Exploring warm/hot intergalactic medium with DIOS

(Diffuse Intergalactic Oxygen Surveyor)

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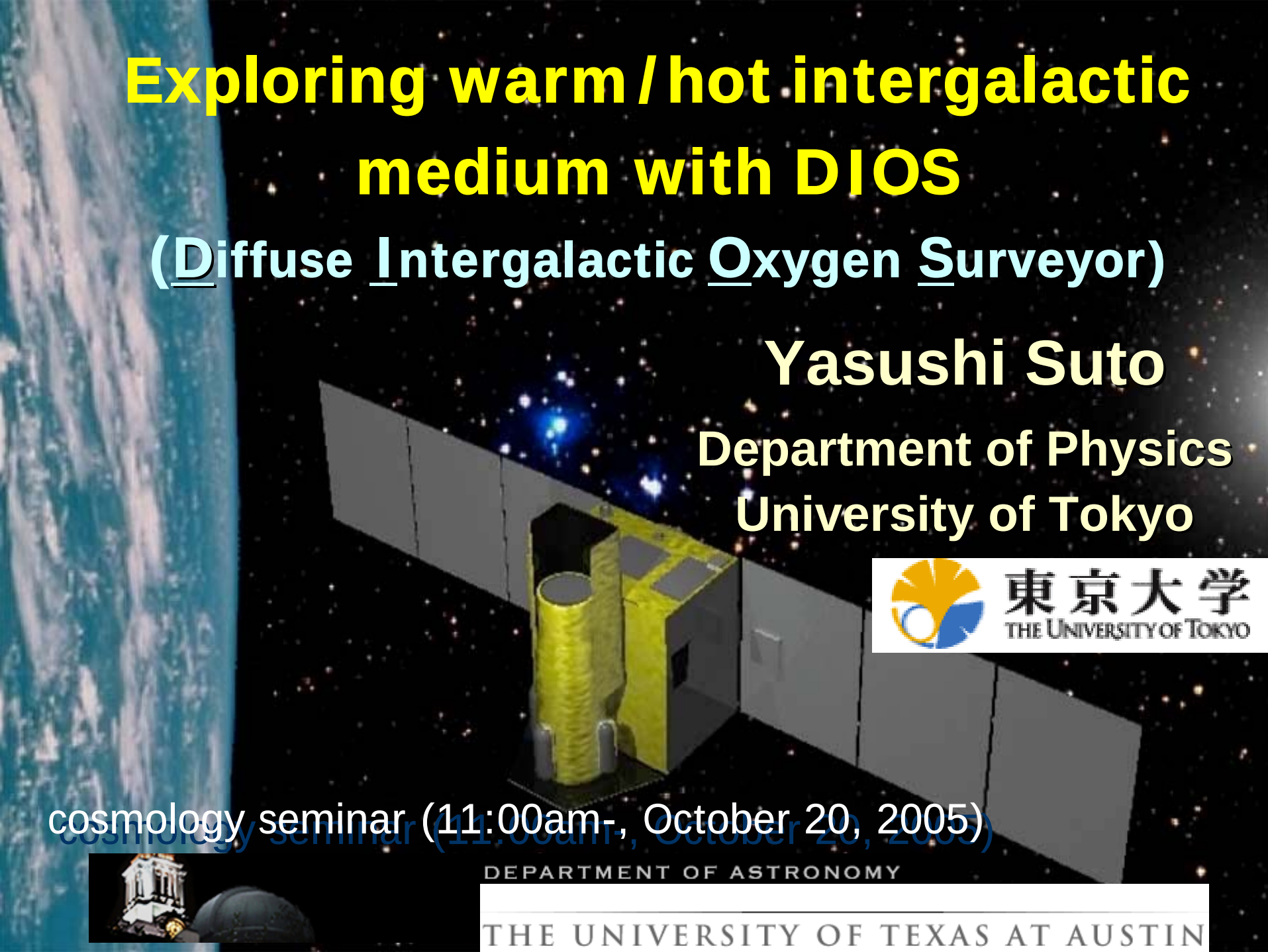


cosmology seminar (11:00am-, October 20, 2005)

cosmology seminar (11:00am-, October 20, 2005)

DEPARTMENT OF ASTRONOMY

THE UNIVERSITY OF TEXAS AT AUSTIN

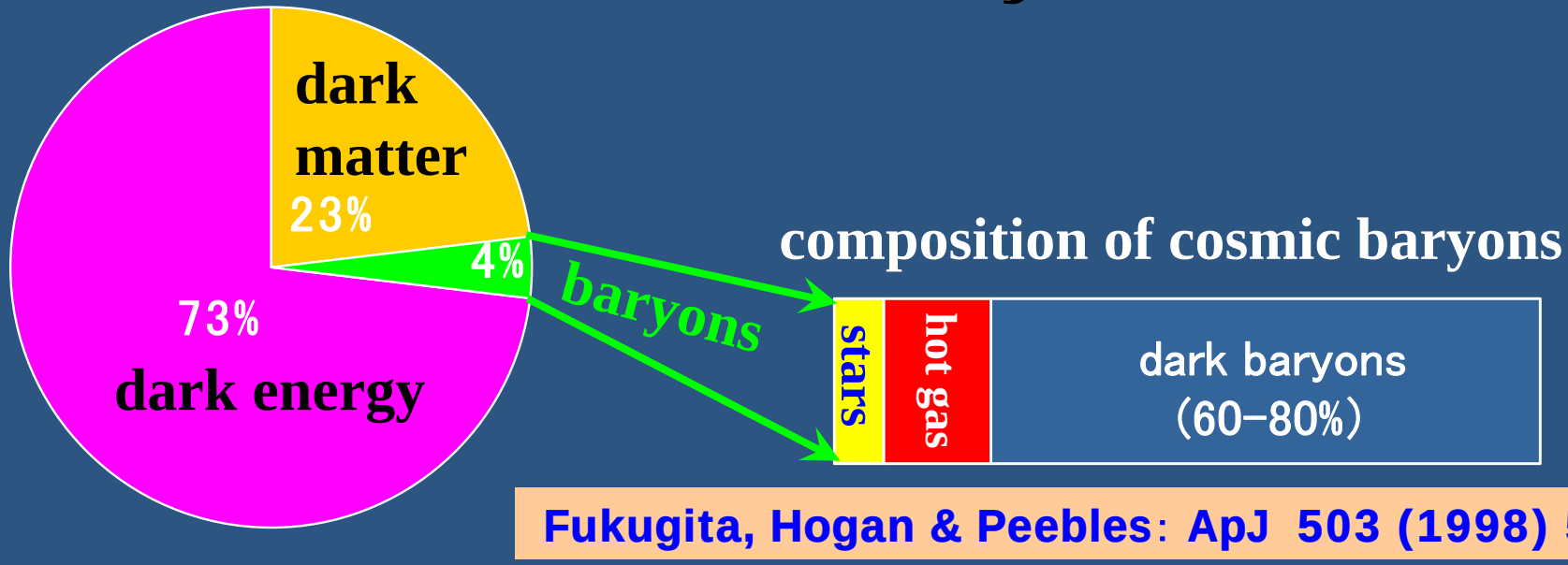
Recent Activities of Observational Cosmology Group, University of Tokyo (1)

- **SDSS galaxy and quasar statistics**
  - topological analysis of galaxy distribution (Hikage et al. 2003, 2004; Park et al. 2005)
  - phase correlation statistics of SDSS galaxies (Hikage, Matsubara, Suto et al. 2005)
  - 3pt correlation functions of SDSS galaxies (Kayo, Suto, Nichol et al. 2004)
  - widest-separation lensed quasar from SDSS (Inada et al. 2003; Oguri et al. 2004)
  - 2pt correlation functions of SDSS quasars and cosmological constant (Yahata et al. 2005)
  - constraints on the deviation from Newton's law of gravity from SDSS galaxy power spectrum (Shirata, Shiromizu, Yoshida & Suto 2005)
  - testing the Galactic dust map against SDSS galaxy number counts (Yahata et al. in preparation)

Recent Activities of Observational Cosmology Group, University of Tokyo (2)

- **Dark halo and galaxy cluster**
  - triaxial modeling of dark matter halos (Jing & Suto 2002; Oguri, Lee & Suto 2003; Lee, Jing & Suto 2005)
  - highest-angular resolution SZ maps in submm and mm (Komatsu et al. 1999, 2001; Kitayama et al. 2004)
- **Warm/hot intergalactic medium (WHIM)**
  - a proposal of oxygen emission line search (Yoshikawa et al. 2003, 2004)
  - feasibility of an absorption line search with XEUS along a GRB afterglow (Kawahara et al. 2005)
- **Spectroscopy of transiting extrasolar planets**
  - constraints on planetary atmosphere (Winn et al. 2004; Narita et al. 2005)
  - first detection of the spin-orbit misalignment in an extrasolar planetary system using the Rossiter effect (Ohta, Taruya & Suto 2005; Winn et al. 2005)

Most of the cosmic baryon is "dark"



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

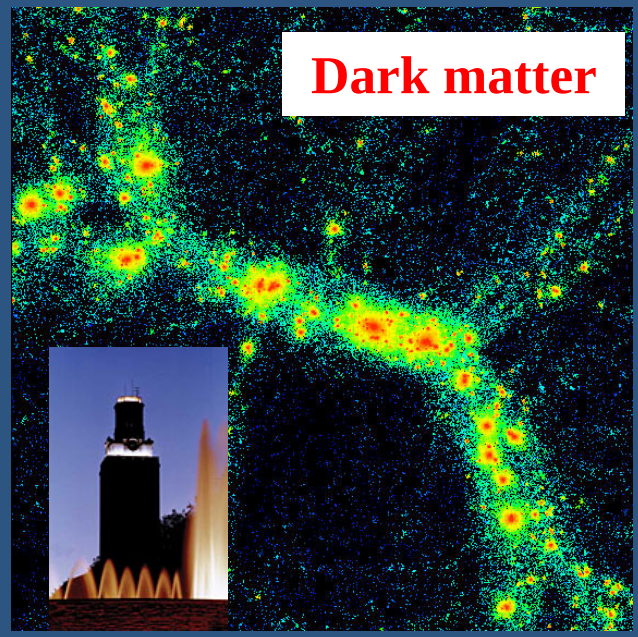
- **Goal: the cosmic baryon budget**
  - WHIM (warm/hot intergalactic medium) is a generic consequence in the standard structure formation scenario
  - locate WHIM and establish a new observational window of the universe via soft X-ray spectroscopy

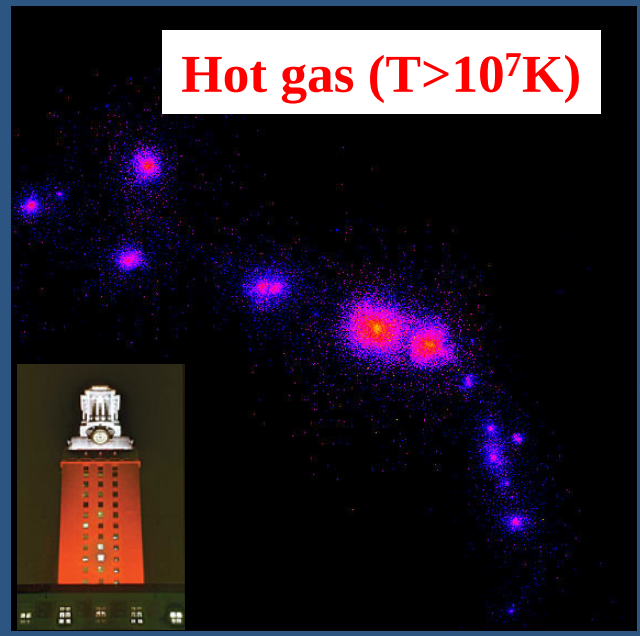
Can we understand the dark sides of the universe in foreseeable future ?

- **Dark matter**
  - maybe new results from on-going experiments in next 5-10 years, but not from astronomy
- **Dark energy**
  - unlikely to have any breakthroughs from future experiments and/or theories in high energy physics in this century
  - astronomy is the key !
- **Dark baryons**
  - only astronomical observations can make a scientific new contribution since high-energy physicists already know baryons too well !

