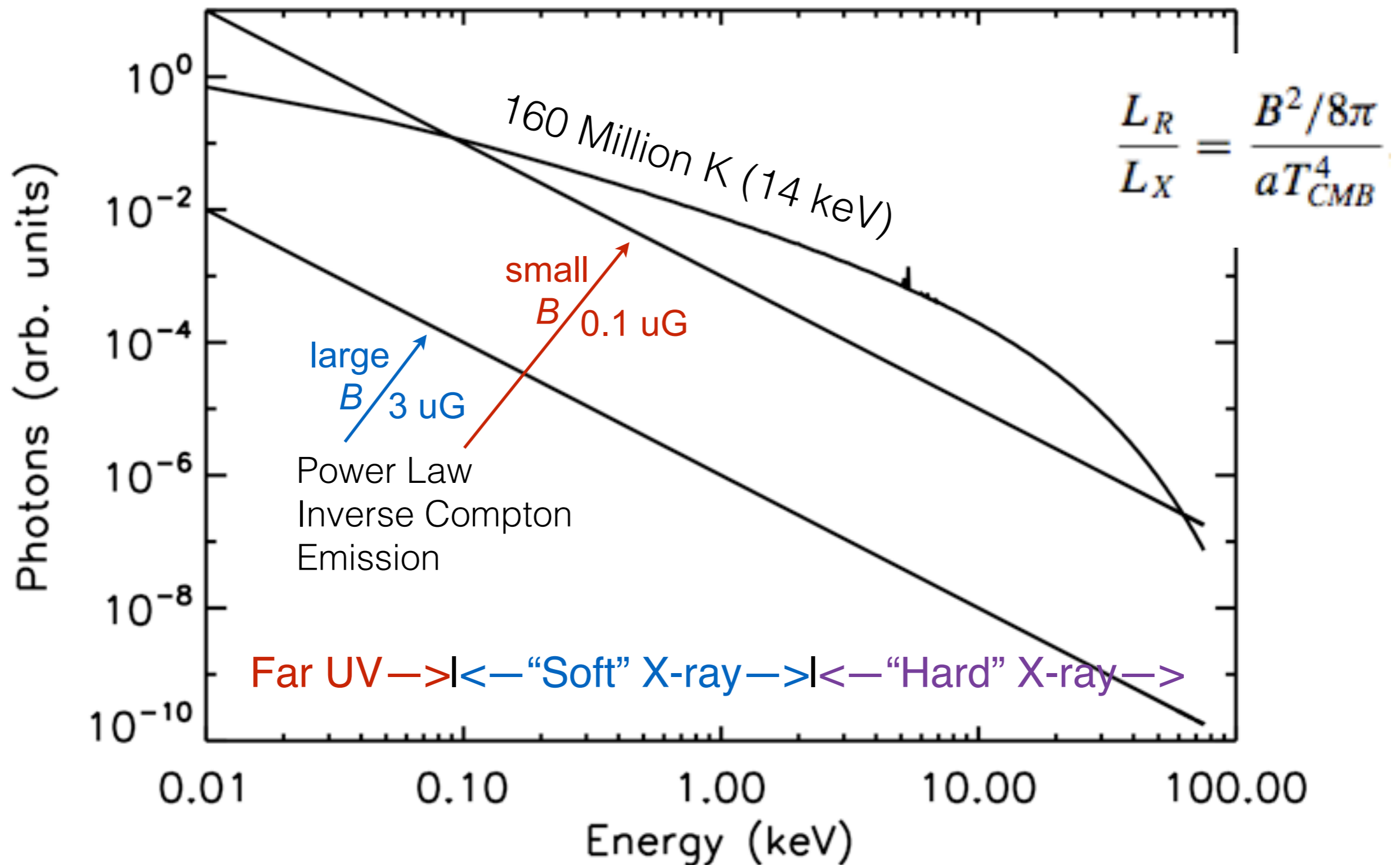


$$\frac{L_R}{L_X} = \frac{B^2/8\pi}{aT_{CMB}^4}$$

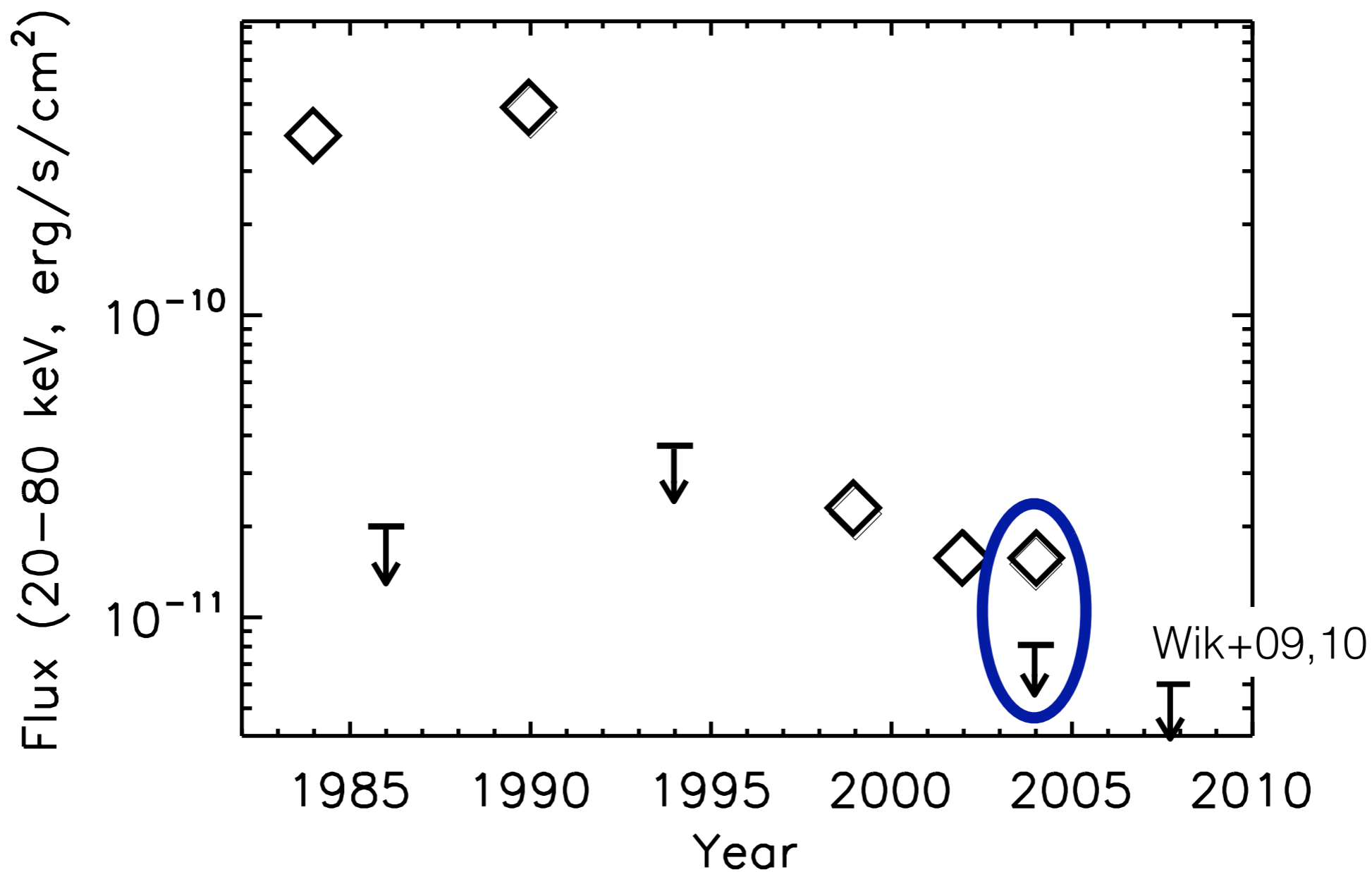
# Low frequency radio observations are a perfect match for hard X-ray IC searches



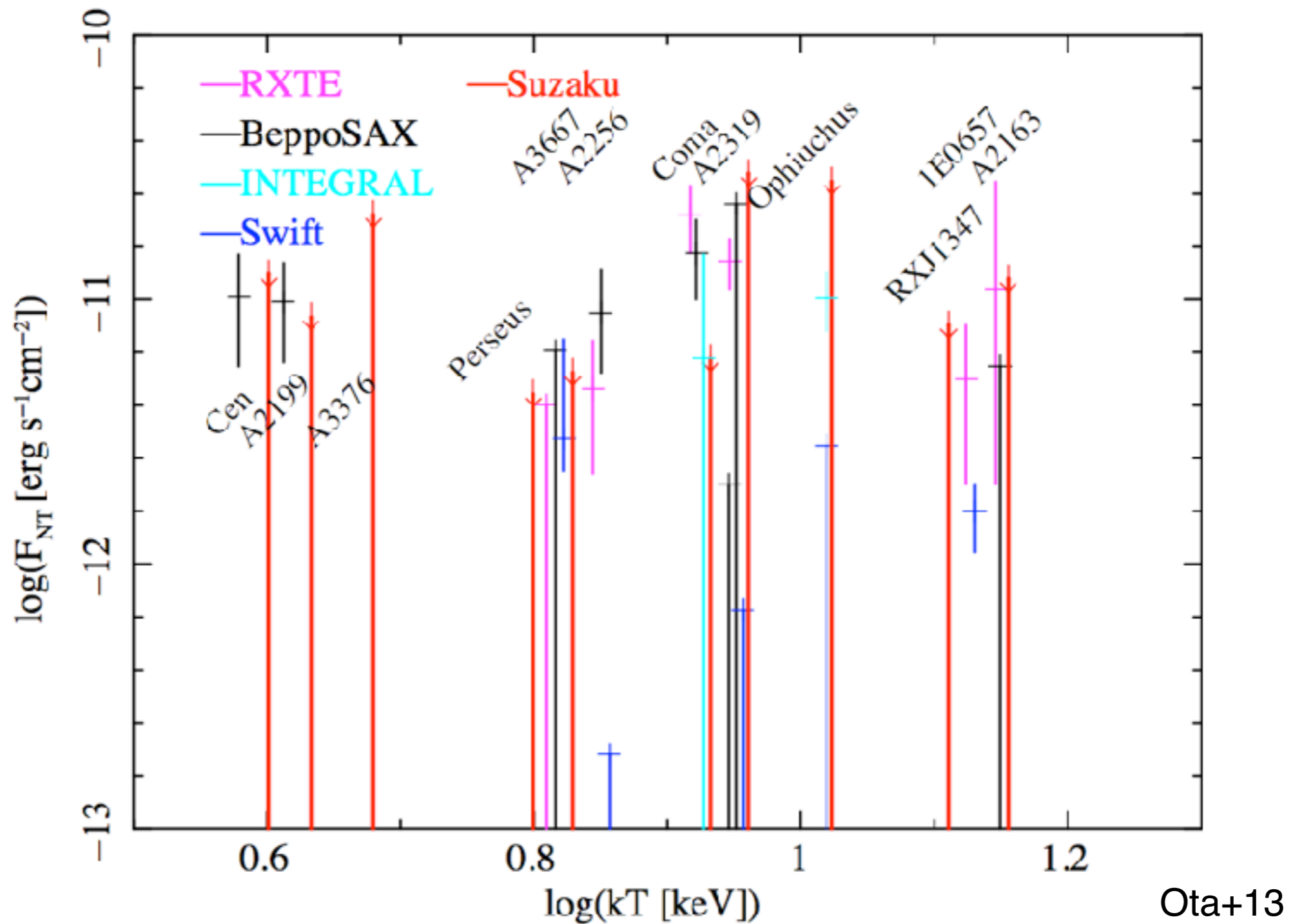
Inverse Compton measurements give you the average strength of the magnetic field in the intracluster medium



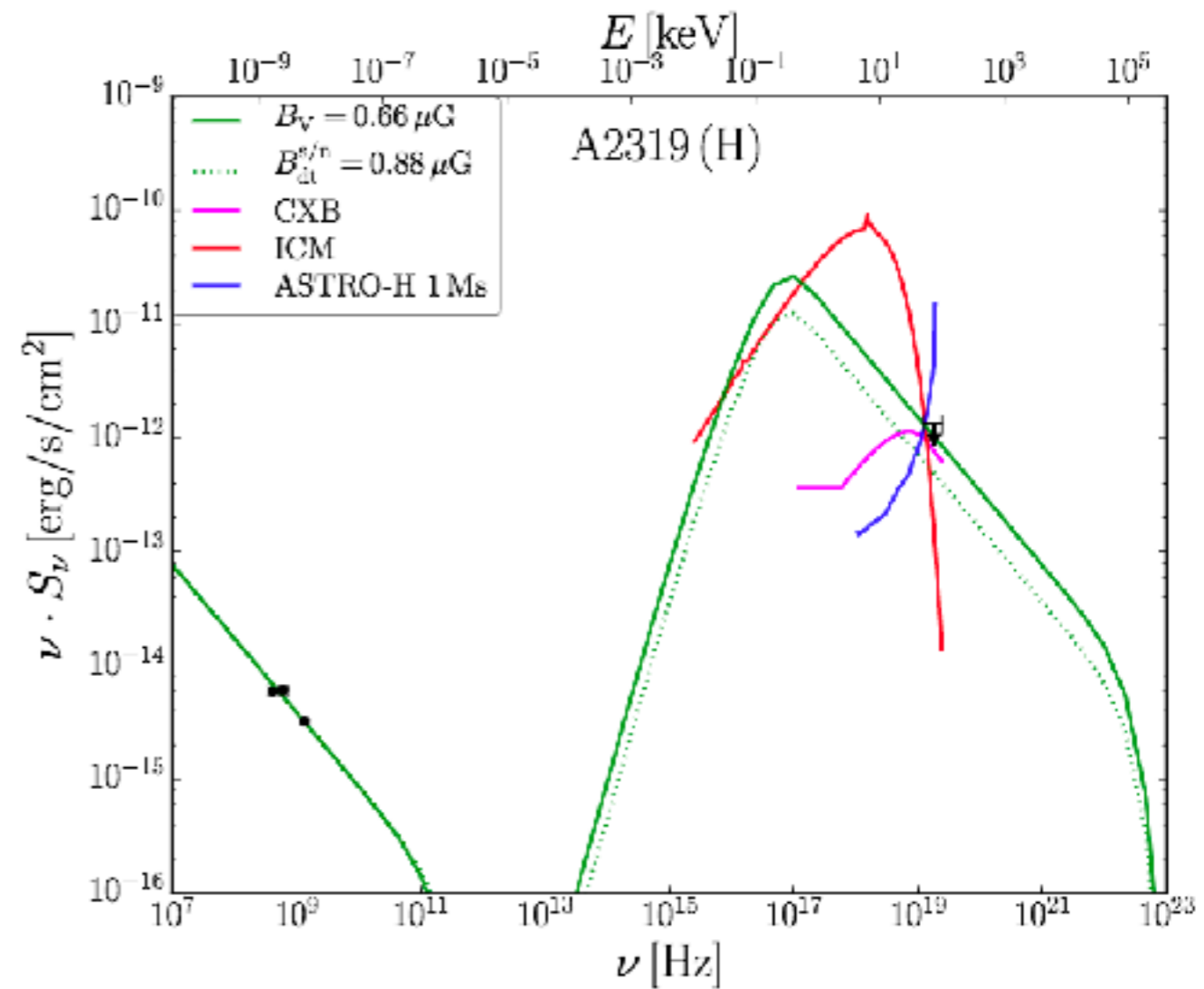
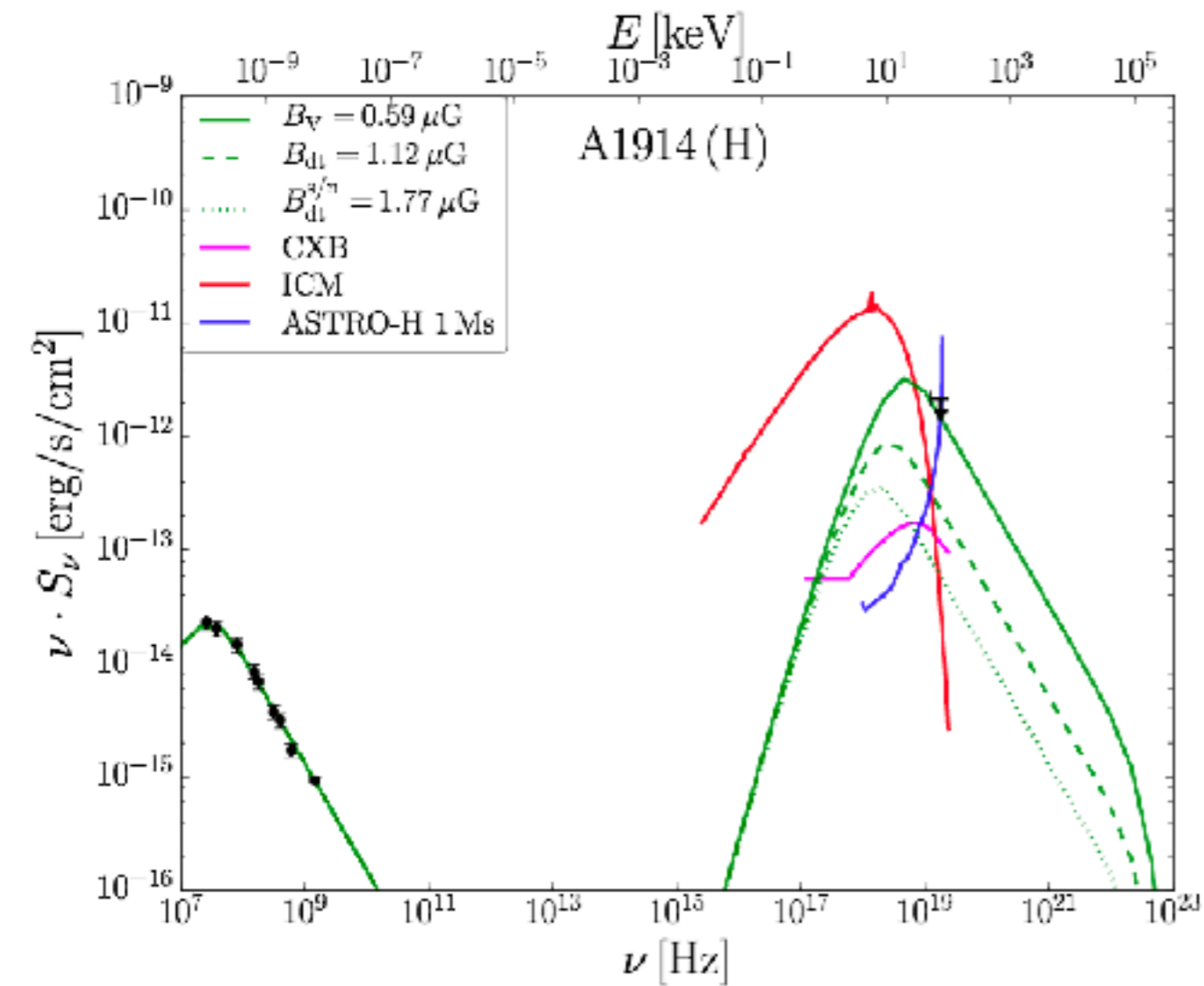
# Estimated IC fluxes of the Coma Cluster



