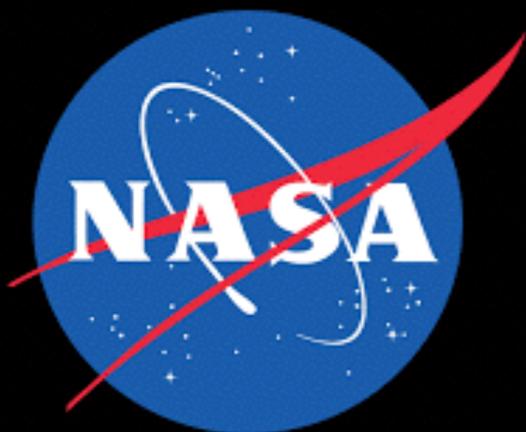


Pushing XRS to Higher Energies: Science and Potential Implementation

Daniel Stern

NuSTAR Project Scientist

Jet Propulsion Laboratory/California Institute of Technology



2016 November 2
X-Ray Surveyor STDT telecon

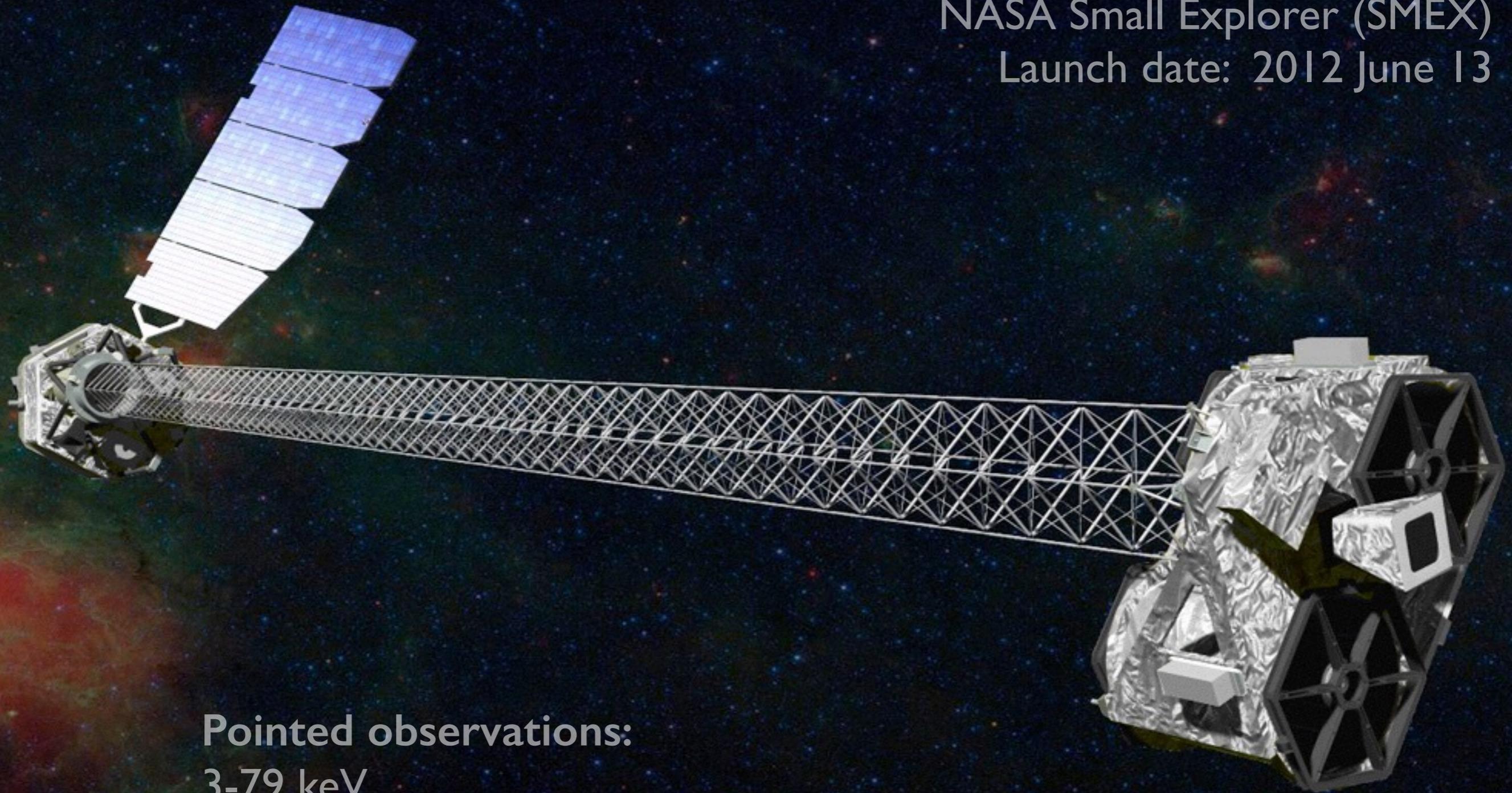
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NuSTAR

(Nuclear Spectroscopic Telescope Array)

NASA Small Explorer (SMEX)

Launch date: 2012 June 13

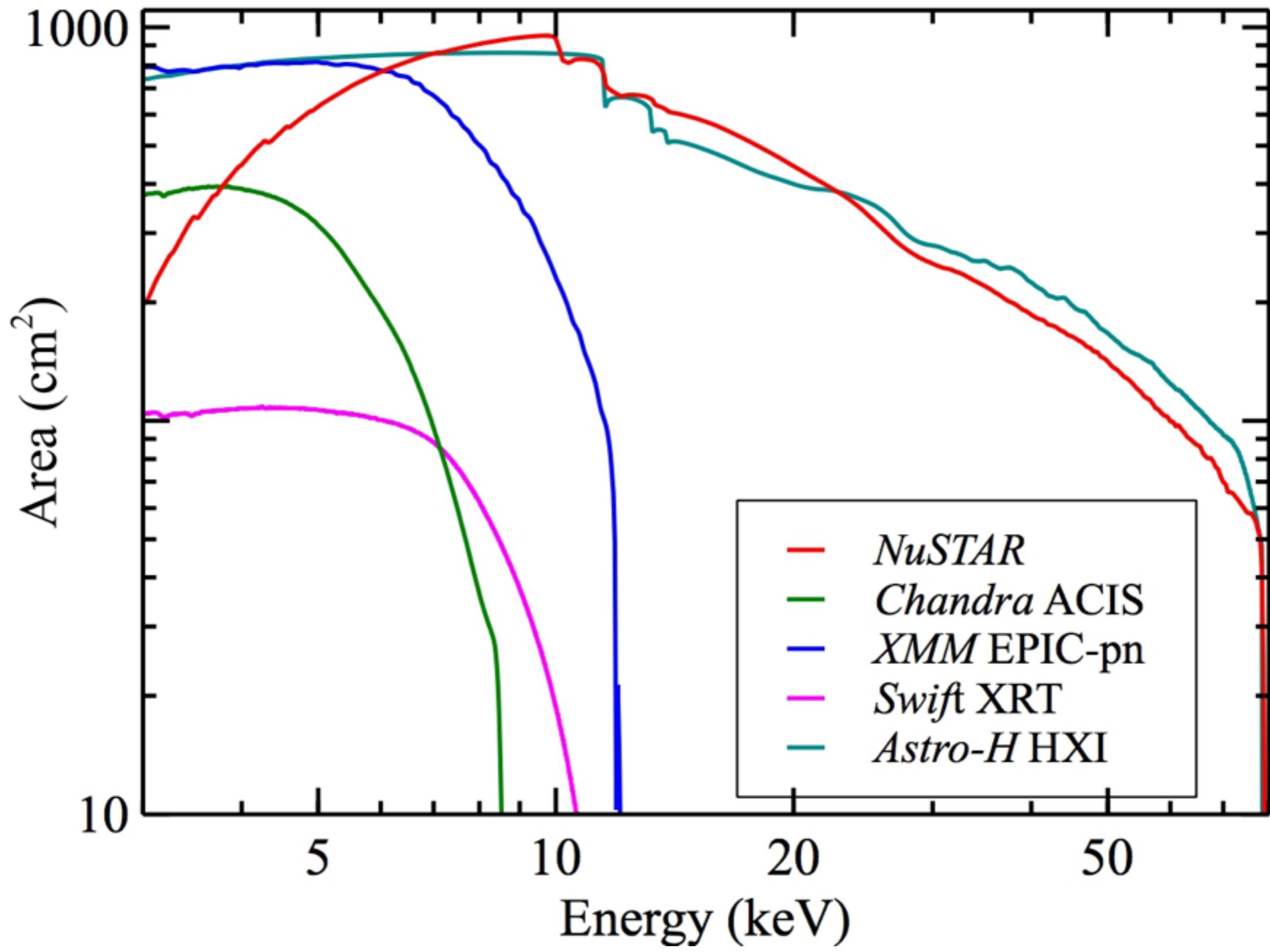


Pointed observations:

