SDSS Observations of AGN Outflows

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SDSS quasar survey collaborators
…

AGN Driven Winds 2017

My outflow of questions

- What are the connection(s) between outflows seen in X-ray absorption, in UV absorption, and at longer wavelengths? [How much of the flow can C IV trace?]
- How do accretion structures (thin/slim/thick disk; chaotic cold accretion; etc.) depend on physical parameters, and what are their impacts on outflows?
- How important are continuum/line/MHD driving?
- What signatures of wind acceleration might we see?
- What are typical mass, momentum, KE loss rates?
- What can continuum and absorption variability tell us about source and outflow properties and structure? [e.g., are there significant azimuthal asymmetries?]

“SDSS Observations of AGN Outflows”

- Too broad!
- Limit to quasars, not all AGN: still too broad!
- Niel Brandt will discuss SDSS surveys tomorrow
- I will focus today on interesting extrema:
  - Dramatic FeLoBAL Variability
  - Fastest confirmed UV outflow
  - Velocity-dependent coordinated trough variability
  - BAL quasars with redshifted troughs (to >10,000 km/s)
  - Maunakea Spectroscopic Explorer

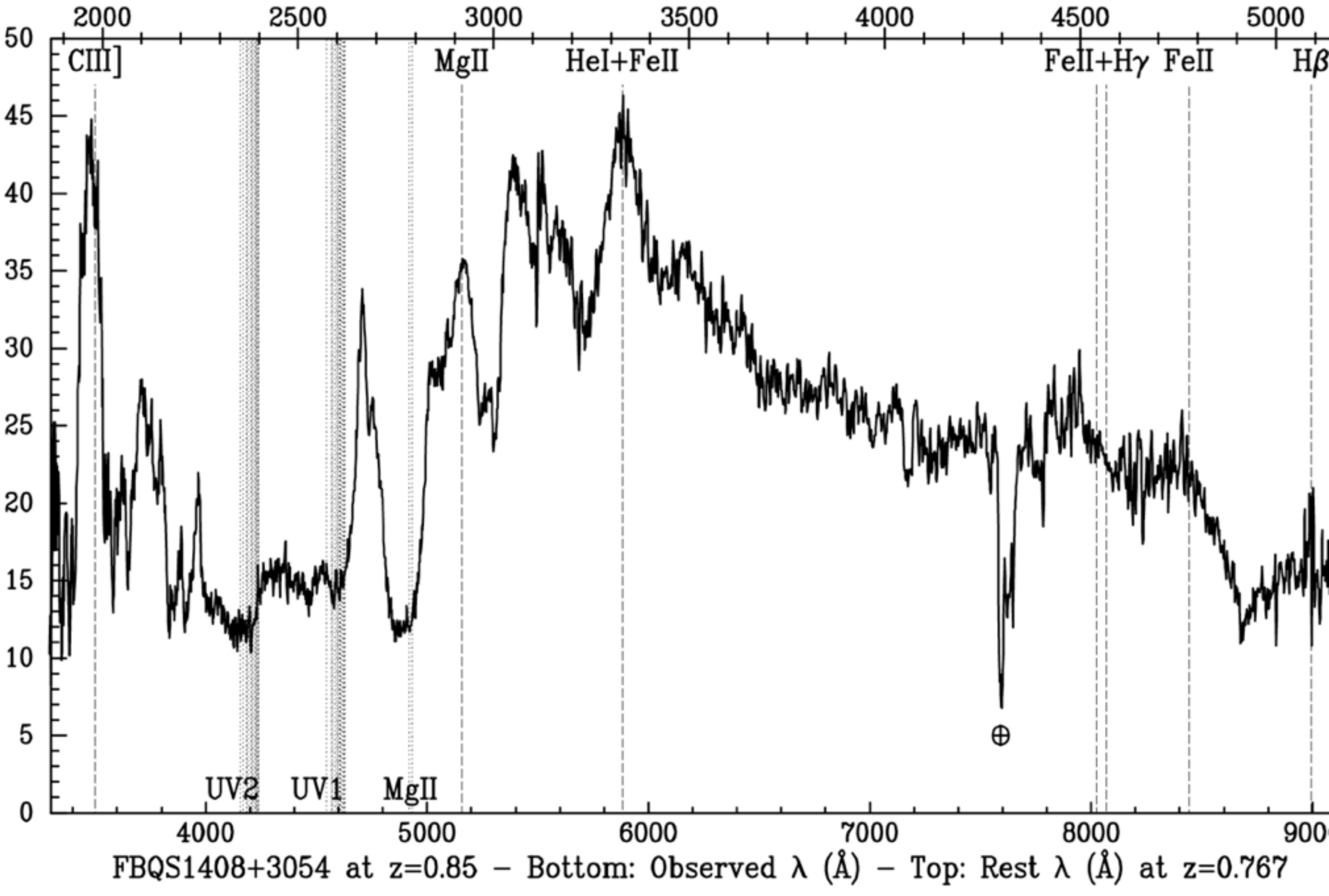
Dramatic Variability of FeLoBALs

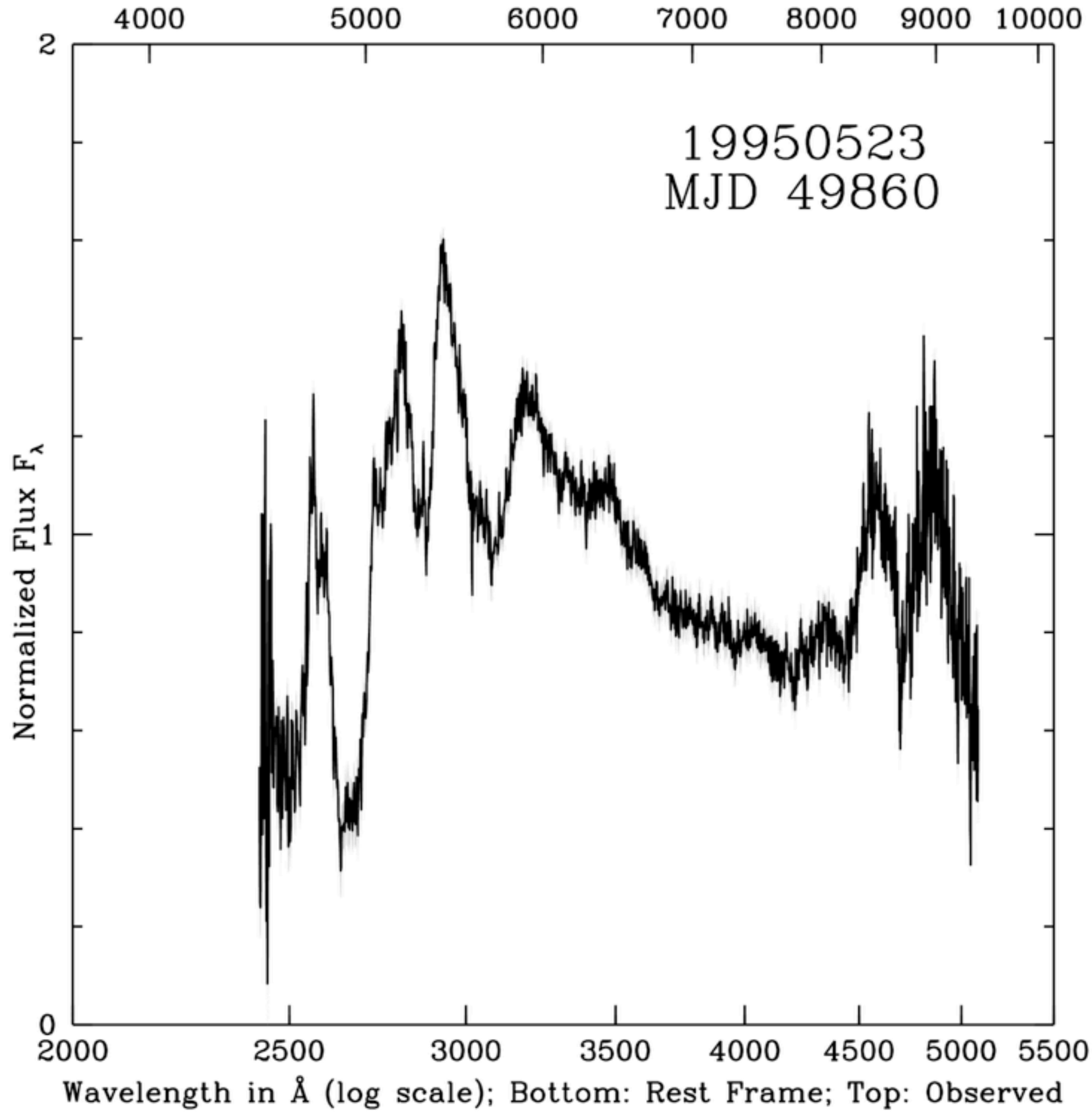
- FeLoBALs are (of course), BALs which show absorption from excited states of Fe II and/or Fe III in low-ionization gas

Variability of FBQS J1408+3054

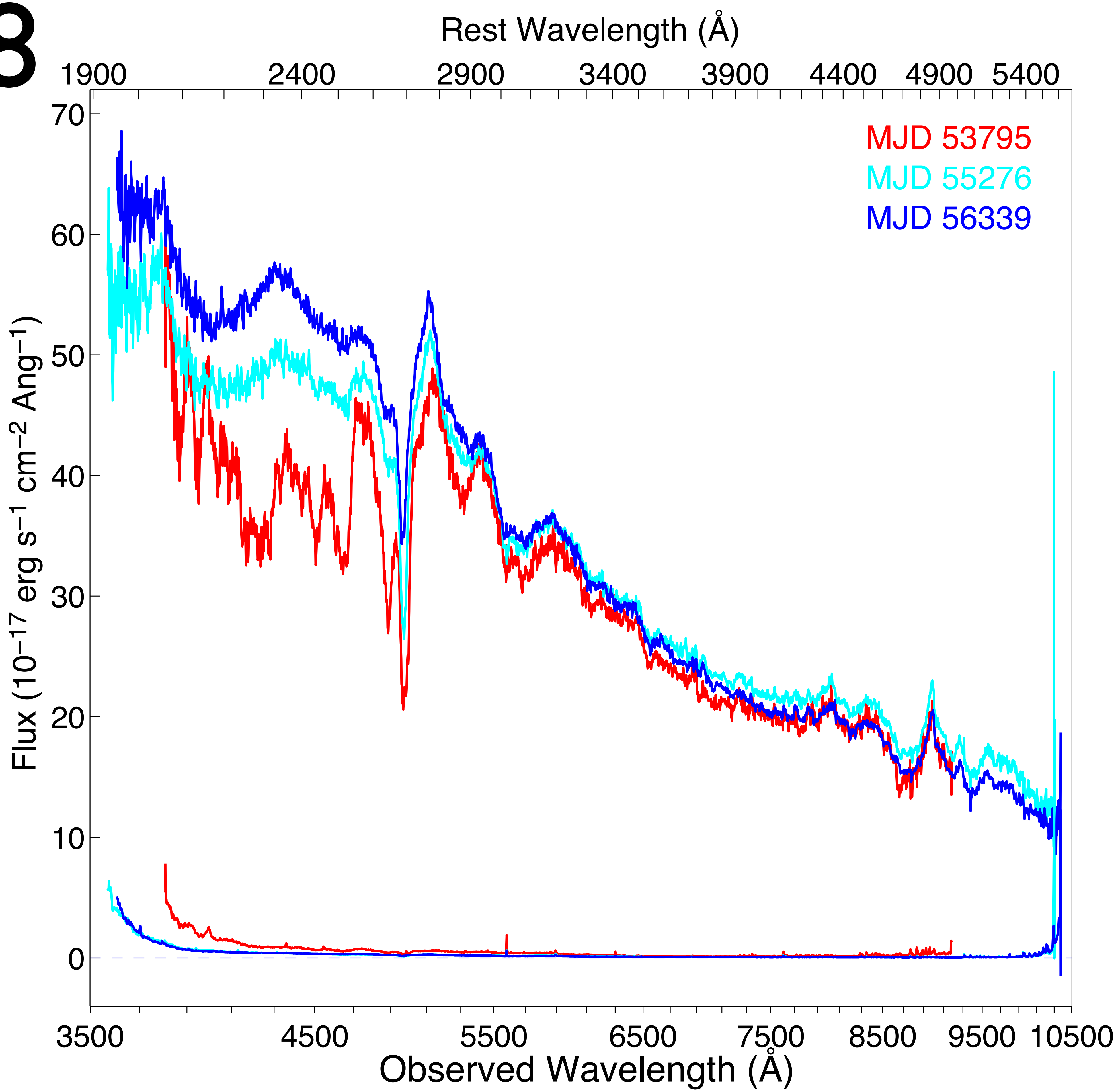
- Paper (Hall et al. 2011, arXiv:1010.3728)
- Movie of all spectral variability from 1995 to 2009 includes uncertainties scaled using a damped random walk (MacLeod et al. 2010, arXiv:1004.0276)
- FBQS J1408+3054 observed by SDSS in March 2006
- Change in spectrum noticed in April 2009
- HET spectrum obtained in July 2009
- Collaboration with FIRST Bright Quasar Survey group yielded access to spectra from 1995 to 2005

FBQS J1408+3054 in 2000




4000
5000
6000
7000
8000
9000
10000
19950523
MJD 49860
2
1
0
Normalized Flux F_λ
2000
2500
3000
3500
4000
4500
5000
5500
Wavelength in Å (log scale); Bottom: Rest Frame; Top: Observed

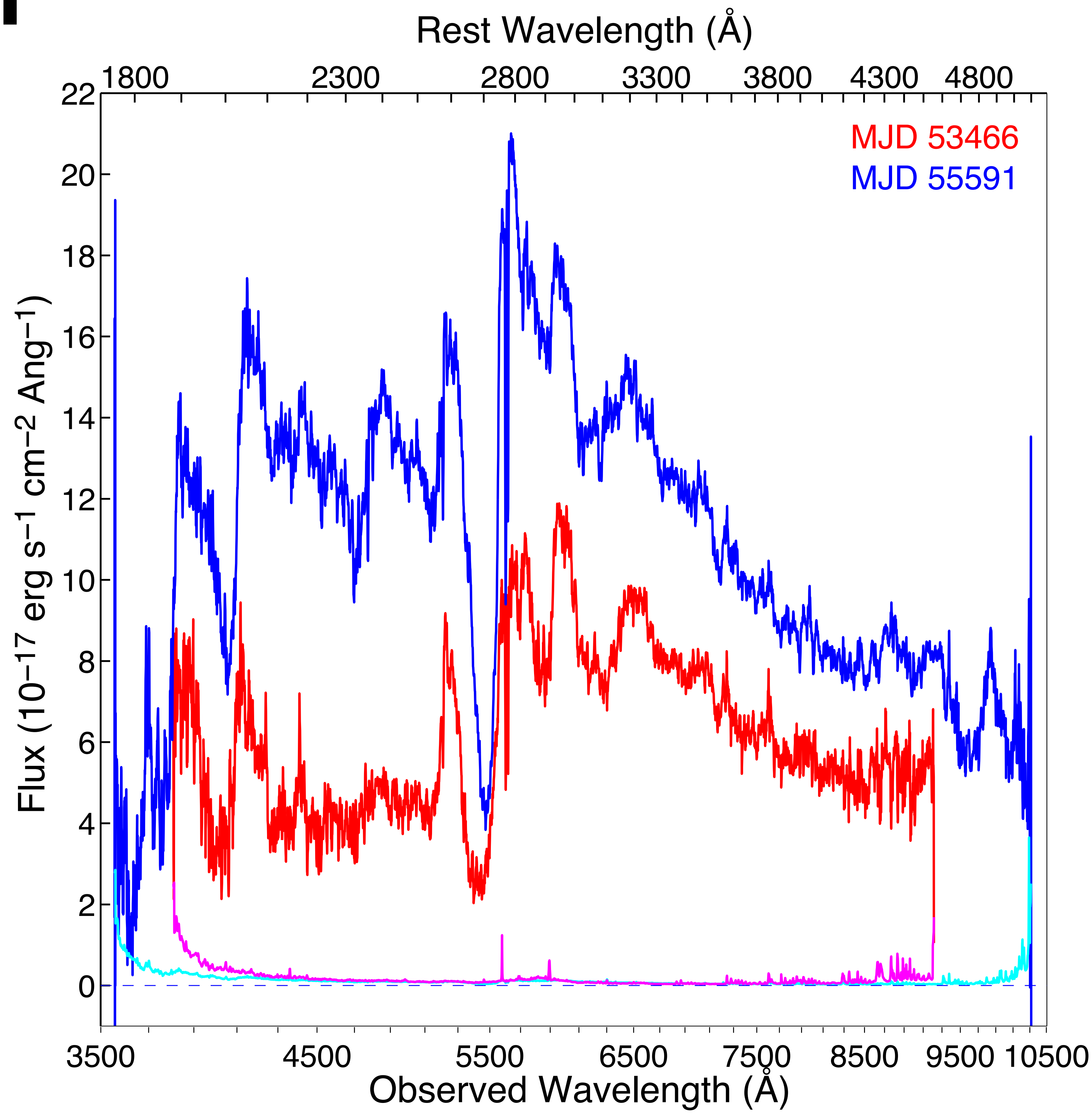
J1408


Rest Wavelength (Å)
1900
2400
2900
3400
3900
4400
4900
5400
MJD 53795
MJD 55276
MJD 56339
Flux (10^{-17} erg s^{-1} cm^{-2} Ang^{-1})
70
60
50
40
30
20
10
0
3500
4500
5500
6500
7500
8500
9500
10500
Observed Wavelength (Å)

Vanishing absorption and blueshifted emission in FeLoBAL quasars (Rafiee+2017)

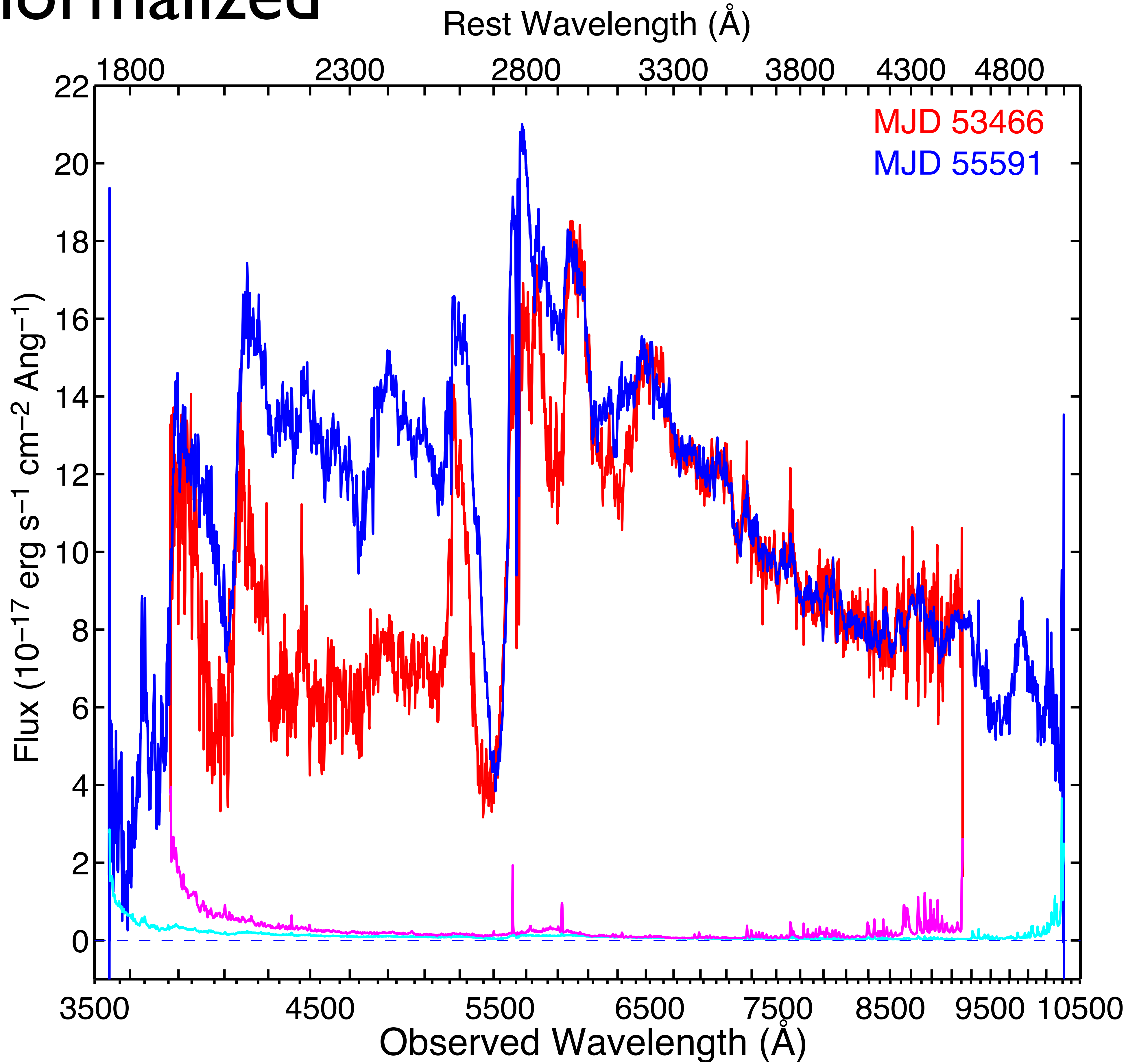
- Further data on J1408 confirms complete disappearance of Fe II absorption. (Simple outflow model would need transverse velocities of 2,600-22,000 km/s to explain.)
- Quasar J1231 shows a similar weakening of Fe II, accompanied by strengthening of the near-UV continuum.
- Quasar J0841, at higher z, shows a decrease in the EW of many transitions, with the consequent increase in flux seen by the CRTS. Would need transverse velocities of 10,000-42,000 km/s to match observed timescale.

