The Warm & Hot Universe
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Evidence For The WHIM in The Diffuse X-ray Emission with Xmm-Newton

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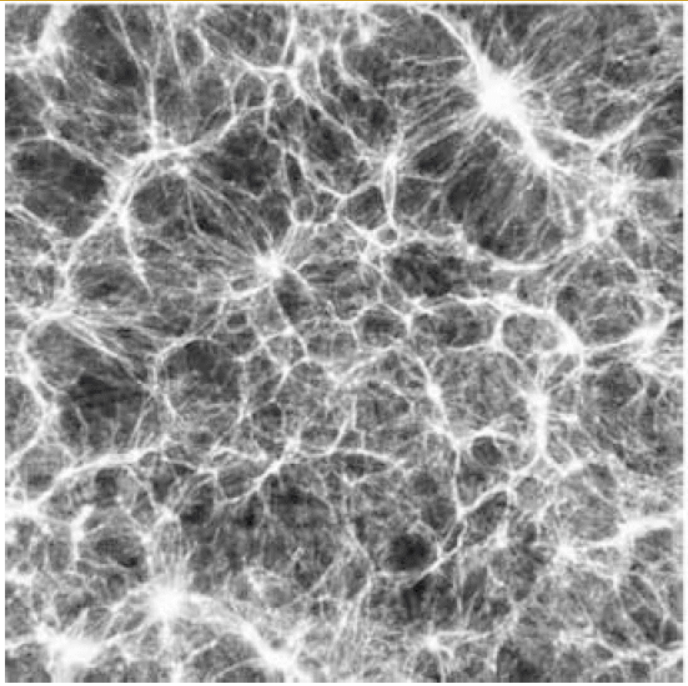
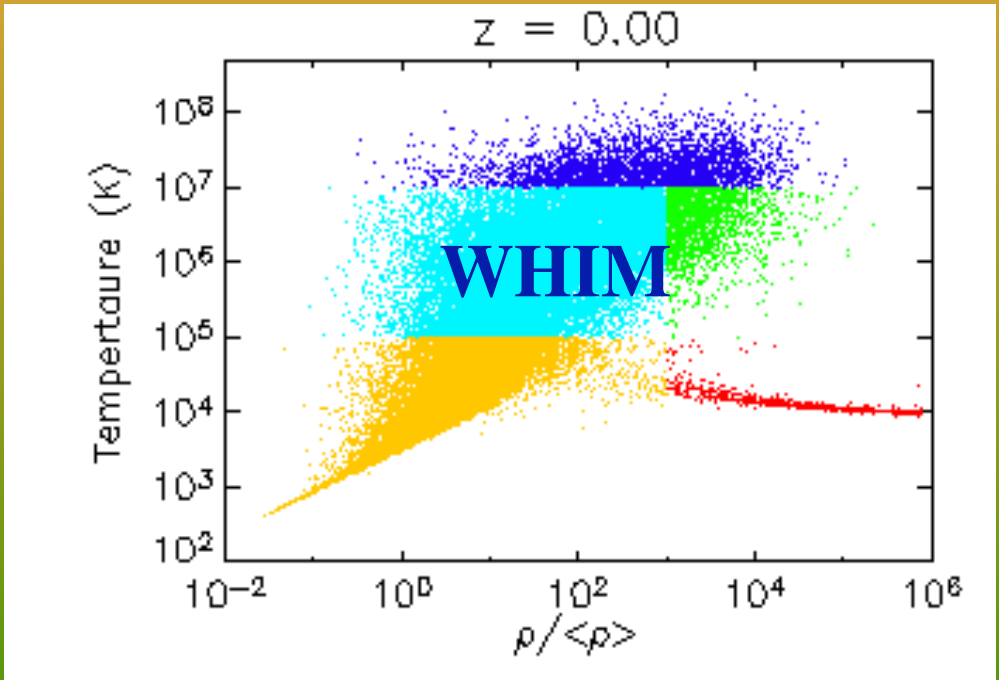
The missing baryon problem





- **More than half the baryons at z=0 are unaccounted for;**
- **Hydrodynamic simulations predict that about 40% of the baryons are "hidden" in filaments with $10^5 < T < 10^7$ and $10 < \rho/\rho_o < 1000$, the Warm-Hot Intergalactic Medium (WHIM);**

WHIM detection

Absorption

- MKN 421 (Nicastro et al., 2005)
- PKS 2155-304 (Fang et al., 2007)

