

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

Paola Rodríguez Hidalgo
Dept. of Physics & Astronomy
Humboldt State University

Some collaborators:

Neil Brandt (PSU)

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)

Jesse Rogerson (CASM)

Joseph Shields (Ohio Univ.)

Andrey Vayner* (UCSD)

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

Paola Rodríguez Hidalgo
Dept. of Physics & Astronomy
Humboldt State University

* Students

Some collaborators:

Neil Brandt (PSU)

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)

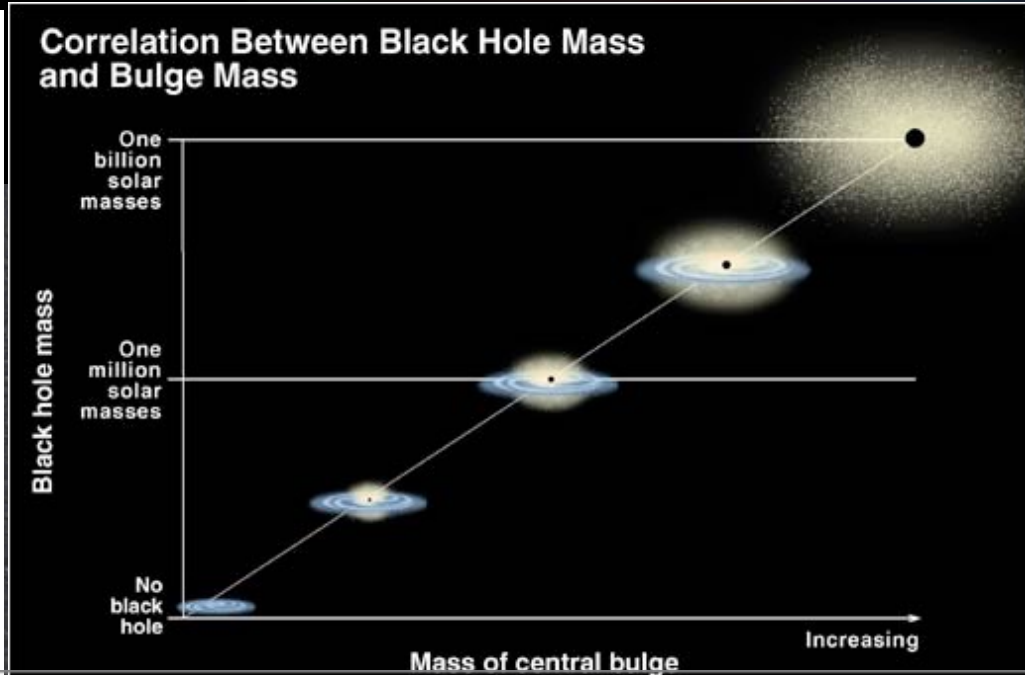
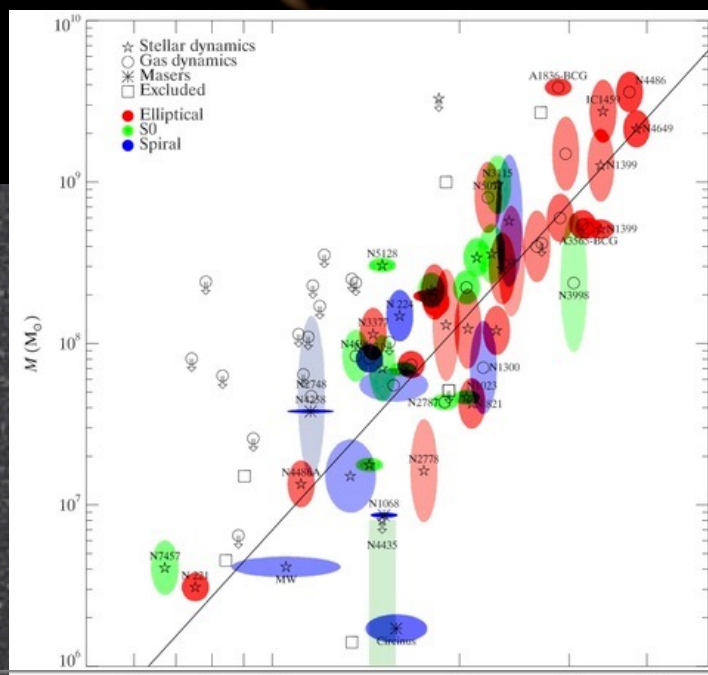
Carla Quintero* (HSU)

Jesse Rogerson (CASM)

Joseph Shields (Ohio Univ.)

Andrey Vayner* (UCSD)

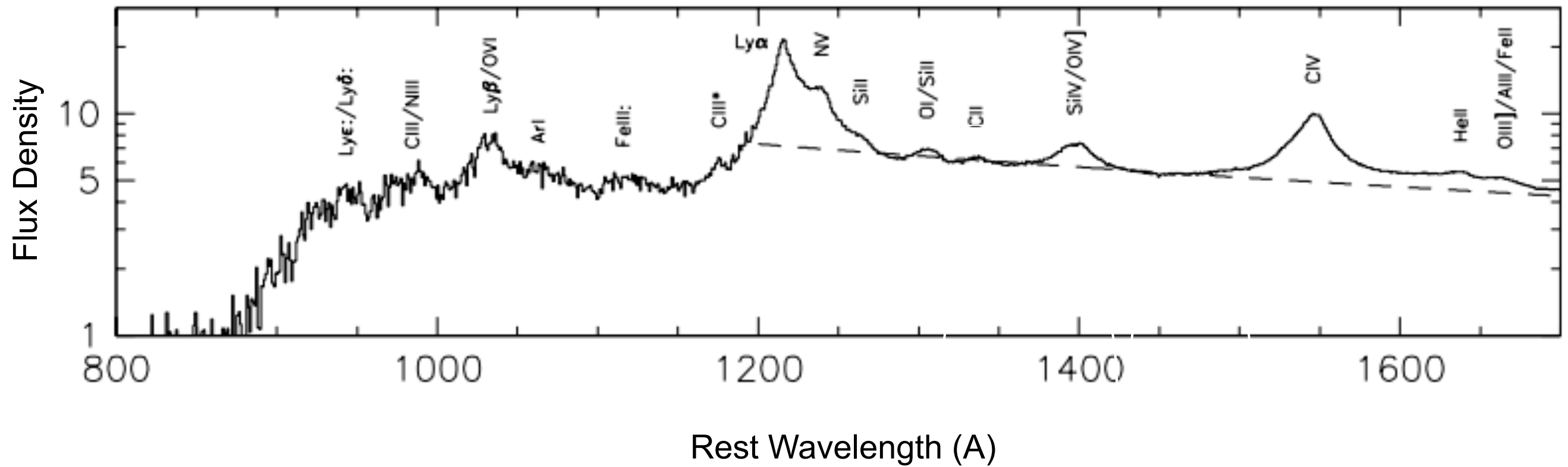
Why study quasar outflows?



(Gültekin+09)

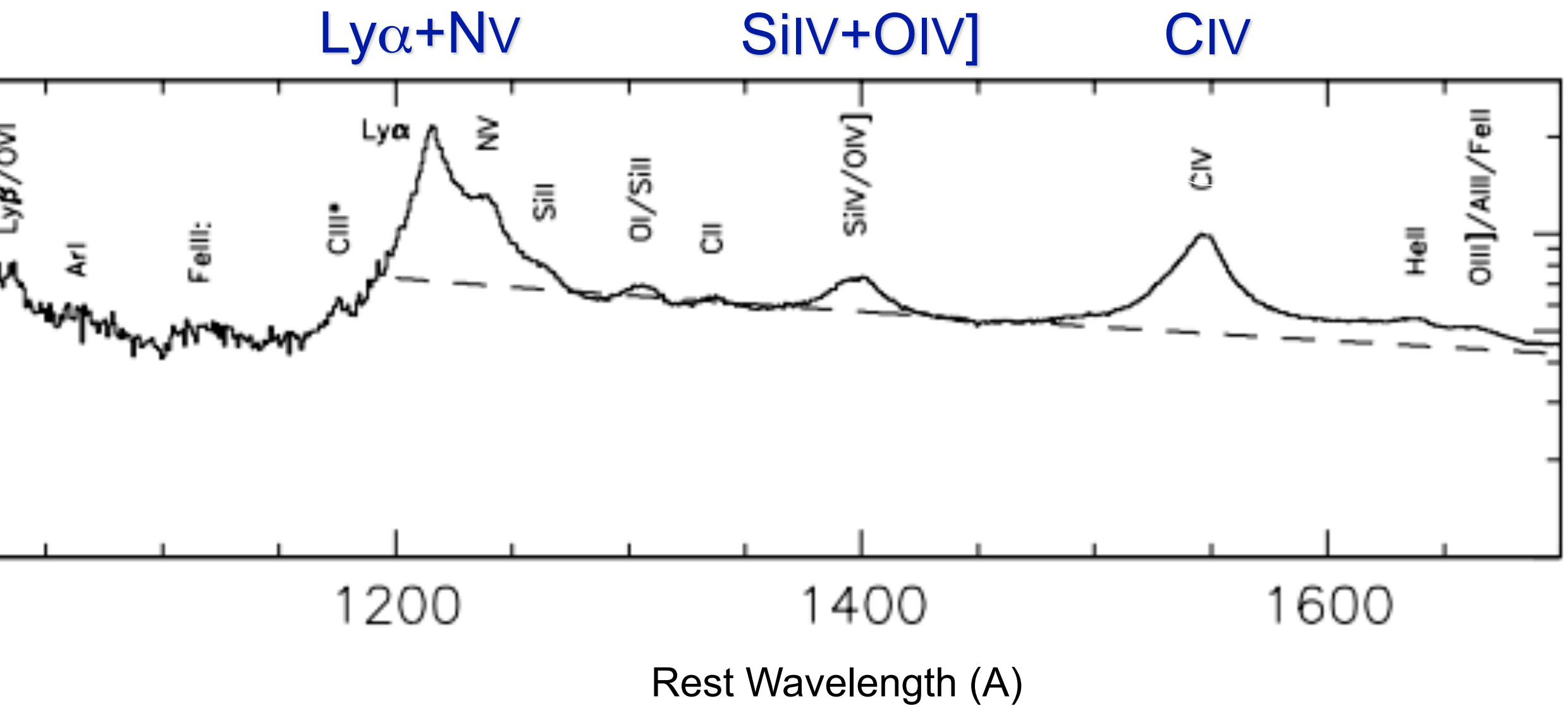
Relation AGN environment - BH - galactic evolution

Quasar spectra

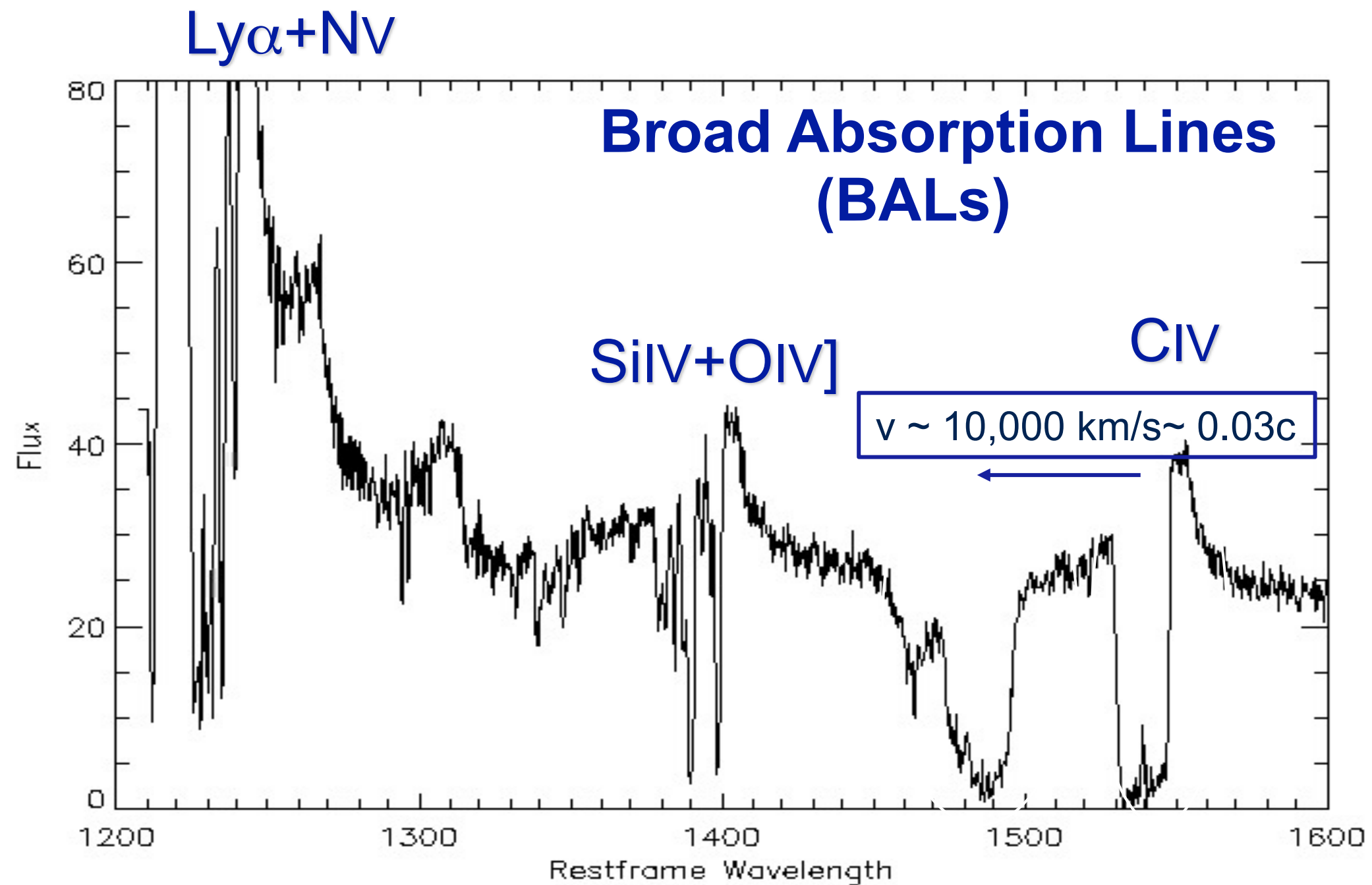


(Vander Berk+01)

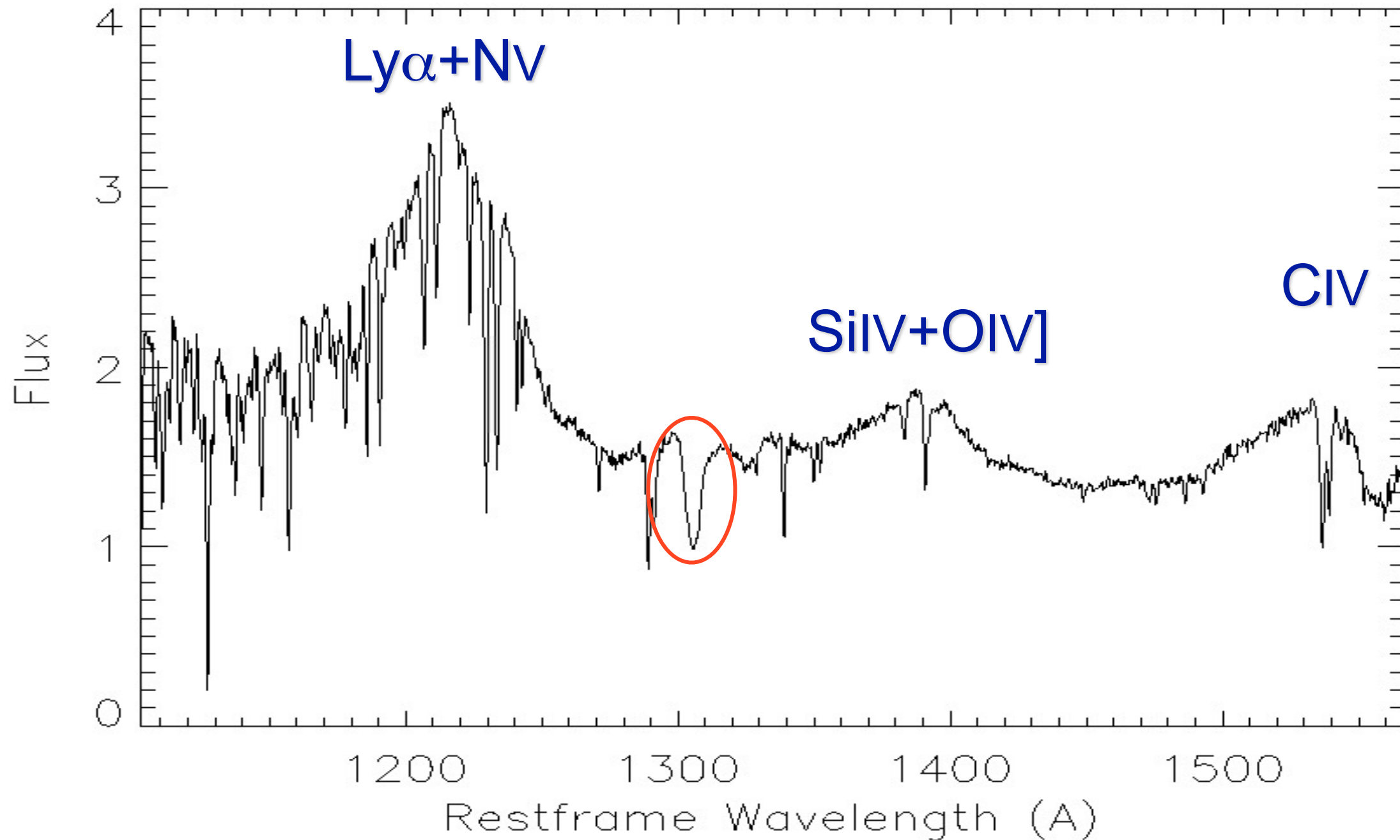
Quasar spectra



Quasar spectra - High Velocity Outflows

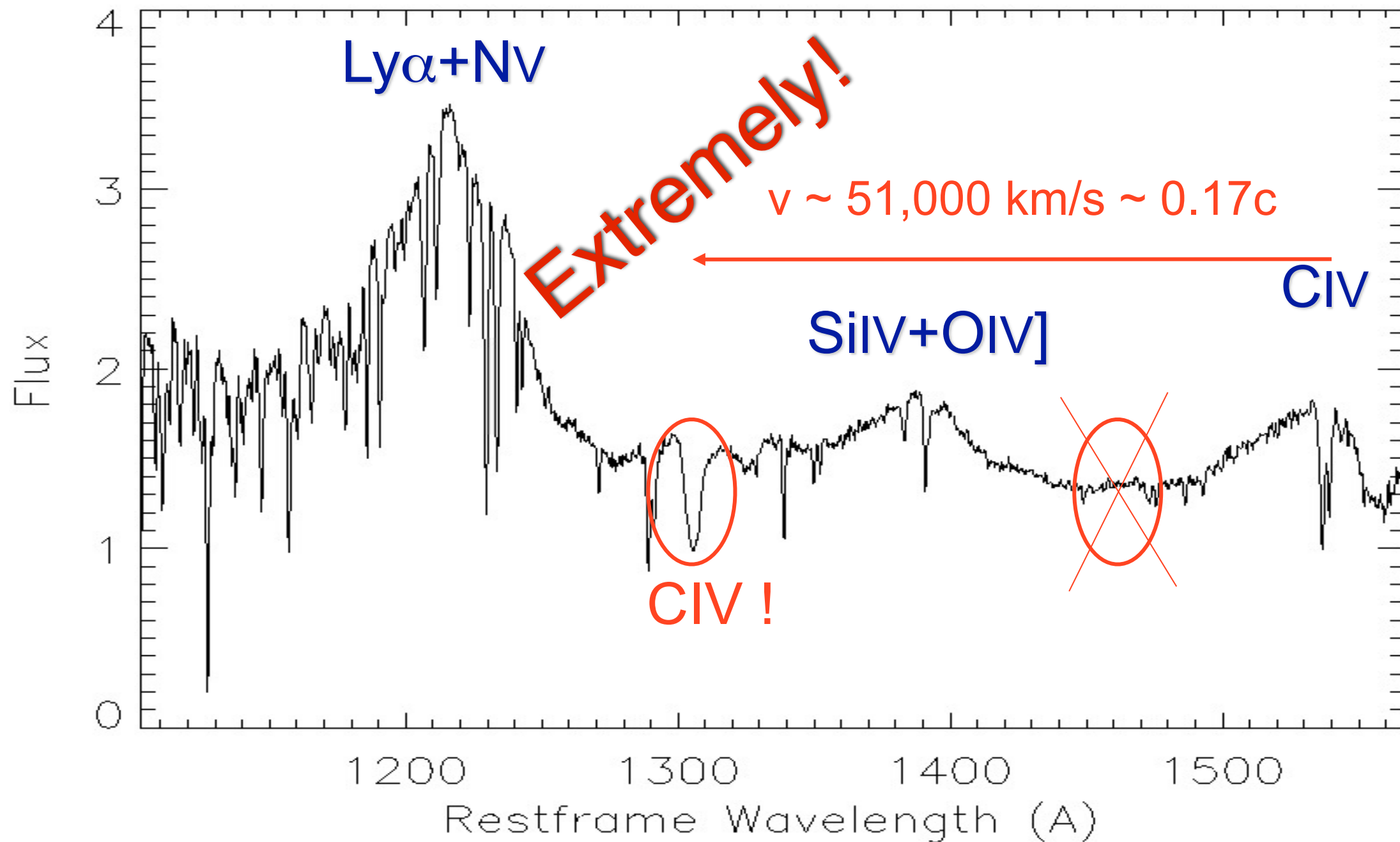


Quasar spectra - High Velocity Outflows



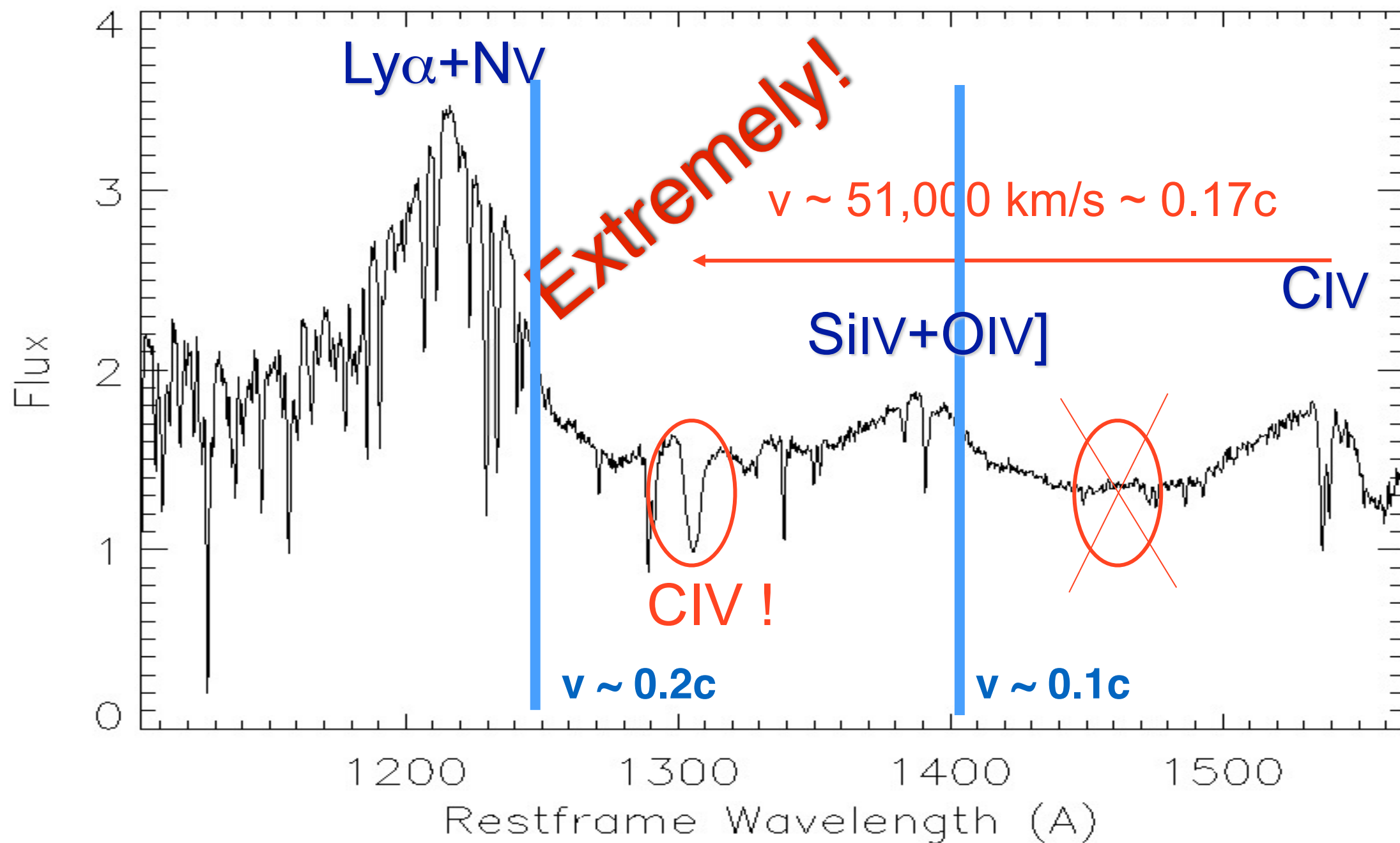
(Hamann+1997)

Quasar spectra - High Velocity Outflows PGO935+417



(Hamann+1997)