J1231

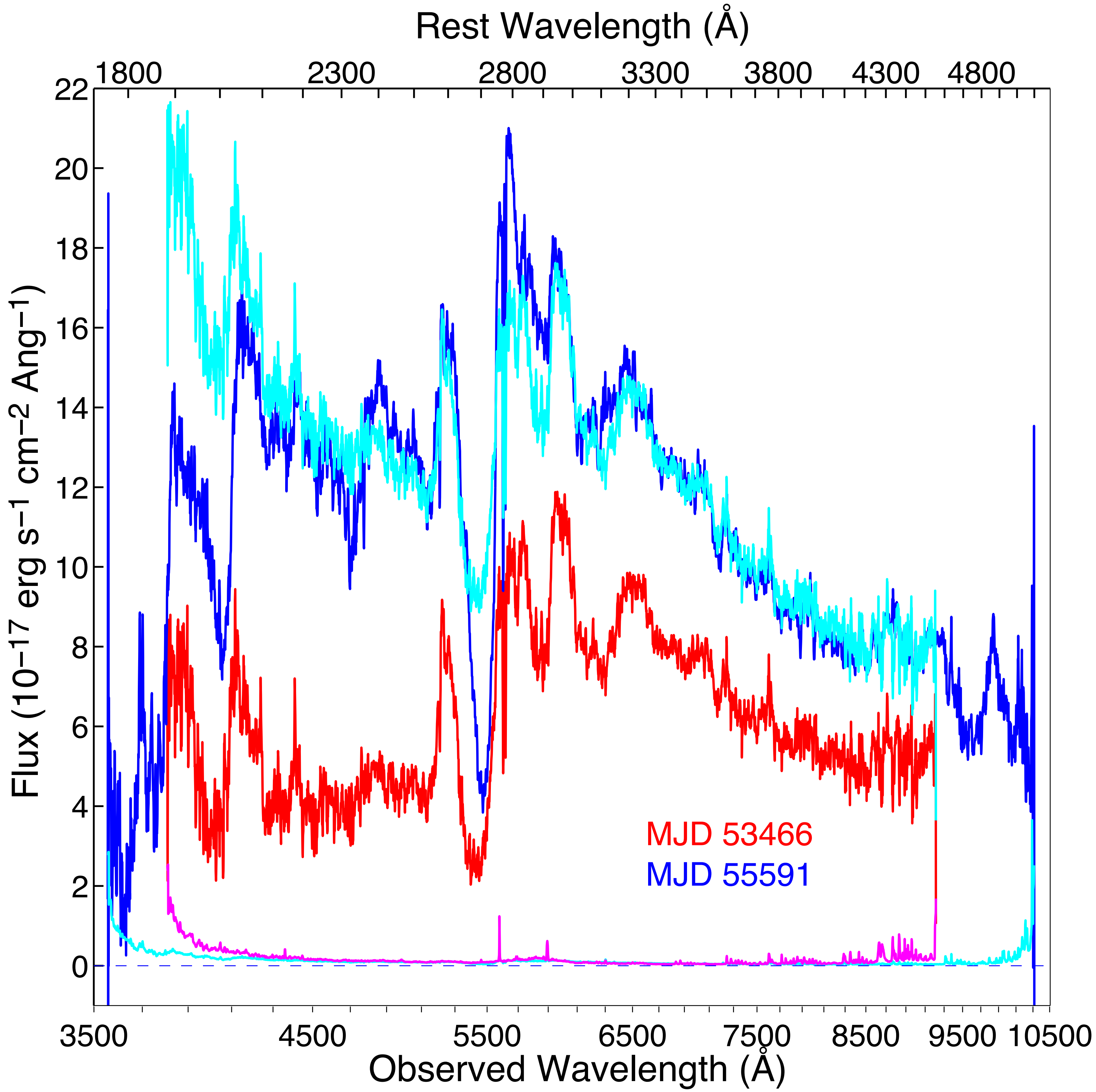


Rest Wavelength (Å)
1800
2300
2800
3300
3800
4300
4800
MJD 53466
MJD 55591
Flux (10^{-17} erg s^{-1} cm^{-2} Ang^{-1})
22
20
18
16
14
12
10
8
6
4
2
0
3500
4500
5500
6500
7500
8500
9500
10500
Observed Wavelength (Å)

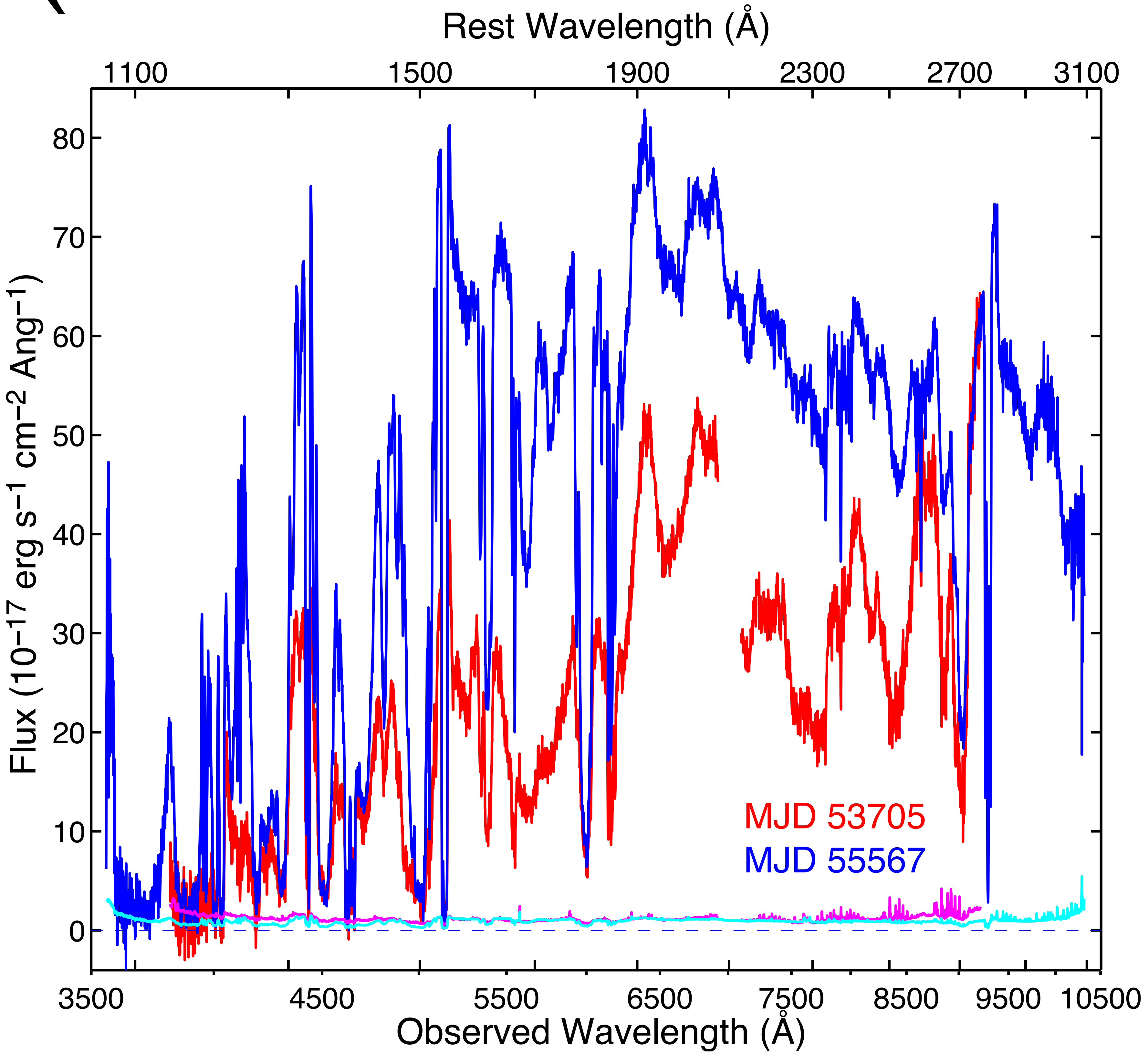
J1231, normalized



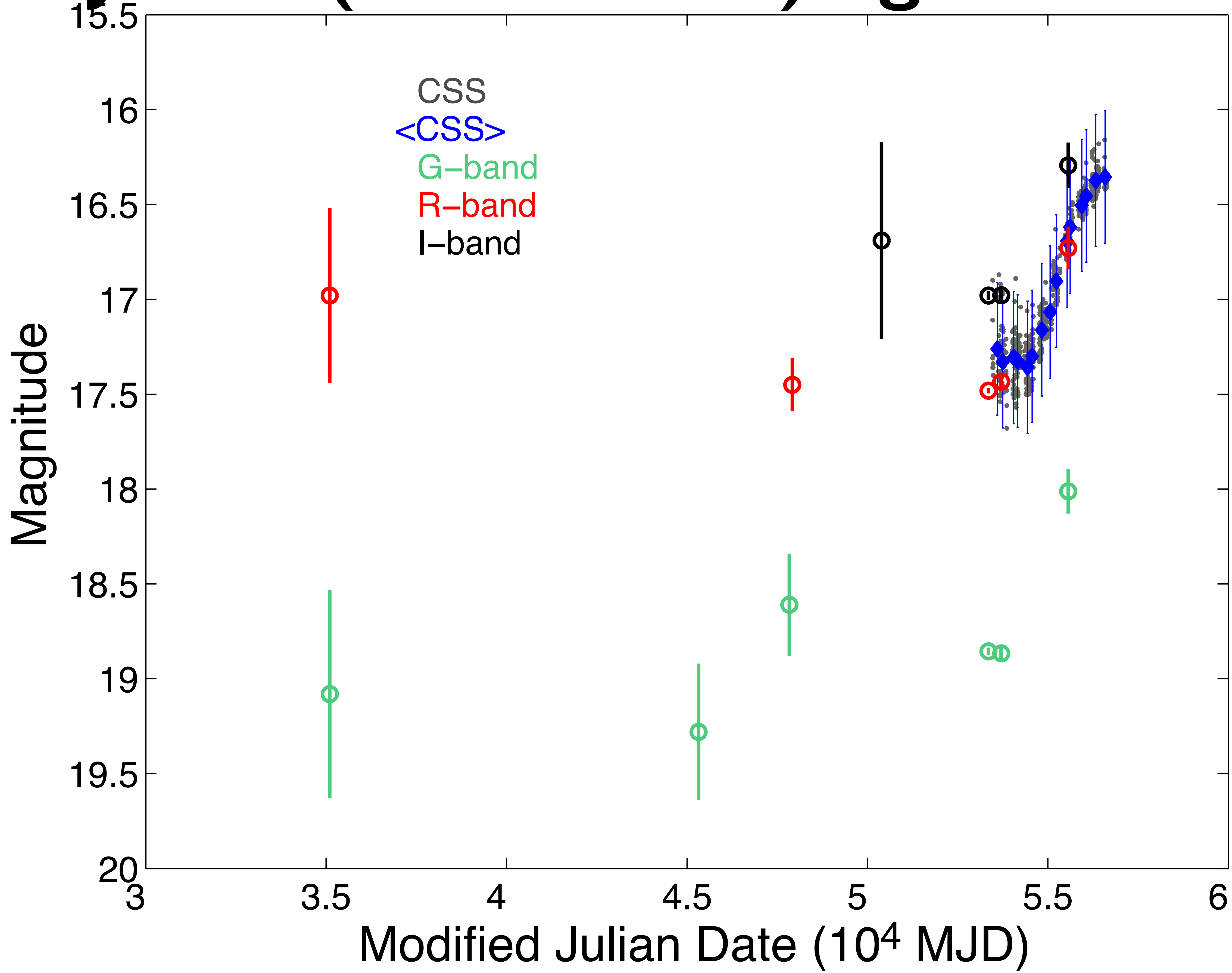
J1231 *not* well fit (cyan) by the addition of a new, unabsorbed, power-law continuum component



J0841 (see also D. Stern et al. 2017)

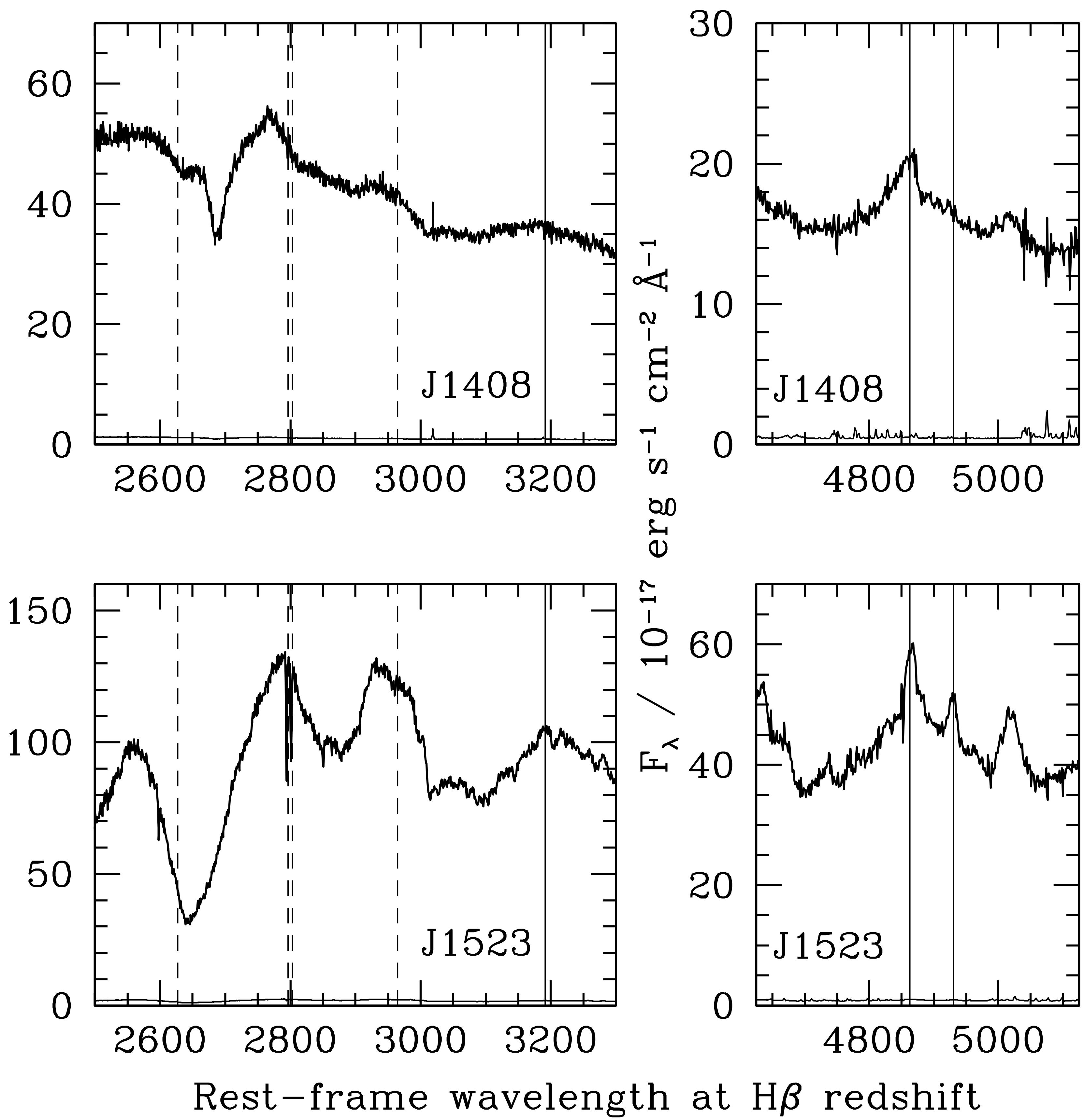


J0841 (normalized) light curve



Vanishing absorption and blueshifted emission in FeLoBAL quasars (Rafiee+2017)

- There are now five FeLoBAL quasars known where the absorption has decreased dramatically, and only one where it has increased dramatically.
- For J0841, Stern et al. 2017 point to ionization variability rather than coordinated motions over several thousands of km/s. Optical fluxes consistent with no change.
- Spectral energy distributions of FeLoBAL quasars with vanishing absorption have a range of properties.
- Mg II and ultraviolet Fe II lines in several of these quasars are blueshifted from their expected wavelengths…



<u>Solid lines show wavelengths</u> of emission features seen at the systemic redshift.

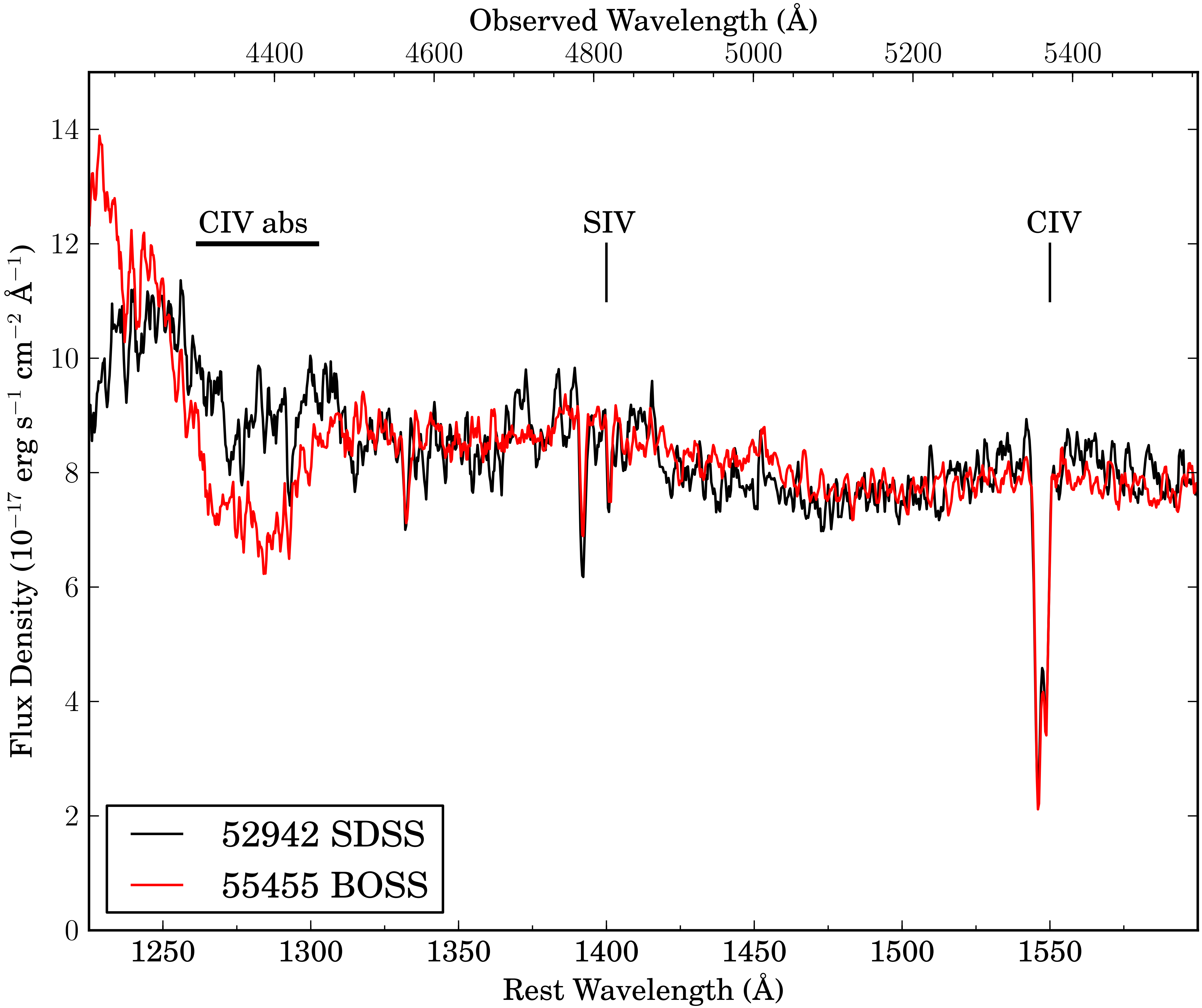
<u>Dashed lines show expected wavelengths</u> for emission features which are instead seen *blueshifted* from the systemic redshift.

Vanishing absorption and blueshifted emission in FeLoBAL quasars (Rafiee+2017)

- Would like spectra of outflow models to test predictions of (lack of) coordinated variability at different velocities.
- What underlying cause(s) for dramatic variability events? Are they consistent with one stage of quasars being born obscured and gradually becoming unveiled? (Nothing special about SEDs, but may have seen five unveiling events vs. only one veiling event to date.)
- Would like to have X-ray observations of quasars before, during, and after dramatic variability events.
- Need dynamical model of BELR for Mg II and UV Fe II lines being blueshifted from their expected wavelengths.

J0230: The Fastest UV-Absorbing Outflow Yet

- Compared 8,317 objects with spectra in both SDSS and BOSS, a few rest-frame years apart.
- Looked for emergent broad absorption line quasars.
- One of the most interesting was 'J0230' (Rogerson et al. 2017, MNRAS).
- We obtained follow-up spectra with the Gemini telescopes of this object and many others (Rogerson et al., submitted).


Observed Wavelength (Å)
4400
4600
4800
5000
5200
5400
CIV abs
SIV
CIV
Flux Density (10^{-17} erg s^{-1} cm^{-2} Å^{-1})
0
2
4
6
8
10
12
14
52942 SDSS
55455 BOSS
1250
1300
1350
1400
1450
1500
1550
Rest Wavelength (Å)

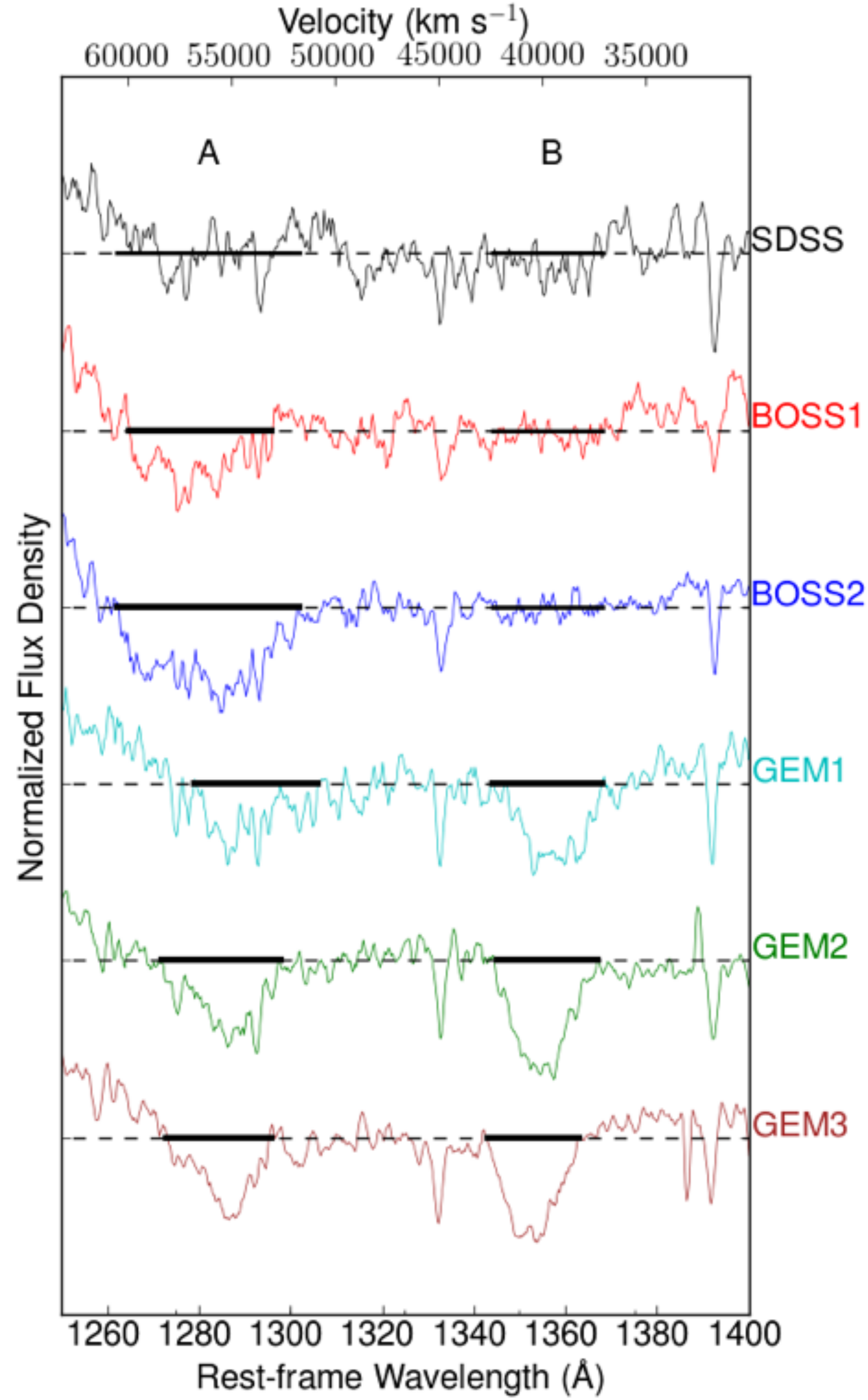
Absorption region of each spectrum is plotted at right.