# Past Detections of Non-thermal Components



# Hitomi had the potential to approach $B \sim \mu\text{G}$



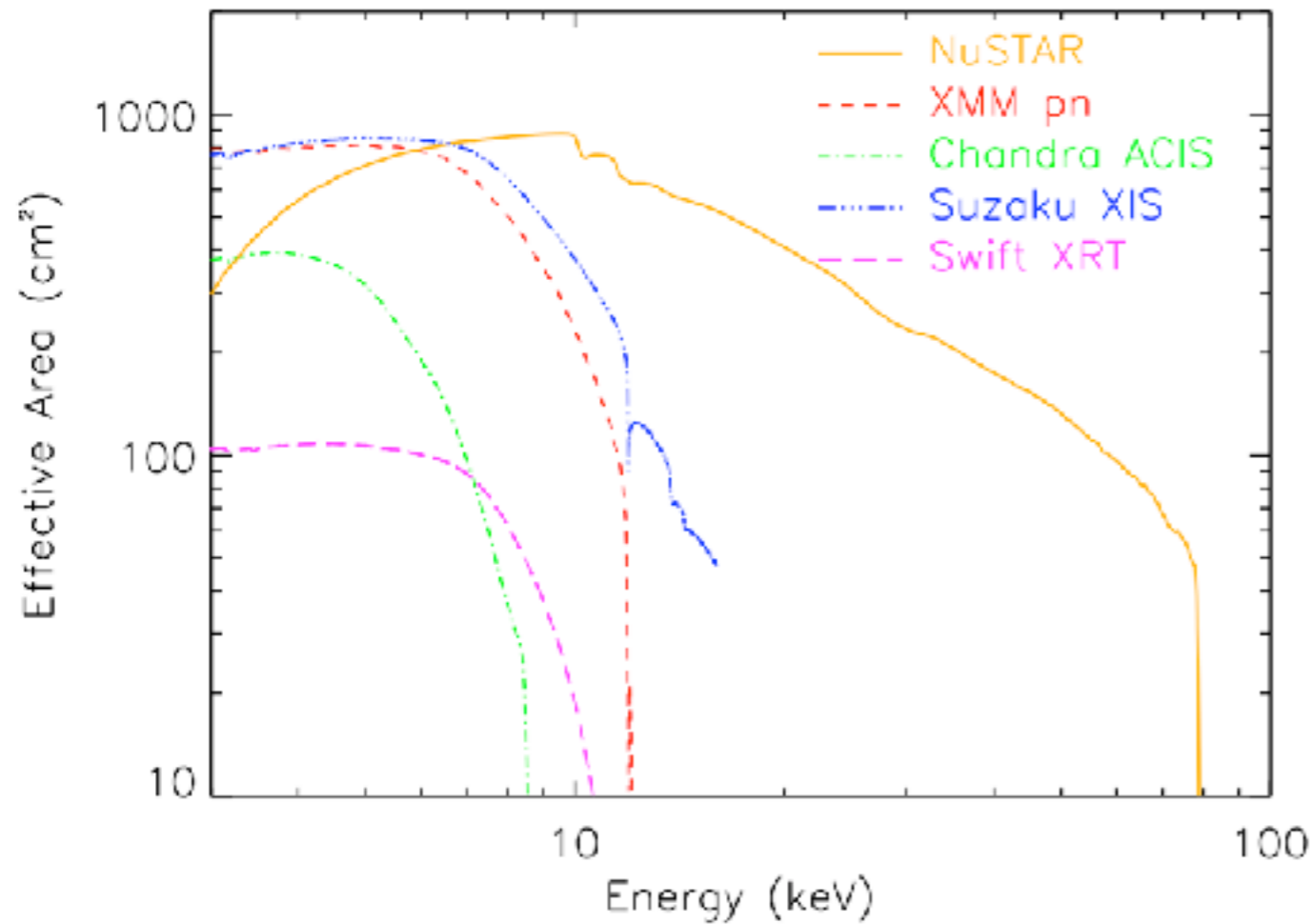
Bartels, Zandanel, & Ando 15



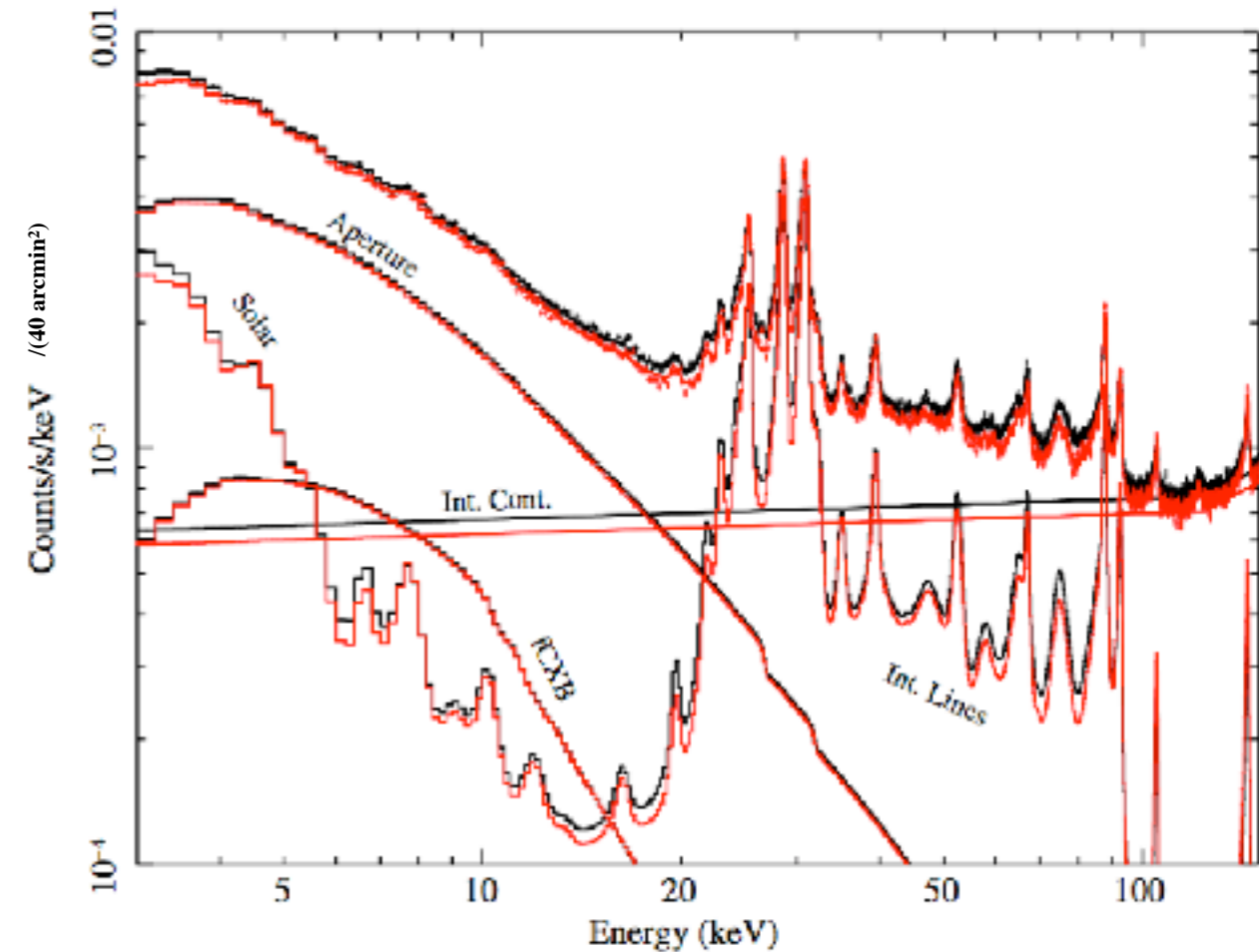
# NuSTAR: Order of Magnitude Improvement in Sensitivity