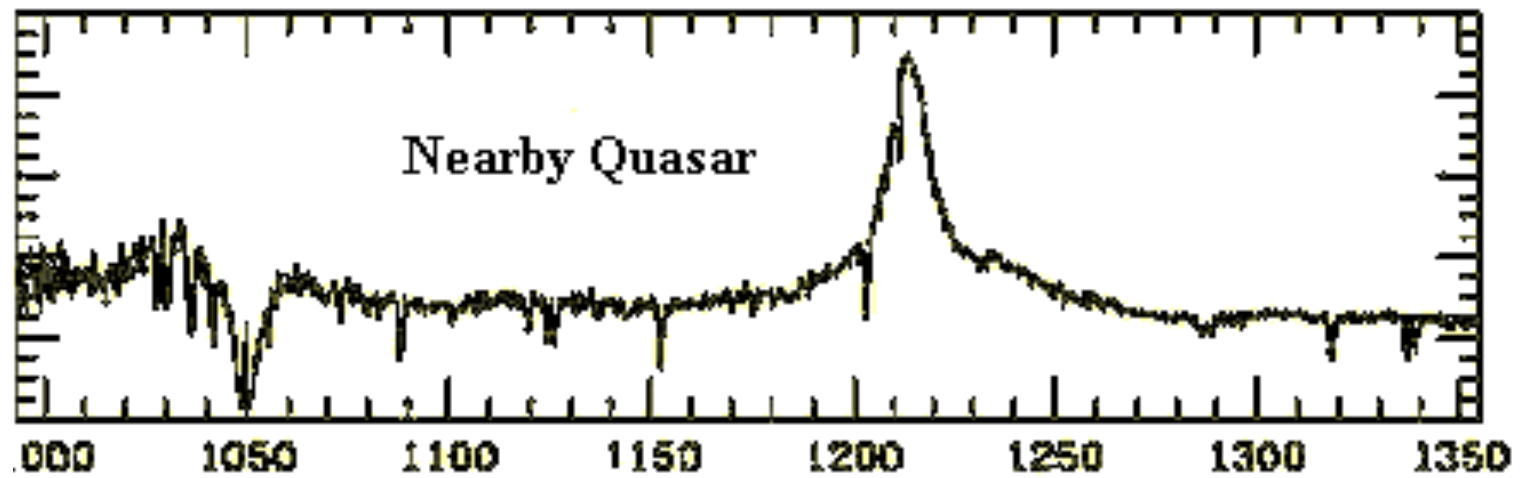
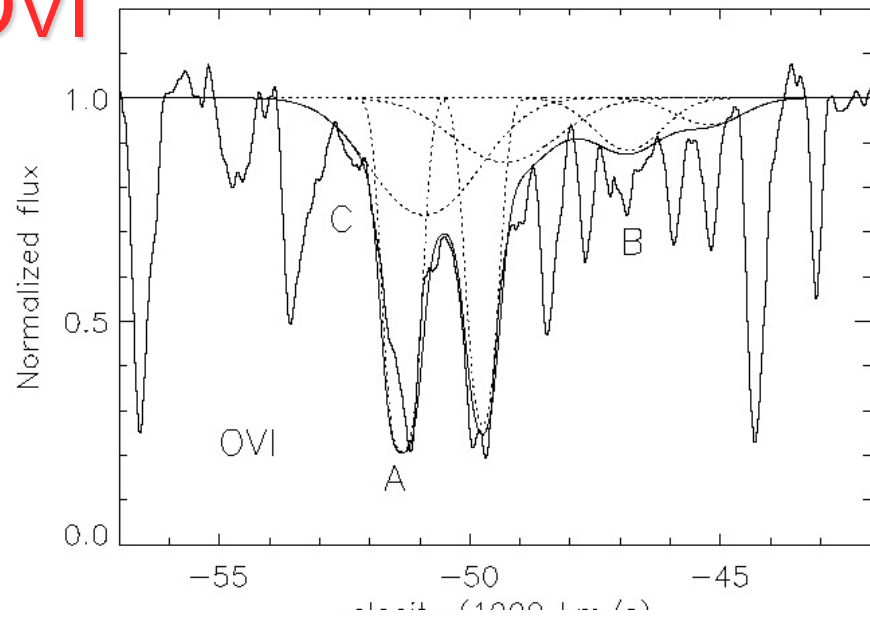
Quasar spectra - Extremely High Velocity Outflows PGO935+417



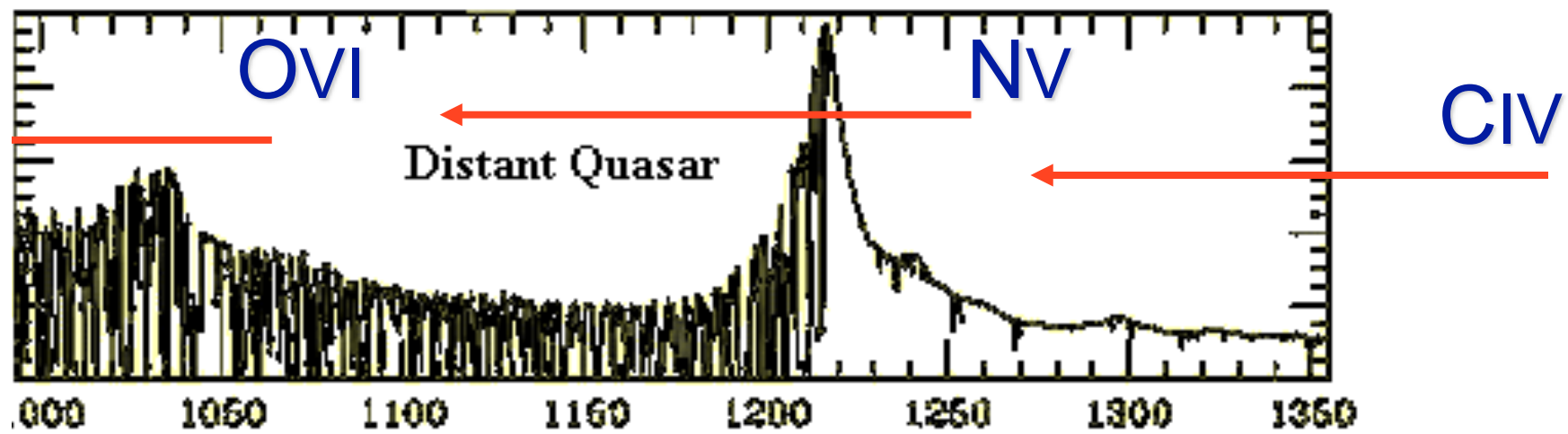
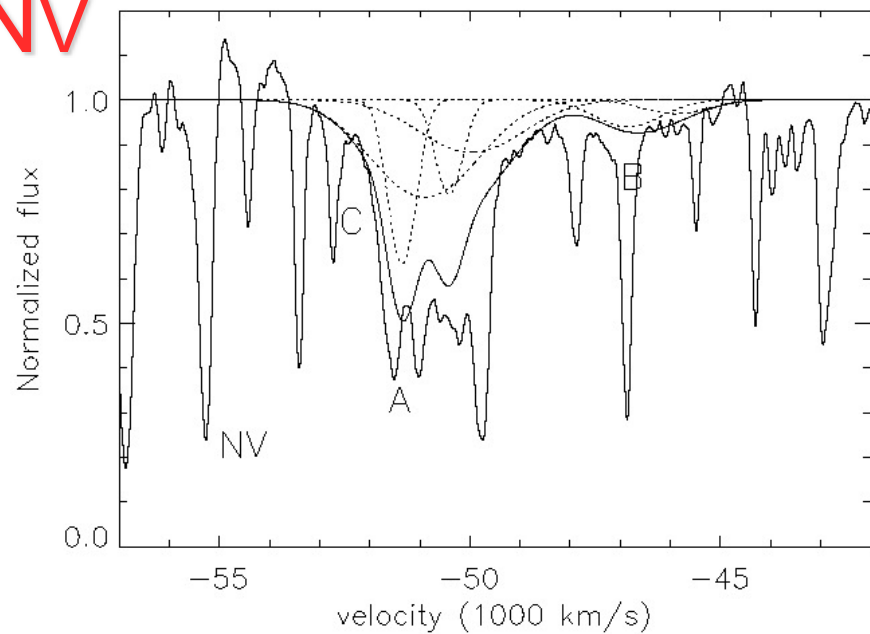
(Hamann+1997)

Quasar spectra - Extremely High Velocity Outflows PGO935+417

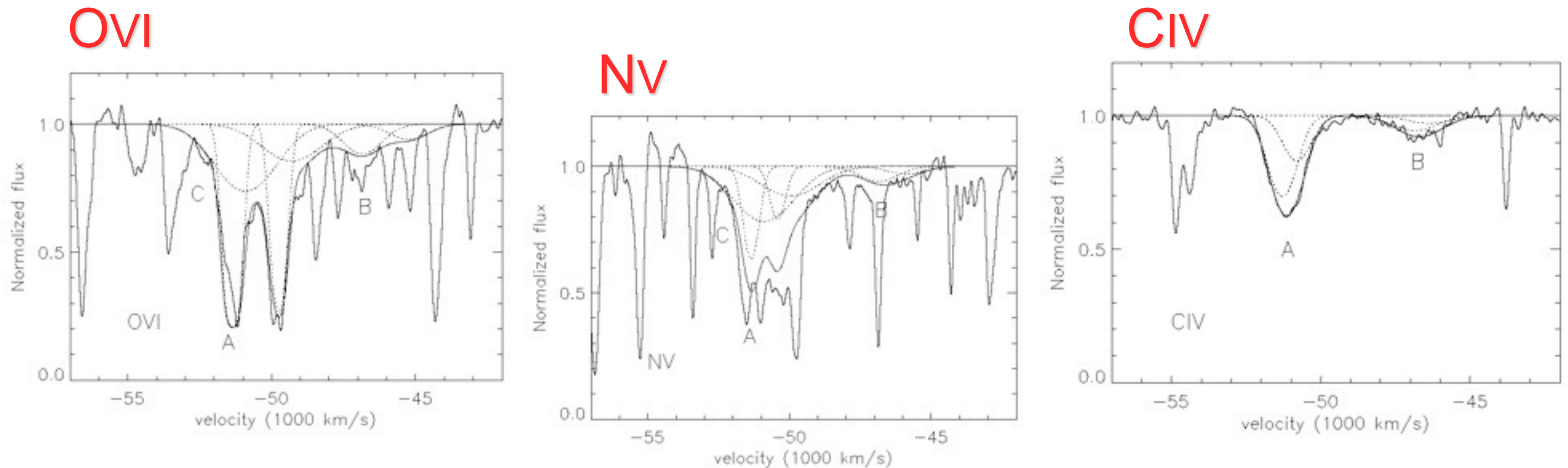
OVI



NV



Quasar spectra - Extremely High Velocity Outflows PGO935+417

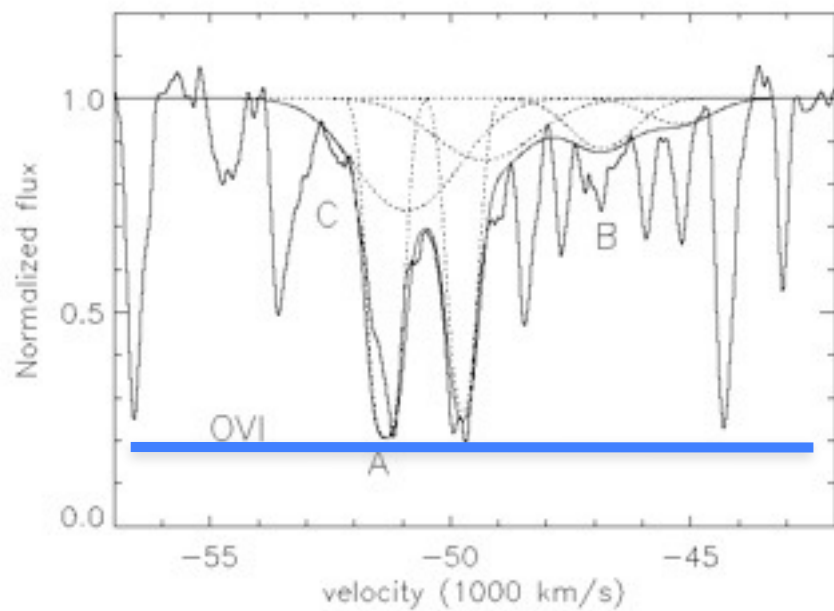


(Rodriguez Hidalgo+2011)

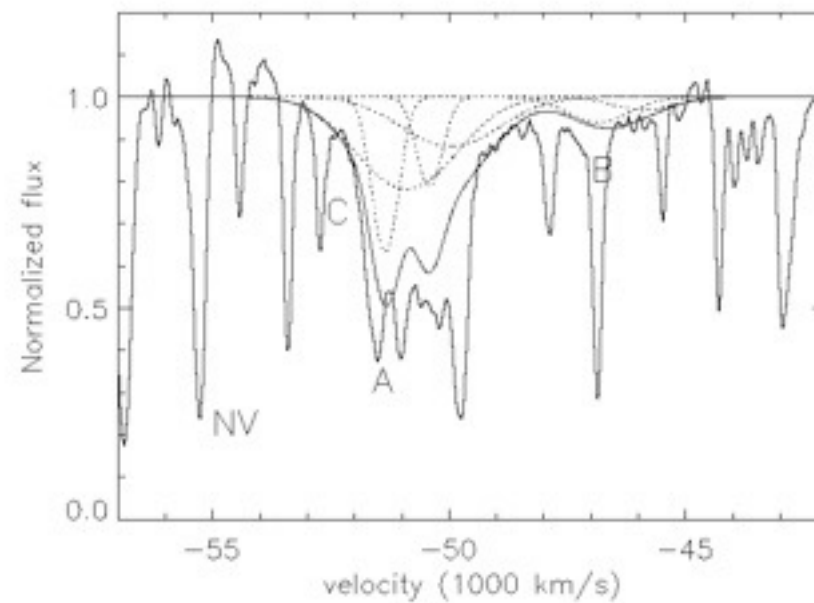
- HST/FOS data
- No other ions had confirmed detections

Quasar spectra - Extremely High Velocity Outflows PGO935+417

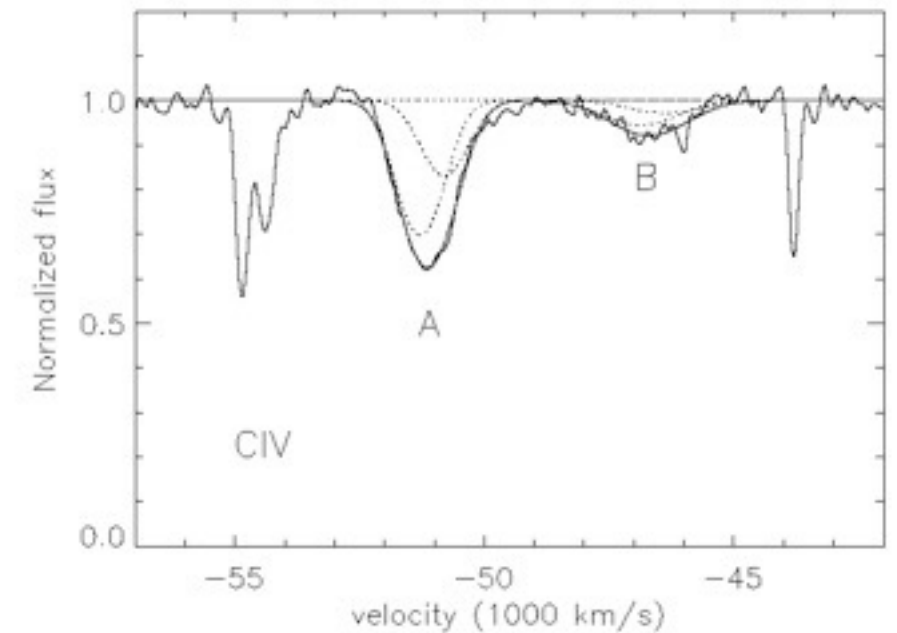
OVI



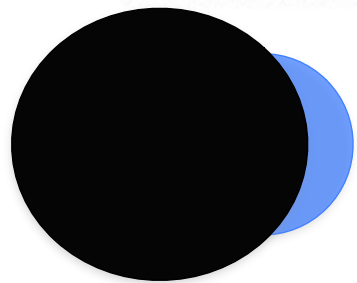
NV



CIV

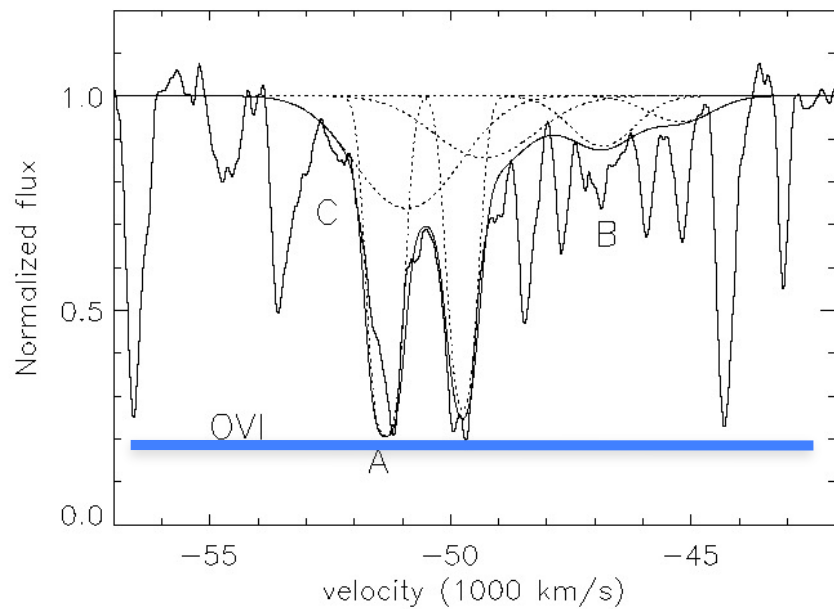


(Rodriguez Hidalgo+2011)

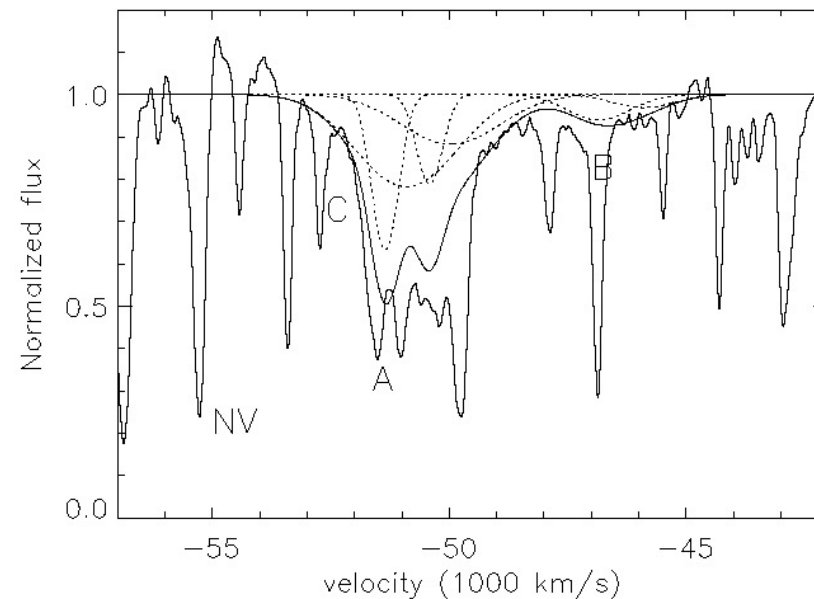


Quasar spectra - Extremely High Velocity Outflows PGO935+417

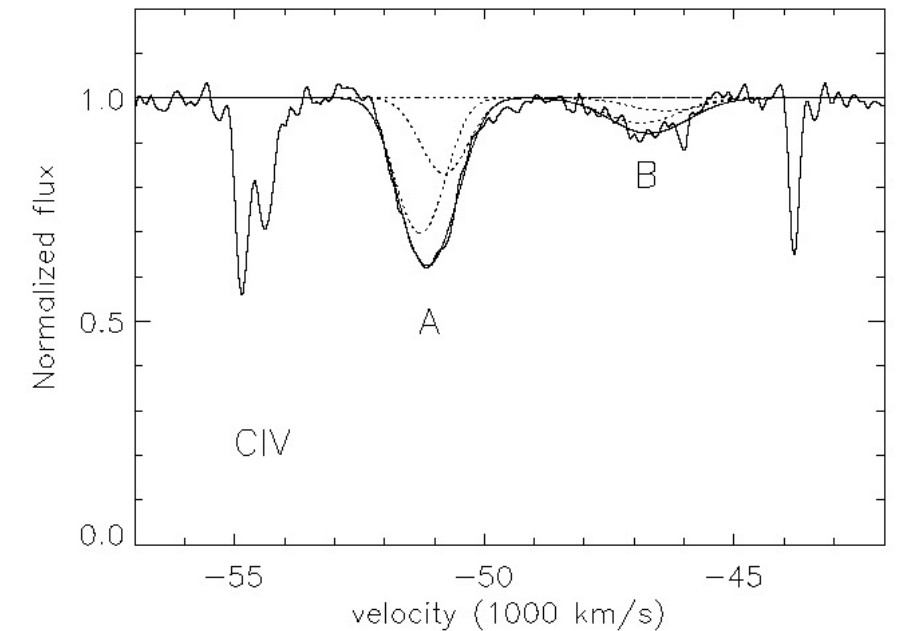
OVI



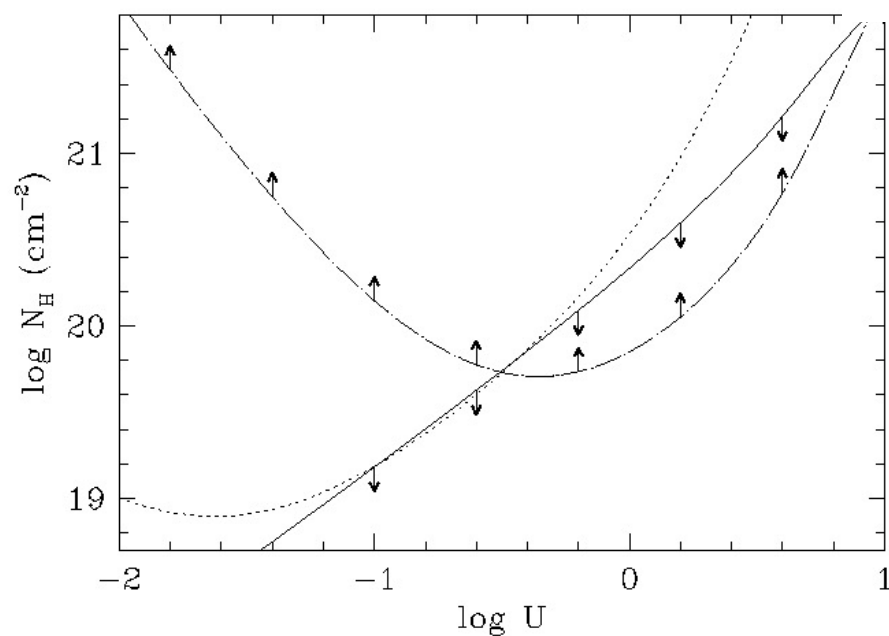
NV



CIV



(Rodriguez Hidalgo+2011)



Coverage Fraction: $C_f = 0.8$

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

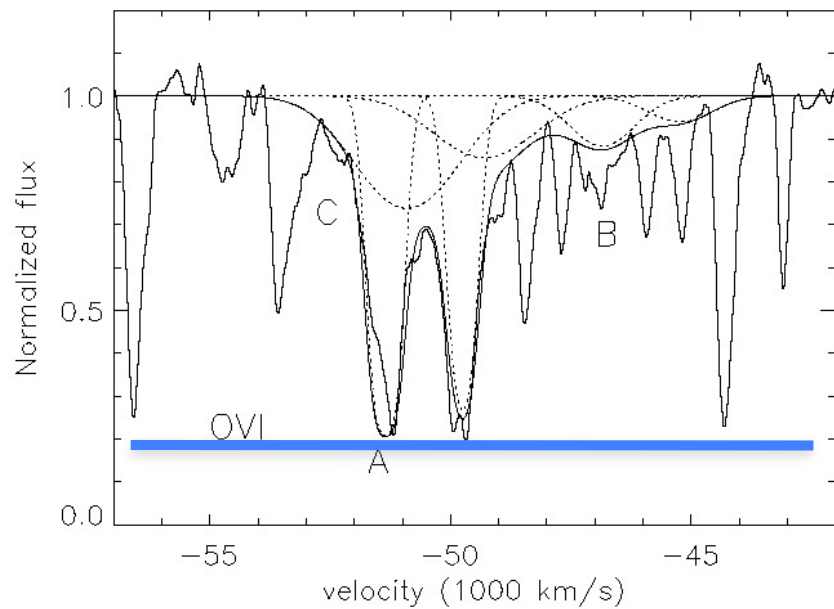
Ionization: $\log U \sim -0.5$

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

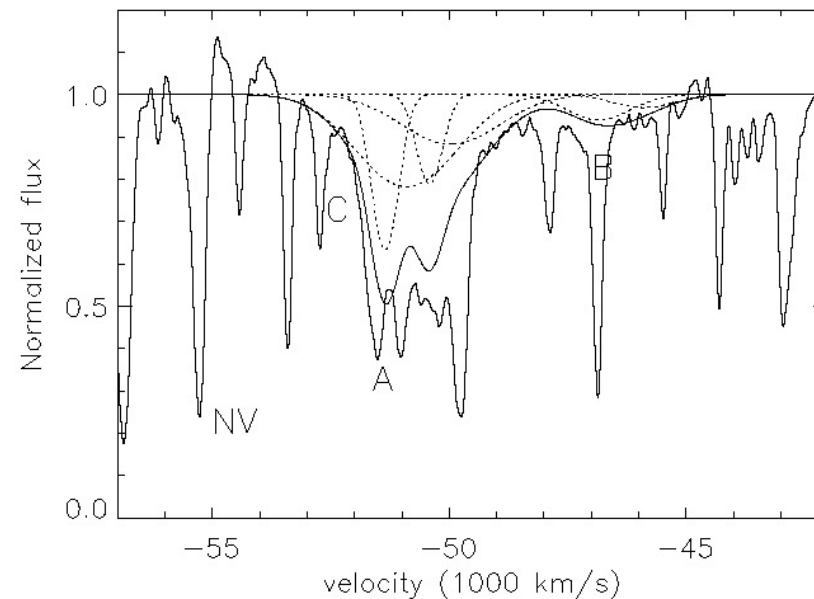
Kinetic Luminosity $\sim 2\pi\Omega R N_H \mu m_p v^3$

