Exploring the Hot and Energetic Universe:

The first scientific conference dedicated to the Athena X-ray observatory

Prospects for the direct WHIM detection by Athena

The soft X-ray WHIM emission with WFI

Andrzej M. Sołtan & Agata Różańska

Nicolaus Copernicus Astronomical Center
Warszawa

Outline

1. Dark baryons
2. WHIM as seen by XMM-Newton
3. WHIM by Athena WFI

Outline

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WHERE ARE THE BARYONS?

RENYUE CEN AND JEREMIAH P. OSTRIKER
Princeton University Observatory, Princeton University, Princeton, NJ 08544; cen@astro.princeton.edu, jpo@astro.princeton.edu
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ABSTRACT

New high-resolution, large-scale cosmological hydrodynamic galaxy formation simulations of a standard cold dark matter model (with a cosmological constant) are utilized to predict the distribution of baryons at the present and at moderate redshift. It is found that the average temperature of baryons is an increasing function of time, with most of the baryons at the present time having a temperature in the range of 10^5–10^7 K. Thus not only is the universe dominated by dark matter, but more than one-half of the normal matter is yet to be detected. Detection of this warm/hot gas poses an observational challenge, which requires sensitive EUV and X-ray satellites. Signatures include a soft cosmic X-ray background, apparent warm components in hot clusters due to both intrinsic warm intracluster and intercluster gas projected onto clusters along the line of sight, absorption lines in X-ray and UV quasar spectra [e.g., O VI (1032, 1038) A lines, O VII 574 eV line], strong emission lines (e.g., O VIII 653 eV line), and low-redshift, broad, low column density Lyα absorption lines. We estimate that approximately one-fourth of the extragalactic soft X-ray background (at 0.7 keV) arises from the warm/hot gas, half of it coming from $z < 0.65$, and three-quarters coming from $z < 1.00$, so the source regions should be identifiable on deep optical images.

Subject headings: cosmology: theory — galaxies: formation — large-scale structure of universe — methods: numerical

1. INTRODUCTION

Where are the baryons, the ordinary nonexotic matter of

But at $z = 0$ in the present-day universe, every analysi
(see, e.g., Fukugita, Hogan, & Peebles 1997) indicates tha

Local baryon deficit

$\Omega_{\rm lum} \simeq \Omega_\star + \Omega_{\rm HI} + \Omega_{\rm X:clusters} \approx 0.012\, h_{70}^{-2}$

$\Omega_{\rm b} \approx (0.045 \pm 0.057)$ (Primeval abundances D, ^{3}He, ^{4}He, Li)

$> 0.037\, h_{70}^{-1}$ (Ly-α forest at $z \approx 2$)

$$\Omega_{\rm lum} < \Omega_{\rm b} < \Omega_{\rm m} \approx 0.3$$

$\Uparrow$ Baryon deficyt

$\Uparrow$ Dark matter

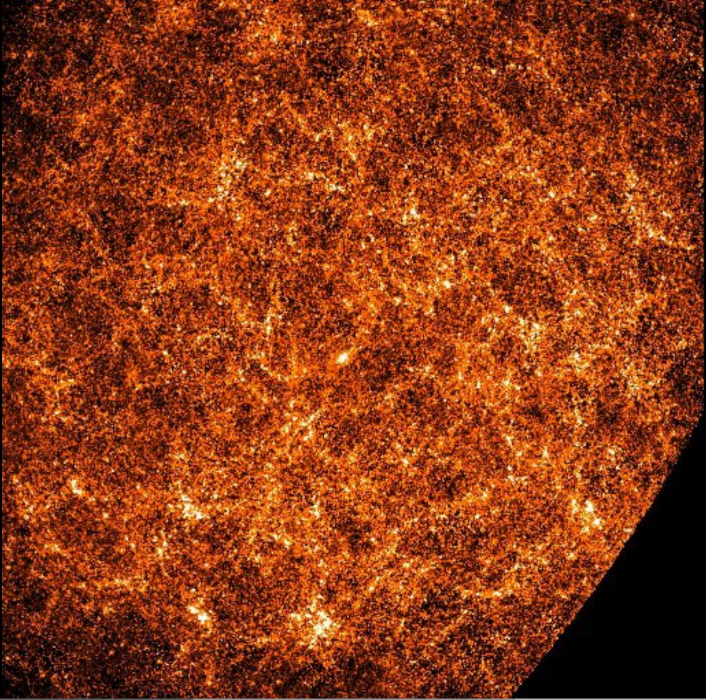
$h_{70} = H_o / 70\,{\rm km\,s^{-1} Mpc^{-1}}$

