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A caleidoscopic view of Active Galactic Nuclei

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Abstract. The central kiloparsec of galaxies contains in many cases an active nucleus. It is therefore fully justified to describe nuclear activity in this conference. The title refers to the fact that some disconnected aspects of nuclear activity will be discussed here. A comprehensive review of AGN activity is clearly beyond the scope of this presentation.
We will first present INTEGRAL hard X-ray observations of the center of our Galaxy. We will then give an update on the multi-wavelength studies we are doing on the bright quasar 3C 273 and finish with a discussion of the role that shocks may play in the transfer of energy from the gravitational energy of accreted nuclei to the radiating electrons.

Key words. Galaxies: active – Galaxy: center

1. Introduction

It is increasingly clear that active nuclei and galaxies live intimately related lives. This has been evident from the beginning onward in the sense that the matter accreted in the deep well created by the supermassive black holes at the origin of the nuclear activity must come from the surrounding galaxy. It is now also emerging that the properties of the surrounding galaxy depend on the nucleus. This is ample reason to link in a conference normal and active galaxies. This is also the case in this presentation during which the variability of one of the most luminous quasars, 3C 273, will be discussed together with some ideas on the accretion process, but during which recent INTEGRAL results on the center of our Galaxy will also be presented. These observations suggest that the center of our Galaxy may well have been considerably brighter in the last centuries, although still far from the Eddington luminosity corresponding to the mass of the black hole.

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2. The Galactic center observed with INTEGRAL

INTEGRAL is a hard X-ray observatory (Winkler et al. 2003) sensitive between few keV and 10 MeV. The ISGRI instrument (Lebrun et al. 2003) provides observations with an angular resolution of 12' from 15 keV to hundreds of keV. This instrument was used repeatedly to observe the central regions of the Galaxy. See Belanger et al. (2004) and Belanger et al. (2006) for a description of these observations. Although the angular resolution of ISGRI is not sufficient to avoid source confusion in this crowded region of the sky, the galactic center Sgr A^* is detected and its flux found to be constant on the timescales

