Solving the Mystery of Weak Emission Line Quasars at High Redshift

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Outline

- ✳ Quasars and Active Galactic Nuclei (AGN)
- ✳ Weak Emission Line Quasars: History and Mystery
- ✳ Insights from Multiwavelength Observations
- ✳ Scenarios for Quenching Emission Lines in Quasars
- ✳ Summary, Open Questions, and Ongoing Work

Quasars

and

Active Galactic Nuclei (AGN)

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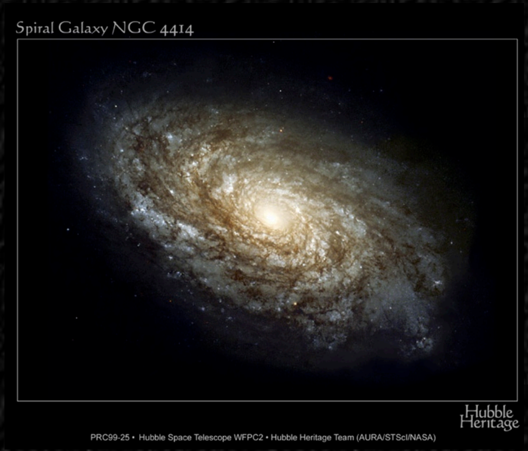
Quasars and Active Galactic Nuclei (AGN)

Most galaxies harbor supermassive (~10^6-10^{10} $M_\odot$) black holes (BHs) in their centers.

AGN are powered by mass accretion onto their central supermassive BHs. $L = \eta \dot{M} c^2$

Ordinary (or `passive') galaxies

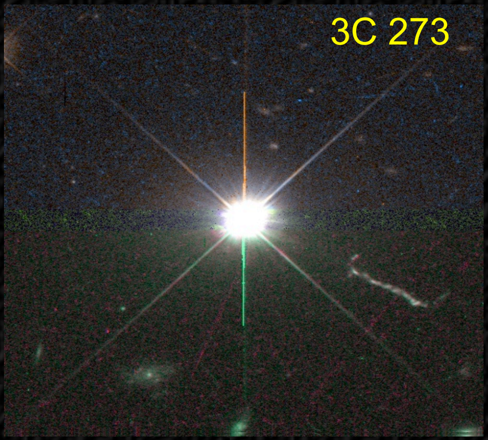


Nuclear Luminosity →

Seyfert galaxy

Active galaxies

Nuclear Luminosity →

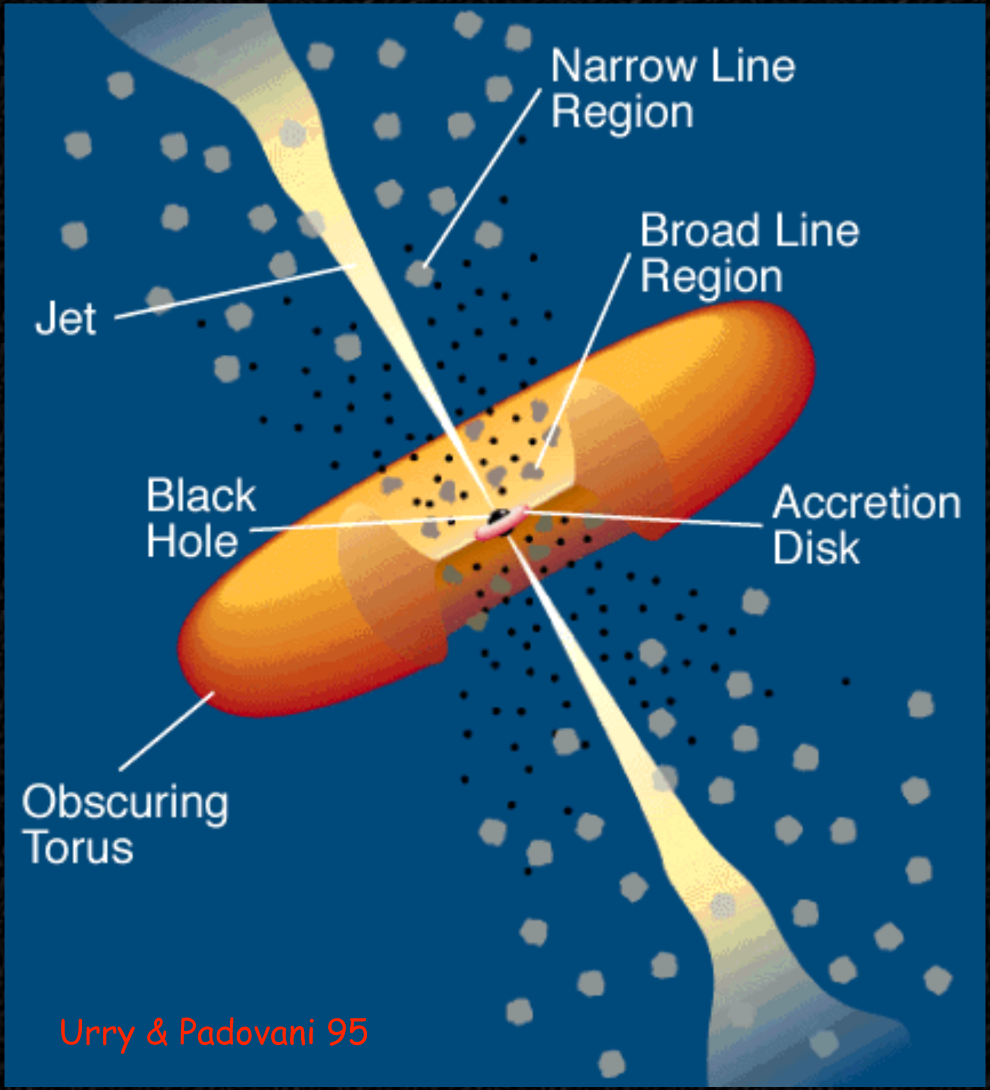


Quasi Stellar Object (QSO), or quasar (Quasi Stellar Radio Source).

Quasars and Active Galactic Nuclei (AGN)

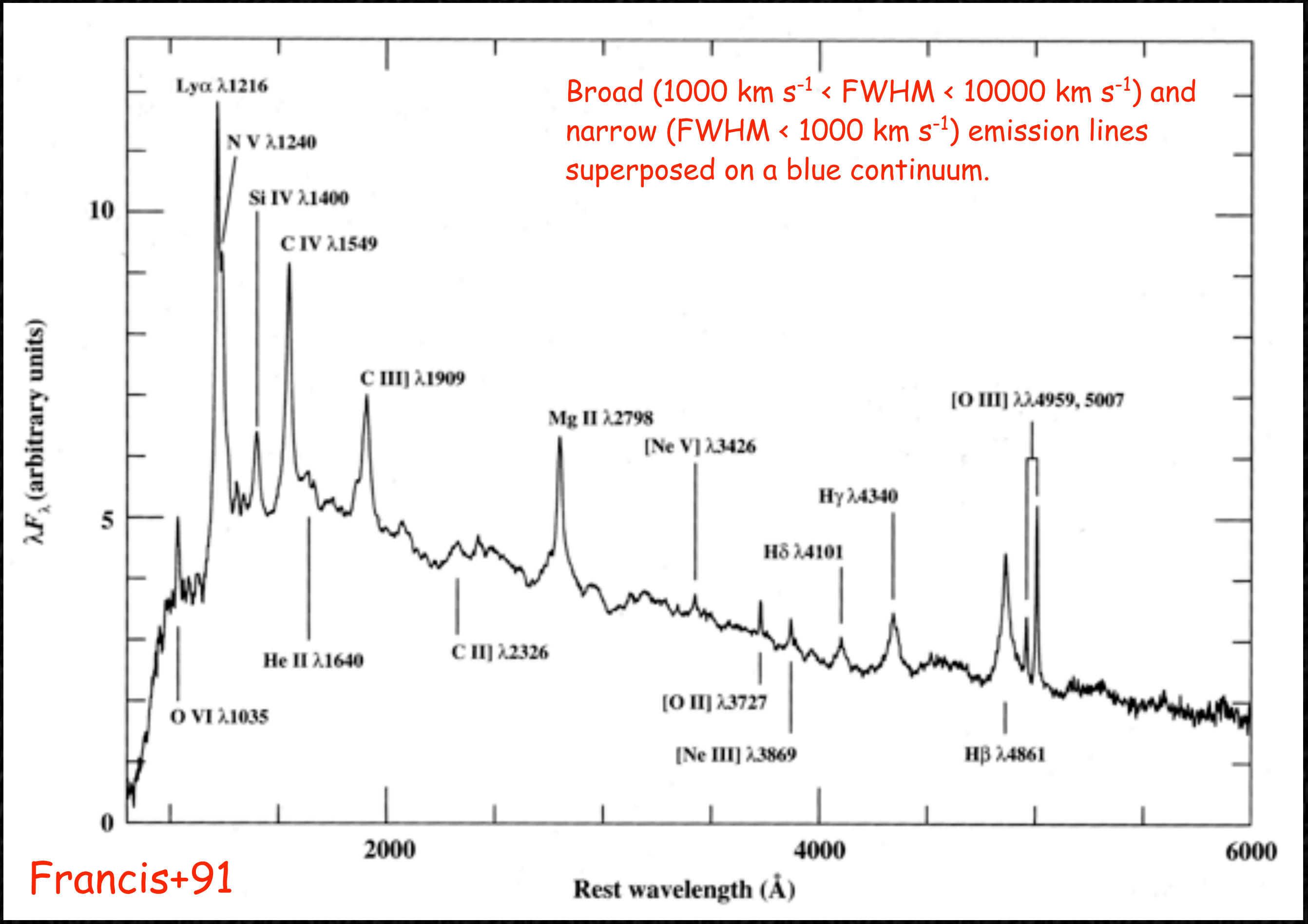
The inner light-year of an AGN:

a unified view of the central engine.



