The Baryons Hunt
A Clean Test of the SCM

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1

The Standard Cosmological Model & the Missing Baryon Problem
Concordance Cosmology: A “Standard” Model??

$$\Omega = \Omega_\Lambda + \Omega_{DM} + \Omega_b = 0.70 + 0.25 + 0.05 = \text{FLAT UNIVERSE}$$

DE ???

$\Lambda (w=-1)$

Axions ???

WIMPs ???

Heavy Neutrinos ???

…and $H_0$…Needed ???

But…

NAF (Trieste): Fabrizio Nicastro
Where are the Baryons?

WHIM
\[ \Omega^\text{Meas}_b = \Omega^\text{CMB}_b \]
validates SCM

\[ \Omega^\text{Meas}_b > \Omega^\text{CMB}_b \]
invalidates SCM
Current Evidence: the WHIM at Cosmological Distances
WHIM Strength & Detectability

UV vs X-Rays

\[ W_{\text{OVI}} < 60-600 (1+z) \text{ mA (FUV)} \]

\[ W_{\text{OVII}} \sim 0.8-8 (1+z) \text{ mA (X-Rays)} \]

Contrast: FUV: \( 1032/(0.06-0.6) \sim 2000-20000 \sim (0.1-1) \times R_{\text{FUSE/HST-STIS}} \)

X-Rays: \( 22/(0.0008-0.008) \sim 3000-30000 \sim (10-100) \times R_{\text{Chandra/XMM}} \)
**FUV: The WHIM *is* out there!**

But...only < 10-20 % of the Missing Mass

**OVI:** 40 OVI systems at z < 0.15

\[ \Omega_b(\text{OVI}) = 0.22 \% \text{, i.e. 10 \% Missing Baryons (} Z_0 \sim 0.1 \text{ } Z_\odot) \]


**BLAS:** \( b_{\text{therm}}(\text{HI}) > 45 \text{ km/s} \)

(Cf \( b(\text{HI}) \sim 10-50 \text{ km/s in } \text{Ly} \alpha-\text{Forest} \))

\[ \Omega_b(\text{BLA}) = 0.27 \% \text{, i.e. } \sim 10 \% \text{ Missing Baryons} \]

\[(\text{Richter+06, A&A)}\]
The WHIM in X-Rays: 80-90 % of the Missing Mass?

(Nicastro+05, Nature)

Controversial

We stand by our Result:
(Nicastro+08, Science; Nicastro+07, ApJ)

1. XMM-Newton does *NOT* rule out Chandra detections (Rasmussen+07, ApJ)

2. Chances of falsely detecting the two systems are 0.05 % and < 0.01 %, *NOT* 40 % and 6 % (Kaastra+06, ApJ)
The Controversy (1)

- N05a,b claim statistical significances of 3.5σ and 4.8σ, i.e. $P_{\text{chance}}=0.05 \%$ & 0.005 \%
- K06 perform MonteCarlo and conclude that: $P=40 \%$ and $P=6 \%$ of falsely detect the two systems.
- N07 perform new MonteCarlo and confirm $P=0.05 \%$ and $P < 0.01 \%$ for the two systems (i.e. 3.5σ and > 3.9σ respectively):

  differences due to different assumptions

A Simple Gaussian Argument (z=0.011; 2 lines @ 3.8σ & 2σ)

$\lambda(\text{OVII})=21.602$; $z(\text{Mkn 421})=0.03 \implies \Delta \lambda = \lambda(\text{OVII})xz(\text{Mkn 421}) = 648 \text{ mA}$

$\Delta \lambda(\text{LETG})=50 \text{ mA} \implies 13 \text{ Ind. Elem.}; \text{ Over-sampling by 4} \implies 52 \text{ bins}$

$\implies P_{\text{Gauss}} \sim \{(1-P(3.8\sigma)) \times 52 \} / 2 \times \{(1-P(2\sigma)) \times 59 \} / 2 = 0.02 \%$
The Controversy (2)

Rasmussen+07 claim no evidence, in XMM-RGS, of the absorption lines seen by Chandra

\[ R_{\text{LETG}} \approx 2.4 \times R_{\text{RGS}} \]

XMM does not rule out Chandra Detections
Current Evidence: the $z=0$ Absorber
Hot Galactic Corona or Local Group WHIM? Or Both?
Hot Gas in the Local Group
Strong Segregation in the LSR

HV-OVI: 90 % l.o.s.

