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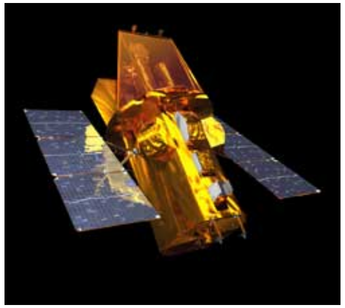
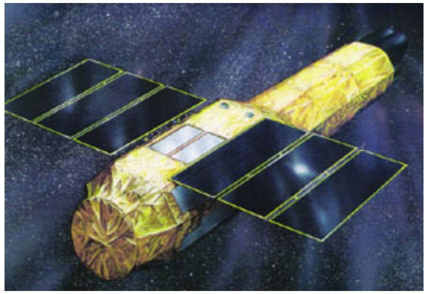
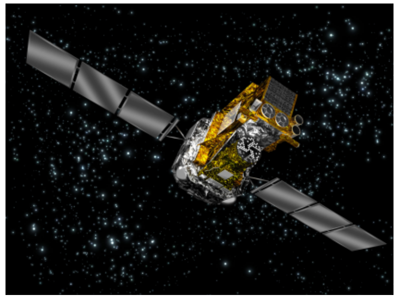
Wide angle soft X-ray transient surveys

Paul O'Brien







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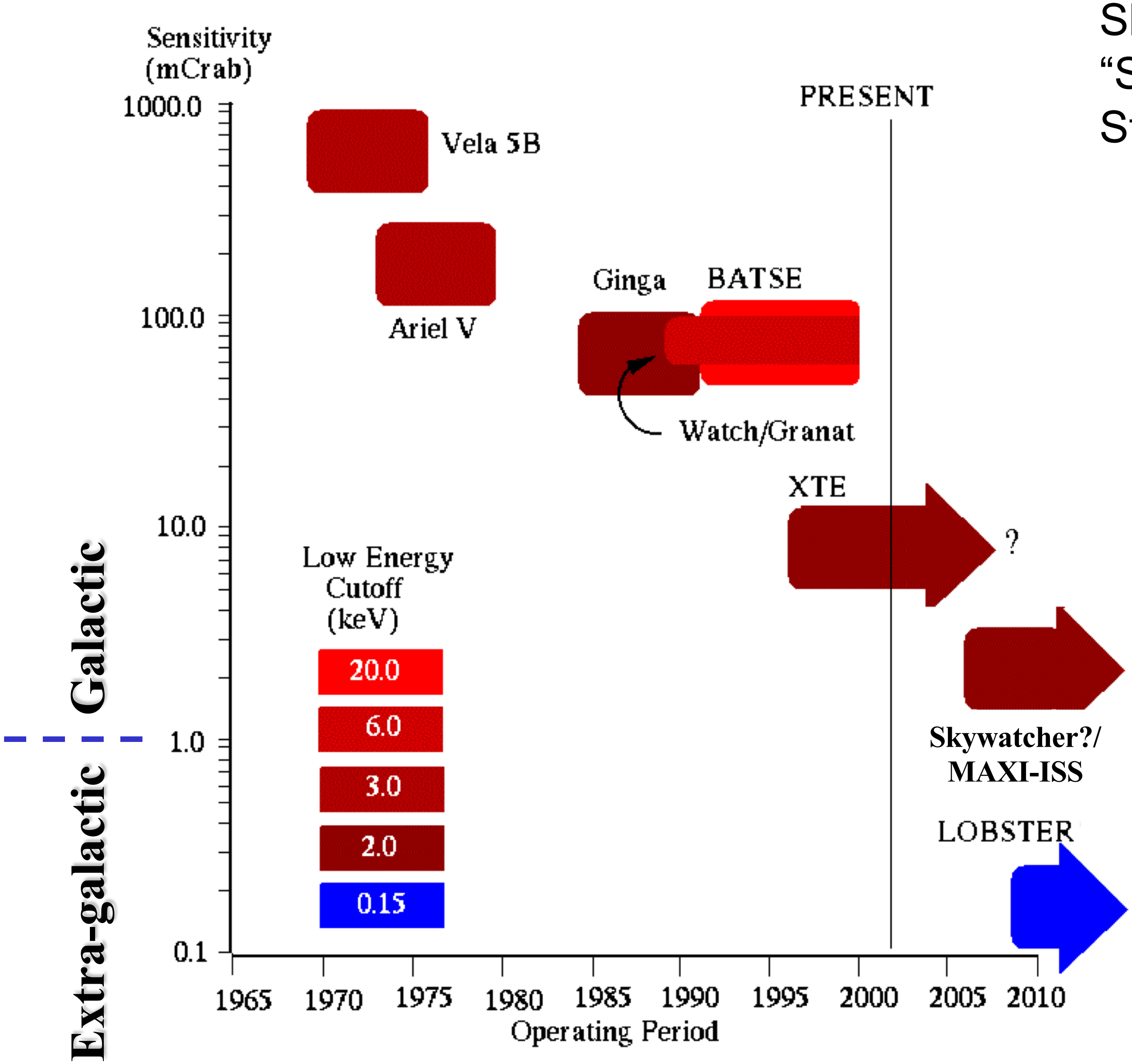
Outline of talk

- Why do we need soft X-ray surveys?
- Limits of current technology
- Disruptive technology – enter the ‘Lobster’
- Missions to come
- Synergy

Previous All-Sky Monitors

Slide from Bill Priedhorsky (2002)
"Science with Lobster" meeting
Still basically correct!



The historical trend of increasing sensitivity and wavelength coverage can be continued – if we choose

Essential support to x-ray and multi-wavelength observatories

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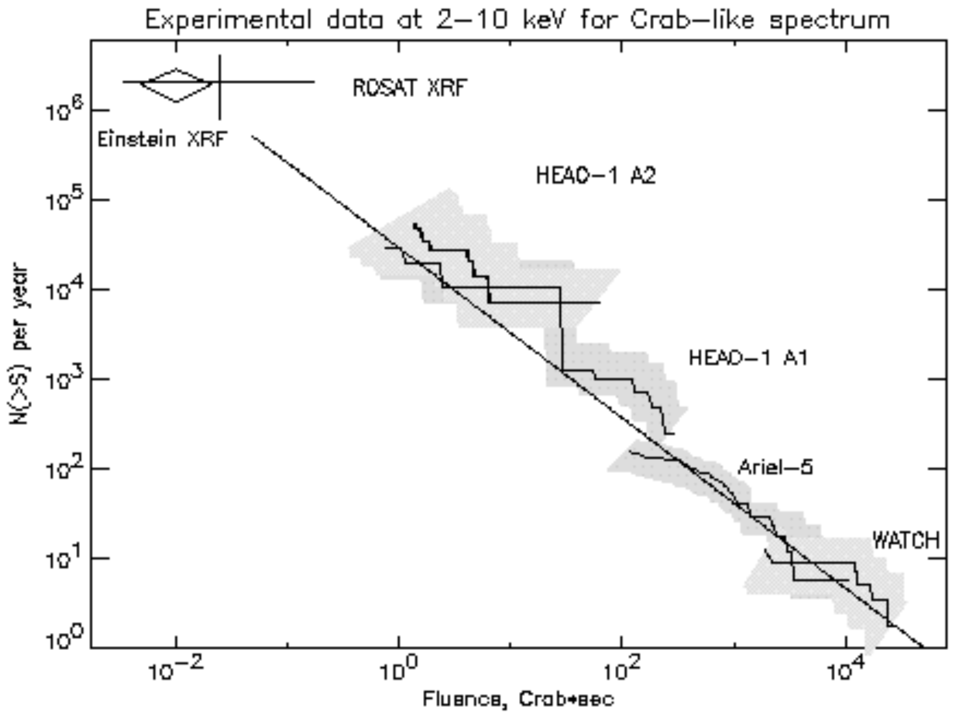
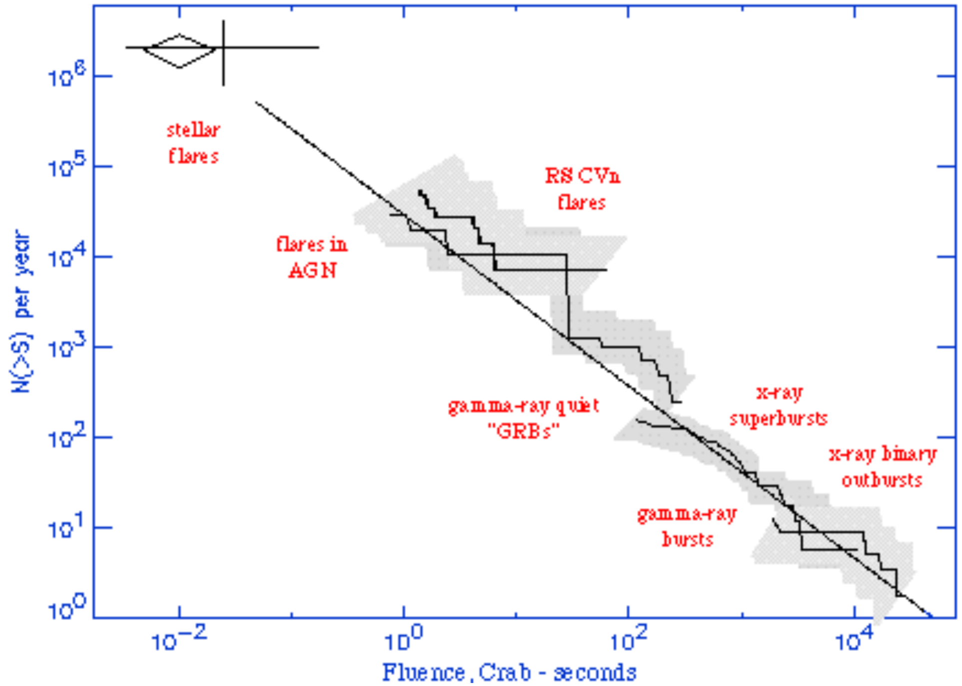
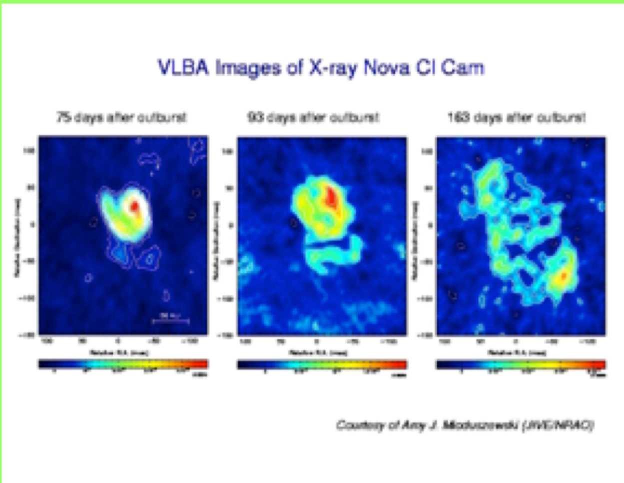
Early x-ray transient surveys

