Max-Planck Institut für Astronomie

Observational features of massive black hole binaries

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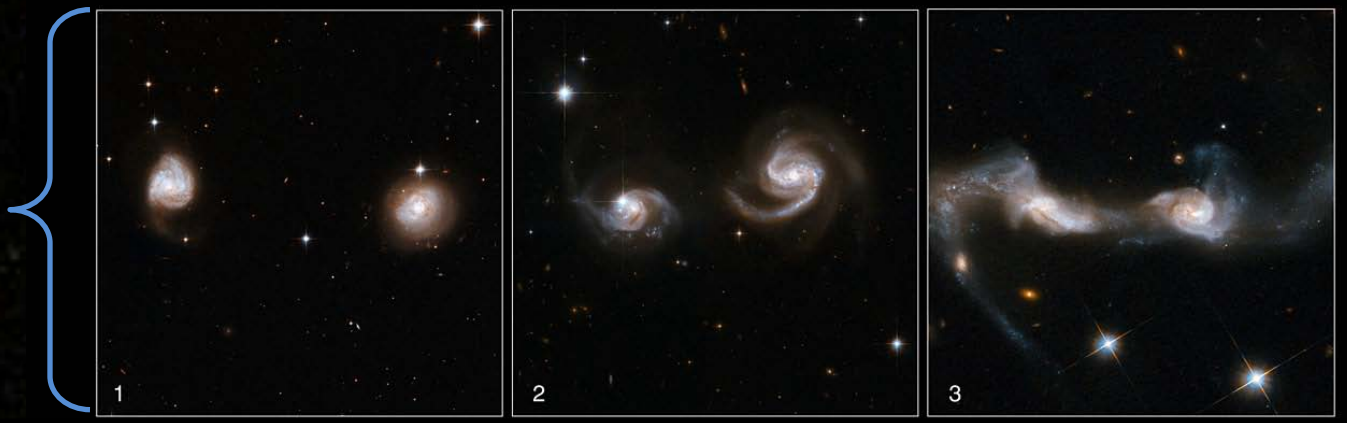
Single and double BHs in galaxies, Aug 24th, 2011

Some Zoology…

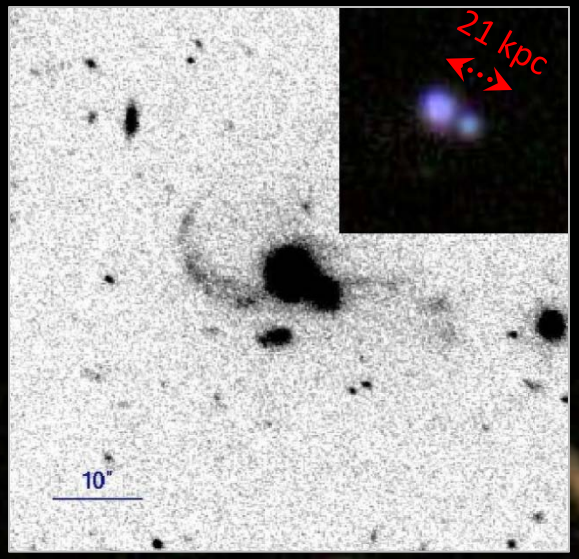
Pre-merger phase
D ~ few 10-100 kpc

PAIRS

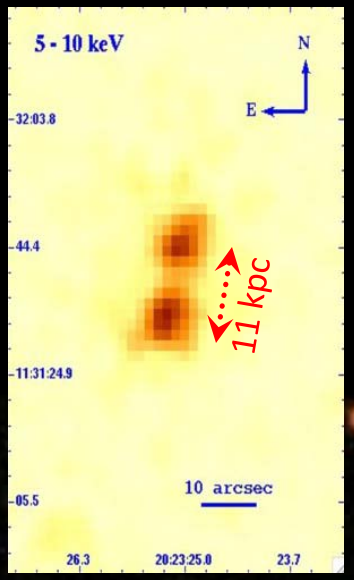
Known: 50-100



SDSS J0927+2943 A,B
(Decarli et al. 2010)



SDSS J1254+0846
(Green et al. 2010)



IRAS J20210+1121
(Piconcelli et al. 2010)

Some Zoology

Pre
D ~

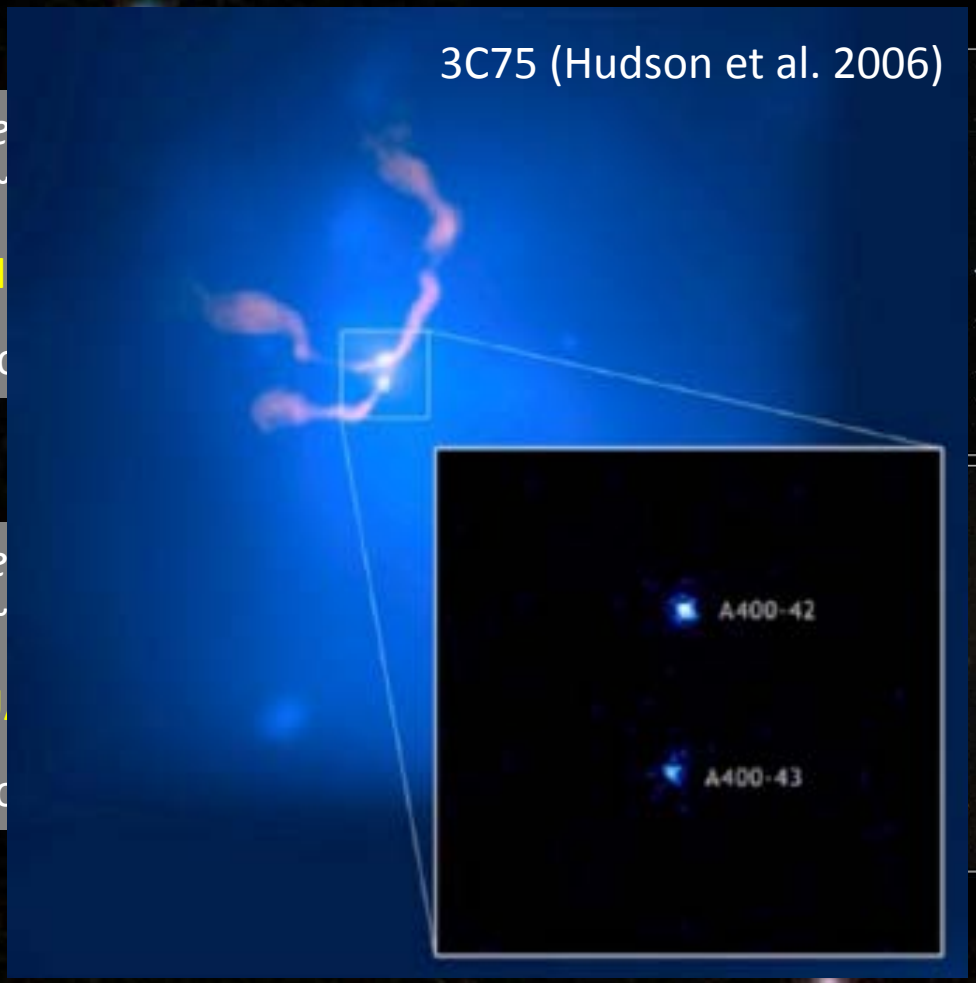
PAI

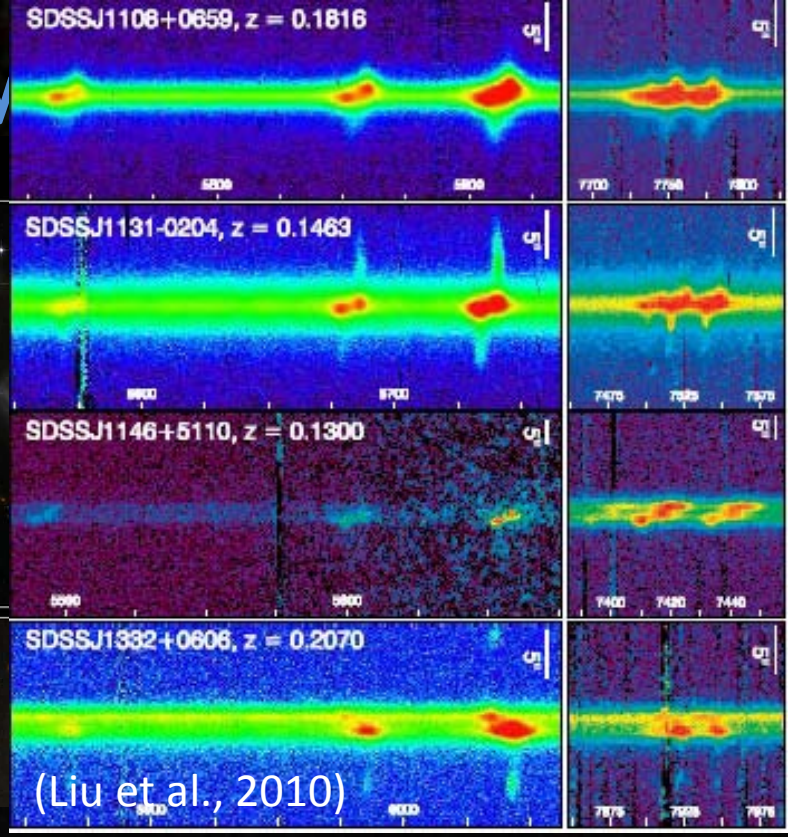
Kno

Me
D ~

DU

Kno





NGC 3341 (Barth et al., 2008)

