Attempts to Reproduce the Rest-Frame UV Spectra of AGN from a Biconical Wind

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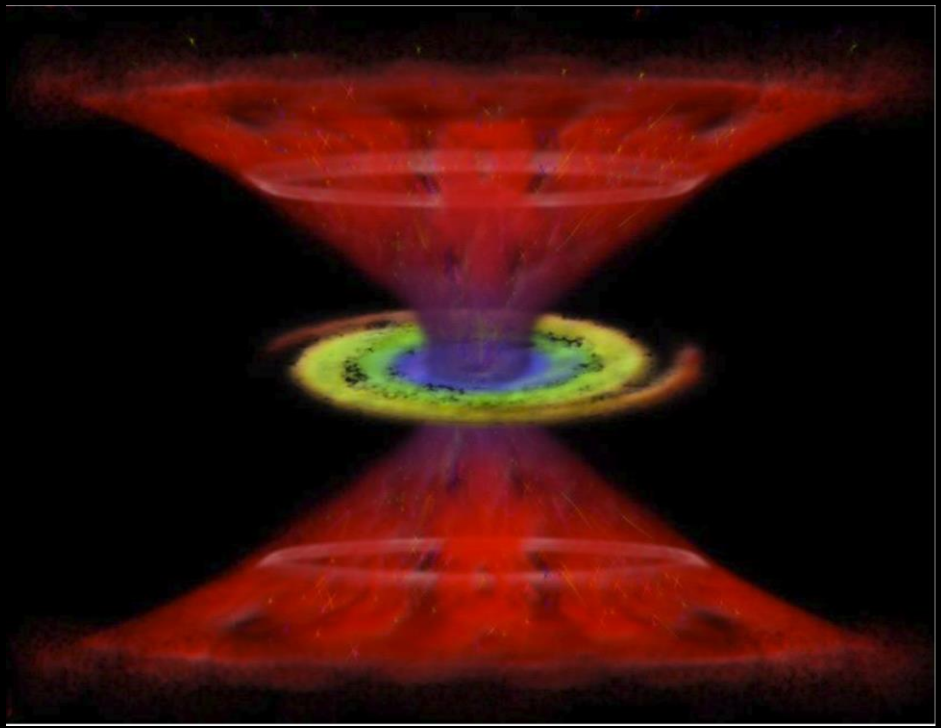
Unified AGN model

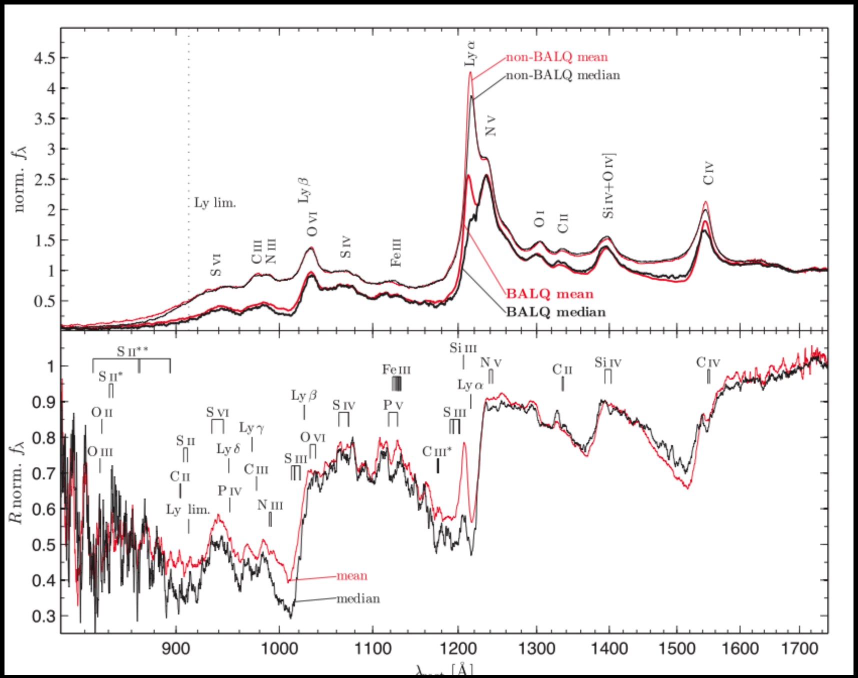
- AGN are BH systems accreting from an accretion disk
- Outflows from AGN arise from the disk and possibly a torus
- Differences in AGN properties arise in part from viewing angle effects



