Redshifted Broad Absorption Troughs in Quasars

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

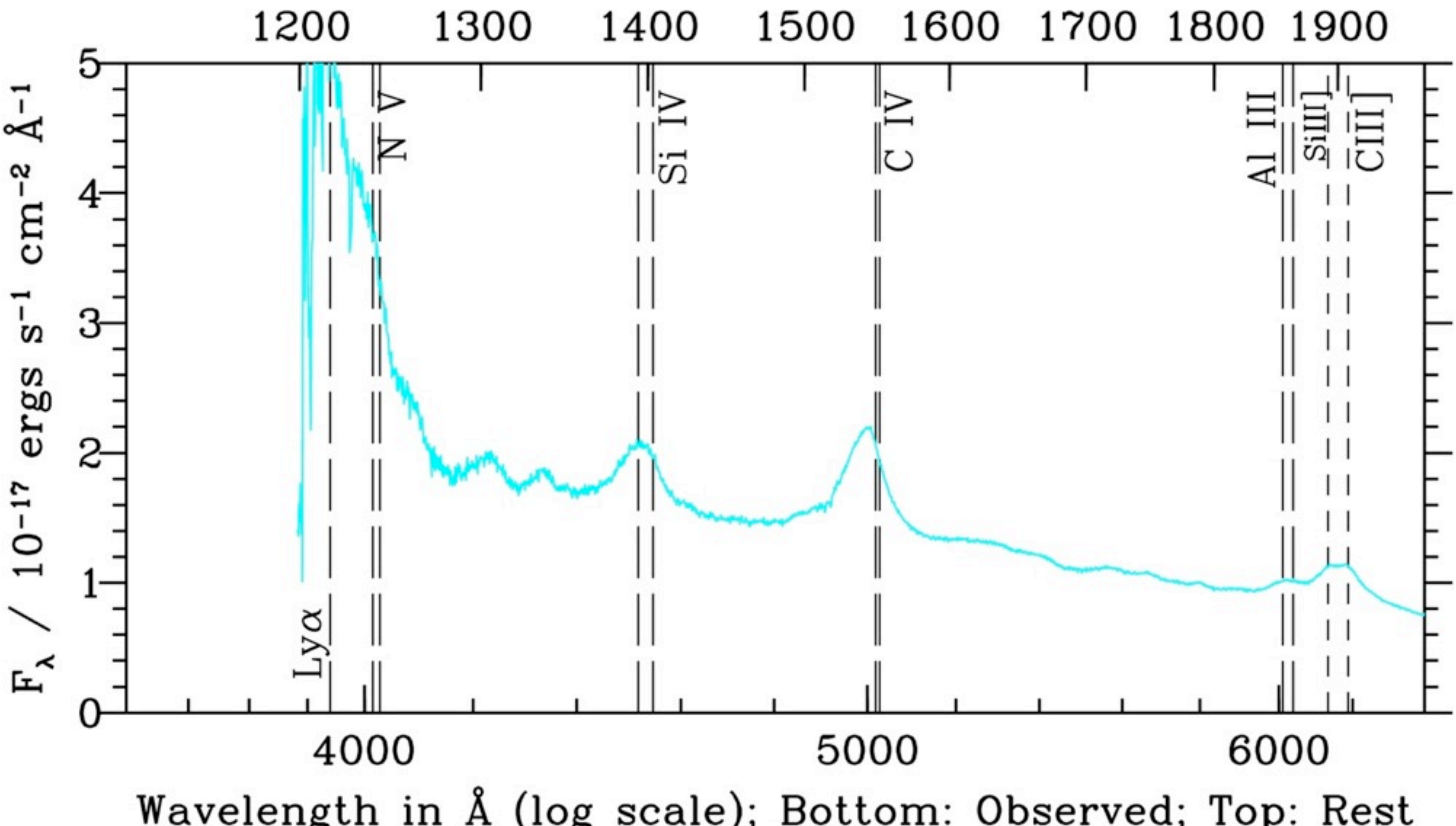
Sloan Digital Sky Survey Data

- Now in SDSS-III phase, including **BOSS** (Baryon Oscillation Spectroscopic Survey); 60,000 faint, distant quasars in first two years.
- Spectra cover <u>3500 to 10500 Angstroms (vs. 3800 to 9200 in SDSS-I and II)</u>, at similar resolution to SDSS but higher signal-to-noise ratio at same magnitude.

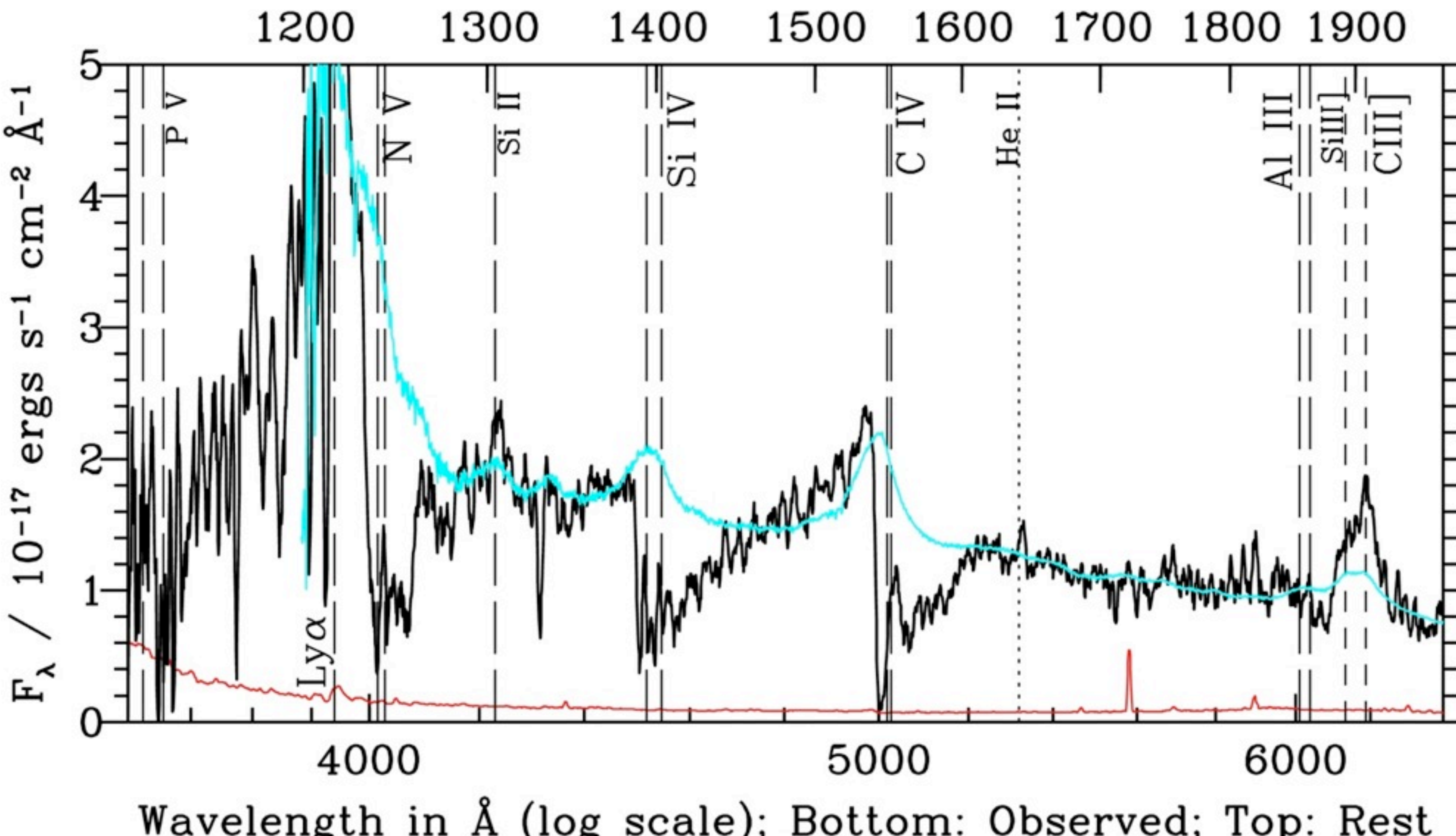
Redshifted-Trough BAL Quasars

- 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 in SDSS-III to date, ten 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.
- Three other high-ionization candidates.
- Two cases of redshifted Mg II at low redshift (Hall et al. 2002), and two candidates.

