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

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ABSTRACT

Various unification schemes for quasars and luminous 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 phenomenology of luminous AGN can be explained by a simple geometrical picture involving an accretion disc 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 disc 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. 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 disc. We briefly explore the effect of relativistic beaming, gravitational redshift and light bending on the angular distribution of disc continuum emission. We find that these general relativistic effects do cause the disc 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 geometric unification involving an accretion disc wind is a promising scenario, but our results pose a number of difficult challenges to such a model.

1 INTRODUCTION

Introduction focussing on key points

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

Quasars and luminous active galactic nuclei (AGN) exhibit spectral energy distributions (SEDs) that typically exhibit 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 emission from a geometrically thin, optically thick accretion disc surrounding the central black hole (REF), similar to that described by Shakura & Sunyaev (1973).

In addition to the inflowing accreting material, outflowing material is ubiquitous in active galactic nuclei (AGN) and quasi-stellar objects (QSOs). These outflows can take the form of highly collimated radio jets (Belloni 2010), or mass-loaded 'winds' emanating from the accretion disc. 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 disc wind (ADW). Within this paradigm, the BALQSO fraction is associated with the covering factor of the outflow.

It is possible that the diverse phenemonology of luminous AGN and QSOs can be broadly explained by into a simple picture of geometric unification (e.g. Murray et al. 1995; Elvis 2000). In such a model, a biconical wind rises from the accretion disc, and the class of object is explained by the material intercepting the line of sight. Depending on viewing angle, an observer may then see a BALQSO, LoBAL-QSO or normal 'Type 1' quasar.

As well as acting as a source of photoionized plasma, a disc wind may also have a profound effect on the structure and emergent continuum of the accretion disc itself. Mass-loss will alter the accretion rate and resultant temperature of the accretion disc, possibly explaining some of the features we typically see in luminous AGN (REF). 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 disc models. In general, mass-loss treatments appear to be critical if an α-disc model is to successfully fit AGN SEDs, particular in the UV region of the spectrum.

In this paper, we attempt to test the disc 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 maintaing realistic X-ray properties. In section 5 we discuss our results, focussing particular on the anisotropy of disc emission and GR effects, and finally, in section 6, we summarise our findings.

2 IONIZATION AND RADIATIVE TRANSFER

We use the MCRT code PYTHON to carry out our radiative transfer and photoionization calculations in non-local thermodynamic equilibrium (non-LTE). The code is described extensively by a series of authors (LK02, S05, H13, M15). For that reason we only briefly describe the key elements of the global ionization calculation and other important aspects.

2.1 Line transfer

To treat line transfer, we adopt the same hybrid scheme described by M15, in which the energy flows through the system are described in terms of indivisible energy quanta interacting with either 'simple ions' or 'macro-atoms'. The macro-atom implementation is described in full by Lucy (2002, 2003). The scheme allows one to treat non-LTE line transfer without approximation for elements which are identified as full macro-atoms.

2.2 Ionization Scheme

Macro-atoms have their ion and level populations derived from MC rate estimators as described by M15. To calculate the ionization fractions of simple-ions the dilute-blackbody modified Saha approach (Mazzali & Lucy 1993) is no longer appropriate due to the presence of a power-law X-ray source. Instead, we model the SED in a cell using the technique described by H13.

We improve on this method by abandoning the modified Saha approach entirely, and instead computing the ionization state by explicitly solving the rate equations in between ions in non-LTE. Photoionization and recombination rates are calculated using MC estimators recorded during the photon propagation. Not only does this dispense with a number of small assumptions made in the modified Saha approach, it is also more numerically stable, and in principle allows the direct addition of extra physical processes such as Auger ionization, which would have to be approximated if using the previous technique.

2.3 Atomic Data

We use the same atomic data as described by LK02 and since updated by H13 and M15, with the addition of direct ionization data from Dere (????). Photoionization cross-sections are from Topbase (REF) and **?**.

3 A CLUMPY BICONICAL DISK WIND MODEL FOR QSOS

Our kinematic prescription for a biconical disc wind model follows Shlosman & Vitello (1993), and is described further by LK02, H13 and M15.

