Probing the ultra-fast outflow BALs in quasars using multi-epoch spectroscopy

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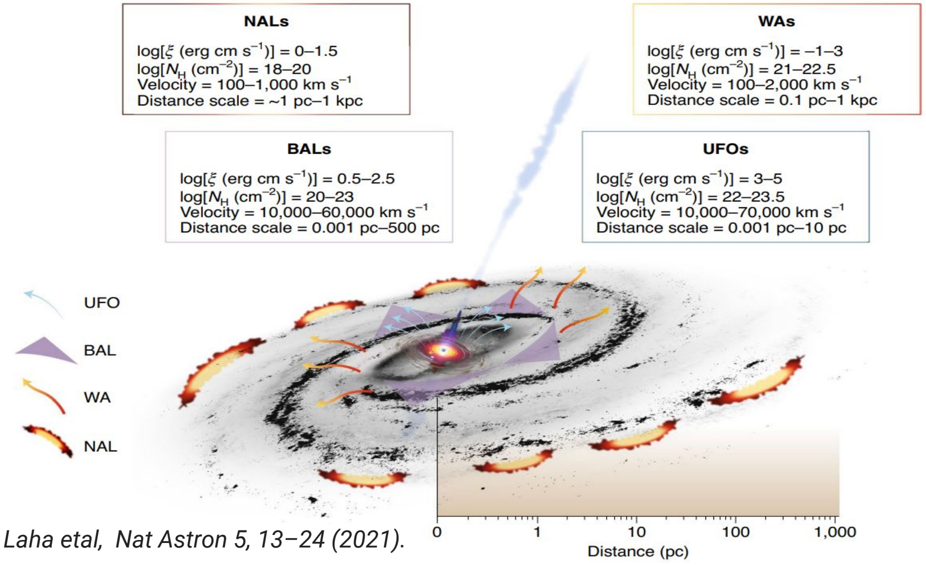
Introduction :

- **Strong outflows from quasars are believed to produce broad absorption lines or BALs**
- **Generally have widths of several 1000 km/s and outflow velocities from 1000 km/s up to several 10,000 km/s.**
- **High ionization BALs (Hi-BALs) from C IV, Si IV, NV etc. or Low ionization BALs (Lo-BALs) from Mg II, Al III etc.**



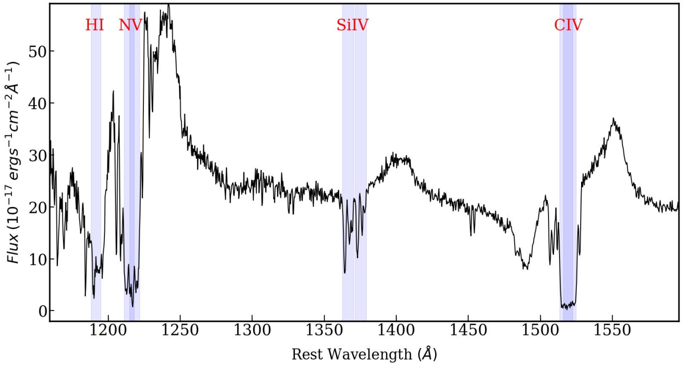
Laha etal, Nat Astron 5, 13−24 (2021).

Radiatively accelerated accretion disk winds :

- UV line driving as the possible mechanism for radiative acceleration.
- Observational evidences such as line-locking and Lyman-α ghost support this scenario.
- Can be either continuous outflows (Murray etal 1995) or individual clouds (Arav etal 1994).

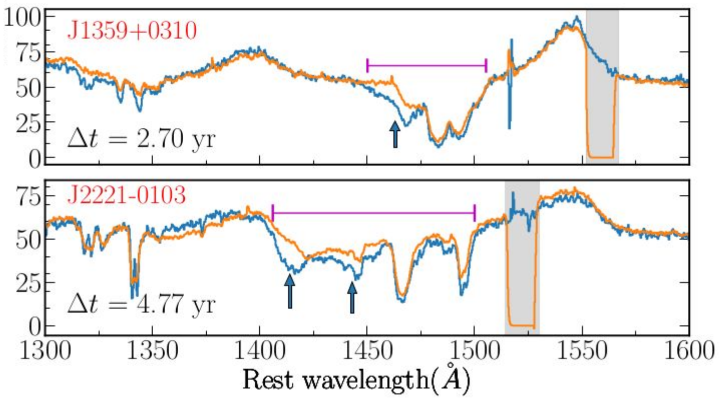
Magnetic driving :

- Magnetic forces can also launch, drive, and constrain the flow.
- It can reach higher terminal velocities due to stronger centrifugal forces.



Why variability is important ?

