Review of the Diffuse Soft X-ray Background

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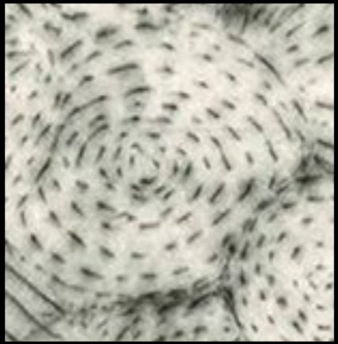


Outline

- History
- DSXB Constituents
  - Unresolved point source
  - Fermi Bubbles
  - Local Bubble & solar wind charge exchange X-rays
  - Halo & circumgalactic gas
  - Whence the hot gas around the Galaxy

History

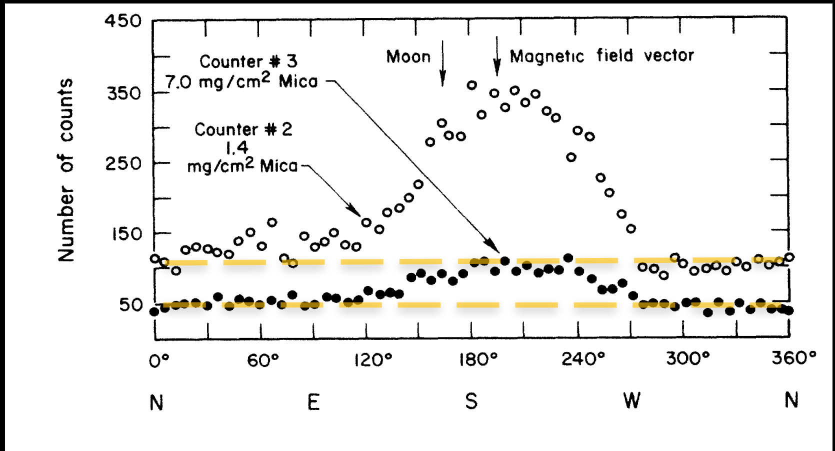
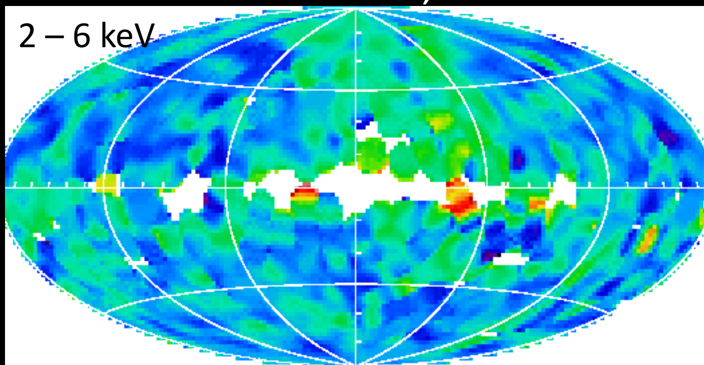


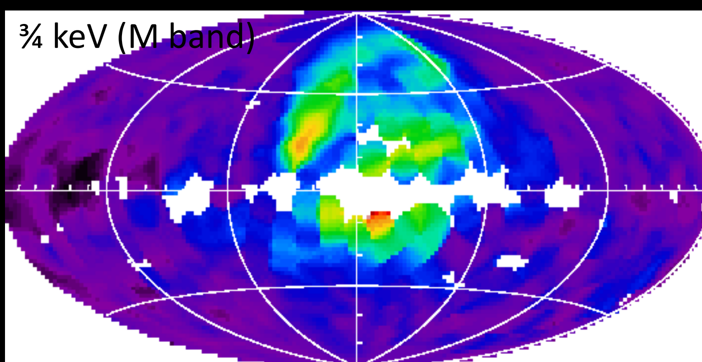
FIG. 1. Number of counts versus azimuth angle. The numbers represent counts accumulated in 350 seconds in each 6° angular interval.

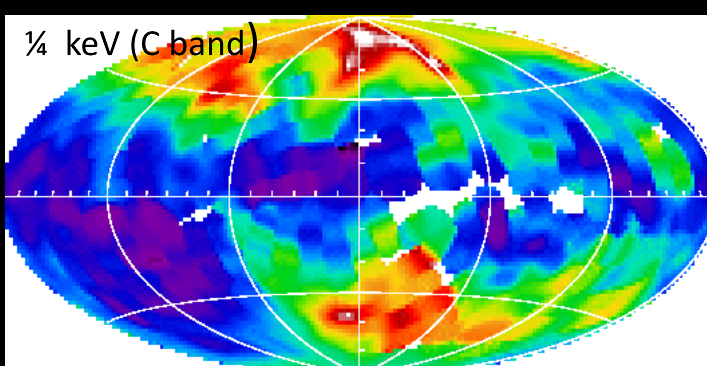
One night in the summer of 1962, Giacconi et al. flew Geiger counters above the Earth's atmosphere in search of X-rays from the Moon. In addition to it, they also found a diffuse background of 2 to 6 keV X-rays. 5 ½ months later, the field of diffuse X-ray astronomy was born – Giacconi et al. 1962.

The picture became clearer as many groups continued the study of this light with better detectors

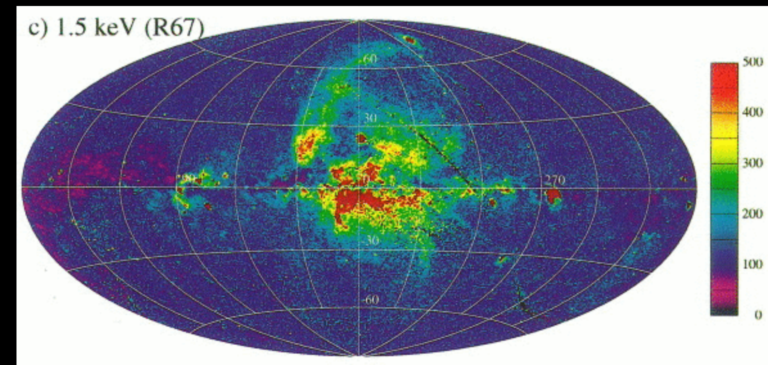
Wisconsin rocket flight observations, McCammon et al. 1983, later colorized