3.1 A Benchmark Model for BALQSOs

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

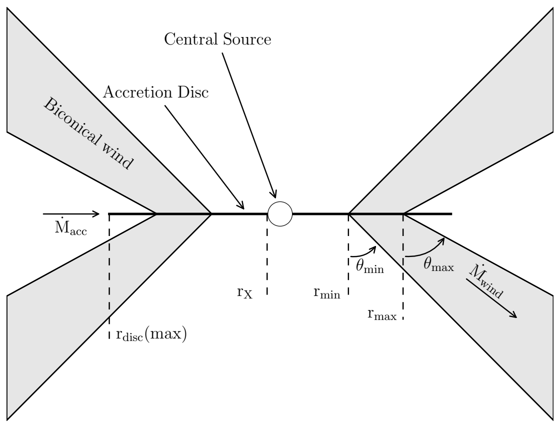

Figure 1. A cartoon showing the geometry and some key parameters of our biconical wind model.

3.1.1 Photon Sources

Describe the photon sources in the model.

The accretion disc in our model is geometrically thin, but optically thick and this adopt a standard multi-temperature blackbody using a Shakura & Sunyaev (1973) temperature profile. The emergent SED is thus determined by the specified accretion rate ($\dot{m}$) and central BH mass (M_{BH}). The inner radius of the disc extends to the innermost stable circular orbit (ISCO) of the BH. We assume a Schwarzchild BH with an ISCO at 6 R_G. The X-ray source in our model is treated as an isotropic sphere at the ISCO, which emits photons according to a power law,

3.2 Potential for unification

What was wrong with H13 model - X-rays + BELs.

3.3 Clumping

Introduce microclumping.

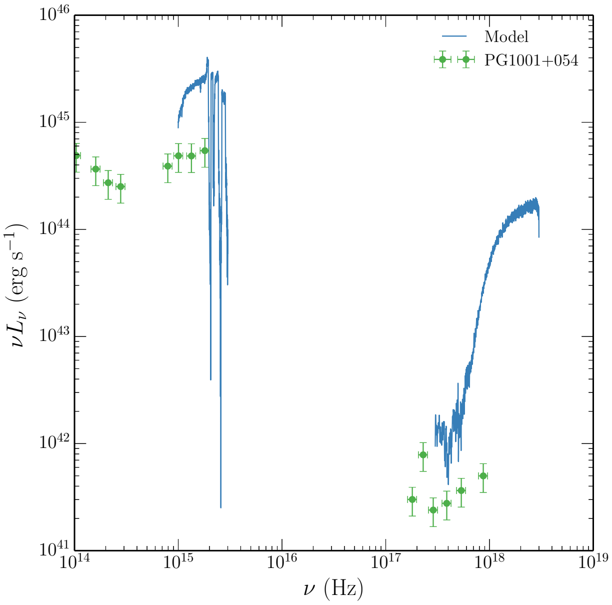

Figure 6. Broadband SEDs compared to IR and X-ray SEDs for selected BALQSOs from Grupe & Nousek (2015).

4 RESULTS

4.1 Physical Conditions and Ionization State

Show that clumping stops over-ionization.

Figure 2: Physical conditions of the wind, showing e.g. CIV fraction.

4.2 Synthetic Spectra

Present a spectrum of the UV and possible optical too.

Figures 3 and 4: UV and optical spectra.

4.3 X-ray Properties

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

Figures 5 and 6: L_{2kev} v L_{2500} plot and X-ray spectrum compared to Grupe and Nousek (broadband SED?)

4.4 LoBALs and trends with inclination

Figure 7: line profiles of CIV, Mg II and Al III as a function of inclination.

