Emergence, Extremely High Velocities, and Strange Variability of Quasar Outflows

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Some collaborators:

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Zane Comden* (HSU)
Jane Charlton (Penn State)
George Chartas (College of Charleston)
Michael Eracleous (Penn State Univ.)
Michael Gibbons* (HSU)
Margherita Giustini (ESA)
Pat Hall (York Univ.)
Sean Haas* (HSU)
Abdul Khatri* (Univ. of Toronto)
Viraja Khatu* (Western Univ.)
Daniel Proga (Univ. Nevada)
Carla Quintero* (HSU)
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Andrey Vayner* (UCSD)

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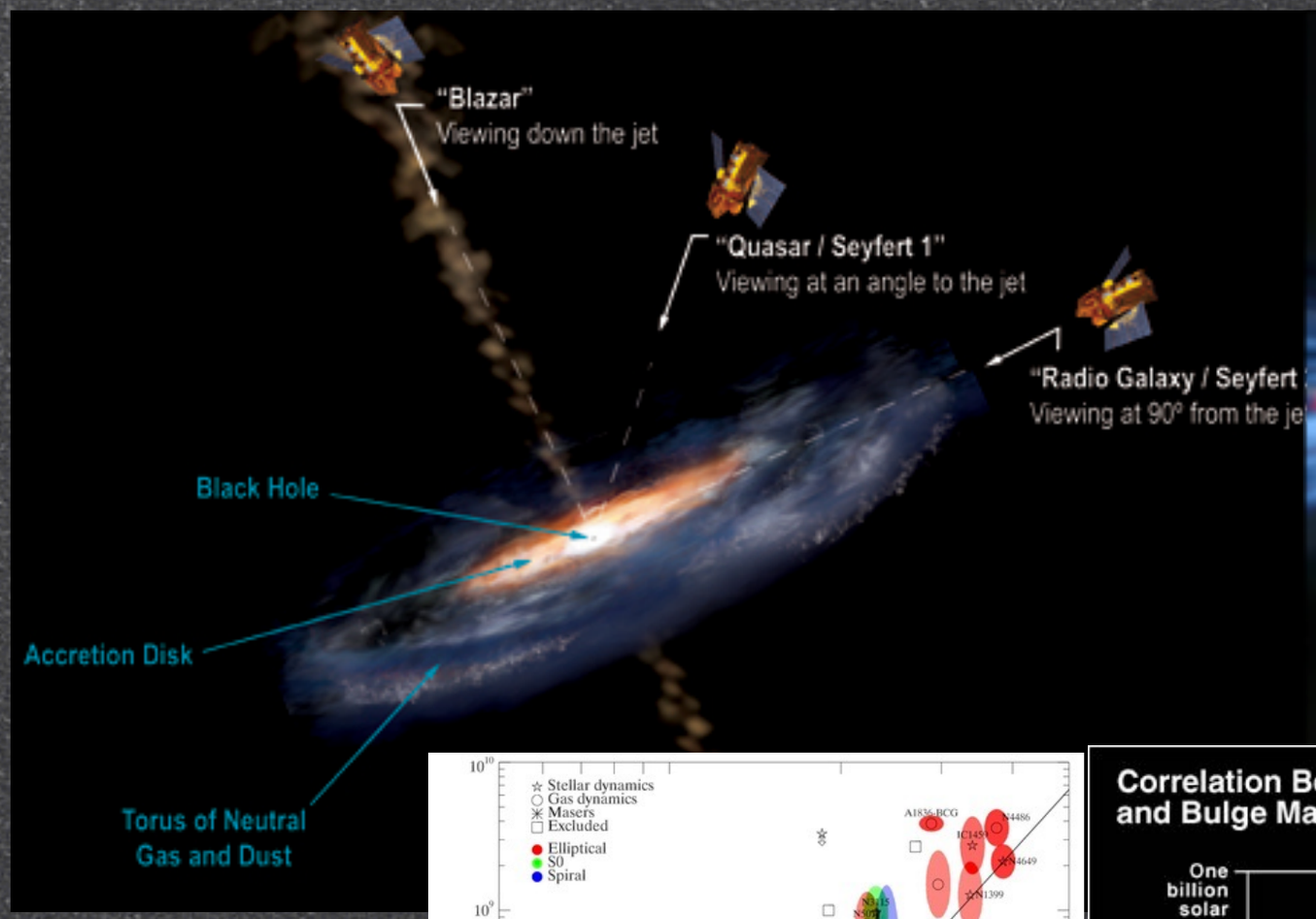
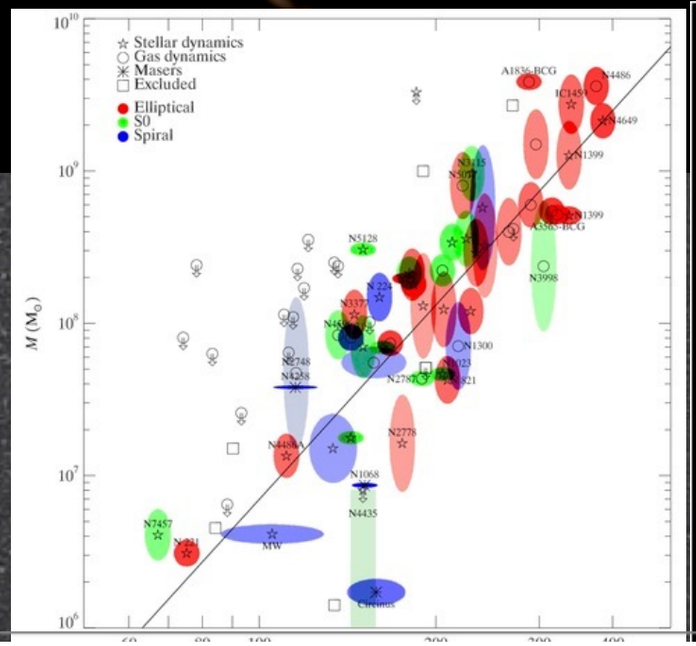
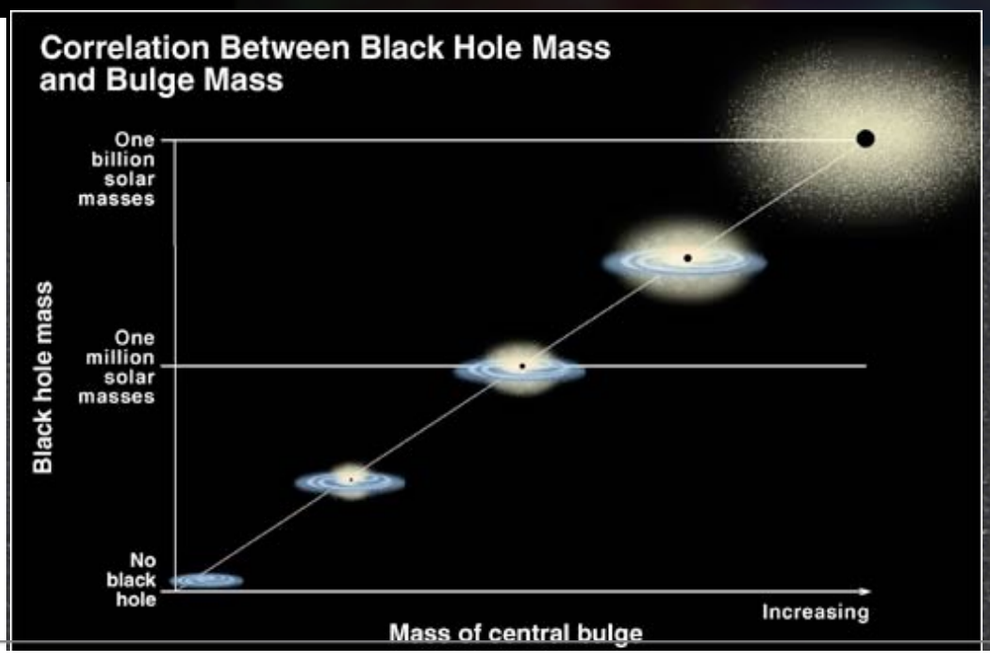
Why study quasar outflows?



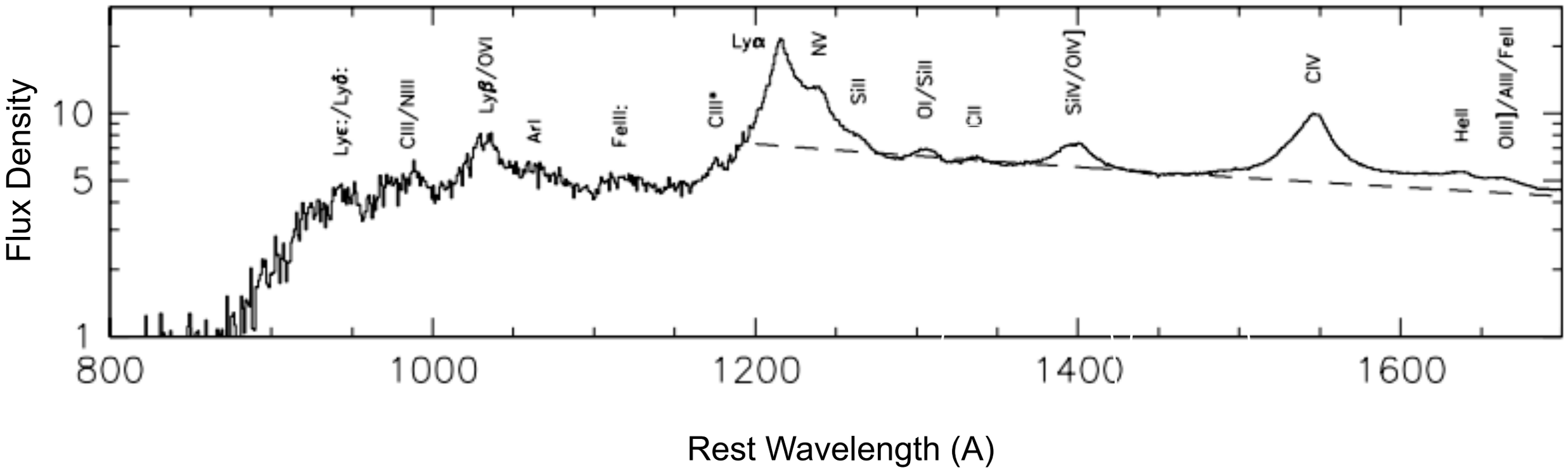
(Gültekin+09)





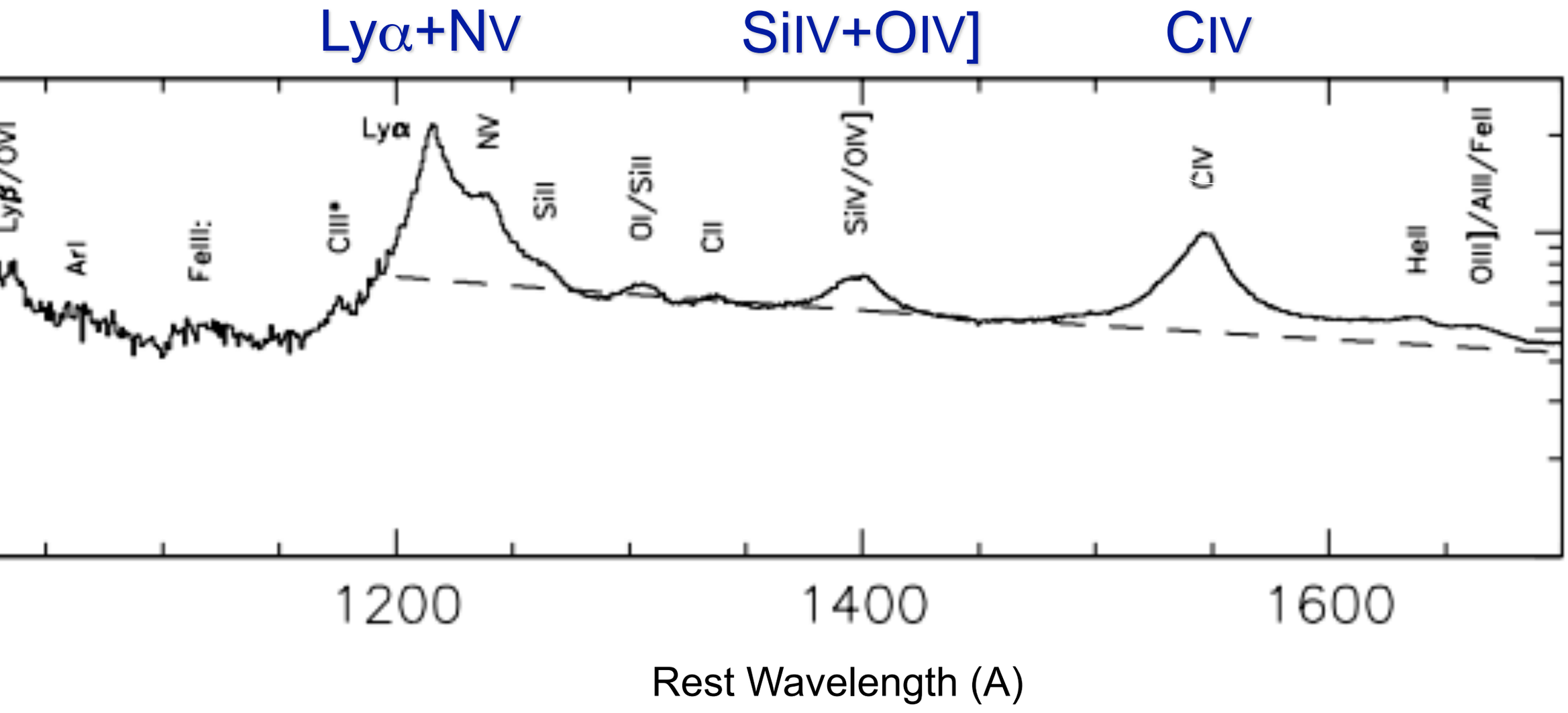
Relation AGN environment - BH - galactic evolution

Quasar spectra

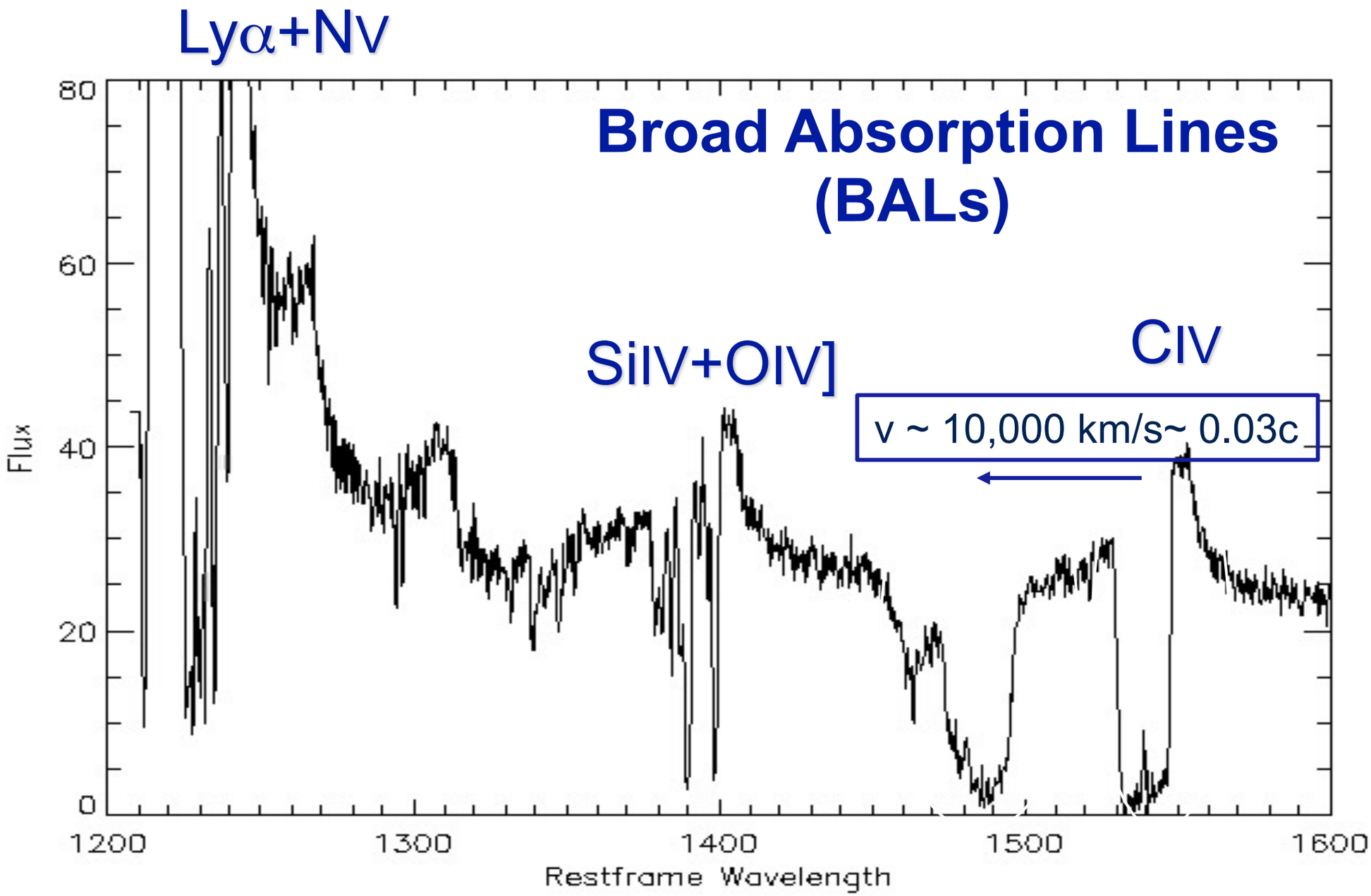


(Vander Berk+01)

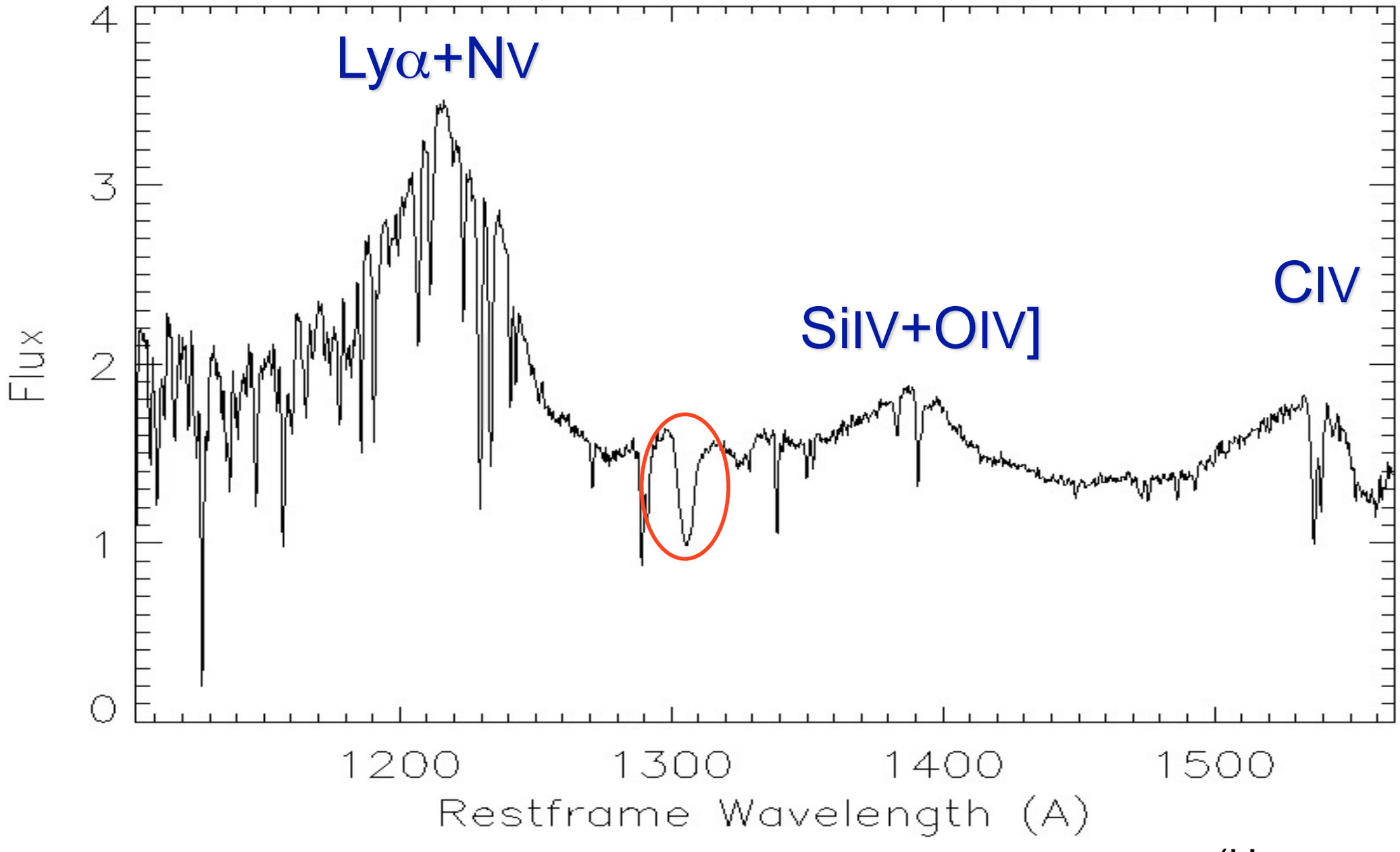
Quasar spectra



Quasar spectra - High Velocity Outflows

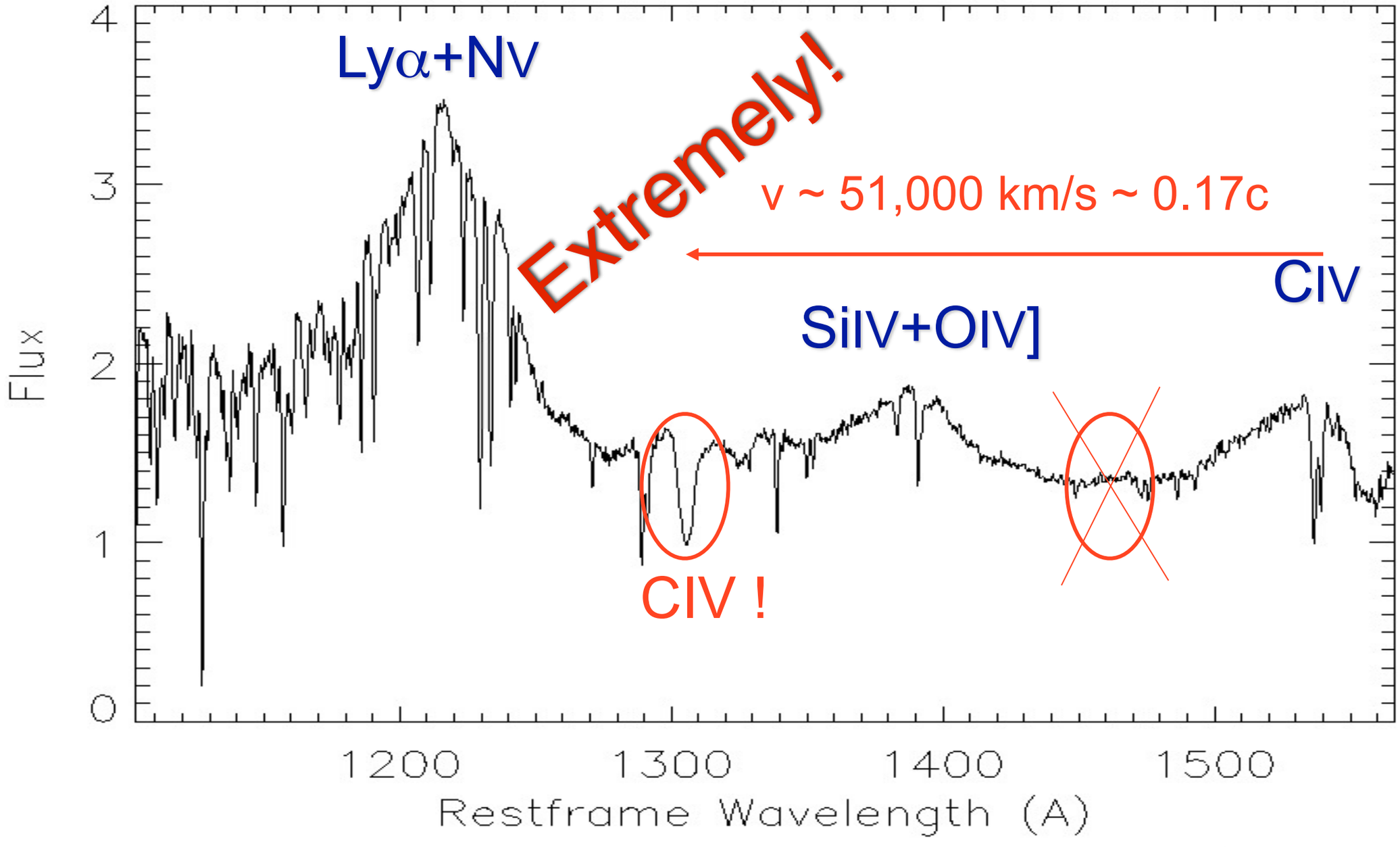


Quasar spectra - High Velocity Outflows



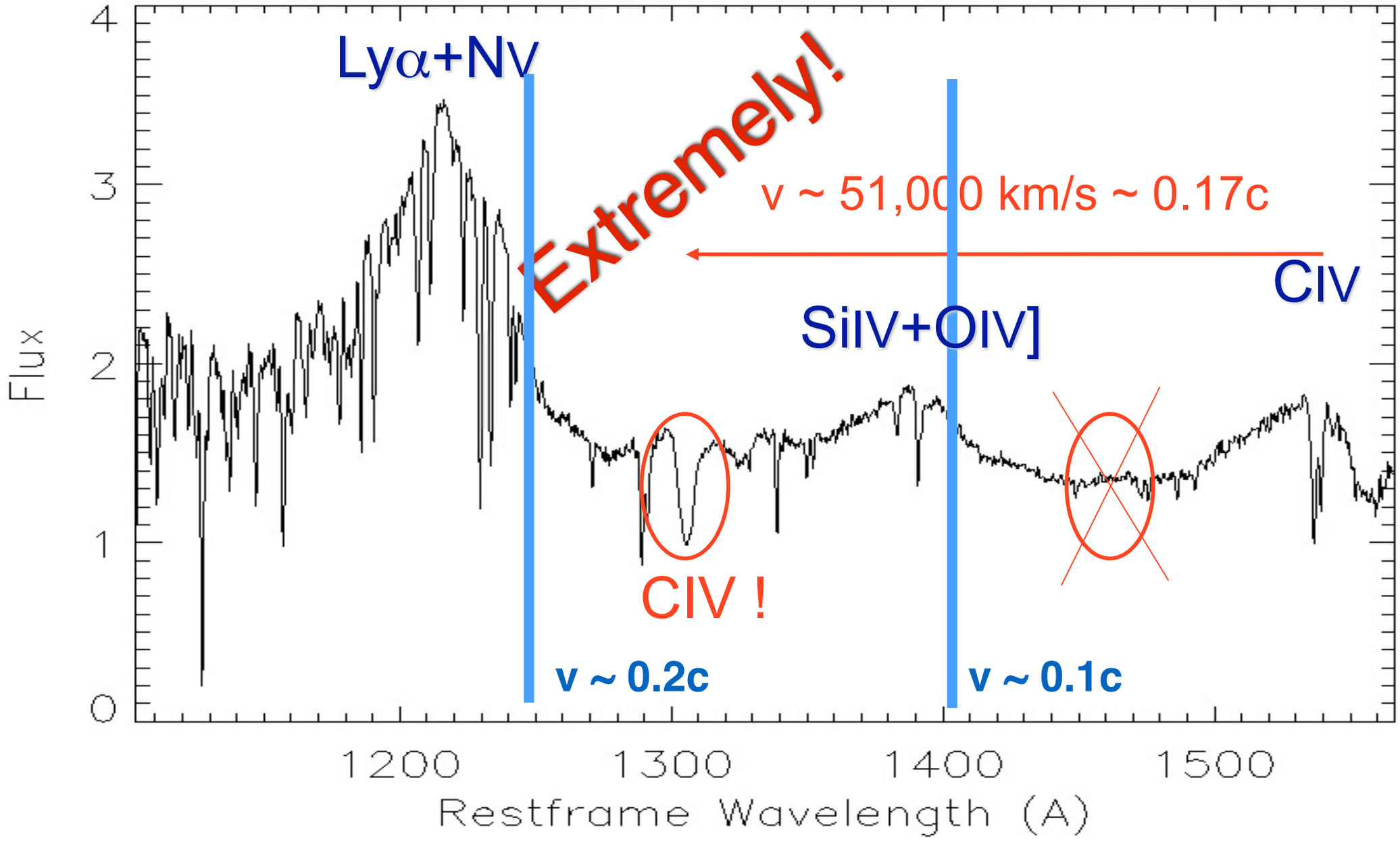
(Hamann+1997)

