HST AND GROUND-BASED SPECTROSCOPY OF QUASAR OUTFLOWS: FROM BALS TO MINI-BALS

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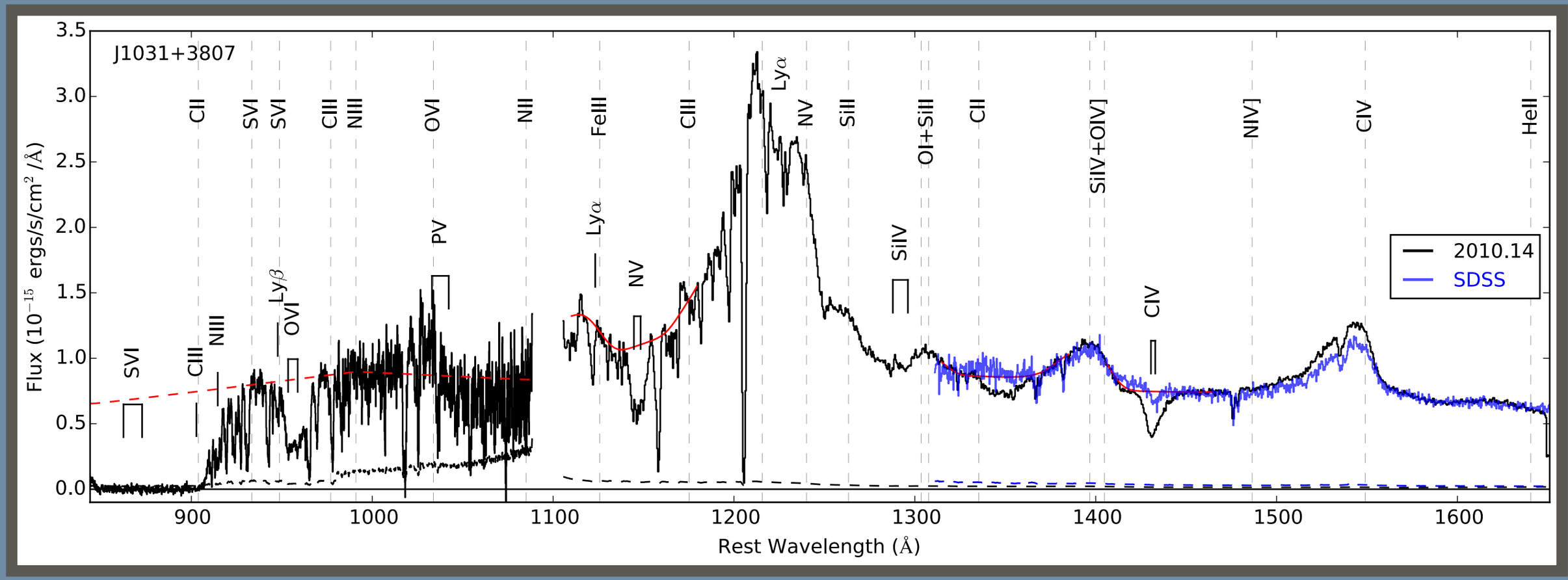
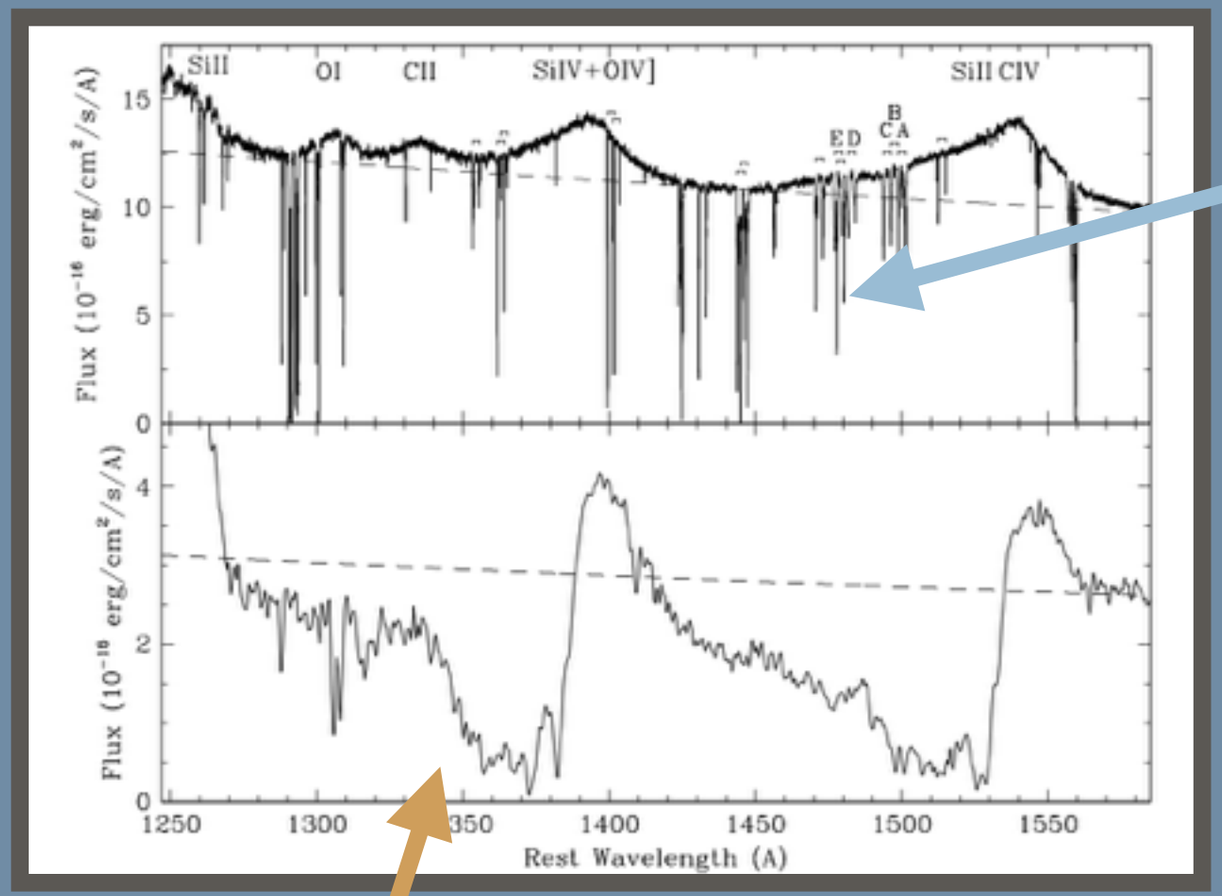