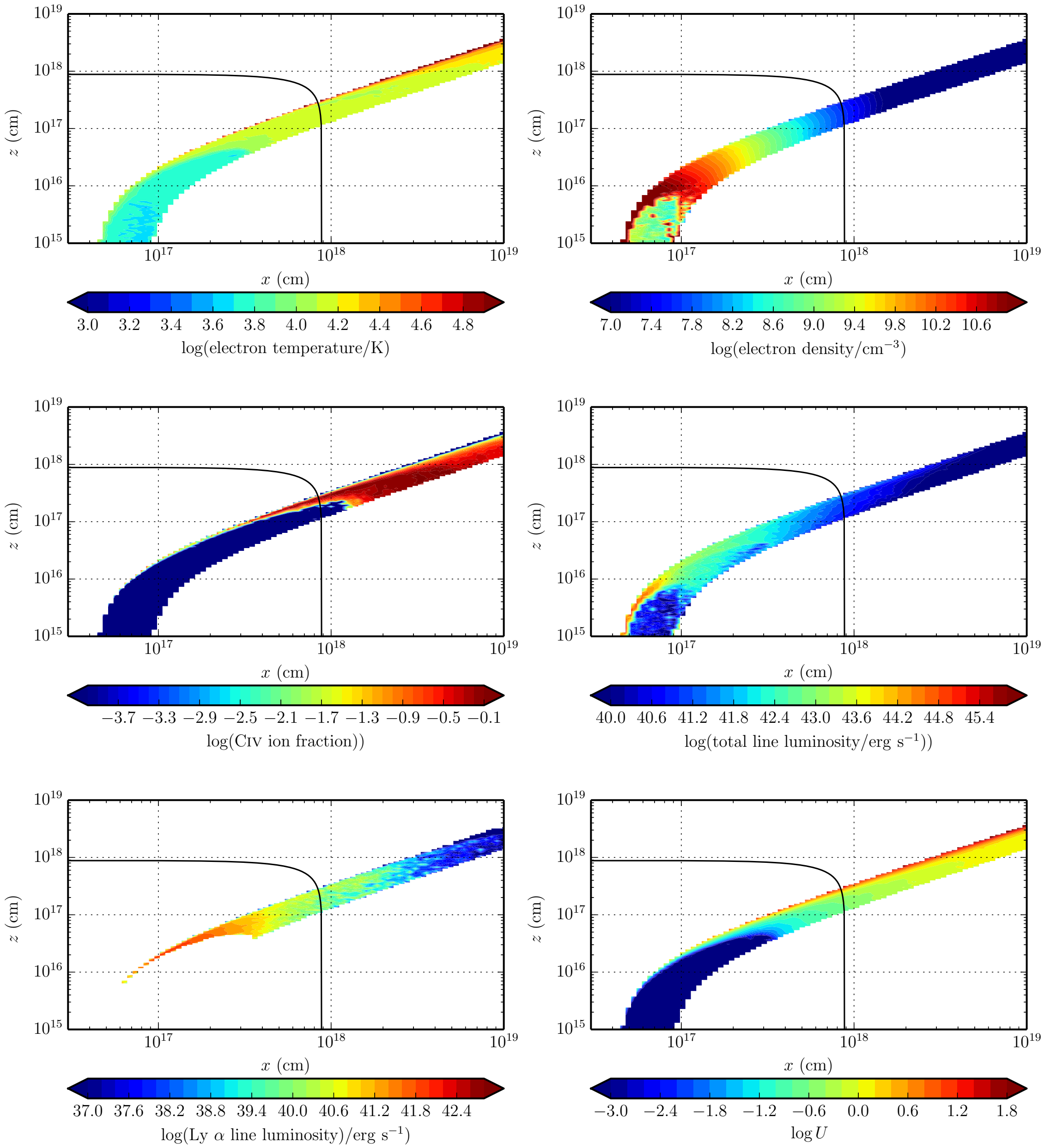

Figure 2. Physical properties of the outflow.