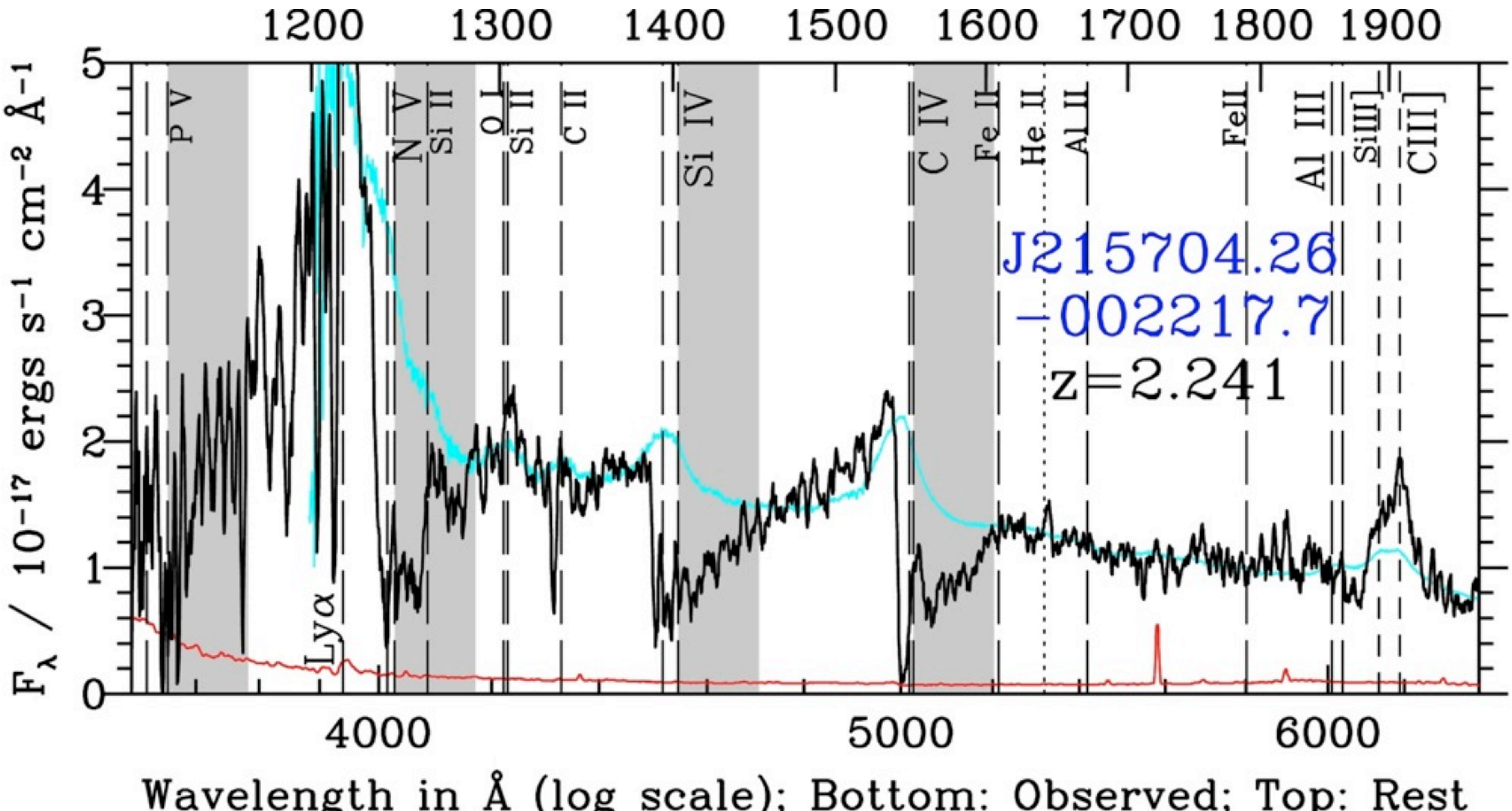
Unabsorbed quasar spectrum

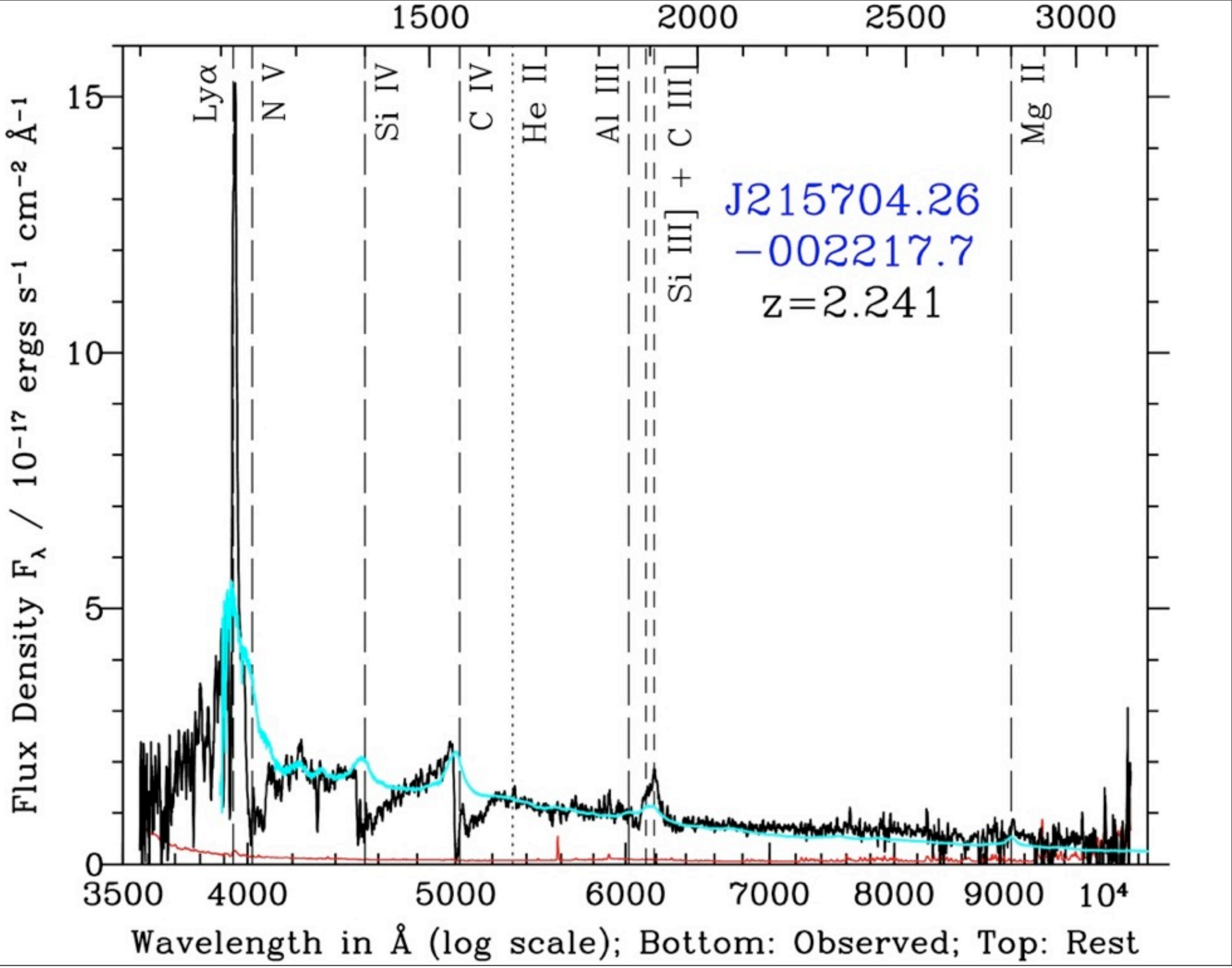


Unabsorbed quasar vs. quasar with redshifted absorption



Gray regions indicate velocity ranges of strongest redshifted absorption

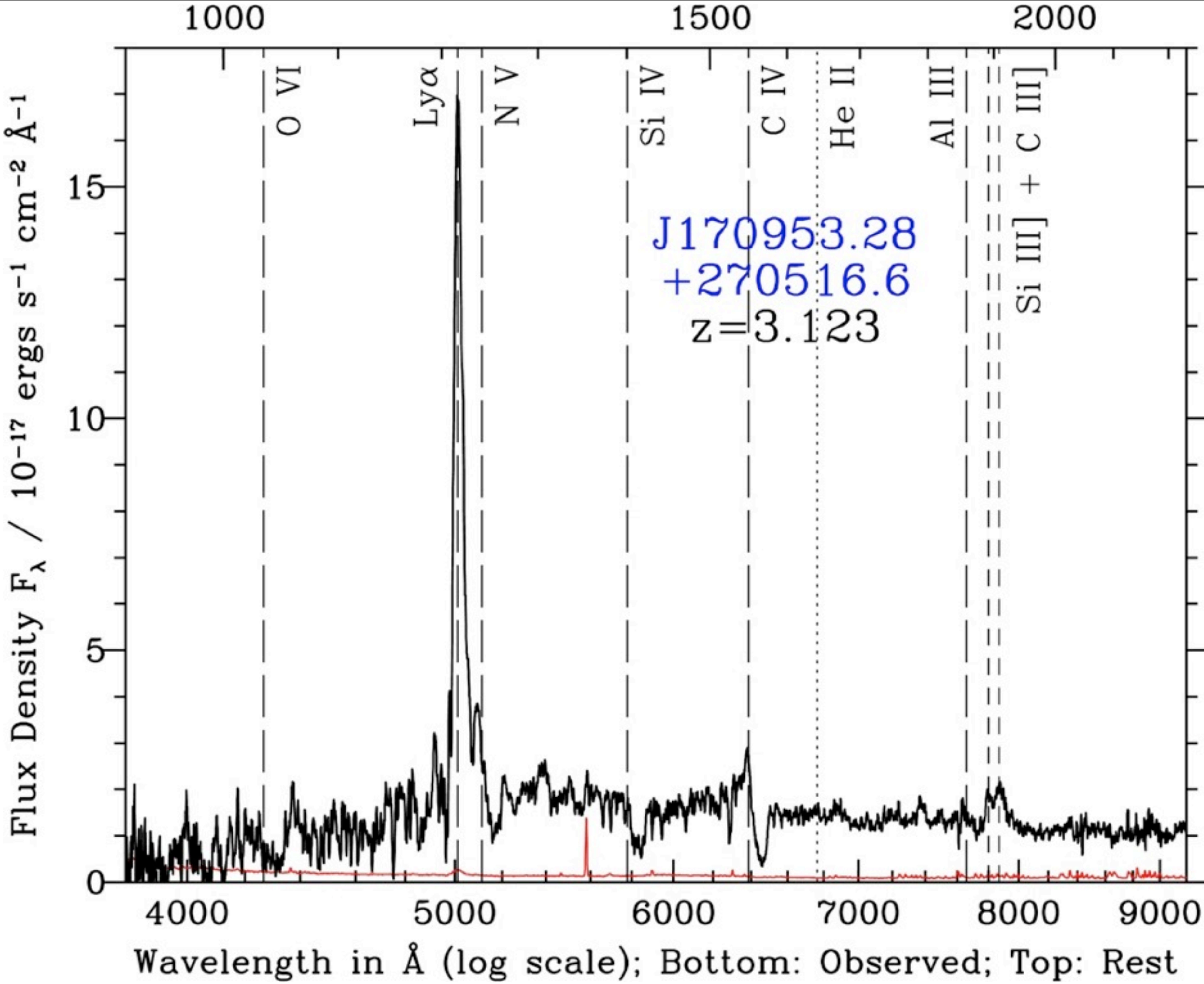




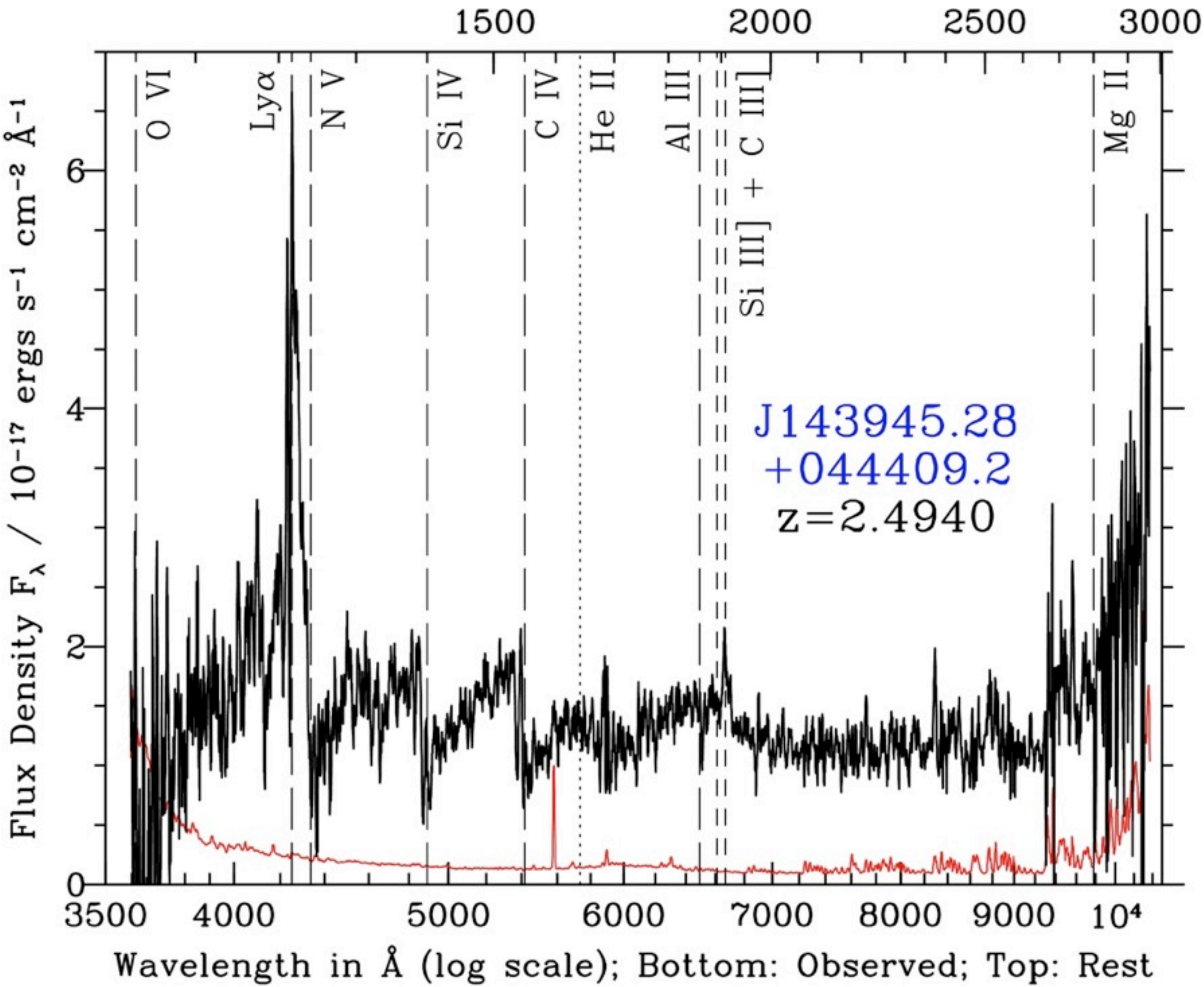
1500
2000
2500
3000
Lyα
N V
Si IV
C IV
He II
Al III
Si III] + C III]
Mg II
J215704.26
−002217.7
z=2.241
Flux Density F$_\lambda$ / 10^{-17} ergs s^{-1} cm^{-2} Å^{-1}
15
10
5
0
3500
4000
5000
6000
7000
8000
9000
10^4
Wavelength in Å (log scale); Bottom: Observed; Top: Rest

Redshifted absorption

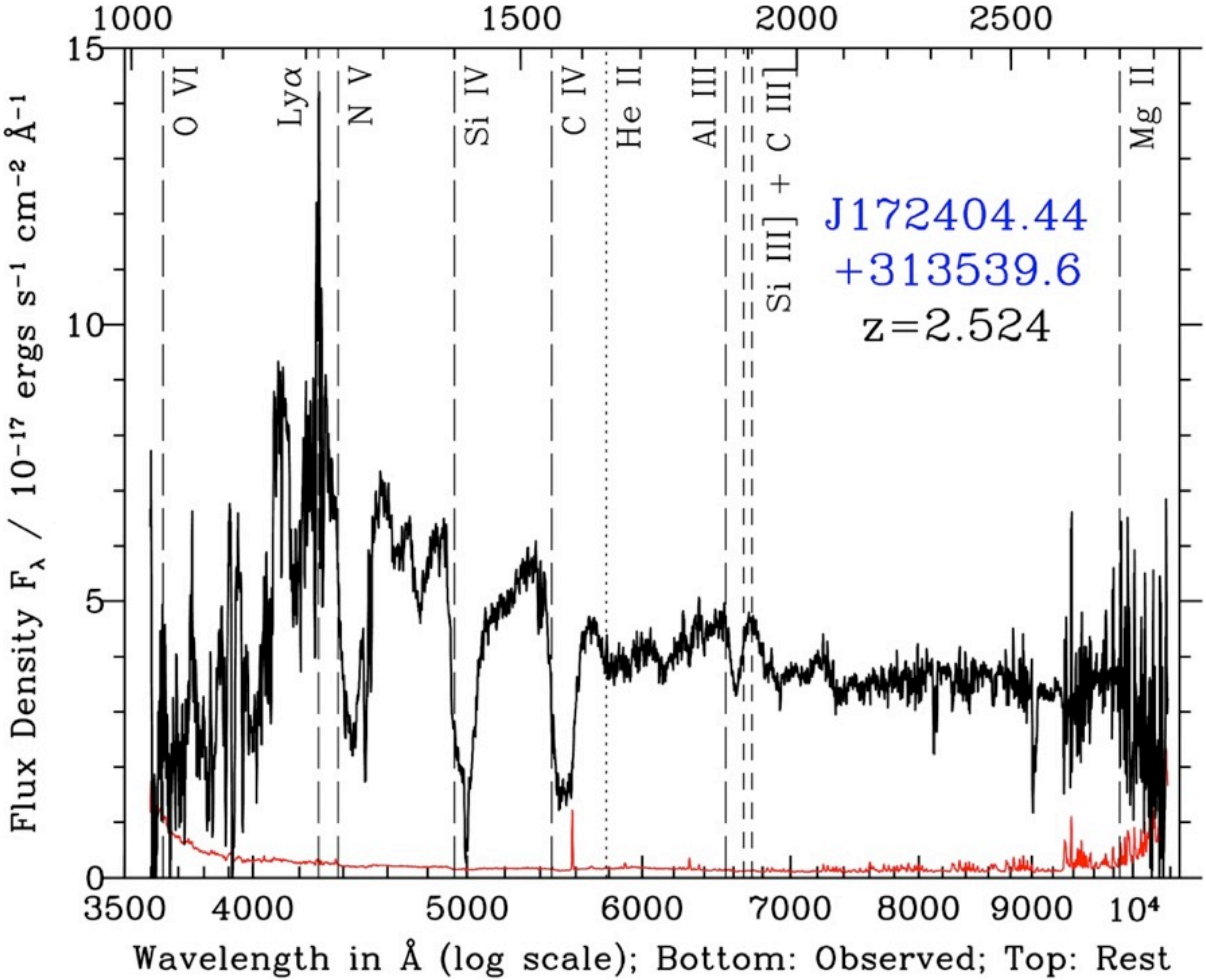
- Sometimes only redshifted absorption is seen



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



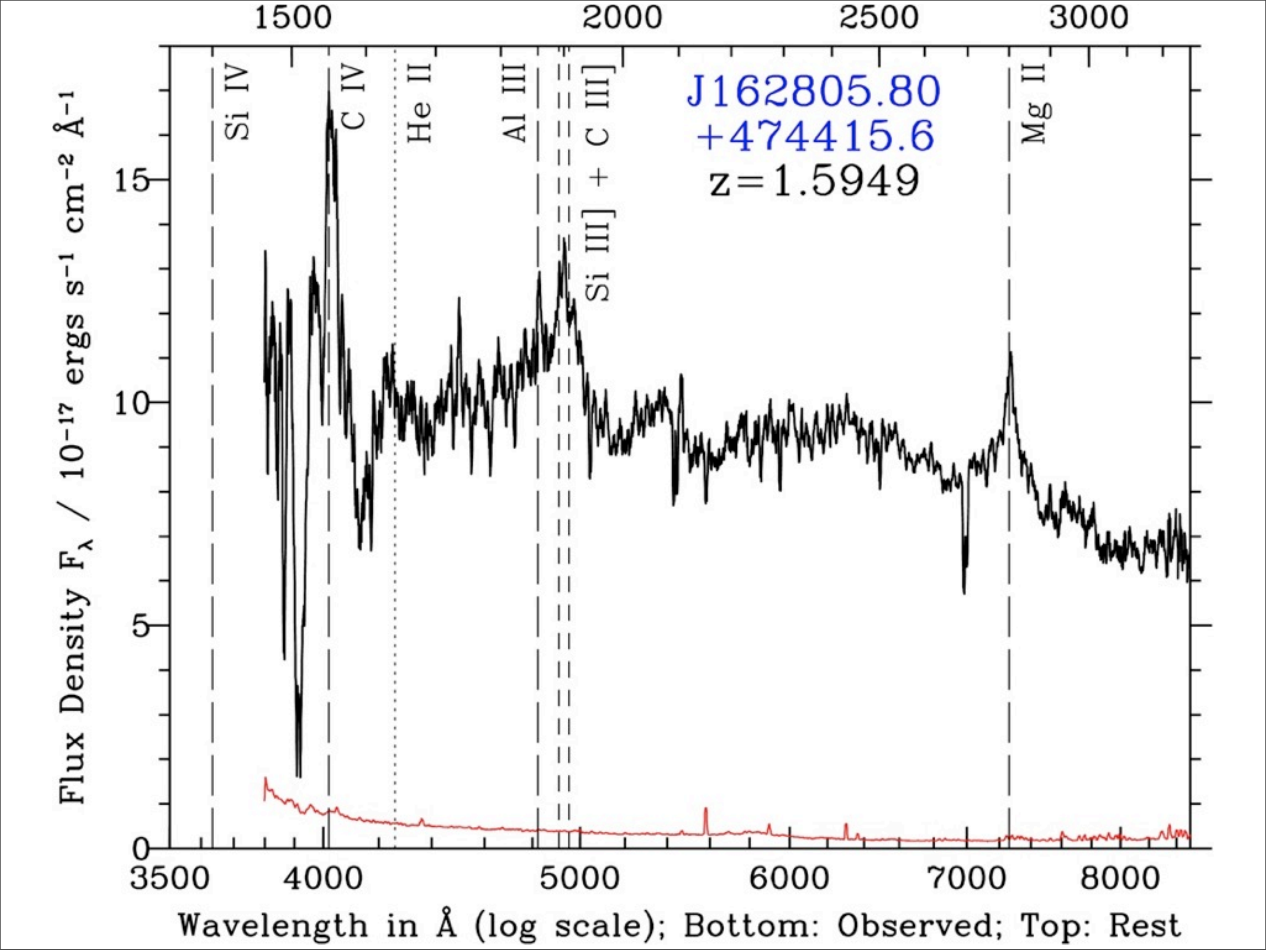
1500
2000
2500
3000
O VI
Lyα
N V
Si IV
C IV
He II
Al III
Si III] + C III]
Mg II
J143945.28
+044409.2
z=2.4940
Flux Density F_λ / 10^{-17} ergs s^{-1} cm^{-2} $Å^{-1}$
0
2
4
6
3500
4000
5000
6000
7000
8000
9000
10^4
Wavelength in Å (log scale); Bottom: Observed; Top: Rest



