X-ray outbursts from nearby ‘normal’ and active galaxies
a review, new radio observations, and an X-ray search for further
tidal disruption flares

Stefanie Komossa and Michael Dahlem

1 Max-Planck-Institut für extraterrestrische Physik, Giessenbachstr., D-85748 Garching, Germany
2 European Southern Observatory, Casilla 19001, Santiago 19, Chile
E-mail (StK): skomossa@mpe.mpg.de

Abstract
In the last few years, giant-amplitude, non-recurrent X-ray flares have been observed from several non-active galaxies (NGC 5905, RXJ1242-11, RXJ1624+75, RXJ1420+53, RXJ1331-32). All of them share similar properties, namely: extreme X-ray softness in outburst, huge peak luminosity (up to \( \sim 10^{44} \text{erg/s} \)), and the absence of optical signs of Seyfert activity. Tidal disruption of a star by a supermassive black hole is the favored explanation of these unusual events.

We present a review of the previous results, a search for radio emission from all outbursters, based on the NVSS database, and dedicated radio observations of NGC 5905 carried out with the VLA. These provide important constraints on the presence of an (obscured) active nucleus (AGN) at the center of each flaring galaxy.

We rigorously explore AGN scenarios to account for the unusual X-ray outbursts from the optically ‘normal’ galaxies and find AGN-related models highly unlikely. We conclude that the previously favored scenario – tidal disruption of a star by a supermassive black hole at the center of each of the outbursters – provides the best explanation for the X-ray observations.

Finally, we present results from our on-going search for further X-ray flares from a sample of \( \sim 140 \) nearby active and non-active galaxies, using the \textit{ROSAT} data base. While we do not find another X-ray flaring normal galaxy among this sample – entirely consistent with the predictions of the tidal disruption scenario – several highly variable active galaxies are detected. Their variability is not linked to tidal disruption, but best explained in terms of absorption or accretion-disk-related models.

Key words: galaxies: X-ray flares — tidal disruption — non-active galaxies — active galaxies — radio observations — individual objects: NGC 5905, RXJ1242-1119, RXJ1624+7554, RXJ1420+5334, RXJ1331-3243

1. The search for supermassive black holes at the centers of galaxies, and flares from tidally disrupted stars as probes

There is strong evidence for the presence of massive dark objects at the centers of many galaxies. Does this hold for \textit{all} galaxies? Questions of particular interest in the context of AGN evolution are: what fraction of galaxies have passed through an active phase, and how many now have non-accreting and hence unseen supermassive black holes (SMBHs) at their centers (e.g., Rees 1989)?

Several approaches were followed to study these questions. Much effort has concentrated on deriving central object masses from studies of the \textit{dynamics of stars and gas} in the nuclei of nearby galaxies. Earlier (ground-based) evidence for central quiescent dark masses in non-active galaxies has been strengthened by recent HST results (see Kormendy & Richstone 1995 for a review). There is now excellent evidence for a SMBH in our galactic center as well (Eckart & Genzel 1996).

Whereas the dynamics of stars and gas probe rather large volumes, i.e., distances from the SMBH, high-energy X-ray emission originates from the very vicinity of the SMBH (see Komossa 2001 for a review). In \textit{active} galaxies, excellent evidence for the presence of SMBHs is provided by the detection of luminous hard power-law like X-ray emission, rapid variability, and the detection of relativistically broadened FeK\( \alpha \) lines (e.g., Tanaka et al. 1995). How can we find \textit{dormant} SMBHs in non-
active galaxies? Lidskii & Ozernoi (1979) and Rees (1988, 1990) suggested to use the flare of electromagnetic radiation produced when a star is tidally disrupted and accreted by a SMBH as a means to detect SMBHs in nearby non-active galaxies.

Historically, tidal disruption of stars by black holes was first considered in relation to star clusters (e.g., Frank & Rees 1976), and was applied to the nuclei of active galaxies where it was suggested as a means of fueling AGN (e.g., Hills 1975), or to explain UV-X-ray variability of AGN (e.g., Kato & Hoshi 1978).