- Provides important clues on the dynamical evolution of BAL outflows.
- Constraints on time-scales related to BAL. eg. BAL lifetime.
- Constraints on location of the outflow using PI models.
- Provide estimates on the approximate size of the outflow.
- Test for disk wind models of quasar outflows.



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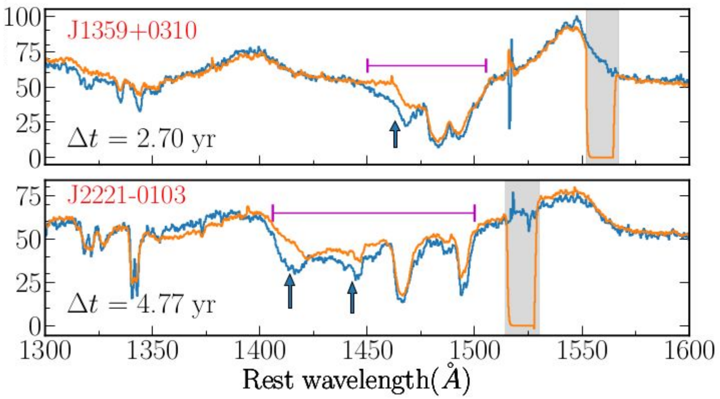
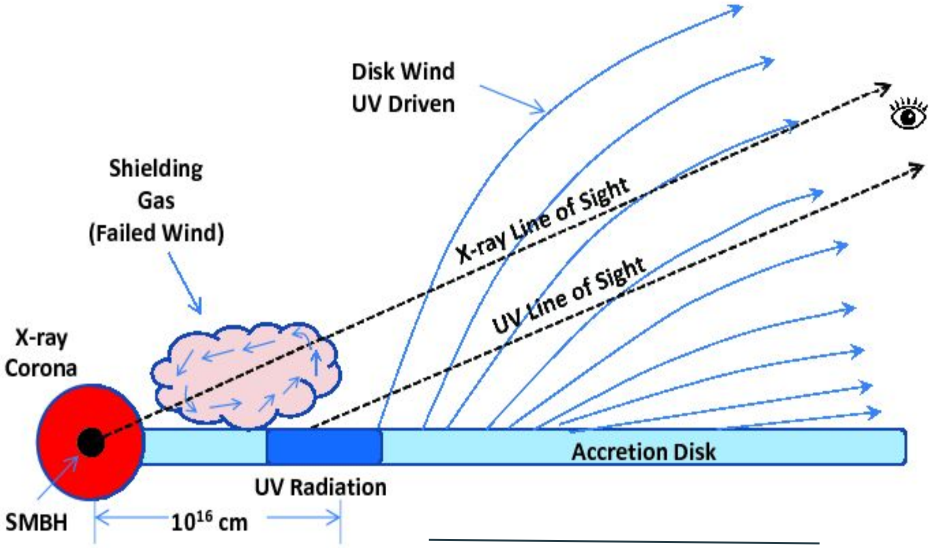




Luo et al.,2013,ApJ,772,153.

Possible reasons for variability

- **Fluctuations in quasar ionizing flux**
- **Changes in covering fraction of the outflow with respect to background source (transverse motion with respect to our LOS)**
- **Bulk motion of the outflowing gas**
- **Changes in properties of the shielding gas**
- **Changes in the mass outflow rate**

Why do we study UFO BALs (v > 15000 km/s) ?

- They are considered to be the largest contributors of AGN feedback due to high velocities.
- Assumed to be originating from the inner parts of the accretion disk.
- They tend to show more extreme variability events such as emergence, disappearance and kinematic shift in short time scales

Sample selection (C IV BALs) :

- ➔ $V_{outflow}$ > 15000 km/s
- ➔ r-band magnitude < 18.5
- ➔ Redshift > 2.0
- ➔ Declination angle < 10°