Far-UV

X-Rays

LMC-X3
(Wang et al., 2005)

PKS 2155-304

3C 273
NGC 3783
Mkn 421

(Nicastro+03, Nature)
(NAF (Trieste): Fabrizio Nicastro
(Williams+05, ApJ)
The Way Forward: An ERC Program and Goals
Goals

• **Direct measure of** $\Omega_b$  
  
  **Test of SCM**

• Metallicity history of the Universe (dZ/dz)  
  
  “Ecology” of the Universe

• Heating history of the Universe (dT/dz)

• 3D-Map of Dark Matter concentrations
**X-Rays**

(a) z>0: Arc. search for OVII, CV in LETG/RGS of bright blazars: Detect MB; \( \Omega_b(X), dN/dz(X) \)
(b) z>0: OVII-Forest Fluctuations: Evidence of WHIM; calibration
(c) z>0: 2-PAC + OVII (COSMOS) WHIM in Emission
(c) Props (LEG,RGS): VLP+TOO

**UV**

(a) z>0: Arc. search for BLA, BLB, OVI, NeVIII:
- refines \( \Omega_b(UV), dN/dz(UV) \)
- (b) z=0: Arc. Search for HV- LV-OVI in host galaxies/groups location and origin of z~0 Abs.
- (c) Proposals (COS, STIS)
  - (PhD A + 1.2+2y PD)

**Gamma**

(a) Upgrading+Updating ISE (die.rec. rate + TEPHOT):
- Fit WHIM spectra + constrain physical state of baryons (1.2y PD + 4 visitor YK)

**UV**

(a) New COS observations \( \Omega_b(UV), dN/dz(UV) + z=0 \)
(b) Large COS prop. for 21 bright X AGNs, w GALEX but not STIS, at z > 0.3
- Detects BALs for Z and mass
  - (PhD A + PD)

**Short Term**

**Theory**

**Mid Term**

**Long Term**

**Galaxy LSS around WHIM filaments**

[LBT, TNG, ESP, VLT, MMT, Magellan: ugriz photo-z+spec. Corr. of vir. Struct. with WHIM => DM (PhD C)]

**New Mission Concepts**


**New Mission Concepts**

**Short Term**

**Mid Term**

**Long Term**

\( \Omega_b, dZ/dz, dT/dz, DM \)
OVII-Forest Fluctuations

Theoretical Expectations

15 L.o.S. from Cen & Ostriker, 2006 (thanks to A. Phillips)
ISE Spectral Simulations (thanks to Y. Krongold)
OVII-Forest Fluctuations: Observations and Comparison with Predictions

\[ \mu \text{(Mean)} \]

\[ 1\sigma \text{(SD)} \]

\[ \lambda \text{(in Å)} \]

\[ \text{Data/Model} \]
Archival UV Search

BLAs

LV- HV-OVI in external galaxies/groups
C-Cosmos

2-PAC
OVII Kα

$1^0 \times 1^0$
Phase \rightarrow ISE

NGC 3783: Krongold+03

NGC 5548: Warm Absorber

Fe-L  Fe-M UTA

OVII  NVII  NVI  CVI
2.7 Ms XMM-RGS (AO7)

(Simulations by YK, AP, FN)
The Way Forward

LETG; RGSs; Con-X (grat); XEUS (cal).

Pharos (R=2500, A=600 cm$^2$)
Edge (R=250; A=800 cm$^2$)

1 mCrab
0.2 mCrab

Log($N_{\text{ovII}}^{\text{Thres}}$) vs. Exposure (in s)

Log($N_{\text{ovII}}^{\text{Thres}}$) vs. Fluence (in erg cm$^{-2}$)
Spin-offs

- XMM Ultra-deep X-ray survey(s) (low NH, Multi-MS):
  - XRB population (O-IR identifications)
  - Obscured AGNs (X-ray colors)
  - Groups & Cluster identifications (diffuse emission)

- Blazar Studies (under extreme conditions - X-ray/Gamma TOOs)
  - Emission mechanisms at work
  - Intrinsic obscuration vs continuum curvature

- LETG/RGS Calibrations to better than 1%
ERC: “Relaunching the ERA”
Guidelines for the Future
(erc.europa.eu/ecc_reflections_era_greenpaper_31080_fck2_en.pdf)

Excerpt 1

Competition should be fair in order to be effective, with similar starting conditions for every party involved. The key problem here is the imbalance between different Member or Associated States in salaries for researchers as well as national support for fundamental research and for research infrastructure. The countries themselves are responsible for rectifying such imbalances. Otherwise, the unintentional effect could be that the ERC’s strategy of attracting the best researchers to work in the EU will unintentionally contribute to growing disparities. For example, world class researchers will not be able to accept the financial conditions offered at the local level in several member states, including some of thewealthier ones.

Excerpt 2

Research excellence should be THE goal everywhere when science funding is concerned. However, enhancing the potential of currently ‘scientifically weaker’ states (including some new member states, for obvious historical reasons) needs to be addressed urgently, through EU structural funding and national or regional investments. This applies to infrastructures, and to research projects and personnel funding, including increases in remuneration levels. Permanent acceptance of great differences in salaries or honoraria paid from EU grants would contribute to a damaging internal brain drain in the EU research sector.

ERA = European Research Area