1000
1500
2000
2500
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
15
10
5
0
3500
4000
5000
6000
7000
8000
9000
10⁴
Wavelength in Å (log scale); Bottom: Observed; Top: Rest

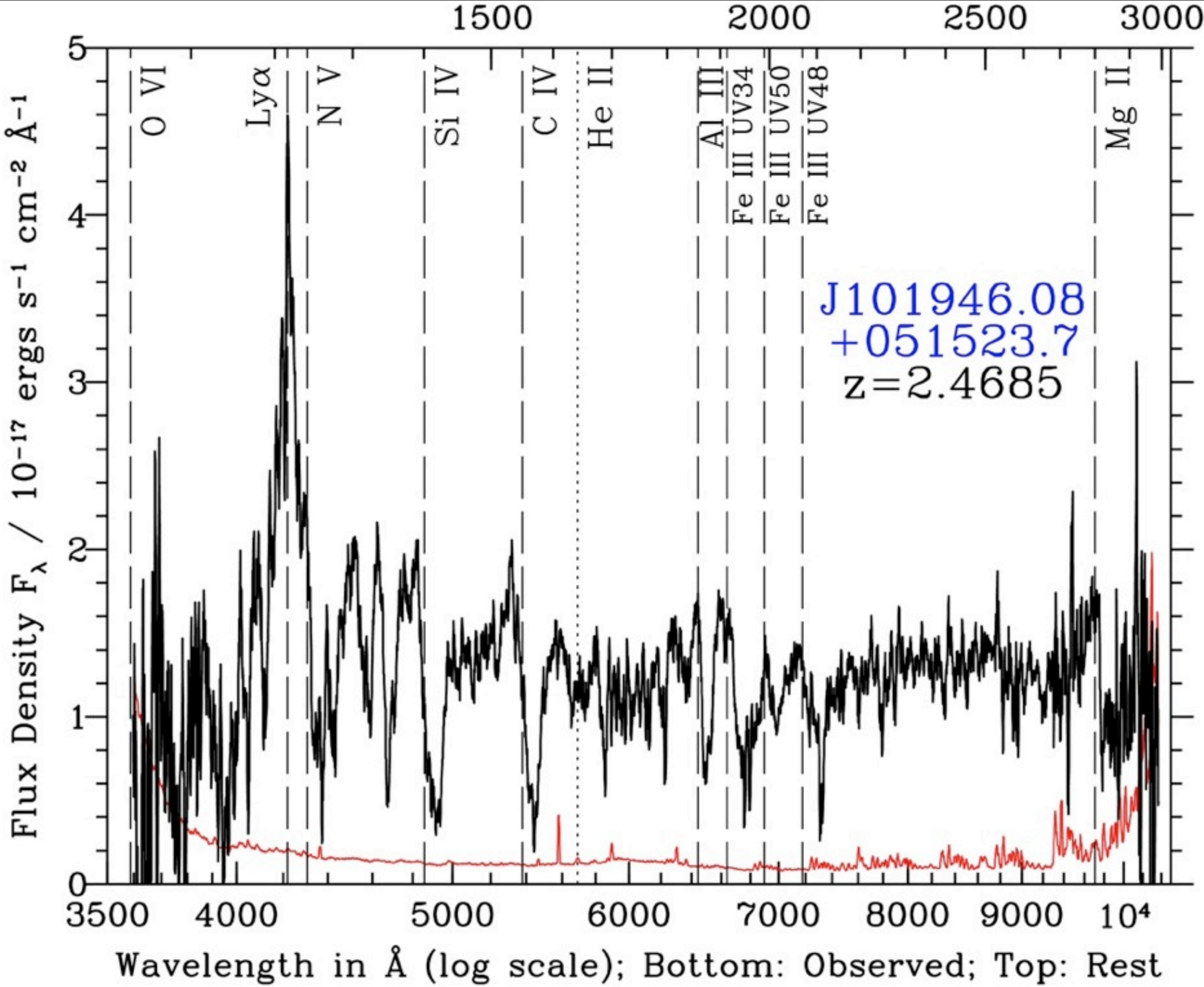
Redshifted absorption

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


1500
2000
2500
3000
Si IV
C IV
He II
Al III
Si III] + C III]
Mg II
J162805.80
+474415.6
z=1.5949
Flux Density F$_\lambda$ / 10^{-17} ergs s^{-1} cm^{-2} Å^{-1}
15
10
5
0
3500
4000
5000
6000
7000
8000
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)



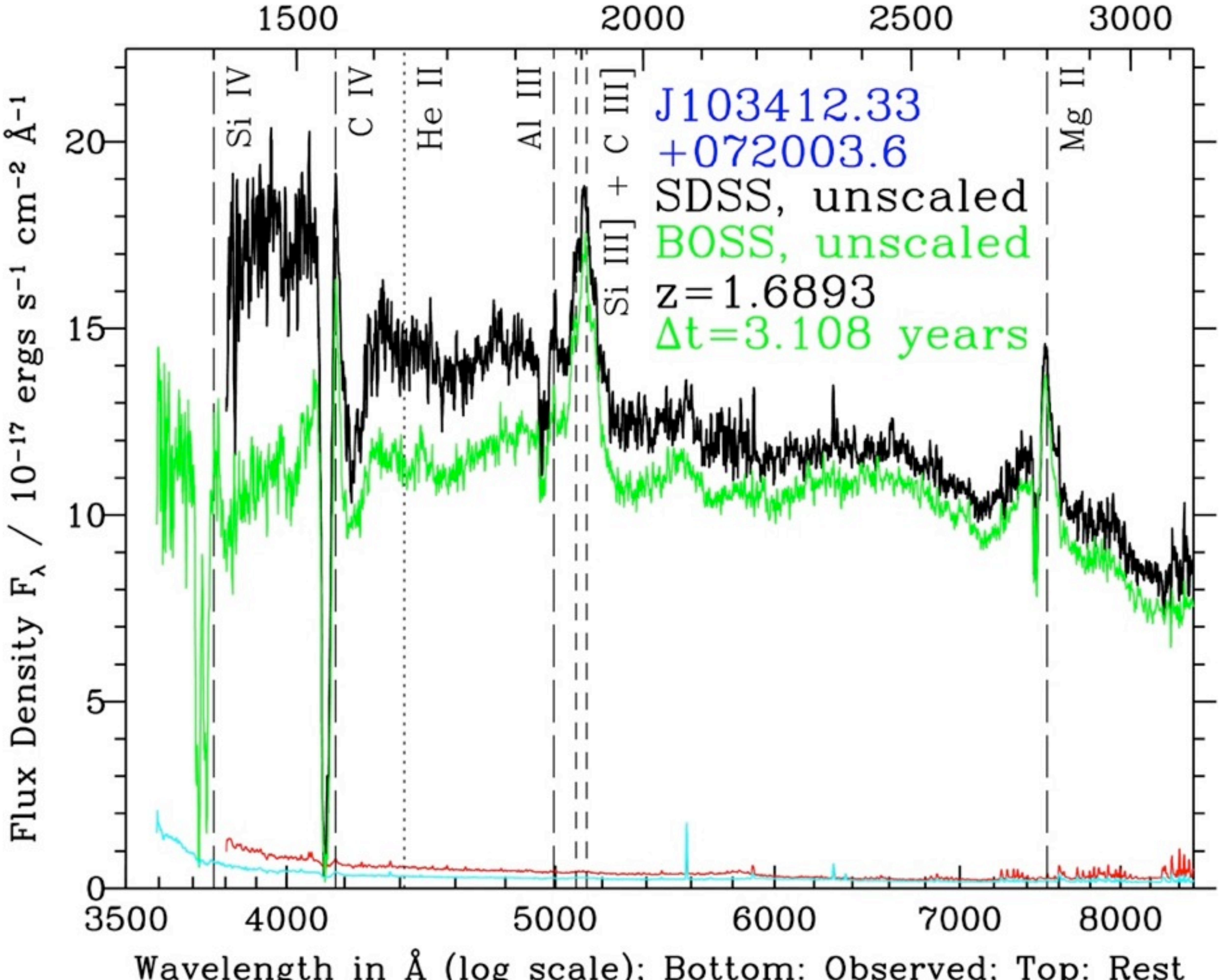
Sunday, November 13, 2011

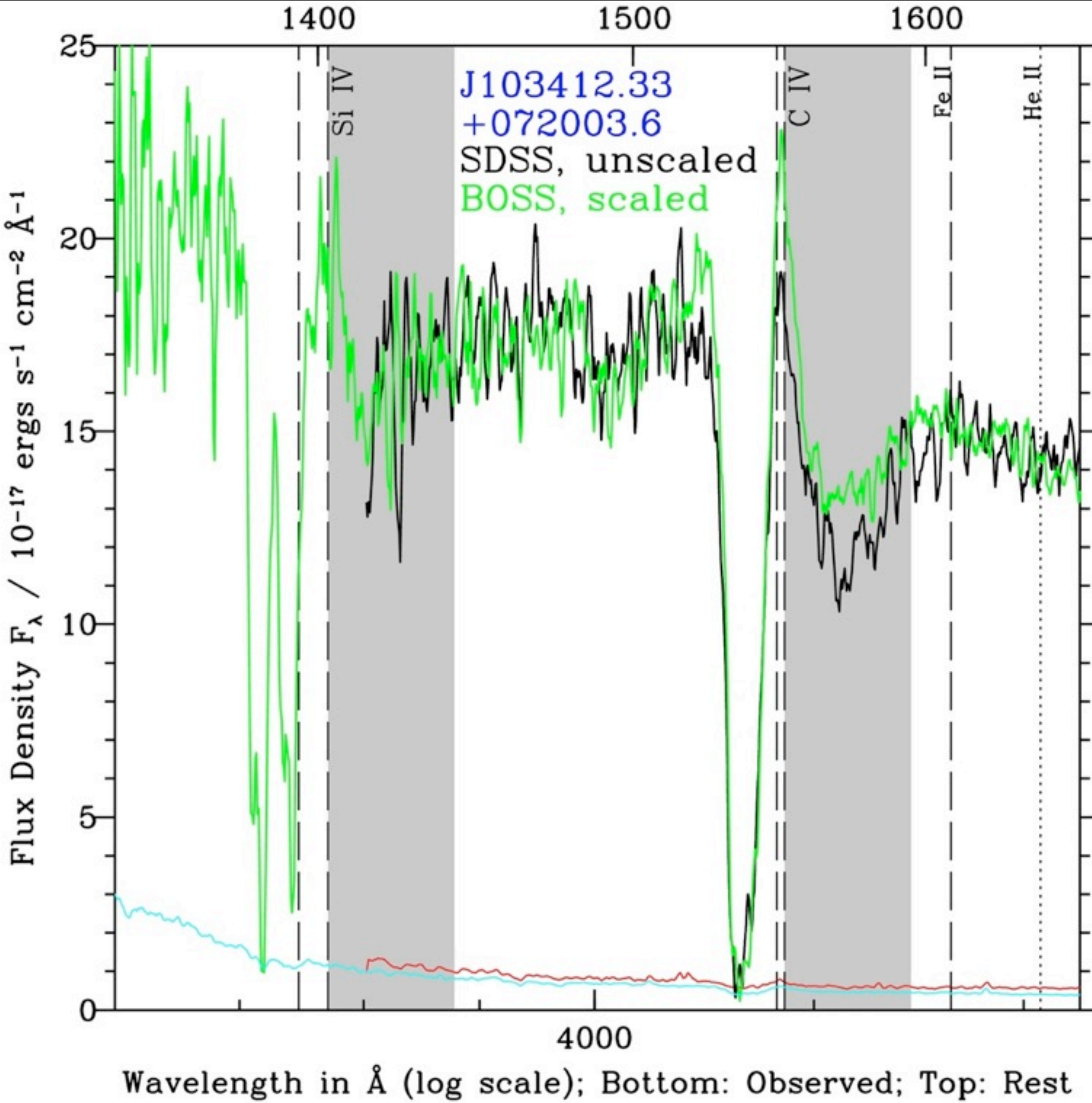
Redshifted absorption

- 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)
- Velocity ranges -13,000 km/s (blueshift) to +13,000 km/s (redshift), in different objects

Variability

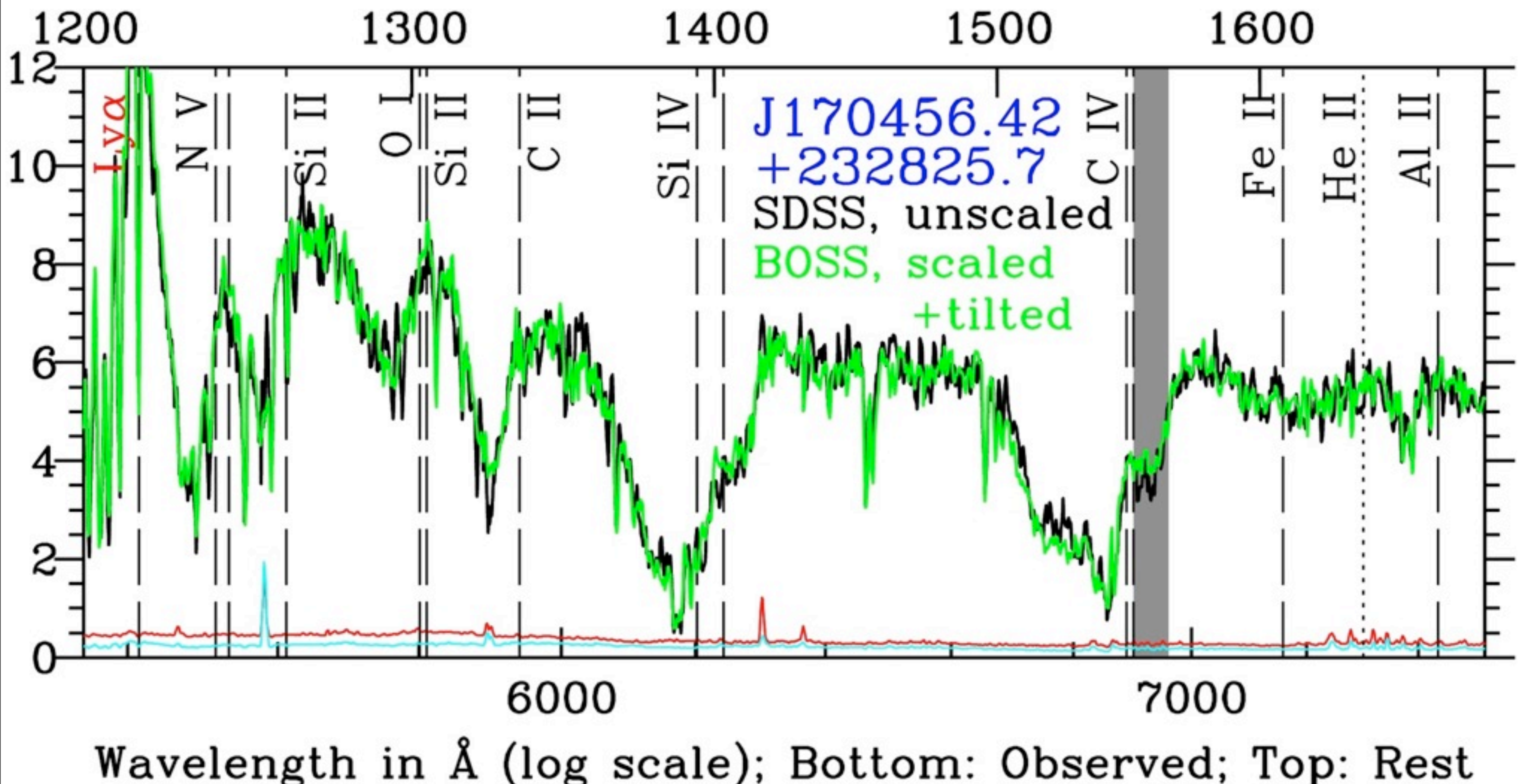
- Very little information to date
- Three high-ionization redshifted-trough objects with spectra from both SDSS and BOSS; one more on the way
- Two low-ionization redshifted-trough objects with spectra from both SDSS and BOSS
- Little variability on 1-5 year timescales
- Crossing time of optical/UV continuum 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
20
15
10
5
0
Flux Density F$_\lambda$ / 10^{-17} ergs s^{-1} cm^{-2} Å^{-1}
3500
4000
5000
6000
7000
8000
Wavelength in Å (log scale); Bottom: Observed; Top: Rest