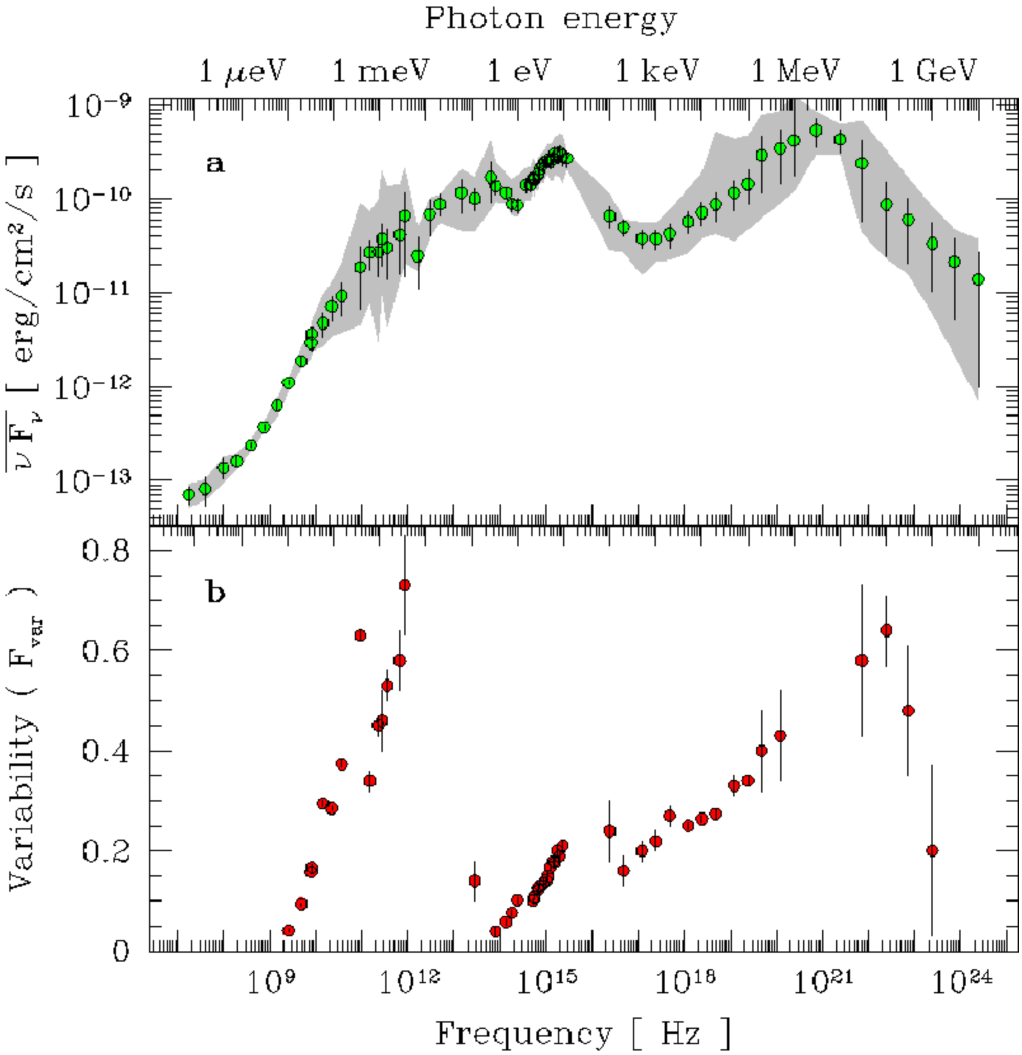

Fig. 1. The time averaged spectrum of 3C 273 (top panel), the grey zone indicates the range of variations observed and the amplitude of the variations (bottom panel) as a function of photon frequency from Soldi et al. (2008)

observed. The luminosity of the INTEGRAL source at a distance of 8 kpc is found to be 5.37±0.21 $\times 10^{35}$ ergs s^{-1} (Belanger et al. 2006).

Kuulkers et al. (2007) have conducted a programme on the galactic center in order to probe the variability properties of the hard X-ray sources. The field is observed every revolution of INTEGRAL (i.e. once per 3 days) during all the periods for which the galactic center is observable by INTEGRAL. The average image they obtained is shown in Fig. 2. The film obtained from the sequence of galactic center observations from February 2005 to April 2006 is available at http://isdc.unige.ch under "images". It shows how all the sources vary and that, at times, none of the bright X-ray sources are visible in these relatively short INTEGRAL

