The Main Sequence of Quasars
(or, the nature of Eigenvector 1)

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Based on the work of Shen & Ho (2014)
Outline

• Background: EV1 and orientation
• New observations of quasar properties (SDSS, WISE, etc)
• A simple unification for broad-line quasars
• Open questions
• **Unification of Type 1 and Type 2 AGN**

• **Eigenvector 1 (EV1, Boroson & Green 1992):** most of the variance in the optical spectra of (Type 1) quasars comes from an anti-correlation between Fell strength and narrow [OIII] strength
• Many other physical properties seem to correlate with EV1 (X-ray properties, CIV properties, narrow-line Seyfert 1s, BALQSOs, etc): Wang et al. 1996, Boller et al. 1996, Laor et al. 1997, Brandt et al. 2000, Sulentic et al. 2000, and many more
Evidence for a flattened BLR

- Radio jet orientation (Wills & Browne 1986, Runnoe et al.)

- Disk emitters (Chen, Eracleous, Halpern et al.)

- Dynamical evidence from reverberation mapping (Pancoast et al.)
Motivation of our work

• What drives EV1?
  – Eddington ratio long suspected as the driver (Laor 2000, Boroson 2002), but a definitive proof is lacking

• How to integrate orientation into this picture?
This 2D FWHM (Hbeta) versus Rfe EV1 plane is also known as the 4DE1 plane used by Sulentic and collaborators.
A closer look at [OIII]

EV1 + Baldwin effect for [OIII] (e.g., Stern et al. 2013, Zhang et al. 2013)
Other properties along EV1
CIV properties along EV1

~130 low-z quasars with UV spectroscopy

Torus emission along EV1

all SDSS quasars
Dissecting the FWHM$_{Hb}$ – R(Fe) plane
Dissecting the FWHM$_{Hb} - R(Fe)$ plane

20,000 SDSS quasars

Accretion efficiency

Fell Strength

Orientation

Broad line width

weak [OIII]  strong [OIII]

more edge-on view

more face-on view
Fell strength (Rfe) correlates with Eddington ratio

- Test using quasar clustering (SDSS quasars roughly have the same luminosity)
Orientation induces FWHM dispersion

\[ \log M_{BH, \text{vir}} \]

all SDSS quasars

\[ \text{FWHM}_{H\beta} [\text{km s}^{-1}] \]

\[ R_{\text{Fell}} \]

\[ w_p [h^{-1}\text{Mpc}] \]

1.6 sigma difference

\[ r_p [h^{-1}\text{Mpc}] \]
Independent BH mass estimates from the M-sigma relation

\[ f \equiv GM_{BH}/(R_{BLR} FWHM_{H\beta}^2) \]

Large symbols: the local RM AGN sample

Small symbols: low-z SDSS AGN from Shen et al. (2008)
Broad line shape as an indicator for orientation (Brotherton 1996, Collin et al. 2006).

Peterson (2011)
A simple unification scheme for quasar phenomenology

• EV1 is an Eddington ratio sequence, where most quasar properties correlate with optical FeII strength

• Dispersion in FWHM_Hbeta at fixed Rfe largely due to orientation --- a flattened BLR geometry in the general quasar population

Implications: virial BH mass estimates based on FWHM_Hbeta should be treated with caution; a shallower dependence of virial BH mass (with a slope <2) on FWHM expected (Wang et al. 2009, Feng et al. 2014)
Open questions

• How Eddington ratio changes emission line strengths (in particular FeII), torus emission, and X-ray properties?
  – SED regulates photoionization
  – Changes in accretion flow structure?

• Outflows?

• Nature of the Baldwin effect?

• Fainter AGNs (smaller BHs) will follow similar EV1 trends, but may have offsets in their physical properties
Evidence for outflows?

Narrow [OIII] line blue wing

Broad Hbeta profile in the EV1 plane