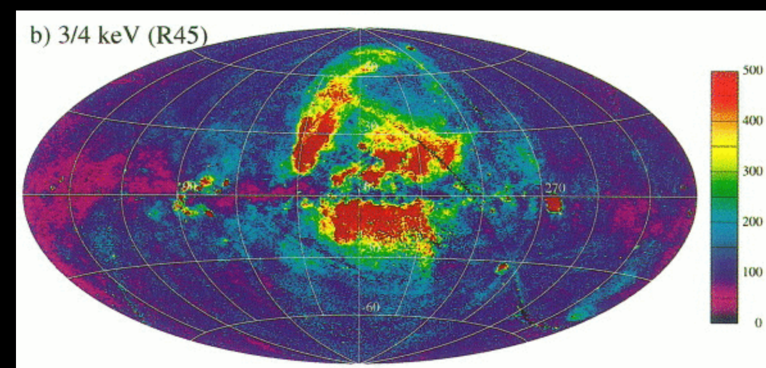


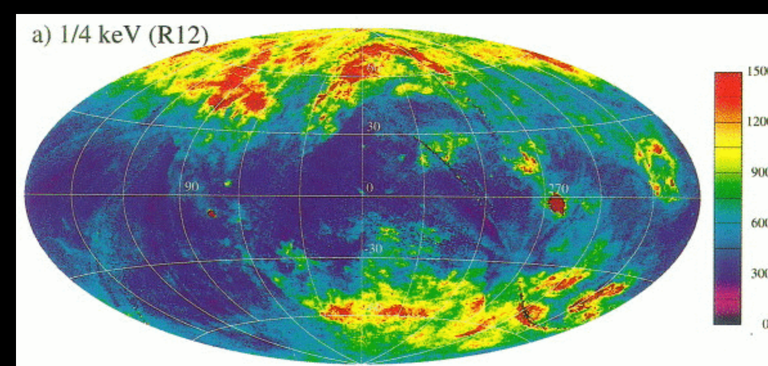




ROSAT, Snowden et al (1997)







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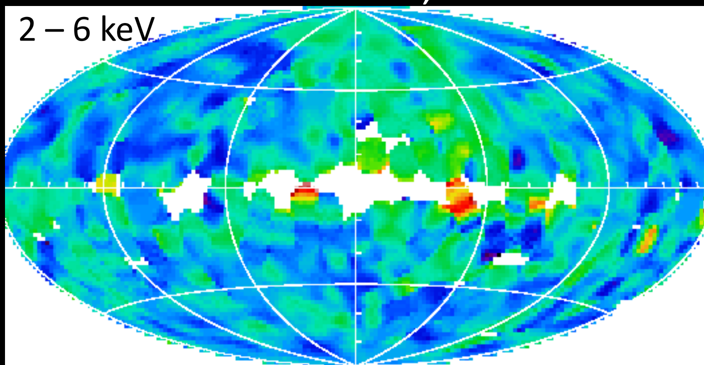
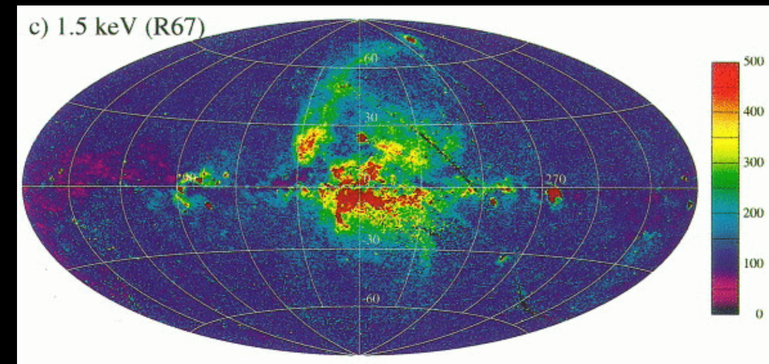
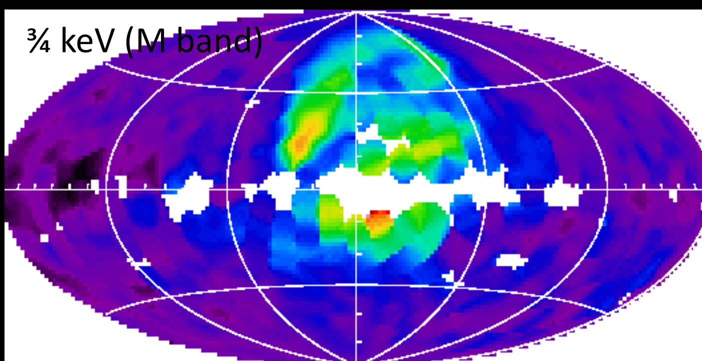


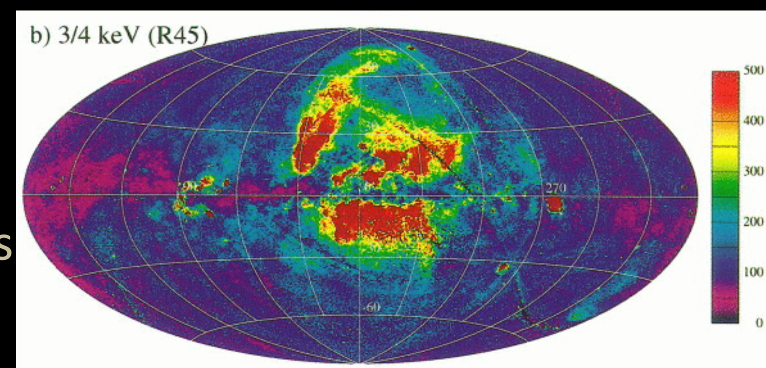
See different structure in different energy regimes

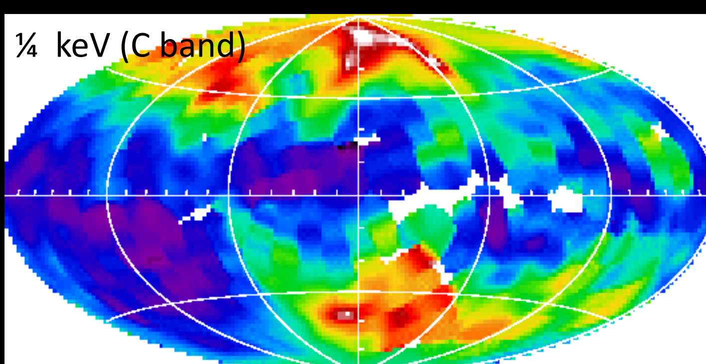
ROSAT, Snowden et al (1997)