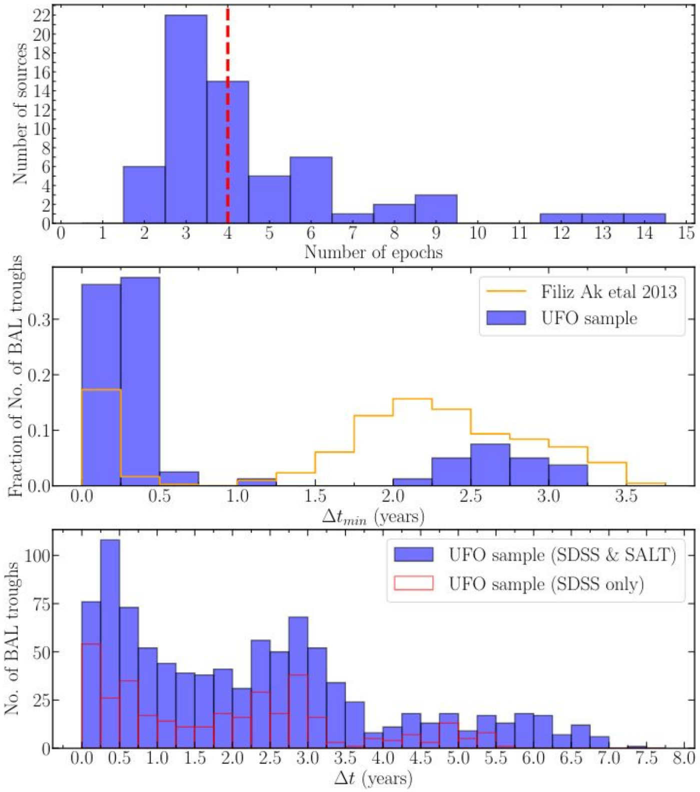
64 UFO BAL quasars

(Out of 388 BAL quasars without the redshift and declination range cut)

from SDSS (paris etal 2017)

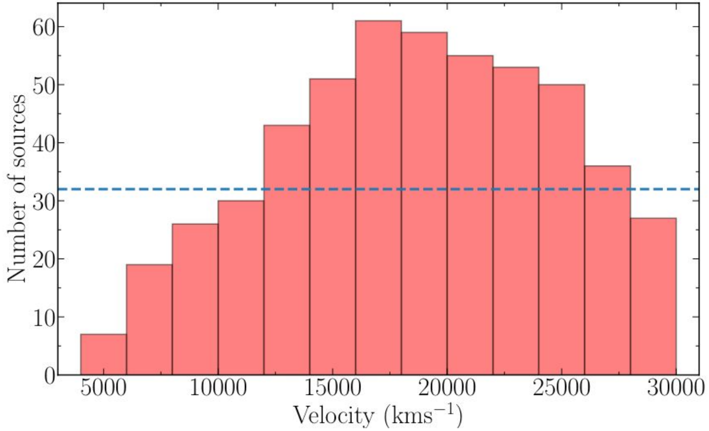
SALT observations along with SDSS make both short- and long time scale study of these special sources possible.

375 spectra (SDSS - 211, SALT - 164)



We have improved the time variability study using SALT observations by observing UFO sources,

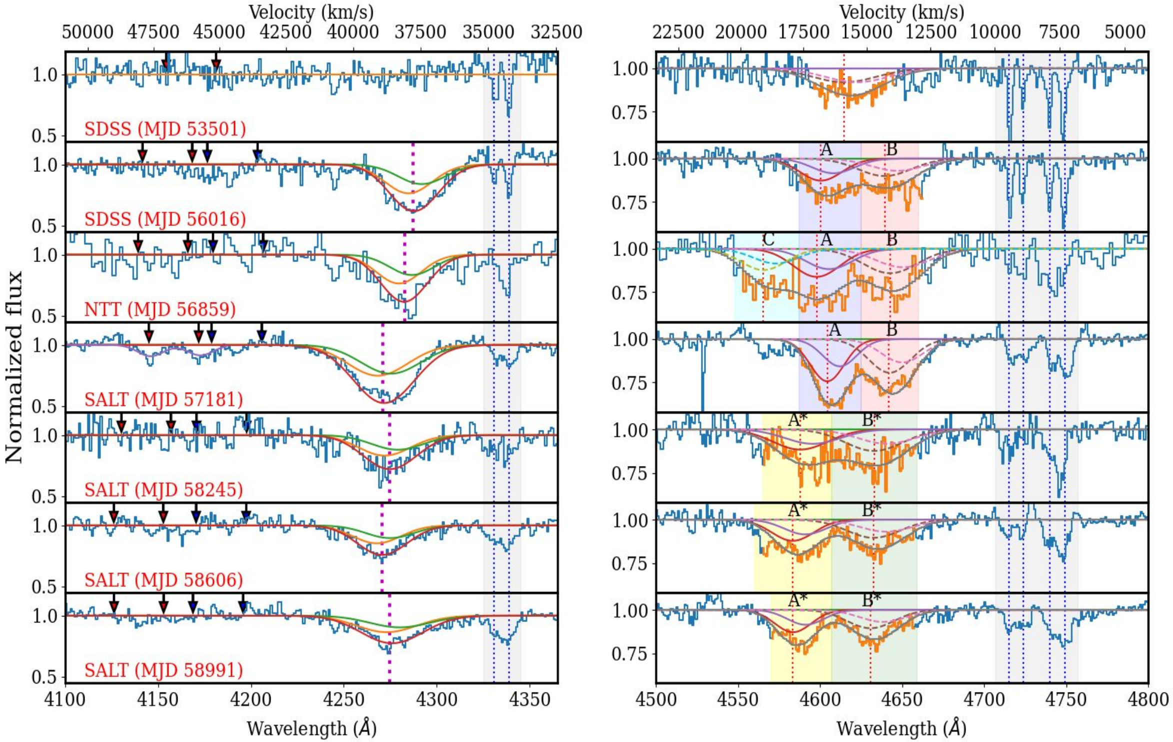
1. **At short time scales (probing rest-frame time scales of a few months)**
2. **At long time scales (gives time scales of ~ 7.5 years combined with SDSS data)**