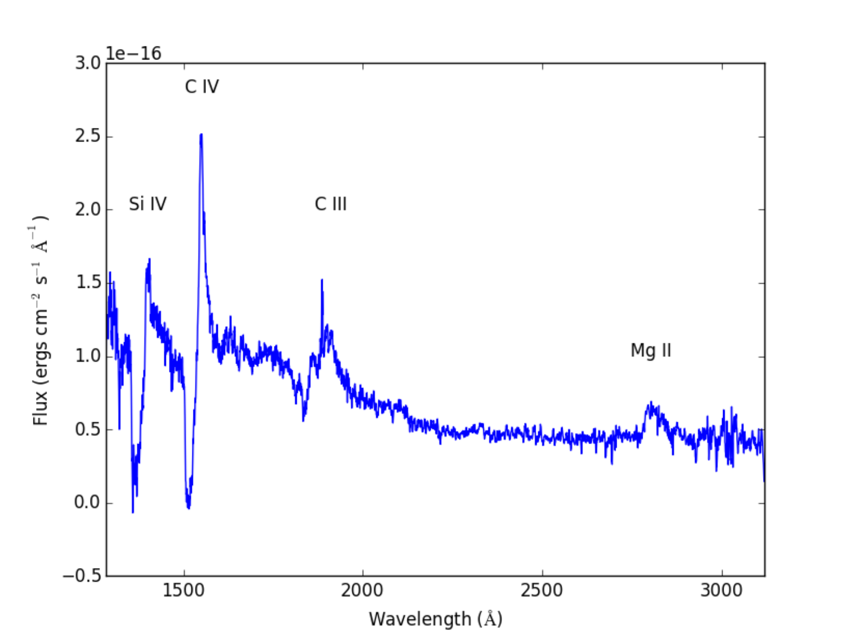
Martin Elvis

BAL QSOs

- 20% of AGN show broad absorption lines
- Goal insofar as possible is to reproduce the spectra of AGN, and particular BAL AGN with plausible AGN parameters



BAL QSOs

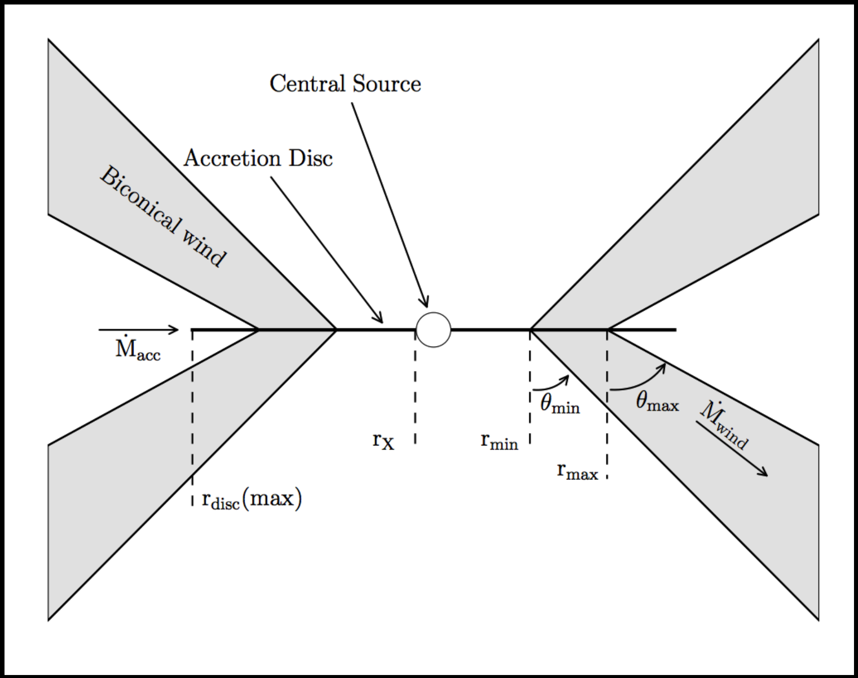


- 20% of AGN show broad absorption lines
- Goal insofar as possible is to reproduce the spectra of AGN, and particular BAL AGN with plausible AGN parameters

