Reading the metal diaries of the Universe with Xenia

J.W. den Herder

L. Piro, T. Ohashi, C. Kouveliotou, D. Hartmann, D. Burrows and the Xenia team

SRON
Netherlands Institute for Space Research

contents

- Introduction
- Science
- Mission
- Conclusions

Message:

How can high-resolution imaging X-ray spectroscopy over a wide field of view advance our understanding of the cosmic chemical evolution

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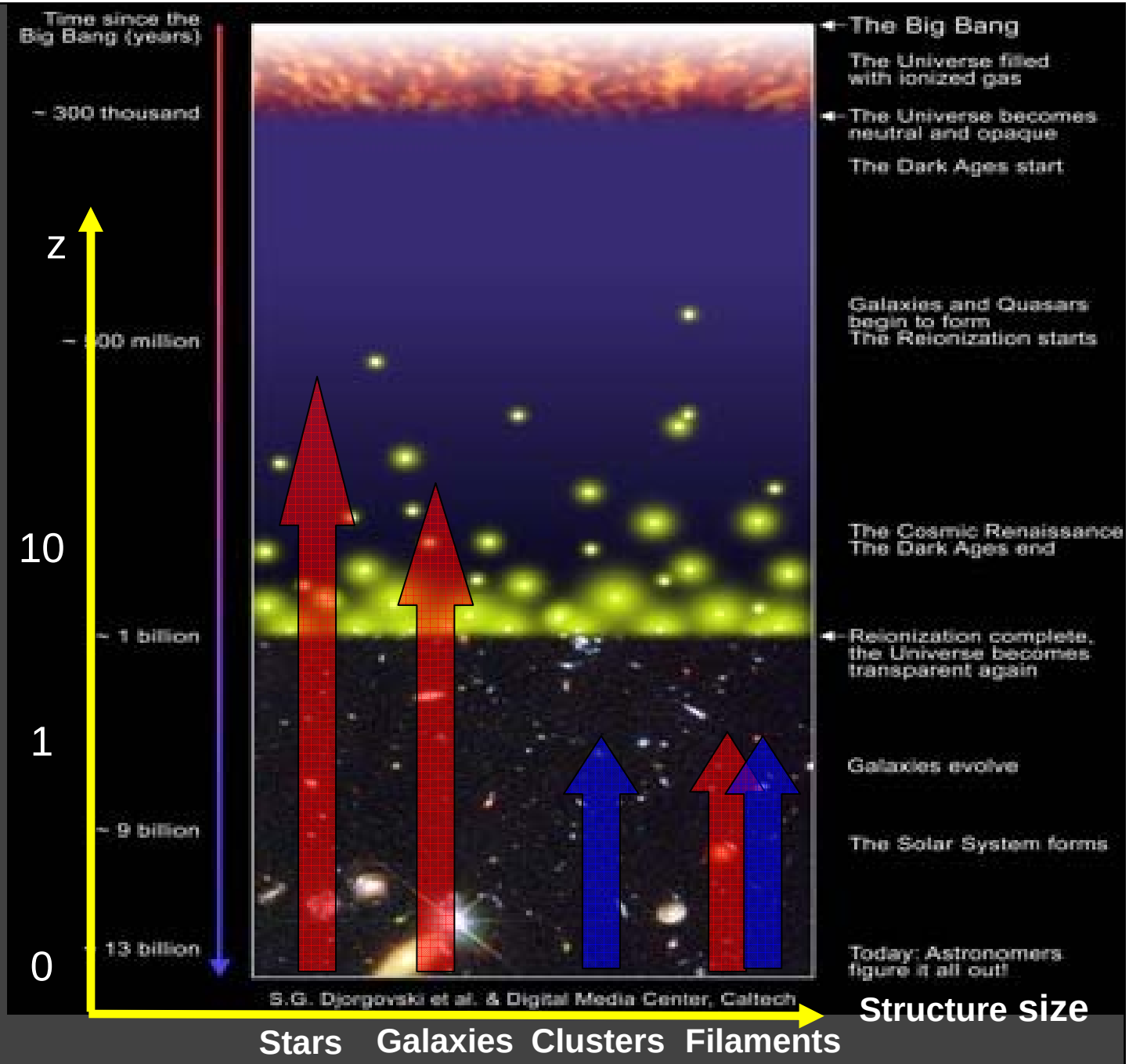
Most of the baryon of the Universe are locked in large scale, low density structures visible only in X-rays

High resolution spectroscopy and spatial resolution, wide field in emission

GRB as cosmological beacons: fast reaction, high res. absorption spectroscopy



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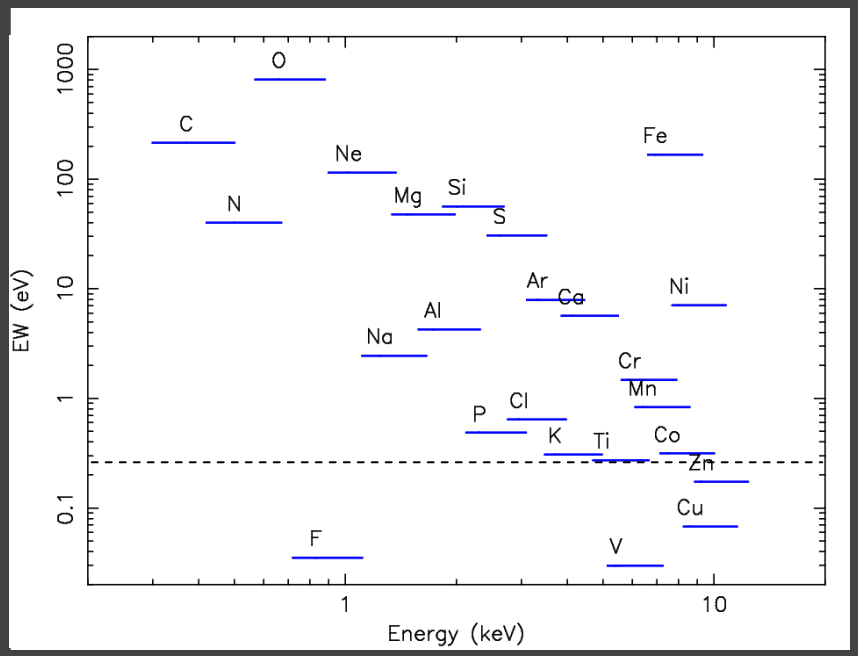
X-ray spectroscopy: key to chemical evolution

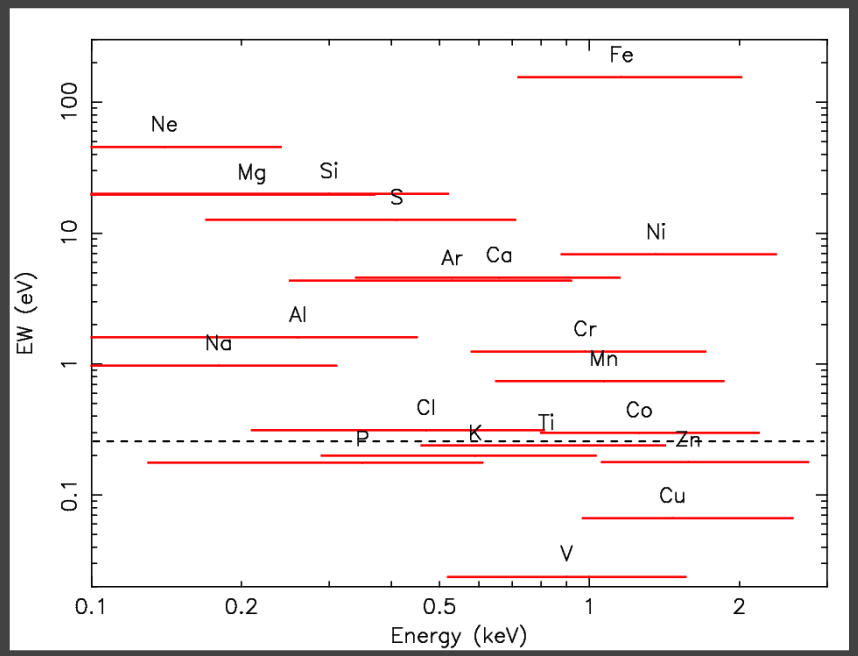
For single temperature plasma

Horizontal axis: energies where lines occur

K-shell



L-shell



Kaastra

X-rays as important probe

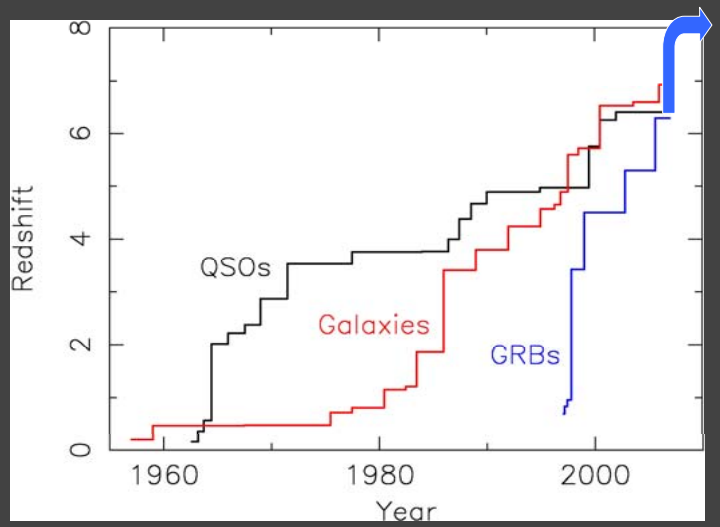
Major fraction of baryonic matter:

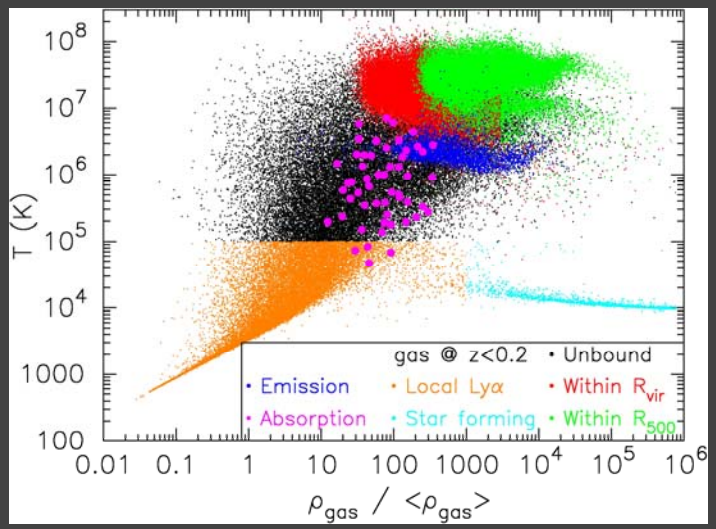
- Diffuse gas in galaxies
- Groups of galaxies
- Clusters of galaxies
- IGM

X-rays indispensible tool

Covers hot gas

Covers large red-shift region





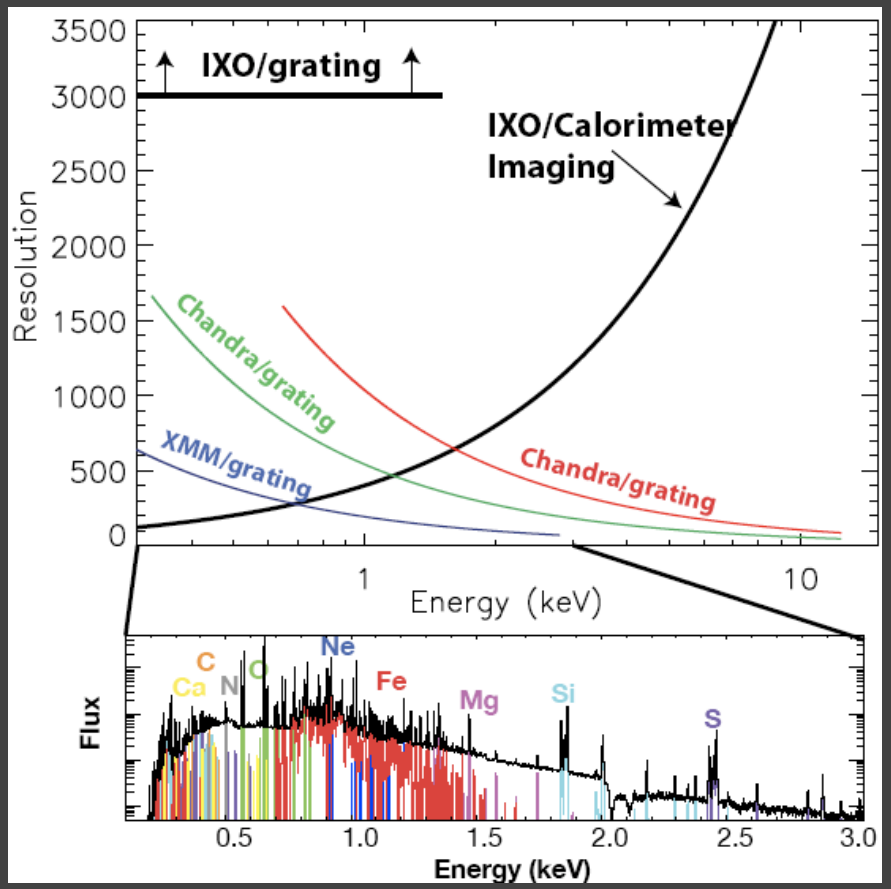
The far red-shifted Universe: International X-ray Observatory

Chemical evolution

- K-line transitions of 25 elements
- Carbon through Zinc
- Abundances
- Temperatures: 10^6-10^8 K
- Velocities ~ 100 km/s

Observatory class mission:

- Large area 3m^2
- Good angular resolution (5”)
- Point sources (gratings) or small field of view (2x2 arcmin)
- L2 orbit



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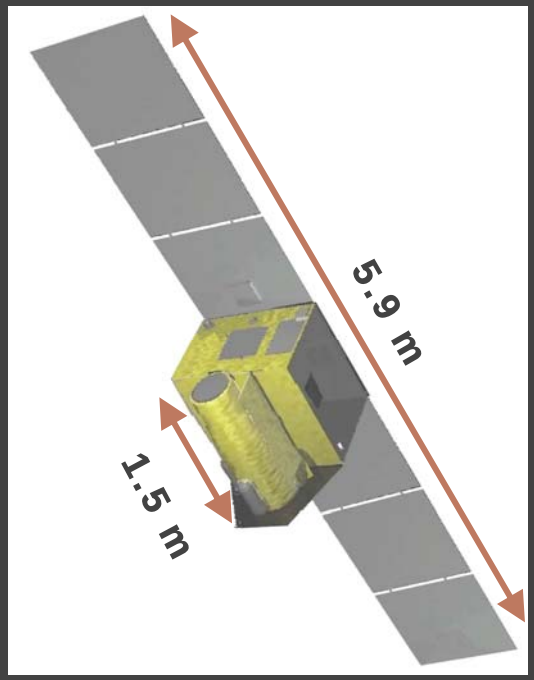
The Local Universe: Diffuse Intergalactic Oxygen Surveyor



Mission concept

- Small Japanese mission
- 400 kg
- LEO
- PI: Ohashi

Performance

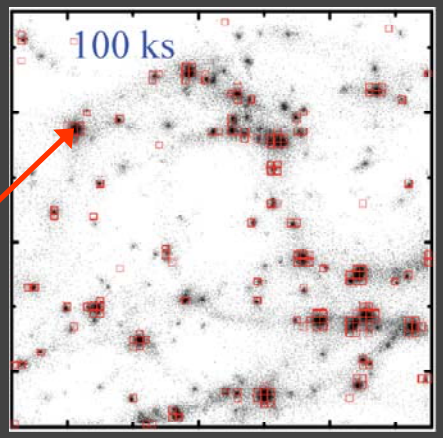
- Effective area: > 100 cm^2
- Field of view: 50′ diameter
- $S\Omega$ > 100 $cm^2 deg^2$
- ΔE: 2 eV (FWHM)
- Energy range: 0.3 – 1.5 keV

mapping WHIM in emission

100 ks – 1 Ms exposure

5 deg x 5 deg

z = 0.2 (60 Mpc)



OVII & OVIII > 3σ
(simultaneous detection)