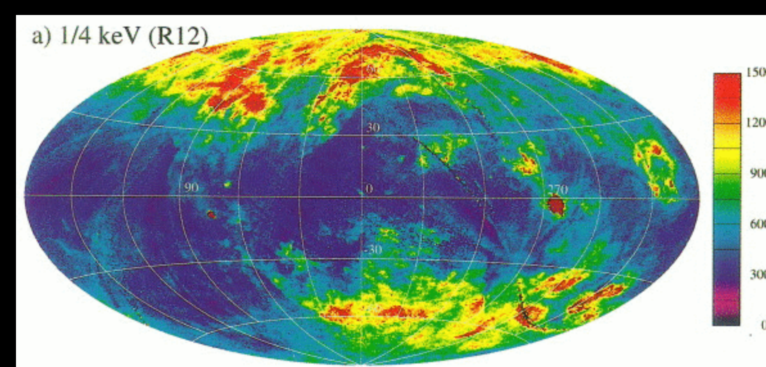


Softer X-rays more easily absorbed, so preferentially see local X-rays in ¼ keV band



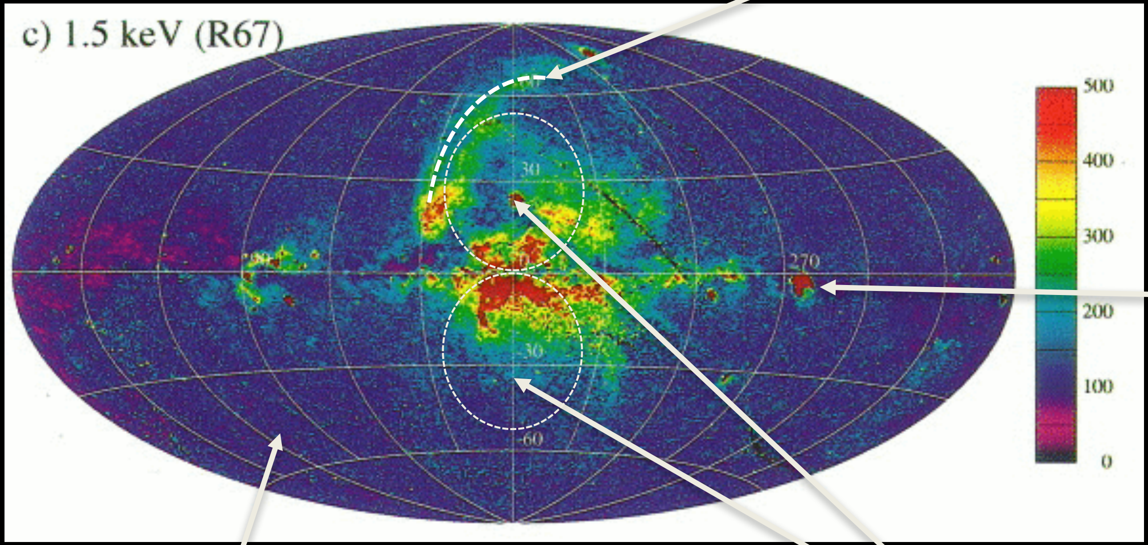


Different regions have different temperatures & photon energies



High-end X-rays

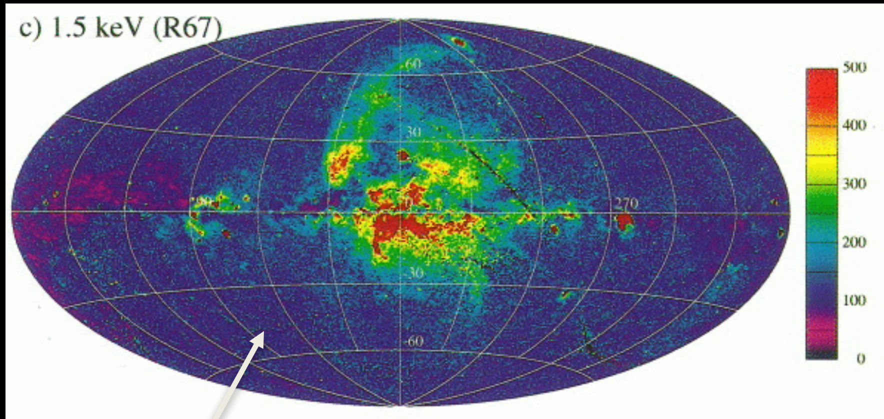
Loop I – North Polar Spur is here



Miscellaneous features, in this case, the Vela supernova remnant

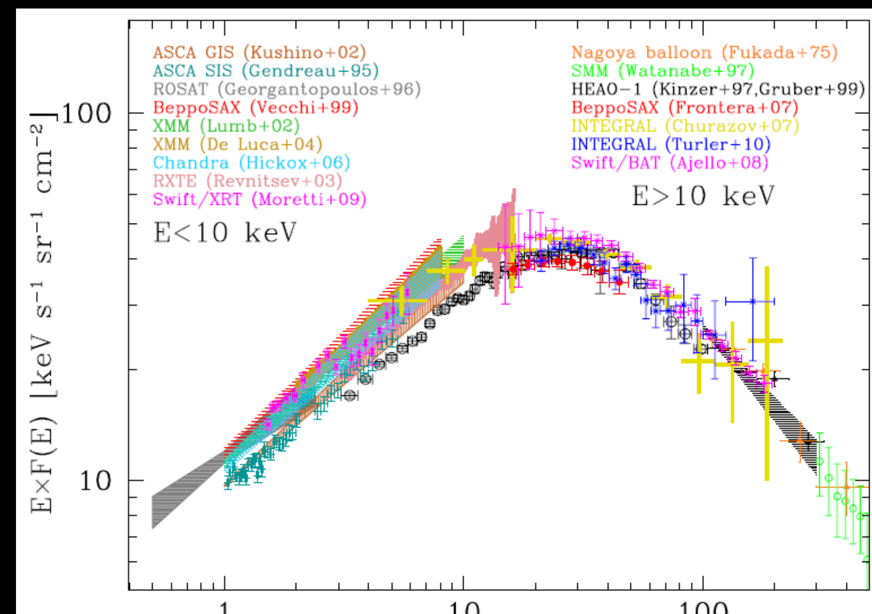
Fermi Bubbles are here

Background of unresolved AGN, galaxy clusters, and starburst galaxies



