Searching for cosmic missing baryons with DIOS

(**D**iffuse **I**ntergalactic **O**xygen **S**urveyor)

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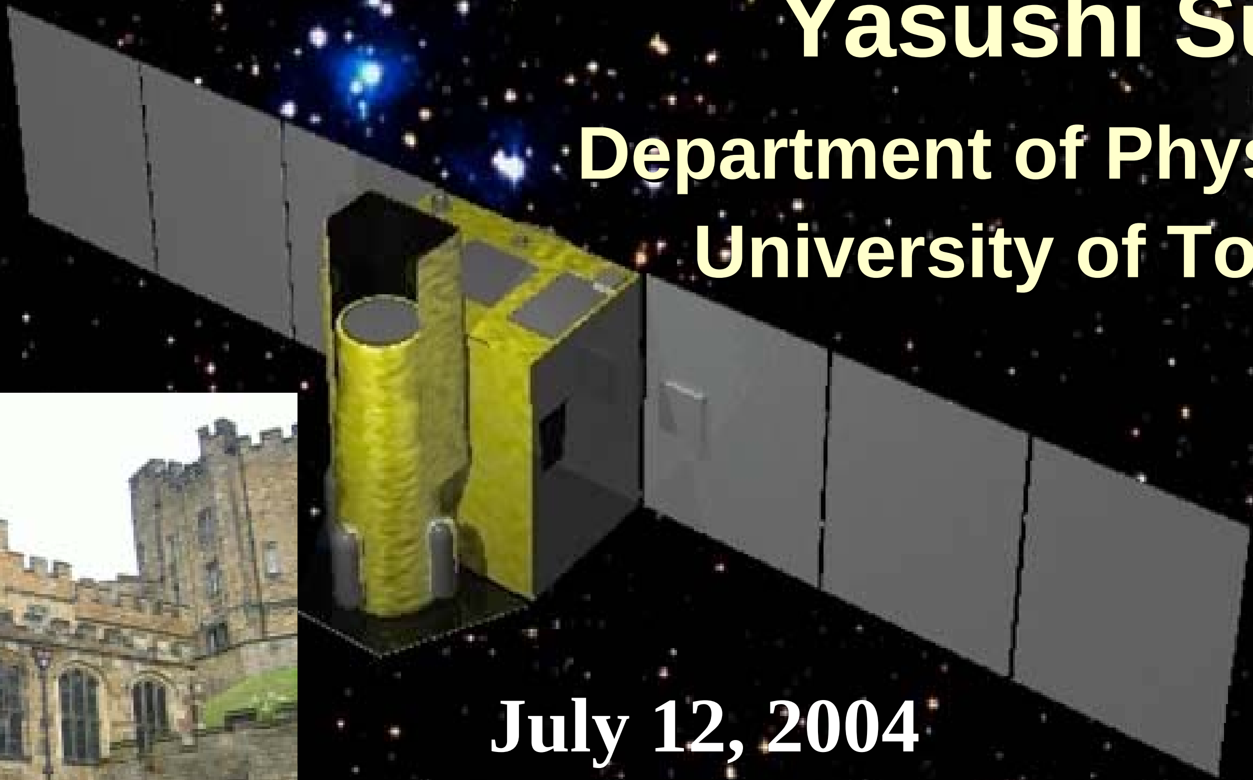


July 12, 2004
University of Durham

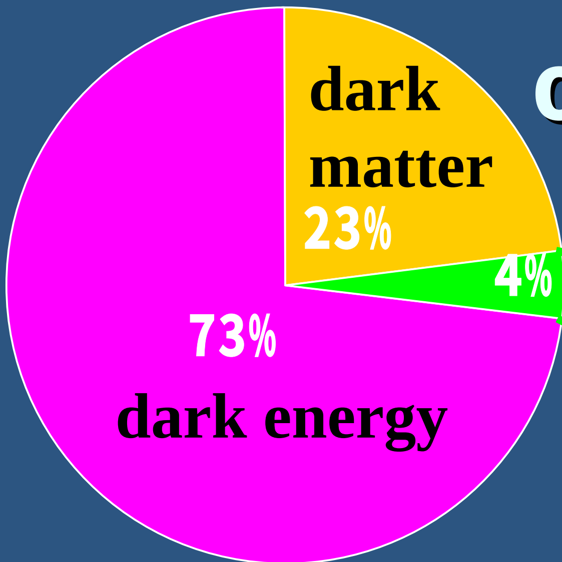
Our recent work at Univ. of Tokyo (1)

1. Triaxial modeling of density profiles of dark matter halos (Jing & Suto 2002), and its application to X-ray/SZ effect (Lee & Suto 2002) and to lensing arc statistics (Oguri, Lee & Suto 2003)
2. Cosmological light-cone effect (Hamana et al. 2001)
3. Properties of Lyman break galaxies and Lyman alpha emitters from their clustering (Hamana et al. 2003)
4. Phase correlation in Fourier space from nonlinear gravitational clustering (Hikage, Matsubara & Suto 2003)
5. Topology (Minkowski functionals) of SDSS galaxy distribution (Hikage et al. 2003)
6. Morphological dependence in two- and three-point correlation functions of SDSS galaxies (Kayo et al. 2004)

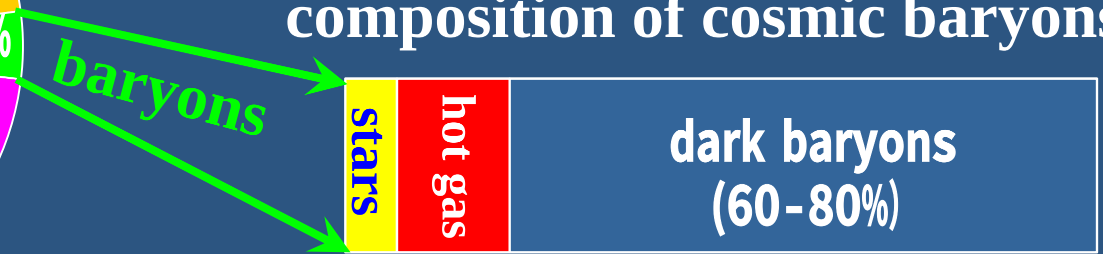
Our recent work at Univ. of Tokyo (2)

7. The largest-separation QSO multiple lensed images from SDSS survey (Inada et al. 2003)
8. Largest-scale clustering and baryonic signatures from two-point correlation function of SDSS QSOs (Yahata et al. 2004)
9. The highest angular-resolution Sunyaev-Zel'dovich map (150GHz) and the first submm SZ map (350GHz) of RX J1347-1145 (Komatsu et al. 1999,2001; Kitayama et al. 2004)
10. Searching for atmospheric signatures from the transiting extrasolar planet HD209458b with Subaru High-Dispersion-Spectrograph (Winn et al. 2004; Narita et al. 2004)
11. Locating missing cosmic baryons via Oxygen emission lines with DIOS (Yoshikawa et al. 2003, 2004)

Where are the baryons ? most of cosmic baryon is "dark"



composition of cosmic baryons



Cosmic Baryon Budget: Fukugita, Hogan & Peebles: ApJ 503 (1998) 518

Component	Central	Maximum	Minimum	Grade[a]
1. Stars in spheroids	$0.0026\ h_{70}^{-1}$	$0.0043\ h_{70}^{-1}$	$0.0014\ h_{70}^{-1}$	A
2. Stars in disks	$0.00086\ h_{70}^{-1}$	$0.00129\ h_{70}^{-1}$	$0.00051\ h_{70}^{-1}$	A –
3. Stars in irregulars	$0.000069\ h_{70}^{-1}$	$0.000116\ h_{70}^{-1}$	$0.000033\ h_{70}^{-1}$	B
4. Neutral atomic gas	$0.00033\ h_{70}^{-1}$	$0.00041\ h_{70}^{-1}$	$0.00025\ h_{70}^{-1}$	A
5. Molecular gas	$0.00030\ h_{70}^{-1}$	$0.00037\ h_{70}^{-1}$	$0.00023\ h_{70}^{-1}$	A –
6. Plasma in clusters	$0.0026\ h_{70}^{-1.5}$	$0.0044\ h_{70}^{-1.5}$	$0.0014\ h_{70}^{-1.5}$	A
7a. Warm plasma in groups	$0.0056\ h_{70}^{-1.5}$	$0.0115\ h_{70}^{-1.5}$	$0.0029\ h_{70}^{-1.5}$	B
7b. Cool plasma	$0.002\ h_{70}^{-1}$	$0.003\ h_{70}^{-1}$	$0.0007\ h_{70}^{-1}$	C
7′. Plasma in groups	$0.014\ h_{70}^{-1}$	$0.030\ h_{70}^{-1}$	$0.0072\ h_{70}^{-1}$	B

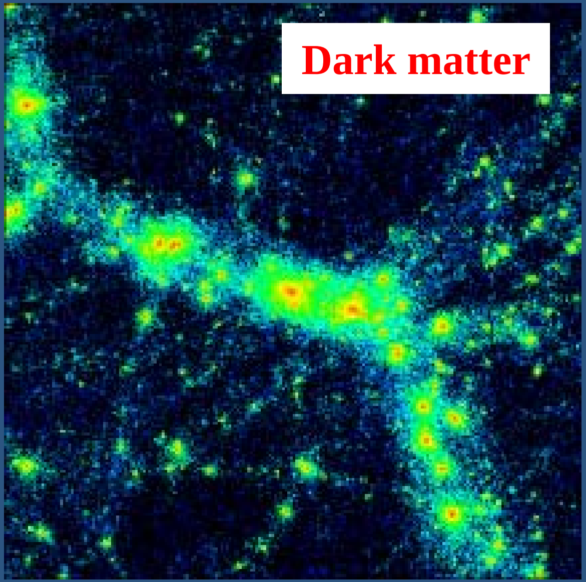
$$\Omega_{star} + \Omega_{HI} + \Omega_{H_2} + \Omega_{hot\ X-ray} = 0.0068^{+0.0041}_{-0.0030} \quad vs \quad \Omega_{BBN} = 0.04 \quad (h = 0.7)$$

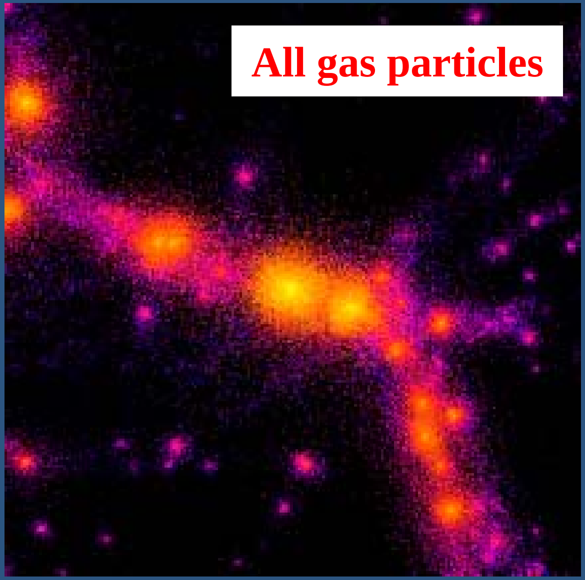
A cluster region in SPH simulation

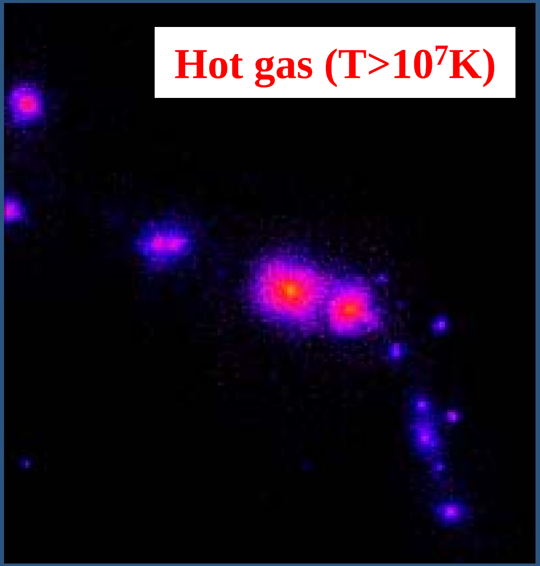
A $(30h^{-1}Mpc)^3$ box around a massive cluster at z=0

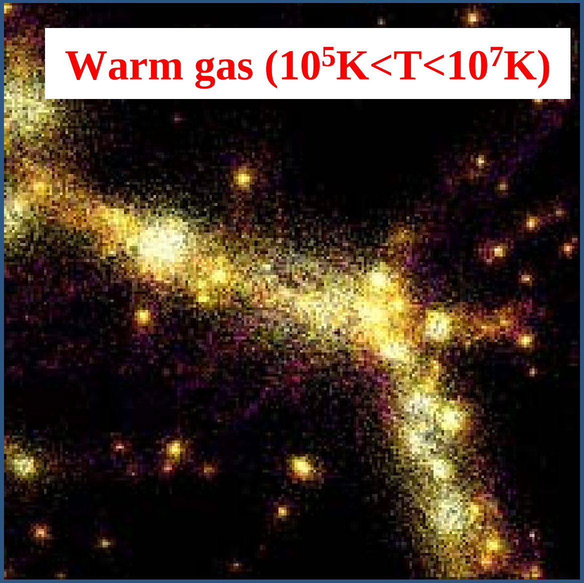
ΛCDM SPH simulation

(Yoshikawa et al. 2001)









Four phases of cosmic baryons

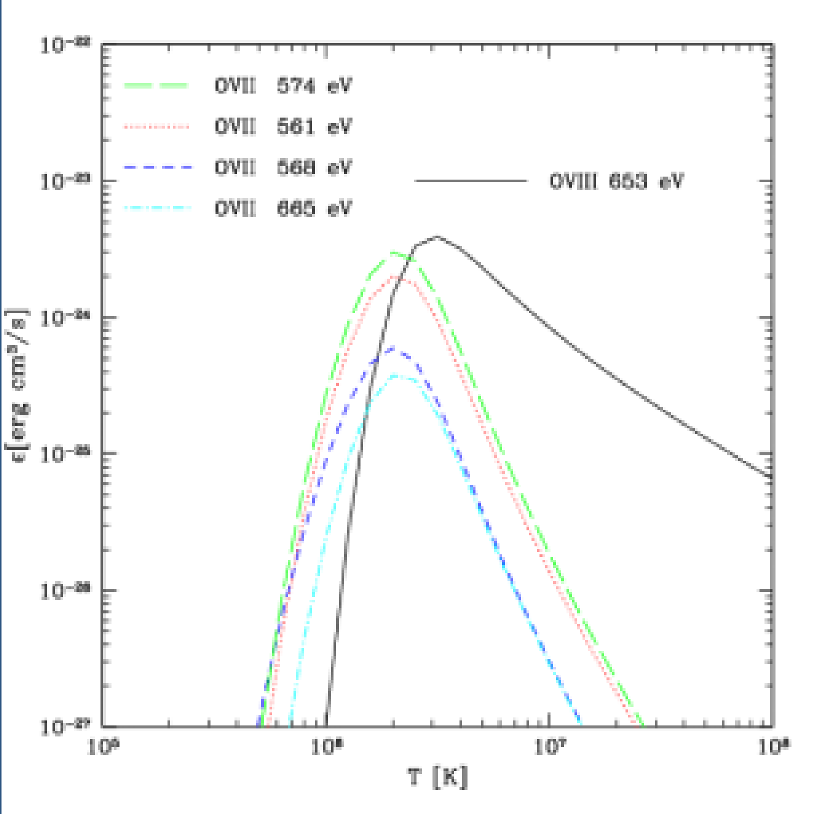
Dave et al. ApJ 552(2001) 473

- ***Condensed:*** **$\delta > 1000$, $T < 10^5$K**
  - Stars + cold intergalactic gas
- ***Diffuse:*** **$\delta < 1000$, $T < 10^5$K**
  - Photo-ionized intergalactic medium
  - Ly α absorption line systems
- ***Hot:*** **$T > 10^7$K**
  - X-ray emitting hot intra-cluster gas
- ***Warm-hot:*** **$10^5\text{K} < T < 10^7$K**
  - Warm-hot intergalactic medium (***WHIM***)

Emission lines of oxygen in WHIM

OVII (561eV, 568eV, 574eV, 665eV) , OVIII (653eV)