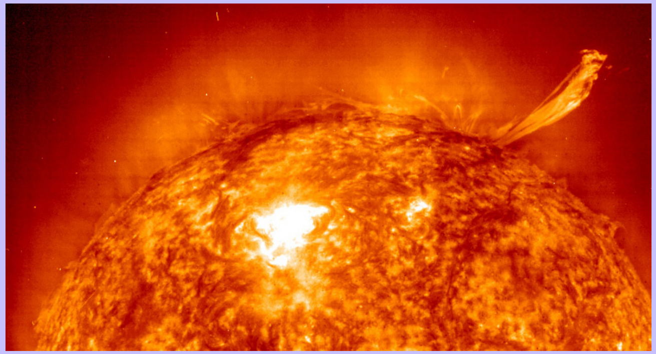




Priedhorsky, 2002

Black hole binaries

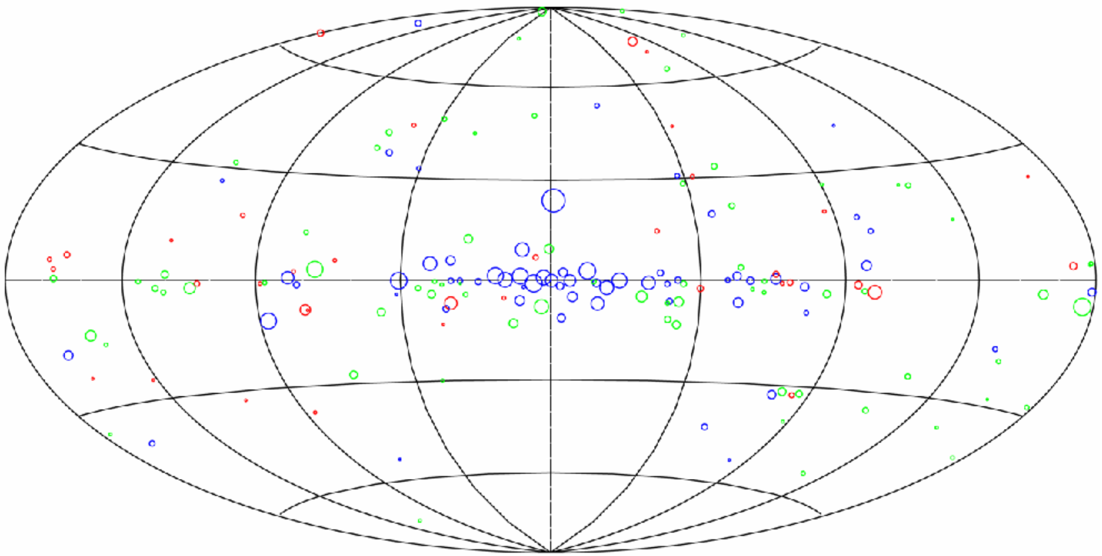




Coronal events

MAXI SSC survey (0.7-7 keV)

(Tomida et al. 2016)



Galaxies/AGNs	22
Clusters of galaxies	29
SNRs	21
X-ray binaries	75
Stars	8
Isolated pulsar	5
Unknown/no identification	11

Can observe GRBs by chance, but low probability

Distributions of the MAXI/SSC sources in galactic coordinates. The radii of circles are proportional to log(flux), and colors represent the softness ratio (*SR*: soft-band flux divided by hard-band flux in table 5); red, green, and blue marks are for sources with *SR* < 0.5, 0.5 ≤ *SR* ≤ 1.0, and *SR* > 1.0, respectively. Soft = 0.7-1.85 keV. Hard = 1.85-7 keV.

XMM slew survey (0.3-10 keV)

(Saxton et al. 2006; Warwick et al. 2011)

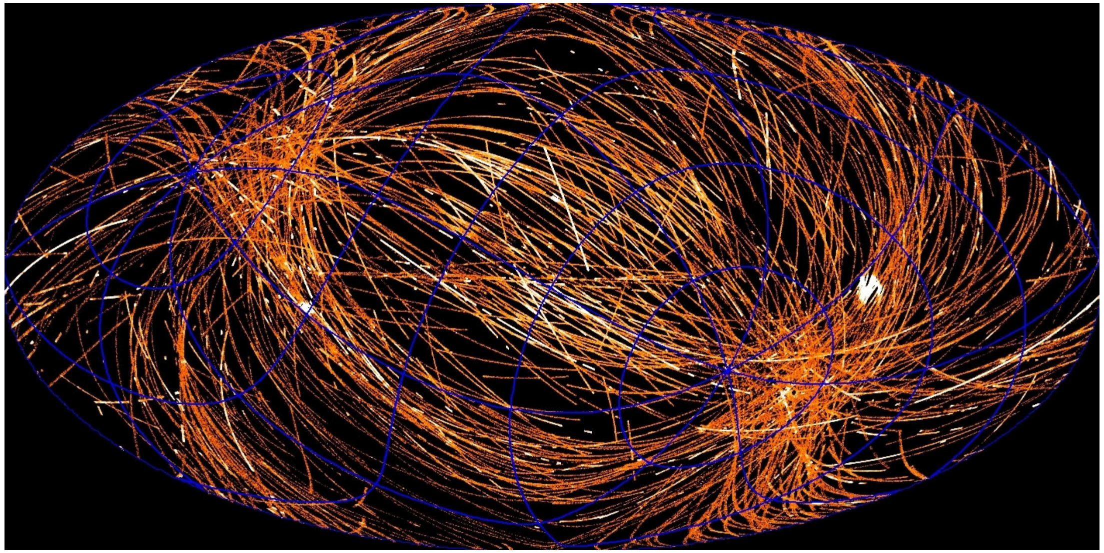


Table 1. Division of the XSS sample into source types.

Source Type	All	Hard+Soft	Hard-only
AGN	181	160	21
Galaxies	38	16	22
Clusters	10	10	0
Stars	53	51	2
Other	27	17	10
Unidentified	178	0	178¶
Total	487	254	233

Left: Sky map (2010) by Andy Read

Right: Warwick et al. (2011), XMM-Newton slew survey at high latitudes in the 2-10 keV band.

Very unlikely to observe a GRB (only a few slews per day)

In the hard band, the XMM-Newton slew survey is x10 deeper than previous surveys

Example: Active Galactic Nuclei

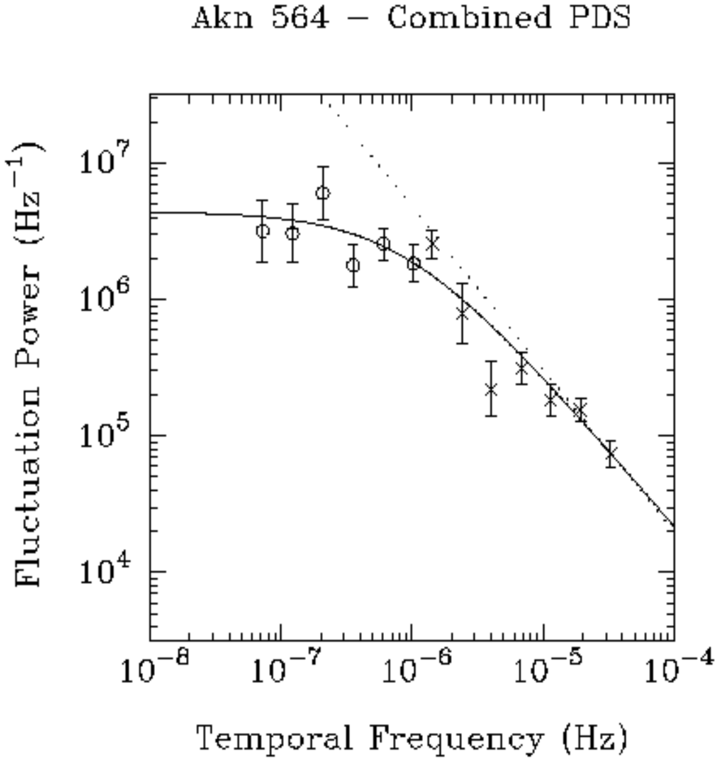
- Is there a "characteristic" variability timescale in AGN? (PDS turnover? linear or non-linear behaviour? etc.)

- Do such timescales relate black hole mass and accretion rate?

- Can we determine the variability mechanism

- Are there periodic phenomena in AGN (cf. binary systems)?

- What process drives variability in blazars?



(Pounds et al. 2001)

RXTE 4.3 day sampling for 18 months + short intensive

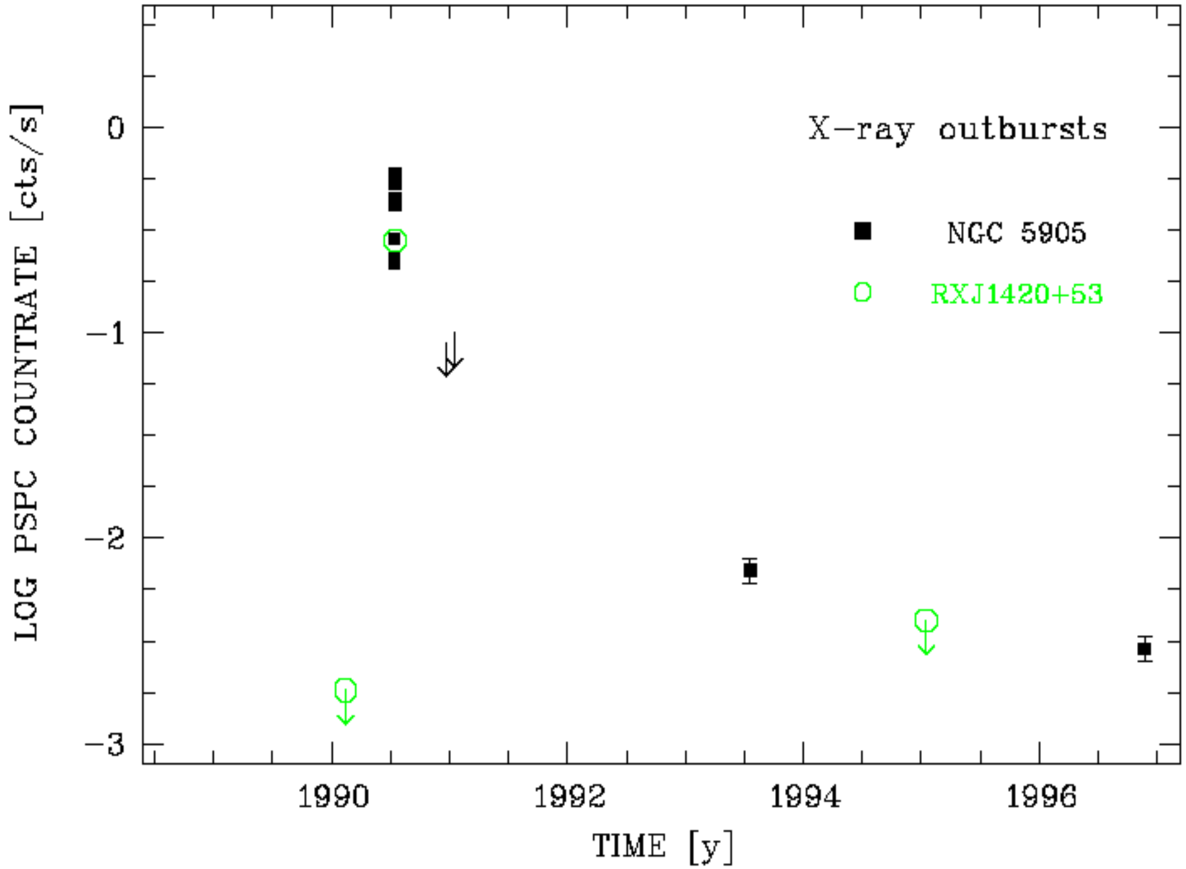
PDS turnover gives BH mass of 10^6 $M_{\odot}$

