Revealing and Constraining Cosmic Winds in Interacting Galaxies

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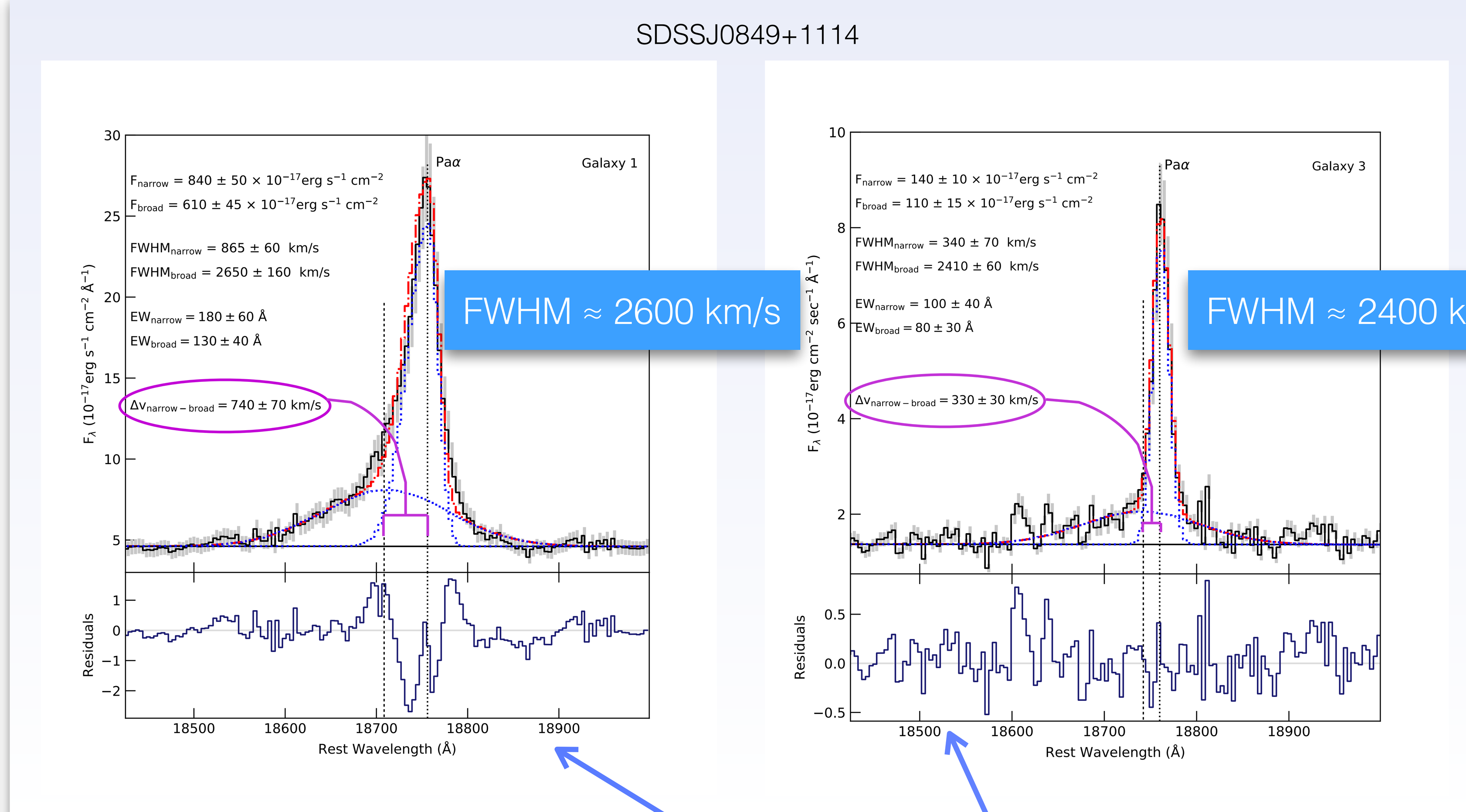
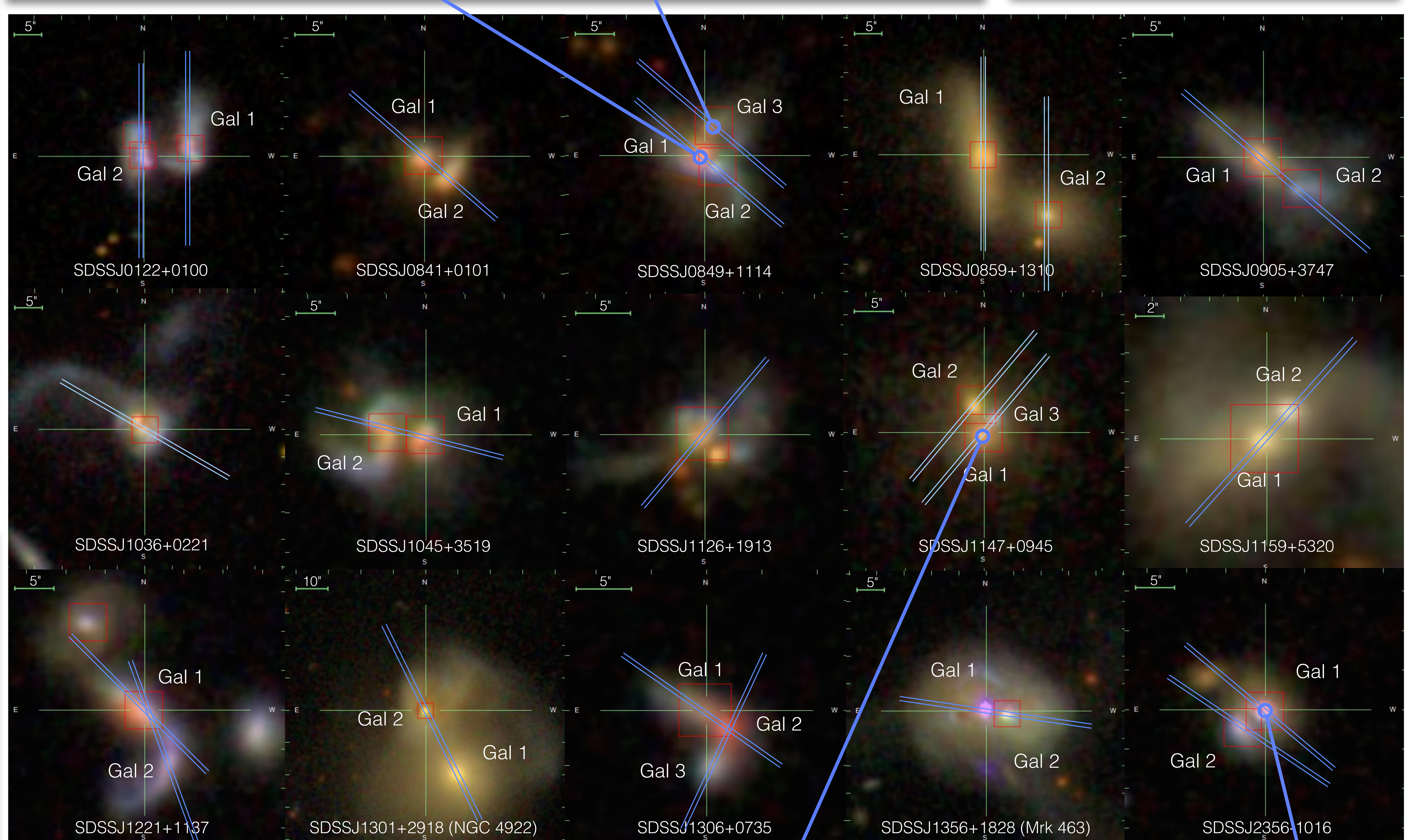
Abstract: Identifying dual accreting supermassive black holes (SMBHs)

