

Exploring the Milky Way's CGM: New Insights from X-ray Observations and a Revised Thermal Model

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How to detect the warm-hot gas?

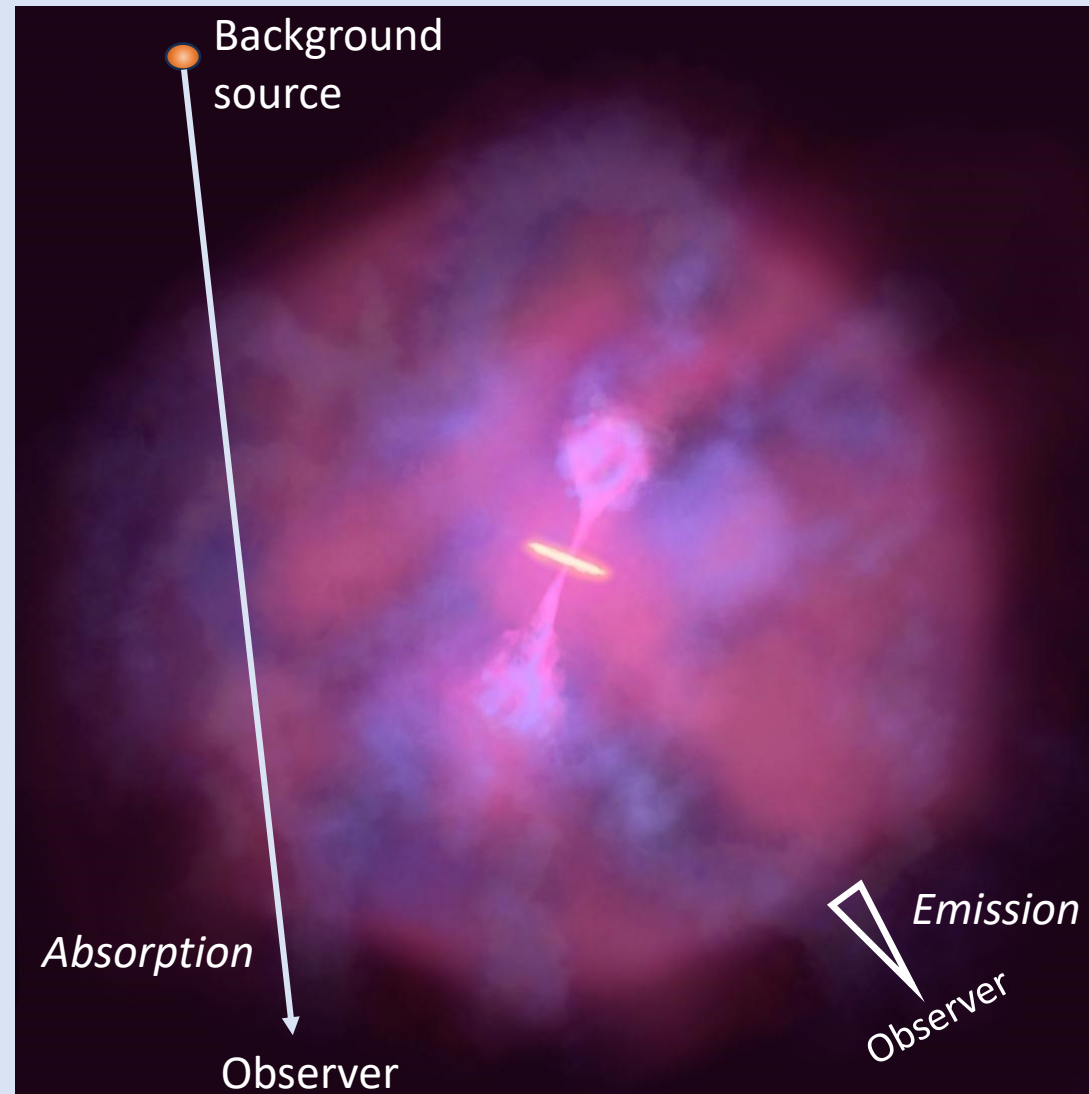
The gas too diffuse to emit continuum

- Hydrogen is fully ionized
- Other metals are highly ionized
- The most abundant metal Oxygen mostly in H-like and He-like states

