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# A main sequence for quasars

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in collaboration with

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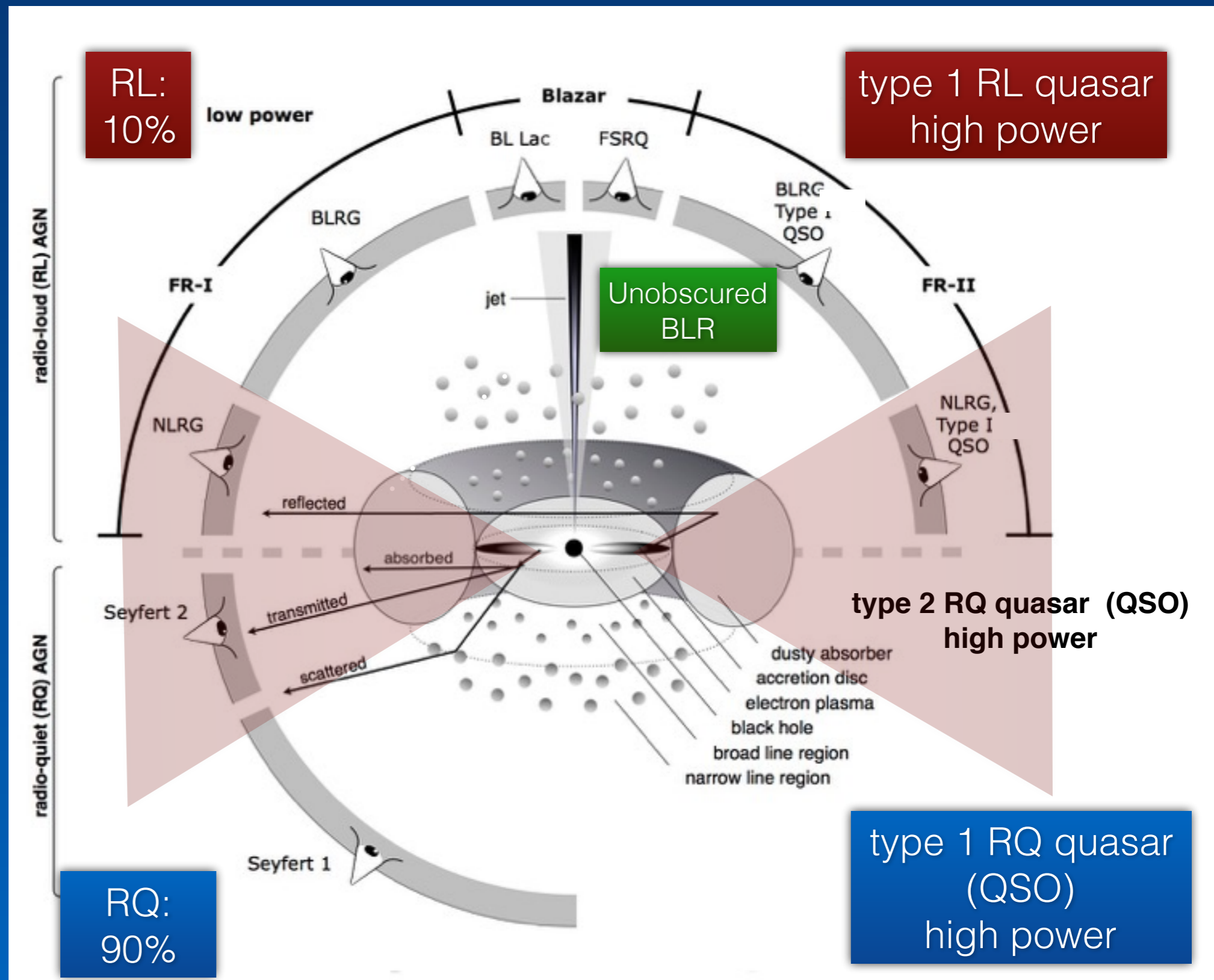
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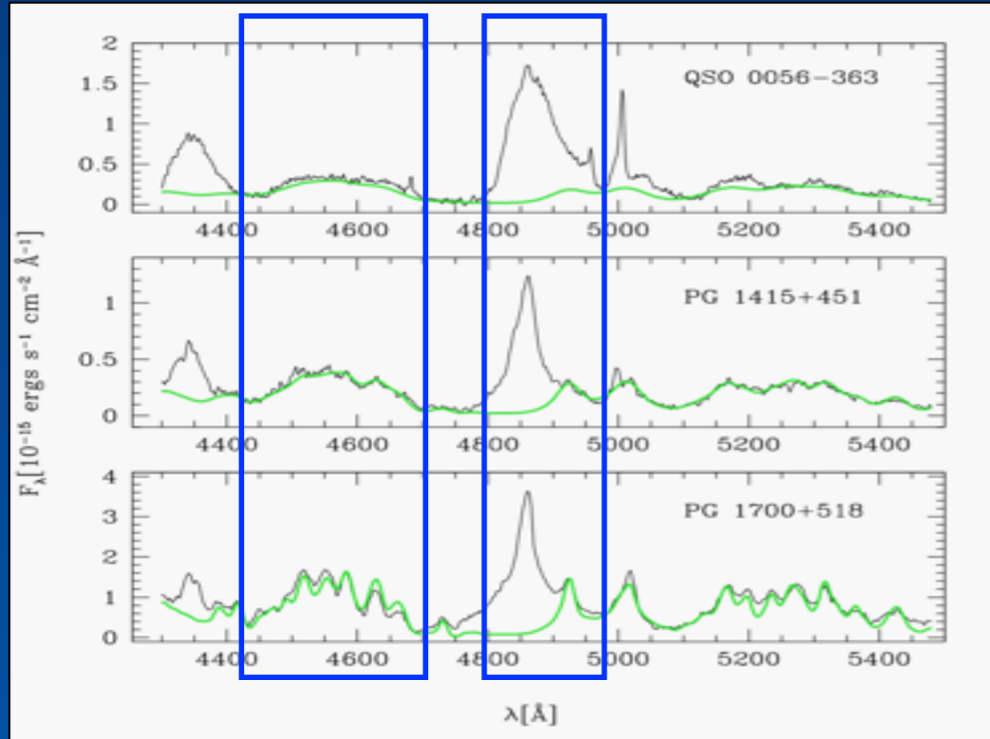
# Introduction: quasar unification scheme(s)

Luminous Seyfert 1 and quasars (i.e., of **type-1 AGN**;  $\log L > 43$ ) are mainly unobscured accretors, offering an unimpeded view of the broad line emitting region (BLR).



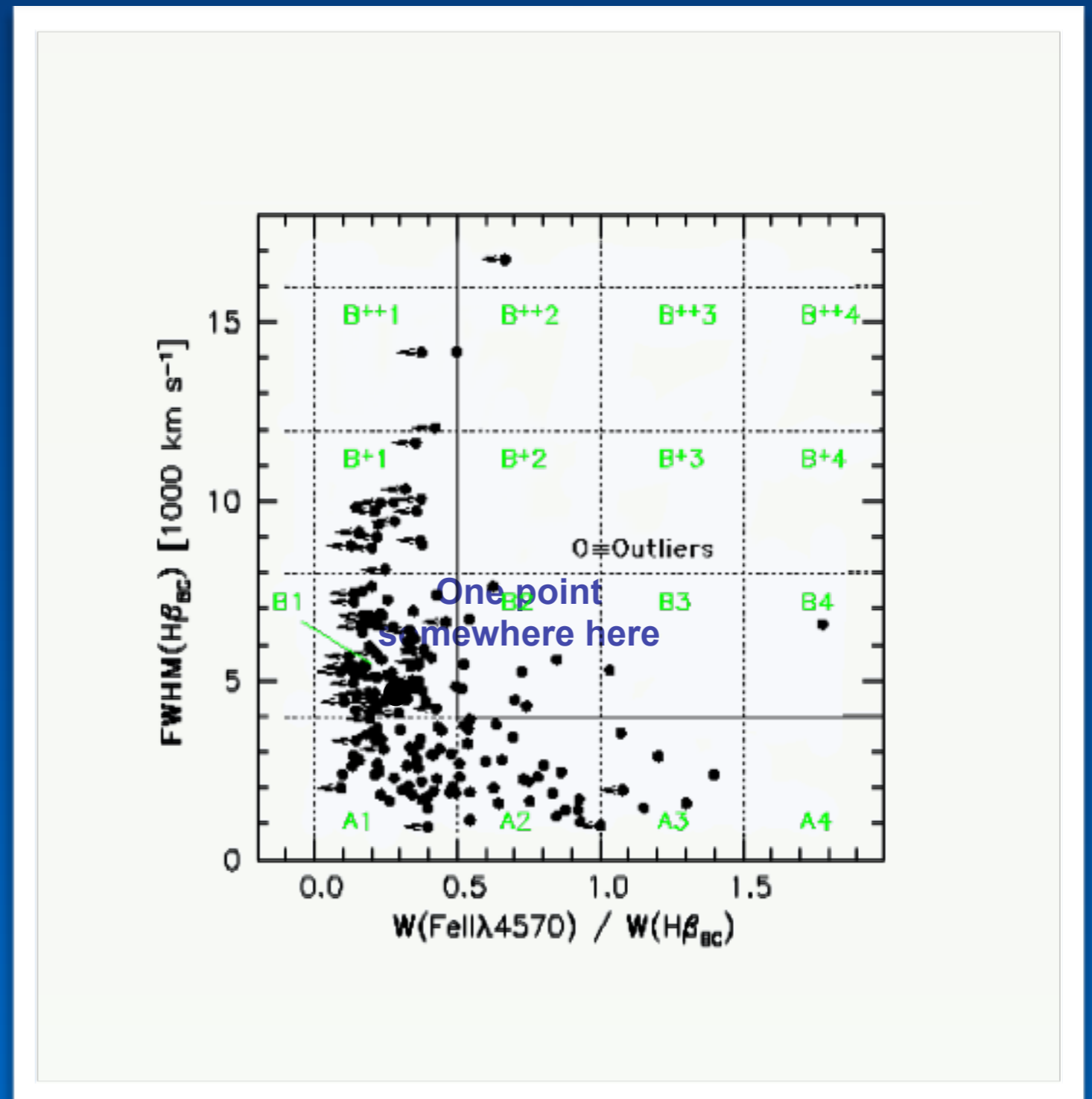
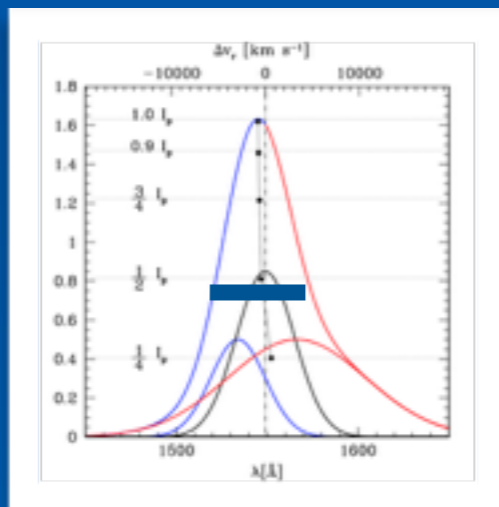
# Introduction: quasar unification scheme(s)