Do UFO BAL quasars show peculiar variability ? :

<u>J1621 + 0758 :</u>

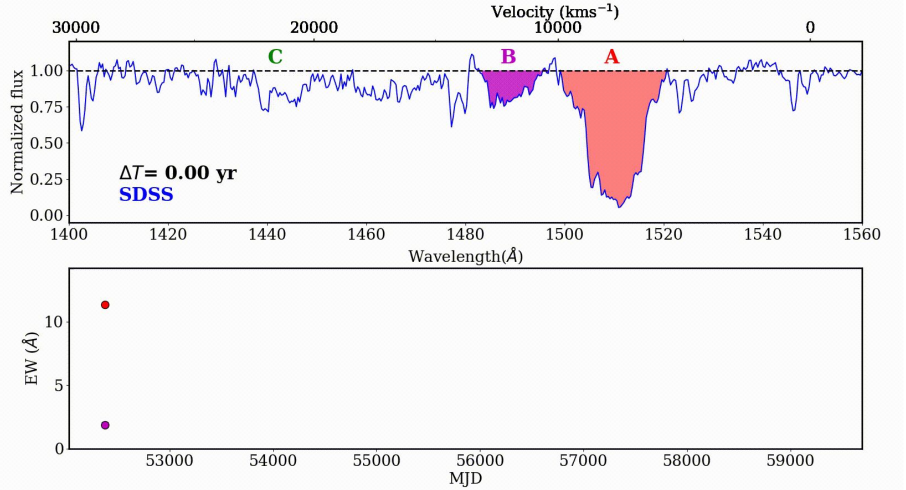
- **Emergence and acceleration.**
- **Correlated variability despite large velocity separation.**

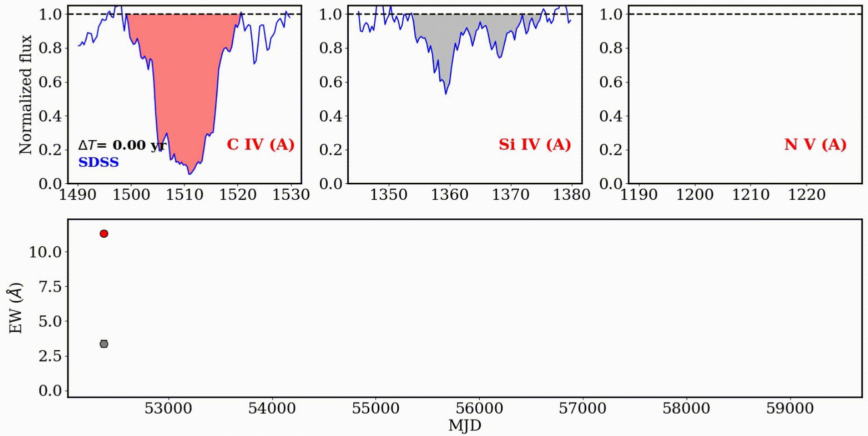


Aromal et al 2021, MNRAS , 504, 5975

J1322 + 0524

- Line-locked stable absorption line complex.
- Emergence of a large width absorption.
- Correlated variability among different BALs.
- Correlated variability of different ionized species.