Depending on its trajectory, a star gets tidally disrupted after passing a certain distance to the black hole (e.g., Hills 1975, Lidskii & Ozernoi 1979, Diener et al. 1997), the tidal radius, given by

$$r_t \approx r_*(\frac{M_{BH}}{M_*})^{\frac{1}{3}}.$$  

(1)

The star is first heavily distorted, then disrupted. About 75% of the gaseous debris becomes unbound and is lost from the system (e.g., Young et al. 1977, Ayal et al. 2000). The rest will eventually be accreted by the black hole (e.g., Cannizzo et al. 1990, Loeb & Ulmer 1997).

Depending on its trajectory, a star gets tidally disrupted after passing a certain distance to the black hole (e.g., Hills 1975, Lidskii & Ozernoi 1979, Diener et al. 1997), the tidal radius, given by

$$r_t \approx r_*(\frac{M_{BH}}{M_*})^{\frac{1}{3}}.$$  

(1)

The star is first heavily distorted, then disrupted. About 75% of the gaseous debris becomes unbound and is lost from the system (e.g., Young et al. 1977, Ayal et al. 2000). The rest will eventually be accreted by the black hole (e.g., Cannizzo et al. 1990, Loeb & Ulmer 1997).

The debris, first spread over a number of orbits, quickly circularizes (e.g., Rees 1988, Cannizzo et al. 1990) due to the action of strong shocks when the most tightly bound debris interacts with other parts of the stream (e.g., Kim et al. 1999). Most orbital periods will then be within a few times the period of the most tightly bound matter (e.g., Evans & Kochanek 1989; see also Nolthenius & Katz 1982, Luminet & Marck 1985).

A star will only be disrupted if its tidal radius lies outside the Schwarzschild radius of the black hole, else it is swallowed as a whole (this happens for black hole masses larger than a few \(\times 10^7 M_\odot\); in case of a Kerr black hole, tidal disruption may occur even for larger BH masses if the star approaches from a favorable direction (Beloborodov et al. 1992)). Larger BH masses may still strip the atmospheres of giant stars. Most theoretical work so far focussed on stars of solar mass and radius.

Explicit predictions of the emitted spectrum and luminosity during the disruption process and the start of the accretion phase are still rare (see Sect. 4.2 for details). The emission is likely peaked in the soft X-ray or UV portion of the spectrum, initially (e.g., Rees 1988, Kim et al. 1999, Cannizzo et al. 1990; see also Sembay & West 1993).

2. Tidal disruption flares from non-active galaxies

With the X-ray satellite ROSAT (Trümper 1983), some rather unusual observations have been made in the last few years: the detections of giant-amplitude, non-recurrent X-ray outbursts from a handful of optically non-active galaxies, starting with the case of NGC 5905 (Bade et al. 1996, Komossa & Bade 1999). Based on the huge observed outburst luminosity, the observations were interpreted in terms of tidal disruption events. Below, we first give a brief review of all published X-ray flaring non-active galaxies\(^{\dagger}\), and then present new radio observations.

There are now four X-ray flaring ‘normal’ galaxies (NGC 5905, RXJ1242-1119, RXJ1624+7554, RXJ1420+5334\(^{\ddagger}\)), and a possible fifth candidate (RXJ1331-3243), all of which show similar properties:

- huge X-ray peak luminosity (up to \(\sim 10^{44}\) erg/s),
- giant amplitude of variability (up to a factor \(\sim 200\)),
- ultra-soft X-ray spectrum (\(kT_{bb} \approx 0.04-0.1\) keV when a black body model is applied),

\(^{\dagger}\) Although not discussed in detail here, we note that during the last several years, tidal disruption was also occasionally invoked to explain some peculiar properties of active galaxies, although alternative interpretations existed in each case: Tidal disruption was applied by Eracleous et al. (1995) in a duty cycle model to explain the UV brightness/darkness of LINERs. Peterson & Ferland (1986) suggested this mechanism as possible explanation for the transient brightening and broadening of the HeII line observed in the Seyfert galaxy NGC 5548. Variability in the Balmer lines of some AGN (the appearance and disappearance of a broad component in H\(\beta\) or H\(\alpha\)) has recently been interpreted in the same way. Brandt et al. (1995) reported the detection of an X-ray outburst from the galaxy IC 3599 (Zwicky 159,034). Besides other outburst mechanisms, tidal disruption was briefly mentioned as possibility (see also Grupe et al. 1995). Based on high-resolution post-outburst optical spectra, Komossa & Bade (1999) classified IC3599 as Seyfert type 1.9. In the UV spectral region, two UV spikes were detected at and near the center of the elliptical galaxy NGC 4552. The central flare was interpreted by Renzini et al. (1995) as accretion event (the tidal stripping of a star’s atmosphere by a SMBH, or the accretion of a molecular cloud). There are several indications (e.g., from radio observations), that NGC 4552 shows permanent low-level activity (see Komossa 1999 for a more complete review on this subject). The X-ray position error circle of RXJ1420+53 contains a second galaxy for which a spectrum is not yet available. Based on the galaxy’s morphology, Greiner et al. (2000) argue that it is likely non-active.

