Pushing XRS to Higher Energies: Science and Potential Implementation

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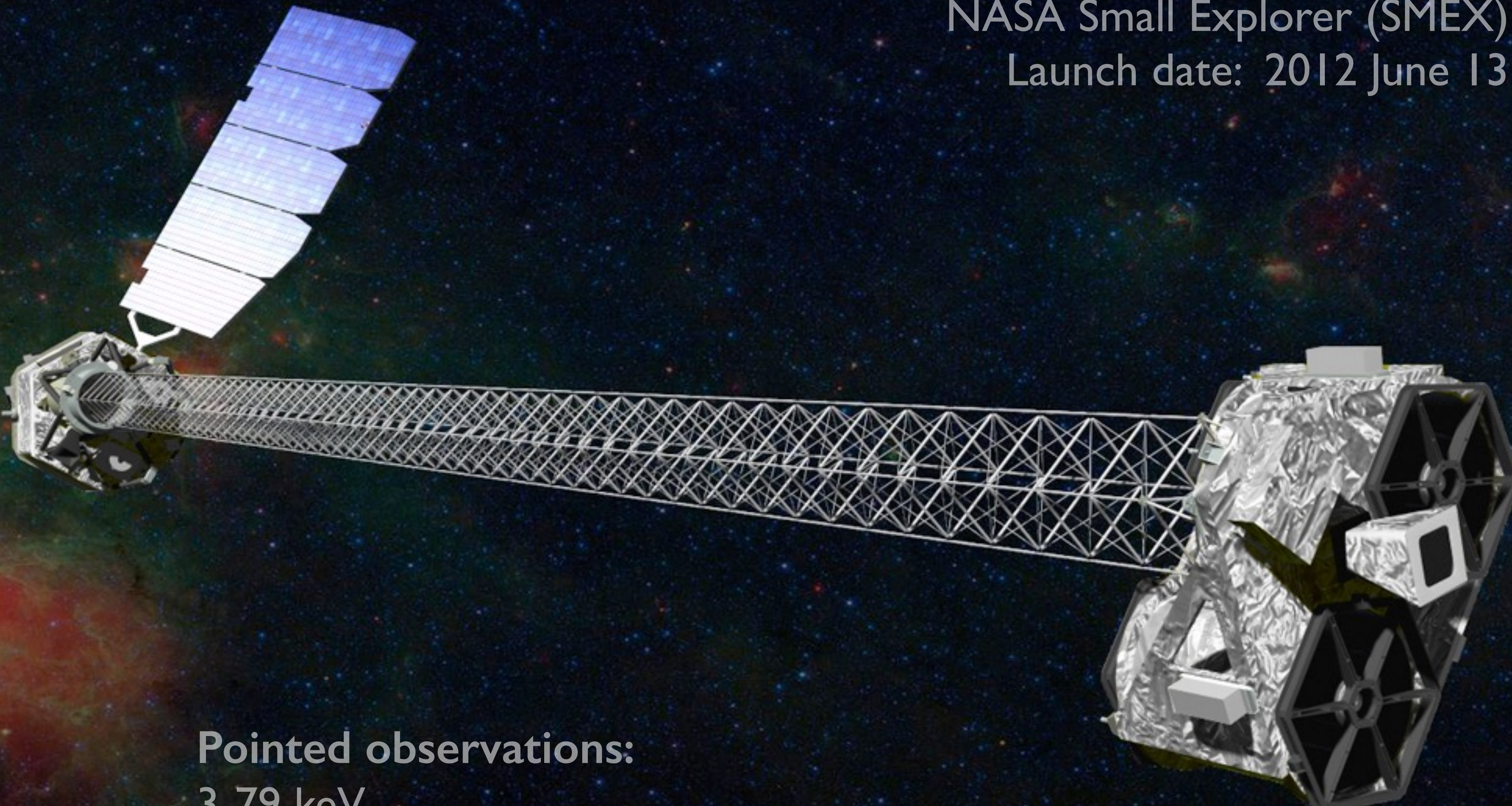
2016 November 2
X-Ray Surveyor STDT telecon

NuSTAR

(Nuclear Spectroscopic Telescope Array)
NASA Small Explorer (SMEX)
Launch date: 2012 June 13

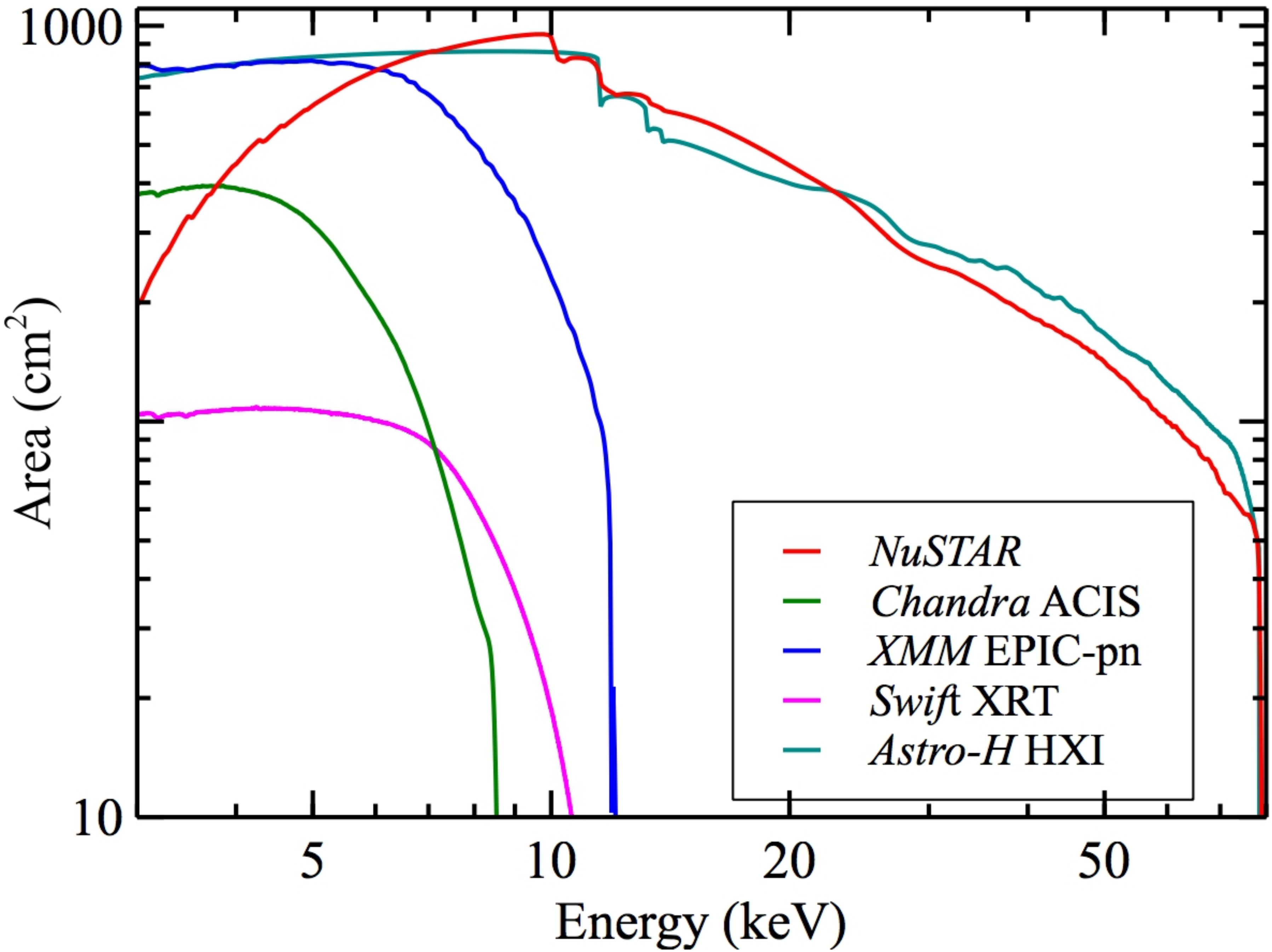


Pointed observations:

