Modelling the X-ray spectra of high-velocity outflows from quasars.

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Introduction

Blueshifted narrow absorption lines have recently been reported in the hard X-ray spectra of several quasars (e.g. Chartas et al. 2002,2003; Pounds et al. 2003a,b). Although there is some ambiguity (e.g. McKernan et al. 2004) it is widely speculated that these features arise in relativistic outflows that are more highly ionized than those previously detected via ultraviolet features. Here, we present new radiative transfer calculations synthesizing hard X-ray spectra for a variety of simply parameterised bi-conical outflow models. These synthetic spectra can be contrasted with observations to test the outflow hypothesis and place constraints on the flow parameters. This initial study is focused on the nearby bright quasar PG1211+143 for which high quality data has been analysed by Pounds et al. (2003a). For full details of this investigation see Sim (2004b).

Method

- The hard (2 – 10 keV) X-ray spectra are computed using a new 2-D Monte Carlo radiative transfer code based on the 1-D code written by Sim (2004a).
- The code adopts the Macro Atom formalism developed by Lucy (2002,2003). The computations include bound-free and bound-bound processes for 27 important ions and Compton scattering by free electrons.
- Atomic data was taken from the Xstar database (Bautista & Kallman 2001).

Results

We describe our parametric outflow model and show sample computed spectra below. We conclude that realistic radiative transfer calculations support the hypothesis that the absorption features in PG1211+143 can be explained by such a model (see Sim 2004b).

Acknowledgements

I thank L. Lucy for many useful discussions and suggestions relating to this work. Thanks also to J. Drew, K. Nandra and A. L. Longinotti for useful comments.

References

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The model

- **Geometry**
  - Bi-conical outflow geometry as discussed by Pounds et al. (2003a) and King & Pounds (2003). [See Fig. 1.]
  - The wind is assumed to reach a terminal velocity ~ 0.1c (based on the observed line shifts from Pounds et al. 2003a).
  - The flow is assumed to be launched at radius $R_c = 100\ R_s$ from the central black-hole, where R_s is the Schwarzschild radius of the black-hole. [The black-hole mass in PG1211+143 is taken as $4 \times 10^7\ M_\odot$ (Kaspi et al. 2000)].
  - The region outside the flow is assumed to contain obscuring material through which photons do not propagate.