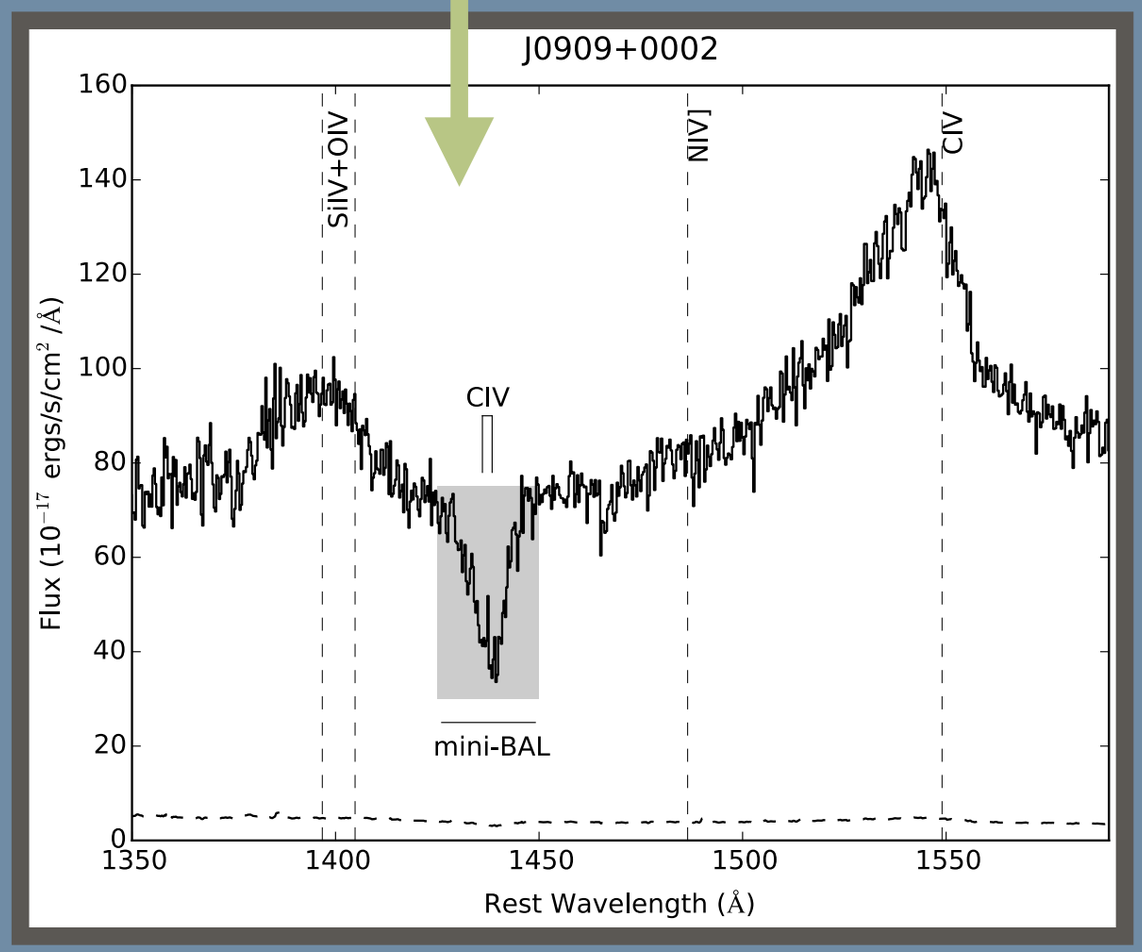
Moravec et al. (in prep)

Types of Absorption Lines



Narrow Absorption Lines (NALs)

Mini-Broad Absorption Lines (mini-BALs)



Broad Absorption Lines (BALs)

Hamann et al. (2012); Moravec et al. (in prep)

Mini-BALs to BAL Sample and Data

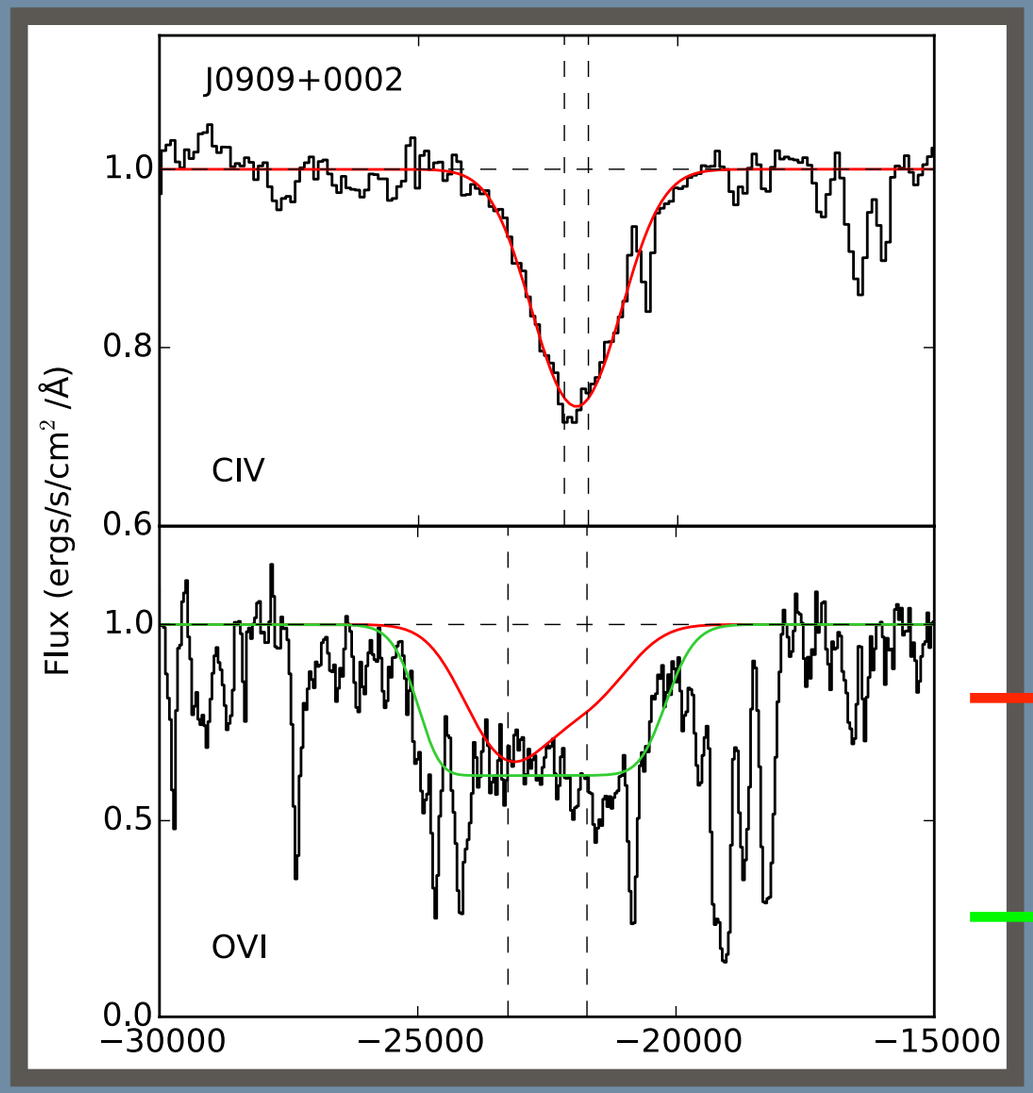
- 7 quasars from SDSS DR4, z = 1.6-1.8
  - Variety of strengths from mini-BAL to BAL in CIV 1550Å
  - Multiple epochs (4-9 across 10 years) ⟶ CIV Variability (SDSS, BOSS, MDM, and KPNO)
  - ~ Simultaneous HST + ground observation provides wide wavelength coverage in UV ⟶ Ionization and Column Densities

Goals of Study

- Location and Structure of the Outflows
- Ionization and Total Column Densities
- Relationship between BALs and Mini-BALs
- Mass Loss Rates and Kinetic Energies Sufficient for Feedback?