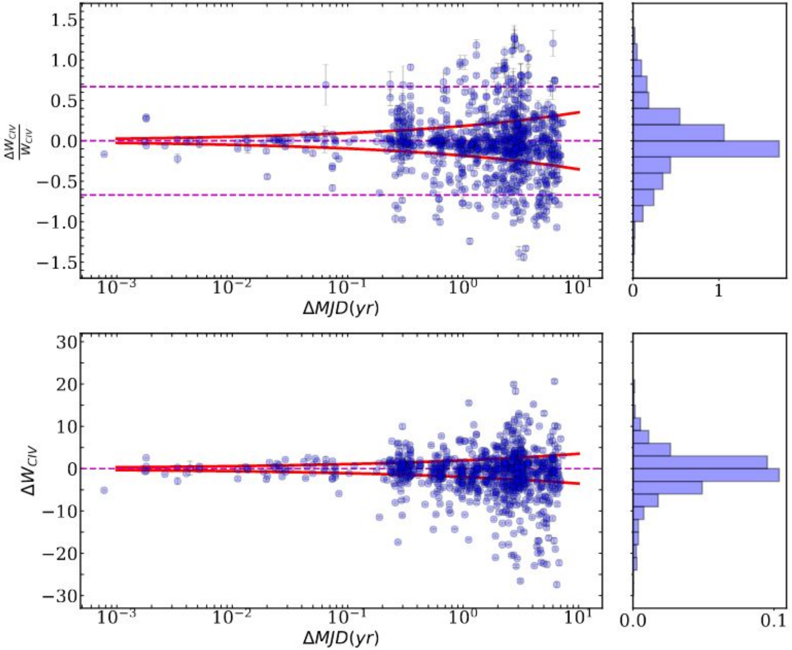




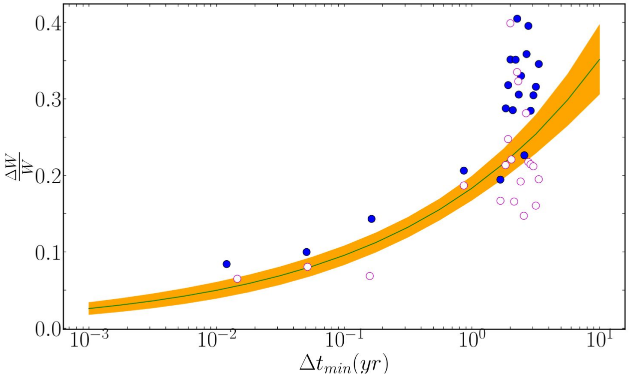
10 epochs spanning 19 years in the observer's frame with good photometric coverage !

Aromal P., Srianand R., Petitjean P., 2022, MNRAS , 514, 1975

Do UFOs vary more ?



Scatter in fractional variations in strength increases with time.

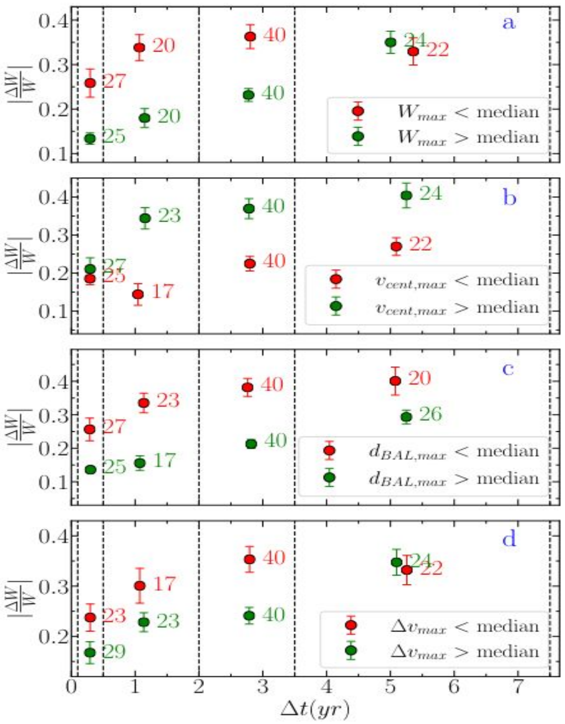


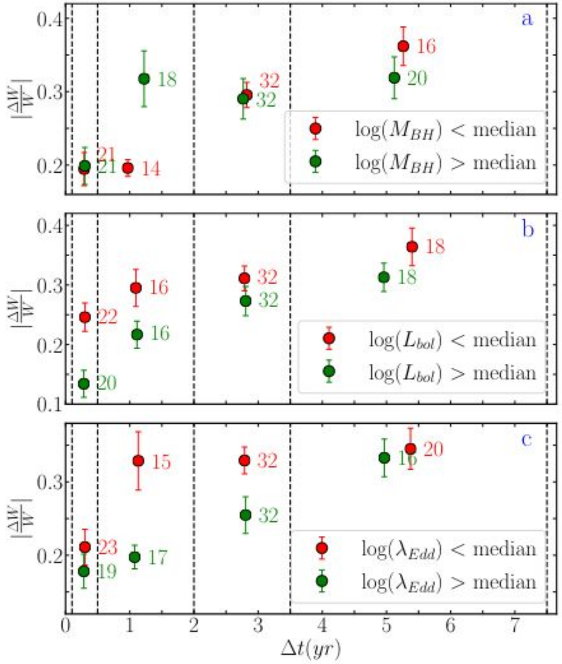
We found UFOs vary more than general BAL population.