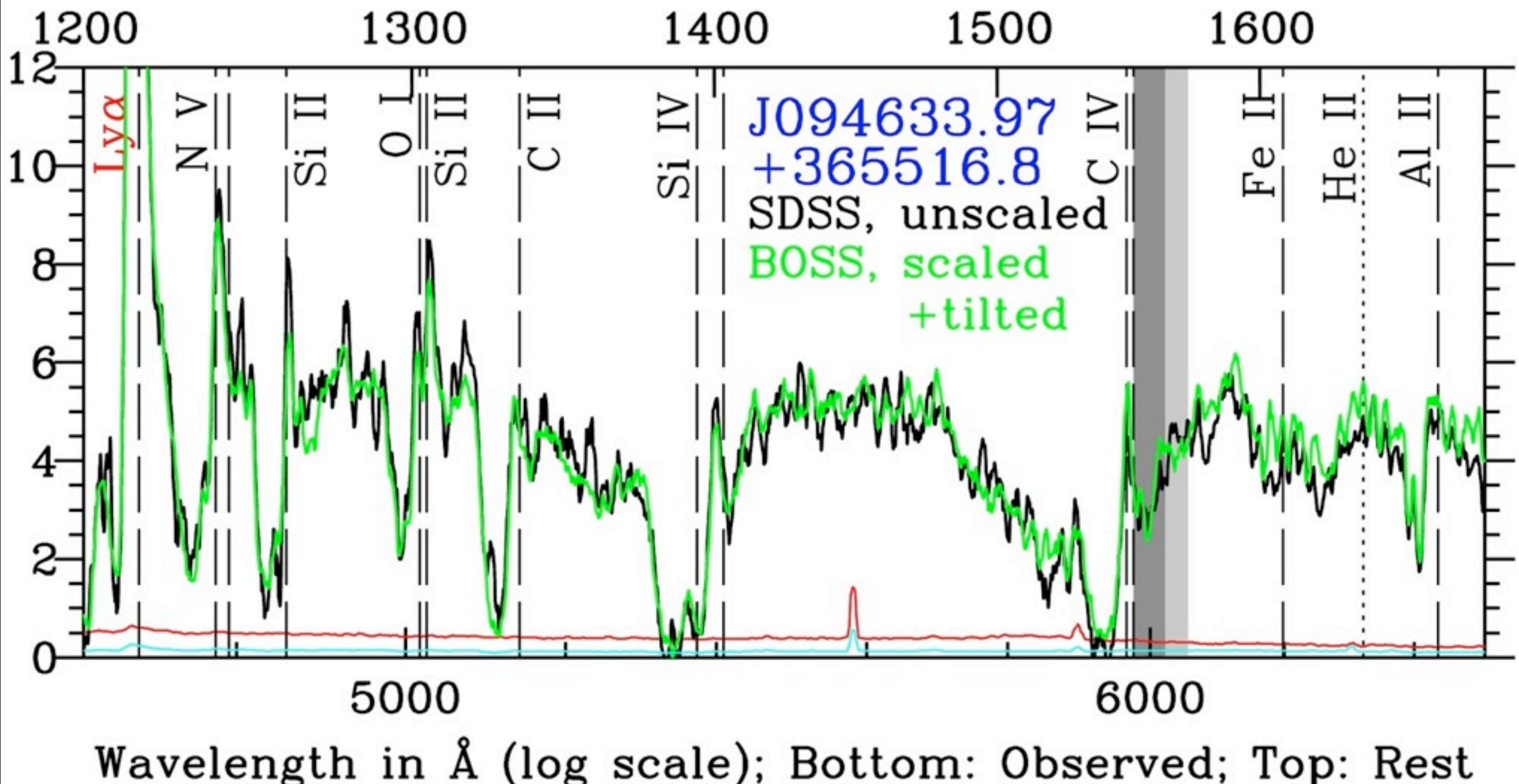


J103412.33
+072003.6
SDSS, unscaled
BOSS, scaled
Si IV
C IV
Fe II
He II
1400
1500
1600
25
20
15
10
5
0
4000
Flux Density F$_\lambda$ / 10^{-17} ergs s^{-1} cm^{-2} Å^{-1}
Wavelength in Å (log scale); Bottom: Observed; Top: Rest

rest-frame Δt=1.5 years



rest-frame Δt=1.8 years



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 (would require gas absorbing in C IV at few tens of r_g, 10x smaller radii than the C IV BELR)

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

Infall? Fallback?

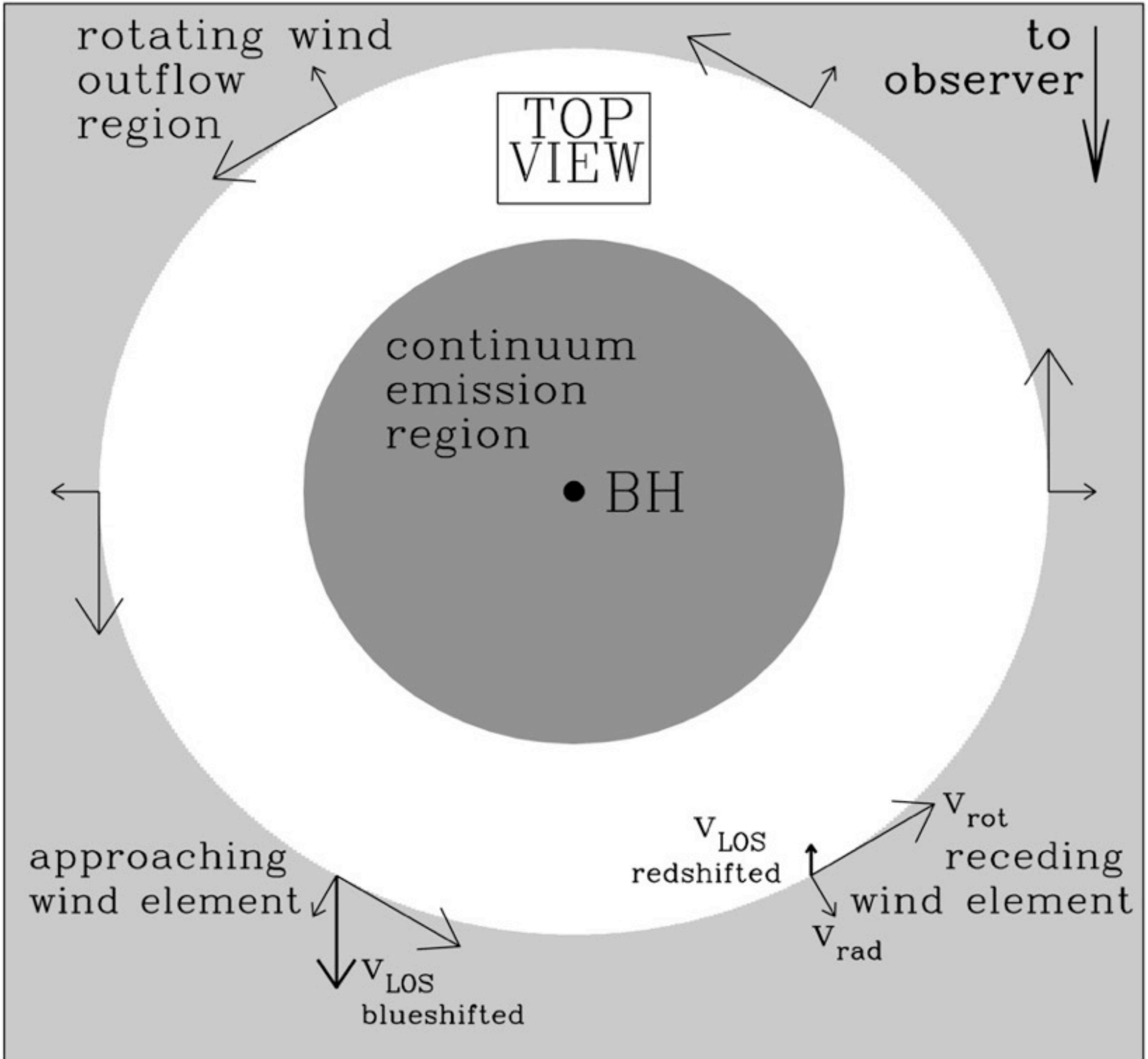
- Characteristic velocity for galaxy centers is <500 km/s
- Characteristic densities for star-forming gas $<10^5$ cm^{-3} *
- Infalling gas not far out in galaxy; must be close to BH
- Infall to radius r from the BH will generate velocities up to the escape velocity from that radius: $v=(2GM_{BH}/r)^{1/2}$
- Requires infall to 1000 r_g (outer BLR). Seen in some simulations, but not with large observed optical depths.
- Also, gas might have orbital motions that would extend the absorption to blueshifted velocities on orbital timescales, even for cases of near-radial infall.

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.

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.
- 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.


rotating wind
outflow
region
to
observer
TOP
VIEW
continuum
emission
region
BH
approaching
wind element
V_{LOS}
blueshifted
V_{LOS}
redshifted
V_{rot}
receding
wind element
V_{rad}

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 no more than 10x larger than that of the extended continuum source.
- Outflow velocity must be small, and rotational velocity considerably larger than observed redshifted velocity.
- Required circumstances are not impossible. They would be uncommon, but so are these quasars...

Quasars with Redshifted Broad Absorption Lines

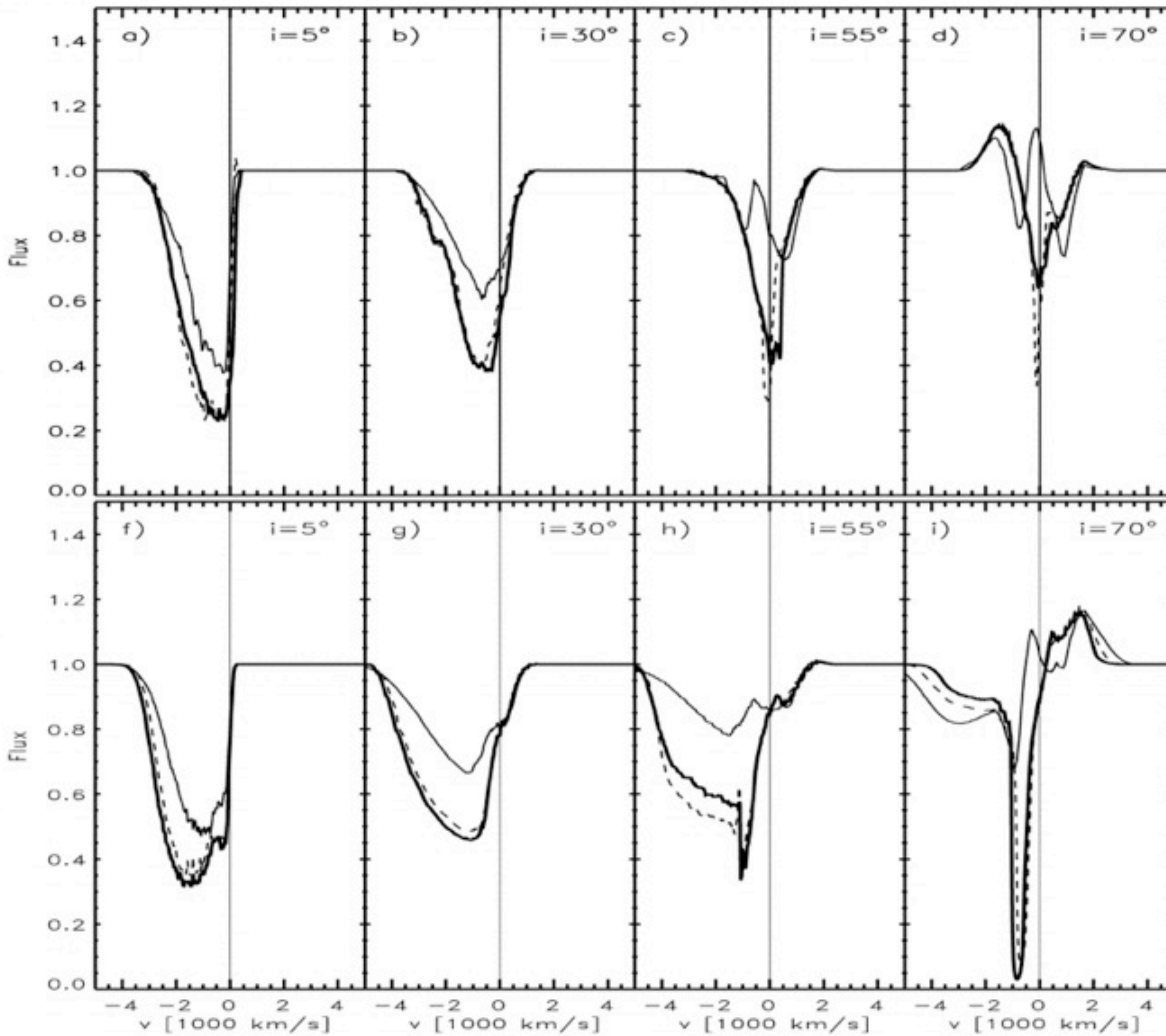
- Not expected, but sort of predicted.
- Proga et al's simulations of rotating winds launched by radiation from accretion disks can show redshifted and blueshifted troughs...

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.

