X線天文学の将来計画と素粒子物理

満田和久
宇宙航空研究開発機構・宇宙科学研究所

高エネルギー物理学将来計画タウンミーティング 2011年7月29日@ IPMU大講義室

Non Baryonic matter

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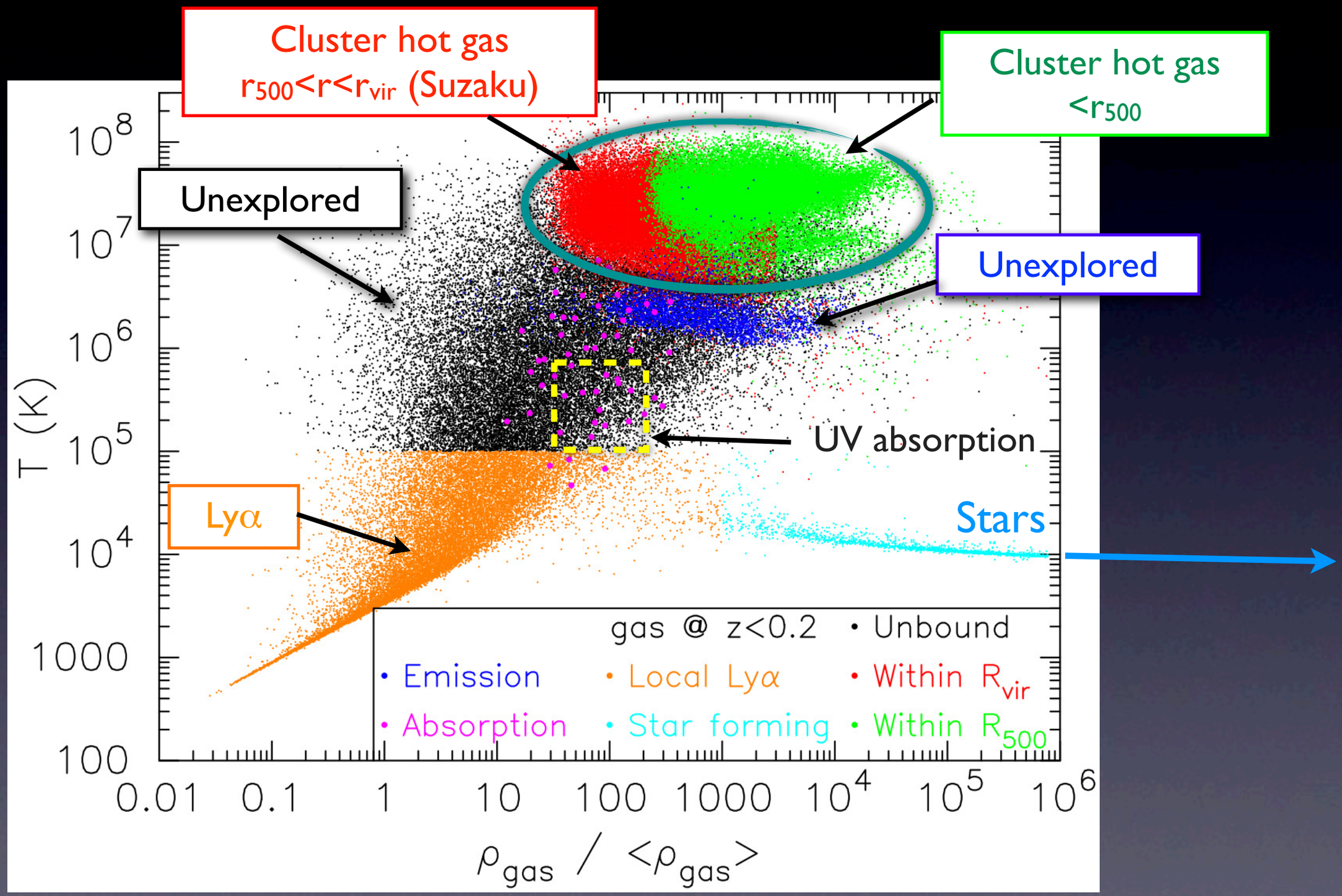
現在の宇宙のバリオン物質



Piro et al. (2009, simulation by Borgani et al. 2004)

Outline

- Clusters as cosmological tool
  - systematics limited
- Next-generation cluster study
  - Astro-H + eROSITA
- Future missions under discussion
  - Cluster with z >2
  - WHIM: Unexplored phase of Baryonic matter

Cluster as cosmological tool

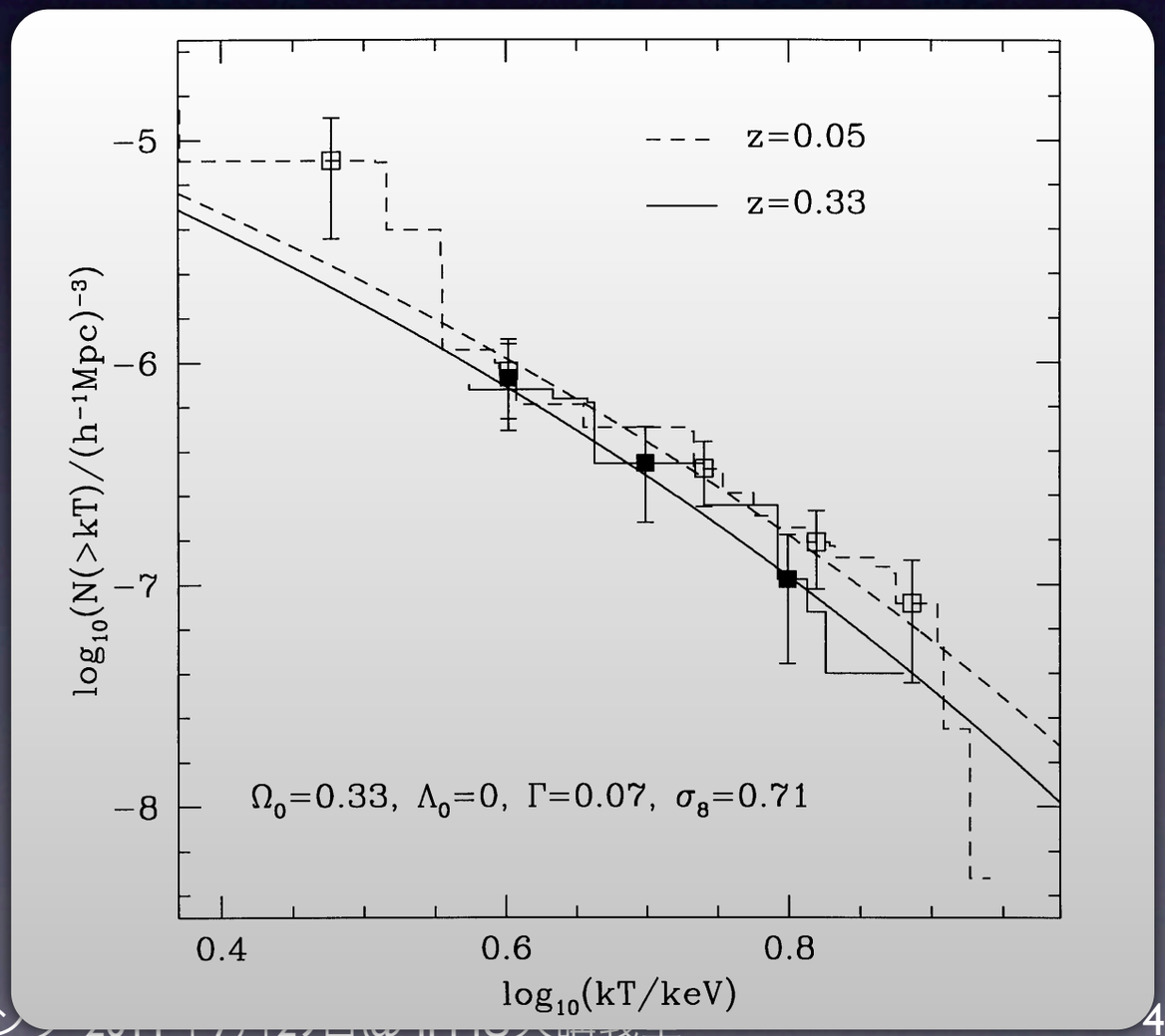
- Cluster進化: 宇宙の密度と膨張速度に依存
- Gas mass ratio, $f_{\rm gas}$, of cluster: "standard candle"(?)