Quasars and Active Galactic Nuclei (AGN)

Typical quasar spectrum



Weak Emission Line Quasars (WLQs):

History and Mystery

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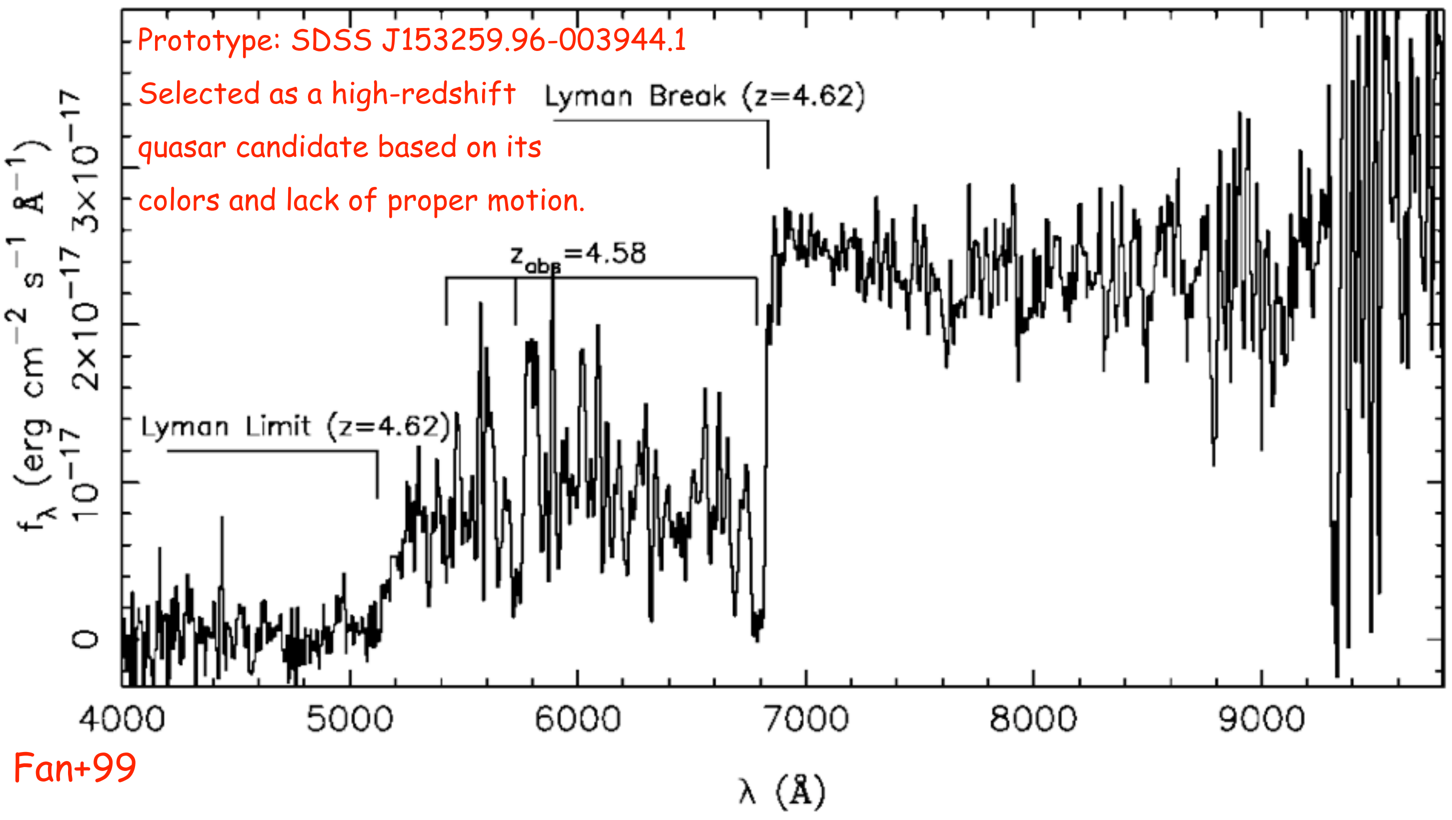
WLQs: History and Mystery

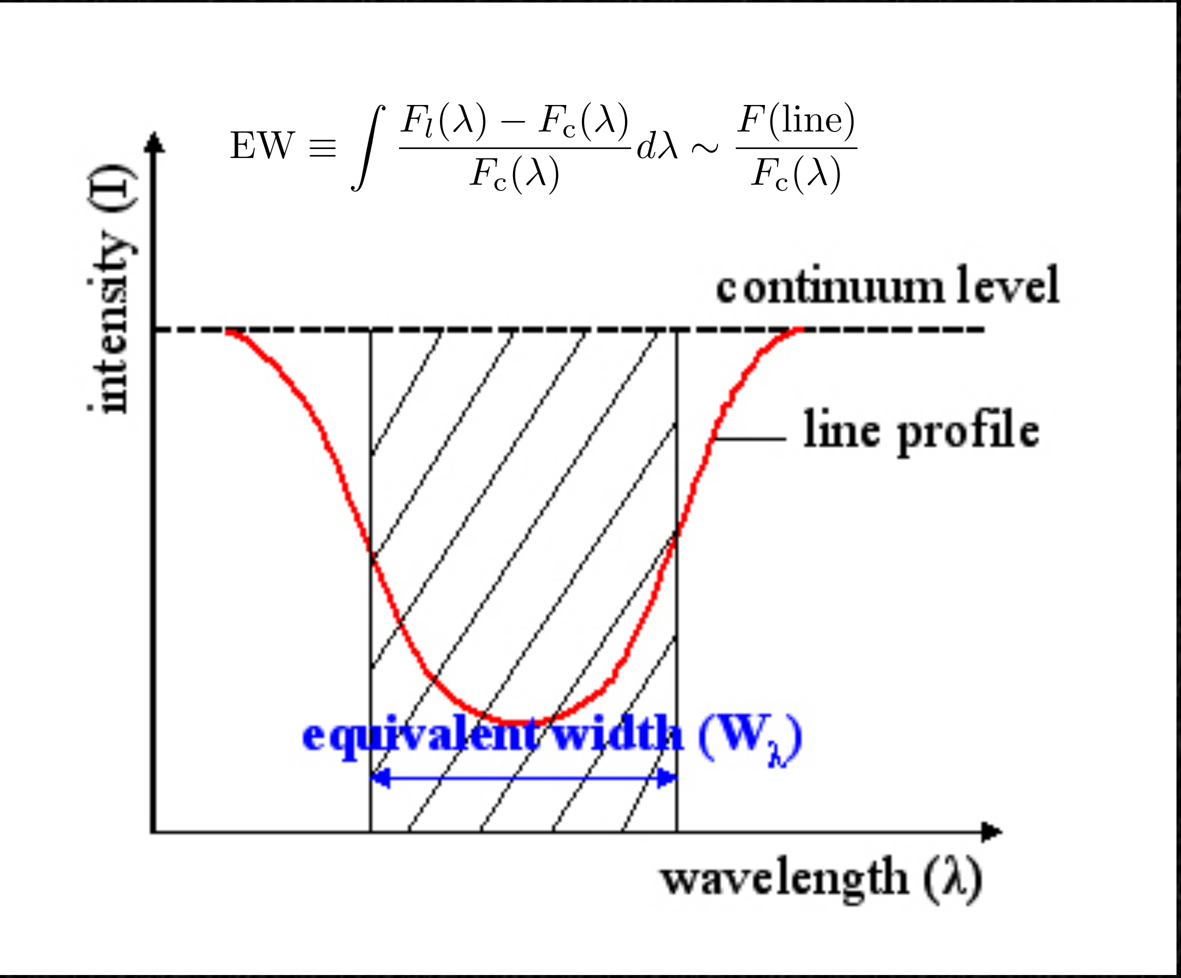
About 100 SDSS sources at z = 2.2 - 5.9 with quasar-like continua but extremely weak or undetectable emission lines in their UV spectra. (Discovered mainly via surveys searching for BL Lacertae objects.)



Fan+99

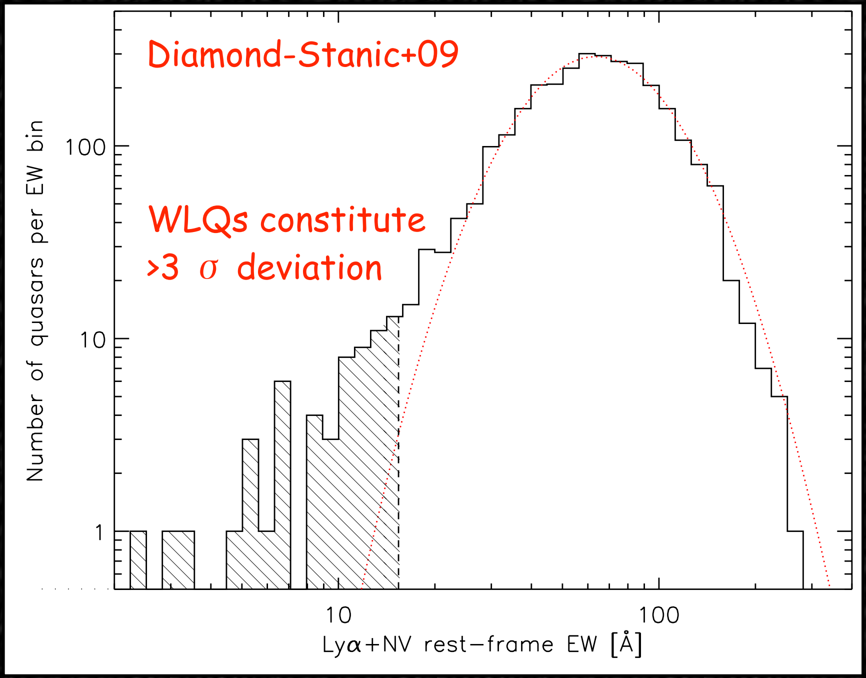
WLQs: History and Mystery

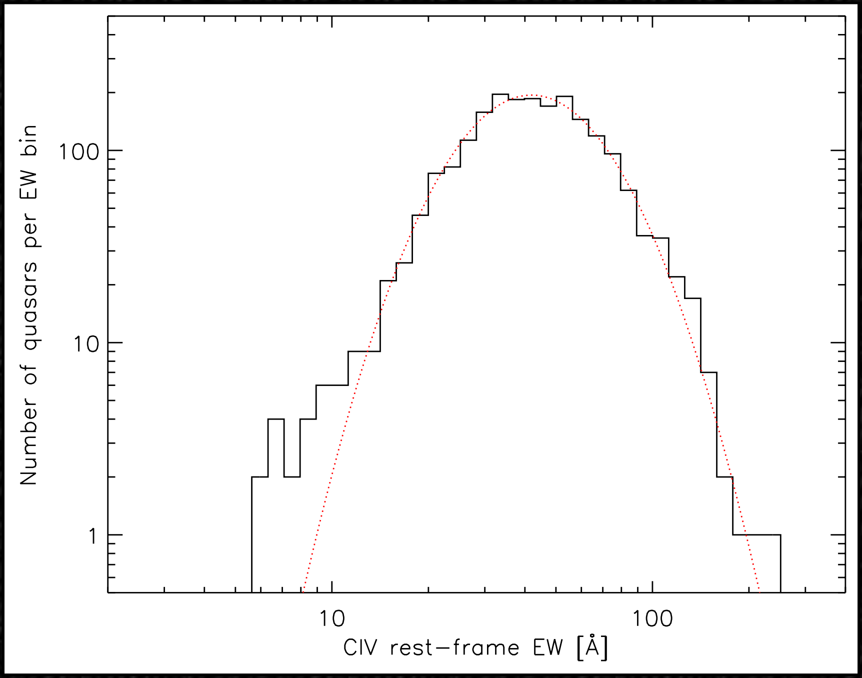
Equivalent Width (EW or W_λ)



