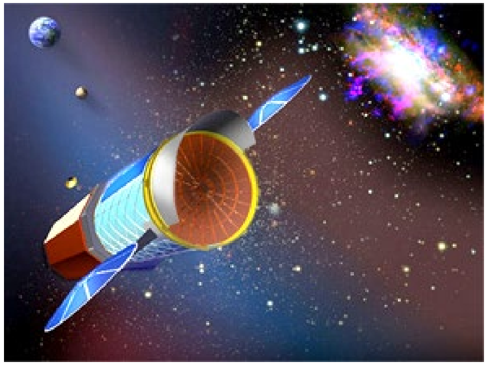
A Hard X-Ray Telescope for an X-ray Spectroscopy Mission, Extending the Bandwidth

Paul Gorenstein, Suzanne Romaine, Ricardo Bruni, CfA

Brian Ramsey, Stephan O'Dell, Marshall Space Flight Center

- Many members of the X-ray astronomy community favor high resolution spectrometers as the principal tool of the next major X-ray astronomy mission.



- Table 1 of the RFI: “Primary IXO Science Objectives” states that an instrument with 150 cm^2 effective area at 30 keV is needed to address the first two science questions it poses.

- In response we advocate for a modest hard X-ray telescope (HXT) to be included in any new high resolution X-ray spectroscopy mission such as AXSIO. The HXT would observe the variable non thermal hard X-ray components simultaneously with the emission lines of the soft X-ray components.

Multiple radiation processes occur simultaneously. For understanding them in depth the spectral energy density function should be observed over a broad energy range.