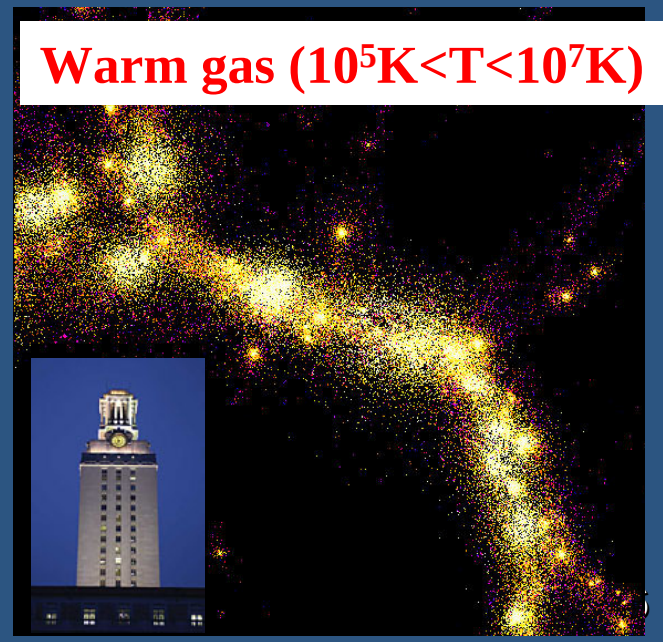
Simulated distribution of matter in the universe

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





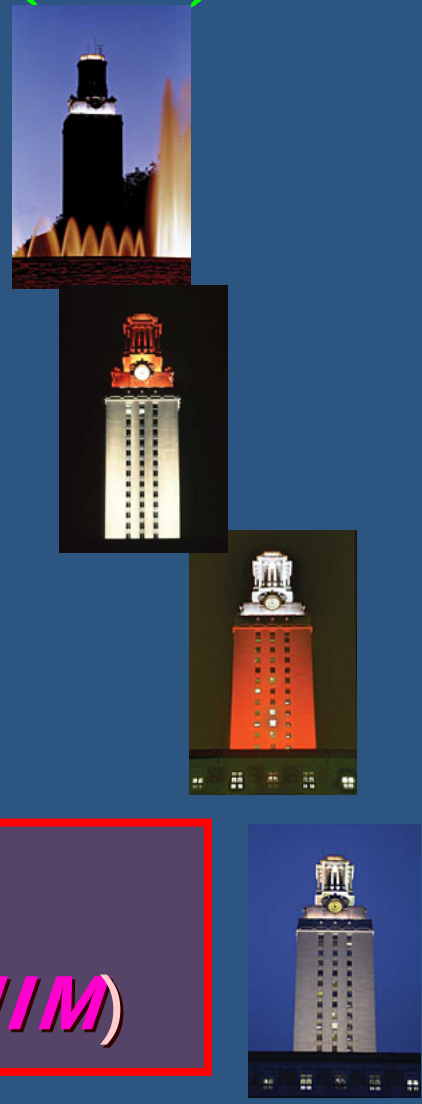
ΛCDM SPH simulation (Yoshikawa, Taruya, Jing & Suto 2001)



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
  - Lyα absorption line systems
- ***Hot:*** $T > 10^7$K
  - X-ray emitting hot intra-cluster gas
- ***Warm-hot:*** $10^5\text{K} < T < 10^7\text{K}$
  - Warm-hot intergalactic medium (***WHIM***)



Three complementary methods to search for dark baryons

- absorption line systems of OVI, OVII and OVIII along background QSOs in UV and soft X-ray

→ several detections reported with FUSE, Chandra, and XMM/Newton (e.g., Fang et al. 2002, Fujimoto et al. 2004, Nicastro et al. 2005)

- emission line survey (mainly of OVII and OVIII)

→ goal of DIOS (Yoshikawa et al. 2003, 2004)

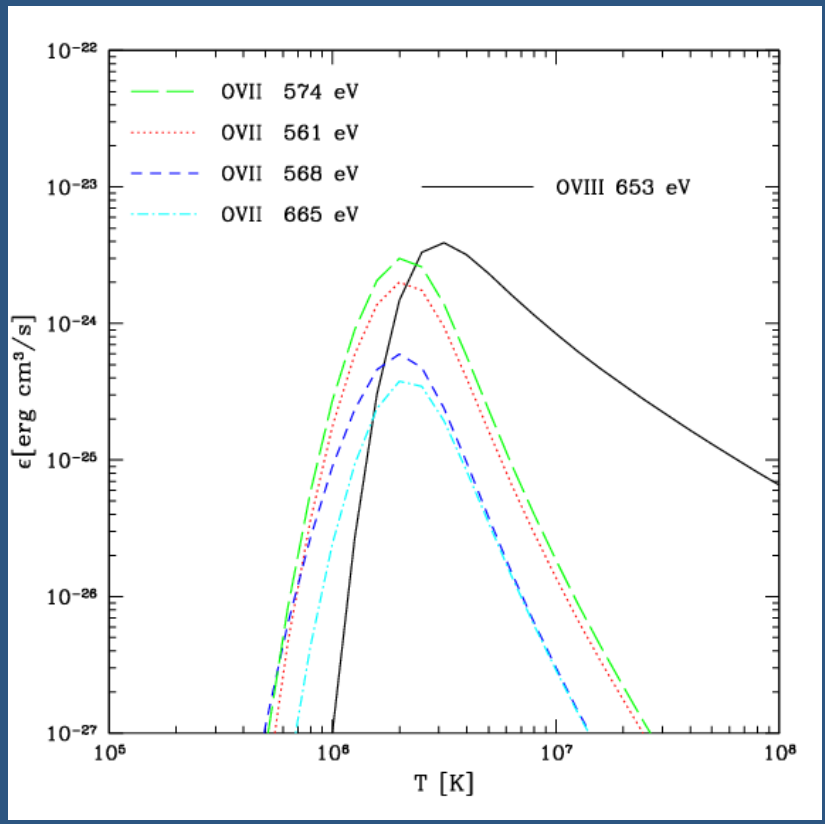
- absorption line systems along a GRB afterglow in soft X-ray

→ feasible with XEUS (X-ray Evolving Universe Spectroscopy) (Fiore et al. 2000, Kawahara et al. 2005)

Emission lines of oxygen in WHIM

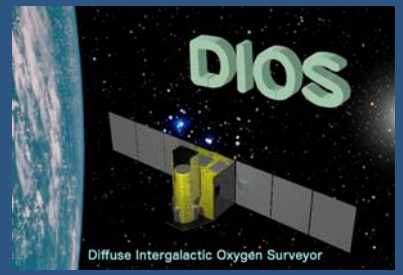
OVII (561eV, 568eV, 574eV, 665eV) , OVIII (653eV)

- **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***

Requirements for detection



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

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

DIOS: Diffuse Intergalactic Oxygen Surveyor

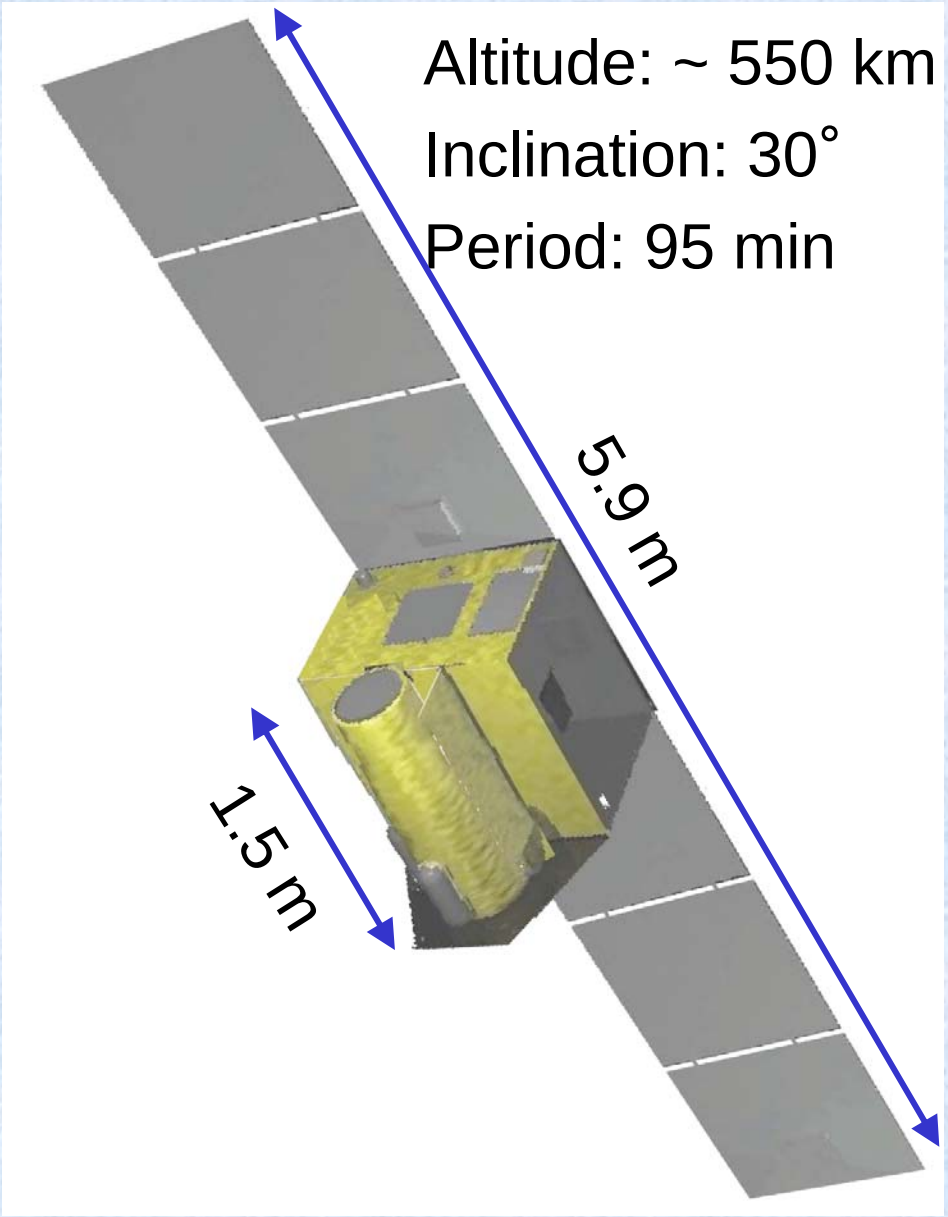
A Japanese proposal of a dedicated X-ray mission to search for dark baryons

- **PI: Takaya Ohashi** (Tokyo Metropolitan Univ.)
  - + Univ. of Tokyo, JAXA/ISAS, Nagoya Univ., Tokyo Metro. Univ.
- A dedicated small satellite with cost < 40M USD
- Proposed launch in **2010** **(not yet approved; looking for international collaboration)**
- Unprecedented energy spectral resolution: **ΔE=2eV in soft X-ray band (0.3-1.5keV)**
- Aim at unambiguous detection of WHIM via **Oxygen emission lines**
- Estimate the dark baryon (WHIM) density contribution to the total cosmic baryon budget

DIOS Spacecraft

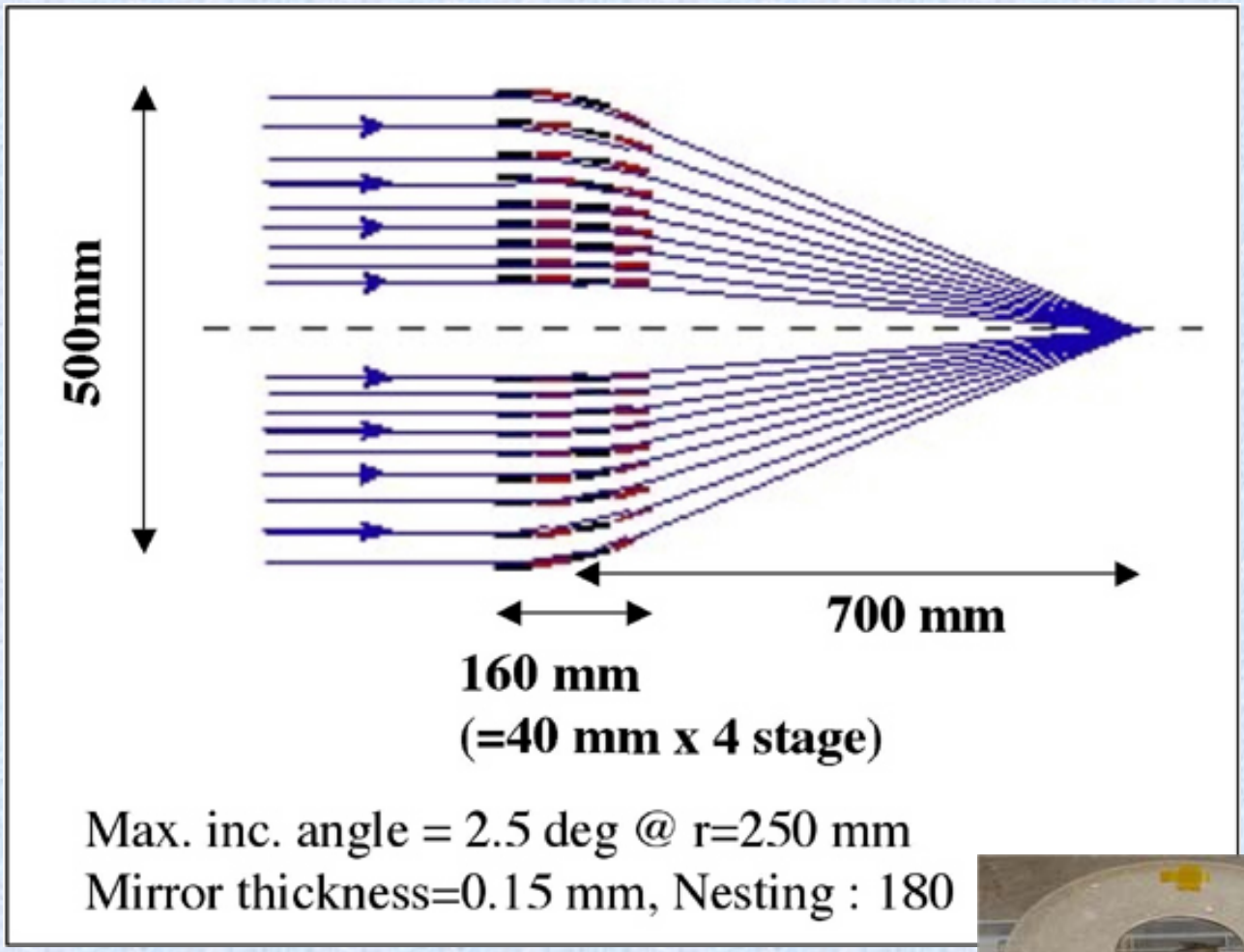
- Launch Target ~2010
  (before NeXT mission ~2012)
- Launch Vehicle
  M5 light/H2-A piggy bag (TBD)

Weight	Total	~ 400 kg
	Payload	~ 200 kg
Size	Launch	1.2 × 1.45 × 1.4 m
	In orbit	5.9 × 1.45 × 1.4 m
Attitude	Control	3-axis
	Accuracy	≦10 arcsec
Power	Total	600 W
	Payload	340 W



Incl. 20% contingency

X-ray Optics: 4 stage thin foil mirror



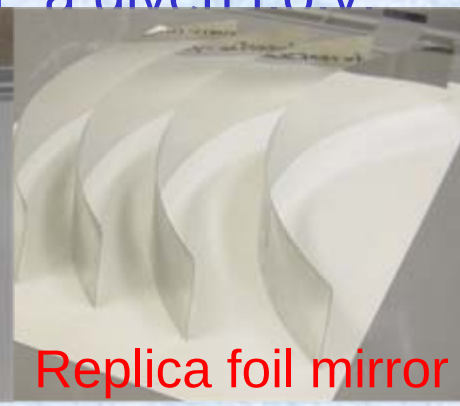
Suzaku

Focal length 1/2 of 2-stage mirror

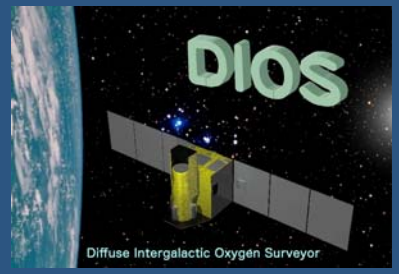
- Compact system
- Small detector for a given f.o.v.