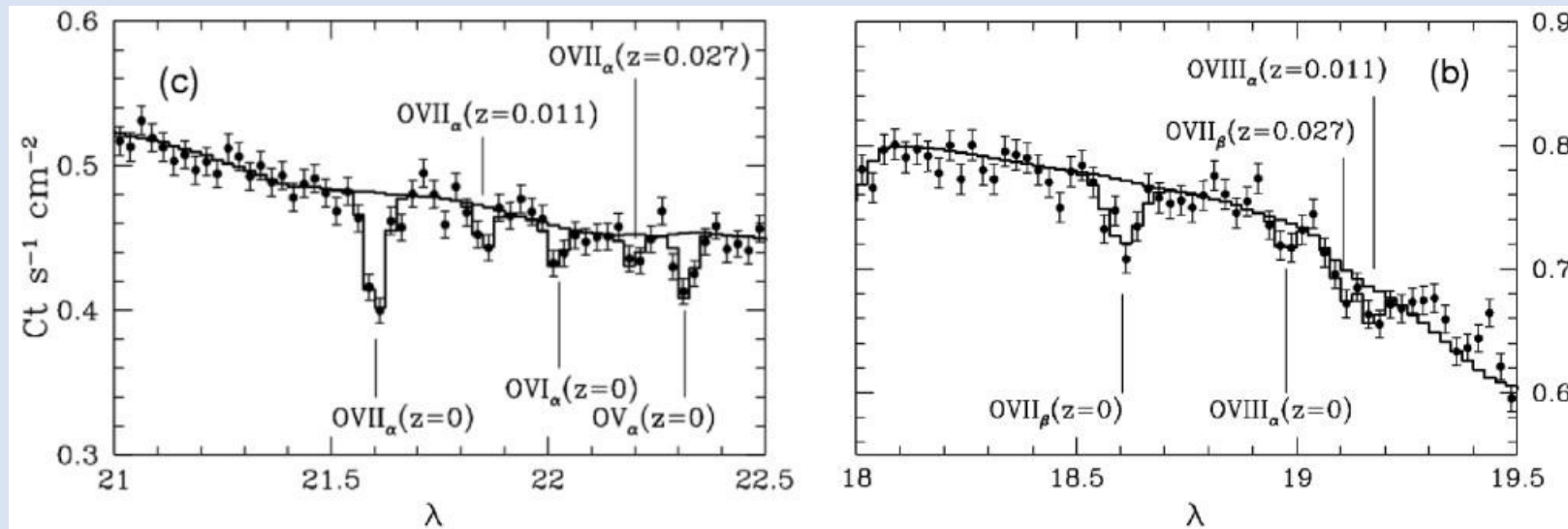
OVII: six times ionized O

OVIII: seven times ionized O

Milky Way CGM in Absorption and Emission

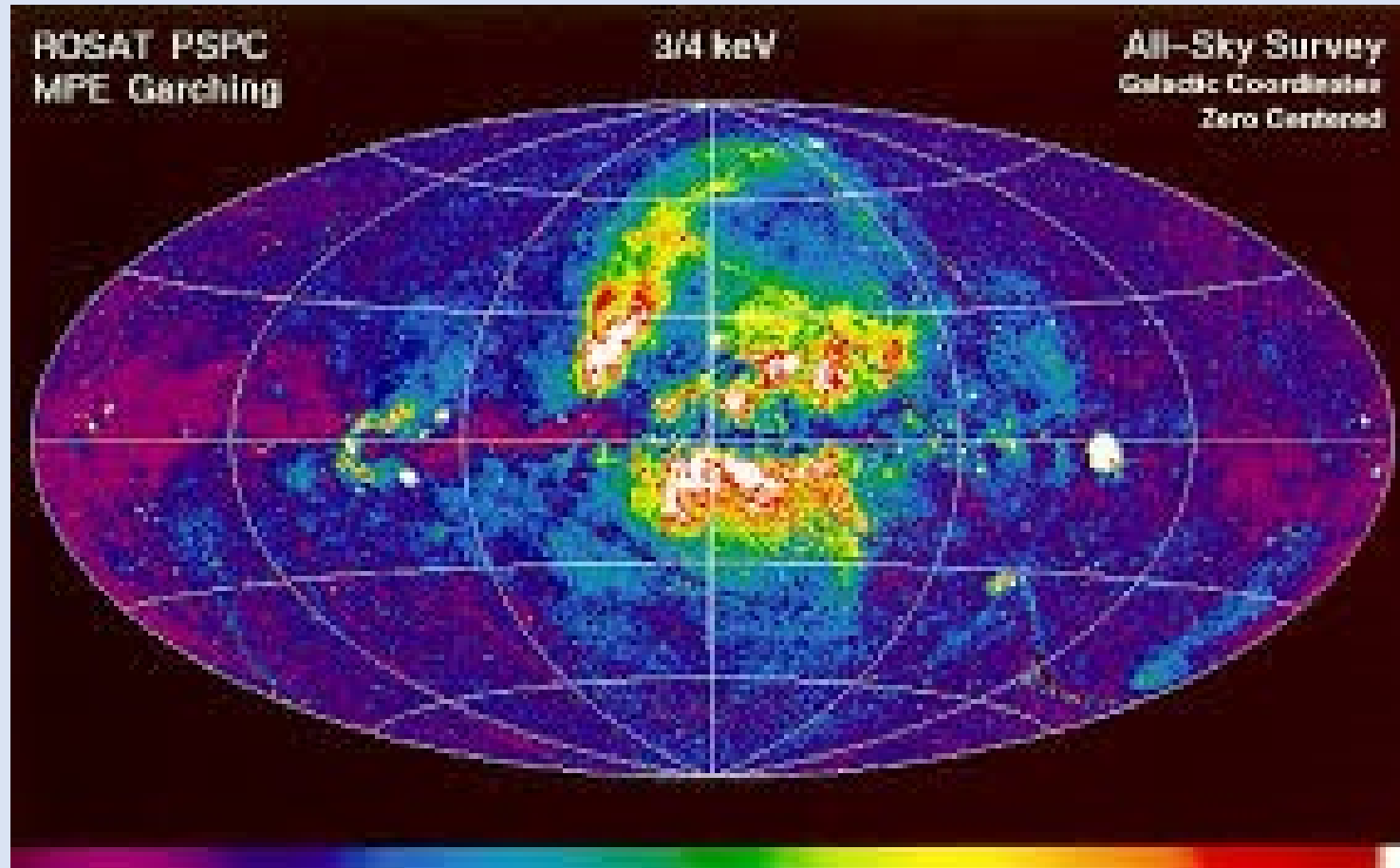


Z=0 X-ray absorption

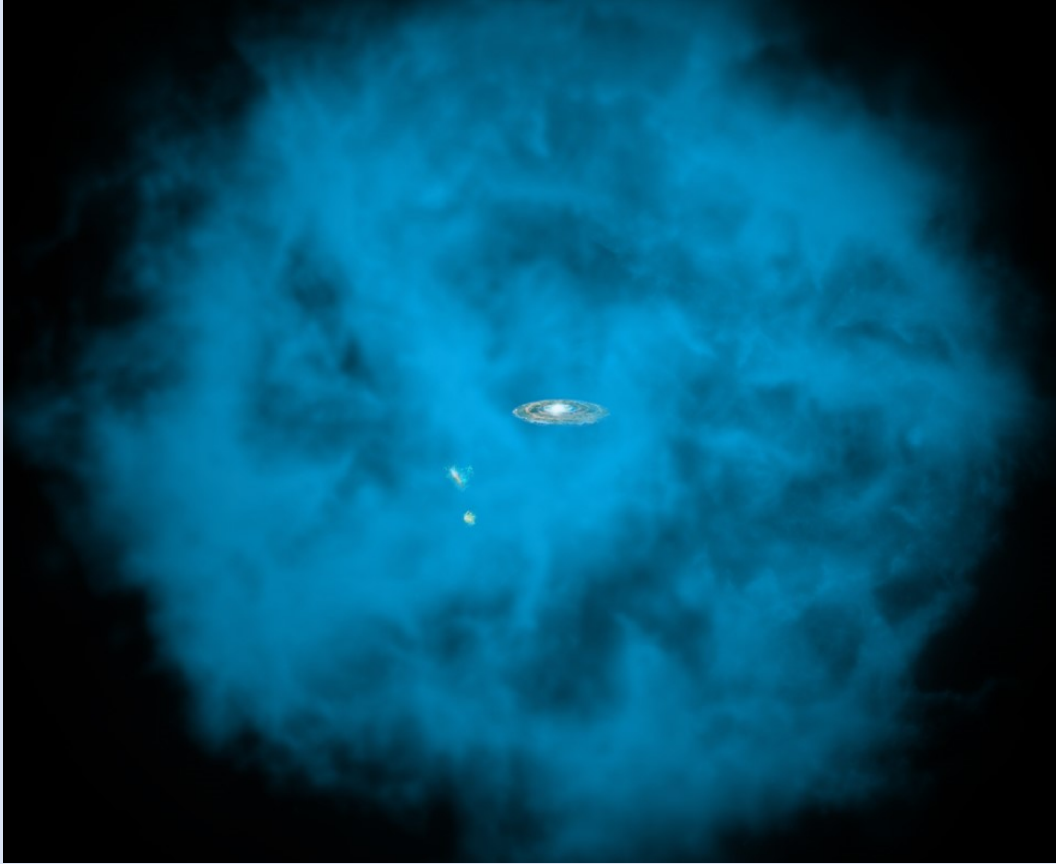


Nicastro, Mathur+ 2003
Williams, Mathur+ 2005

ROSAT All Sky Survey: Soft Diffuse X-ray Background



Massive, Extended, hot Galactic halo



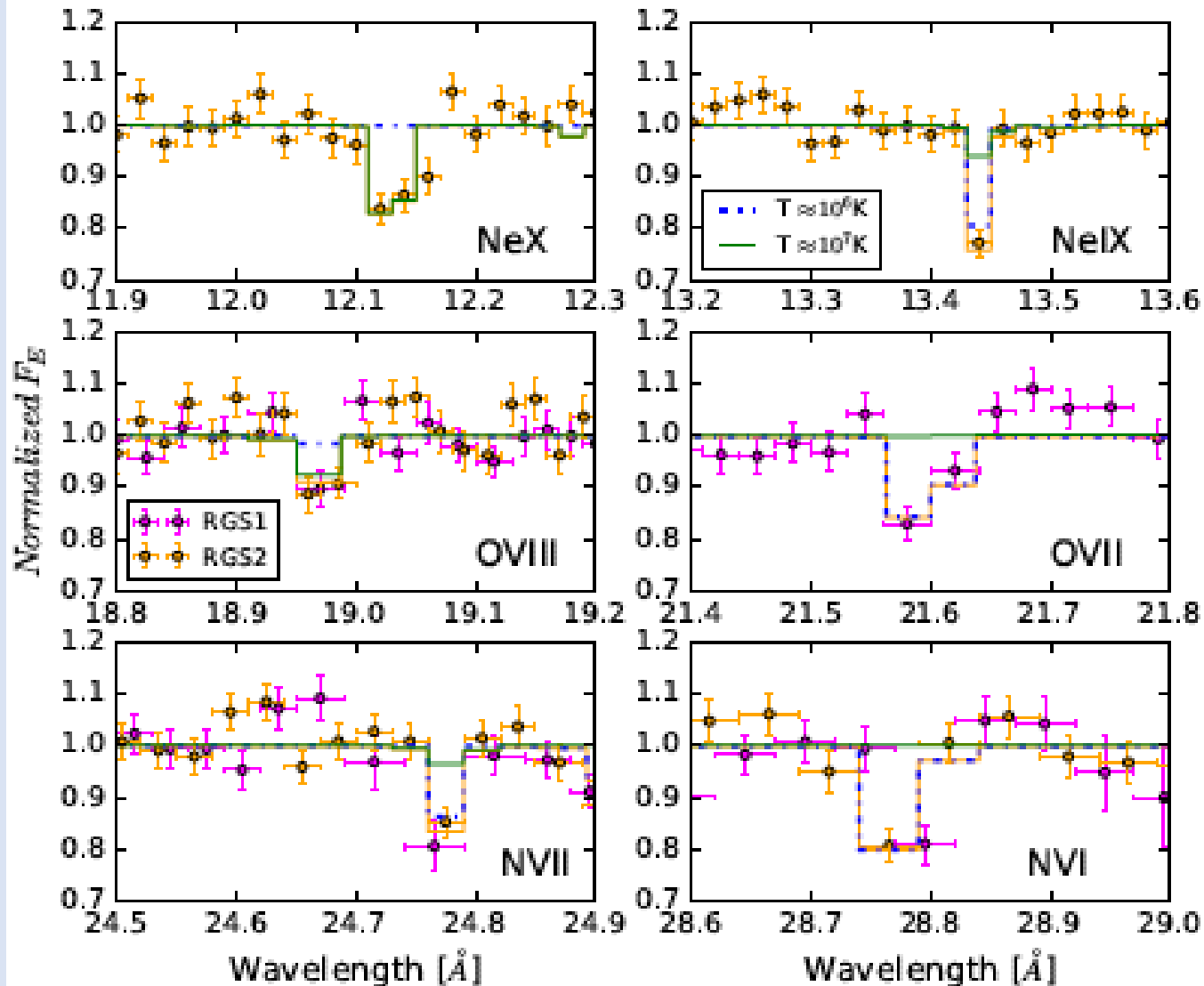
Temperature $\sim 2 \times 10^6$ K

[X/O] = Solar

X = N, Ne, Fe, Mg

Courtesy: Chandra press office/Gupta et al.