Quasar spectra - Extremely High Velocity Outflows PGO935+417

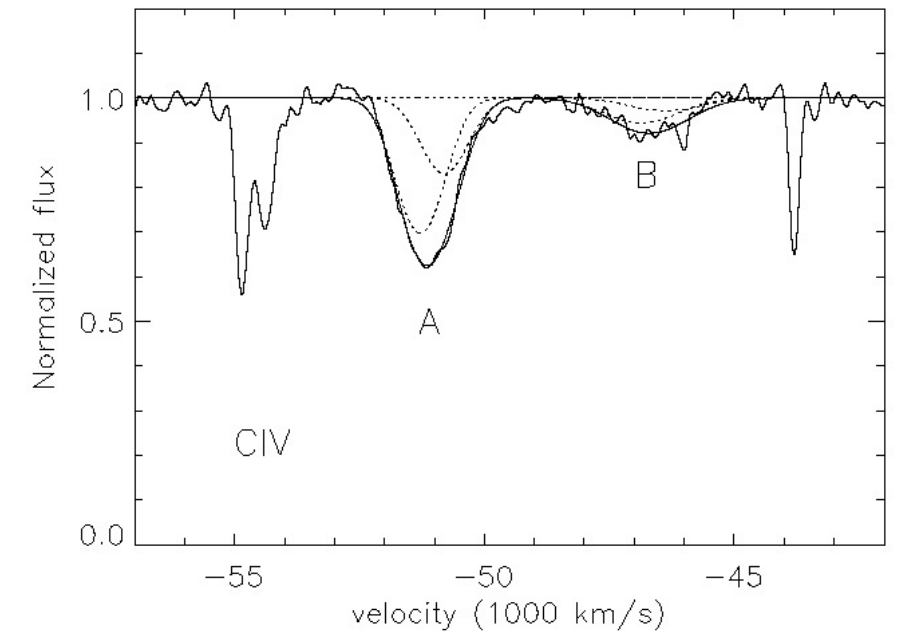
OVI



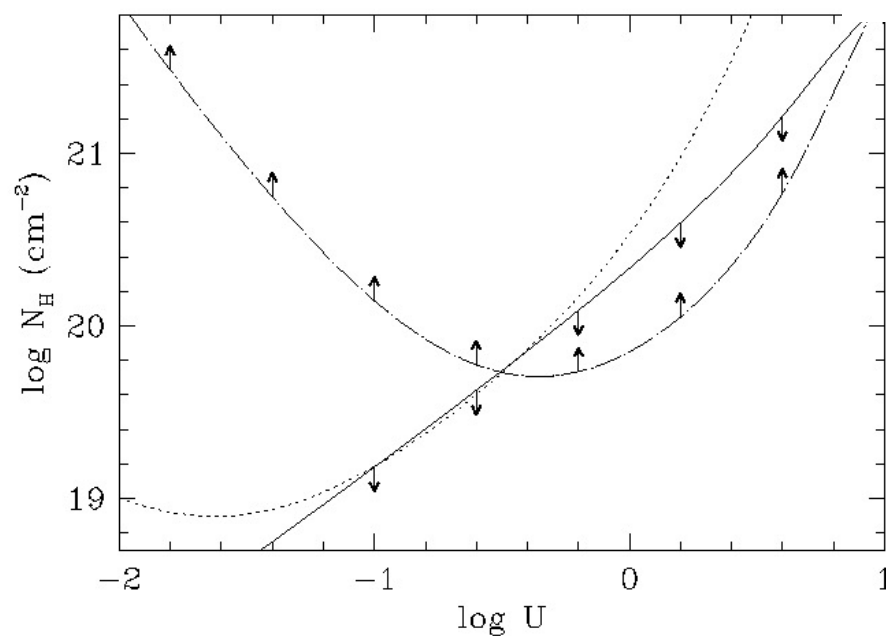
NV



CIV



(Rodriguez Hidalgo+2011)



Coverage Fraction: $C_f = 0.8$

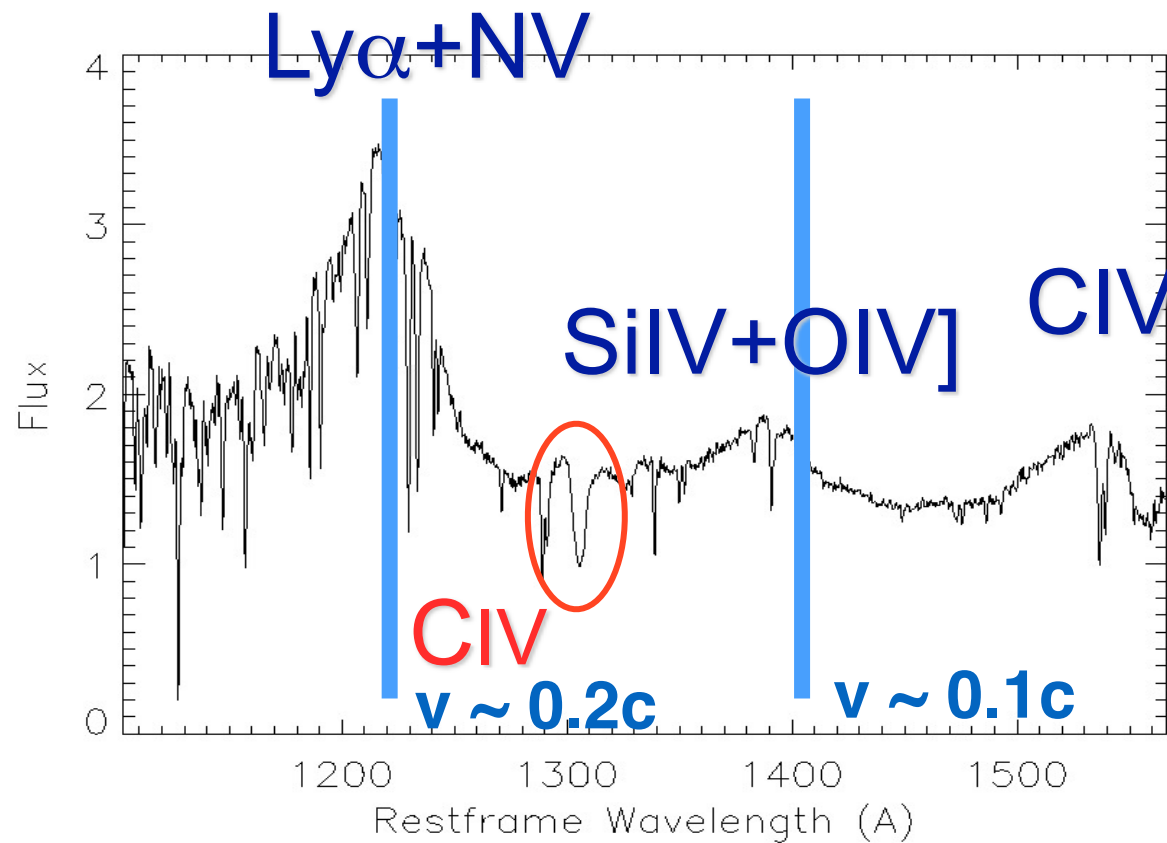
Total Column Density: $N_H \sim 5 \times 10^{19} \text{ cm}^{-2}$

Ionization: $\log U \sim -0.5$

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

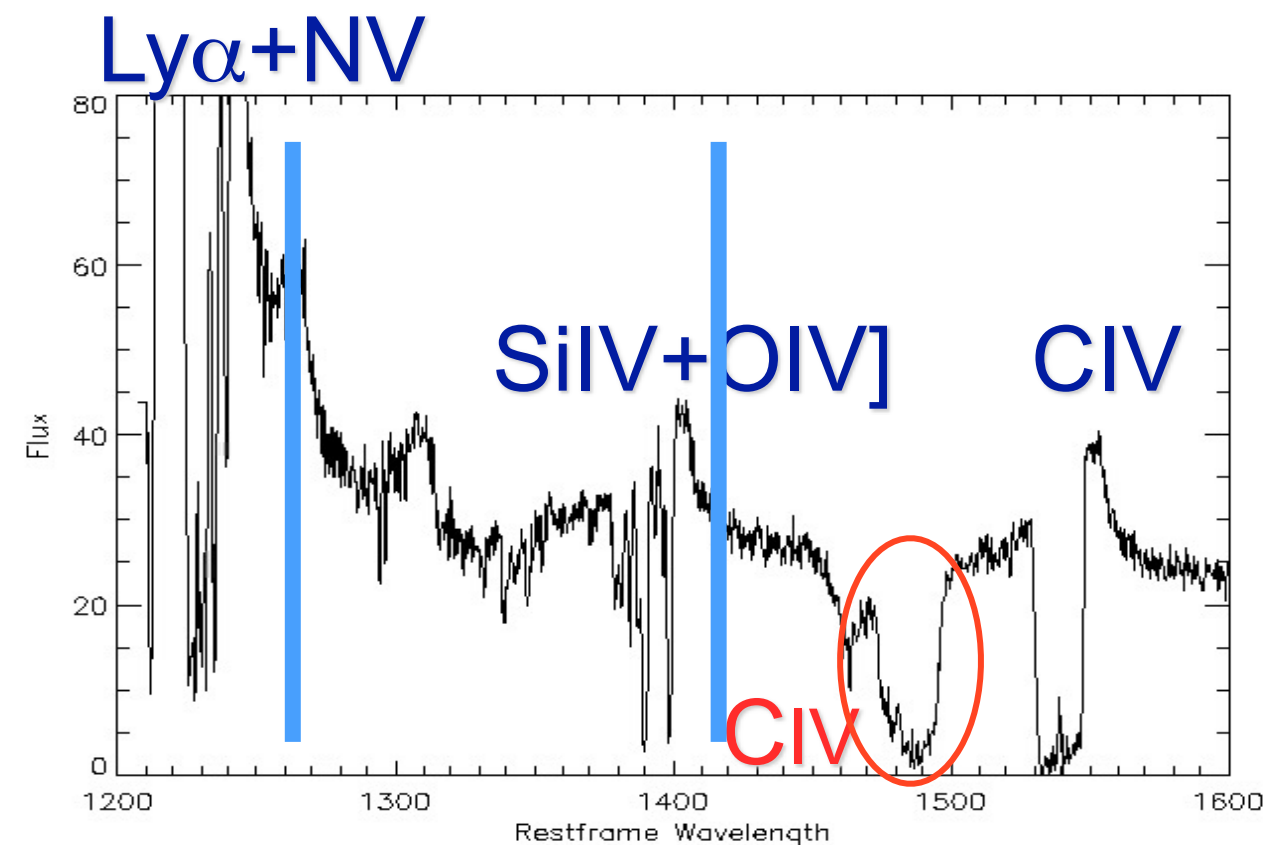
Kinetic Luminosity $\sim 2\pi R N_H \mu m_p v^3$

Quasar spectra - Extremely High Velocity Outflows PGO935+417

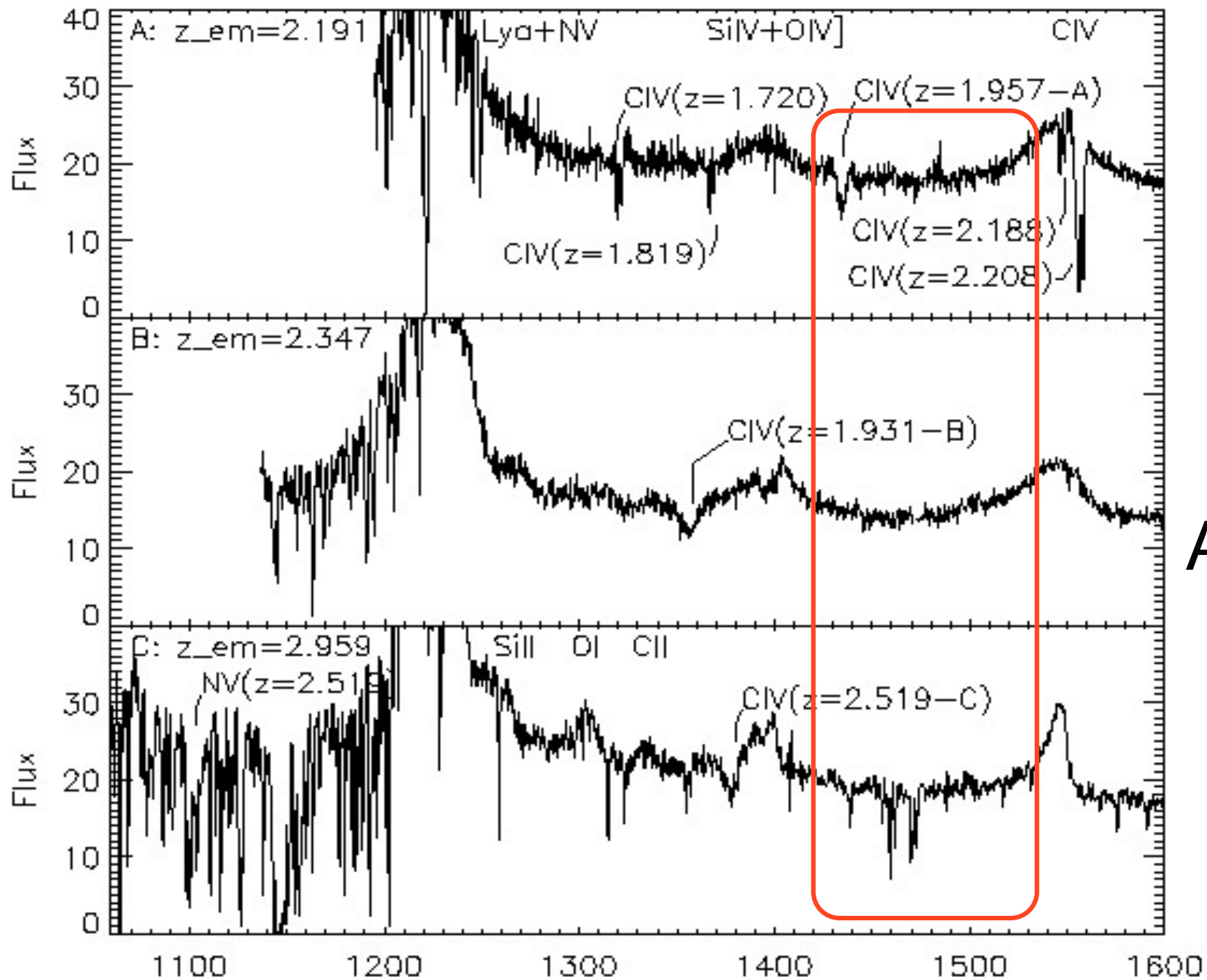


$$\text{Kinetic Luminosity} \sim 2\pi R N_H \mu m_p v^3$$

The Kinetic Luminosity of an outflow at $\sim 0.2c$ 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
 - $1300 < \text{spectral resolution (R)} < 2500$
 - spectral coverage 3600-10500 Å
- **Search for CIV $\lambda\lambda 1548, 1550$ in the velocity range 0.1-0.2c**
 - ➔ $z_{\text{em}} > 1.9$
 - ➔ $S/N \geq 10$ (brightest quasars)

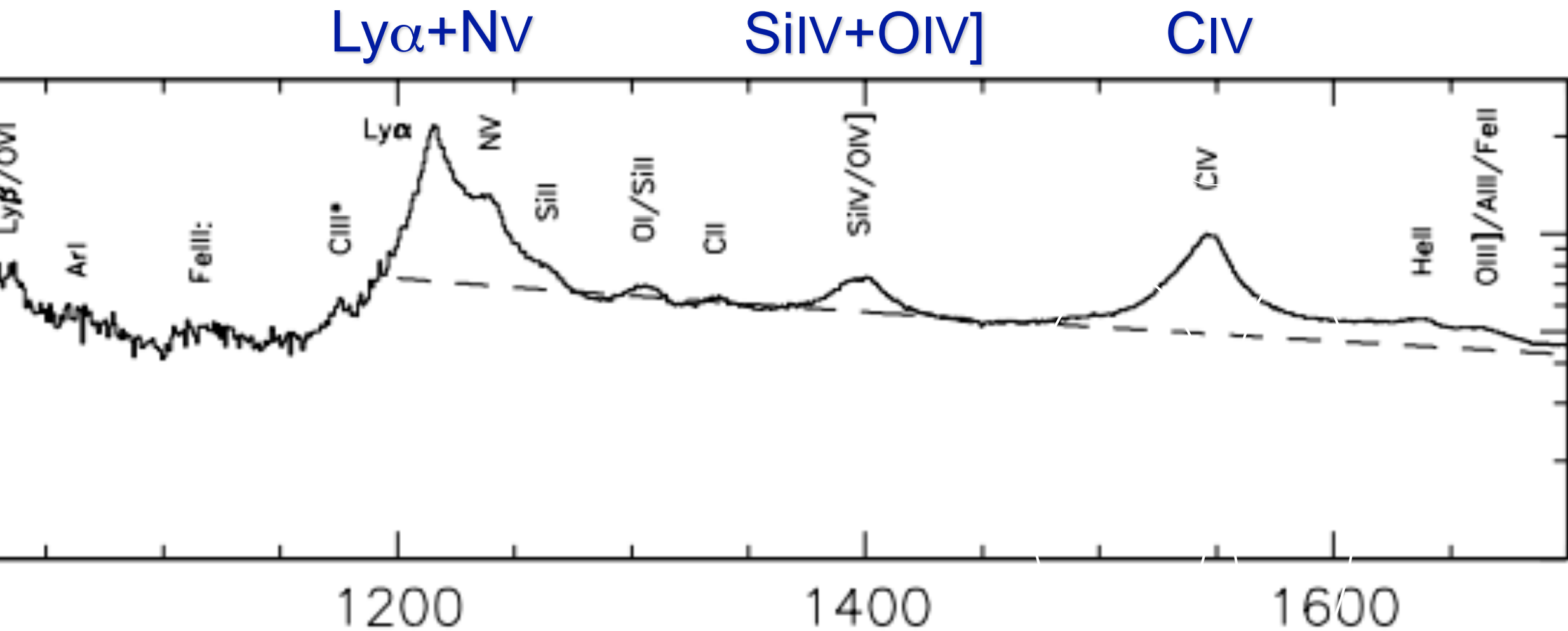
6760 quasar spectra

Searching for Extremely-high velocity outflows

6760 quasar spectra

- **Normalize all spectra with a simple power-law**

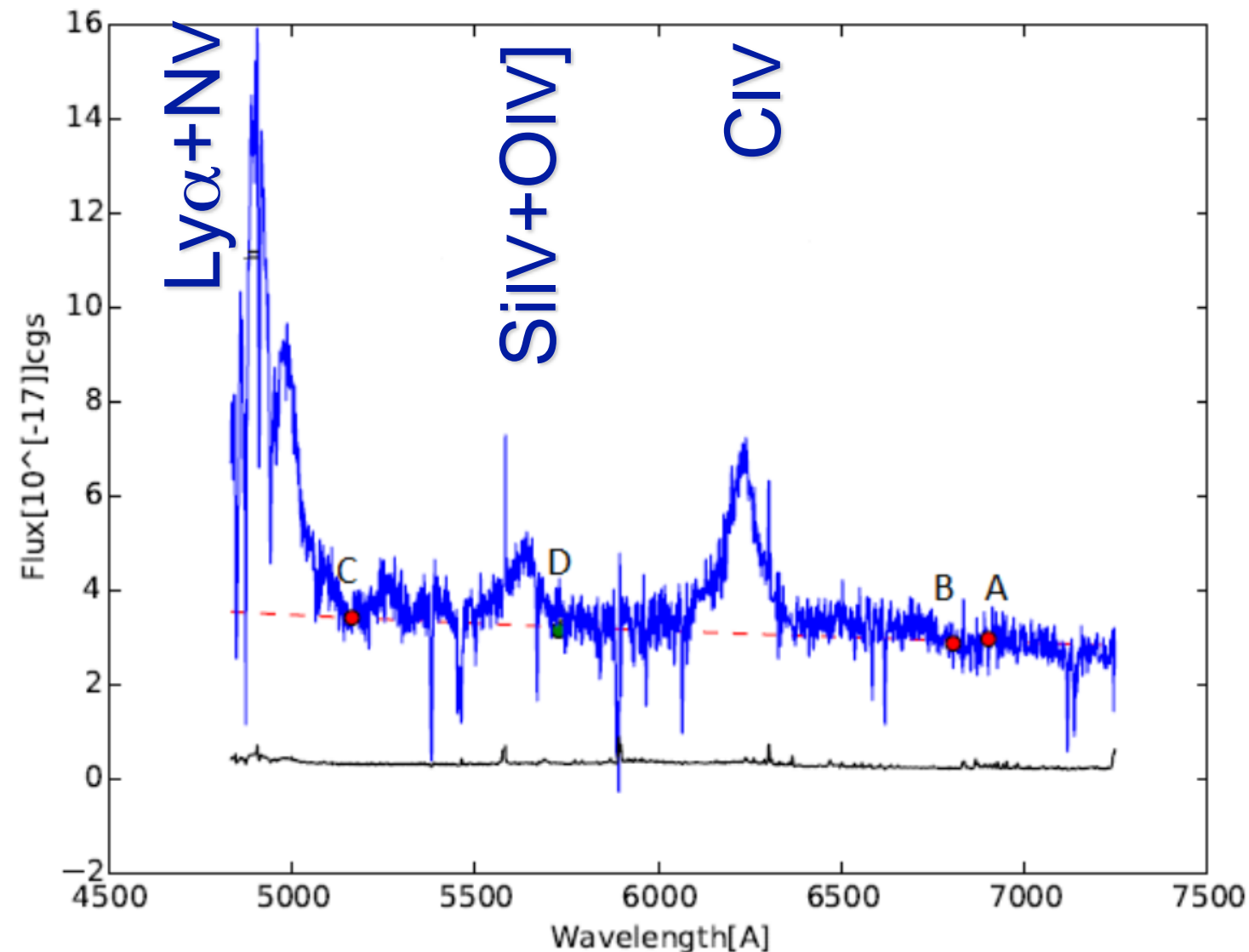
Searching for Extremely-high velocity outflows



Searching for Extremely-high velocity outflows

6760 quasar spectra

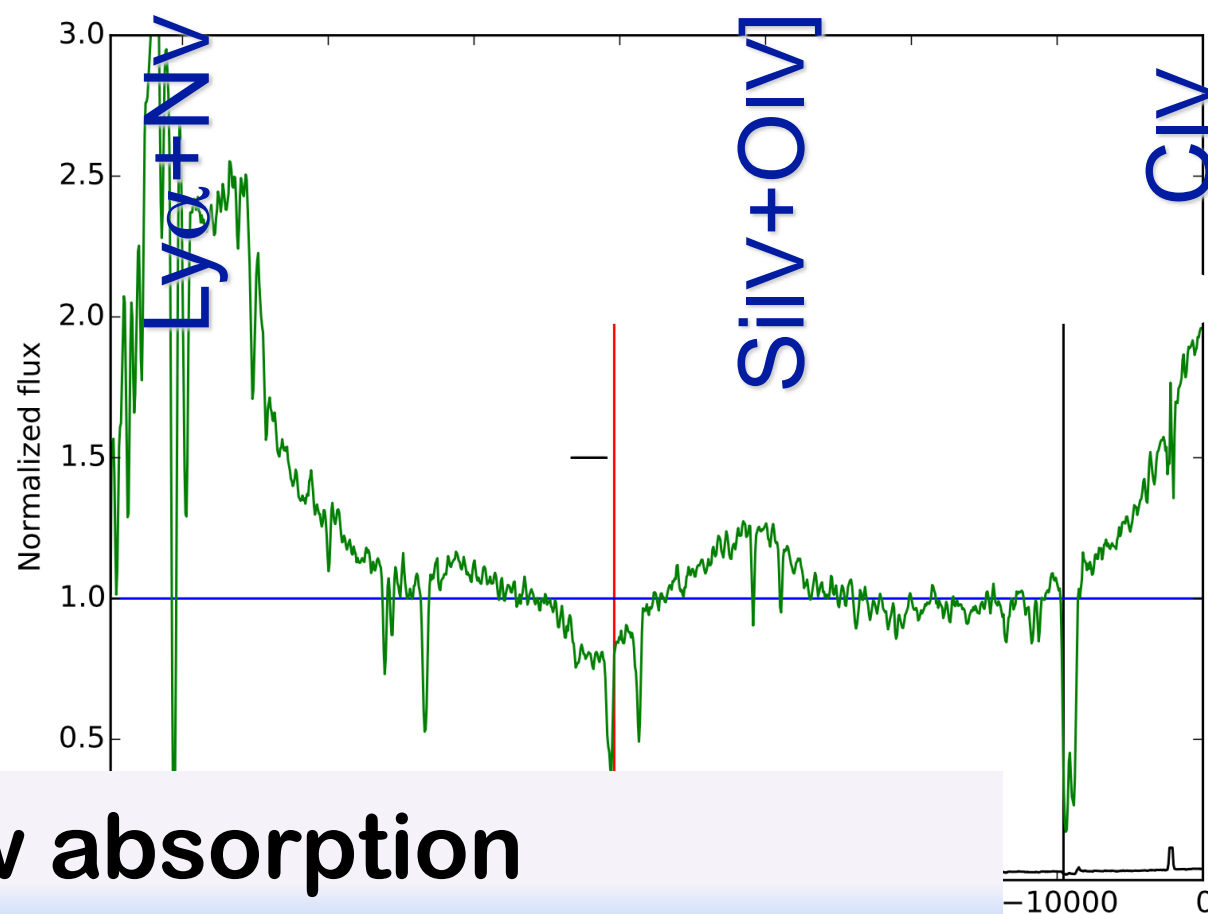
- Normalize all spectra with a simple power-law



