Future X-ray Spectroscopy Missions

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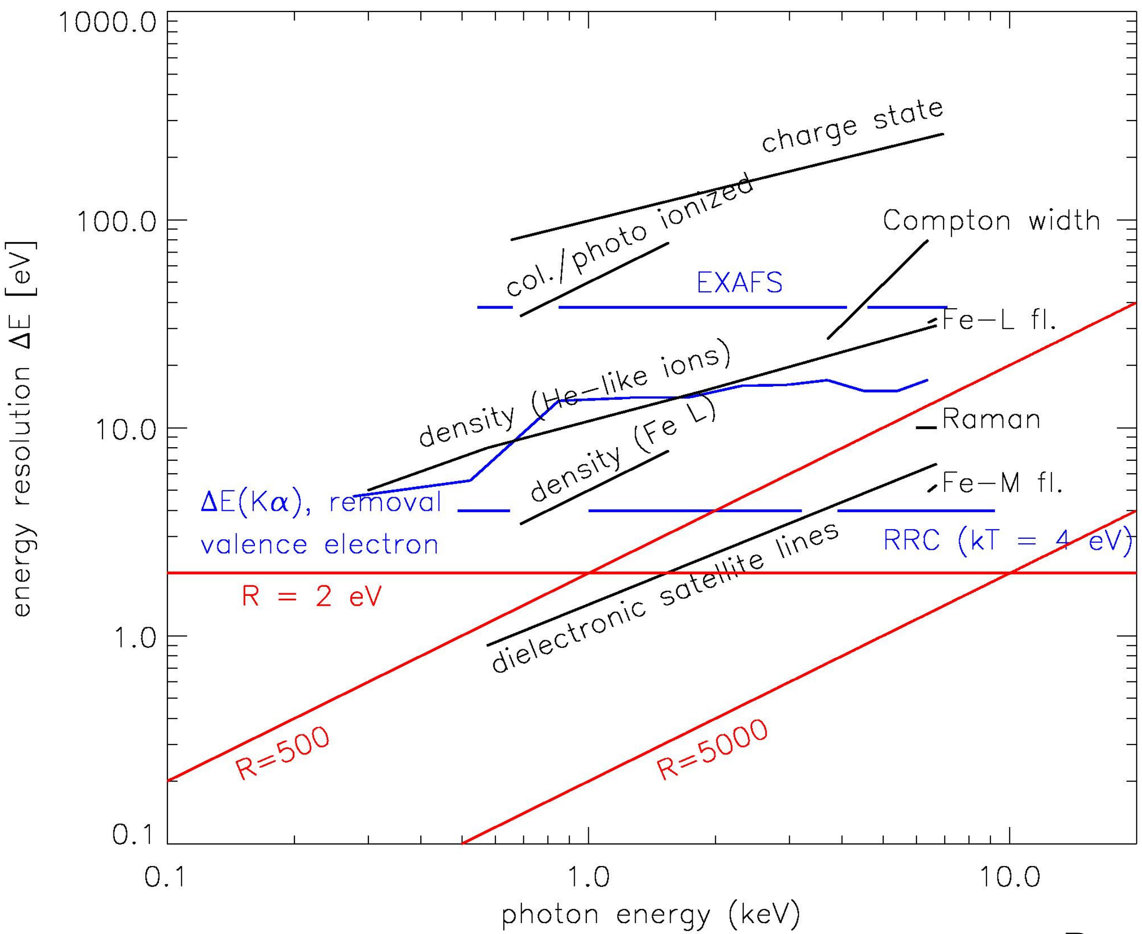
contents

- Plasma diagnostics in the 0.1 to 10 keV band with resolution > 100
- X-ray spectrometers: instrumental promises
- Future missions (a dream)

Physical processes for 1 – 10 keV band



Paerels

current spectrometers have access to most physical processes, major open items:

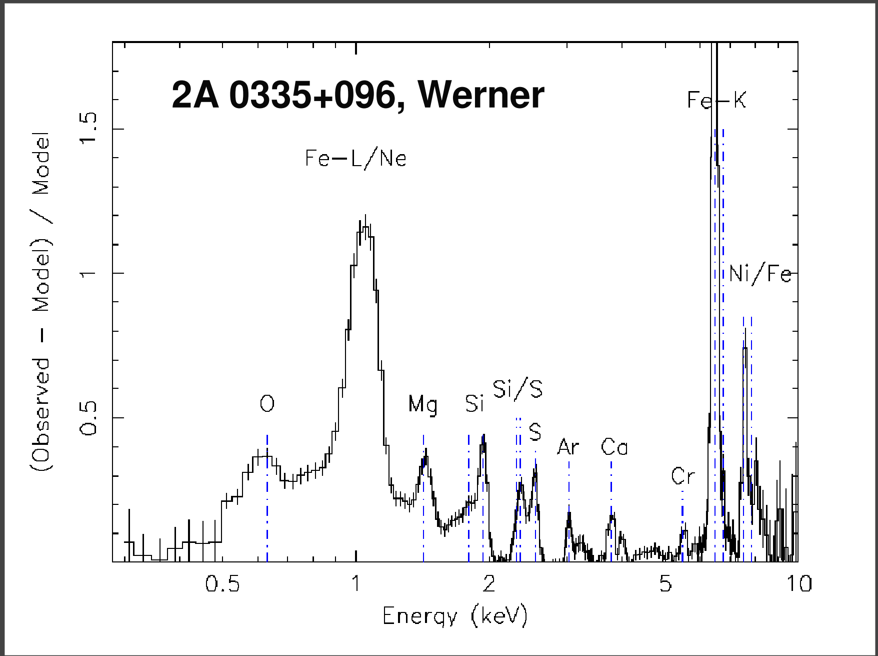
- Study of high-z Universe: high sensitivity (large area, low background) (AGN, BH)
- Physical properties of astrophysical plasmas: densities, ionization state, temperatures and abundances (common and rare elements)
- Dynamical processes in point-like objects:
  Time resolved HR-spectroscopy of variable sources (AGN, compact stellar objects, stars)
- Dynamical processes in extended thin plasma sources:
  Spatially resolved HR-spectroscopy (SNR, clusters)