Eke et al. 1998

温度関数

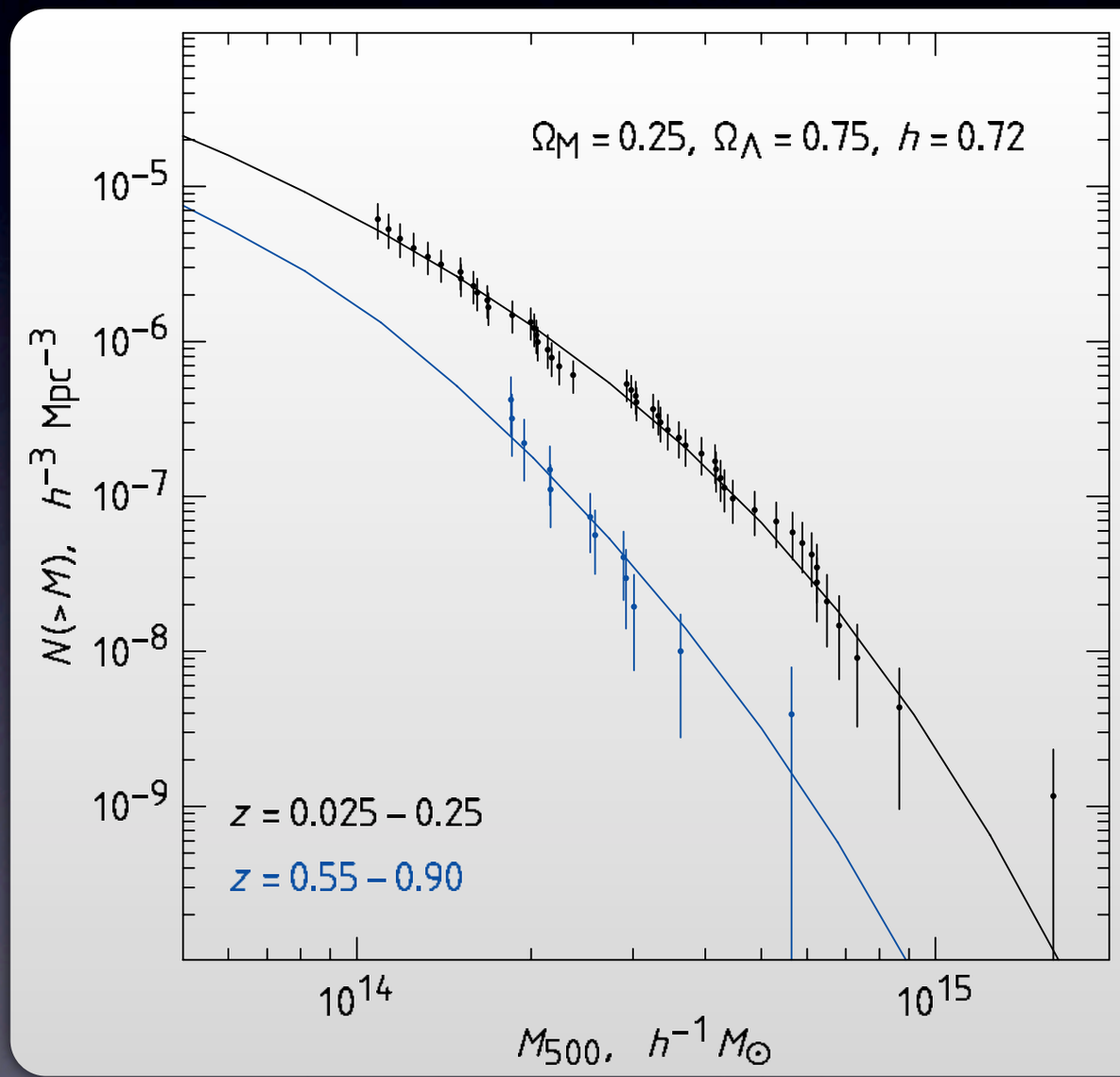
Best fit parameter

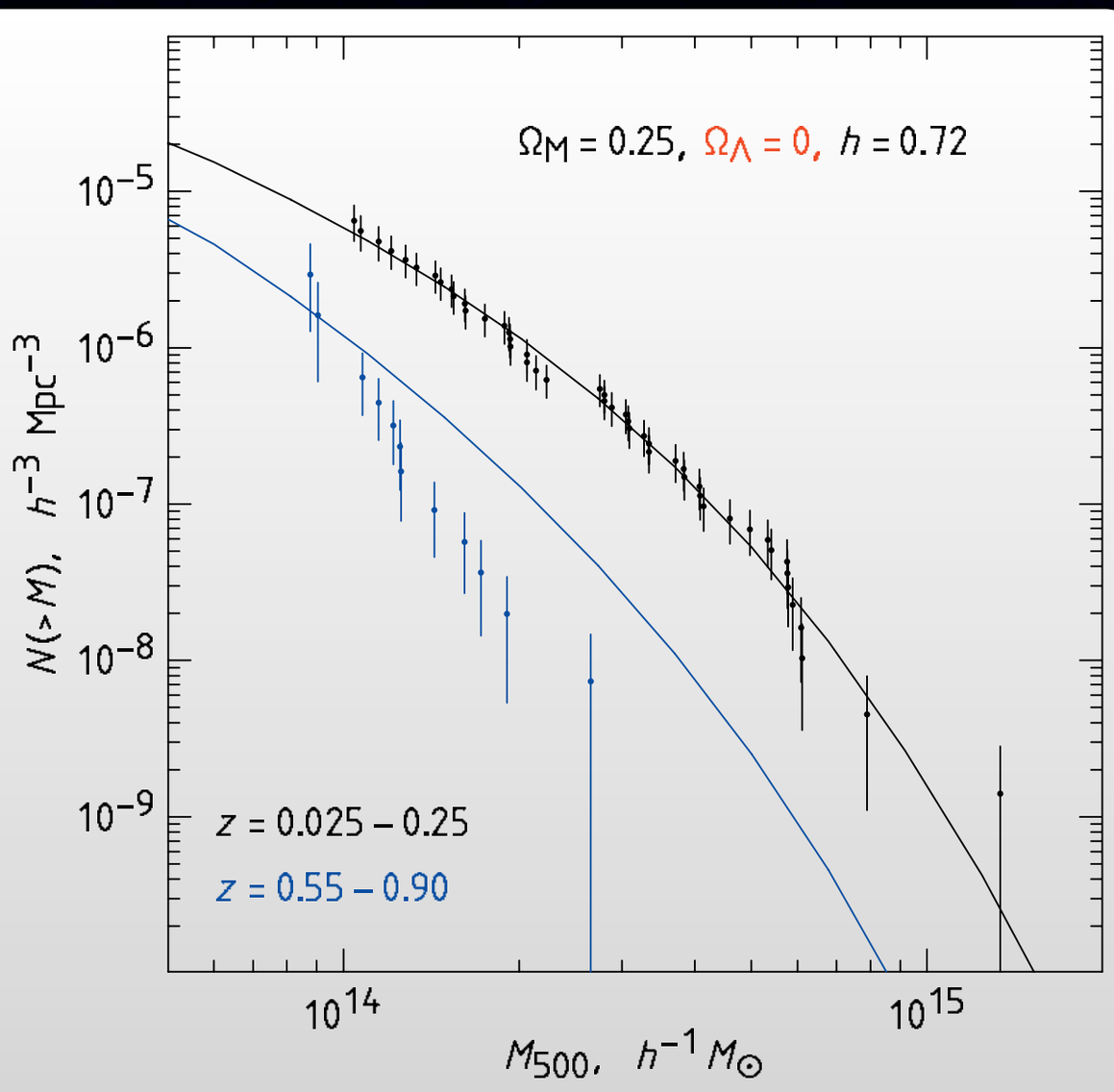
$$\Omega_{\rm M} = 0.45 \pm 0.25$$



Cluster 進化

質量関数

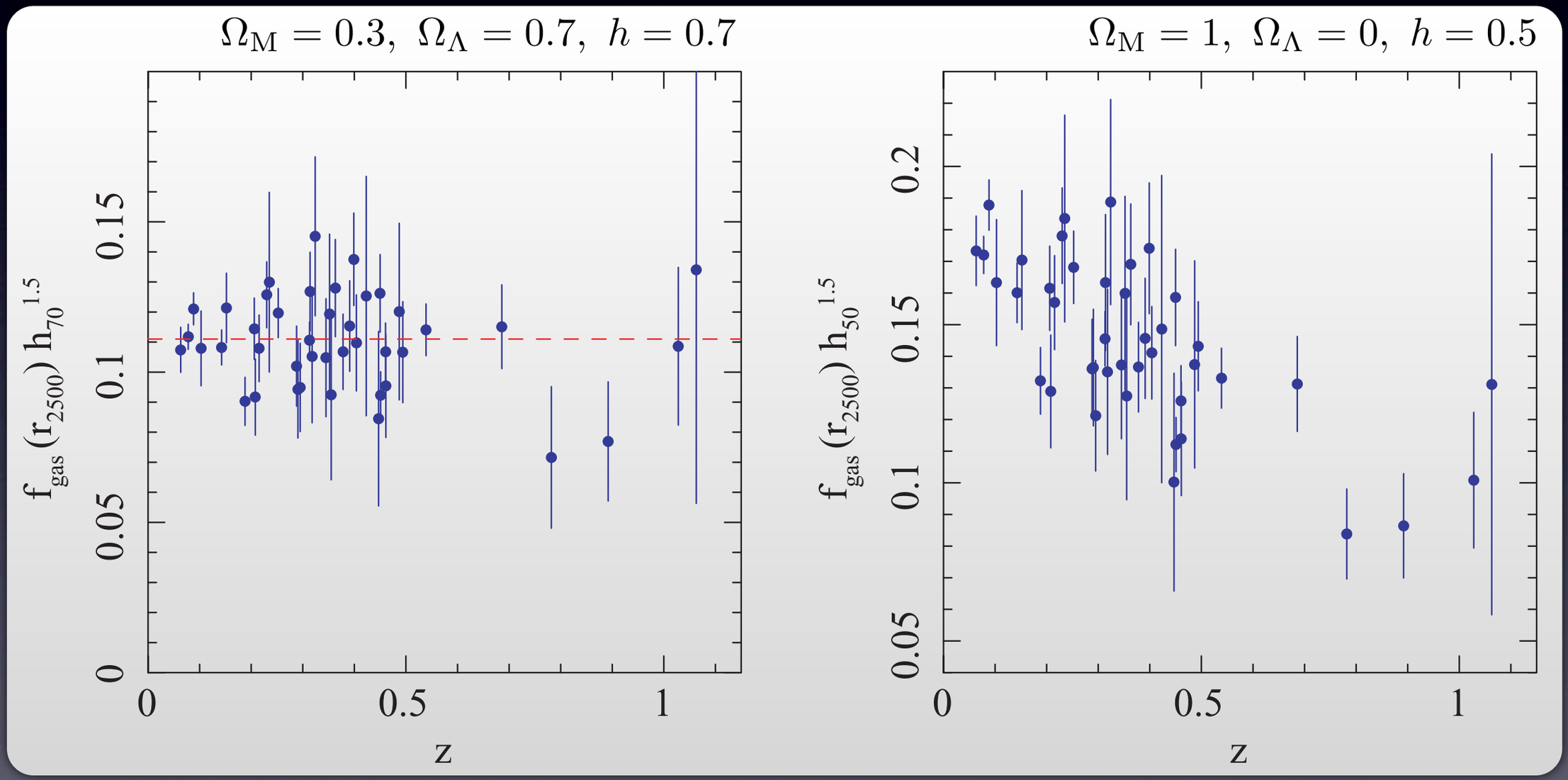




37 Chandra clusters, Vikhlinin+2009

Gas-mass ratio, $f_{\rm gas}$

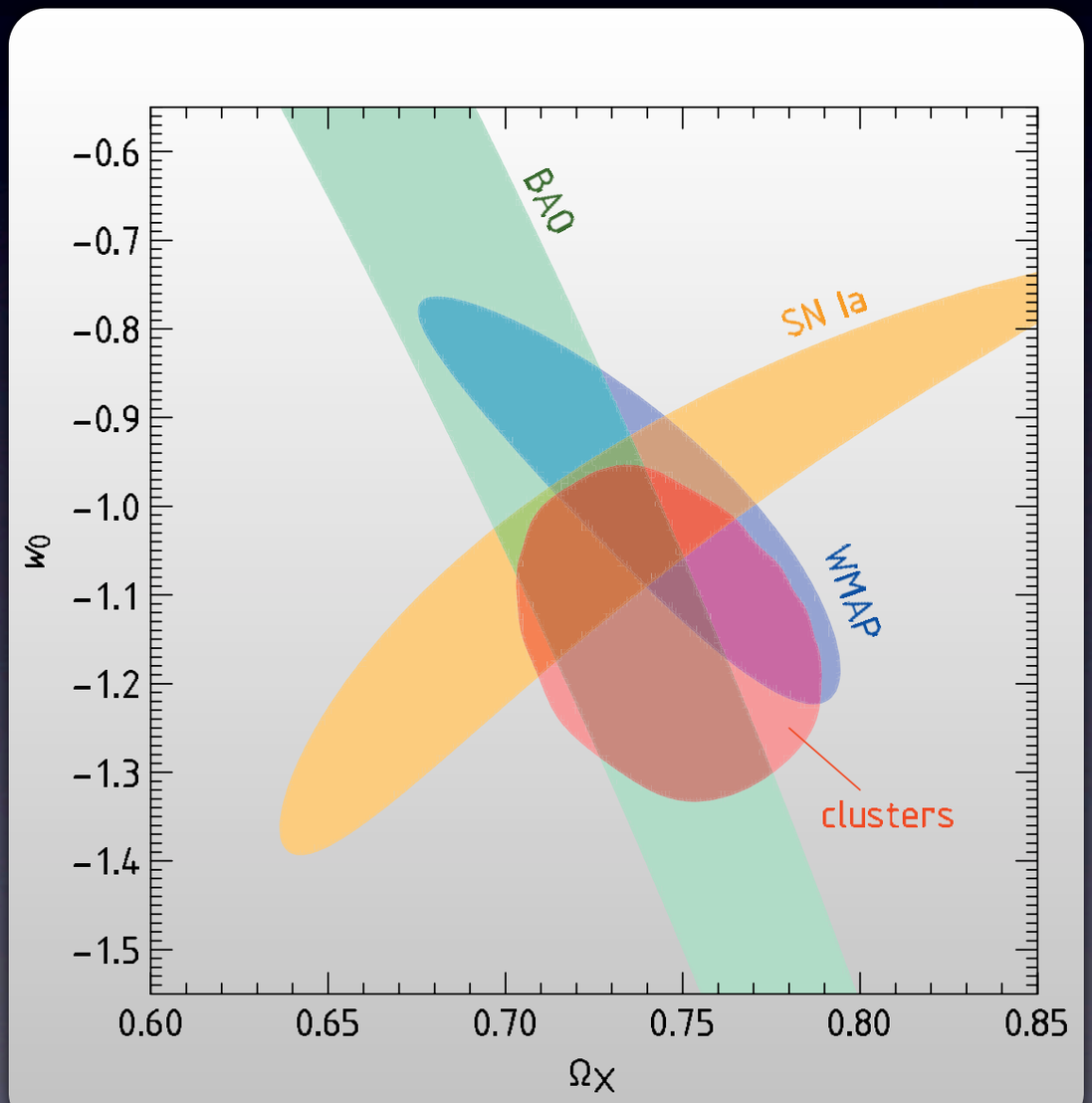
$$f_{\rm gas} \equiv \frac{M_{\rm gas}}{M_{\rm tot}} \propto \frac{d^{2.5}}{d} = d^{1.5}$$ (Sasaki 1996)