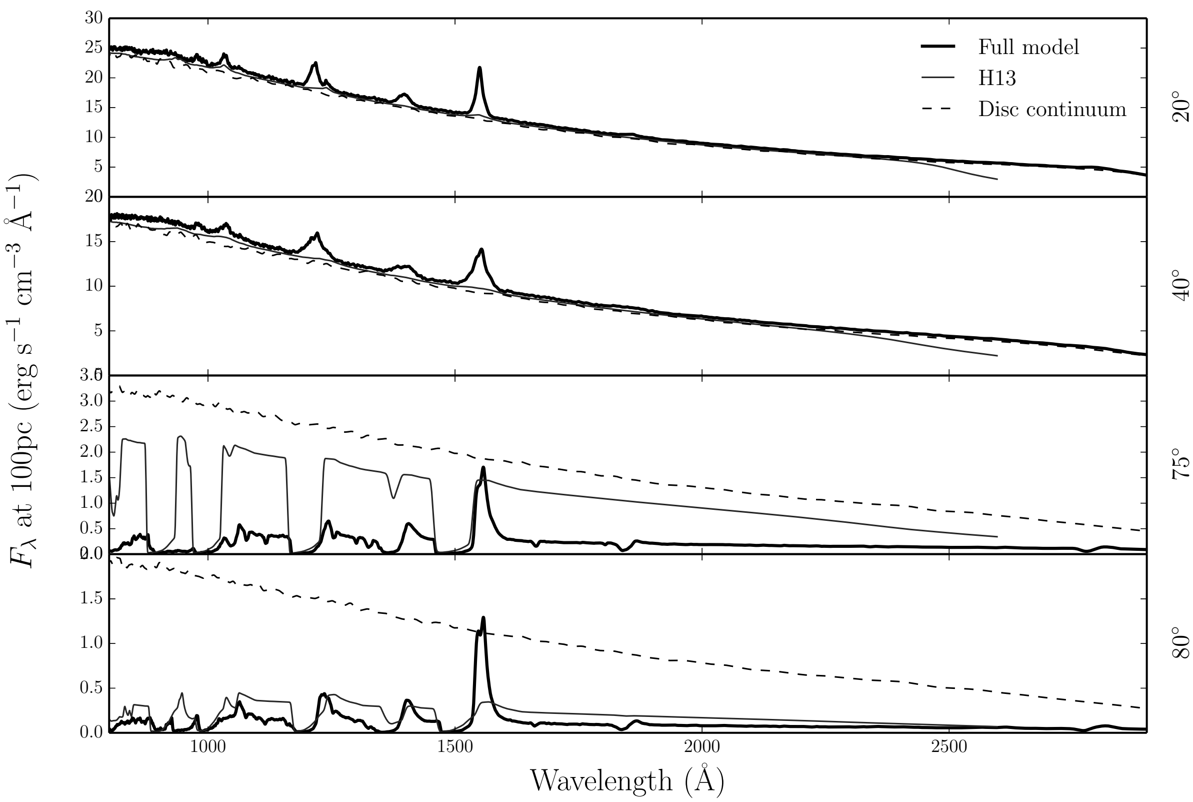

Figure 3. Synthetic spectra at four viewing angles in the clumpy model. Plot would look different probably, and may show composites, but this would be the main synthetic spectrum plot.