Quasar spectra - High Velocity Outflows PG0935+417



(Hamann+1997)

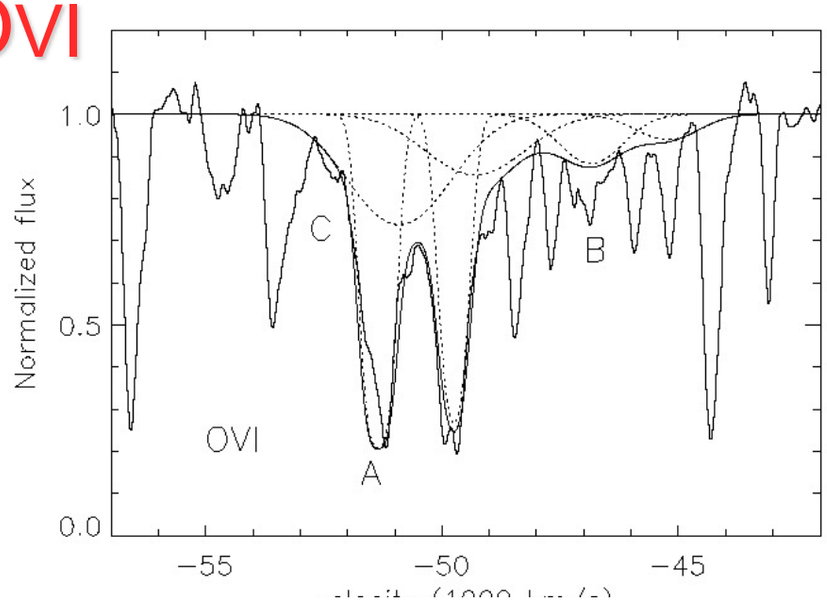
Quasar spectra - Extremely High Velocity Outflows PG0935+417



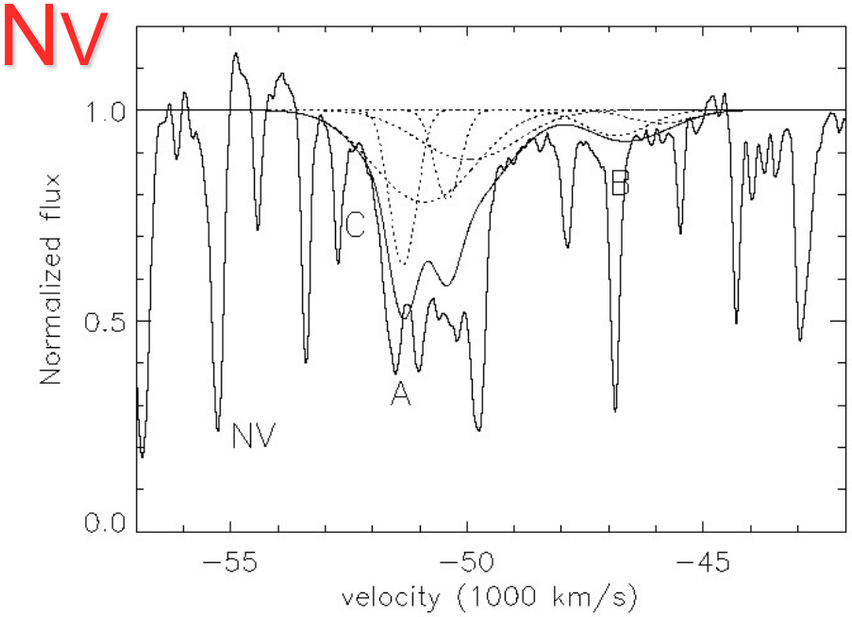
(Hamann+1997)

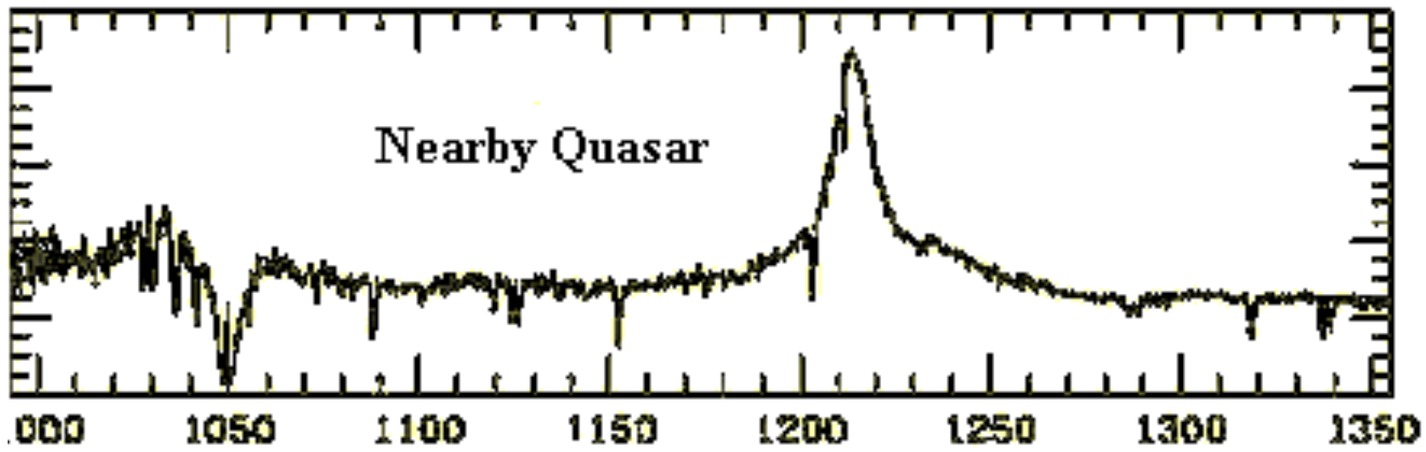
Quasar spectra - Extremely High Velocity Outflows PG0935+417

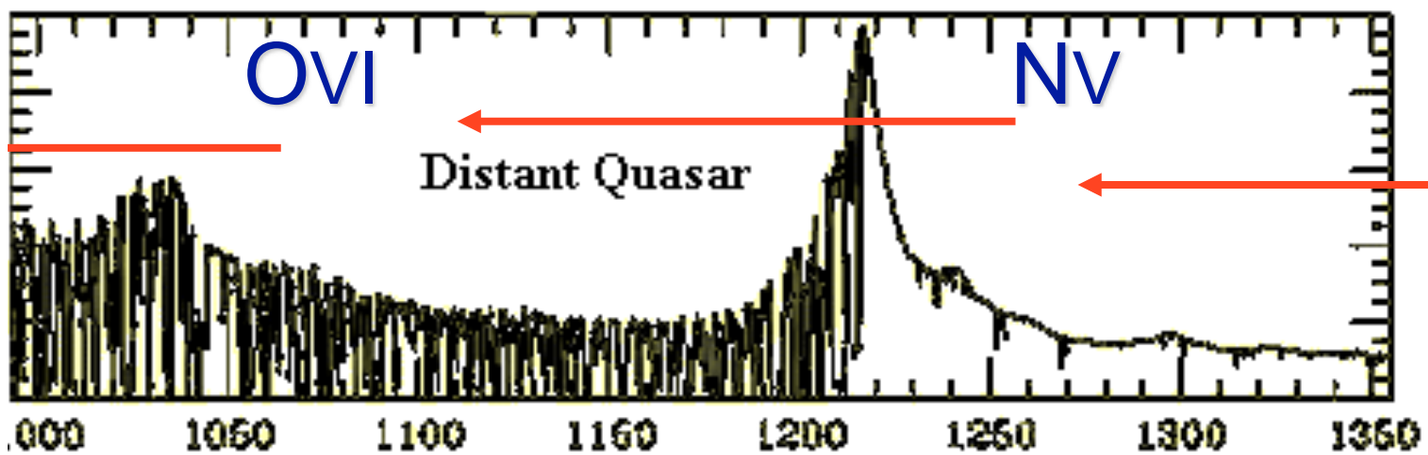
OVI



NV

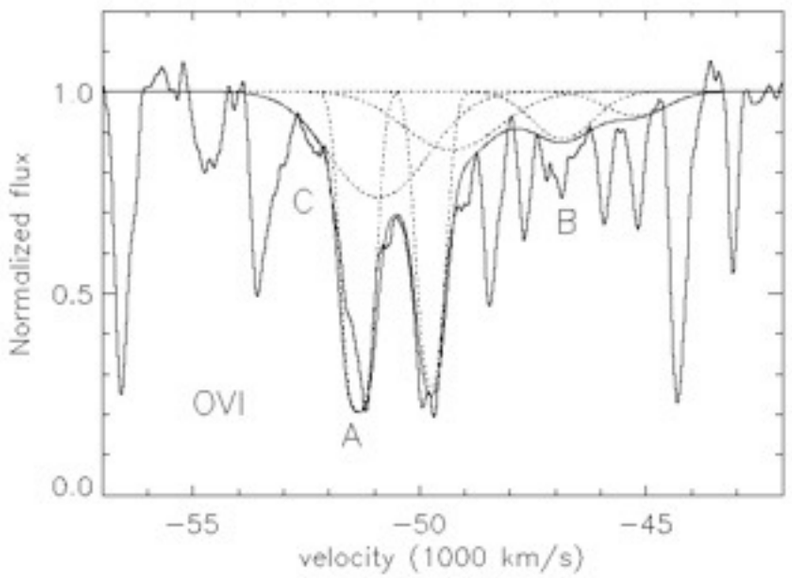




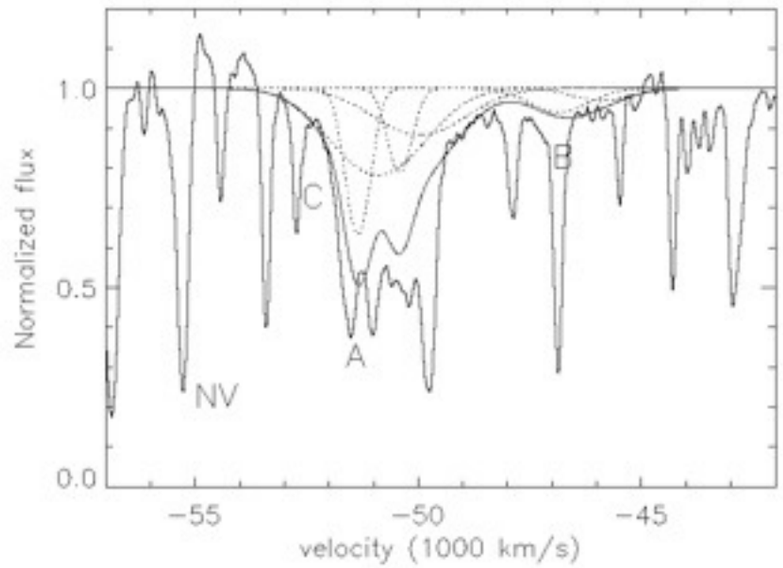


Quasar spectra - Extremely High Velocity Outflows PG0935+417

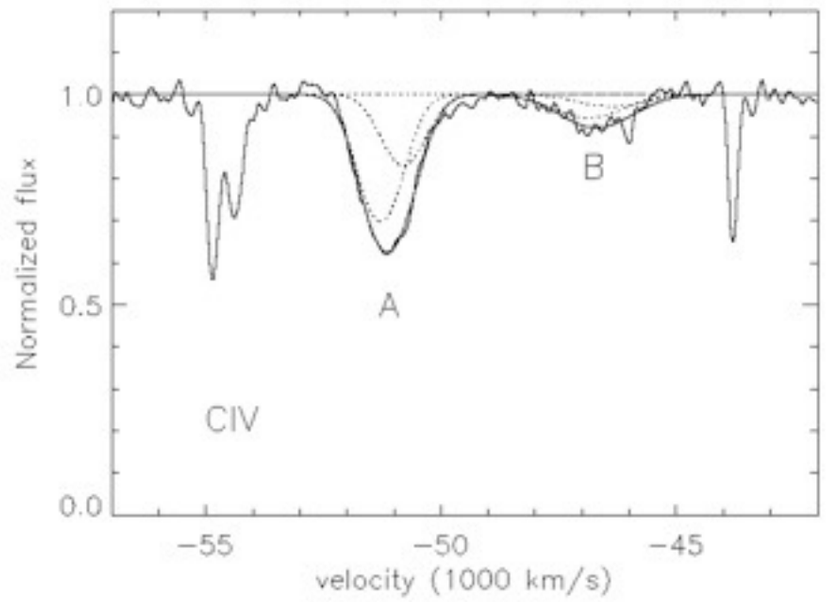
OVI



NV



CIV

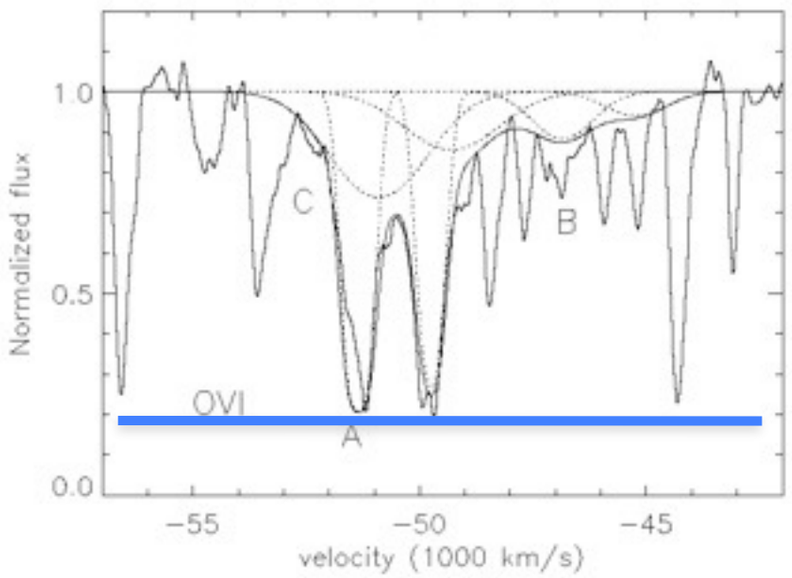


(Rodriguez Hidalgo+2011)

- HST/FOS data
- No other ions had confirmed detections

Quasar spectra - Extremely High Velocity Outflows PG0935+417

OVI



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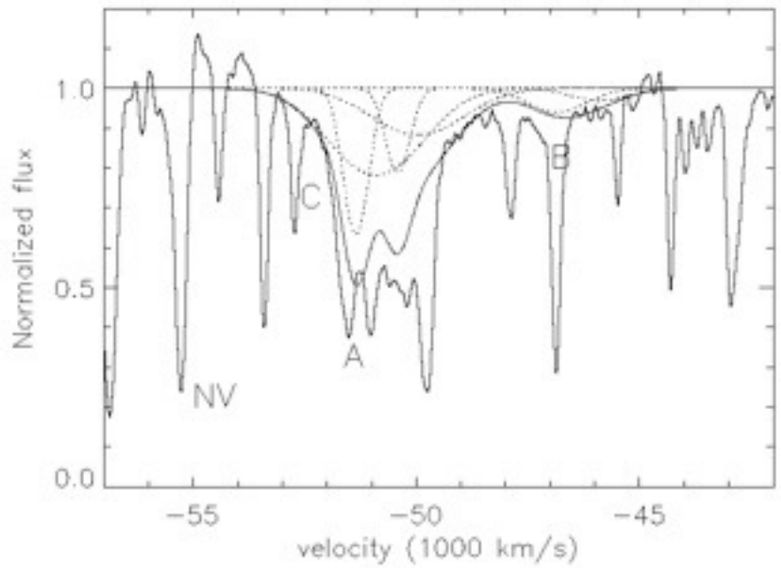

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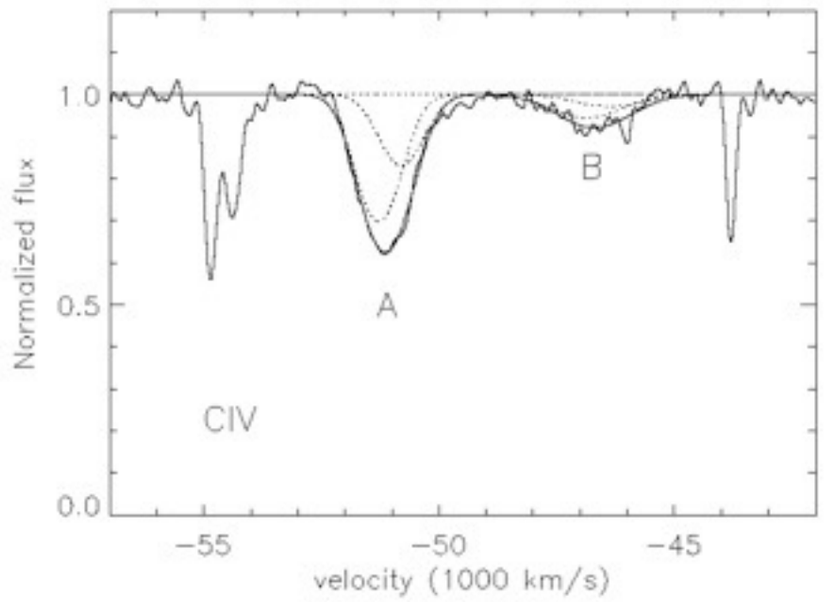

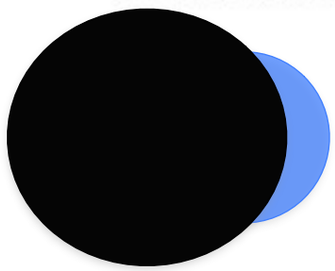

(Rodriguez Hidalgo+2011)

Quasar spectra - Extremely High Velocity Outflows PG0935+417

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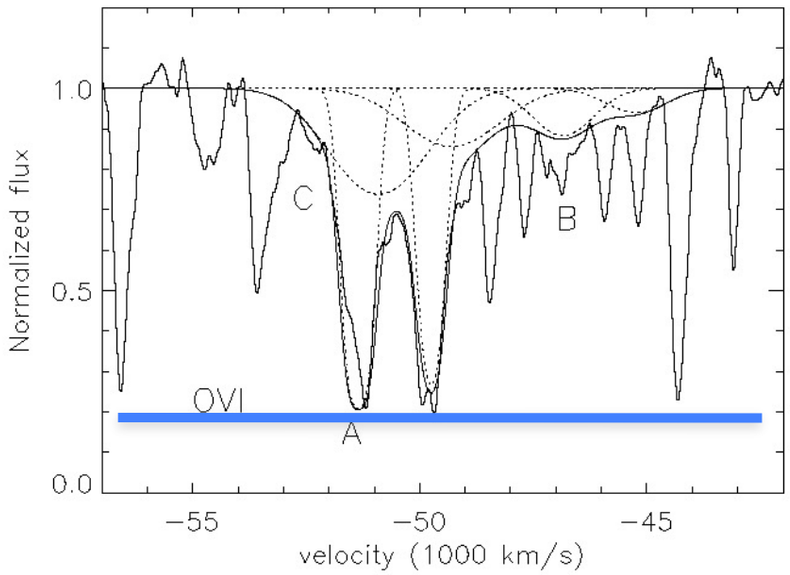

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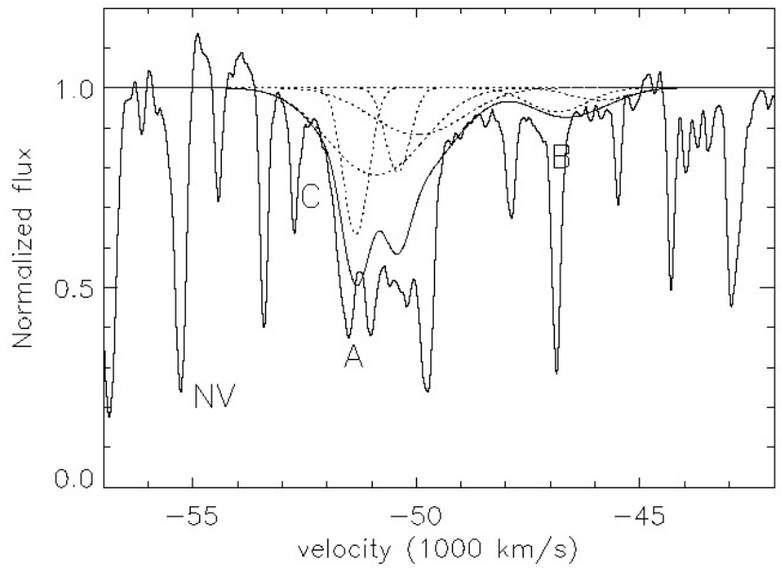

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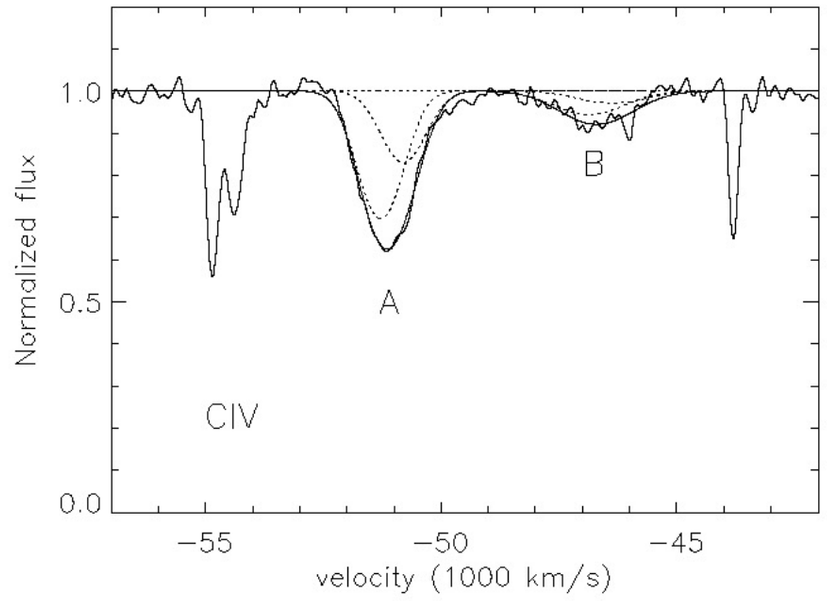
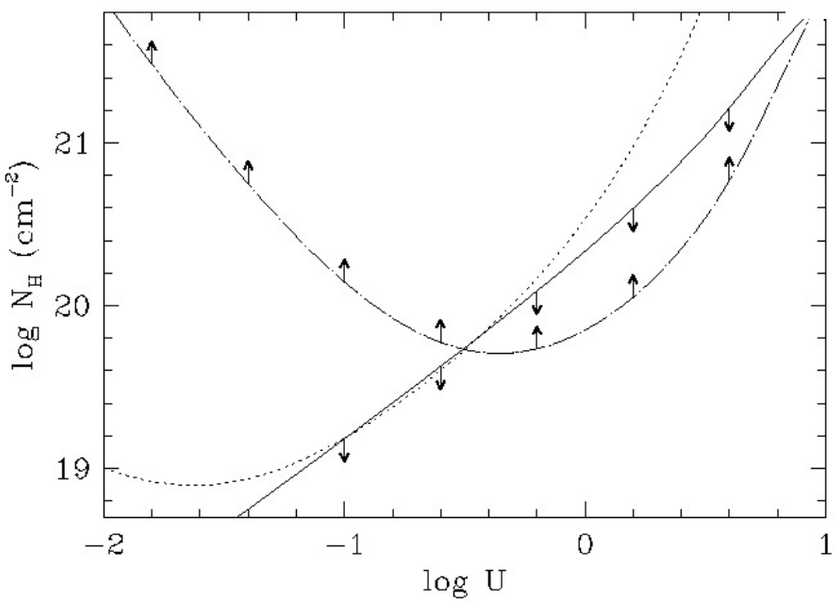