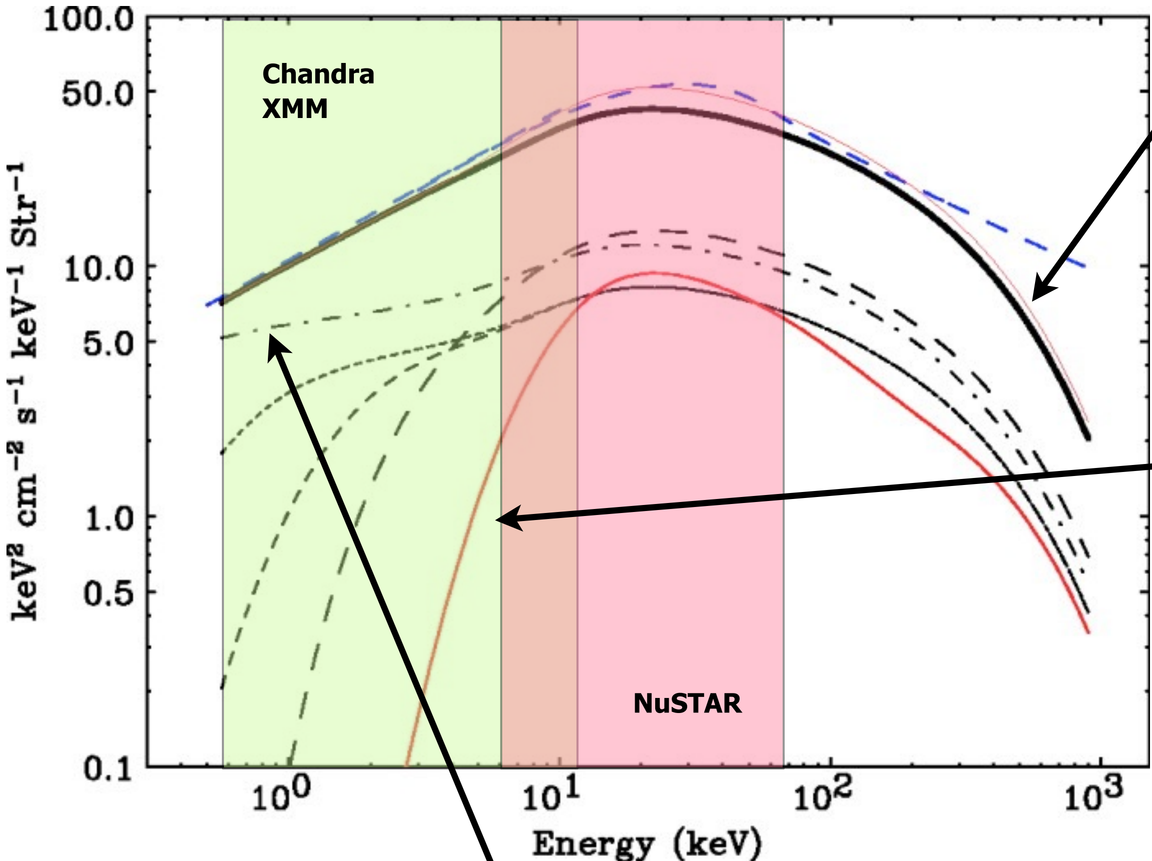
3-79 keV

12' x 12' FoV

as of Nov 1, **288** refereed papers submittted


1000
10
Area (cm^2)
5
10
20
50
Energy (keV)
NuSTAR
Chandra ACIS
XMM EPIC-pn
Swift XRT
Astro-H HXI

Resolving the Peak of the Cosmic X-Ray Background



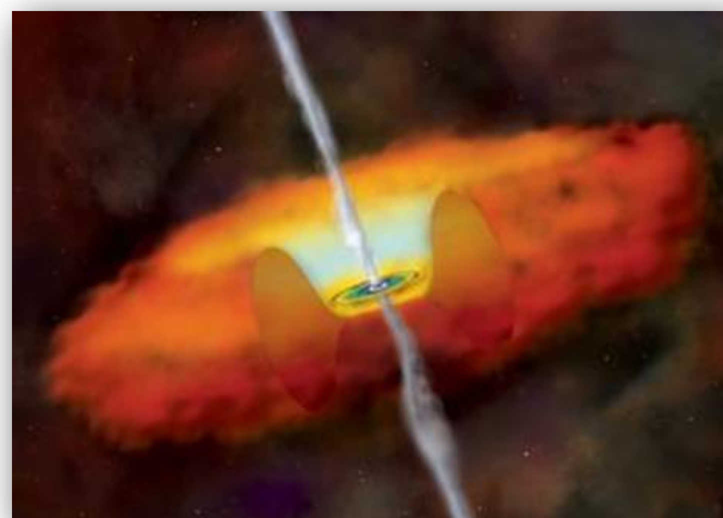
cosmic X-ray background:

- >80% resolved below 8 keV
- NuSTAR resolves ~35% at 8-24 keV

XRS could resolve most of the CXB at its peak!

heavily obscured sources

unobscured sources



Ueda et al. 2003, ApJ, 598, 886

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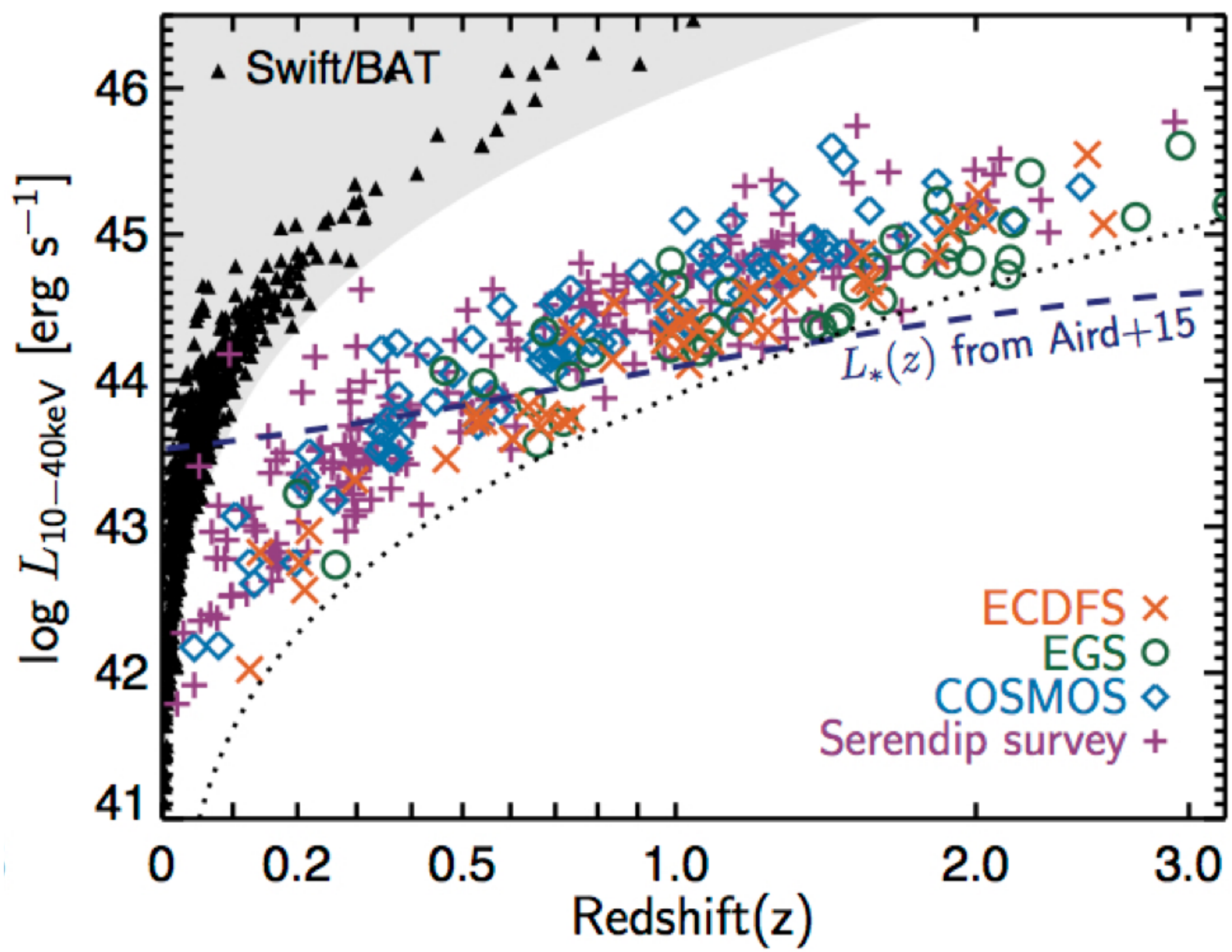
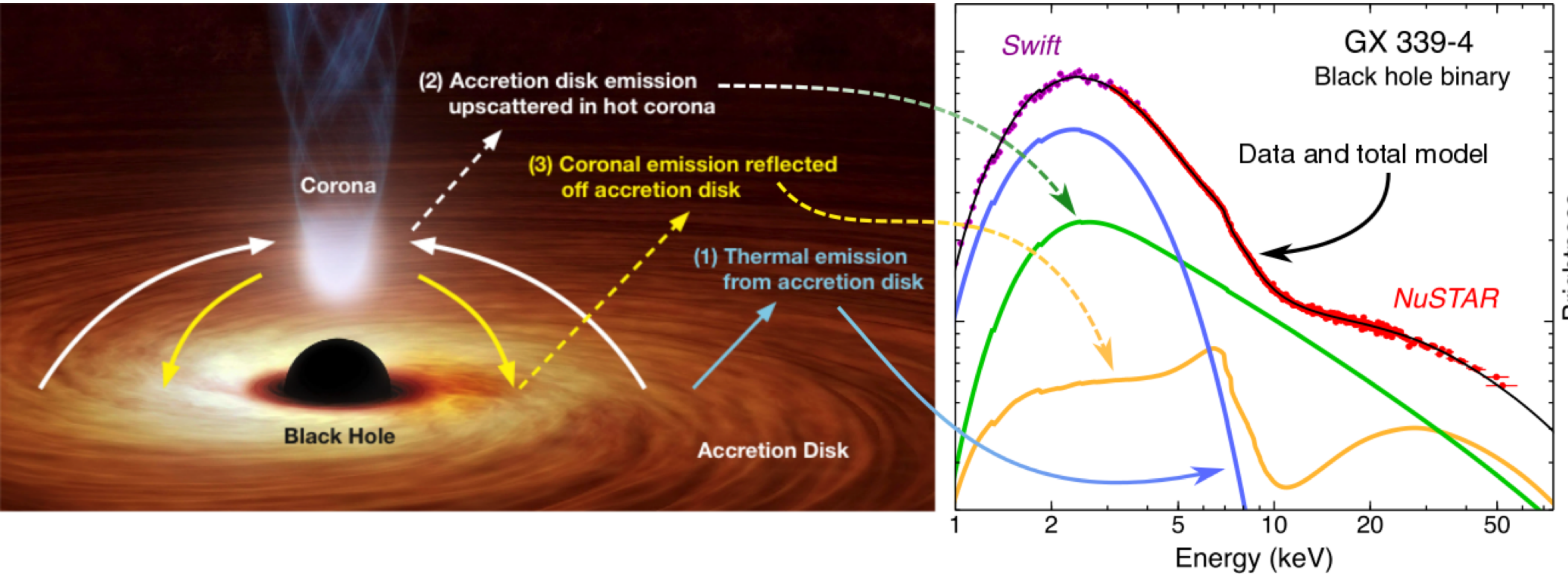


