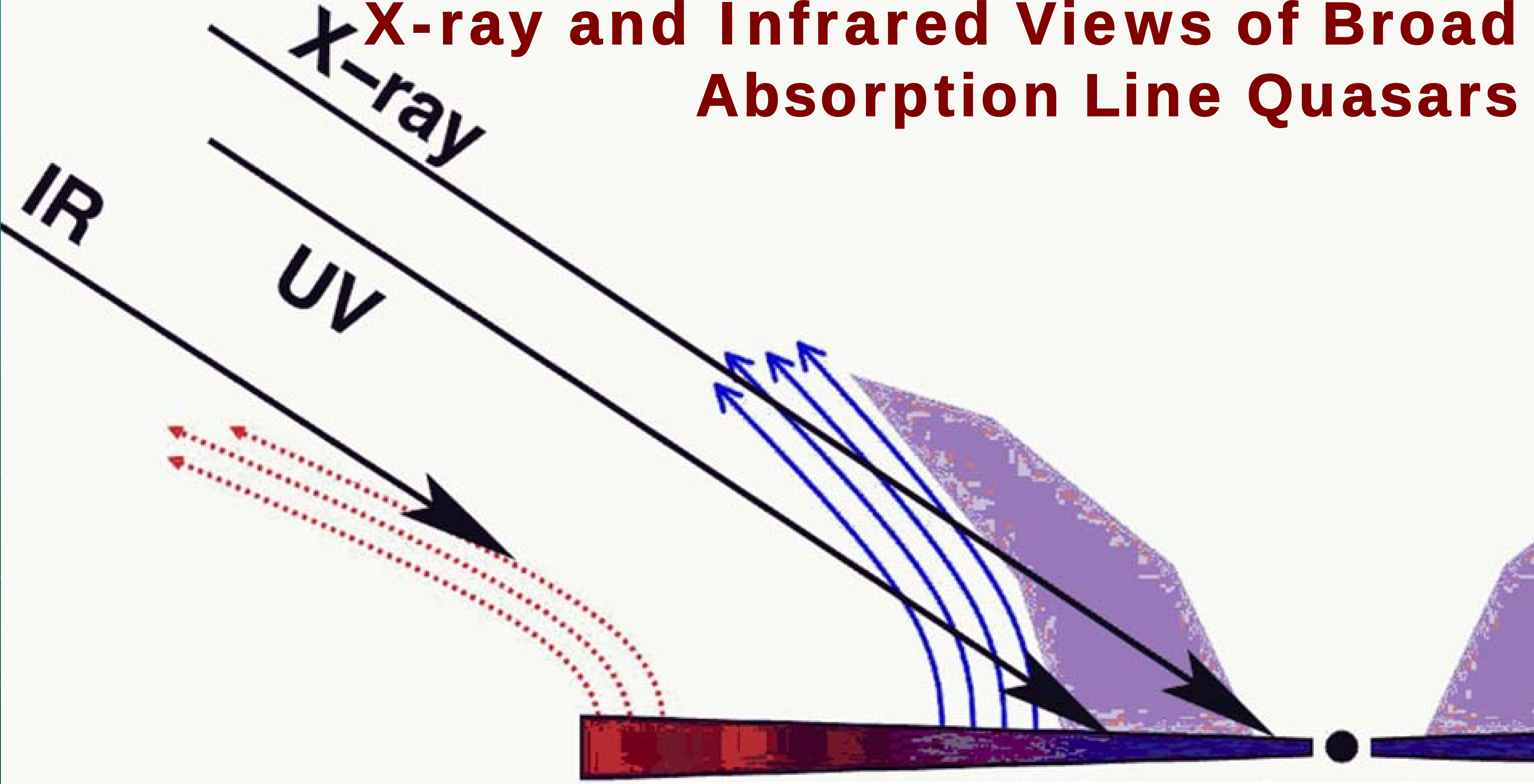
Stratified Quasar Winds: Integrating X-ray and Infrared Views of Broad Absorption Line Quasars



Sarah Gallagher (University of Western Ontario/UCLA)

Cospar - July 2008

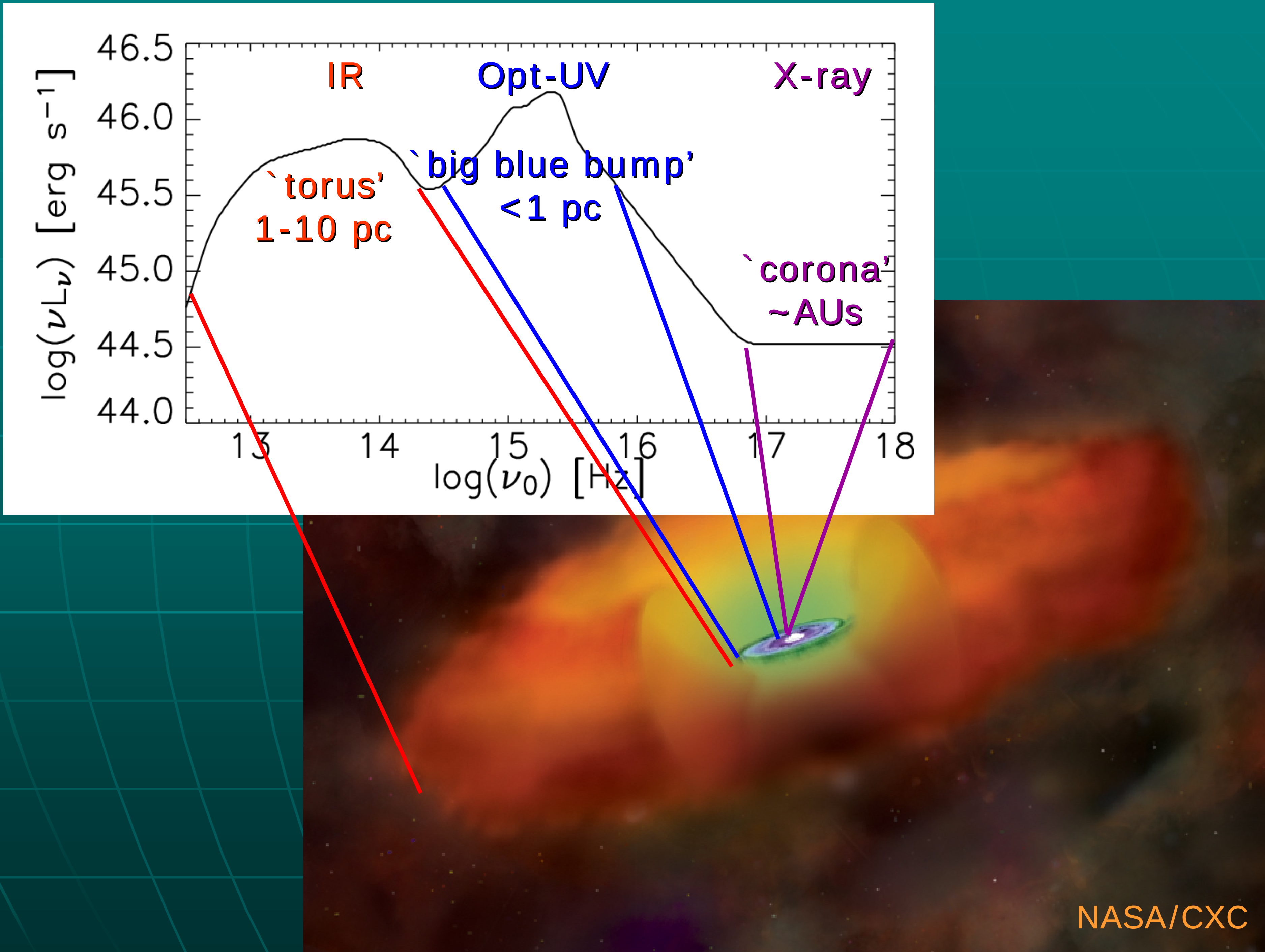
Quasar Jets vs. Winds

Jets:

1. Relativistic, highly collimated
2. Relevant for galaxy groups and clusters
3. Rare

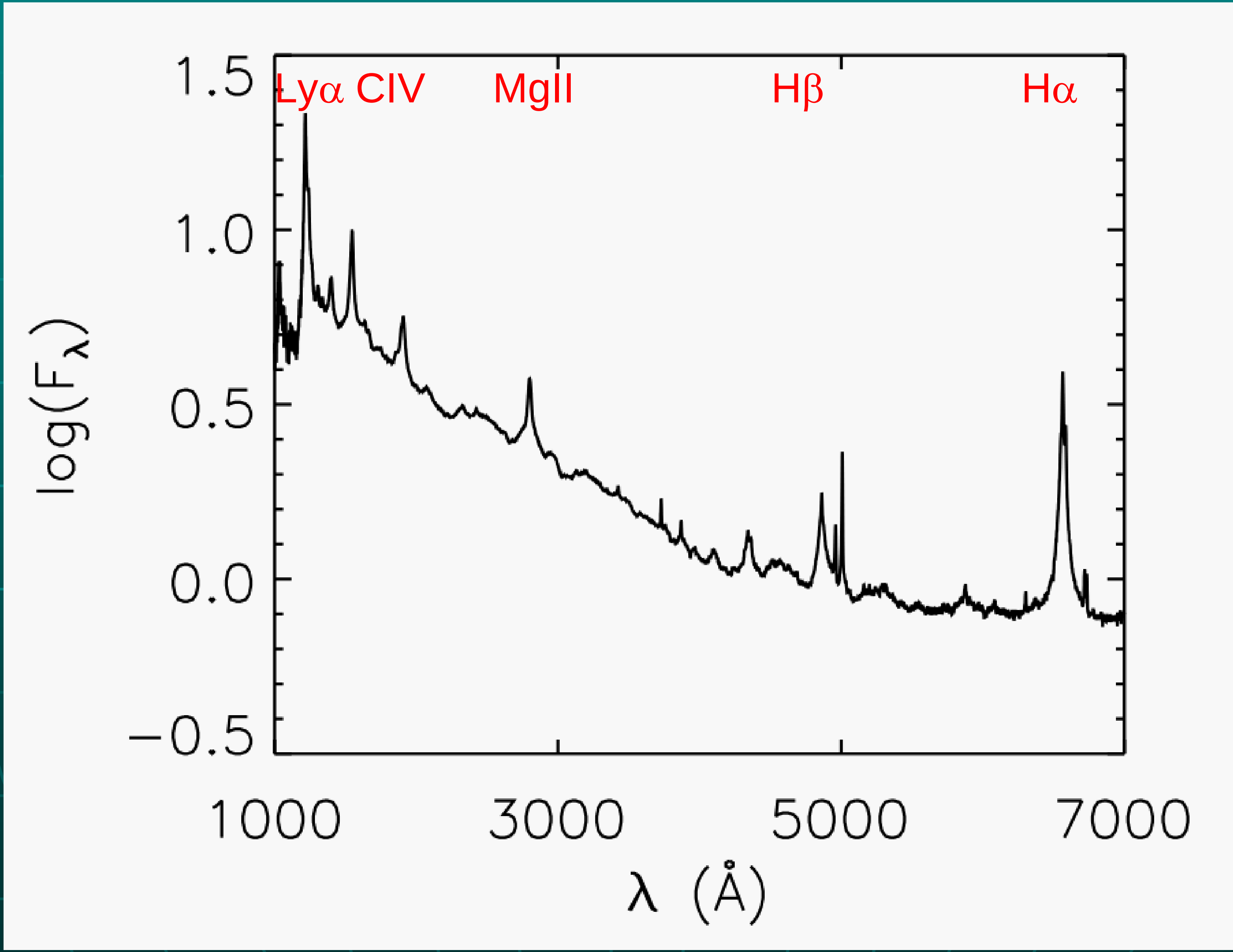
Winds:

