Unveiling the Thermal Structure and Super-Solar Nitrogen Abundance in the Milky Way's CGM

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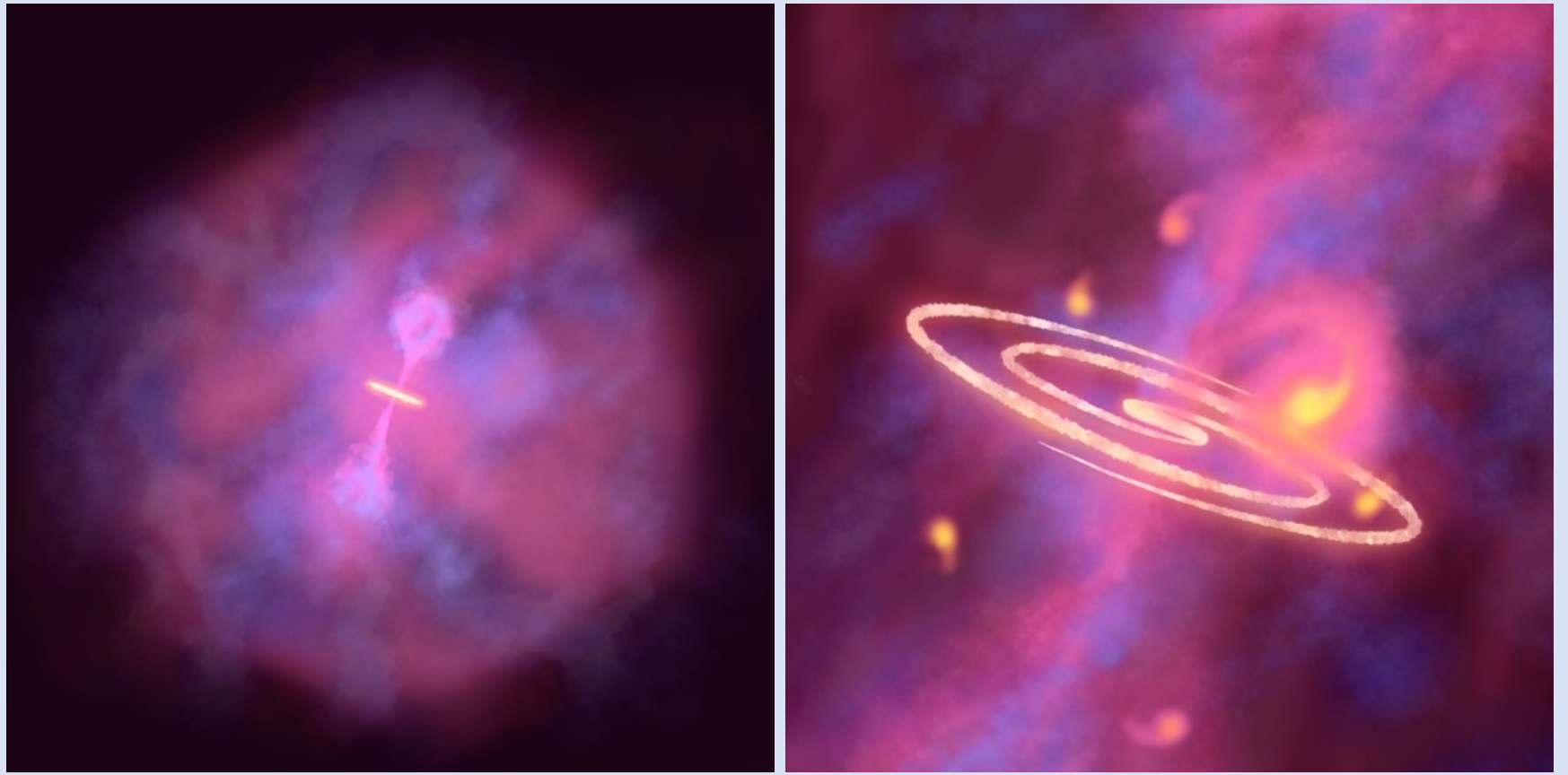
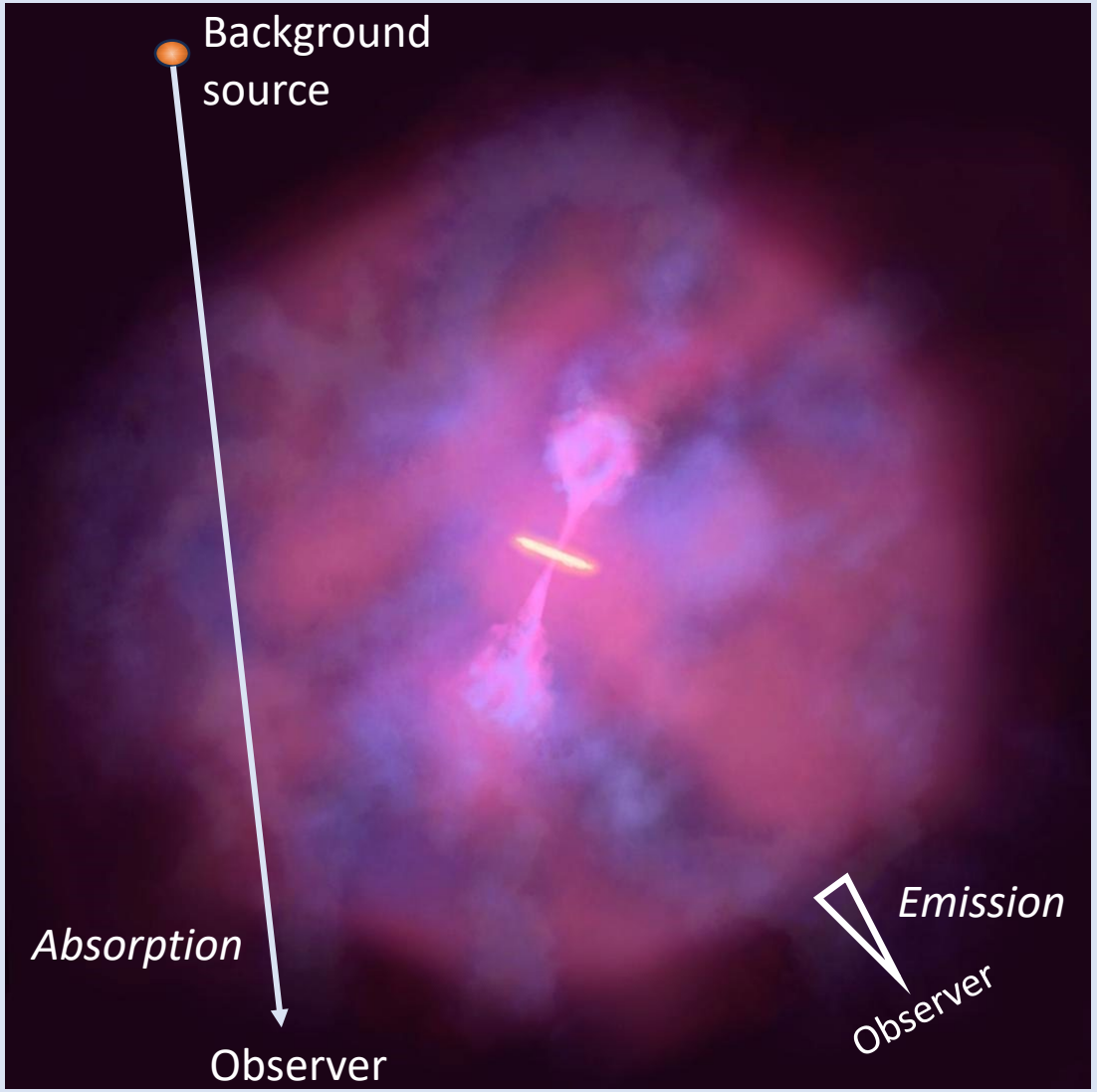
The Circumgalactic Medium (CGM)



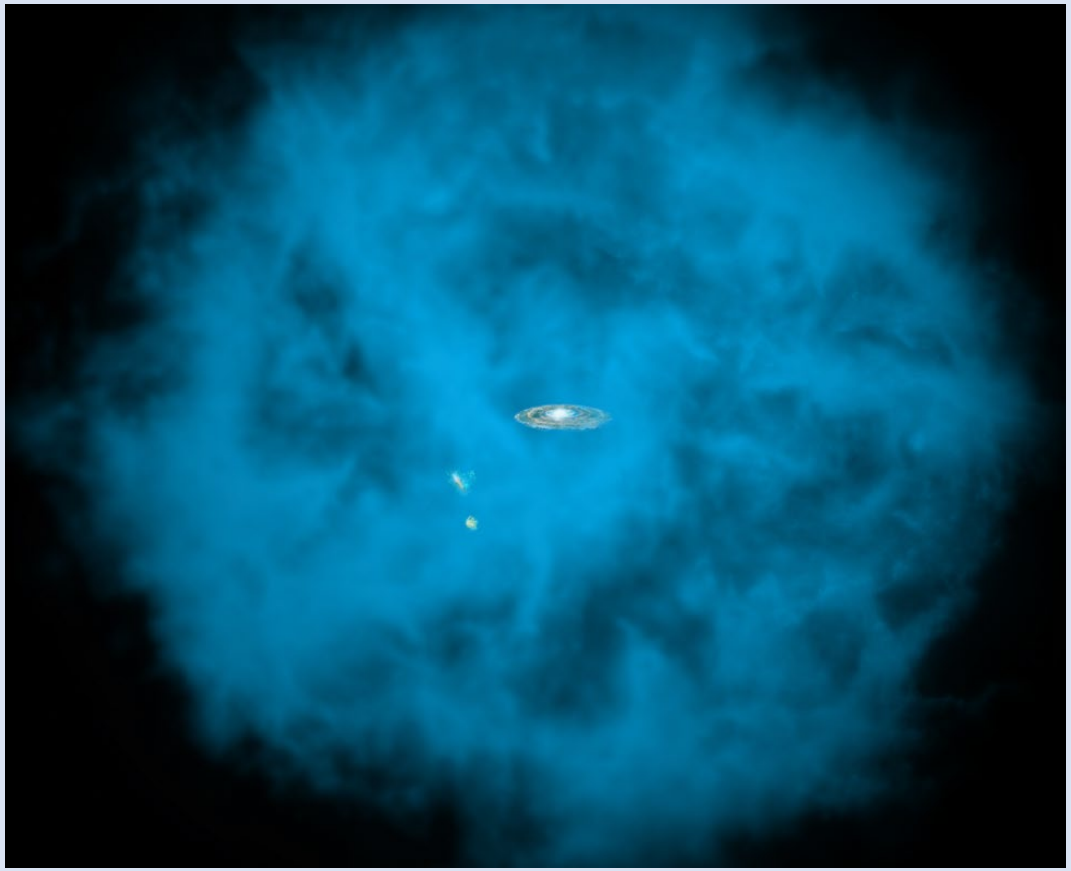
Mathur 2022

The CGM is now recognized as a **key regulator** of galaxy evolution: it's where galaxies **gain**, **store**, and **lose** their baryons and metals.