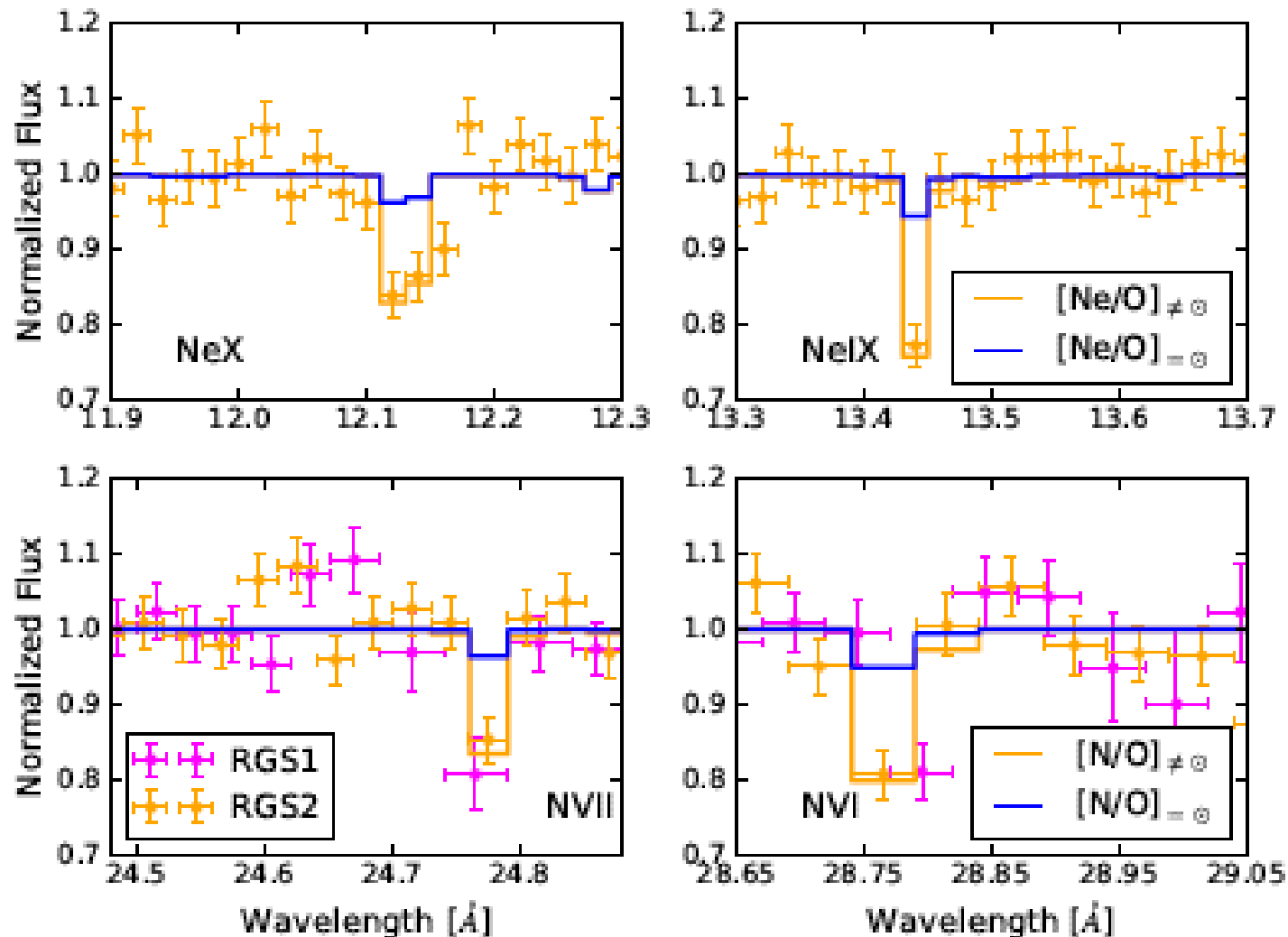
Result 1: Discovery of a hot ($T = 10^7 \text{ K}$) component



$T_{\text{warm-hot}} \sim 1.3 \times 10^6 \text{ K}$
 $T_{\text{hot}} \sim 1.3 \times 10^7 \text{ K}$

