Mon. Not. R. Astron. Soc. **000**, 000–000 (0000) Printed 16 July 2015 (MN LATEX style file v2.2)

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

J. H. Matthews[1⋆], C. Knigge[1], N. Higginbottom[1], K. S. Long[2], S. A. Sim[3], S. W. Mangham[1].

[1]*School of Physics and Astronomy, University of Southampton, Highfield, Southampton, SO17 1BJ, United Kingdom*
[2]*Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD, 21218*
[3]*School of Mathematics and Physics, Queens University Belfast, University Road, Belfast, BT7 1NN, Northern Ireland, UK*

16 July 2015

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. Paragraphs:

(i) standard wind + BALQSO introduction
(ii) Can an outflow also be the BLR? (unification)
(iii) some discussion of scales, referencing e.g. reverb maps, variability, microlensing, Arav
(iv) AGN variability leading to clumping background: stellar winds, clumping in AGN winds.
(v) Modelling efforts so far (Proga, Higginbottom, etc.)
(vi) Plan of paper

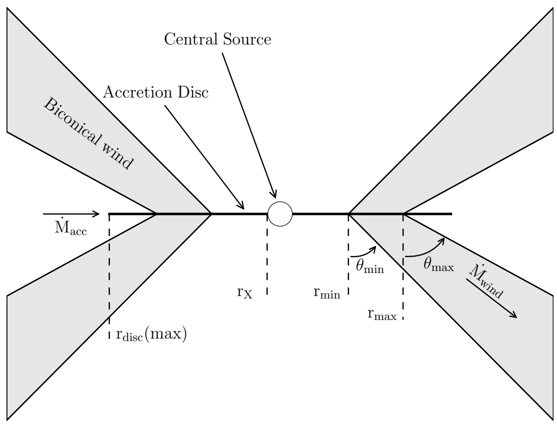

Figure 1. A cartoon showing the geometry and some key parameters of our biconical wind model.

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...

2.2 Ionization Scheme

Describe the ionization scheme. Combination of H13 and M15 but with rate equations solved explicitly for ionization solution.

2.3 Atomic Data

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 Simple Biconical Disc Wind Model

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

3.1.1 Photon Sources

Describe the photon sources in the model.

3.2 Potential for unification

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

3.3 Clumping

Introduce microclumping.

4 RESULTS

4.1 Physical Conditions and Ionization State

The wind rises slowly from the disc at first, with clumped densities of $n_H \sim 10^{11}$ cm^{-3} close to the disc plane. The flow then accelerates over a scale length of $R_V = 10^{19}$ cm up to a terminal velocity of around 3 times the escape velocity ($\sim$ 10,000 km s^{-1}). This gradual acceleration means that the wind exhibits a stratified ionization structure, with low ionization material in the base of the wind giving way to highly ionized plasma further out. By clumping the wind, we are able to produce the range of ionization states observed in Quasars and BALQSOs, while adopting a realistic 2−10 keV X-ray luminosity of $L_X 1 \times 10^{43}$ ergs s^{-1}. Without clumping, this wind would be over-ionized to the extent that opacities in e.g., C IV would be entirely negligible (see H13).

One useful measure of the ionization state is the ionization parameter, U, given by

$$U = \frac{4\pi}{n_H c} \int_{13.6\mathrm{eV}}^{\infty} \frac{J_\nu d\nu}{h\nu}. \quad (1)$$

where $\mathrm{n_H}$ is the local number density of H, and ν denotes photon frequency. The ionization parameter is a useful measure of the ionization state of a plasma, as it evaluates the ratio of the number density of ionizing photons to the local H density.

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.

