Narrow (UV) Absorption Line Outflows from Quasars

Fred Hamann

University of Florida

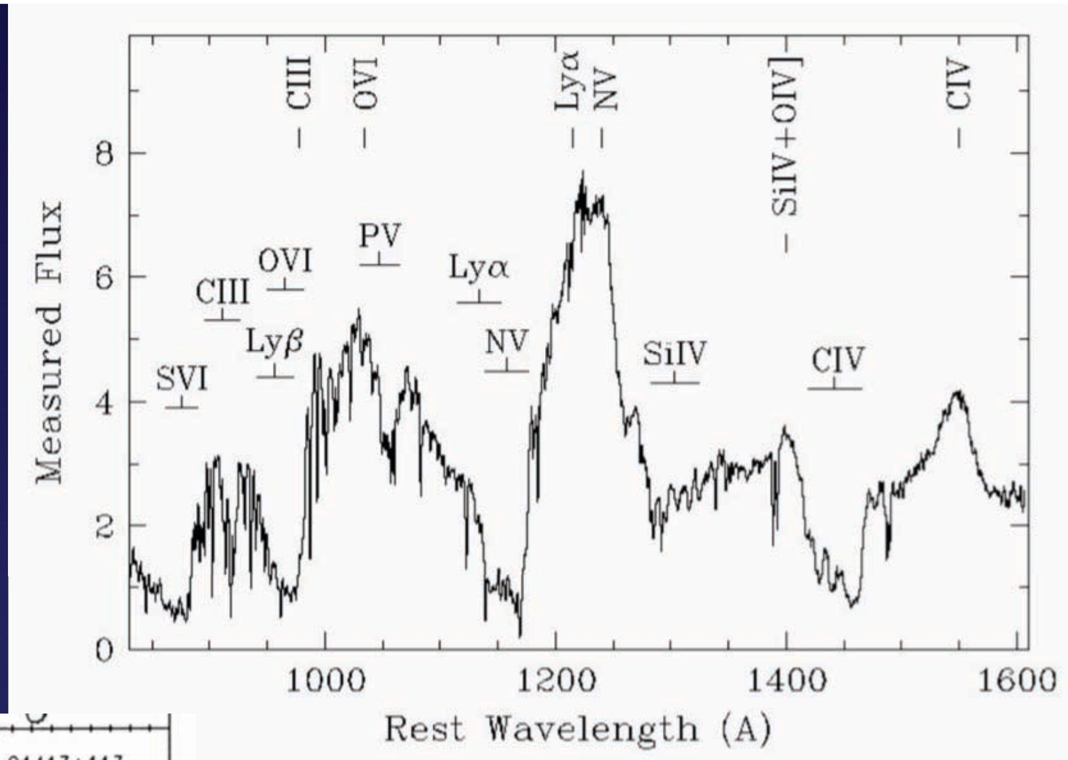
Leah Simon (Berea), Paola Rodriguez Hidalgo (PSU),
Daniel Nestor (UCLA), Dan Capellupo (UF),
Jason Prochaska (UCSD),
Michael Murphy (Swinburne), Max Pettini (IofA)

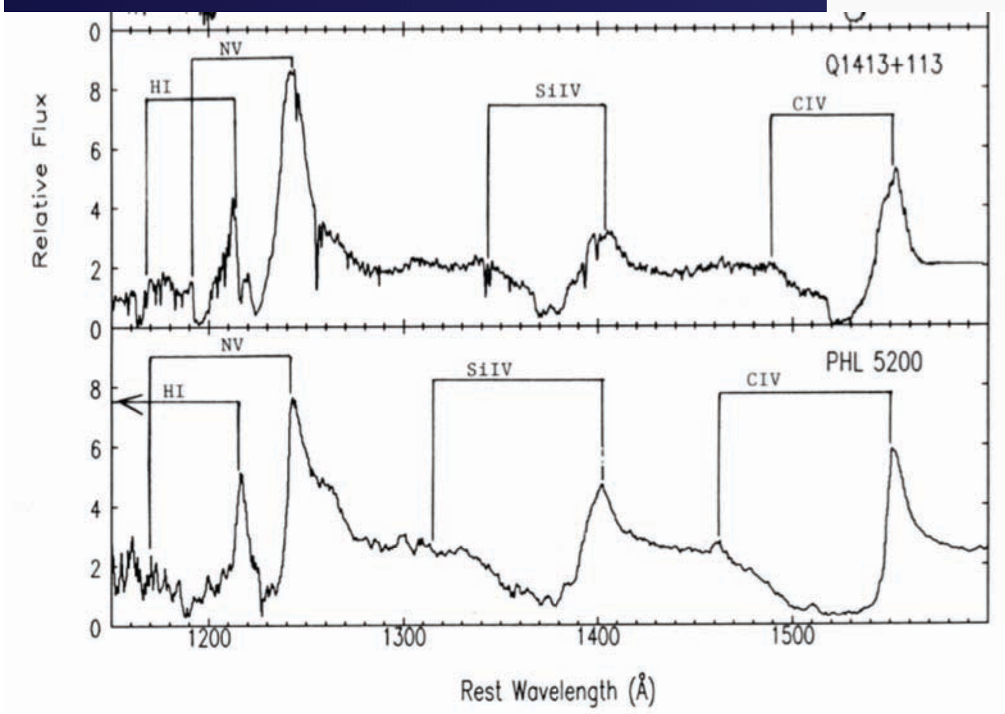
Outflow Features:

Broad Absorption Lines (BALs)

Observed in 10-23% of optically-selected quasars

Probably present in all quasars (with ~10-23% covering)



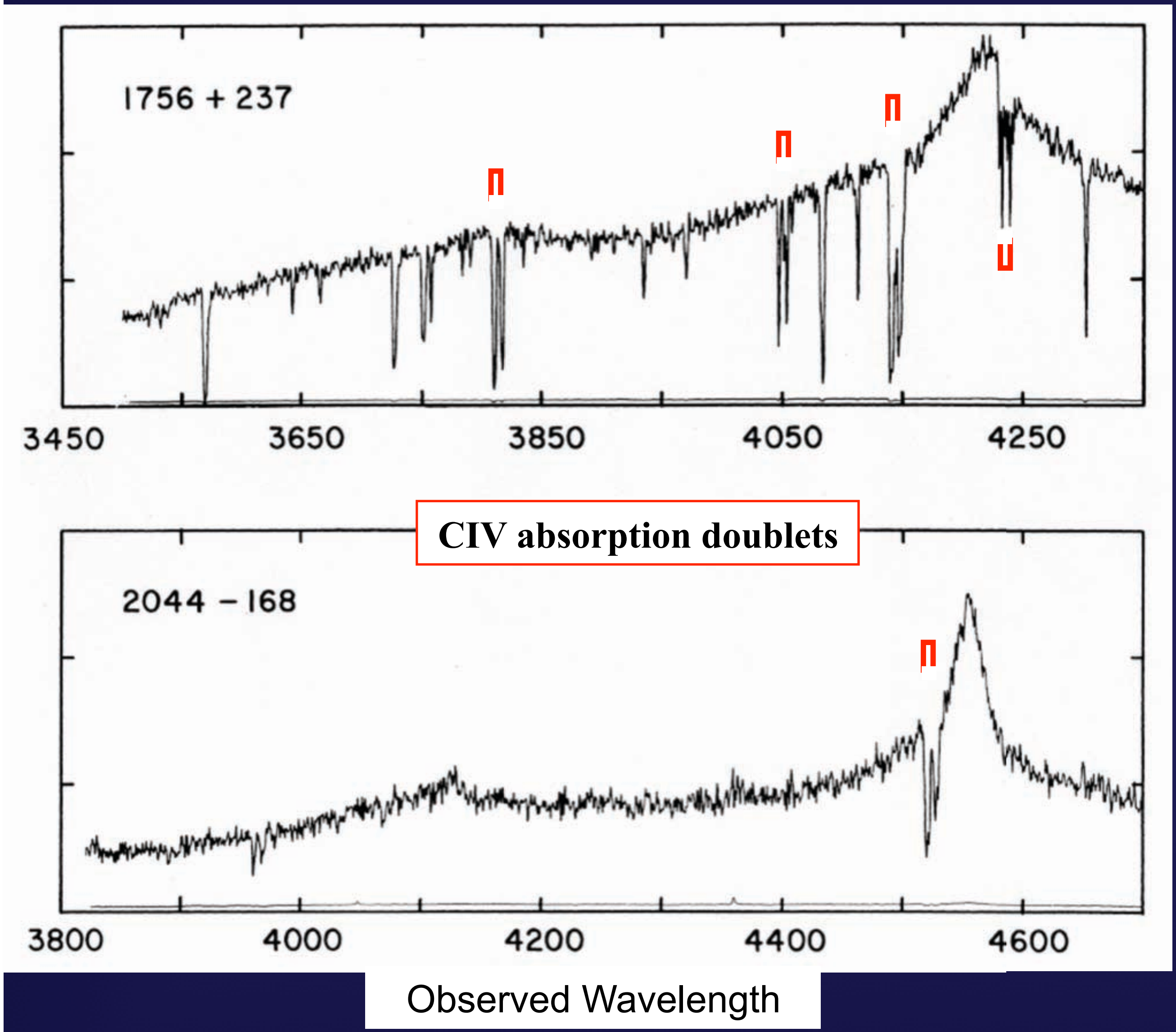


Measured flow speeds:
a few to >30,000 km/s

FHWM / v ~ 1

Possibly large mass loss rates

Narrow Absorption Lines (NALs):



Foltz et al. 1986

Where do NALs form?

1) Quasar outflows

2) Intervening gas or galaxies

At v < 1000 km/s:

3) Mass-loaded quasar flows

4) Starburst-driven winds

5) Ambient halo gas

6) Merger remnants

How can we find NALs in quasar-driven outflows??

Measure all NALs in ~2200 SDSS quasars

Huge excess at low v.

