Quasar emission lines as virial broadening estimators

Paola Marziani[1]

with the "extreme team"

E. Bon,[2] N. Bon,[2] A. del Olmo[3], D. Dultzin[4], A. Negrete[4], J. W. Sulentic[3],

M.L. Martínez-Aldama[5], G. M. Stirpe[6], M. D'Onofrio[7], J. Perea[3]

[1]INAF - Osservatorio Astronomico di Padova, Padova, Italia

[2]Astronomical Observatory, Belgrade, Serbia

[3]Instituto de Astrofísica de Andalucía (CSIC), Granada, España

[4]Instituto de Astronomía, UNAM, México, D.F., México

[5]Center for Theoretical Physics, Polish Academic of Sciences, Warsaw, Poland

[6]INAF - Osservatorio Astrofísica e Science dello Spazio, Bologna, Italia

[7]Dipartimento di Fisica ed Astronomia "Galileo Galilei", U. di Padova, Padova, Italia

June 2019

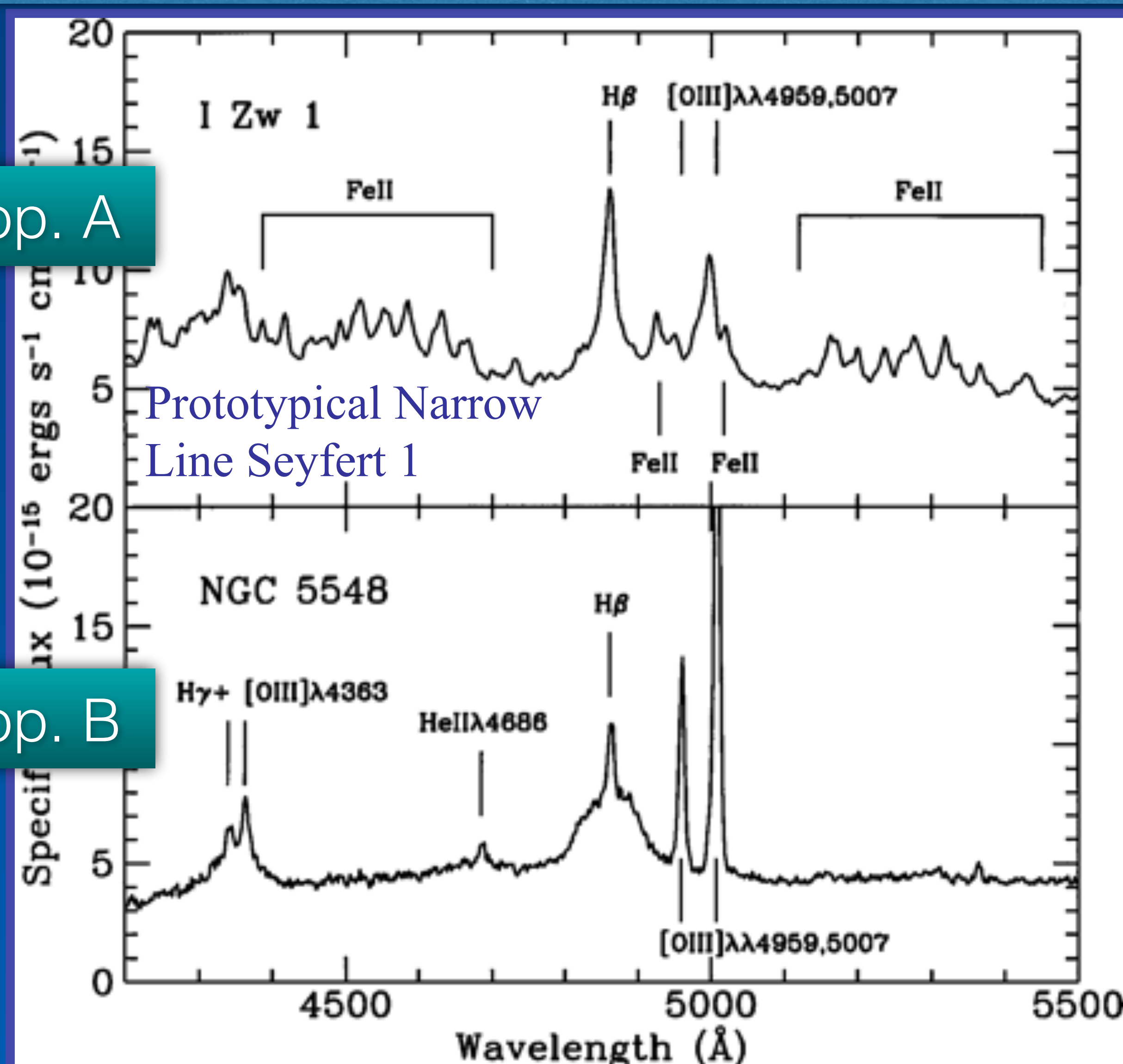
SCSLSA 12

Introduction: a main sequence (MS) for type-1 (unobscured) quasars

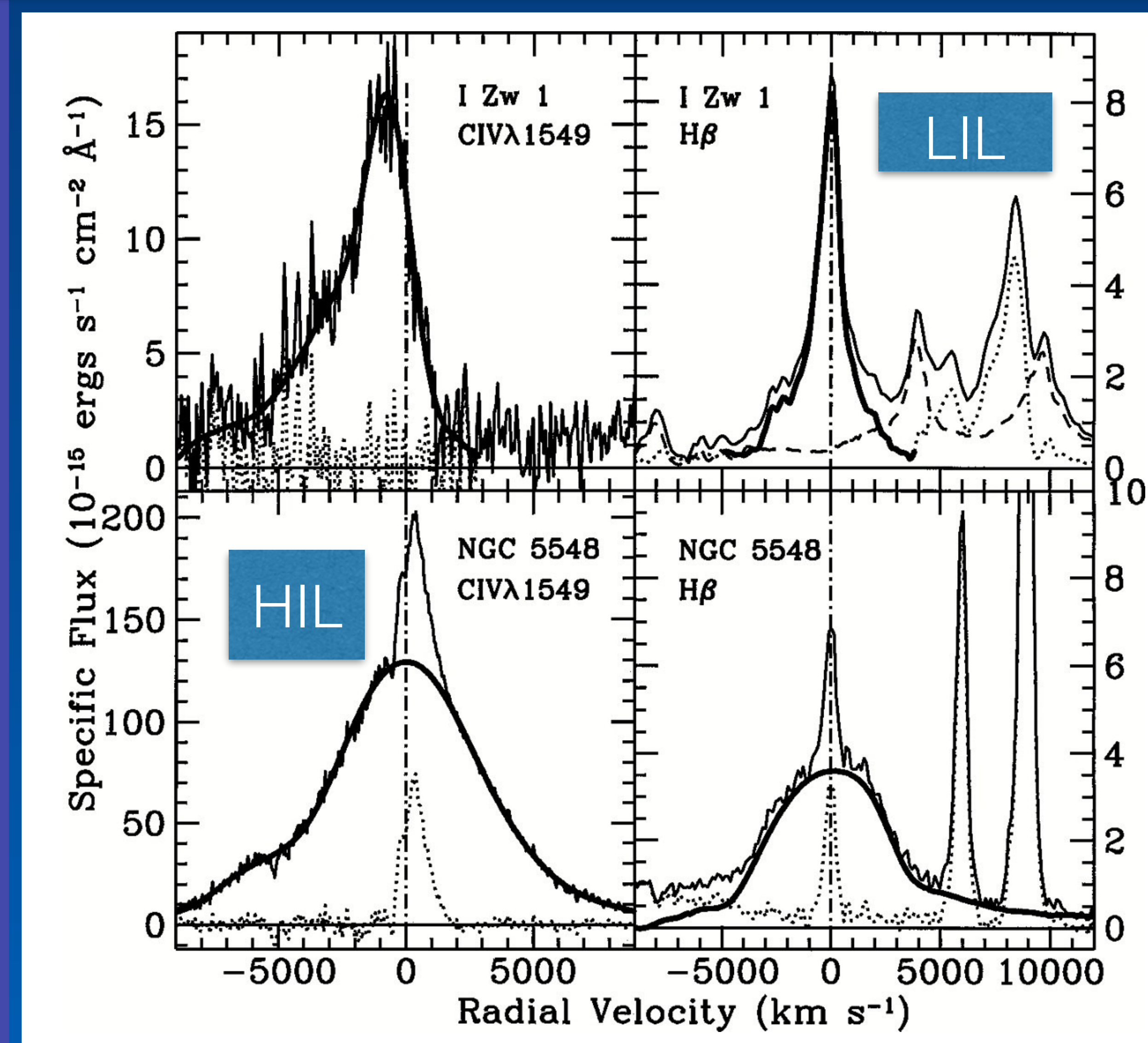
An extreme ("tip") of the MS

Cosmological applications?

Quasar spectra show a wide range of line profiles, line shifts, line intensities ➜ differences in dynamical conditions and ionization levels of the broad line region (BLR)