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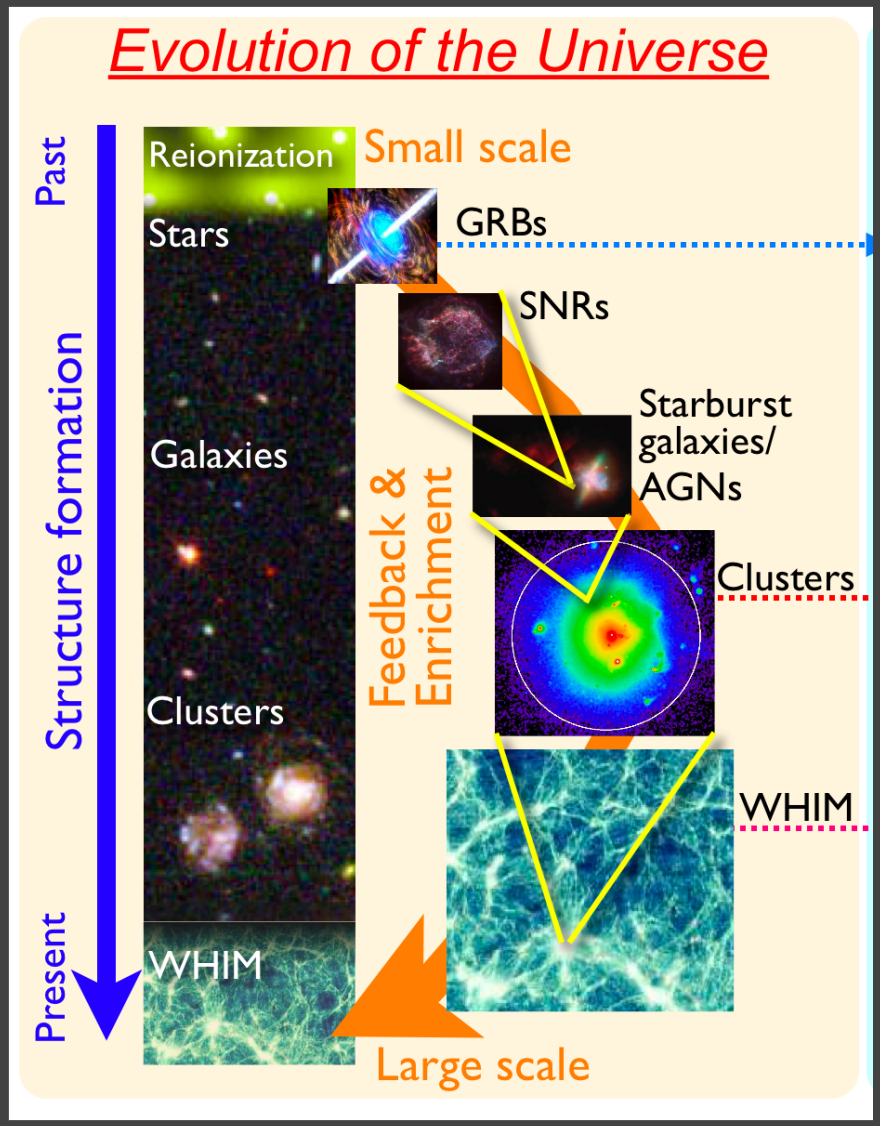
The high red-shifted and the local Universe



Gamma-Ray Bursts

- Evolution of massive star formation using GRBs to trace their explosions back z > 6
- Measure the metals in the host galaxies of GRBs

Clusters of galaxies

- evolution and physics of clusters out to their formation epoch (z>1)
- Measure the thermodynamical and chemical properties of a fair sample out to the virial radius, (cosmological probes, link with the WHIM)

Cosmic filaments

- Characterize WHIM filaments with densities down to 10^{-5} cm^{-3} (~30 times smaller than currently probed)
- constraints on interplay between diffuse baryons and star formation

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Key characteristics

CRIS: Cryogenic Imaging Spectrometer

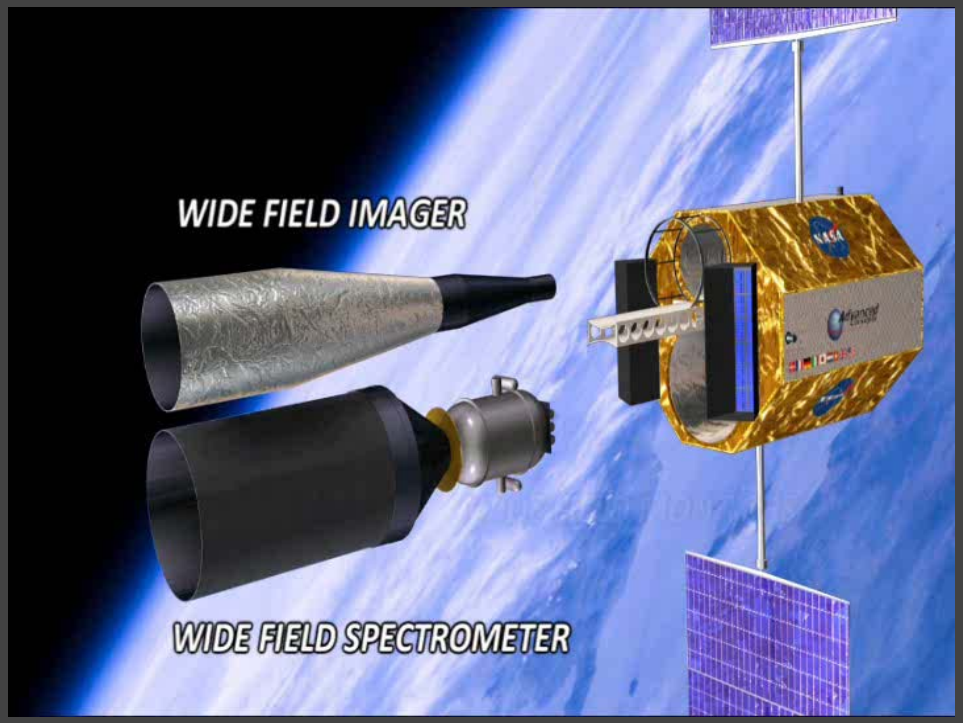
1000 cm^2, 2.5 eV, 1 deg^2, 3 arcmin

HARI: High Angular Resolution Imager

600 cm^2, CCD, 1.5 deg, 15”

TED: Transient Event Detector

80 GRB/year with appropriate fluence > 10^{-6} erg/cm^2/s in 15-150 keV

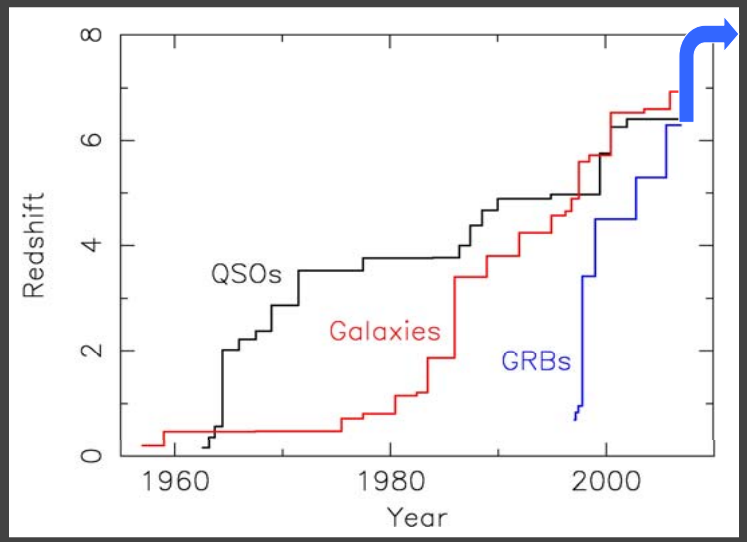


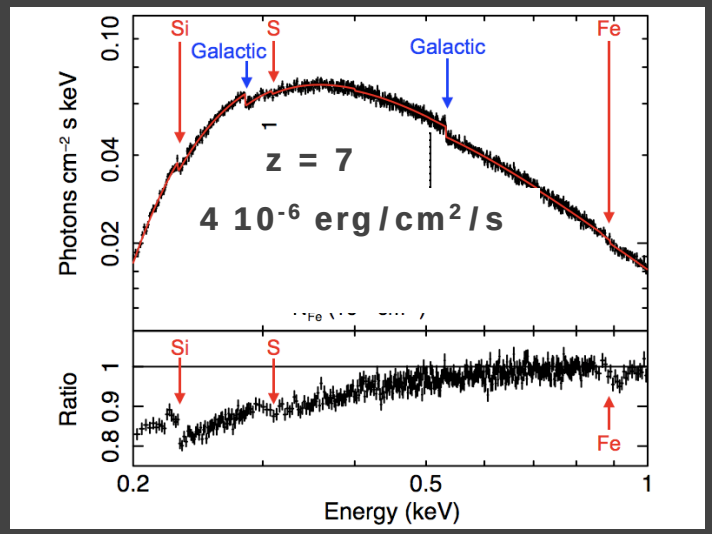
fast reaction

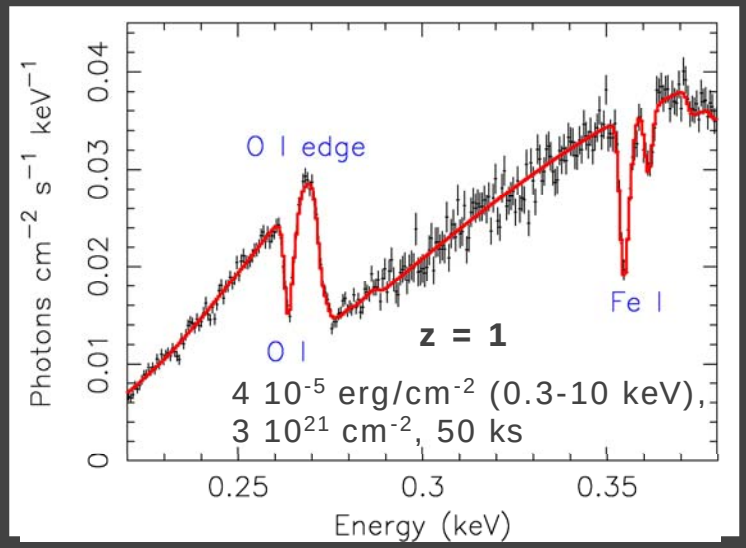
< 65 sec for 80% GRB

Gamma-Ray Bursts

- Observe metal enrichment in the environment of the most massive stars z > 6-7 (pop III stars ?)
- ISM in GRB host galaxies including kinematics (10^{-3})







