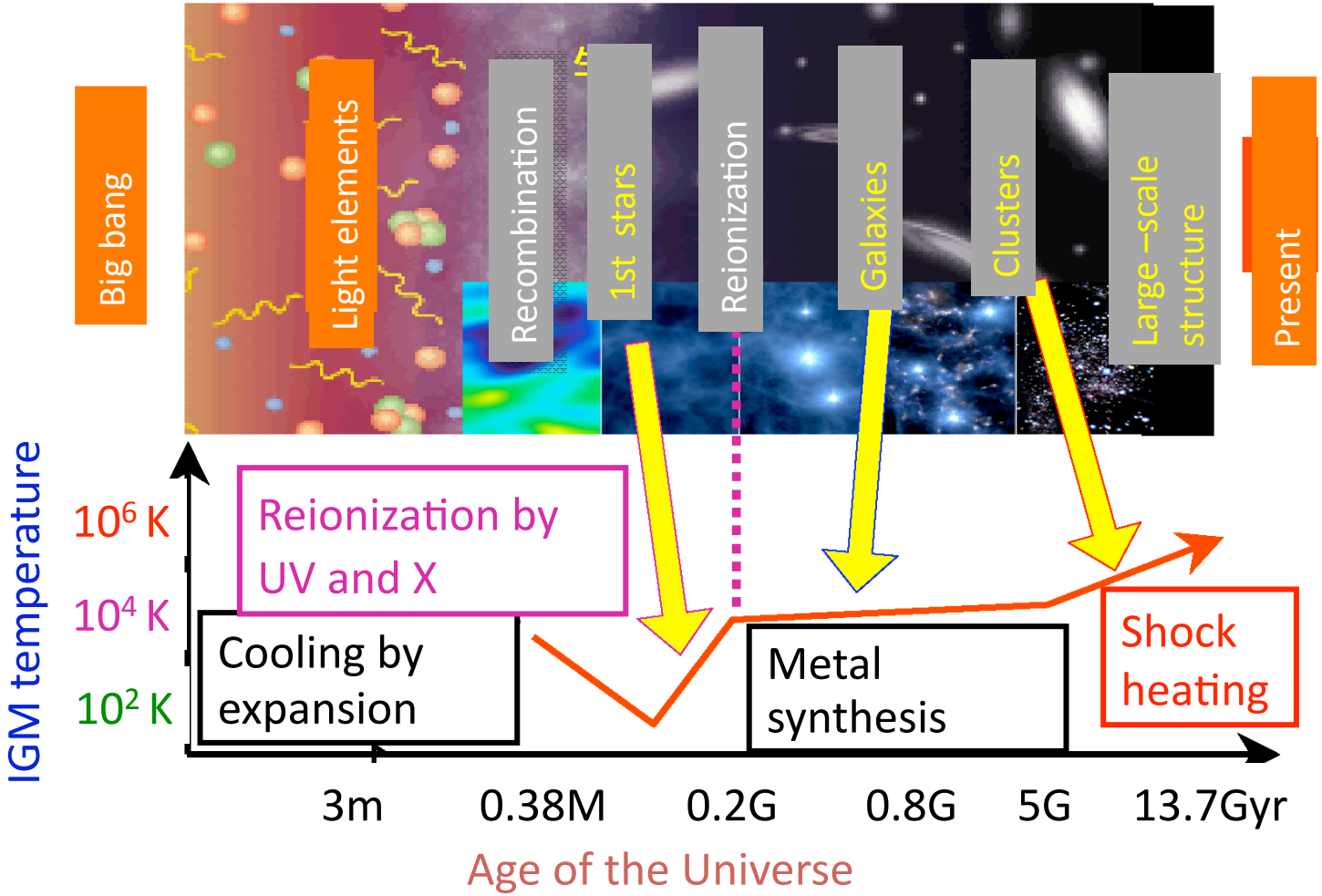
Chemical Evolution and WHIM Measurements

T. Ohashi (Tokyo Metropolitan University)

- WHIM and its science
- Observational status of WHIM (Chandra, XMM, Suzaku)
- Future WHIM study with DIOS (small version of Xenia)
- WHIM study with IXO

Thermal history of the universe

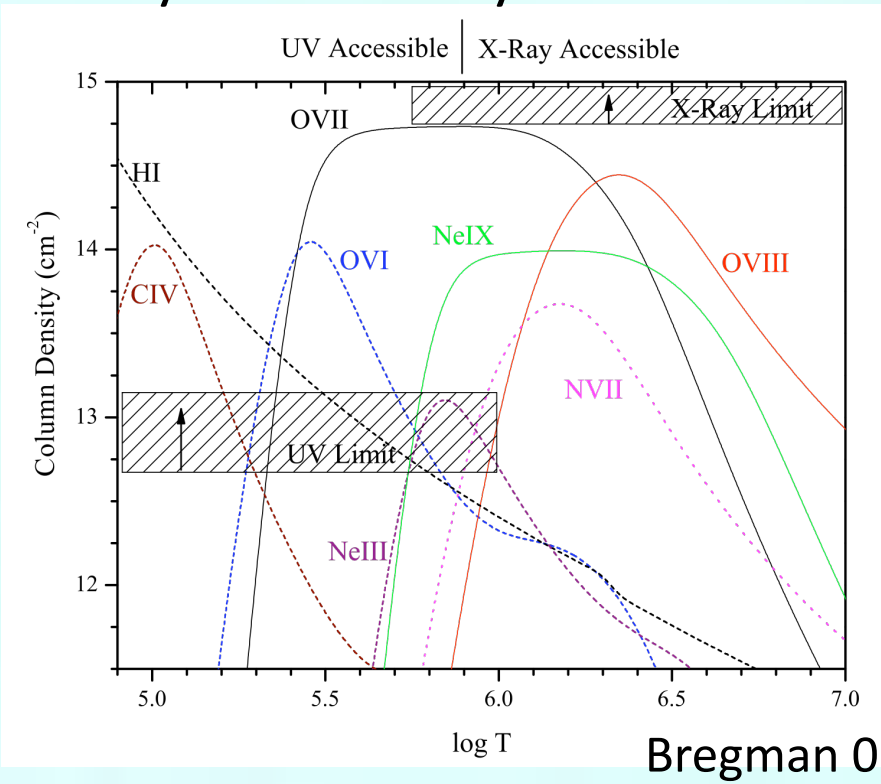


WHIM (warm-hot intergalactic medium) will tell us the evolution of the hot-phase material in the universe

Baryon phase

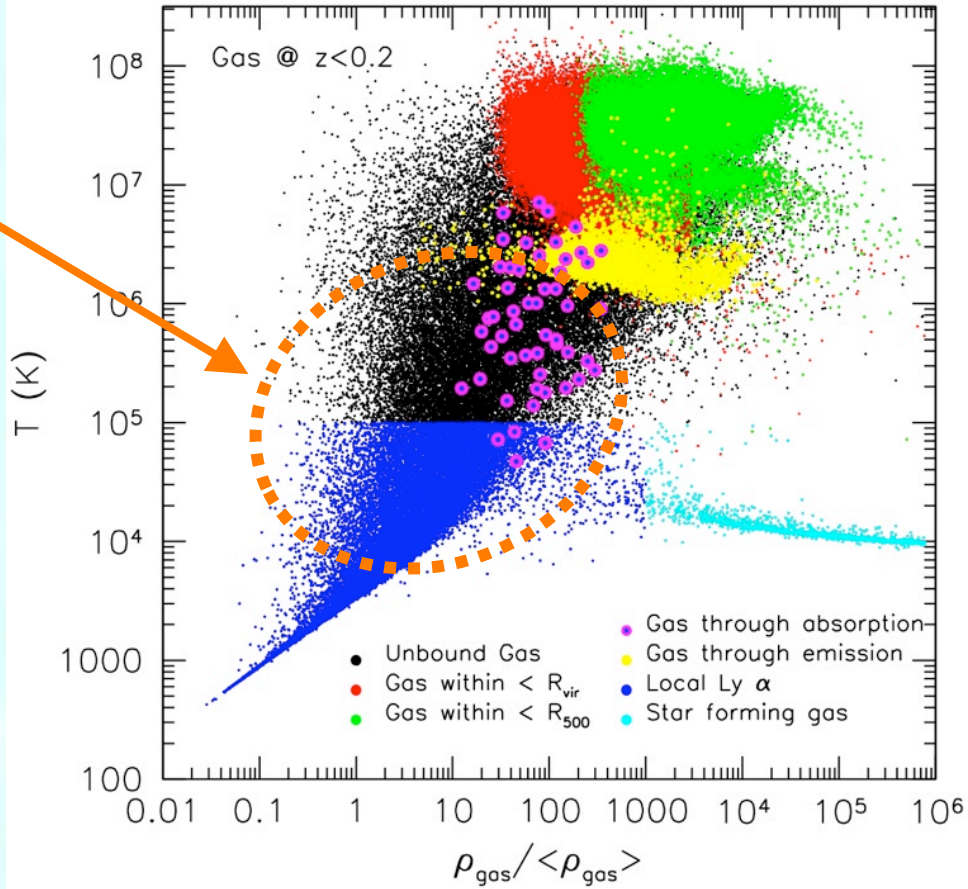
Wide area in the baryon phase space is unexplored