Hβ spectral range

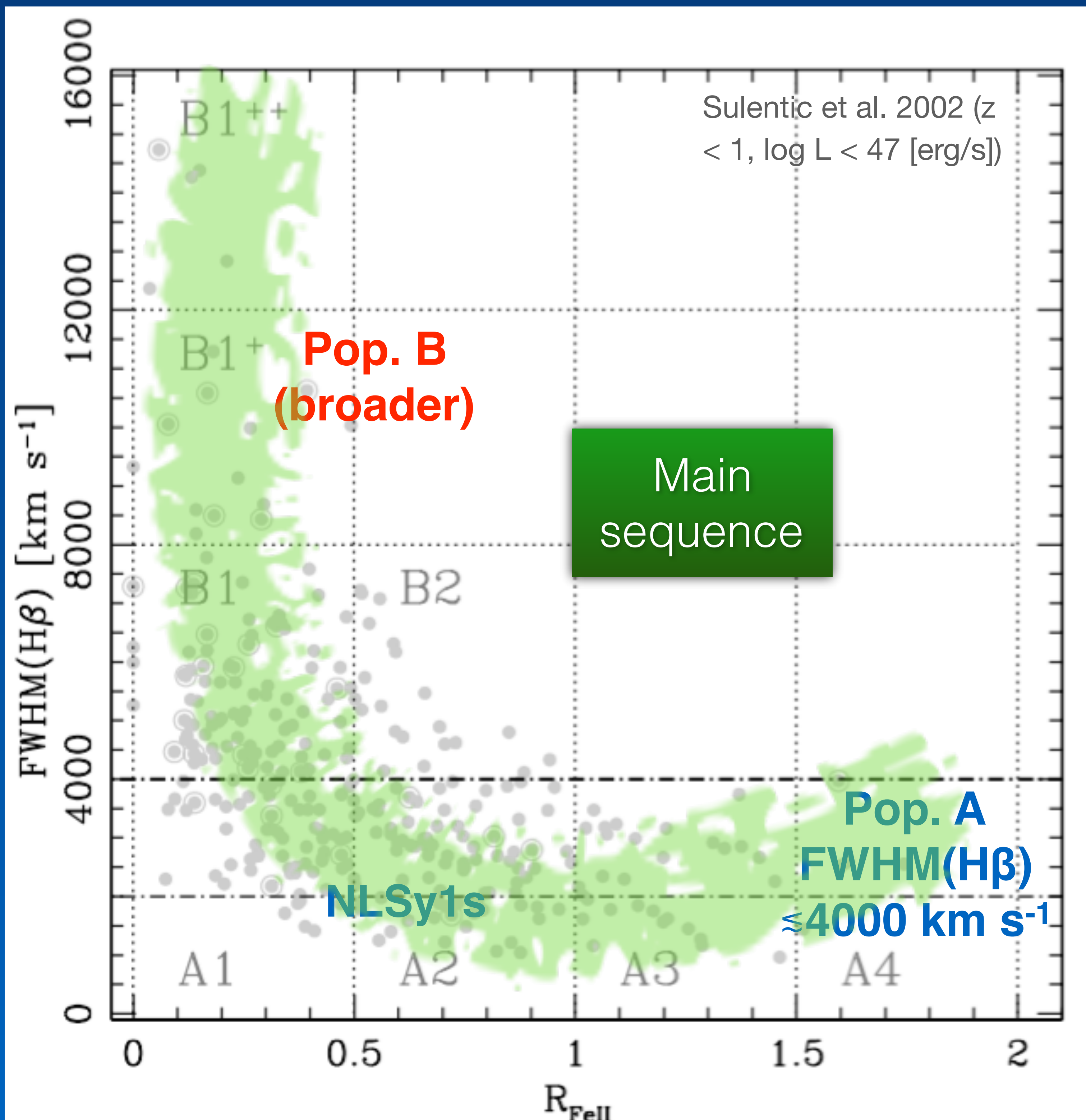


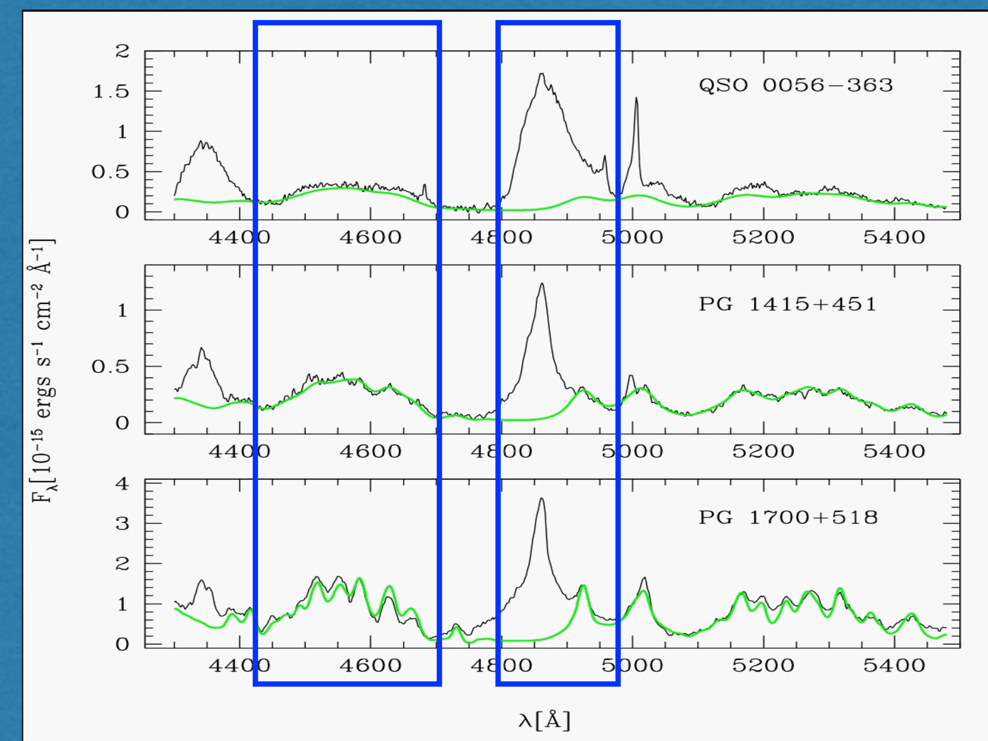
CIV and Hβ (high and low ionization lines)

I Zw 1 and NGC are the prototypes of two different quasar populations

Sulentic et al. 2000

A main sequence (MS) for quasars organizing quasar diversity





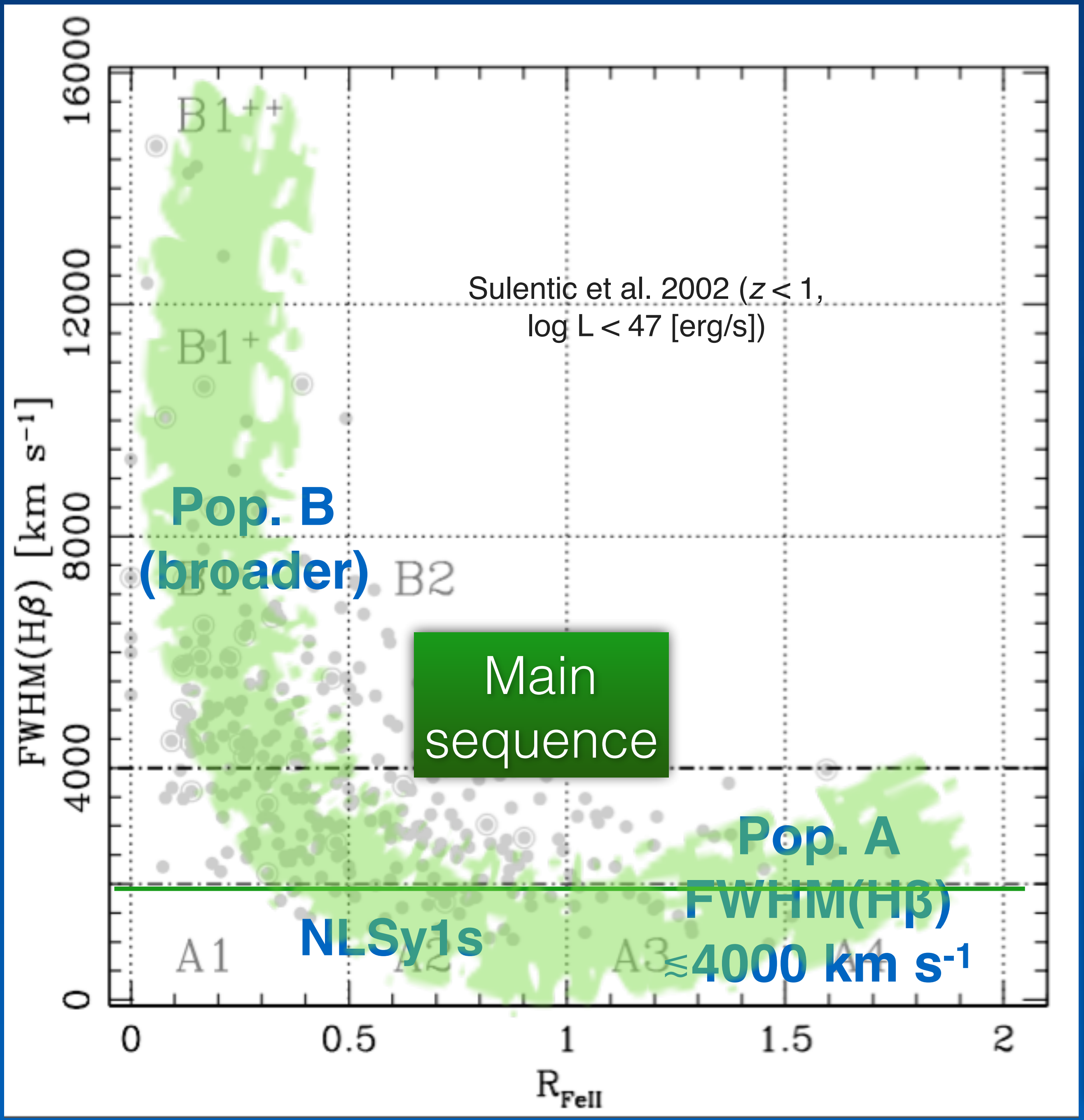
$$R_{\rm FeII} = \frac{I(\mathrm{FeII}\lambda 4570)}{I(H\beta)} \approx \frac{W(\mathrm{FeII}\lambda 4570)}{W(H\beta)}$$

FeII emission can dominate the thermal balance of the BLR

FeII emission is self-similar but intensity with respect to Hβ changes from object to objects

$R_{\rm FeII}$ is a descriptor of the LIL-BLR physical conditions

The quasar Eigenvector 1: a Main Sequence (MS) for quasars



Eigenvector 1: Originally defined by a Principal Component Analysis of PG quasars; since 1992, the E1 MS has been found in increasingly larger samples.

E1 MS first associated with the anti-correlation between strength of FeIIλ4570 (or [OIII] 5007 peak intensity) and width of Hβ, but several multifrequency parameters related to the accretion process and the accompanying outflows are also correlated.

The E1 sequence is probably due to a combination of effects dependent on Eddington ratio, viewing angle, and metal content (more detail in Swayamtrupta Panda's talk).

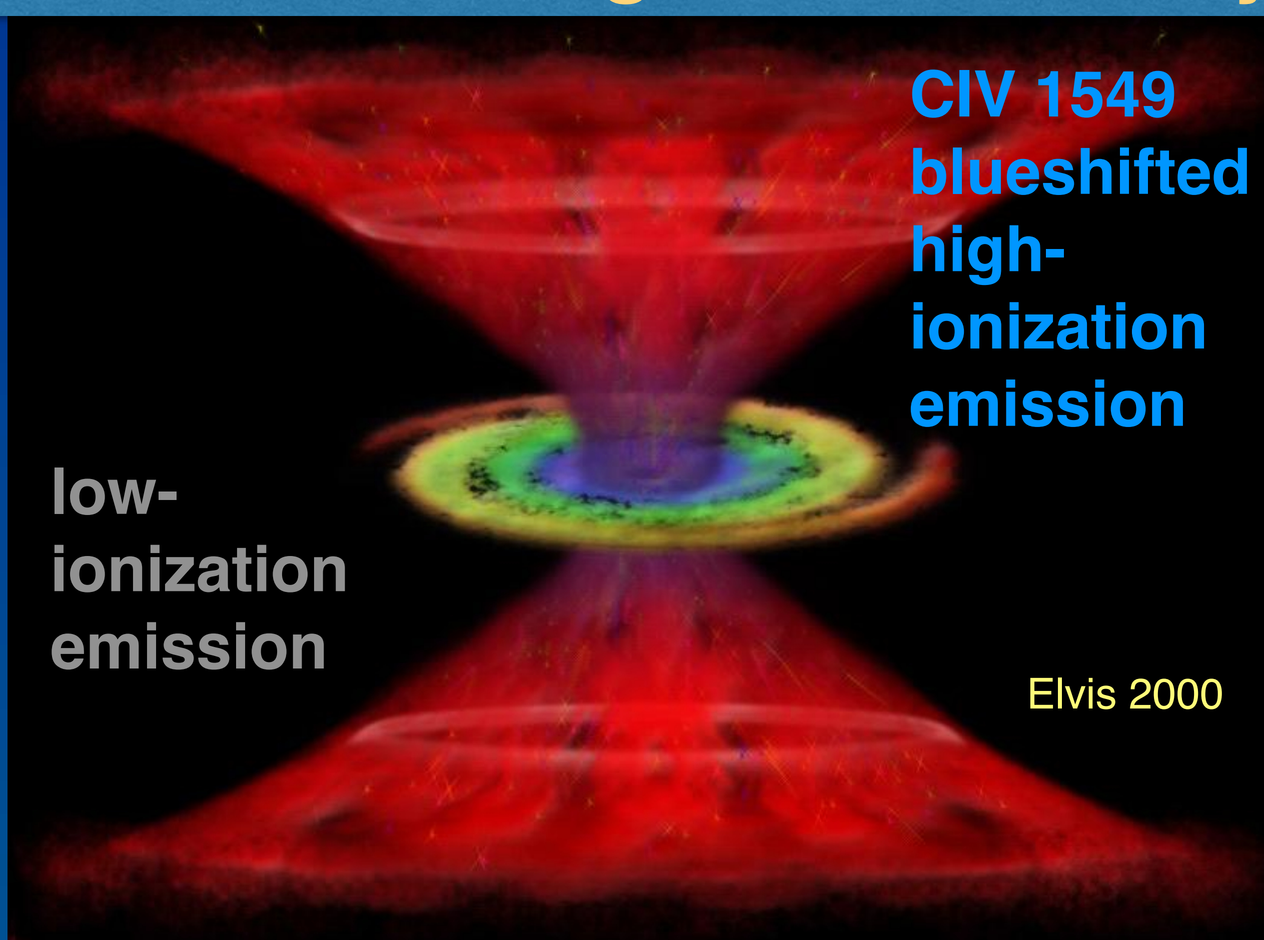
Boron & Green 1992; Dultzin-Hacyan et al. 1997; Shang et al. 2003, Yip et al.2004, Sulentic et al. 2000, 2002, 2007; Kruzcek et al 2011; Tang et al. 2012; Kuraszkiewicz et al. 2008; Mao et al. 2009; Grupe 2004, Wang et al. 2006; Panda et al. 2018, 2019. SDSS data : Shen & Ho 2014, Sun & Shen 2015, Brotherton et al. 2015; Du et al. 2016.