Emission

- Redshifted emission lines
- Angular distribution

WHIM detection

Absorption

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Emission

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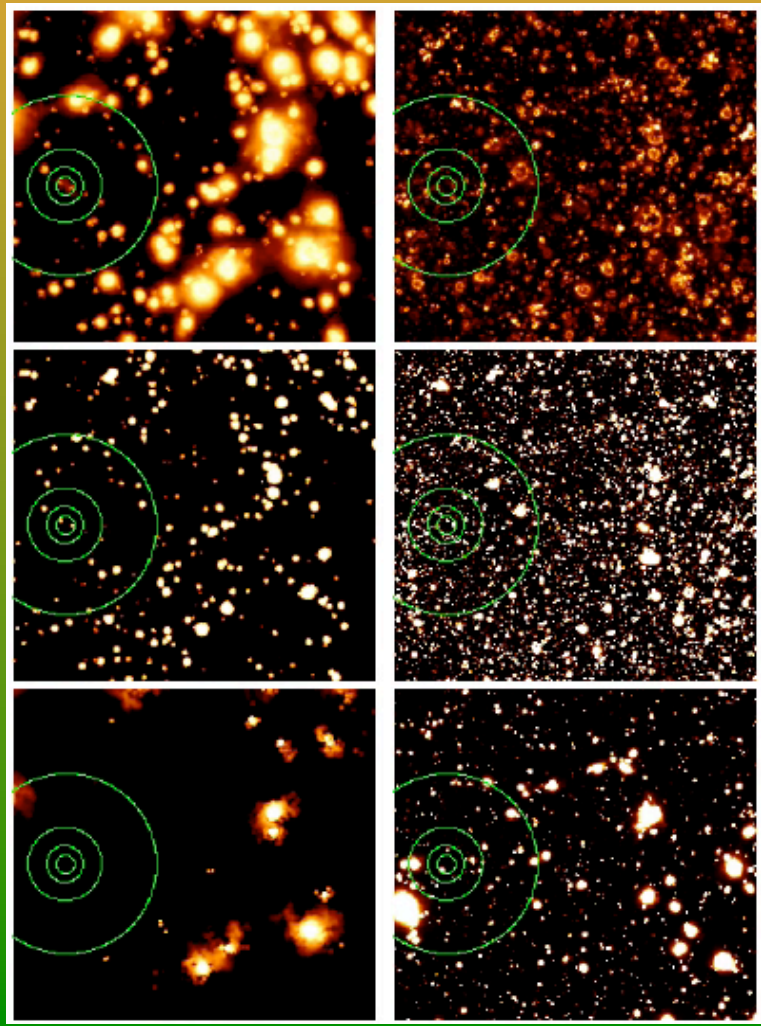
WHIM angular distribution

