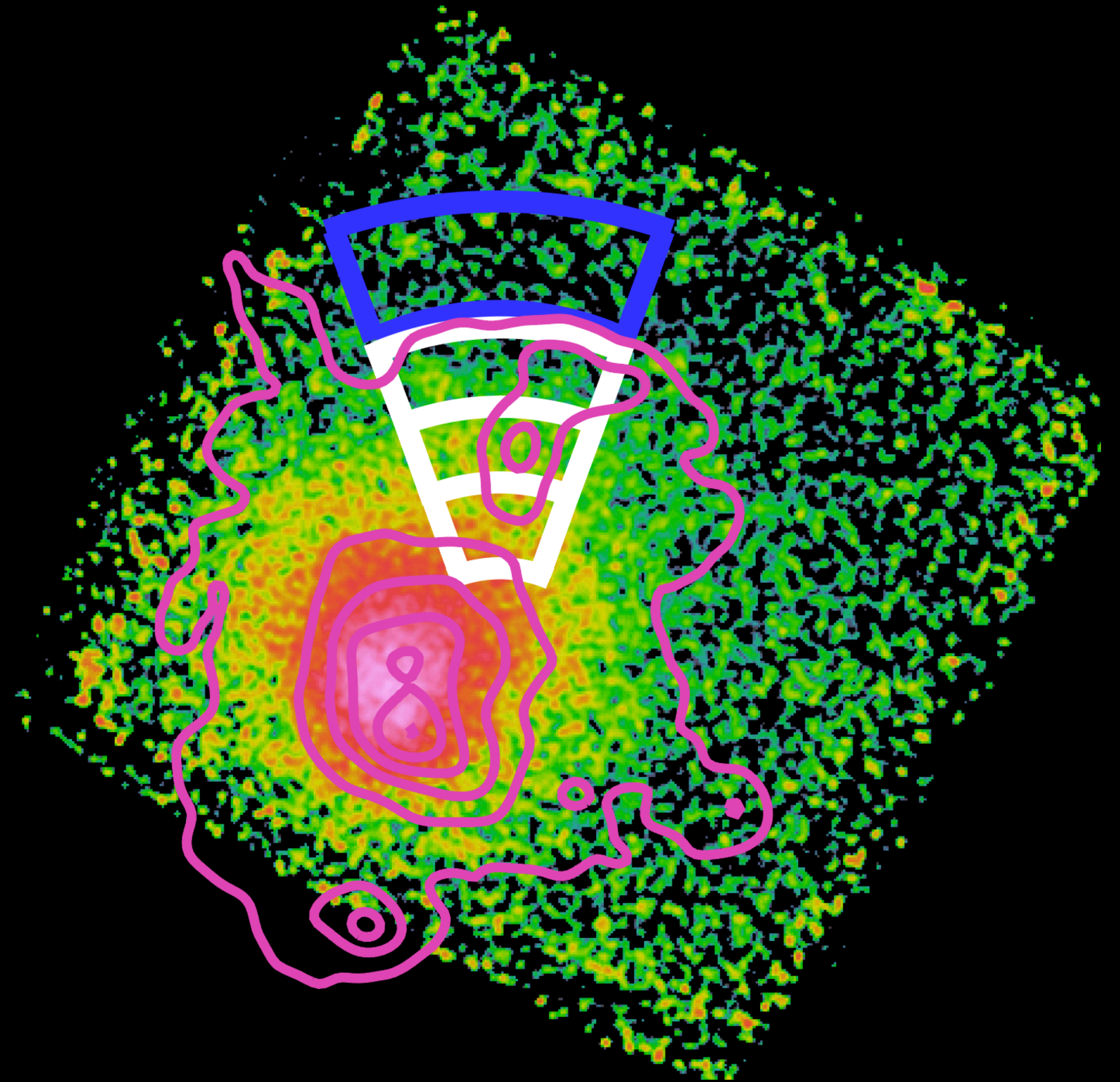


Galaxy Cluster Thermalization

Electron-Ion Equilibration in the
Merging Galaxy Cluster A665

Christian Norseth
University of Utah, UT, USA
AAS 248, 2026



Electron-Ion Equilibration in the Merging Galaxy Cluster A665

Christian T. Norseth¹, Daniel R. Wik¹, Craig L. Sarazin², Ming Sun³, and Fabio Gastaldello⁴

¹Department of Physics & Astronomy, The University of Utah, 115 South 1400 East, Salt Lake City, UT 84112, USA

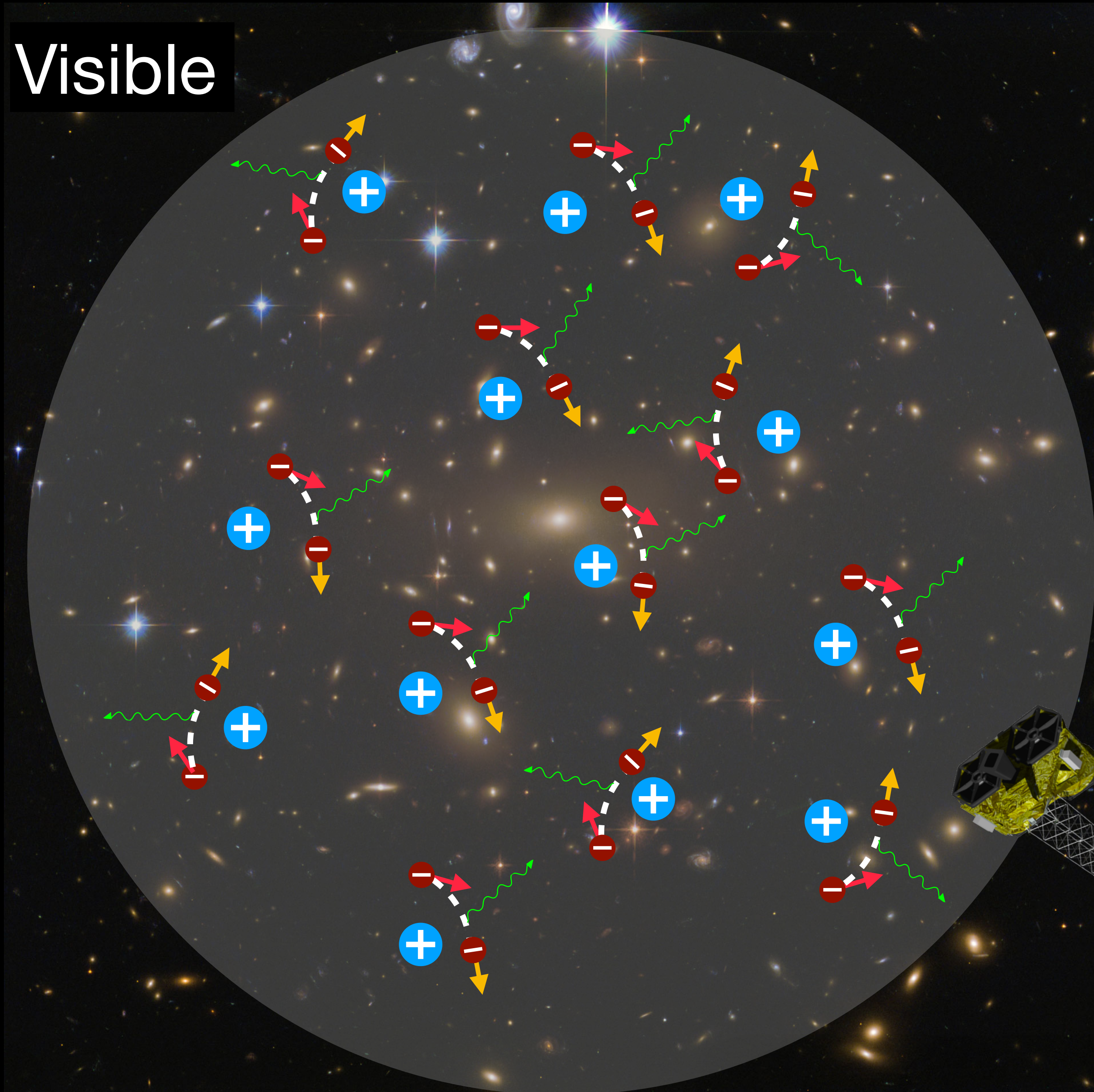
²Department of Astronomy and Virginia Institute for Theoretical Astronomy, University of Virginia, P.O. Box 400325, Charlottesville, VA 22904, USA

³Department of Physics & Astronomy, University of Alabama in Huntsville, 301 Sparkman Drive, Huntsville, AL 35899, USA

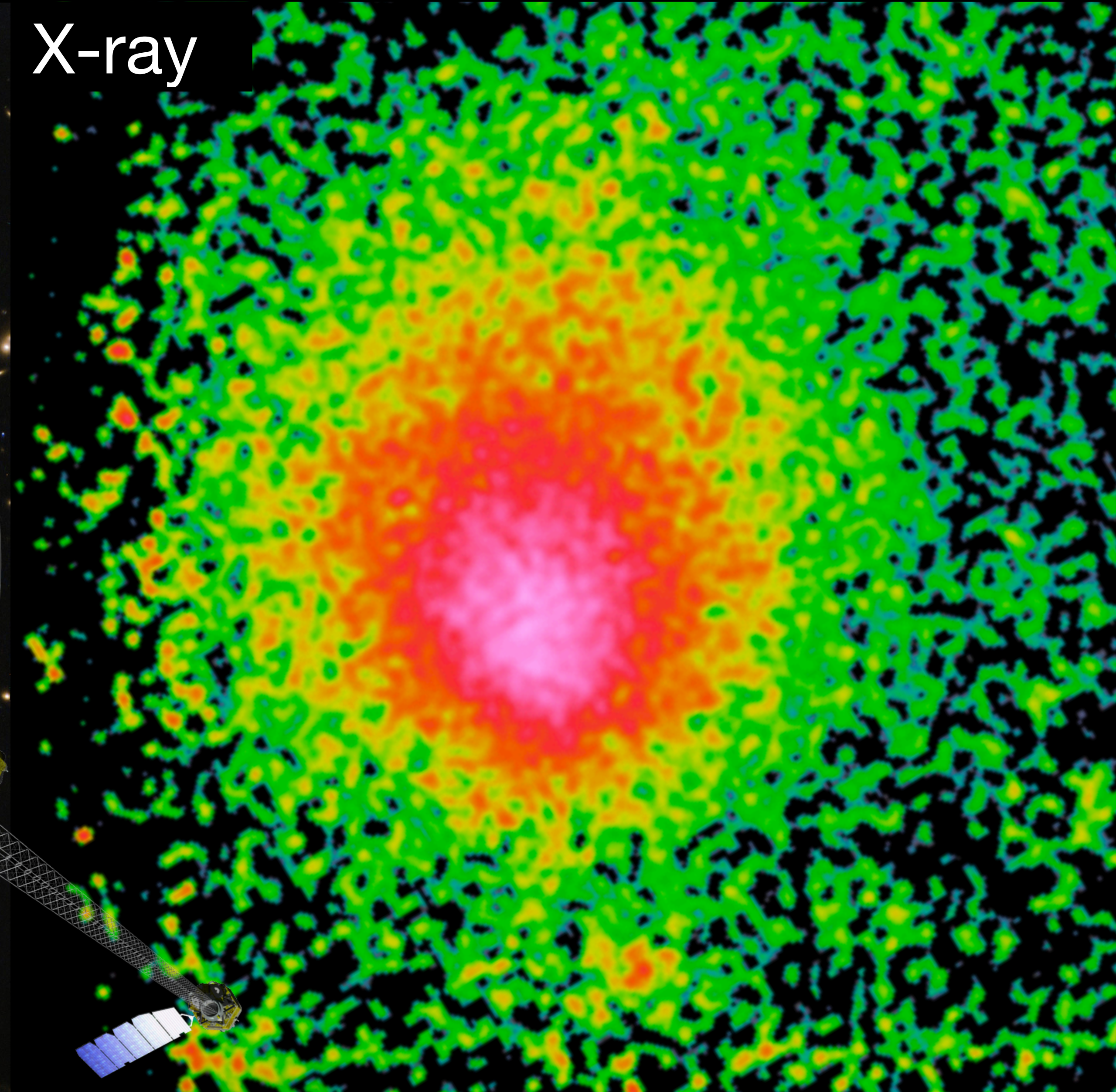
⁴INAF—IASF Milano, via A. Corti 12, I-20133 Milano, Italy

Galaxy Clusters

Visible

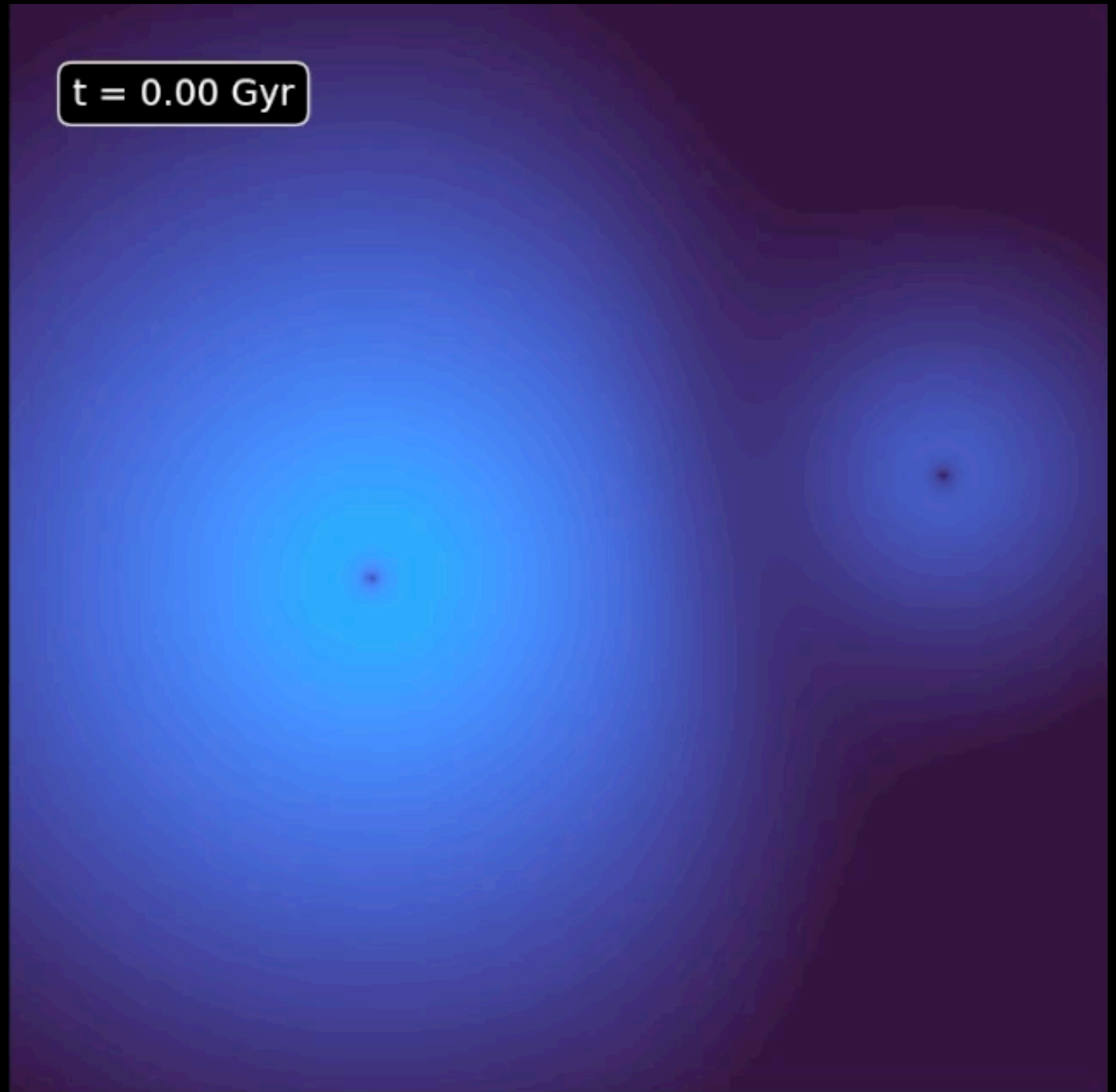


X-ray



Clusters Grow Through Mergers

- Shocks form
- Redistributes $\sim 10^{64}$ erg of energy
- Heats and thermalizes ICM