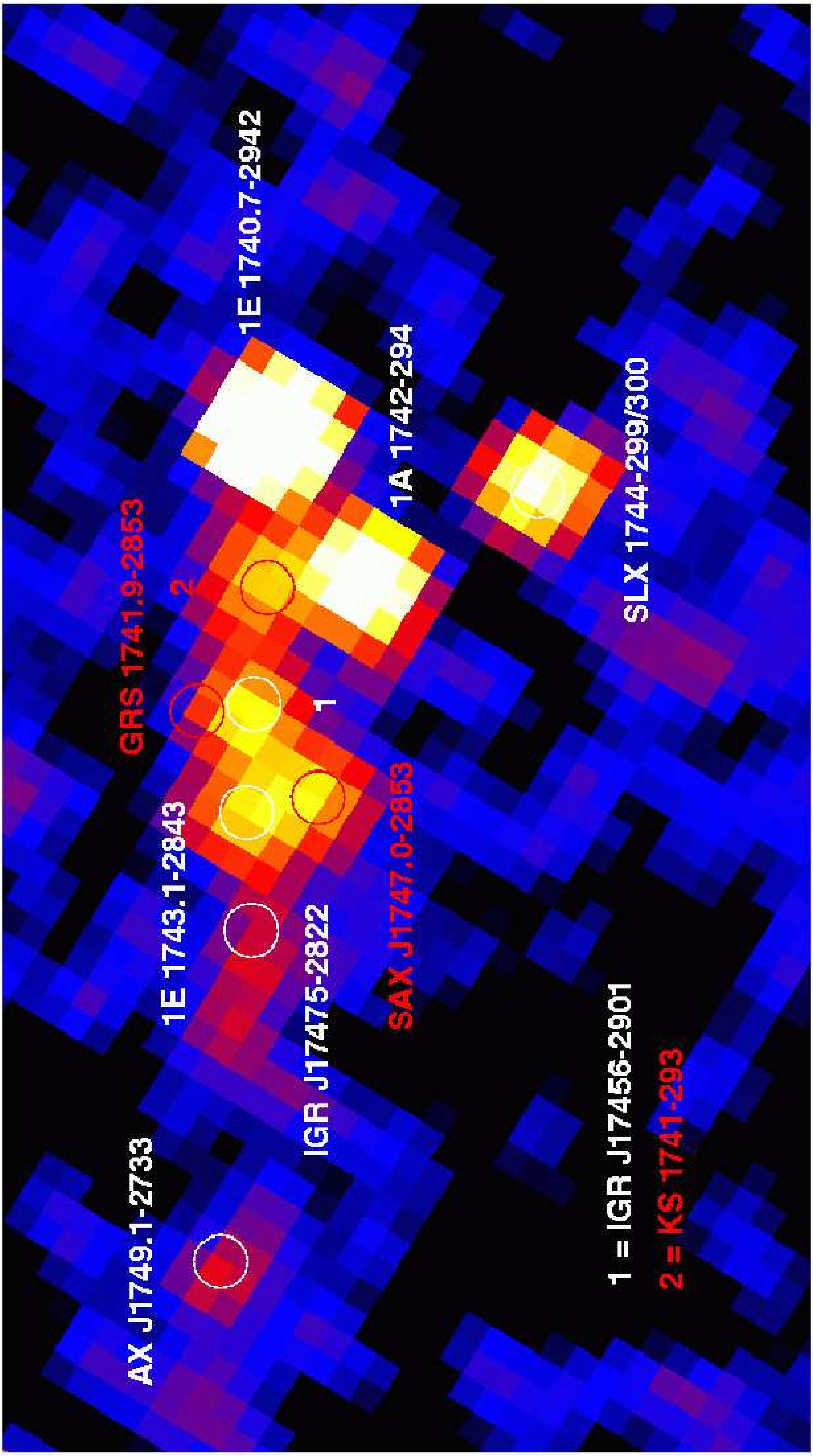

Fig. 2. The center of our Galaxy as observed by INTEGRAL between 20 and 60 keV, from Kuulkers et al. (2007)

exposures. Galactic Center INTEGRAL data were used by Revnivtsev et al. (2004) to analyse the source IGR J17475-2822 which is identified with the molecular cloud Sgr B2. These authors show that the Fe line detected from this source by the ASCA satellite and the INTEGRAL data can be well described as Compton reflection emission. They then suggest that Sgr B2 acts like a mirror that reflects the light from Sgr A* in our direction. Should this interpretation be right, it implies that Sgr A*, the center of our Galaxy, was some 10^4 times brighter some 300 years ago, the time corresponding to the longer path to us of the reflected light compared to the direct light travel path.

The galactic center region is also at the origin of a powerful electron-positron annihilation activity that has been described by Weidenspointner et al. (2008) using INTEGRAL data. The morphology of the line emitting region is a sphere of some 8 deg FWHM, with a contribution from the Galactic disk. The latter may be asymmetric. Assuming the distance of the galactic center for the electron-positron annihilation source, some 10^{43} annihilations per second are observed. The origin of the positrons is still unknown.

3. New results on the variability of the bright quasar 3C 273

Over the years we have been accumulating a wealth of data on the quasar 3C 273 and have assembled them in a publicly accessible data base (http://isdc.unige.ch/3c273; Türler et al. 1999). This data base has recently been augmented in particular with a large number of X-ray data from the satellites RXTE, CGRO (BATSE), XMM-Newton, Chandra and INTEGRAL (Soldi et al. 2008). These authors have also provided a variability analysis over the radio-gamma ray part of the electro-magnetic spectrum, emphasizing specially the new high energy data. The amount of data now available allows the authors to give not only the time averaged spectrum, but also the amplitude of the variability as a function of the photon frequency and the characteristic timescale of the variations also for different energy bands, (Figs. 1 and 3).

The data shown in Figs. 1 and 3 indicate that the amplitude of the variations and the characteristic times differ significantly in the medium energy X-rays (up to about 20 keV) and in the hard X-rays. In addition considering the cross correlations between the medium energy and the hard X-ray light curves and between these light curves on one side and the light curves in lower frequency spectral domains on the other shows that medium energy and hard X-rays have quite different behaviours. We conclude from this that the X-ray emission must be either due to two independent components or, at the very least, must be described by spectral parameters that change in such a way that the variations in the soft X-rays are fast and of small amplitude and those at high energies are slower and of larger amplitude. In other words, the normalisation and the overall spectral slope of the 2-100 keV X-ray component vary differently.

