The Baryons Hunt

A Clean Test of the SCM

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The Standard Cosmological Model & the *Missing Baryon* Problem

Concordance Cosmology:
A "Standard" Model ??

$$\Omega = \Omega_\Lambda + \Omega_{DM} + \Omega_b =$$

$$= 0.70 + 0.25 + 0.05 =$$

FLAT UNIVERSE

DE ???

Λ (w=-

Needed ???

Axions ???

WIMPs ???

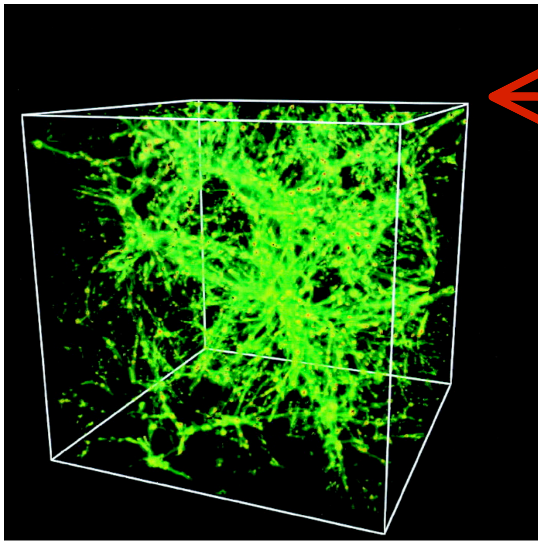
Heavy Neutrinos ???

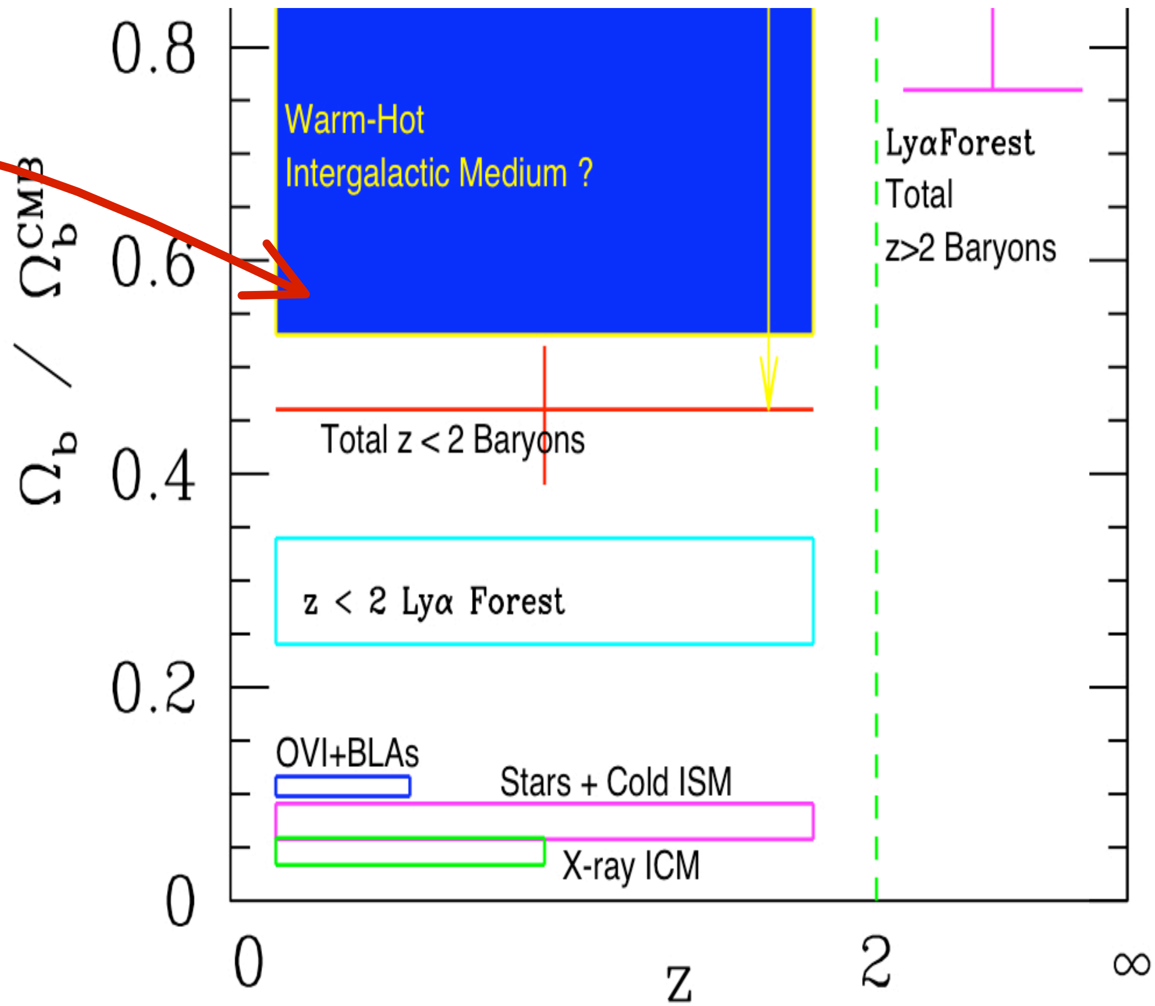
...and H_0...Needed ???

But...

Where are the Baryons?

WHIM





$$\Omega_b^{Meas} = \Omega_b^{CMB}$$

validates SCM

$$\Omega_b^{Meas} > \Omega_b^{CMB}$$

invalidates SCM

2

Current Evidence: the WHIM at Cosmological Distances

WHIM Strength & Detectability

UV vs X-Rays

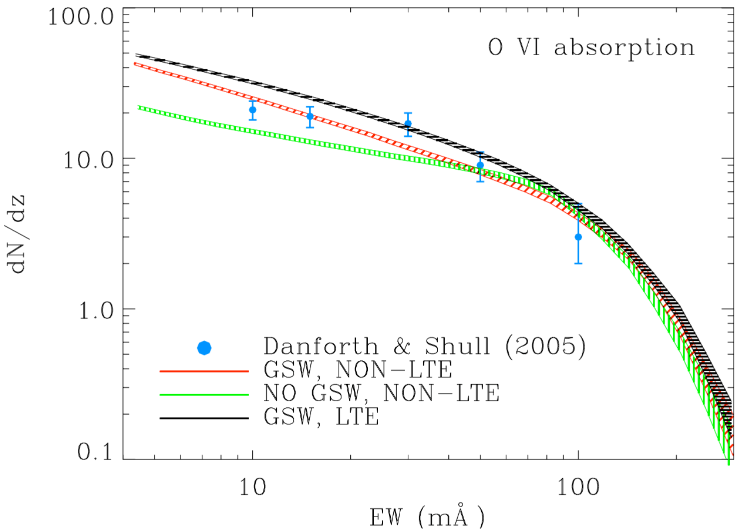
$W_{OVI} < 60\text{-}600\ (1+z)$ mA (FUV)

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

Contrast: FUV: 1032/(0.06-0.6) ~ 2000-20000 ~
~ (0.1-1) x $R_{FUSE/HST\text{-}STIS}$
X-Rays: 22/(0.0008-0.008) ~ 3000-30000 ~
~ (10-100) x $R_{\mathit{Chandra}/XMM}$

FUV: The WHIM *is* out there!