WLQs: History and Mystery

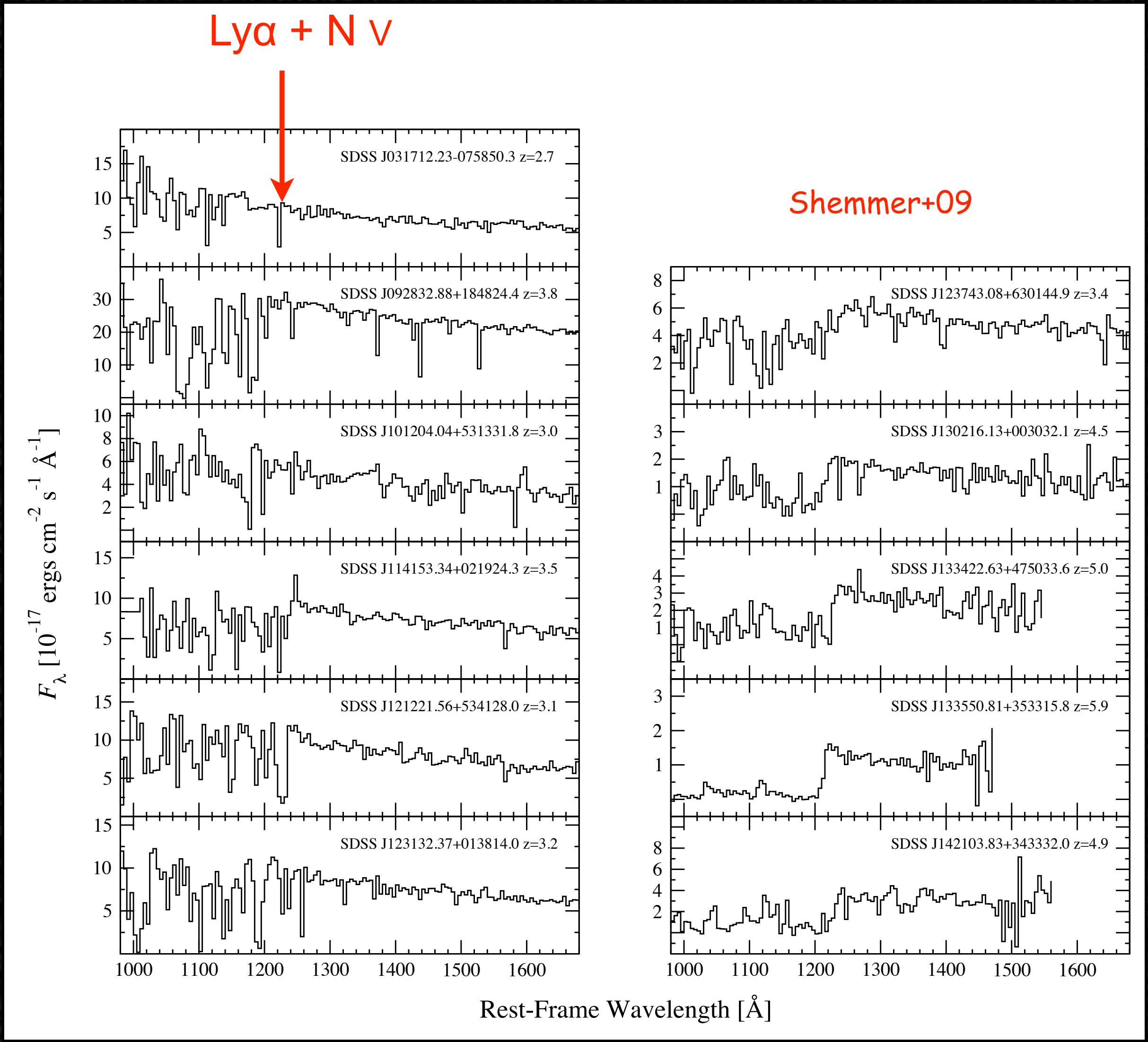
Distributions of broad emission line equivalent widths (EWs) in SDSS quasars at z>3





WLQs are defined as quasars having EW ≤ 15.4 Å for the Lyα+N V emission-line complex (EW ≤ 10 Å for C IV).

WLQs: History and Mystery



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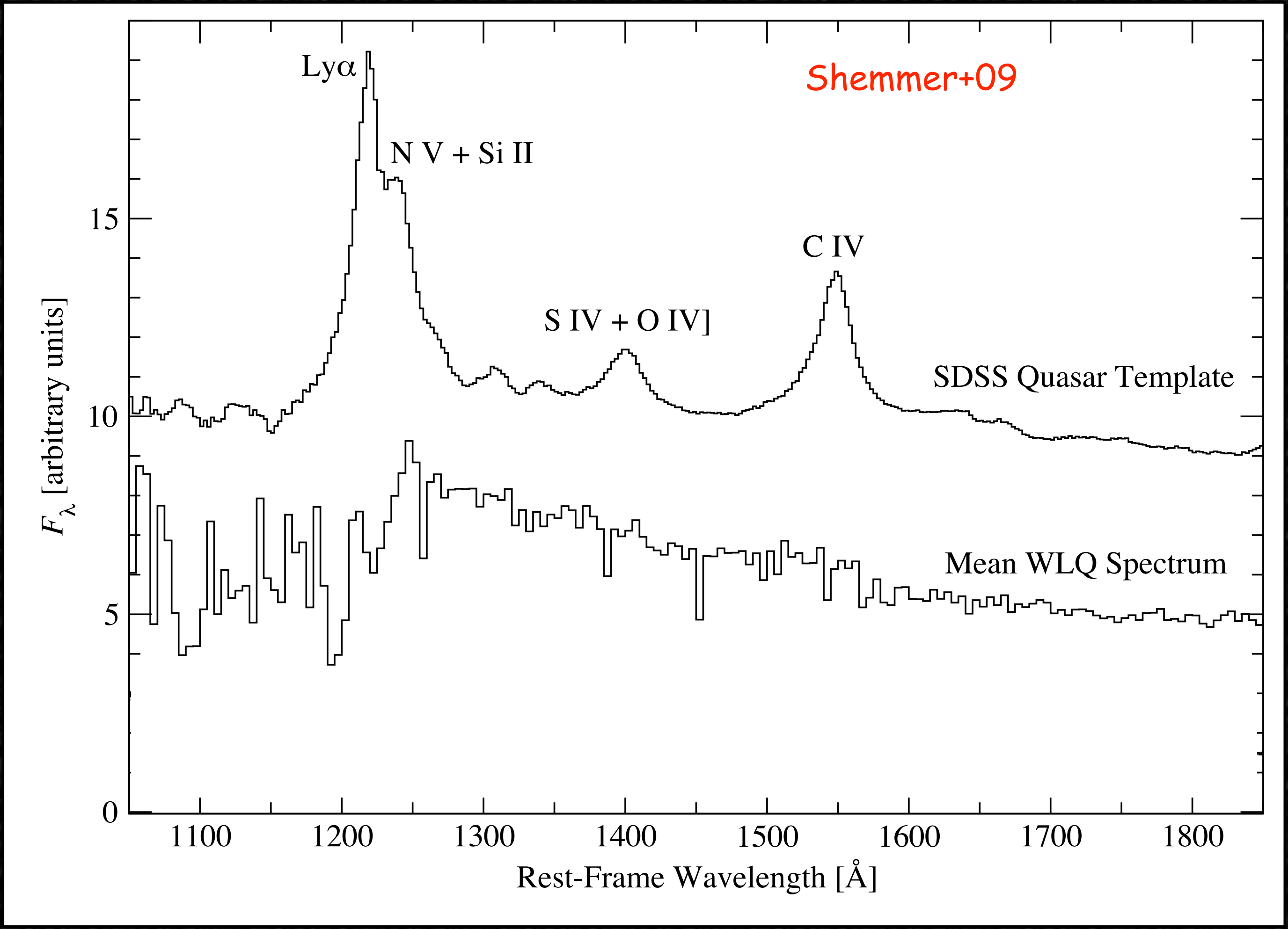
WLQs: History and Mystery



Why are the UV emission lines in WLQs so weak or absent?