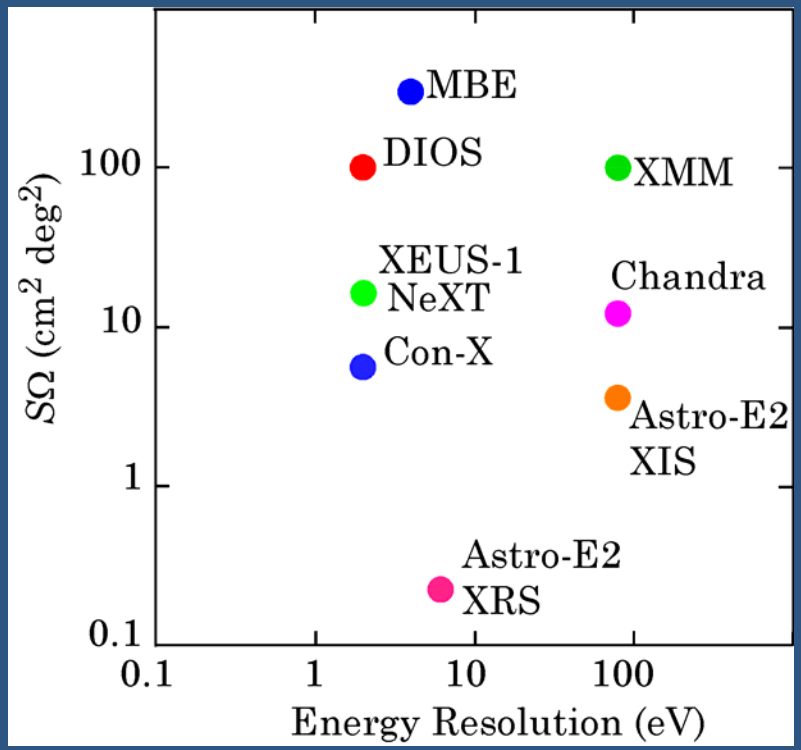
- Fabrication of test model started at Nagoya Univ.

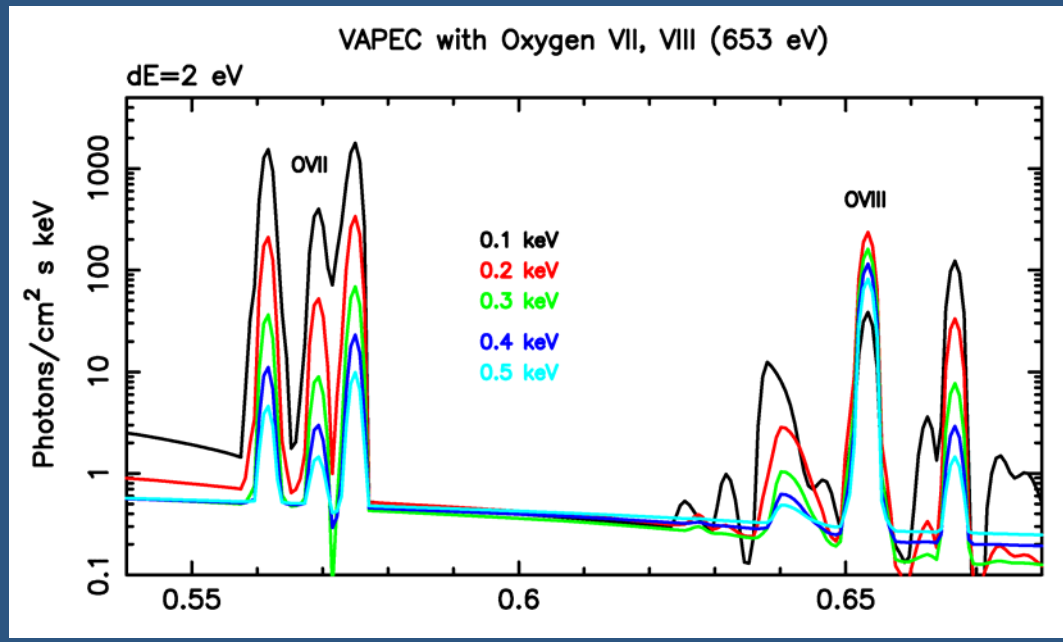

Mandrel


Replica foil mirror

DIOS: comparison with other missions

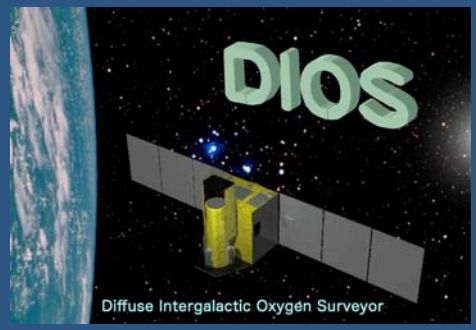




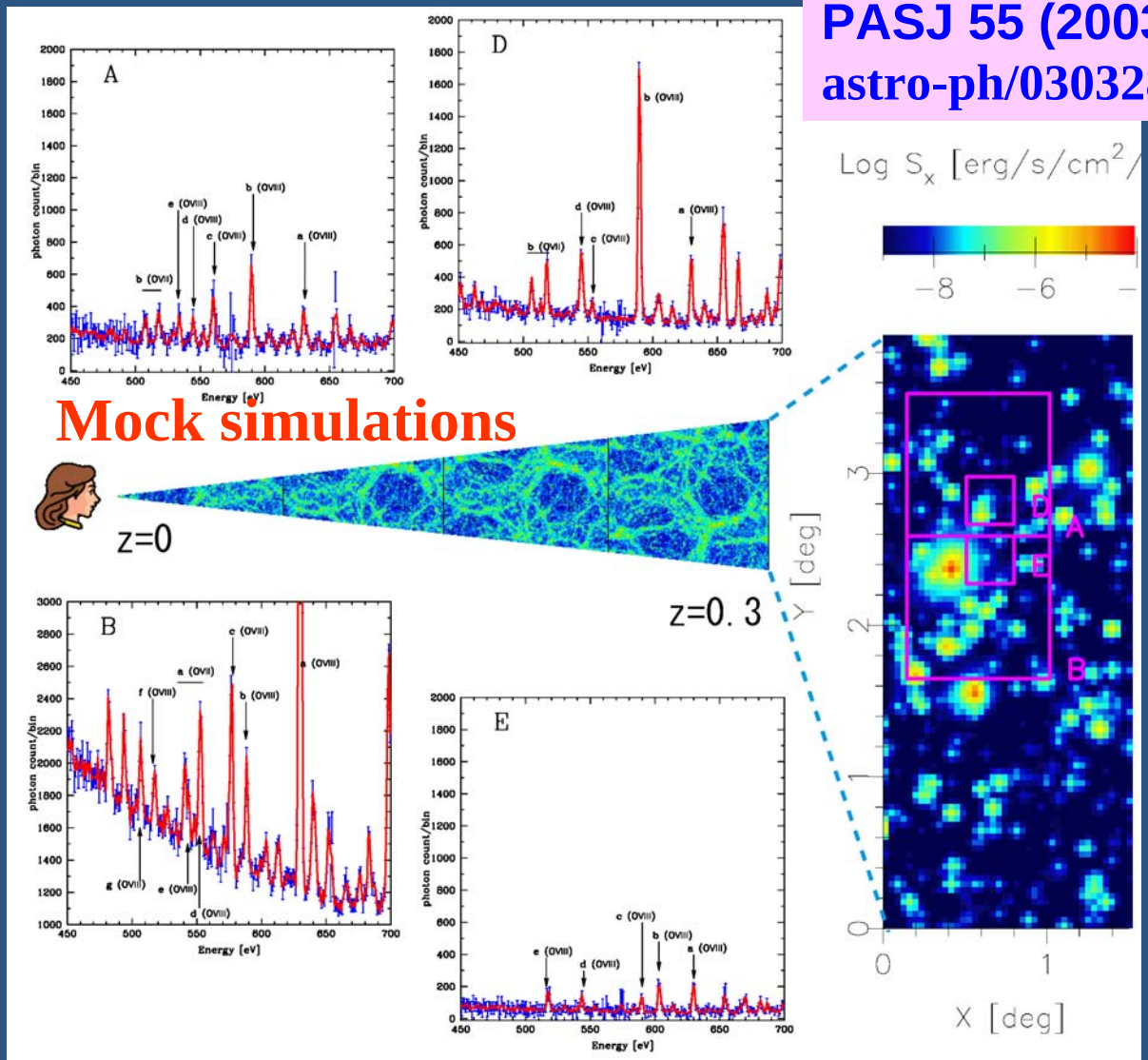


- Very high sensitivity ($S\Omega$ and ΔE) in detecting oxygen emission lines
- Intensity ratios of the lines reveal the temperature and ionization condition of WHIM

Searching for dark baryons with DIOS
(Diffuse Intergalactic Oxygen Surveyor)

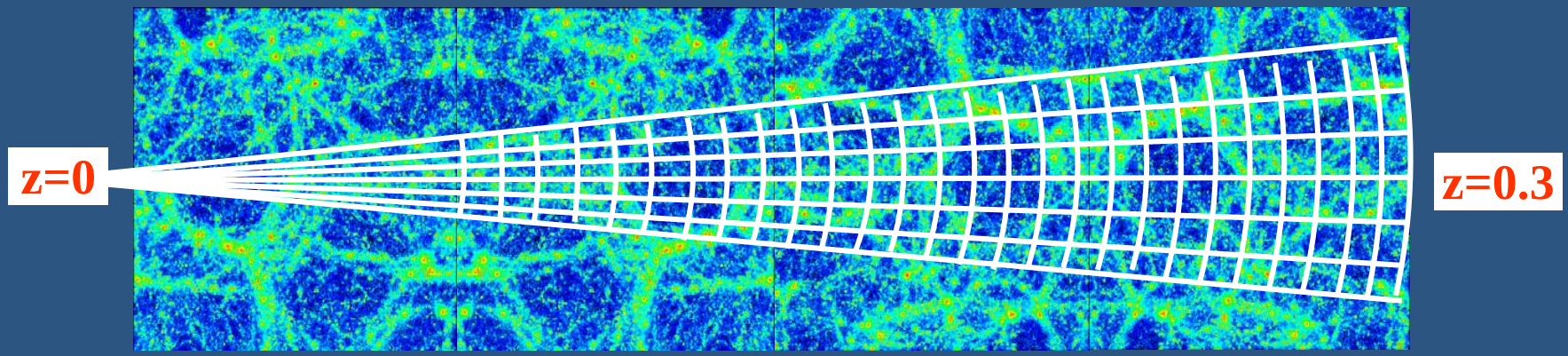


PASJ 55 (2003) 879
astro-ph/0303281



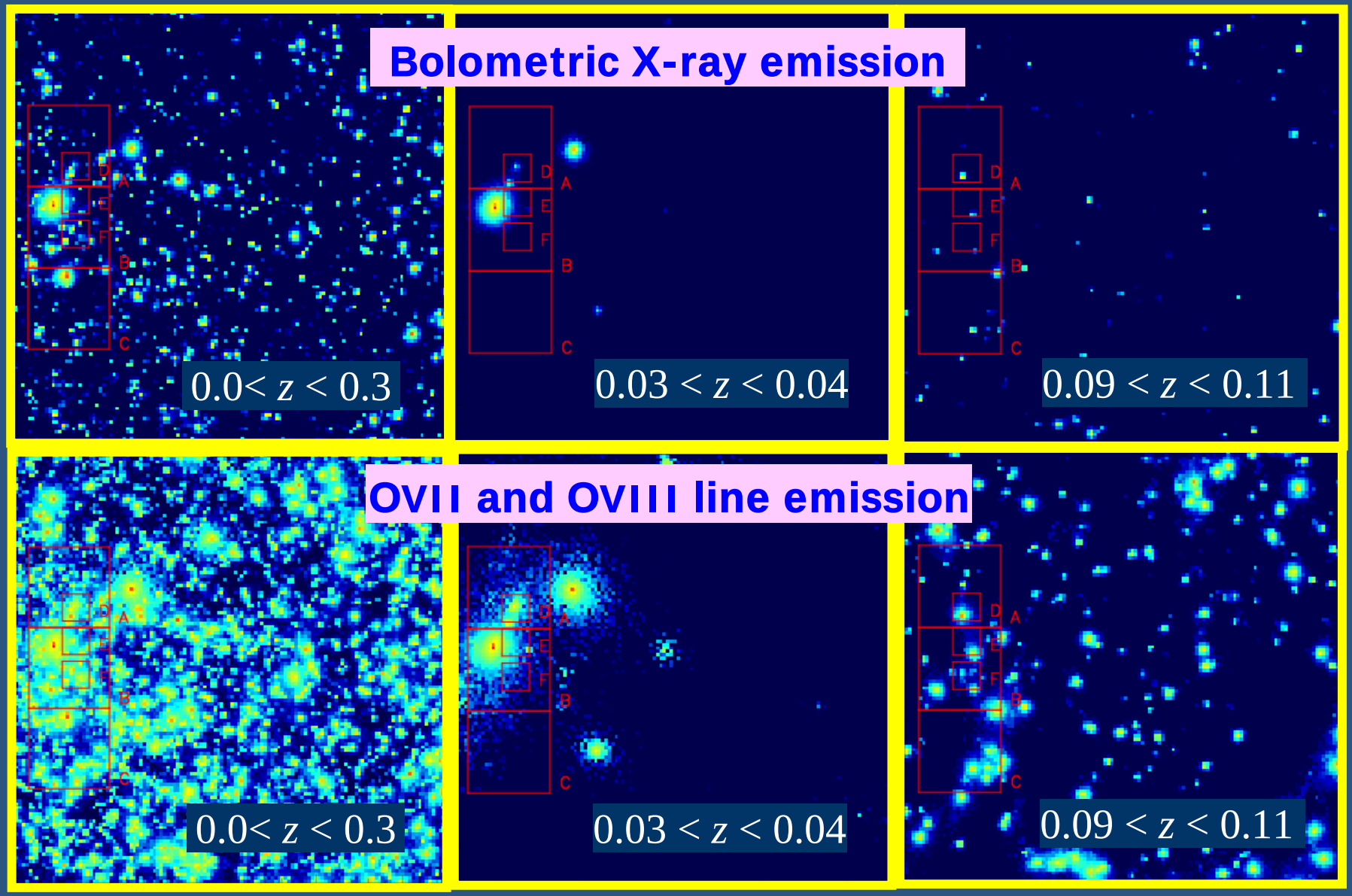
Univ of Tokyo:
K. Yoshikawa
Y.Suto
JAXA/ISAS:
N. Yamasaki
K. Mitsuda
Tokyo Metropolitan Univ.:
T. Ohashi
Nagoya Univ.:
Y. Tawara
A. Furuzawa

