Detectability of warm intergalactic medium and the DIOS mission

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"Cosmic Baryon Budget" requires missing baryon

- ✓ The observed baryons are only 10-40% of the expected valued from big-bang nucleosynthesis.

  $\Omega_{star}+\Omega_{HI}+\Omega_{H2}+\Omega_{hot\ X\text{-}ray} = 0.0068^{+0.0041}_{-0.0030}$ vs $\Omega_{BBN}=0.04$

  (Fukugita, Hogan, & Peebles 1998)

- ✓ The other phase of cosmological baryons?

  Star: Condensed $T<10^5$K, $\delta>1000$

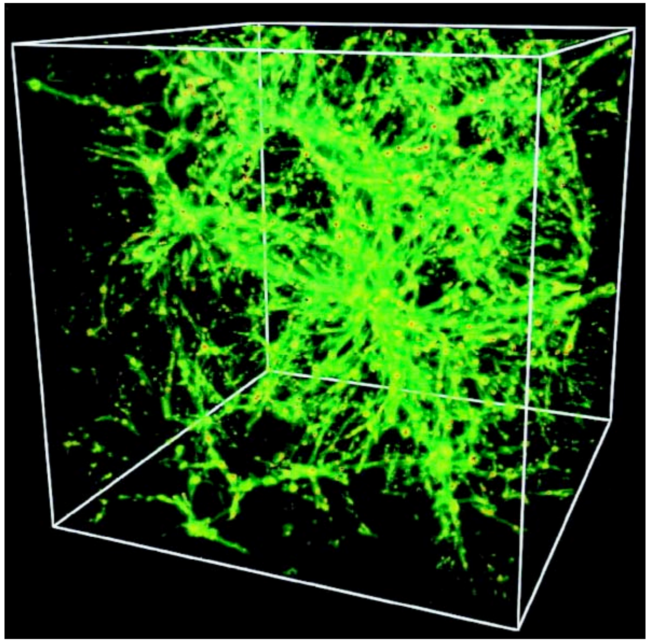
  Lyman alpha forest: Diffuse $T<10^5$K, $\delta<1000$

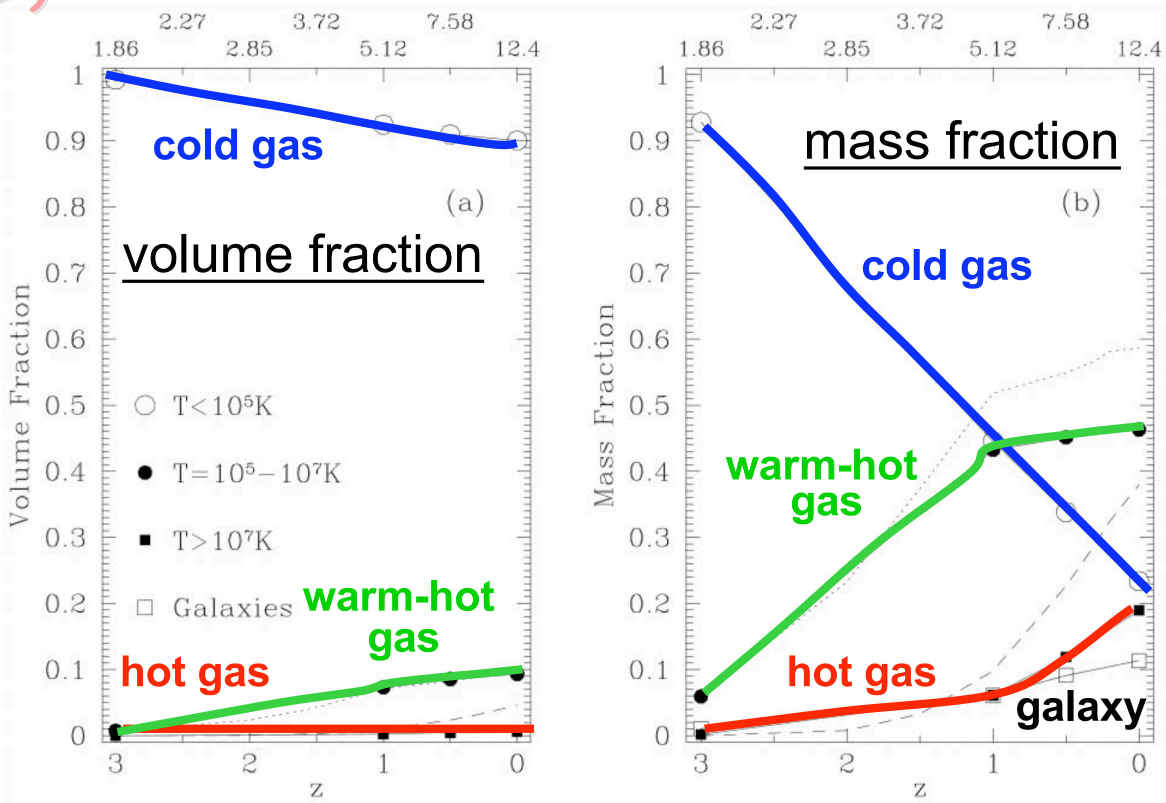
  X-ray:hot ICM $T>10^7$K

Is there other phase of baryon ?

Where are missing baryons in the Universe ?

~40% of total baryons at z=0 are IGM with 10^5K<T<10^7K
(Cen & Ostriker 1999)



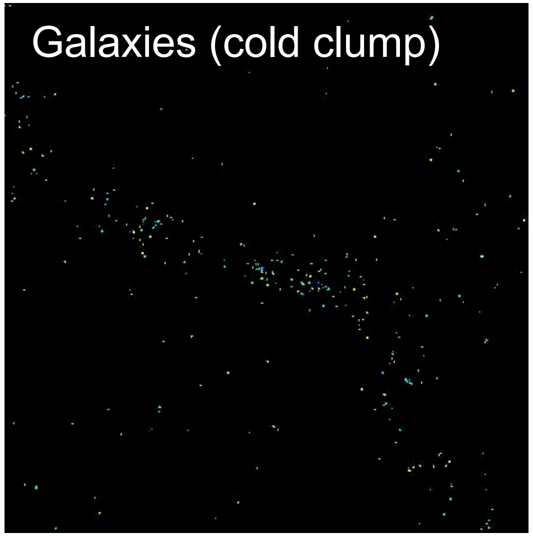


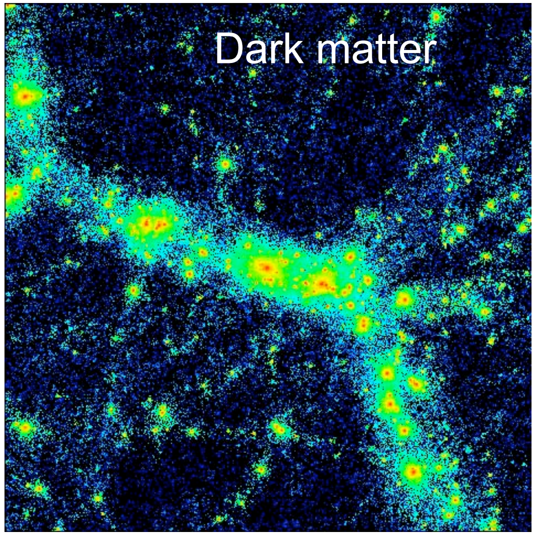
A close-up view of a filament

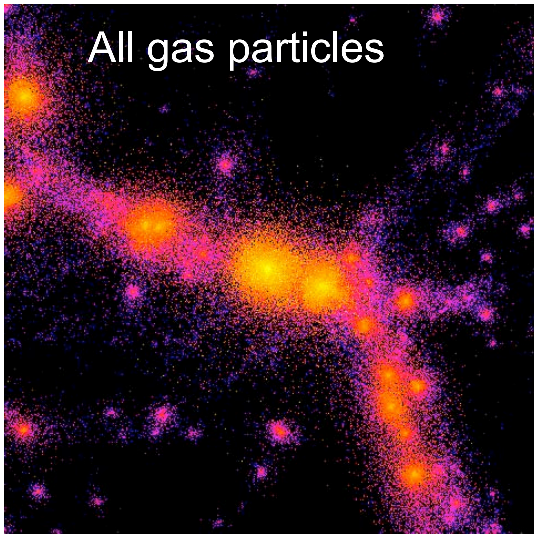
A 30 Mpc/h box around a massive cluster at z=0

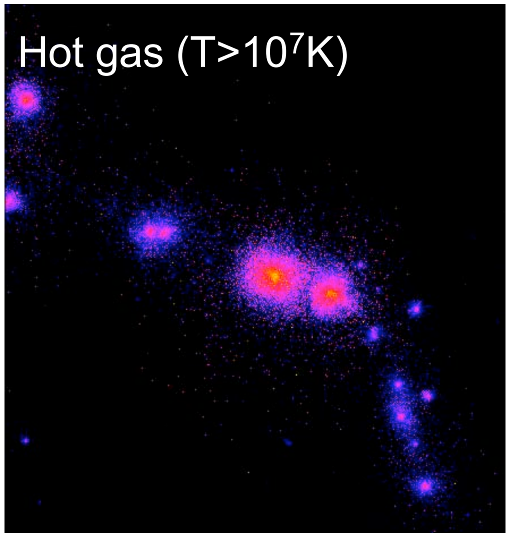
Warm gas follow dark matter very well.