- **Why oxygen emission lines ?**
  - Most abundant other than H and He
  - Good tracers of gas around $T=10^6 \sim 10^7$ K
  - No other prominent lines in E=500-660eV
  - Not restricted to regions towards background QSOs



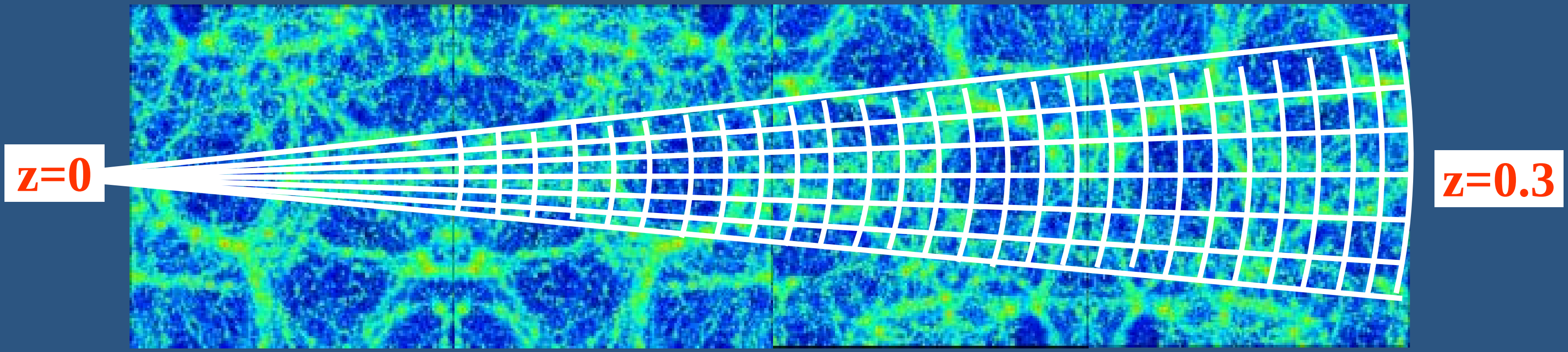
⇒ ***systematic WHIM survey***

DIOS: Diffuse Intergalactic Oxygen Surveyor

A Japanese proposal of a dedicated X-ray mission to search for missing baryons

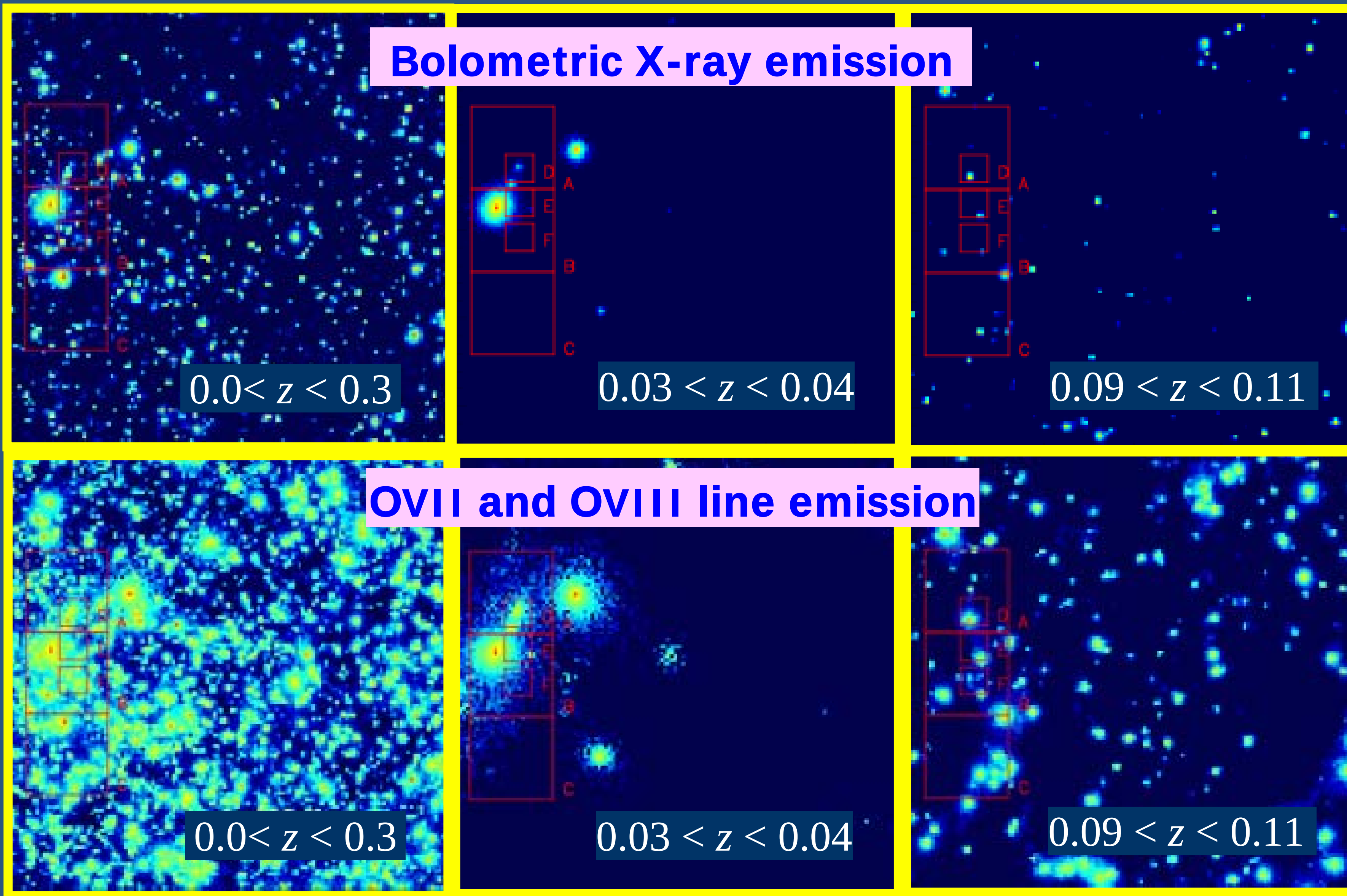
- A dedicated satellite with cost < 40M USD to fill the gap between Astro-E2 (2005) and NeXT (2010?). Launch proposed in 2008 (?).
- Unprecedented energy spectral resolution ΔE=2eV in soft X-ray band (0.1-1keV)
- Aim at detection of (20-30) percent of the total cosmic baryons via Oxygen emission lines
  - ΔE=2eV, $S_{eff}\,\Omega$=100 [cm^2 deg^2]
  - flux limit = 6×10^{-11} [erg/s/cm^2/str]
- PI: Takaya Ohashi (Tokyo Metropolitan Univ.)

Light-cone output from simulation



- **Cosmological SPH simulation** in Ω_m=0.3, Ω_Λ=0.7, σ_8=1.0, and h=0.7 CDM with N=128^3 each for DM and gas (Yoshikawa, Taruya, Jing, & Suto 2001)
- **Light-cone output from z=0.3 to z=0** by stacking 11 simulation cubes of $(75h^{-1}Mpc)^3$ at different z
- **5°×5° FOV mock data** in 64x64 grids on the sky
- 128 bins along the redshift direction (Δz=0.3/128)

Surface brightness on the sky



Metallicity models

Oxygen enrichment scenario in IGM

Type-II SNe → galaxy wind merging → metal pollution in IGM

Metallicity of WHIM is quite uncertain

Adopted models for metallicity distribution

Model I : uniform and constant

$$Z = 0.2\, Z_{solar}$$

Model II : uniform and evolving

$$Z = 0.2\, Z_{solar}\,(t/t_0)$$

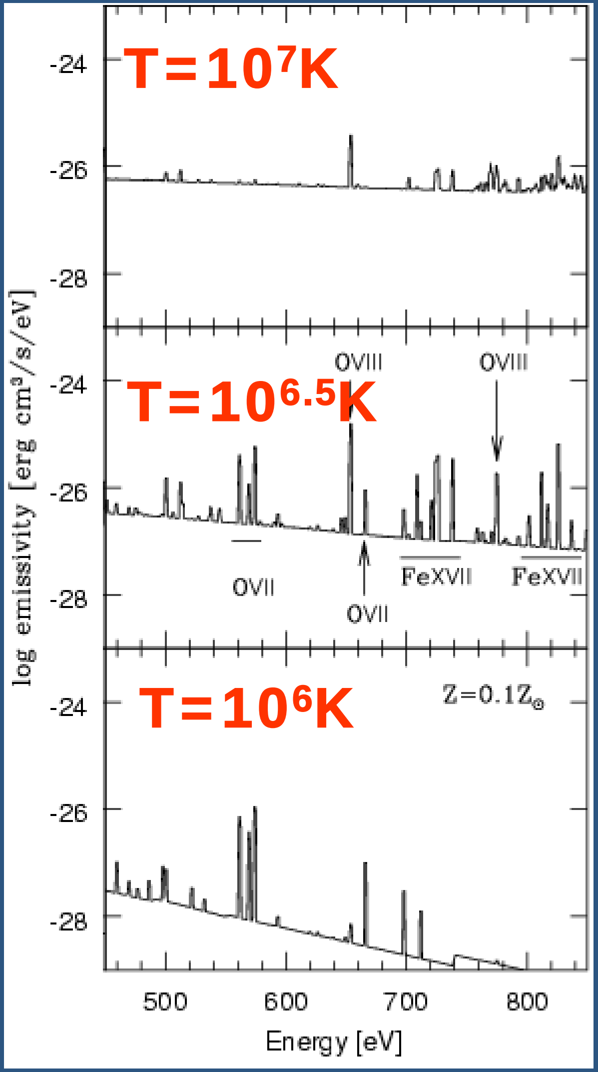
Model III : density-dependent (Aguirre et al. 2001)

$$Z = 0.005\, Z_{solar}\,(\rho/\rho_{\rm mean})^{0.33}$$ (galactic wind driven)

Model IV : density-dependent (Aguirre et al. 2001)

$$Z = 0.02\, Z_{solar}\,(\rho/\rho_{\rm mean})^{0.3}$$ (radiation pressure driven)

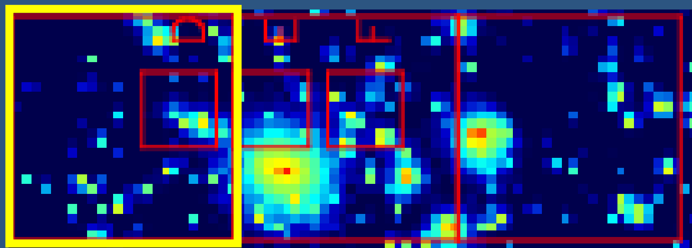
Creating Mock spectra from light-cone simulation output



- For a given exposure time,
  - convolve the emissivity according to gas density and temperature in $(5° /64)^2$ pixels over the lightcone
  - Add the Galactic line emission (McCammon et al. 2002)
  - Add the cosmic X-ray background contribution (power-law+Poisson noise)
- Then statistically subtract the Galactic emission and the CXB and obtain the residual spectra for ΔE=2eV resolution.

Simulated spectra: region A

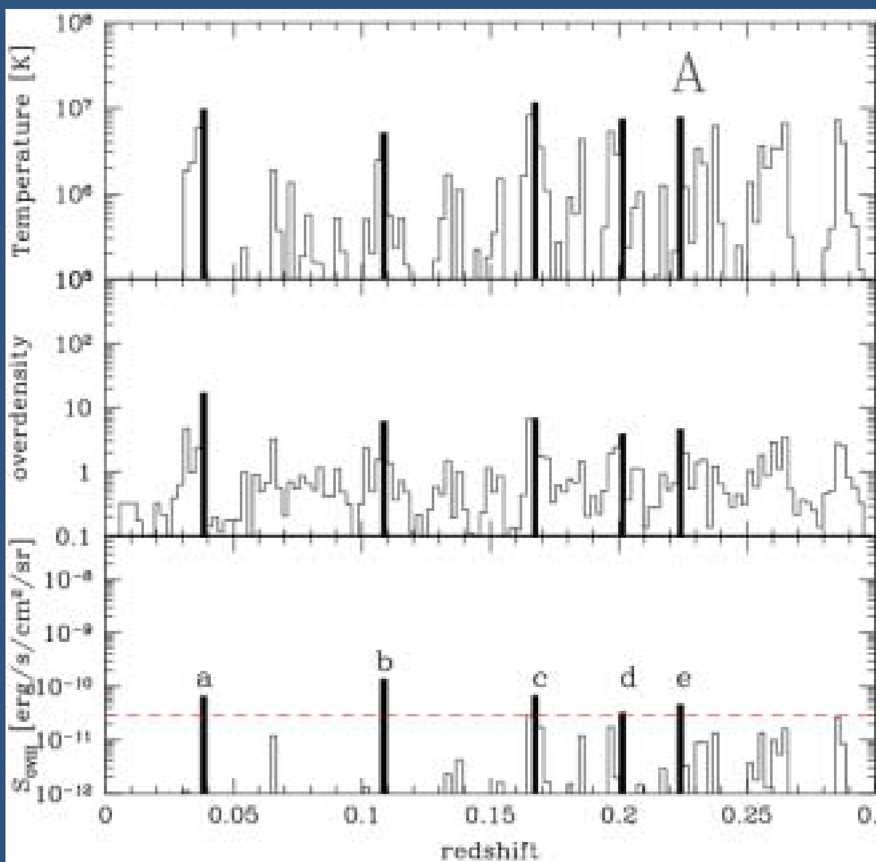
Shallow survey observation with the DIOS field-of-view (16^2pixels)