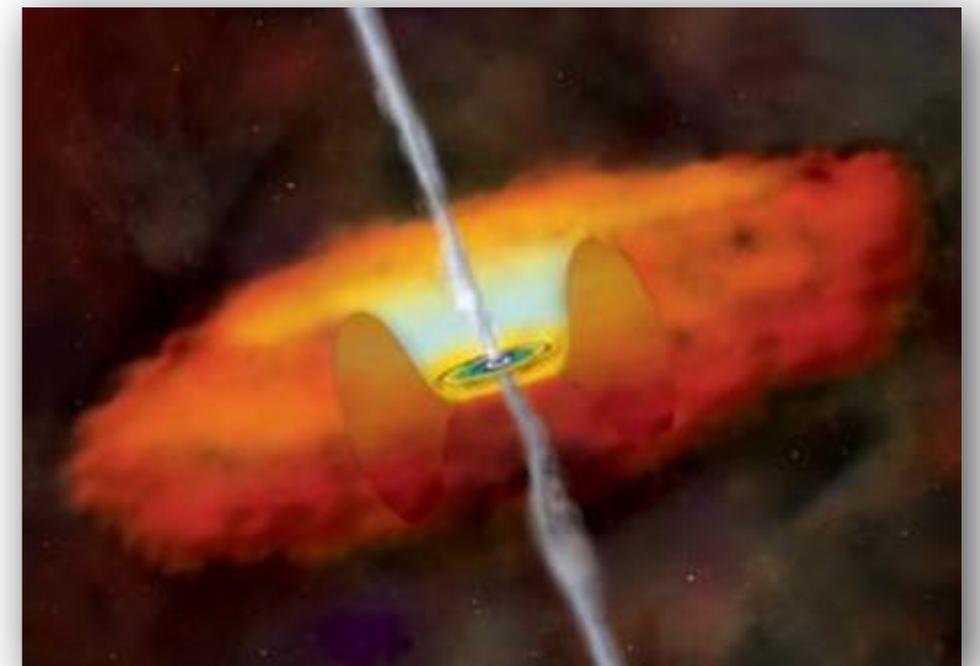
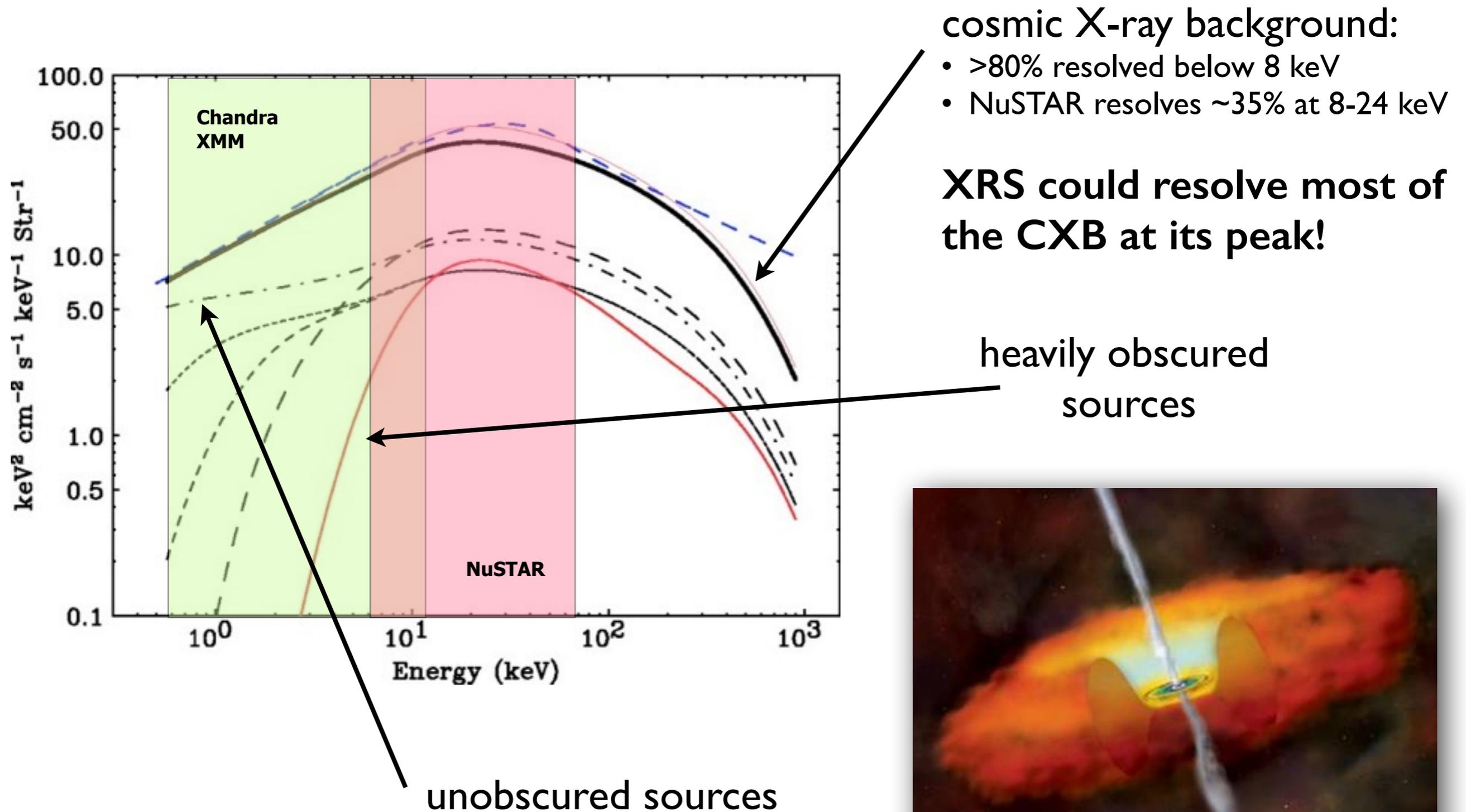
3-79 keV

12' x 12' FoV

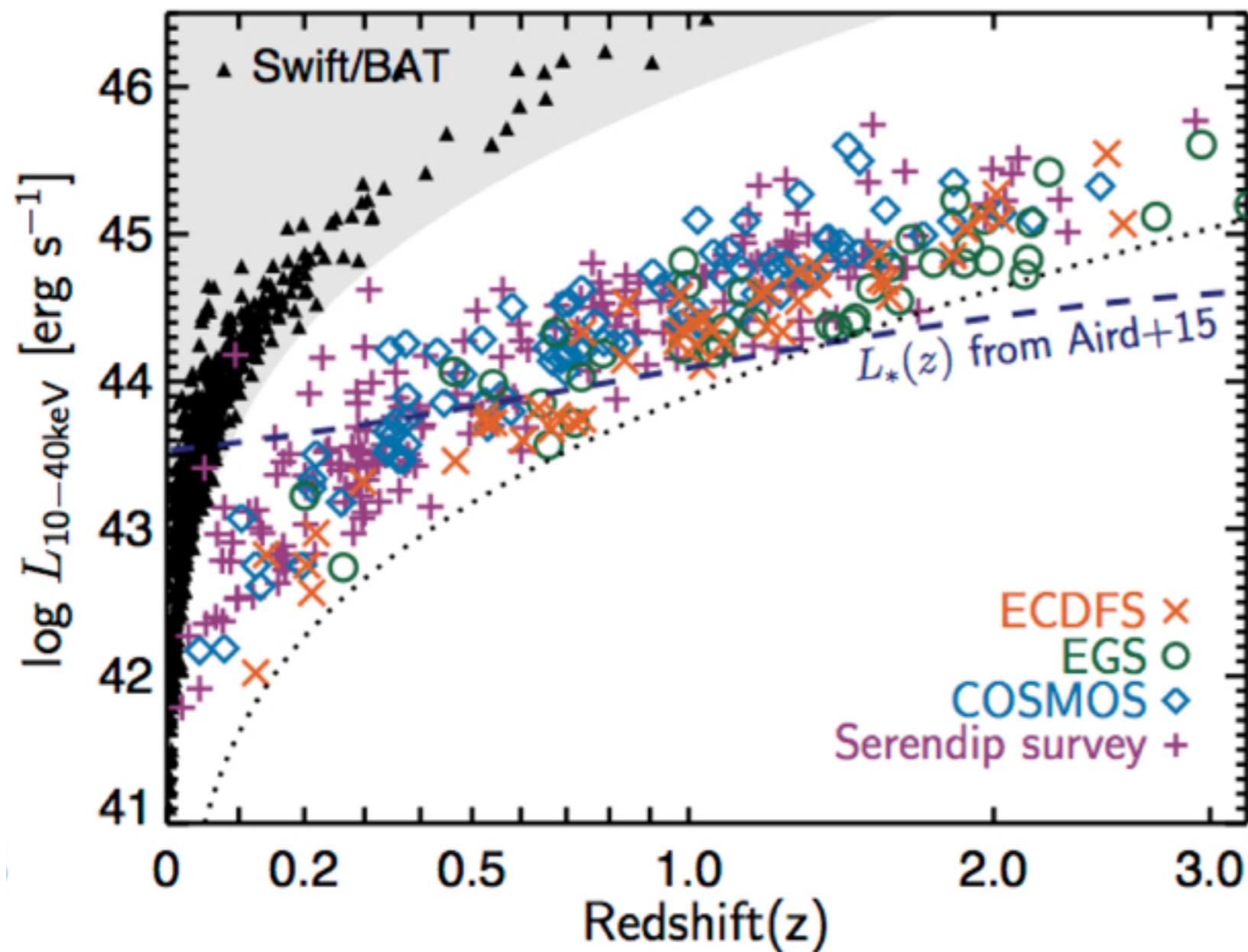
as of Nov 1, 288 refereed papers submitted



