Mem. S.A.It. Vol. 79, 112

Memorie della

Black holes: from stellar mass to AGNs

Giorgio Matt

Dipartimento di Fisica, Università degli Studi Roma Tre, via della Vasca Navale 84, 00146 Roma, Italy e-mail: matt@fis.uniroma3.it

Abstract. Accretion onto a Black Hole, either stellar (as in Galactic Black Hole Binaries, GBHB) or supermassive (as in Active Galactic Nuclei, AGN), is known to produce a broad band X–ray spectrum, with significant emission above 10 keV. These classes of objects are therefore very promising targets for Simbol–X. In this paper I will highlight the main questions, regarding GBHB and AGN, to which Simbol–X is expected to give an answer, and I will also briefly discuss its contribution to the understanding of Ultraluminous X–ray sources (ULX), which are candidates to host Intermediate Mass Black Holes.

Key words. Accretion, accretion disks – Galaxies: active – X-rays: binaries – X-rays: galaxies

1. Introduction

1.1. Black holes, from S to XL

Black Holes are known to accrete matter from a stellar companion in Galactic Black Hole Binaries (where the BH have masses of the order of 10 $M_{\odot}$) and maybe in Ultraluminous X–ray sources (where the BH may have masses as high as about a thousand solar masses) and from the ISM in AGN, which host at their center supermassive (10^6-10^9 $M_{\odot}$) Black Holes. Many similarities exist between the X–ray properties of these systems (not surprisingly, as the basic processes are the same. It's always accretion, after all... and moreover GR effects are scale invariant), even if differencies do also exist, related to the dependence of the maximum disc temperature on the BH mass and to the different enviroments. That there are fundamental similarities between accreting BH across the range of masses is proved by the existence of scaling relationships, like the fundamental plane for BH (Merloni et al. 2006, and references therein) and the 'break frequency'–BH mass–$\dot{m}$ relation (McHardy et al. 2006).

Accreting Black Hole systems emit in X–rays over a broad band, with significant emission above 10 keV (at least in GBHB and AGN. No good quality hard X-ray observation exists for ULX). While the soft X-ray emission is due to thermal disc emission in GBHB, and is of unknown origin in AGN, the hard X-ray emission is likely due to Comptonization of soft disc photons by T$\sim 10^9$ K electrons (see contributions to this volume by P.O. Petrucci). The resulting spectrum is usually very complex, including also the Compton reflection component, peaking at about 30 keV (e.g. George & Fabian 1991; Matt et al. 1991). This component arises from the reprocessing of the primary continuum by circumnuclear matter, and is accompanied by fluorescent lines, the most promiment of them being the iron Kα fluorescent line. All these components are shown in Fig. 1. This version of the spectrum is much simplified, not including further absorp-

Send offprint requests to: G. Matt

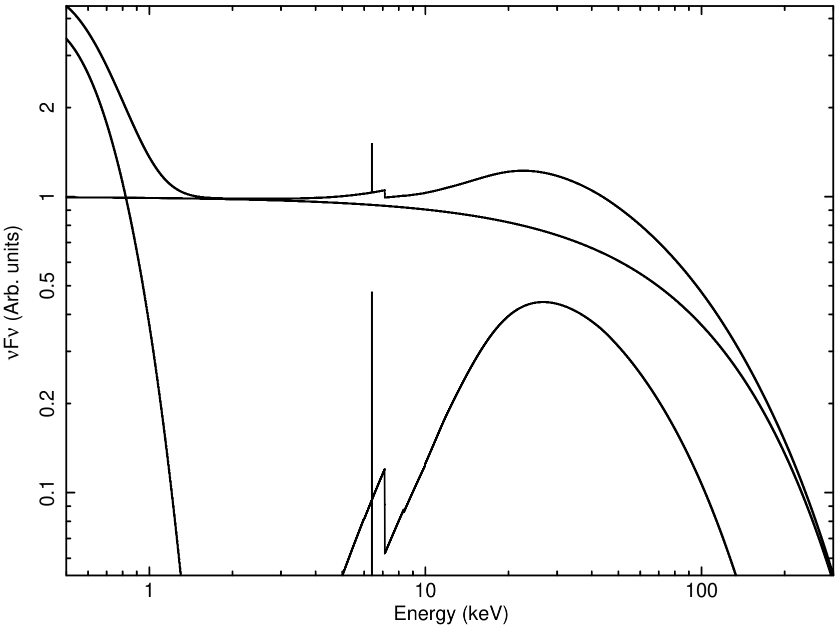

Fig. 1. The (much simplified) spectrum of accreting Black Hole systems. A soft thermal emission, a hard Comptonization spectrum (here represented by a power law with high energy cutoff), a Compton reflection component peaking at about 30 keV and an iron Kα emission line are usually present. Further absorption/emission components are often present, especially in AGN.

tion and emission components often present, especially in AGN (e.g. the warm aborber). However, it makes already clear the need for broad band coverage, to disentangle the various components.

