Relativistic X-ray disk reflection in Ultra-Luminous X-ray sources

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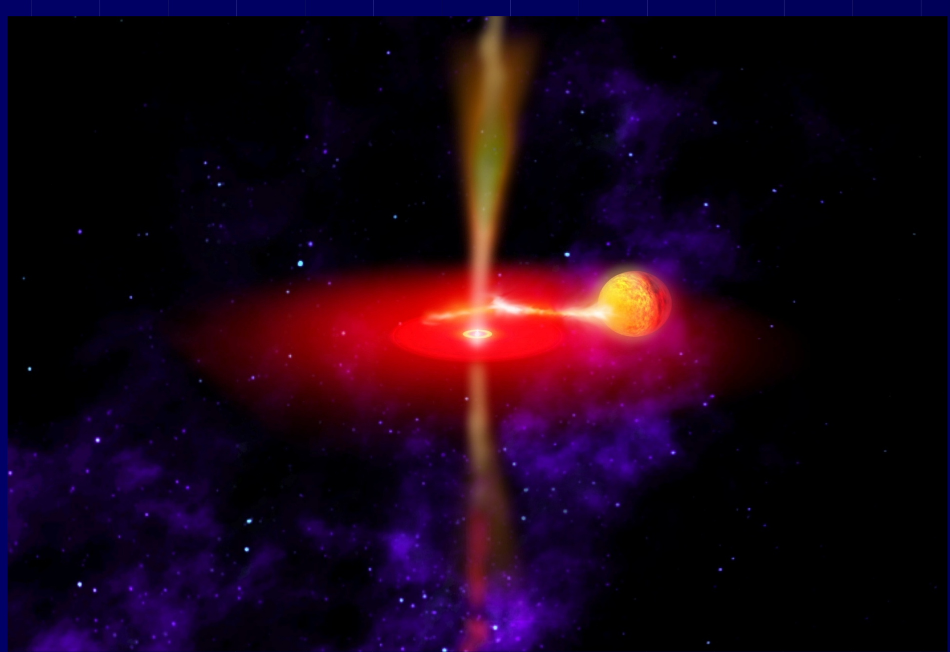
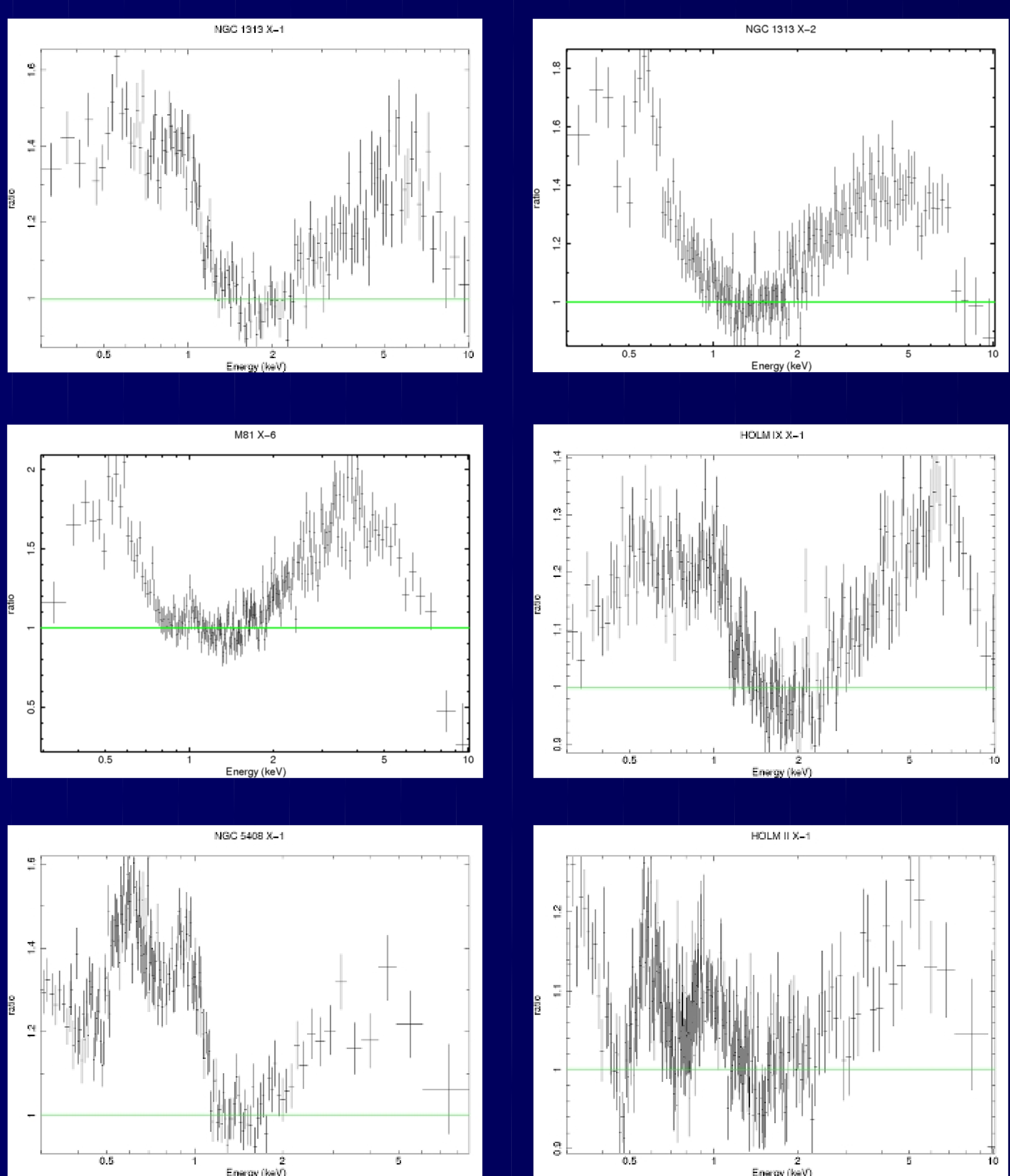
A model based on relativistic disc reflection has proved to be successful in modeling the best XMM-Newton spectra of Ultra-luminous X-ray sources (NGC 1313 X-1, NGC 1313 X-2, M 81 X-6, Holmberg IX X-1, NGC 5408 X-1 and Holmberg II X-1). A spectral drop is apparent in the data of all the sources at energies 6-7keV. The drop is interpreted here in terms of relativistically blurred ionized reflection from the accretion disc. A soft excess is also detected from these sources [as usually found in the spectra of active galacic nuclei (AGN)], with emission from O K and Fe L, in the case of NGC 5408 X-1 and Holmberg II X-1, which can be understood as features arising from reflection of the disc. Remarkably, ionized disc reflection and the associated power-law continuum provide a good description of the broad-band spectrum, including the soft excess. In the case of the nearby and bright ULX M82 X-1 a reflection-based model of a highly spinning black hole with the inner part of the accretion disk emiting most of the flux provides the best description of the long XMM-Newton and Suzaku observations. There is no requirement for thermal emission from the inner disc in the description of the spectra. The black holes of these systems must then be highly spinning, with a spin close to the maximum rate of a maximal spinning black hole. The results require the action of strong light bending in these sources. We suggest that they could be strongly accreting black holes in which most of the energy is extracted from the flow magnetically and released above the disc thereby avoiding the conventional Eddington limit.