Oxygen line probes the dark baryon efficiently



Bregman 07

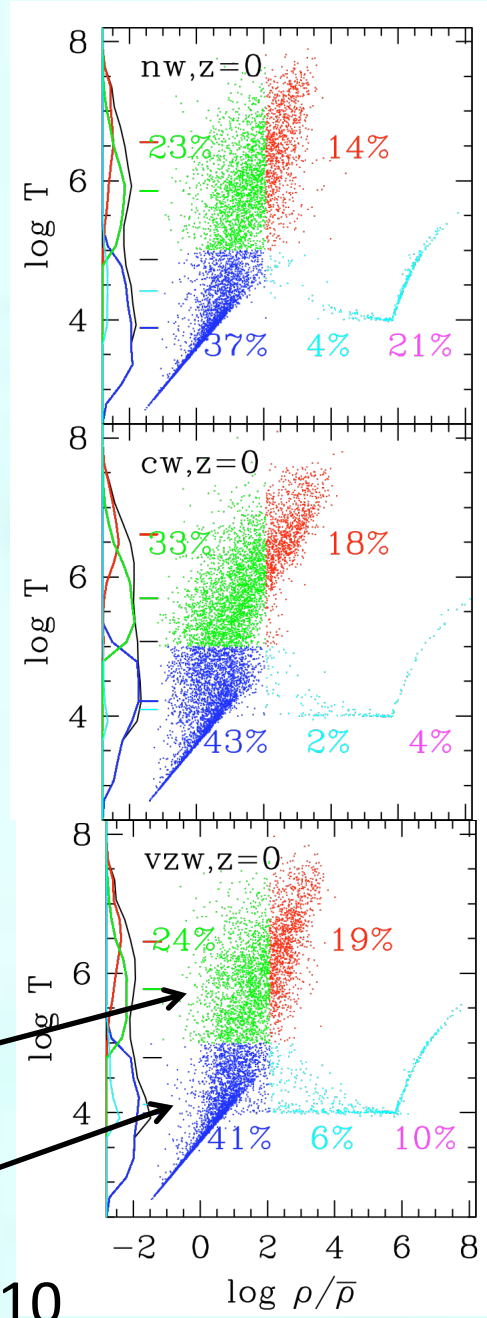
Branchini et al. 09



EDGE consortium

WHIM and galaxy evolution

- Amount of WHIM depends on enrichment history: such as strength of supergalactic winds
- X-ray (WHIM) and UV (diffuse IGM) measurements can probe whole dark baryon in the universe
- Absorption lines detect low-density medium
- Emission lines give us spatial structure of high density group-like regions

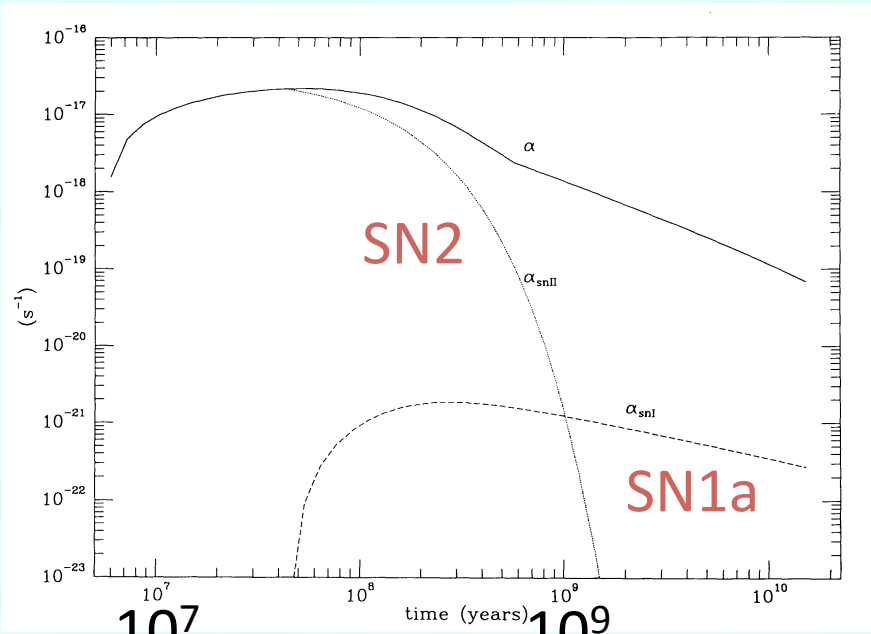


Dave+ 10

Enrichment history

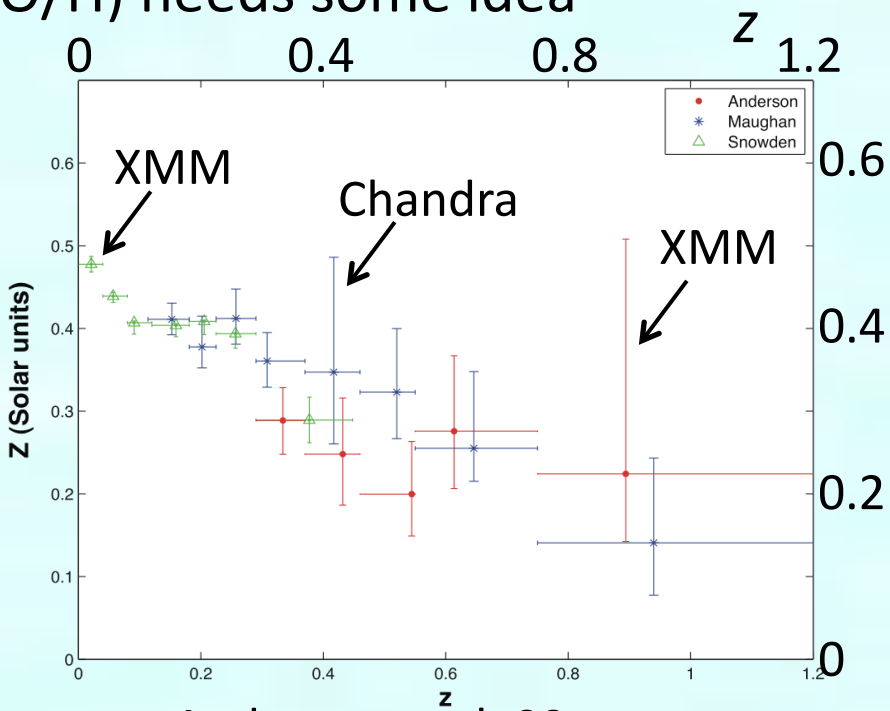
- Cluster Fe abundance may increase from *z* =1 to now (Balestra + 07, Maughan+ 08, Anderson+ 09)
- O, Ne, Si enrichment occurred in earlier epoch?
- WHIM metals (O) would constrain enrichment history in large scales
- Conversion to metal abundance (O/H) needs some idea

Mass ejection rate



10^7 → 10^9 Time (yr)

David, Forman & Jones 90



Anderson et al. 09

Cosmic structure

WHIM (10^5-10^7 K) traces the cosmic large-scale structure

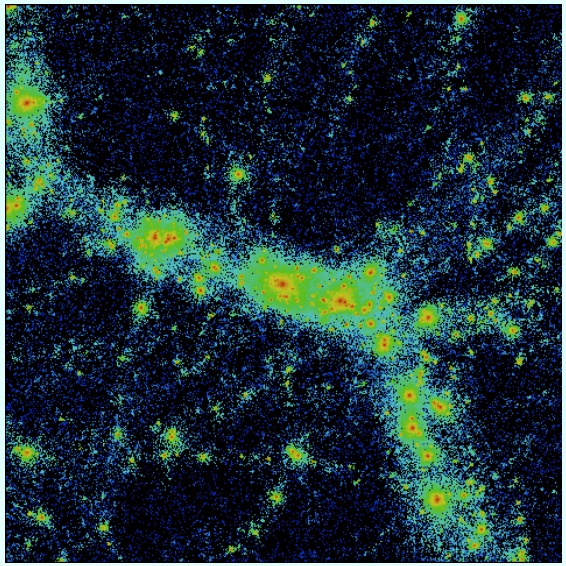
= "Missing baryon"