1.2. Why Simbol–X?

With Fig. 1 in mind, the role of Simbol–X to study Black Hole accreting systems may be summarized as follows:

- To study the primary (Comptonization) emission: to measure the temperature, to search for non thermal emission and for anisotropic effects, to study variability.
- To study the Compton reflection component: in AGN, disc vs. torus emission; in GBHB, its relation with states; its very presence in ULX. To compare it with the iron line EW to derive the iron abundance and the optical depth of the reflecting matter.
- To address unsolved problems thanks to the broad band coverage: e.g., in AGN the origin of the soft excess (see sec. 4.2) and of the spectral drop at ~7 keV observed in some Narrow Lines Seyfert 1s, most notably 1H 0707-49 (Boller et al. 2002).
- To better constrain the parameters of the iron lines from relativistic discs thanks to a better knowledge of the underlying continuum (see also J. Wilms's contribution to this volume).

2. Galactic Black Holes Binaries

X–ray Binaries in our own Galaxy with a Black Hole as the compact object (Galactic Black Hole Binaries, GBHB) are characterized by different states, defined by both flux (in the medium X–ray range) and spectral properties: Quiescence, Low/Hard, Intermediate, Soft/High, Very High[1], likely in increasing order of accretion rate (e.g. Esin et al. 1997) (but the situation may be more complicated than that, and the position of the Very High state is not fully clear). See Done et al. (2007), Remillard & McClintock (2006) for recent reviews, and references therein. It is important to note that the state is not related to any intrinsic property of the system (like the BH mass or the nature of the companion star): in some sources, changes of states are indeed observed.

2.1. GBH binaries in quiescence

Many sources, however, spend most of their time in the Quiescent state, with luminosities several orders of magnitude lower than in the active states. Not much is known about this state apart from the rather obvious fact that it occurs when the accretion rate is very low. At so low accretion rates, a radiatively inefficient flow is expected (e.g. Narayan et al. 1998), which in turns should result in a rather hard emission (e.g. thermal bremstrahlung with $kT \sim 100$ keV).

The brightest GBHB in quiescence have fluxes of (0.1-1)$\times 10^{-12}$ erg cm^{-2} s^{-1} (Kong et al. 2002), too faint for *Beppo*SAX and *Suzaku* but bright enough for Simbol–X.

2.2. The disc-jet connection

One of the most interesting recent result on the GBHB is the discovery of a connection between radio emission (related to jets) and X-ray states (likely related to the disc; see e.g. Fender et al. (2004)). This topic is discussed in detail by J. Malzac in his contribution to this volume. Here it suffices to remind that the canonical interpretation is in term of disc truncation in the hard state resulting in the lunching of a jet, while in the soft state the disc extends down to the last stable orbit, and jet emission is quenched. However, the discovery of a relativistic line in GX 339-4 in hard state (Miller et al. 2006) argues against this interpretation. A good control of the underlying continuum (including the reflection component) is fundamental in this respect, and requires a very good broad band sensitivity like that provided by Simbol–X. This sensitivity will also help addressing the issue of the contribution, in the hard state, of the jet in hard X–rays.

[1] This is the 'classical' classification of states, but somewhat different classifications, and new names have also been recently proposed.

3. ULX: Intermediate mass BHs?

Ultraluminous X–ray sources[2] (ULX) are one of the most intriguing class of astrophysical sources (if indeed they form a single class, which is still matter of dispute). Their very nature is still unclear. Sub-Eddington Accretion onto Intermediate Mass Black Holes (IMBH, hundreds or thousands solar masses Black Holes) (e.g. Colbert & Mushotzky 1999), Super-Eddington accretion onto tens of solar masses Black Holes (e.g. Ebisawa et al. 2003), or beamed emission (e.g. King et al. 2001; Kaaret et al. 2003) have been invoked (excluding from the list those sources which are spatially extended, and therefore likely associated to SNRs). Of course, it is well possible that ULX are in fact a mixed bag.