Moravec et al. (in prep)

Method: Line Profile Fitting



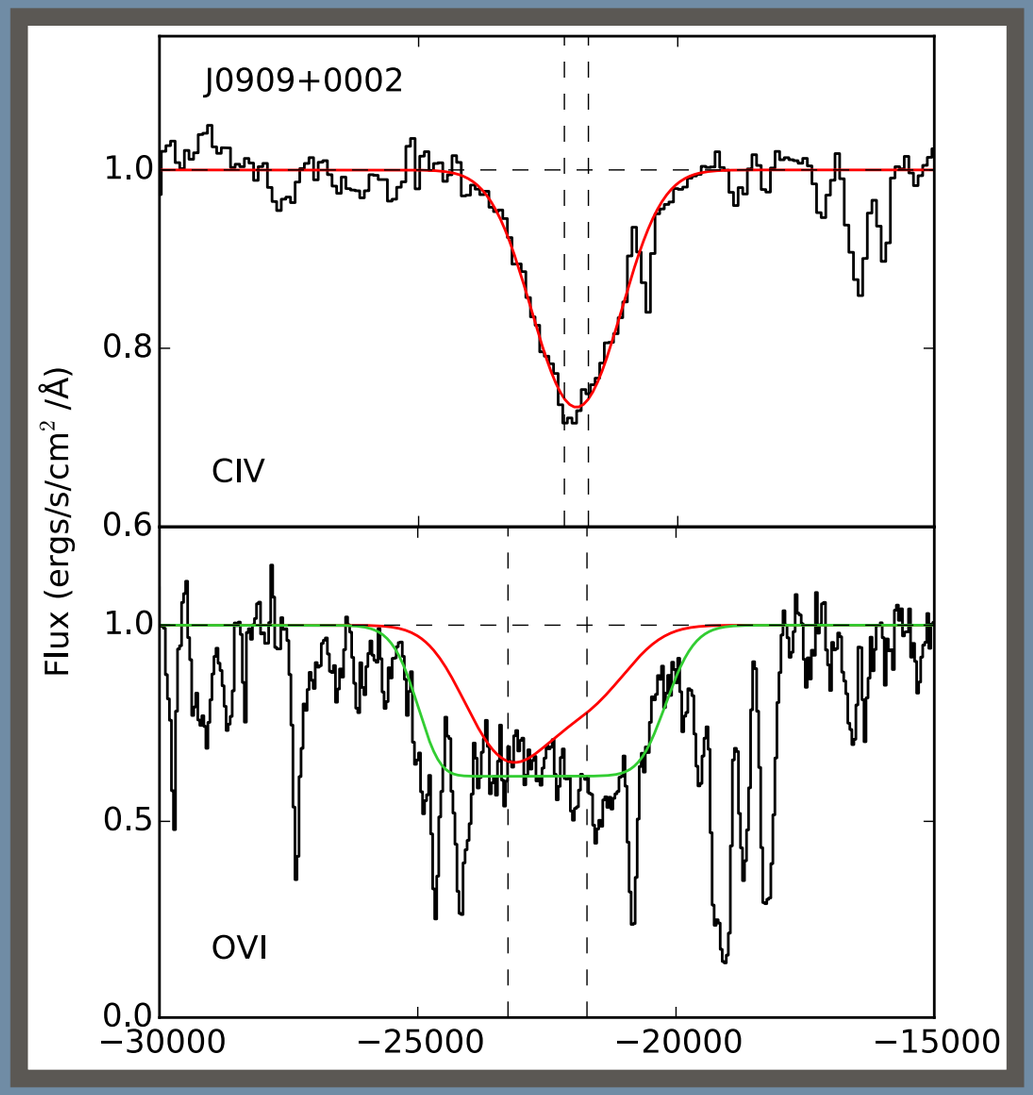
$$I_\lambda = I_0(1 - C_\lambda) + C_\lambda I_0 e^{-\tau_\lambda}$$