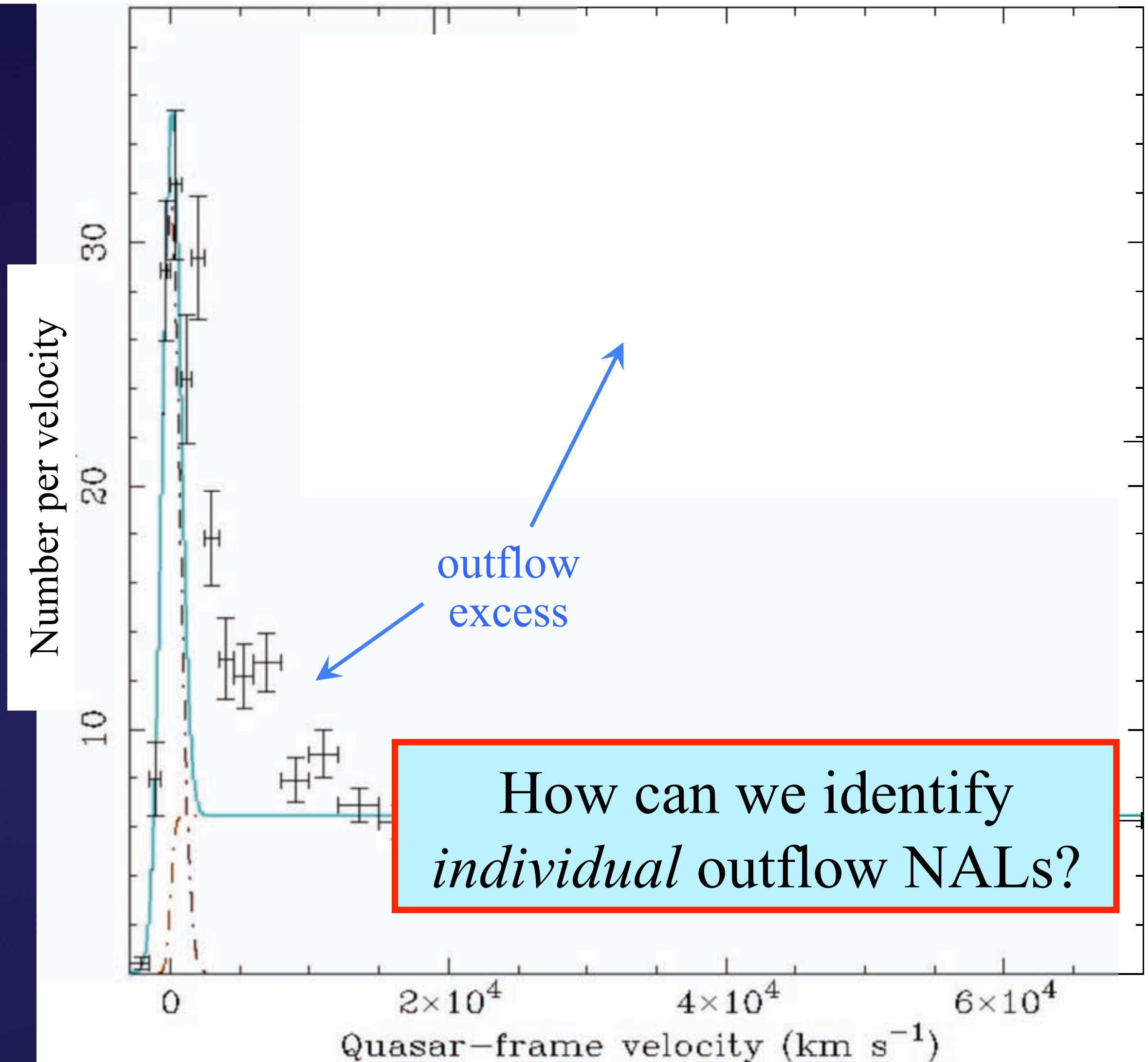
NALs at v < 1000 might be "environmental" (host halos, starburst-driven winds)

Assume all lines at very high v are unrelated/intervening

Others must be quasar outflows!

>50% of NALS from 2000-8000 km/s are outflows

14% of quasars have at least one narrow outflow line



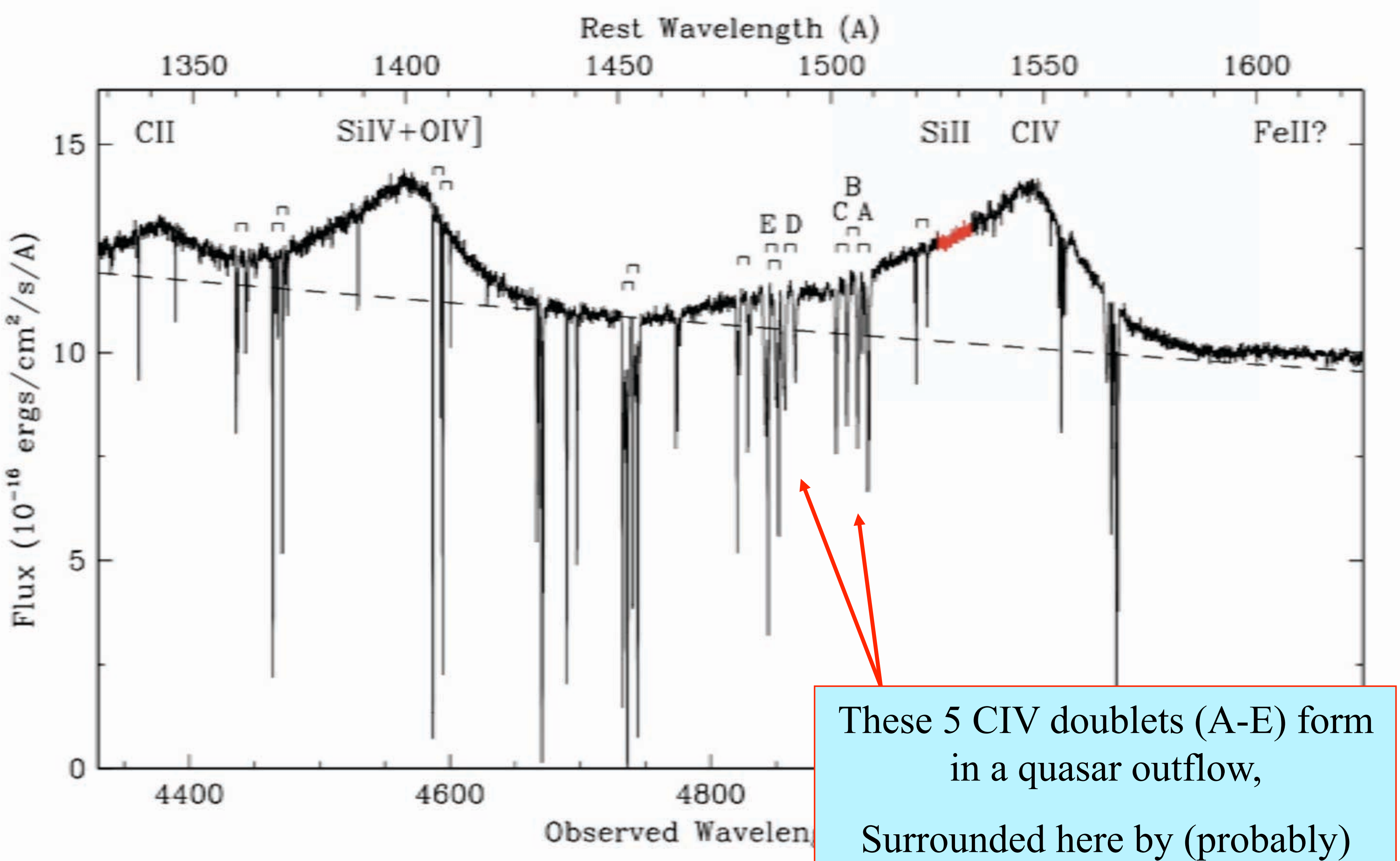
How can we identify *individual* outflow NALs?

Nestor et al. 2008

But strong lines only, some higher v NALs *are* in outflows (Simon talk):

➔ True outflow fractions are larger

Outflow NALs at 9700-14,000 km/s (in R~70,000 to 100,000 spectra, Keck, VLT)

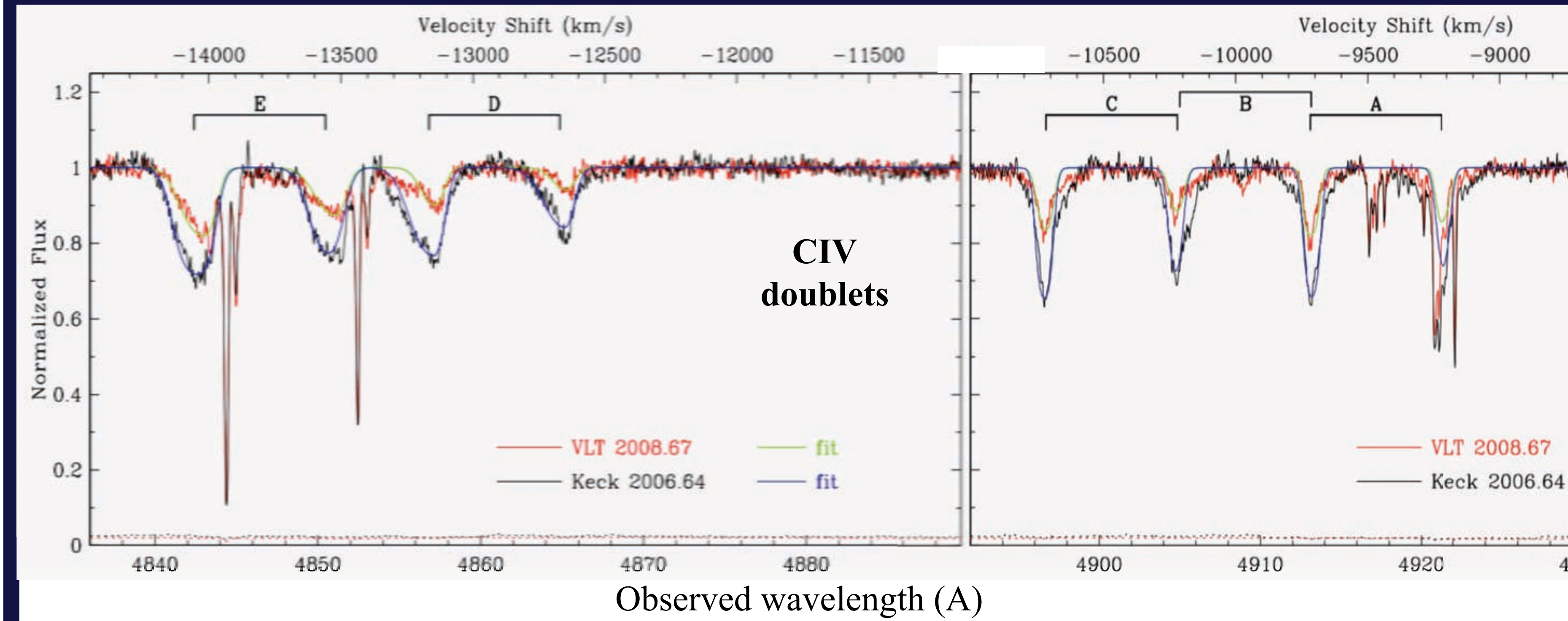


These 5 CIV doublets (A-E) form in a quasar outflow,

Surrounded here by (probably) unrelated intervening lines

QSO: z ~ 2.3, L ~ 8×10^{47} ergs/s, L/L_E ~ 0.4

Hamann et al. 2011



Formation in a <u>quasar-driven outflow</u> confirmed by:

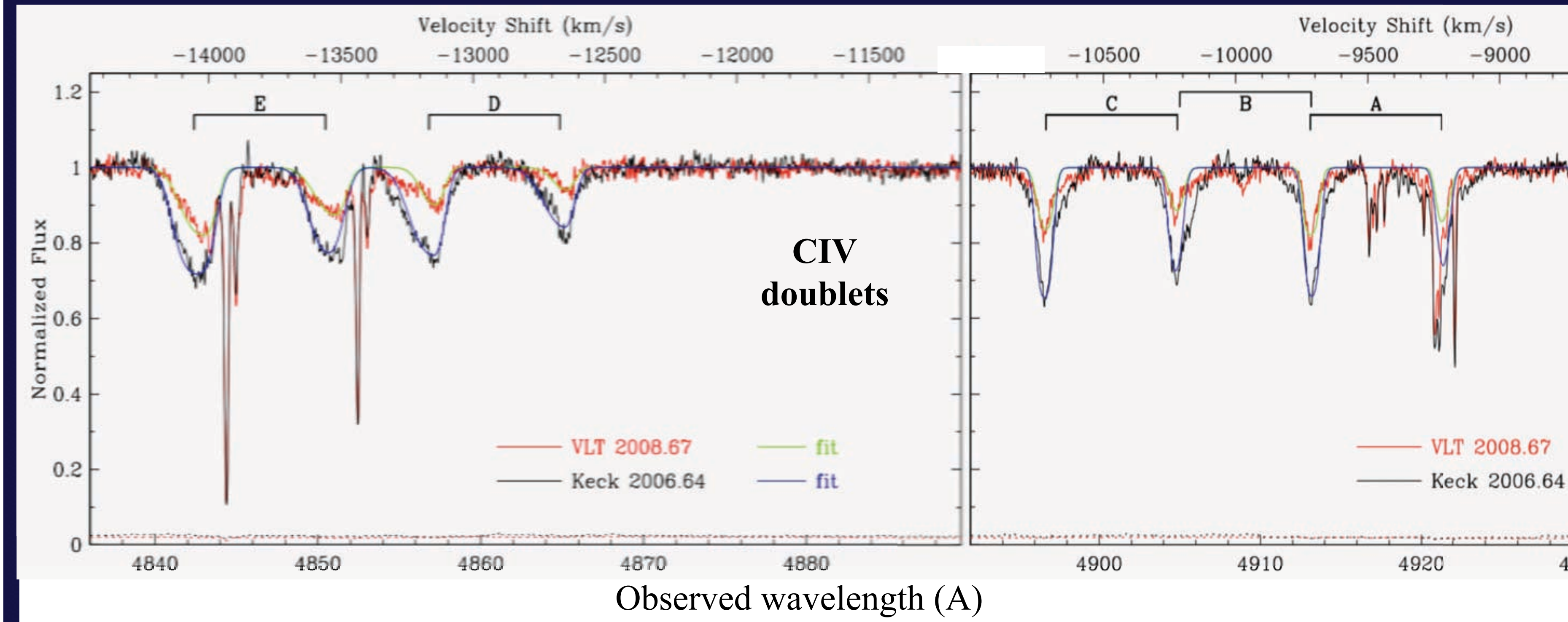
1) Line variability

2) Smooth "broad" (very super-sonic) line profiles

3) Partial covering of the continuum source

→ "Intrinsic" at speeds *much* too high for "environmental" gas.

Hamann et al. 2011



NAL outflow properties:

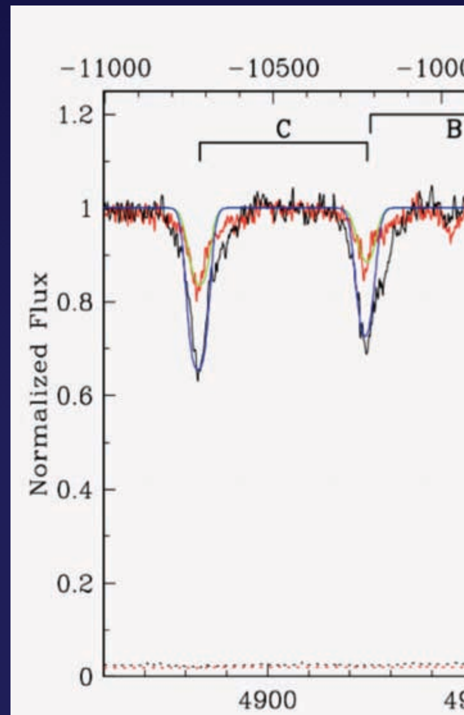
- Outflow speeds ~ 9700 – 14,000 km/s
- FWHMs ~ 62 – 164 km/s
- Coordinated variability in 5 distinct systems (<0.63 yr rest)
- NAL strength changes commensurate with covering factor changes (~0.35 to 0.2 in CIV)

Hamann et al. 2011

Partial Covering

Lines can be saturated
(1:1 doublet ratios)
but not "black"

if the absorber only
partially covers the
background light source

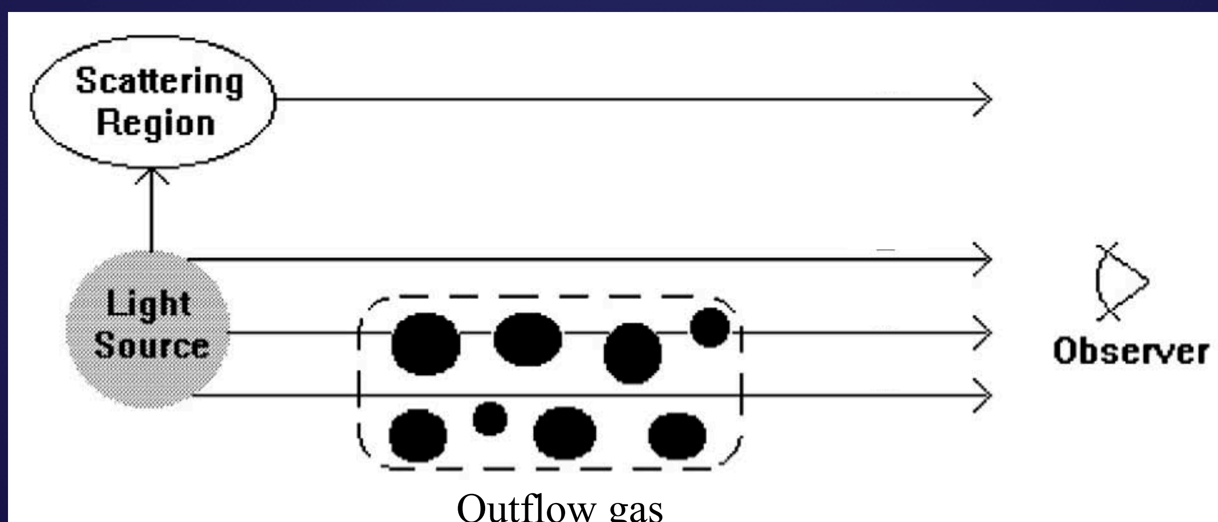


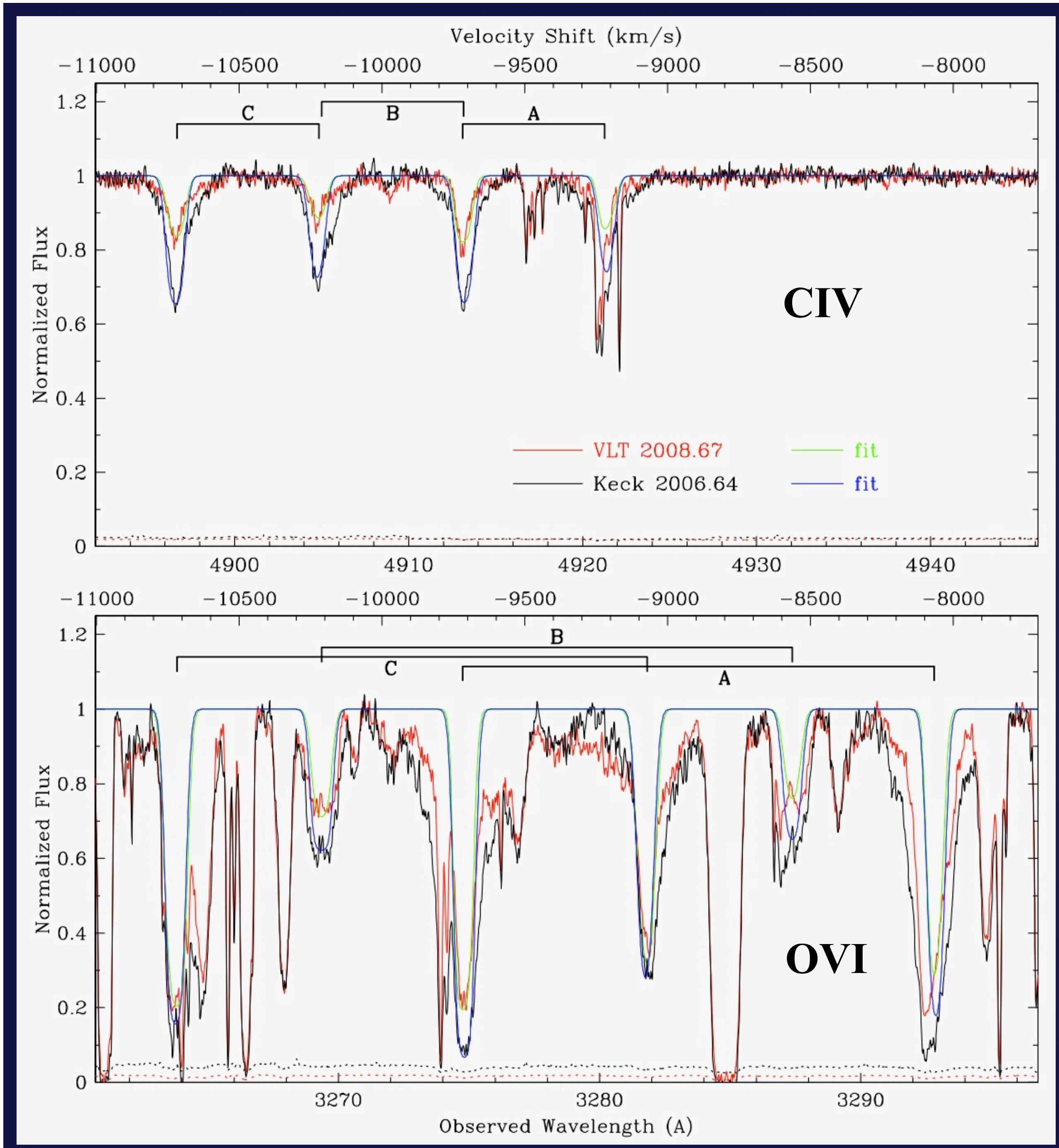
Requires *small* structures:
< 0.01 pc for partial covering
of the continuum source