Milky Way CGM in Absorption and Emission



Massive, Extended, hot Galactic halo



Temperature ~ 2 X 10^6 K

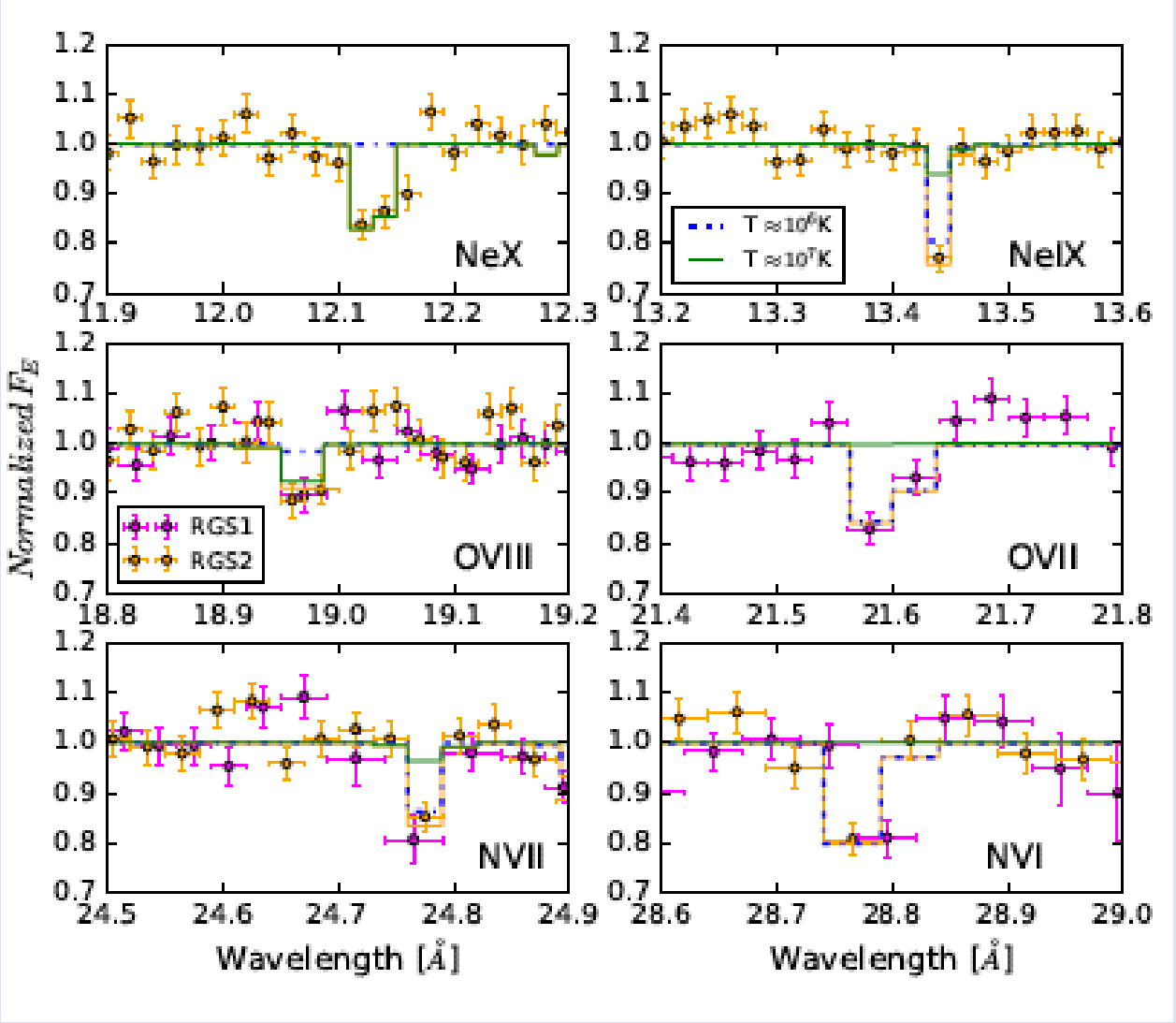
Z = 0.3 Z_{solar}

(X/O) = Solar

X = N, Ne, Fe, Mg …..

Courtesy: Chandra press office/Gupta et al.