## Prediction of unification schemes on spectral properties of type-1 AGN

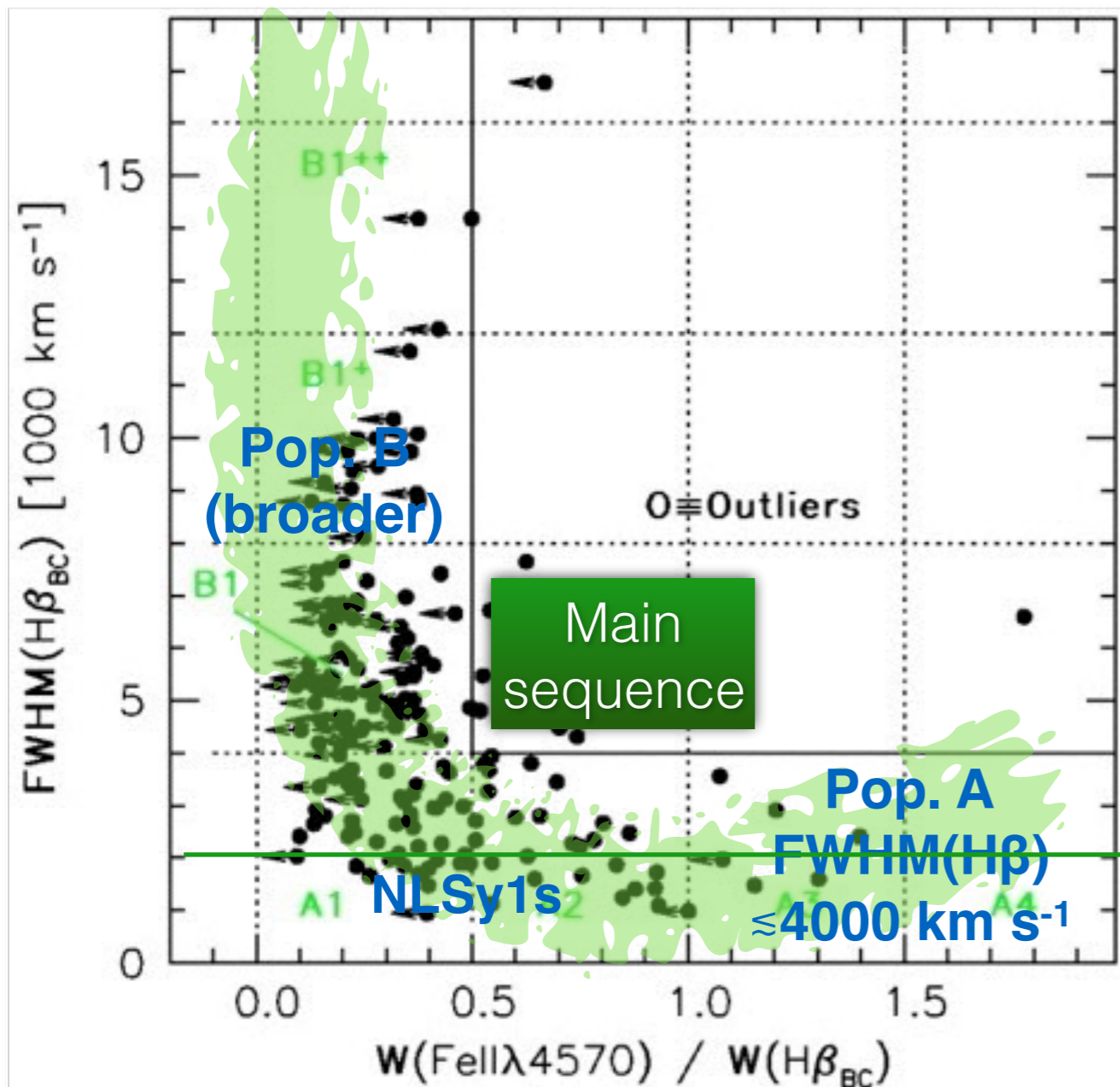


$$R_{\text{FeII}} = \frac{I(\text{FeII}\lambda 4570)}{I(\text{H}\beta)} \approx \frac{W(\text{FeII}\lambda 4570)}{W(\text{H}\beta)}$$

$FWHM(\text{H}\beta)$



# The quasar Eigenvector 1: a main sequence for quasars



Principal Component Analysis (PCA):  $n \times m$  matrix with  $m$  parameters for  $n$  objects finds axes in  $m$ -dimensional space that maximize projection onto vectors.

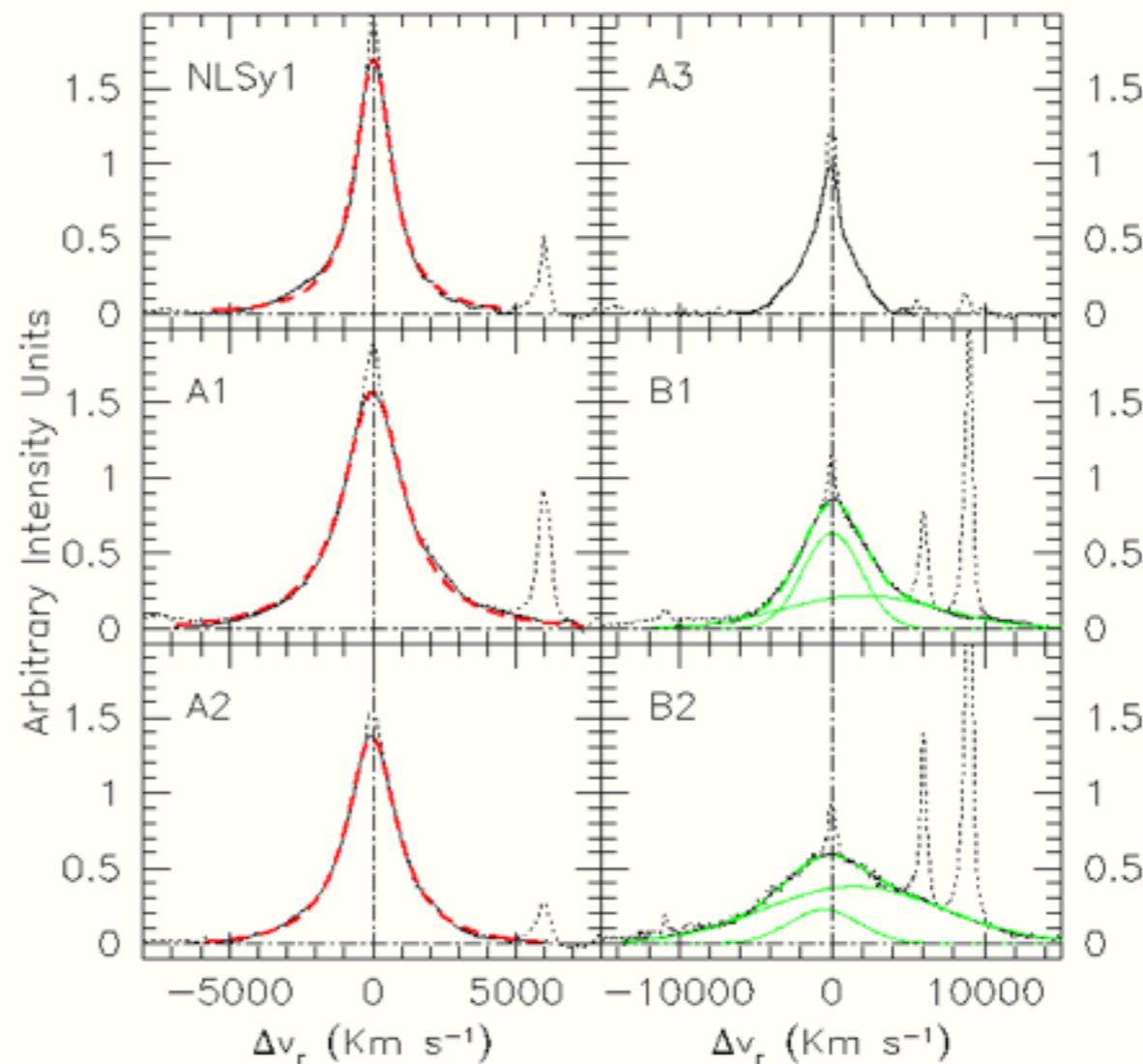
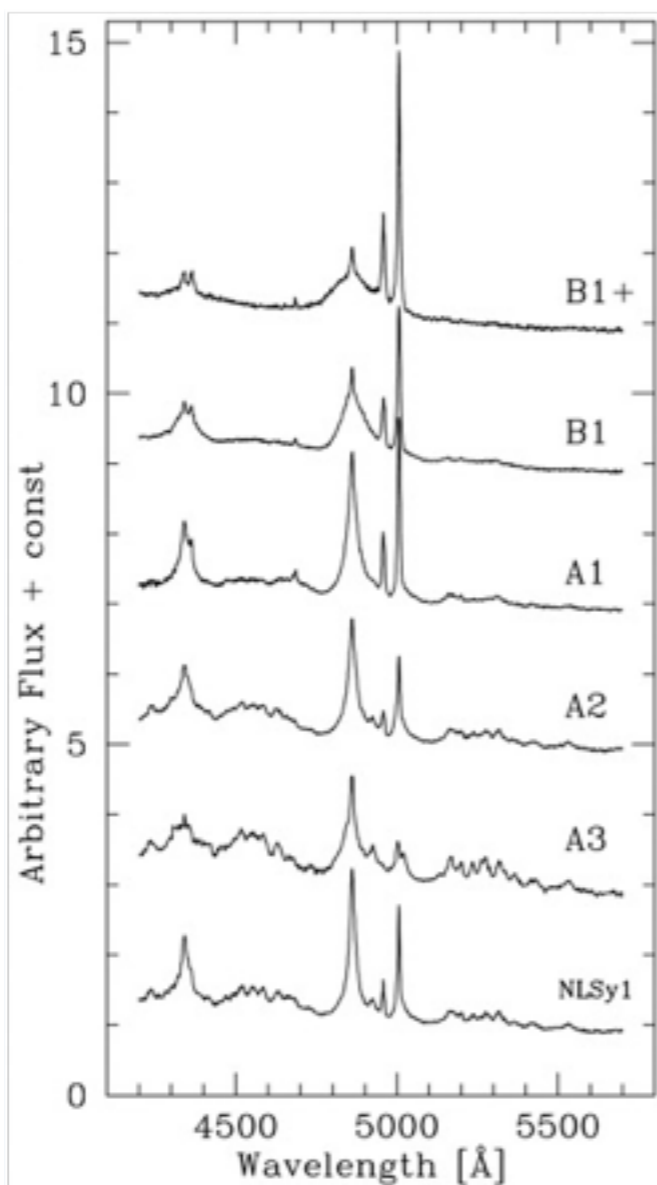
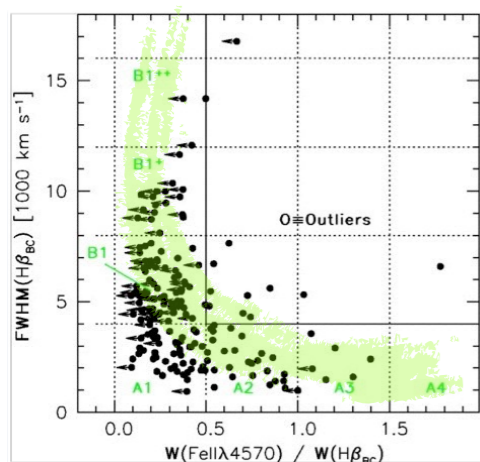
Eigenvector 1: Originally defined by a PCA of PG quasars (Boroson & Green 1992), and associated with an anti-correlation between **strength of Fe II  $\lambda 4570$**  (or [O III] 5007 peak intensity) and **width of H $\beta$** .

The E1 main sequence (MS) allows for the definition of spectral types.

Since 1992, E1 has been found in increasingly larger samples with multifrequency parameters.

## MS Correlates: The H $\beta$ profile

Pop. A.: “Lorentzian” H $\beta$  profile, symmetric, unshifted;  
 Pop. B.: Double Gaussian (broad + very broad component H $\beta_{BC}$ +H $\beta_{VBC}$ ), most often redward asymmetric



Sulentic et al.  
 2002 ( $z < 1$ ,  $\log L < 47$  [erg/s])