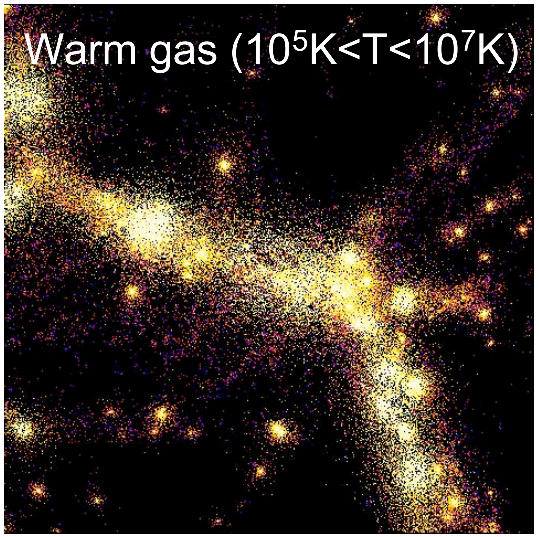
(Λ CDM simulation by Yoshikawa et al. 2002)











How can we observe the WHIM ?

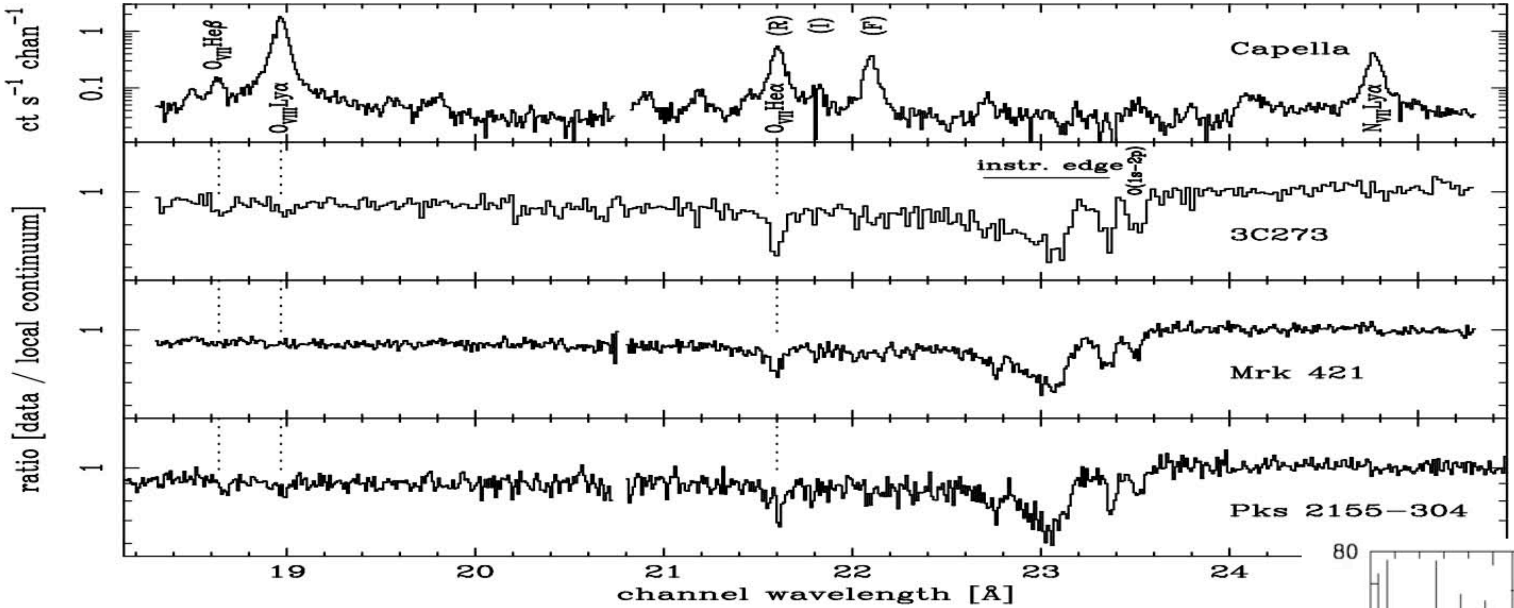
1. OVI ,OVII, & OVIII absorption lines ?
2. Bumpy soft X-ray background ?

   Some published trials and our new results around Virgo cluster
3. OVII and OVIII emission lines with good energy resolution ?

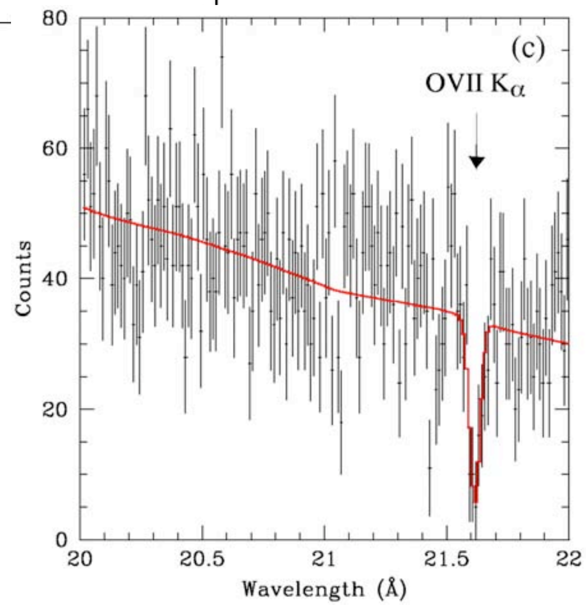
   Difficult for a large X-ray observatory, so we need a new approach

Absorption lines in QSO spectra

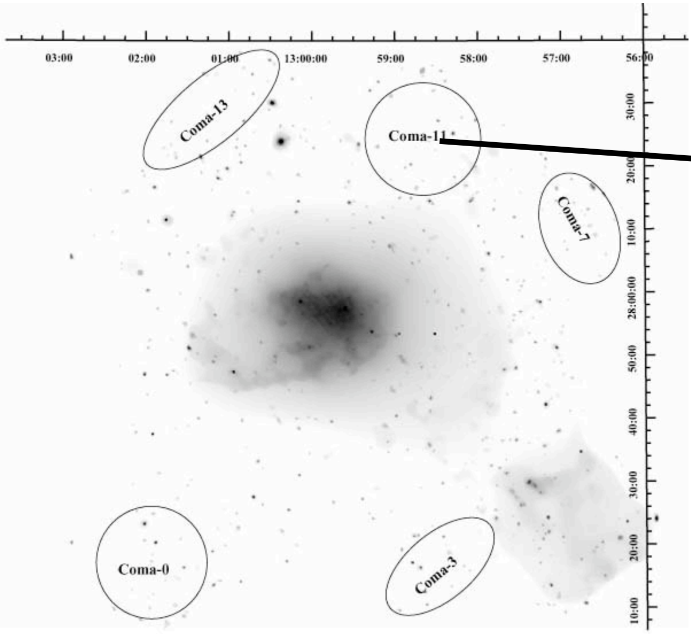
- ✓ OVII, OVIII absorption lines at z=0/Local group ?
  PKS2155-304, 3C273, Mrk 421, 3C120 (Rasmussen et al. 2003)

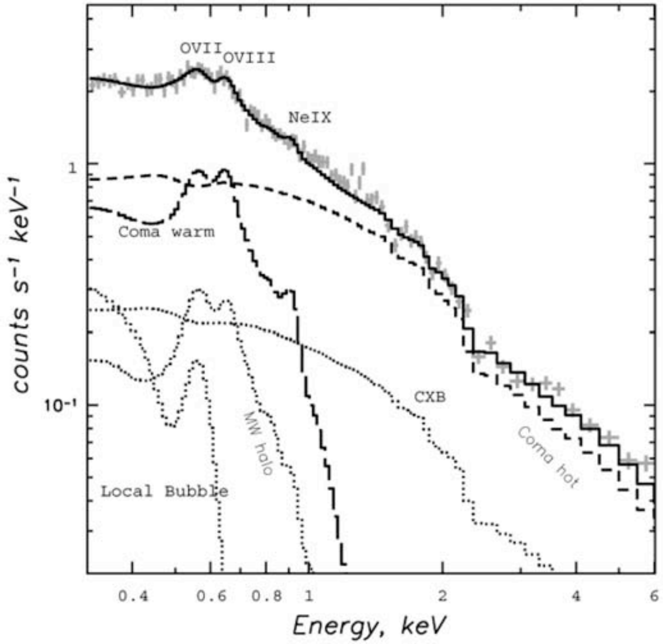


- ✓ ISM toward a LMXB also make an absorption line.
  (4U1820-303 in Futamoto et al. 2004)



Soft X-Ray excess around a cluster ?

