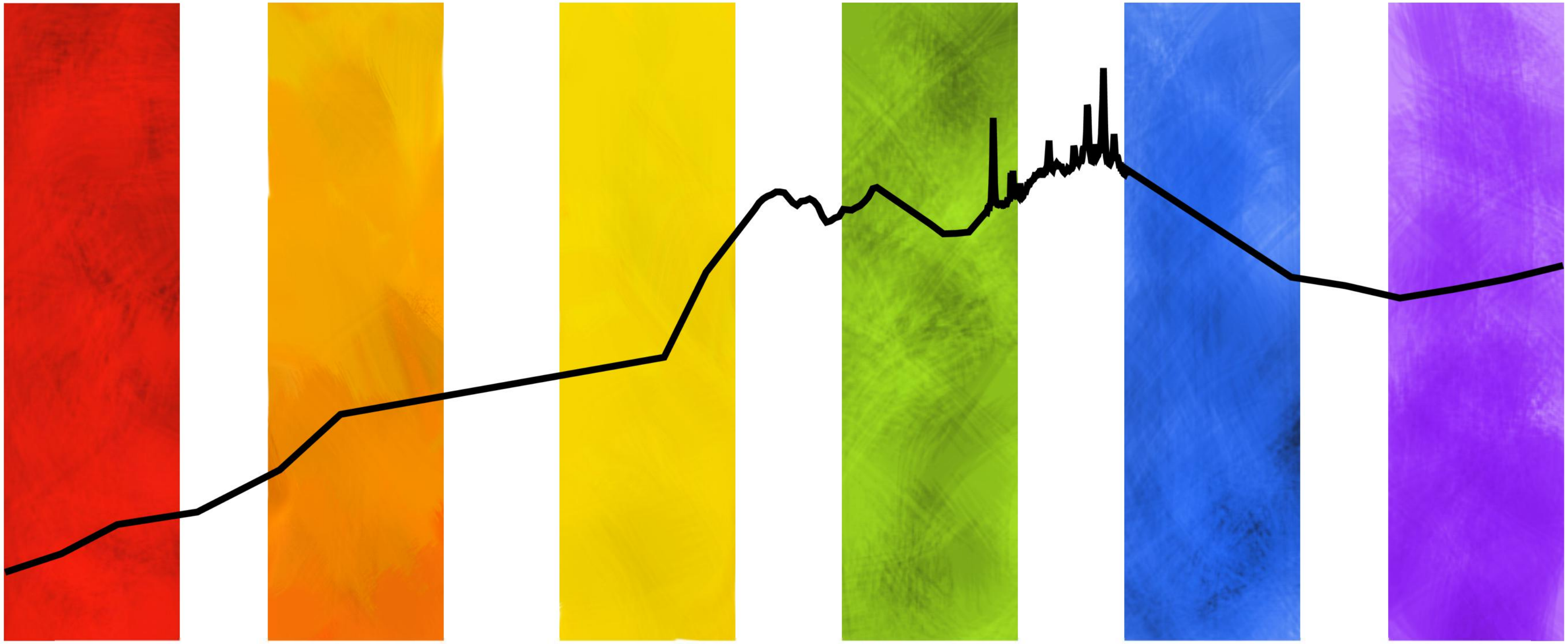
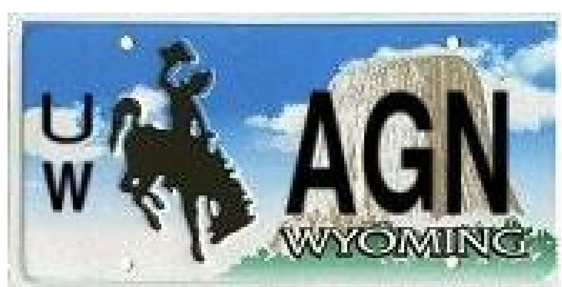
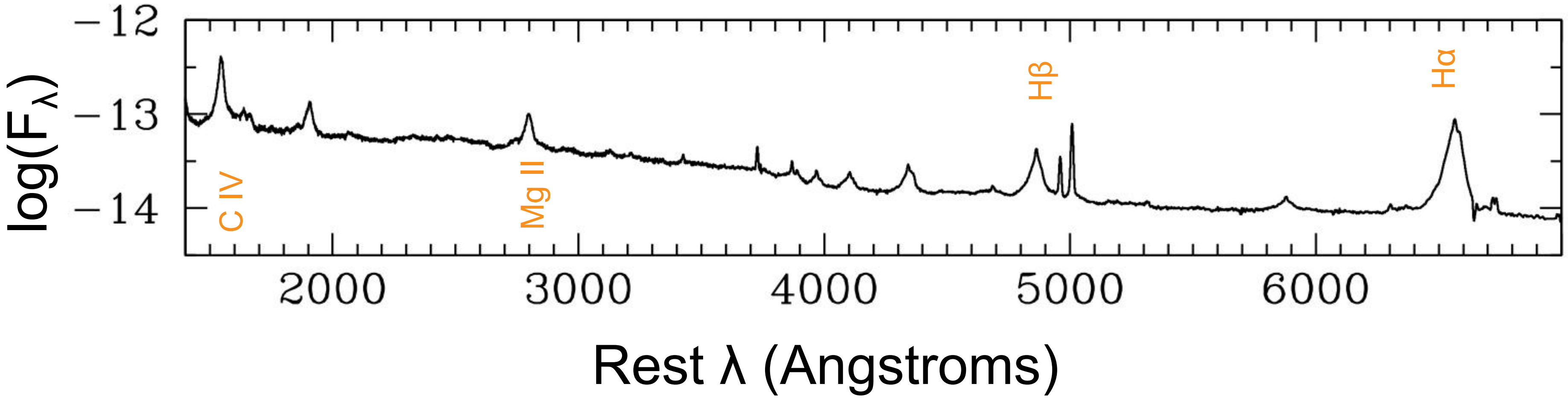


What Have We Really Learned About the Quasar Broad Line Region?

Mike Brotherton (University of Wyoming)



Quasars and their Optical/UV Spectra



Fundamental Quasar Parameters

- Black Hole Mass
- Geometry: Axisymmetry and viewing angle
- Accretion Rate (Eddington fraction, L/Ledd)
- Luminosity
- Others, e.g., abundances

Parameters <-> Observables (Spectra) <-> Picture?

