Toward a Prescription for Feedback from Quasar Outflows

Rajib Ganguly (University of Michigan-Flint)

- A major theme in most recent simulations of galaxy evolution is AGN feedback, quantified by the *kinetic luminosity*, or power.

- In this ongoing work, we wish to provide a prescription for how much feedback is yielded by quasar outflows from a given object, focusing on solid angle, column density, and outflow velocity.

Feedback Primer

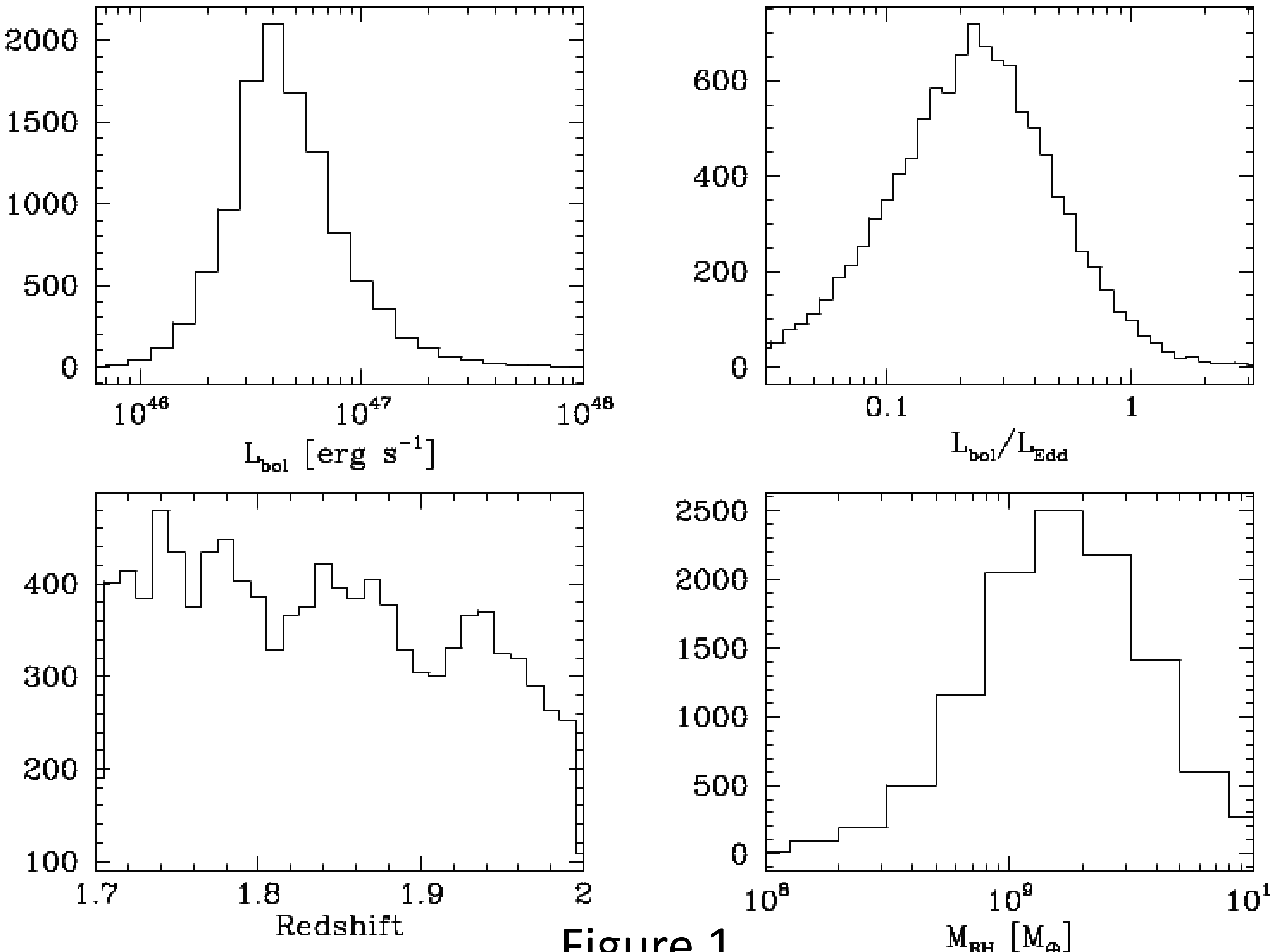
- The kinetic luminosity, or kinetic power, is related to the outflow velocity and the mass outflow rate…

$$L_K = \frac{1}{2}\dot{M}_{out}v^2 = \frac{1}{3}\Omega N_H m_H r v^3$$

- …or to the **solid angle**, the **column density**, the size scale, and the **outflow velocity** in observer-friendly parameters.

Methodology and Sample

- We adopt a statistical approach, taking a large sample of quasars, determining outflow properties, and physical properties, and considering correlations.
- Sample: 10963 z=1.7-2.0 quasars from SDSS, supplemented with ROSAT, GALEX, 2MASS, and WISE data for completion of the SED.
- The redshift range provides coverage of:
  - C IV, for measurements of outflow properties
  - Mg II, for estimation of black holes masses
- The SED yields a more refined estimate of the bolometric luminosity.
- Figure 1 shows the distributions of redshift, black hole mass, bolometric luminosity, and Eddington ratio.