WHIM

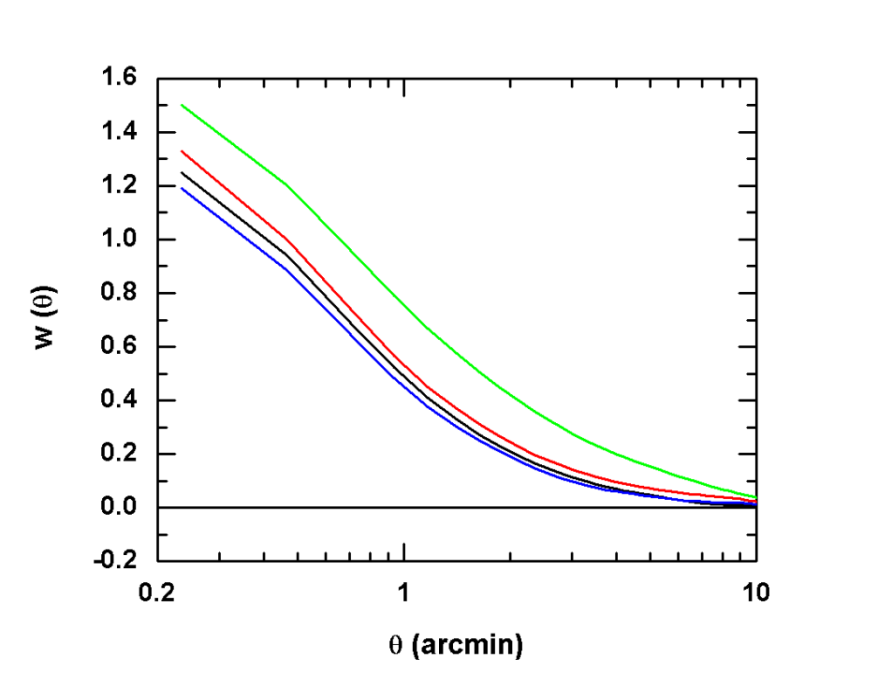
Groups

Clusters

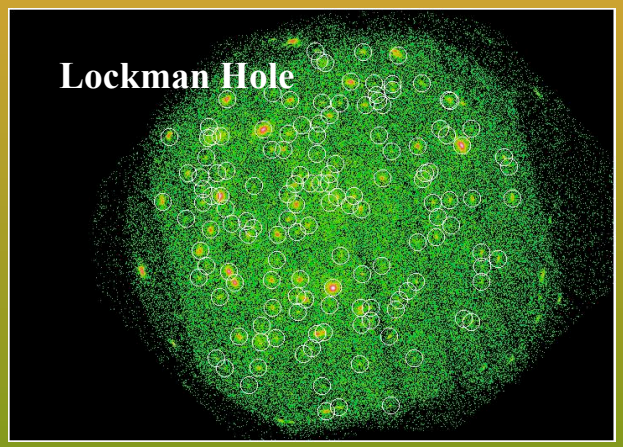


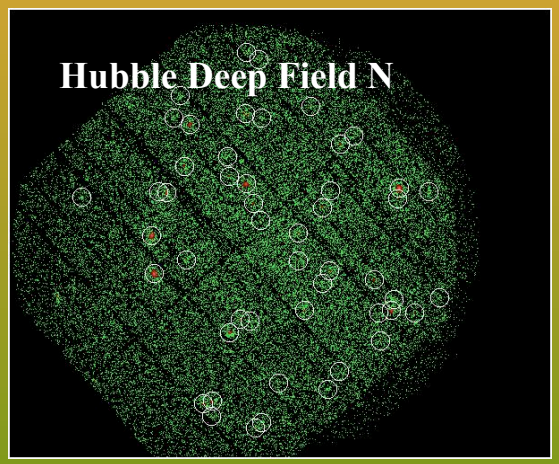
Angular Autocorrelation Function

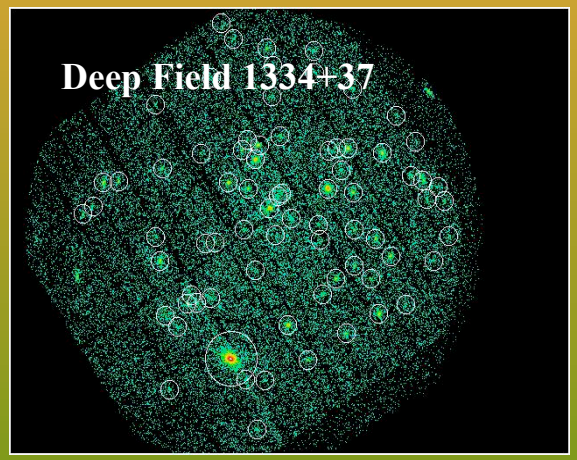
$$w(\theta) = \frac{\langle I(n)I(n')\rangle}{\langle I\rangle^2} - 1$$