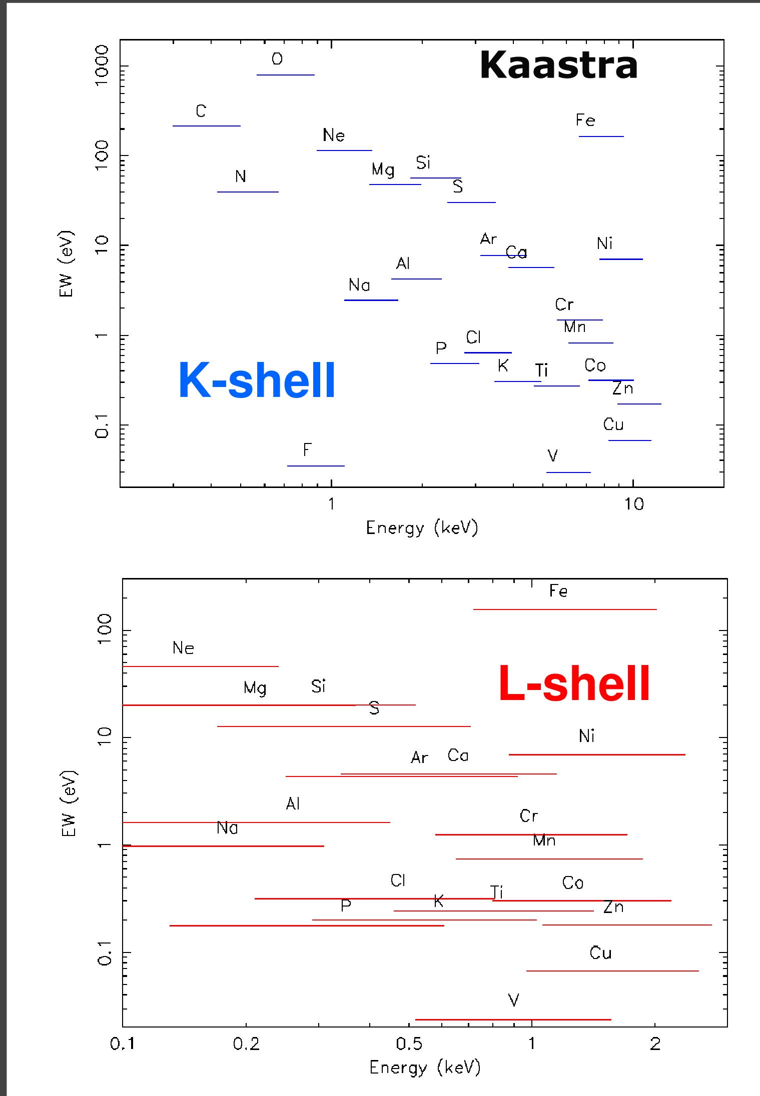
Rare elements

$$S = \left(\frac{N_l \quad EW}{EW + \Delta E} \right)^{1/2}$$

EW for coronal source (solar abundances)

