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AGN MODELLING USING ACCRETION DISCS

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Abstract. Active galactic nuclei are modelled using the accretion disc model, with a central massive object, in this case a supermassive black hole. The gas slowly moves inward, under the implacable attraction of the black hole. The accretion disc has strong jets coming from the inner regions of the disc. The jets are made of ionized matter (electrons and protons). Due to shocks in the jet, protons are accelerated via the Fermi mechanism. The protons diffuse in the region above the disc, finally hitting the disc surface, which is where they came from, in the first place. Once inside the disc, the protons initiate specific interactions, giving birth to the X-ray component of the accretion disc spectrum. This cycle of matter is ideal for producing short term variability. Data is fitted to the UV-X-ray correlation of NGC 5548, as an example.

1. INTRODUCTION

Active Galactic Nuclei (AGN) are among the most studied objects in current astrophysical research. Their most striking characteristic is the enormous energy output, which, until not too long ago, looked like defying known physics. Various theories have been put forward to explain this powerful emission; a so called *unified model* evolved gradually (Blandford 1990). The important characteristic of this model is that, by varying its parameters one can get the observational signature of sources which seem to be of different nature - hence the *unification*. Indeed, in spite of the many differences, there seem to be common observational elements to all AGN: a bright compact nucleus, wide continuum, time variability.

All these lead to a picture of the system as consisting of a black hole or massive object, surrounded by an accretion disc, and possibly a torus of gas near the disc (Fig. 1 shows a cross-section of the system; the jets and torus are not shown).

In addition, there is enough experimental evidence that jets of matter can be thrown out of the so-called *boundary layer*, the region of the disc close to the black hole. Since the black hole very likely rotates with maximum speed ($a_\star$ as close to 1 as radiation pressure would allow it), the accretion disc extends to very small radii ($r_{min} = 1.23$, in gravitational radii).

Depending upon the relative importance of the model's constituents and also upon viewing angle, such a system yields different emissive signatures, accounting for a host of observationally different types of active nuclei. Indeed, the same object can look like a Seyfert 1, a Seyfert 2, a QSO or a quasar, largely due to the inclination angle to the observer, the mass of the black hole and the mass accretion rate. For example, in quasars the AGN system is seen almost face-on, this making only the core visible optically; jets are close to the line of sight. On the other hand, in radio galaxies (system seen edge-on) the jets may be more conspicuous than the central nucleus.

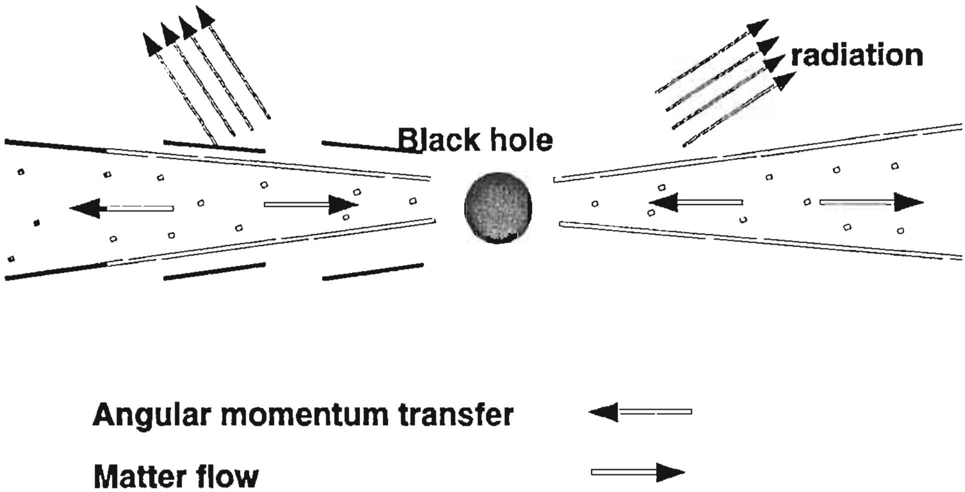

Fig. 1. Accretion disc around a black hole.

The gas in the accretion disc rotates around the black hole, with almost keplerian angular speed. Since ω is varying with radius, there will inevitably be friction between successive regions, and energy will be dissipated as heat due to viscosity effects. In the classical, steady, optically thick case, the spectrum of the heated disc has a characteristic $F_\nu \approx \nu^{1/3}$ specific flux (Frank, 1985).The resulting spectrum differs from the blackbody spectrum because regions that have different temperatures are geometrically separated, and superposition does not apply in this case to the specific flux.