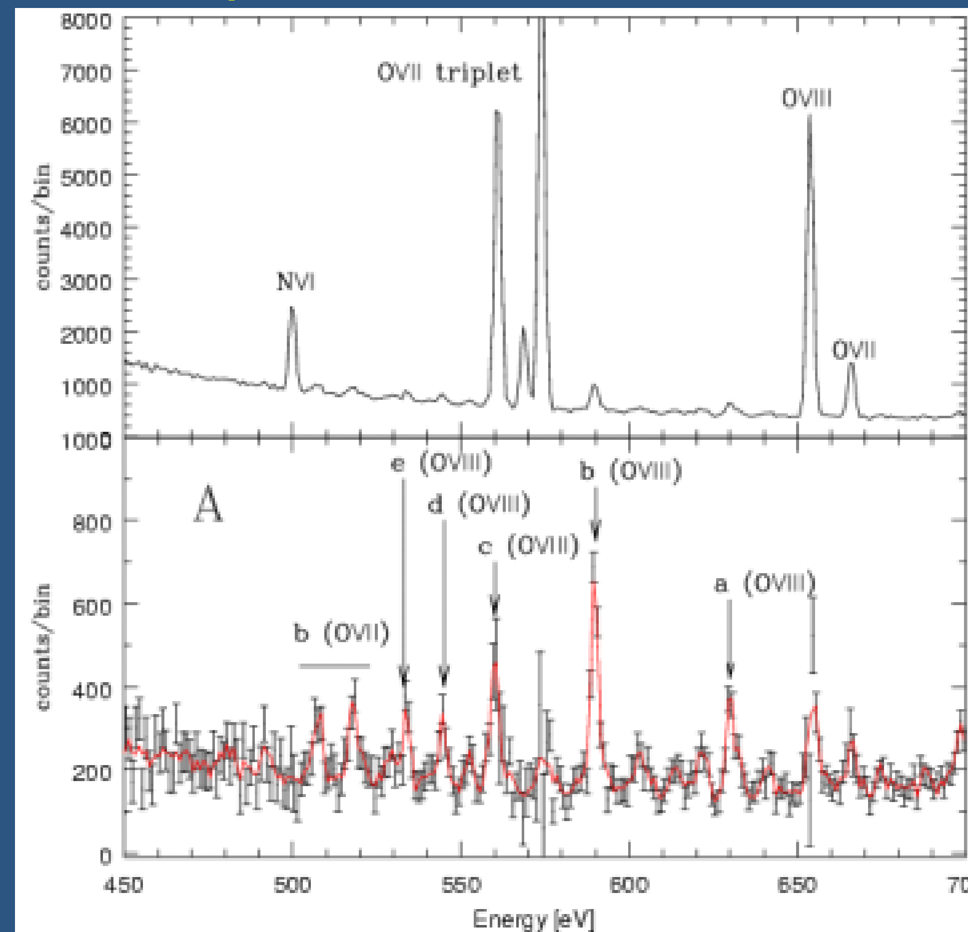


A

$0.94° \times 0.94° = 0.88\ deg^2$

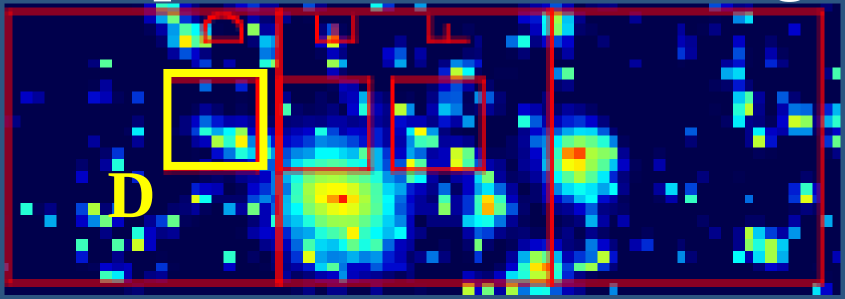
$T_{exposure} = 3x10^5 sec$





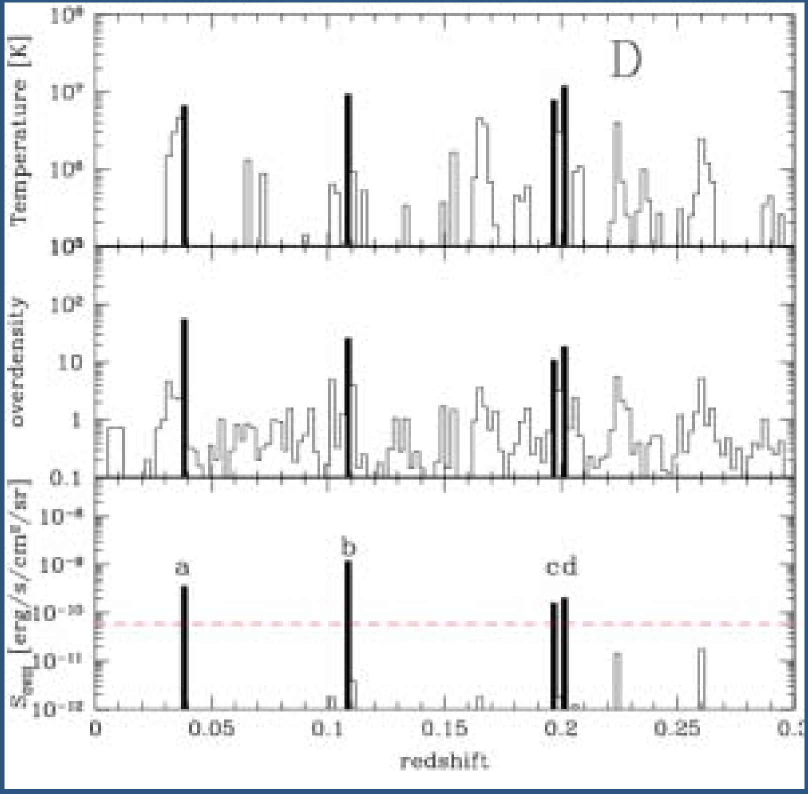
Simulated spectra: region D

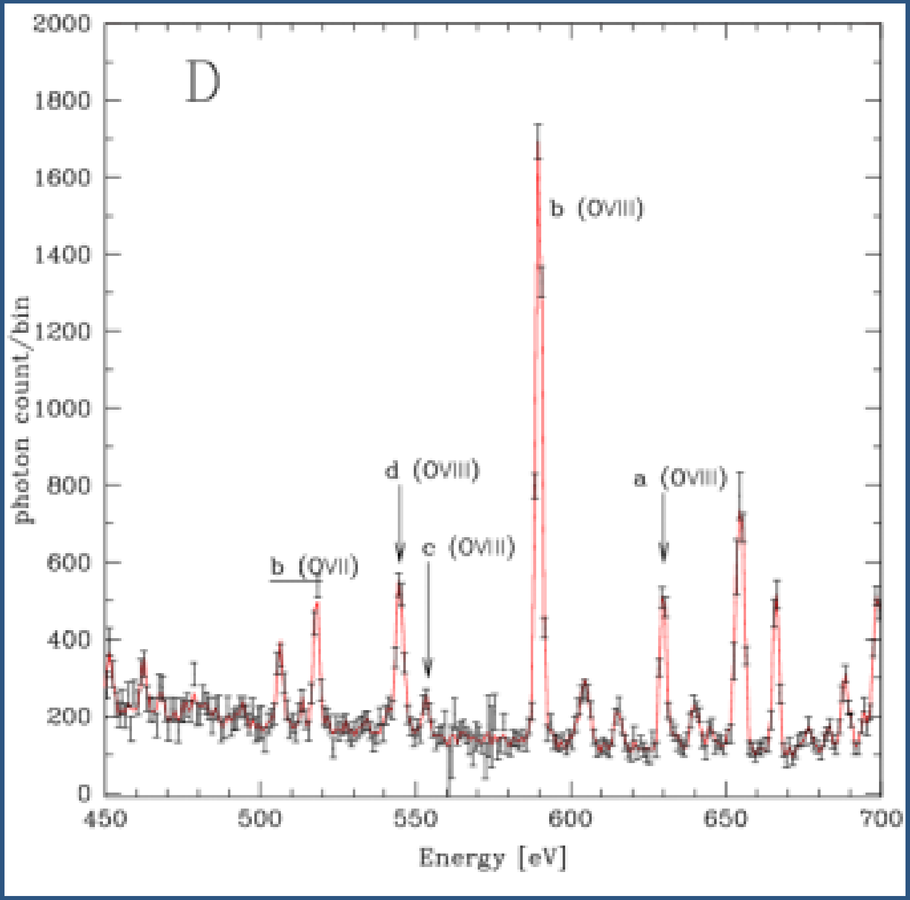
Deeper observation of targeted fields with DIOS (5^2pixels)



$19' \times 19' = 0.098$ deg^2

$T_{exposure} = 10^6$sec





Searching for cosmic missing baryons with DIOS (Diffuse Intergalactic Oxygen Surveyor)

astro-ph/0303281

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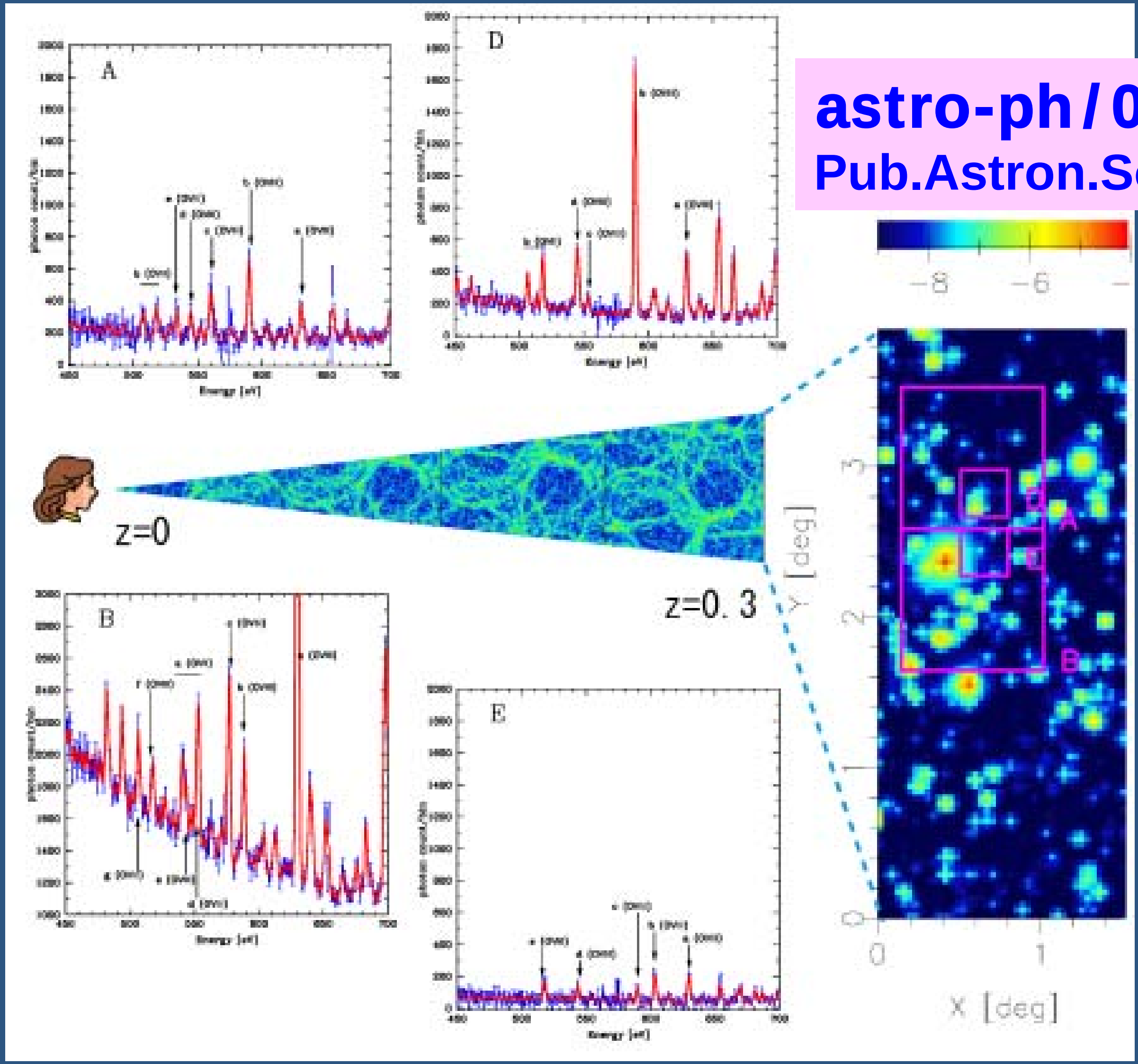

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Nagoya Univ.:

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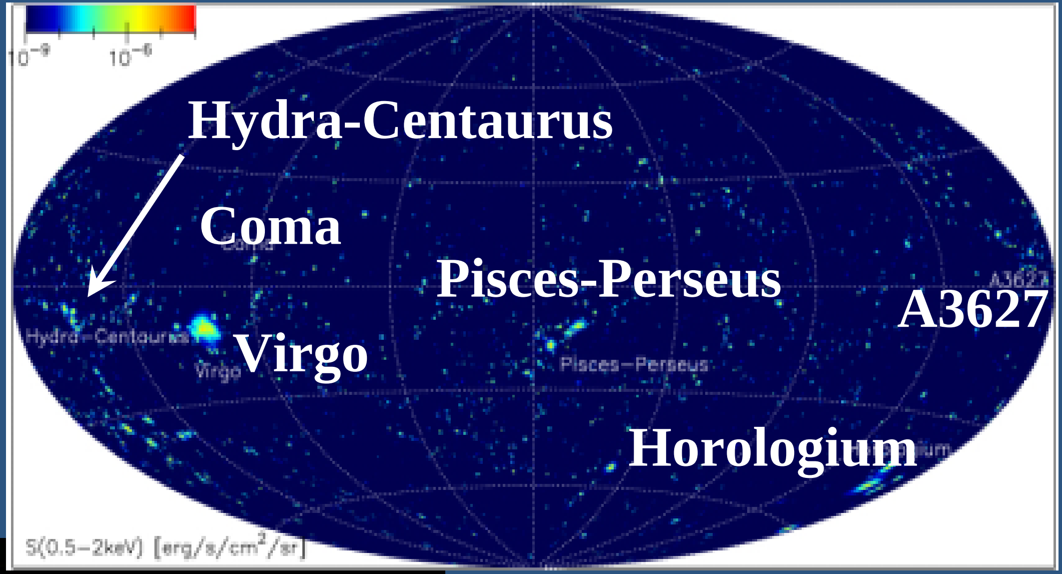
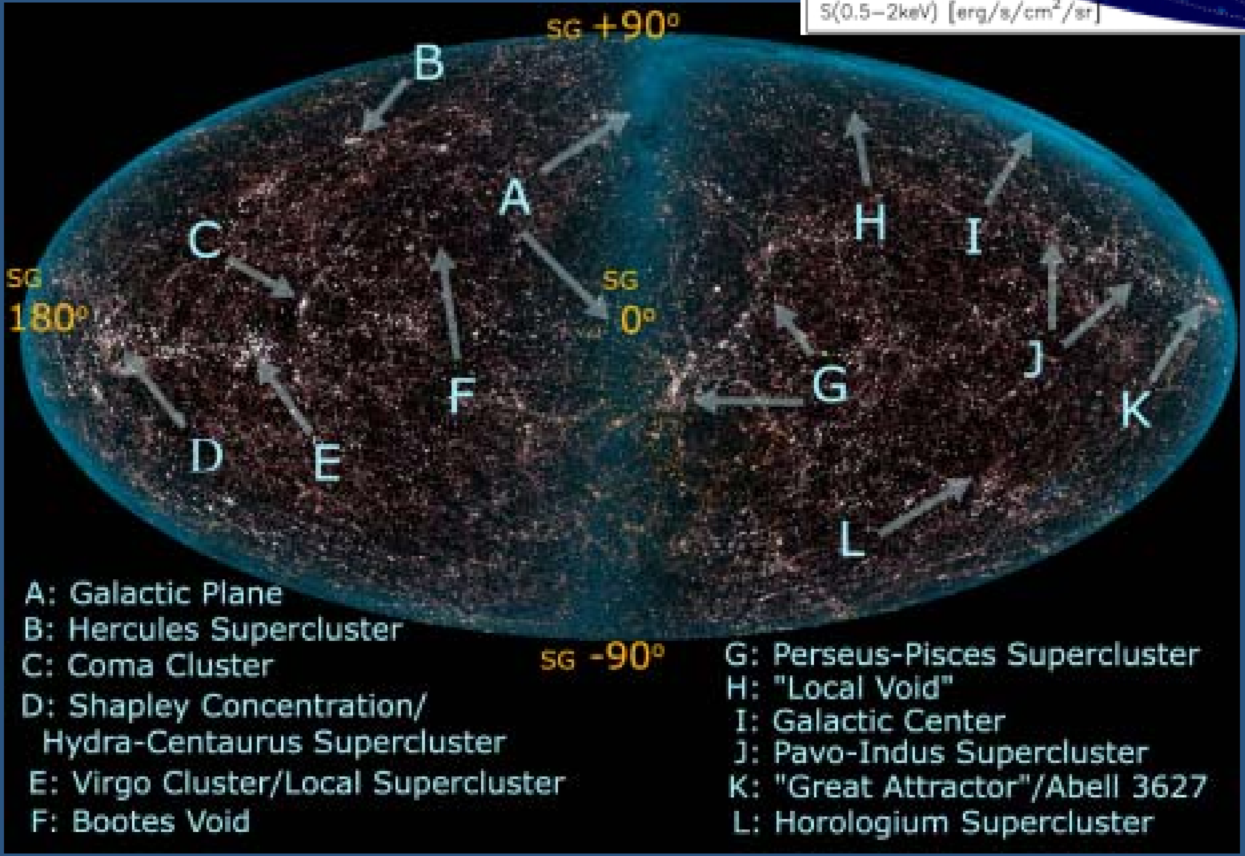
Simulating the local universe

- Simulation by Dolag et al. (astro-ph/0310902)
  - Initial condition: smoothing the observed galaxy density field of IRAS 1.2 Jy galaxy survey over $5h^{-1}$Mpc
  - adiabatic run of dark matter and baryons (without cooling or feedback) in a canonical LCDM model
- Locating the WHIM in the local universe
  - mock observation of the local universe via oxygen emission from WHIM
  - Yoshikawa, Dolag, Suto, Sasaki, Yamasaki, Ohashi, Mitsuda, Tawara, Fujimoto, Furusho, Furuzawa, Ishida & Ishisaki (2004) submitted to PASJ