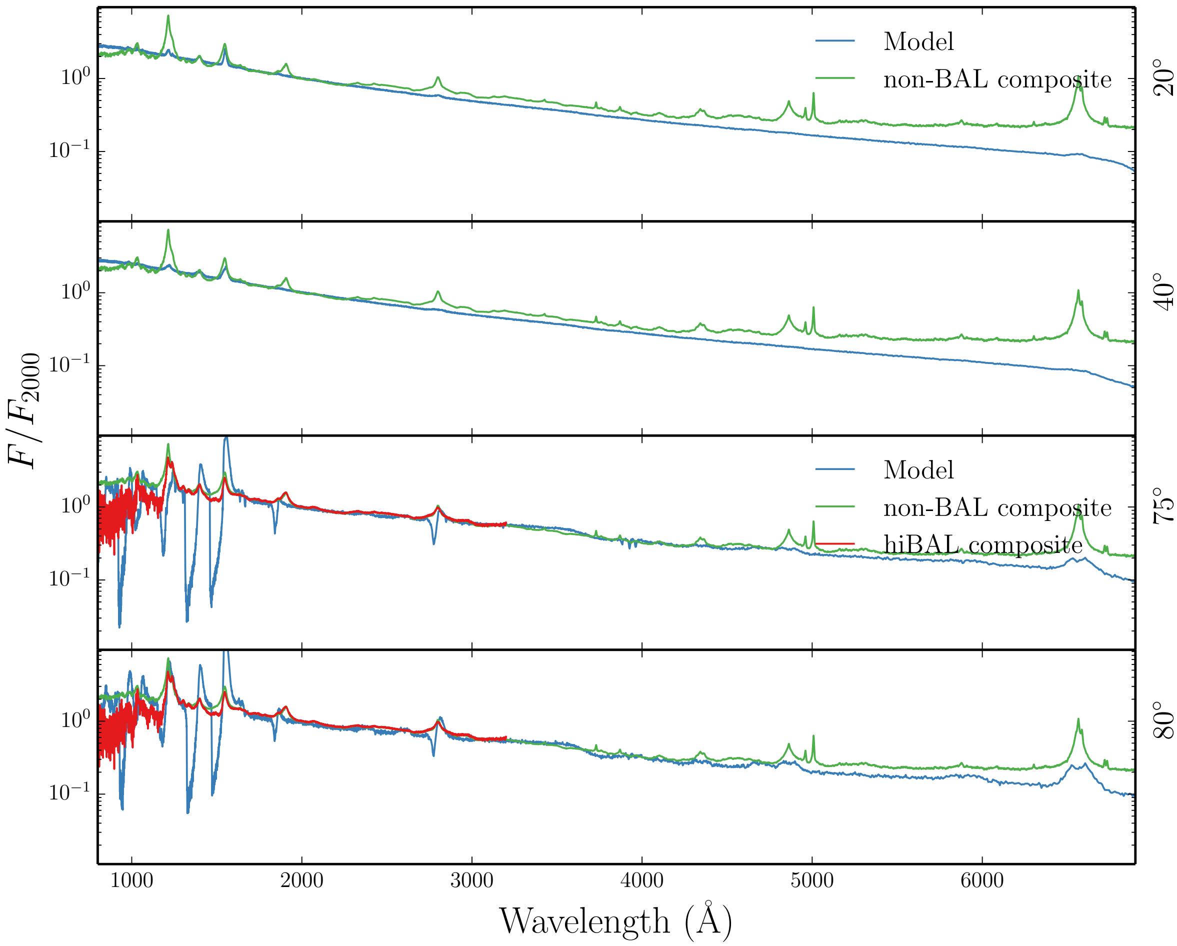

Figure 4. Figure designed to show optical spectrum and comparison to composite.