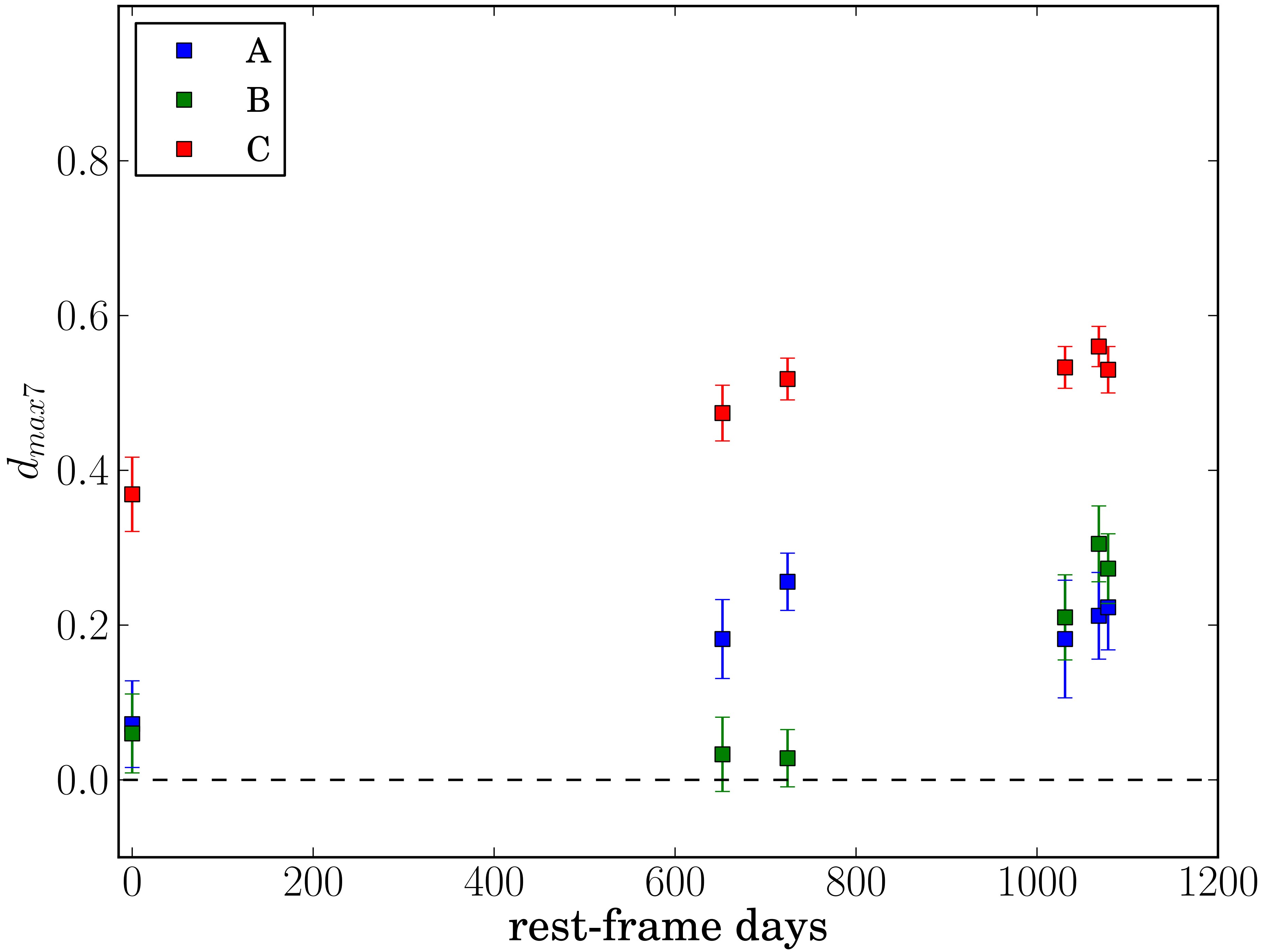
Earliest spectrum is at top; later spectra are shown below, in sequence.

Highest-velocity trough is A (55,000 km/s); next-highest is B (40,000 km/s).

Trough at systemic redshift (not shown) is C.

Variability seen on timescales from ~10 days to 3 years.





- How to explain absorption troughs whose depth changes with time?
- Ionization variability, transverse motion, or both?

Ionization variability … ?

- Perhaps the absorbing gas is always present, but with a changing amount of C IV along our sightline.
- Filiz Ak et al. (2013) showed that <u>this explanation is correct at least half the time</u>, because troughs widely separated in velocity tend to show coordinated variability.

Ionization variability … or transverse motion?

- Perhaps the absorbing gas is always present, but with a changing amount of C IV along our sightline.

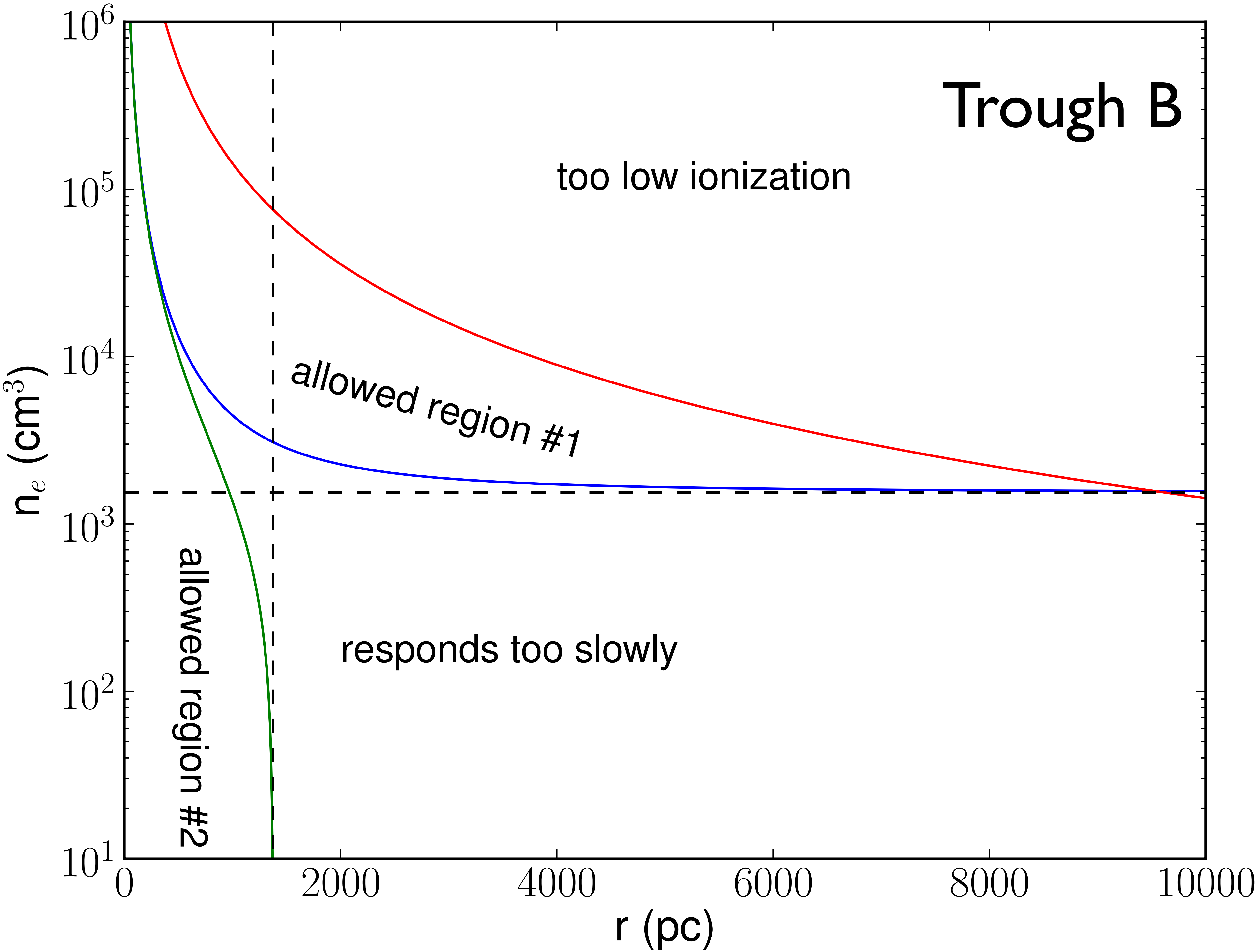
- Filiz Ak et al. (2013) showed that this explanation is correct at least half the time, because troughs widely separated in velocity tend to show coordinated variability.

- A wind launched from a rotating disk will exhibit rotation and outflow, leading to transverse motion of absorbing gas across our l.o.s. (how much will MHD driving increase v_{rot} at large r?).

- Transverse motion thus **will** occur in part of the flow. But is it relevant in the parts of the flow we see in the UV, and on what timescales can it be significant?

Ionization variability

- In equilibrium, amount of C IV along sightline is set by balance between photoionization (C III→C IV; C IV→C V) and recombination (C IV→C III; C V→C IV).
- If ionizing flux changes, the amount of C IV changes on a timescale set by F_{ion} and the carbon number density (e.g., Hamann+1997, Arav+2012, Wang, Yang, Wang & Ferland 2015, He+2017; Grier+2015, Rogerson+2017).
- For conditions where rates of C III↔C IV = C IV↔C V, the initial response to ionizing flux changes is very slow.
- Observing changes in C IV on a given timescale constrains density and distance from the quasar of optically thin gas.

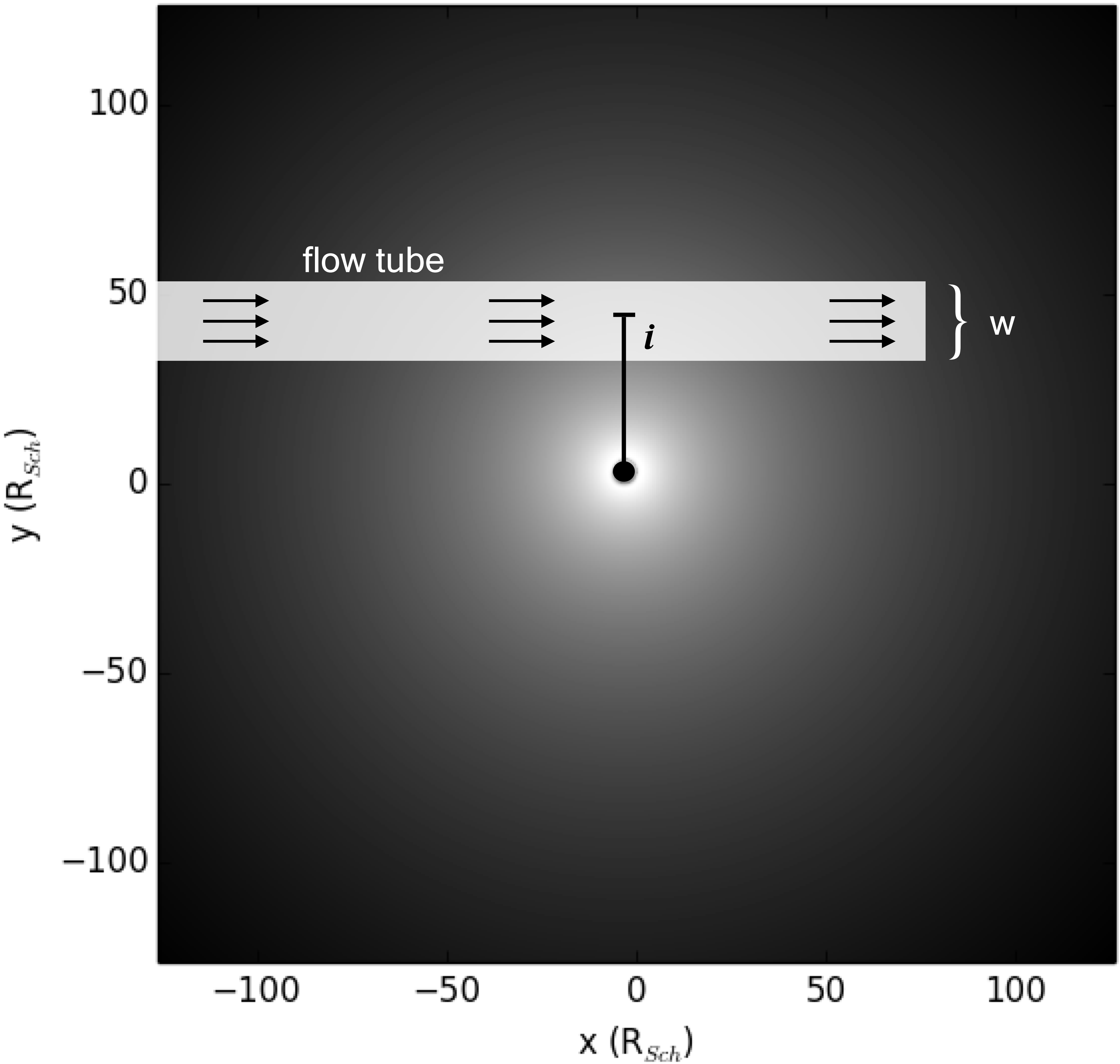

Trough B
too low ionization
allowed region #1
allowed region #2
responds too slowly
n_e (cm^3)
r (pc)
10^6
10^5
10^4
10^3
10^2
10^1
0
2000
4000
6000
8000
10000

Ionization variability

- Observing changes in C IV on a given timescale constrains the gas density and distance from the quasar.
- If ionization variability away from photoionization equilibrium caused the observed changes…
- The gas producing trough B is located 1.4 to 9.6 kiloparsecs from the quasar (4000-32,000 light-years) with density >1540 cm^-3, or is located <1.4 kpc from the quasar with little constraint on its density.
- The gas producing trough A is located 2 to 14 kpc from with quasar with density >720 cm^-3, or <2 kpc from the quasar with little constraint on its density.
- More detailed modeling justified if more data available.

Transverse motion

- Perhaps the absorbing gas in J0230 moved into our sightline to the quasar's continuum source between the two spectral epochs.
- To explain gas that appears, reaches a certain depth of absorption, and stays at roughly that same depth can be matched by an optically thick 'flow tube' of gas entering the line of sight and moving across the face of the continuum-emitting part of the accretion disk.
- Flow tubes that match our observed depths yields a required transverse velocity of 10,000-18,000 km/s (trough A) or 8,000-56,000 km/s (B).

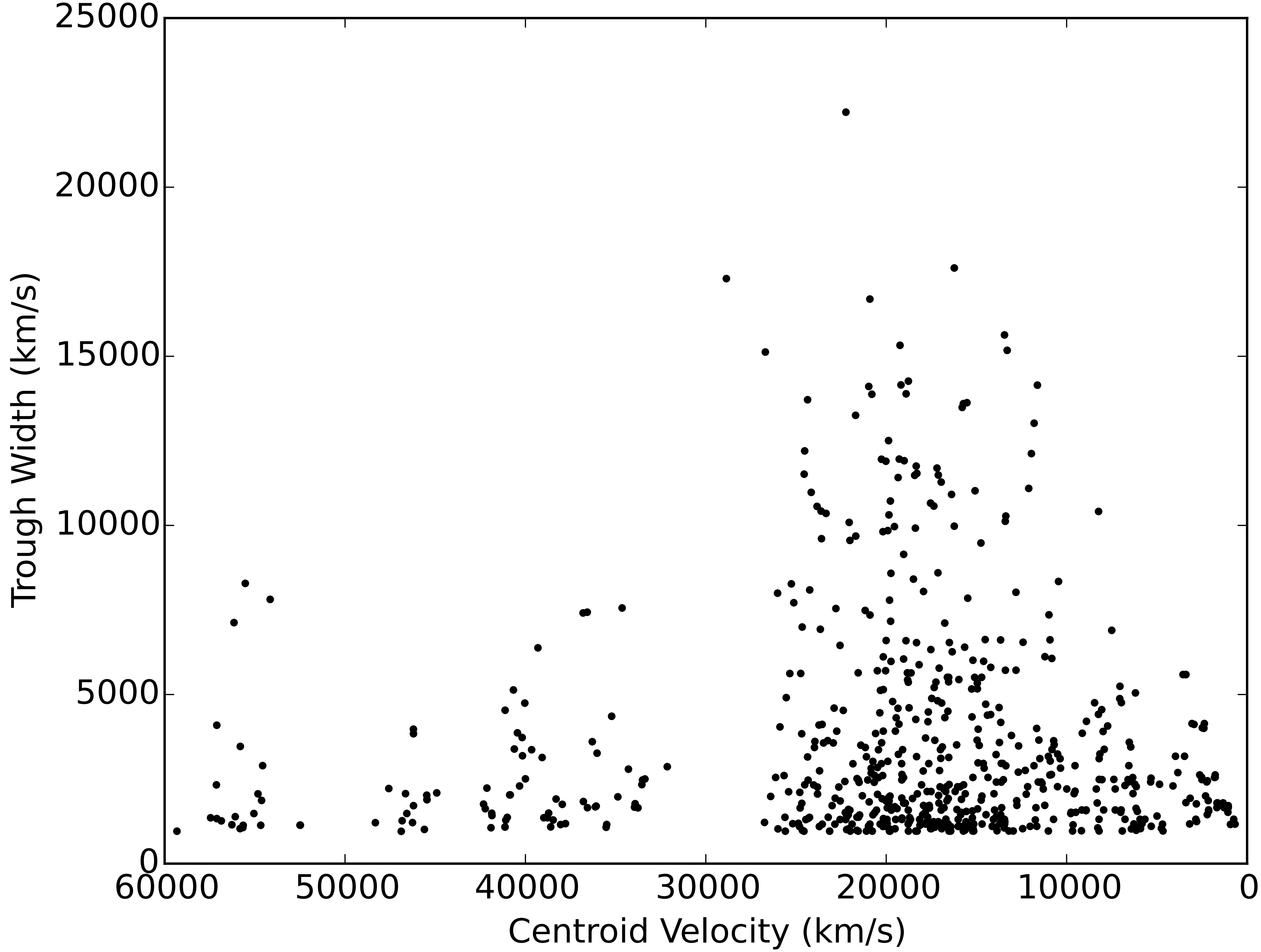


flow tube
w
i
100
50
0
−50
−100
y (R$_{Sch}$)
−100
−50
0
50
100
x (R$_{Sch}$)

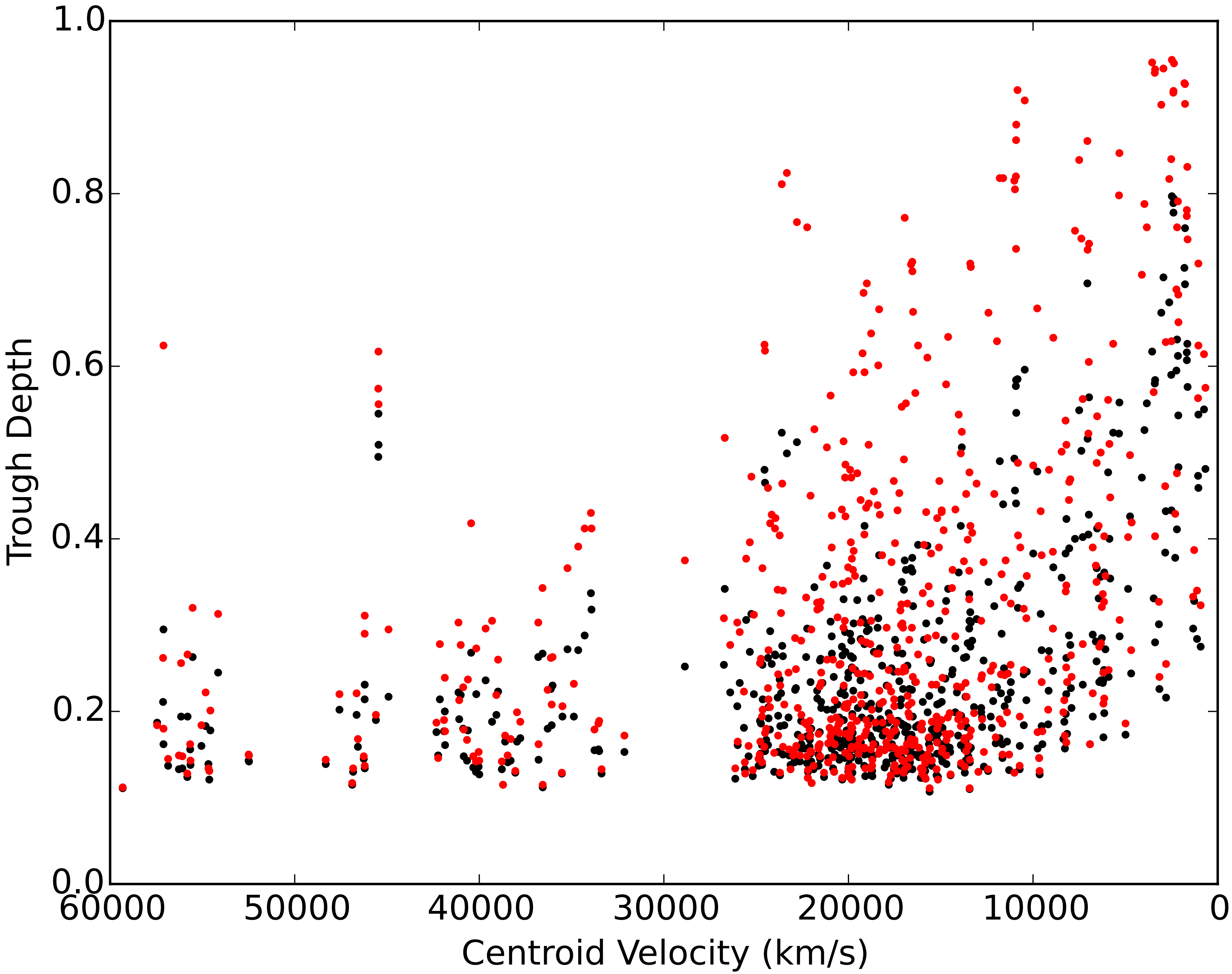
v-dependent Coordinated Variability

- Rogerson et al., submitted
- Compare SDSS-I/II DR7 spectra to SDSS-III/BOSS DR9+DR10 spectra
- Identified 292 quasars with candidate emergent BAL troughs
- Followed up 105 targets with Gemini spectroscopy
- Identified absorption complexes using multi-epoch spectra (the same absorption complex might be seen as one trough in some epochs and two troughs in other epochs, due to variability)

