Quasars and Cosmology

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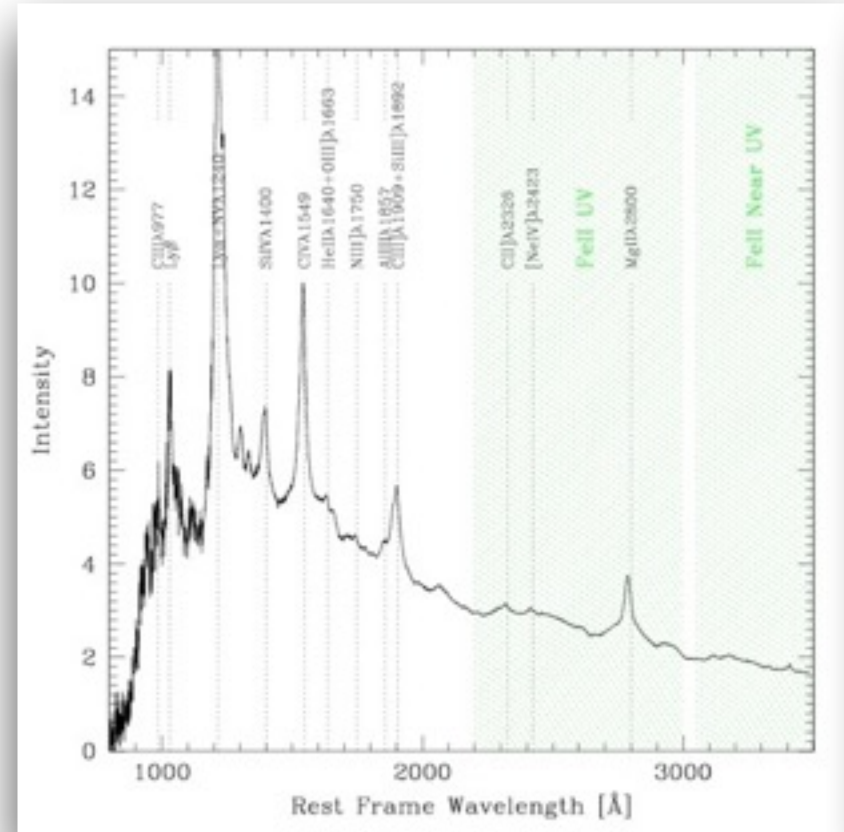
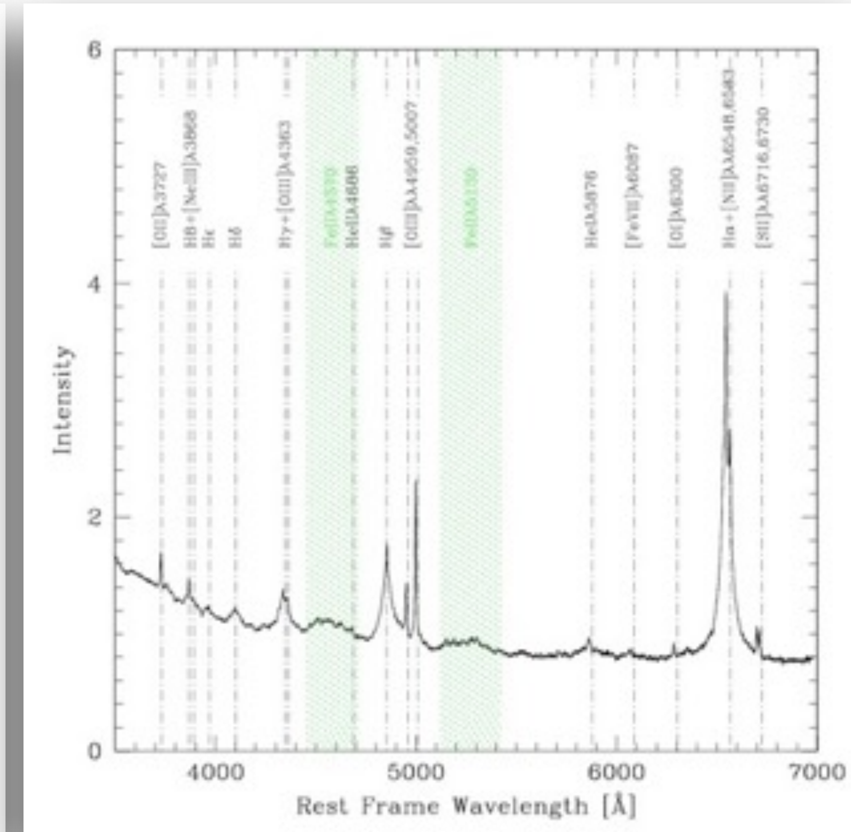