Some Zoology…

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D ~ few 10-100 kpc

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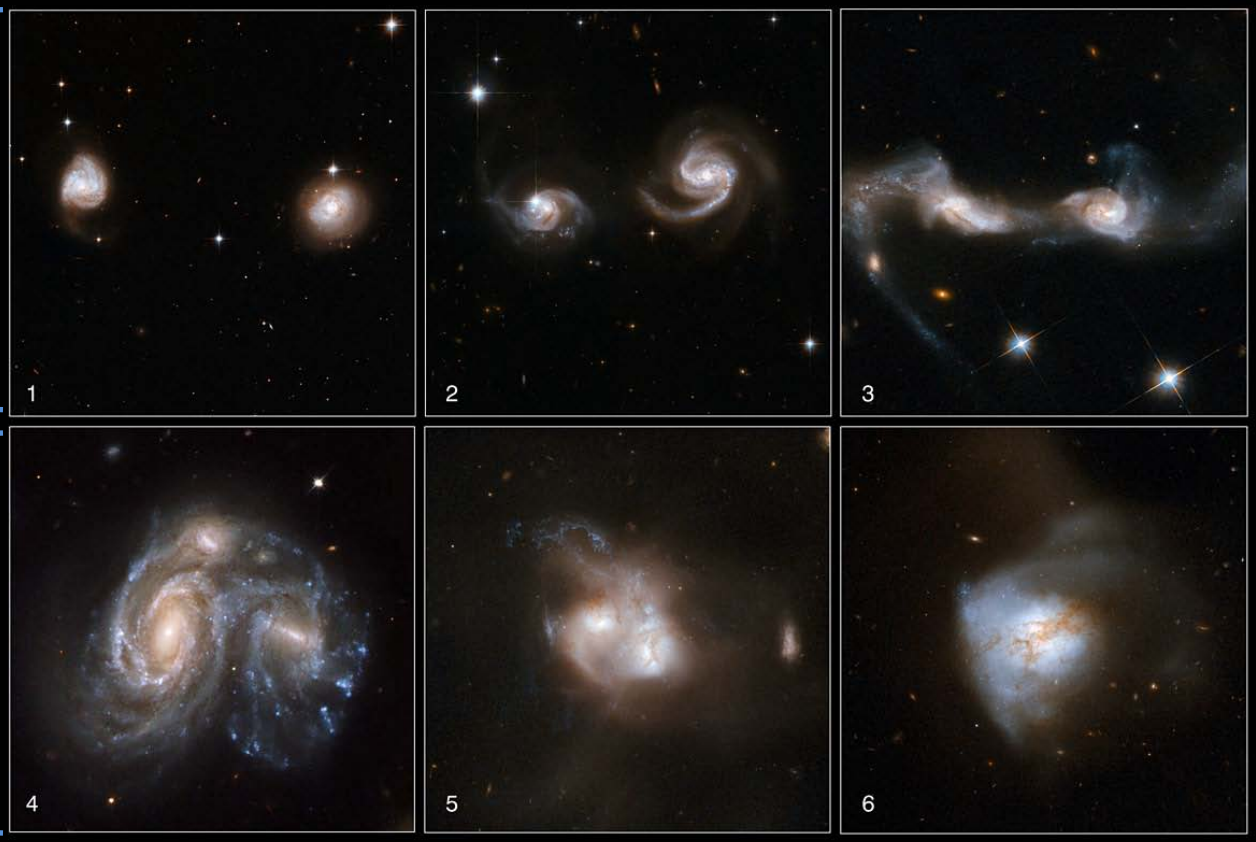
Known: 50-100



Merger phase
D ~ 10 pc -10 kpc

DUAL black holes

Known: ~20

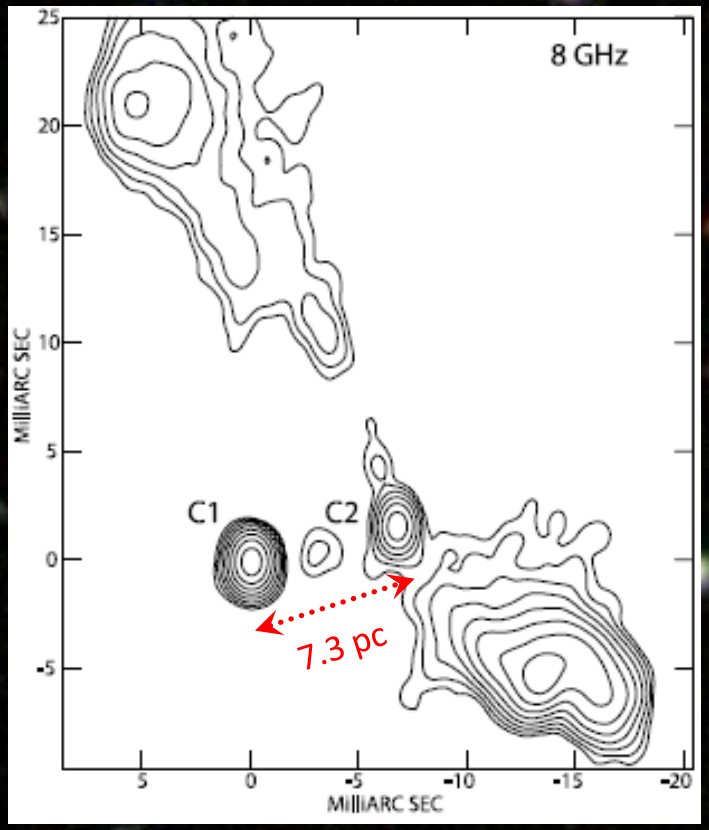
Towards Coalescence
D < 10 pc

Black hole BINARIES

Can we detect them?

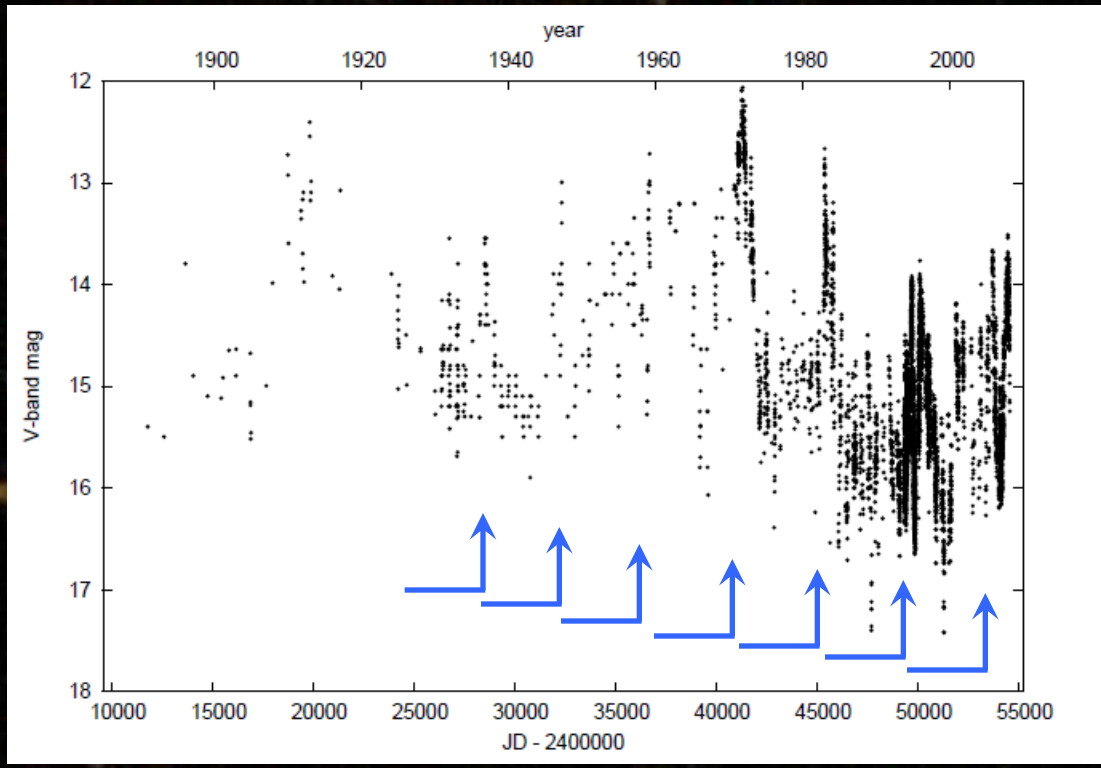
(Do they exist?)
(Time scales?)
(What's the fate of the BHs?)

A good candidate: 0402+379



(Rodriguez et al., 2006)

A dubious one: OJ287



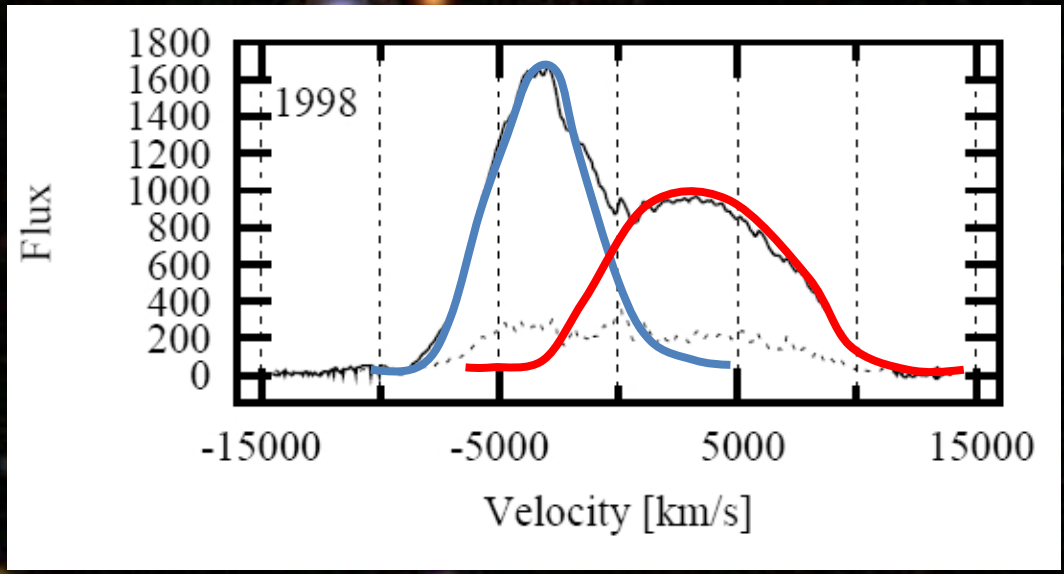
(Valtonen et al., 2008)

Other indirect signatures are needed

Spectroscopic signatures

If the binary is bound, the orbital velocity can be high (> 500 km/s)

If the two BHs are accreting, the BLs will show two peaks, respectively blue and red shifted with respect to the host galaxy rest frame (NLs)



(plot taken from Popovic et al., 2011)

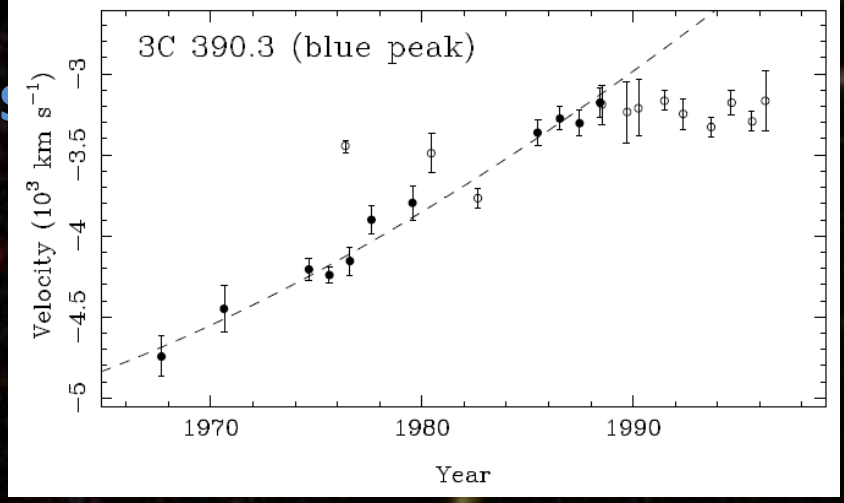
Spectroscopic s

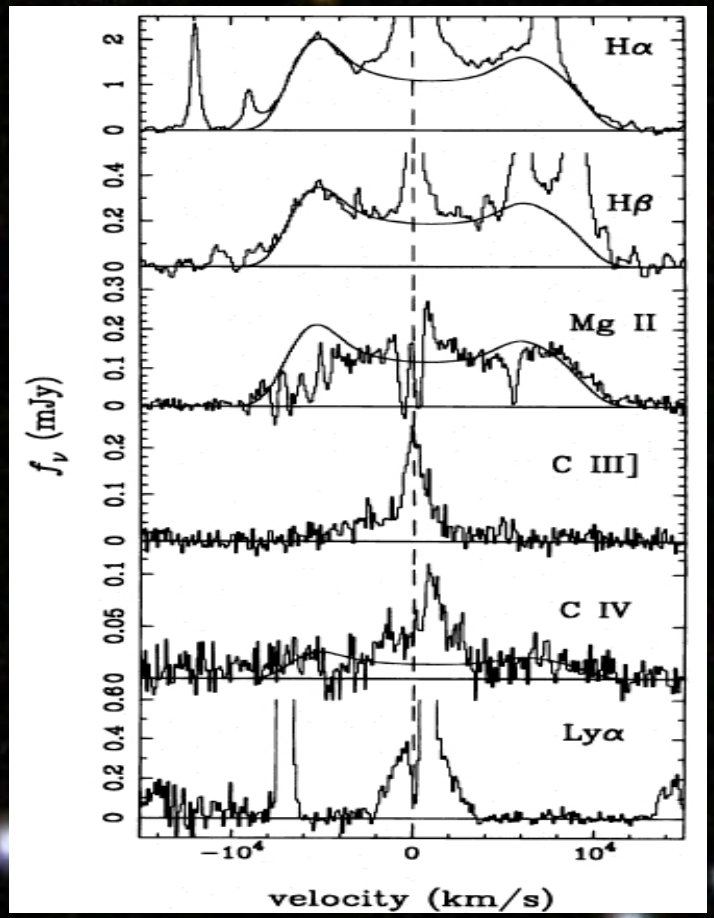
If the binary is bound, the orbital velocity can be high (> 500 km/s)

