Modeling The Spectra of Quasars: Clumpy Winds & X-ray Properties

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The Extremes of Black Hole Accretion, Madrid
BALQSOs

- ~20% of the QSO population (Knigge+ 2008, Allen+2011)
  - (depending on selection effects – we’ll come back to this!)
- Blue-shifted Broad Absorption Line QSOs
- Smoking gun for outflowing material -> disk winds
- Potentially ‘line-driven’
Geometric Unification

e.g. Elvis 2000, Murray+ 1995, 1998
Geometric Unification
Geometric Unification

See Sim+ 2008, 2010
Unified Model Checklist

- BAL resonance line profiles (high i)
- Realistic X-ray properties
- Broad emission lines (low i)
- Good comparison to composite spectra
Testing The Paradigm

Quasar Radiative Transfer and Ionization Project

Tool: Monte Carlo Radiative Transfer (MCRT) w/ global ionization balance
Photon Sources

Biconical Wind

Cylindrical Grid \((x, z, \theta)\)

Track Photons

Photon Sources

Biconical Wind

Accretion Disk

Central Source

\(\dot{M}_{\text{acc}}\)
Benchmark BALQSO model
Higginbottom+2013 (H13)
X-ray Properties: H13

Data: Saez+ 2012, Steffen+ 2006
UniZied Model Checklist, H13

- ✔ BAL resonance line profiles (high i)
- ✗ Realistic X-ray properties
- ✗ Broad emission lines (low i)
- ✗ Good comparison to composite spectra
Clumping

- Predicted by theory
- Required in O-star winds (AGN variability?)
- ‘Microclumping’ assumes optically thin clumps i.e.

$$R_{\text{clump}} \ll 1/(\sigma n) \, (\sim 10^{14} \text{cm w/ Thomson, } n_e = 10^{10})$$

- Introduce a fill factor f, which produces a density enhancement D

$$D = 1/f$$

- Consequences:
  - $\rho^2$ processes should **increase** by a factor D
  - Ionization will **decrease** (less ionizing photons per atom)
New model \( (f = 0.01, L_X \times 100) \)
X-ray Properties: H13

Data: Saez+ 2012, Steffen+ 2006
X-ray Properties: New Model

Data: Saez+ 2012, Steffen+ 2006
Producing BELs

Must reprocess (relatively) more flux and make it emerge in lines at low inclinations. How?

- Cover UV bright portion of disk
- Larger covering factors / emission regions
Producing BELs

- BAL angles: higher line/continuum
- Due to foreshortening, limb darkening, attenuation
- Intrinsic fraction: 63%-> naïve prediction observed: 5%!

Could BALQSOs dominate the intrinsic QSO population!?
Unified Model Checklist

- BAL resonance line profiles (high i)
- Realistic X-ray properties
- Broad emission lines (low i)
- Good comparison to composite spectra
Unified Model Checklist

- BAL resonance line profiles (high $i$)
- Realistic X-ray properties
- Broad emission lines (low $i$)
- Good comparison to composite spectra
- Correct BAL fraction

“TO DO” list!
Summary

• With clumping, X-ray properties now agree well with data.
  • Clumping may not be the solution- but you need something to prevent over-ionization
• BALQSO winds can produce BELs - not yet at right EW
  • higher mass loss? modified disk prescription? (Laor & Davis 2014, Capellupo+ 2015)
• The ‘accepted’ BALQSO geometry may need rethinking
  • Equatorial, 10-20% covering factor? Perhaps not!
• Must explore $M_{BH}$ & $L/L_{edd}$ space

*Outflows may be crucially important in shaping the spectra of QSOs at all angles (Matthews+, in prep)*

*More observational constraints needed: Geometric and Multi-wavelength.*
Reverberation with MCRT

Mangham+\textcolor{red}{\textsuperscript{\textdagger}}, in prep