Quasar Outflow Kinematics and Energetics using Absorption Line Variability Studies

Great Lakes Quasar Symposium
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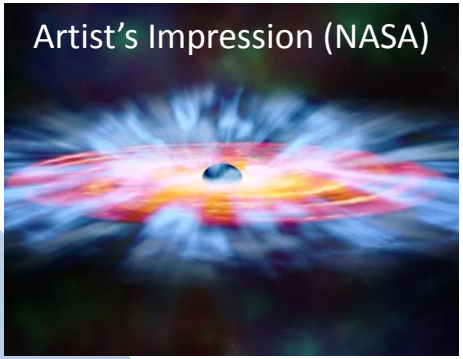
Motivation: AGN Feedback

Quasar outflows are important candidates in **SMBH – galaxy co-evolution**

Star formation
Accretion onto SMBH
M–σ relation



Understanding outflows in feedback requires **observational constraints**

Kinematics
Energetics

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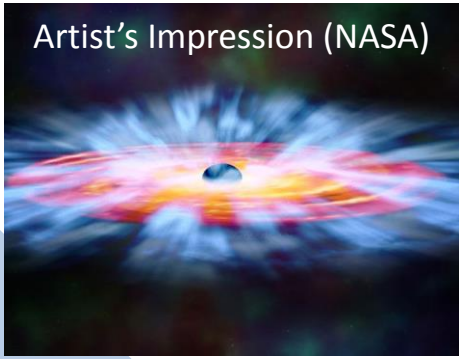
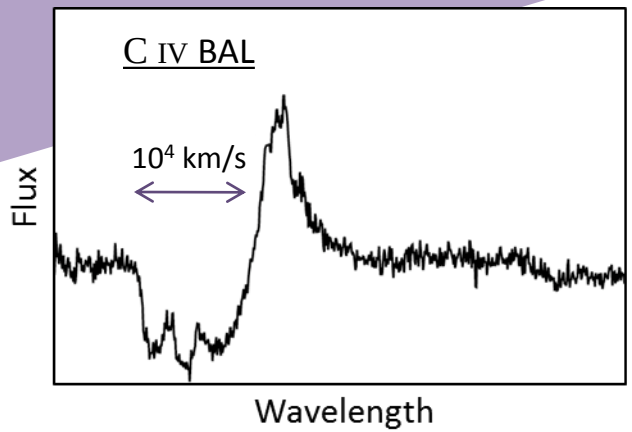


Understanding outflows in feedback requires **observational constraints**

Kinematics
Energetics

Broad Absorption Lines (BALs) in rest-frame UV spectra trace quasar outflows

Column Density (P V BALs)
Distance (BAL variability)
Velocity
Coverage

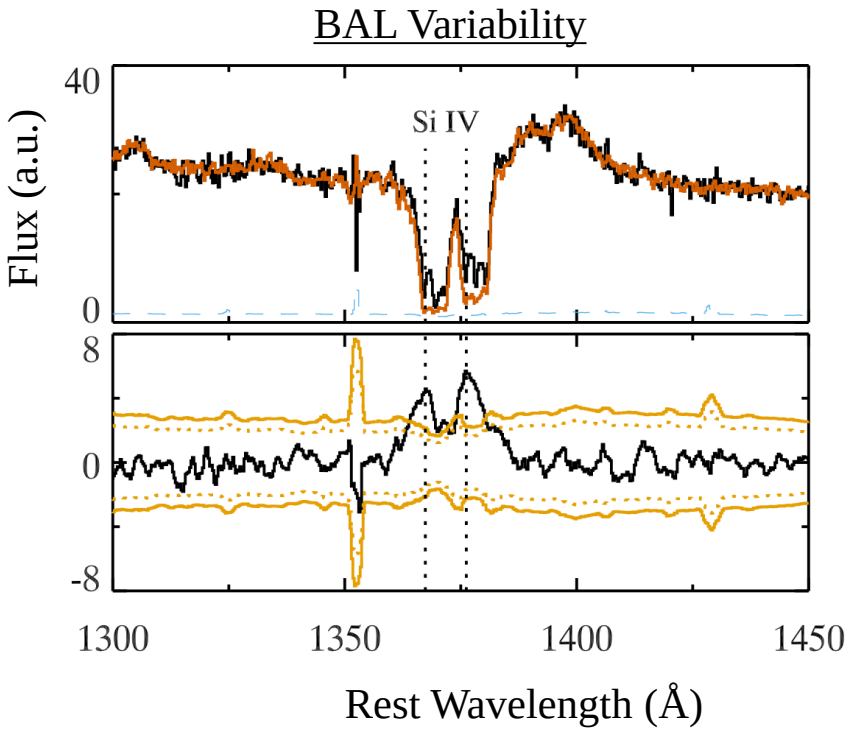


Absorption Line Variability Studies

Outflow distances obtained using **BAL variability**

Detection
Interpretation

Detecting real BAL changes requires **statistical tests** and **confirmations** by eye