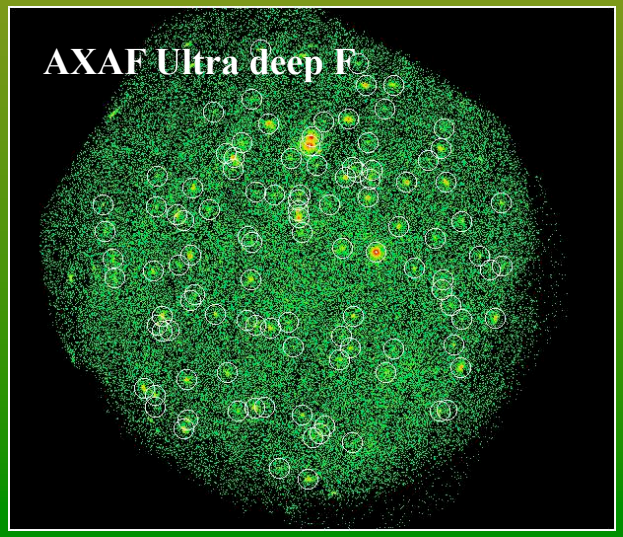


XMM-Newton Data





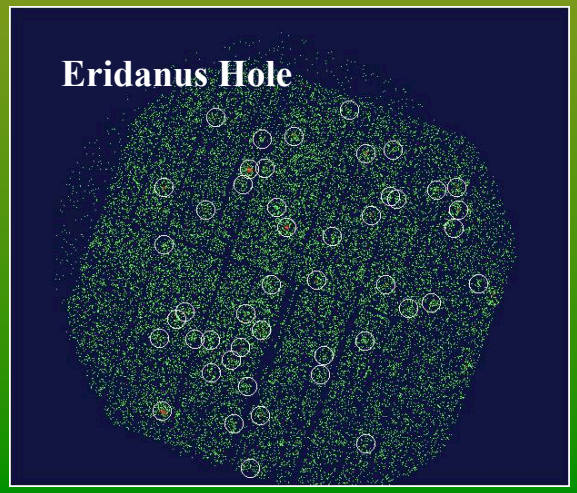




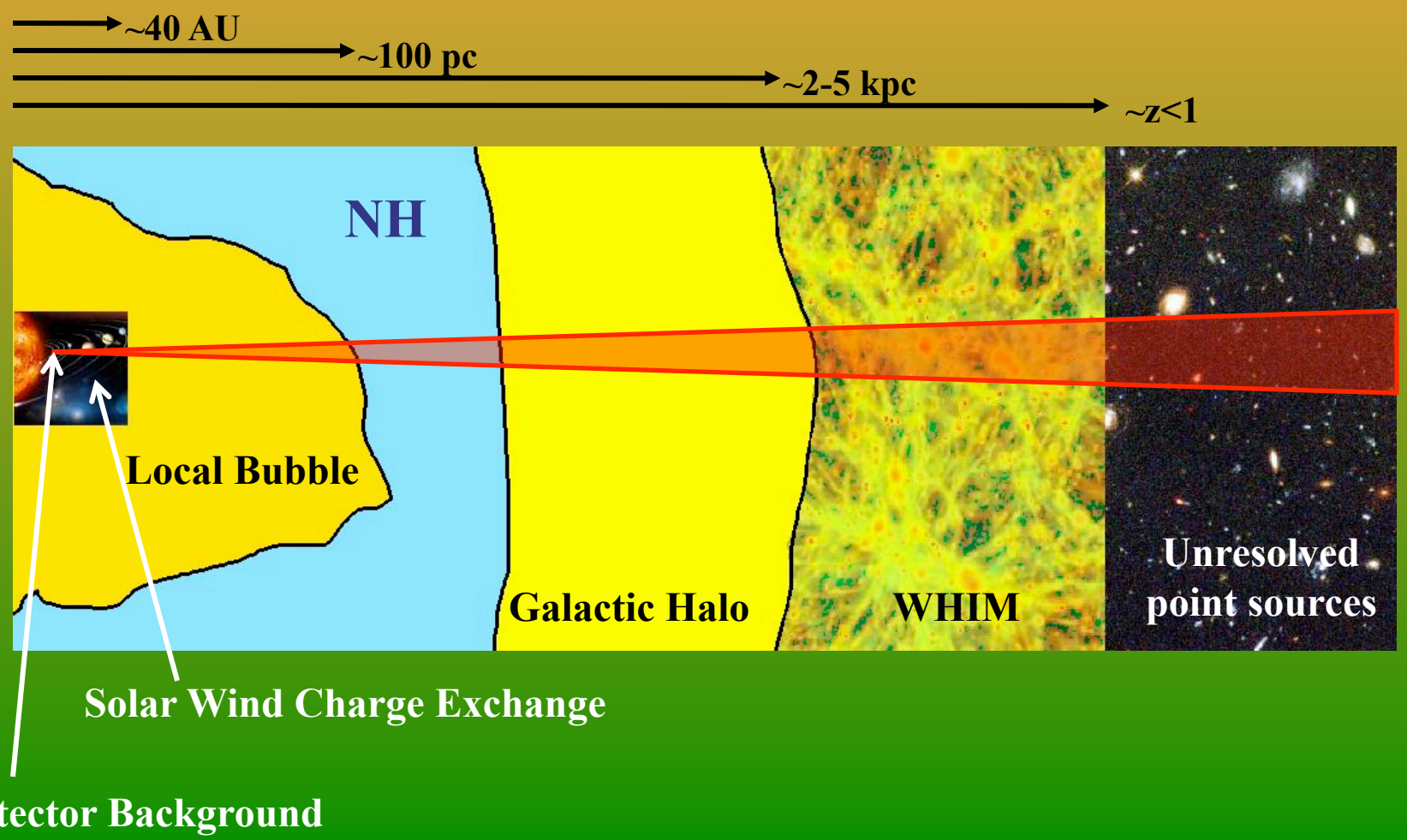
Mosaic images of the targets used in this investigation.

Energy range 0.4-0.6 keV

The white circles represent the identified point sources.