Example: Galactic Flares: TDEs

Observations from ROSAT:

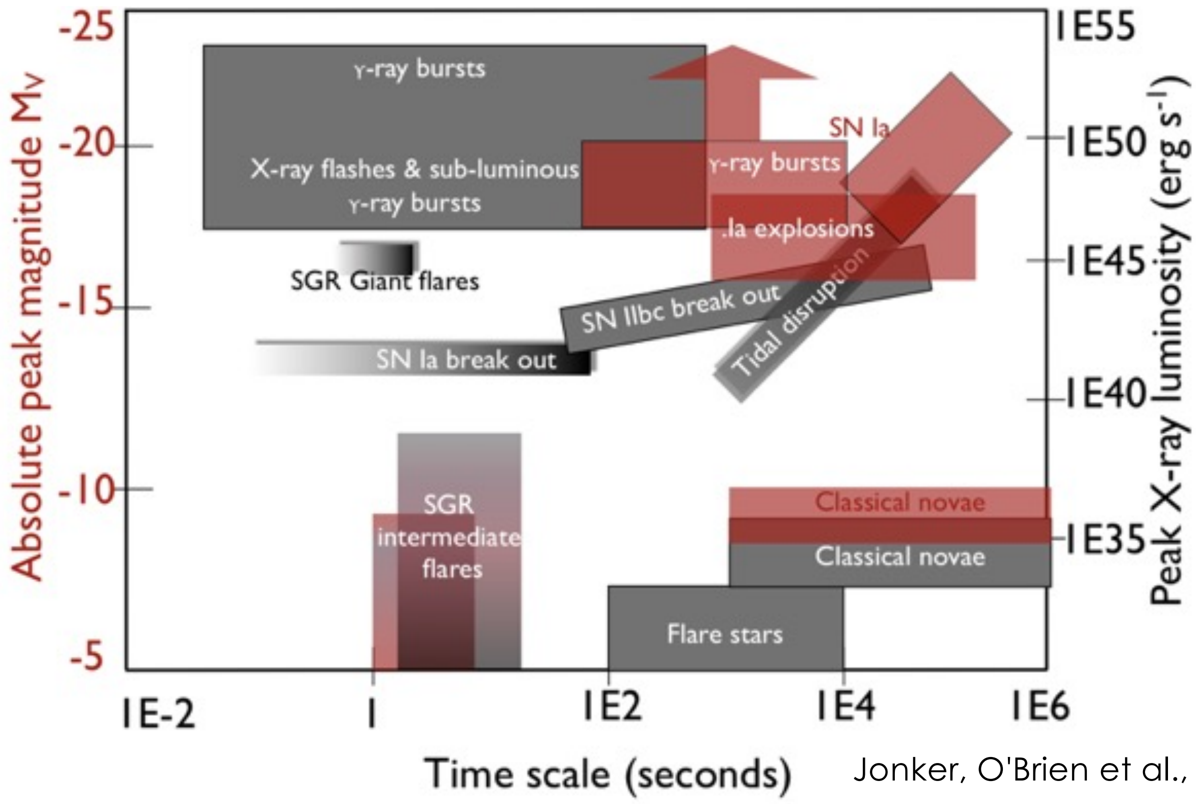
(Komossa & Bade (1999); Donley et al., (2002))

- ~5 X-ray flaring “normal” galaxies
- Peak luminosity up to 10^{44} erg s^{-1}
- Very soft X-ray spectrum
- Up to 200 *x* variability amplitude
- Fast rise; decay over months/years
- Expect 1 event every ~100,000 yrs per galaxy
- Small number have since been seen (XMM-slew), including a few with jets (Swift)



Outburst in non-AGN NGC 5905 & RXJ 1420+53

Explosive transients



Jonker, O'Brien et al., 2013 arXiv1306.2336

Many transients are more X-ray than gamma-ray or have spectral peaks in X-ray (e.g. TDEs, cocoons, high-z, SN shock breakout, compact binaries, AGN…)
Calls for wide-area X-ray survey capability, and then follow-up capability

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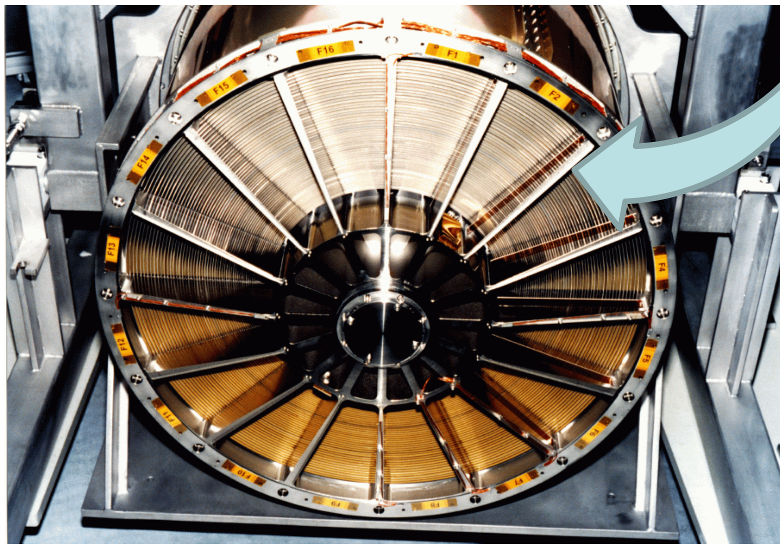
Traditional X-ray mirrors have drawbacks

- Field of view is small due to the requirement for grazing incidence – about 0.5 degree (full moon size)
- Mass is high – not good for small or planetary spacecraft

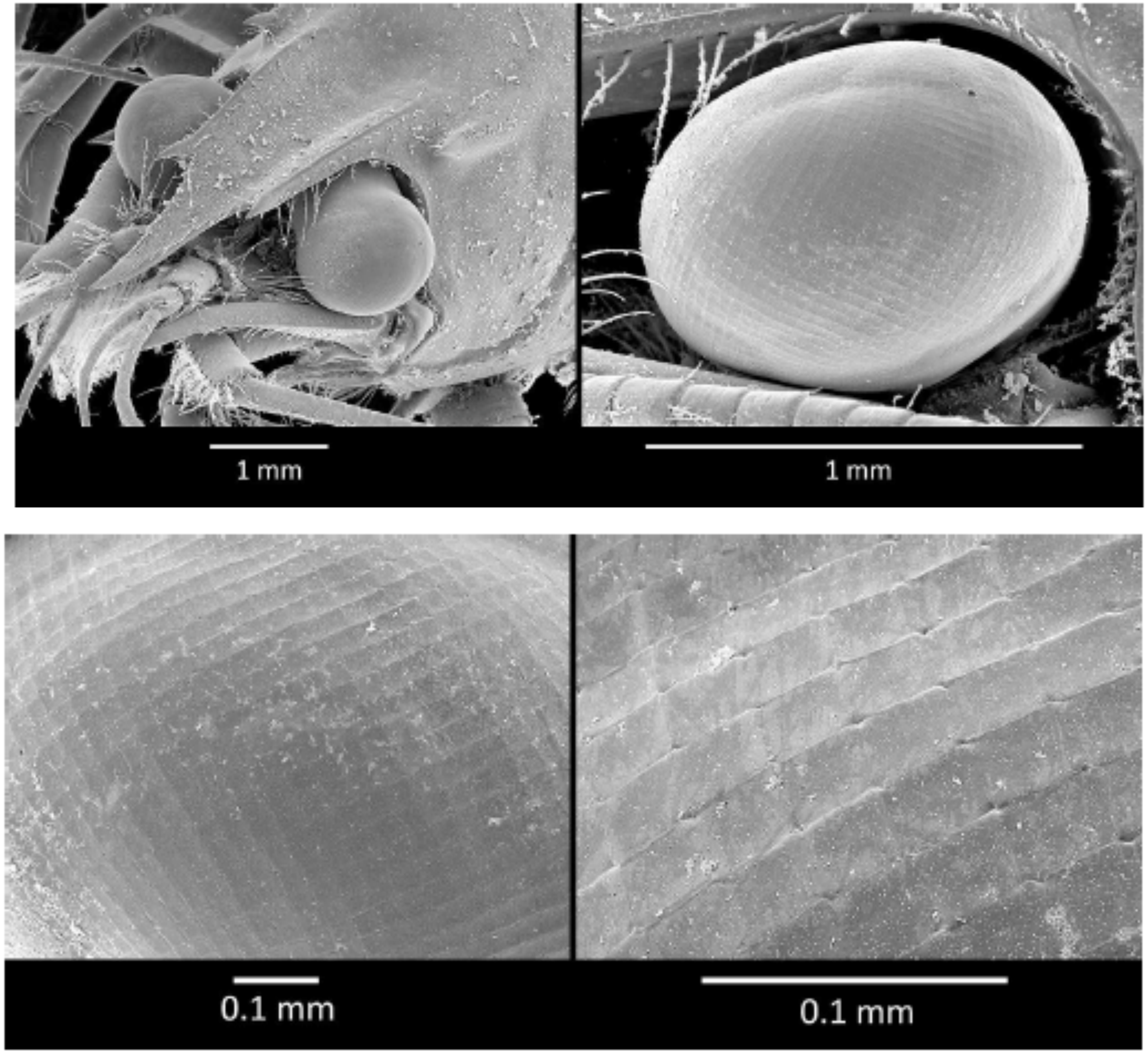
Q. How do we make a very lightweight and/or wide-field focusing X-ray telescope?