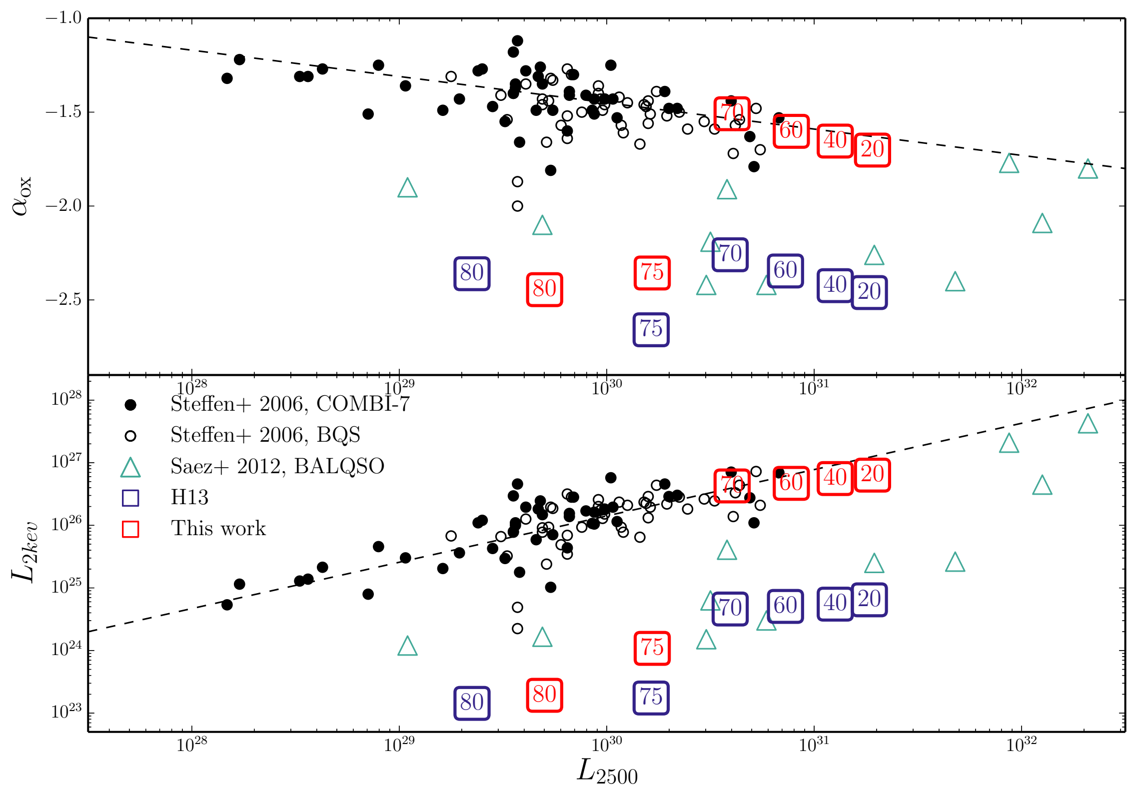

Figure 5. X-ray properties of the H13 and clumped model (text filled squares), plotted against monochromatic luminosity at 2500Å. Also plotted are the samples considered by Saez et al. 2012 on a similar plot; The COMBI-7 AGN sample (ref), the BQS sample (ref) and the Saez et al. (2012) sample of BALQSOs.