The Main Sequence — Organizing quasar diversity

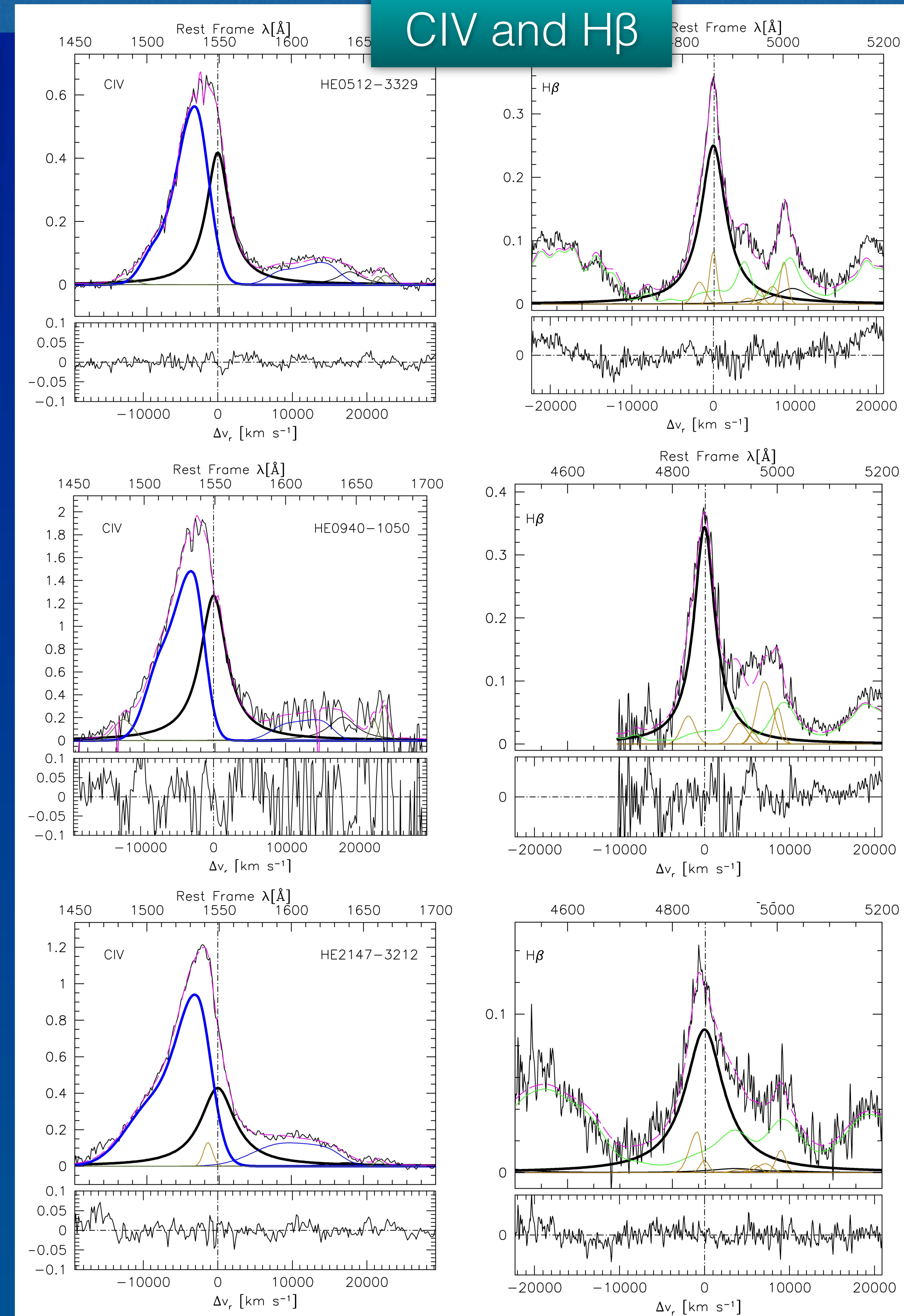
$L > 10^{47}$ erg s^{-1}: extremely high amplitude blueshifts in CIV 1549 profiles of Pop. A quasars

Virialized: symmetric and unshifted with respect to rest frame

A virialized system emitting mainly LILs coexists with outflowing gas in Pop. A sources, even at the highest luminosity



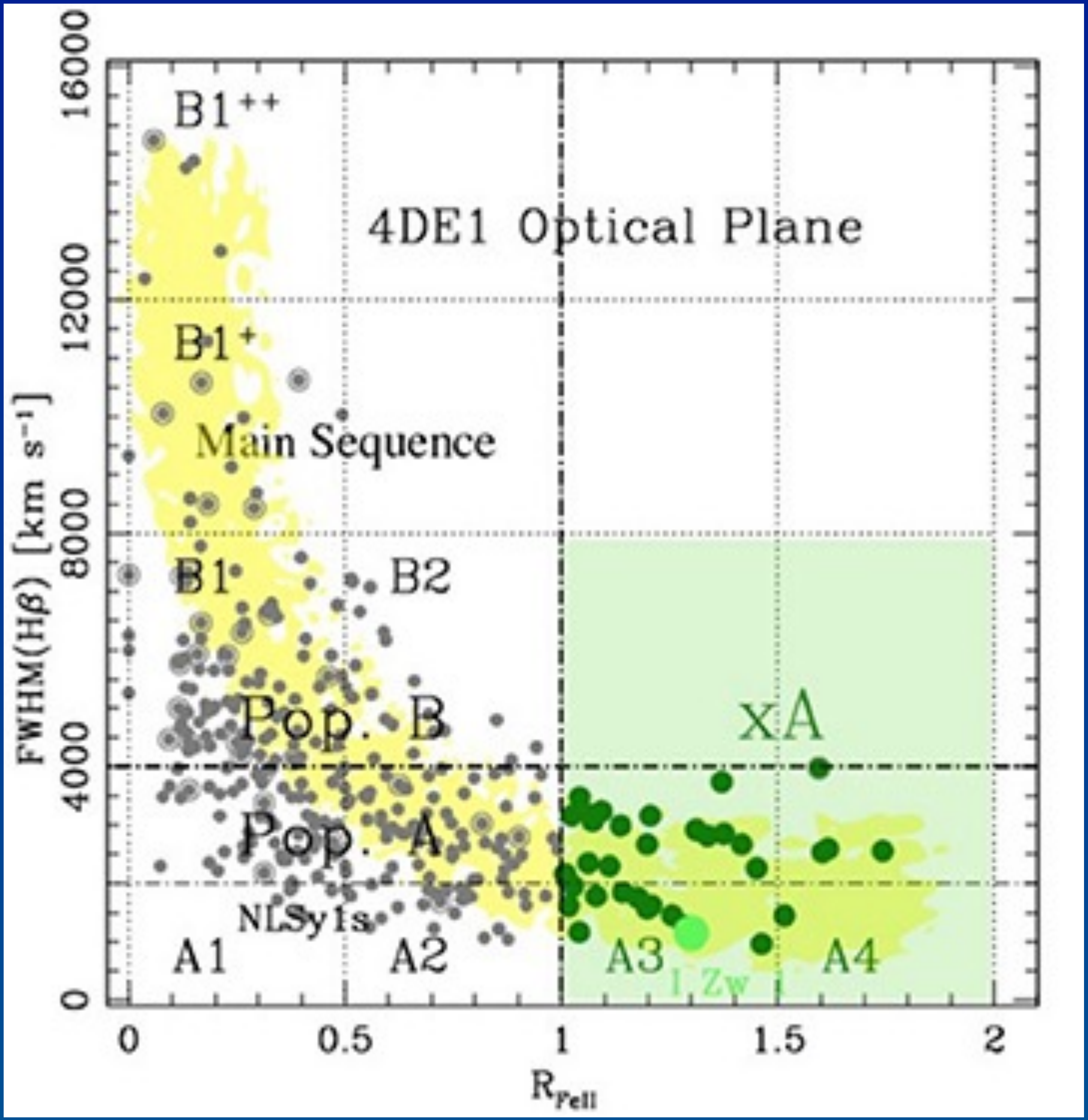
CIV and Hβ



Sulentic et al. 2017; Vietri et al. 2017; Coatman et al 2016

The "high $R_{\rm FeII}$ end" of the quasar MS (extreme Population A, xA, at $R_{\rm Fe} \gtrsim 1$)

Extreme Population A — Selection and physical conditions



The MS allows for the definition of spectral types, and 2 populations: A (FWHM Hβ<4000 km/s) and B

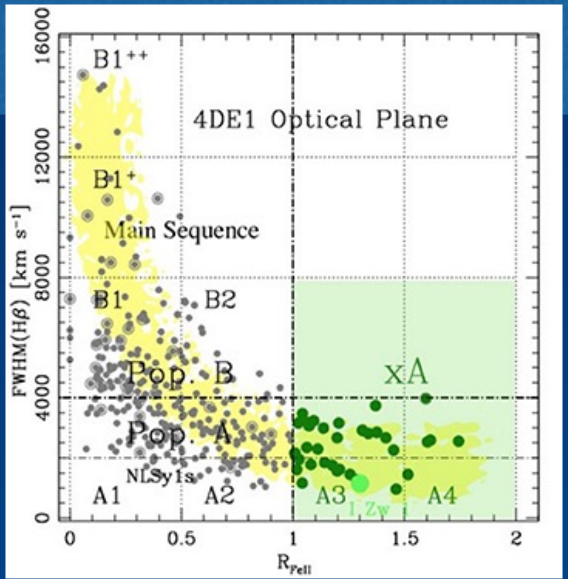
Pop. A includes the Narrow Line Seyfert 1 (NLSy1s)

Gradient of R_{FeII} in Pop. A Spectral type within Pop. A are defined by R_{FeII} ranges;

Extreme Population A (xA) quasars satisfy $R_{FeII} > 1$; ~ 10% of quasars in low-z, optically selected samples

Boron & Green 1992; Sulentic et al. 2000; Marziani et al. 2001; Shen & Ho 2014; Du et al. 2016; Panda et al. 2019, in preparation