2000
1500
1000
500
0
10^{46}
10^{47}
10^{48}
L_{bol} [erg s^{-1}]
600
400
200
0
0.1
1
L_{bol}/L_{Edd}
400
300
200
100
1.7
1.8
1.9
2
Redshift
2500
2000
1500
1000
500
0
10^{8}
10^{9}
10^{10}
M_{BH} [$M_{\oplus}$]

Figure 1

Feedback vs. Solid Angle

- With the rest-frame 1400-1600 Å spectral region, we classify objects into three categories
  - Unabsorbed (6371)
  - Broad Absorption Line Quasars (BAL, 2775)
  - Associated Absorption Line Quasars (AAL, 1751)

- The incidence of BALs and AALs, and their sum is plotted against black hole mass and Eddington ratio below.
- There is **a slight correlation with increasing black hole mass, but is rather constant with Eddington Ratio**.

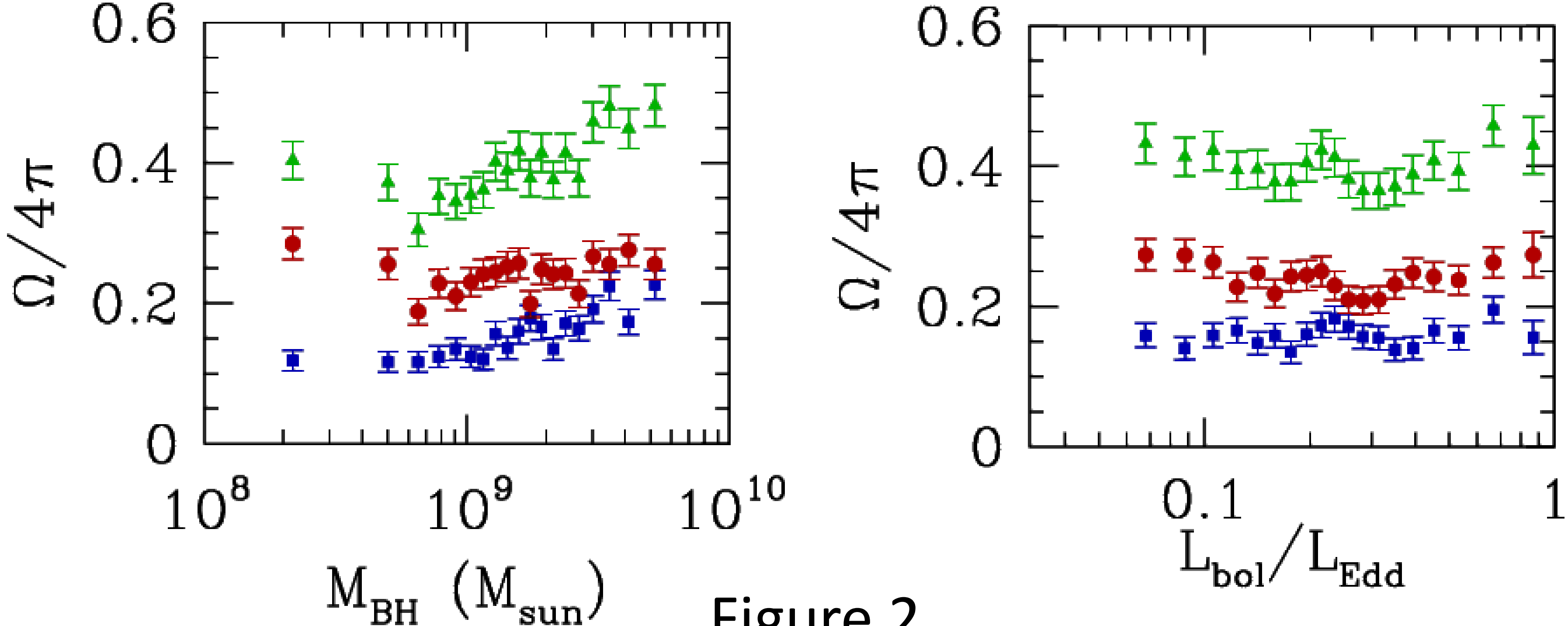


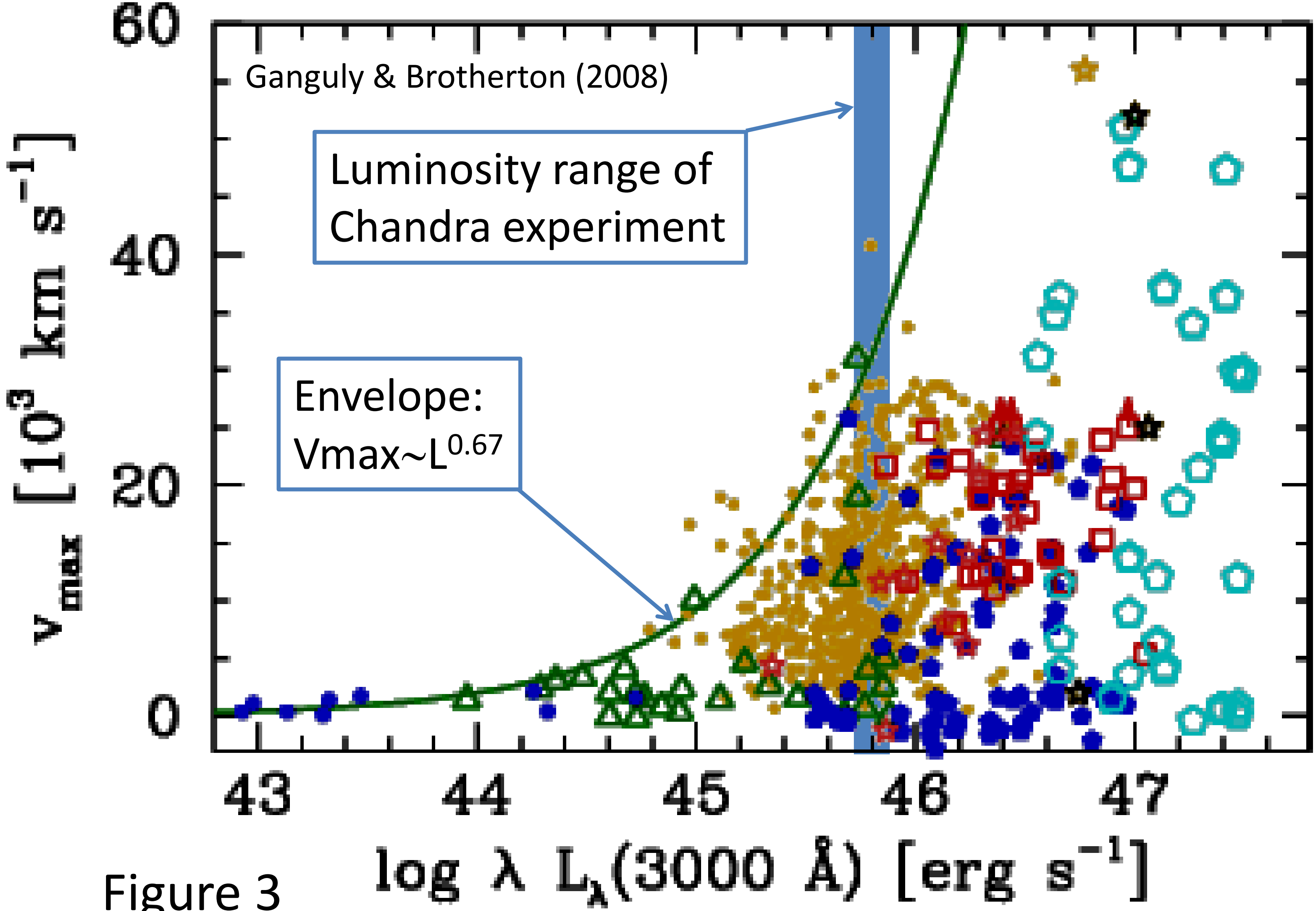
Figure 2

Feedback vs. Outflow Velocity

- Kinetic luminosity is most sensitive to outflow velocity ($L_k \propto v^2$).

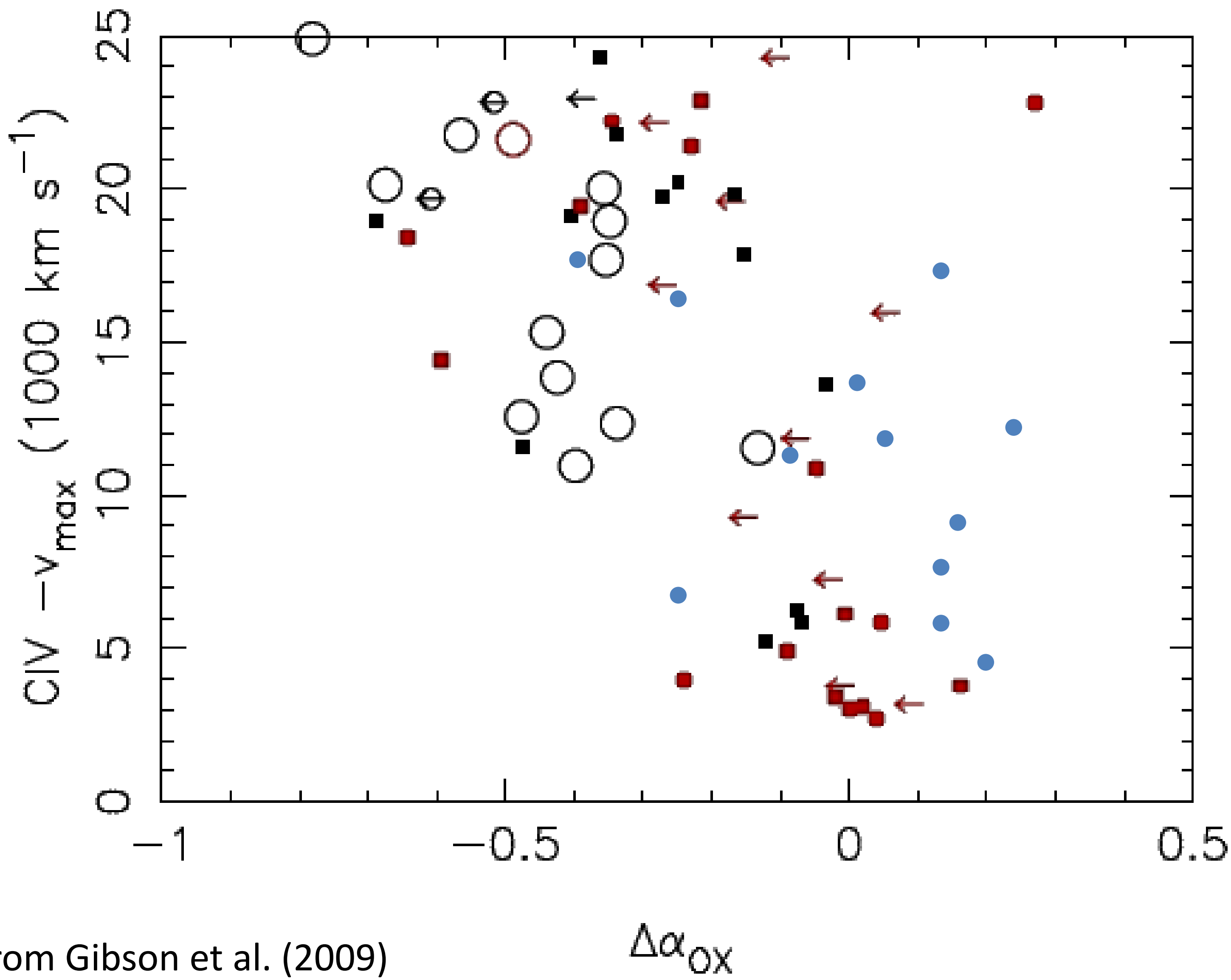
- Outflow velocity is a complicated function of both the UV luminosity (Fig. 3) and the amount of the X-ray absorption (as gauged by $\Delta\alpha_{ox}$, Fig. 4).