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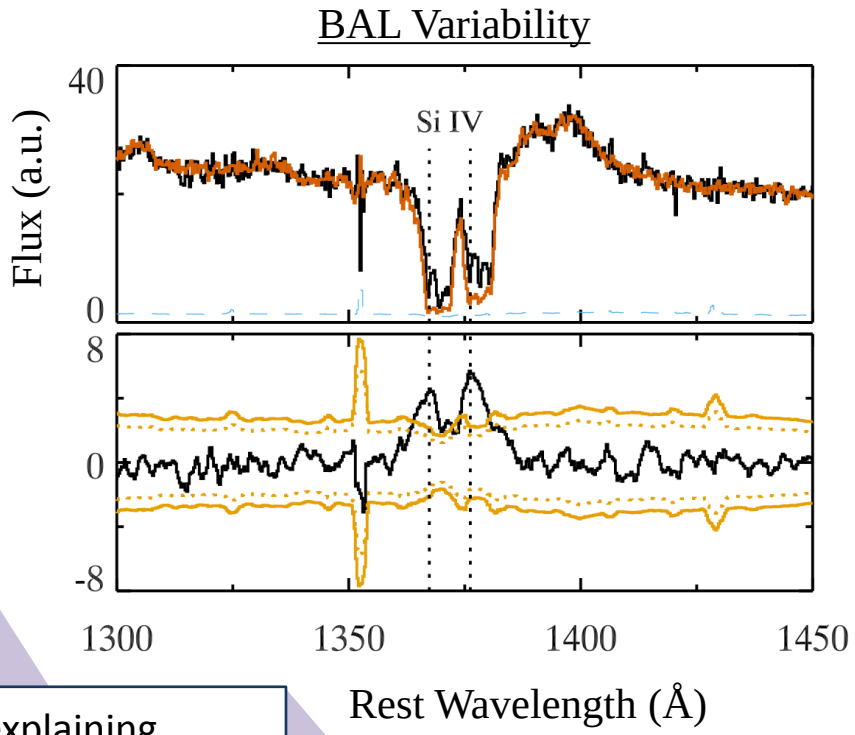


Two scenarios for explaining BAL variability

1) **Transverse motions** of gas across LOS

$$r = \frac{GM_{\bullet}}{v_{\mathrm{trans}}^2}$$

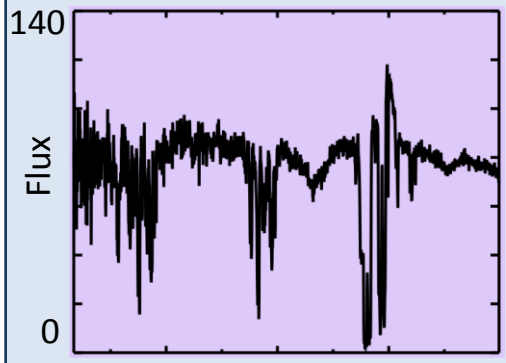
2) **Ionization change** within absorber