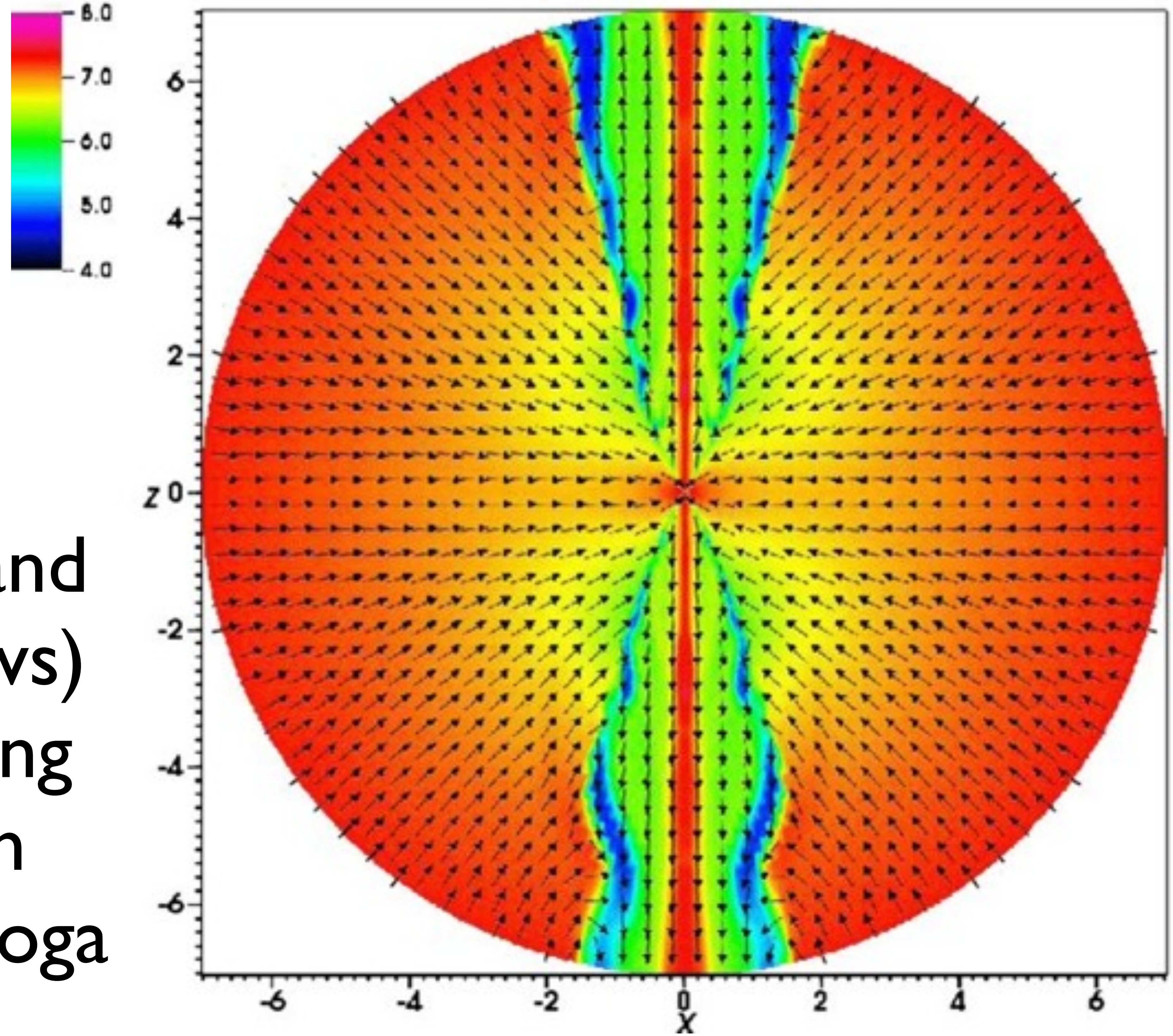


Proga et al. line profiles

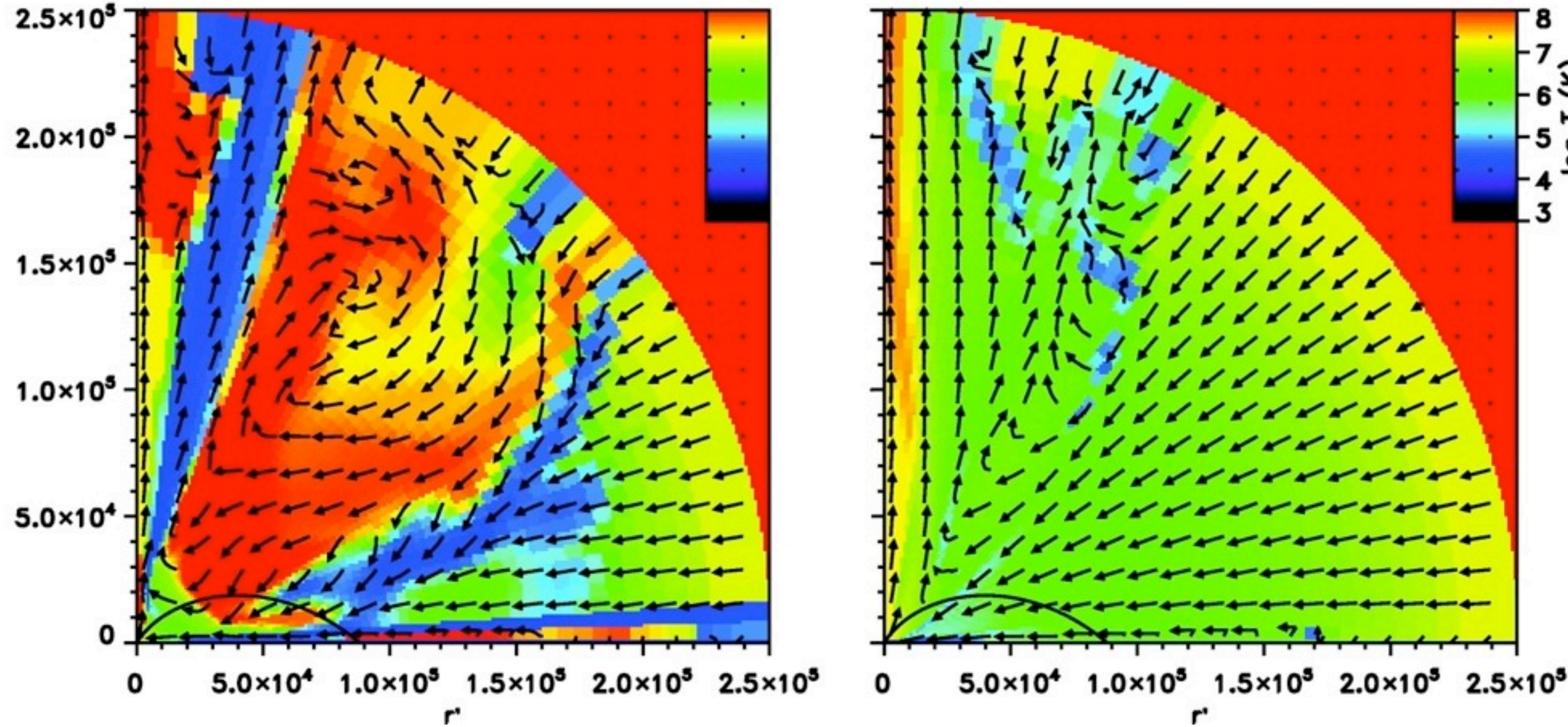
- Winds which quickly get overionized as they reach larger radii might explain objects with blueshifted and redshifted troughs.
- Proga et al. don't explicitly predict redshifted-only troughs.
- Can appeal to azimuthal asymmetry to do so. In that model such asymmetries should vanish on one-quarter the orbital timescale or less (one-quarter orbital timescale is 8 years at outer edge of BELR).

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

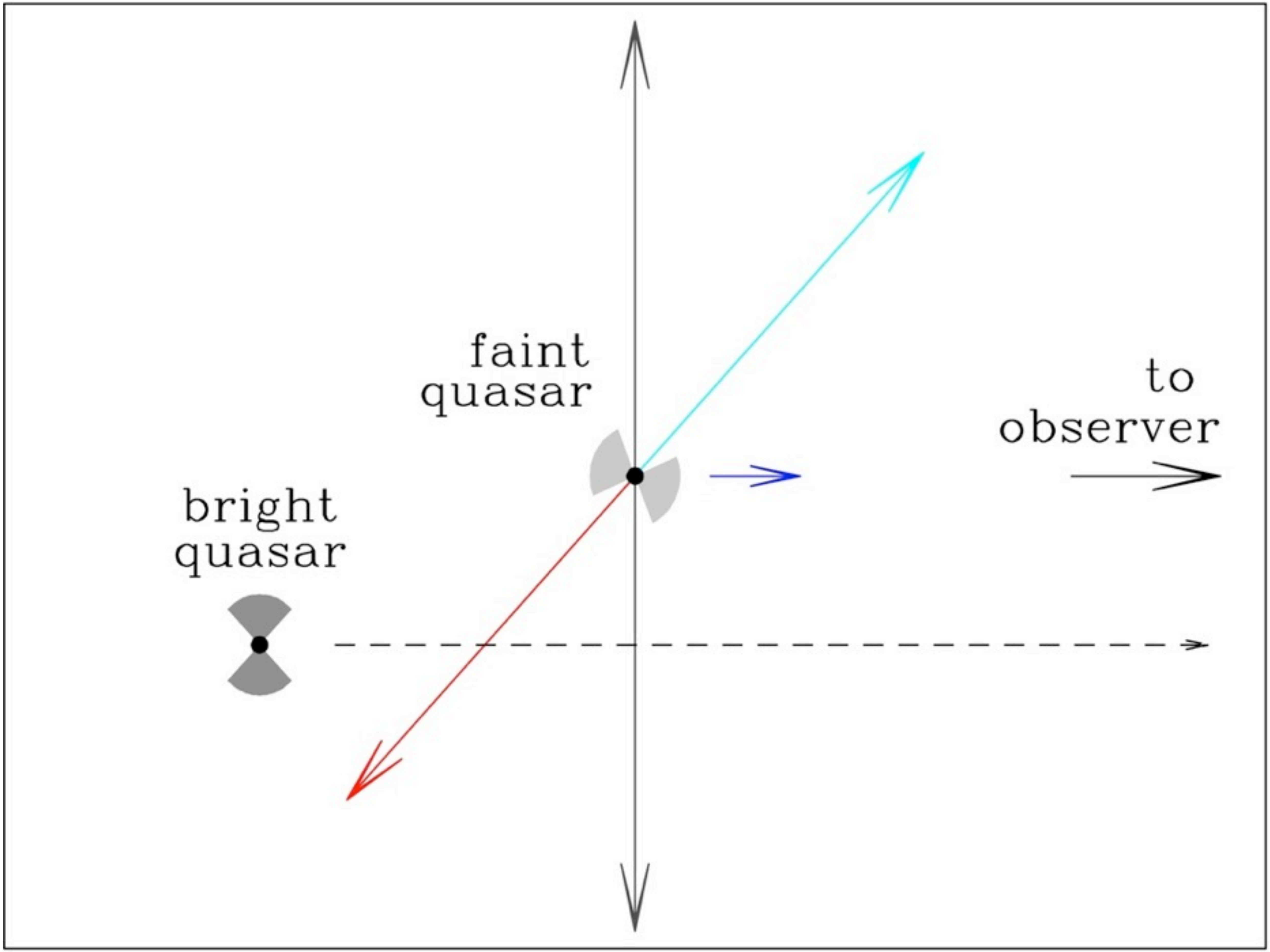
- *Proga et al's simulations of rotating winds launched by radiation from accretion disks can show redshifted and blueshifted troughs... but if those models are correct, why are BAL quasars with redshifted troughs so rare?*
- Proga, Ostriker & Kurosawa (2008) and Kurosawa & Proga (2009) also see infall 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.

Binary Quasars + silhouetted BAL outflow?

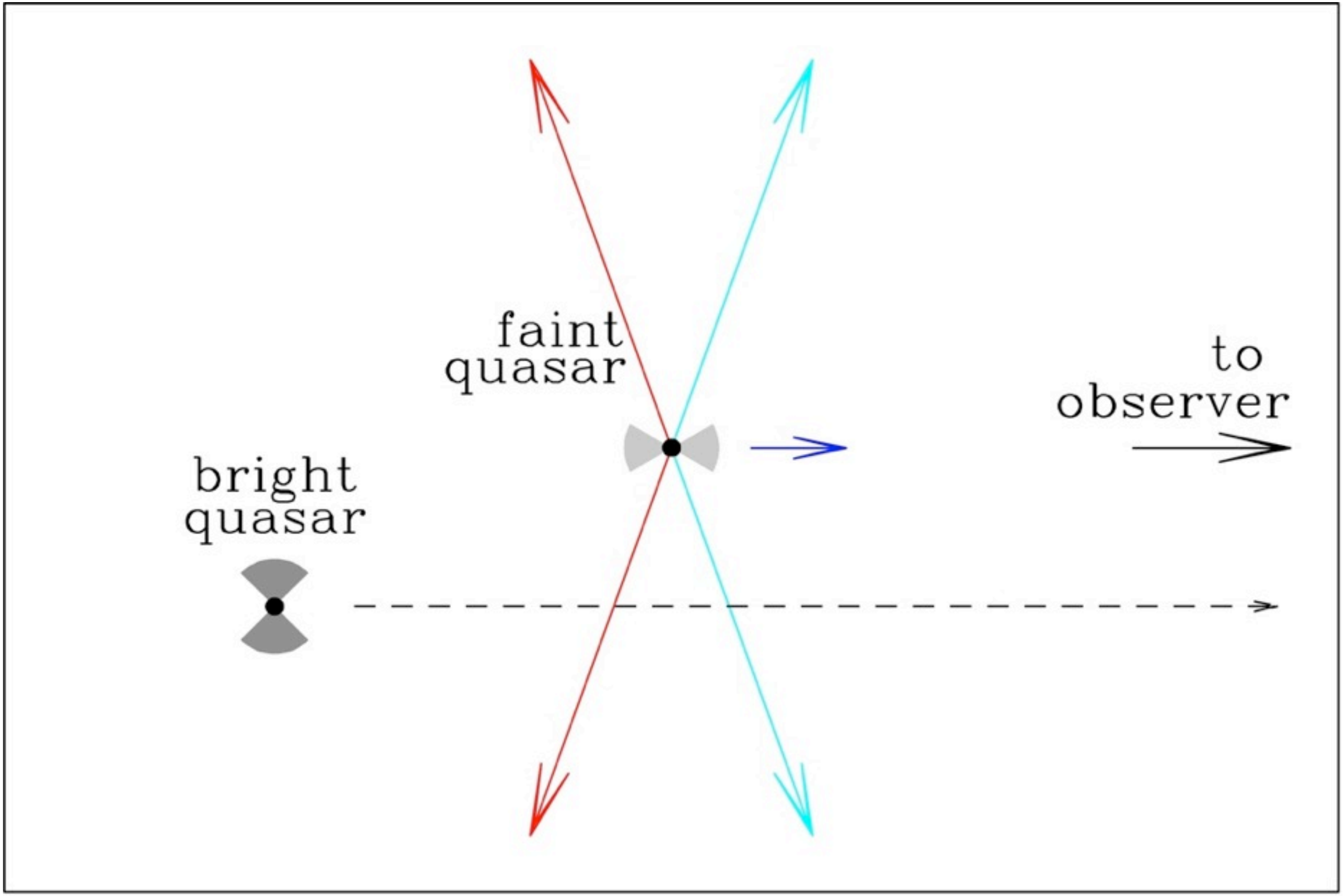
- BAL outflow from one quasar, backlit by another quasar. Requires a spatially unresolved quasar pair where:
  - The background quasar is the more optically luminous one, and produces the broad emission lines we see

Binary Quasars + silhouetted BAL outflow?

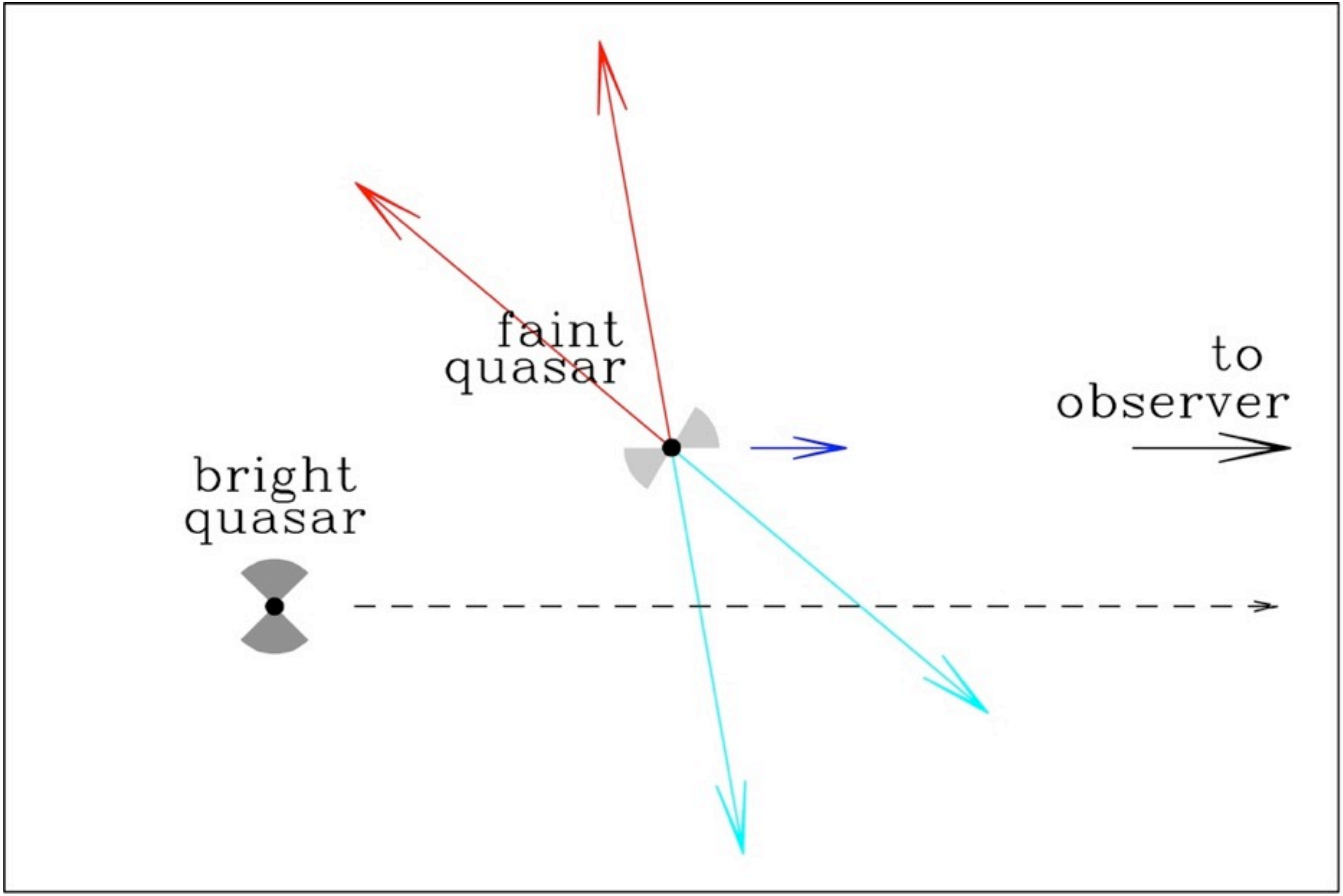
- BAL outflow from one quasar, backlit by another quasar. Requires a spatially unresolved quasar pair where:
  - The background quasar is the more optically luminous one, and produces the broad emission lines we see
  - The foreground quasar produces a BAL outflow oriented such that the background quasar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