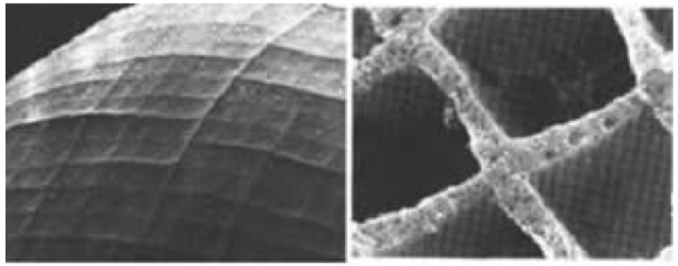
A. Look to nature for a solution

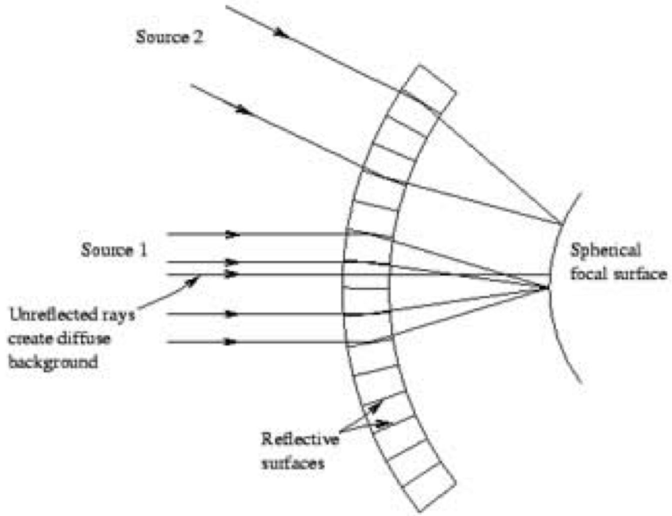


XMM mirror, 425kg x 3

Lobster-eye Wide-field Vision





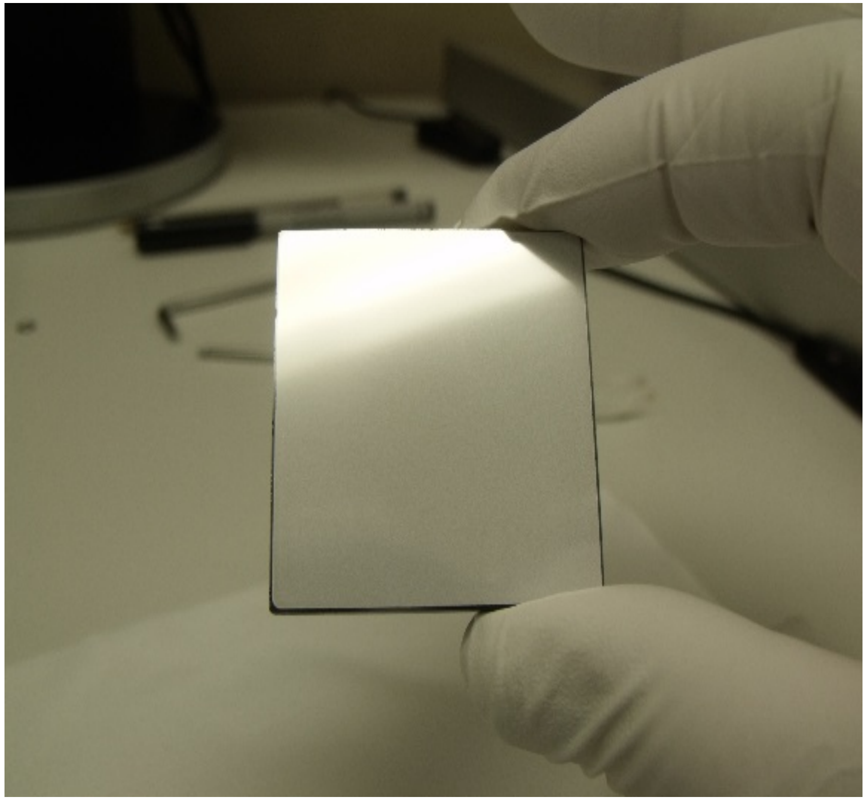


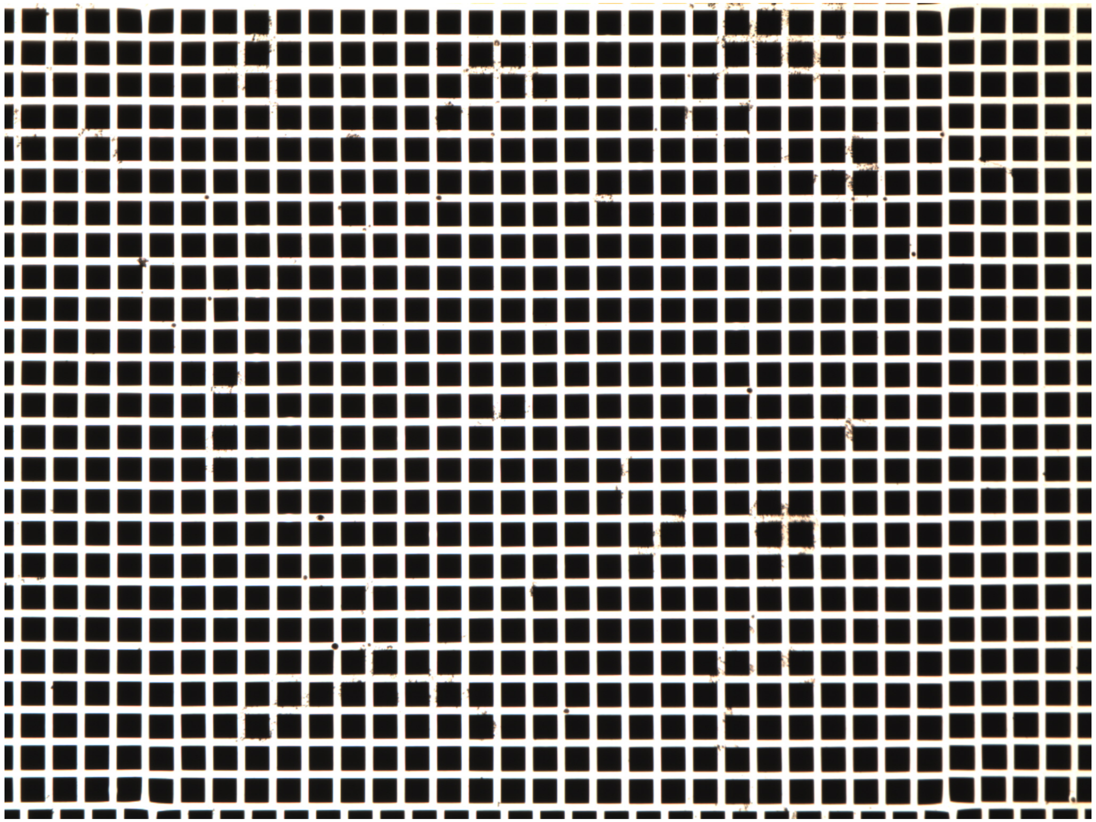
No single optical axis

X-ray option originally described by Angel (1979)

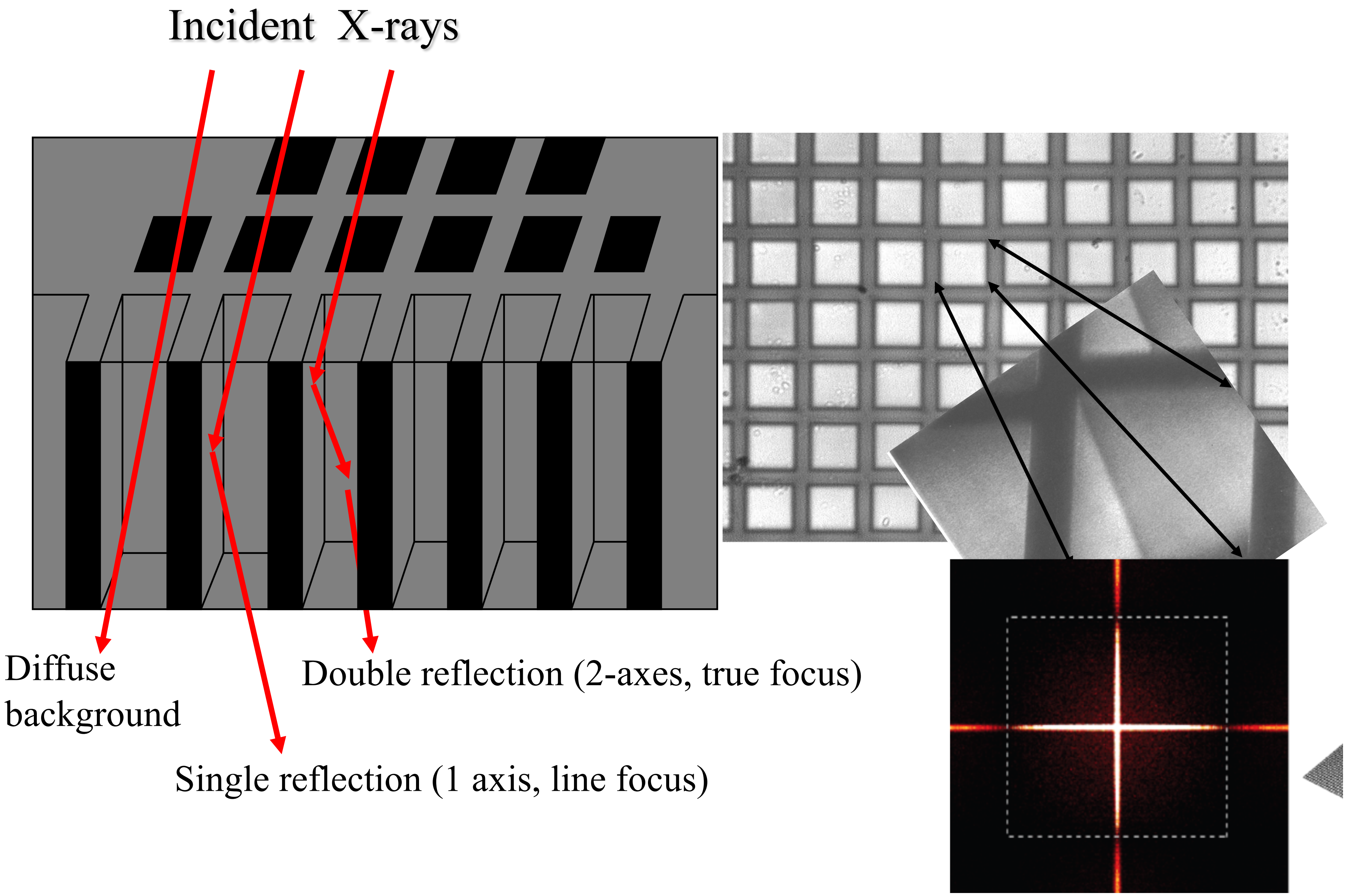
Square Pore Microchannel plates

- Glass plate – thickness L=1.0-2.5 mm – transmission ~60%
- Square pores size d=20 or 40 μm, wall~4 μm,   L/d~25-125
- Slumped to spherical form R_c=2F