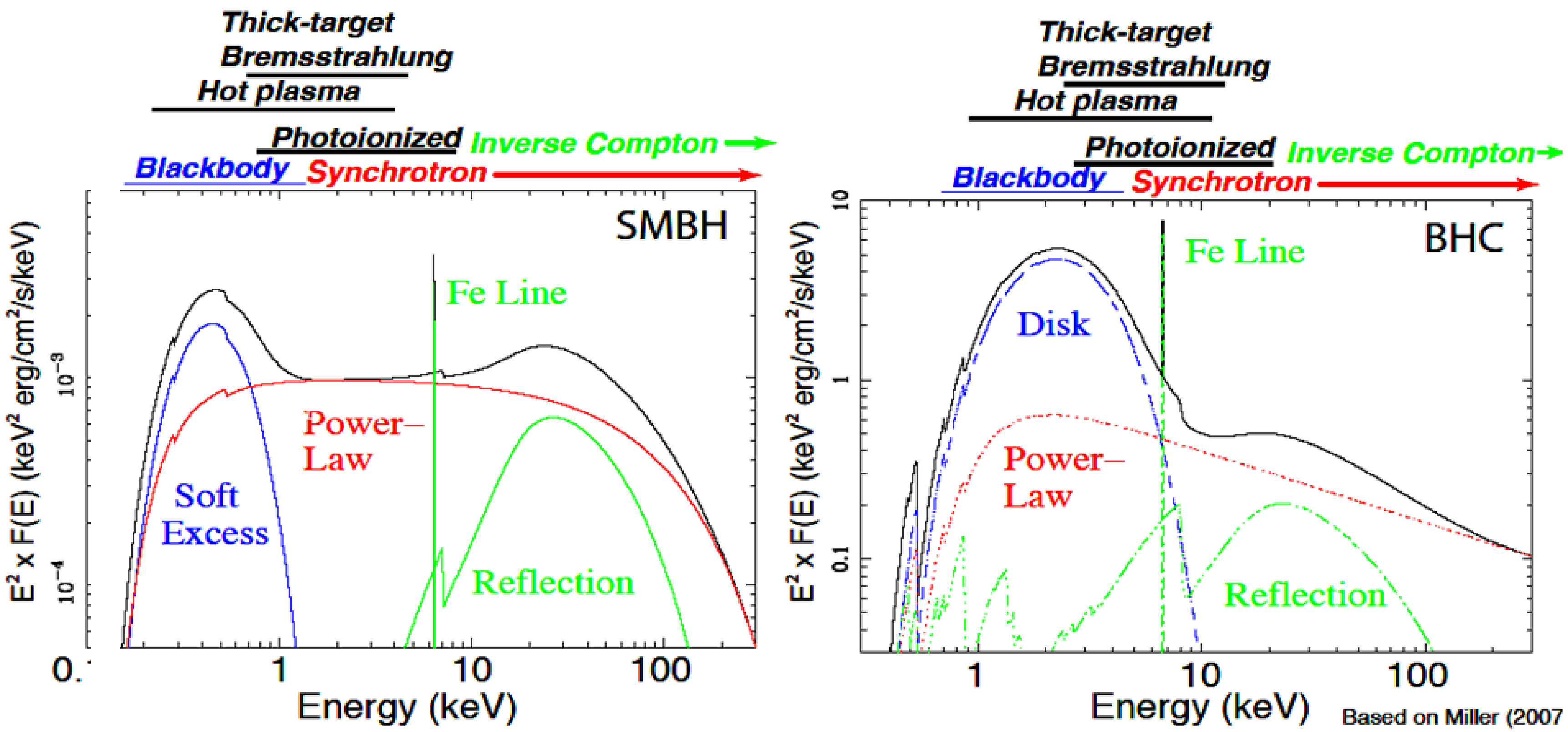
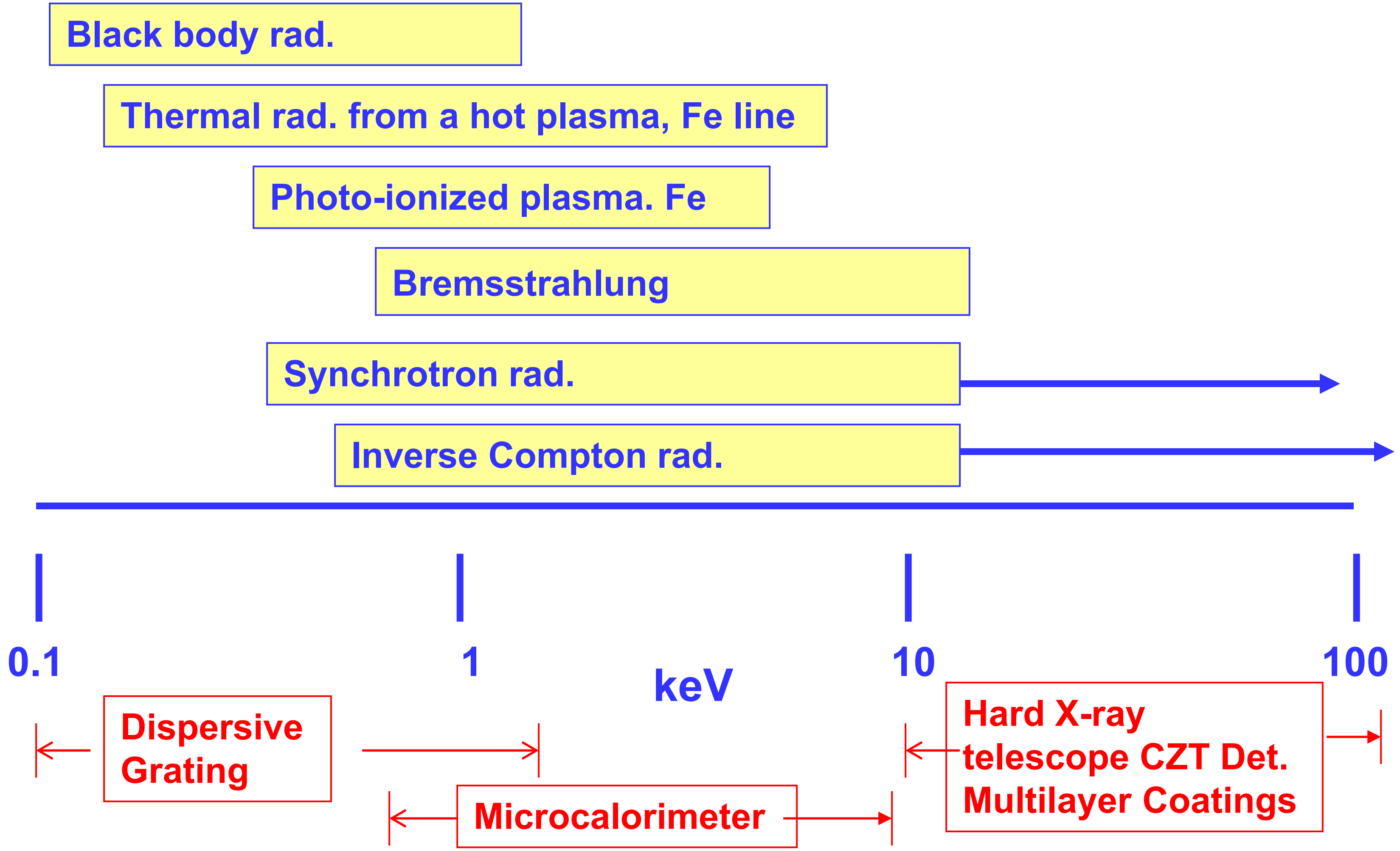


Figure by R. Smith

Multiple radiation processes occur at black holes simultaneously. All processes are variable



A comprehensive multiple objective high energy resolution X-ray spectroscopy observatory that serves the broad X-ray astronomy community just as Chandra does for X-ray imaging, should contain all of the following instruments observing simultaneously.