Extreme Population A — Selection and physical conditions

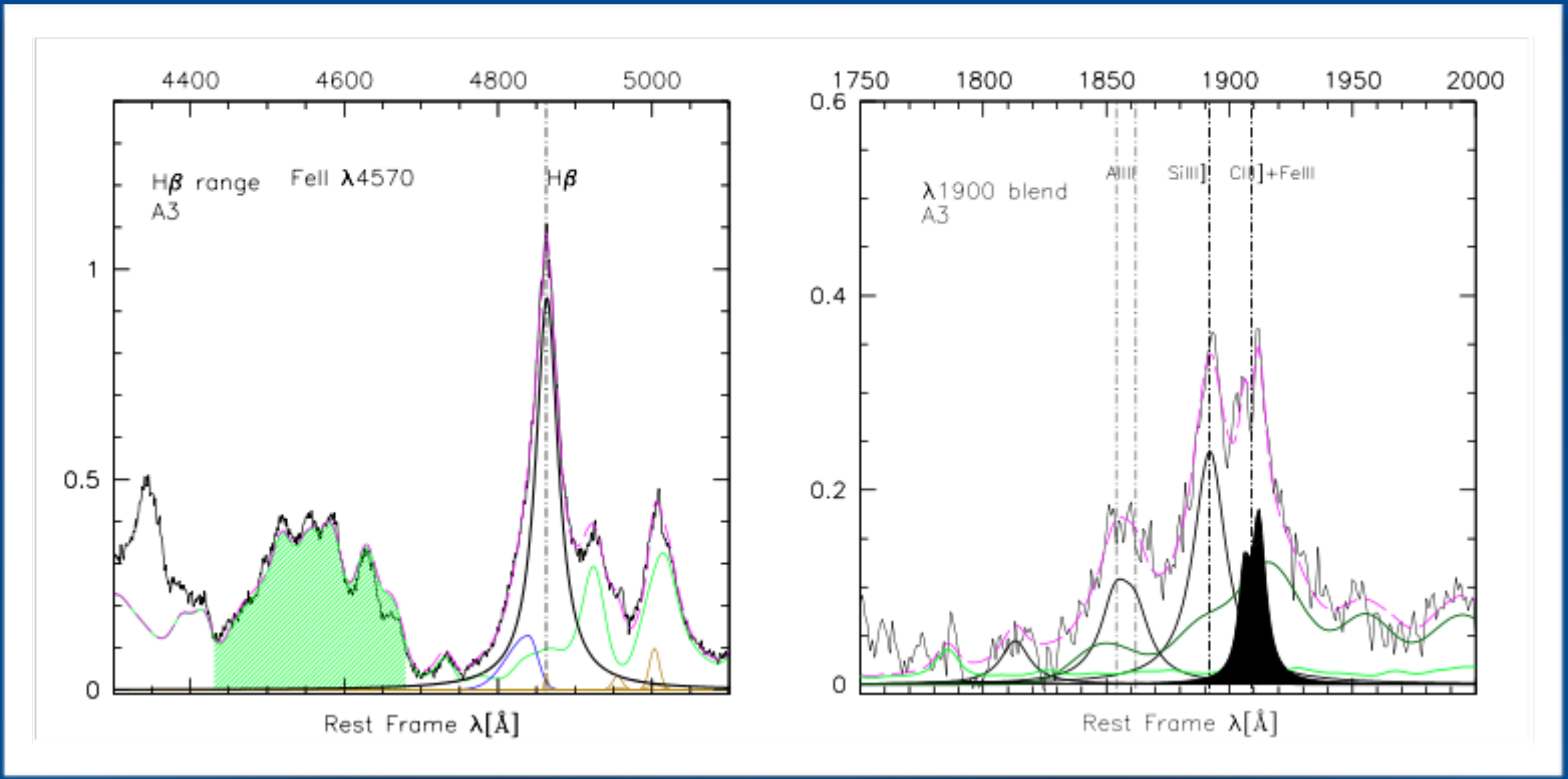


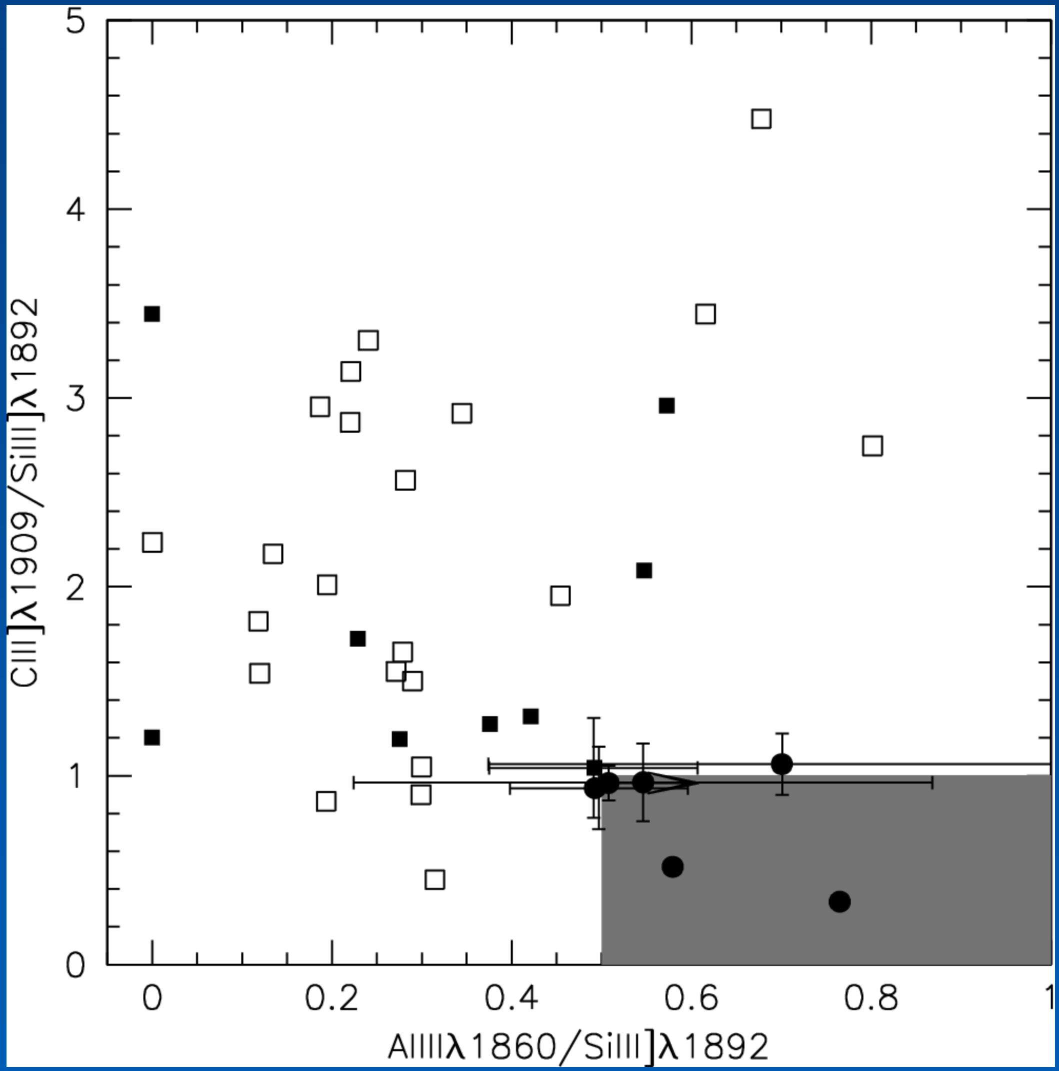
Extreme Pop. A quasars (xA)

Simple selection criteria from diagnostic line ratios

1) R_{FeII} = FeIIλ4570 blend/Hβ > 1.0

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



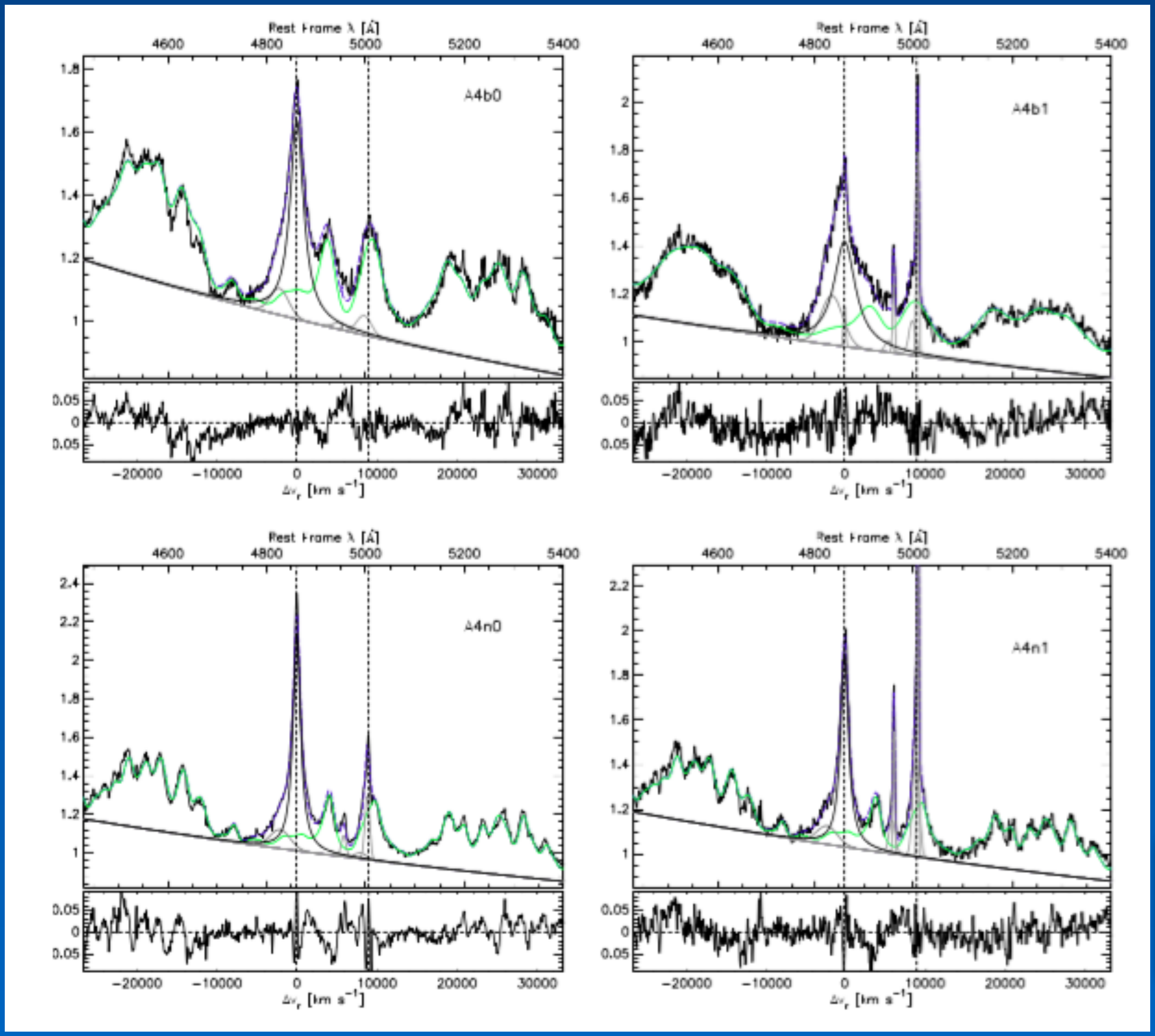


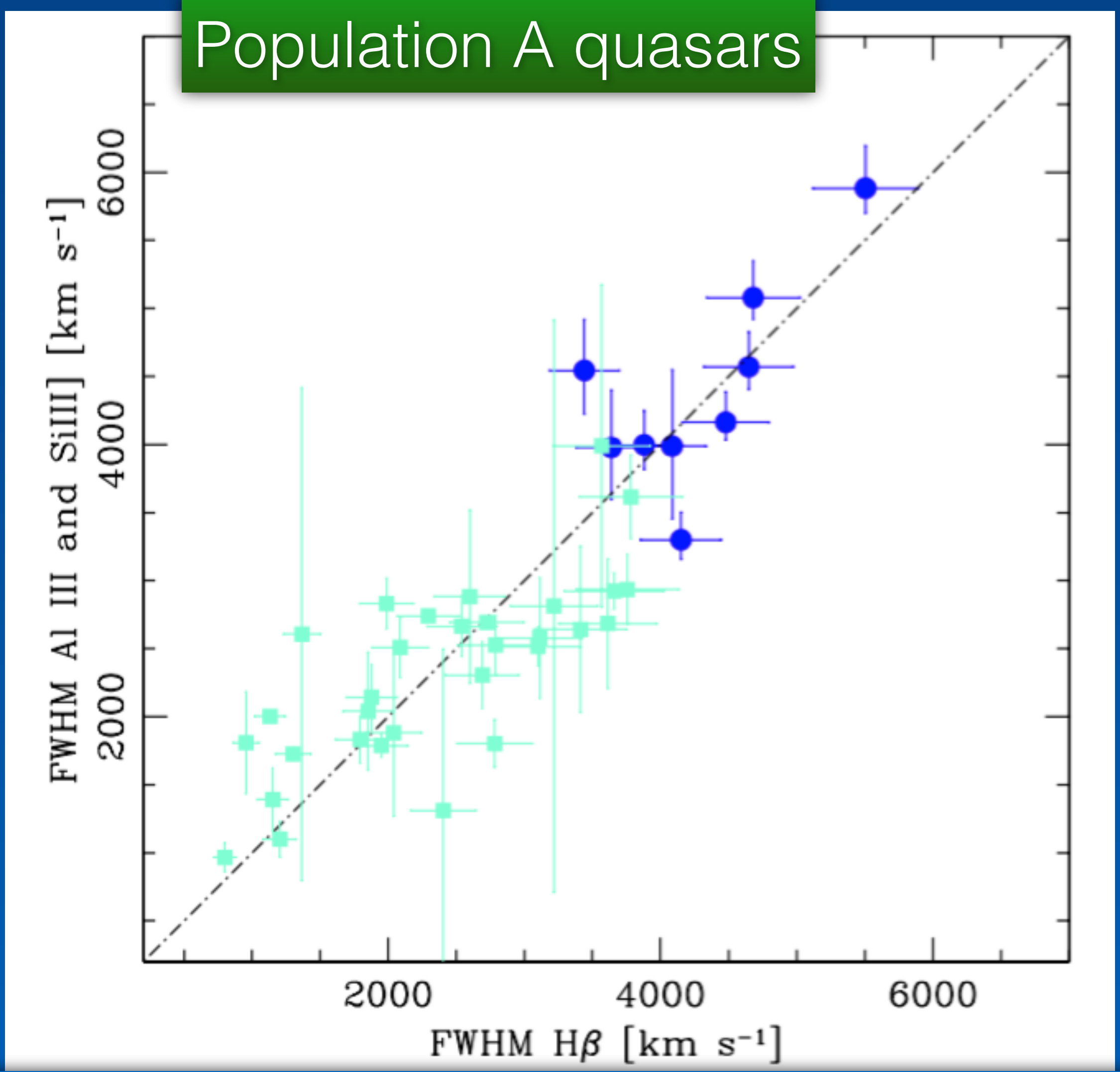
UV and optical selection criteria are equivalent

