X線分光天文学の展望
Prospect of X-ray spectroscopic astronomy

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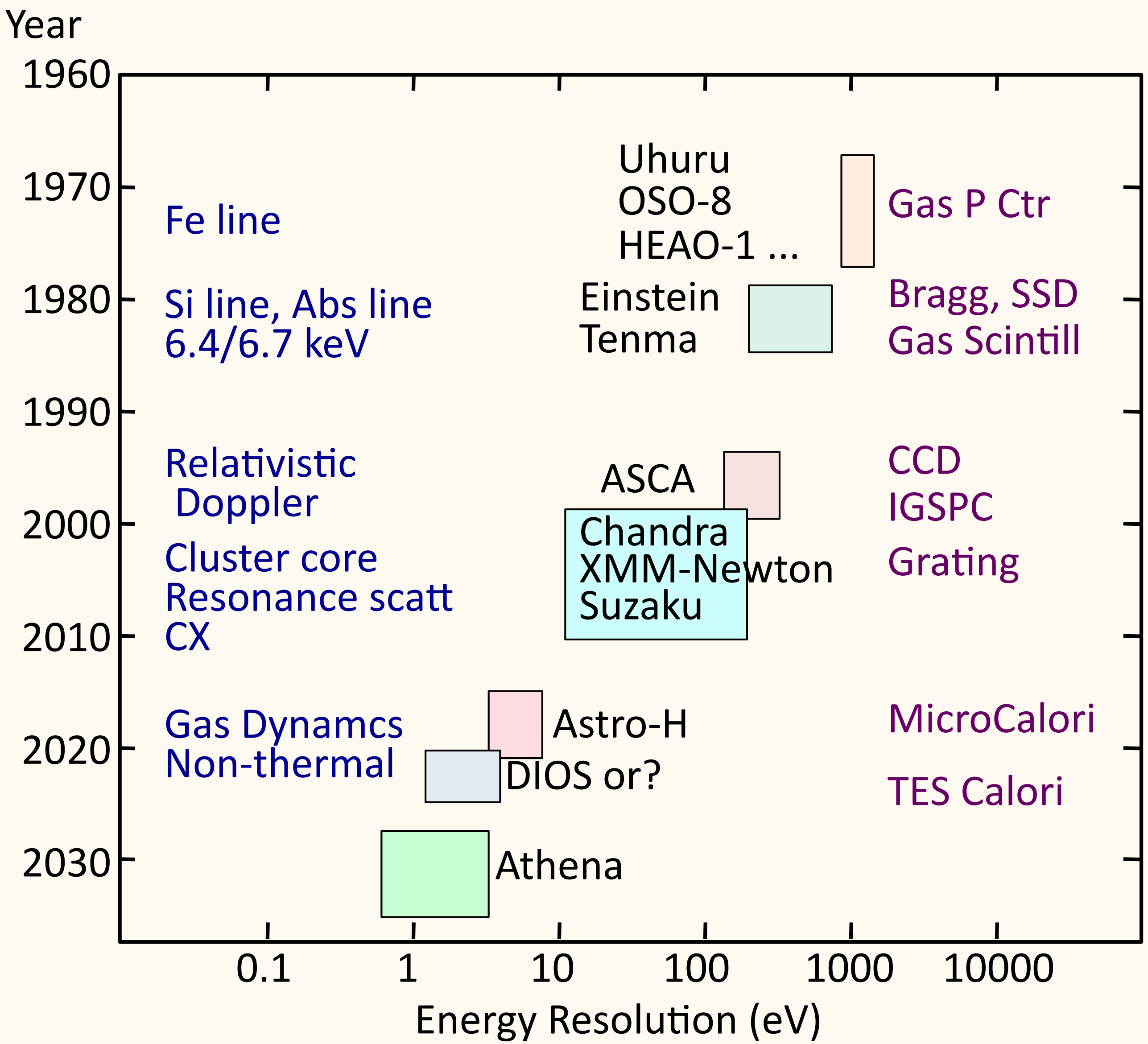
- X-ray spectroscopy
- ASTRO-H (1 page)
- Athena and Cosmic Vision
- DIOS and WHIM
- Future X-ray spectroscopy (some thoughts)

History of energy resolution

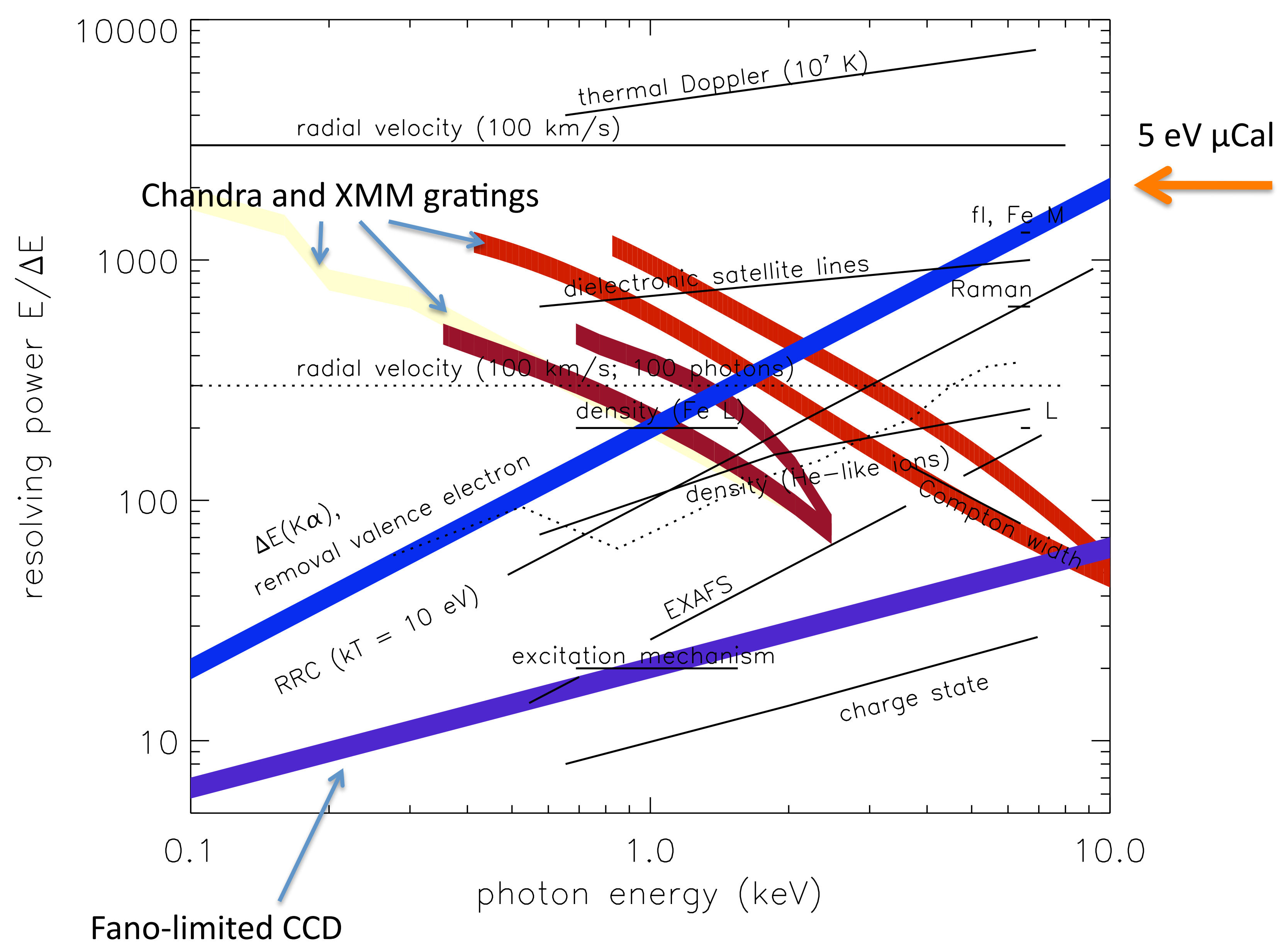
New physics came in with ~10 times advance in resolving power