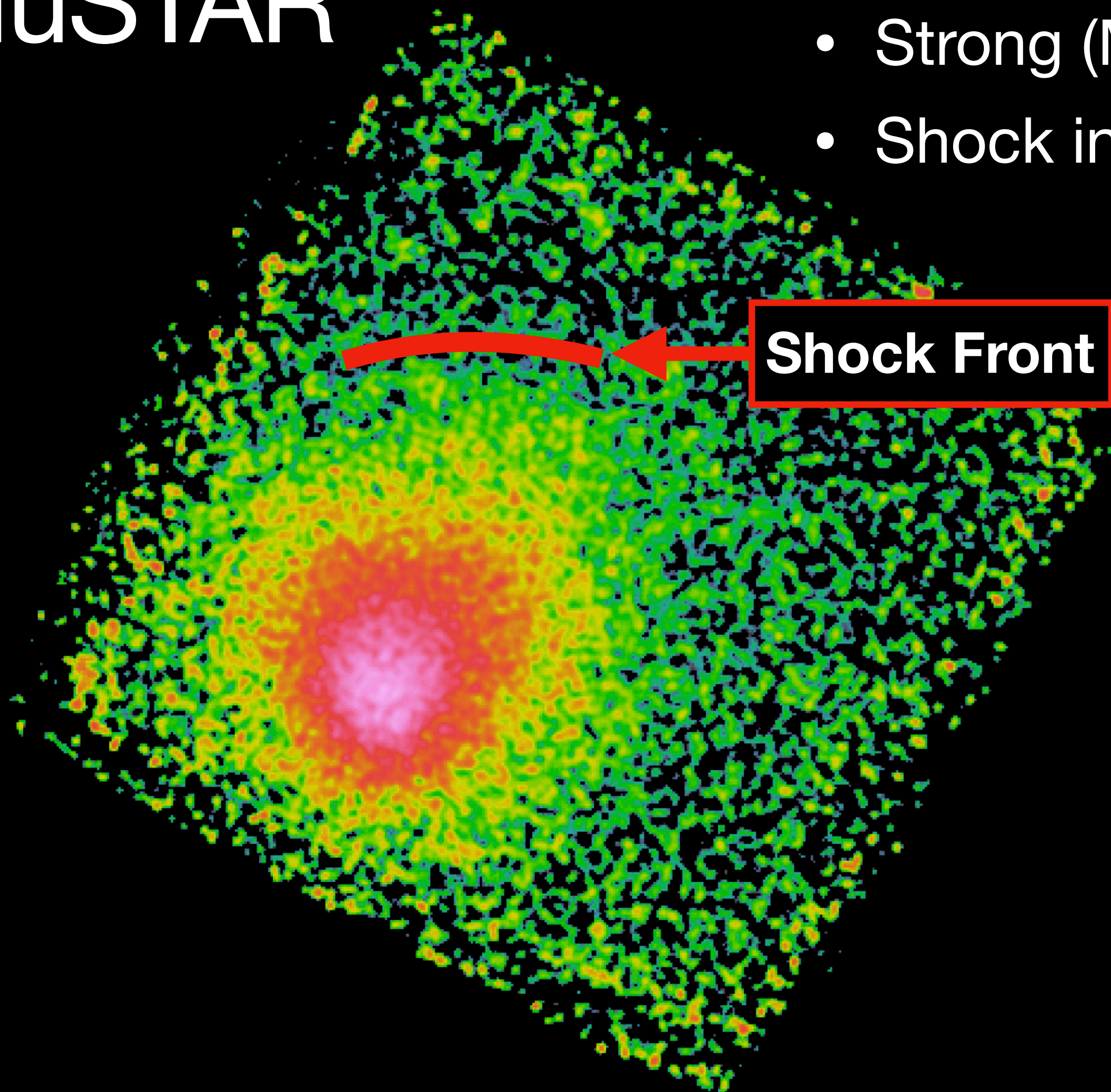


Credit: John ZuHone

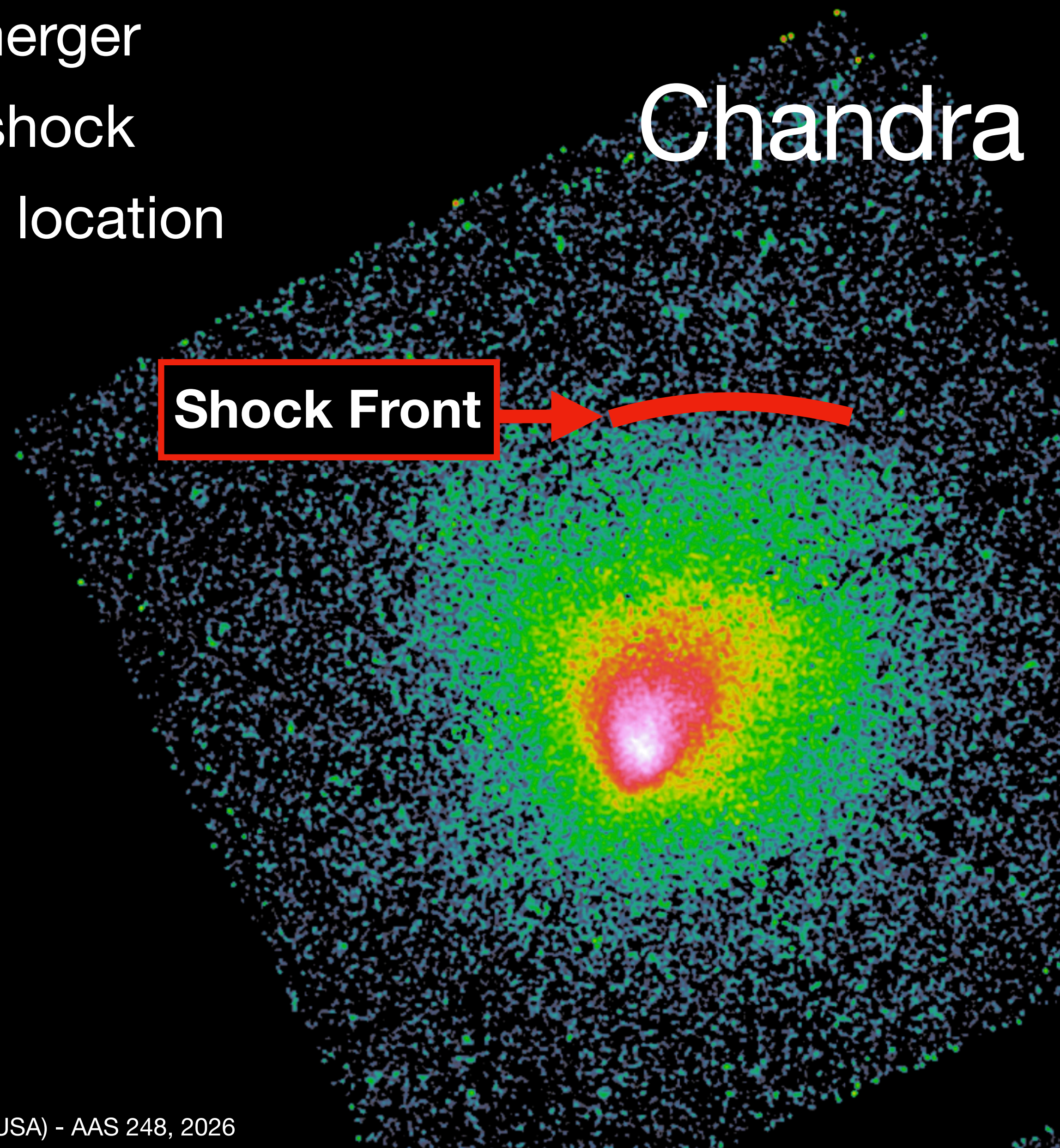
Abell 665

NuSTAR

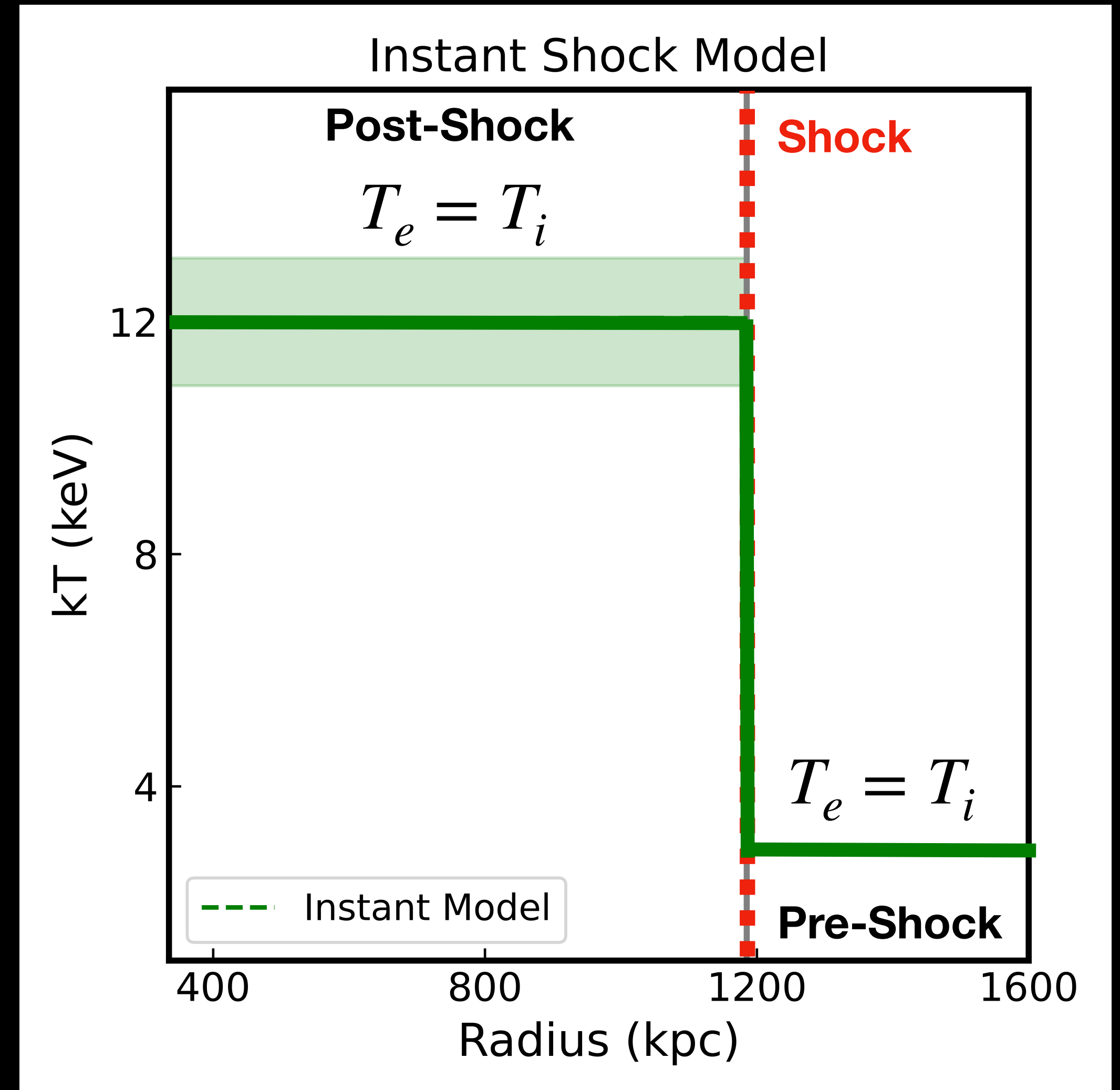
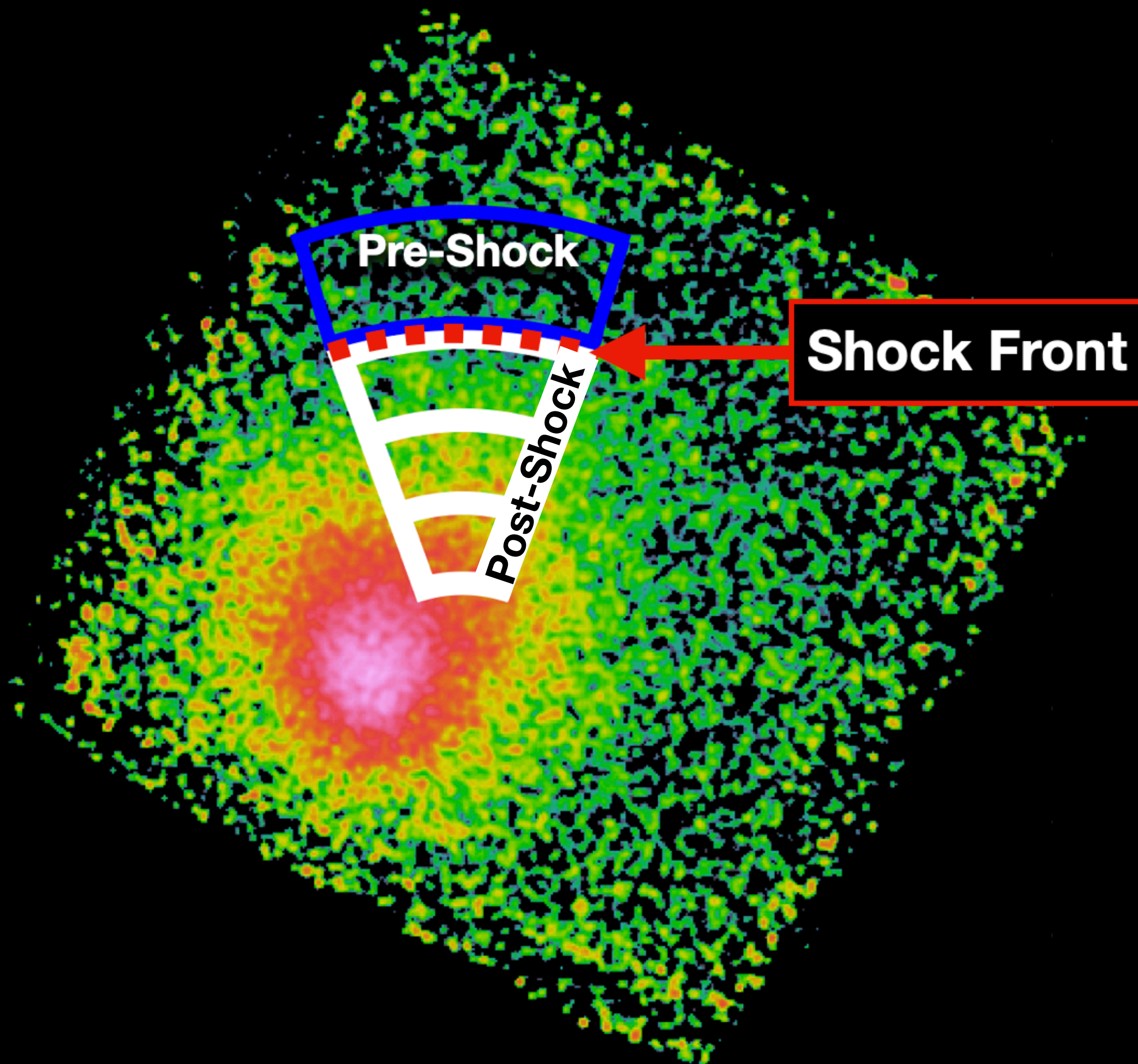
- Plane of sky merger
- Strong ($M \sim 3$) shock
- Shock in good location



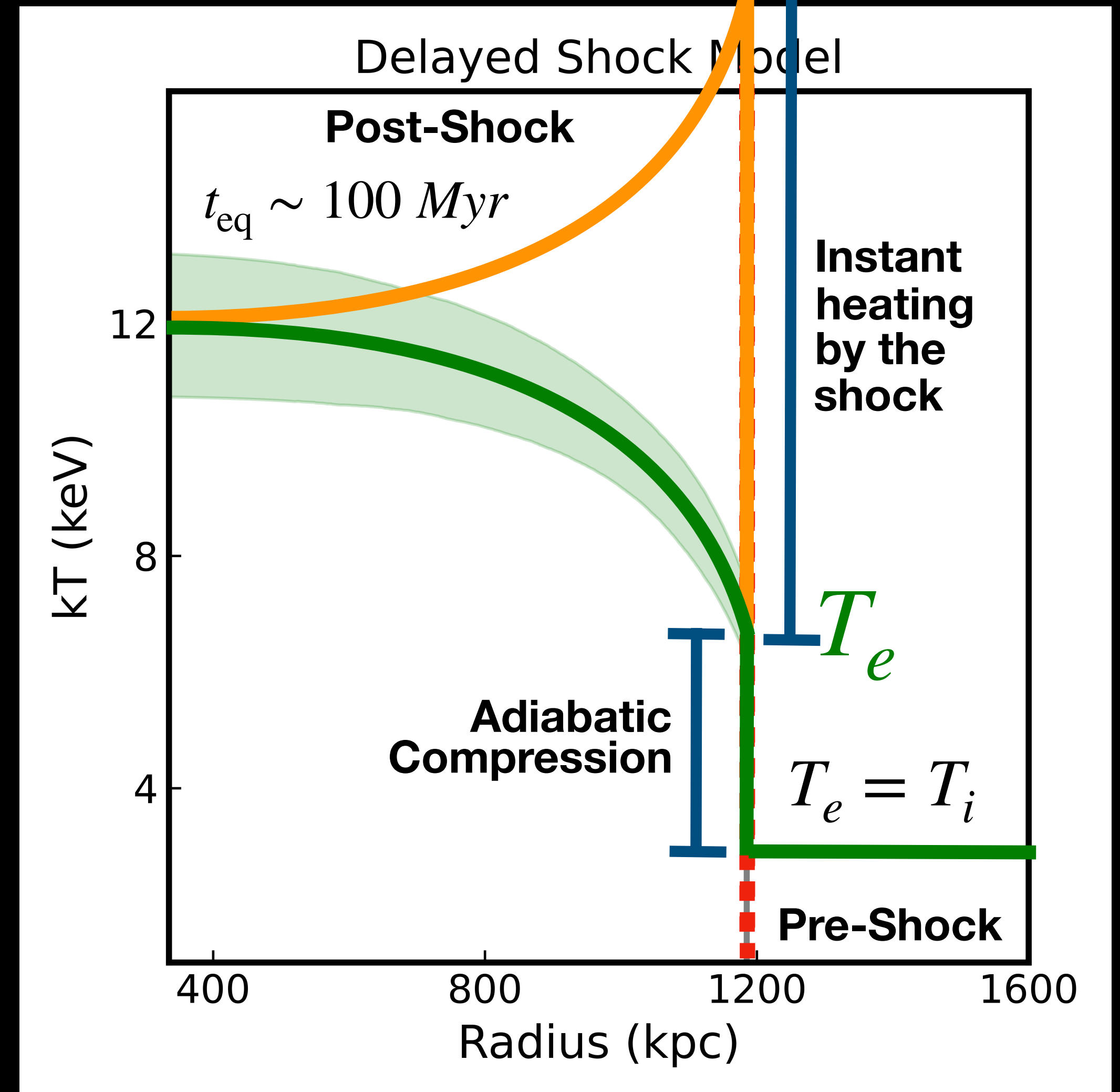
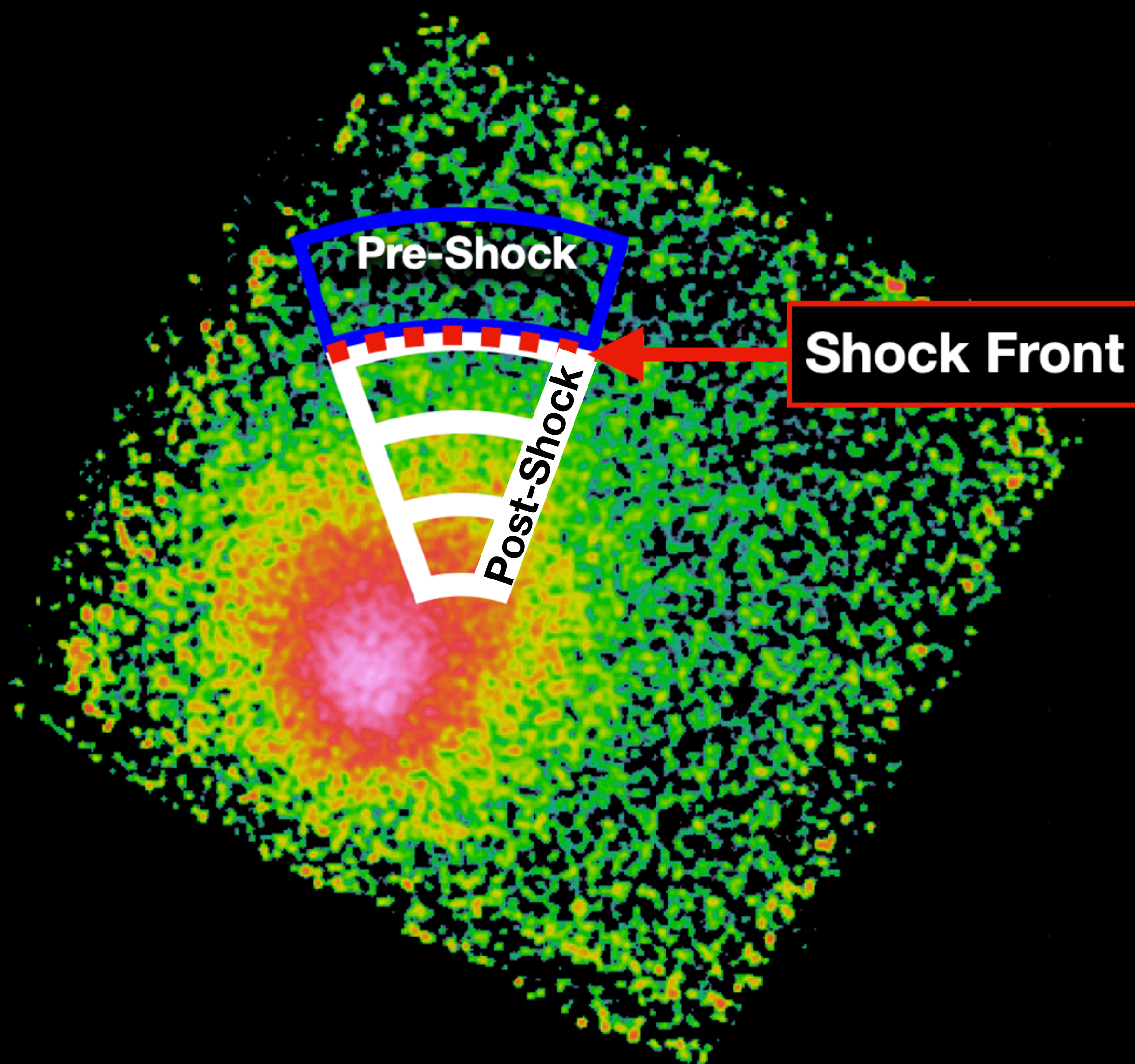
Chandra