1. Sub-relativistic, wider opening angle
2. Relevant for massive galaxies
3. Common

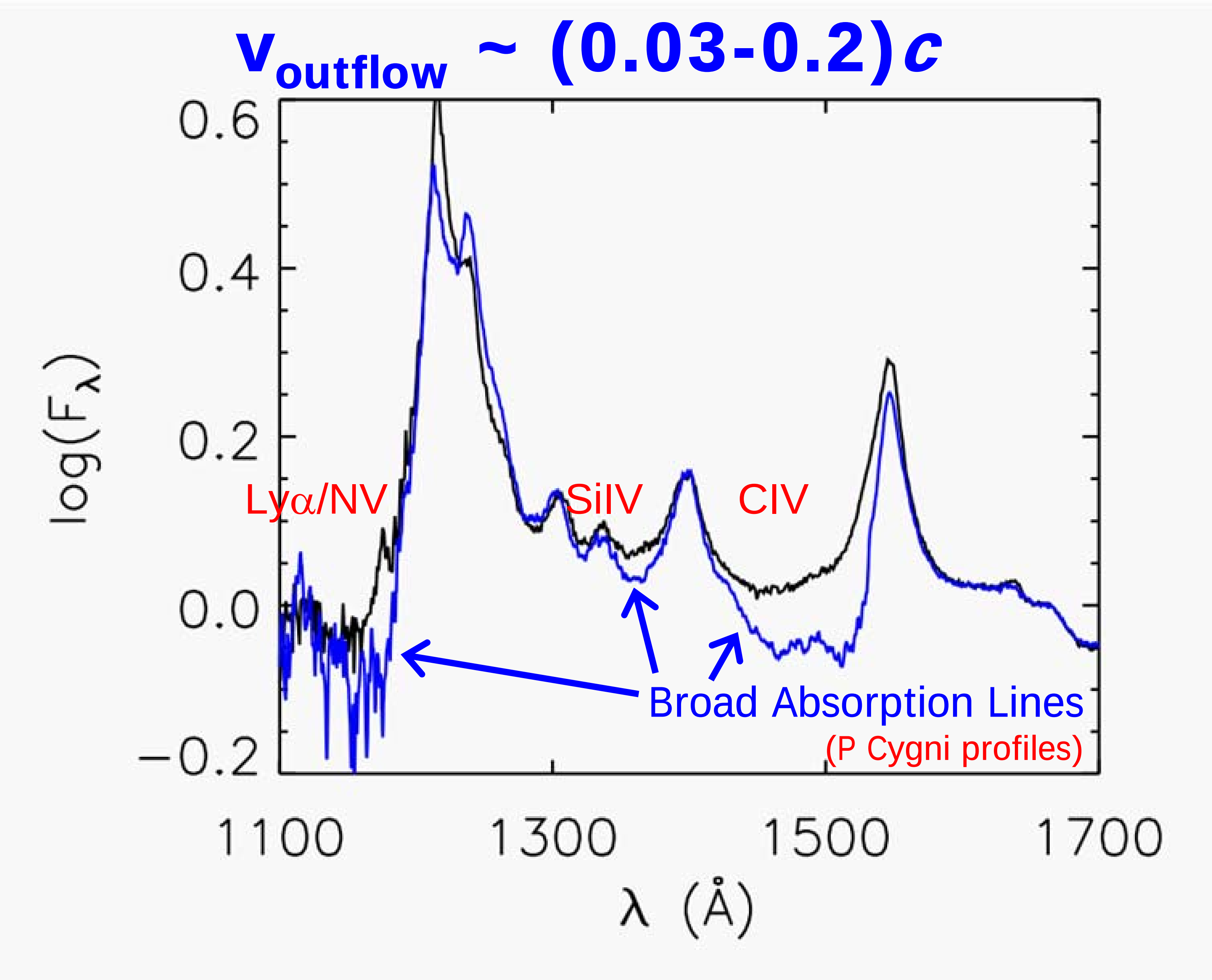


IR
Opt-UV
X-ray
`torus'
1-10 pc
`big blue bump'
<1 pc
`corona'
~AUs
46.5
46.0
45.5
45.0
44.5
44.0
13
14
15
16
17
18
log(νL_ν) [erg s^-1]
log(ν_0) [Hz]
NASA/CXC

Normal Quasar



Quasars with Outflows: BAL Quasars*

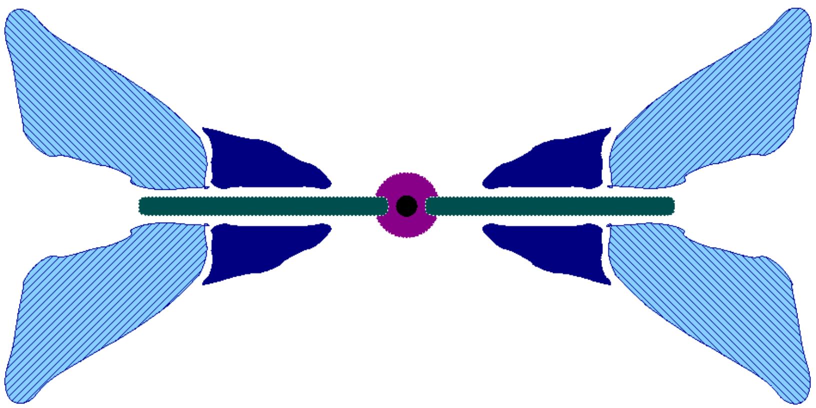


* ~20%

(Hewett & Foltz 2003; Dai et al. 2007)