(Rodriguez Hidalgo+2011)

Coverage Fraction: $C_f = 0.8$

Total Column Density: $N_H \sim 5 \times 10^{19}$ cm^{-2}

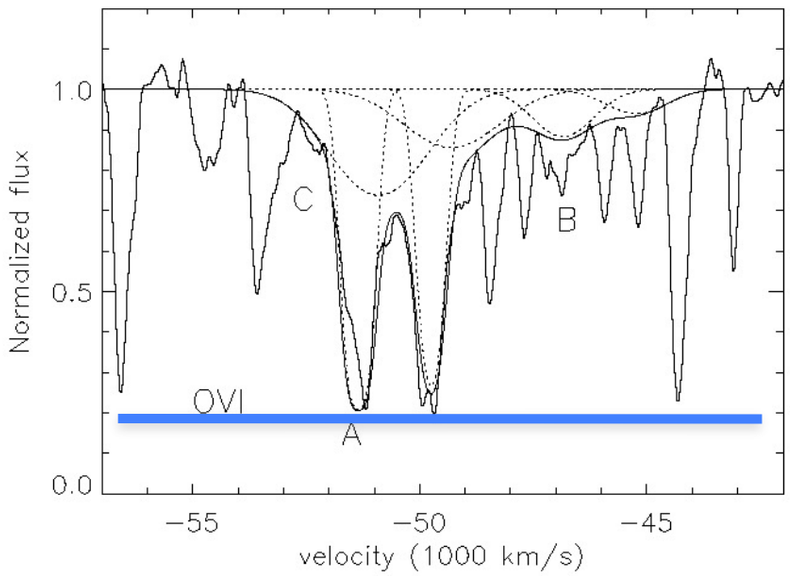
Ionization: log $U \sim -0.5$

Mass Outflow Rate $\sim 8\pi\Omega R N_H \mu m_p v$

Kinetic Luminosity $\sim 2\pi\Omega R N_H \mu m_p v^3$

Quasar spectra - Extremely High Velocity Outflows PG0935+417

OVI



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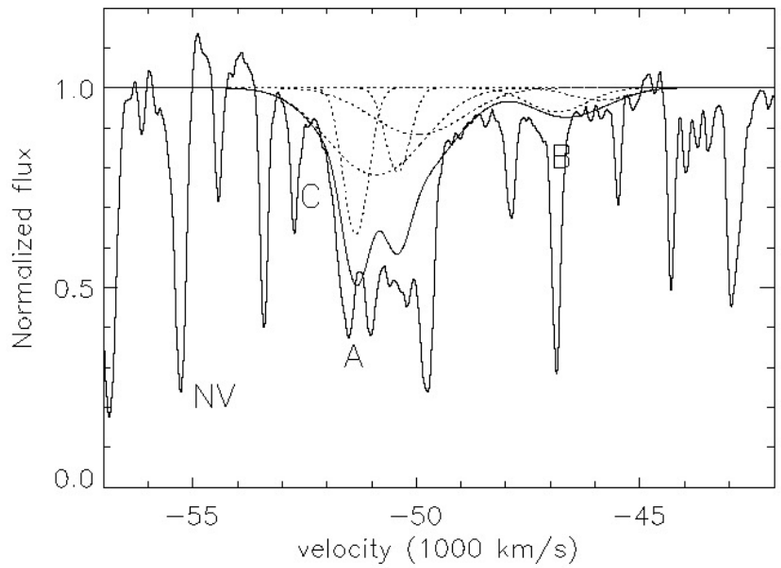
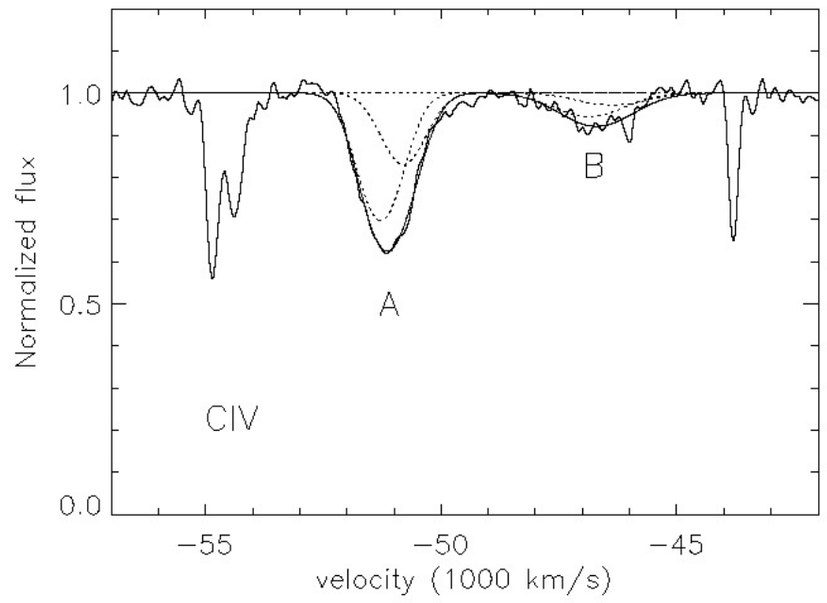
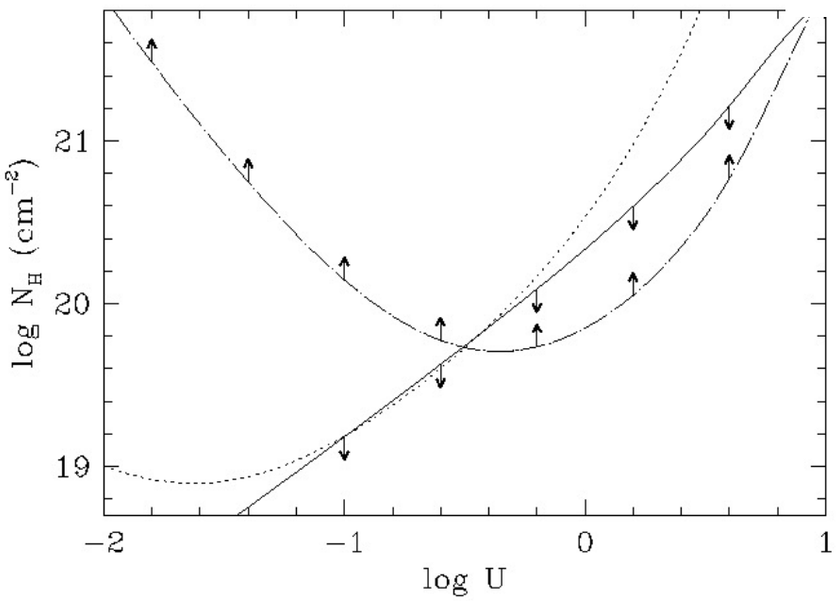


CIV



(Rodriguez Hidalgo+2011)



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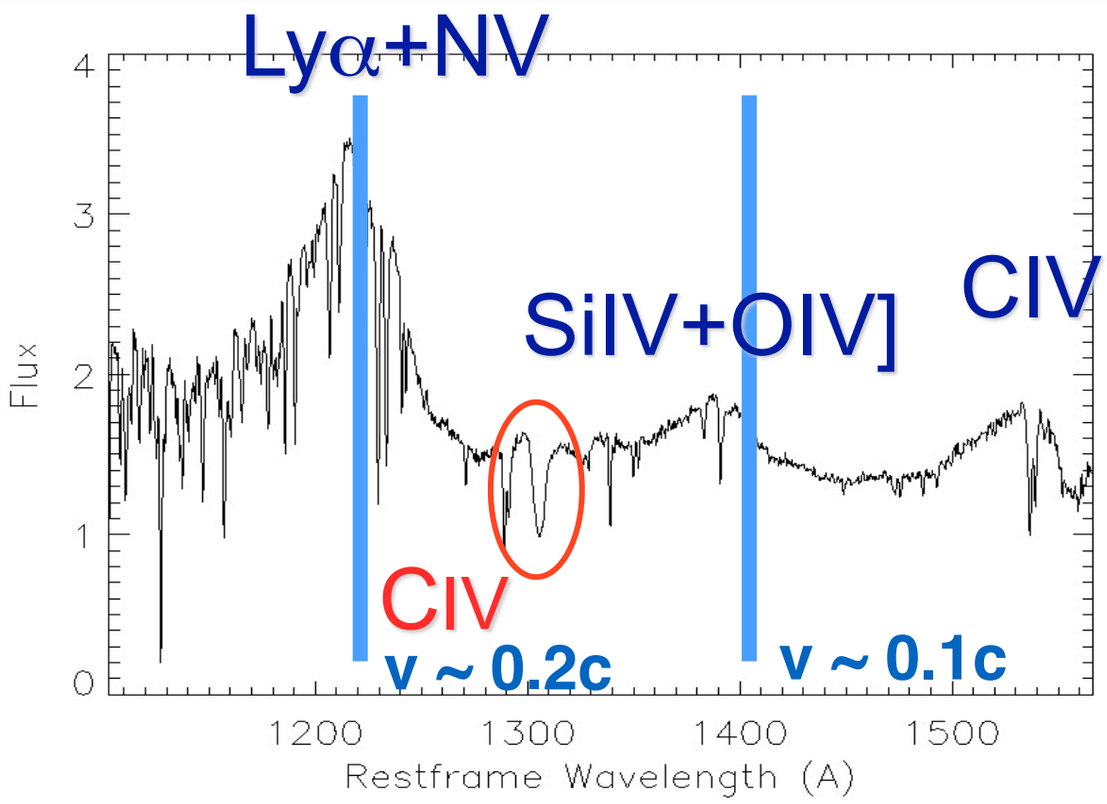
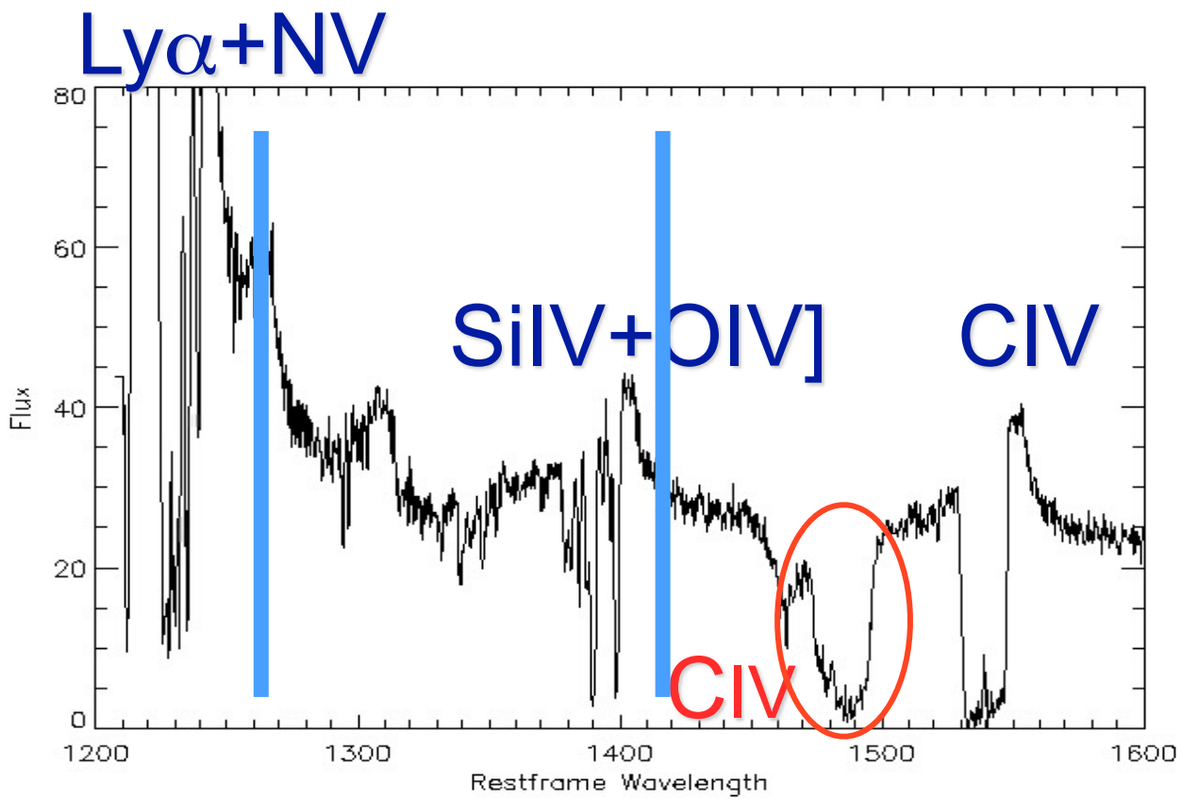
Quasar spectra - Extremely High Velocity Outflows PG0935+417

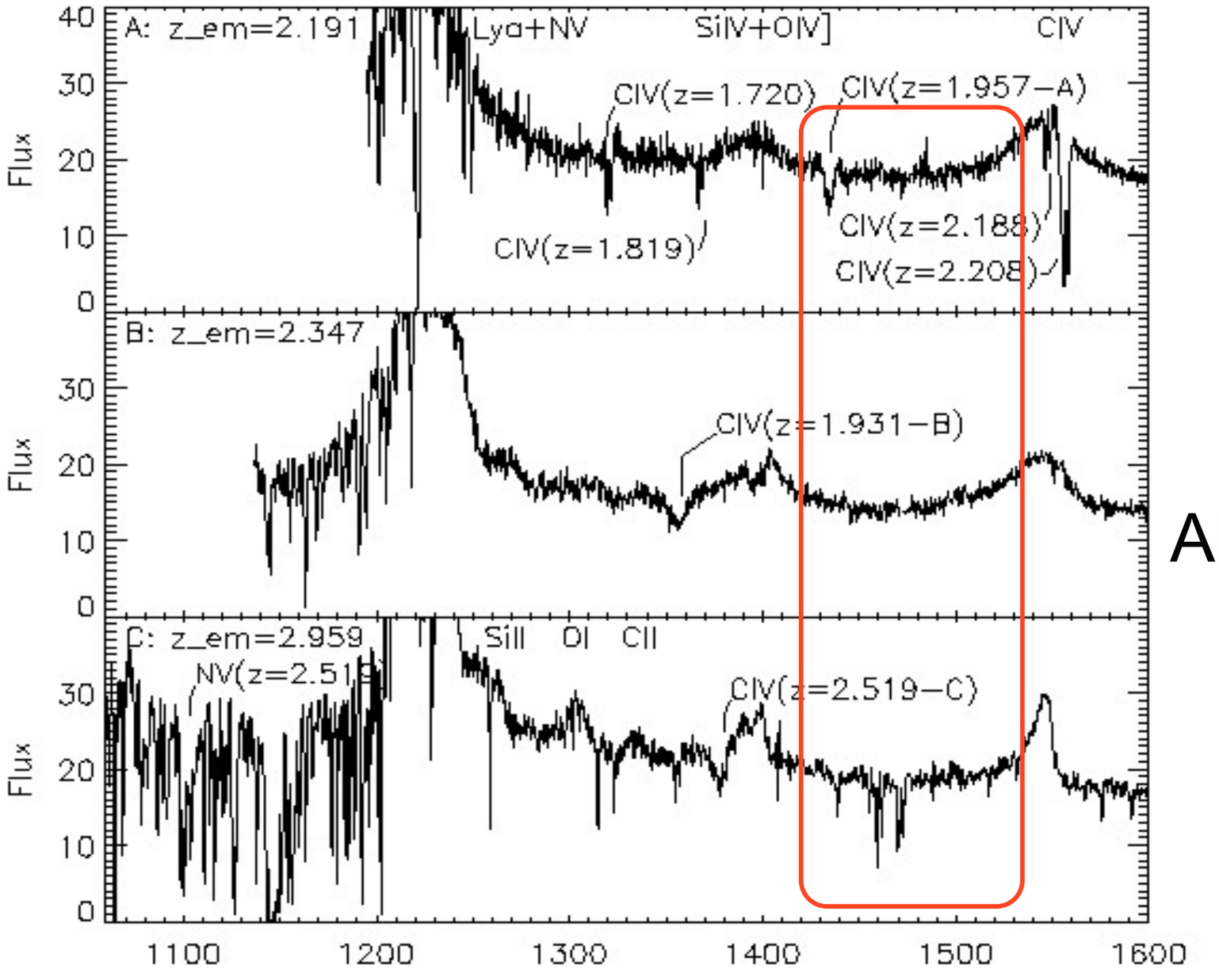


Kinetic Luminosity $\sim 2\pi\Omega R N_H \mu m_p v^3$

The Kinetic Luminosity of an outflow at ~0.2c is *216 times larger* than an outflow at 0.05c (!)



Searching for Extremely-high velocity outflows



Balnicity Index (BI)

Absorption Index (AI)

(Weymann+91, Hall+02)

Searching for Extremely-high velocity outflows

- SDSS DR9 Quasar spectra (Pâris+12):
  - 87,822 quasars
  - 1300< spectral resolution (R) < 2500
  - spectral coverage 3600-10500 A

- Search for CIV λλ1548,1550 in the velocity range 0.1-0.2c
  - ➡ $z_{em} > 1.9$
  - ➡ S/N >= 10 (brightest quasars)

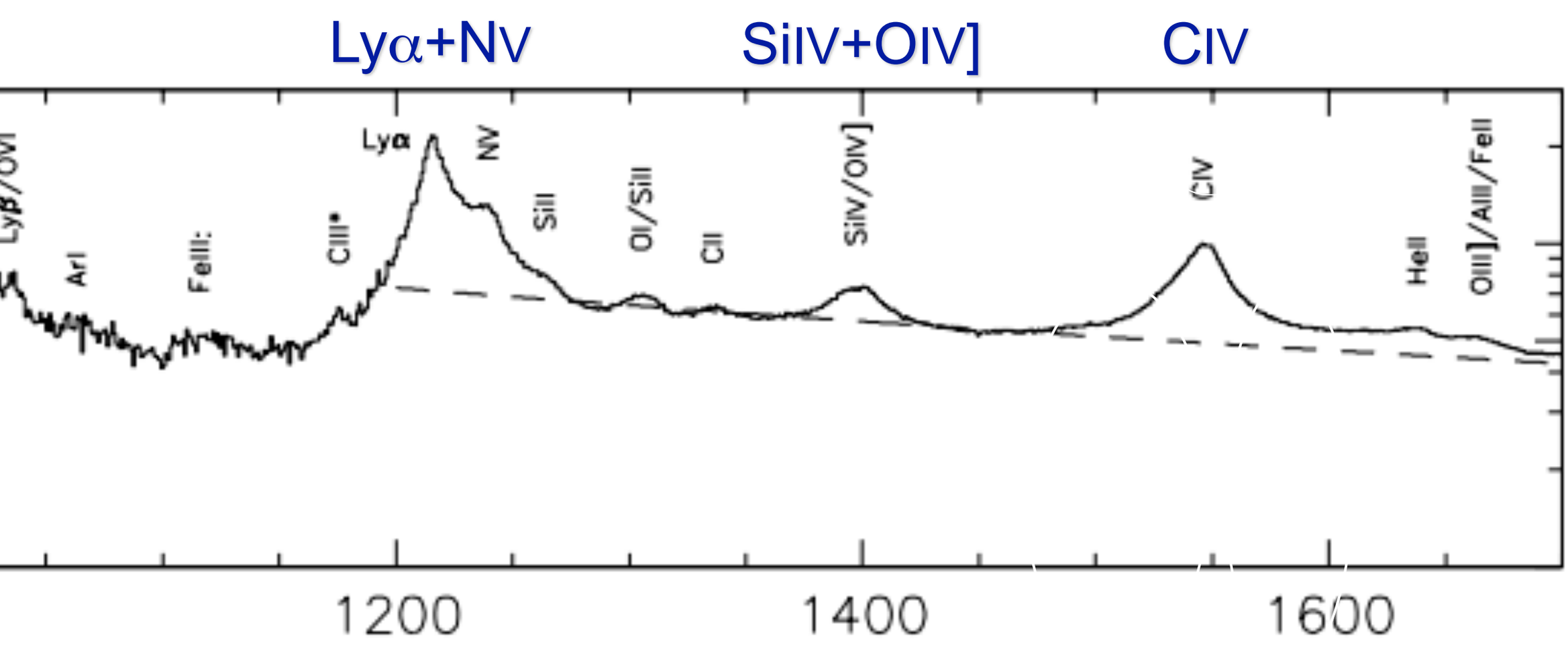
6760 quasar spectra

Searching for Extremely-high velocity outflows

6760 quasar spectra

- Normalize all spectra with a simple power-law

Searching for Extremely-high velocity outflows



Searching for Extremely-high velocity outflows

6760 quasar spectra

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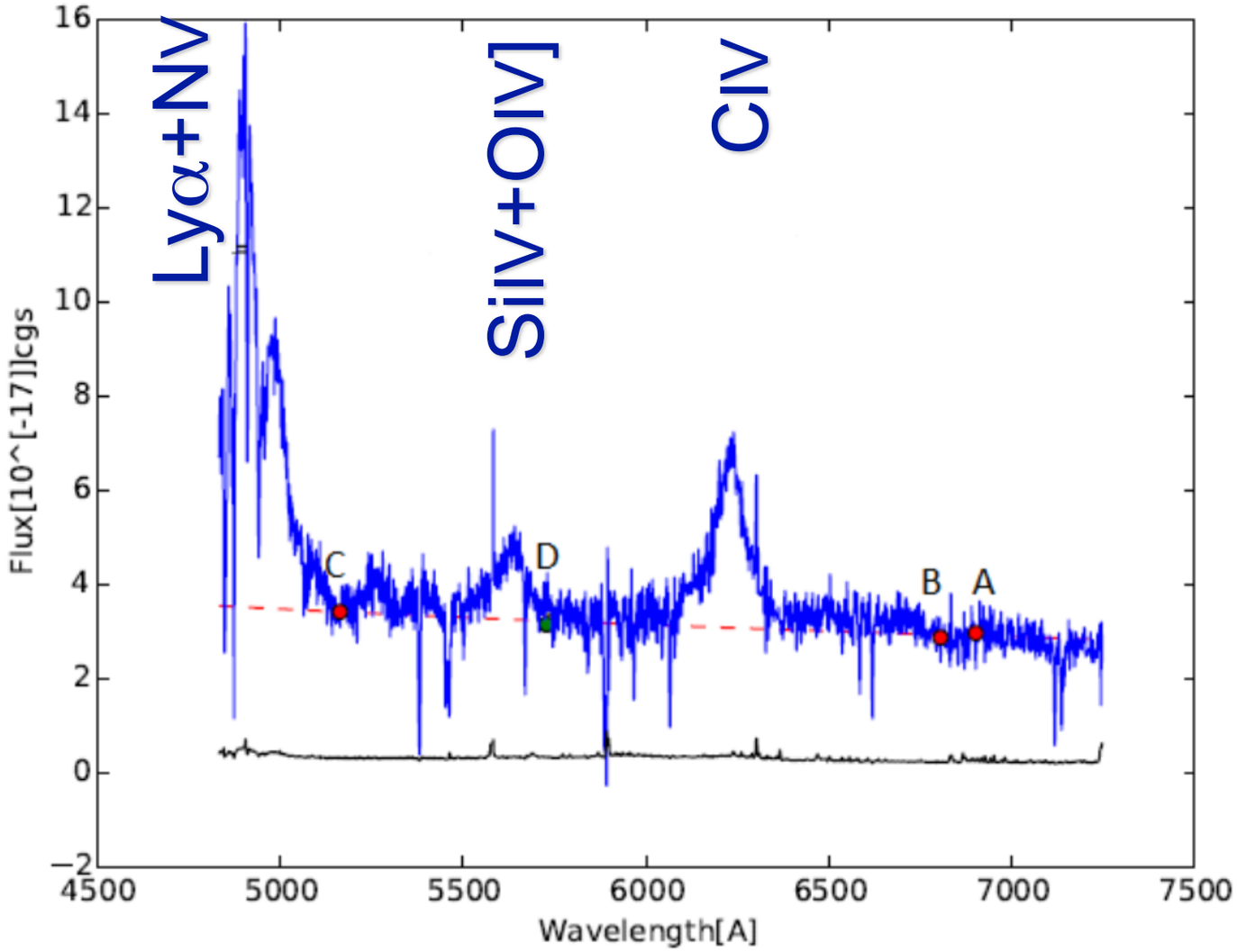
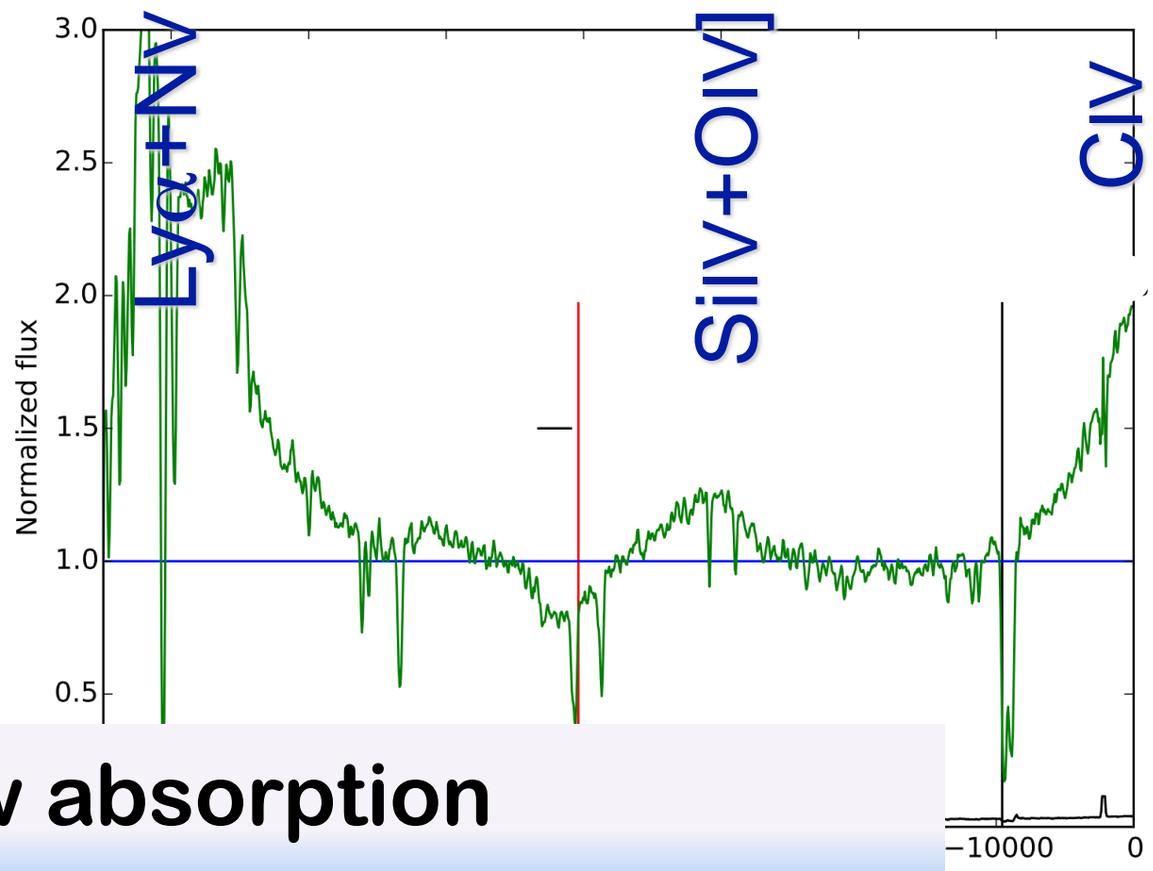