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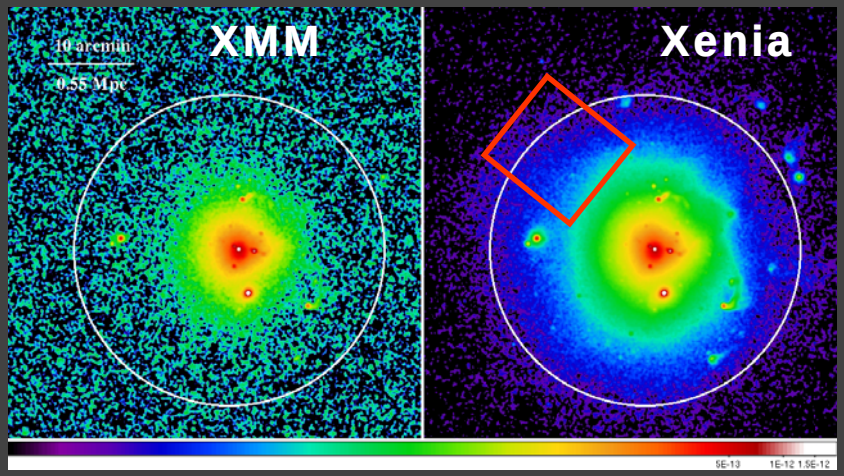
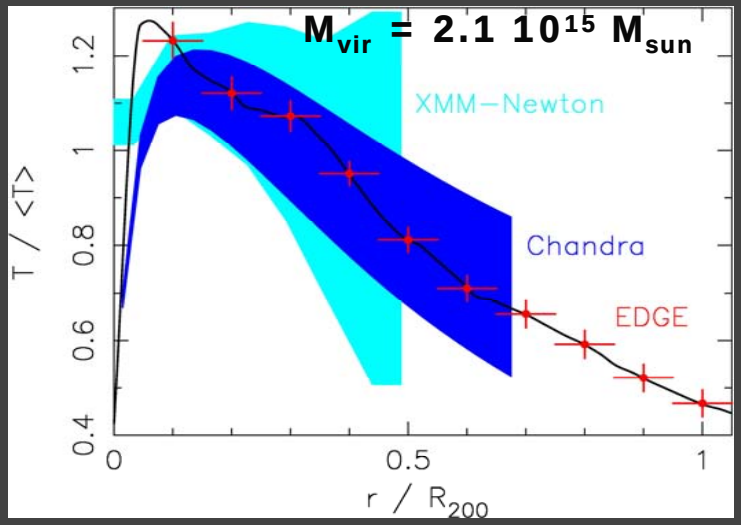
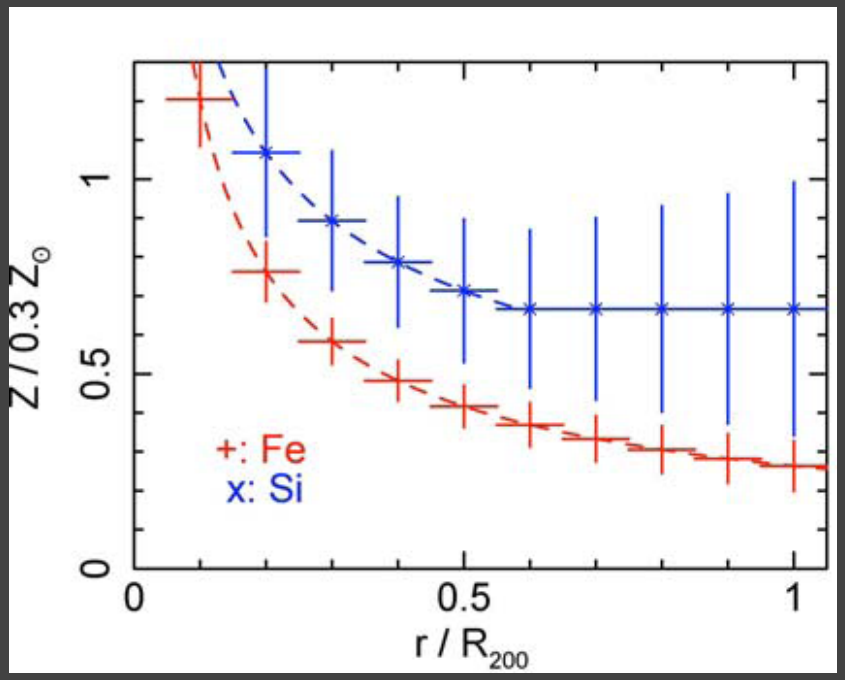
Cluster properties

- Measure the thermodynamical and chemical properties out to the virial radius (important to understand systematics using clusters as cosmology probe)
- Directly connected to the WHIM
- Measure surface brightness, temperature and metal abundances



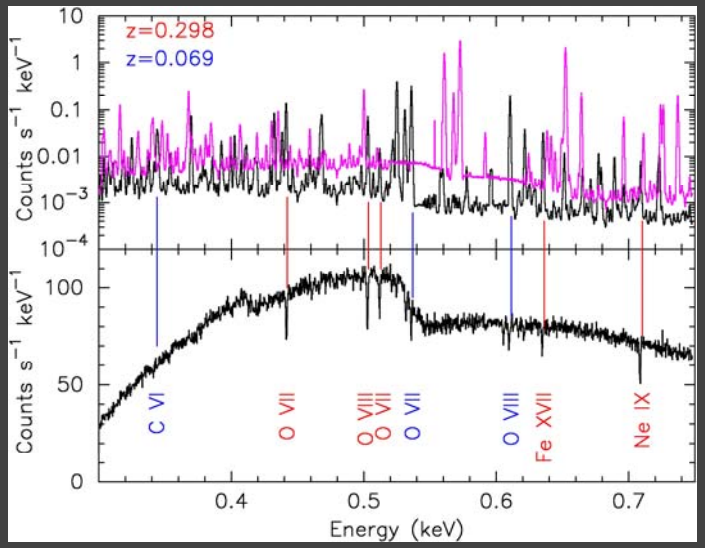


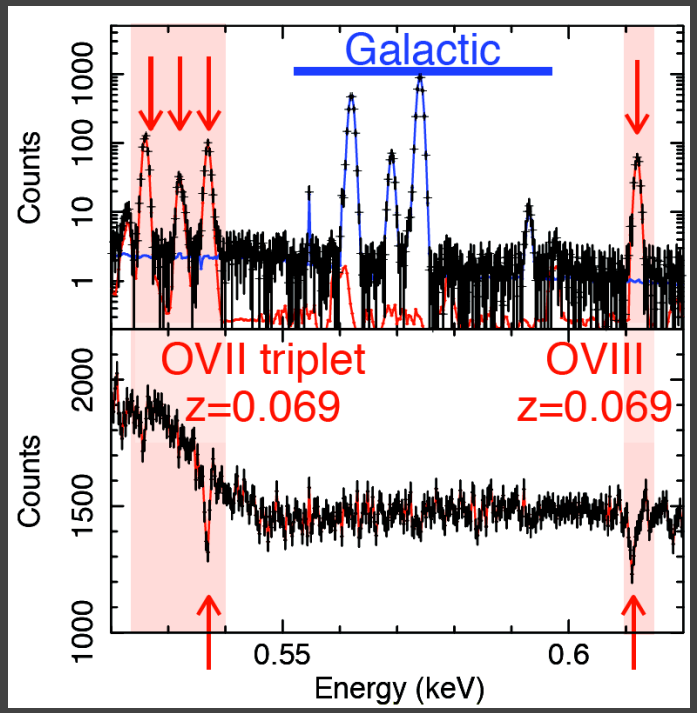


GRB as backlight for the Warm-Hot Intergalactic Medium

- Requires good spectral resolution for separation of galactic foreground
- Requires spectral and angular resolution for unresolved background
- Typical angular scale 8' (1Mpc@z=0.1)
- Emission: 3D structure (~ ρ^2)
- Absorption: lowest density absorbers (~ ρ)