New developments are paving the road to the use of quasars as distance indicators:

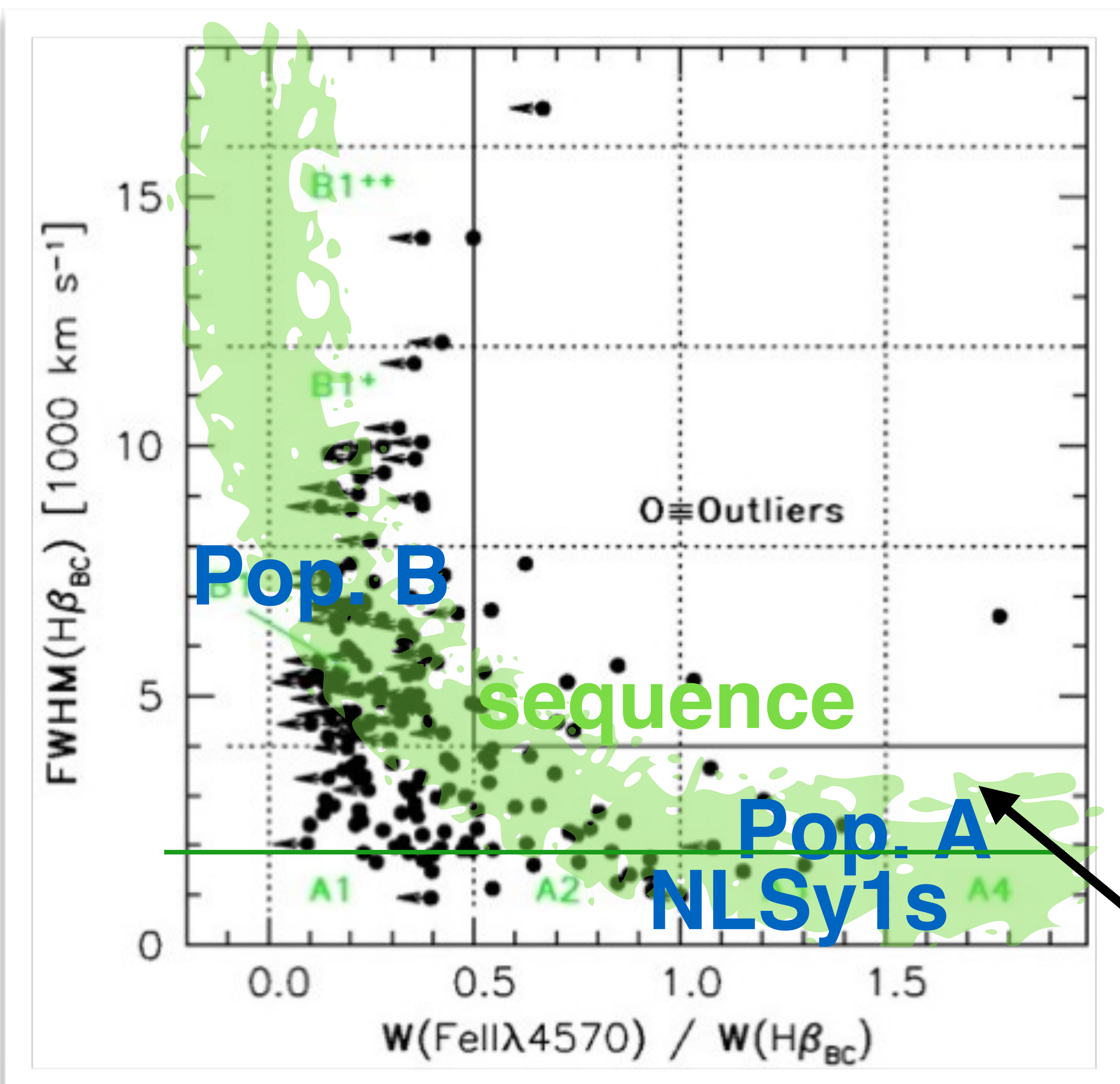
A “main sequence” organizes the diverse quasar properties and makes it possible to identify quasars in different accretion states