Discovery of a hot (T= 10^7K) component

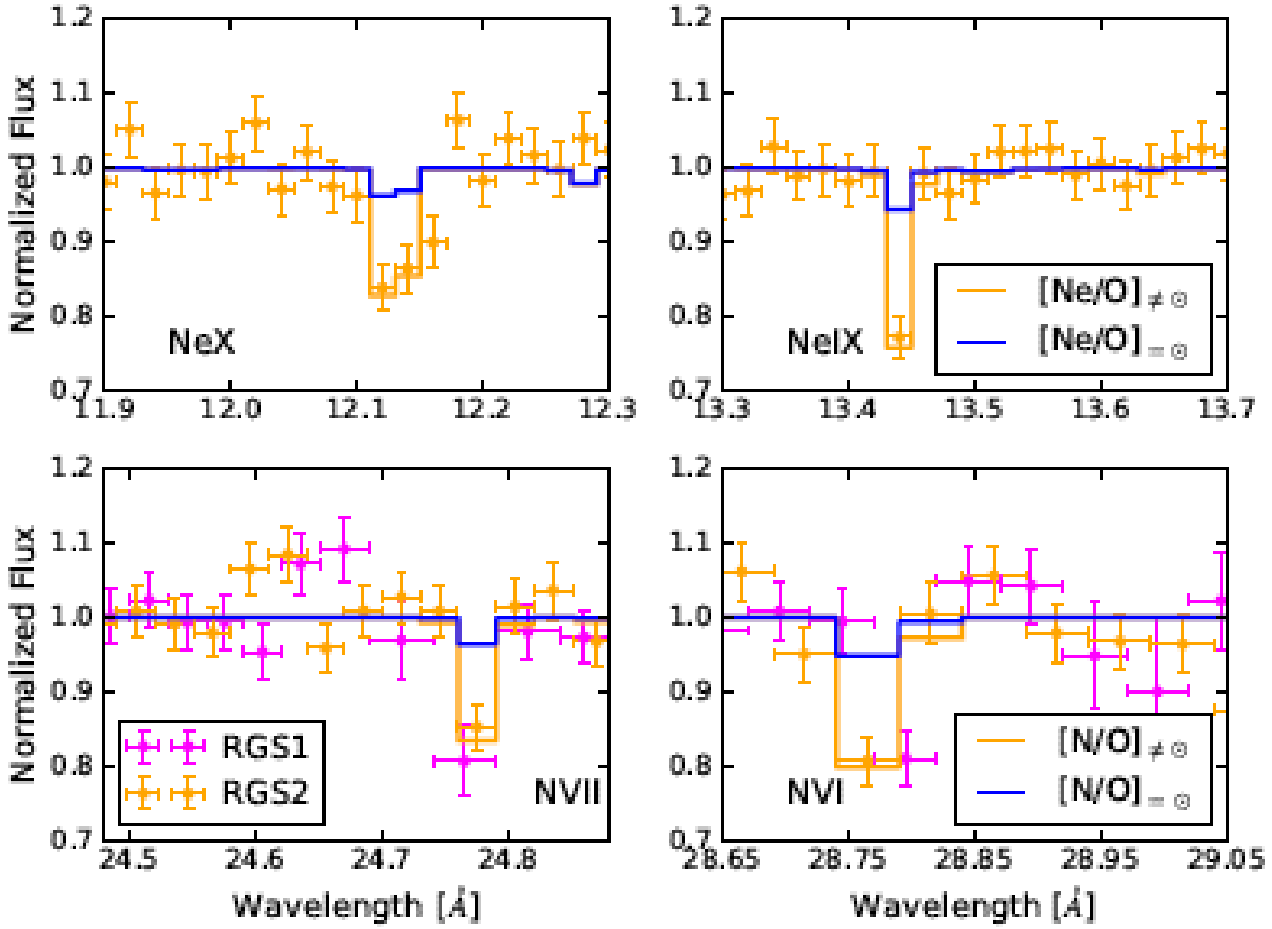


$T_{warm\text{-}hot}$ ~ 1.3 X 10^6 K

T_{hot} ~ 1.3 X 10^7 K

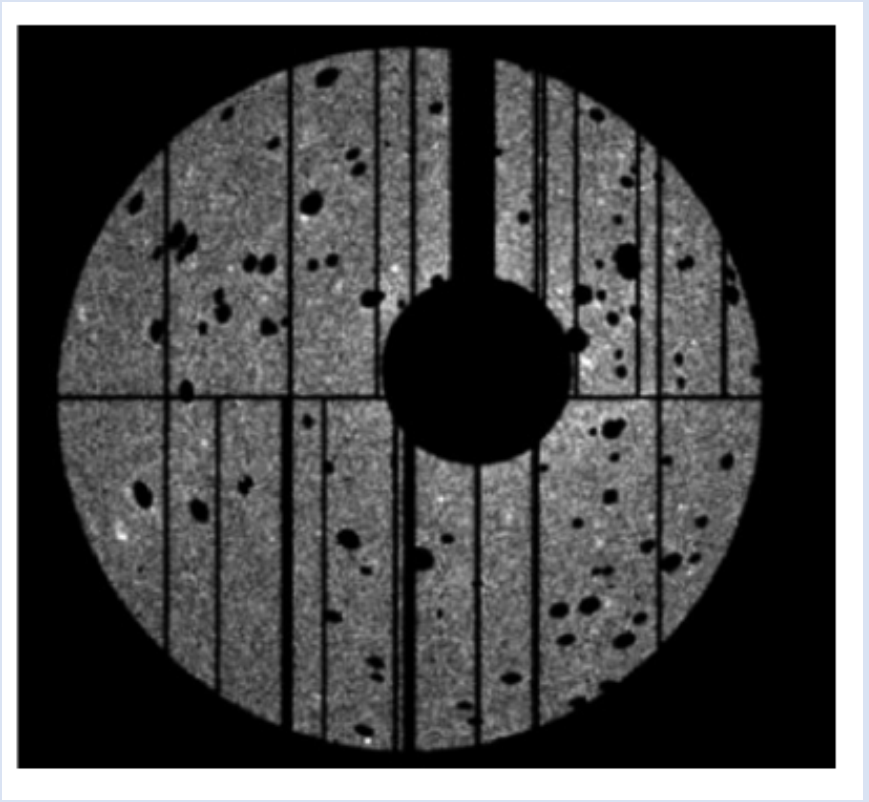
Das+2019

Non-solar mixture



Das+2019

Milky Way CGM emission around the same sightline

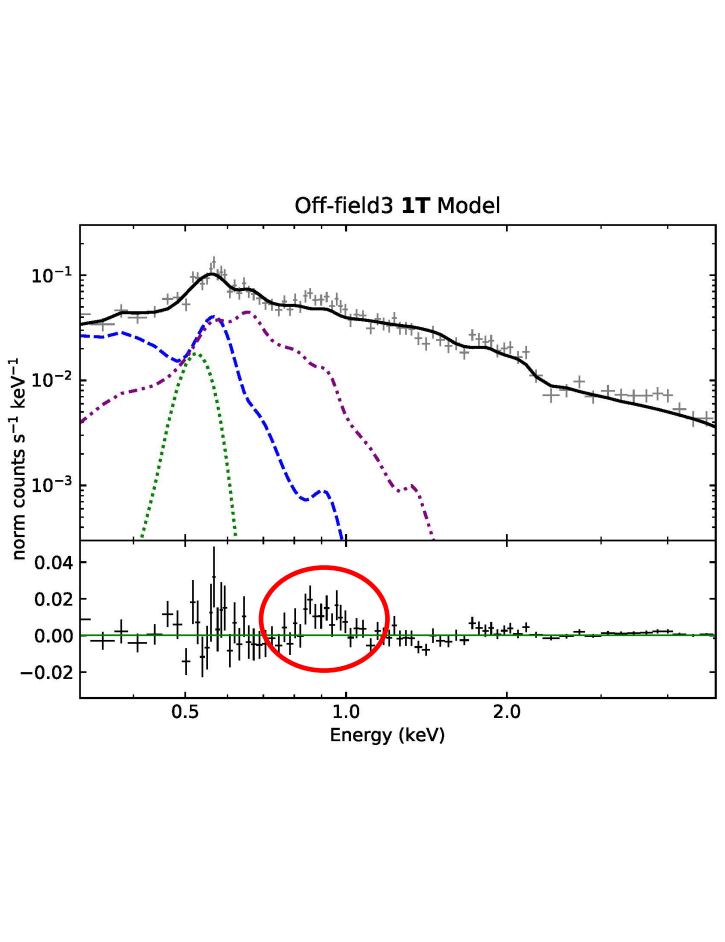


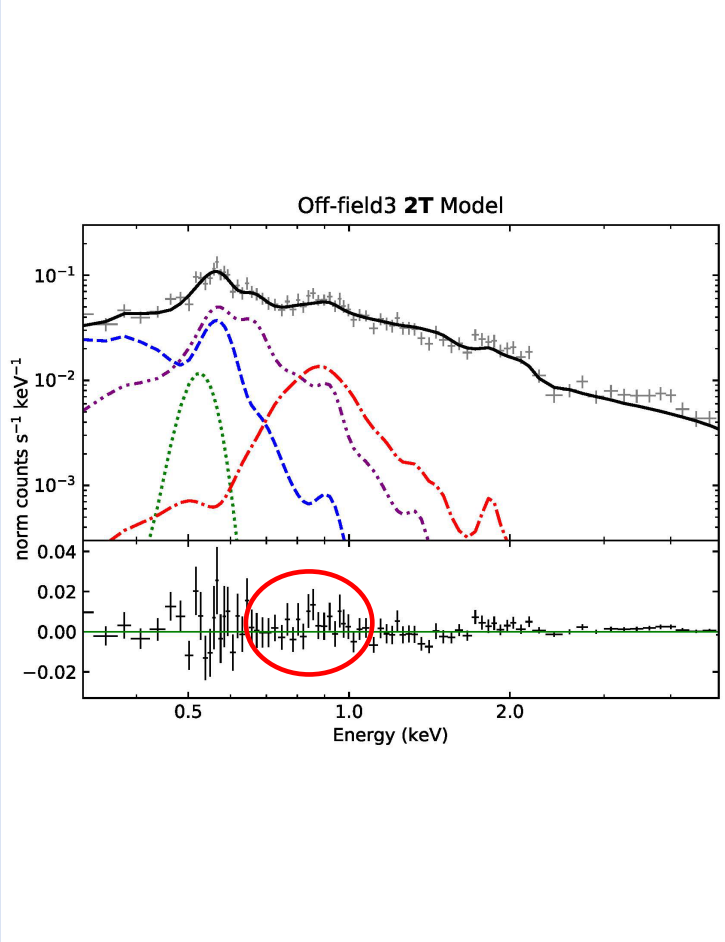
$T_{warm-hot}$ = 1.8-2.6 X 10^6 K

T_{hot} = 4.8-8.3 X 10^6 K

Das, Mathur, Gupta+2019c

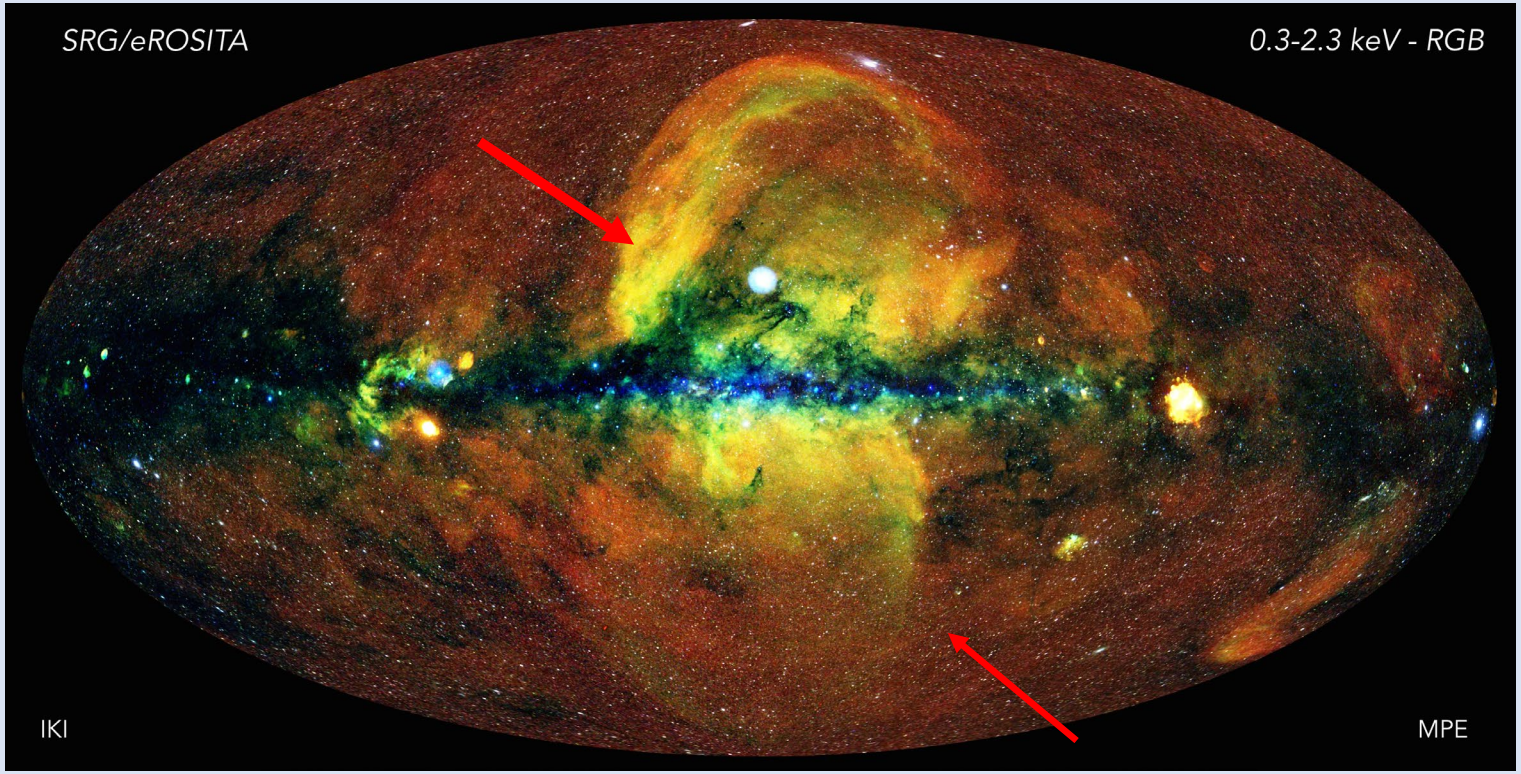
Suzaku Observations: Super-virial temperature