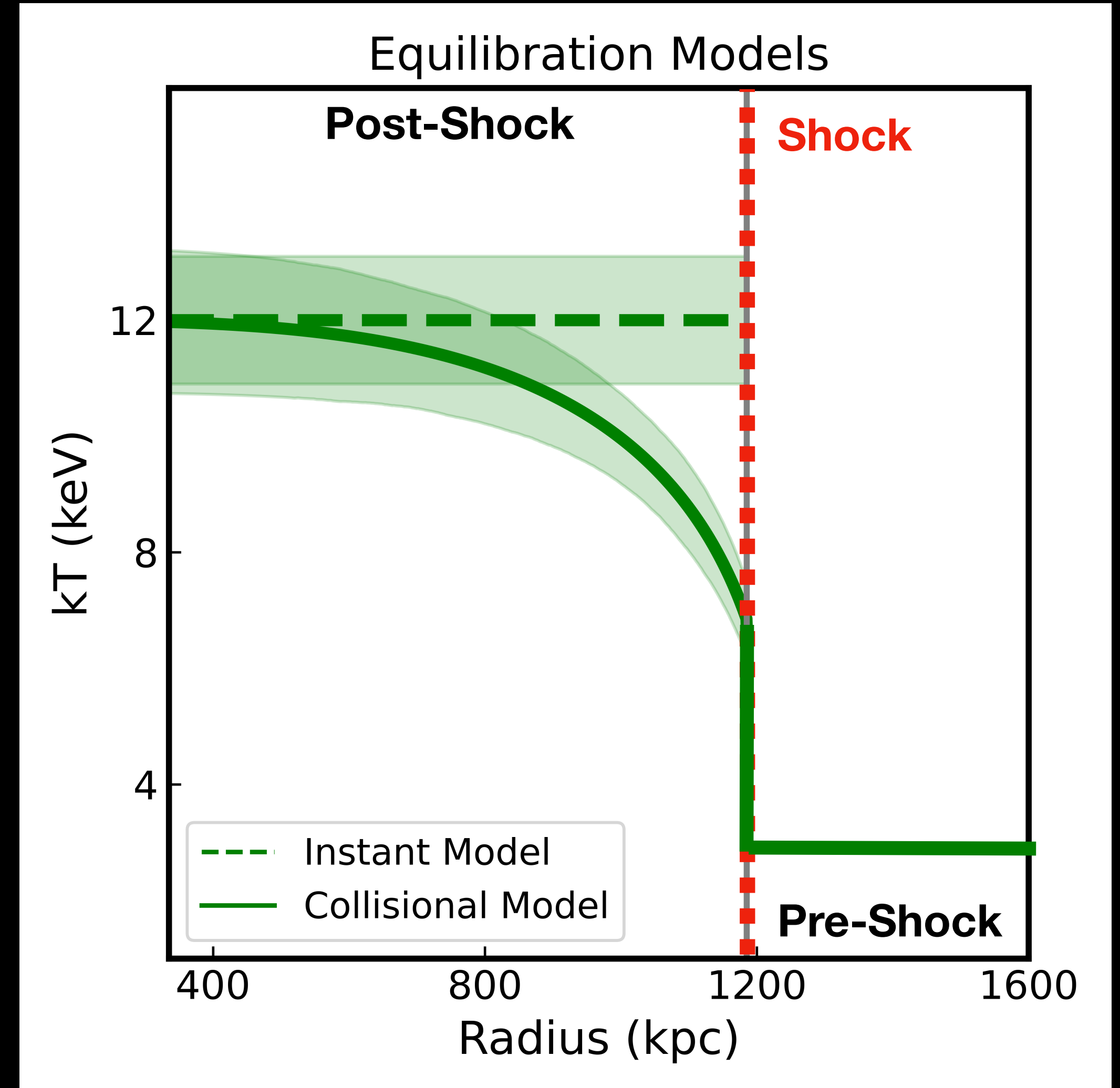
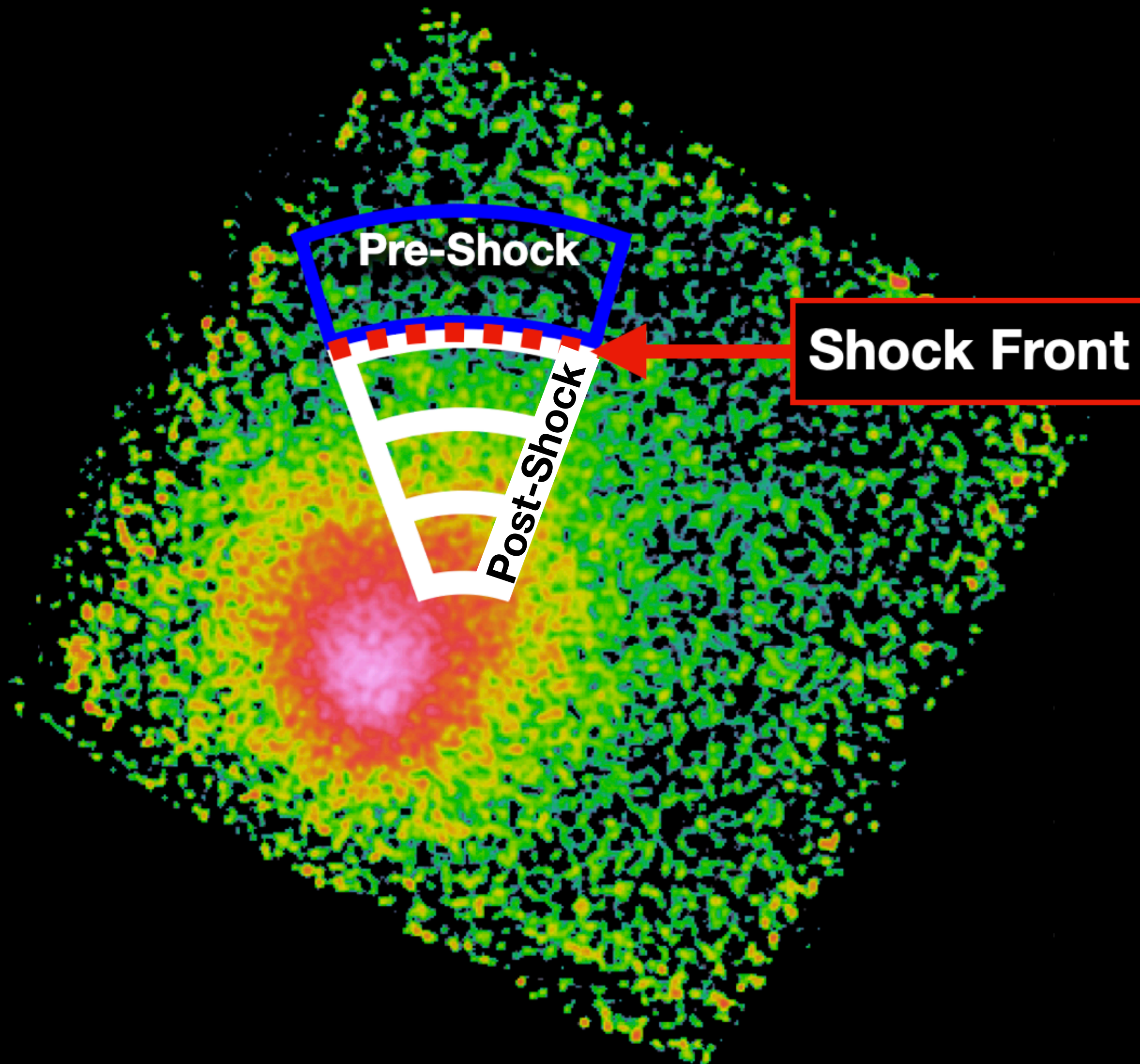
Electron-Ion Equilibration



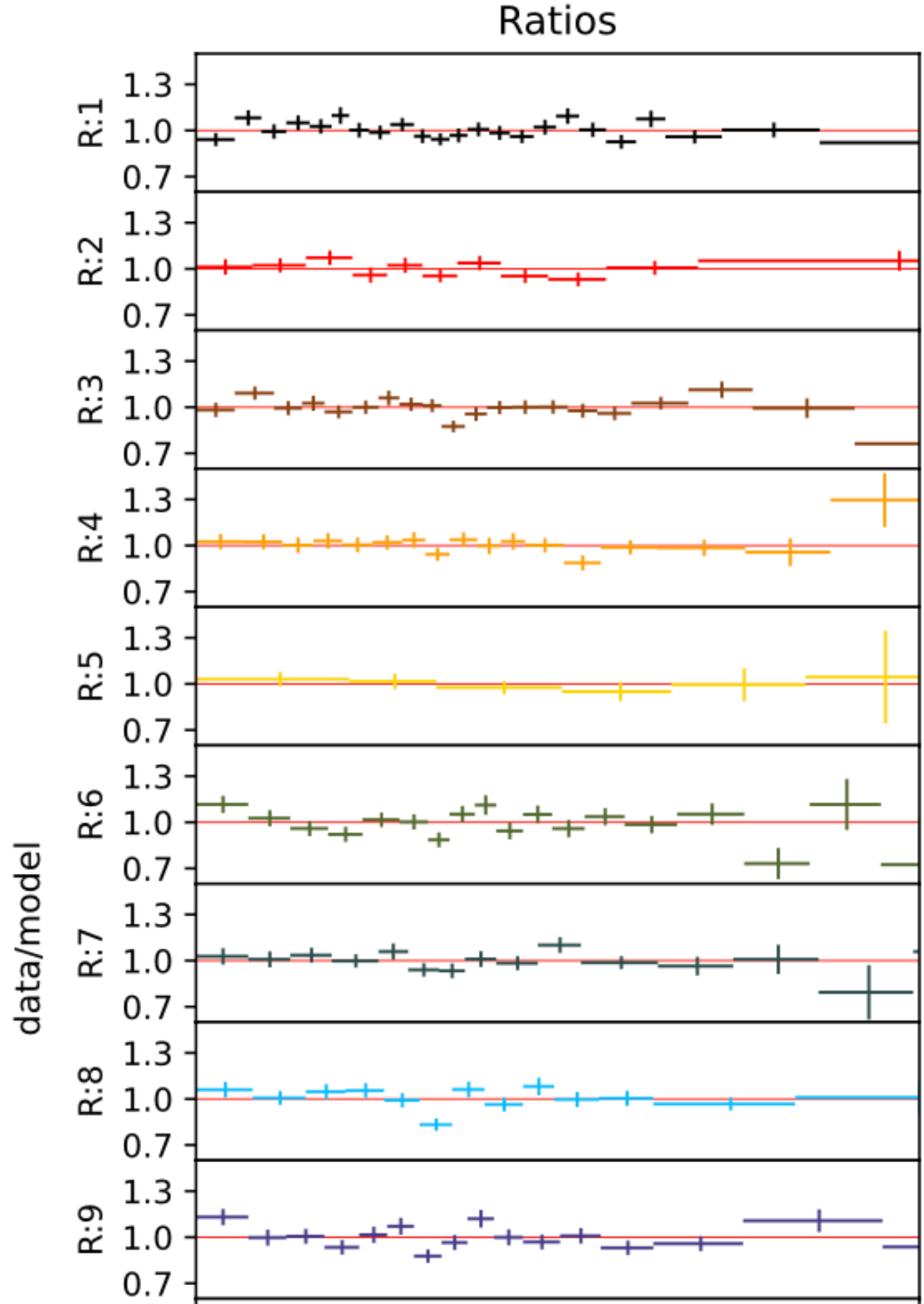
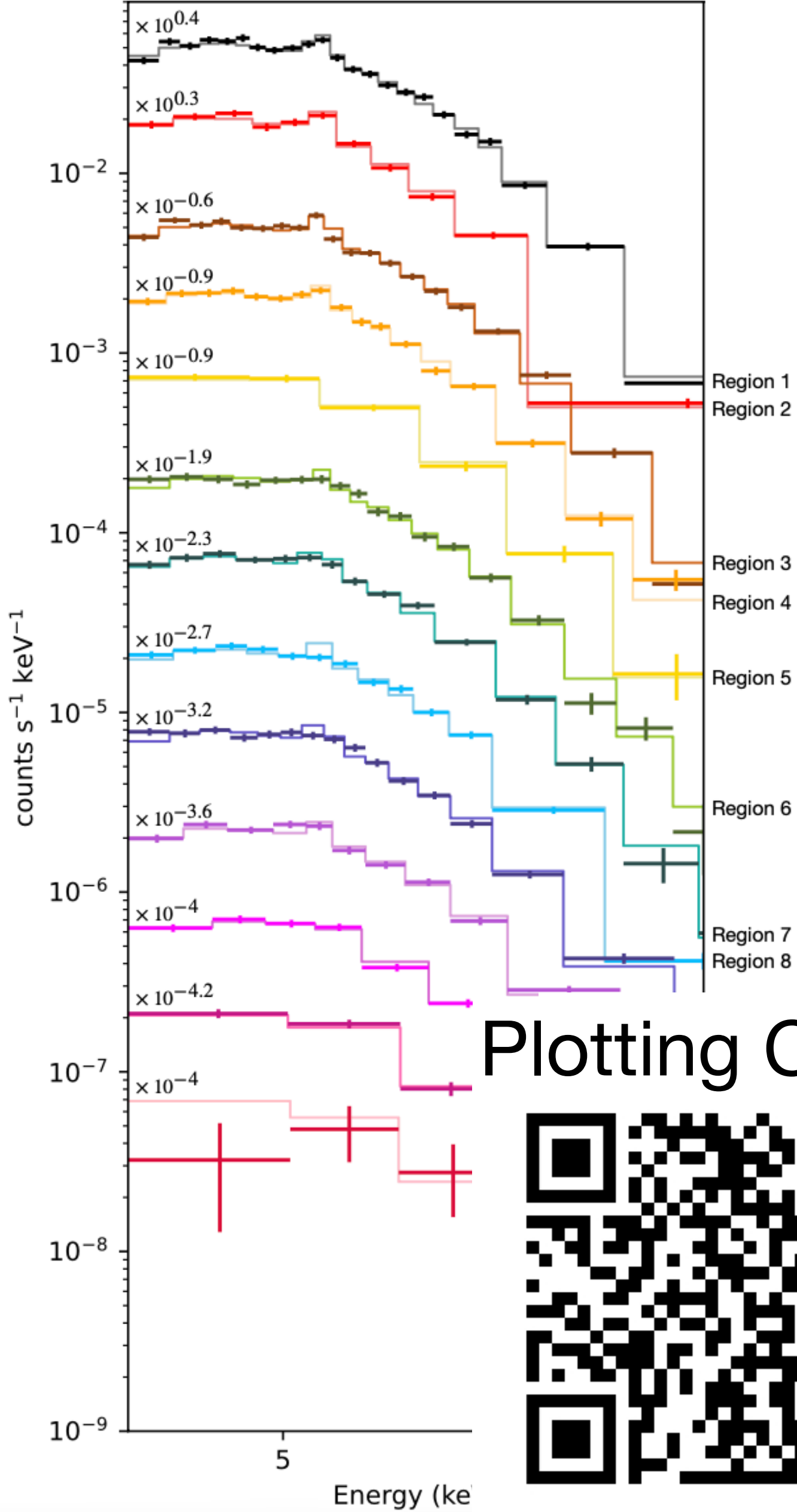
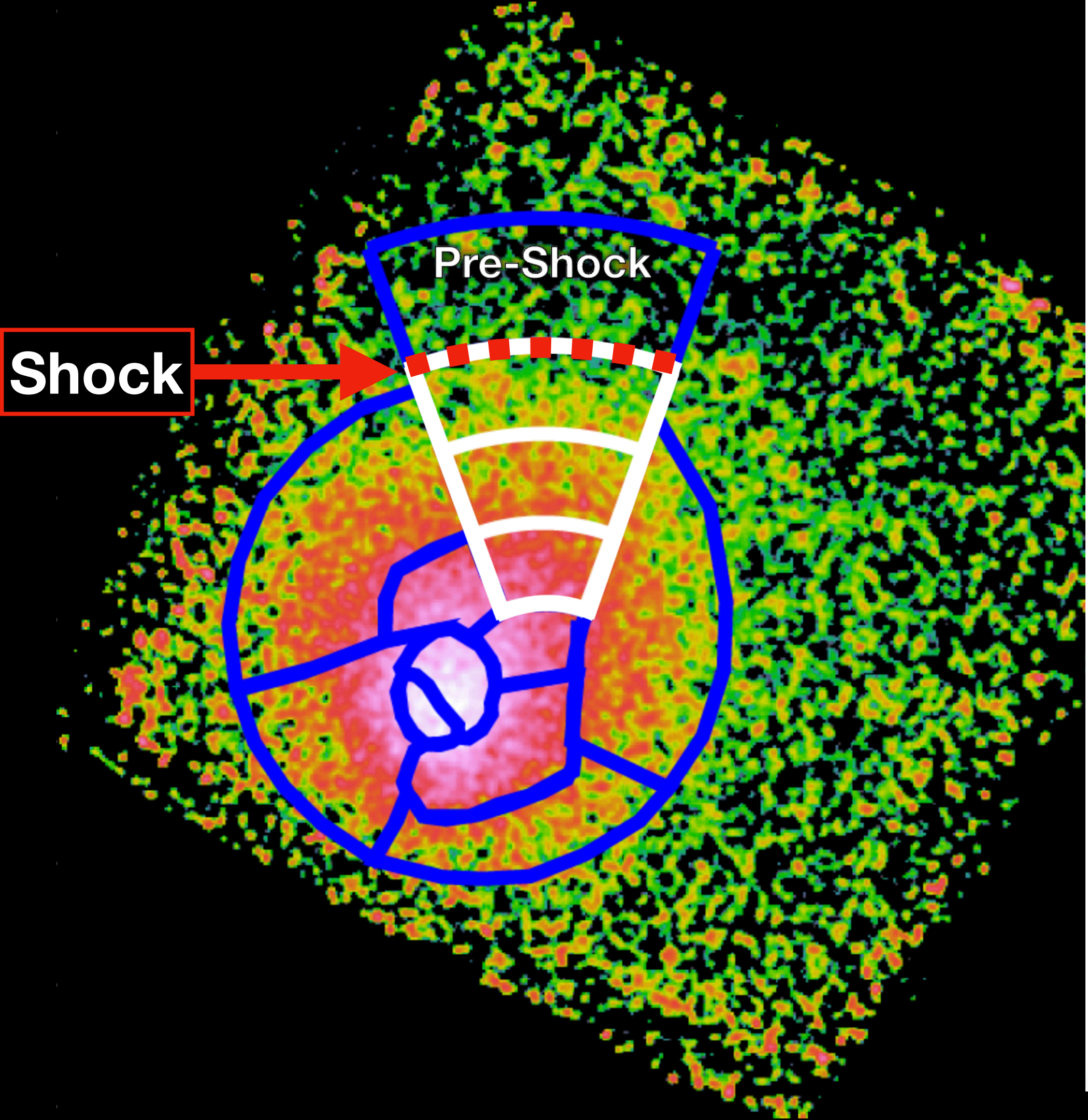
Electron-Ion Equilibration



Electron-Ion Equilibration



Cross-Talk (SSM)



