Determining Emissivity Profiles of AGN Accretion Discs

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Abstract

The common approach to modelling the X-ray reflection spectrum from the accretion disc around the central black hole of an AGN is to fit a power law for the emissivity profile. Here, rather than fitting a profile, we attempt to directly obtain the emissivity profile of the disc from the observed spectrum by considering the spectrum as the sum of contributions from successive radii and fitting to find the weightings of these components. This method has successfully recovered known emissivity profiles from synthetic spectra and is applied to an XMM spectrum of the Narrow Line Seyfert 1 galaxy 1H0707-495, recovering a profile similar to that determined theoretically. Once found, the emissivity profile can give information about the geometry and structure of the accretion disc and could be a starting point for ray-tracing around the central black hole, probing the spacetime geometry and potentially locating the hard X-ray source in the corona.

Accretion Disc Emissivity

The X-ray emission from AGN is modelled as consisting primarily of two components; a hard X-ray source due to inverse-Compton scattering in the hot corona surrounding the central black hole (a power law spectrum) and the reflection of this from the accretion disc (Fabian et al, 1989), giving rise to a number of spectral features, particularly atomic lines and is modelled by, *e.g.*, the reflionx model (Ross & Fabian, 2005).

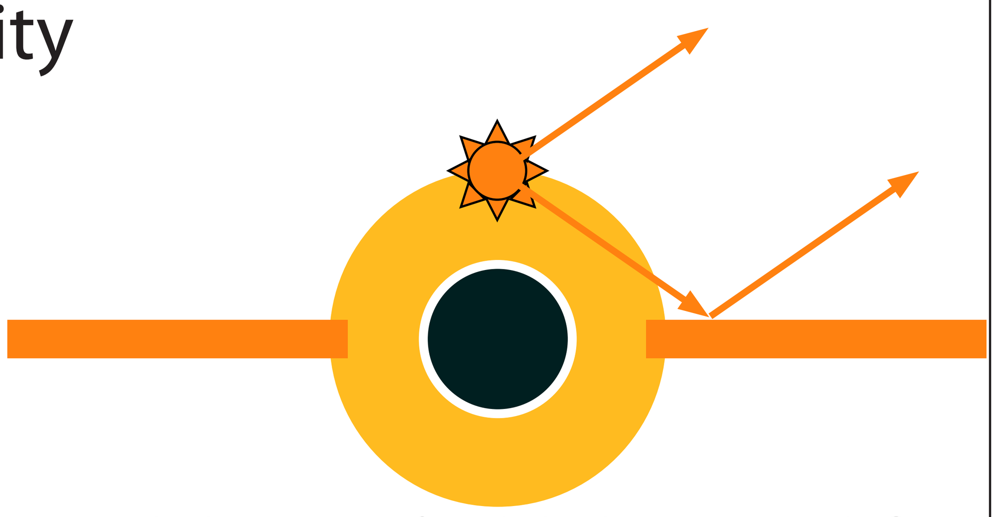

Figure 1: The direct emission from the hard X-ray source and reflection from the accretion disc in the model of AGN.

The **emissivity profile** characterises the reflected flux as a function of radius in the disc. In the simplest case of a point source above the disc in flat, Euclidean space, the emissivity is simply given by the distance between the source and the point of interest in the disc (Figure 2) as the flux received by the disc falls off as the inverse square of this distance. In the Kerr spacetime around the black hole, this is modifed by the gravitational light-bending which tends to focus rays to the inner part of the disc, causing a steeper fall-off in the emissivity (Figure 3) (Miniutti, Fabian, Goyder & Lasenby, 2003).

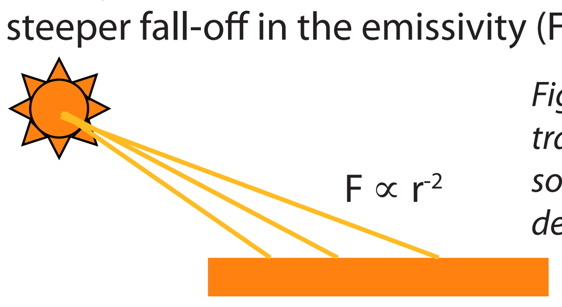

Figure 2: Light rays travelling from point source to disc in Euclidean space.