- NuSTAR only seeing L* AGN out to z~1.5, so not seeing typical AGN at the peak of the quasar era
- most distant NuSTAR 8-24 keV survey sources at z~3

Black Hole Physics

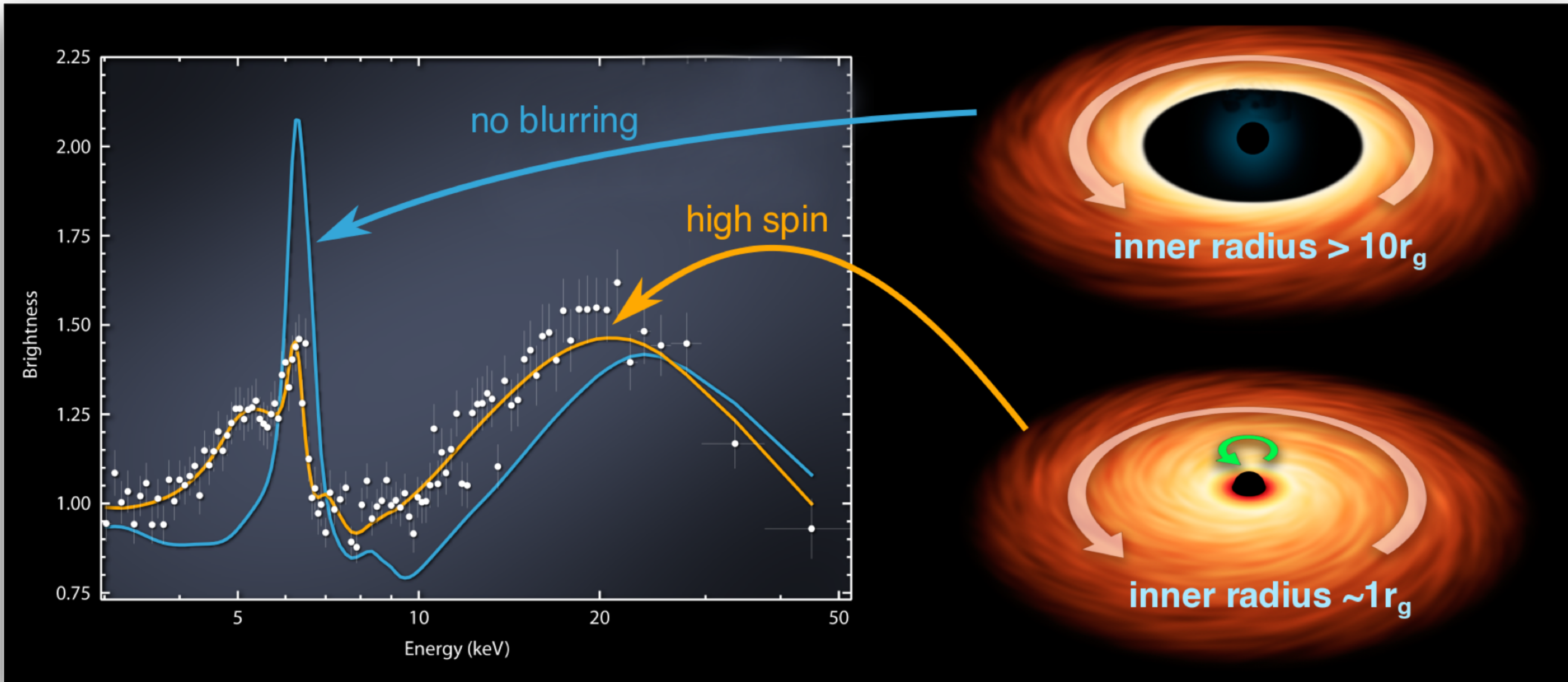


- improved black hole spin measurements
- improved understanding of the corona

Black Hole Physics: Nature of the Corona

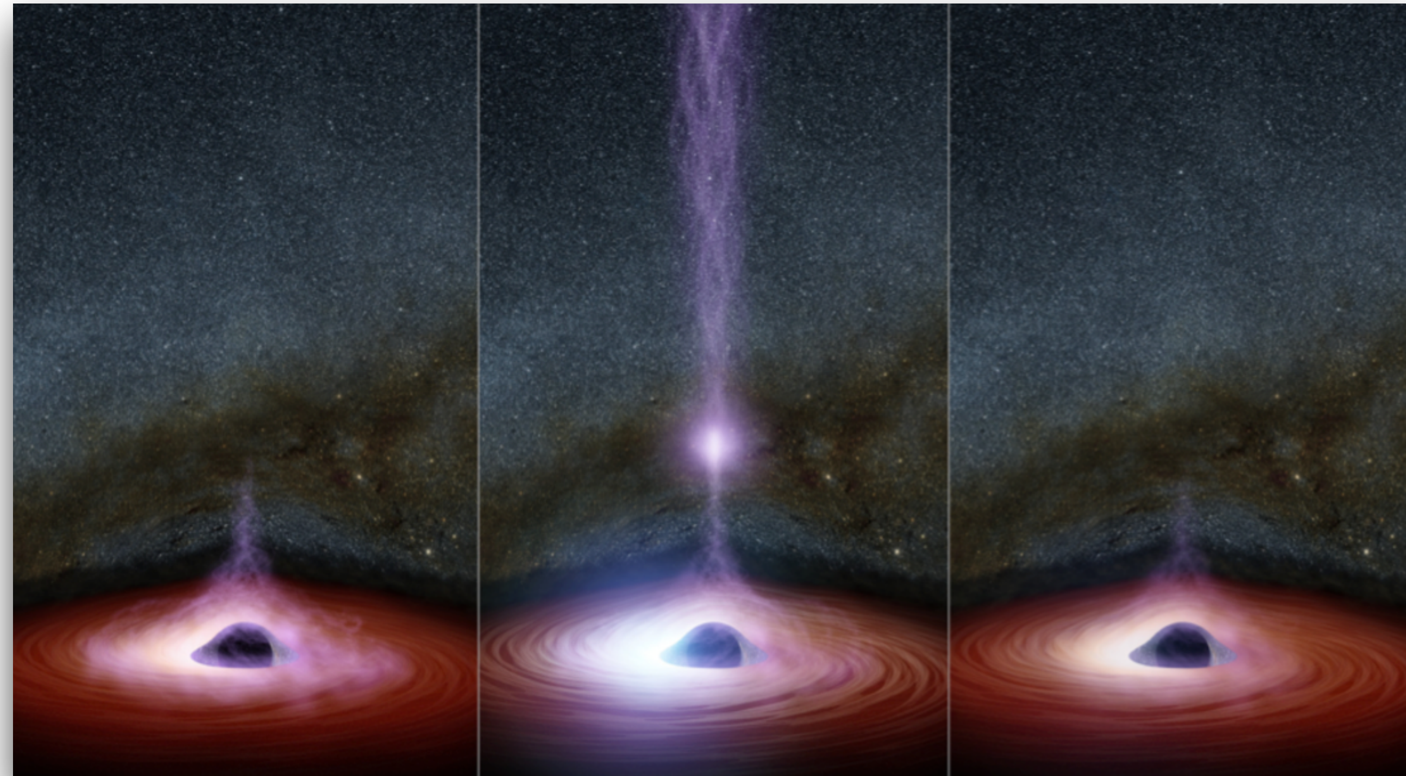
- base of the jet? atmosphere of the inner accretion disk?
- cut-off temperatures combined with sizes (e.g., from reverberation mapping) show coronae to be hot and compact, but based on just 16 sources with cut-off temperatures measured/constrained to date (and not all with size measurements)