Even if major observational constraints indicate powerful high-ionization wind, part of the broad line emitting regions remains “virialized”

A MAIN SEQUENCE FOR TYPE-1 QUASARS

The “main sequence,” also known as the “eigenvector 1 sequence”

(Sulentic et al. 2000, 2002, c.f. Shen & Ho 2014)



Radio, IR, UV and soft and hard X-ray properties change systematically along the sequence; the MS allows for the definition of spectral types

The sequence is a starting point to connect observational parameter spaces to theoretical parameter spaces of quasars seen as accreting systems
(Sulentic et al 2014, recent review)

Two populations, A (wind dominated) and B (disk dominated, large fraction radio-loud) associated with a critical Eddington ratio and probably with different accretion modes

Extreme Pop. A: highly-accreting sources, of interest for cosmology
(Wang et al. 2013; Marziani & Sulentic 2014)

Several methods aimed at obtaining the Hubble diagram for quasars

Sources	Parameters	Basic equation	Reference	Virial
extremely accreting quasars (xA)	Hard X-ray slope, velocity dispersion	$\mathcal{D}_{\bullet} = \frac{1}{\sqrt{4\pi}} \left[\frac{l_0 (1 + a \ln \dot{m}_{15}) f_{\rm BLR} R_0}{G \kappa_{\rm B}} \right]^{1/2(1-\alpha)} \frac{V_{\rm FWHM}^{1/(1-\alpha)}}{F_{5100}^{1/2}}.$	Wang et al.2013	V
extremely accreting quasars (xA)	virial velocity dispersion: FWHM(Hβ) Eddington ratio = const	$L \propto \mathrm{FWHM}(\mathrm{H}\beta)^4$	Marziani & Sulentic 2014	V
general quasar populations	X-ray variability, velocity dispersion	$\log \frac{L}{\rm erg\,s^{-1}} + 4 \log \frac{\rm FWHM}{10^3\,\rm km\,s^{-1}} = \alpha \log \sigma_{\rm rms}^2 + \beta,$	La Franca et al. 2014	V
mainly quasars at z<1	Reverberation mapping time delay τ	$\tau/\sqrt{F} \propto d_L$	Watson et al 2011, 2013; Czerny et al. 2013; Melia 2015	
general quasar populations	non linear relation between soft X and UV	$\log(F_X) = \Phi(F_{UV}, D_L) = \beta' + \gamma \log(F_{UV}) + 2(\gamma - 1)\log(D_L),$	Risalti & Lusso 2016	