Resolving the Peak of the Cosmic X-Ray Background

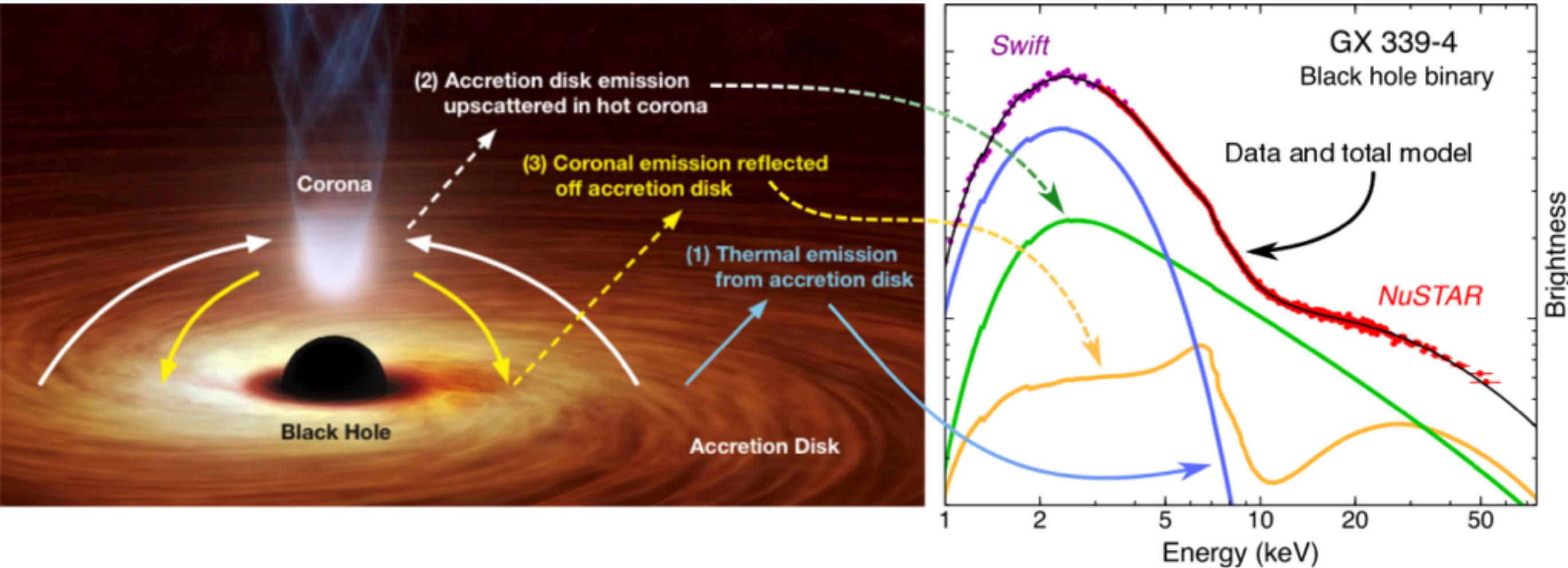


Resolving the Peak of the Cosmic X-Ray Background



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

Black Hole Physics



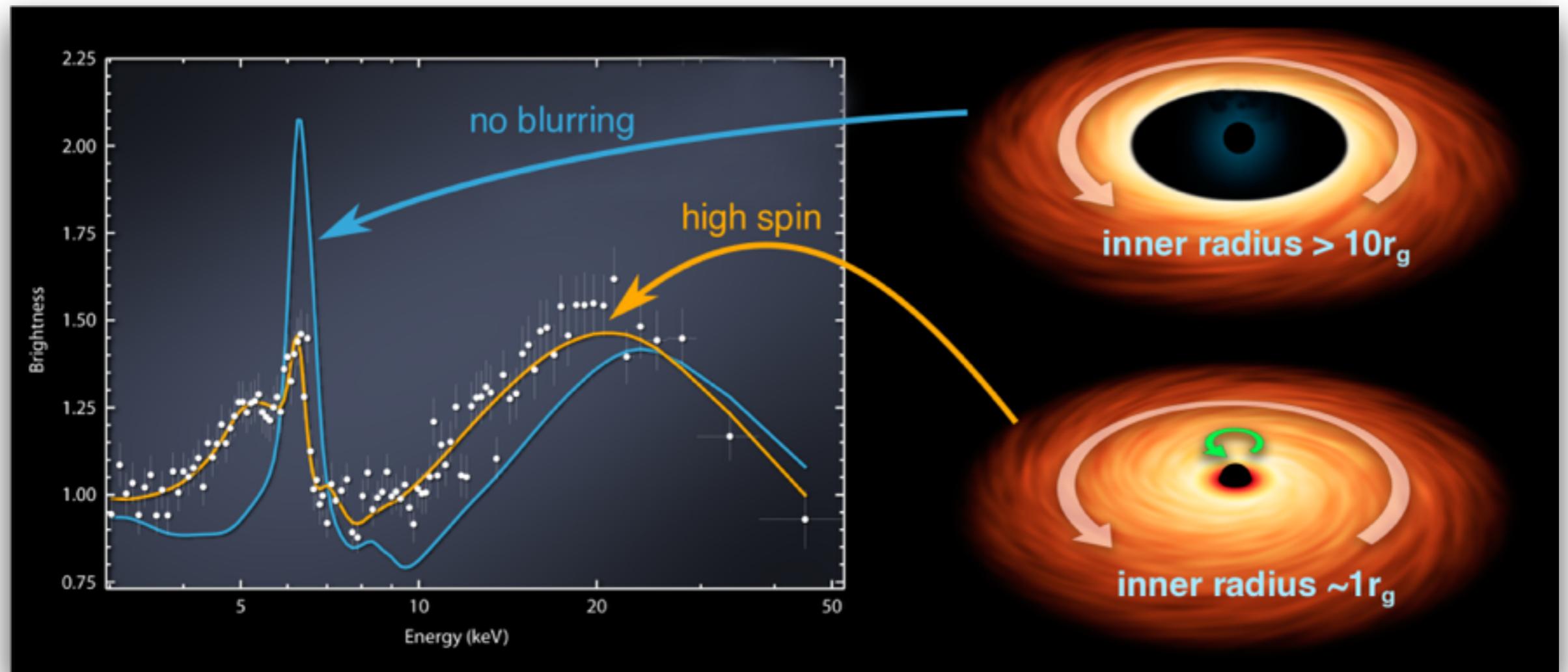
- improved black hole spin measurements
- improved understanding of the corona

Black Hole Physics: Nature of the Corona



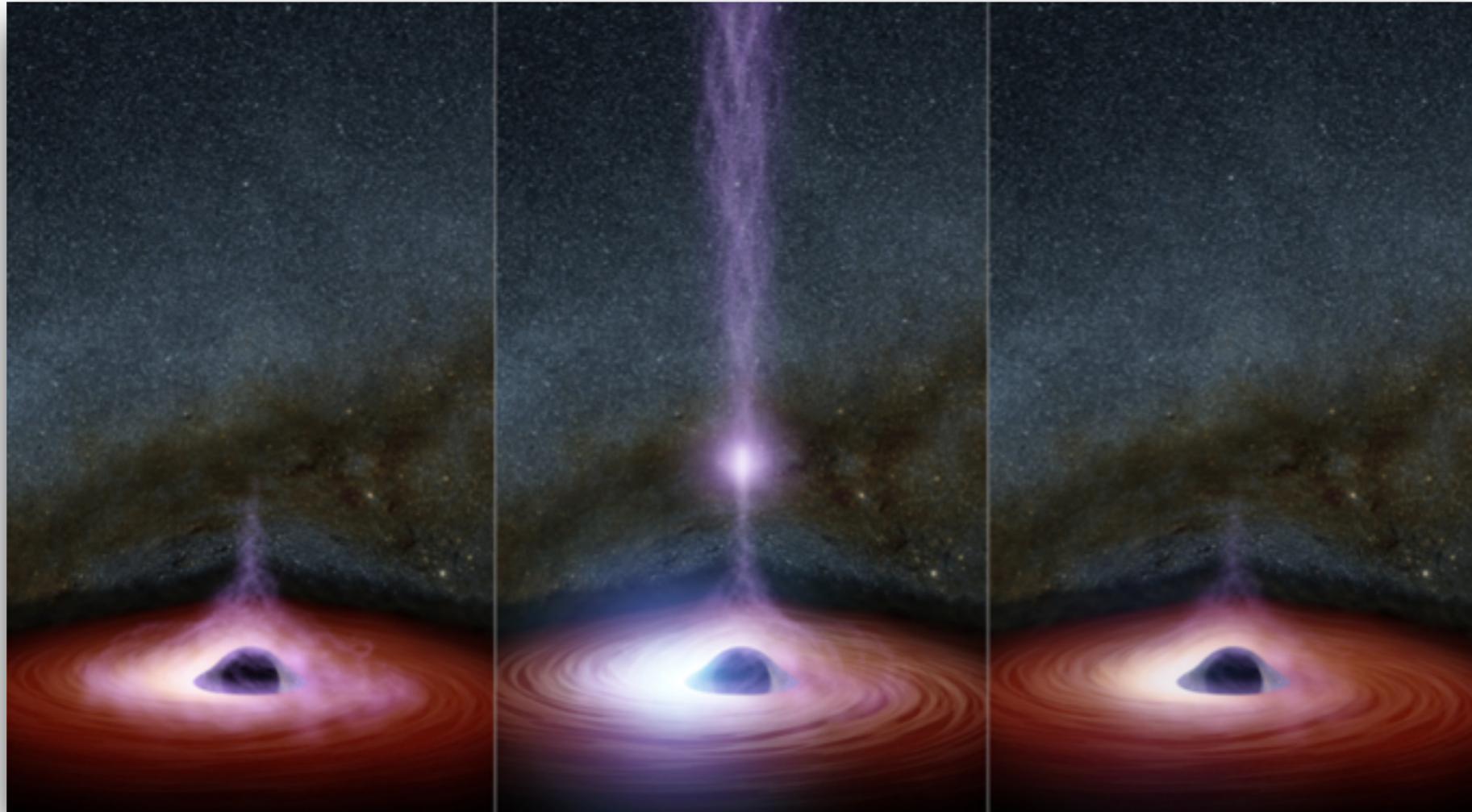
- base of the jet? atmosphere of the inner accretion disk?
- cut-off temperatures combined with sizes (e.g., from reverberation mapping) show coronae to be hot and compact, but based on just 16 sources with cut-off temperatures measured/constrained to date (and not all with size measurements)