It is also found in this data set that the relationship between the X-ray emission and the jet emission as observed in the mm domain are more complex than expected. The hard X-ray flux is indeed not correlated at small lags with the mm emission, as would be expected if the hard X-ray emission were due to the Compton emission caused by those relativistic jet electrons that emit synchrotron radiation in the mm domain.

The good correlation observed between the hard X-ray variability and the V light curve (Fig. 4) leads Soldi et al. (2008) to suggest that the V-IR emission and the hard X-ray emission in 3C 273 may be due to a relativistic electron population emitting synchrotron self-Compton processes in the magnetic field of the core of the nucleus.

4. Shocks in Active Galactic Nuclei

The loss of angular momentum necessary to accrete matter in the deep well of a supermassive black hole is most of the time discussed in the frame of accretion disks. There are, however, a number of difficulties and open questions with this picture, related to spectral

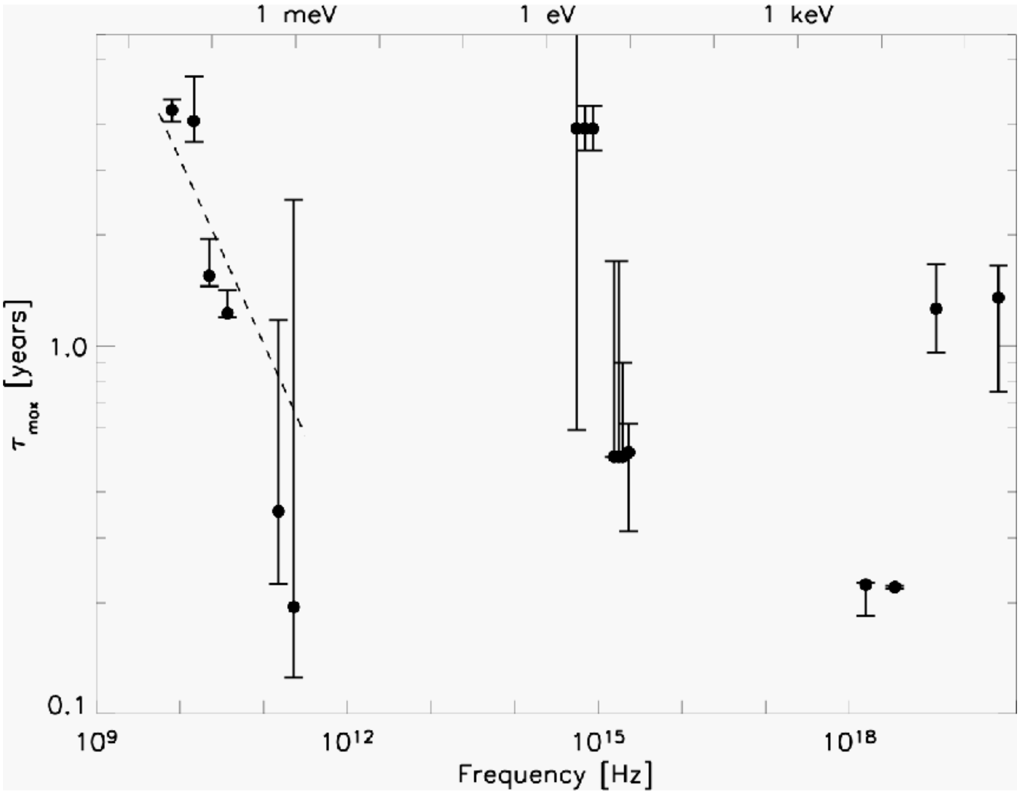

Fig. 3. The maximum time over which a given light curve shows variablity. See Soldi et al. (2008) for the method used to estimate this characteristic time.

shape and time variability of the visible-X-ray emission of several AGN (Courvoisier 2001). Based on this remark and on the fact that between 1 kpc and $100\,R_S$ the accreted matter loses angular momentum by a factor 1000 or so, we suggested that shocks may play an essential role in the angular momentum loss process. Indeed the matter is unlikely to loose angular momentum in a completely coherent way. Matter will therefore arrive in the AGN deep potential well with a distribution of orbital parameters, leading to collisions and interactions, which, we suggested, play an important role not only in the angular momentum losses, but also in the transfer of energy between the accreted nuclei and the radiating electrons (Courvoisier & Türler 2005). This model assumes that the accreted material is clumpy and that clumps interact in optically thick shocks at a distance of some $100R_S$. The shocks result in expanding gas that falls further in the potential well, again causing a number shocks. These latter shocks take place in an optically thin environment. Calculating the different shock properties, one finds that the first, optically thick, shocks radiate in the UV domain, while the second ones radiate in the X-rays.