- [α_{ox} is the two-point spectral index measured between 2500Å and 2keV. $\Delta\alpha_{ox}$ is the difference between the absorbed and unabsorbed α_{ox}.]



Ganguly & Brotherton (2008)
Luminosity range of Chandra experiment
Envelope: Vmax~L0.67
60
40
20
0
43
44
45
46
47
vmax [10^3 km s^-1]
log λ Lλ(3000 Å) [erg s^-1]

Figure 3



Adapted from Gibson et al. (2009) and Gallagher et al. (2006).
Blue data from Stark et al. (2011)

Figure 4

Velocities: A Puzzling Experiment…

- To disentangle the effects of luminosity and X-ray absorption, we conducted an experiment with Chandra.
- Observed BALs showing a variety of outflow velocities, but a narrow range in luminosity, and other properties.
- Observed only BAL quasars with the following attributes:
  - λL_λ(3000Å) : $10^{45.65-45.85}$ erg/s
  - α(3000Å) :1-1.5 ($F_\lambda \sim \lambda^{-\alpha}$)
  - Δv :4000-6000 km/s
- Results are shown as blue points in Figure 4. **The velocity-$\Delta\alpha_{ox}$ correlation appears to worsen!**

Feedback vs. Column Density

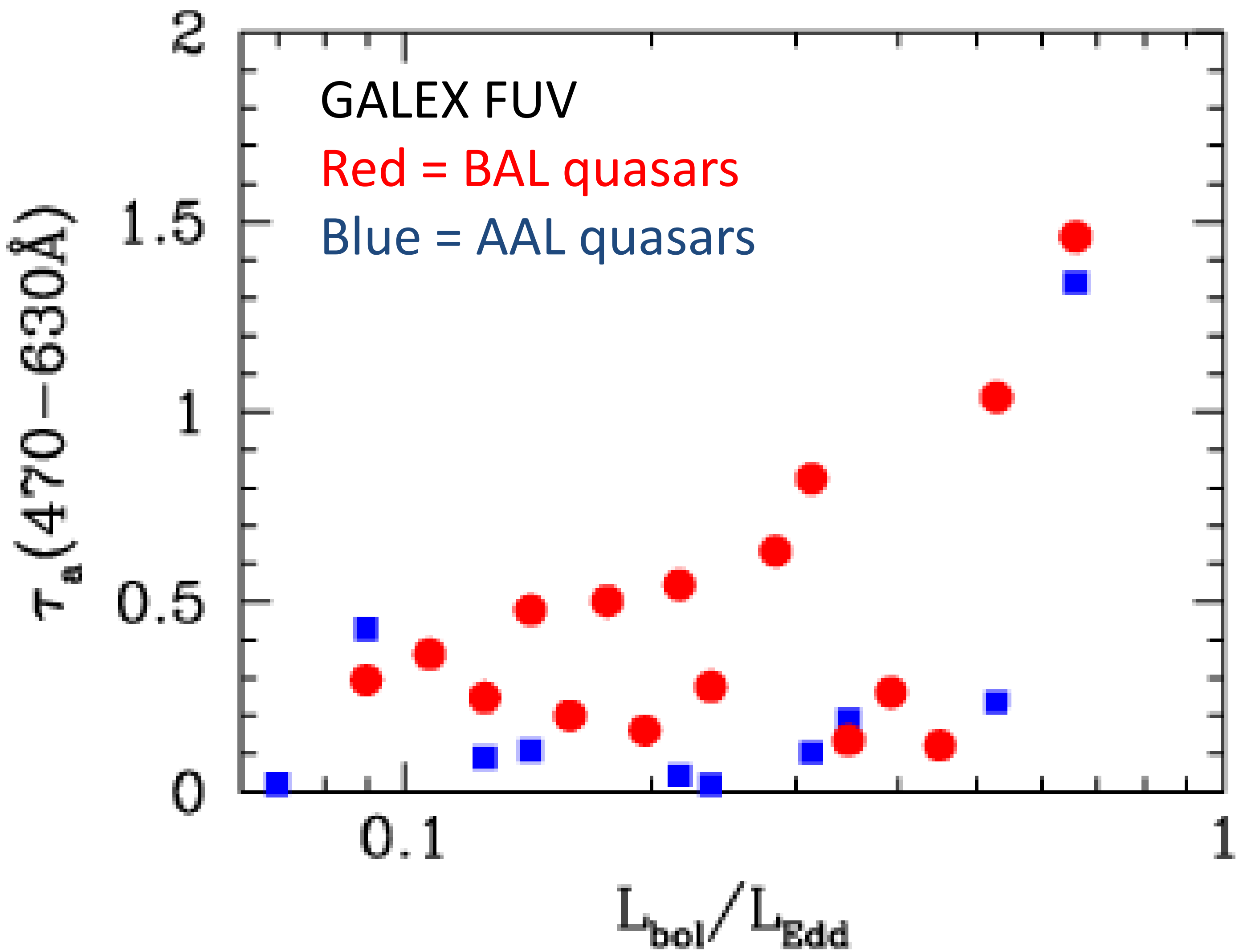
- Strictly speaking, low-dispersion spectra and photometric data do not yield precise column density information. High dispersion spectra are required to disentangle detailed kinematic, ionization and abundance variations.