A few times larger than *Suzaku* HXD-PIN

Up to 10x lower than *Suzaku* HXD-PIN



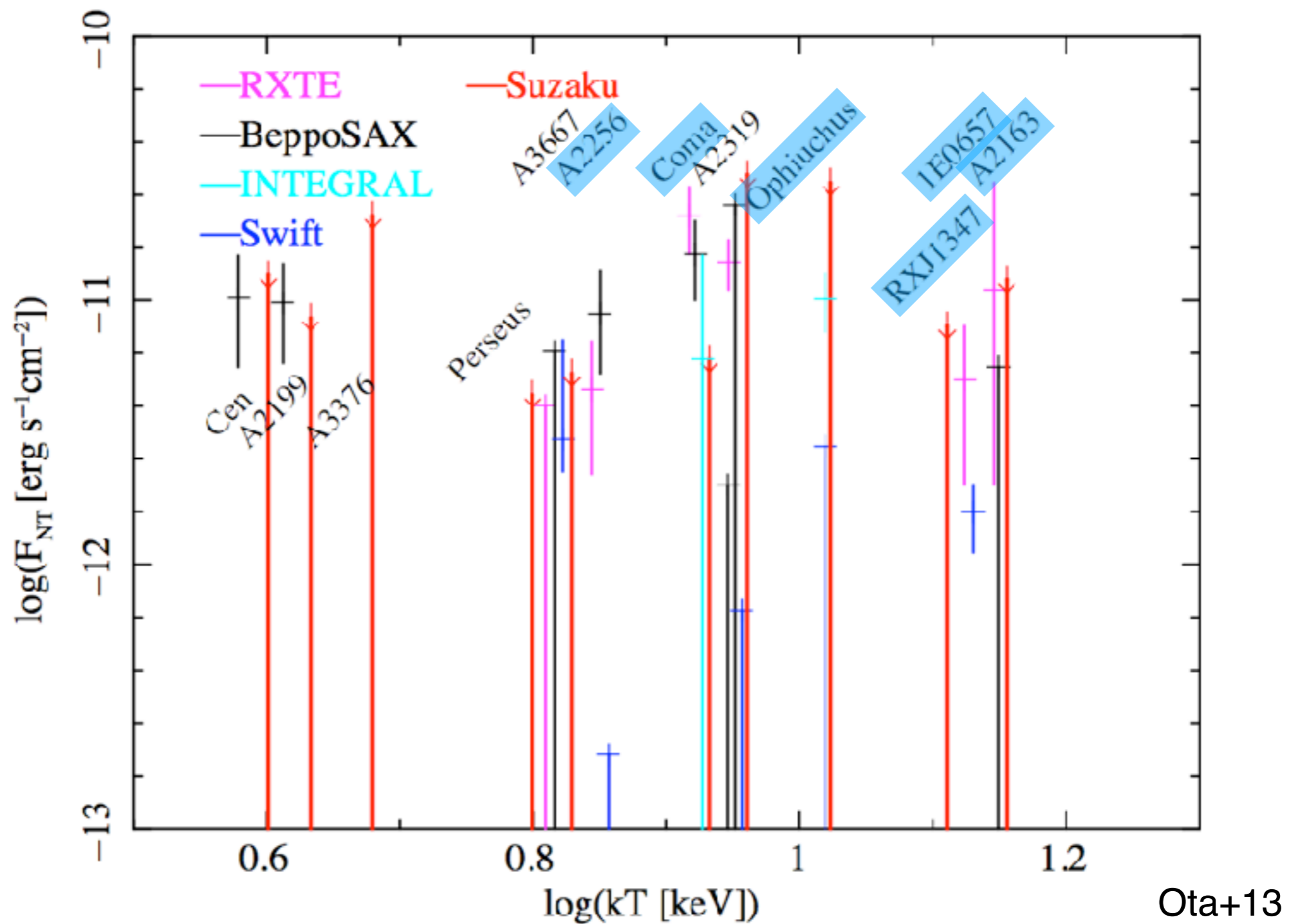
Harrison+13



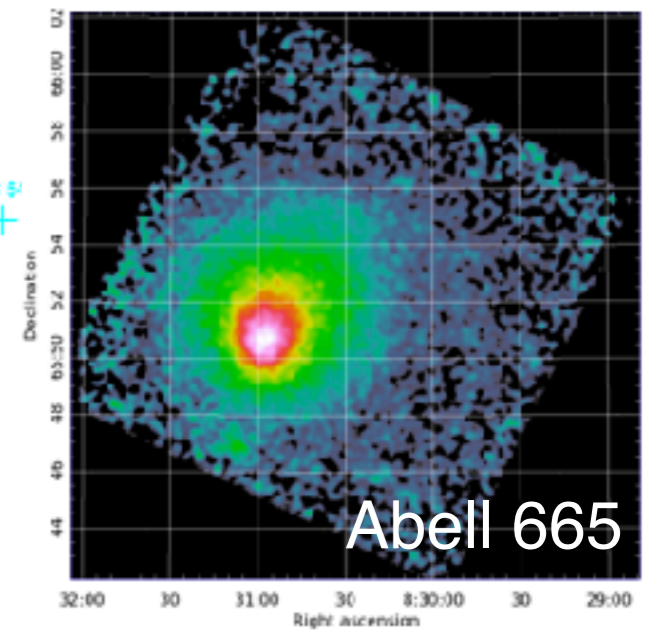
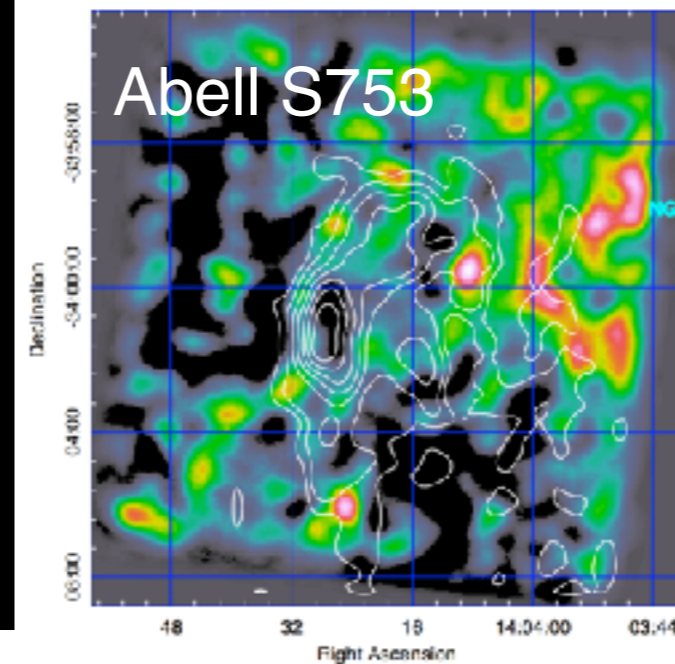
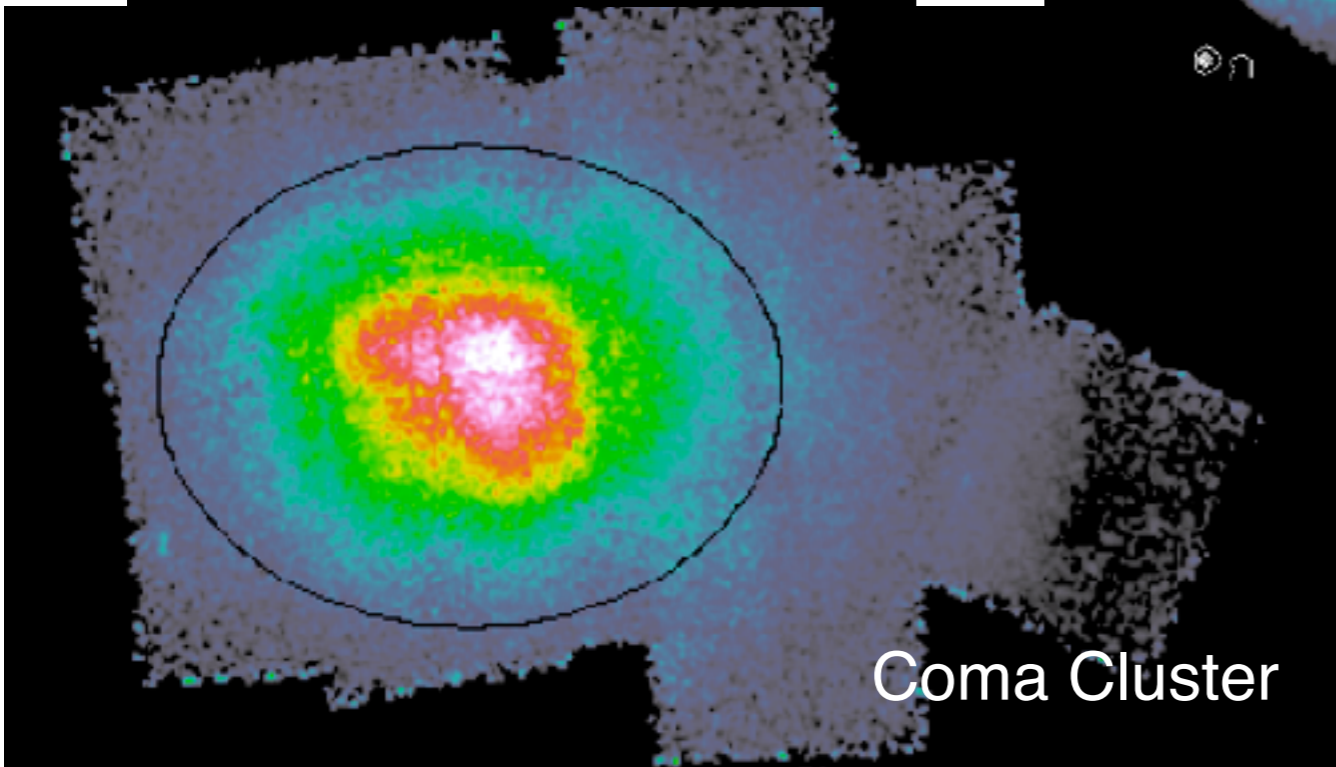
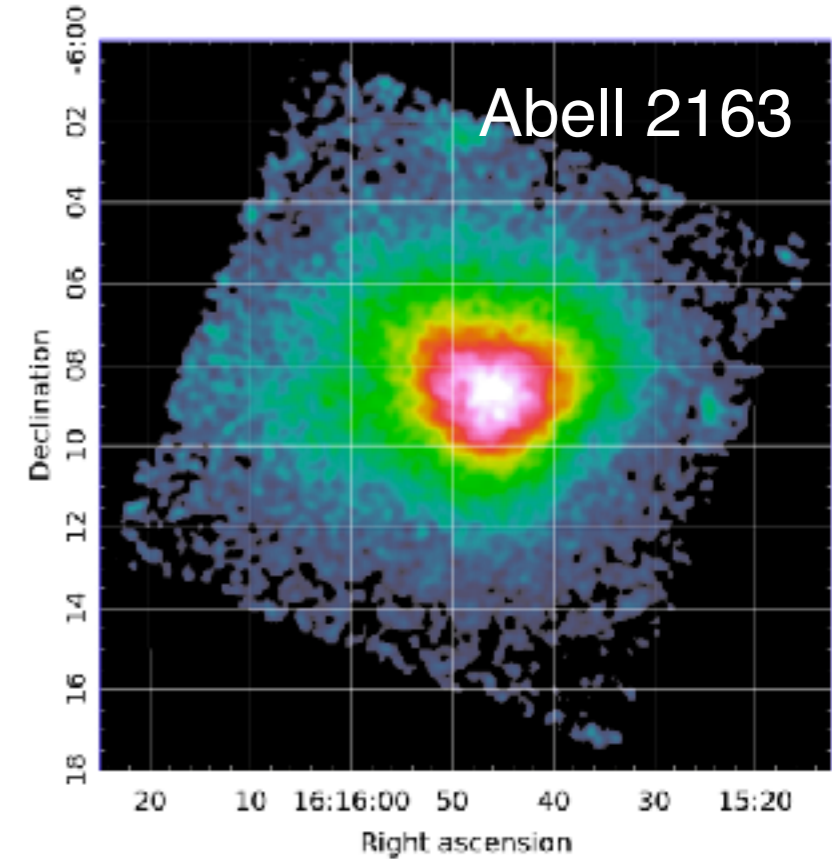
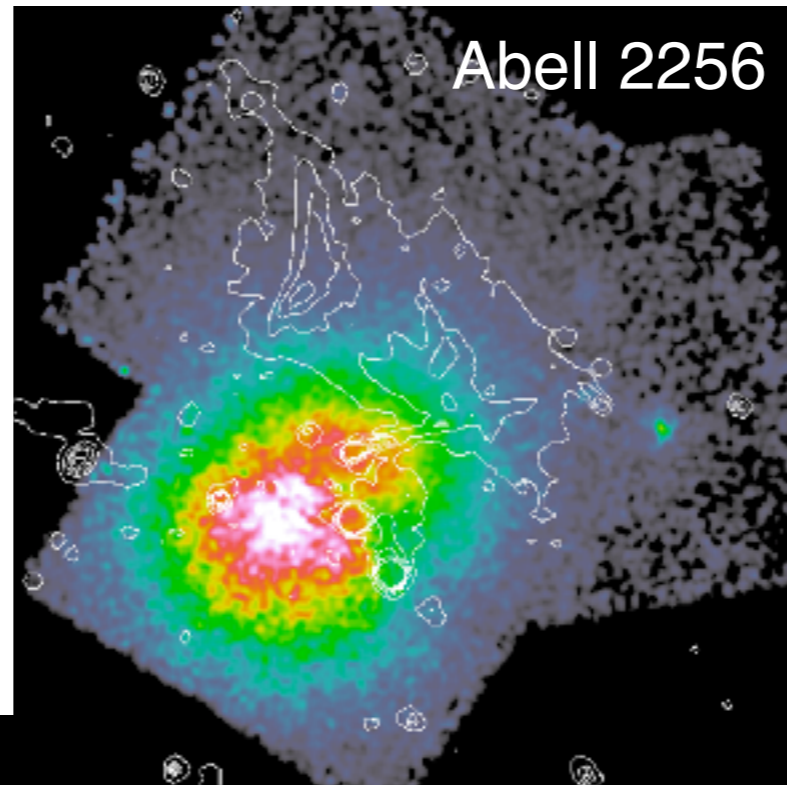
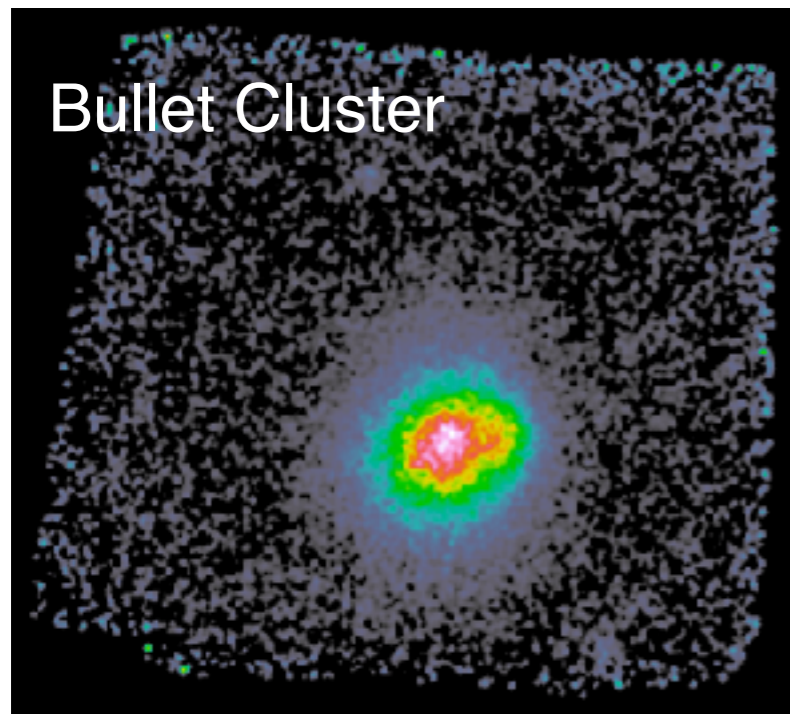
Wik+14

PSF: 18" FWHM, 58" HPD  
Field of View: 13' x 13'