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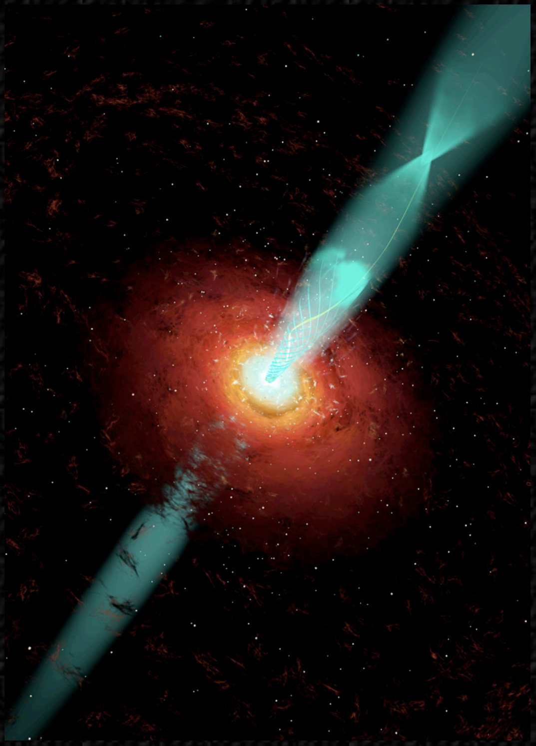
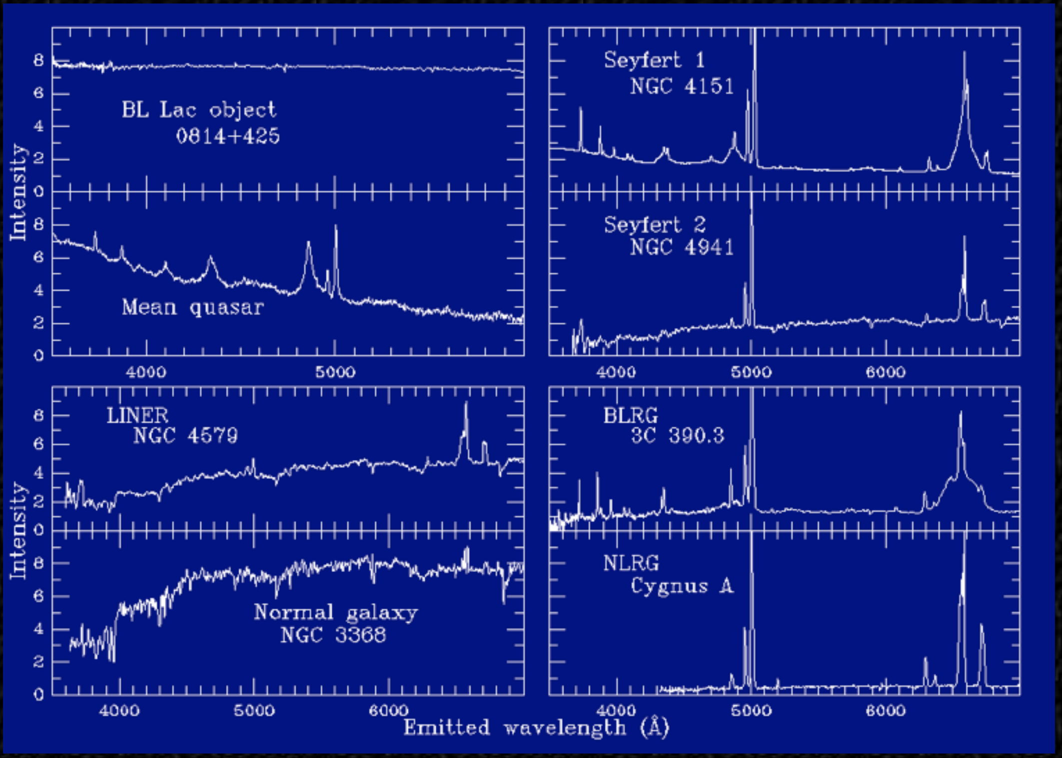
WLQs: History and Mystery

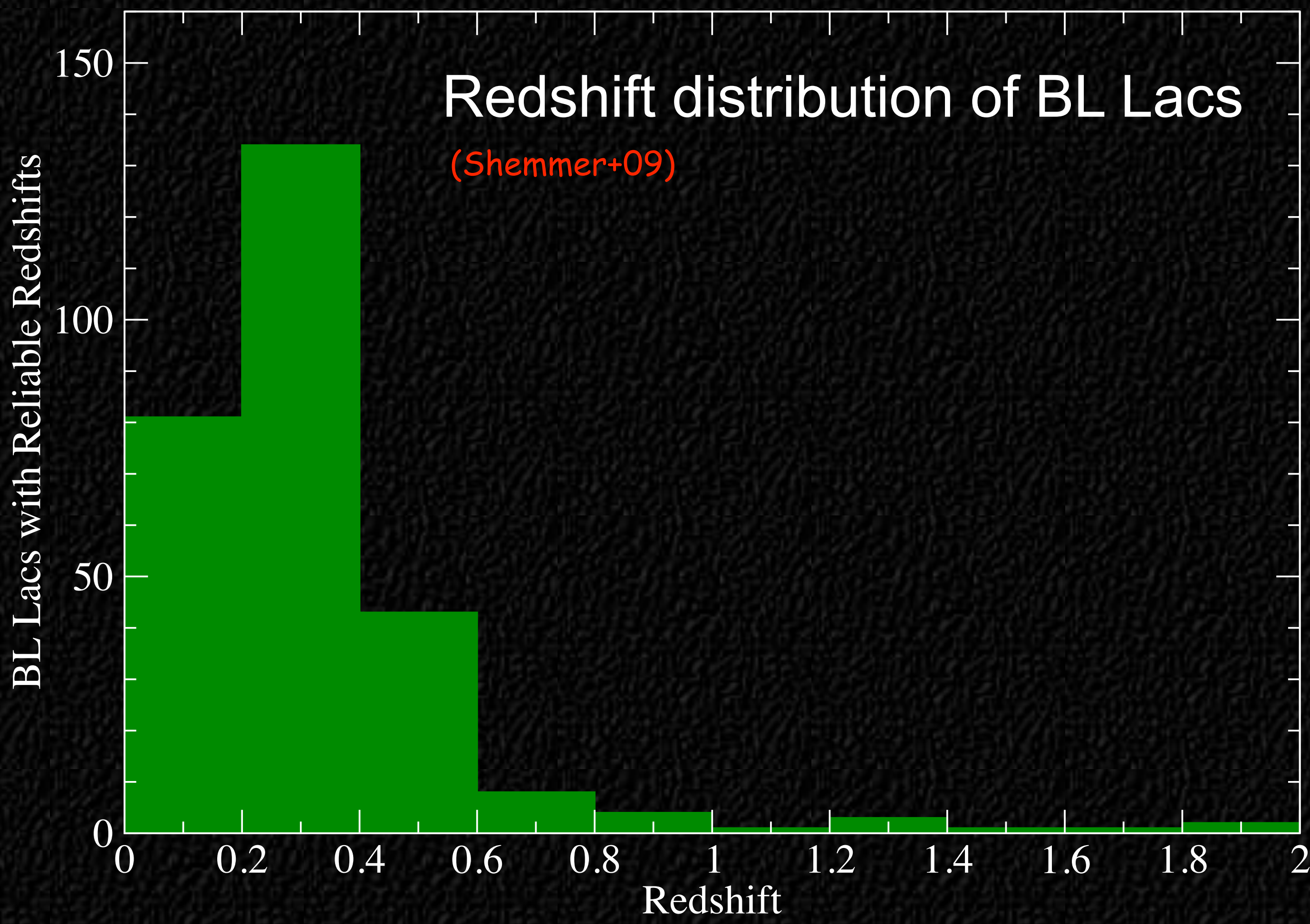
Are WLQs simply high-redshift BL Lacertae objects?





BL Lacs are blazars almost bereft of emission lines due to relativistically boosted continua. Found mostly at *low* redshifts; display rapid and large-amplitude variability as well as significant polarization.

WLQs: History and Mystery



Insights

from

Multiwavelength Observations

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Insights from Multiwavelength Observations

UV - optical

Clues from the UV - optical band

WLQs show:

- quasar luminosities (L_{Bol}~10^{47}-10^{48} erg s^{-1}).
- no broad absorption lines.
- no significant variability.
- no significant polarization.
- typical (blue) quasar continua.
- no detection of multiple images (not lensed).

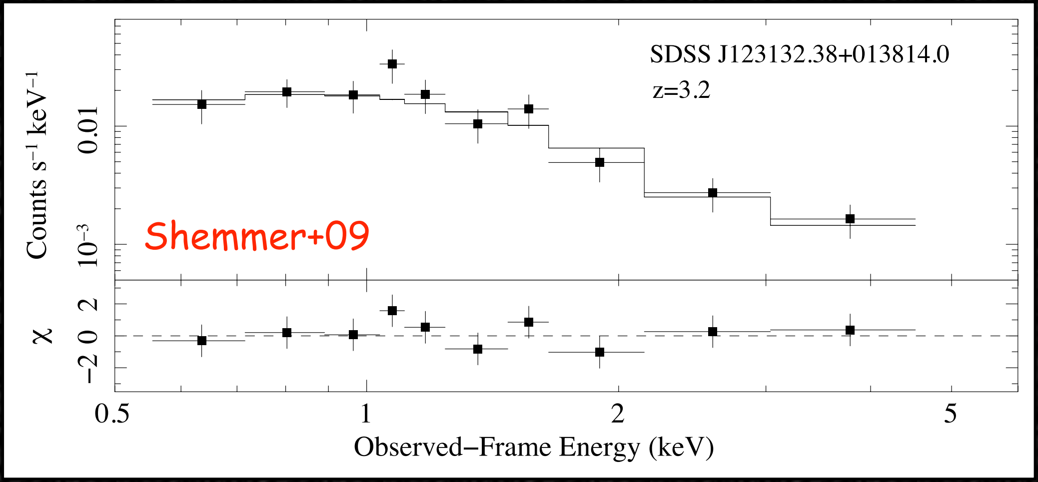
Insights from Multiwavelength Observations

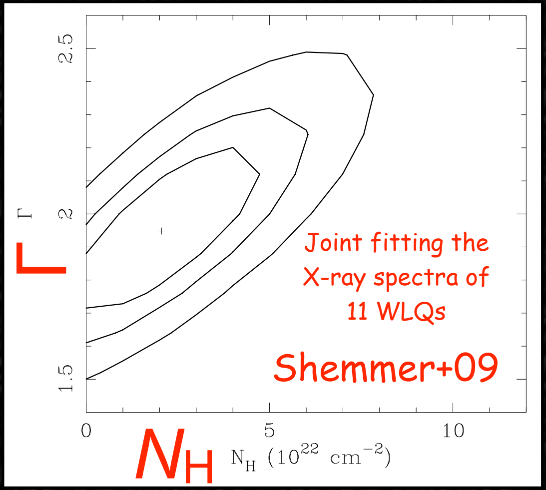
X-ray

X-ray clues:

- ✳ no sign of significant absorption.
- ✳ typical quasar power-law spectra.