Eddington standard candles

The physical foundation of xA-based methods is the Eddington ratio "asymptotic" behavior expected from optically thick ADAFs for dimensionless accretion rates >> 1

$$L_{\bullet} = \ell_0 \left(1 + a \ln \dot{m}_{15}\right) M_{\bullet}$$

e.g., Mineshige et al.2000; Wang et al. 2013; Sadowski et al. 2014

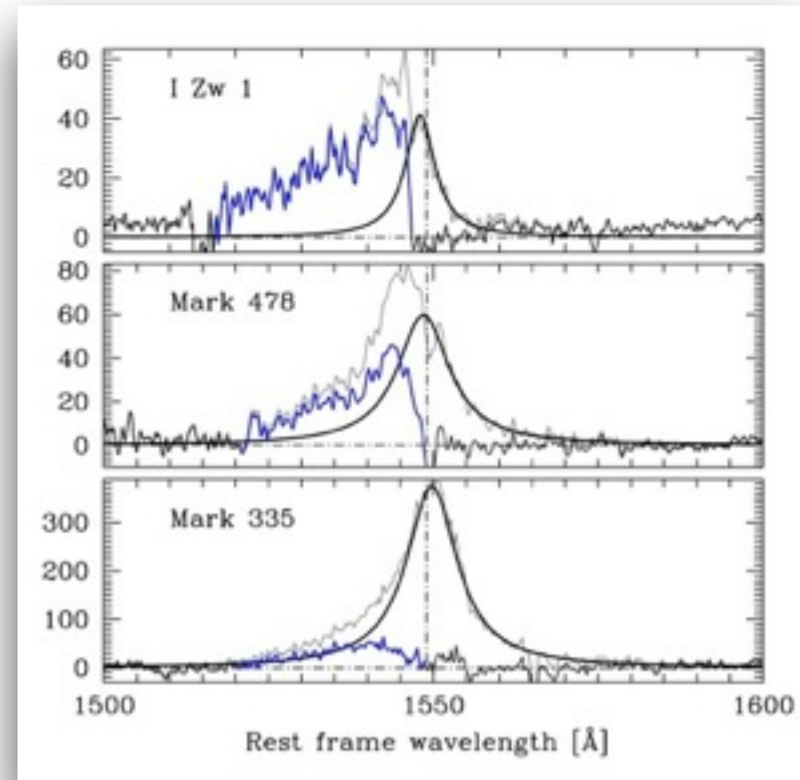
A virialized low-ionization broad emission line region