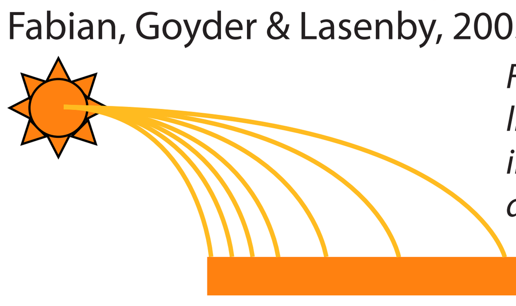

Figure 3: Gravitational light bending focussing light on to the inner disc.

The emissivity profile will also be dependent on the geometry of the disc (Figure 4) and of the hard X-ray source in the corona (Figure 5) as these will alter the ray-paths and flux at the disc.

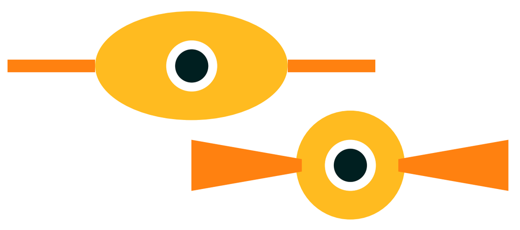

Figure 4: The emissivity will be affected by the disc geometry and extent.

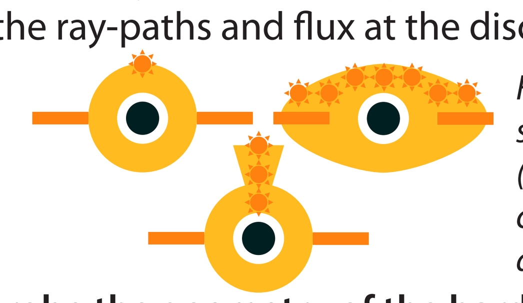

Figure 5: Potential source geometries (point, extended in corona, jet)which will affect the emissivity.

Determining the emissivity profile of the disc will probe the geometry of the hard X-ray source and the disc as well as the spacetime geometry around the black hole.

Determining the Emissivity Profile

Spectral lines emitted from the accretion disc are broadened by the combined effects of graviational redshift and Doppler shift due to motion of the emitting material in the disc (Laor, 1991). The combined blurring is a function of the position in the disc from which the photon is emitted (Figure 6) and the observed line is the integral over the whole disc.

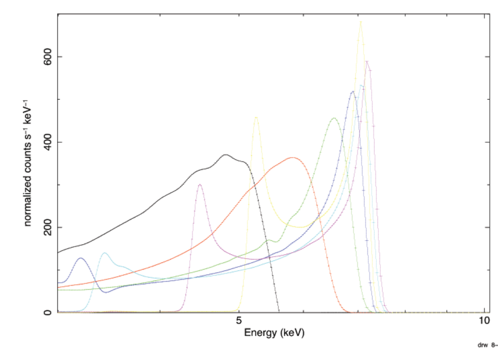

Figure 6: Broadened lines from successive annuli, from $1.235R_g$ (black) to $20R_g$ (yellow).

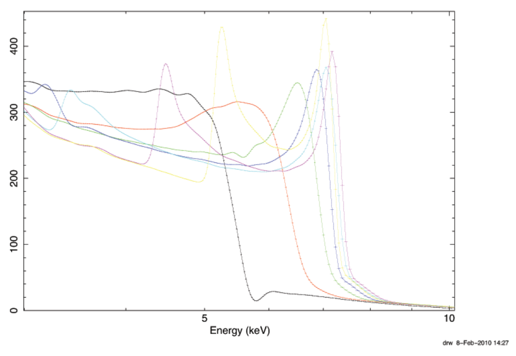

Figure 7: Iron Kα line in the reflection spectra from successive annuli, from $1.235R_g$ (black) to $20R_g$ (yellow).

The same blurring can be applied to the reflection model (with the kdblur model), giving rise to different shaped contributions from successive annuli in the disc (Figure 7).

To determine the emissivity profile, the observed reflection spectrum can be considered as the sum of contributions from successive annuli in the disc.

The weighting of each of these components in the observed spectrum is the product of the emissivity (flux emitted from the local region of the disc) and the area of the annulus projected onto the observer (by the null geodesics along which the photons travel), thus the emissivity profile is obtained by dividing the weightings of components in the observed spectrum by the projected areas of the annuli from which the components originate.