Black Hole Physics: Spin Measurements



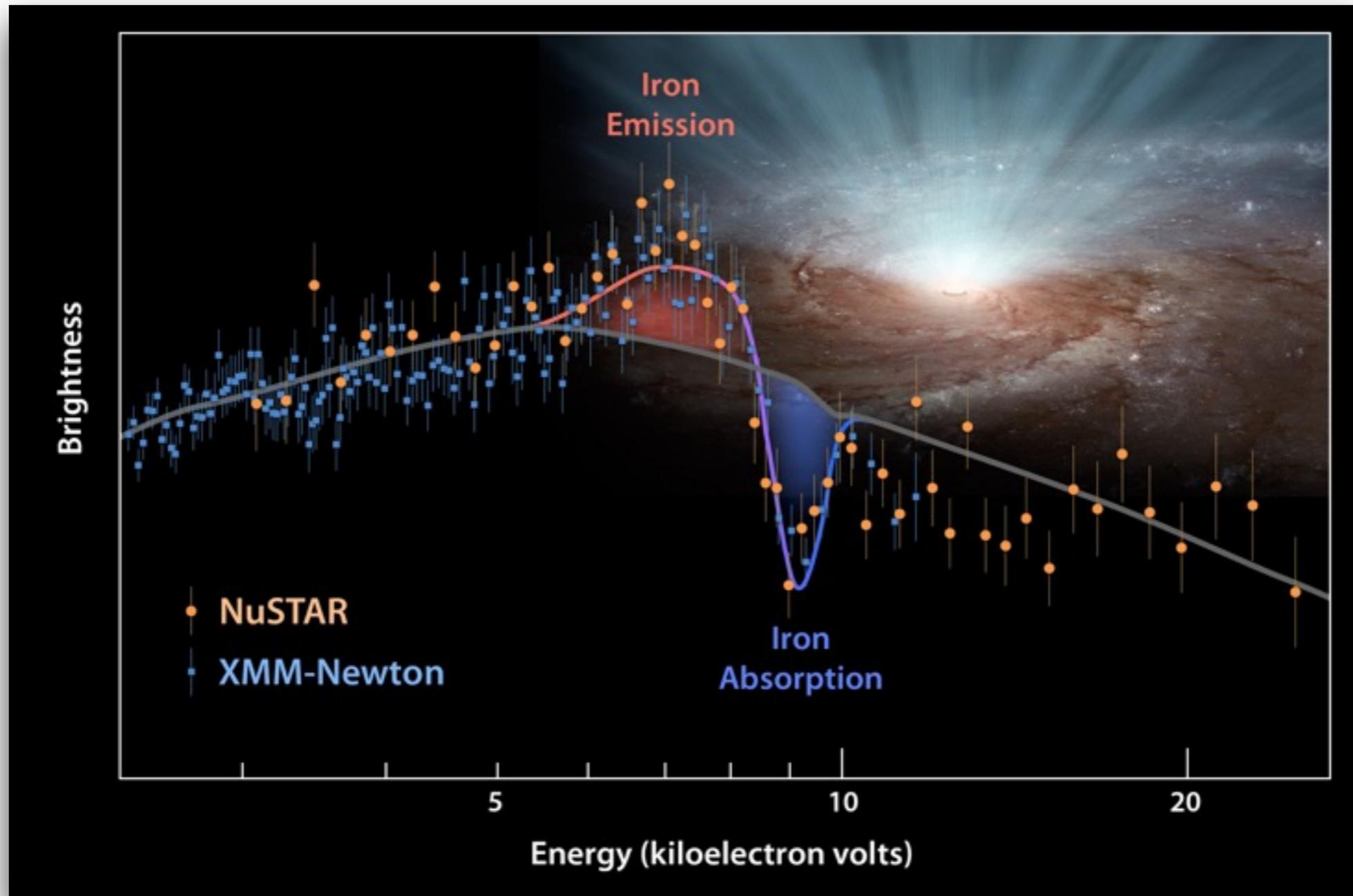
- improved measurement of continuum straddling Fe K α
- model degeneracies broken by relativistic blurring of Compton reflection hump

Black Hole Physics: Reverberation Mapping



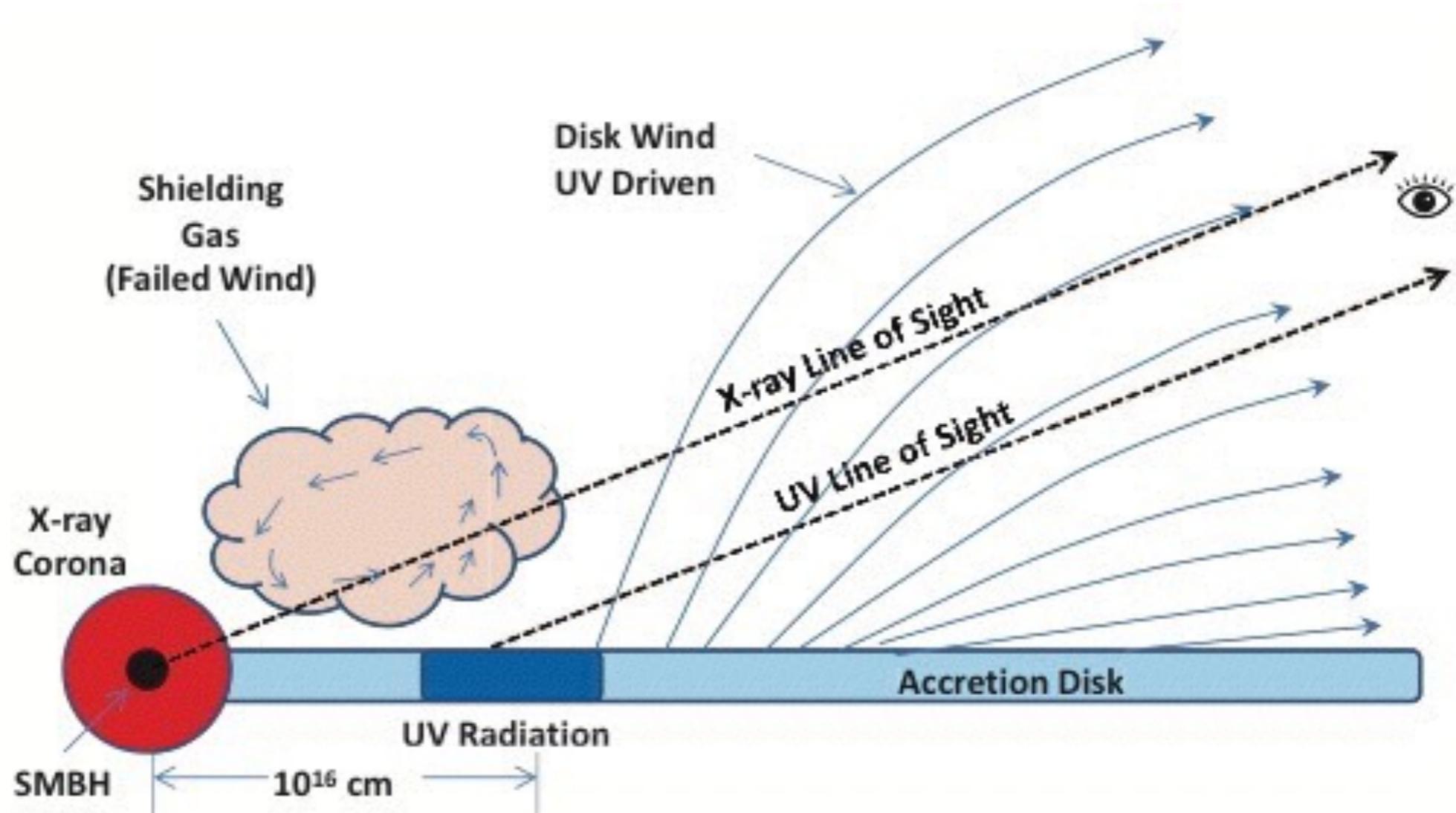
- time domain data allows dissection of various spectral components and derivation of their spatial separations (key to observe reflection hump)
- many NuSTAR observations consistent with the “lamppost model”, where corona is compact region along axis of the black hole