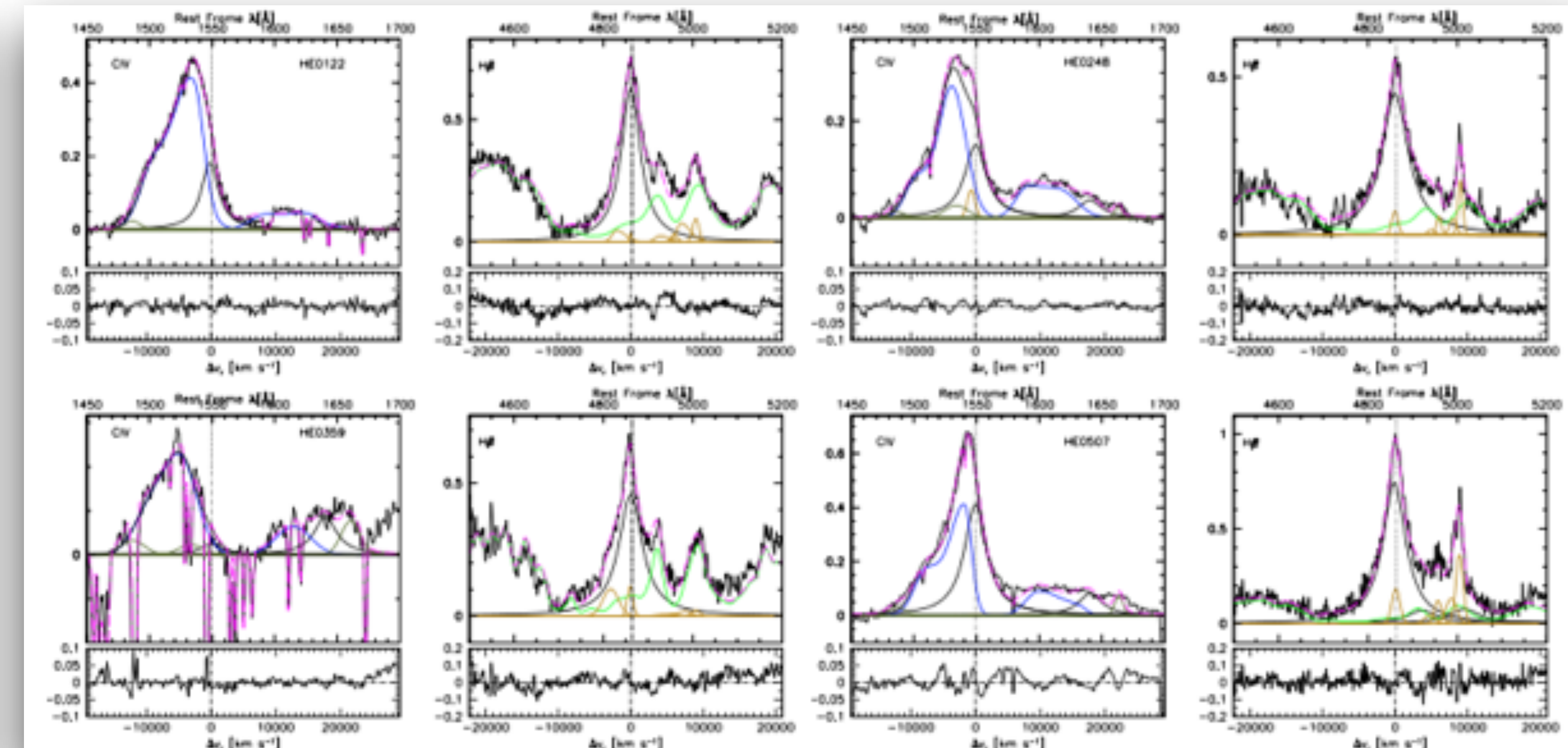
present even at the highest quasar luminosities, coexists with high ionization winds

CIVλ1549 (high-ionization) vs. Hβ (low-ionization)