Horizontal axis: energies where emission is relatively large



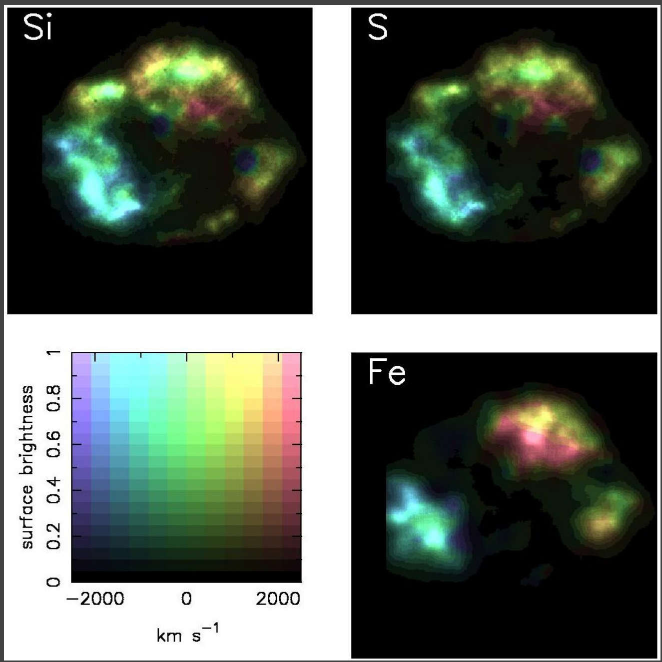


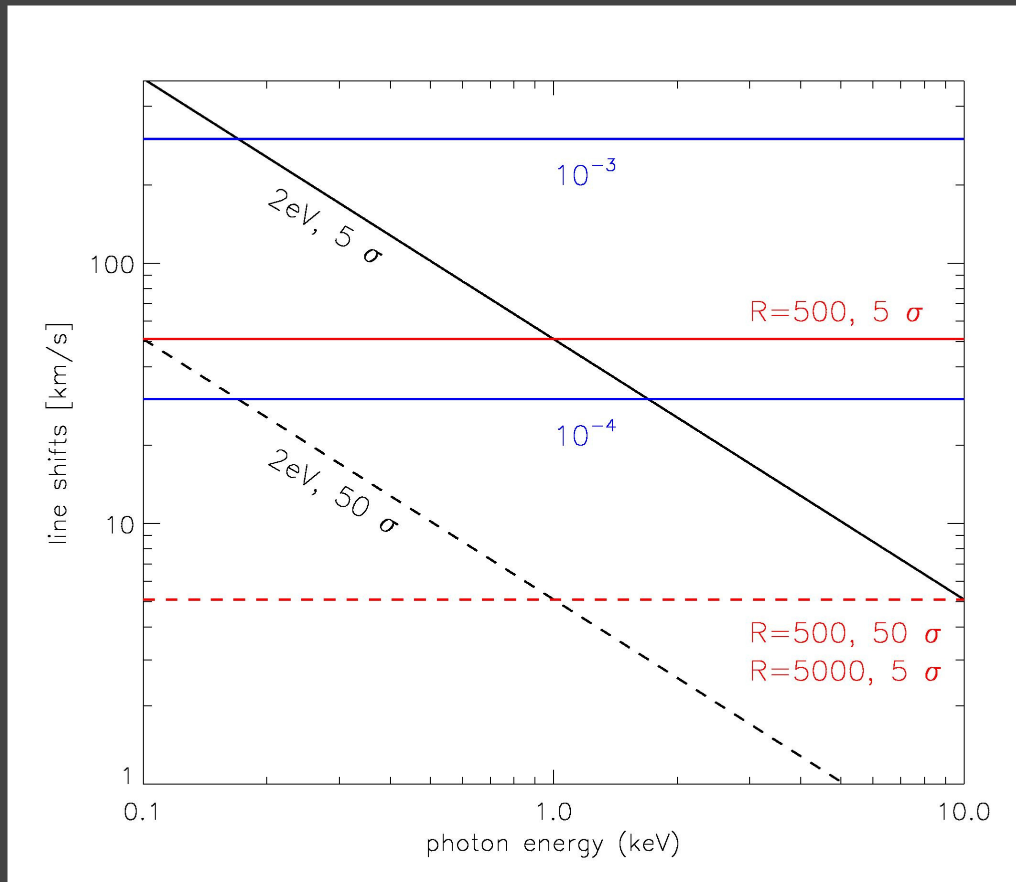
Bulk motion

$$\Delta v = \frac{c\Delta E}{2.35E} \frac{1}{S}$$

spatially resolved line centroids

Challenge: stability/uniformity of detectors



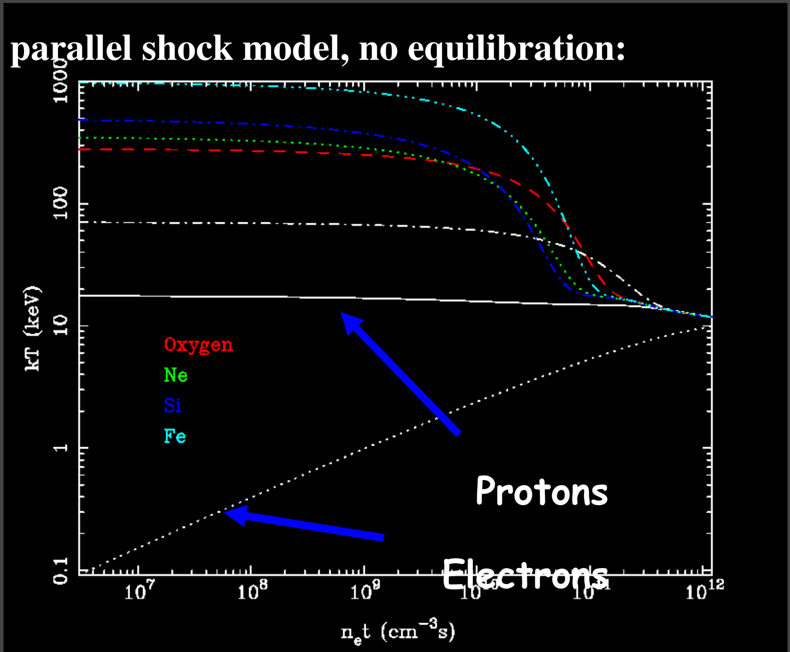


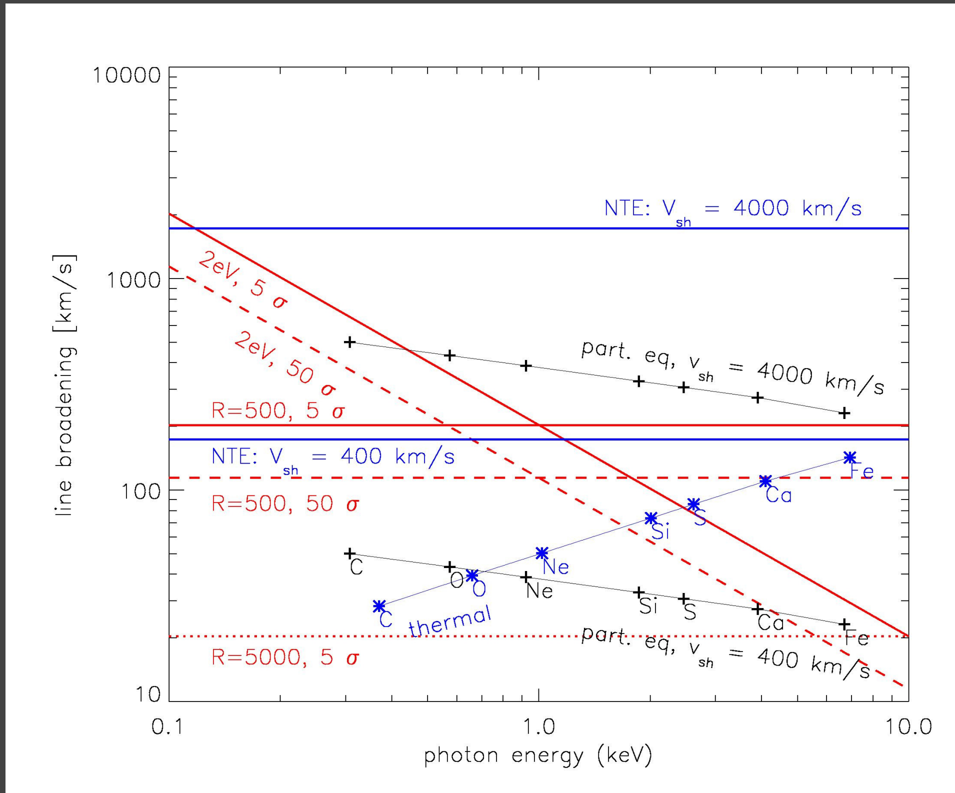
Willingale

Line broadening

- Thermal (≤ ~ 100 km/s)
- Turbulent motion(100 – 1000 km/s)
- Broadening due to partial temperature equilibration (shock heating physics)

$$\Delta\sigma_v = \frac{c\Delta E}{2.35E}\left(\frac{2}{S}\right)^{1/4}$$





Instrument optimization (line spectroscopy)

Science	Figure of merit	Comment
Extended sources (cluster evolution, WHIM in emission)	$A\Omega/\Delta E$	
Point sources (WHIM in absorption, galaxies, stars)	$A/\Delta E$	
Lines in outbursts (GRB, Equation of State)	$A/\Delta E * f$	*f* =factor for slewing
Enrichment dynamics	$A\Omega/\Delta E$	
Strong field limit	A @ 6 keV	

Spectrometers

- Reflective gratings (in and out-of-plane)
- STJs
- Micro-calorimeters
- Magnetic micro calorimeters

Diffractive spectrometers (Cash)

- In-plane gratings: R ~6000 for XMM-RGS behind Chandra mirrors (in-plane gratings)

- Out-of-plane gratings give higher dispersion and R ~6000 but:
  - need 5” FWHM mirror assembly
  - good control over grating scattering (e.g. Chandra/ XMM-Newton)

- Complexity (line density, image shape, focal depth)

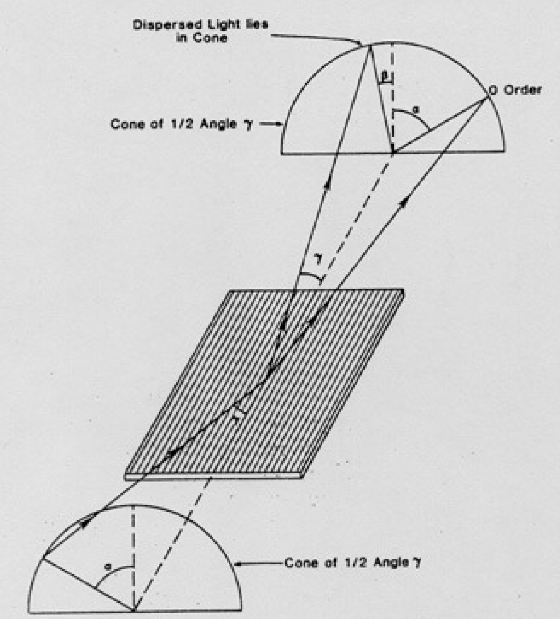
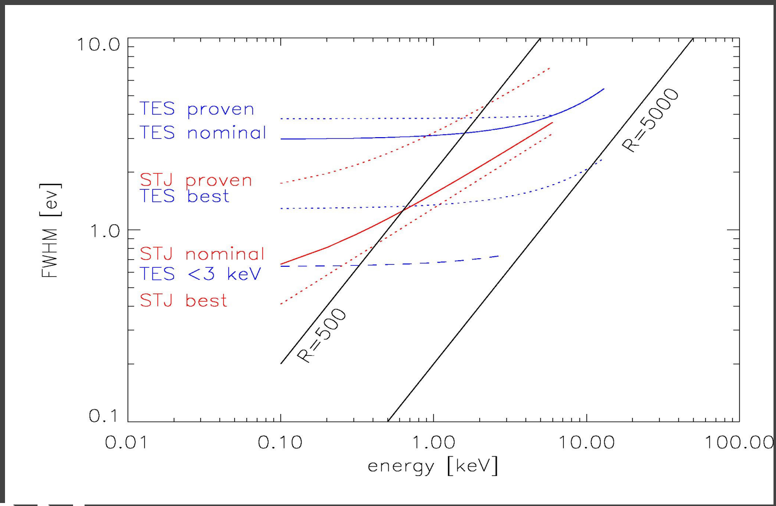


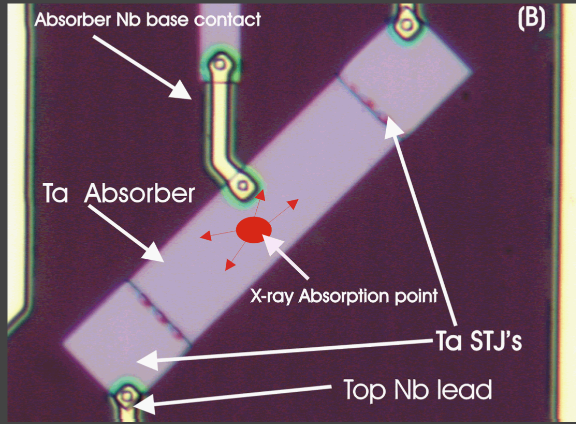
Fig. 2. Light strikes a grating with a polar angle of γ and an azimuthal angle of α. It diffracts to polar angle γ and azimuthal angle β. γ is the angle between the direction of the incoming ray and the direction of the rulings. α is the azimuthal angle along the cone of half-angle γ around the direction of the rulings. All the diffracted light emerges along the same cone of half-angle γ, and β is the azimuthal angle of the diffracted light. The off-plane mount is sometimes called the conical diffraction mount.