Black Hole Physics: Outflows



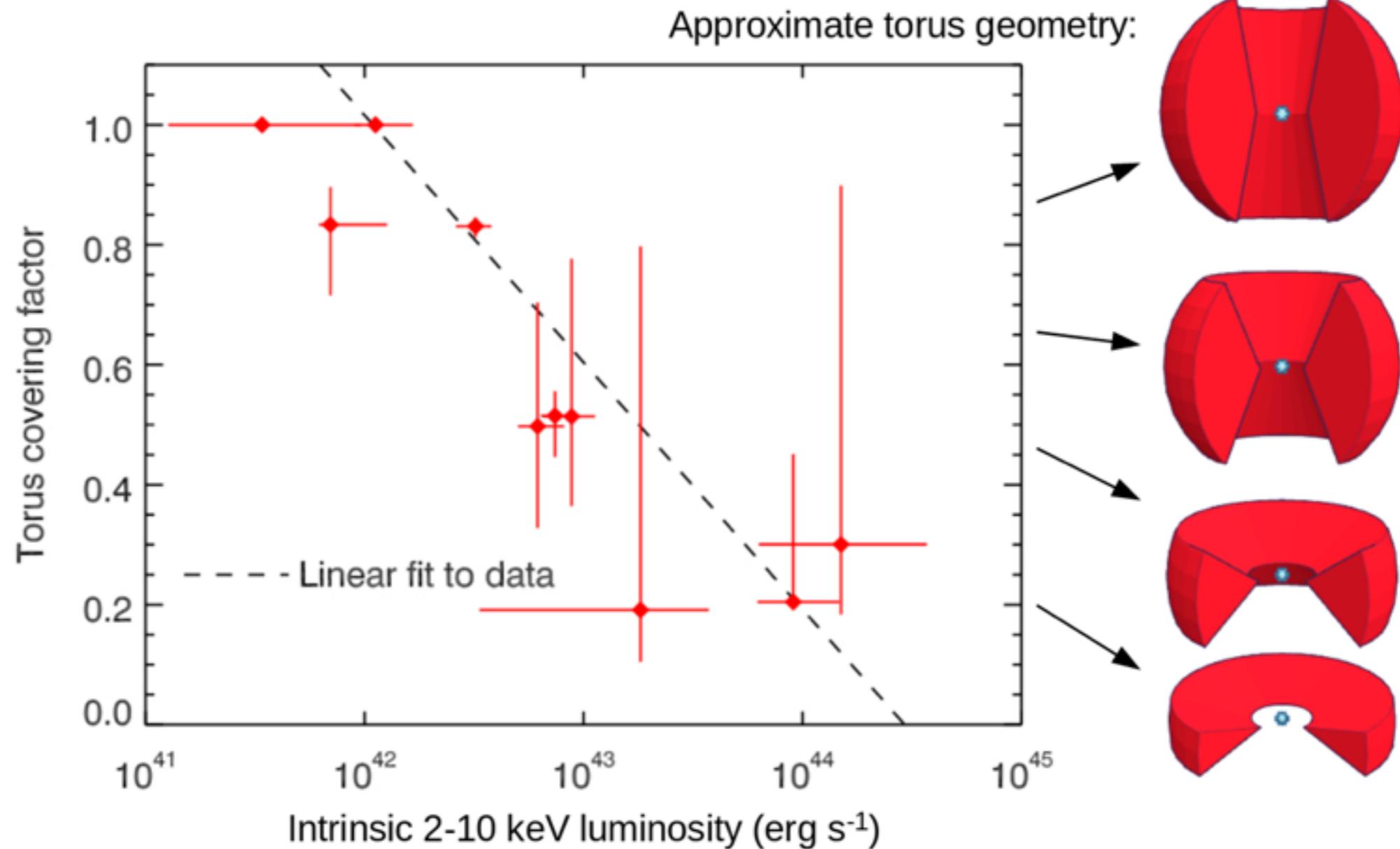
- NuSTAR sensitivity above 10 keV crucial for modeling P-Cygni Fe profiles for PDS456, allowing measurement of wind opening angle and energetics

Black Hole Physics: Intrinsically Weak Coronae?



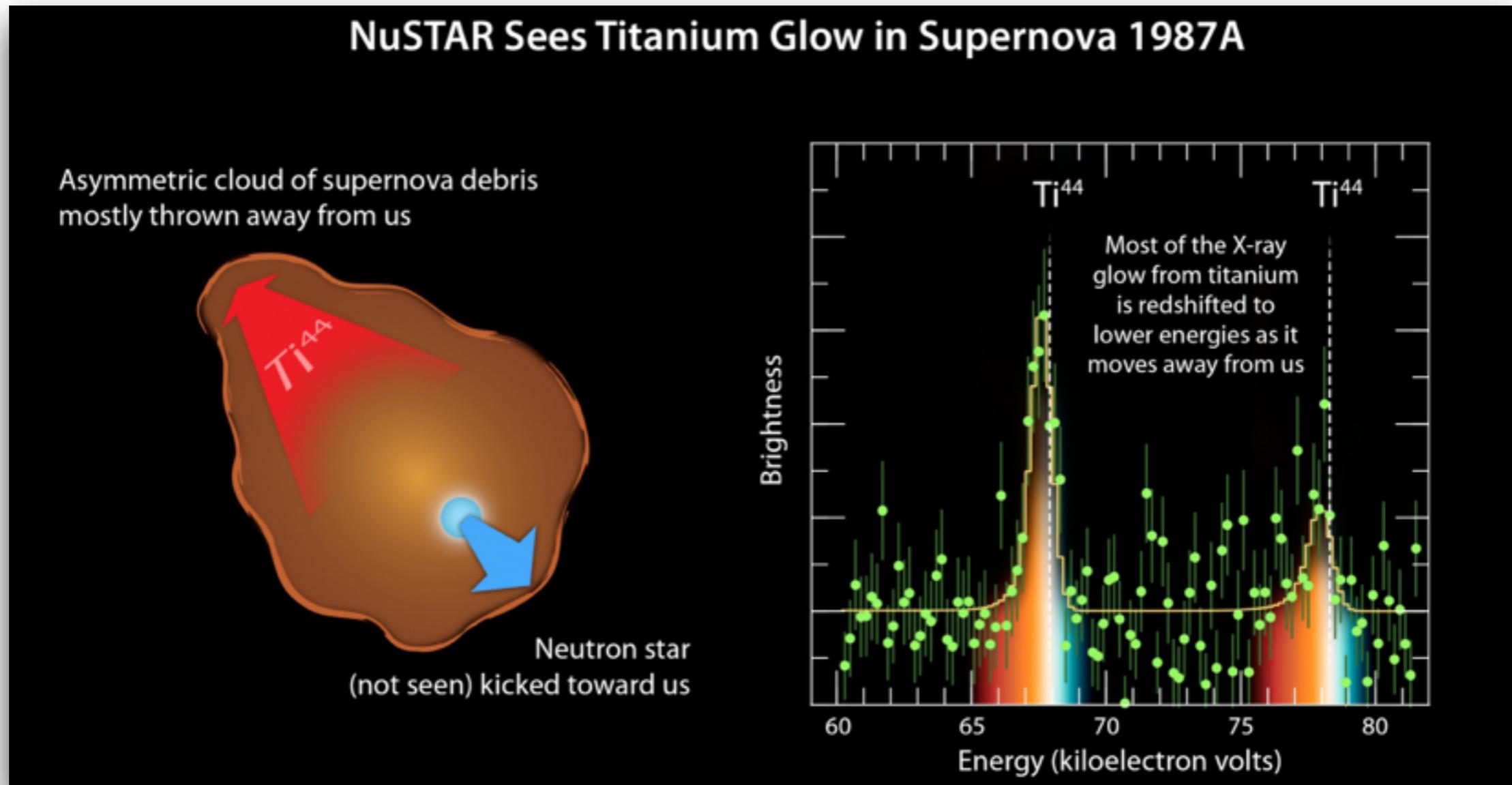
- NuSTAR has identified several (BAL) AGN (e.g., Mrk 231) which are very faint in the X-rays, even out to high energies:
 - obscuration hiding the X-ray emission?
 - intrinsically weak / quenched coronae?