# Past Detections of Non-thermal Components

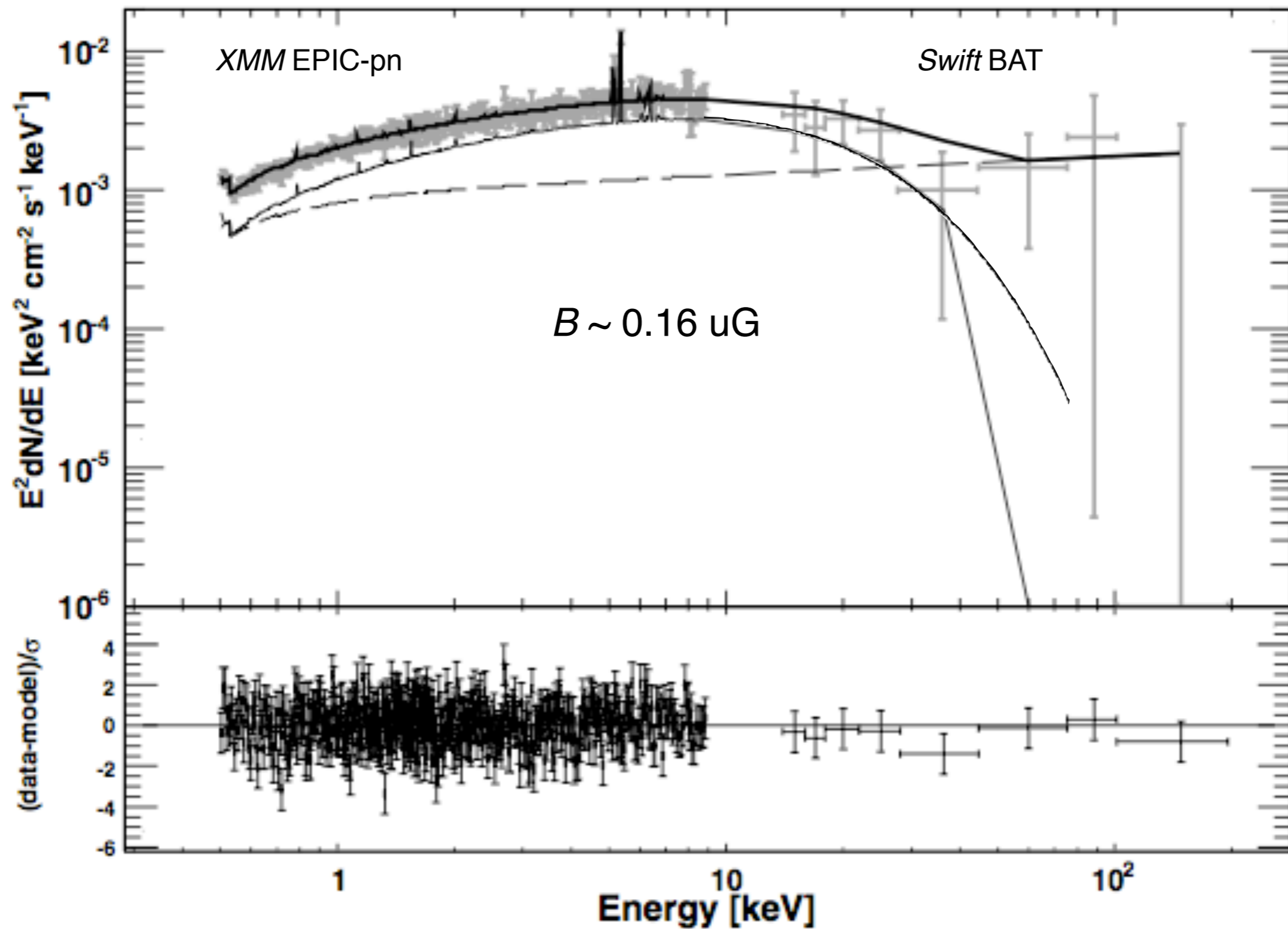


# Sample of *NuSTAR* Observations



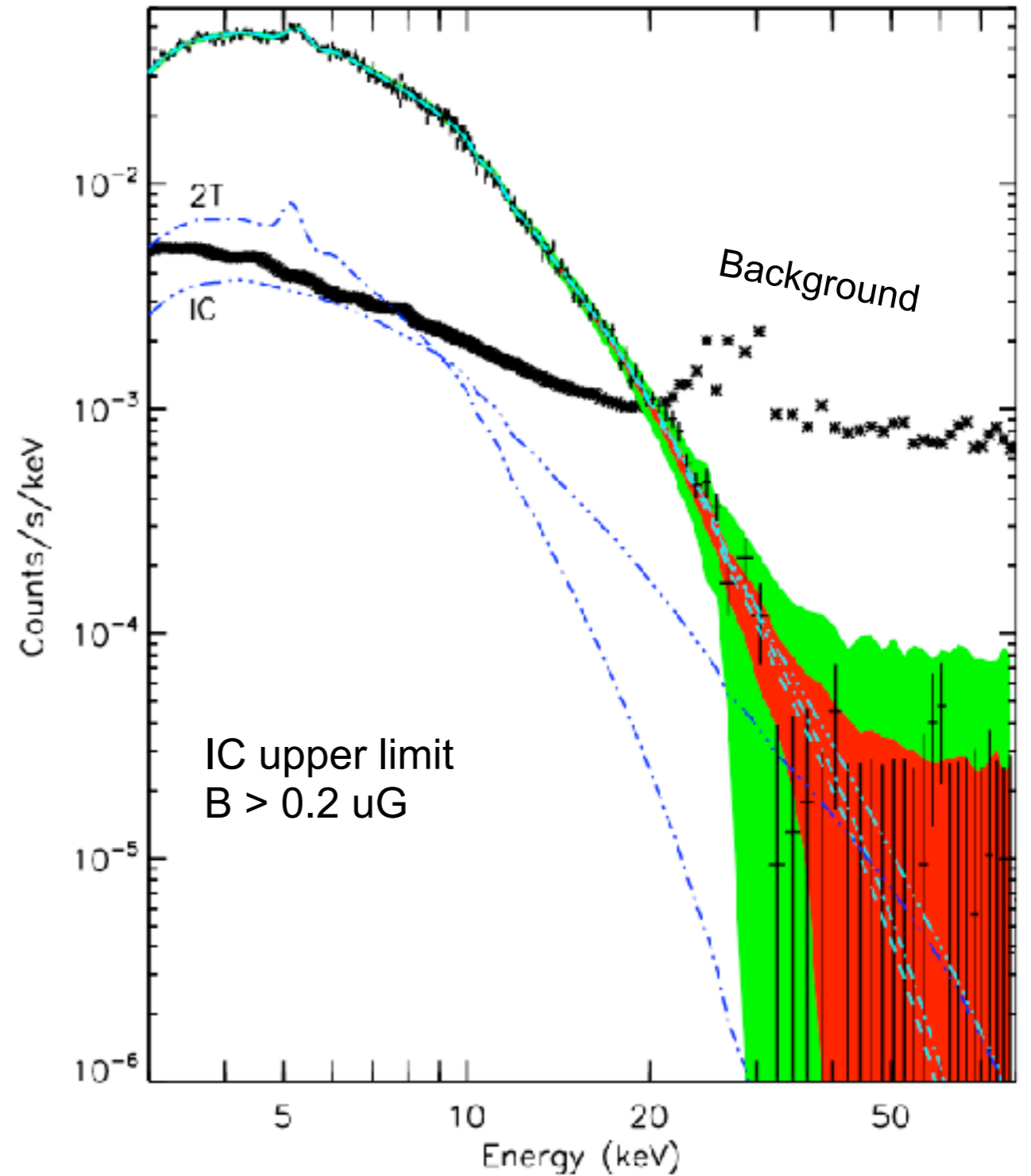
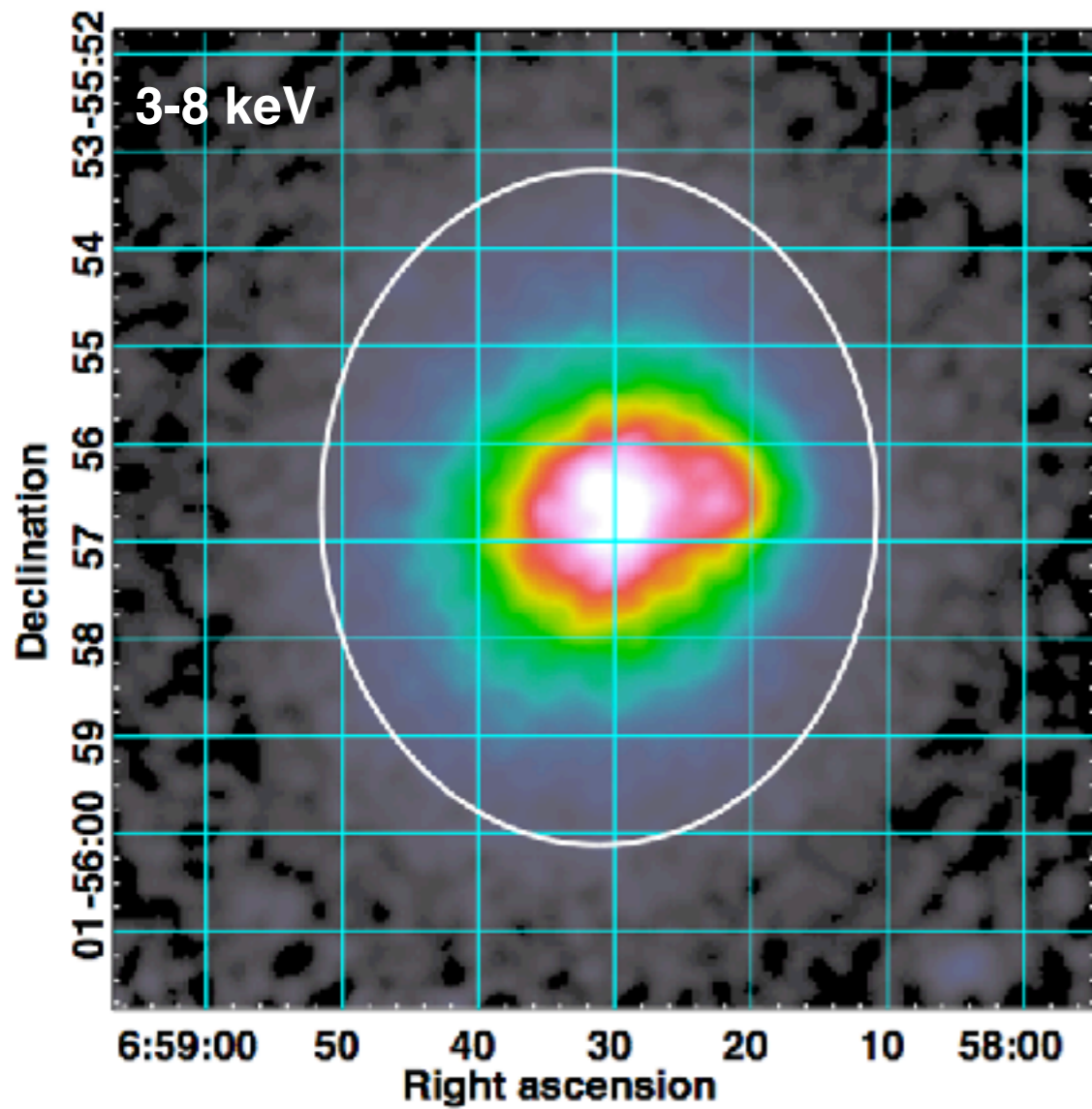
Also the Cygnus A cluster, the Abell 754 shock, Abell 523, RX J1437 (not yet observed), and Ophiuchus (unfortunately already observed)

# Motivation for Choosing the Bullet Cluster



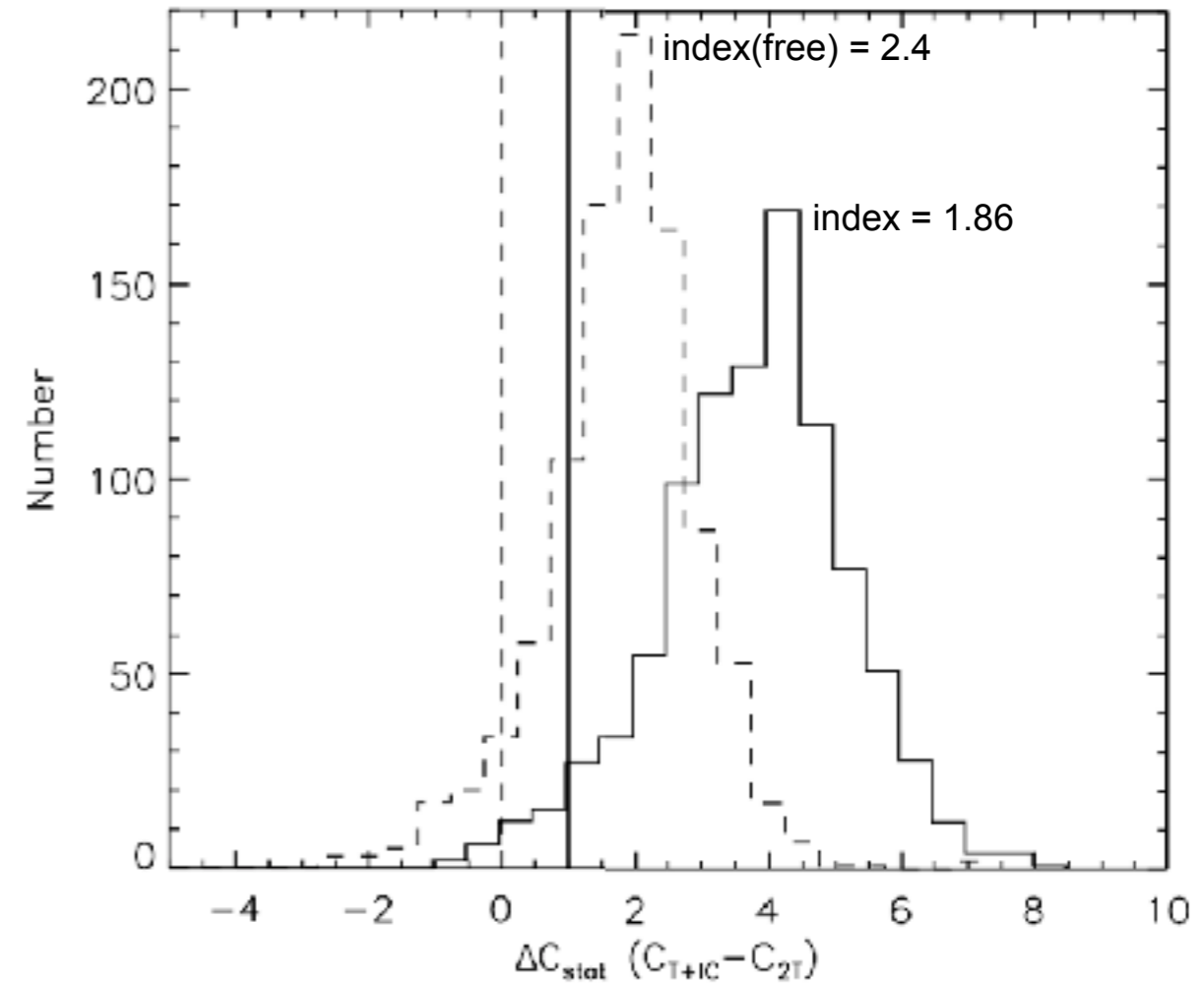
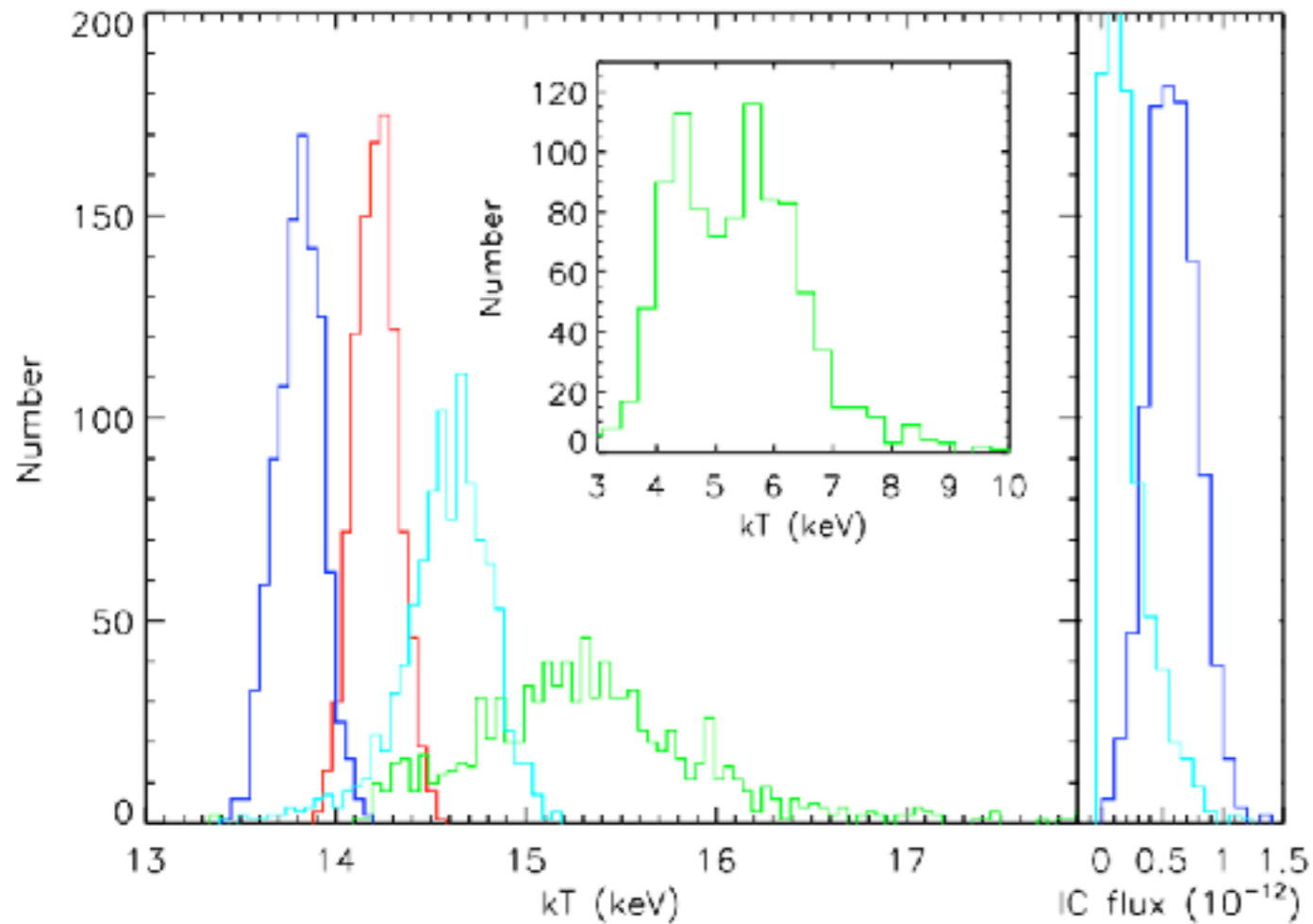
Ajello+10