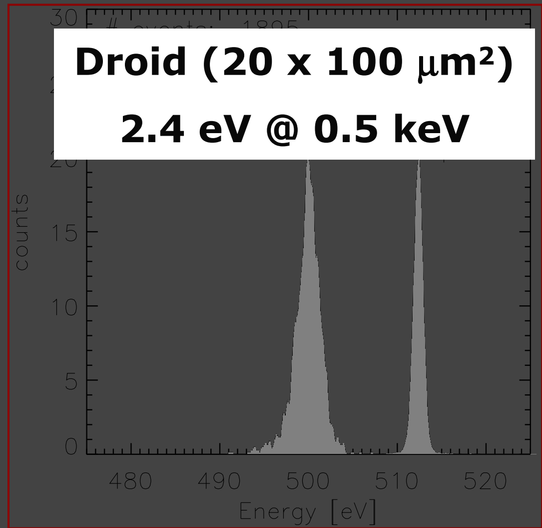
Off-plane

$$R = \frac{2 \tan \beta \sin \gamma}{B} \approx \frac{4\theta}{B}$$

Superconducting Tunnel Junctions
(Verhoeve, Martin,..)

- **Small devices (33x33 μm^2): need for droids**
- **No multiplexing foreseen: smaller FoV**
- **T ~ 300 mK, no need for ADR but < 1 eV requires different devices (T ~ 100 mK)**
- **Thin absorbers (QE → 0 for 2-3 keV)**
- **High count rate capability**
- 





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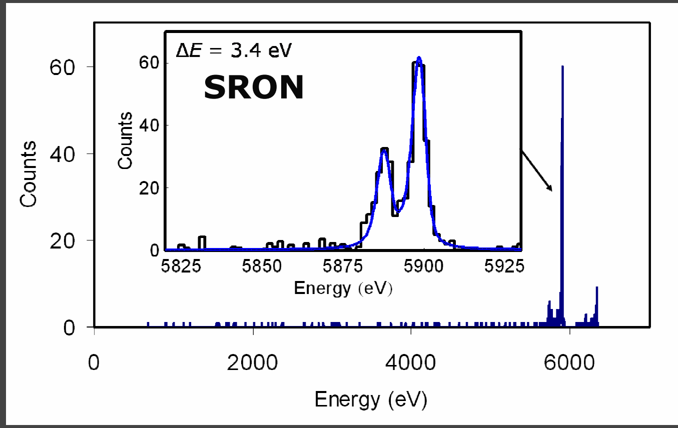
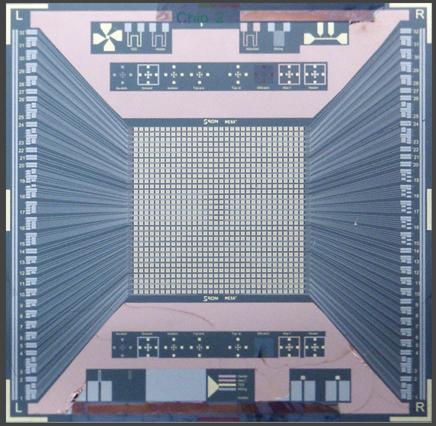
X-ray calorimeters
(GSFC,NIST,SRON,…)

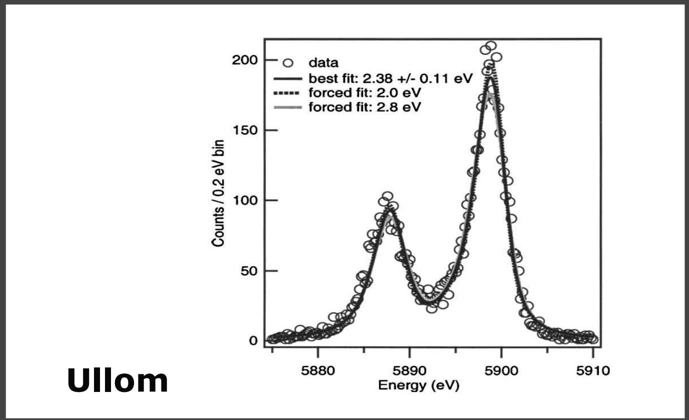
- TES based (larger arrays) and NtDGe (available but only small arrays)
- Provide few eV resolution: 2.4 eV @ 6 keV (NIST), 3.4 @ 6 keV (SRON), potential for < 1 eV around 0.5 keV
- Allow for array production (32x32 arrays are produced)
- Allow for good filling factor (> 90%) and stopping power (> 90%)

Major challenges:

- Cryogenic detectors in space (100 mK)
- Array read-out (FDM or TDM)







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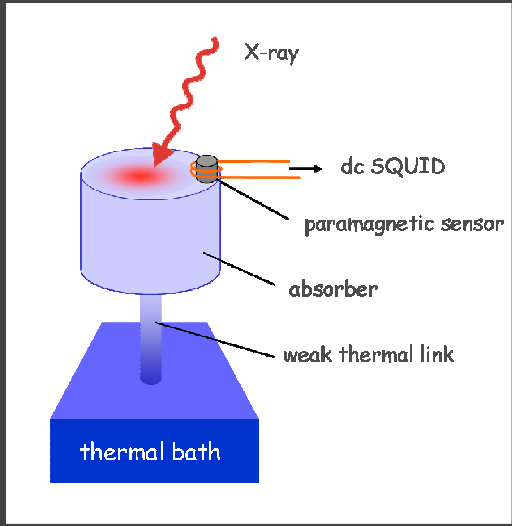
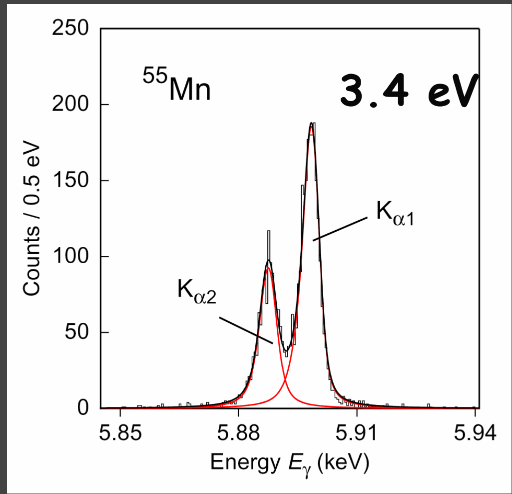
Magnetic calorimeters (Enns, ..)

$$\Delta E_{\mathrm{FWHM}} \simeq 2.36\,\sqrt{4k_{\mathrm{B}}C_{\mathrm{a}}T^2}\,\sqrt{2}\left(\frac{\tau_0}{\tau_1}\right)^{1/4}$$