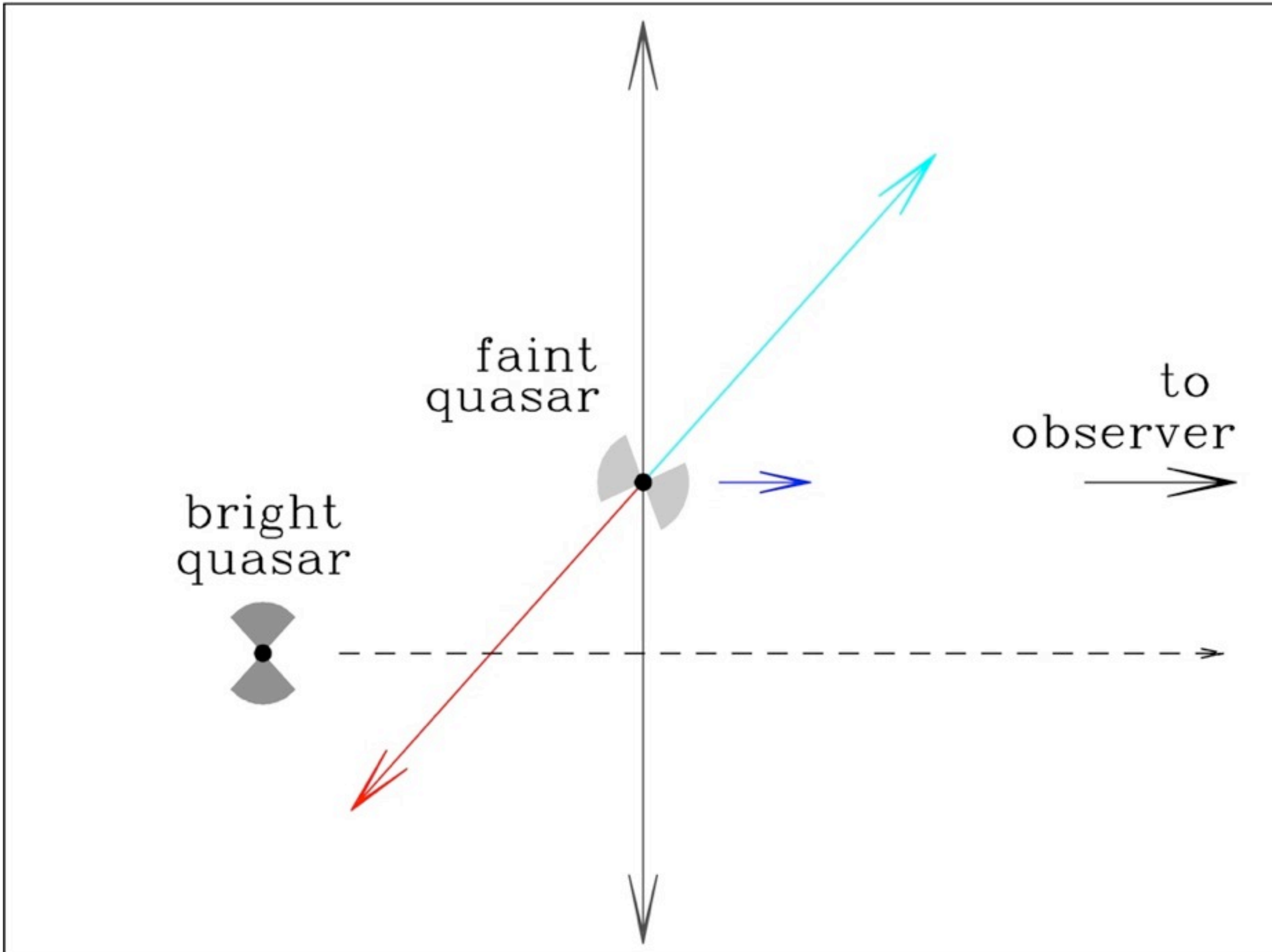
Binary Quasar Scenario for Redshifted Absorption Troughs



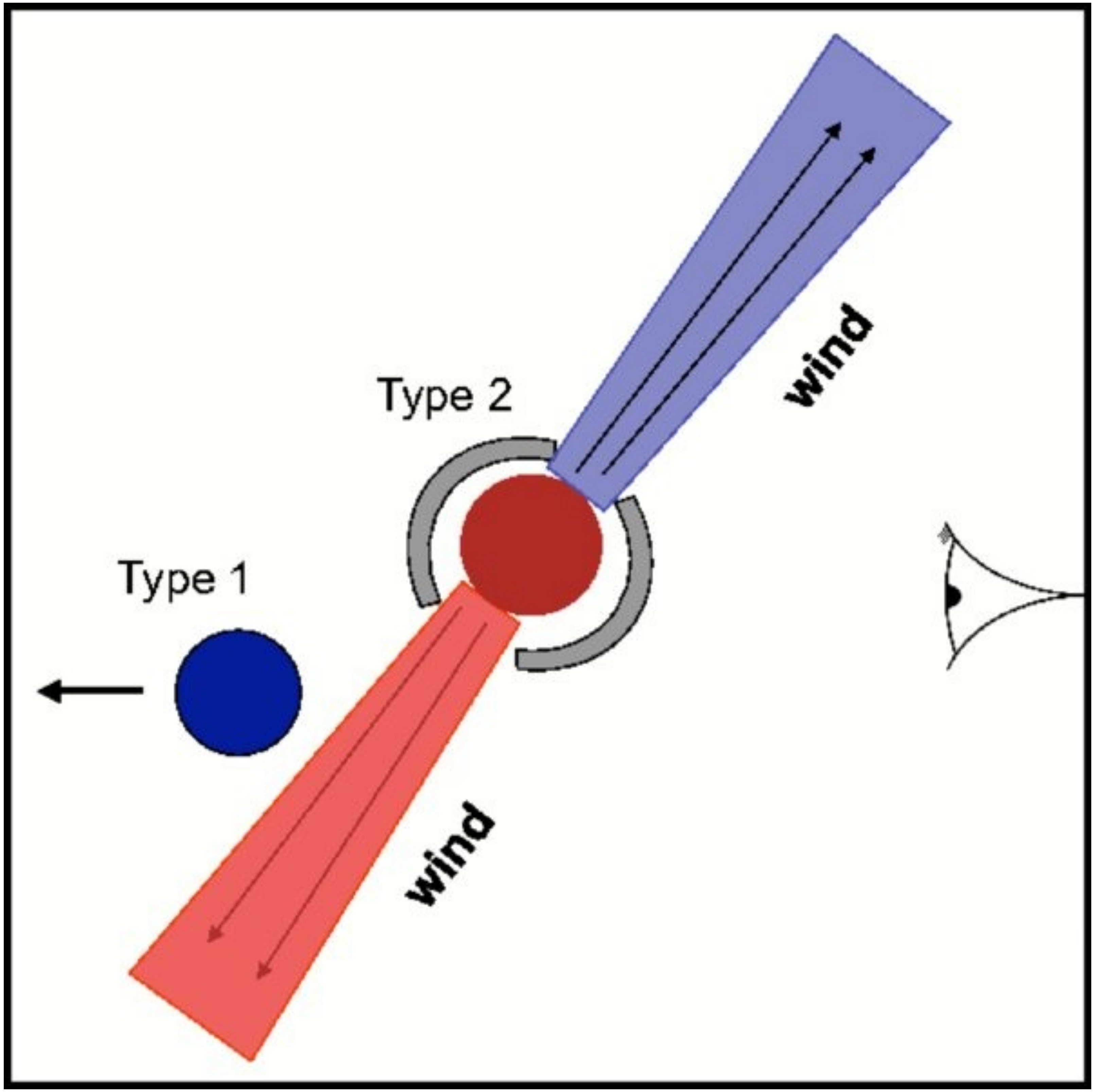
Binary Quasar Scenario



Binary Quasar Scenario



Binary Quasar Scenario for Redshifted Absorption Troughs



Similar scenario invoked by Civano et al. (2010, left) as one possibility to explain a redshifted X-ray absorption line in the spectrum of a possible binary (Type 1 + Type 2) AGN.

Binary Quasar numbers

- About 60,000 BOSS quasars through mid-2011.
- Say 0.4% of AGN are unresolved binaries (Liu+2011). Assume quasars are obscured along 50% of sightlines. Then 0.3% of AGN are *broad-line* quasar pairs, and only 1 in 3 of those have the foreground quasar obscured, as required in our scenario. That leaves ~60 candidates.
- If all quasars produce BAL outflows with covering fraction between 1 in 12 and 1 in 6 within 5 kpc, expect 5 to 10 backlit BAL outflows in BOSS.
- Just over half will yield some redshifted absorption, so expect 3 to 6 backlit objects in BOSS so far (found 9).

Relativistic Doppler Shift?

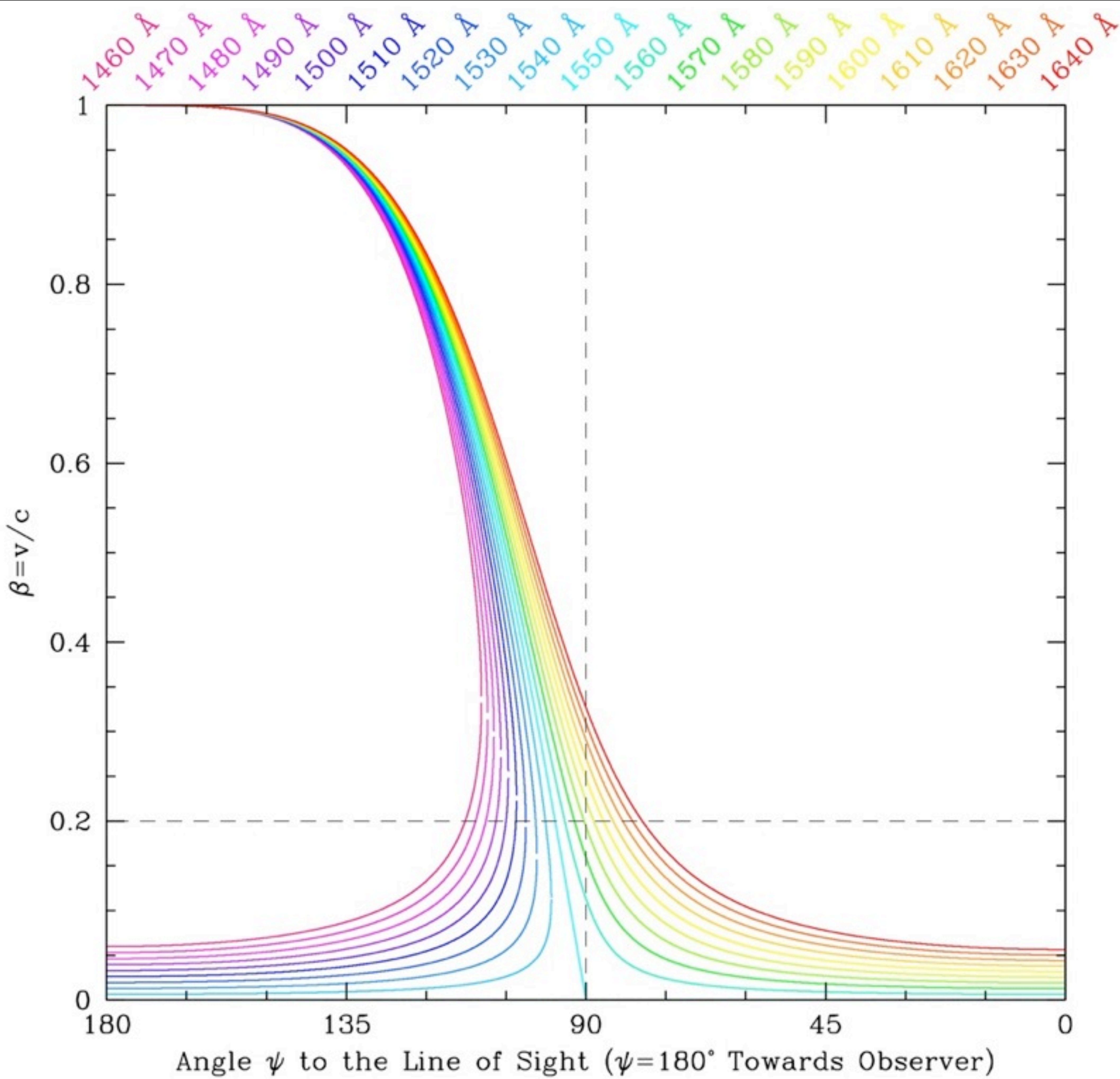
- If observed optical depths of gas difficult to achieve at observed velocities through fallback or rotation, other explanation(s) needed
- BAL outflows are known to reach 0.2*c*
- At such velocities, <u>relativistic Doppler effect can contribute to observed redshifting</u>
- Difficult to observe a BAL outflow at a 90° orientation in front of the quasar that generated it, so relativistic Doppler shift only like to be significant in binary quasar cases

Relativistic Doppler Shift:

- Relativistic Doppler shift due to time dilation.
- In its own rest frame, an ion absorbs at the rest wavelength of a given transition.
- In our frame, if the ion is moving in any direction then time dilation from that motion means that the ion will absorb photons of a longer wavelength, on top of the normal Doppler effect.
- Normally negligible, but has been observed in the Galactic microquasar SS433.

Quasars w/ redshifted BAL troughs have C IV absorption which must arise in the range of velocities β and angles Ψ shown.

BAL flows known with velocities up to β=0.2.