\(^{\ddagger}\) Numerical simulations of the disruption process, the stream-stream collision, the accretion phase, the change in angular momentum of the black hole, the changes in the stellar distribution of the surroundings, and the disruption rates have been studied in the literature (e.g., Nihara 1971, Masshoo 1975, Nolthenius & Katz 1982, 1983, Carter & Luminet 1985, Luminet & Marck 1985, Evans & Kochanek 1989, Laguna et al. 1993, Diener et al. 1997, Ayal et al. 2000, Ivanov & Novikov 2001; Lee et al. 1995, Kim et al. 1999; Hills et al. 1975, Gurzadyan & Ozernoi 1979, 1980, Cannizzo et al. 1990, Loeb & Ulmer 1997, Ulmer et al. 1998; Beloborodov et al. 1992; Frank & Rees 1976, Rauch & Ingalls 1998, Rauch 1999; Syer & Ulmer 1999, Magorrian & Tremaine 1999). DiStefano et al. (2001) recently considered the case of \(M > M_\odot\), and suggested that some ultra-soft X-ray sources (like the one at the center of M31) could be the remnants of tidally stripped stars.
NVSS source was already reported by Grupe et al. 1999. Mean luminosity during the outburst; since the flux varied by a factor unlikely. It is very important, though, to discussed by Komossa & Bade (1999) this possibility is AGN at the center of each flaring galaxy. As already scenario is the presence of a peculiar, optically hidden A potential alternative to the favored tidal disruption 2.1. decline on a time scale of months to years. 'merged' lightcurve is consistent with a fast rise and a The last column summarizes our results on the radio properties of the galaxies.

| galaxy name       | z    | $kT_{bb}$ [keV] | $L_{bb}$ [erg/s] | radio results                                      |
|-------------------|------|----------------|------------------|---------------------------------------------------|
| NGC 5905          | 0.011| 0.06           | $3 \times 10^{42}$ | no 8.5 GHz core source: $f < 0.15 \text{ mJy} \rightarrow L < 10^{20} \text{ W/Hz}$ extended NVSS emission at 1.4 GHz, flux $f_{1.4} = 21.4 \text{ mJy}$ |
| RXJ1242–1119      | 0.050| 0.06           | $9 \times 10^{43}$ | no NVSS detection (closest source is 4.6' away)   |
| RXJ1624+7554      | 0.064| 0.097          | $\sim 10^{44}$   | no NVSS detection (closest source is 7.1' away)** |
| RXJ1420+5334      | 0.147| 0.04           | $8 \times 10^{43}$ | no NVSS detection (closest source is 3.3' away)   |
| RXJ1331+3243      | 0.051|                |                  | no NVSS detection (closest source is 89' away)    |

*Mean luminosity during the outburst; since the flux varied by a factor $\sim 3$ during the observation, the peak luminosity is higher. ** Absence of NVSS source was already reported by Grupe et al. 1999.

- absence of optical signs of Seyfert activity (the spectrum of NGC 5905 is of HII-type; the other galaxies do not show any emission lines).

A summary of the observations is provided in Table 1. In Fig. 1 we have overplotted the X-ray lightcurves of NGC 5905 and RXJ1420+53, shifted in time to the same date of outburst to allow direct comparison. So far, the best sampled lightcurve is that of NGC 5905. The 'merged' lightcurve is consistent with a fast rise and a decline on a time scale of months to years.