Plotting Code



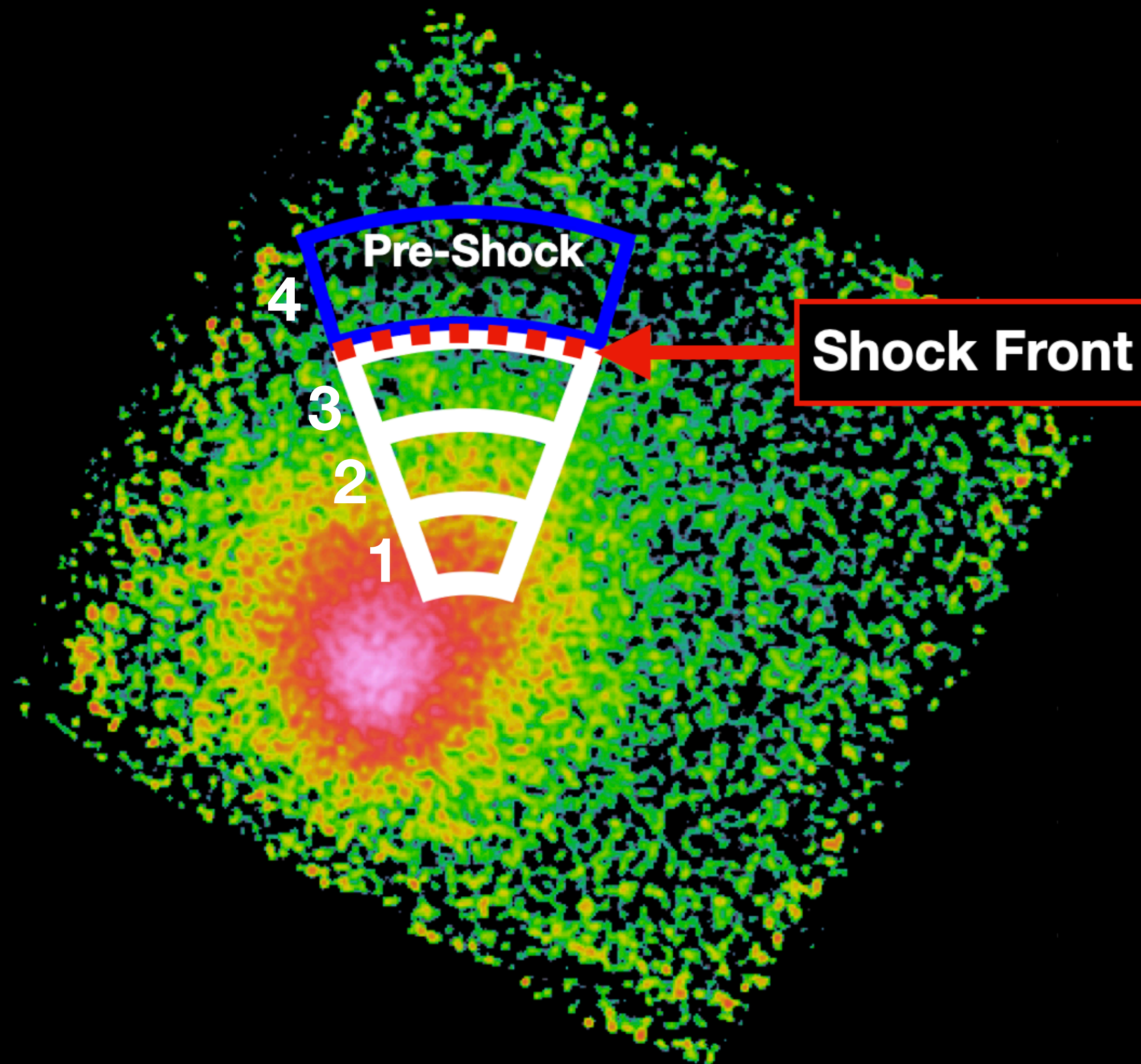
XRISM+NuSTAR



Abell 665

$$M = 3.0 \pm 0.6$$

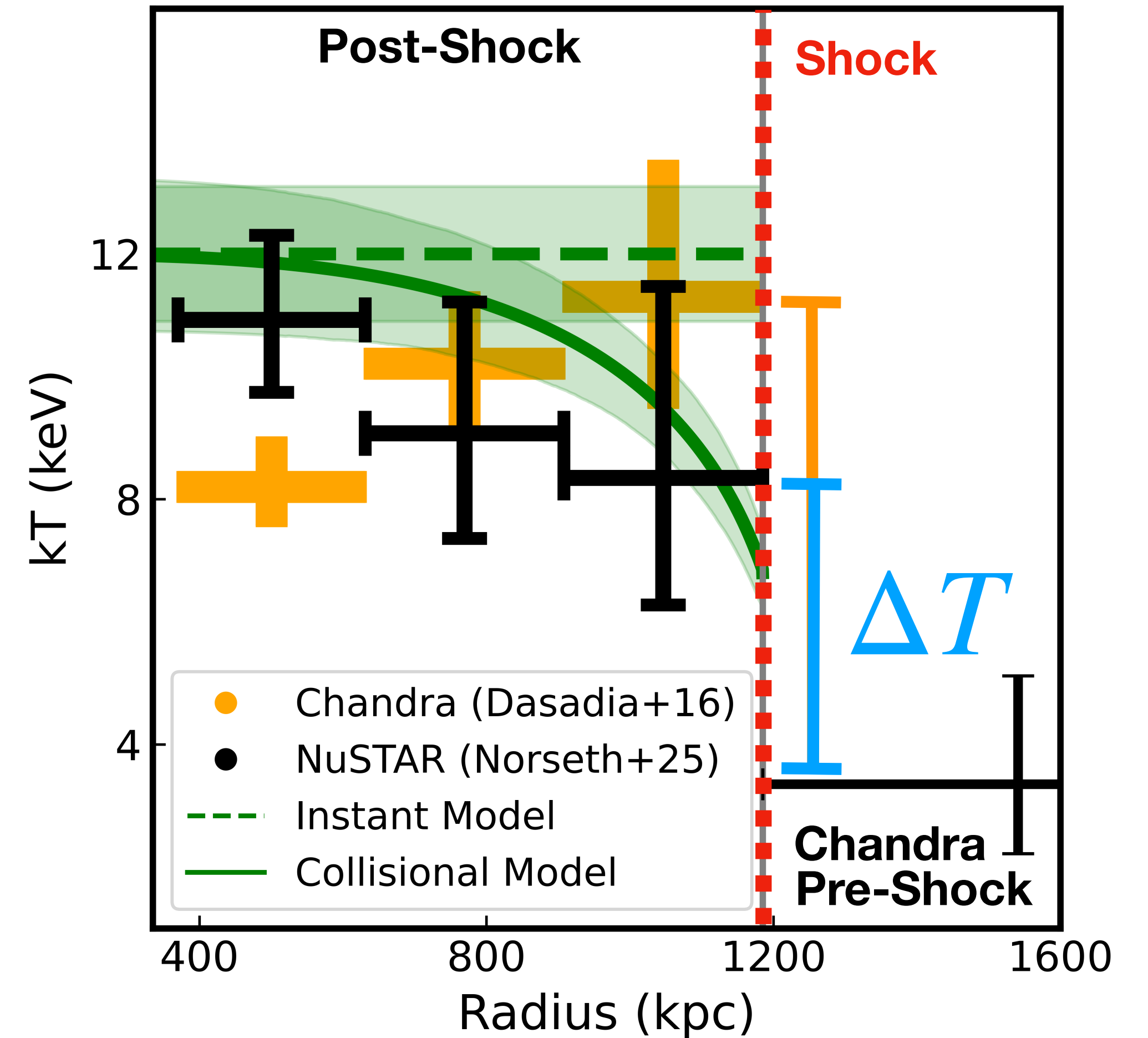
$$M = 2.8 \pm 0.7$$



NuSTAR

Delayed Equilibration Favored

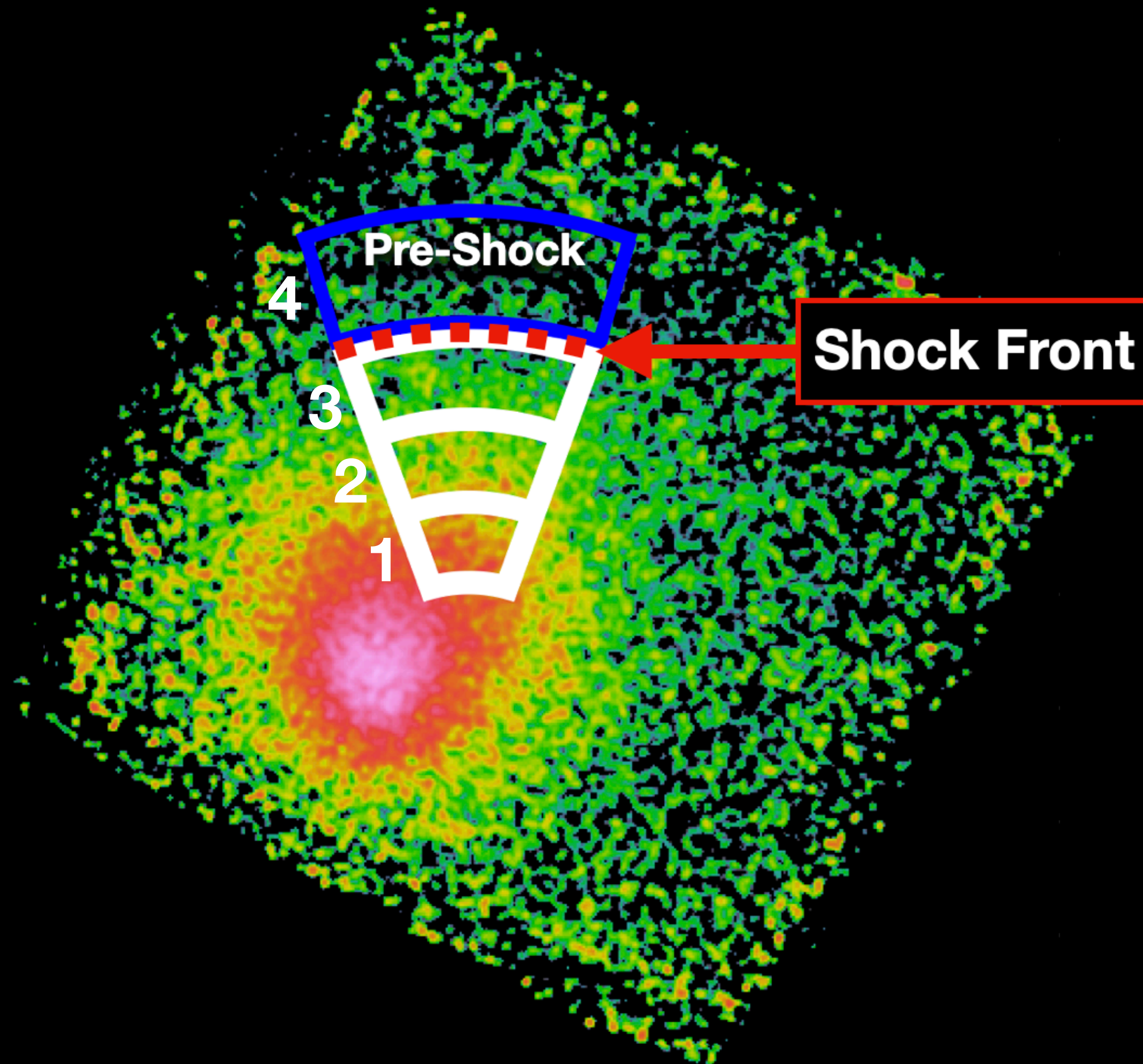
NuSTAR A665 Deprojected Temperatures



Abell 665

$$M = 3.0 \pm 0.6$$

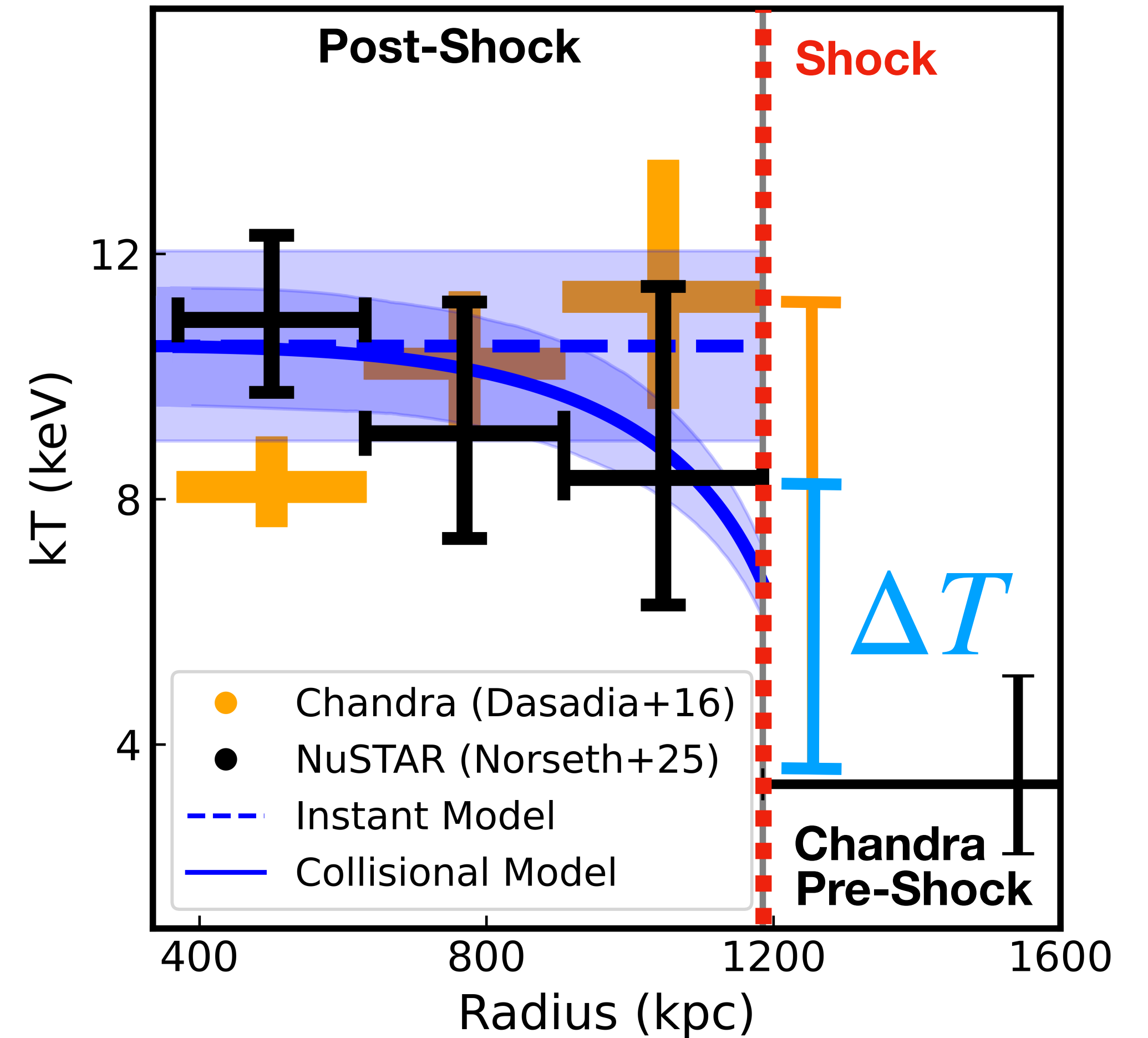
$$M = 2.8 \pm 0.7$$