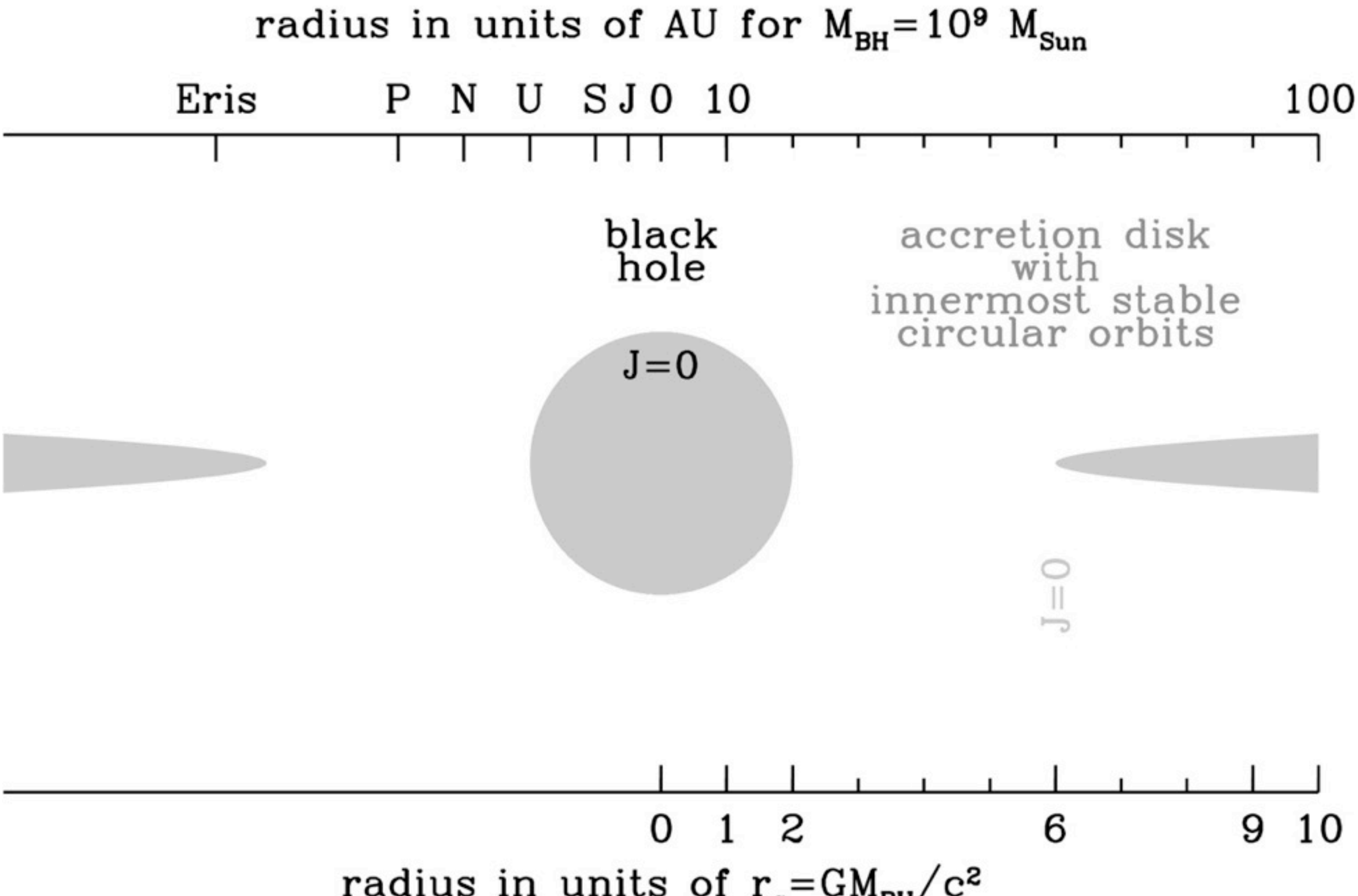


Summary

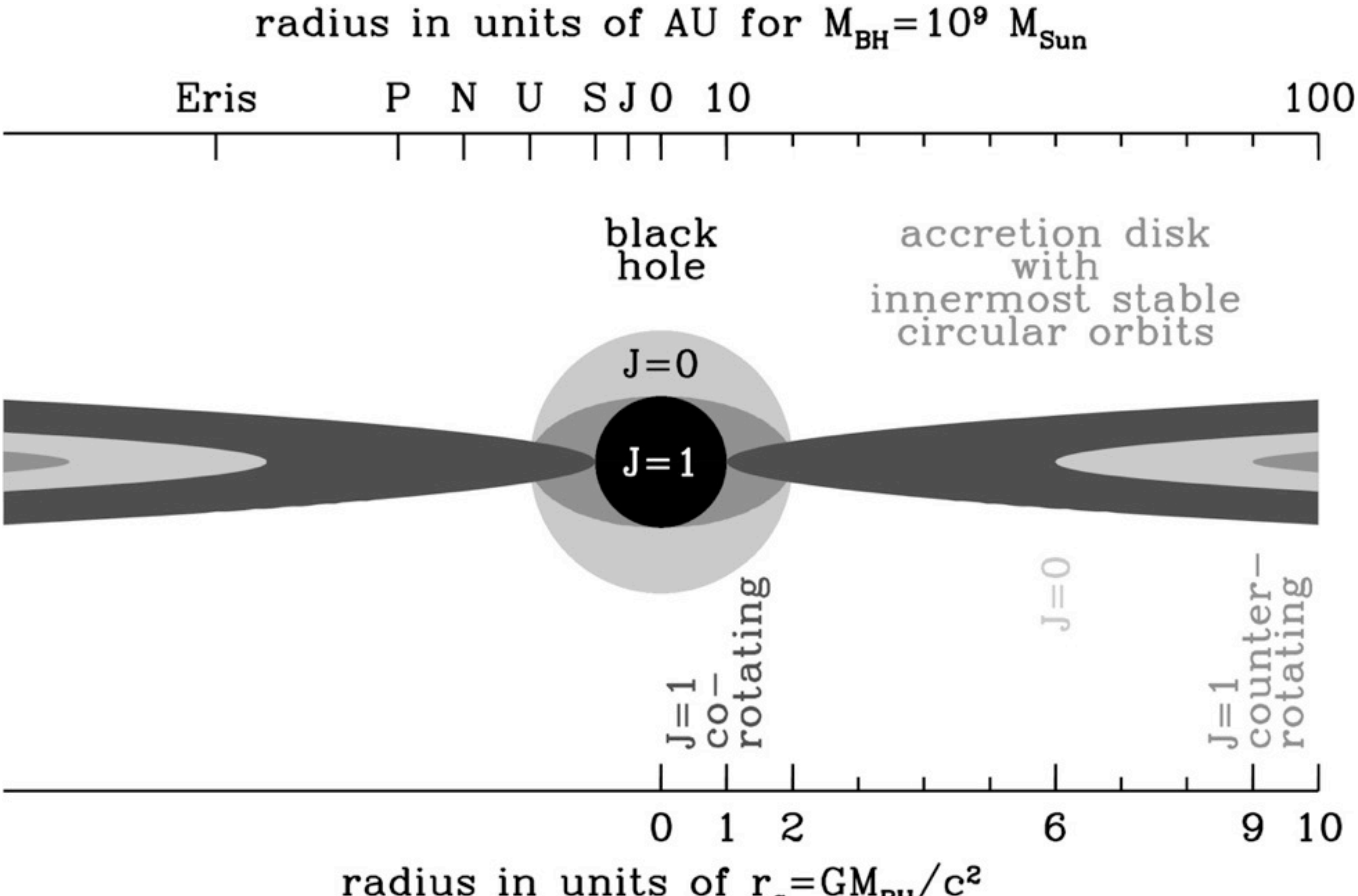
- About 1 in 1200 BAL quasars has redshifted absorption
- Not due to gravitational redshifts
- If due to fallback or rotation, challenges models
- If due to binaries, new lines of sight through outflows
- Binary quasar scenario could include redshifting effect from time dilation (relativistic Doppler shift)
- Can newer simulations reproduce observations?
- NIR spectra: test binary hypothesis
- Variability monitoring: timescale-distance connection

Questions?