High-end X-rays: Background of extra-galactic emission

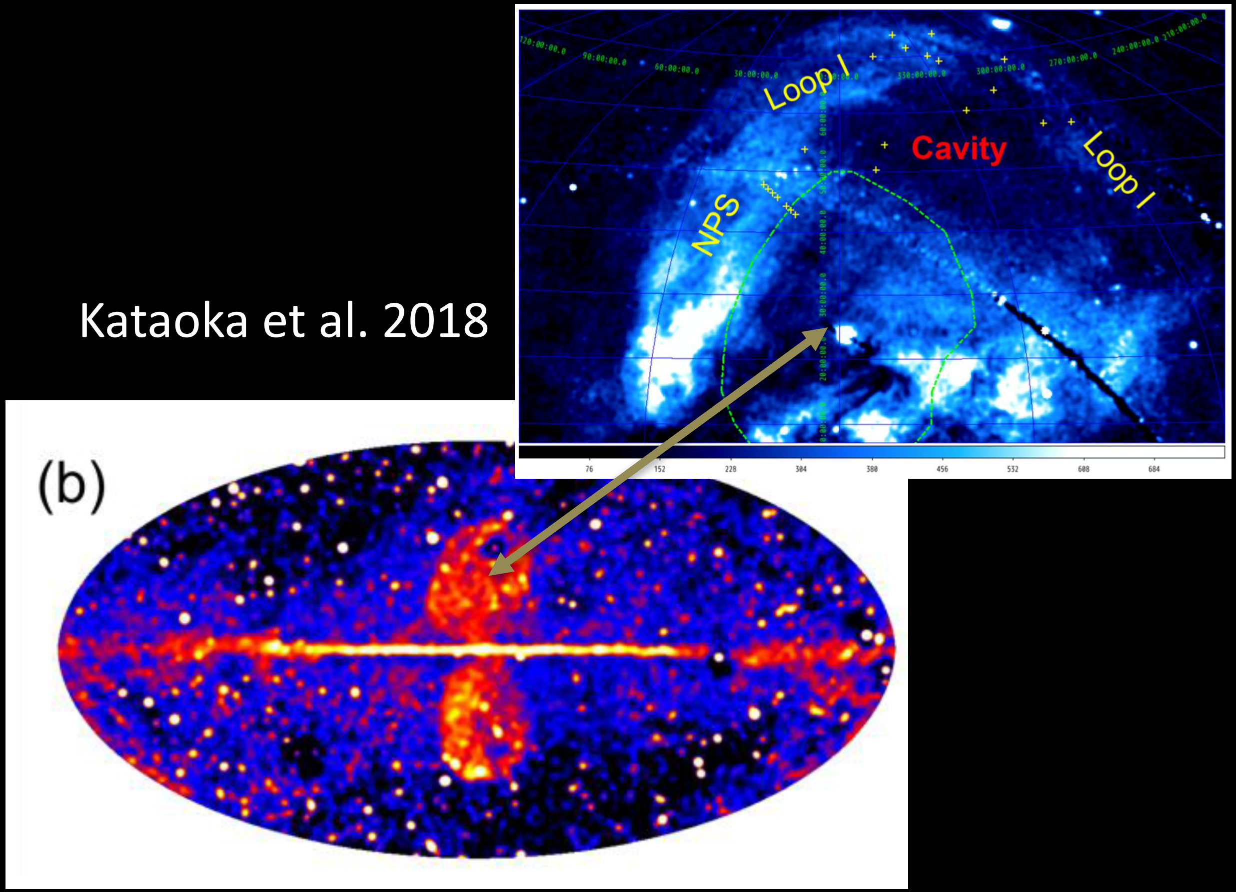
- Away from interesting features, the X-ray spectrum follows a power law up to ~ 10 keV
- $N(E) = E^{-\Gamma} e^{E/Ec}$ photons/cm^2/s/keV
- Γ = 1.4 (Gilli, 2013)
- Confirmed with many instruments
- Long suspected to be due to unresolved extragalactic point sources, generally AGN
- Point sources in Chandra Deep Field South nearly explains 2 to 8 keV extragalactic background as AGN
- Below that, galaxy clusters and starbursts also contribute
- Slope changes at low end of range