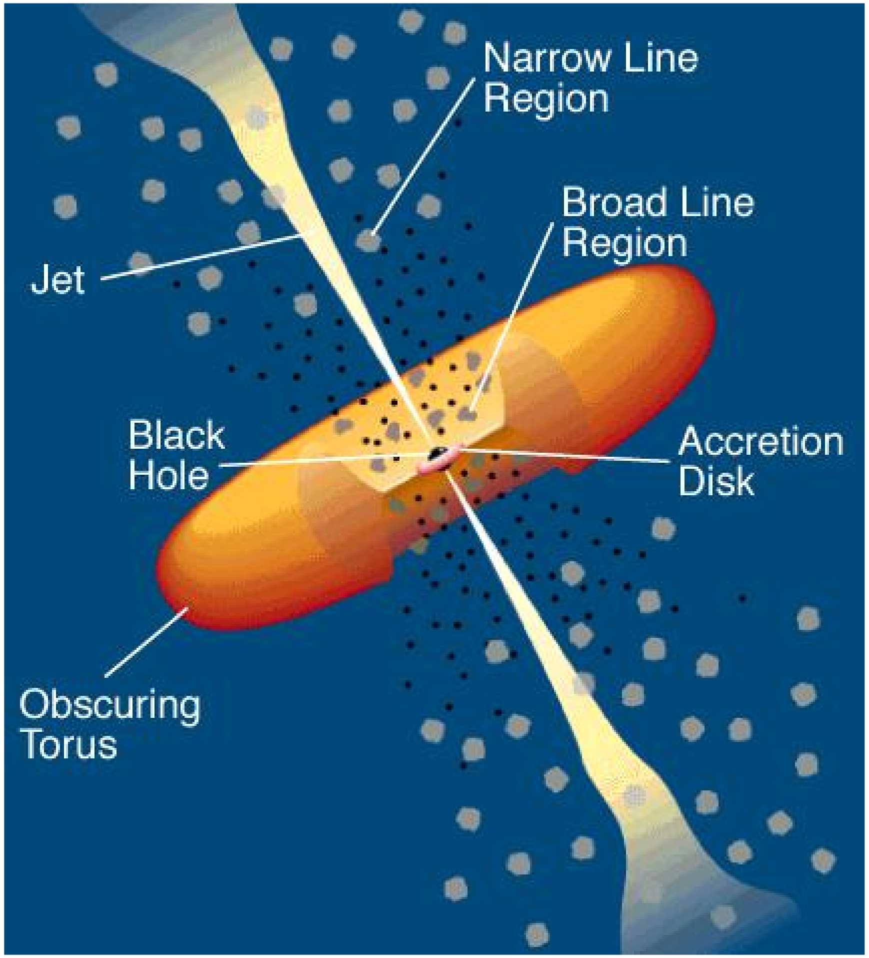
The BLR "Standard Model" circa 1990

- Very large number of optically thick BLR "clouds" with density $\sim 10^{10}$ cm^{-3}, with low filling factor and ~10% covering fraction

- photoionization distances of light days to light months

- photoionized by a thin accretion disk, corona, log U = -2

- Some hints only about geometry and dynamics



Urry & Padovani (1995)

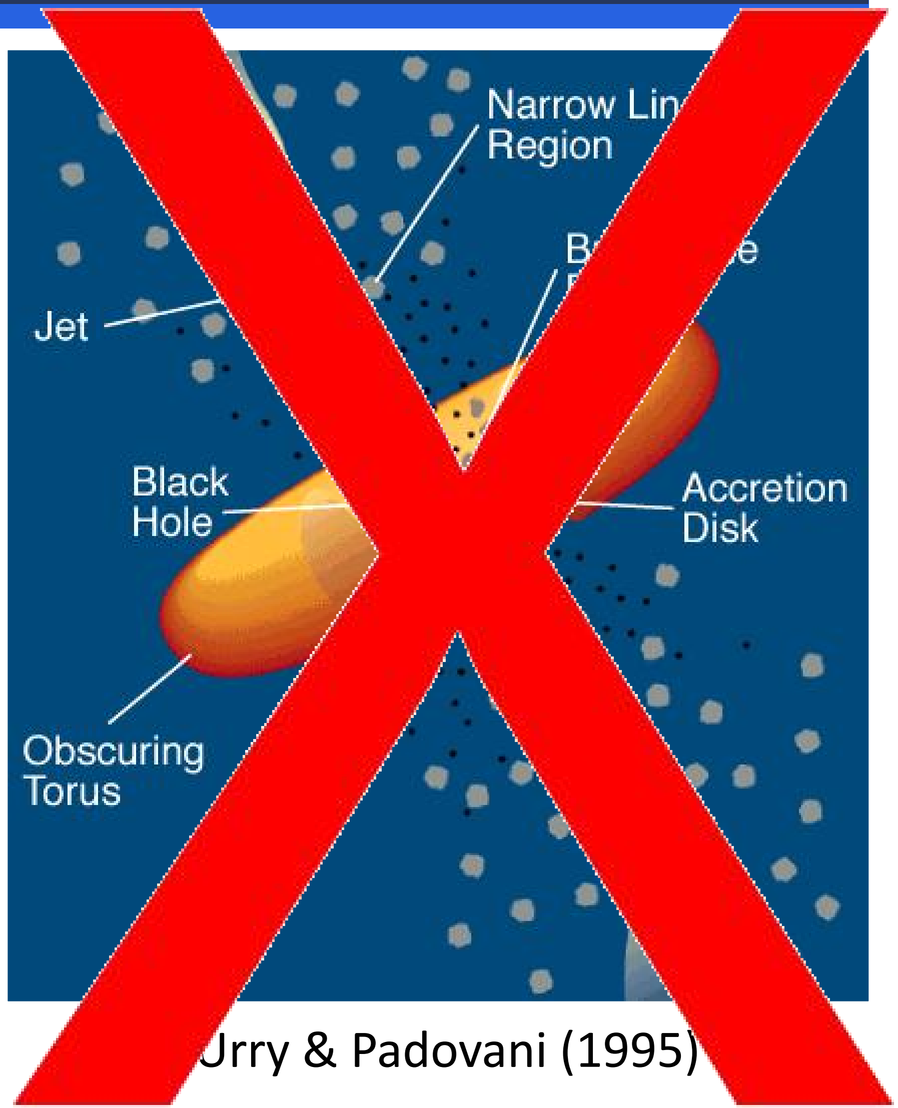
The BLR "Standard Model" had problems!

○ Cloud equilibrium a problem, and emission lines very smooth at high resolution, implying flows (e.g. Arav et al. 1998)

○ Empirical BLR distances, different but still ~light days to months, via RM

○ "LOC" models (Baldwin et al. 1995) to explain ionization parameter fine-tuning

○ High velocity component is stratified with flattened geometry



Urry & Padovani (1995)

Stratified, Likely Virial BLR Gas

- Virial mass:

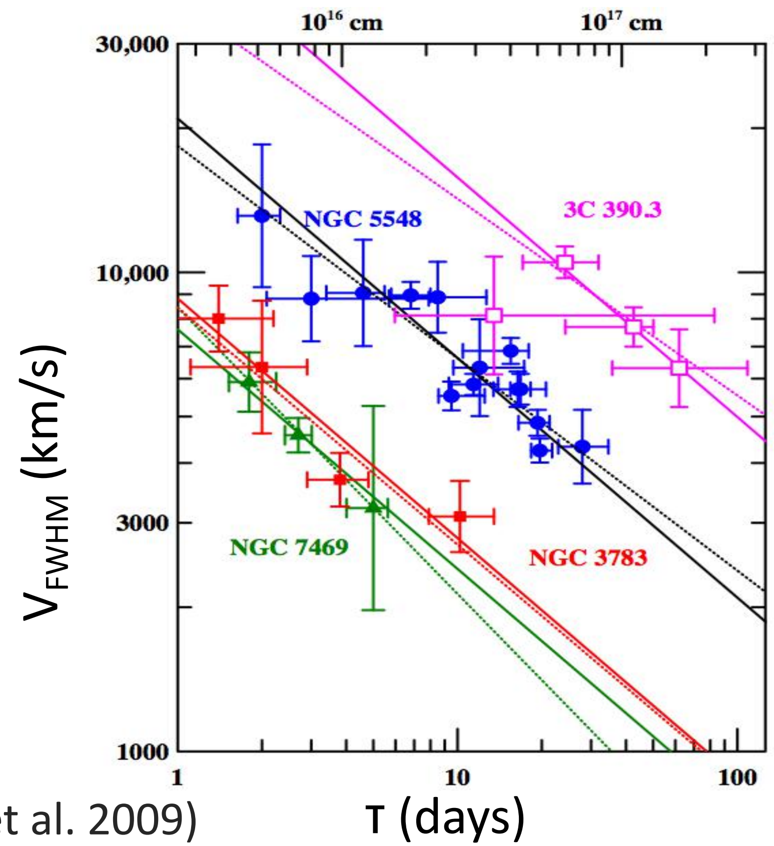
$$M = f\frac{V^2 R}{G}$$

- Radius:

$$R = c\tau$$

$$R \propto L^{1/2}$$

(Kaspi et al. 2000; Bentz et al. 2009)



- Virialized fit:

$$V \propto \tau^{-1/2}$$

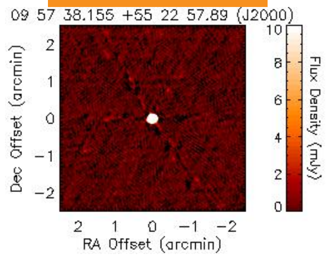
Peterson (2011) after Peterson & Wandel (1999,2000)

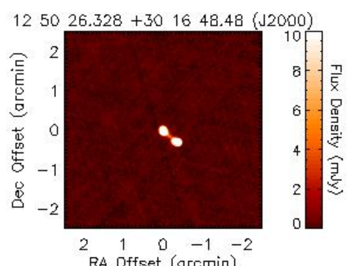
Orientation: Wills & Browne (1986)

- Hβ line widths in radio-loud quasars depend on orientation in a way that suggests a flattened or disk-like BLR and a higher edge-on velocity.

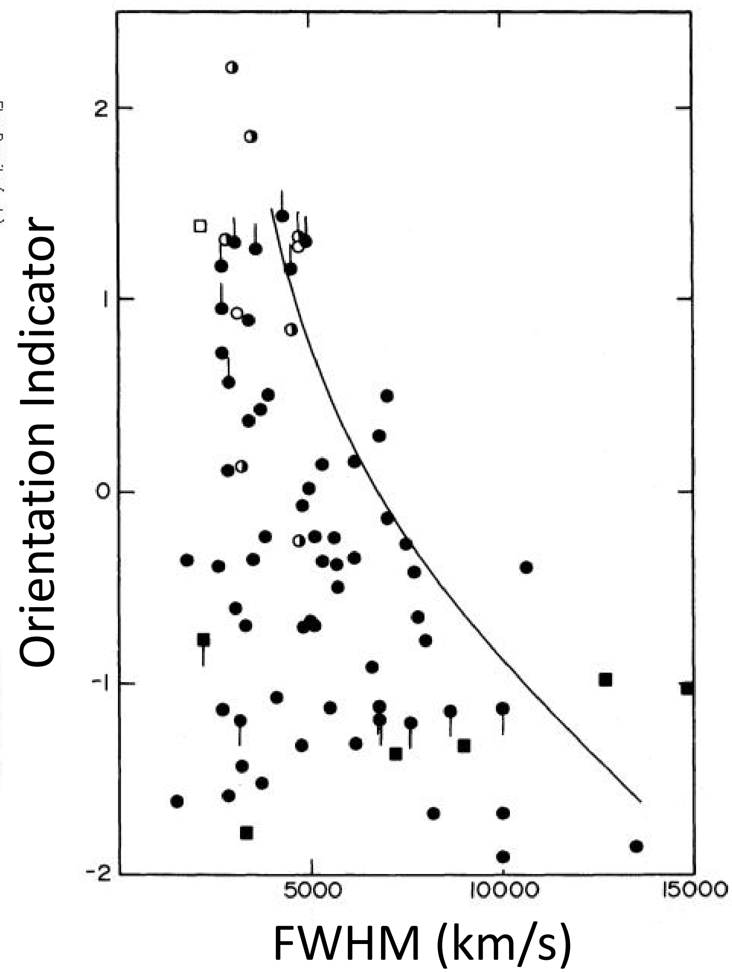
- Black hole masses need individual correction for orientation (the “f” factor).