Black Hole Physics: Spin Measurements



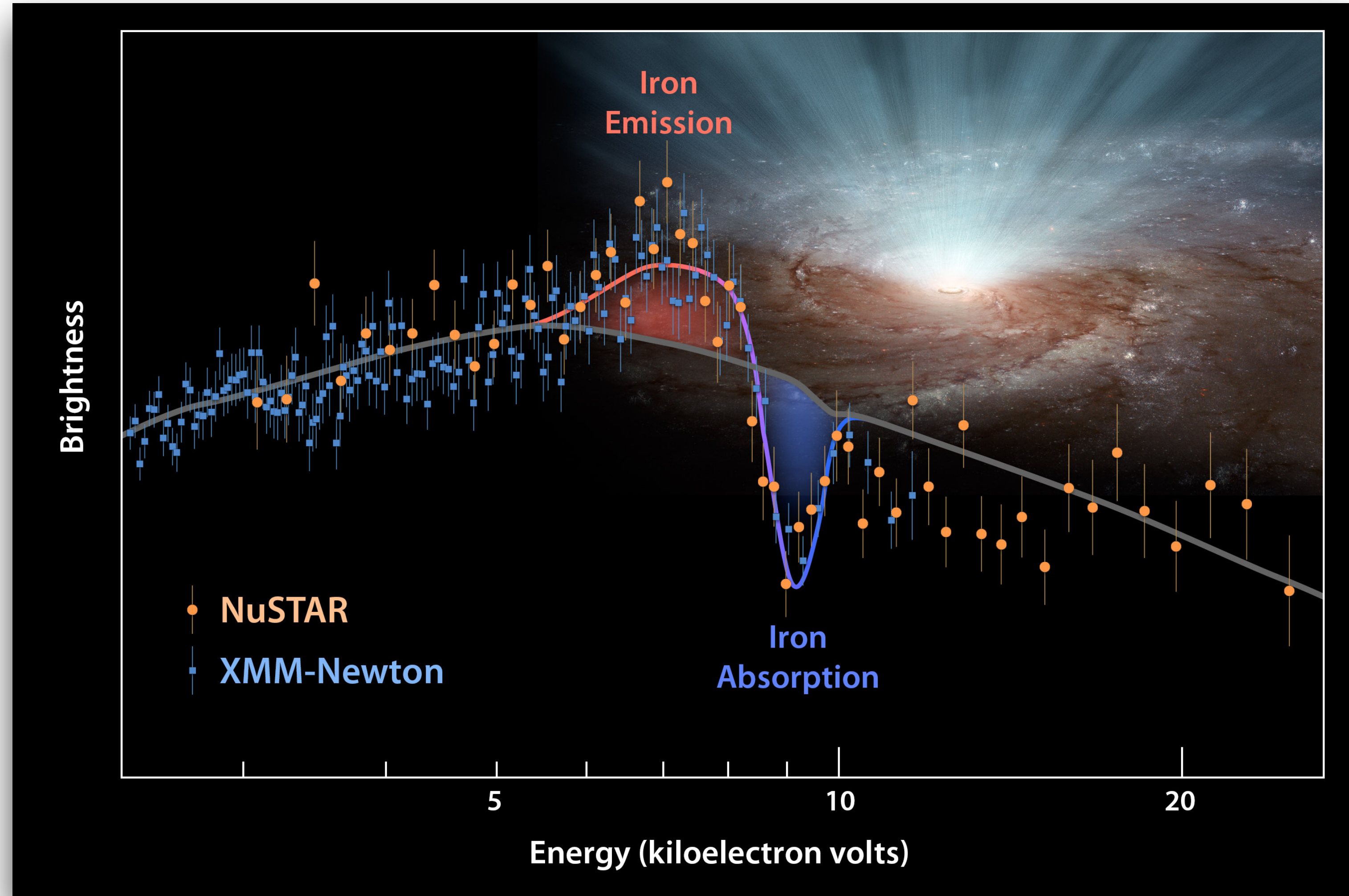
- improved measurement of continuum straddling Fe Kα
- model degeneracies broken by relativistic blurring of Compton reflection hump

Black Hole Physics: Reverberation Mapping



- time domain data allows dissection of various spectral components and derivation of their spatial separations (key to observe reflection hump)
- many NuSTAR observations consistent with the “lamppost model”, where corona is compact region along axis of the black hole

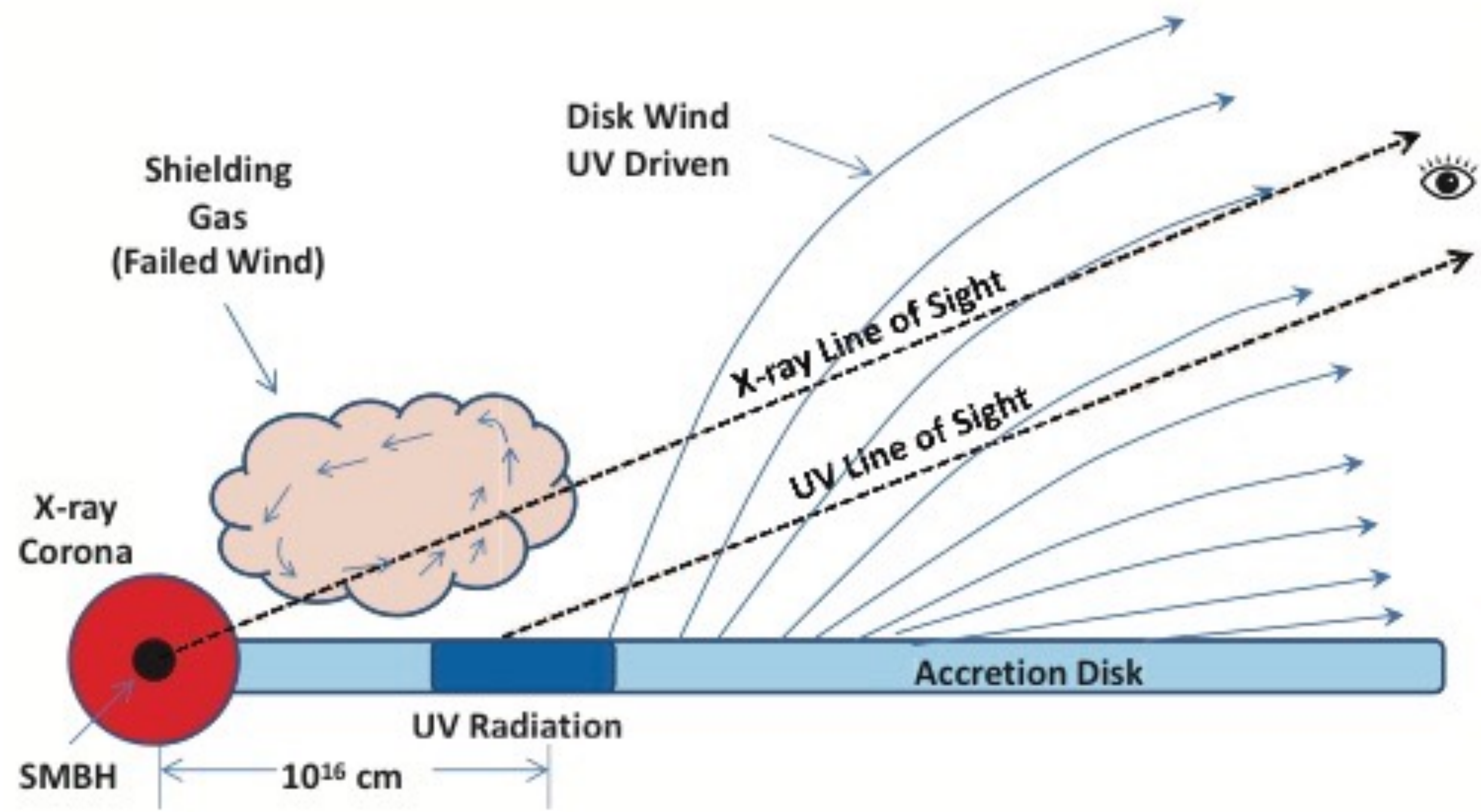
Black Hole Physics: Outflows



- NuSTAR sensitivity above 10 keV crucial for modeling P-Cygni Fe profiles for PDS456, allowing measurement of wind opening angle and energetics

Nardini et al. 2015, Science, 347, 860

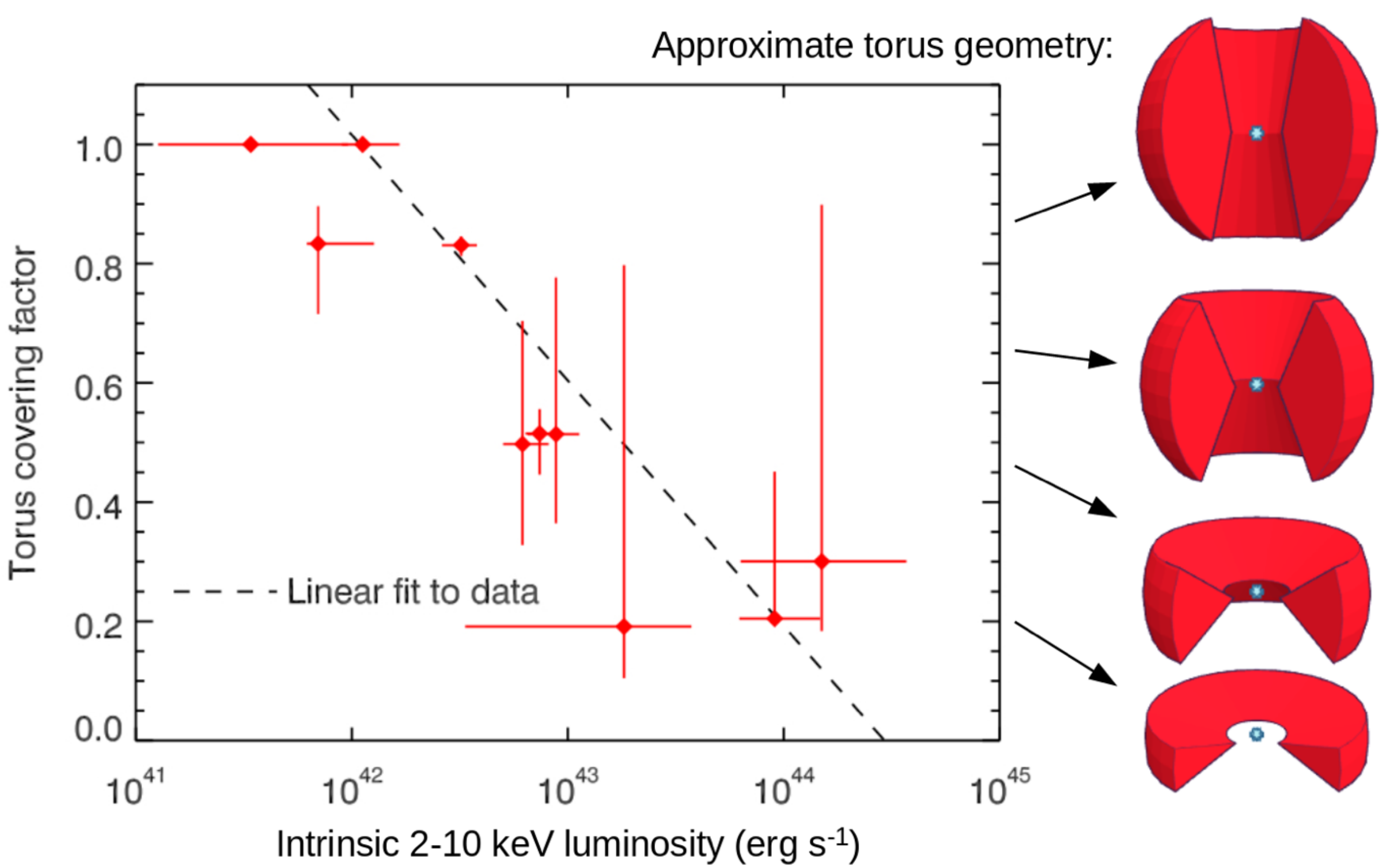
Black Hole Physics: Intrinsically Weak Coronae?



