Suzaku Science Highlights & Consequences of Mission Termination

ROB PETRE
NASA/GSFC
US SUZAKU PROJECT SCIENTIST
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

ASTRO-H, scheduled for launch in 2014

Suzaku Instrumentation

- **XRT (X-ray Telescope)**
  - Images of XRT
- **XIS (X-ray Imaging Spectrometer)**
  - Images of XIS
- **Nearly seamless and simultaneous coverage over ~3 decades**
- **HXD (Hard X-ray Detector)**
  - Images of HXD

Graph showing energy distribution from various sources:
- G.C. diffuse
- Cyg X-1
- Her X-1
- V2400 Oph
- AXP 0142+61

Energy range from 1 keV to 200 keV.
## Unique Science Enabled by Suzaku

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Unique Science Enabled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simultaneous broad band energy coverage</td>
<td>Simultaneous measurement of disk emission, warm absorber composition and velocity, reflection bump and broad Fe lines in X-ray binaries and supermassive black holes</td>
</tr>
<tr>
<td>(0.2-600 keV)</td>
<td></td>
</tr>
<tr>
<td>Highest CCD spectral resolution in 0.2-1.0 keV band</td>
<td>Measurement of C, N, O abundances in ISM and SNRs</td>
</tr>
<tr>
<td></td>
<td>Determination of properties of geocoronal and heliospheric soft X-ray charge exchange emission</td>
</tr>
<tr>
<td>Highest spectral resolution and sensitivity in 6-10 keV band</td>
<td>Detection and separation of Fe band feature in cataclysmic variables, X-ray binaries, AGN and the Galactic Plane and Ridge</td>
</tr>
<tr>
<td></td>
<td>Modeling of relativistic effects in broad Fe lines in neutron star binaries and stellar and supermassive black holes</td>
</tr>
<tr>
<td>Lowest background in the 0.2-10 keV band</td>
<td>Measurement of cluster temperatures and abundances to the virial radius</td>
</tr>
<tr>
<td></td>
<td>Mapping of low surface brightness sources (e.g., extended HESS Galactic sources)</td>
</tr>
<tr>
<td>Highest sensitivity in the 10-50 keV band</td>
<td>Spectroscopy of all AGN detected by Swift – determination of the contribution of absorbed AGN to the cosmic X-ray background</td>
</tr>
<tr>
<td></td>
<td>Measurement of the magnetic field strength in XRBs and AXPs through detection of cyclotron features</td>
</tr>
<tr>
<td></td>
<td>Search for nonthermal emission from clusters and SNRs</td>
</tr>
</tbody>
</table>
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.
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:
“Assessing black hole spin in deep Suzaku observations of Seyfert 1 AGN”, A.Patrick et al., MNRAS, in press (indep. team)
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.

Papers resulting from these data:


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


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.
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

Red: from relativistic Fe line
Black: from disk continuum

Suzaku

RXTE

J. Miller et al. 2011
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

**Perseus: the nearest, brightest massive cluster**

- Suzaku
- Metallicity ~0.3 solar
- "Cold front" in eastern arm

**Simionescu et al. 2011, Science, 331, 1576**
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

RXCJ0605

temperature
electron density

E. Miller et al. 2011
SUZAKU & CLUSTERS

RXCJ0605

entropy

gas fraction

S $\propto R^{1.1}$

E. Miller et al. 2011
SUPERSOLAR METAL ABUNDANCES IN A TYPE Ia SNR

- $M_{\text{Mn}}/M_{\text{Cr}}$ is in Type Ia SNRs diagnostic of progenitor metallicity
  - Prompt Ia: Younger progenitors, supersolar metallicity, brighter SNe, SN rate $\propto$ star-formation rate
  - Delayed Ia: Older progenitors, subsolar or solar metallicity, dimmer SNe, SN rate $\propto$ total stellar mass

- $M_{\text{Mn}}/M_{\text{Cr}}$ 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
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

NASA's Fermi telescope reveals best-ever view of the gamma-ray sky

Fermi

MAXI: X-ray Monitor on ISS

TeV Observatories (HESS)

Swift/BAT
MAXI: THE SUZAKU ASM

MAXI data are public!
SUZAKU: XTE J1752-223

(new stellar-mass black hole)

40 ks, Feb 24 '10
strong disk line
\( a > 0.8 \) (Miller ++)

Suzaku
FUTURE SUZAKU SYNERGIES

NuSTAR

Advanced LIGO

Astro-H
**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!
US scientists are involved in the majority of Suzaku publications

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
US withdrawal would cause serious negative impact..
Changes for FY2012 (and beyond?)

**Observation 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
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