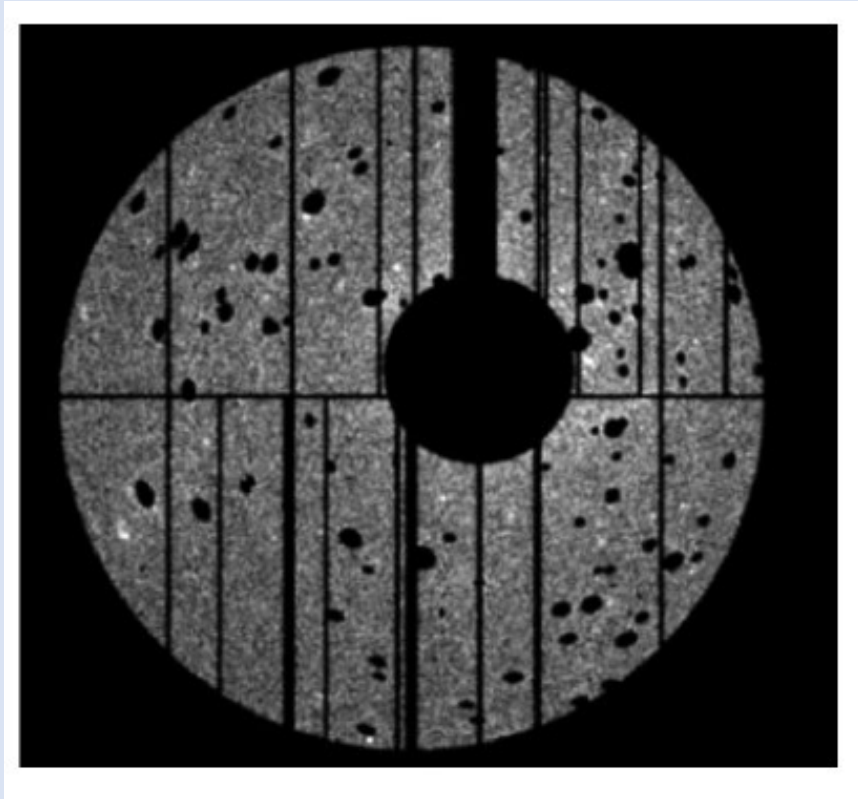
Das+2019

Result 2: Non-solar mixture



Das+2019

Milky Way CGM emission around the same sightline

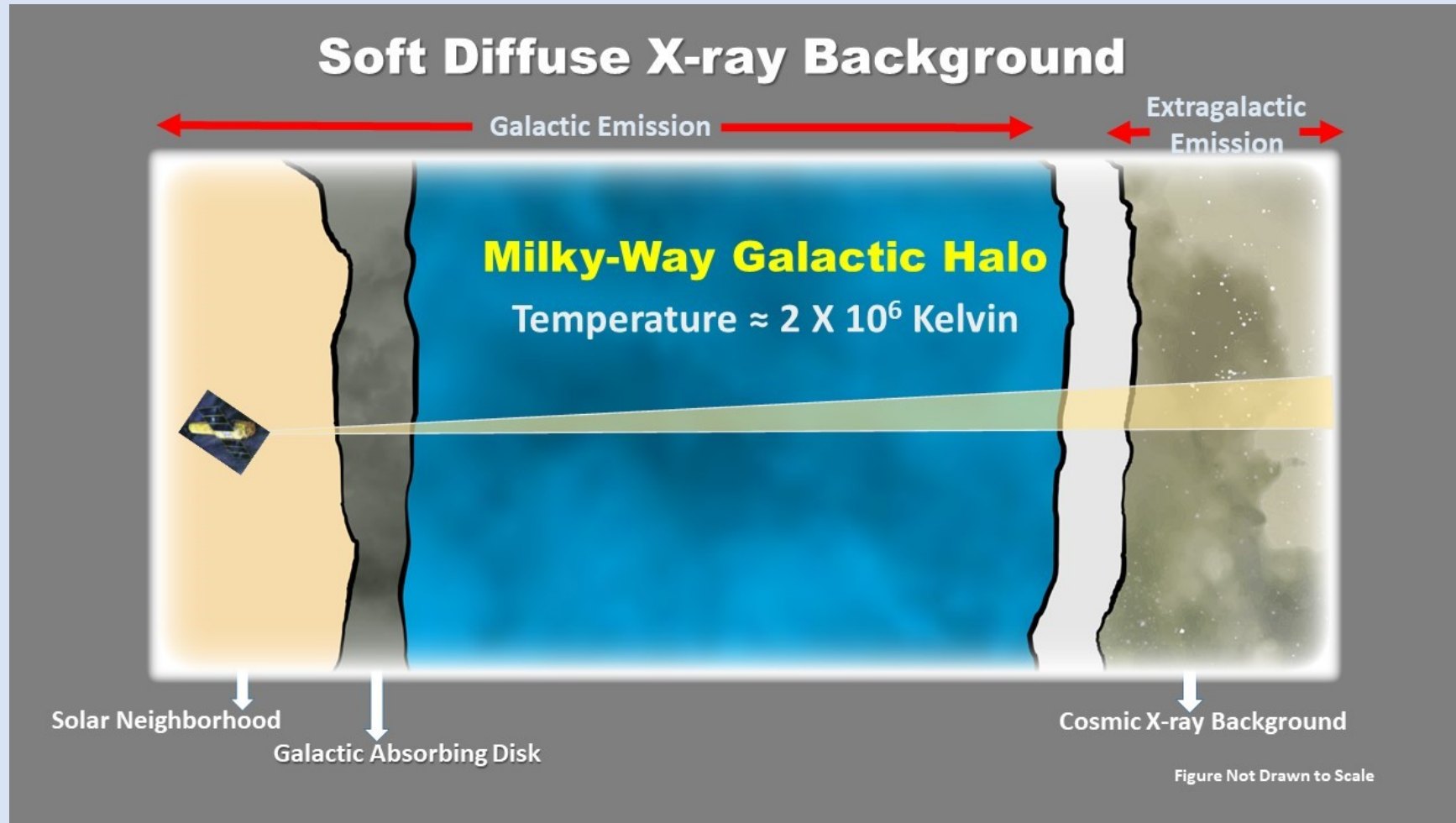


$$T_{\text{warm-hot}} = 1.8\text{-}2.6 \times 10^6 \text{ K}$$

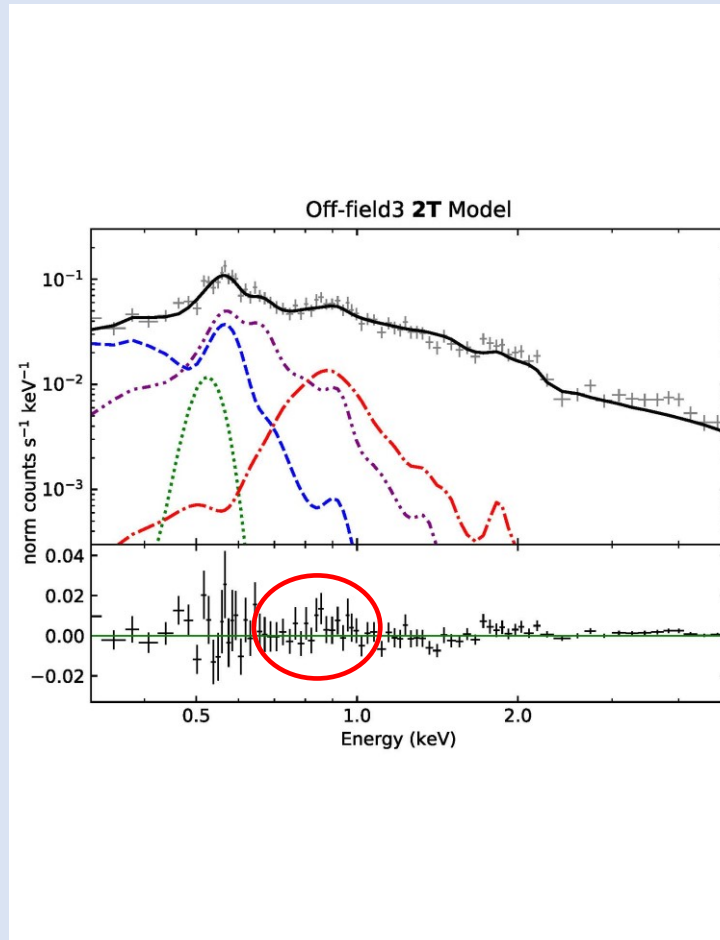
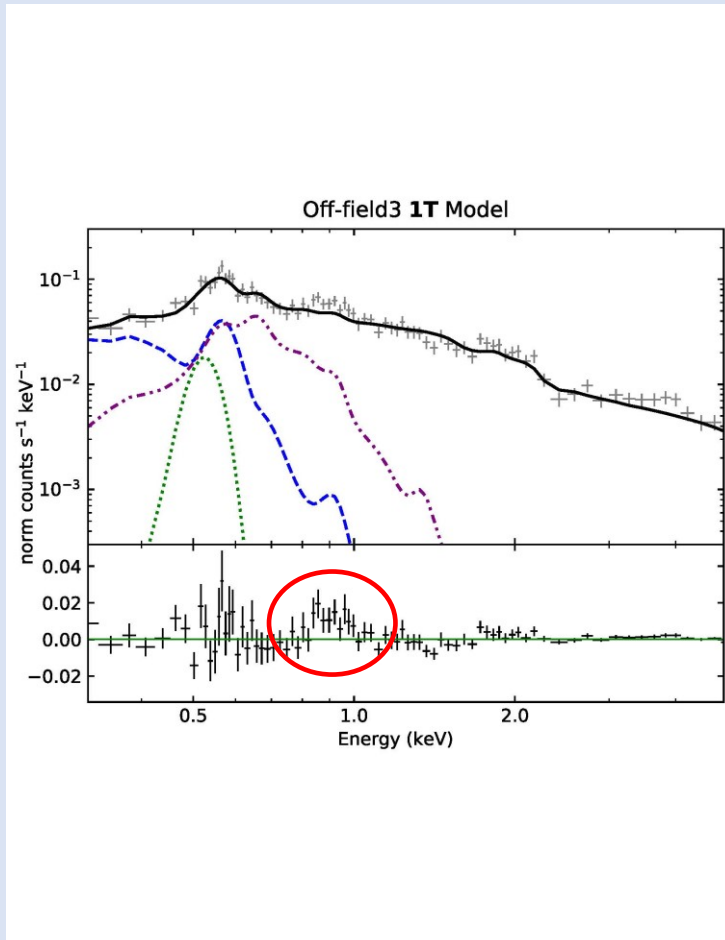
$$T_{\text{hot}} = 4.8\text{-}8.3 \times 10^6 \text{ K}$$