Typical matter density:
$\delta\ (=n/\langle n_B \rangle)$ = 10 - 100

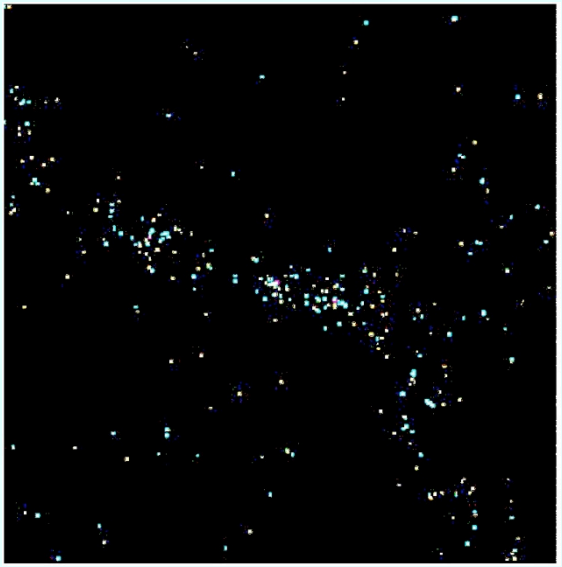
Yoshikawa et al. 2001, ApJ, 558, 520

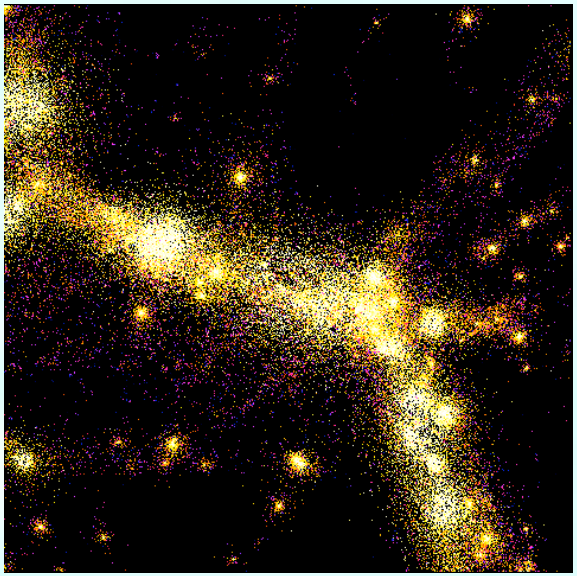
size = 30 h^{-1} Mpc
≈ 5 deg at z=0.1

Dark matter

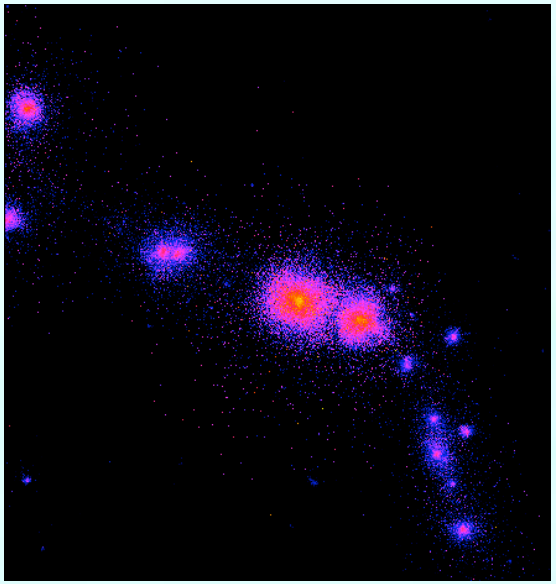


Galaxies (~10^4K)





IGM (10^5-10^7K)

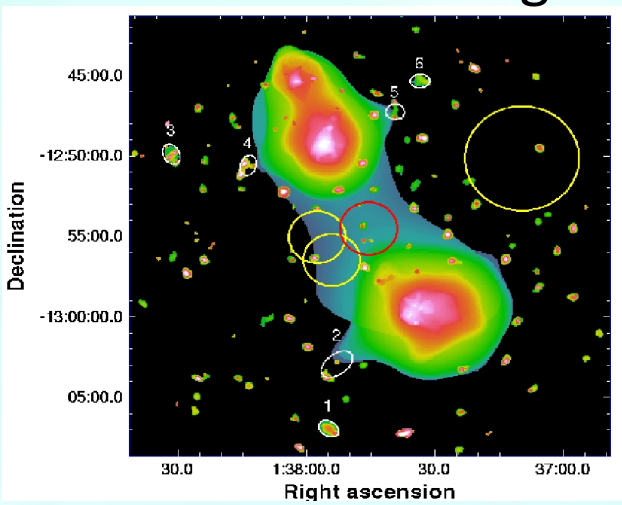


Cluster gas (10^7K)

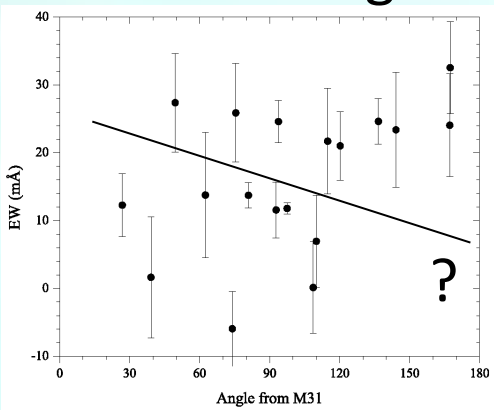
XMM study of WHIM

- Werner et al. 2008: X-ray bridge between A222 and A223 (z = 0.21)
  - kT ~ 0.9 keV, $\rho/\langle\rho\rangle$ ~ 150, continuum only
- Bregman & Lloyd-Davis 2008: Local OVII absorption is due to Galactic halo (not by Local group medium)

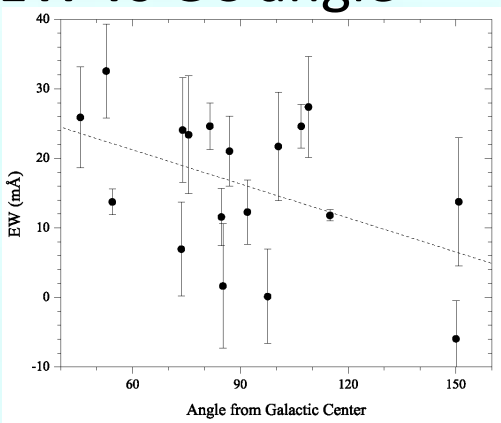
A222-A223 bridge



EW vs M31 angle



EW vs GC angle

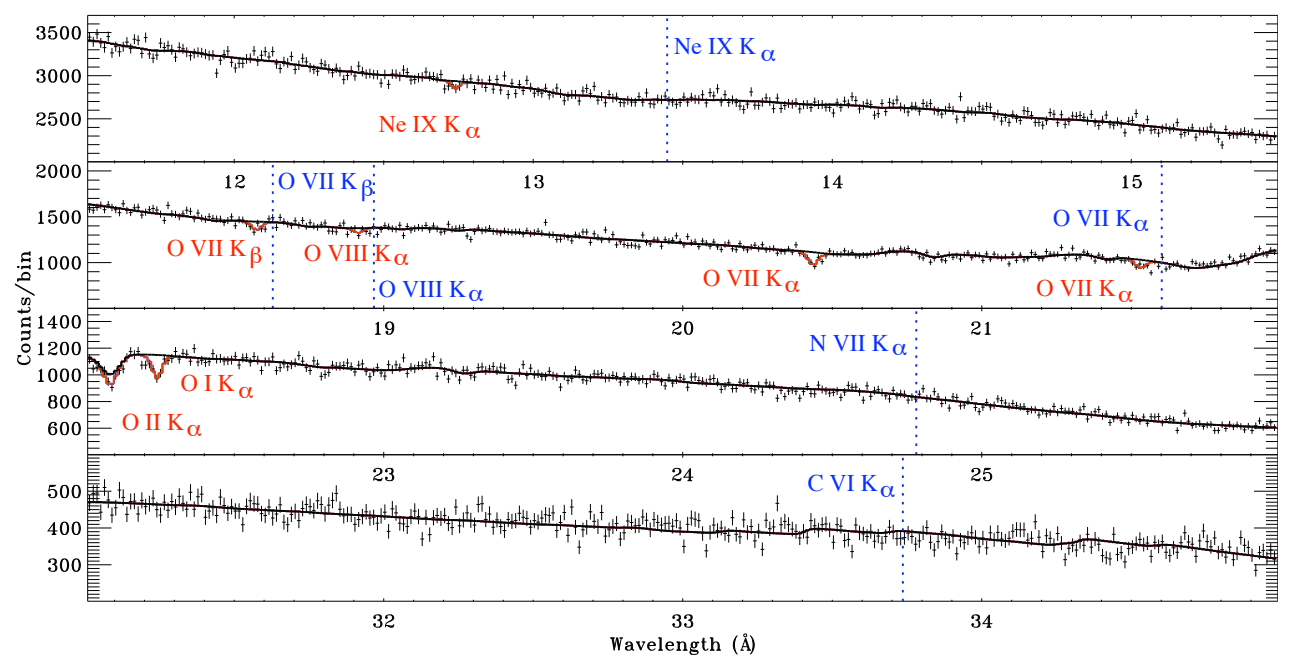


Chandra absorption study

- Sculptor wall: probably the 1st significant detection of redshifted OVII absorption line → talk by T. Fang
- Search of OVII absorption associated with OVI absorption clouds (Yao et al. 09): negative
  → $N_{OVII} \leq 10^{15}$ cm^{-2} and $N_{OVII} < 10\ N_{OVI}$: contrary to collisional ionization case