Dispersive grating………………………..0.1 – 2 keV

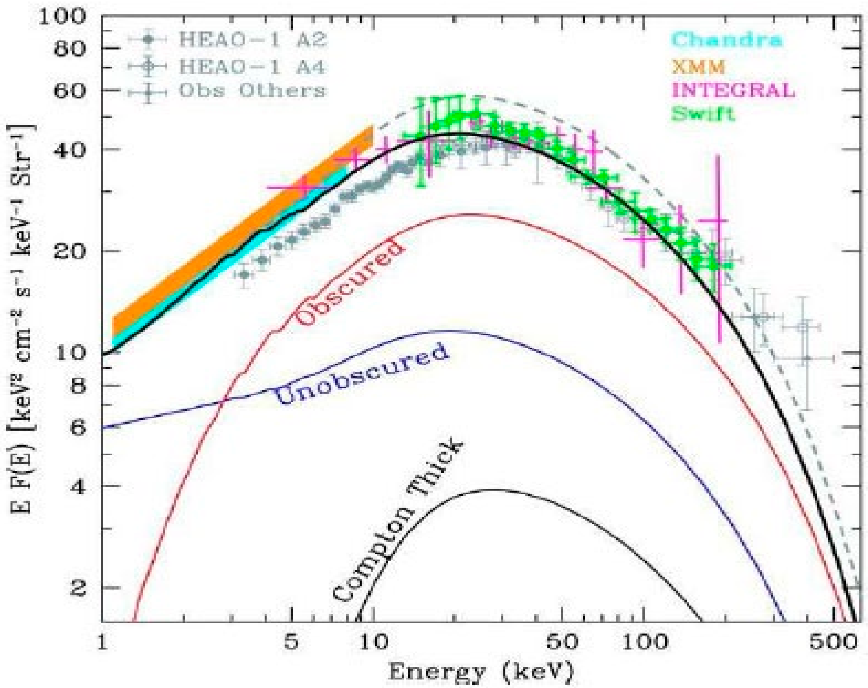
Microcalorimeter…………………………..0.8 – 10 keV

Hard X-ray telescope w. ML coatings….6 – 80+ keV

Non of these require proof of feasibility; merely some technology development.

The peak spectral energy density of the extragalactic XRB occurs in the hard X-ray band

Extragalactic XRB (Treister et al, 2009)

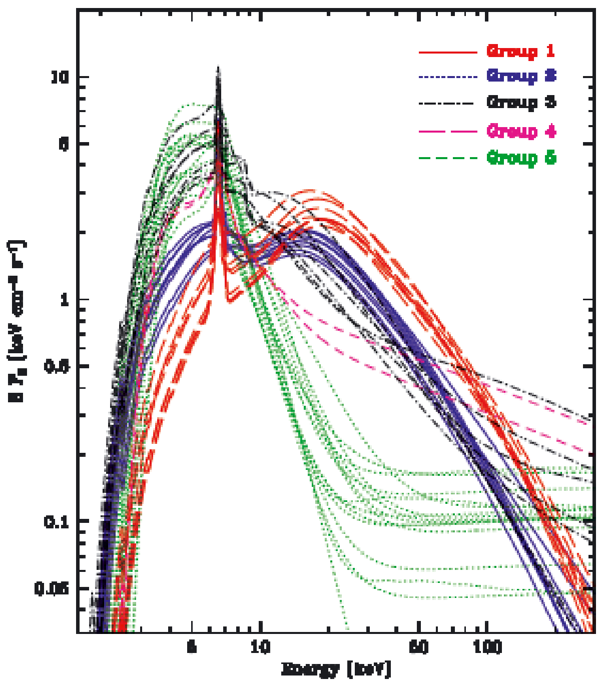


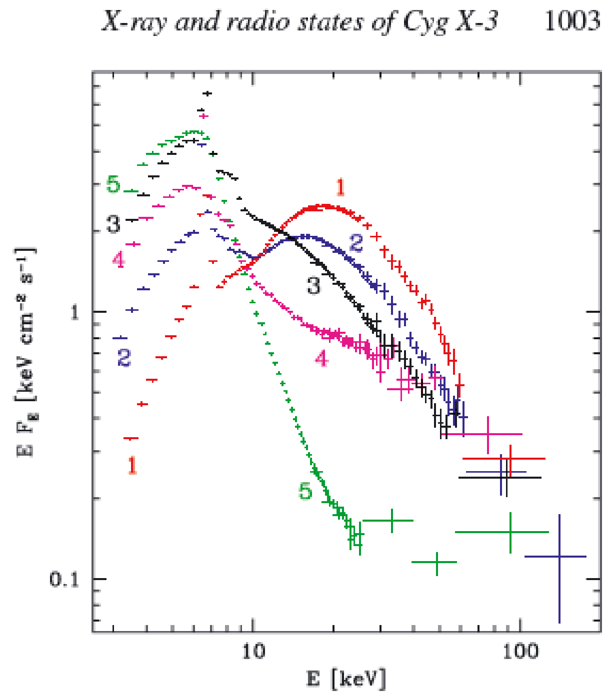
The XRB consists of unresolved SMBH's so the peak X-ray spectral energy density of a typical SMBH must be in the hard X-ray band.

i. e. SMBH's are primarily hard X-ray sources.

