Suzaku Science Highlights & Consequences of Mission Termination

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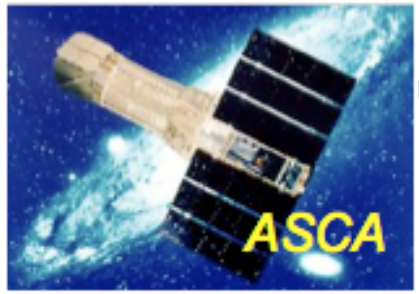
SUZAKU

- Current joint Japan/US X-ray observatory; launched July 10, 2005
- US contributed X-ray Spectrometer and 5 XRT's; participated in XIS (CCD) and data center
- Data division - 37% US, 50% Japan, 13% joint; all data available from archive after 1 year
- Spacecraft performance nominal; components aging as expected
  - Critical components are orbit, gyro, and batteries

Long and successful US-Japan collaboration



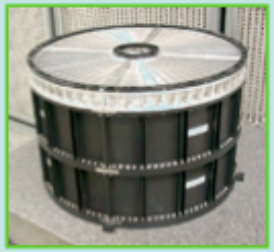
Launch Feb. 1993
Re-entry Mar. 2001

Launch July 2005
Exp. Orbital life >2015

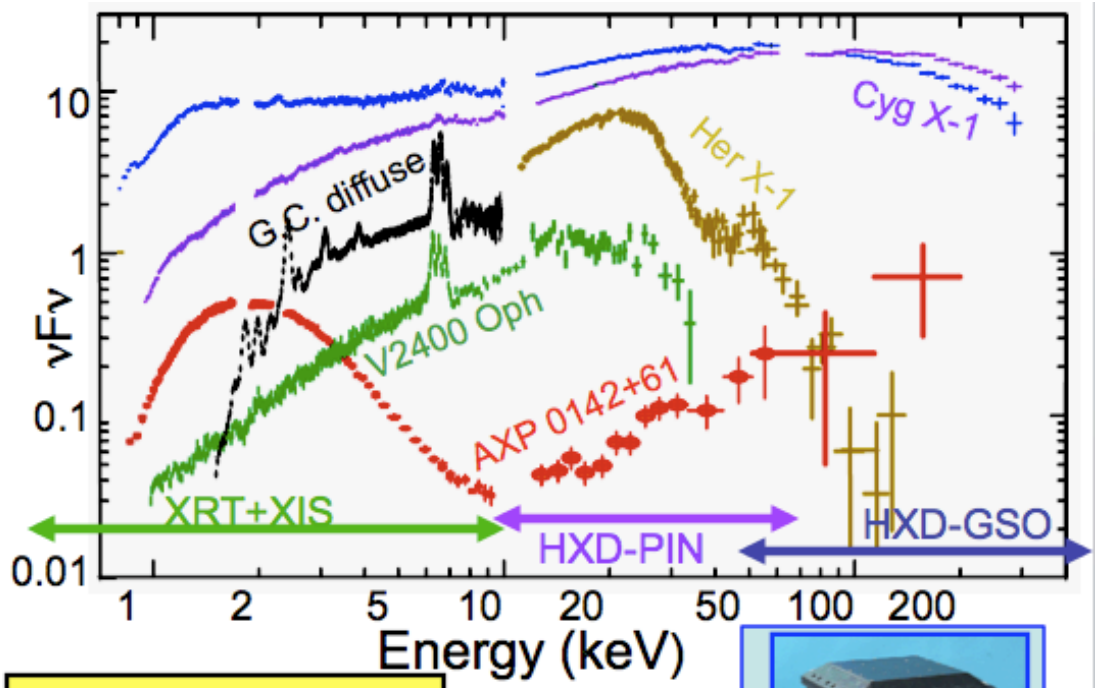
Japan-US collaboration

SUZAKU INSTRUMENTATION

XRT (X-ray Telescope)



XIS (X-ray Imaging Spectrometer)



Nearly seamless and simultaneous coverage over ~3 decades

HXD (Hard X-ray Detector)

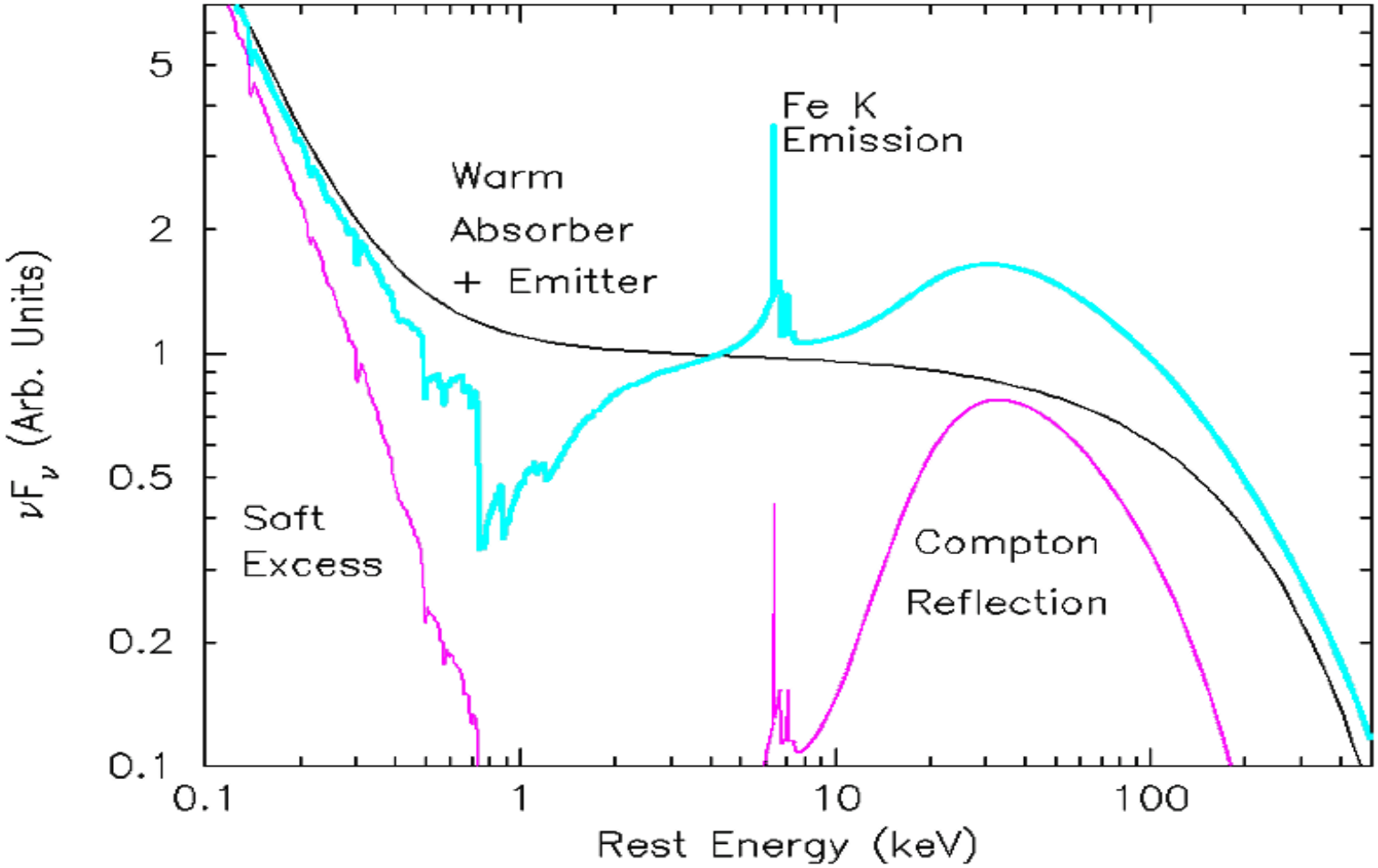
UNIQUE SCIENCE ENABLED BY SUZAKU

Attribute	Unique Science Enabled
Simultaneous broad band energy coverage (0.2-600 keV)	Simultaneous measurement of disk emission, warm absorber composition and velocity, reflection bump and broad Fe lines in X-ray binaries and supermassive black holes
Highest CCD spectral resolution in 0.2-1.0 keV band	Measurement of C, N, O abundances in ISM and SNRs Determination of properties of geocoronal and heliospheric soft X-ray charge exchange emission
Highest spectral resolution and sensitivity in 6-10 keV band	Detection and separation of Fe band feature in cataclysmic variables, X-ray binaries, AGN and the Galactic Plane and Ridge Modeling of relativistic effects in broad Fe lines in neutron star binaries and stellar and supermassive black holes
Lowest background in the 0.2-10 keV band	Measurement of cluster temperatures and abundances to the virial radius Mapping of low surface brightness sources (e.g., extended HESS Galactic sources)
Highest sensitivity in the 10-50 keV band	Spectroscopy of **all** AGN detected by Swift – determination of the contribution of absorbed AGN to the cosmic X-ray background Measurement of the magnetic field strength in XRBs and AXPs through detection of cyclotron features Search for nonthermal emission from clusters and SNRs