High-v troughs are narrow…



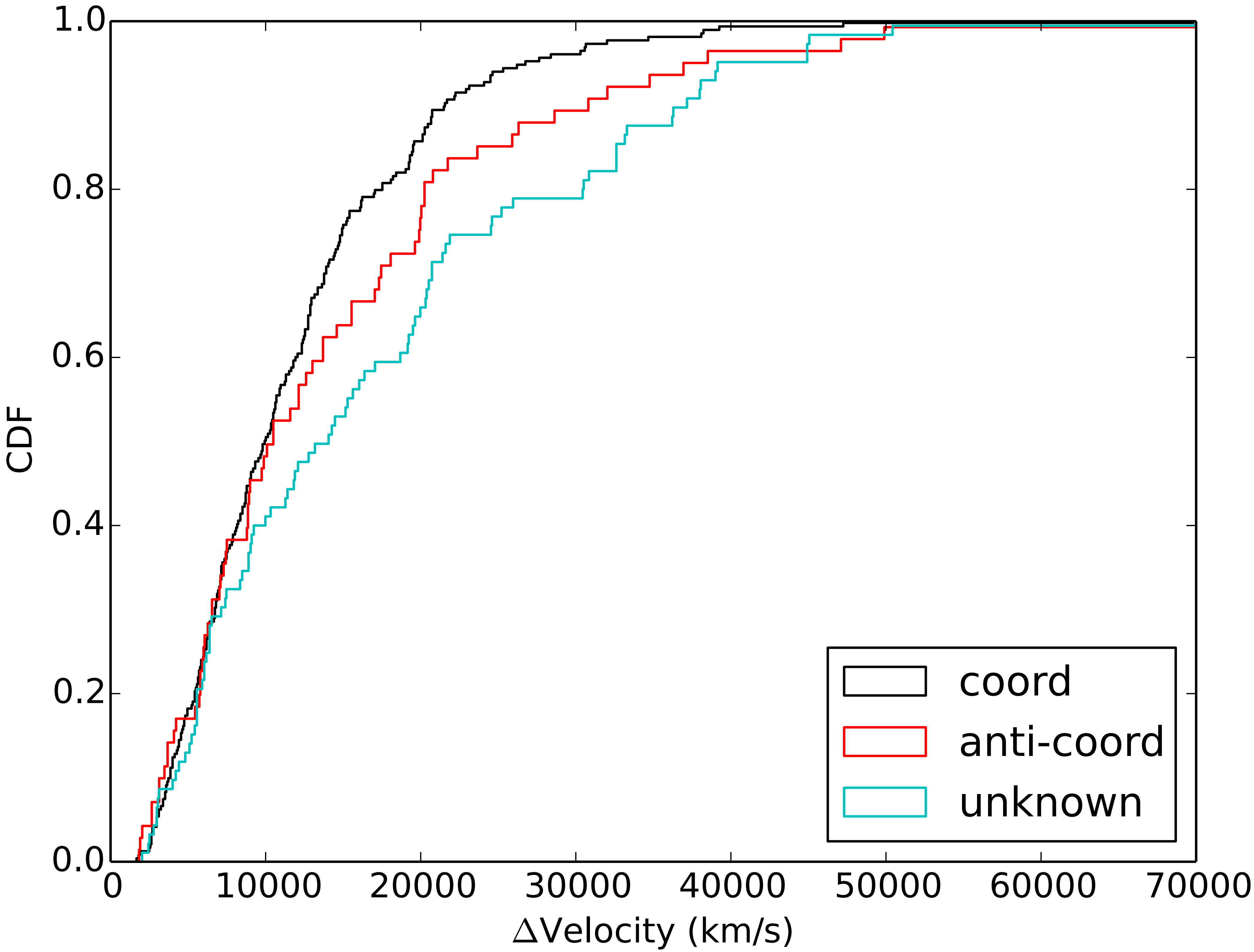
…and shallow. Seen to v=60,000 km/s search limit.



v-dependent Coordinated Variability

- From spectra in two epochs, measure the direction of variability of an absorption complex (strengthen, weaken, or no change [< 3 sigma variation in EW])
- Compare to next absorption complex at a higher outflow velocity in same quasar: are the changes in the same direction (coordinated) or opposite (anti-coordinated), or indeterminate (unknown)?
- Repeat for all pairs of complexes and plot the three cumulative distribution functions.

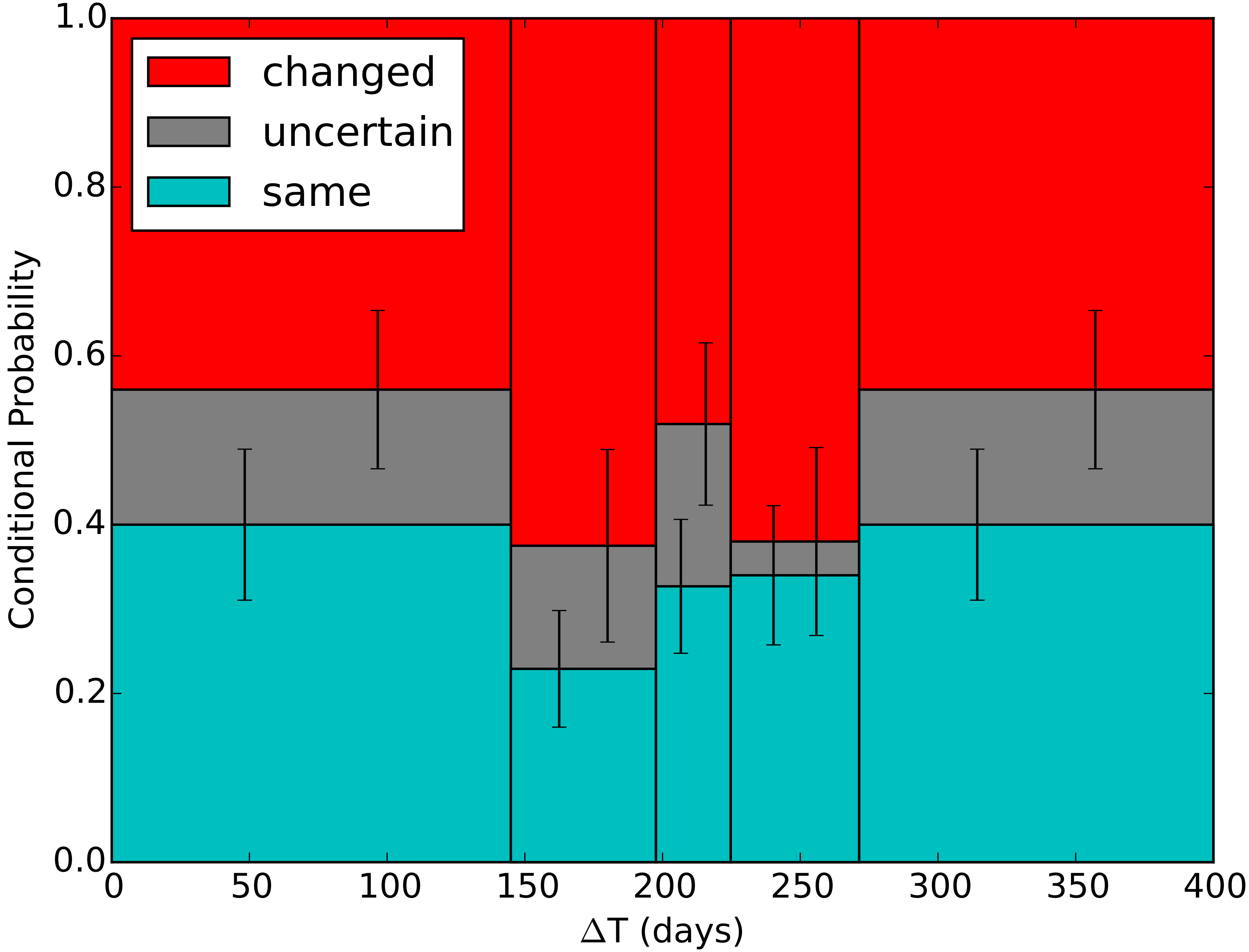
Coordinated variability (black line) is relatively less common at higher velocities.



v-dependent coordinated variability

- p=0.017 chance that coordinated and anti-coordinated variability in our sample are drawn from the same parent distribution
- p=0.0001 that coordinated and unknown variability drawn from same parent distribution
- p=0.15 that anti-coordinated and unknown variability drawn from same parent distribution
- Troughs closer in velocity are more likely to vary in a coordinated manner. If outflows decrease in density as they are accelerated, then outflows at similar velocities are more likely to vary in concert, since ionization variability response is ρ-dependent.

Direction of variability between epochs 2-3 uncorrelated with direction between epochs 1-2 on rest-frame timescales of 100 days or more…



…consistent with Grier et al. (2015) timescale of 40 days.

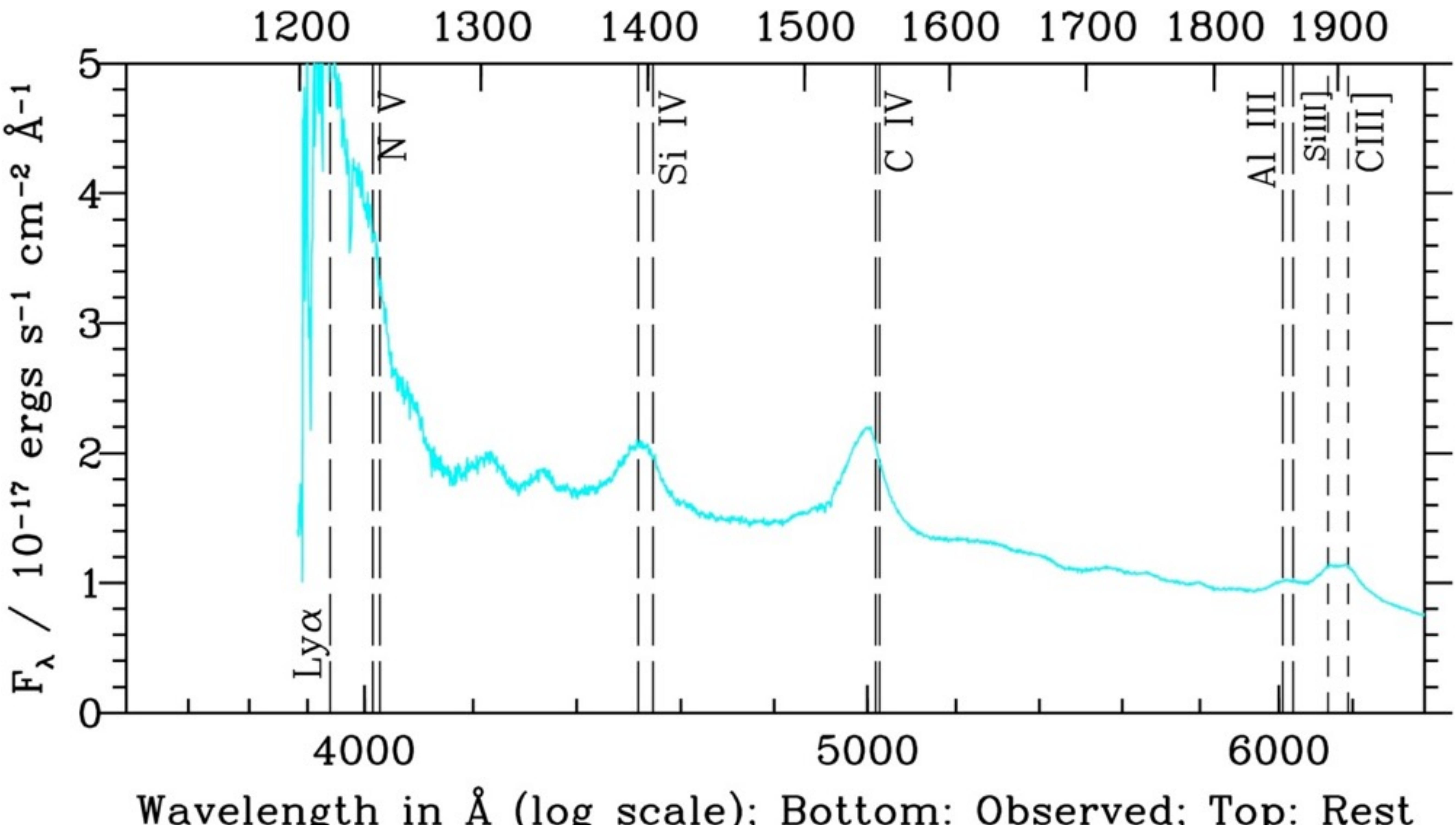
Redshifted Broad Absorption Troughs in Quasars

- If due to fallback or rotation, challenge models
- Any due to binary quasars would offer new sightlines through BAL outflows

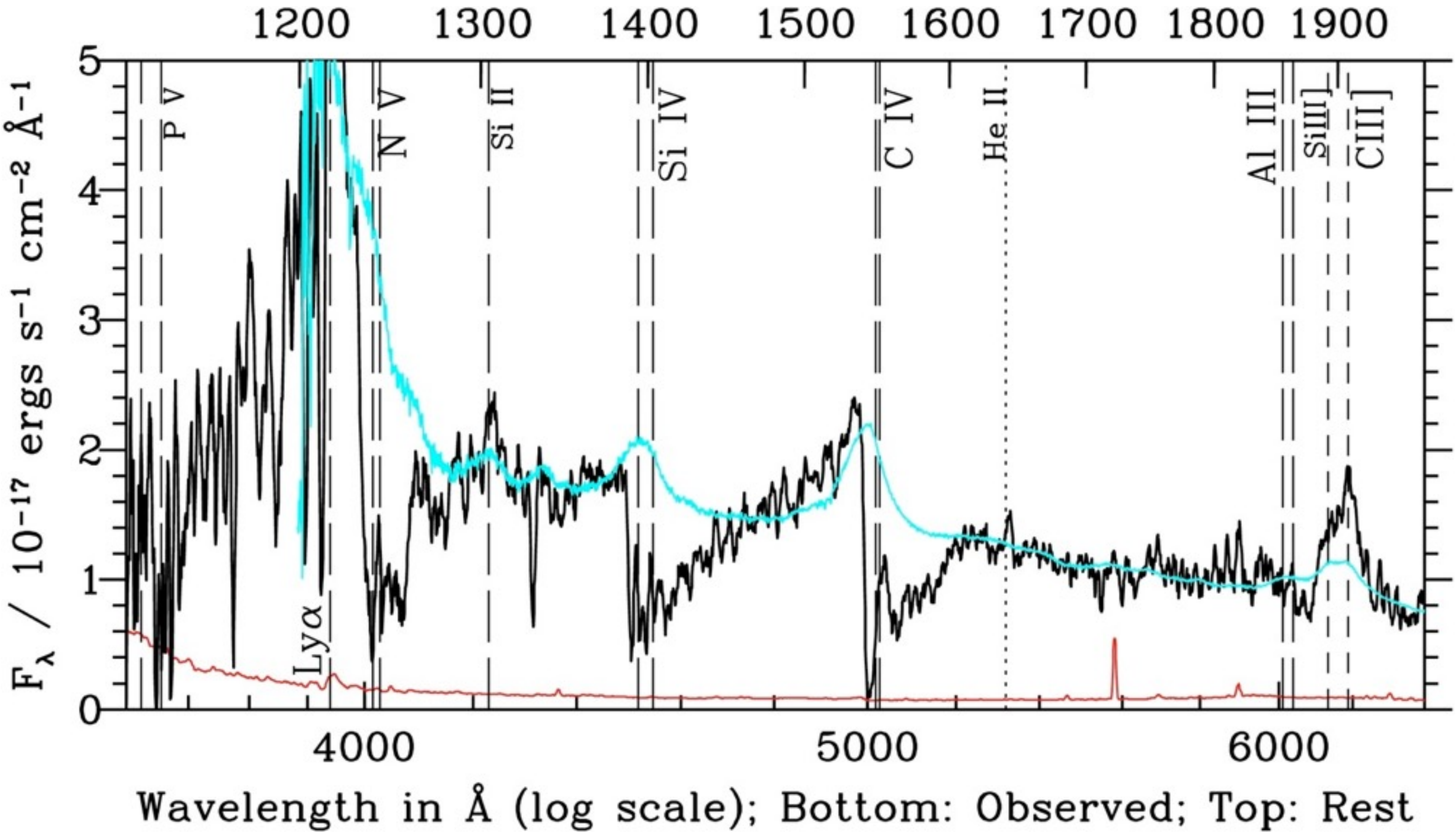
Redshifted-Trough BAL Quasars

- Work in the quasar rest frame, so that redshifted refers to gas that appears to be moving in the direction away from us, and blueshifted to gas that appears to be moving towards us.
- Among ~12,000 BAL quasars studied in SDSS-III, 17 found with *redshifted* absorption in C IV and other ions of similar ionization state, from gas that appears to be moving in the direction away from us.
- Seven additional high-ionization candidates.
- Two cases of redshifted Mg II at low redshift (Hall et al. 2002), and one candidate.