- **Similar to calorimeter but using a non-contact magnetic read-out**
- **Resolution of few eV easily reached (fast learning curve)**
- **potential for < 1 eV resolution up to higher energies (6 keV)**
- **Most requirements can be met but schemes for arrays and muliplexing is a very complex problem**





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Mission concepts: identify separate ionization stages in hot gas (R > 100 in 0.1- 10 keV)

Mission	type	E	R	Aeff	@ keV
• **Pharos**	**diffr**	**0.1–2**	**6000**	**100 cm^2**	**0.5**
• **ESTREMO**	**image**	**0.2-10**	**500**	**1000 cm^2**	**1.0**
• **NEW**	**image**	**0.1-1.5**	**500**	**500 cm^2**	**0.5**
• **DIOS**	**image**	**0.3-1.5**	**500**	**100 cm^2**	**0.5**
• XEUS	image	0.2-15	500	50000 cm^2	1.0
			1000	10000 cm^2	6.0
• Con-X	image	0.6-10	800	15000 cm^2	1.0
			1200	6000 cm^2	6.0
	diffr.	0.2-2.0	1000	1000 cm^2	0.5
• **NeXT (SXT)**	**image**	**0.1-10**	**500**	**1000 cm^2**	**1.0**

But more concepts are studied: micro-X (rocket), baryonic structure probe (UV)

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Pharos (Elvis/Nicastro/astro-ph0303444)

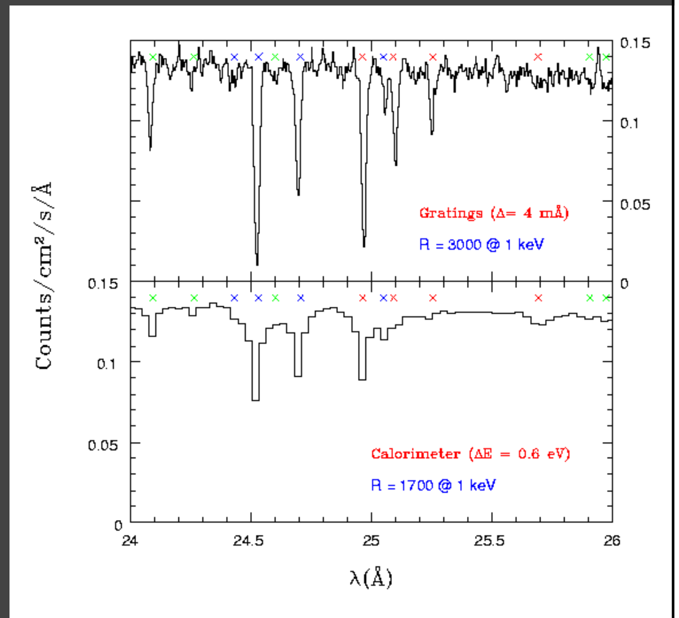
- Study WHIM in absorption
- Most energetic events (GRB)

- Very high resolution (R > 6000)
- Off-plane gratings (e = 0.1)
- Modest area (1000 cm^2)
- Fast repointing after GRB
- Optimize A * R * *f* (gain fluence)

- FoM_{Pharos} 600.000 (2.500.000)
- FoM_{XEUS} (GF^2) 80.000
- FoM_{Con-X} (4 units) 200.000
- FoM_{NEW} (1eV) 500.000

provides unique kinematics

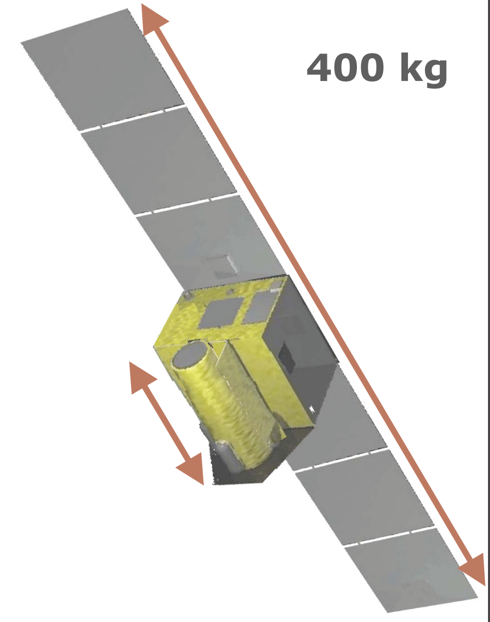
Fluence(2-10 keV) = 10^{-5} ergs cm^{-2}
~ 1-5/year



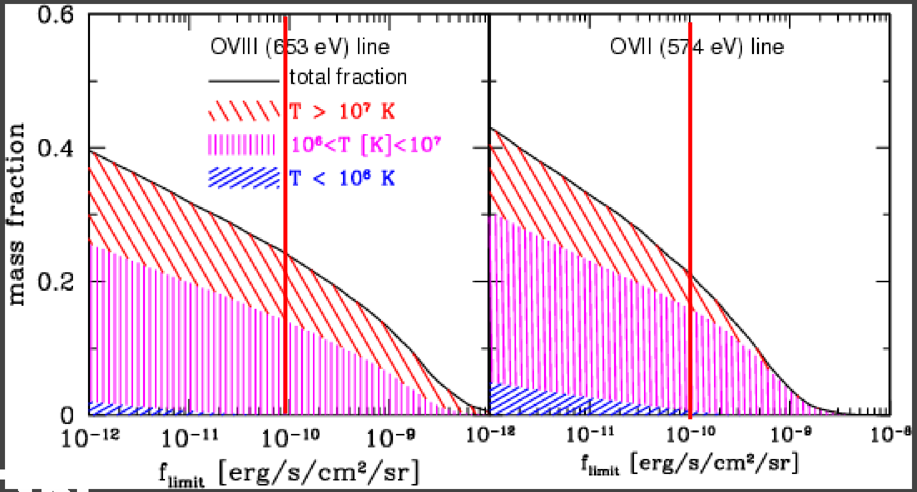
DIOS (Ohashi et al.)

- Study WHIM in emission
- Dynamics of local WHIM, galactic hot gas
- Clusters outskirts

- Smallest mission
- Large grasp (~ 100cm²deg²)
- Good energy resolution
- Foil mirror with 4 stages