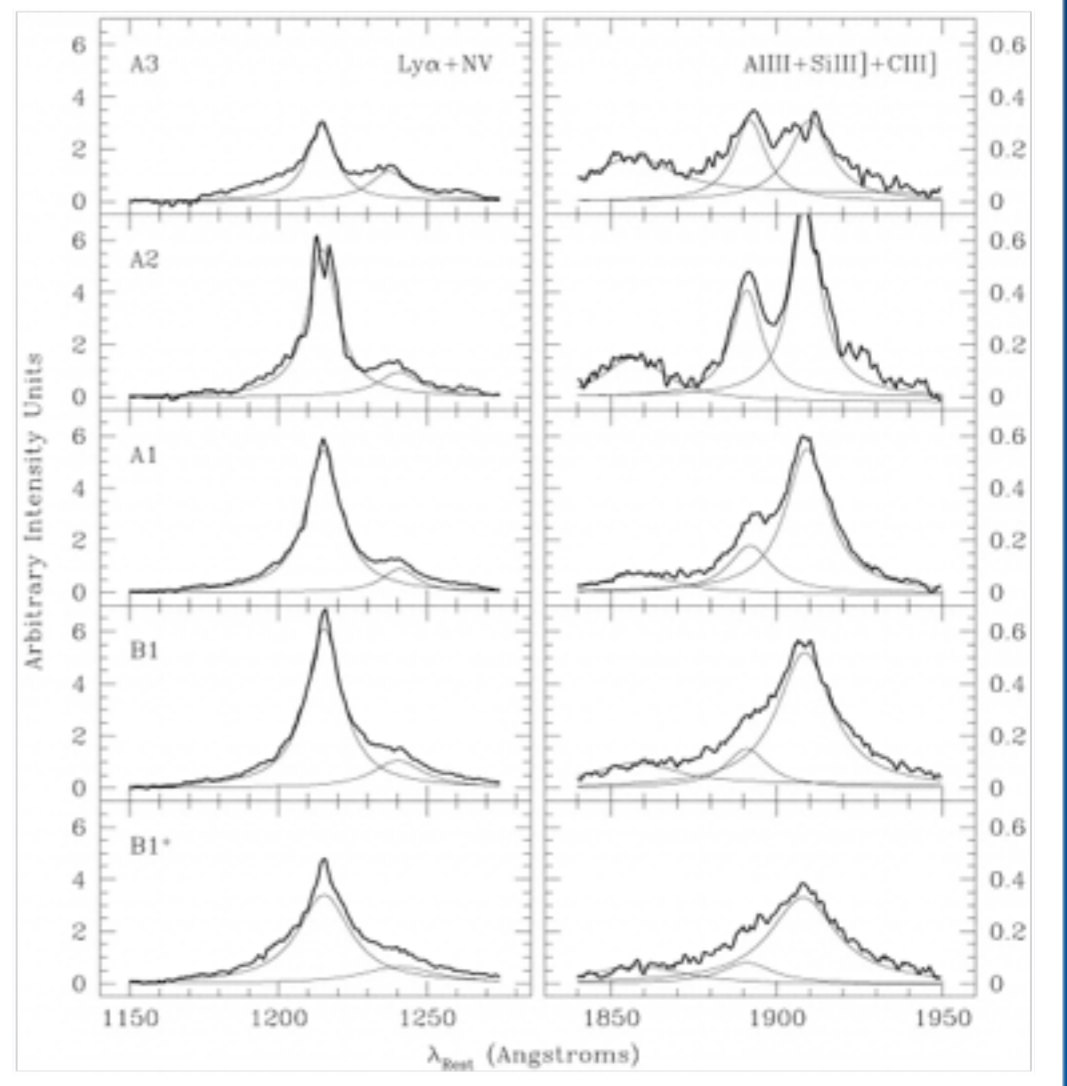
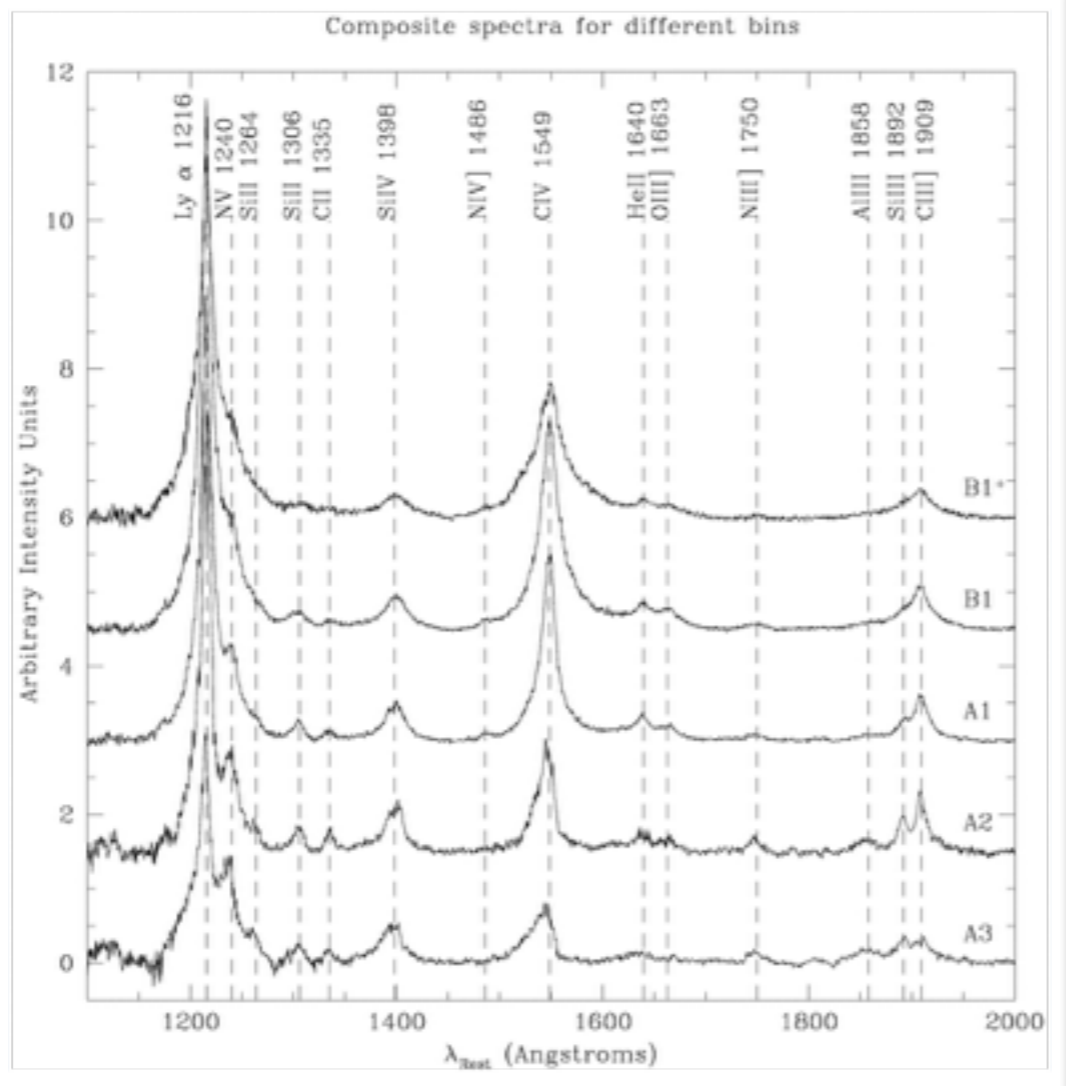
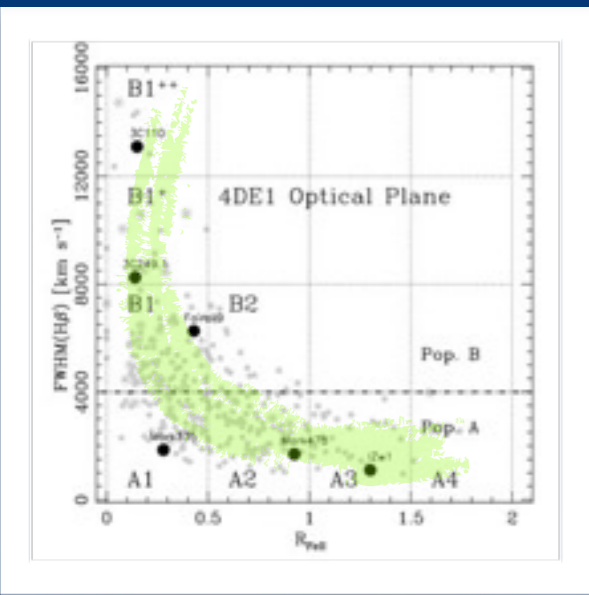
# MS correlates: UV lines

(B1<sup>++</sup> → A4) NVλ1240 ↑ AIIIλ1860 ↑ CIII]λ1909 ↓  
 NIII]1750 ↑ CIVλ1549 ↓

Metallicity- and density-sensitive emission line ratios  
 imply growth of density and metallicity toward A4

$n$ : AIIIλ1860/  
 SiIII]λ1892  
 SiIII]λ1892/  
 CIII]λ1909  
 $Z/Z_{\odot}$  NVλ1240/  
 CIVλ1549  
 NVλ1240/  
 Heλ1640

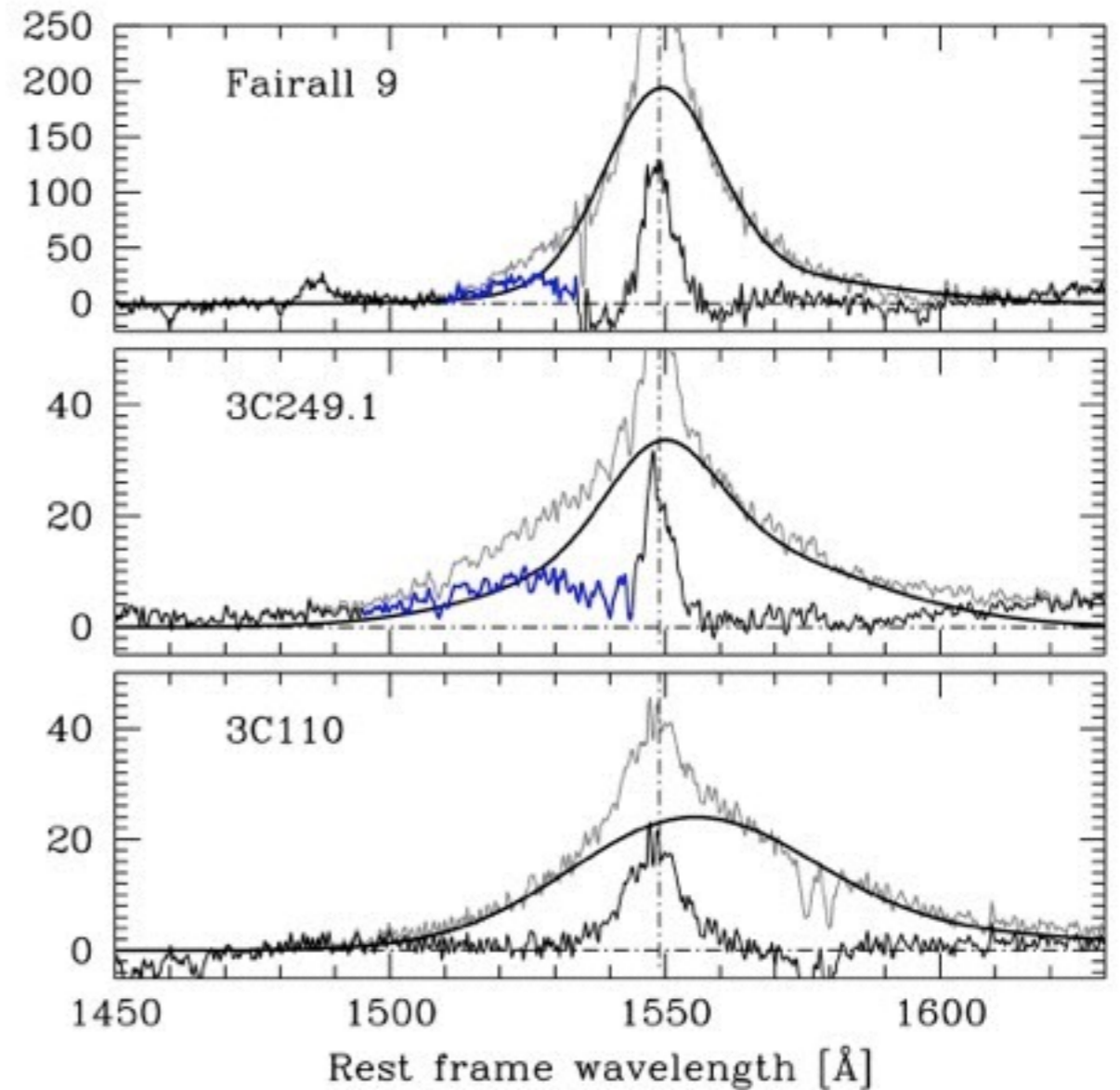
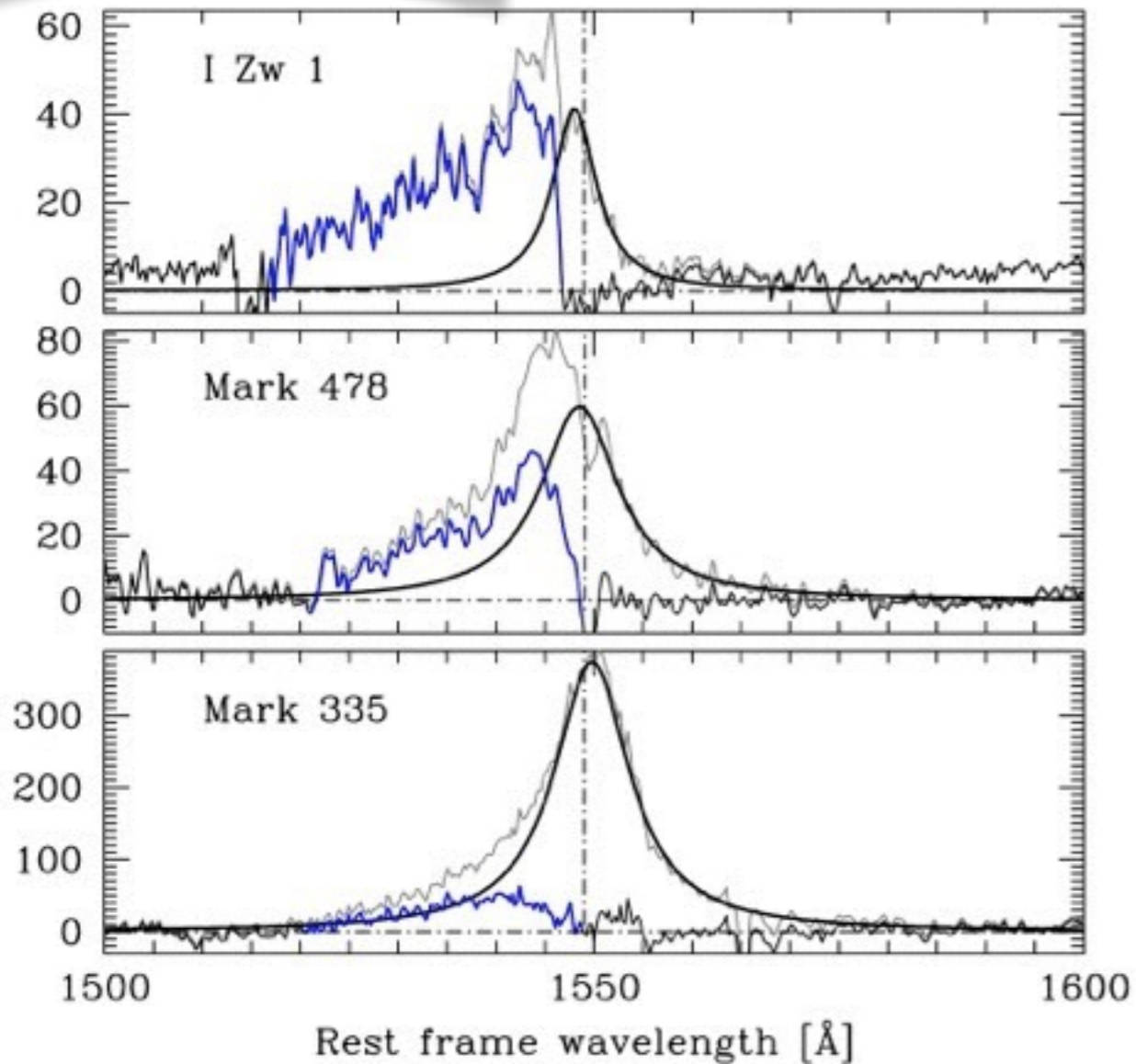
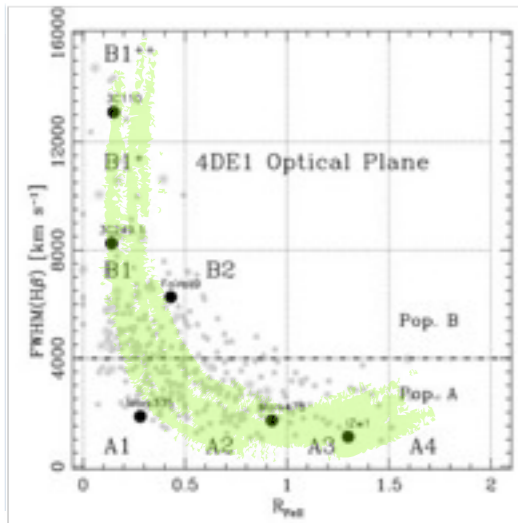
Bachev et al. 2004;  
 Negrete et al. 2012  
 HST/FOS composite  
 spectra of quasars at  
 $z < 0.7$ ; cf. Sulentic et al.  
 2015