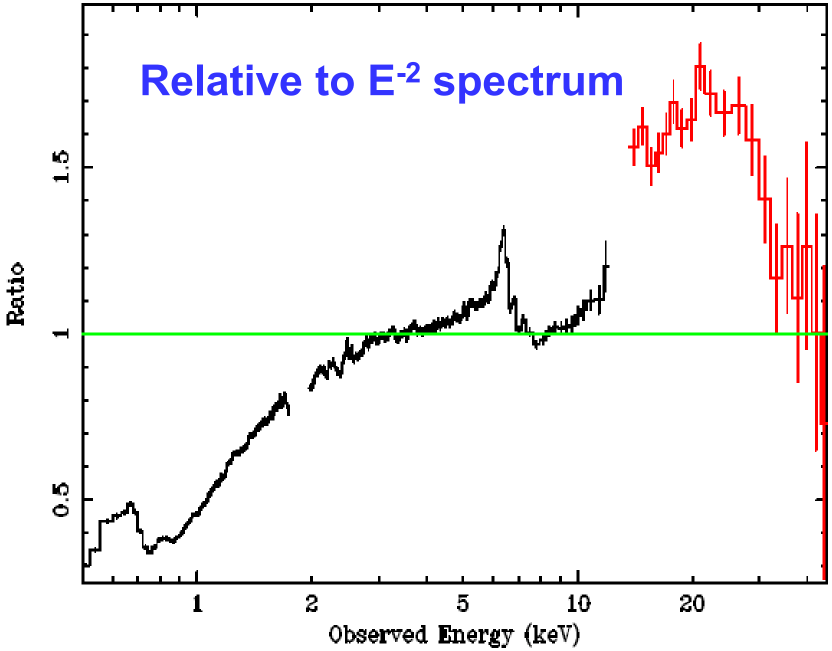
X-ray Spectral States of Cyg X-3

Szostek, Zdziarski and McCollough, 2008



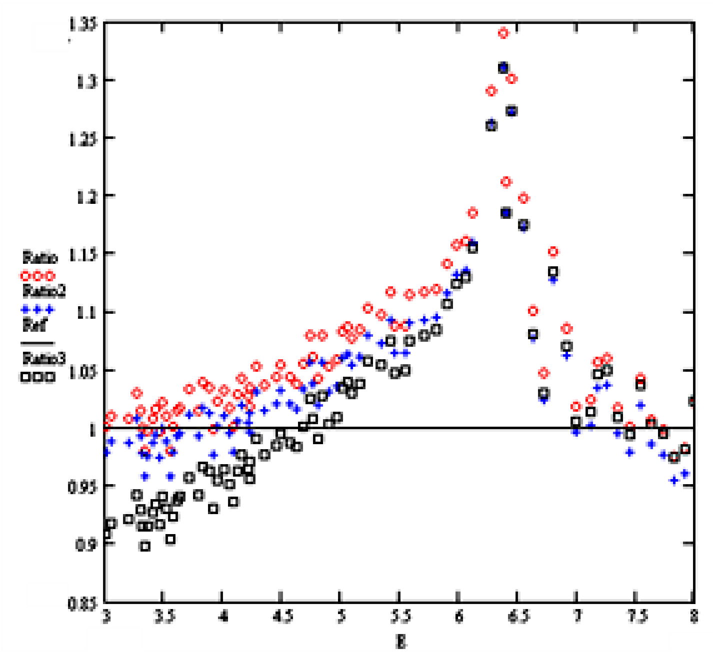


A gravitationally broadened Fe line emitted by **MCG-6-30-15** observed by Suzaku, (Minuitti et al, 2006)



Measuring the detailed shape of an Fe line broadened by a gravitational red shift is a prime objective of a high resolution X-ray spectroscopy mission. The hard X-ray component clearly has an important influence upon the continuum spectrum underlying the Fe line.

Effect of errors in continuum upon measurement of the profile of the broadened Fe line in MCG-6-30-15



- E^{-2} continuum, original
- E^{-2} continuum with 2% increase in amplitude
- $E^{-2.1}$ continuum, original amplitude

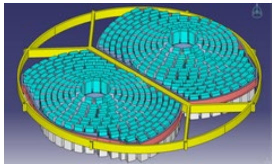
Determining the shape of the broadened Fe unambiguously is dependent on obtaining an accurate measurement of the continuum