Face On



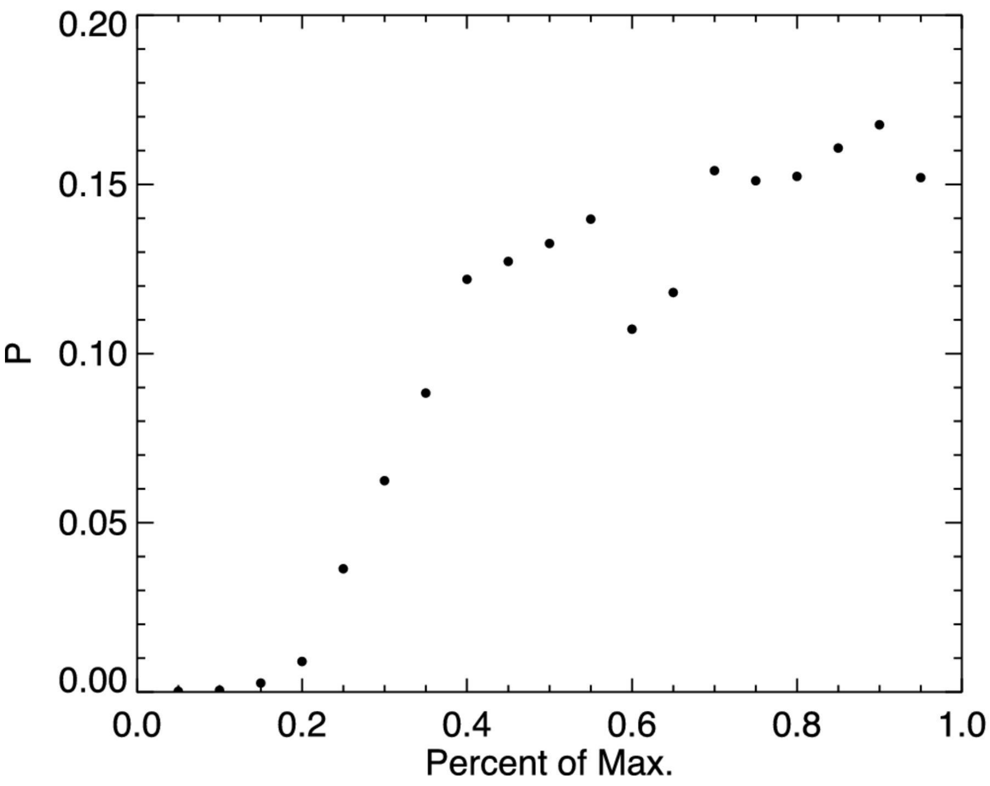


Edge On

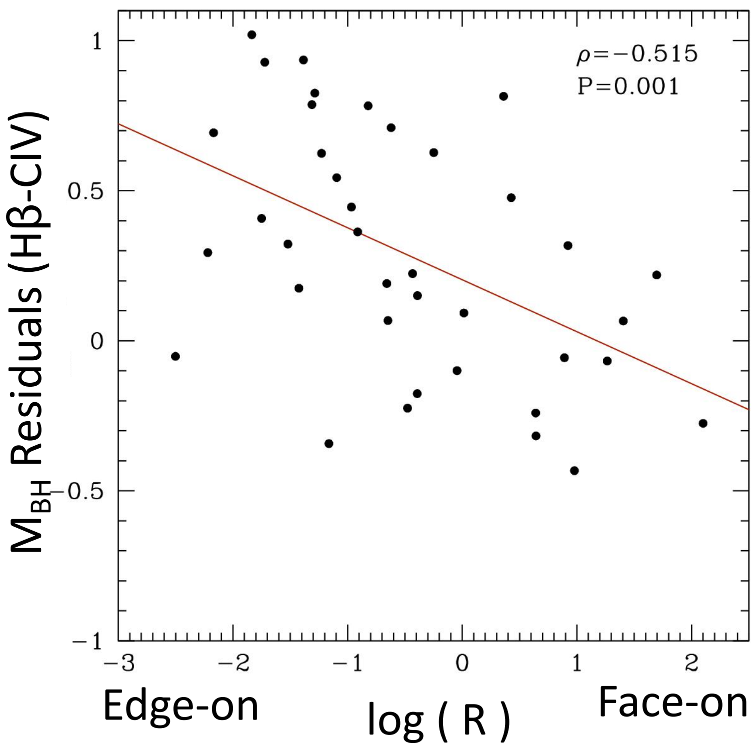


Also the High-Velocity Gas for C IV

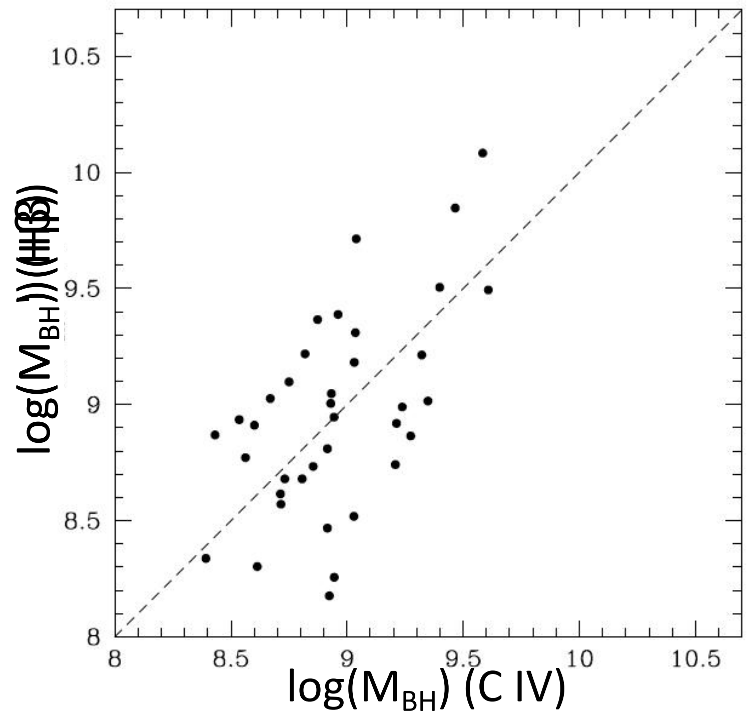
- C IV shows the same behavior, with edge-on radio-loud quasars having the broadest profiles, but cannot see using the FWHM
- Runnoe et al. (2014) shows very significant correlation but only when looking at the line wings (e.g., FWZM)



Orientation correction to M_{BH}



Before
After



Runnoe et al. (2013)

Scatter: 0.35 dex

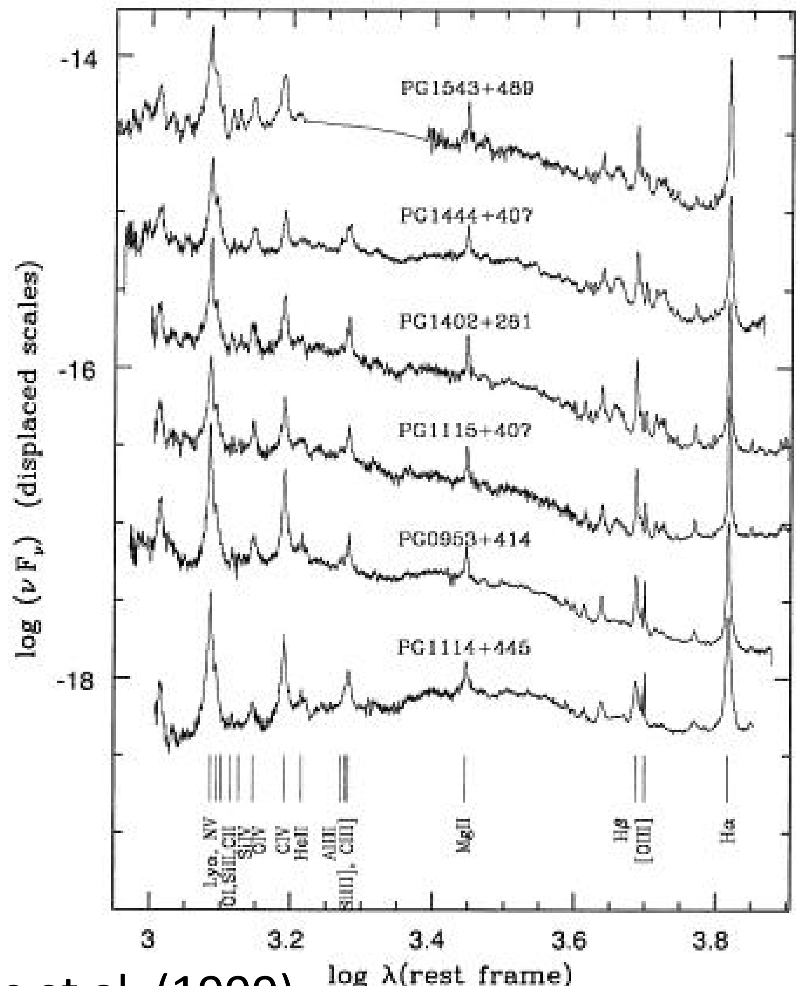
EV1/Eddington fraction/non-virial ILR

Inverse correlation between Narrow Line Region (NLR) and optical Fe II

Intermediate Line Region (ILR) varies with NLR, is non-virial, affects C IV (Brotherton et al. 1994; Denney 2012)

SED changes, disk structure changes?