Individual spectra vary and can have lines which are almost black

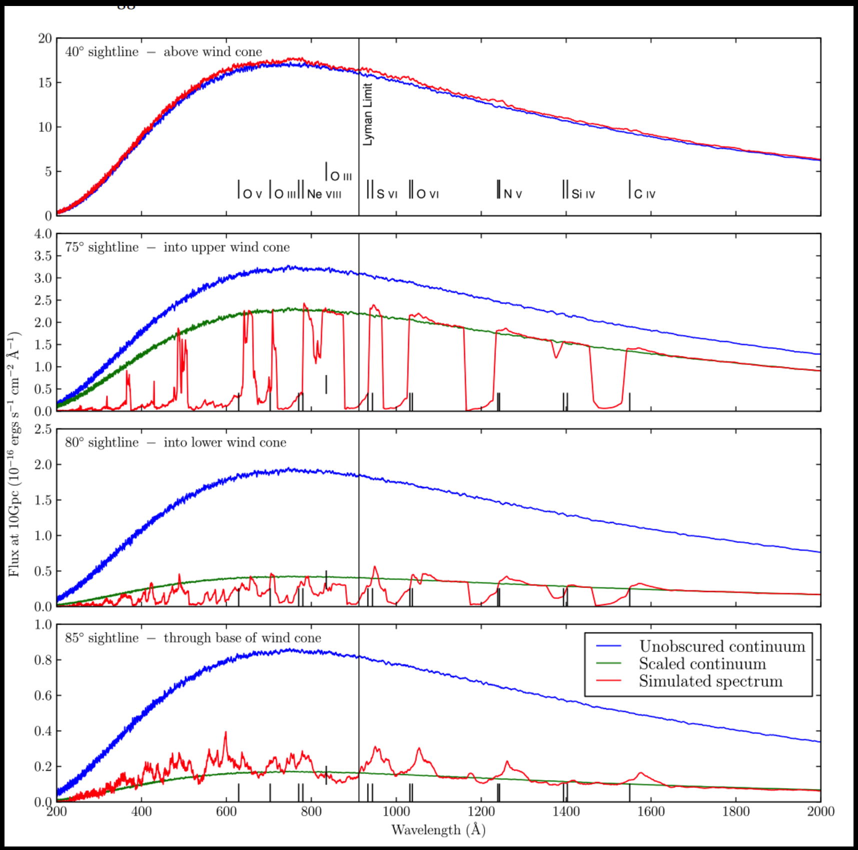
Python

- Monte Carlo radiative transfer program for modeling bi-conical flows
- Radiation sources
  - Disk – standard Shakura-Sunyaev disk radiating as an ensemble of BB
  - BH – modeled as a power law (radiating from ISCO) with a given L_x and γ
- Bi-conical Wind
  - Kinematic description
  - (Hydro calculation)
- Like Cloudy & X-star, the code calculates
  - the ionization structure of the wind, and
  - Uses this to calculate the emergent spectrum
- Unlike Cloudy & X-star radiative transfer is carried out in 3D