Das, Mathur, Gupta+2019c

Soft Diffuse X-ray Background

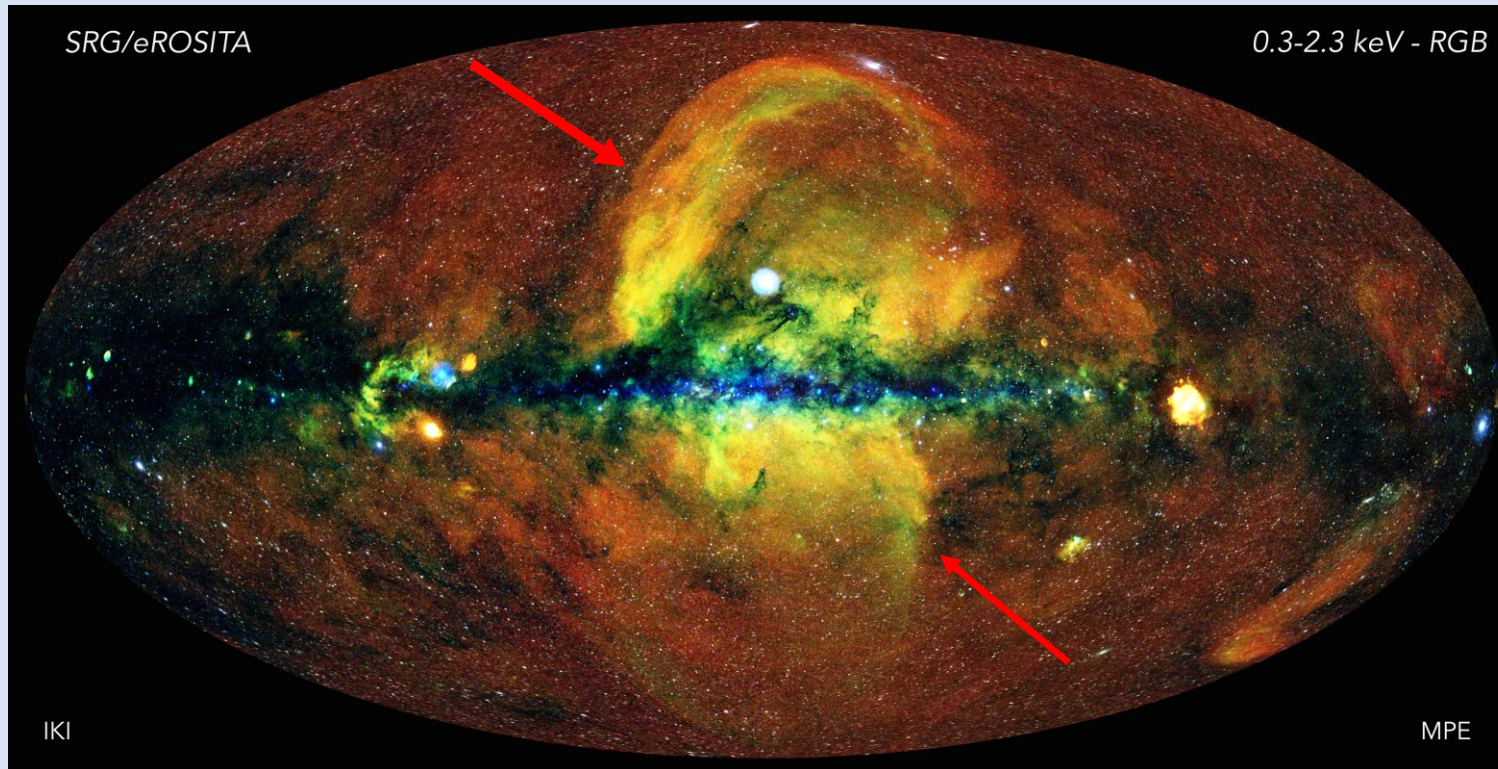


Suzaku Observations: Super-virial temperature



Gupta +21

eROSITA First All-Sky Survey

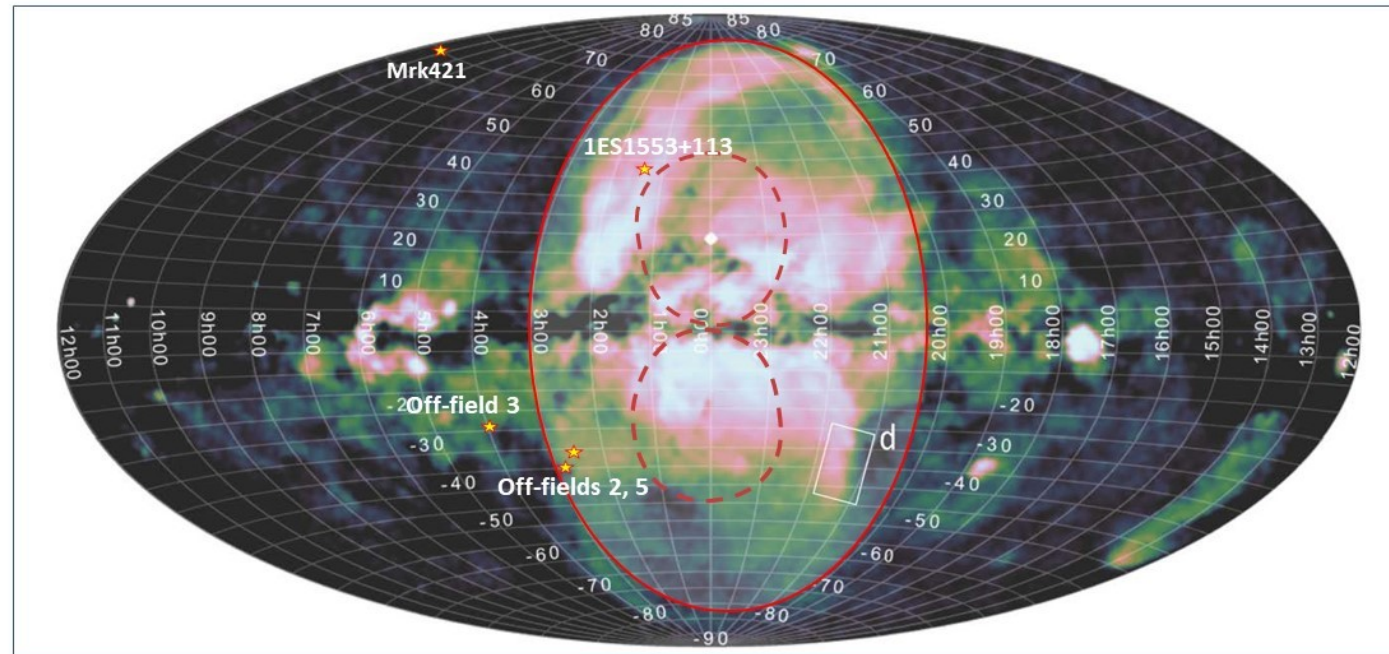


Predehl et al. 2020, Nature, 588, 7837

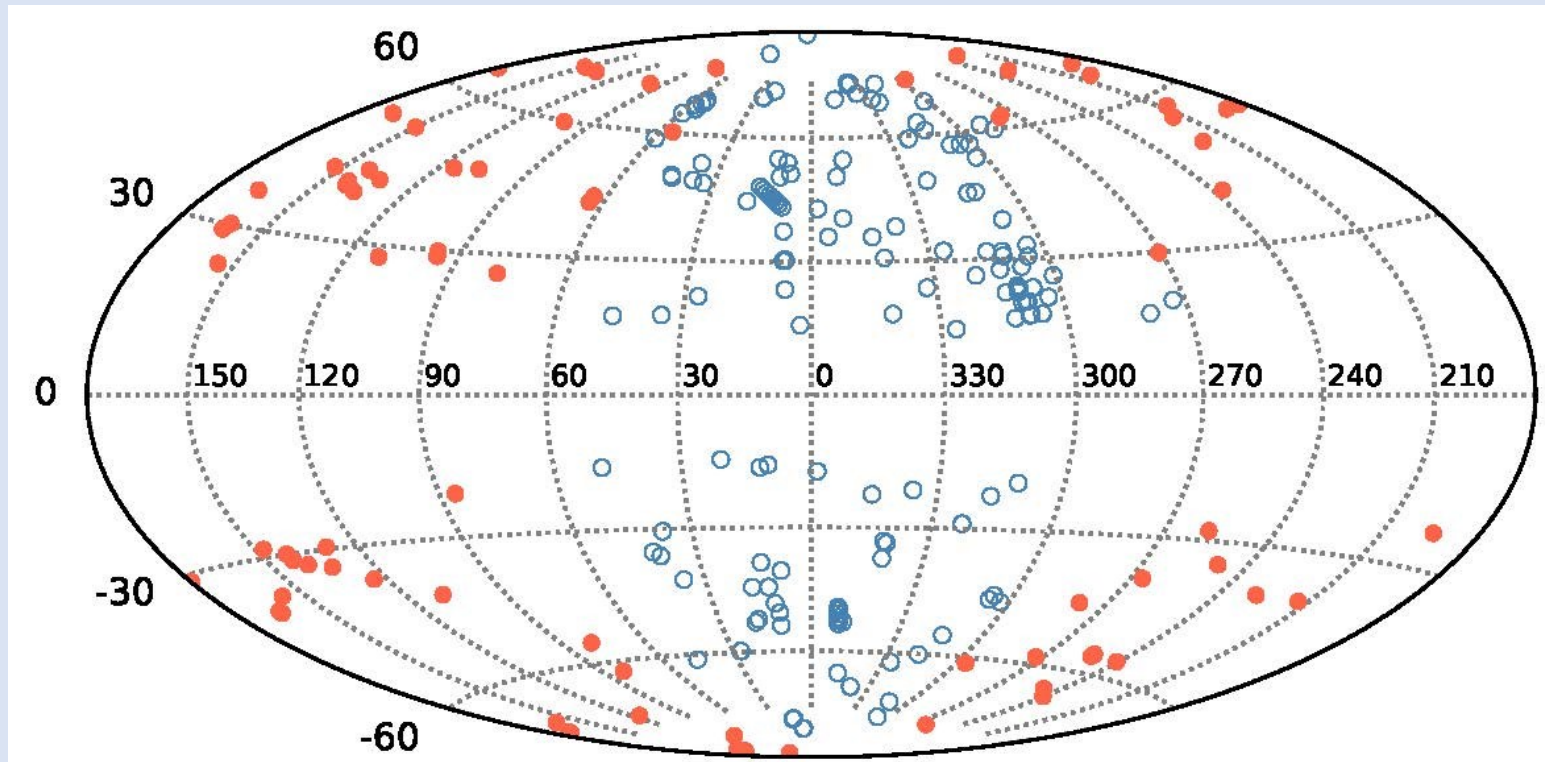
Image: <https://www.mpe.mpg.de/7461950/erass1-presskit>

Credit: Jeremy Sanders, Hermann Brunner and the eSASS team (MPE); Eugene Churazov, Marat Gilfanov (on behalf of IKI)

Hollistic View of the Milky-Way Diffuse X-ray Emission



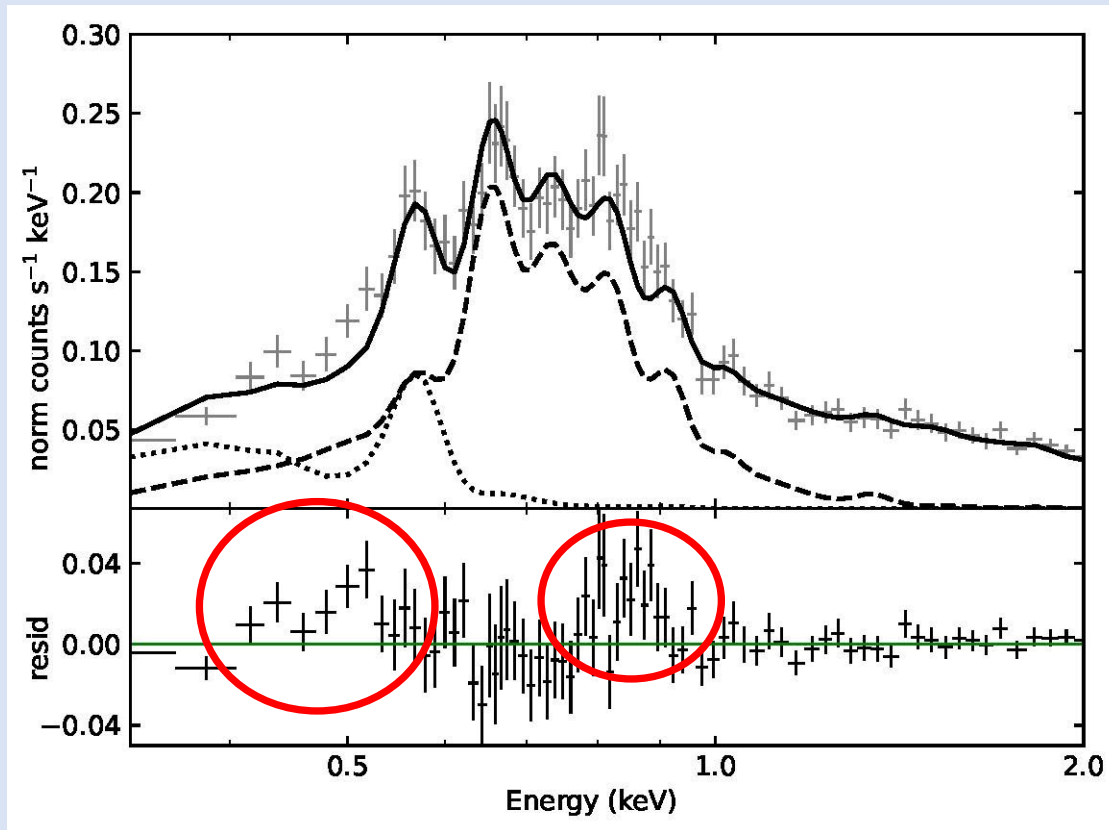
Our Recent Suzaku Survey: The Galactic Bubbles and the Surrounding Halo