Light-cone output from simulation



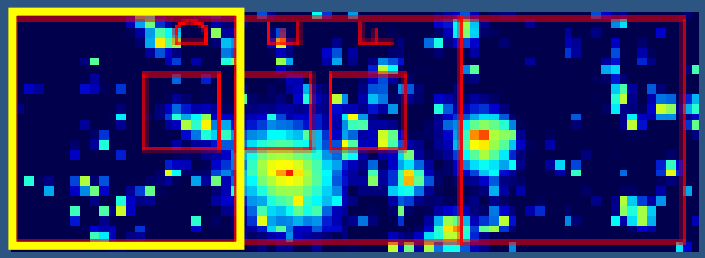
- **Cosmological SPH simulation** in Ω_m=0.3, Ω_Λ=0.7, σ_8=1.0, and h=0.7 CDM with N=128^3 each for DM and gas (Yoshikawa, Taruya, Jing, & Suto 2001)
- **Light-cone output from z=0.3 to z=0** by stacking 11 simulation cubes of $(75h^{-1}\mathrm{Mpc})^3$ at different z
- **5° ×5° FOV mock data** in 64x64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

Surface brightness on the sky



Simulated spectra: region A

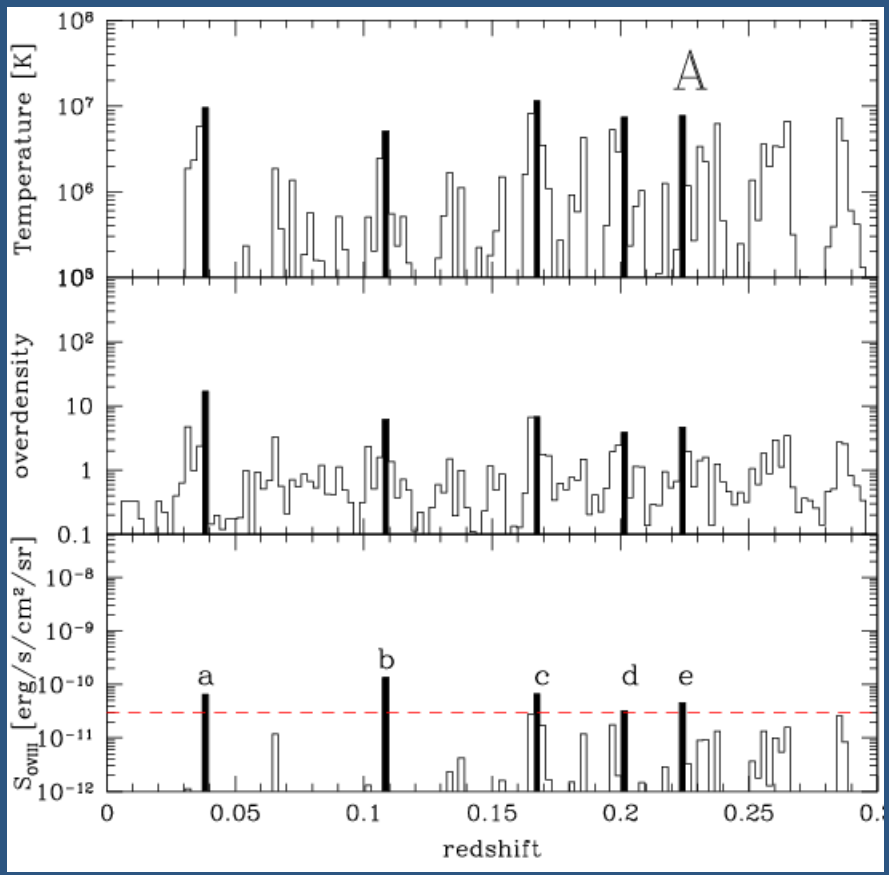
Shallow survey observation with the DIOS field-of-view (16^2pixels)

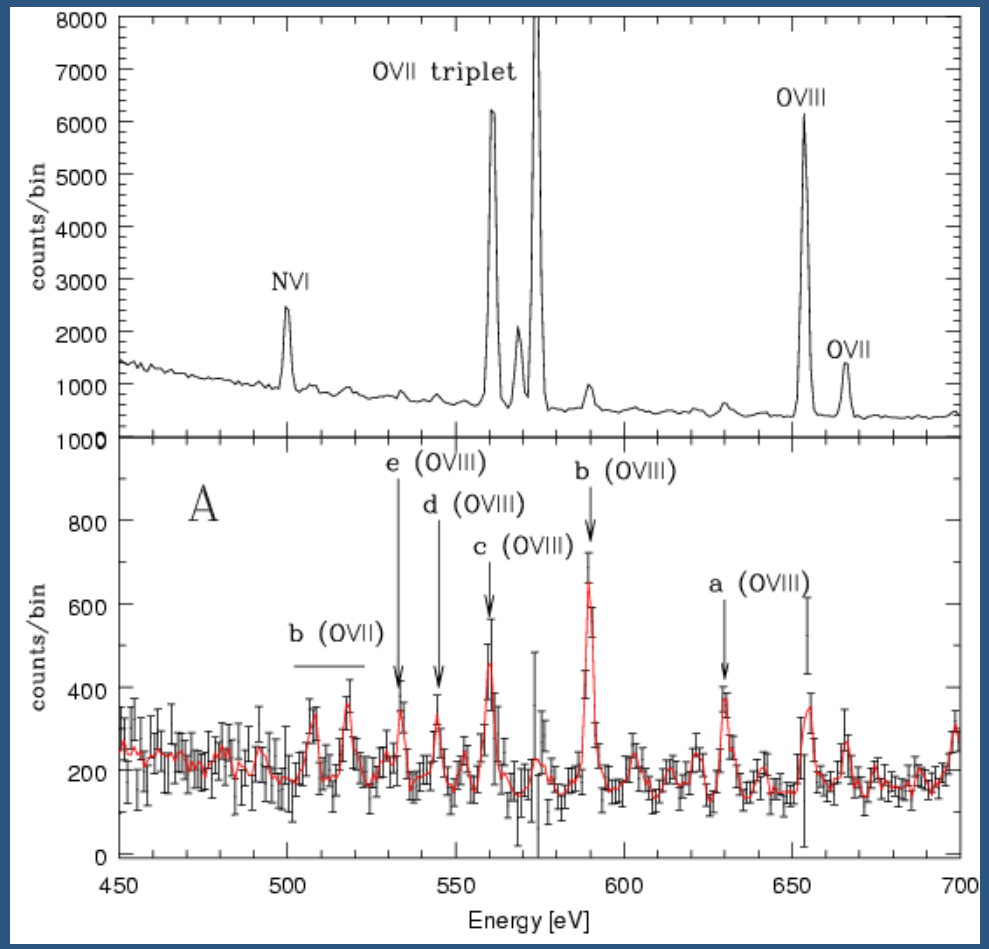


A

$0.94^\circ \times 0.94^\circ = 0.88\ \mathrm{deg}^2$

$T_{exposure} = 3\times10^5\mathrm{sec}$





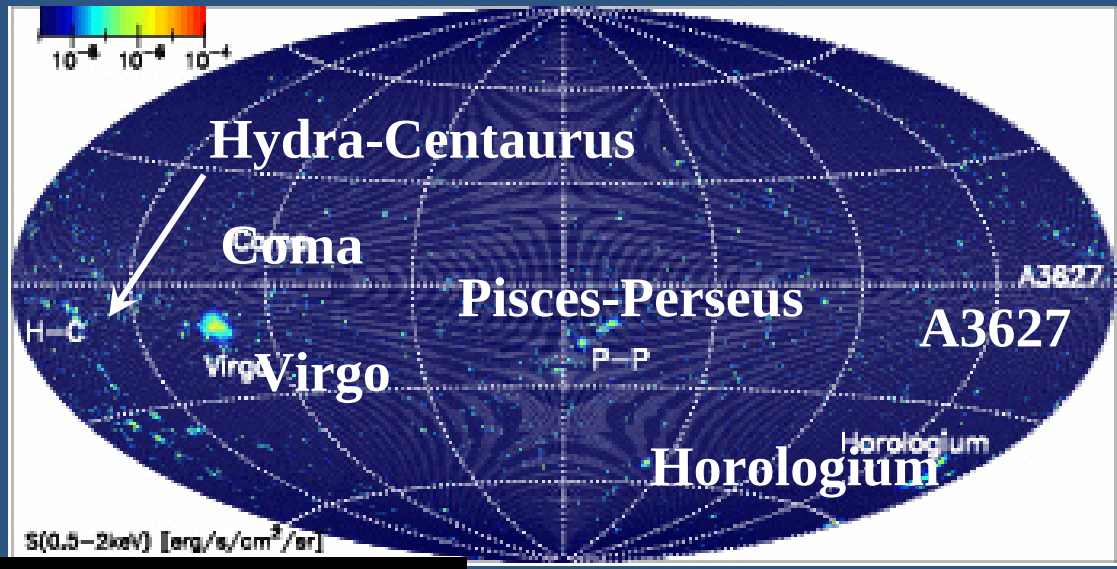
Locating the WHIM in the local universe

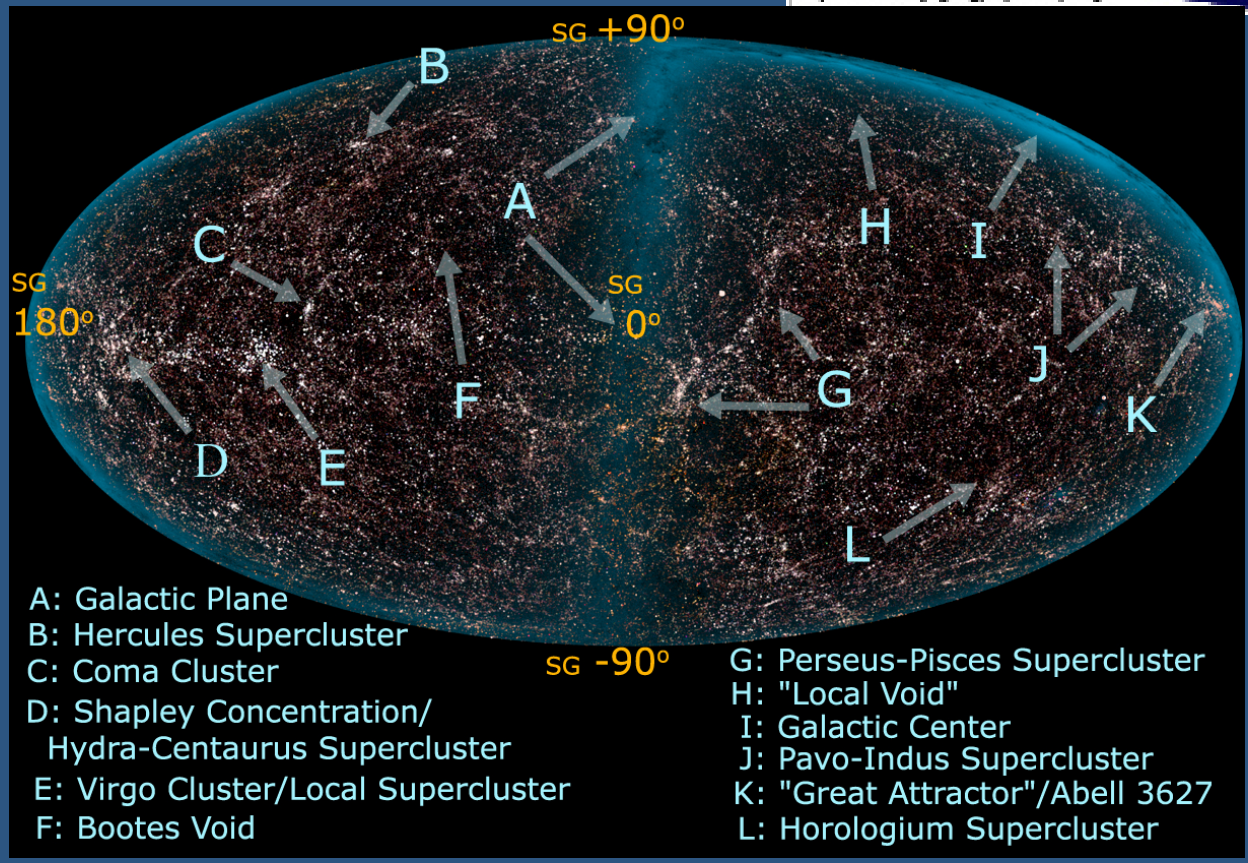
Yoshikawa, Dolag, Suto, Sasaki, Yamasaki, Ohashi, Mitsuda, Tawara, Fujimoto, Furusho, Furuzawa, Ishida, Ishisaki & Takei