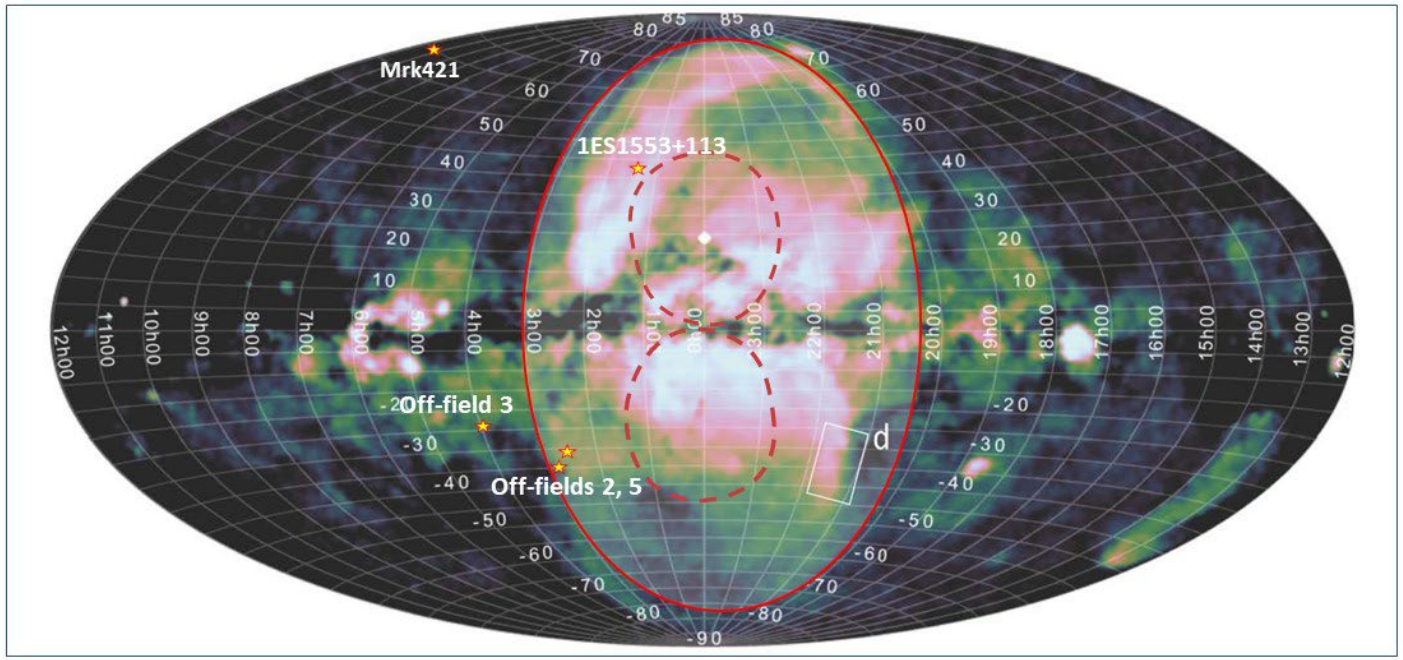
Gupta +21

eROSITA First All-Sky Survey



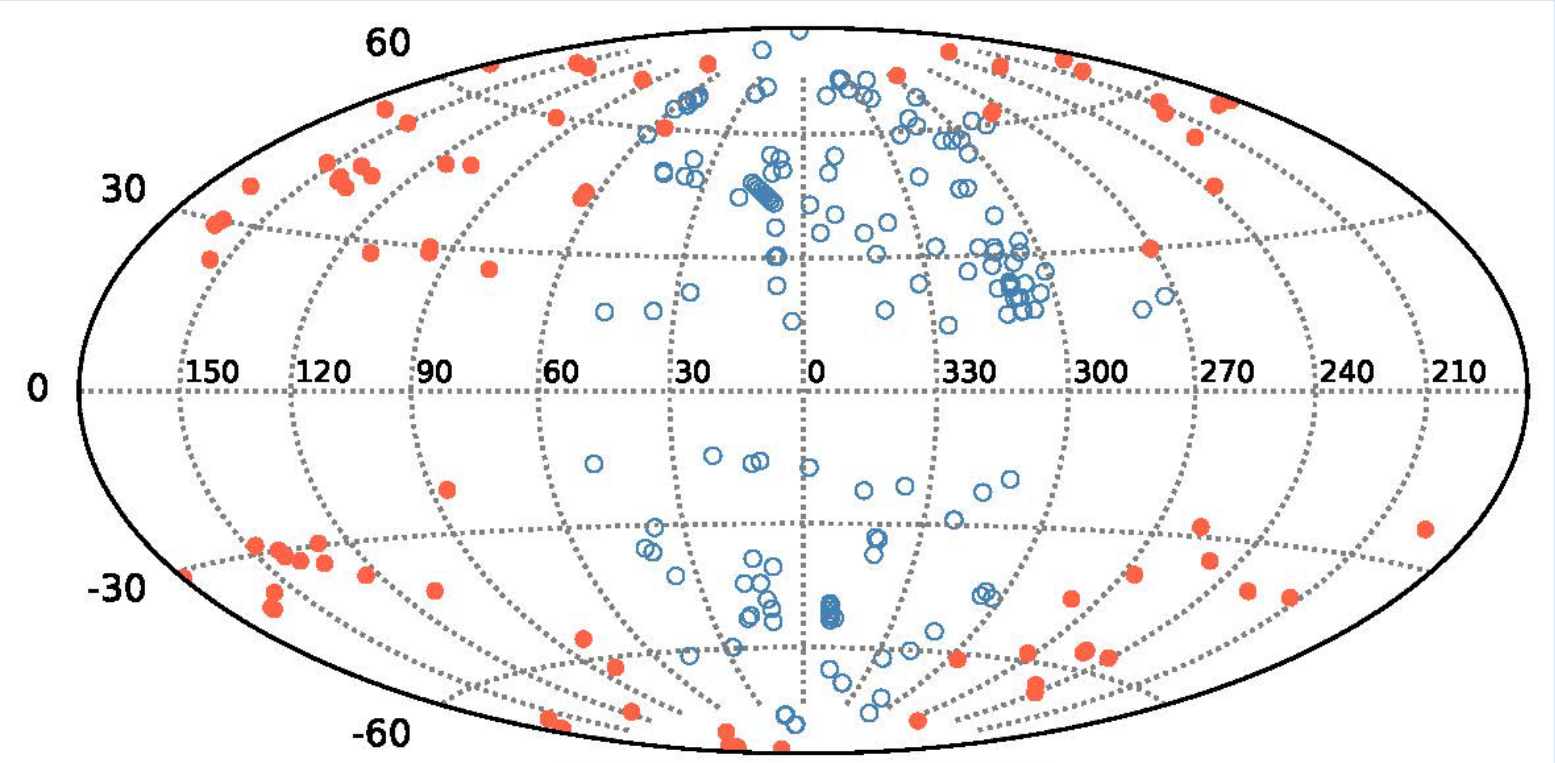
Predehl et al. 2020, Nature, 588, 7837

eROSITA First All-Sky Survey



False-colour map of extended emission detected by eROSITA in the 0.6–1.0-keV range from **Predehl et al. 2020, Nature, 588, 7837**

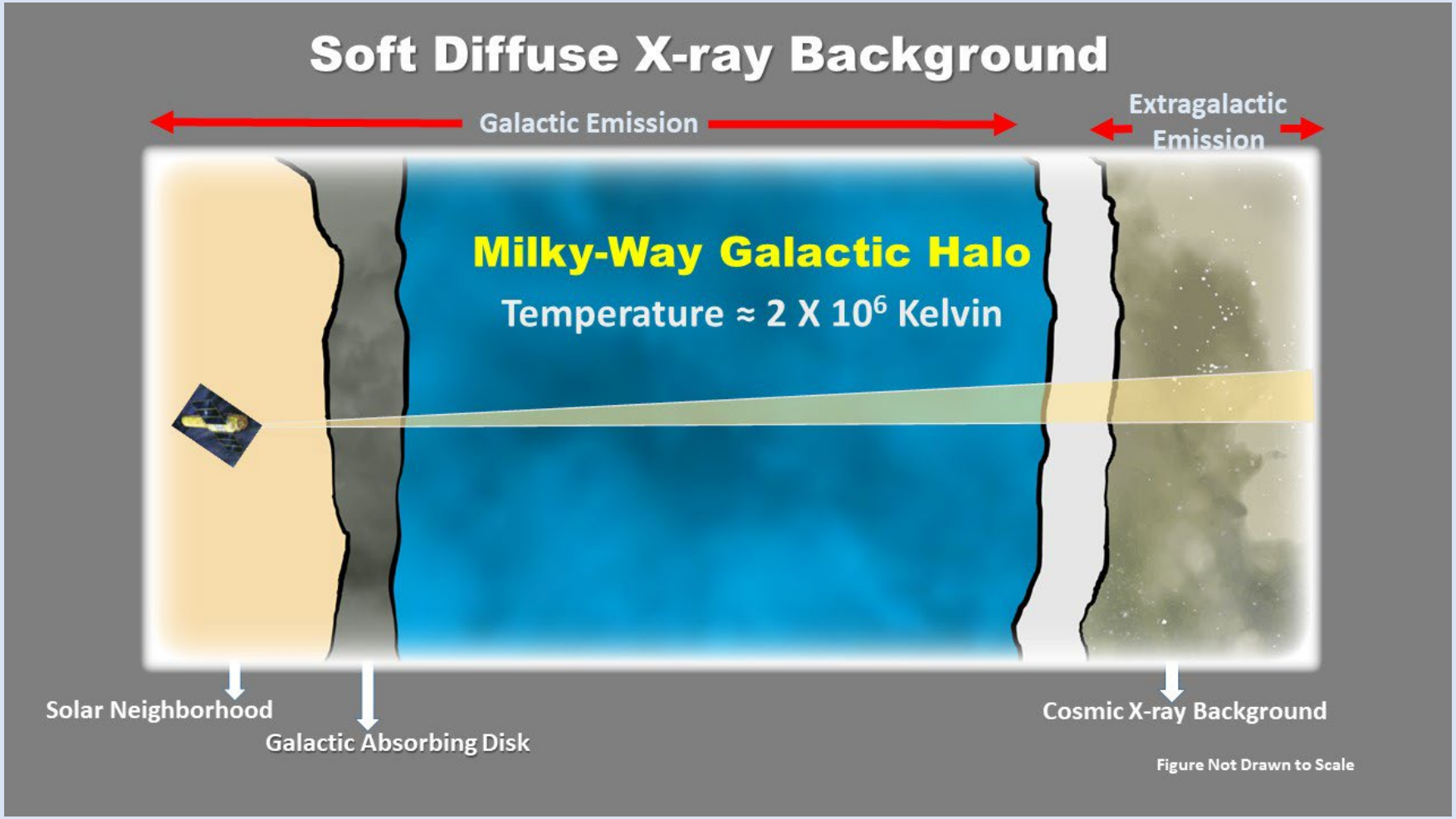
Our Recent Suzaku Survey:
The Galactic Bubbles and the Surrounding Halo