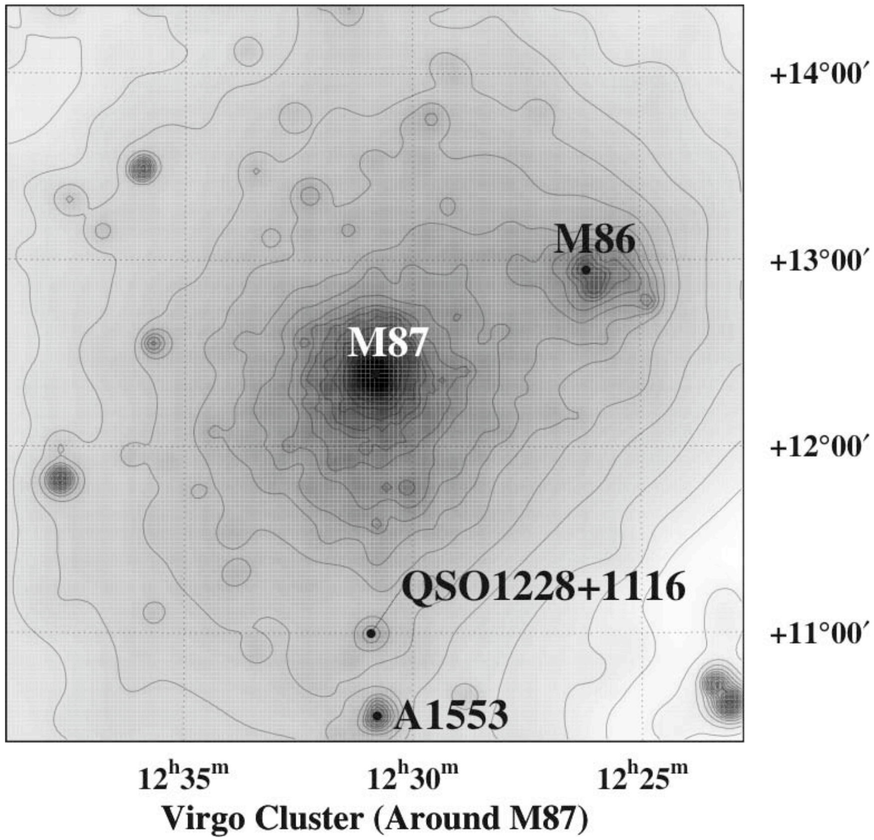




From the outer region of Coma cluster, soft emission with kT~0.2 keV and abundance of 0.1 is found.
Looks stronger than Galactic emission, which has large uncertainty in modeling.
(Finoguenov et al. 2003)

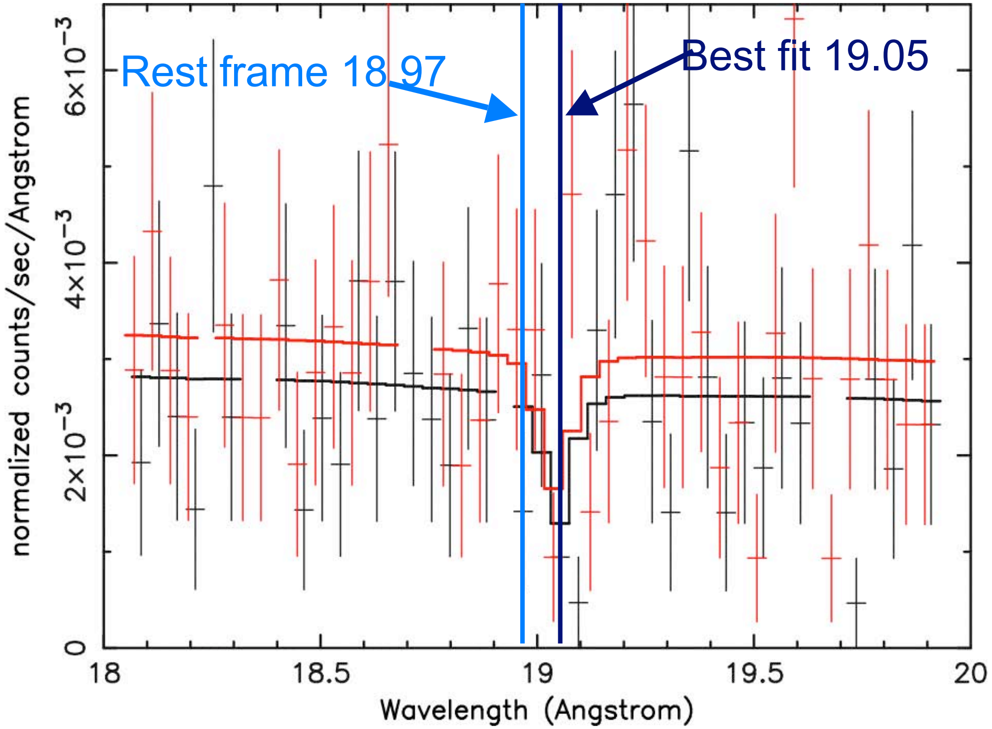
Detection of OVIII absorption lines associated with Virgo cluster

- ✓ Virgo cluster: nearby and very elongated
- ✓ LBQS 1228+1116 (z=0.237) 83 arcmin away from M87
- ✓ 54 ksec exposure with XMM-Newton



(Fujimoto et al. submitted)

Marginal detection of red-shifted line



2.3 σ detection with maximum likelihood method.

cz is consistent with that of M87, 1307 km/s

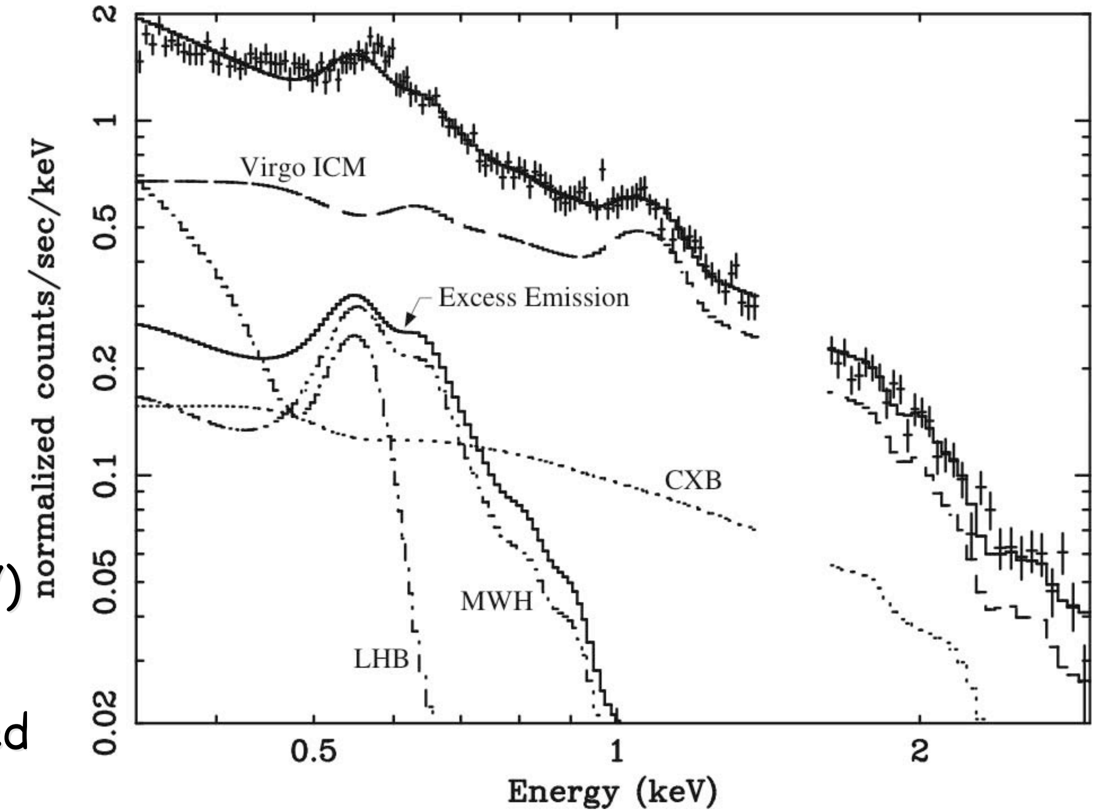
kT>0.20 keV

	O VIII	O VII
Energy (eV)	650.9 (+0.8 -1.9)	571.6 (fixed)
Cz (km/s)	1253 (+881-369)	--
EW (eV)	2.8 (+1.3 -2.0)	<2.8 (3σ)
N_{ion} (/cm^2)	6.2(+3.3 -4.4)x 10^{16}	<3.7 x10^{16} (3σ)