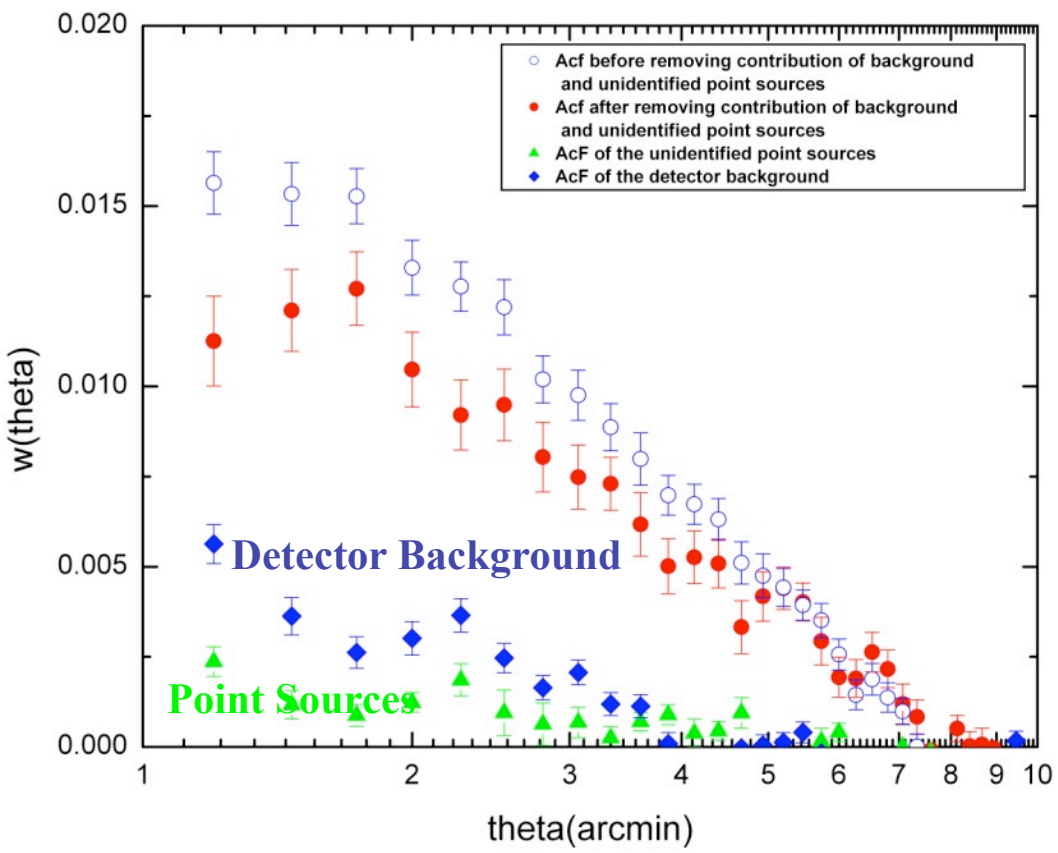


The Diffuse X-ray Background

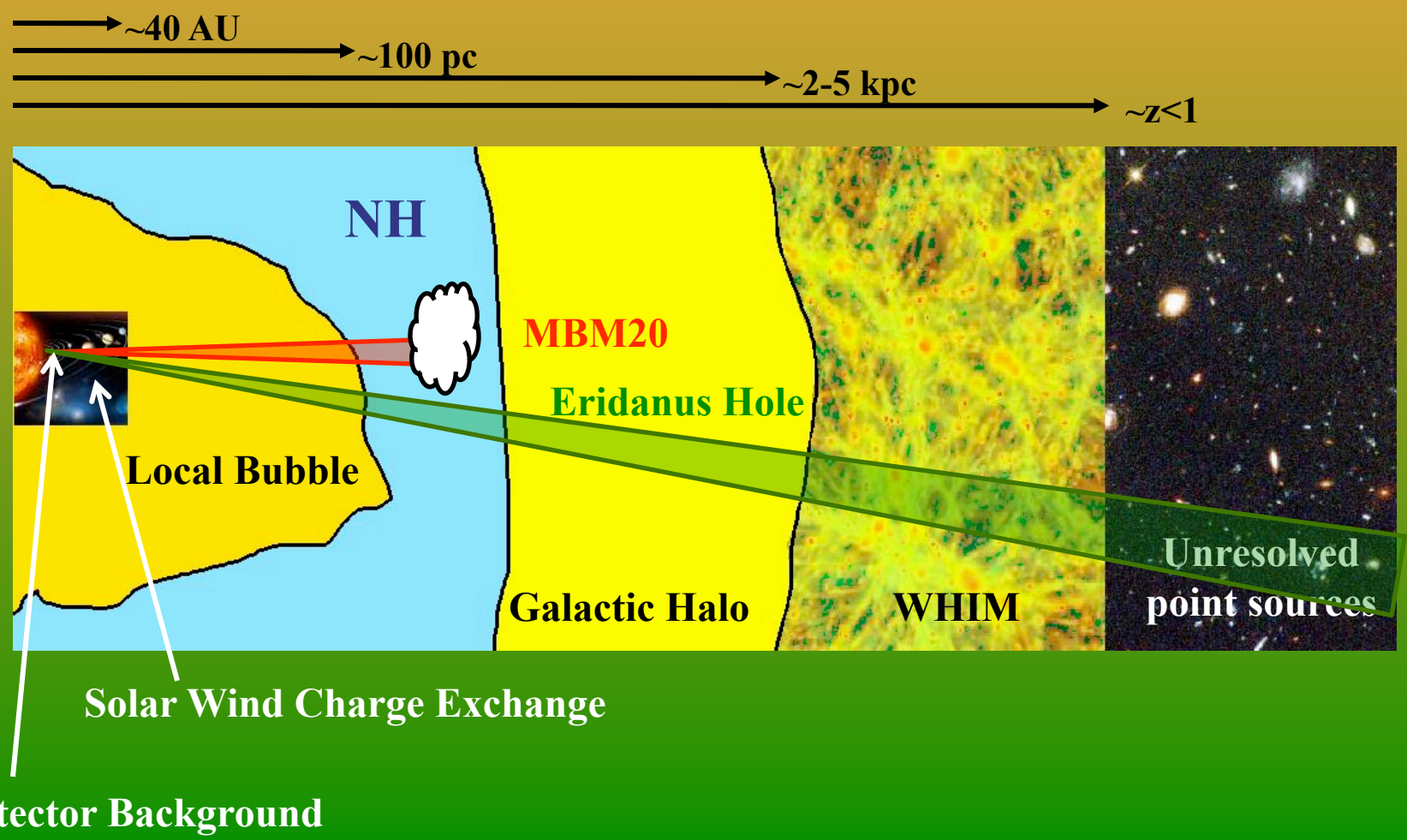


Removal of contamination

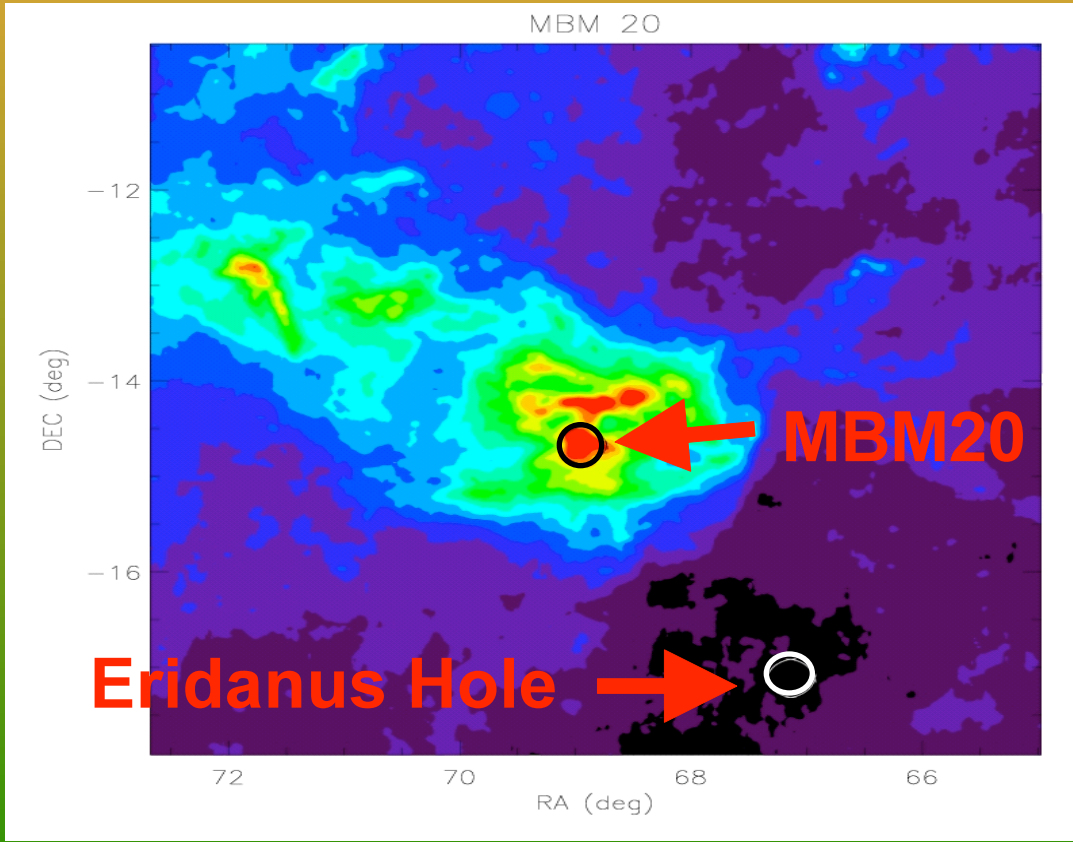
$$n^2\, w(\Theta)=n_p^{\,2}\, w_p(\Theta)+n_b^{\,2}\, w_b(\Theta)+n_w^{\,2}\, w_w(\Theta)$$



