The Interplay among Black Holes, Stars and ISM in Galactic Nuclei
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The extremes of (X-ray) variability among galaxies: Flares from stars tidally disrupted by supermassive black holes

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Abstract. We discuss follow-up X-ray observations of giant-amplitude, non-recurrent X-ray flares, interpreted as tidal disruptions of stars by supermassive black holes at the centers of the flaring galaxies. The flare observations open up a new window to study supermassive black holes and their environment, and the physics of accretion events, in non-active galaxies.

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1. Introduction

An unavoidable consequence of the existence of supermassive black holes at the centers of non-active galaxies would be occasional tidal disruption of stars and subsequent accretion of their debris by these supermassive black holes (e.g., Hills 1975; Gurzadyan & Ozernoi 1979; Carter & Luminet 1982; Rees 1988). The events would appear as luminous flares of radiation emitted when the stellar debris is accreted by the black hole. Stellar capture and disruption is – apart from accretion of gas and black hole merging – one of the three major processes studied in the context of black hole growth. The relative importance of these three processes in feeding black holes is still under investigation. In particular, tidal capture may play a role in explaining the $M_\bullet - \sigma$ relation of galaxies (e.g., Zhao et al. 2002).

Various aspects of tidal disruption were studied intensely theoretically (see Sect. 3 of Komossa 2002 for references). It is therefore of great interest to see whether these events occur in nature and how frequent they are. This paper concentrates on observations of giant-amplitude X-ray flares from the centers of several (optically non-active) galaxies, and their interpretation in terms of stellar tidal disruption events. Several X-ray outbursts were detected with *ROSAT* (review by Komossa 2002); three optically non-active galaxies and the HII galaxy NGC 5905 (Komossa & Bade 1999) which shows a low-luminosity high-excitation core detected with *HST* (Gezari et al. 2003), either excited by the flare emission, or, perhaps more likely, a permanent very low-luminosity AGN. Here, I summarize recent *Chandra* follow-up observations which allowed some key tests of the previous suggestion (Komossa & Bade 1999) that we have observed flares from stars tidally disrupted by supermassive black holes (see Komossa et al. 2004 for the full results).

2. Chandra imaging and XMM spectroscopy of the late flare phase of RXJ1242-1119

A flare from the direction of the galaxy RX J1242–1119 was detected by *ROSAT* in 1992 with an X-ray luminosity of $L_{\rm x} \simeq 9 \times 10^{43}$ ergs s^{-1} (Komossa & Greiner 1999), which is exceptionally large given the absence of any optical signs of Seyfert activity of RX J1242–1119. We re-observed RX J1242–1119 with *Chandra* and *XMM-Newton* in order to confirm the otpical counterpart, follow the long-term temporal behavior, study the spectral evolution and measure the post-flare spectrum, and to use these results to test the favored outburst model, tidal disruption of a star by a supermassive black hole. Among the few known X-ray flaring galaxies, RX J1242–1119 was our target of choice for follow-up X-ray observations because it flared most recently, so the probability of catching the source in the declining phase - before it had faded away completely - was highest.

The *Chandra* data allowed to locate precisely the counterpart of the X-ray source which coincides with the center of the galaxy RXJ1242-1119A. The X-ray emission is pointlike, and the X-ray flux dropped dramatically by a factor ∼200.

With *XMM*, for the first time a a good-quality X-ray spectrum of one of the few flaring galaxies was obtained. The spectrum is well fit by a power law (photon index $\Gamma_{\rm x} = -2.5$). There is no evidence for excess absorption, and the post-flare spectrum is harder than the flare maximum.

Compared with the blue luminosity of RX J1242–1119A, inferred from the extinction-corrected blue magnitude $m_{B,0} = 17.43$ mag measured with the Optical Monitor aboard *XMM* (Komossa et al. 2004), the X-ray emission of this galaxy is still very high, even in its low state. A further decline of the X-ray emission is expected as more and more of the stellar debris is accreted by the black hole. Continued monitoring of RX J1242–1119 with *Chandra* is in progress, in order to follow further the late stages of tidal disruption.

3. Joint X-ray lightcurve of the flare events

Two more *ROSAT* flares were followed up with *Chandra* and data for a third one are expected soon. Only few, if any, photons from the galaxies centers were detected, making their total amplitude of variability extremely large, a factor >1000 (NGC 5905; Halpern et al. 2004) and >6000 (RXJ1624+75; Halpern et al. 2004, Vaughan et al. 2004).

Fig. 1 shows the collective X-ray lightcurve of the flare events, shifted in time to the same high-state time as NGC 5905. The lightcurves of all events are relatively similar, and consistent with a faster rise, and a slower decline on the timescale of months - years.