Stacked Chandra grating data for 6 AGNs: no OVII absorption at the OVI redshift

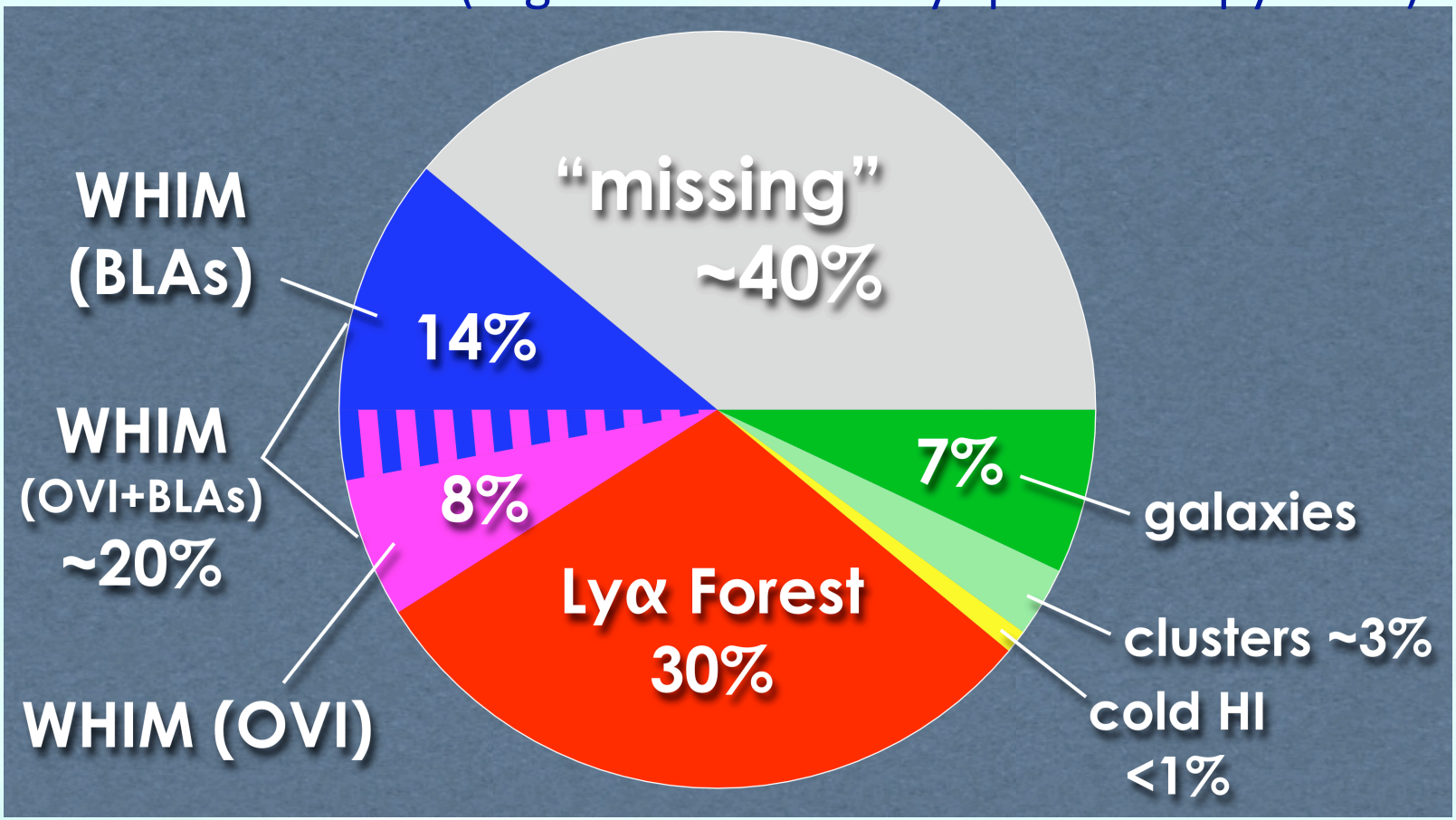
Does OVI probe WHIM?



Yao et al 09

Baryon census

M. Shull (High resolutionX-ray spectroscopy 2010)



Based on OVI measurements

Some part of OVI may be from Lyα forest (photoionized)

COS observations will clarify origins of OVI line

Sculptor supercluster

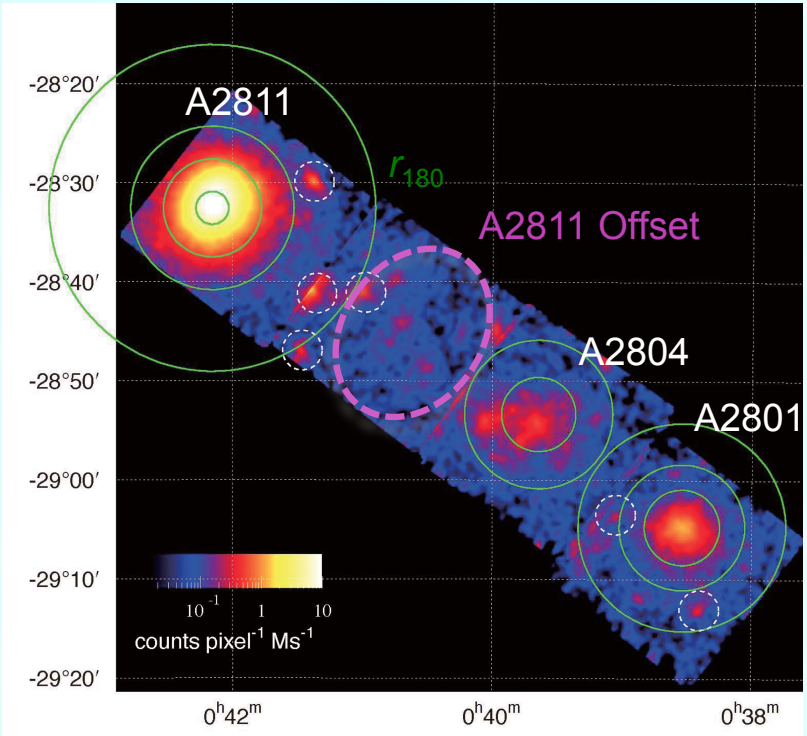
- z = 0.11 with > 20 clusters
- Soft excess by ROSAT (Zappacosta+ 05)
- No excess by ASCA (Obayashi+ 98)
- Upper limits on O lines

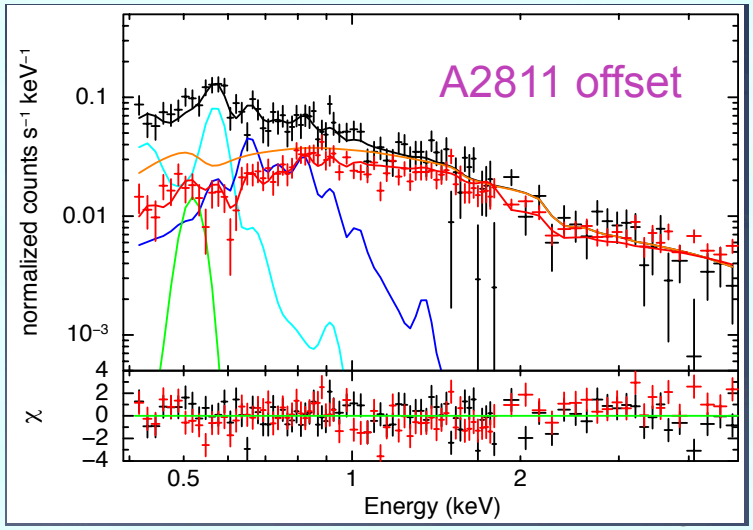
  OVII < 7.5×10^{-8} ph cm^{-2} s^{-1} amin^{-2}