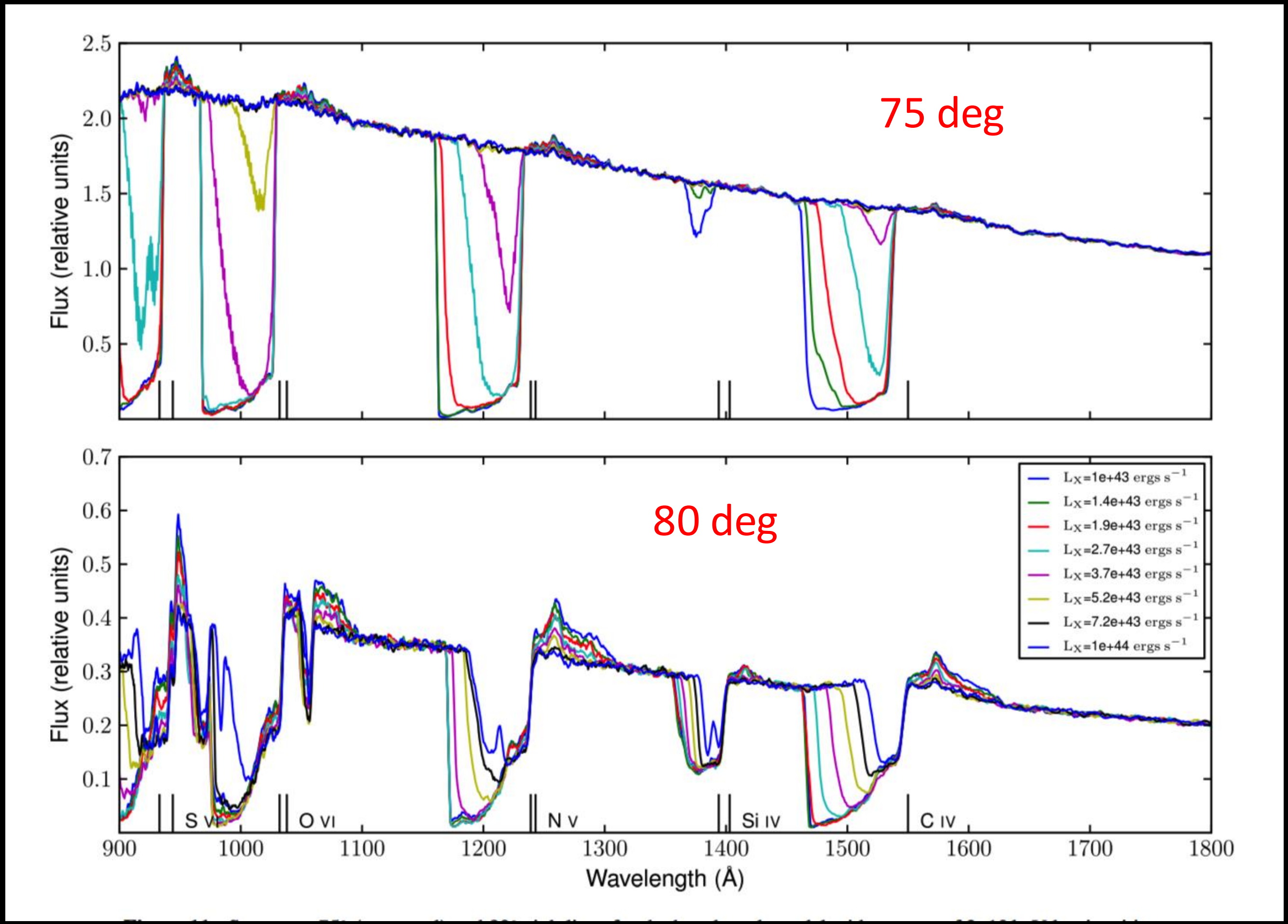
Initial Benchmark

Free parameters	Value
$M_{\rm BH}$	$1 \times 10^9\,{\rm M}_\odot$
$\dot{M}_{\rm acc}$	$5\,{\rm M}_\odot\,{\rm yr}^{-1} \simeq 0.2\,\dot{M}_{\rm Edd}$
α_X	-0.9
L_X	$1 \times 10^{43}\,{\rm ergs\,s}^{-1}$
$r_{\rm disc}({\rm min}) = r_X$	$6r_g = 8.8 \times 10^{14}$ cm
$r_{\rm disc}({\rm max})$	$3400r_g = 5 \times 10^{17}$ cm
$\dot{M}_{\rm wind}$	$5\,{\rm M}_\odot\,{\rm yr}^{-1}$
$r_{\rm min}$	$300r_g = 4.4 \times 10^{16}$ cm
$r_{\rm max}$	$600r_g = 8.8 \times 10^{16}$ cm
$\theta_{\rm min}$	$70^\circ\!.0$
$\theta_{\rm max}$	$82^\circ\!.0$
λ	0
v_∞	$v_{\rm esc}$(f=1)
R_v	1×10^{18} cm
α	1.0
Derived parameters	**Value**
$L_\nu(2500\,\text{Å})$	$6.3 \times 10^{30}\,{\rm erg\,s}^{-1}\,{\rm Hz}^{-1}$
$L_\nu(2\,{\rm keV})$	$1.2 \times 10^{25}\,{\rm erg\,s}^{-1}\,{\rm Hz}^{-1}$
$L_{\rm bol}$	$2.4 \times 10^{46}\,{\rm erg\,s}^{-1}$
$M_{\rm bol}$	-27.4
M_u	-26.2
$\alpha_{\rm OX}$	-2.2