$$r = \sqrt{\frac{L_{\mathrm{ion}}}{4\pi U n_e c}}$$

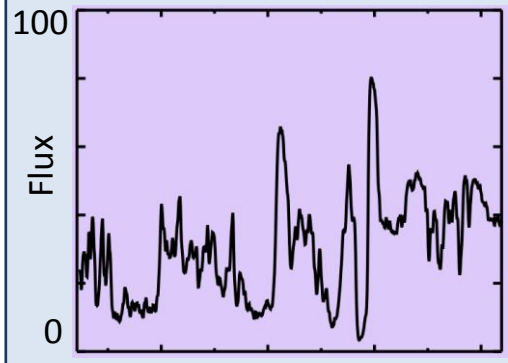
Data: Spectroscopic and Photometric

Multiple-epoch spectra acquired using multiple facilities

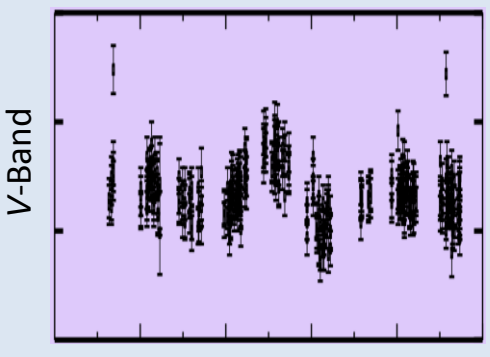
MDM Observatory
Observations, Reductions



Sloan Digital Sky Survey
DR7 and DR12



Catalina Sky Survey
V-band Photometry



Absorption Line Variability Studies to Date

1) Iron Low-Ionization BALs (FeLoBALs) . . . . . Rare, may represent transient phase

2) Phosphorus V BALs . . . . . High column density outflows

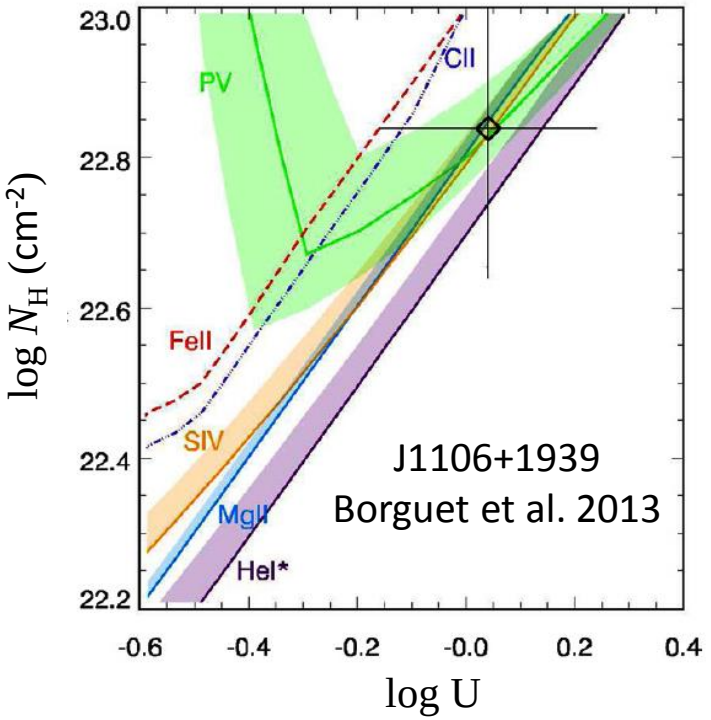
3) Mini-BALs . . . . . Interesting behavior compared to BALs

Energetics using BAL Variability and P V BALs

Outflow **energetics** rely on absorber **column density** and **distance**

P V λλ1117,1128 BAL traces **high column density** outflows

log N_H ≈ 22.0 cm^{-2}
≈1000 times less abundant than C



$$L_{\text{kinetic}} = \frac{1}{2}\dot{M}v^2$$

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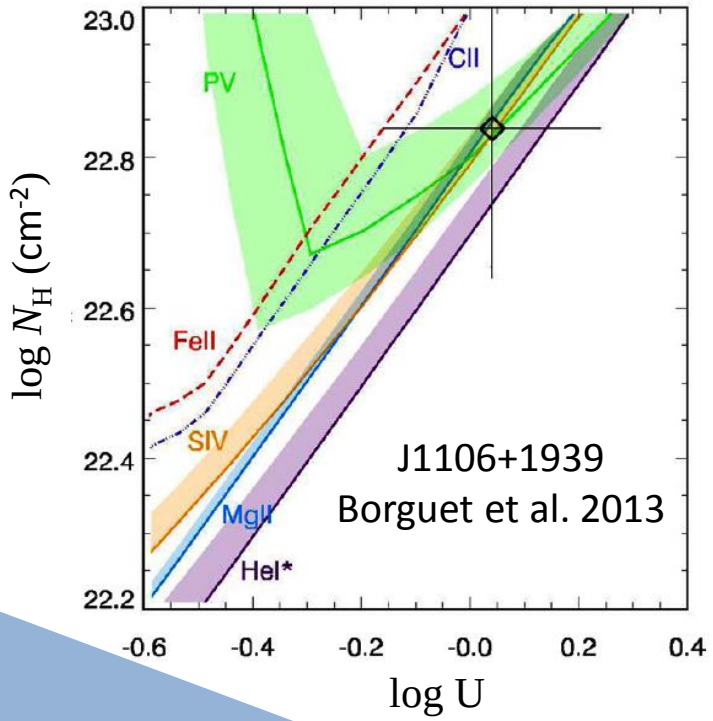
Previous work used **density-sensitive lines + CLOUDY**