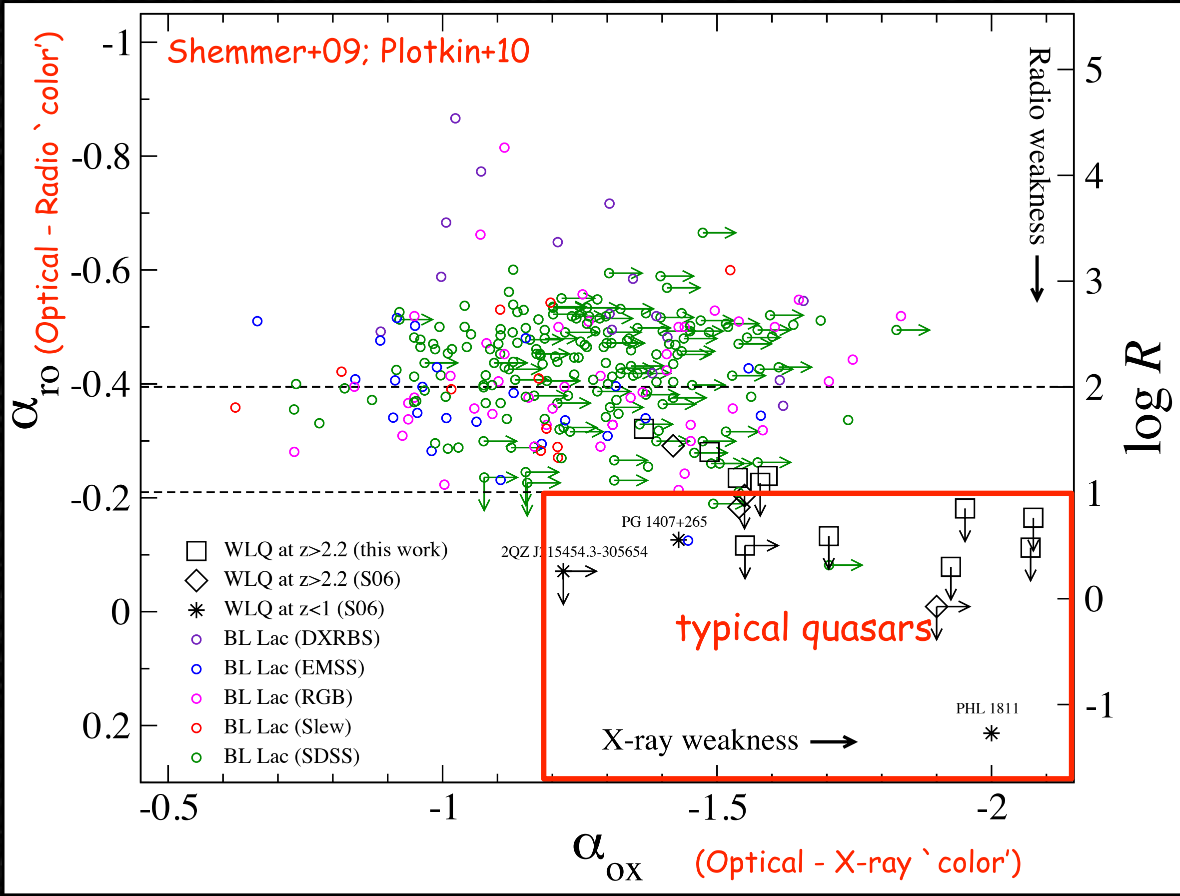
(However, so far, results are tentative: based mostly on shallow *Chandra* observations.)





Insights from Multiwavelength Observations

radio - optical - X-ray

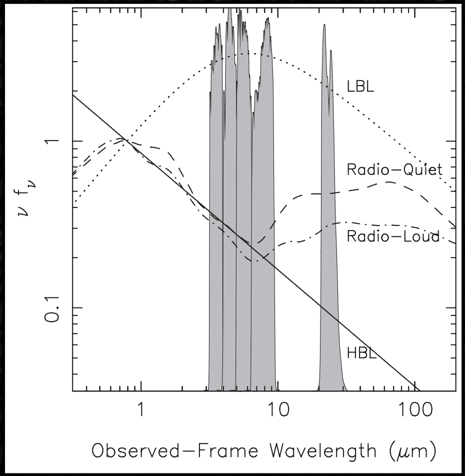


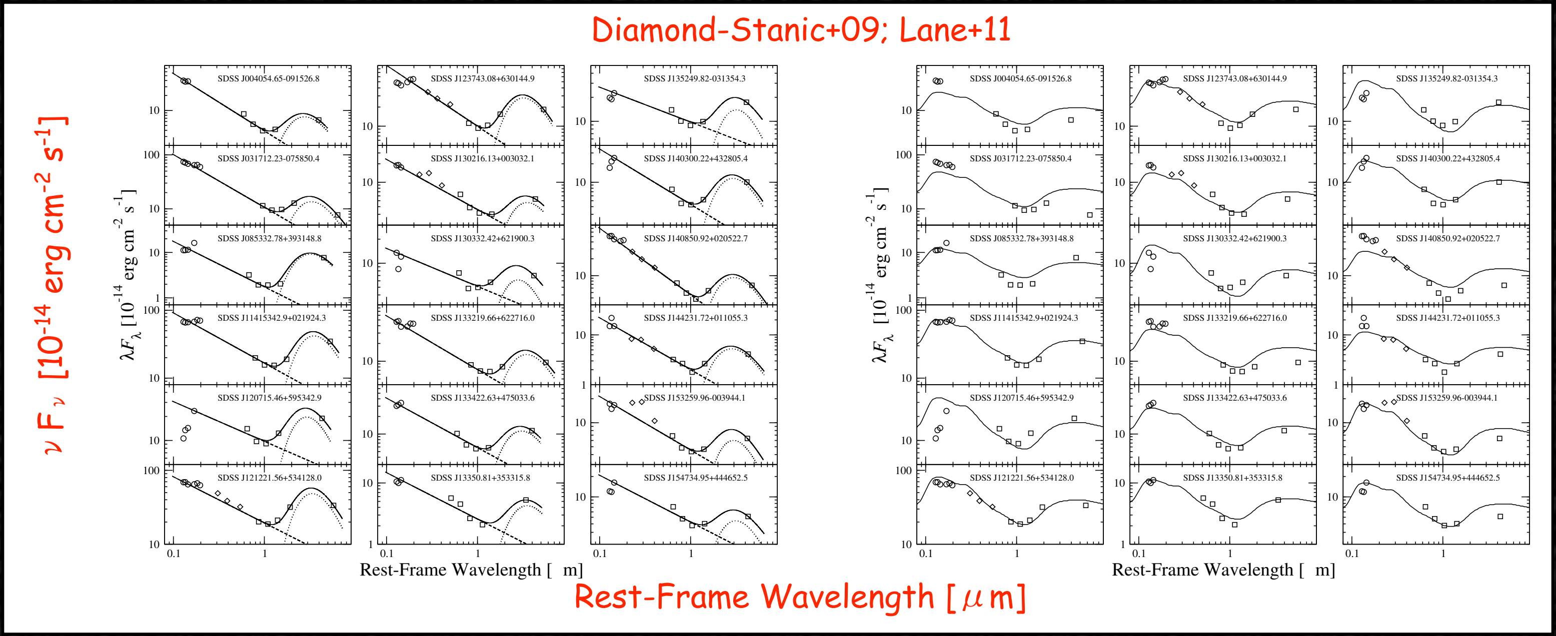
If WLQs are the long-sought, high-redshift BL Lacs, then where is the 'parent' population of X-ray and radio **bright** weak-lined sources at high redshift?

Insights from Multiwavelength Observations

UV - optical - mid-IR

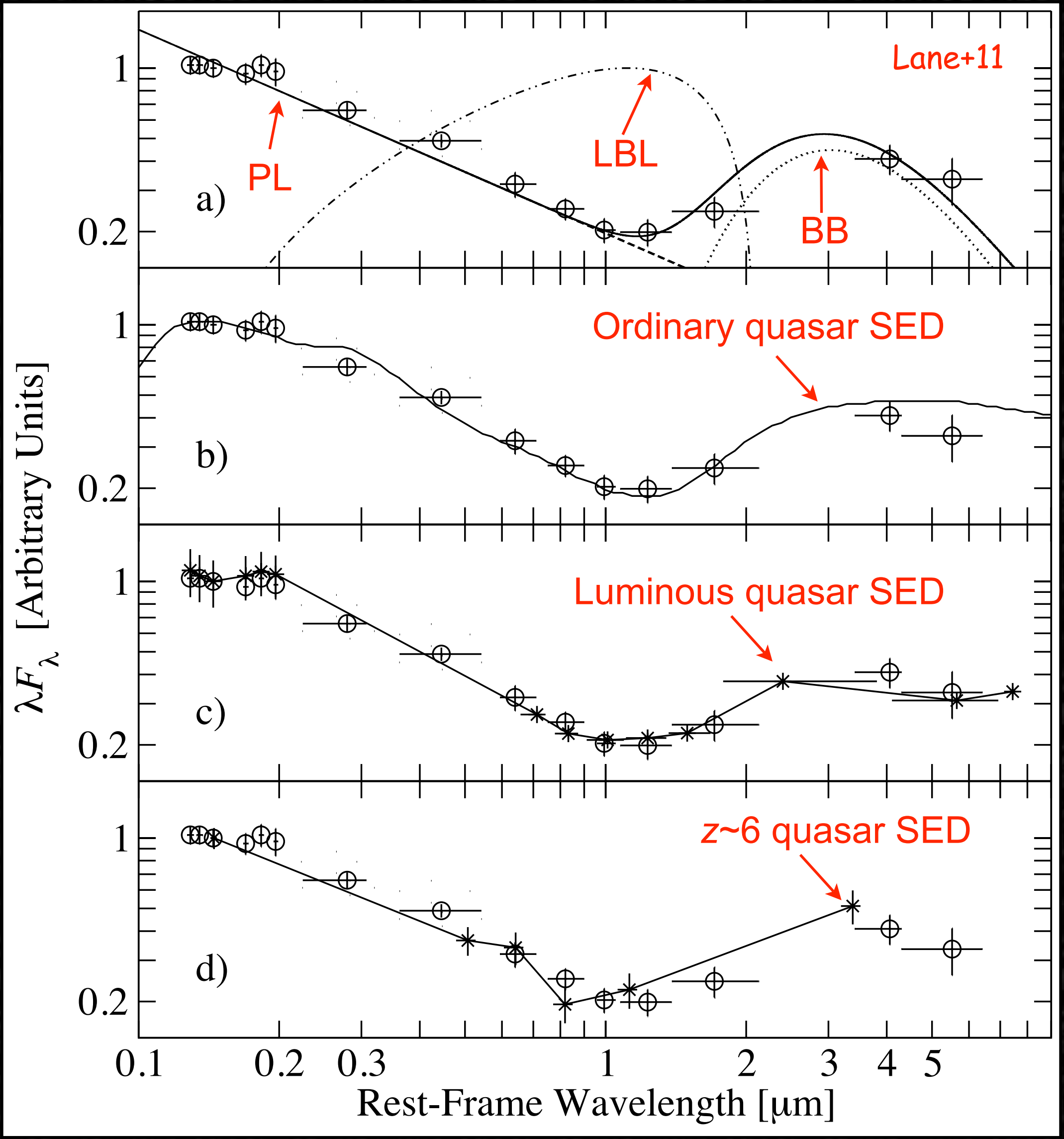
Tracing the WLQ UV-to-mid-IR spectral energy distribution (SED) with *Spitzer* IRAC+MIPS 24μm photometry. Distinguishing a quasar SED from a BL Lac SED.