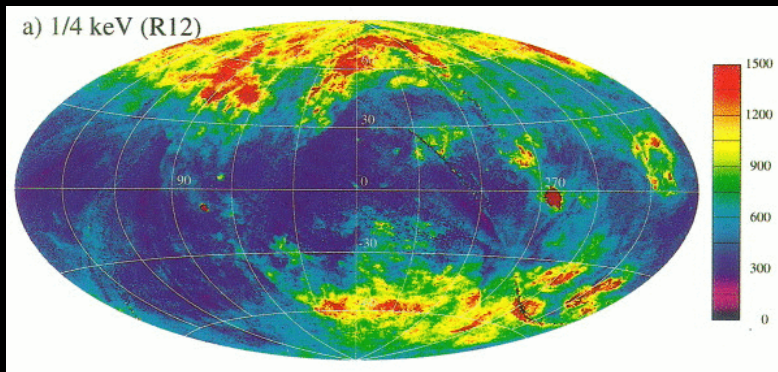
Gilli, 2013

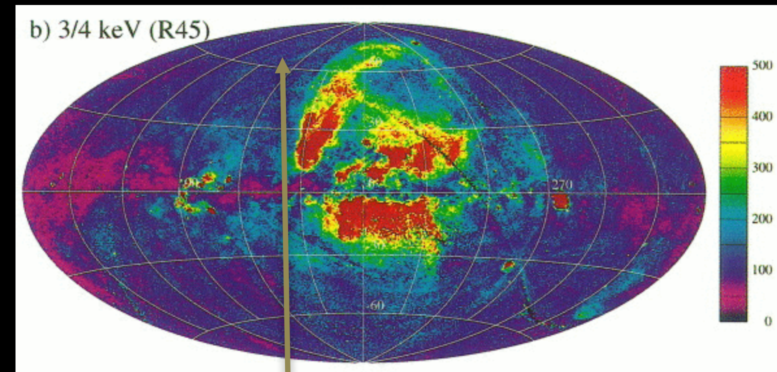
Fermi Bubbles

Kataoka et al. 2018



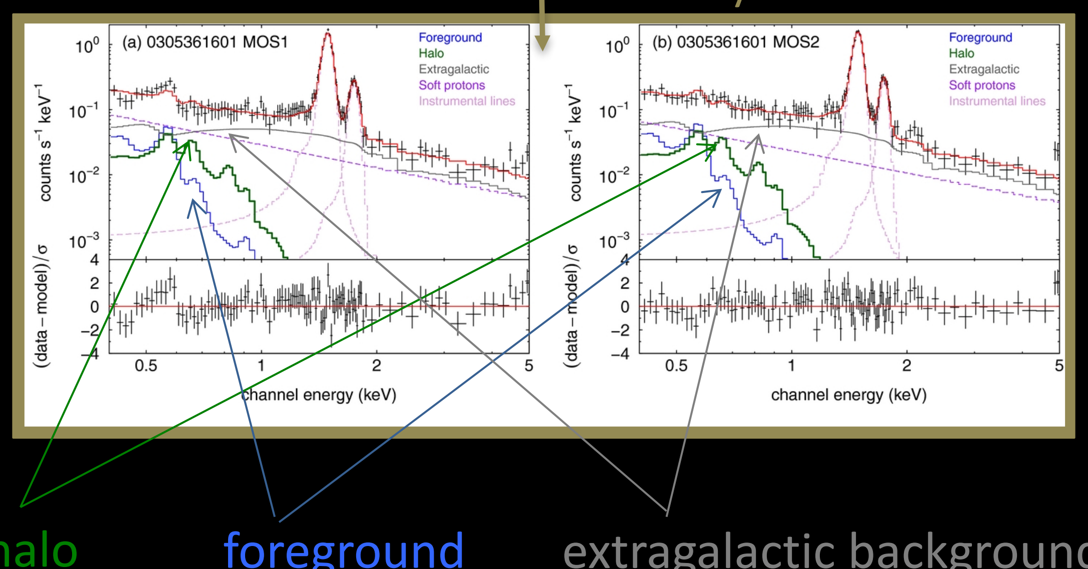
¼ and ¾ keV X-rays



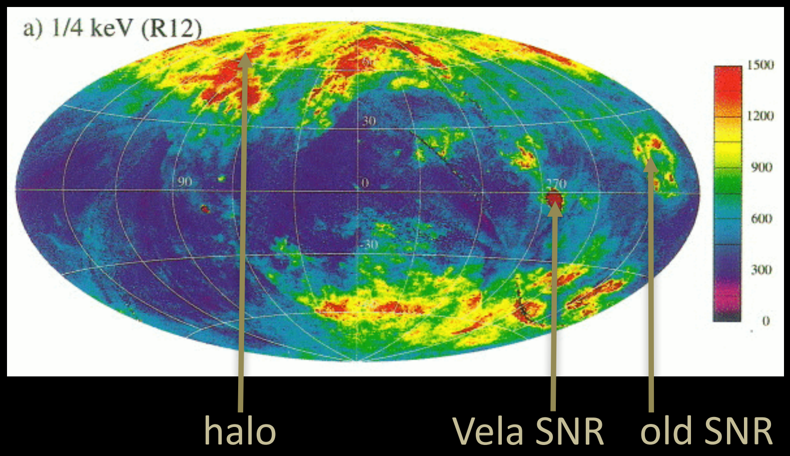


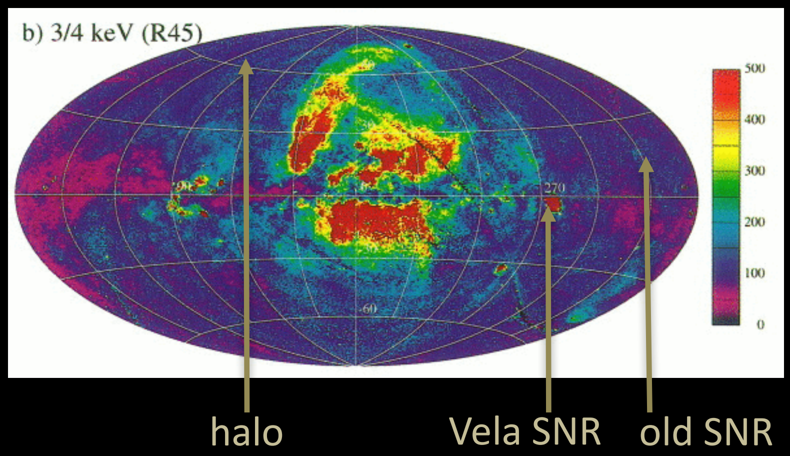
Start to see other structures at ¼ and ¾ keV, but the extragalactic background is still present. Figure = XMM spectra of random high latitude direction, modeled with extragalactic background + 2 galactic components + 2 non-cosmic components

XMM MOS spectra
Henley & Shelton 2013



What do we see and why is the sky look so different in ¼ keV vs ¾ keV X-rays?