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

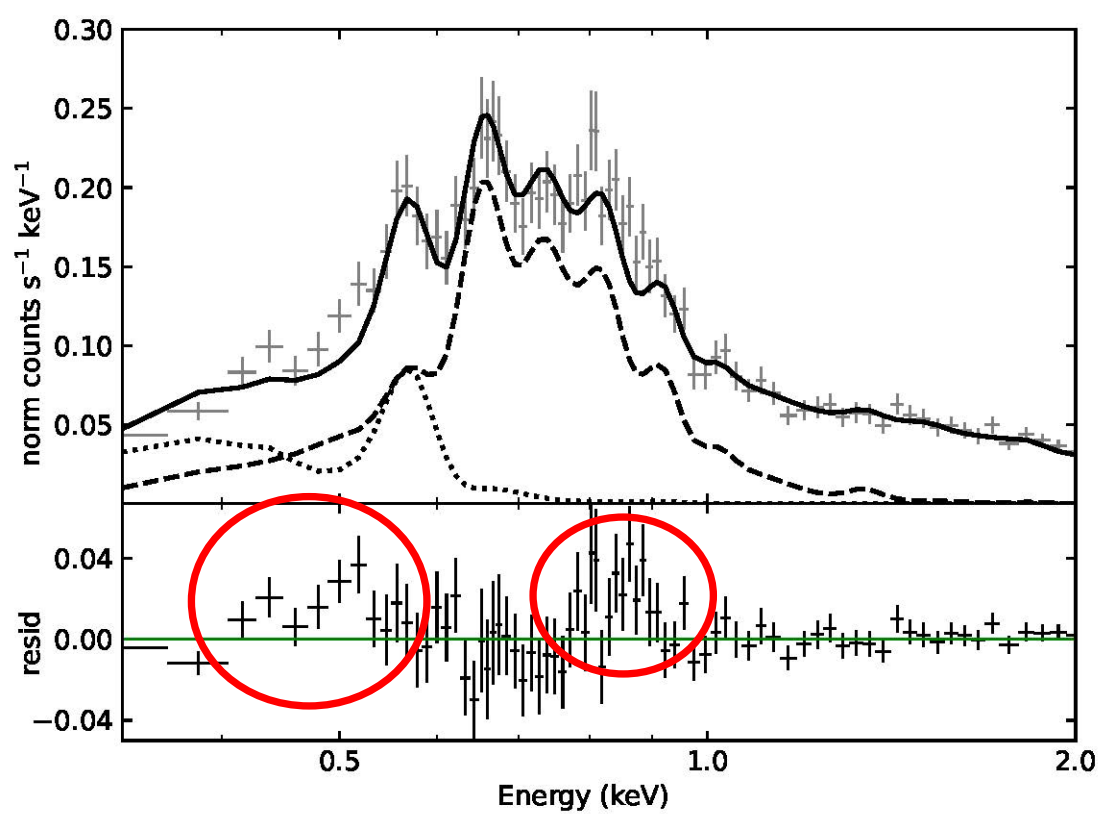
Gupta et al. 2023, Nature Astronomy, 7, 799-804

Soft Diffuse X-ray Background

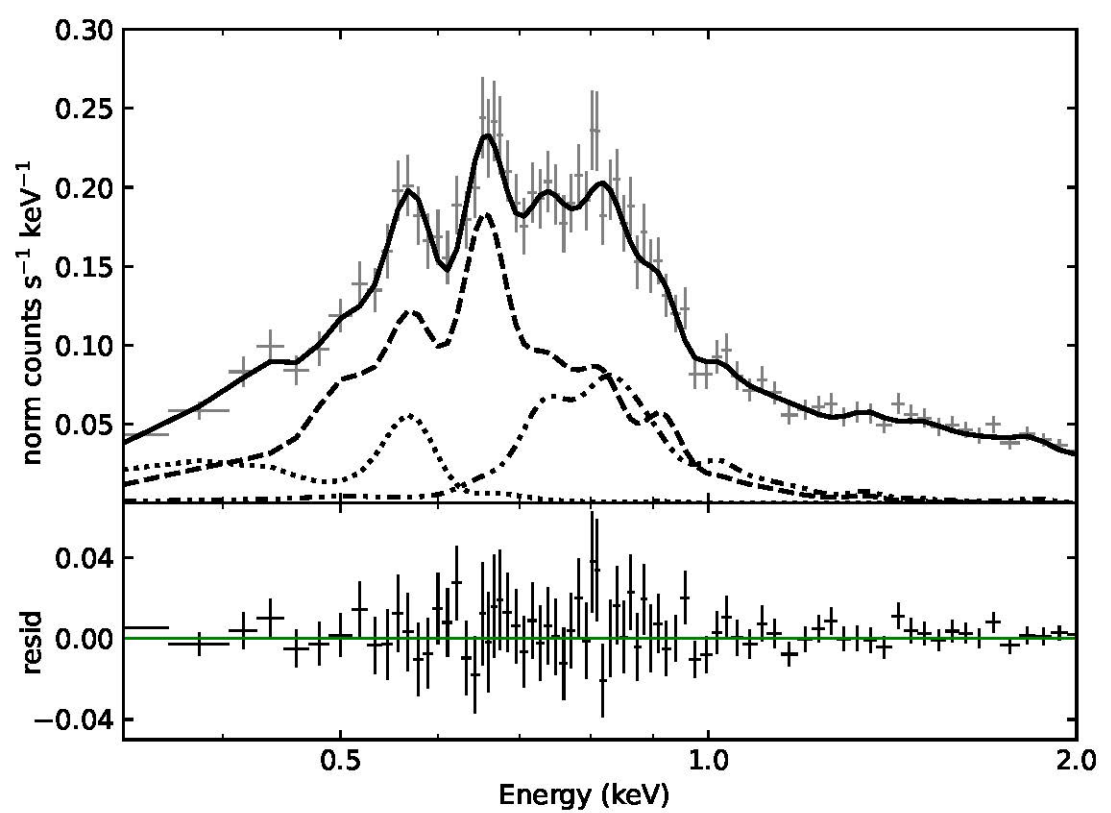


Milky-Way (MW) Halo/Bubbles Thermal Models

One-Temperature MW Halo Model

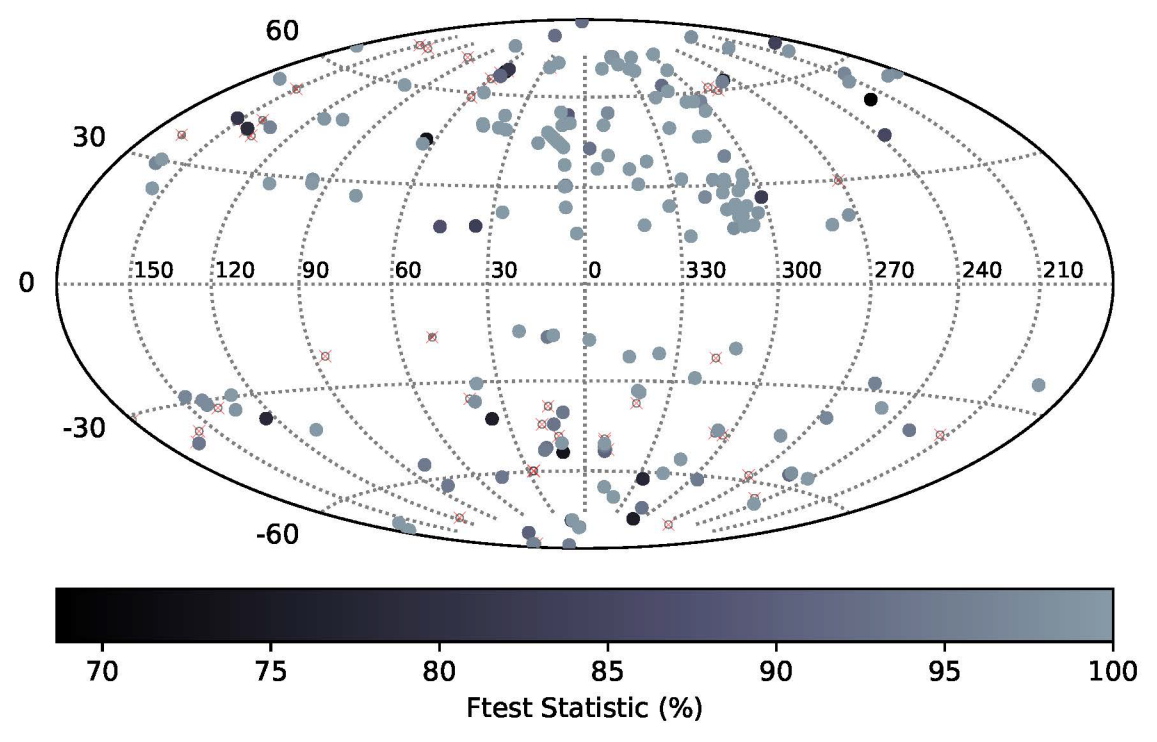


Two Temperature with Super-solar Nitrogen



Gupta et al. 2023, Nature Astronomy, 7, 799-804

F-test probability map: Hot Thermal Component



Galactic Bubbles Sightlines

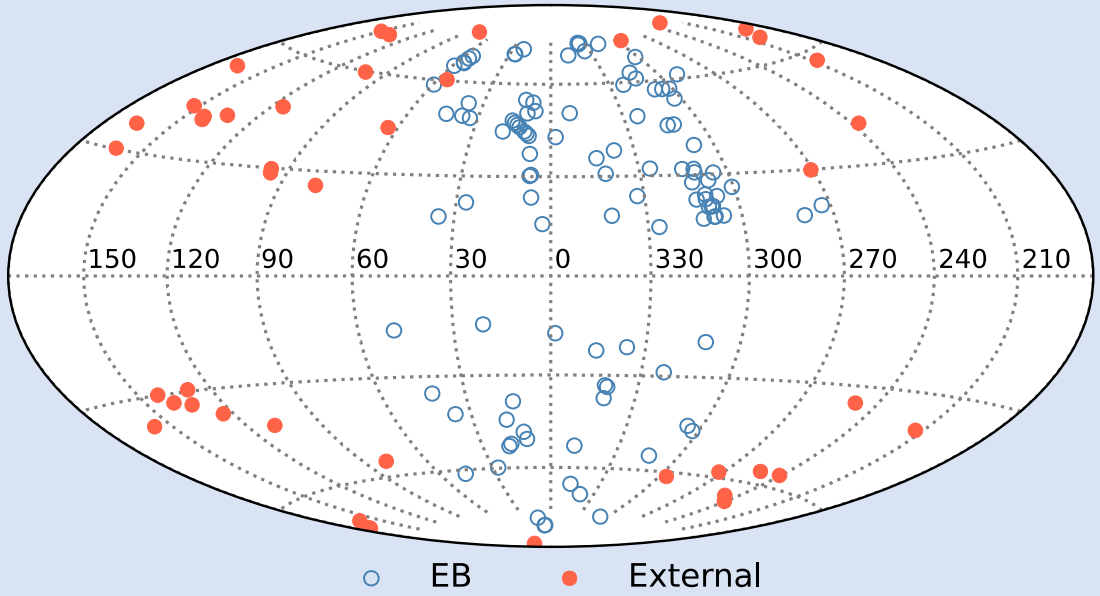
- >99.99% in 55 sightlines
- >90.00% in 80 sightlines