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

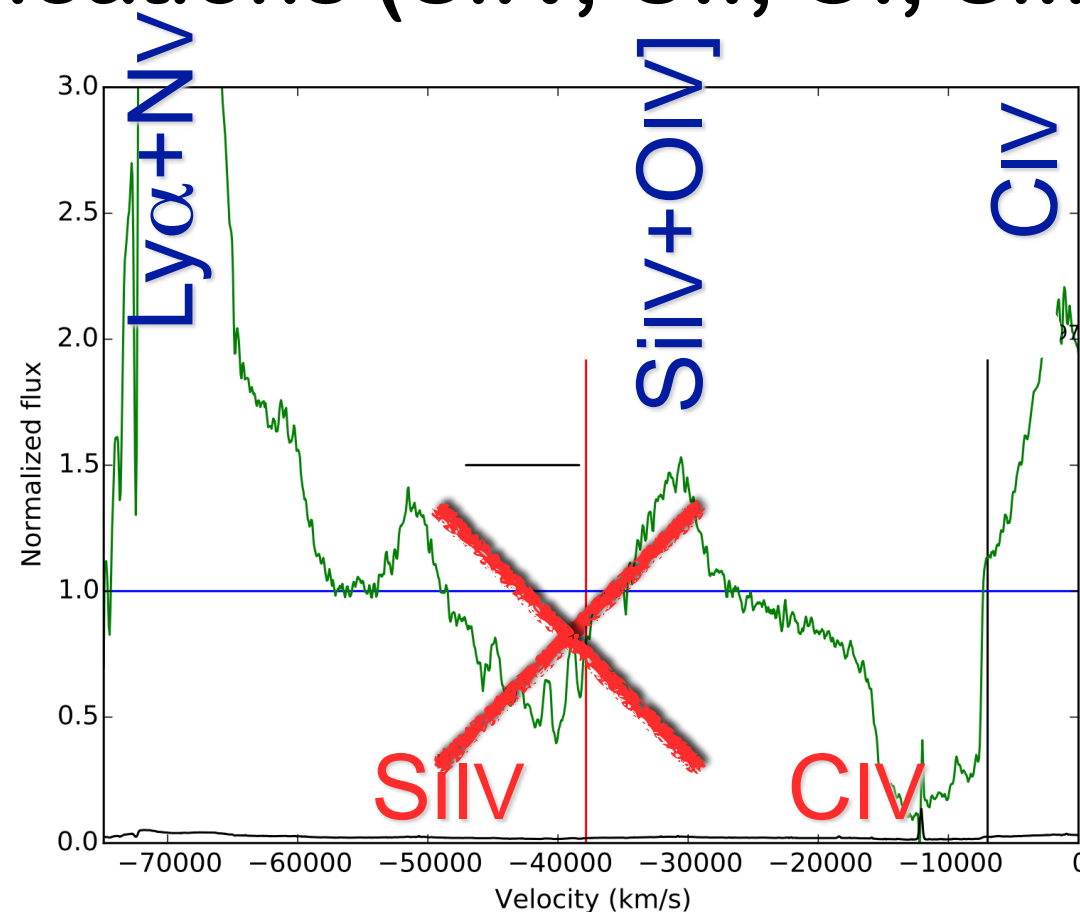


- miss shallow absorption
- miss absorption on top of emission

Searching for Extremely-high velocity outflows

6760 quasar spectra

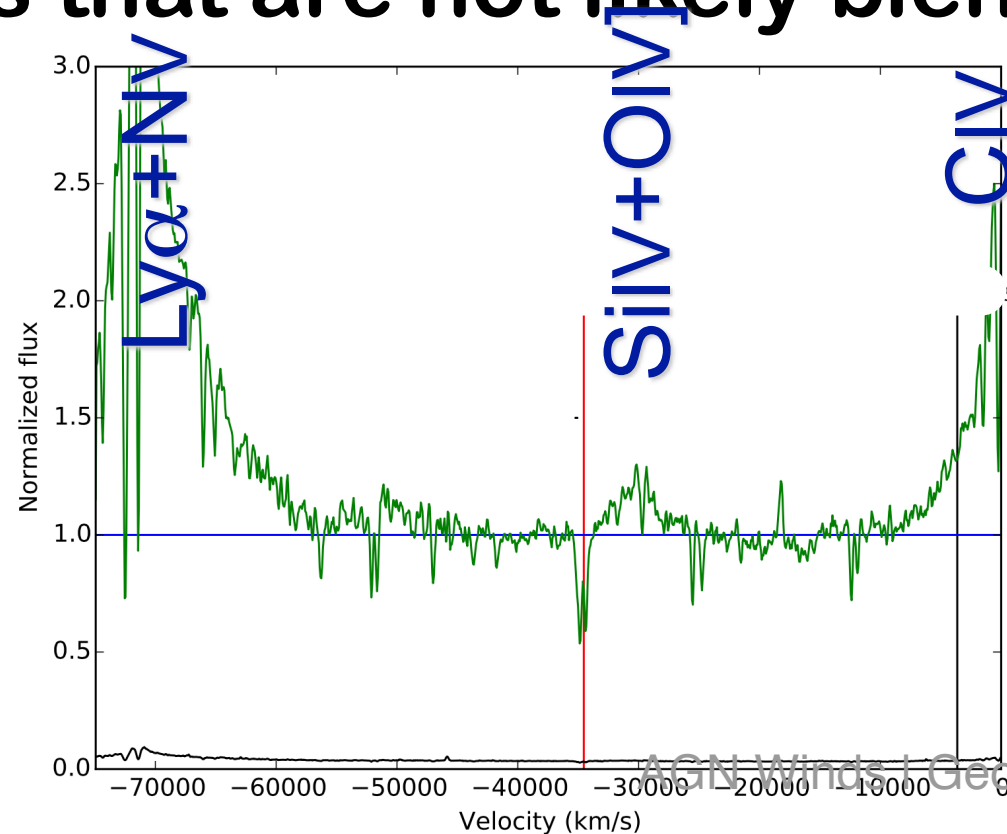
- Normalize all spectra with a simple power-law
- Identify absorption with width >1000 km/s
- Visually inspect every case and remove possible other identifications (SiIV, CII, OI, SiII...)



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

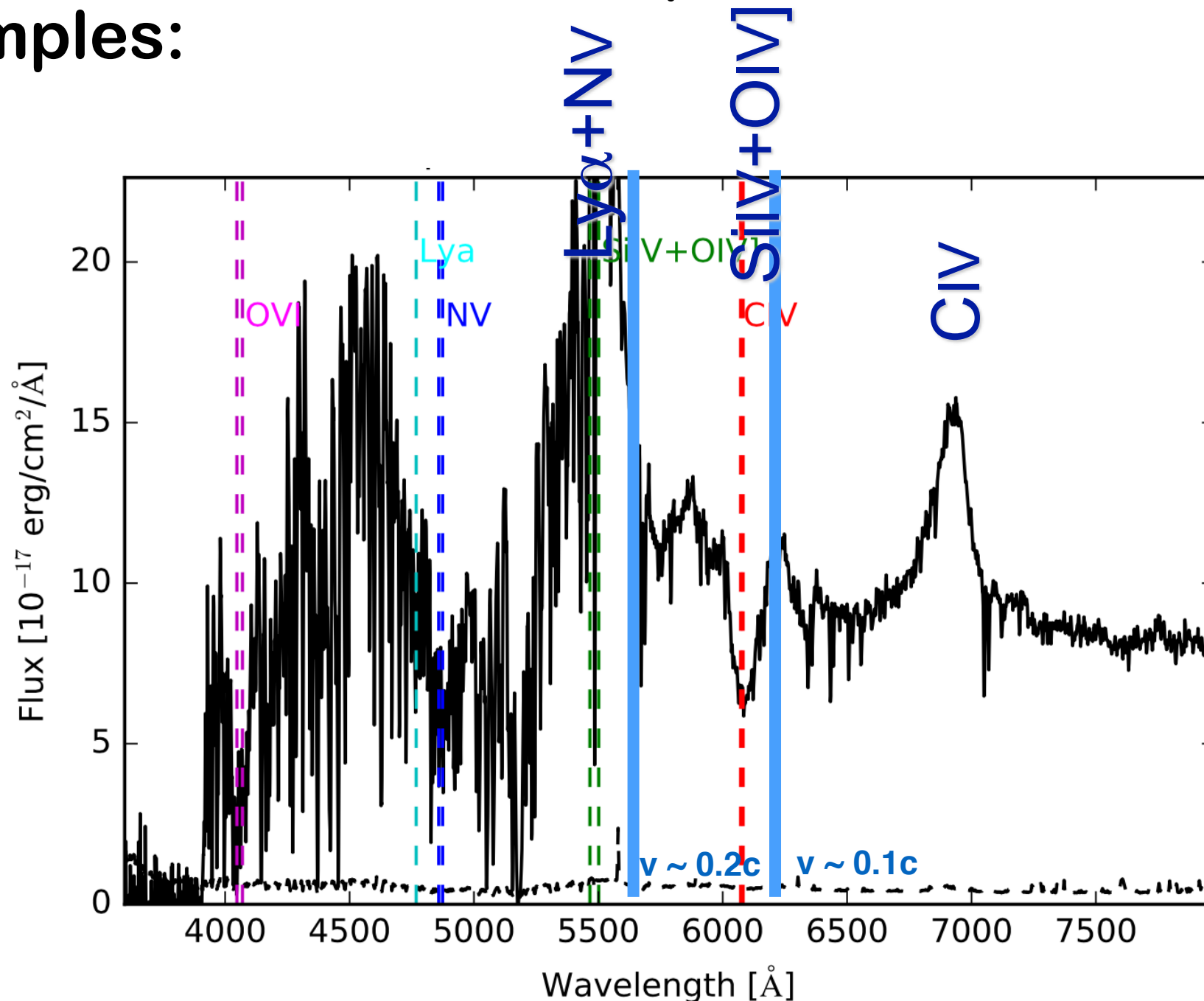
Just best and secured cases

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

Extremely High Velocity Outflows

45/6760 quasars found

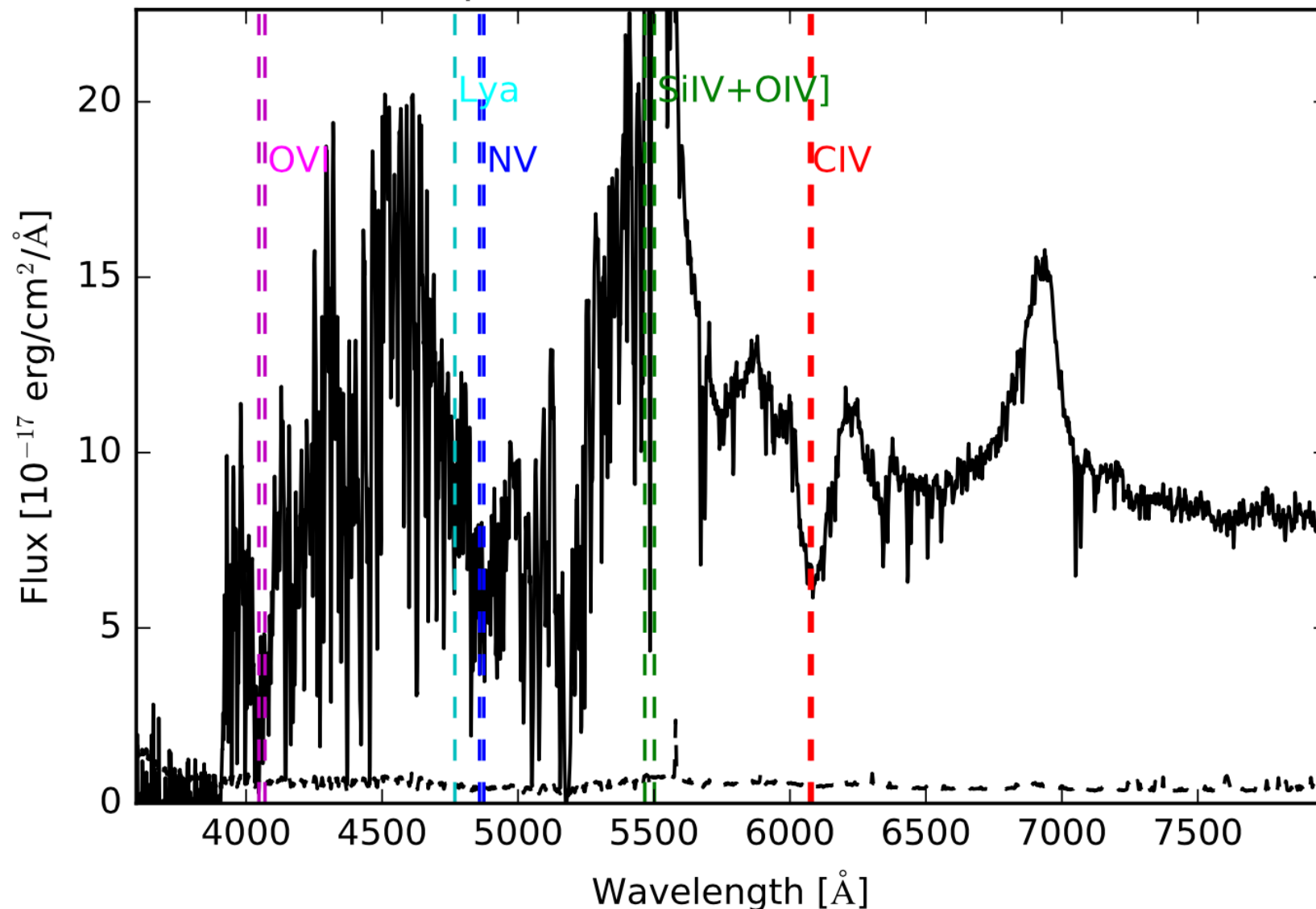
- Examples:



Extremely High Velocity Outflows

45/6760 quasars found

- Examples:

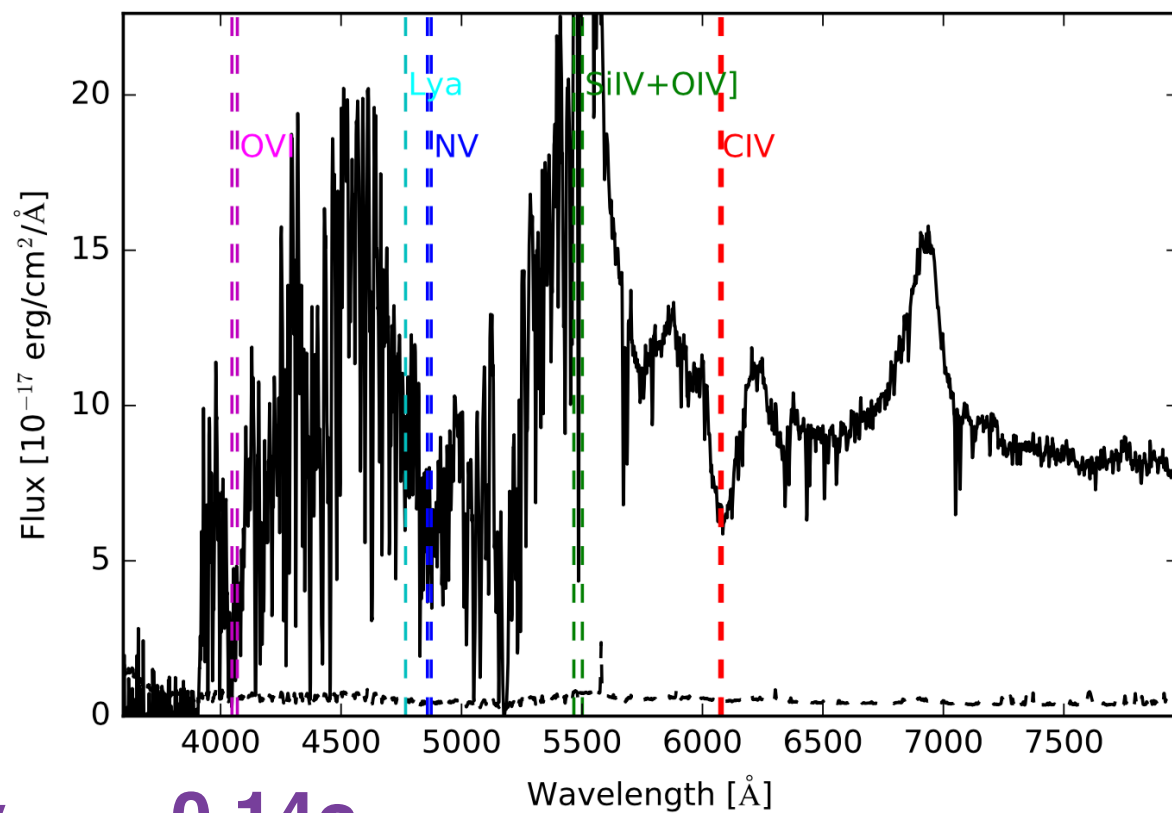


$v_{\text{max}} \sim 0.14c$

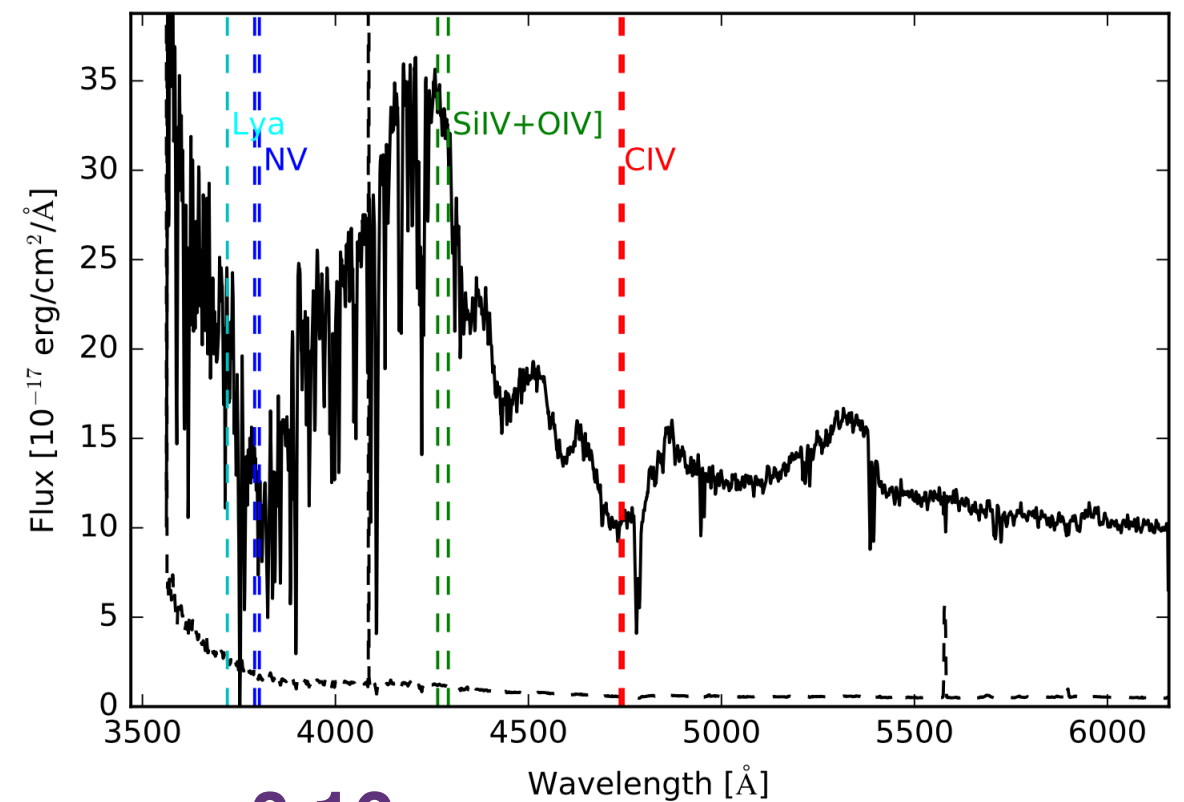
Extremely High Velocity Outflows

45/6760 quasars found

- Examples:



$v_{\max} \sim 0.14c$



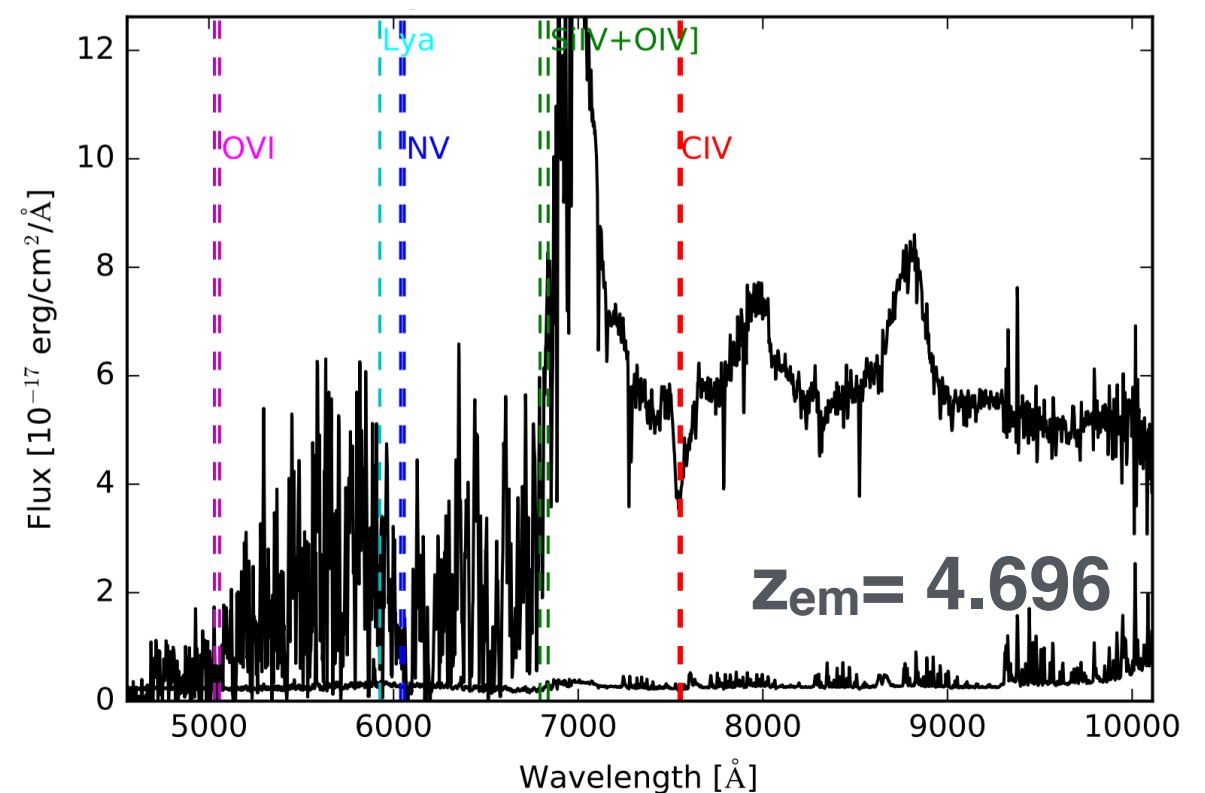
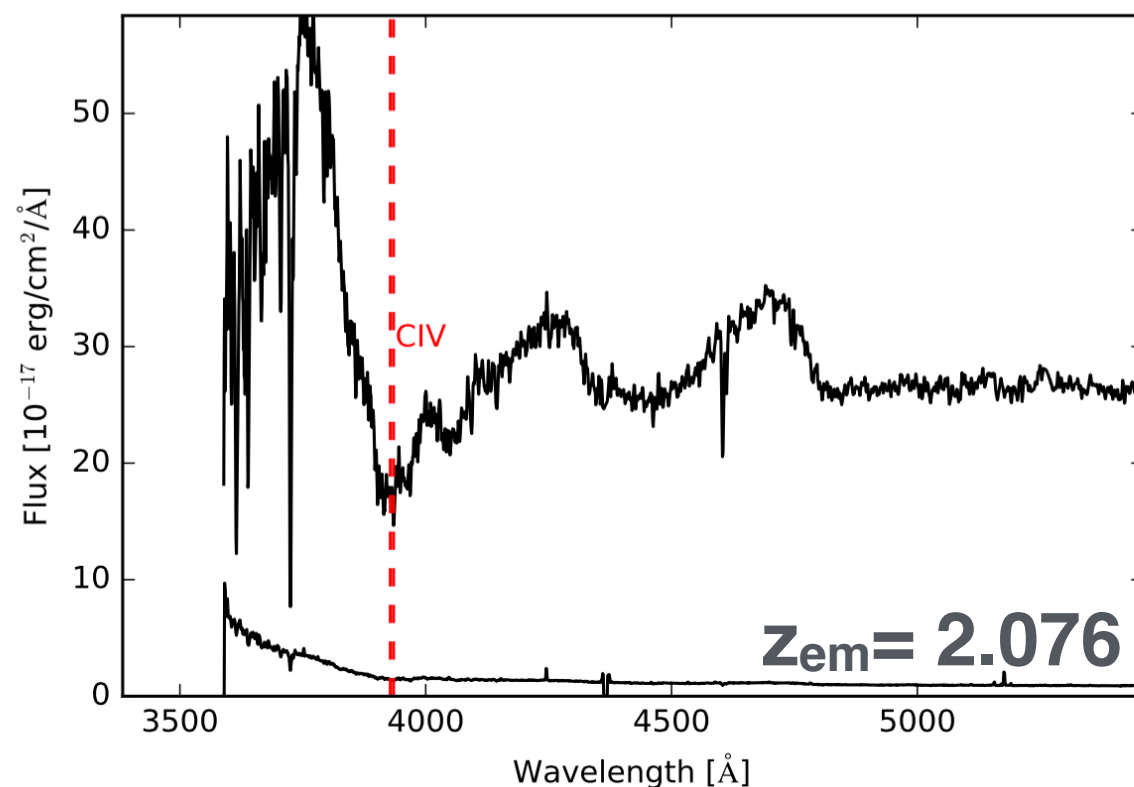
$v_{\max} \sim 0.16c$

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

Extremely High Velocity Outflows

45/6760 quasars found

- Examples:



$V_{\text{max}} \sim 0.20c$

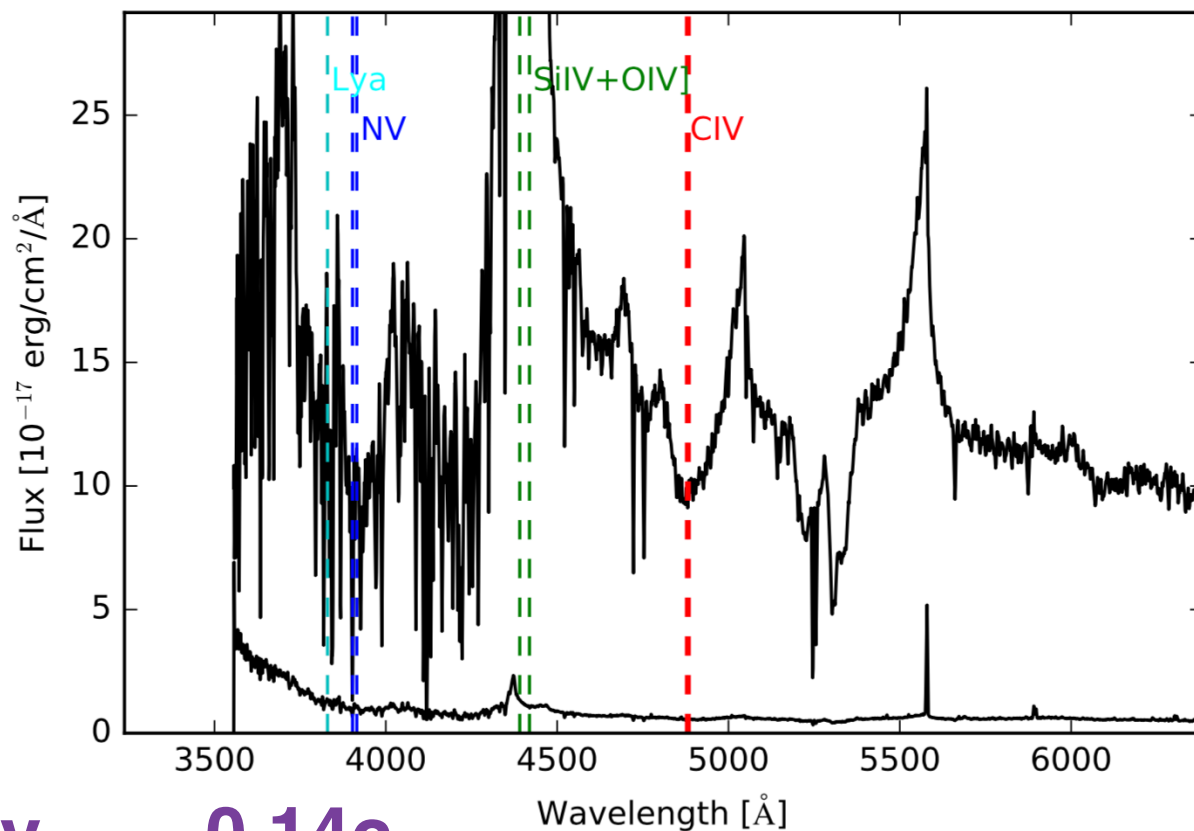
$V_{\text{max}} \sim 0.16c$

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

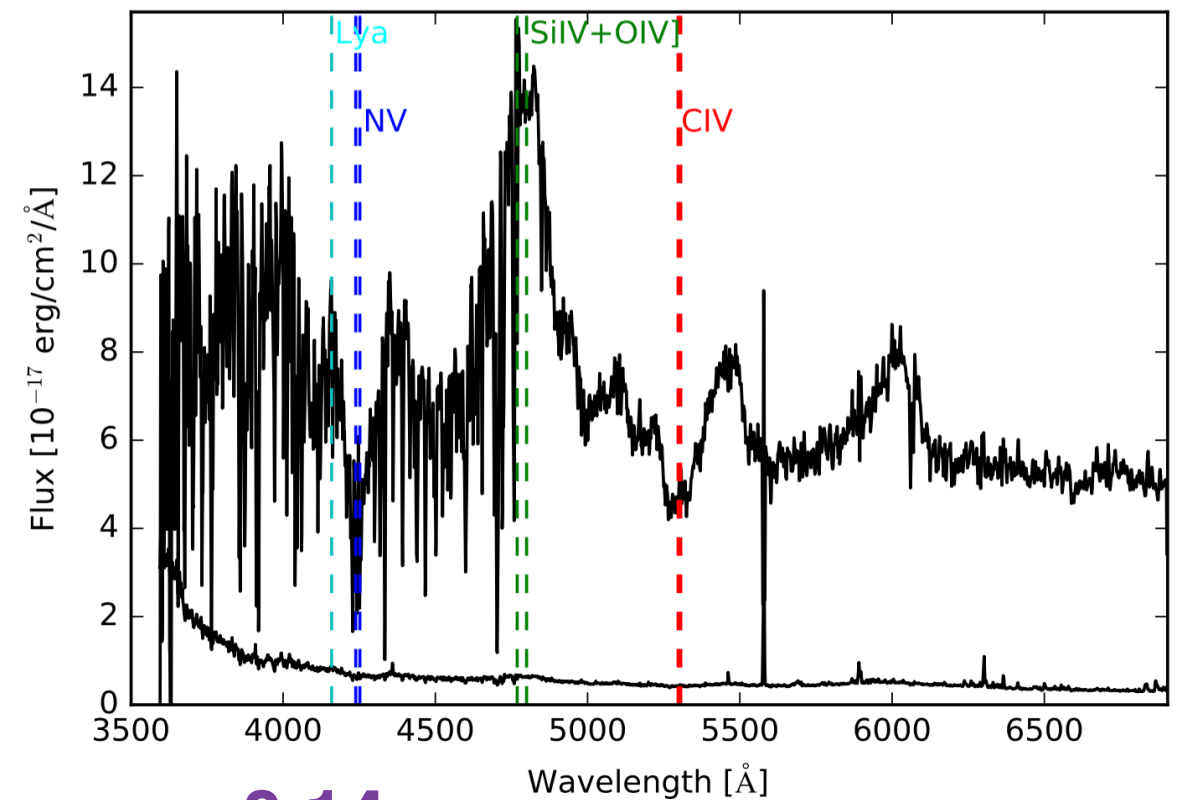
Extremely High Velocity Outflows

45/6760 quasars found

- Examples:



$v_{\max} \sim 0.14c$



$v_{\max} \sim 0.14c$

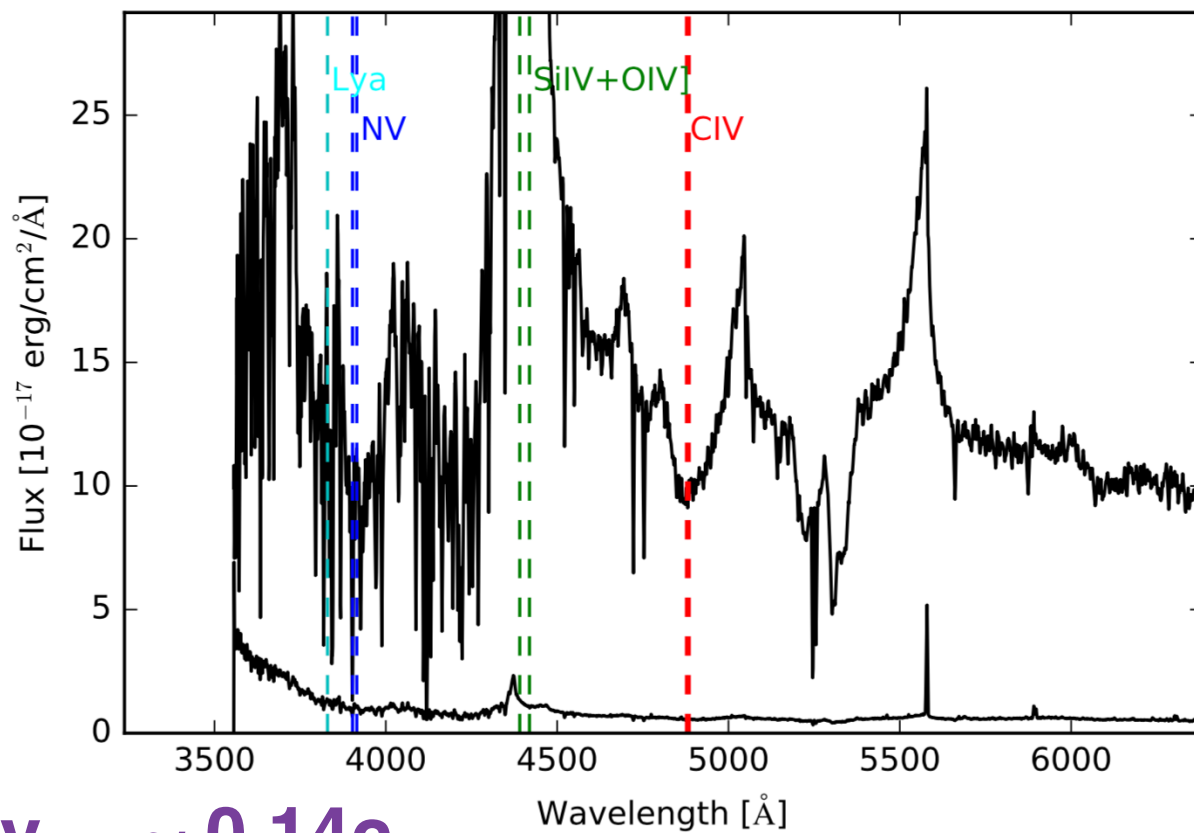
NV always present when strong CIV and typically seems stronger; OVI probably too

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

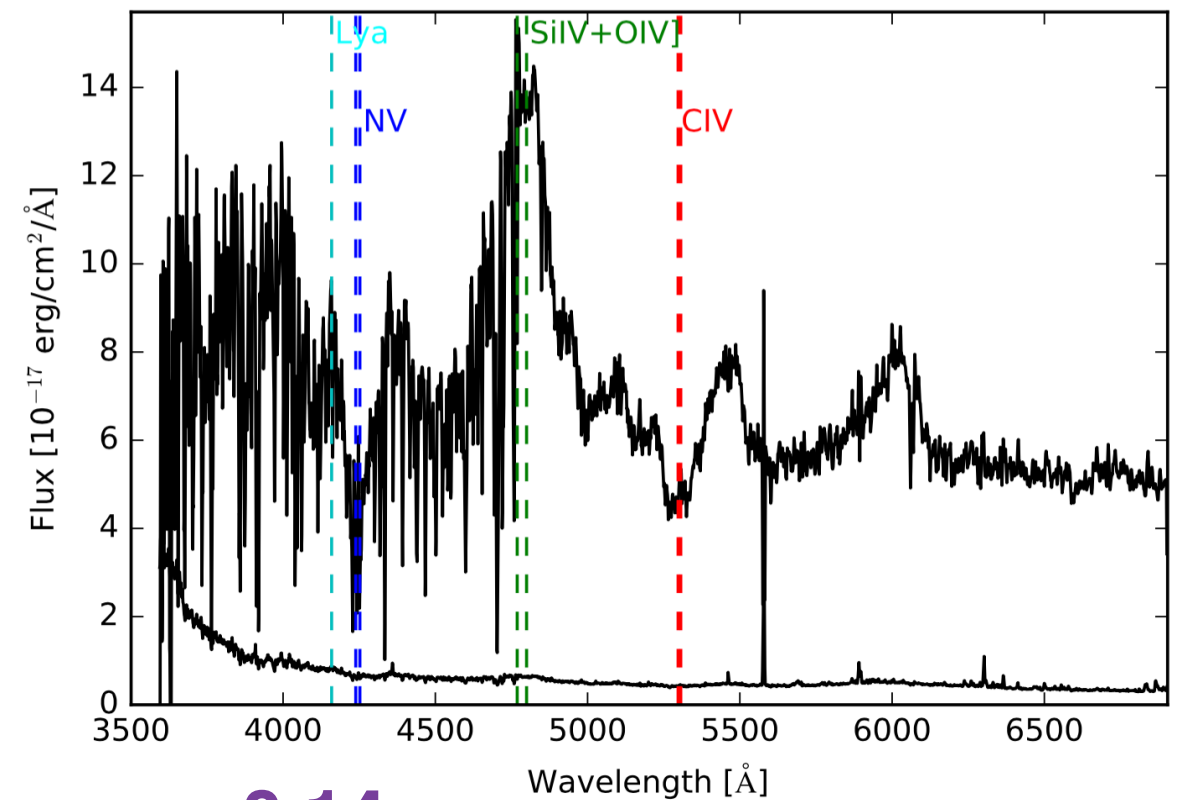
Extremely High Velocity Outflows

45/6760 quasars found

- Examples:



$v_{\max} \sim 0.14c$



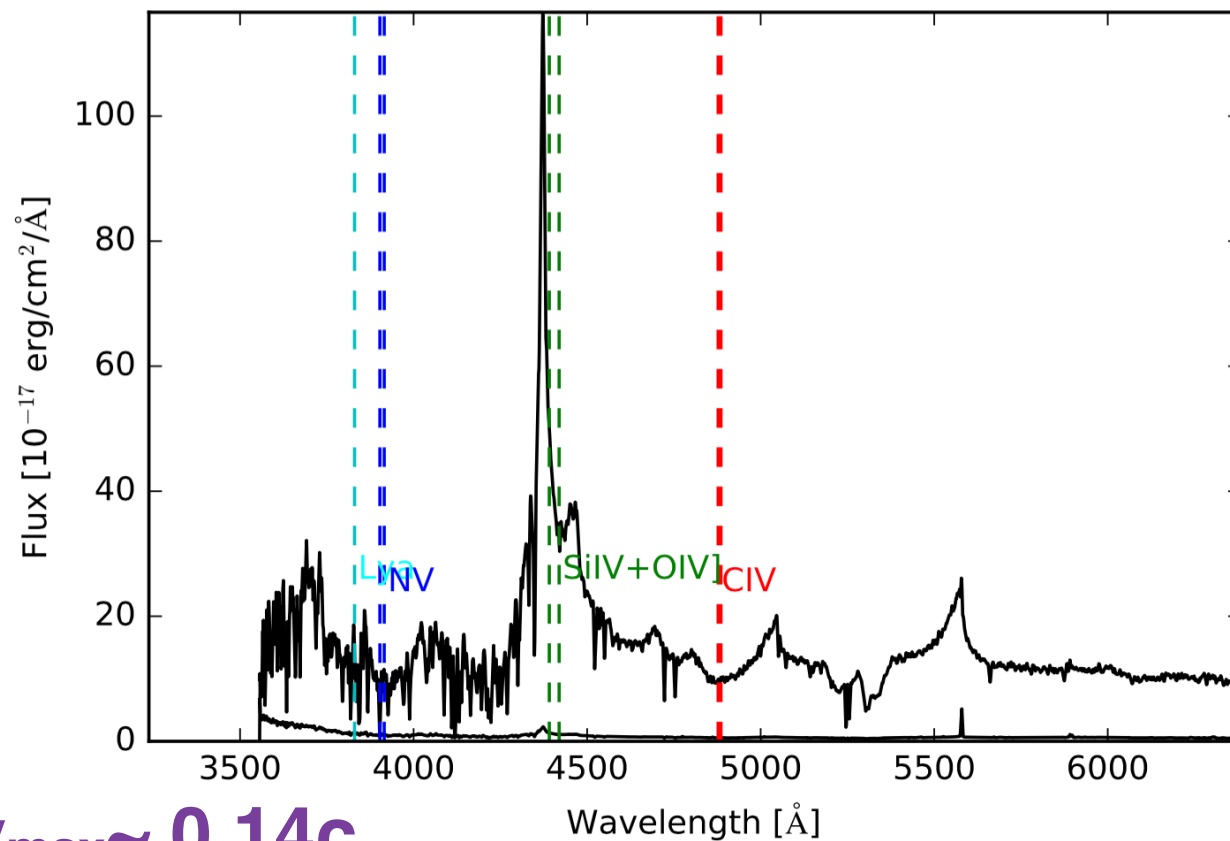
$v_{\max} \sim 0.14c$

No Ly α stronger than NV in any case

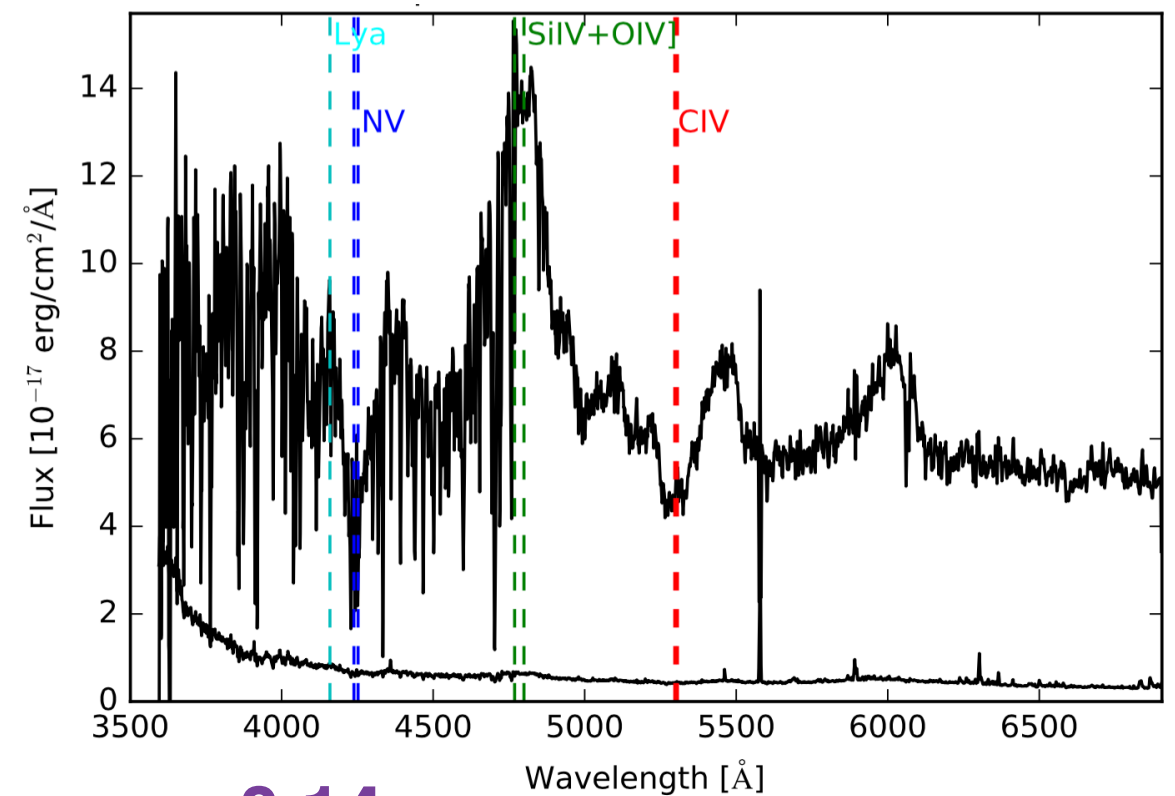
Extremely High Velocity Outflows

45/6760 quasars found

- Examples:



$v_{\max} \sim 0.14c$



$v_{\max} \sim 0.14c$

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

Extremely High Velocity Outflows

- **Constraints for theoretical studies:**

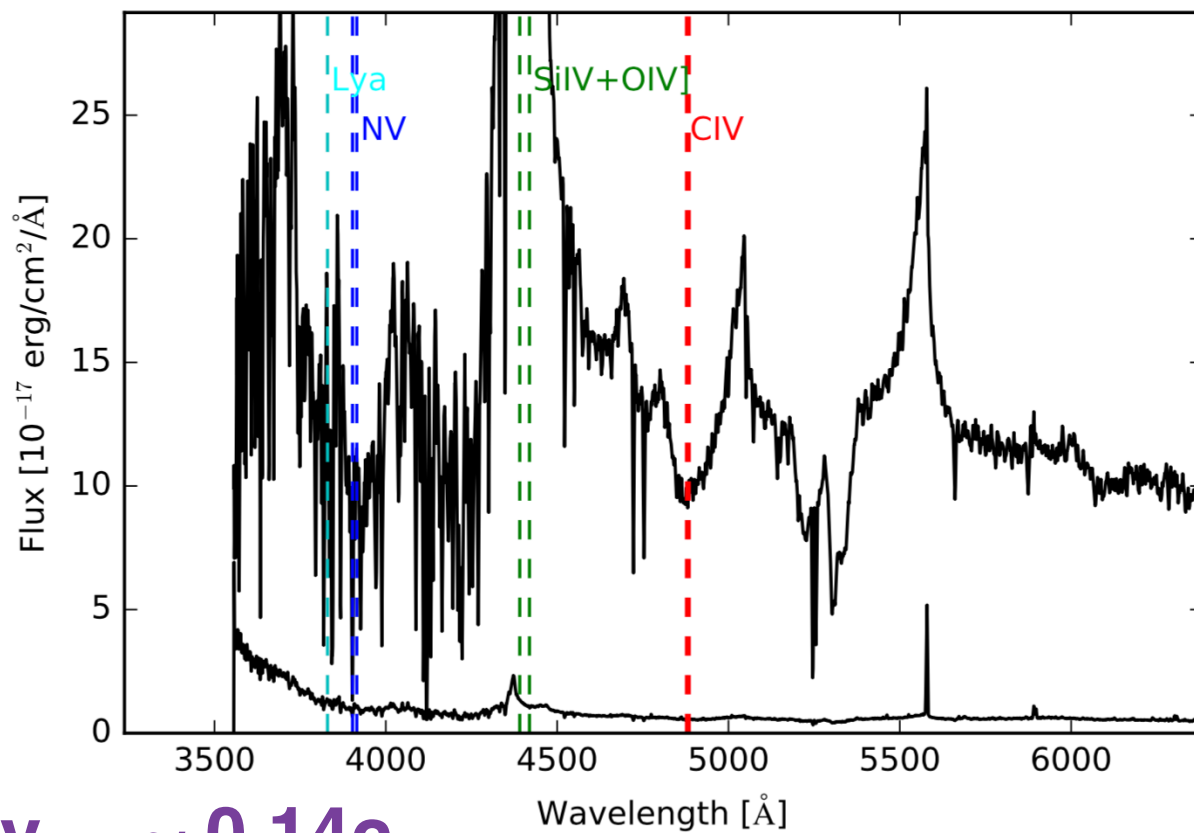
- 1) **What we find:**

- **NV always present when strong CIV and typically seems stronger; OVI probably too**
 - **No Ly α stronger than NV in any case**
 - **SiIV doesn't seem to be present but(!) on top of Ly α +NV emission line**
 - **Similar radio-loudness ratio than lower velocity BALs (6 \pm 2%; 3/45 cases have FIRST detections)**
 - **Typically* smaller depths than lower velocity BALs**
 - **smaller coverage fractions?**

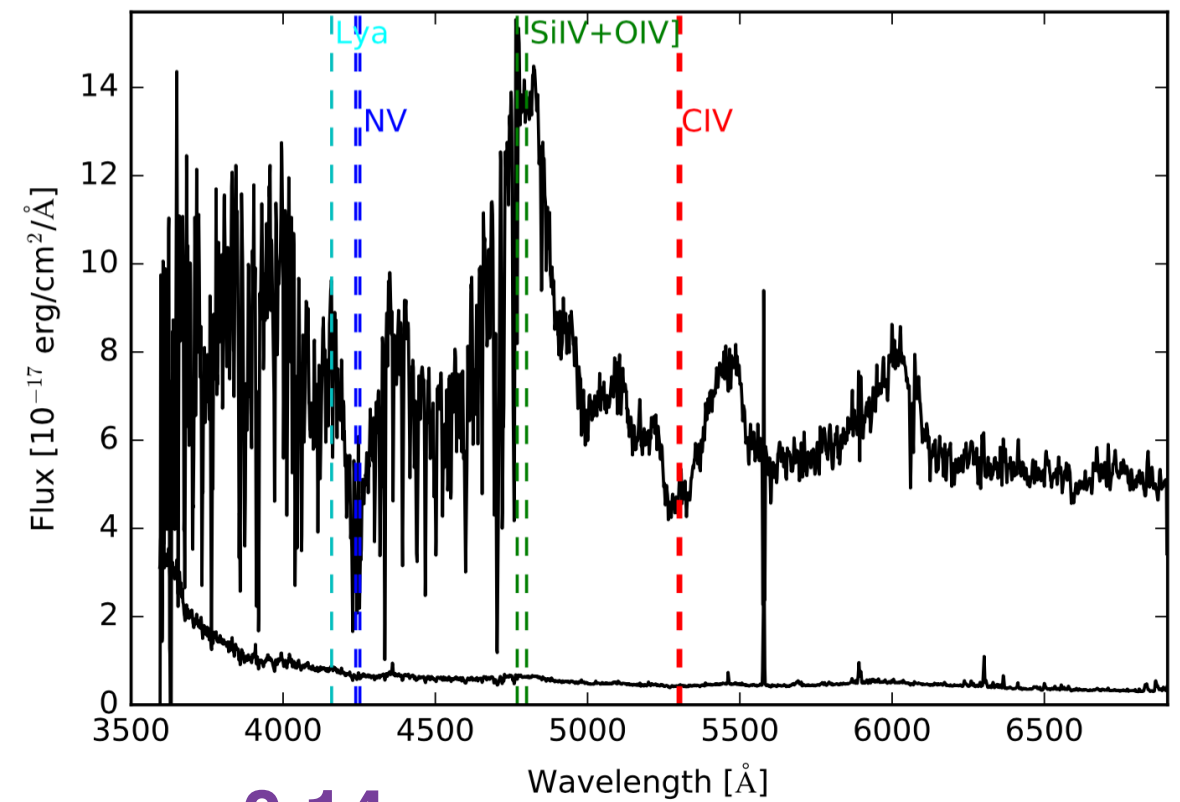
Extremely High Velocity Outflows

45/6760 quasars found

- Examples:

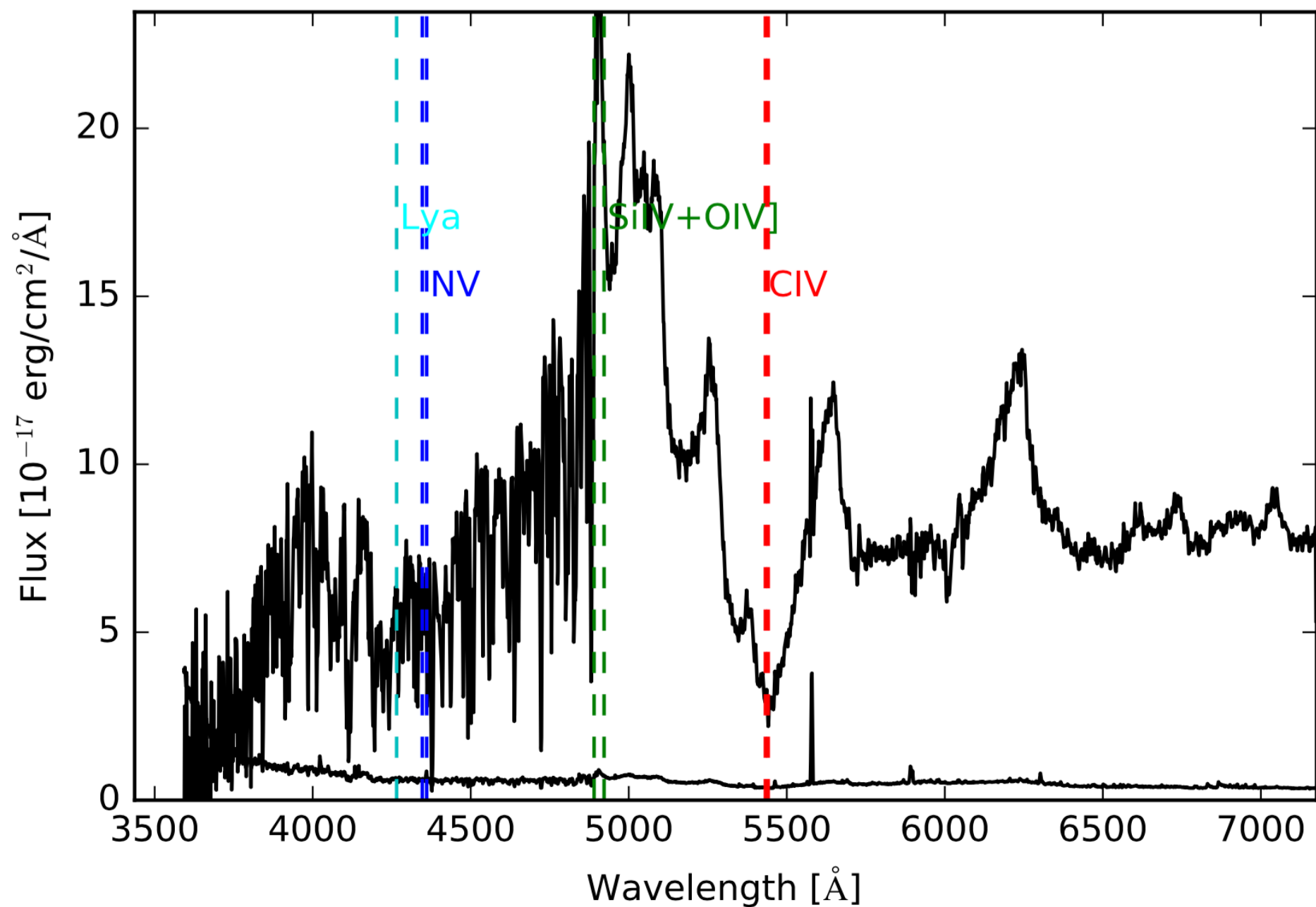


$v_{\max} \sim 0.14c$



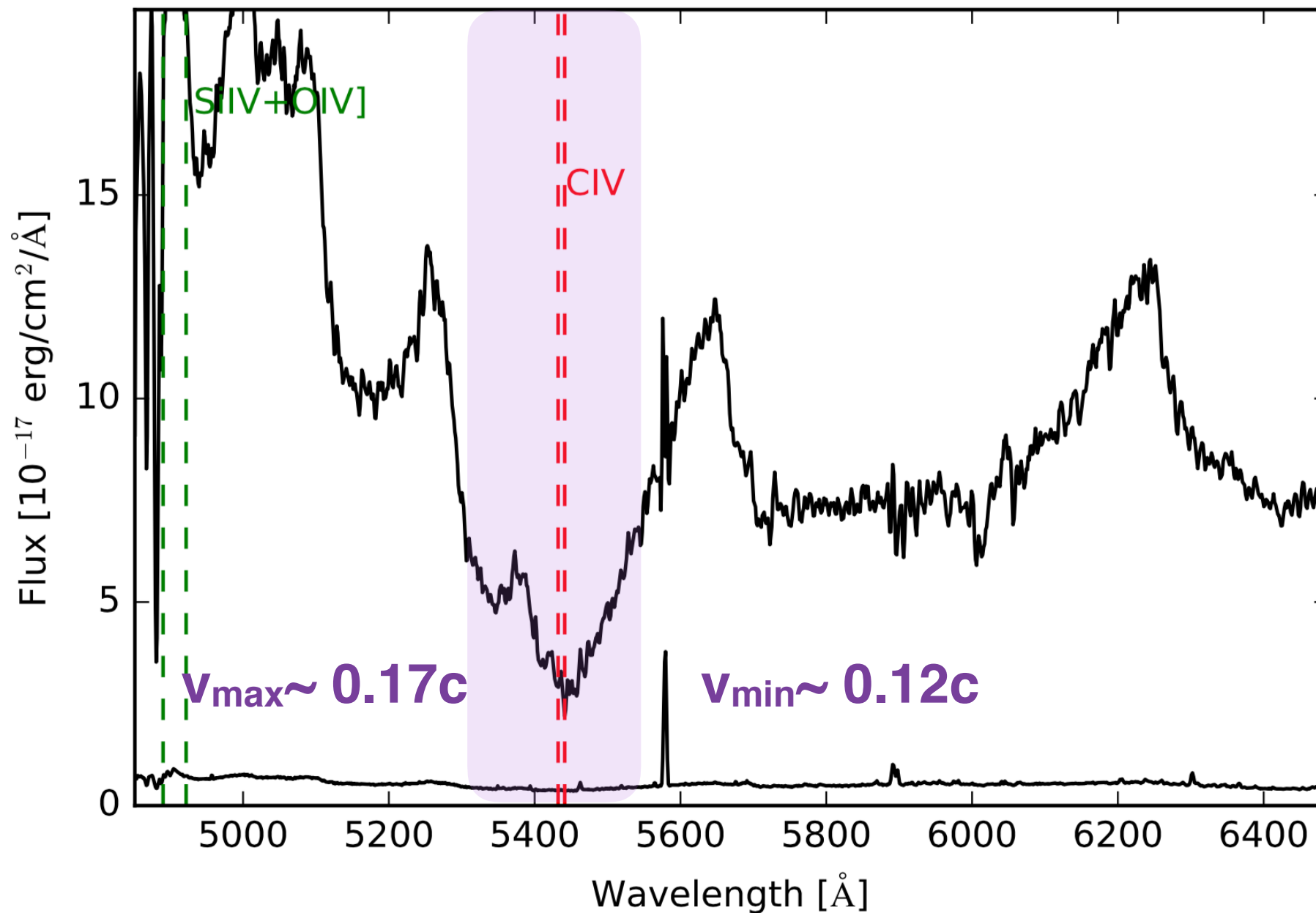
$v_{\max} \sim 0.14c$

Extremely High Velocity Outflows



Fast and Furious

Strong BAL at v



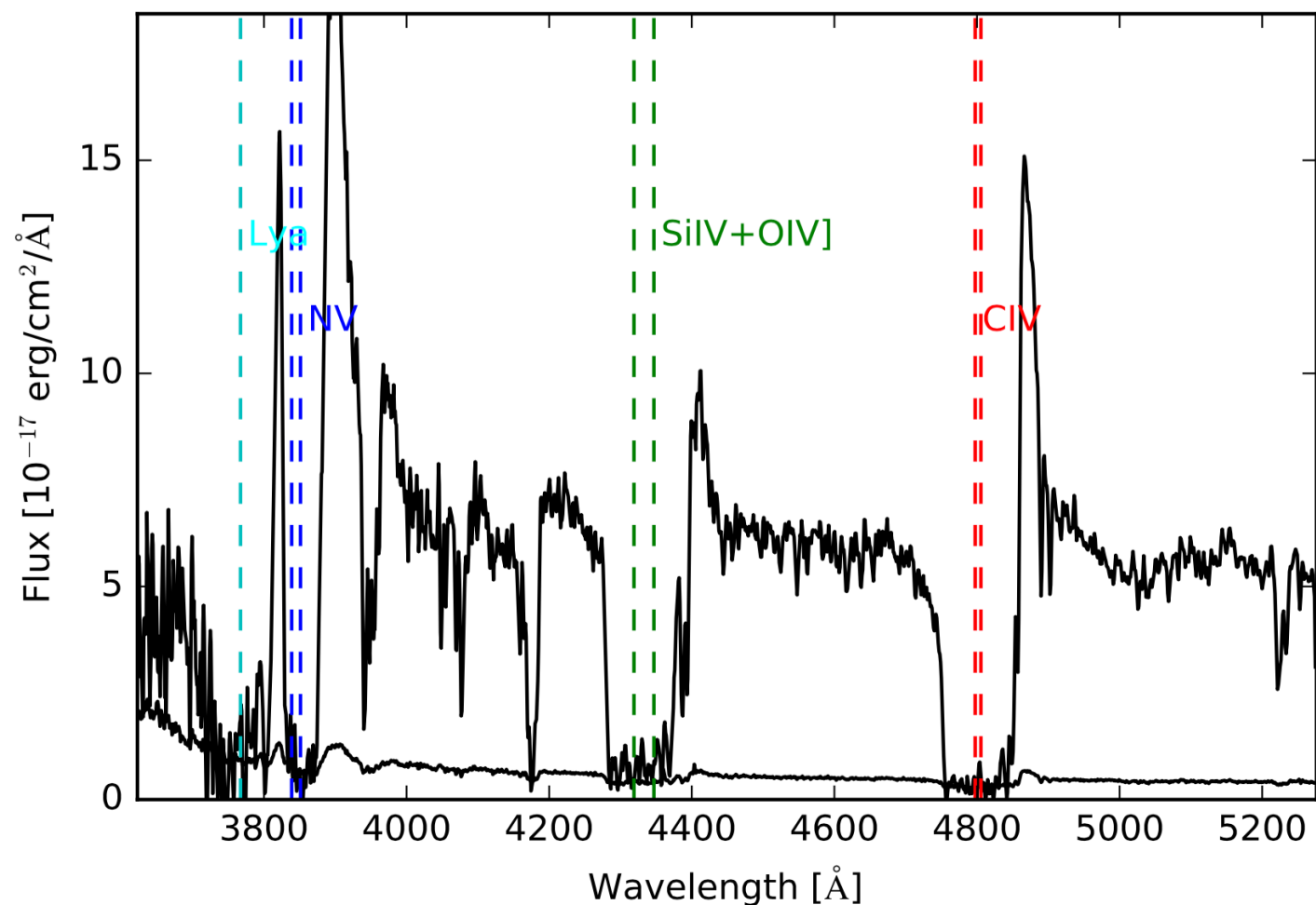
Extremely High Velocity Outflows

- 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

db Queries Search

Data Access: EHVO-I Survey of SDSS DR9Q

[View EHVO-I DR1 Catalog](#)

This catalog presents the results of spectrum analysis carried out on a sample set of quasars from Sloan Digital Sky Survey Data Release 9 (SDSS DR9). Our methodology, data sources, and catalog access is detailed below.

1. Methodology

The first step in generating our survey was applying a filter set to our data. The filtering criteria and data sets used are explained in detail below, in Section 2. After filtering we passed our spectra off to a program we wrote to do the actual spectrum analysis. First, our spectra were normalized using a powerlaw fit. After fitting, the spectra were smoother using a 3 point boxcar algorithm. Finally, a balnicity index was calculated for each spectra. Once our program was finished we visually inspected each spectra to remove false positives.

2. Data Sources and Selection Criteria

Our spectrum analysis was carried out using spectra from SDSS DR9. We selected candidate spectra from SDSS DR9's Quasar Catalog (Paris et al.) using two main criteria. First, we limited our search to spectra with a signal-to-noise ratio (S/N) ≥ 10 . This was done because we found that BAL features were difficult to distinguish from noise in samples with lower S/N. We also filtered for redshift (z) ≥ 1.9 . This was done to shift CIV features into SDSS's spectral coverage range. From our filtering criteria we ended up with 6760 candidate spectra.

We also present data from value added SDSS catalogs: DR9Q and DR7Q.

DR9Q contains both data calculated by Paris et al. 2012 and VLA Faint Images of the Radio Sky at 20-cm (FIRST) radiometric data where available. This was the data set we used to generate our survey. More information about DR9Q can be found [here](#).

DR7Q contains data calculated by Shen et al. 2011. More information about DR7Q can be found [here](#).

3. Data Access

This catalog presents the results of our EHVO survey of SDSS DR9Q, as well as other related data sources. At its base, each entry contains DR9Q data, with EHVO-I and DR7Q data where available. Data can be accessed either through this web interface, or a REST API using both manual and templated queries. Additionally, the web interface provides links to data associated to each sample on SDSS's main sites for DR9 and DR7, where available.

Extremely High Velocity Outflows

(For theoretical and non-theoretical people:)

We have made a database of these **EHVO** objects

Ready by Fall 2017 — *Stay tuned!*

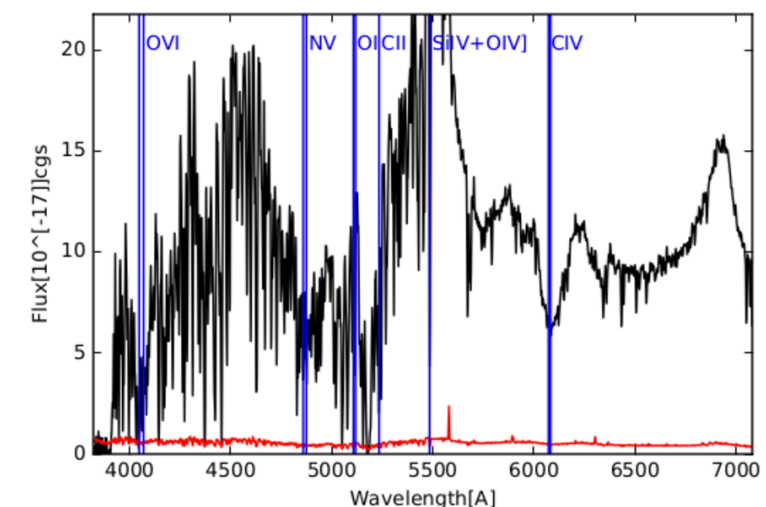
z_em (z_PCA)	
3.417	121.356384
2.584	145.098163
2.001	212.328013
4.691	253.653559
2.468	259.501636
2.648	187.200906
2.691	181.540379
2.63	109.681265
3.491	187.734541
2.606	220.984209

Showing 11 to 20 of 45 entries

BAL Data

Field	Value
vMax [km/s]	-43135.7035
vMin [km/s]	-37846.0163
Individual EW [km/s]	1377.5742
BAL depths	0.4437
Individual BI	1204.5664
BI total	1204.5664

Spectrum Plot



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

DR9Q Data

View SDSS: [Spectrum](#) [Object](#)

Field	Value
-------	-------

View SDSS: [Spectrum](#) [Object](#)

Field	Value
-------	-------

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 $\sim 50 \text{ \AA}$ missing	+ 7
• # AGN used (currently)	27

Extremely High Velocity Outflows at low z?

0*/27 AGN show EHVO

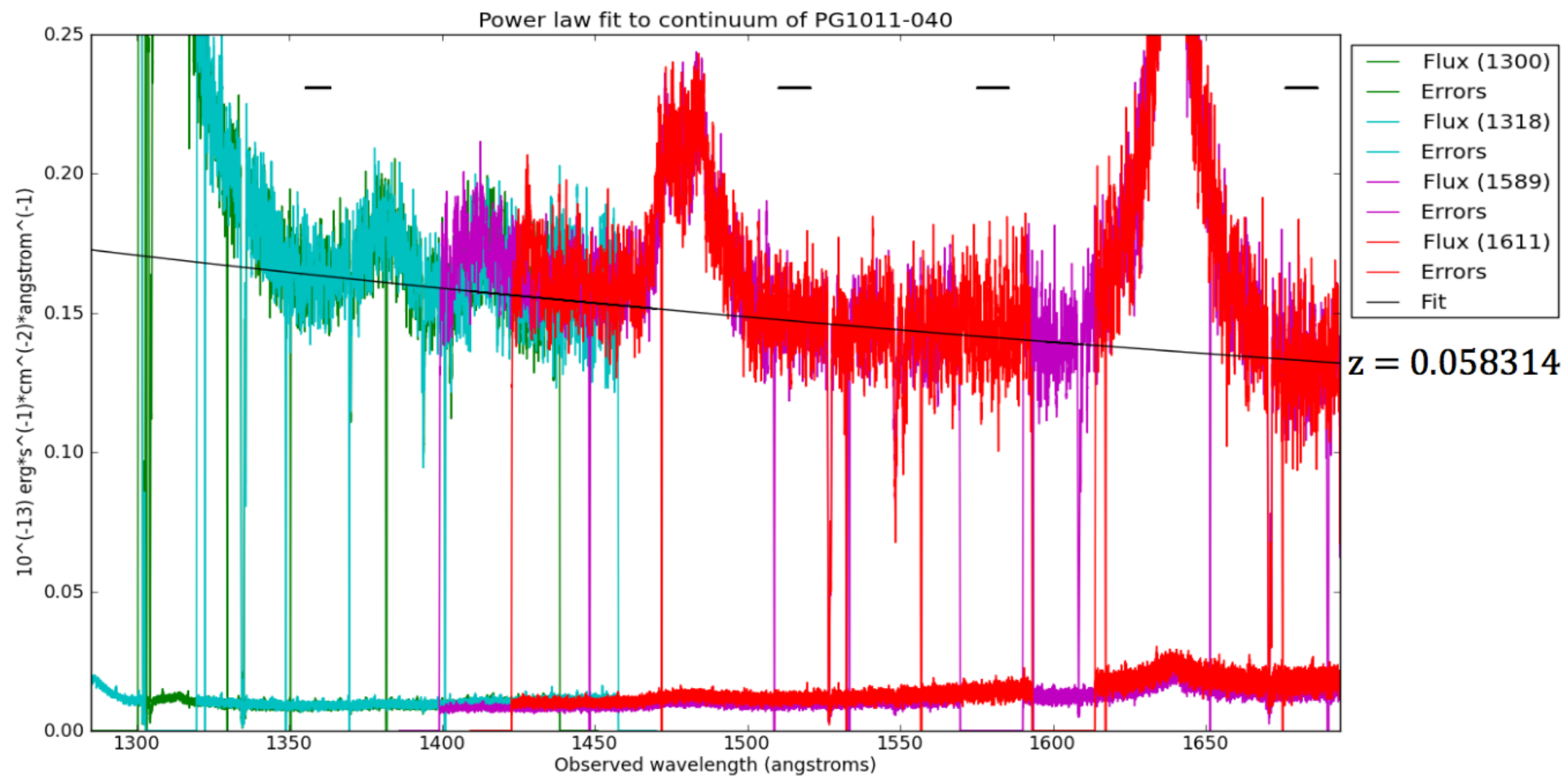
Sample of 27 AGN

AGN name	Redshift	Magnitudes (B; M _v)	AGN name	Redshift	Magnitude (B; M _v)
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)

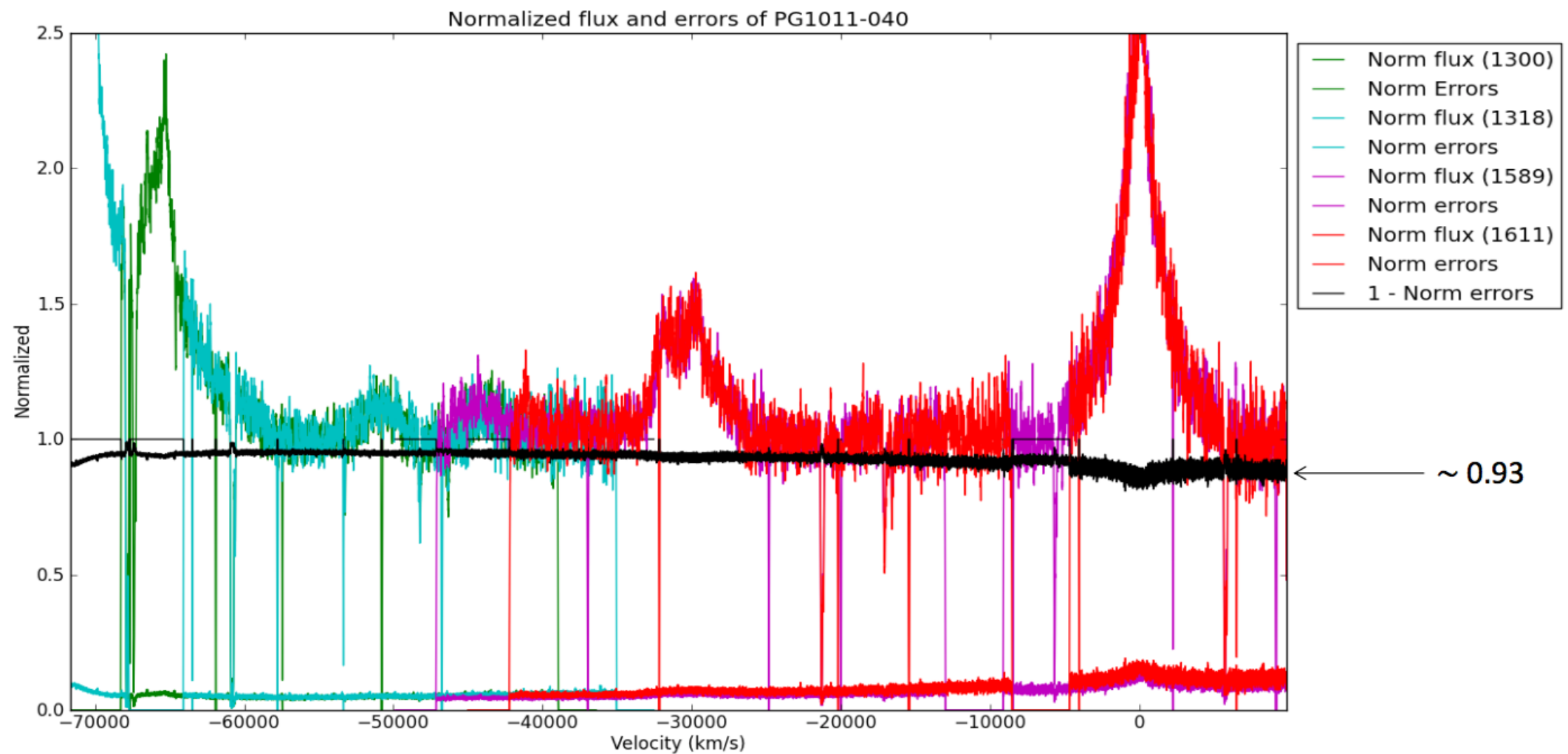
Extremely High Velocity Outflows at low z?

Example spectrum: PG1011-040



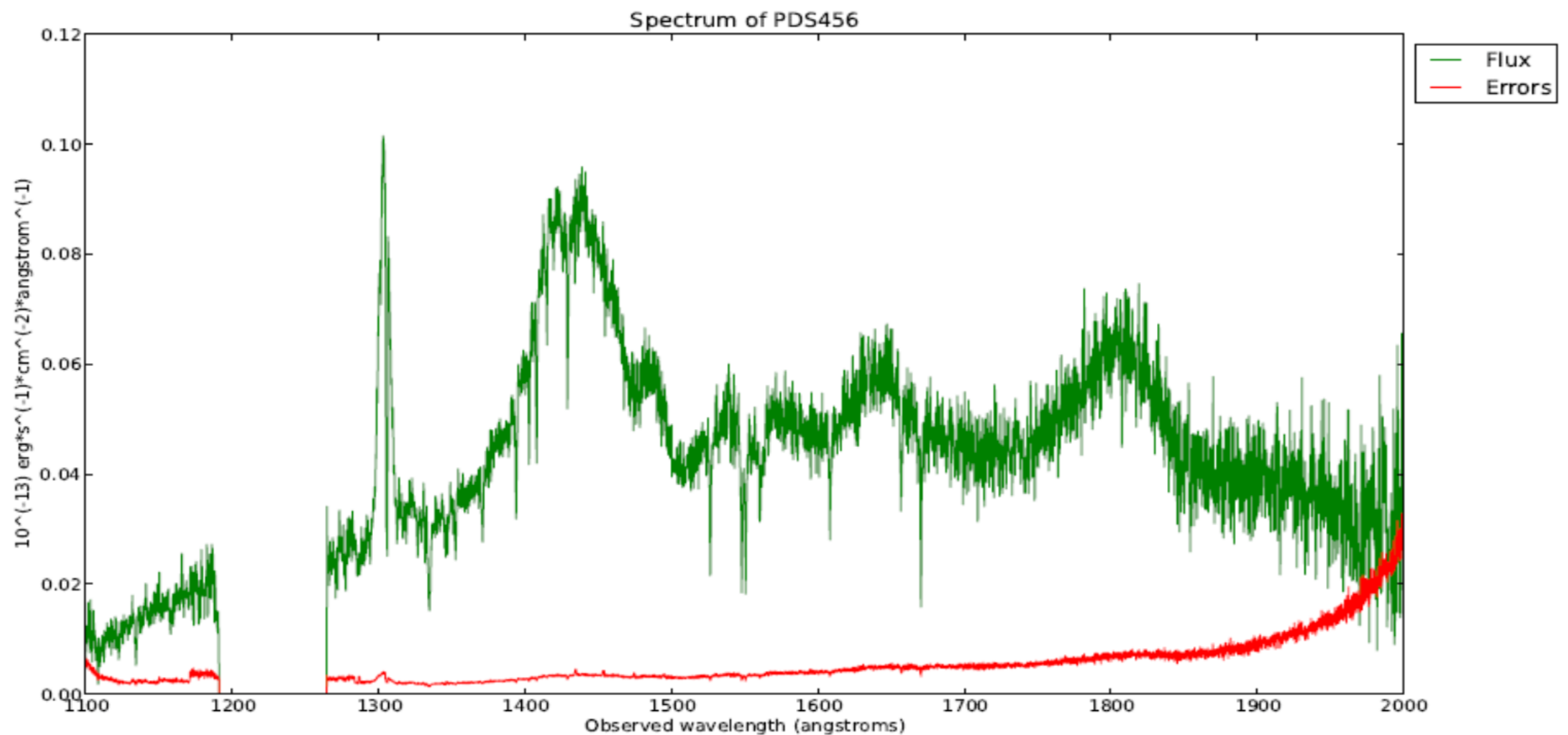
Extremely High Velocity Outflows at low z?