- Not only existence but characterizing also the physical conditions (density, temperature, ionization balance, abundance)

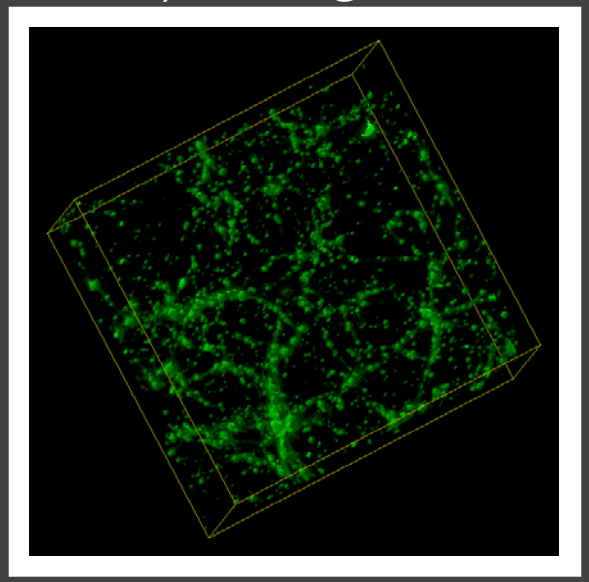




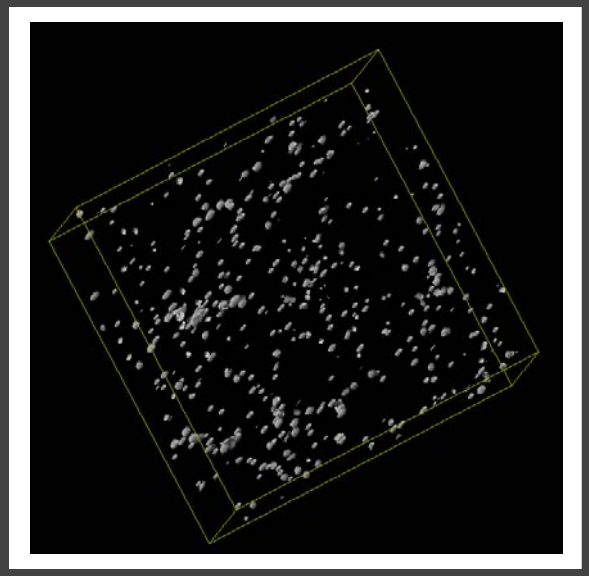
WHIM: mapping 3D structure

Model, $\Delta z=0.02$ @z=0.22

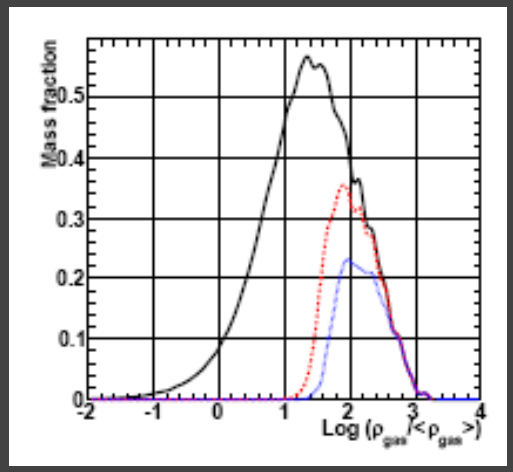
5 x 5 °



Detected, OVII+OVIII in emission, 5 σ, 1 Ms



- Down to overdensities ~ 30
- Factor 10-30 fainter than currently accessible



100 ks

1 Ms

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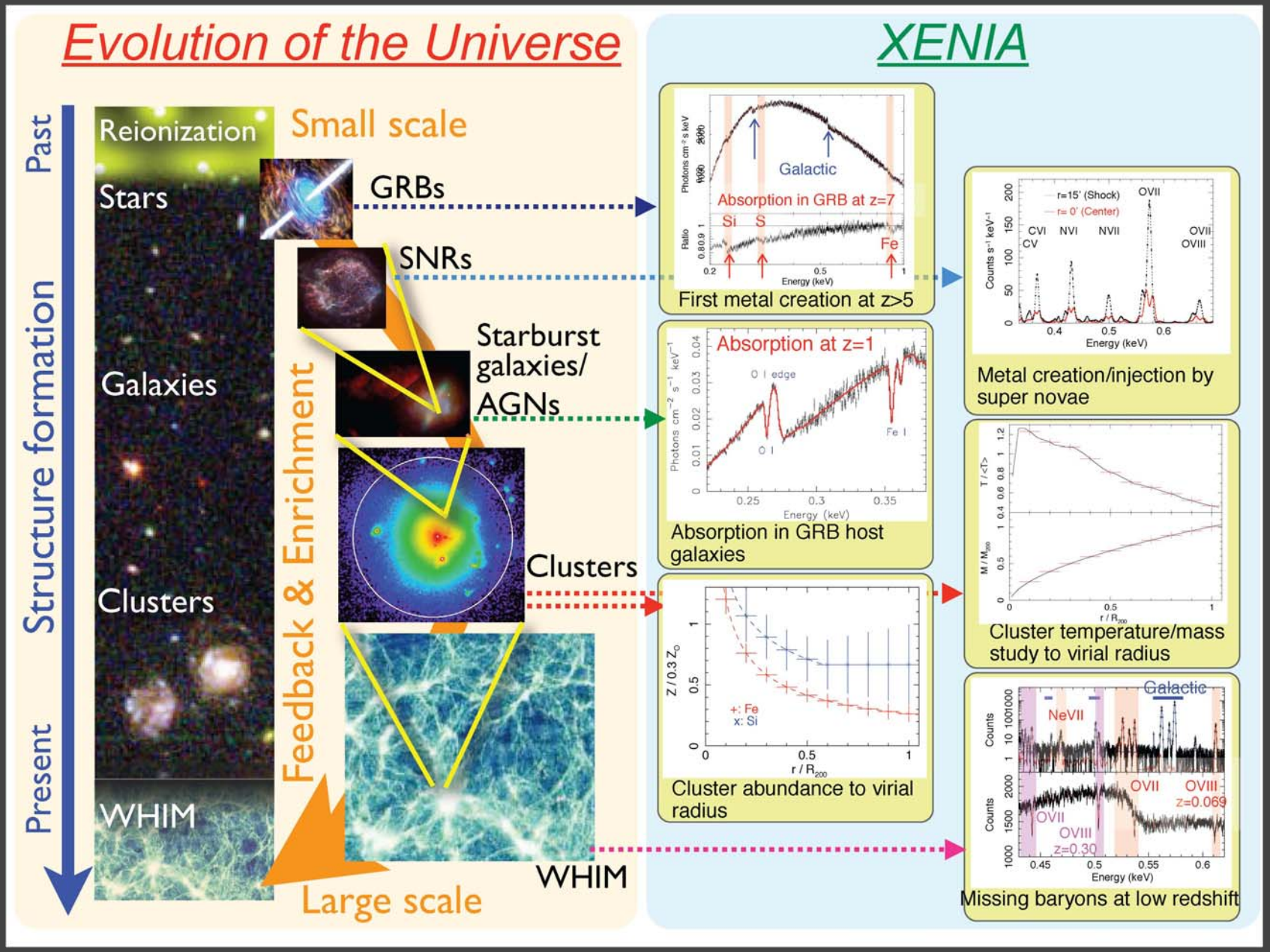
Evolution of the Universe
XENIA
Past
Structure formation
Present
Reionization
Stars
Galaxies
Clusters
WHIM
Small scale
Large scale
Feedback & Enrichment
GRBs
SNRs
Starburst galaxies/ AGNs
Clusters
WHIM
Galactic
Absorption in GRB at z=7
Si
S
Fe
Energy (keV)
First metal creation at z>5
Absorption at z=1
O I edge
O I
Fe I
Absorption in GRB host galaxies
+: Fe
x: Si
Cluster abundance to virial radius
r=15' (Shock)
r= 0' (Center)
CVI
CV
NVI
NVII
OVII
OVIII
Metal creation/injection by super novae
Cluster temperature/mass study to virial radius
Galactic
NeVII
OVII
OVIII
z=0.069
OVII
OVIII
z=0.30
Missing baryons at low redshift