From the spectral point of view (e.g. Feng & Kaaret 2005; Stobbart et al. 2006, for XMM–*Newton* results), above ~2 keV ULX may be classified in Power Law (PL) and Convex Spectrum (CS) (see e.g. Makishima 2007), even if other classifications have been introduced. The two kind of spectra are not related to a different nature of the source – the same source may switch from one type to the other (Kubota et al. 2001), reminding the changes of state of Galactic Black Hole Binaries.

Hard X-ray observations would be very helpful to get deeper insight to these spectral states. Several key questions could be answered by sensitive observations above 10 keV:

[2] There is no consensus in the literature on the limiting luminosity above which a source is called a ULX. A 2–10 keV X–ray luminosity exceeding 10^{39} erg s^{-1}, corresponding to a $\geq 10\ M_{\odot}$ Black Hole emitting at the Eddington luminosity, seems a reasonable choice.

- Is there always a PL component in the CS state? And *what is the (energetically) dominant component, and how does their ratio change with the state?*
- Is there a relation between ULX and GBHB states?
- Is the high energy cutoff in the PL state lower than in GBHB, as seems to be the case in some objects?
- Is there a reflection component? (intriguingly, no iron line has been found yet in ULX).
- More generally, how the ULX broad band spectra compare with those of GBHB and AGN? (if ULX are accreting IMBHs, a continuity of behaviours may be expected).

*Beppo*SAX and *Suzaku* do not have the needed sensitivity and spatial resolution (to avoid confusion) to address these issues, which instead are well within the Simbol–X capabilities.

4. Active Galactic Nuclei

In this paper I will consider only Radio–quiet and unobscured AGN. Radio–loud and obscured AGN are the subject of other contributions to this volume.

The primary X–ray emission of AGN is widely believed to be due to Comptonization of the accretion disc soft photons by a $T \sim 10^9$ K population of electrons. Comptonization processes are dealt with in detail by P.O. Petrucci in his contribution to this volume. Here I just want to emphasize that the broad band of Simbol–X will be extremely useful to study the Comptonization spectra of AGN, at least for electron temperatures not much exceeding one hundred keV.

In the following, I will briefly discuss two issues in which Simbol–X is expected to provide significant advances.

4.1. The Compton Reflection

The energy coverage of Simbol–X is ideal to study the Compton reflection continuum. Beppo*SAX* and *Suzaku* have already established the presence of the Compton reflection in most of bright, local AGN, but for low flux (and implicitely high-z) sources not much information is available. Simbol–X will enormously extend the sample of sources accessible to this kind of measurements, allowing for the first time to search for correlation of this component with other quantities (see also G. Miniutti's contribution to this volume).

As an example of the Simbol–X potential in this field, let us consider the Iwasawa–Taniguchi (IT; a.k.a. X–ray Baldwin) effect, i.e. the anticorrelation between the equivalent width (EW) of the iron fluorescent line and the X–ray luminosity (Iwasawa & Taniguchi 1993; Bianchi et al. 2007, and references therein). The IT effect may be explained as a decrease of the covering factor of the circumnuclear matter with luminosity or, more likely, with the Eddington ratio (Bianchi et al. 2007). It is interesting to note that a similar conclusion has been drawn by Maiolino et al. (2007) from IR data. If this indeed is the explanation, a similar effect should be observed for the Compton reflection component, an impossible task for the present generation of X–ray satellites, but an easy one for Simbol–X. A different shape of the relation with luminosity for the Compton reflection would instead suggest other, non geometric explanation like a L–dependence of the iron abundance (e.g. Matt et al. 1997) or of the optical depth of the reprocessing material (Matt et al. 2003).

In Fig. 2 the Simbol–X simulated relation between the iron line EW and the reflection component (parameter R, corresponding to the solid angle of the reflecting matter in units of 2π) is shown. R is derived from the EW of the iron line for the sources in the Bianchi et al. (2007) sample, assuming solar iron abundance and Compton thick matter. Only the 43 sources with an error on R less than 25% are shown. In practice, this is the expected relation if the IT effect is entirely due to a L-dependence of the covering factor. If instead due to e.g. a decrease of the iron abundance, a completely different relation (i.e. a value of R independent of the iron line EW) is expected.