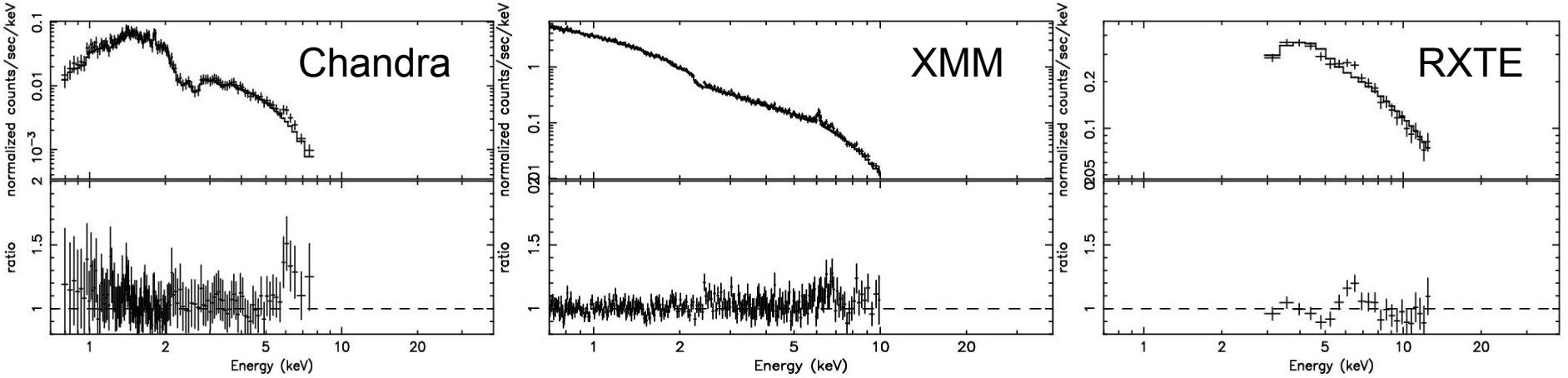
SUZAKU ADDRESSES MAJOR THEMATIC QUESTIONS

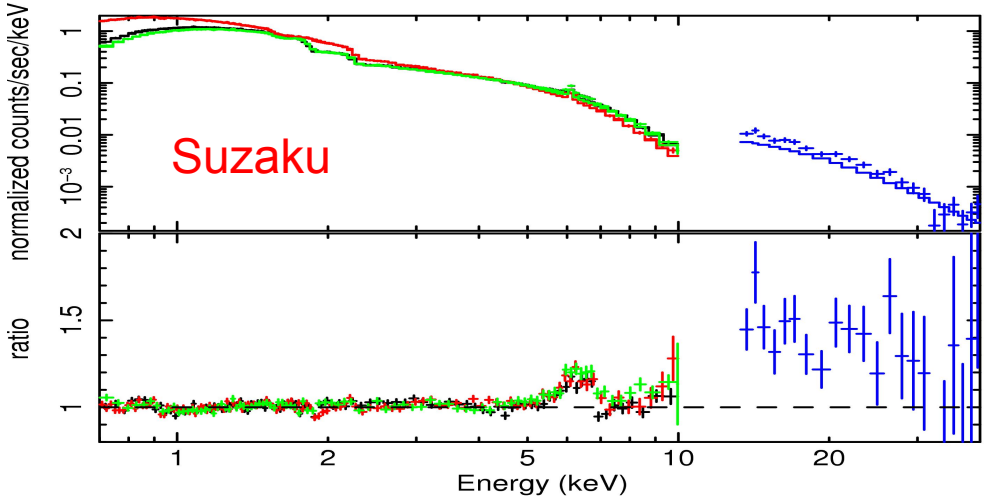
- What is the nature of space and time near black holes?
- What is the nature of dark energy?
- How do cosmic accelerators work?
- What are the cycles of matter in the Universe?

Relativistic Fe line studies require broad band, moderate resolution spectroscopy



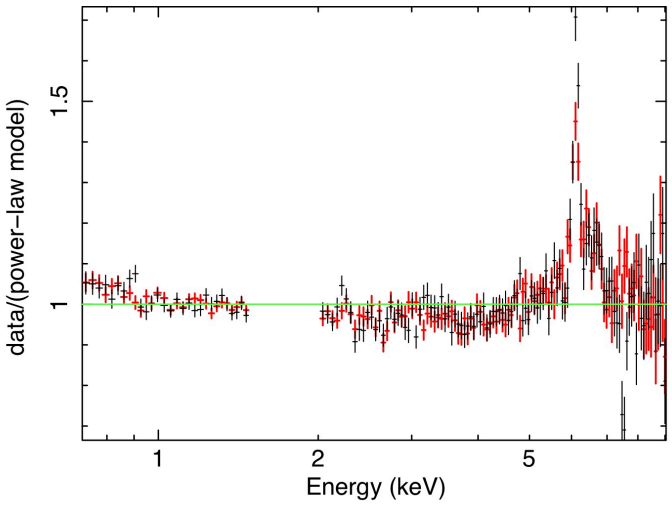
SUZAKU IS THE *BEST* OBSERVATORY FOR SPECTROSCOPY OF MODERATELY BRIGHT AND FAINT ACCRETING SOURCES





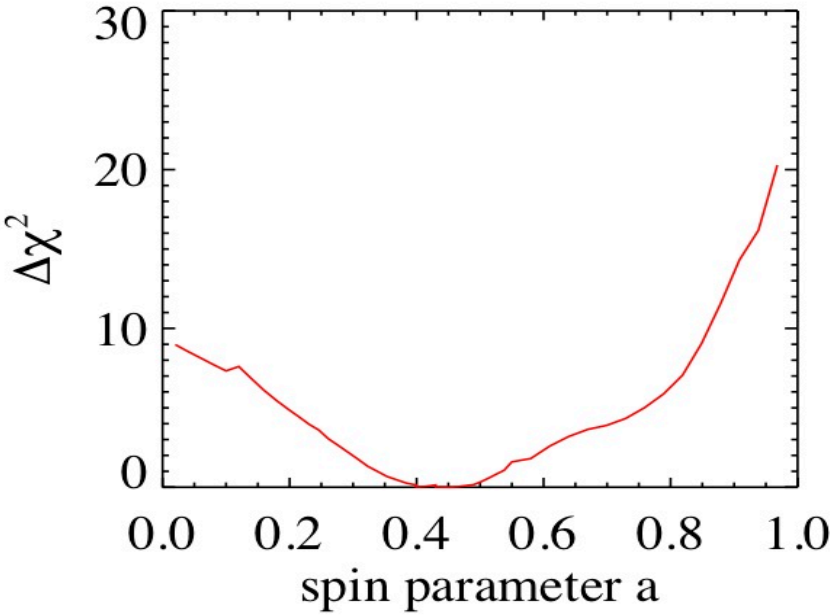
Fairall 9

Deep Observation of Powerful Seyfert/QSO FAIRALL 9 (C. REYNOLDS KEY PROJECT)



XIS data ratioed against simple power-law. Very "clean" object - no evidence for any intrinsic absorption. Broad iron line is weak but clearly seen to low-energy side of strong narrow iron line.

Joint analysis of deep Suzaku plus XMM data find intermediate spin (a=0.26-0.62). This constraint includes uncertainties due to presence of narrow Fe25/Fe26 lines, and presence of the soft excess

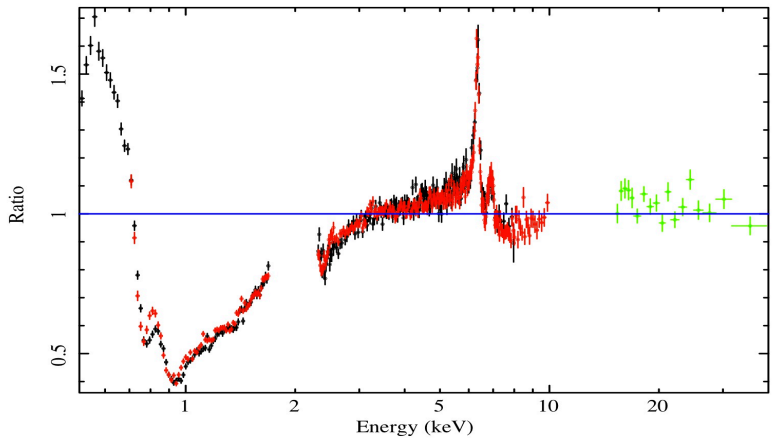


Papers resulting from these data:

"Systematic errors on black hole spin : A case study of Fairall 9", A.Lohfink, C.S.Reynolds et al., 2011, in prep.

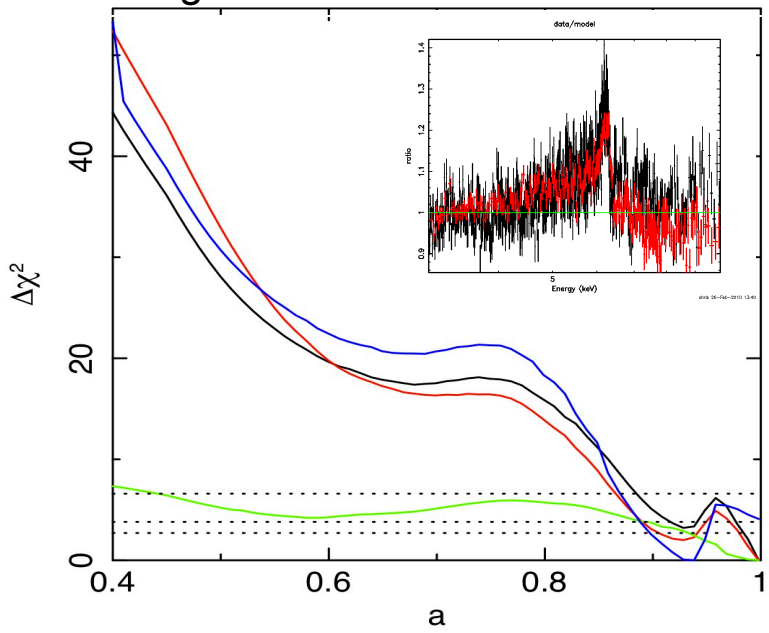
"Assessing black hole spin in deep Suzaku observations of Seyfert 1 AGN", A.Patrick et al., MNRAS, in press (indep. team)

SEYFERT 1.5 NUCLEUS IN NGC 3783



Suzaku XIS+PIN spectrum ratioed against simple power-law. A global model of this spectrum requires multi-zone ionized absorption, reflection from distant matter, and reflection from inner accretion disk

Require high spin (a>0.90 at 90% CL). This includes all uncertainties associated with ionized absorption, irradiation profile of inner disk, iron abundance, and treatment of PIN background.