Spectroscopy is the major driving force in future X-ray astronomy

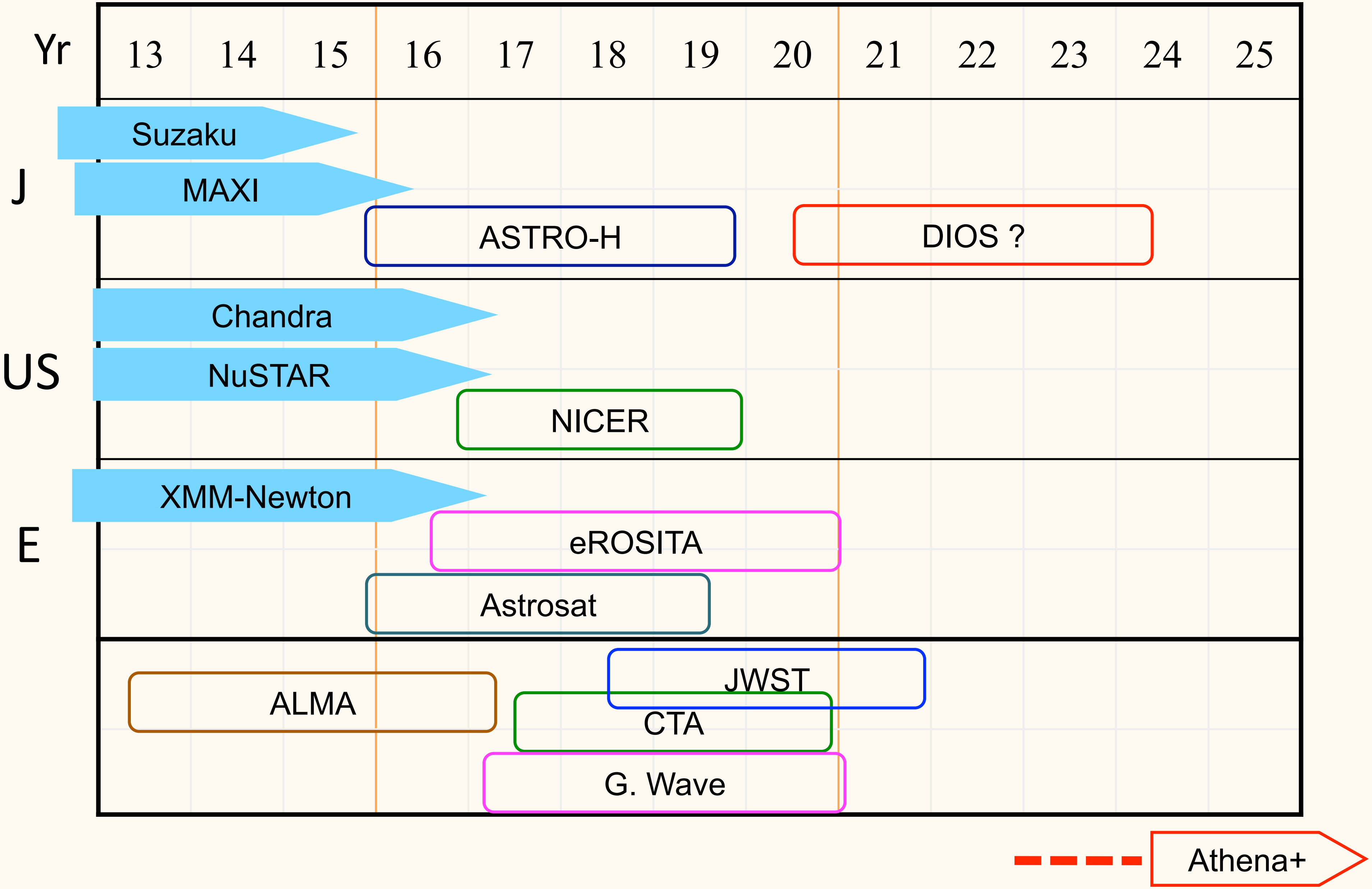


Resolvable features

by F. Paerels

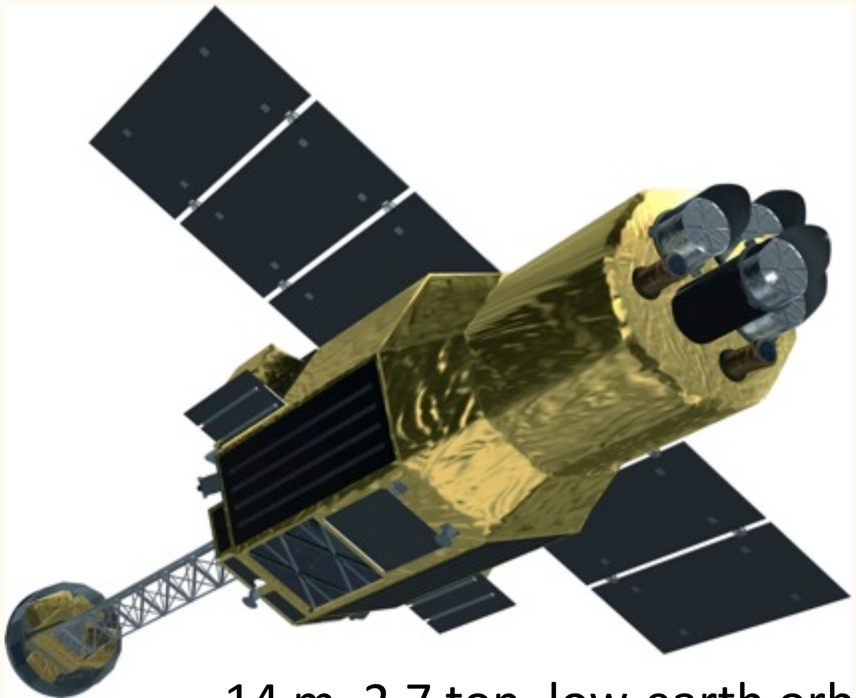


X-ray missions



ASTRO-H (1 page)

- Launch: November 2015
- Instruments:
  SXS (Microcalorimeters)
  SXI (CCD)
  HXI (Hard-X imager)
  SGD (Soft gamma-ray det.)



14 m, 2.7 ton, low-earth orbit

- 1st satellite use of microcalorimeters with ΔE ~ 5 eV
- Key Science
  - Measurement of gas motions at a few 100 km s^{-1} accuracy
  - Resolving line complexes (resonance, forbidden, intercombination ...) → plasma diagnostics
  - Systematic study of non-thermal processes by combining gas motions (SXS) and hard X-ray image (HXI)

Athena

Long history of discussion: XEUS (~2000) – IXO (2008) – Athena (2011)
Con-X (~2000) ⁄

ESA's Cosmic Vision Program: Large class and Medium class

- L1: 2022, JUICE (Jupiter Icy moon Explorer)
- L2: 2028, Hot and energetic Universe (→ Athena) [Nov. 2013]
- L3: 2034, Gravitational waves

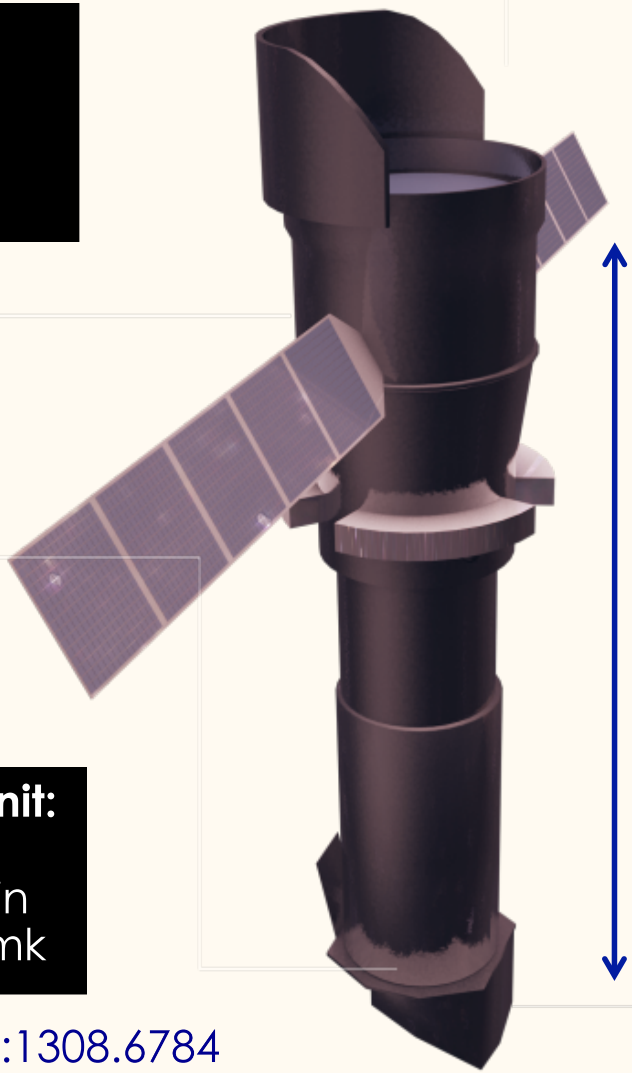
- M1: 2017, Solar orbiter
- M2: 2020, Euclid
- M3: 2024, Exoplanet x 2, LOFT, Sample return, Gen.Relativity [selection in 2014]
- M4: [new call in 2015?]