# MS correlates: CIV emission line profile

The CIV $\lambda$ 1549 line profile:  
scaled H $\beta$  from + excess blueshifted emission  
virialized BLR symmetric + outflow/wind component

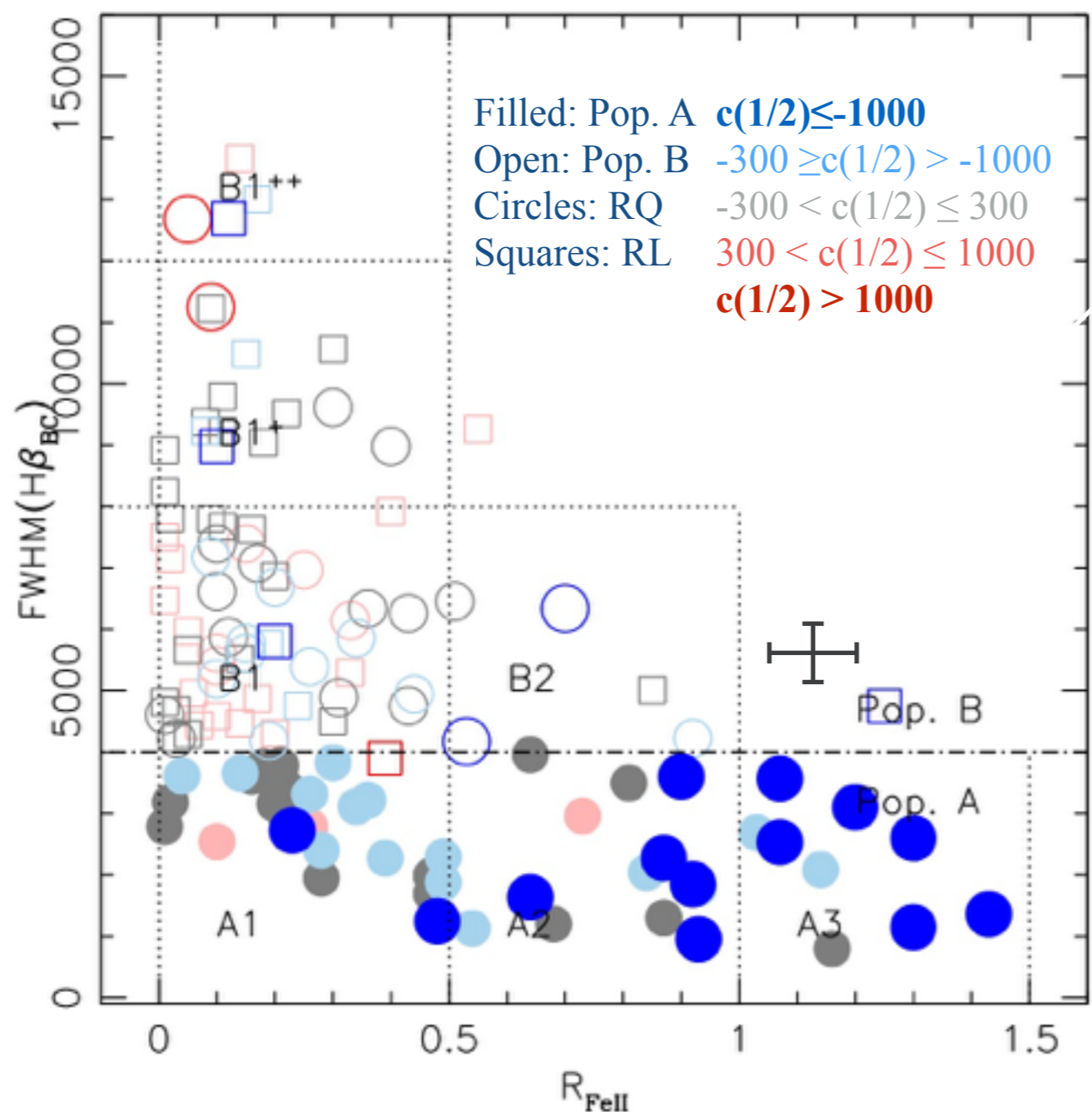
e.g., Leighly 2000, Bachev et al. 2004, Marziani et al. 2010; Denney et al. 2012



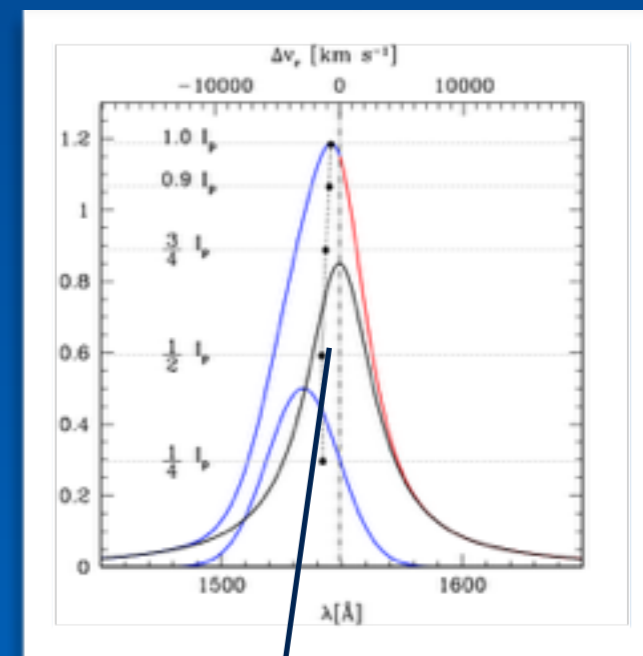


## MS correlates: CIV centroid

Large shift of CIV $\lambda$ 1549 centroid at  $\frac{1}{2}$  along the main sequence are found for  $\text{FWHM}(\text{H}\beta) < 4000 \text{ km s}^{-1}$



This result also reinforces the suggestion of a discontinuity at  $\text{FWHM}(\text{H}\beta) \approx 4000 \text{ km s}^{-1}$