We also find that these UFO sources do not differ from non-BAL and general BAL quasar population in terms of Quasar and optical light curve properties.

Aromal P., Srianand R., Petitjean P., 2023, MNRAS, 522, 6374

Do UFO BAL variability depend on Quasar and/ or BAL properties ?

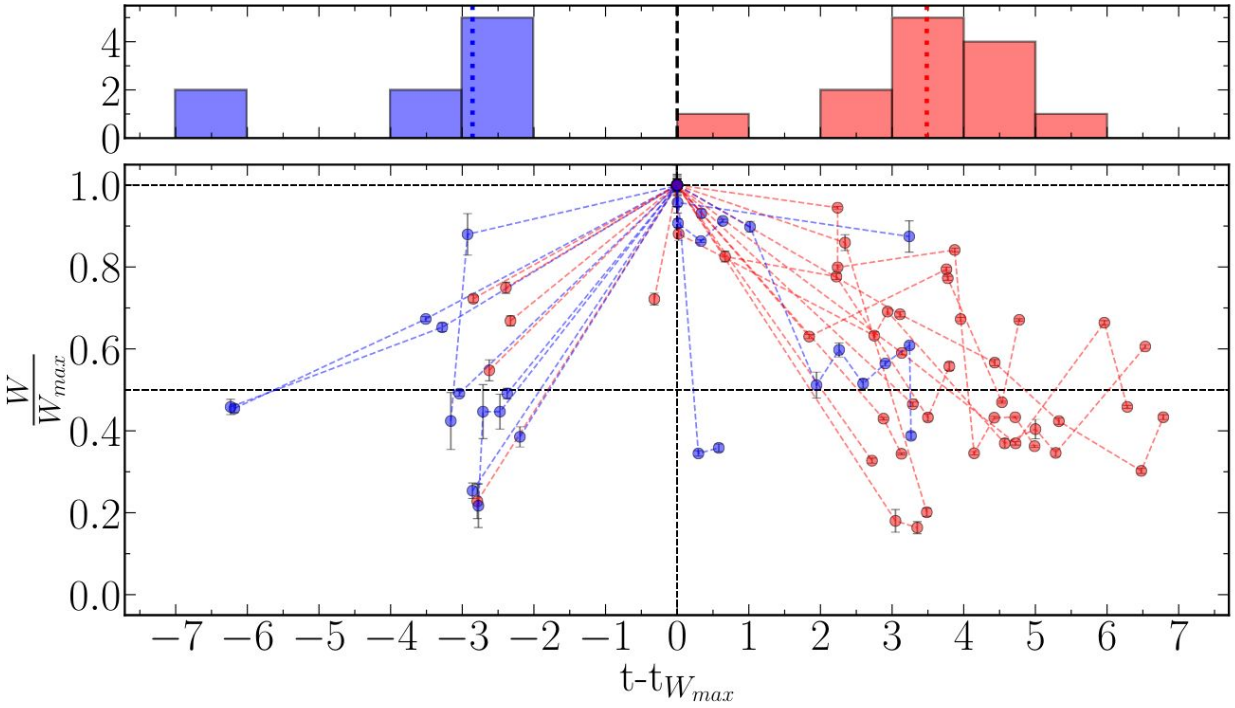




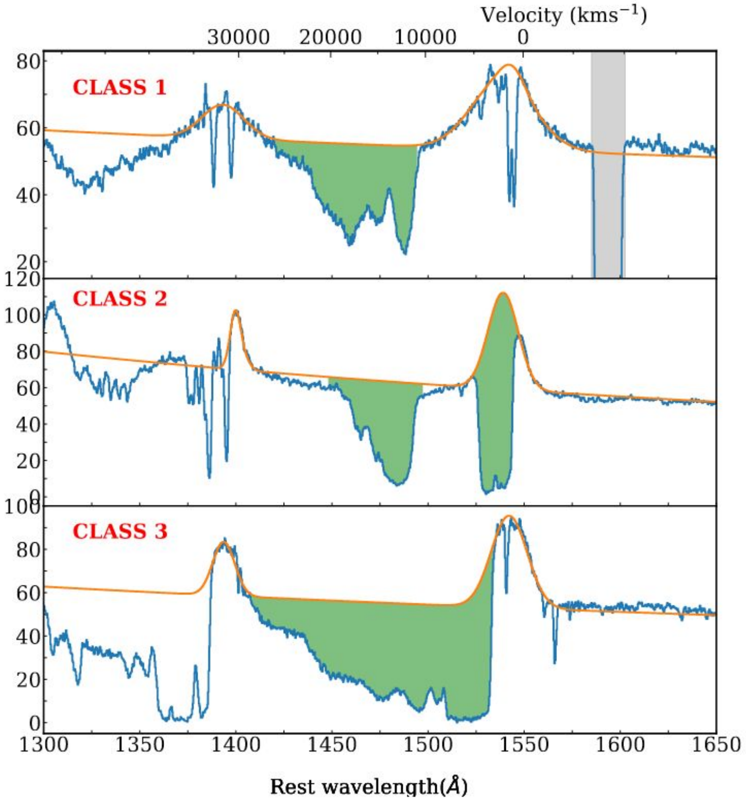
Weak, shallower, high-velocity, low-width BALs tend to show more variability !