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**

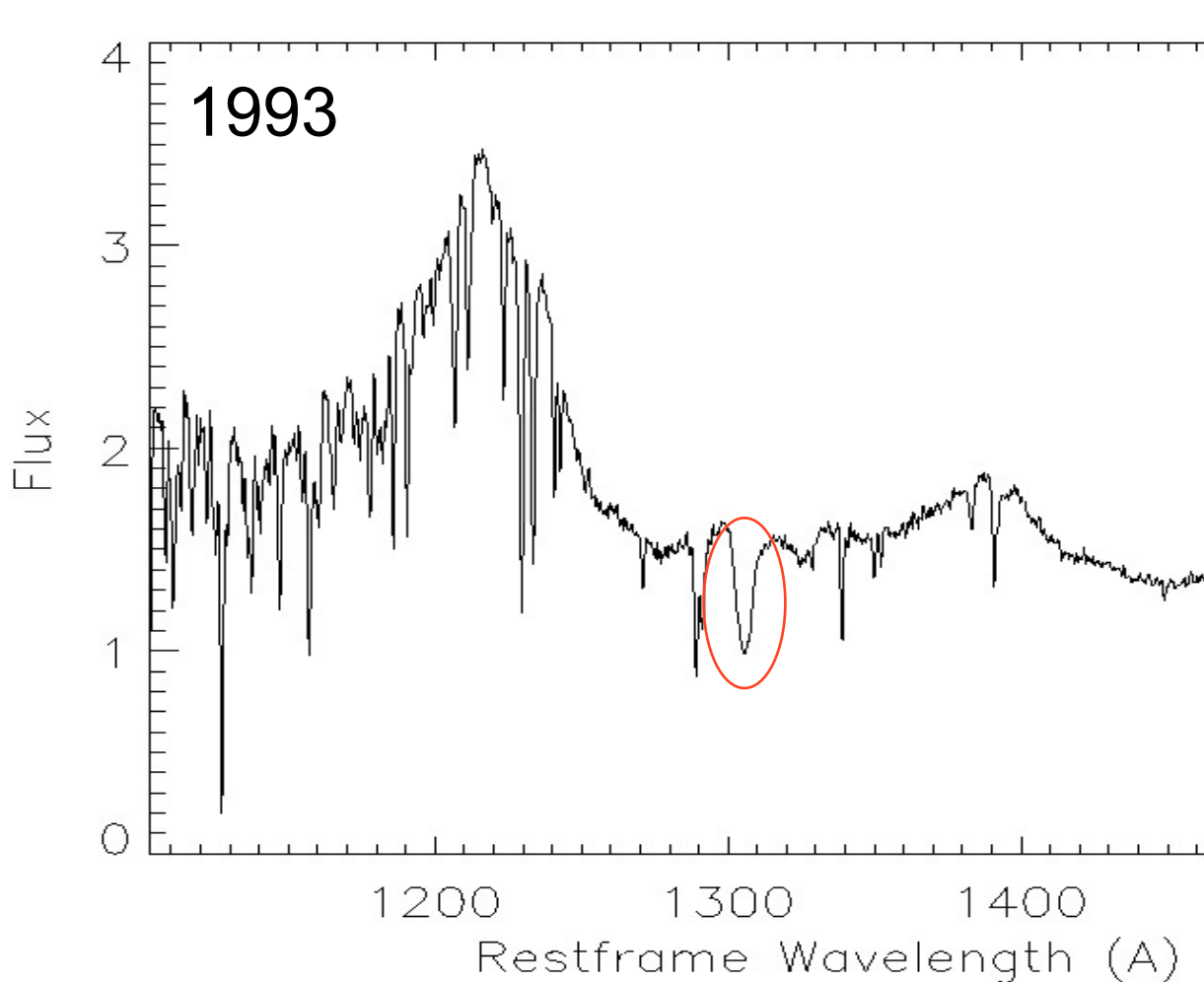
We are probing a significant population of particular bins of the parameter space

Extreme Variability

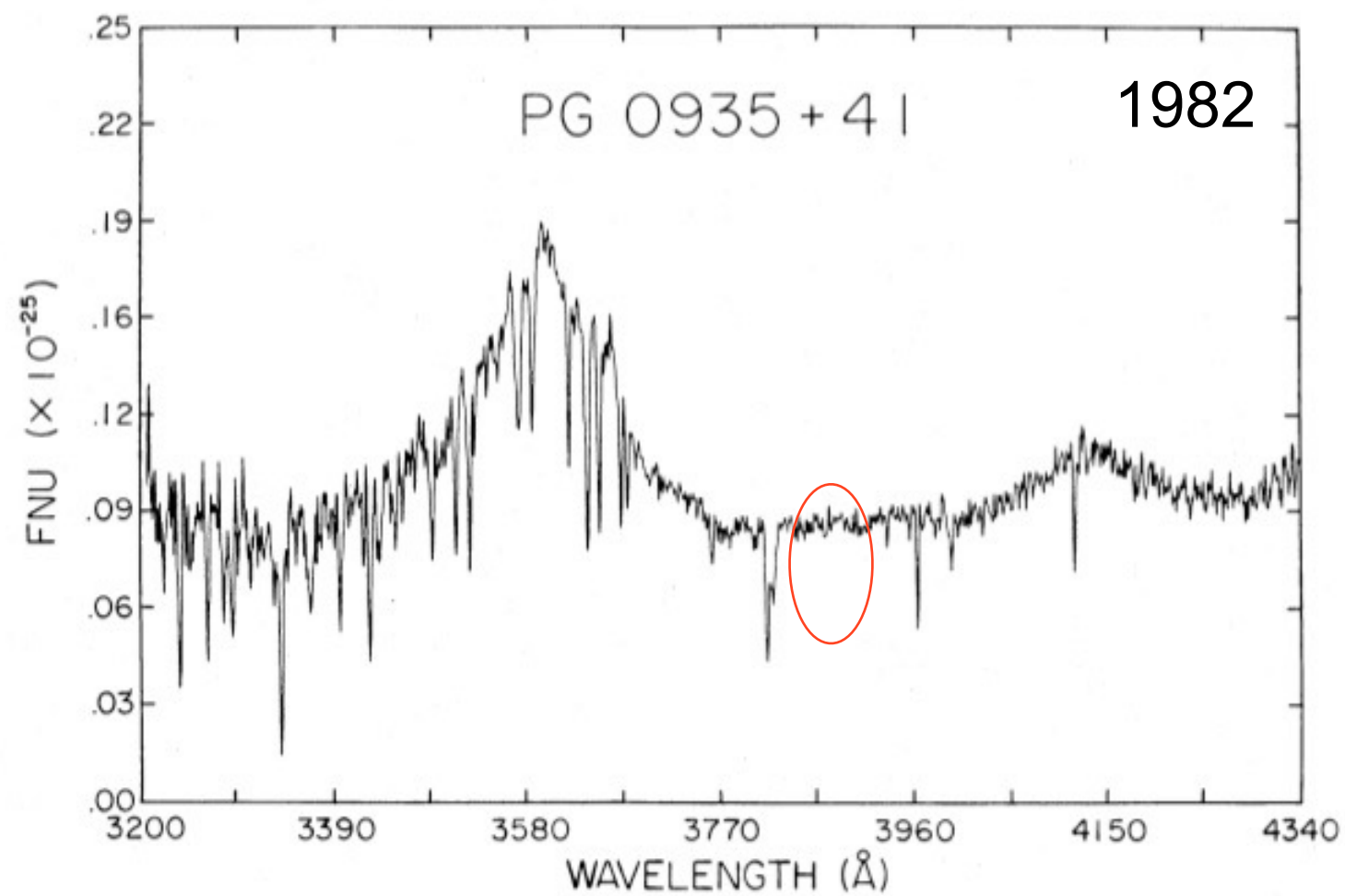
But absorption lines tend to *vary* often!

Extreme Variability

Study case of PG0935+417



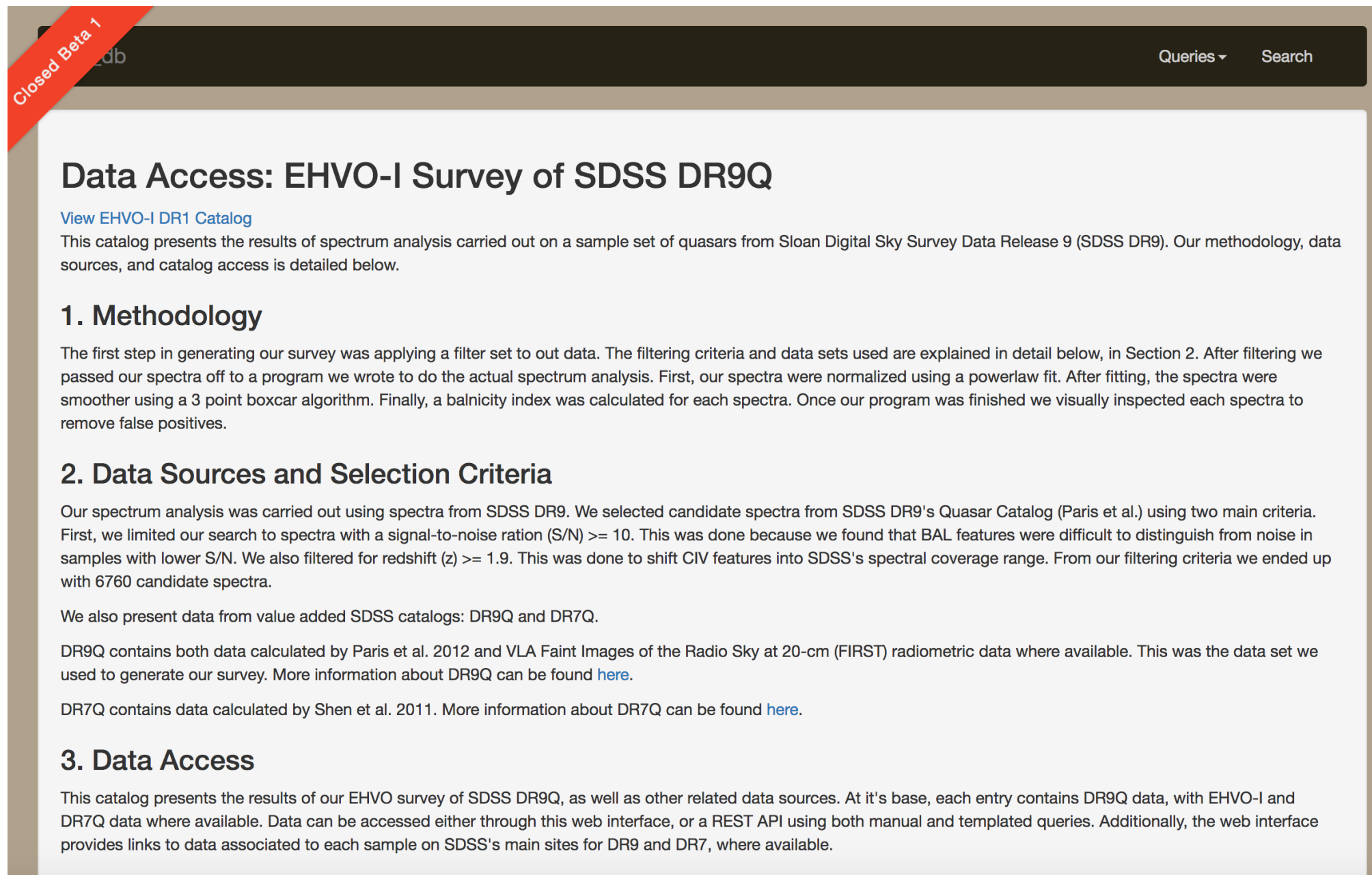
(Hamann+1997)



(Bechtold+1984)

Extremely High Velocity Outflows

The database includes previous epochs if available



db Queries ▾ Search

Closed Beta 1

Data Access: EHVO-I Survey of SDSS DR9Q

[View EHVO-I DR1 Catalog](#)

This catalog presents the results of spectrum analysis carried out on a sample set of quasars from Sloan Digital Sky Survey Data Release 9 (SDSS DR9). Our methodology, data sources, and catalog access is detailed below.

1. Methodology

The first step in generating our survey was applying a filter set to our data. The filtering criteria and data sets used are explained in detail below, in Section 2. After filtering we passed our spectra off to a program we wrote to do the actual spectrum analysis. First, our spectra were normalized using a powerlaw fit. After fitting, the spectra were smoother using a 3 point boxcar algorithm. Finally, a balnicity index was calculated for each spectra. Once our program was finished we visually inspected each spectra to remove false positives.

2. Data Sources and Selection Criteria

Our spectrum analysis was carried out using spectra from SDSS DR9. We selected candidate spectra from SDSS DR9's Quasar Catalog (Paris et al.) using two main criteria. First, we limited our search to spectra with a signal-to-noise ratio (S/N) ≥ 10 . This was done because we found that BAL features were difficult to distinguish from noise in samples with lower S/N. We also filtered for redshift (z) ≥ 1.9 . This was done to shift CIV features into SDSS's spectral coverage range. From our filtering criteria we ended up with 6760 candidate spectra.

We also present data from value added SDSS catalogs: DR9Q and DR7Q.

DR9Q contains both data calculated by Paris et al. 2012 and VLA Faint Images of the Radio Sky at 20-cm (FIRST) radiometric data where available. This was the data set we used to generate our survey. More information about DR9Q can be found [here](#).

DR7Q contains data calculated by Shen et al. 2011. More information about DR7Q can be found [here](#).

3. Data Access

This catalog presents the results of our EHVO survey of SDSS DR9Q, as well as other related data sources. At its base, each entry contains DR9Q data, with EHVO-I and DR7Q data where available. Data can be accessed either through this web interface, or a REST API using both manual and templated queries. Additionally, the web interface provides links to data associated to each sample on SDSS's main sites for DR9 and DR7, where available.

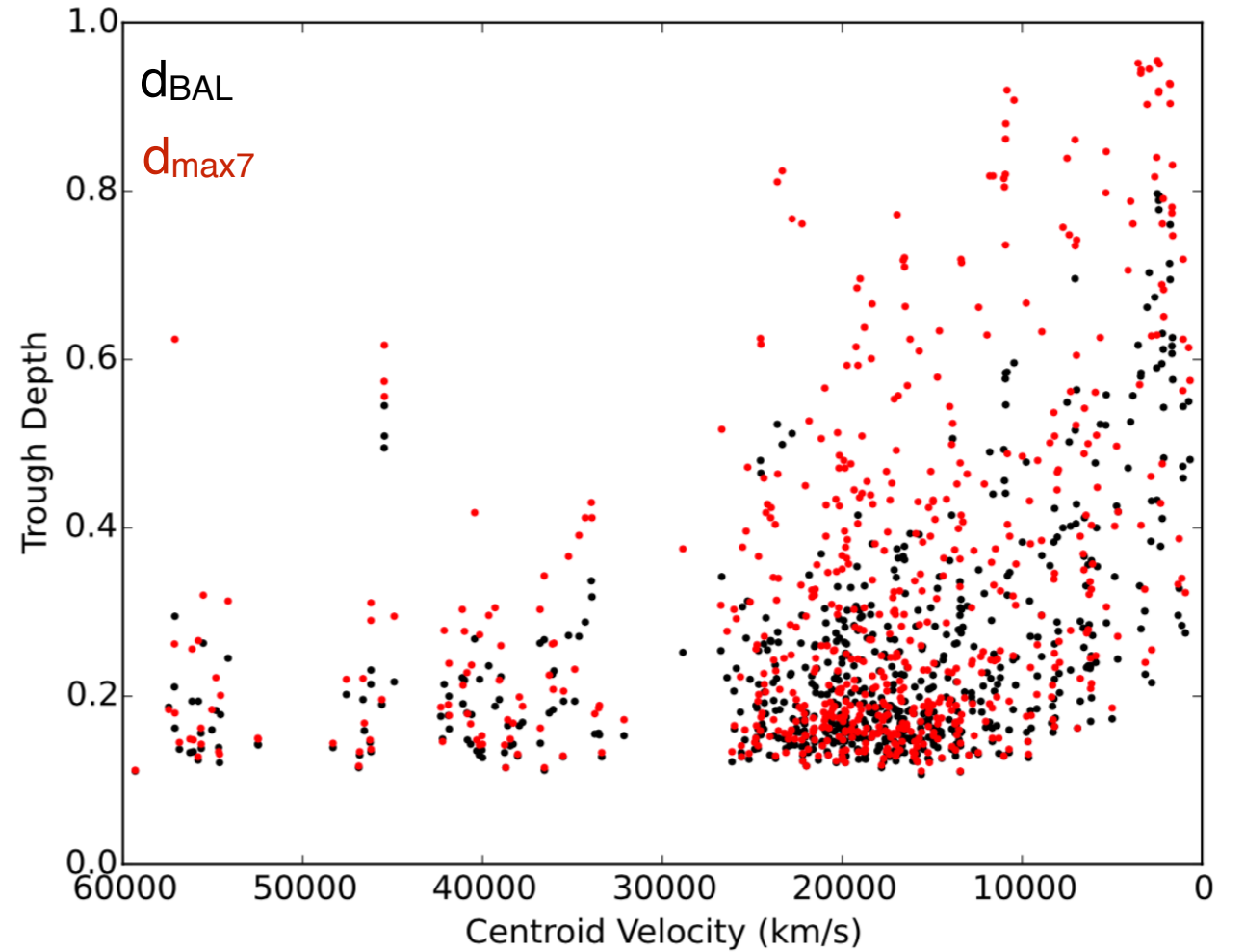
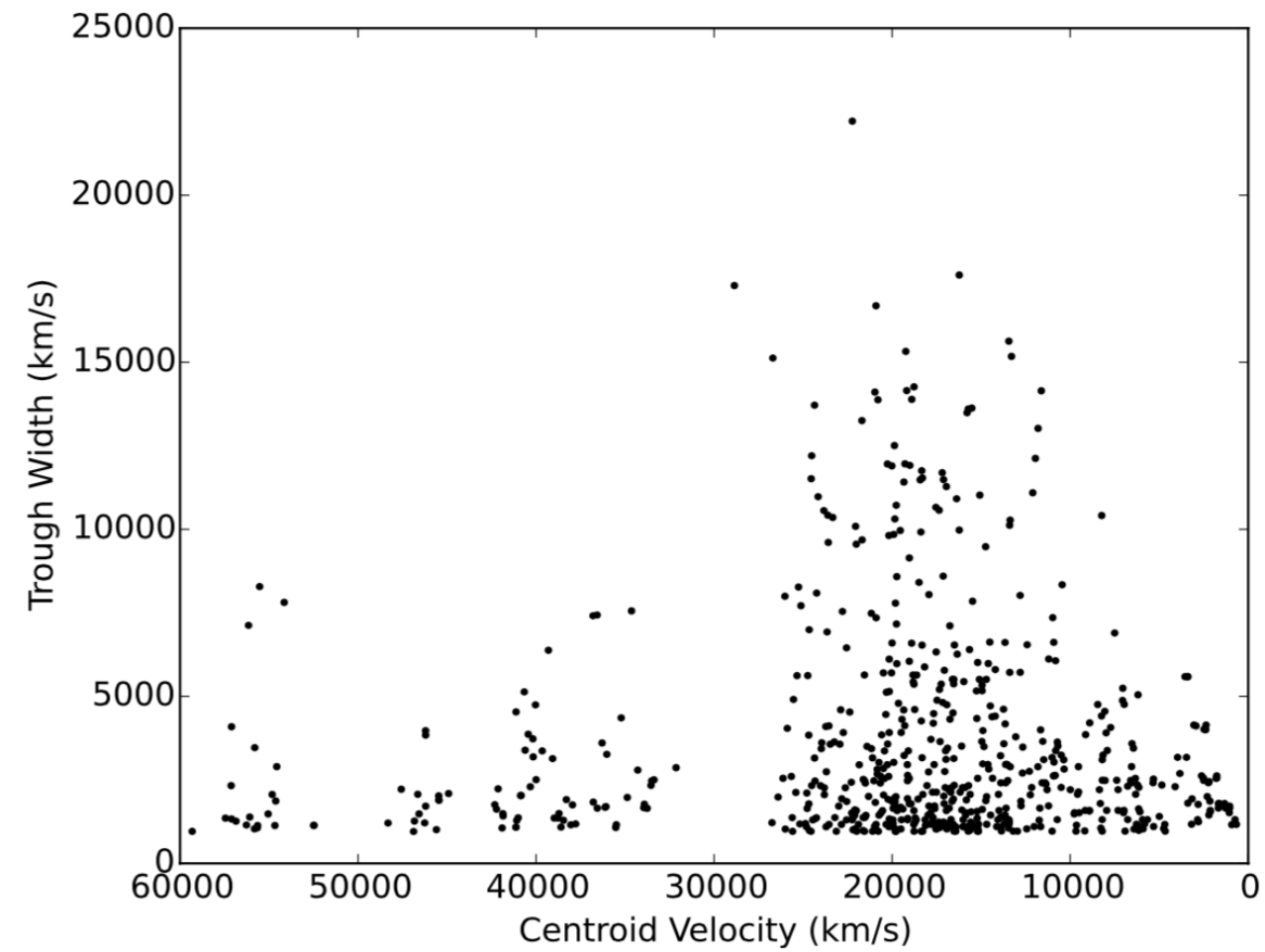
quez Hidalgo

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 $S/N > \sim 9$**

Emergence of BALs



(Rogerson+17)

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

Extreme Variability

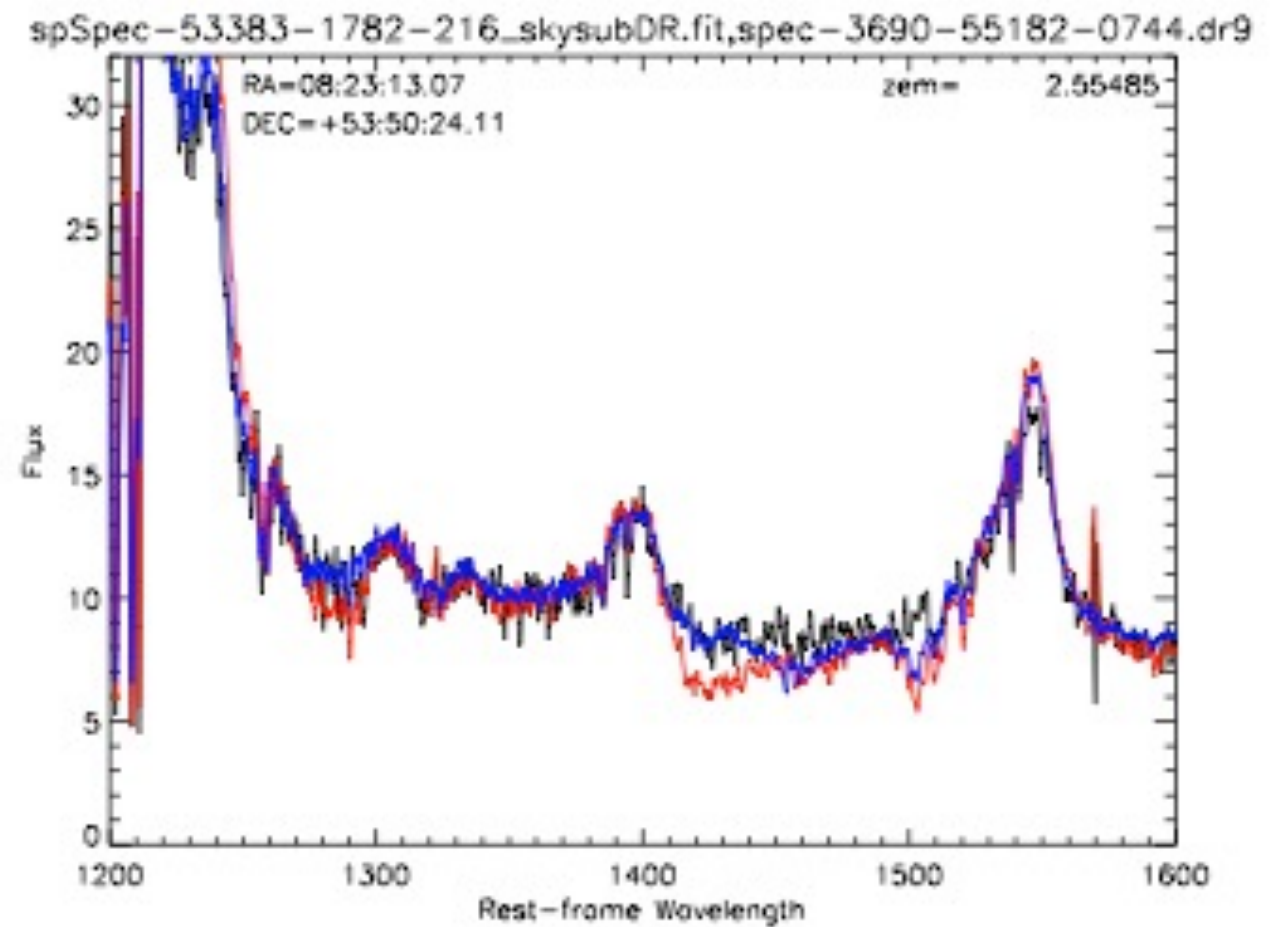
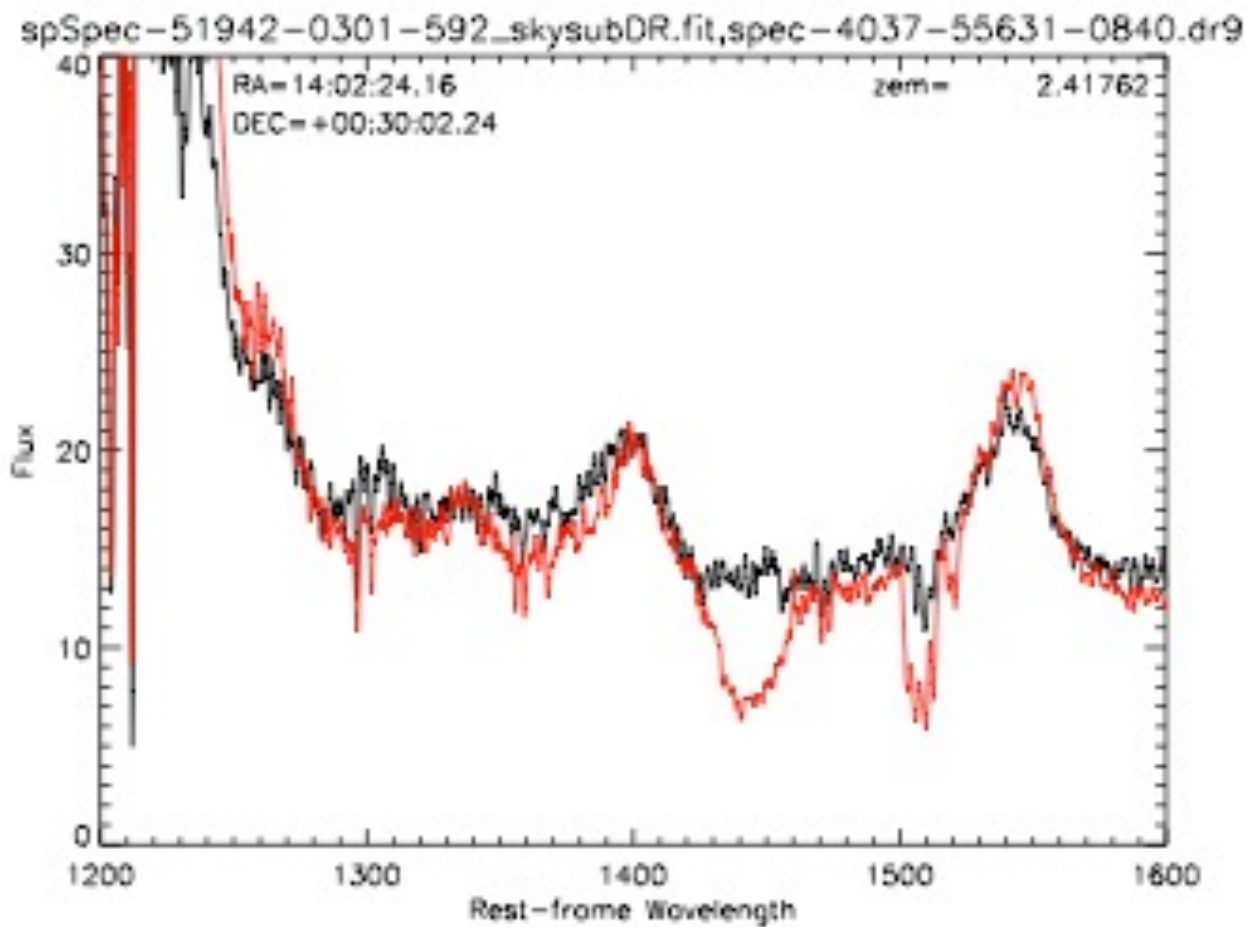
Emergence Survey