Operation of an MPO telescope



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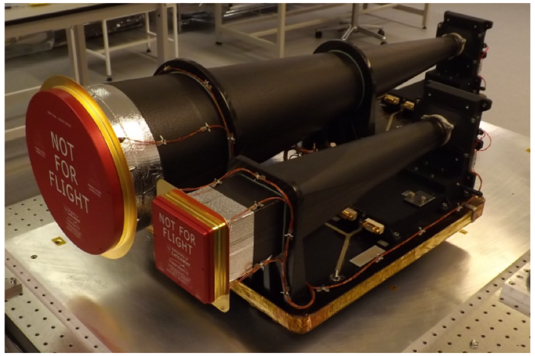
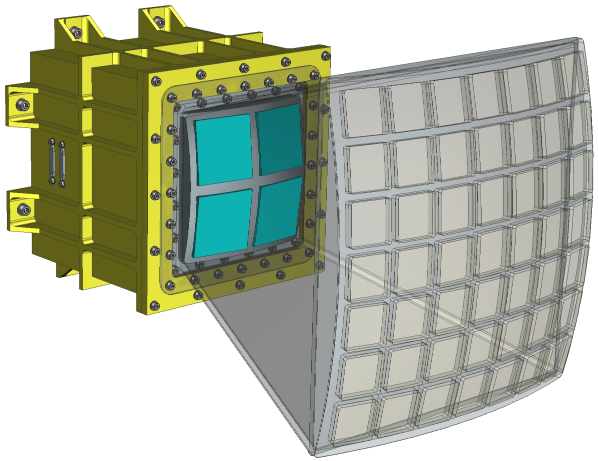
Flexible technology – two main uses

- Lightweight X-ray telescope
- Like a ‘normal’ X-ray telescope but optics only weigh a couple of kg
- Good for planetary science
- E.g. Bepicolombo, SMILE

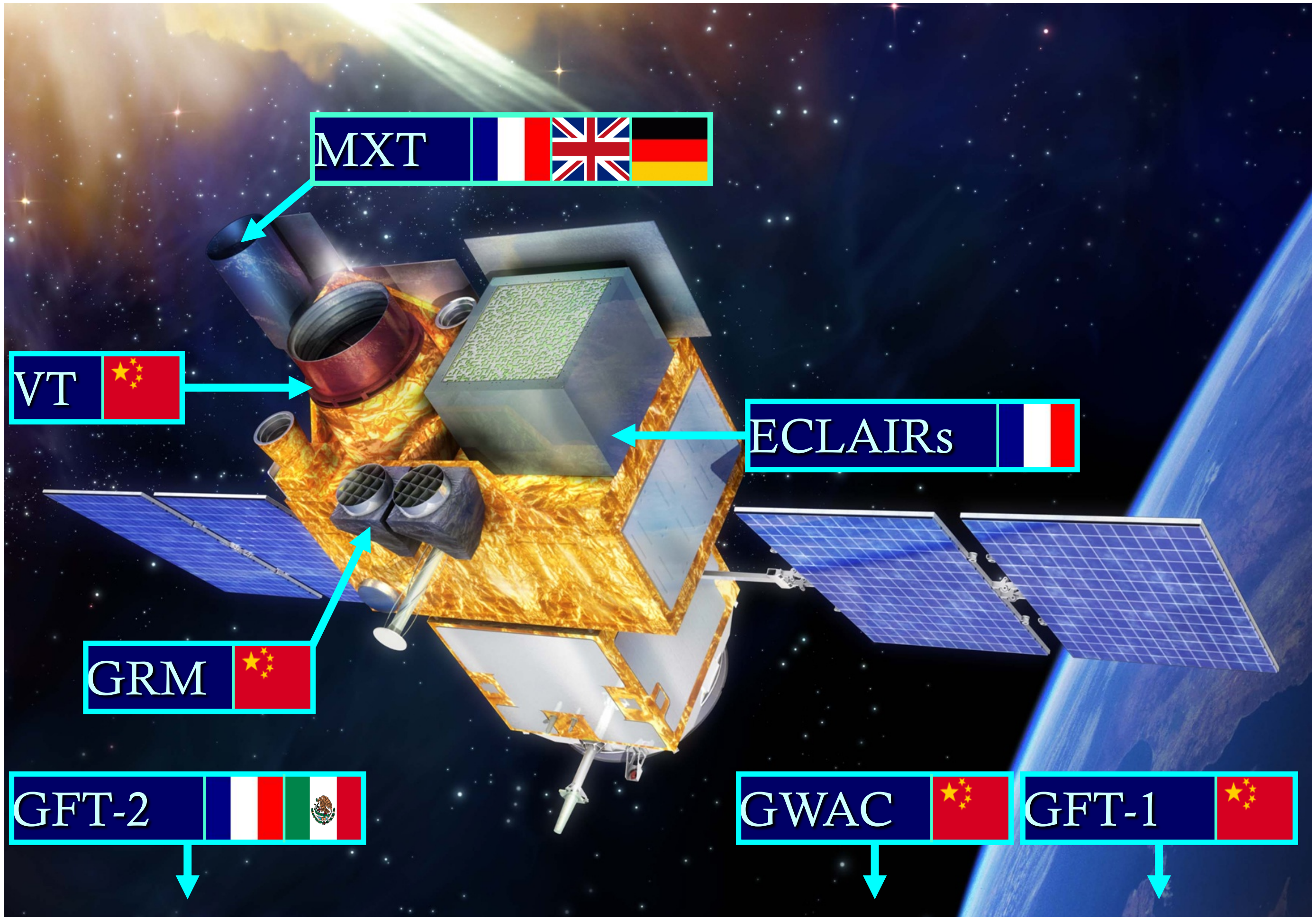


- Wide-angle telescope
- Compact and lightweight
- Can image large sky area by using a number of modules side by side
- E.g. SVOM, EP, THESEUS, TAP…

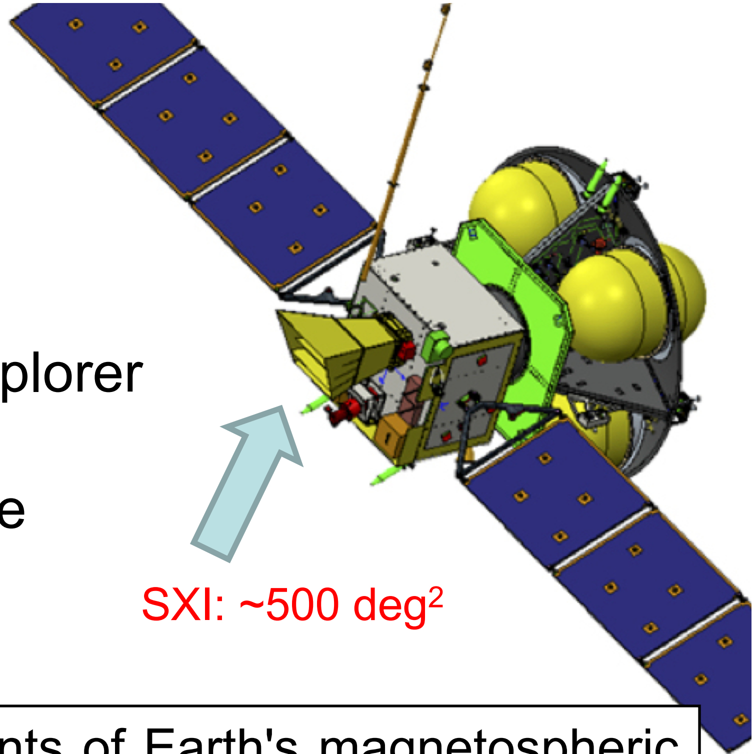


SVOM

To find transients the rapid response Chinese spacecraft requires lightweight instruments. Lobster X-ray optics in the MXT (FOV ~1 degree)



SMILE

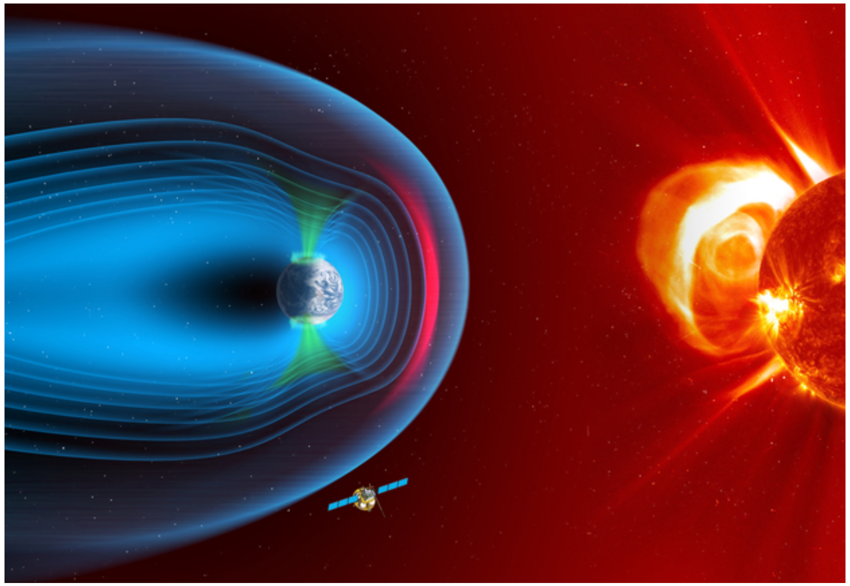


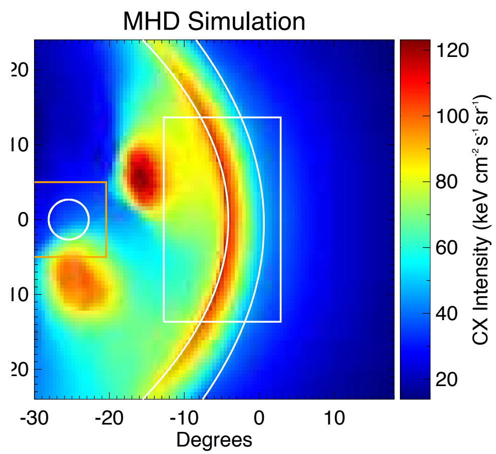
Solar wind Magnetosphere Ionosphere Link Explorer

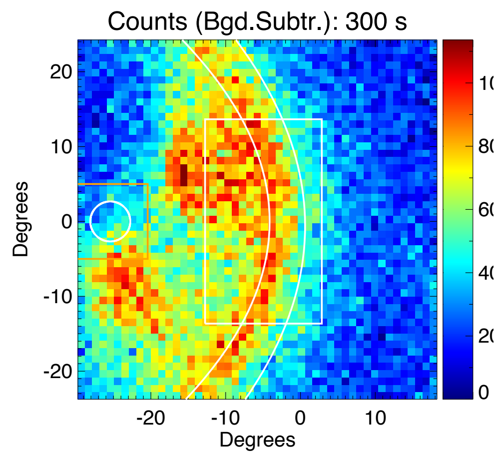
ESA-CAS Joint Mission. S2 on ESA programme