In order to determine the emissivity profile from the observed spectrum, a model is constructed containing the power law continuum and reflection components (and other contibutions such as warm absorbers if more complex models are to be built). The reflection component is the sum of contributions from successive annuli, each with a constant emissivity and a free normalisation. The weightings are then found by fitting the normalisation parameters of the reflection components. Finally, the normalisations are divided by the equivalent values for a modelled disc of flat emissivity to deproject the contributions and determine the local emissivity.

Fits are performed on regions of the spectrum containing a broad line, paritcularly the Iron Kα line.

Testing the Method

Before applying to real data, the method must be tested on synthetic spectra with known emissivity profiles, to ensure that enough data are available in the spectrum to perform the inversion and that a unique emissivity profile can be found for a given spectrum.

Synthetic spectra of initially, single broadened (Laor) lines were constructed by folding models through the XMM-Newton response matrix. Later models for testing were constructed from blurred reflection (reflionx) spectra.

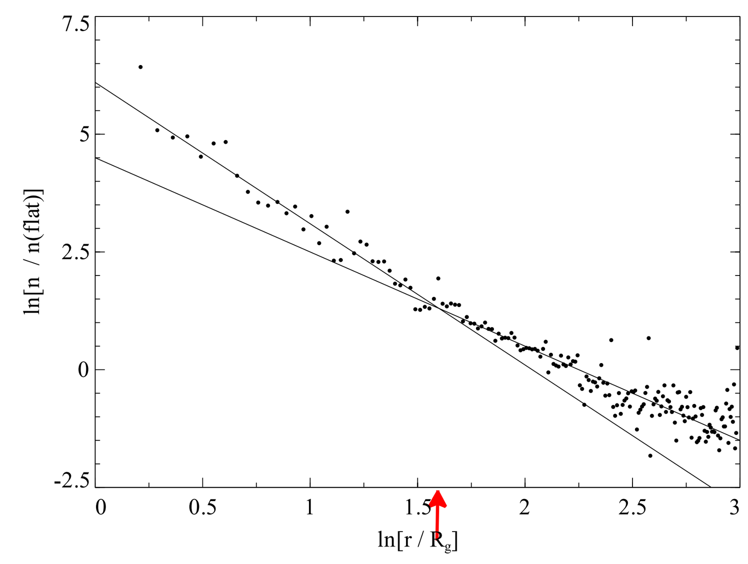

Figure 8: Broken power law emissivity (indices 3 then 2 with break radius $5R_g$) recovered from broadened emission line.

Emissivity profiles were successfully recovered for both single blurred lines and modelled reflection spectra. In order to obtain a good fit, the size of the annuli and the energy range of the spectrum to which the fit was performed were varied.

It was found that the emissivity profile is recovered well for the inner regions of the disc where the annuli are smaller and the contributions vary greatly in shape. The fit is not so good at larger radius where there is greater degeneracy in the shapes of the contributions from successive annuli, so each contribution is less well distinguished.

In order to recover the emissivity profile, a region of the spectrum must be selected where there is a large contibution to the line (not just the continuum) from the annulus of interest and there is little degeneracy between the contributions from successive annuli. Tests on modelled reflection spectra found that the Iron Kα line around 6.4keV gave good results as this single feature is clear above the continuum. Inner parts of the disc are recovered well in the 3-5keV range, whereas the outer regions need a fit up to 10keV (however including this region obscures the inner disc which gives a smaller signal due to its smaller area).

The Narrow-Line Seyfert 1 Galaxy, 1H0707-495

The emissivity profile of the accretion disc in the narrow-line Seyfert 1 galaxy 1H0707-495 is determined by applying the above method to a spectrum obtained during a ~300ks observation with XMM-Newton.

The best-fit model for 1H0707 (Zoghbi et. al. 2009) consists of a power law continuum and a relativistically blurred reflection from the disc, in addition to black body emission from the disc and a warm absorber component. The emissivity of the disc affects the other components in the construction of this model, so here, the spectrum is analysed in the region of the iron Kα line (3-10keV) where only the power law and reflection comonents are significant in order to give a simple model with a clearly defined emissivity.