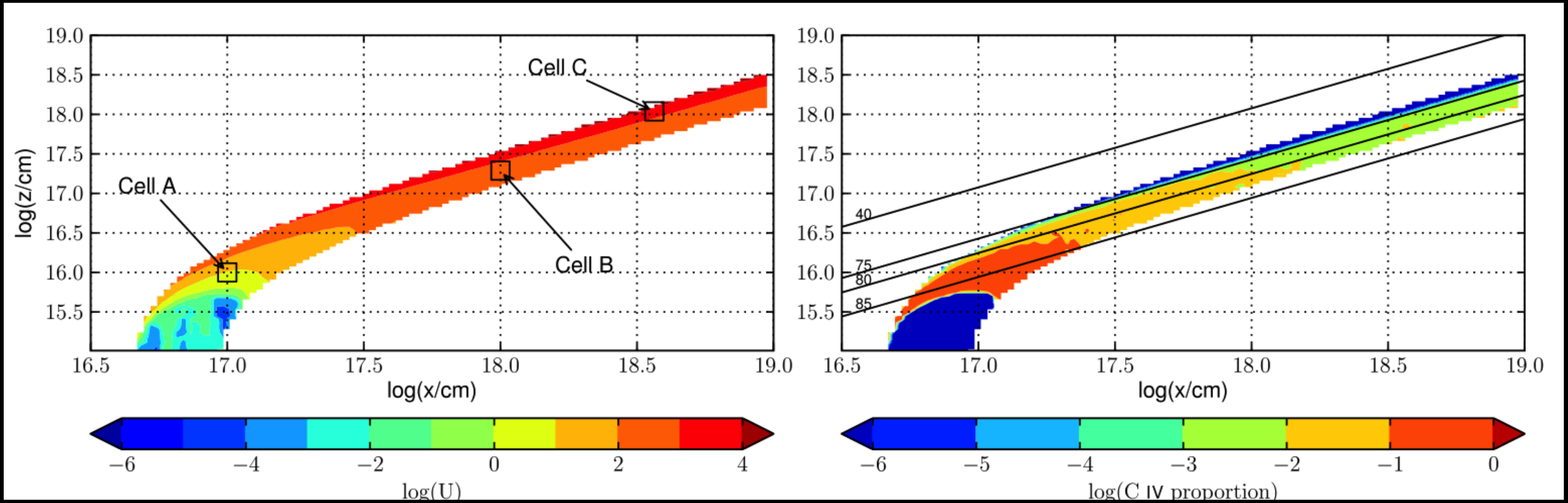


Higginbottom+13

Initial Benchmark – UV region



Success and failure



- Success
  - Broad absorption lines, which plausibly arise from the broad line region
  - Lines go from emission to absorption as inclination changes
- Failure
  - Lines fade as L_x exceeds 10^{44} erg s^{-1} because the wind is too highly ionized
    - Scattering from the inner disk wind does not shield the outer disk wind sufficiently
  - Emission line profiles are too weak