$\tau_0 = 0.2, C_0 = 1.0$

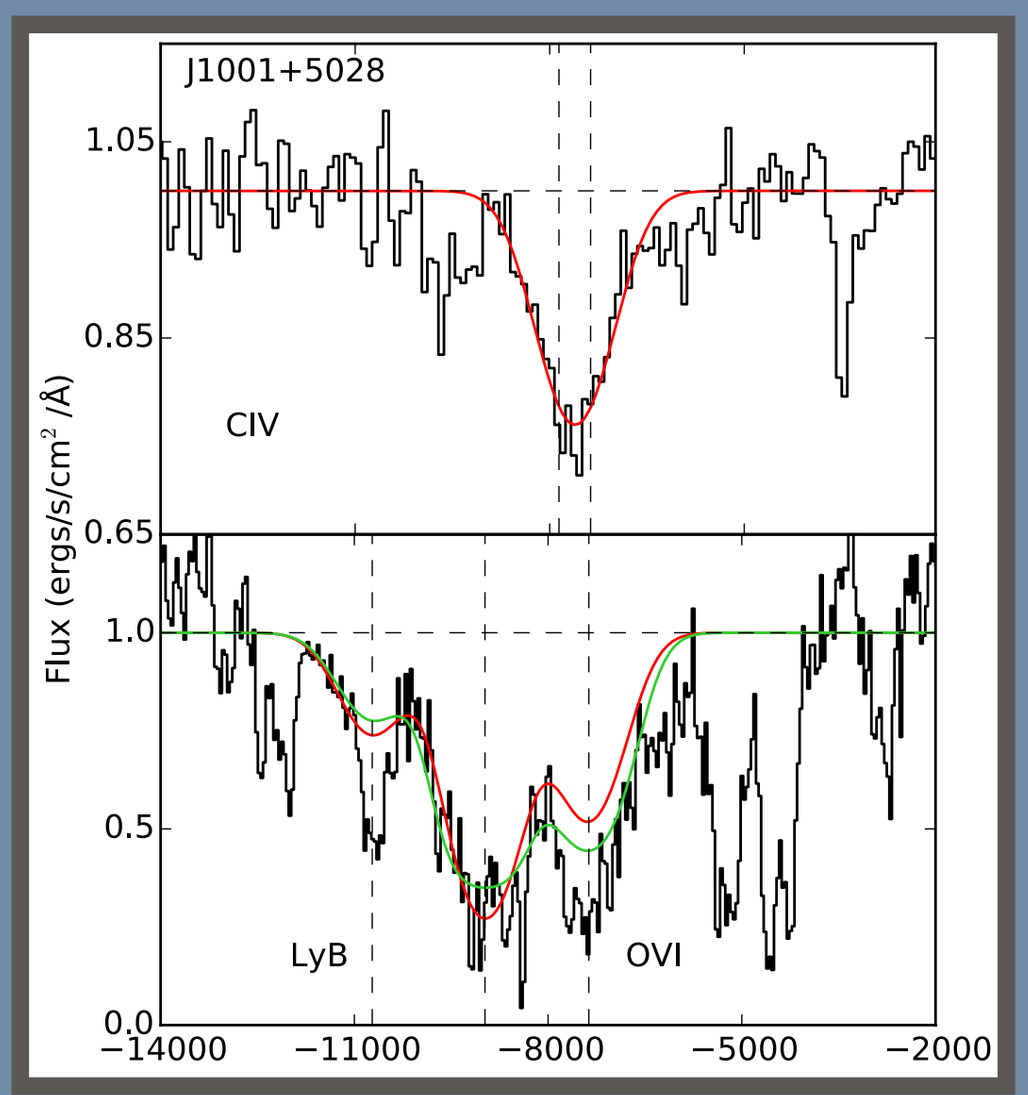
$\tau_0 = 5.4, C_0 = 0.4$

Eqn: Hamann et al. (2011)

Results: Mini-BAL Fitting



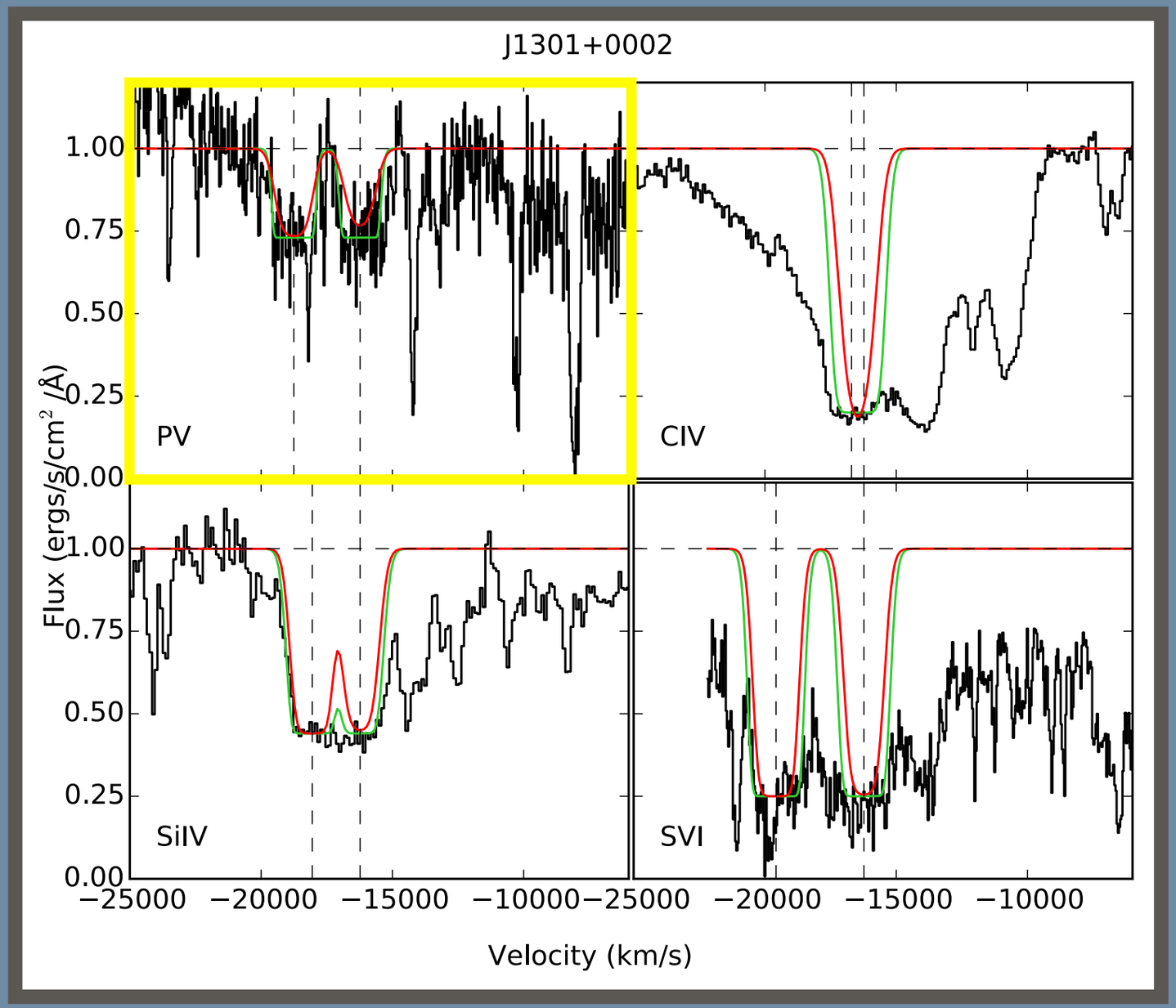
Velocity (km/s)



Velocity (km/s)

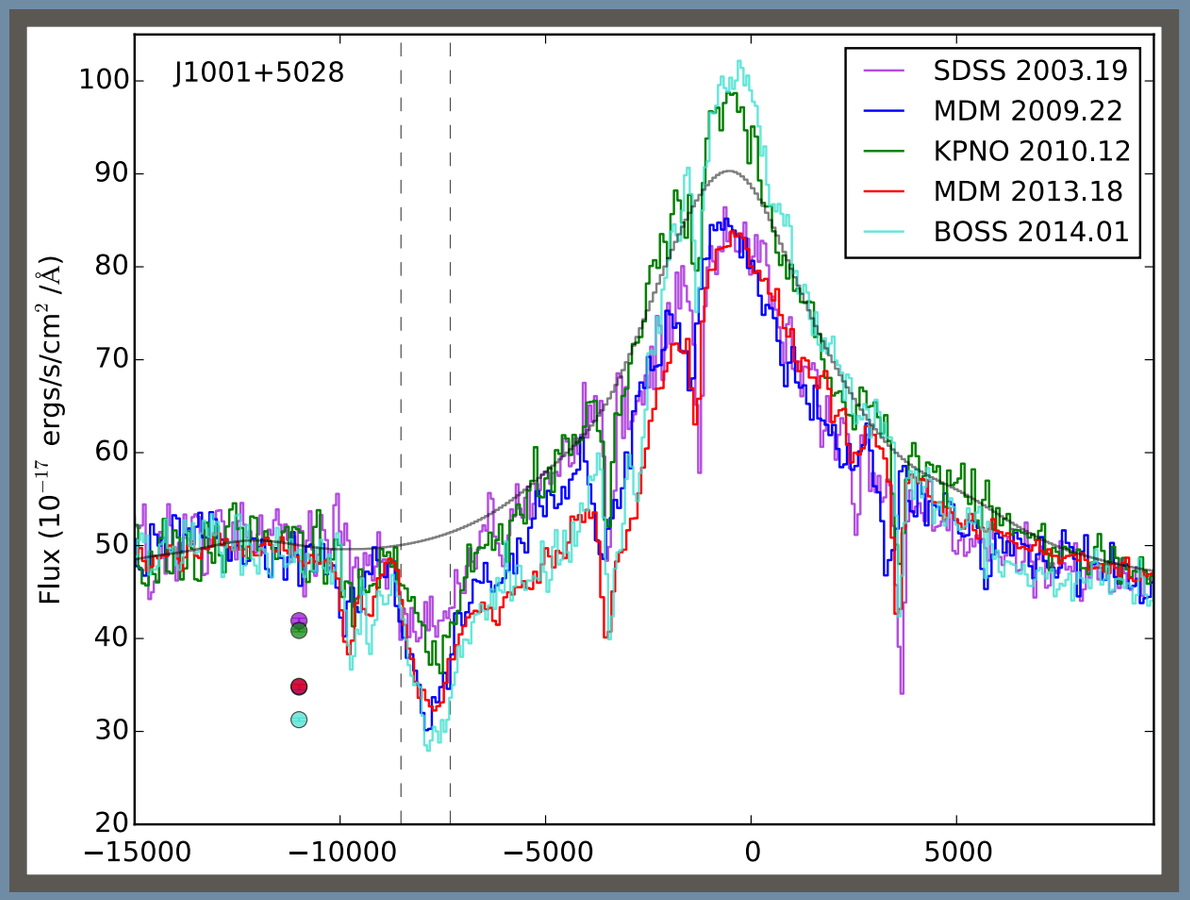
- OVI stronger than CIV
- 3/6 - evidence for saturation with partial covering

