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The effect of clumpy outflows and disk anisotropy on quasar unification scenarios

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ABSTRACT

Various unification schemes for QSOs and active galactic nuclei (AGN) have proposed that the broad emission line region is roughly cospatial with broad absorption line (BAL) gas and much of the phenomenonology of AGN can be explained by a simple geometrical picture involving an accretion disk and associated outflow. Here, we test this paradigm by utilising our state-of-the-art radiative transfer code to produce synthetic spectra from simple biconical disk wind models. In particular, we expand on our previous work in which a benchmark model for BAL quasars was produced. We find that a simple treatment of clumping ('microclumping') allows for a more realistic X-ray luminosity in the model by lowering the ionization parameter. We examine the X-ray properties of this new model and find good agreement with existing X-ray samples of AGN and QSOs. We find that clumping enhances the H recombination and collisionally excited resonance lines, causing strong line emission (???EW) to emerge at the low inclination angles, which represent quasars within this unification scenario. We also treat Hydrogen using a 'macro-atom' approach in order to examine the effect of recombination on Hydrogen emission lines, and this results in significant line emission in Lyman α and the Balmer series. However, we are unable to produce line emission with comparable equivalent widths to existing quasar composites, due to a fundamental constraint arising from the anisotropy of emission from a classical thin disk. We briefly explore the effect of relativistic beaming, gravitational redshift and light bending on the angular distribution of disk continuum emission. We find that these general relativistic effects do cause the disk to emit more isotropically, but this is not yet sufficient to produce a self-consistent model. We discuss a number of potential solutions. Overall, our work suggests that a geometric unification scenario involving an ADW is a promising candidate, but our results pose a number of challenges to such a model. Determining the true geometry of ADWs and uncovering the true disk spectral (and angular) energy distribution are key next steps if we are to build up a holistic picture of the Quasar population.

1 INTRODUCTION

Introduction focussing on key points

- standard wind + BALQSO introduction
- focus on unification scenarios
- some discussion of scales, referencing e.g. reverb maps, variability, microlensing, Arav
- clumping background: stellar winds, clumping in AGN winds, variability

Approximately 20% of QSOs exhibit broad absorption lines (BALs) in the ultraviolet, providing clear evidence for outflowing absorbing material (Weymann et al. 1991; Knigge et al. 2008; Turner & Miller 2009; Allen et al. 2011). The simplest explanation for the incidence of BALs in quasar samples is in terms of an accretion disk wind (ADW). In this paradigm, the BALQSO fraction is associated with the covering factor of the outflow. Indeed, many have gone further, and suggested that the diverse phenemonology of luminous AGN and QSOs can be broadly explained by into a simple picture of geometric unification (Murray et al. 1995; Elvis 2000, e.g.). In such a model, a biconical wind rises from a thin accretion disk Shakura & Sunyaev (1973), approaching velocities close to $\sim 0.1c$. Depending on viewing angle, an observer may then see a BALQSO, LoBAL-QSO or normal 'Type 1' quasar- with broad emission lines superposed on a disk-like continuum.

The UV spectrum of *non-BAL* QSOs is typified by a series of strong emission lines (e.g. Lyα, C IV, N V) with an underlying blue continuum - the so-called *'big blue bump'* (BBB). The BBB is normally attributed to blackbody-like emission from an accretion disk surrounding the central black hole (REF), similar to that described by Shakura &

Sunyaev (1973). However, a number of issues have arisen relating to this model. First, AGN/QSO spectra exhibit a 'break' in the spectrum at around 1000 Åwhich scales only weakly with black hole mass. This potentially suggests a problem with a thin disk model (e.g. Antonucci). However, it is possible that this is the result of incorrect intergalactic medium (IGM) corrections (REF) or corresponds to the temperature at which a line-driven wind carries mass away from the system (laor davis). Second, results from microlensing (REFs) imply that the disk emission region is ~ 4 times larger than one might expect from a Shakura-Sunyaev model. Inhomogenous disks have been proposed as an alternative (REFs). These observations appear to pose problems for the thin disk model of luminous, sub-Eddington AGN. However, recent results from **?** find that if one includes a combination of mass-loss, general relativity (GR) and Comptonisation then AGN SEDs can, in general, be fitted well with accretion disk models. Uncovering the intrinsic disk SED and understanding the effect of the outflow on the accretion mechanism is clearly crucial if we are to properly understand the physical nature of AGN.

The geometry and size of the BLR is also a matter of contention. The main constraints on the emission region size come from microlensing (REFs) and reverberation mapping (REFs). While these observations have mostly been carried out for Seyfert galaxies, there are also a few instances of these methods being applied to quasars (REFs). A number of different proposals have been made for the origin of the BLR. Early AGN unification scenarios posited that the broad emission lines where produced by clouds of plasma orbiting fairly close to the BH (refs). Since then, multiple interpretations of a disk wind model have been proposed, with varying radii and geometries (refs).