# Bullet Cluster: No IC Detection



Wik+14

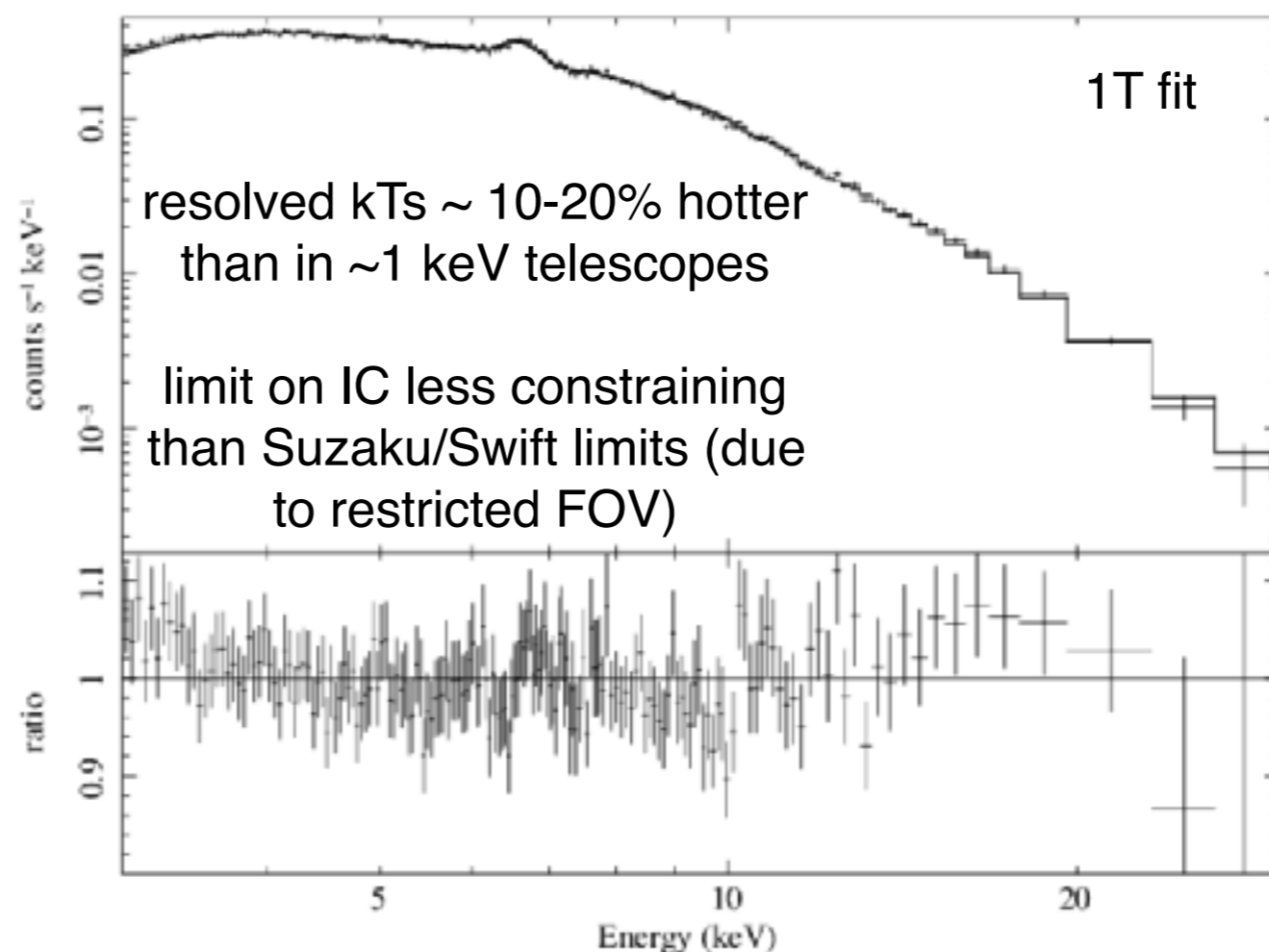
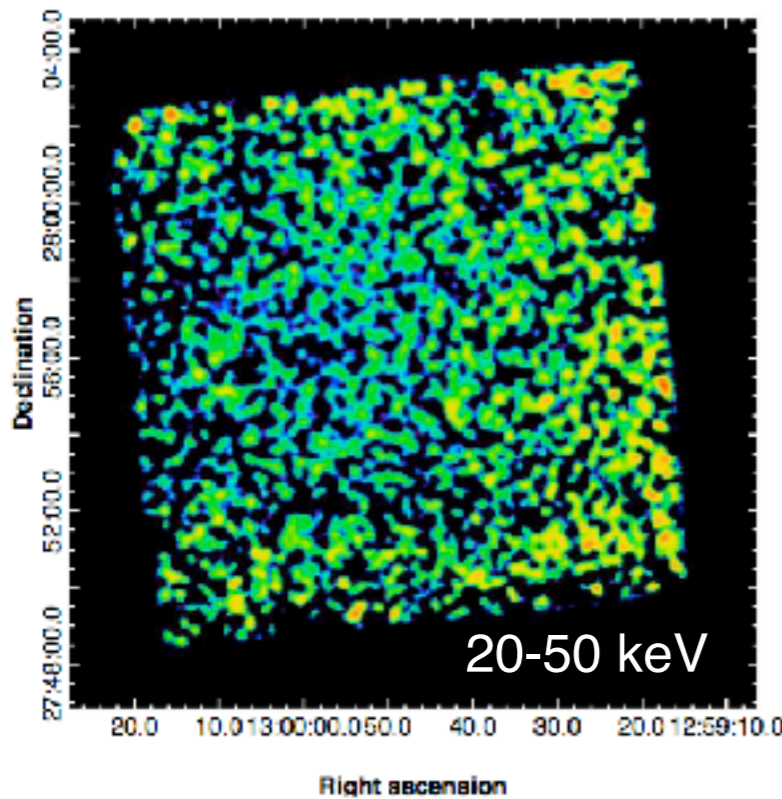
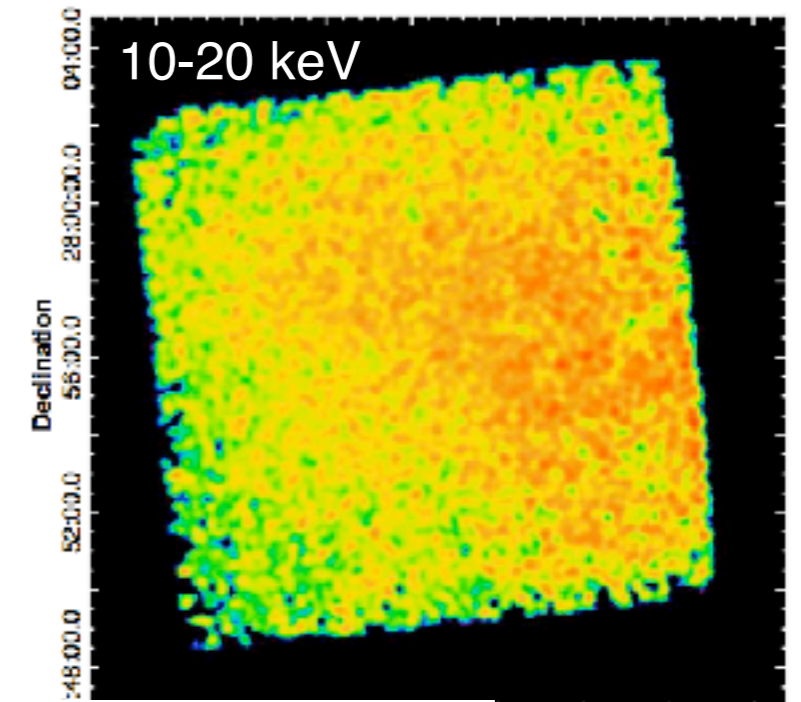
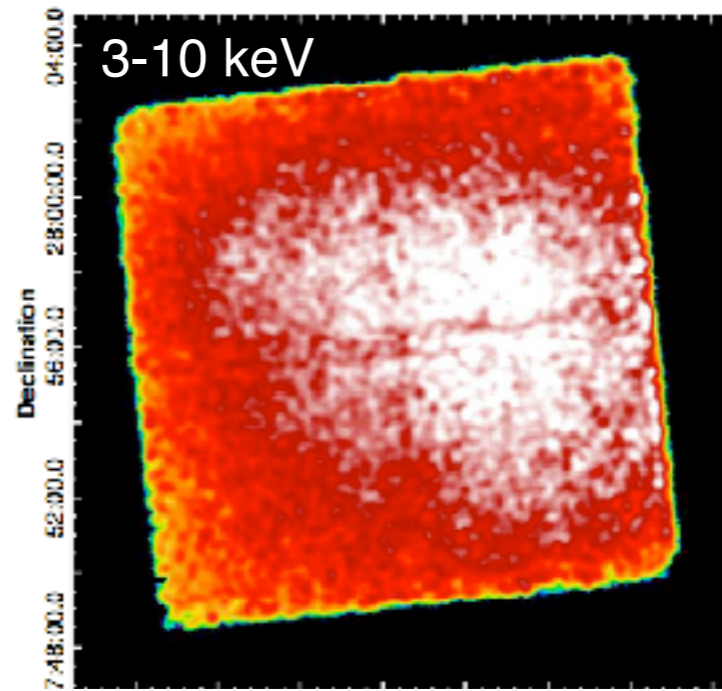
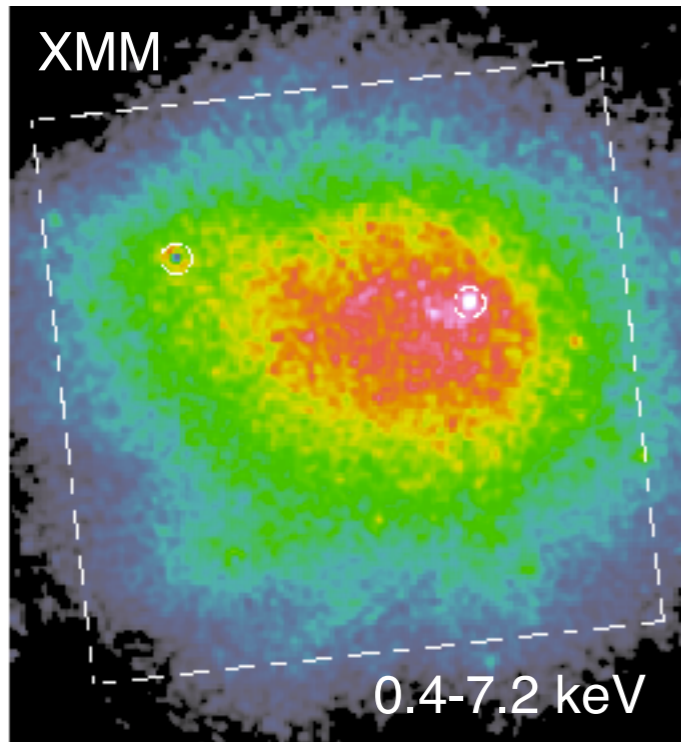
# Bullet Cluster: No IC Detection



2T model preferred 98.8%  
(92.4%) of the time

Wik+14

# Coma Cluster: Center (the most well-studied galaxy cluster)



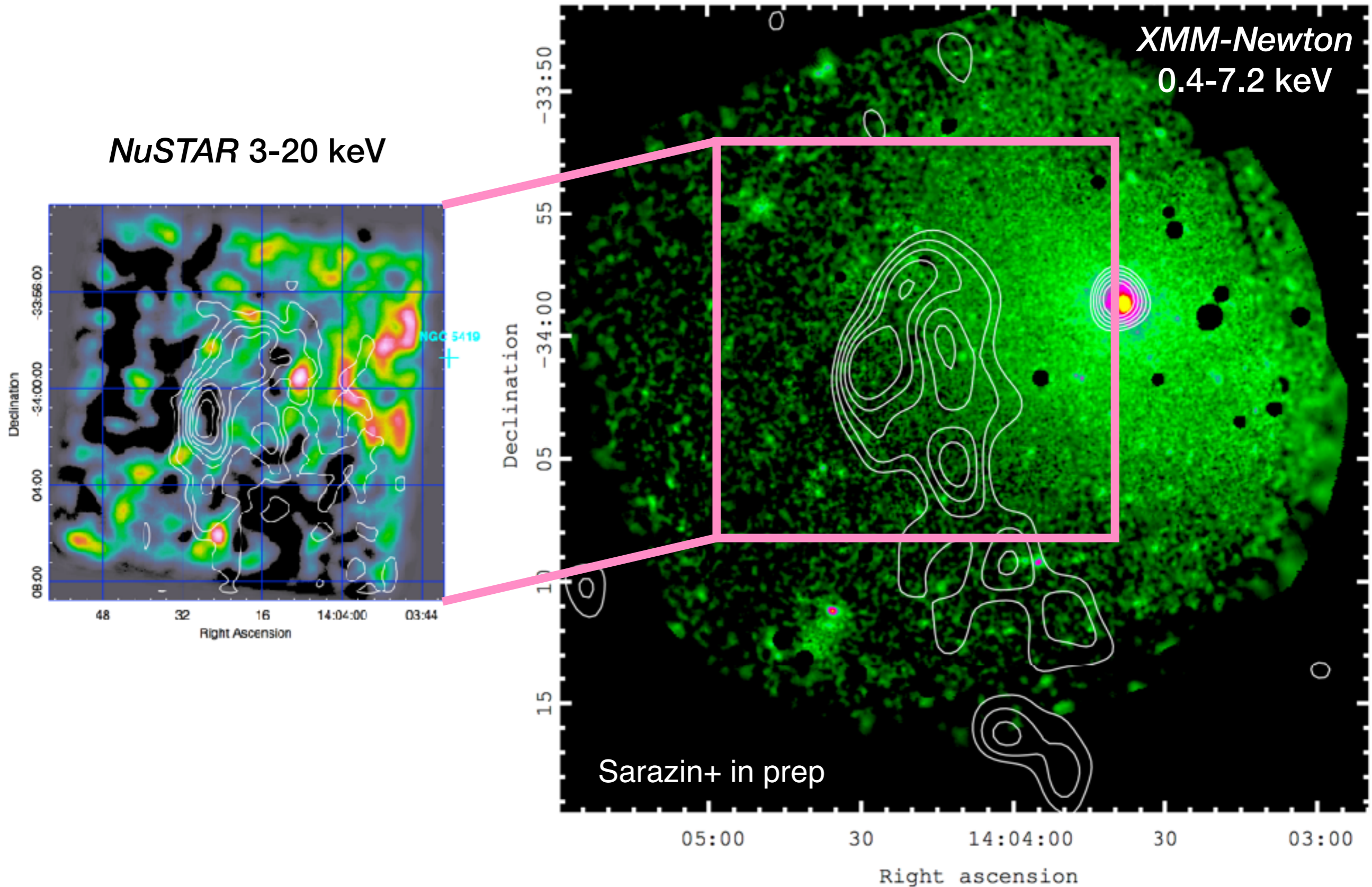
0.0 30.0 20.012:59:10.0

ion

Gastaldello+15

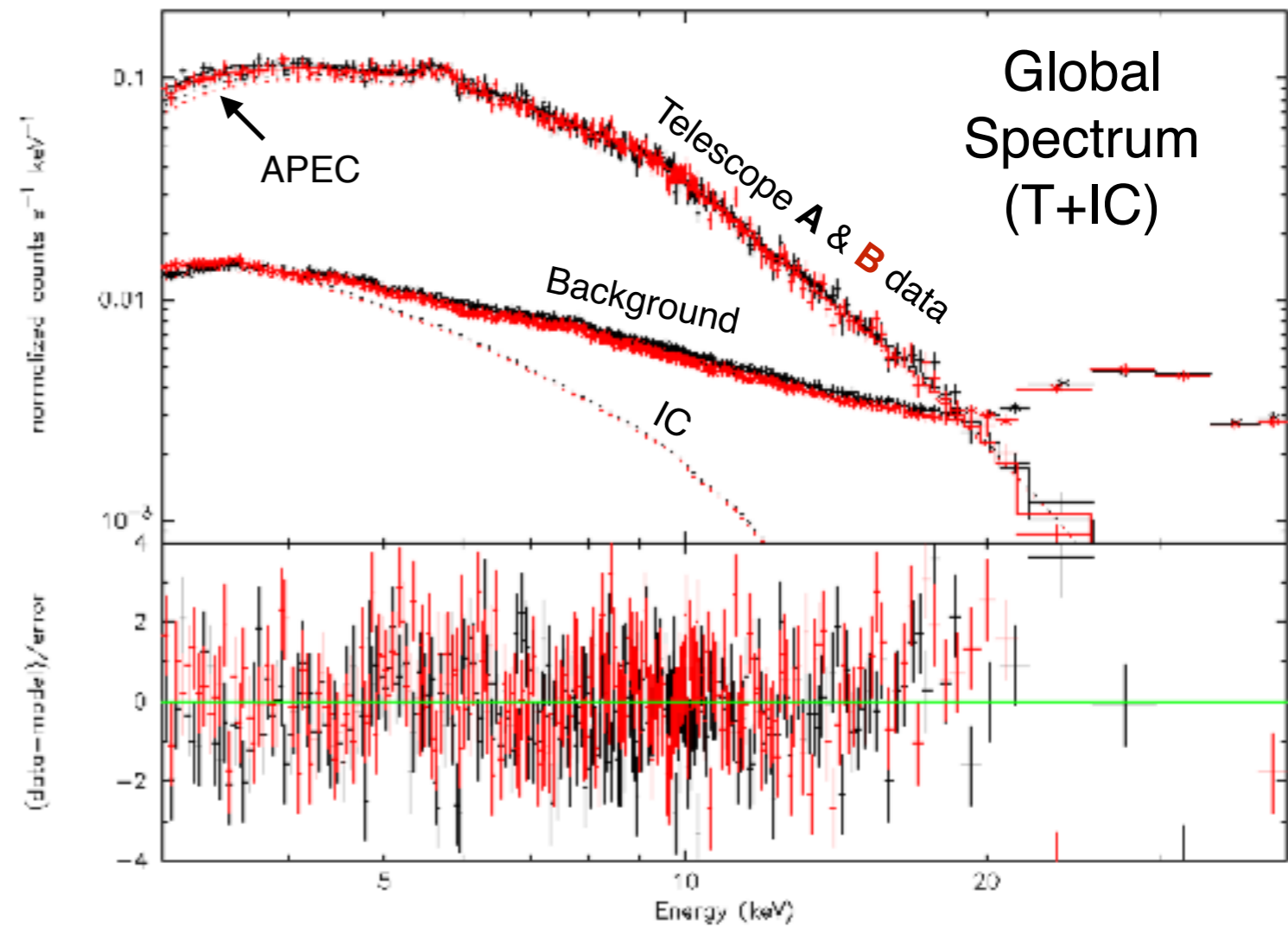
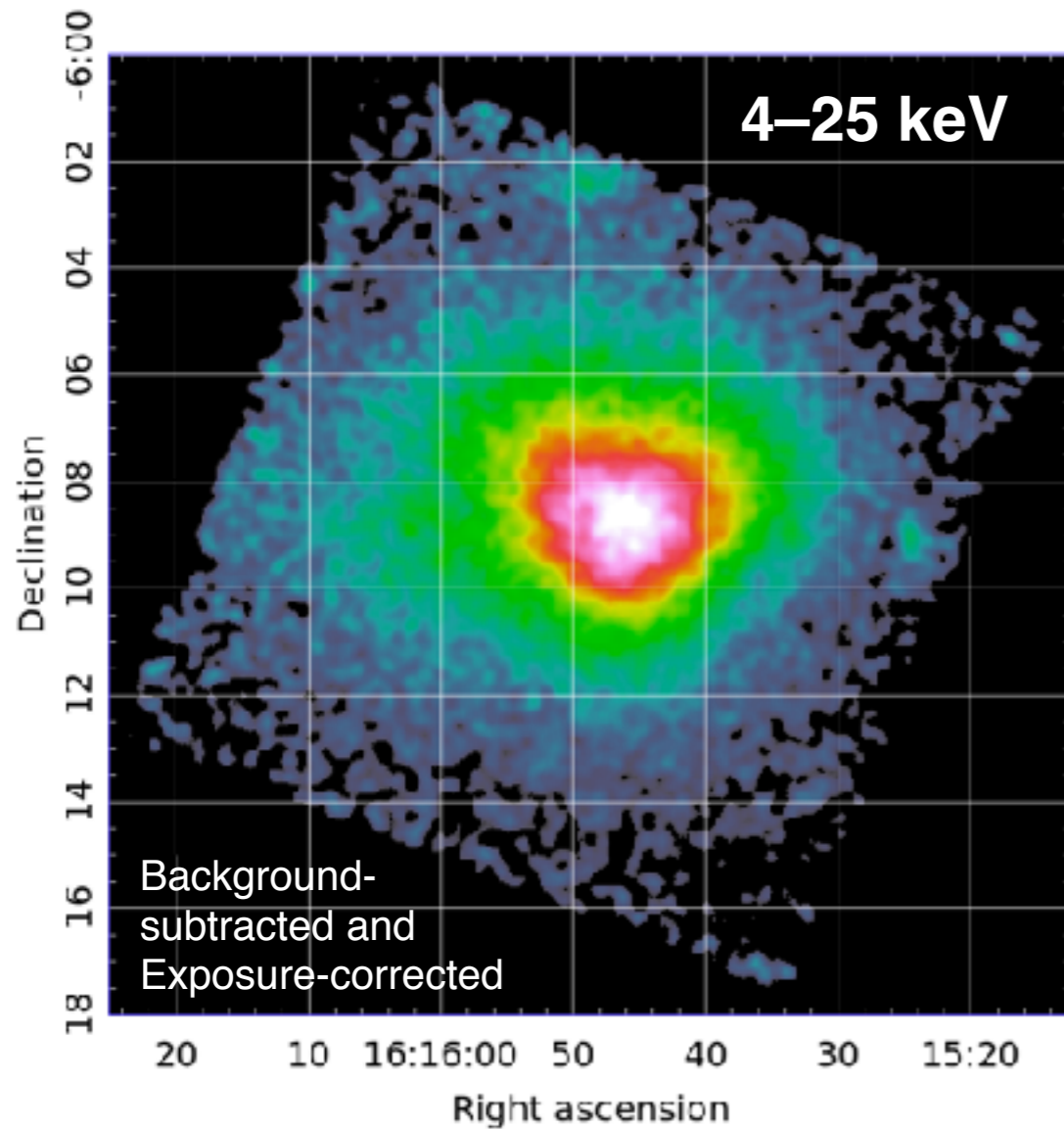
# Abell S753