Results: BAL Fitting

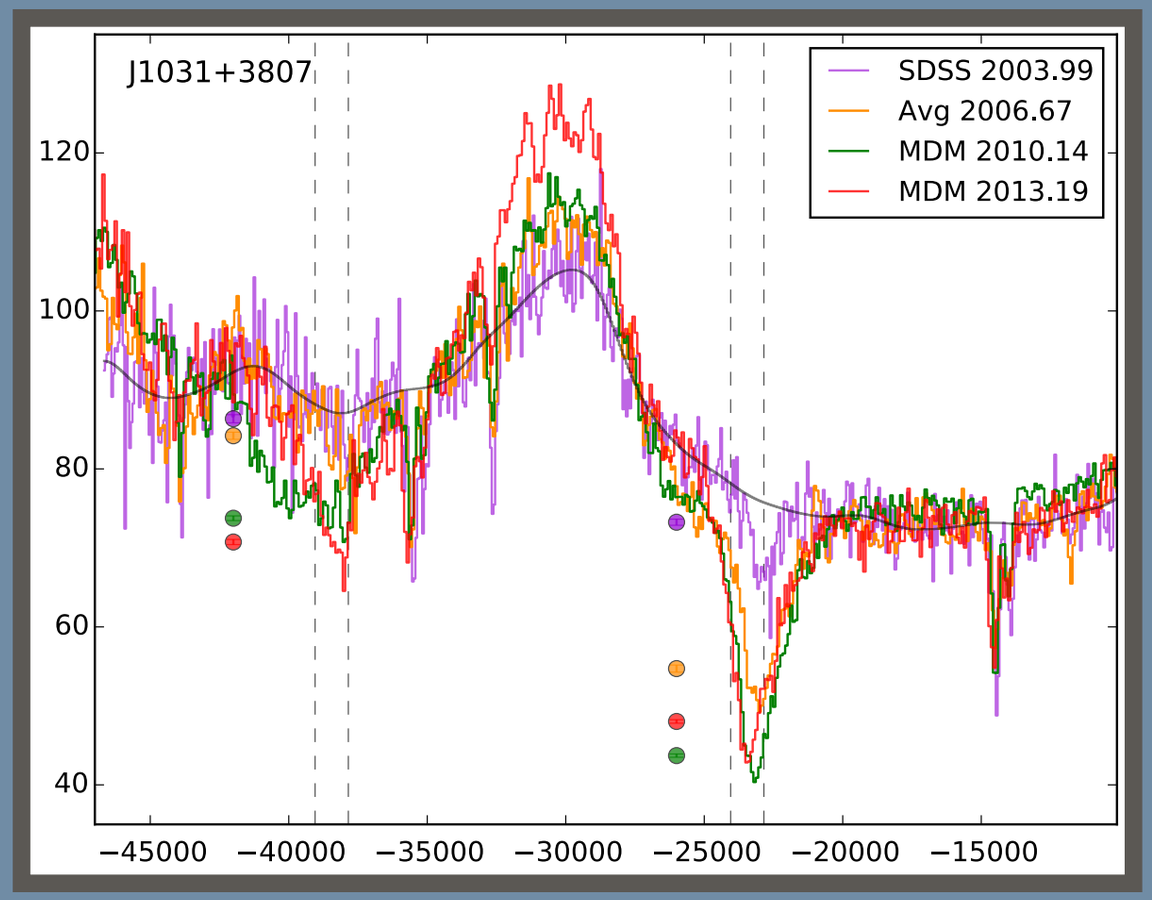


- PV ⟶ large column densities + resolved = large optical depths
- OVI Stronger than CIV
- Many saturated ions with evidence of partial covering

Variability: Method and Results



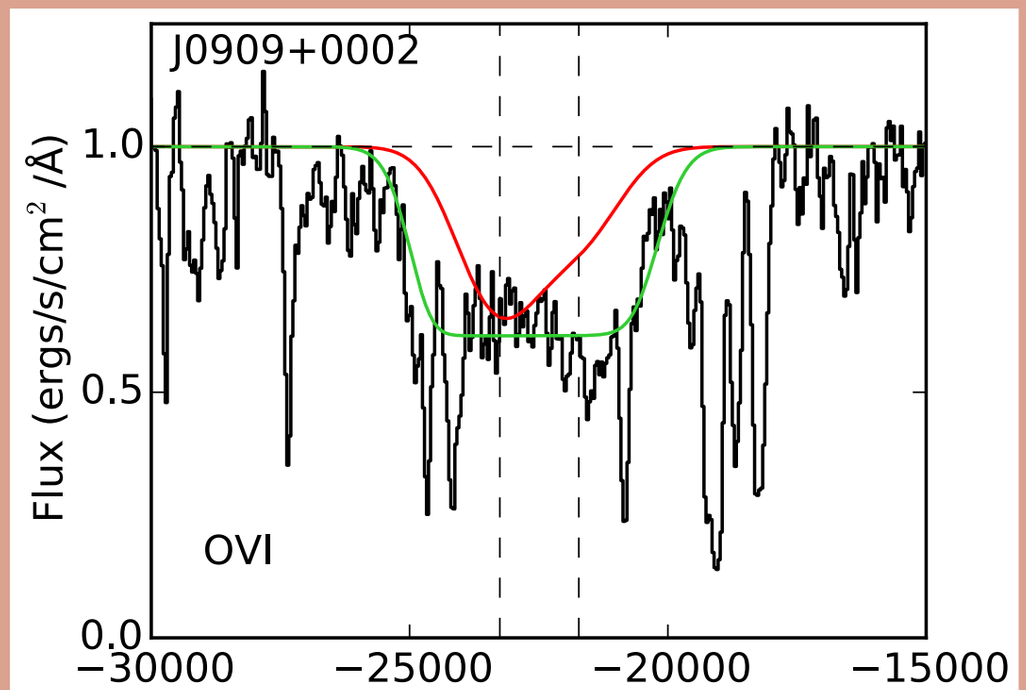
Velocity (km/s)