Suggests a location near the
continuum source

Often goes with line variability
and smooth "broad" profiles

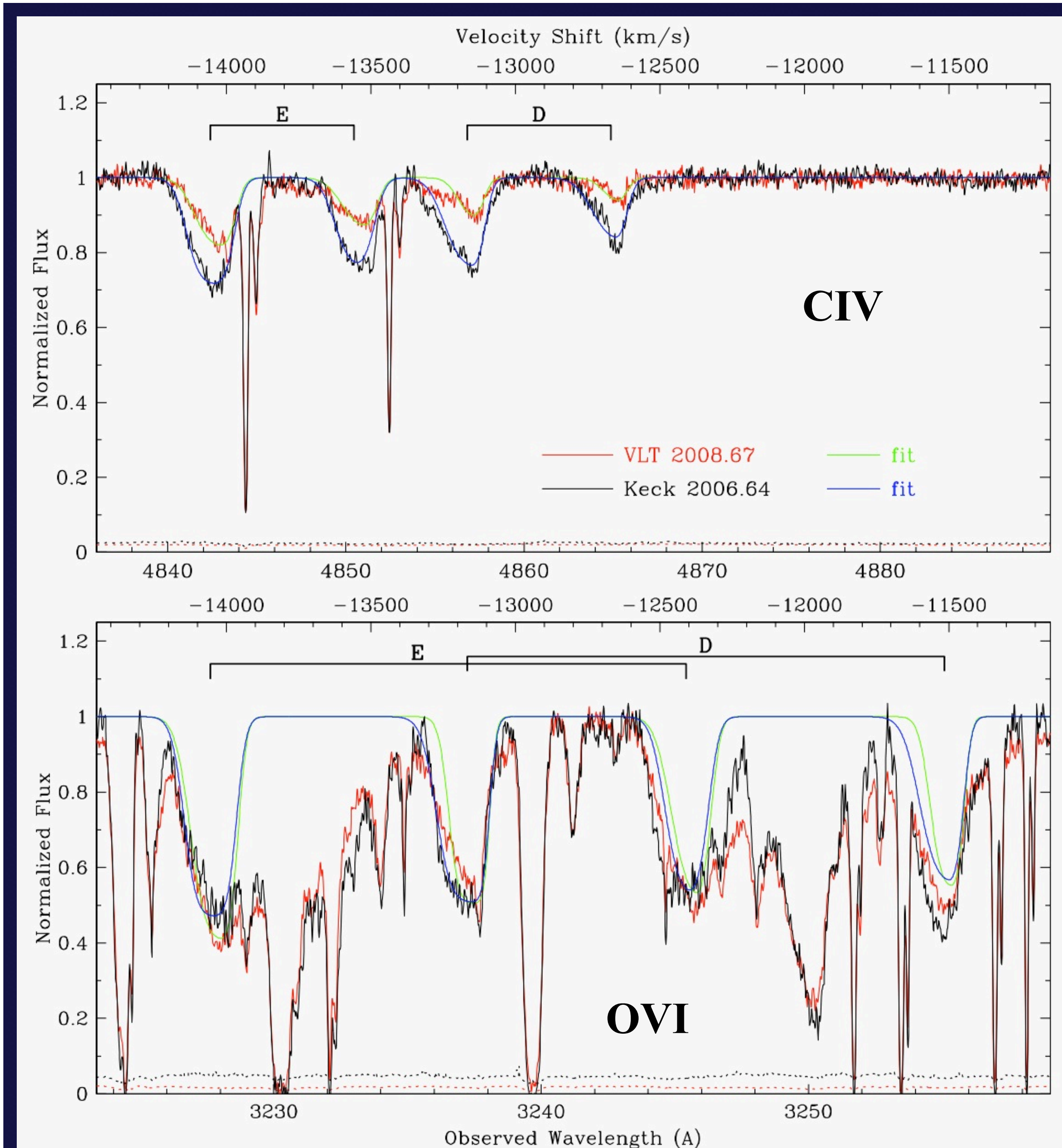
➔ Quasar outflows





OVI stronger and broader than CIV, and less variable, in all 5 systems

Lower ions not detected



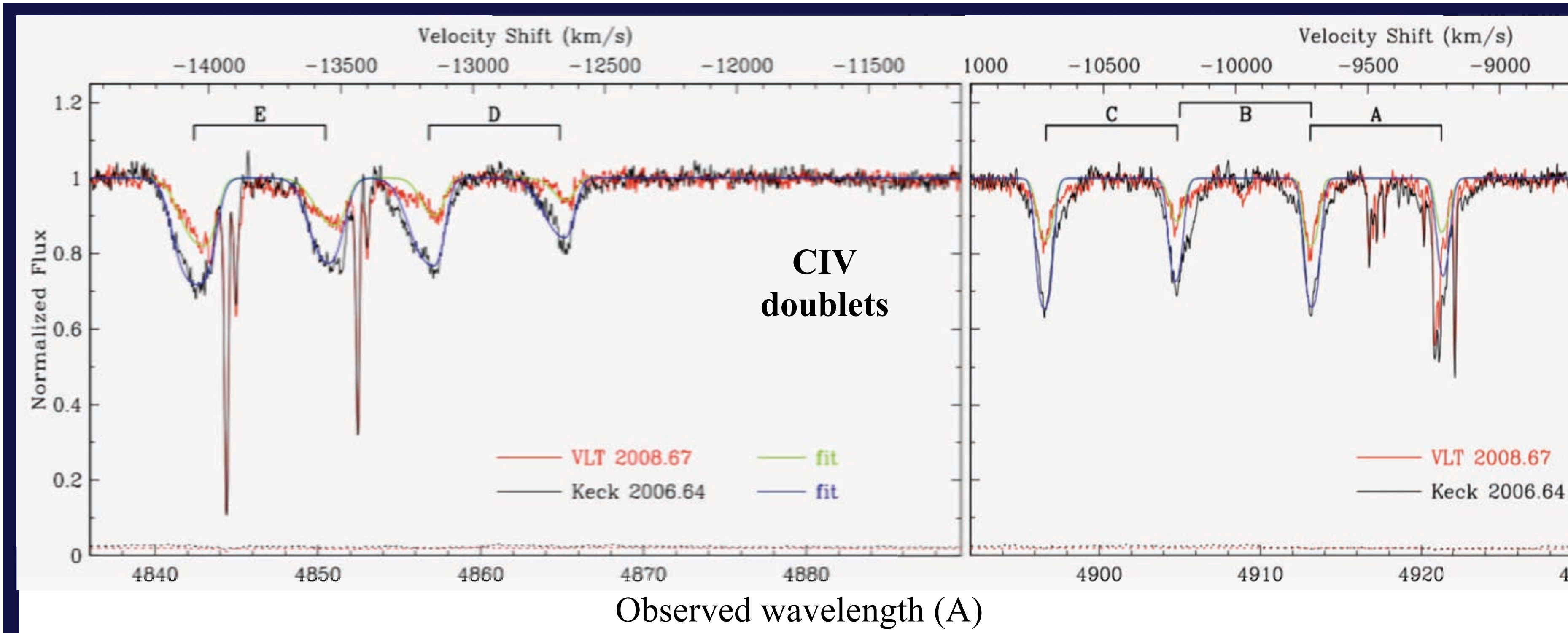
OVI stronger and broader than CIV, and less variable, in all 5 systems

Lower ions not detected

Altogether:

Five distinct flow structures with similar:

kinematics, sizes, ionizations, locations?

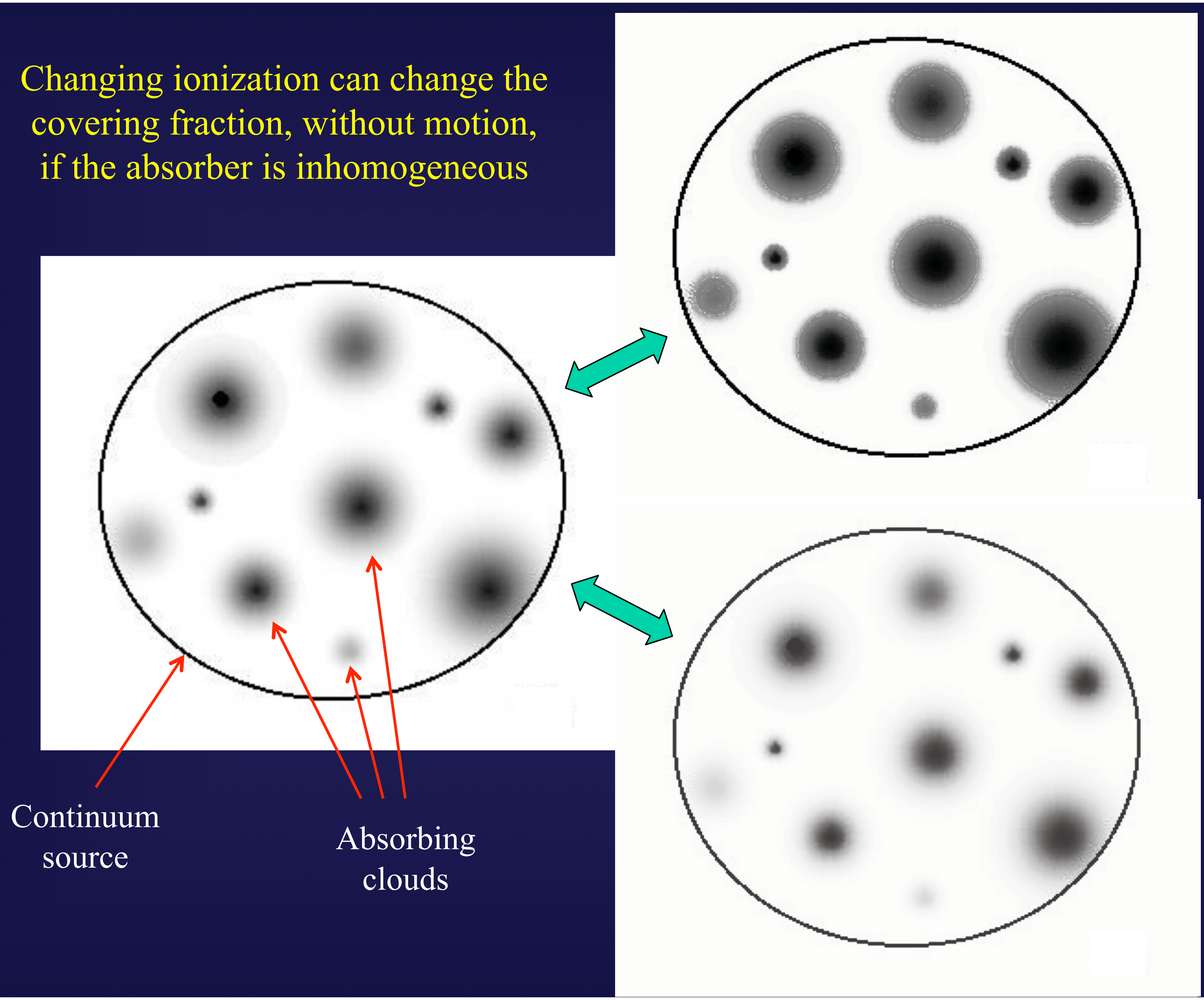


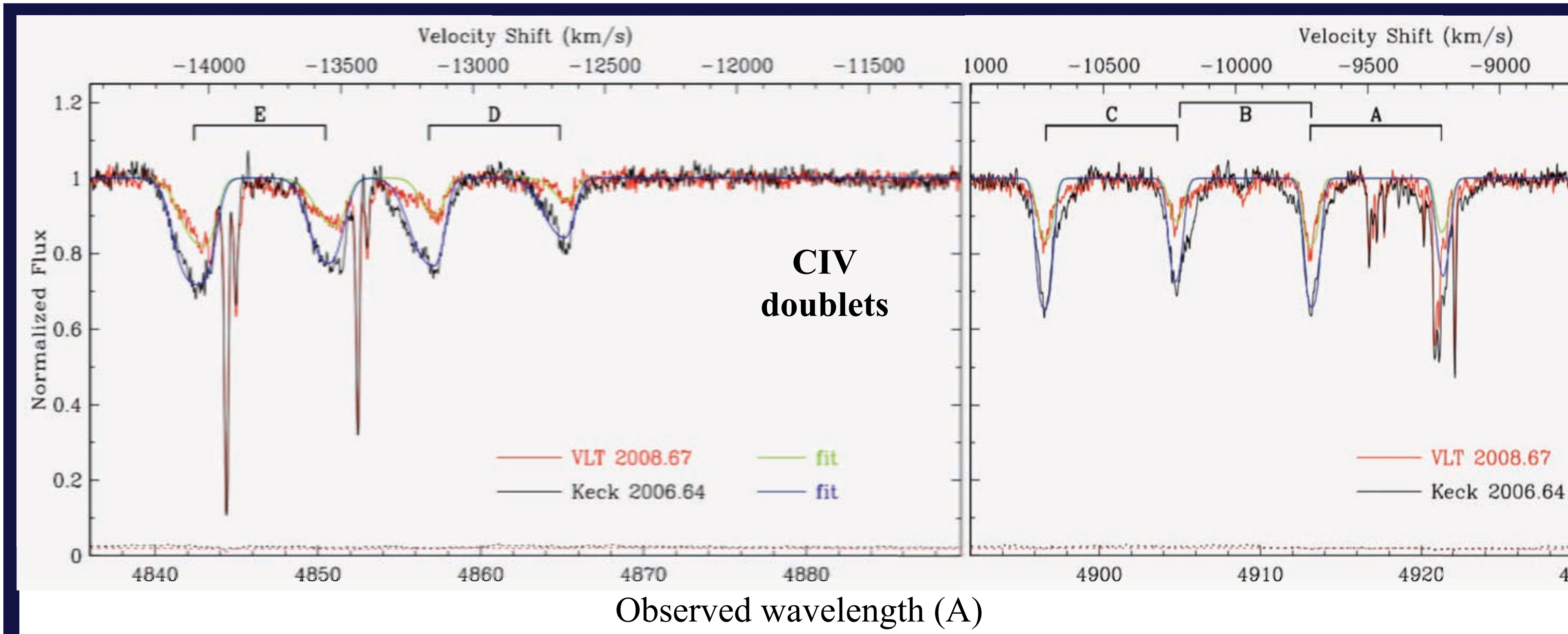
NAL outflow properties:

- Coordinated changes suggest global changing ionization
- No acceleration, < 3 km/s/yr → coasting freely >~ 5 pc from SMBH
- Short survival times → within ~5 pc of origin (quasar)
- Max distance ~1 kpc (recombination time)
- Line-lock in A-B-C → driven by radiation pressure, moving directly toward us (w/in 16^{o})

Hamann et al. 2011

Changing ionization can change the covering fraction, without motion, if the absorber is inhomogeneous

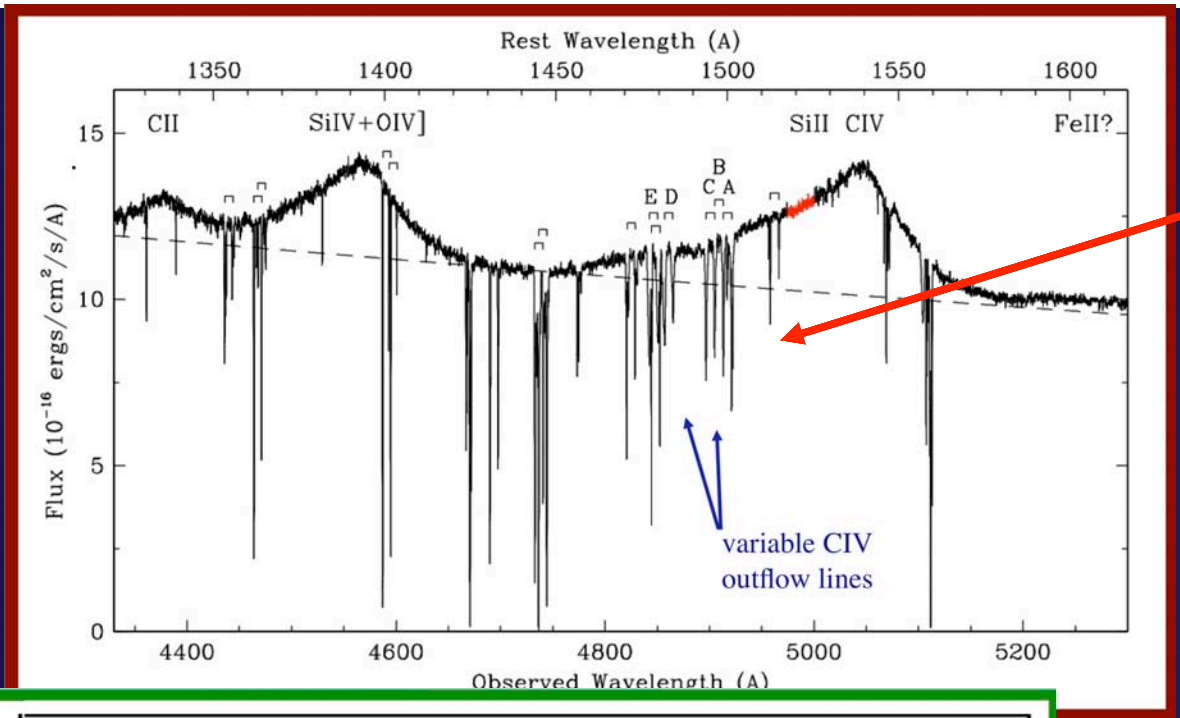




NAL outflow properties:

- Total $N_H \sim 5 \times 10^{19}$ cm^{-2} in all 5 systems
- Kinetic energy too small by >100x for "feedback"
- Metallicty ~2x solar → consistent with merger-starburst-quasar evolution sequence

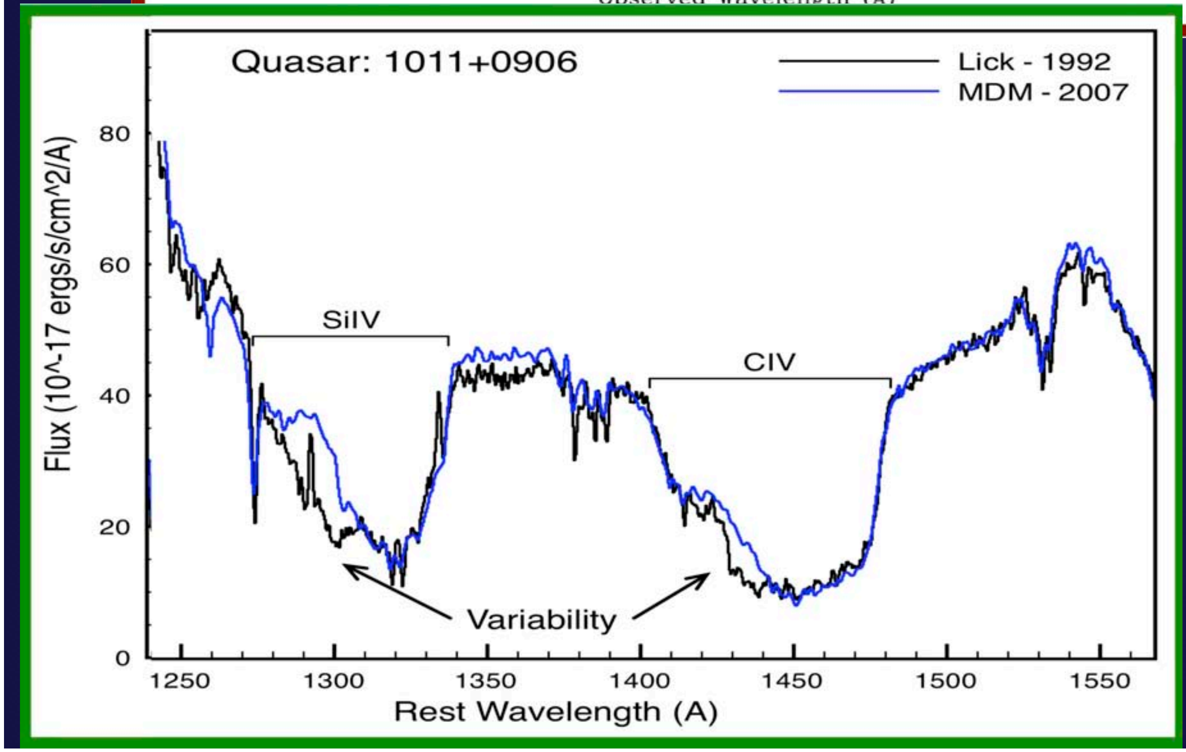
Hamann et al. 2011



These outflow NALs are ~100x narrower and weaker than BALs, but with the same speeds, same ionization

Also negligible X-ray absorption

(Just et al. 2007; also Chartas et al. 2009, Gibson et al. 2010)

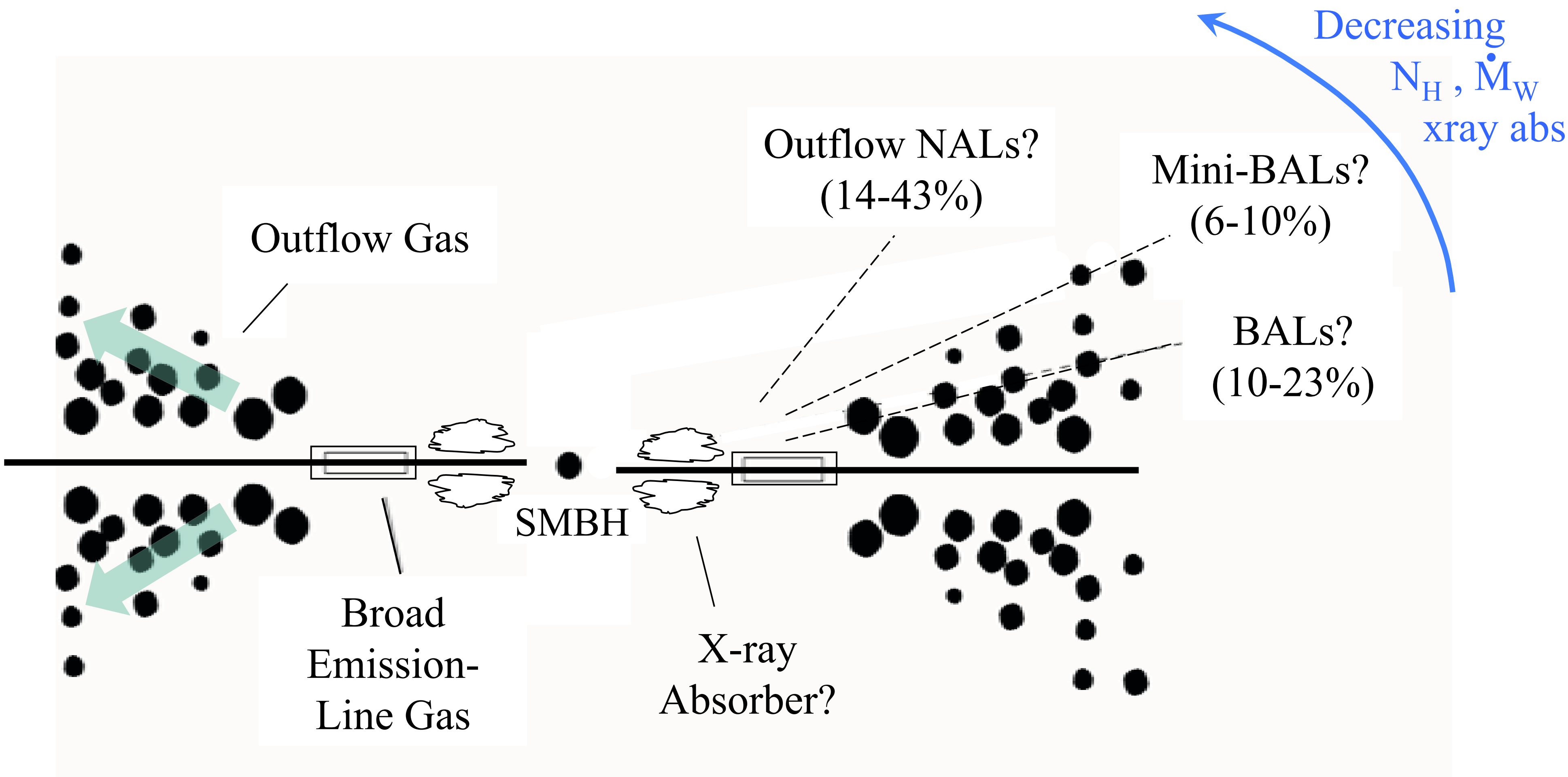


BALs come with *strong* X-ray absorption

(Gallagher et al. 2002, 2006)