No clear dependence on Quasar properties.

Disappearing time-scales longer than emerging time-scales for UFO BAL sources ?



Do UFO BAL variability depend on its profile nature ?

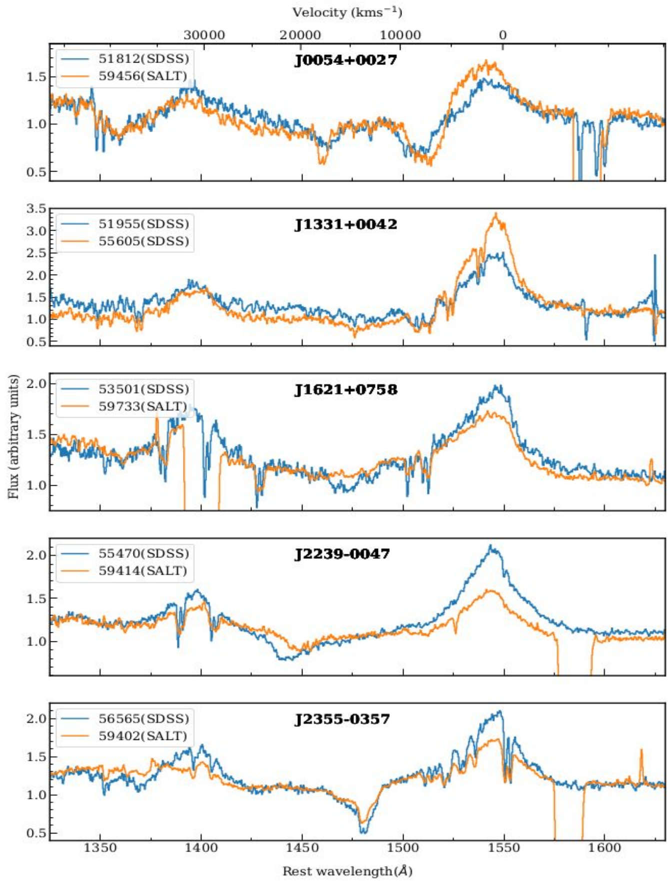


- Almost 30 % of UFO sources show EW variations more than factor 2 ("Highly variable sources")
- They are mostly sources from Class 1 and Class 2 and UFOs in Class 2 tend to vary more dramatically than detached UFOs in Class 1.

Do UFO sources support photo-ionization induced BAL variability scenario ?

BEL variations :

- ❑ Several BEL properties are correlated with BAL properties indicating possible connection between the two mechanisms. For example, C IV BEL blueshift shows correlation with the strength and maximum velocity of the BAL profile.
- ❑ Significant BEL variability is always associated with considerable BAL variability.