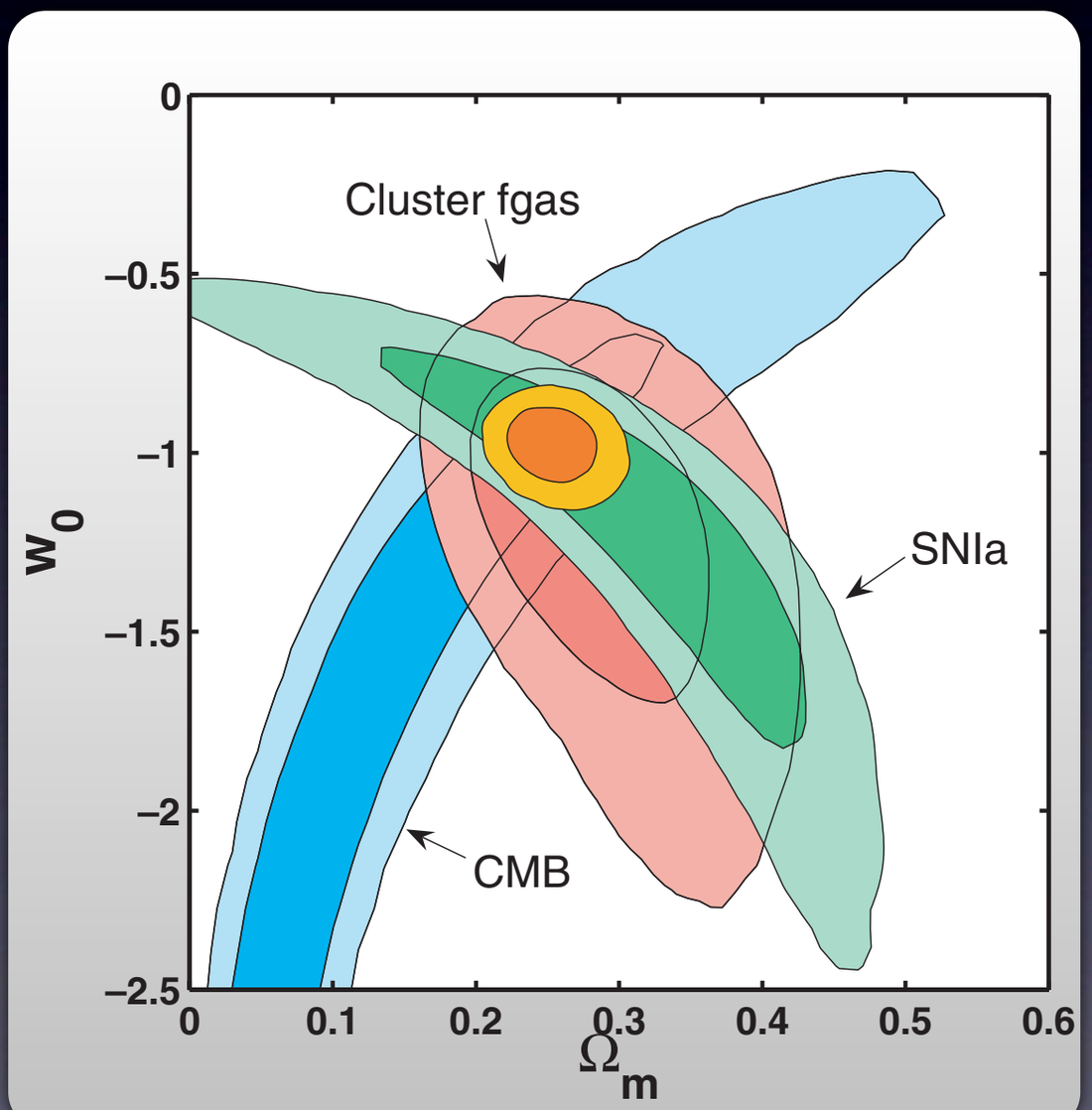
42 Chandra clusters, Allen+2008

w_0 from clusters

Cluster evolution (Vikhlinin+2009)



$f_{\rm gas}$ (Allen+2008)



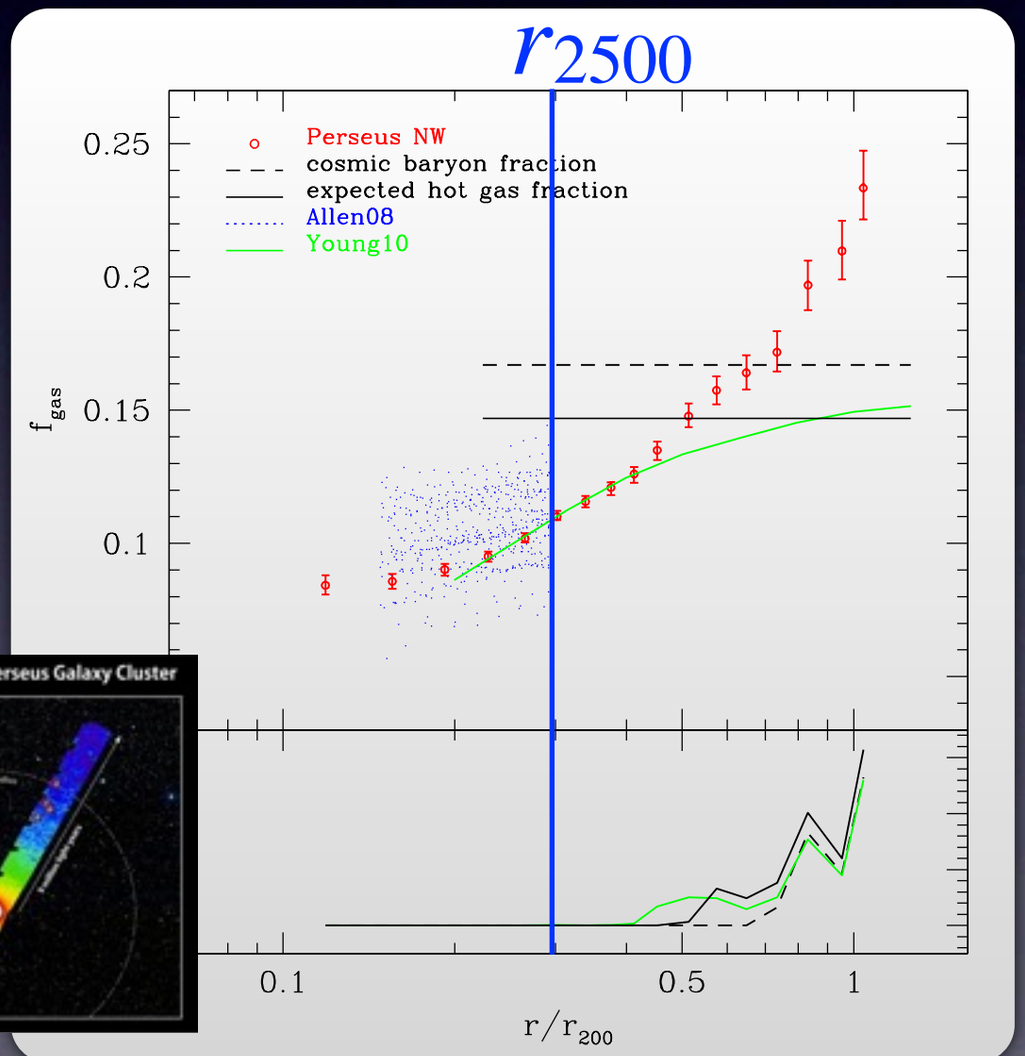
$f_{\rm gas}$ は universal か?

$$f_{\rm gas}^{\Lambda{\rm CDM}}(z) = \frac{K\,A\gamma b(z)}{1+s(z)}\left(\frac{\Omega_{\rm b}}{\Omega_{\rm m}}\right)\left[\frac{d_{\rm A}^{\Lambda{\rm CDM}}(z)}{d_{\rm A}(z)}\right]^{1.5}$$

(Allen+2008)

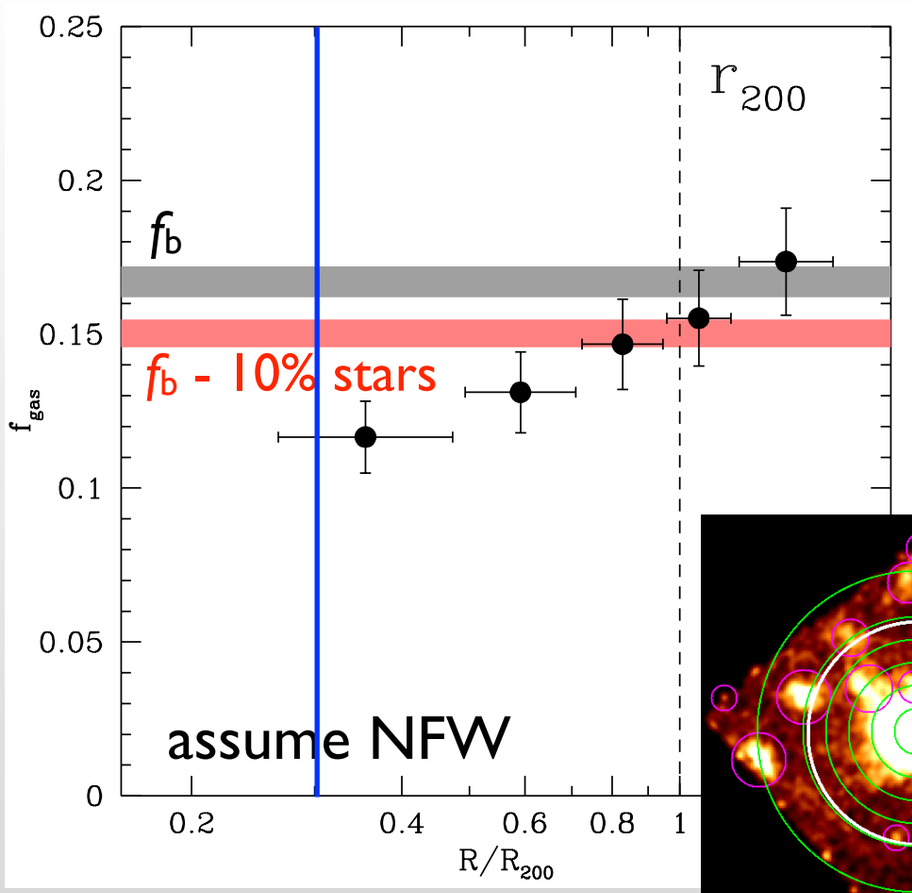
Suzaku observations of outer region of clusters

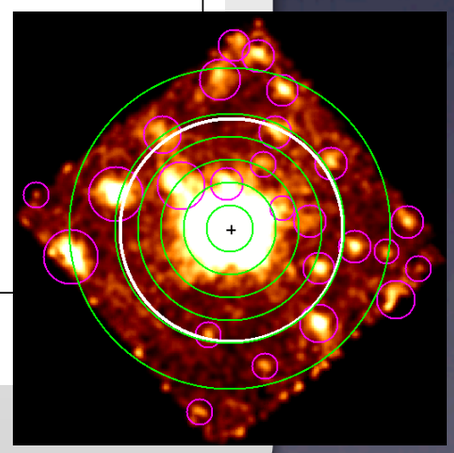
Perseus cluster



(Simionescu+2011)

RXCJ0605





(Miller+2011)

Non-thermal pressures

質量推定

$$\frac{d}{dr}[P_{\rm g}+P_{\rm k}+P_{\rm mag}+P_{\rm cr}]=-\rho_{\rm g}\frac{GM_r}{r^2}$$

Resonant scattering
X-ray Line center

~30% (?)

XMM: Sanders+2010
Suzaku: Tamura+2011

Astro-H SXS

Rotation measure
Radio+Hard X-ray

~ 1% (?)