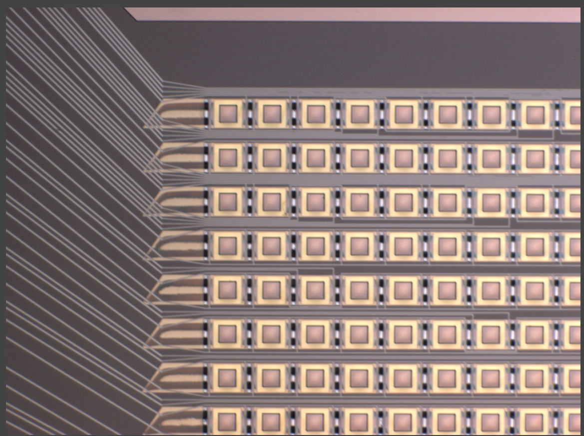
Detection limit 10^5 s, S/N = 10

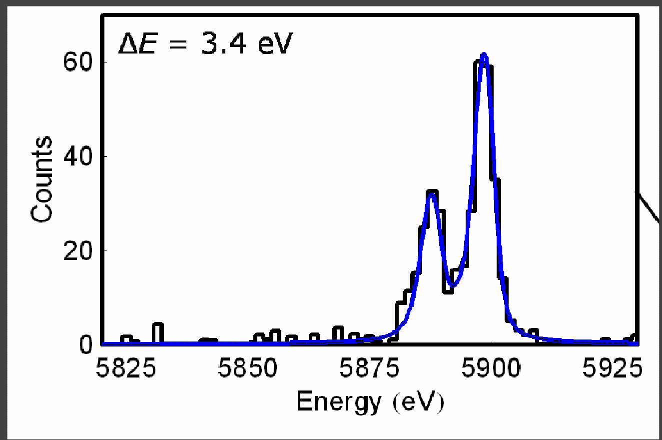


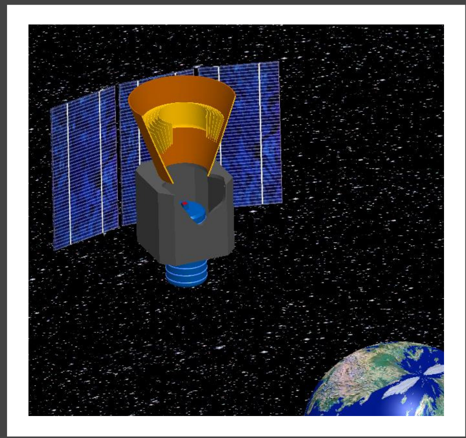
New Explorer of the cosmic Web (den Herder et al)

Baseline (goal):

- **Large area :** 500 (1000) cm^2
- **Large FoV:** 1 x 1 (1.5 x 1.5) $degree^2$
- **Excellent energy resolution:** 3 (1) eV
- **Limited energy range:** 0.2 – 1.0 (0.1 – 1.5) keV
- **Modest angular resolution:** 3 (1) arcmin
- **Reasonable detector array:** 32 x 32 (64 x 64) pixels
- **Fast repointing:** 180º < 1 minute
- **Long observations:** 1 – 2 weeks
- **Orbit:** LEO
- **Lifetime:** 3 (5) year







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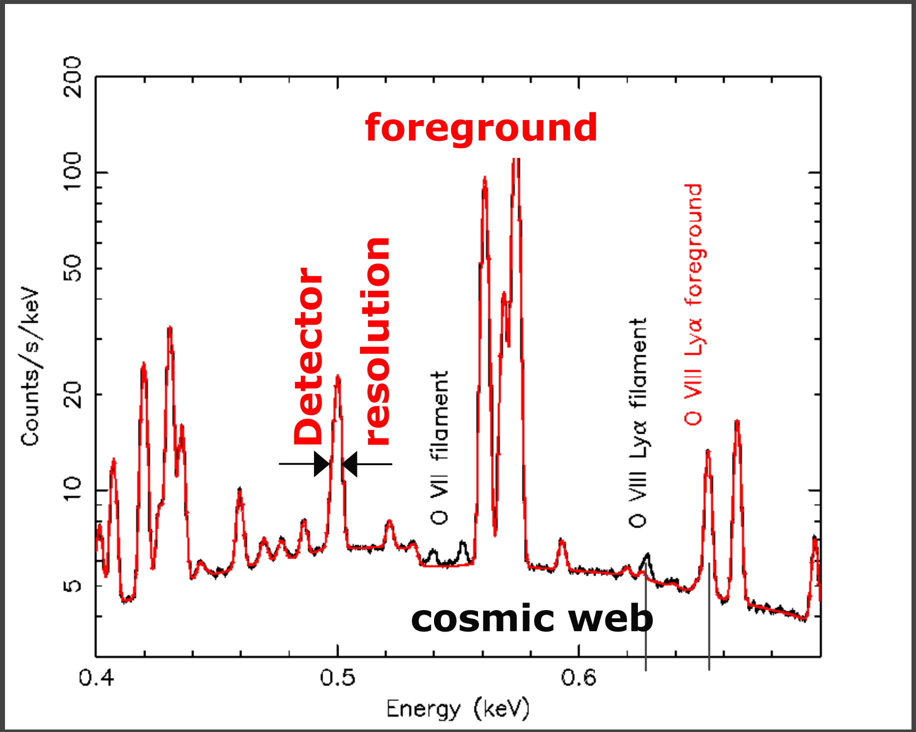
NEW: measuring the WHIM and ….

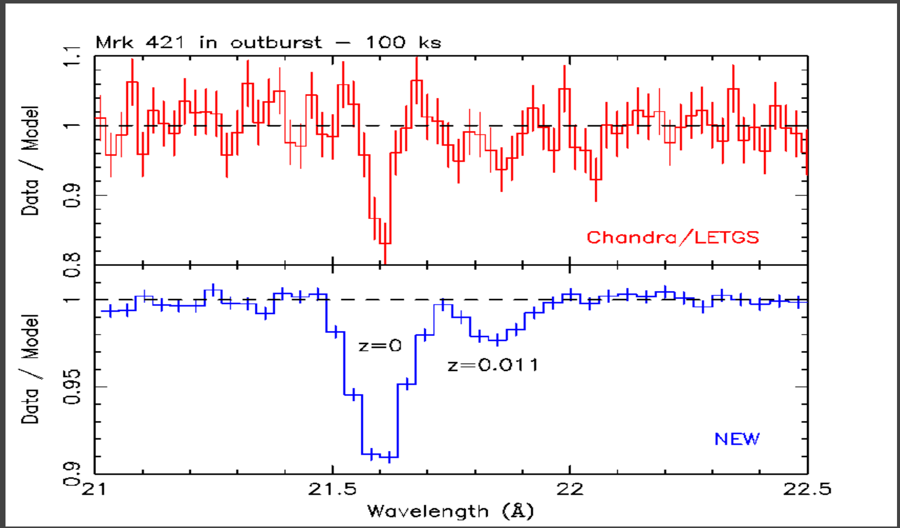
In emission

- Large scale structure (2-6 Mpc)
- Temperatures 10^5 – 10^6 K
- Densities: 50 - 150 m^{-3}
- Solar abundances: 0.1
- Overdensities 3 – 30

And in absorption

- Also fast pointing
- Right: 100 ks Mrk 421 (in outburst). The simulated spectra: z=0.00 and z=0.011 only (Nicastro et al.)