  OVIII < 3.9×10^{-8} ph cm^{-2} s^{-1} amin^{-2}
- Implied gas density

  $\rho/<\rho>$

  $< 200\ (L/2\ \mathrm{Mpc})^{-1/2}(0.1/Z_O)^{-1/2}$



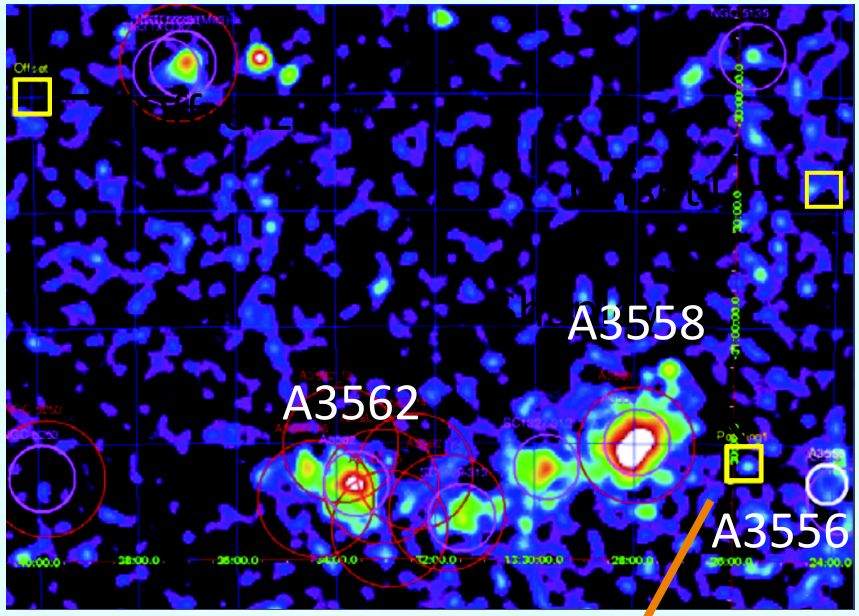


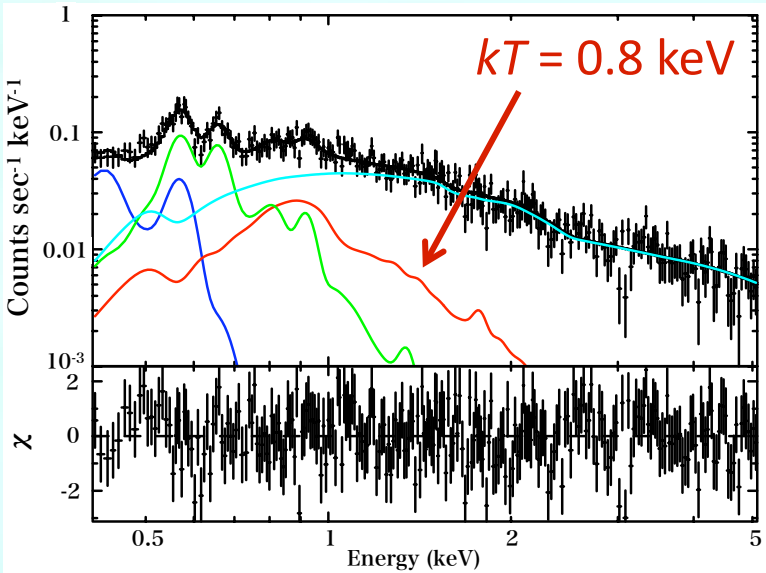
Consistent with Galactic and extragalactic BGD

Sato et al. in prep

Shapley supercluster

- z = 0.048, 25 Abell clusters
- Excess by ROSAT (Kull+ 99)
- Upper limits on O lines
  OVII < 1.2×10^{-7} ph cm^{-2} s^{-1} amin^{-2}
  OVIII < 5.6×10^{-8} ph cm^{-2} s^{-1} amin^{-2}
- Implied gas density from O line
  $\rho/\langle\rho\rangle$
  $< 290\ (L/2\ \mathrm{Mpc})^{-1/2}(0.1/Z_O)^{-1/2}$
- Suggestion of a 0.8 keV emission (assuming z = 0.048), which implies $\rho/\langle\rho\rangle \sim 360$

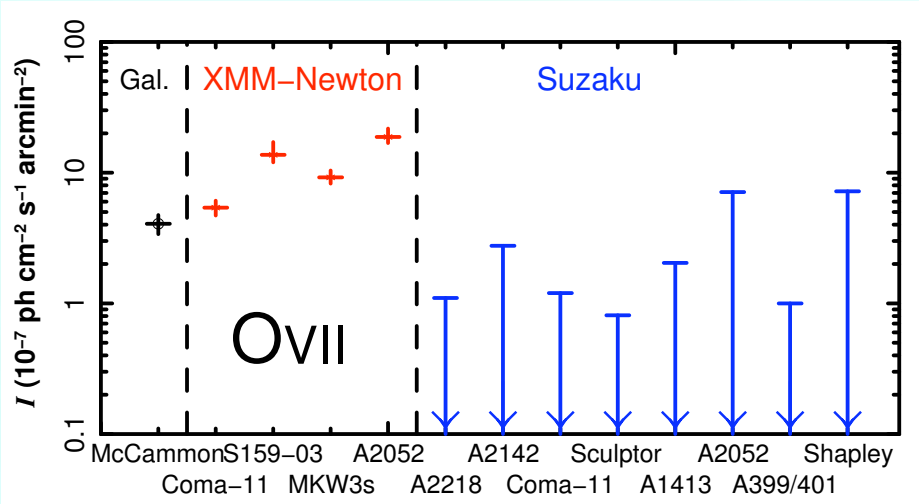


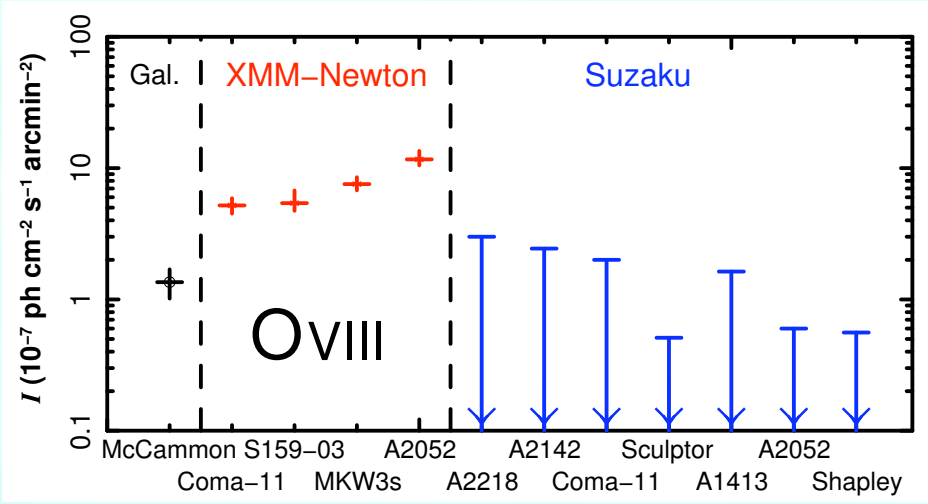


Mitsuishi et al. in prep

Suzaku search for WHIM

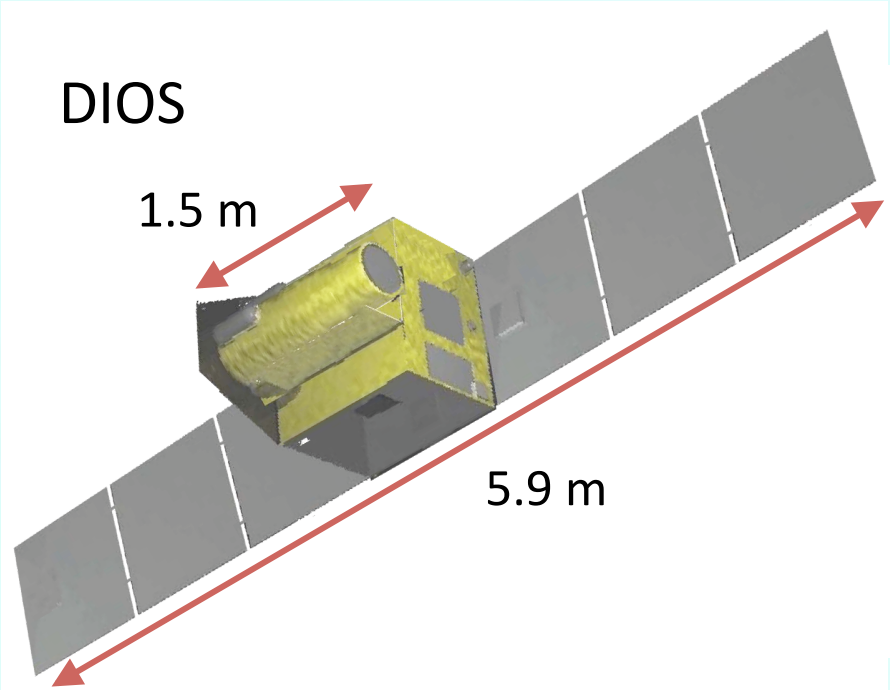
- Suzaku is searching for WHIM emission in cluster outskirts and in superclusters, with no positive detection of redshifted O lines yet
- Fairly low upper limits (δ < 200-300 assuming line-of-sight depth of 2 Mpc and Z_O = 0.1 solar) are derived
- Suzaku will continue searching for WHIM emission