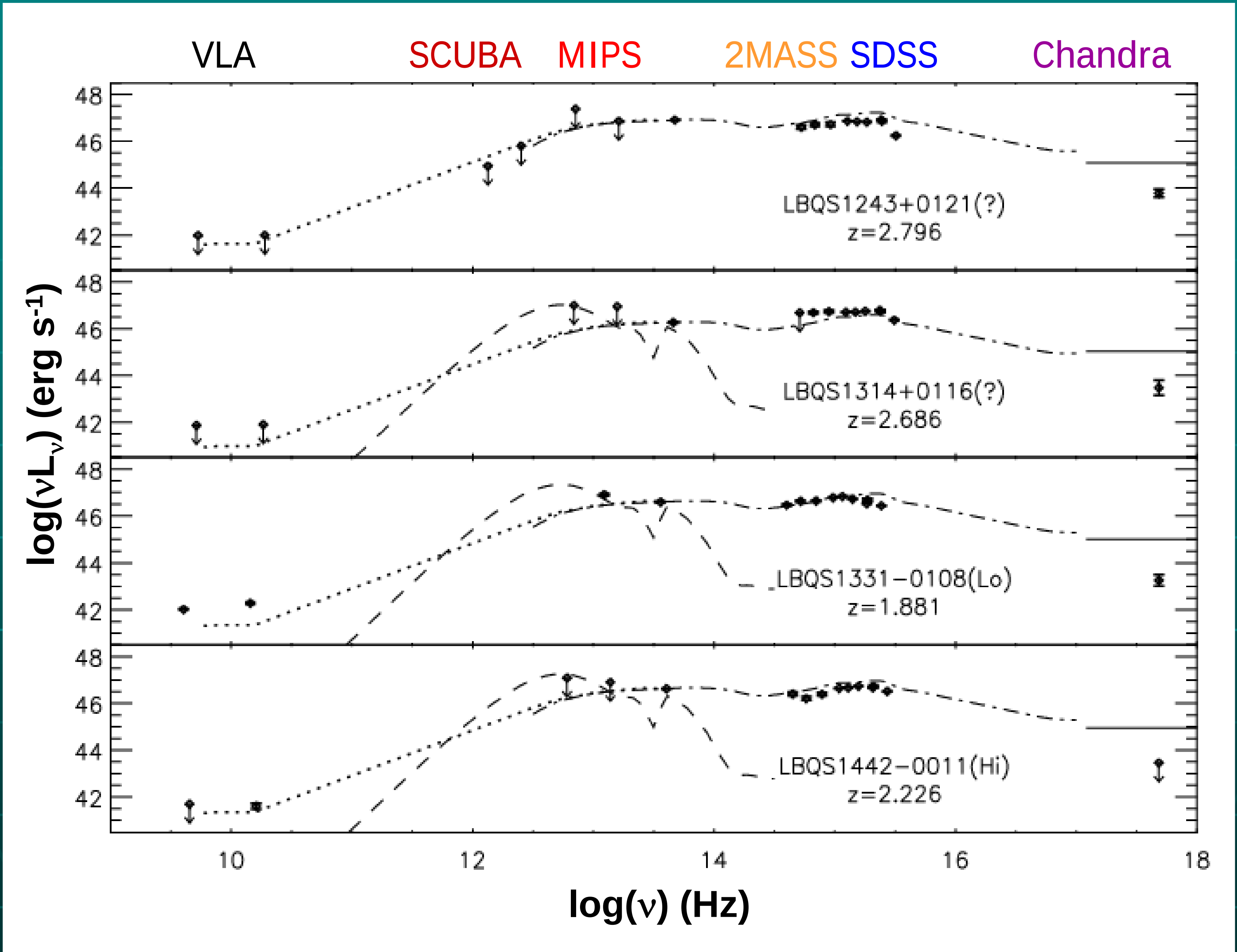
Two Extreme Explanations

Cocoon vs. Disk-wind



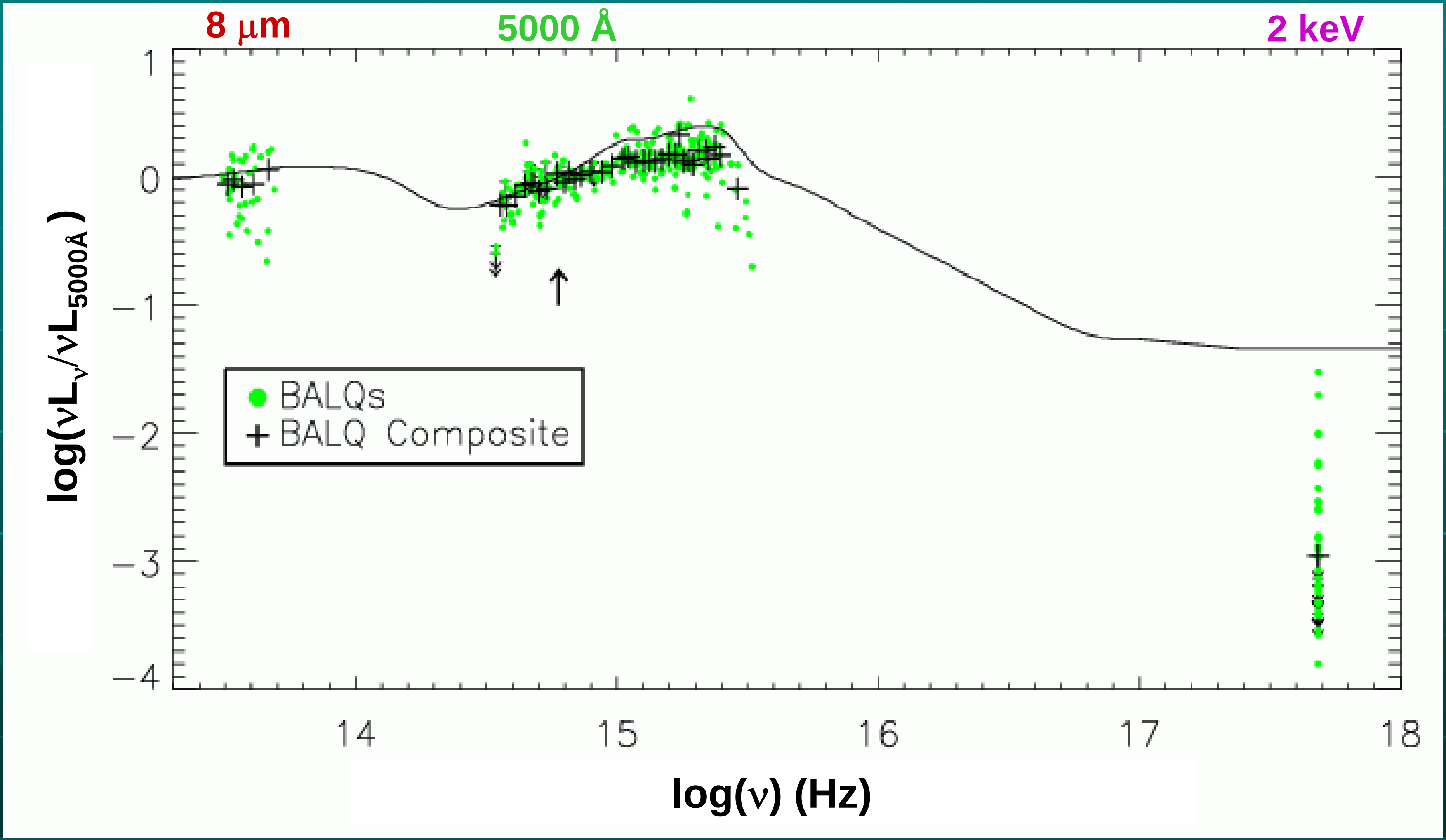
The wind covers all of the sky for 20% of the time.

The wind covers 20% of the sky for all of the time.



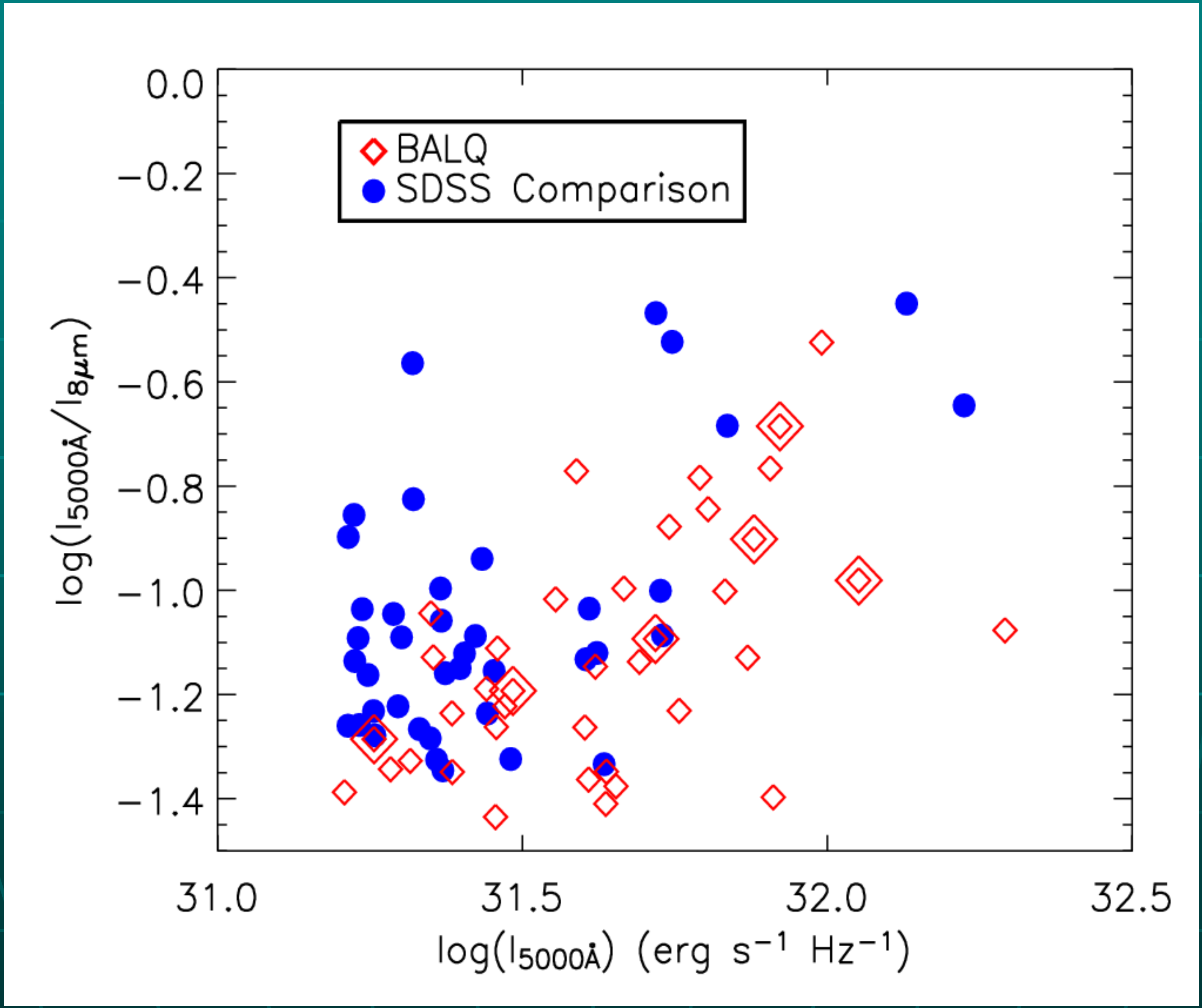
Sample LBQS BAL Quasar SEDs. (Gallagher et al. 2007)