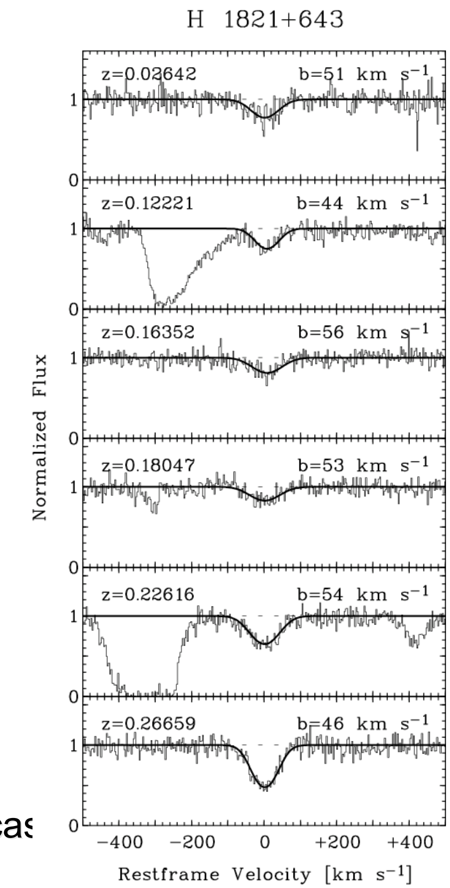
But…only < 10-20 % of the Missing Mass



OVI: 40 OVI systems at z < 0.15

Ω_b(OVI) = 0.22 %, i.e. 10 % Missing Baryons ($Z_O \sim 0.1\ Z_\odot$)

(Danforth & Shull, 2005, ApJ)



BLAs: b_{therm}(HI) > 45 km/s

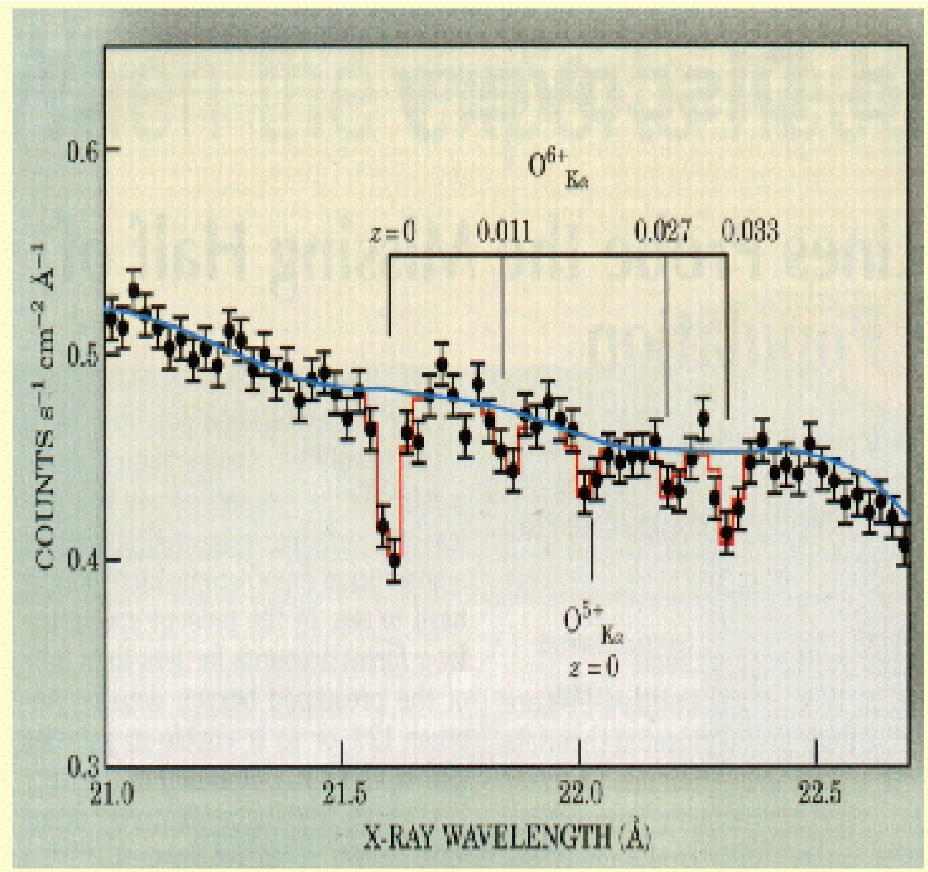
(Cf b(HI) ~ 10-50 km/s in Lyα-Forest)

Ω_b(BLA) = 0.27 %, i.e. ~ 10 % Missing Baryons

(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^{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)

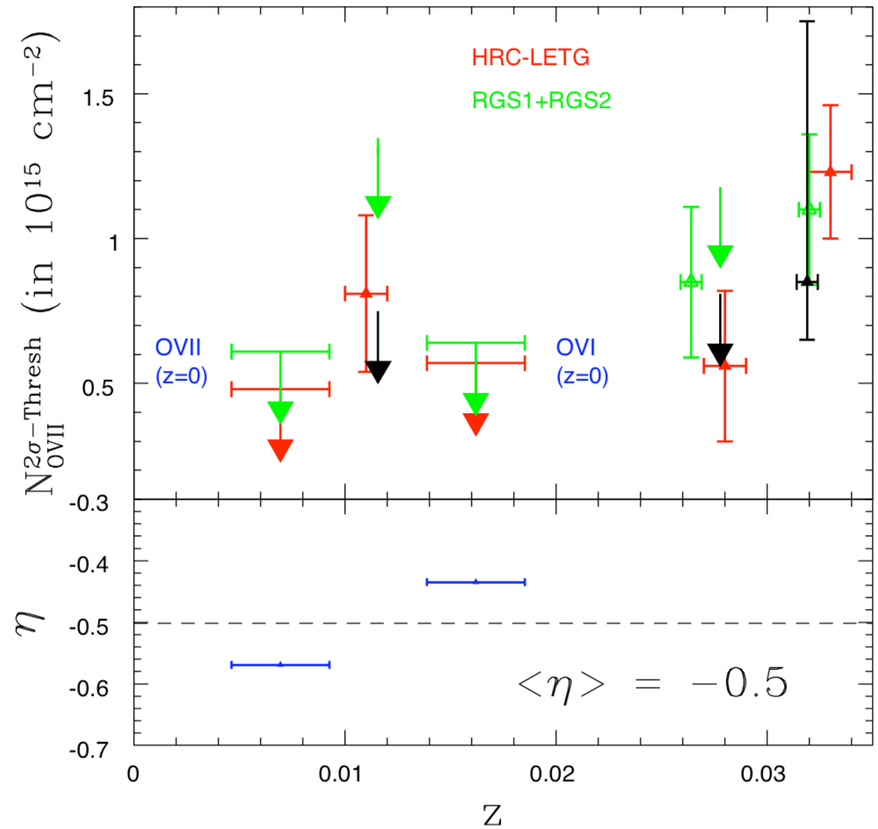
λ(OVII)=21.602; z(Mkn 421)=0.03 ==> $\Delta\lambda$= λ(OVII)xz(Mkn 421) = 648 mA