(one of the brightest relics, in the lowest kT cluster host)





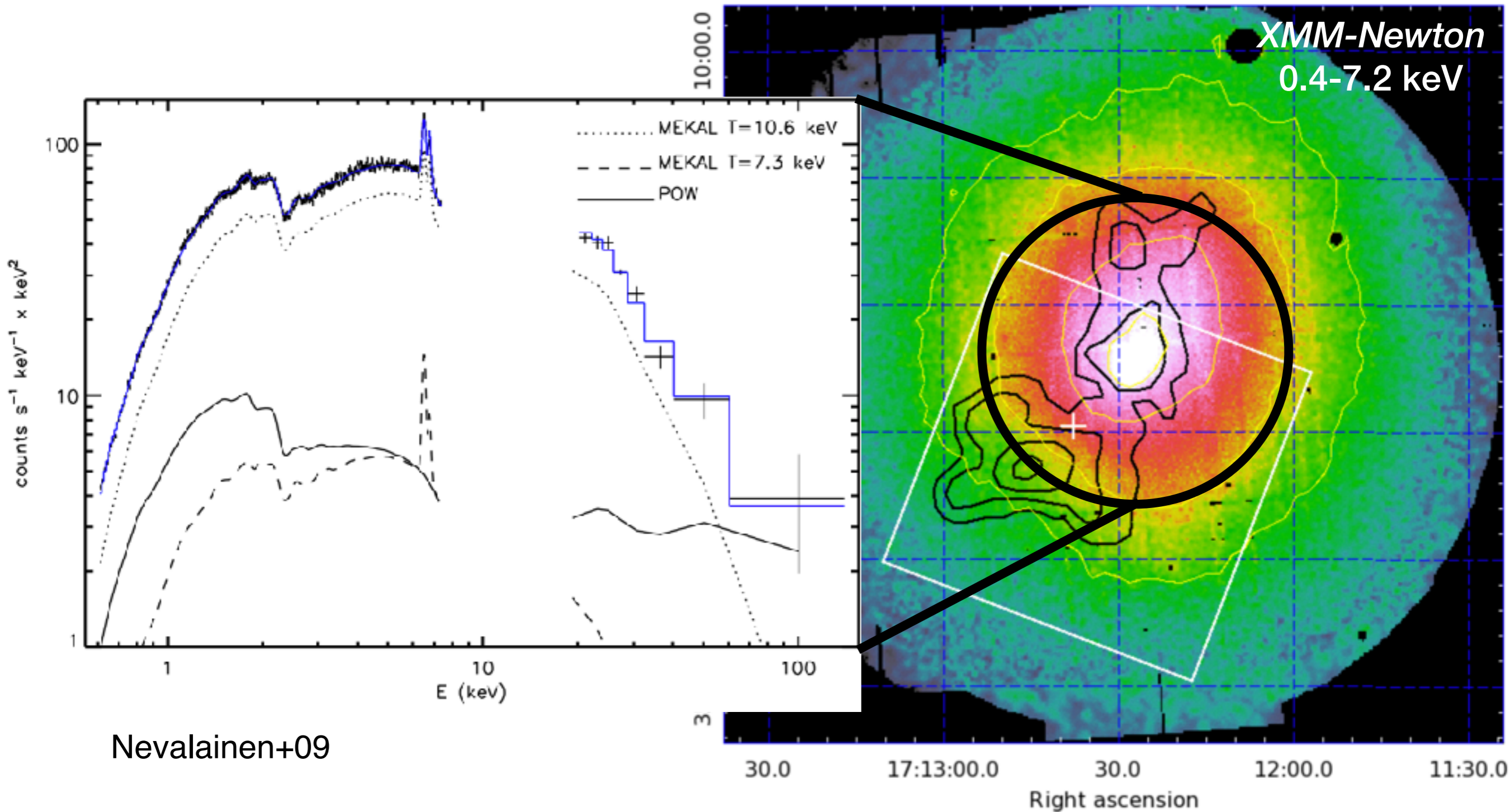
# Abell 2163 (the hottest Abell cluster)



Preliminary Analysis  
(passed to a gullible student)

# Ophiuchus Cluster

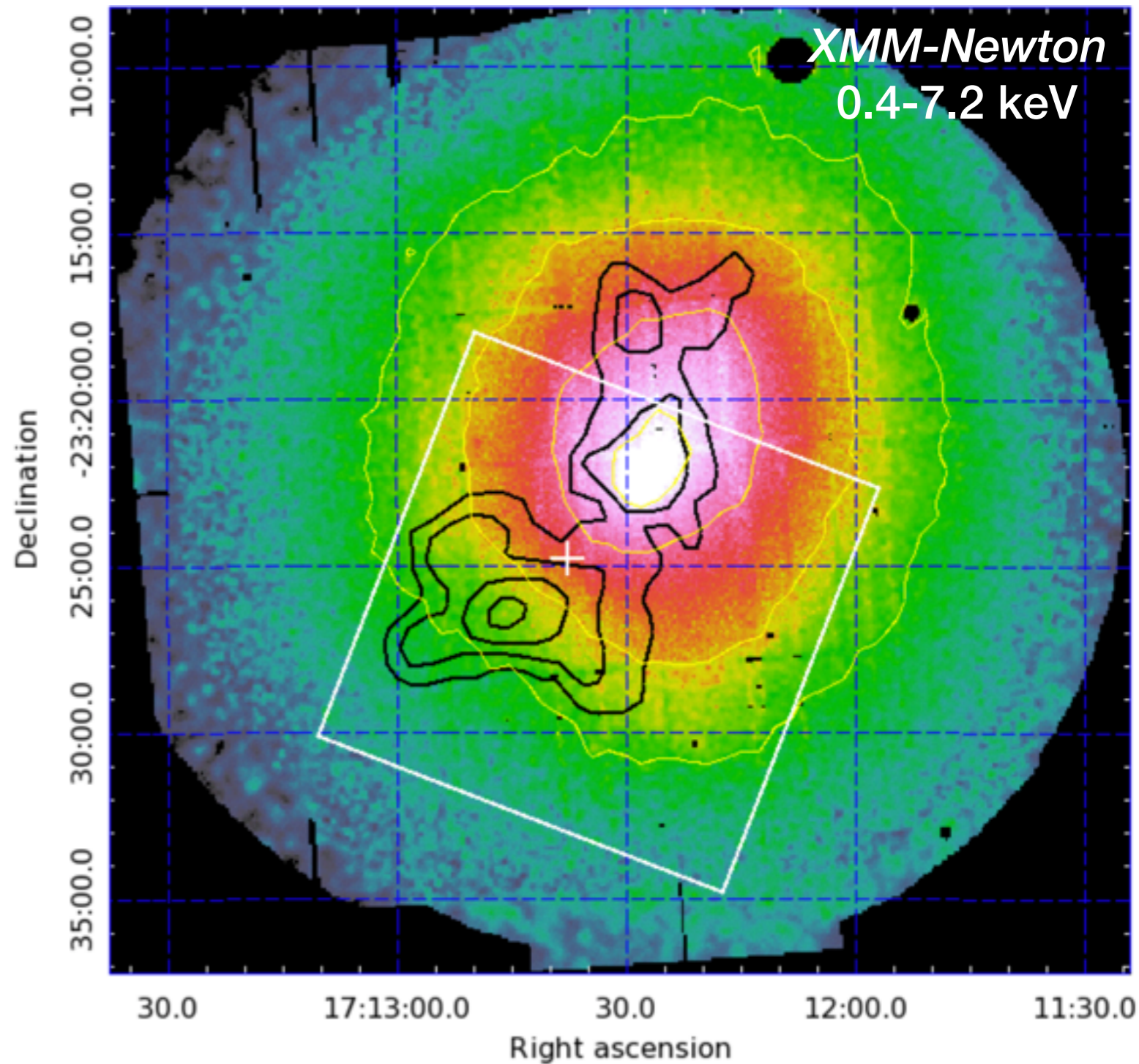
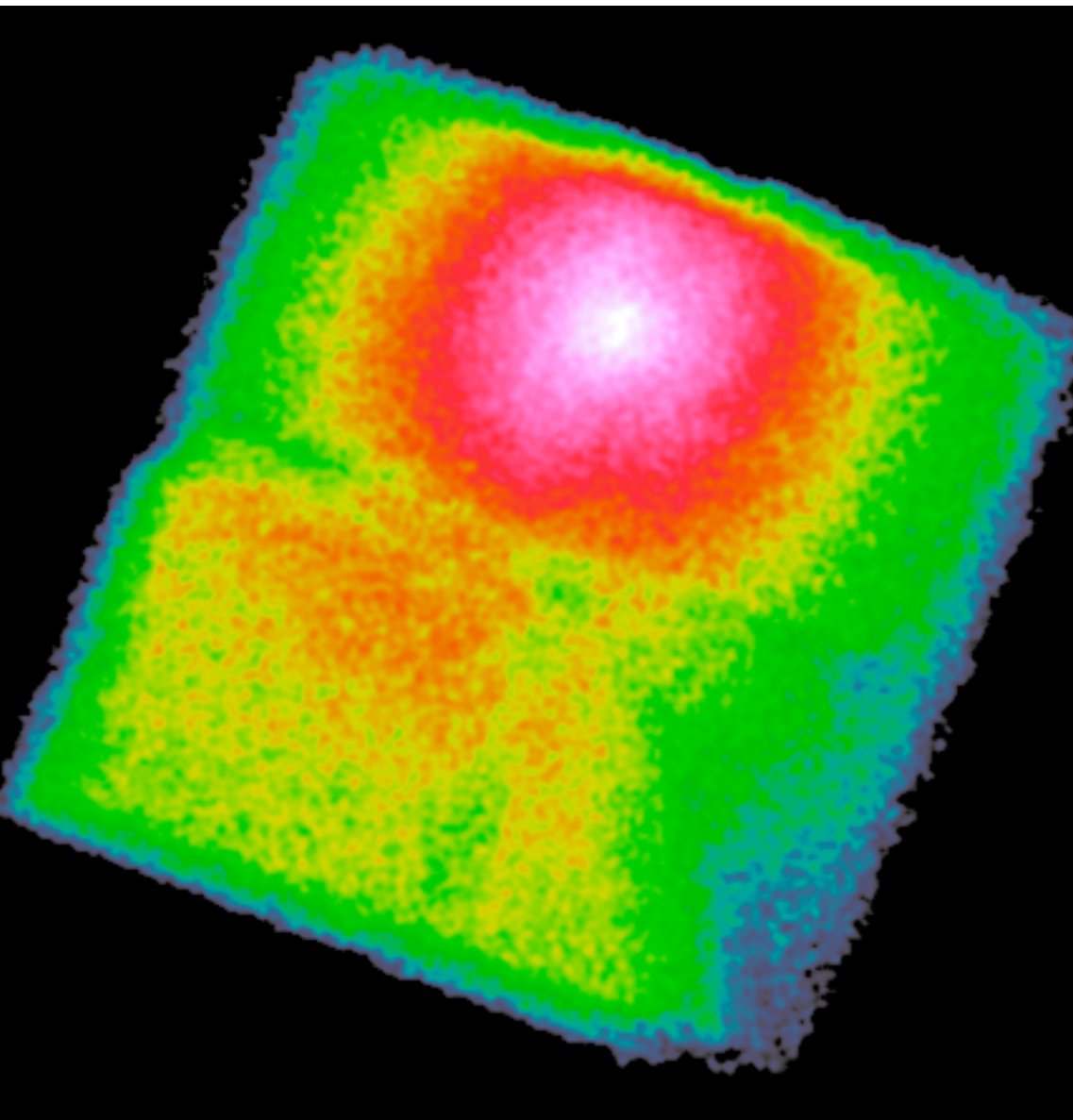
(most nearby cluster in the constellation of Ophiuchus)