Due for launch 2023

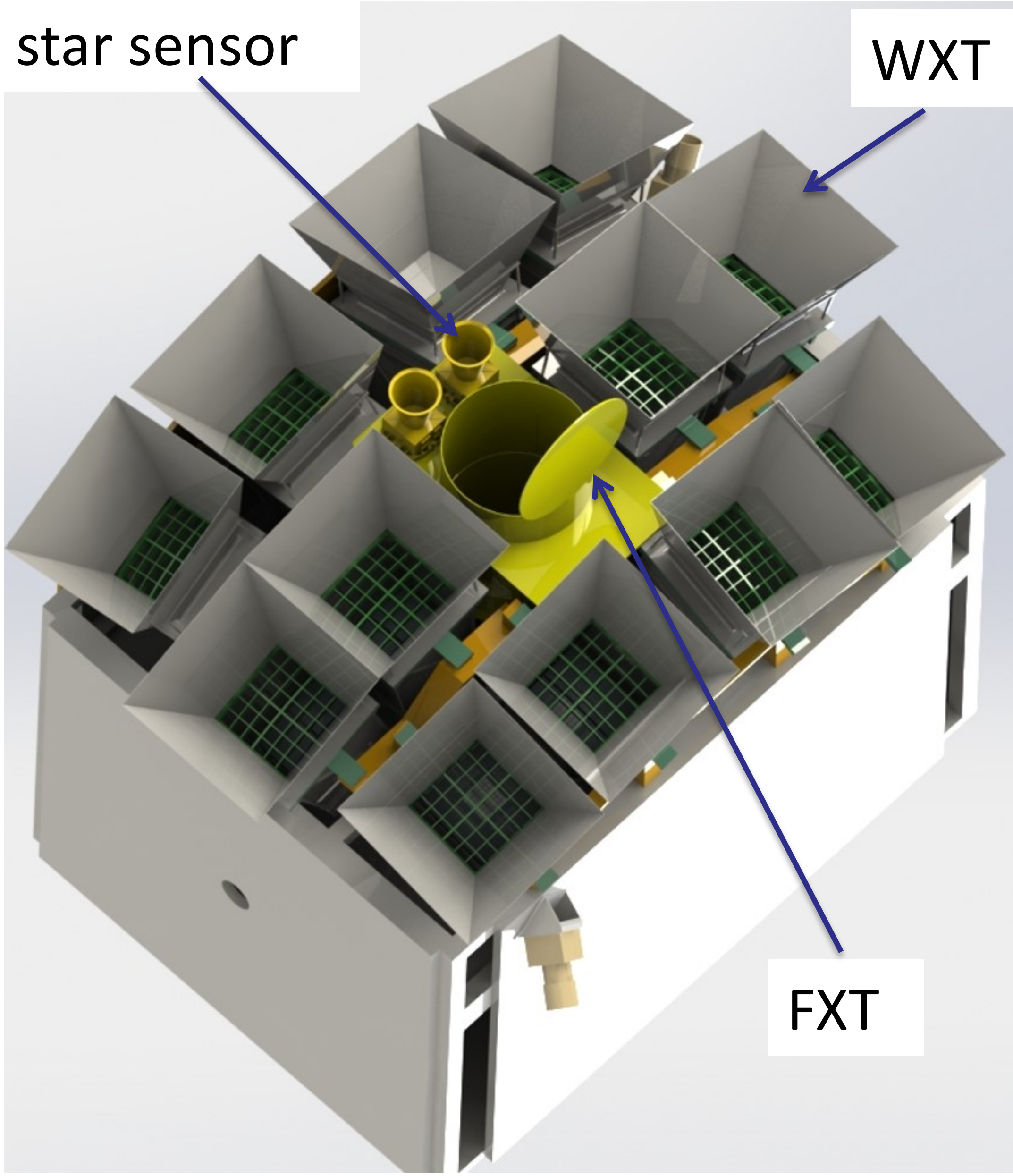
“SMILE will gather remote-sensing (X-ray) measurements of Earth's magnetospheric cusps, magnetopause, and bow shock, while also providing simultaneous auroral imaging (UV) of Earth, and coordinated *in situ* measurements (plasma and magnetic)”

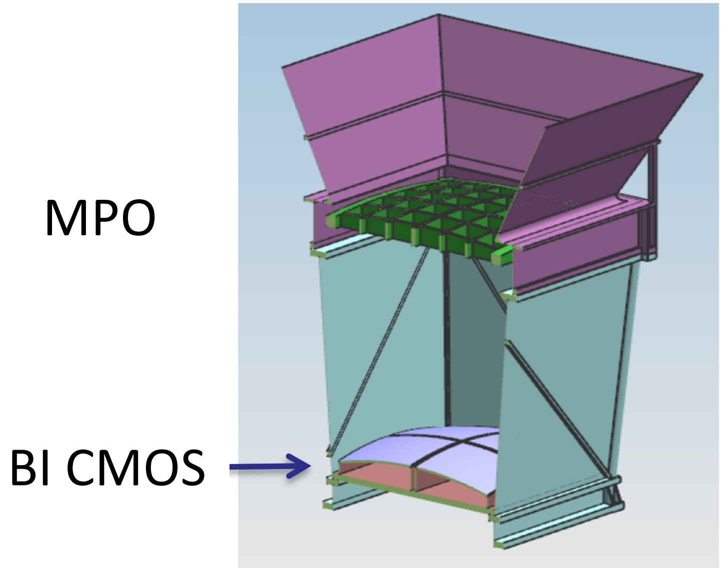




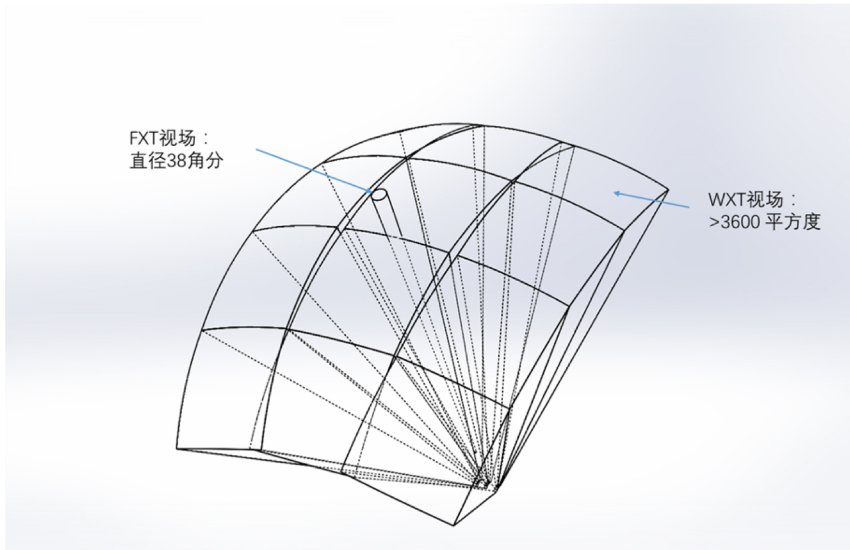


Einstein-Probe 爱因斯坦探针



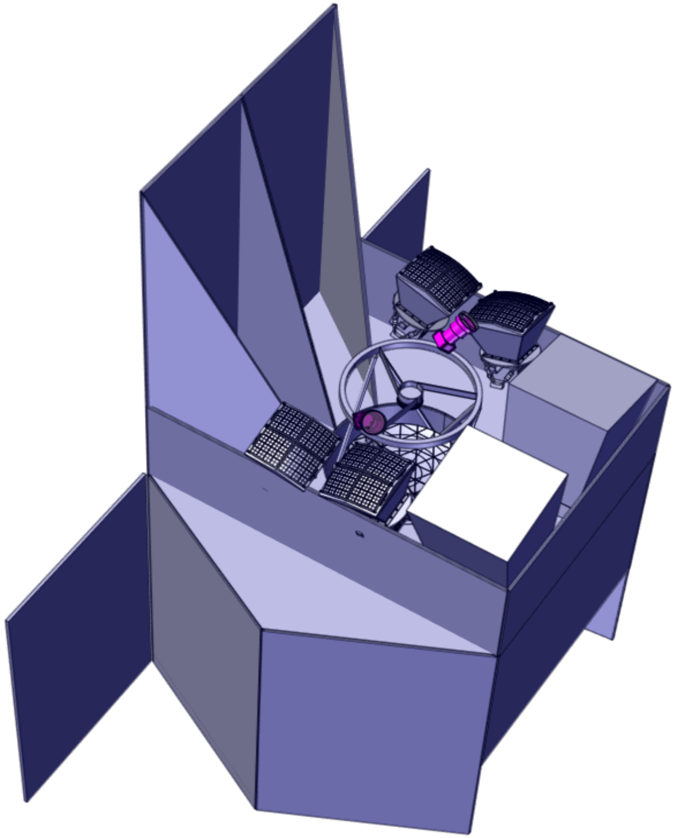


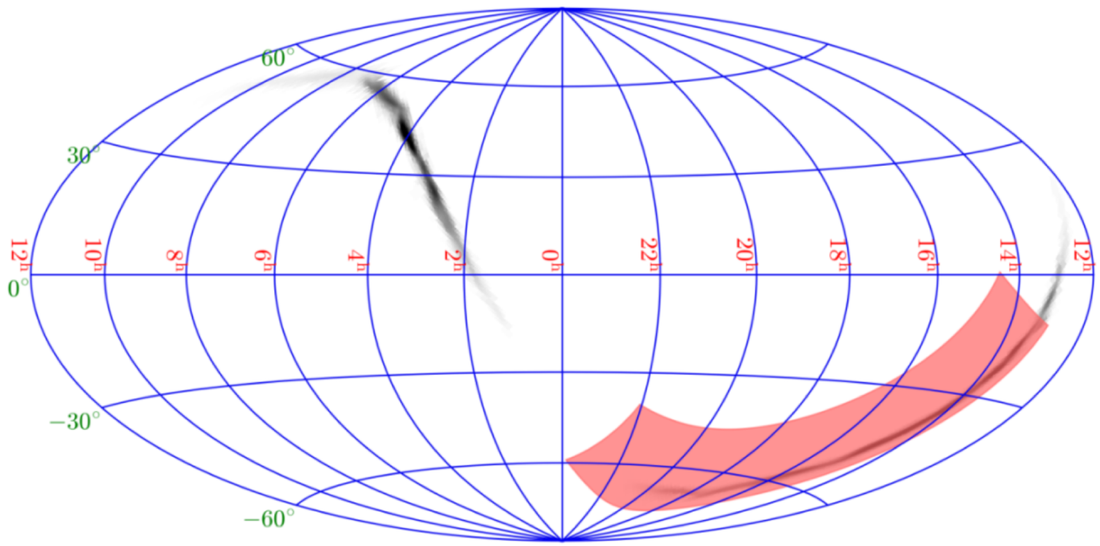
FoV: 3600 sq. deg. !!