An analysis of the UV light curves of 3C 273 leads to the conclusion that the UV emission is due to the superposition of events of some 10^{51} ergs each (Paltani et al. 1998), that we model as the dissipation of the kinetic energy of individual clouds of $\simeq\ 10^{33}$ g in free fall in the optically thick shocks at a distance of about $100R_S$ from the central black hole. Shocked clumps radiate in the UV range, as expected from the velocity of the clumps at this

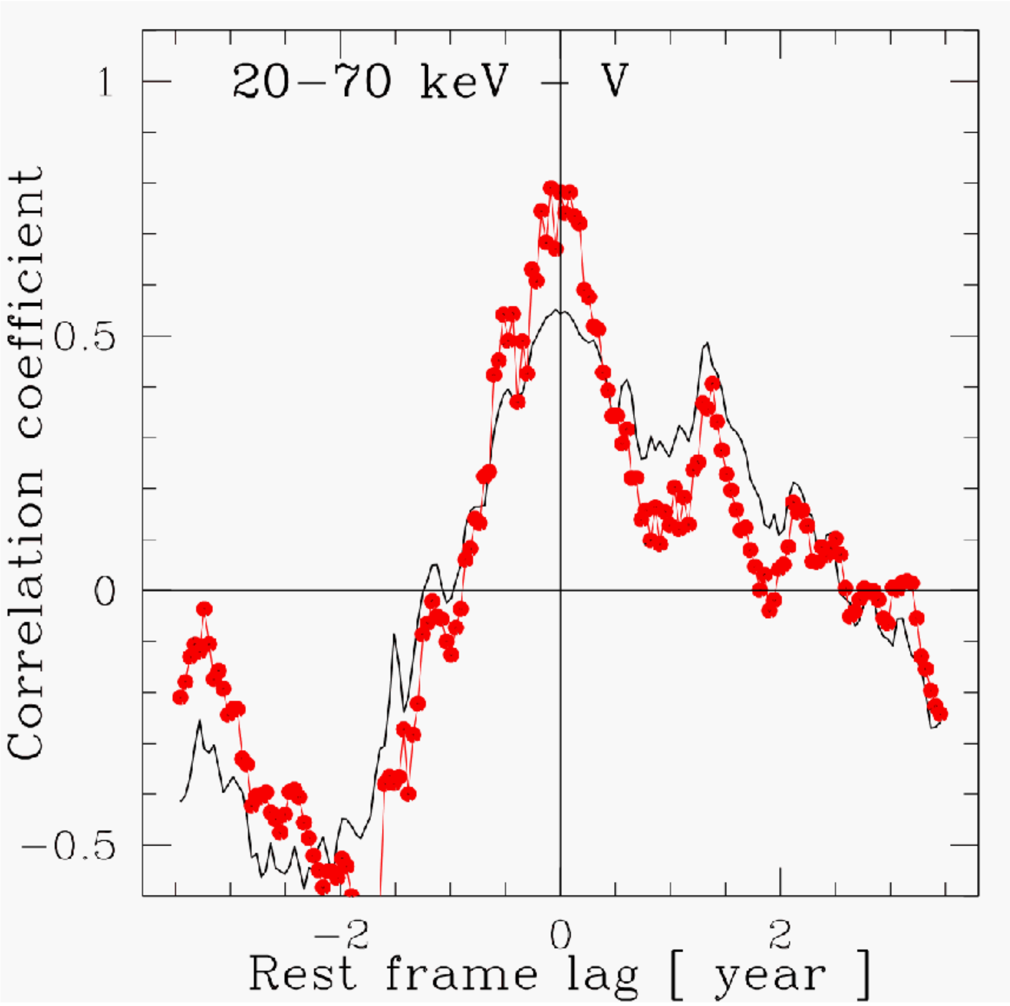

Fig. 4. The cross correlation between the 20-70 keV light curve and the V light curve. See Soldi et al. (2008) for the method with which the cross correlations are calculated. This shows that the V and hard X-ray variations are closely connected.

distance. The shocked material than expands in a geometry which we assume for simplicity to be spherical.