Obscured AGN



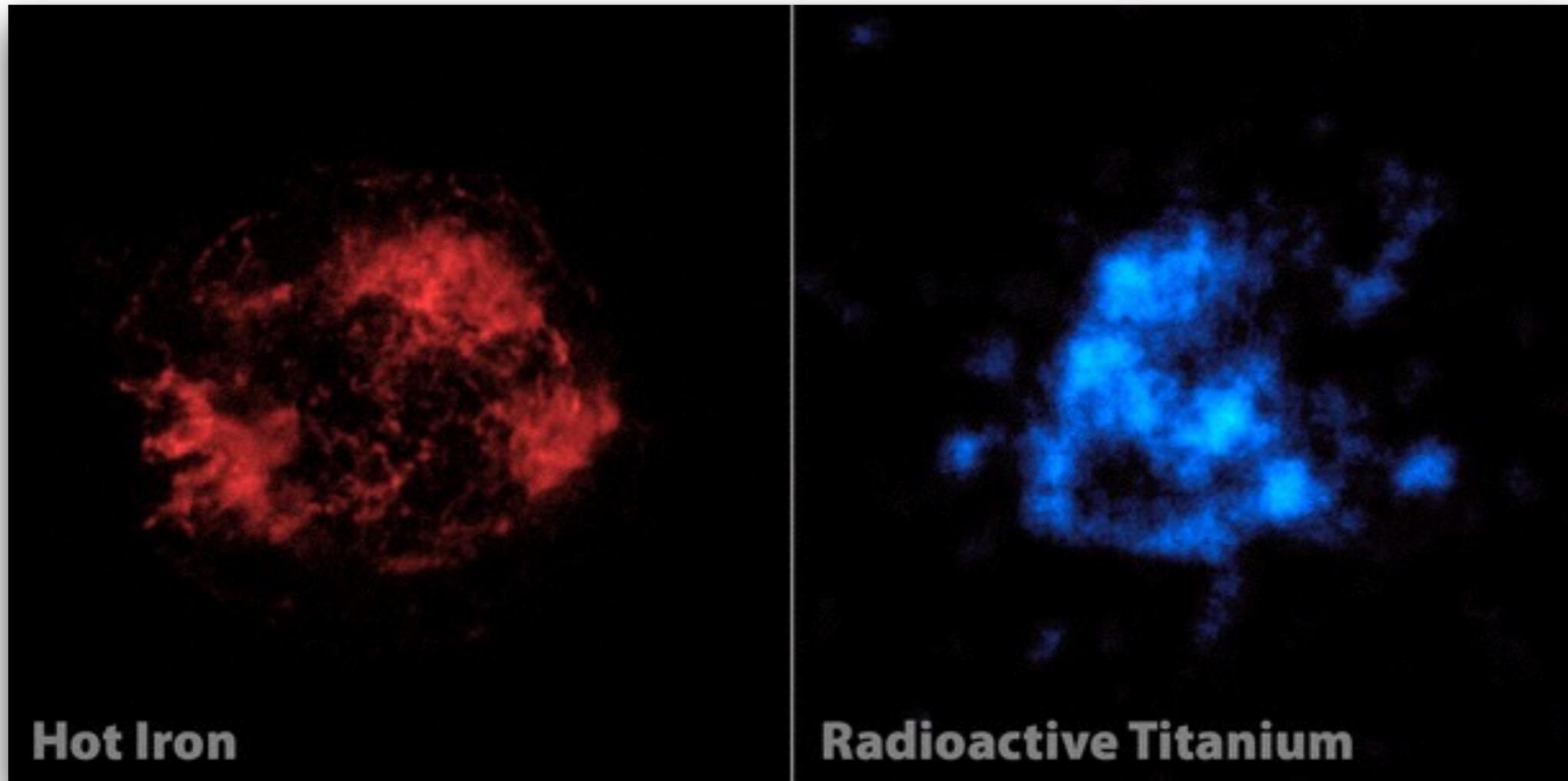
- NuSTAR has found, with scant statistics, evidence for an inverse correlation between AGN luminosity and torus covering factor

Supernova Remnants



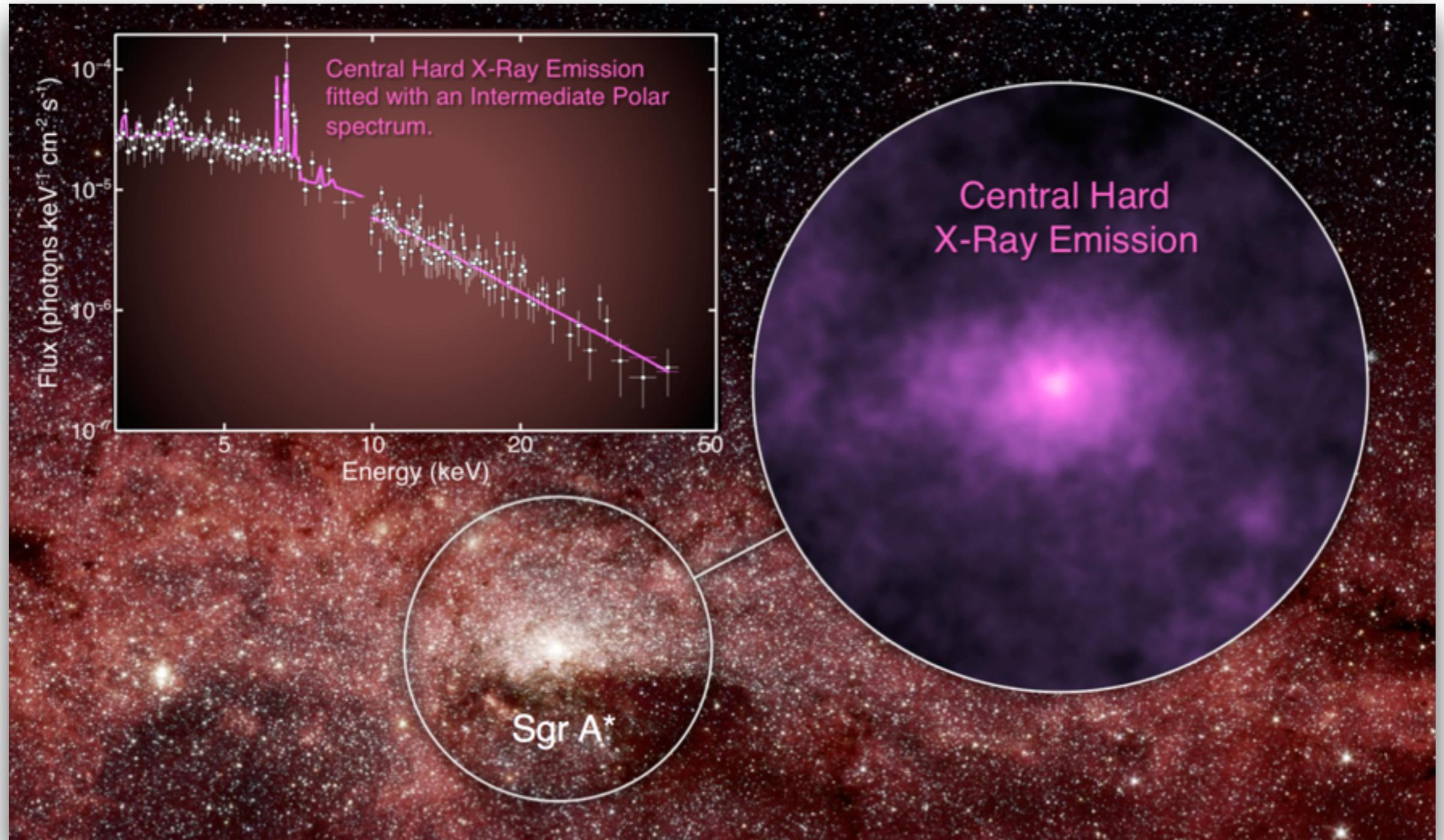
- Ti^{44} is an ideal tracer of supernova explosion, since it is a radioactive line associated with material created close to the “fallback region” in the explosion

Supernova Remnants

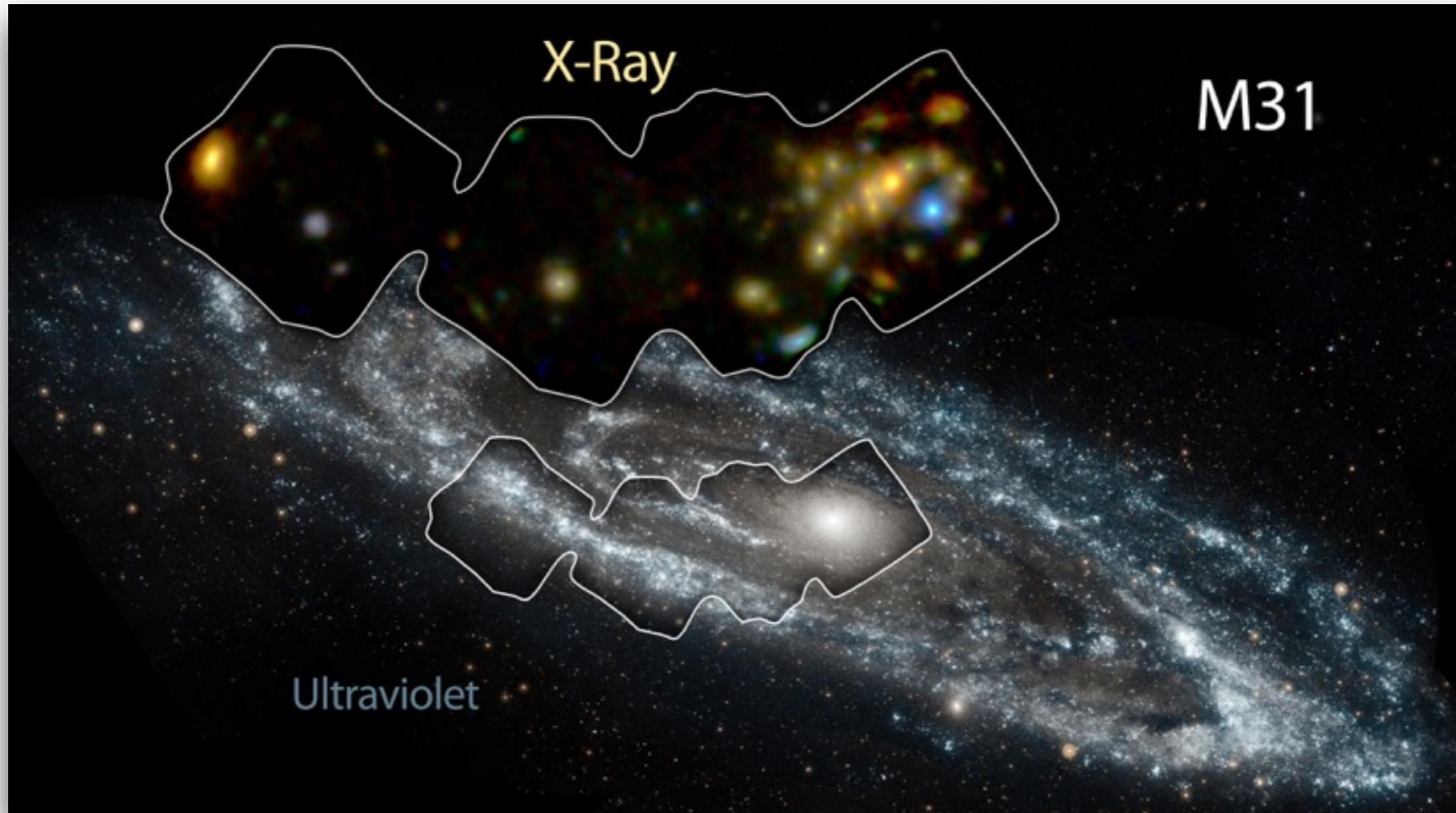


- how do stars explode?
 - clumpy distribution of radioactive titanium in Cassiopeia A indicates that the expected stall in the supernova explosion is broken by a “sloshing” instability

