eROSITA: The Largest Survey of AGN Fe Kα Lines and Line of Sight Absorbers

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ABSTRACT:

Once *SRG* is launched, eROSITA will conduct the first hard-X-ray survey of the entire sky and thus provide a monitoring database of high-quality spectra and light curves with which to conduct the largest survey of AGN Fe lines and line-of-sight absorbers to date. This database will thus allow us to pursue several investigations, including determining how frequently in Seyferts the accretion disk extends to the innermost stable orbit, the location of the Fe line-emitting gas (molecular torus, BLR gas, etc.), and how the geometry of the accreting gas changes with luminosity (testing the X-ray Baldwin effect). Quantification of variable line of sight absorption will constrain models describing torii as clumpy rather than homogenous. Time-averaged and time-resolved spectroscopy on statistically large samples of AGN can tell us how the parameters which govern accretion flows change with luminosity and redshift.

Motivation: Insights into Accretion from Long Term X-ray Monitoring

Key open questions in Active Galactic Nuclei (AGN) include the details of how supermassive black holes (SMBHs) are fueled, the co-evolution between SMBHs and the host galaxies which nurture them, and why the universal SMBH accretion rate peaked at z~1-2 (e.g., Hasinger et al. 2005, Yencho et al. 2009).

Breakthroughs have come from sustained, long-term flux and spectral monitoring. For example, sustained X-ray monitoring with the *Rossi X-ray Timing Explorer* (*RXTE*) has yielded a flux and spectroscopy database for dozens of nearby, X-ray bright AGN. In the case of Seyferts (e.g., AGN whose emission is not jet-dominated), such monitoring has yielded connections between X-ray variability characteristics, black hole mass M_{BH} and accretion rate relative to Eddington $\dot{m}=L_{BOL}/L_{EDD}$, and revealed striking similarities to BH X-Ray Binaries (e.g., Markowitz et al. 2003, McHardy et al. 2006). When supplemented by coordinated ground-based optical and/or radio monitoring, we can probe interband correlations and test disk-jet connections (e.g., Chatterjee et al. 2011) and accretion disk structure in Seyferts (e.g., Breedt et al. 2009).

In this poster, I review prospects for additional breakthroughs in AGN science courtesy of the eROSITA instrument aboard the upcoming *Spectrum Roentgen/Gamma* (*SRG*) mission. I focus on monitoring of variations in the Fe Kα line flux and in the column density N_H of neutral gas along the line of sight, which will yield insight into the structure of the accreting gas. I review relevant contributions from previous missions and discuss how the forthcoming eROSITA all-sky survey will allow us to make further progress.

Line of sight N_H monitoring

Moderate variations in the line of sight column density of cold/neutral gas N_H (ΔN_H ~10^{23-24} cm^{-2}) in *both* types of Seyferts on time scales spanning hours to years are commonly reported, e.g., Risaliti et al. (2002, 2009), Lamer et al. (2003), Puccetti et al. (2007), Turner et al. (2008), Rothschild et al. (2011), Rivers et al. (2011, subm.). Such observations argue against the presence of the ``classical'' homogeneous, Compton-thick, pc-scale torus commonly invoked in Seyfert 1/2 unification schemes being solely responsible for line of sight X-ray obscuration. They instead support the existence of sub-pc scale and/or clumpy absorbers (e.g., Nenkova et al. 2008a, 2008b); such models describe the amount of X-ray absorption for a given source as a viewing dependent *probability* based on the size and location distribution of clumps.

Accumulation of as many observations of ΔN_H and discrete clumps transiting the line of sight as possible is needed to provide observational constraints for these models; this can be done through time-resolved spectroscopy and/or hardness ratio light curves. A recent example from *RXTE* is a 5-month duration event in Cen A where N_H increased by ~8×10^{22} cm^{-2} then decreased (Rivers et al., 2011, subm.; Figure 1); the clump was likely commensurate with the IR torus and had a diameter of ~2×10^{15} cm and a central number density of ~2×10^{7} cm^{-3}. A decade ago, *RXTE* also captured an eclipse by an X-ray absorbing cloud located in the BLR of NGC 3227 in 2000-1 (Lamer et al. 2003). *eROSITA is expected to identify numerous additional BLR and NLR obscuration events in many additional Seyferts.*