Control Observations



Control Observations



IRAS 100 μm map of MBM20 and surroundings with the two XMM pointing used in our investigation.

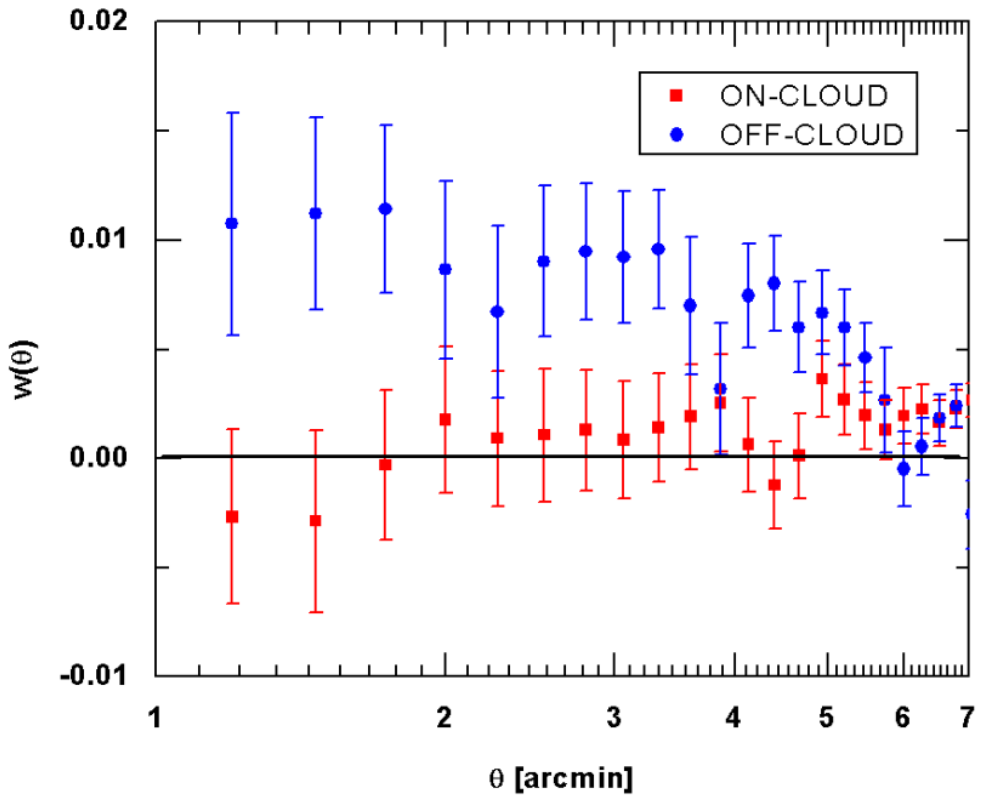
MBM20

- l=211º24'15.7", b=-36º33'46.7"
- N_H=15.9*10^{20} cm^{-2}
- Absorption=75% at ¾ keV
- 112±15 pc < d < 161±21 pc

Eridanus Hole

- l=213º25'52.3", b=-39º5'26.6"
- N_H=0.86*10^{20} cm^{-2}
- Absorption=8% at ¾ keV