- NuSTAR has identified several (BAL) AGN (e.g., Mrk 231) which are very faint in the X-rays, even out to high energies:
  - obscuration hiding the X-ray emission?
  - intrinsically weak / quenched coronae?

Luo et al. 2013, ApJ, 772, 153
Teng et al. 2014, ApJ, 785, 19
Luo et al. 2014, ApJ, 794, 70

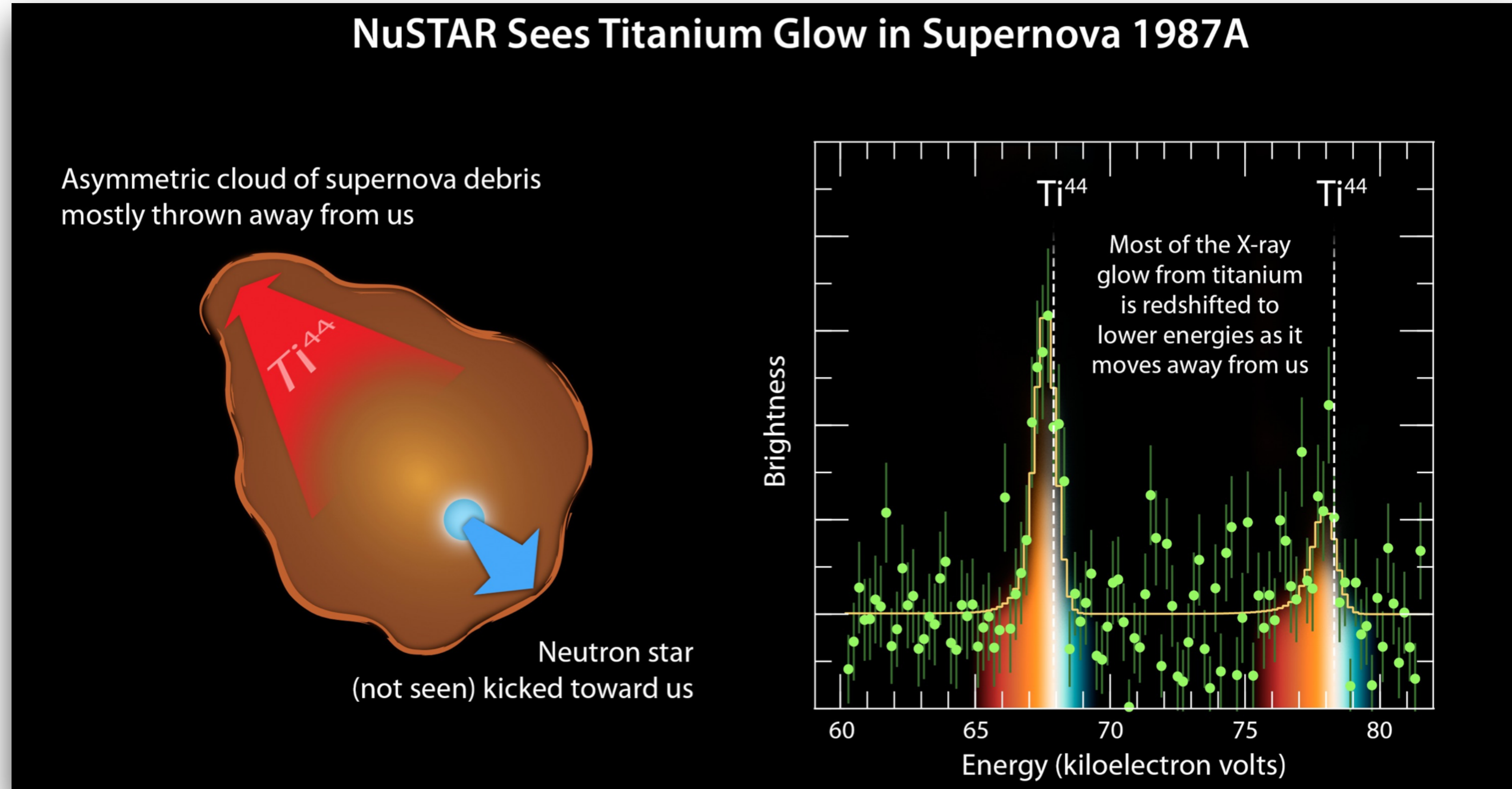
Obscured AGN



- NuSTAR has found, with scant statistics, evidence for an inverse correlation between AGN luminosity and torus covering factor

Brightman et al. 2015, ApJ, 805, 41

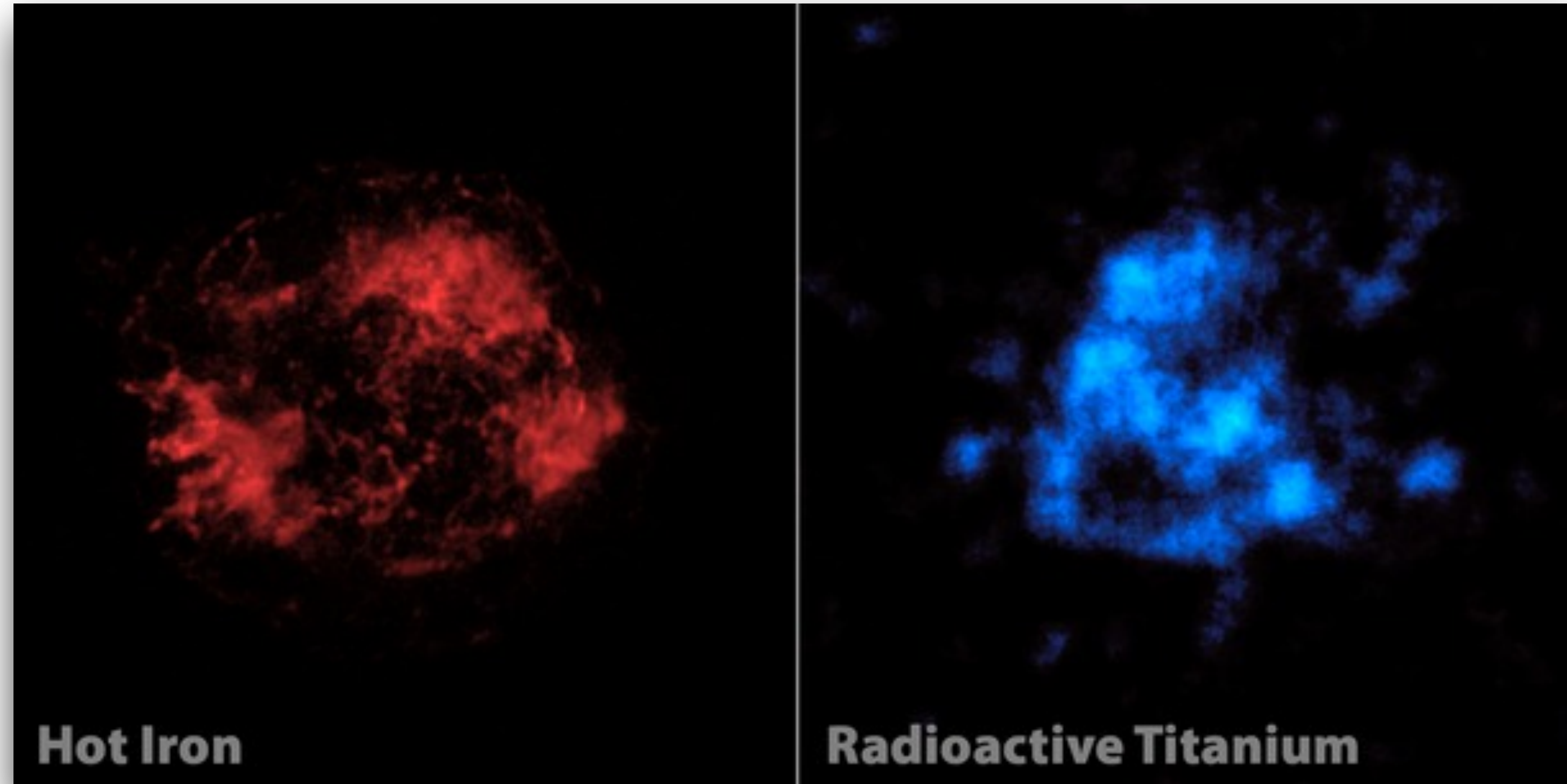
Supernova Remnants



- Ti^{44} is an ideal tracer of supernova explosion, since it is a radioactive line associated with material created close to the "fallback region" in the explosion