- With our data, we aim to characterize, in a statistical manner, the overall level of absorption in the rest-frame ultraviolet bands sampled by the GALEX FUV (rest: 470-630Å) and NUV (rest: 620-990Å) bandpasses.

- GALEX FUV and NUV fluxes for the “unabsorbed” class of quasars are used to gauge the extreme ultraviolet fluxes, and how they are affected by intervening structures.
- These are used for comparison to assess the average amount of absorption in BAL and AAL quasars (colors correspond to Figure 5).
- “Absorption level” is couched as a pseudo-apparent optical depth:

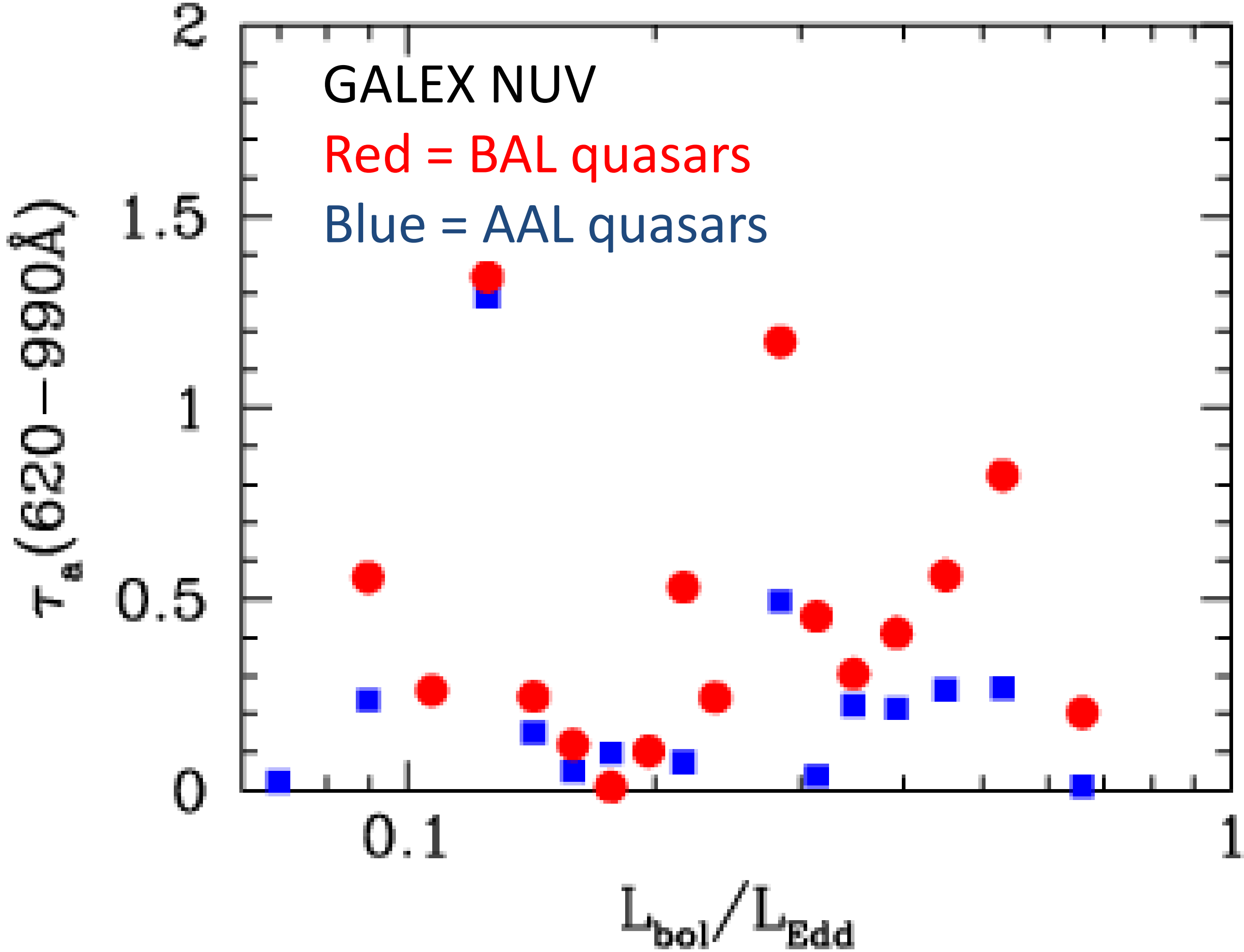
$$\tau_a = -\ln\left[F(\text{absorbed}) \Big/ F(\text{continuum}) \right]$$

- We then compare the gross estimate of absorption as a function of Eddington ratio (Figure 5ab), and black hole mass (Figure 5cd).