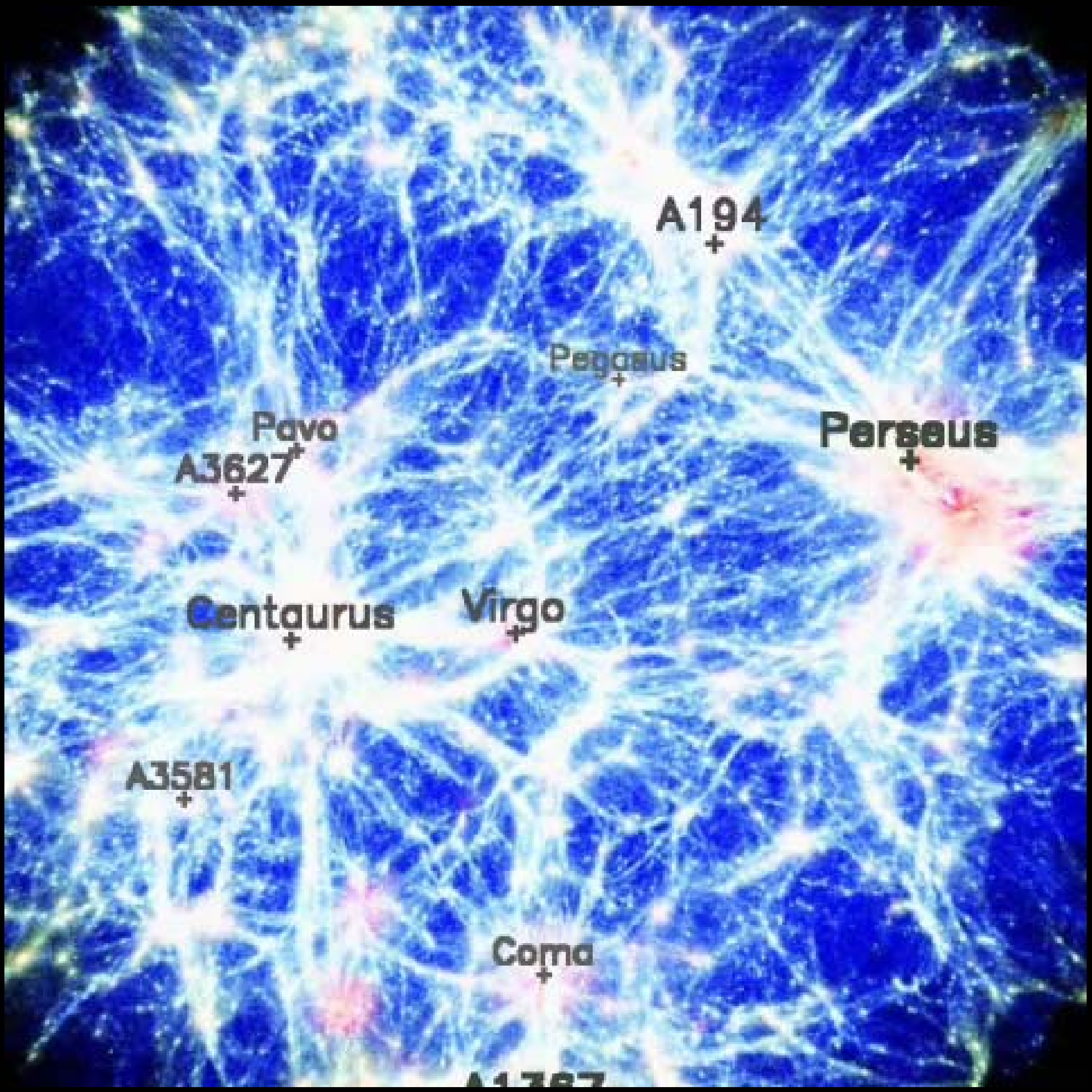
Simulated local universe vs. 2MASS map



Soft X-ray map of the simulated local universe (Yoshikawa et al. 2004)



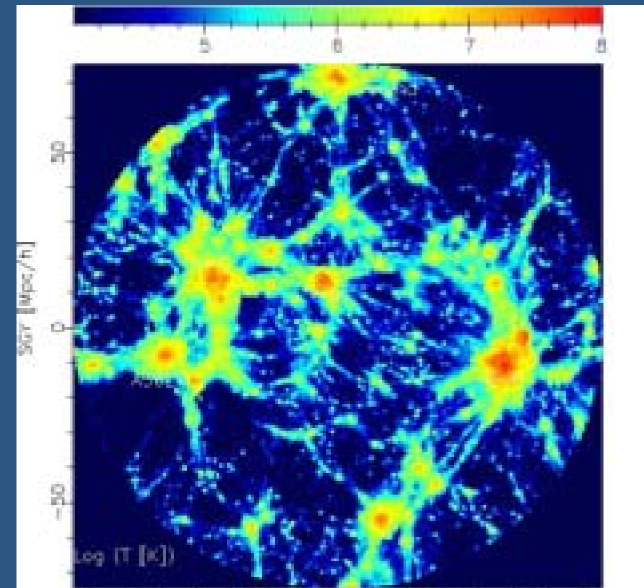
Tour of the simulated local universe

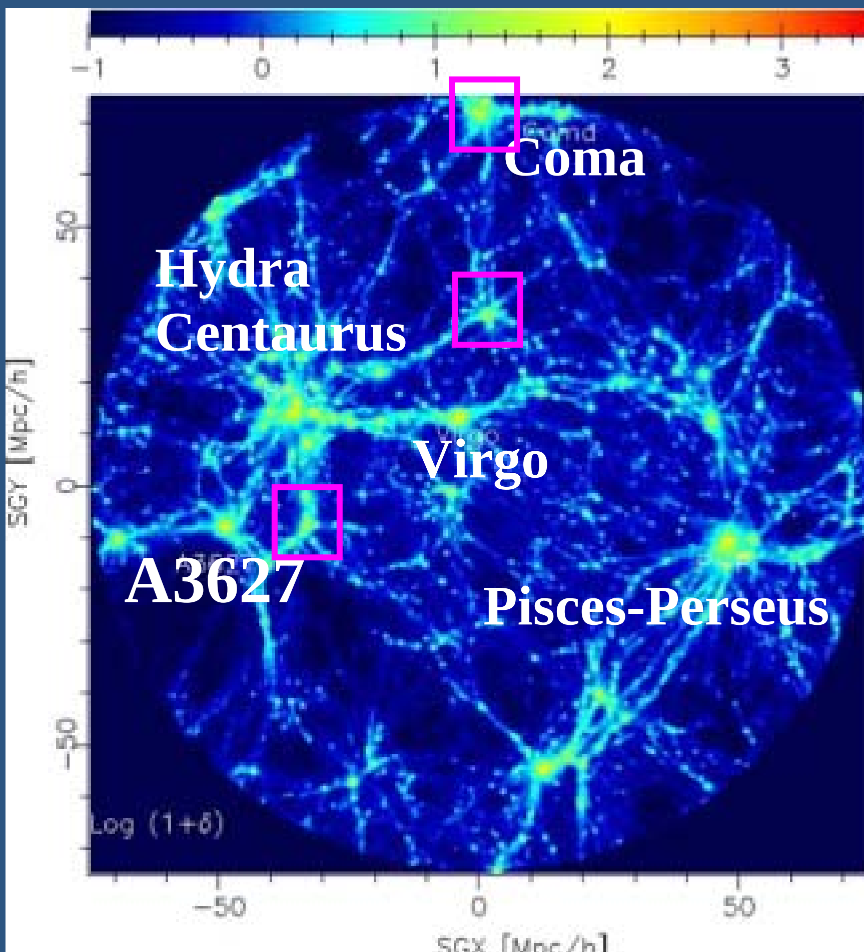


Klaus Dolag (2003)

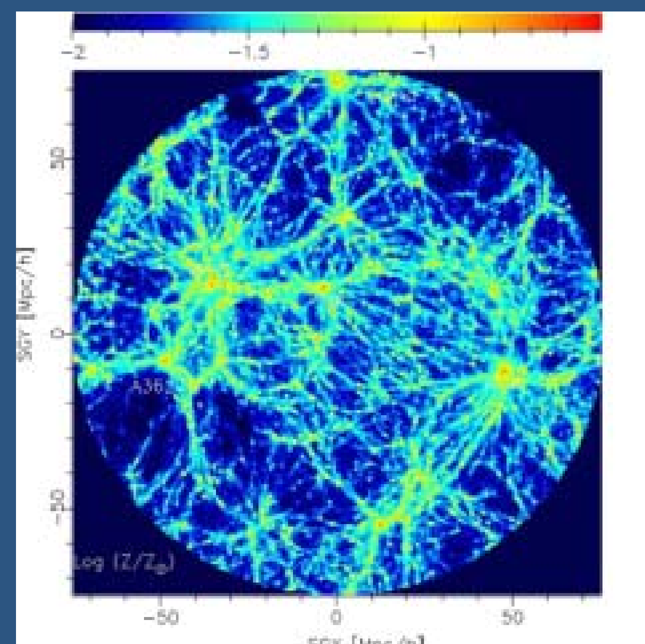
Simulated gas distribution on the supergalactic plane

gas temperature



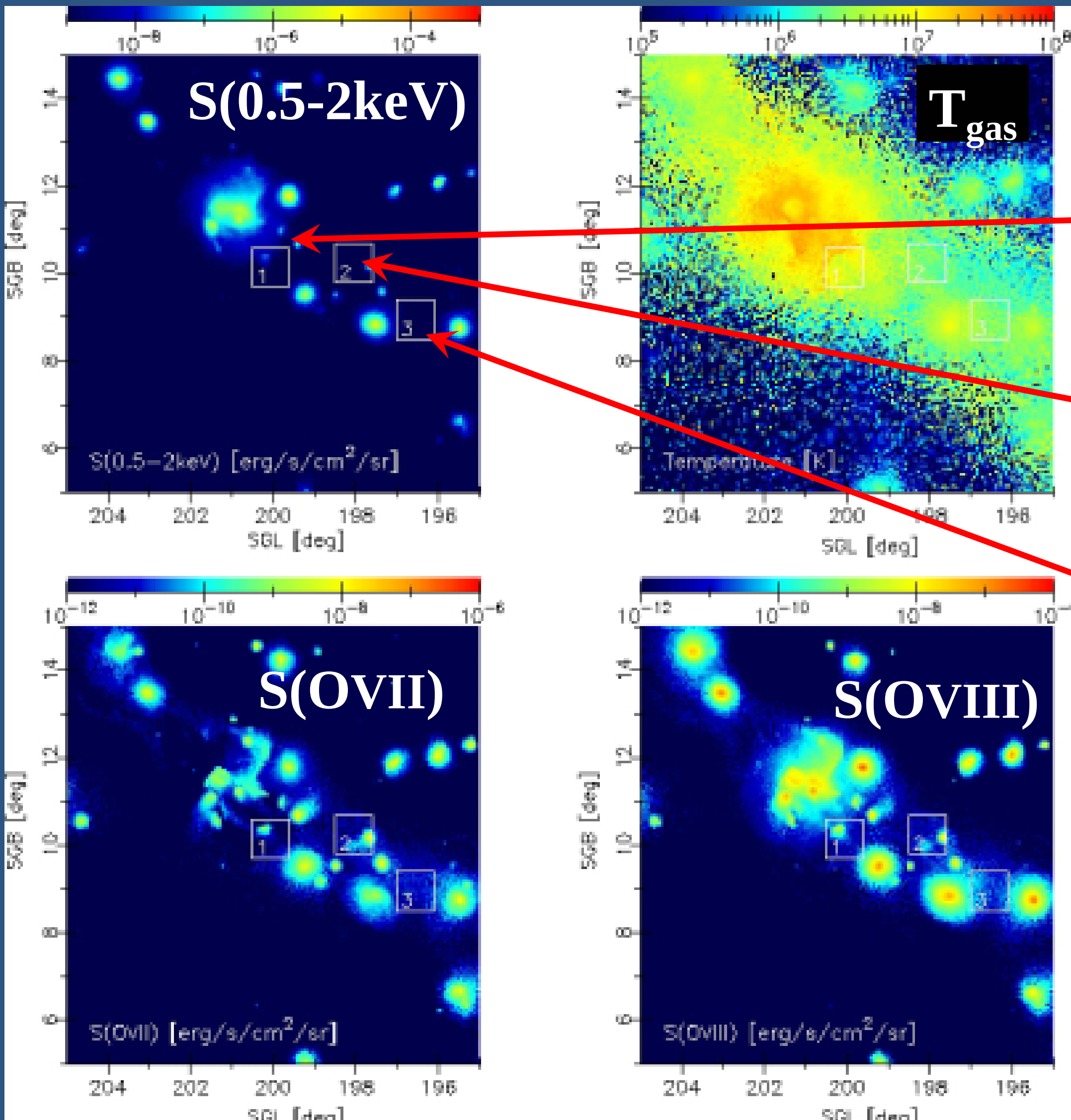


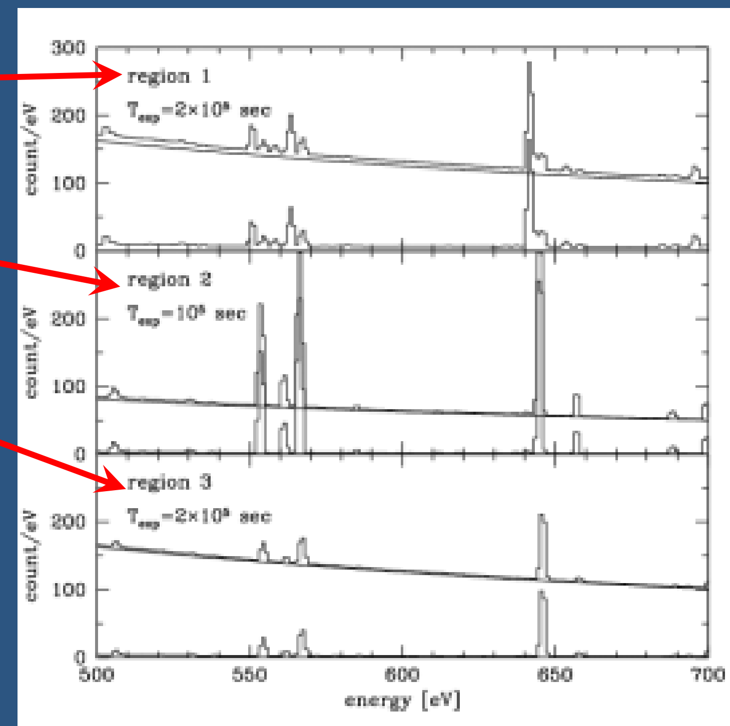
gas density



(adopted) metallicity

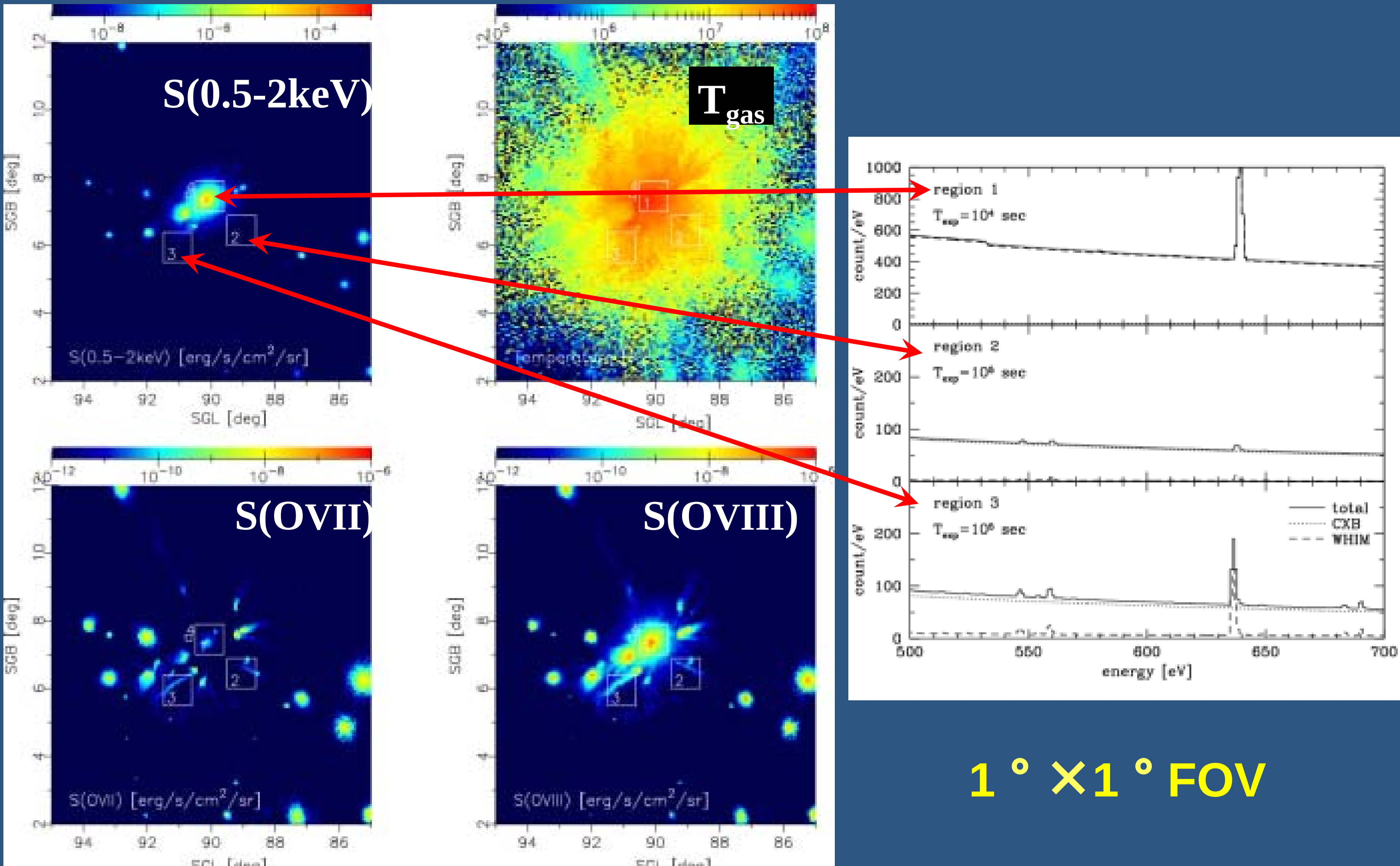
Mock observation of X-ray filament extending around simulated A3627