Dedicated X-ray missions for WHIM search

den Herder



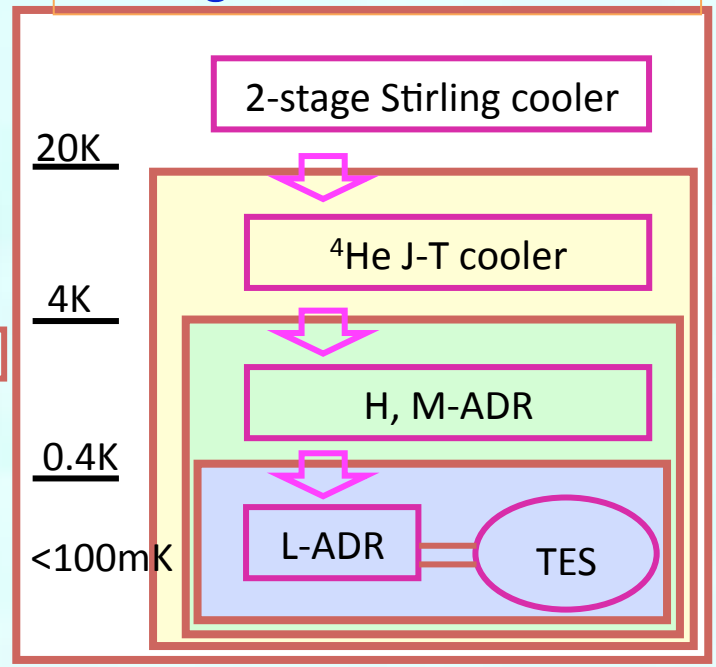
Expected results → Yoh Takei

DIOS: spacecraft

Mass	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-axix
	accuracy	≦30 arcsec
Power	total	500 W
	payload	300 W

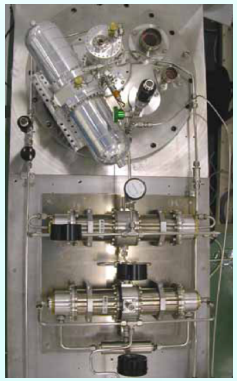
no cryogen, mechanical cooling

Radiation
225, 300 K
> 1.1 m^2



Attitude turns in every orbit to avoid earth shining the radiator

Stirling cooler

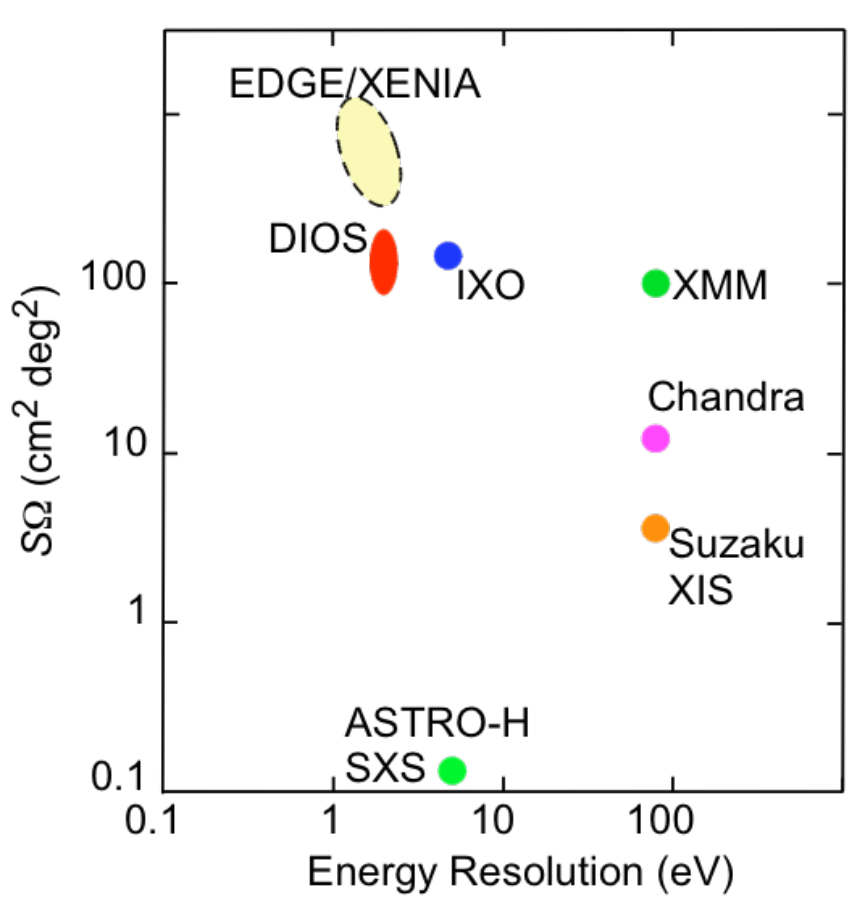


J-T cooler

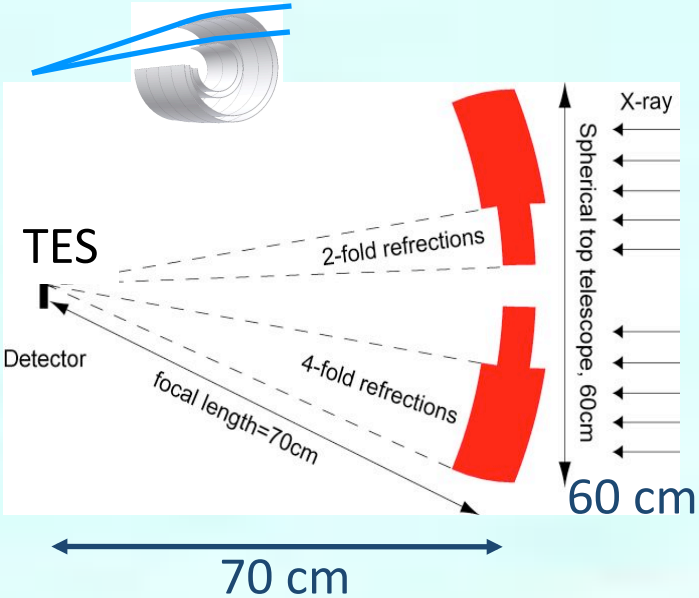
14

DIOS: microcalorimeter instrument

Eff. Area	> 100 cm^2
F. o. v	50′ diameter
$S\Omega$	> 100 $cm^2 deg^2$
Angular resol.	3′ (16 x 16 pix)
Energy resol.	2 eV (FWHM)
Energy range	0.3 – 1.5 keV
Mission life	> 5 yr



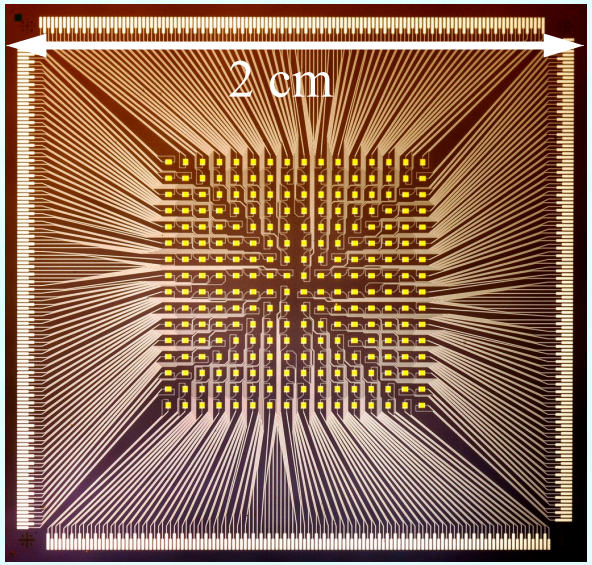
Hardware development in Japan



4-reflection X-ray telescope, with focal length 70 cm and ~100 cm effective area including TES efficiency
Energy range is up to 1.5 keV, and angular resolution is 3-4 arcmin

Poster by Y. Tawara

256 pixel array of TES microcalorimeter, showing ΔE= 4.4 eV without X-ray absorbers
Frequency-domain multiplexing under development