Few studies utilize **P V diagnostic** and **BAL variability**



We utilize multiple-epoch **spectra** of **71 quasars** with P V BALs to estimate outflow **kinetic luminosities**

$2.4 < z < 4.4$
$0.5\ \mathrm{d} < \Delta t_{\mathrm{rest}} < 3.8\ \mathrm{yr}$

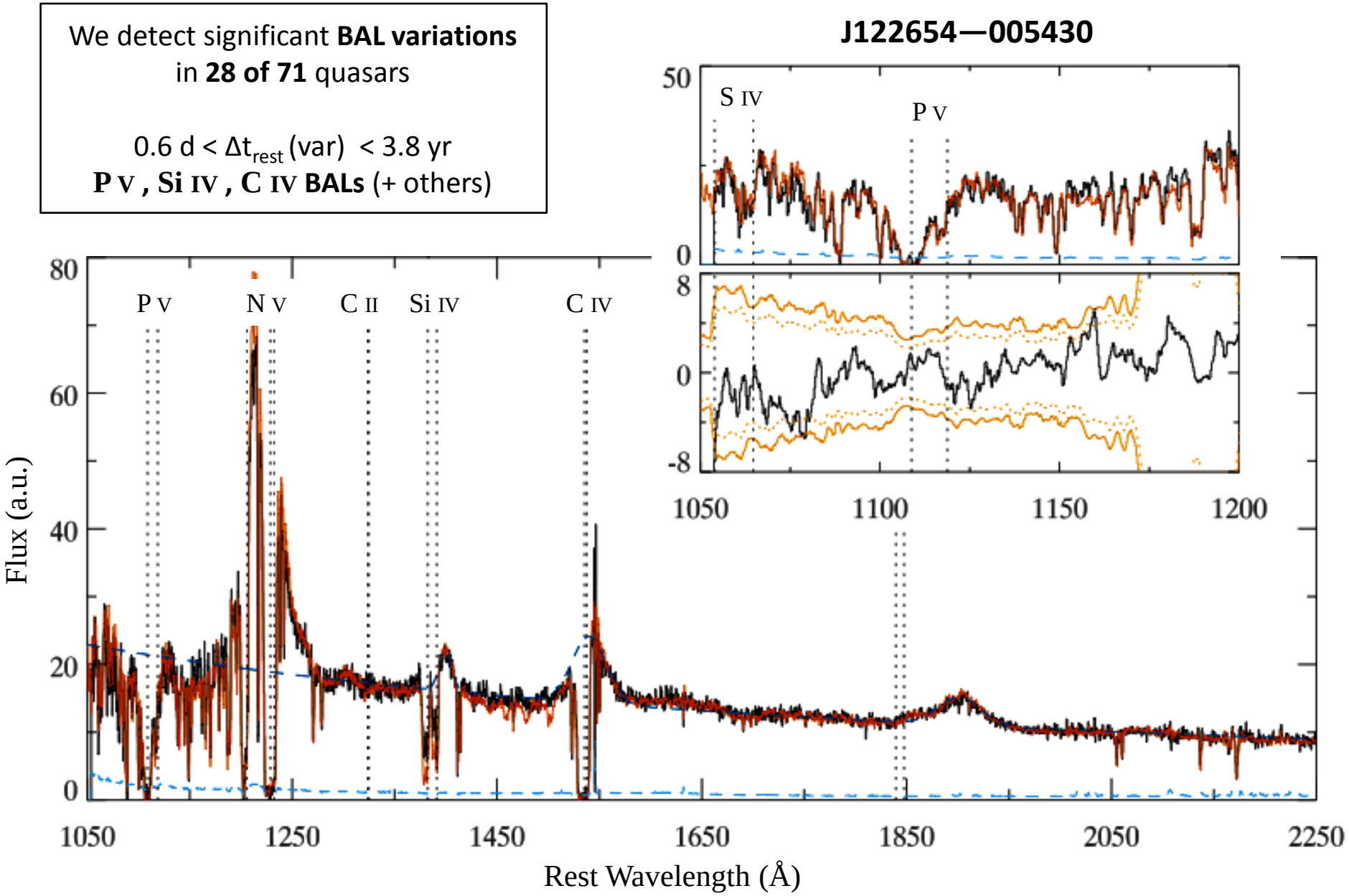
$$L_{\mathrm{kinetic}} = \frac{1}{2}\dot{M}v^2$$