Four phases of baryonic matter

1	Condensed	$\delta > 1000$	$T < 10^5$ K	stars, interstellar matter
2	Hot		$T > 10^7$ K	intracluster gas
3	Diffuse	$\delta < 20$	$T < 10^5$ K	Ly-α forest
4	Warm		$10^5 < T < 10^7$ K	WHIM

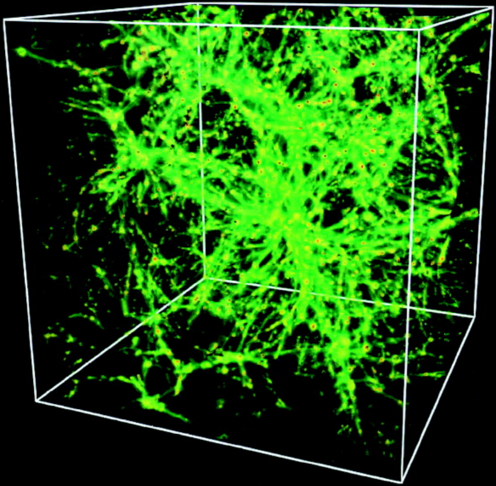
Warm-Hot Intergalactic Medium

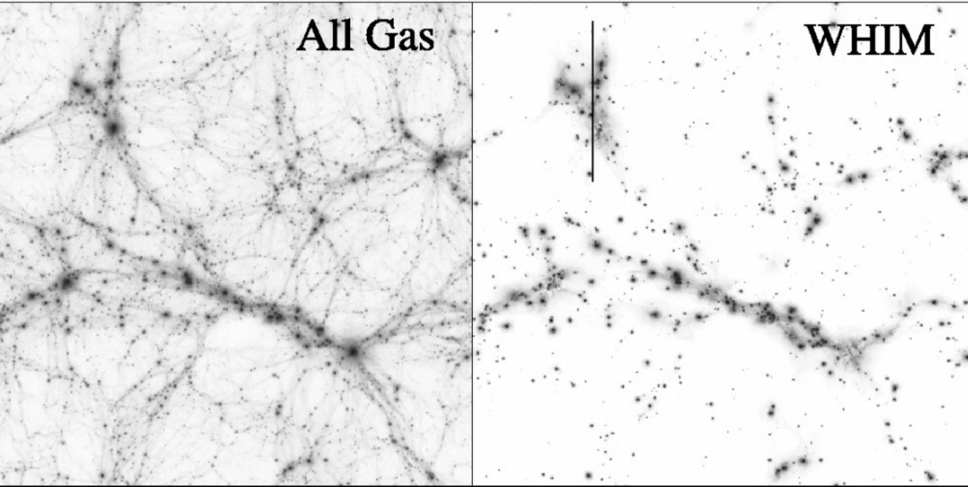
Davé et al., ApJ, 552, 473 (2001).



Shane & Wirtanen, Lick counts

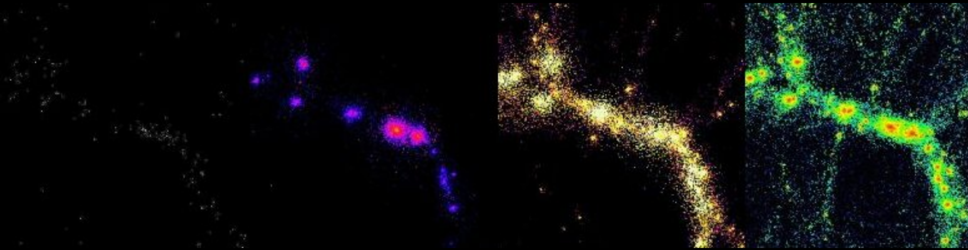
Where are the baryons ?