Nevalainen+09

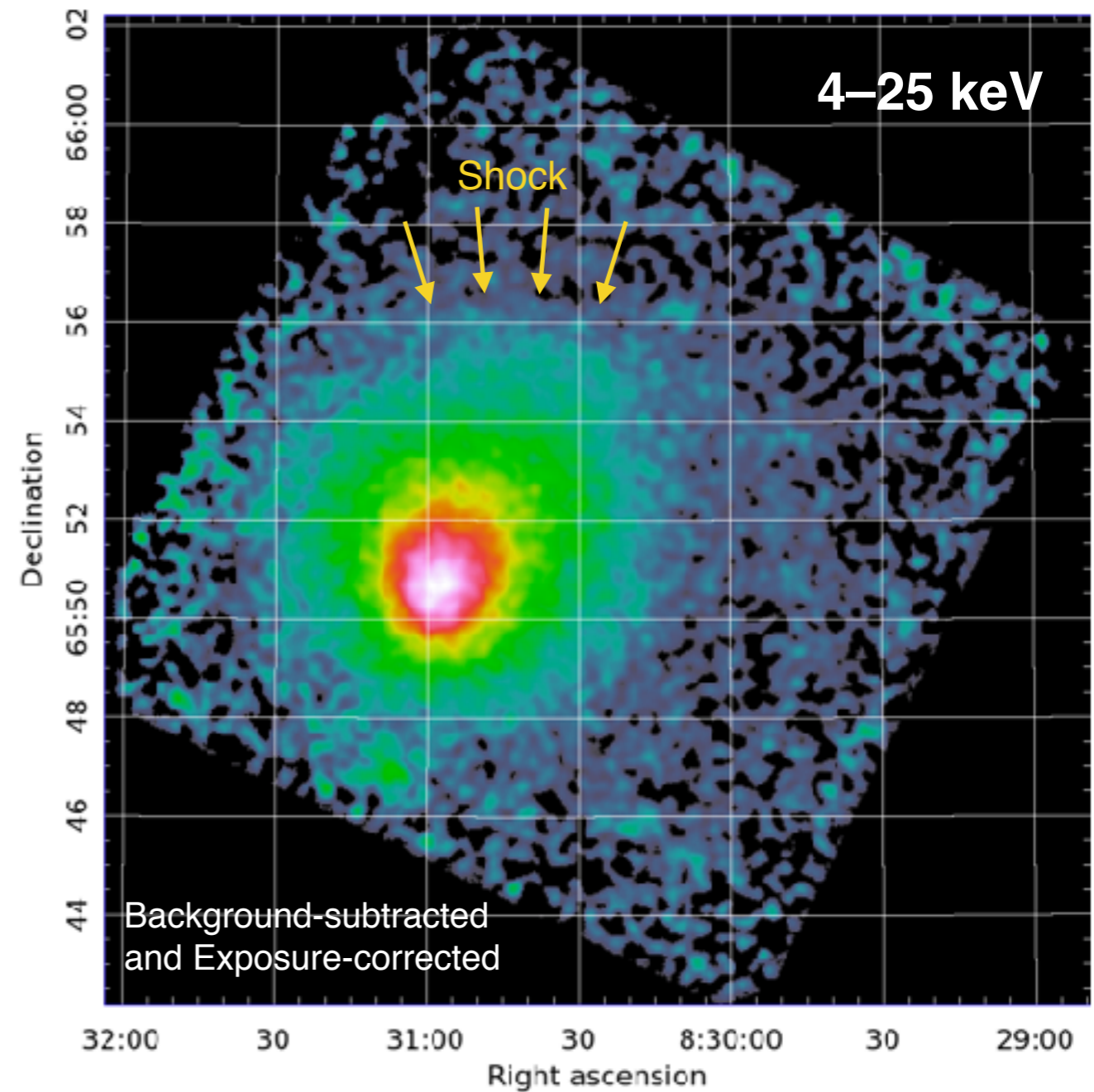
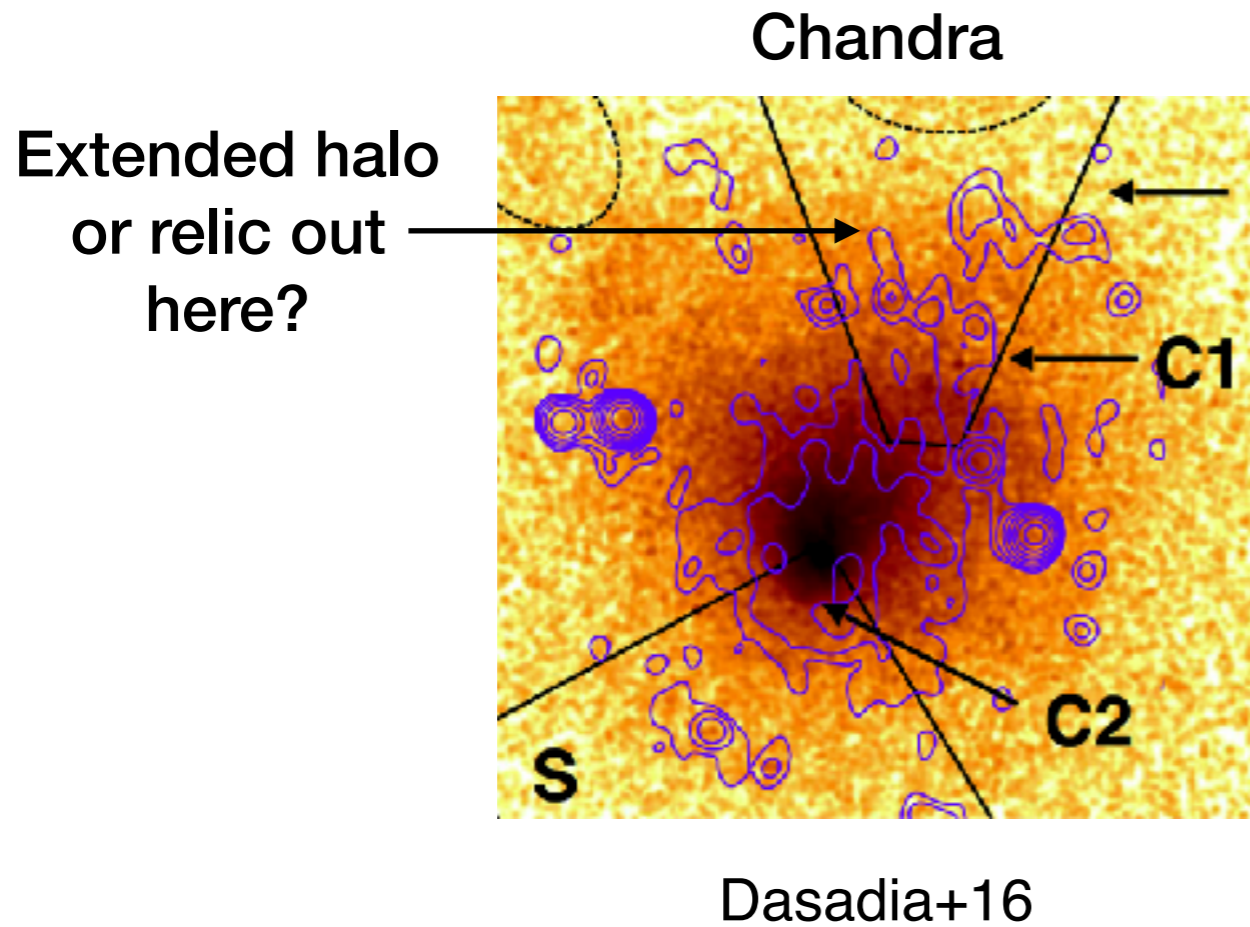
# Ophiuchus Cluster

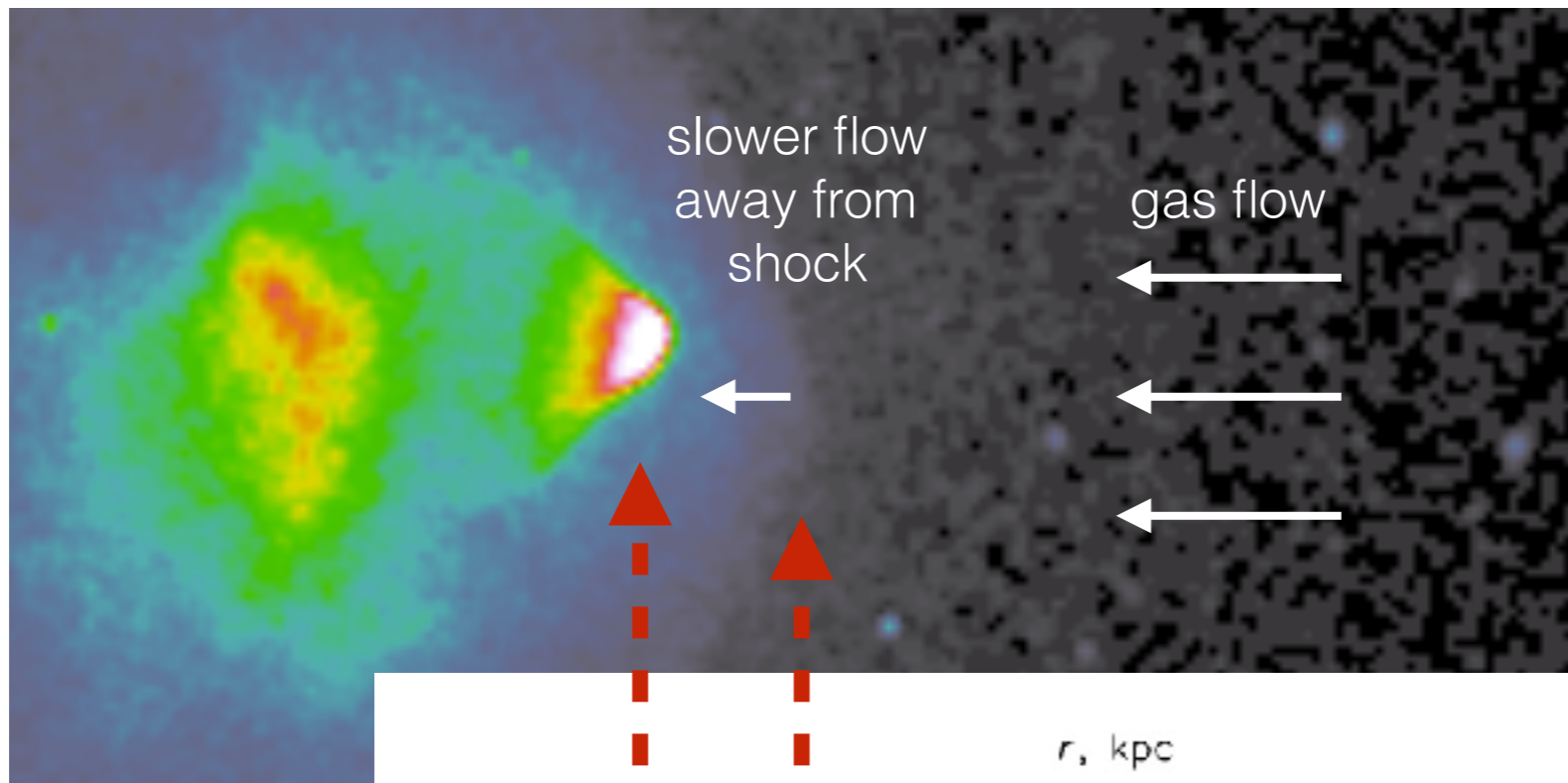
(most nearby cluster in the constellation of Ophiuchus)



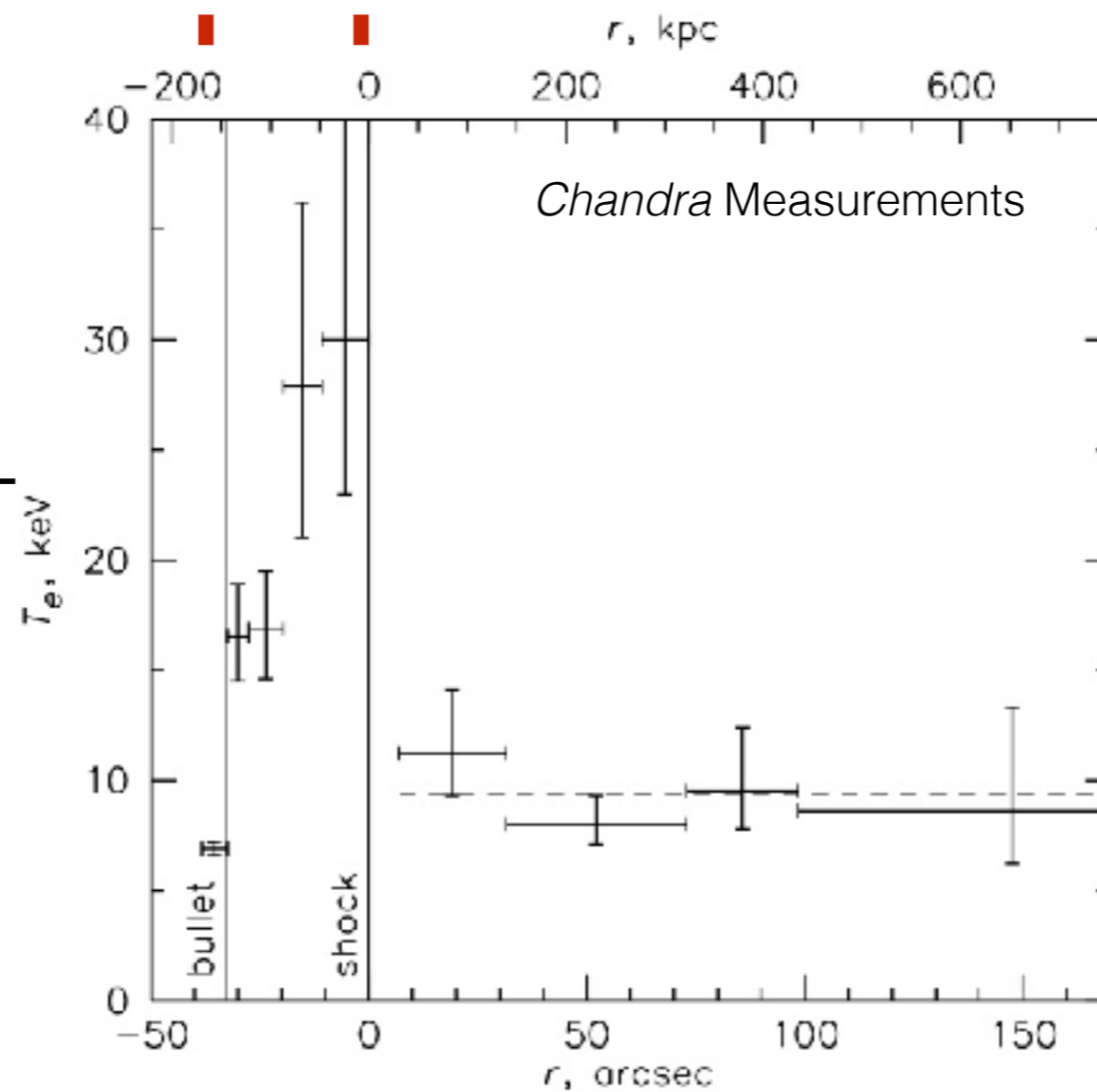
# Abell 665

(next strongest shock after that in the Bullet cluster <or>  
strongest shock in an Abell cluster)