Extreme Population A — Selection and physical conditions

xA spectra show distinctively strong FeII emission and Lorentzian Balmer line profiles

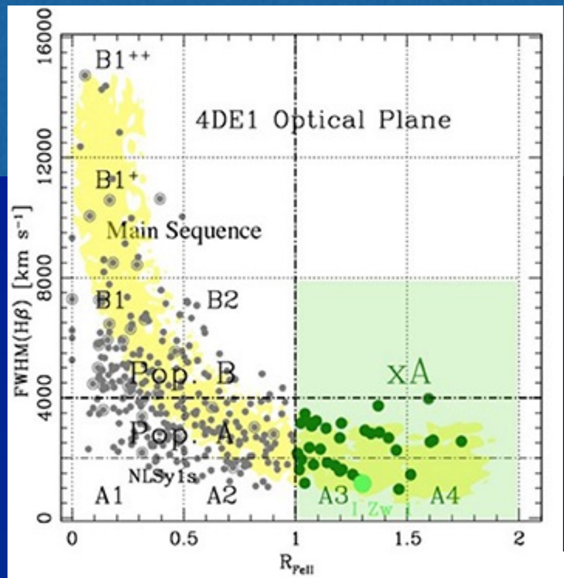
FWHM(Hβ) ~ FWHM(AlIII 1860)
AlIII 1860 virial broadening estimator equivalent to Hβ





Allows for the consideration of xA quasars at high z (>1.2)

Negrete et al. 2013; del Olmo et al. 2019, in preparation

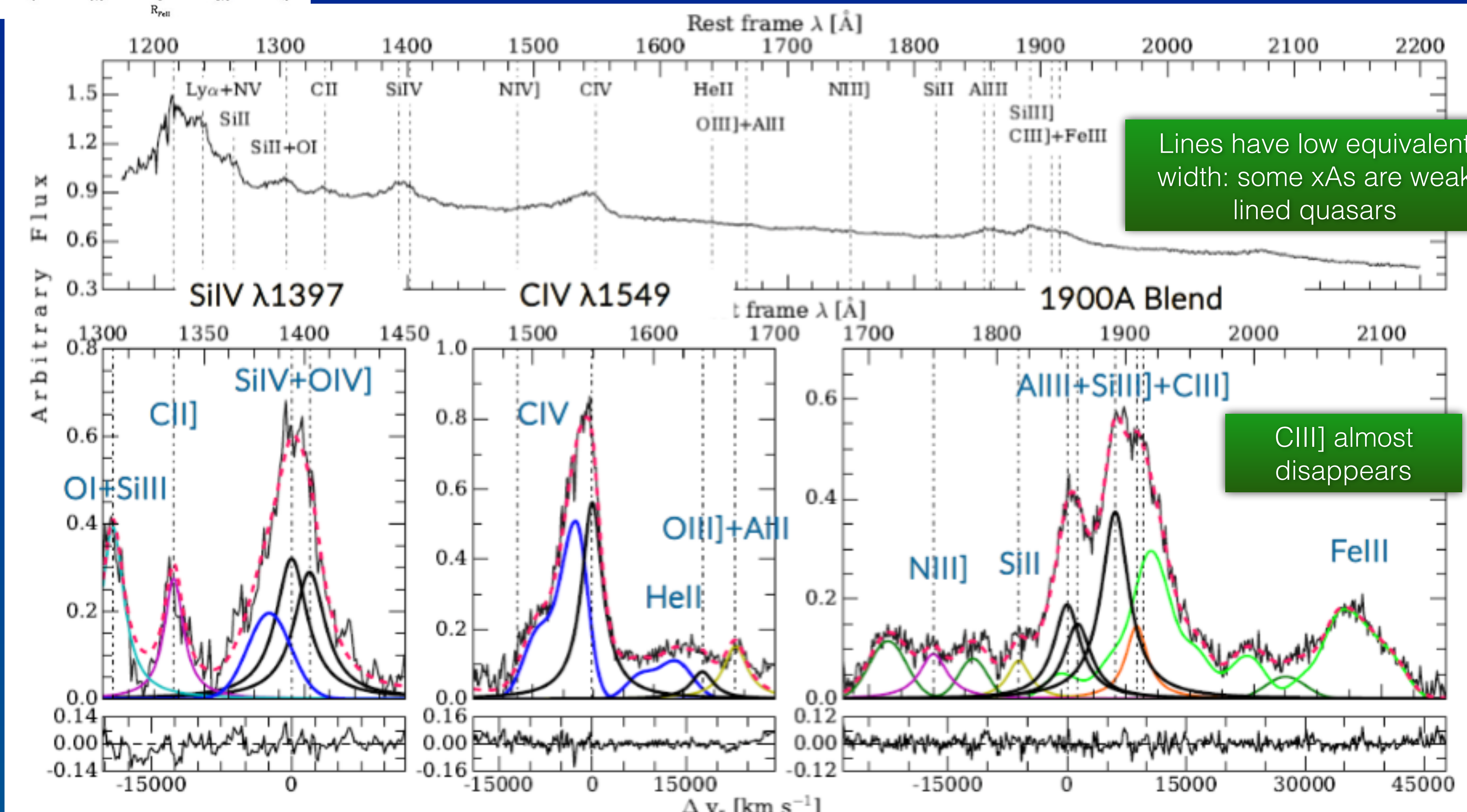


Extreme Population A — Selection and physical conditions

The UV spectrum of xA quasars at z ~ 2

Symmetric low-ionization and blueshifed high-ionization lines even at the highest luminosity

Martínez-Aldama et al. 2018, and reference therein

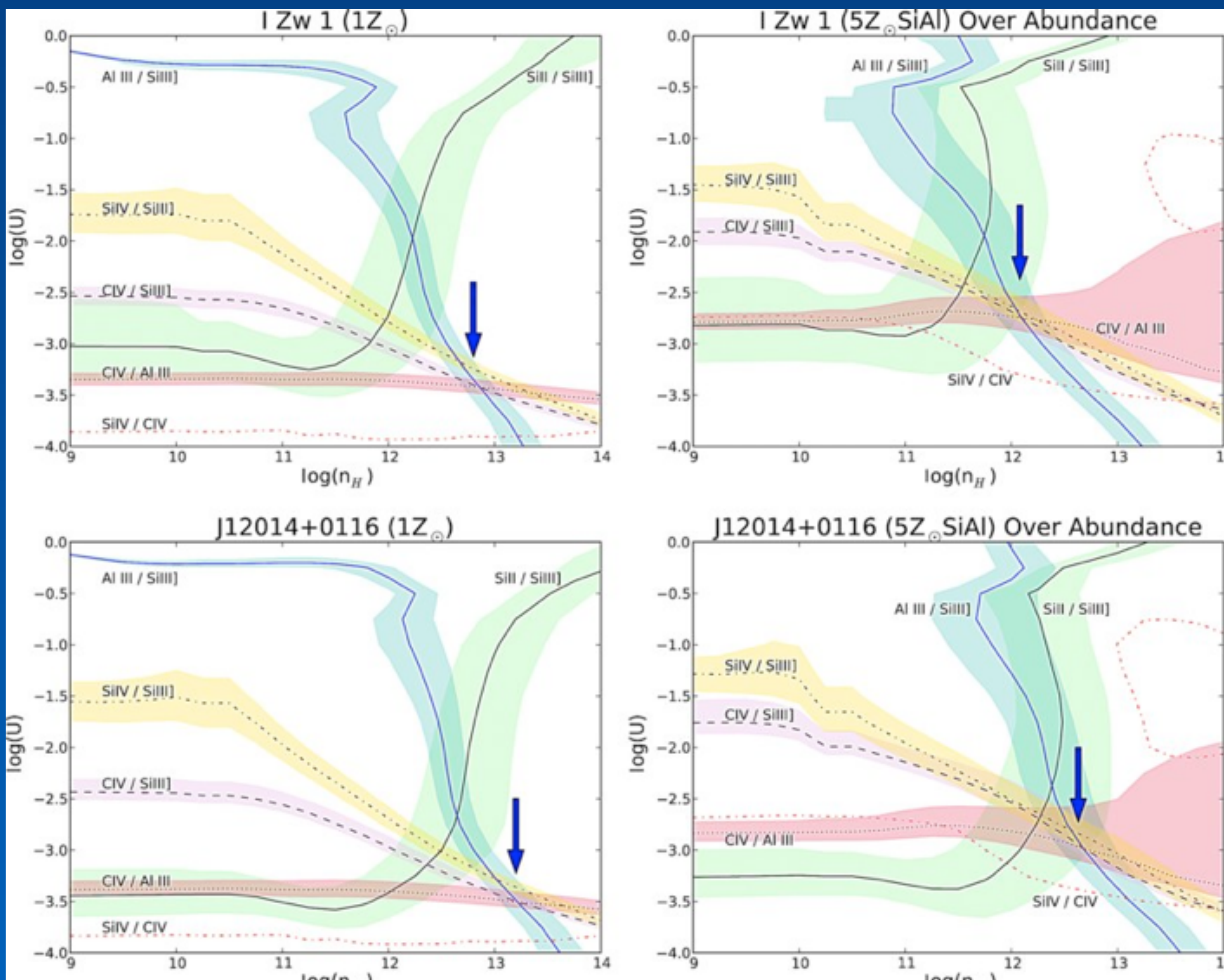


Lines have low equivalent width: some xAs are weak lined quasars

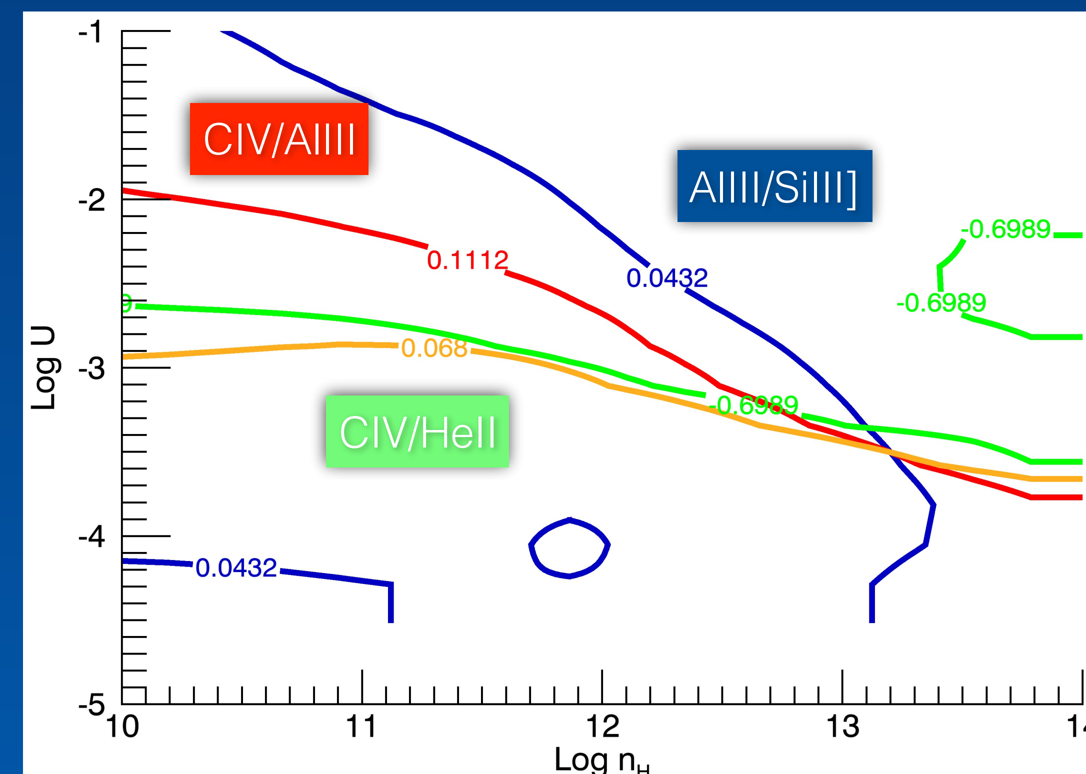
CIII] almost disappears

Extreme values for density (high, n > 10^{12-13} cm^{-3}), ionization (high, U~10^{-3})

Extreme values of metallicity (Z>20 Z$_\odot$)



(Negrete et al. 2012; Martínez-Aldama et al. 2018; Sniegowska et al. 2019 in preparation)



Plane ionization parameter versus density from arrays of CLOUDY simulations

Emitting region a dense compact remnant of the LI-BLR?

