Catching Galactic X-ray Transients in the Act

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XRT Observations of Galactic Transients

• Low-Mass X-ray Binaries
  – Compact Jets and the Accretion Disk Geometry in Black Hole Binaries (Tomsick)
  – The Final Stages of Outbursts in Soft X-ray Transients (Homan)
  – The Rise to Outburst of Black Hole X-ray Transients (Brocksopp)
  – Swift TOO Observations of Galactic X-ray Transients (Steeghs)
  – Accreting millisecond X-ray pulsars (Kennea)
  – Faint X-ray Transients (Degenaar talk)

• High-Mass X-ray Binaries
  – Be X-ray Binaries
  – Supergiant Fast X-ray Transients (Romano talk)

• Magnetars: SGRs and AXPs (Israel talk tomorrow)

• Symbiotics (Sokoloski talk tomorrow)

• Novae (session yesterday)
Triggering Observations of Galactic Transients

- **Using Swift/BAT**
  - e.g., TOO observations of Swift J1539.2-6227 (See poster T-3 by Krimm et al.)

- **Using INTEGRAL**
  - Rodriguez, Tomsick, Chaty, Paizis, Corbel

- **Using RXTE Galactic Bulge Monitoring**
  - Markwardt, Strohmayer, Swank

- **Using RXTE/ASM**

- **... and now MAXI and Fermi**
Outline

• Follow-up of INTEGRAL Sources
  – Identification of IGR J19294+1816 (Rodriguez et al. 2009)

• Black hole binaries in the hard state
  – X-ray/radio correlations (Jonker et al. 2009)
  – Thermal components (“hot” topic)
  – Using iron lines to constrain the accretion geometry
    • XMM, Swift, and RXTE results (2006-2008)
Follow-up of INTEGRAL Sources

  – Analysis of archival Swift observations of 29 IGR sources
  – X-ray positions and spectra for 26 sources (includes AGN, X-ray binaries, and CVs)

• “The nature of the X-ray binary IGR J19294+1816 from INTEGRAL, RXTE, and Swift observations” by Rodriguez et al., to appear in A&A

INTEGRAL light curve for IGR J19294+1816

• Observations largely from GRS 1915+105 monitoring campaign
• The source was first reported from a 14 mCrab flare seen in 2009 March (Turler et al. 2009).
IGR J19294+1816: Swift+RXTE Follow-up

XRT image with INTEGRAL error circle
- IR identification (2MASS catalog):
  - K = 12.1, J-K = 2.5
  - Large J-K suggests large distance (AGN or X-ray binary)
- XRT spectrum:
  - power-law with absorption
  - \( N_H = (3-4) \times 10^{22} \text{ cm}^{-2} \), \( \Gamma = 0.9-1.2 \)
  - Hard X-ray spectrum suggests magnetic compact object (NS or WD)
- An X-ray binary with a magnetic NS is very likely an HMXB

RXTE confirmation of 12.44 s pulsations
- ATEL#1998: Rodriguez suggested a periodic signal using Swift/XRT
- ATEL#2002: Strohmayer et al. report of the above signal
- ATEL#2008: Corbet & Krimm use long-term Swift/BAT light curve to find the 117 day orbital period.
Accreting Black Holes: The Hard State and Current Questions

- What is the inner radius ($R_{in}$) of the optically thick disk?
  - While there is evidence in favor of the truncated disk picture, it is not quantitative.

- What conditions are necessary for the production of the compact jet?
  - Is the compact jet (radio) tied to the disk (X-ray) or the corona (X-ray)?

**Hard Energy Spectrum**
- Power-law (often with a cutoff)
- $\Gamma = 1.4-2.0$
- (e.g., IGR J17497-2821, Rodriguez et al. 2007)

**Noisy Power Spectrum**
- High level of timing noise
- Rms > 10%
- (e.g., XTE J1118+480, Hynes et al. 2003)

**Compact Radio Jet**
- Flat or inverted spectrum
- (e.g., GRS 1915+105, Dhawan et al. 2000)

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**Swift 5 years Conference: Tomsick**
X-ray and radio emission from H 1743-322

- H 1743-322 long-term light curve
- The time of our X-ray/radio study is marked
- Pointed observations are essential!