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

=> P_{Gauss} ~ {[(1-P(3.8σ)) x 52] / 2} x
x {[(1-P(2σ)) x 59] / 2} = 0.02 %

The Controversy (2)

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



$R_{LETG} \sim 2.4 \times R_{RGS}$

XMM does not rule out Chandra Detections

3

Current Evidence: the z=0 Absorber Hot Galactic Corona or Local Group WHIM? Or Both?

Hot Gas in the Local Group

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INTERGALACTIC MATTER AND THE GALAXY

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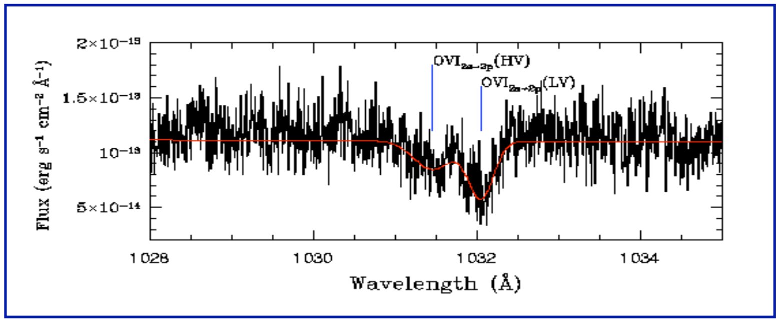
ABSTRACT

It is shown that the Local Group of galaxies can be dynamically stable only if it contains an appreciable amount of intergalactic matter. A detailed discussion shows that this matter consists mainly of ionized hydrogen and that stars can contribute only a small fraction to its total mass. The most likely values for the intergalactic temperature and density are found to be 5×10^5 degrees and 1×10^{-4} proton/cm^3, respectively. It is thought that this gas confines the halo. The distortion of the disk of the Galaxy, revealed by 21-cm observations, is analyzed. This effect cannot be regarded as a relic from a primeval distortion, which occurred at the time of formation of the Galaxy; a more promising explanation for it can be given in terms of the flow pattern of the intergalactic gas past the Galaxy and of the resulting pressure distribution on the halo.

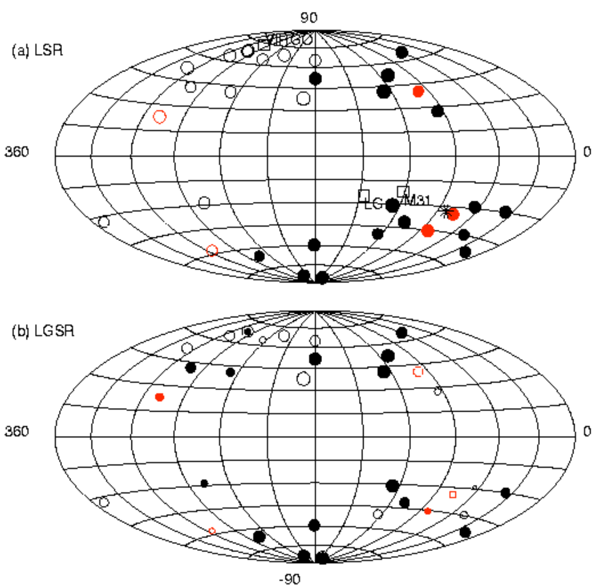
Far-UV

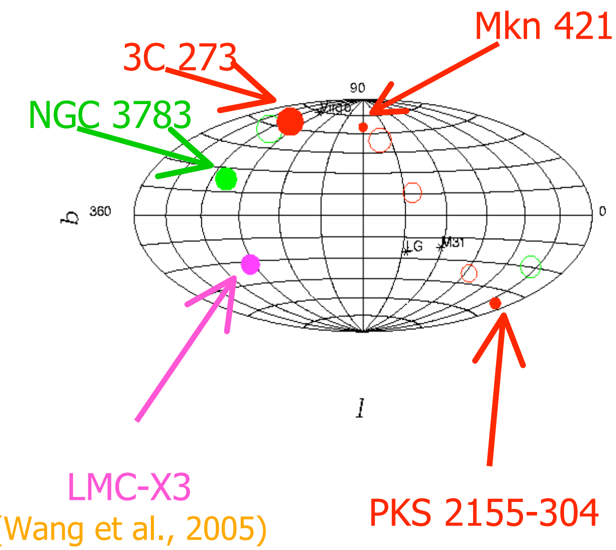
X-Rays

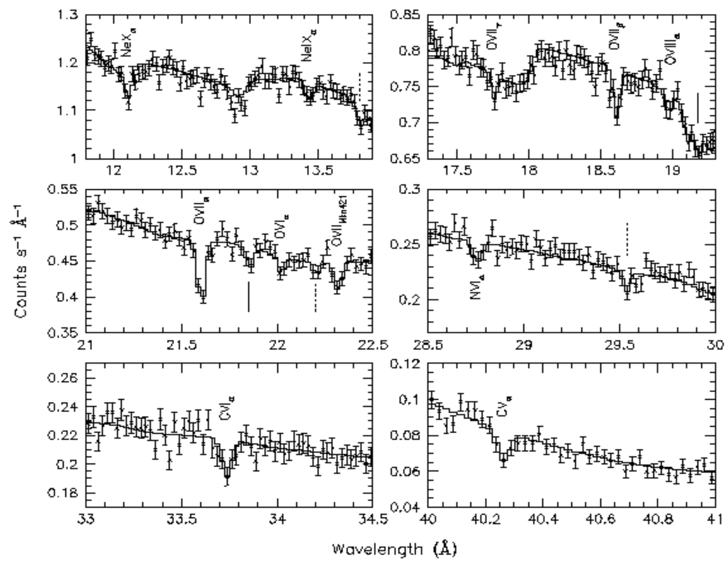
HV-OVI: 90 % l.o.s.