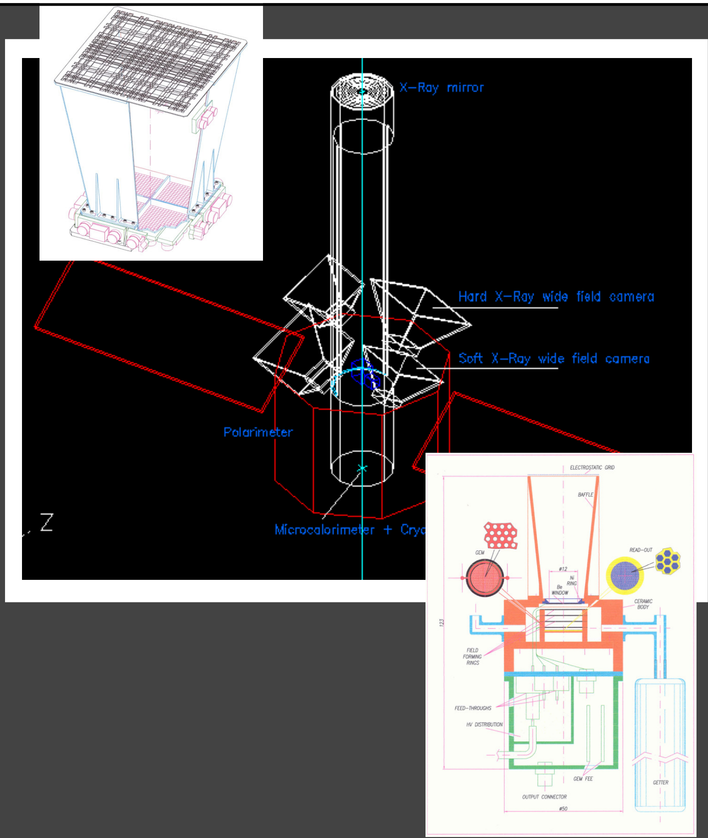


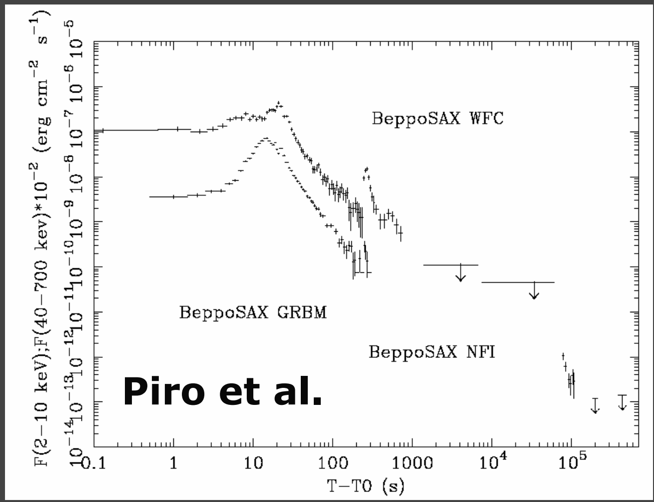
ESTREMO (Piro et al.)

- Cosmology (GRB as beacon): high-z GRB, evolution of metals, WHIM, dark matter
- Extreme physics (GR in BH, GRB engines and progenitors)

- High resolution (2-4 eV)
- Energy range up to 10 keV, FL: 4 m
- Polarimeter
- GRB monitor
- Fast repointing: figure of merit comparable to XEUS

- 10th of sources/year with
  F_x > 6 10^{-7} erg/cm^2 at >60s





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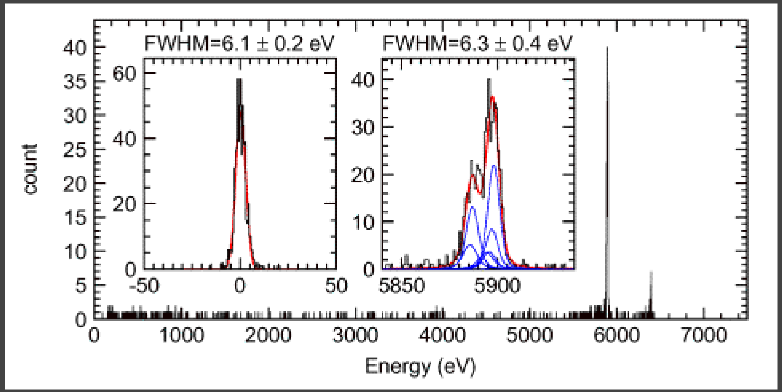
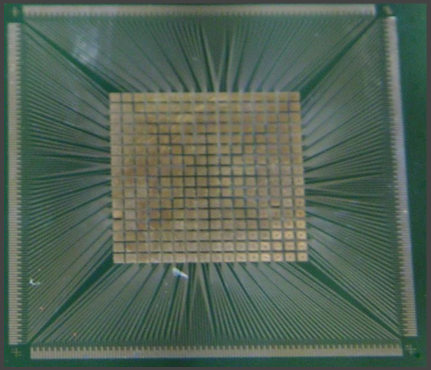
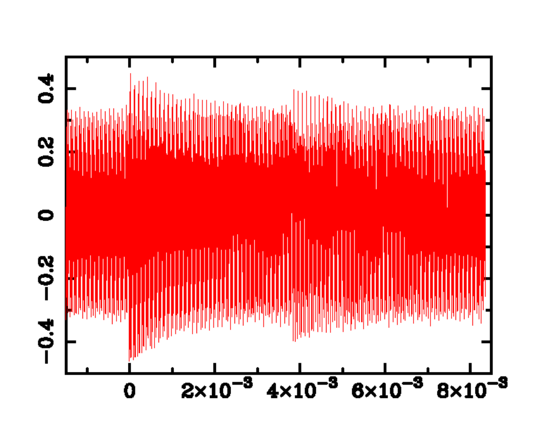
NeXT (Ohashi, Yamasaki)

- Main goal non-thermal emission
- Soft X-ray Spectrometer to study origin of shocks

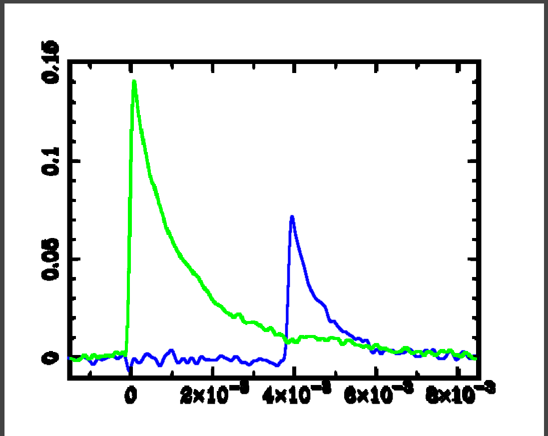
- Broadband coverage 1 keV – 1 MeV
- Includes soft X-ray telescope
- 1000 pixels, 2 eV resolution
- Mechanical cooler