Yoshida et al., ApJ 618, 91 (2005)

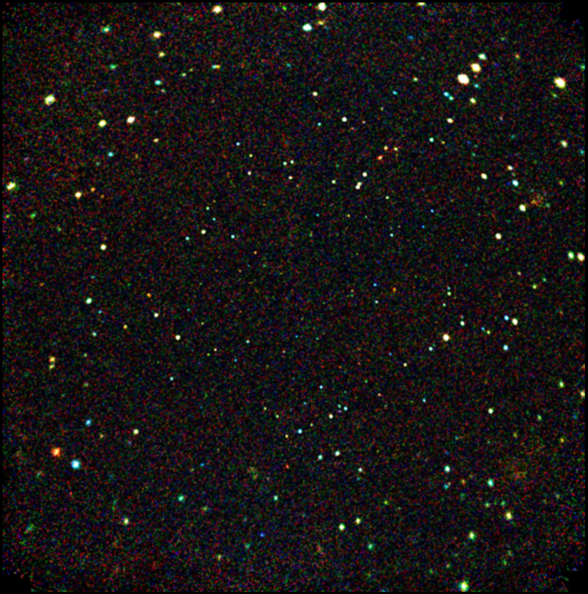
Baryons and Dark Matter



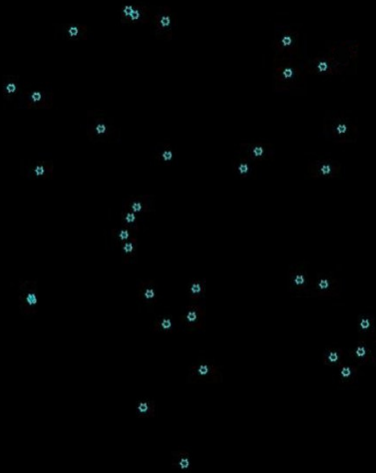
Suto et al., JKAS 37, 387 (2004)

Outline

X-ray sky



XRB vs galaxies



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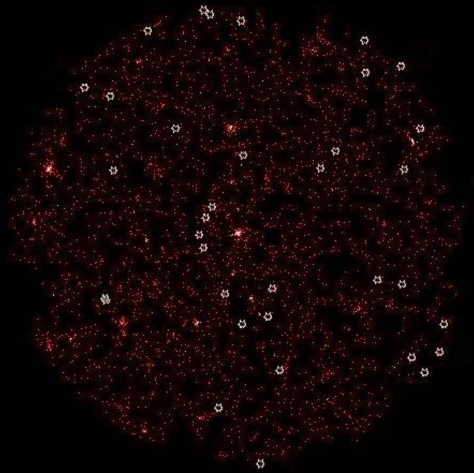

X-ray background (XRB)

- The XRB at energies above $\sim 1\,\text{keV}$ is generated by a population of discrete extragalactic sources (mostly AGNs).
- At enegries below $\sim 1\,\text{keV}$ some (basicly unknown) contribution to the XRB generate also: local (Galactic) hot plasma and the WHIM.
- Fluctuations of the XRB at arcmin scale are generated by a nonuniform distribution of sources contributing to the XRB: AGNs and WHIM.
- The WHIM is strongly correlated with galaxies.
- WHIM in emission: spherical halos rather than filaments.

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- Whim emission expected extremely weak

  $\downarrow$
- stacking of observations
- $\equiv$ cross-correlation function
- Azimuthal symmentry
- X-ray sky — XMM-Newton archive
- Galaxy data — APM + MAPS catalogue

  ($17 - 20$ mag, $0.06 \lesssim z \lesssim 0.22$)
- 150 pointings $\times$ 16000 s $\times$ 20 galaxies
- $\sim 5 \times 10^7$ s
- Order of magnitude 'deeper' than 4Ms CDFS

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Correlation analysis

- The WHIM is strongly correlated with the galaxy distribution.
- At small angular scales, the WHIM structure defines the signal of the cross-correlation function (CCF).
- At large scales the CCF signal is generated by the large scale fluctuations of the galaxy distribution (the galaxy autocorrelation function).