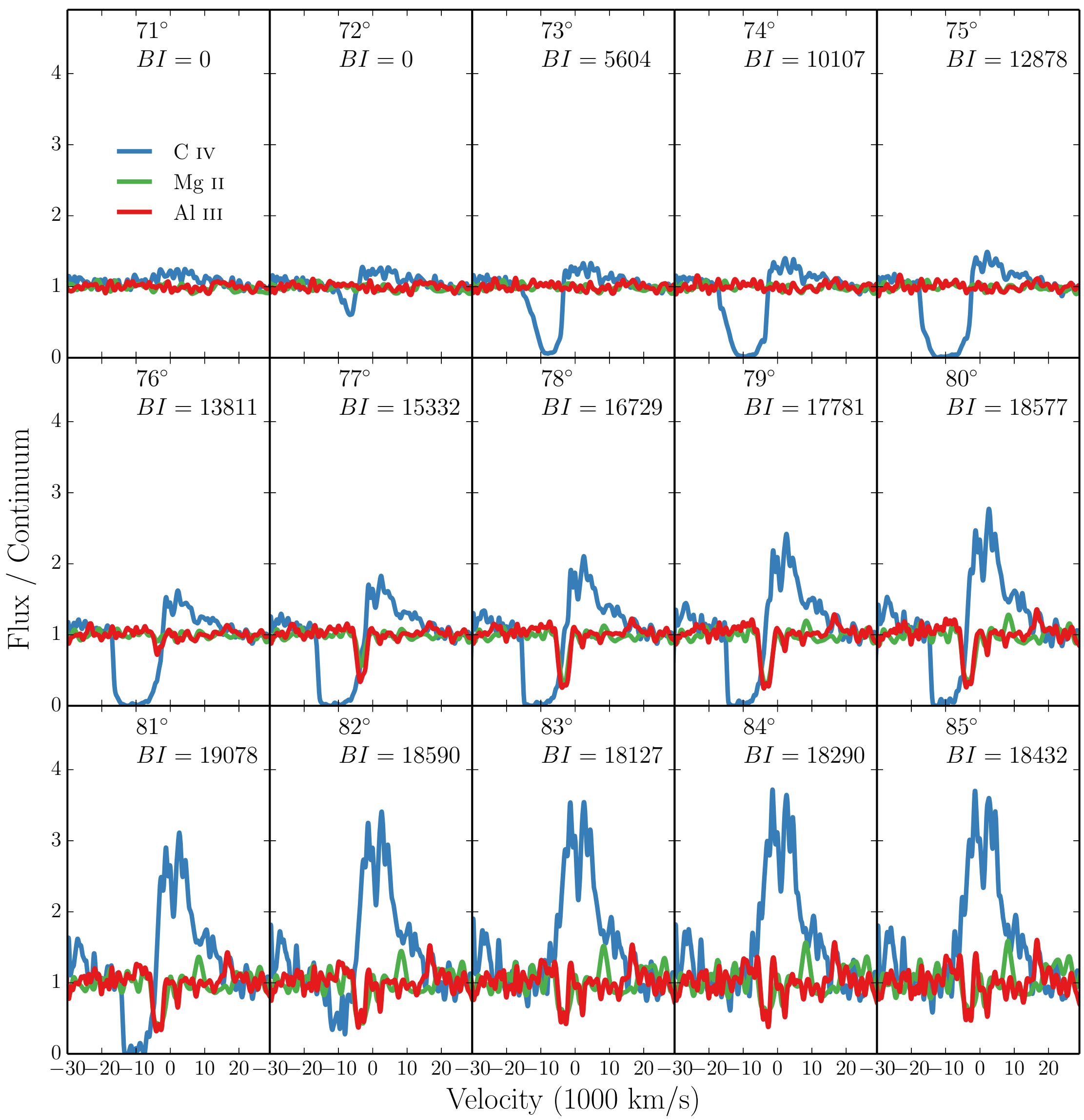

Figure 7. Carbon IV, Al III and Mg II line profiles with inclination for wind angles. Showing how the line profiles change and how LoBALs kick in at particularly high inclinations.

5 DISCUSSION

5.1 Anisotropy of disc emission

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

5.2 General relativistic effects

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

Figures 8 and 9: AGNSPEC F(2000) as a function of viewing angle compared to a BB disc. spectrum compared to composites with AGNSPEC correction.

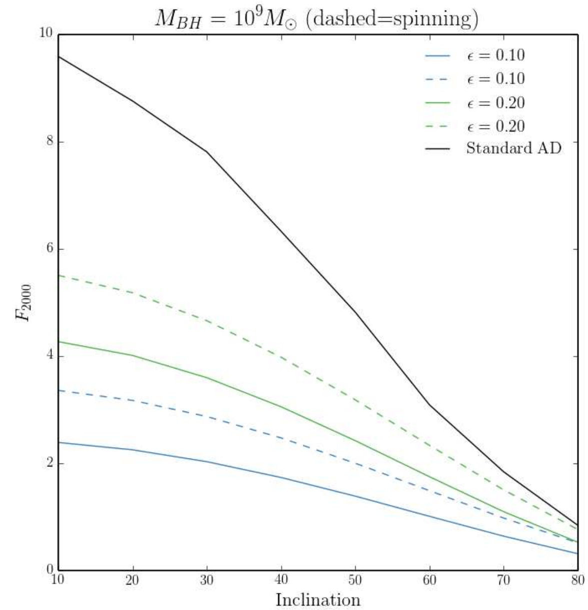

Figure 8. F_{2000} as a function of inclination from AGNSPEC models, compared to a classical AD. **This is a placeholder- it will show the effect of GR on the anisotropy of the disk for different wavelengths and eddington fractions, compared to limb darkened and foreshortened classical AD**.

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. We also need to be aware that there will be a number of selection effects in building up the composites, and we should discuss these and the subtleties involved.