Search the Emission from Warm Gas

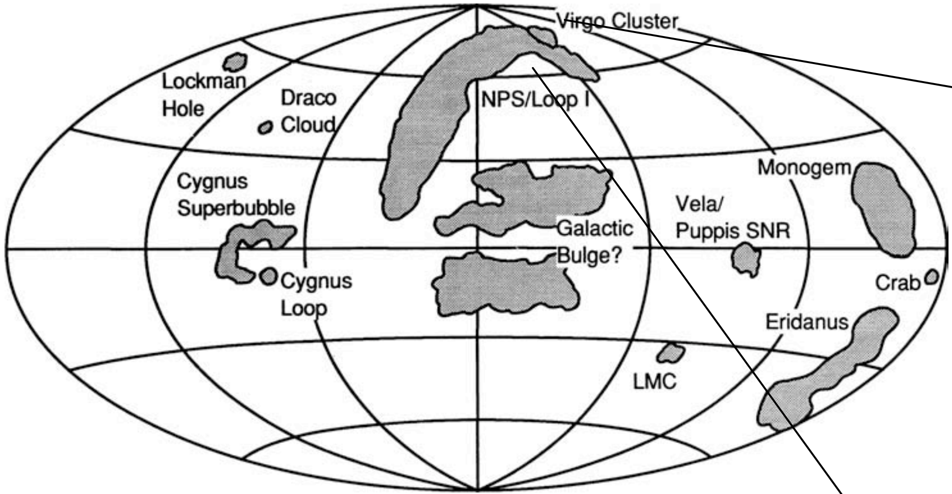
- ✓ The backgrounds are
  - Non X-ray particles
  - CXB
  - Virgo Hot ICM (kT~2keV)
  - Local hot bubble (kT~0.07 keV)
  - Milky way halo (kT~0.2 keV)

    LHB and MWH temperature are studied by Lumb et al. 2002
  - Contribution from North Polar Spur ?

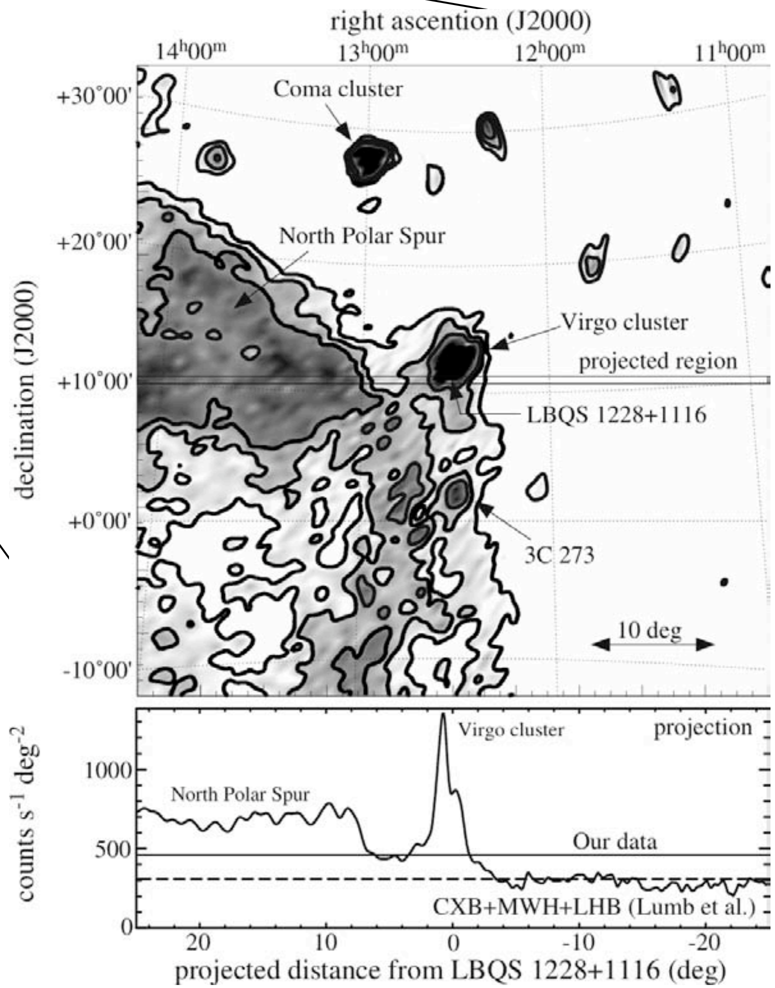


PN spectrum from 247 arcmin^2 area around the QSO

Warm IGM or North Polar Spur ?



(Contours from RASS 3/4keV band)



- ✓ The 0.2 keV component is 2.3 times higher than Lumb et al's value (the reported fluctuation is ~35 %)
- ✓ Strongly suggested that the emission coma from IGM, but some contribution from NPS can not be excluded because the edge of Loop I emission is hard to determined.
- ✓ The 0.2 keV component is an upper limit of the emission from the IGM.

Combining the absorption lines and excess emission

- ✓ OVIII absorption line at cz=1253 km/s
  - Consistent with a narrow line (<5.1 eV) , which means $\Delta z<0.02$ or 80 Mpc
- ✓ $N_{OVIII}\sim 6.2\times10^{16} cm^{-2}$ (assuming a velocity dispersion of 2100 km/s)
- ✓ OVIII/OVII ion ration >1.7 (kT>0.2 keV)
- ✓ Emission of kT~0.21 keV
- ✓ Assuming $N_{OVIII}=fAZn_eL$ and $EM\sim n_e^2LS$

  *N (column density),ne(electron density), A(relative O abundance), Z(Solar abundance), L(depth), S(Area)

  $n_e<6\times10^{-5}cm^{-3}(A/0.1)(f/0.4)$ ($\delta<250$)

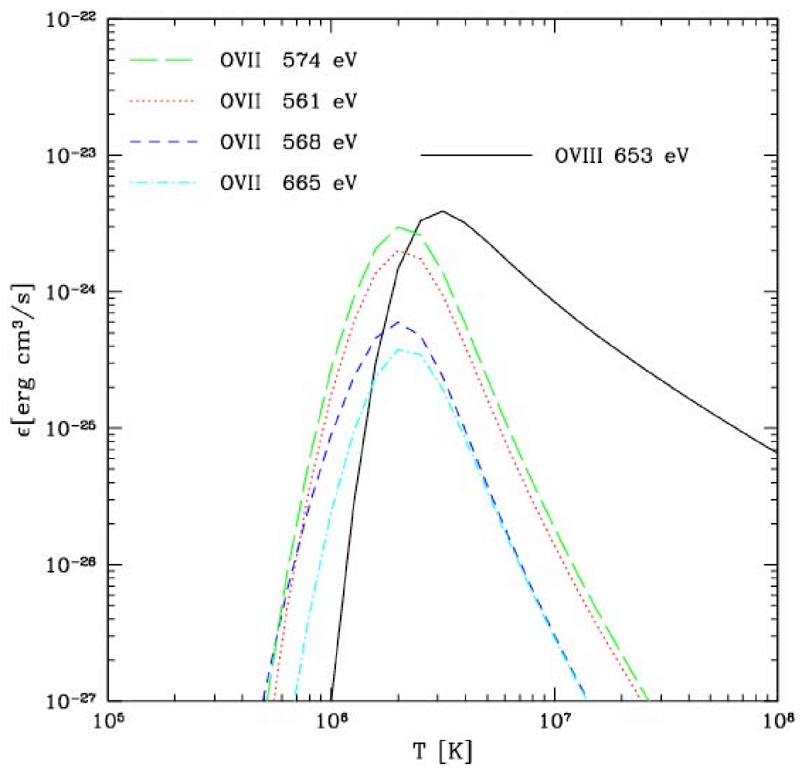
  $L> 9Mpc\ (A/0.1)^{-2}\ (f/0.4)^{-2}$
- ✓ If the redshift of the Oxygen lines are measured by as good energy resolution as by gratings , we can determine the origin of the soft X-ray emission.