Athena: European-led large X-ray observatory with international contribution around 20% level

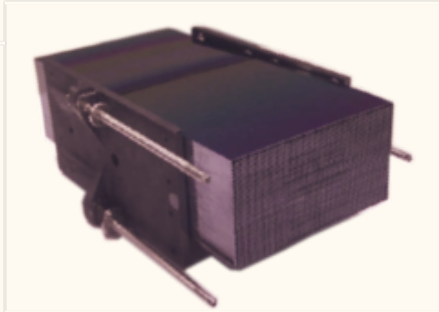
The Athena+ Observatory

Willingale et al, 2013 arXiv1308.6785

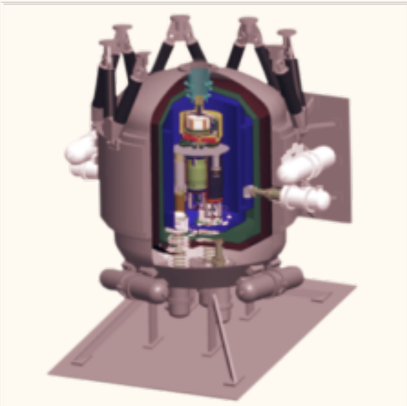
L2 orbit Ariane V
Mass < 5100 kg
Power 2500 W
5 year mission



12m

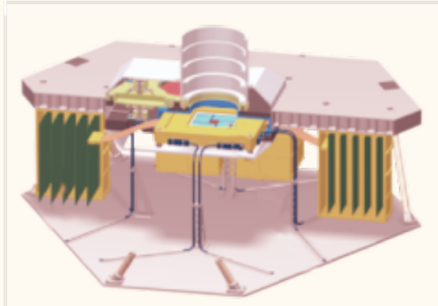


Silicon Pore Optics:
2 m^2 at 1 keV
5 arcsec HEW
Focal length: 12 m
Sensitivity: 3 10^{-17} erg cm^{-2} s^{-1}



X-ray Integral Field Unit:
ΔE: 2.5 eV
Field of View: 5 arcmin
Operating temp: 50 mk

Barret et al., 2013 arXiv:1308.6784



Wide Field Imager:
ΔE: 125 eV
Field of View: 40 arcmin
High count-rate capability

Rau et al. 2013 arXiv1307.1709

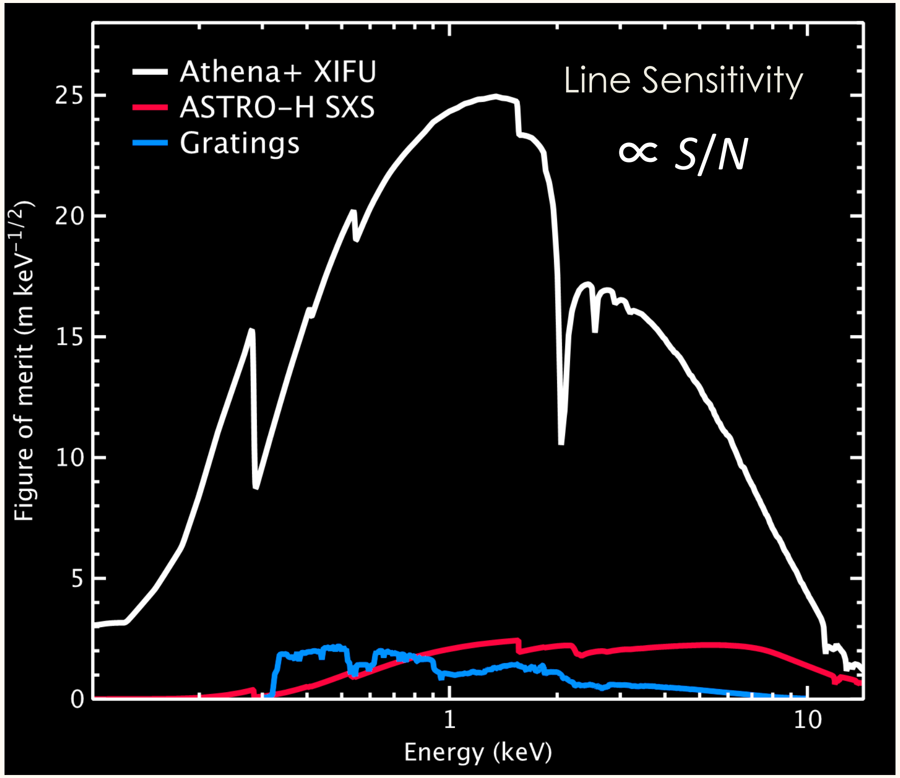
Athena: Key parameters

Parameter	Requirements	Enabling technology/comments
Effective area	2 m^2 @ 1 keV (goal 2.5 m^2) 0.25 m^2 @ 6 keV (goal 0.3 m^2)	Silicon Pore Optics developed by ESA. Single telescope: 3 m outer diameter, 12 m fixed focal length
Angular Resolution	5" (goal 3") on-axis 10" at 25' radius	Detailed analysis of error budget confirms that a performance of 5" HEW is feasible.
Energy range	0.3-12 keV	Grazing incidence optics & detectors
Instrument field of view (diameter)	*Wide-Field Imager:* (**WFI**): 40' (goal 50')	Large area DEPFET Active Pixel Sensors
	X-ray Integral Field Unit: (**X-IFU**): 5' (goal 7')	Large array of multiplexed Transition Edge Sensors (TES) with 250 micron pixels
Spectral Resolution	**WFI**: <150 eV @ 6 keV	Large area DEPFET Active Pixel Sensors
	X-IFU: 2.5 eV @ 6 keV (goal 1.5 eV @ 1 keV)	Inner array (10"x10") optimized for goal resolution at low energy (50 micron pixels).
Count Rate capability	> 1 Crab[3] (**WFI**)	Central chip for high count rates without pile-up and with micro-second time resolution
	10 mCrab, point source (**X-IFU**) 1 Crab (30% throughput)	Filters and beam diffuser enable higher count rate capability with reduced spectral resolution
TOO response	4 hours (goal 2 hours) for 50% of time	Slew times <2 hours feasible; total response time dependent on ground system issues

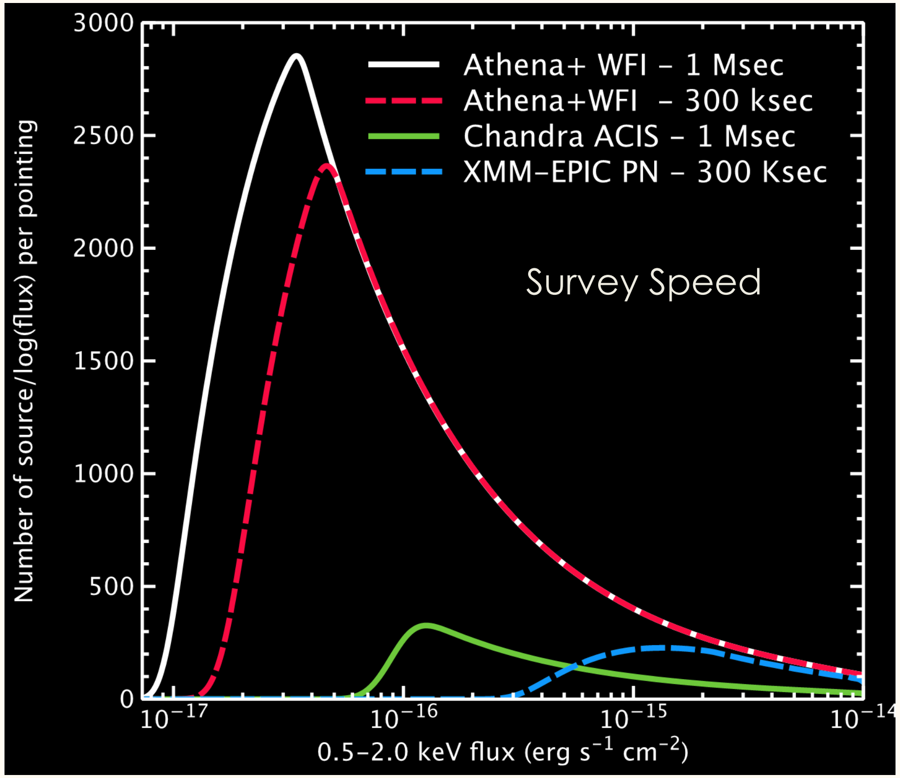
Only 2 detectors (DEPFET and TES calorimeters) are used and share the focal plane