GALEX FUV
Red = BAL quasars
Blue = AAL quasars
2
1.5
1
0.5
0
0.1
1
$\tau_a(470-630\text{Å})$
L_{bol}/L_{Edd}

Figure 5a



GALEX NUV
Red = BAL quasars
Blue = AAL quasars
$\tau_a(620-990\text{Å})$
L_{bol}/L_{Edd}
0
0.5
1
1.5
2
0.1
1

Figure 5b

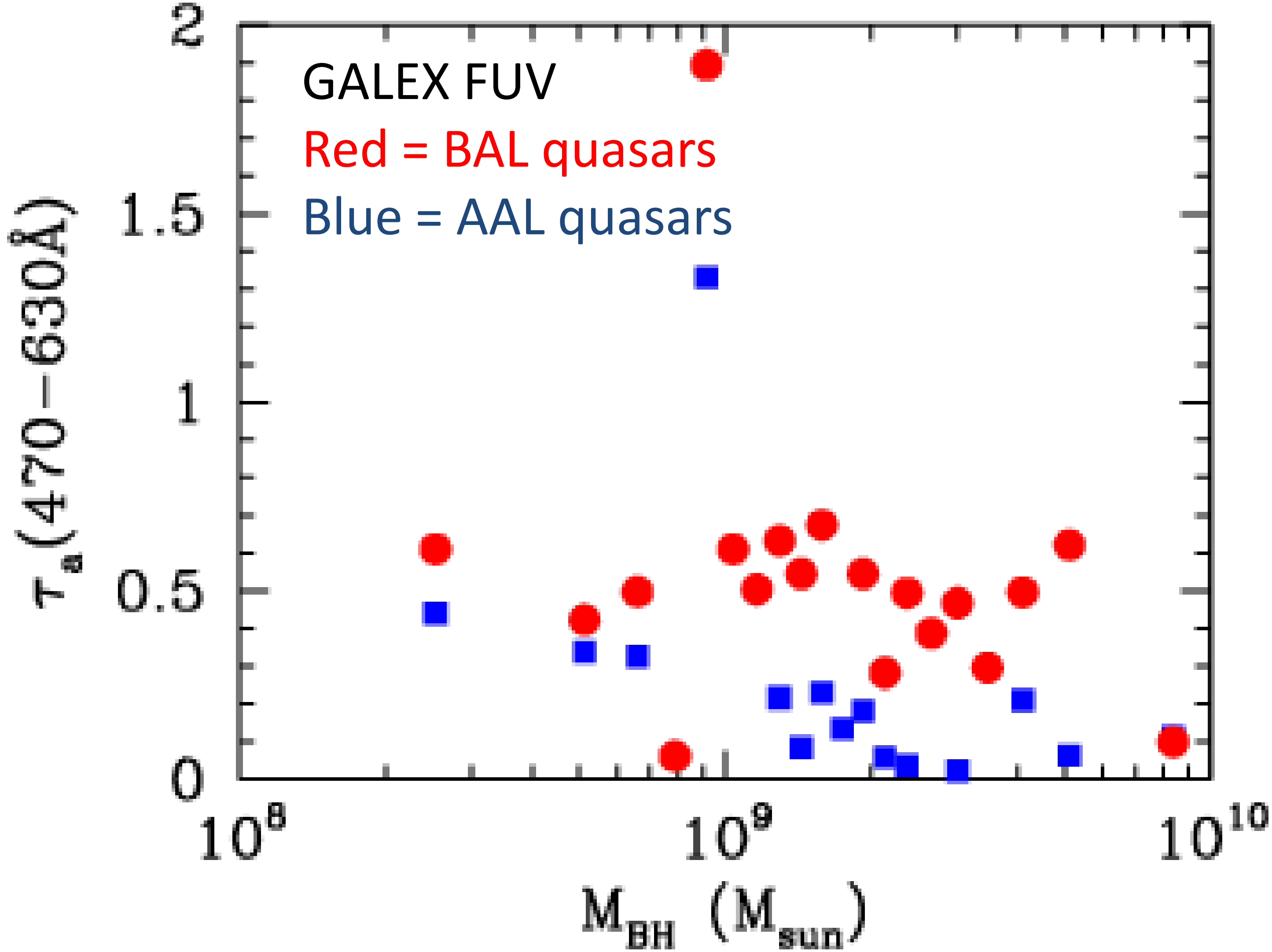
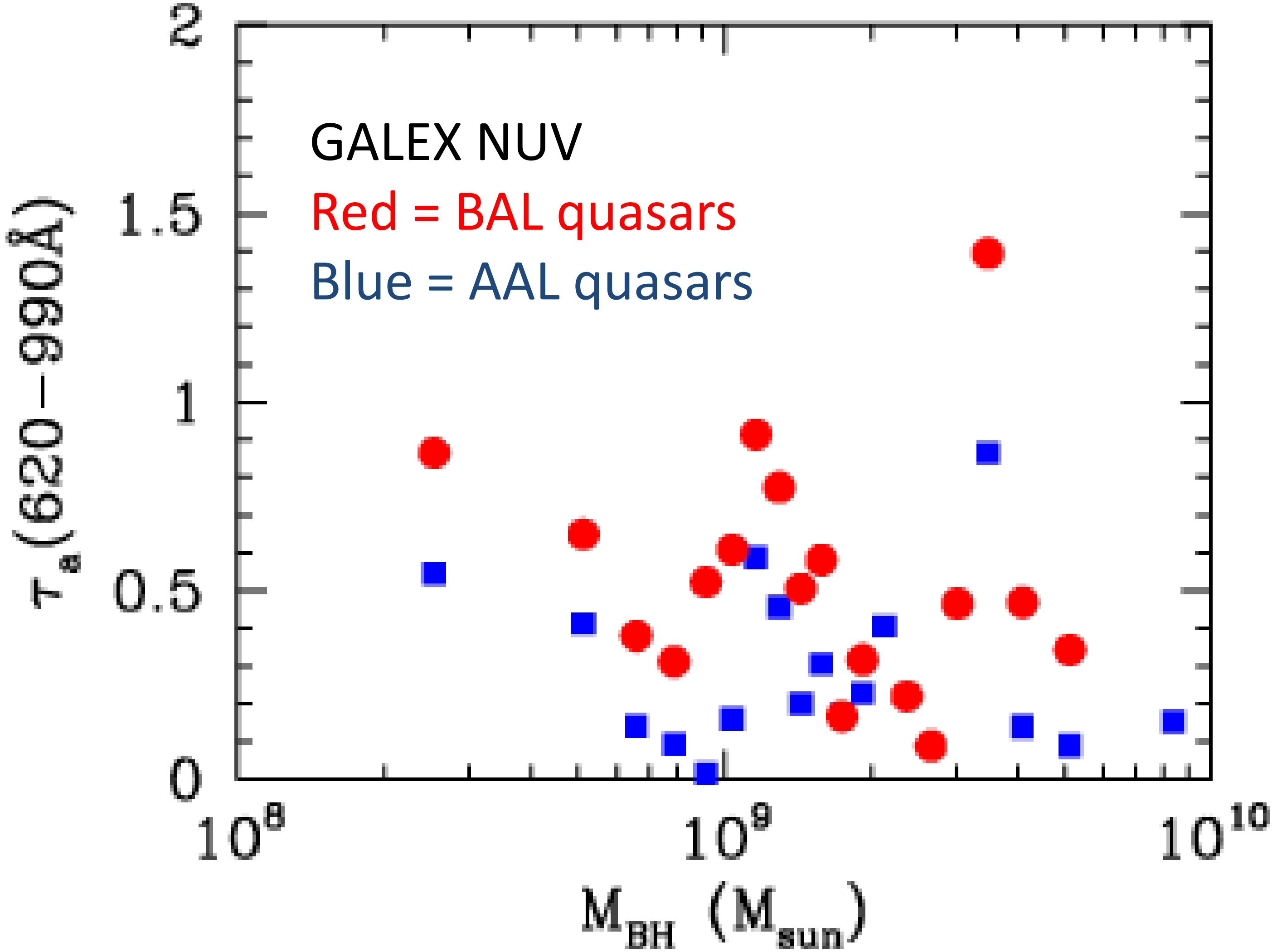