Apart from the classical model, one can and should use the more elaborate models of Shakura and Sunyaev (Shakura & Sunyaev, 1973) and also the relativistic model of Novikov and Thorne (Novikov & Thorne, 1983)

2. DESCRIPTION OF THE MODEL

The basic ingredients of the model are those mentioned above: a massive black hole surrounded by an accretion disc. The accretion disc model used is essentially Novikov and Thorne's, but with the addition of a jet of matter starting from the central regions of the disc (A.C.Donea & P.L.Biermann 1996). This model accounts for the UV part of the spectrum of the accretion disc. The paramater defining the geometrical extent of the jet is r_j (positive, non-dimensional, higher r_j means larger jet). A fraction

q_m of the accretion energy is released into the jet. The jet consists of ionized matter (electrons and protons). Protons, rather than electrons get to be accelerated in shocks in the jet, through Fermi processes. The resulting accelerated protons have a power law distribution in energy as they diffuse out of the jet. We take the proton power of the jet to be a fraction of the jet power.

For the X-ray domain we use the model provided by Niemeyer and Biermann (1993). In this model, the protons diffuse in the region above the disc, due to magnetic field irregularities. For a steady, time-independent diffusion process, having a source of protons in the jet, most of the protons will hit the disc surface again and enter it, causing hadronic interactions. The resulting X-ray spectrum is largely dependent upon incoming proton power, with mass accretion rate playing a smaller role.

3. APPLICATION TO NGC 5548

NGC 5548 is a Seyfert I galaxy, with low redshift ($z = 0.0174$), whose emission is typical for its class. It has variability and its X-ray luminosity is moderate ($L_{2-10\text{ keV}} = 4.5 \times 10^{43}$ergs s^{-1}). We use the data provided in Clavel (1992). It is known that the UV and X-ray emissions are correlated to within 1-2 days. We take the Hubble constant $H = 50$km/(sec $\cdot$ Mpc) for deriving the distance to the galaxy,

For the UV part, the 1350 Å continuum intensity is computed, while for X-rays, one computes the (almost) integral 2-10 kev flux. Experimental points and theoretical curves are then plotted.

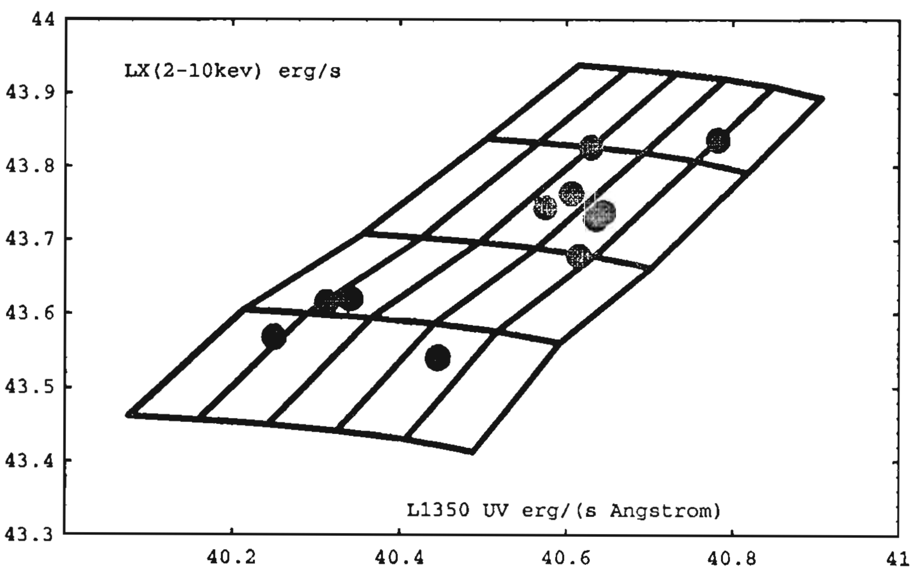

Fig. 2. UV - X-ray correlation diagram for NGC 5548.

Figure 2 shows the experimental data points (the dots) and the range of validity of the theoretical model (the lines). The decimal logarithms of the UV continuum and the X-ray fluxes are plotted. We use sub-Eddington accretion rates. $\eta = 30\%$ of the jet power is assumed to be converted into proton energy.The almost horizontal curves are for constant accretion rate $\dot{M}$ with, respectively, the values: 0.018, 0.023, 0.03, 0.04, 0.05, in $\frac{M_\odot}{yr}$ (increasing upwards). The other curves are for constant jet geometry parameter r_j: 4, 5, 6, 7, 8, and 9, respectively (increasing from right to left). The q_m parameter has the value of 0.1. Other parameters are: $M = 10^8 M_\odot$ (the central mass) and $a_\star = 0.9981$ (Kerr black hole).

The best fits are obtained with either Schwarzschild black holes of huge mass or Kerr black holes with less mass. To choose between the two variants we resort to variability timescale arguments. While the Schwarzschild case ($a_\star = 0$) is not excluded by the model, it would require central masses too large for the given (short) timescale of variability. The high inertia of systems with central mass higher than $10^8 M_\odot$, would make it hard for black holes with $a_\star$ significantly lower than 0.9981 (the maximally accepted value for Kerr black holes with accretion discs) to really fit the data.

4. CONCLUSIONS

The black hole and accretion disc model is a valid model for explaining AGN emission. Coupled with time and size arguments it is able to explain both the huge energy output and the short term variability of such objects. Kerr black holes with close to maximum angular velocity are preferred to Schwarzschild black holes.

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