The first Deep Universe X-ray Observatory

- Athena+ has vastly improved capabilities compared to current or planned facilities, and will provide **transformational** science on virtually all areas of astrophysics



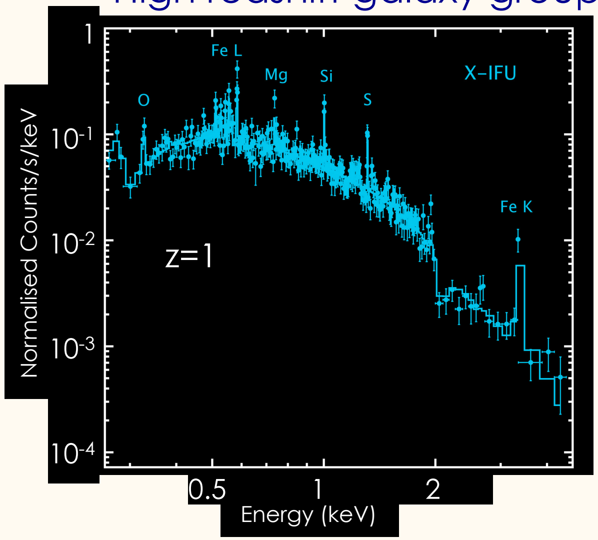
X-ray spectroscopy at the peak of the activity of the Universe



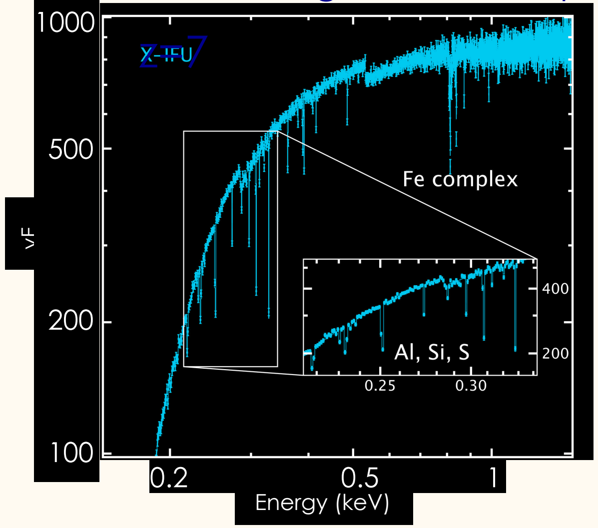
Deep survey capability into the dark ages and epoch of reionization

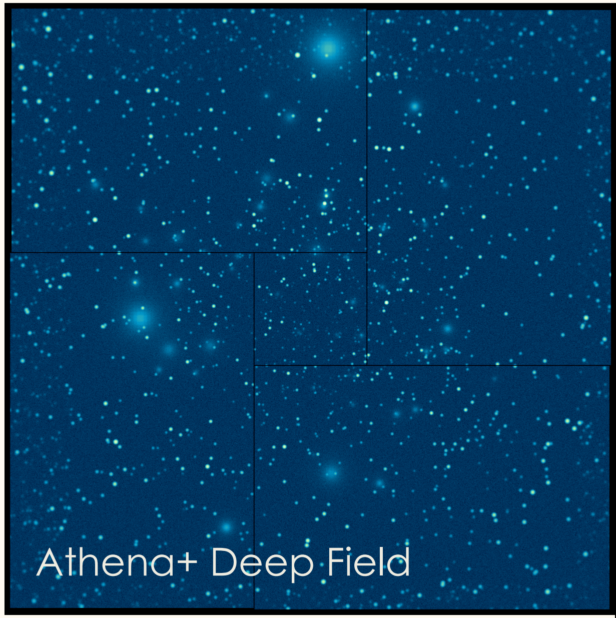
Athena+
The first Deep Universe X-ray Observatory

High redshift galaxy group

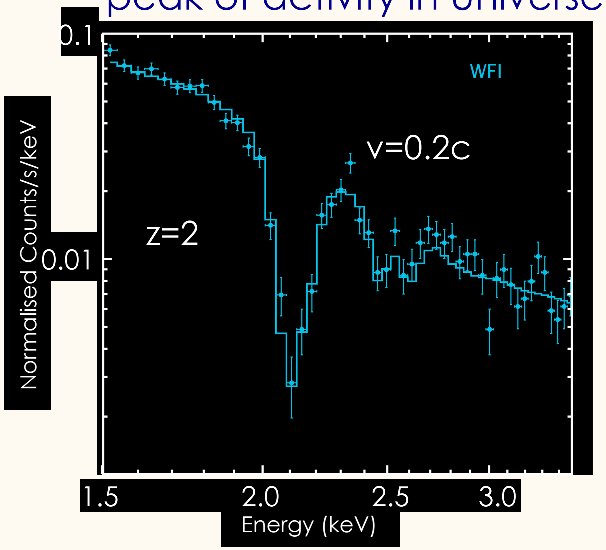


Primordial stellar populations via GRB afterglow follow up

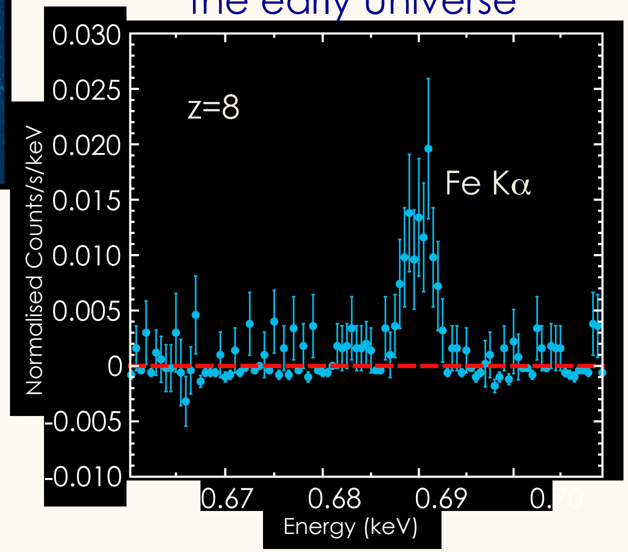




Black hole feedback at peak of activity in Universe

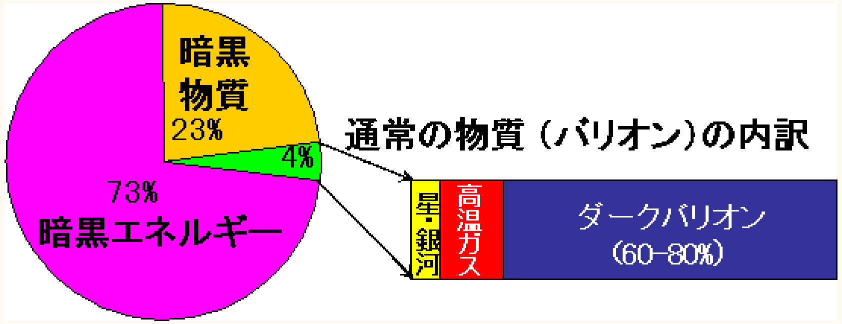


Obscured black hole in the early Universe

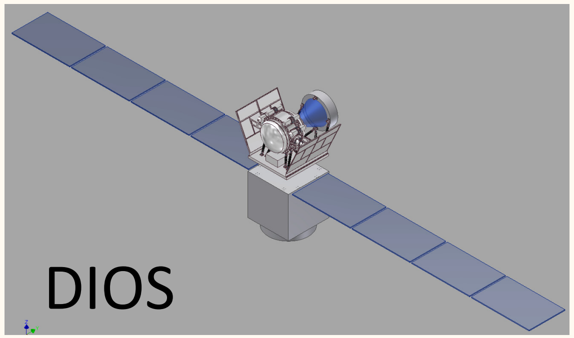


Nandra, Barret, Barcons, Fabian, den Herder, Piro, Watson et al. 2013 arXiv 1306.2307