Control Observations



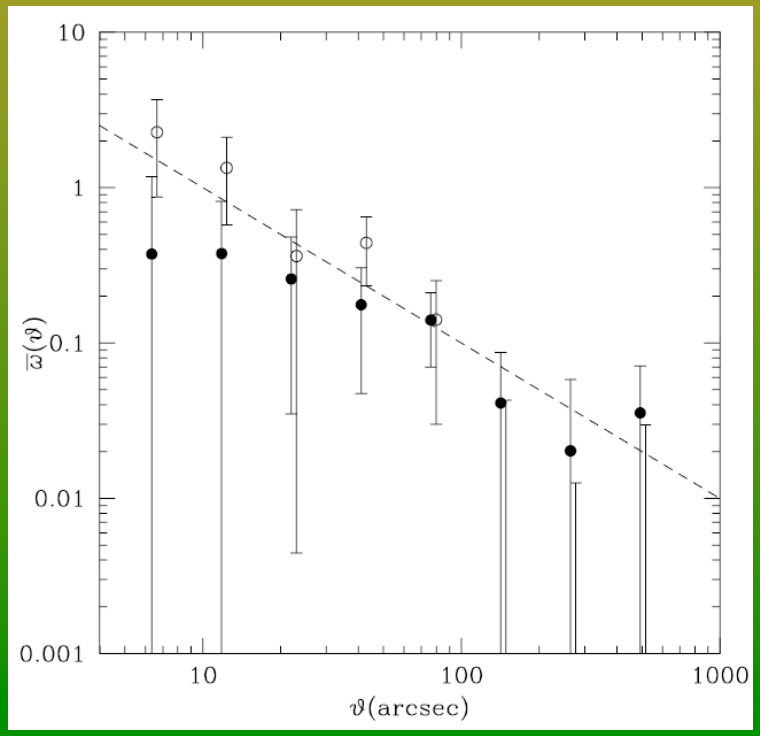
Calculated AcF for the two control targets: MBM20 (red) and the Eridanus hole (blue)

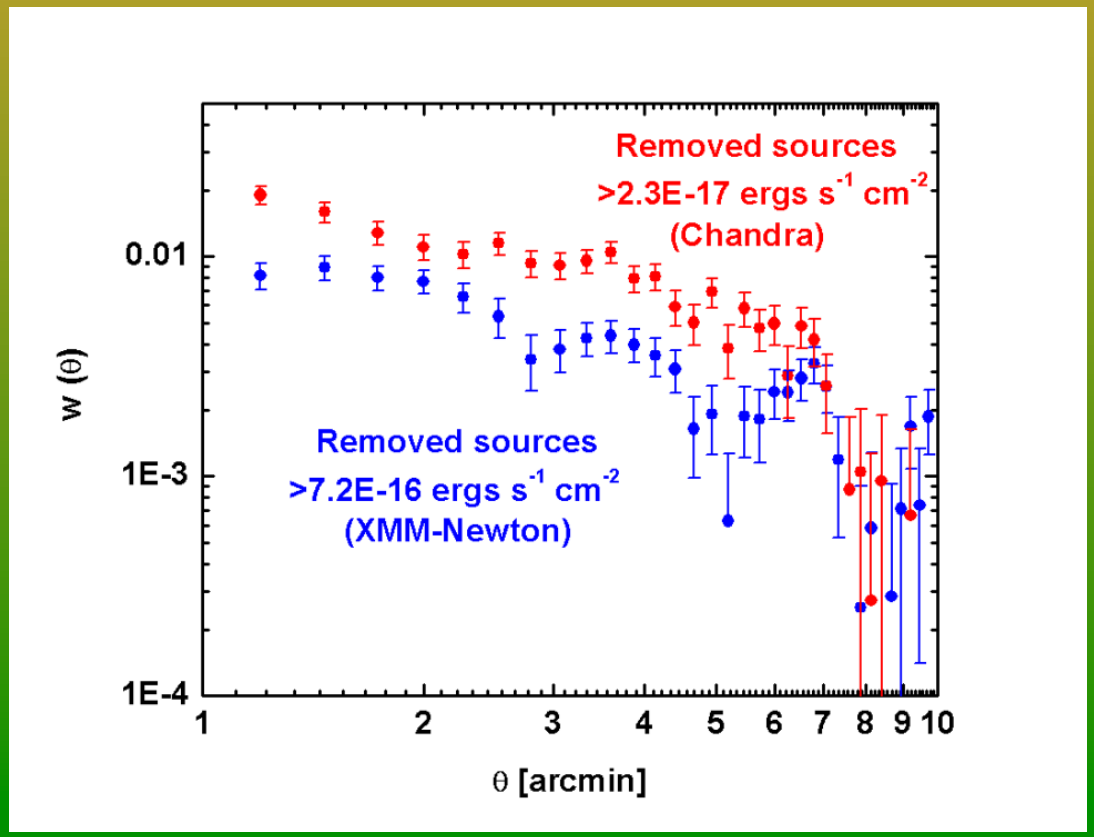
ON-CLOUD: χ^2=16, n=19
OFF-CLOUD: χ^2=60, n=19