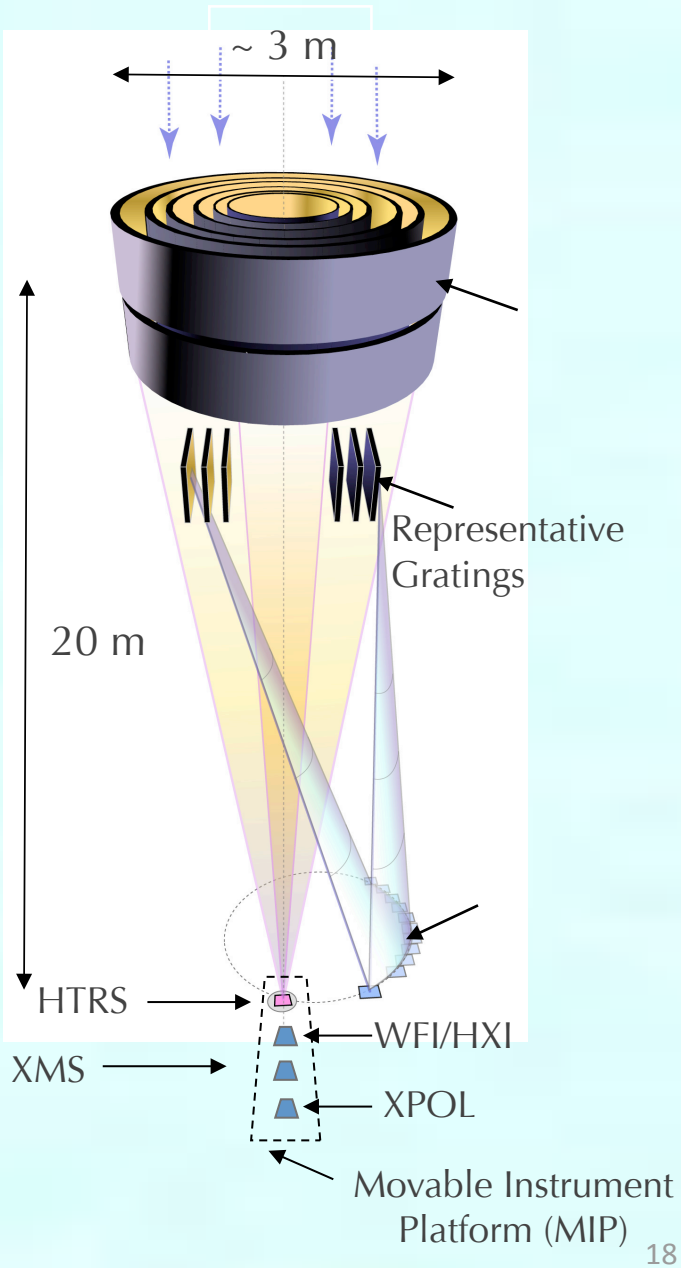


DIOS: schedule

- JAXA started small scientific satellite program:
- ~ 3 missions within 5 year timeframe
- 1st mission: Sprint-1 (Exceed, Tops) in 2012
  - UV spectroscopy of planets in solar system
- 2nd mission: ERG in 2013-2014
  - Shocks and particles in earth neighborhood
- 3rd mission: call for proposal in 2011, launch ~ 2016
  - Reasonably fits after the ASTRO-H launch (2014)
- We plan to propose DIOS for the 3rd mission
- All the resources developed for ASTRO-H will be used
- International collaboration will be essential

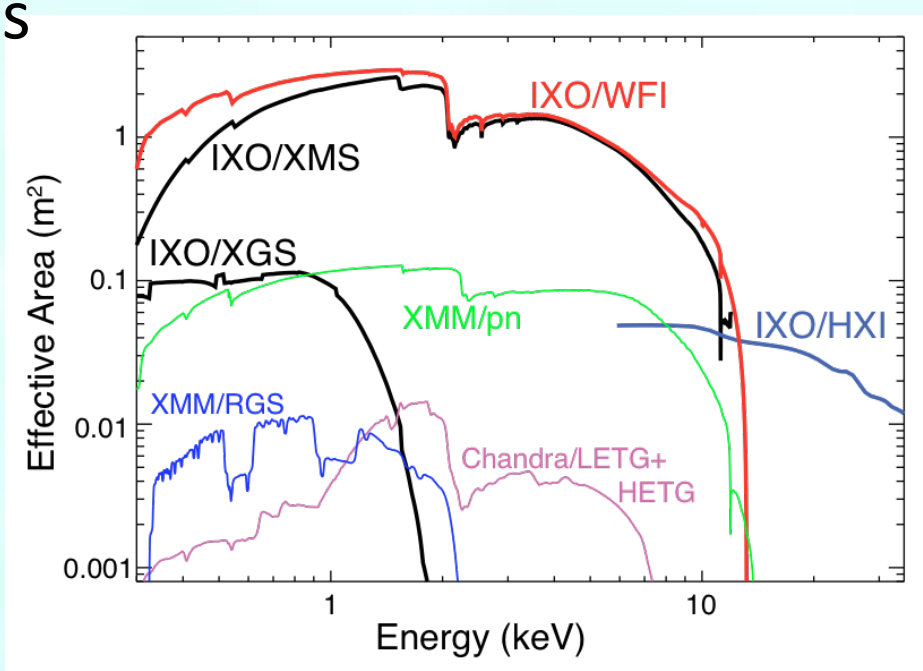
IXO: International X-ray Observatory

- NASA + ESA + JAXA collaboration
- Aiming for launch in 2021
- X-ray telescope with ~ 3 m^2 effective area
- Microcalorimeters: 5' fov with ΔE = 2-10 eV
- Grating spectrometer: 1000-3000 cm^2 with resolving power 3000



IXO: grating spectrometer

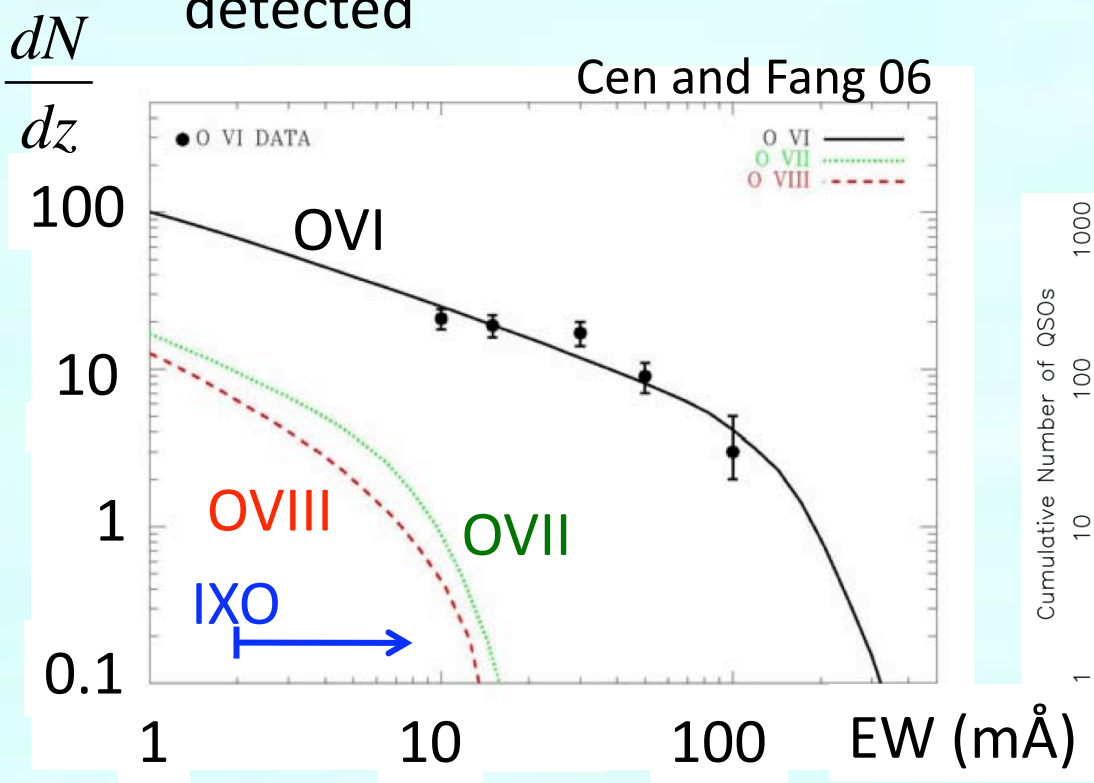
- Big jump from Chandra and XMM-Newton grating spectrometers by factor of 10 in effective area and 15 times higher sensitivity
- Sensitive to Equivalent Width ≈ 2 meV
- R = 3000 can resolve v = 100 km/s, such as structures of galactic winds