ESA M5 candidate: THESEUS (2032)

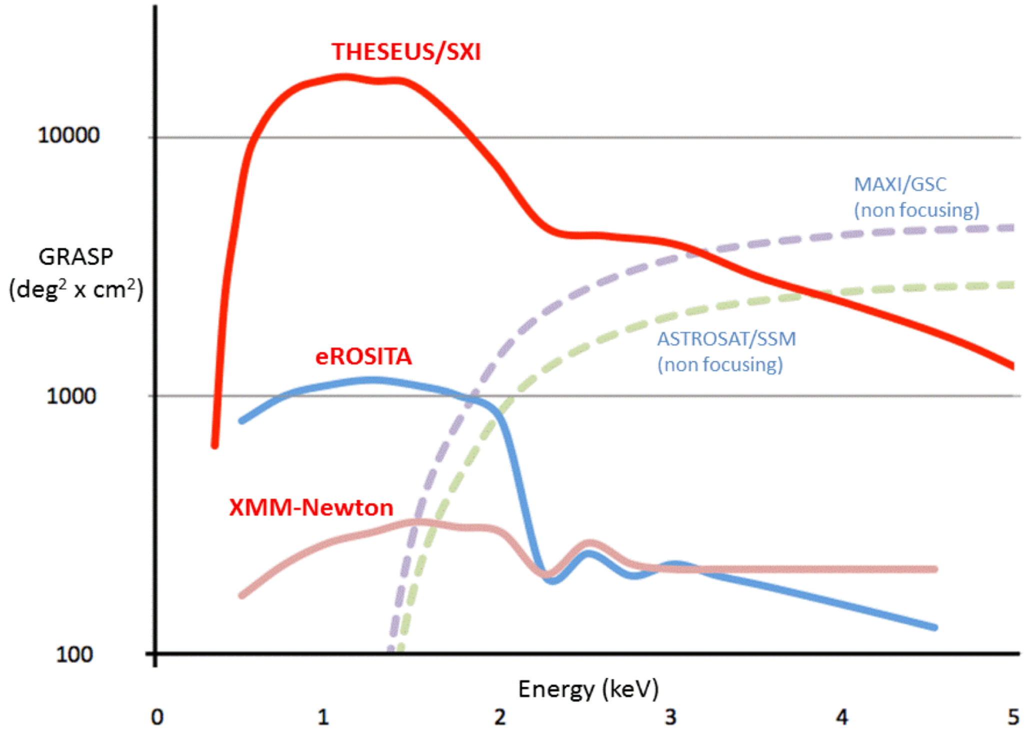
- **Soft X-ray Imager (SXI):** Lobster-Eye X-ray (0.3 - 6 keV). FOV of 3200 sq. deg. UK led consortium.
- **InfraRed Telescope (IRT):** 70 cm near-infrared telescope (IRT) to measure distance French led consortium.
- **X-Gamma Imaging Spectrometer (XGIS)**: FOV 7800 sq. deg. Extends high-energy band up to 20 MeV. Italian led consortium.

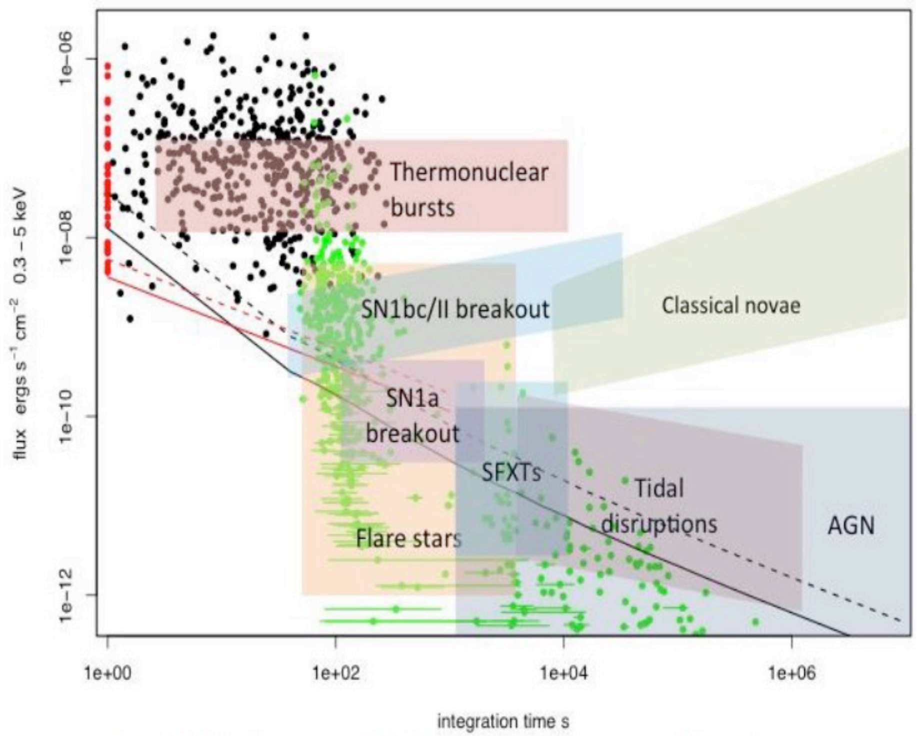




The SXI could observe a large GW error region very quickly. Example: GW151226

Survey machines

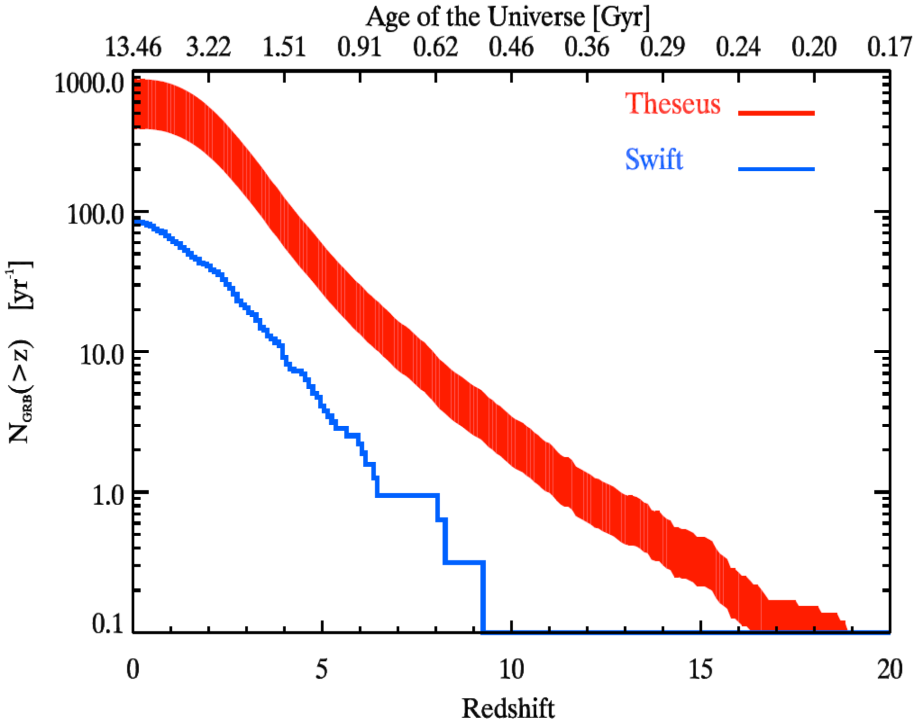


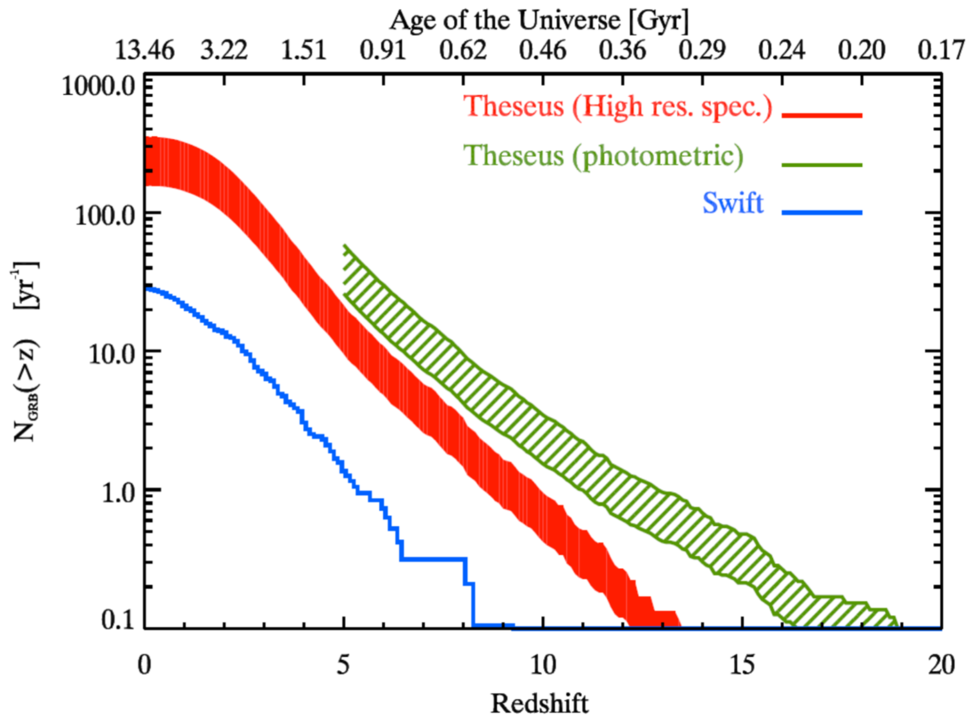


Facilities like THESEUS have huge GRASP in soft X-rays and hence they would detect very large numbers of transients, including GRBs at all redshifts (focused, so few counts needed for detection)

Transient type	SXI rate
Magnetars	40 day^{-1}
SN shock breakout	4 yr^{-1}
TDE	50 yr^{-1}
AGN+Blazars	350 yr^{-1}
Thermonuclear bursts	35 day^{-1}
Novae	250 yr^{-1}
Dwarf novae	30 day^{-1}
SFXTs	1000 yr^{-1}
Stellar flares	400 yr^{-1}
Stellar super flares	200 yr^{-1}

Shedding light on the early Universe





THESEUS GRB#/yr	All	z > 5	z > 8	z > 10
Detections	387 - 870	25 – 60	4 – 10	2 - 4
Photometric z		25 – 60	4 – 10	2 - 4
Spectroscopic z	156 - 350	10 - 20	1 - 3	0.5 - 1

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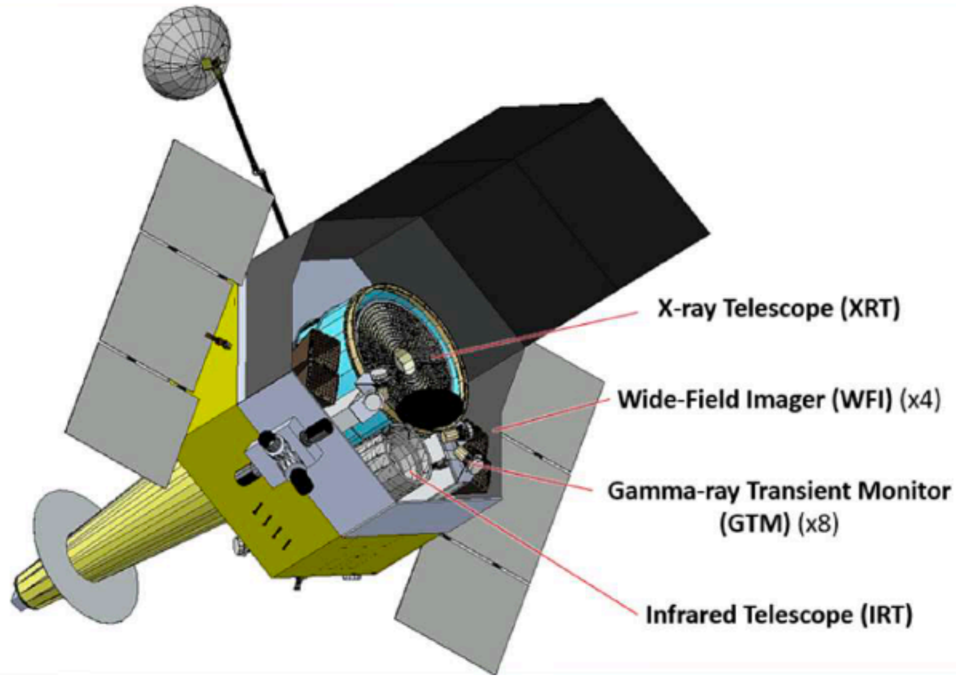
Transient Astrophysics Probe

(to be submitted to the Decadal Survey – could launch in 2030s?)