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Science	Effective area [cm^2]	Energy range [keV]	Angular resolution	Field of view [deg^2]	Spectral resolution
Missing baryons in absorption	1000 @ 0.5 keV	0.2 – 1	n/a	n/a	3 eV @ 0.5 keV
Missing baryons in emission	1000 @ 0.5 keV	0.2 – 1	4'	0.7 x 0.7	3 eV @ 0.5 keV
Cluster physics	500 @ 1 keV	0.3 – 4	15"	1.4 ∅	80 eV @ 1 keV
Cluster formation and evolution	500 @ 1 keV	0.3 – 4	15"	1.4 ∅	80 eV @ 1 keV
Metal enrichment	1000 @ 0.5 keV	0.2 – 2	n/a	n/a	3 eV @ 0.5 keV
Dark ages	1000 @ 0.5 keV	0.2 – 2	n/a	n/a	3 eV @ 0.5 keV

80 bursts per year with fluence > 10^{-6} erg cm^{-2} in the 15 – 150 keV energy band

Fast repointing

Transient Event Detector

High angular imaging

HARI

Imaging spectroscopy:

Cryogenic Imaging Spetrometer

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Mission profile

- GRB: wide-field monitor with fast repointing
  (60 degree / 80 seconds)
  80 burst/yr; F>10^{-6} erg/cm^2/s 15-150 keV
- Large scale structures: wide field of view (1 deg^2)
- Low surface brightness: low background (LEO, short focal length)
  long observations (1Ms)
  spectral (< 3 eV) resolution
  angular (~15'') resolution
- Observing program: 3 years with ¼ for guest observers,
  cryogen free design (5 years or more)

  deep surveys (10 deg^2:1 Ms, 100 deg^2: 50 ks)
  GRB follow up
  and GO program
- Affordable: LEO, < 2200 kg

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Satellite and payload

CRIS: cryogenic Imaging Spectrometer

High spectral resolution imager using an array of micro-calorimeters and modest angular resolution

Poster by Tawara-san

HARI: High Angular Resolution Imager

CCD camera with high angular resolution over full field of view

TED: Transient Event Detector

CZT based coded mask detectors to localize bright GRBs

Talk by Ubertini

and

fast reaction (< 65 sec for 80% GRB)

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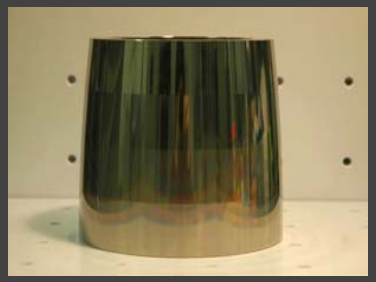
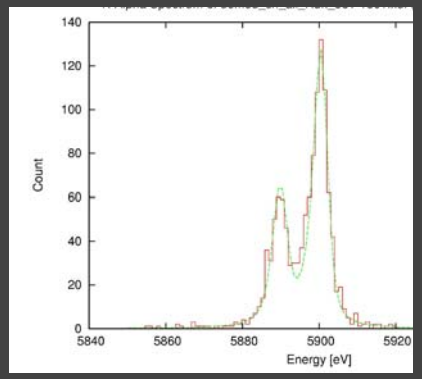
Cryogenic Imaging Spectrometer

Prime instrument

- Mirror with 2/4 fold reflections
- TES calorimeter with section out-off focus for high countrate
- Cryogen free cooler
- FoV: 1.0 degree^2
- E-range: 0.1 – 2.2 keV
- E resolution: 2.5 eV (goal 1 eV)
- $A_{effective}$ (1 keV): 1163 cm^2



2.9 eV, FDM



Observational strategy

- 150 GRB/year, 80 with fluence (15-150 keV) > 10^{-6} erg/cm^2/s
- wide field imaging when waiting for a GRB

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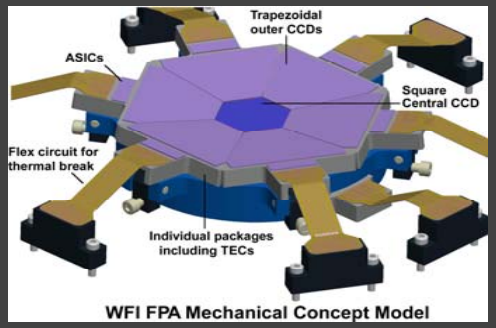
High Angular Resolution Imager

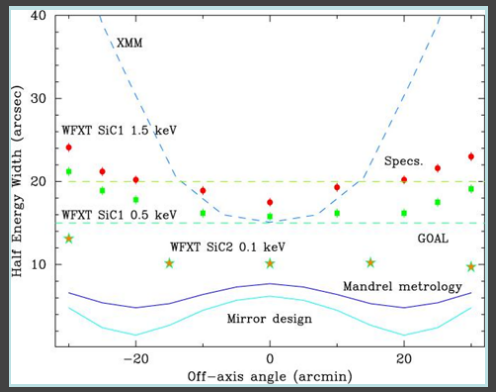
Instrument

- Based on polynomial optics combined with a curved focal plane (CCDs)
- FoV: 1.5 degree (diameter)
- E-range: 0.3 – 6 keV
- Aeffective (1 keV): 580 cm^2
- Angular resolution: 15”



Observational strategy

- Low background allows to observe cluster filaments
- High angular resolution used to identify point source contributions in CRIS data



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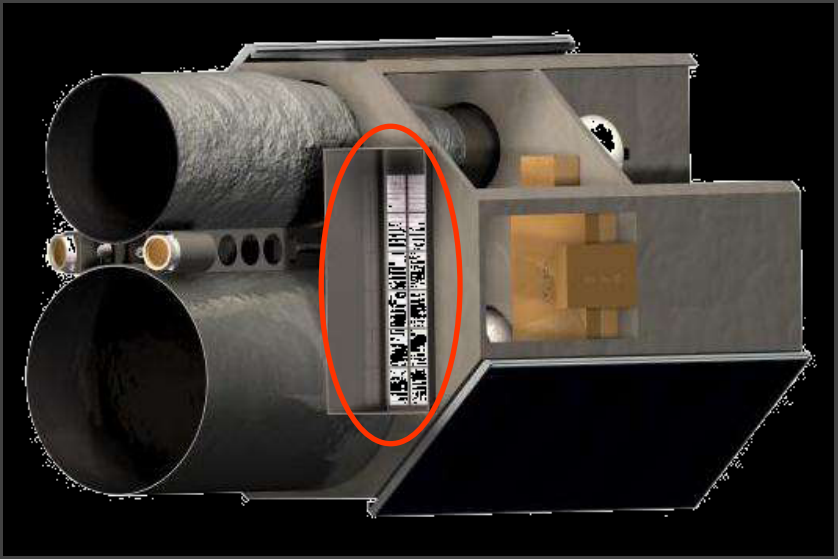
Transient Event Detector

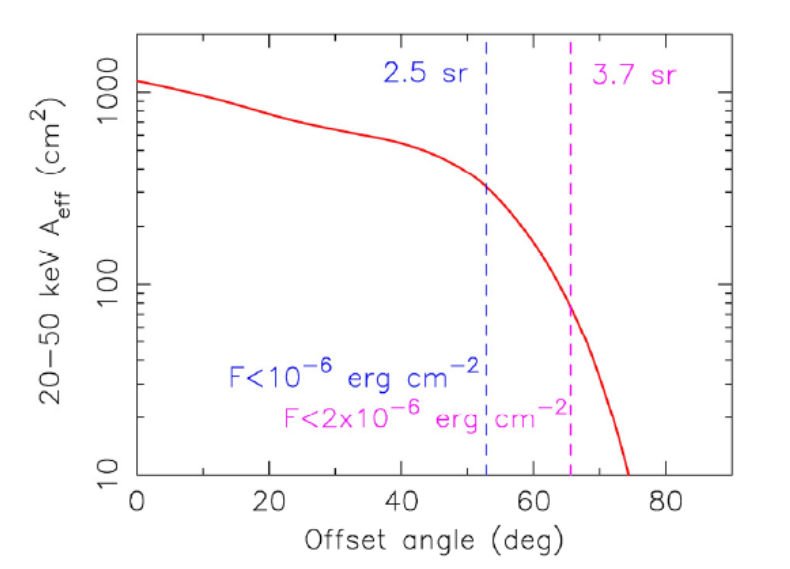


Instrument

- 2 detectors
- coded mask, CZT detector
- Fov: 2.6 sr
- E-range: 8 – 200 keV
- $A_{effective}$: 1500 cm^2
- Location accuracy: 4 arcmin