BAL Quasar Composite SED



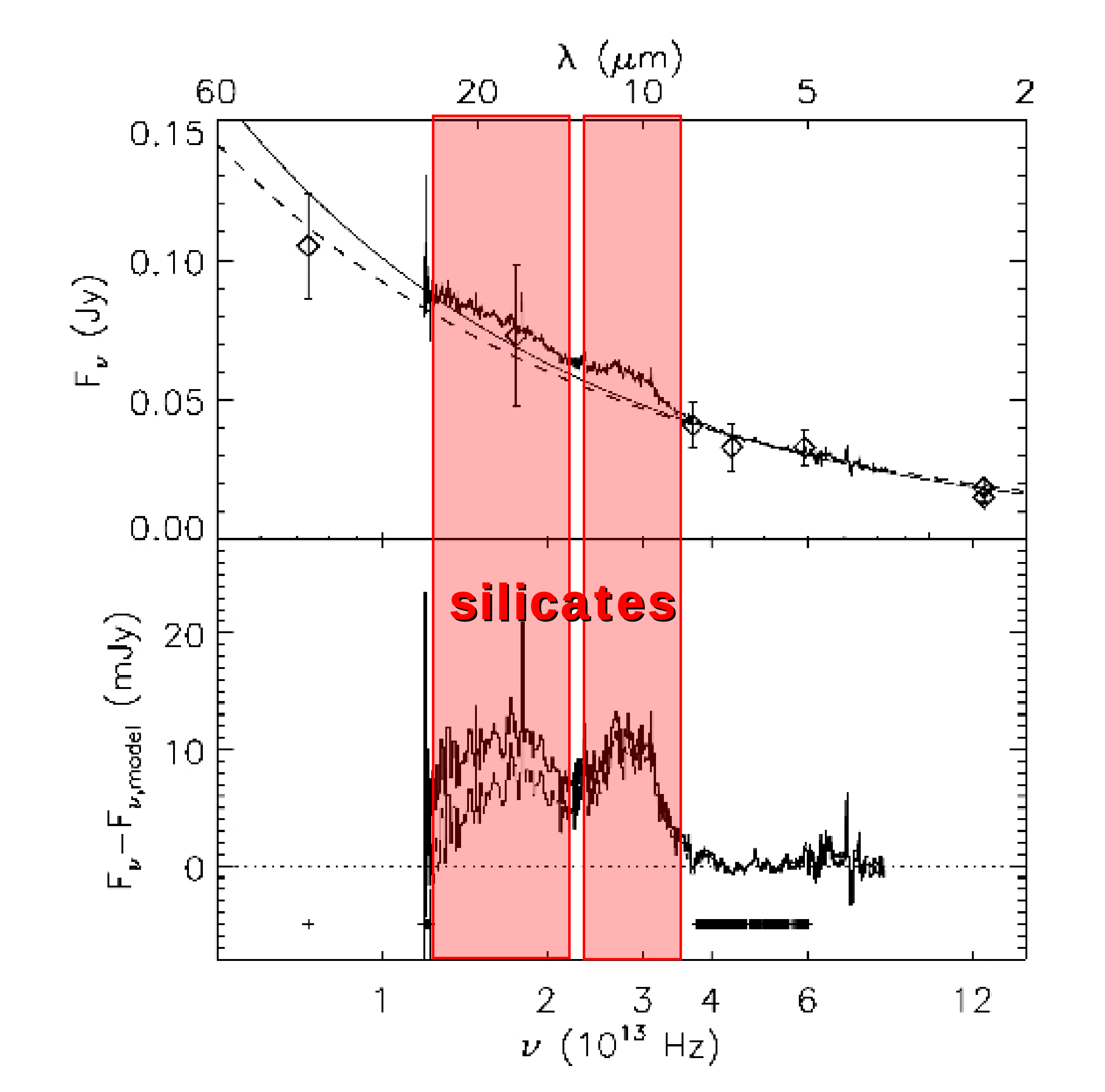
Comparison SED: SDSS luminous ($L_{bol} > 10^{46.2}$ erg s^{-1}) composite

BAL Quasars: *not* mid-infrared bright



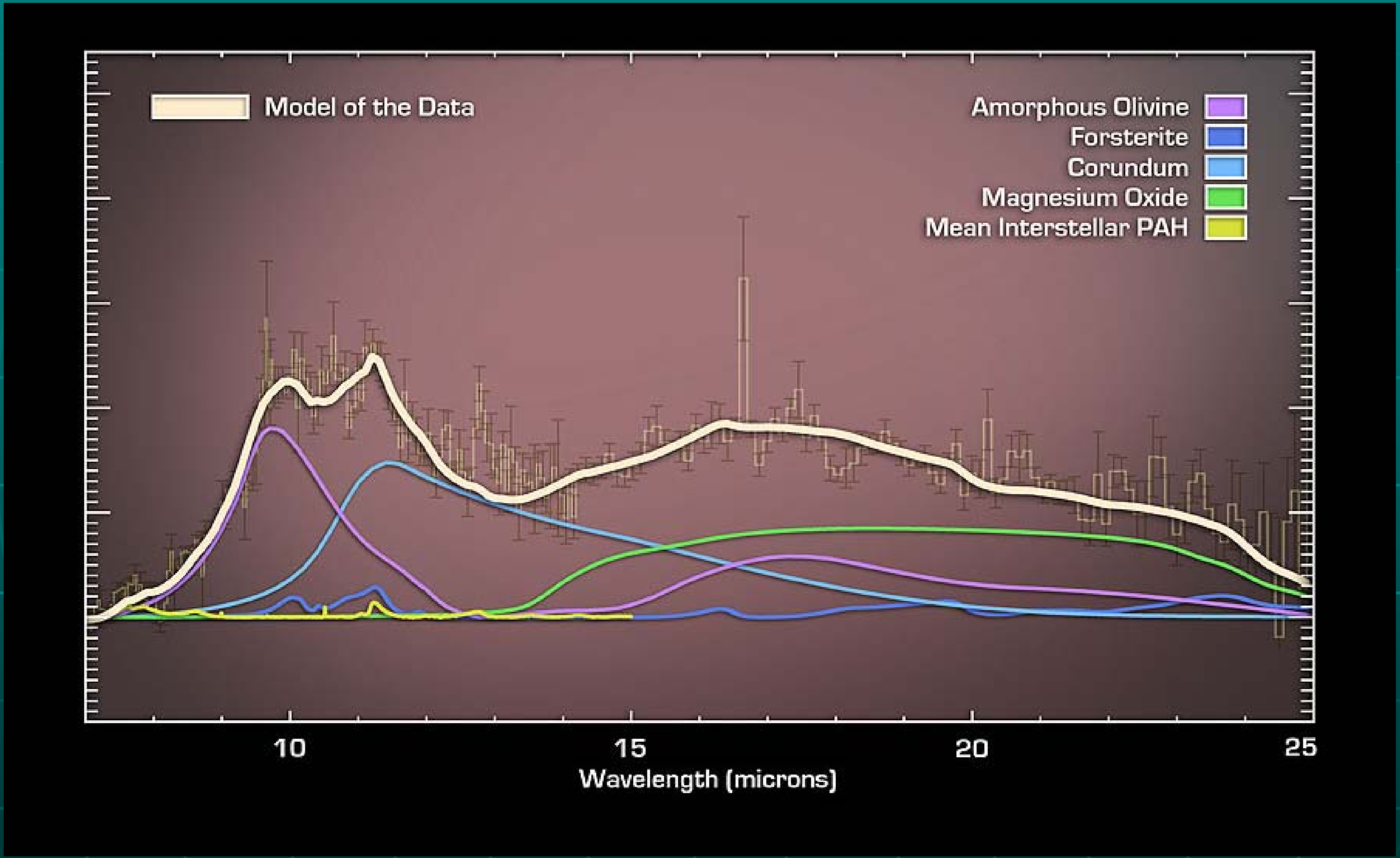
LBQS BALQs and SDSS comparison sample — statistically indistinguishable.

IRS Spectrum of BAL Quasar PG 2112+059



(Markwick-Kemper et al. 2007)

Evidence for Clumpy, Dust-Forming Wind

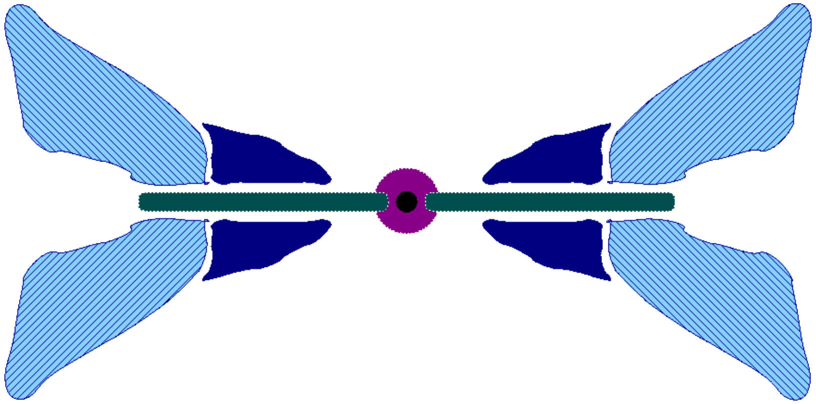


Presence of corundum indicates density inhomogeneities while cooling; crystalline silicates require replenishment.

(Markwick-Kemper et al. 2007)

Two Extreme Explanations

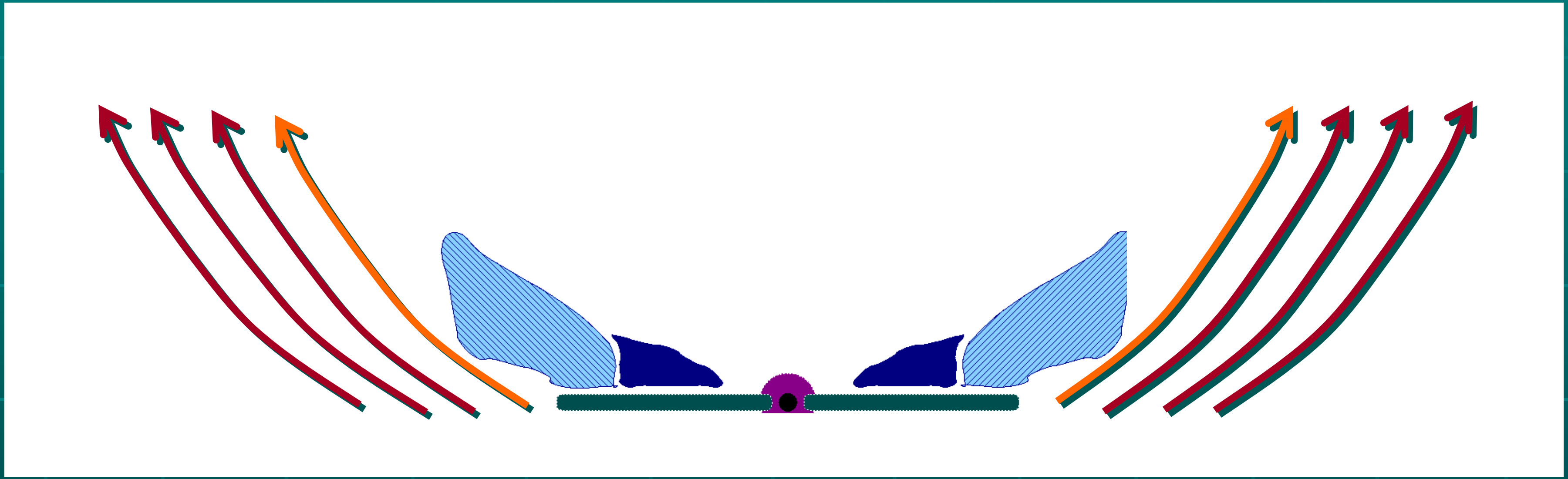
Cocoon vs. Disk-wind



The wind covers all of the sky for 20% of the time.