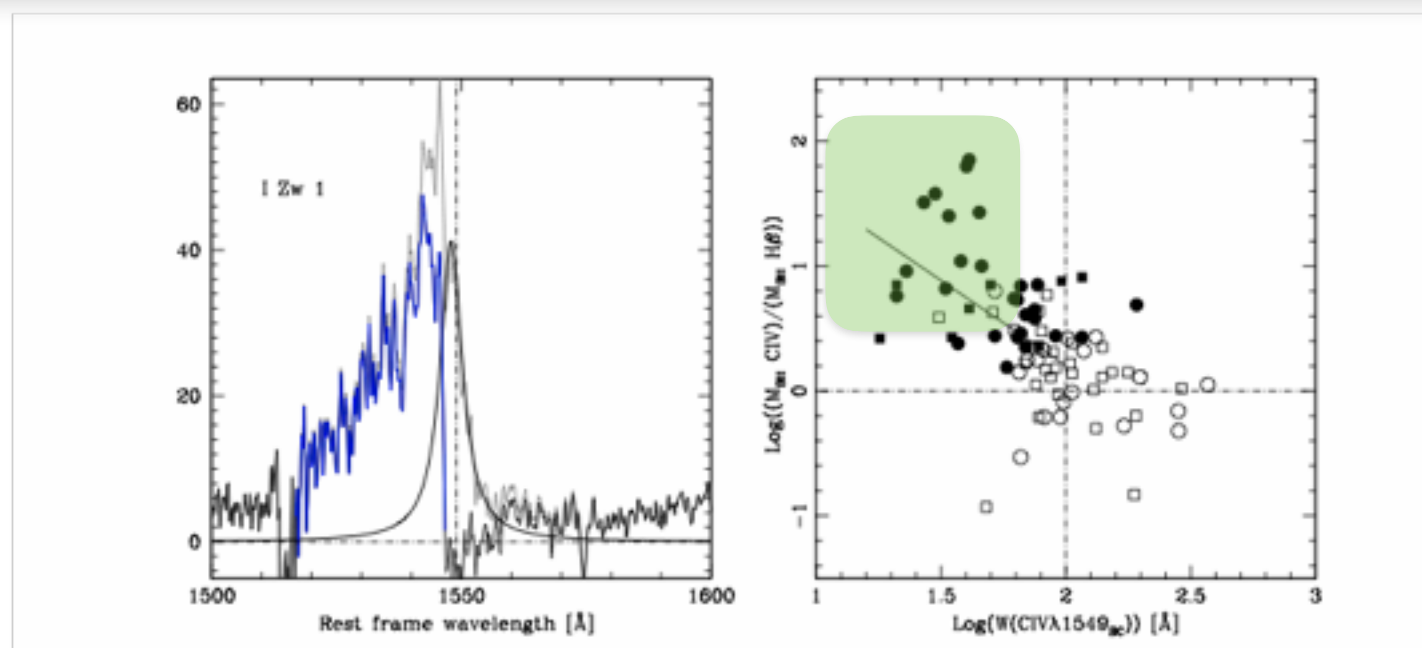
at low z, L< 10^{47} ergs/s

at z ~ 1.5, L> 10^{47} ergs/s





Marziani et al.2010; Sulentic et al. 2007, Marziani et al. 2016



said parenthetically:
use of CIV as a black hole mass estimator can yield to a strong bias dependent on the location of the eigenvector 1 sequence

Extreme Pop. A sources

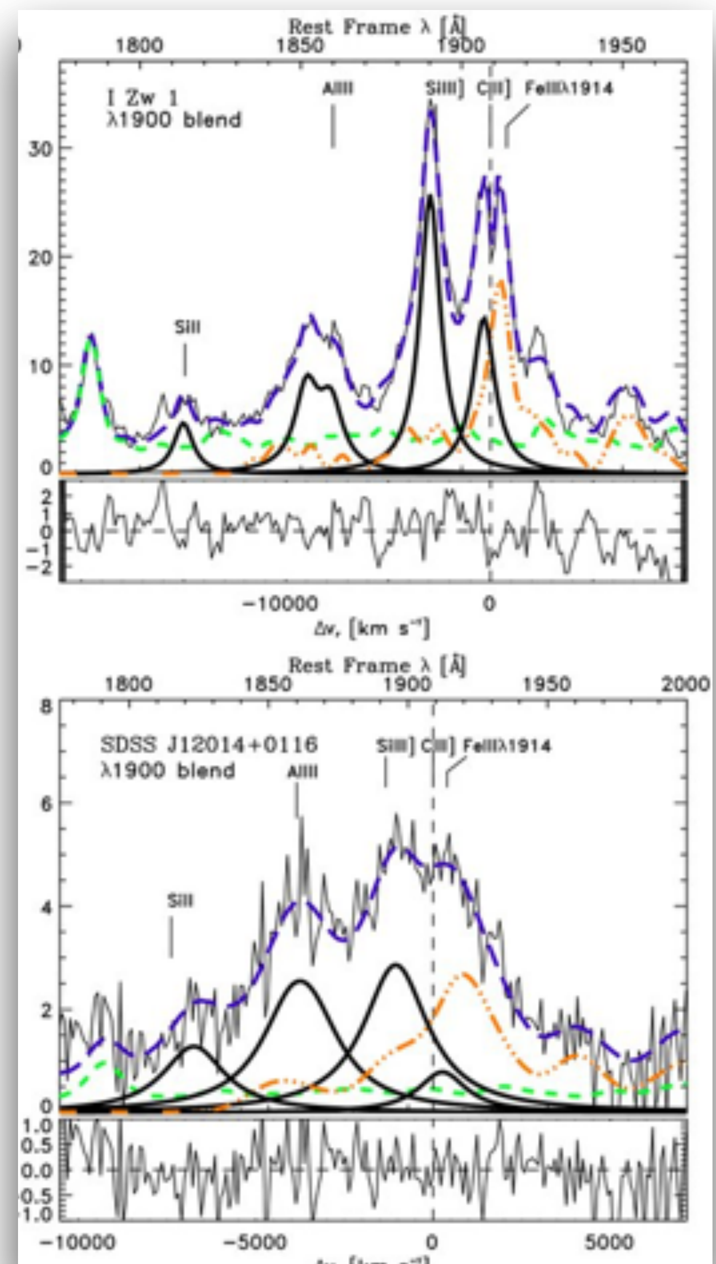
(super-Eddington accreting massive black holes (SEAMBHs)