In this paper, we attempt to test the disk wind paradigm using Monte Carlo radiative transfer and photoionization calculations. In section 2, we describe our code. In section 3, we briefly discuss some of the successes and failures of our previous benchmark model for BALQSOs (Higginbottom et al. 2013, hereafter H13) and outline the model, including a description of our clumping prescription. In section 4, we present the results from a clumped model which successfully reproduces the observed ionization state while maintaining realistic X-ray properties. In section 5 we discuss our results, focussing particular on the anisotropy of disk emission and GR effects, and finally, in section 6, we summarise our findings.

2 METHOD: IONIZATION AND RADIATIVE TRANSFER

We use a code Python...

2.1 Ionization Scheme

We adopt the same hybrid scheme described by Matthews et al. (2015)...

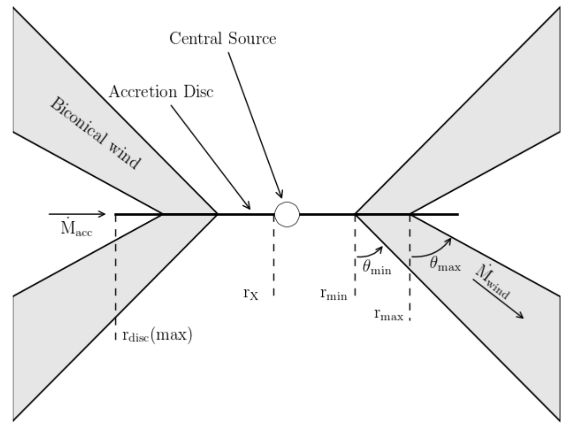

Figure 1. A cartoon showing the geometry and some key parameters of our biconical wind model.

2.2 Macro-atoms

2.3 Microclumping

To take account of clumping in our outflow we adopt a simple parameterization used in stellar wind modelling. The key assumption here is that typical clump sizes are much smaller than the typical photon mean free path, and thus the clumps are both geometrically and optically thin. This approach is typically known as microclumping and allows one to introduce a 'filling factor', f, which is the fraction of the volume of the plasma filled by clumps. We can then introduce the 'density enhancement', D, which is simply

$$D = \frac{1}{f} \tag{1}$$

One can then multiply all densities in the model by D, and all emitting volumes by f, meaning that all ρ^2 processes (such as collisional excitation and recombination) will be enhanced, while opacities remain unchanged (for fixed ionization state). A factor f is also applied to the opacities such that opacities which scale only with ρ are not increased. Clumping the wind has an important effect on the ionization state and has been proposed as a solution to the so-called 'over-ionization problem' in disk winds (refs). This is the main motivation for incorporating microclumping into our model.

3 A SIMPLE BICONICAL DISK WIND MODEL FOR QSOS

3.1 A Benchmark Model for BALQSOs

Higginbottom et al. (2013) presented a benchmark model for (BAL)QSOs...introduce key parameters.

3.2 Potential for unification

4 RESULTS

4.1 Physical Conditions and Ionization State

Show that clumping stops over-ionization.

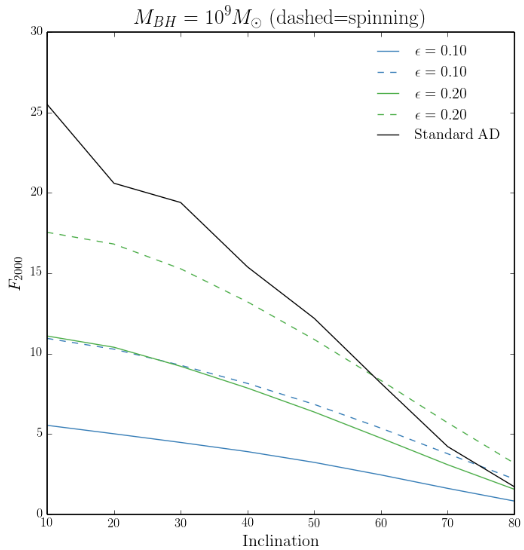

Figure 3. F_λ at 2000 Å as a function of inclination from AGNSPEC models. Spectra are computed for BH of 10^9 $M_\odot$ with a number of different BH spins and Eddington fractions. The black line shows a standard multi-temperature blackbody AD model.

4.2 Synthetic Spectra

Present a spectrum of the UV and possible optical too.

4.3 X-ray Properties

discuss the figure showing X-ray properties briefly. Present an X-ray spectrum? compare to observations e.g. Giustini?

5 DISCUSSION

5.1 Anisotropy of disk emission

Discuss the importance of the angular distribution of the disk SED on line (limb-darkened, foreshortened, etc.)