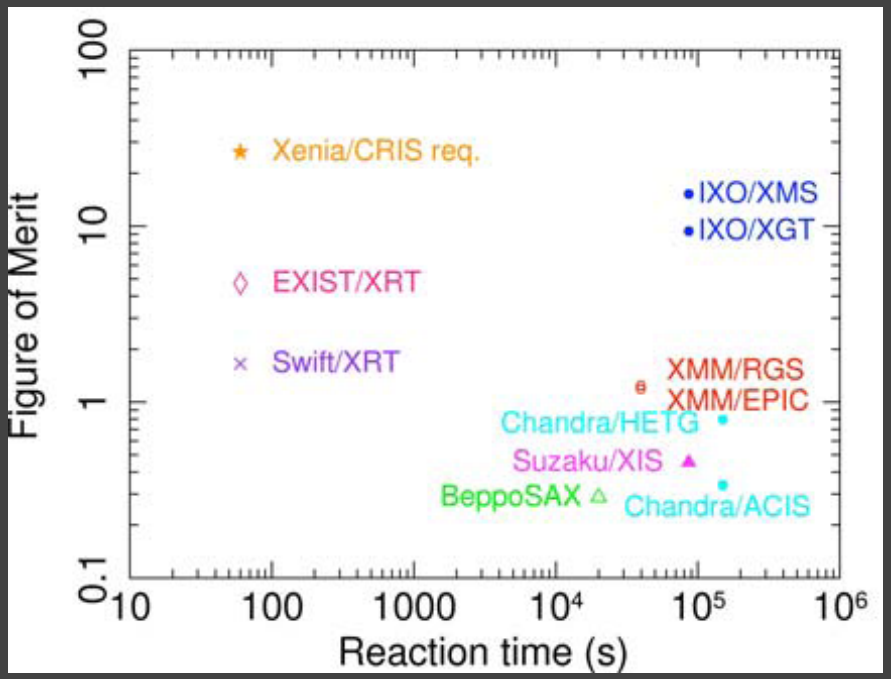
Observational strategy

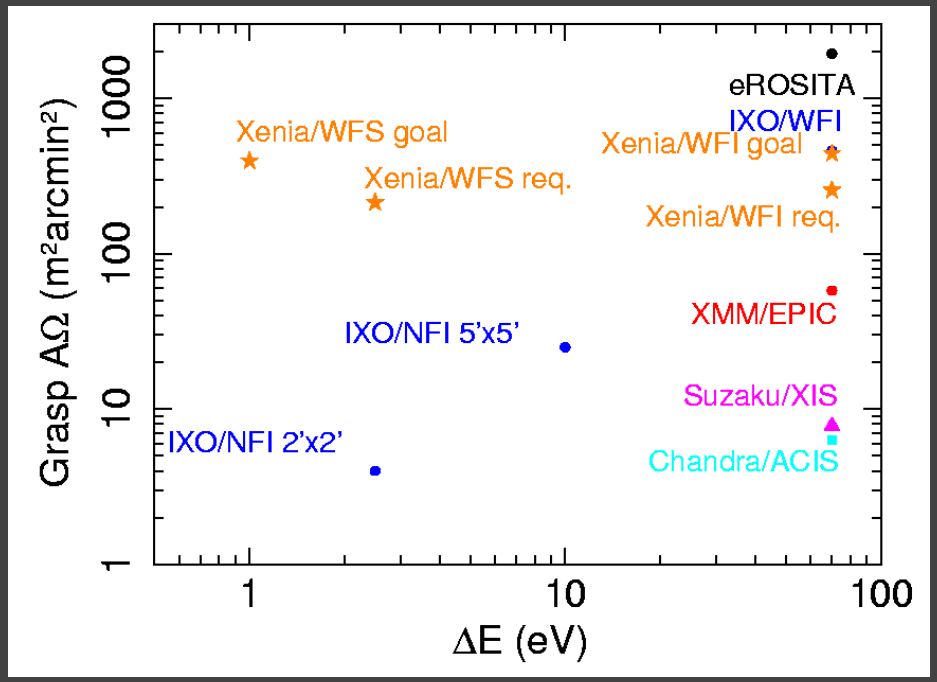
- Autonomous repointing similar to SWIFT



Complementarity

Spectroscopy with fast reaction and wide field





Line spectroscopy merit factor for variable sources = S/N for EW=1eV for a typical GRB afterglow

Conclusions

- Xenia is a medium scale mission addressing key science covering the cosmic chemical evolution including:
  - GRB and their environment
  - Evolution of clusters of galaxies
  - Characterization of cosmic web
- Xenia provides a wealth of auxiliary science
- There is a wide international community capable to provide the instruments and explore the science: Japan, USA, Europe (Italy, Netherlands, …)

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Warm-Hot Intergalactic Medium

tracer of LSS

Large fraction not detected

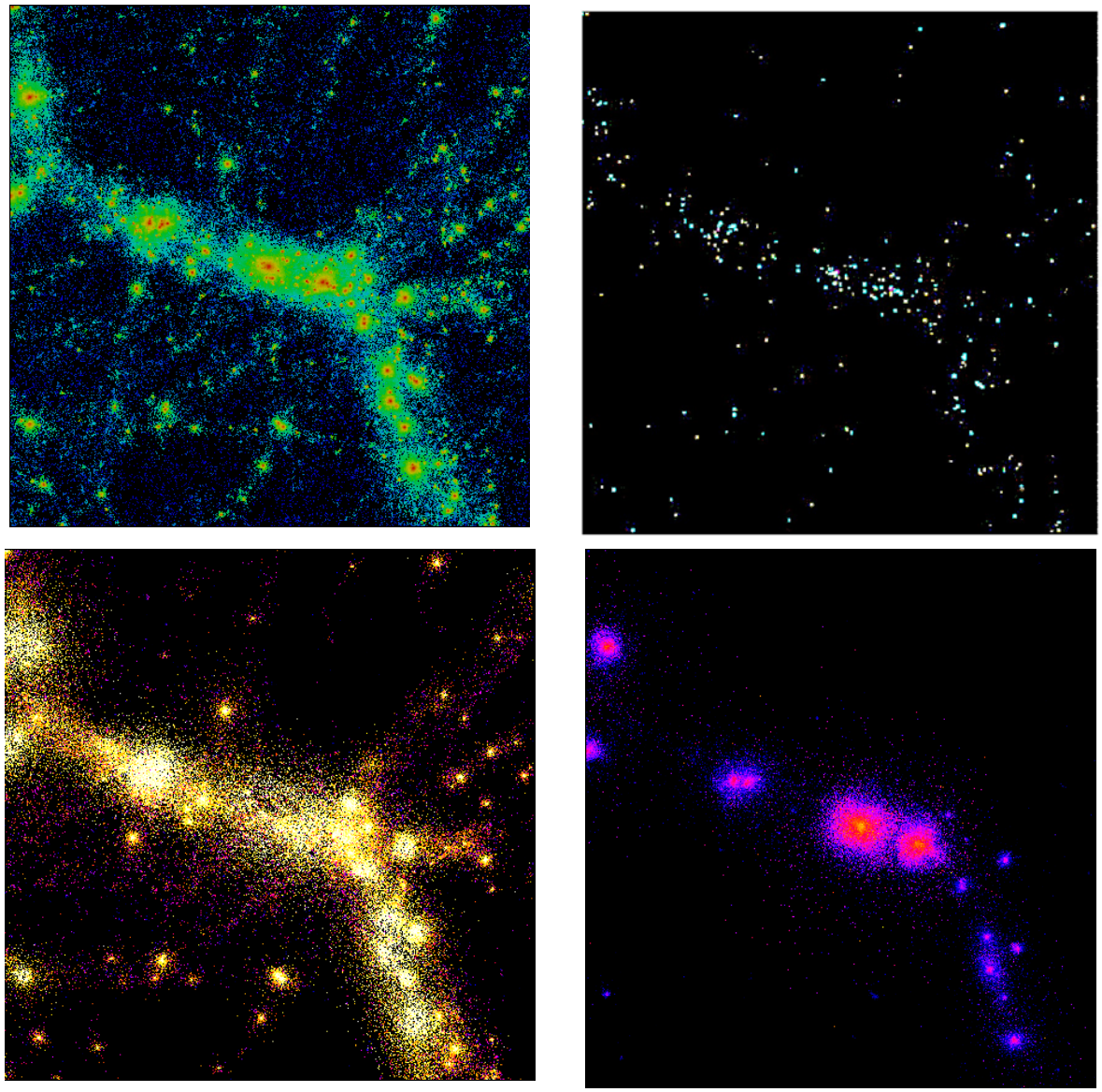
Yoshikawa et al. 2001,

ApJ, 558, 520

size = 30 h^{-1} Mpc ≈ 5 deg at z=0.1

Darkmatter

Galaxies (~10^4K)