Boggs et al. 2015, Science, 348, 670

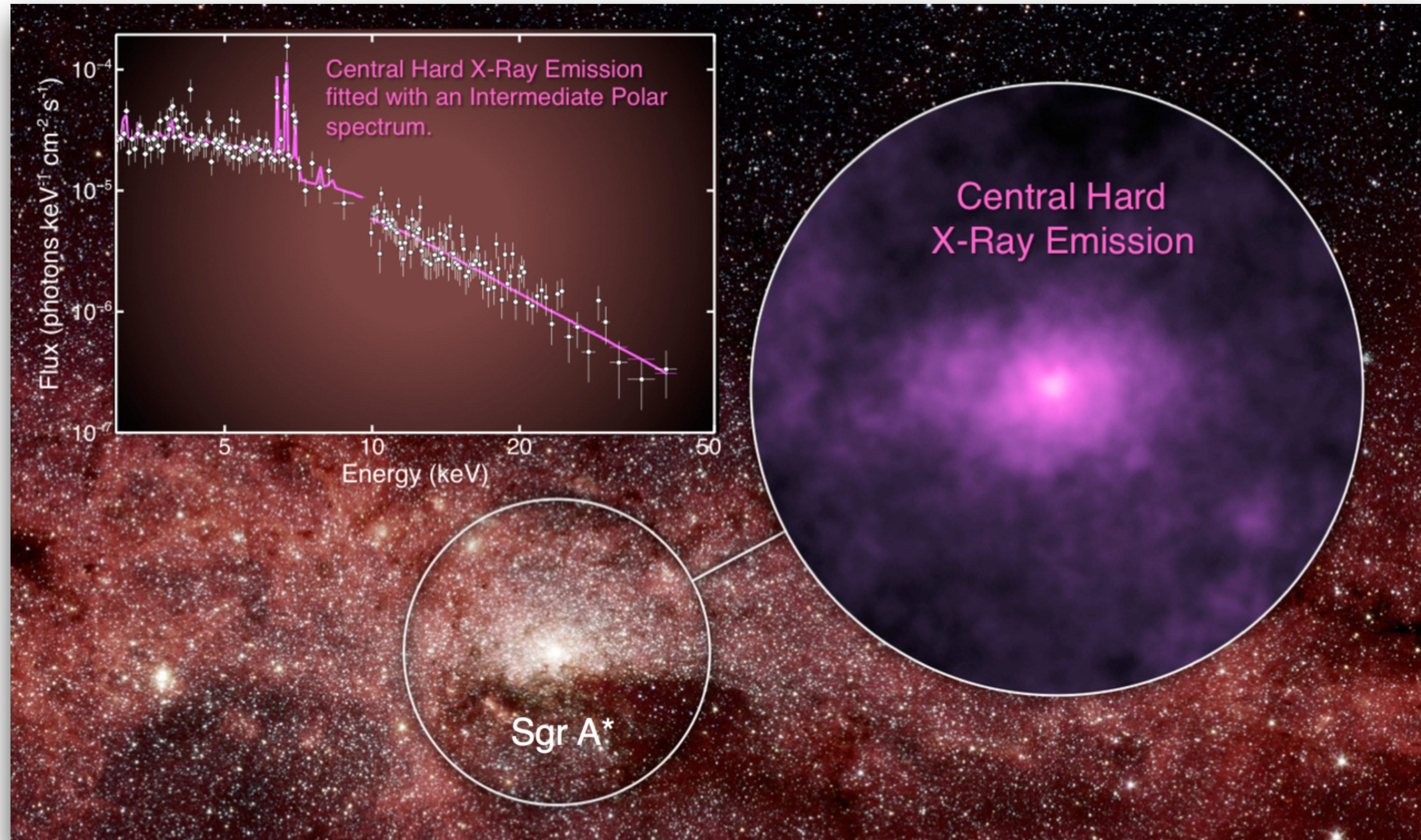
Supernova Remnants



- how do stars explode?
  - clumpy distribution of radioactive titanium in Cassiopeia A indicates that the expected stall in the supernova explosion is broken by a "sloshing" instability

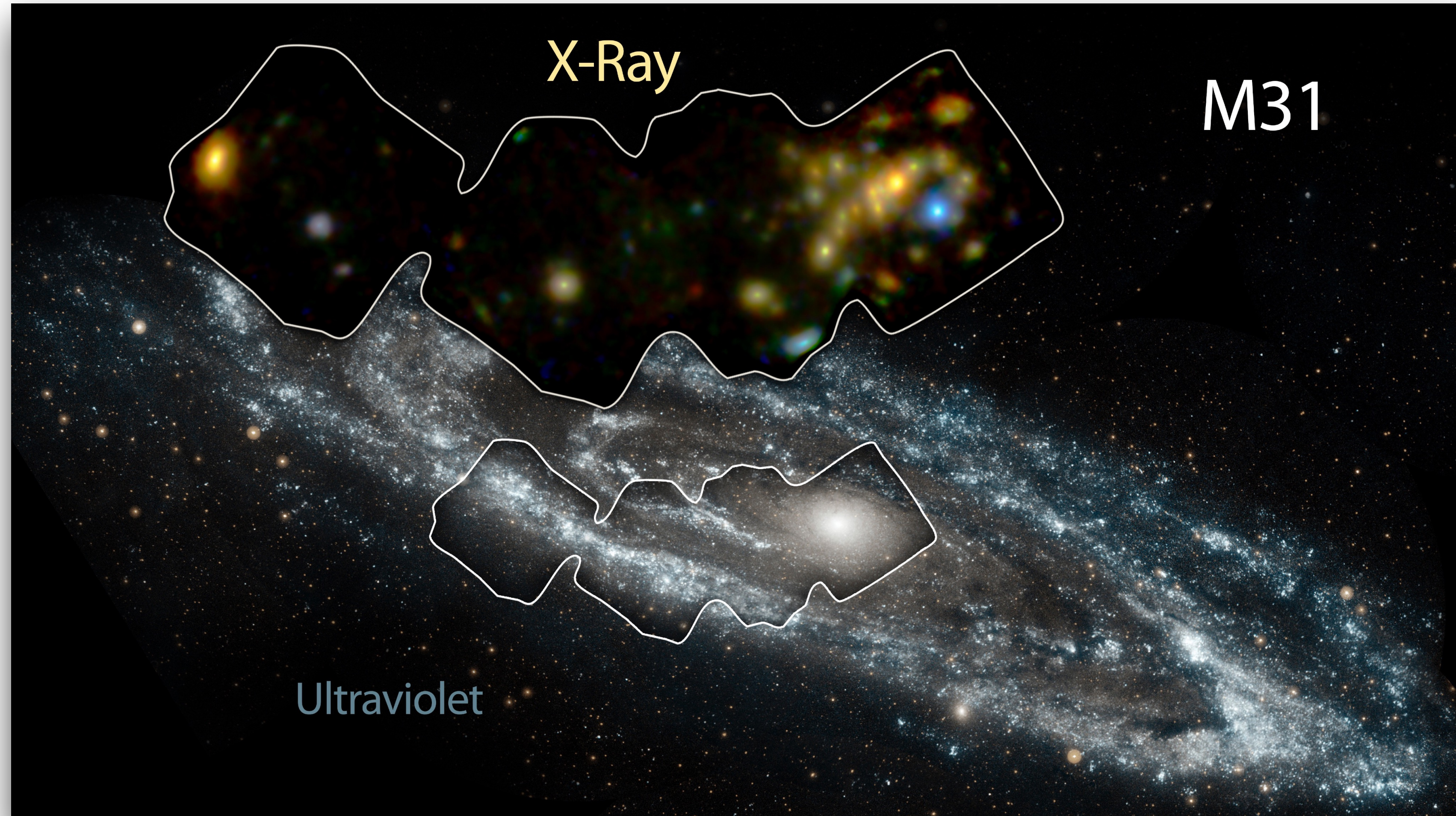
Grefenstette et al. 2014, Nature, 506, 339