The wind covers 20% of the sky for all of the time.

The Dusty Outflow

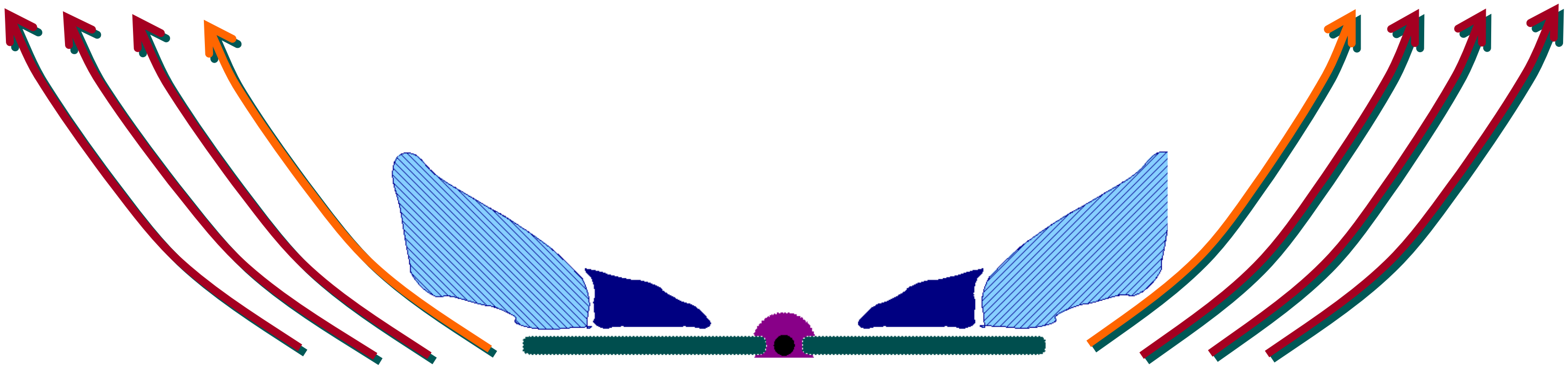


The inner radius of the dusty outflow is set by the temperature at which dust sublimates:

$$r = 1.3 (L_{uv}/10^{46})^{½} (T/1500)^{-2.8} \text{ pc}$$

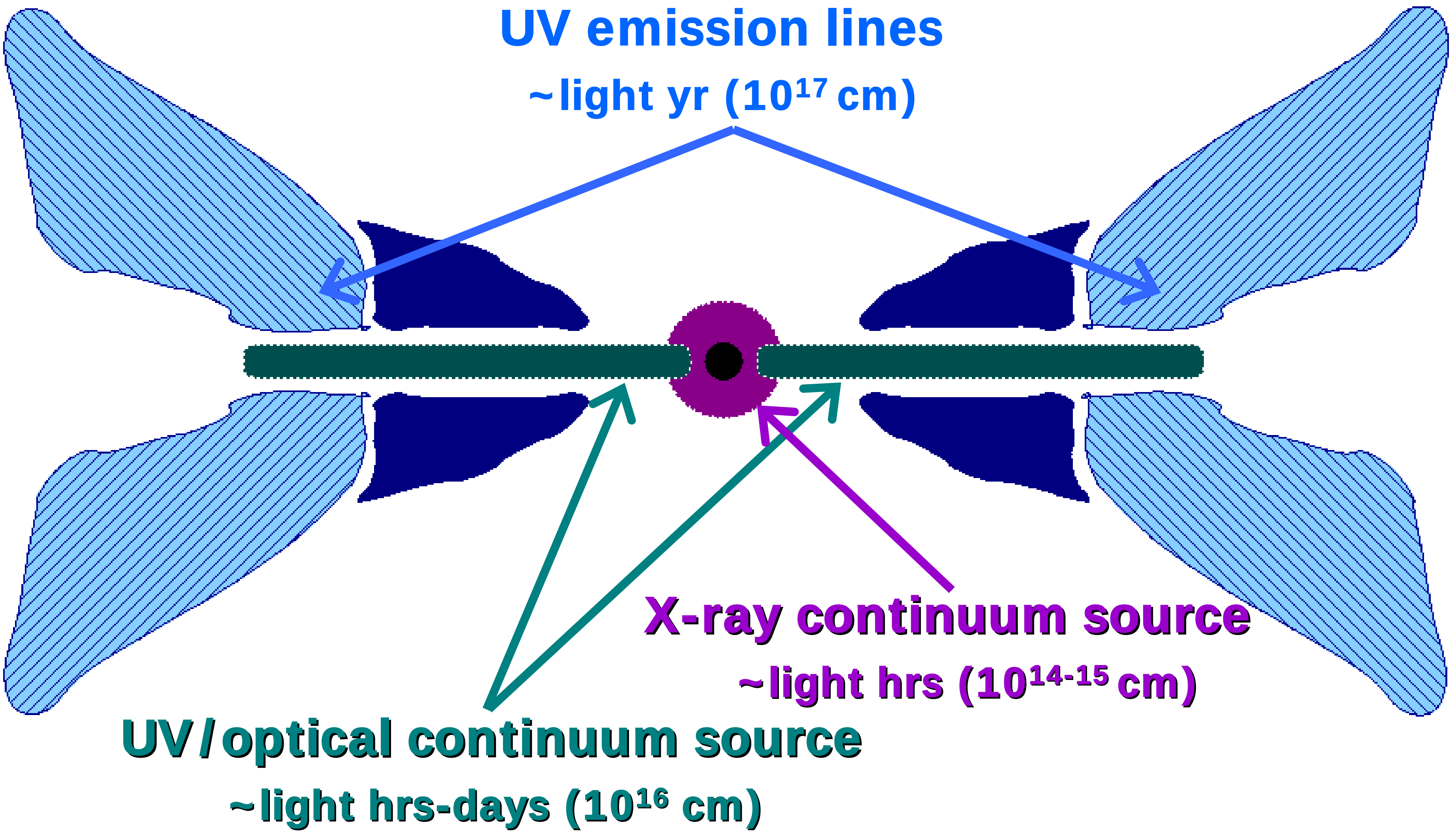
(Adapted from Königl & Kartje 1994)

Conclusions I



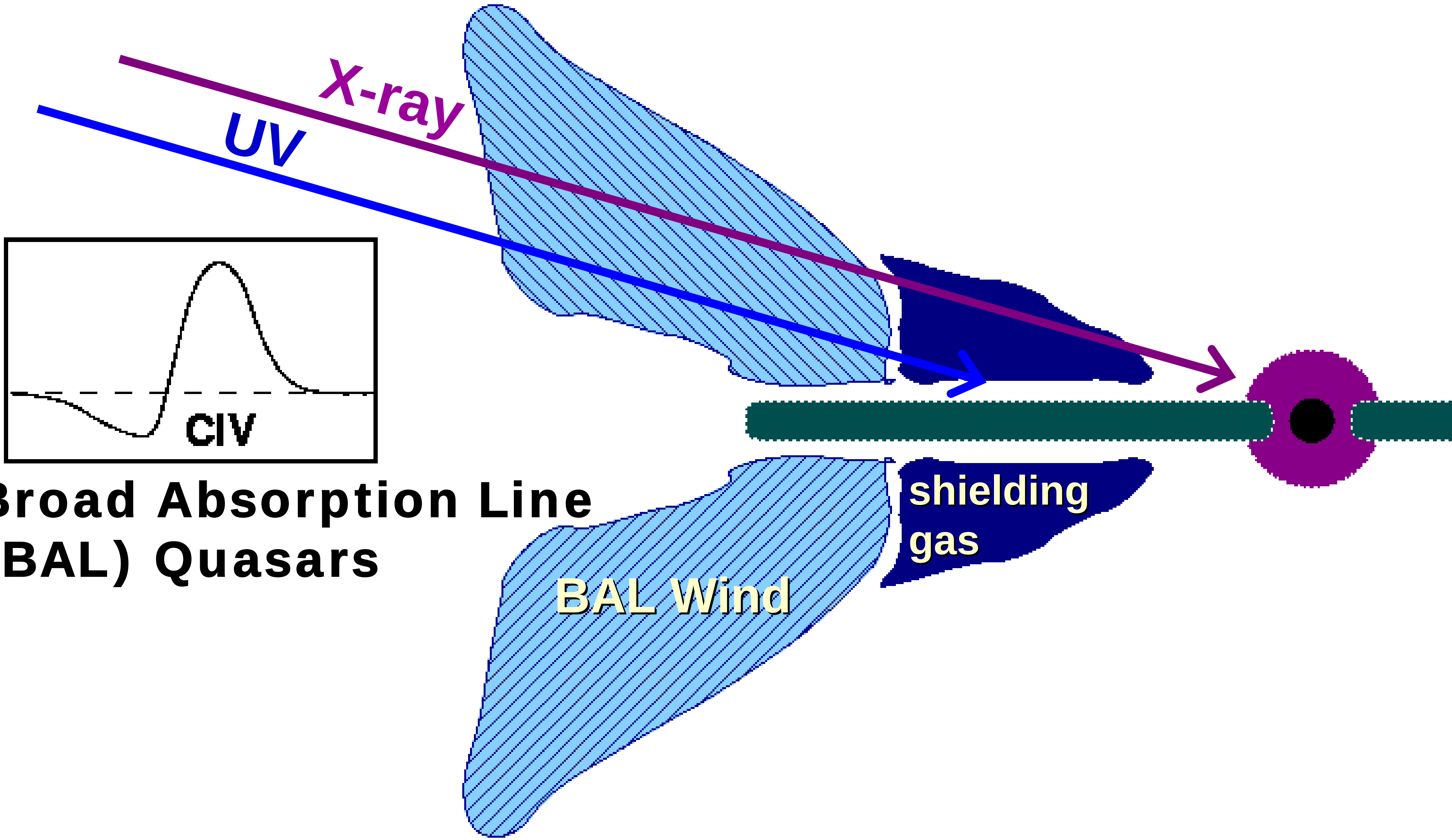
- No evidence for mid-IR excesses in BAL quasars.
- No evidence we are looking *through* the dusty outflow from IRS spectra.
  - → **“cocoon” picture is not supported for bulk of BAL quasar population**
- We may be seeing dust *forming* in the wind.