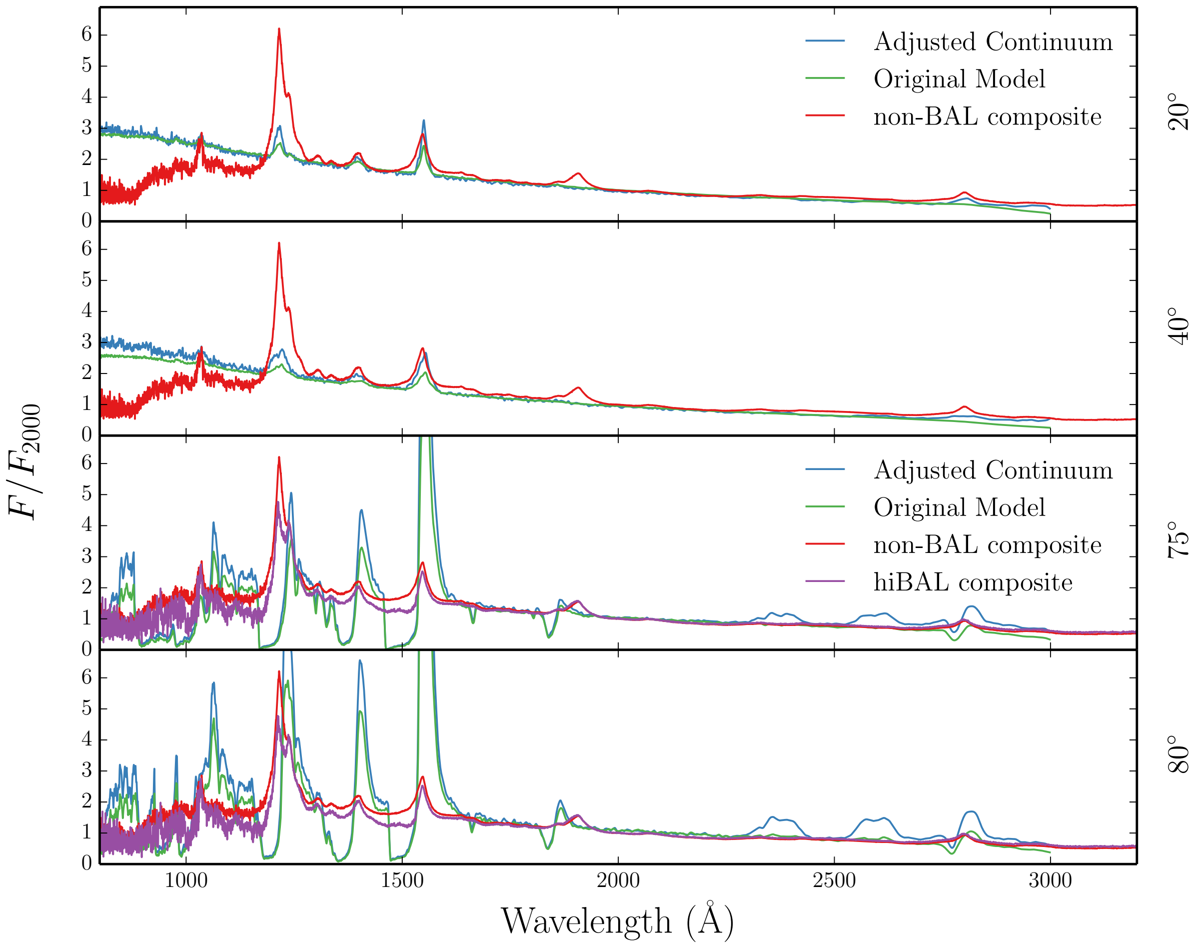

Figure 9. F_λ normalised to F_{2000}. **Again, this is a placeholder- but I'm thinking some kind of comparison to composite including the adjusted continuum, showing that we can't get it exactly right**.

6 SUMMARY

We have carried out MCRT simulations using a simple prescription for a biconical disc wind, with the aim of expanding on the work of H13 and assessing the viability of such a model for geometric unification of quasars. We find the following 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 a foreshortened, limb-darkened classical thin accretion disc 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 disc SED, using the disc atmosphere and GR ray-tracing code AGNSPEC. While including GR effects does cause the disc 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.

Our work confirms a number of expected outcomes from such a model, and suggests that a simple geometry such as this can come close to explaining much of the phenomenology of quasars. Nevertheless, our conclusions pose a clear challenge to the current unification picture.

ACKNOWLEDGEMENTS

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