(Eracleous et al., 1997)

If the two BHs are accreting, the BLs will show two peaks, respectively **blue** and **red** shifted with respect to the host galaxy rest frame (NLs).

However, **disk** emission can mimic a **double BLRs**

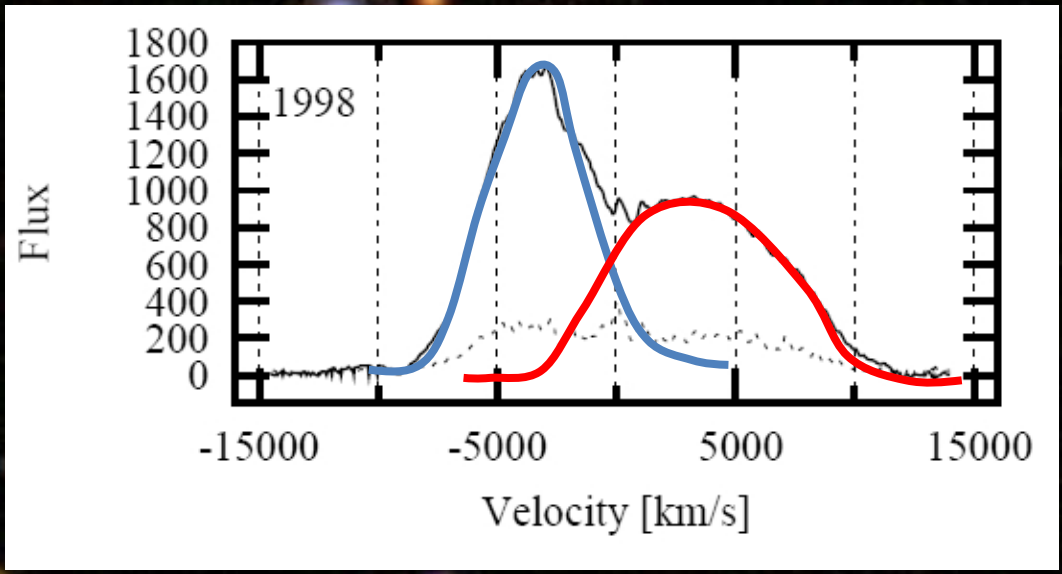




(Haplern et al., 1996)

Spectroscopic signatures

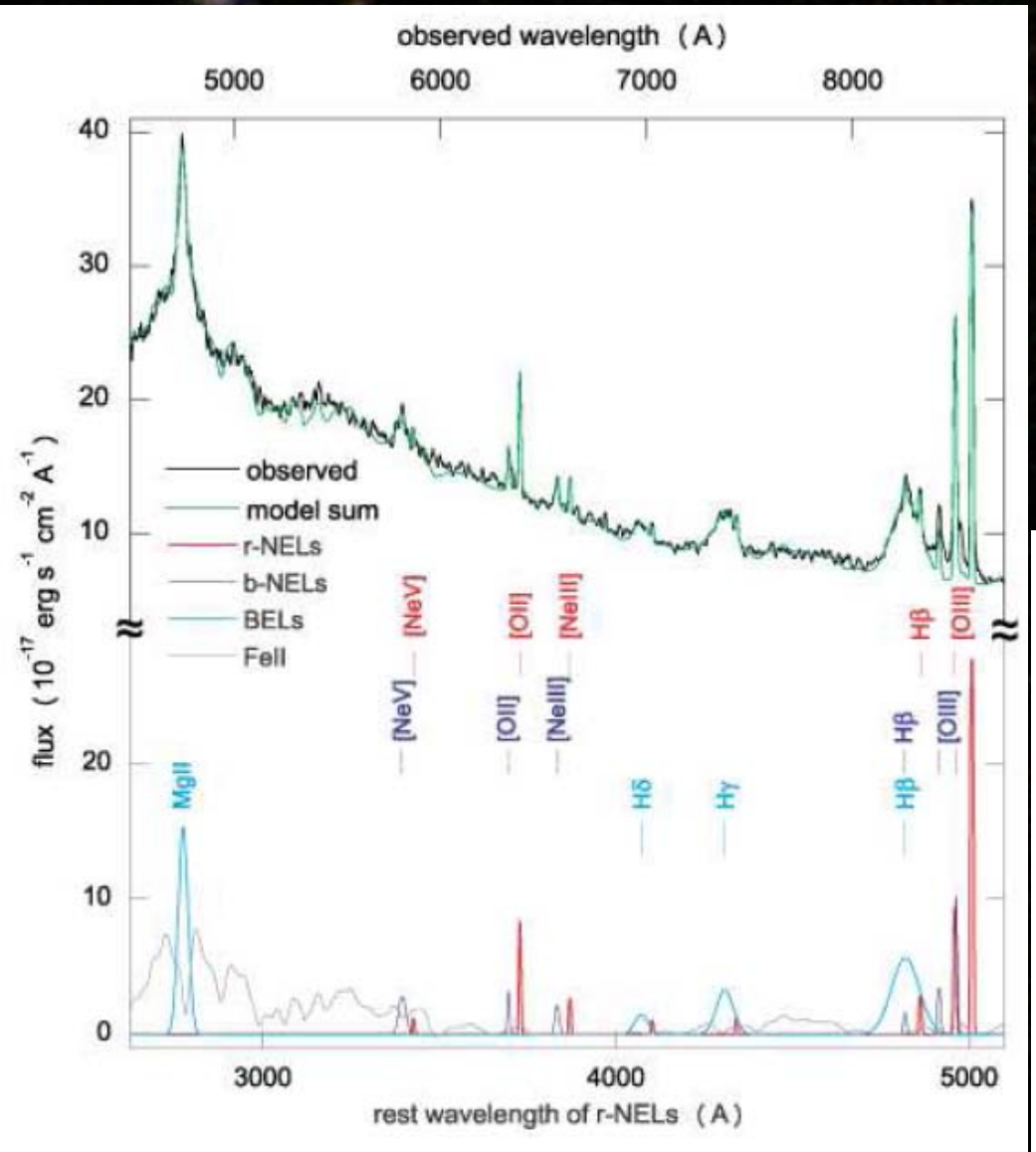
If instead only one BH is accreting, the BLs will be systematically blue/red shifted



(plot taken from Popovic et al., 2011)

SDSS J0927+2943 and SDSS J1050+3456

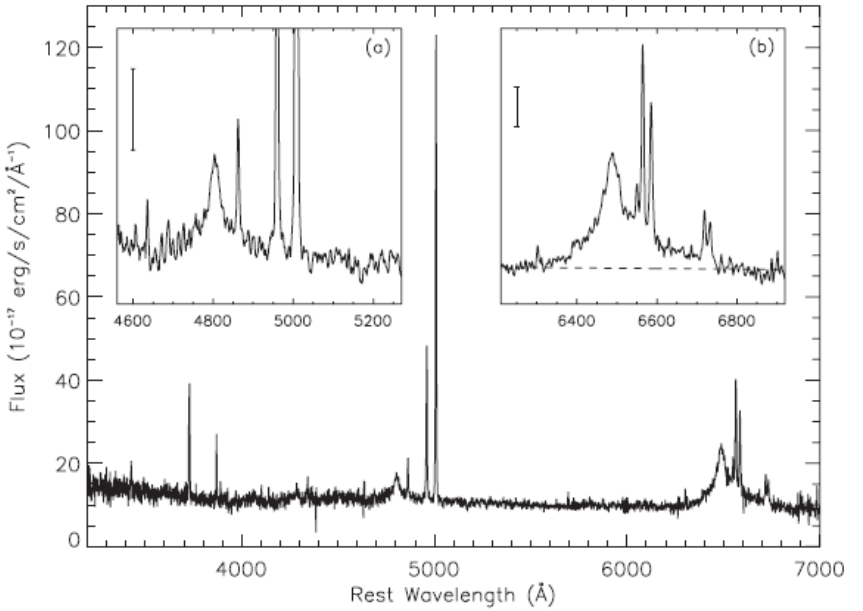
(Komossa et al., 2008)