GALEX FUV
Red = BAL quasars
Blue = AAL quasars
2
1.5
1
0.5
0
$\tau_a(470-630Å)$
10^8
10^9
10^{10}
M_{BH} (M_{sun})

Figure 5c



GALEX NUV
Red = BAL quasars
Blue = AAL quasars
2
1.5
1
0.5
0
$\tau_a(620-990\text{Å})$
10^8
10^9
10^{10}
M_{BH} (M_{sun})

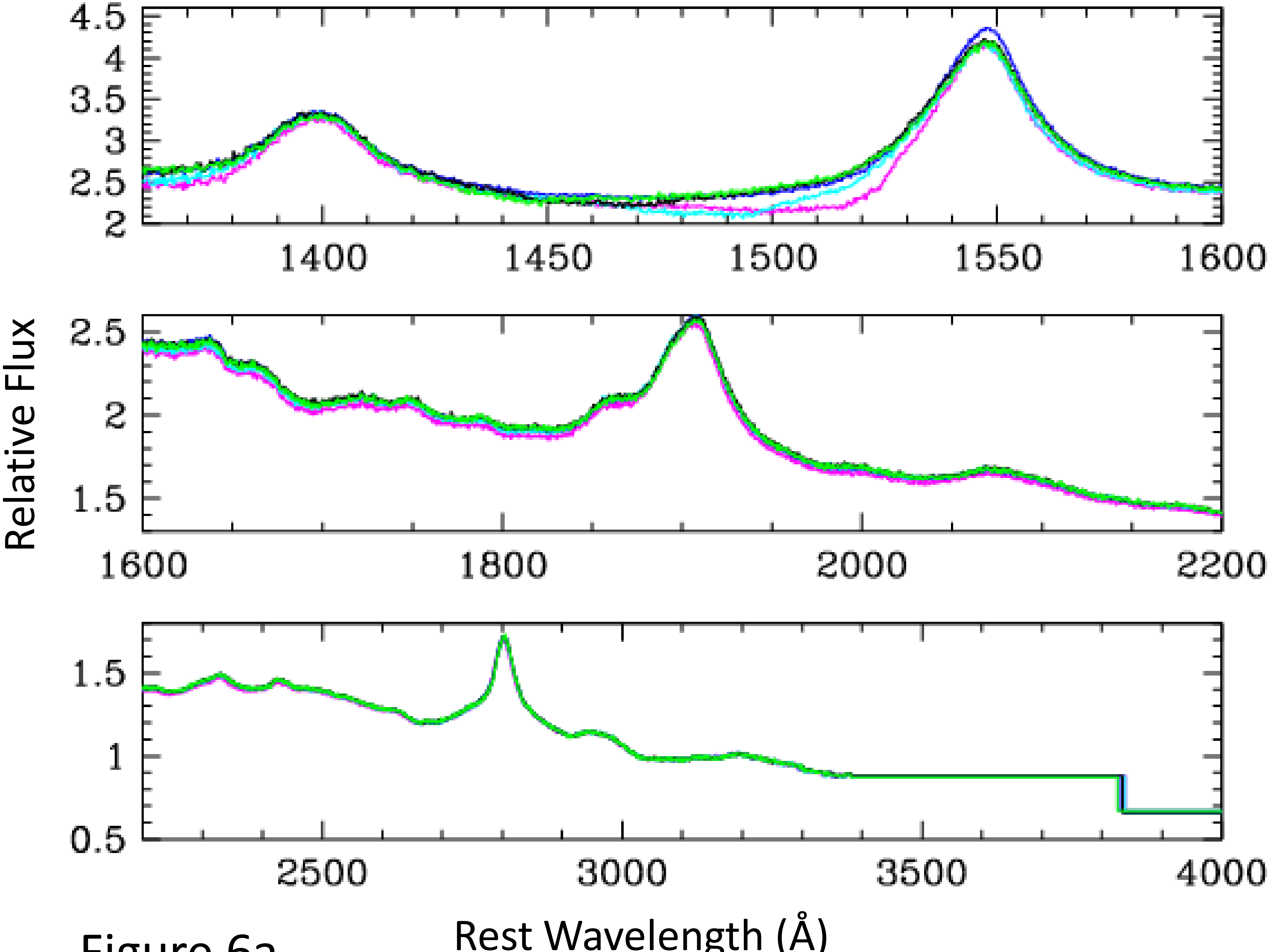
Figure 5d

Composite BAL Spectra vs. Velocity

- To investigate potential differences in SED and emission line shapes with velocity, we compute composite spectra from our BAL quasars.
- To create composites by normalizing the 3000-3100Å flux, and then median combining the spectra.
- We construct composites of BAL spectra that show absorption in different velocity ranges (5-10 Mm/s, 10-15 Mm/s, 15-20 Mm/s, 20-25 Mm/s).