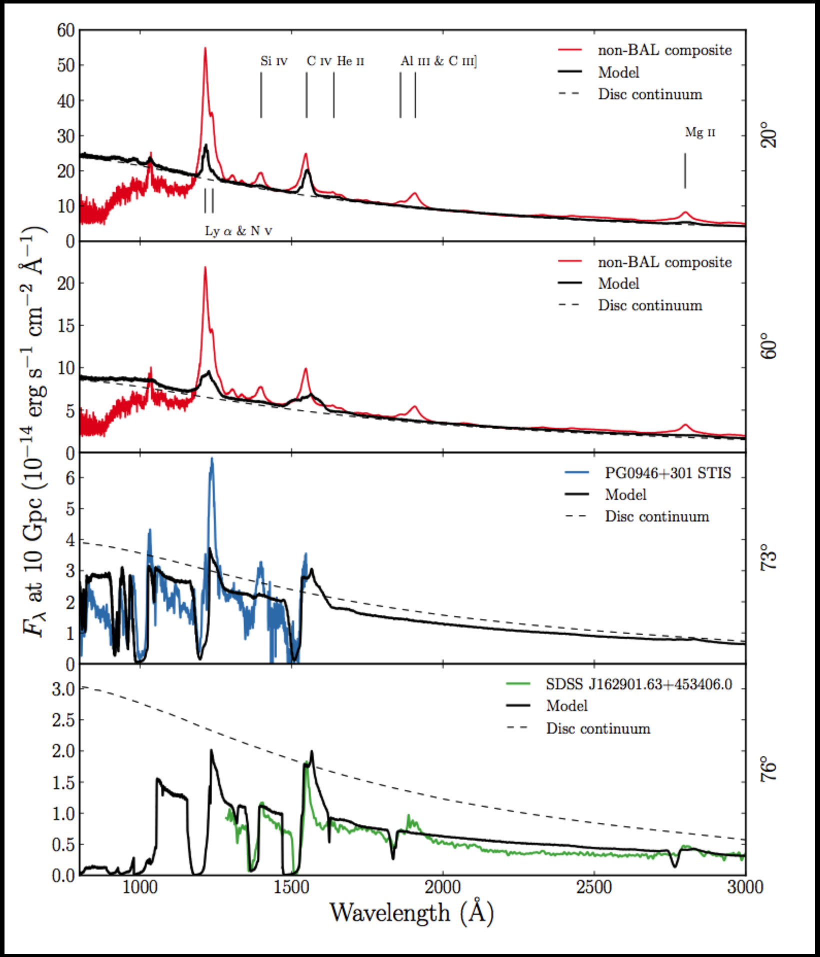
Modifications to original calculation

- Introduce clumping in the wind
  - Use the same micro-clumping approach that are used to model O-star winds
- Intent → Lowers the ionization parameter for the same mass loss rates

- Improve treatment of line radiation
  - Before – All lines treated in the two level approximation → no recombination cascade, and no Hβ and no He II 1604
  - After – H and He treated as macro-atoms (Lucy 02, 03) → proper treatment of all of the above processes
- Intent → more accurately produce emission lines

New benchmark model

- Same as Higginbottom+13, except
- L_x 10^{43} → 10^{45} erg s^{-1}
- Filling factor 1 → 0.01
- R_v 10^{18} → 10^{19} cm
- Wind acceleration parameter α 1→ 0.5
- All these items make the wind interaction region denser and hence lower the ionization parameter