A Model for **All** Radio-Quiet Quasars



(Gallagher et al. 2002a: Adapted from Königl & Kartje 1994; Murray et al. 1995)

Two Views Through the Wind

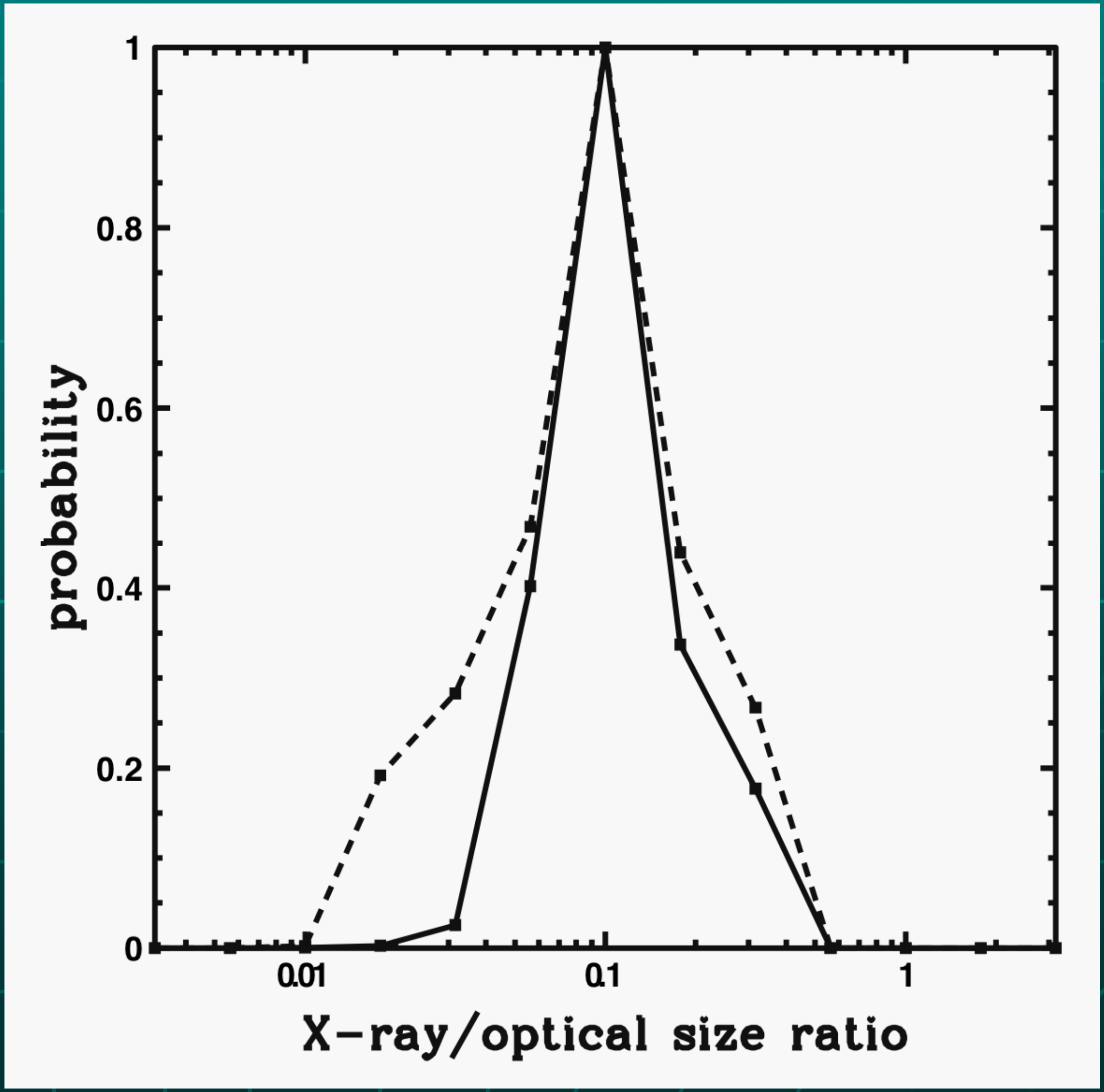


Broad Absorption Line (BAL) Quasars

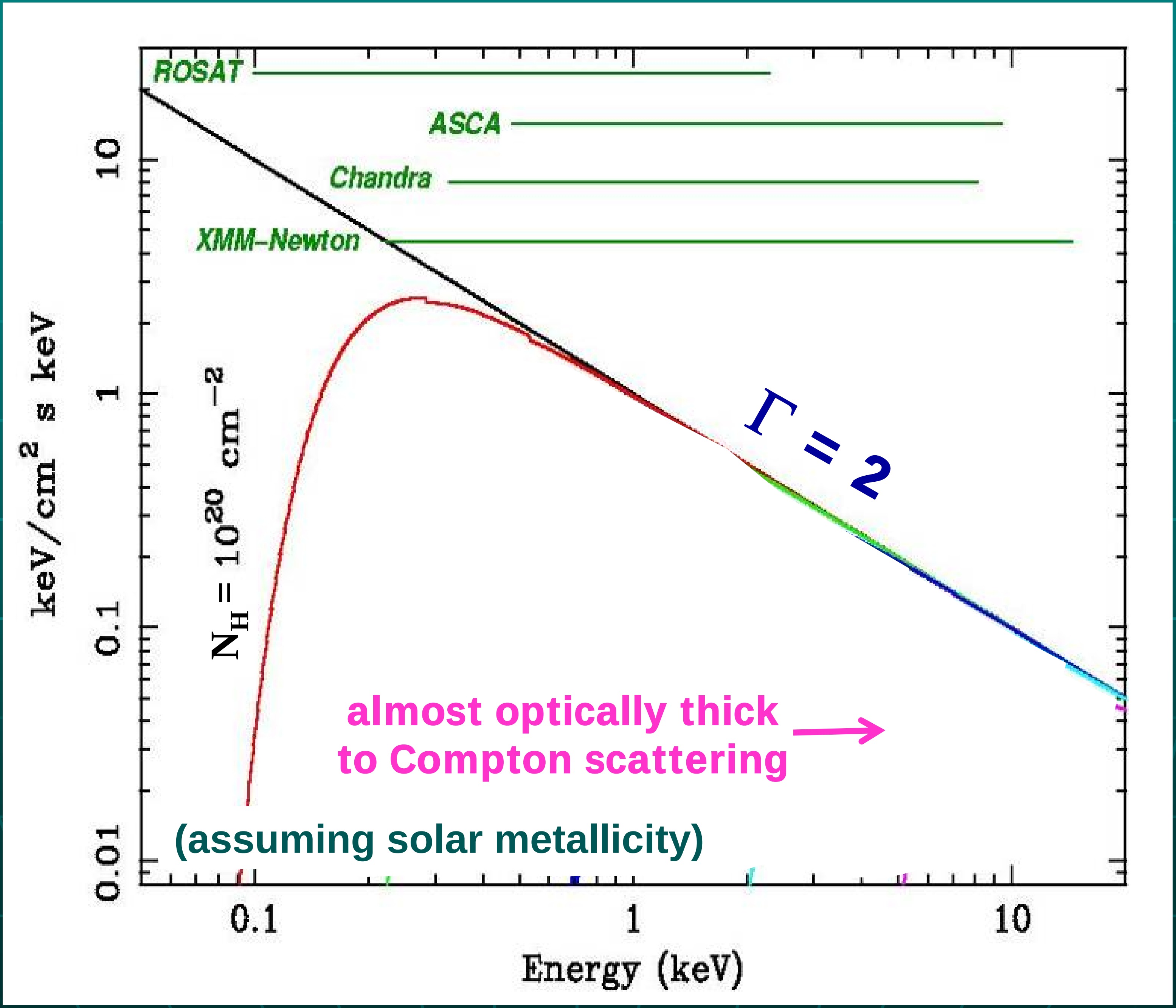
X-ray and UV Continuum Emitting Regions Are Not Cospatial

From gravitational micro-lensing.