- Figure 6a shows the resulting composite spectra for different velocities. In Figure 6b, we show the composite spectra normalized by the unabsorbed composite, enhancing the median BAL profiles.

- The composite spectra show essentially no difference in the shapes or strengths of the C IV emission profile.



4.5
4
3.5
3
2.5
2
1400
1450
1500
1550
1600
Relative Flux
2.5
2
1.5
1600
1800
2000
2200
1.5
1
0.5
2500
3000
3500
4000
Rest Wavelength (Å)

Figure 6a

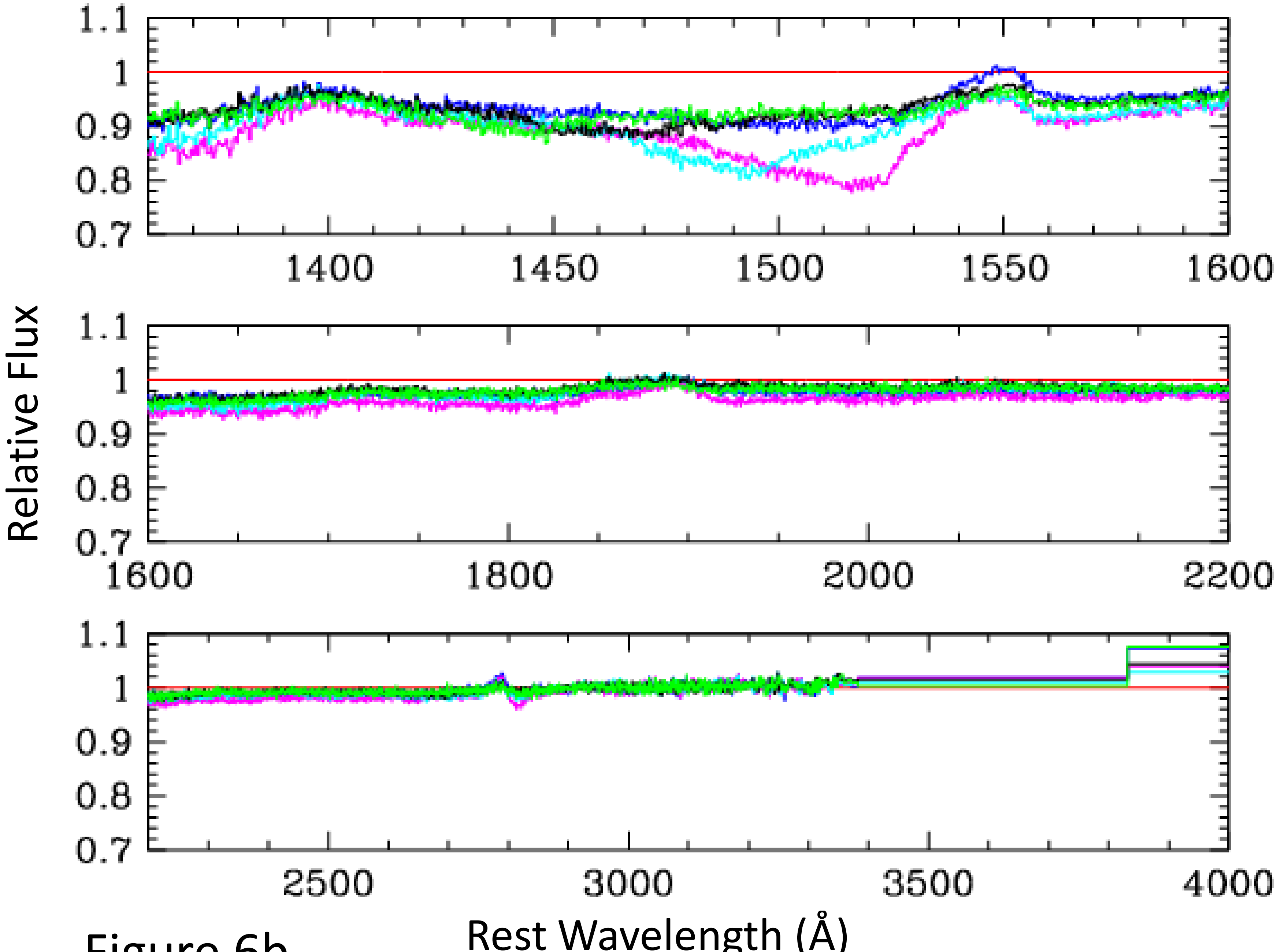

Relative Flux
1.1
1
0.9
0.8
0.7
1400
1450
1500
1550
1600
1600
1800
2000
2200
2500
3000
3500
4000
Rest Wavelength (Å)

Figure 6b

Acknowledgments

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