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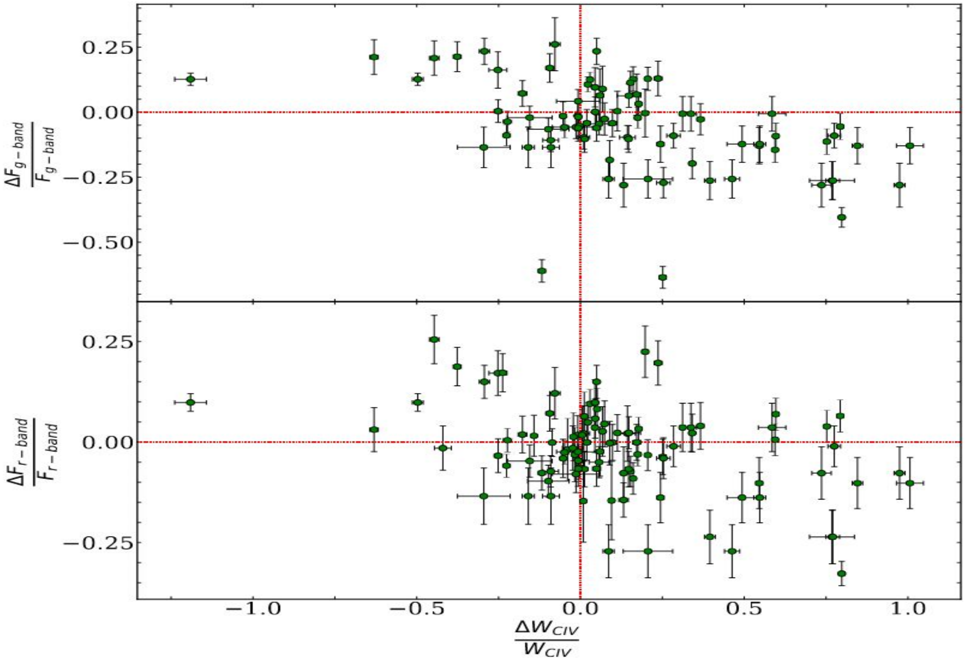
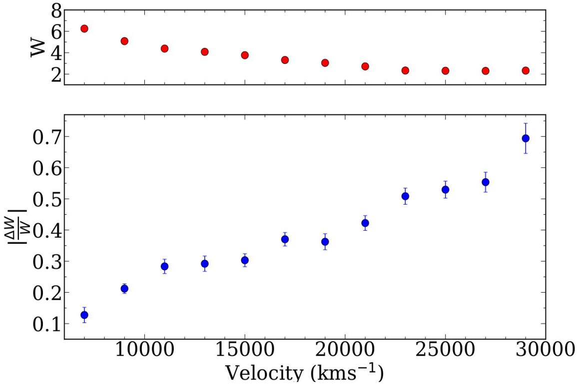
<u>Photometric light curve variations :</u>

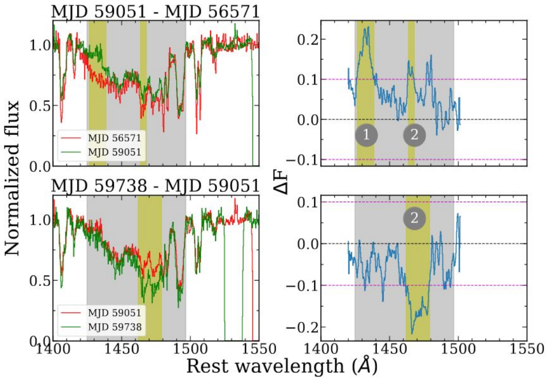
- ❑ Both g-band and r-band photometric light curves show strong anti-correlation with BAL strength variations.
- ❑ Large variations in r-band indicates significant BAL variability in UFO sources.



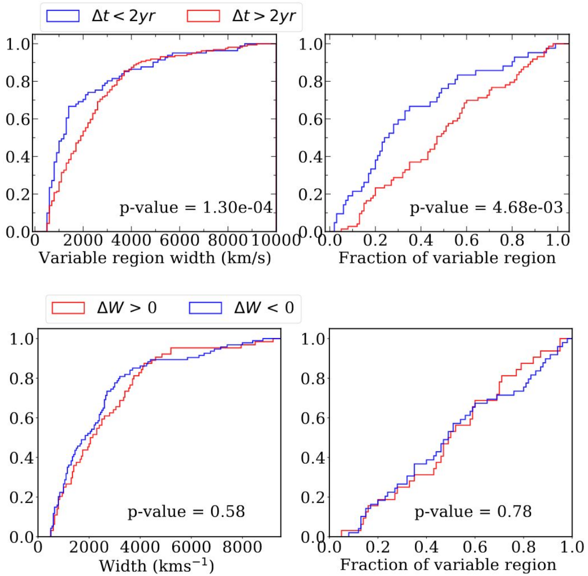
Does the entire BAL profile vary uniformly ?



Pixel based analysis reveals variability is highly dependent on the outflow velocity.



Variable regions of BALs vary in position and width in-between epochs.



The variable regions in a BAL constitutes mostly < 50 % of the BAL width.

Aromal etal 2023 (in prep.)

Summary :

- ❖ We find that UFO BAL sources vary more than general BAL quasar population.
- ❖ In general, disappearing timescales of UFO BALs are higher than emerging timescales.
- ❖ BAL variability has no clear dependence on any quasar physical properties.
- ❖ In terms of BAL properties, weak, shallower, high-velocity, low-width BALs tend to show more variability in UFO sources.
- ❖ The presence of lower velocity BALs in the same source make UFO BALs vary significantly compared to others.
- ❖ Variable regions inside a BAL typically constitutes a few tenth of the total width and also change in position and width with time.
- ❖ Correlated BEL and photometric light curve variations point towards photo-ionization induced BAL variability due to continuum flux changes.