Energetics using BAL Variability and P V BALs

We detect significant **BAL variations** in **28 of 71** quasars

0.6 d < Δt_{rest} (var) < 3.8 yr

P V , Si IV , C IV BALs (+ others)



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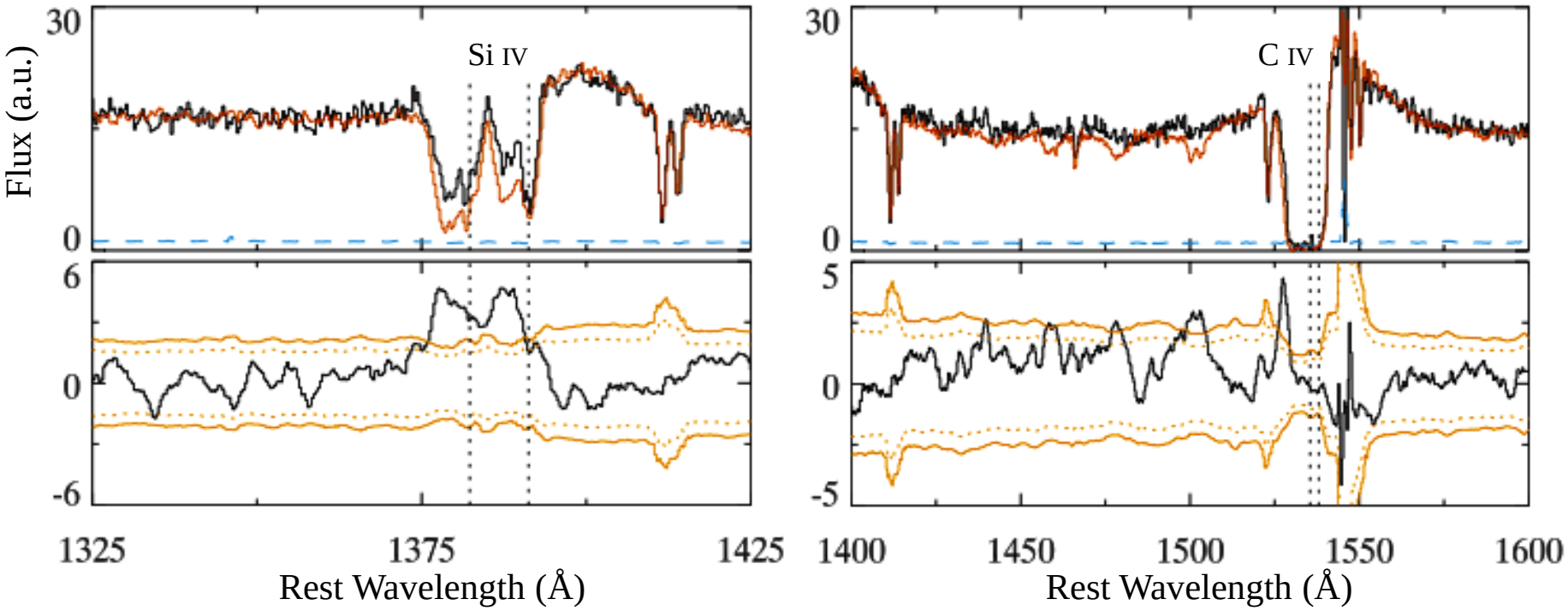
Interpretations support **ionization changes** and **transverse motions**

Distances < 10 pc , < 1 kpc

We estimate outflow **kinetic luminosities** $L_k \approx 10^{-6}$ **to 1** L_{bol} (feedback requires 10^{-2} **to** 10^{-1} L_{bol})