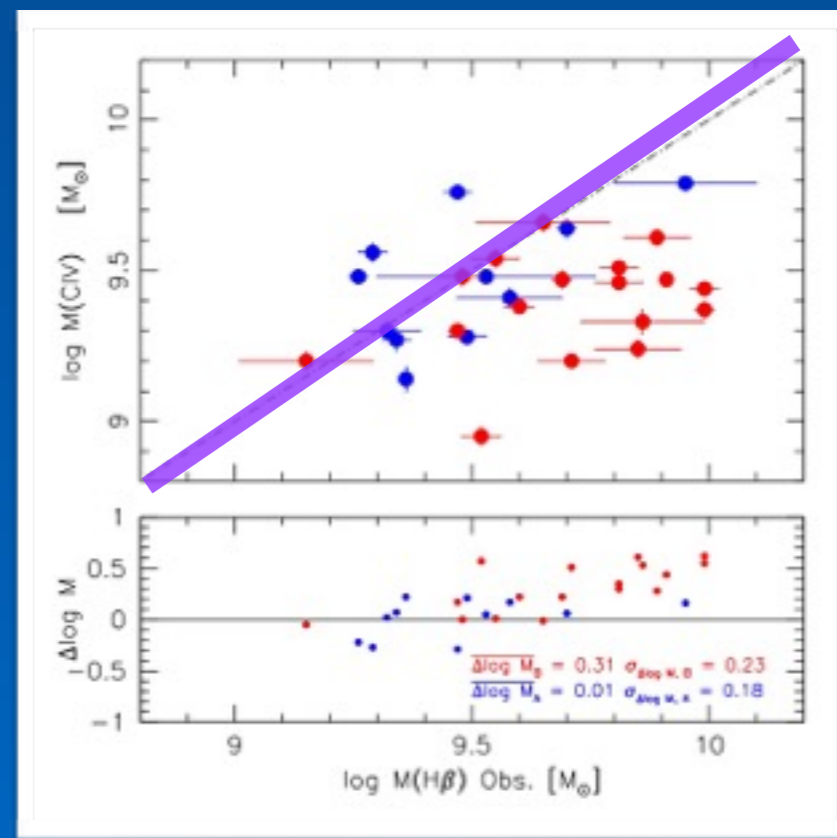
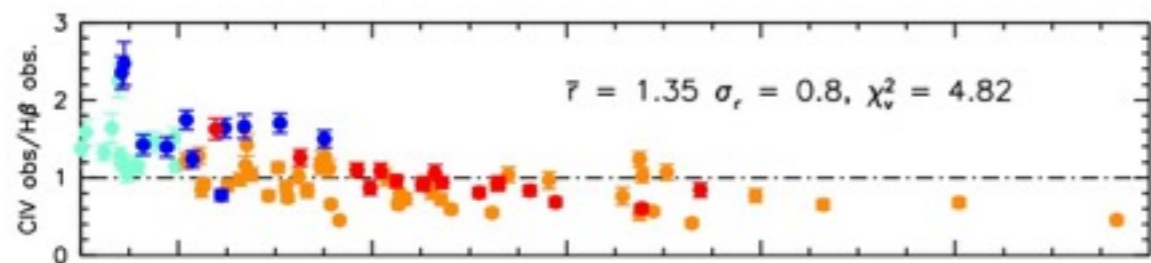
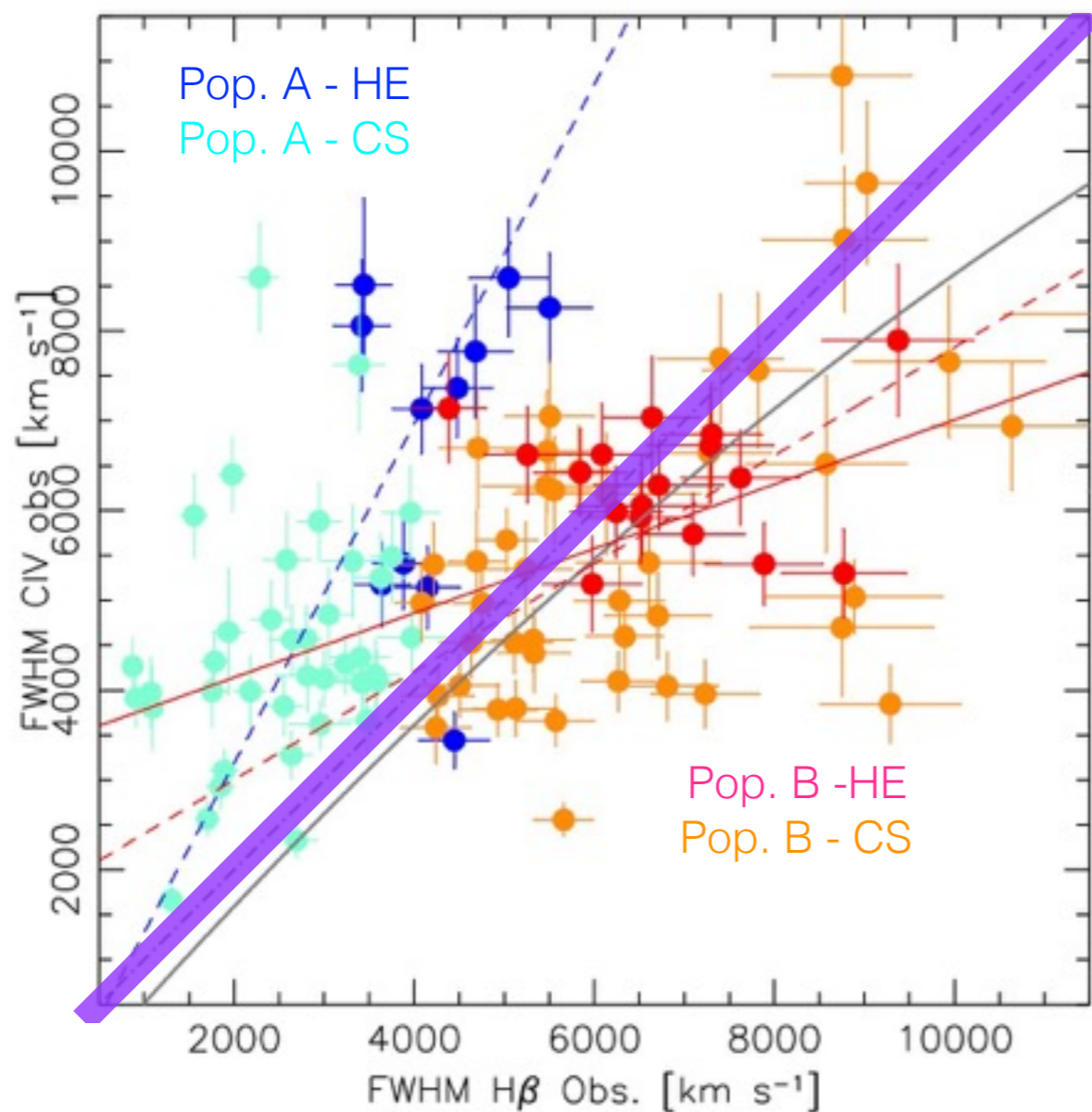
$c(1/2)$  CIV $\lambda$ 1549

## MS correlates: CIV centroid

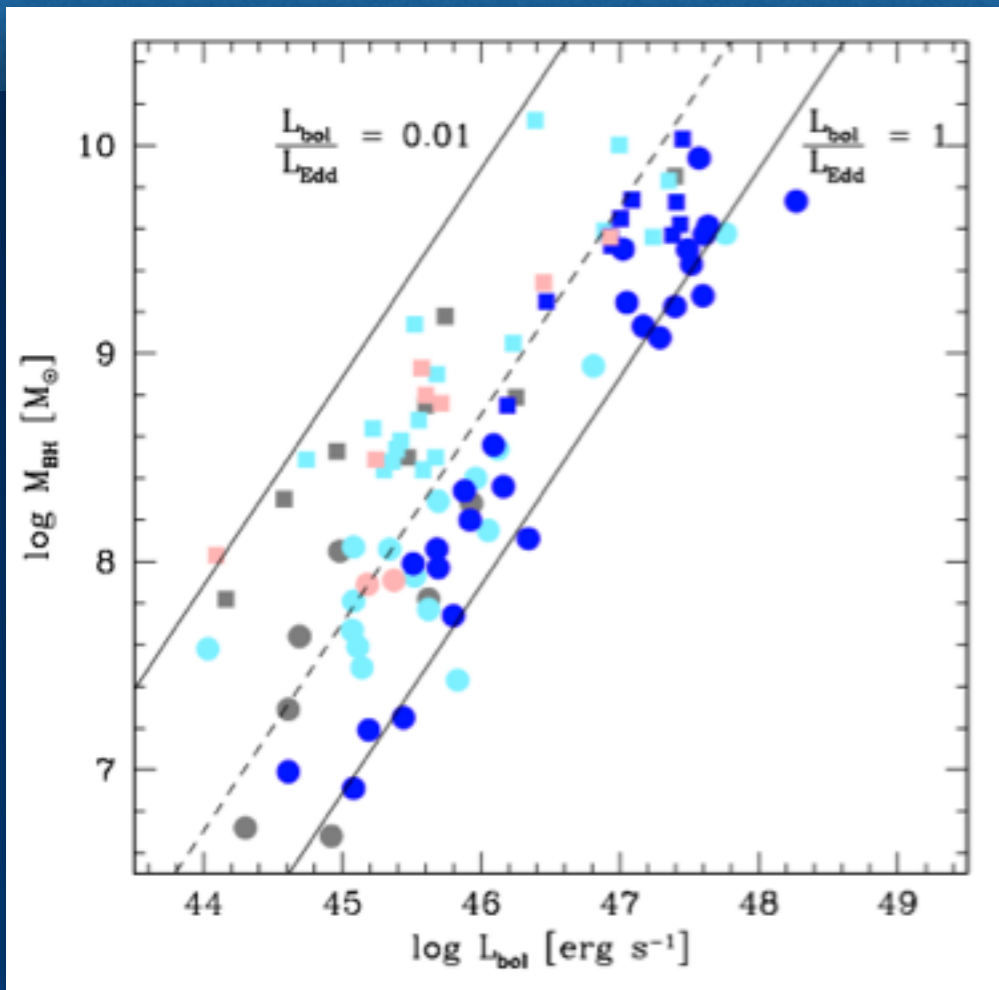
The CIV line width is not usable as a virial broadening estimator

FWHM(CIV $\lambda$ 1549) for Pop.A sources is always above equality line with H $\beta$ ; large scatter for Pop. B.

The Park et al. 2013 scaling: consistent  $M_{\text{BH}}$  estimates only for Pop. A, assuming  $M_{\text{BH}} \propto \text{FWHM}^{0.5}$

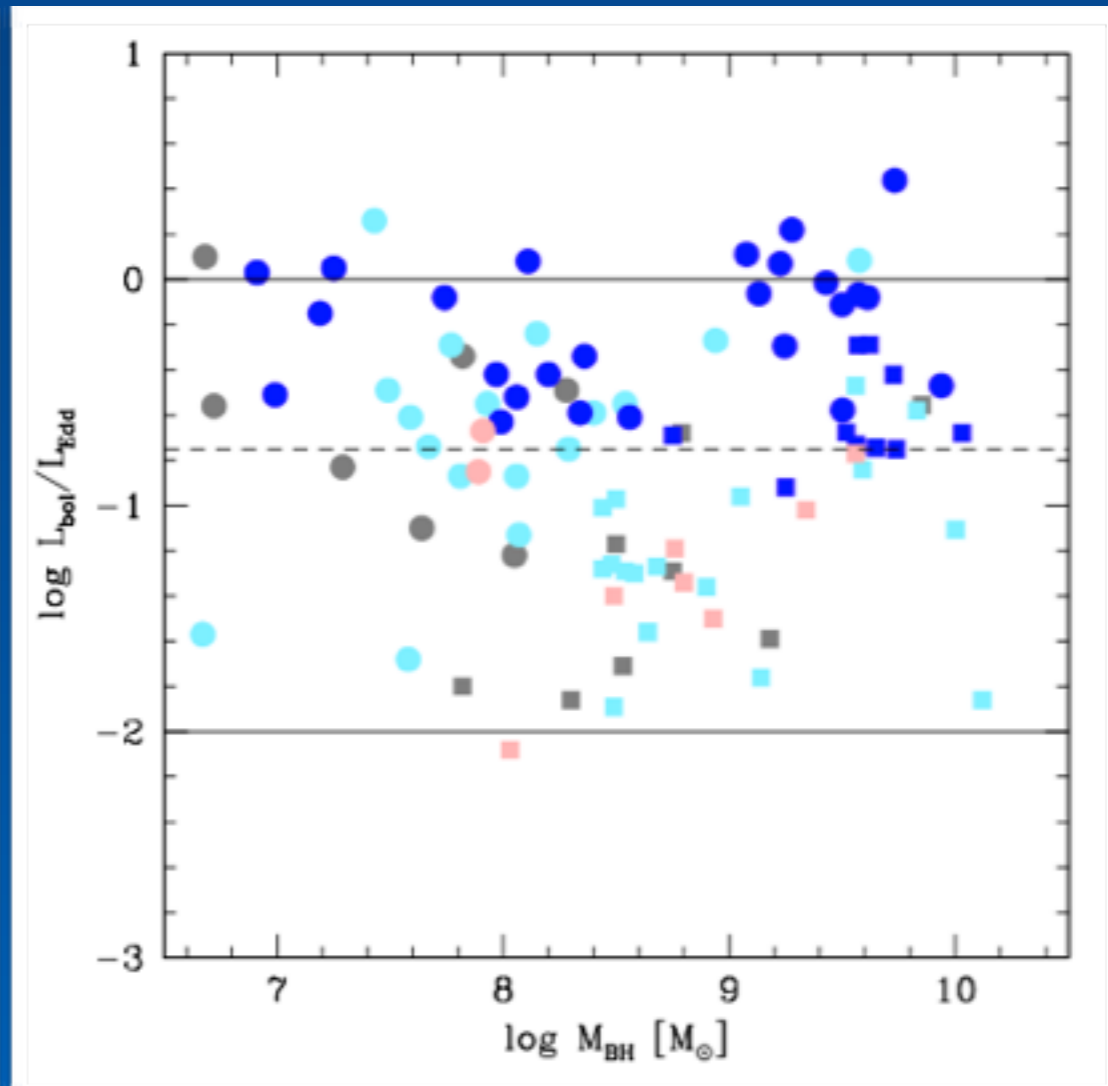
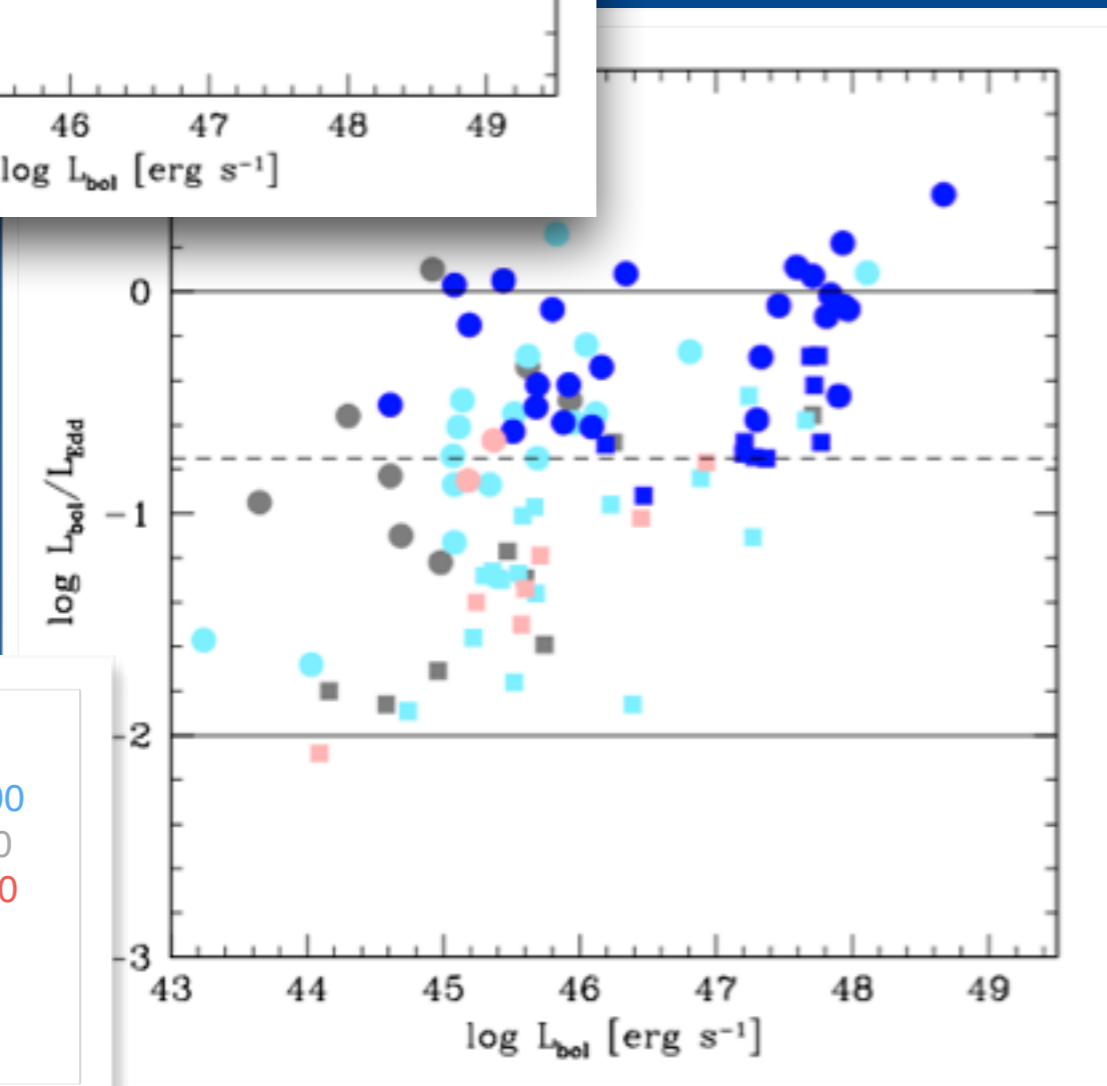