A single set of BLs shifted wrt NLs

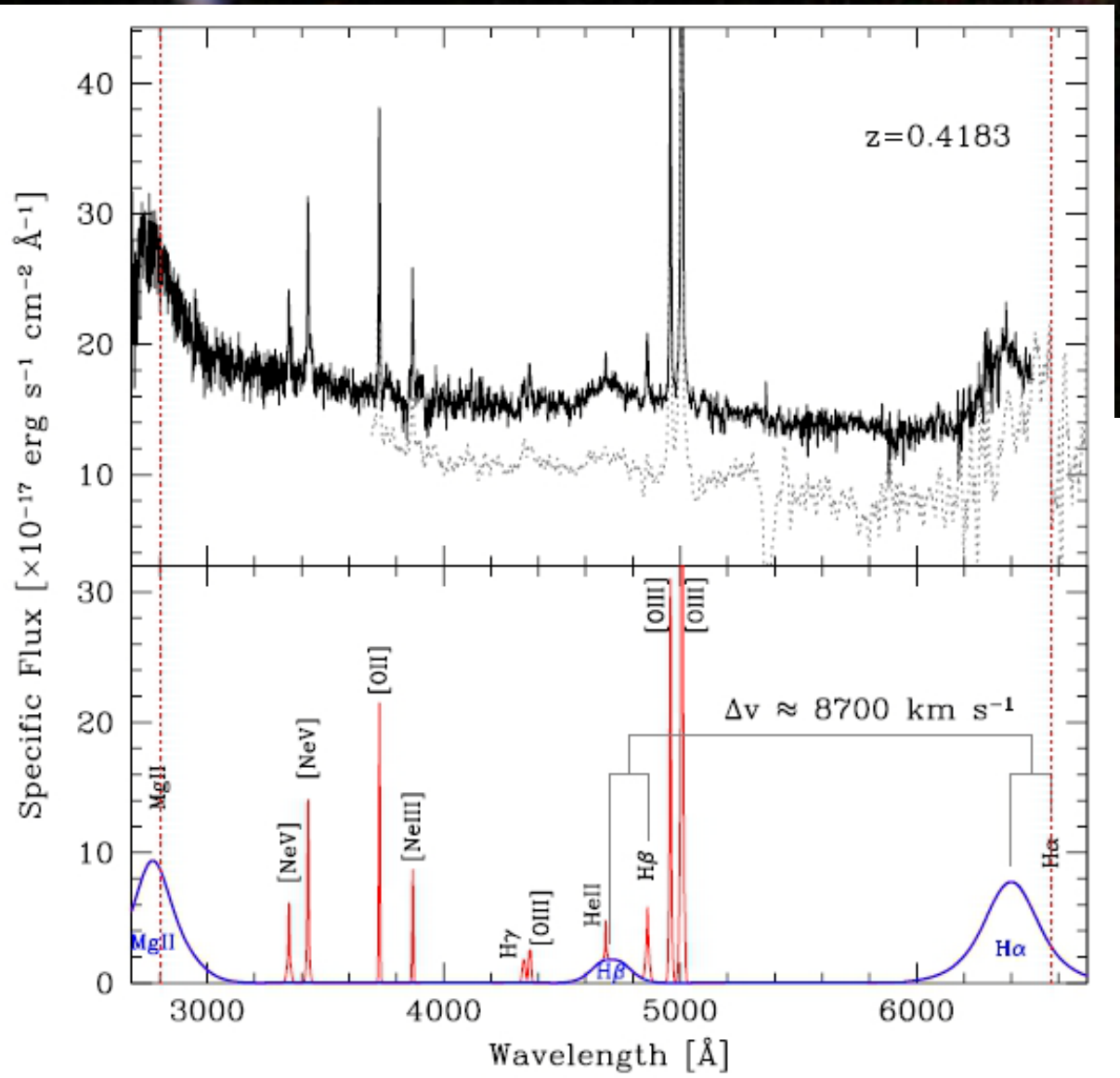
Δv > 2000 km/s!

(Shields et al., 2009)



SDSS J1000+2233: The record holder

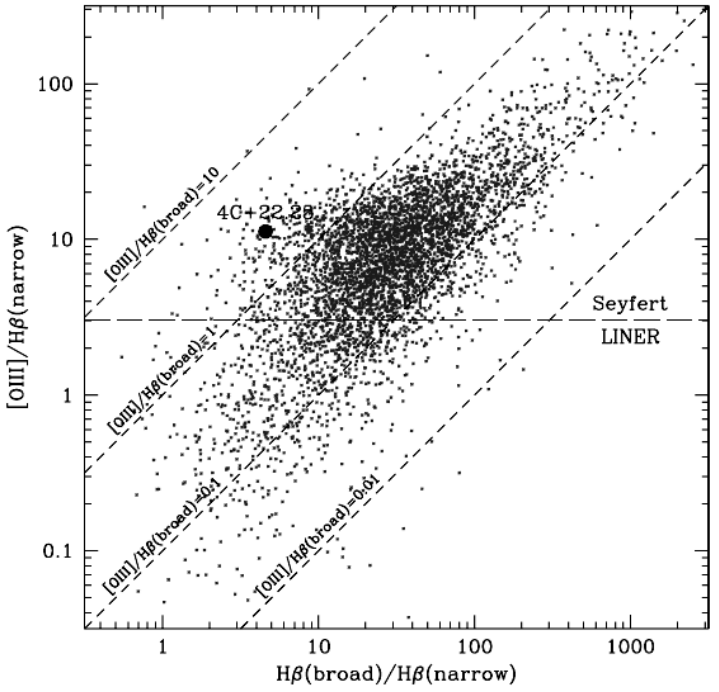
(Decarli et al., 2010)



Faint BLs with extreme velocity shift wrt NLs

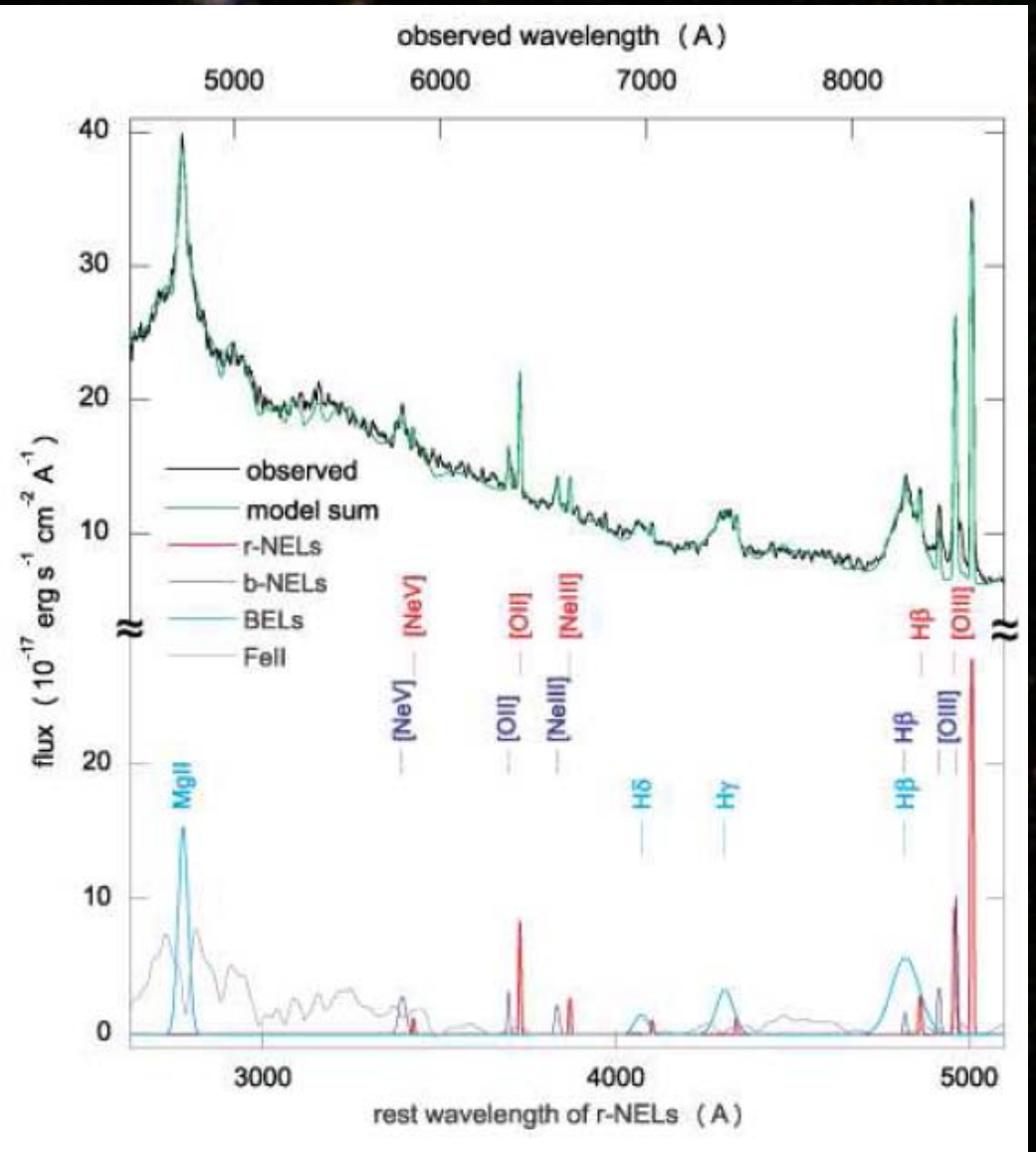
Δv = 8700 km/s!

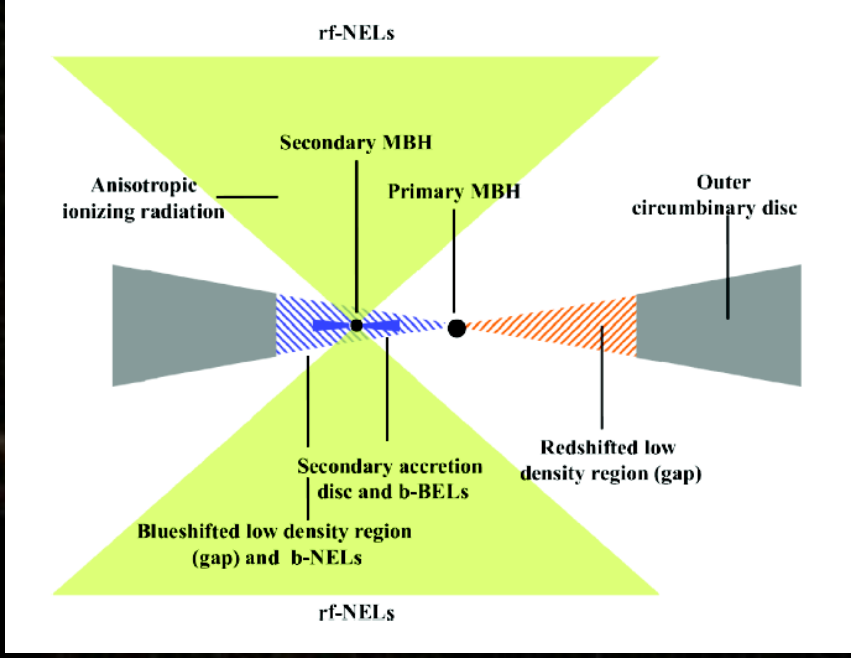
But... No evolution over 3.1 yr



SDSS J0927+2943

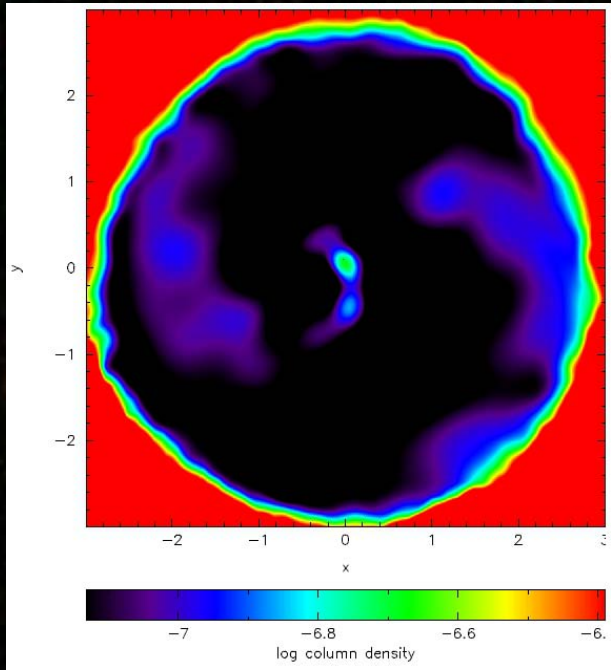
(Komossa et al., 2008)





(Dotti et al., 2009)

(Sesana et al., 2011)



SDSS J0927+2943: Alternative interpretations

Recoiling black hole (Komossa et al. 2008)?