Papers resulting from these data:

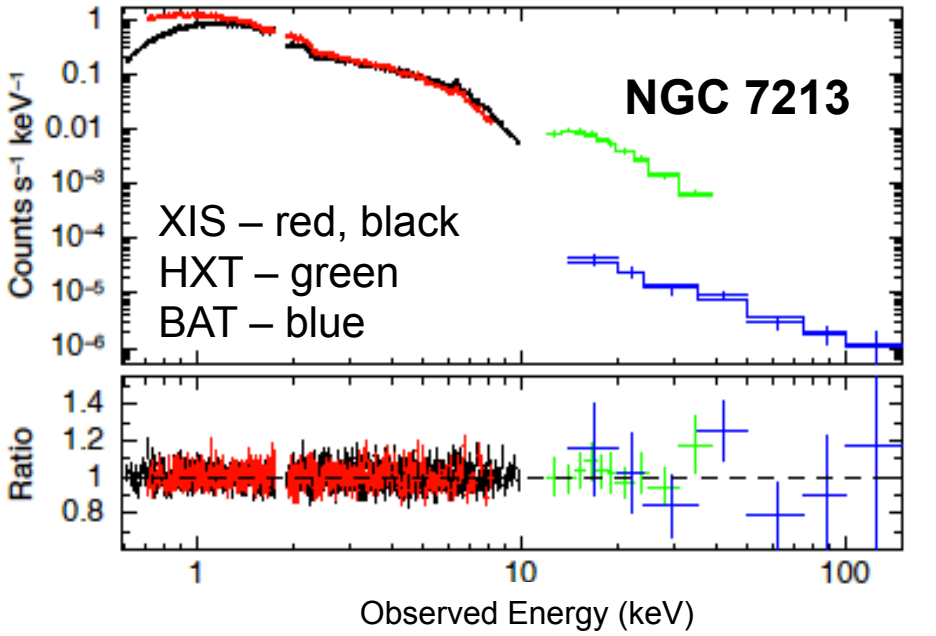
"The Spin of the Black Hole in NGC3783", L.W.Brenneman, C.S.Reynolds et al., 2011, ApJ, in press

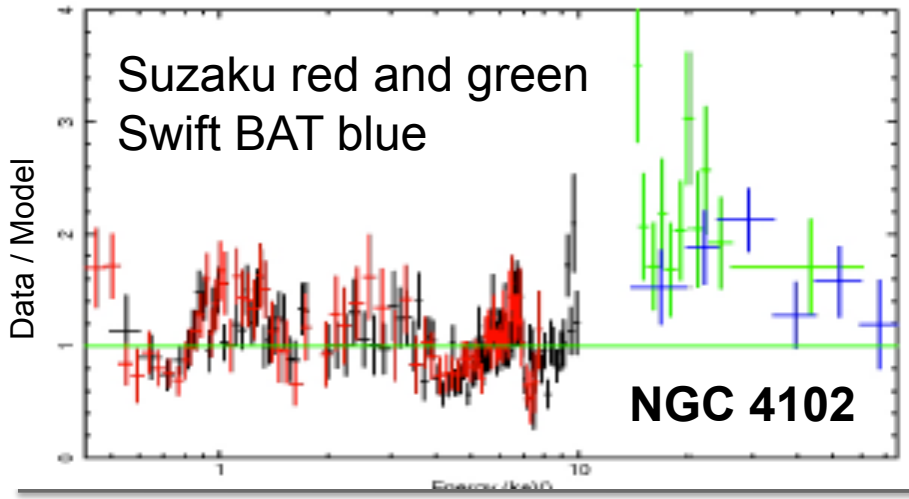
"X-ray Spectral Variability in NGC3783", R.Reis, A.C.Fabian, C.S.Reynolds et al., MNRAS, submitted

"Assessing black hole spin in deep Suzaku observations of Seyfert 1 AGN", A.Patrick et al., MNRAS, in press (indep. team)

"Broad Emission Lines from a Negatively Spinning Black Hole", T.Dauser, et al., 2010, MNRAS, 409, 1534 (theory)

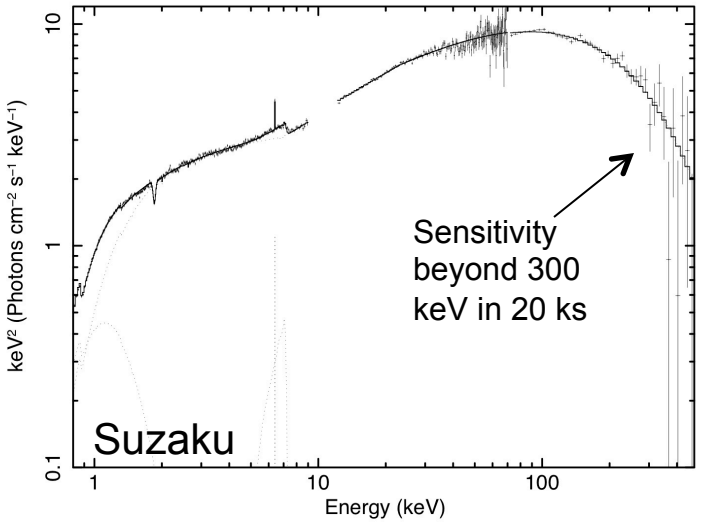
SUZAKU FOLLOWUPS OF BAT AGN

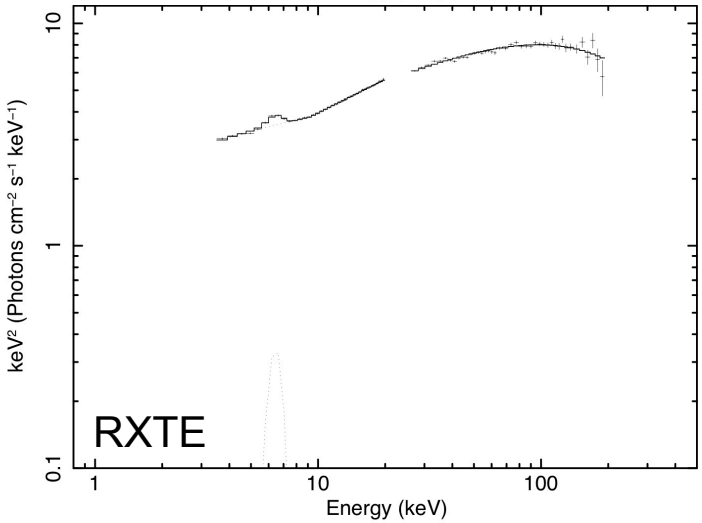


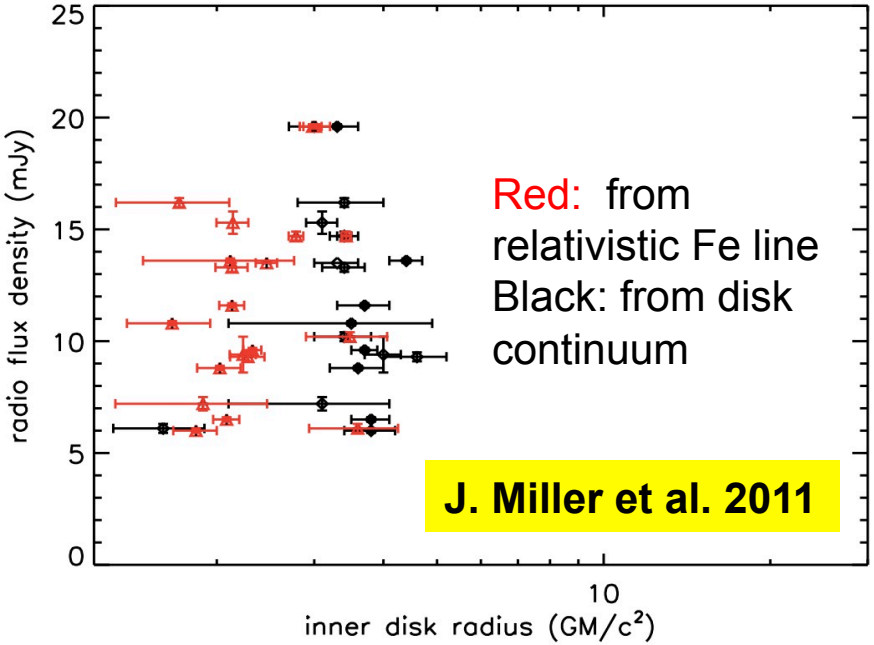


- Swift BAT has provided a large 'unbiased' sample of AGN in the 15-200 keV band
- Combination of Swift +Suzaku allows the continuum to be properly modeled
  - Suzaku + BAT combination crucial for Compton thick objects
  - BAT provides the “reference” flux
- Suzaku follow-ups have:
  - shown the existence of 'new' class of AGN (Ueda et al. 2008)
  - allowed detailed physical modeling of the torus (Eguchi et al. 2010, 2011)
  - strong upper limit on reflection indicates existence of radiatively inefficient accretion flow (Lobban et al. 2011)
  - detailed studies of Compton thick objects
  - 75 objects observed out of ~700 accessible