Swift: Ajello+2009
Suzaku: Ota+2011

Astro-H HXI system

$P_{\rm g}$の~10%あれば
Fermiでみえるはず
Reimer+2004

開発中の X線ミッション

- ASTRO-H (Japan + US + Europe) 2014
  - High resolution X-ray spectroscopy: Kinetic pressure
  - Imaging hard X-ray spectroscopy: magnetic pressure of clusters
- eROSITA (Germany + Russia) 2013
  - High sensitivity X-ray all sky survey with medium energy resolution: detection of ~7,000 clusters (>1000 photons) up to z~1.5

Astro-H

- 次の日本の major X-ray astronomy mission
- “X-ray observatory”，国際協力: 日+米 にヨーロッパの参加
- 2014年打ち上げ予定
- Scientific objectives
  - revealing the large-scale structure of the universe and its evolution
  - understanding the extreme conditions in the universe
  - exploring the diverse phenomena of the non-thermal universe
  - elucidating dark matter and dark energy
- High-resolution soft X-ray spectroscopy and wide-band imaging X-ray spectroscopy

Astro-H science payloads

Hard X-ray Imaging System (HXIS)

5-80 keV

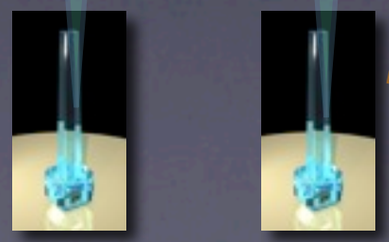
ΔE=1.5 keV@60keV

9'x9'x FOV

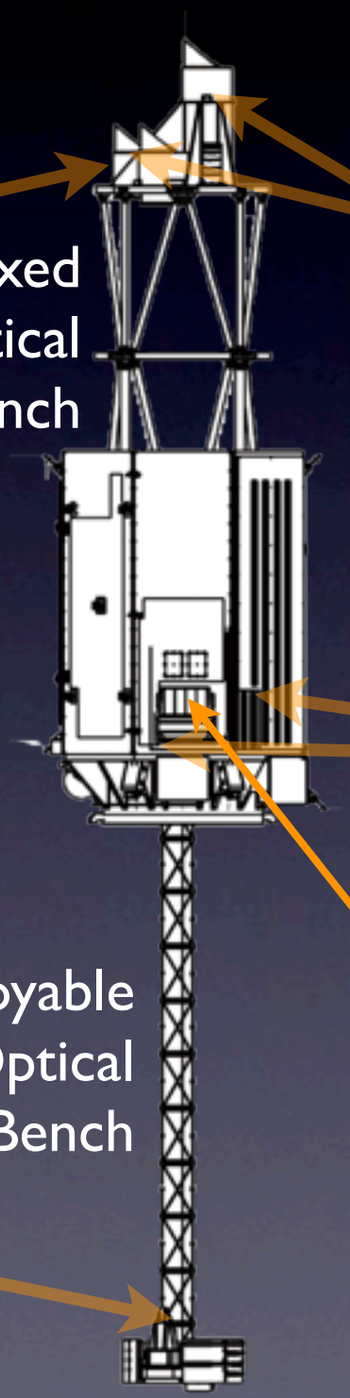
Multi-layer coated thin-foil mirrors

Focal Length = 12 m

CdTe & SI double-side strip detectors



Fixed Optical Bench



Deployable Optical Bench

Soft X-ray Spectrometer (SXS)

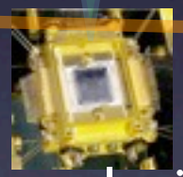
0.3-12 keV

$\Delta E \leq$ 7eV

3'x3' FOV

Thin-foil mirrors

Focal Length = 5.6 m



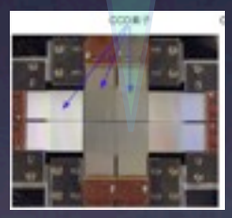
micro-calorimater array

Soft X-ray Imaging system (SXIS)

0.3-12 keV

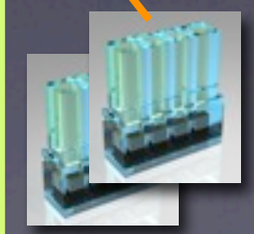
$\Delta E \leq$ 150eV@6keV

38'x38' FOV



X-ray CCD

Non-imaging Soft γ-ray detectors (SGD)



30-600 keV

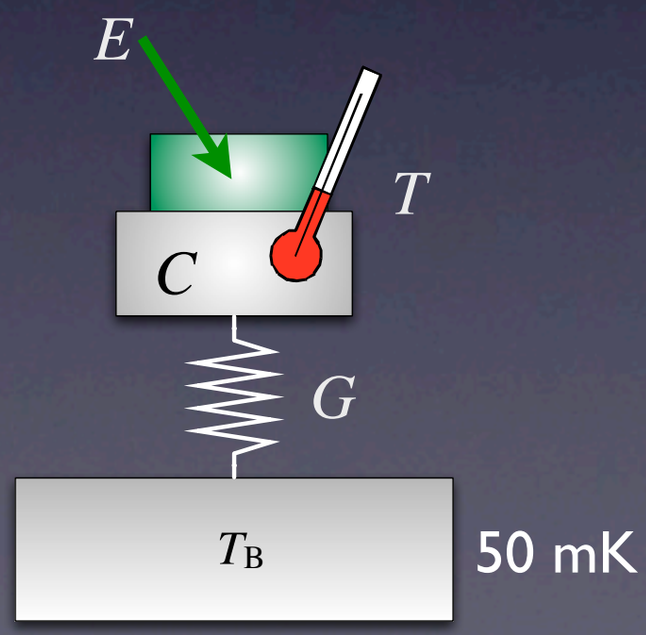
ΔE = 2keV@40 keV

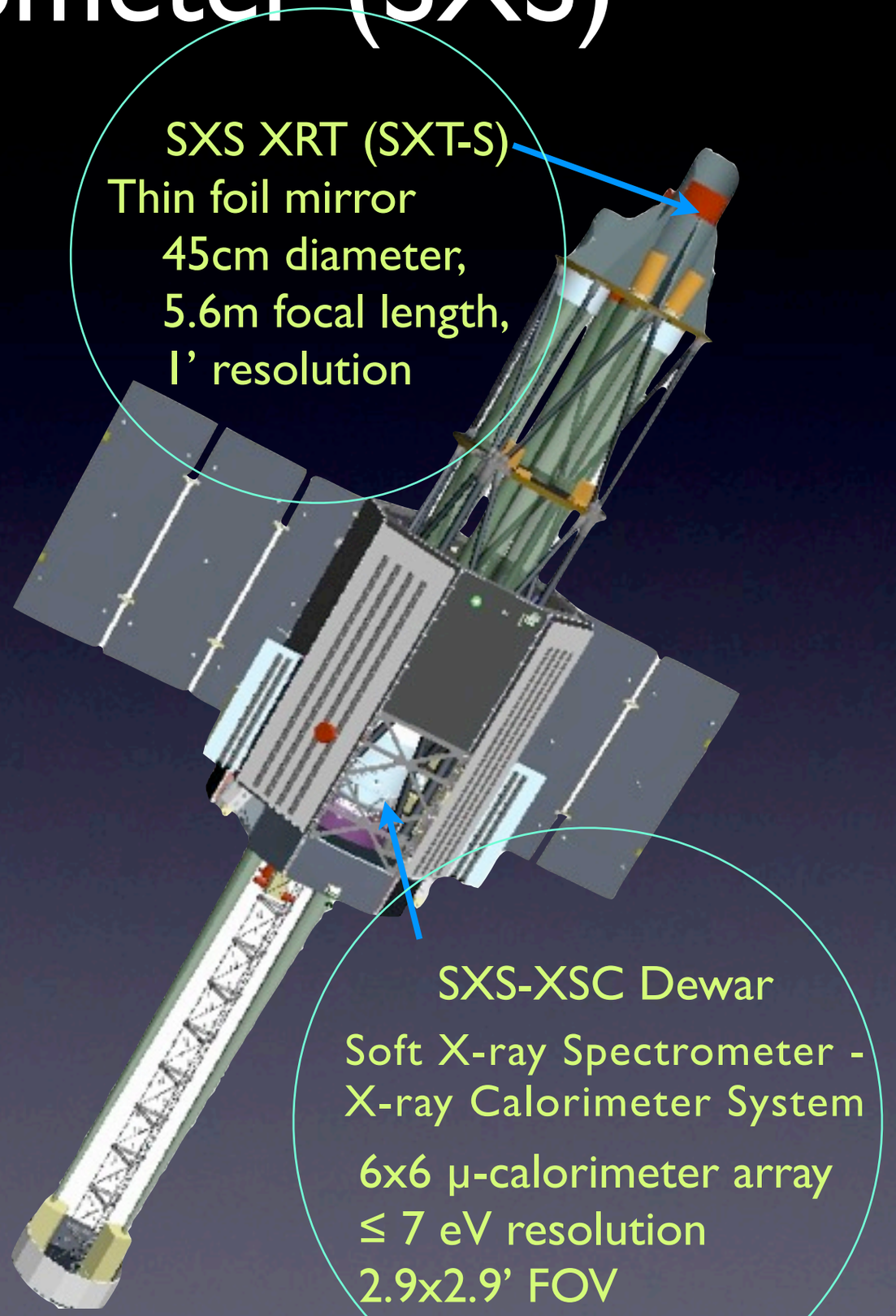
0.6°x0.6° FOV

Soft X-ray Spectrometer (SXS)

- High resolution X-ray spectrometer using a microcalorimeter array
- High Energy resolution (FWHM<7eV) and modest imaging (6x6) capabilities
- Will be most sensitive high-resolution spectrometer ever built for energies above ~ 1 keV
- No degradation of energy resolution for spatially extended sources
- Recovery of Suzaku XRS with improved sensitivity

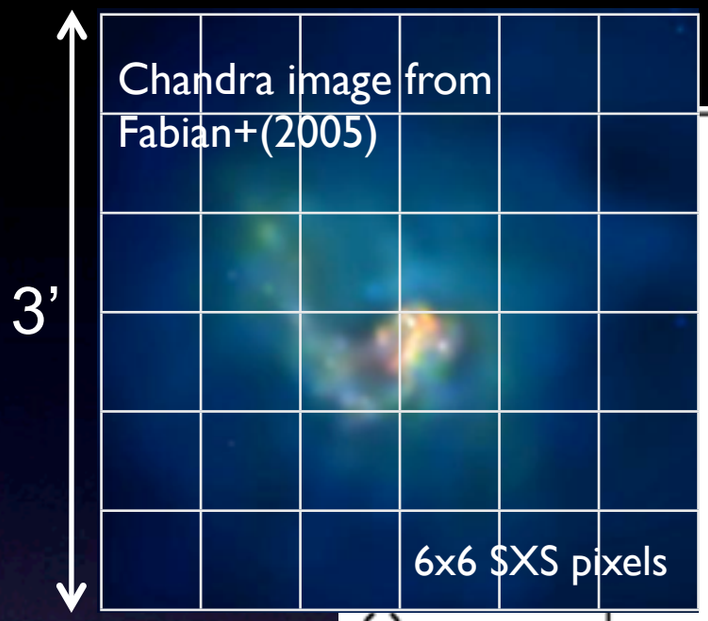
Microcalorimeters
- High quantum efficiency
- Imaging capability