1°×1° FOV

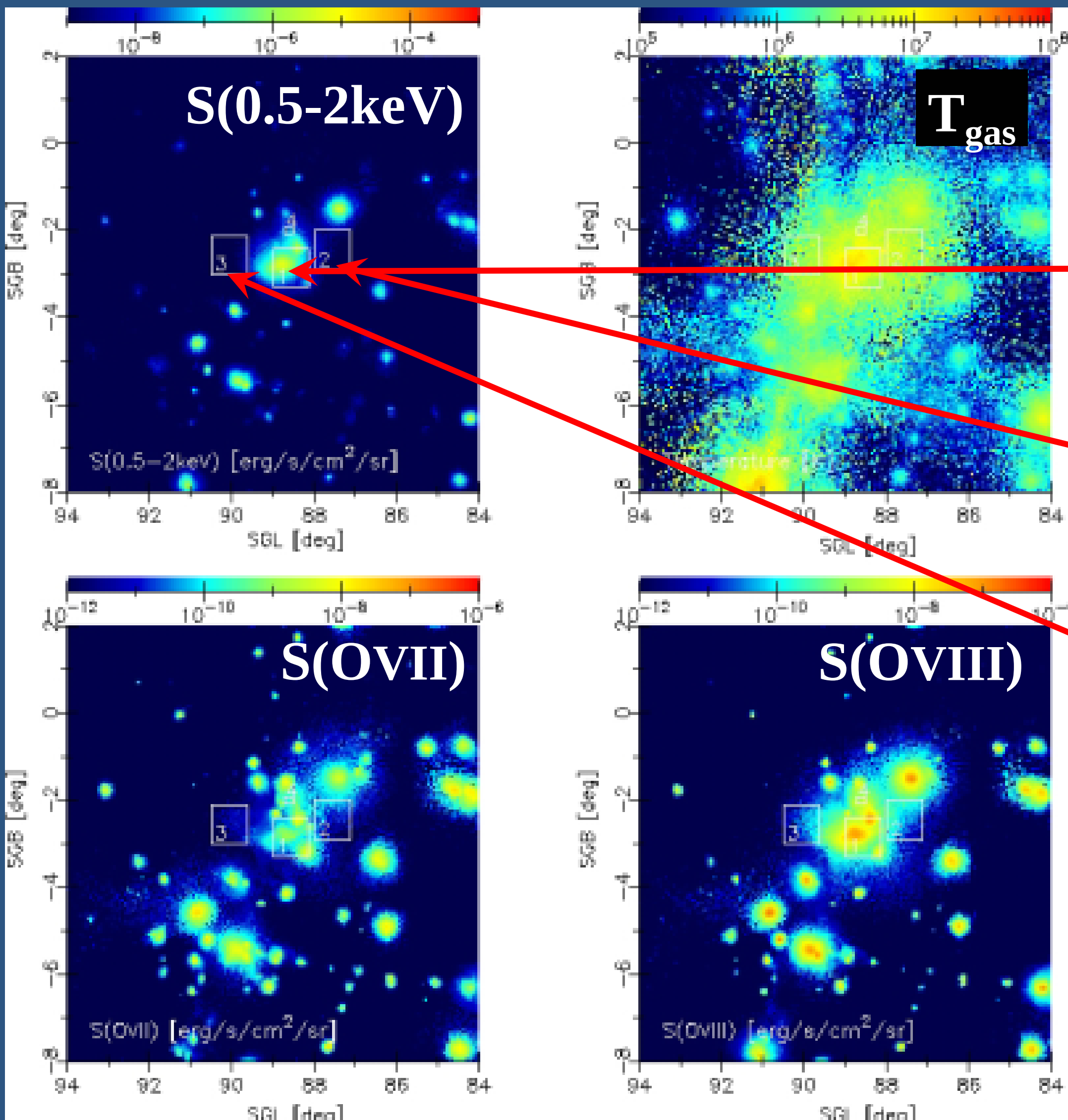
Mock observation of simulated Coma

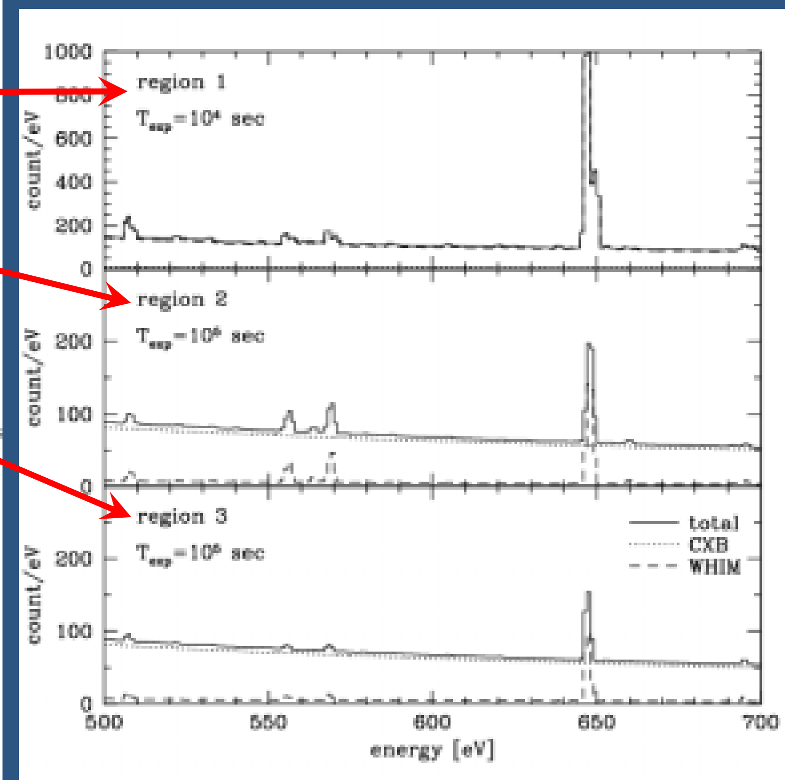


1°×1° FOV

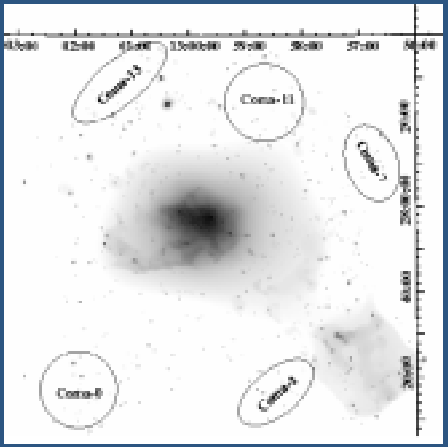
a small clump in front of simulated Coma