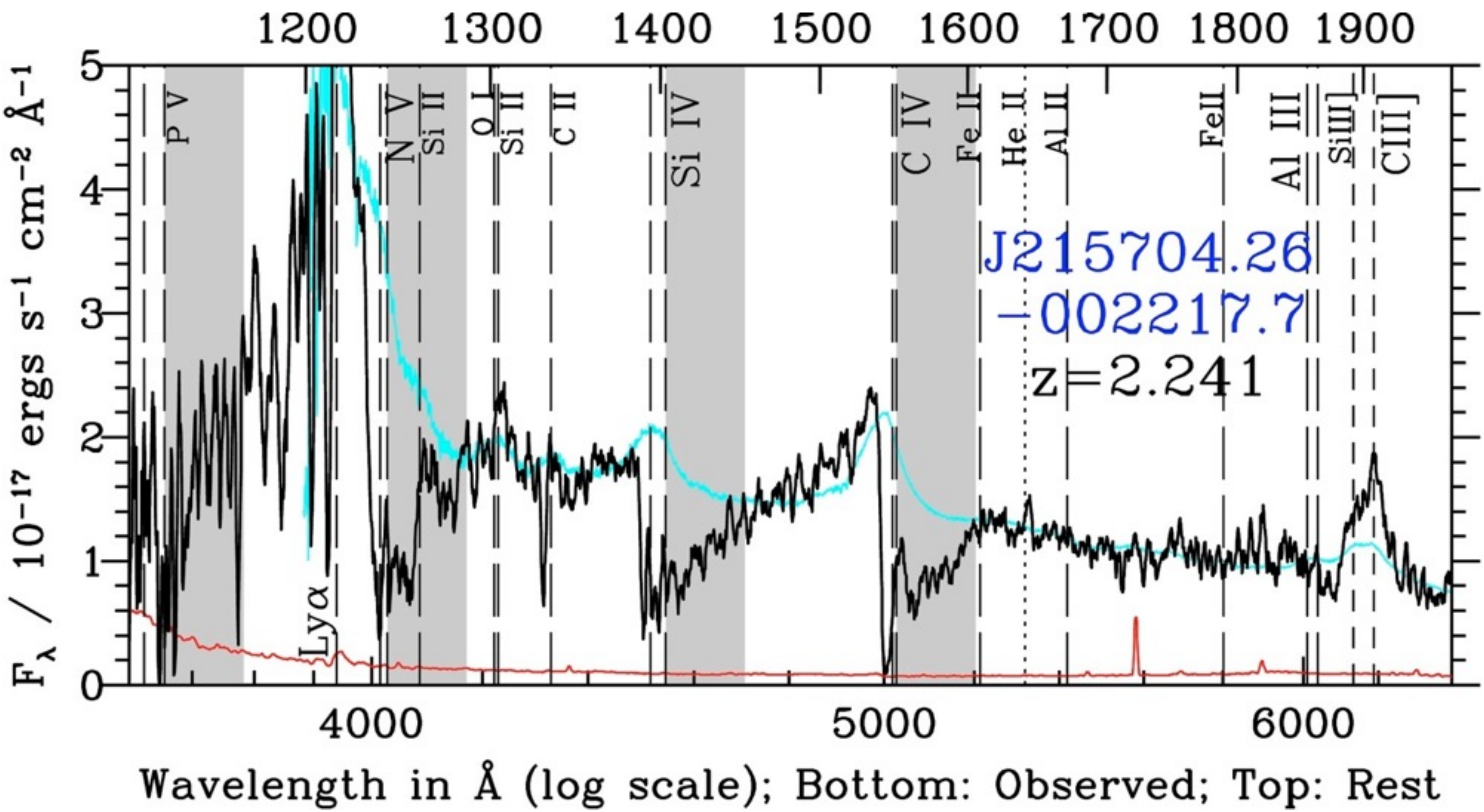
Unabsorbed quasar spectrum

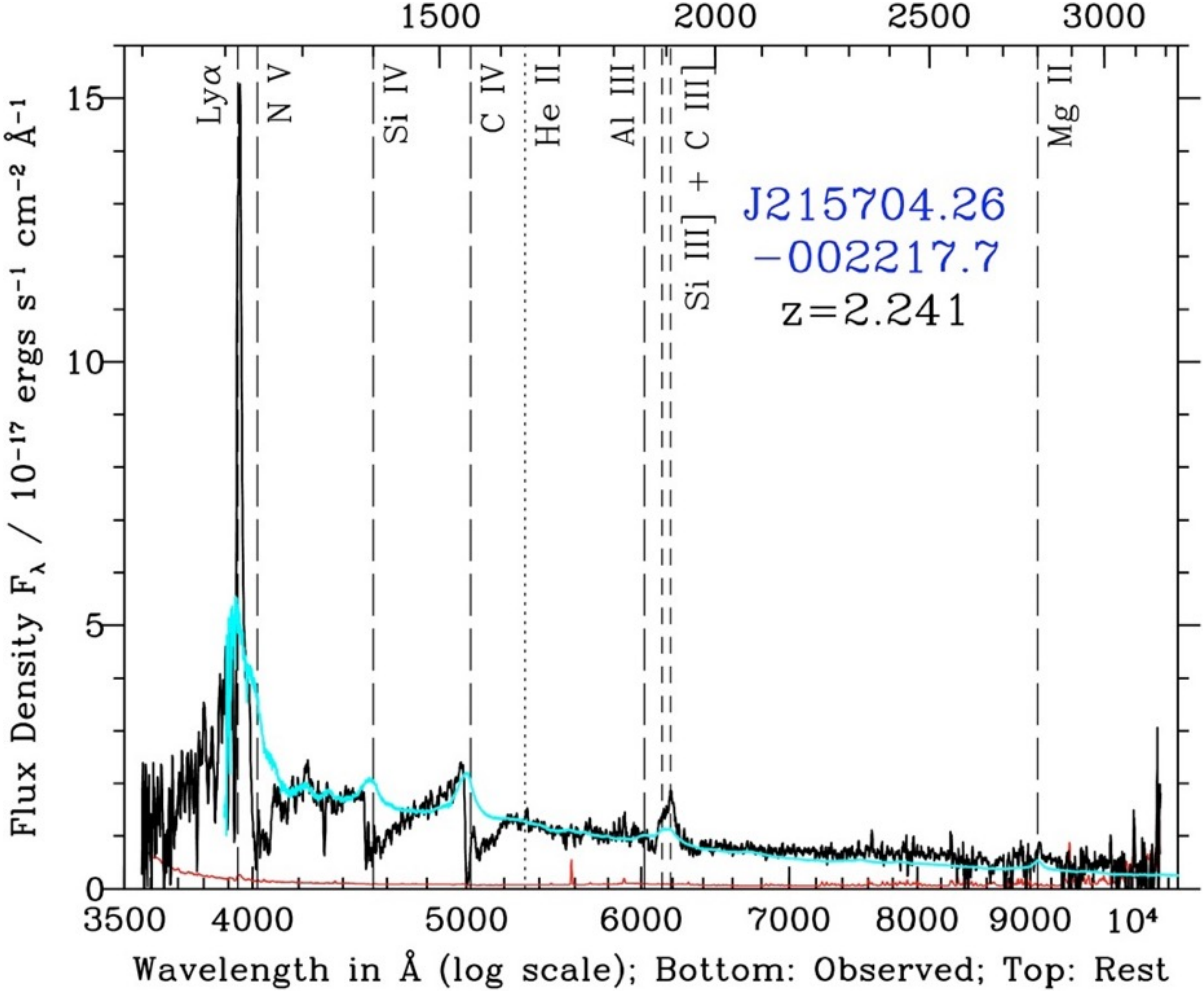


Unabsorbed quasar vs. quasar with redshifted absorption



Gray regions indicate velocity ranges of strongest redshifted absorption

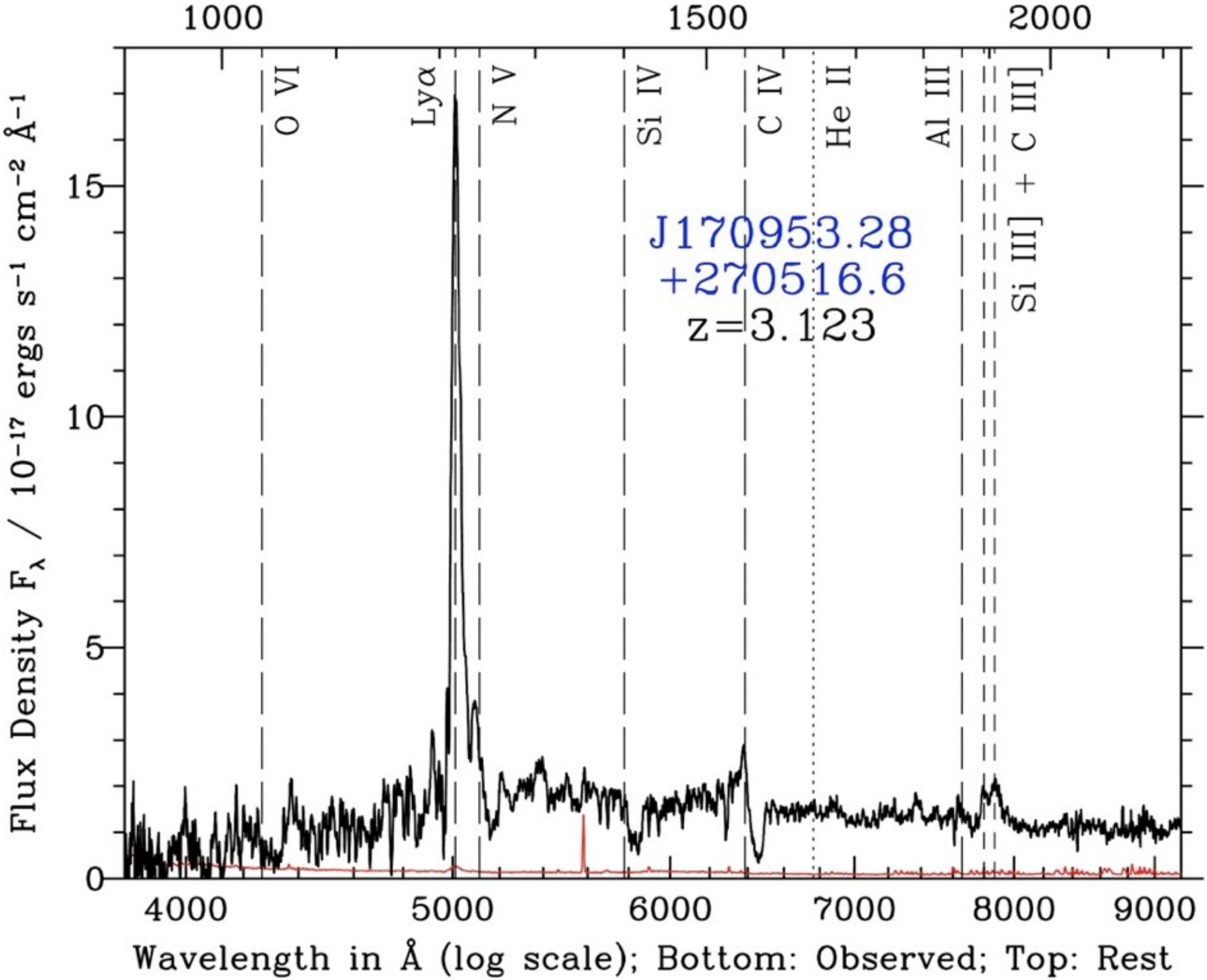




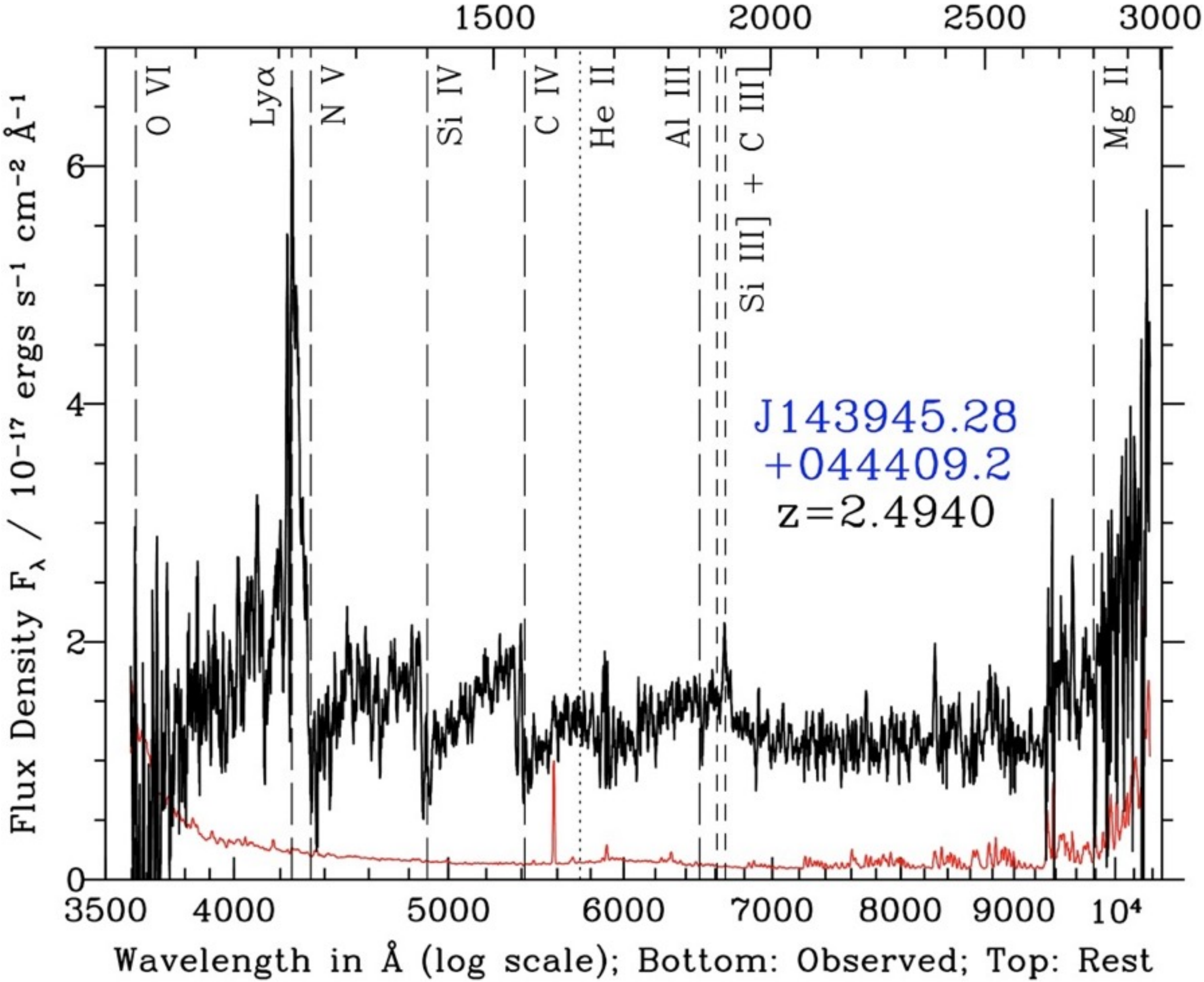
1500
2000
2500
3000
Lyα
N V
Si IV
C IV
He II
Al III
Si III] + C III]
Mg II
J215704.26
−002217.7
z=2.241
Flux Density F_λ / 10⁻¹⁷ ergs s⁻¹ cm⁻² Å⁻¹
15
10
5
0
3500
4000
5000
6000
7000
8000
9000
10⁴
Wavelength in Å (log scale); Bottom: Observed; Top: Rest

Redshifted absorption

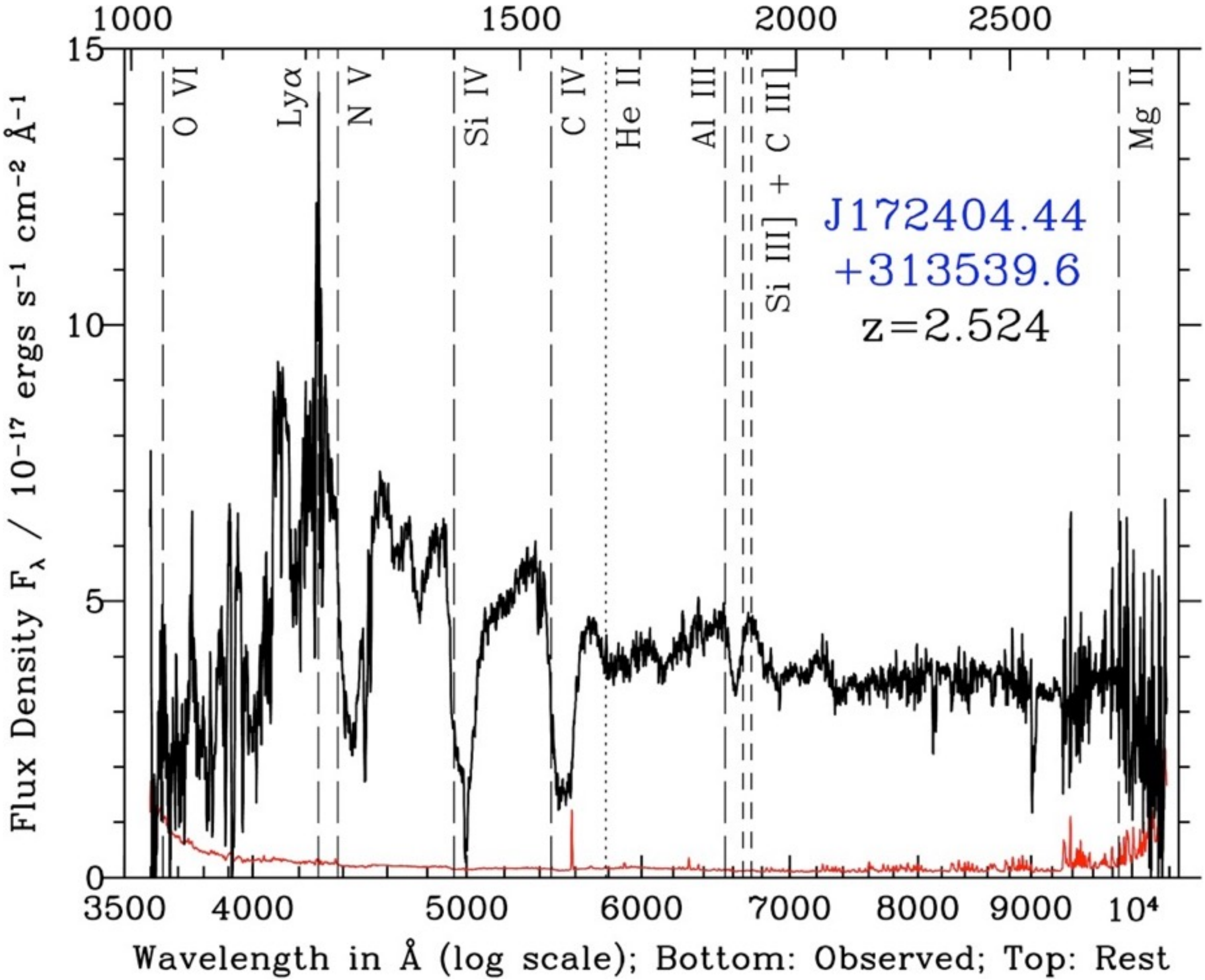
- Sometimes only redshifted absorption is seen



1000
1500
2000
O VI
Lyα
N V
Si IV
C IV
He II
Al III
Si III] + C III]
J170953.28
+270516.6
z=3.123
Flux Density F_λ / 10^{-17} ergs s^{-1} cm^{-2} $Å^{-1}$
0
5
10
15
4000
5000
6000
7000
8000
9000
Wavelength in Å (log scale); Bottom: Observed; Top: Rest



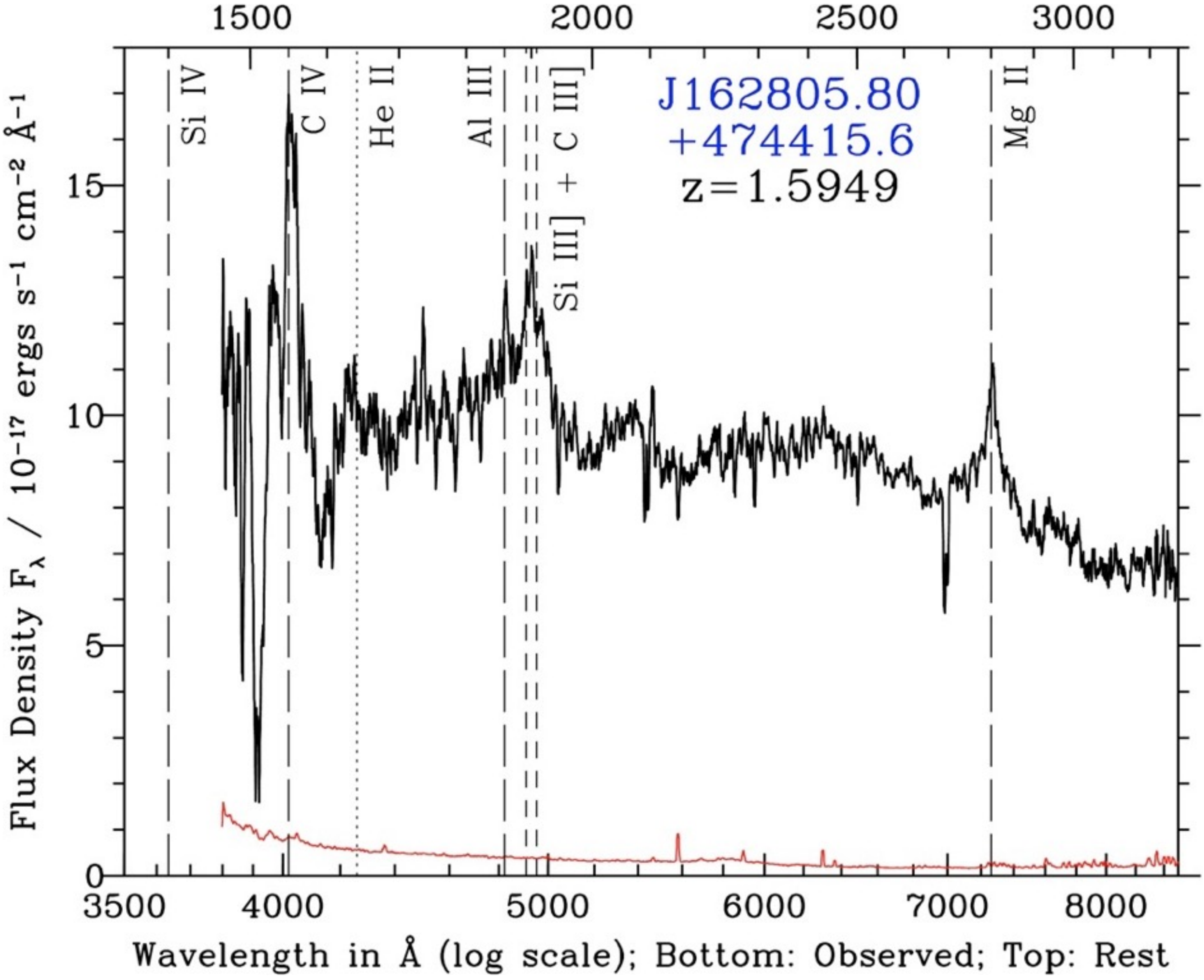
1500
2000
2500
3000
O VI
Lyα
N V
Si IV
C IV
He II
Al III
Si III] + C III]
Mg II
J143945.28
+044409.2
z=2.4940
Flux Density F_λ / 10^{-17} ergs s^{-1} cm^{-2} $Å^{-1}$
0
2
4
6
3500
4000
5000
6000
7000
8000
9000
10^4
Wavelength in Å (log scale); Bottom: Observed; Top: Rest



1000
1500
2000
2500
15
10
5
0
O VI
Lyα
N V
Si IV
C IV
He II
Al III
Si III] + C III]
Mg II
J172404.44
+313539.6
z=2.524
Flux Density F_λ / 10⁻¹⁷ ergs s⁻¹ cm⁻² Å⁻¹
3500
4000
5000
6000
7000
8000
9000
10⁴
Wavelength in Å (log scale); Bottom: Observed; Top: Rest

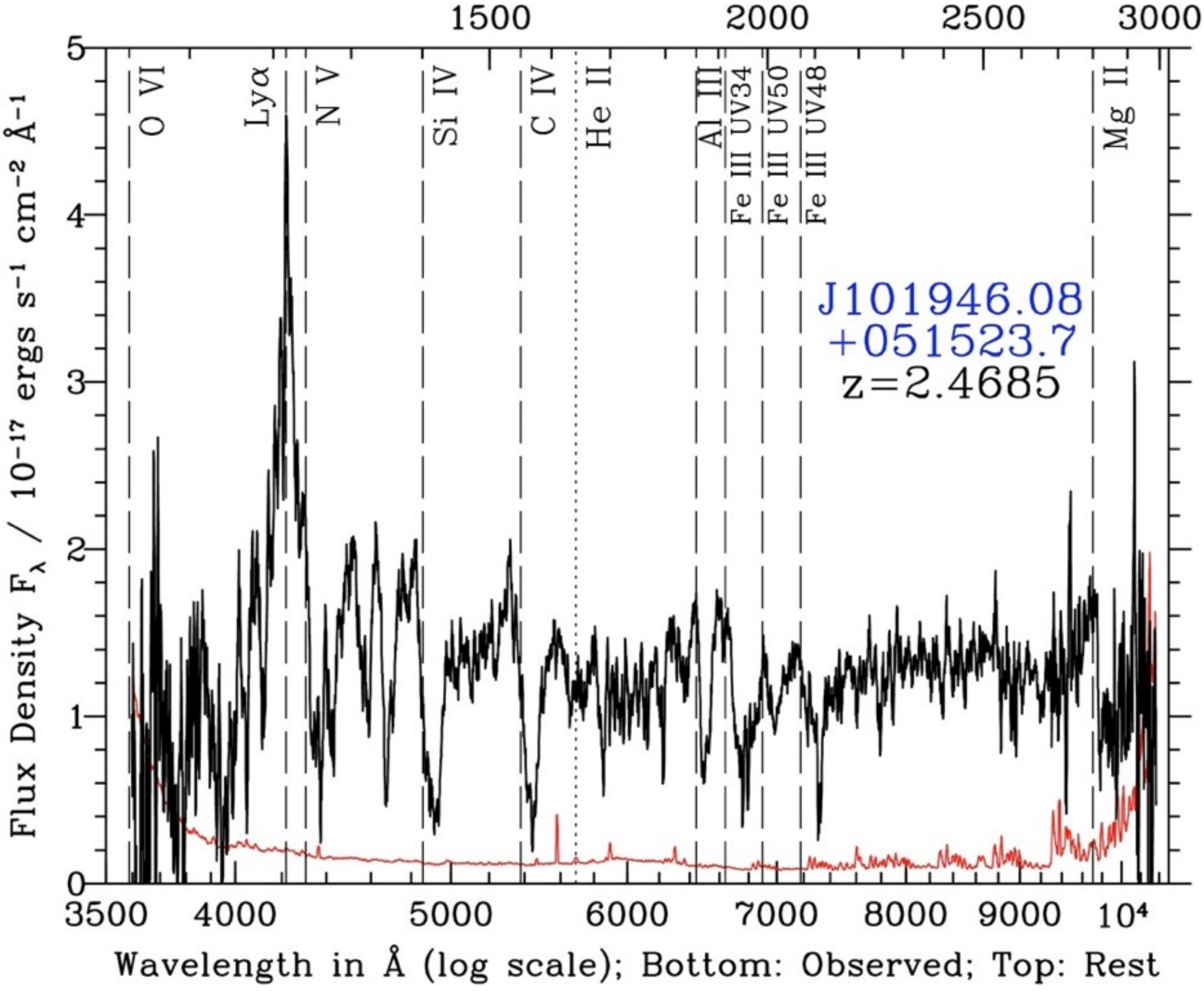
Redshifted absorption

- Sometimes only redshifted absorption is seen
- Sometimes seen in conjunction with blueshifted absorption (continuous or not)