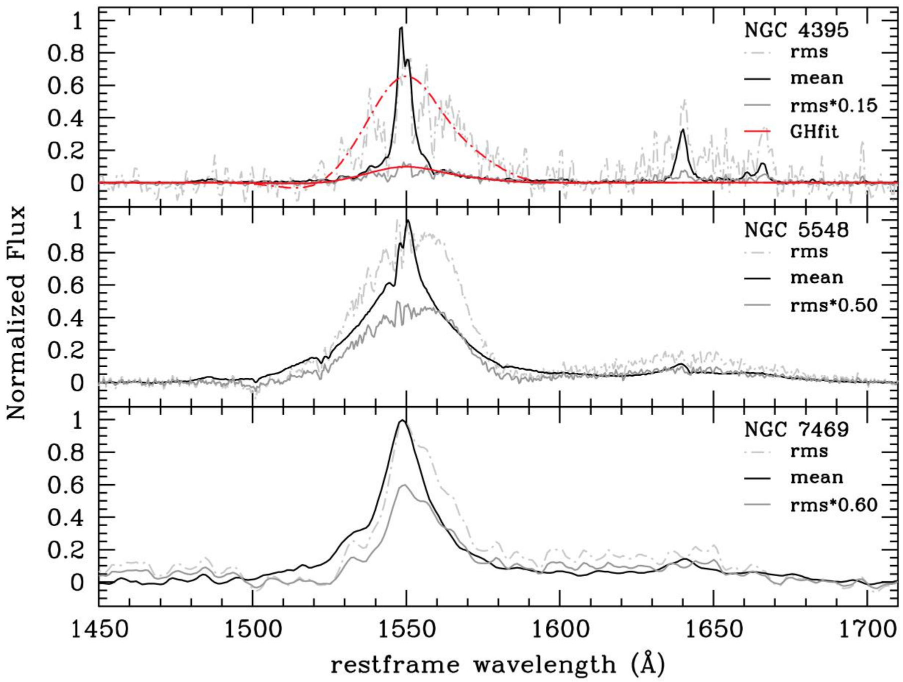
Emission-line spectra vary with (probably) Eddington fraction (Boroson & Green 1992; Boroson 2002; Shen & Ho 2014; Sun & Shen 2105)



Wills et al. (1999)

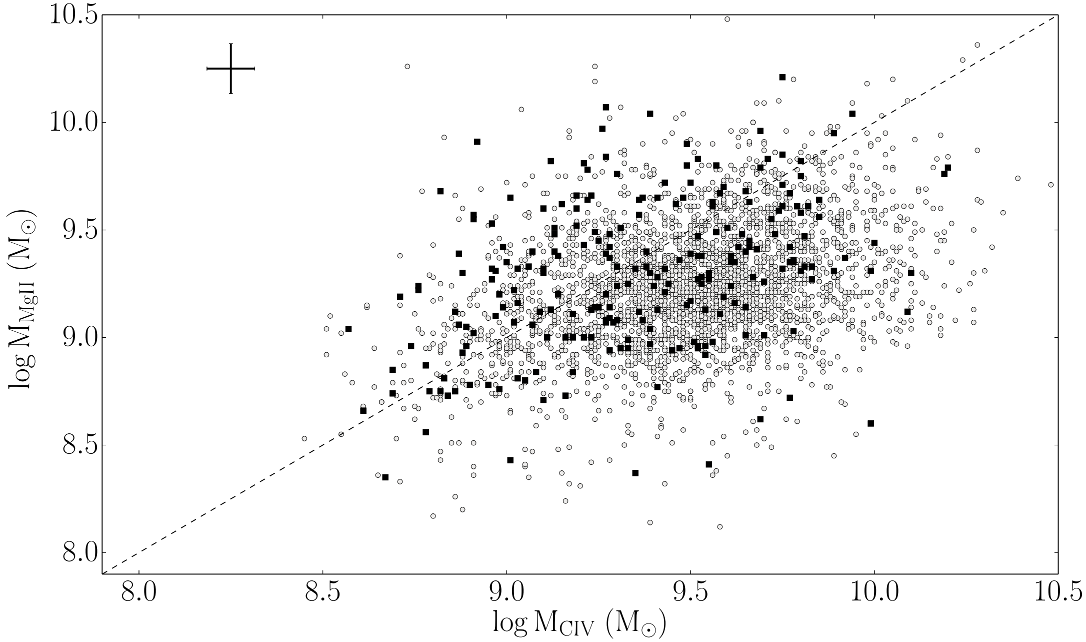
C IV Reverberation: RMS vs. SE Profiles

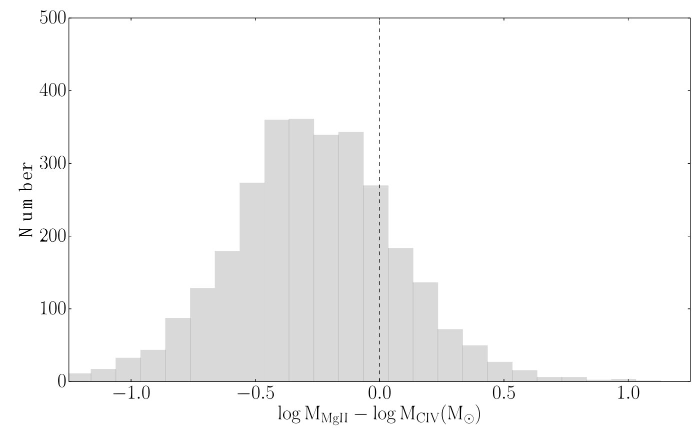
Denney (2012)



○ RMS C IV profiles broader than single epoch (SE) profiles. Low-velocity line cores (ILR component) don't vary on same timescale, vary object-to-object with EV1. Different behavior from Mg II, Hbeta!