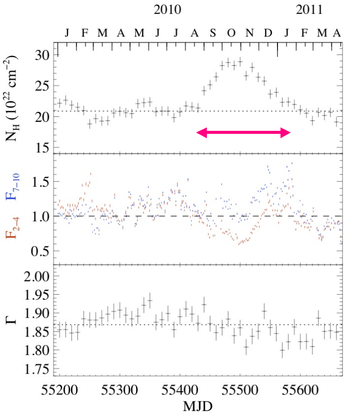
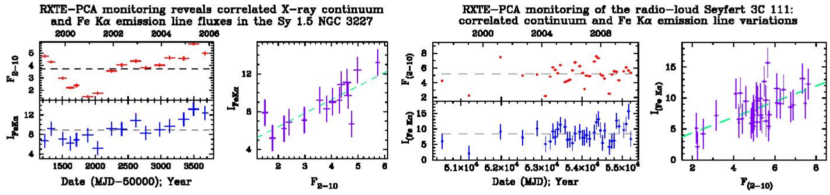


Figure 1: Sustained long-term monitoring of Cen A with *RXTE* catches an obscuration event caused by a discrete clump of gas transiting the line of sight to the X-ray continuum source (Rivers et al. 2011, subm.). The middle panel shows deviation between the 2-4 and 7-10 keV continuum light curves (the former being sensitive to variations of ΔN_H~10^{23} cm^{-2}). The top and bottom panels respectively show the N_H and Γ light curves derived from time-resolved spectroscopy, using bins of 10 days. Long-term monitoring with eROSITA will identify numerous additional events in Seyferts!

Broad & Narrow Fe Kα lines

The Fe Kα emission line at 6.4 keV is a key tracer of the accreting gas in compact accreting systems. Broad components (FWHM ~10^5 km s^{-1}) trace emission from the innermost radiatively-efficient accretion disk, originating from within a few Schwarzschild radii of the black hole and sculpted by special and general relativistic effects. It is detected in (very roughly) about half of the bright, nearby Seyferts studied so far and it has yielded constraints on black hole spin (e.g., Nandra et al2007). A narrow component (FWHM ~ 10^3 km s^{-1} is ubiquitous in Seyfert spectra but originates in more distant gas, such as gas commensurate with the optical BLR or the pc-scale molecular torus (e.g., Shu et al. 2010, Nandra 2006). CCD resolution is required to deconvolve the two (e.g., NGC 2992, Yaqoob et al. 2007; MCG–5-23-16, Reeves et al. 2007, both observed with *Suzaku*).

Sustained long-term monitoring with *RXTE* has yielded constraints on the location of the line-emitting gas via "reverberation mapping." Upper limits on the light-travel time between the X-ray source and the origin of the Fe line have been obtained so far (see Figures 2 & 3). Samples of Seyferts observed with single-epoch spectroscopy with *Suzaku* and *XMM-Newton* have, as mentioned above, yielded constraints on black hole spin (e.g., Brenneman et al. 2011, Patrick et al. 2011) but so far have concentrated on bright, nearby Seyferts. To determine the degree to which Seyferts' accretion processes are (in)homogenous, a full picture of accretion requires observations spanning a function of luminosity and redshift. For example, there may exist the "X-ray Baldwin effect" (Iwasawa & Taniguchi 1993; Page et al. 2004, 2005): the Fe line equivalent width has been claimed to anti-correlate with L_X across samples of AGN. One possibility to explain this is that relatively higher-luminosity AGN may contain outflows which blast away portions of the circumnuclear, line-emitting gas, creating a lower covering fraction and leading to a lower equivalent width. *eROSITA will play a significant role in these investigations, as described below.*


RXTE–PCA monitoring reveals correlated X-ray continuum and Fe Kα emission line fluxes in the Sy 1.5 NGC 3227

RXTE–PCA monitoring of the radio–loud Seyfert 3C 111: correlated continuum and Fe Kα emission line variations

As revealed by *RXTE* monitoring, a substantial fraction of the line flux responds to continuum variations on a time scale < 700 days in NGC 3227 (Markowitz et al. 2009) or < 60 light-days in 3C 111 (Chatterjee et al. 2011); at least in NGC 3227, the narrow component dominates the total line flux.

What will eROSITA do for AGN & Accretion Science?

Current X-ray missions covering the medium/hard X-ray band allow detailed study of the brightest, low-z AGN only. *RXTE* (and occasionally *Swift*) are the only ones to provide sustained long-term monitoring in this band, though the *RXTE*-PCA's resolution is low compared to *Suzaku* and *XMM-Newton* ($\Delta E/E$ ~ 50 @ 6 keV). *RXTE* is also a non-imaging, background-limited instrument: sources fainter than ~ 3×10^{-12} erg cm^{-2} s^{-1} are inaccessible. Finally, the *RXTE* mission is scheduled to end in December 2011/January 2012.