DIOS: Diffuse Intergalactic Oxygen Surveyor

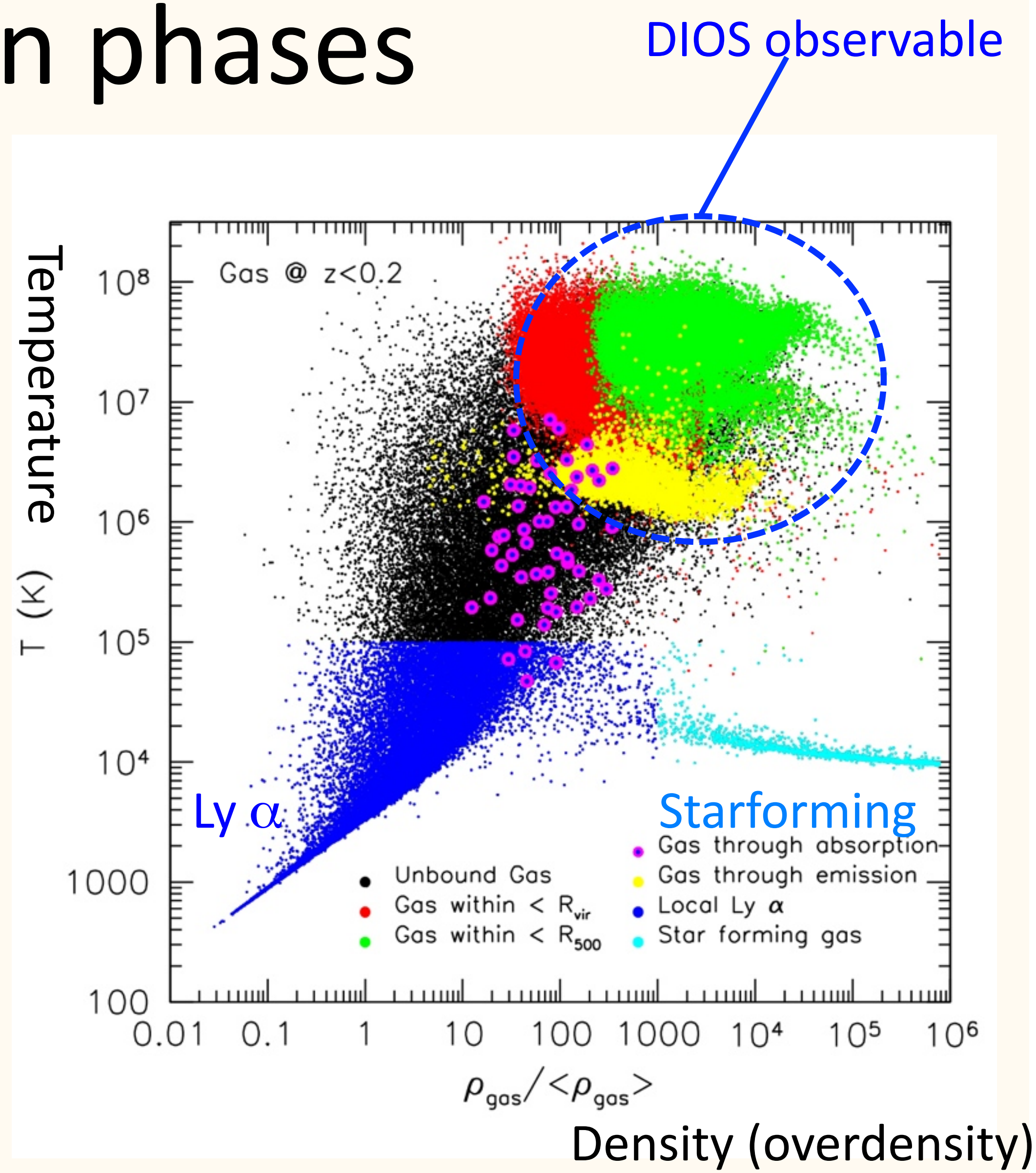


- More than half of baryons in the local universe remain unidentified (Fukugita et al. 98)
- Warm-hot intergalactic medium (WHIM):
  - Intergalactic gas with $T = 10^{5-7}$ K occupies a large fraction
  - Predicted from numerical simulation of structure formation
  - UV and X-ray absorption lines indicate WHIM, but observed fraction is small (< 10%)
- DIOS :
  - High resolution survey of oxygen emission lines from WHIM ($\Delta E < 5$ eV, with 200-300 times the ASTRO-H grasp [$S\Omega$])
  - 3-dimensional distribution of WHIM will be observed
  - Constrains thermal evolution of the Universe, by measuring "warm-hot" phase gas



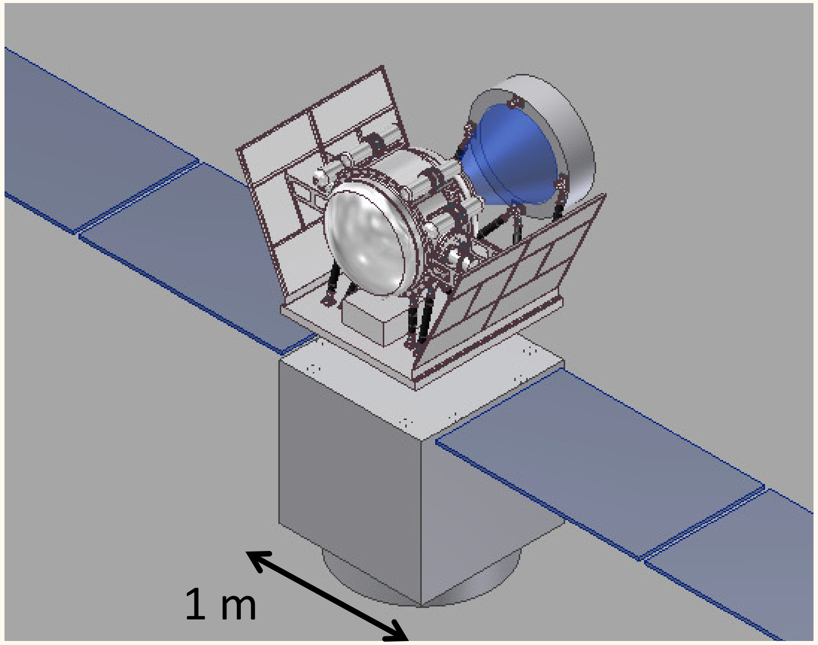
Baryon phases

- Local baryon distribution based on numerical simulation
- This depends on simulation codes and can vary significantly
- Absorption lines can detect low-density gas – but, geometry and thermal structure difficult to estimate
- Emission lines like He-like triplets are simple, and the structure can be measured

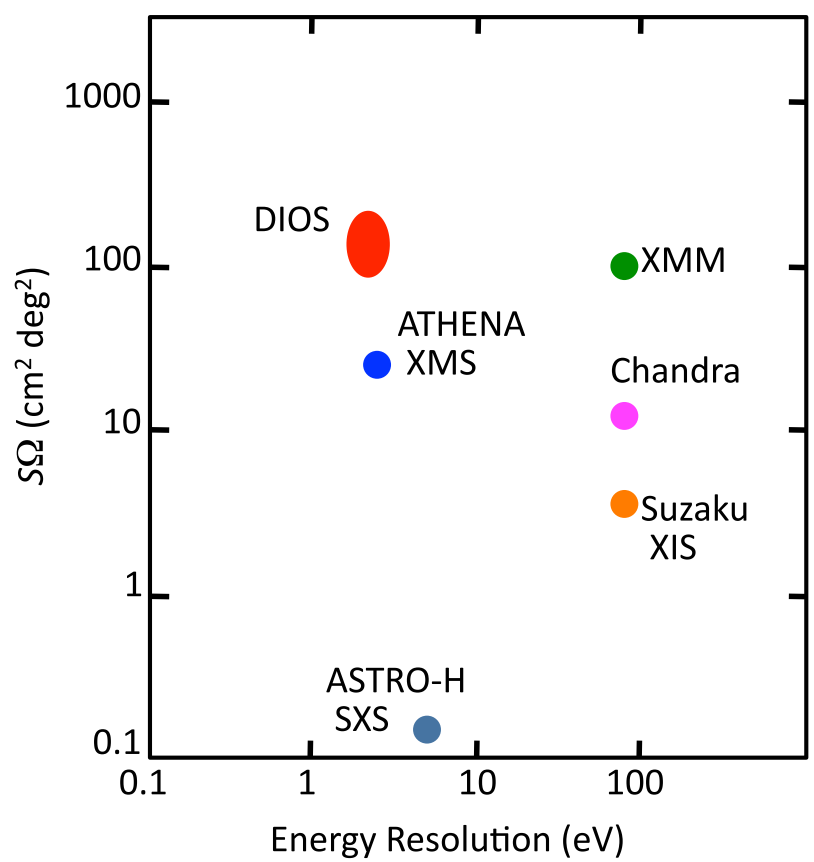


Branchini et al. 2009

DIOS and its grasp ($S\Omega$)