Further simulations of the Compton reflection IT effect can be found in the contribution to this volume by Bianchi et al.

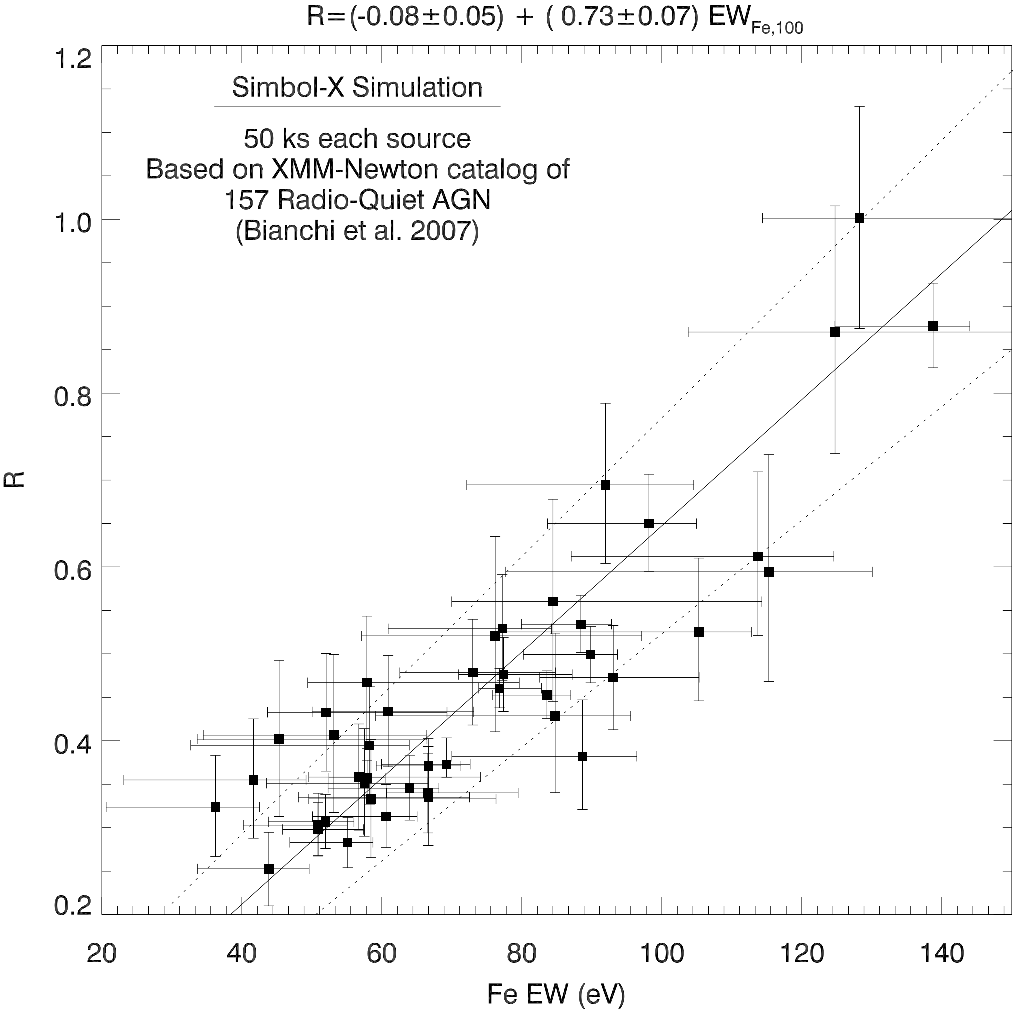

Fig. 2. The Simbol–X simulated relation between the iron line EW and the reflection component, assuming solar iron abundance and Compton–thick matter. Sources are from the Bianchi et al. (2007) sample. Only the 43 sources with an error on R less than 25% are shown. (Courtesy of S. Bianchi).

4.2. The soft excess

Paradoxically enough, the hard X–ray coverage of Simbol–X will be fundamental in addressing the long standing problem of the nature and origin of the soft excess in radio–quiet AGN. This component was believed for long time to be related to the accretion disc thermal emission. However, it has been recently noted (e.g. Gierlinski & Done 2004) that, when fitted with thermal emission, the temperature turns out to be almost constant at about 0.15-0.2 keV, despite the large intervals of Black Hole masses involved (remember than in standard disc models the maximum temperature is predicted to decrease with the Black Hole mass as $T \propto M_{BH}^{-\frac{1}{4}}$). It has therefore been suggested that the soft excess in not thermal emission at all, but that the constancy of the temperature is simply indicating that there is some characteristic energy involved.