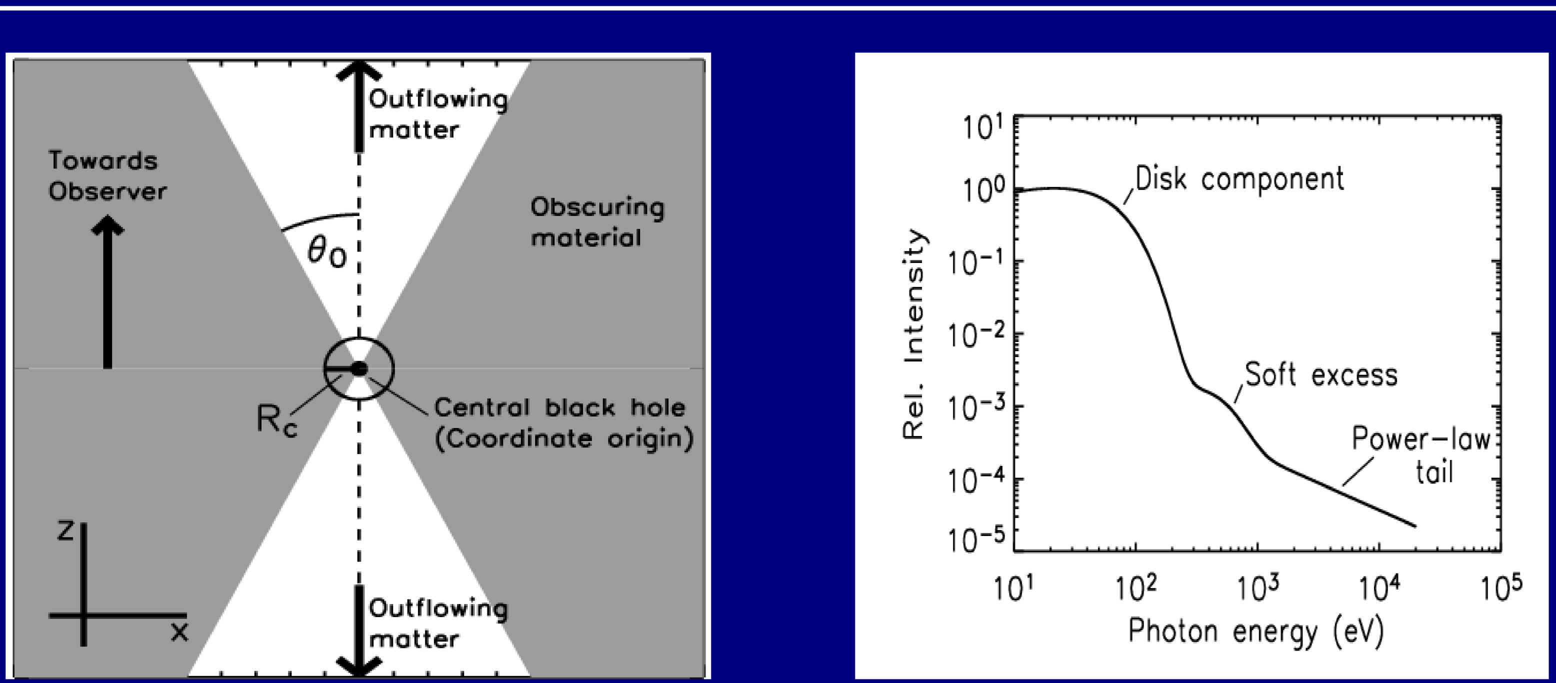

Fig. 1: Left: cartoon of the bi-conical outflow geometry under consideration. Right: form of the input radiation field launched at the base of the wind.

- **Input radiation field**: At the base of the flow the radiation field is assumed to consist of three components (see Fig. 1):
  - A multi-colour black-body accretion disk spectrum [see e.g. Mitsuda et al. (1984)] for a disk assumed to extend from 3 R_s to 100 R_s. Since PG1211+143 is accreting close to the Eddington limit (Boroson 2002, Gierlinski & Done 2004), the total disk luminosity is fixed at the Eddington luminosity for the central black-hole.
  - A hard X-ray power-law continuum. The slope and normalisation of this component are fixed to match the observed X-ray properties of PG1211+143.
  - A soft excess. This is modelled as a black-body with temperature fixed at that fitted to the X-ray spectrum by Pounds et al. (2003a).

Computed spectra

Fig. 2 shows sample computed spectra for flows with differing mass-loss rates and opening angles. Small opening angles predict features that are stronger and narrower than those obtained with wide opening angles. This is due to photon leakage through the conical boundaries which influences the ionization state (see Fig. 3). Given that the observed spectral features are narrow (Pounds et al. 2003a) an interpretation in terms of a wind (or jet) which subtends a fairly small solid angle as viewed from the black-hole is favoured.