2.1. Radio observations
A potential alternative to the favored tidal disruption scenario is the presence of a peculiar, optically hidden AGN at the center of each flaring galaxy. As already discussed by Komossa & Bade (1999) this possibility is unlikely. It is very important, though, to exclude the presence of an AGN. Besides hard X-ray observations, compact radio emission is a good indicator of AGN activity because radio photons can penetrate even high-column density dusty gas which is not transparent to optical or soft X-ray photons.

2.1.1. NVSS search for radio emission from the X-ray outbursters
We have performed a search for radio emission from the X-ray flaring galaxies. We used the NRAO VLA Sky Survey (NVSS) catalogue (Condon et al. 1998) which contains the results of a 1.4 GHz radio sky survey north of $\delta = -40^\circ$. The survey reaches a limiting source brightness of $\sim 2.5 \text{ mJy/beam}$. Except NGC 5905, no flaring galaxy has a NVSS detection. The emission of NGC 5905 appears extended and is thus likely related to the galaxy instead of the nucleus (see also next Section).

2.1.2. VLA 8.5 GHz observations of NGC 5905
In order to search for a radio source at the nucleus of NGC 5905 we have carried out a radio observation with the VLA A array at 8.46 GHz. The observation was performed on November 3, 1996 with a duration of 2380 sec. The band width was 100 MHz. A resolution of about 0.2" was achieved.

No radio source is detected within the central field of view of $100'' \times 100''$. Based on the background noise level, we derive a 5$\sigma$ upper limit for the presence of a central point source of 0.15 mJy. Assuming a distance of 75.4 Mpc of NGC 5905 this translates into an upper limit on the luminosity of $L_{8.46 \text{ GHz}} \leq 1.0 \times 10^{20} \text{ W/Hz}$.

3. Outburst scenarios
3.1. Alternatives to tidal disruption
3.1.1. Stellar sources, lensing, GRBs
Firstly, we note that based purely on a positional coincidence, interlopers (flaring Galactic foreground objects) could not be completely excluded, given the limited spatial positional accuracy of ROSAT of at least several arc-seconds. However, known populations of galactic flaring sources show different temporal properties. Furthermore, in the case of the nearby galaxy NGC 5905 we can clearly locate the X-ray emission at the nuclear region of this galaxy.

Other sources of the X-ray emission related to sources within the galaxies NGC 5905 and RXJ1242–11 were reviewed by Komossa & Bade (1999) in some detail, in-

* In the other cases, X-ray error circles are larger. The superb spatial resolution of Chandra will provide a crucial test, by precisely locating the post-flare X-ray emission which should coincide with the nucleus of each flaring galaxy.
including some order of magnitude estimates: Most outburst scenarios do not survive close scrutiny, because they cannot account for the huge maximum luminosity (e.g., X-ray binaries within the galaxies, or a supernova in a dense medium), are inconsistent with the optical observations (gravitational lensing), or predict a different temporal behavior (X-ray afterglow of a Gamma-ray burst).

### 3.1.2. AGN-related scenarios

Standard AGN scenarios cannot account for the X-ray flares and the absence of optical AGN-like emission lines (Komossa & Bade 1999). Below, we describe more complicated AGN scenarios, and why we consider them unlikely.

#### 3.1.2.1. Scenario (1): pure source variability; accretion-disk instability in an LLAGN

Basic idea: We have a direct view on the central engine. The observed variability is caused by some accretion-disk instability mechanism (e.g., Honma et al. 1991). In that case, we already know: if there is an AGN at all in NGC 5905, it is a low-luminosity AGN (LLAGN) because $L_{X,\text{low-state}} \approx 4 \times 10^{40}$ erg/s is observed. Such luminosities have been seen in LINERs, but they are not strongly X-ray variable (e.g., Komossa et al. 1999). A similar number ($10^{40-41}$ erg/s) should hold for RXJ1242-11 and the other outbursters because, if they had $10^{42}$ erg/s or more in low-state, we should have detected NLR emission lines. A low-state luminosity of $10^{40-41}$ erg/s would make the total amplitude of variability of RXJ1242-11, RXJ1624+75, RXJ1420+53, and RXJ1331-32 giant: a factor $10^{3-4}$. When trying to explain this with AGN-related scenarios, it has to be kept in mind that such variability has never been observed in known AGN.