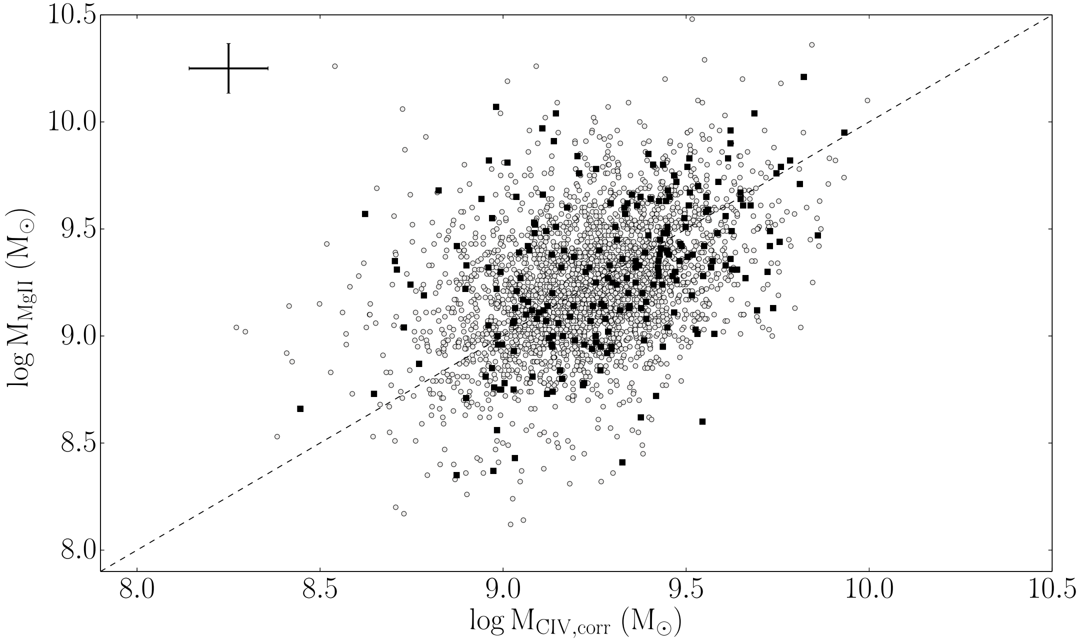
SE C IV Mass Corrections (vs. Mg II)

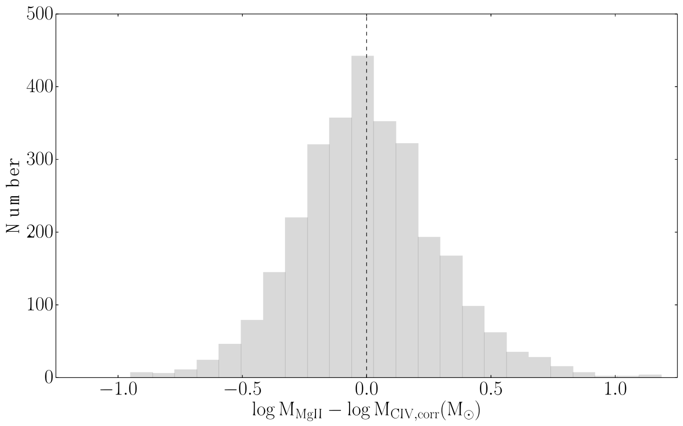




- SE C IV masses too large compared to Mg II masses by almost a factor of two, due to EV1 mismatch between RM samples and luminous high-z SDSS quasars.

SE C IV Mass Corrections (vs. Mg II)

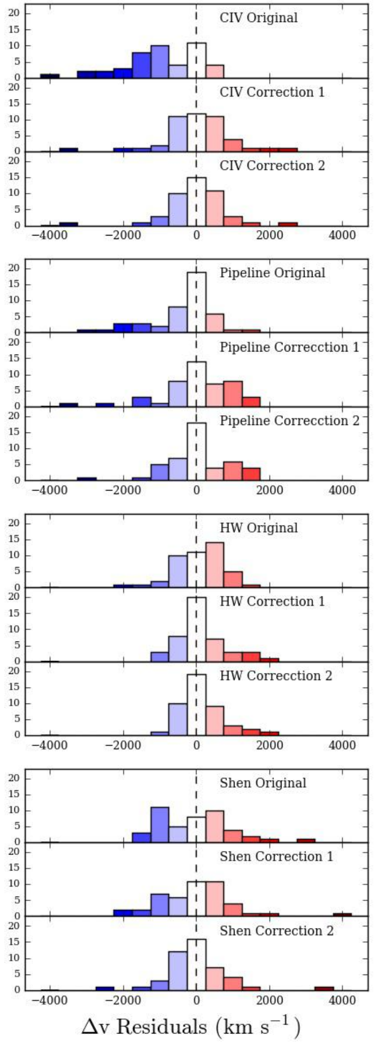




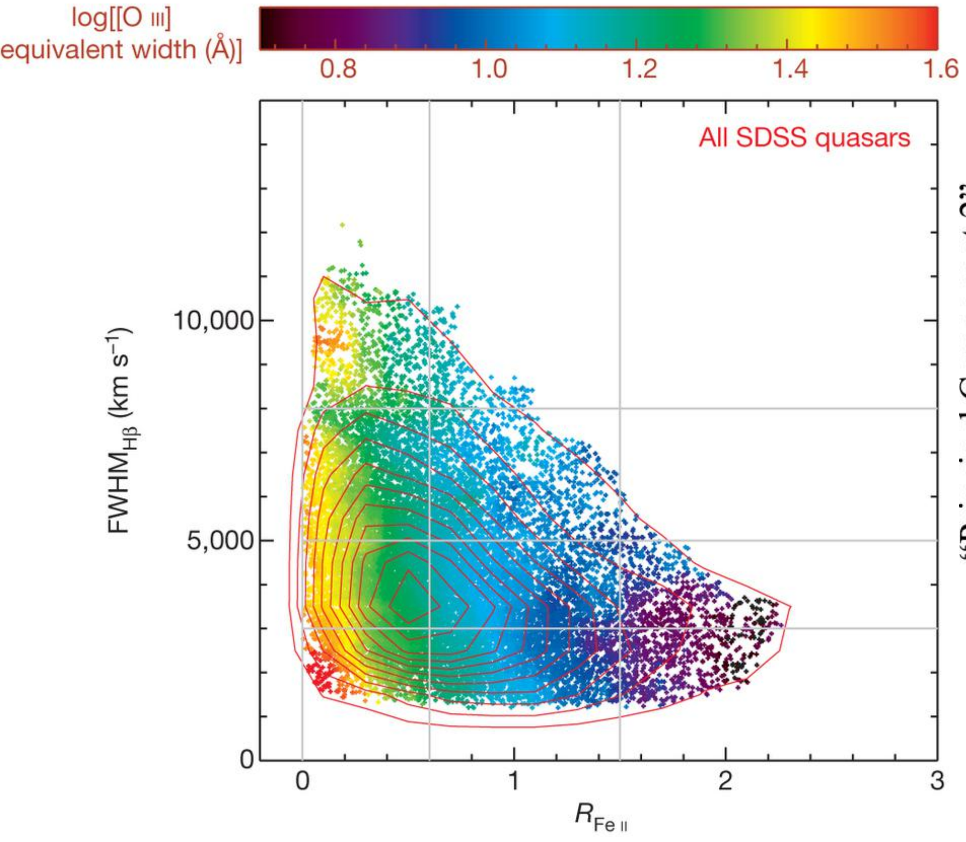
- Can correct for EV1 effects using C IV profile measurements alone. RL and RQ need slightly different corrections (likely blazar continuum). Does not work for WLQs. Brotherton et al. (2016).