Wang et al. 2003

Simple selection criteria from diagnostic line ratios

1) optical FeIIλ4570 blend/Hβ > 1.0

2) UV AlIII λ1860/SiIII]λ1892>0.5 & SiIII]λ1892/CIII]λ1909>1



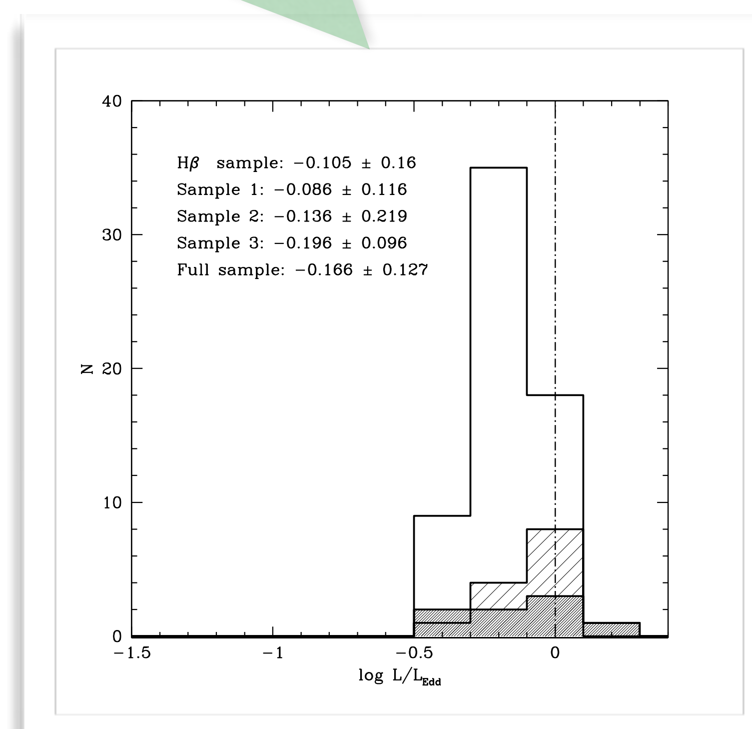
Negrete et al. 2012

Advantages	Drawbacks
Easy to recognize large samples up to z~ 4	The physical basis of the selection criteria is poorly understood
relevant properties should scatter with small dispersion around a well defined mean	xA sources are poorly understood in terms of emission properties
Clustering around a limiting Eddington ratio, as expected from theory	Orientation effects on line width not known
consistent accretion disk properties, similar metal enrichment	Consistency of properties at high and low z barely tested

Very similar spectrophotometric properties over a range of L ~ 10^{44} - 10^{48} erg/s

$$L(\delta v) \approx \left(\frac{\zeta_L^2}{4\pi c h G^2}\right) f_S^2 \left(\frac{L}{L_{Edd}}\right)^2 \left(\frac{\kappa}{\bar{\nu}_i}\right) \frac{1}{(n_H U)} (\delta v)^4,$$