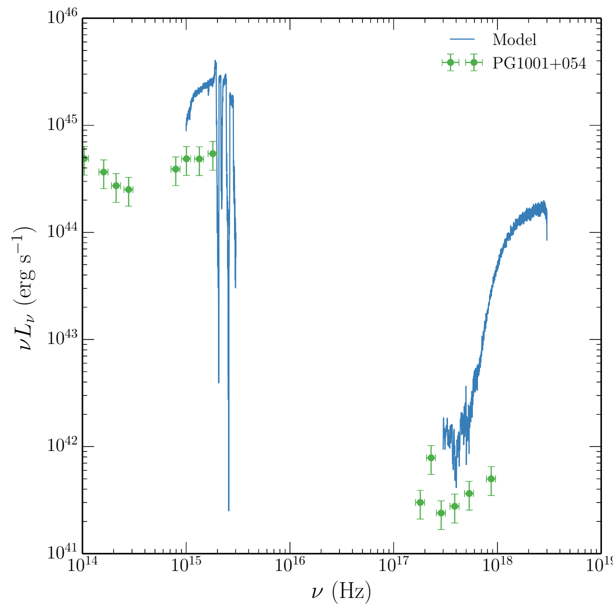

Figure 6. Broadband SEDs compared to IR and X-ray SEDs for selected BALQSOs from Grupe & Nousek (2015).