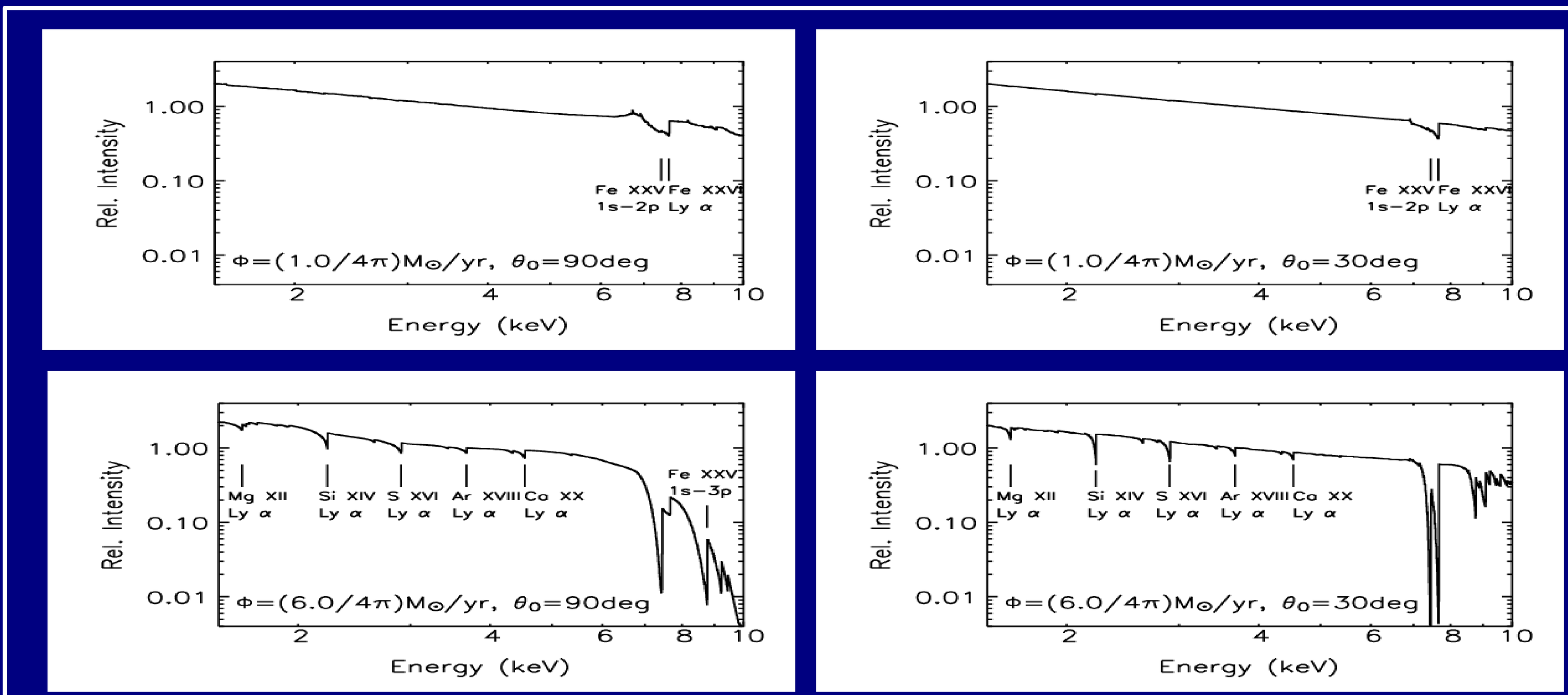

Fig. 2: The panels show computed X-ray spectra for outflows with mass-loss rate per unit solid angle, $\Phi = (1/4\pi)\ M_\odot\ yr^{-1}$ and opening angle θ_0 = 90deg (upper left); $\Phi = (6/4\pi)\ M_\odot\ yr^{-1}$, θ_0 = 90deg (lower left); $\Phi = (1/4\pi)\ M_\odot\ yr^{-1}$, θ_0 = 30deg (upper right); and $\Phi = (6/4\pi)\ M_\odot\ yr^{-1}$, θ_0 = 30deg (lower right). The most important spectral features are identified in the figures. Pounds et al. (2003a) report narrow absorption lines due to Fe XXV/XXVI (7.5 keV), S XVI (2.9 keV) and Mg XII (1.6 keV) in the spectrum of PG1211+143.

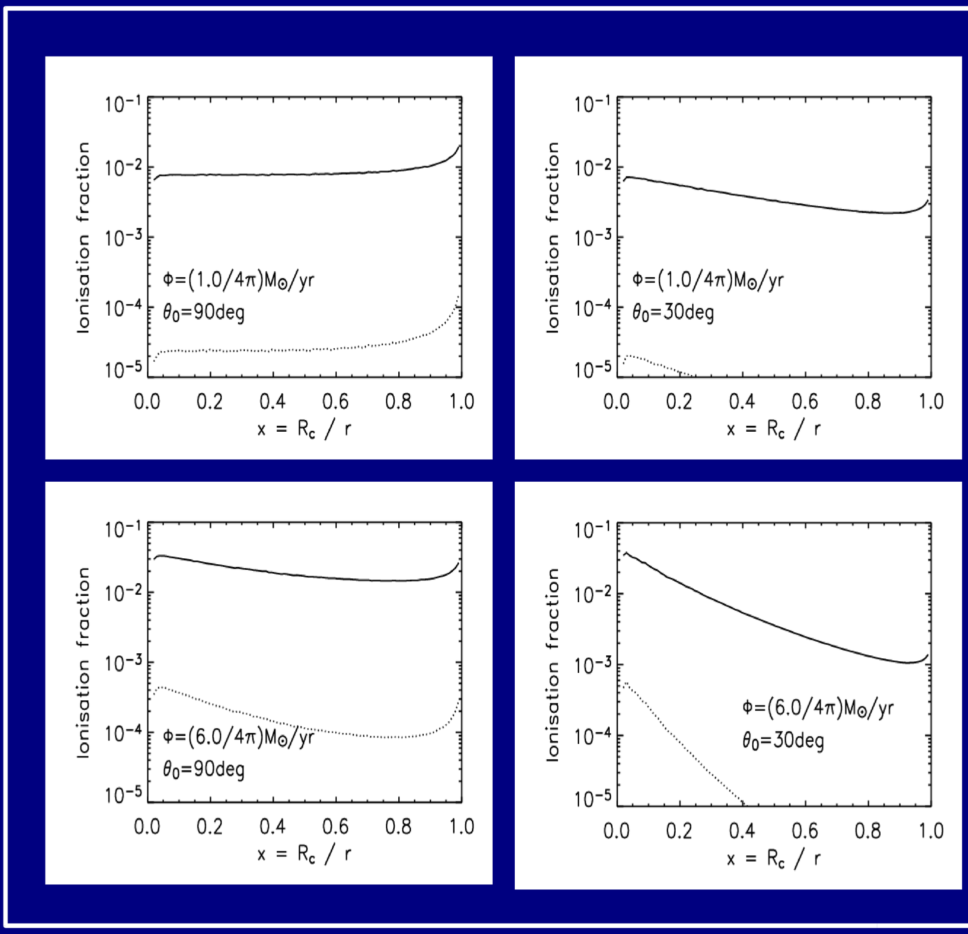

Fig. 3: Ionization fractions of S XVI (solid) and S XV (dotted) as functions of radial position (r) in the flow, computed for the same models for which spectra are shown in Fig. 2. High mass-loss rates and narrow opening angles lead to ionization gradients within the flow. Steep gradients concentrate the line opacity in velocity-space leading to narrow spectral lines, as observed.