Searching for Extremely-high velocity outflows

6760 quasar spectra

- Normalize all spectra with a simple power-law

- Identify absorption (10% below continuum) with width >1000 km/s



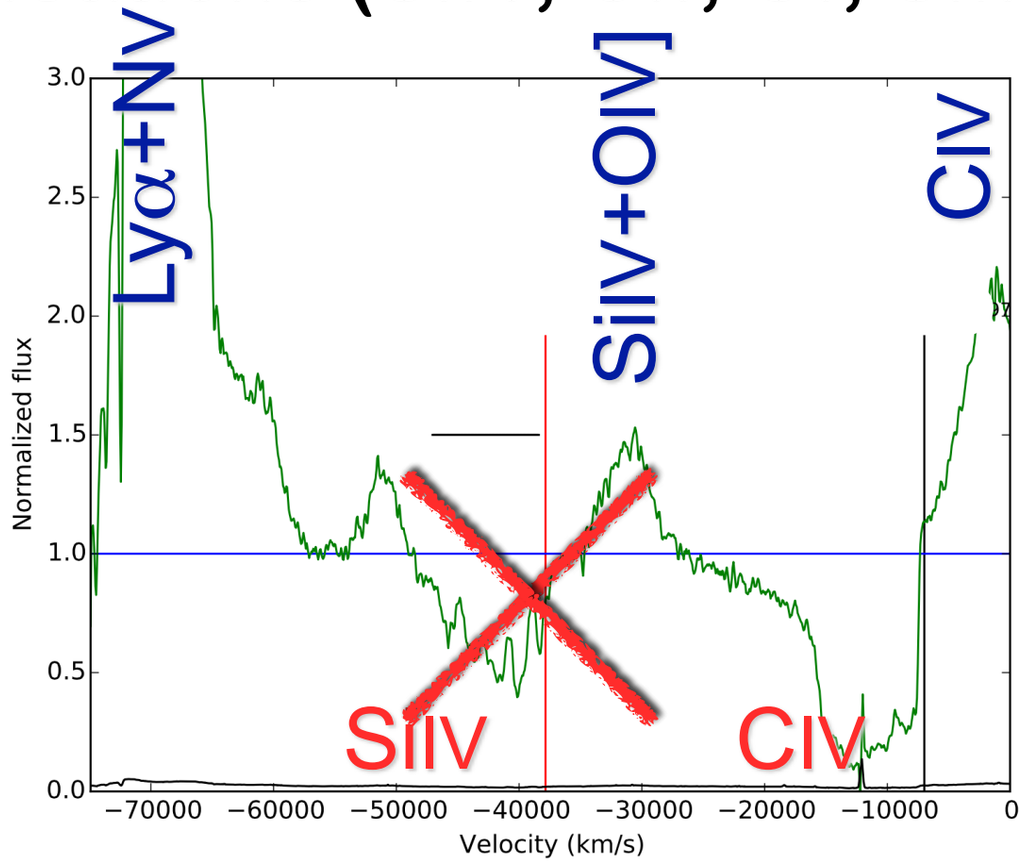
- miss shallow absorption

- miss absorption on top of emission

Searching for Extremely-high velocity outflows

6760 quasar spectra

- Normalize all spectra with a simple power-law
- Identify absorption with width >1000 km/s
- **Visually inspect every case and remove possible other identifications (SiIV, CII, OI, SiII…)**

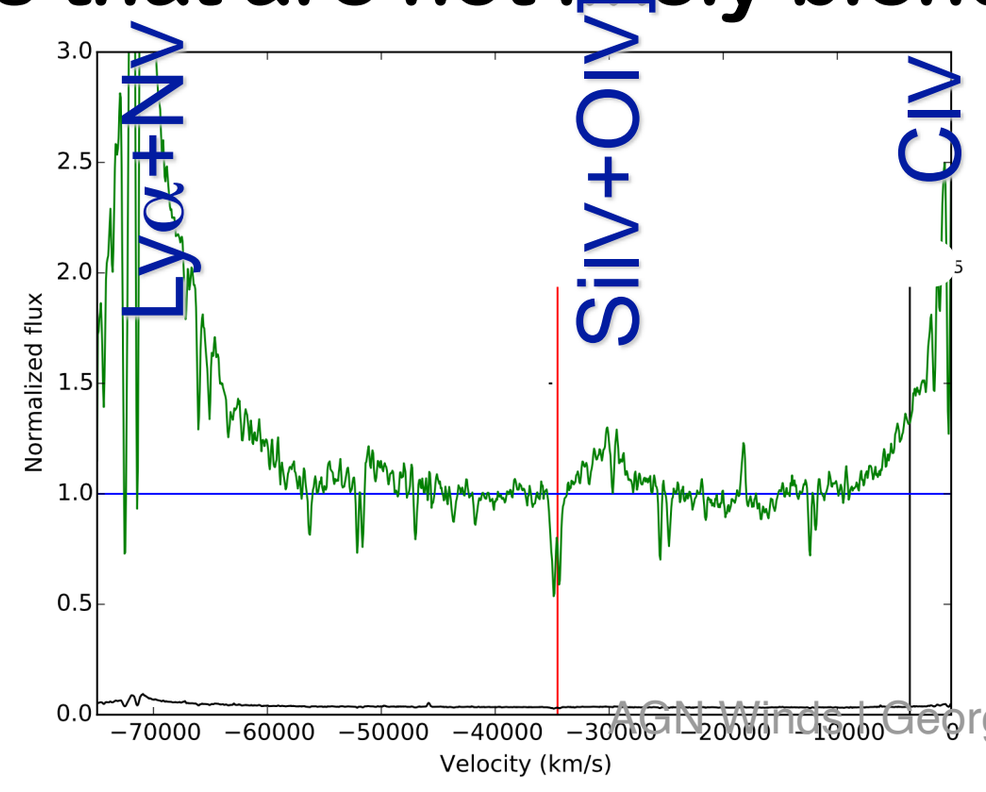


Searching for Extremely-high velocity outflows

6760 quasar spectra

- Normalize all spectra with a simple power-law
- Identify absorption with width >1000 km/s
- Visually inspect every case and remove possible other identifications (SiIV, CII, OI, SiII...)

- Select cases that are not likely blends of narrow lines



Searching for Extremely-high velocity outflows

6760 quasar spectra

- Normalize all spectra with a simple power-law
- Identify absorption with width >1000 km/s
- Visually inspect every case and remove possible other identifications (SiIV, CII, OI, SiII...)
- Select cases that are not likely blends of narrow lines

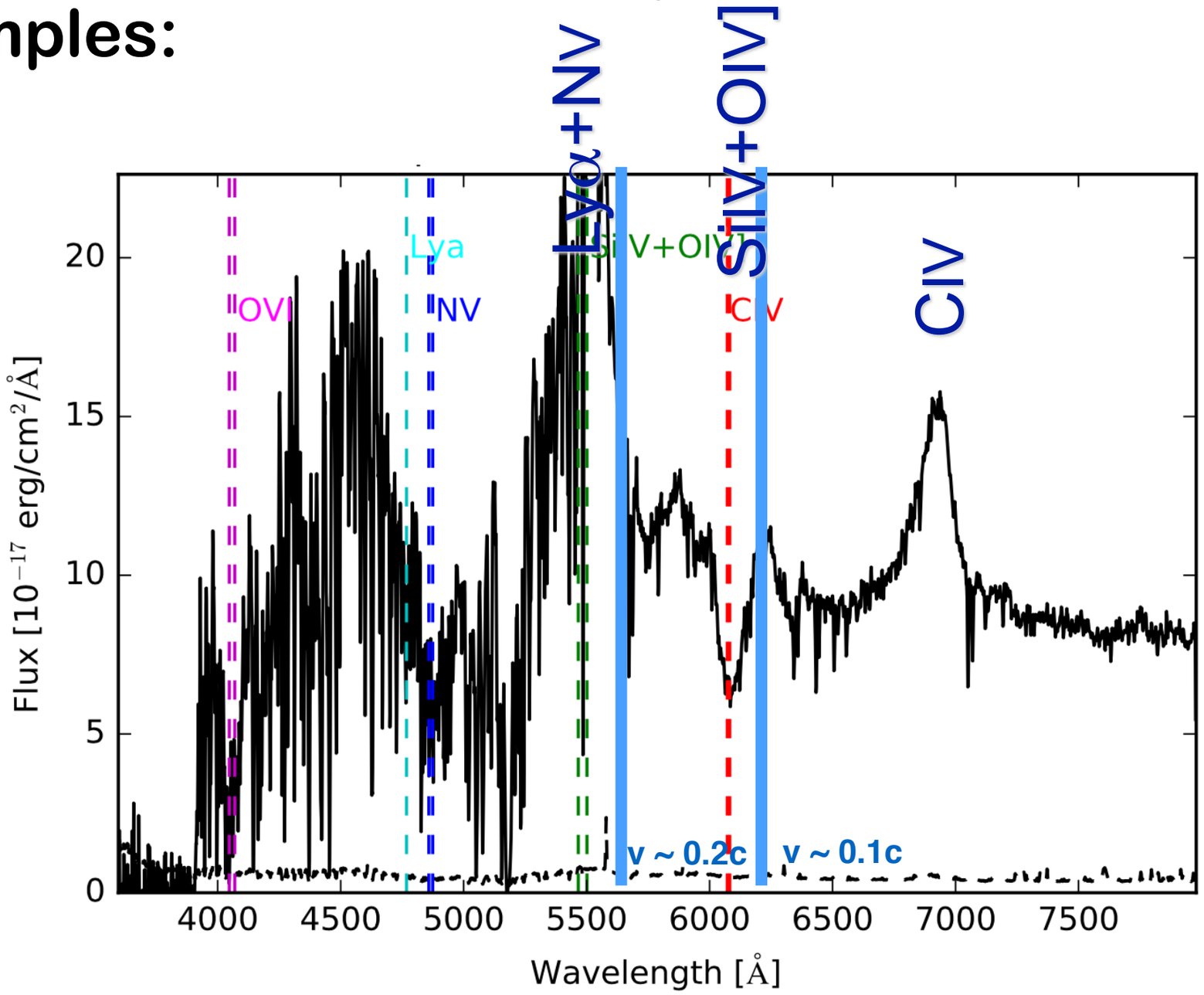
Just best and secured cases

(additional list of candidates not included, but available upon request)