~10°(~5h^{-1}Mpc) away from los toward Coma



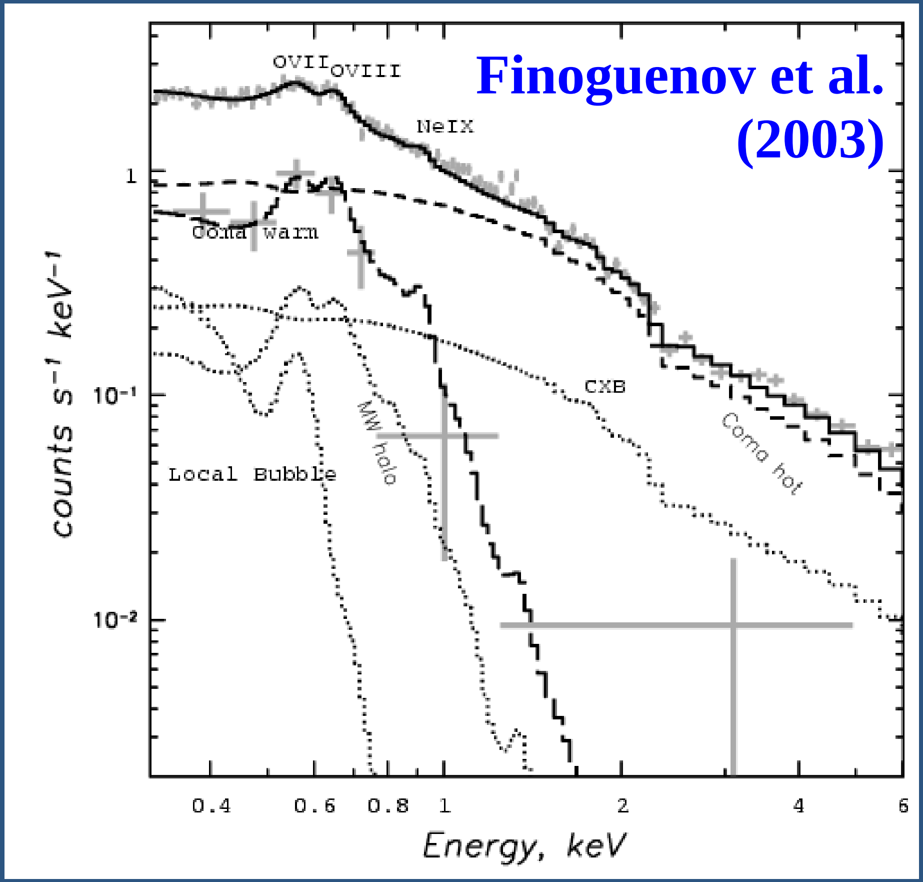


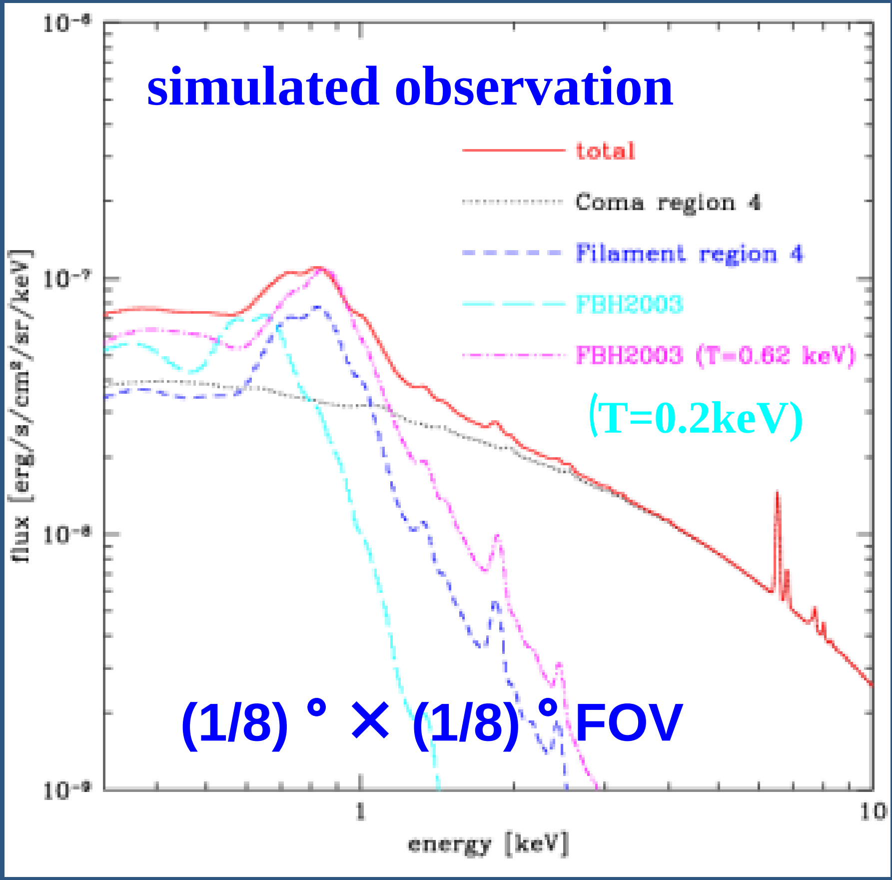
1°×1° FOV



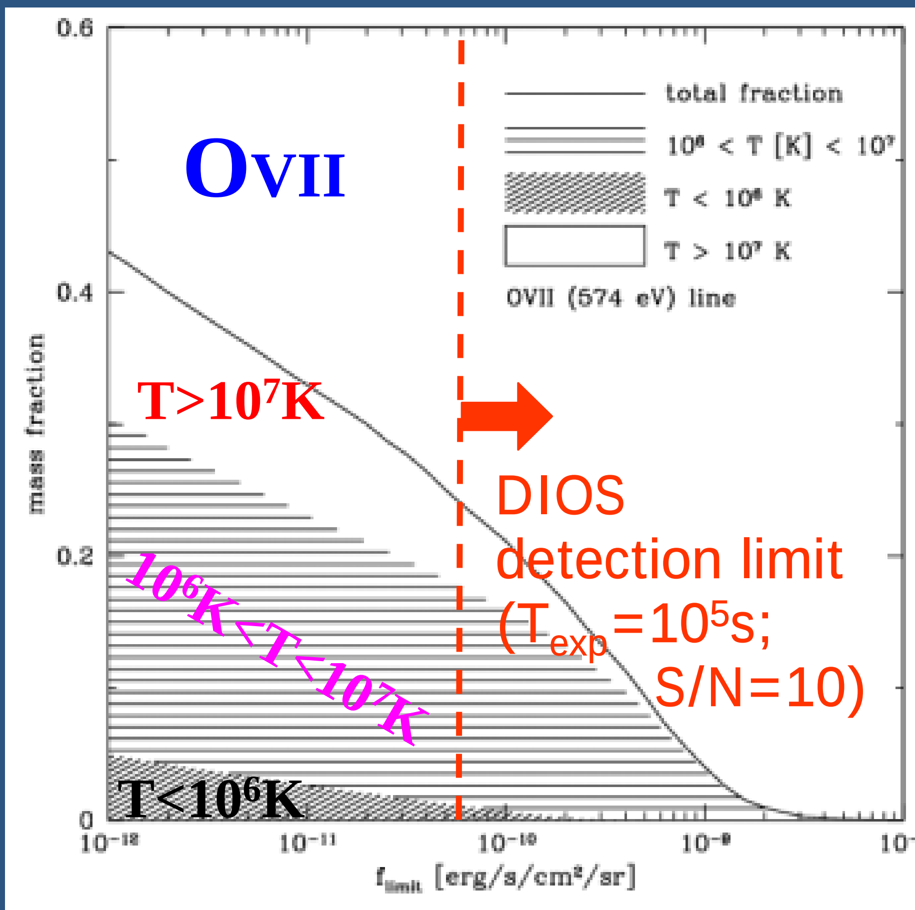
Soft X-ray excess of Coma

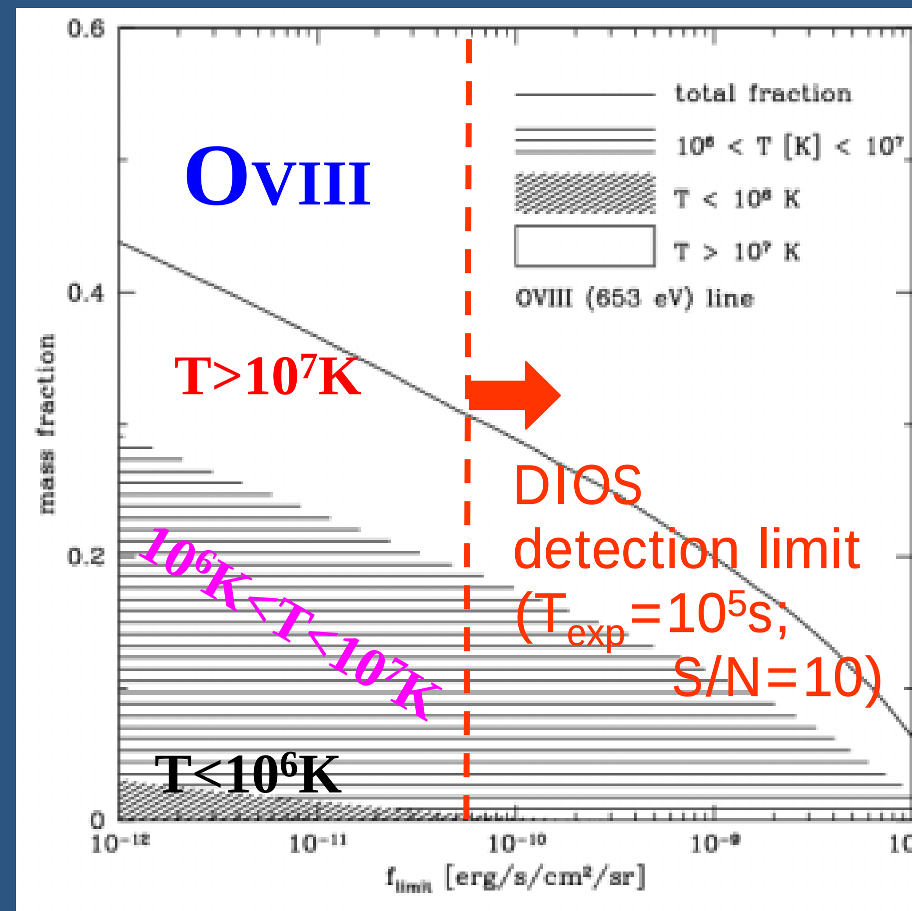
- XMM-Newton observations of the outskirts of Coma (Finoguenov, Briel & Henry 2003, A&A 410, 777)
- X-ray filament of 0.2keV warm gas ?





Fraction of cosmic baryons detectable via oxygen emission

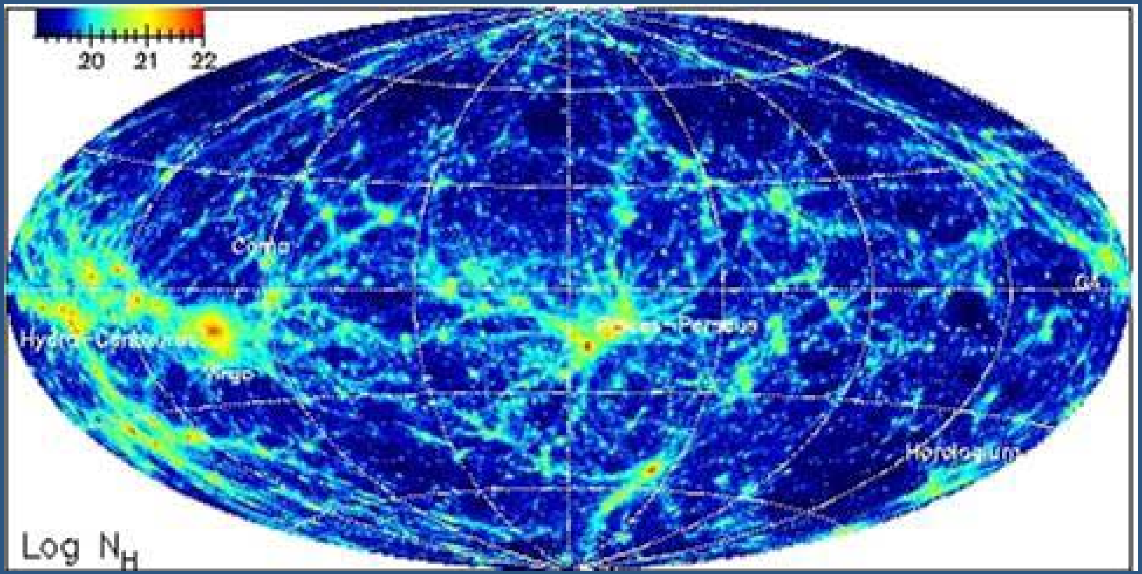




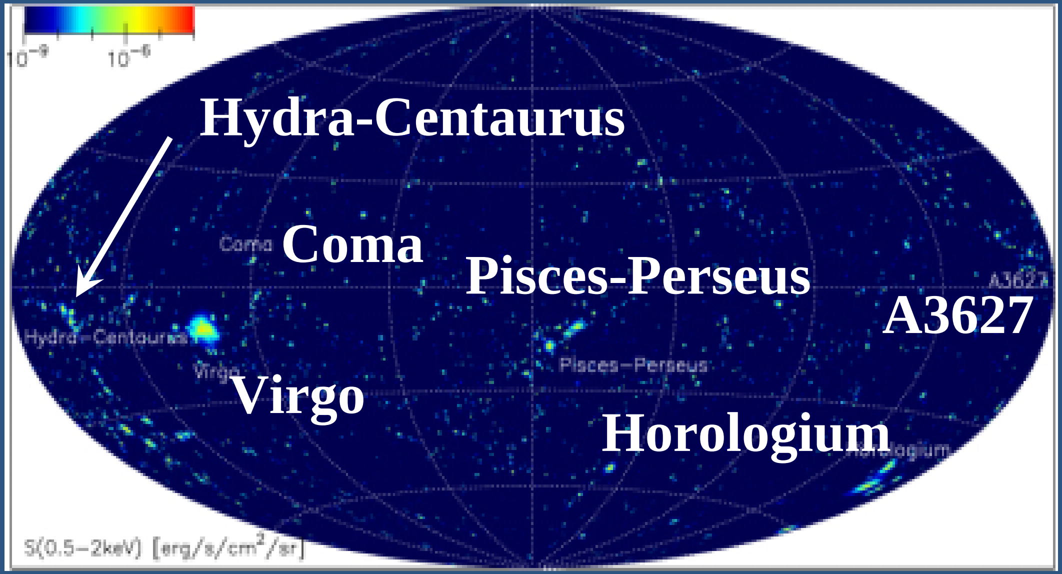
Locating Warm-Hot Intergalactic Medium via Oxygen emission lines

- Mock spectral observation of oxygen emission (Yoshikawa et al. 2003, 2004)
- **DIOS will be able to locate ～20 percent of the total cosmic baryons**
  - ΔE=2eV, $S_{eff}\,\Omega$=100 [cm^2 deg^2], T_{exp}=10^5s, S/N=10
  - flux limit = 6×10^{-11} [erg/s/cm^2/str]
- Things remain to be checked
  - Validity of the collisional ionization equilibrium ?
  - Strategy to quantify the fraction of WHIM; targeted observations vs. blank survey
  - Sciences with DIOS other than WHIM search

Hydrogen column density and X-ray maps

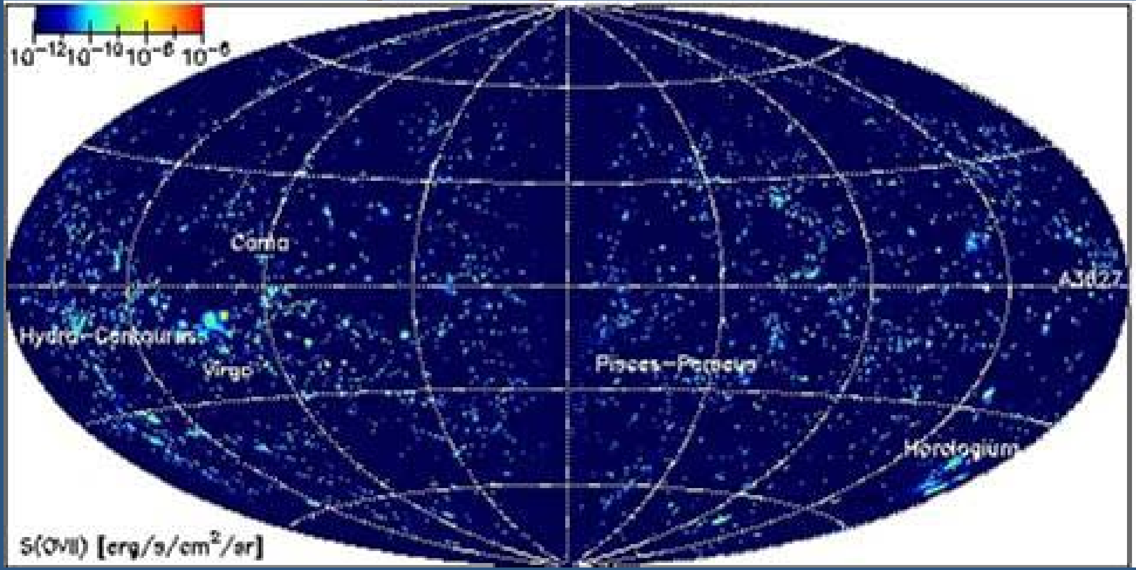


N_H



S(0.5-2keV)