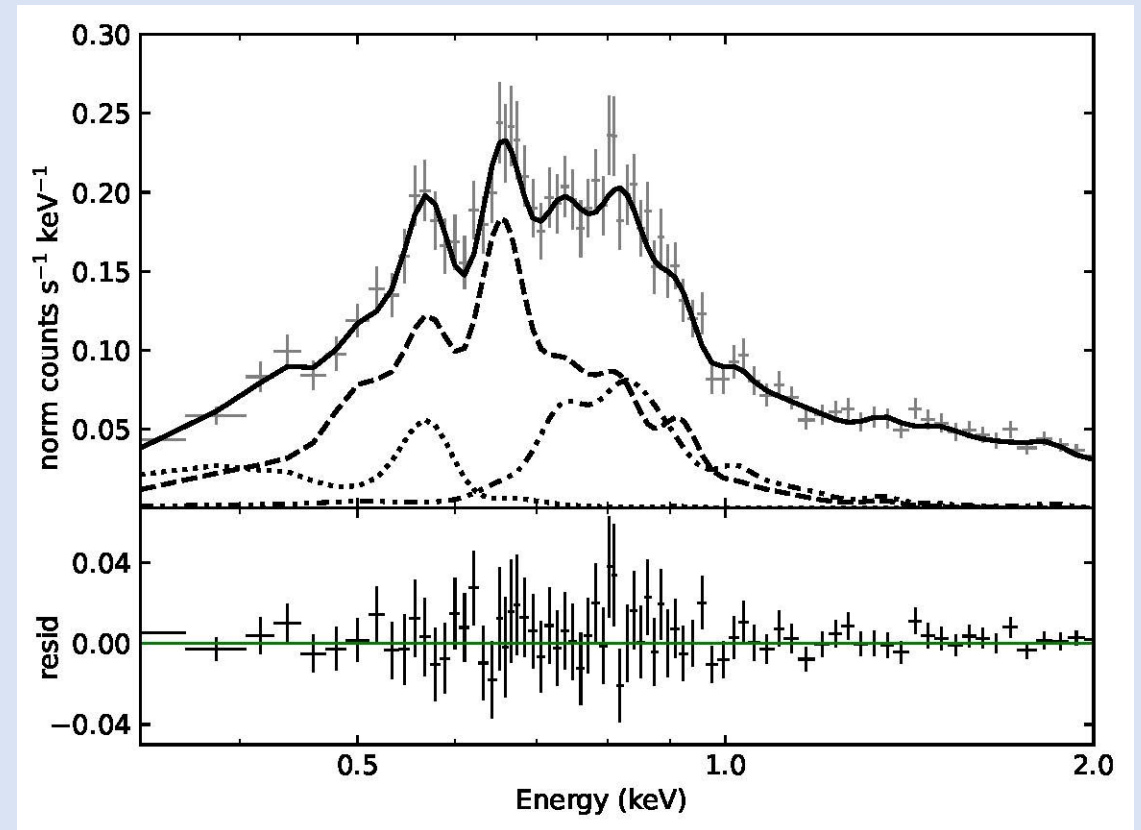
- Galactic Bubbles Sightlines = 150
- Surrounding Halo Sightlines = 80