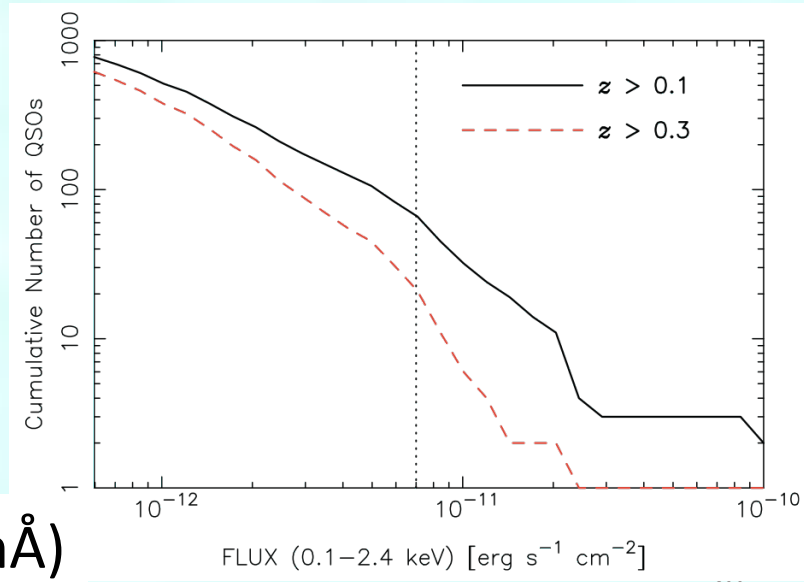


IXO: absorption study

- Detection of OVII, OVIII absorptions: WHIM presence beyond any doubt
- There are > 100 useful AGNs for absorption study
- Predicted *dN/dz* of OVII, OVIII clouds (normalized with OVI results) shows several absorption systems per AGN will be detected

Cen and Fang 06

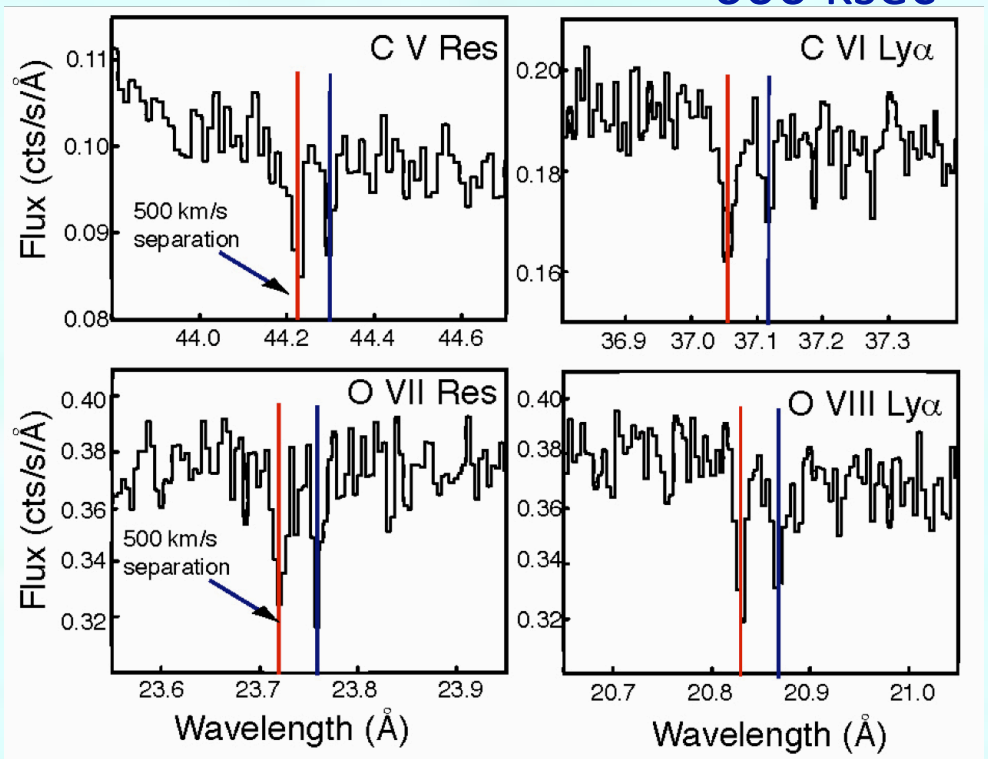




Expected absorption features

- AGN with $F_X = 5 \times 10^{-11}$ erg cm^{-2} s^{-1} (0.5 – 2 keV) will give enough signal for IXO
- A total of 18 Msec observations for ~ 30 AGN
  → 100 absorption clouds

600 ksec



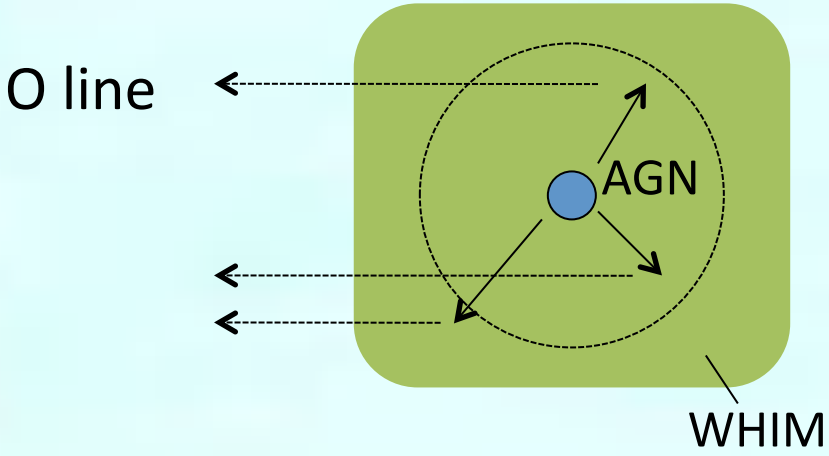
Bregman et al. IXO-WP

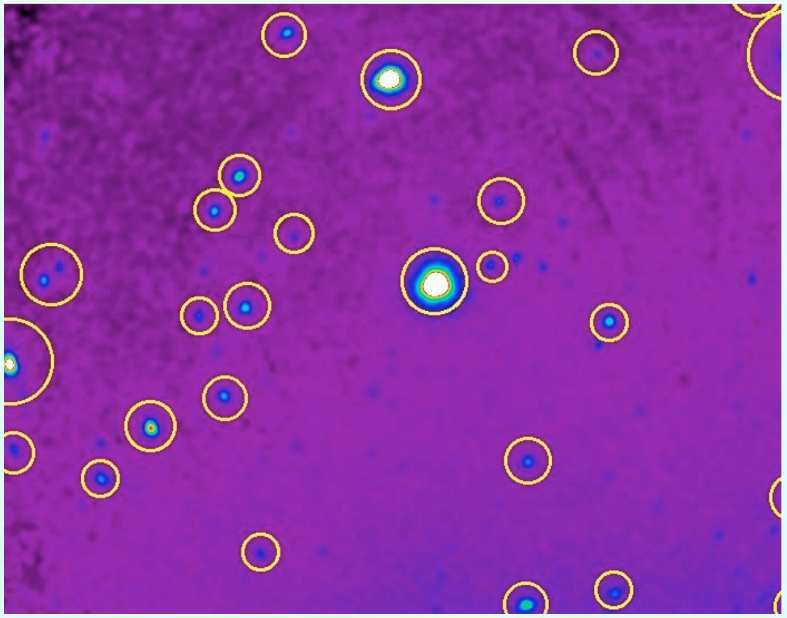
WHIM search using resonance scatting

- Churazov et al. 01, MN 323, 93
- WHIM can be surrounding bright AGNs
- Part of continuum X-rays undergoes resonant scattering by WHIM gas
- A few Mpc region around bright AGNs will shine in OVII and/or OVIII lines
- Rough estimation shows that an AGN with L_X = 10^{46} erg/s at z = 0.2 can produce about 100 OVII counts with IXO over ~ 5 arcmin region in 100 ksec observation

WHIM with resonance scattering

- Part of AGN X-rays will be resonantly scattered by OVII and OVIII ions in surrounding WHIM
- This will produce oxygen-line halos around AGNs





Churazov: High-res X-ray spectroscopy 2010

Summary

- WHIM will give us unique information about thermal and chemical evolution and galaxy formation in the universe
- For WHIM emission, Suzaku gives a typical upper limit of $\rho/<\rho>$ ~ 300 in cluster outskirts and in superclusters
- Majority of WHIM still awaits detection with improved X-ray and UV measurements
- We try to propose DIOS to JAXA's small satellite program for launch around 2016
- Although IXO will be powerful in detecting WHIM, direct mapping of large-scale WHIM distribution needs wide field high-resolution spectroscopy