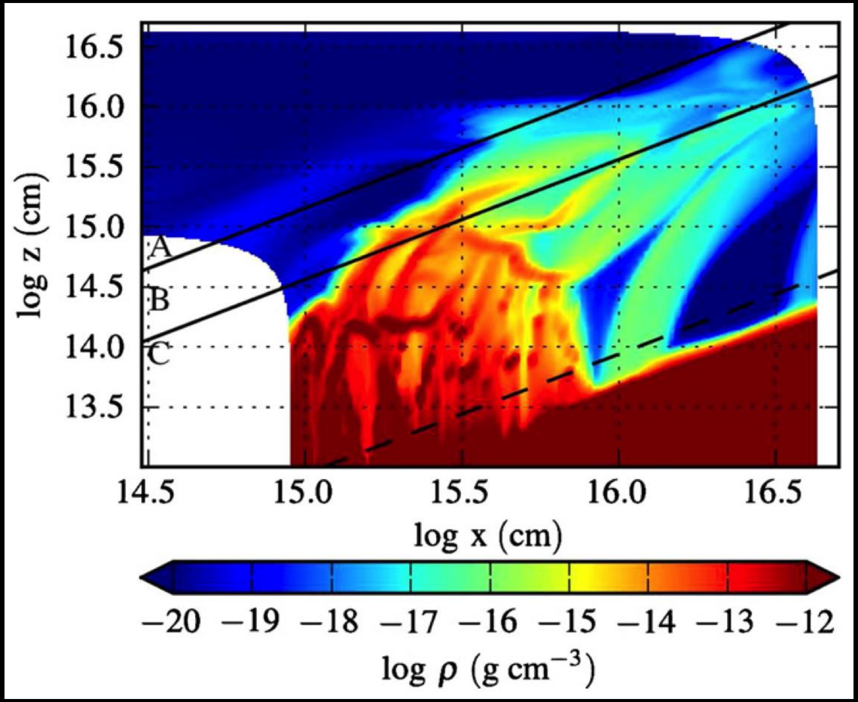
Matthews+16

Success and Failure

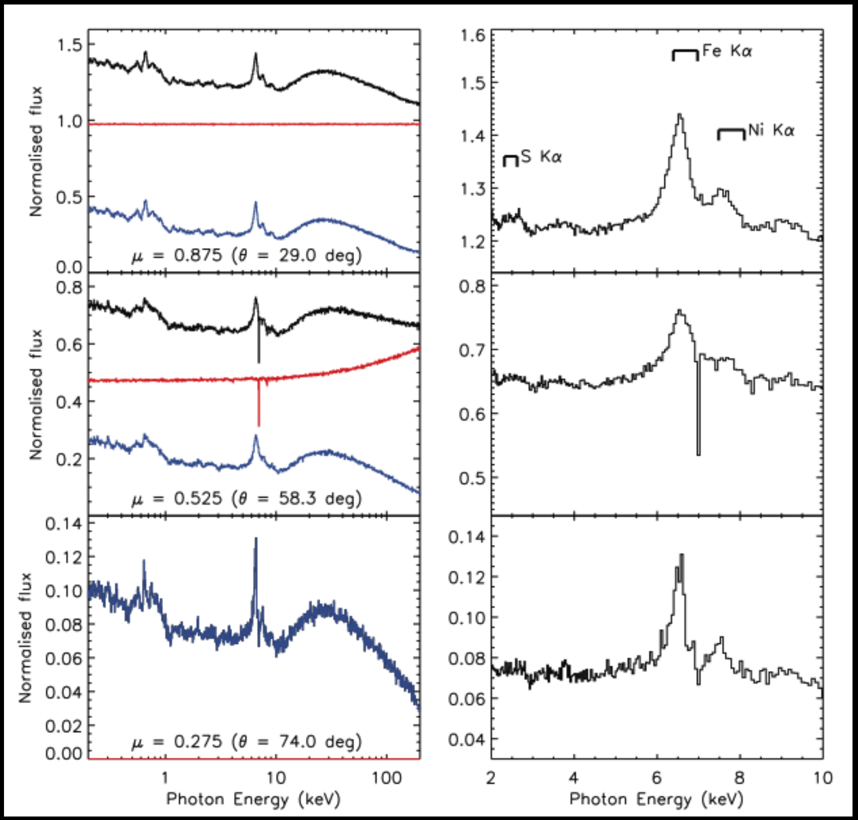
- Success
  - Clumping allows the production of UV lines at X-ray luminosities as high as 10^{45} erg s^{-1}
  - Clumping produces the range of ionization states seen in AGN (in optical and UV)
  - Line emission is increased (and we now see Balmer lines and the Balmer continuum) at high inclinations angles
- Failure
  - Line emission is still too weak overall
  - The obseved EWs of the emission lines are about the same in non-BAL and BAL AGN, but our models show a gradual increase with inclination (as one would expect due to disk fore shortening)

Beyond kinematic models

- Kinematic models
  - Pros
    - more physically motivated than 1-d (Cloudy models)
    - allow for 3-d radiative transfer
  - Cons
    - More “organized” than hydrodynamical simulations suggest
- Next steps
  - Post-processing
    - Start with a hydro-simulation, which provides the density and velocity structure for the wind
    - Calculate the ionization structure and spectra for snap shots
- Nirvana
  - Full radiative-hydro