Oxygen emission lines as WHIM probe

- ✓ Why oxygen emission lines?
  - Most abundant metal
  - Good tracers at $T=10^6$-10^7K
  - Not restricted to region toward background QSO

Suitable for systematic WHIM survey

OVII :574, 561, 568, 665 eV
OVIII :653 eV

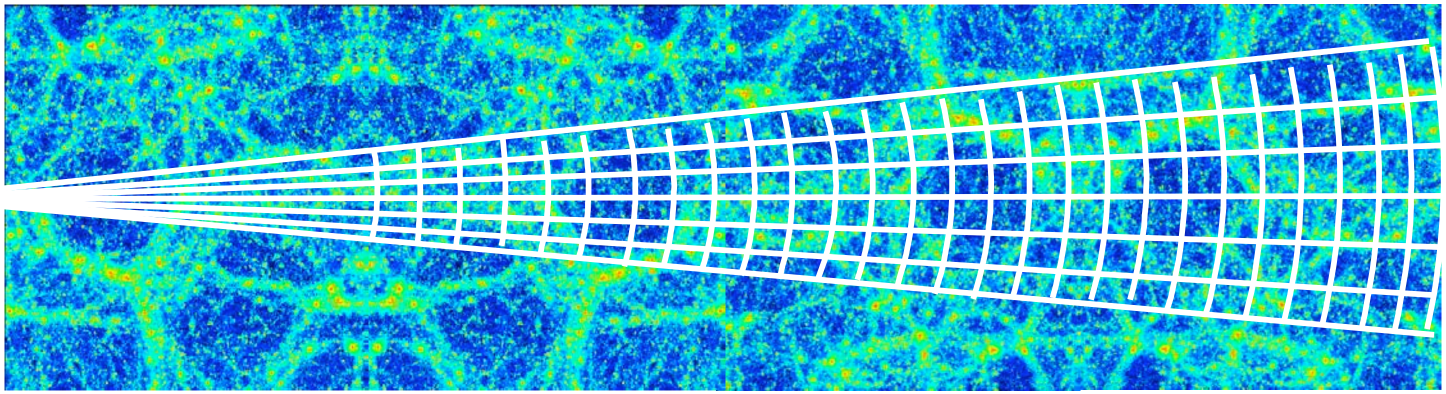


Simulation for Oxygen lines from WHIM

(See Yoshikawa et al. 2003 for details)

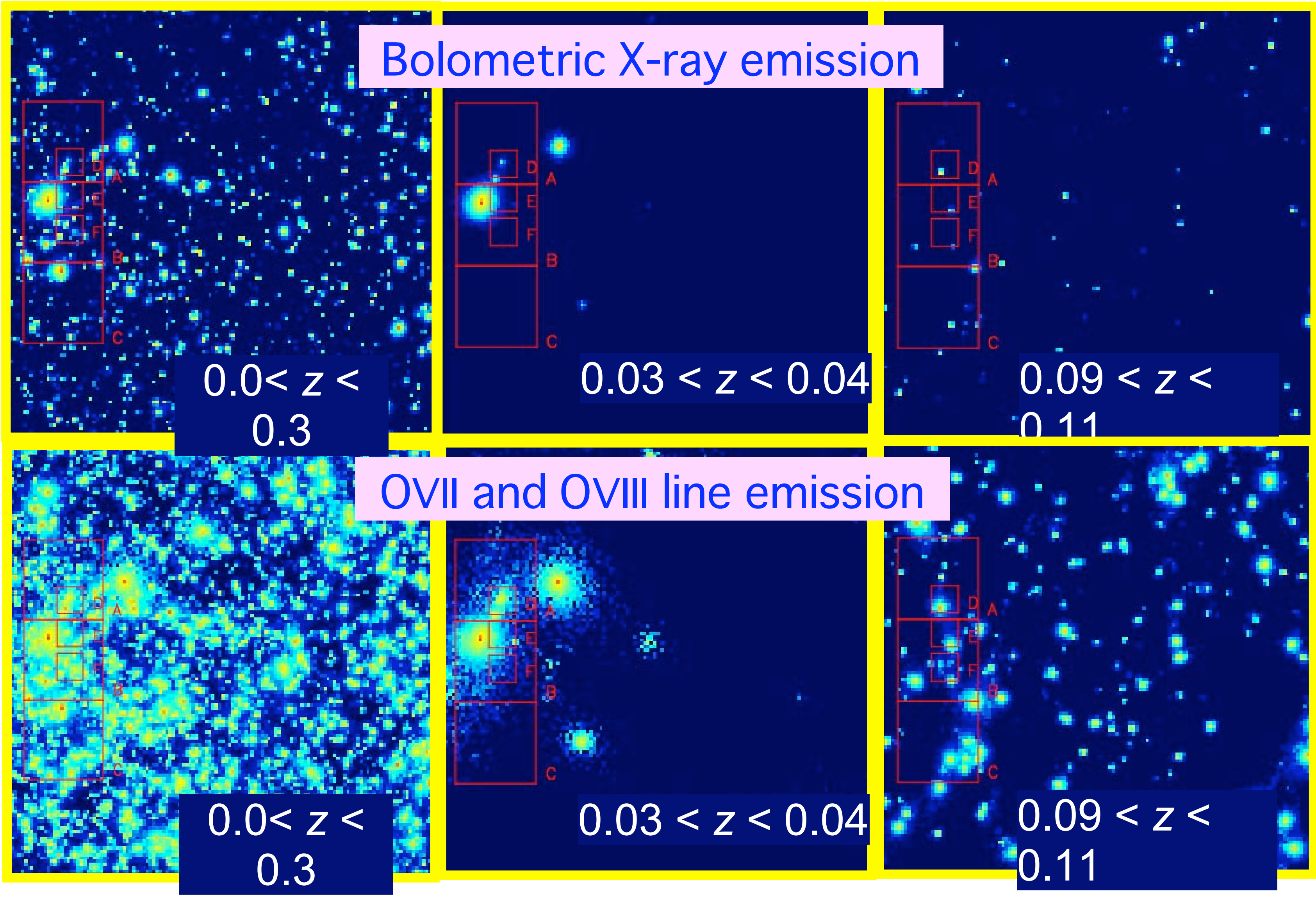
- ✓ Cosmological SPH simulation in Ω=0.3,Λ=0.7,σ_8=1.0,h=0.7 Λ-CDM with 128^3 each for DM and gas (Yoshikawa et al. 2001) ->gas density and temperature (potential)
- ✓ Various Metallicity models based on the density
- ✓ Convolve the emissivity (continuum and lines) over the lightcone from z=0 to z=0.3
- ✓ Add Galactic emission lines (McCammon et al. 2002) and CXB continuum to simulate energy spectrum