Insights from Multiwavelength Observations

UV - optical - mid-IR



WLQs are **unbeamed** quasars with **intrinsically** weak UV emission lines. Can be selected *only* via spectroscopic surveys.

Insights from Multiwavelength Observations

Q: What mechanism can hinder the formation of broad emission lines in luminous quasars?

Q: Are the broad emission line regions in WLQs unusually gas deficient or subject to exotic ionization conditions?

Q: Do WLQs mark a brief evolutionary phase that all quasars go through?

Insights from Multiwavelength Observations

What determines broad emission line strength in AGN?

- Ionizing continuum SED
- Broad emission line region properties
- Orientation (i.e., obscuration)
- AGN evolution or AGN “states”?
- ....

Scenarios for Quenching Emission Lines in Quasars

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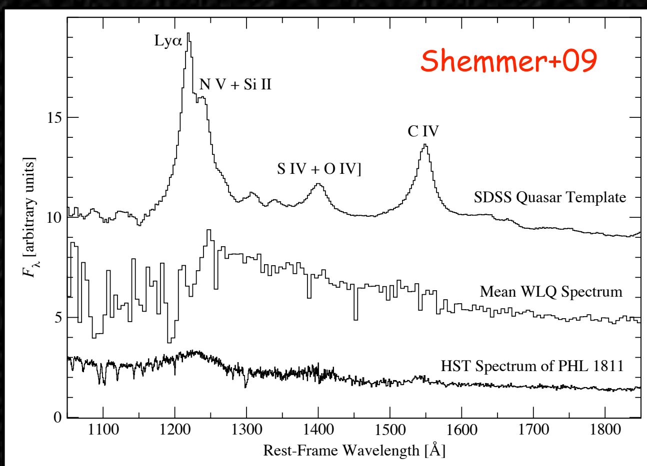
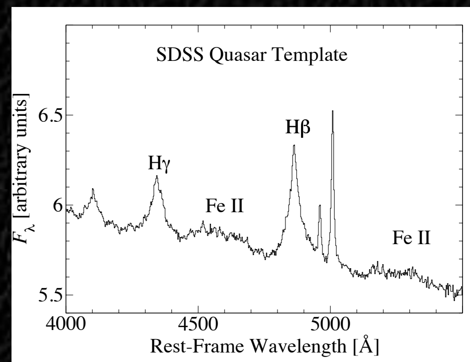
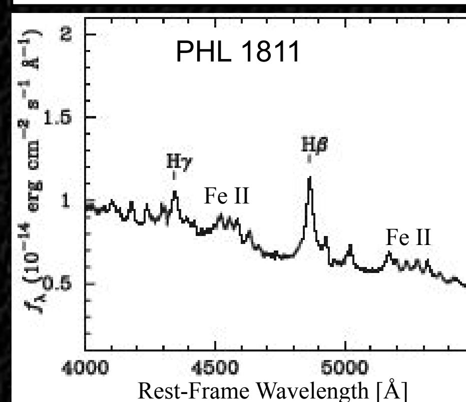
Extremely High Accretion Rates or Abnormal Broad Emission Line Regions?

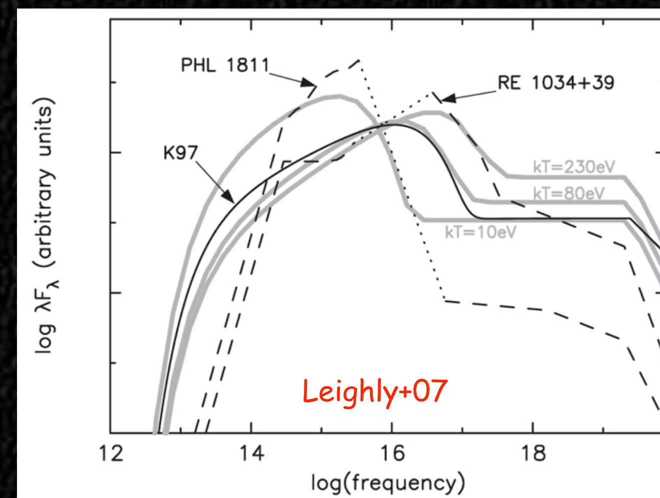
Clues from low redshift





WLQ ?





Are there low-redshift analogs to high-redshift WLQs?

Soft SED responsible for weak high-ionization emission lines in WLQs?

Extremely High Accretion Rates or Abnormal Broad Emission Line Regions?

Eddington Luminosity

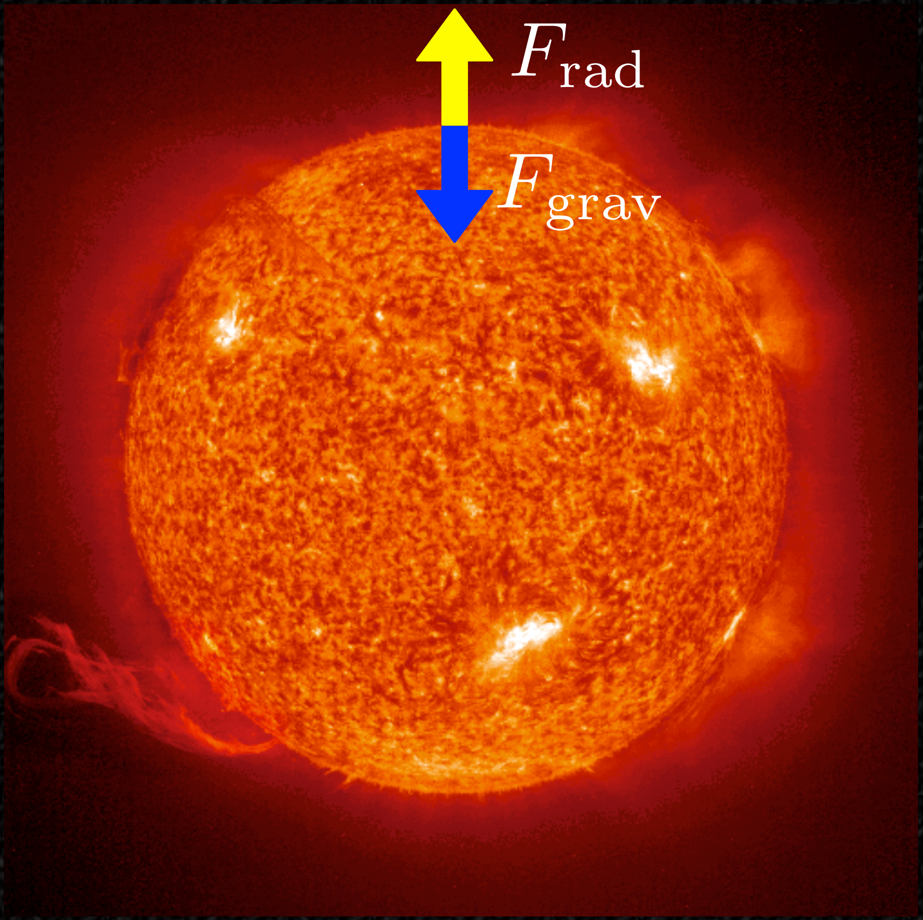
$$L_{\rm Edd} = \frac{4\pi G M m_{\rm p} c}{\sigma_{\rm T}} \simeq 1.3 \times 10^{38} \left(\frac{M}{M_{\odot}}\right) \ {\rm erg\ s^{-1}}$$