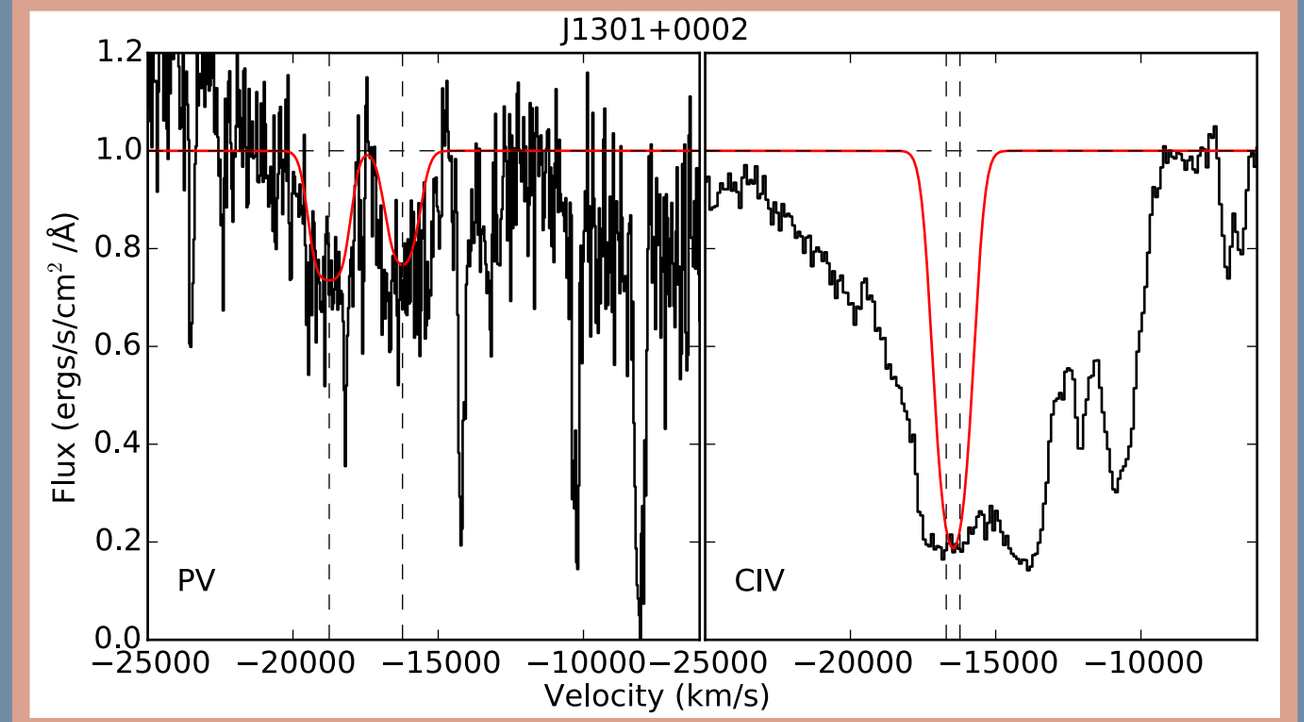


Velocity (km/s)

- All CIV varied in ≲ 1.9 yrs
- Typical timescale ~ 1.1 yrs

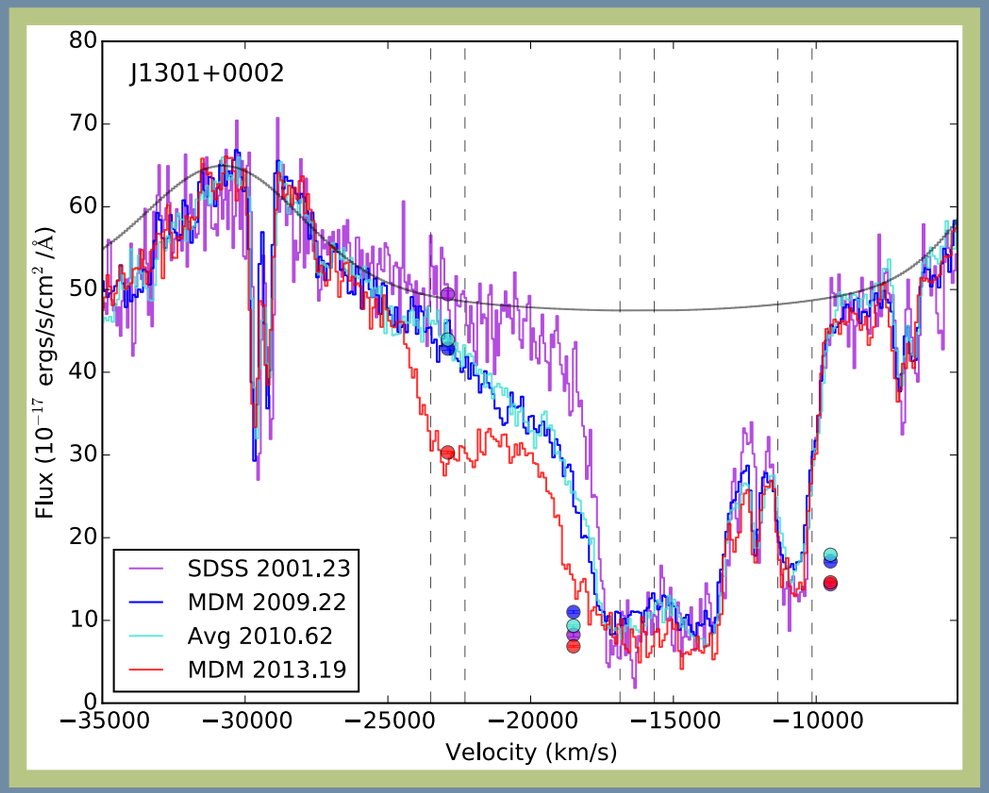
Implication: Location of Absorber





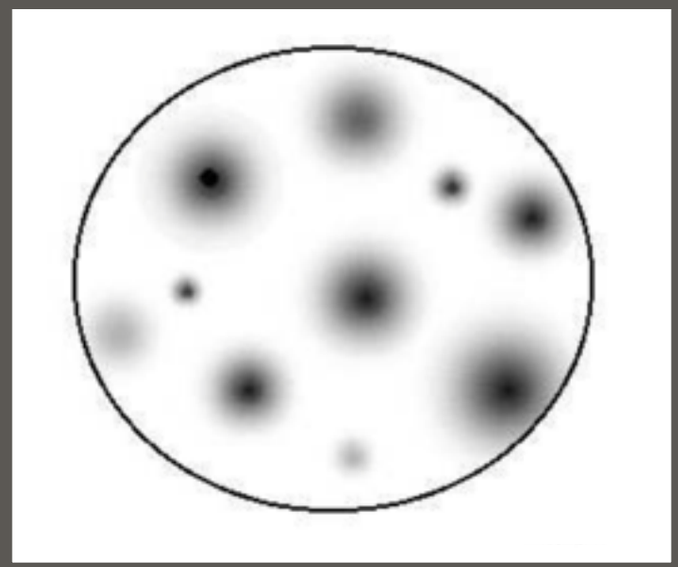
Saturation + Variability =
Crossing Clouds