Options for simultaneous hard X-ray observing

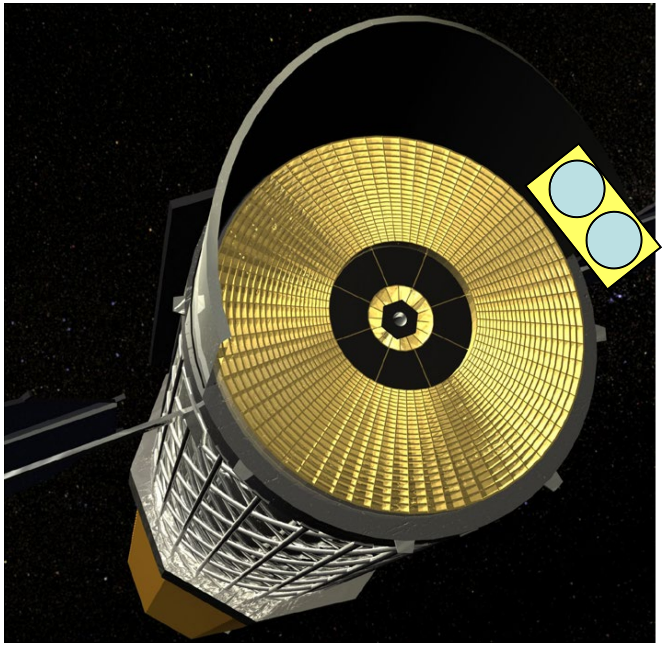
Method	Advantages	Problems
1. Extend bandwidth of of soft X-ray telescope by adding more inner mirrors with multilayer coatings	Only small increase in mass	Extending the microcalorimater bandwidth will reduce its energy resolution Adding more mirrors with ML coatings and poorer resolution will make construction of telescope more difficult and more expensive
2. Separate S/C with HXT (Harrison et al, this workshop)	No impact upon soft X-ray spectrometer Can work also with ATHENA if missions overlap	High cost of 2nd mission No guarantee of simultaneous observing.
3. Modest HXT aboard same S/C with soft X-ray spectrometers	Simultaneous observing certain Relatively low cost package Minimal impact upon soft X-ray spectrometers	Will add some mass and volume to payload or force slight reduction in size of spectroscopy telescope

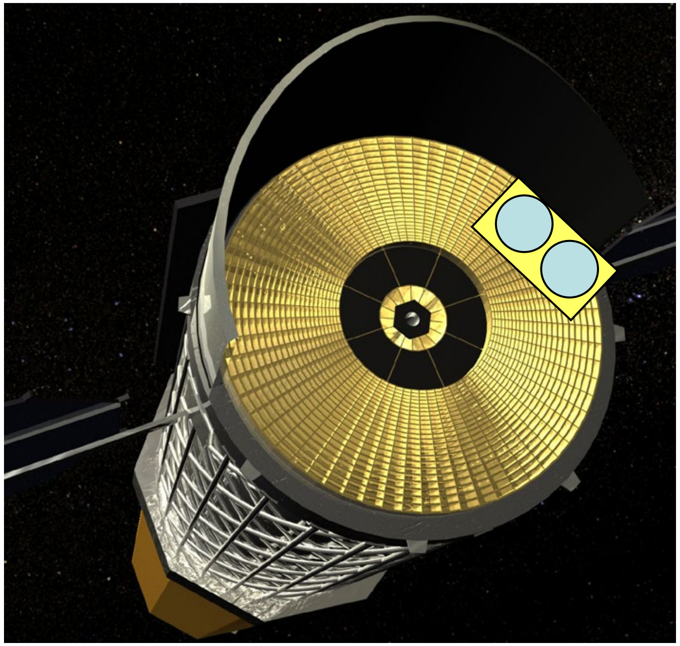
We advocate the 3rd option, a separate HXT package aboard same S/C as the dispersive grating & microcalorimeter

Modular structure of the spectroscopy telescope allows space, for the HXT to be created, if needed, within its circular envelope



ATHENA





Preferred

Workshop on X-ray Mission Architectural Concepts, Dec. 14-15, 2011

Allowed

Hard X-Ray Telescope

Approved for public release, distribution unlimited

Simultaneous X-Ray Observing

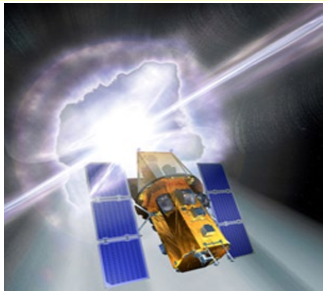
The preceding slides demonstrated:

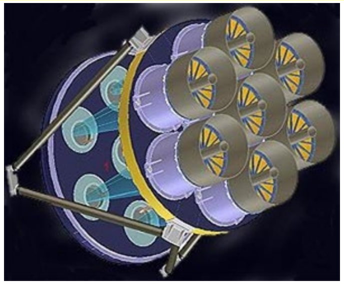
The need to measure the hard X-ray spectrum simultaneously with the soft X-ray spectrum. A dedicated focusing hard X-ray telescope (HXT) is required

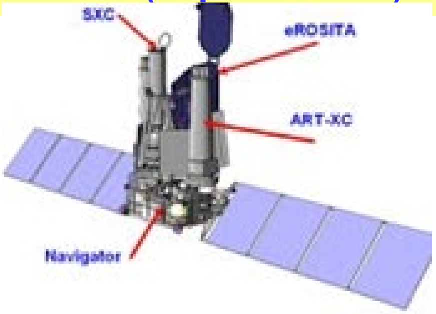
The HXT technology with the best combination of large effective area and good angular resolution for maximum sensitivity is electroforming integral mirror shells.