Strong Segregation in the LSR







(Williams+05, ApJ)

(Nicastro+03, Nature)

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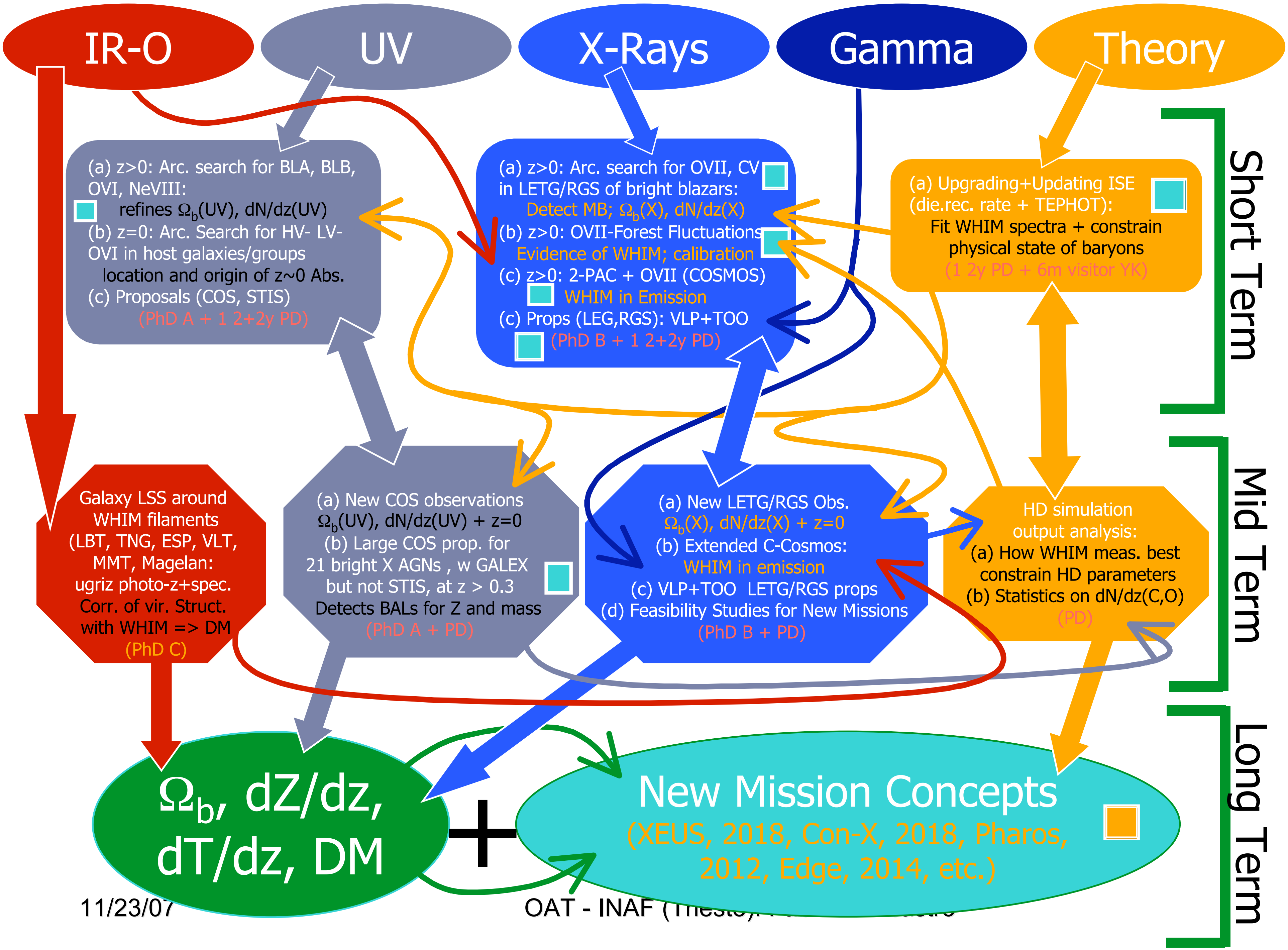
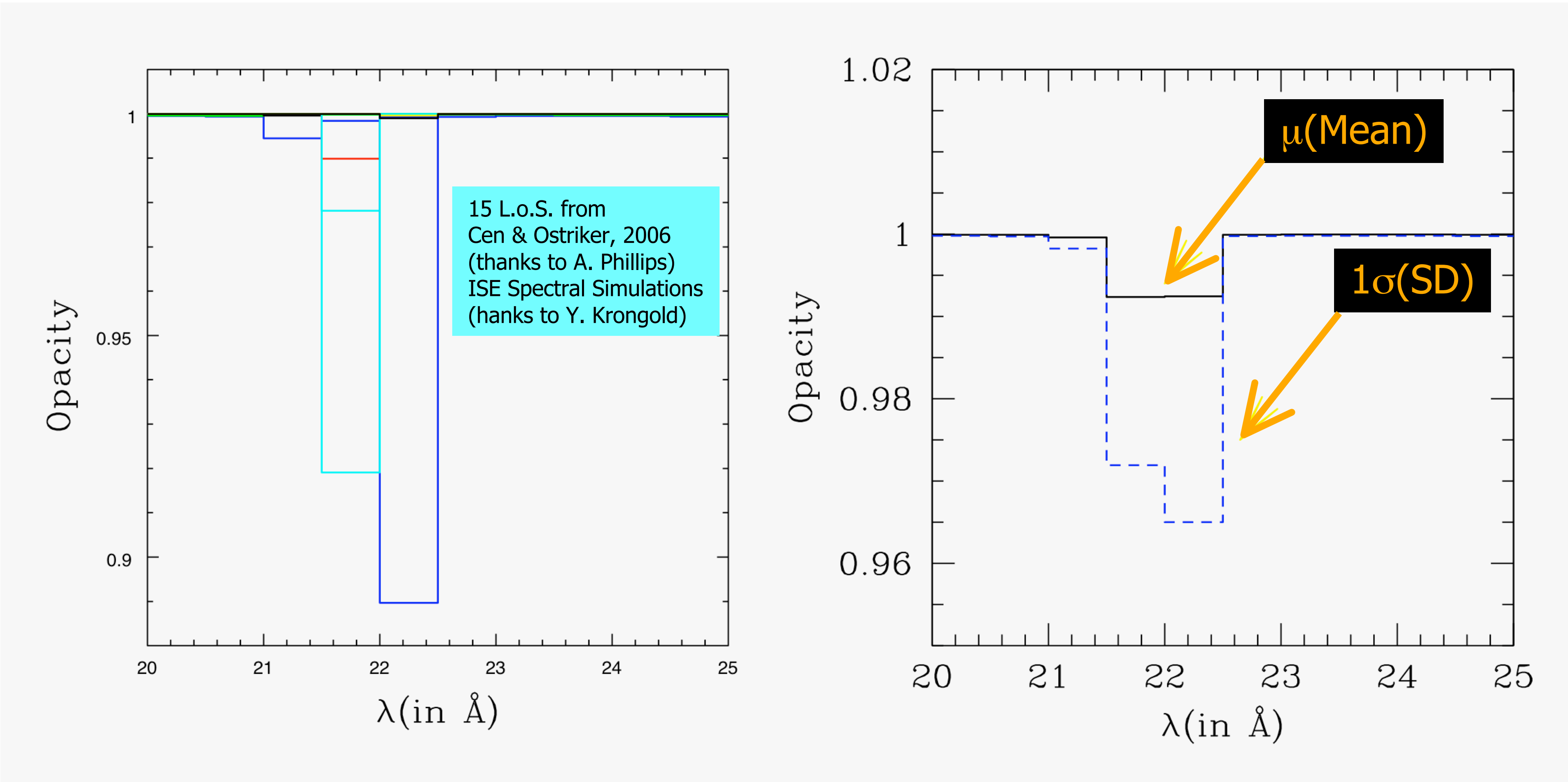
The Way Forward: An ERC Program and Goals