#### 3.1.2.2. Scenario (2): pure absorption variability; orbiting cold, dusty absorber with a ‘hole’

Basic scenario: The AGN is absorbed by a cold absorber in nearly all directions. If this absorber has a hole, and if this hole passes our line-of-sight, we have a short view on the intrinsic AGN, thus see a flare. Instead of an ‘orbiting hole’, an ensemble of clouds, covering the intrinsic source most of the time, might produce occasional non-shadowing of the central source. Such a scenario is invoked by Risaliti & Elvis (2001) to explain the variable cold absorption detected in many Seyfert 2 galaxies. In order to shield the NLR totally, the cold material would have to be dusty and cover nearly $4\pi$. However, this model does not explain the extreme X-ray softness of the outbursters. If we have a short glimpse on a ‘normal’ AGN, we would expect to see a more typical AGN spectrum in high-state.

#### 3.1.2.3. Scenario (3): source + absorption variability; intrinsic source variability plus related variability in the ionization state of an absorber

Basic idea: Presence of an AGN which is surrounded by an absorber. The AGN is intrinsically variable. In high-state, the originally cold absorber becomes a warm absorber. Ionized absorption then automatically explains the very soft X-ray spectrum in the ROSAT band (see Komossa & Bade 1999 for explicit spectral fits). In source low-state, the absorber is cold and absorption is complete in the ROSAT band. Medium-amplitude source variability would then cause high-amplitude observed variability.

This model cannot account for the absence of optical emission lines. They can only be shielded if dust is mixed with the ionized absorber. The model of a dusty warm absorber does no longer provide a successful X-ray spectral fit to NGC 5905, though (Komossa & Bade 1999).

### 3.2. Tidal disruption model

Except for GRB-related emission mechanisms, the huge peak outburst luminosity nearly inevitably calls for the presence of a SMBH. This, in combination with the complete absence of any signs of AGN activity from all wavebands, makes tidal disruption of a star by a SMBH the most plausible outburst mechanism.

Intense electromagnetic radiation will be emitted in three phases of the disruption and accretion process: First, during the stream-stream collision when different parts of the bound stellar debris first interact with themselves (Rees 1988). Kim et al. (1999) have carried out numerical simulations of this process and find that the initial burst due to the collision may reach a luminosity of $10^{44}$ erg/s, under the assumption of a BH mass of $10^{6}$ M$_{\odot}$ and a star of solar mass and radius. Secondly, radiation is emitted during the accretion of the stellar gaseous debris. Finally, the unbound stellar debris leav-
ing the system may shock the surrounding interstellar matter and cause intense emission.

The luminosity emitted if the black hole is accreting at its Eddington luminosity can be estimated by \( L_{\text{edd}} \simeq 1.3 \times 10^{38} M/M_\odot \text{erg/s} \). In case of NGC 5905, a BH mass of at least \( 10^5 M_\odot \) would be required to produce the observed \( L_x \), and a higher mass if \( L_x \) was not observed at its peak value. For comparison, BH masses of \( M_{\text{BH}} \lesssim 10^{5–7} M_\odot \) have recently been reported by Salucci et al. (2000) for the centers of several late-type spiral galaxies. Alternatively, the atmosphere of a giant star could have been stripped instead of a complete disruption event. It is interesting to note that NGC 5905 possesses a complex bar structure (Wozniak et al. 1995, Friedli et al. 1996) which might aid in the fueling process by disturbing the stellar velocity fields.

Using the black body fit to the X-ray spectra of NGC 5905 and RXJ1242–11, we find the fiducial black body radius to be located between the last stable orbit of a Schwarzschild black hole, and inside the tidal radius.

We note that many details of the tidal disruption and the related processes are still unclear. In particular, the flares cannot be standardised. Observations would depend on many parameters, like the type of disrupted star, the impact parameter, the spin of the black hole, effects of relativistic precession, and the radiative transfer is complicated by effects of viscosity and shocks (Rees 1990). Uncertainties also include the amount of the stellar debris that is accreted (part may be ejected as a thick wind, or swallowed immediately). Related to this is the duration of the flare-like activity, which may be months or years to tens of years (e.g., Rees 1988, Cannizzo et al. 1990, Gurzadyan & Ozernoi 1979).