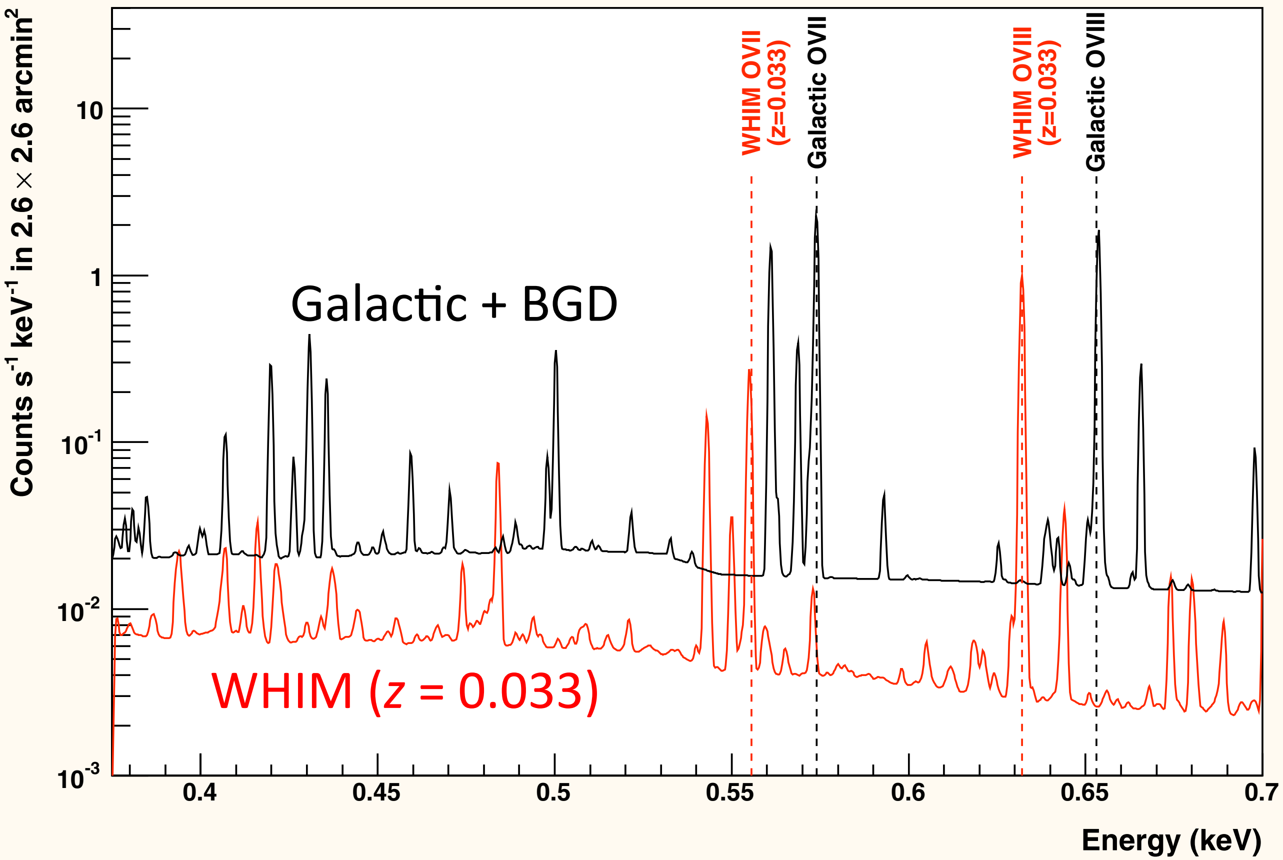
Orbit: 550 km altitude,
Inclination 30°, period 95 min



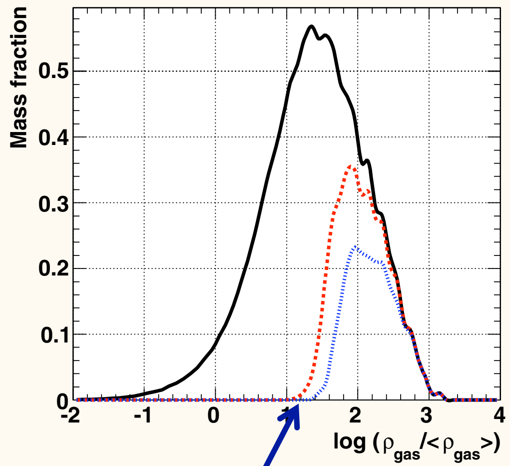
4-reflection telescope, TES calorimeter array, $E < 2$ keV,
FOV = 50 arcmin diameter
Coolers are ASTRO-H engineering model refurbished.

DIOS: Expected spectrum

Takei et al. 2011



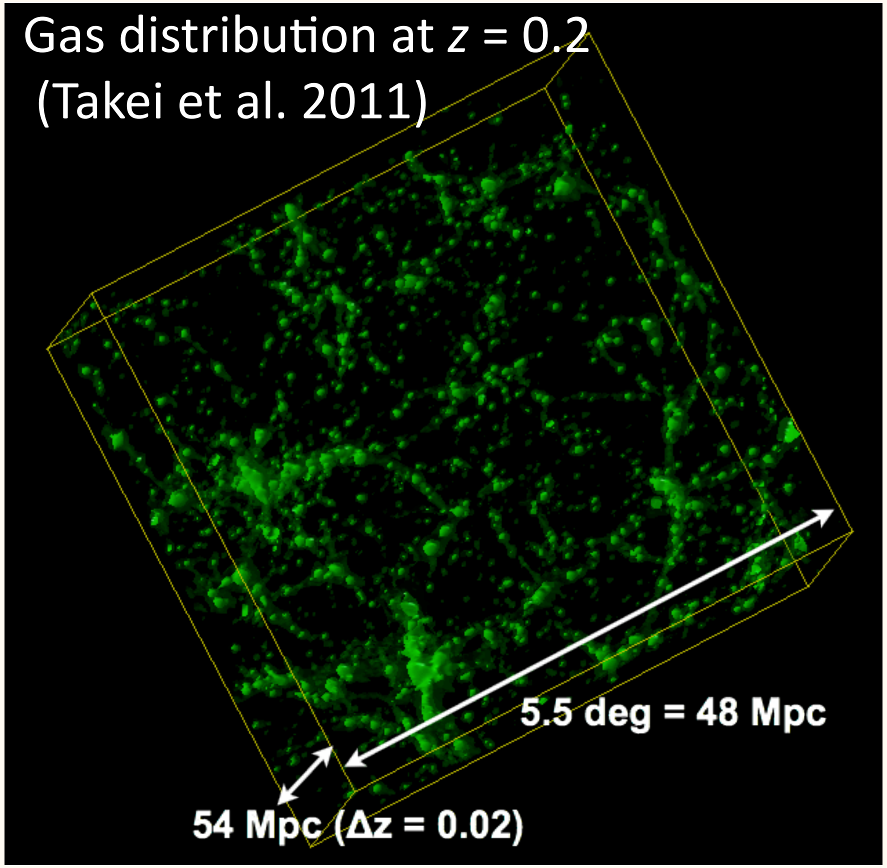
Detectable fraction

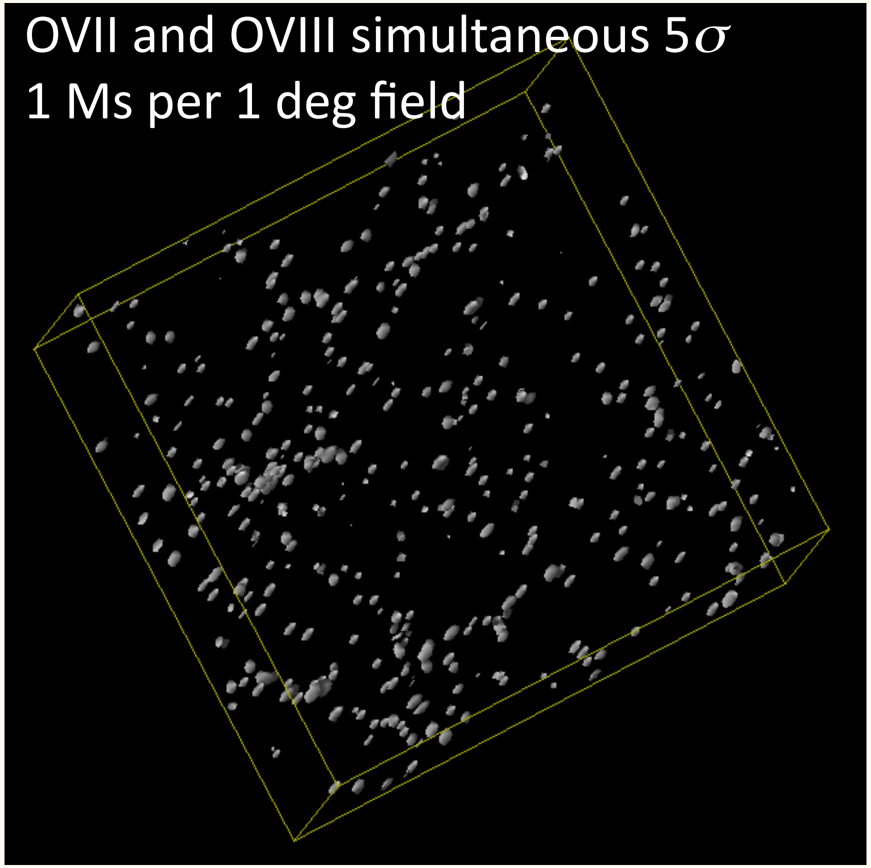


5 Ms (!) with DIOS

- Line-free energy ranges of MW emission give us windows in redshift space for WHIM detection
- 5 deg x 5 deg survey (1 Ms x 30) plus one deep (5 Ms) pointing can be a plan