Goals

- Direct measure of Ω_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

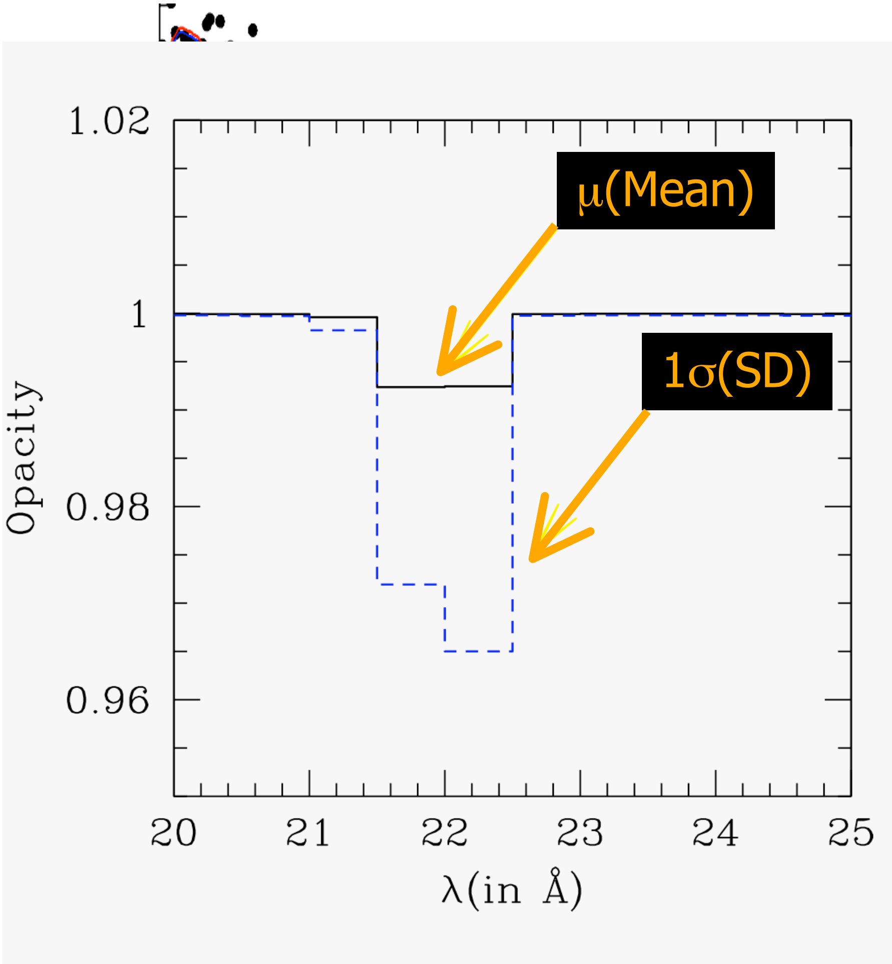

IR-O
UV
X-Rays
Gamma
Theory
Short Term
Mid Term
Long Term
(a) z>0: Arc. search for BLA, BLB, OVI, NeVIII:
refines Ω_b(UV), dN/dz(UV)
(b) z=0: Arc. Search for HV- LV-OVI in host galaxies/groups
location and origin of z~0 Abs.
(c) Proposals (COS, STIS)
(PhD A + 1 2+2y PD)
(a) z>0: Arc. search for OVII, CV in LETG/RGS of bright blazars:
Detect MB; Ω_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
(PhD B + 1 2+2y PD)
(a) Upgrading+Updating ISE (die.rec. rate + TEPHOT):
Fit WHIM spectra + constrain physical state of baryons
(1 2y PD + 6m visitor YK)
Galaxy LSS around WHIM filaments (LBT, TNG, ESP, VLT, MMT, Magelan:
ugriz photo-z+spec.
Corr. of vir. Struct. with WHIM => DM
(PhD C)
(a) New COS observations
Ω_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)
(a) New LETG/RGS Obs.
Ω_b(X), dN/dz(X) + z=0
(b) Extended C-Cosmos:
WHIM in emission
(c) VLP+TOO LETG/RGS props
(d) Feasibility Studies for New Missions
(PhD B + PD)
HD simulation output analysis:
(a) How WHIM meas. best constrain HD parameters
(b) Statistics on dN/dz(C,O)
(PD)
Ω_b, dZ/dz, dT/dz, DM
+
New Mission Concepts
(XEUS, 2018, Con-X, 2018, Pharos, 2012, Edge, 2014, etc.)

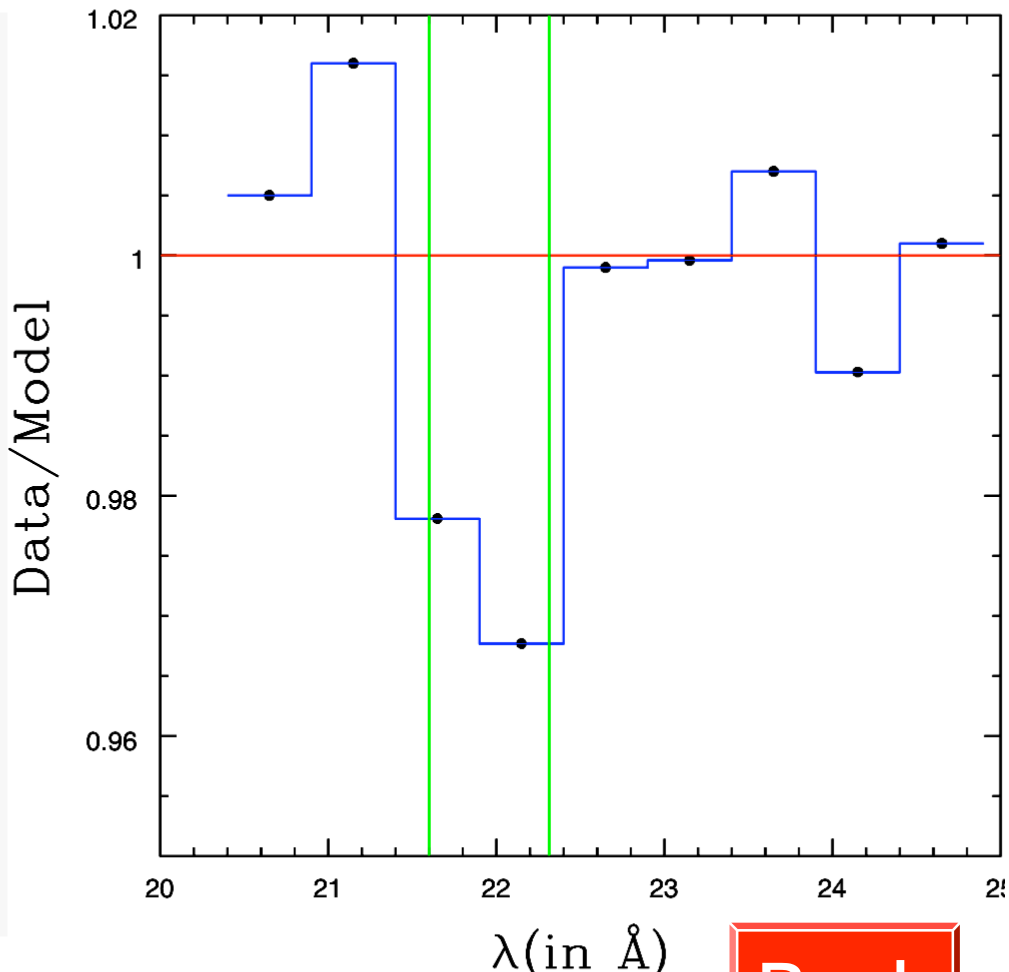
OVII-Forest Fluctuations
Theoretical Expectations