This is the method used and being used to fabricate the telescopes for :

XMM-Newton Swift XRT eROSITA and ART-XC (in production)







New, stronger NiC alloys allow the next generation mirror shells to be lower mass

Electroformed Hard X-ray Telescope

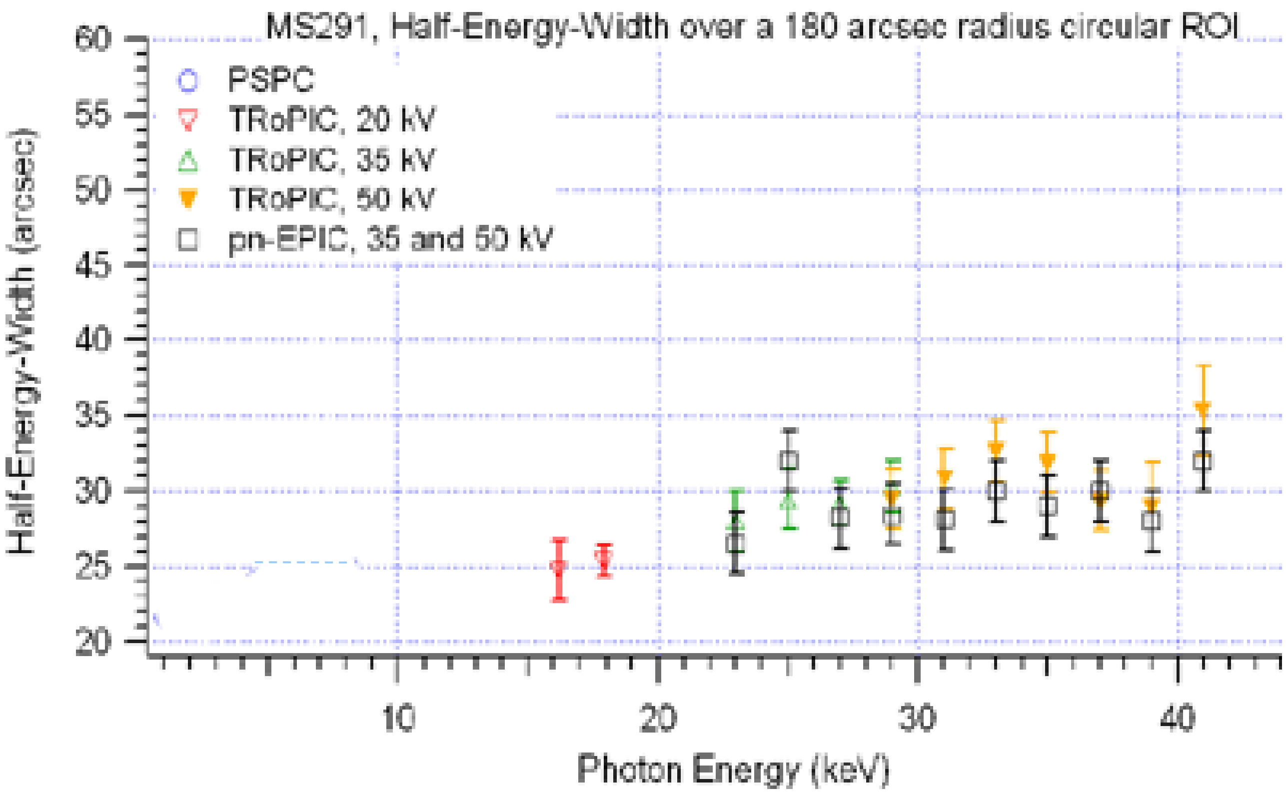
Developed with support from NASA (Con-X & APRA) and OAB (ASI)

Tested at the Panter Facility

The thickness/diameter ratio of the mirror shells is 1/3 that of XMM

130-micron-thick test mirror shells installed in structure prior to testing at the Panter facility.

Results of hard X-ray tests at Panter Facility



Prospects for improved electroformed HXTs in an advanced X-ray spectroscopy mission

- We identified factors in the design of the structure and the procedure for integrating the mirror shells into the structure that limited the angular resolution of the optic tested.