Expected 3D map at z = 0.2

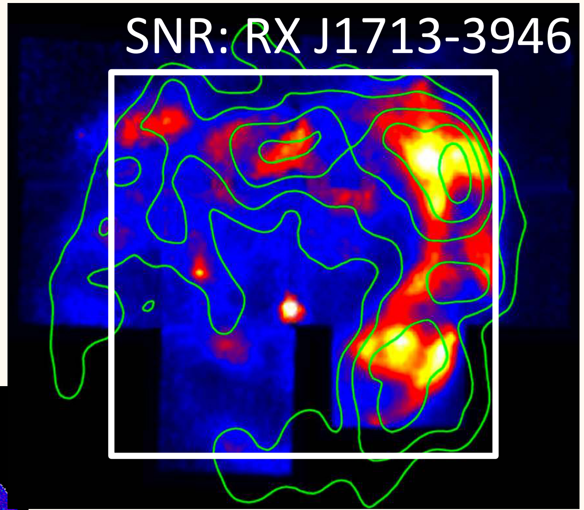


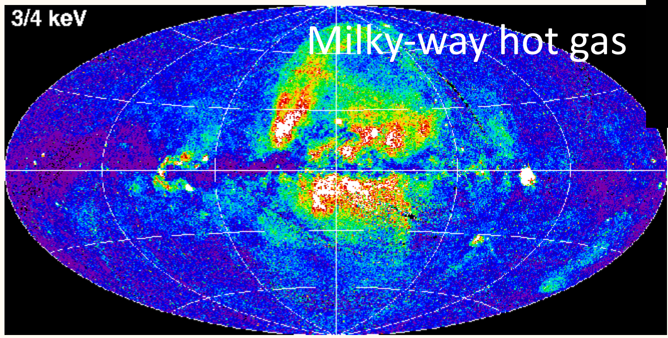


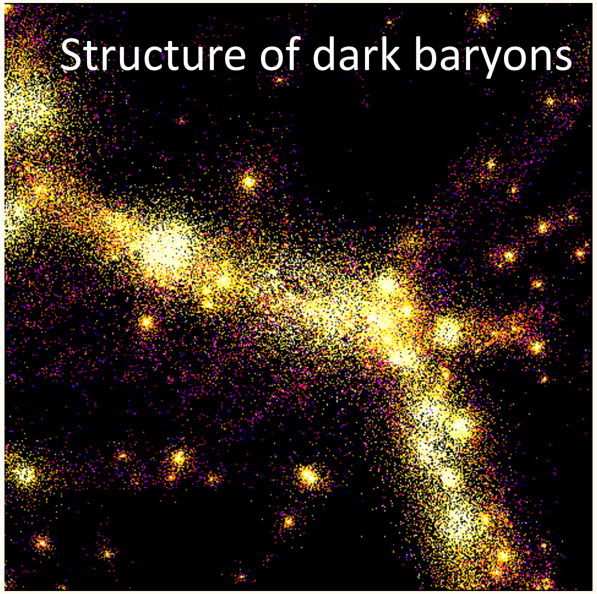
500 k – 1 Msec pointing per position. About 30 points mapped
DIOS can pick up filaments and faint galaxy groups
Overdensity $\rho/\langle\rho\rangle \sim 30$ is explored revealing 30-40% of the dark baryons

Wide range of targets for DIOS

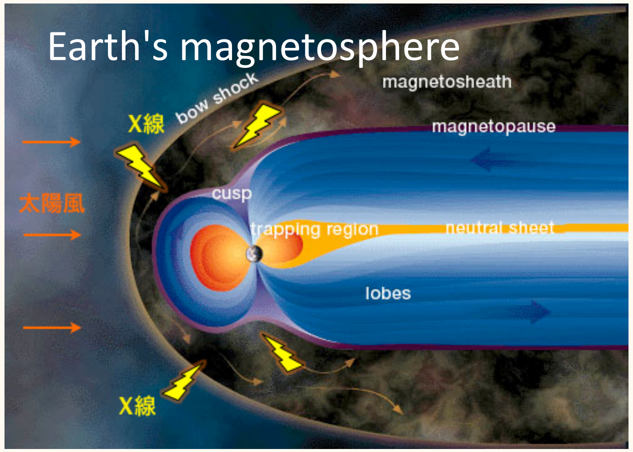
- 3-dim structure of dark baryons
- Charge exchange lines from low density atmosphere
- Dynamics of hot interstella gas (Galactic fountain and galactic winds)
- Large-scale shocks and particle acceleration
- Beyond the edge of clusters of galaxies

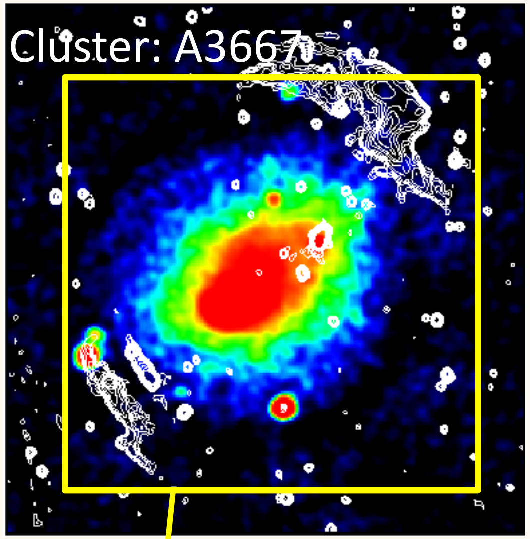






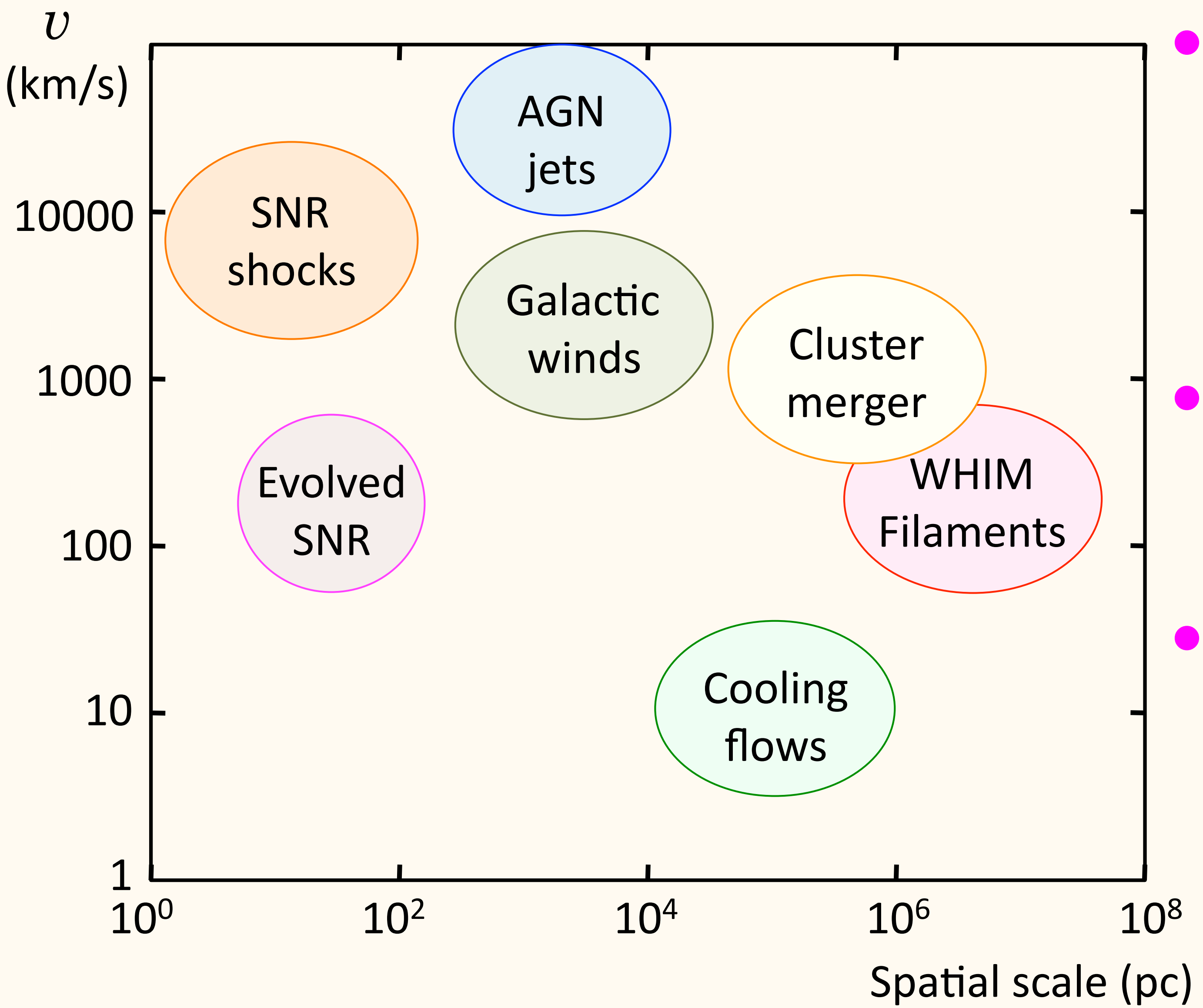
IGM (10^5-10^7K)