- 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 = $3.5 \pm 0.6\%$

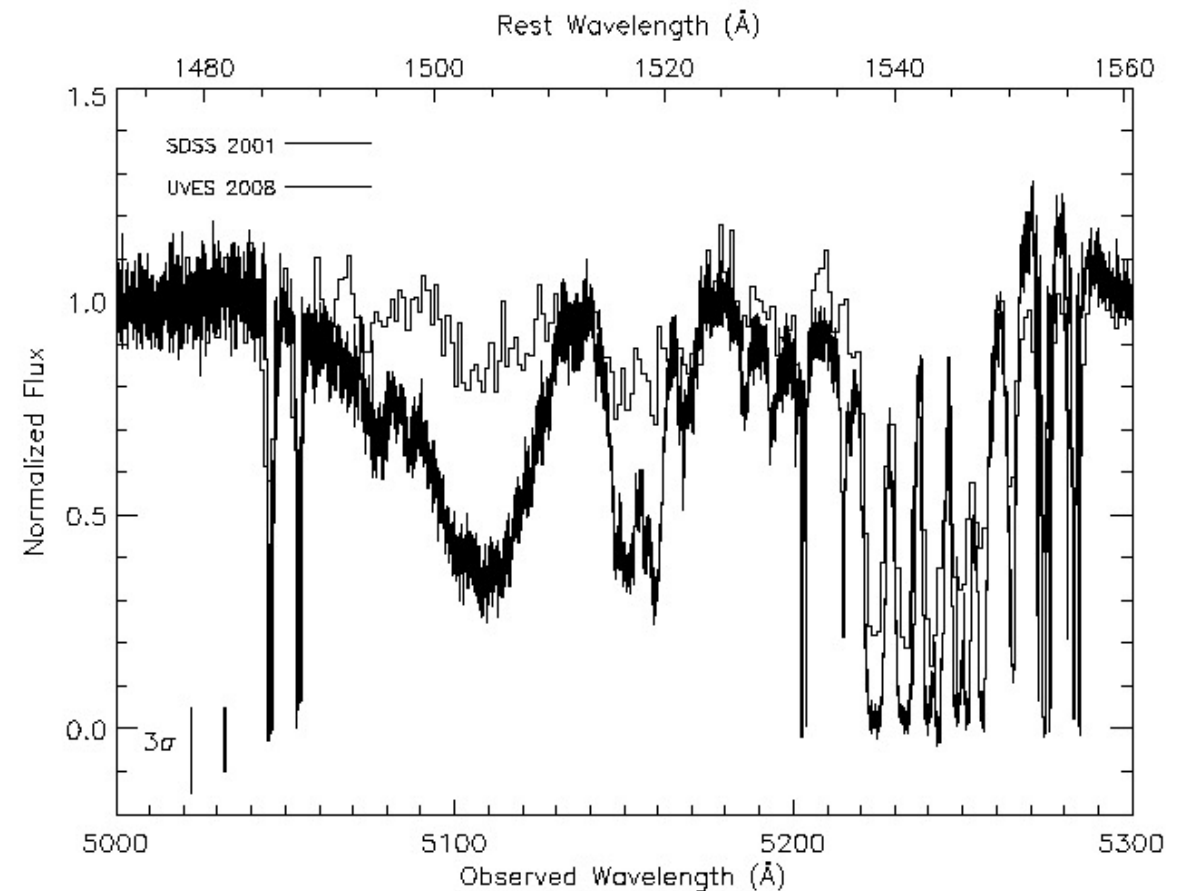
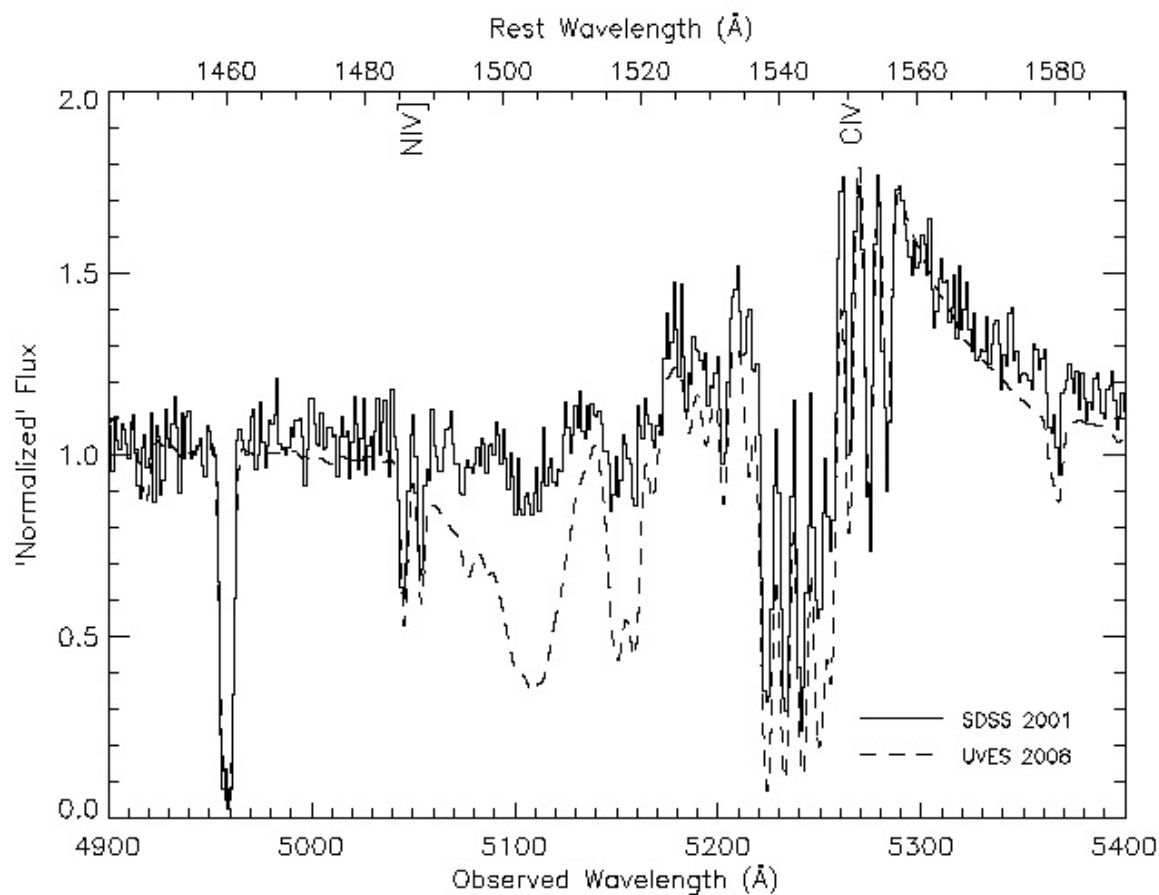
Emergence of BALs

- 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.

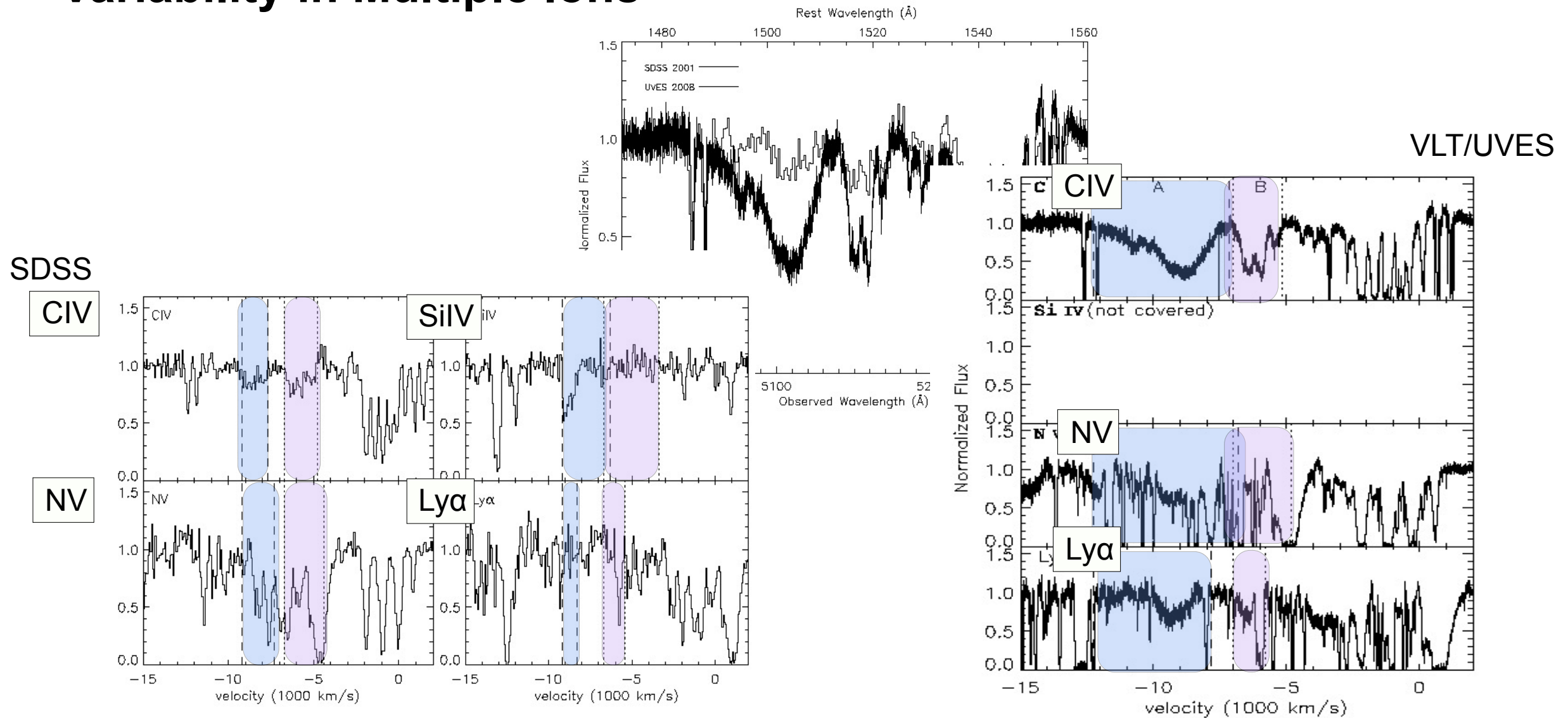


**Intermediate Phase:
mini-BALs are turning into BALs and BALs into mini-BALs**

(Rodriguez Hidalgo+12, Rodriguez Hidalgo+13)

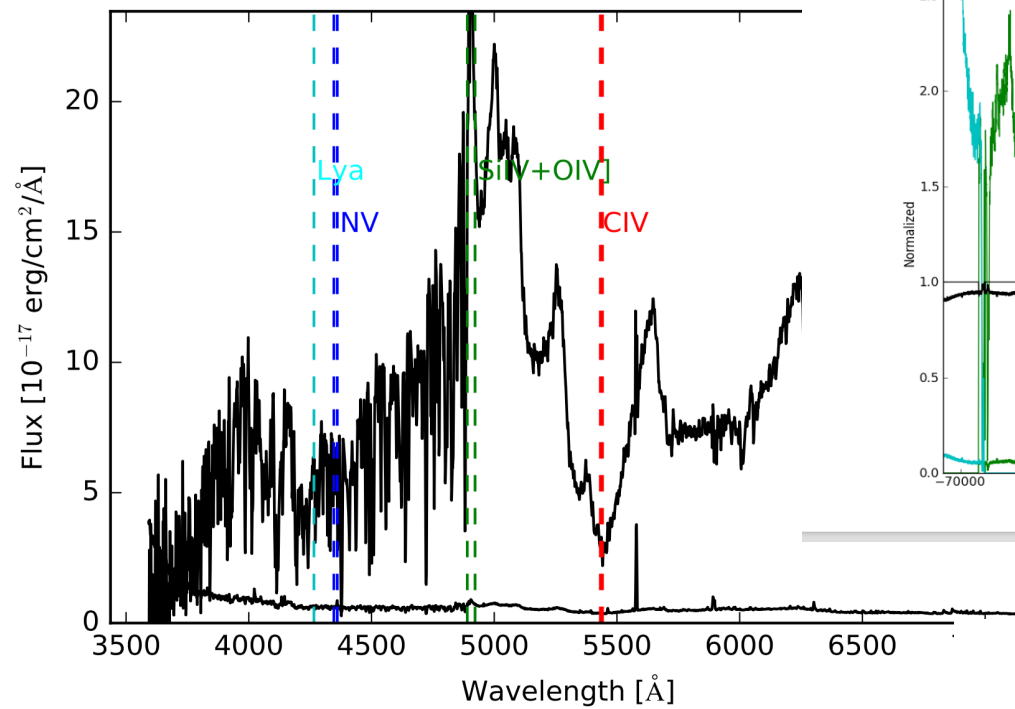
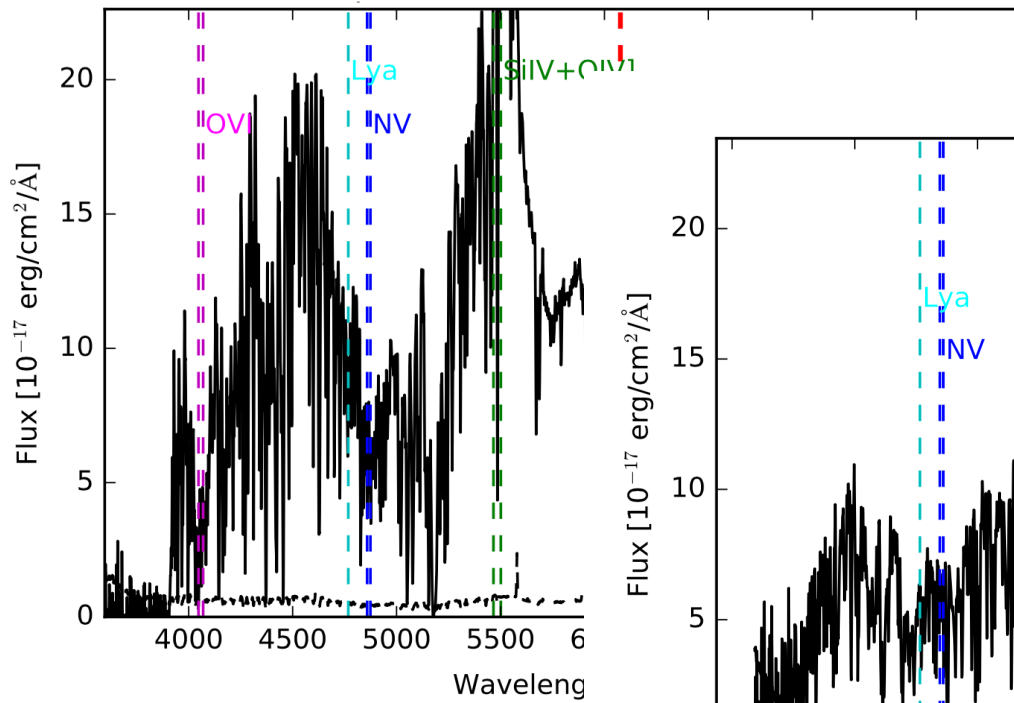
Extreme Variability

Variability in Multiple Ions

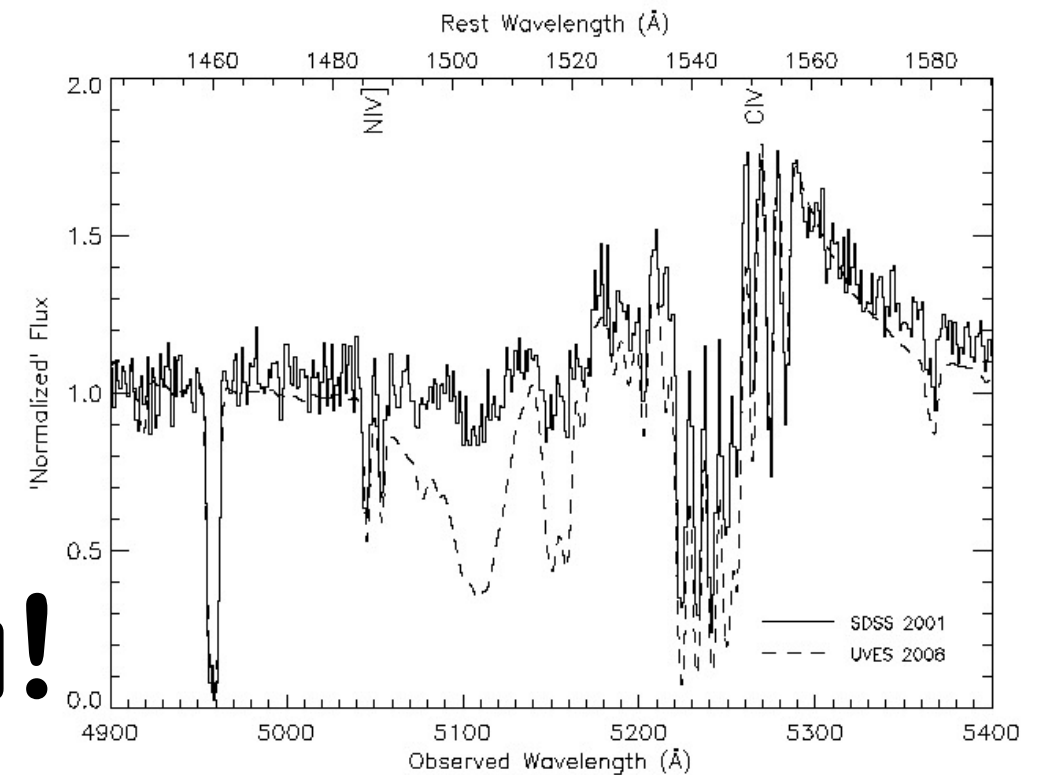
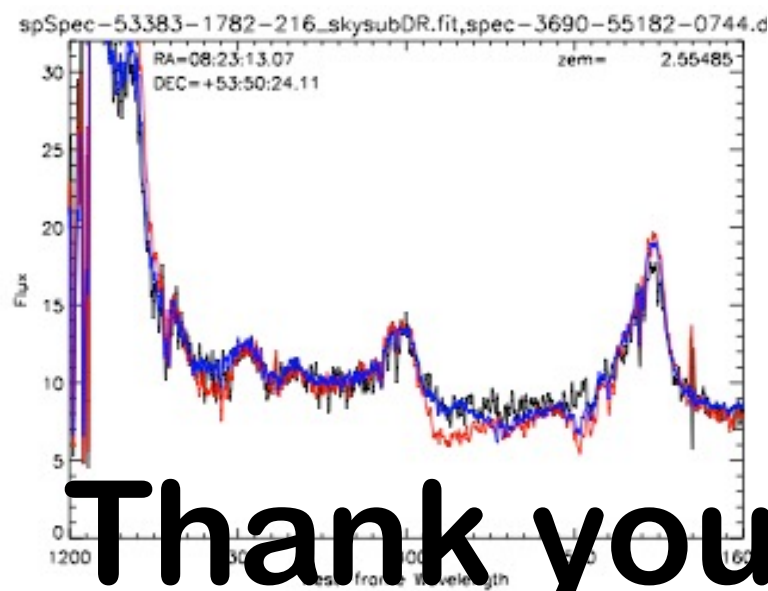
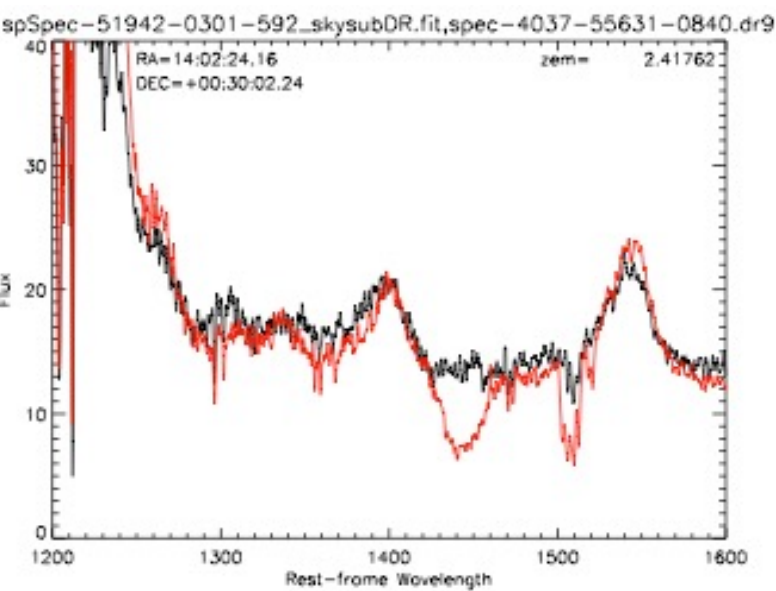
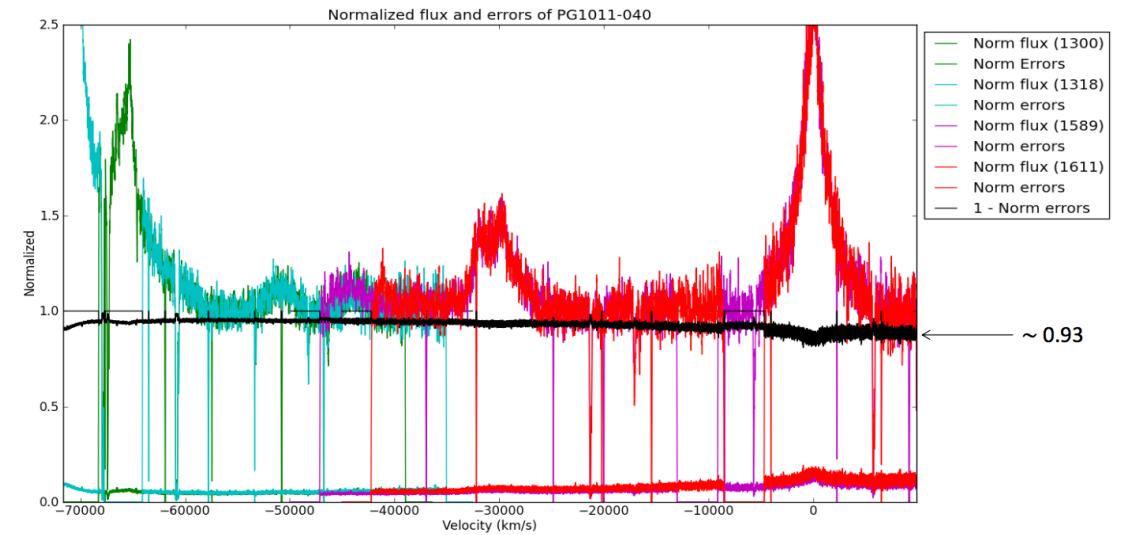


(Rodriguez Hidalgo+13)

Summary



Example spectrum: PG1011-040



Thank you!