BROAD BAND STUDIES OF GALACTIC BLACK HOLES – CYG X-1

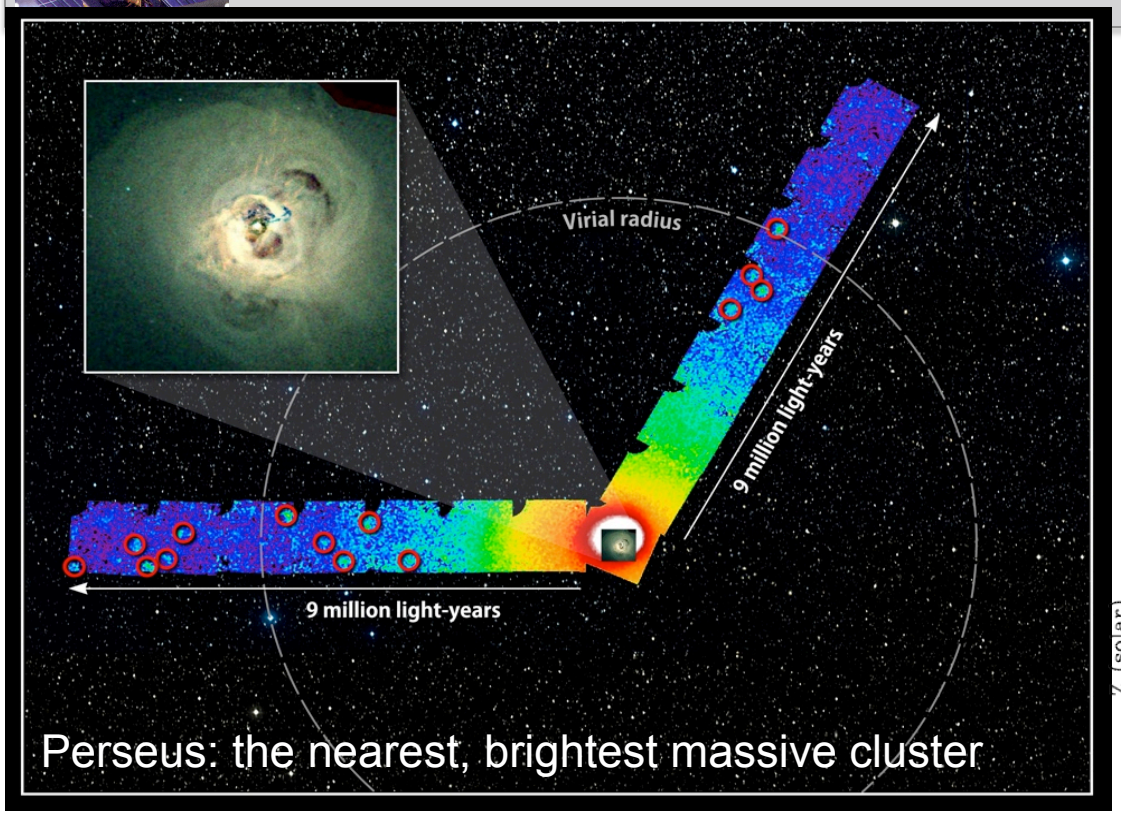




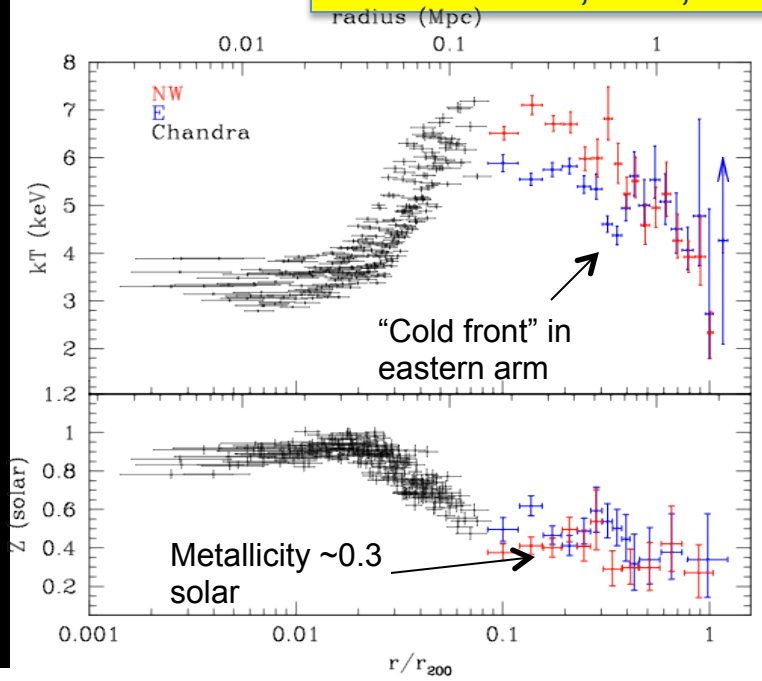


- Series of 20 ks Suzaku exposures simultaneous with radio
- Two measures of inner disk radius differ by only $1GM/c^2$ – systematics under study
- Both show radio flux is *independent* of disk radius
- Major insight into disk/jet connection – defies conventional wisdom

THE OUTSKIRTS OF GALAXY CLUSTERS

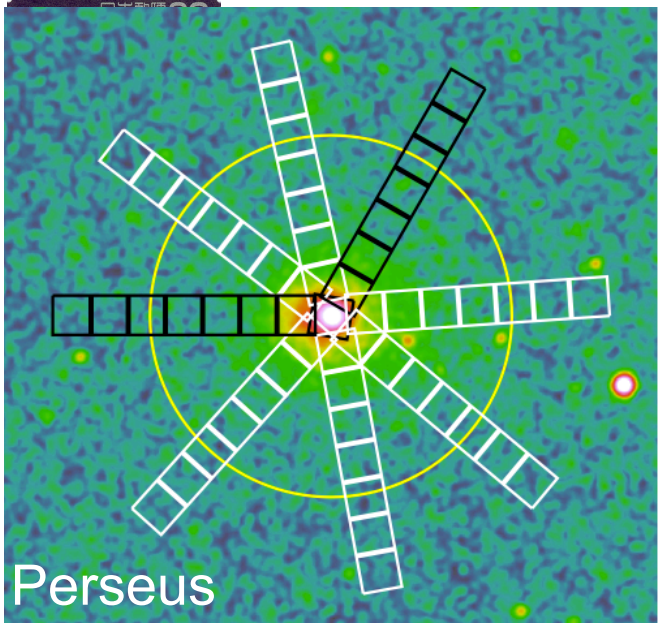


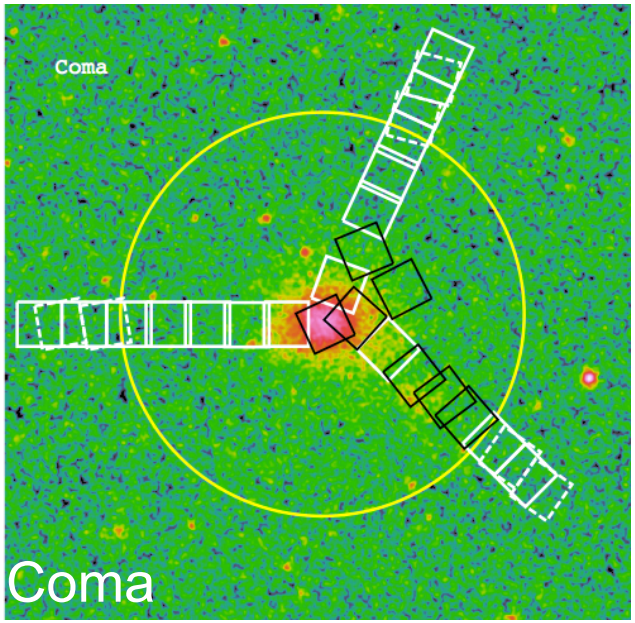
Simionescu et al. 2011, Science, 331, 1576

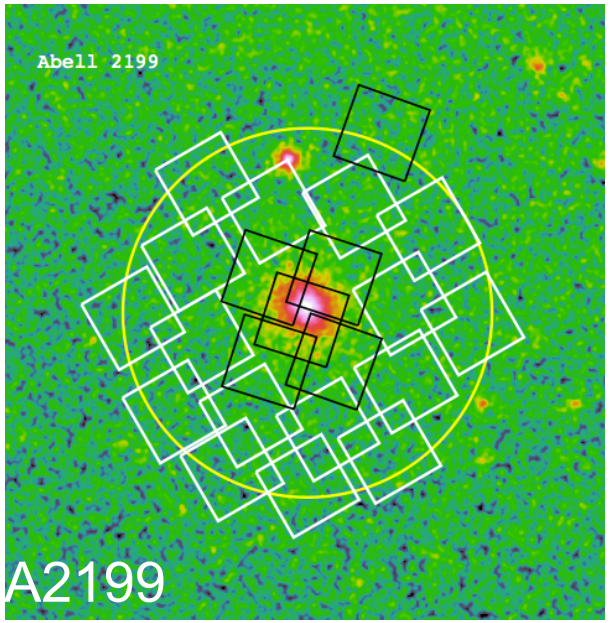


- Suzaku provides our clearest view of the previously unexplored outskirts of galaxy clusters; see large scale structure formation *as it happens!*
- Most precise determination of the baryon content, solving the "missing baryon" problem in clusters
- Discovery of clumping in the intracluster gas, with implications for large scale structure formation

CLUSTERS: THE NEXT STAGE (SUZAKU AO-6+)







- First measurements of *azimuthal* variations at large radii (Perseus)
- Extension to other nearby, bright clusters (Coma, A2199) to study *system-to-system* variations

➔ Important implications for cluster astrophysics (thermodynamics, formation process) and cosmology (dark energy studies)

SUZAKU & CLUSTERS

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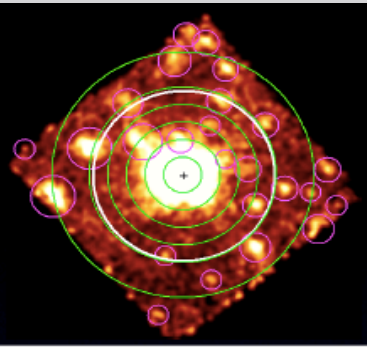
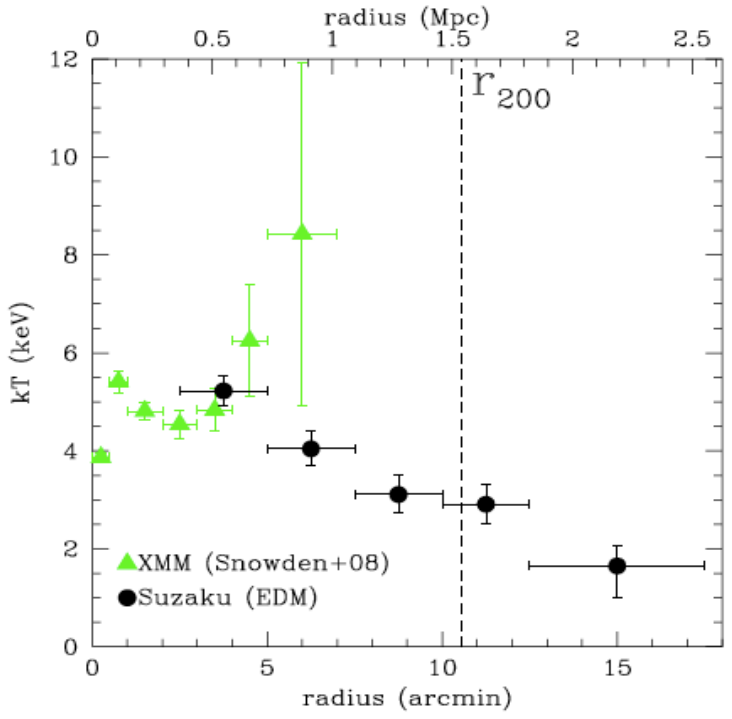
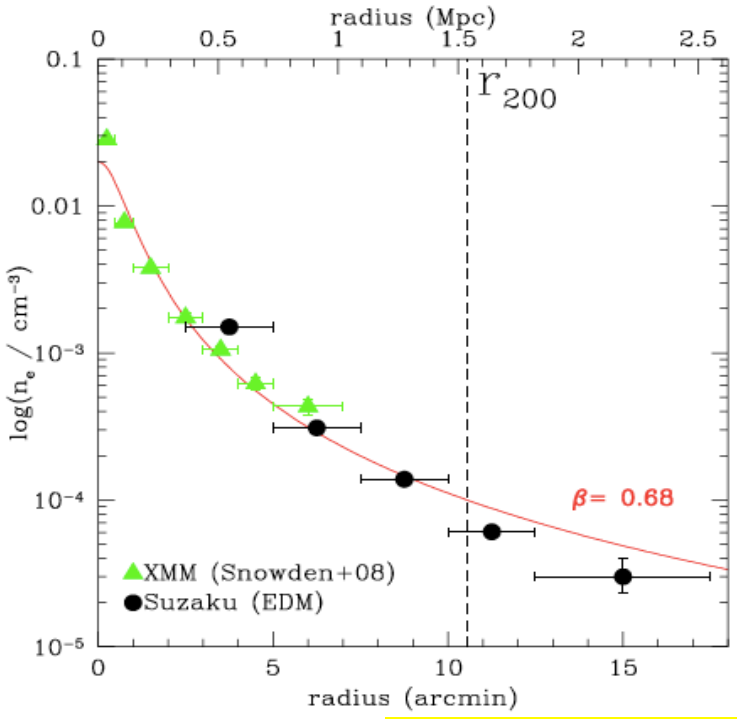