Extremely High Velocity Outflows

45/6760 quasars found

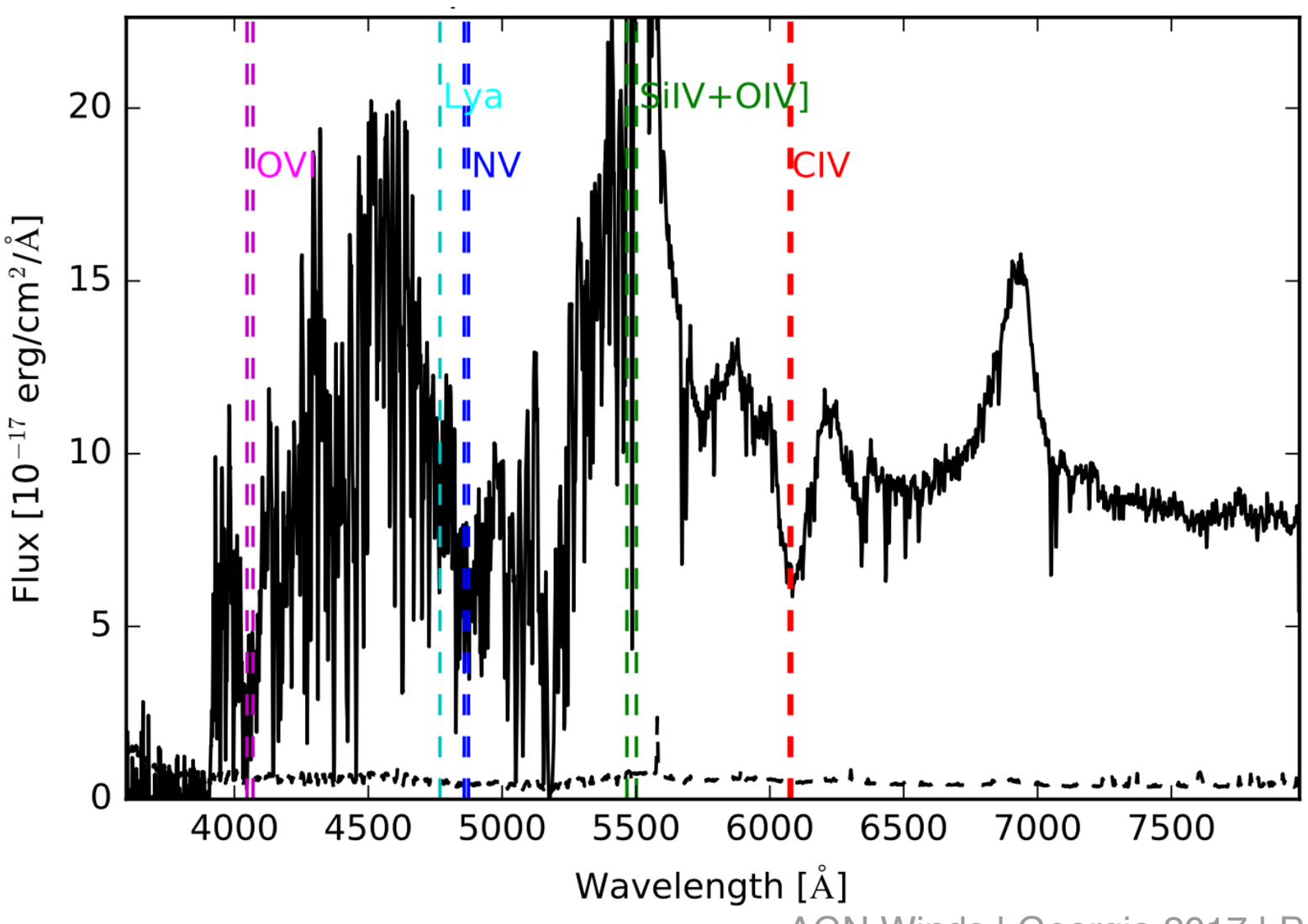
- **Examples:**



Extremely High Velocity Outflows

45/6760 quasars found

- **Examples:**

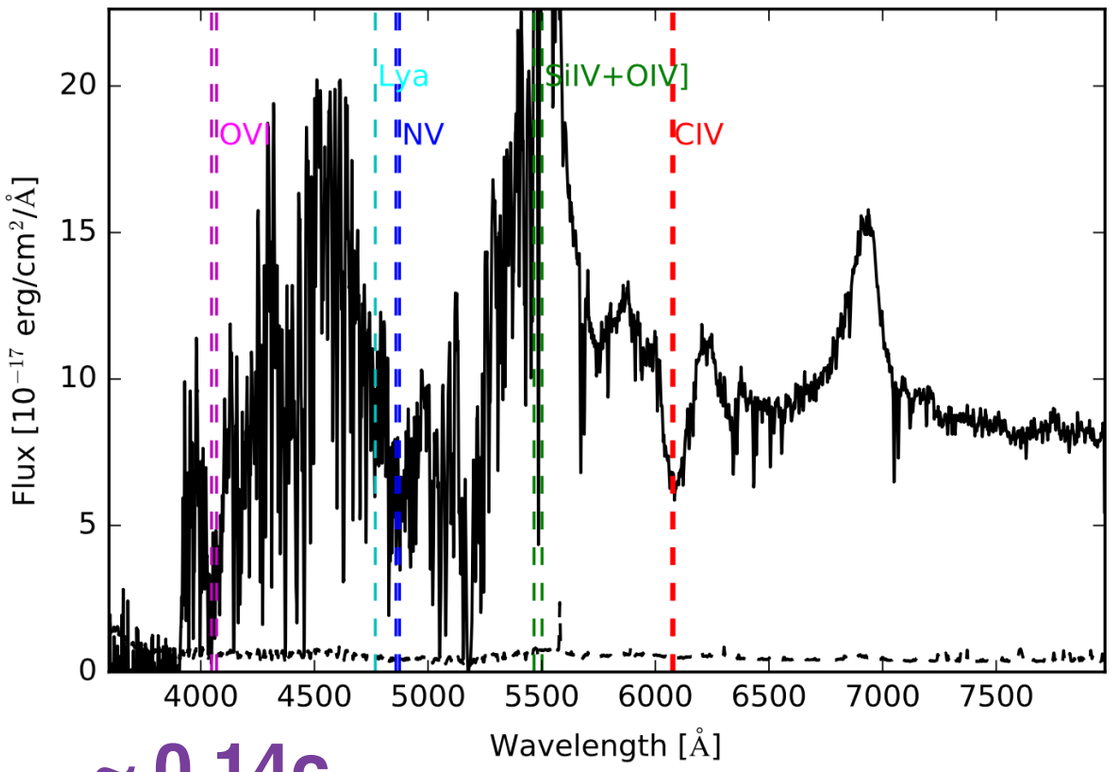


v_{max}~ 0.14c

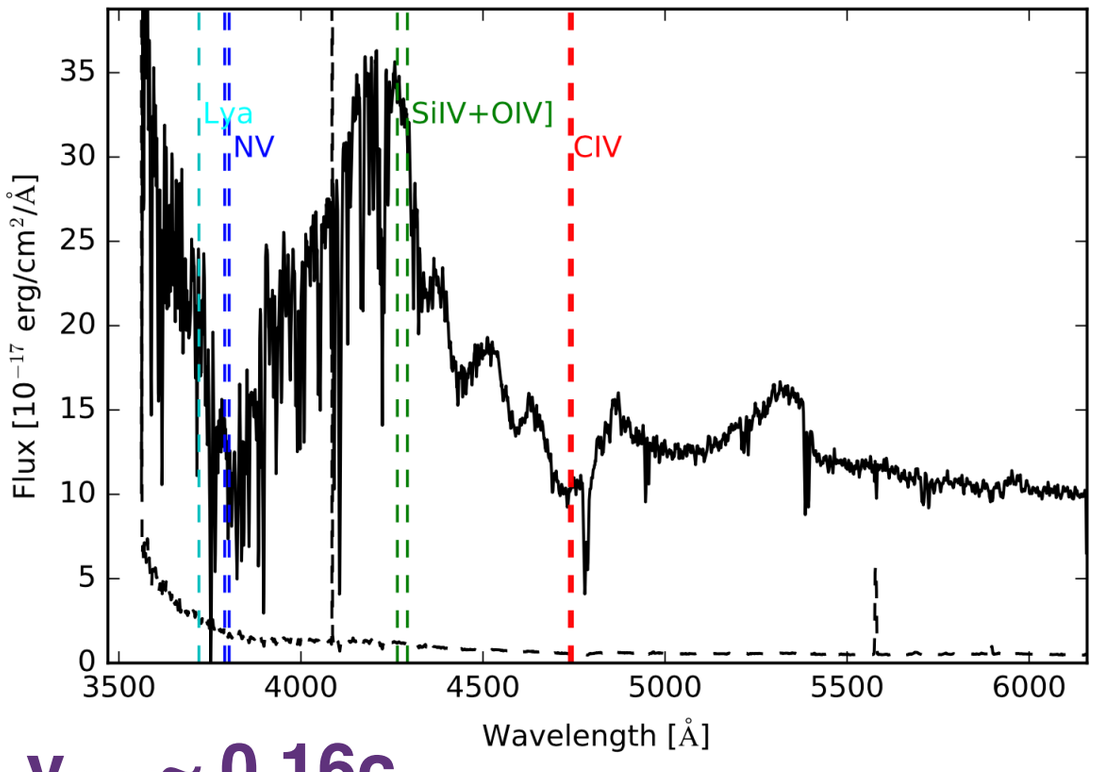
Extremely High Velocity Outflows

45/6760 quasars found

- **Examples:**



v_{max}~ 0.14c



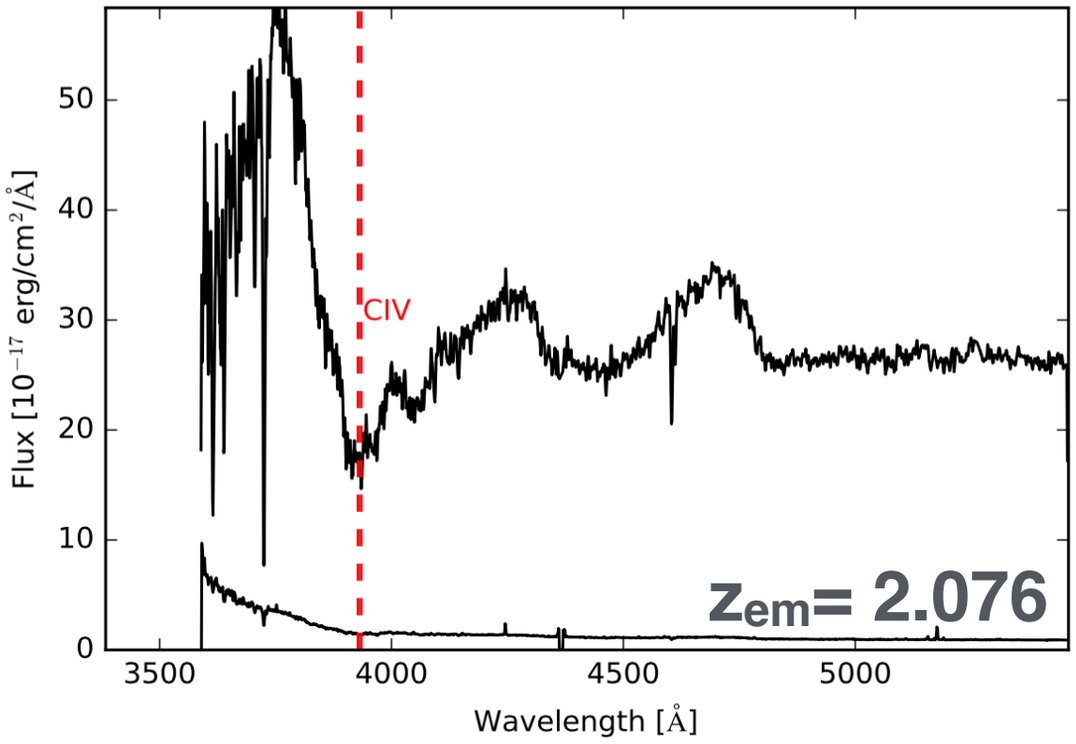
v_{max}~ 0.16c

NV always present when strong CIV and typically seems stronger; OVI probably too

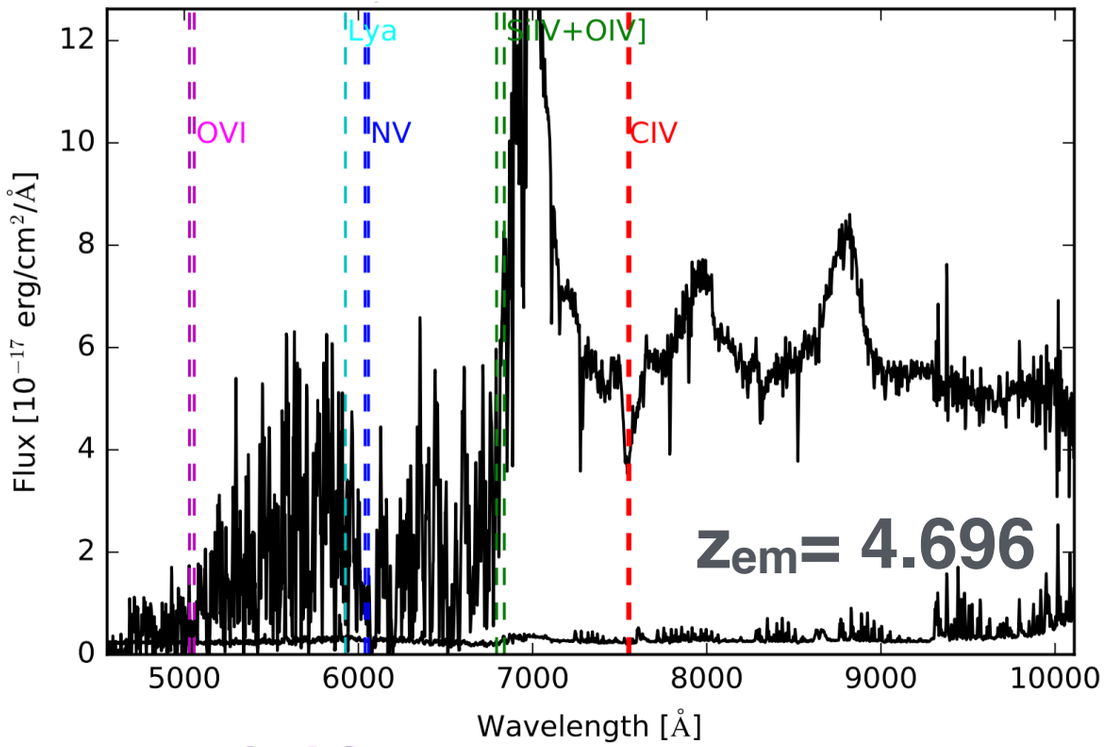
Extremely High Velocity Outflows

45/6760 quasars found

- **Examples:**



v_{max}~ 0.20c



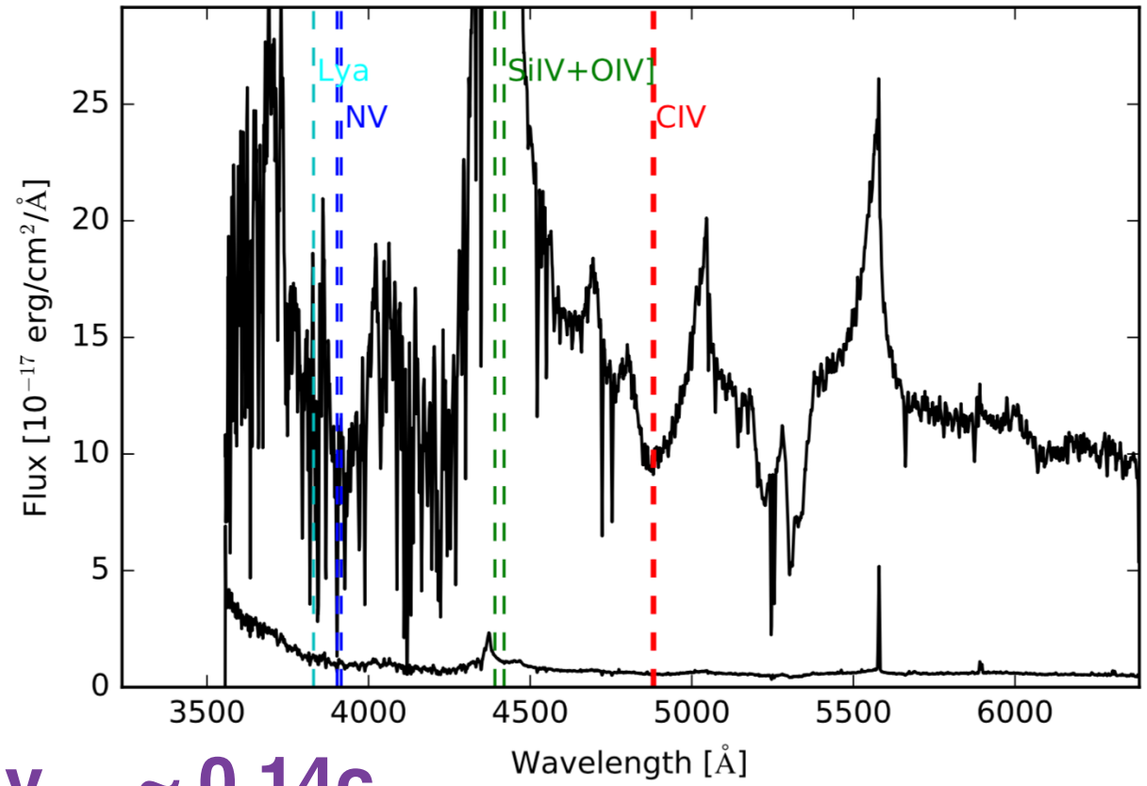
v_{max}~ 0.16c

NV always present when strong CIV and typically seems stronger; OVI probably too

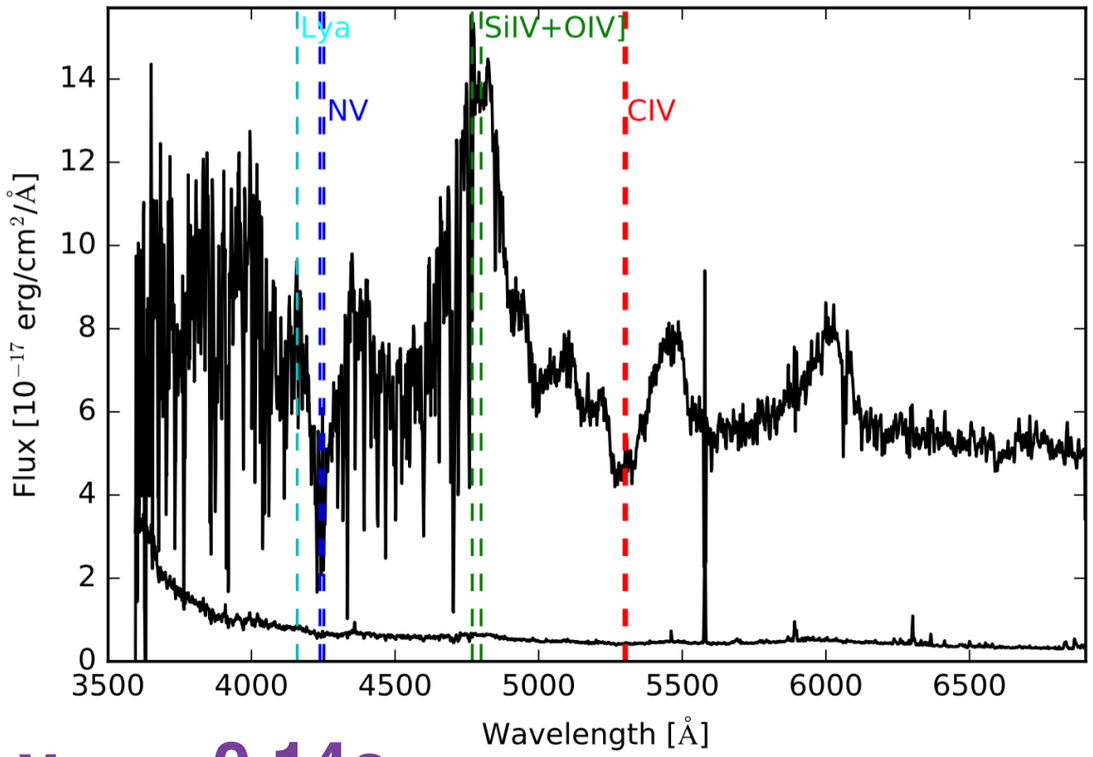
Extremely High Velocity Outflows

45/6760 quasars found

- **Examples:**



v_{max}~ 0.14c



v_{max}~ 0.14c

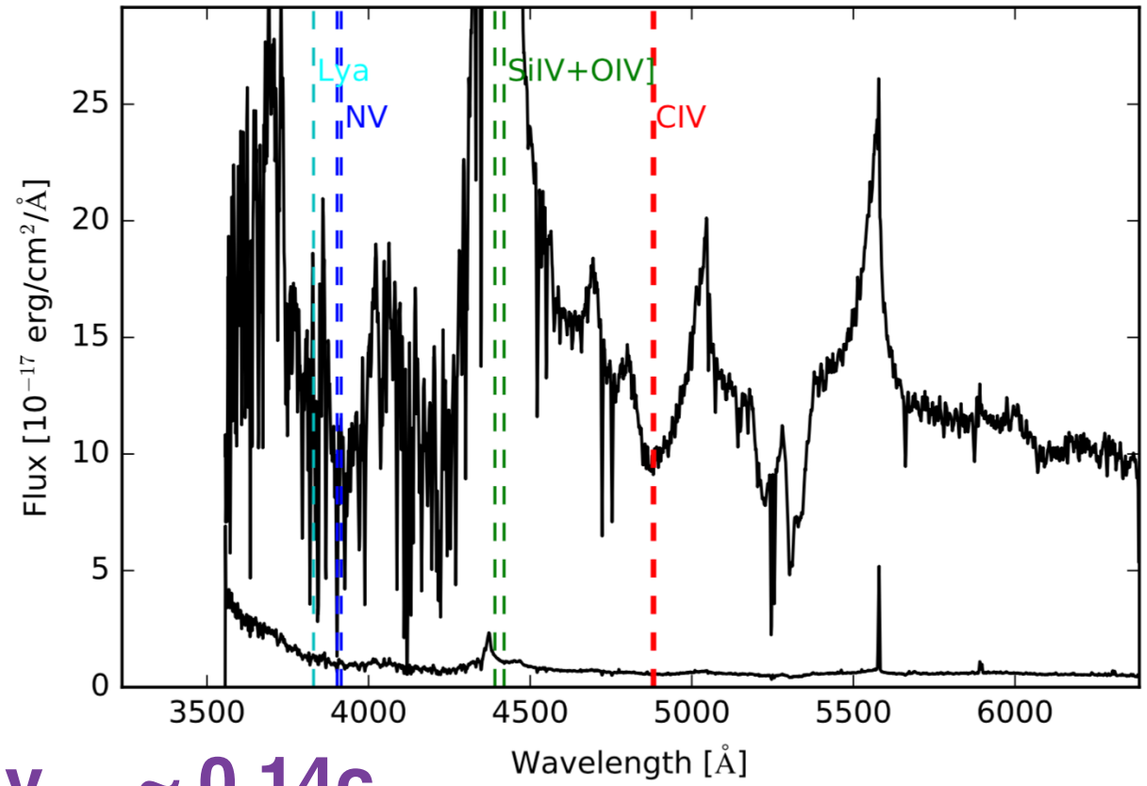
NV always present when strong CIV and typically seems stronger; OVI probably too

(similar to intrinsic NALs — Misawa+07; and mini-BALs at lower velocity — Moravec+17)

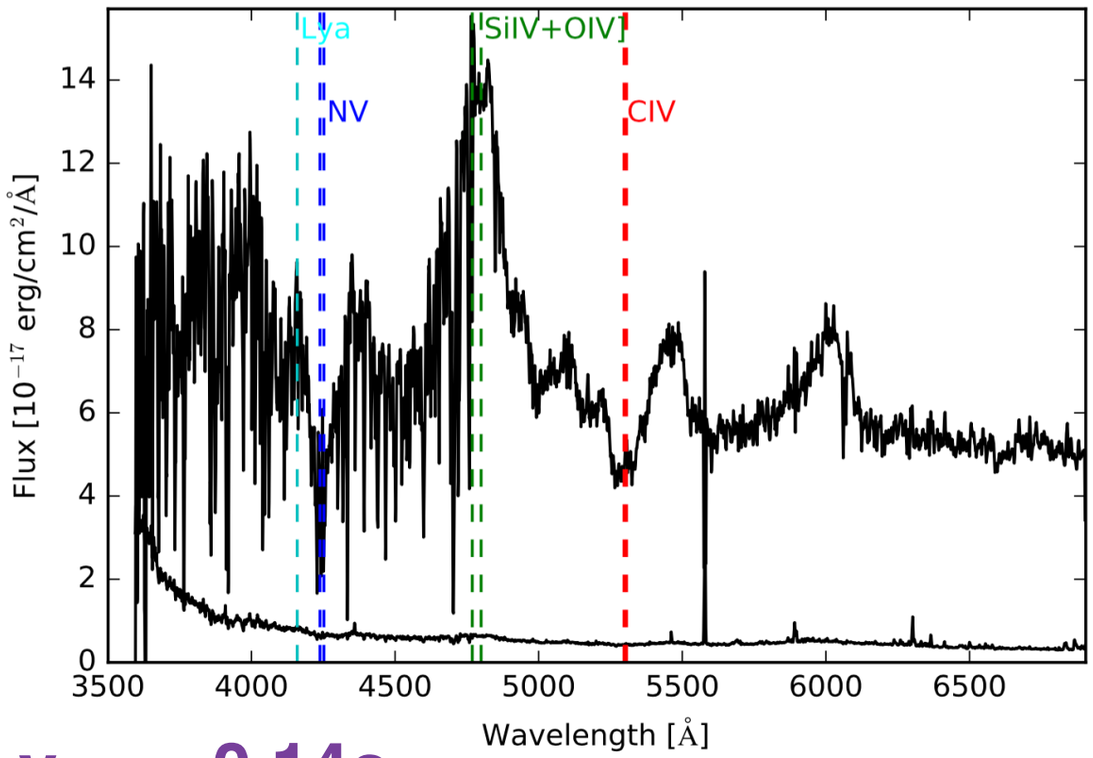
Extremely High Velocity Outflows

45/6760 quasars found

- **Examples:**



v_{max}~ 0.14c



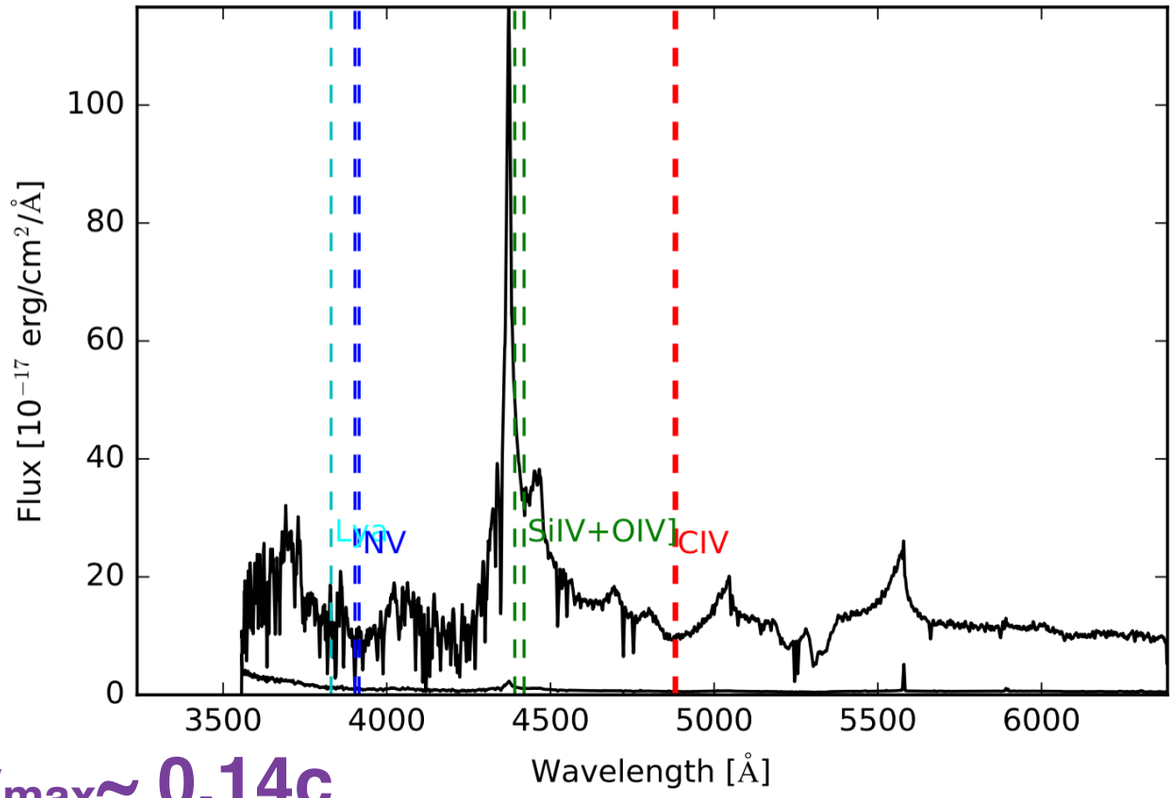
v_{max}~ 0.14c

No Lya stronger than NV in any case

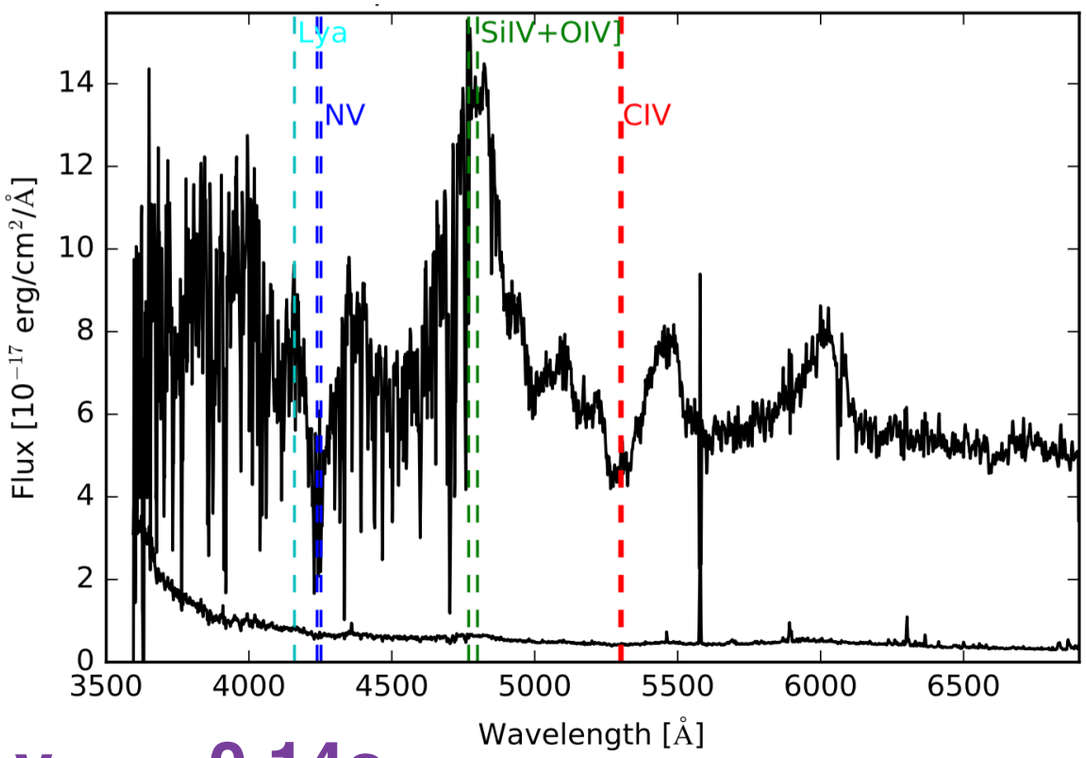
Extremely High Velocity Outflows

45/6760 quasars found

- **Examples:**



v_{max}~ 0.14c



v_{max}~ 0.14c

SiIV doesn't seem to be present but(!) on top of Lya+NV emission line

Extremely High Velocity Outflows

- **Constraints for theoretical studies:**

1) What we find:

- NV always present when strong CIV and typically seems stronger; OVI probably too

- No Lya stronger than NV in any case

- SiIV doesn't seem to be present but(!) on top of Lya +NV emission line

- Similar radio-loudness ratio than lower velocity BALs (6+-2%; 3/45 cases have FIRST detections)

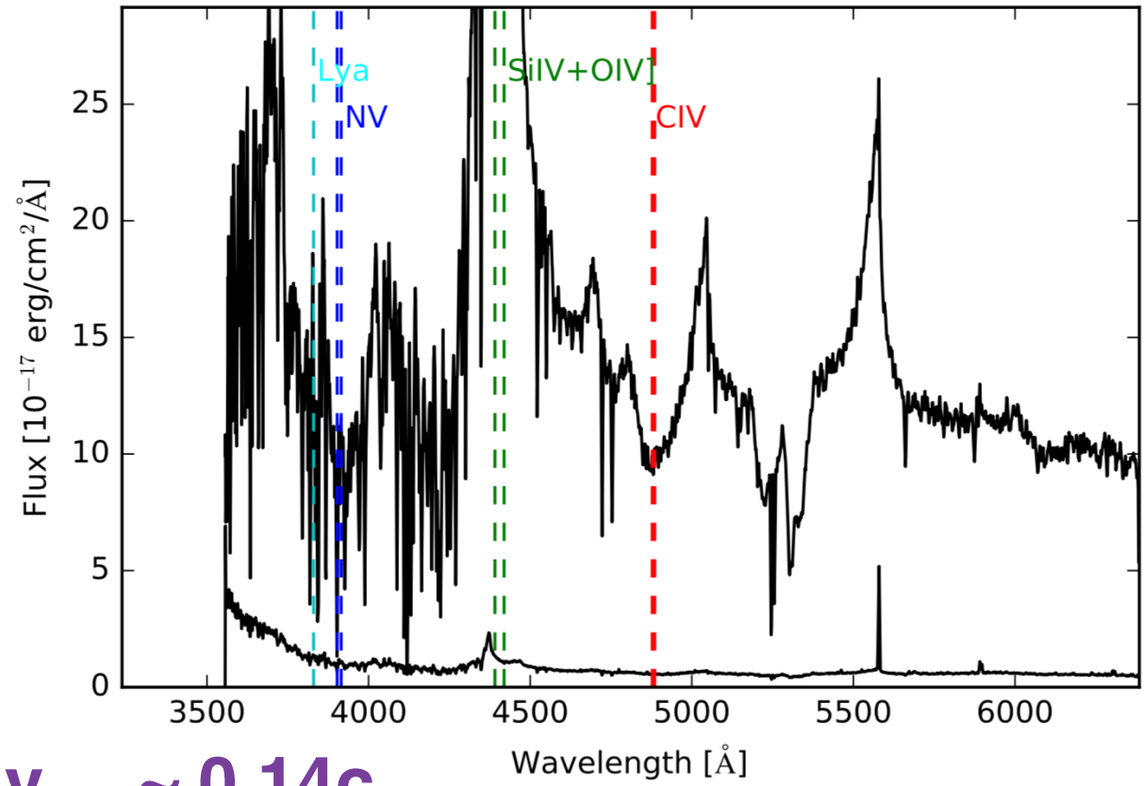
- Typically* smaller depths than lower velocity BALs

— smaller coverage fractions?