NuSTAR

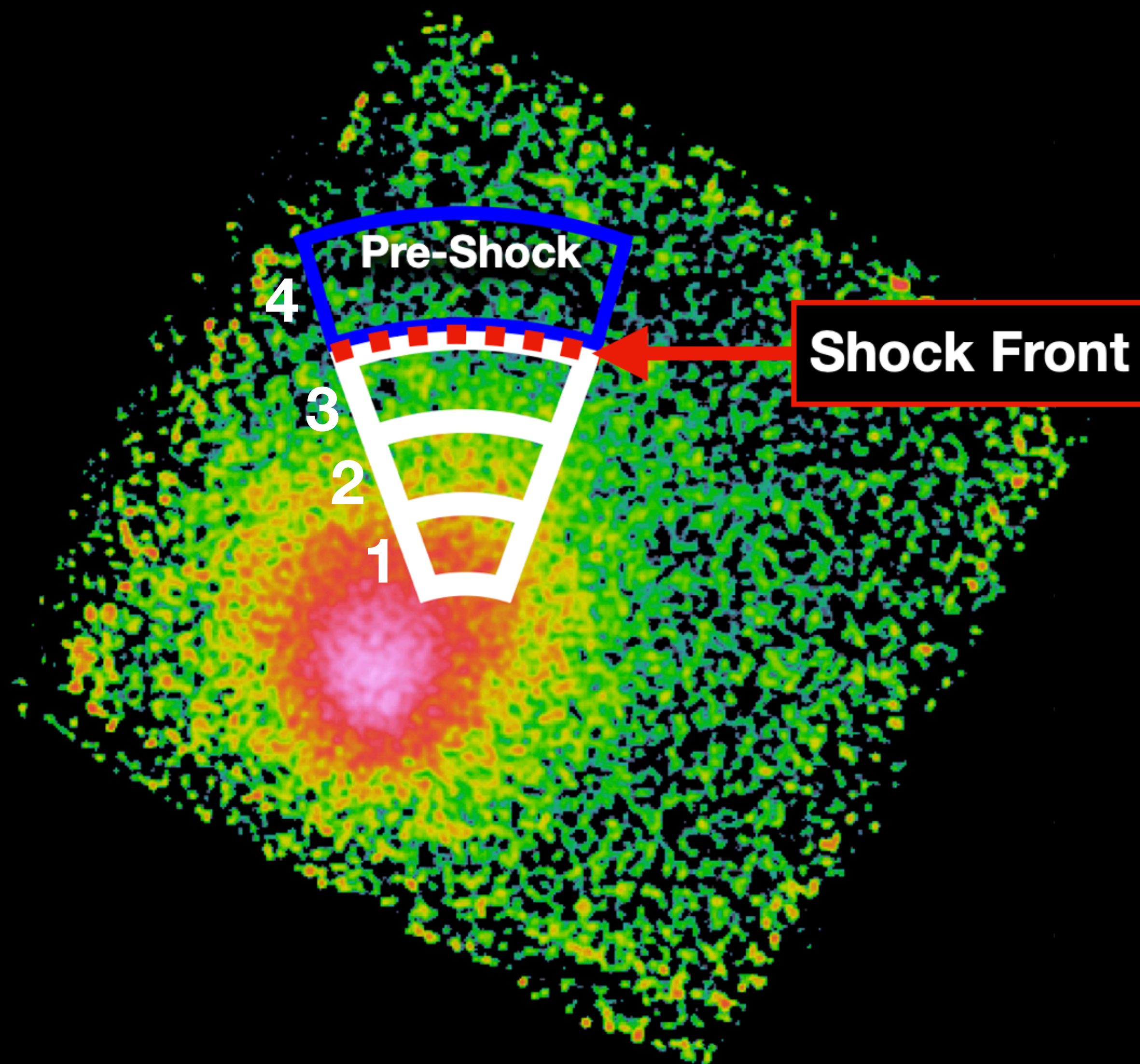
Delayed Equilibration Favored

NuSTAR A665 Deprojected Temperatures



Abell 665

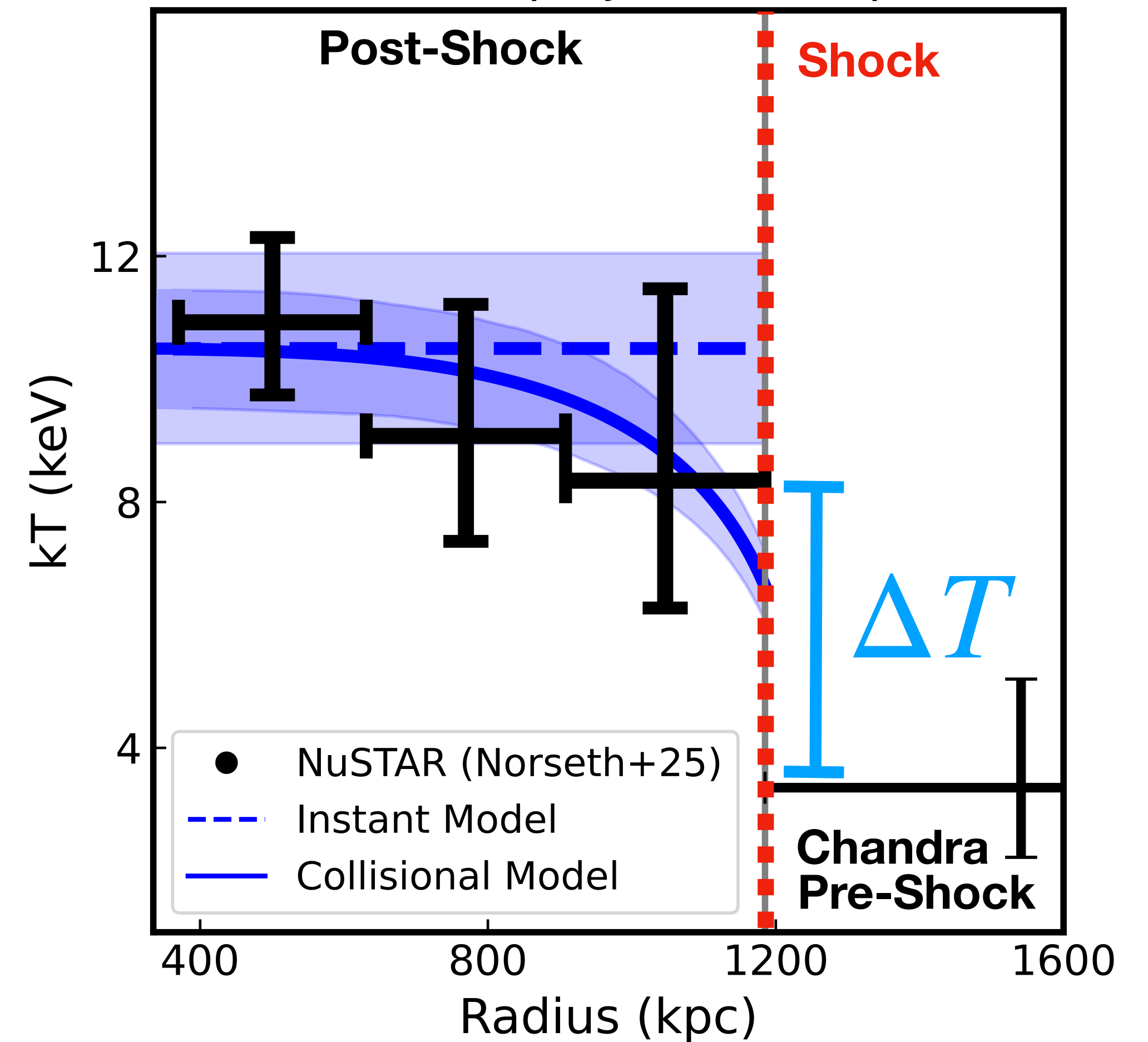
$$M = 2.8 \pm 0.7$$



NuSTAR

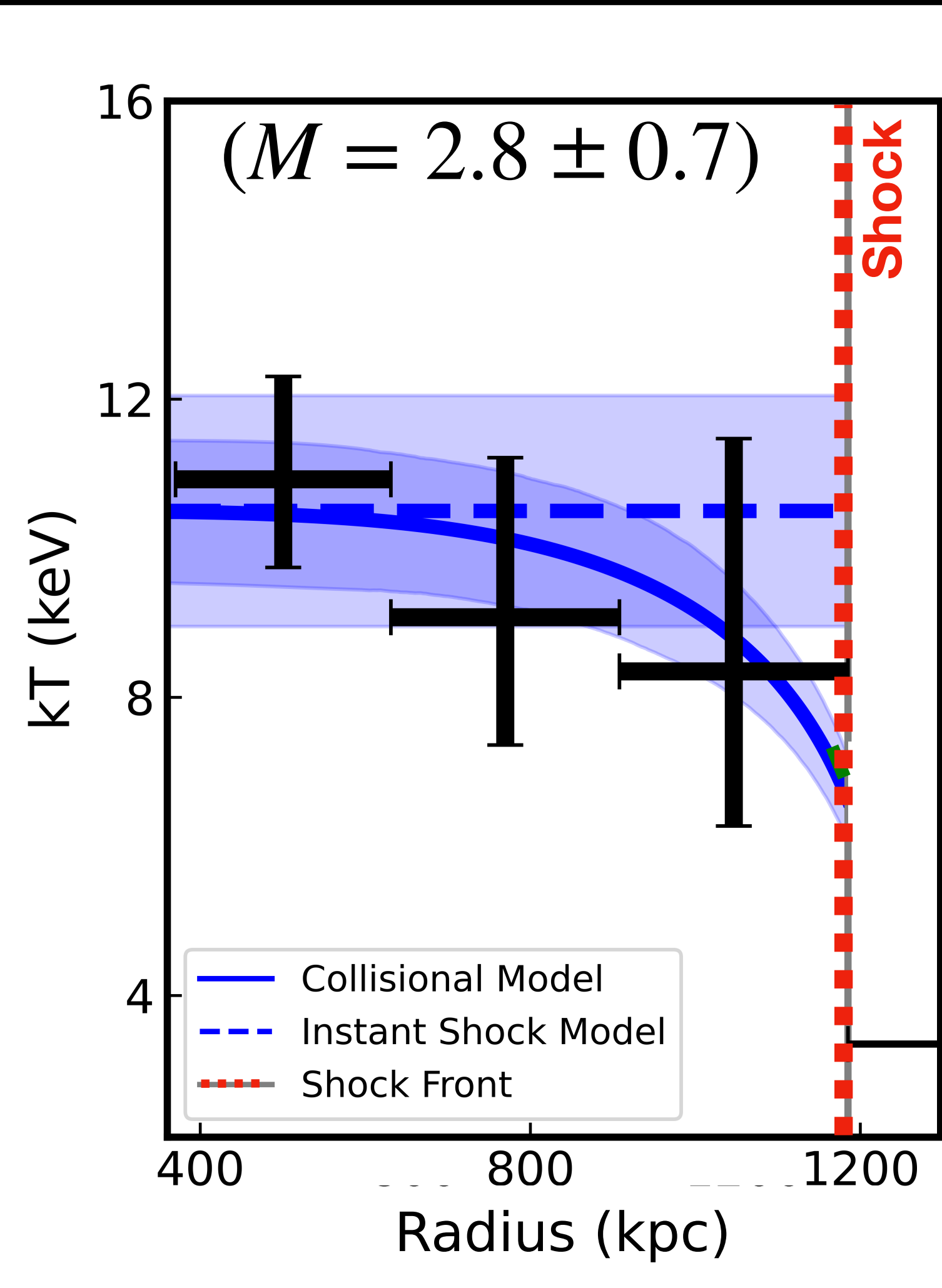
Delayed Equilibration Favored

NuSTAR A665 Deprojected Temperatures

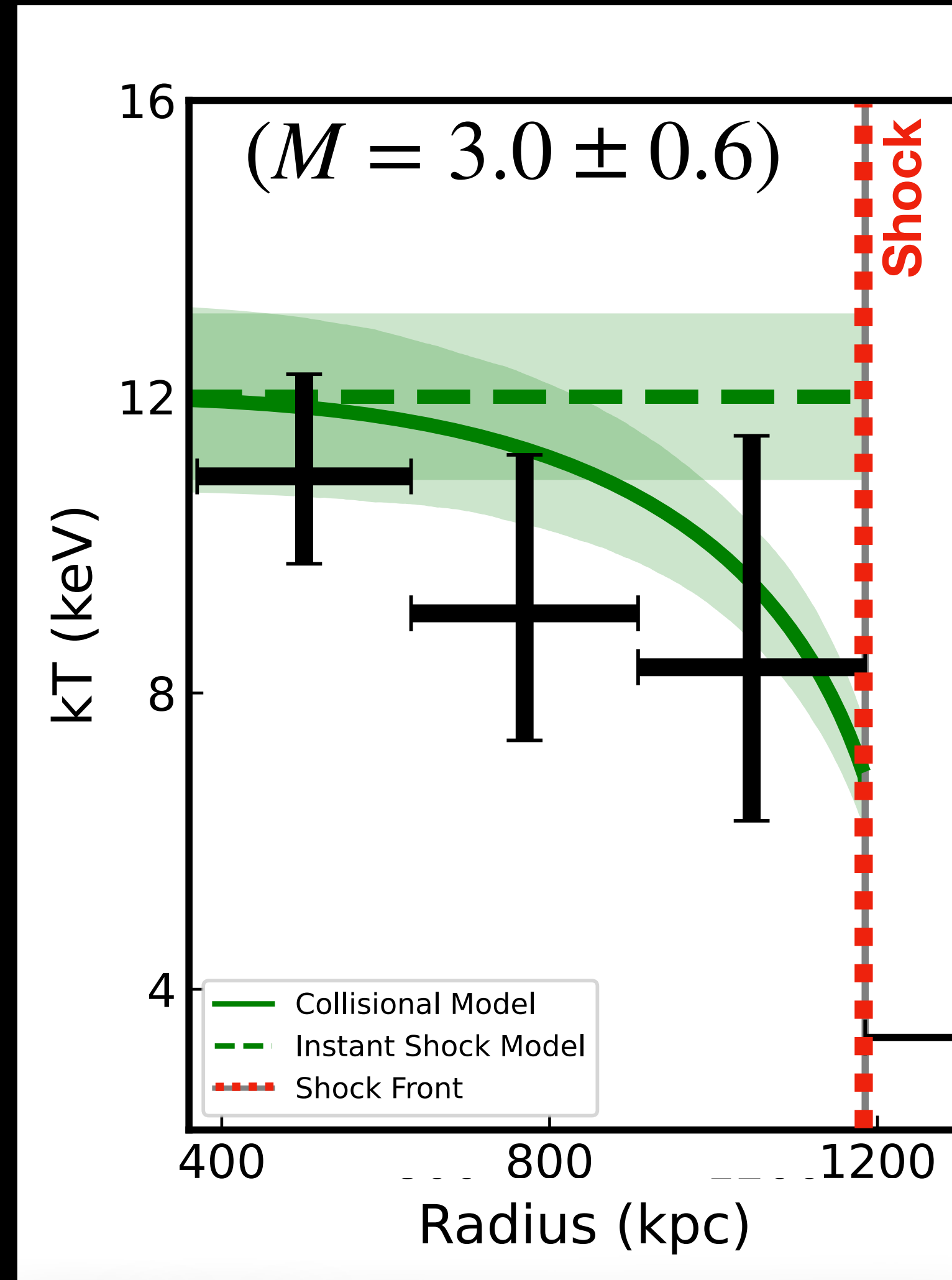


Mach Number

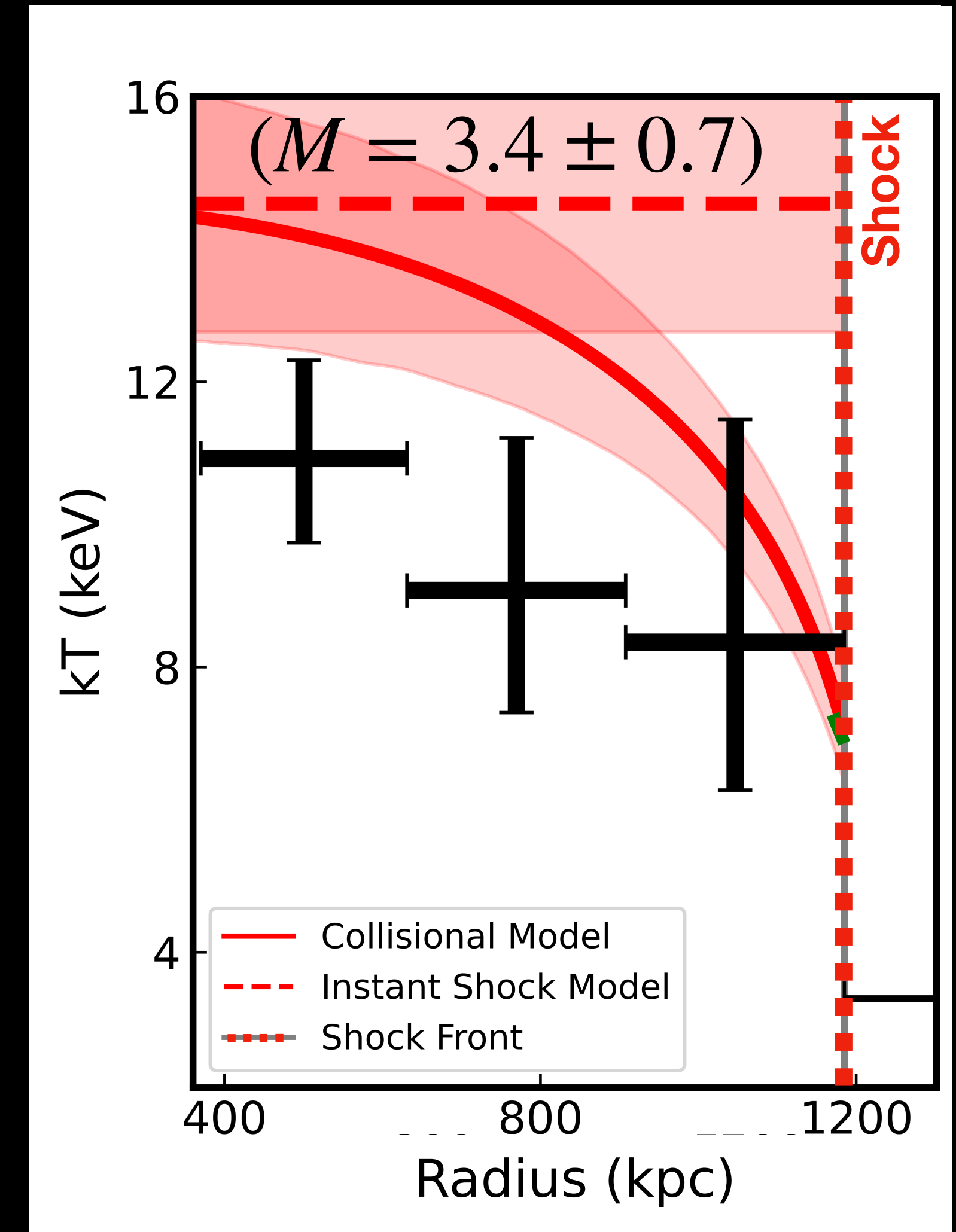