The observed events match basic predictions expected from stars tidally disrupted by supermassive black holes at the centers of the flaring galaxies (see Komossa & Bade 1999, Komossa 2002, and Komossa et al. 2004 for a much more detailed discussion).

4. Future applications of tidal disruption flares

The search for more tidal disruption flares is presently ongoing using *Chandra* and *XMM* data. In particular, future X-ray surveys should be efficient in finding more events, like the surveys planned with *DUO*, the *LOBSTER* ISS X-ray all-sky monitor, *ROSITA* and *MAXI*. Dedicated X-ray follow-up observations with high spectral and temporal resolution might allow to follow the complex stellar debris evolution in detail, and, e.g., search for signs of relativistic precession.

After the discovery of new X-ray flares from *non-active* galaxies, *rapid follow-up multi-wavelength* observations will be essential. If the soft X-ray flare emission has an extension into the EUV, which is highly likely, then optical observations will be important in order to detect potential emission lines that were excited by the outburst emission. Any gaseous material close to the nucleus is expected to show an emission-line response. The time variability of these lines will allow a reverberation mapping of the circumnuclear gas; line profiles, and line-ratios will allow to estimate the velocity structure and physical

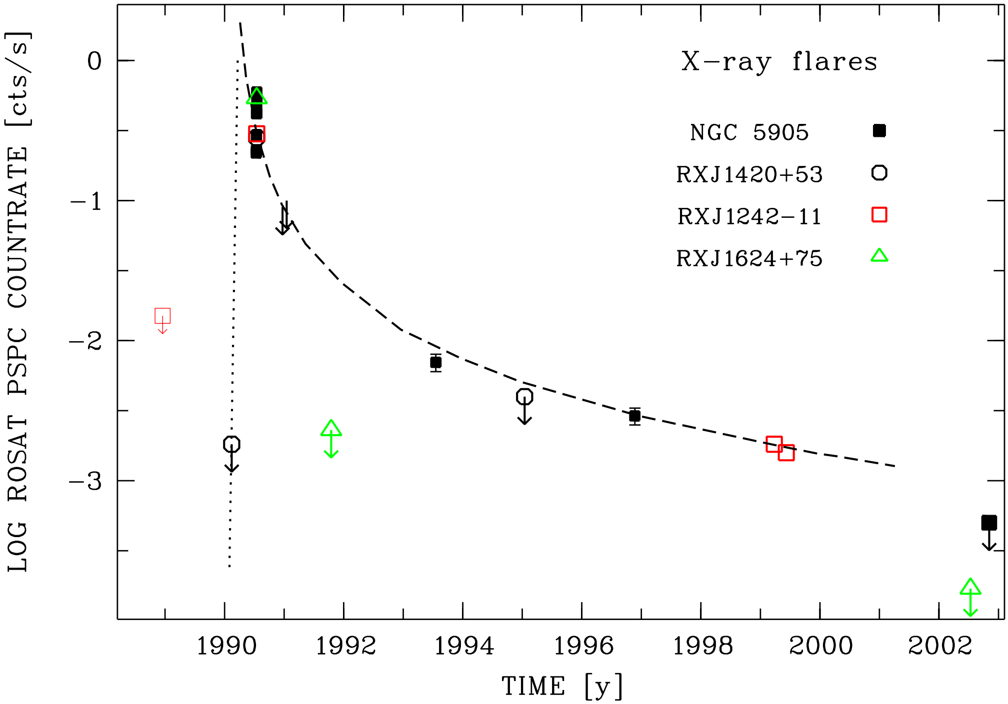

Figure 1. X-ray lightcurves of the four flaring galaxies, all shifted to the same high-state time. The dashed line follows a $t^{-5/3}$ law, compared to the data of RXJ 1242-1119. The last data point for NGC 5905 (arrow; Halpern et al. 2004) is an upper limit on any core emission while previous data points are the sum of core and extended emission, not resolved by previous missions.

conditions (density, abundances) of this gas. Results would also allow us to address important questions related to the link between active and non-active galaxies: e.g, do these (in quiescence non-active) galaxies permanently harbor a braod-line region (BLR) which is usually invisible, because the black hole is not accreting, or is the BLR absent ?

If a long-lasting, relatively stable accretion disk forms from the stellar debris, the outer parts of that disk itself may radiate emission lines, as suggested to be the case in the LINER NGC 1097 (Storchi-Bergmann et al. 2003).

Finally, it is interesting to note that tidal capture of compact sources (NS, BH) at the centers of galaxies or capture of main sequence stars at the center of our galaxy might produce gravitational wave radiation strong enough for detection with *LISA* (e.g., Sirgudsson 2003).

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