- velocities are very high (must be < 4000 km/s)
- what about the blue-shifted NLs?

Disk emission?

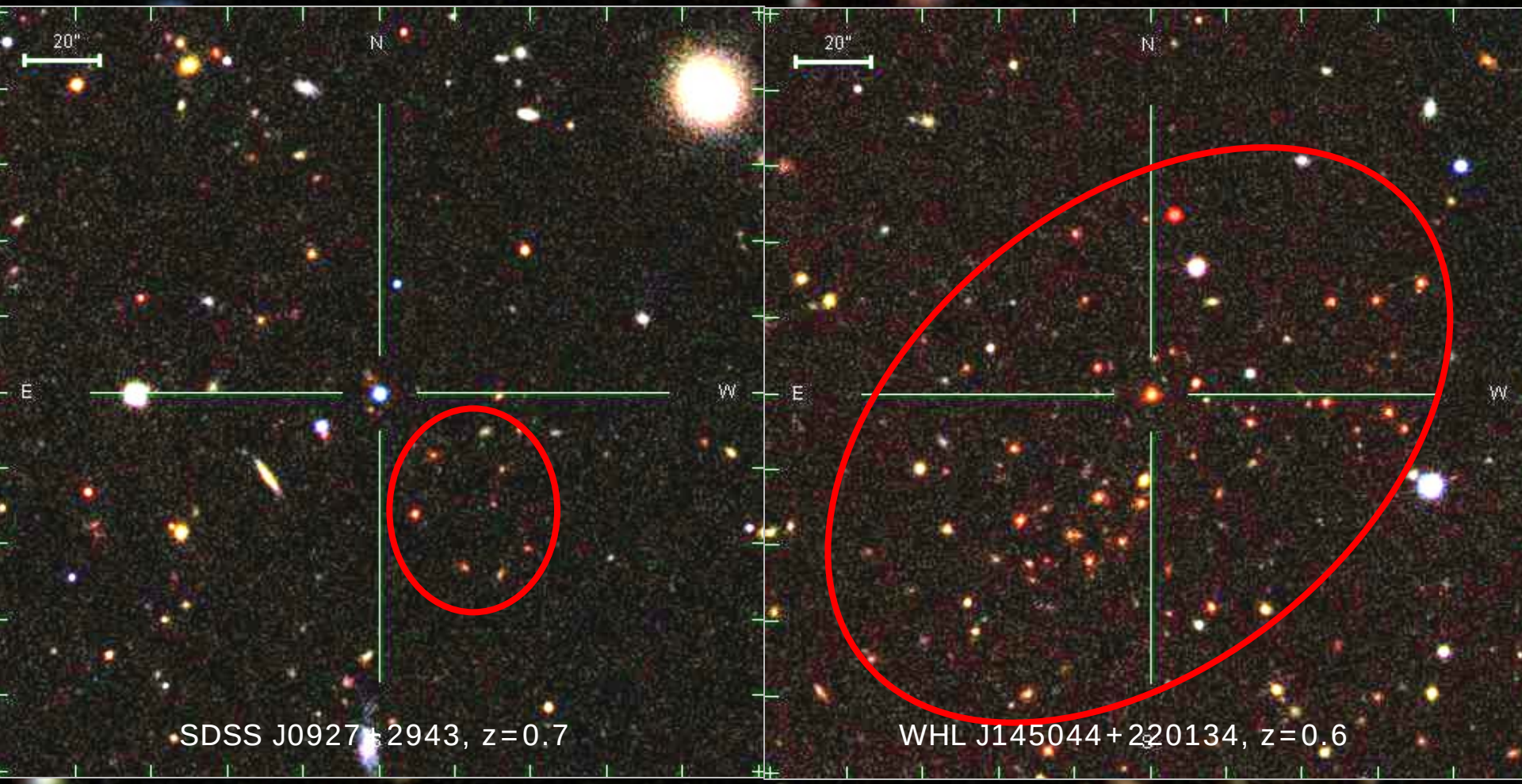
- no secondary peak
- what about the blue-shifted NLs?

Cosmological superposition?

- sub-arcsec alignment of 2 AGN is unlikely

Superposition in a cluster (Heckman et al. 2009)?

- velocity differences are very high
- no cluster is observed (Decarli et al. 2009)


20"
N
E
W
SDSS J0927+2943, z=0.7
20"
N
E
W
WHL J145044+220134, z=0.6

A systematic search for BL shifts in the SDSS

We systematically search the SDSS spectroscopic database for quasars with two sets of emission lines at different redshifts

$$f(\lambda) = \sum_k a_k g_k(\lambda)$$

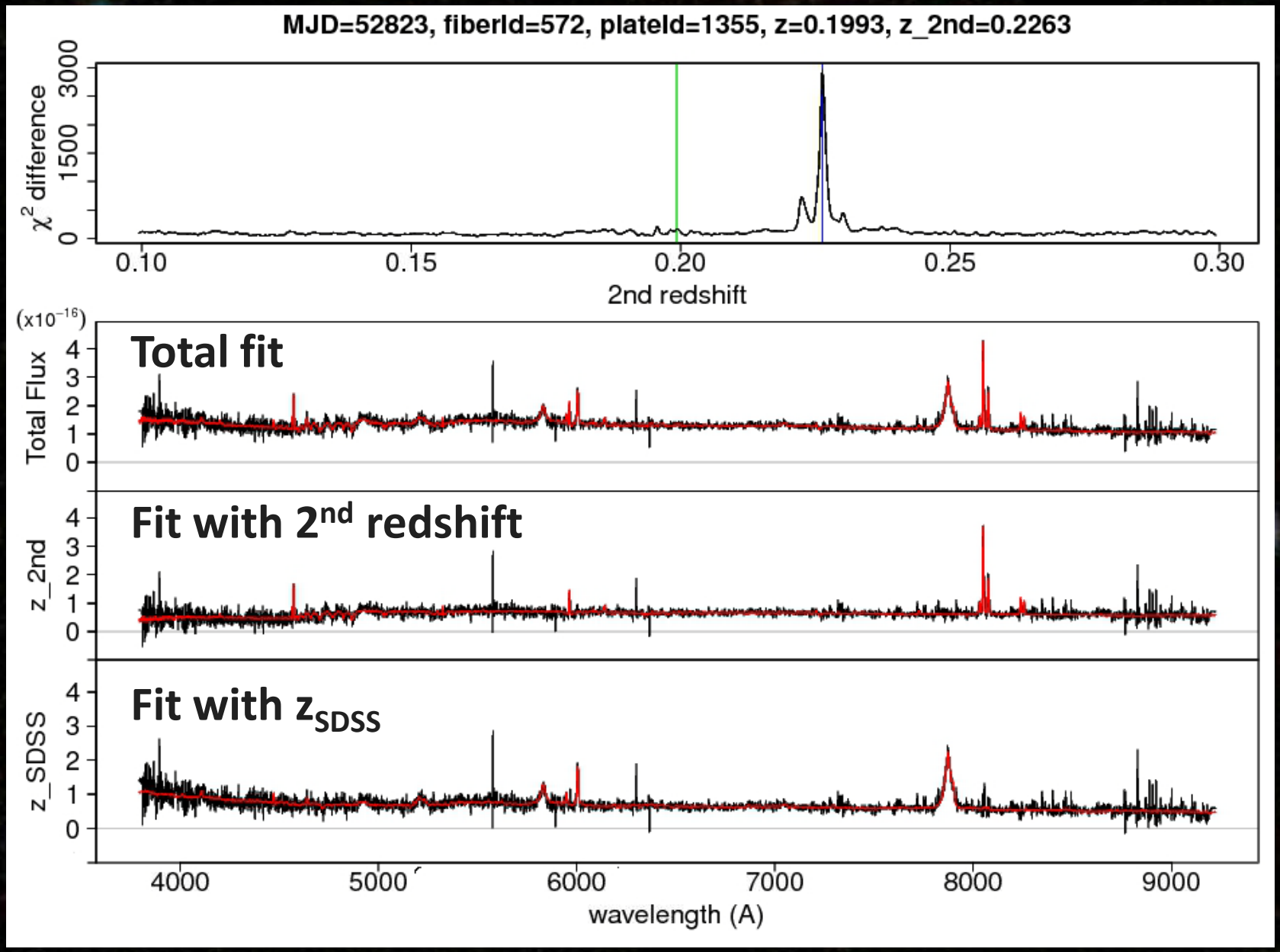
j → *wavelengths*
k → *components*

1 z fit: $$\chi_1^2 = \sum_j \frac{[f_j - \sum_k a_k g_{kj}(\lambda[1+z])]^2}{\sigma_j^2}$$

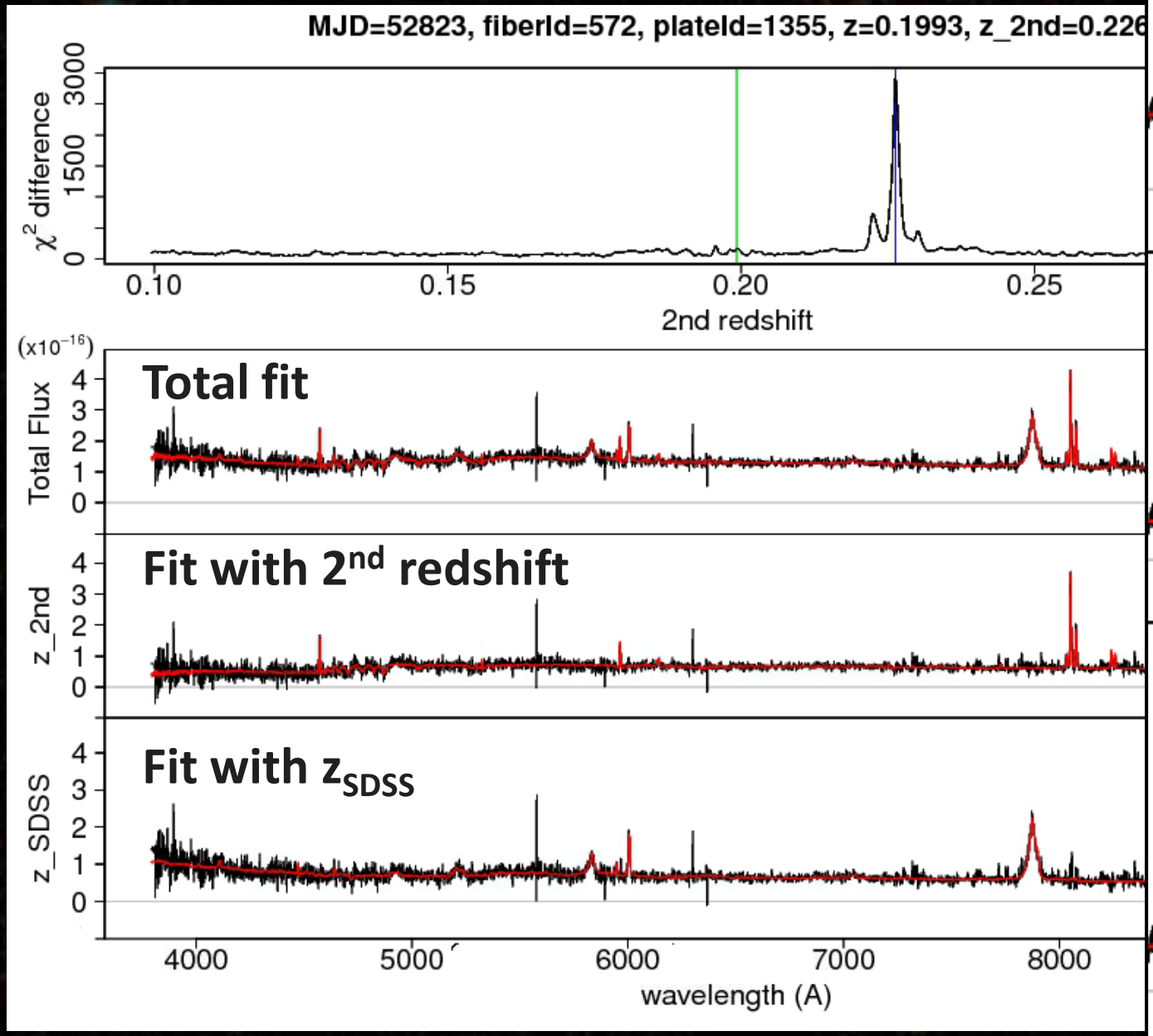
$$\chi^2_{difference} = \chi_1^2 - \chi_2^2$$