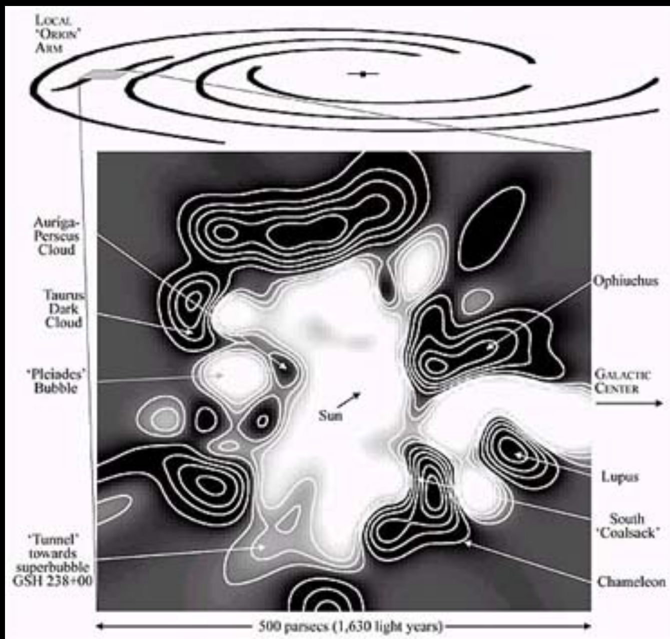
Intervening material more effectively absorbs softer X-rays

Loop I – North Polar Spur disappears as go to softer X-rays

¼ keV X-rays can be made by $T = 10^6$ K gas, but that gas makes little ¾ keV light so the Monogem Ring (old SNR) is brighter in the ¼ keV map than the ¾ keV map

There are significantly weird local contributions from material within the solar System and within an interstellar cavity

The Local Bubble before Solar Wind Charge Exchange

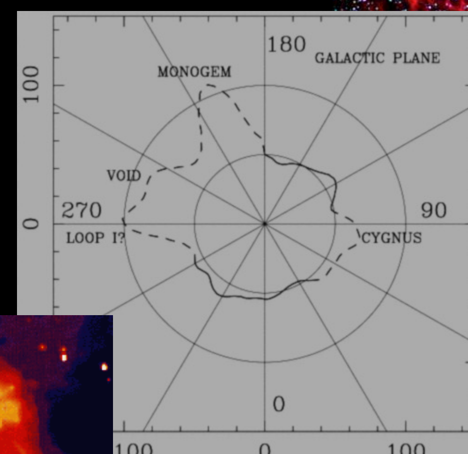


The Sun is in a large cavity where there is little neutral ISM   and

The spectra of ¼ keV photons in the plane don't show spectral hardening effect of absorption

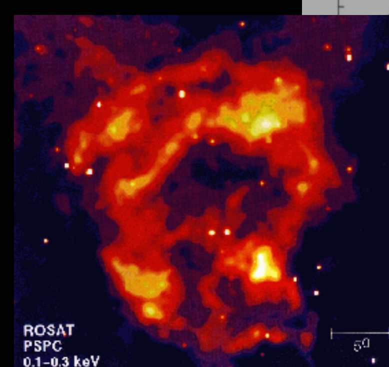
=> Idea of a Local Bubble of 10^6 K gas that makes ¼ keV X-rays coming to us from all directions

N70 Superbubble



Local Bubble

Expected the Local Bubble to be a mid-sized bubble, larger than a single old SNR and smaller than a superbubble



Monogem Ring (single old SNR)

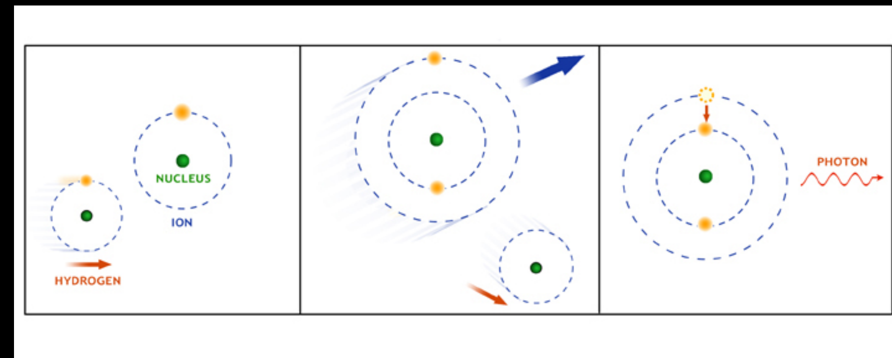
Solar Wind Charge Exchange (SWCX)

Solar Wind floods heliosphere with highly charged ions: H^+, He^{++}, O^{7+}, O^{8+}, etc.

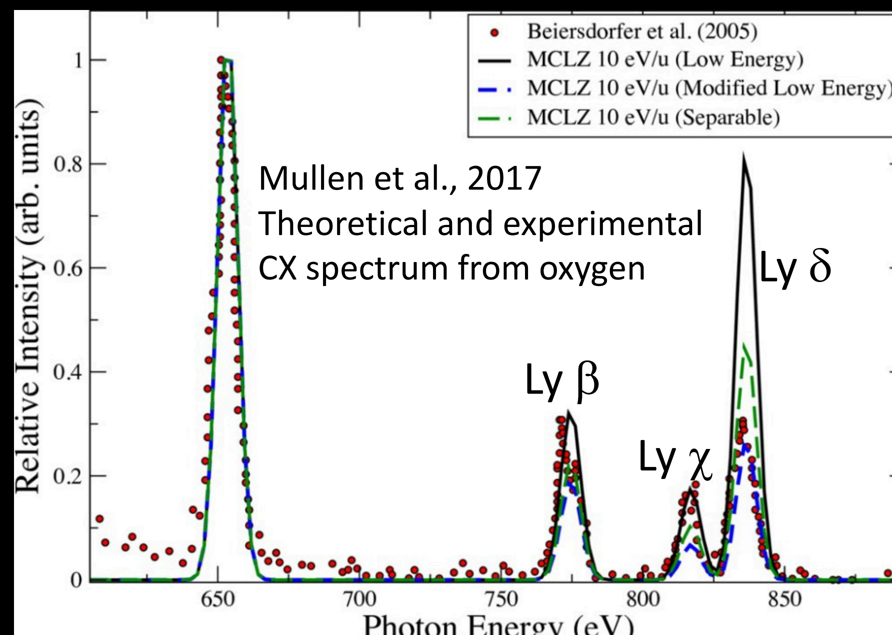
They "charge exchange", then emit X-rays

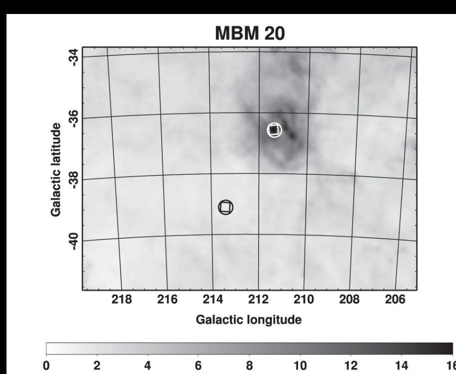
ex: $O^{+7} + H \rightarrow O^{+6*} + H^+$