Milky-Way (MW) Halo/Bubbles Thermal Models

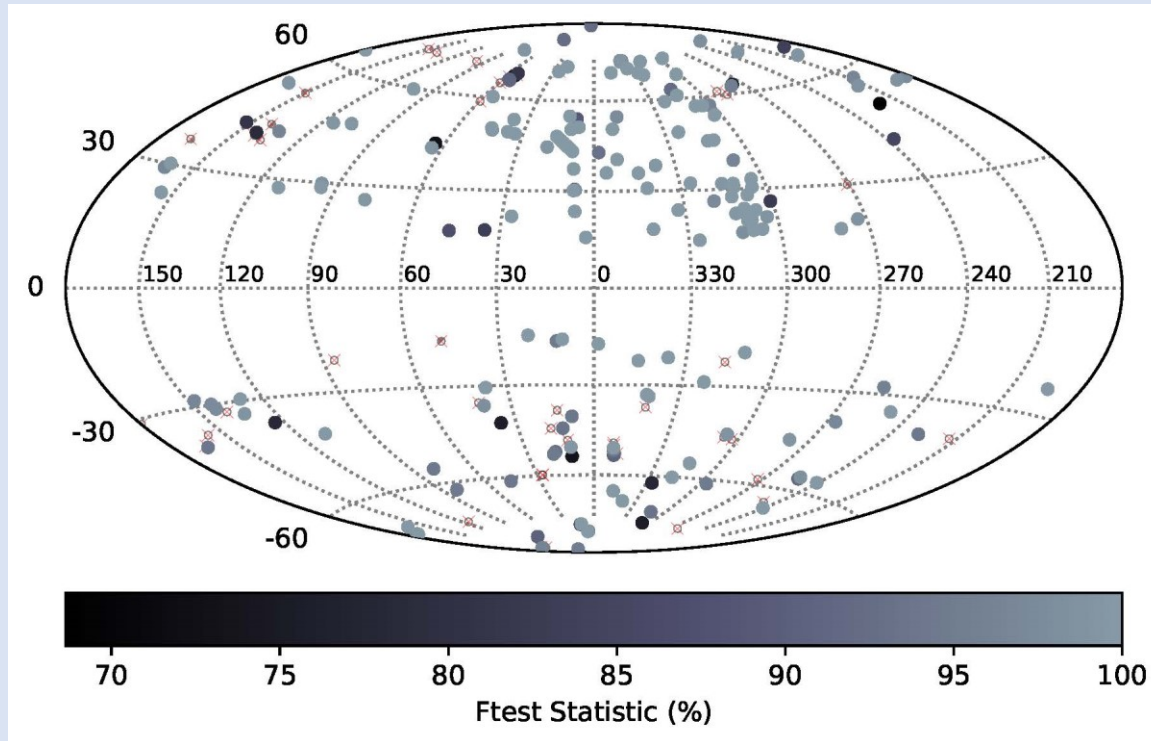
One-Temperature MW Halo Model



Two Temperature with Super-solar Nitrogen



F-test probability map: Hot Thermal Component



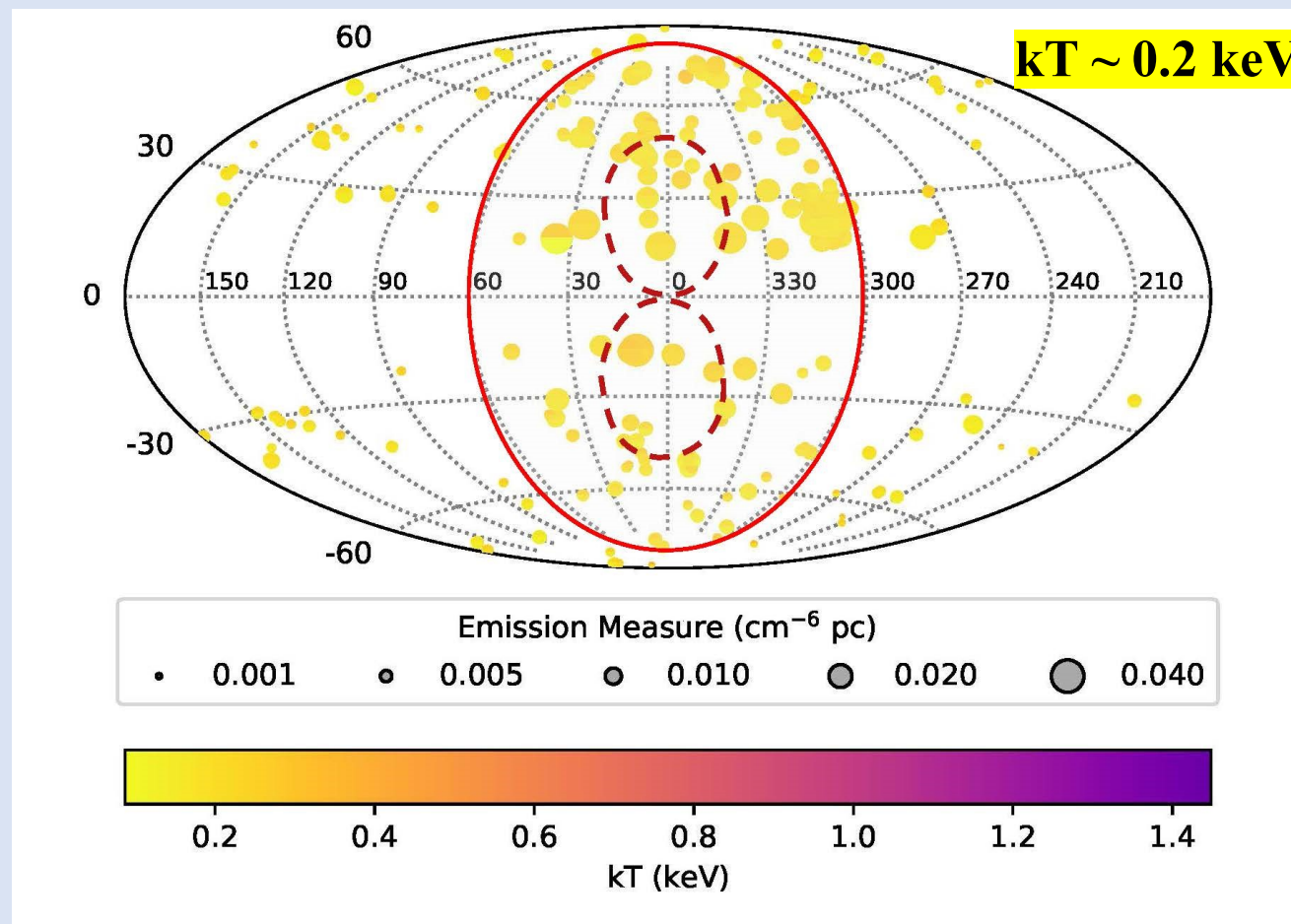
Galactic Bubbles Sightlines

- >99.99% in 55 sightlines
- >90.00% in 80 sightlines

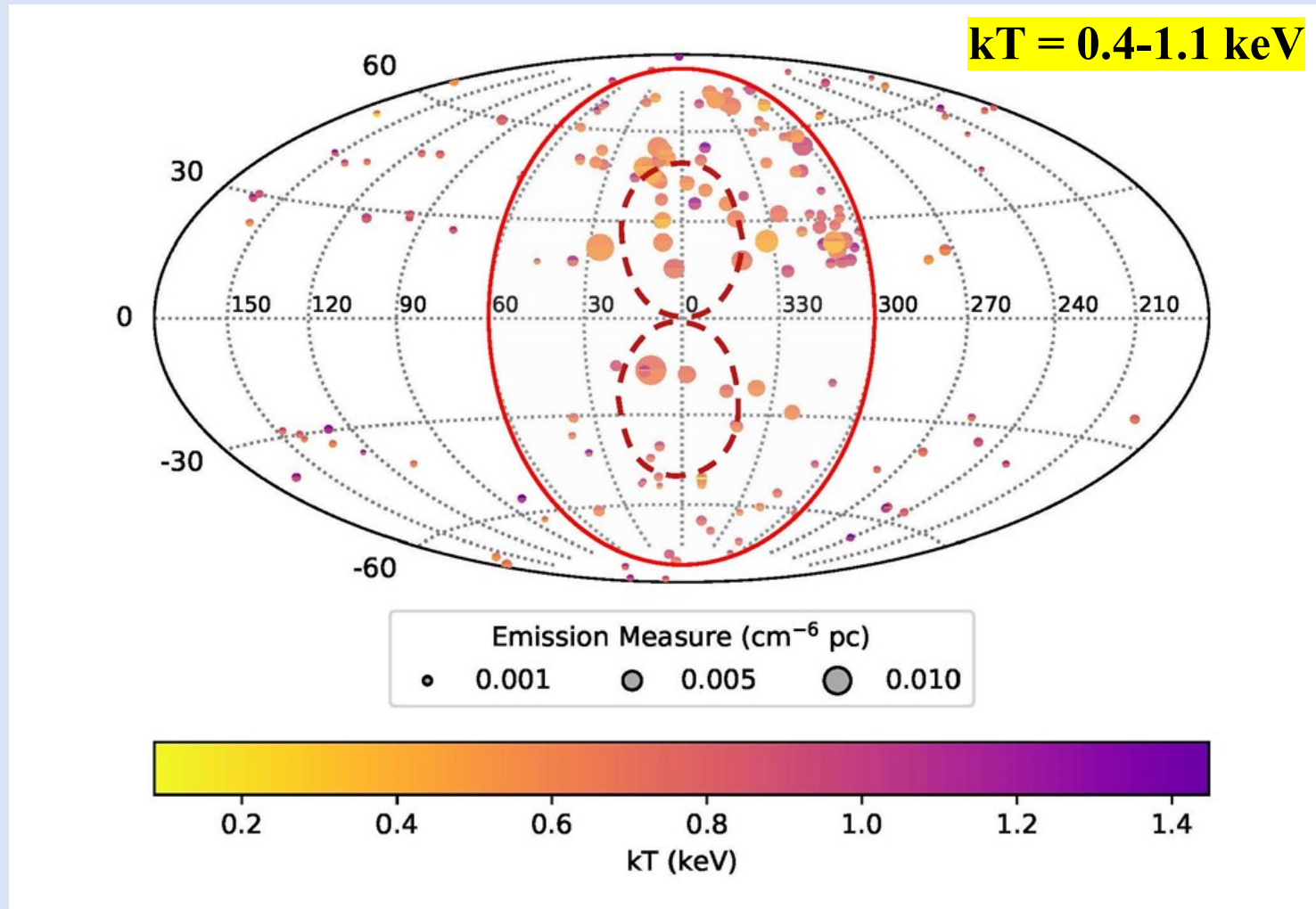
Outside Bubbles Sightlines

- >99.0% in 26 sightlines
- >90.0% in 51 sightlines

X-ray emission maps from our Suzaku survey: Warm-Hot Virial Temperature Component

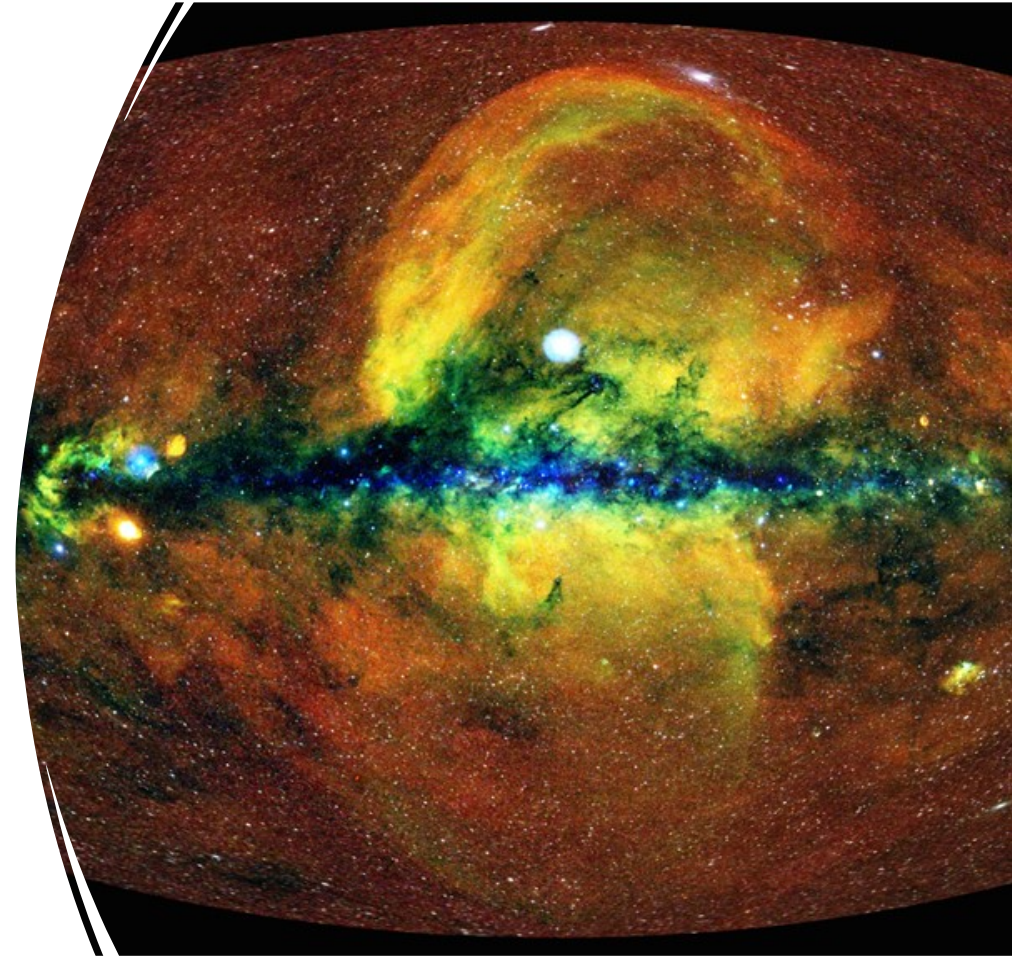


X-ray emission maps from our Suzaku survey: Hot Super Virial-Temperature Component