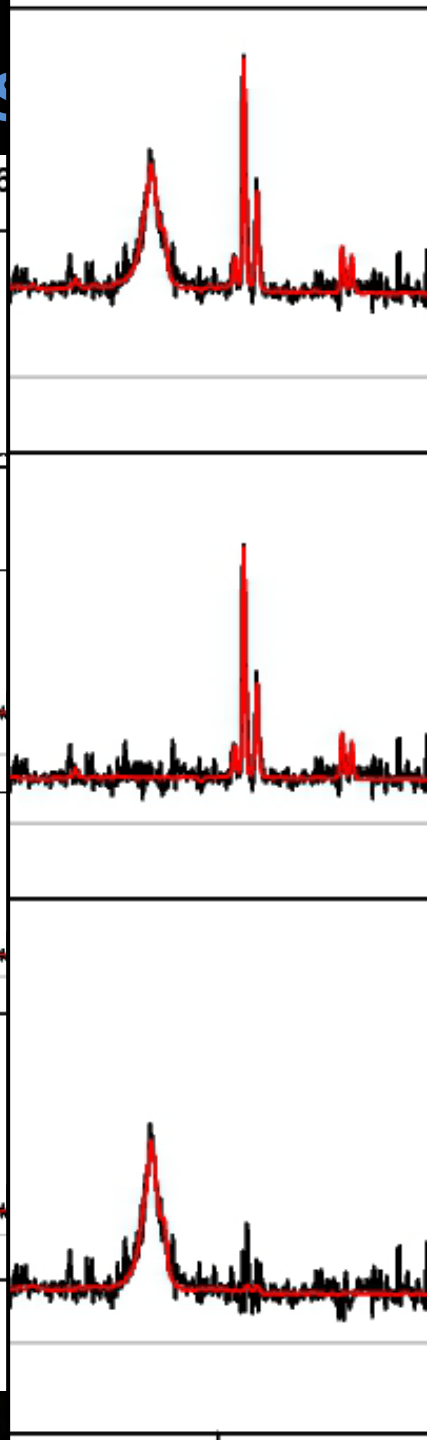
2 z fit: $$\chi_2^2 = \sum_j \frac{[f_j - \sum_k a_k g_{kj}(\lambda[1+z]) - \sum_k \beta_k g_{kj}(\lambda[1+z_n])]^2}{\sigma_j^2}$$

A systematic search for BL shifts in the SDSS



A systematic search for BL shifts in the S





Results

We ran our analysis on **55,000 quasars** and **4,000 galaxies** in the SDSS

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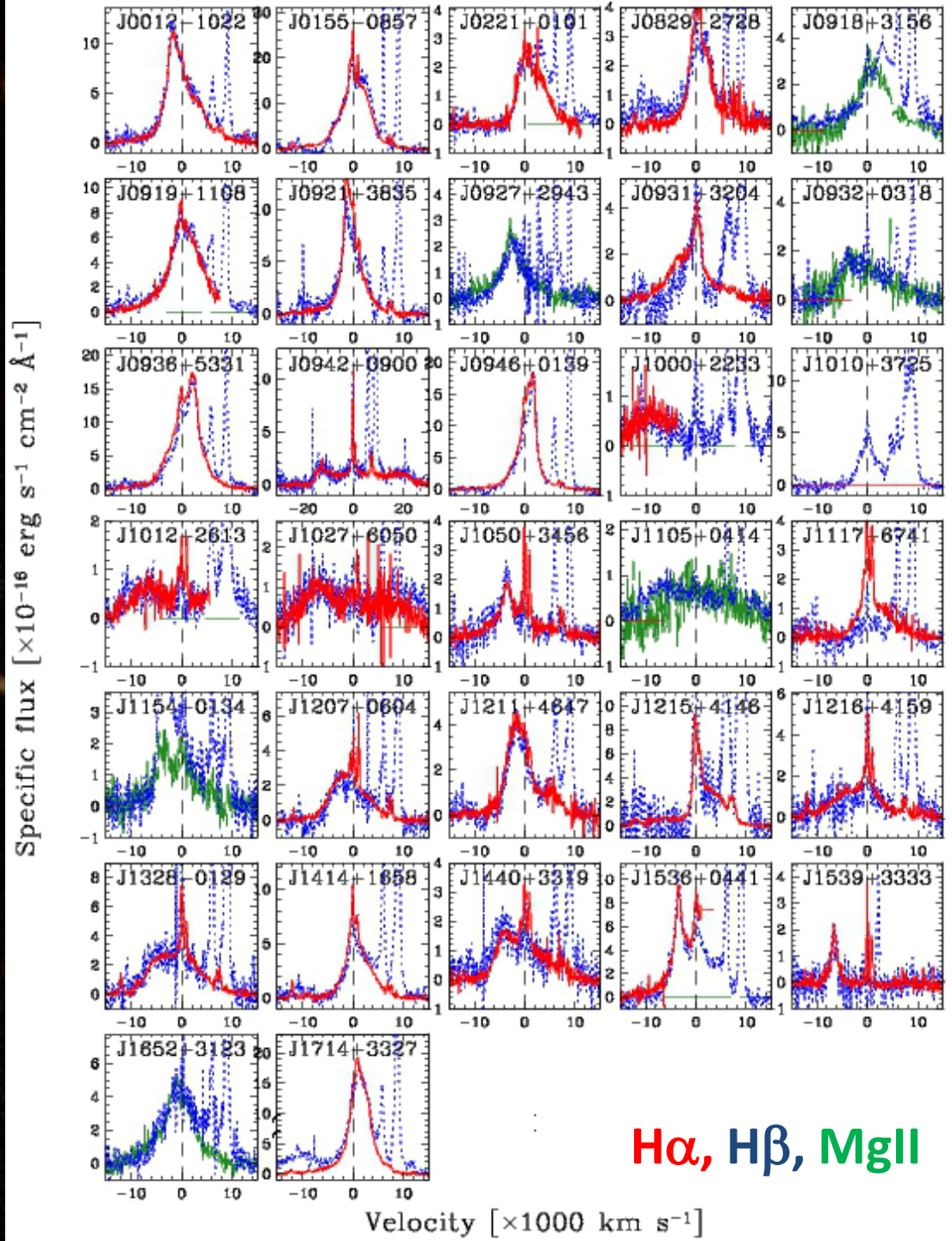
32 `interesting' objects