PASJ 56(2004)939, astro-ph/0408140

- **Simulation by Dolag et al. (astro-ph/0310902)**
  - Initial condition: smoothing the observed density field of IRAS 1.2 Jy galaxy survey (over $5h^{-1}$Mpc), linearly evolving back to z=50
  - adiabatic run of dark matter and baryons (without cooling or feedback) in a canonical ΛCDM model
- **see also**
  - **Viel et al. MNRAS 360(2005)1110**
  - **Zichichi et al. (2005)**

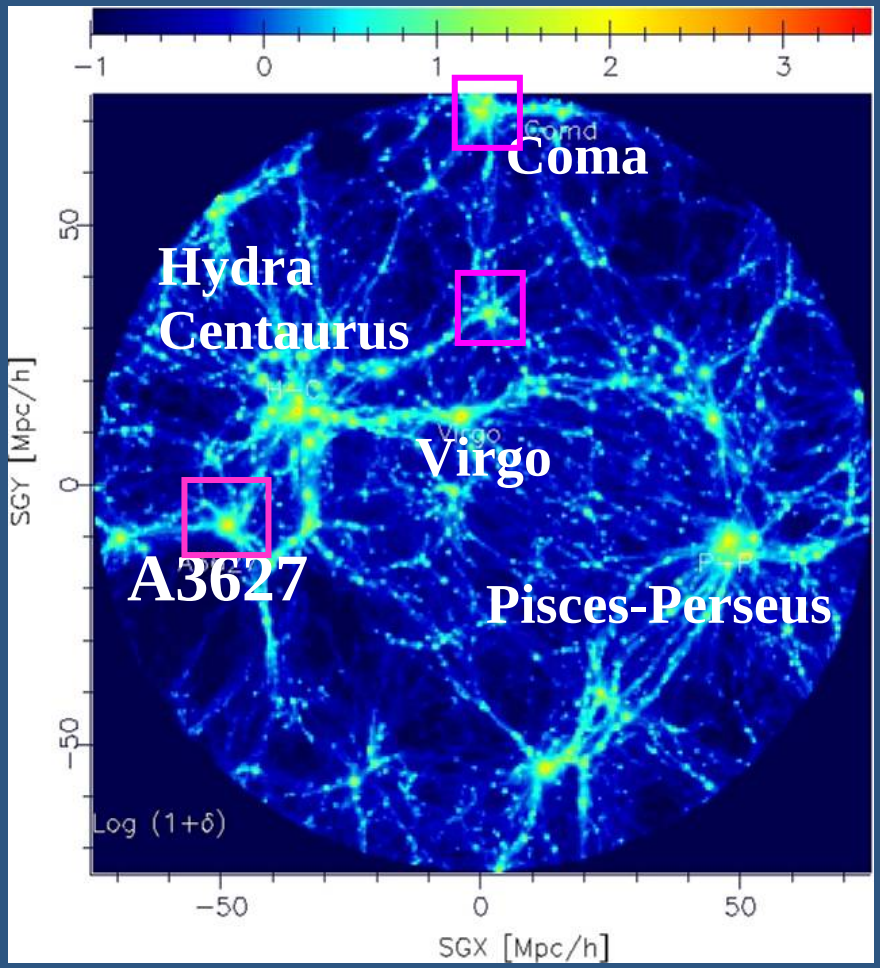
Simulated local universe vs. 2MASS map





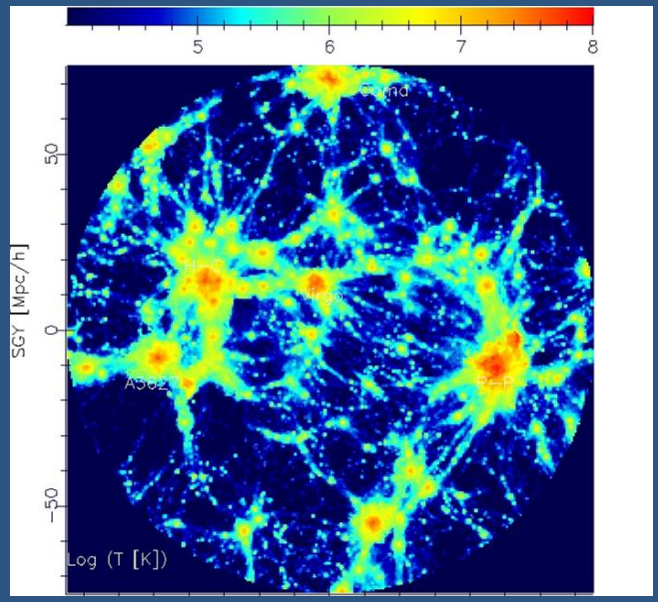
Soft X-ray map of the simulated local universe (Yoshikawa et al. 2004)

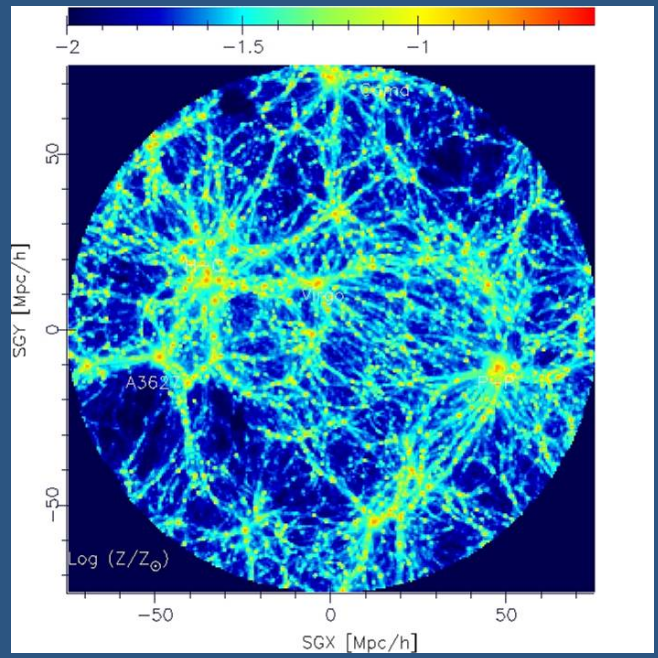
Simulated gas distribution on the supergalactic plane