MS “correlates:” Eddington ratio



Largest CIV $\lambda$ 1549 blueshifts are observed at high  $L/L_{\text{EDD}}$  but not necessarily at high  $M_{\text{BH}}$  or high  $L$

FOS + high L HE sample of 28 objects Sulentic et al. 2016, submitted



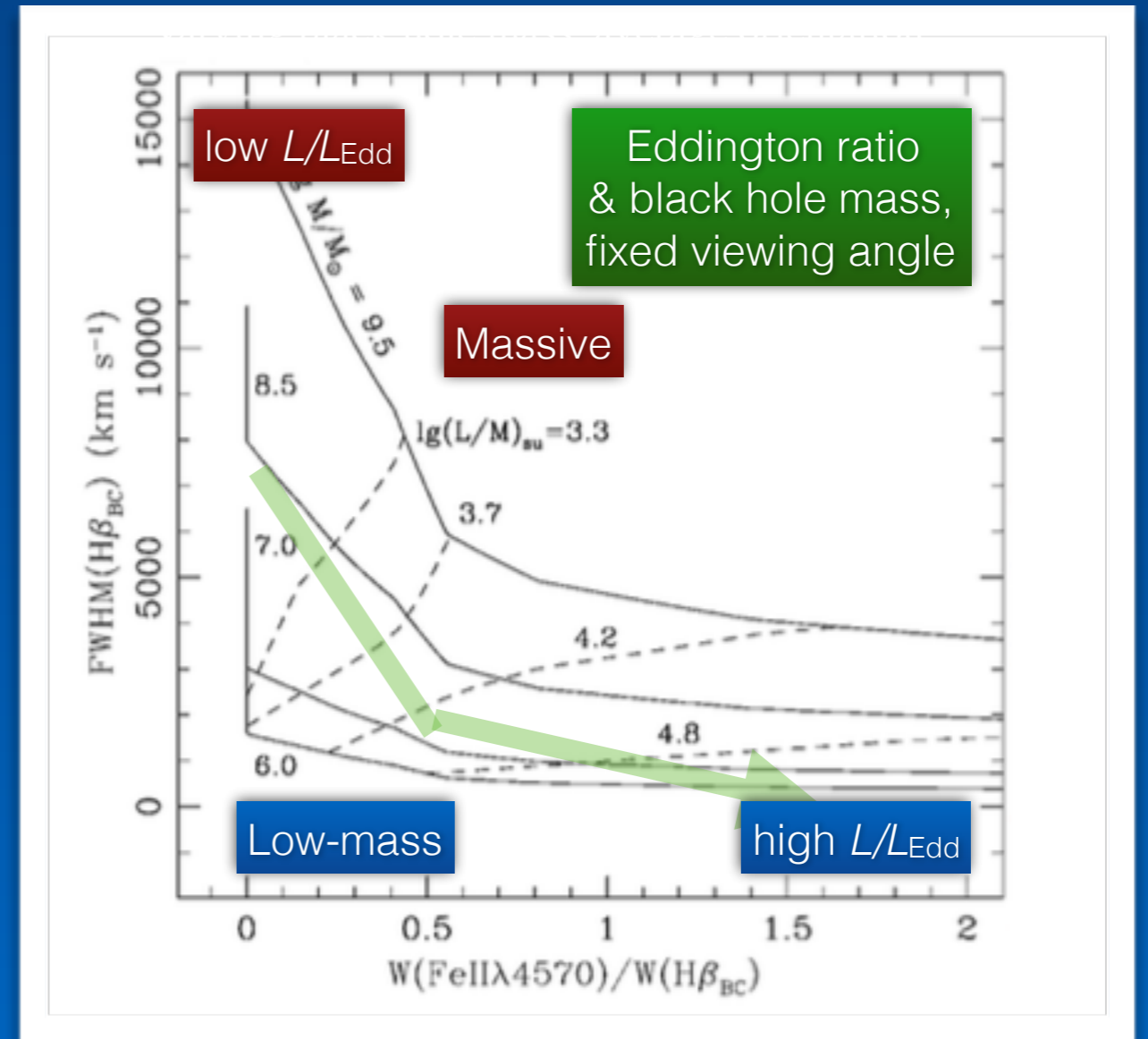
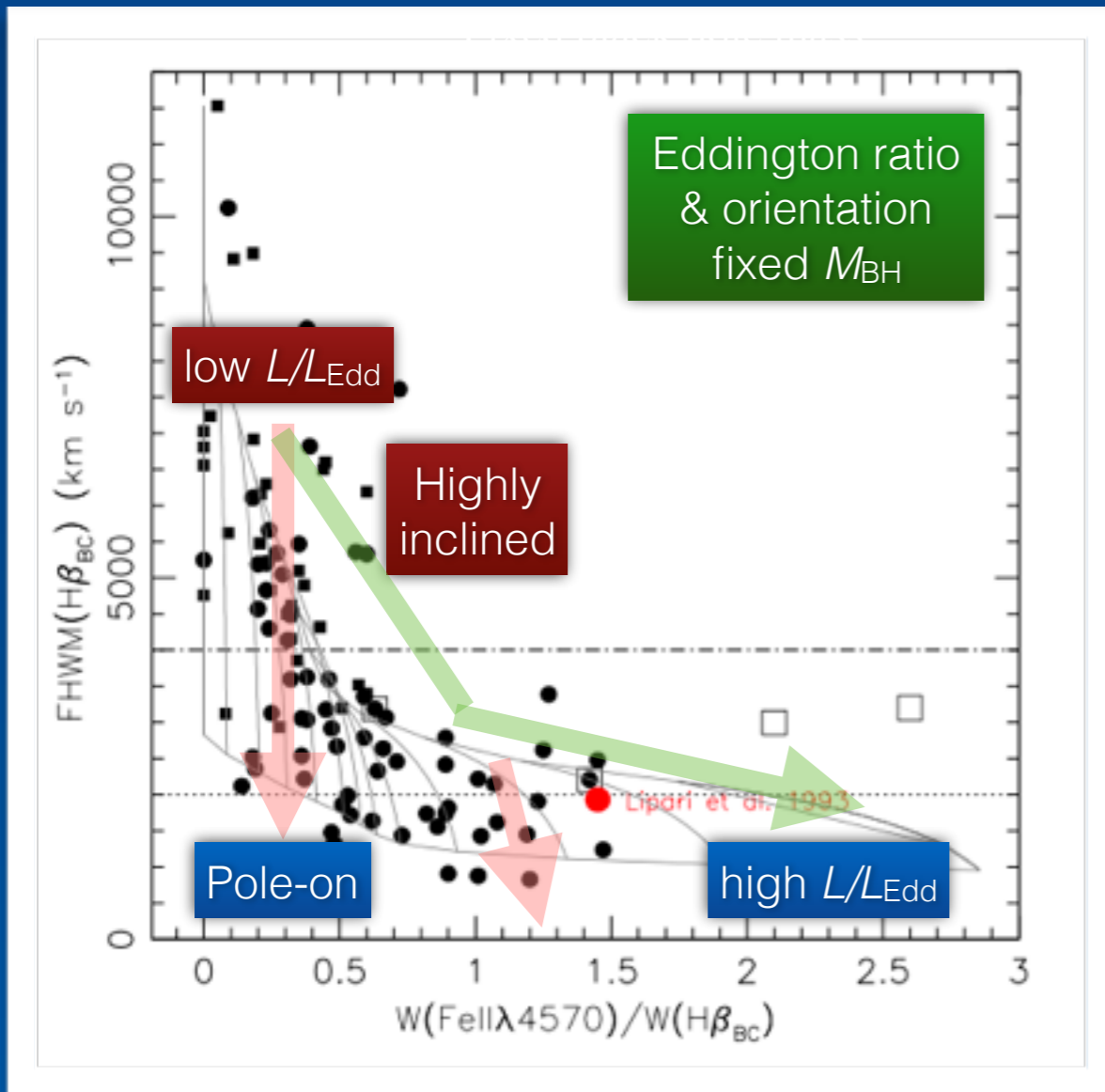
**$c(1/2) \leq 1000$**   
 $-300 \geq c(1/2) > -1000$   
 $-300 < c(1/2) \leq 300$   
 $300 < c(1/2) \leq 1000$   
 **$c(1/2) > 1000$**   
 Circles: Pop. A  
 Squares: Pop. B

# The MS: Governing physical parameters

MS: mainly a sequence of Eddington ratio

Ionization parameter  $U \propto L/r_{\text{BLR}}^2 n \propto L^{1-2a}/n \propto L^{1-2a}/\text{FWHM}^{1.33}$   
 $U \rightarrow R_{\text{FeII}} \propto (L/M)^{-(1+x)} M^{-1}$  written as a function  $L/M_{\text{BH}}$  and  $M_{\text{BH}}$ , considering  $r_{\text{BLR}} \propto L^a$ ,  $n \propto \text{FWHM}^{1.33}$  (empirical relation)

Occupation reproduced assuming flattened geometry,  
 $\text{FeII} \propto \sec \theta$ ;  $\text{FWHM}^2 \propto \delta v_{\text{iso}}^2 + \delta v_{\text{rot}}^2 \sin^2 \theta$



## MS correlates: Two populations

Separation of Population A (FWHM  $H\beta < 4000$  km/s) and Population B (roadier) sources.