temperature

electron density

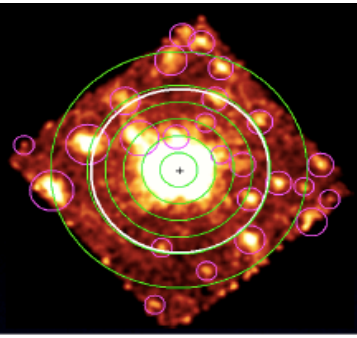




E. Miller et al. 2011

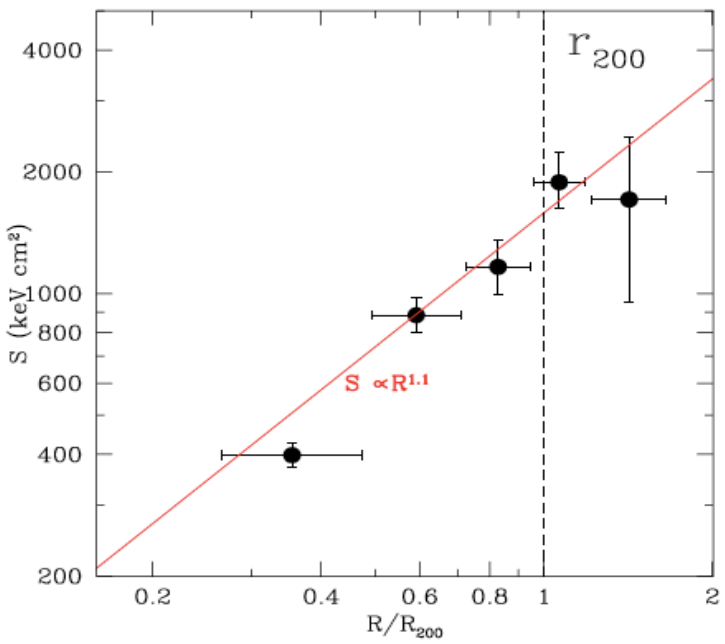
SUZAKU & CLUSTERS

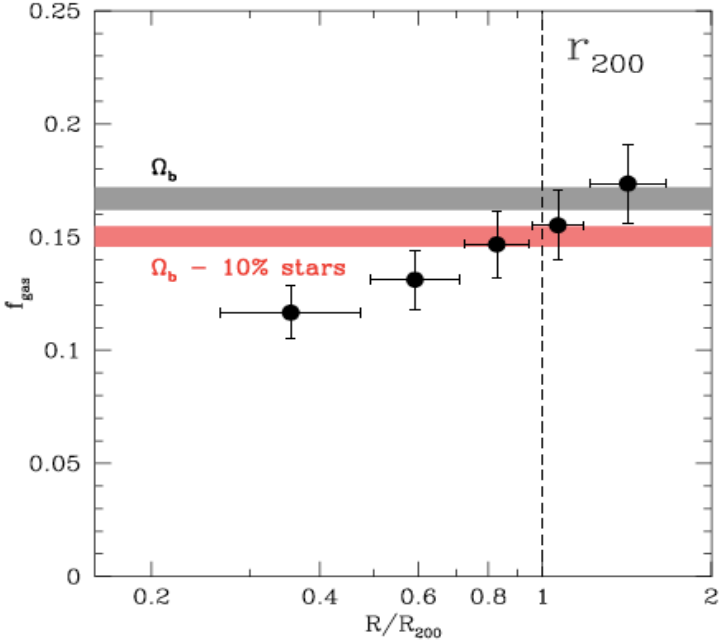
RXCJ0605



entropy

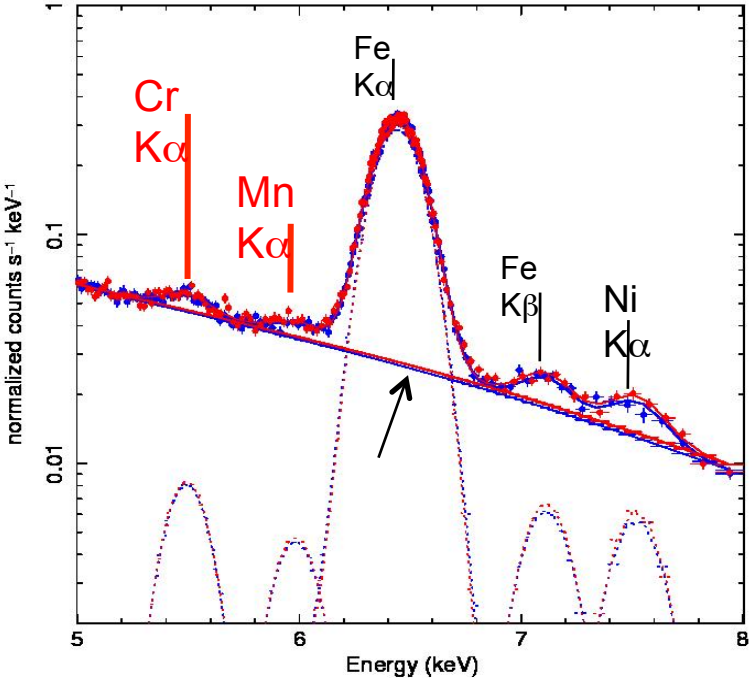
gas fraction

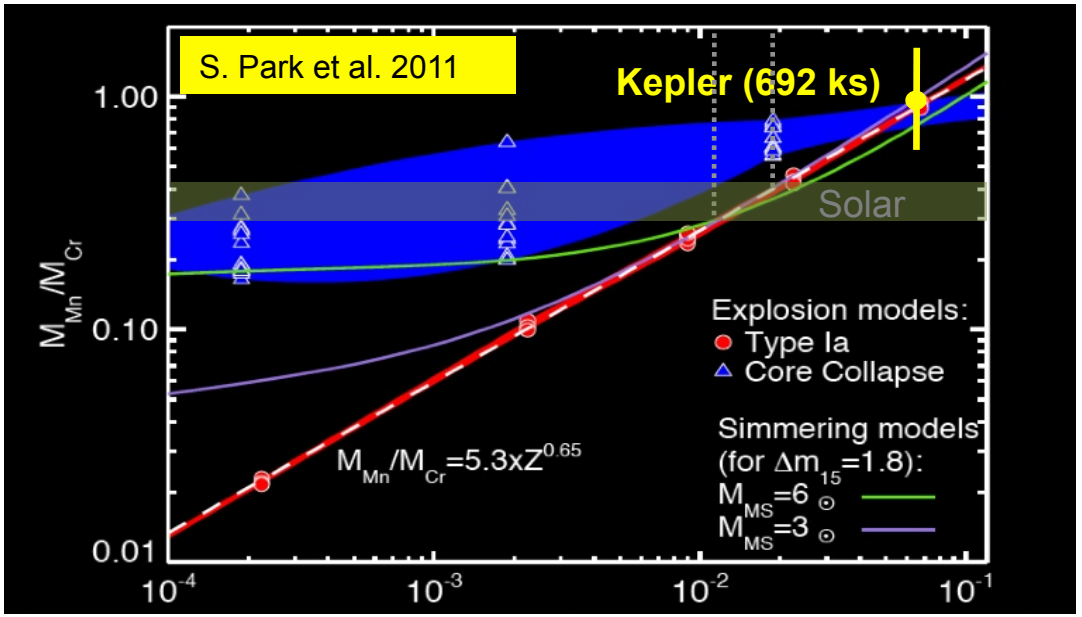




E. Miller et al. 2011

SUPERSOLAR METAL ABUNDANCES IN A TYPE IA SNR

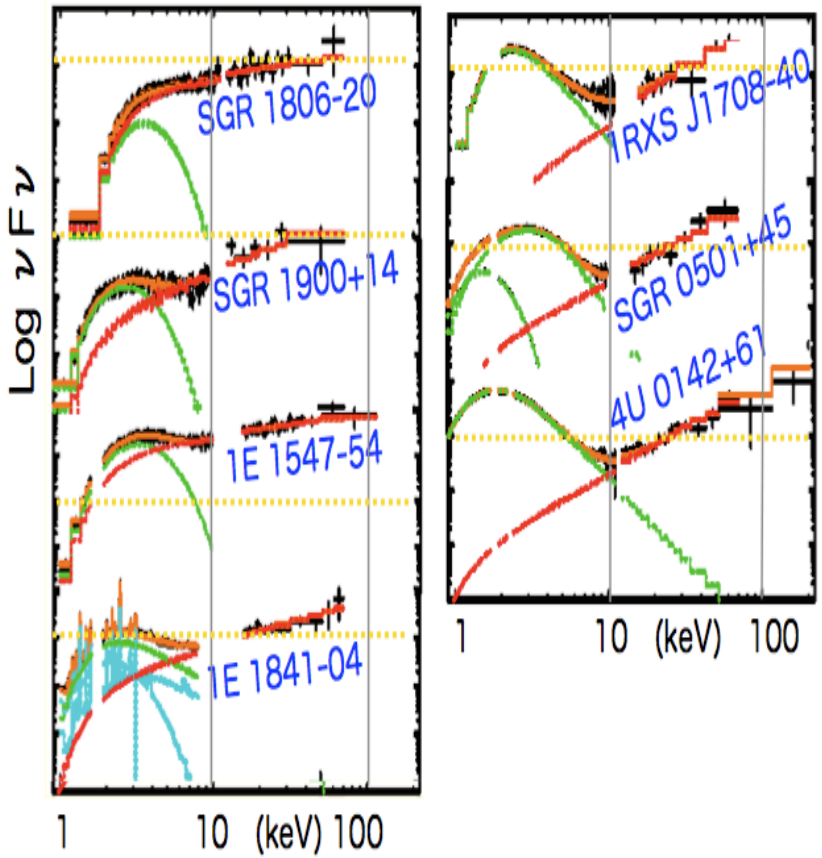




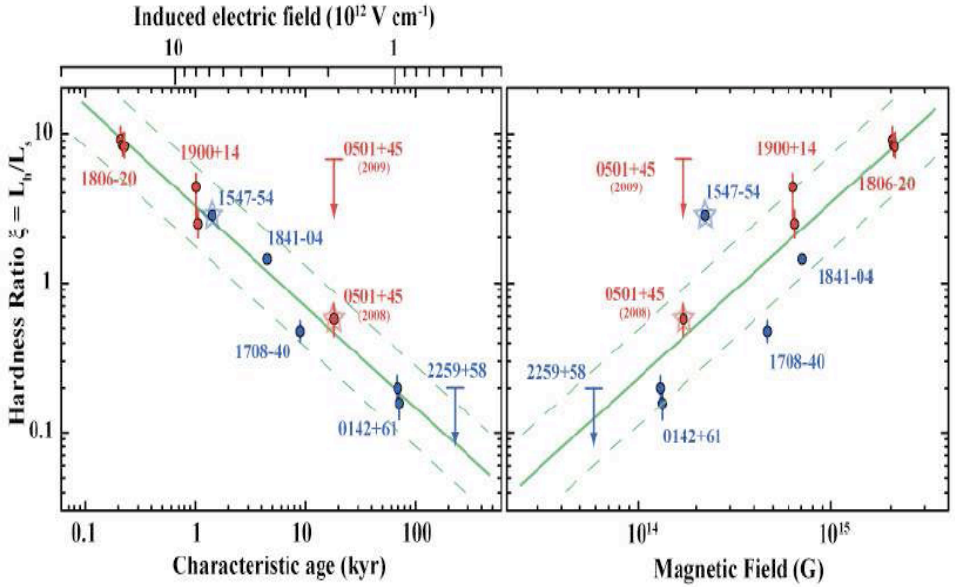
- M_{Mn}/M_{Cr} is in Type Ia SNRs diagnostic of progenitor metallicity
  - Prompt Ia: Younger progenitors, supersolar metallicity, brighter SNe, SN rate ∝ star-formation rate
  - Delayed Ia: Older progenitors, subsolar or solar metallicity, dimmer SNe, SN rate ∝ total stellar mass
- M_{Mn}/M_{Cr} ratio in Kepler reveals a significantly overabundant $Z/Z_{\odot} \sim 4$.
- This high metallicity of the progenitor supports a prompt SN Ia for Kepler.
- Implications for Dark Energy studies using SNe Ia