$\rightarrow O^{+6} + H^+ + h\nu$



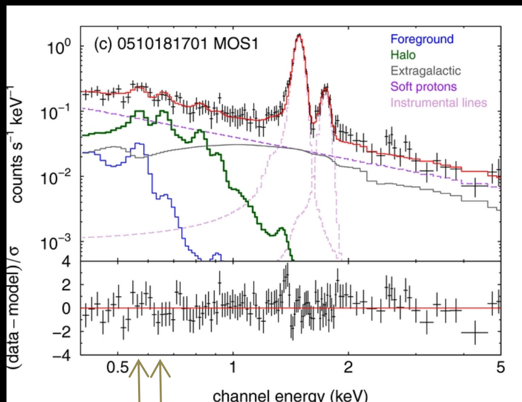
SWCX is a pain, because it varies in time in unpredictable ways.
Pairs of observations could experience different SWCX intensities.
Hard to determine the minimum SWCX intensity that affects all observations – hard to distinguish from Local Bubble





Better Spectral Resolution

XMM MOS: example of emission spectrum

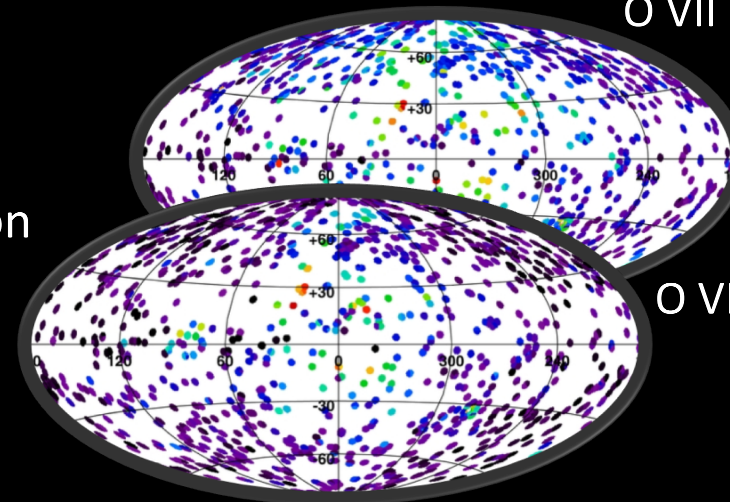


O VII O VIII

Catalog:

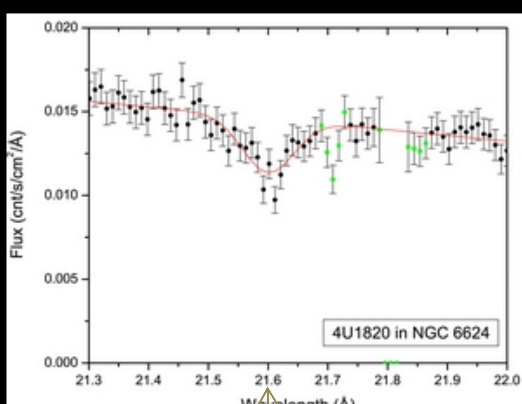
Henley & Shelton (2010, 2012)

O VII



O VIII

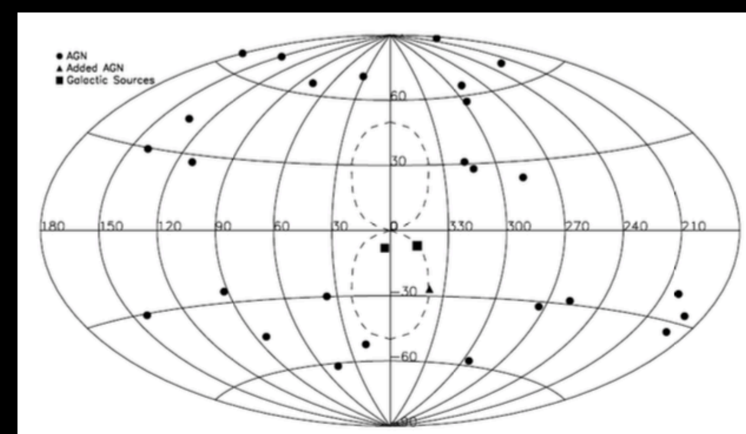
XMM RTG: example of absorption spectrum



O VII

Catalog:

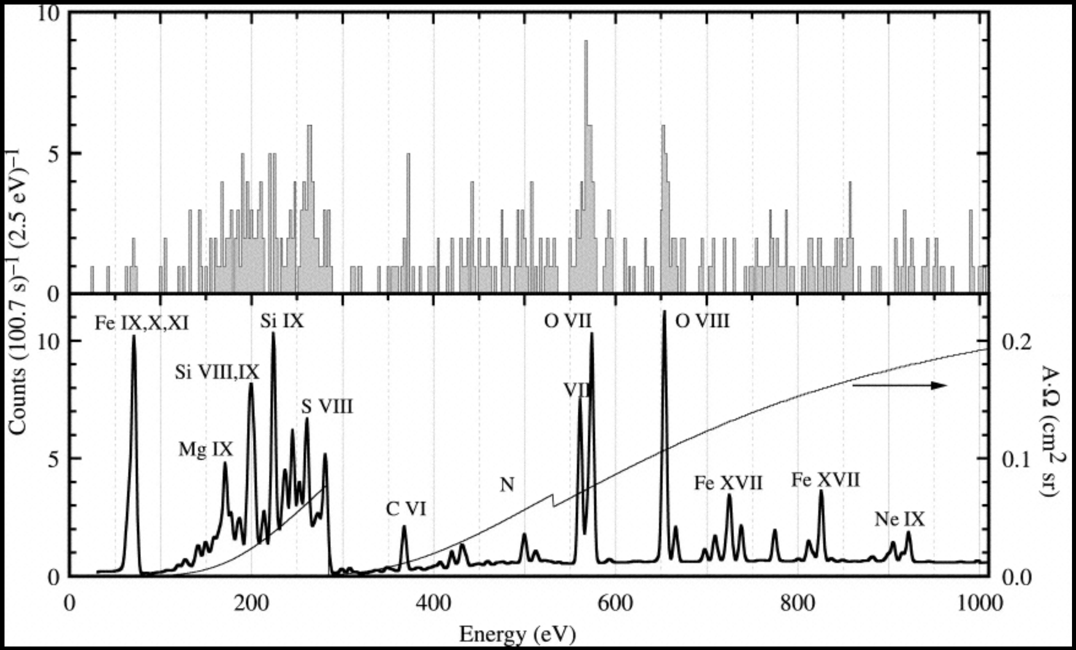
Miller & Bregman 2013



The future is even brighter -- more instruments, higher spectral resolution

❖ Microcalorimeters

McCammon et al. 2002
view of l = 90, b = 60,



Compared with 2 thermal component + power law model

convolved with instrumental response function

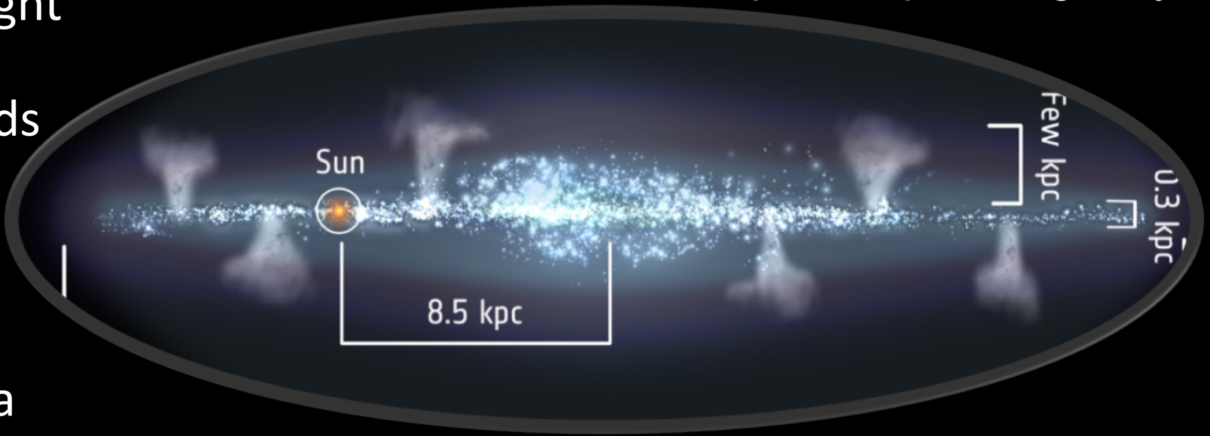
Trying to Understand the Data

- Several groups have tried to determine the spatial and temperature distribution of the hot gas above the disk
  - Separate local from halo/circumgalactic using shadows
  - Exponential models (Wang+, Yao+, Sakai+: few kpc scaleheight)
  - Circumgalactic models (Gupta+, Bregman+
    find hot gas extends several 10s of kpc to a hundred kpc, depending upon the study)
  - Velocity (Hodges-Kluck+ find halo has significant rotational velocity)
  - Hydrodynamic stability (Henley+)
  - These are early days – just finding clear trends is hard, as Dan McCammon will discuss

Whence the Hot Halo Gas?

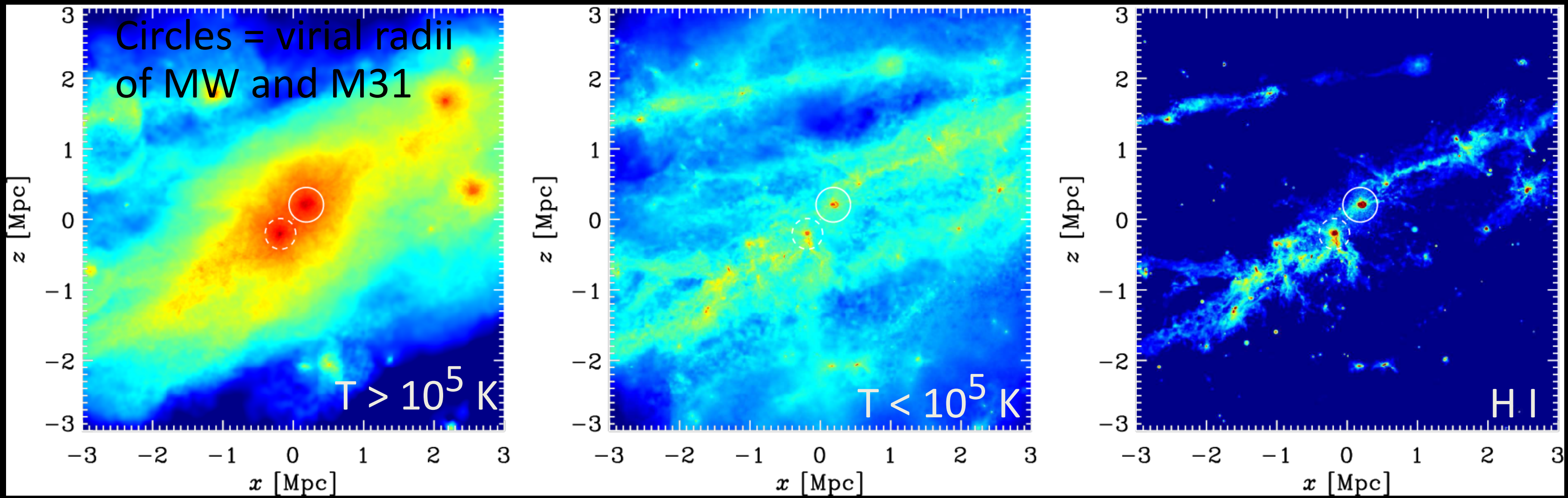
In the past, most of us thought on a galactic scale, in which supernova explosions + winds heated gas in the disk and pushed it into the halo

European Space Agency



We are starting to think on a larger scale, where hot gas is part of the cosmological evolution of the Local Group

Nuza et al. 2014



The End

- Stay tuned for Dan McCammon’s talk on why the hot gas is so puzzling.