At low  $z (< 0.7)$  Pop. A: low  $M_{BH}$ , high  $L/L_{EDD}$ ; Pop. B: high  $M_{BH}$ , low  $L/L_{EDD}$ ; a reflection of the “downsizing” of nuclear activity

**Table 1. MAIN TRENDS ALONG THE 4DE1 SEQUENCE**

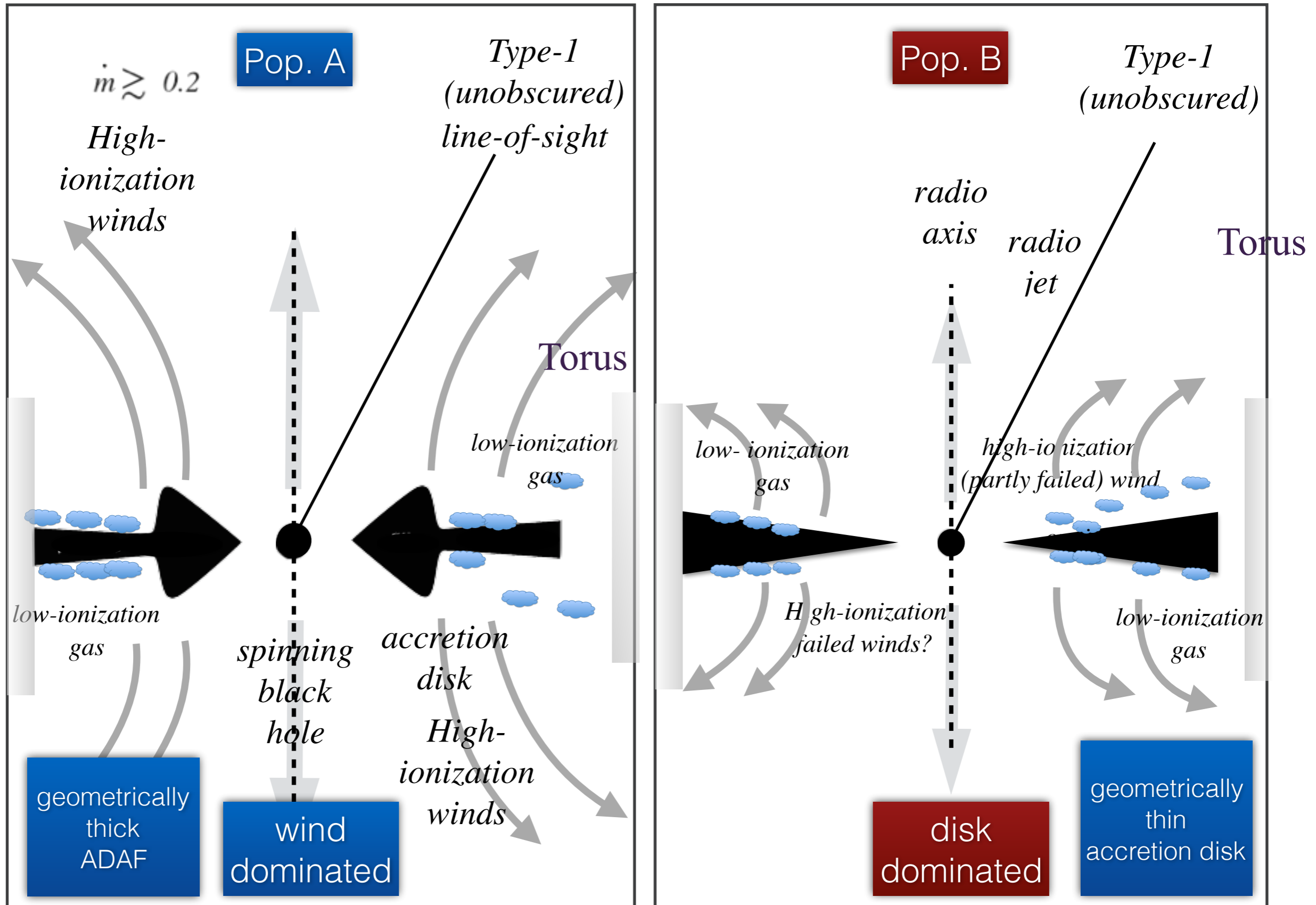
Parameter	Population A	Population B	References
FWHM( $H\beta_{BC}$ )	800 – 4000 km s <sup>-1</sup>	4000 – 10000 km s <sup>-1</sup>	1, 2, 3, 4
$R_{Fe}$	0.7	0.3	1, 2
$c(\frac{1}{2})$ CIV $\lambda$ 1549 <sub>BC</sub>	-800 km s <sup>-1</sup>	zero	5, 6, 7, 8
$\Gamma_S$	often large	rarely large	2, 9, 4, 10
W( $H\beta_{BC}$ )	~ 80 Å	~ 100 Å	2
$H\beta_{BC}$ profile shape	Lorentzian	double Gaussian	11, 12, 13
$c(\frac{1}{2})$ $H\beta_{BC}$	~ zero	+500 km s <sup>-1</sup>	13
SiIII / CIII]	0.4	0.2	14, 15, 16
FWHM CIV $\lambda$ 1549 <sub>BC</sub>	(2–6) · 10 <sup>3</sup> km s <sup>-1</sup>	(2–10) · 10 <sup>3</sup> km s <sup>-1</sup>	5, 17
W(CIV $\lambda$ 1549 <sub>BC</sub> )	58 Å	105 Å	4, 6, 7
AI(CIV $\lambda$ 1549 <sub>BC</sub> )	-0.1	0.05	5
W([OIII $\lambda$ 5007])	1 – 20	20 – 80	1, 18, 19
$v_r$ ([OIII $\lambda$ 5007])	negative / 0	~ 0	4, 18, 19, 20
FIR color $\alpha(60, 25)$	0 – -1	-1 – -2	21
X-ray variability	extreme/rapid common	less common	22, 23
optical variability	possible	more frequent/higher amplitude	24
probability radio loud	≈ 3–4%	≈ 0.25 %	4, 25
BALs	extreme BALs	less extreme BALs	36, 37
log density <sup>1</sup>	> 11	9.5 – 10	14, 28
log $U^1$	-2.0/-1.5	-1.0/-0.5	14, 28
log $M_{BH}$	6.5 – 8.5	8.0 – 10.0	7, 8, 29
$L/L_{Edd}$	0.1 – 1.0	0.01 – 0.5	1, 4, 7, 29, 30, 31

1: Bosorson & Green 1992; 2: Sulentic et al. 2000a; 3: Collin et al. 2006; 4: Shen & Ho 2014; 5: Sulentic et al. 2007; 6: Baskin & Laor 2005; 7: Richards et al. 2011; 8: Sulentic et al. 2016; 9: Wang et al. 1996; 10: Bensch et al. 2015; 11: Veron-Cetty et al. 2001; 12: Sulentic et al. 2002; 13: Marziani et al. 2003b; 14: Marziani et al. 2001; 15: Wills et al. 1999; 16: Bachev et al. 2004; 17: Coatman et al. 2016; 18: Zhang et al. 2011; 19: Marziani et al. 2016; 20: Zamanov et al. 2002; 21: Wang et al. 2006; 22: Turner et al. 1999; 23: Grupe et al. 2001; 24: Giveon et al. 1999; 25: Zamfir et al. 2008; 26: Reichard et al. 2003; 27: Sulentic et al. 2006; 28: Negrete et al. 2012; 29: Boroson 2002; 30: Peterson et al. 2004; 31: Kuraszkiwicz et al. 2000.

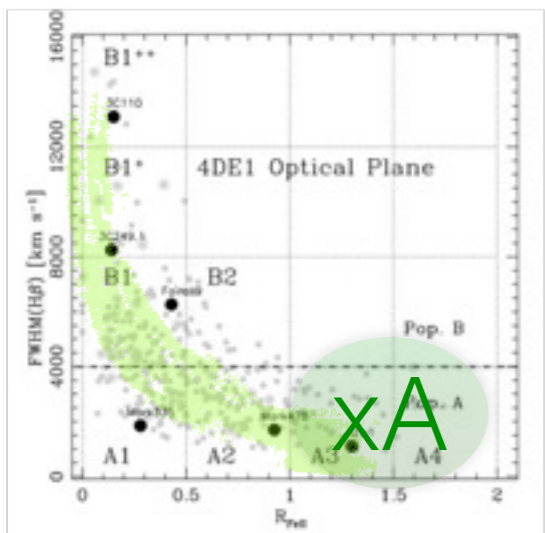
# Pop. A/B transition: geometrically thick/thin disk?

Not drawn to scale

Abramowicz et al. 1988, Shakura & Sunyaev 1973



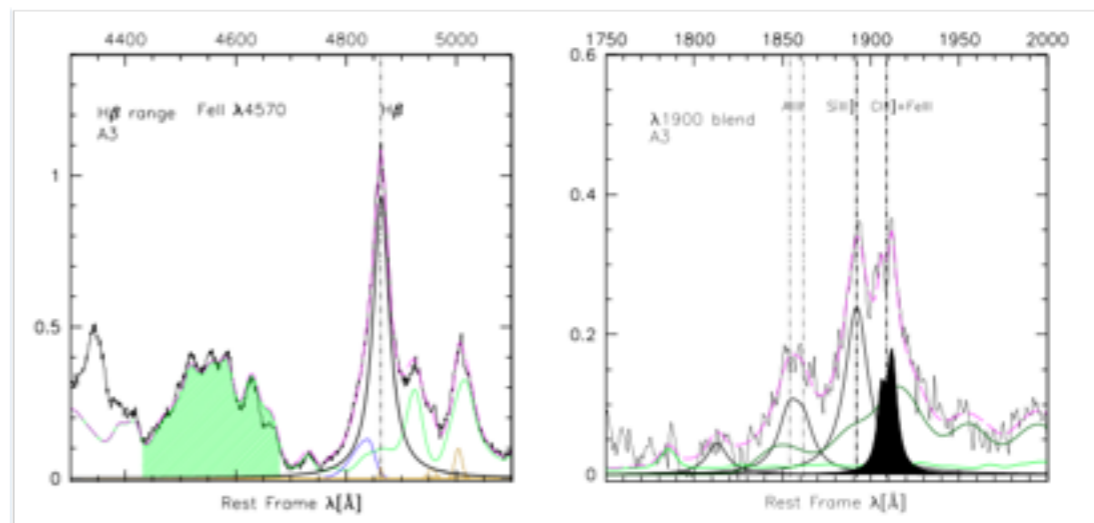
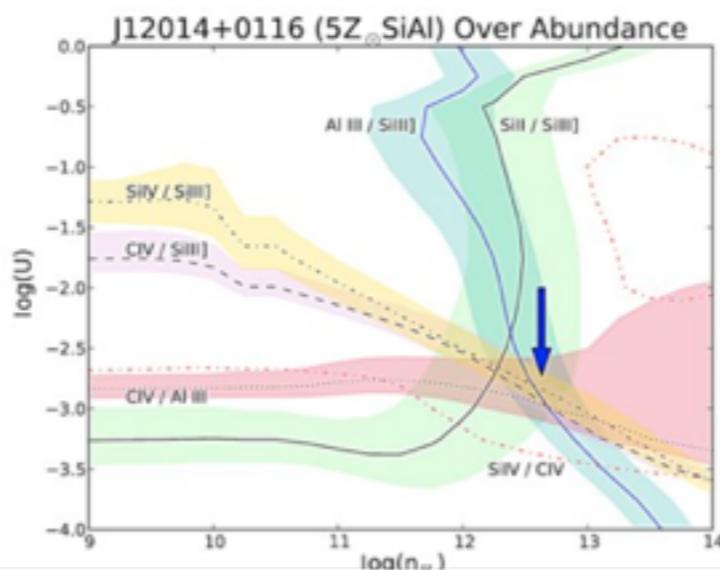
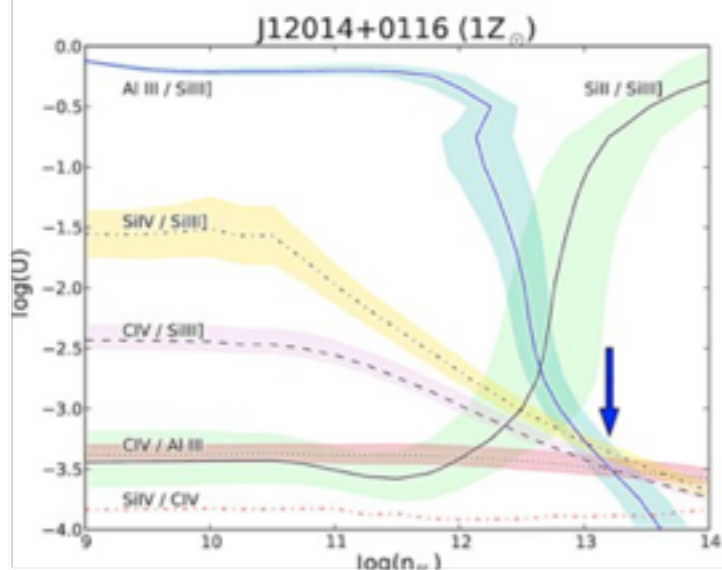
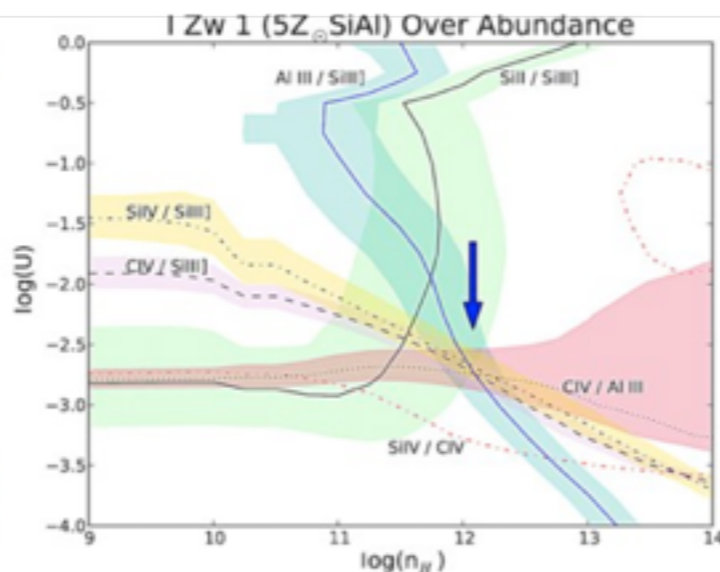
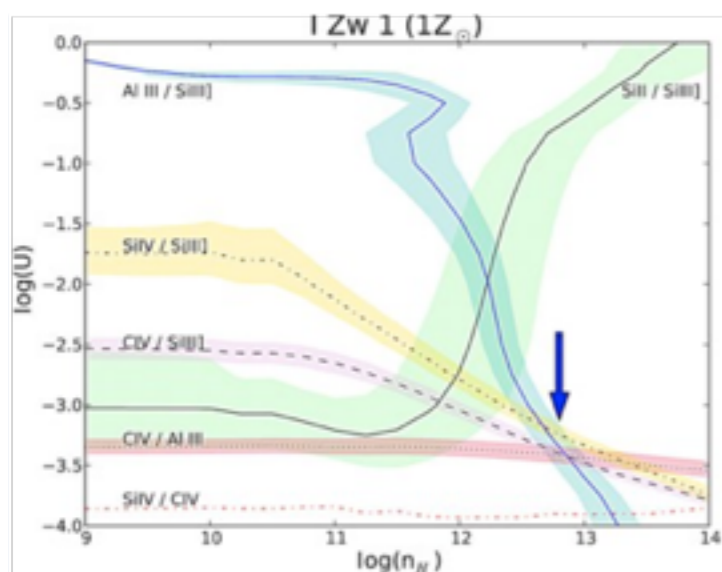
# The MS: The MS “tip”