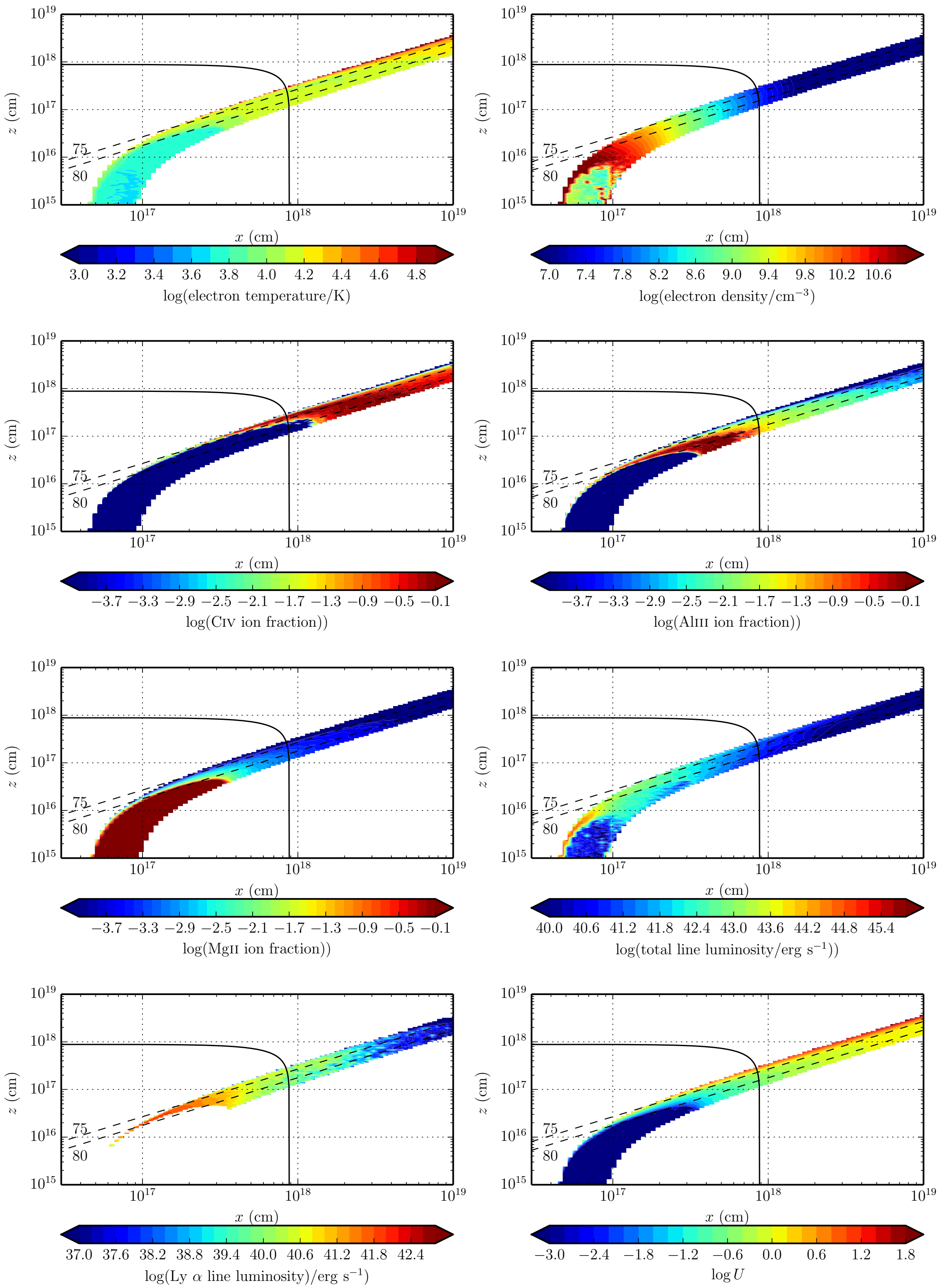

Figure 2. Physical properties of the outflow.

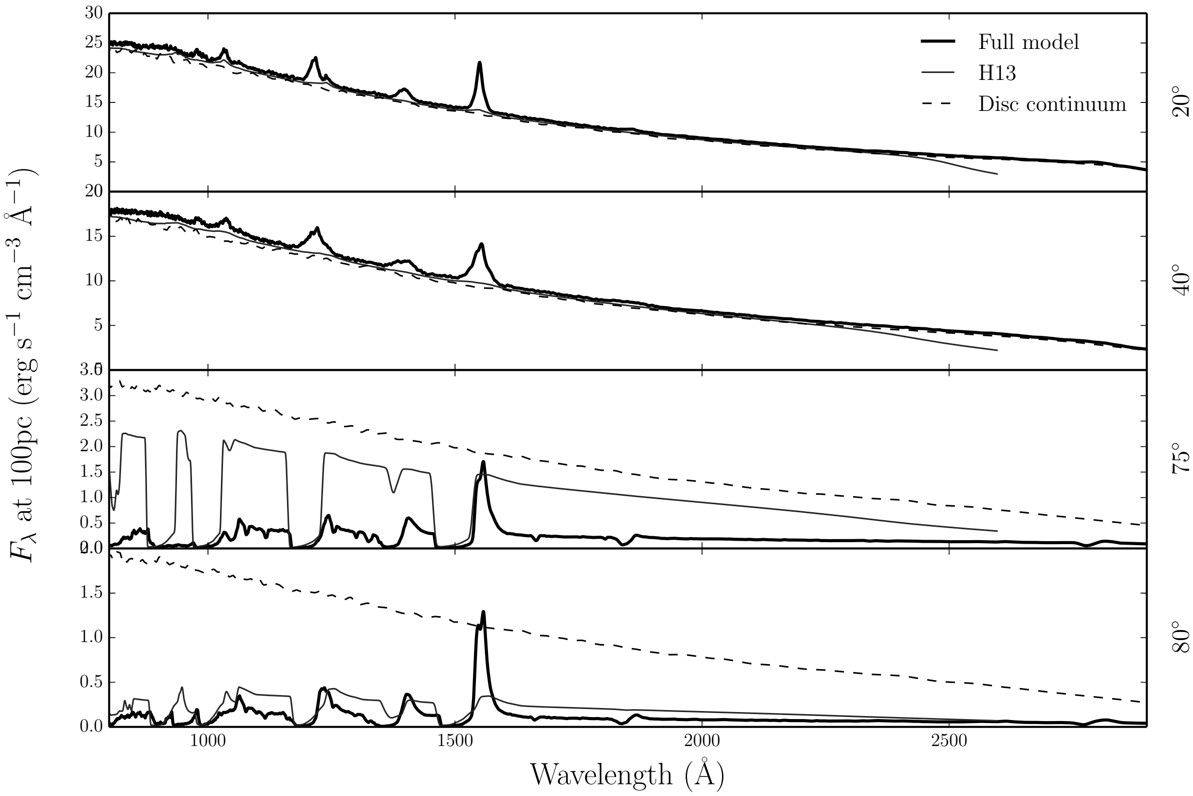

Figure 3. Synthetic spectra at four viewing angles in the clumpy model. Plot would look different probably, and may show composites, but this would be the main synthetic spectrum plot.