(Kochanek et al. 2007)



X-ray Absorption by Neutral Gas



X-ray Spectroscopy of ~12 RQ BAL Quasars

- normal underlying X-ray continua
- significant intrinsic absorption
  - $N_H = (0.1\text{-}5.0) \times 10^{23}$ cm^{-2}
- normal UV/X-ray flux ratio
- not just simple absorption
  - partial coverage and/or ionized gas
- variability mismatch between UV & X-ray
  - UV & X-ray absorbers not the same

(e.g., Gallagher et al. 2002b, 2005; Chartas et al. 2002, 2003; Aldcroft & Green 2003; Grupe et al. 2003; Page et al. 2005; Shemmer et al. 2005)

Chandra BAL Quasar Survey

Large, well-defined sample

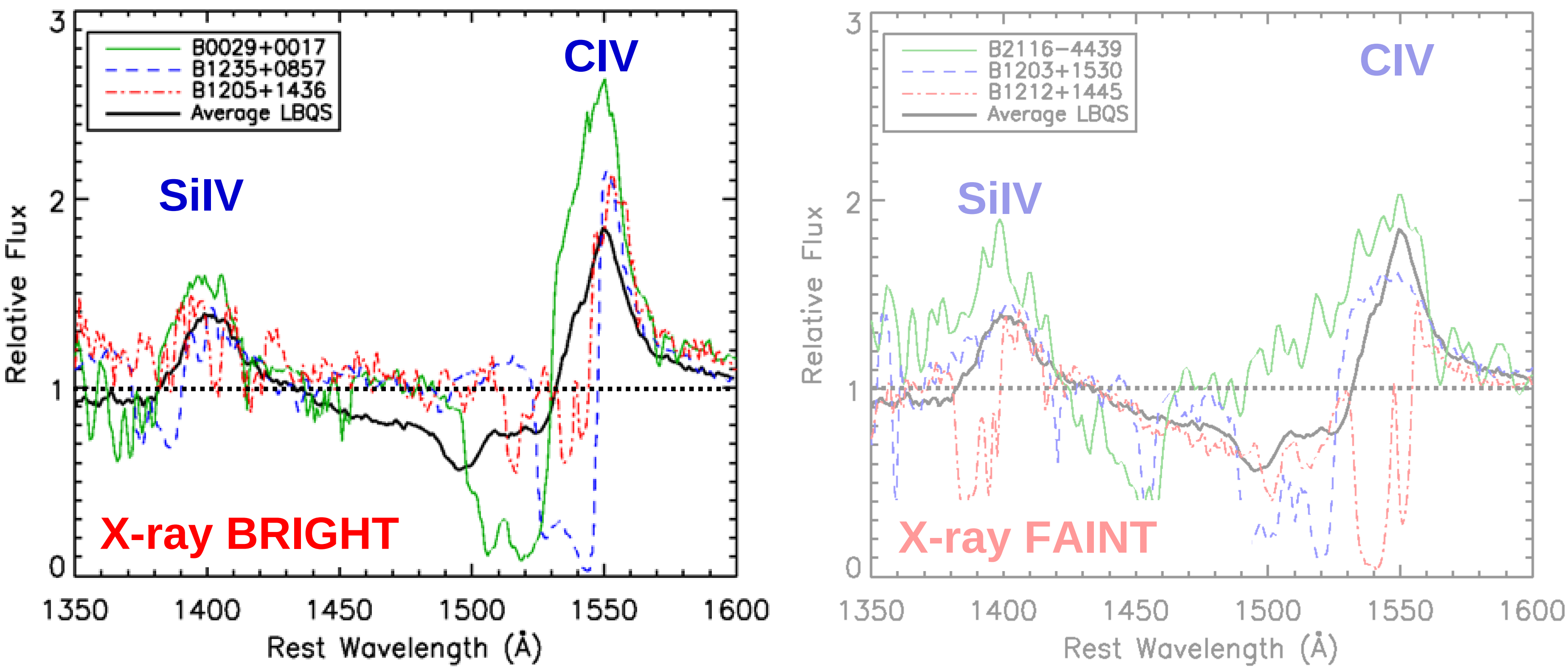
- 35 luminous BAL quasars
  - z = 1.4—2.9
  - M_B ~ -26.1 to -28.4
  - UV spectra for all (from literature)

- Relative UV-to-X-ray power: $\Delta\alpha_{ox}$

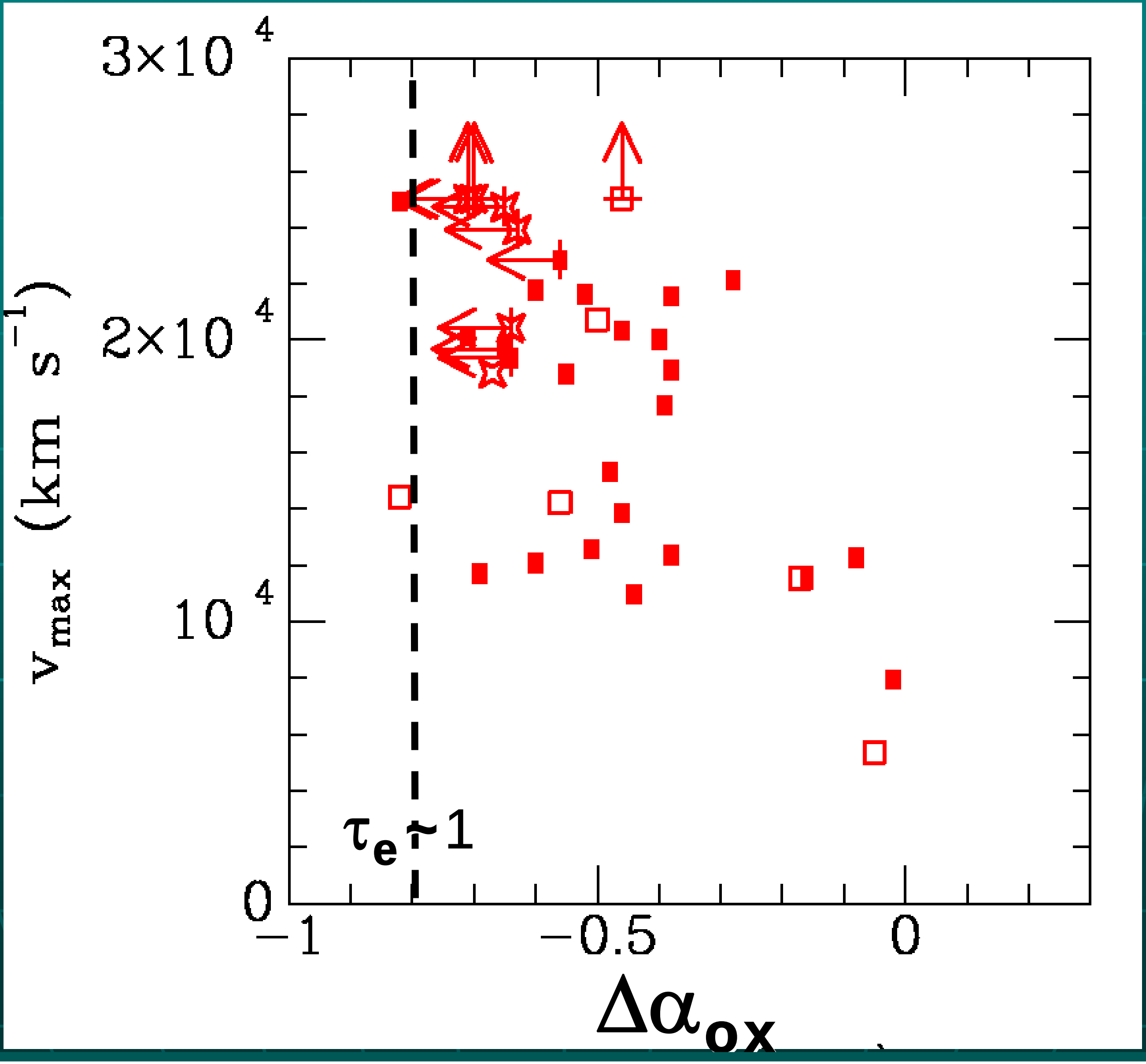
(Gallagher et al. 2006)

Collaborators: **Niel Brandt, George Chartas, Gordon Garmire (Penn State), Robert Priddey (Hertfordshire), & Rita Sambruna (Goddard)**