SUZAKU SPECTRA OF MAGNETARS

The first set of high-quality, simultaneous broadband spectra of magnetars severely constrains emission models (Enoto et al. 2010).



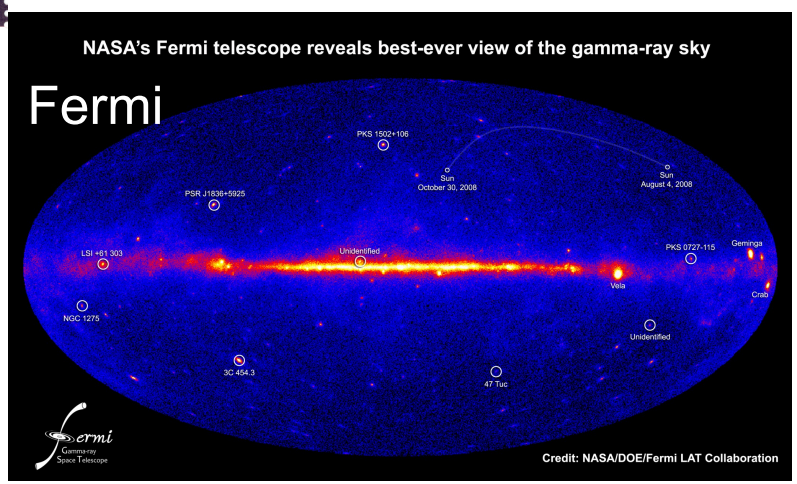
- Tight correlation between hardness ratio and:
  - Characteristic age
  - Magnetic field
- No existing magnetar model predicts these effects

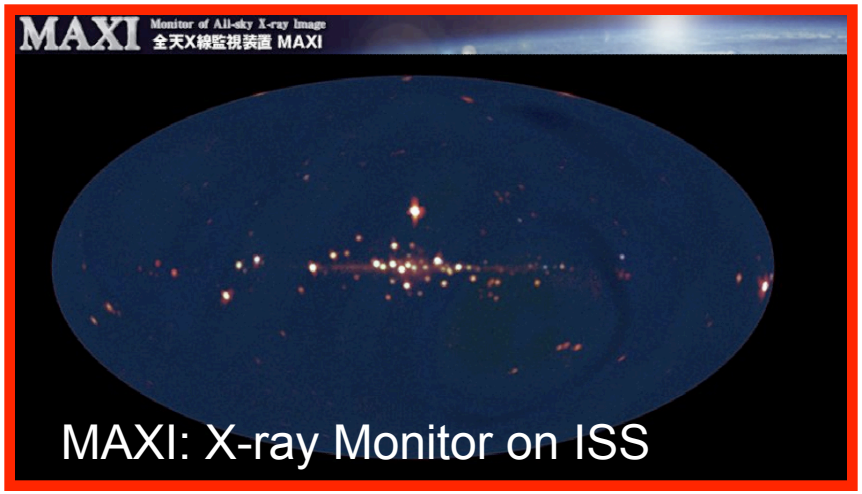


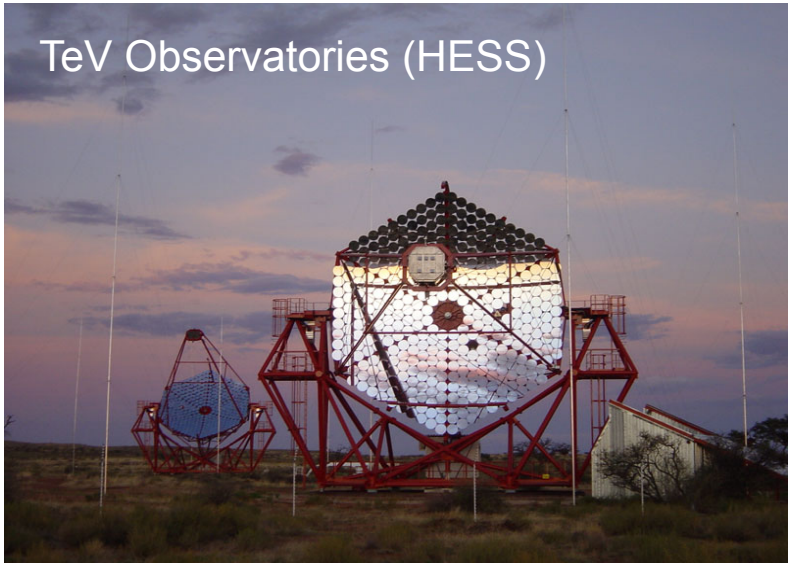
ADDITIONAL SUZAKU SCIENCE HIGHLIGHTS

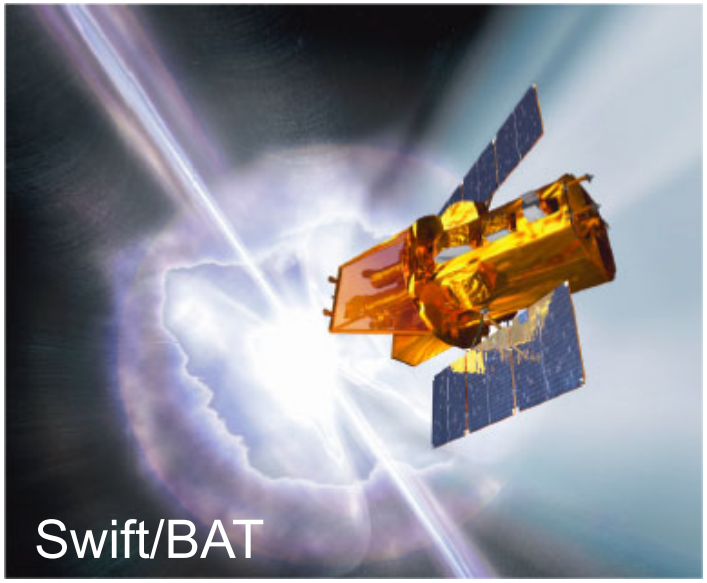
- Discovery of new atomic processes in SNR
  - Resonant scattering (Cygnus Loop)
  - Radiative recombination continua (IC 443, W49B, …)
  - Charge exchange (Cygnus Loop)
- Cataloging of diffuse Galactic TeV sources
  - Discovery of “dark accelerators”
- Relativistic line profiles in BLRGs (3C 382)
  - Distinction between BLRGs and Seyferts is blurred, and depends on variation of a few parameters (e.g. spin)
- Quantification of contribution of Charge Exchange to soft X-ray background