Diffuse Hard X-ray Emission at Galactic Center



Galactic and Nearby Galaxy Surveys

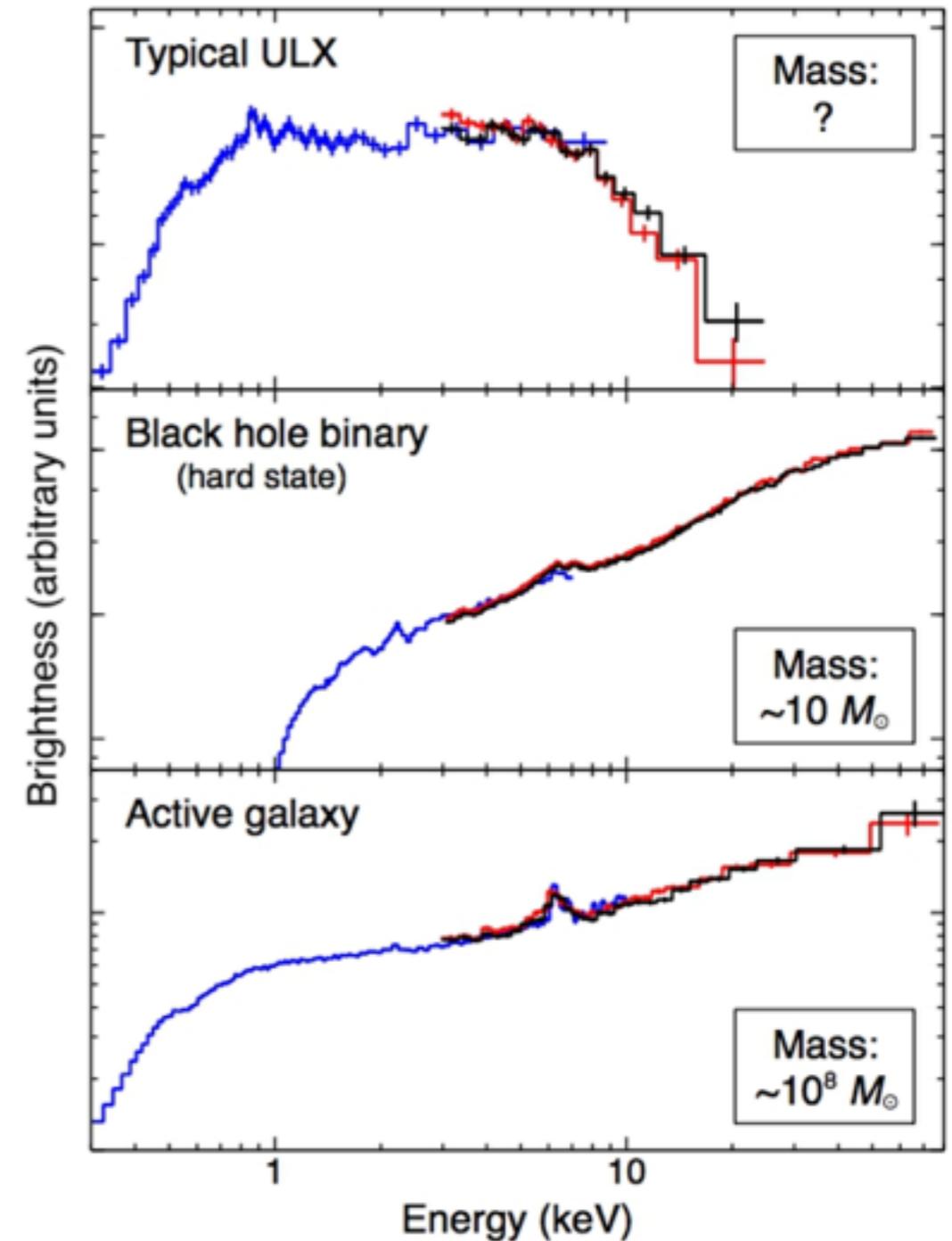


- compact remnants in the Milky Way and nearby galaxies (as a function of age, metallicity, etc...)

Ultraluminous X-Ray Sources (ULXs)



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



Ultraluminous X-Ray Sources (ULXs)

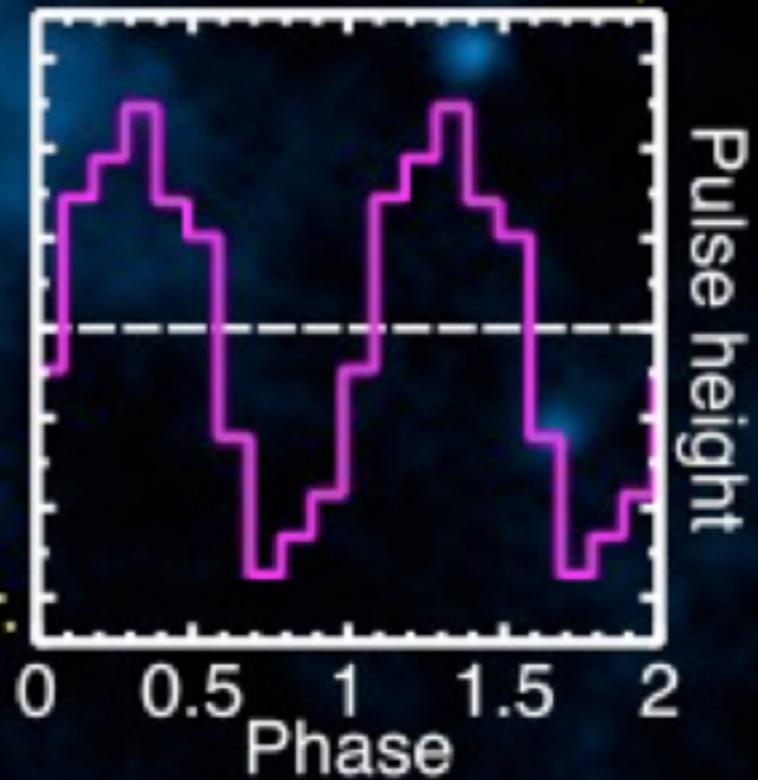
NuSTAR detects coherent pulsations from a ULX