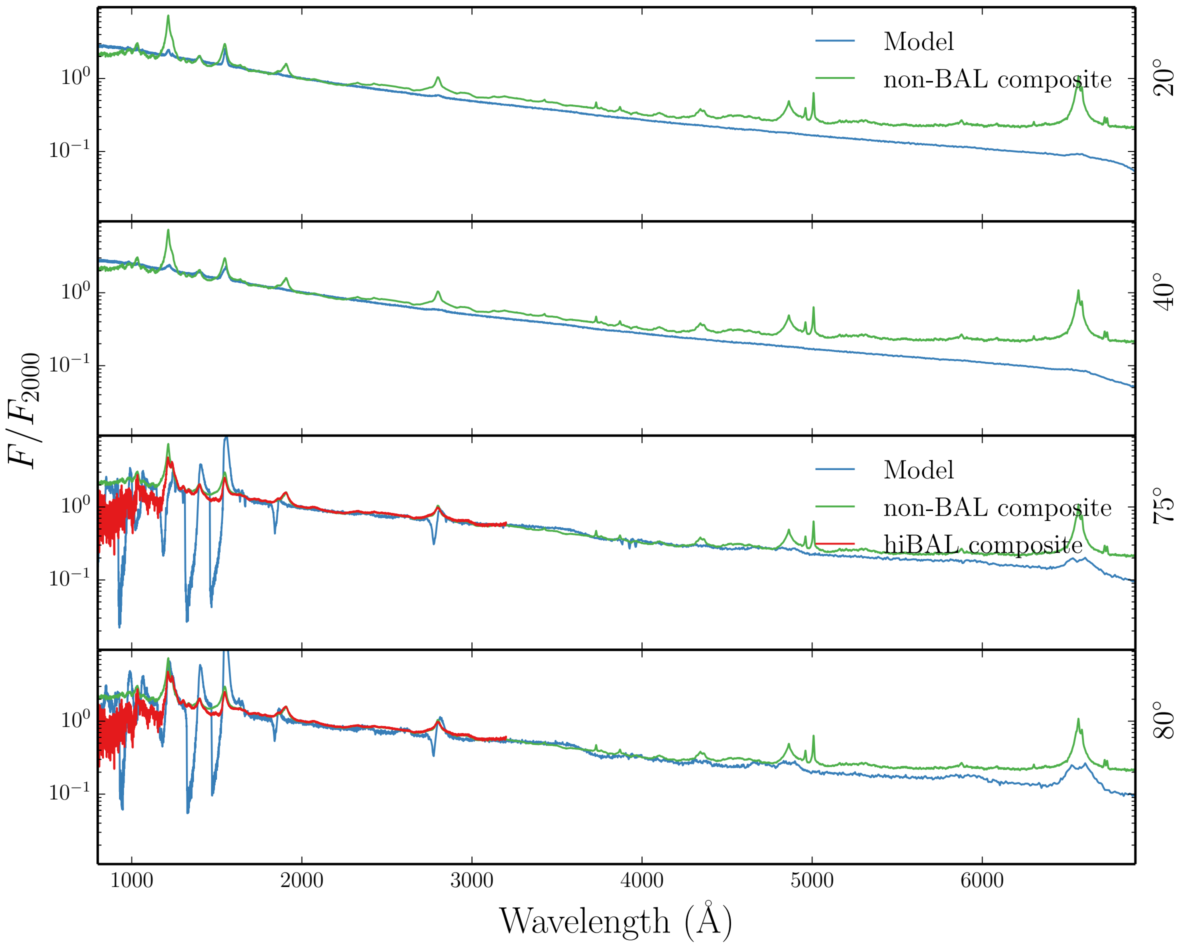

Figure 4. Figure designed to show optical spectrum and comparison to composite.