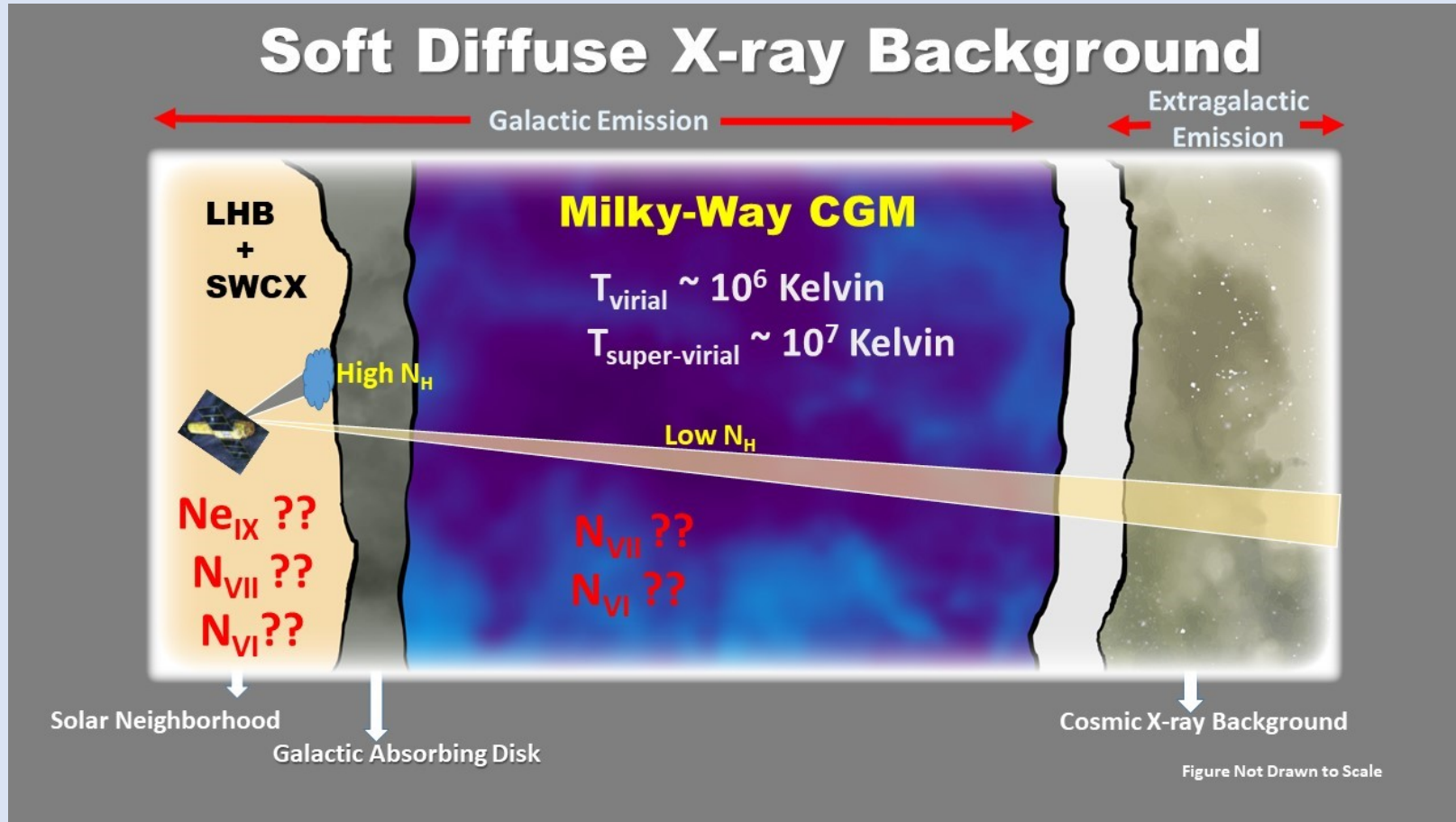


Distribution of Thermal Parameters

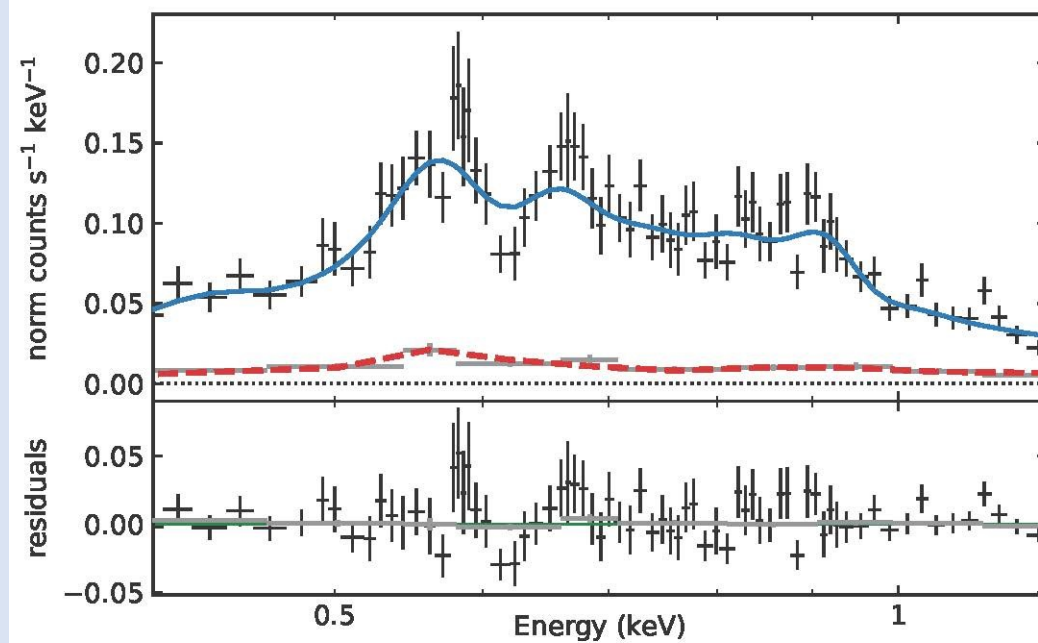
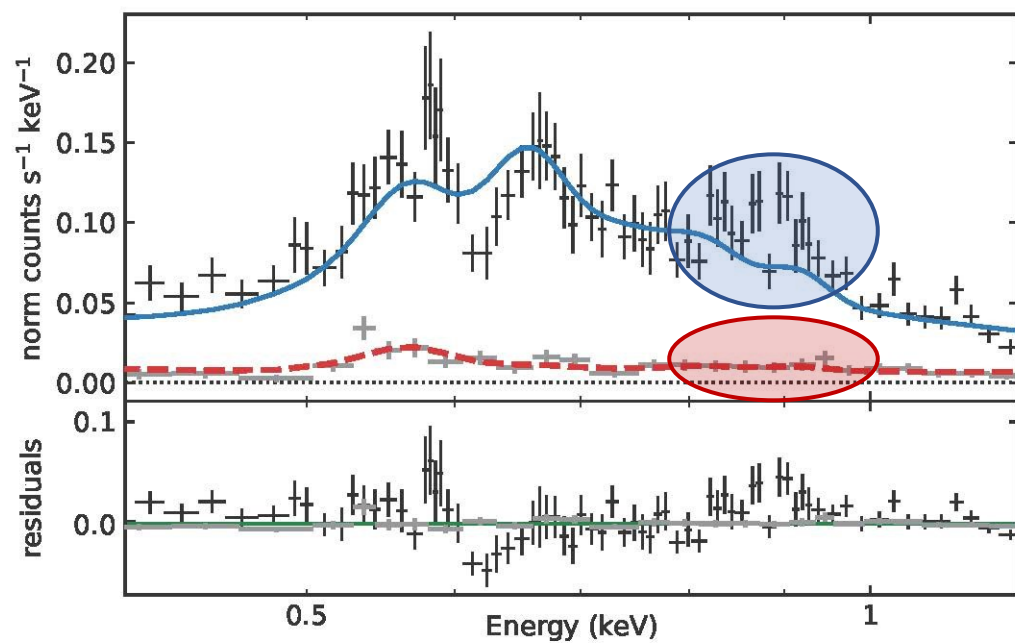
- The temperatures of the warm-hot and the hot components are similar in/outside the bubbles shells.
- Emission Measures are significantly higher for sightlines piercing the bubbles compared to the outer halo sightlines.
- Overabundance of Nitrogen is widespread all over the sky.
- Toward few Galactic bubbles sightlines (but not outside the bubbles), there is evidence of super-solar Neon and Magnesium.



Shadow Observations



Shadow Observations



Revised Model of Milky-way CGM X-ray Emission

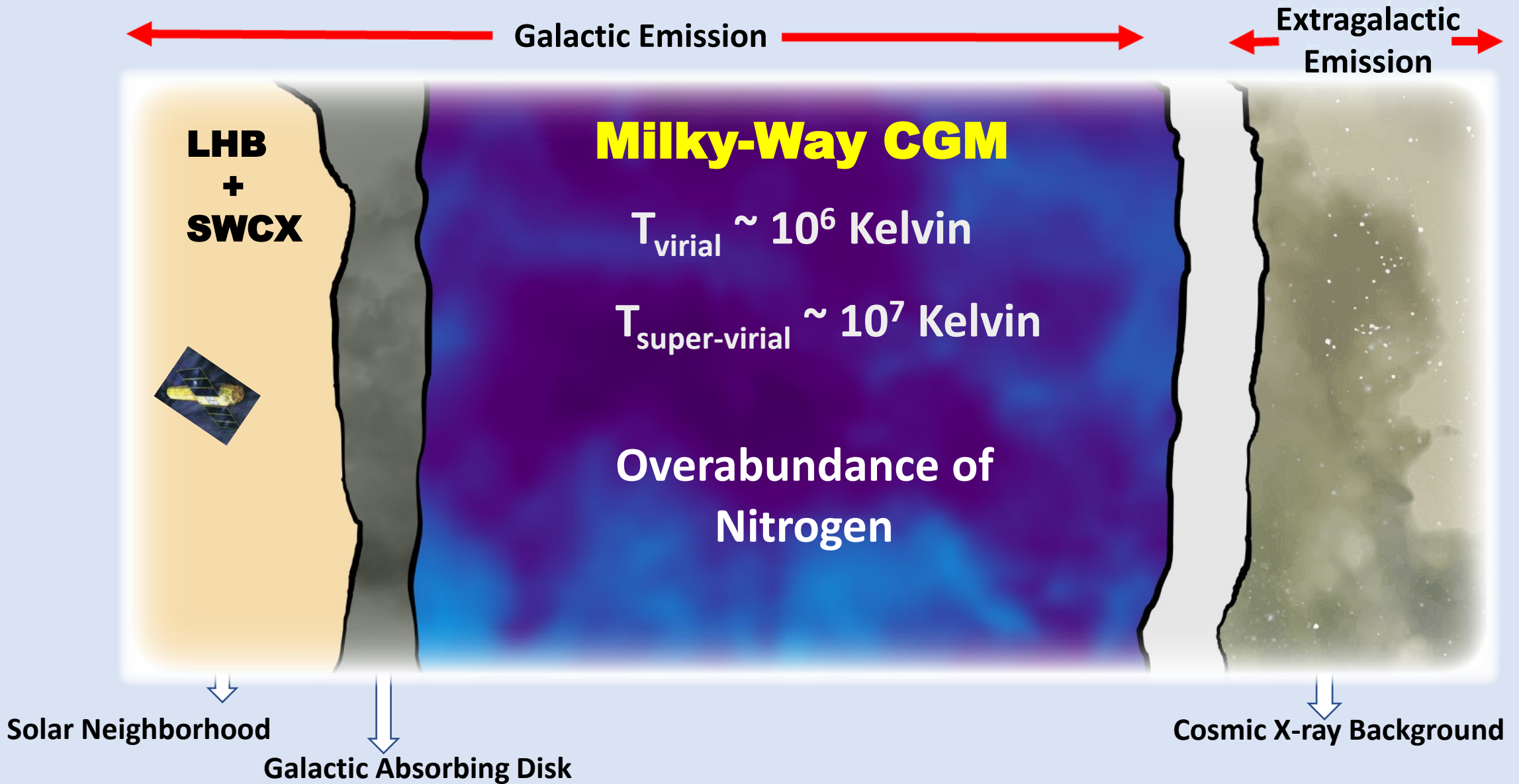


Figure Not Drawn to Scale

A Schematic of the Milky-way CGM



Open Questions

- How is the CGM heated to such high temperatures?
- what leads to multiple-temperature hot components?
- what kind of supernova feedback is responsible for enriching the CGM with metals?
- is oxygen depleted?

Summary

- Hot warm-hot gas exists in the CGM of the Milky Way at the virial temperature.
- The Milky Way CGM is warm-hot, diffuse, extended and massive, accounting for the missing baryons.
- Discovery of the hot super-virial gas in the MW CGM
- Gas has non-solar abundance ratios of observed elements

Thank You