Bolometric luminosity of the Sun

$$L_{\odot} = 3.83 \times 10^{33} \ {\rm erg\ s^{-1}}$$

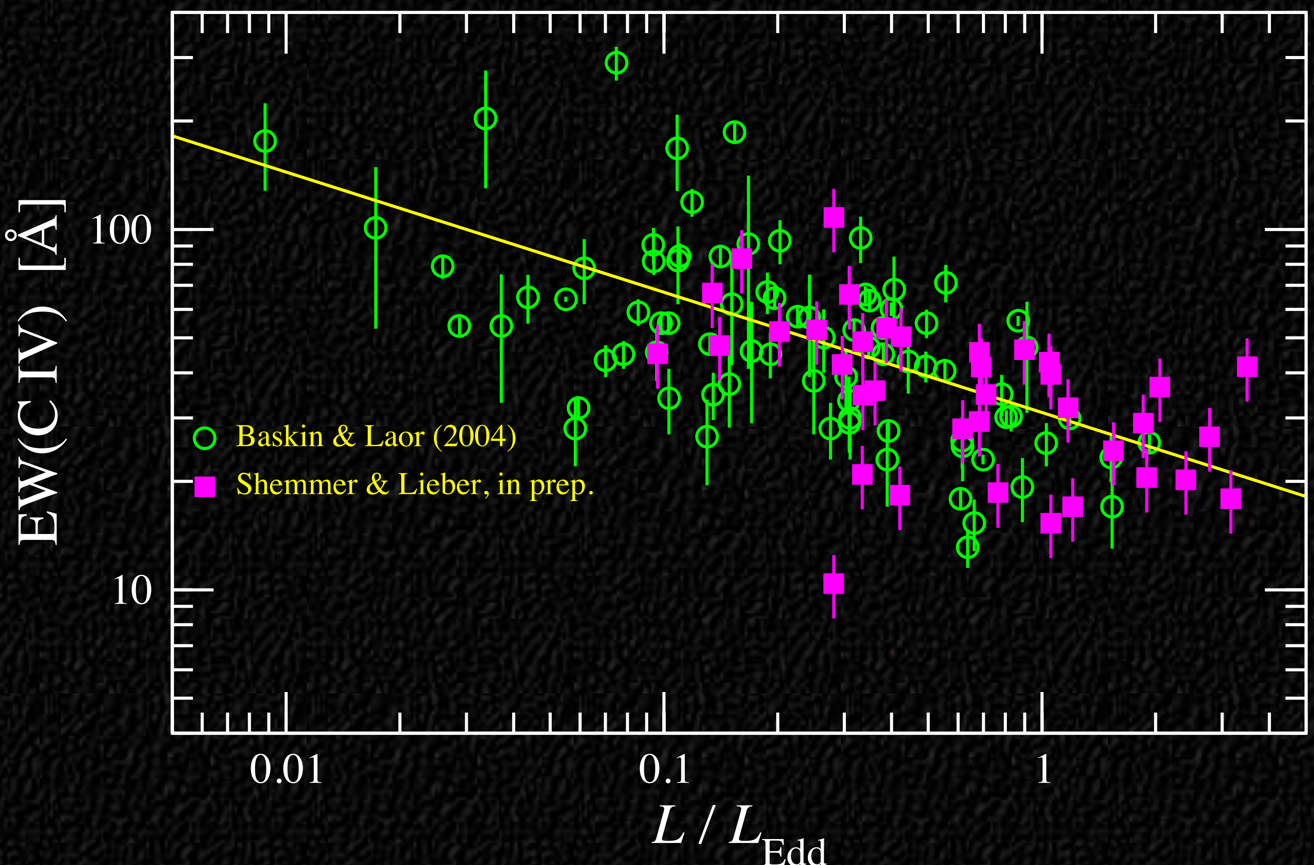
The Sun's Eddington ratio

$$\left(\frac{L}{L_{\rm Edd}}\right)_{\rm sun} \equiv \frac{L_{\odot}}{L_{\rm Edd}} \sim 3 \times 10^{-5}$$



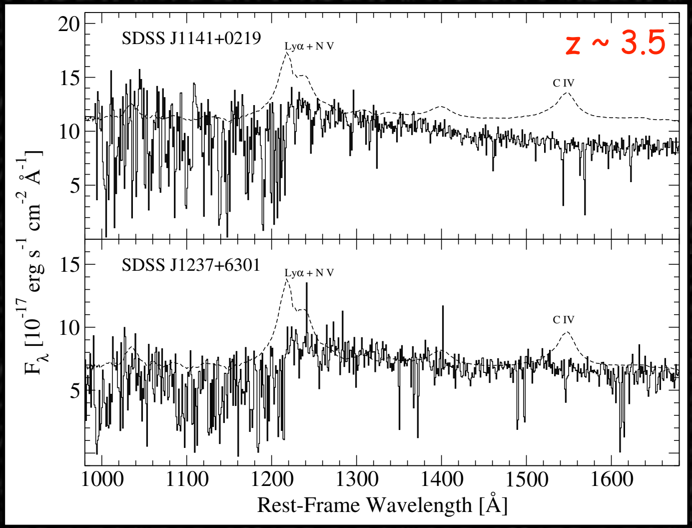
Extremely High Accretion Rates or Abnormal Broad Emission Line Regions?

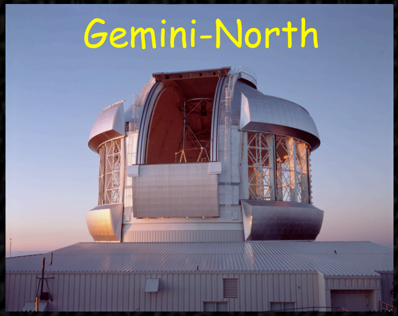
The accretion rate - line strength relationship

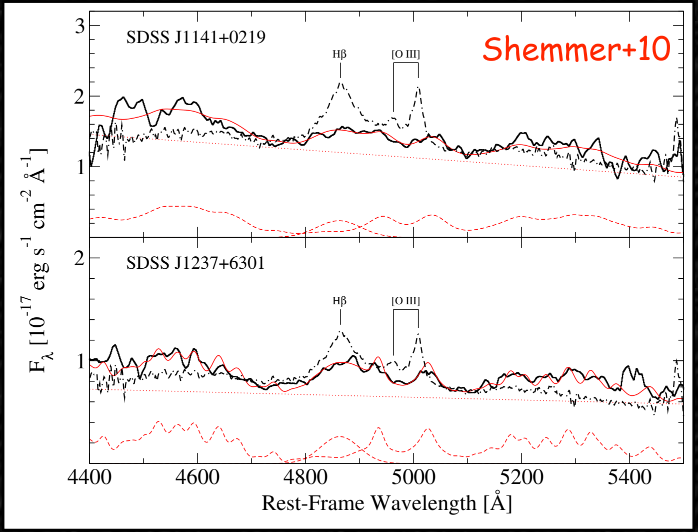


Extremely High Accretion Rates or Abnormal Broad Emission Line Regions?

Determining low ionization emission line EWs and $L/L_{\rm Edd}$ in WLQs







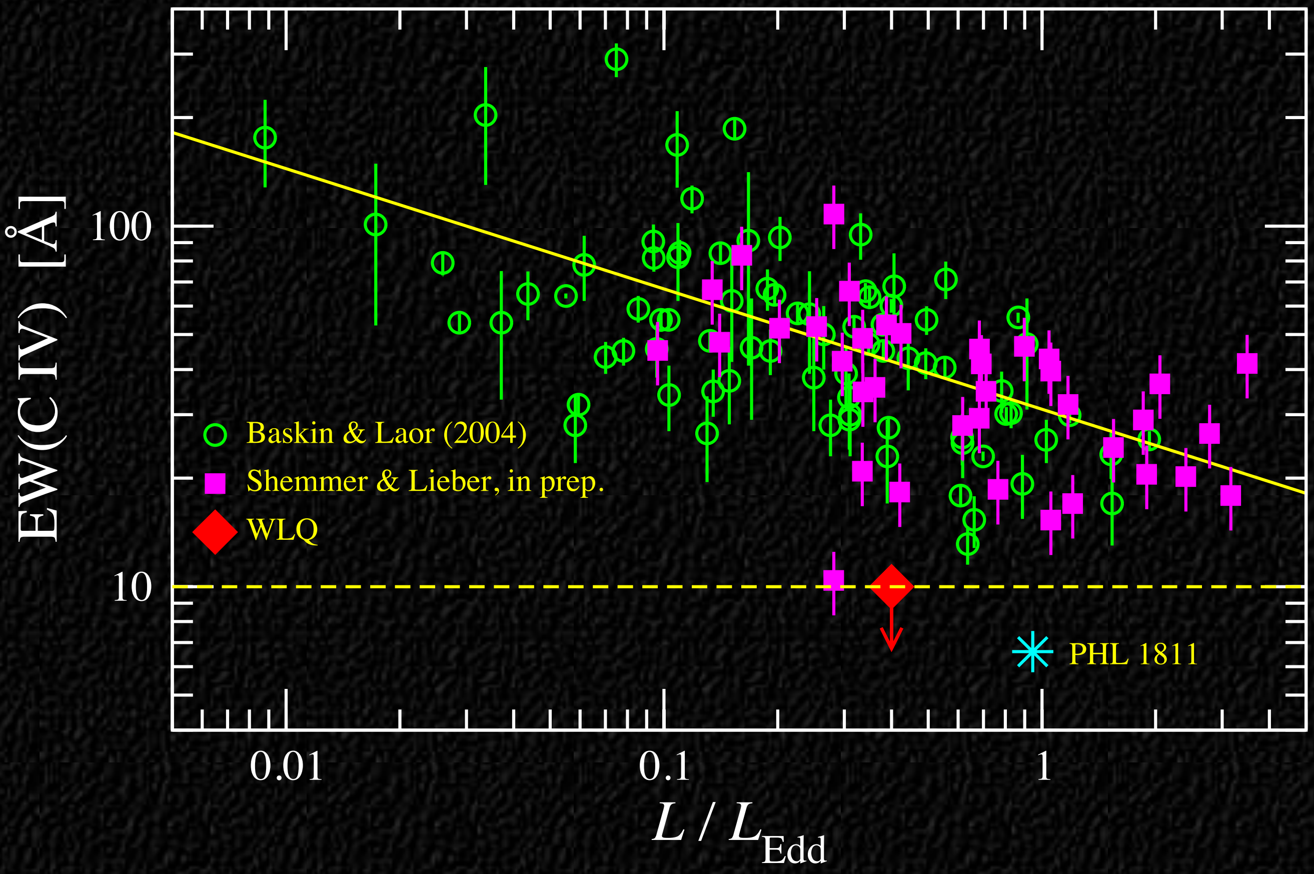
Determine accretion rates from near-IR spectra of the Hβ region:

$$L/L_{\rm Edd} \propto \nu L_\nu(5100\text{Å})^{0.5}\,{\rm FWHM(H\beta)}^{-2}$$

For two WLQs: typical quasar $L/L_{\rm Edd}$ values and exceptionally weak Hβ lines.

Extremely High Accretion Rates or Abnormal Broad Emission Line Regions?