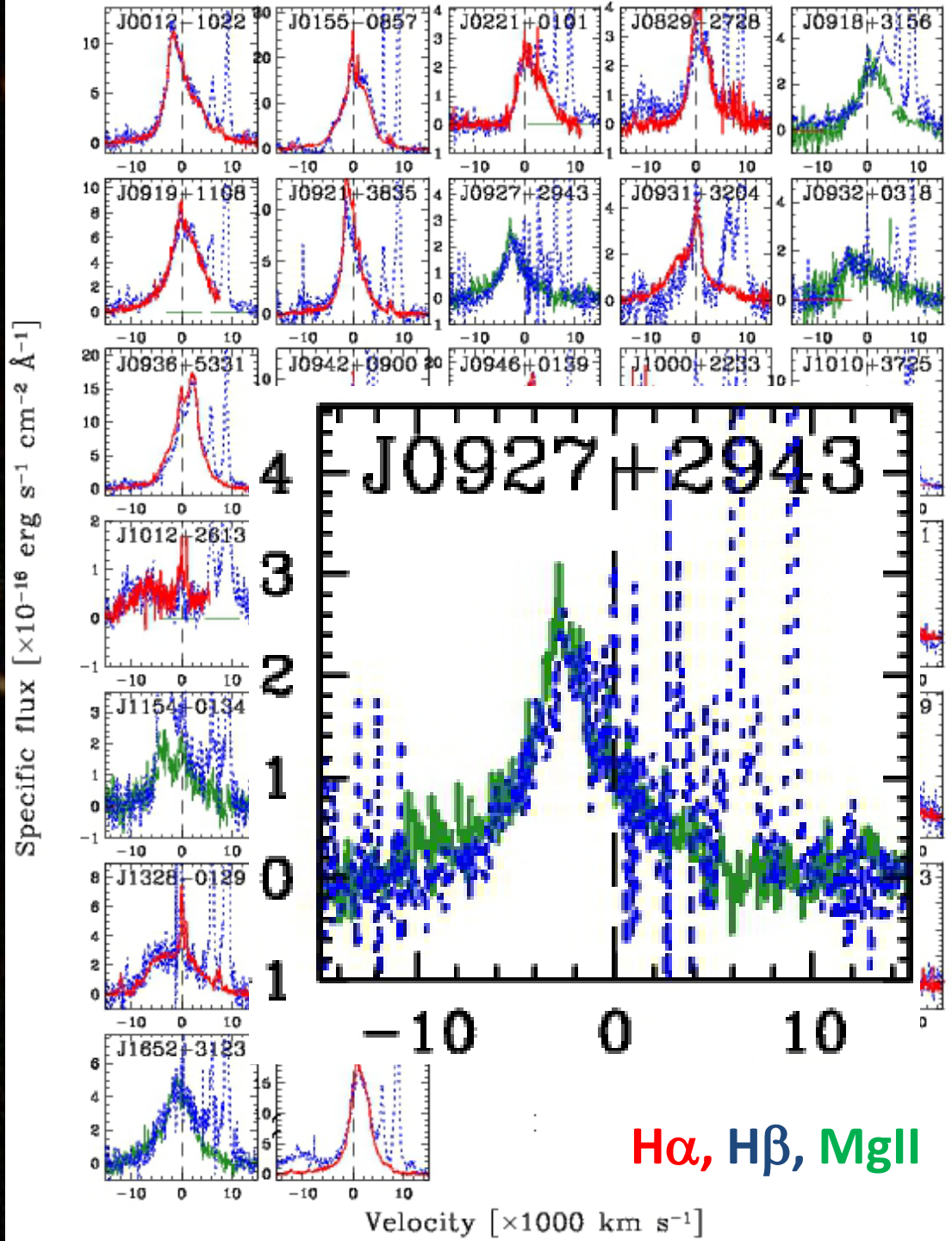


Tsalmantza, RD, et al., 2011

Results

We ran our analysis on **55,000 quasars** and **4,000 galaxies** in the SDSS

32 `interesting' objects
- **All** the known **BHB** candidates



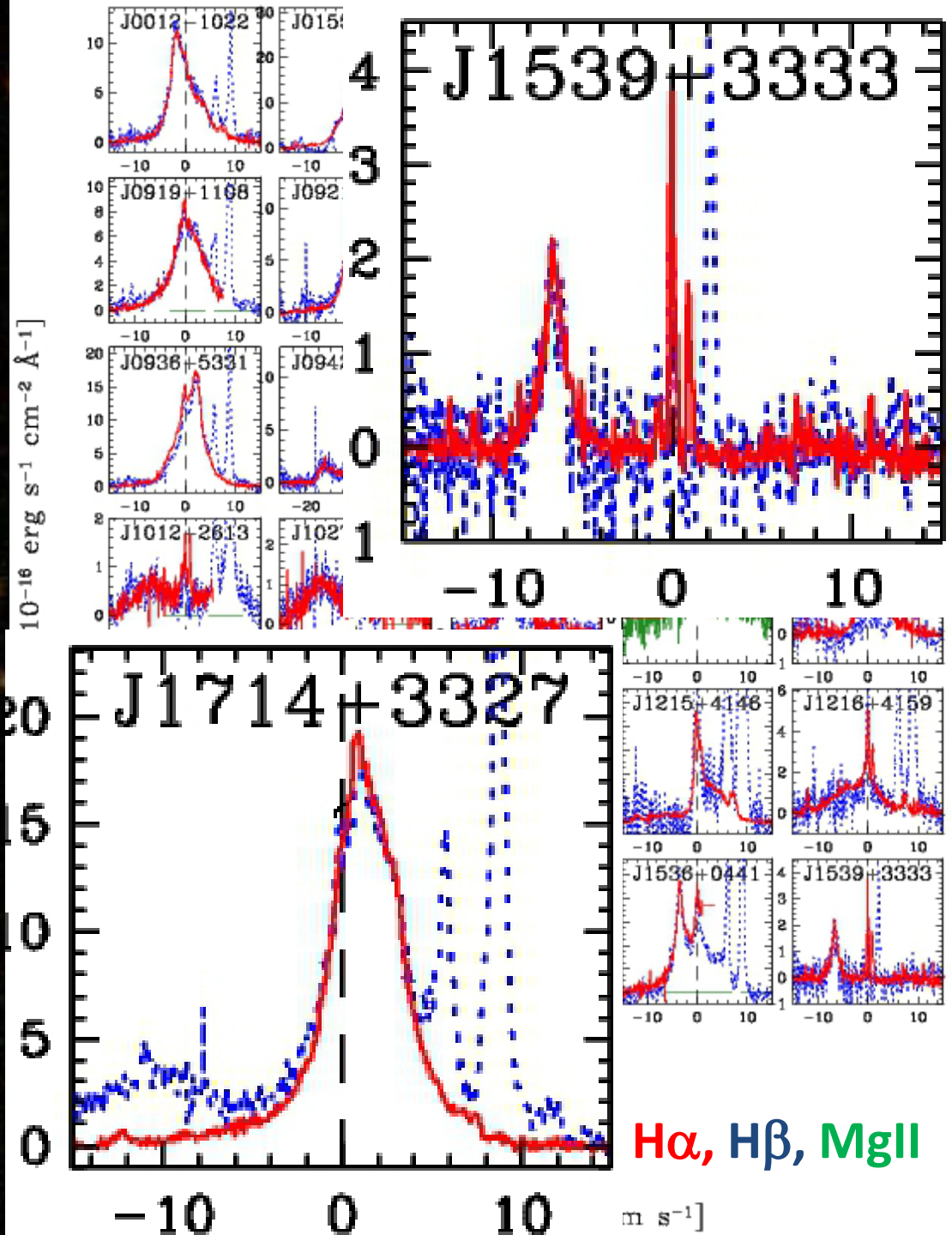
Tsalmantza, RD, et al., 2011

Results

We ran our analysis on **55,000 quasars** and **4,000 galaxies** in the SDSS

32 `interesting' objects

- All the known BHB candidates
- 4 new BHB candidates



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Results

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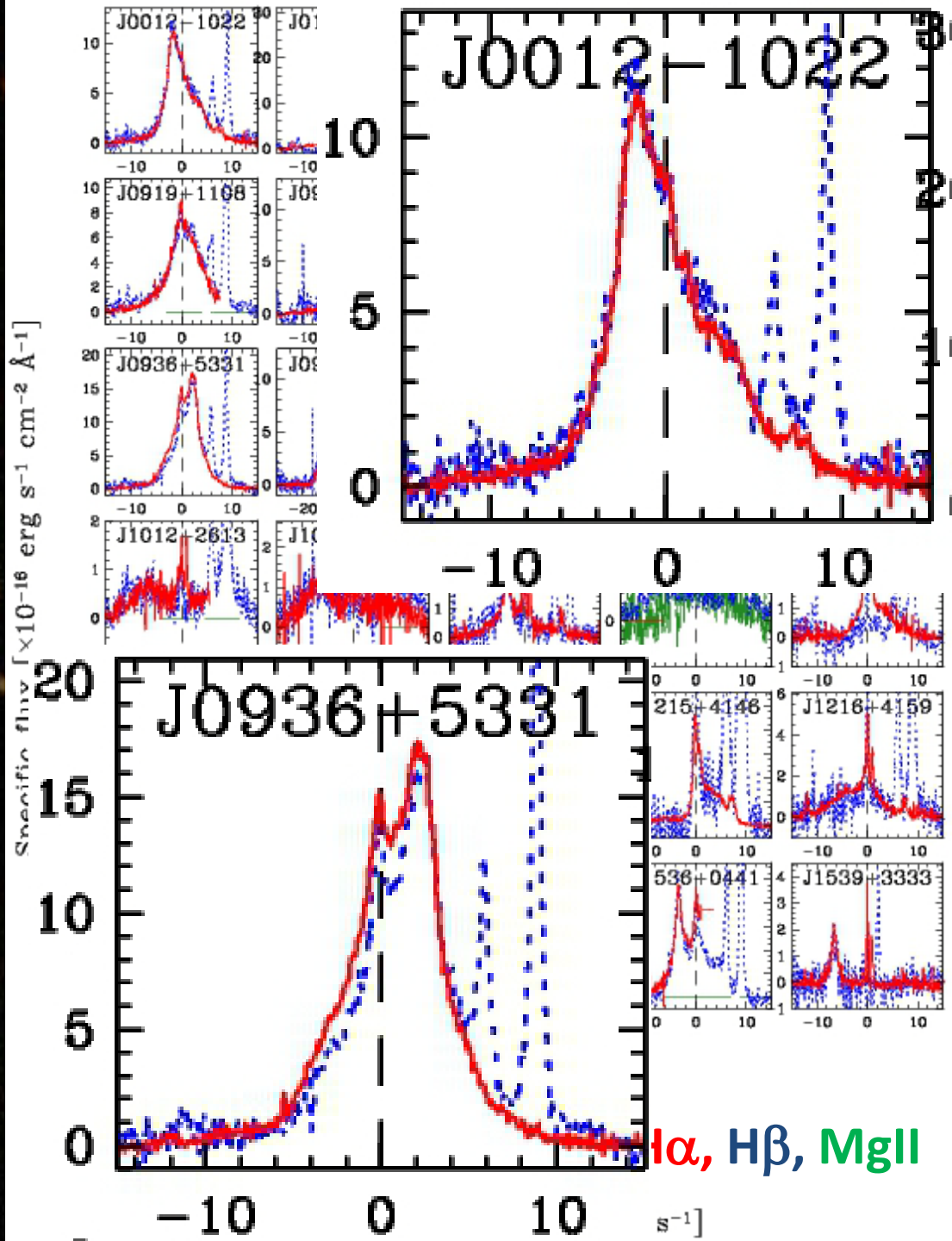
- 4 quasars w. asymmetric lines



Tsalmantza, RD, et al., 2011

Results

We ran our analysis on **55,000 quasars** and **4,000 galaxies** in the SDSS

32 `interesting' objects

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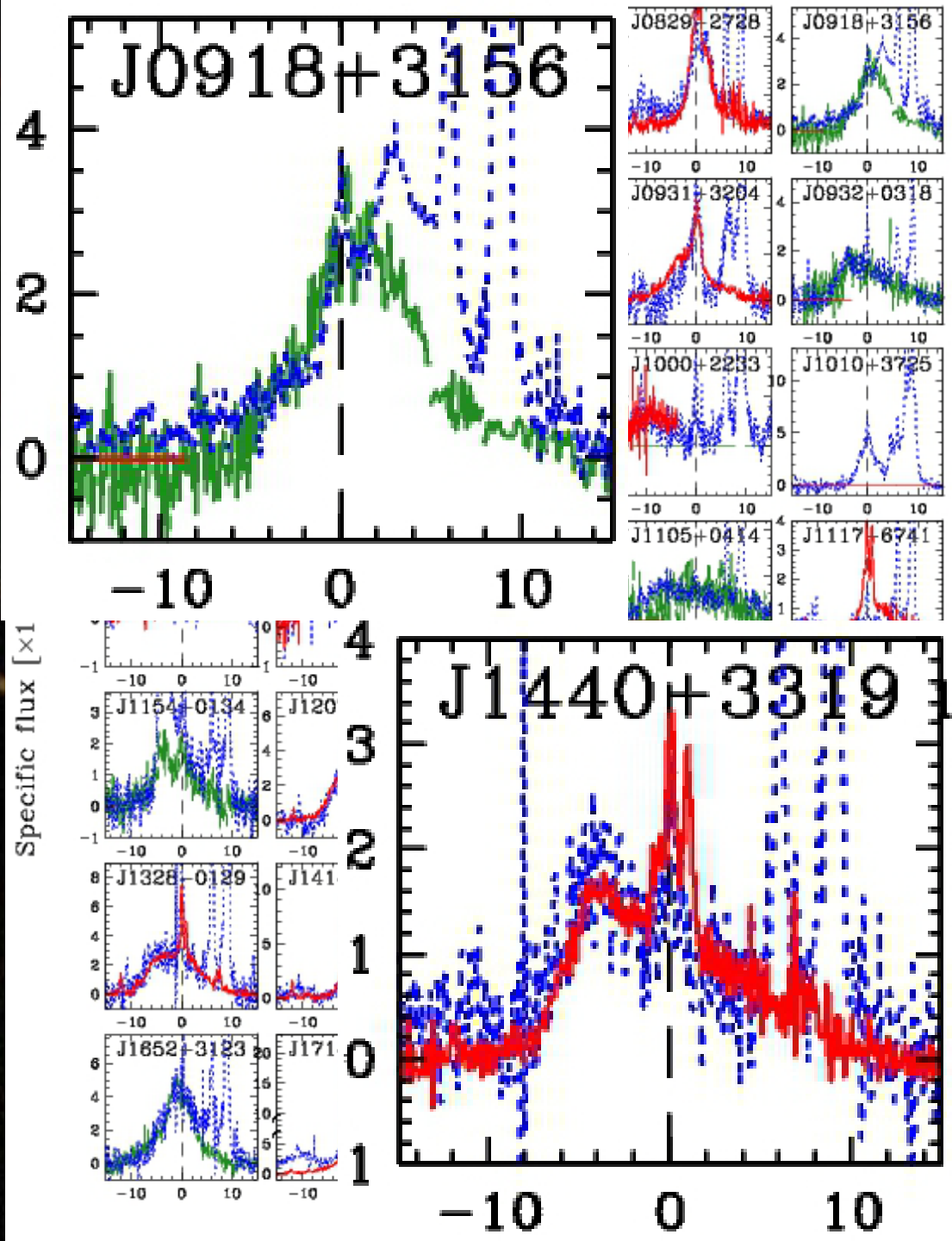
- 4 new BHB candidates
- 4 quasars w. asymmetric lines
- 3 DPE candidates