X-ray spectral phenomenology

The detection for most ULX of spectral curvature, in the form of a deficit of photons at energies *$E \geq 2$ keV (Roberts, Warwick & Ward* 2005; Stobbart et al. 2006; Miyawaki et al. 2009), has led to the suggestion that most ULX have spectral properties that do not correspond to any of the accretion states known in BH binaries (BHBs), making it unlikely that ULX are powered by sub-Eddington flows on to an IMBH (Roberts 2007). The application of Comptonization models to the data (Stobbart et al. 2006; Gladstone, Roberts & Done 2009 and references therein) results in strikingly high and low values for the coronal opacity (*$\tau \geq 5$) and the electron temperature* (*$kTe = 1{-}3$ keV), difficult to explain for the expected physical* conditions in a corona surrounding the BH. This is very different to the typical values found for BHB during the *low/hard state, with* spectra dominated by Comptonization, and appears irreconcilable with the IMBH model, which assumes that they operate as simple scaled-up BHB.

The XMM-Newton sample



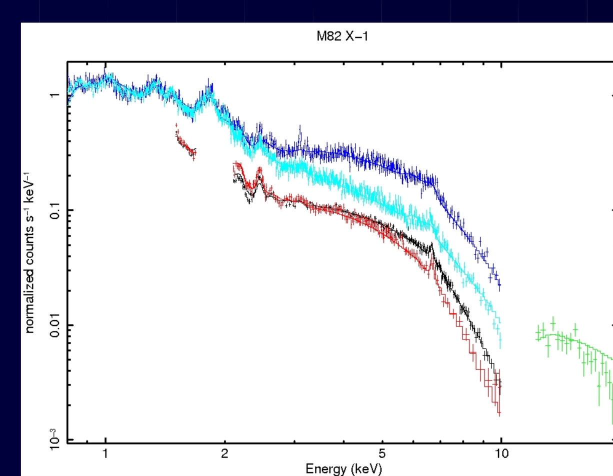
In Caballero-Garcia et al (2010a, in press) we present an alternative interpretation of the spectral shape, based on a physically justified model commonly used on other accreting BHs. The soft part of the spectrum (*$E \leq$ keV)* – the soft X-ray excess – and the high-energy curvature are just aspects of a reflection spectrum expected from accretion (Guilbert & Rees 1988; George & Fabian 1991). A major component of reflection, the broad iron K line, has been found in many Seyfert galaxies (Tanaka et al. 1995; Nandra et al. 2008), accreting stellar mass BHs (Miller 2007; Reis et al. 2009a) and even accreting neutron stars (Cackett et al. 2008; Reis, Fabian & Young 2009b). Both the soft excess and the relativistic broad iron K line have recently been demonstrated to be part of the same physical process, i.e. the reaction of the disc to irradiation from a high-energy source, in the type 1 Seyfert galaxy 1H 0707-495 (Fabian et al. 2009).

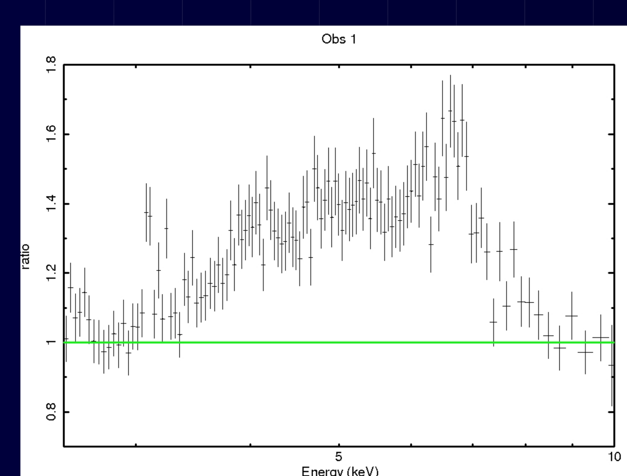
The case of M82 X-1

In Caballero-Garcia et al. (2010b, in prep.) we report the detection of a very broad and relativistic Fe line in the *XMM-Newton and Suzaku spectra of the accreting black hole and Ultra-Luminous* Black-Hole M82X-1. The line is clearly detected and broad under the assumption of several different models for the continuum., confirming its existence.