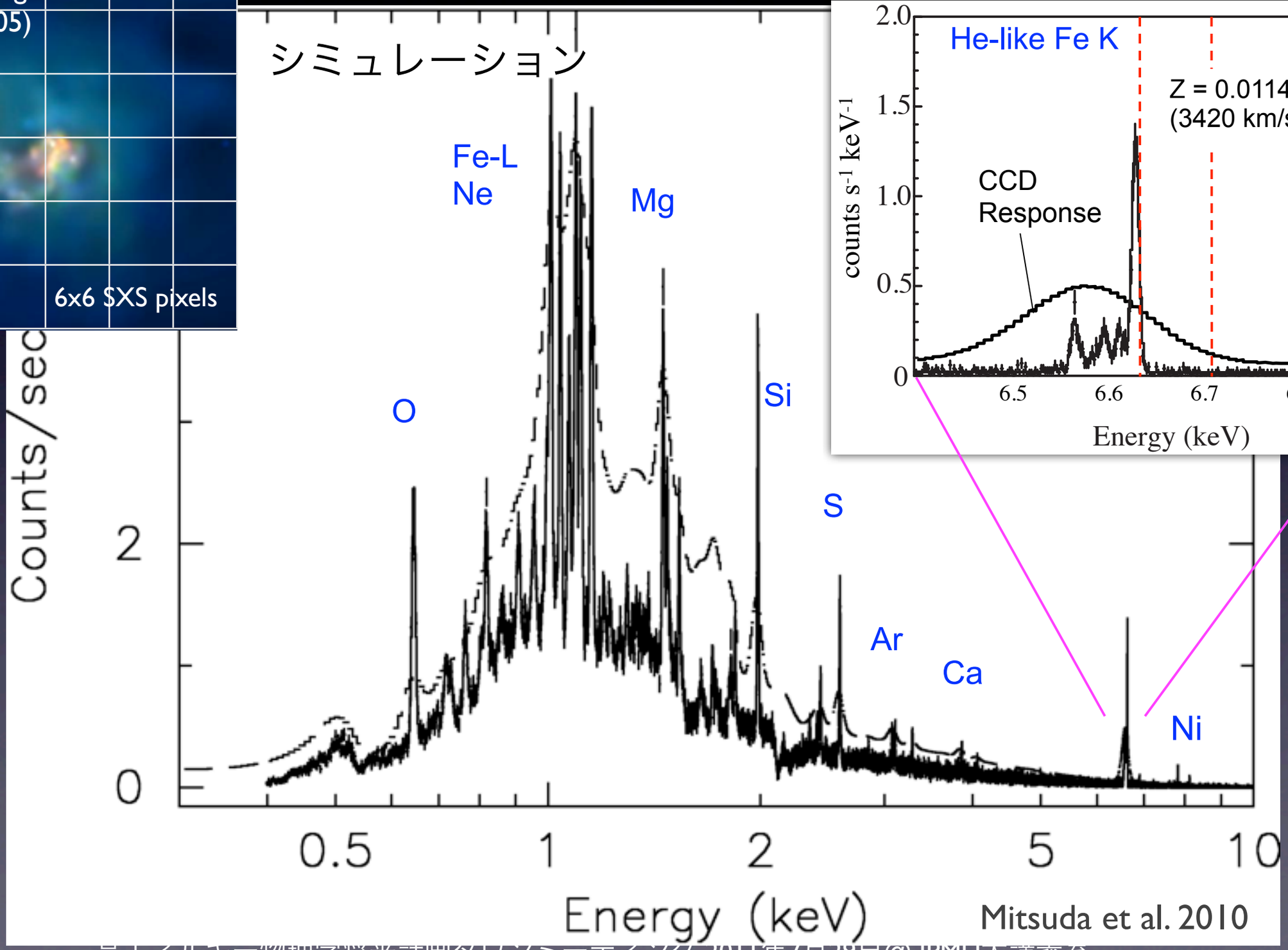


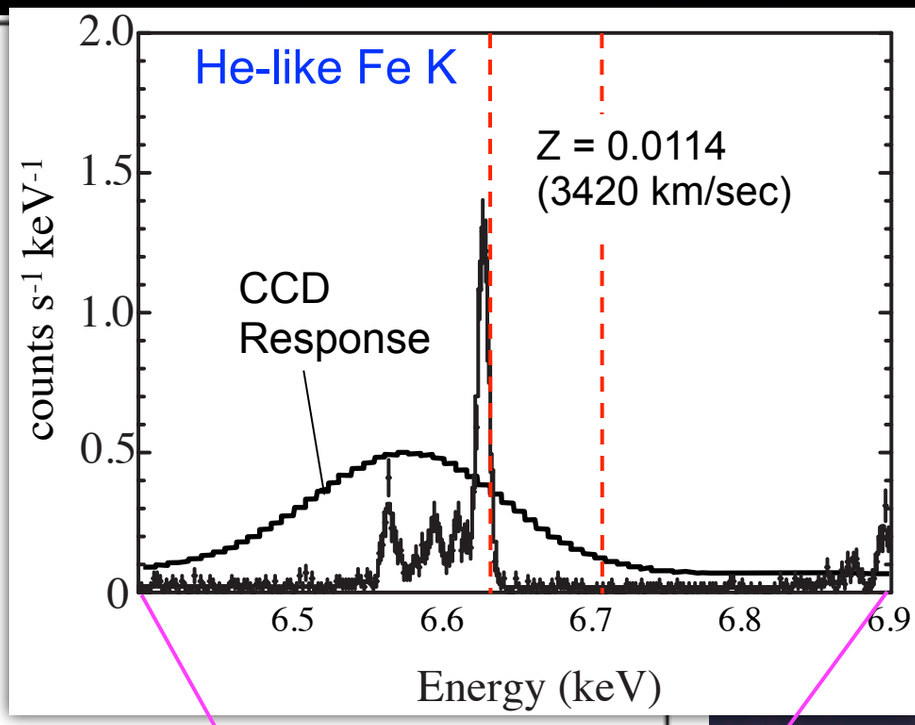


Cluster with SXS

ケンタウルス座銀河団



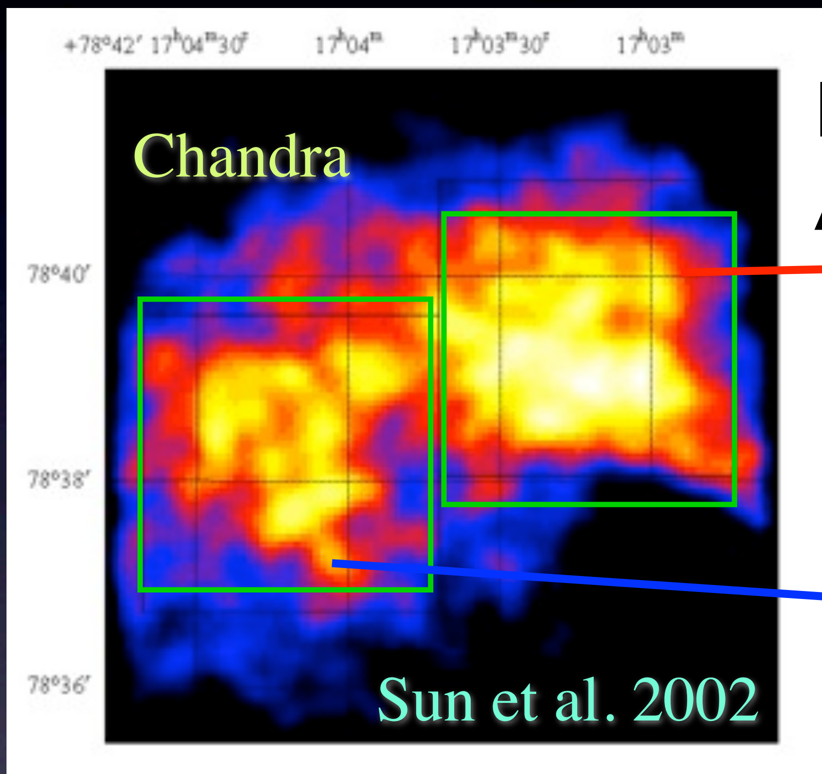




Kinematic motion

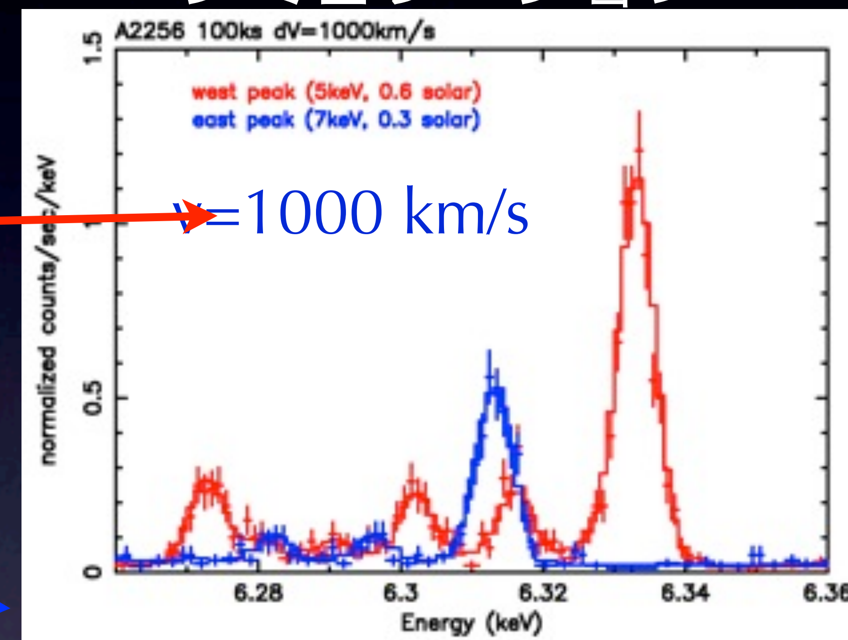
(Probed down to ~100km/s)

衝突する銀河団A2256

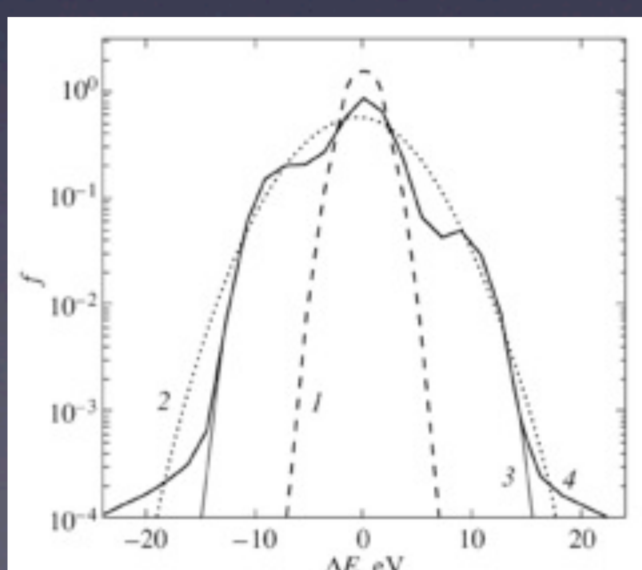


Merger, A2256 (z = 0.058)

シミュレーション

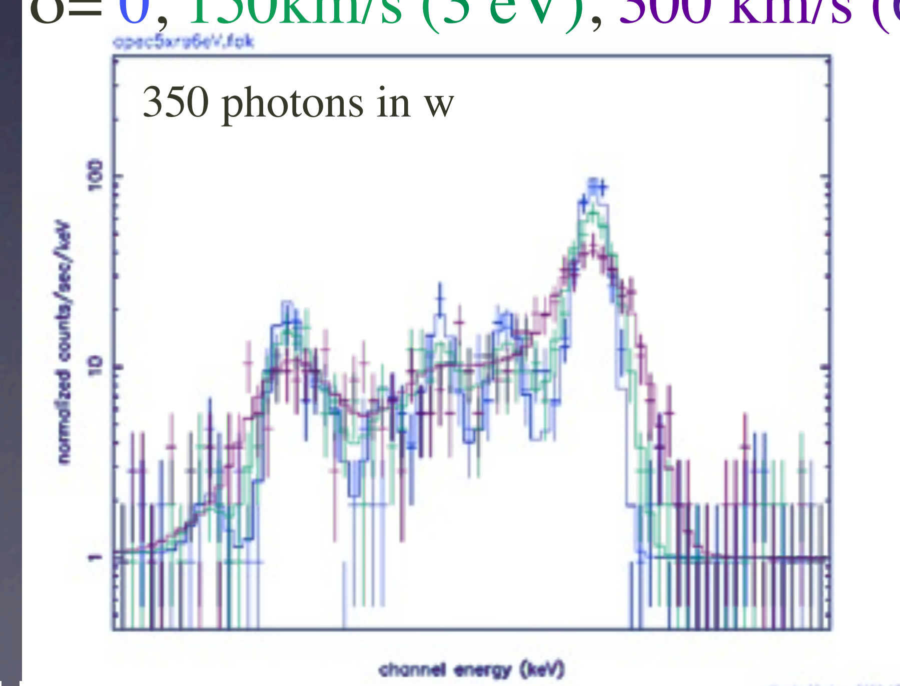


Turbulence

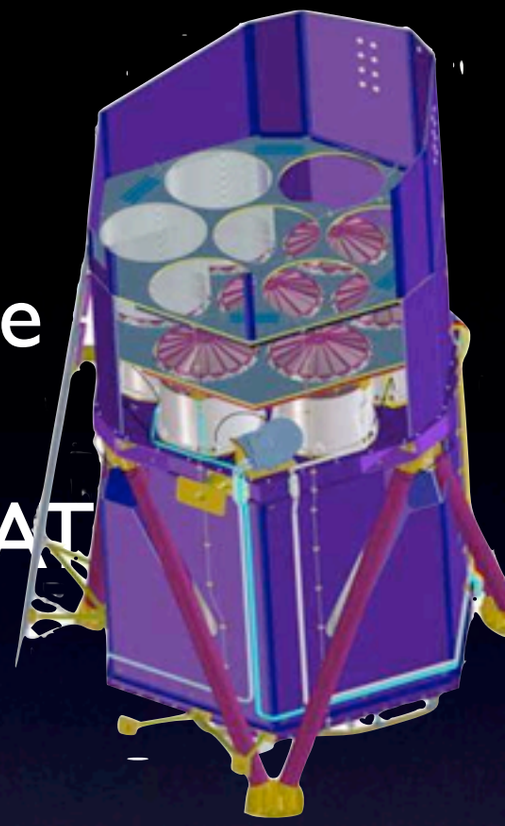


Inogamov and Sunyaev 2003

σ= 0, 150km/s (3 eV), 300 km/s (6 eV)