- $\delta\rho(\theta) = s \cdot P(\theta) + s \cdot w_{gg}(\theta) \cdot n_g$

  $\delta\rho(\theta)$ – average excess of the X-ray flux,
  s – brightness of the individual WHIM halo around galaxy,
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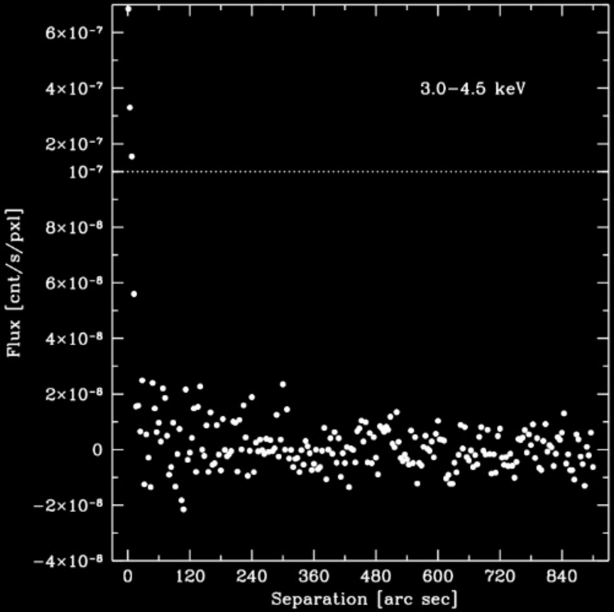
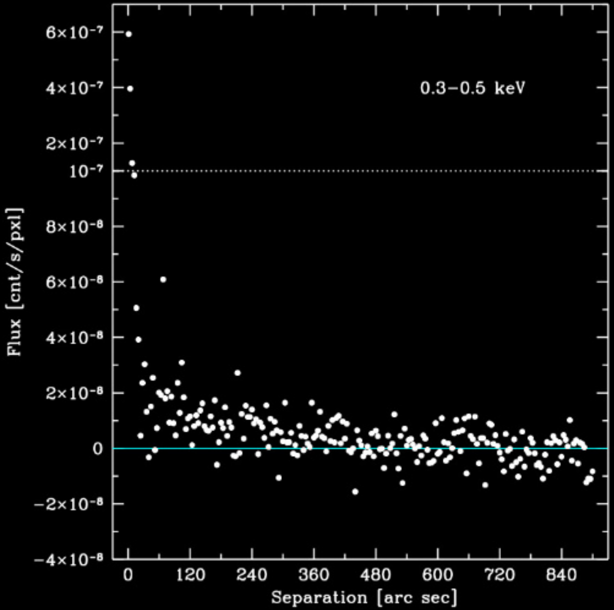
CCF at high energies



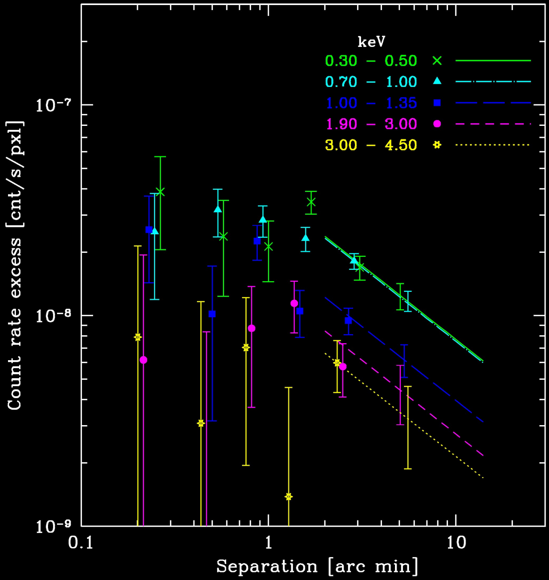
Sołtan, A&A 460, 59 (2006)

CCF at soft energies



Sołtan, A&A 460, 59 (2006)

WHIM – surface brightness profile



Sołtan, A&A 460, 59 (2006)

Outline

$$E = 0.3 - 0.5 \ \mathrm{KeV}$$

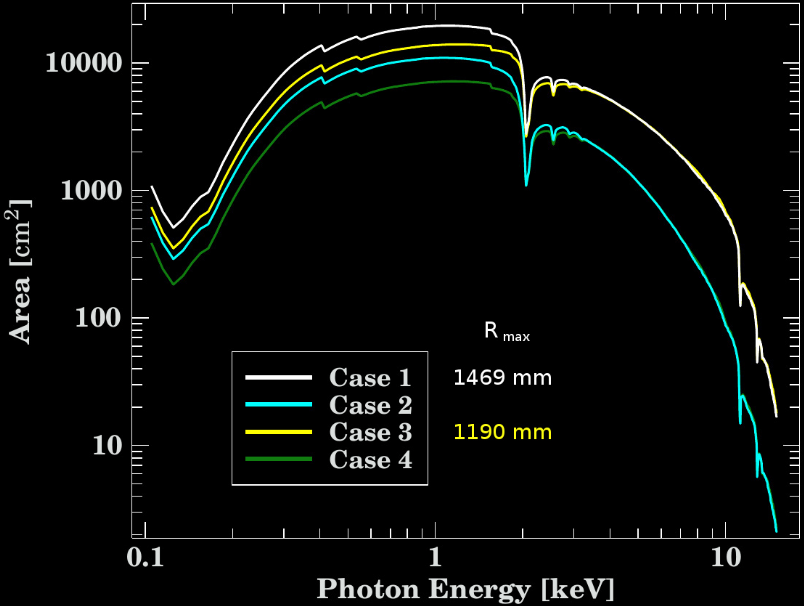
$$\sigma = (2-3) \times 10^{-8} \ \mathrm{cnt\ s^{-1}\ pxl^{-1}}$$