OVII-Forest Fluctuations:

Observations and Comparison with Predictions





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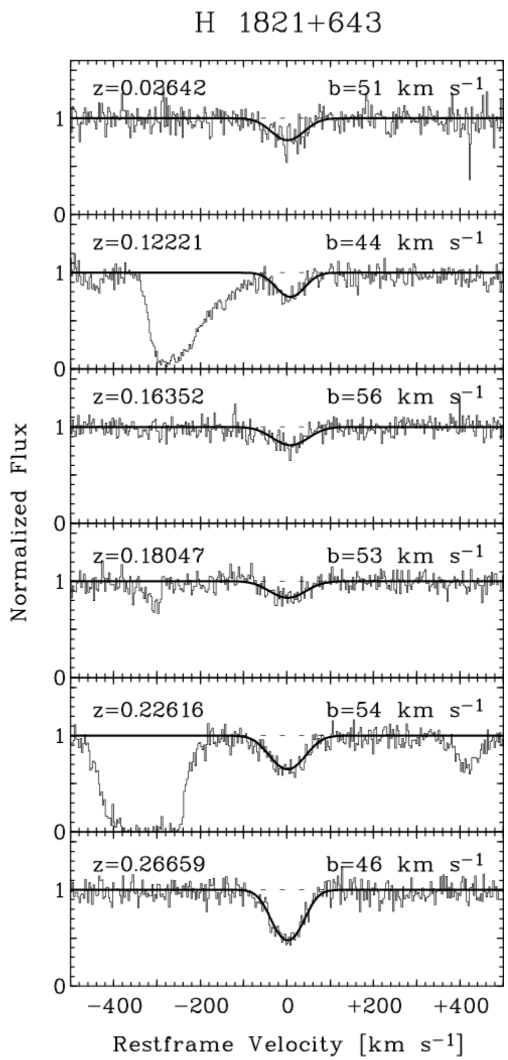
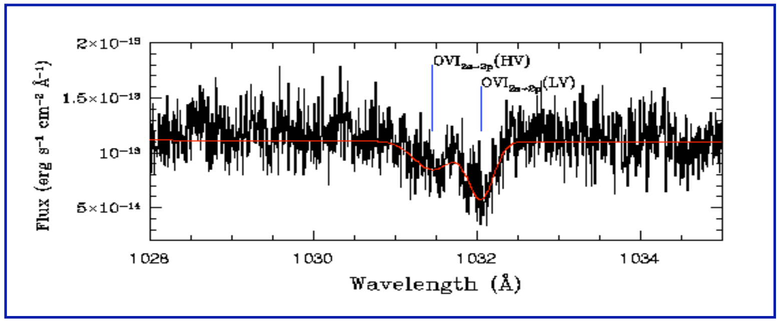
Archival UV Search

BLAs



LV- HV-OVI
in external galaxies/groups



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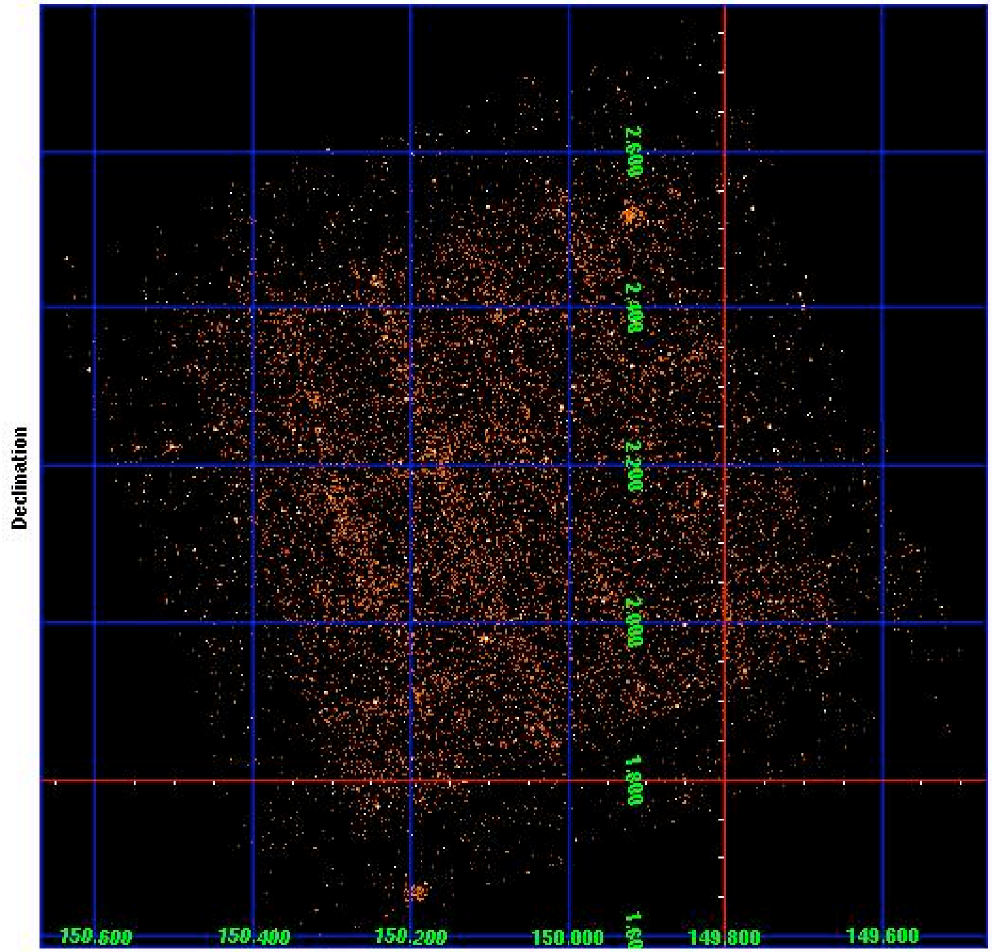
C-Cosmos