gas density

gas temperature

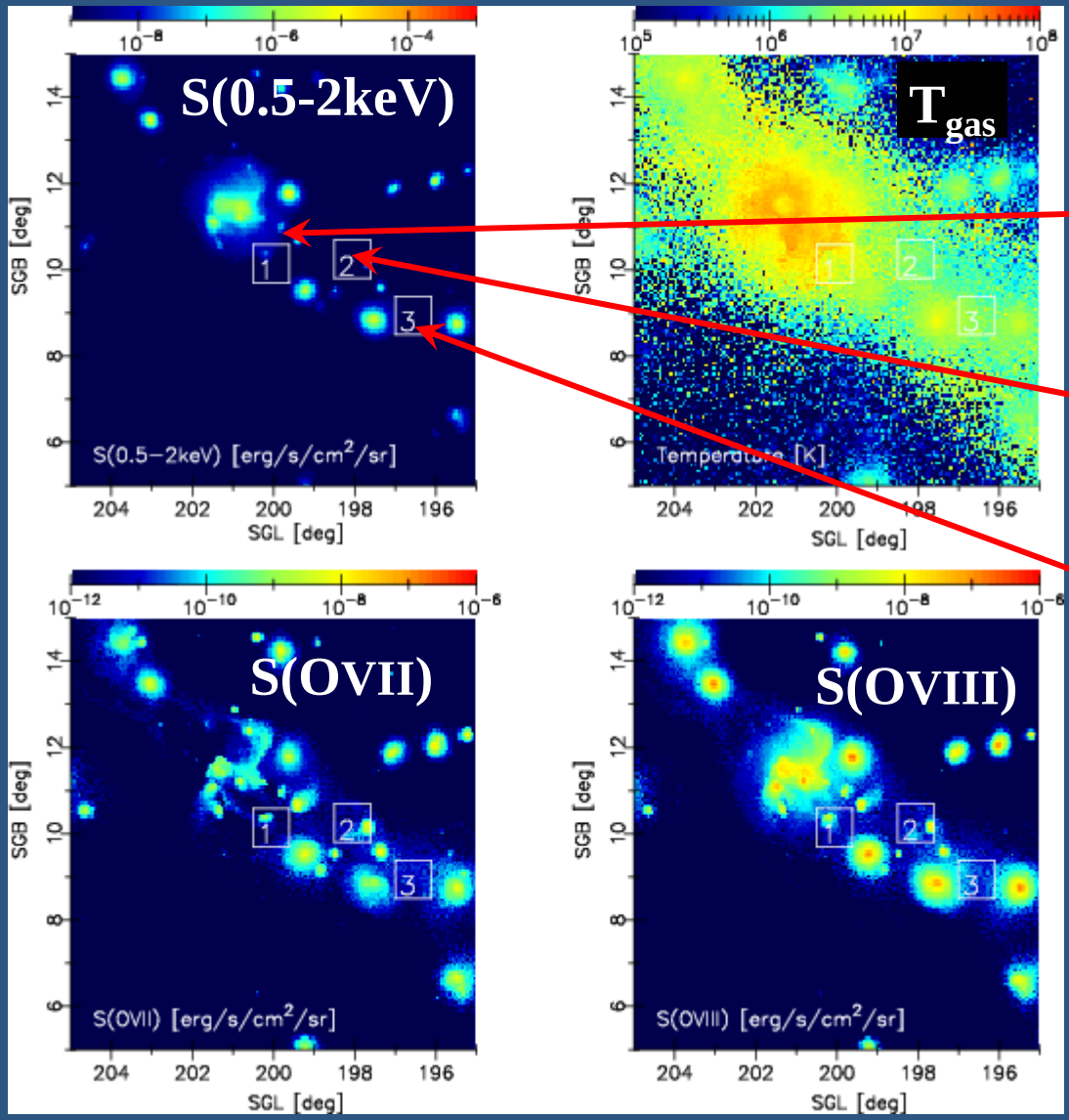


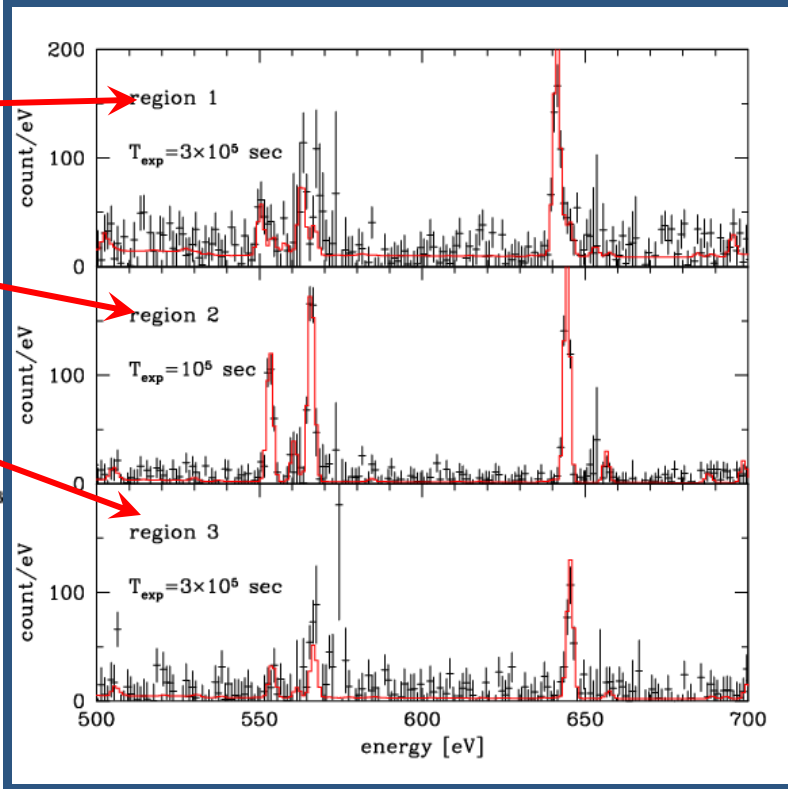


(adopted) metallicity

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

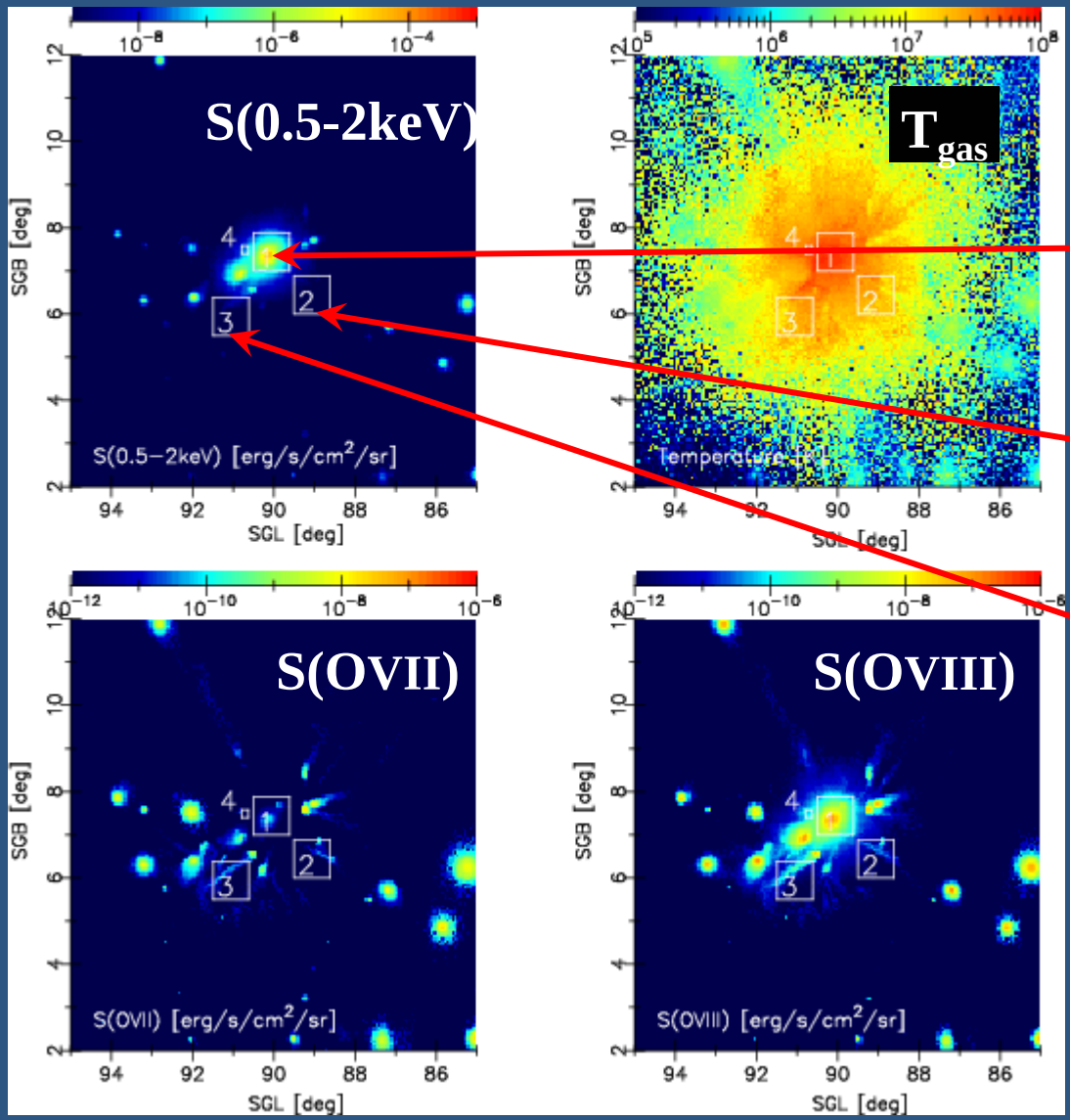
Mock observation of X-ray filament extending around simulated A3627





1° ×1° FOV

Mock observation of simulated Coma

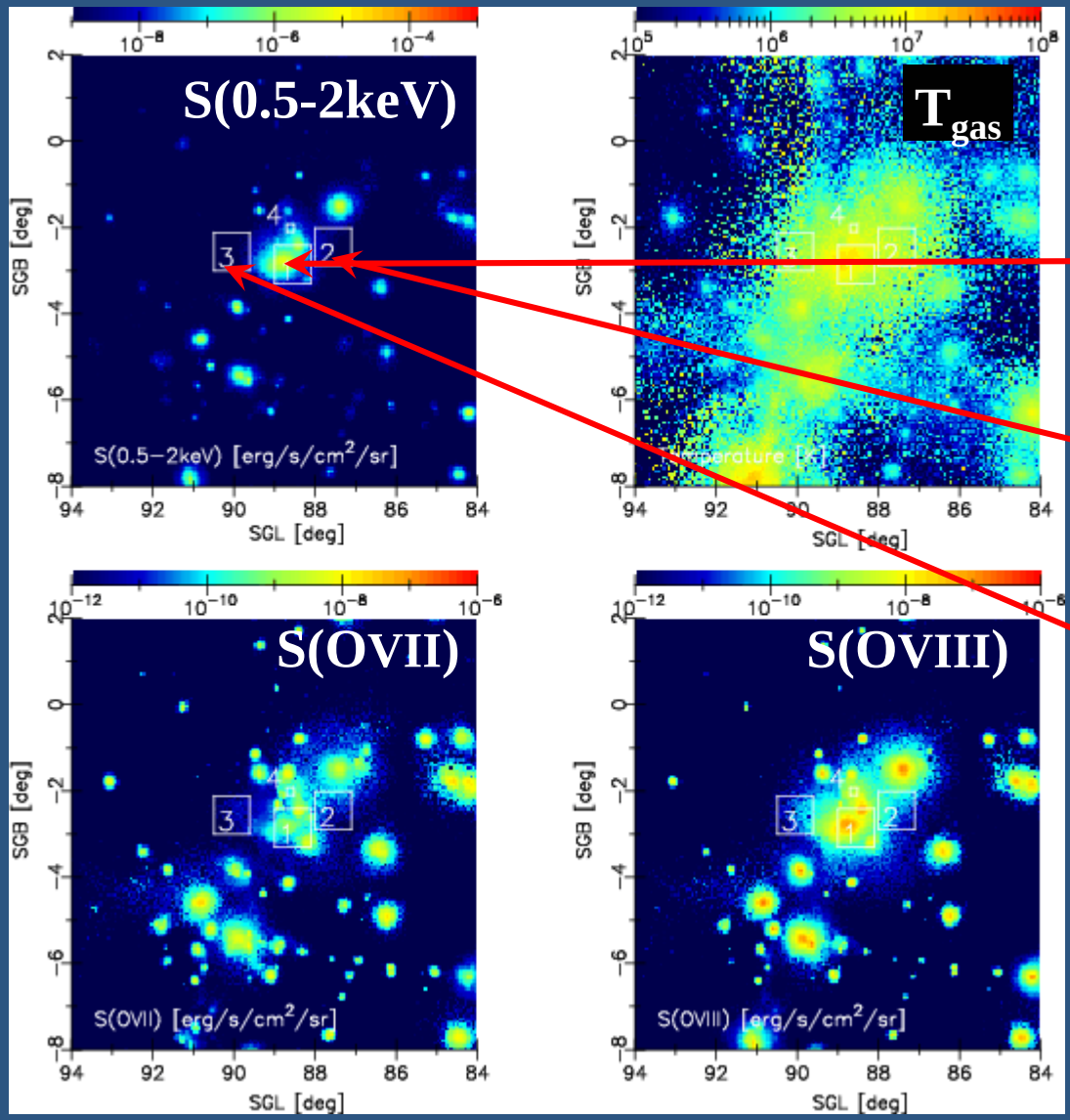


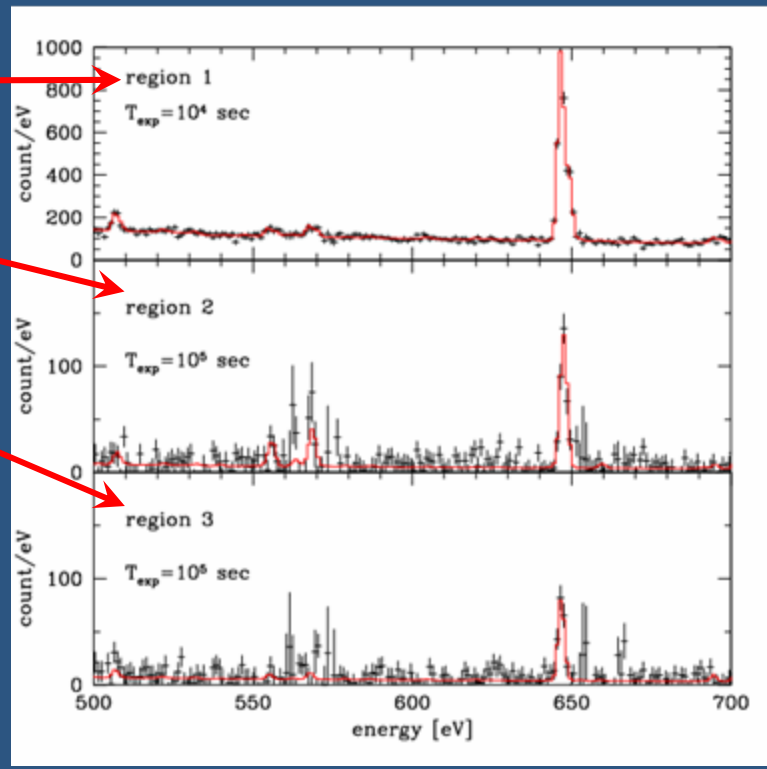
1° ×1° FOV

Surface brightness map [erg $s^{-1}cm^{-2}sr^{-1}$]

a small clump in front of simulated Coma

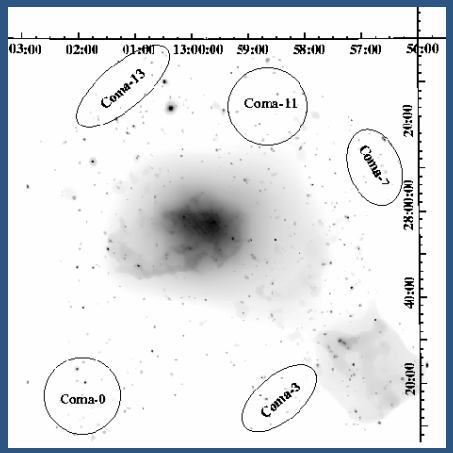
～10° (～5h^{-1}Mpc) away from the line of sight toward Coma





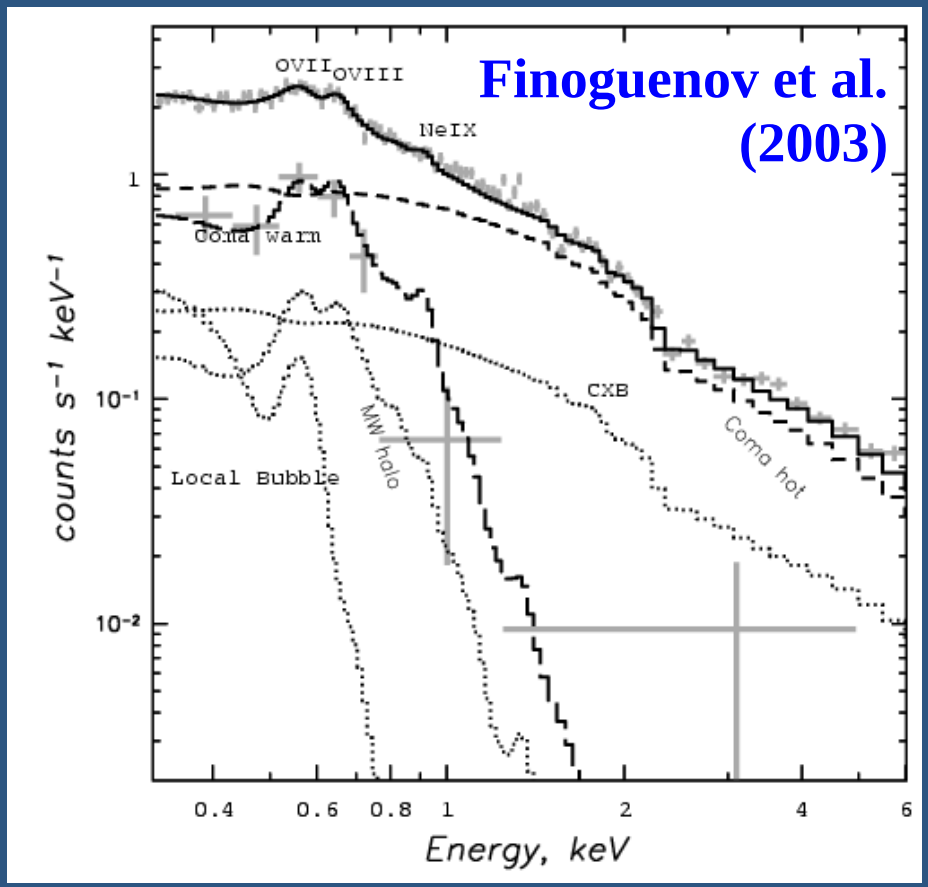
1° ×1° FOV

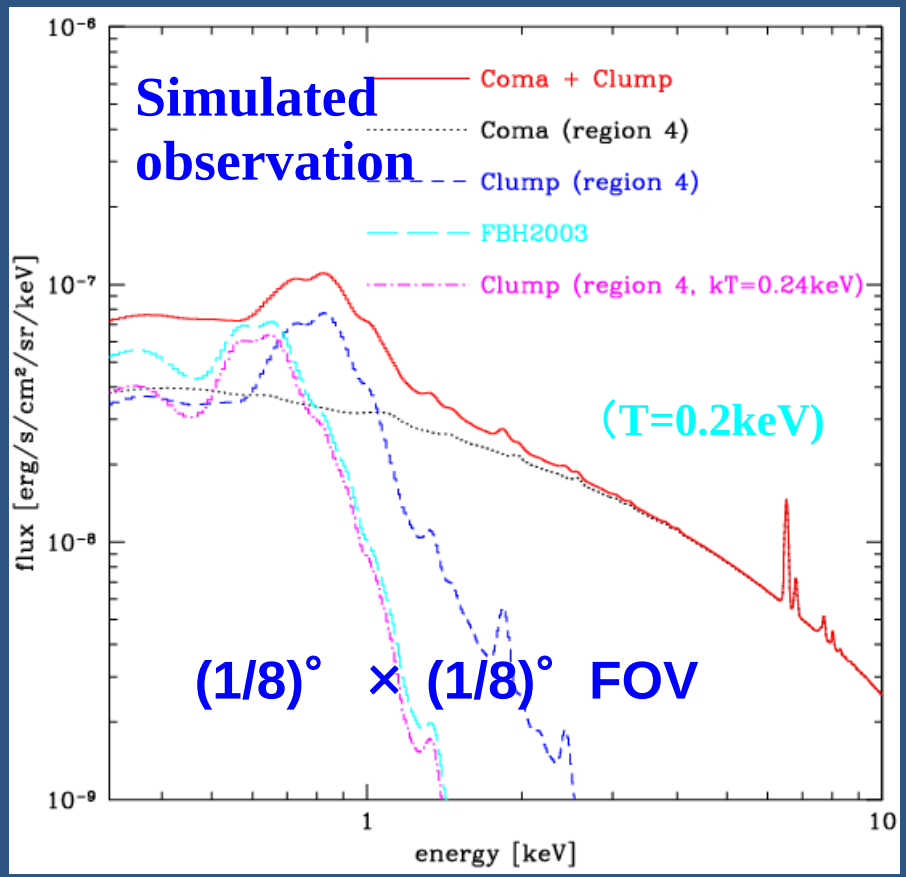
Surface brightness map [erg s^{-1}cm^{-2}sr^{-1}]