J122654—005430



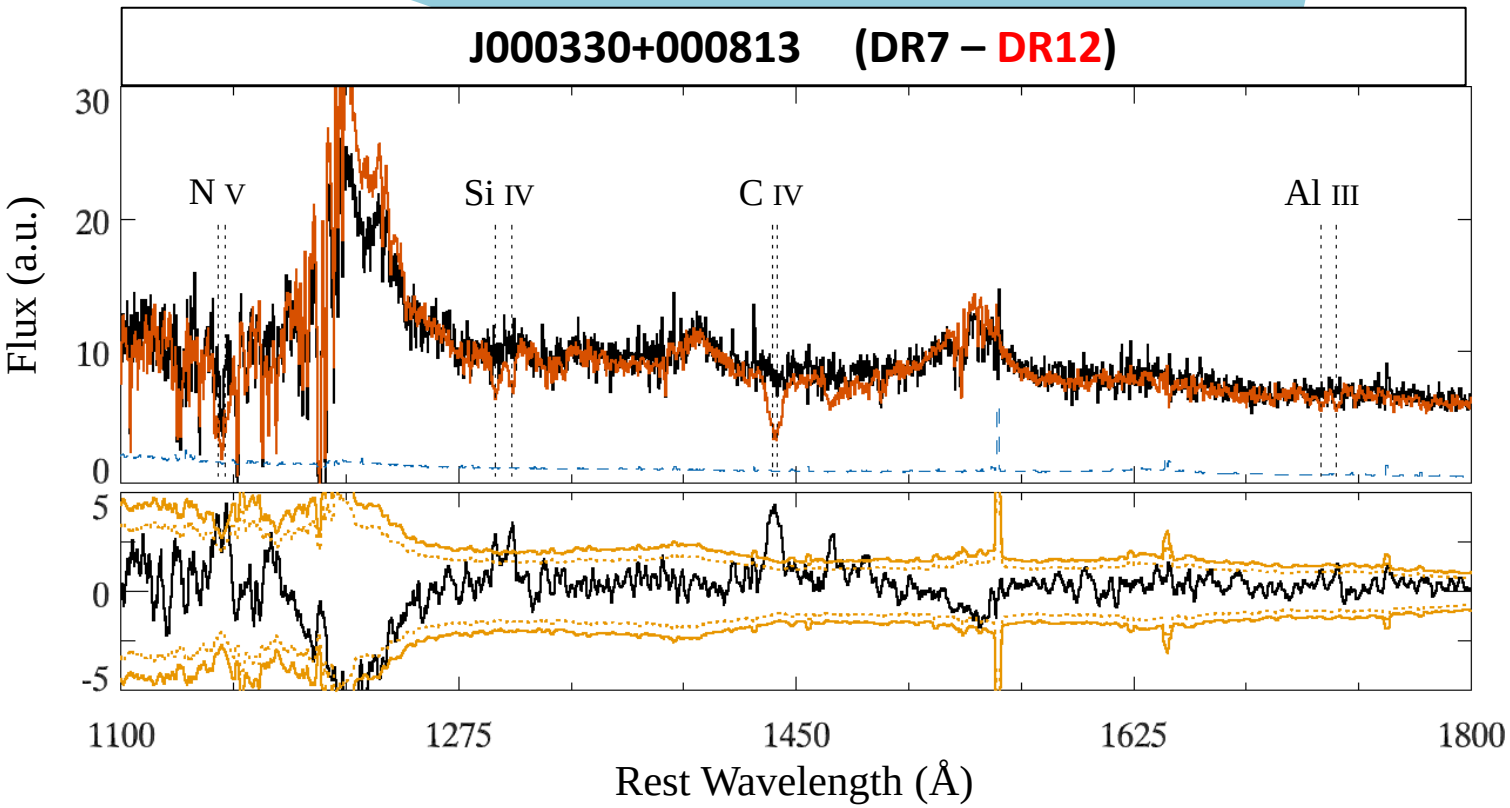
Characterizing Mini-BAL Outflows

Mini-BALs are **10^2 – 10^3 km/s wide**, may trace distinct outflow phase

Orientation
Evolution

Probe variability patterns of **22 mini-BAL** quasars

$7\ d < \Delta t_{rest} < 11\ yr$
N V , Si IV , C IV, Al III mini-BALs



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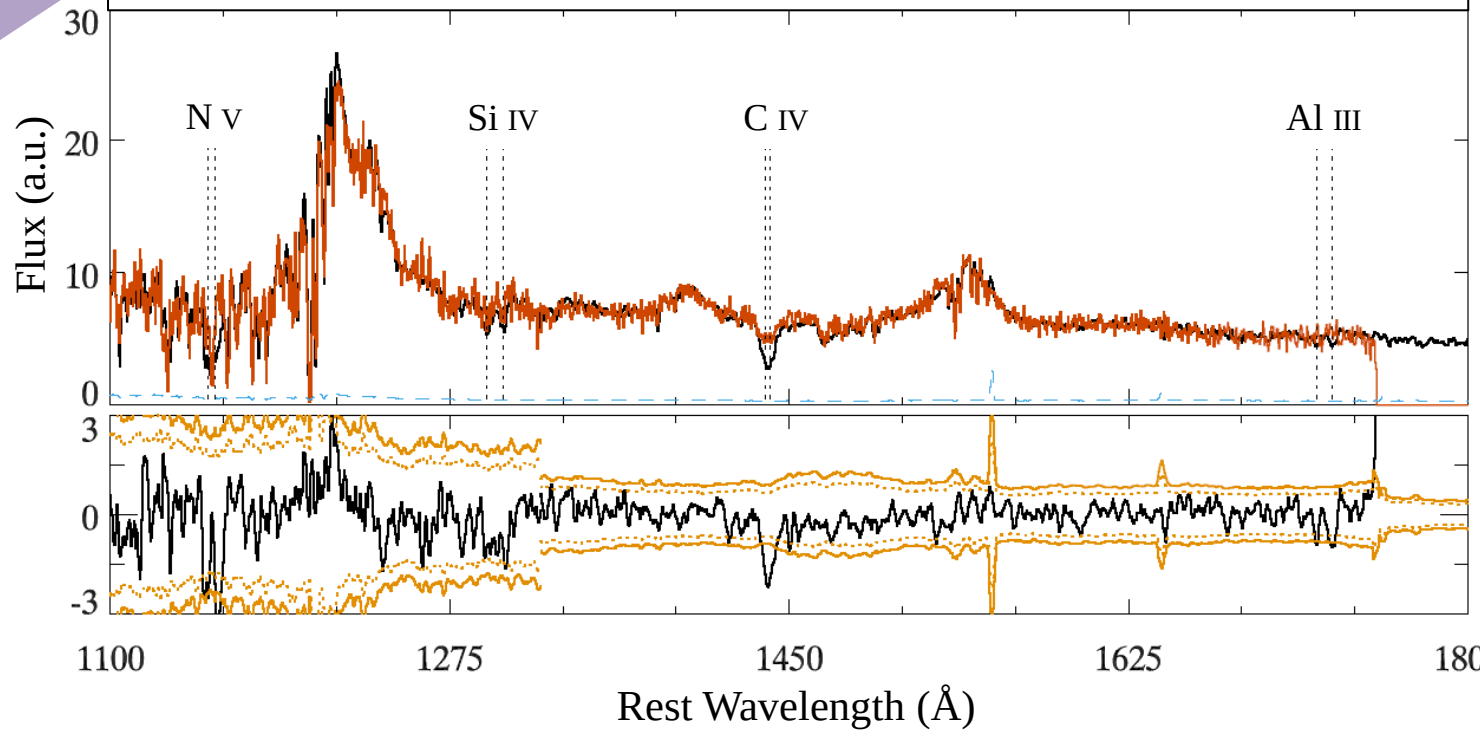
<u>Results</u>
(J000330)

Distance
0.2 pc

Transverse Speed
7200 km/s

Transverse Size
0.02 pc

J000330+000813 (DR12 – MDM)



Summary and Future Directions

BALs probe **quasar outflows** and allow constraints on outflow **kinematics** and **energetics**

We detect **BAL variability** on multi-year time-scales from a number of ions (**P V, N V, Si IV, C IV, Al III**) and probe outflows **within 1 pc, 10 pc, 100 pc, 1 kpc**

We estimate **outflow kinetic luminosities** over **seven orders of magnitude** between **10^{-6} to 1 L_{bol}** (only **some** outflow energies sufficient for **AGN feedback**)

Future Directions

High-resolution spectroscopy (Si IV and Al III BAL doublets)

BAL variations over **shorter time-scales**

Column Densities using P V-like diagnostics (S IV and Al III)