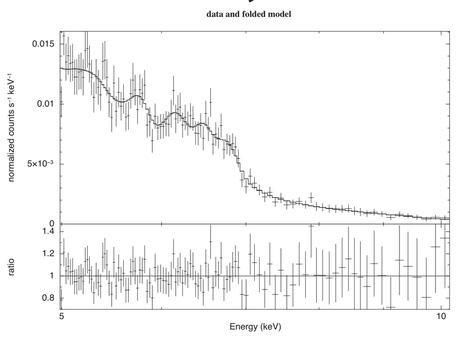

Figure 8: 1H0707 iron Kα edge with power law plus sum of reflection components fitted to determine emissivity.

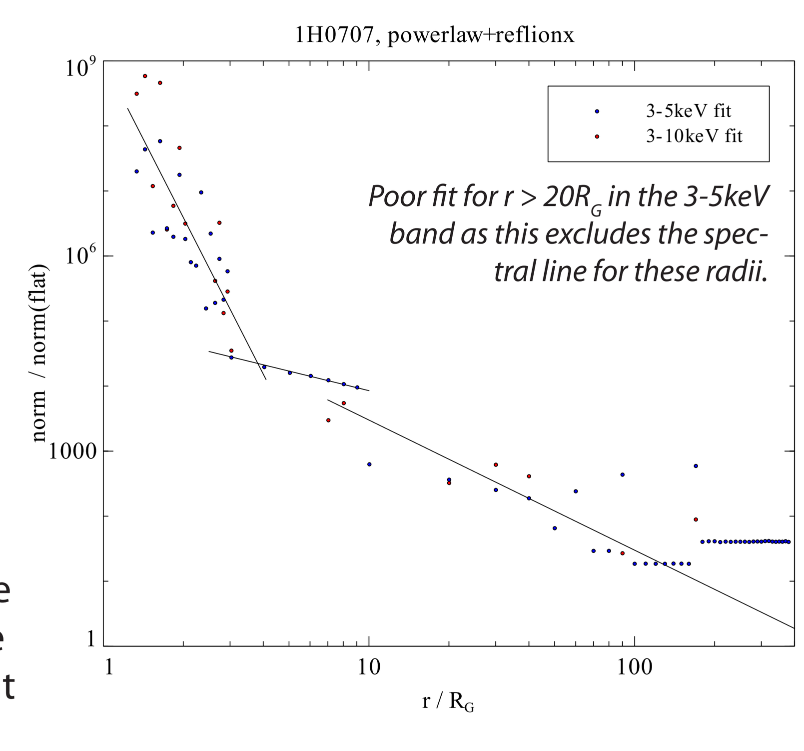

Figure 9: Emissivity profile of 1H0707 from fit to spectrum in 3-5keV and 3-10keV bands with fits for power law indices 8, 1 and 2 respectively.

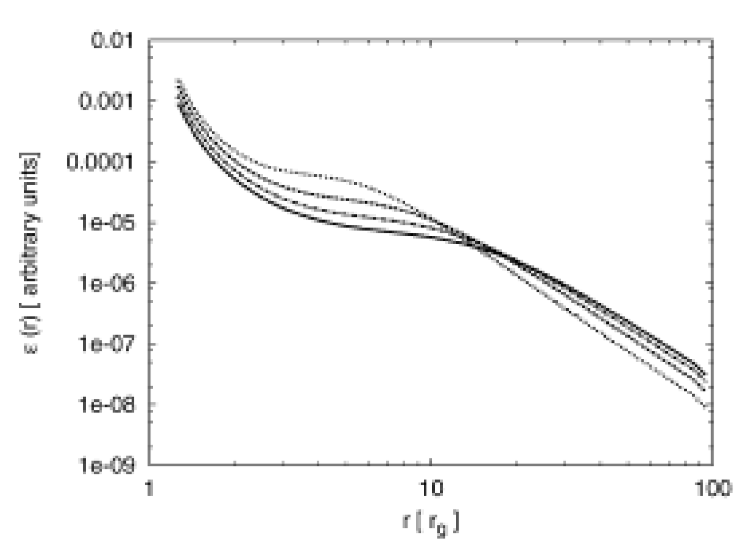

Figure 10: Theoretical iron Kα line emissivity profile for a ring-like hard X-ray source above the accretion disc (Miniutti, Fabian, Goyder and Lasenby, 2003). Note the profile flattening between $3R_G$ and $10R_G$ bas seen in 1H0707.