## Extreme Pop. A quasars (xA)

Simple selection criteria from diagnostic line ratios

- 1)  $R_{FeII} = FeII\lambda 4570 \text{ blend}/H\beta > 1.0$
- 2)  $UV \text{ AIII } \lambda 1860/SiIII] \lambda 1892 > 0.5 \text{ \& } SiIII] \lambda 1892/CIII] \lambda 1909 > 1$



Extreme, well defined-values for density (high), ionization (high) and metallicity (high):  
Some xA are weak lined quasars

Plane ionization parameter versus density (Negrete et al. 2012)

# The MS Main sequence “tip:” implications for cosmology?

Extreme Pop. A (xA) sources:  
 associated with  
 a tight distribution of  
 Eddington ratio, in agreement  
 with theoretical expectations

It is then possible to retrieve  
 the quasar luminosity if the  
 virial mass is known

$$\frac{L}{L_{\text{Edd}}} = \eta \quad L = \eta L_{\text{Edd}} = \text{const} \eta M_{\text{BH}}$$

$$L \approx 7.8 \cdot 10^{44} \frac{\eta_1^2 \kappa_{0.5} f_2^2}{\bar{v}_{12.42} 10^{16} (nU)_{9.6}} v_{1000}^4 \text{ erg s}^{-1}$$

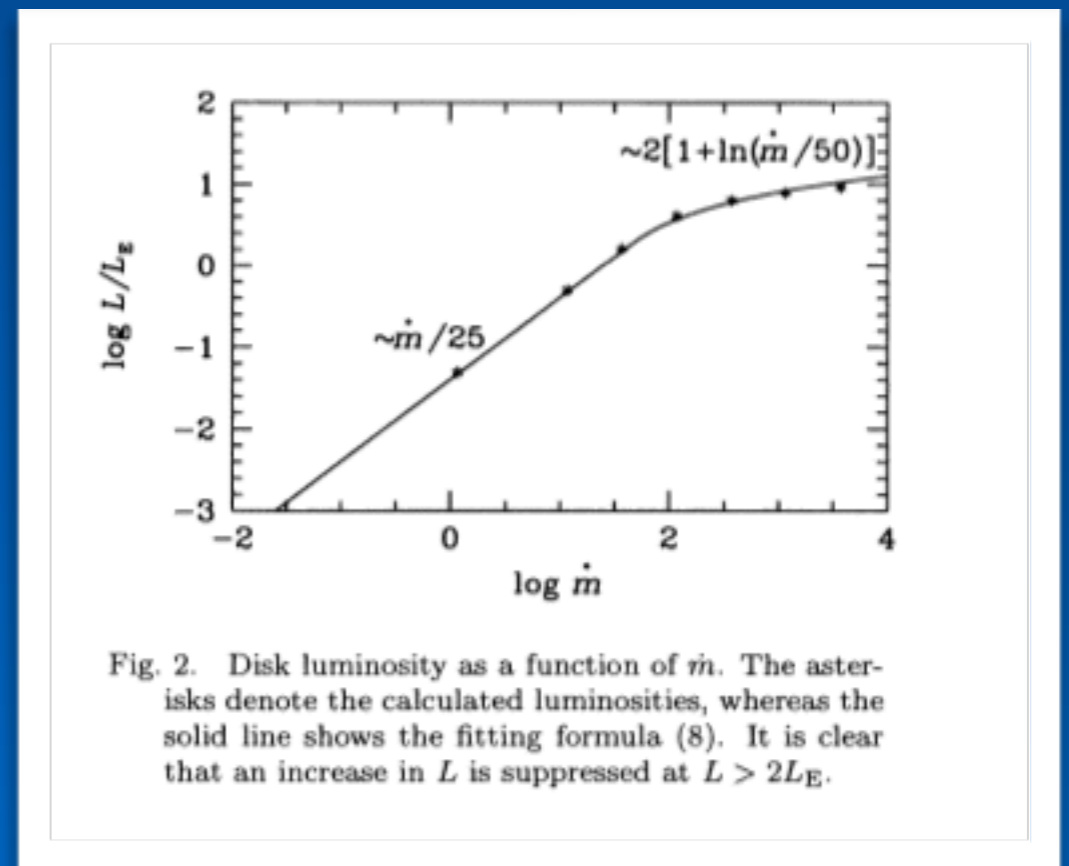
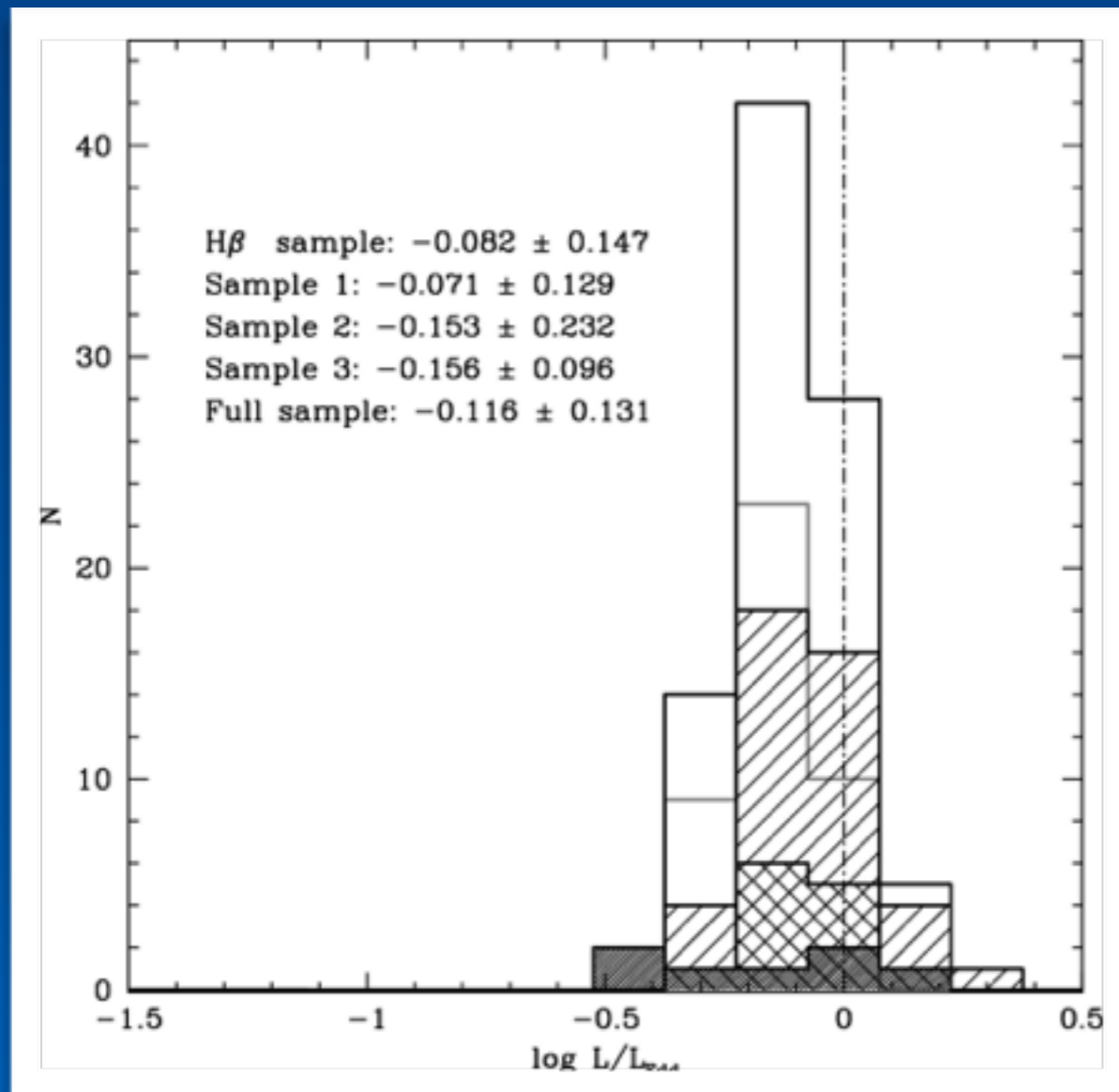


Fig. 2. Disk luminosity as a function of  $\dot{m}$ . The asterisks denote the calculated luminosities, whereas the solid line shows the fitting formula (8). It is clear that an increase in  $L$  is suppressed at  $L > 2L_E$ .



## Conclusion

The MS is most likely a sequence of  $L/L_{\text{Edd}}$ . An accretion mode change may be associated with a critical  $L/L_{\text{Edd}} \sim 0.2$ , leading to two quasars populations: A (wind-dominated), and B (disk dominated).

(preliminary)

xA quasars at the high  $R_{\text{FeII}}$  end of the MS show a small scatter in  $L/L_{\text{Edd}}$  and may be suitable as Eddington standard candles.

Huge quasar samples ( $\sim 10^5$  sources) are now available from major surveys completed and in progress (LBQS, SDSS, 2dF, BOSS). The E1 approach offers contextualization for internal line shifts, profiles of spectral lines, as well as many multifrequency spectrophotometric measures.