4. Search for further X-ray flares

We performed a search for further cases of strong X-ray variability using the sample of nearby galaxies of Ho et al. (1995) and ROSAT all-sky survey (Voges et al. 1999) and archived pointed observations. The sample of Ho et al. has the advantage of the availability of high-quality optical spectra, which are necessary when searching for ‘truly’ non-active galaxies. 136 out of the 486 galaxies in the catalogue were detected in pointed observations. For these, we compared the countrates with those measured during the RASS.

4.1. Non-active galaxies

We do not find another flaring normal galaxy.

The absence of any further flaring event among the sample galaxies is entirely consistent with the expected tidal disruption rate of one event in at least \( \sim 10^4 \) years per galaxy (e.g., Magorrian & Tremaine 1999).

4.2. AGN

Several of the sample galaxies show variability by a factor 10–30. All of these are well-known AGN.

Many active galactic nuclei are variable in X-rays with a range of amplitudes, typically a factor 2–3, and on many different time scales (e.g., Mushotzky et al. 1993). The cause of variability is usually linked in one way or another to the central engine; for instance by changes in the accretion disk (e.g., Piro et al. 1988, 1997), or by variable obscuration (e.g., Komossa & Fink 1997, Komossa & Meerschweinchen 2000).

As an example for a highly variable AGN among the present sample galaxies, we show in Fig. 2 the long-term ROSAT X-ray lightcurve of NGC 4051 which exhibits variability in countrate of a factor \( \sim 30 \). Only a small part of the variability of NGC 4051 can be explained with a variable warm absorber, the rest is likely intrinsic.

Even higher total amplitude of variability is detected in two subsequent ROSAT observations of NGC 3516. The X-ray countrate varies by a factor \( \sim 50 \) (Komossa & Bade 1999, Komossa & Halpern 2001, in prep.); variable cold absorption likely plays a major part in explaining the observations.

5. Future perspectives

X-ray outbursts from non-active galaxies provide important information on the presence of SMBHs in these galaxies, and the link between active and normal galaxies. Future X-ray surveys, like those planned with the LOBSTER ISS X-ray all-sky monitor (Fraser 2001), MAXI (Mihara 2001), and ROSITA (Predehl 2001), will be valuable in finding more of these outstanding sources.

In particular, rapid follow-up optical observations will be important in order to detect potential emission lines that were excited by the outburst emission. In case a giant-amplitude X-ray flare occurs in an active galaxy,
this would also provide an excellent chance to map the properties of the broad line region.

Acknowledgements: It is a pleasure to thank Jules Halpern, Martin Elvis, and David L. Meier for fruitful discussions. The ROSAT project has been supported by the German Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie (BMBF/DLR) and the Max-Planck-Society. Preprints of this and related papers can be retrieved at http://www.xray.mpe.mpg.de/~skomossa/