Mini-BALs : ~ 0.4 - 8 pc
BAL Distance : ~ 1 pc



Implication: Structure

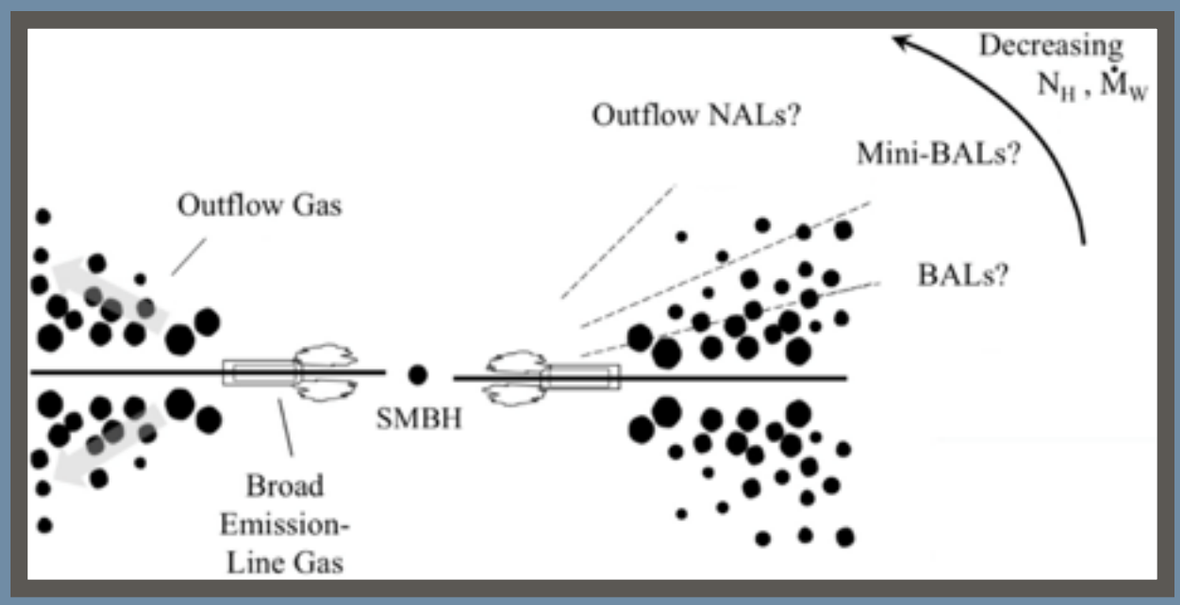
High-column lower-ion clumps surrounded by diffuse lower density high-ion gas



- OVI has higher C_0 and low abundance ions have smaller C_0
- PV correlated gas only in small high-velocity part of CIV

Mini-BALs more variable than BALs?

Clumps or filamentS at the edges of BAL outflows?



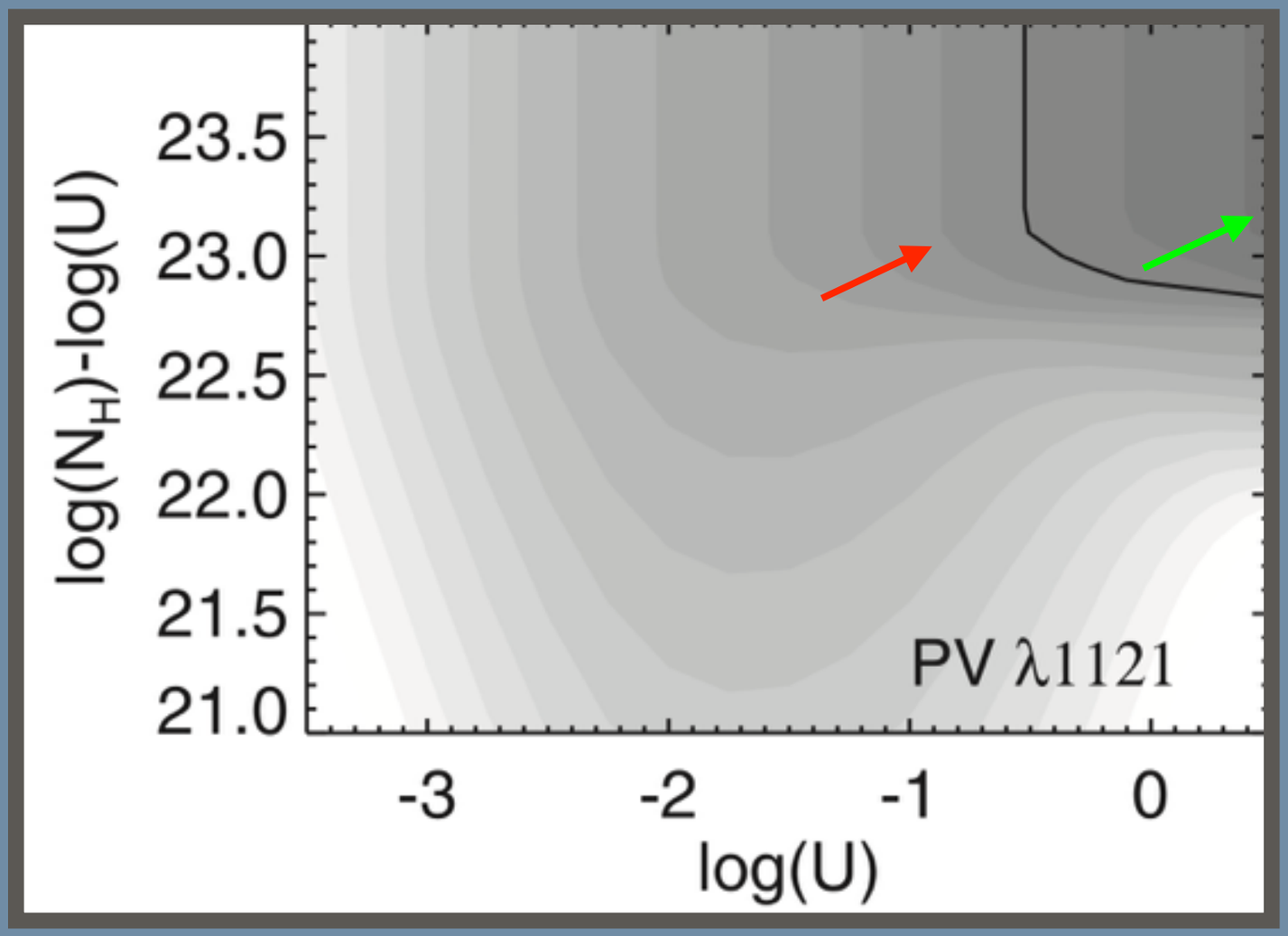
Hamann et al. (2004); Hamann et al. (2012)