5.2 General relativistic effects

Can GR effects offer a potential solution? (not quite!)

5.3 Wind reprocessing

How would wind reprocessing help?

5.4 The BALQSO fraction and wind covering factor

A brief comment, citing Goodrich / Krolik & Voit on the way in which anisotropy / attenuation affect the inferred BAL fraction.

6 SUMMARY

Main points:

(i) We have introduced a simple, first-order treatment of clumping in our model, and found that it can now maintain the required ionization state while agreeing well with the X-ray properties of AGN/QSOs.

(ii) We find that clumping also causes a significant increase in the strength of the emission lines produced by the model. This is true both of collisionally excited resonance lines (such as C IV, N V) and recombination lines (such as Lyα, Hα and the Balmer series).

(iii) The line EWs in our models are not comparable to those in Quasar composite spectra. This is due to a fundamental constraint discussed in section ?. If the BLR emits fairly isotropically then for an anisotropic classical thin accretion disk it is not possible to achieve line ratios at low inclinations that are comparable to those at high inclinations. This is a robust conclusion which is independent of the assumed BLR geometry.

(iv) We have examined the effect of GR on our disk SED, using the disk atmosphere and GR ray-tracing code AGNSPEC. While including GR effects does cause the disk SED to become significantly more isotropic, the effect is not large enough to produce uniform line to continuum ratios with viewing angle. We discuss other solutions to this problem in section ?; It is possible that a combination of GR and reprocessing by the wind could provide a solution, and a number of complicated selection effects may be at work in the building of the quasar composites. Nevertheless, our conclusions pose a challenge to the current unification picture.

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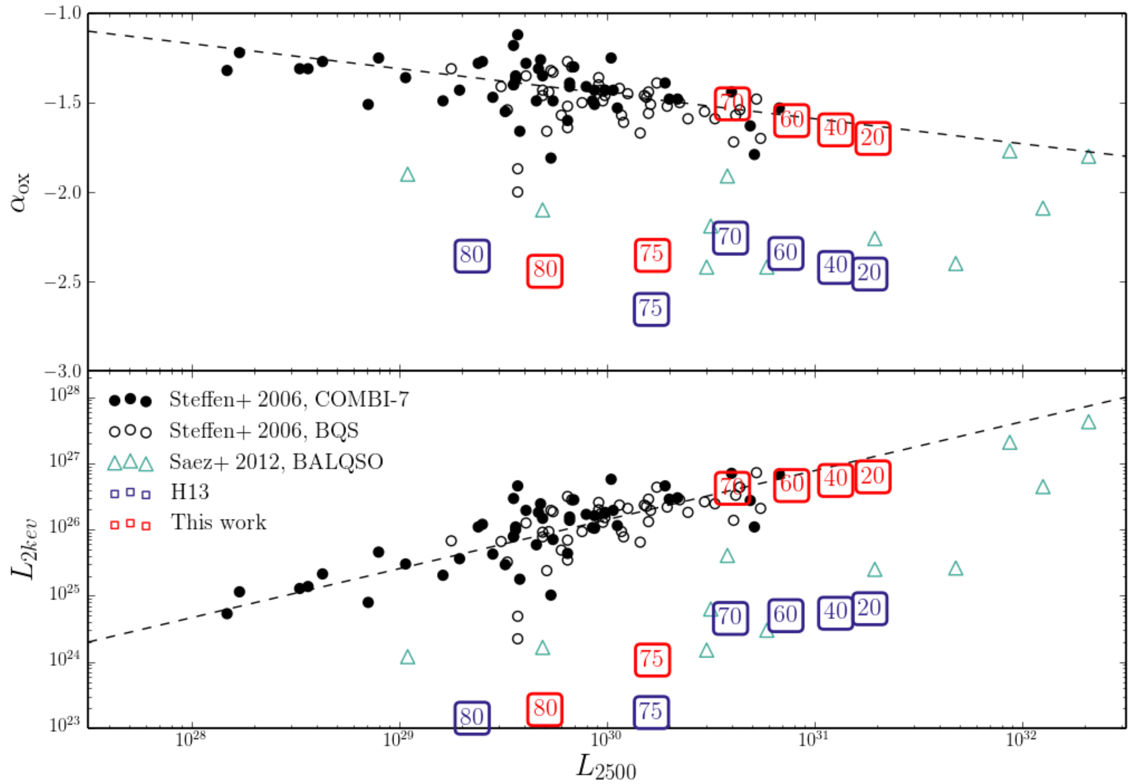

Figure 2. X-ray properties of the H13 and clumped model (text filled squares), plotted against monochromatic luminosity at 2500Å. Also plotted are the samples considered by Saez et al. 2012 on a similar plot; The COMBI-7 AGN sample (ref), the BQS sample (ref) and the Saez et al. (2012) sample of BALQSOs.