- We can expect 15 arc second or better resolution with a much larger ratio of area to mass than XMM-Newton

Estimated Cost for Constructing 2 Hard X-Ray Telescopes and Detectors (FY 2011 Dollars)

Item	Cost ($)
Mandrels	6,250,000
Shells + coatings	2,750,000
Housings	140,000
Assembly	65,000
Testing	55,000
Detectors + electronics	9,000,000
Calibration	100,000
Integration	220,000
Contingency (30%)	5,570,000
Total	**24,150,000**

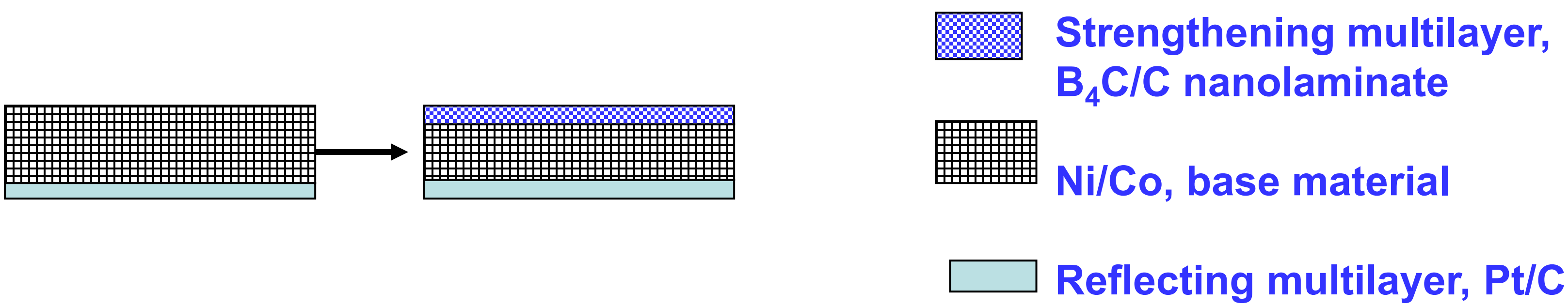
Technology Development Support needed for:

- **Electroformed Telescope (TRL 6, space experience: XMM, Swift BAT)**

• Improve the angular resolution. Sensitivity ~ $\frac{1}{\text{HPD}}$

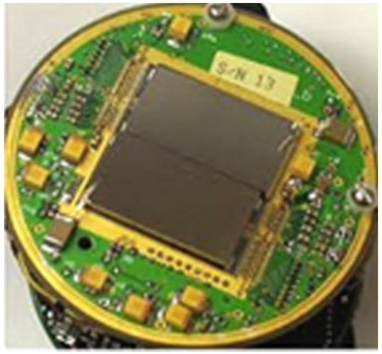
- 25 arc sec HPD demonstrated so far, goal is 15 arc sec
- Redesign integrating structure
- Improve procedure for integrating and mounting the cylindrical mirror shells

• Reduce mass of mirror shells: Ni/Co thickness below 100 microns by replacing part of Ni/Co with lower density B_4C/C nanolaminate.



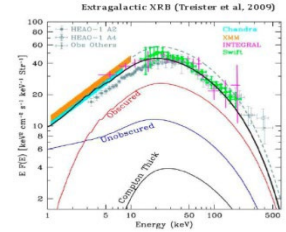
Modest Technology Development Support needed for:

- **Detector CZT (TRL 7, Swift BAT, NuSTAR)**

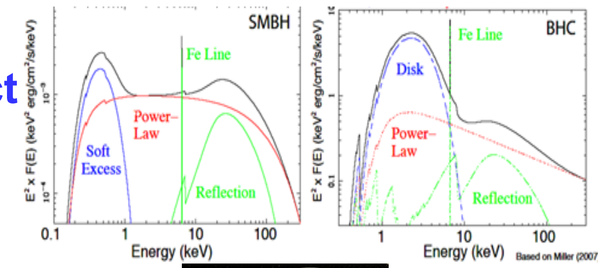


- **Improve spatial resolution to 100 microns (2” for 10m F.L.) to take advantage of good angular resolution of telescope**

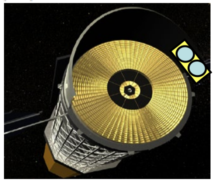
Summary



- The maximum spectral energy density of SMBHs occurs in the hard X-ray band.

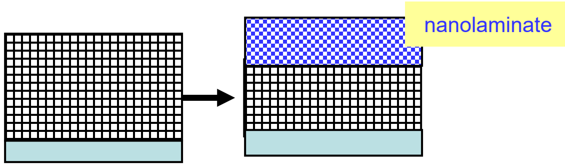


- **Simultaneous observing of soft and hard X-ray bands is required to understand the behavior of AGNs, compact binaries, CV's etc.**

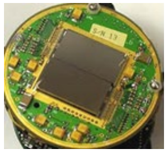


- Including a modest HXT in the same payload with high resolution spectrometers is the least expensive and most effective method of simultaneous broad band observing.

- Lower mass electroformed telescopes have achieved a resolution of 25 arcsec HPD. Planned Improvements in the design of the structure and method of assembly should allow 15 arc sec resolution.