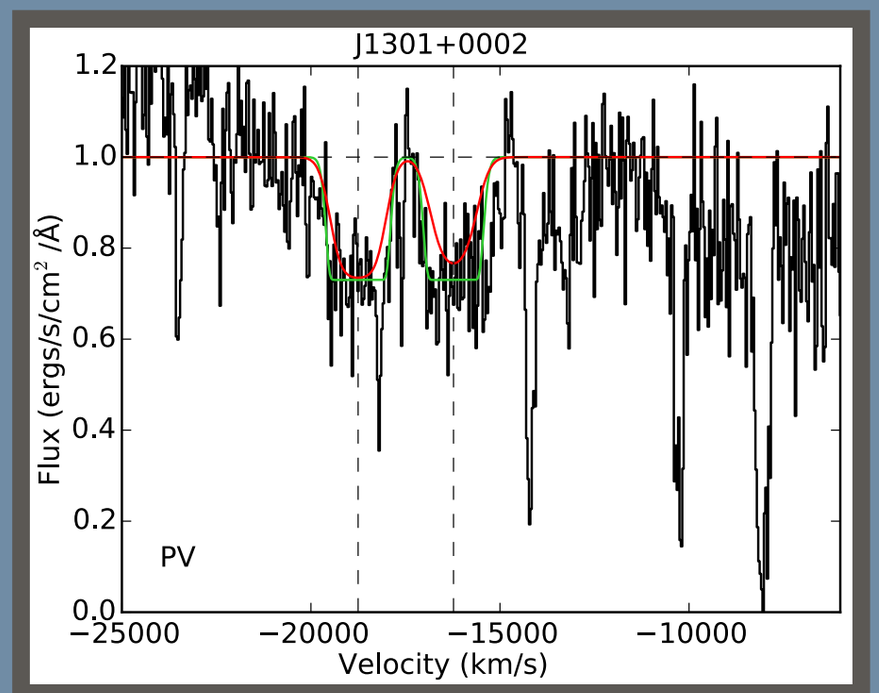
Implication: Mass

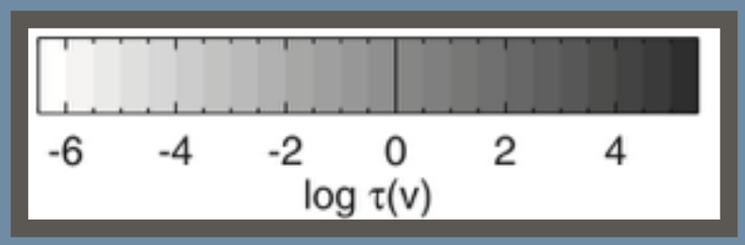
$$M = Q(4\pi R^2 * N_H m_H)$$

R ~ 1 pc,

2 ≲ τ(PV) ≲ 80



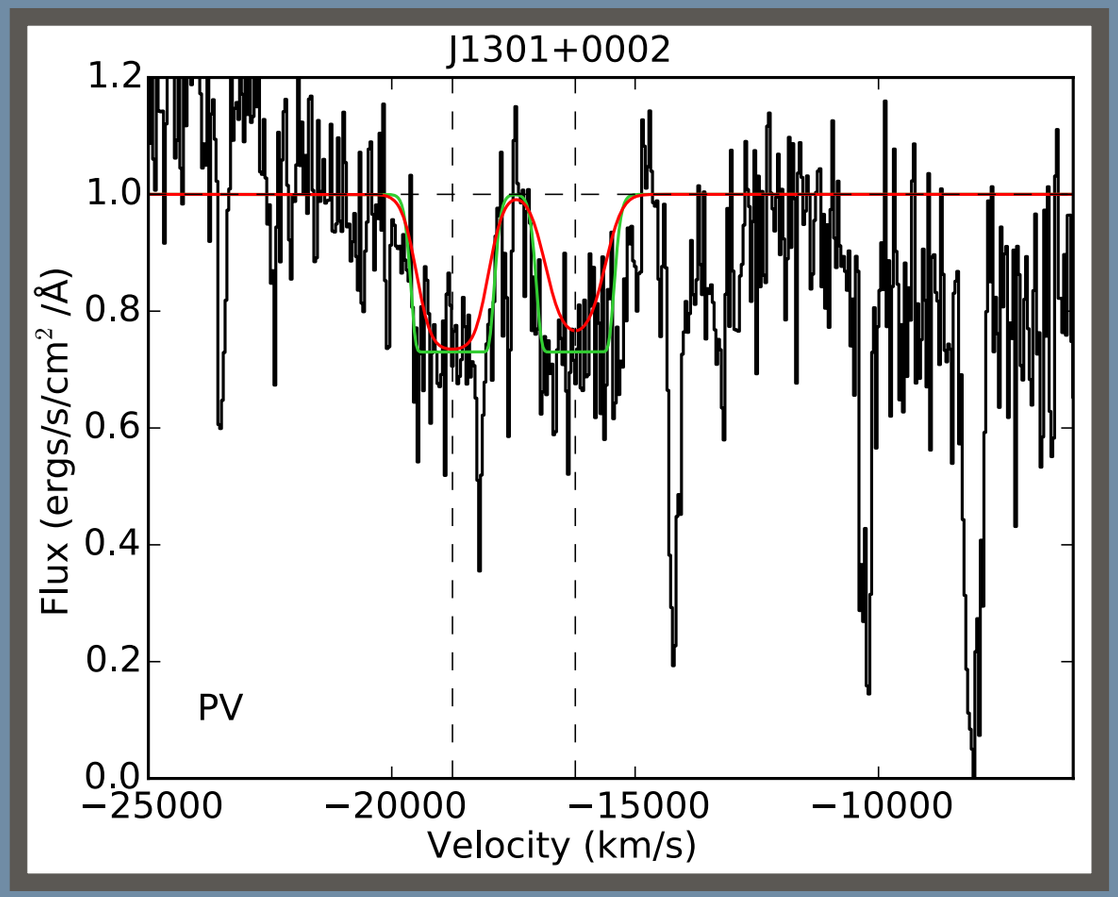




$N_H > 2.0 \times 10^{22}$ cm^{-2} Mass > 265 $M_\odot$

Fig: Leighly et al. (2011)

Implication: Kinetic Energy



$$K = \frac{Mv^2}{2}$$

	K (ergs)	L_K/L
$\tau_0 = 2$	5.5E+53	0.0021
$\tau_0 = 80$	1.5E+55	0.052

→ Consistent with $L_K/L \gtrsim 0.5\%$ needed for feedback

Ratio: Hopkins et al. 2010

Summary

- Saturation and partial covering: τ(PV) > 2 in BAL => large N_H
- Ionization: OVI stronger than CIV for whole sample
- Variability: all varied in CIV within 1.9 yrs, typical timescale 1.1 yrs
- Locations: moving clouds => ~ a few pc
- Structure: high-column lower-ion clumps surrounded by diffuse lower density gas
- BAL KE roughly consistent with feedback. Mini-BALs: future work

Moravec et al. (in prep)