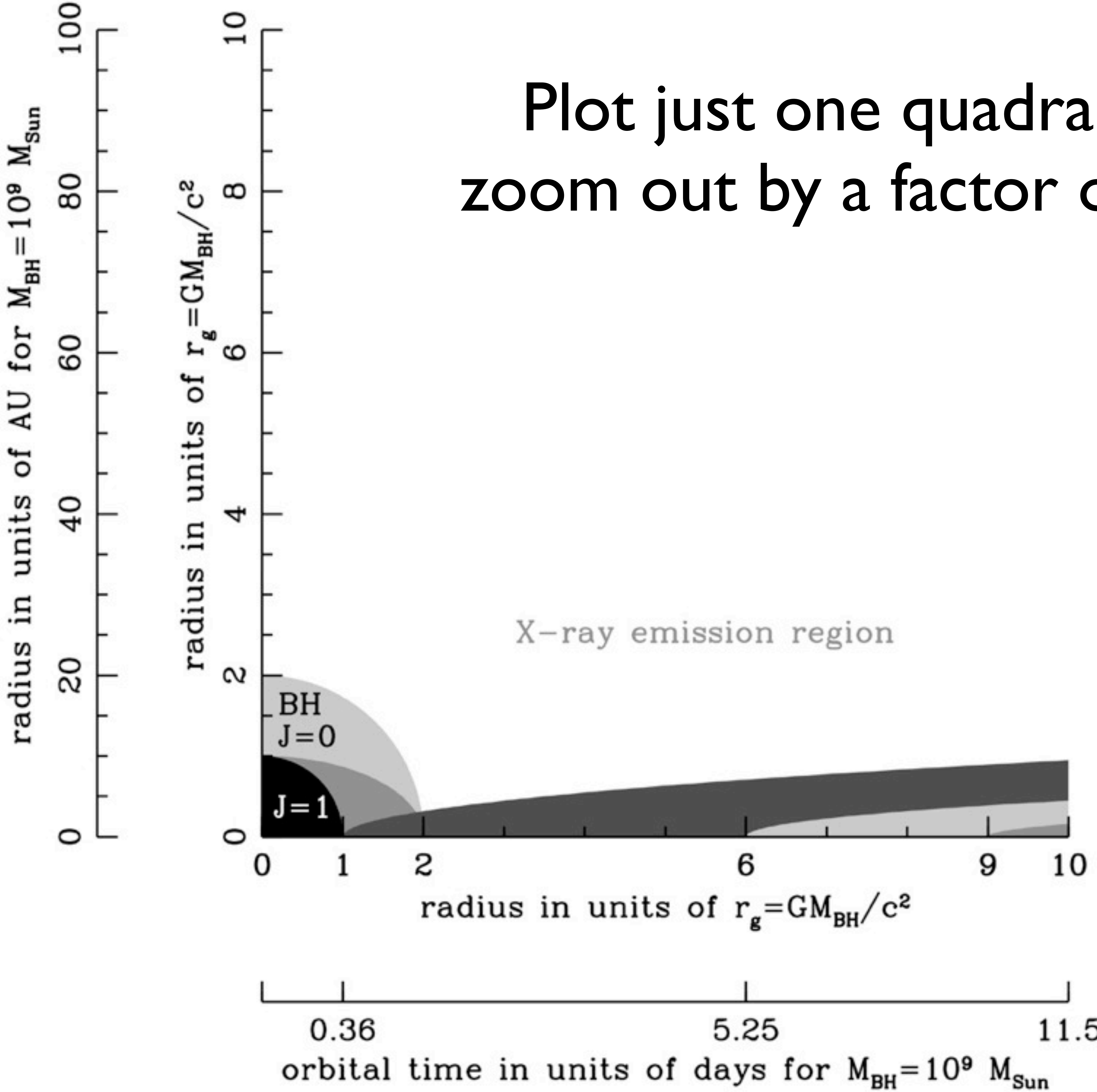
Quasar Powers of Ten

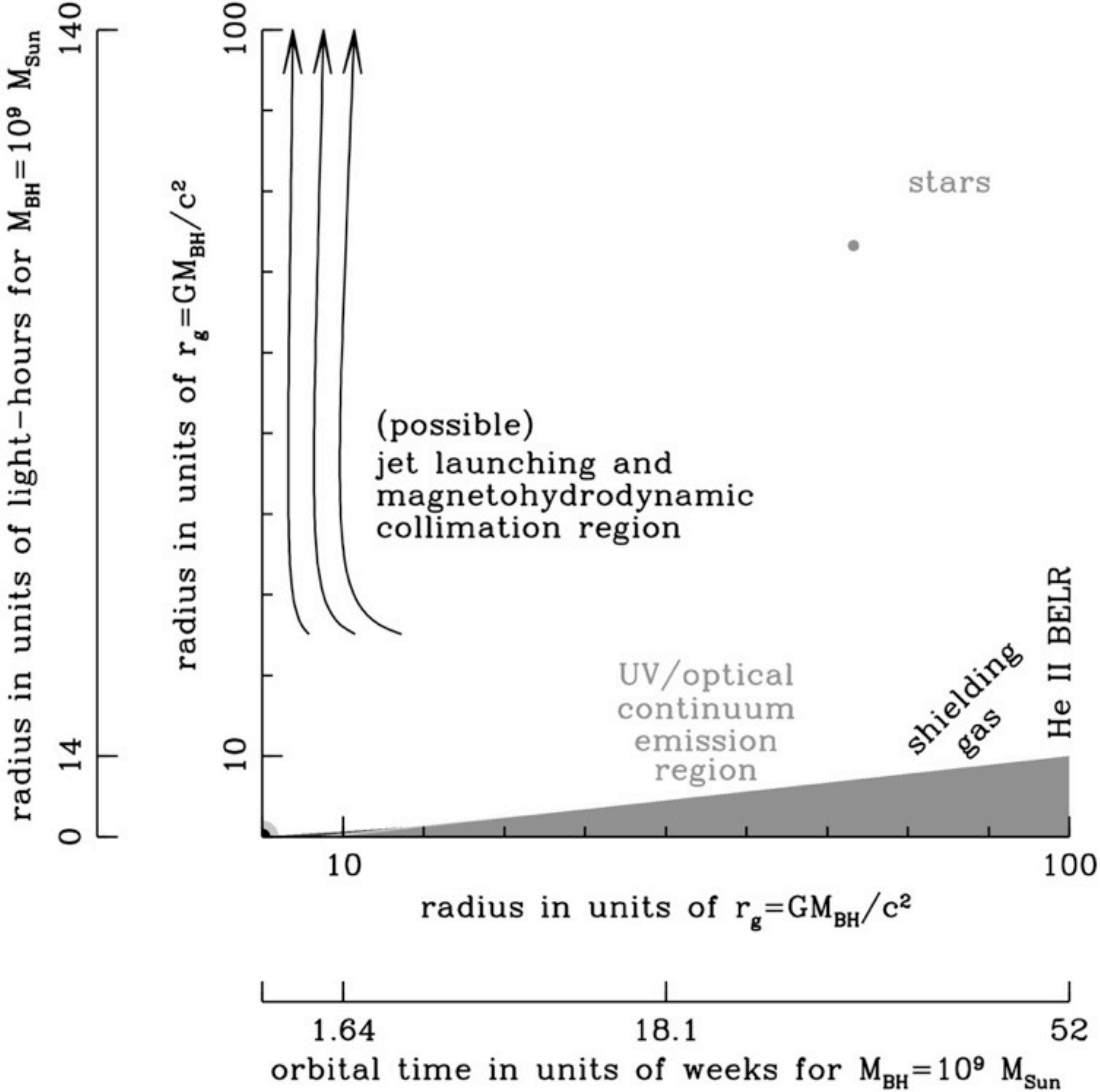


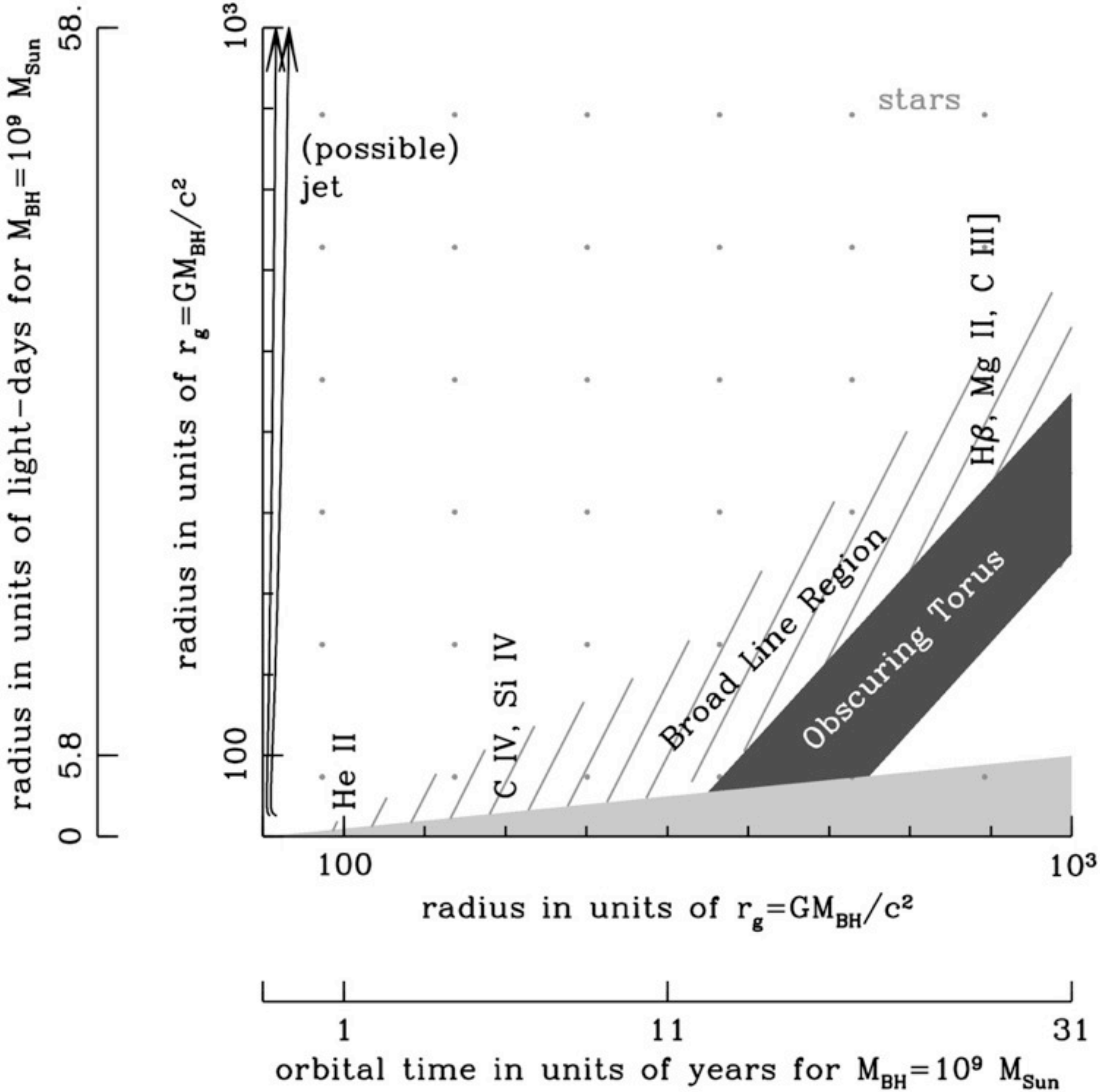
Quasar Powers of Ten



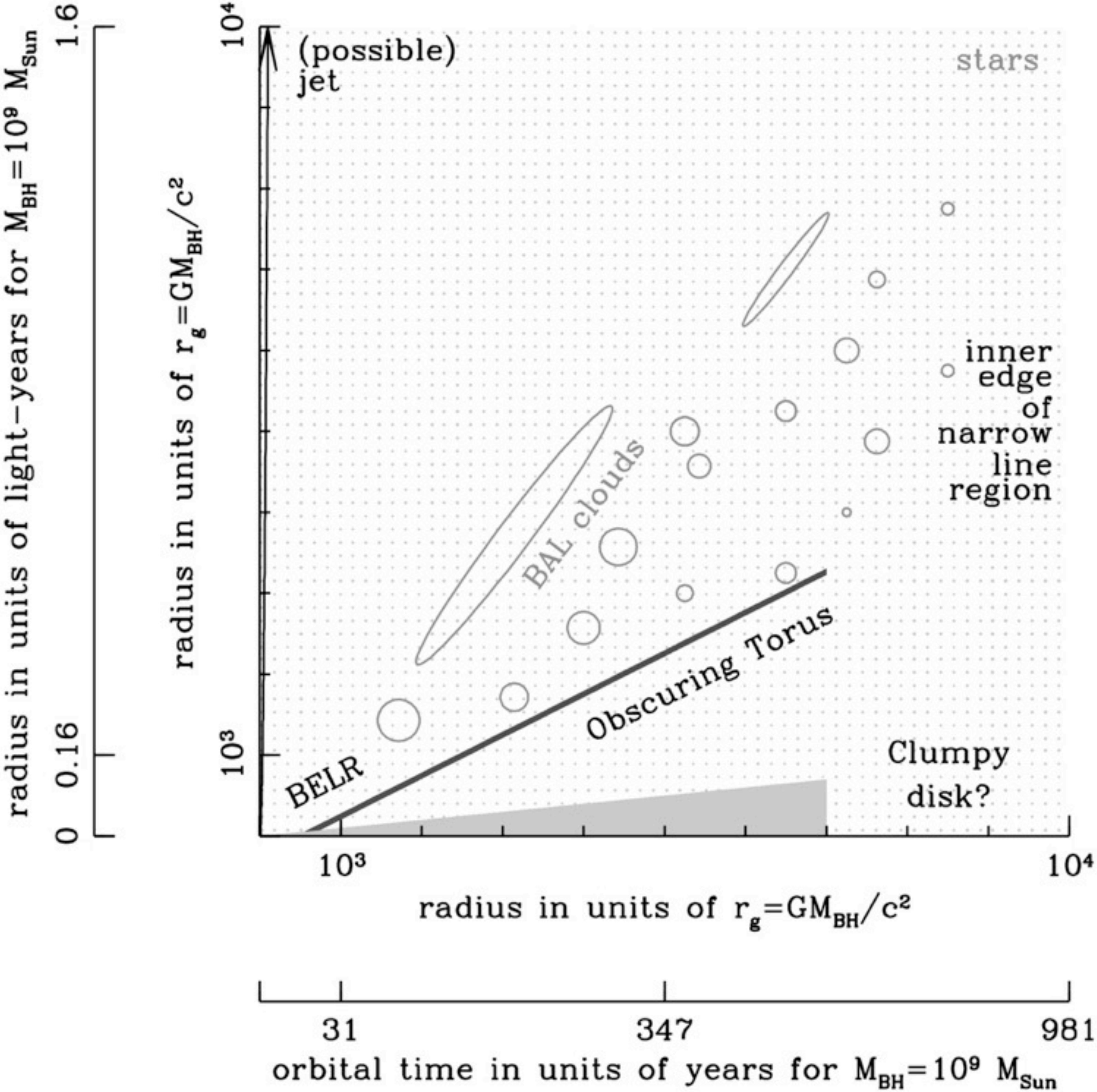
Plot just one quadrant; zoom out by a factor of 10



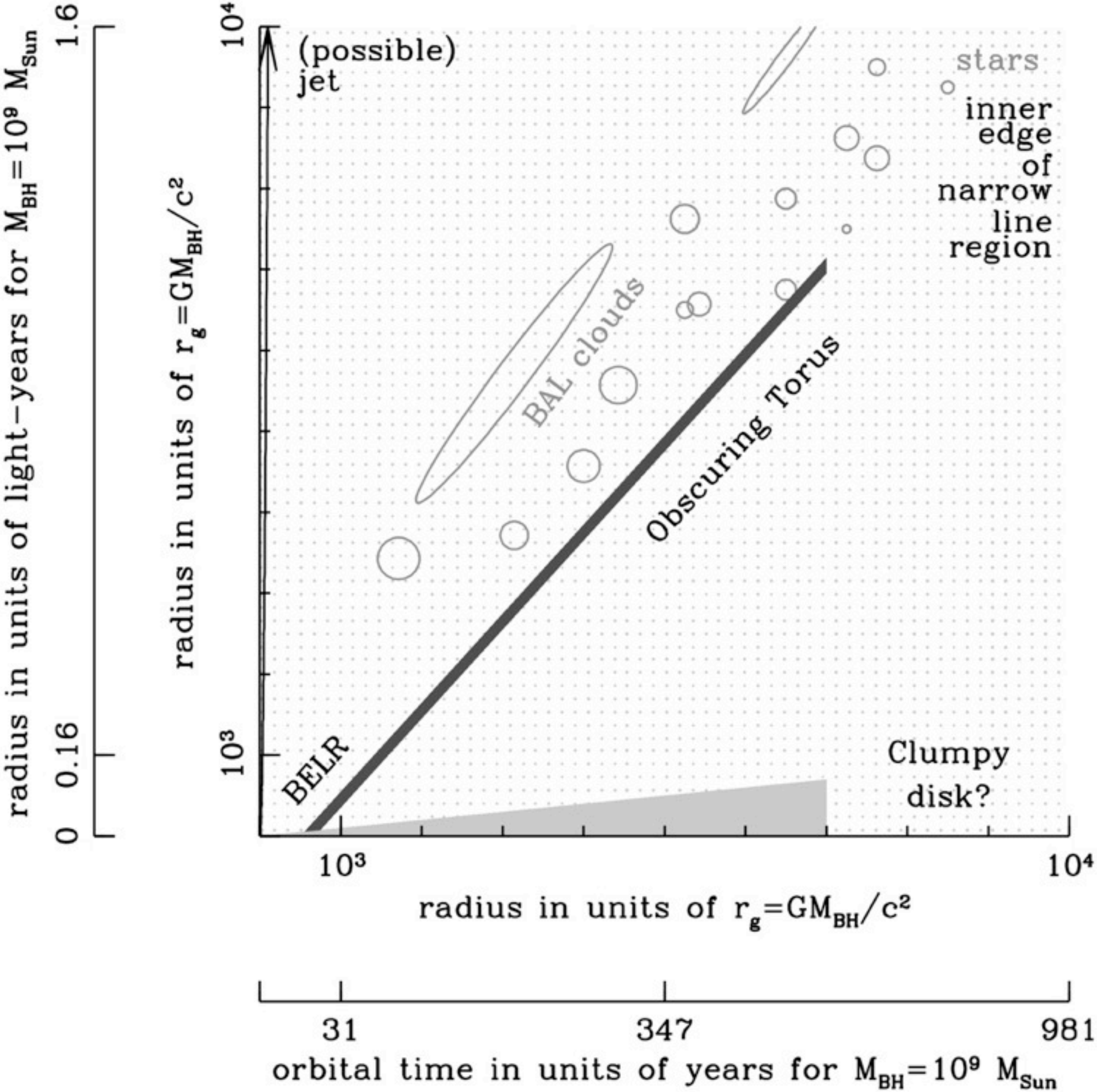

radius in units of light-hours for $M_{BH}=10^9\ M_{Sun}$
140
14
0
100
10
radius in units of $r_g=GM_{BH}/c^2$
stars
(possible)
jet launching and
magnetohydrodynamic
collimation region
UV/optical
continuum
emission
region
shielding
gas
He II BELR
10
100
radius in units of $r_g=GM_{BH}/c^2$
1.64
18.1
52
orbital time in units of weeks for $M_{BH}=10^9\ M_{Sun}$



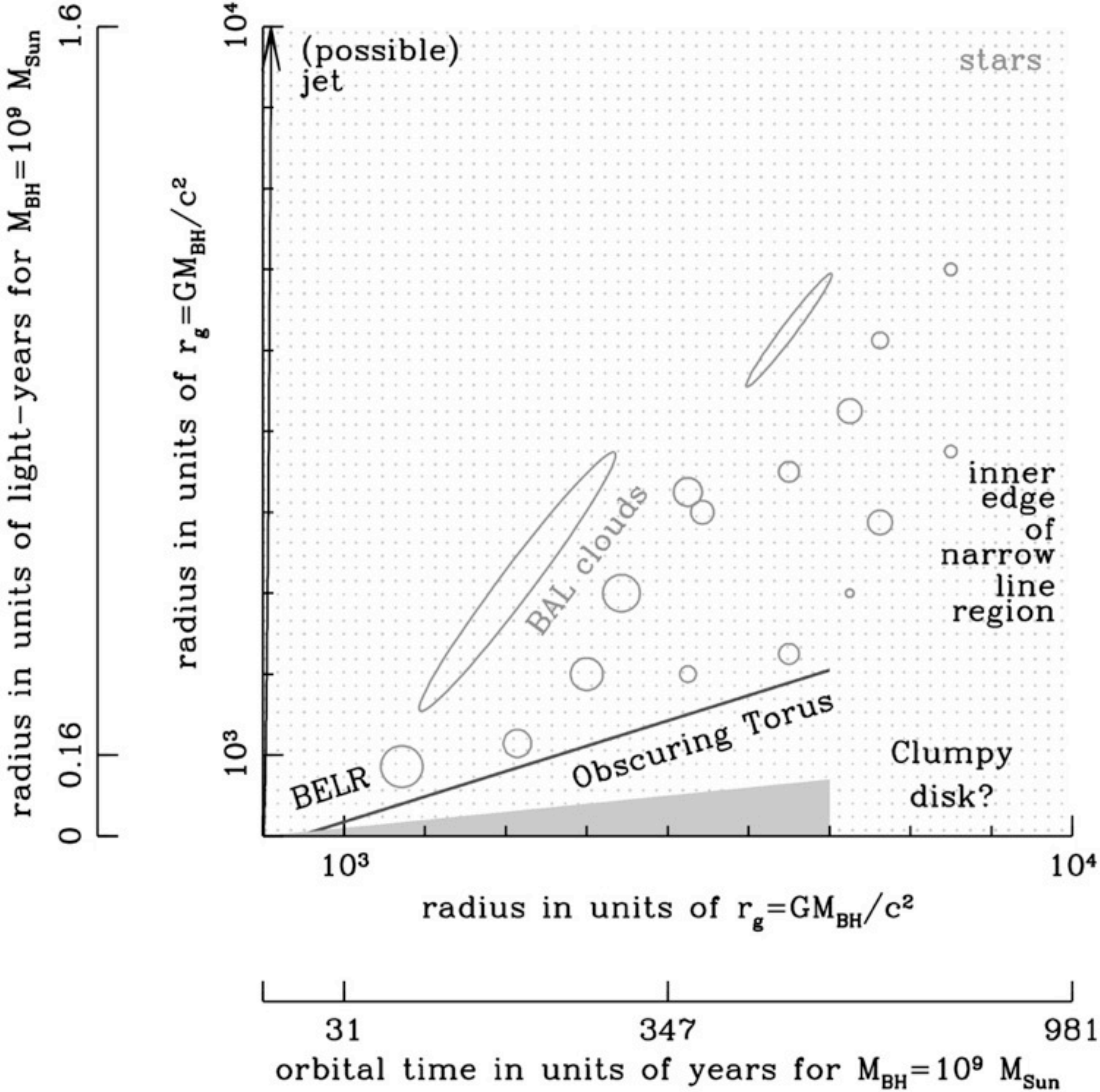
58.
5.8
0
radius in units of light-days for $M_{BH}=10^9\ M_{Sun}$
10^3
100
radius in units of $r_g=GM_{BH}/c^2$
(possible)
jet
stars
He II
C IV, Si IV
Broad Line Region
Obscuring Torus
Hβ, Mg II, C III]
100
10^3
radius in units of $r_g=GM_{BH}/c^2$
1
11
31
orbital time in units of years for $M_{BH}=10^9\ M_{Sun}$



radius in units of light−years for $M_{BH}=10^9\ M_{Sun}$
1.6
0.16
0
radius in units of $r_g=GM_{BH}/c^2$
10^4
10^3
(possible)
jet
stars
inner
edge
of
narrow
line
region
BAL clouds
Obscuring Torus
BELR
Clumpy
disk?
10^3
10^4
radius in units of $r_g=GM_{BH}/c^2$
31
347
981
orbital time in units of years for $M_{BH}=10^9\ M_{Sun}$



radius in units of light−years for $M_{BH}=10^9$ M_{Sun}
1.6
0.16
0
radius in units of $r_g=GM_{BH}/c^2$
10^4
10^3
(possible) jet
stars
inner edge of narrow line region
BAL clouds
Obscuring Torus
BELR
Clumpy disk?
10^3
10^4
radius in units of $r_g=GM_{BH}/c^2$
31
347
981
orbital time in units of years for $M_{BH}=10^9$ M_{Sun}



radius in units of light−years for $M_{BH}=10^9\ M_{Sun}$
1.6
0.16
0
radius in units of $r_g=GM_{BH}/c^2$
10^4
10^3
(possible)
jet
stars
BAL clouds
inner
edge
of
narrow
line
region
Obscuring Torus
BELR
Clumpy
disk?
10^3
10^4
radius in units of $r_g=GM_{BH}/c^2$
31
347
981
orbital time in units of years for $M_{BH}=10^9\ M_{Sun}$