Figure 9 shows the recovered emissivity profiles for 1H0707 and a broken power law with an index of around 8 in the inner regions tending to 2 (the classical limit for a point source above the disc) further out can be seen. The fit to the 3-5keV part of the spectrum shows the emissivity profile flattening to an index of around 1 in a transition region between $3R_G$ and $10R_G$, in agreement with theoretical predictions made by Miniutti, Fabian, Goyder & Lasendy (2003) shown in Figure 10.

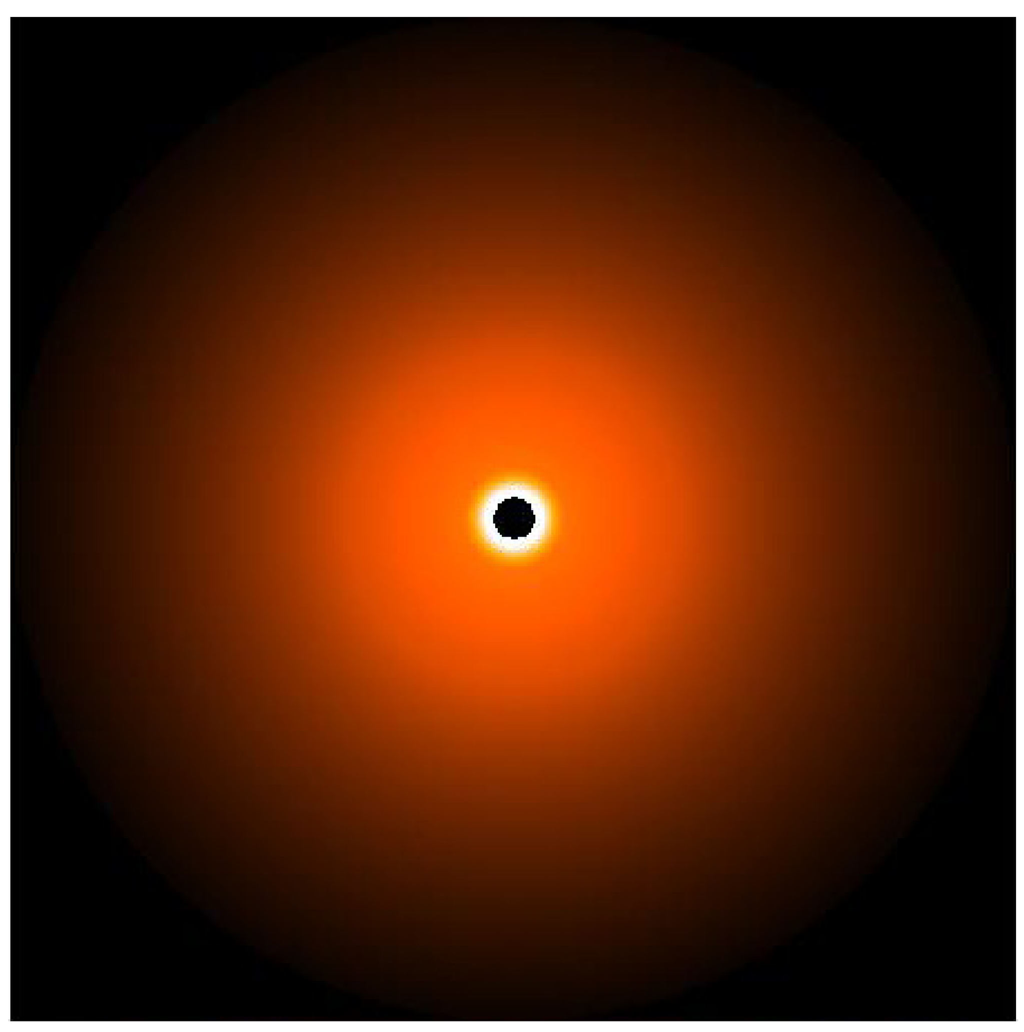

Figure 11: Pseudoimage of the accretion flow in 1H0707-495 out to $30R_G$, constructed from the emissivity profile (logarithmic).

Conclusions and Next Steps

- Method for determining emissivity profiles from observed spectra tested for robustness.
- Emissivity profile of disc in 1H0707-495 determined and found to agree with theoretical prediction, with emission seen right down to the innermost stable orbit.
- Given this observed emssivity profile:
  - Determine for other sources (AGN and galactic black holes) and compare.
  - Calculate theoretical profiles for a range of source and disc geometries and compare.

References

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