Working out the UV luminosity in this model Ishibashi & Courvoisier (in preparation) find

$$< L_{UV} >\simeq 1.2 \cdot 10^{45} \eta_{1/3} \zeta_{UV}^{-1} \left(\frac{\dot{M}}{10 M_{\odot}/yr} \right), \quad (1)$$

and

$$T \simeq 2.6 \cdot 10^{4} \eta_{1/3}^{1/4} M_{33}^{-1/*} \zeta_{UV}^{-3/16} K, \quad (2)$$

where η is the radiation efficiency in unit of 1/3, M_{33} is the mass of the clumps in unit of 10^{33} g and ζ_{UV} is the location of the shocks in unit of $100 R_S$. This is only very weakly depending on the mass of the central black hole, a property well in line with the lack of correlation between the UV spectral shape and the luminosity of AGN (Walter & Fink 1993; Walter et al. 1994). Courvoisier & Türler (2005) also showed that the time evolution of the UV to V light curves observed in 3C 273 is well in line with the evolution of the expanding shells. Internal kinetic energy dissipation is thus adequate to explain the blue bump variability properties in this model without requiring that the UV emitting matter be externally heated as required in standard accretion disk models to account for the very short lags observed in the blue bump light curves.

Ishibashi and Courvoisier (in preparation) calculate the X-ray luminosity resulting from the optically thin shocks that result from the interaction of the expanding UV emitting material. The high velocities reached in the innermost regions of AGN imply that the nuclei temperature lies in the MeV range. The ions exchange energy through Coulomb collisions with the electrons that radiate their energy through Compton processes. The electron temperature is given by the equilibrium between the Coulomb collision heating and the Compton cooling. Temperatures in the range of 100s keV are obtained.

The X-ray luminosity depends on the distance of the UV shocks, hence on R_S and the mass of the supermassive black hole, and on the ratio of free fall and cooling time. The resulting ratio of $\frac{L_X}{L_{UV}}$ is thus a function of the object parameters and is found to decrease with the luminosity of the objects. This is observed in a wide sample of objects and has proven difficult to explain in the standard accretion disk models (Kelly et al. 2008).

Although the cascade of shocks model summarized here is still very simple, it stresses the importance of shocks in the accretion process and in the radiation processes. The model has several appealing properties, it provides a natural explanation for the individual events that make the UV light curves, it provides temperatures and temperature evolutions that are in line with observations and it provides X-ray to UV luminosities that depend on the luminosity in a way that matches observations.

5. Conclusions

It is striking that in the X-ray domain also, the center of our Galaxy differs enormously from that of more active galaxies that host black holes of the same mass as Sgr A*. Clearly describing the phenomenology of both active and ”normal” galaxies side by side is insufficient to highlight the common elements, it encourages, however, to think of these objects as one class.

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References

Belanger, G., Goldwurm A., Goldoni P., et al., 2004, Ap.J. 601, L163
Belanger, G., Goldwurm A., Renaud, M., et al., 2006, Ap.J. 636,275
Courvoisier, T.J.-L., 2001 in ”Quasars, AGN and related research across 2000”, Eds Setti, G. and Swings J.-P., Springer-Verlag, Berlin, p. 155
CourvoisierT.J.-L. and Türler, M., 2005, A&A 444, 417
Lebrun, F., Leray, J. P., Lavocat, P., et al. 2003, A&A 411, L141
Kelly, B.C.,, Bechtold, J., Trump, J.R., Vestergaard, M., Siemiginowska, A., 2008, ApJS 176, 331
Kuulkers, E., Shaw S.E., Paizis, A., et al., 2007, A&A 466, 595
Paltani, S., Walter, R. & Courvoisier, T.J.-L., 1998, A&A 340, 47
Revnivtsev, M.G., Churazov, E.M., Sazonov, S.Yu., et al., 2004, A&A 425, L49
Soldi, S., Türler, M., Paltani, S., et al., 2008, A&A 486, 411
Türler, M., Paltani, S., Courvoisier, T.J.-L., et al., 1999, A&AS 134, 89
Walter, R. & Fink, H.H., 1993, A&A 274, 105
Walter, R., Orr, A., Courvoisier, T.J.-L., et al., 1994, A&A 285, 119
Weidenspointner, G., Skinner G., Jean, P., et al., 2008, Nature 451, 159
Winkler, C., Courvoisier, T. J.-L., Di Cocco, G., et al. 2003,A&A 411, L1