Outside Bubbles Sightlines

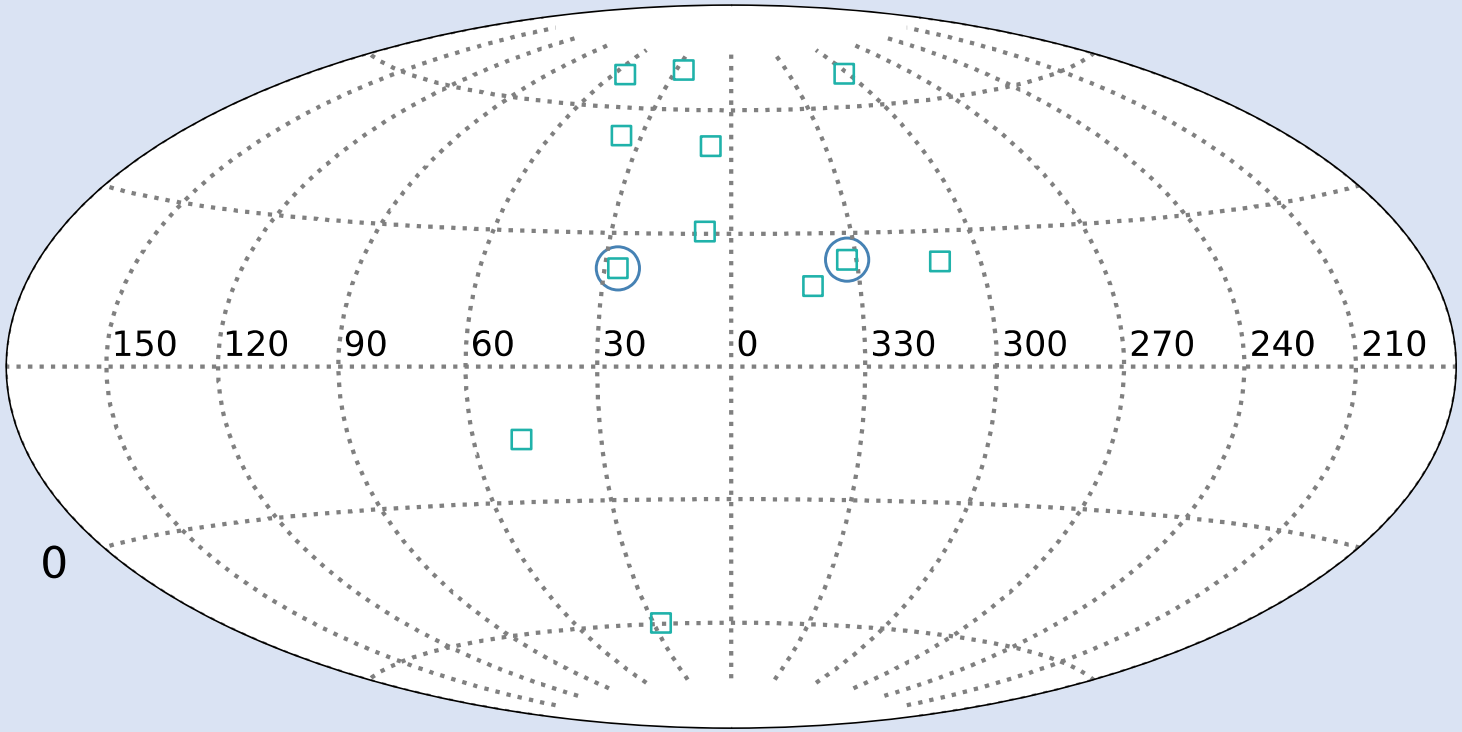
- >99.0% in 26 sightlines
- >90:0% in 51 sightlines

Gupta et al. 2023, Nature Astronomy, 7, 799-804

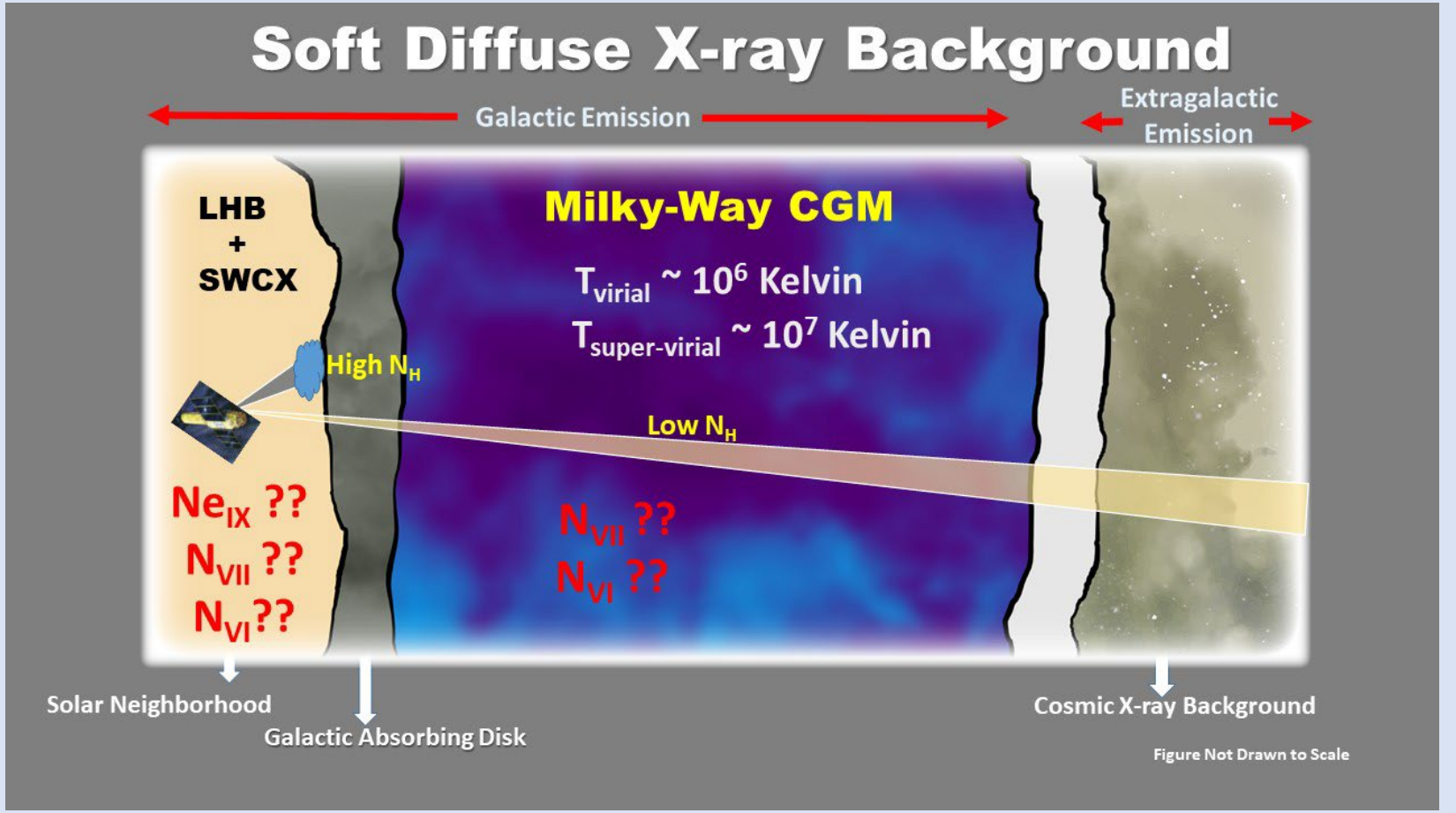
Super-solar abundance of Nitrogen-to-Oxygen (N/O)



Few Bubbles sightlines: Enhanced Ne/O and Mg/O

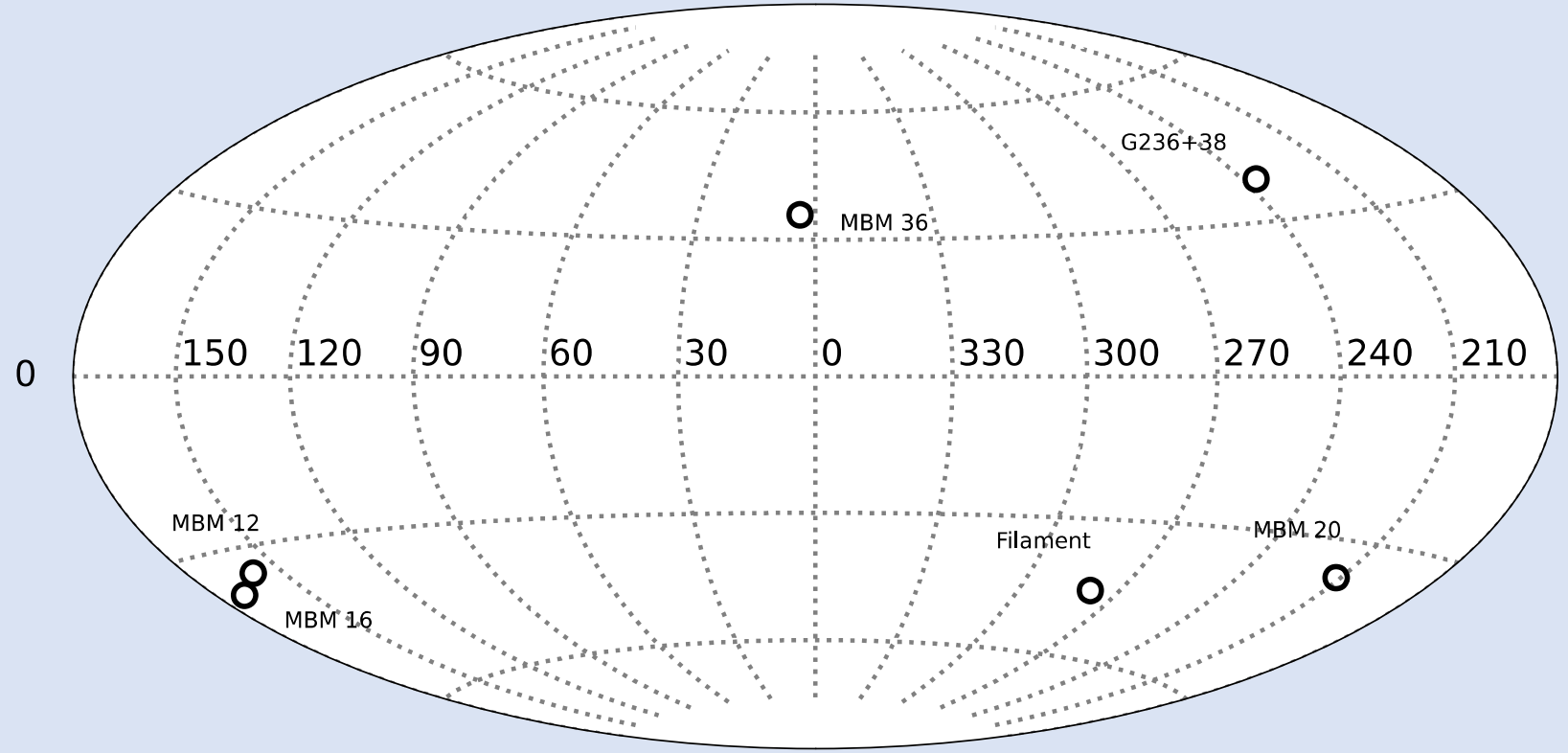


Shadow Observations



Gupta et al. 2025 (in-review)