M82 center



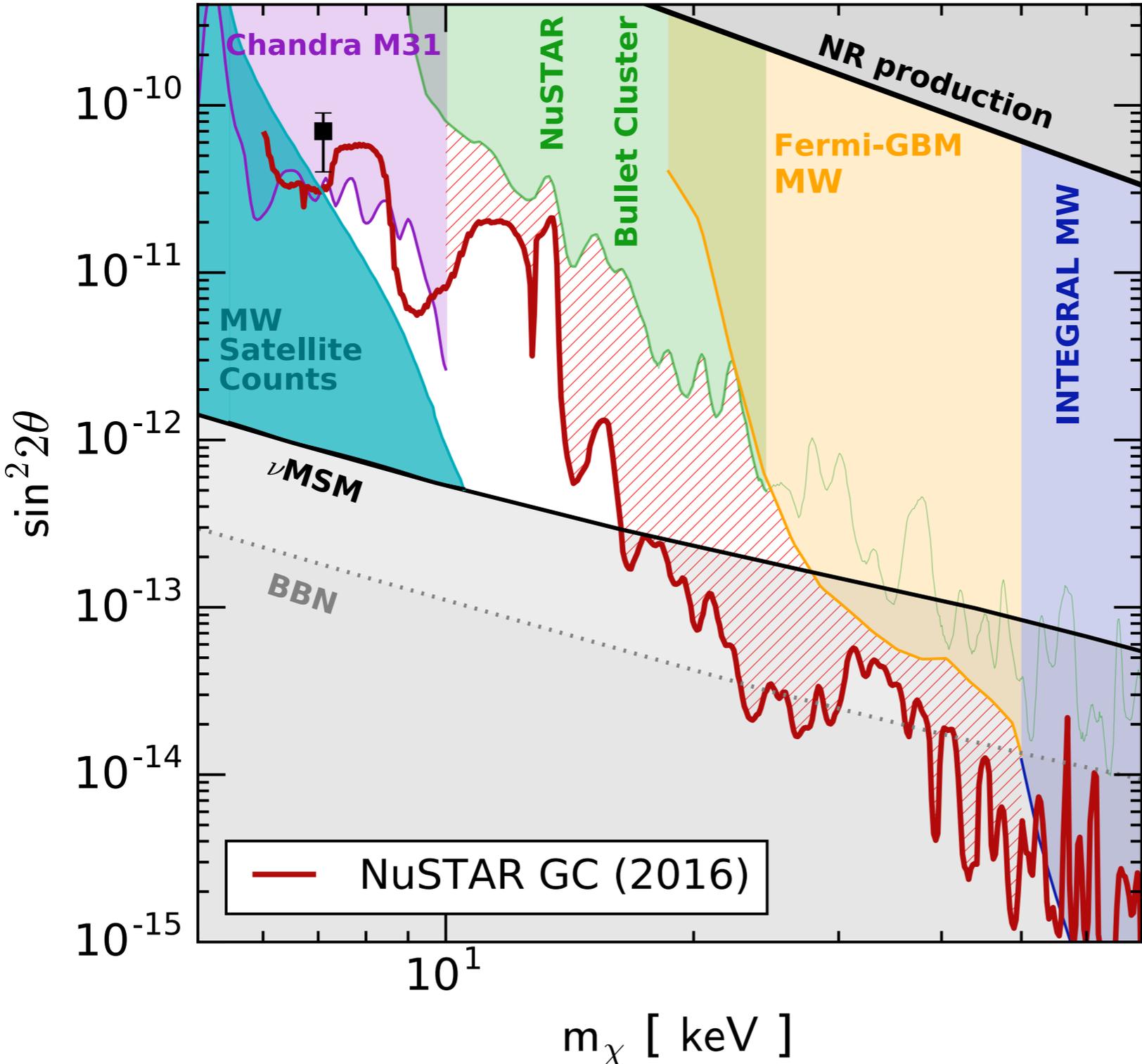
M82 X-1

M82 X-2



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

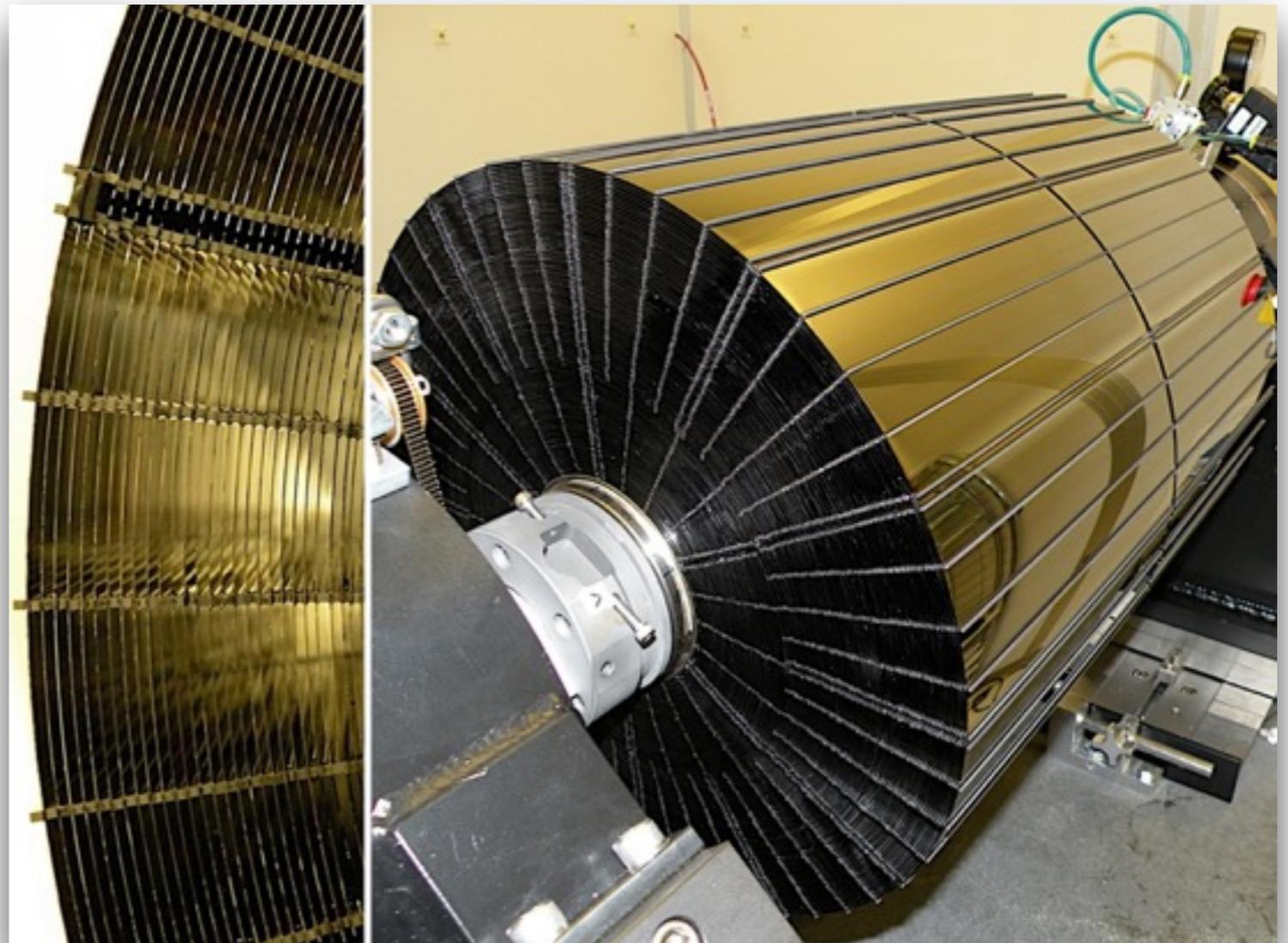


Science Summary, Selected Sample

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

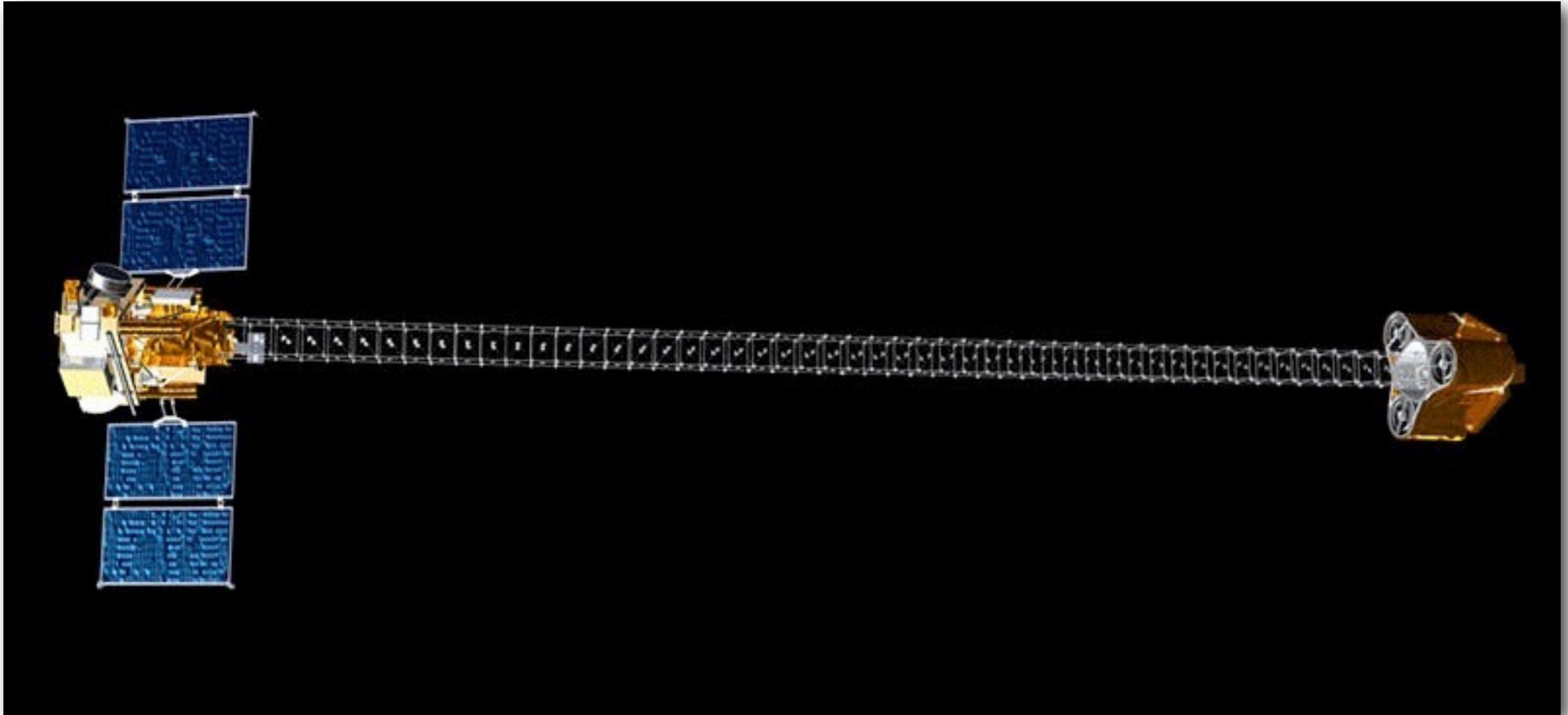
- separate high-energy telescope(s)?
- dedicate inner shells of the optics to highest energy photons?
 - hybrid detector, with lower-energy sensitive Si CCDs sitting atop higher-energy sensitive Cd(Zn)Te detectors (ala NuSTAR)?



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