Possibly enough to “shield” UV absorber downstream

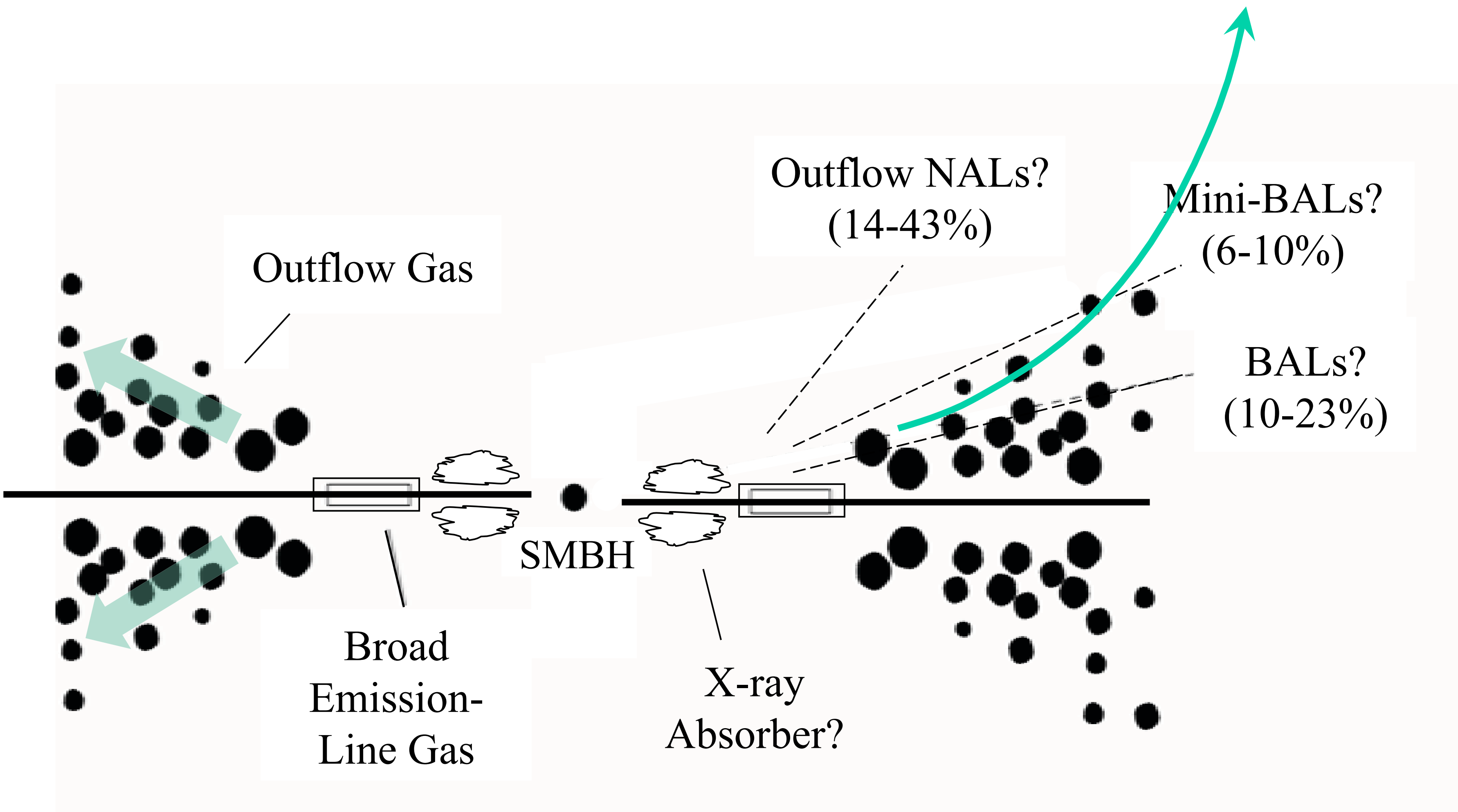
Possibly *needed* to moderate ionization and radiatively drive BAL gas



Is this geometry correct?

The radiative (x-ray) shield might be necessary to moderate the ionization and allow radiative acceleration of BAL gas…

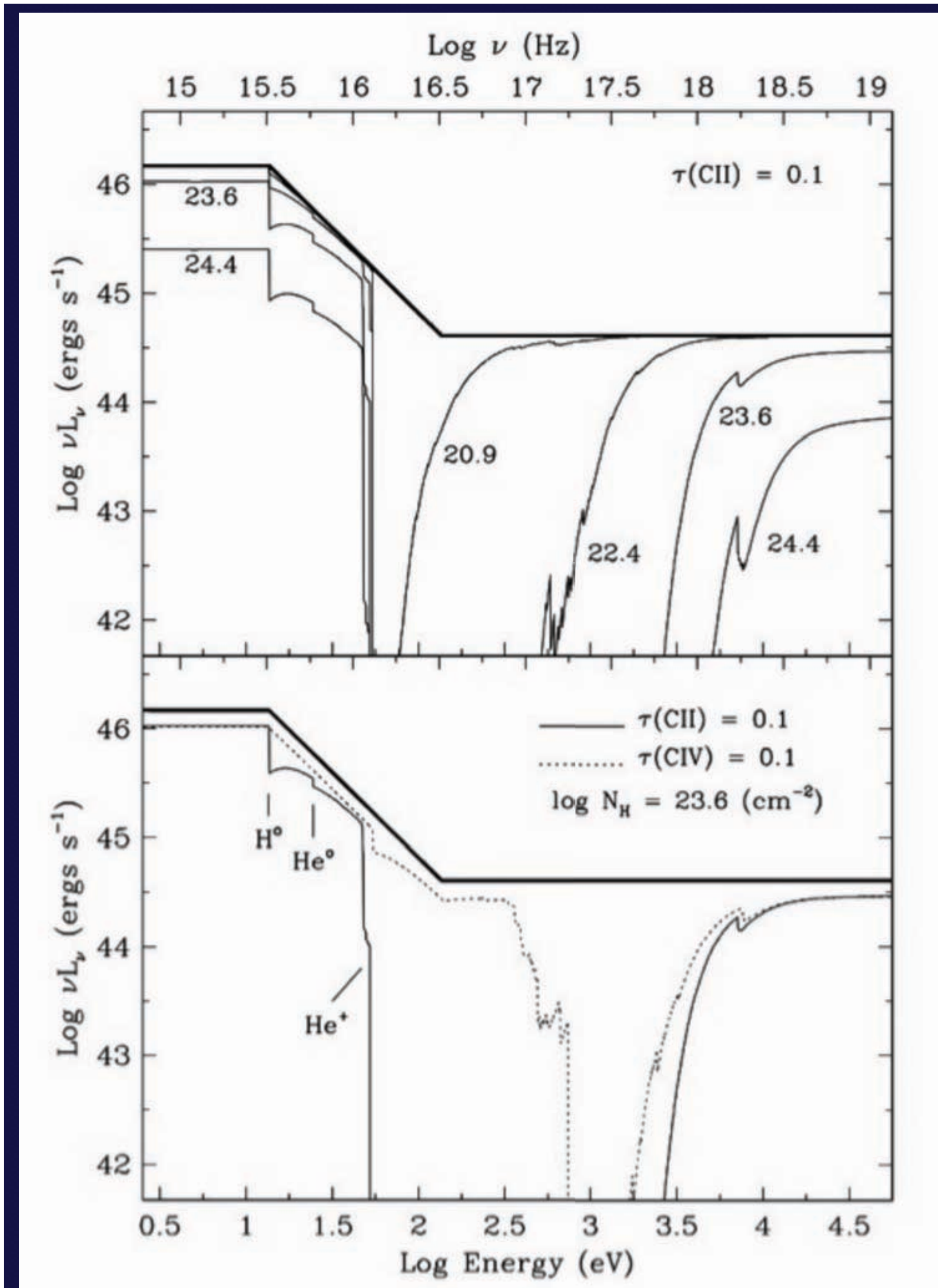
But what about the NAL and mini-BAL outflows?



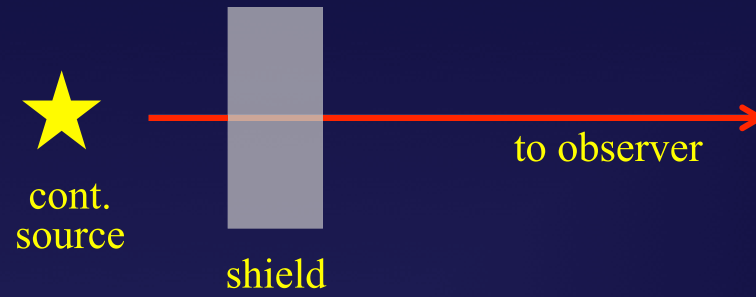
How are NAL flows driven without a radiative (x-ray) shield?

Curved trajectories? But what is the vertical force? And why do NAL clouds keep moderate BAL-like ionizations after leaving the shielded BAL environment?

(Radiative shielding is difficult, and maybe not important.)