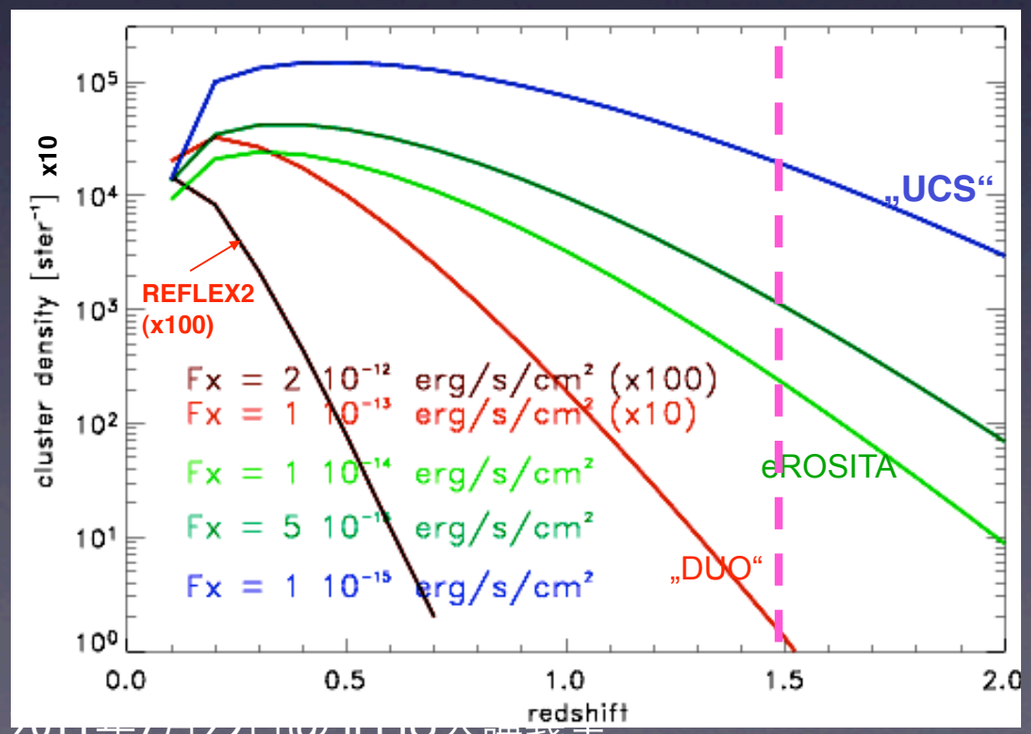
eROSITA



- "All sky X-ray survey mission" on SRG satellite
  - Much better spatial resolution, sensitivity, & spectral resolution (30") compared to ROSAT
- Germany + Russia
- Planned to be put in orbit in 2013
- Detection of 100000 clusters (>100 photons)

7000 clusters (>1000 photons)up to z ~1.5

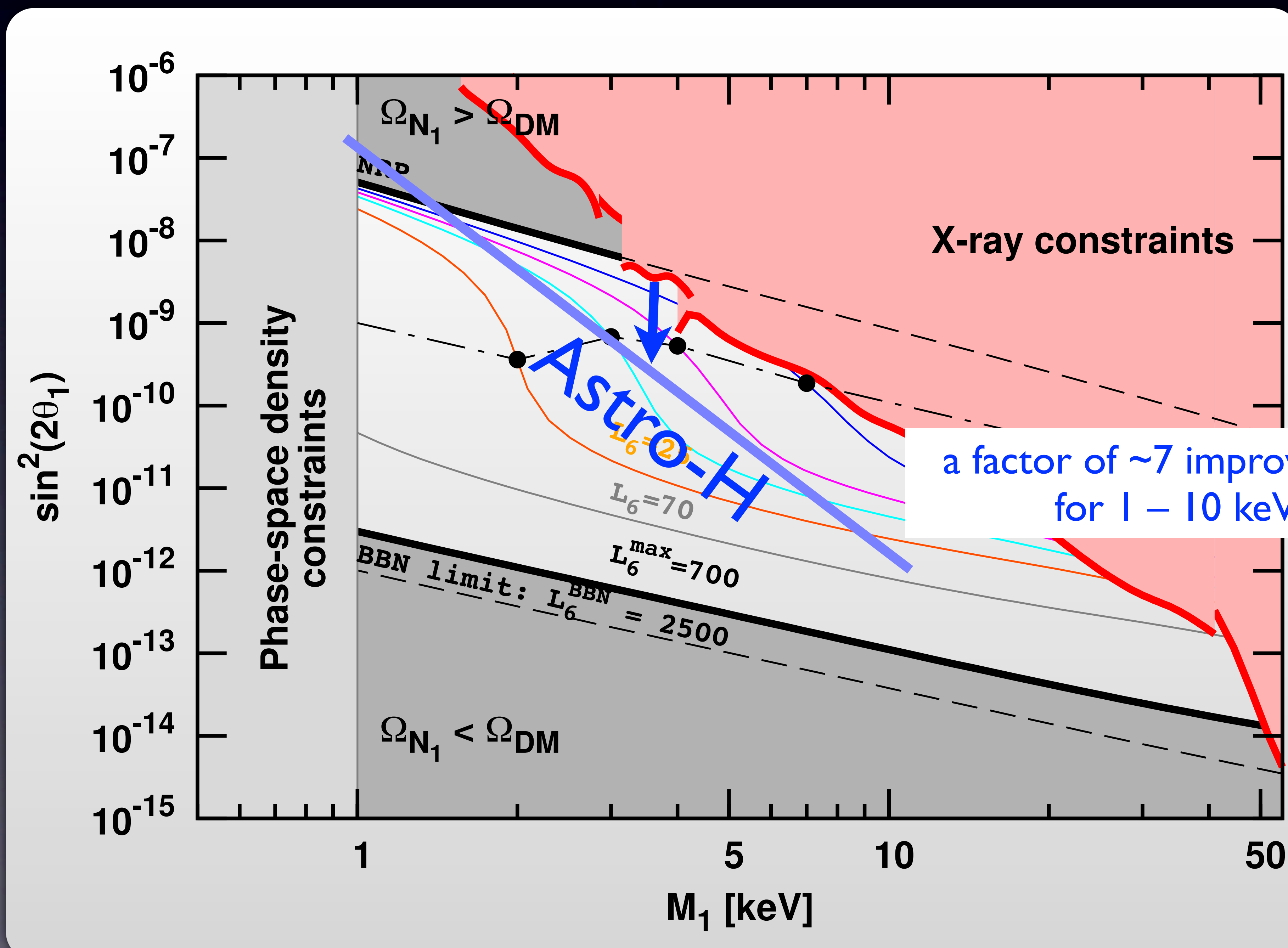
- Synergy with Astro-H
  - 10^4 cluster samples z<1.5 calibrated with local sample by Astro-H
  - Mass function, f_{gas}, BAO



Sterile Neutrinos

$$S/N = \sqrt{\frac{N}{1+\Delta E/EW}}$$

	Suzaku		Astro-H
ΔE	~200 eV	→	4 eV



Boyarsky et al. (2009)

Astro-H と eROSITAの先へ

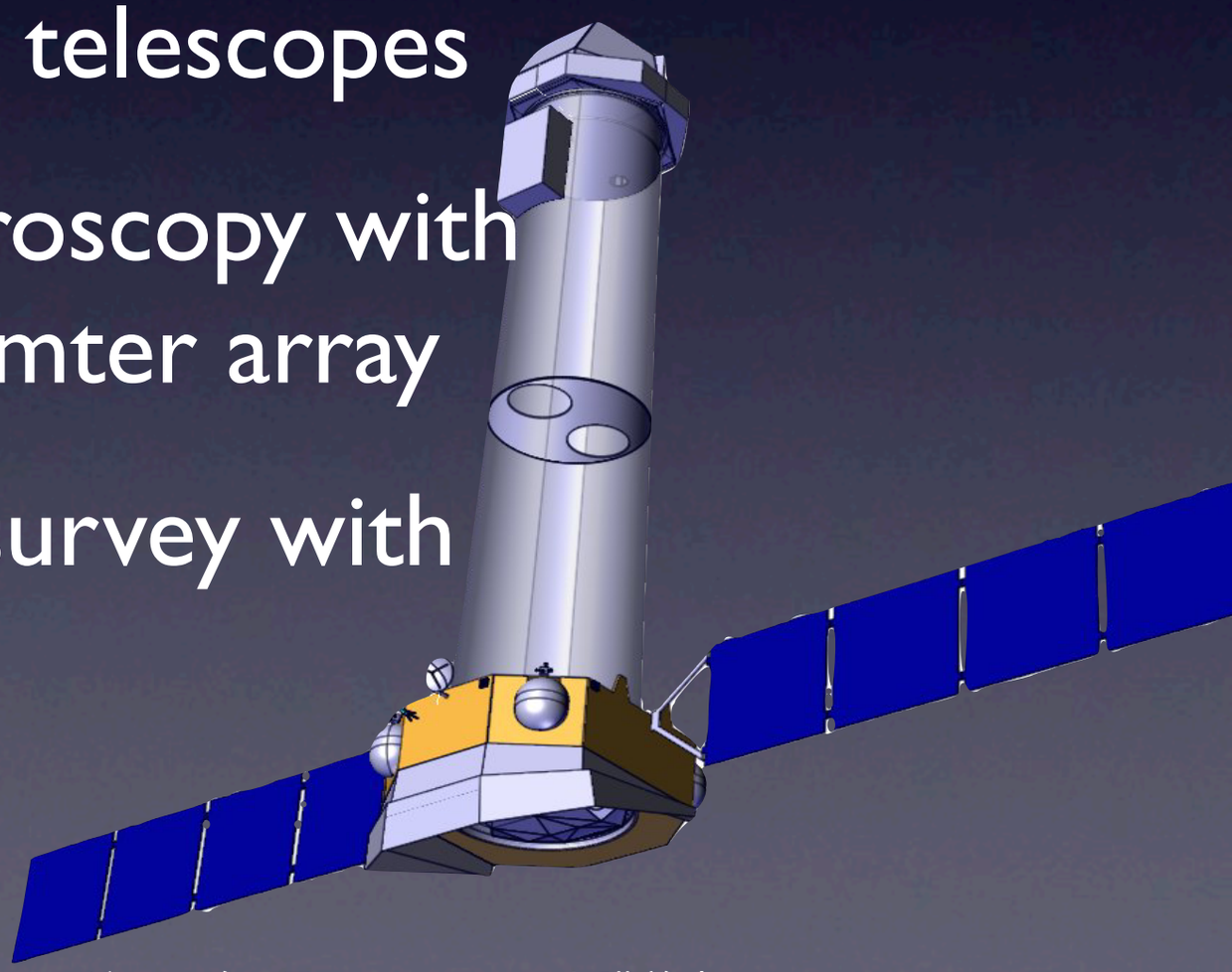
- Under discussion
  - High resolution spectroscopy of distant clusters (z ~ 2 and beyond)
    - “Observatory” type mission
      - Athena (ESA + Japan+US)
  - Probing ‘unexplored’ phase of baryonic matter
    - “Survey” type small mission (survey of selected sky areas)
    - DIOS, DIOS+ (Edge, Xenia..) (Japan + Europe+US)