eROSITA will be the first all-sky X-ray survey since the *ROSAT* All-Sky Survey (RASS), which uncovered ~10^5 AGN in the soft X-ray band (<2 keV). Once *SRG* is launched in 2012, eROSITA's all-sky survey will begin to produce a complete census of AGN in the X-ray band, with excellent sensitivity (down to ~3×10^{-15} erg cm^{-2} s^{-1}), and covering up to 10 keV. Highly-obscured AGN are quite common in the local universe, but they are revealed only in deep exposures and/or at harder X-ray energies (above a few keV), prior surveys conducted with *XMM-Newton* and *Chandra* and covering areas < 1 deg^2 (such as *Chandra*-COSMOS, Elvis et al. 2009) may be missing a large number of them. eROSITA will do this with high effective area and high (CCD-quality) spectral resolution (Predehl et al. 2010), and is thus expected to uncover roughly 10^6 AGN spanning a wide range of luminosities.

eROSITA will thus be the first mission to combine long-term monitoring with high energy resolution (CCD-quality like *XMM-Newton*). **eROSITA will provide the largest X-ray spectral sample of AGNs to date, providing a wealth of information on Fe lines and line of sight absorbers.**

eROSITA will yield time-resolved spectra and multi-band light curves spanning time scales of up to years for a substantial fraction of sources. eROSITA will be sensitive to variations in N_H of up to ~10^{23} cm^{-2}. The ~ a hundred square degrees near the survey poles get mapped with the deepest exposure time; for AGN in this viewing area, eROSITA will be most valuable.

Summary: Overall Impact of eROSITA

The eROSITA spectral monitoring database will thus allow us to pursue several investigations:

Just how clumpy are Seyferts' torii? The eROSITA sample will yield observational constraints for clumpy-torus models; the numbers and types of X-ray-obscured Seyferts detected, and the frequency and duration of obscuration events (detected via time-resolved spectroscopy and/or hardness-ratio light curves), will be related to the probability-dependent line-of-sight column density

How frequently in Seyferts does the optically-thick accretion disk extend to the innermost stable orbit? We will use eROSITA to assess the frequency of occurrence of relativistically broadened Fe Kα lines; resolved lines at CCD resolution can indicate a range of thin-disk structures, ranging from disks around spinning BHs to truncated thin-disks (e.g., inner radius at tens–hundreds of R_{Sch})

What is the location of the narrow Fe line-emitting gas? Complementary to resolving narrow lines with gratings data, long-term monitoring will allow us to quantify the response of the narrow Fe line flux to continuum variations. For line-variable sources, "reverberation" mapping will constrain the location of the line-emitting gas, thereby expanding the sample of objects tested beyond those in the *RXTE* database.

How does the geometry of the accreting material change with luminosity? Studying objects spanning a range in luminosity will allow us to critically test the X-ray Baldwin effect claimed in previous samples and explore models which relate the covering fractions of accreting material to luminosity, e.g., Elitzur & Shlosman (2006).

References: Breedt, E. et al. 2009, MNRAS, 394, 427; Brenneman, L.W. et al. 2011, ApJ, 736, 103; Chatterjee, R. et al. 2011, ApJ, 734, 43; Elitzur, M. & Shlosman, I. 2006, ApJ, 648, L101; Elvis, M., Civano, F., Vignali, C., et al. 2009, ApJS, 184, 158; Hasinger, G., Miyaji, T. & Schmidt, M. 2005, A&A, 441, 417; Iwasawa, K. & Taniguchi, Y. 1993, ApJ, 413, L15; Lamer, G., Uttley, P. & McHardy, I.M. 2003, MNRAS, 342, L41; Markowitz, A., Edelson, R., Vaughan S., et al. 2003, ApJ, 593, 96; Markowitz, A., Reeves, J.N., George, I.M., et al. 2009, ApJ, 691, 922; McHardy, I.M. et al. 2006, Nature, 444, 730; Nandra, K. 2006, MNRAS, 368, L62; Nandra, K., O'Neill, P.M., George, I.M. & Reeves, J.N. 2007, MNRAS, 382, 194; Nenkova, M. et al. 2008, ApJ, 685, 147; Nenkova, M. et al. 2008, ApJ, 685, 160; Patrick, A.R. et al. 2011, MNRAS, 416, 2725; Page, K.L. et al. 2004, MNRAS, 347, 316; Page, K.L. et al. 2005, MNRAS, 364, 195; Predehl, P. et al. 2010, arXiv:1001.2502; Puccetti, S., Fiore, F., Risaliti, G., et al. 2007, MNRAS, 377, 607; Reeves, J.N. et al. 2007, PASJ, 59S, 301; Risaliti, G., Elvis, M. & Nicastro, F. 2002, ApJ, 571, 234; Risaliti, G. et al. 2009, MNRAS, 393L, 1; Shu, X.W., Yaqoob, T., & Wang, J.X. 2010, ApJS, 187, 581; Turner, T.J., Reeves, J.N., Kraemer, S.B. & Miller, L. 2008, A&A, 483, 161; Yaqoob, T. et al 2007, PASJ, 59S, 283; Yencho, B. et al. 2009, ApJ, 698, 380