H1743 X-ray and radio light curves from the hard state to quiescence
- Fast X-ray decay with an e-folding time of 4 days.
- The Swift/XRT capabilities are ideal for covering intermediate fluxes.
X-ray/radio correlations in BH binaries

X-ray/radio correlation for 14 different black hole systems
- The original study (Gallo et al. 2003) suggested a universal \( L_{\text{radio}} = aL_x^{0.7} \) relation.
- The index of 0.7 is predicted if the X-ray corona is at the base of the jet (Heinz & Sunyaev 2003).

- \( L_{\text{radio}} = aL_x^{0.18 \pm 0.01} \)
- Two differences from the “0.7” correlation:
  - X-ray excess
  - The flatter slope of the correlation ...
- Radio spectral index changes from flat (\( \alpha \approx 0 \)) to negative (\( \alpha = -0.50 \pm 0.15 \)), consistent with optically thin synchrotron emission
  - Two types of radio emission from H 1743-322
Black Hole Energy Spectra and Thermal Components in the Hard State

- X-ray instruments from ASCA (Ebisawa et al. 1996) to Suzaku (Makishima et al. 2008) have seen a thermal component in the hard state with $kT_i$ near 0.2 keV for Cyg X-1.

- Now, this component has also been seen for:
  - GX 339-4, GRO J1655-40, and XTE J1817-330
  and perhaps:
  - XTE J1118+480 and Swift J1753.5-0127

- In some cases, the component has been seen near 0.2 keV down to very low luminosities, 0.1% $L_{Edd}$.

BeppoSAX spectrum of Cygnus X-1 in the hard state at 2% $L_{Edd}$ (Di Salvo et al. 2001; Done et al. 2007)
The Case of XTE J1817-330

Rykoff et al. (2007)

- At least 5 papers on this data set:
  - Rykoff et al. 2007
  - Gierlinski et al. 2008, 2009
  - Cabanac et al. 2009
  - Reis et al. 2009
- 22 Swift/XRT observations over a wide range of disk temperatures.
- \( L_{\text{disk}} = (4\pi \sigma) R_{\text{in}}^2 T_{\text{in}}^4 \)
- Rykoff et al. showed that \( L_{\text{disk}} \approx T_{\text{in}}^4 \), which is consistent with constant \( R_{\text{in}} \).

Gierlinski et al. (2008): Re-analysis

- Disk model uncertainties include:
  - changes to the temperature profile due to irradiation
  - inner boundary condition
  - effect of spectral hardening (\( T_{\text{color}} = f T_{\text{eff}} \))
- The detailed interpretation of this component is still an unsolved problem.
- Cannot currently use it to measure \( R_{\text{in}} \), but can it be calibrated?

11/19/09  Swift 5 years Conference: Tomsick
Iron Line and Reflection

- Consider the following values of $\Delta E$ (FWHM) at 6 keV:
  - Ginga LAT: 1080 eV
  - BeppoSAX MECS: 480 eV
  - ASCA/GIS: 460 eV
  - XMM/MOS and pn: 130 eV
  - Swift/XRT: 140 eV
  - Suzaku/XIS: 120 eV

- Also, there have been improvements in reflection modeling.

- Iron line shows that disk is very close to the BH at high mass accretion rates.

- Relatively few high-quality hard state spectra
Going to Lower Luminosity: GX 339-4

- **GX 339-4:**
  - Black hole binary with a 1.7 day orbital period.
  - $M_{\text{BH}} > 6 \ M_{\odot}$ (Hynes et al. 2003; Munos-Darias et al. 2008)
  - $d \approx 8 \ kpc$ (Hynes et al. 2004; Zdziarski et al. 2004)
  - $L_{\text{Edd}} = 1.3 \times 10^{39} \ ergs/s$ ($d = 8 \ kpc, M_{\text{BH}} = 10 \ M_{\odot}$)

- Three X-ray telescope observations made in the hard state
  - XMM at 3.2% $L_{\text{Edd}}$
  - Swift at 1.3% $L_{\text{Edd}}$
  - Suzaku at 0.14% $L_{\text{Edd}}$
Hard State at 1-4% $L_{\text{Edd}}$:
Broad Iron lines and thermal components

- Iron line profile from the XMM+RXTE observation at 3.2% $L_{\text{Edd}}$ (Miller et al. 2006)
- Laor (1991) relativistic modeling of the iron line gives $R_{\text{in}} = 4\pm1 \, R_g$
- Thermal component with $kT_{\text{in}} = 0.39$ keV
- However, a very recent re-analysis suggests that the line might be somewhat narrower (Done & Diaz Trigo 2009).