J162805.80
+474415.6
z=1.5949
Si IV
C IV
He II
Al III
Si III] + C III]
Mg II
1500
2000
2500
3000
0
5
10
15
3500
4000
5000
6000
7000
8000
Flux Density F_λ / 10^{-17} ergs s^{-1} cm^{-2} Å^{-1}
Wavelength in Å (log scale); Bottom: Observed; Top: Rest

Redshifted absorption

- Sometimes only redshifted absorption is seen
- Sometimes seen in conjunction with blueshifted absorption (continuous or not)
- Sometimes seen in Fe III but not Fe II, which requires high density ($n_e \sim 10^9$ cm^{-3} or higher)



1500
2000
2500
3000
O VI
Lyα
N V
Si IV
C IV
He II
Al III
Fe III UV34
Fe III UV50
Fe III UV48
Mg II
J101946.08
+051523.7
z=2.4685
Flux Density F_λ / 10^{-17} ergs s^{-1} cm^{-2} $Å^{-1}$
3500
4000
5000
6000
7000
8000
9000
10^4
Wavelength in Å (log scale); Bottom: Observed; Top: Rest

Redshifted absorption

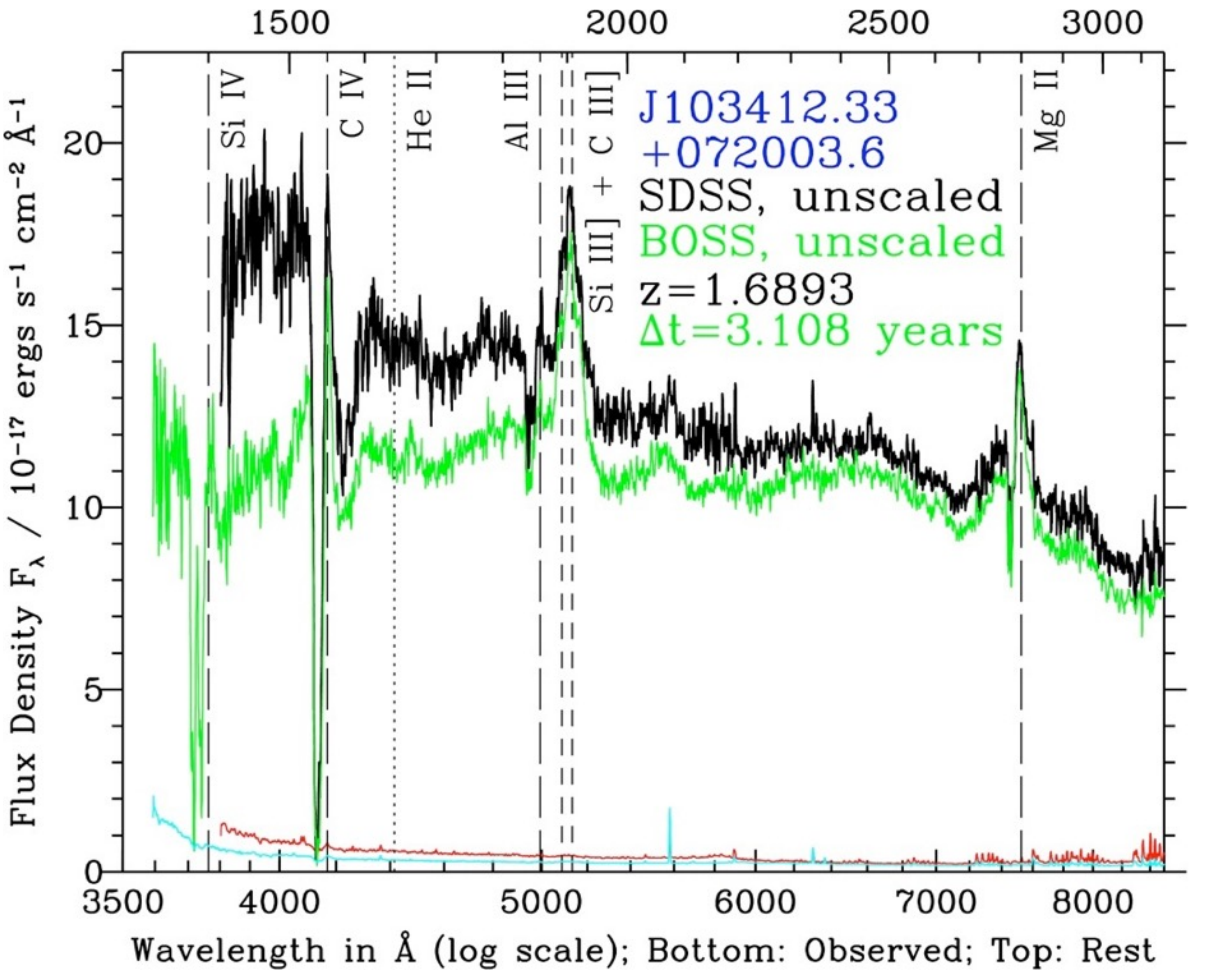
- Sometimes only redshifted absorption is seen
- Sometimes seen in conjunction with blueshifted absorption (continuous or not)
- Sometimes seen in Fe III but not Fe II, which requires high density (n_e~10^9 cm^{-3} or higher)
- Velocity ranges -13,000 km/s (blueshift) to +13,000 km/s (redshift), in different objects

Follow-up Studies

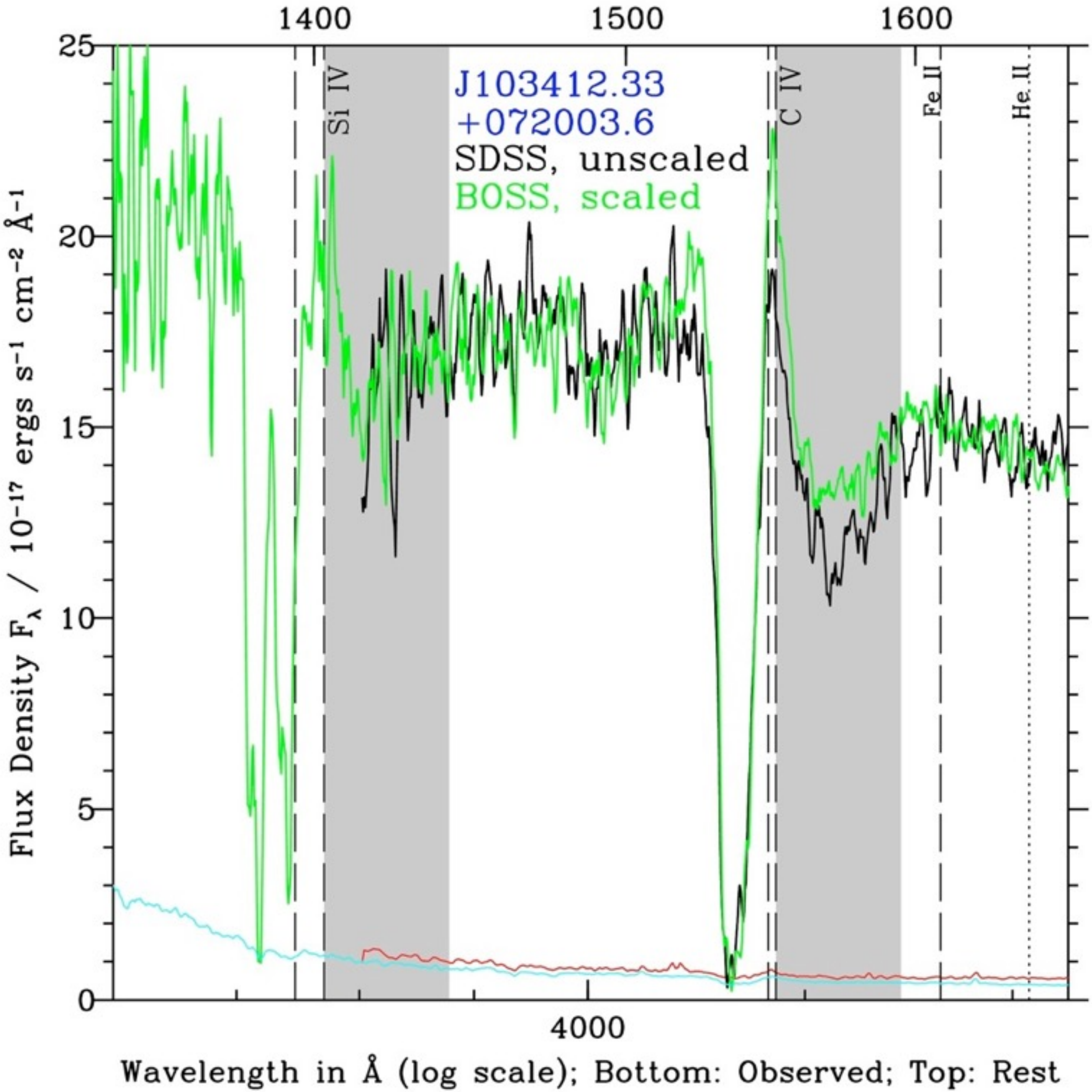
- Zhang et al. 2017 (ApJ): X-ray observations
- Ahmed et al. 2017 (in prep): follow-up spectroscopy and modelling of radial infall

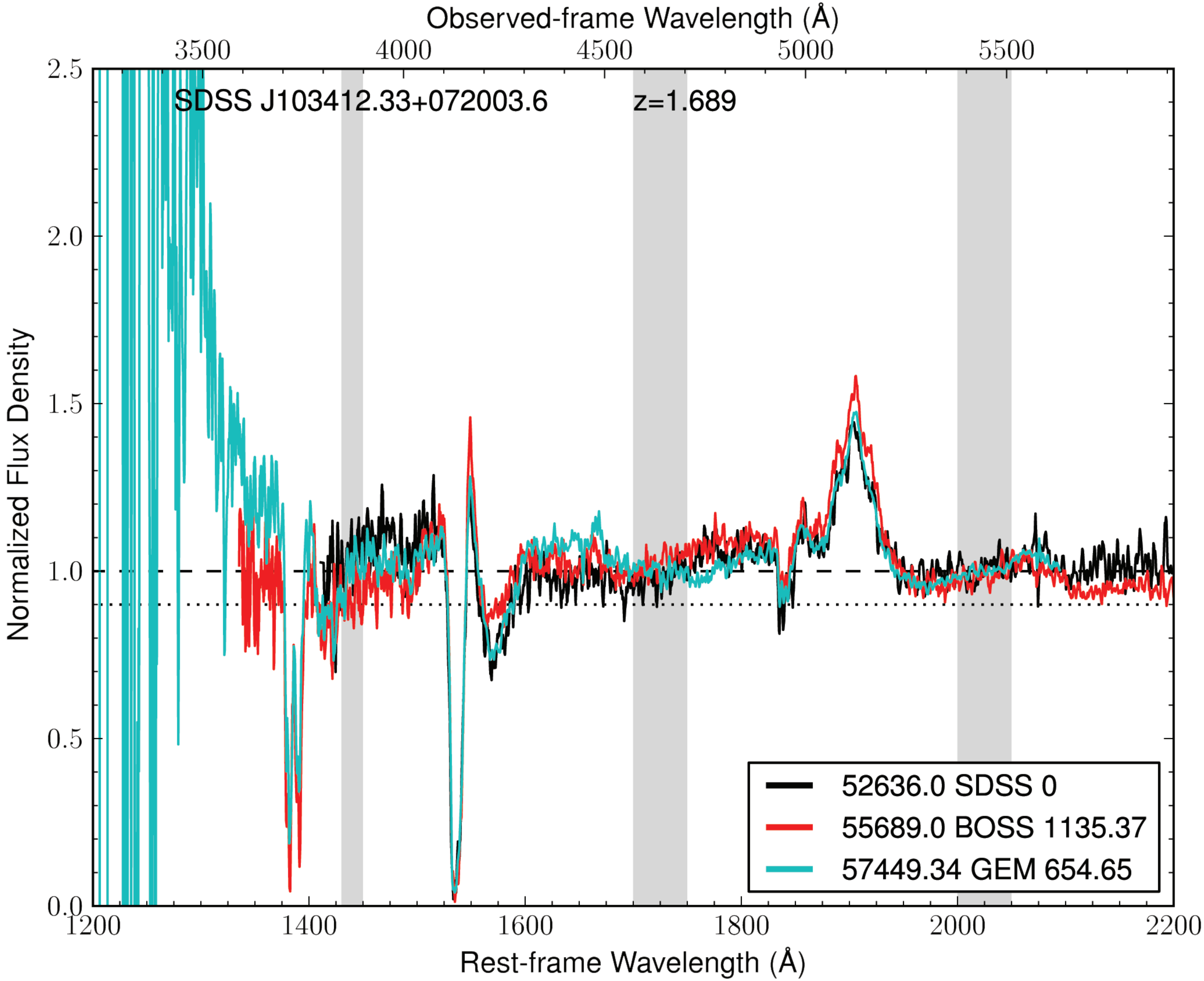
Variability

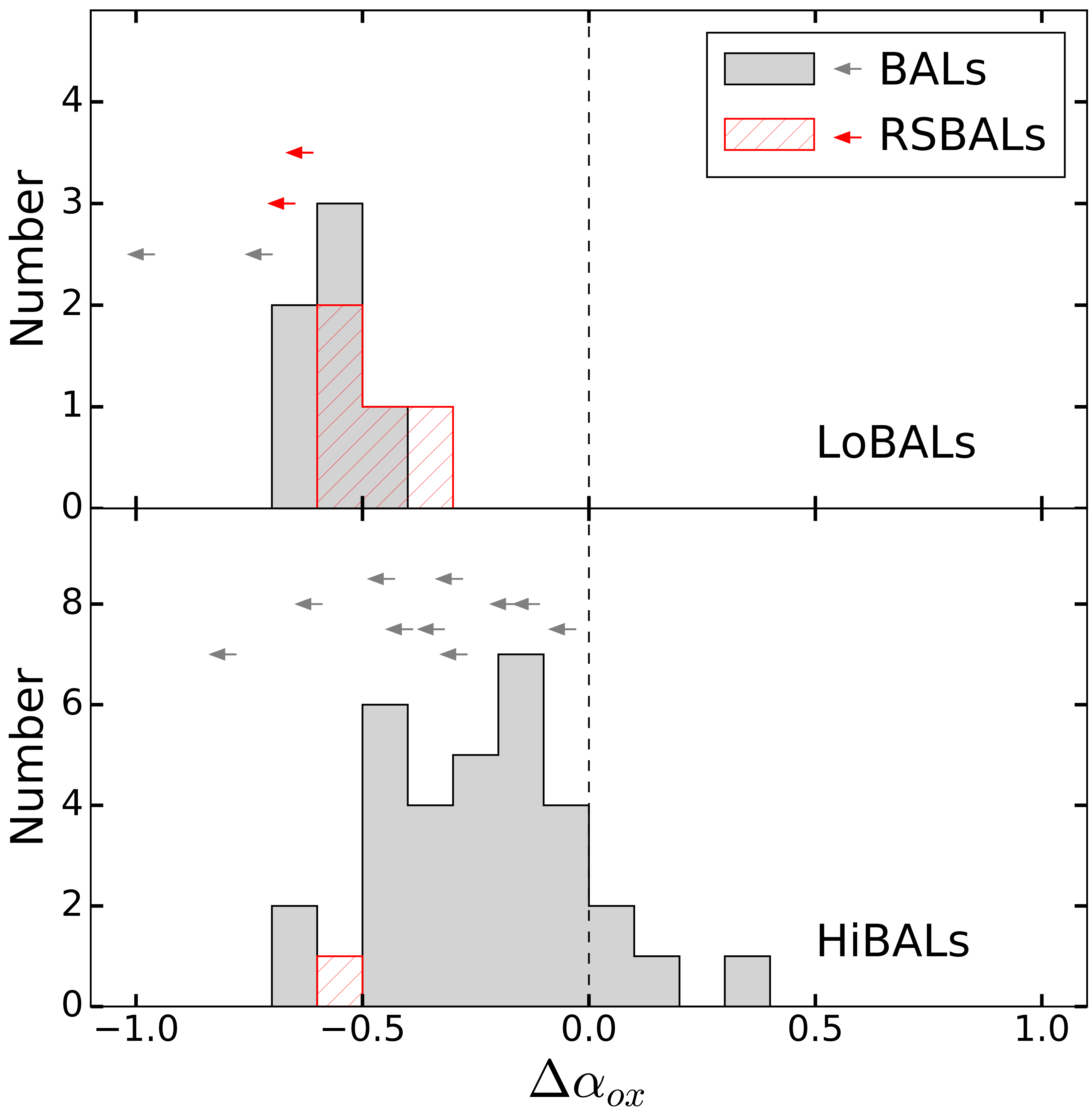
- Four high-ionization redshifted-trough objects with spectra from both SDSS and BOSS
- Two low-ionization redshifted-trough objects with spectra from both SDSS and BOSS
- 7 Chandra targets with Gemini followup spectra
- Little variability on 1-5 year timescales
- Crossing time of optical/UV continuum source of a 10^9 M_{Sun} BH at 1% lightspeed is roughly 1 year (all timescales rest-frame)



1500
2000
2500
3000
Si IV
C IV
He II
Al III
Si III] + C III]
Mg II
J103412.33
+072003.6
SDSS, unscaled
BOSS, unscaled
z=1.6893
Δt=3.108 years
Flux Density F_λ / 10^-17 ergs s^-1 cm^-2 Å^-1
0
5
10
15
20
3500
4000
5000
6000
7000
8000
Wavelength in Å (log scale); Bottom: Observed; Top: Rest


J103412.33
+072003.6
SDSS, unscaled
BOSS, scaled
Si IV
C IV
Fe II
He II
1400
1500
1600
25
20
15
10
5
0
4000
Flux Density F_λ / 10^{-17} ergs s^{-1} cm^{-2} $Å^{-1}$
Wavelength in Å (log scale); Bottom: Observed; Top: Rest


Observed-frame Wavelength (Å)
3500
4000
4500
5000
5500
2.5
2.0
1.5
1.0
0.5
0.0
SDSS J103412.33+072003.6
z=1.689
Normalized Flux Density
52636.0 SDSS 0
55689.0 BOSS 1135.37
57449.34 GEM 654.65
1200
1400
1600
1800
2000
2200
Rest-frame Wavelength (Å)



Zhang et al.: RSBALs have alpha_ox distribution consistent with normal BAL quasars; i.e., <u>similar X-ray absorption levels</u>

Possible Explanations

- Infall or Fallback
- Rotating wind + extended continuum source
- Binary quasars + silhouetted BAL outflow
- Relativistic Doppler shift
- Some combination of the above
- Ruled out: gravitational redshift (requires infalling gas absorbing in C IV at few tens of r_g, 10x smaller radii than the C IV BELR)

Binary Quasars + silhouetted BAL outflow?

- BAL outflow from one quasar, backlit by another quasar. Requires a spatially unresolved quasar pair where:
  - The background quasar is the more optically luminous one, and produces the broad emission lines we see

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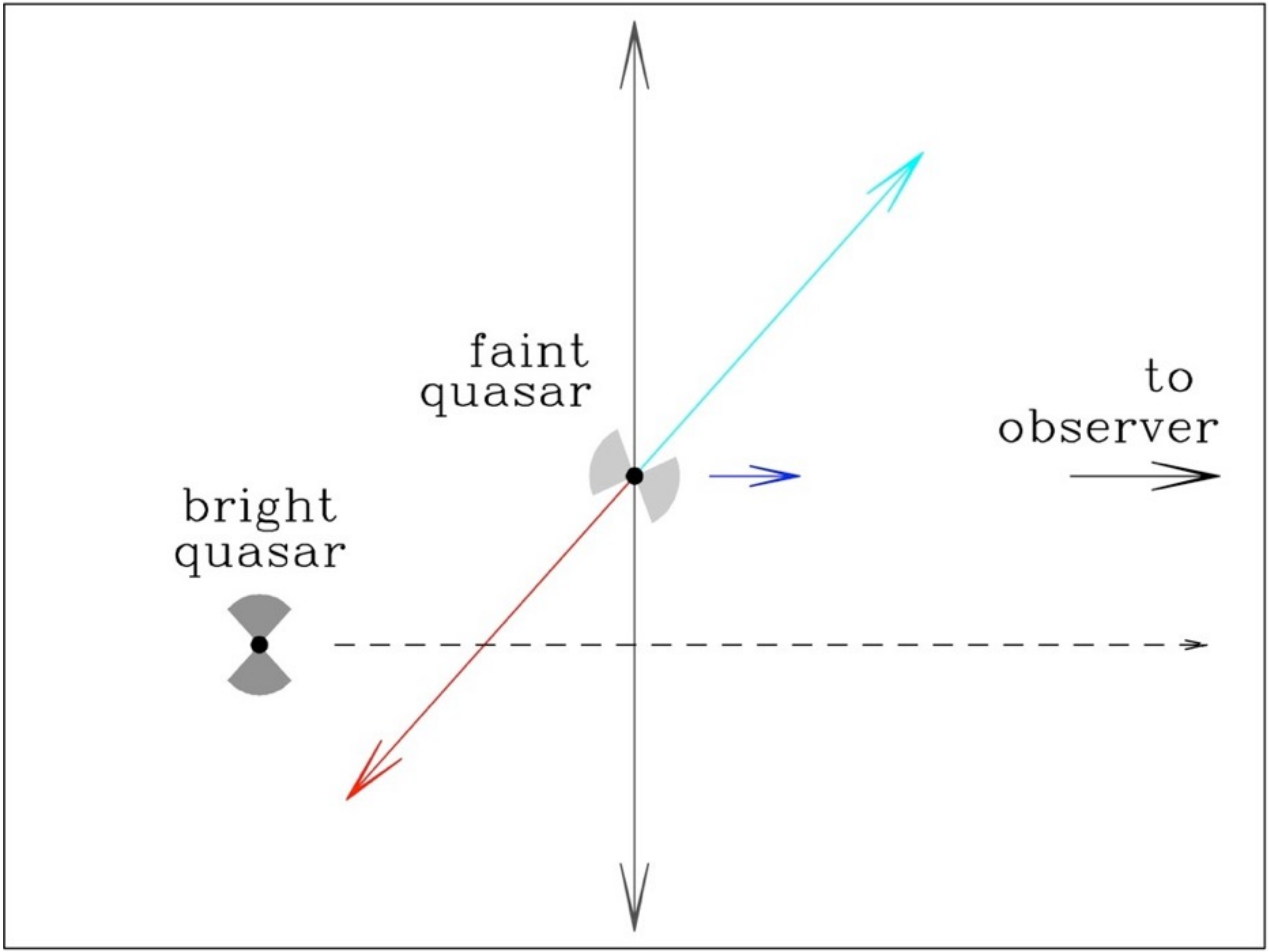
  - The background quasar is the more optically luminous one, and produces the broad emission lines we see
  - The foreground quasar produces a BAL outflow oriented such that the background quasar backlights it with a relative velocity producing redshifted absorption (The foreground quasar must be less luminous or obscured so that its unabsorbed continuum is not prominent in the summed spectrum.)