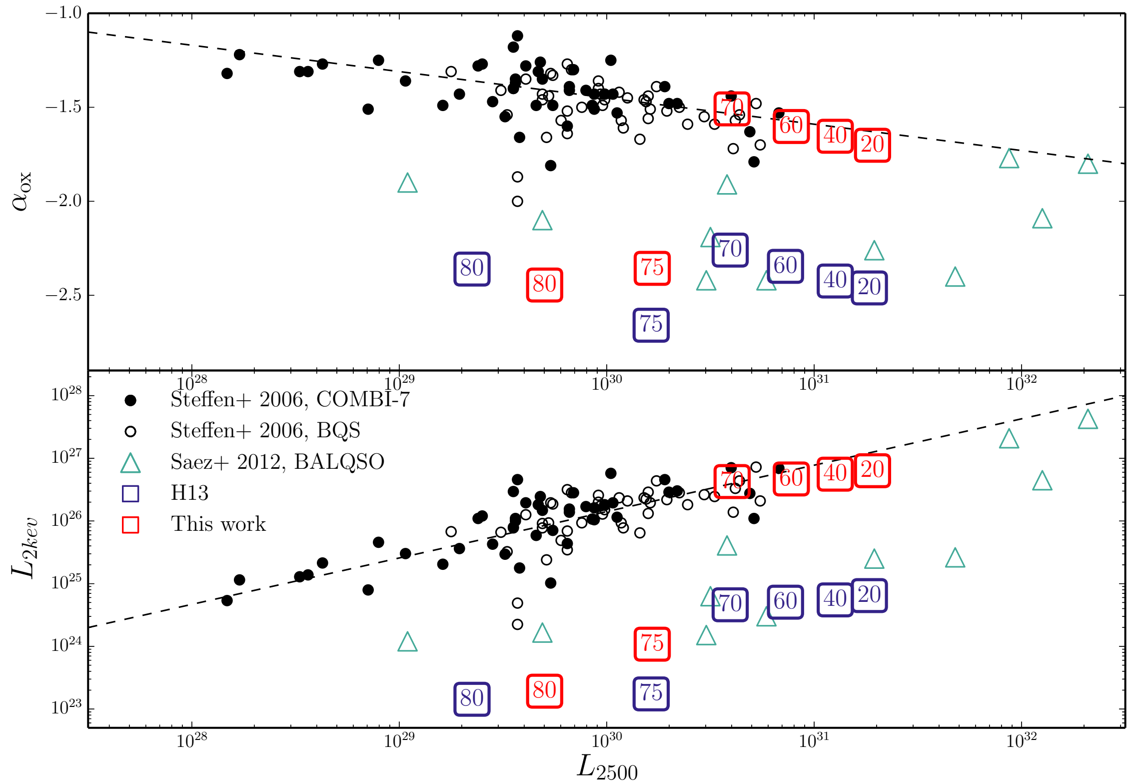

Figure 5. X-ray properties of the H13 and clumped model (text filled squares), plotted against monochromatic luminosity at 2500Å. Also plotted are the samples considered by Saez et al. 2012 on a similar plot; The COMBI-7 AGN sample (ref), the BQS sample (ref) and the Saez et al. (2012) sample of BALQSOs.