- Swift+RXTE spectrum at 1.3% $L_{\text{Edd}}$ (Tomsick et al. 2008)
- 6 ks XRT observation, WT mode, 10.4 c/s (even longer observations would be helpful)
- Relativistic modeling of the iron line gives $R_{\text{in}} = 3.6^{+1.4}_{-1.0} \, R_g$
- Thermal component with $kT_{\text{in}} = 0.19$ keV
Inner disk model

- Due to radial variations in thermal conduction from corona to disk, an inner optically thick disk can form (Liu et al. 2002, 2007).

- To persist, matter can condense into the inner disk from a Compton-cooled corona (Liu et al. 2006, 2007; Meyer et al. 2007; Taam et al. 2008).

- One prediction is that the entire inner disk will evaporate below about 0.1% \( L_{\text{Edd}} \) (Liu et al. 2007; Taam et al. 2008).
New Result: Hard State at 0.14% $L_{\text{Edd}}$
Narrow Iron Line

- 105 ks of Suzaku/XIS exposure time obtained during a 2.2 day pointing.
- Power-law continuum:
  - $\Gamma = 1.573 \pm 0.006$
  - $L/L_{\text{Edd}}$ (1-100 keV) = 0.14%
- Iron line parameters:
  - $E_{\text{line}} = 6.45^{+0.03}_{-0.02}$ keV
  - $\sigma_{\text{line}} = 0.14^{+0.04}_{-0.03}$ keV
  - $\text{EW} = 77^{+12}_{-10}$ eV

Suzaku+RXTE spectrum for GX 339-4 taken in 2008 September (Tomsick et al. 2009)
Is the line really from GX 339-4?

• Could this narrow line be from the background or part of the Galactic Ridge emission?

• Suzaku/XIS background rate is 1.9% of source rate and does not have a strong line at 6.4 keV.

• We made a second XIS spectrum with an extraction region that is 25 times smaller, and the iron line EW does not change.

• We conclude that the iron line is from GX 339-4.

GX 339-4 spectrum (black) and Suzaku/XIS background (red)
Constraints on $R_{\text{in}}$ at 0.14% $L_{\text{Edd}}$

- GX 339-4 Suzaku/XIS iron line profile with theoretical profiles (Laor 1991) for different values of $R_{\text{in}}$, assuming $i = 18^\circ$ (from Miller et al. 2008).

- 68% and 90% confidence error regions for $R_{\text{in}}$ and disk inclination
  - $R_{\text{in}} > 35 R_g$ at $i = 0^\circ$ (90% conf.)
  - $R_{\text{in}} > 175 R_g$ at $i = 30^\circ$ (90% conf.)
Iron Line Summary and Implications

- Results tell us about accretion models
  - e.g., ADAF is viable at low luminosities

- Results tell us about accretion disk evaporation
  - evolution is consistent with the inner disk model

- Results tell us about jets
  - radio emission from jets detected during all 3 hard state observations
  - jets may not be related to optically thick disk ...
    strengthens connection to corona

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GX 339-4 Iron line constraints on $R_{in}$ and EW as a function of $L_{Edd}$ (Miller et al. 2004, 2006, 2008; Reis et al. 2008; Tomsick et al. 2008, 2009)
Summary of Results and the Swift Connection

- **Identification of IGR J19294+1816 as an HMXB**
  - A lot can be learned (XRT position, hard spectrum, candidate period) even from a short XRT observation of a new source.
  - BAT light curve uncovered 117 day orbital period

- **Radio/X-ray correlations**
  - For H 1743-322, the correlation is significantly flatter than the “0.7” correlation.
  - XRT covers a critical intermediate flux range

- **Black hole accretion geometry**
  - The disk becomes truncated by 0.14% $L_{\text{Edd}}$, but it is still important to determine the evolution from non-truncated to truncated.
  - XRT is making two critical contributions:
    - XRT can measure the iron line at intermediate flux levels.
    - XRT can trigger observations with Suzaku and XMM at low flux levels.