Binary Quasar Scenario for Redshifted Absorption Troughs

Binary Quasars + silhouetted BAL outflow?

- BAL outflow from one quasar, backlit by another quasar.
- Cannot explain why quasars with redshifted BAL troughs are X-ray weak: would expect most RSBALs to be X-ray normal. (Possible wiggle room if the X-ray absorption arises in the outflow itself.)
- So, cannot be the generic explanation for this population of objects. But, could still be an explanation for some individual objects.

Infall? Fallback?

- Characteristic velocity for galaxy centers is <500 km/s
- Characteristic densities for star-forming gas $<10^5$ cm^{-3} *(however, Swinbank et al. arXiv:1110.2780 suggest that at redshift ~ 2, star-forming gas might reach 10^8 cm^{-3} before forming stars, due to supersonic turbulent support)*
- Infalling gas not far out in galaxy; must be close to BH

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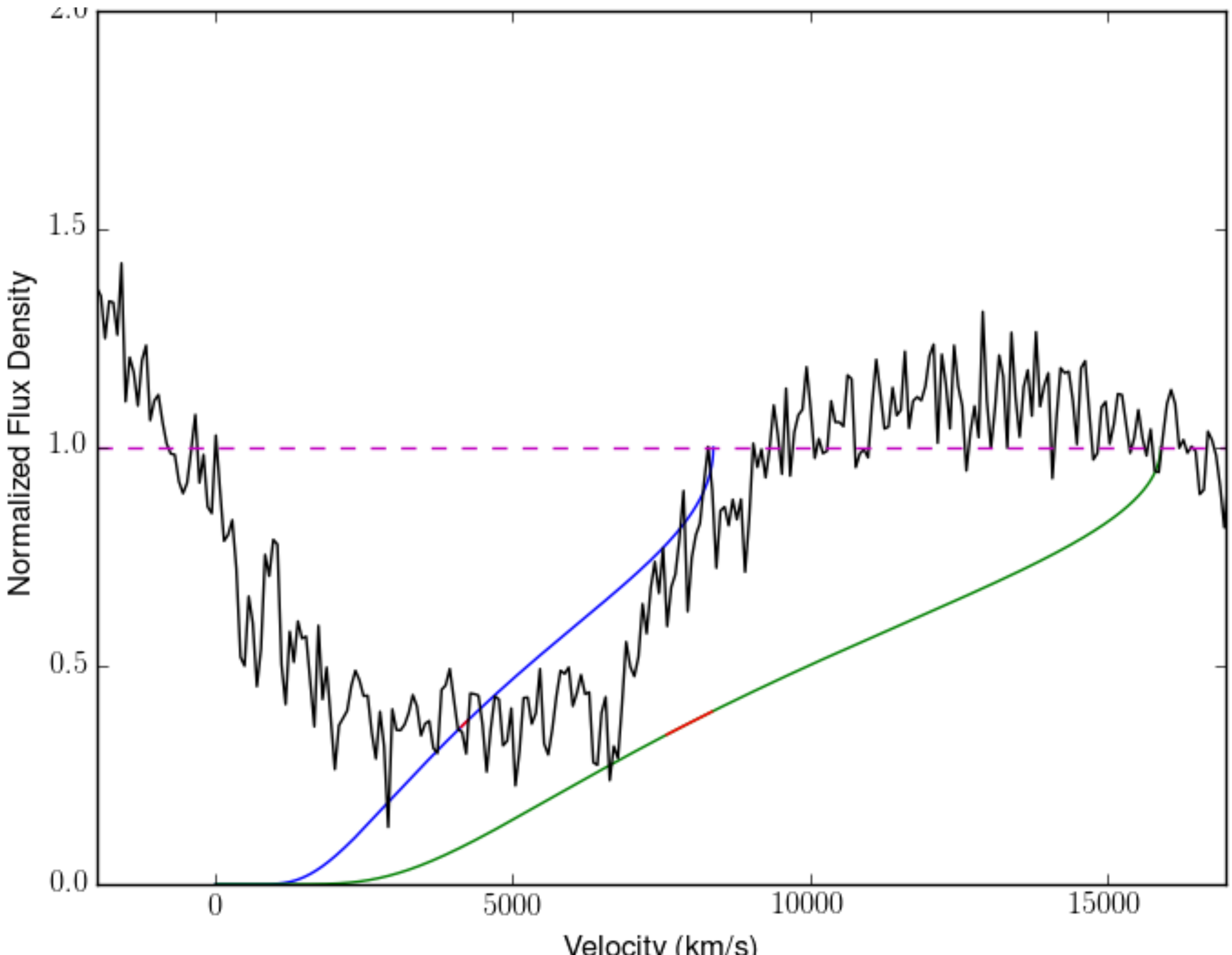
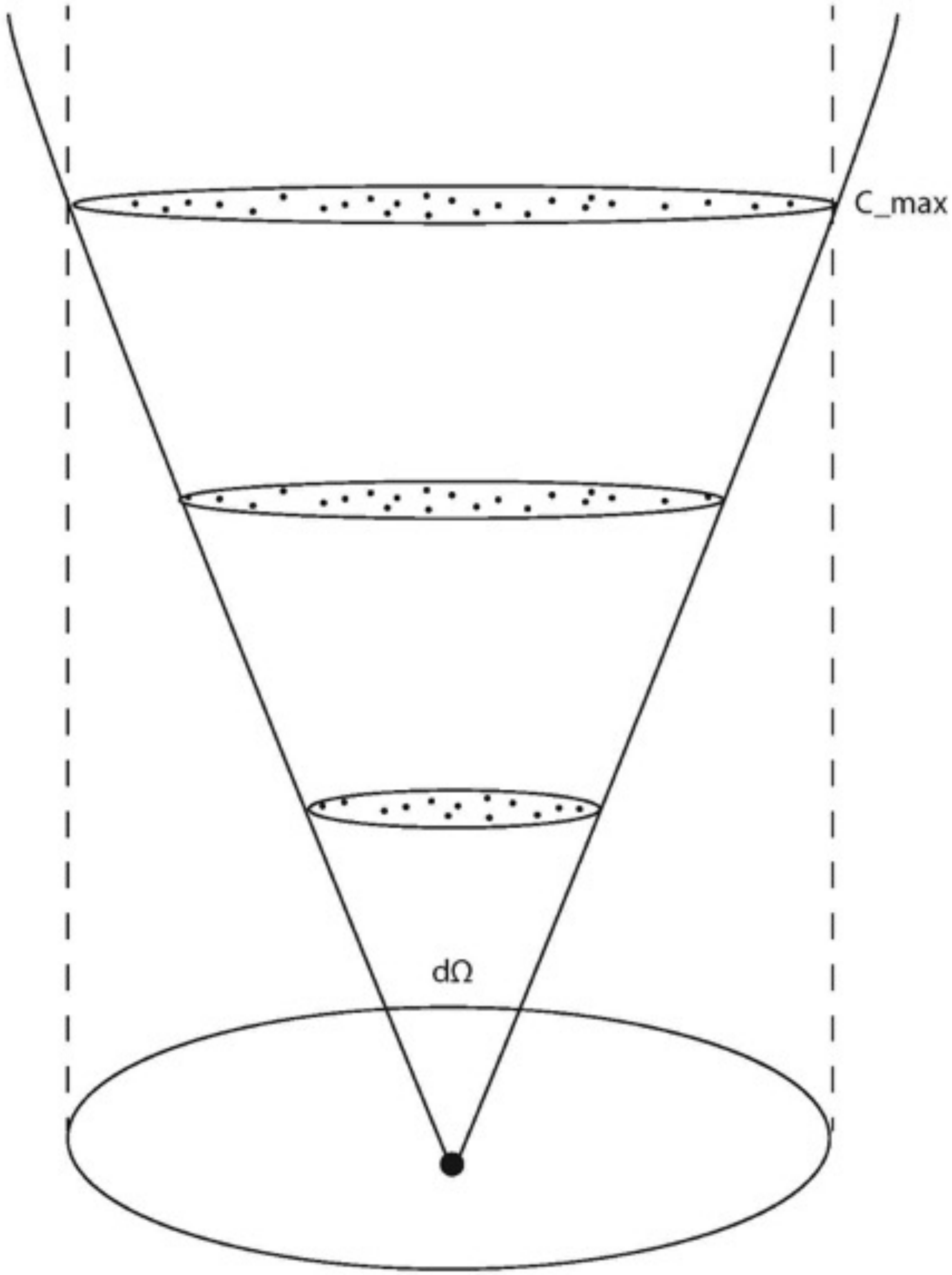
- Infalling gas not far out in galaxy; must be close to BH
- Infall to radius r from the BH will generate velocities up to the escape velocity from that radius: $v=(2GM_{BH}/r)^{1/2}$
- Requires infall to 1000 r_g (outer BLR). Seen in some simulations, but not with large observed optical depths.

Parabolic infall? No. (see red line segments)

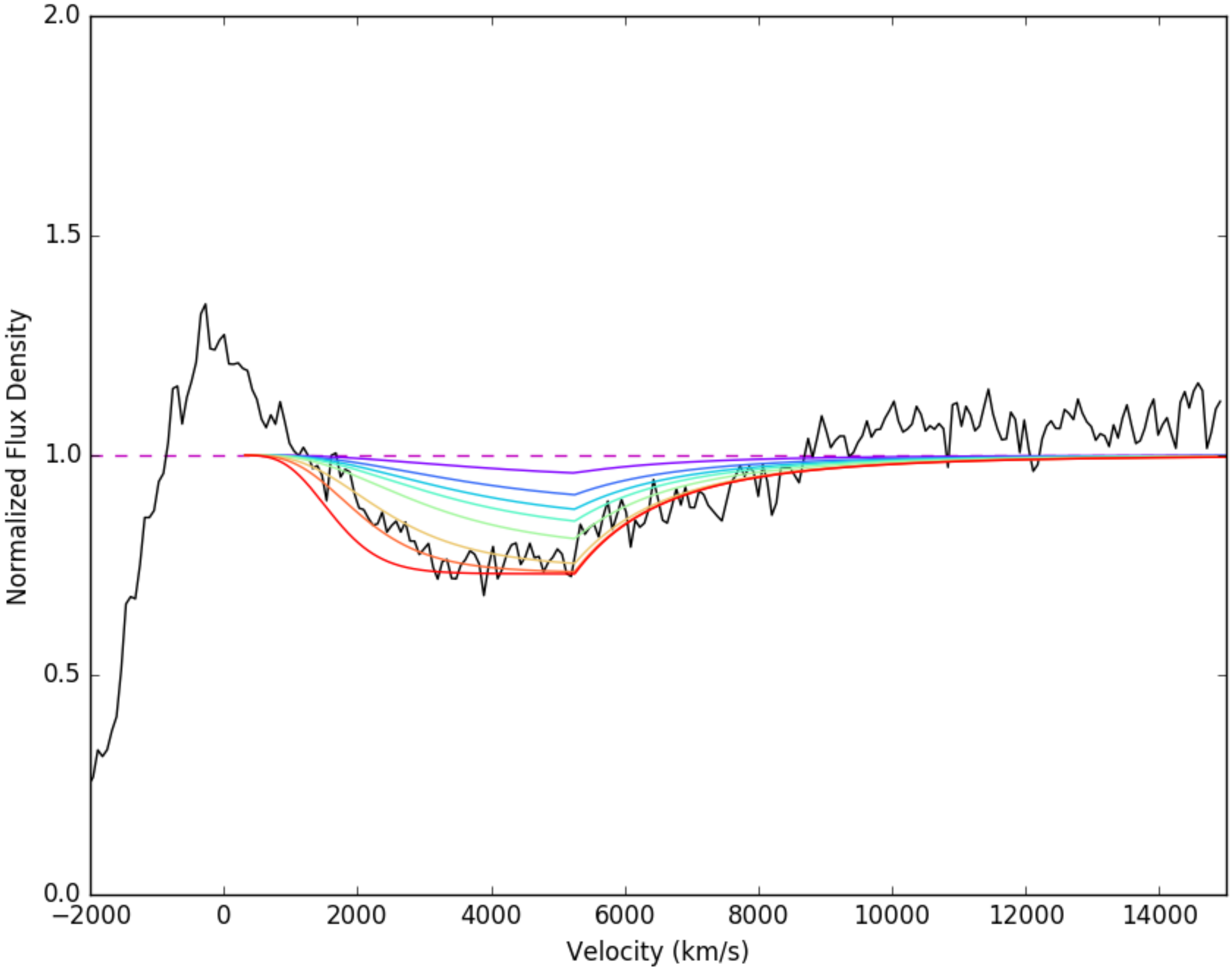




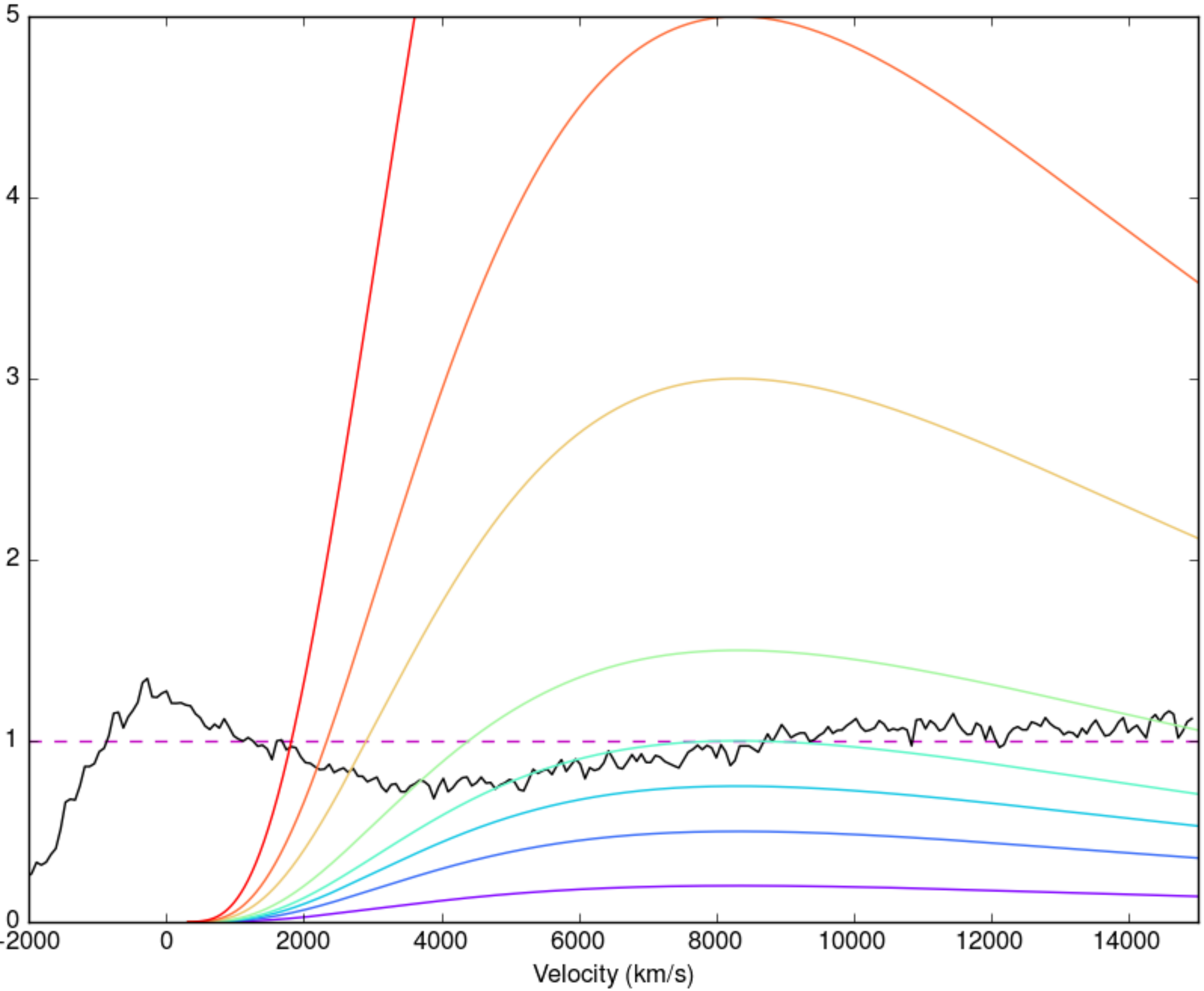
Radial infall of distinct clumps along fixed solid angle can reasonably reproduce some objects.

Model accounts only for C IV ionization fraction and radial acceleration due to gravity.

J1034 infall fits to normalized flux profile.



J1034 model tau values for infall fits.



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- Requires infall to 1000 r_g (outer BLR). Seen in some simulations, but not with large observed optical depths.
- Parabolic infall doesn't match observations, but radial infall can in some cases.
- Infall doesn't readily explain high LoBAL fraction.

Rotating wind + extended continuum source?

- *This effect originally proposed in Hall et al. (2002) to explain two cases of low-ionization (Mg II) absorption extending to redshifts of ~1,000 km/s; see also Ganguly et al. (1999).*
- Both rotational and outflow velocity components in wind.

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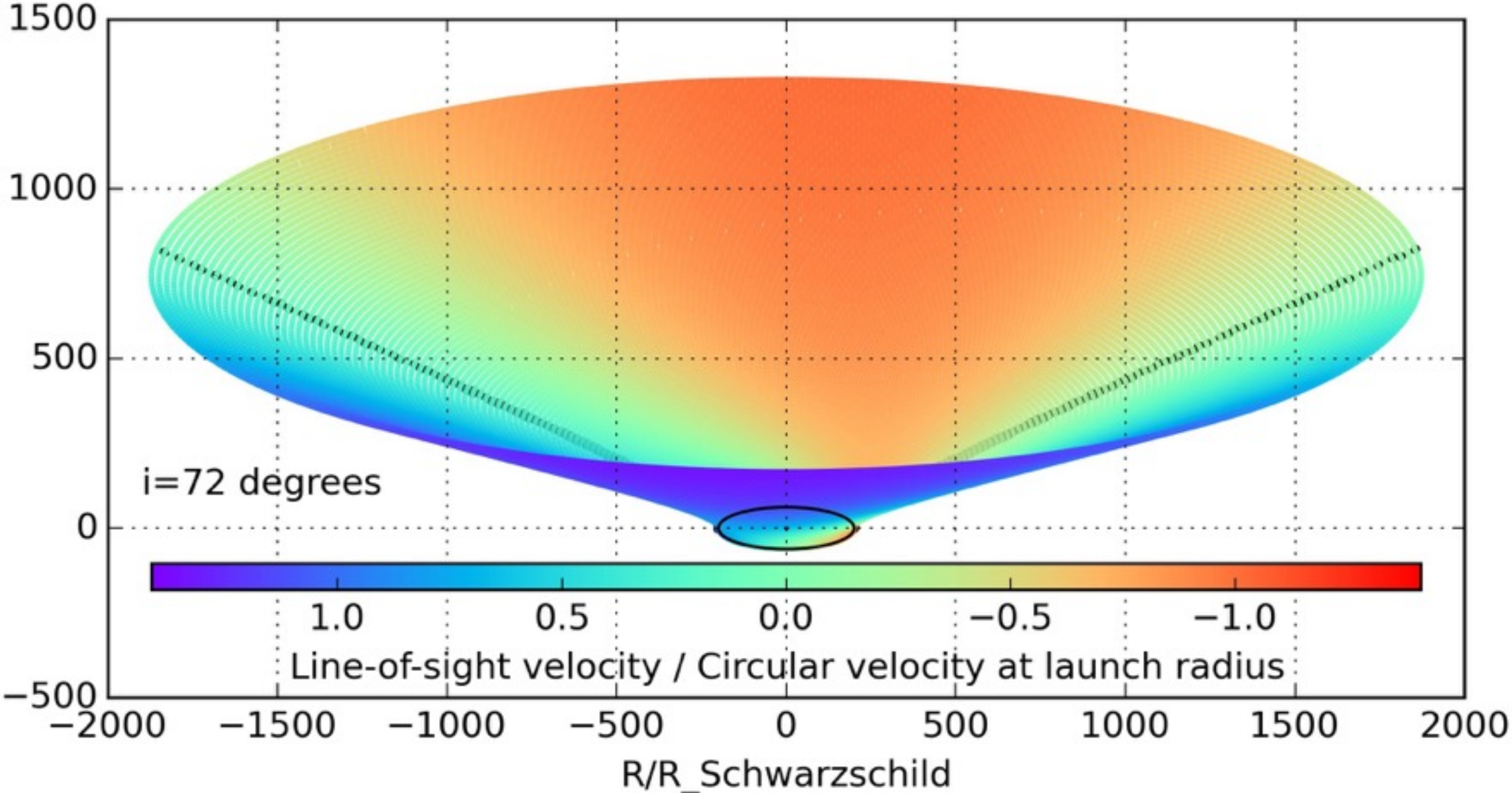
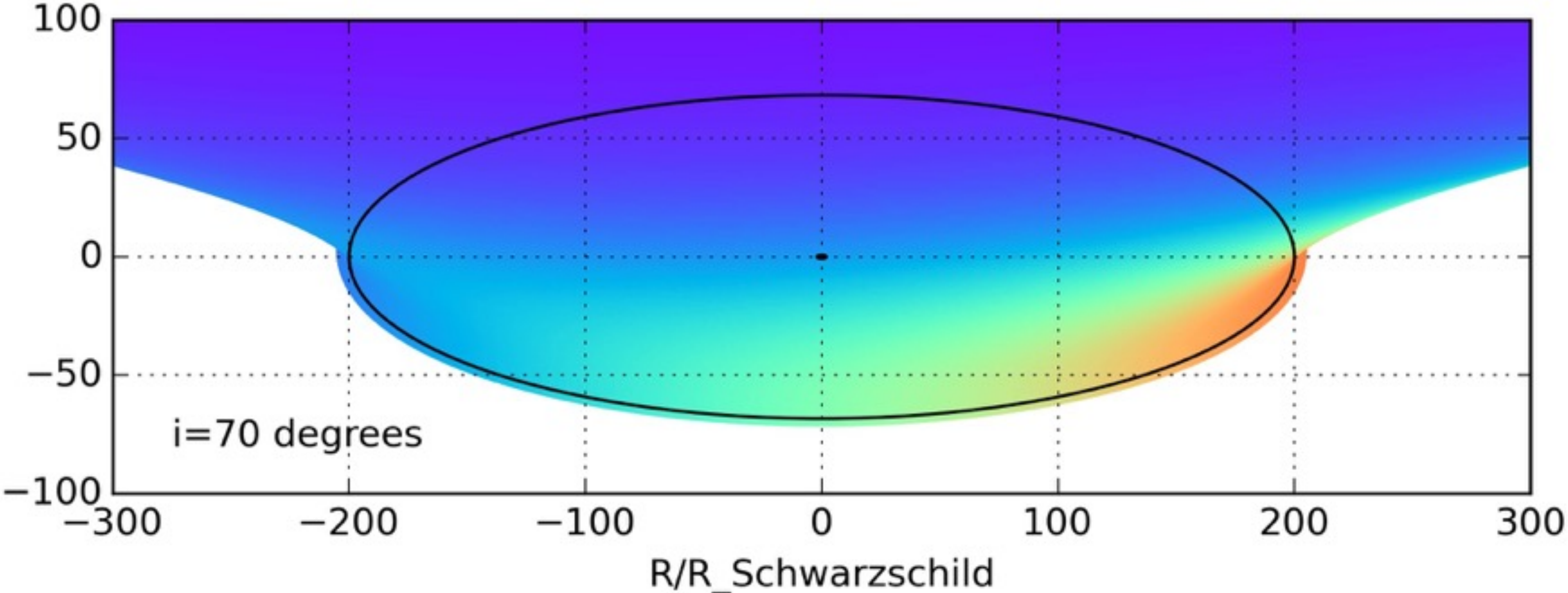
- Both rotational and outflow velocity components in wind.
- If the wind originates close enough to the extended continuum source, then parts of the wind rotating away from us will contribute to the absorption.
- If rotational velocity is large enough, net radial velocity vector from those parts of the wind will be redshifted.