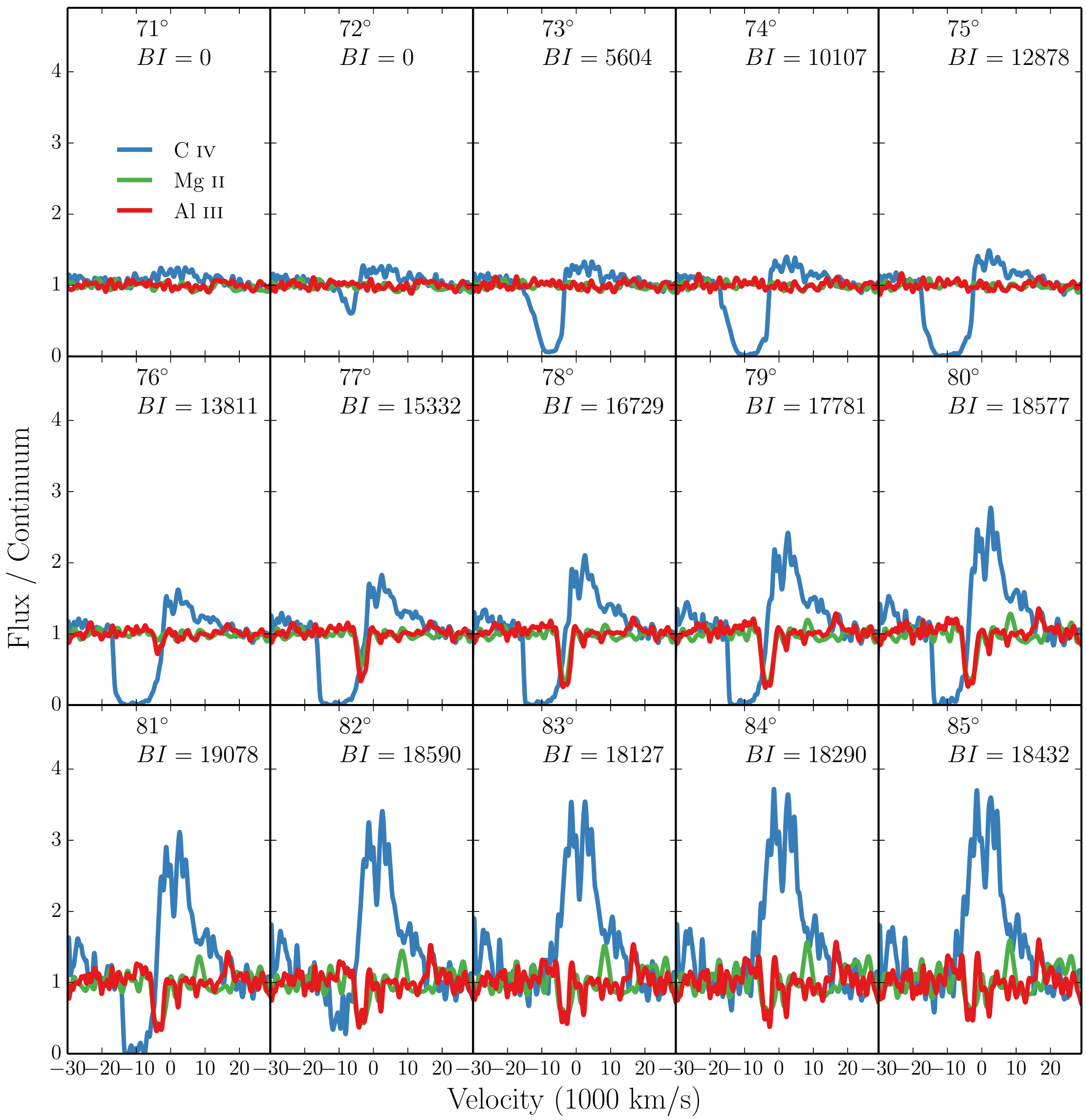

Figure 7. Carbon IV, Al III and Mg II line profiles with inclination for wind angles. Showing how the line profiles change and how LoBALs kick in at particularly high inclinations.

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.

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.

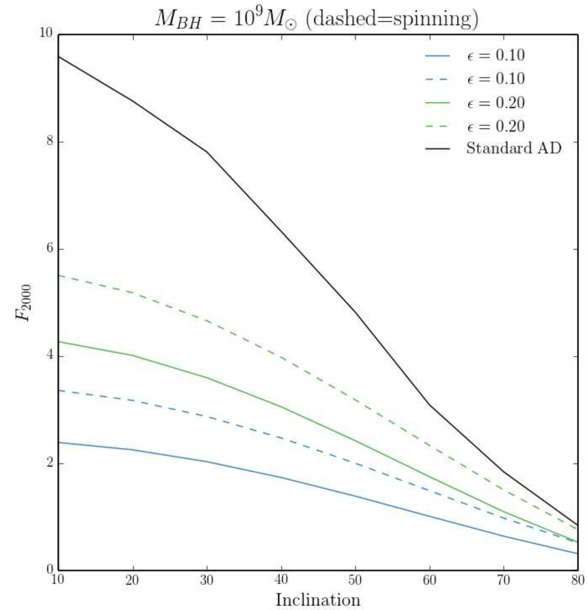

Figure 8. F_{2000} as a function of inclination from Agnspec models, compared to a classical AD. **This is a placeholder- it will show the effect of GR on the anisotropy of the disk for different wavelengths and eddington fractions, compared to limb darkened and foreshortened classical AD**.