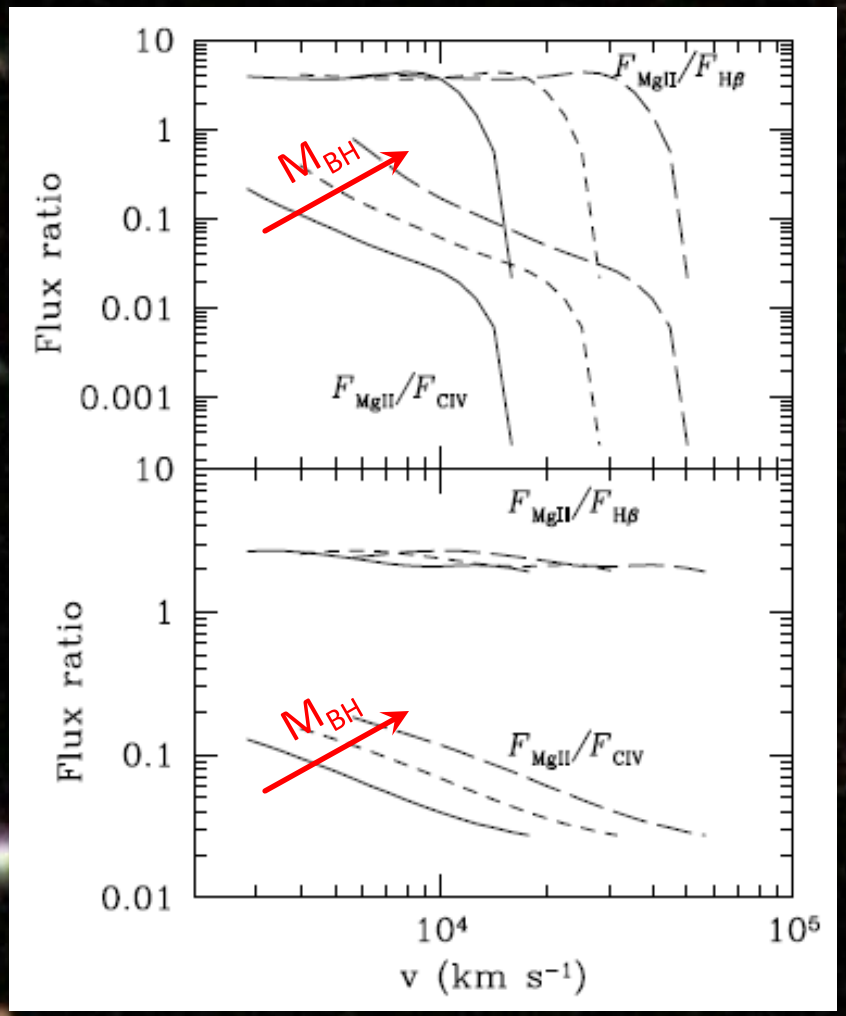


Tsalmantza, RD, et al., 2011

Anomalous BL flux ratios

When $R_{loche} < R_{BLR}$ external regions of the BLR are lost
→ fainter, flat-top low-ionization lines

Montuori et al., 2010



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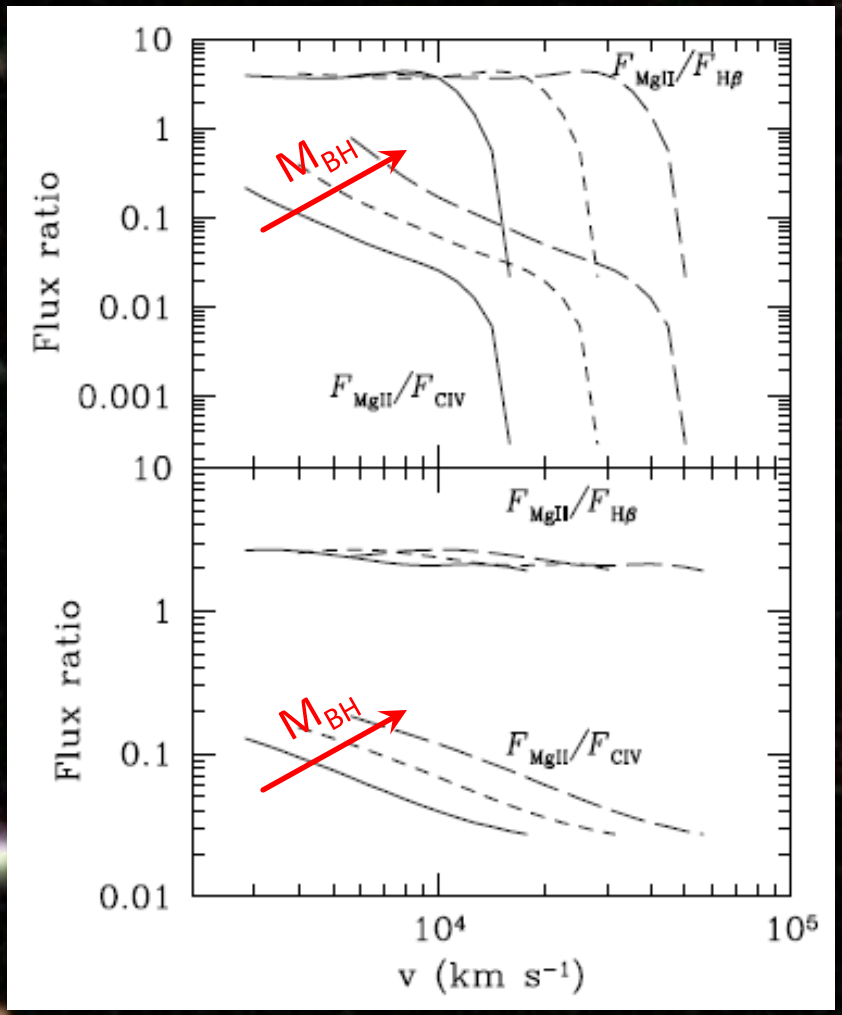
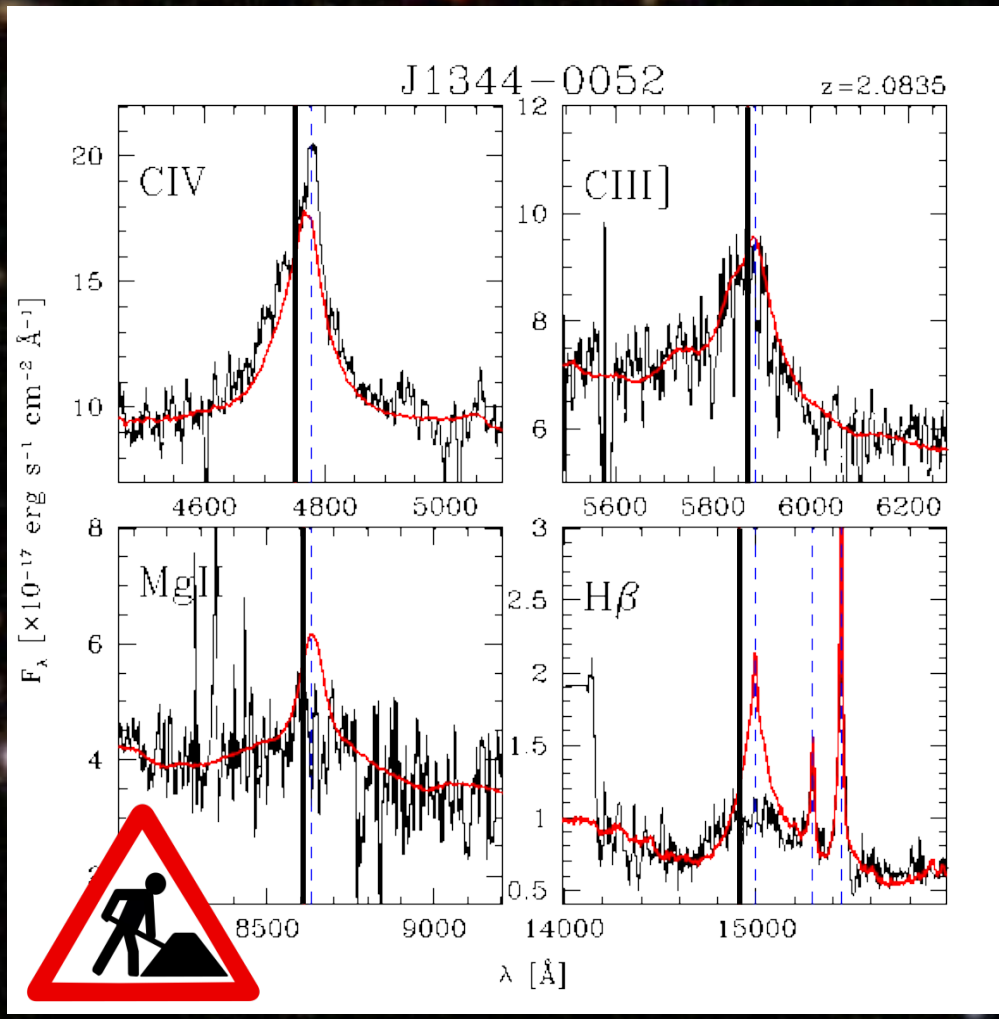


Montuori et al., in prep.



Conclusions

Broad line shifts seem an efficient tool to search for BHB candidates

The number of candidates inflated **from 2 to few tens**

However this feature is not a **unique signature** of BHBs

Follow-up observations **can rule out contaminants** (e.g., galaxy superposition)

Coupling with other observable feature is needed:

- UV lines
- Long term variability
- Flux ratios & line profiles

Open Questions

Do these candidates tell anything useful to constrain models?

What else can we use as tracers of BHBs?

How can we distinguish BHBs from
- **hot spots in the BLR?**
- **recoiling BHs?**

(Does a “bullet-proof” BHB feature actually exist?)