Marziani & Sulentic 2014



Some relevant open issues

relevant for the use of quasars as distance indicators

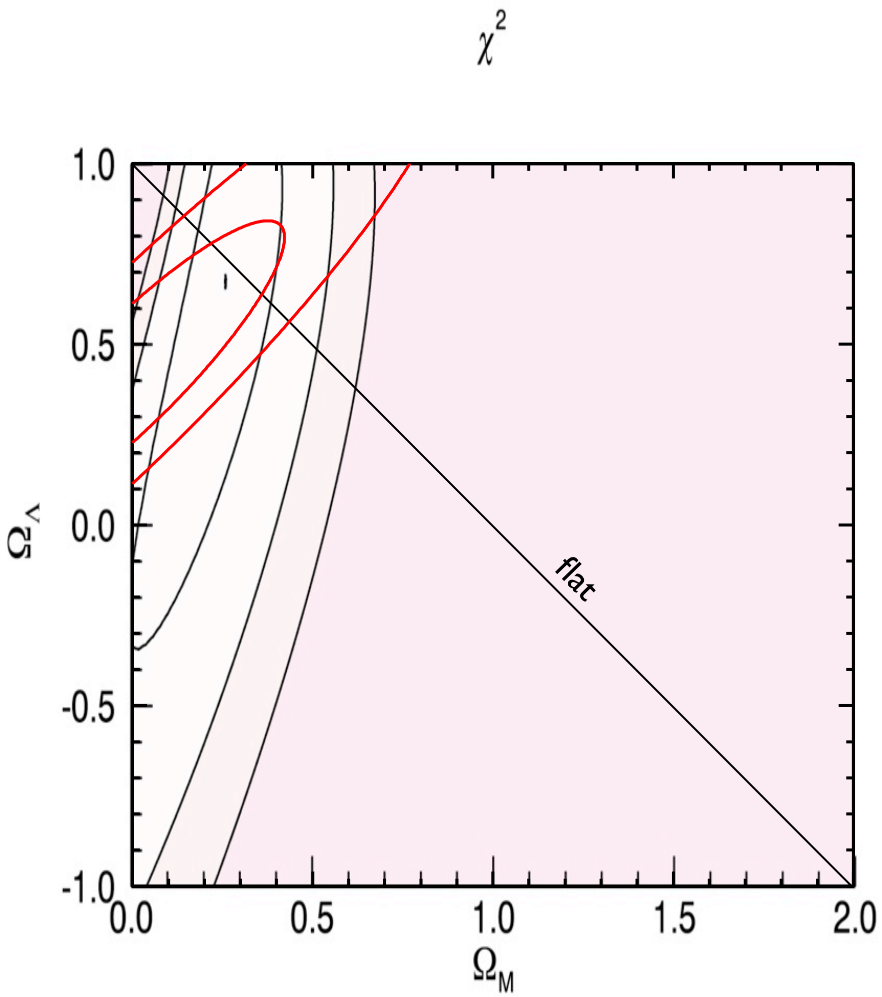
The **connection between physical (accretion) and observational space**: the eigenvector 1 sequence is still poorly understood. A major feat would be the ability to assign to each quasar a value of M_{BH}, Eddington ratio, spin, and viewing angle with a relatively small uncertainty. (Well-suited for instruments with NUV/Vis/NIR multiplexing ability)

The accretion disk structure and its connection to the **dynamics of the line emitting gas**. (Theoretical modeling and line/continuum fitting)

The **anisotropy** and multifrequency properties of radio-quiet quasars

The **metal enrichment** of the broad line region from circumnuclear star formation (SPH, chemo-dynamical modeling of galactic nuclei)

The potential for cosmology is enormous.



Constraints from a sample of 400 mock quasars with rms = 0.4 dex over 1 < z < 3 using the method based on xA and the supernova photometric survey (Campbell et al. 2013)