UV Spectra: X-ray Bright vs. X-ray Weak

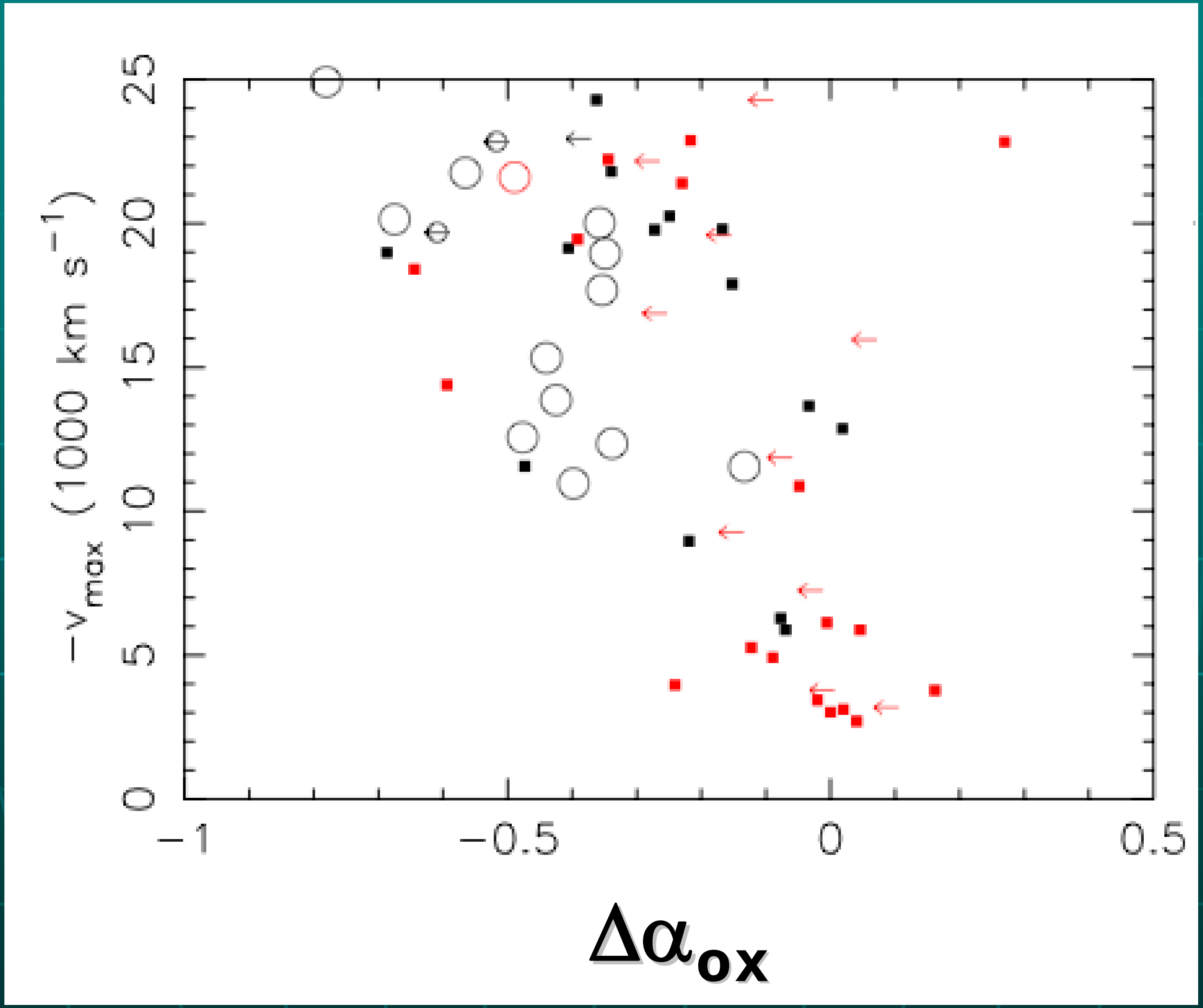


v_{max} vs. $\Delta\alpha_{ox}$



High velocity appears to require large N_H.

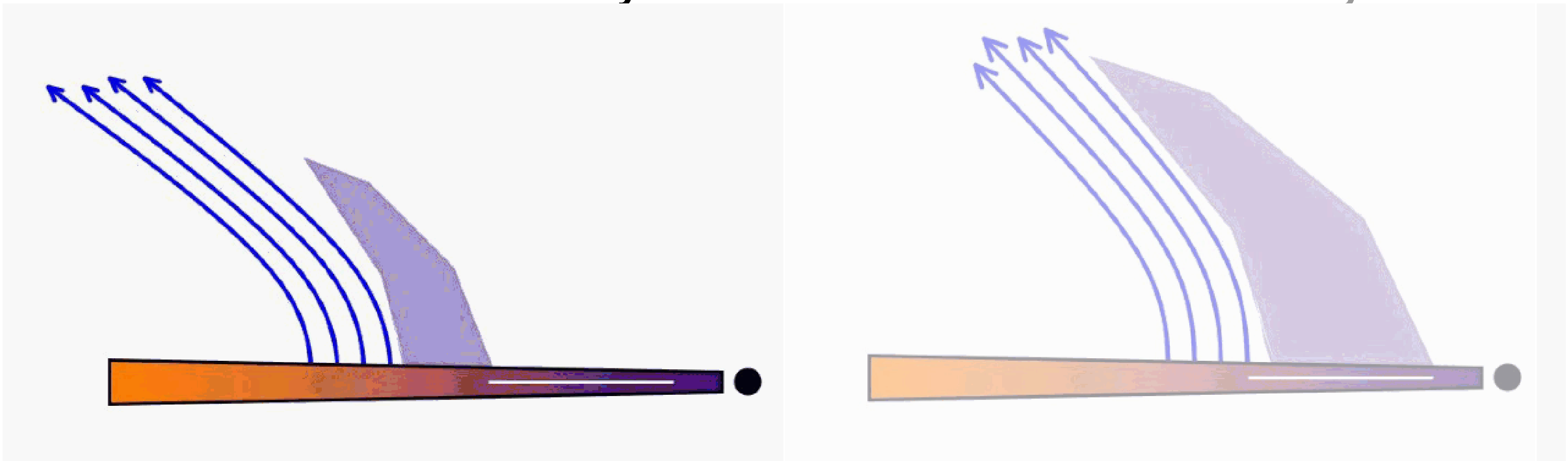
v_{max} vs. $\Delta\alpha_{ox}$ (larger sample)



(Gibson et al., astro-ph/0810.2747)

Link Between Shielding Gas and v_{max}

thinner shield → less X-ray weak | thicker shield → more X-ray weak



larger R_{launch} → lower v_{term} | smaller R_{launch} → higher v_{term}

(Gallagher et al. 2006; Gallagher & Everett 2007)

$$v_{term} \sim (GM_{BH}/R_{launch})^{1/2}$$

(cf. Chelouche & Netzer 2000; Everett 2005)

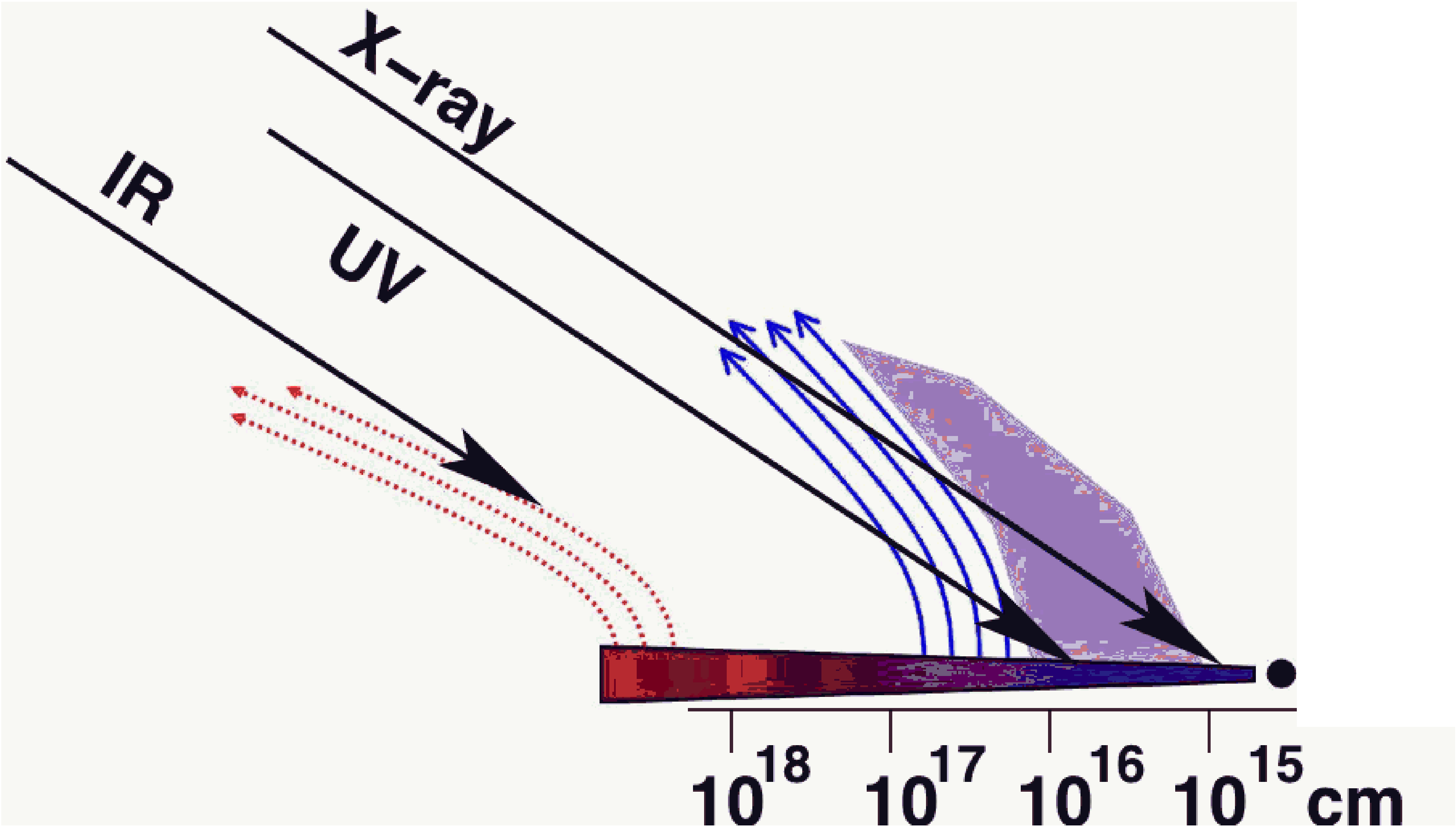
Conclusions II:
X-ray Observations

- compact & thick 'X-ray—only' absorbers
  - X-ray & UV absorption not consistent
  - **some may be Compton-thick!**
    - (τ_e ~ 1; $N_H \sim 1.5 \times 10^{24}$ cm^2)
- correlation of v_{max} & $\Delta\alpha_{ox}$

  → supports ***radiative driving*** of UV outflows

(Gallagher et al. 2006)

Multiwavelength Synthesis: The Stratified Wind Picture



Physical Parameters of the Stratified Wind

Wind Component	R (cm)	f_{cov}	ξ (erg cm)	N_H (cm^{-2})	v (km/s)
X-ray	10^{15-16}	$>f_{UV}$	~100 (OVII/OVIII)	10^{22-24}	???
Ultraviolet	10^{17-18} (R_{BLR})	$0.2(1-f_{QSO2})$	~1 (CIV/OVI)	10^{21-22}	10^{3-4}
Mid-IR	>1pc	f_{QSO2}	neutral	…	10^2

Stratified Wind Driving Mechanisms

- UV BAL wind
  - Radiation pressure on UV resonance lines
- Dusty Outflow
  - Radiation pressure on dust
- Shielding Gas
  - Continuum radiation pressure
  - Magneto-hydrodynamic driving?

Summary

BAL Quasar SEDs are inherently consistent with those of comparably luminous quasars.

→ range of star-formation contributions to far-infrared

→ no mid-infrared excess

→ supports ubiquity of quasar winds

Wind has multiple components with different locations, covering fractions, ionization states, and driving mechanisms.

Measuring the kinetic energy in the wind will likely require the next generation of X-ray spectroscopy (*IXO*) coupled with dynamical modeling.