Extreme Population A ($R_{Fe} \gtrsim 1$): implications for Cosmology?

xA: Marziani & Sulentic 2014 (MS14); Negrete et al. 2018; Martínez-Aldama et al. 2018; related to “Super-Eddington” accreting massive black holes (SEAMBHs): Wang et al. 2013; 2014; Du et al. 2016; Czerny et al. 2018 for a review; Czerny et al. 2013; Risaliti & Lusso 2015, and La Franca et al. 2014 for alternative methods.

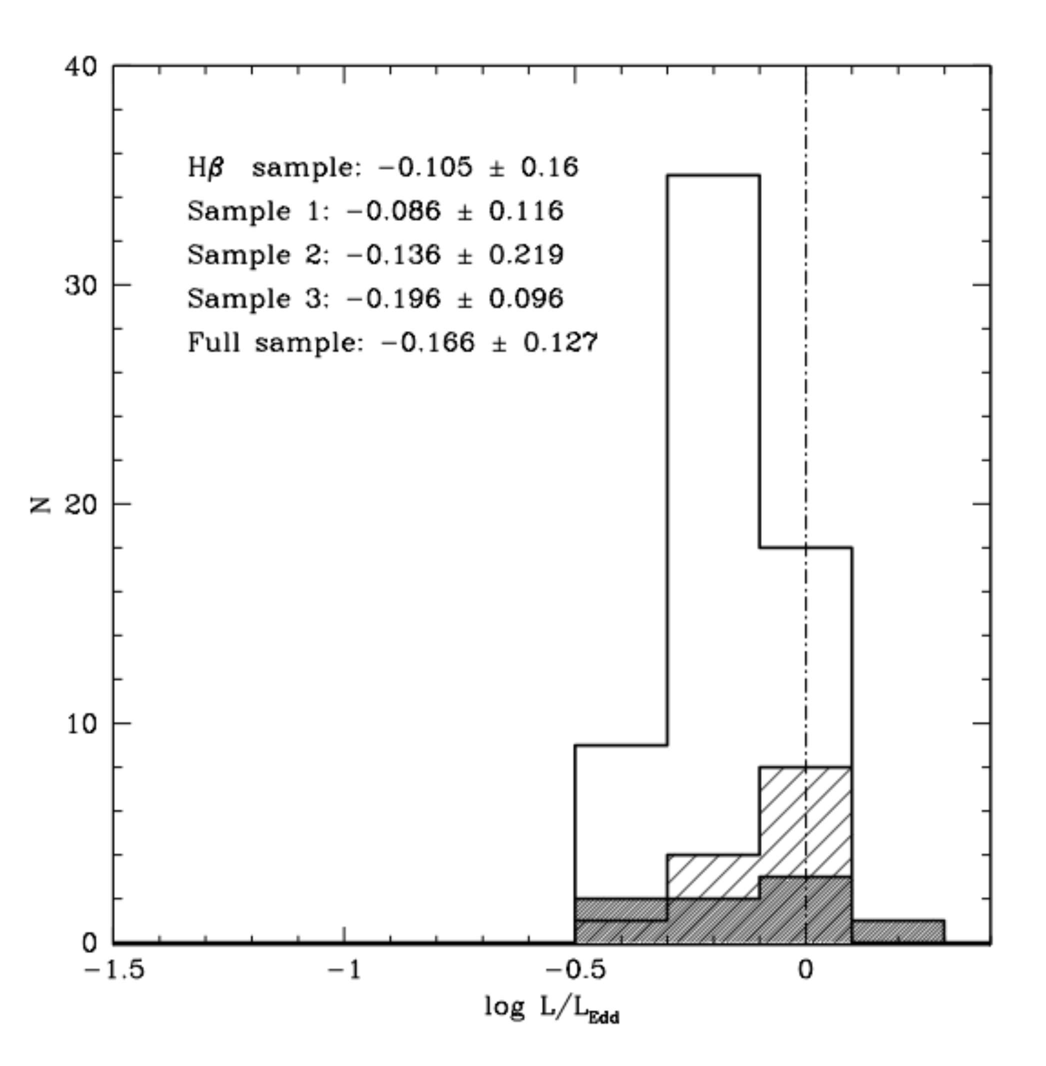
Extreme Population A: cosmological applications?

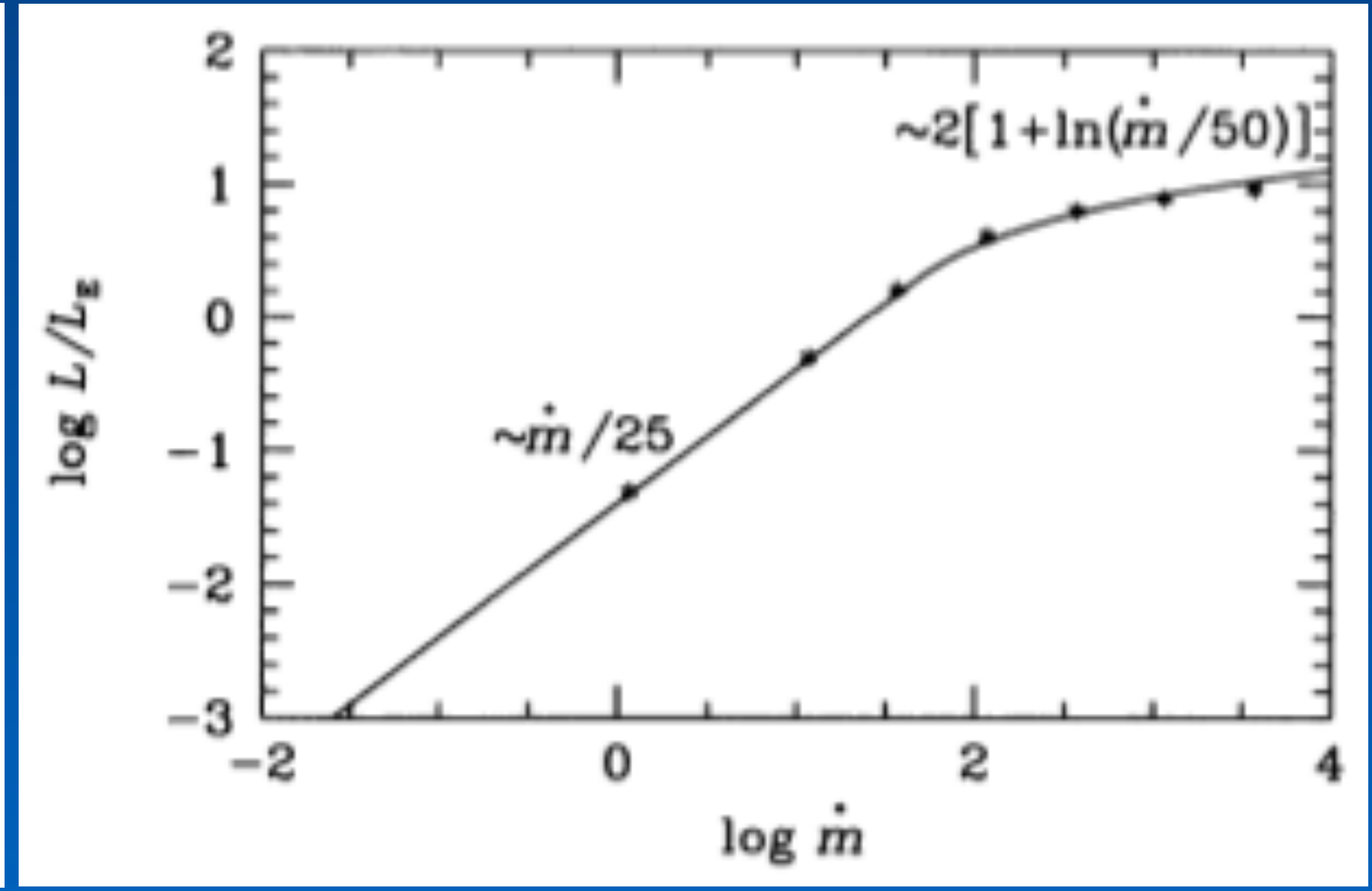
xA quasars: Extreme L/L_{Edd} along the MS with small dispersion

Accretion disk theory: low radiative efficiency at high accretion rate; L/L_{Edd} saturates toward a limiting values

$$L = \eta L_{\rm Edd} = {\rm const}\,\eta M_{\rm BH}$$

$$L/L_{\rm Edd} \rightarrow {\rm const.} \quad {\rm for} \quad \dot{m} \gg 1$$





Marziani & Sulentic 2014 (MS14); Mineshige 2000; Abramowicz et al. 1988; Sadowski 2014

Eddington standard candles

1. xA quasars radiate close to Eddington limit $\eta \sim 1$

$$L = \eta L_{\rm Edd} = {\rm const}\,\eta M_{\rm BH}$$

$$M_{\rm BH} = \frac{f r (\delta v)^2}{G}$$

geometry dynamics

$r_{\rm BLR}$

FWHM σ,FWZI

2. Assuming **virial motions** of the low-ion. BLR, **$L \propto \eta\, M_{\rm BH} \propto \eta\; r_{\rm BLR}\, (\delta v)^2$**

3. xA quasars have similar BLR physical parameters ($n_{\rm H}$ and U), implying that the BLR radius rigorously scales with L **$r_{\rm BLR} \propto (L\, n_{\rm H}\, U)^{1/2}$**

4. If we know a **virial broadening estimator δv** (in practice, the FWHM of a low-ionization line), we can derive a *z*-independent

"virial luminosity" $L_{\rm vir} \propto \eta^2\, (n_{\rm H}\, U)^{-1}\, (\delta v)^4$