Oxygen emission in supergalactic coordinates



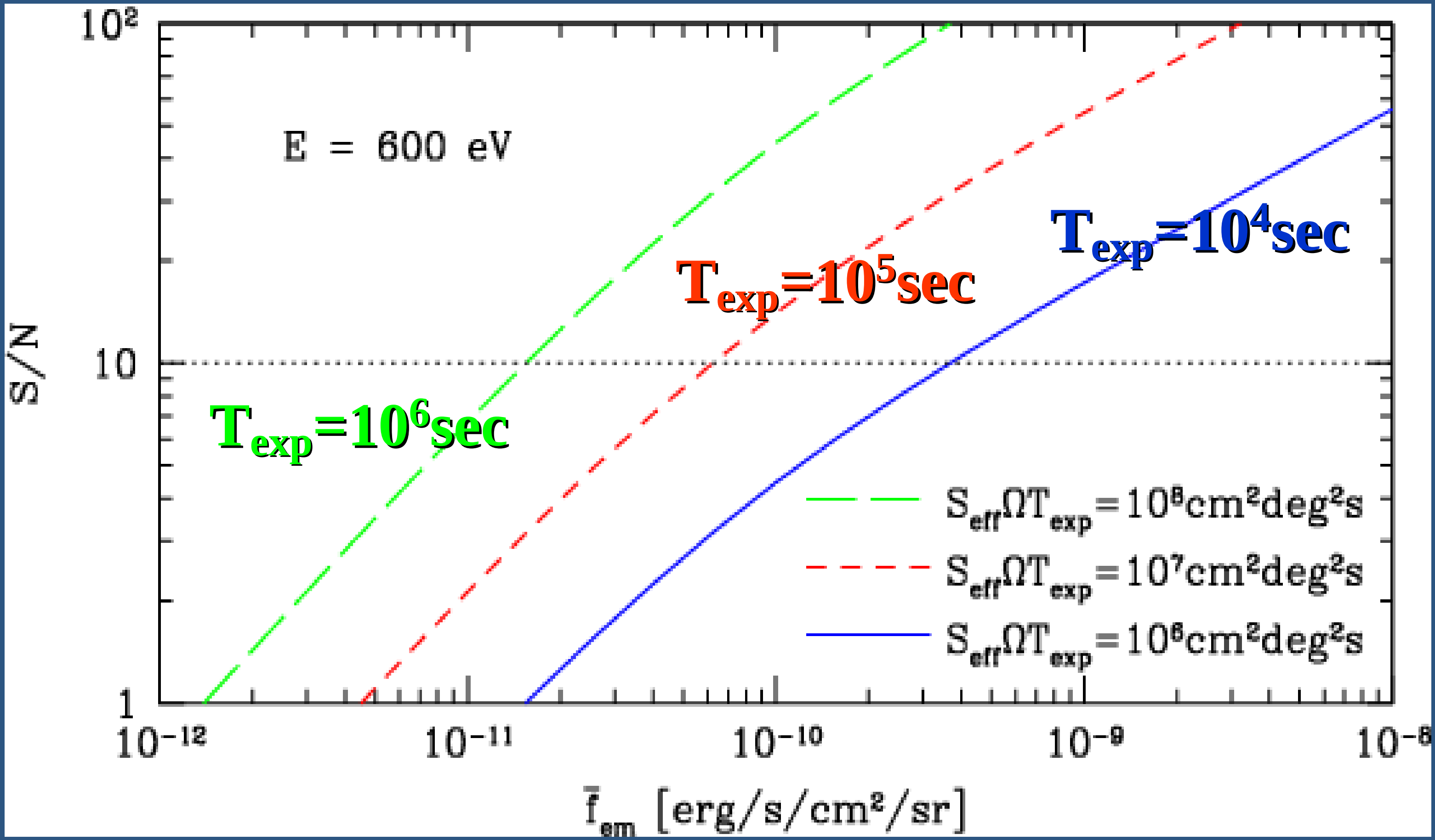
OVII

soft X-ray

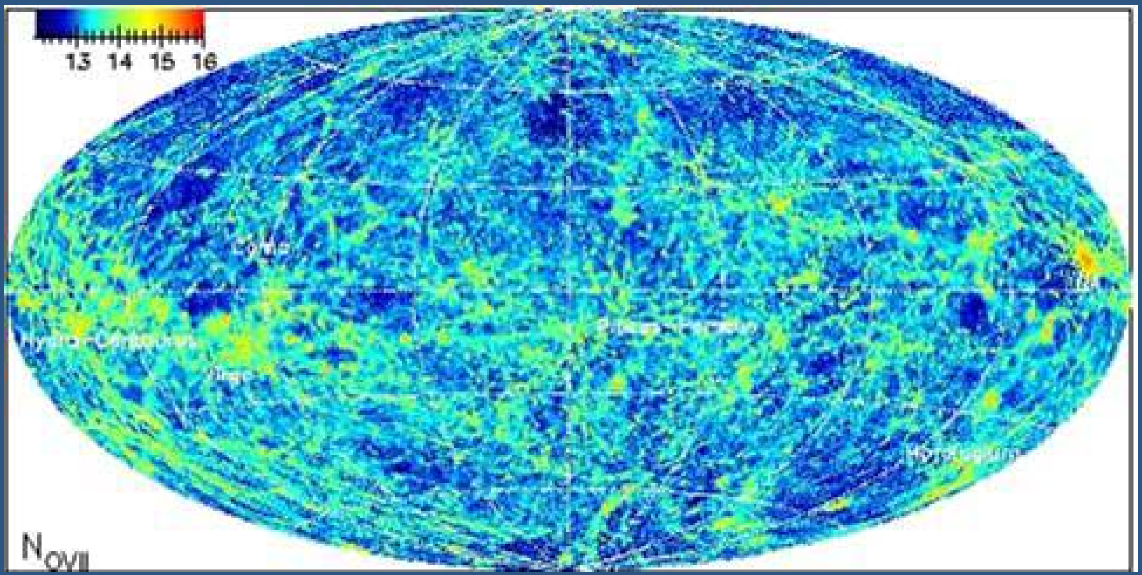
OVIII

Expected S/N for OVIII line

For a detector of $S_{eff}\Omega$ = 100 cm^{2}deg^2 and ΔE=2eV

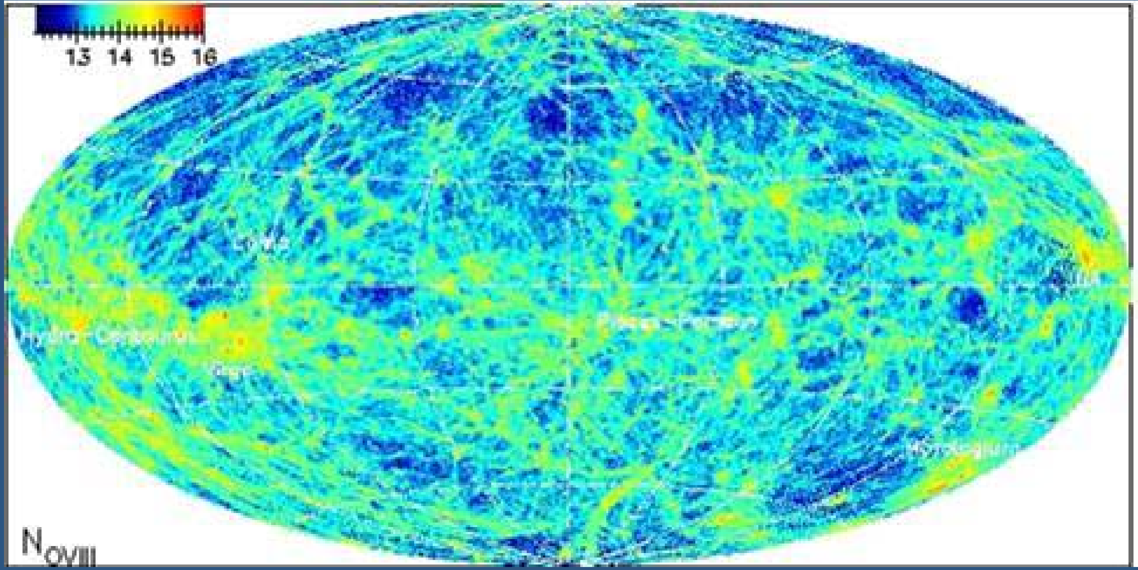


Oxygen column densities in supergalactic coordinates

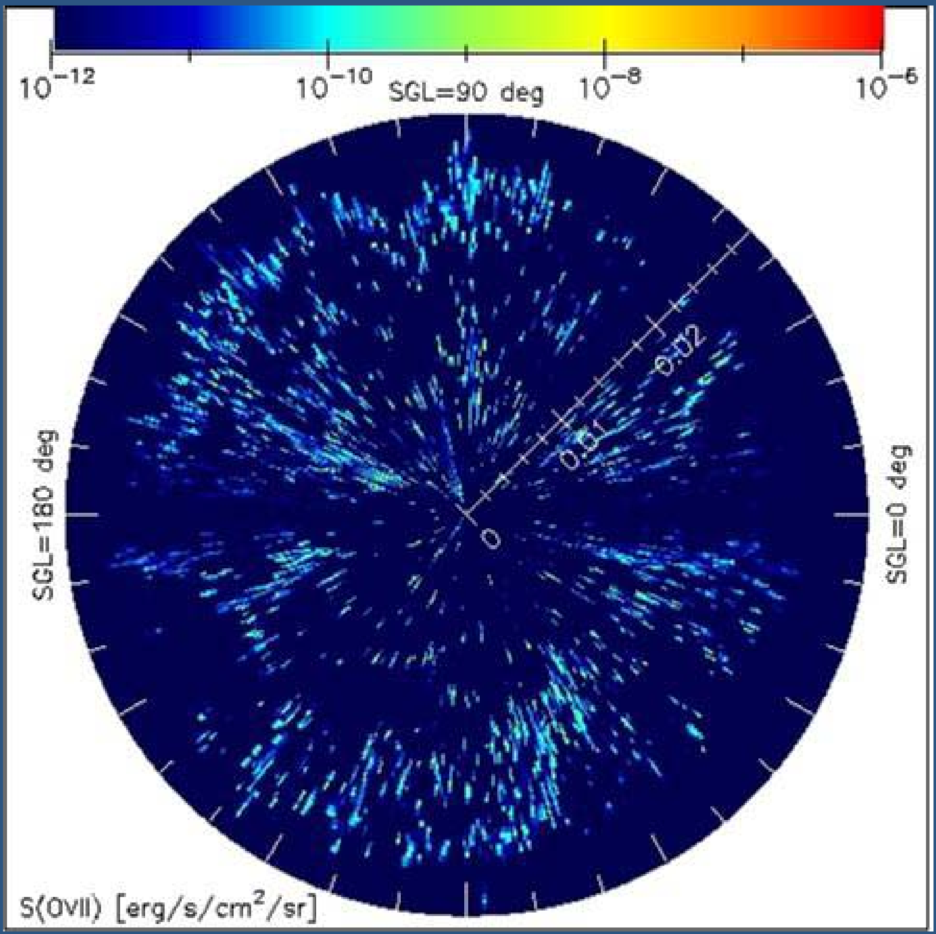


OVII

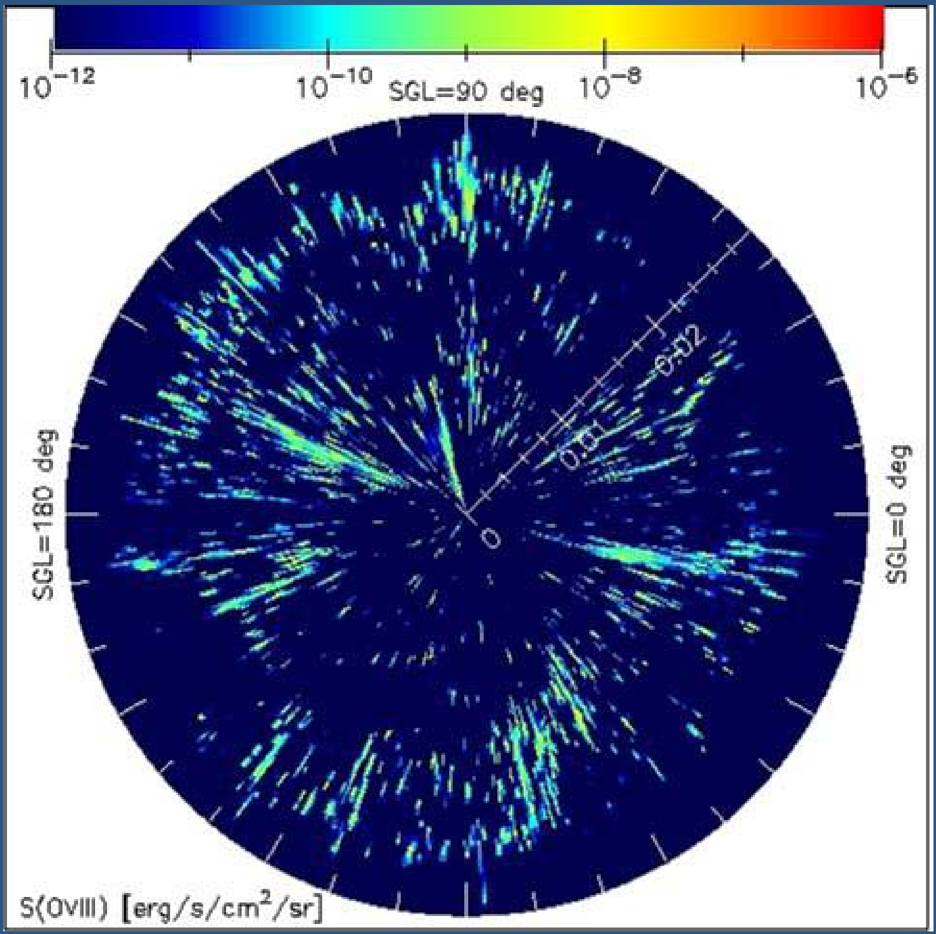
OVIII



Redshift-space map of oxygen emission

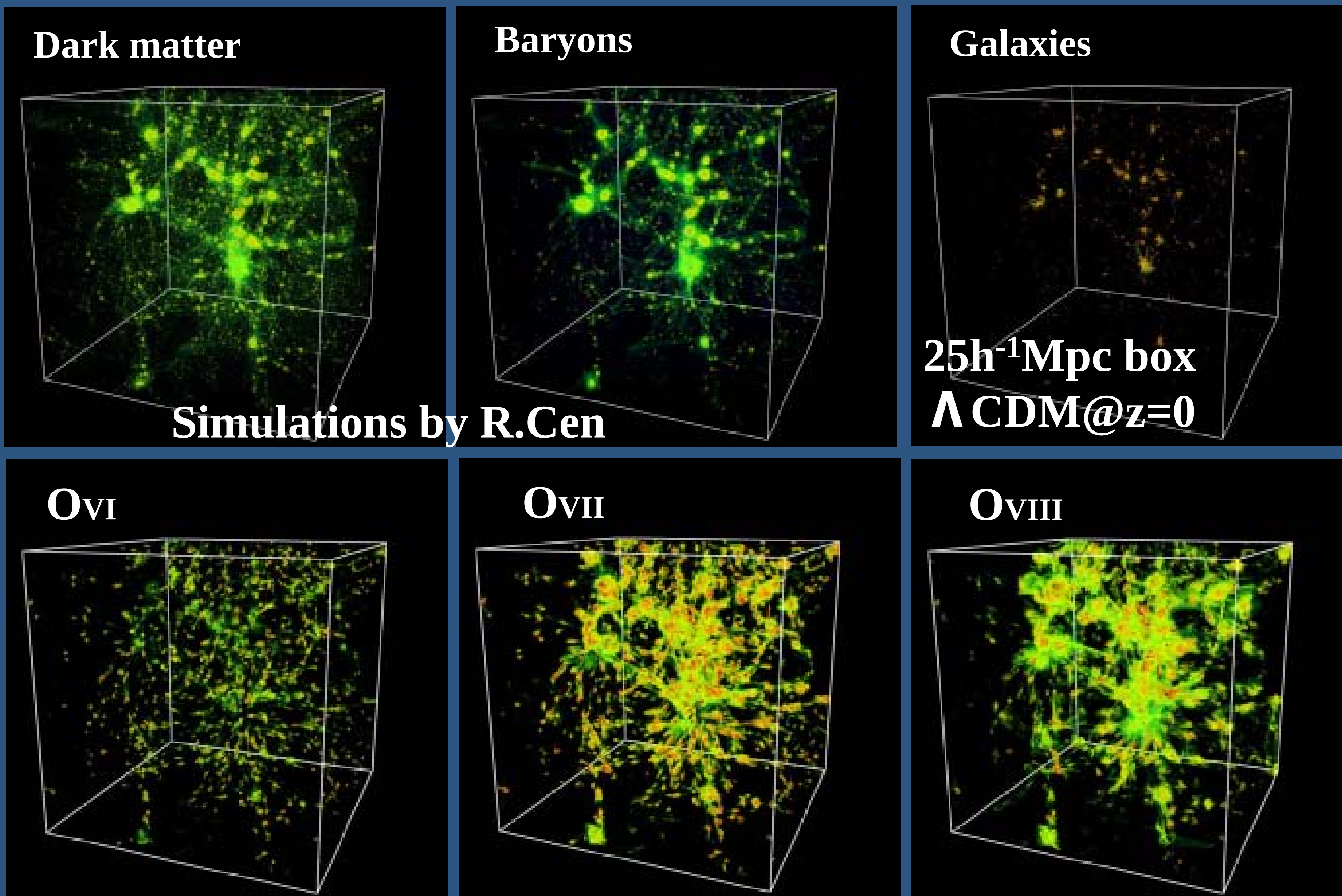


OVII



OVIII

Tracing the structure with Oxygen



Oxygen lines

O VII	$1s^2 - 1s2s\ (^3S_1)$	561eV	22.1 Å
O VII	$1s^2 - 1s2p\ (^3P_1)$	568eV	21.8 Å
O VII	$1s^2 - 1s2p\ (^1P_1)$	574eV	21.6 Å
O VIII	1s – 2p (Ly α)	653eV	19.0 Å
O VII	$1s^2 - 1s3p$	665eV	18.6 Å
O VIII	1s – 3p (Ly β)	775eV	16.0 Å
Ne IX	$1s^2 - 1s2s\ (^3S_1)$	905eV	13.7 Å
Ne IX	$1s^2 - 1s2p\ (^3P_1)$	914eV	13.6 Å
Ne IX	$1s^2 - 1s2p\ (^1P_1)$	921eV	13.5 Å

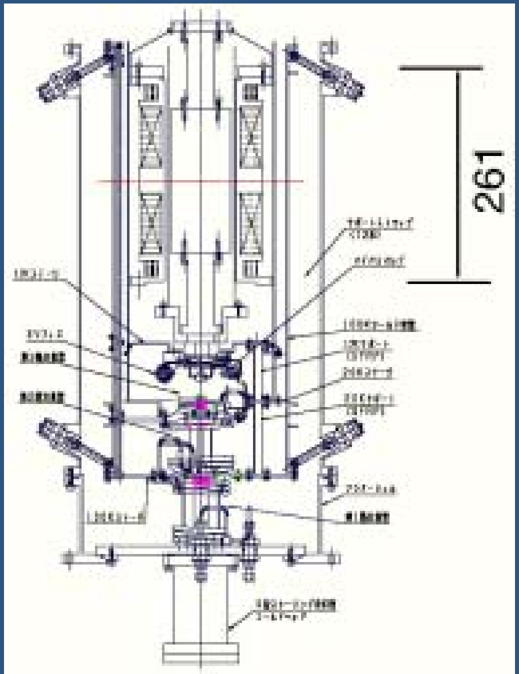
Requirements for detection

- **Good energy resolution** to identify the emission lines from WHIM at different redshifts
  - $\Delta E < 5$eV ⇒ X-ray calorimeter using superconducting TES (Transition Edge Sensor)
- **Large field-of-view** and effective area for survey
  - $S_{eff} = 100\text{cm}^2$, $\Omega = 1\text{deg}^2$ ⇒ 4-stage reflection telescope
- Angular resolution is not so important (but useful in removing point source contaminations)

$$\theta \approx 1^\circ \left(\frac{600\, h^{-1}\text{Mpc}}{D} \right) \left(\frac{L}{10\, h^{-1}\text{Mpc}} \right)$$

DIOS: instrument summary

Area	> 100 cm^2
Field of View	50' diameter
$S\Omega$	~100 cm^2deg^2
Angular Resol.	3' (16^2 pixels)
Energy Resol.	2 eV (FWHM)
Energy Range	0.1 - 1 keV
Life	> 5 yr



Mechanical coolers + ADR: < 100 mK

Initial cooling ~ 3 months

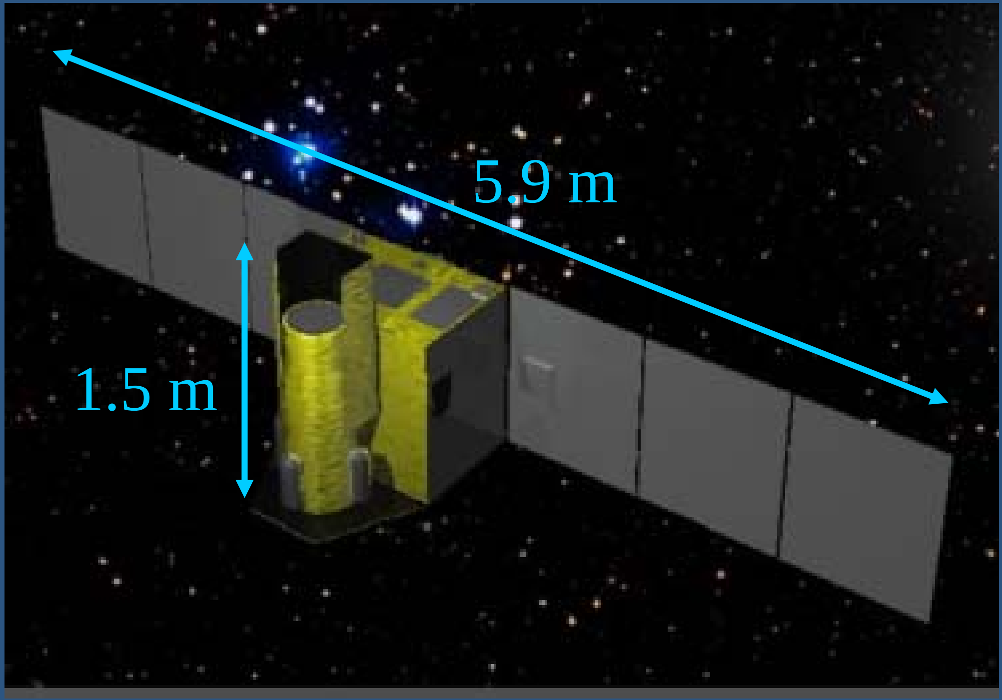
DIOS: spacecraft

Weight	Total	~ 400 kg
	Payload	~ 280 kg
Size	Launch	1.2×1.45 ×1.4 m
	In orbit	5.85×1.45 ×1.4 m
Attitude	Control	3-axis bias momentum wheel, Sun pointing in 1 axis
	Accuracy	≦10 arcsec
Power	Total	450 W
	Payload	250 W