Post processing – X-rays

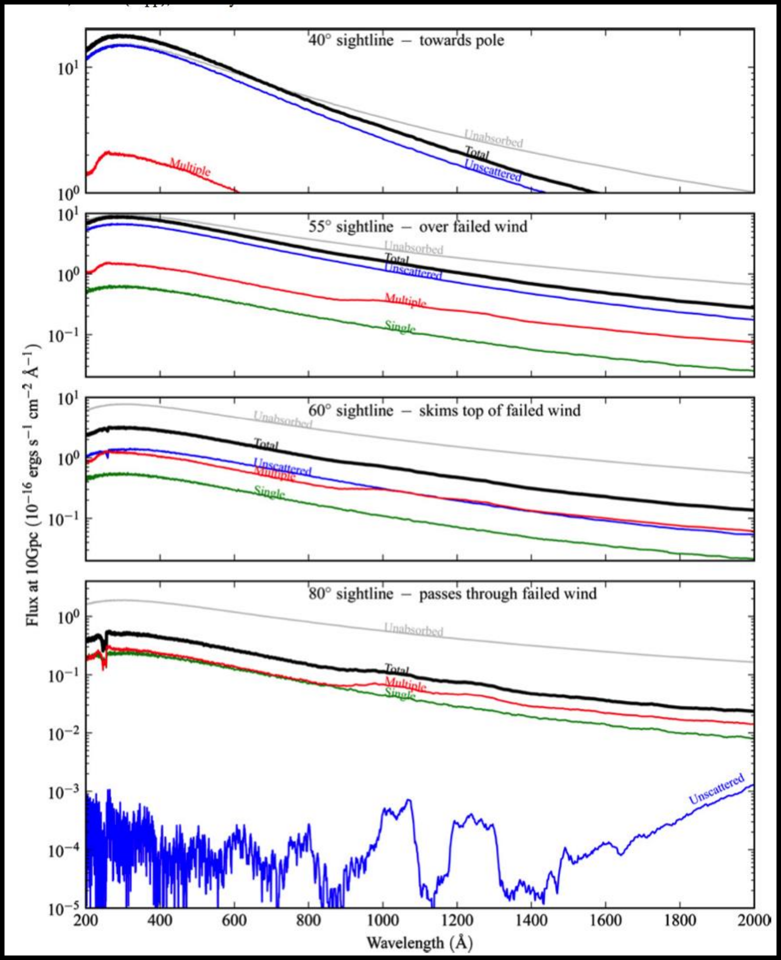


- Density and velocity structure from Proga & Kalman 2004
- Ionization structure and spectra calculated with a program similar to Python
- $L_x = 2.4\ 10^{44}$ erg s^{-1}
- X-ray spectra qualitatively similar to those observed AGN
  - Prominent Compton hump
  - Broad Fe lines with red wind arising from wind (not disk reflection)

Sim+10

Post-Processing - UV

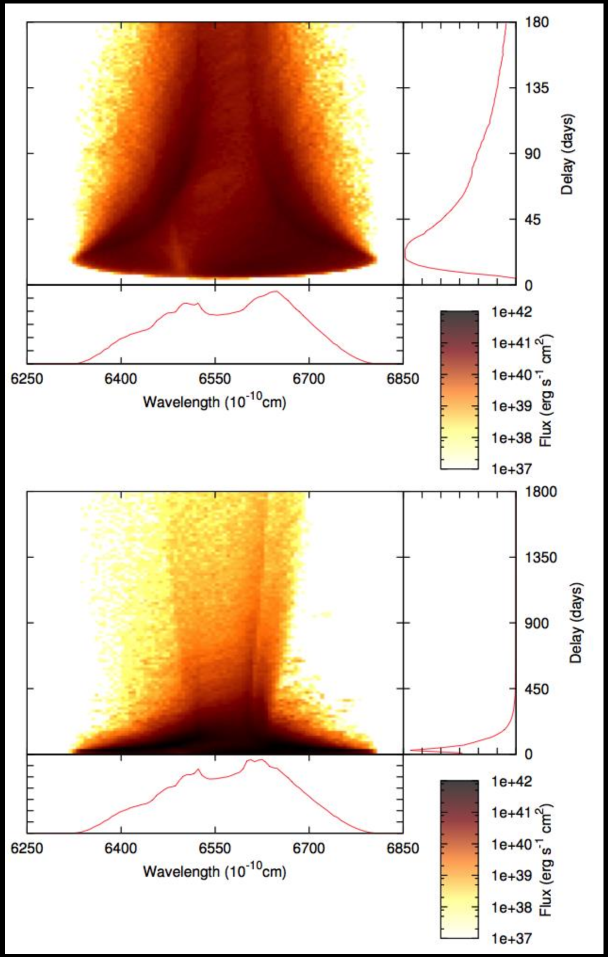
- Same PK04 hydrodynamical simulation
- Ionization structure and spectra calculated with Python
  - Better representation of central source and disk spectrum than used by PK04
- Wind too ionized to produce emission or absorption lines in the UV
  - There is some shielding
  - Compare un-scattered to transmitted light at, for example 60°
  - But partly because or scattering around the inner wind, shielding does not reduce IP enough to make CIV
- → Important to carry out a self-consistent calculation → couple a better radiative transfer calculation into the hydro simulation



Higginbottom+14

Conclusions

- A proper treatment of radiative transfer is needed to arrive at realistic determination of whether the UV lines of AGN can be explained in terms of a wind from the inner disk
- It is hard to make shielding work in the sense of having the inner disk wind shield the outer disk
  - More realistic hydro simulations may help
- Spectra that resemble AGN in the UV can be produced with plausible mass lost rates if the wind is clumped
- Aside: If anyone is interested in using Python, please contact me
- Teaser: Reverberation mapping is coming



Maugham+16 (in prep)