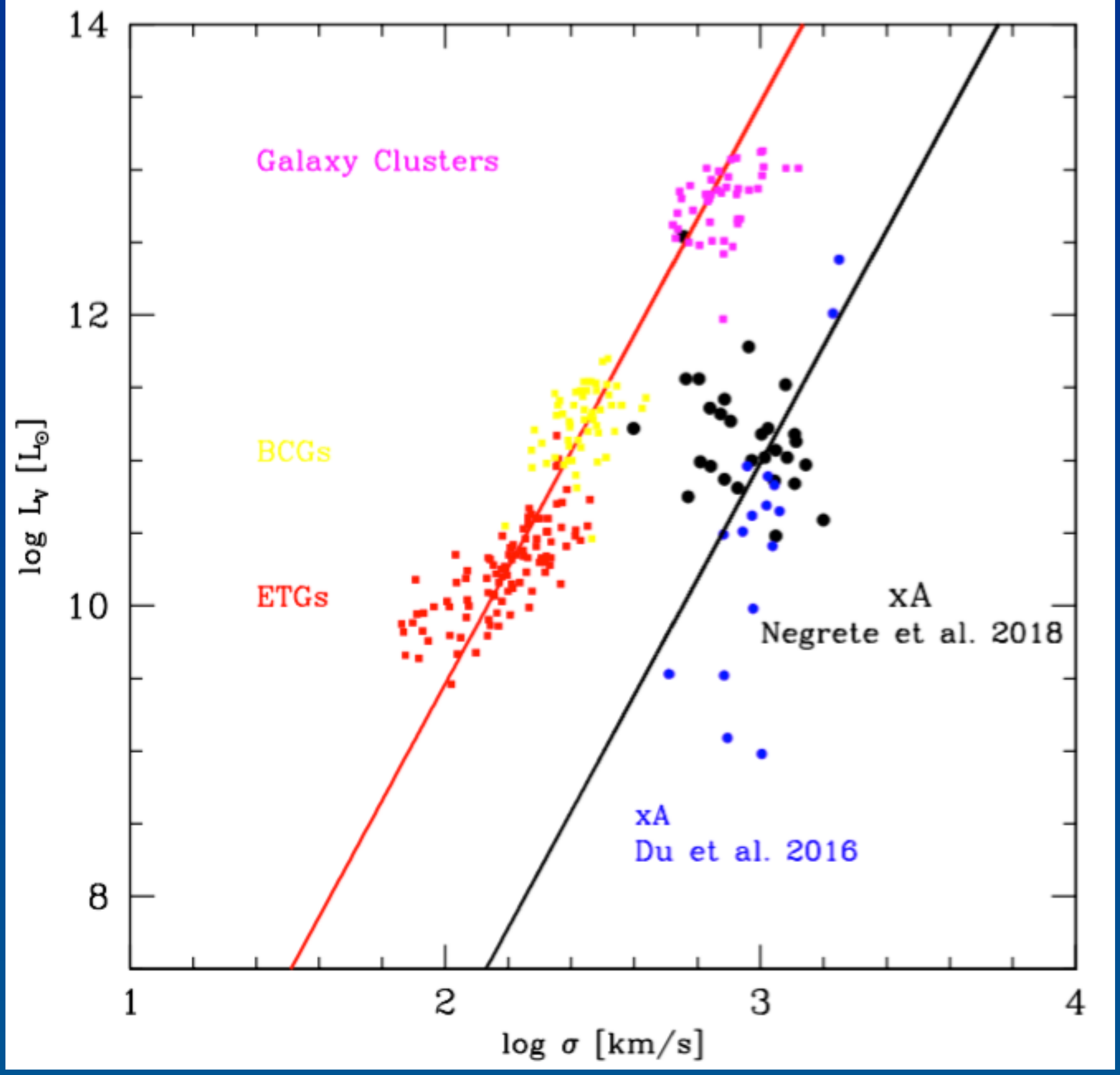
Extreme Population A: cosmological applications?

"Virial luminosity"

fraction of ionizing luminosity

$$L \approx 7.8\ 10^{44} \frac{\eta_1^2 \kappa_{0.5} f_2^2}{\bar{\nu}_{\mathrm{i}2.42\ 10^{16}}} \frac{1}{(nU)_{9.6}} \delta v_{1000}^4 \quad \mathrm{erg\ s^{-1}}$$

average frequency of ionizing photons

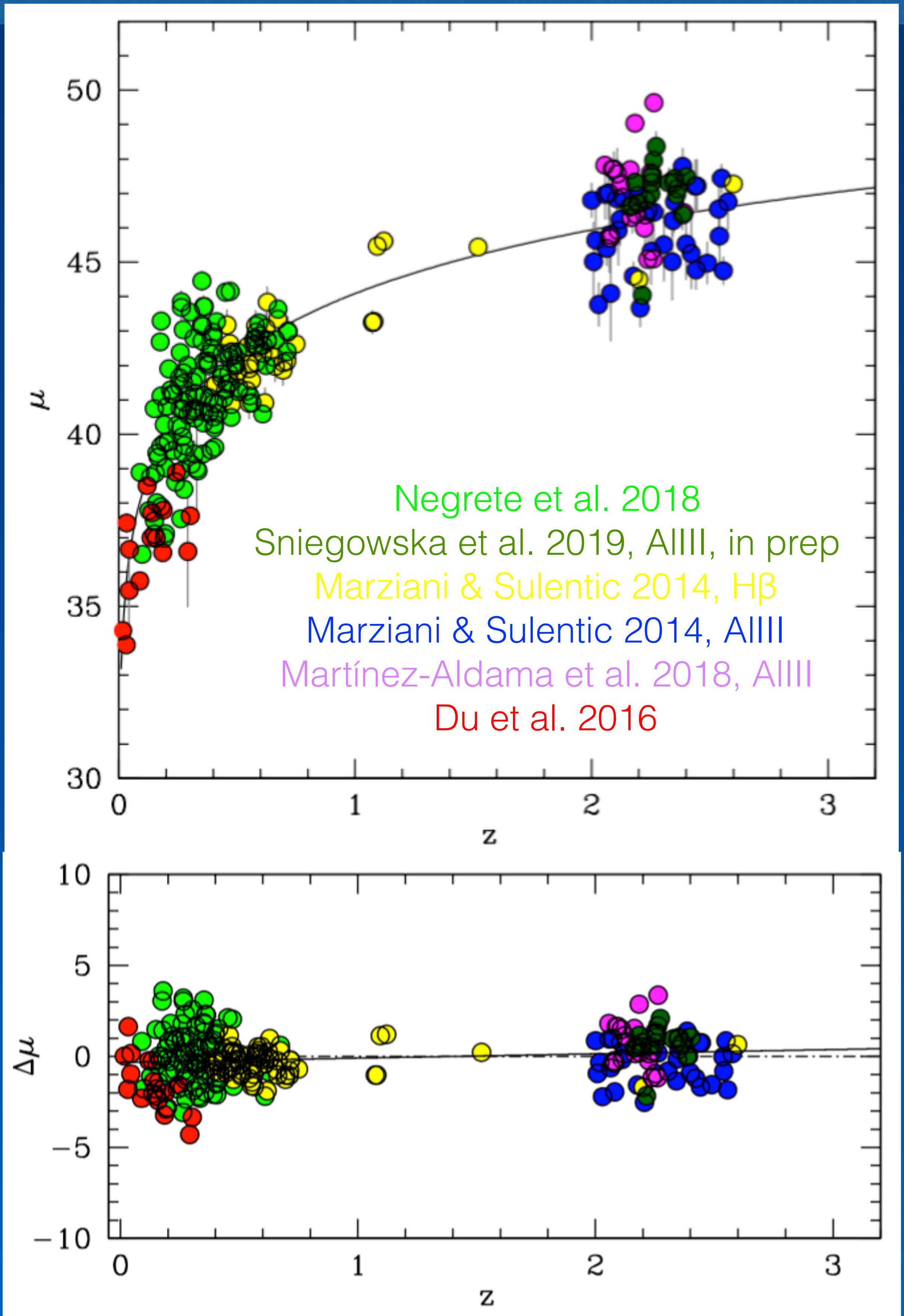


Analogous to the Tully-Fisher and the early formulation of the Faber Jackson laws for early-type galaxies; galaxies and even clusters of galaxies are virialized systems that show an overall consistency with an $L \propto \sigma^4$ law

Applicable to xA quasars ($L/L_{Edd} = \eta \Rightarrow 1$) over a wide range of luminosity and redshift

MS14; cf. Teerikorpi 2011

Extreme Population A: cosmological applications?

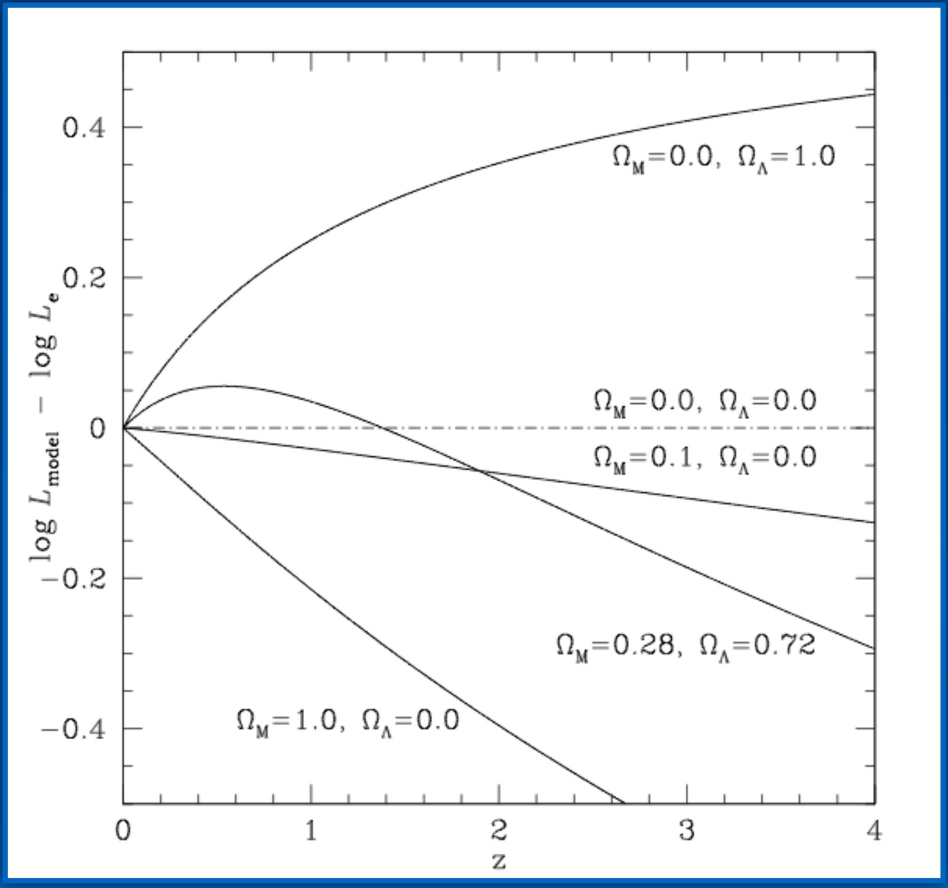


A Hubble Diagram for quasars: consistent with concordance ΛCDM

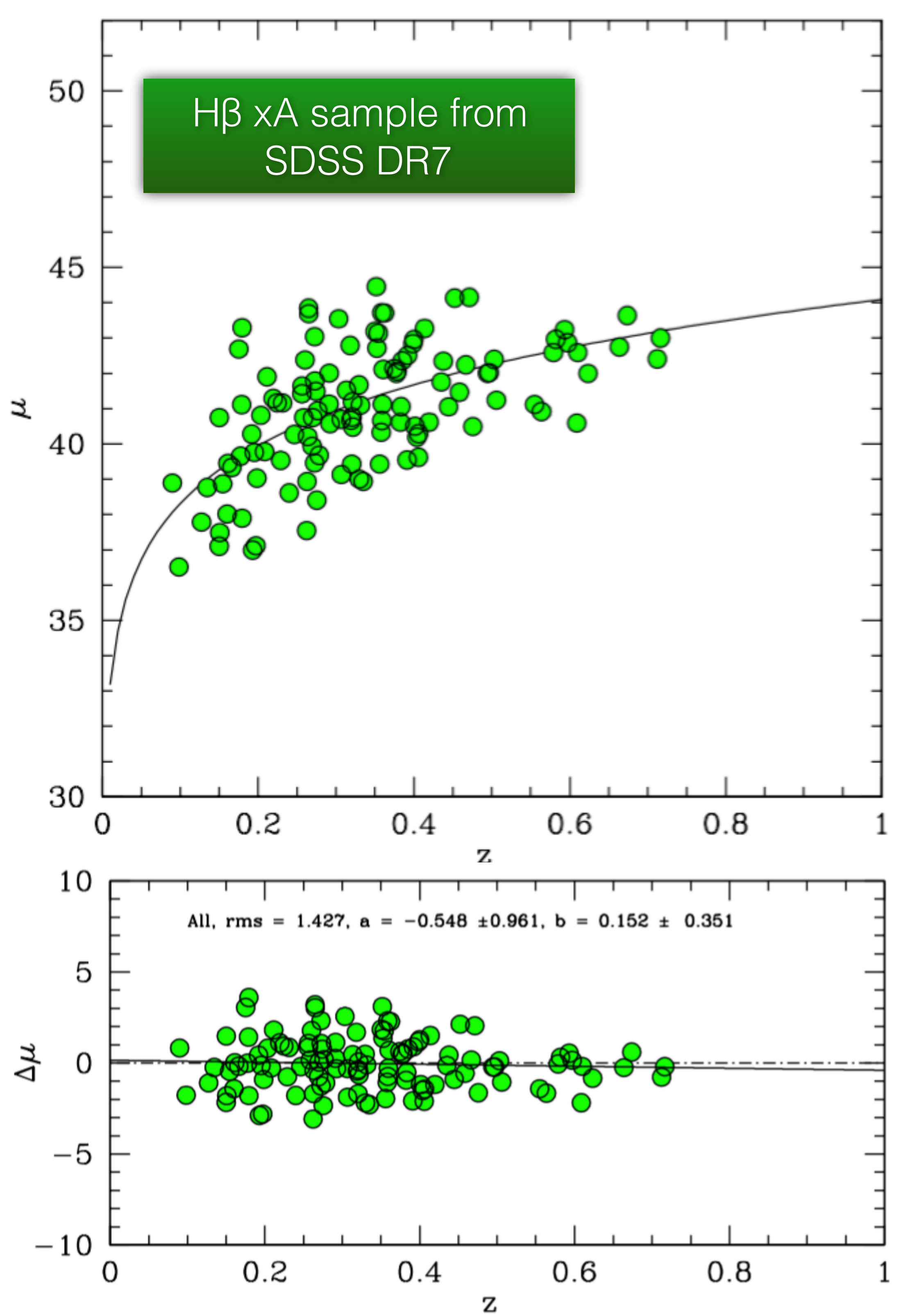
Significant scatter, $\sigma_{\Delta\mu}$ ~ 1.1 - 1.3 mag