Athena

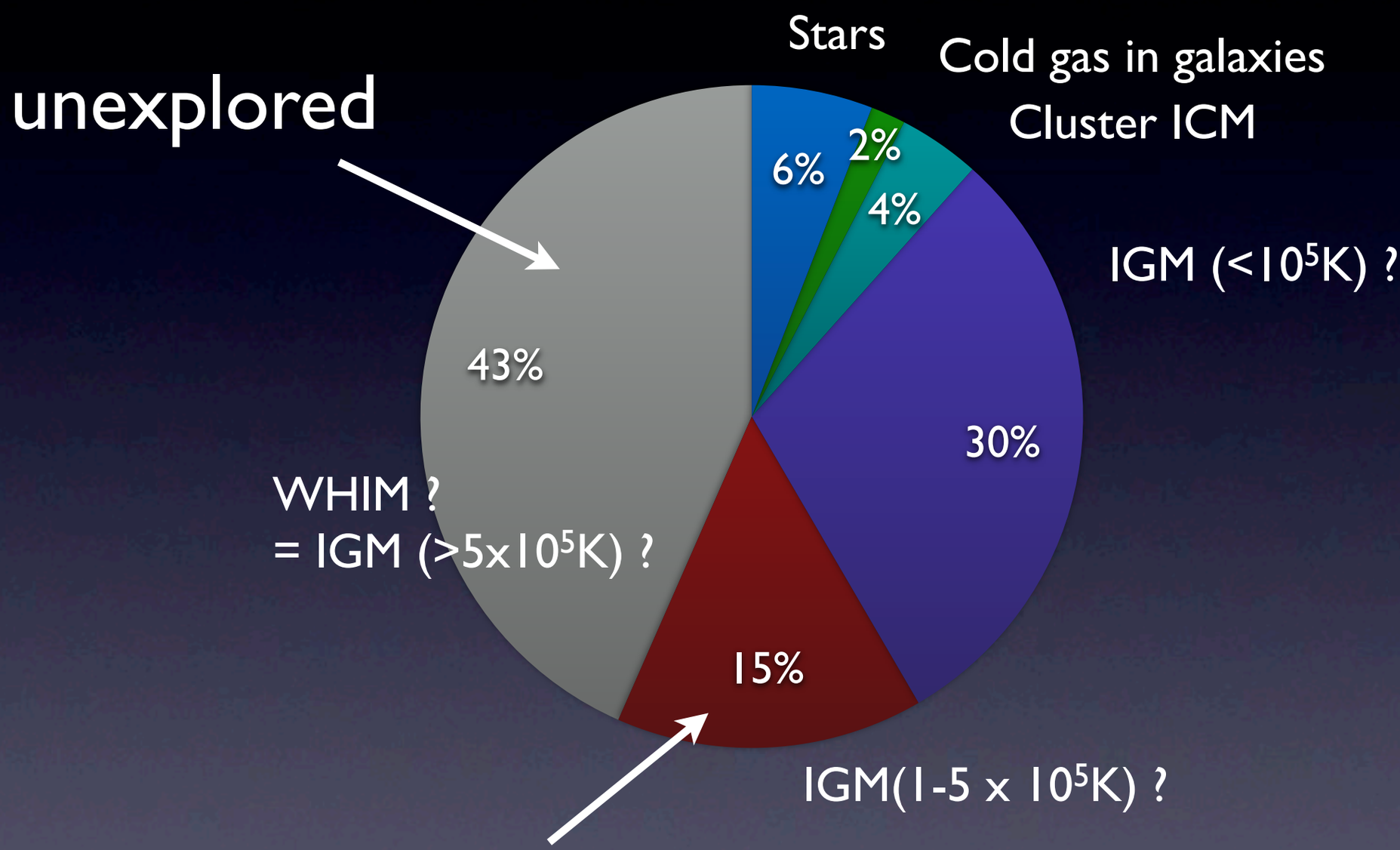
- Key science
  - Probe the behavior of matter moving around black holes.
  - Determine how supermassive black holes grow in obscured environments in galaxy centers
  - Trace the formation of Large Scale Structure through the fate of hot baryons in galaxy clusters, their structure and evolution.
  - Study the physics of feedback, by measuring the energy deposited by starbursts and AGNs galaxies, clusters and beyond.
  - Study hot cosmic plasmas on all astrophysical environments, from solar system bodies to stars, galaxies and beyond.
- Science instruments
  - Two science instruments

Athena

- Proposed as a L-class mission to ESA cosmic vision. target launch date: 2022
- ESA + J+US
- Two 11 m focal length telescopes
- High resolution spectroscopy with >1 k pixel microcarolimter array
- High sensitivity deep survey with SDD array



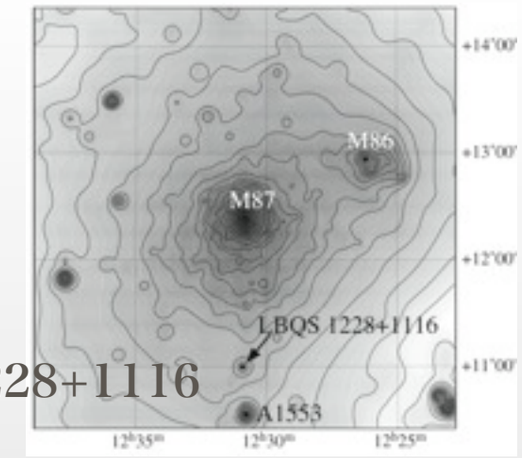
Unexplored phase of Baryonic matter



Fukugita & Peebles (2004)
Bregman (2010)

