Broad Absorption Line Variability in Sloan Digital Sky Survey Quasars

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Image Credit: NASA/CXC/M. Weiss

Quasar Outflows & Broad Absorption Lines (BALs)





BALs: Widths of $> 2000 \text{ km s}^{-1}$

Produced by winds/outflows launched from the quasar accretion disk

Winds affect environments within quasars; could also be agents of feedback to quasar hosts!



BAL Variability

• BALs are variable on timescales of days to years

(e.g., Lundgren et al. 2007, Capellupo et al. 2011, 2012, 2013; Filiz Ak et al. 2012, 2013, 2014; Grier et al. 2015;)

- Variability can be used to learn about various BAL properties, including:
 - Structure
 - Location
 - Dynamics & Stability
 - Wind energetics



From Filiz Ak et al. (2012, 2014)

BAL Variability Studies: A BOSS and TDSS Ancillary Program



See poster by M. Eracleous (PSU) for more info on TDSS! SDSS-III/BOSS: Baryon Oscillation Spectroscopic Survey (2009-2014)

Ancillary projects of smaller scale: includes BAL variability!

<u>SDSS-IV/TDSS: Time Domain</u> <u>Spectroscopic Survey (2014– present)</u>

Main goal: Obtain spectra for classification of variables

About 10% of fibers are allocated for repeat observations of objects --- including BAL quasars.

BAL Variability Ancillary Program with BOSS and TDSS



- BAL Quasar sample: ~2100 BAL Quasars from Gibson et al. (2009) catalog, all bright (*i* = 16.5-19.2) and have good BAL coverage
- Time span between SDSS and BOSS observations probes rest-frame timescales of typically 1-6 yr. (TDSS is extending this even longer)
- This sample is ~ 100 times larger than other samples probing multi-year timescales

Ancillary Program Results (Filiz Ak et al. 2012, 2013, 2014; Hall et al. 2013)







Some major results:

- Variability is common, but some BALs stable!
- Variability amplitude increases with timescale
- BALs can disappear
- BALs at different velocities vary in a coordinated fashion
- Some BALs are redshifted (infall? Rotation?)

And much more! (See these works for details)

Ongoing BAL Disappearance Work

D. De Cicco, W. N. Brandt, C. J. Grier et al. (in preparation)

More than 1500 targets with 2 epochs (582 in Filiz Ak et al. 2012)

More than 100 disappearing BALs found!



De Cicco et al. (in prep)

A Search for Accelerating Outflows via BALs

Grier et al. (2016), arXiv: 1604.07410



The idea: Search for "accelerating" outflows by looking for velocity shifts in BAL features. This is the first systematic large-sample search for this phenomenon!

The Sample:

140 quasars with **three epochs**: one epoch each from SDSS-I/II, BOSS, and TDSS

Properties similar to the larger parent sample of 2005 BAL quasars

151 distinct CIV BAL trough complexes

Searching for Velocity Shifts

- Look for BALs that don't vary in shape much (or in only small parts)

 about 80 BALs passed this test
 (66 BALs were too variable to detect acceleration)
- 2. Use cross correlation to identify velocity shifts between epochs
- 3. For BALs that don't shift OR vary in shape, measure upper limits!



(This is an example of a stable, nonshifting BAL)

Acceleration Candidates



Grier et al. (2016), arXiv: 1604.07410



Possible Causes of Velocity Shifts



We've considered a few scenarios:

- Radiative Acceleration
- Rotational "acceleration"
- Deceleration from "feedback"

None of these seem to explain our data super well...





Non-Variable BALs are remarkably stable in velocity!



- We measured upper limits to acceleration/deceleration for 76 lowvariability BAL quasars
- Majority are stable to within < 2% of their outflow velocities.
- What does this mean?!
 - BALs are far from the central source?
 - Issues with "standing flow" model?

Future Prospects

- Future BAL Acceleration studies:
 - TDSS is ongoing; over the years it will increase the sample of quasars with 3 epochs (hopefully up to 1600 quasars!) This will allow us to find more possible acceleration candidates.
 - Follow-up of acceleration candidates:
 - Are they continuing to accelerate?
 - Is the acceleration magnitude similar? Does it continue to change in amplitude from epoch to epoch?
 - Theoretical work, simulations, etc. addressing velocity shifts/acceleration as an observable may yield further insight into the mechanisms responsible for our observations.

Thank you very much!

Time between Observations



Acceleration Candidates