Funnel-shaped rotating outflow: blue/red for blueshift/redshift



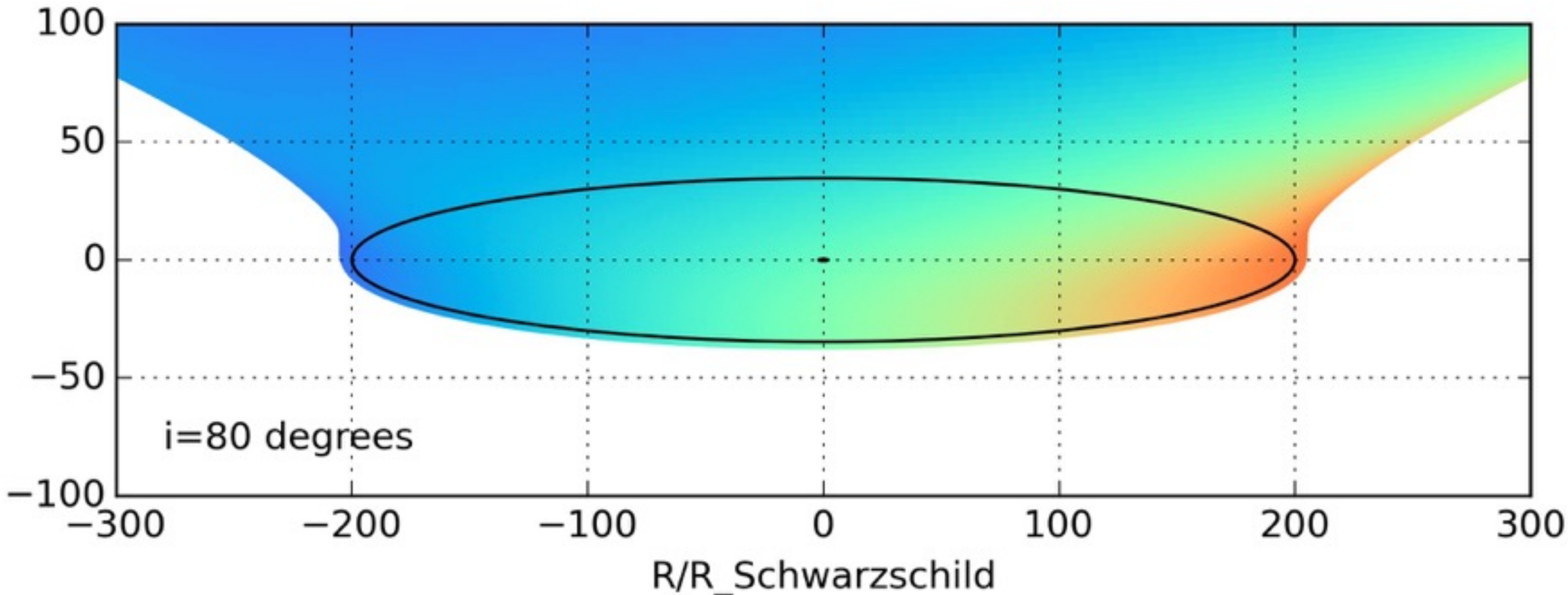
(near side velocities only)

Funnel-shaped rotating outflow: blue/red for blueshift/redshift



Black ellipse=continuum emission region; i=70 degrees

Funnel-shaped rotating outflow: blue/red for blueshift/redshift

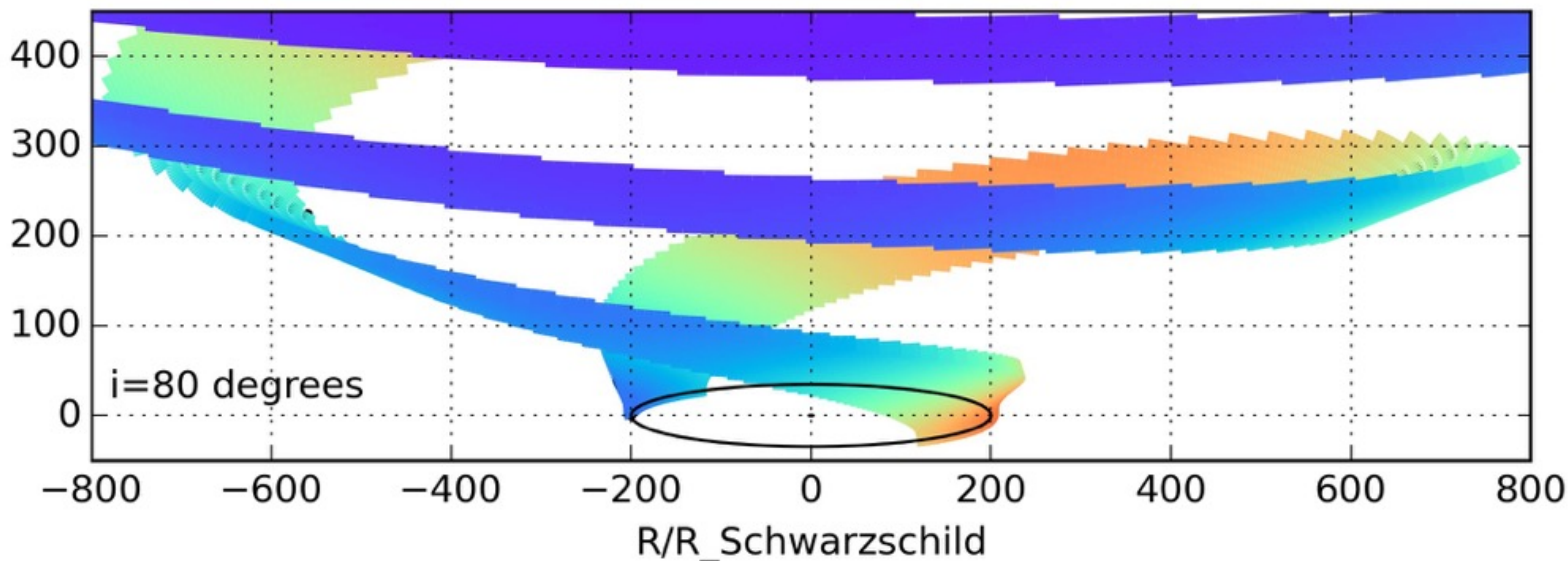


Black ellipse=continuum emission region; i=80 degrees

Rotating wind + extended continuum source?

- Applies to quasars with both blue- and redshifted troughs (though only redshifted absorption could be present at times if azimuthal symmetry of outflow is broken).
- Absorption must originate at radii not much larger than that of the extended continuum source.
- Disk must be viewed close to edge-on at launch radii; requires torus misaligned to that disk plane, or gappy.
- Required circumstances are not impossible. They would be uncommon, but so are these quasars...

Azimuthal asymmetries can yield cases of just redshifted absorption



(absorption seen only in front of black ellipse); i=80 degrees

Quasars with Redshifted Broad Absorption Lines

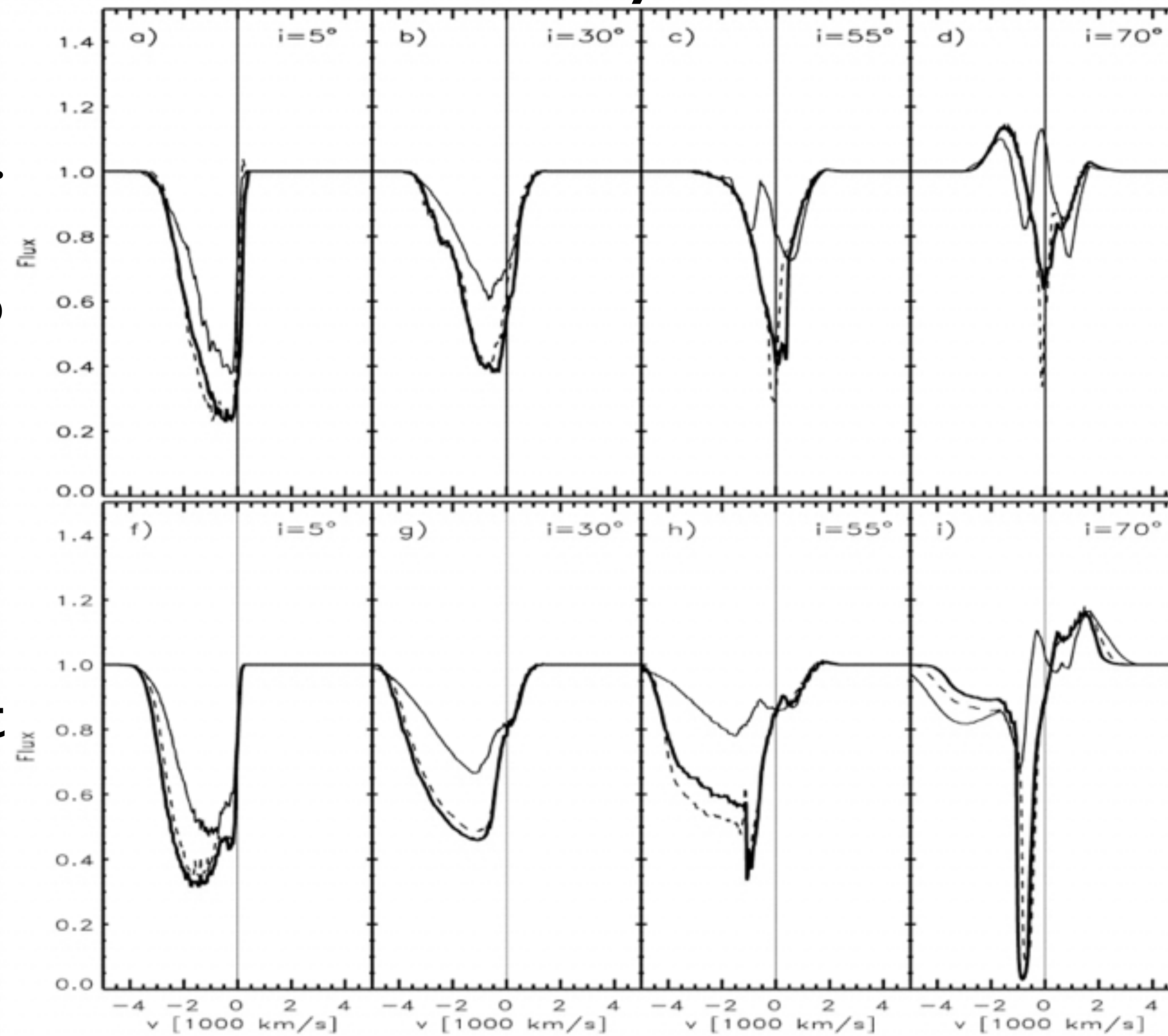
- Not expected, but sort of predicted.
- Proga et al’s simulations of rotating winds launched by radiation from accretion disks can show redshifted and blueshifted troughs...

Proga et al. 2003 (no BELR included)

Leftmost panels face-on, rightmost panels edge-on. Thick line is full wind; thin line is only at small radii.

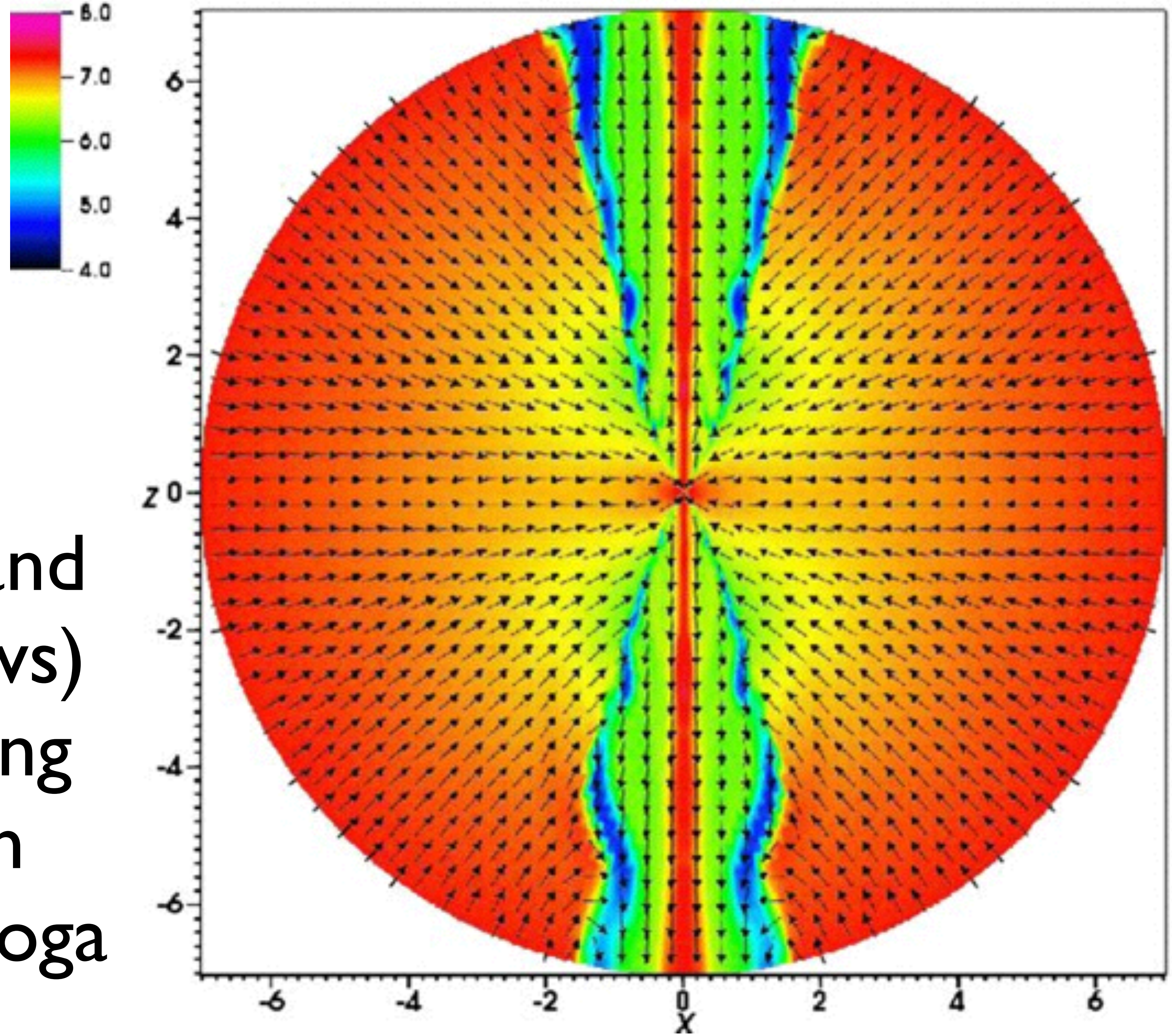
BAL troughs are really broad scattering troughs. Scattered flux is conserved, and shows up at large polar angles in these models. BELR would contribute at all angles.

Top row is without point source contribution from central star or inner disk; bottom row with such contribution.

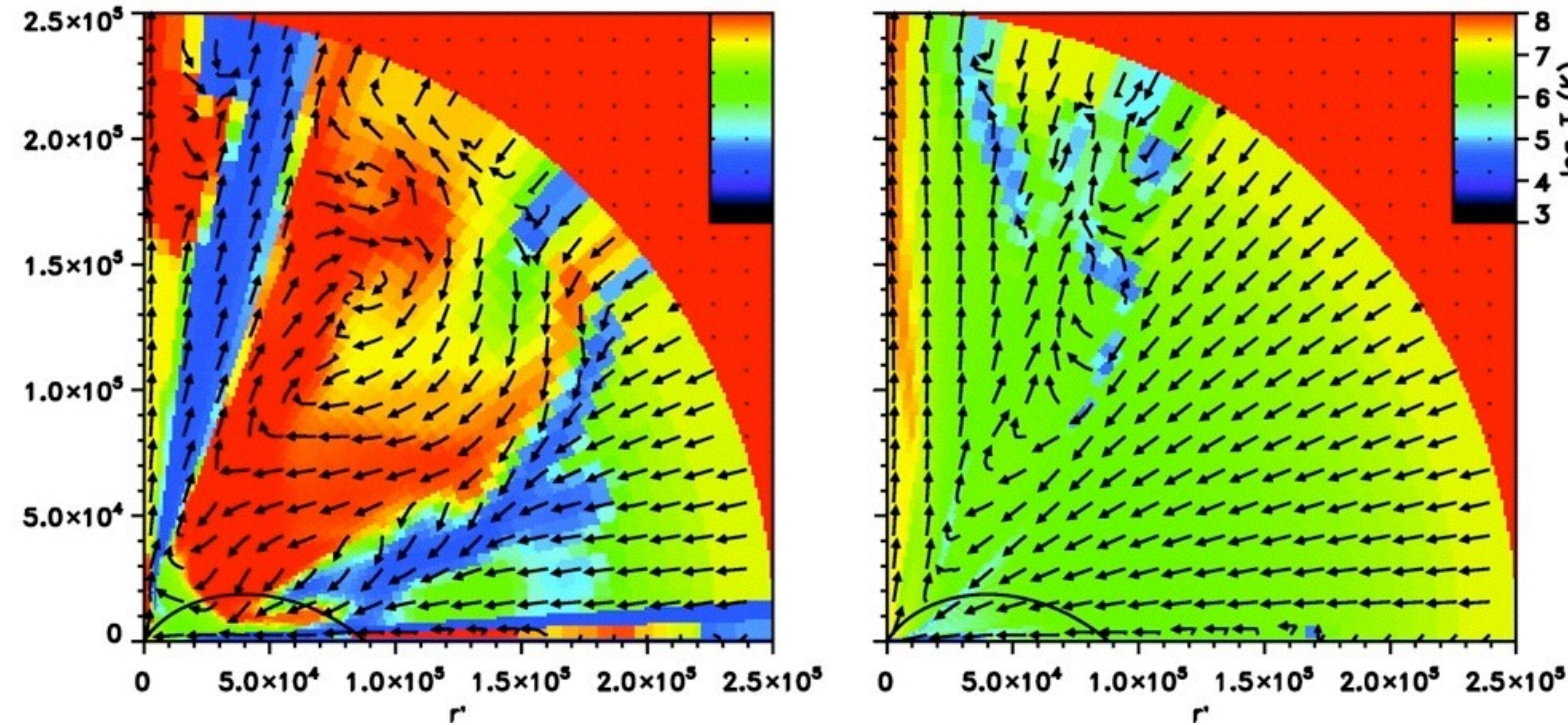


Quasars with Redshifted Broad Absorption Lines

- *Not expected, but sort of predicted.*
- *Proga et al's simulations of rotating winds launched by radiation from accretion disks can show redshifted and blueshifted troughs... but if those models are correct, why are BAL quasars with redshifted troughs so rare?*
- Kurosawa & Proga (2009) also see infall at velocities up to 7000 km/s...



Temperature and velocity (arrows) plot for rotating outflow from Kurosawa & Proga (2009).



Proga, Ostriker & Kurosawa 2008, temperature (color) and velocity (vector) plots; arrow length maxes out at 1000 km/s, velocities at 4000-6000 km/s. Highest density simulation shown; allows gas to cool quickly (left), unless it is pre-heated by a uniform X-ray background (right).

Quasars with Redshifted Broad Absorption Lines

- *Proga et al's simulations of rotating winds launched by radiation from accretion disks can show redshifted and blueshifted troughs... but if those models are correct, why are BAL quasars with redshifted troughs so rare?*
- Proga, Ostriker & Kurosawa (2008) and Kurosawa & Proga (2009) also see infall at velocities up to 7000 km/s... though ionization states of their infalling gas (C IV optical depth, etc.) may not match observations. However, KP09's simulation was aimed at large scales, future smaller-scale simulations might match better.

RSBALs: Summary

- About 1 in 1200 BAL quasars has redshifted absorption
- Not due to gravitational redshifts
- NIR spectra: no evidence to support binary hypothesis
- X-rays: suggest same (disk wind) origin as normal BALs
- Any due to binaries=new lines of sight through outflows

Maunakea Spectroscopic Explorer

MSE will efficiently obtain very large numbers (>1,000,000) of

- low- (R~2000), medium- (R~6500) and high-resolution (**R=40,000**) spectra
- for faint (20 < g < 24) science targets, 3200 fibers at a time (800 med/high-res)
- over large areas of the sky (1000 – 10,000 sq.deg, 1.5 sq.deg. at a time)
- spanning blue/optical to near-IR wavelengths, 0.37 – **1.8 micron**
- at the highest resolutions, with velocity accuracy of <<1 km/s
- at low resolution, with complete wavelength coverage in a single observation

- **Unique science cases for MSE stem from:**
  - **11.25 m diameter aperture on the CFHT site**
  - **Operation at a range of spectral resolutions**
  - **Dedicated operations, producing stable, well-calibrated and characterised data**
  - **Long lifetime (allows for upgrades such as IFUs and R=90,000 modes)**
- *Natural path from 4m-class facilities (KPNO4m+DESI, WHT+WEAVE, 4MOST, AAT+HERMES...) and 8m-class, shared-time, small-FOV instruments (Subaru/PFS, VLT/MOONS) to MSE*
- *ESO is thinking along similar lines, with the report of the working group led by Richard Ellis*

My outflow of questions

- What are the connection(s) between outflows seen in X-ray absorption, in UV absorption, and at longer wavelengths? [How much of the flow can C IV trace?]
- How do accretion structures (thin/slim/thick disk; chaotic cold accretion; etc.) depend on physical parameters, and what are their impacts on outflows?
- How important are continuum/line/MHD driving?
- What signatures of wind acceleration might we see?
- What are typical mass, momentum, KE loss rates?
- What can continuum and absorption variability tell us about source and outflow properties and structure? [e.g., are there significant azimuthal asymmetries?]