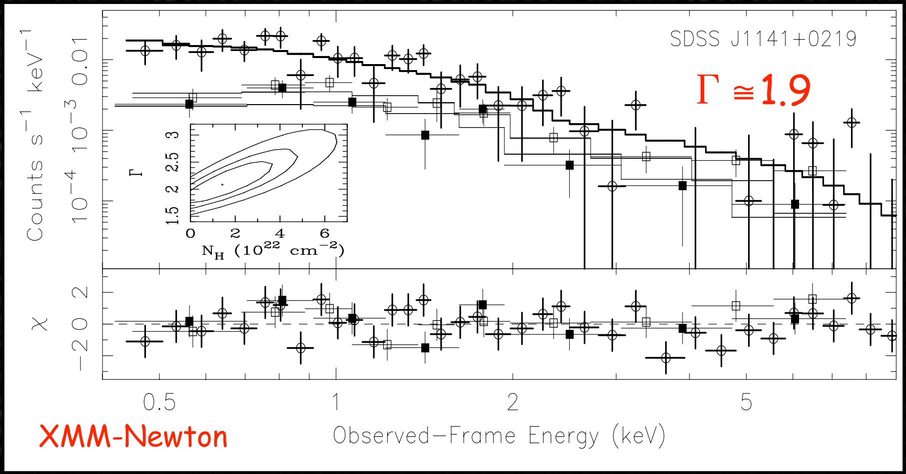
The accretion rate - line strength relationship

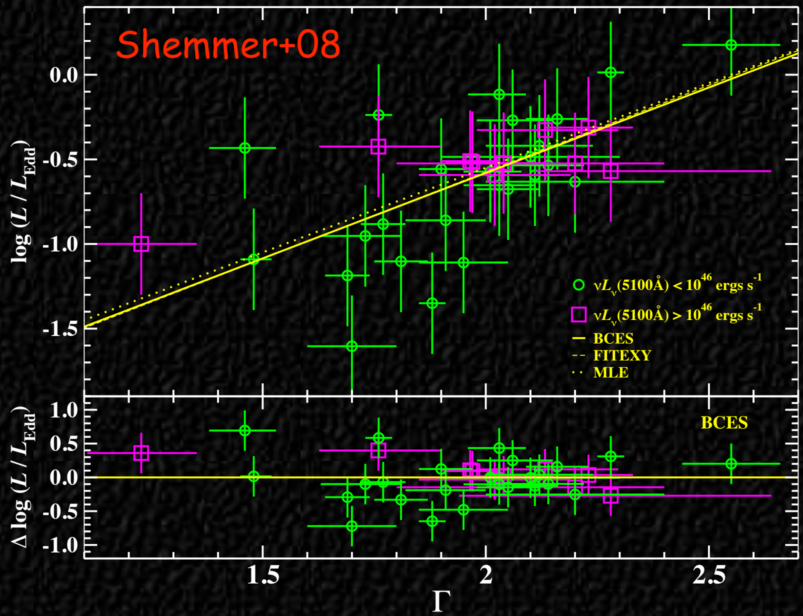


The only two WLQs observed are clear outliers

Extremely High Accretion Rates or Abnormal Broad Emission Line Regions?

Cross-checking $L/L_{\rm Edd}$ determinations

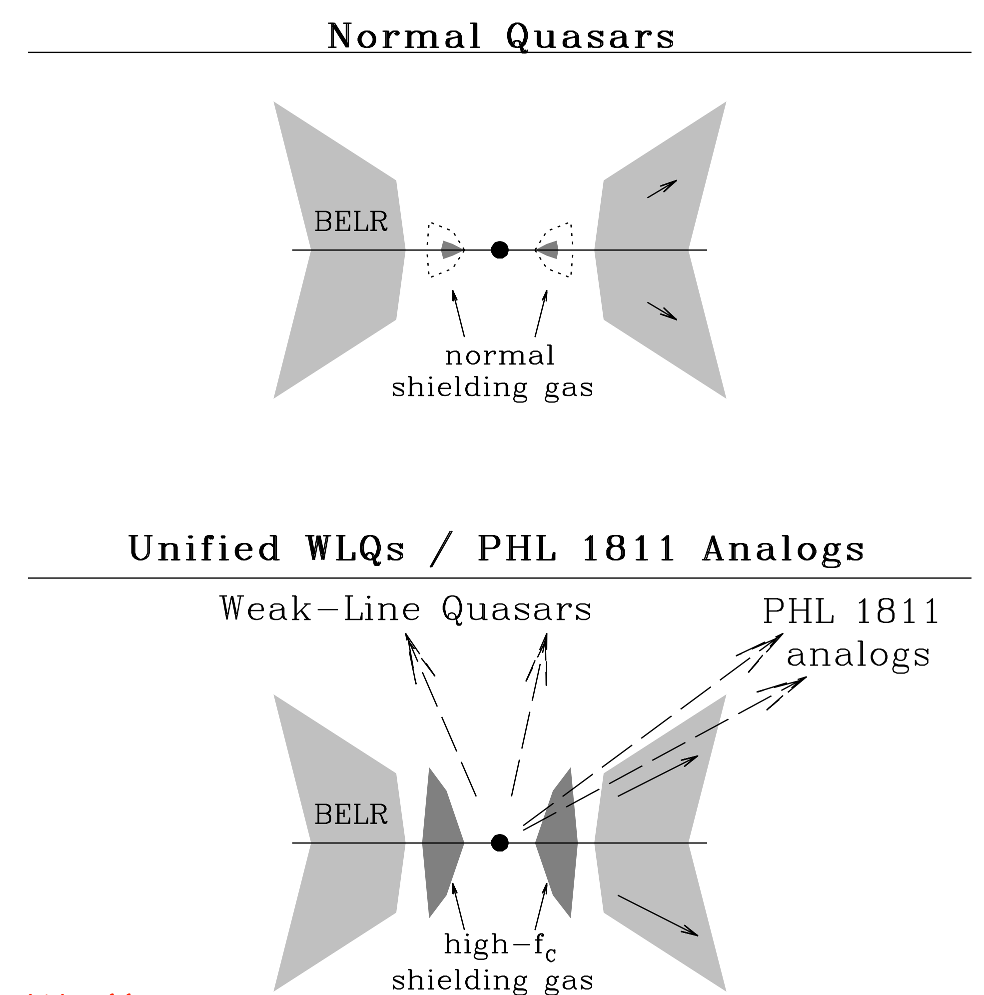




$$\log(L/L_{\rm Edd}) = (1.0 \pm 0.3)\Gamma - (2.5 \pm 0.5)$$

XMM-Newton observations of WLQs: utilizing the hard-X-ray power-law photon index as an accretion-rate indicator (Stein+13, in prep.).

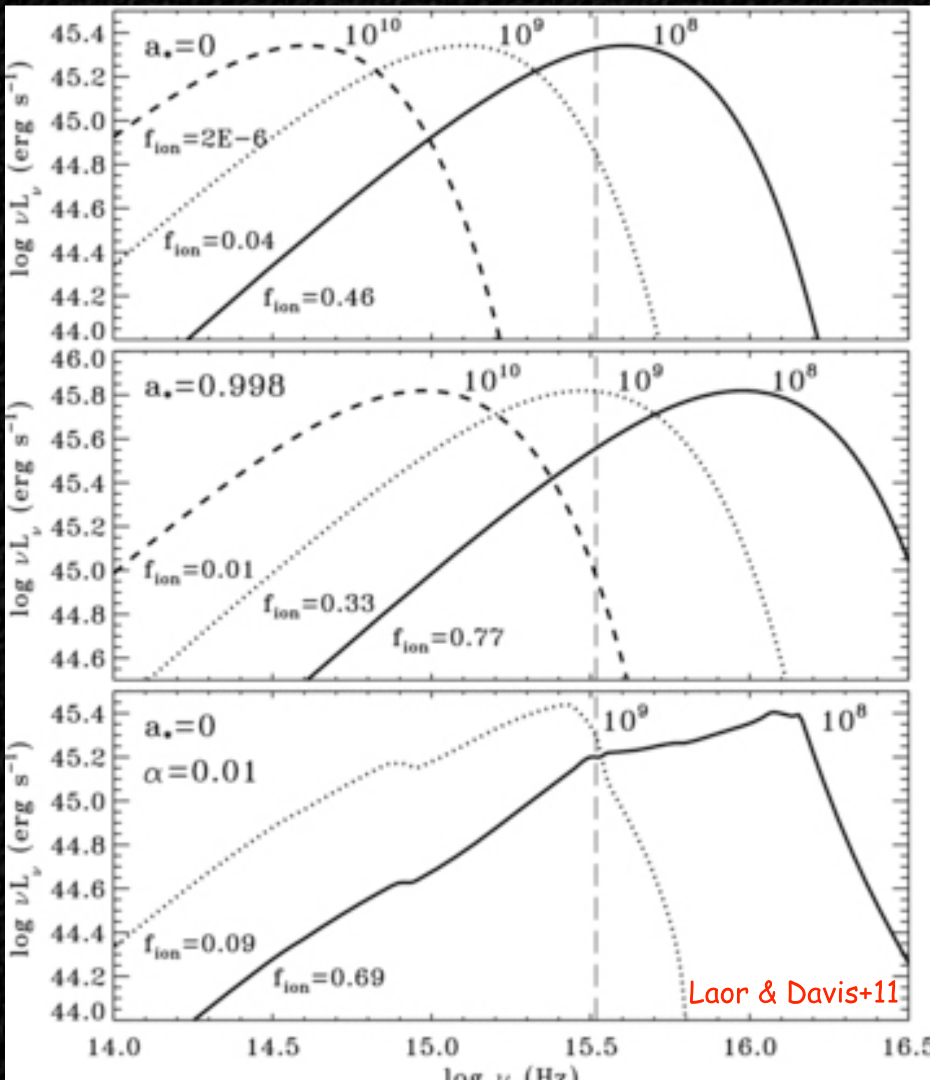
Orientation?



Wu+11

- ✳PHL 1811 analogs at high redshift - a subset of WLQs?
- ✳Thicker shielding gas in WLQs?
- ✳X-ray 'normal' WLQs observed at lower inclinations, and PHL 1811 analogs at high redshift are viewed at higher inclinations?

'Cold' Accretion Disk?



Disk SED peak frequency decreases as black-hole mass increases and black-hole spin decreases. Fewer energetic photons are available for ionizing the broad emission line region.

Summary, Open Questions,

and

Ongoing Work

Summary, Open Questions, and Ongoing Work

- ✳ WLQs are a remarkable new class of quasars. They may constitute a missing link in our understanding of emission-line formation and the accretion process in AGN.
- ✳ Should distinguish between (at least) two competing scenarios: extremely high L/L_{Edd} or 'anemic' broad emission line region.
- ✳ The key to understanding the weakness of the UV lines lies in near-IR (rest-frame optical) and X-ray spectroscopy of many WLQs in conjunction with photoionization modeling.
- ✳ Ultimate goal: understanding the role that L, M_{BH}, L/L_{Edd}, the SED, and the broad emission line region physical properties play in determining the relative strengths of low- and high-ionization emission lines in *all* AGN.