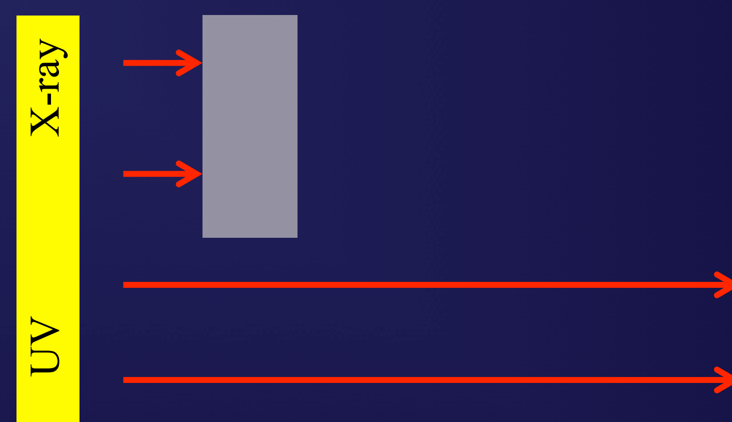


Hamann & Simon 2011

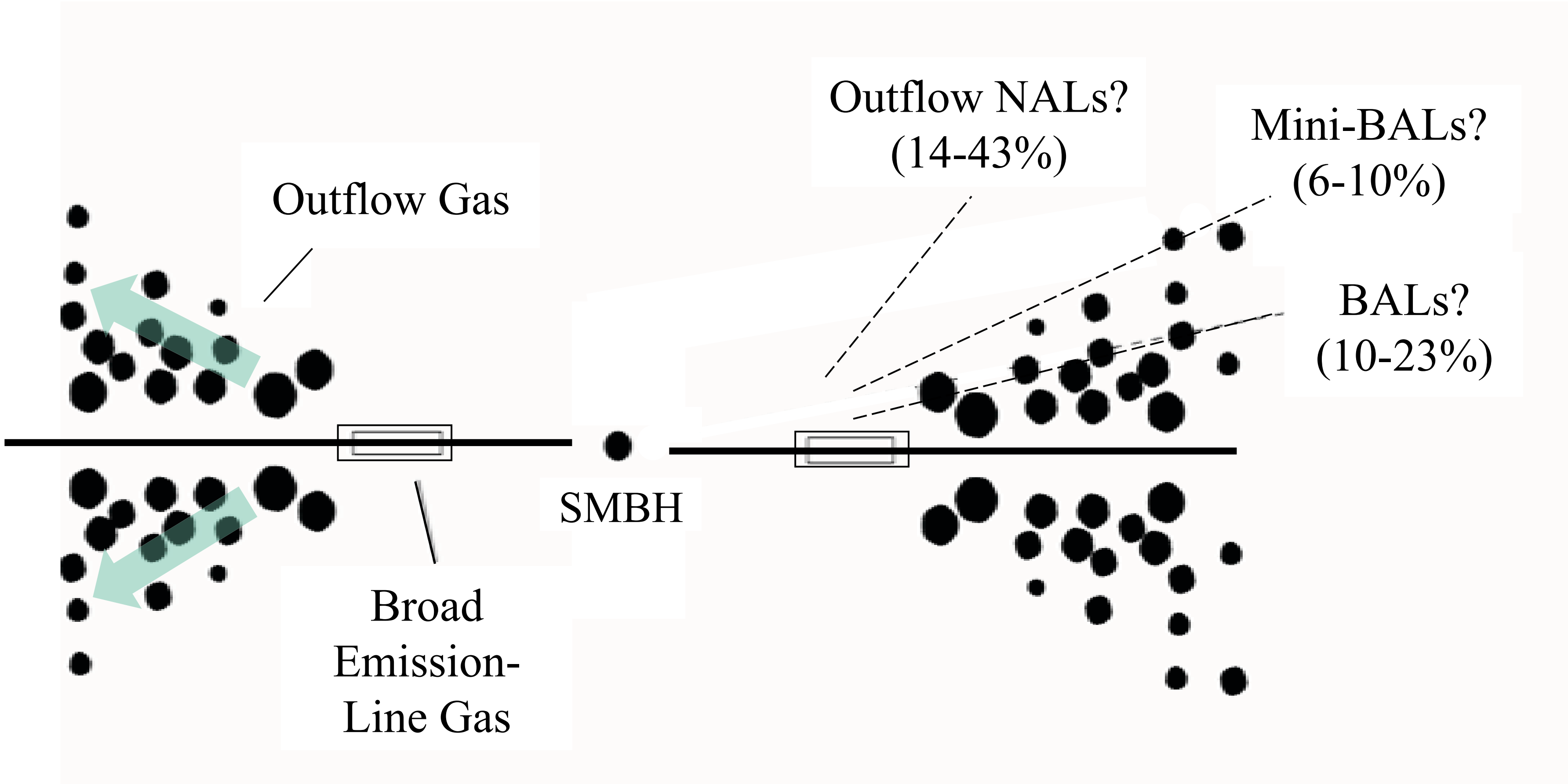


1-D radiative shields will produce strong absorption lines (at v~0) unless they are highly ionized,

but then they are not useful shields!



Opaque shields in stratified geometries need spatial tuning

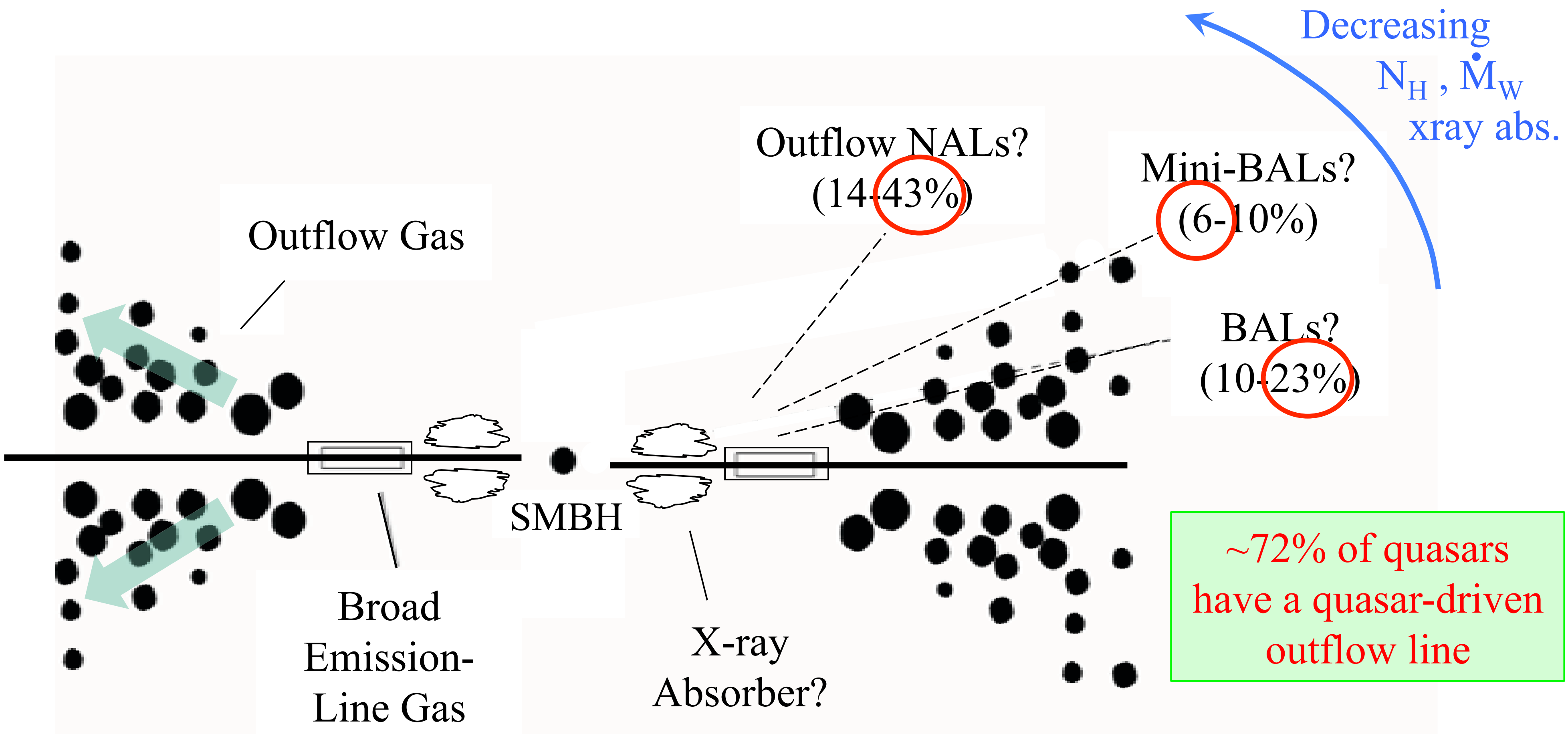


In any case, no x-ray absorption → no shield in NAL and mini-BAL outflows

In our luminous quasar, moderate ionization at r ~ 5 pc requires $n_H \sim 10^8$ cm^{-3}

Which means the flow is in *tiny* sub-structures with size $\Delta r \sim N_H/n_H \sim 10^{11}$ cm !

Even at r ~ 1 kpc, $\Delta r < 10^{15}$ cm and $\Delta r/r << 10^{-6}$

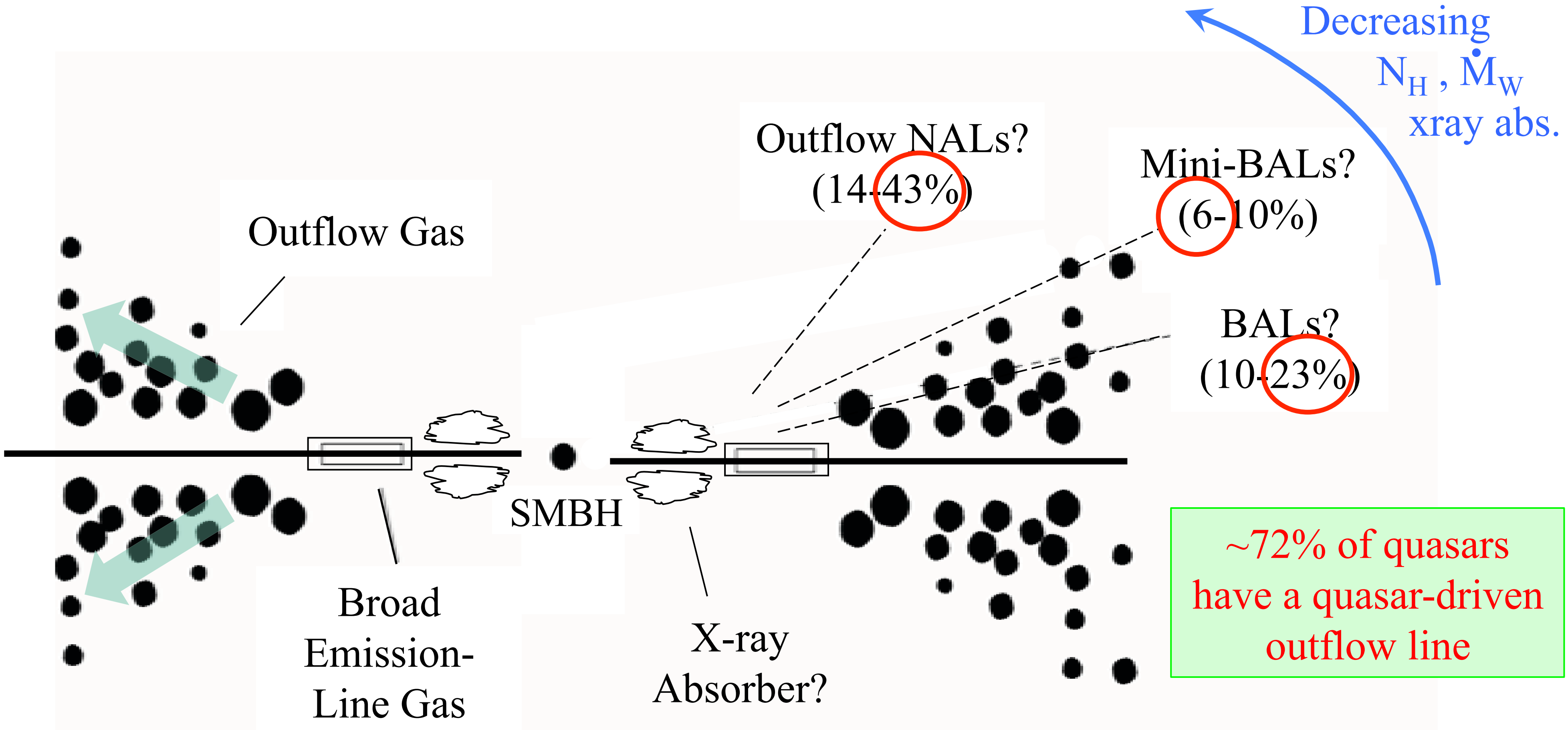


Is this geometry correct? (Are these global covering fractions?)