z=0

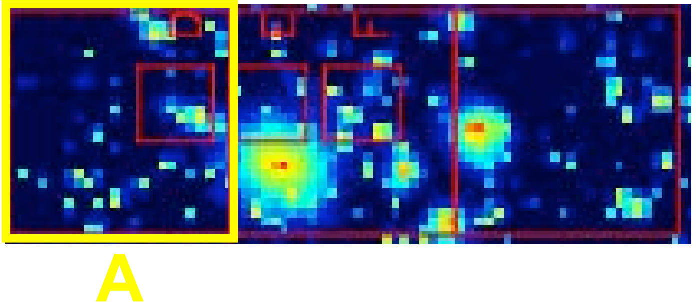


z=0.3

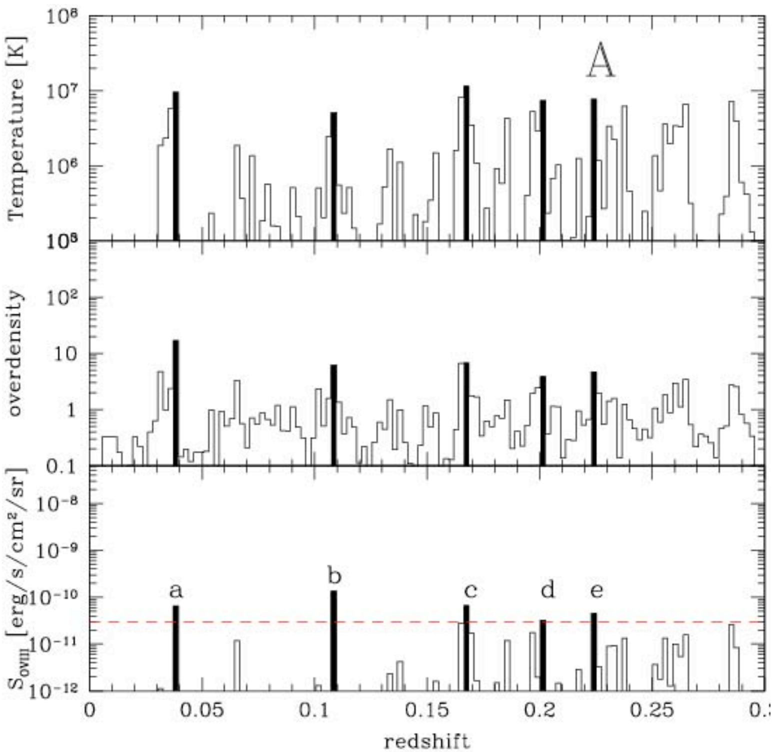
Surface Brightness of the Sky

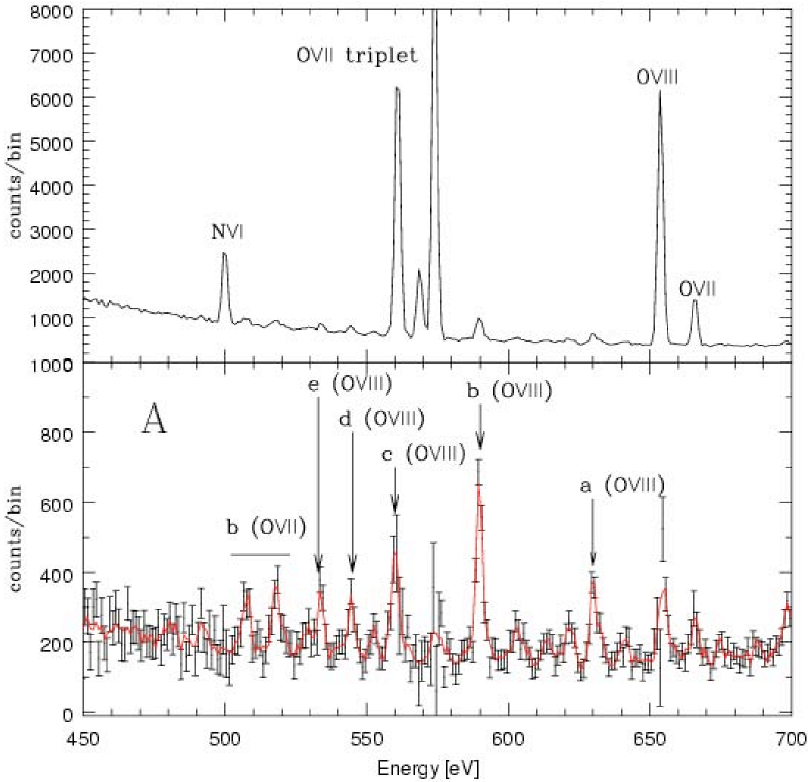


Simulated Spectra with ΔE=2 eV:

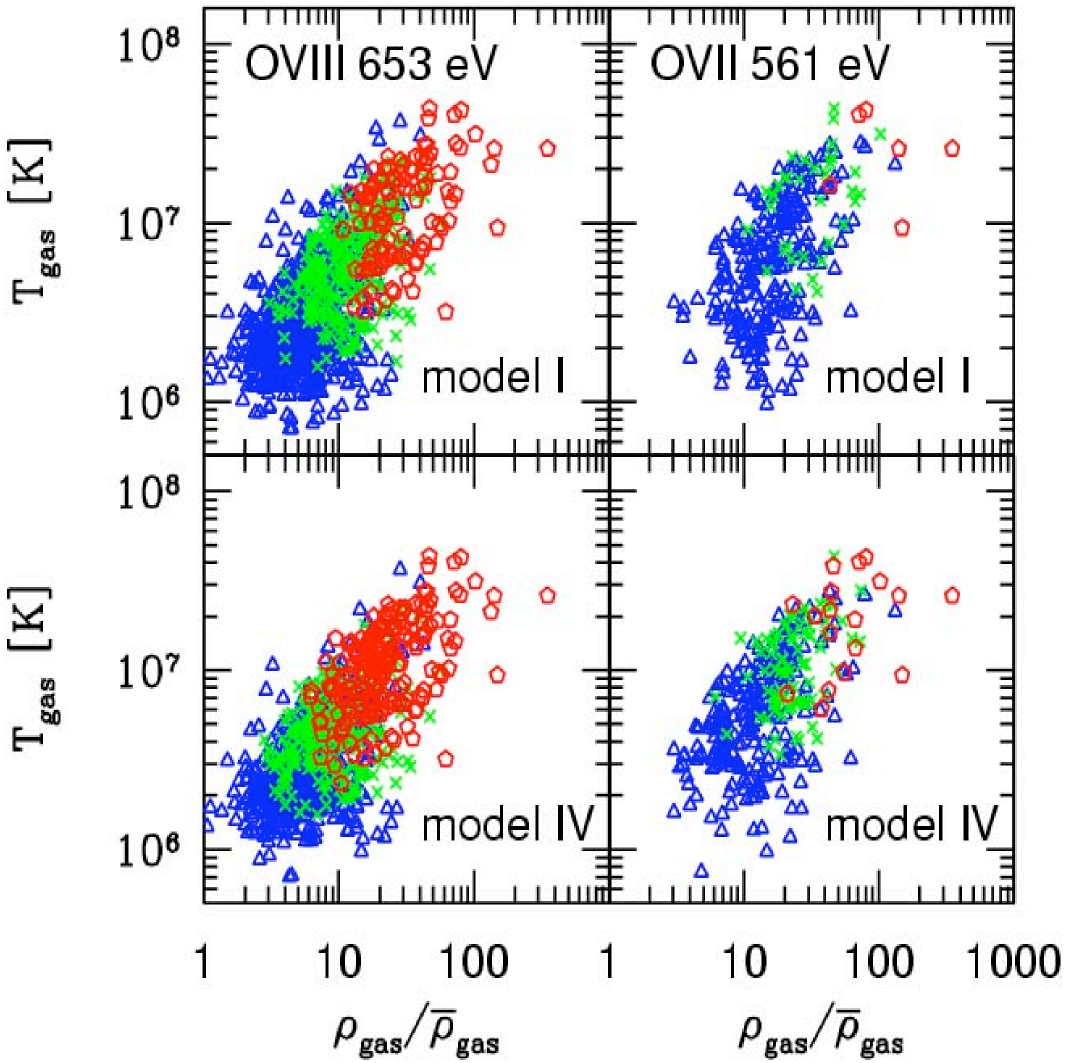


Region A: Ω=0.88deg^2,
S=100cm^2 , T=3x10^5 sec





Properties of the detected baryons



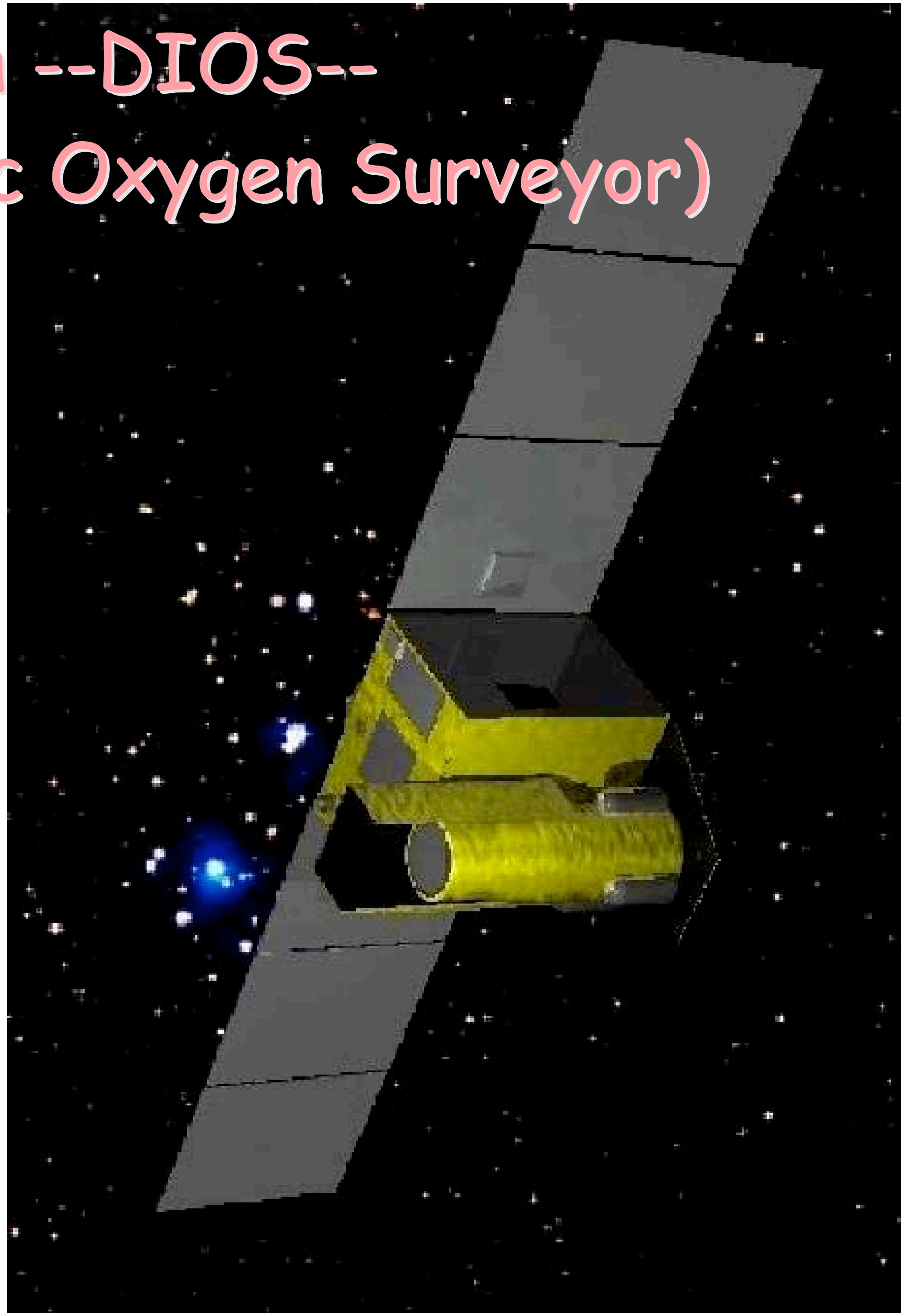
Each symbol indicate the temperature and the over-density of gas at each simulation grid (4x4 smoothed pixels over the sky and Dz=0.3/128)

- $S_x > 3\times10^{-10}$ [erg/s/cm^2/sr]
- $S_x > 6\times10^{-11}$[erg/s/cm^2/sr]
- $S_x > 10^{-11}$[erg/s/cm^2/sr]

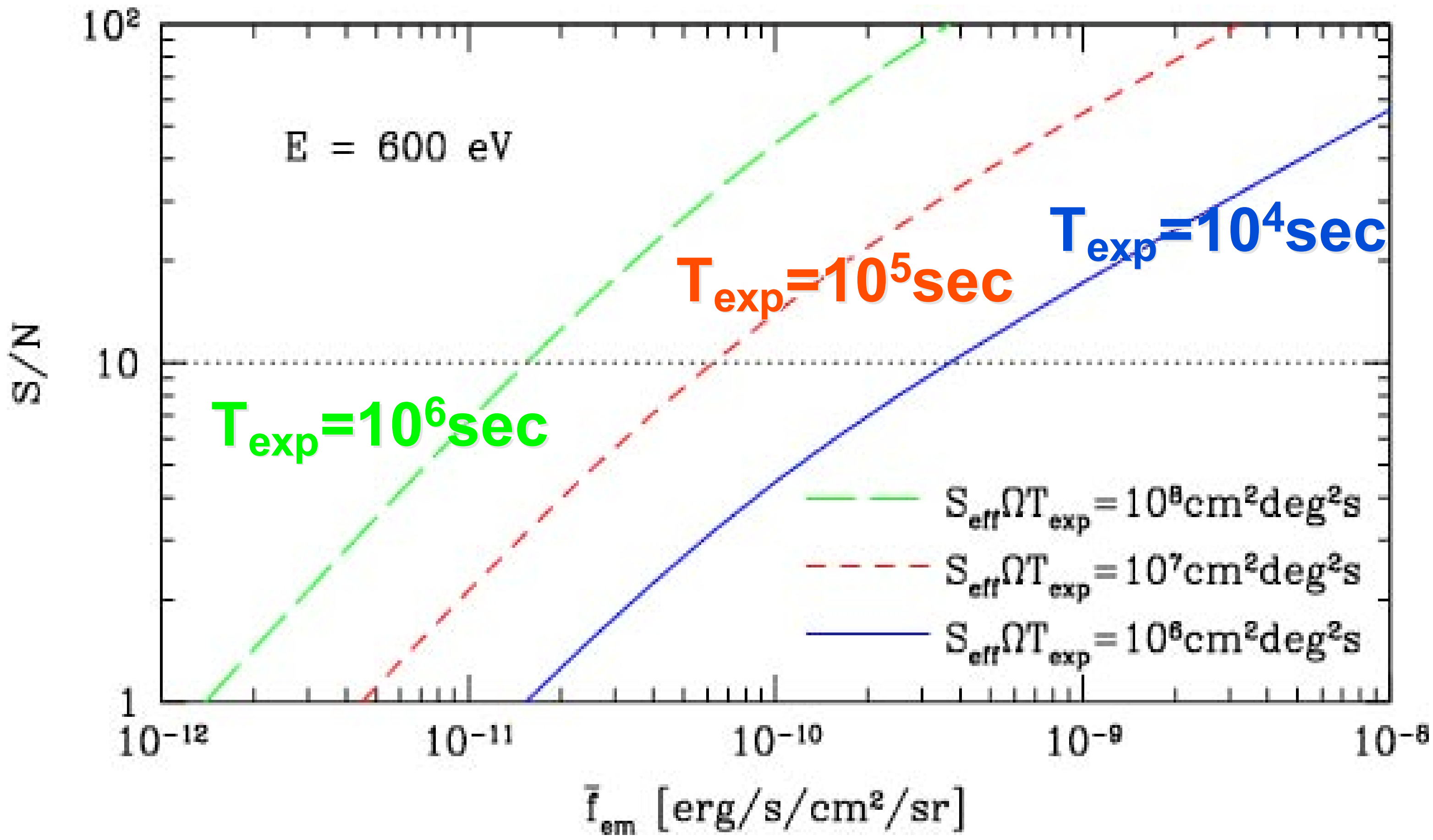
Proposed small mission --DIOS--
(Diffuse Intergalactic Oxygen Surveyor)

ΔE=2eV and
$S\Omega$=100cm^{2}deg^2 with
small (<500kg) satellite

- ✓ Use TES micro calorimeter array for good energy resolution
- ✓ 4-reflecting X-ray mirror to obtain wide field-of-view
- ✓ 3D mapping of Oxygen lines of 10x10 degree^2 sky into z=0.3



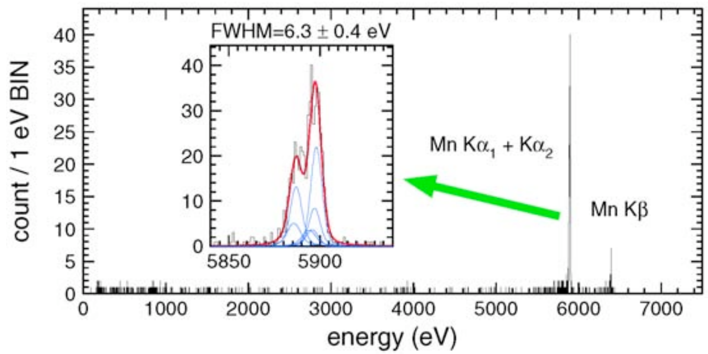
Expected S/N for OVIII line

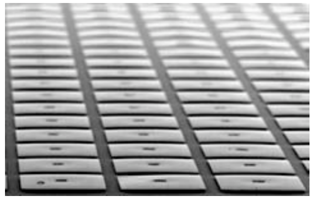


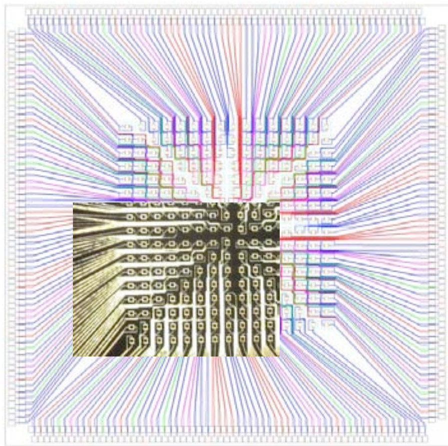
ΔE=2 eV and SW=100deg^{2}cm^2 is necessary