Data already rule out extreme Universes (Ω_Λ=1,Ω_M=0) or the Einstein-de Sitter Universe

Data already provide significant constraints on Ω_M ($0.19^{+0.17}_{-0.08}$): the redshift range 2 - 3 is highly sensitive to Ω_M

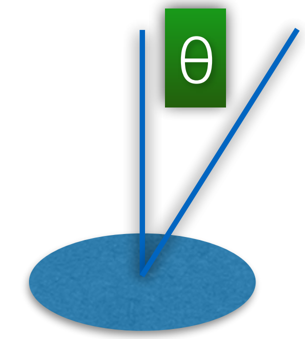


Extreme Population A: cosmological applications?

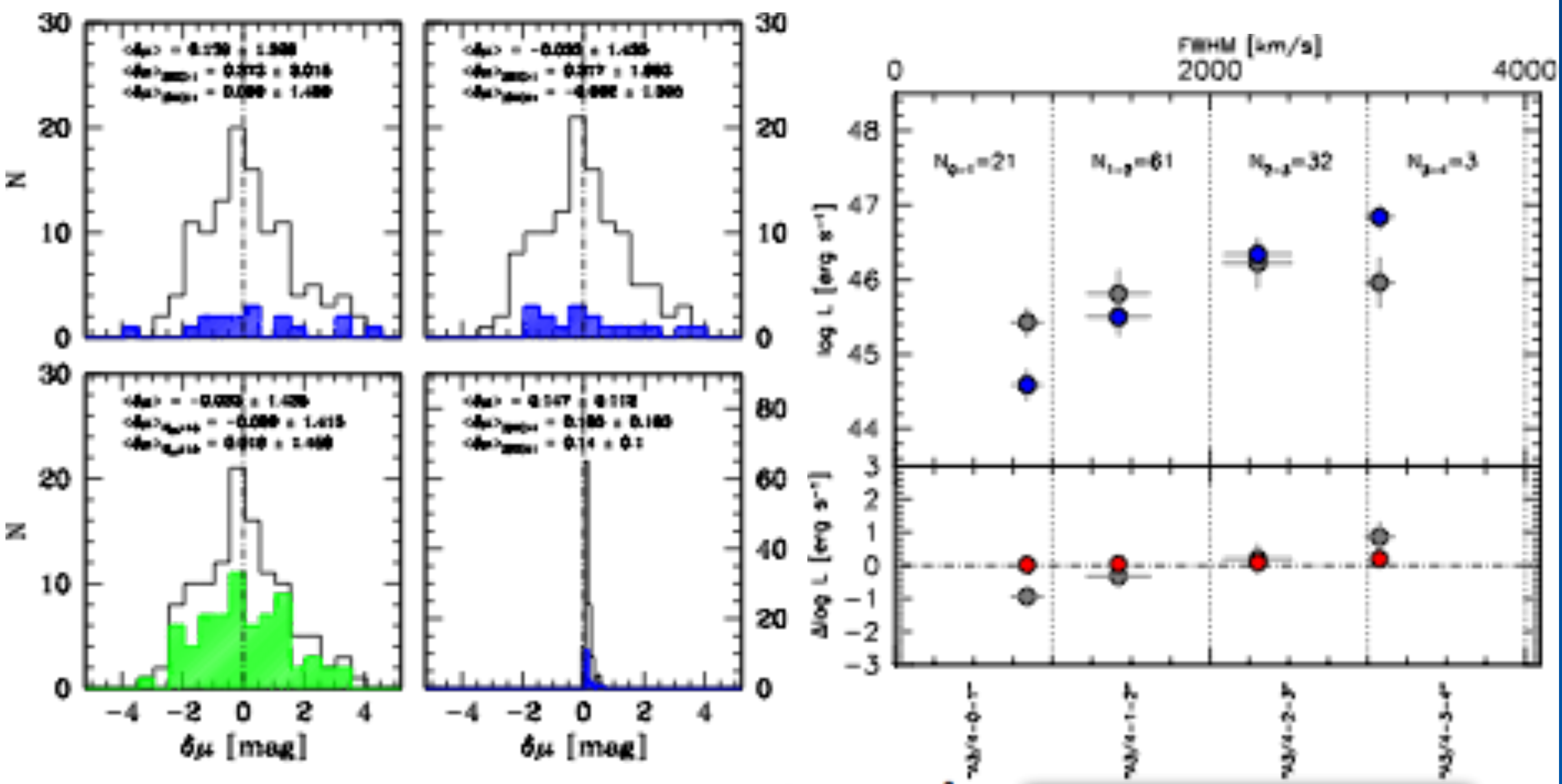


$$\delta\mu = \mu^{\rm vir} - \mu^{z} = 2.5 \log L(FWHM) - 2.5 \log L(z, H_0, \Omega_M, \Omega_\Lambda).$$

Orientation dependent form factor
Highly flattened system



$$f_{\rm S} = \frac{1}{4\left[\frac{1}{3}\left(\frac{\delta v_{\rm iso}}{\delta v_{\rm K}}\right)^2 + \sin^2\theta\right]} \qquad M_{\rm BH} = f_{\rm S}\frac{rFWHM^2}{G}$$



$$\delta \log L = \log 16 \mathcal{L}_0^{\bullet} \delta v_{\rm K}^4 \left[\frac{\kappa^2}{3} + \sin^2\theta\right]^2 - \log\left[\frac{L_0(z, H_0, \Omega s)}{2}\cos\theta\frac{(1+\beta\cos\theta)}{1+\beta} + \frac{L_0(z, H_0, \Omega s)}{2}\right],$$

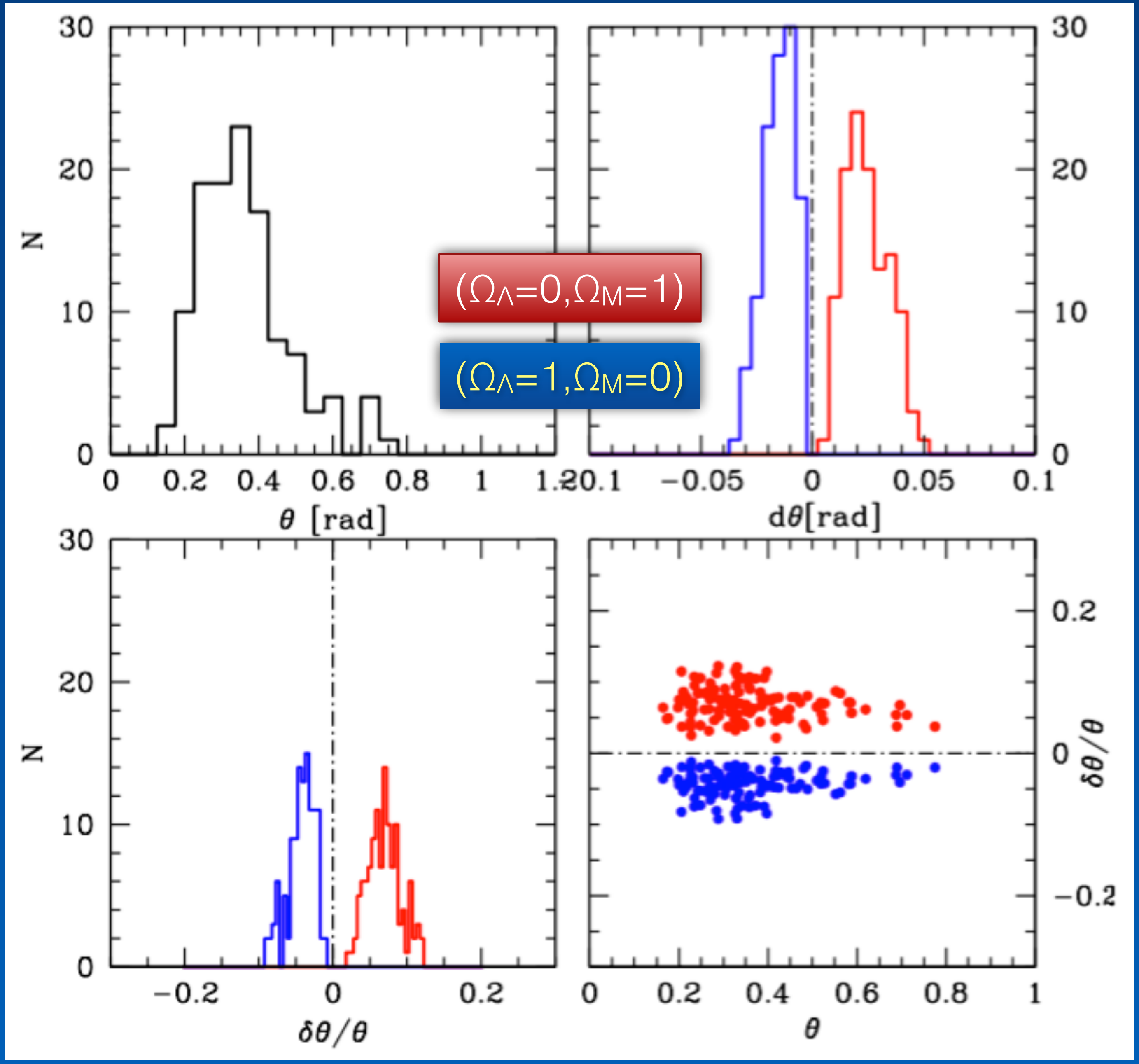
δlogL -> θ.

Difference between virial and concordance L estimate

Orientation accounts for most of the scatter if lines are emitted in a flattened system (k~0.1).

Negrete et al. 2018; cf. Afanasiev, Popovic, et al. 2018 from spectropolarimetry)

Make θ estimates independent from the cosmology



The assumption of extreme cosmologies yield modest differences in θ estimates, dθ<0.05 rad.

Randomization and de-correlation should make the estimate of the viewing angle independent from the cosmology and strongly reduce the scatter in the Hubble diagram.

A full Bayesian analysis is in progress.

Work to improve the accuracy of black hole mass and Eddington ratio using θ is in progress.

Conclusion

The MS offer contextualization of quasar observational and physical properties.

Extreme Population A (xA) quasars at the high R_{FeII} end of the MS appear to radiate at extreme L/L_{Edd}. Low ionization lines are apparently emitted in a highly-flattened, virialized BLR.

xA quasars show a relatively high prevalence (10%) and are easily recognizable. They might be suitable as “Eddington standard candles” especially if orientation effects can be accounted for.