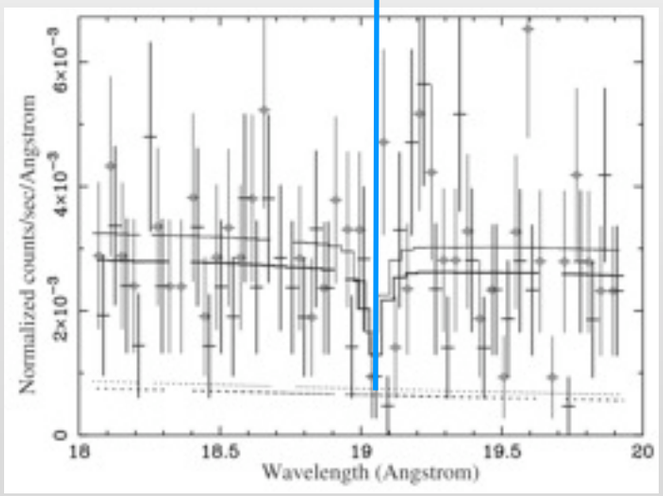
WHIMのしっぽ

Virgo cluster



LBQS1228+1116

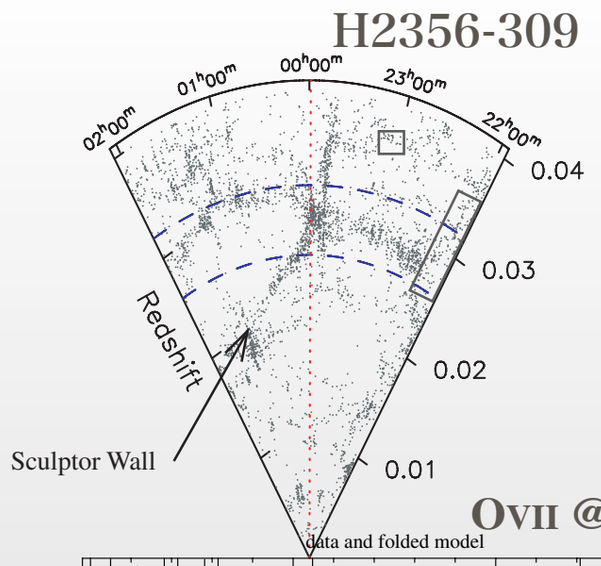
OVII @ z =0.004



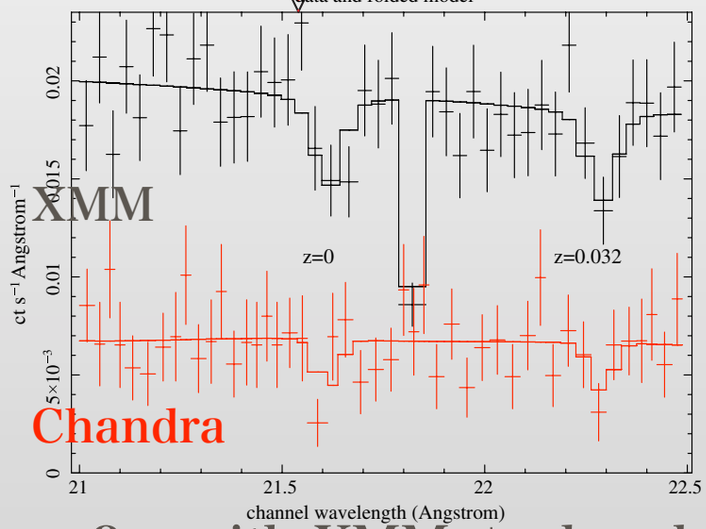
2.8-σ with XMM

Fujimoto+2004

Sculptor wall



OVII @ z =0.032

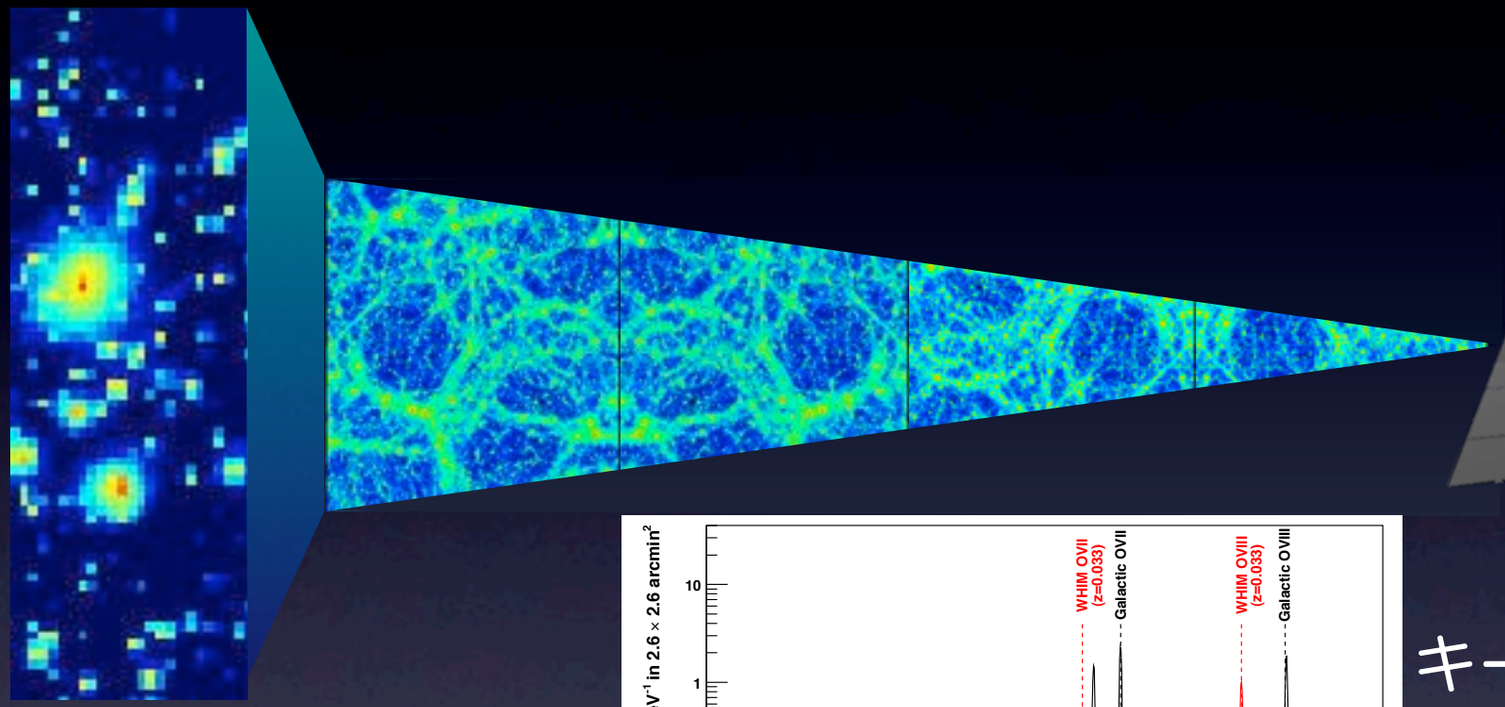


3-σ with XMM + chandra

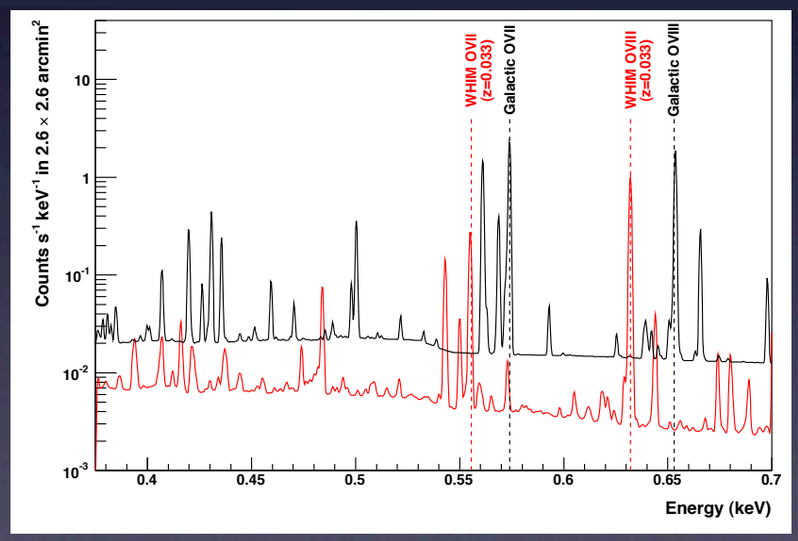
Buote+2009

WHIM with emission

高電離酸素輝線 (500-700eV) の撮像分光



DIOS
(or DIOS+)



Takei+ 2011

目的

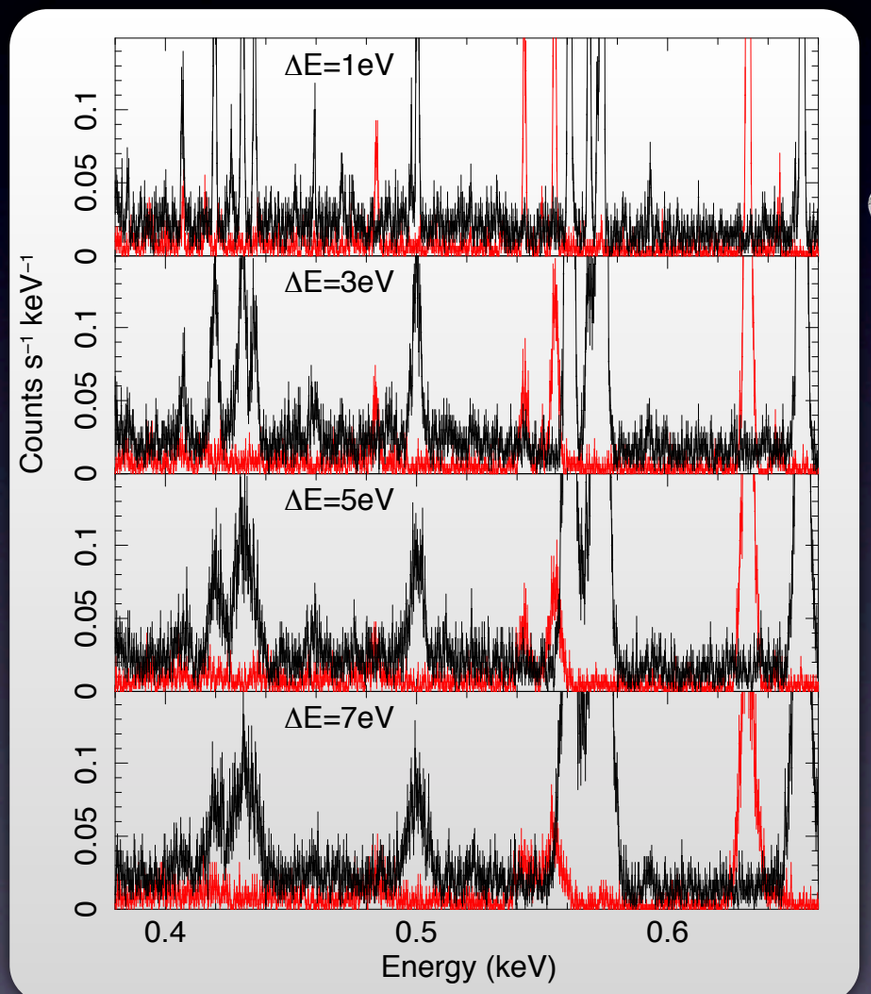
- 約100万度の銀河間物質を初めて捉え，それがミッシングバリオンの何割を占めるのかを理解する
- ３次元分布図を作る

キー技術

- 短焦点 (~1m) 広視野X線反射望遠鏡
- 撮像型高エネルギー分解能X線分光検出器
  - 16x16 TESマイクロカロリメータアレイ

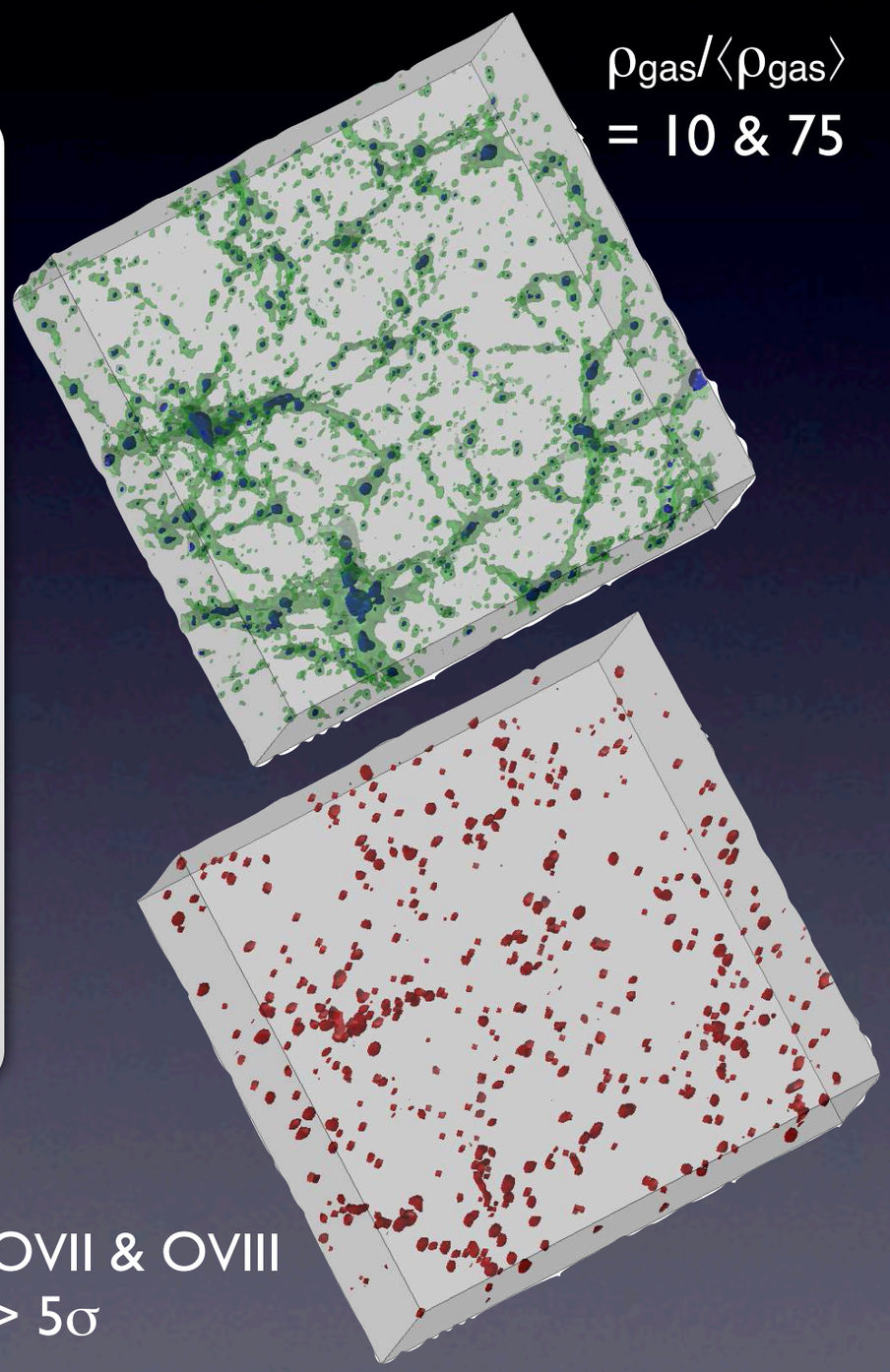
DIOS+ simulation

ΔE≤3eVの分解能が必須



Foreground (black)
Signal (red)

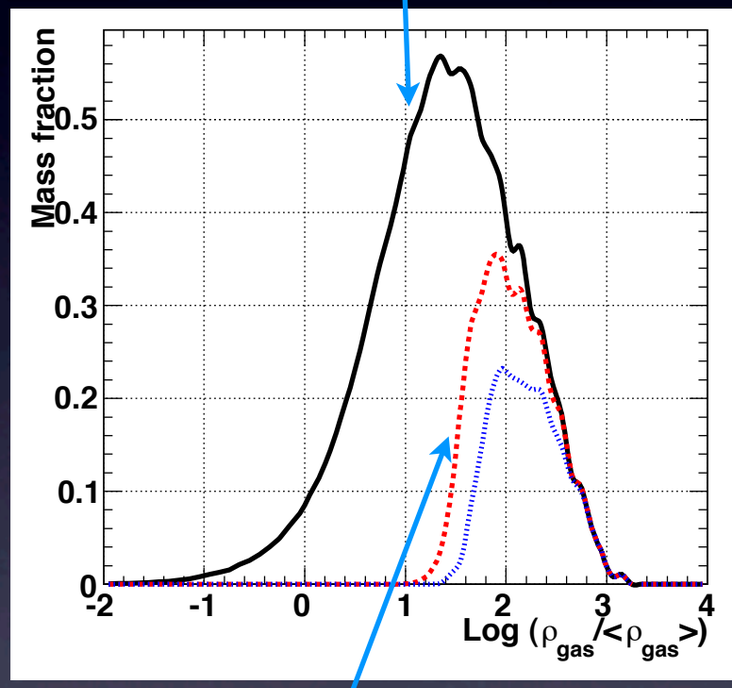
z = 0.2117 – 0.2317 slice



$\rho_{gas}/\langle\rho_{gas}\rangle$
= 10 & 75

OVII & OVIII
> 5σ

>10^5K, unbound



5σ detection with
1Ms

Takei+ 2011

Summary

- X線が探査するBaryonic matter:
  - 銀河団 ICM ($T>5\times10^6$K & $\rho_{gas}/\langle\rho_{gas}\rangle$ >70)
  - $>5\times10^6$ K IGM (WHIM: unexplored yet)
- Cluster ICM as cosmological tools
  - 現状： $z<0.5$, systematics limited
  - 次世代：ASTRO-Hによる近傍銀河団＋eROSITAによる $z<1.5$までのsurvey
- さらに将来の計画：議論中
  - $z>2$の銀河団へ
  - $>5\times10^6$ K IGMの3D分布: $\rho_{gas}/\langle\rho_{gas}\rangle > 10$
    - 加熱機構，重元素の伝搬