References
Ayal S., Livio M., Piran T., 2000, ApJ 545, 772
Bade N., Komossa S., Dahlem M., 1996, A&A 309, L35
Beloborodov A.M., Illarionov A.F., Ivanov P.B., Polnarev A.G., 1992, MNRAS 259, 209
Brandt W.N., Pounds K.A., Fink H.H., 1995, MNRAS 273, L47
Cannizzo J.K., Lee H.M., Goodman J., 1990, ApJ 351, 38
Carter B., Luminet J.P., 1985, MNRAS 212, 23
Condon J.J., Cotton W.D., Greisen E.W., et al., 1998, AJ 115, 1693
Diener P., Frolov V.P., Khokhlov A.M., Novikov I.D., Pethick C.J., 1997, ApJ 479, 164
Di Stefano R., Greiner R., Murray S., Garcia M., 2001, ApJL, in press
Eckart A., Genzel R., 1996, Nature 383, 415
Eracleous M., Livio M., Binette L., 1995, ApJ 445, L1
Evans C.R., Kochanek C.S., 1989, ApJ 346, L13
Frank J., Rees M.J., 1976, MNRAS 176, 633
Fraser G., 2001, in: MAXI workshop on AGN variability, these proceedings
Friedli D., Wozniak H., Rieke M., Martinet L., Bratschi P., 1996, A&AS 118, 461
Greiner J., Schwarz R., Zharikov S., Ori o M., 2000, A&A 362, L25
Grupe D., Beuermann K., Mannheim K., et al., 1995, A&A 299, L5
Grupe D., Leighly K., Thomas H., 1999, A&A 351, L30
Gurzadyan V.G., Ozernoi L.M., 1979, Nature 280, 214
Gurzadyan V.G., Ozernoi L.M., 1980, A&A 86, 315
Hills J.G., 1975, Nature 254, 295
Ho L.C., Filippenko A.V., Sargent W.L.W., 1995, ApJS 98, 477
Honma F., Matsumoto R., Kato S., 1991, PASJ 43, 147
Ivanov P.B., Novikov I.D., 2001, ApJ 549, 467
Kato M., Hoshi R., 1978, Prog. Theor. Phys. 60/6, 1692
Kim S.S., Park M.-G., Lee H.M., 1999, ApJ 519, 647
Komossa S., Fink H., 1997, A&A 327, 555
Komossa S., Bade N., 1999, A&A 343, 775
Komossa S., Böhringer H., Huchra J., 1999, A&A 349, 88
Komossa S., Greiner J., 1999, A&A 349, L45
Komossa S., 1999, in Proc: ASCA/ROSAT Workshop on AGN and the X-ray Background, T. Takahashi, H. Inoue (eds), ISAS Report, p. 149; [also available at astro-ph/0001263]
Komossa S., Meerschweinchen J., 2000, A&A 354, 411
Komossa S., 2001, in Proc: IX. Marcel Grossmann Meeting on General Relativity, Gravitation and Relativistic Field Theories, V. Gurzadyan et al. (eds), in press astro-ph/0101289
Kormendy J., Richstone D.O., 1995, ARA&A 33, 581
Laguna P., Miller W.A., Zurek W.H., Davies M.B., 1993, ApJ 410, L83
Lee H.M., Kang H., Ryu D., 1995, ApJ 464, 131
Lidskii V.V., Ozernoi L.M., 1979, Sov. Astron. Lett. 5(1), 16
Loeb A., Ulmer A., 1997, ApJ 489, 573
Luminet J.P., Marcck J.-A., 1985, MNRAS 212, 57
Magorrian J., Tremaine S., 1999, MNRAS 309, 447
Mashoon B., 1975, ApJ 197, 705
Mihara T., 2001, in: MAXI workshop on AGN variability, these proceedings
Mushotzky R.F., Done C., Pounds K.A., 1993, ARA&A 31, 717
Nolthenius R.A., Katz J.I, 1982, ApJ 263, 377
Nolthenius R.A., Katz J.I, 1983, ApJ 269, 297
Peterson B.M., Ferland G.J., 1986, Nature 324, 345
Piro L., Massaro E., Perola G.C., Molteni D., 1988, ApJ 325, L25
Piro L., et al., 1997, A&A 319, 74
Predehl P., 2001, in: MAXI workshop on AGN variability, these proceedings
Rauch K.P., 1999, ApJ 514, 725
Rauch K.P., Ingalls B., 1998, MNRAS 299, 1231
Rees M.J., 1988, Nat 333, 523
Rees M.J., 1989, Rev. mod. Astr. 2, 1
Rees M.J., 1990, Science 247, 817
Reiprich T., Greiner J., 2001, in Proc: ESO workshop on black holes in binaries and AGN, p. 168
Renzini A., et al., 1995, Nature 378, 39
Risaliti G., Elvis M., 2001, ApJ, submitted
Salucci P., Ratnam C., Monaco P., Danese L., 2000, MNRAS 317, 488
Sembay S., West R.G., 1993, MNRAS 262, 141
Syer D., Ulmer A., 1999, MNRAS 306, 35
Tanaka Y., et al., 1995, Nature 375, 659
Trümper J., 1983, Adv. Space Res. 2, 241
Ulmer A., Paczynski B., Goodman J., 1998, A&A 333, 379
Voges W., et al., 1999, A&A 349, 389
Wozniak H., Friedl D., Martinet L., Martin P., Bratschi P., 1995, ApJS 111, 115
Young P., Shields G., Wheeler J.C., 1977, ApJ 212, 367