NuSTAR Temperature Jump



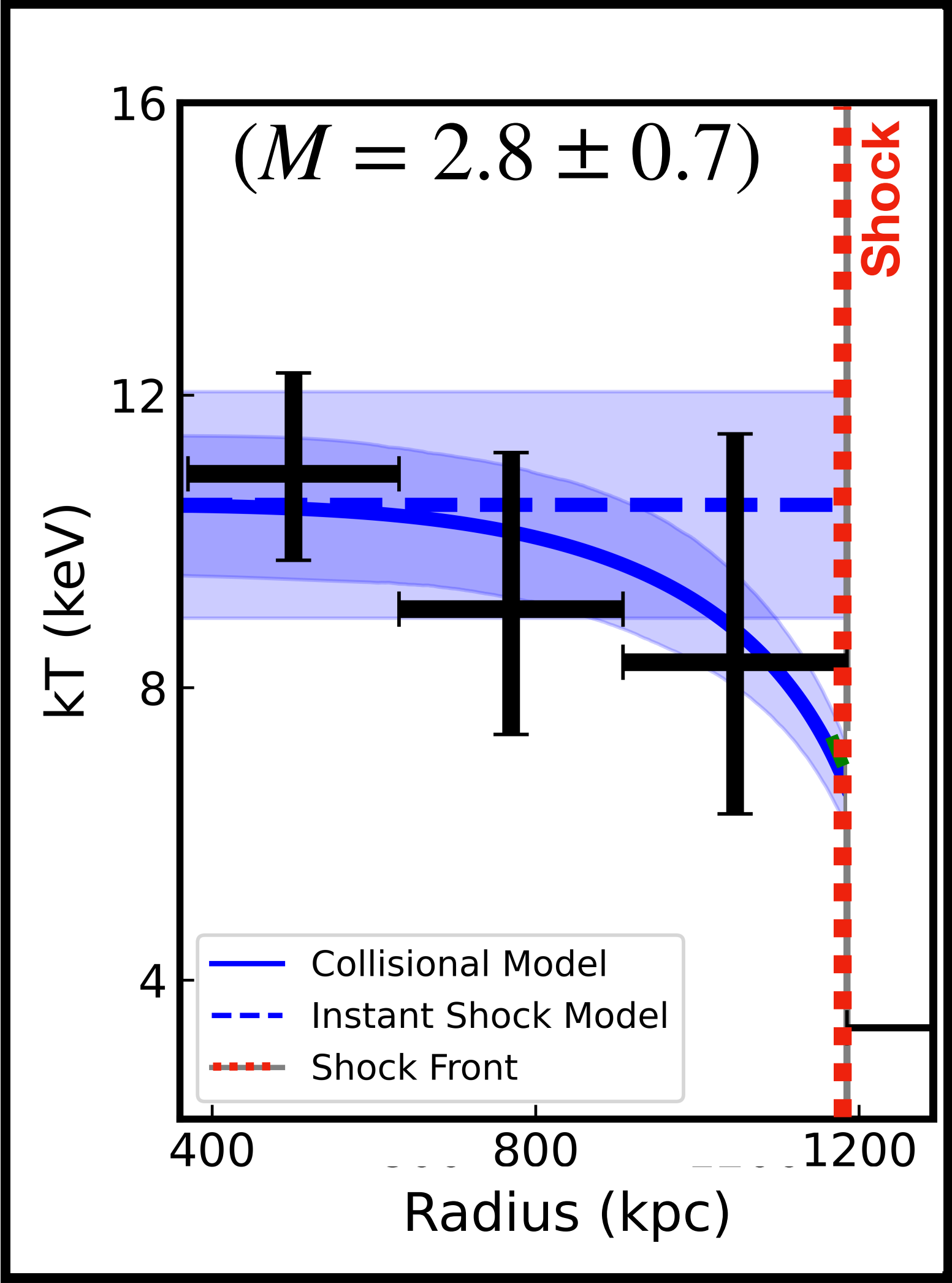
Chandra Temperature Jump



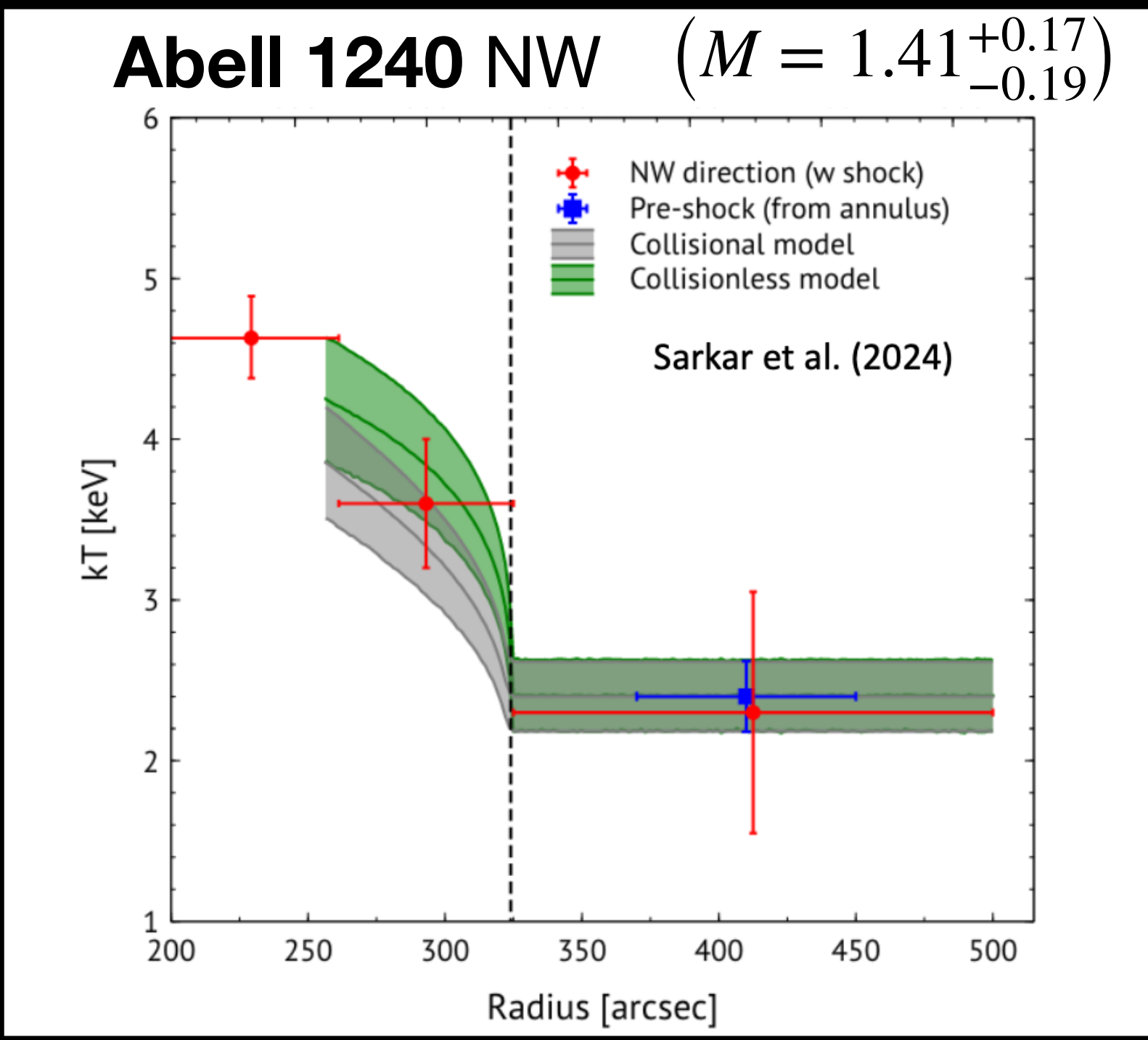
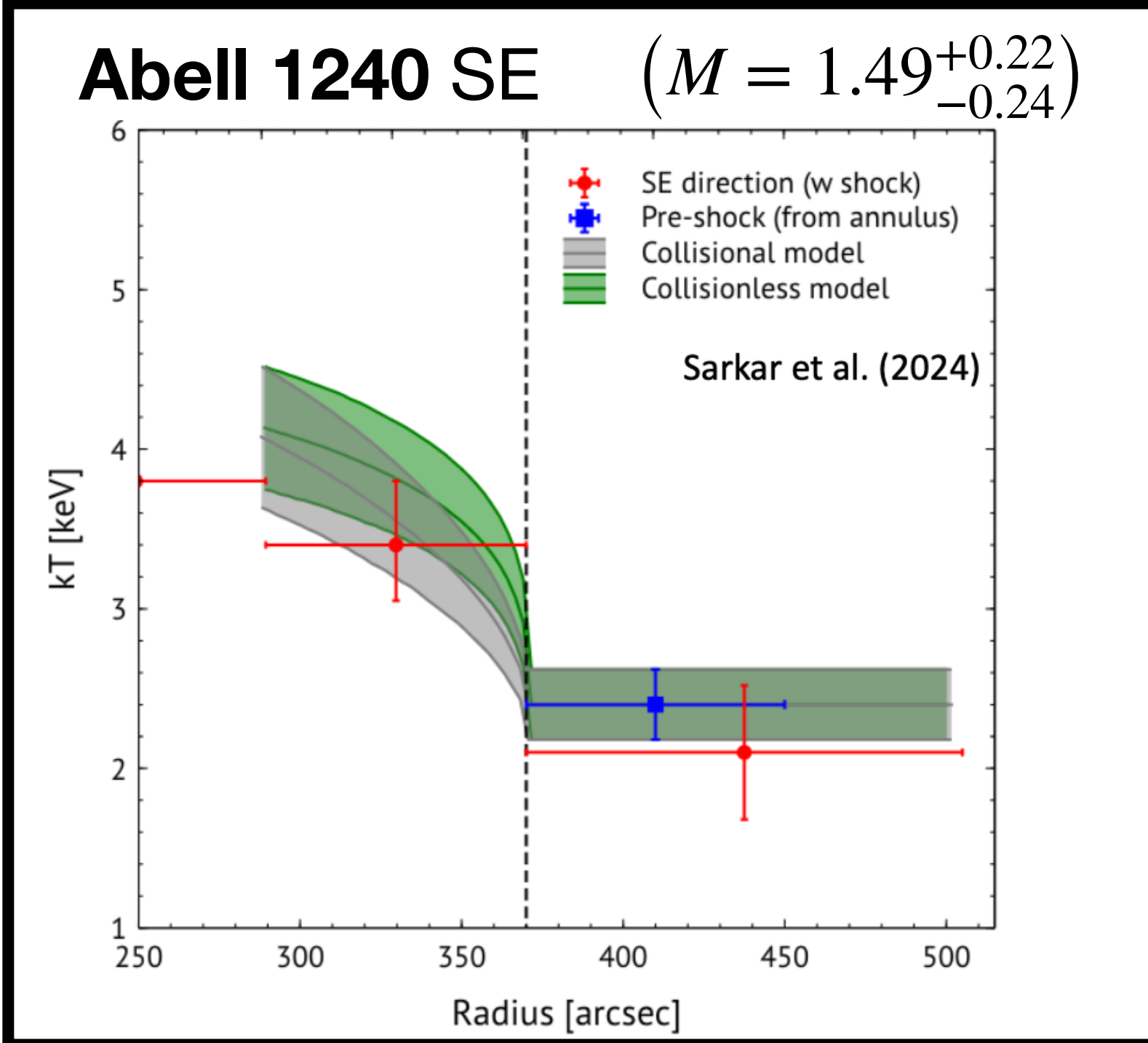
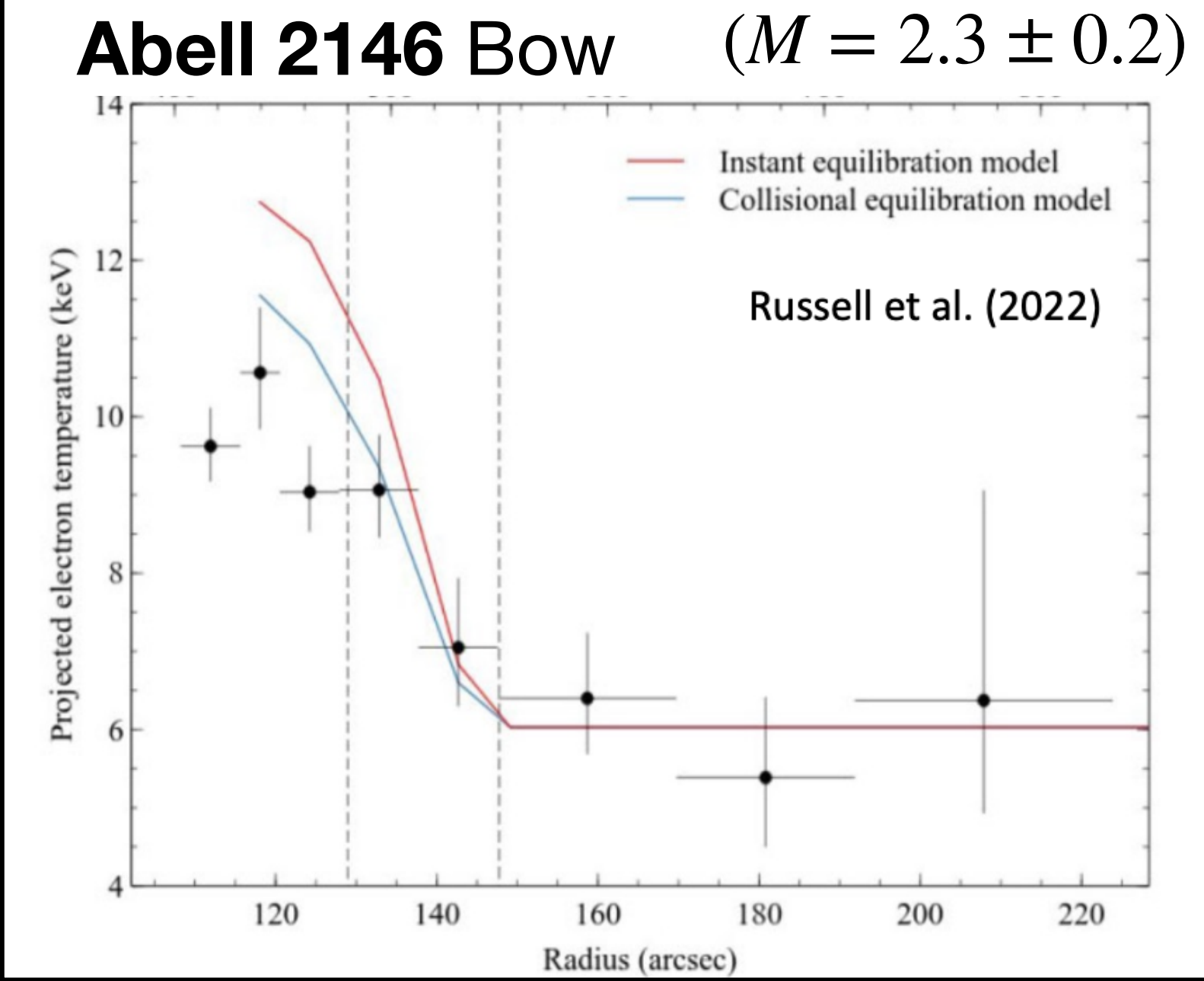
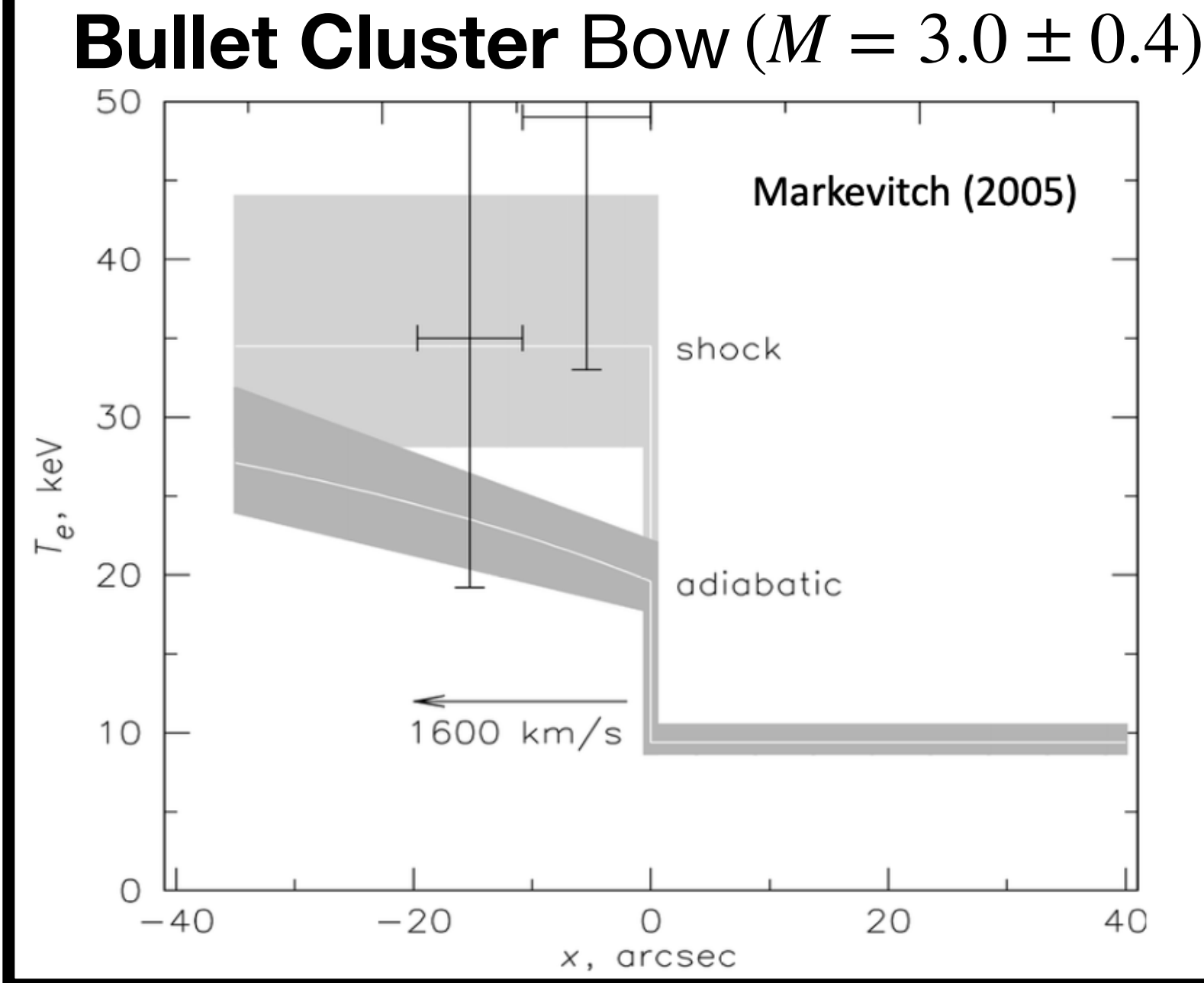
Chandra Density Jump



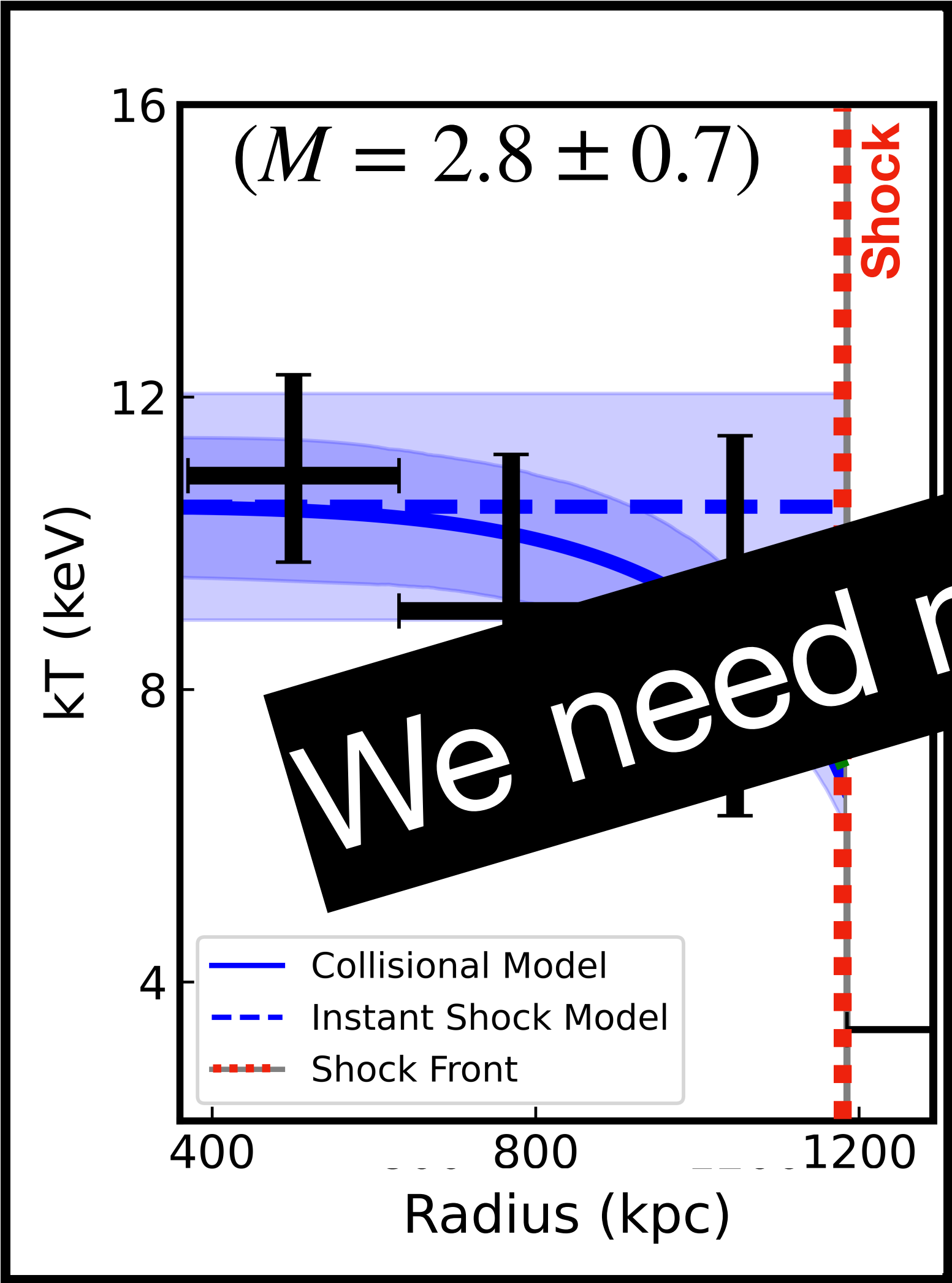
Addition to small handful
of other such work:



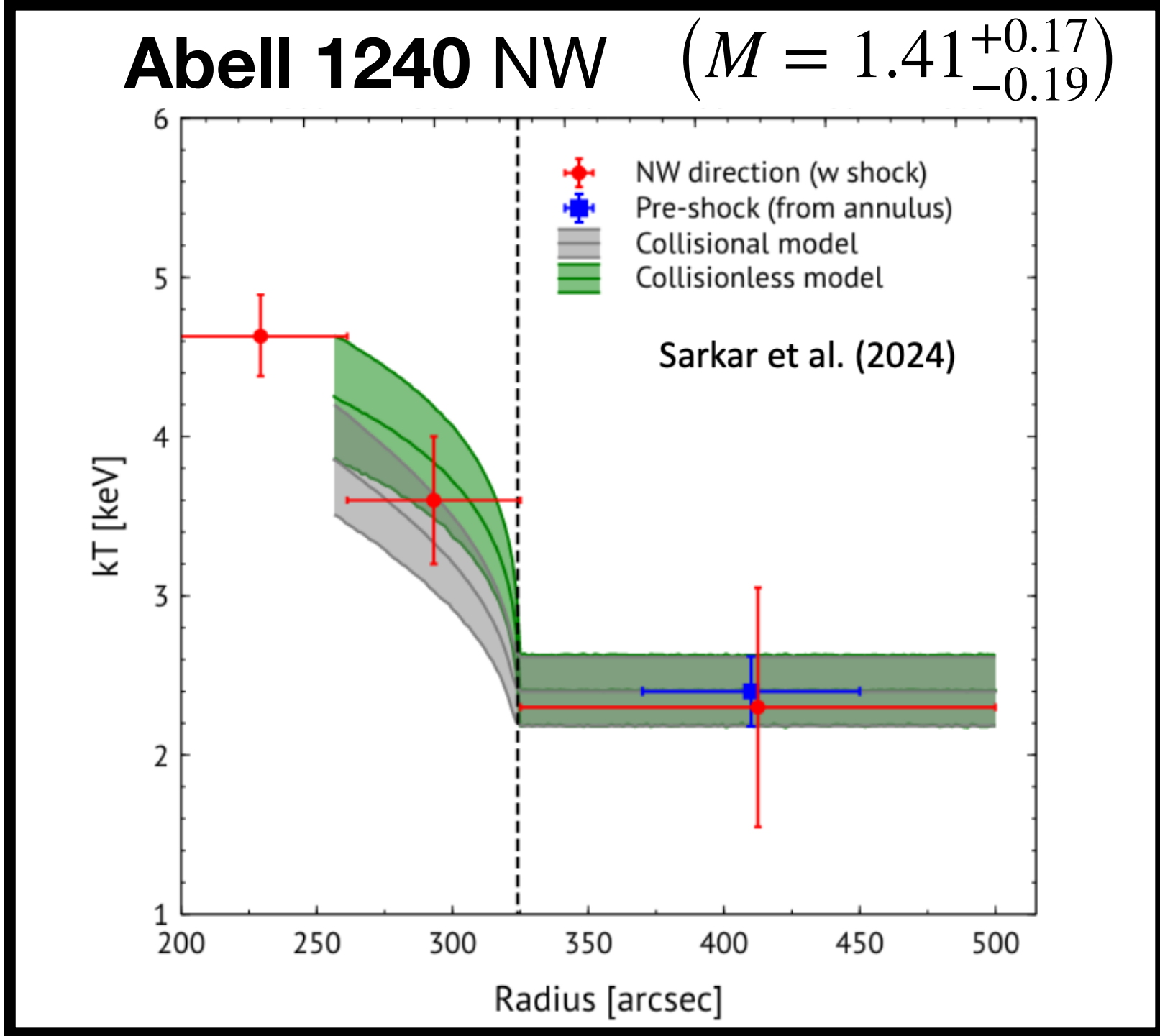
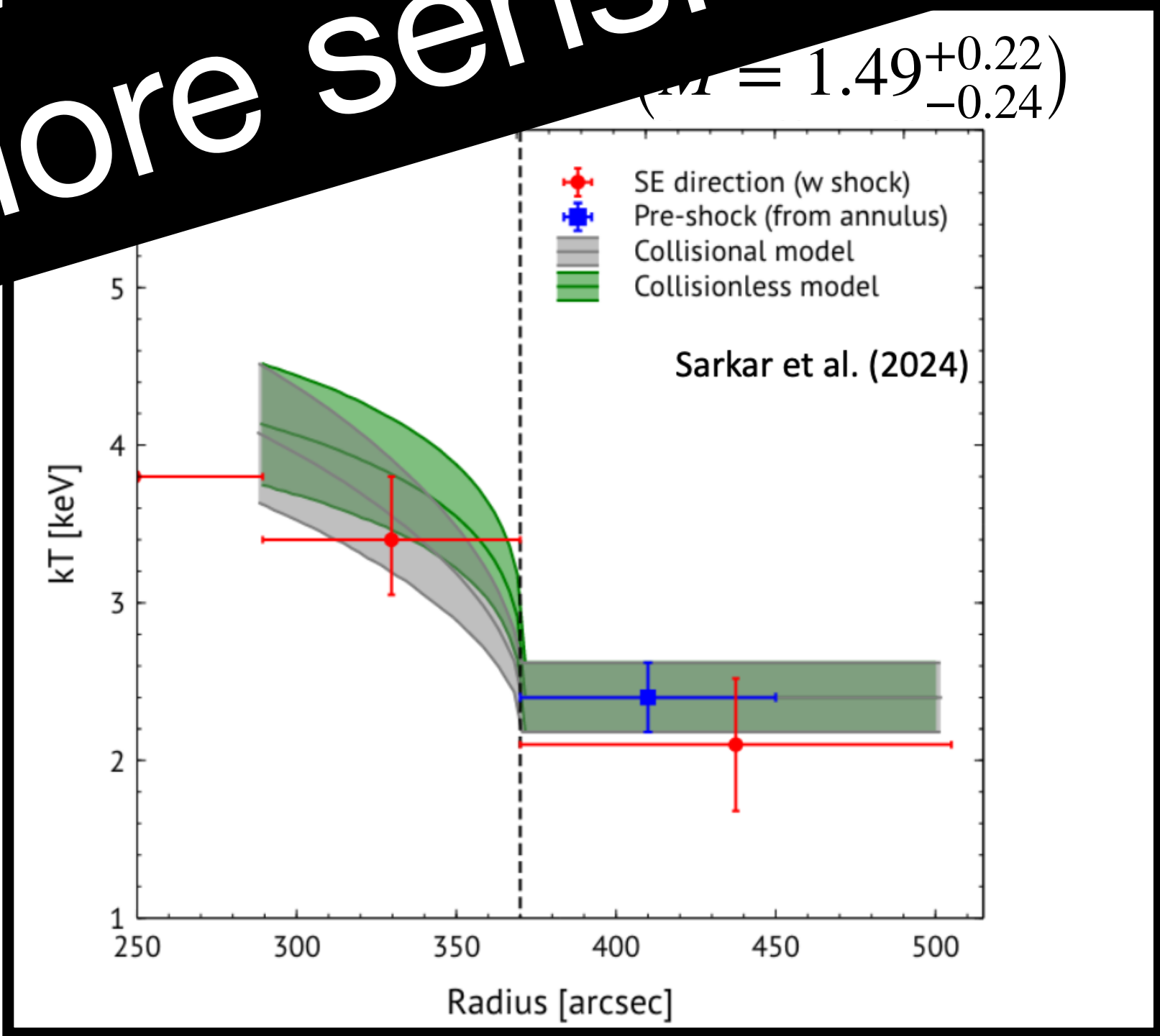
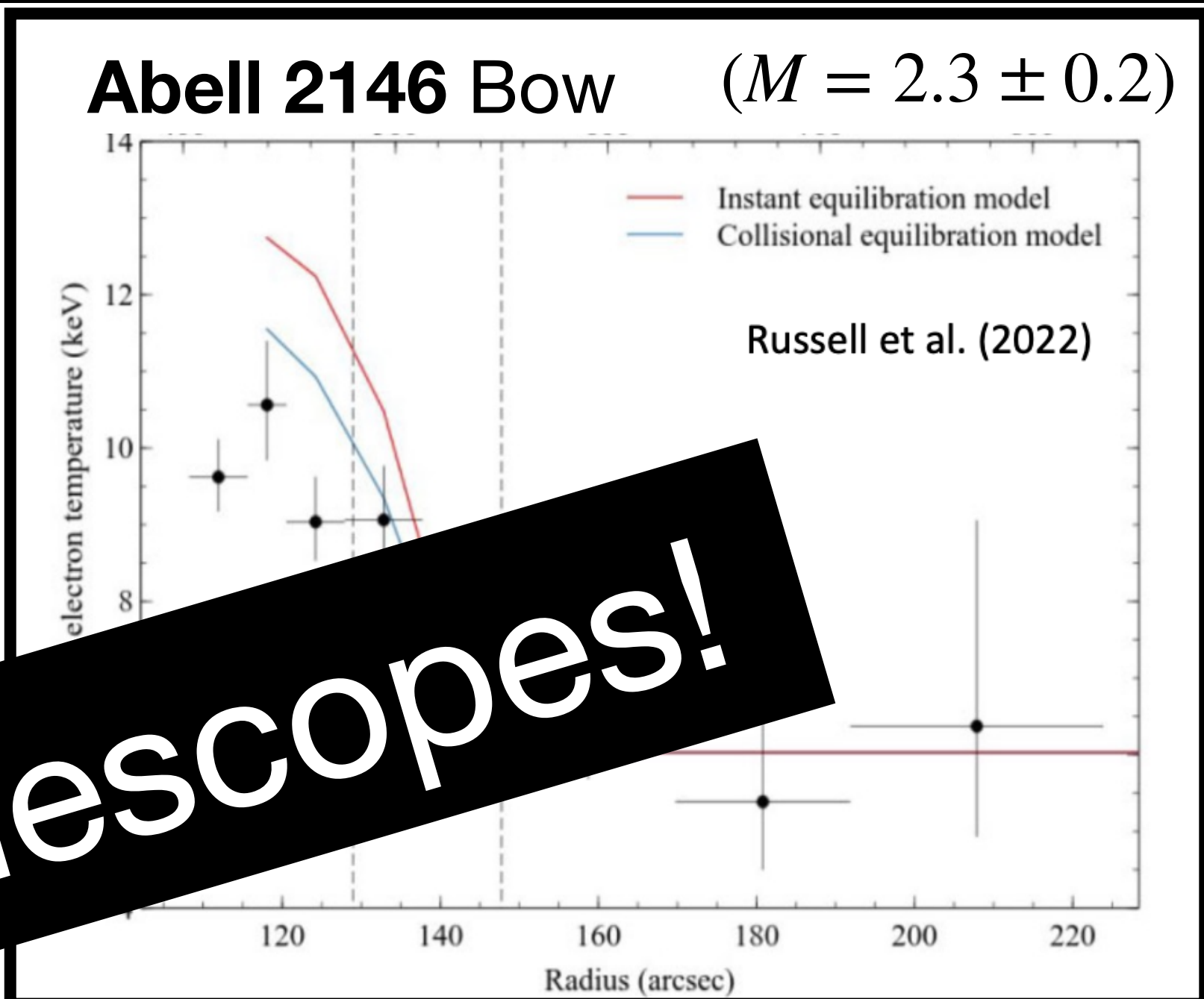
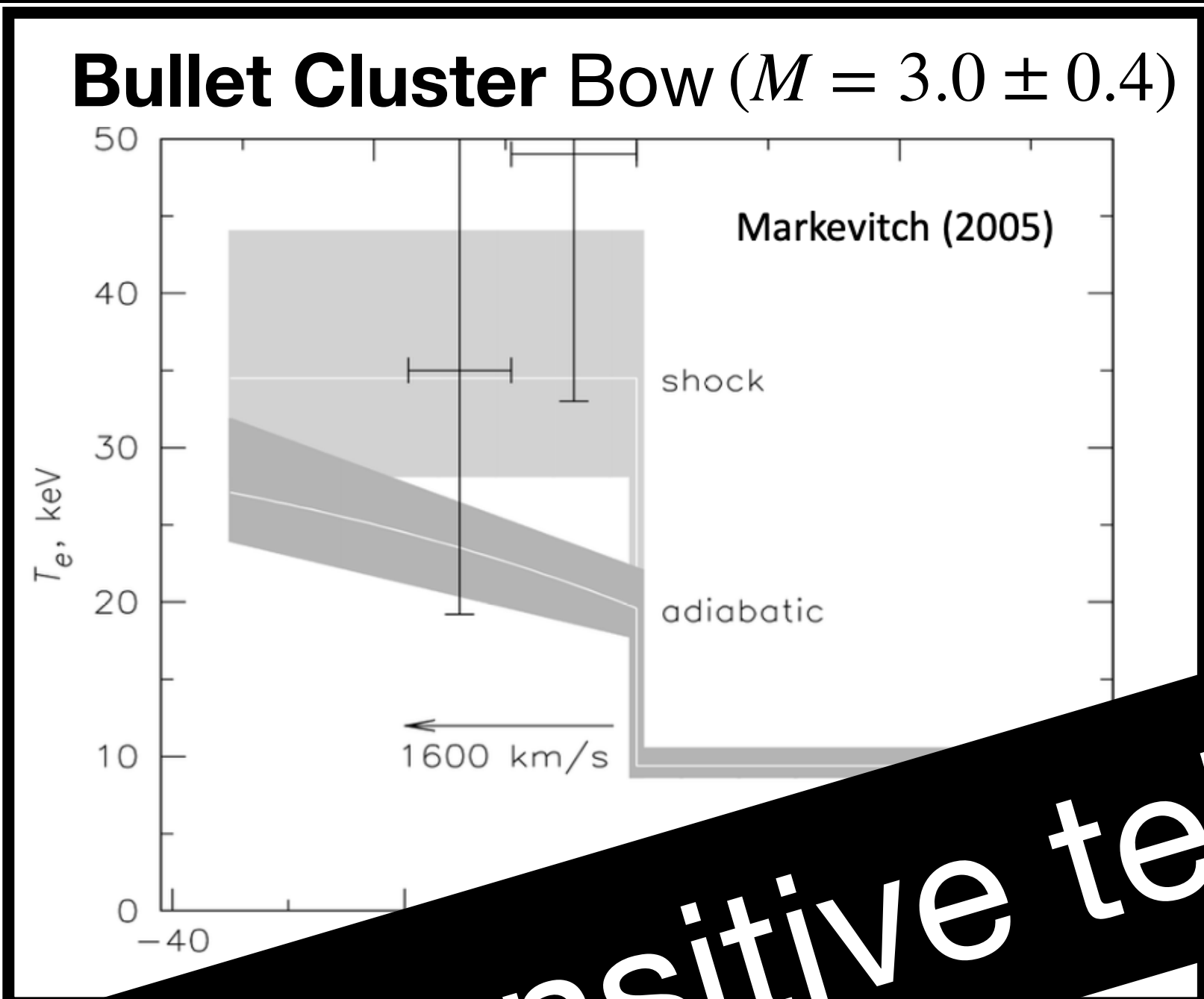
Norseth+2025



Addition to small handful
of other such work:



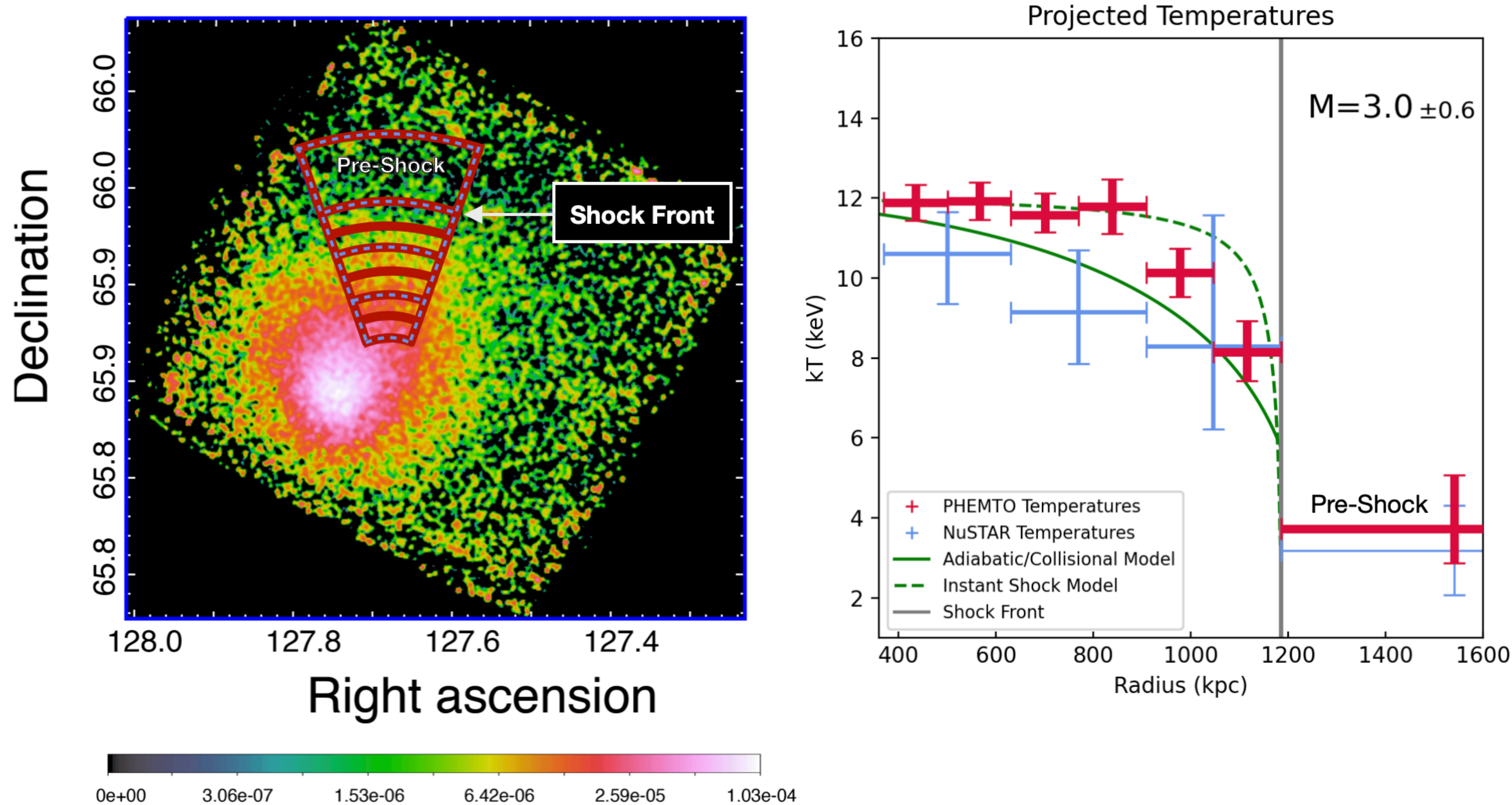
Norseth+2025



We need more sensitive telescopes!

PHEMTO

The Polarimetric High-Energy Modular Telescope Observatory



Summary

christiannorseth.com



- Cluster merger shocks thermalize the ICM:

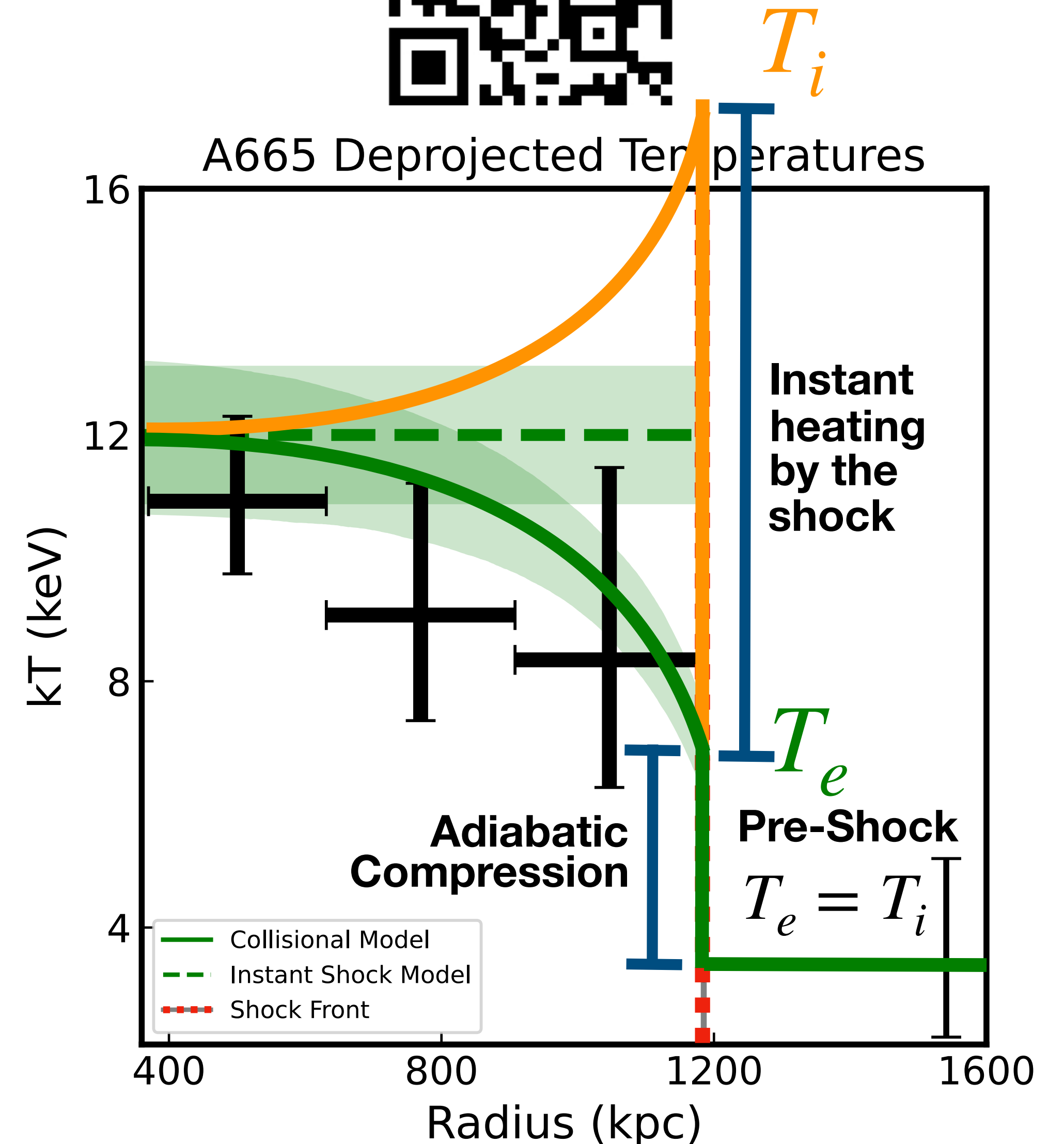
Instant model:

- Electrons and ions **both** heated by shock

Delayed model:

- Ions receive more energy from shock
- Electrons adiabatically compressed
- Collisionally equilibrate over ~ 100 Myr

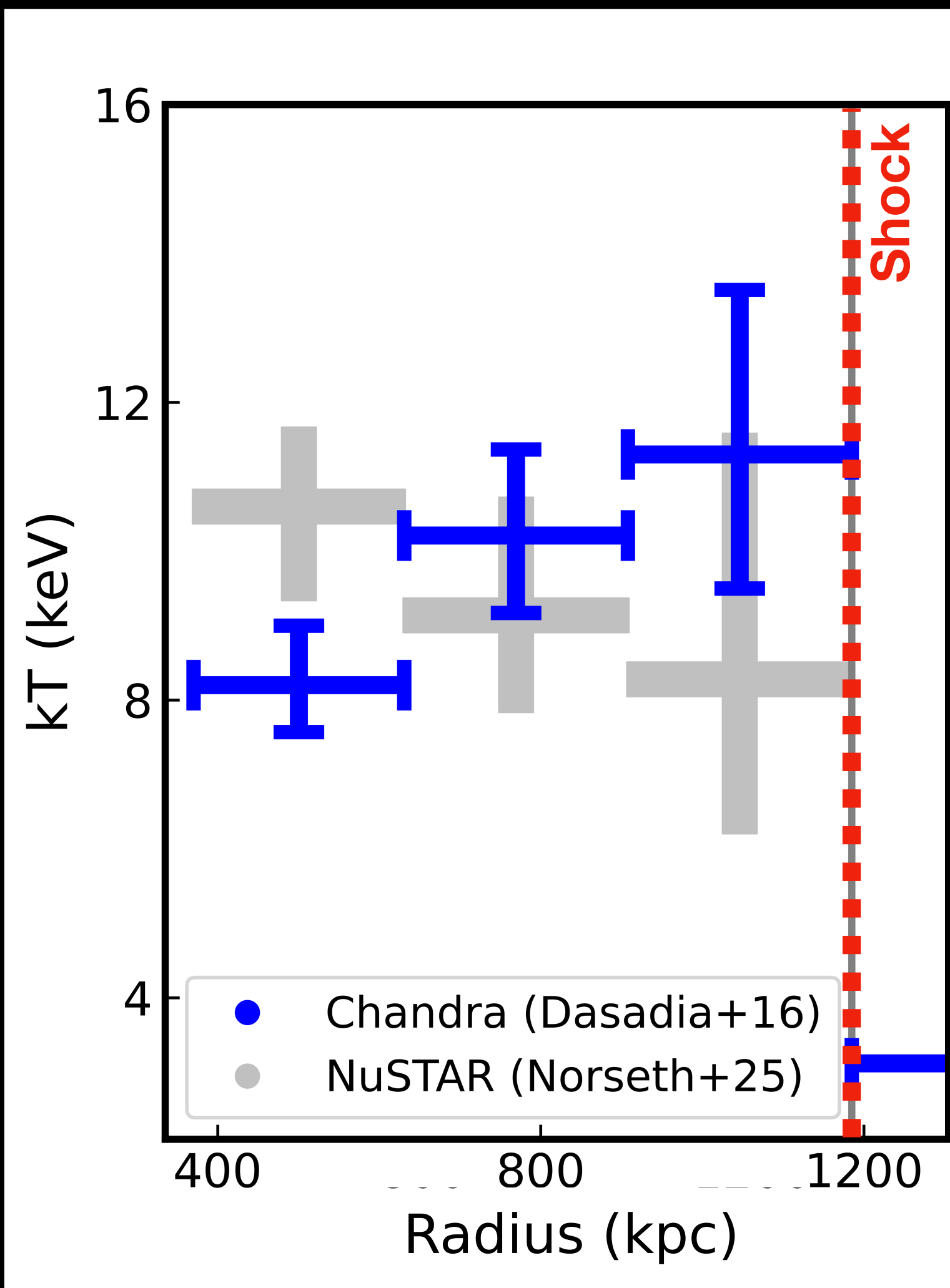
- NuSTAR data favors delayed heating
- Improves understanding of ICM microphysics
- We need more sensitive telescopes!