Diffuse Hard X-ray Emission at Galactic Center



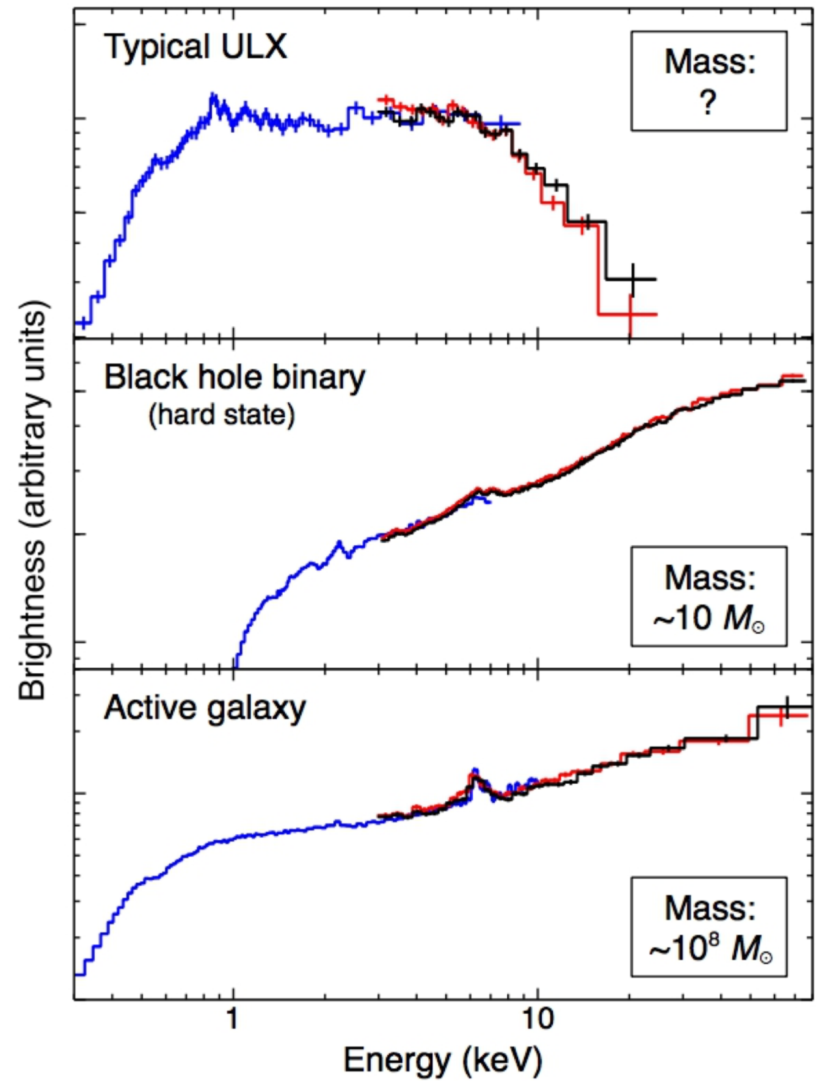
Perez et al., 2015, Nature, 520, 646
Hailey et al. 2016, ApJ, 826, 160

Galactic and Nearby Galaxy Surveys



- compact remnants in the Milky Way and nearby galaxies (as a function of age, metallicity, etc…)

Ultraluminous X-Ray Sources (ULXs)



- ULXs have unique spectra above ~8 keV, indicative of distinct (super-Eddington?) accretion modes

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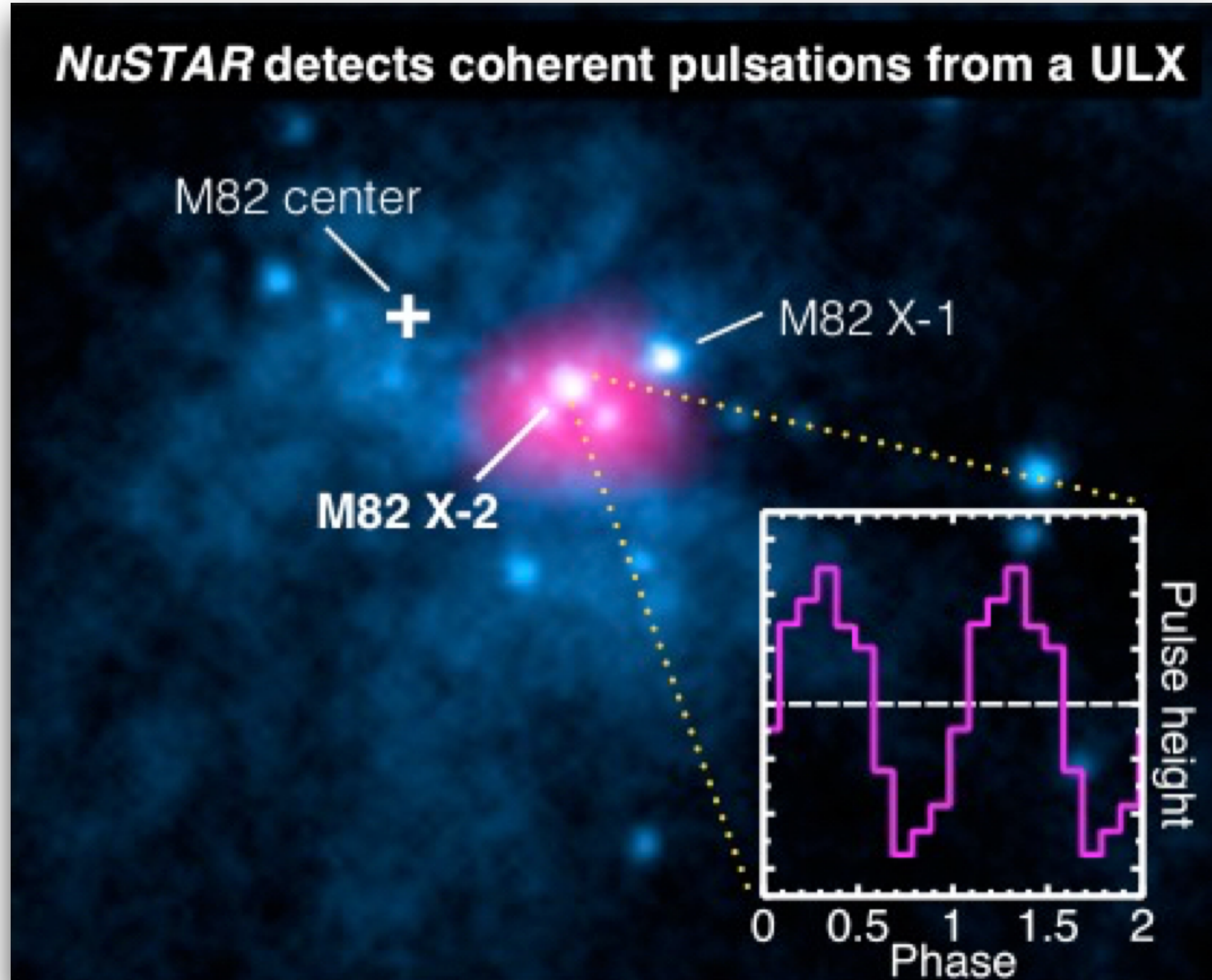
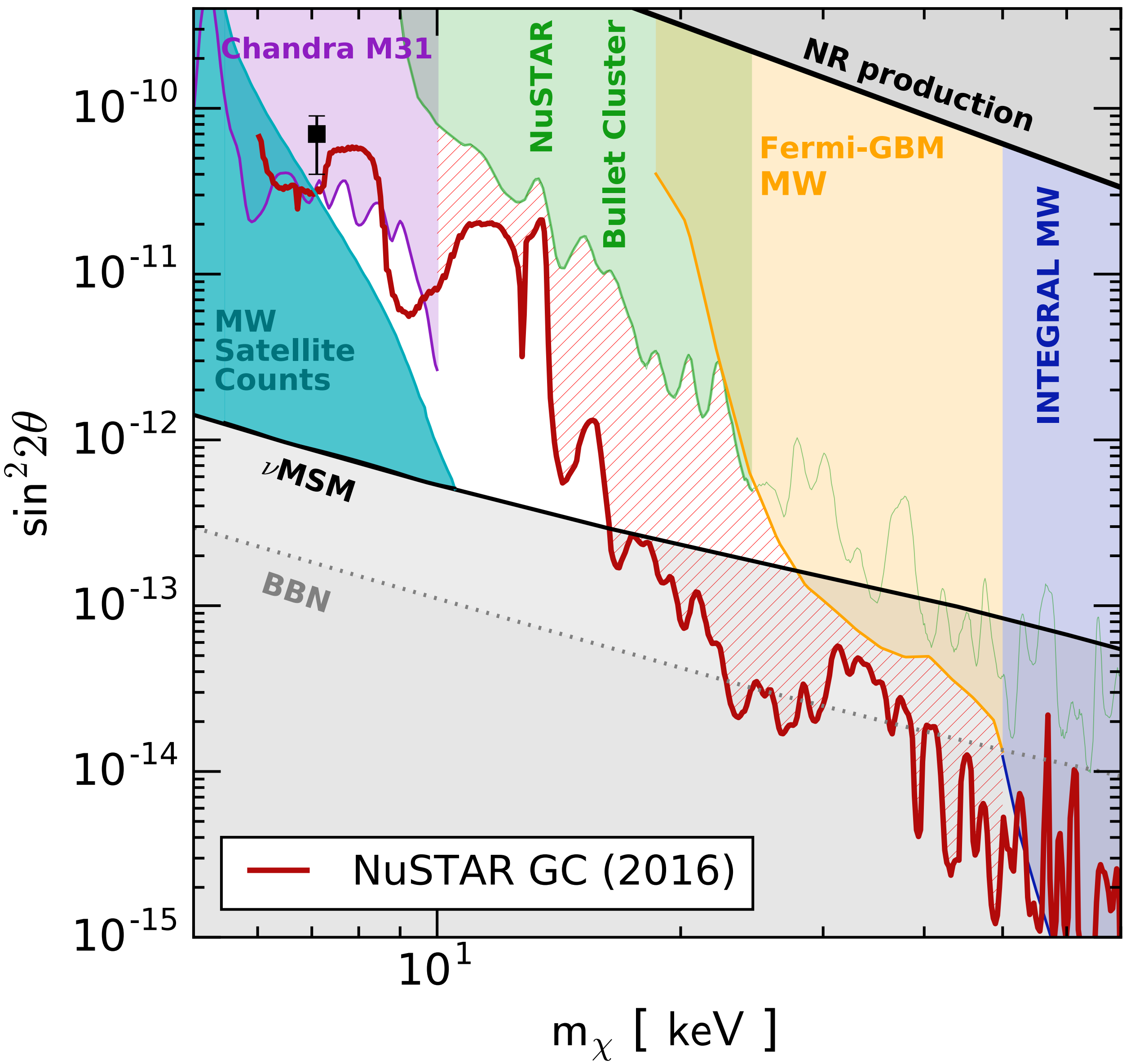