ACTIVE SUZAKU SYNERGIES

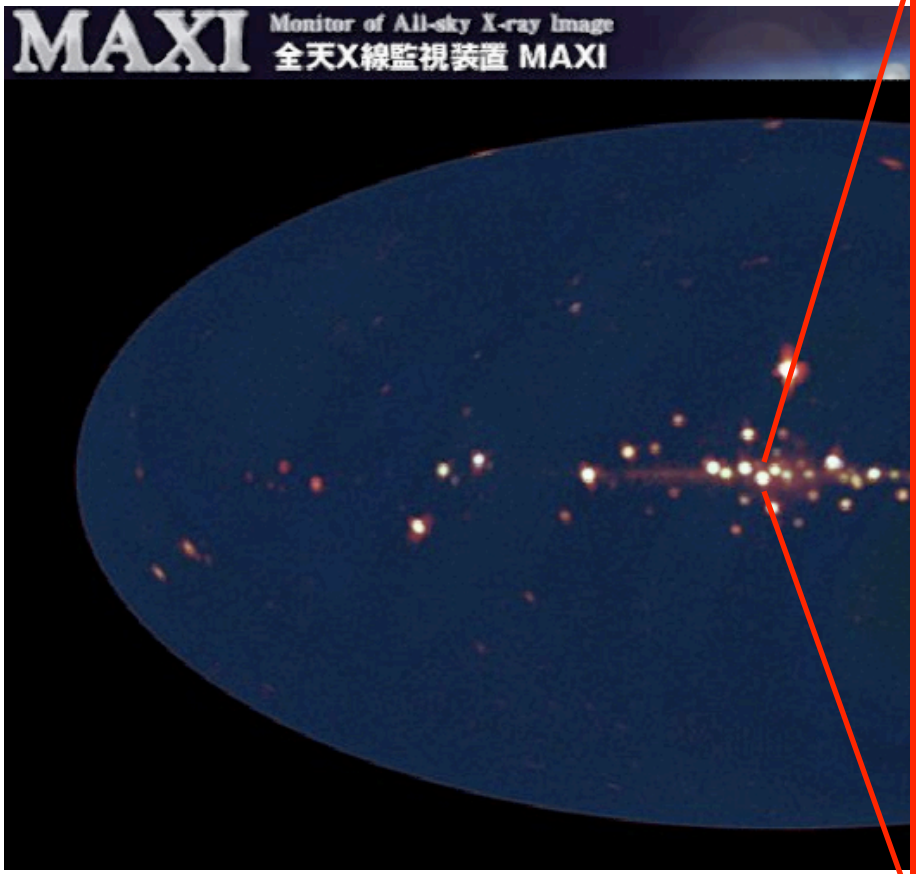


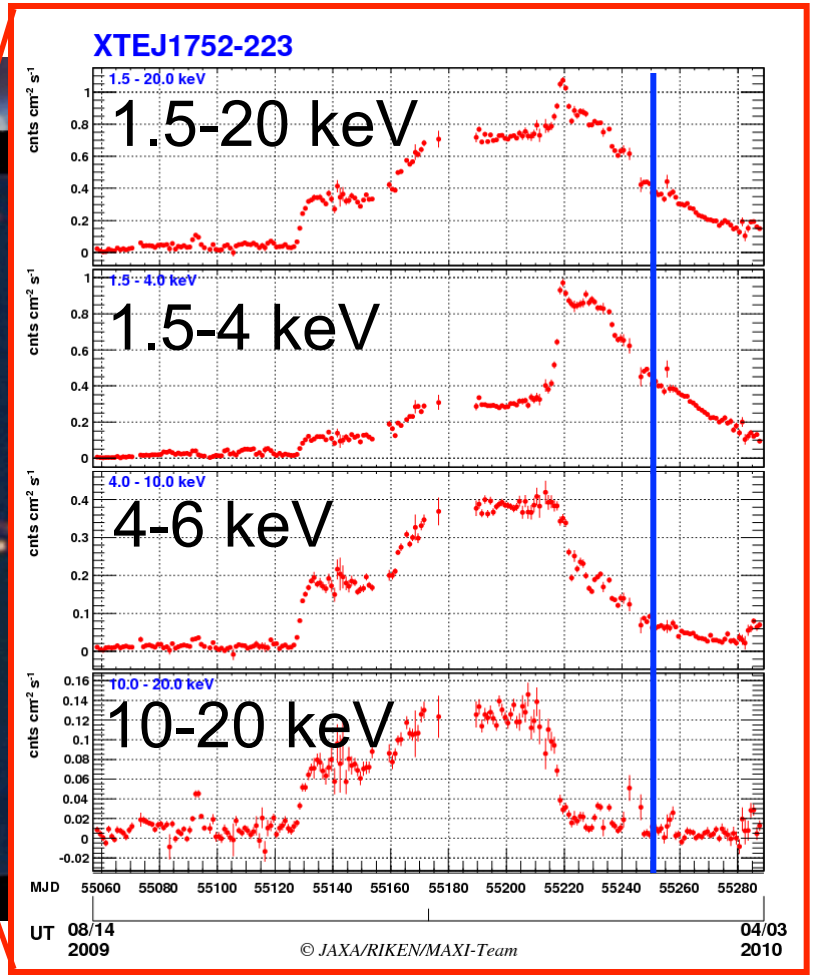






MAXI: The Suzaku ASM

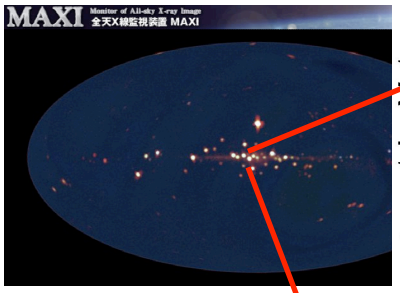


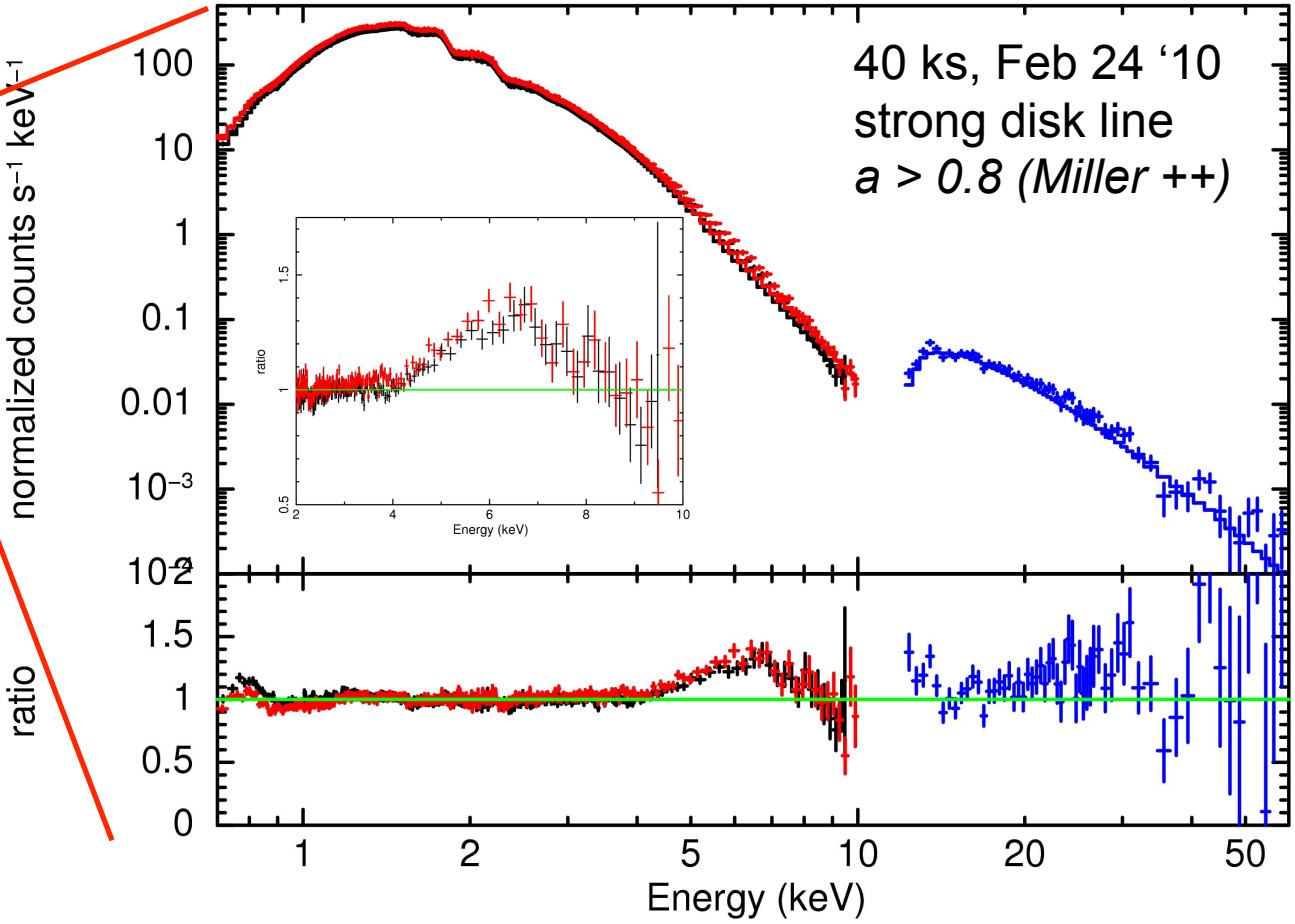


MAXI data are public!