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

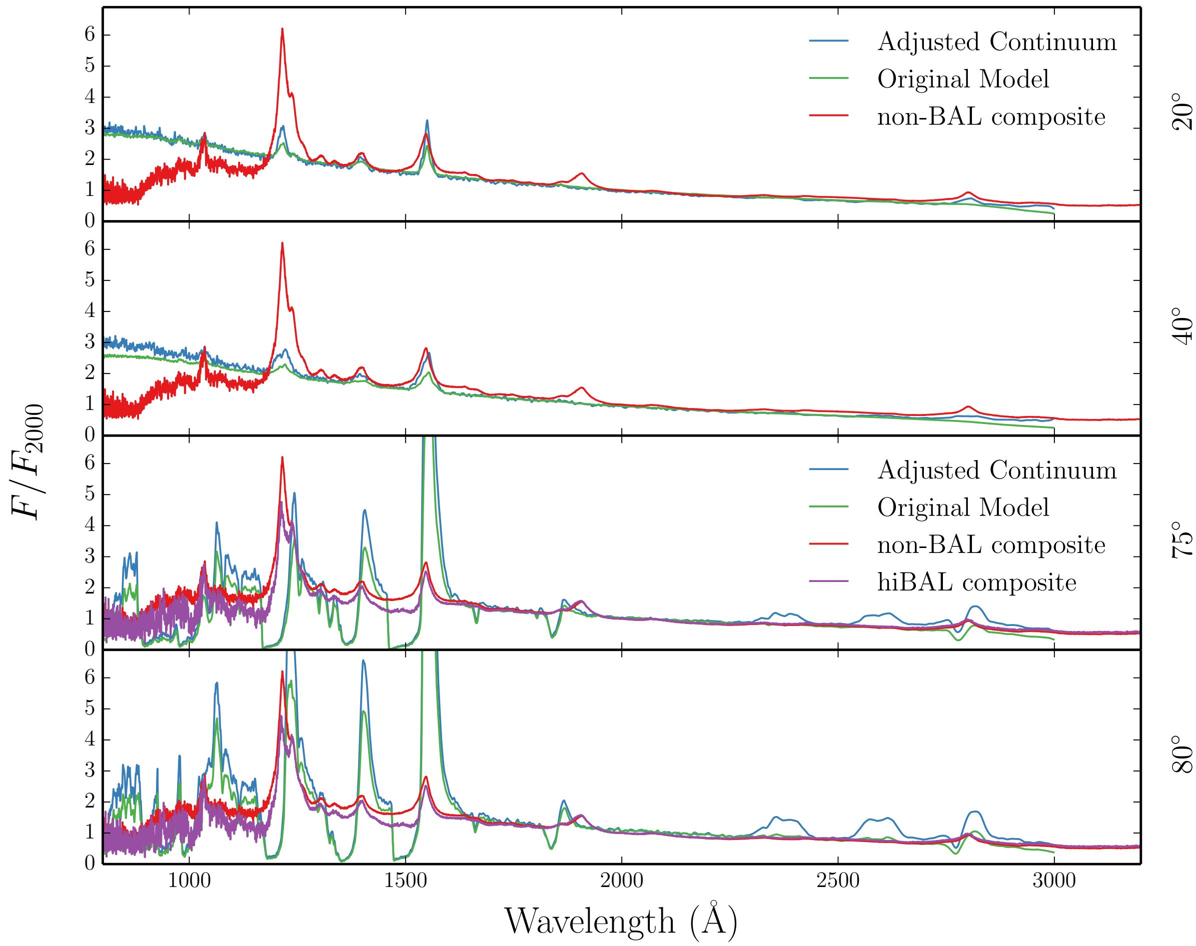

Figure 9. F_λ normalised to F_{2000}. **Again, this is a placeholder- but I'm thinking some kind of comparison to composite including the adjusted continuum, showing that we can't get it exactly right**.

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

REFERENCES

Higginbottom N., Knigge C., Long K. S., Sim S. A., Matthews J. H., 2013, MNRAS 436, 1390
Shlosman I., Vitello P., 1993, ApJ 409, 372