- Lobster modules (4)
  - 1400 deg^2
  - $2x10^{-11}$ erg/cm^2/sec in 2000 sec
- IR Telescope
  - 1 deg^2
  - 0.3 – 2.5 micron, 70 cm diameter
  - 23 mag in 300 sec
- X-ray Telescope
  - 1 deg^2
  - 3 x 10^{-15} erg/cm^2/sec in 3000 sec
- Gamma-ray transient monitor (4pi)
  - 10 – 1000 Kev



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Surveys and synergy

- Bright survey: daily (or faster) monitoring of few dozen targets
- Medium survey: ~weekly monitoring of hundreds-thousands of targets
- Faint survey: flaring survey of entire sample

- ❑ With a Lobster we do not need to decide sampling rate ahead of time
- ❑ Do need way to trigger other facilities – requires an alert system
- ❑ Almost all future facilities have time domain studies in their science case (e.g. ELT, SKA, CTA, Athena, ET…) but generally assume someone else will find the target!

cta cherenkov telescope array

SKA SQUARE KILOMETRE ARRAY

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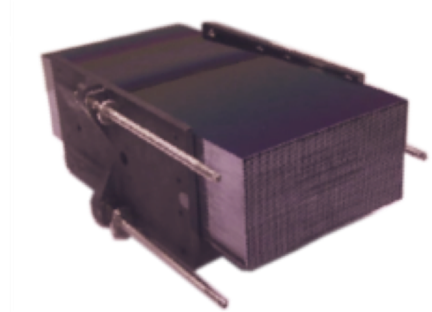
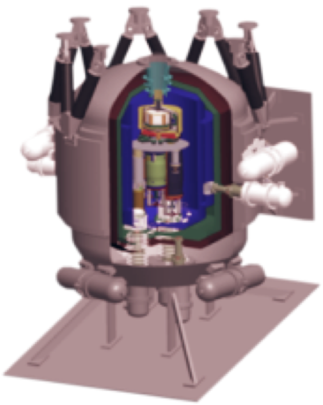
The Athena Observatory

L2 orbit Ariane V
<5100 kg
power 2500 w
5 year mission (2028+)

Willingale et al, 2013
arXiv1308.6785

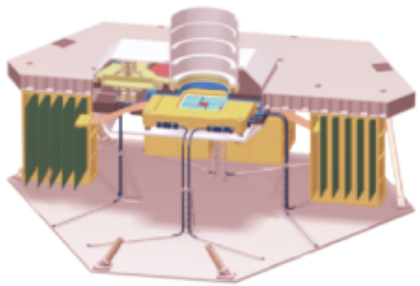


Silicon Pore Optics:
2 m^2 at 1 keV
5 arcsec HEW
Focal length: 12m
Sensitivity: 3 10^{-17} erg cm^{-2} s^{-1}



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

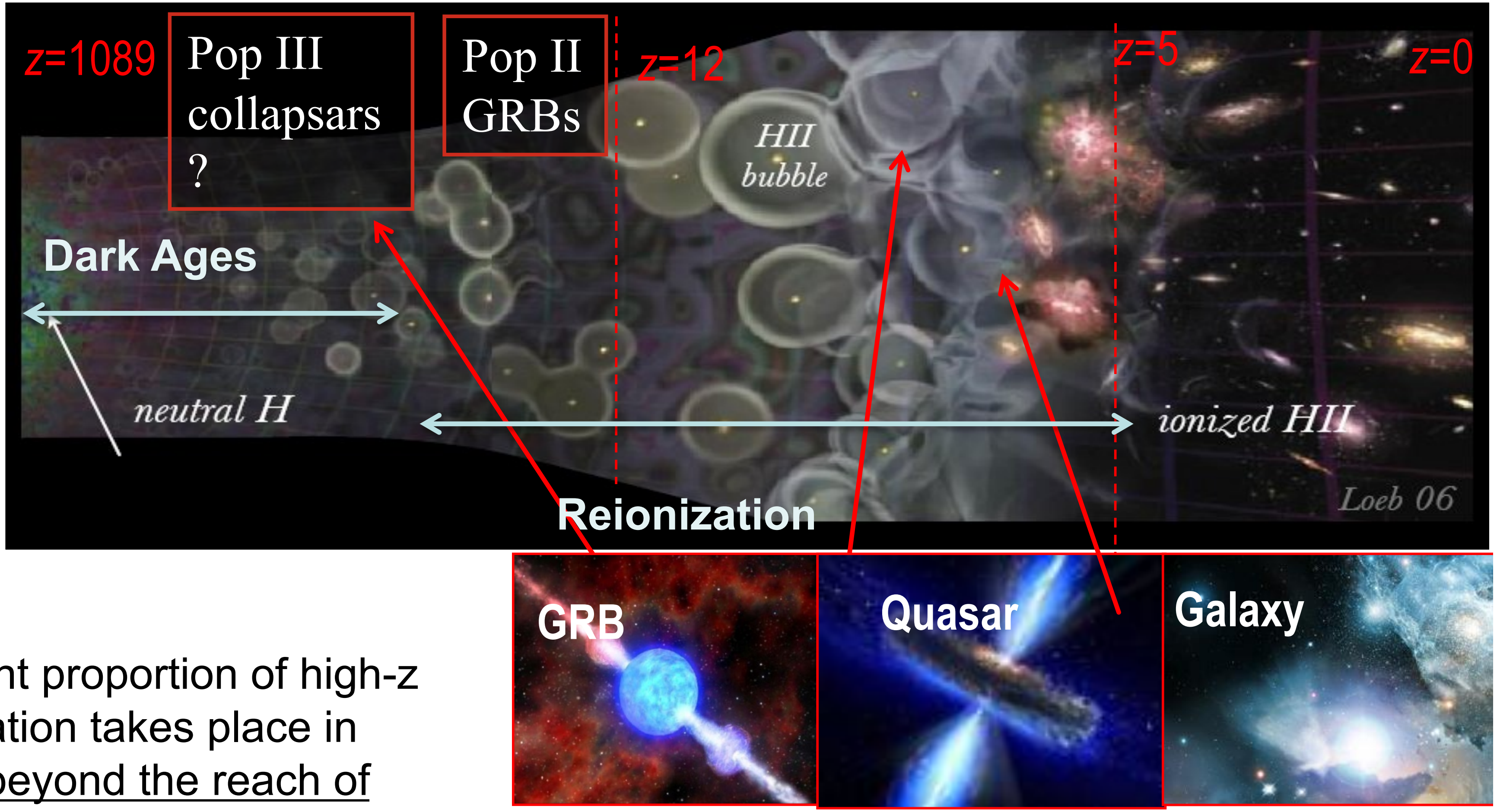
Barret et al., 2013 arXiv:1308.6784



Wide Field Imager:
ΔE: 125 eV
Field of View: 40 arcmin
High countrate capability

Rau et al. 2013 arXiv1307.1709

First stars, BHs and metals



- A dominant proportion of high-z star formation takes place in galaxies beyond the reach of JWST at z > 8 ; their nature will hardly be known, but **they will be GRB hosts**.
- There will likely be no direct detections of population III sources; **pop III collapsars predicted to produce GRB-like events**.

GRBs with Athena

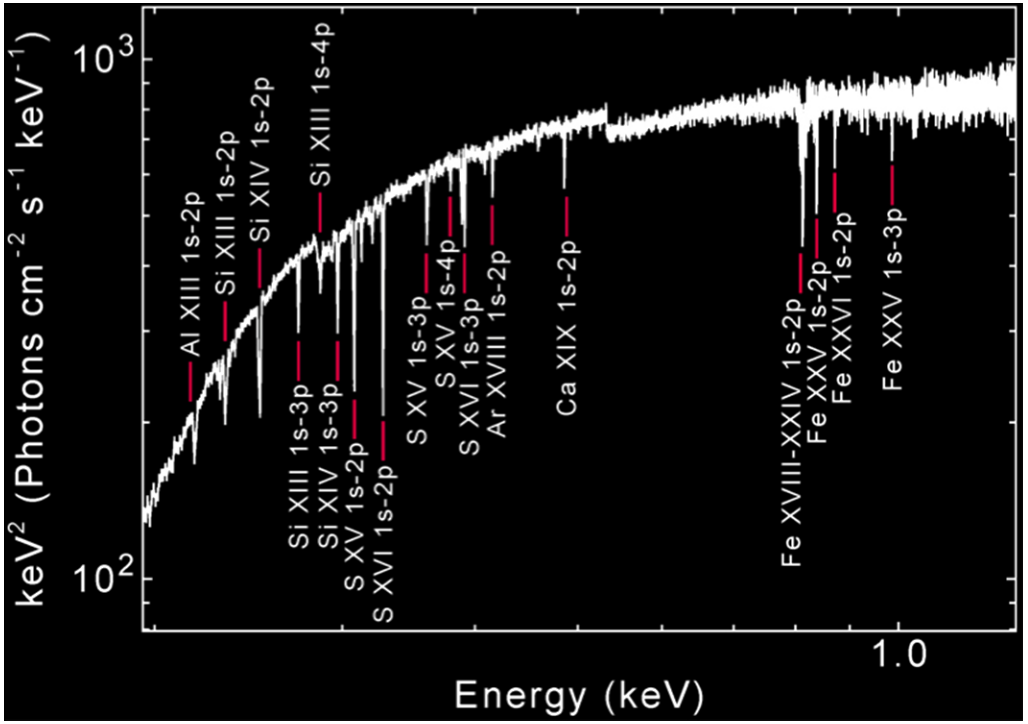
- Find the missing baryons in the WHIM using the X-IFU:

✓ Select targets based on prompt brightness

- Find star forming sites in the high-z Universe:

✓ Select targets fast based on brightness and redshift indicator

- Mission requirement: TOO response in 4hrs for 50% of sky



Jonker, O'Brien et al., 2013 arXiv1306.2336

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Conclusions

- Lobsters are coming!
- A powerful addition to the more traditional X-ray astronomy facilities
- Lightweight applications for solar system science
- Wide-field applications for monitoring the universe
- They will feed transients to giant facilities like ELT, JWST, CTA, SKA, etc.

Moral of the story: look to nature for good ideas – nature has had longer to develop them and evolution weeds out bad designs

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The end