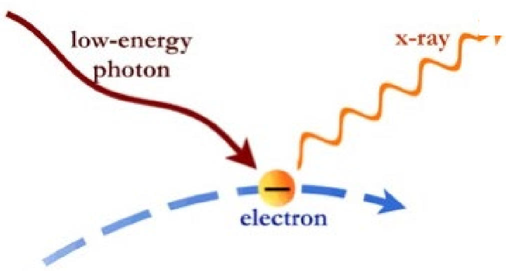


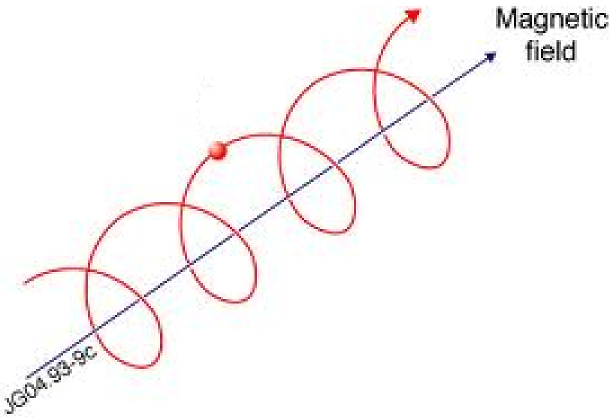
- Reinforcing Ni/Co electroformed substrates with nanolaminate materials should add strength and permit further mass reduction.

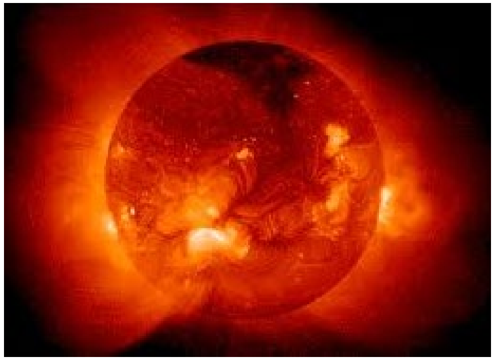


- The spatial resolution of CZT detectors should be improved to 100 microns or better to take advantage of the improved telescope resolution.

Most sources of X-ray emission are fueled initially by energetic particles that emit hard X-rays



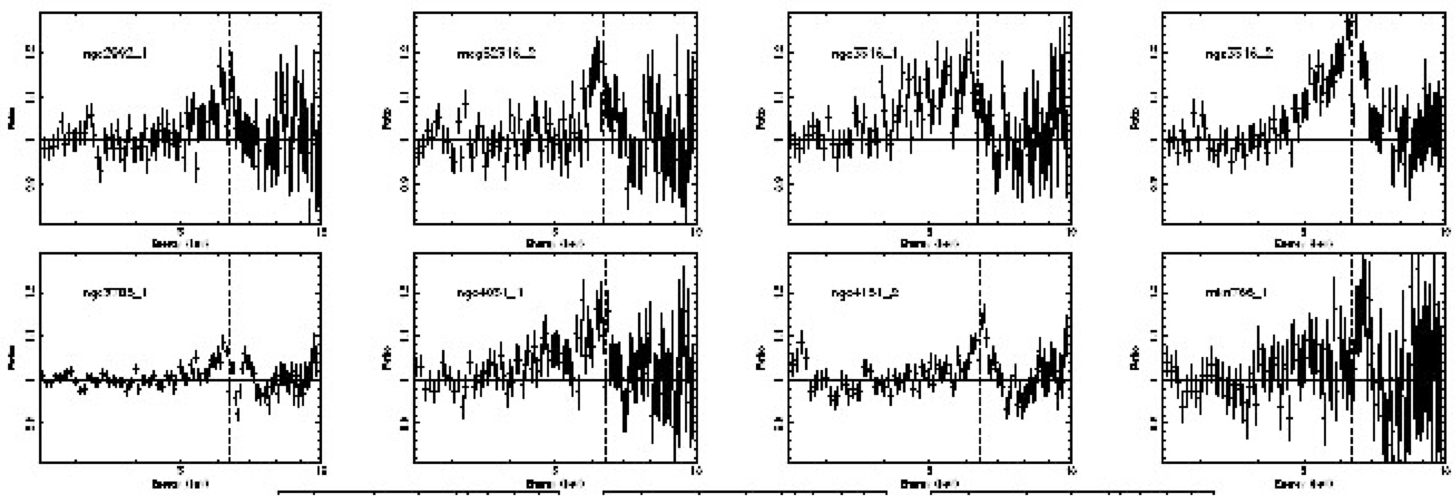




Inverse Compton   synchrotron & cyclotron rad. Fast electrons ⟶ Sync. radiation bremsstrahlung

i.e. Non-thermal hard X-Rays are more closely connected to the power source than the soft thermal X-rays

Fainter SMBH sources



Spectra of eight Seyfert galaxies relative to a power law reference as observed by XMM-Newton (Nandra et al, 2006).