Modulated



de-modulated

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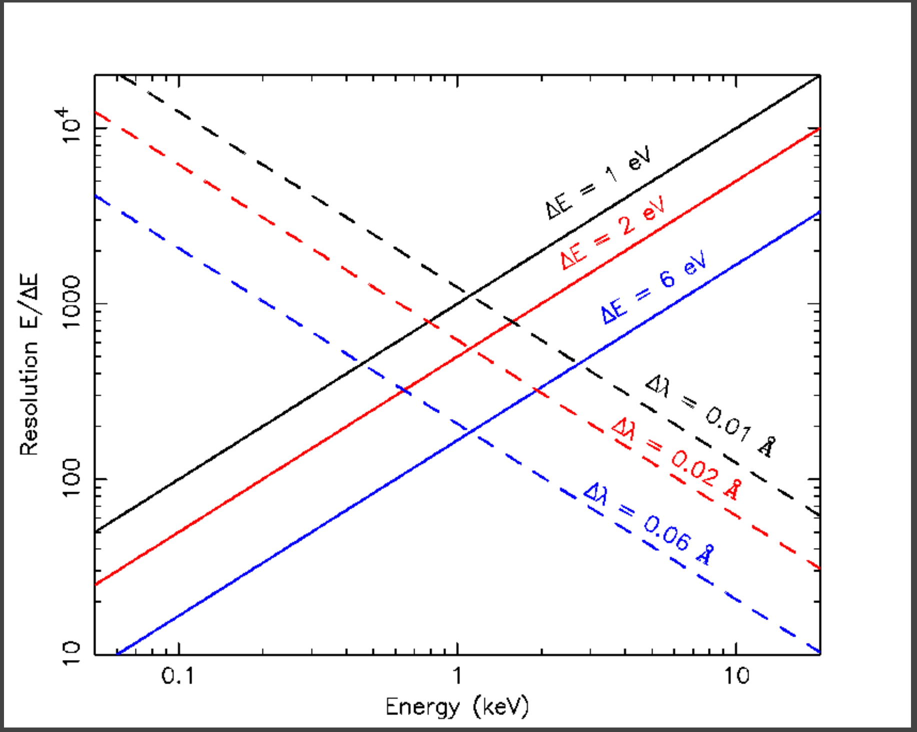
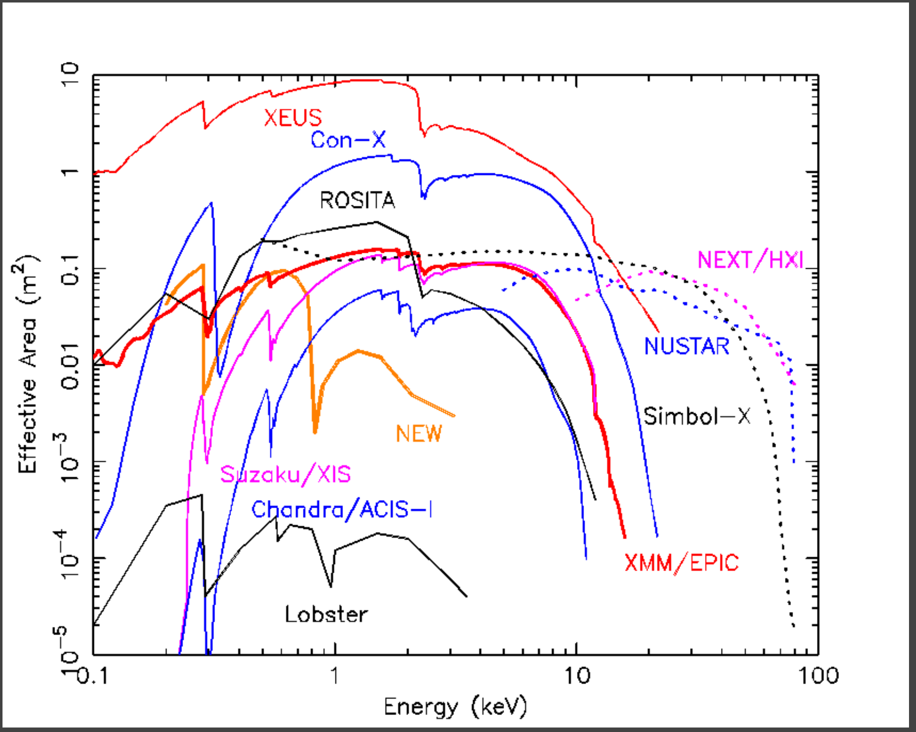
Comparison: the classical way





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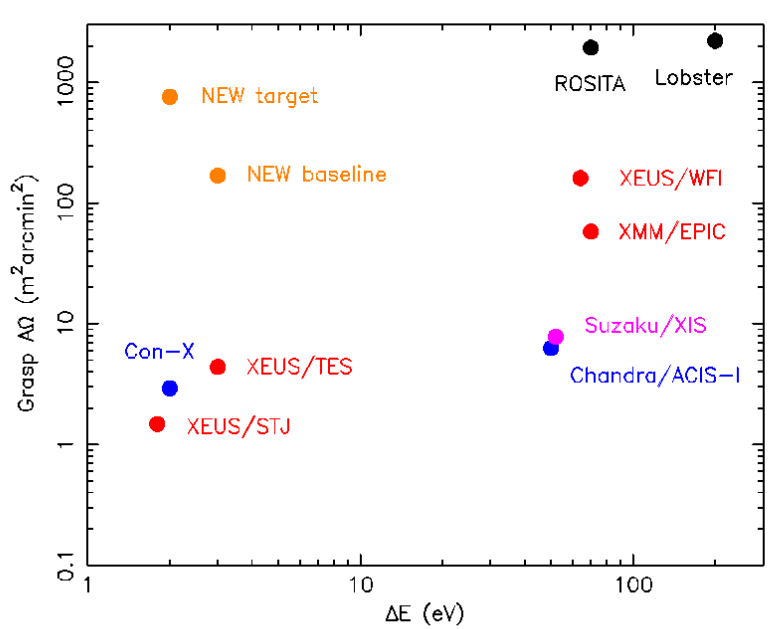
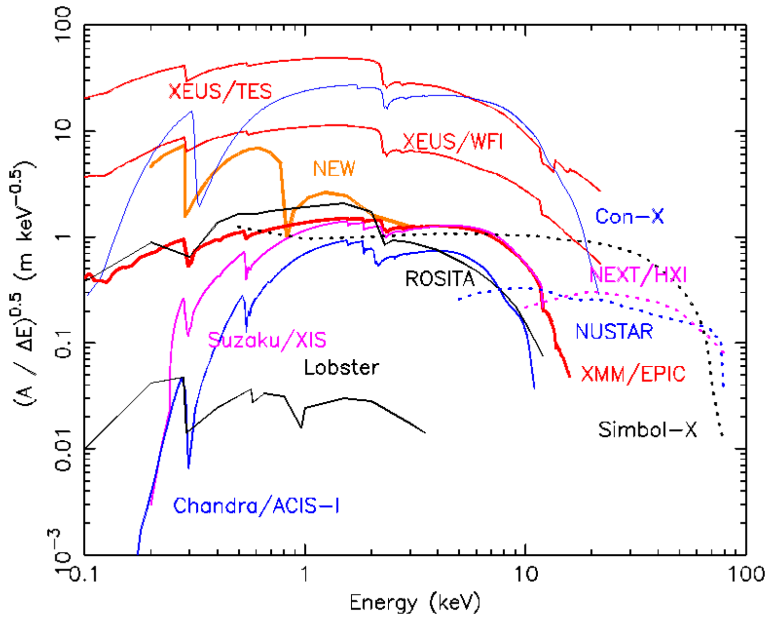
Comparison

Large scale strutures

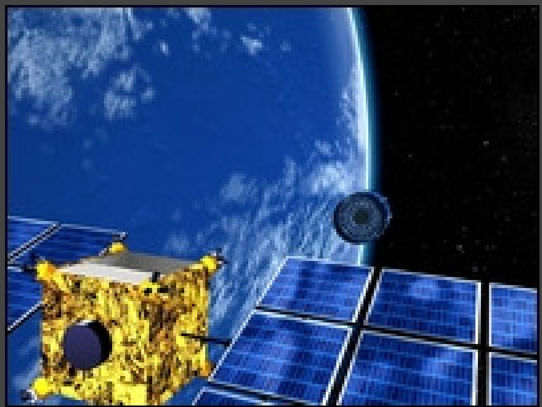


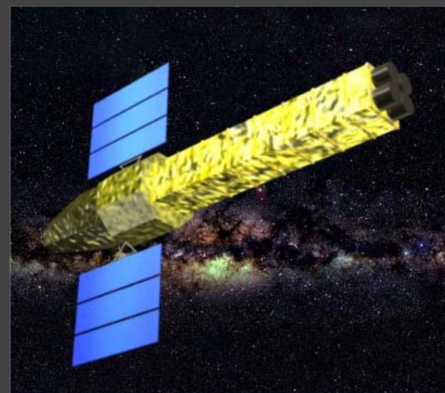
weak lines



conclusion

- X-ray spectroscopy addresses fundamental astrophysics and cosmology
- These can be addressed by the large observatories (ESA, NASA and JAXA)





- But we need a flight opportunity NOW: scientifically important results can be achieved with modest X-ray spectroscopy missions