Unidentified Point Sources

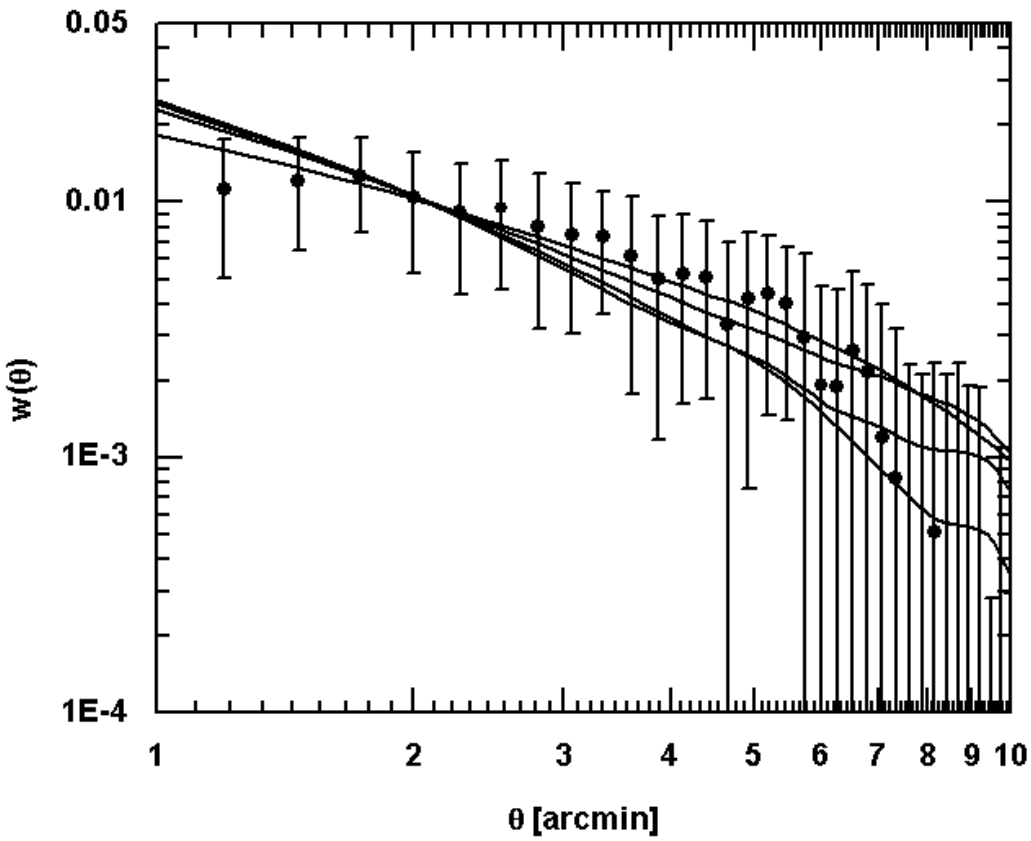
$$n^2\, w(\Theta)=n_p^{\,2}\, w_p(\Theta)+n_b^{\,2}\, w_b(\Theta)+n_w^{\,2}\, w_w(\Theta)$$

- n_p from McCammon et al.
- $w_p(\theta)$ from indentified point sources
  - Giacconi et al.
  - Hubble Deep Field N





Results



Conclusions

Several sigma detection of the WHIM signature in the AcF of XMM-Newton blank fields.

The fraction of X-rays due to the WHIM in the energy band 0.4-0.6 keV is 18±5% of the total diffuse X-ray emission.

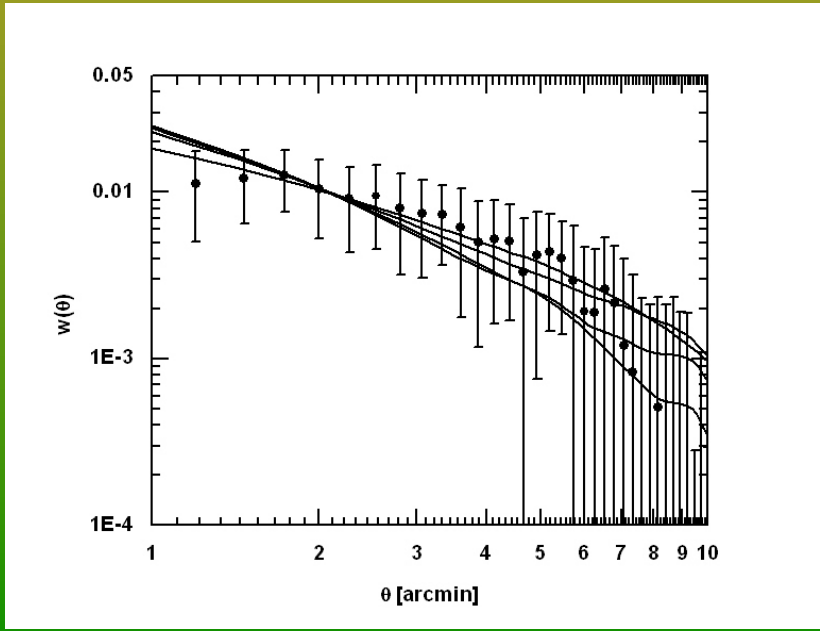
Detecting the WHIM

- Soft X-ray signature (redshifted OVII and O VIII lines)
- Only "controversial" evidence is absorption from MRK421 (Nicastro et al. 2005)
- Possibility of detecting it in emission through the Autocorrelation function (AcF – Ursino and Galeazzi, 2007)

AcF

$$w(\theta) = \frac{\langle I(n)I(n')\rangle}{\langle I\rangle^2} - 1$$

Target	Observing time (s)	l	b	NH (10^{20} cm^{-2})
Lockman hole	401928	149 16 48.1	53 08 45.9	0.7
AXAF Ultra deep F	248123	223 34 36	-54 26 33.3	1.0
Hubble deep Field N	95229	125 53 31.3	54 48 52.4	1.4
Deep Field 1334+37	88779	85 37 22.5	75 55 16.4	0.8
Eridanus hole	111320	213 25 17.9	-39 04 25.6	0.86
MBM20	111320	210 51 18.6	-36 33 43.1	15.9



0.4 kev < E < 0.6 keV