Suzaku Shadow Observations:



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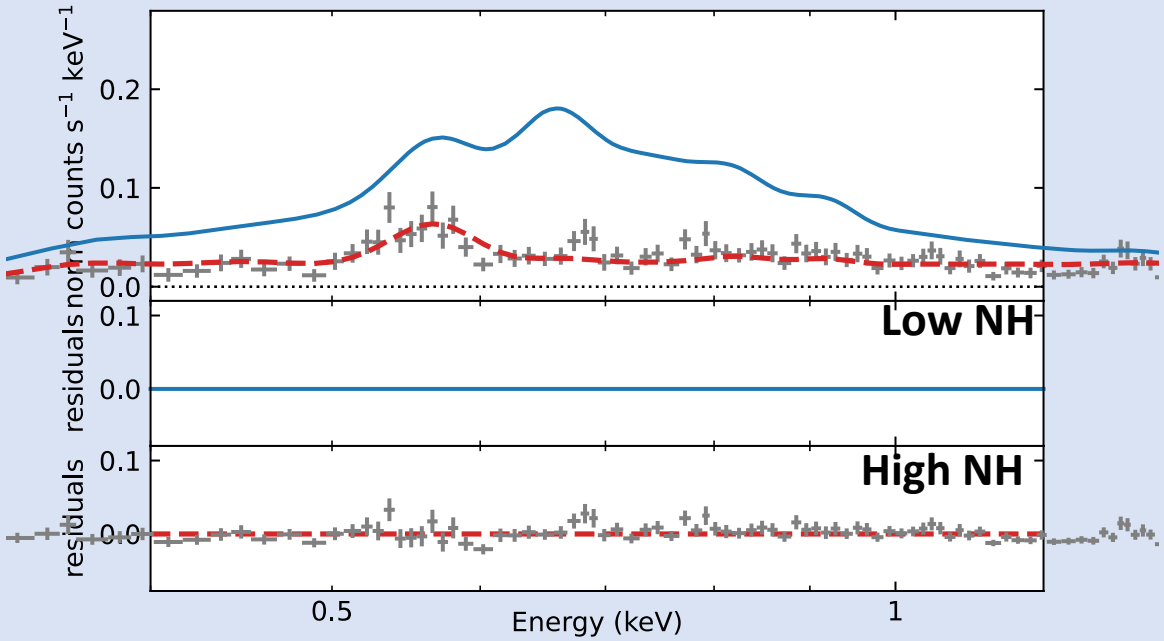
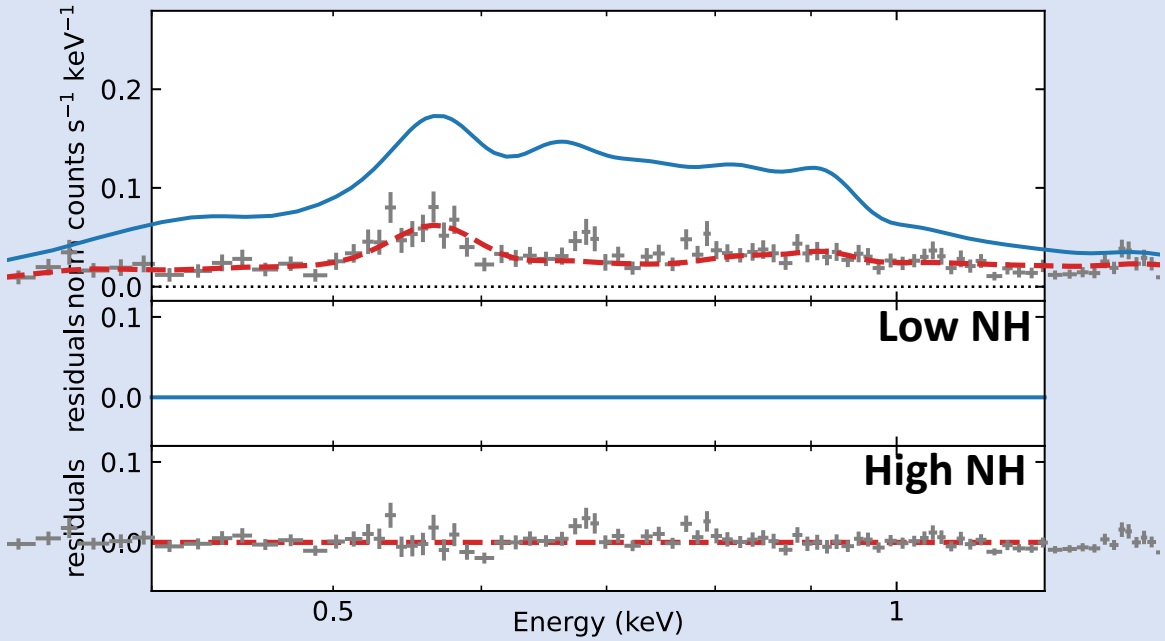
Shadow Observations





Gupta et al. 2025 (in-review)

Results: Suzaku all sky survey + Shadow Obs.

1. Detection of Super-virial temperature phase of CGM all over sky
    - confirmed by HaloSat (Bluem et al. 2022) and eROSITA (Ponti et al. 2023) observations

2. Toward few Galactic bubbles sightlines, there is evidence of super-solar Neon and Magnesium

Ne/O = 2.1 ± 0.2 solar (average, 10 sightlines)

Mg/O = 3.6 ± 1.4 solar (2 sightlines)

3. Overabundance of Nitrogen is widespread all over the sky

N/O = 3.2 ± 0.2 Solar (Bubbles Region)

N/O = 4.3 ± 0.5 Solar (Outer Halo)

Enhanced N/O → tracer of Intermediate-Mass Stars Feedback

- **Nitrogen** is primarily produced in **intermediate-mass stars** through secondary nucleosynthesis (in **CNO cycle**), released via **AGB winds** on Gyr timescale.
- Therefore, an **enhanced N/O ratio** pointing to a significant contribution of **older stellar populations** to the CGM enrichment, particularly from **AGB stars.**

Ne/O and Mg/O excesses → trace Massive Stars Feedback

- **Neon** and **magnesium** are α-elements, primarily produced in massive stars and released via **core-collapse supernovae**.
- The detection of Ne/O and Mg/O enhancement along **few sightlines intersecting the eROSITA bubbles** suggests **localized, possibly recent** feedback activity tied to **massive star winds or past nuclear outflows**.

Abundance Patterns and Interpretation

Observation	**Interpretation**
Widespread Super-solar N/O	Well-mixed nitrogen from AGB stars throughout the CGM.
Super-solar Ne/O & Mg/O in bubbles	Recent, energetic feedback from massive star supernovae or AGN outflows enriched in alpha elements (Ne, Mg), heating and ejecting material into the bubbles.

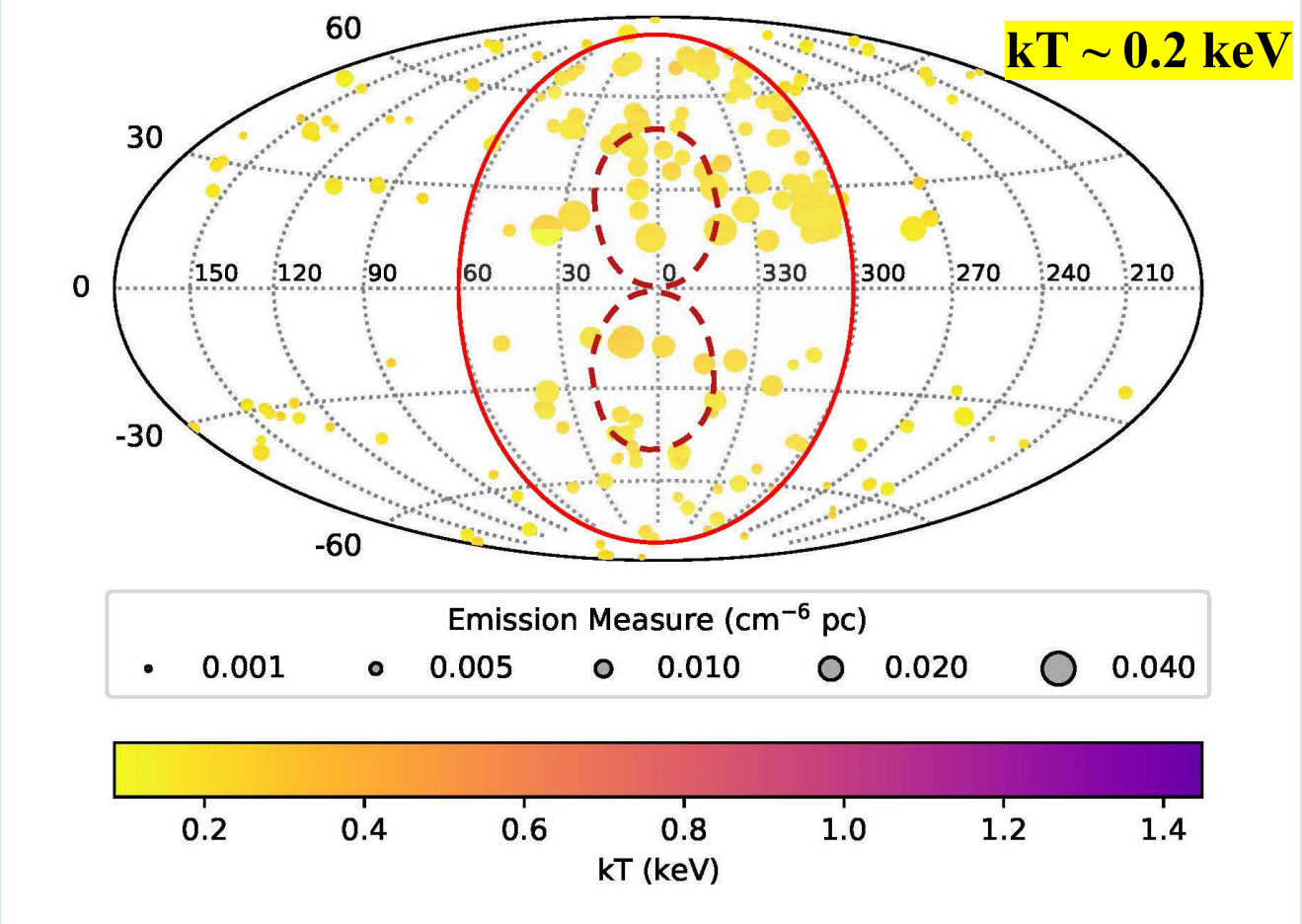
Layered Feedback in the Milky-way CGM:
N/O, Ne/O and Mg/O as Chemical Chronometers

- The contrast between widespread **elevated N/O** and localized **Ne/O, Mg/O** excesses paints a picture of a **chemically stratified CGM**.