NALs: Simon et al. 2011, Nestor et al. 2008, Misawa et al. 2007

Mini-BALs: Rodriguez Hidalgo 2008

BALs: Hewett et al. 2003

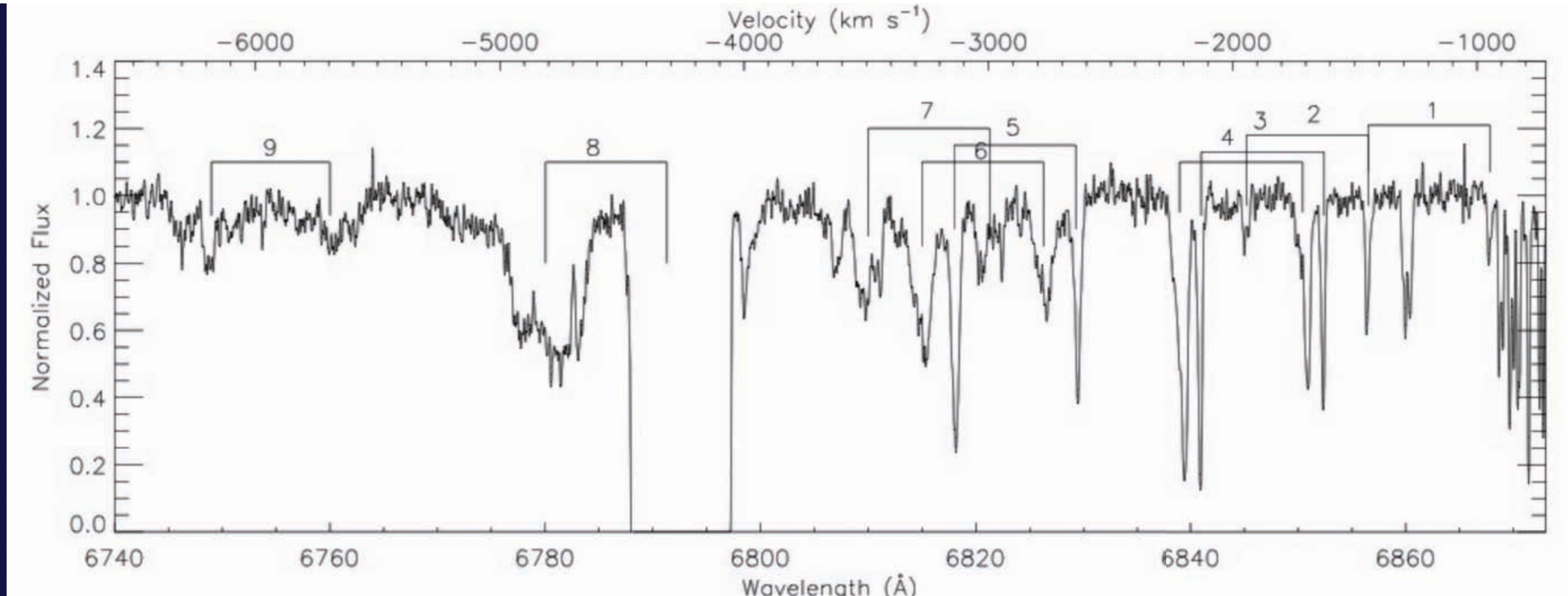


Is this geometry correct?

Is there evolution: FeLoBAL → BAL → mini-BAL → NAL ??

Low → High ionization (more → less reddening) ??

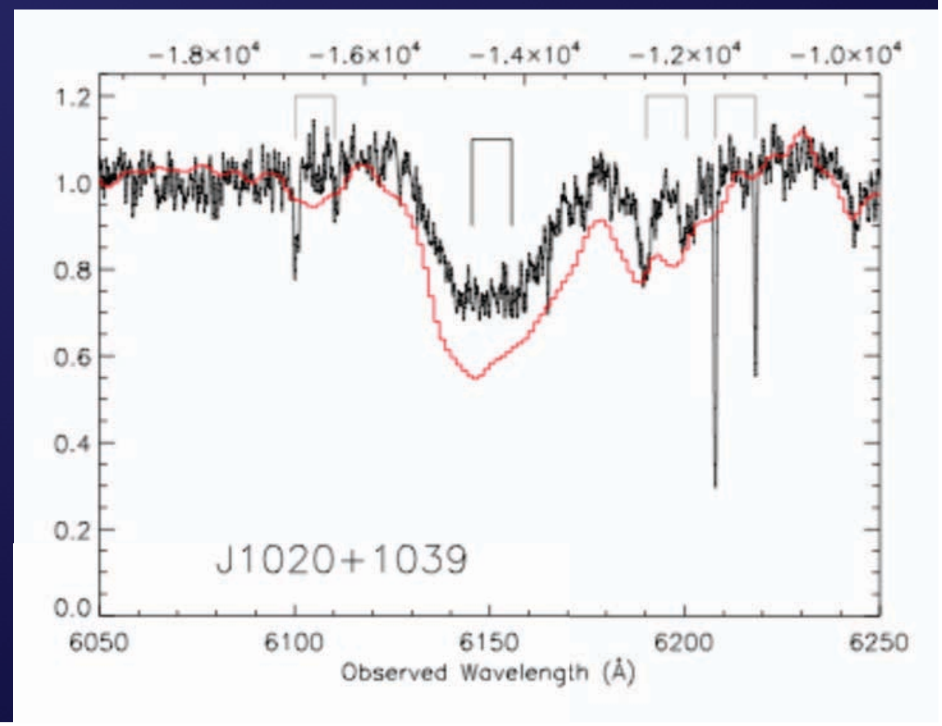
What about extended & multi-component flows (diff. structures, same los)?



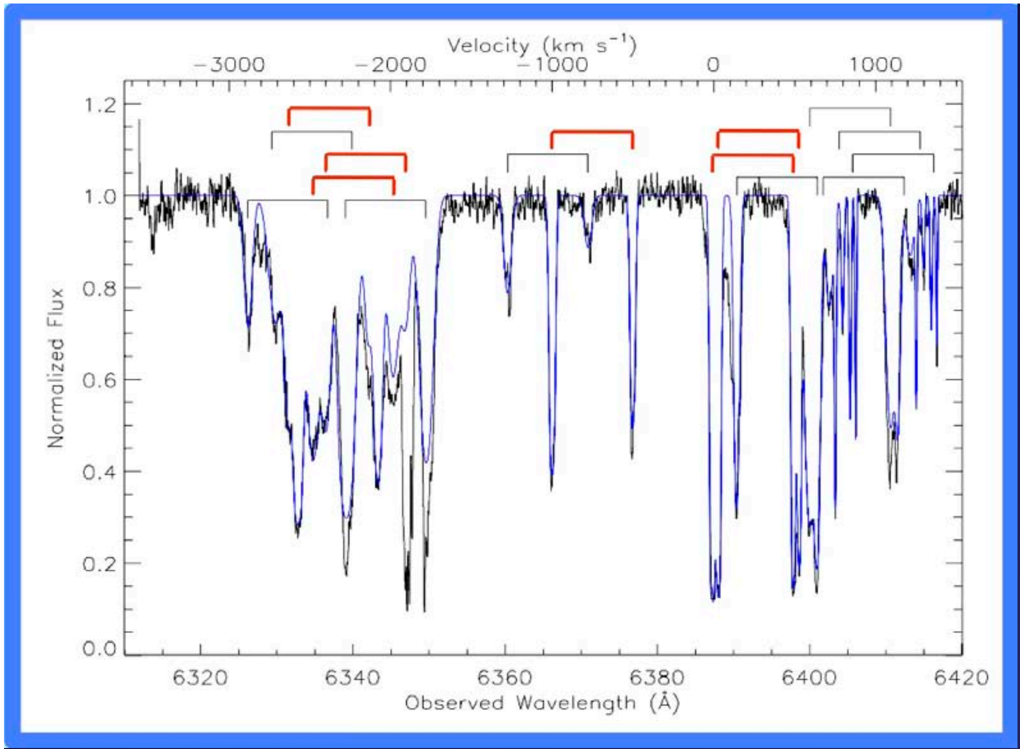
Plot above shows 9 CIV doublets, likely to be an outflow complex (partial covering, broad smooth profiles)

This mini-BAL with FHWM ~ 1200 km/s is accompanied by NALs with FWHM ~ 150 km/s

The whole complex is variable



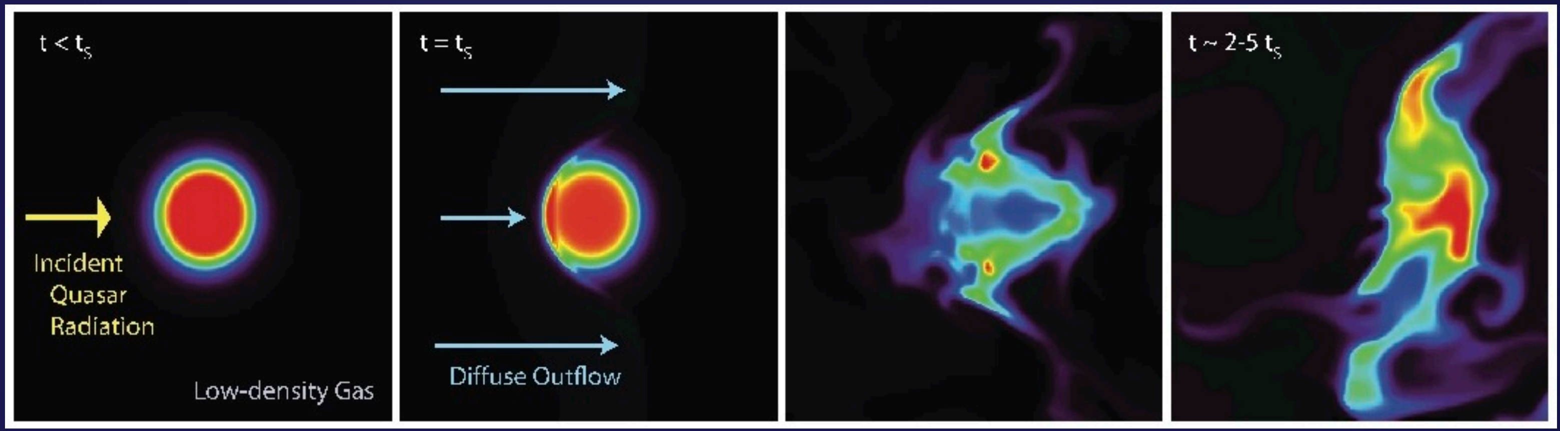
Simon et al. 2011



Outflow complexes like this (CIV – partial covering in red) might form on galaxy scales.

High speeds ⟶ launch near the quasar, not the mass loaded galaxy-wide "blowout"…

Maybe quasar ejecta mixed with "shreds" from ISM clouds



In this simulation (Hopkins & Elvis 2010) a hot fast flow creates pressure dips and instabilities that shred a cool dense ISM cloud

Conclusions:

- Quasar-driven NAL (and mini-BAL) flows appear at same speeds and ionizations as BAL flows, but ~100 times weaker/narrower.
- NAL flows are a common/important part of the outflow phenomenon (43% of quasars compared to ~23% for BALs, 6% for mini-BALs)
- Wide range in kinematic properties (Simon talk), possibly locations: rich narrow complexes, single lines, FWHMs merging with "mini-BALs"
- Probably not (or less) energetically important (for feedback)
- What is the geometry/relationship to BAL and mini-BAL flows?
- Moderate ionizations near the quasar, without a shield, require high densities and *tiny* sub-structures ($\Delta r/r << 1$)
- Shielding not needed for radiative acceleration.

End