2-PAC
OVII Kα



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Phase → ISE

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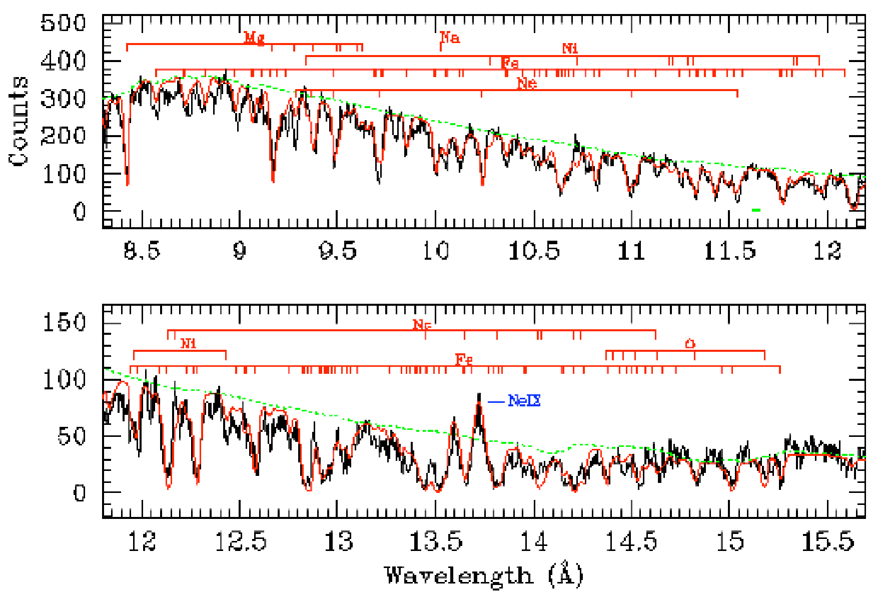
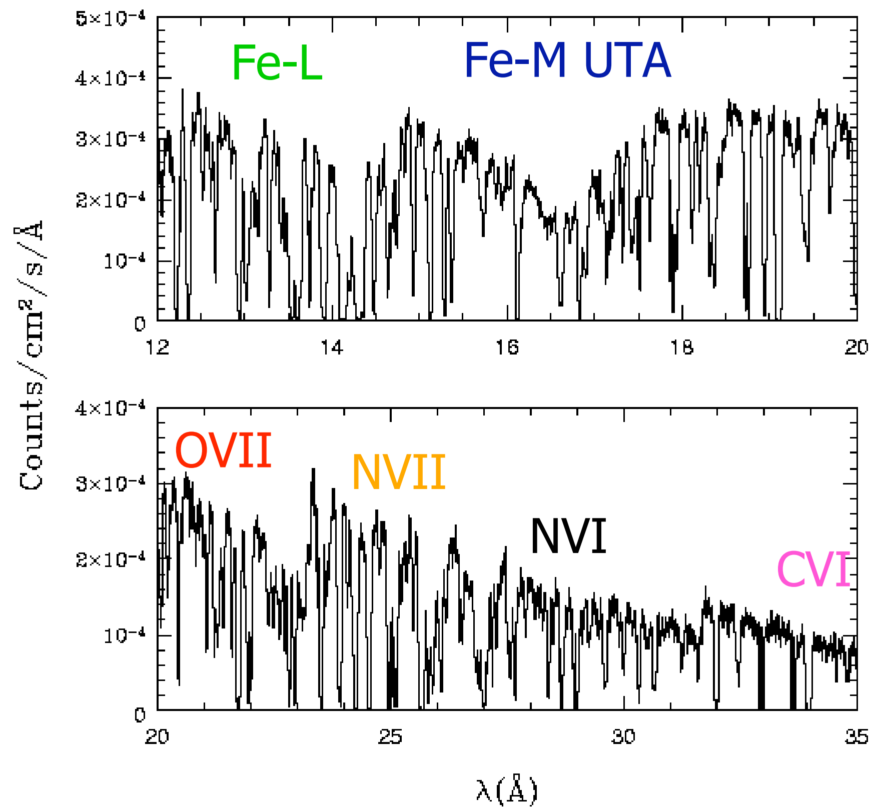
NGC 3783: Krongold+03



NGC 5548: Warm Absorber



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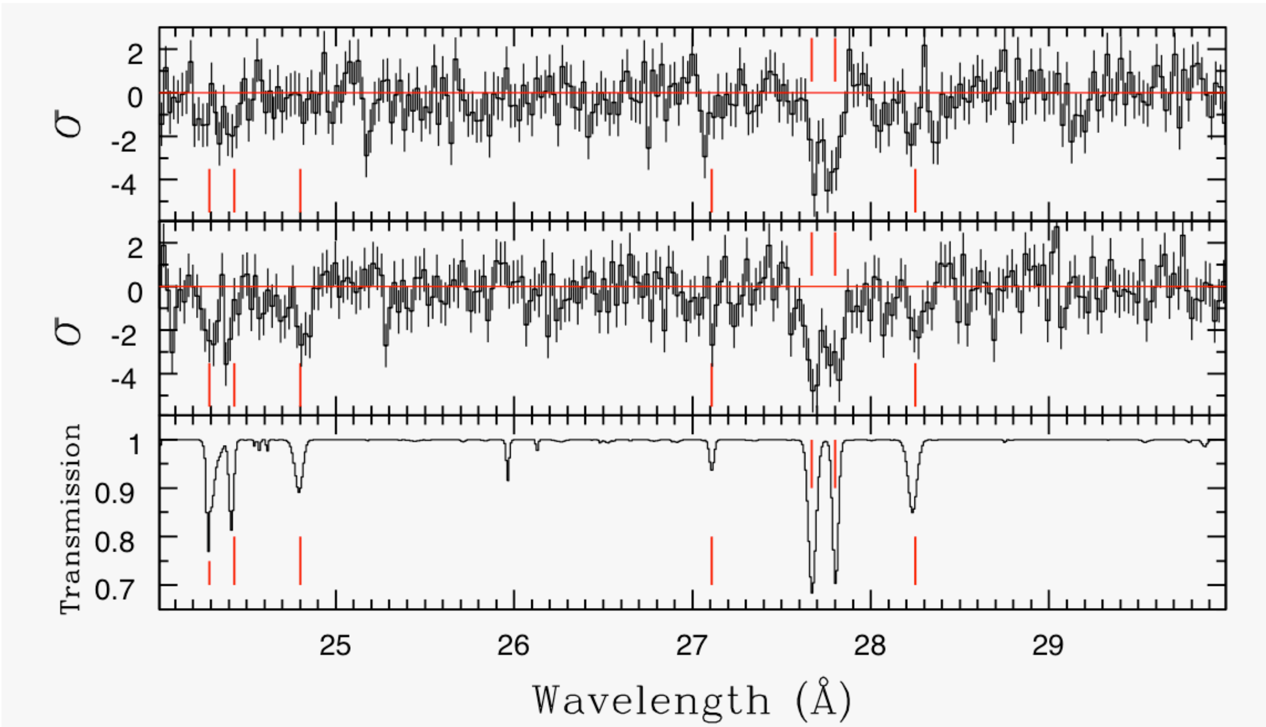
2.7 Ms XMM-RGS (AO7)