Soft X-ray excess of Coma

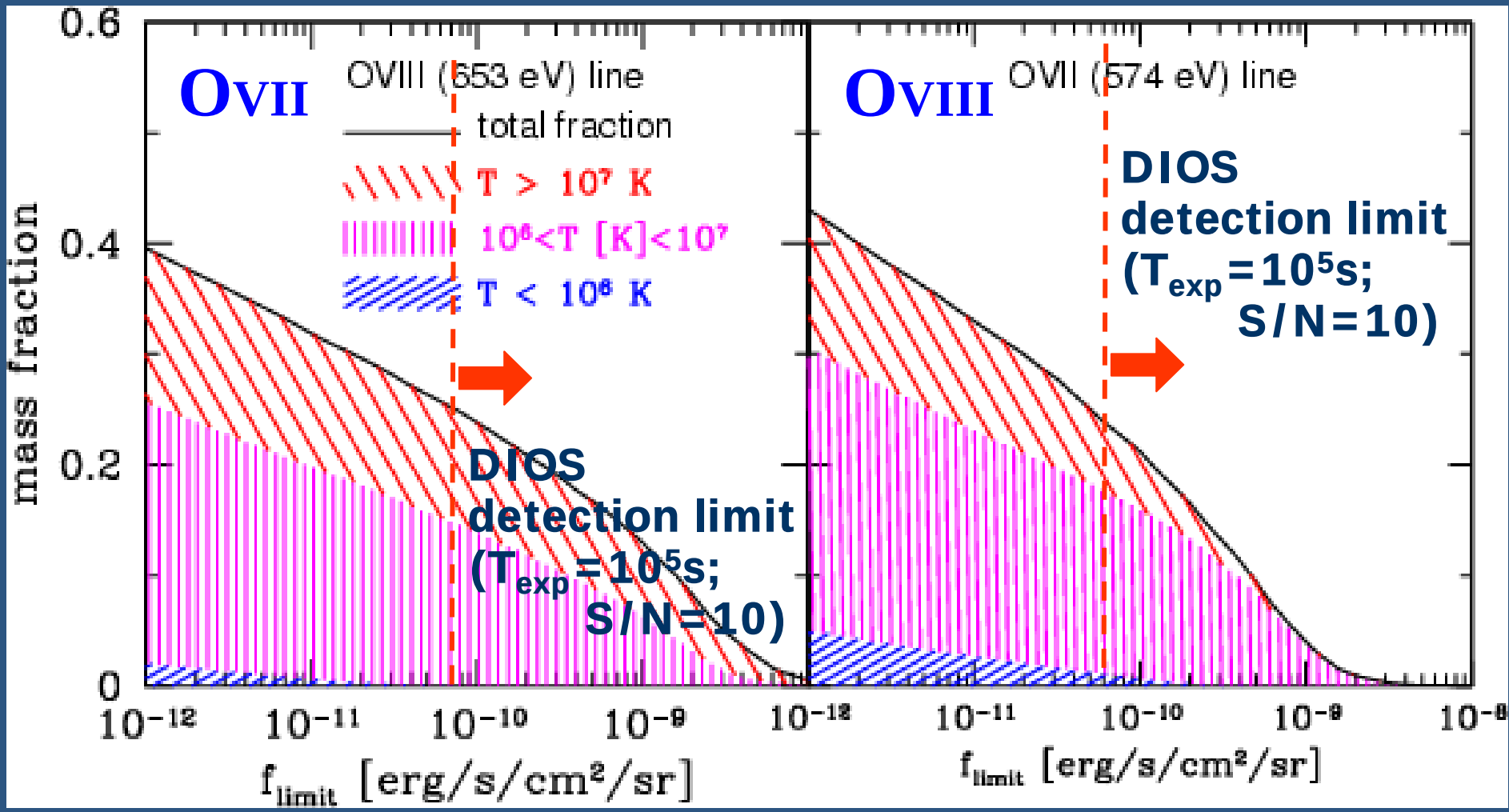
- XMM-Newton observations of the outskirts of Coma (Finoguenov, Briel & Henry 2003, A&A 410, 777)
- associated X-ray filament of 0.2keV warm gas ?
- an intervening WHIM clump along the line of sight ?





Yoshikawa et al. (2004)

Fraction of cosmic dark baryons detectable via oxygen "emission"



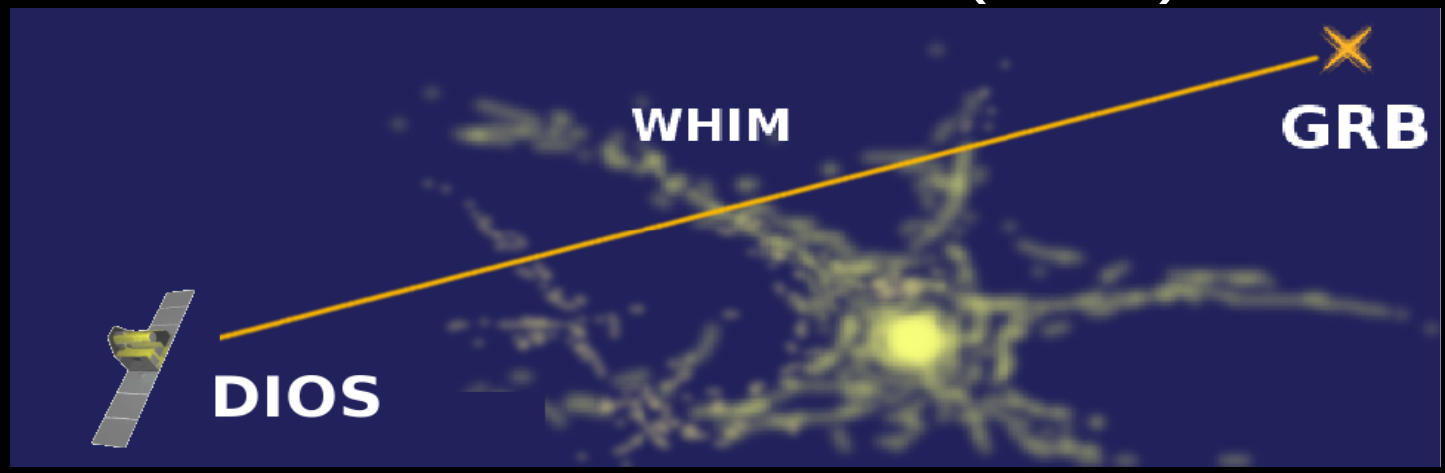
Yoshikawa et al. (2004)

Searching for dark baryons via absorption line systems in a Gamma-ray burst afterglow

H.Kawahara, K.Yoshikawa, S.Sasaki, Y.Suto, N.Kawai, T.Ohashi, N.Yamasaki & K.Mitsuda

astro-ph/0504594 (submitted to Pub.Astron.Soc.Japan 2005)

- first proposed by Fiore et al. (2000)
- can probe higher z
- can search for emission line counterparts later
- see also Viel et al. MNRAS 341(2003)792



Model for GRB afterglow

- Average spectrum fitted by Piro (2004)

$$F_{\mathrm{GRB}}(t,E) = F_0 \left(\frac{t}{40\mathrm{k\,sec}}\right)^{-1.2} \left(\frac{E}{1\mathrm{keV}}\right)^{-1.13} \mathrm{erg\,s^{-1}cm^{-2}keV^{-1}}$$

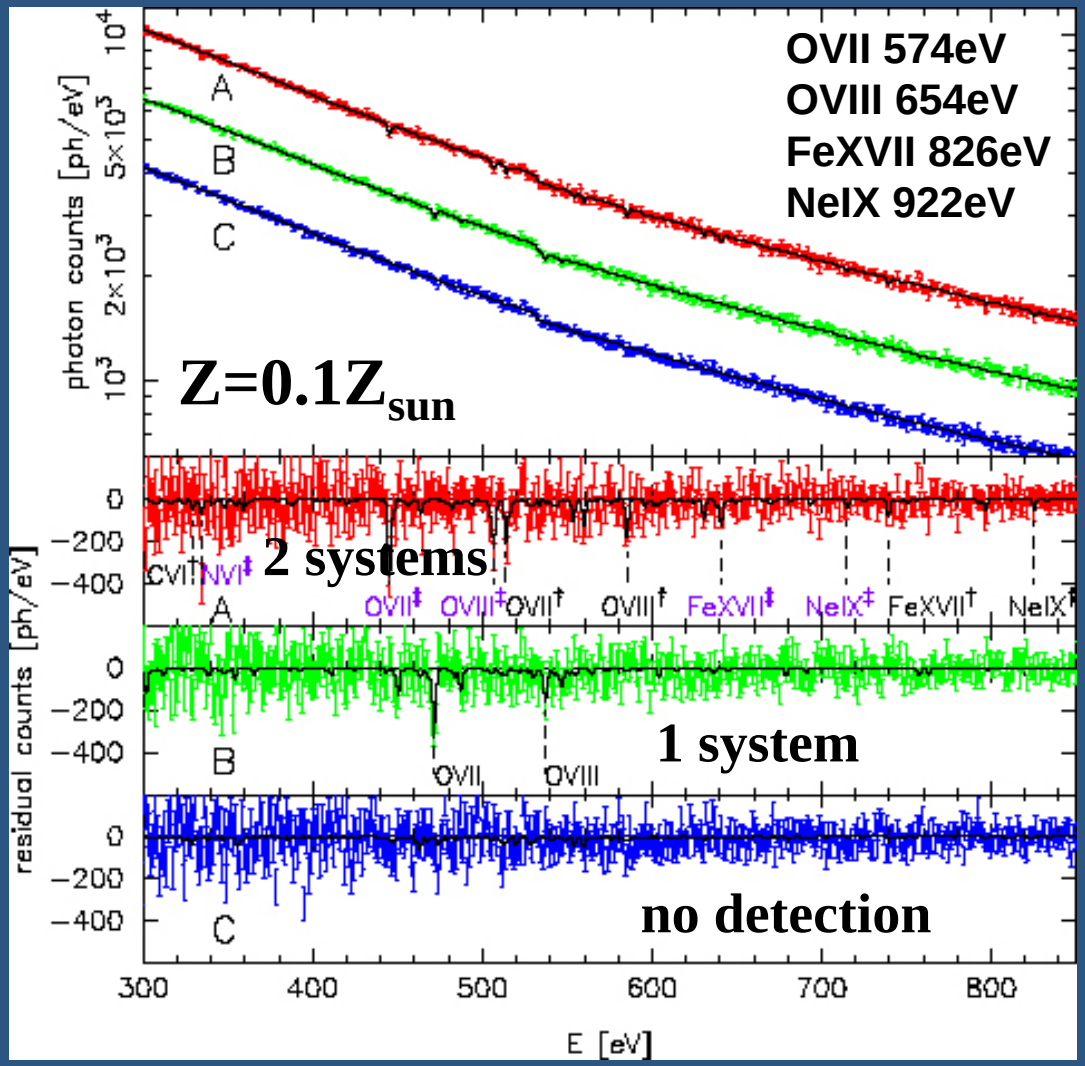
- Frequency of GRB afterglow with

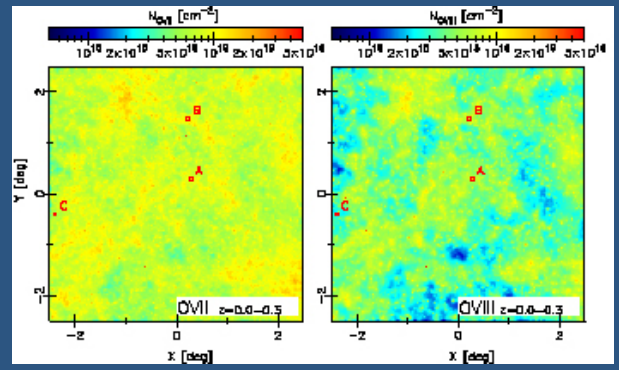
$F > F_0 = 6 \times 10^{-11}$ erg/s/cm^2/keV