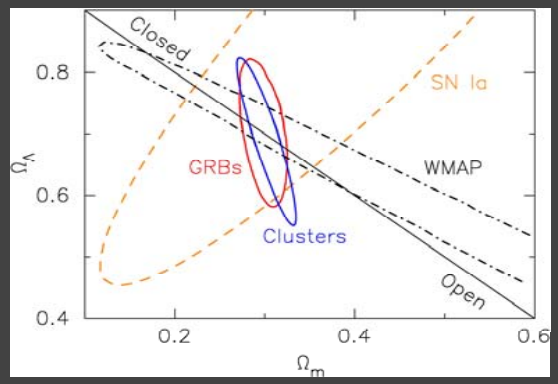


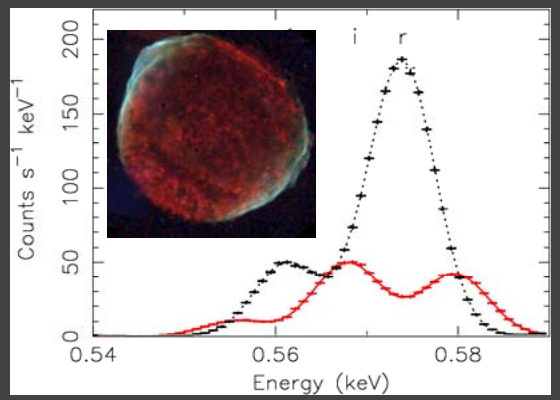
WHIM (10^5-10^7K)

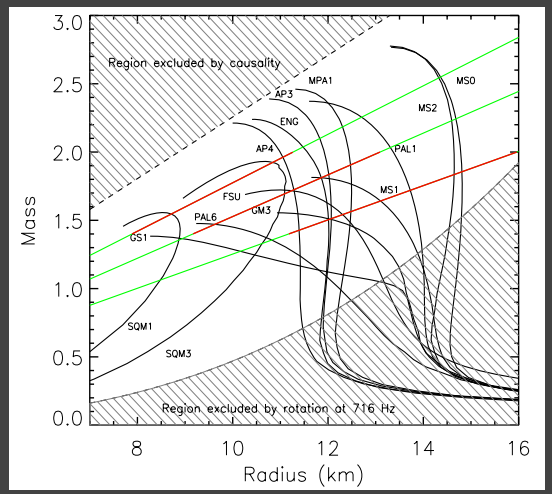
Cluster gas (10^7K)

Auxiliary science (20%)
but most for free

- Cosmological parameters
- Feedback processes
- Active Galactic Nuclei
- Physics and progenitors of GRBs
- The densest matter
- Violent accretion onto compact objects
- Stars
- The solar system
- Search for light dark matter (sterile neutrinos)
- Gravitational waves

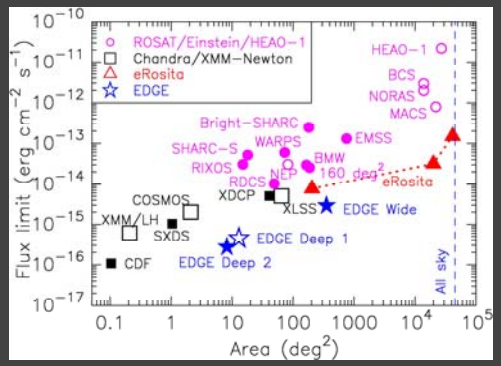




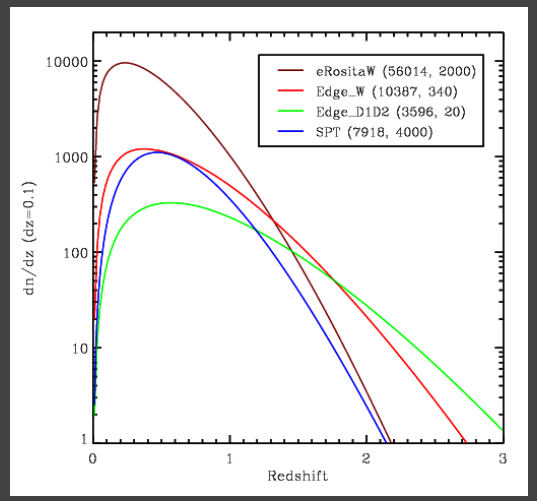


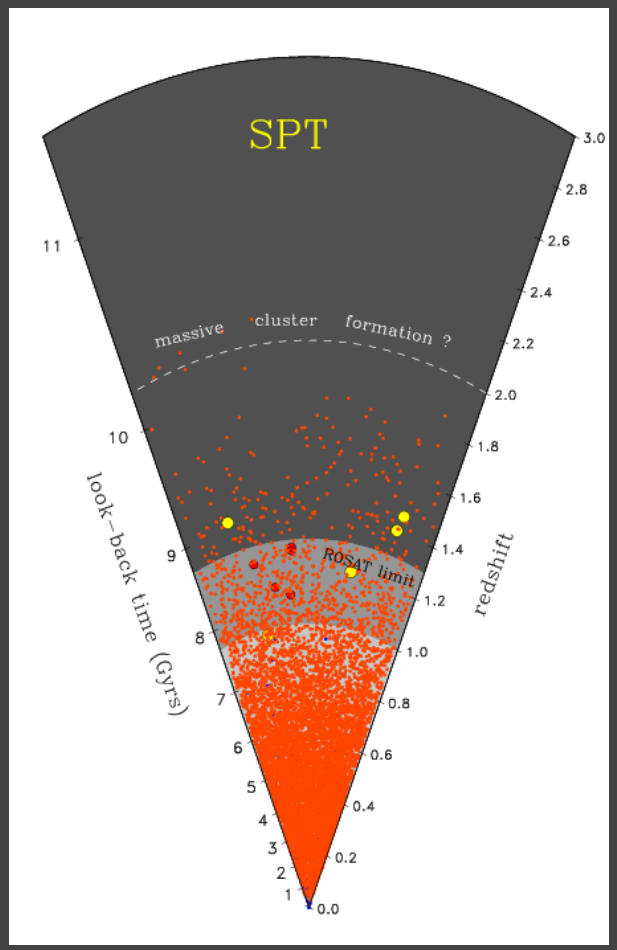
Cluster evolution

Survey	Exp time	Area	Clusters	Clusters + T
Wide	50 ks	340	1800	450
Deep-1	1 Ms	11.5	510	140
Deep-2	2 Ms	8	600	170



($N_{clusters}$, Ω)

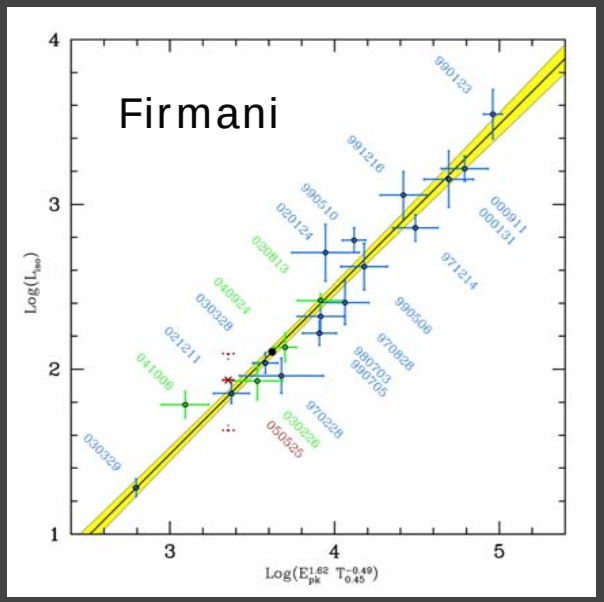
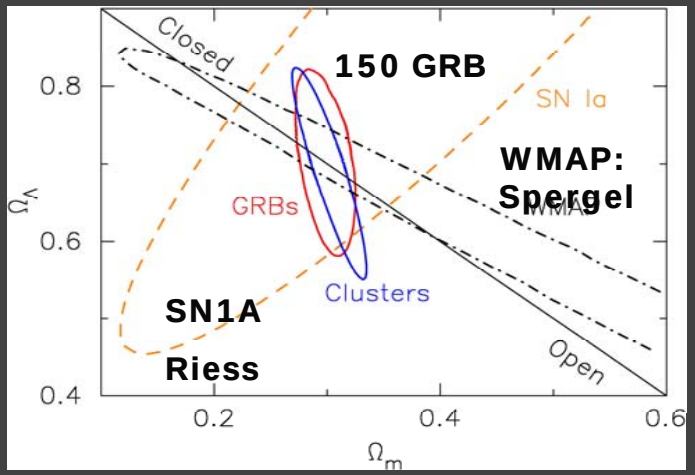




GRB as cosmology probe
(also SVOM/ÉCLAIR and GLAST + SWIFT

- GRB standard candles:

  L_{iso} - E_{pk}-$T_{0.45}$ correlation (all from prompt GRB spectrum + redshift)

- Allow accurate determination of Ω_Λ, Ω_m but require sufficient GRBs: > 10^{-6} erg cm^{-2} in 50 – 300 keV with and accurate determination of parameters (E_{pk})

- complementary to SN1a, clusters (but covers larger redshift)