(Simulations by YK, AP, FN)

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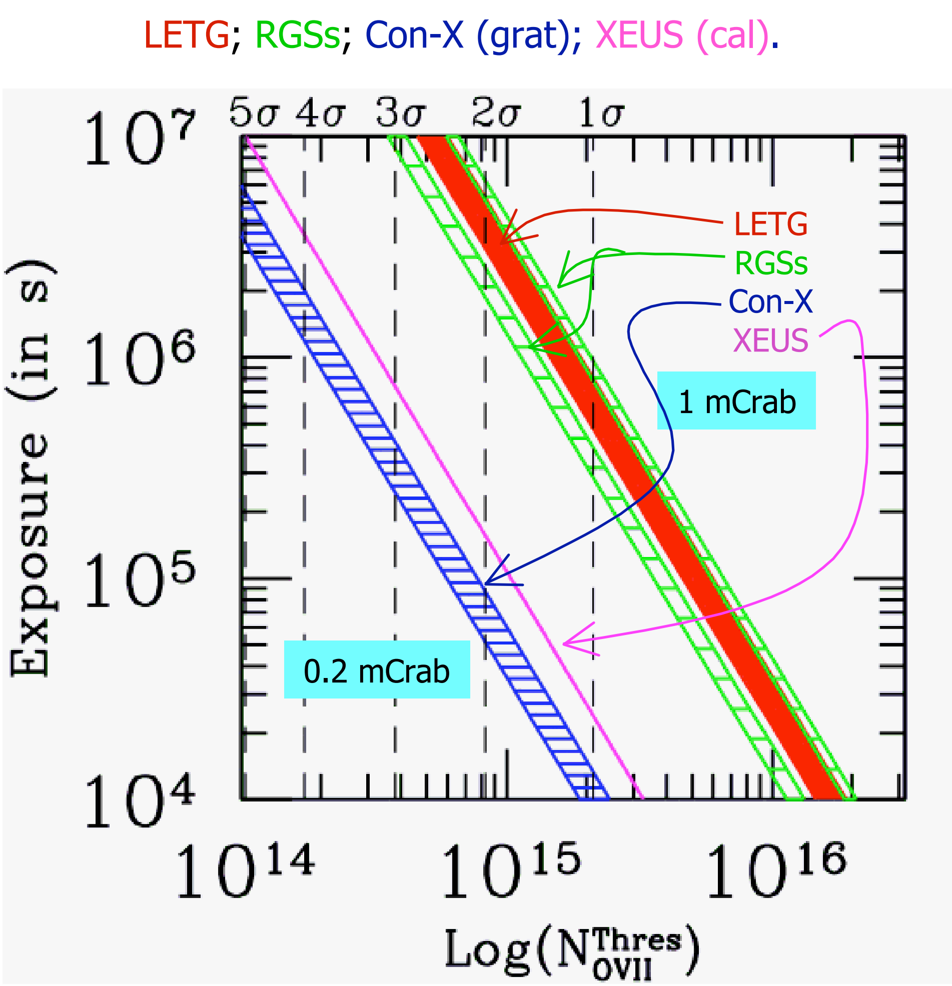
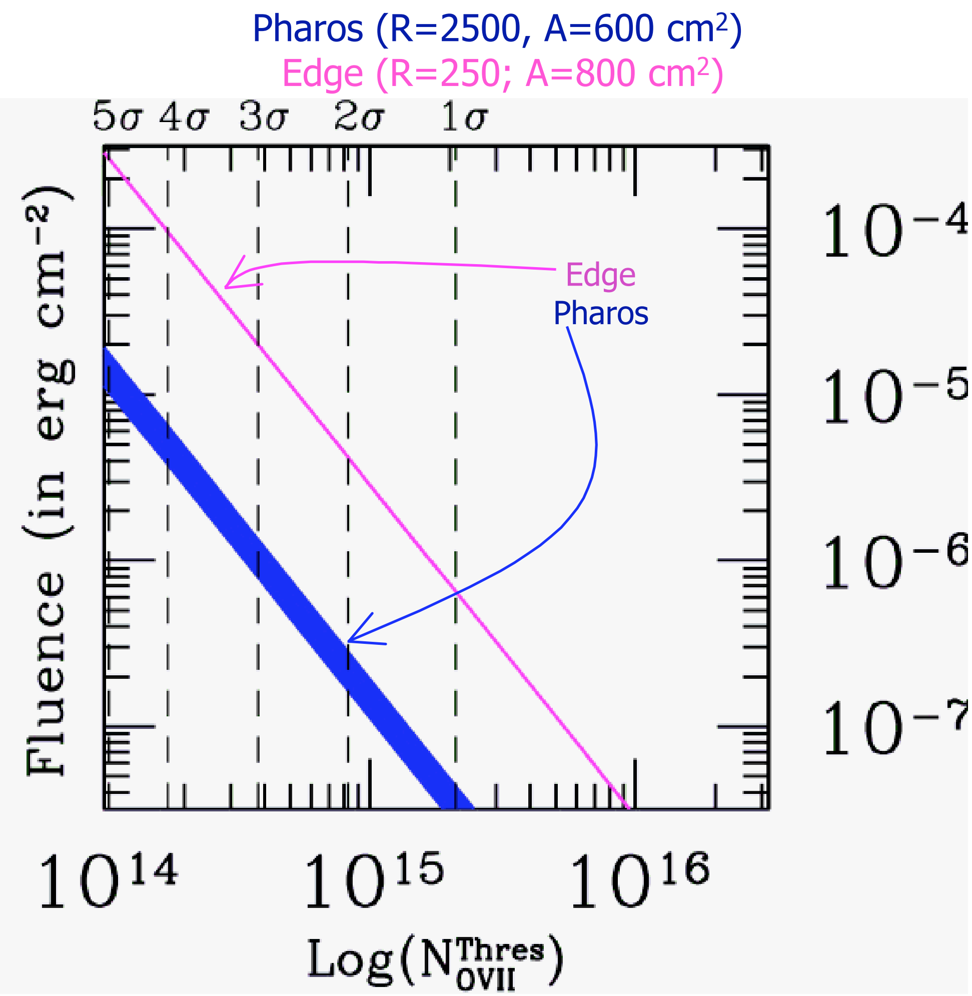
The Way Forward





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 the wealthier 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