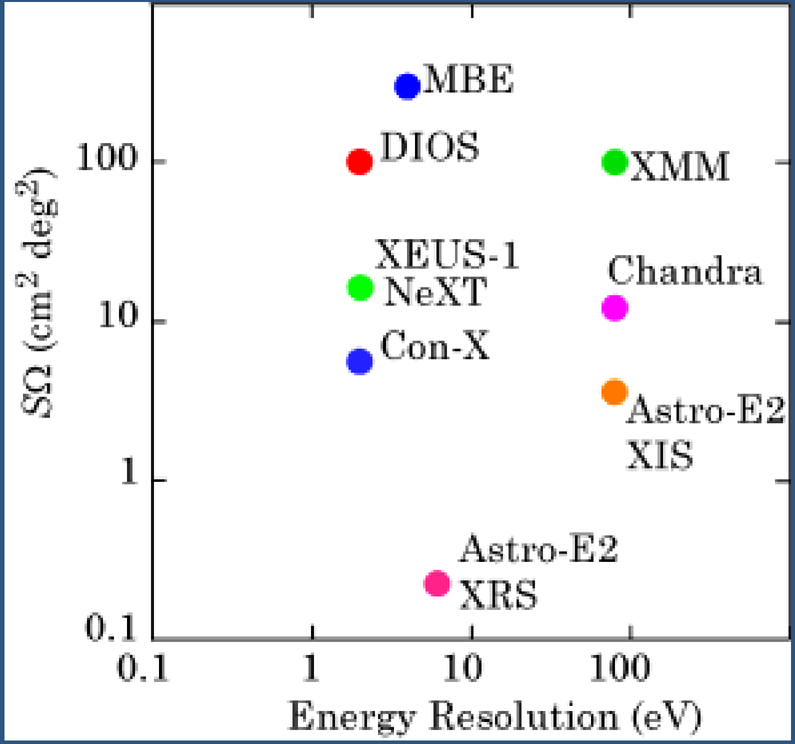
Altitude: ~ 550 km

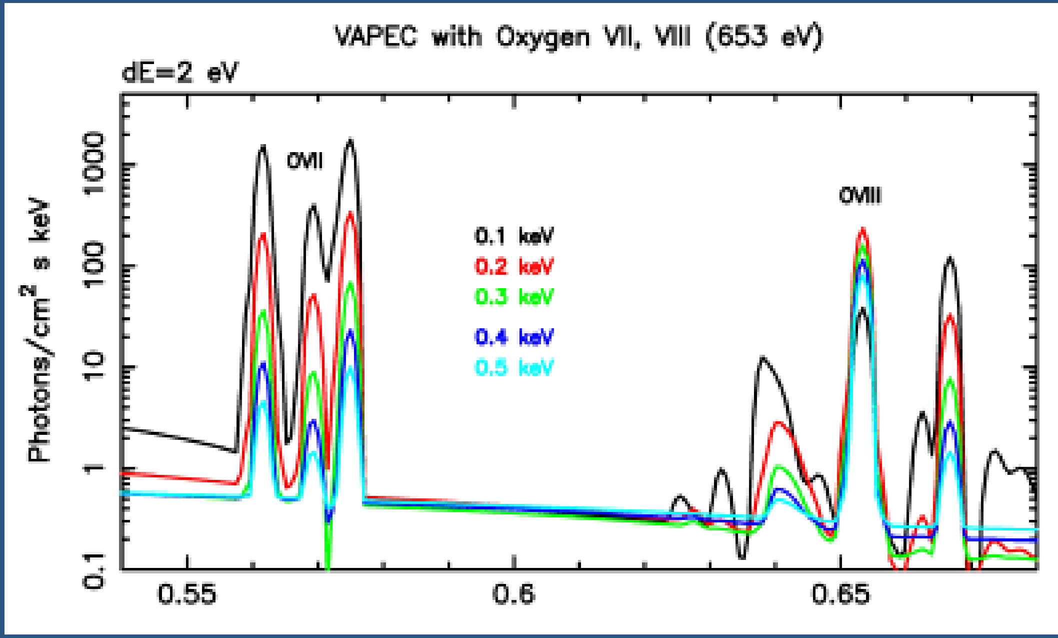
Inclination: 30 °

Rotation period: 95 min



DIOS: comparison with other missions



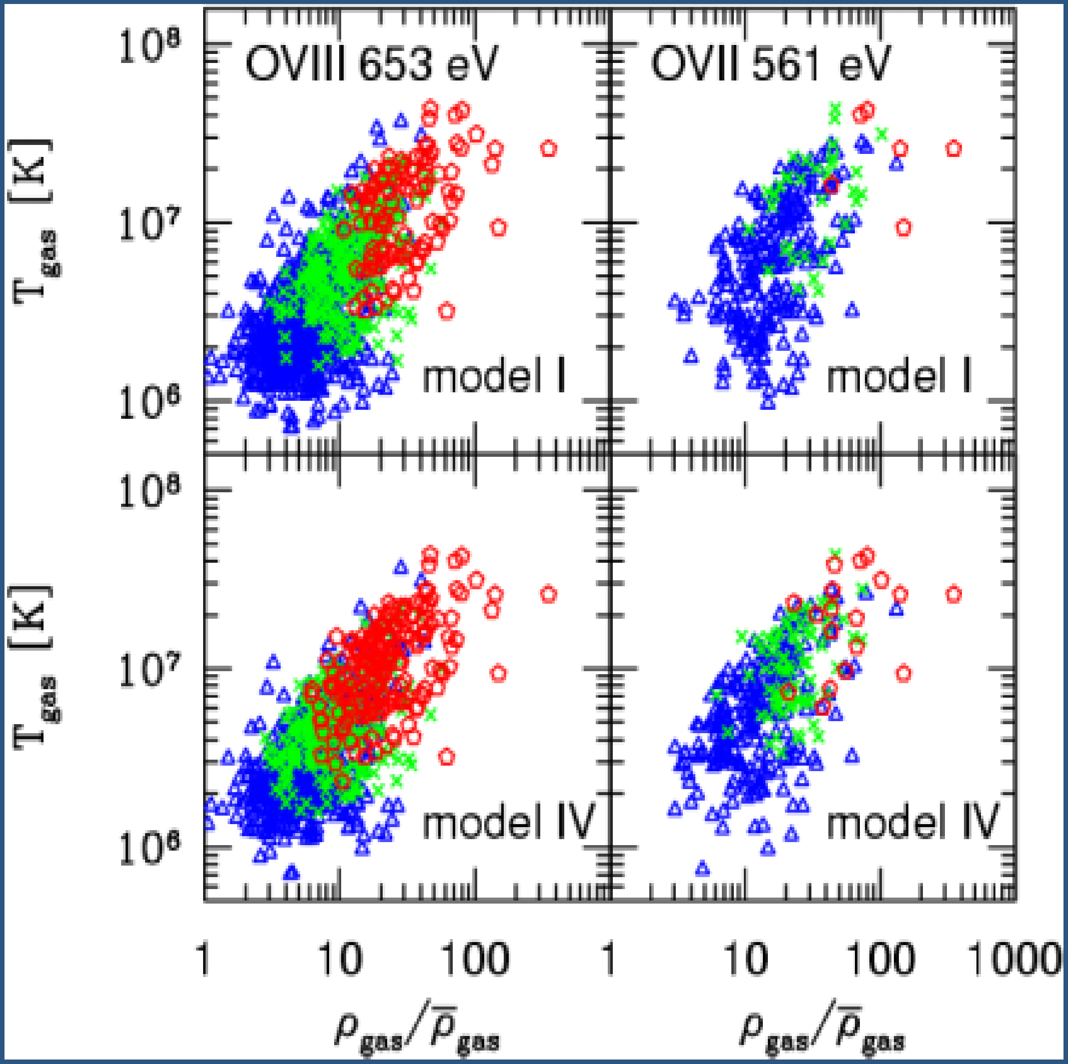


- Very high sensitivity ($S\Omega$ and ΔE) in detecting oxygen emission lines
- Intensity ratios of the lines reveal the temperature and ionization condition of WHIM

Comparison with other missions

	$S_{eff}\Omega$ [cm^2 deg^2]	ΔE [eV]	f_{limit} [erg/s/cm^2/sr]
Chandra ACIS-S3	12	80	10^{-9}
XMM-Newton EPIC-pn	100	80	$3x10^{-10}$
Astro-E II XRS	0.23	6	$2x10^{-8}$
Astro-E II XIS	36	80	$6x10^{-10}$
XEUS-I	16.7	2	$2.5x10^{-10}$
	**100**	**2**	**$6x10^{-11}$**

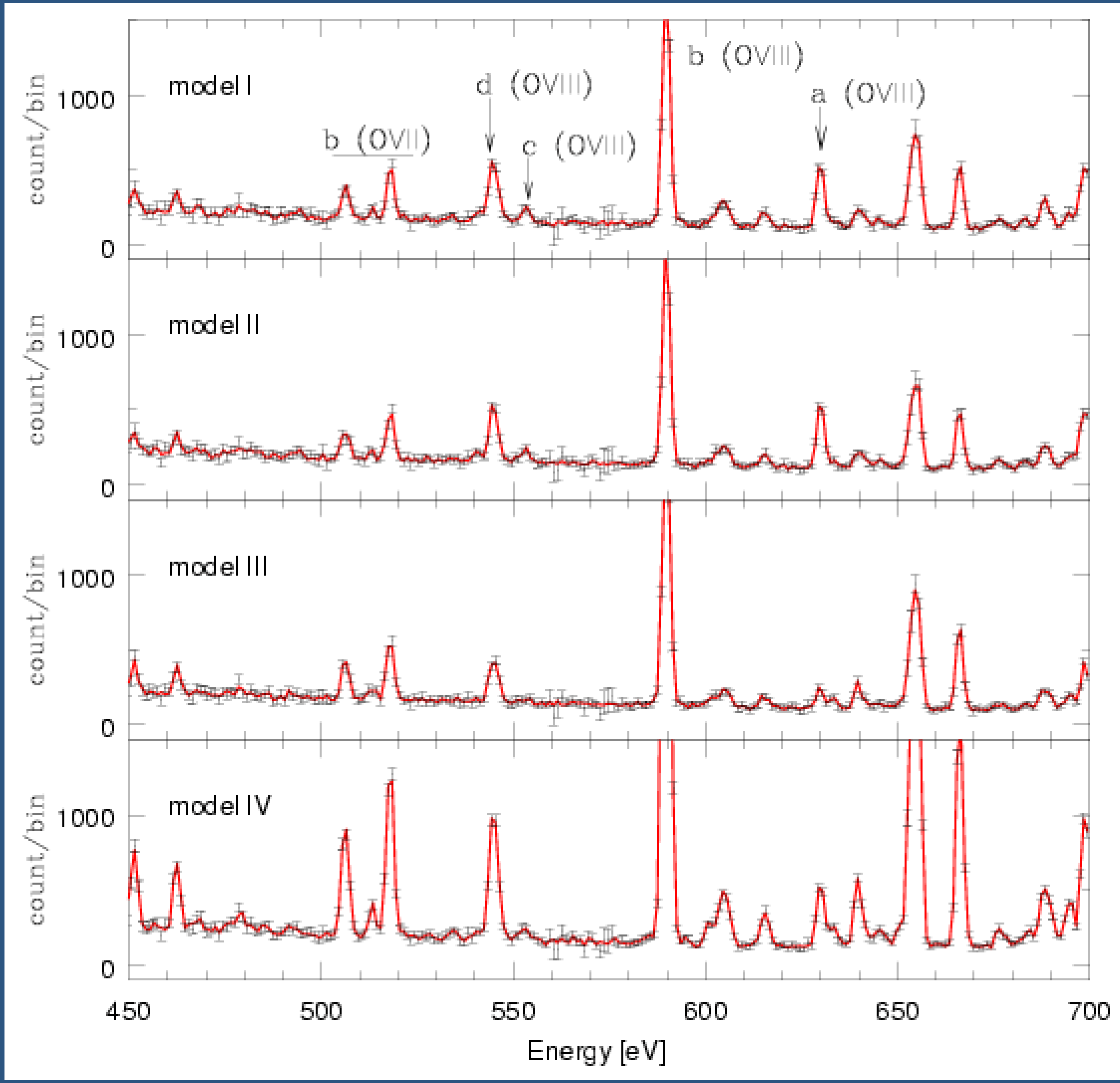
Physical properties of the probed baryons



Each symbol indicate the temperature and the over-density of gas at each simulation grid (4x4 smoothed pixels over the sky and Δz=0.3/128)

- $S_x > 3 \times 10^{-10}$ [erg/s/cm²/sr] (red pentagon)
- $S_x > 6 \times 10^{-11}$ [erg/s/cm²/sr] (green cross)
- $S_x > 10^{-11}$ [erg/s/cm²/sr] (blue triangle)

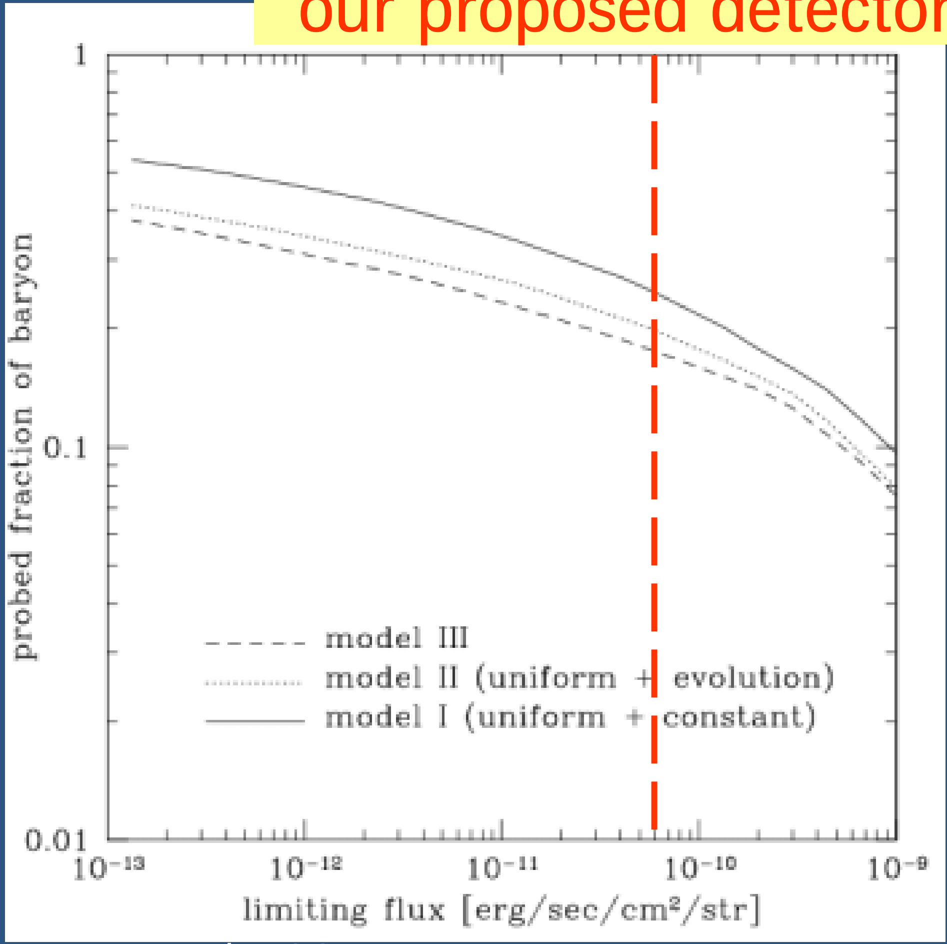
Dependence on the metallicity model



- We have adopted model I (constant 0.2 solar metallicity) so far
- Density-dependent metallicity models show stronger emission lines.
- ⇒ WHIM will be unambiguously detected with our proposed mission

Expected fraction of WHIM detectable via Oxygen emission lines (in principle)

Detection limiting flux of our proposed detector



- Our proposed mission (flux limit = 6×10^{-11} [erg/s/cm^2/str]) will be able to detect (20-30) percent of the total cosmic baryons via Oxygen emission lines **in principle**.