$$\sigma = 5.6 \times 10^{-6} \ \mathrm{cnt\ s^{-1}\ arcmin^{-1}}$$

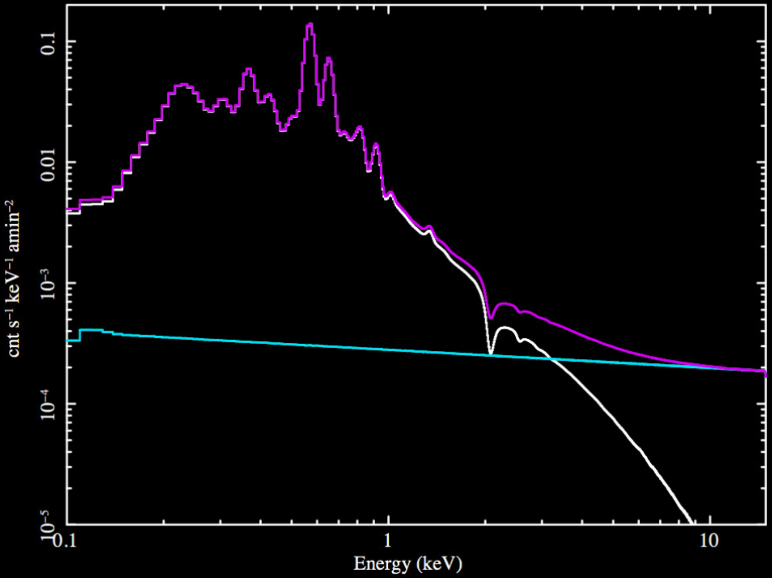
$$1 \ \mathrm{cnt} = 0.65 \times 10^{-11} \ \mathrm{erg\ cm^{-2}}$$

$$\sigma = 5.7 \times 10^{-8} \ \mathrm{ph\ cm^{-2}\ s^{-1}\ arcmin^{-1}}$$

WFI ARF (no filter)



WFI background



Signal against Noise

$$\Delta n = \mathrm{ARF} \cdot \sigma$$

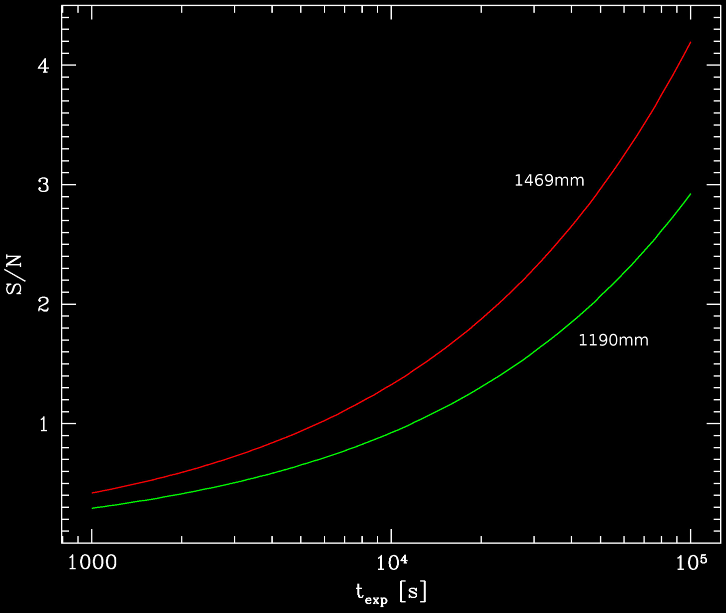
$$S = \Delta n \cdot A \cdot t_{\mathrm{exp}}$$

$$N = \sqrt{b \cdot A \cdot t_{\mathrm{exp}}}$$

$$S/N = \Delta n \cdot \sqrt{\frac{A \cdot t_{\mathrm{exp}}}{b}}$$

where:
Δn – count excess generated by WHIM per arcmin^2
A – solid angle of the WHIM halo
t_{exp} – exposure time

S/N for two mirror modules on-axis



Athena ...

... most likely will have the capability to detect the soft X-ray emission from individual WHIM halos accumulated around nearby galaxies. A moderate exposure time would be required.

Imaging of the detailed structure will need long but still feasible exposures.

Thank you