This in turn points towards atomic processes. Along this line of tought, two main models have been proposed: absorption by a wind (Gierlinski & Done 2004) with a large enough velocity dispersion to smear out any individual absorption line (no features are present in high resolution spectra); and reflection from an ionized disc (Crummy et al. 2006), based on models developed by Ross & Fabian (1993; 2005 and references therein). The two models give equally good fits to the data, even for bright sources (e.g. Petrucci et al. 2007). On the other hand, the two models predict very different hard X-ray spectra. In their contribution to this volume, Ponti et al. show that Simbol–X will easily distinguish between the two models in a large sample of sources.

5. Conclusions

To summarize, the main contributions to the study of Accreting BH systems which Simbol–X is expected to provide are:

To explore for the first time the hard X–ray emission of GBHB in quiescence and of ULX, i.e. IMBH candidates.

To expand significantly the number of AGN with precise measurements of the reflection component, searching for correlations with e.g. the lumiinosity.

To help solving the long standing problem of the soft excess in radio–quiet AGN.

Acknowledgements. This contribution has benefited from very useful discussions with many collegues, and in particular with S. Bianchi (who also provided Fig. 2), M. Cappi, M. Dadina, P.O. Petrucci, G. Ponti and L. Zampieri. I acknowledge financial support from ASI.

References

Bianchi S., Guainazzi M., Matt G., Fonseca Bonilla N., 2007, A&A, 467, L19
Boller T., et al., 2002, MNRAS, 329, L1
Colbert E.J.M., Mushotzky R.F., 1999, ApJ, 519, 89
Crummy J., Fabian A.C., Gallo L., Ross R.R., 2006, MNRAS, 365, 1067
Done C., Gierlinski M., Kubota A., 2007, Astronomy and Astrophysics Reviews, in press
Ebisawa K., Zycki P., Kubota A., Mizuno T., Watarai K., 2003, ApJ, 597, 780
Esin A., McClintock J.E., Narayan R., 1997, ApJ, 489, 865
Fender R.P., Belloni T., Gallo E., 2004, MNRAS, 355, 1105
Feng H., Kaaret P., 2005, ApJ, 633, 1052
George I.M., Fabian A.C., 1991, MNRAS, 249, 352
Gierlinski M., Done C., 2004, MNRAS, 349, L7
Iwasawa K., Taniguchi Y., 1993, ApJ, 413, L51
Kaaret P., Corbel S., Prestwich A.H., Zezas A., Science, 299, 365
King A.R., Davies M.B., Ward M.J., Fabbiano G., Elvis M., 2001, ApJ, 552, L109
Kong A.K.H., McClintock J.E., Garcia, M.R., Murray S.S., Barret D., 2002, ApJ, 570, 27
Kubota A., Makishima K., Ebisawa K., 2001, ApJ, 560, L147
Maiolino R., et al., 2007, A&A, 468, 979
Makishima K., 2007, in Black Holes from Stars to Galaxies (eds. V. Karas and G. Matt), Cambridge University Press, p.209
Matt G., Perola G.C., Piro L., 1991, A&A, 247, 25
Matt G., Fabian A.C., Reynolds C.S., 1997, MNRAS, 289, 175
Matt G., Guainazzi M., Maiolino R., 2003, MNRAS, 342, 422
McHardy I.M., Koerding E., Knigge C., uttley P., Fender R.P., 2006, Nat, 444, 730
Merloni A., et al., 2006, NewA, 11, 567
Miller J.M., et al., 2006, ApJ, 653, 525
Narayan R., Mahadevan R., Quataert E., 1998, in Theory of Black Hole Accretion Disks (eds M. Abramowicz, G. Bjornsson and J.E. Pringle), Cambridge University Press, p.148
Petrucci P.O., et al., 2007, A&A, 470, 889
Remillard R.A., McClintock J.E., 2006, ARA&A, 44, 49
Ross R.R., Fabian A.C., 1993, MNRAS, 261, 74
Ross R.R., Fabian A.C., 2005, MNRAS, 358, 211
Stobbart A.-M., Roberts T.P., Wilms J., 2006, MNRAS, 368, 397