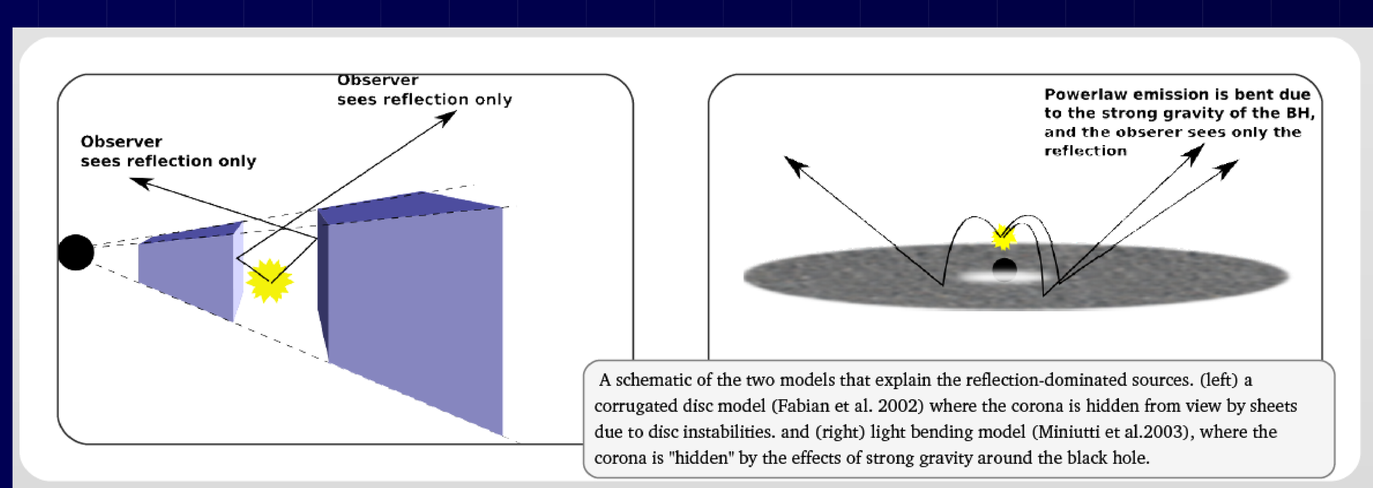
This line extends down to 4 keV and the application of the laor and reflection models indicate a very small inner disk radius (1.4−1.6 R_g). *This result implies a near-maximally spinning black-hole (0.985±0.001).*

The extreme characteristics inferred from this line (inner disk, black hole spin, spectrum fully reflection dominated) indicate that general relativistic effects (light bending) are very extreme and important in the hard X-ray emission of this source (Reynolds & Fabian, 1997).

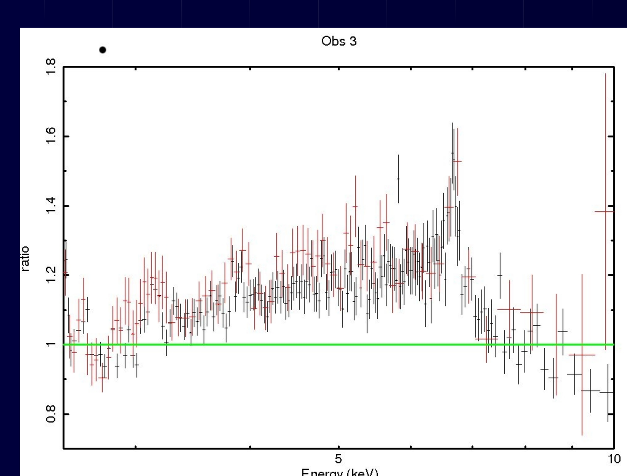




Powerful light-bending and black hole mass



A schematic of the two models that explain the reflection-dominated sources. (left) a corrugated disc model (Fabian et al. 2002) where the corona is hidden from view by sheets due to disc instabilities. and (right) light bending model (Miniutti et al.2003), where the corona is "hidden" by the effects of strong gravity around the black hole.



The spectral solution we have found here for ULX suggests a new explanation for accretion on to spinning BHs. Our model assumes that the dominant source of radiation is a power-law continuum produced a few gravitational radii above a rapidly spinning BH. Little thermal radiation is produced by the disc and is undetected by the current data. We assume that the power for this source is extracted magnetically from the disc and transferred to the emission region by magnetic fields. Some of the power may even be extracted magnetically from the spin of the BH (Blandford & Znajek 1977). Since radiation is only produced above the disc, radiation pressure need not oppose accretion. Indeed, it will help squash the disc and maintain the high surface density required for our relatively low ionization parameters and thus observable reflection.

The relevant radiation for computing the physical Eddington limit in this situation is the thermal disc radiation, not the power-law continuum and reflection associated with it. Since we detect no such thermal radiation, then the situation may be sub-Eddington, even for stellar mass BHs. Whether this solution can work depends on the extent to which magnetic energy extraction can be clean, in the sense of not requiring considerable thermal energy release. We note that the accretion flow is super-Eddington in the conventional interpretation in which the total energy release is considered (especially since some radiation falls straight into the BH).

If the above solution is appropriate for these objects then they can either be stellar mass BHs with masses of ≈10 $M_\odot$ or IMBH of 100s $M_\odot$.