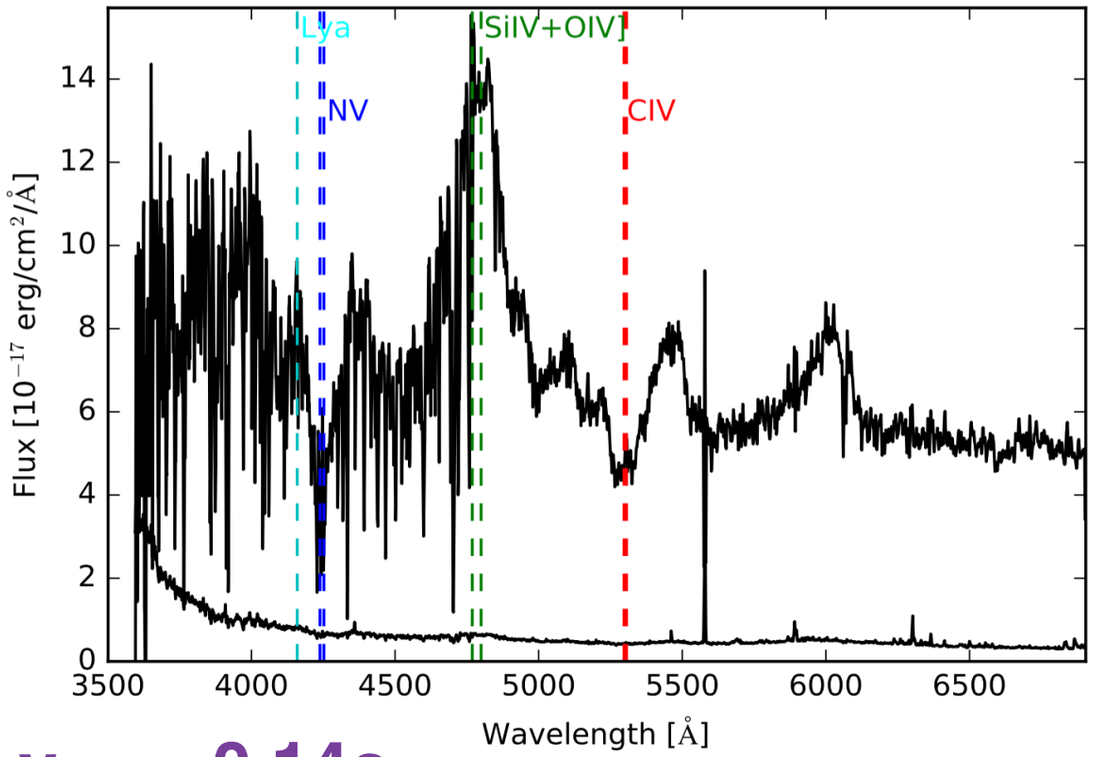
Extremely High Velocity Outflows

45/6760 quasars found

- **Examples:**

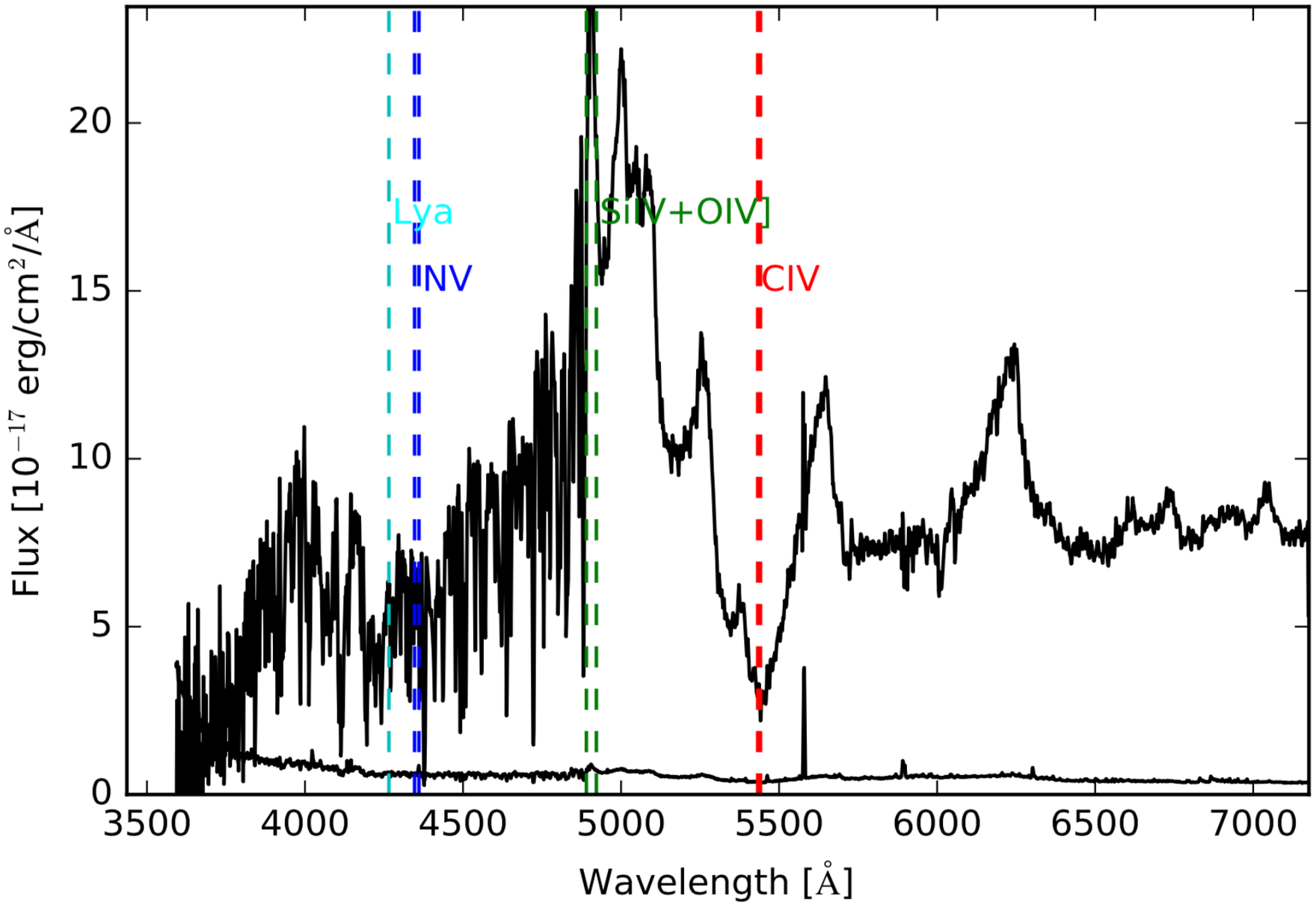


v_{max}~ 0.14c



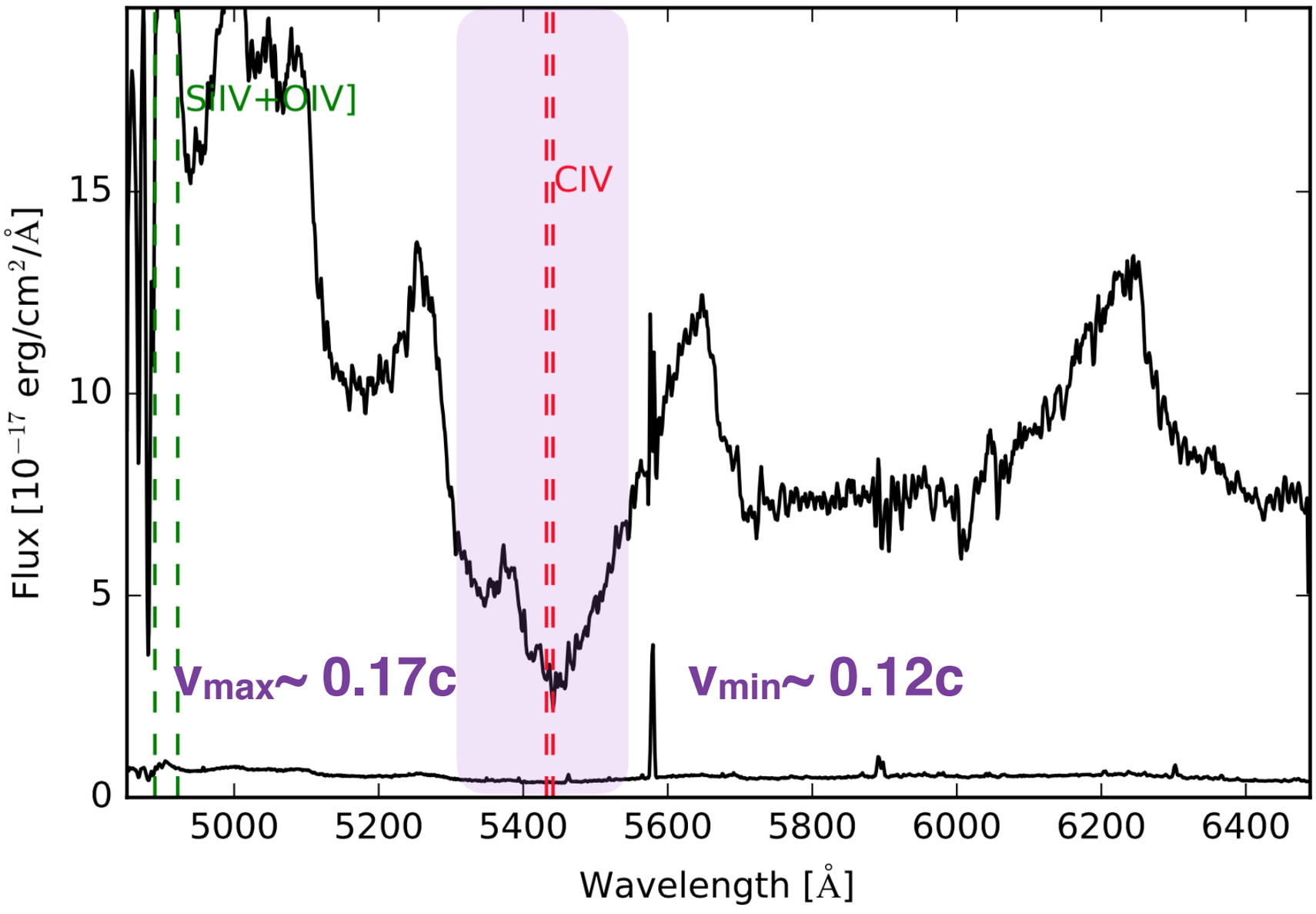
v_{max}~ 0.14c

Extremely High Velocity Outflows



Fast and Furious

Strong BAL at v



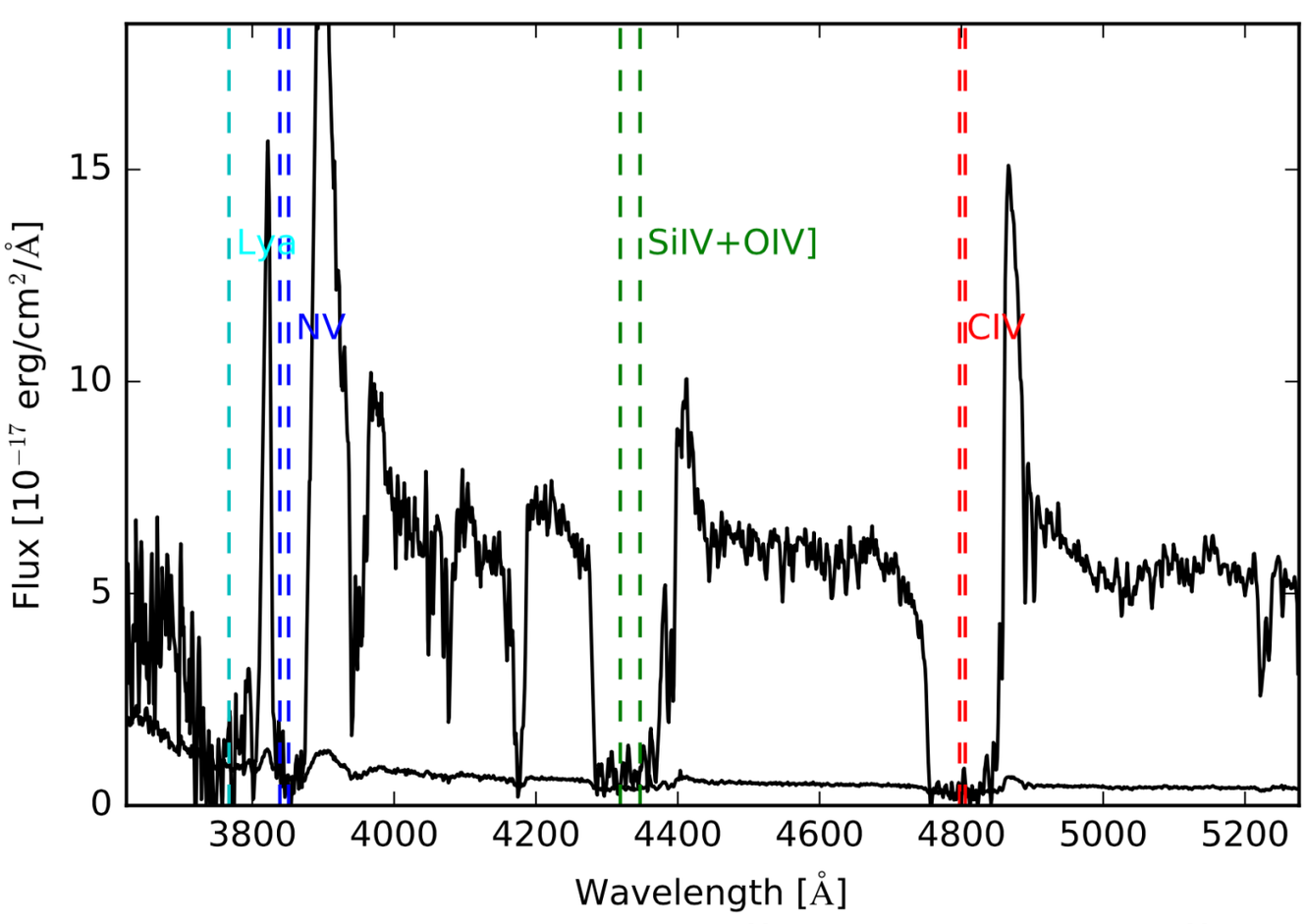
Extremely High Velocity Outflows

- **Constraints for theoretical studies:**

  2) What we don't find:

  - Saturated cases (zero or close to zero flux)

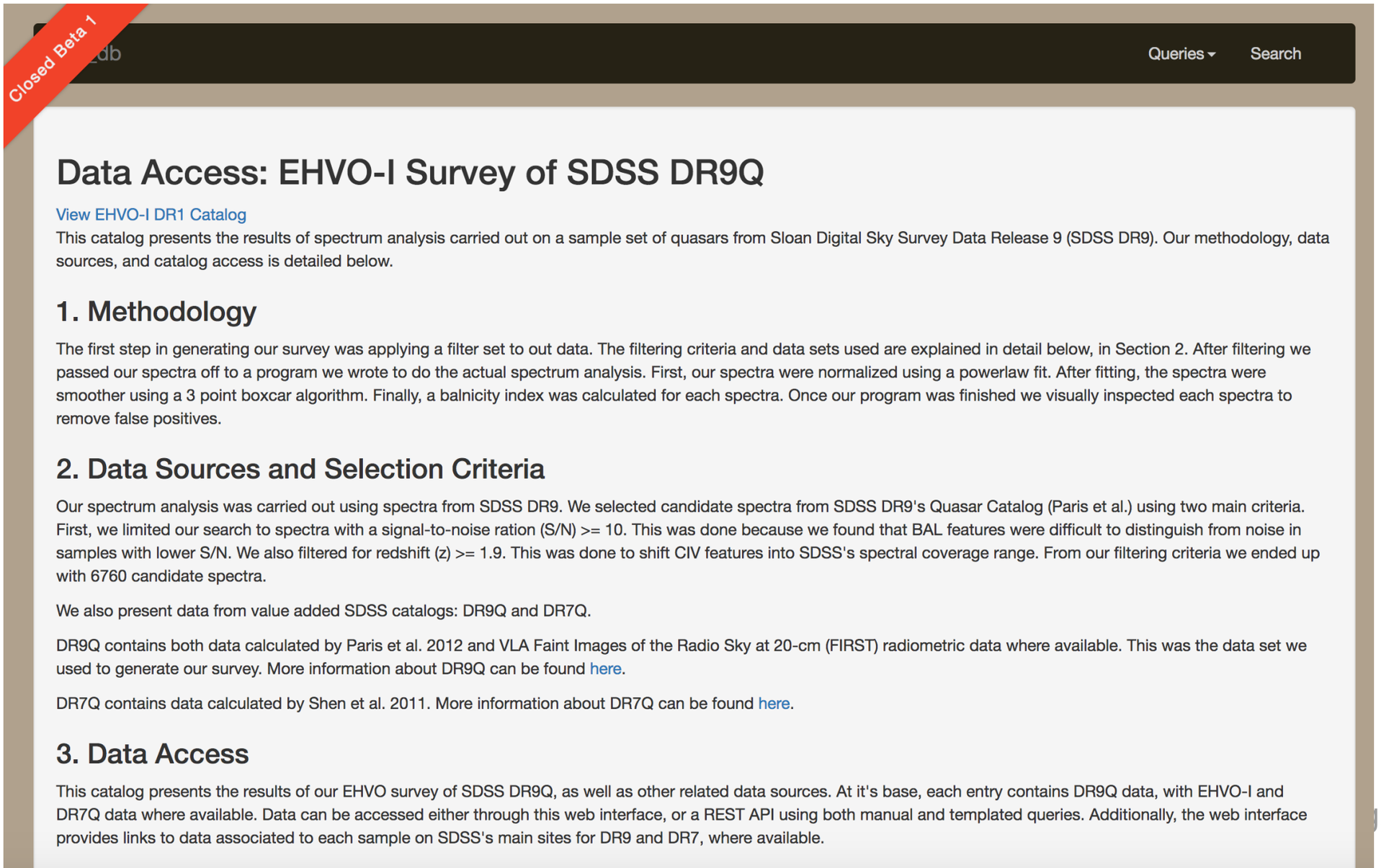
  - "Boxy" profiles



Extremely High Velocity Outflows

(For theoretical and non-theoretical people:)

We have made a database of these EHVO objects



guez Hidalgo

Extremely High Velocity Outflows

(For theoretical and non-theoretical people:)

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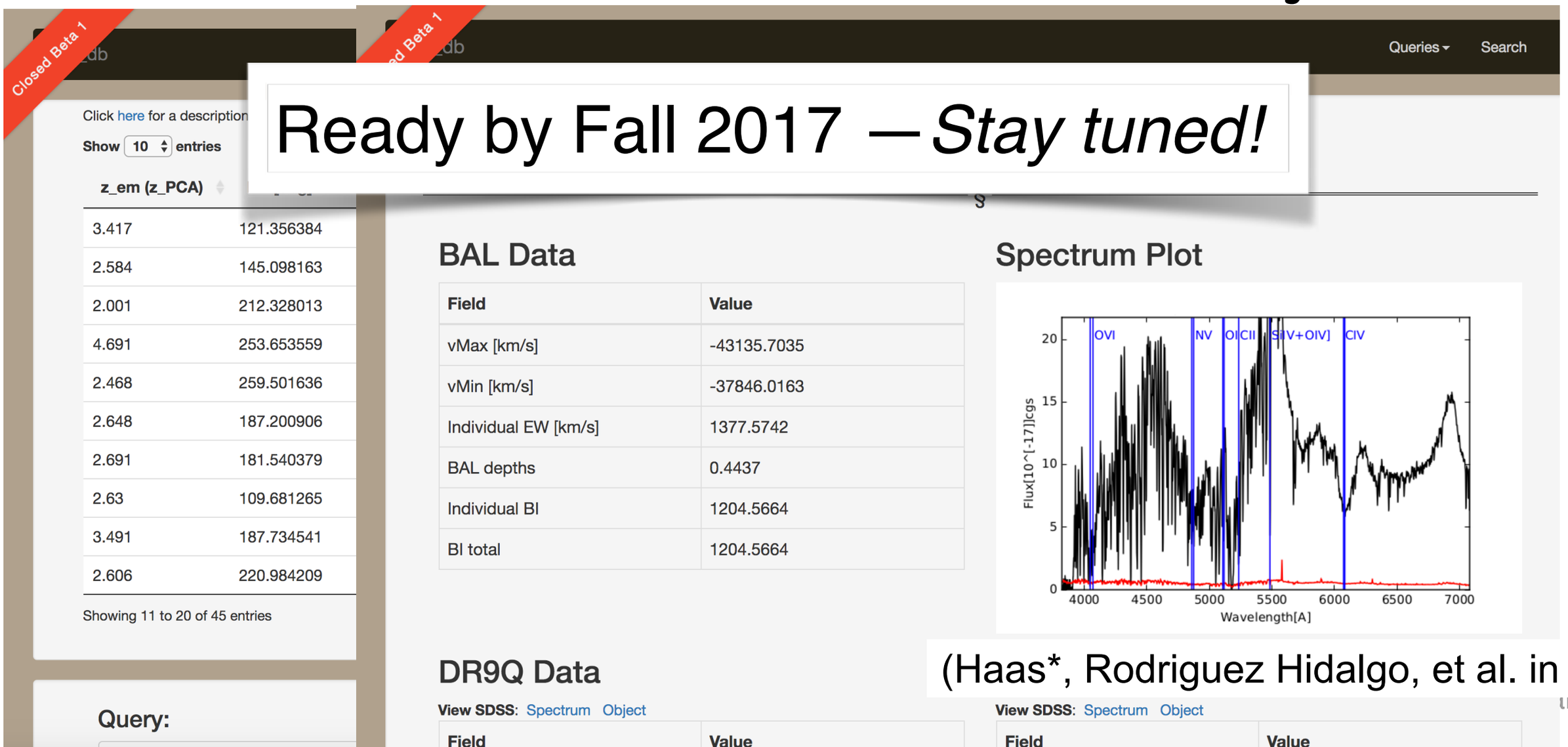


(Haas*, Rodriguez Hidalgo, et al. in prep)

Extremely High Velocity Outflows at low z?

- **What we don't find: extremely high velocity outflows at low redshift (z<2)**

HST archival data

# AGN observed using COS spectrograph (upto Dec. 16, 2014)	452
# AGN with z > 2	- 7
# AGN with no redshift available in the NASA/IPAC Extragalactic Database (NED)	- 15
# AGN not having the required spectral coverage	- 366
# AGN with required spectral coverage	34
# AGN for which no public data or large errors	- 14
# AGN used (initially)	20
# AGN with upto ~ 50 Å missing	+ 7
# AGN used (currently)	27

Khatu, Rodríguez Hidalgo, & Abraham (in prep)

Extremely High Velocity Outflows at low z?

0*/27 AGN show EHVO

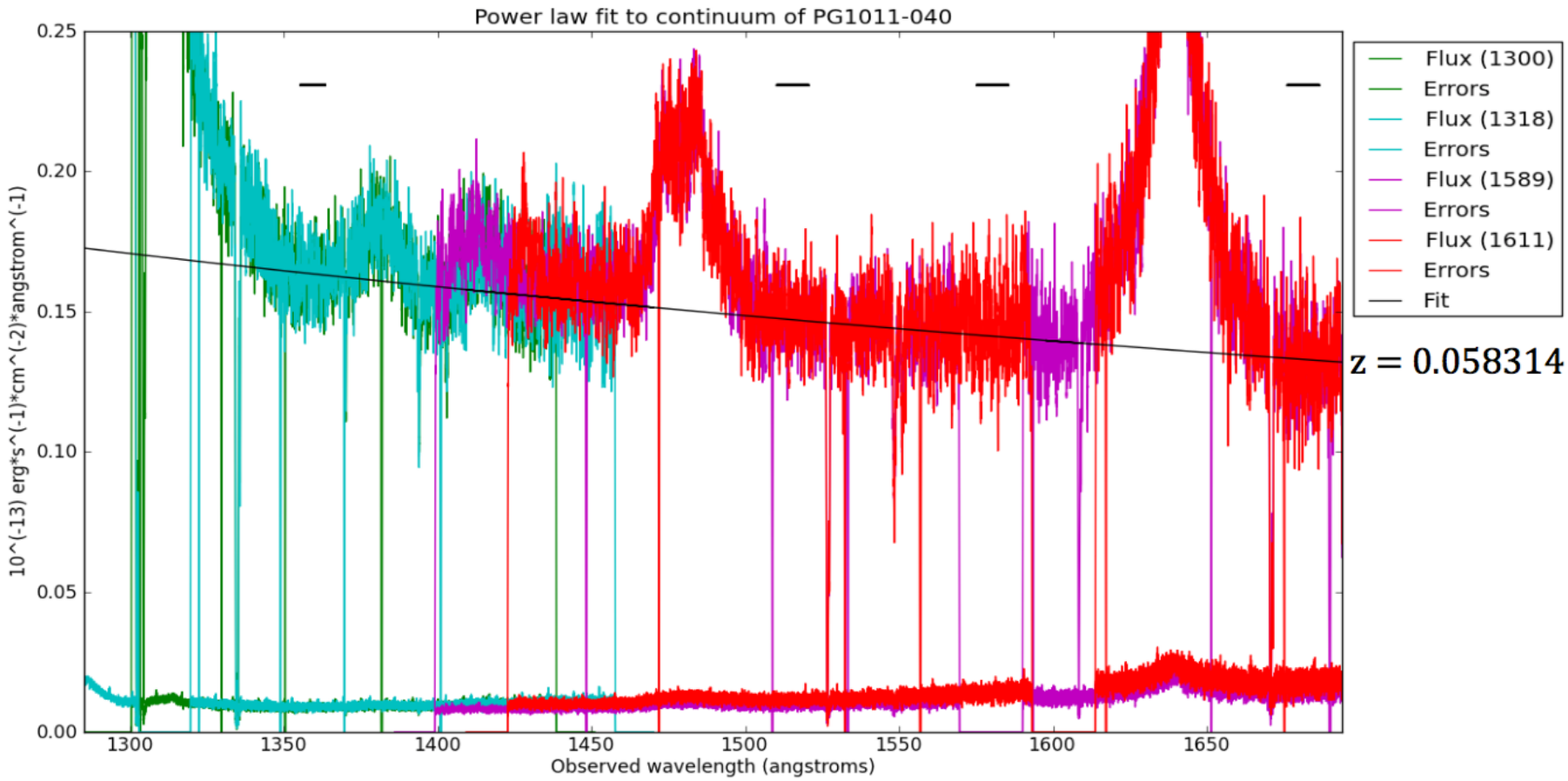
Sample of 27 AGN

AGN name	Redshift	Magnitudes (B; Mv)	AGN name	Redshift	Magnitude (B; Mv)
NEWQZ004	0.118000	17.245; -23.353	QSO-B1309+3531	0.182923	15.450; -24.987
NEWQZ015	0.188000	17.916; -22.687	IRAS-F04250-5718	0.104000	14.375; -24.821
PG1351+640	0.088200	14.858; -23.949	IRAS-F22456-5125	0.100000	16.804; -22.300
PG2214+139	0.065762	15.104; -23.038	SDSSJ015530.02-085704.0	0.164427	17.238; -23.031
PG0804+761	0.100000	14.051; -25.050	SDSSJ031027.82-004950.7	0.080139	16.255; -22.339
PG1011-040	0.058314	16.890; -20.976	SDSSJ145108.76+270926.9	0.065000	15.889; -22.222
MRK106	0.123366	16.265; -23.330	SDSSJ094733.21+100508.7	0.139540	16.848; -23.030
MRK290	0.029577	15.567; -20.785	PG1115+407	0.154338	16.166; -23.960
MRK335	0.025785	14.780; -21.261	MRK876	0.129000	14.874; -24.825
MRK817	0.031455	14.891; -21.592	PG1626+554	0.133000	15.874; -23.897
MRK1513	0.062977	14.970; -23.070	PDS456	0.184000	14.759; -25.781
MR2251-178	0.063980	15.240; -22.835	ESO-141-55	0.037109	14.32; -22.530
RXJ1230.8+0115	0.117000	15.087; -24.385	1H-2129-624	0.058561	16.660; -21.215
QSO-B0923+201	0.192142	15.854; -24.796			

(NASA/IPAC Extragalactic Database)

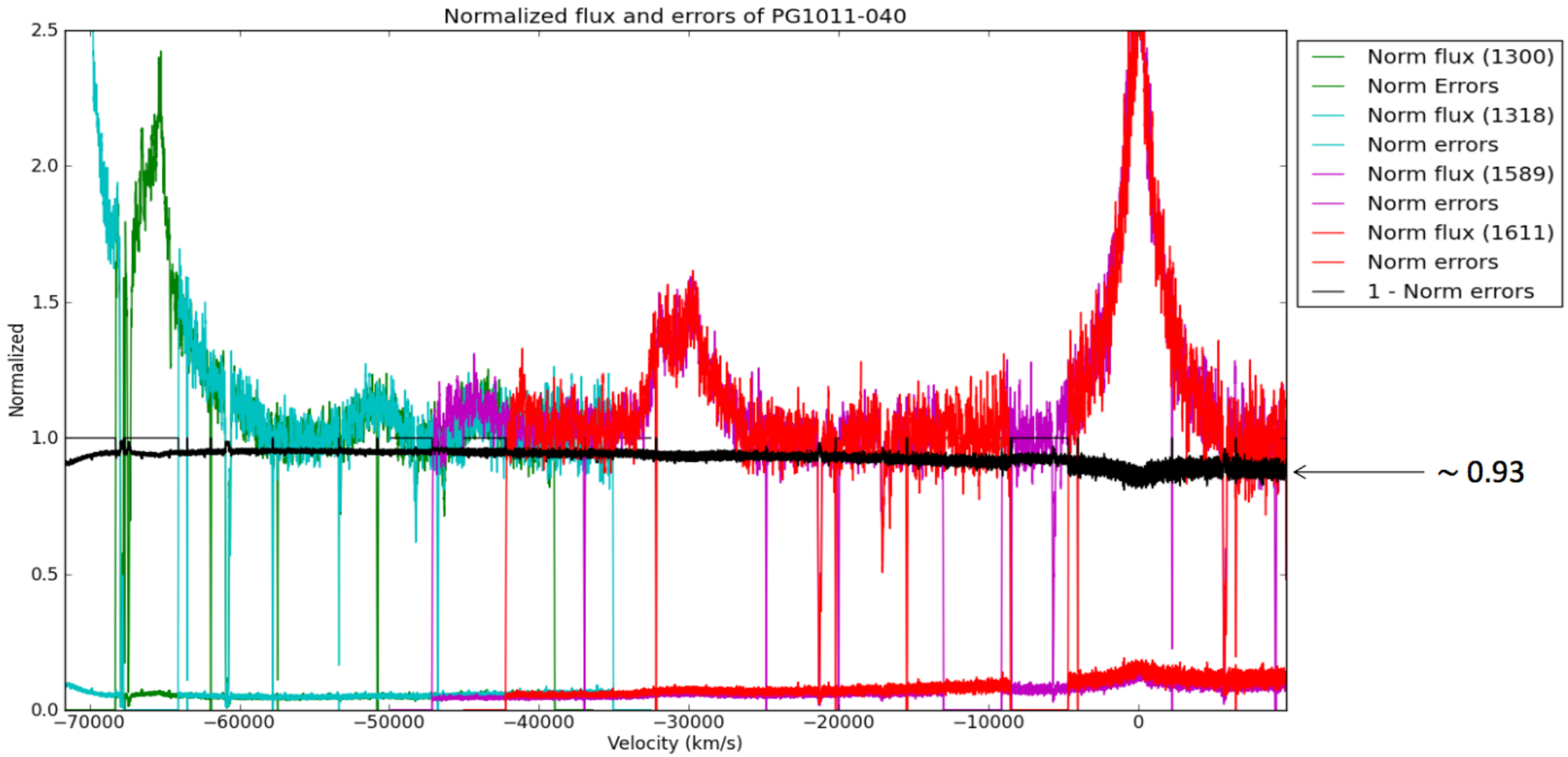
Extremely High Velocity Outflows at low z?