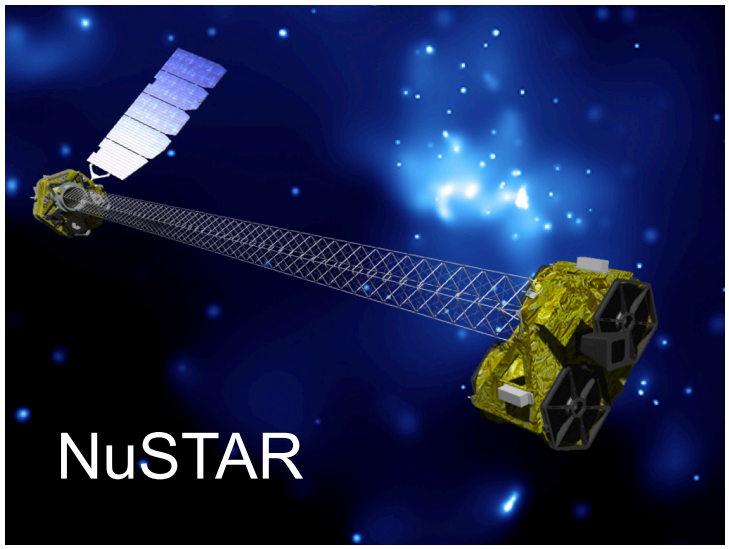
SUZAKU: XTE J1752-223

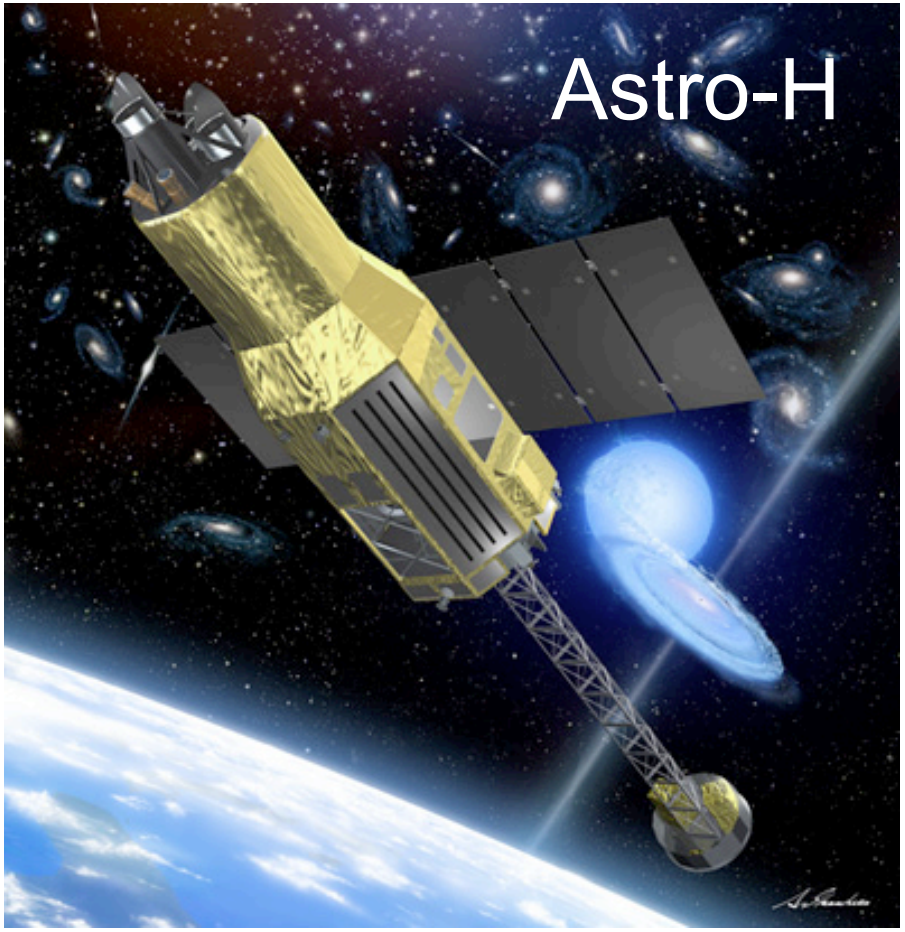
(new stellar-mass black hole)





FUTURE SUZAKU SYNERGIES



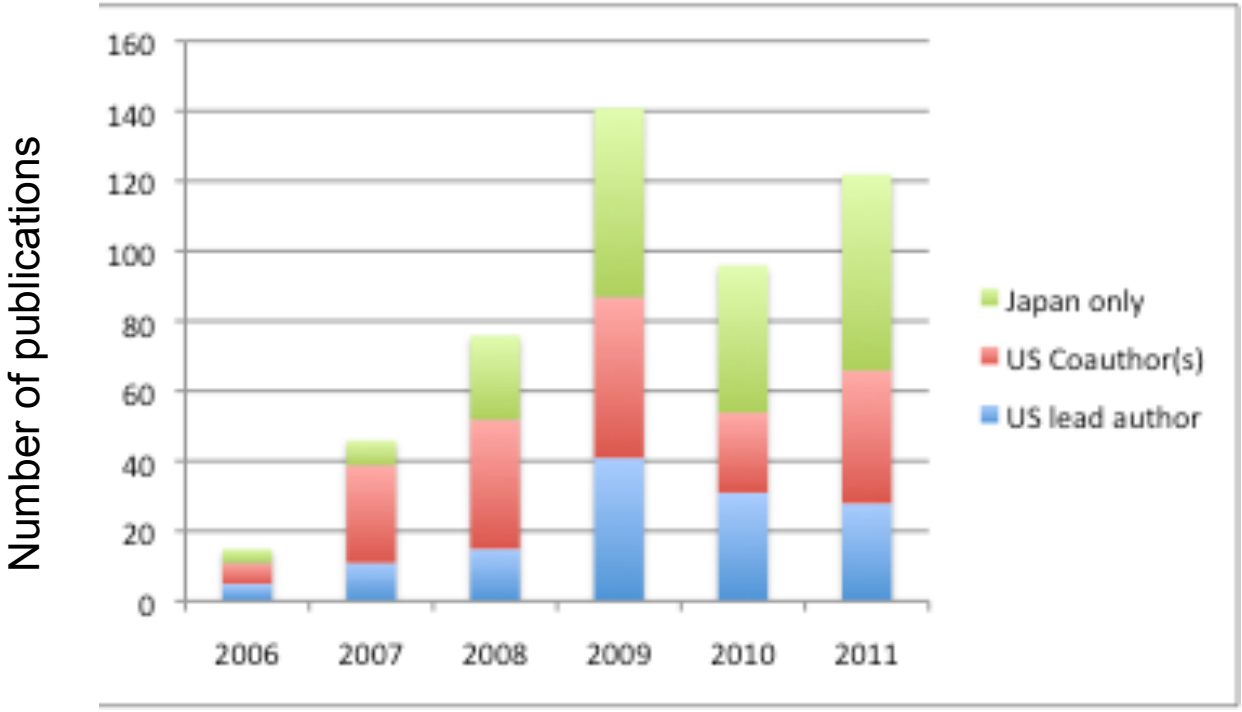


POSSIBLE FUTURE KEY PROJECTS

- Search in evolved SNR for recombination features (underway)
- Radial profile studies of additional clusters to trace evolution of properties near virial radius (some underway; up to 30 more)
- Systematic survey of large number of clusters to measure temperature, for dark energy studies (100's)
- Comprehensive survey of absorbed (BAT) AGN (100's)
- Observations on and off nearby ISM clouds to decouple local charge exchange emission from the soft X-ray background
- Survey of unidentified diffuse Galactic TeV and/or Fermi sources
- Survey of broad Fe lines from 20 AGN, 20 Galactic black holes and 20-30 accreting neutron stars
- Mapping of large, low surface brightness ISM structures (Vela SNR, North Polar Spur, Monogem)

Many more years of high quality, unique science!

SUZAKU PUBLICATIONS



- US scientists are involved in the majority of Suzaku publications
- Special PASJ editions in 2007, 2008, 2009; 2011 edition being planned

Implications of Termination of US Participation in Suzaku

- JAXA plans to operate mission as long as possible
  - Suzaku has some attributes not duplicated by Astro-H (or any other mission)
  - Cross calibration with Astro-H
  - Distinct operations teams
- Suzaku is viewed by our Japanese colleagues as part of a continuum: ASCA => Suzaku => Astro-H (=> IXO)
- US/Japan Suzaku data center roles were optimized to make best use of participants' strengths
- Impractical for JAXA to assume full role
  - Some activities, like processing pipeline maintenance, has only US expertise
  - JAXA under financial pressure
- JAXA has asked NASA to continue its participation in Suzaku
  - JAXA has offered to maintain current data share in perpetuity

JAPAN – US INTERDEPENDENCE

US | Japan | joint | parallel

Obs. Implementation

- S/C TRACKING, DATA RECEIVING & COMMANDING
- OBSERVATION SCHEDULING

Maintenance & Calibration

- SPACECRAFT & BUS INSTRUMENTS
- HXD | XRT | XIS

Guest Observer Interface

- REMOTE PROPOSAL SYSTEM
- US PIs ← PROPOSAL SELECTION, CONTACT SCIENTIST, DATA DISTRIBUTION → J PIs
- ANALYSIS SOFTWARE SYSTEM
- ANALYSIS HELPDESK

Data Processing & Archive

- PROCESSING SOFTWARE
- CALIBRATION DATABASE
- PIPELINE PROCESSING
- US ARCHIVE
- JAPAN ARCHIVE

US withdrawal would cause serious negative impact..

CHANGES FOR FY2012 (AND BEYOND ?)

US | Japan | joint | parallel

Obs. Implementation

- S/C TRACKING, DATA RECEIVING & COMMANDING
- OBSERVATION SCHEDULING

Maintenance & Calibration

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Guest Observer Interface

- REMOTE PROPOSAL SYSTEM
- US PIs ← PROPOSAL SELECTION, CONTACT SCIENTIST, DATA DISTRIBUTION → J PIs
- ANALYSIS SOFTWARE SYSTEM
- ANALYSIS HELPDESK

Data Processing & Archive

- PROCESSING SOFTWARE
- CALIBRATION DATABASE
- PIPELINE PROCESSING
- US ARCHIVE
- JAPAN ARCHIVE

WHY SHOULD US PARTICIPATION IN SUZAKU CONTINUE?

- Suzaku's capabilities enable unique and fundamental science that connects with broad and important themes in astrophysics
- Unique synergy with many missions that remains to be fully exploited (Fermi, Swift, TeV observatories, MAXI, NuSTAR, Astro-H,…)
- Key projects provide new ways of exploiting Suzaku's unique capabilities for legacy science
  - Only just beginning to see results
- Very high return for US investment
  - 10% of total mission cost yields 50% data share
- US plays vital role in Suzaku, tightly intertwined with Japan; sharing of responsibilities maximizes cost effectiveness