Bachetti et al. 2014, Nature, 514, 202
Israel et al., arXiv:1609.06538
Fuerst et al, arXiv:1609.07129
Israel et al., arXiv:1609.07375

Dark Matter



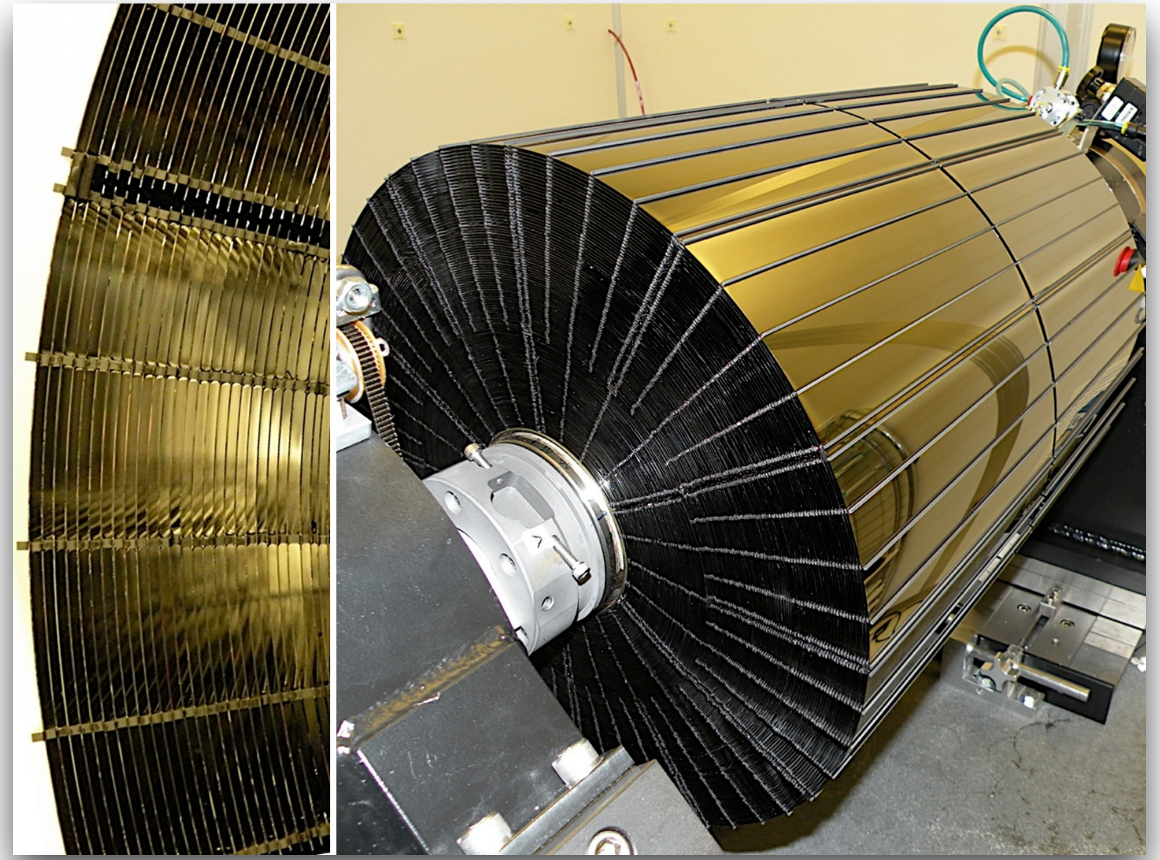
Perez et al., arXiv:1609.00667

Science Summary, Selected Sample

Science	Key Energy Range
cosmic X-ray background	20-40 keV
black hole coronae	to at least ~100 keV
relativistic reflection	to ~40 keV
outflows	to ~20 keV
obscured AGN	to ~40 keV
supernova remnants (Ti^{44})	to ~85 keV
ULXs	to ~20 keV
dark matter	to ~40 keV
galaxy clusters	to ~20 keV
blazars / jets	to at least ~100 keV

Implementation

- separate high-energy telescope(s)?
- dedicate inner shells of the optics to highest energy photons?
  - hybrid detector, with lower-energy sensitive Si CCDs sitting atop higher-energy sensitive Cd(Zn)Te detectors (ala NuSTAR)?

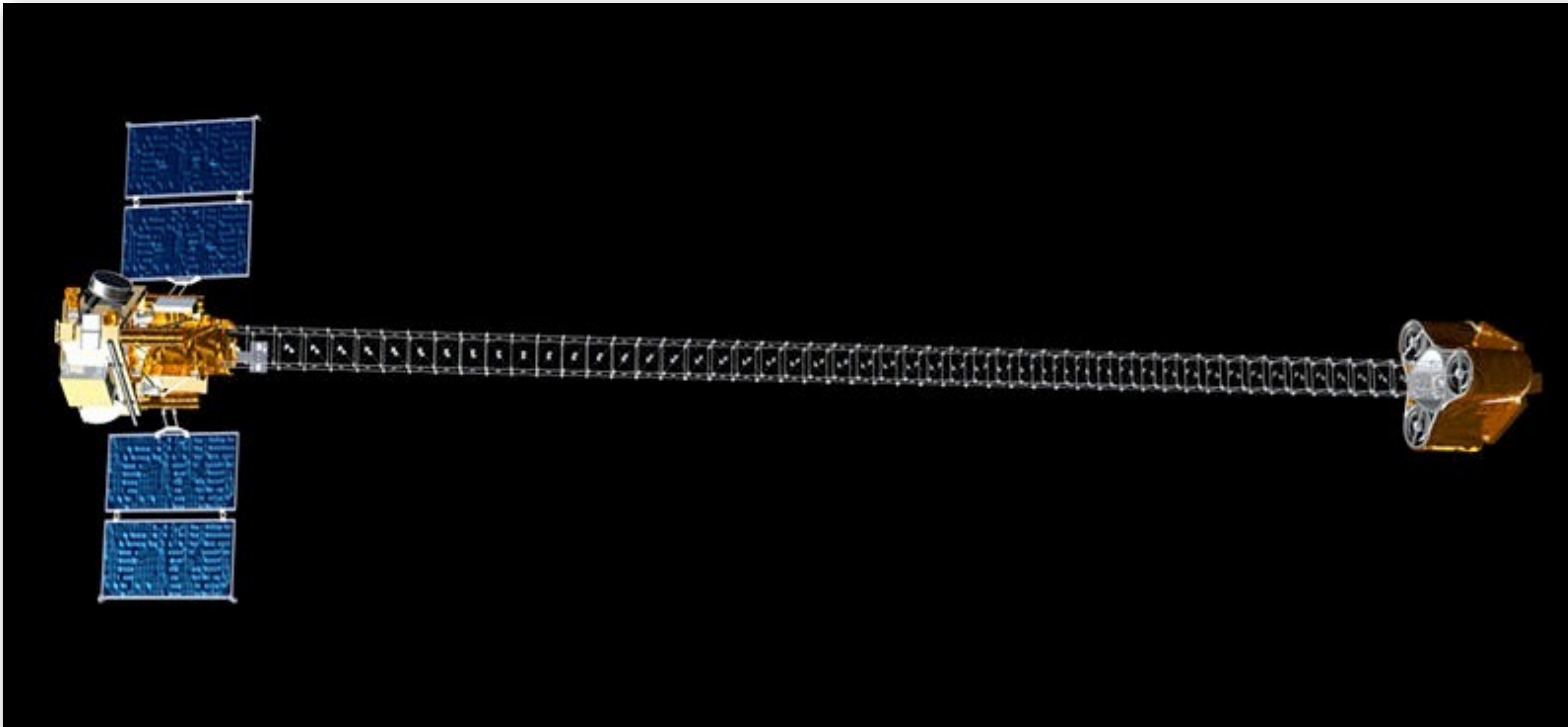


My Assessment

- Lots of very exciting science if we go past 10 keV. In particular, since only comparison is a SMEX, we can counter fears that XRS only provides incremental science gains.
- There's a range of science gains for different energy range enhancements. Even just going to 20 keV buys some science, reaching 40 keV buys even more, etc….
- Much of the enhanced science doesn't require the exquisite optical quality of XRS at lower energies.

- On the flip side, I see the most likely path to the selection of XRS is that we come in significantly cheaper than the other Flagships, so we want to stay simple.

HEX-P



- the High-Energy X-ray Probe (HEX-P), a probe-class NuSTAR follow-on under development for the current mission concept study call
- contact me (and/or Fiona Harrison) if you're interested