TES calorimeter array

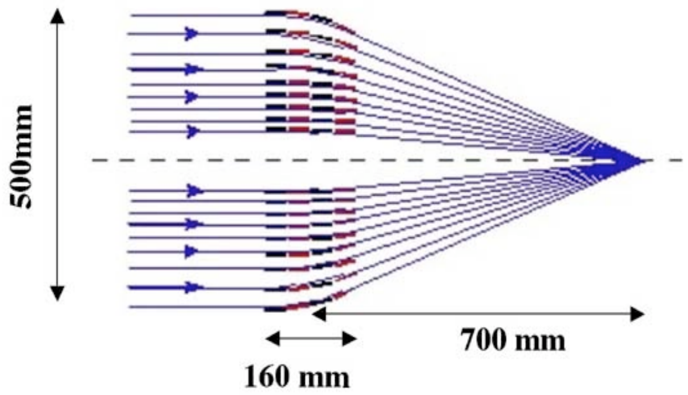
- ✓ XRS -type detector is hard to be enlarged more than 64 pixels..
- ✓ ISAS/TMU team achieved 6eV resolution with a single pixel TES
- ✓ Array structure model with absorbers has been fabricated
- ✓ Signal multiplexing is under developing (AC bias & multi-input SQUID)

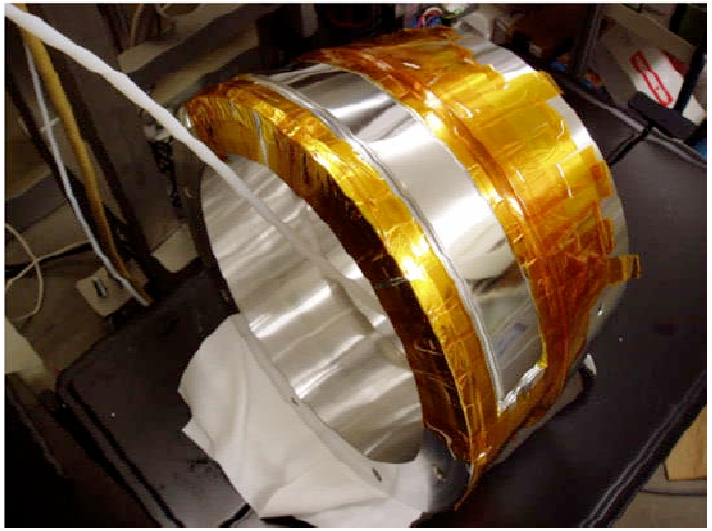






4-stage X-ray mirror

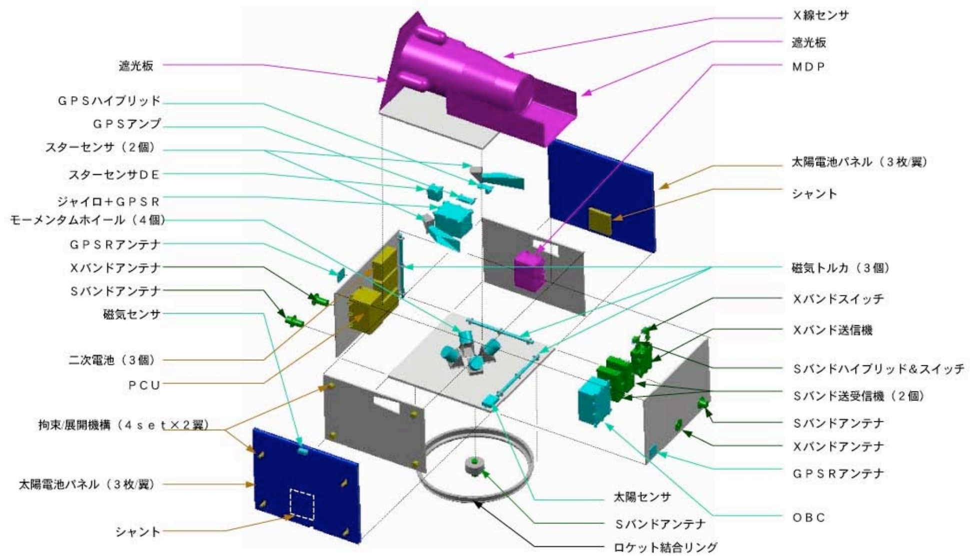


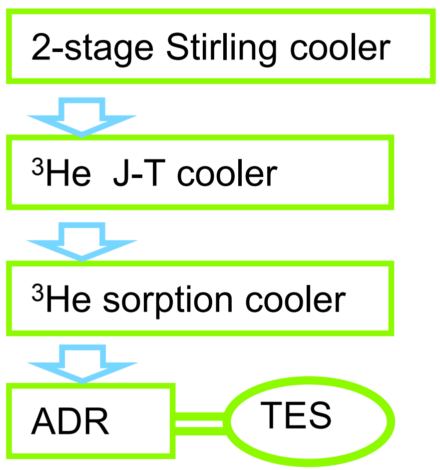


- ✓ 4-stage reflection
  wide field of view (50′) with short focal length (70cm)
- ✓ Suitable to small mission
- ✓ Angular resolution of 3′
  not so good, but enough to observe diffuse mission
- ✓ Fabrication test has been started at Nagoya Univ.

Current satellite design

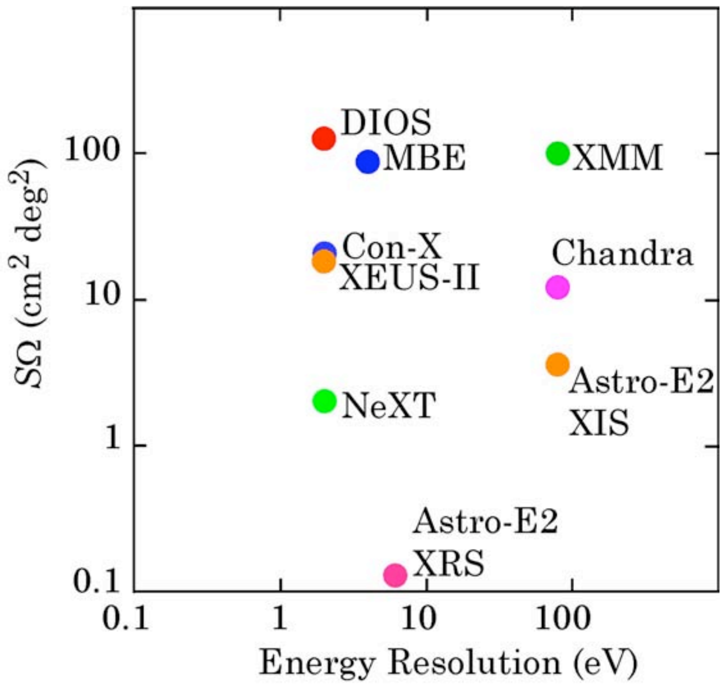
- ✓ Total Weight & Mass :<400kg, 1.5m | x 1.5m φ (within ASAP-5 criteria)
- ✓ Weight and power budget
  - bus: 200kg and 170W
  - instrument :200 kg and 280W
- ✓ Orbit: 550km , inclination <30 degree
- ✓ Attitude control: 3-axis bias momentum
  - Accuracy <0.5 arcmin.
- ✓ Life and weight depends on cryogenic system





DIOS Performance

Effective area	> 100 cm^2
Field of view	50' diameter
SΩ	~100 $cm^2 deg^2$
Angular resolution	3' (16 x 16 pix)
Energy resolution	2 eV (FWHM)
Energy range	0.1 - 1 keV
Mission life	> 5 yr



Larger SΩ than those of Con-X and XEUS

Summary

- ✓ Warm-hot IGM (10^5K<T<10^7K) is the most plausible missing baryon candidate.
- ✓ X-ray will be a window to the missing baryon. But the contamination from the Galactic hot gas should be excluded.
- ✓ Oxygen line mapping with fine energy resolution will reveals the large scale structure of baryons in the Universe.
- ✓ For that purpose, not a large X-ray observatory but an alternative approach like DIOS is required.