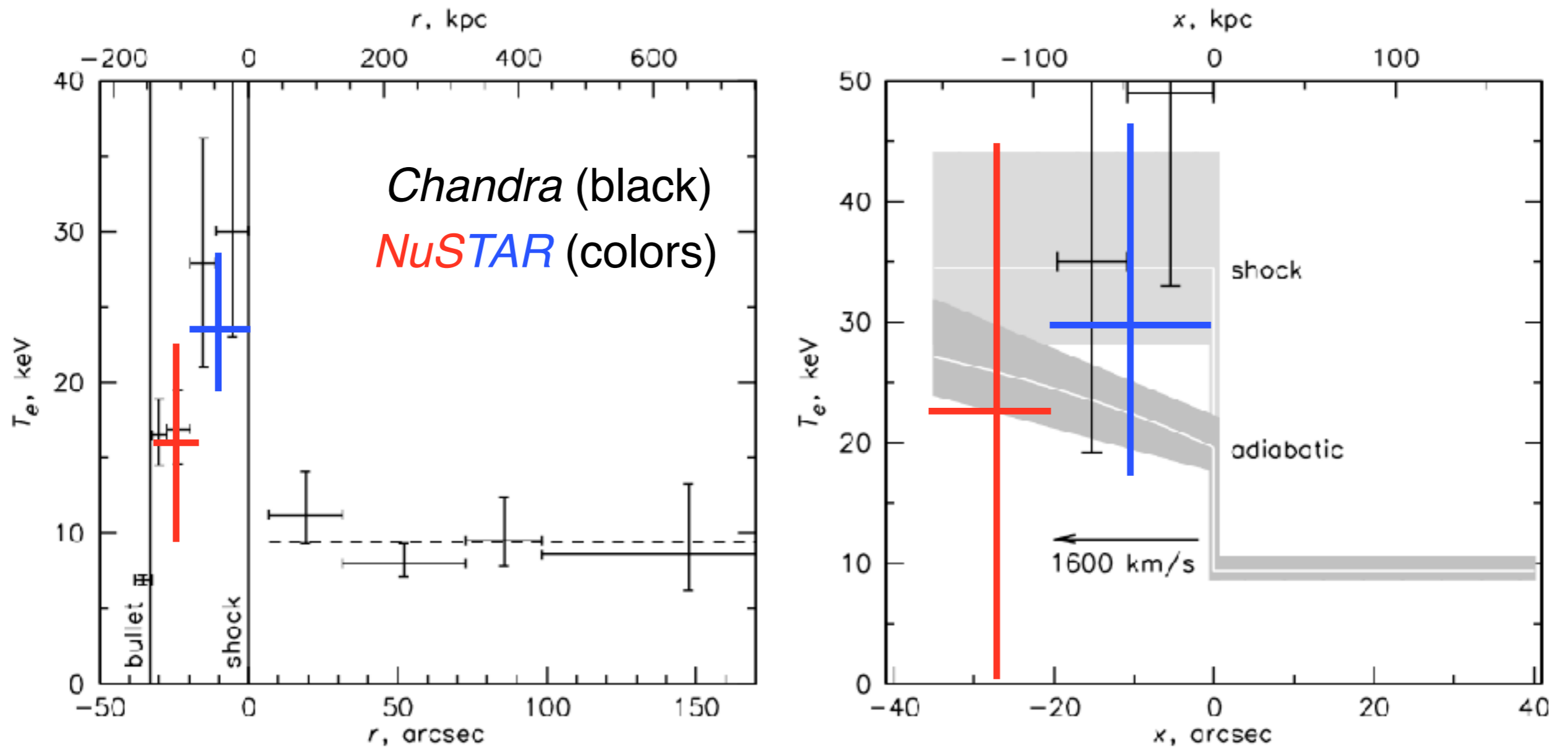


Electron Temperature



Markevitch 06

# *NuSTAR* temperatures could tell a different story.

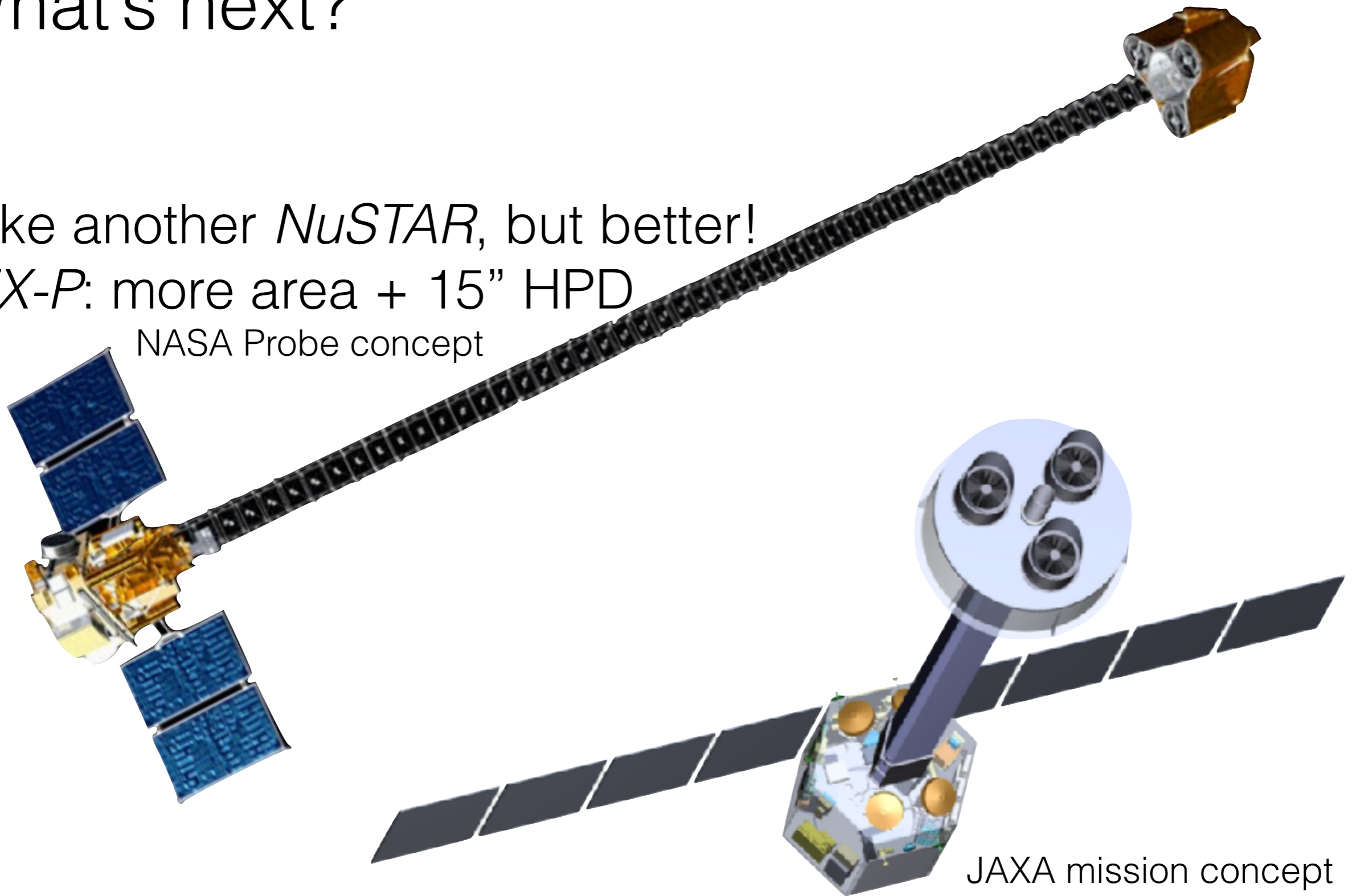


Wik+ in prep.

Analysis of Abell 665 shock will be comparatively trivial, but care must still be taken

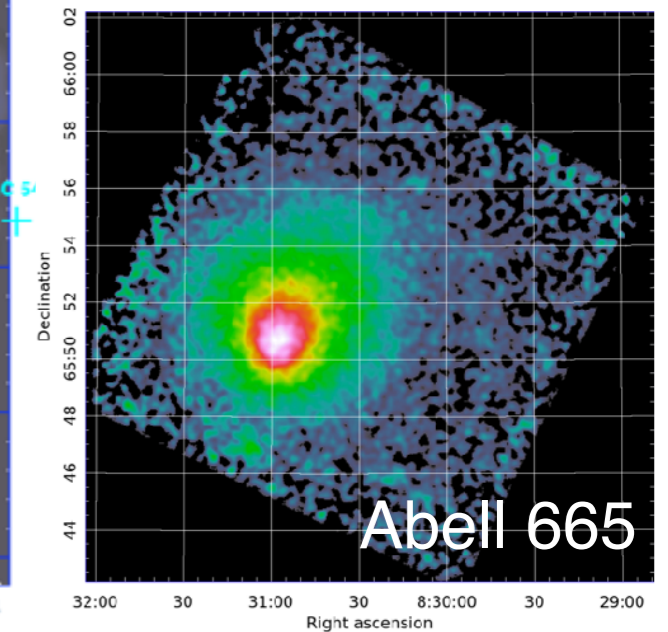
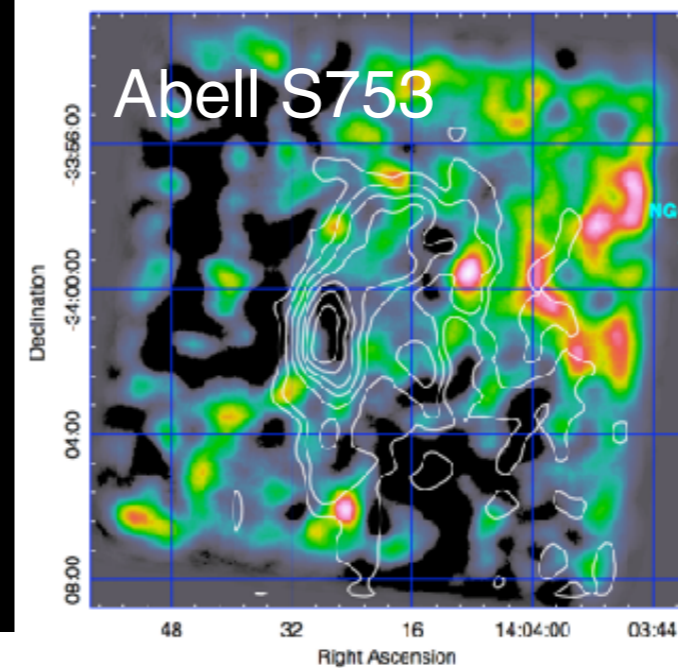
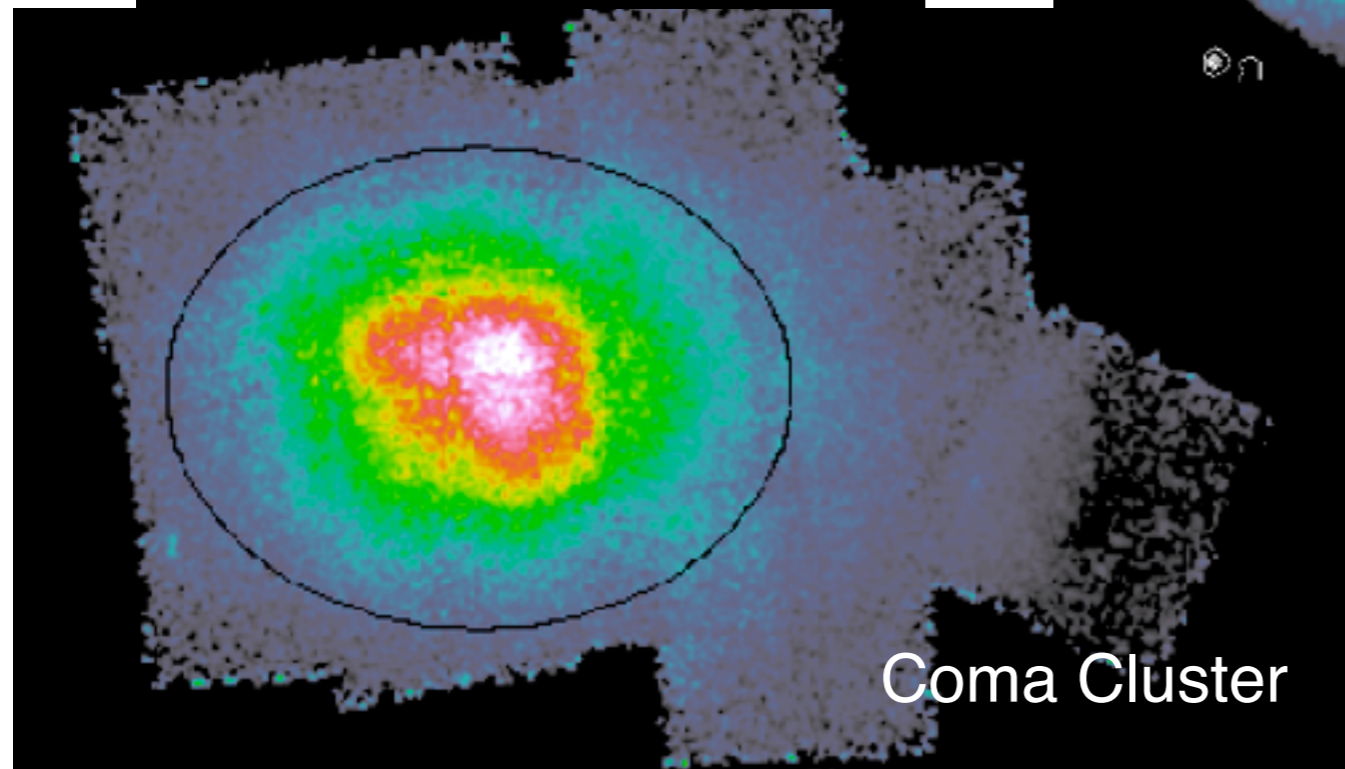
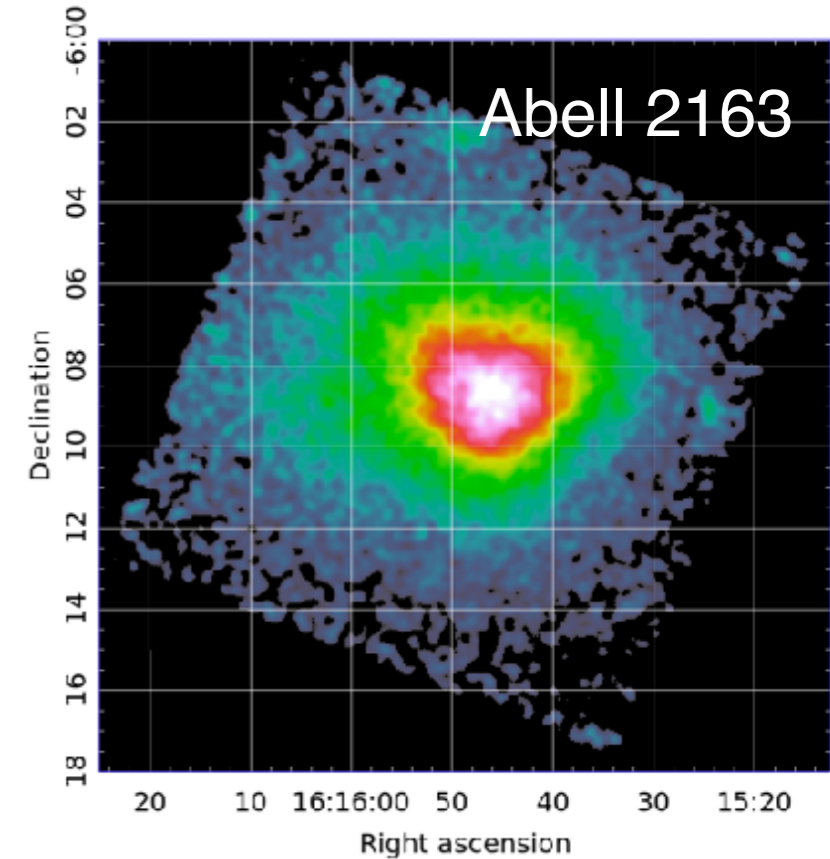
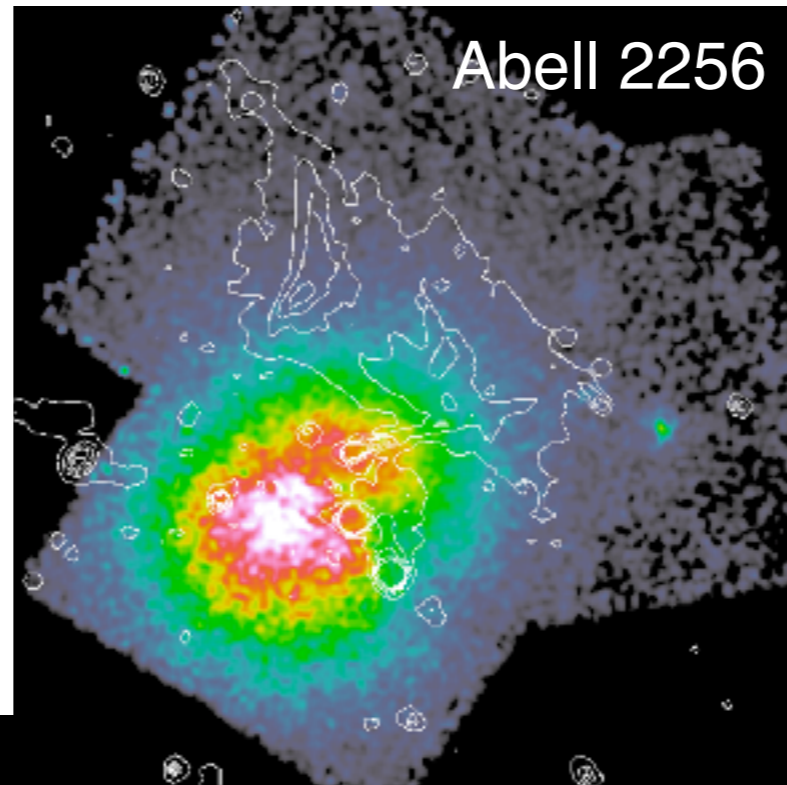
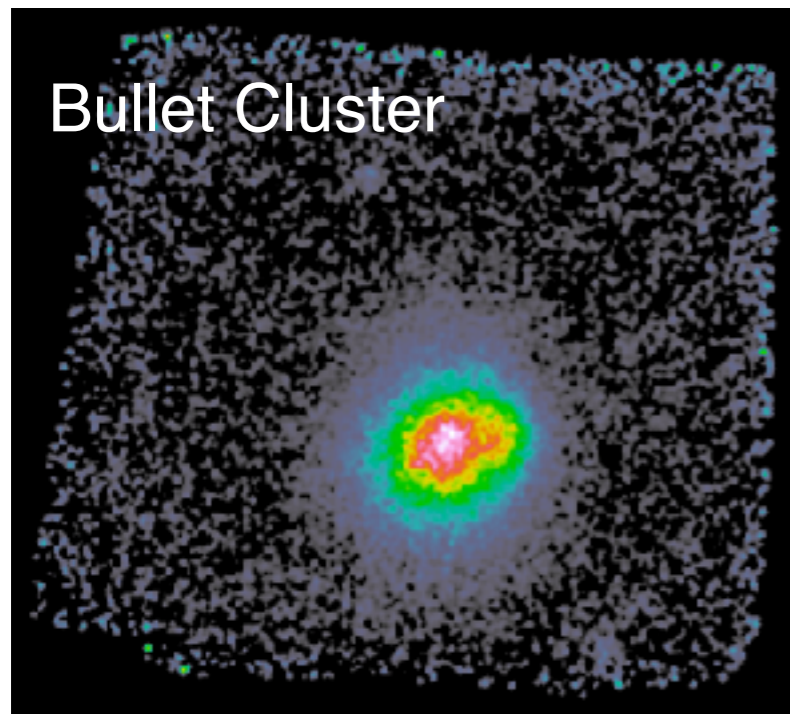
# What's next?

Make another *NuSTAR*, but better!  
*HEX-P*: more area + 15" HPD  
NASA Probe concept



JAXA mission concept  
Or use the *FORCE* Luke!  
*NuSTAR* area with 15" HPD. Or Both.

# Story not over, but has a Game of Thrones-esque feel...



Also the Cygnus A cluster, the Abell 754 shock, Abell 523, RX J1437, and Ophiuchus



# Spatial Modeling