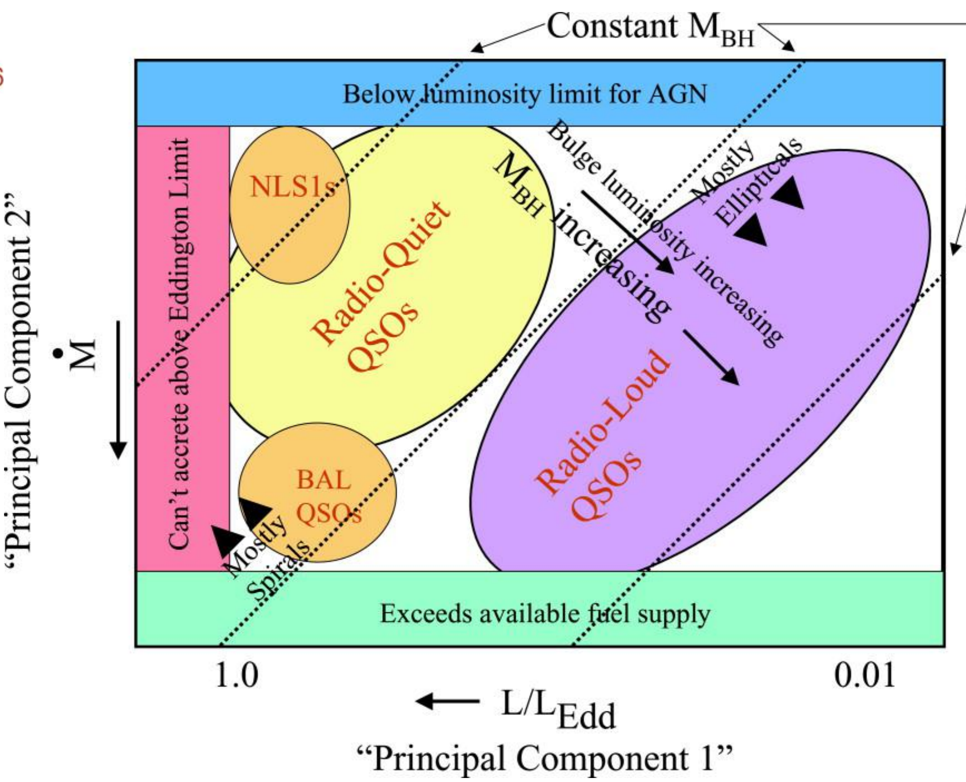
EV1 and C IV Blueshifts (vs. [O III])

- High-ionization lines like C IV on average blueshifted relative to narrow lines, Mg II, Hbeta (Gaskell 1982).
- Velocity shifts correlated with EV1 parameters, primarily* due to changing ILR component, revealing intrinsic blueshift of high-velocity gas (Brotherton et al. 1994). Can similarly statistically correct redshift for EV1 in quasars (Mason et al. 2016).
- “Virial” gas in a disk-wind? Or something more subtle? Let’s be careful.



Eigenvector 1 Relationships

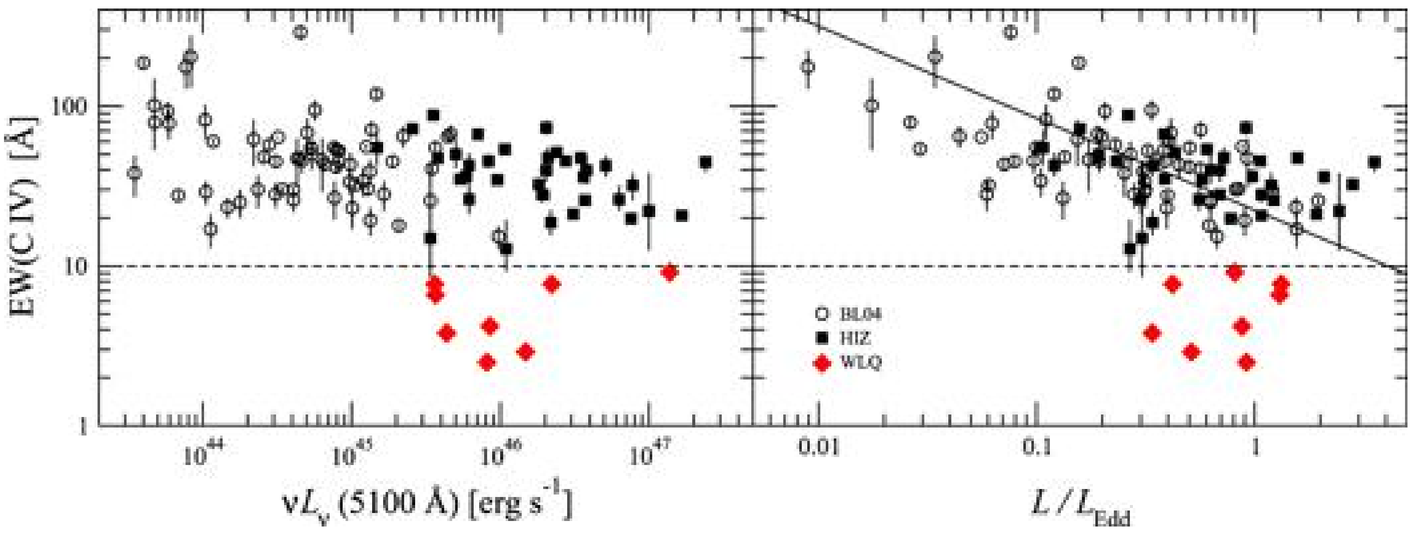




- Shen & Ho (2014)
- Boroson (2002)