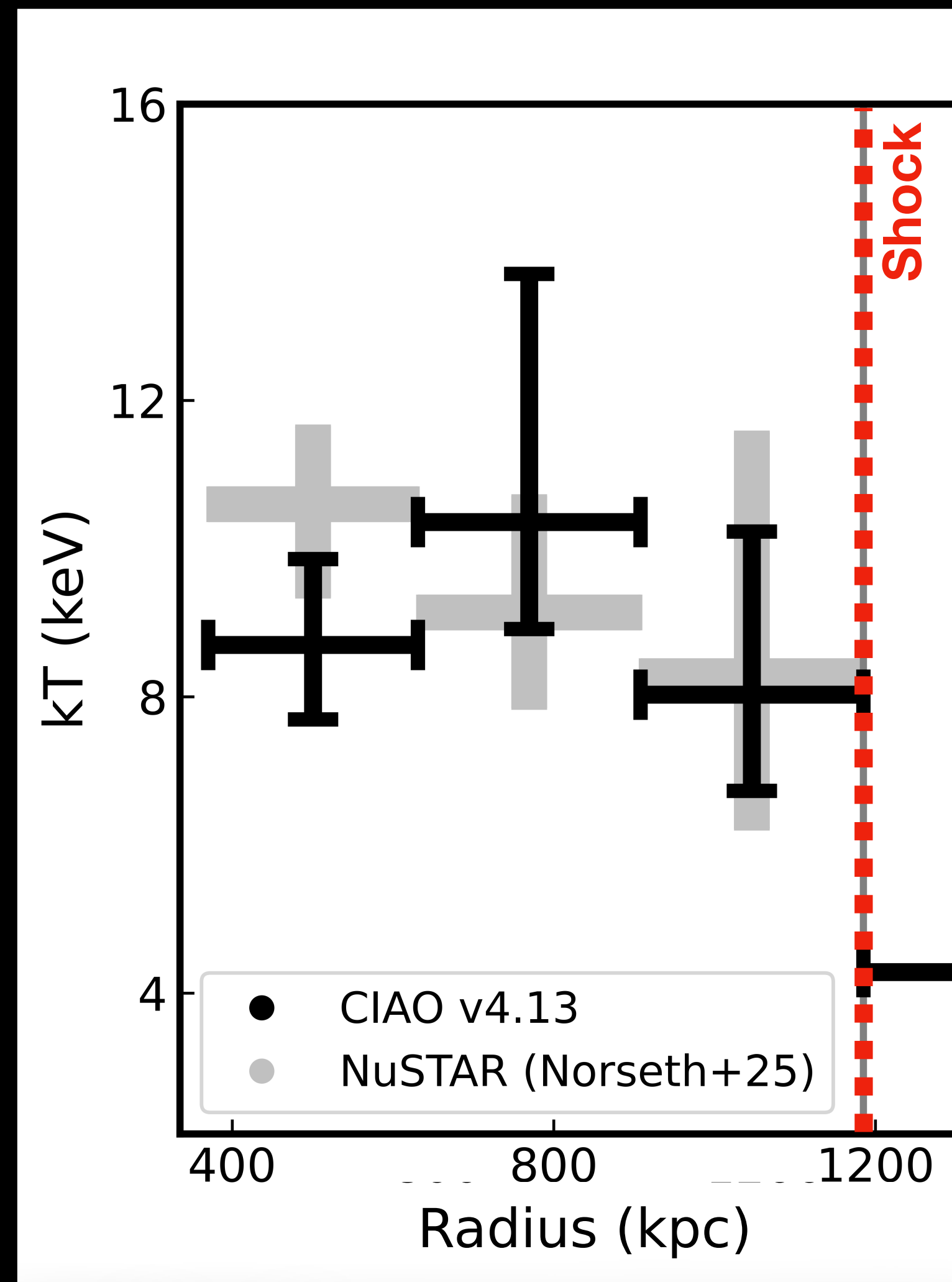
Backup

Cross-Calibration

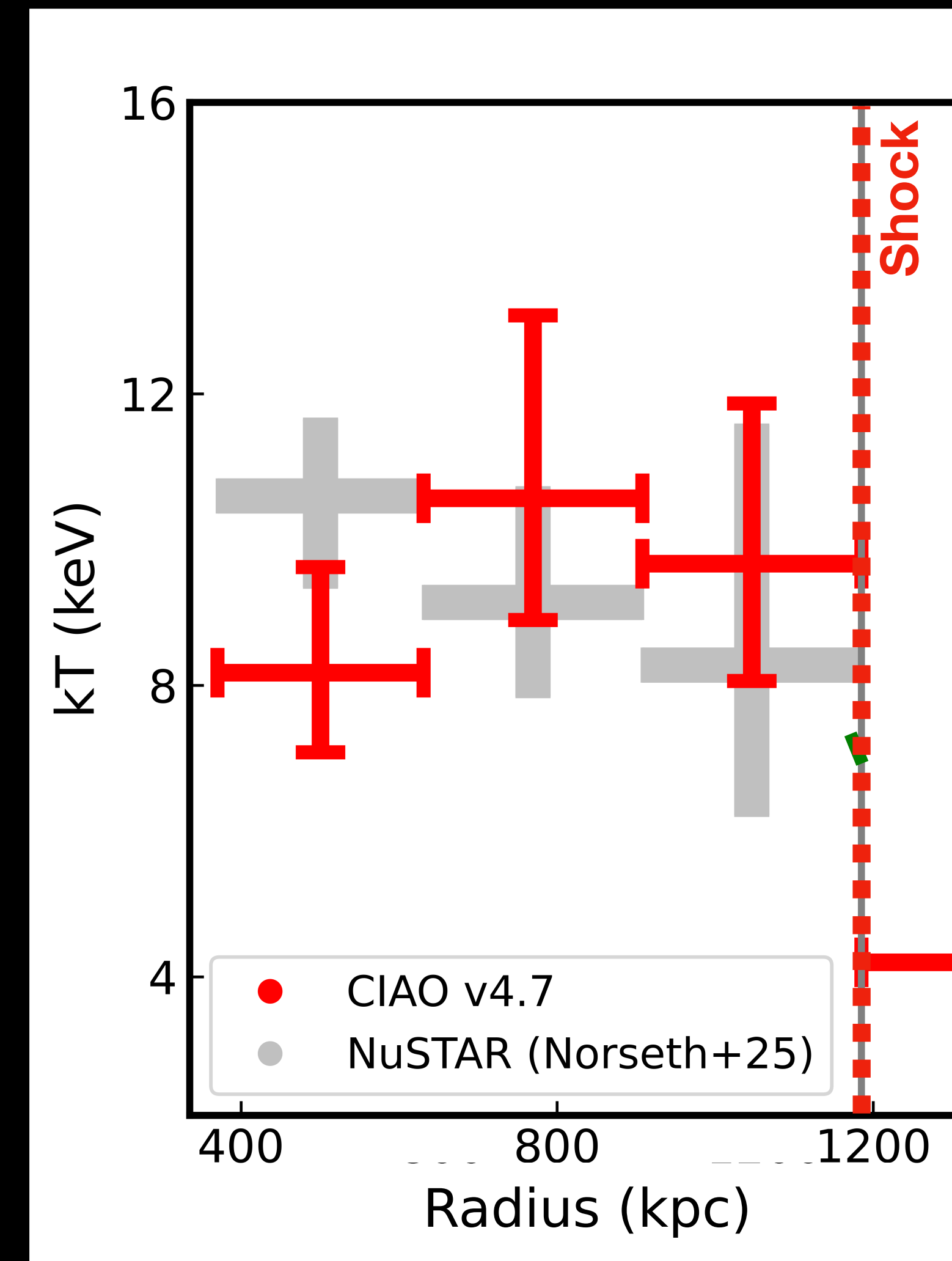
Dasadia+16



CIAO 4.13

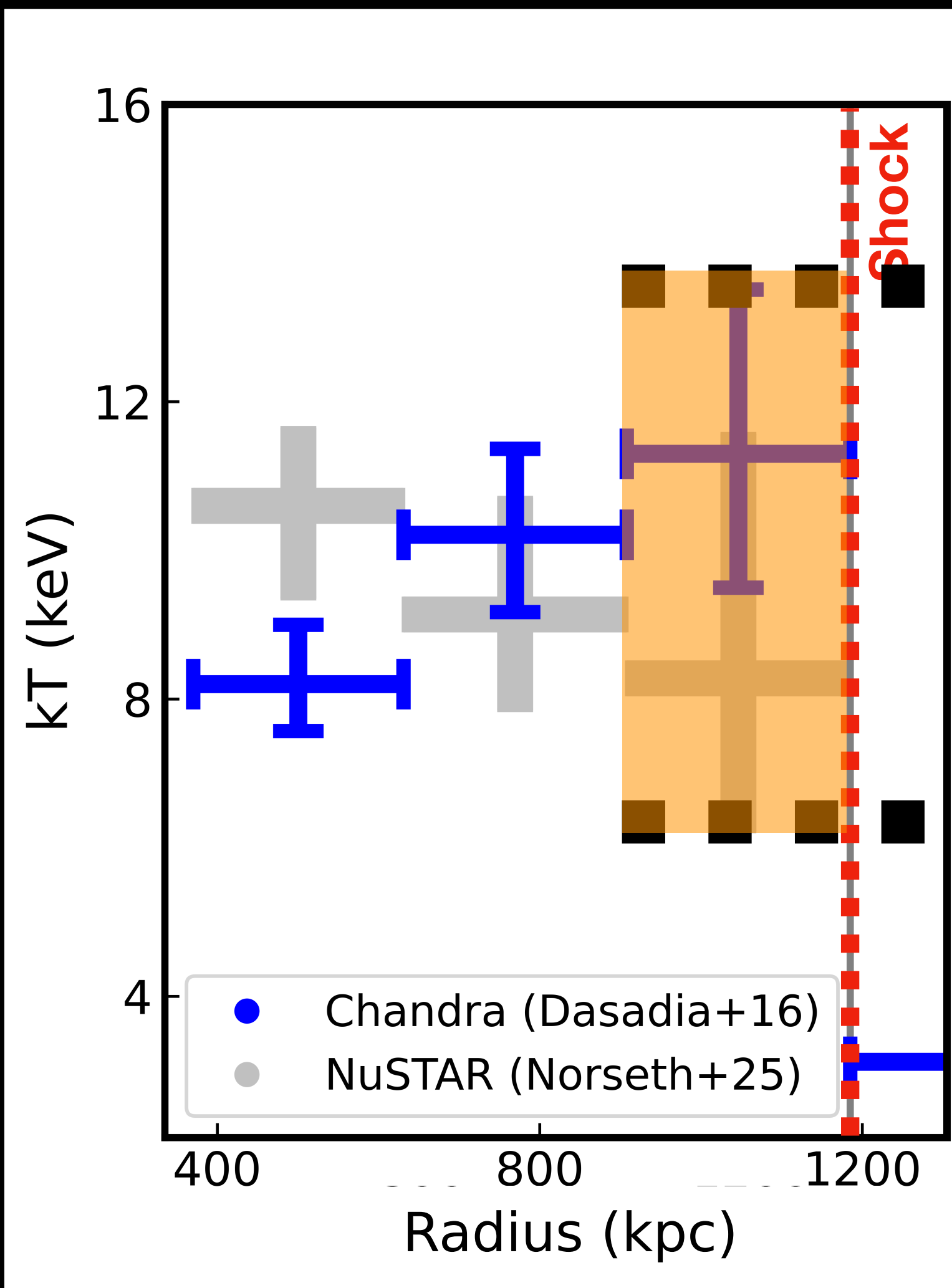


CIAO 4.7

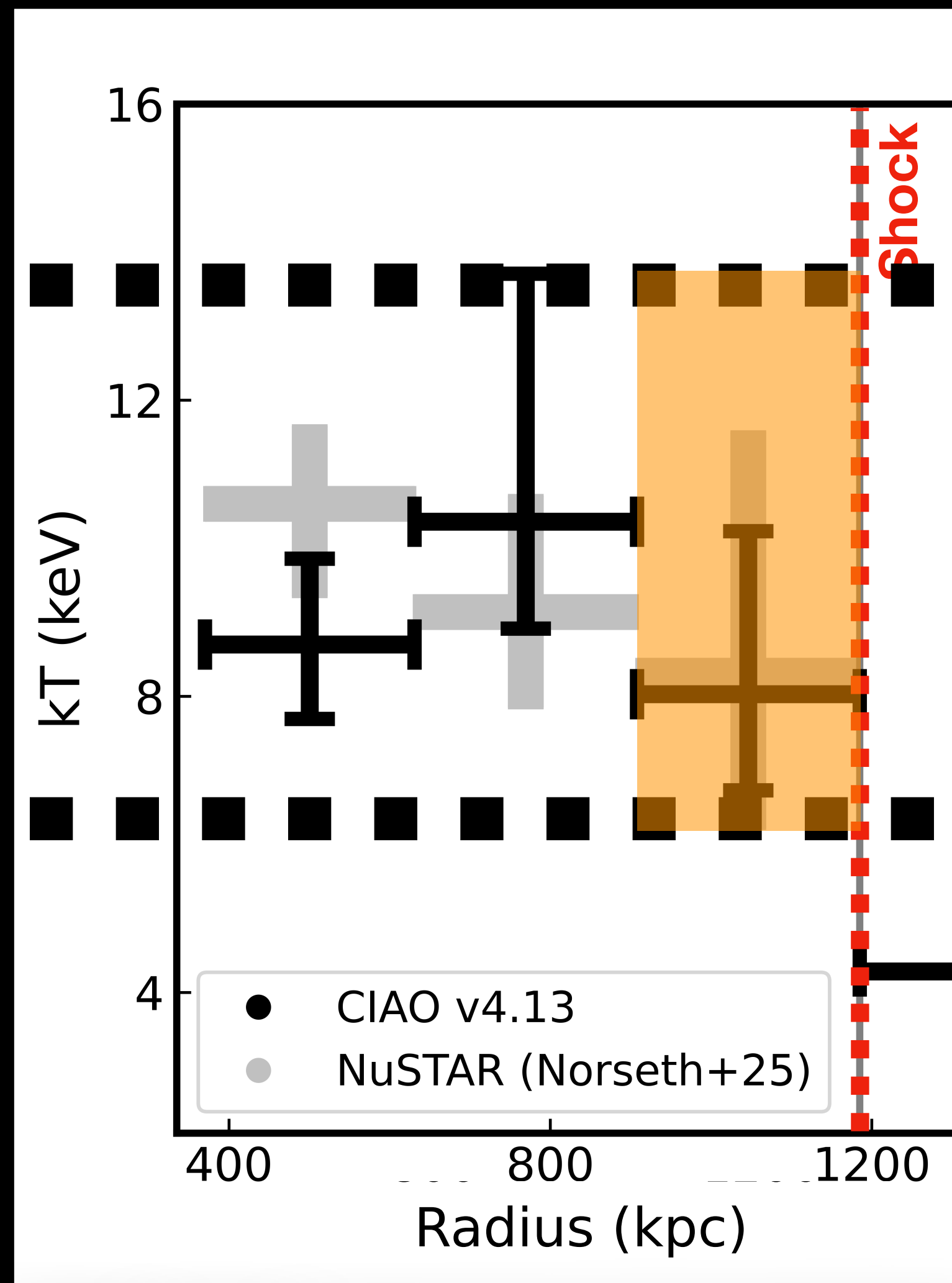


Cross-Calibration

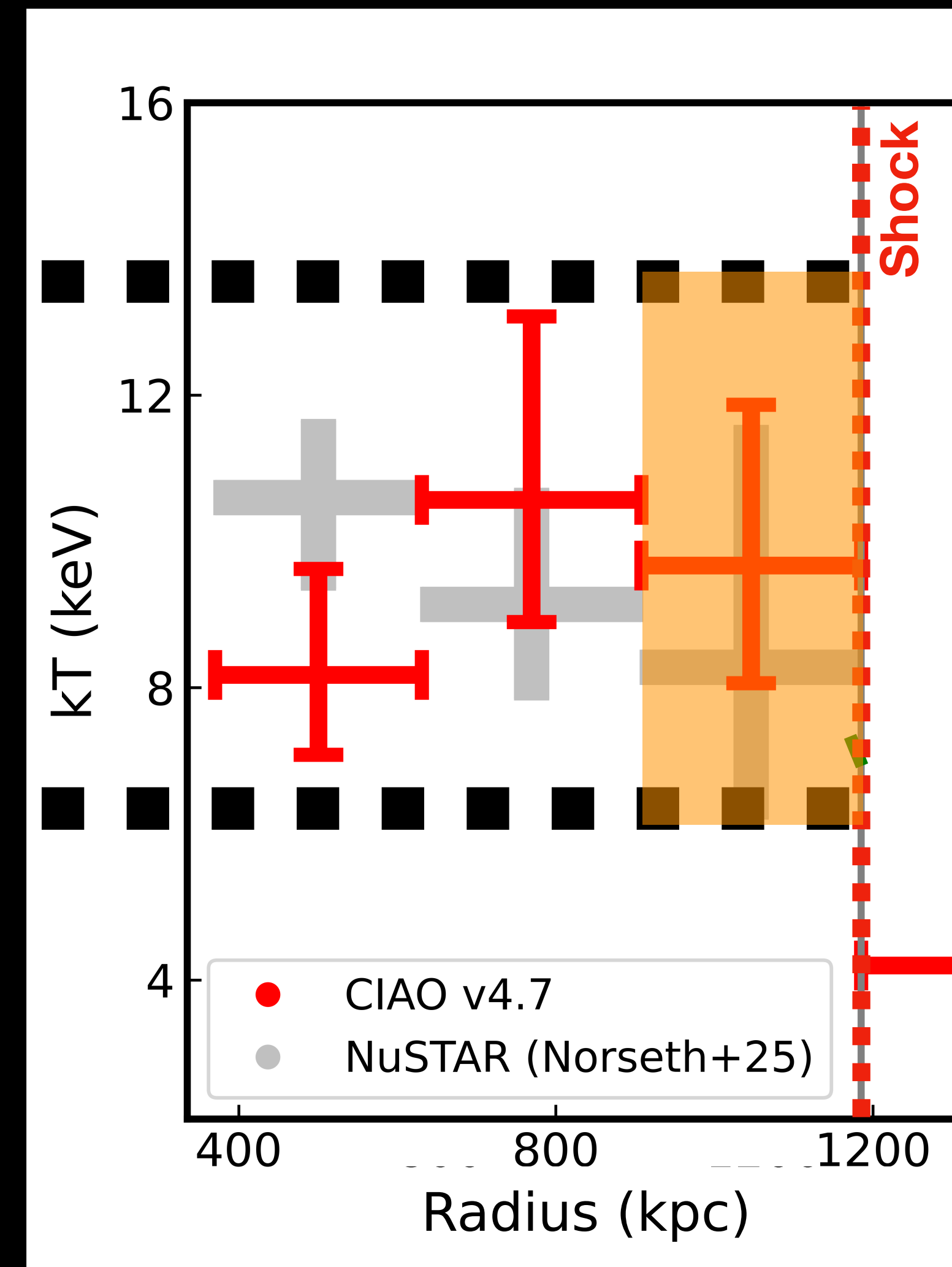
Dasadia+16



CIAO 4.13/CALDB v4.9.1



CIAO 4.7/CALDB v4.6.9



Cross-Calibration

Preliminary Results

Cluster Region Comparisons