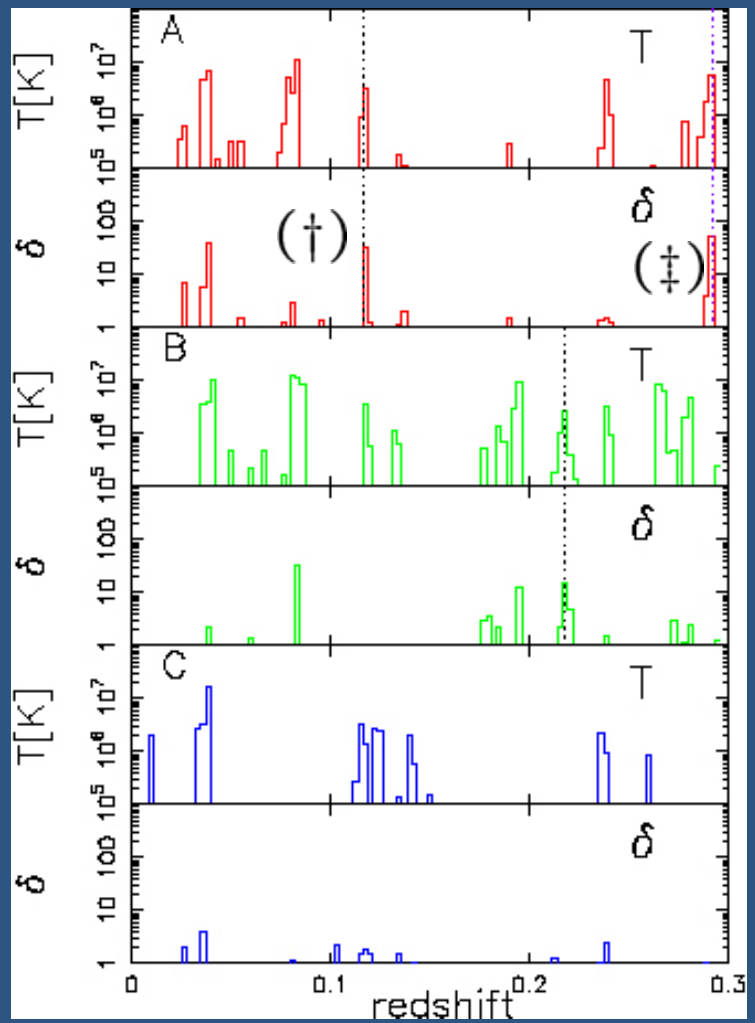
→ ～40/year/sky (from 6 years' BeppoSAX data)

- observing strategy: start of the observation and exposure time for 5000 photons/eV@500eV with XEUS (unfortunately impossible with DIOS...)
  - t_i = 1 hour and t_{exp} = 5 ksec (for F_0)
  - t_i = 2 hour and t_{exp} = 12 ksec (for F_0)
  - t_i = 1 day and t_{exp} = 15 ksec (for $10F_0$)

Mock transmission spectra of a GRB afterglow



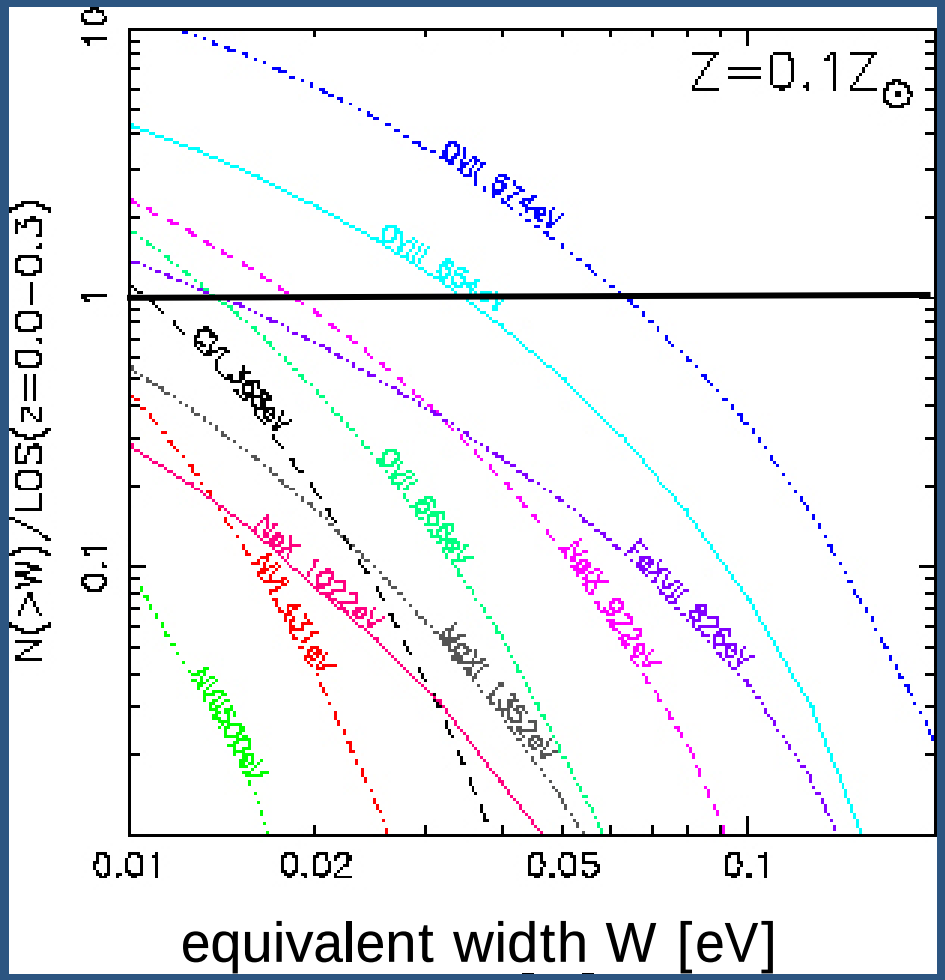


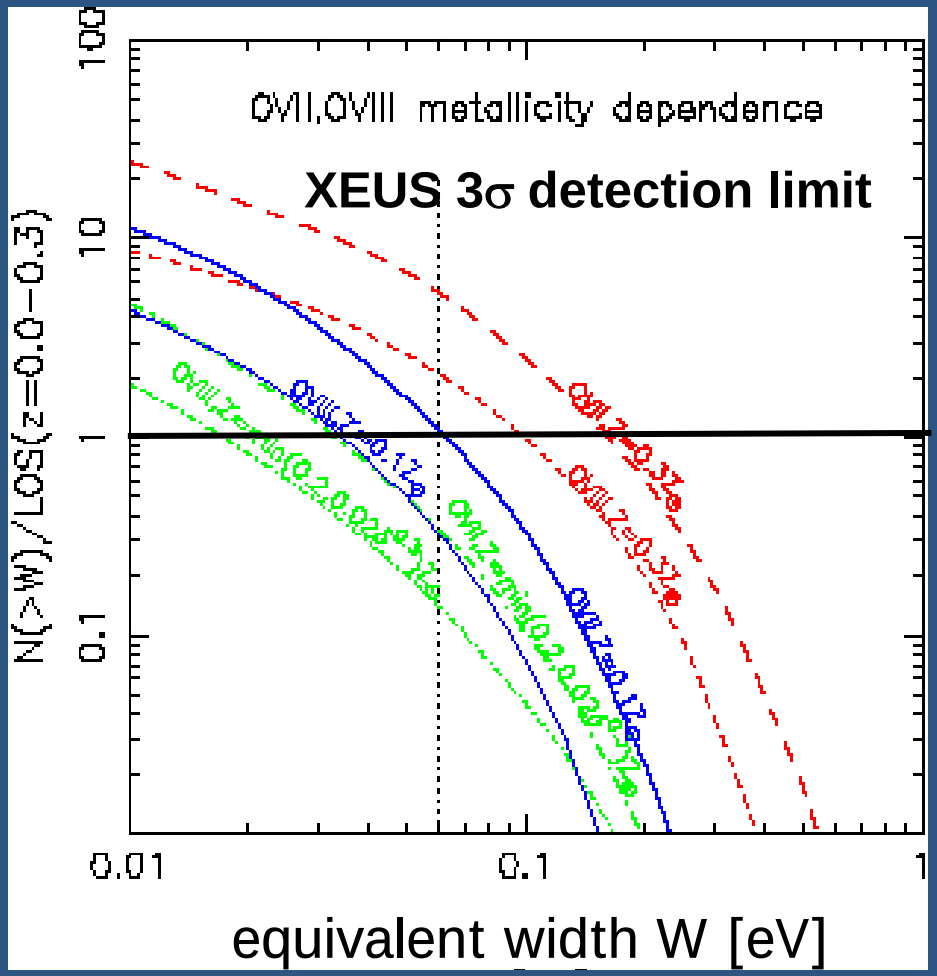


Kawahara et al. (2005)

Statistics of absorption line systems

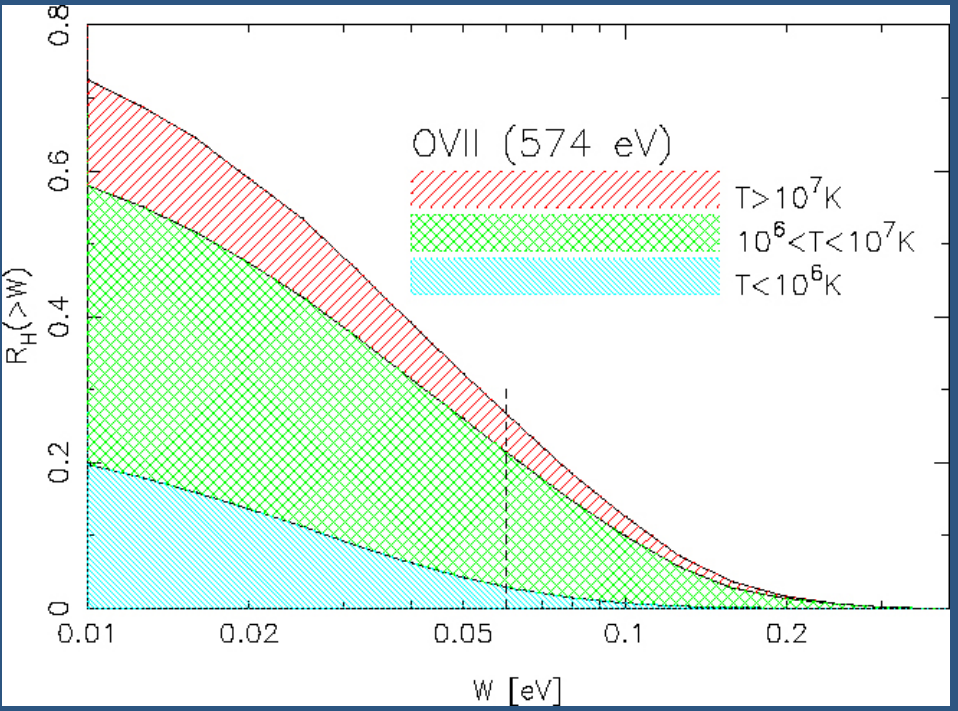
assuming collisional and photo-ionization equilibrium under CXB (Miyaji et al. 1998) and UVB (Shull et al. 1999)

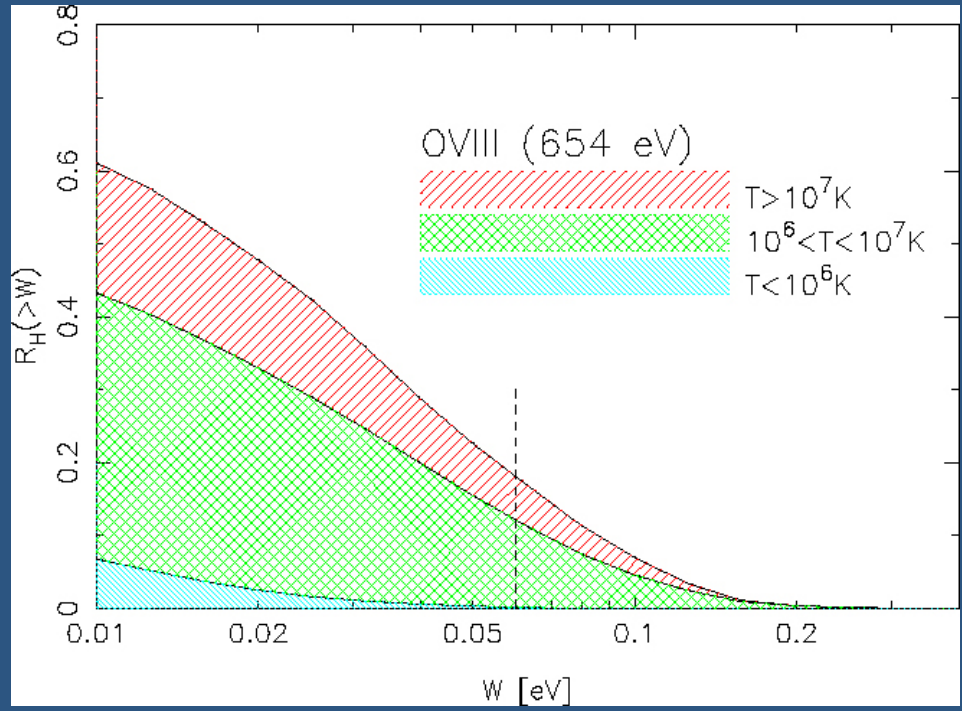




Kawahara et al. (2005)

baryon fraction detectable by absorption lines in the GRB afterglow





W: equivalent width

R_H(>W): cumulative gas mass fraction

$$R_H(>W) = \frac{\sum_{i=1}^{6400} N_{H,i}^{sim}(>W)}{\sum_{i=1}^{6400} N_{H,i}^{sim}(>0)}$$

Prospects for dark baryon search via WHIM spectroscopy

- **DIOS** will detect dark baryons in the form of WHIM from oxygen emission line survey (Yoshikawa et al. 2003)
  - ΔE=2eV, $S_{eff}\,\Omega$=100 [cm^2 deg^2], T_{exp}=10^{5}s, S/N=10
  - flux limit = 6x10^{-11} [erg/s/cm^2/sr]
- **DIOS** will detect WHIM at outskirts of known galaxy clusters in the local universe (Yoshikawa et al. 2004)
  - origin of soft X-ray excess reported for clusters (e.g., Coma)
- **XEUS** will identify ~1 OVII absorption line system along a bright GRB (40 per year) with >3σ (Kawahara et al. 2005)
  - interesting but statistics is inevitably limited
  - estimate of baryon density is subject to big uncertainties such as temperature and metallicity ... complementary to emission line study


Thanks !
This presentation file is located at
http://www-utap.phys.s.u-tokyo.ac.jp
/~suto/mypresentation_2005e.html