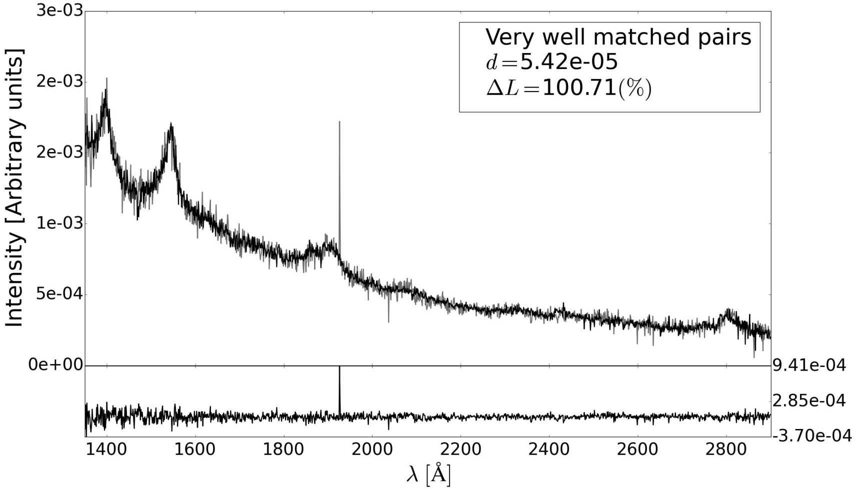
Line-Continuum Correlations

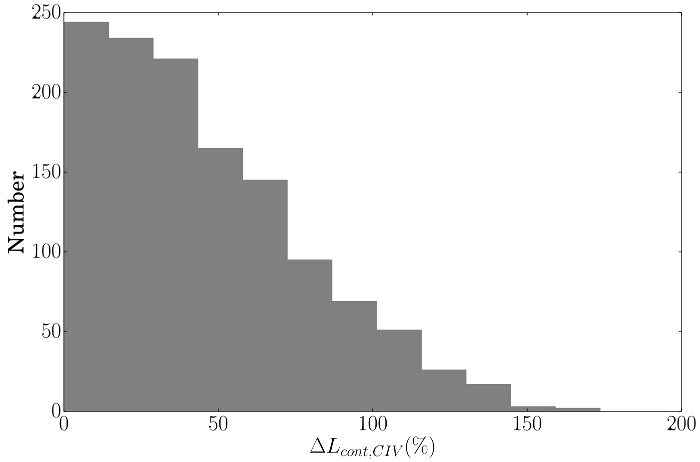
Shemmer & Lieber 2015



Baldwin effect (left; e.g., Baldwin 1978) and Modified Baldwin effect (e.g., Baskin & Laor 2004). Red points Weak Line Quasars (WLQs).

Identical Spectra, Less Identical Luminosity

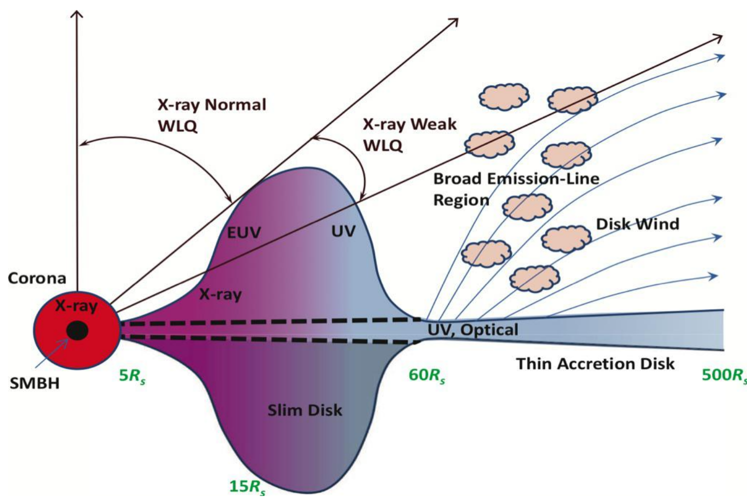




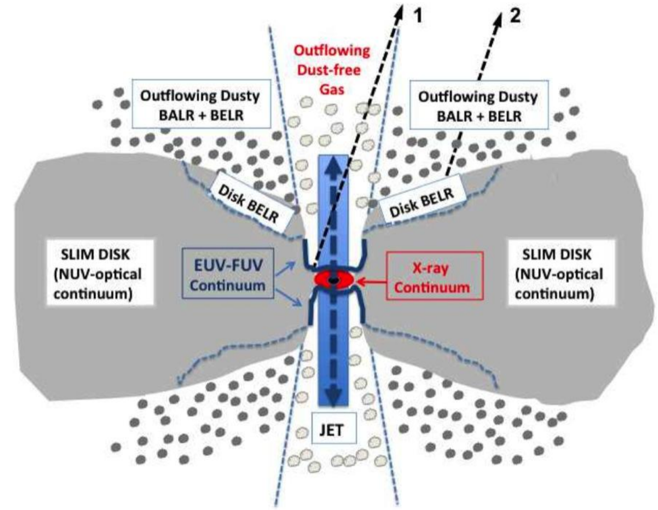
Rochais et al. (2016). Quasars with nearly identical spectra ("Doppelgangers") have similar luminosity in general, but can differ by large factors (x5-7). Characterizing the Baldwin effect this way, and thinking about flux-limited samples and luminosity functions varying with z, shows why so difficult to use for cosmology. Variability and time lags contribute to this luminosity variation. A Gaskell type reddening, too?

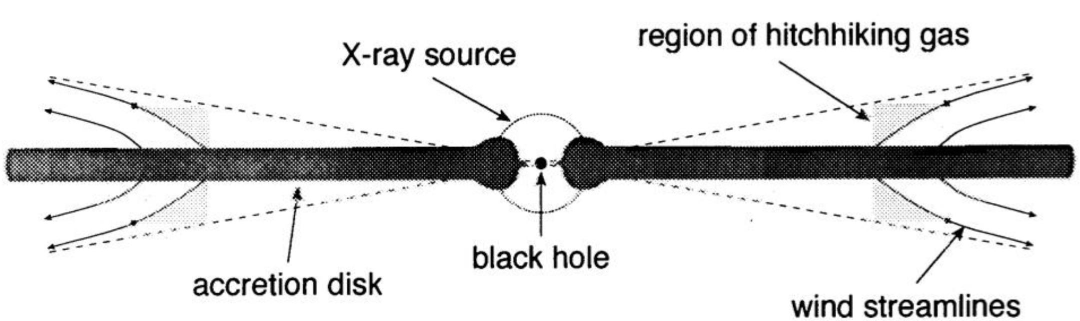
Modern BLR Pictures, but No Consensus

Luo et al. 2016

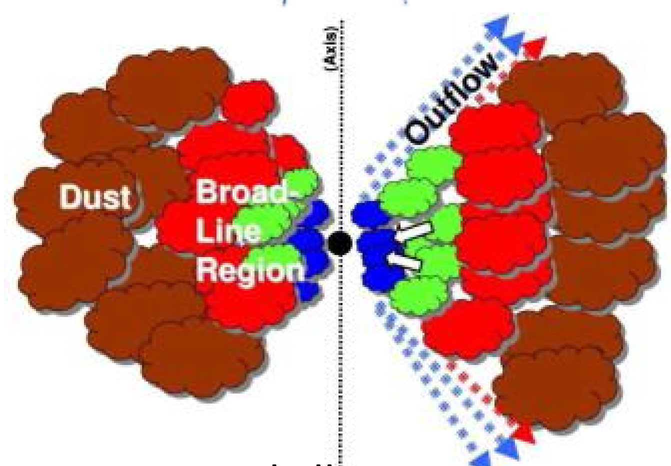


Veilleux et al. 2016





○ Murray et. al 1995



Gaskell 2009

Outstanding BLR Questions

- Broad line widths: reliably accounting for competing effects of geometry and mass
- EV1 Mechanisms?
  - Density, SED, illumination, NLR gas
- Disks and Disk winds with Eddington fraction?
- Meta-level: M-sigma$_*$ & R-L, vary with EV1, Orientation, Host?
- Statistical vs. Individual: real BLRs have huge diversity
- Still no “standard model” under new paradigm – is one possible?