- Nitrogen has had time to distribute uniformly through **slow winds or fountains**, whereas α-elements may still trace their **feedback origin points**, especially in association with structures like the **eROSITA or Fermi Bubbles**.

Thank You

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



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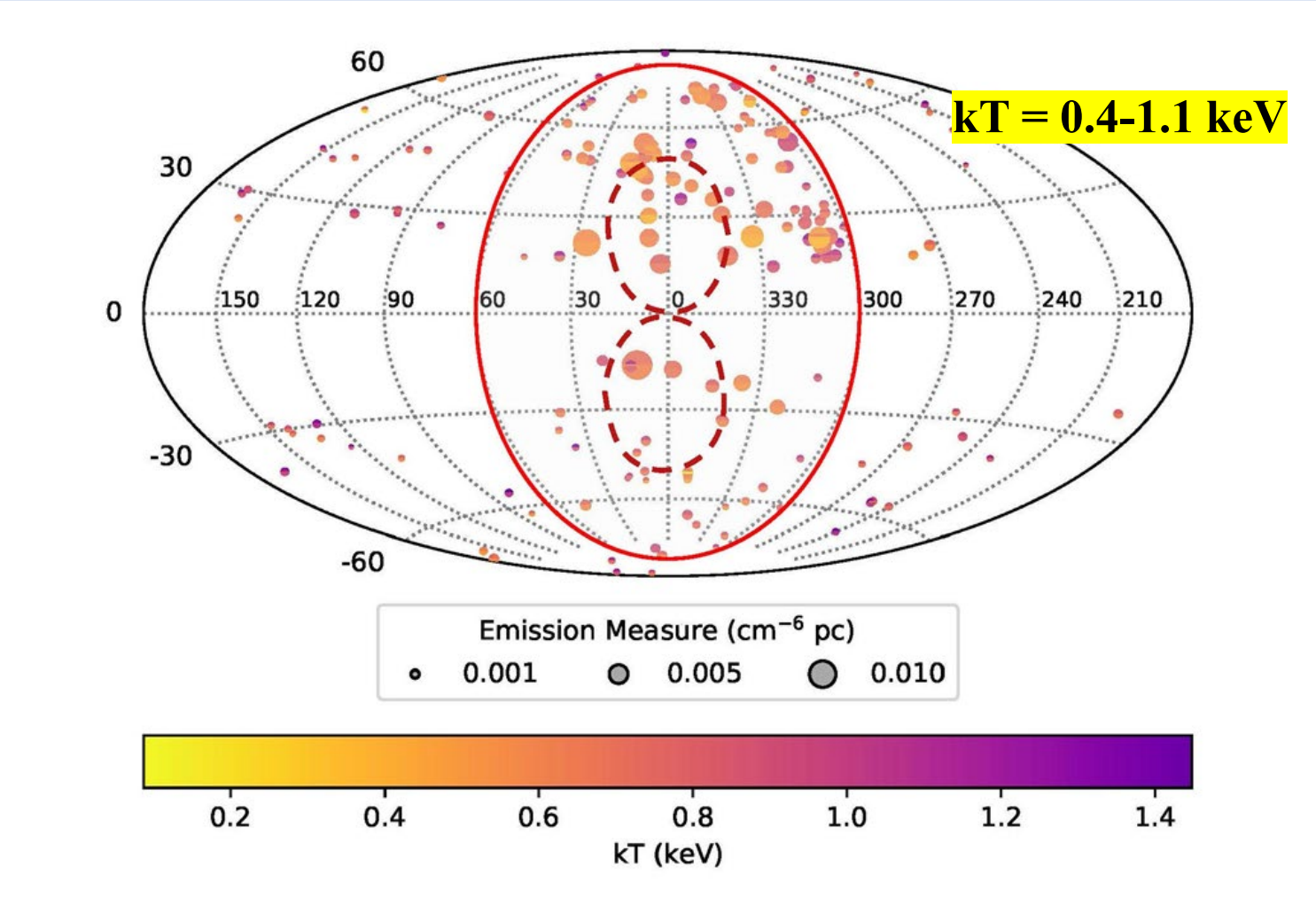
X-ray emission maps from our Suzaku survey: Hot Super Virial-Temperature Component



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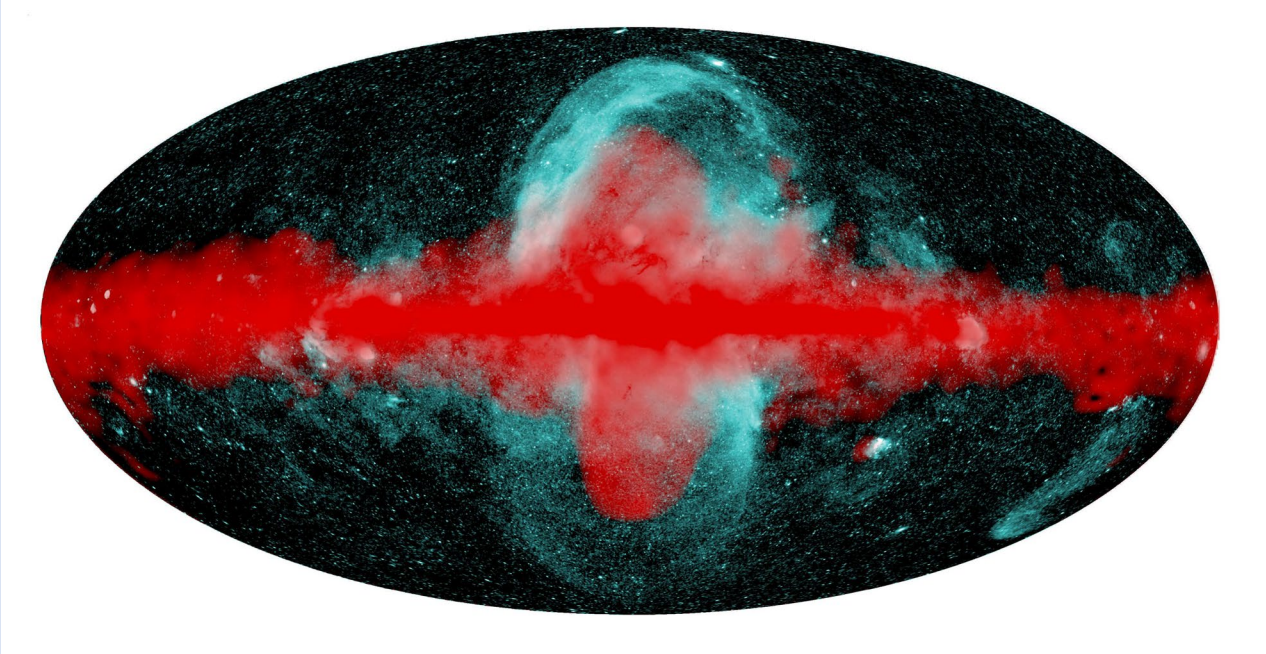
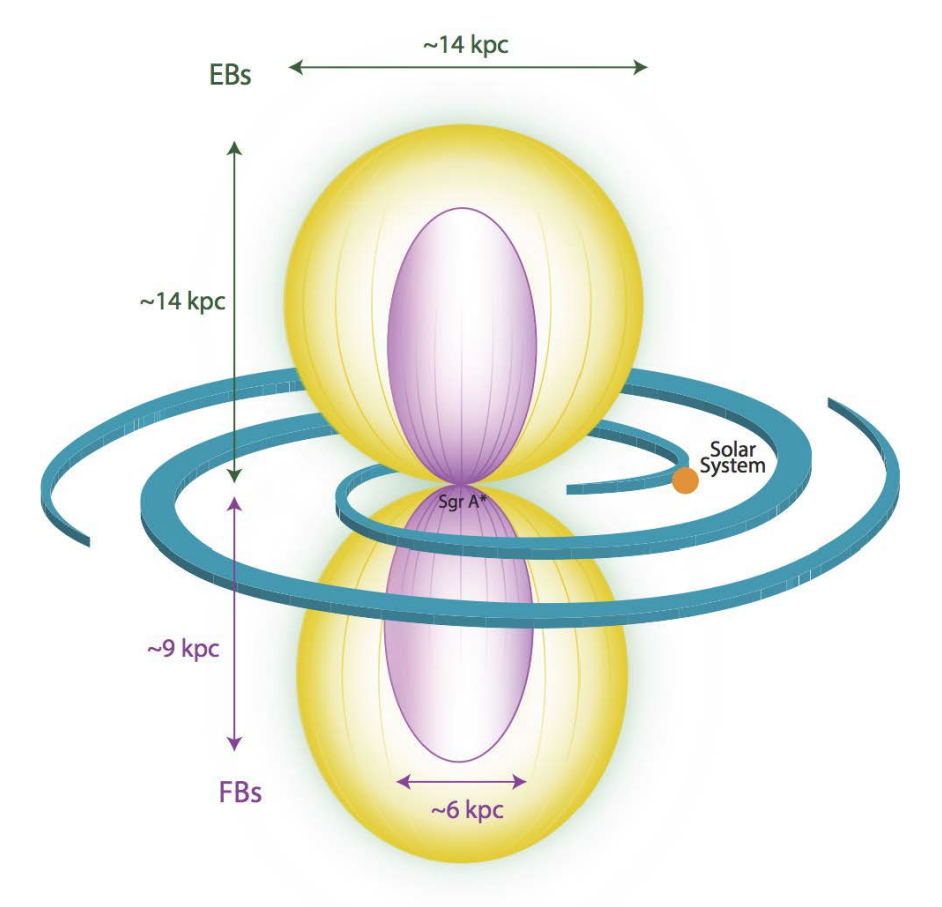
eROSITA First All-Sky Survey





Figures from Predehl et al. 2020, Nature, 588, 7837

$E_{\rm th} \approx 1.3 \times 10_{56}\,{\rm erg}.$

Revised Model of Milky-way CGM X-ray Emission