Example spectrum: PG1011-040



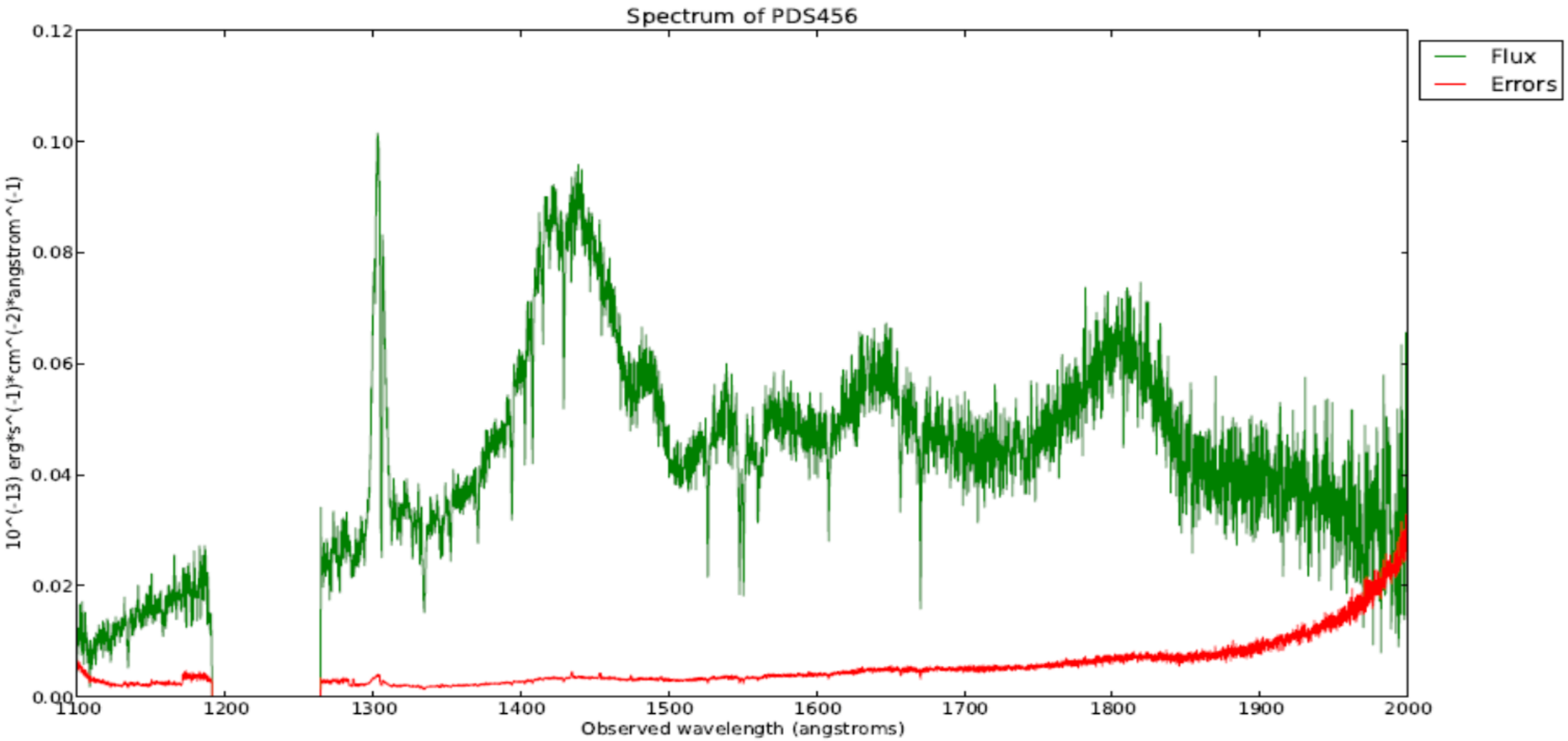
Extremely High Velocity Outflows at low z?

Example spectrum: PG1011-040



Extremely High Velocity Outflows at low z?

Special case: PDS456



Extremely High Velocity Outflows

z>2: 45*/6760 quasars show EHVO

z<2: 0*/27 AGN show EHVO

In each category we are searching among the brightest

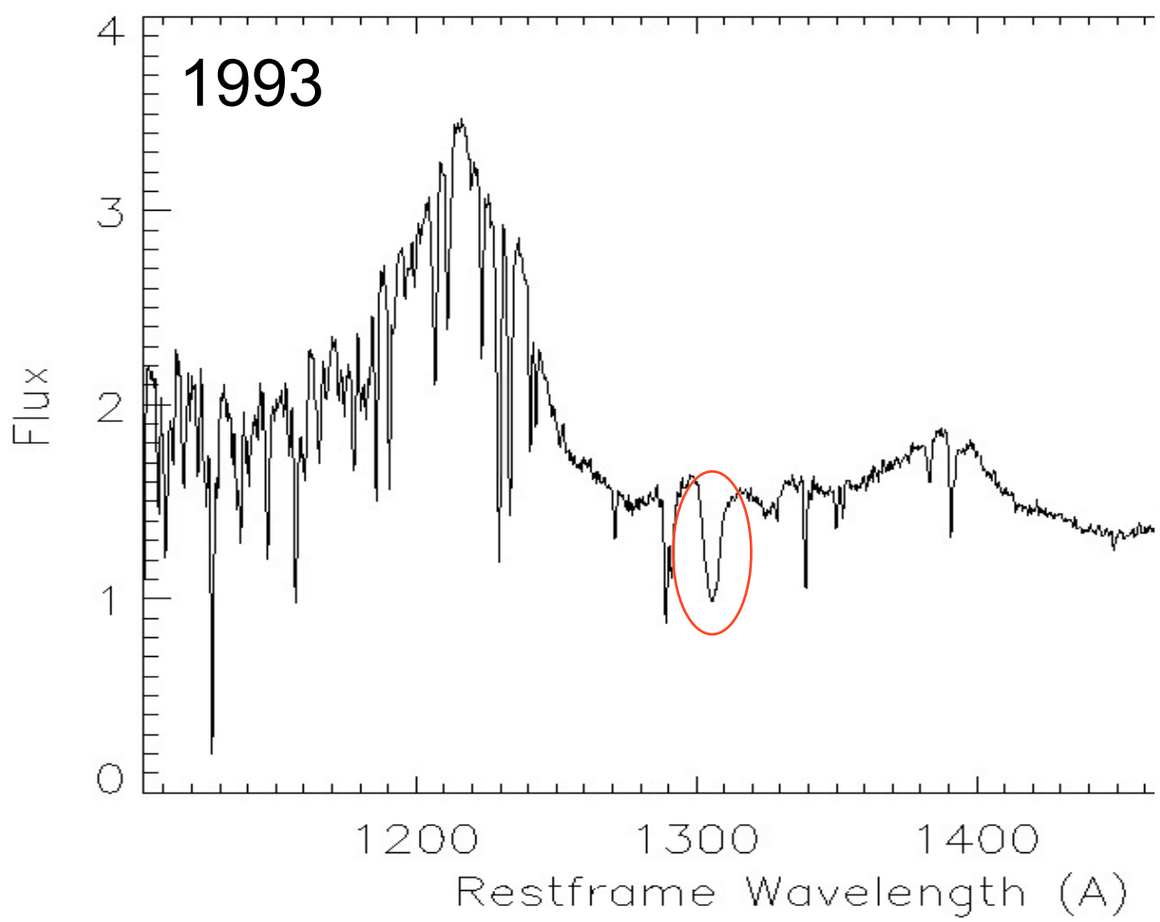
We are probing a significant population of particular bins of the parameter space

Extreme Variability

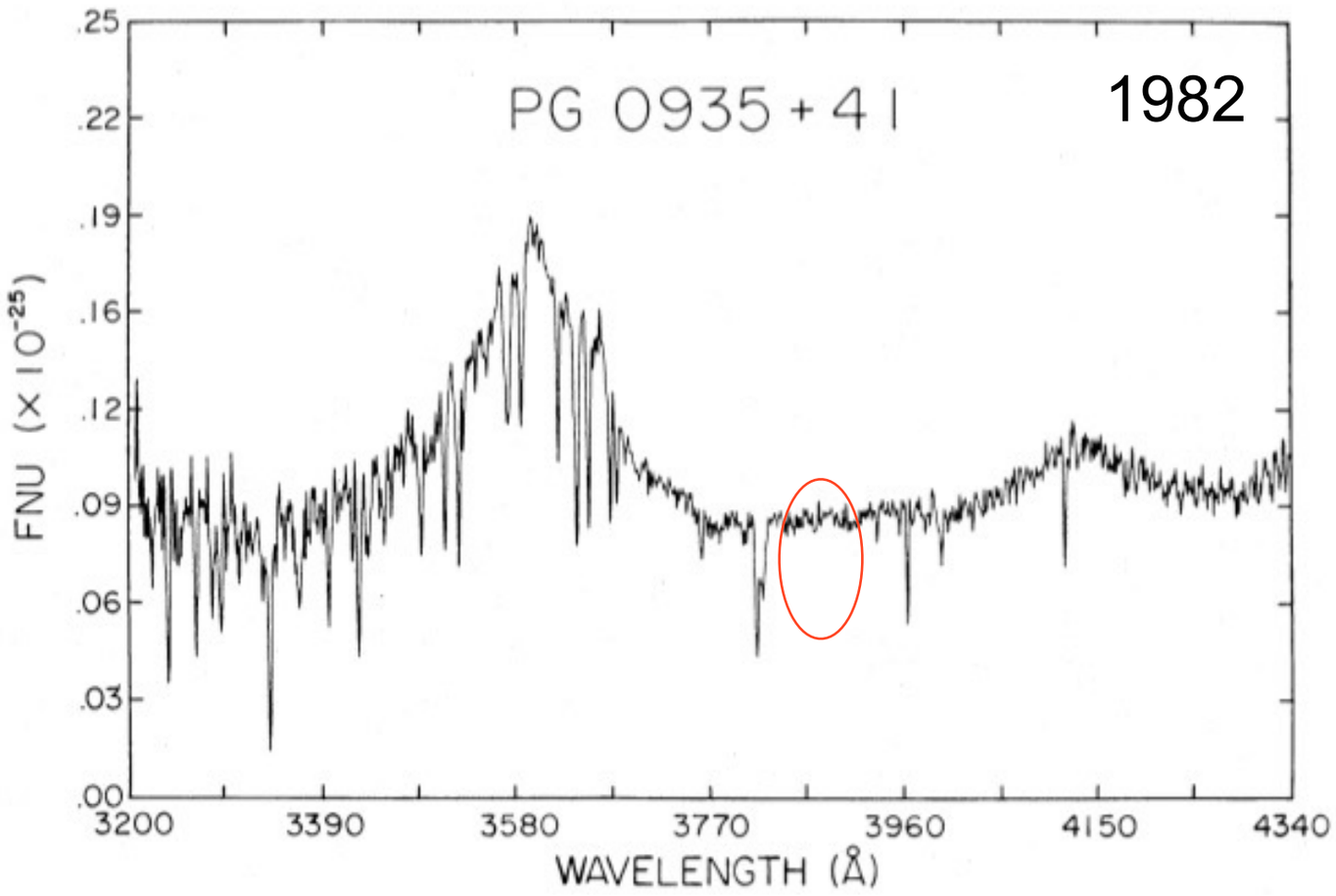
But absorption lines tend to vary often!

Extreme Variability

Study case of PG0935+417



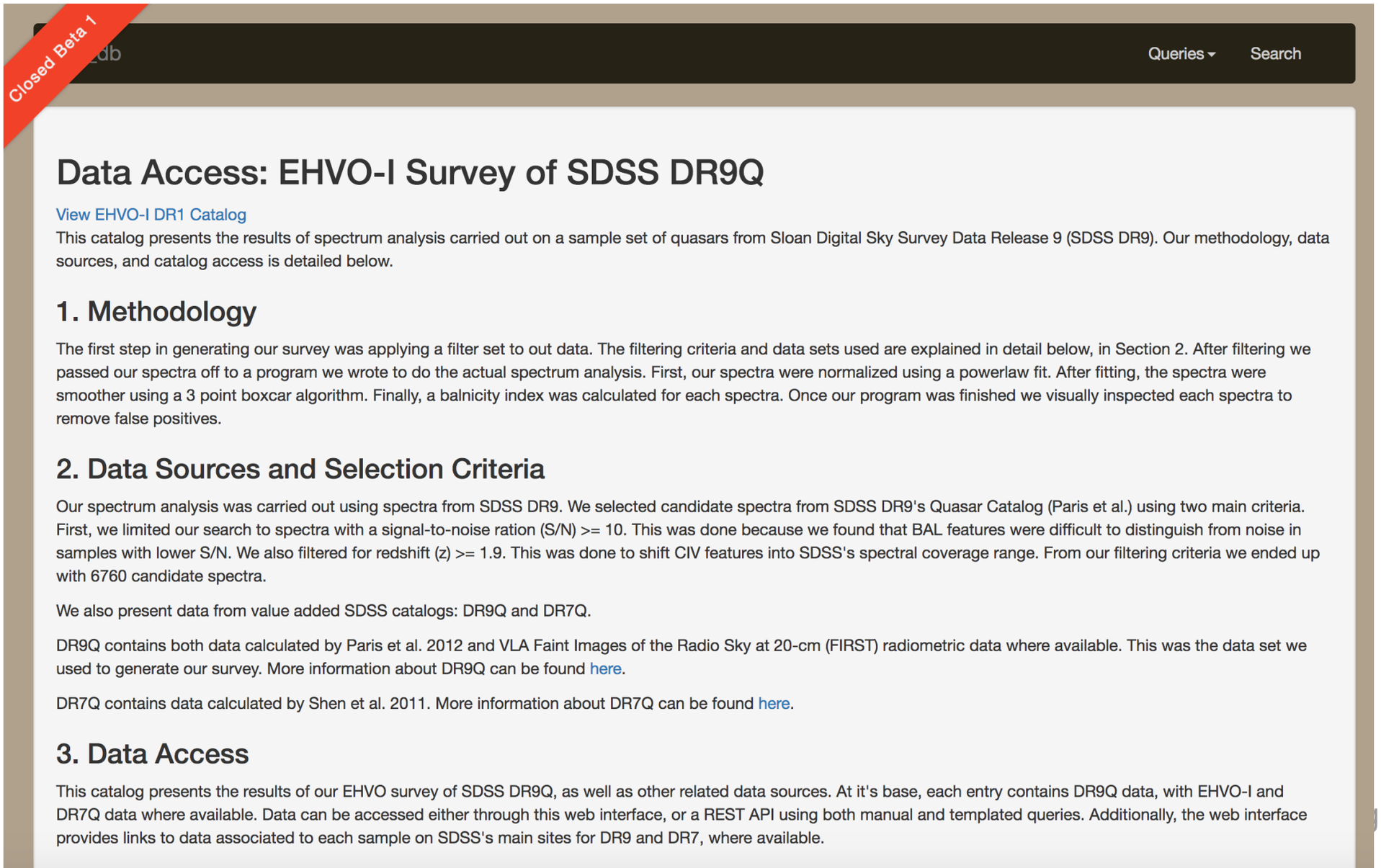
(Hamann+1997)



(Bechtold+1984)

Extremely High Velocity Outflows

The database includes previous epochs if available



guez Hidalgo

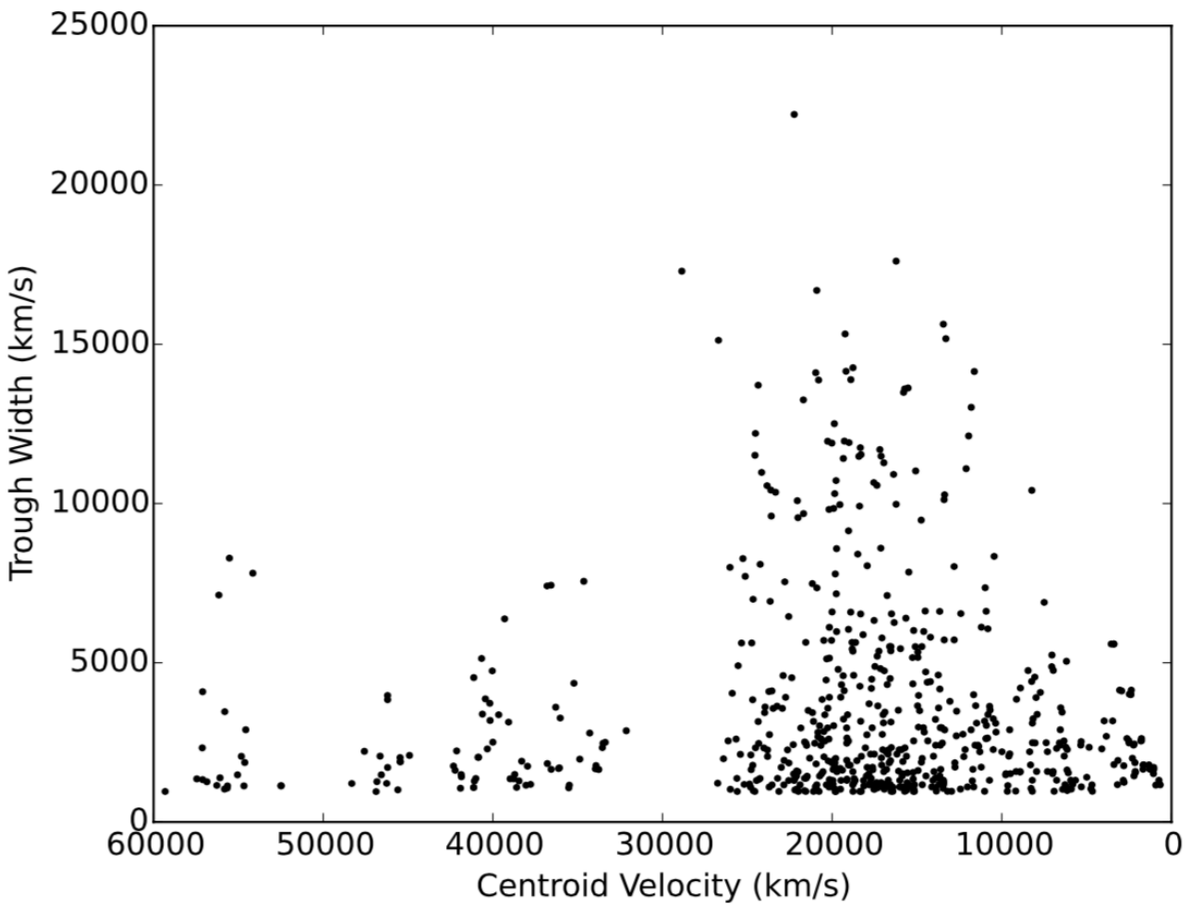
Extreme Variability Emergence Survey

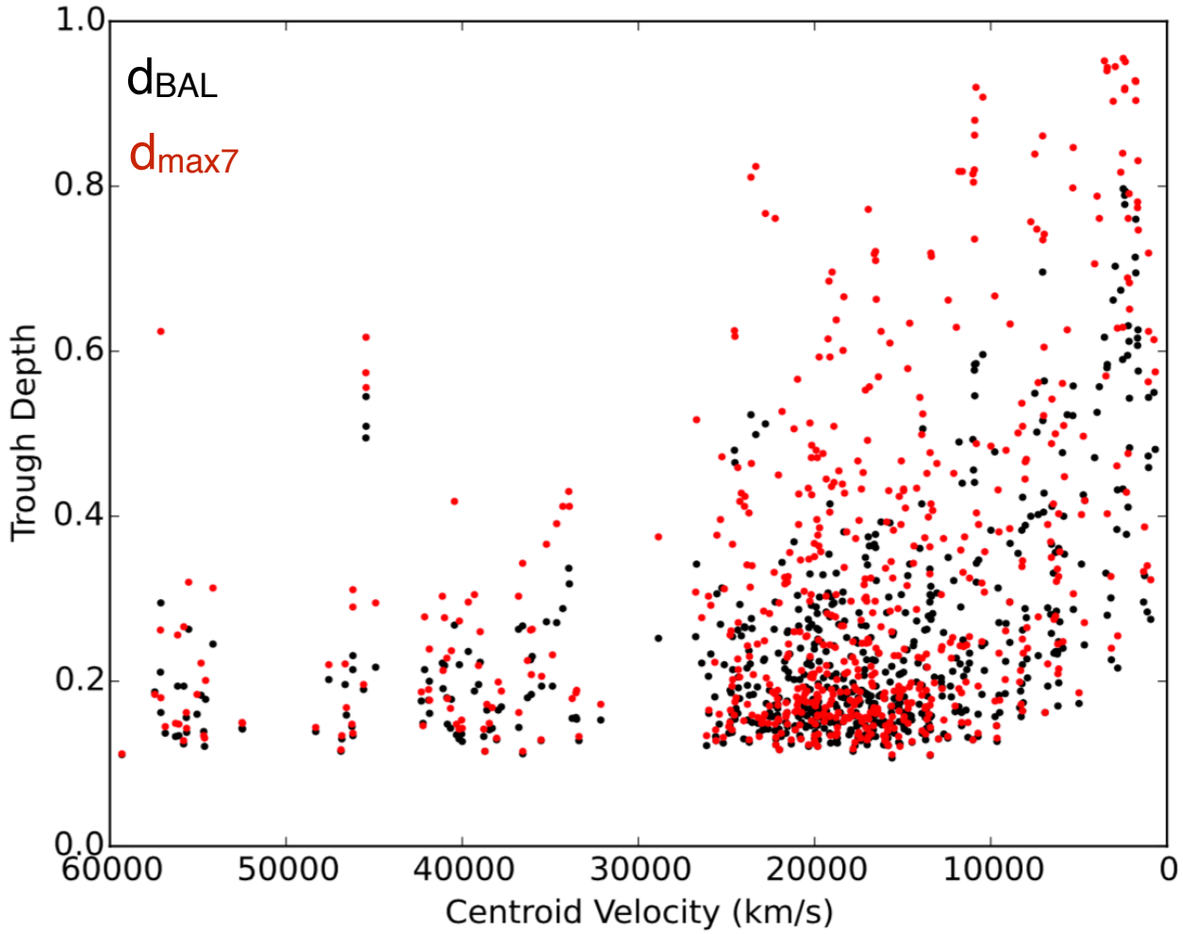
- **BOSS (DR9 & DR10) compared to SDSS/DR7 quasar spectra searching for new emergent CIV outflows**

- **Visual inspection & previous method (powerlaw normalization and BI search)**

- **Redshift z > 1.68 and S/N >~ 9**

Emergence of BALs





(Rogerson+17)

(Rodriguez Hidalgo, Hall, et al. +17)

Extreme Variability

Emergence Survey

- 111/7510 in DR9/DR7 and 178/8940 in DR10/DR7

- Emergence of troughs in both previous BALQSO and non-BALQSO

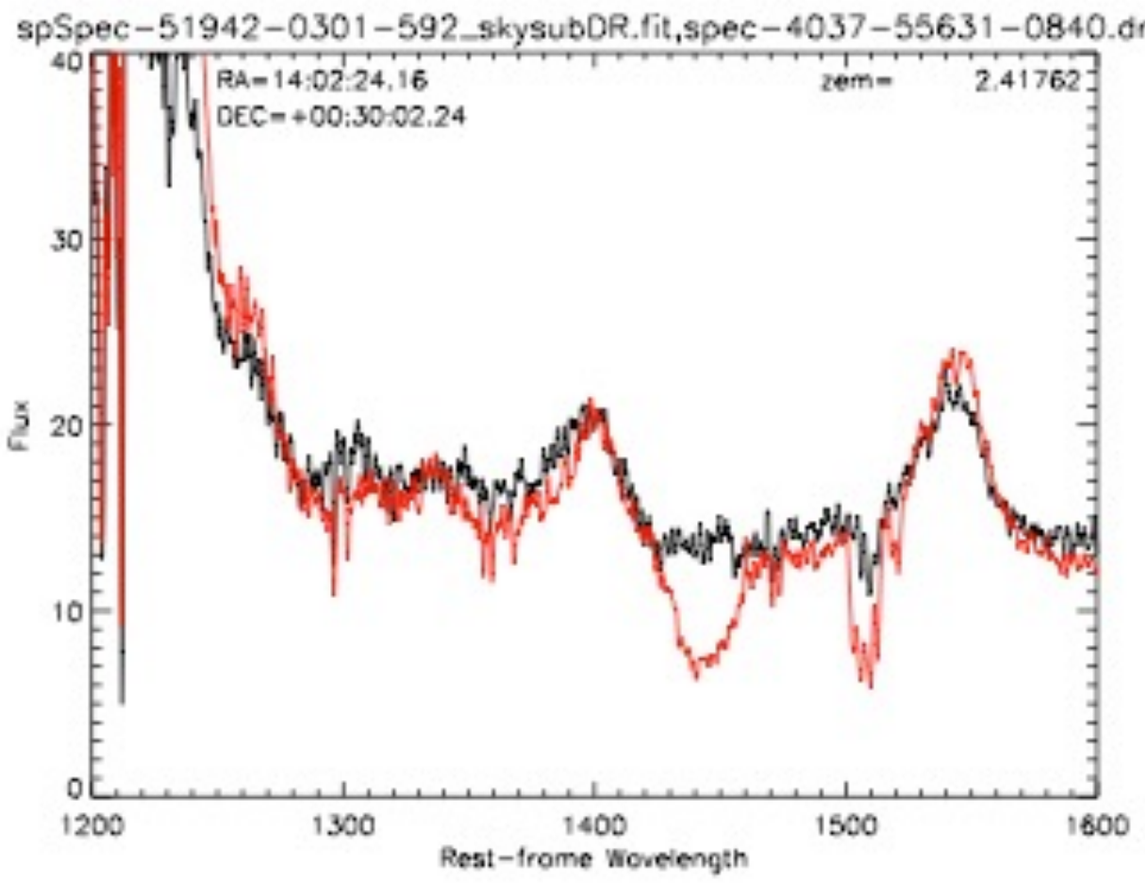
- Rate compared to disappearance:

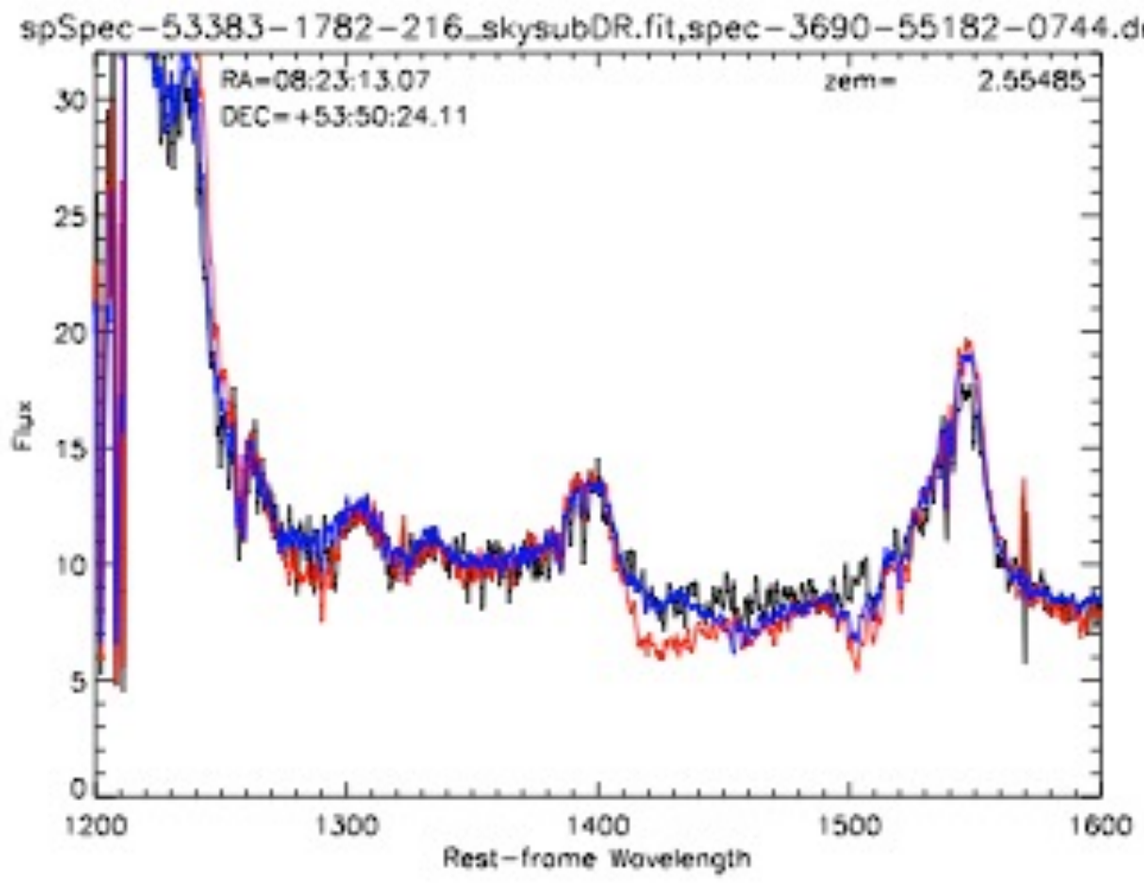
  Probability of appearance = 3.5+-0.6%

Emergence of BALs

- Survey of emergence BAL troughs between two SDSS observations (RH+ in prep)

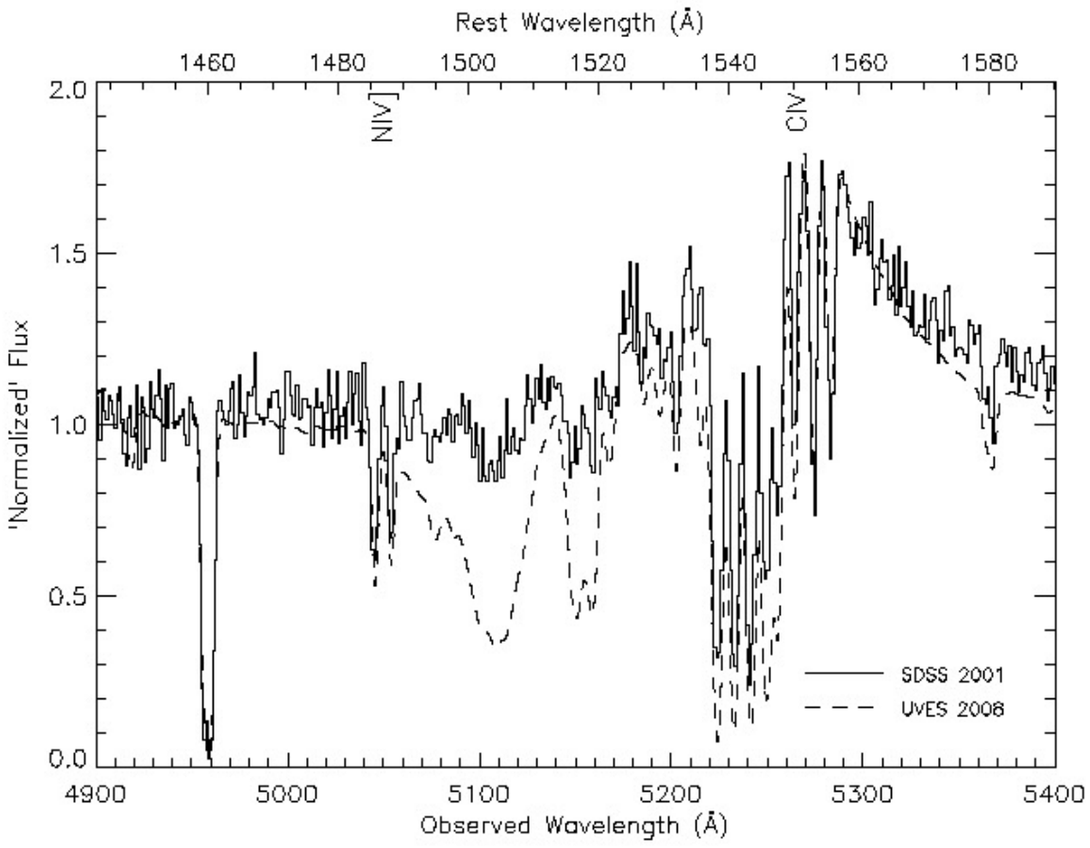
- Monitoring observations with Gemini to understand life cycles of these outflows (Rogerson+17)

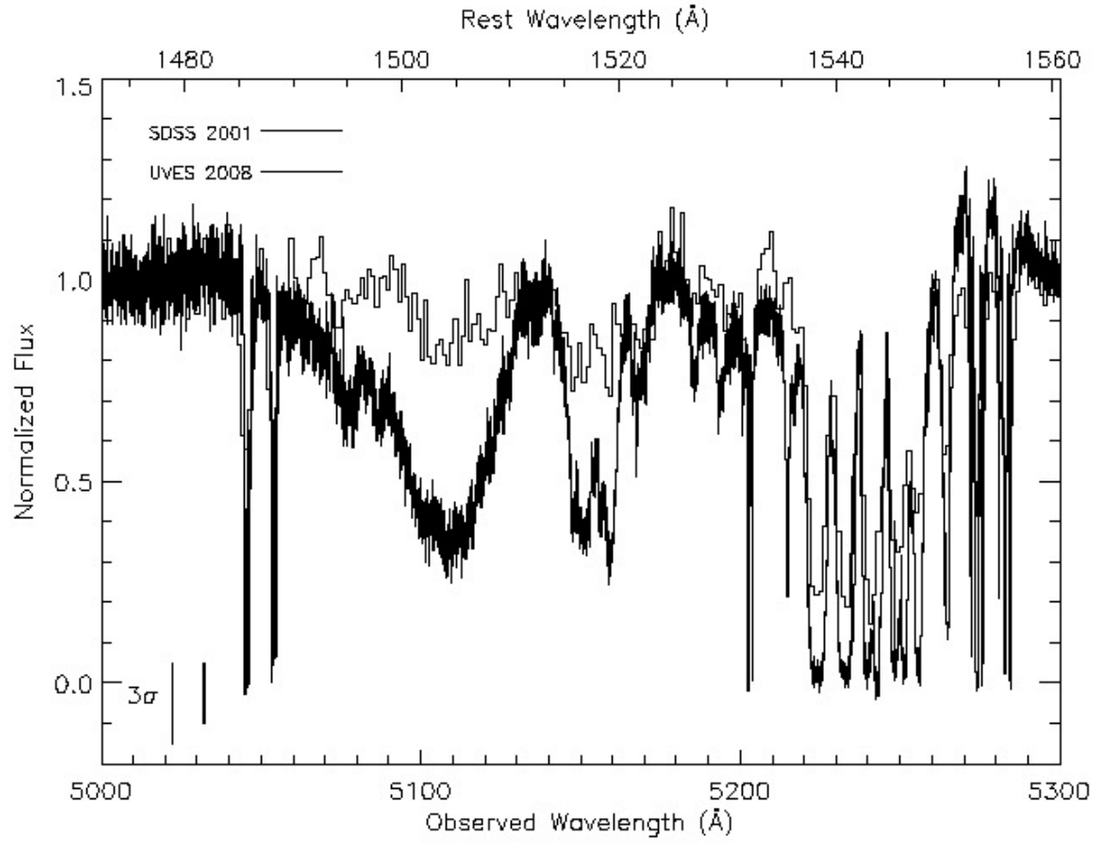




Extreme Variability

Cross-correlation of our SDSS sample to VLT/UVES archival spectra.





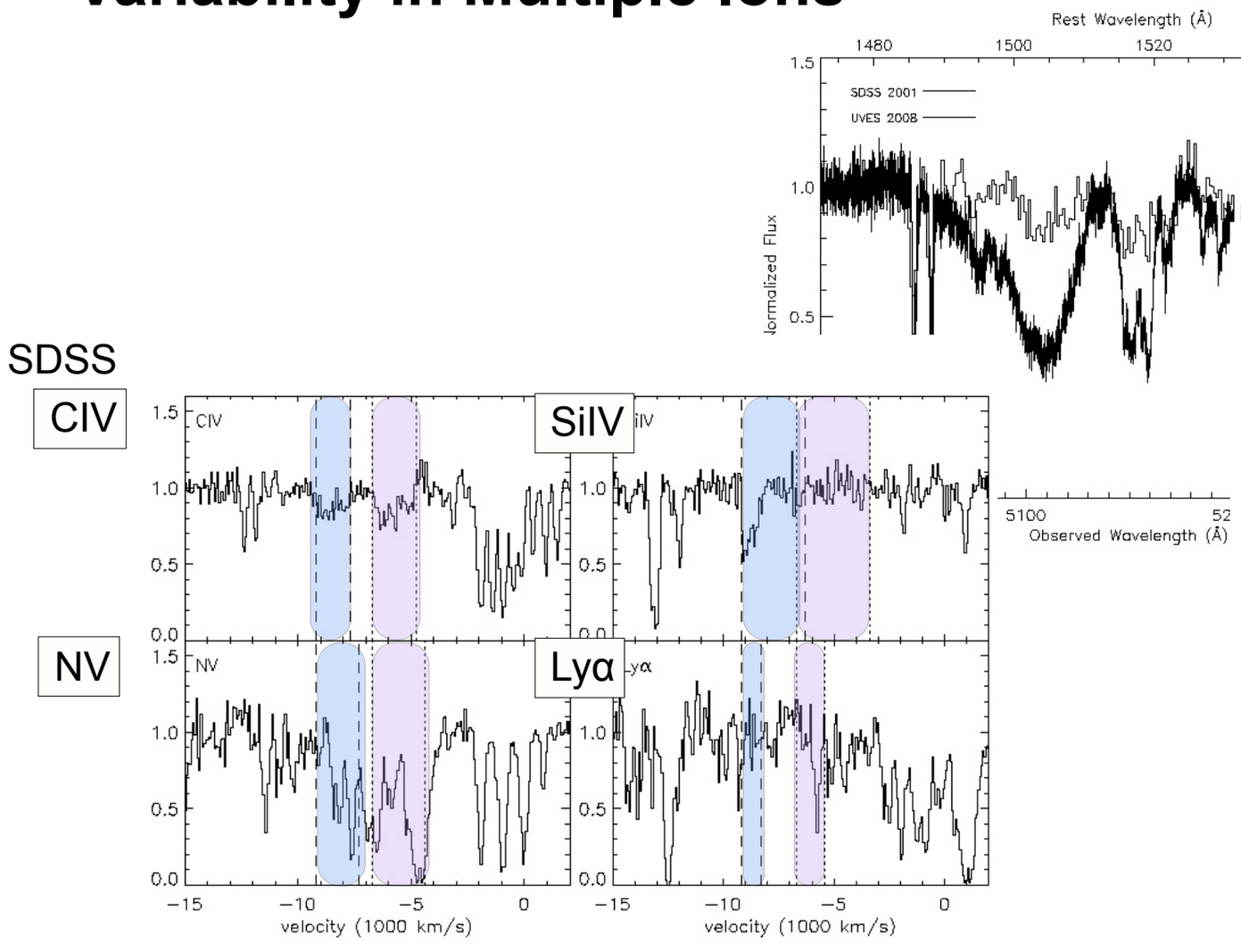
Intermediate Phase:

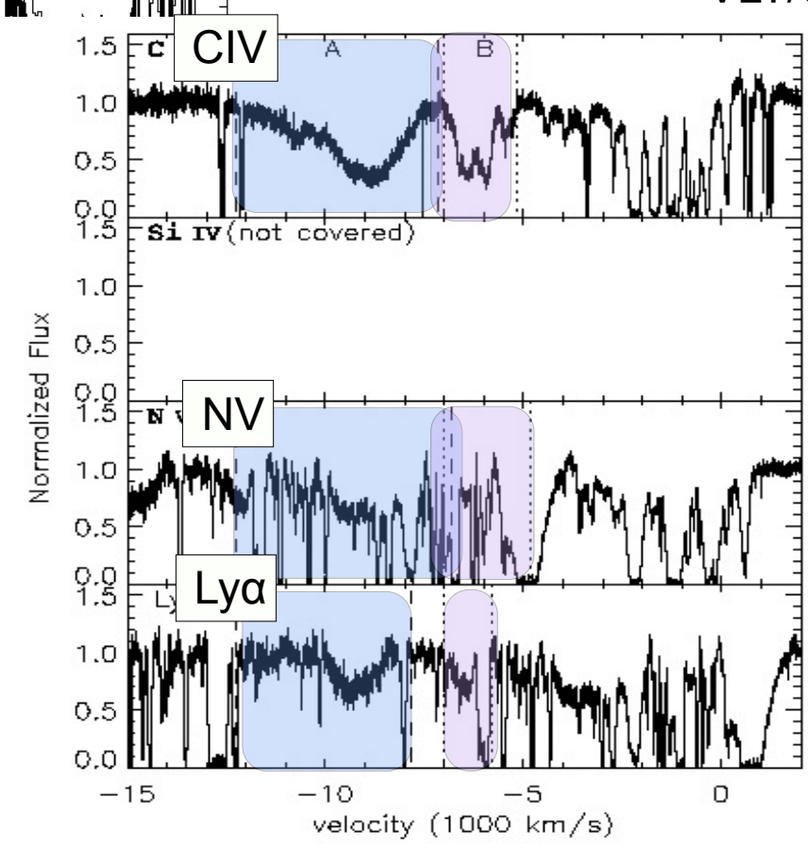
mini-BALs are turning into BALs and BALs into mini-BALs

(Rodriguez Hidalgo+12, Rodriguez Hidalgo+13)

Extreme Variability

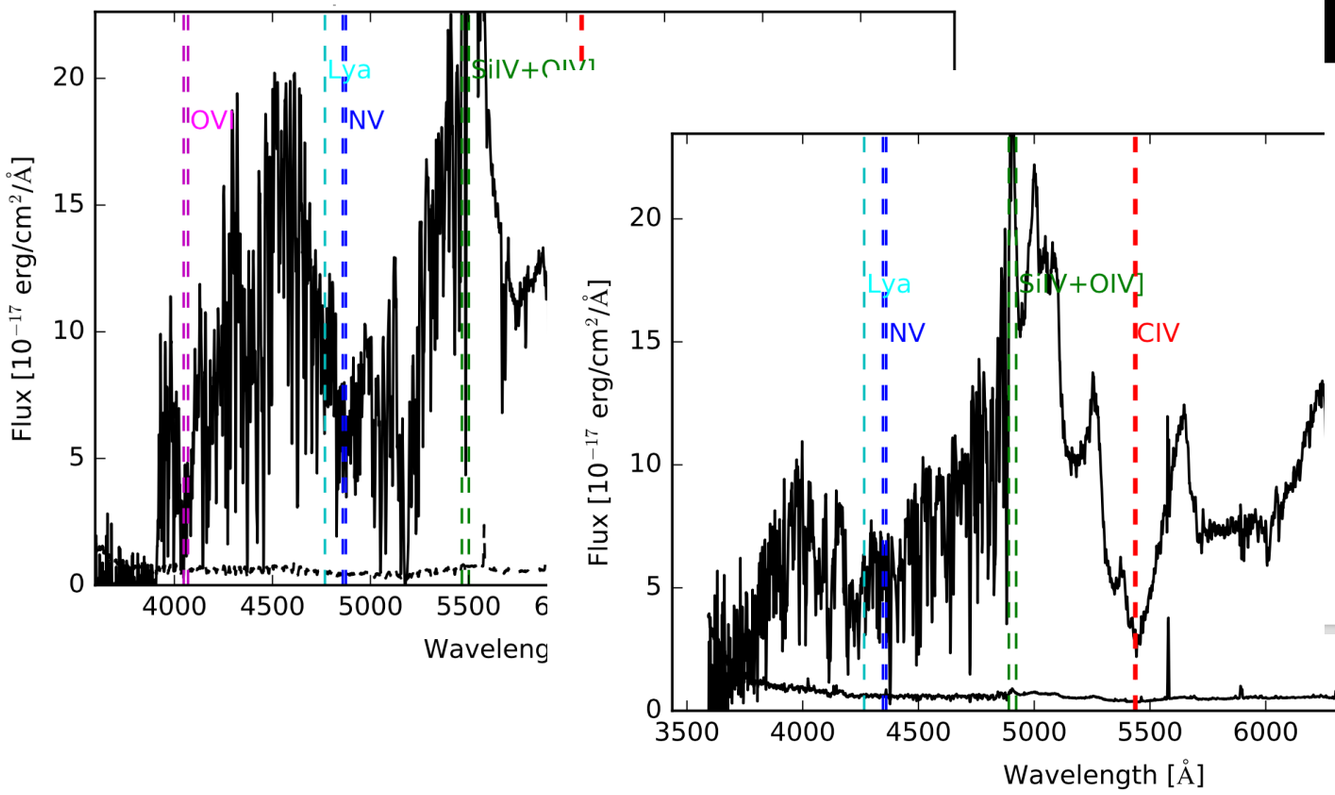
Variability in Multiple Ions

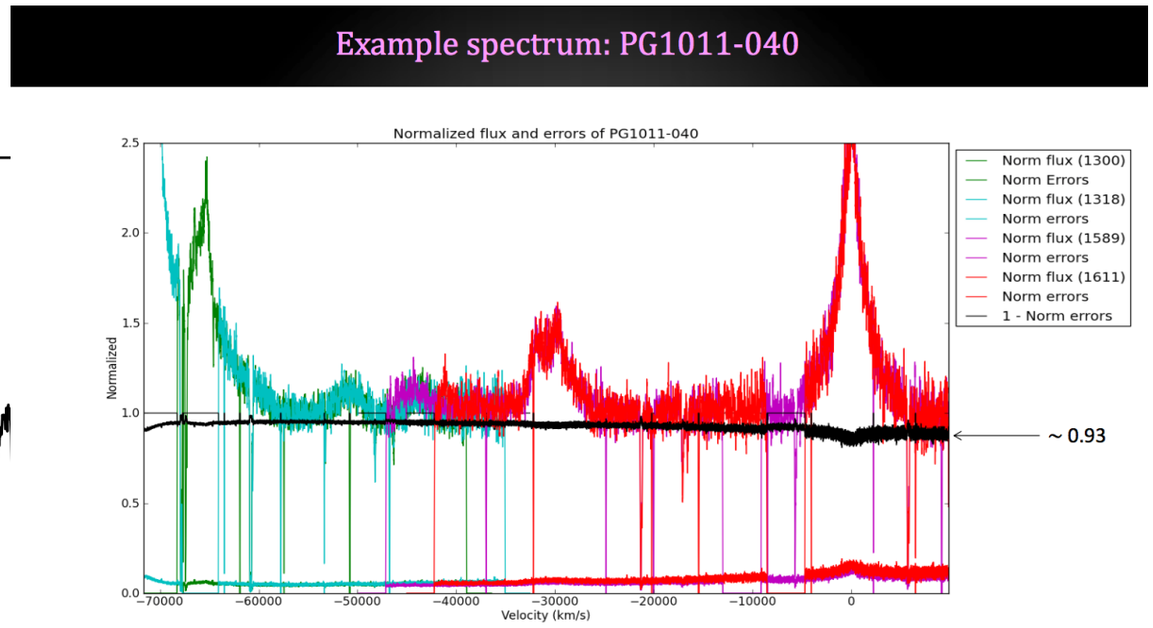


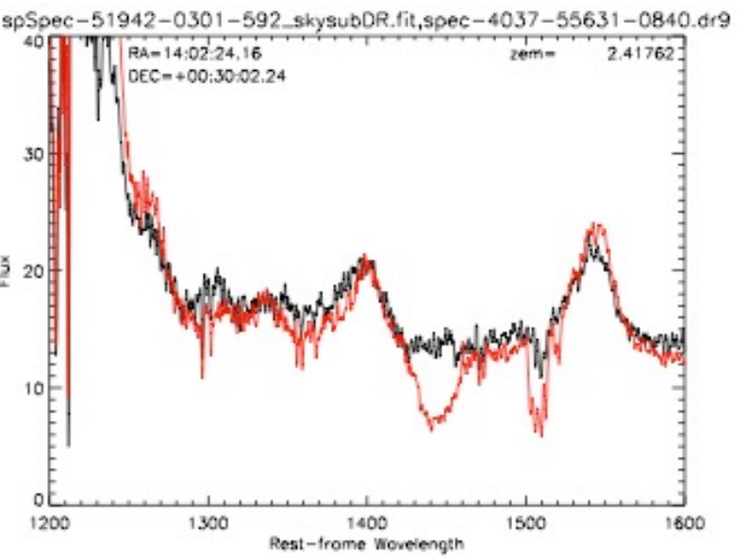


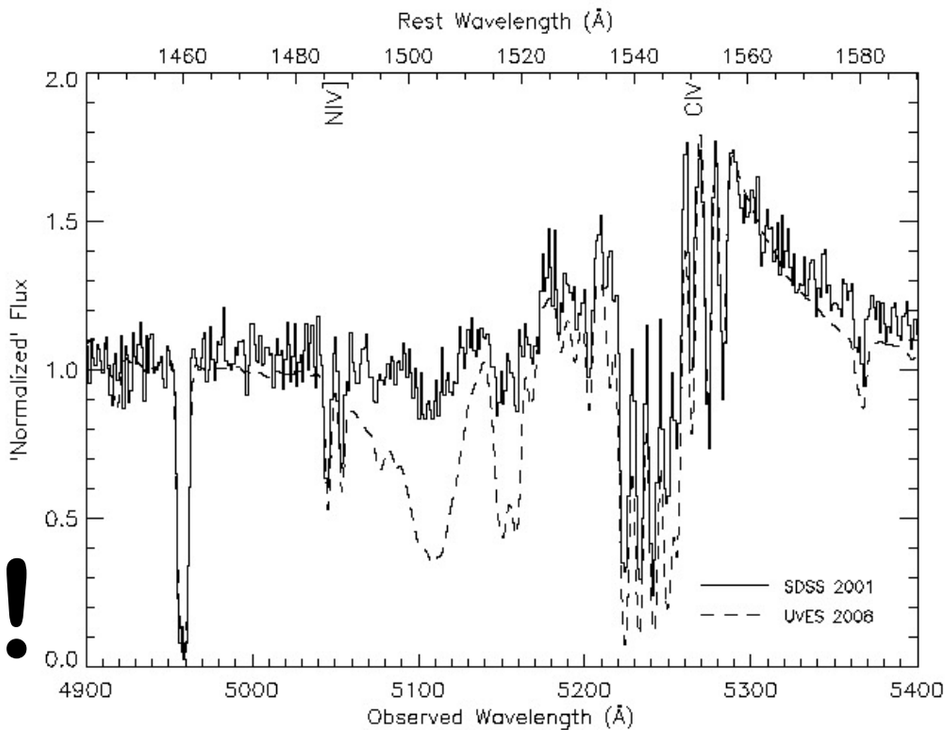
(Rodriguez Hidalgo+13)

Summary









Thank you!