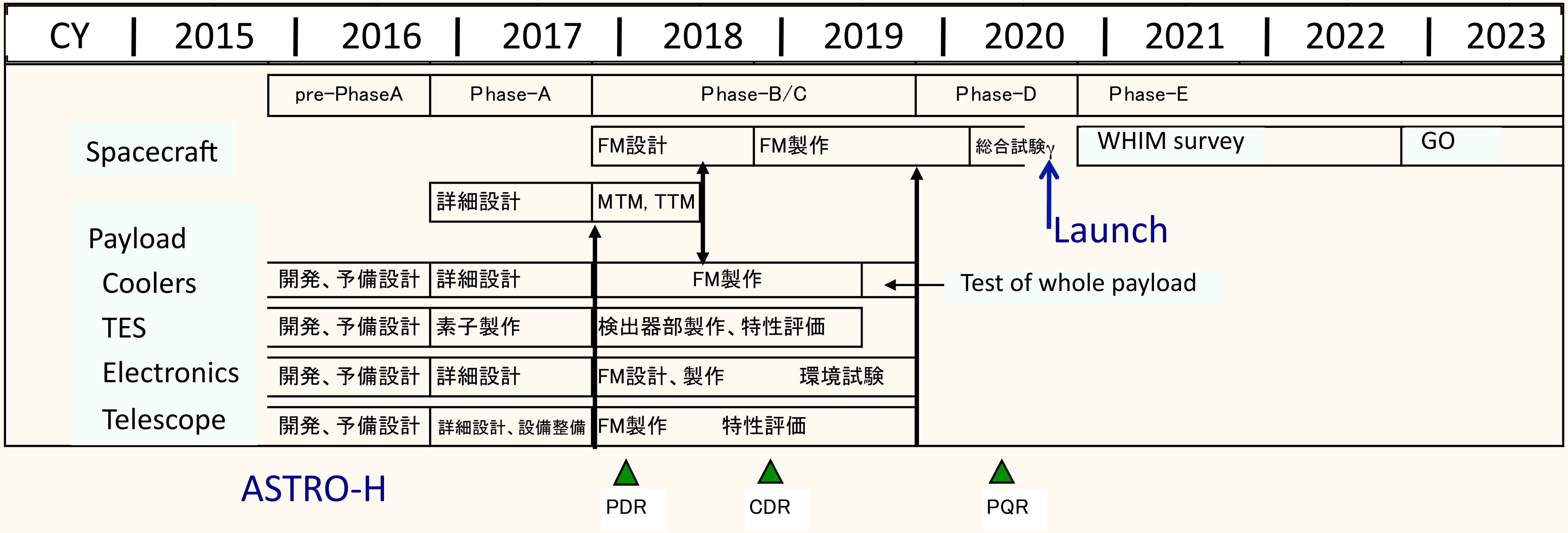
DIOS f.o.v.

Large-scale gas dynamics



- Important means to look at the structural, thermal and chemical evolution of the universe.
- Thermal and non-thermal energy concentration can be distinguished.
- Complementary and extension of ASTRO-H science

Schedule of DIOS



More future?

Science with $E/\Delta E > 10^4$, if it becomes possible in a long future:

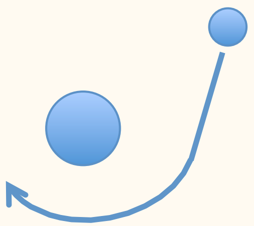
- Gas dynamics: resolving low-velocity components (~ 10 km s^{-1})
  - Search for dark-matter blobs
- Line width: detection of natural width
  - Separation of resonance, forbidden, inter-comb lines by line width only
- Gravitational redshift:
  - Matter at 10^{16} cm from a 10^7 $M_\odot$ black hole
  - Clusters of galaxies: $\Delta E/E \sim 5 \times 10^{-5}$ is expected everywhere, which will be an independent measurement of dark matter potential
- Detection of very weak features:
  - Low abundance metals
  - High –z universe probed with emission/absorption lines

Missing satellites

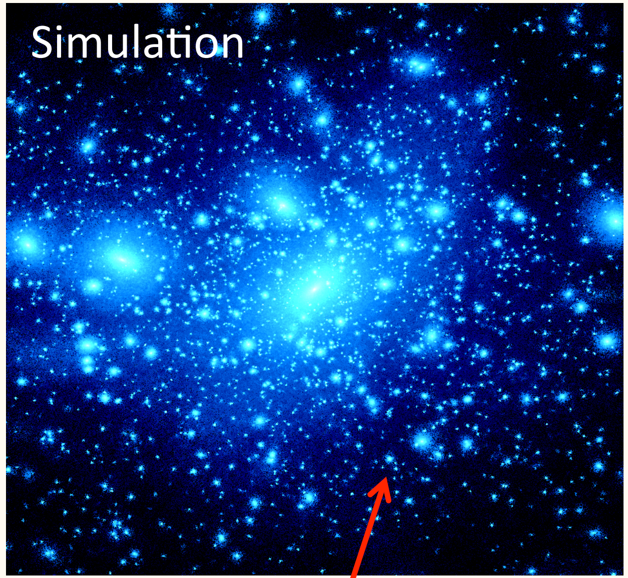
CDM predicts many subhalos around galaxies: 10-100 times more than observed

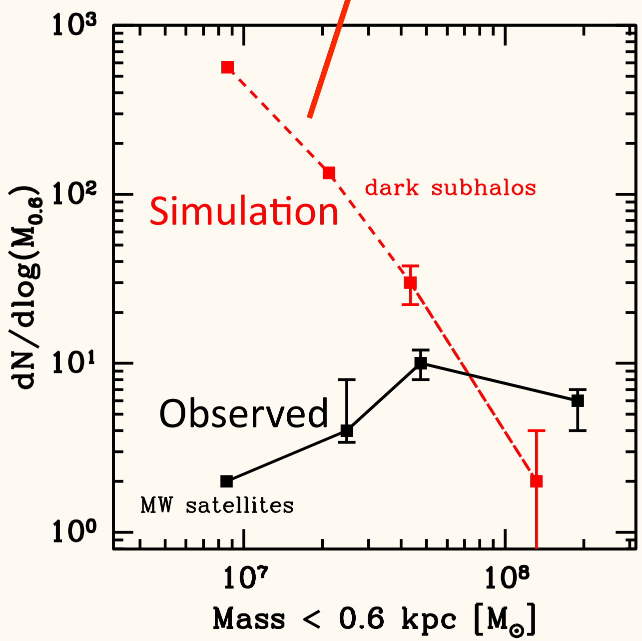
→ Dark subhalos

- Star formation inefficient in low mass clumps
- Only detectable with gravitational lens or with swing-by gas motions



Kravtsov 2010





Summary

- X-ray astronomy is a rich field regarding spectroscopy (atomic, gravitational, dynamical)
- High resolution spectroscopy is the major driver for past and future X-ray astronomy
- A lot of new science will emerge, giving clear views of dynamical and non-thermal universe; to be opened by ASTRO-H
- Advances with DIOS (wide field) and then with Athena (large area and good angular resolution) will show us further possibility of X-ray spectroscopy
- International collaboration has kept and will keep Japanese position strong

END