Interacting galaxies are abundant in the universe and are believed to play an essential role in the evolution and formation of galaxies by enabling gas inflows towards the central region of galaxies. Accretion of matter onto the central supermassive black holes, which are observed as Active Galactic Nuclei (AGN), is potentially triggered by these galaxy interactions. Although it is expected that dual AGN systems are ubiquitous, only a handful of dual AGN systems have been confirmed observationally and remain extremely rare despite decades of searching. Optical detection of merger-induced dual AGN is vulnerable to dust obscuration or contamination of the nuclear emission by the host galaxy, however longer wavelength observations (e.g. near-IR) overcome this inconvenience. We present here measurements of gas kinematics in galaxy nuclei of fifteen interacting systems based on data obtained with the Large Binocular Telescope Near-Infrared Utility with Camera and Integral Field Unit for Extragalactic Research. We reveal new evidence for Doppler broadening of hydrogen emission lines consistent with supermassive black hole accretion (> 1000 km/s) along with velocity shifts highly suggestive of strong galactic scale winds in a fraction of these systems. These results support previous findings that optical studies miss a substantial amount of single and dual AGNs in interacting galaxies and offer new insights into the gas kinematics associated with merging supermassive black holes, which are of great interest for future studies of gravitational waves.

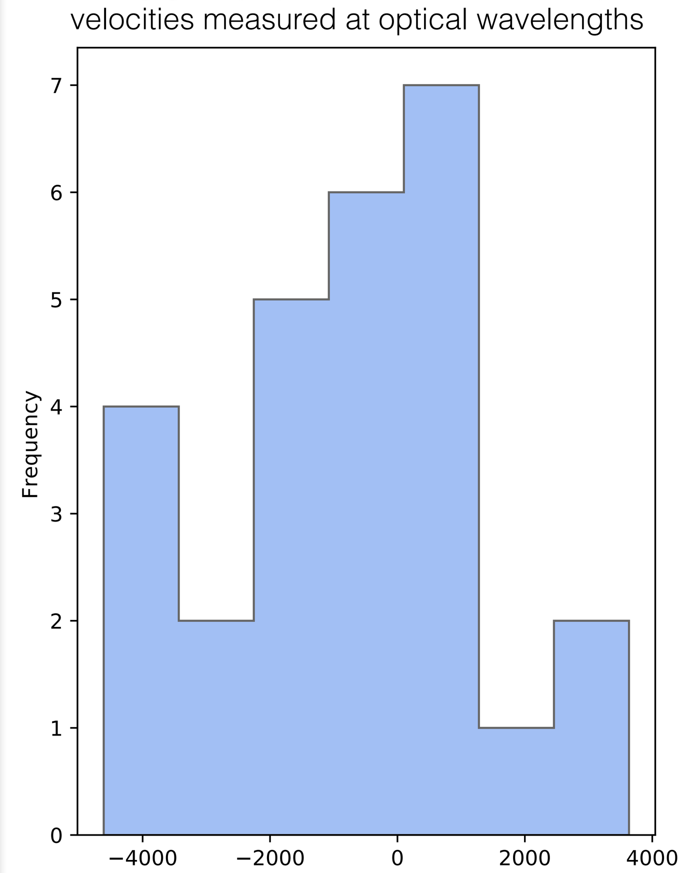
Sample Selection

- Galaxy Zoo project (Lintott et al. 2008):
  - Citizen scientists classified a sample of ~700,000 galaxies and identified morphological signs of interactions and labeled these galaxies as "mergers".
- Weighted-merger-vote-fraction, f_m:
  - Used to examine those galaxies identified as interacting by participants, with galaxies having a value of $f_m > 0.7$ being a high probability of being an interacting galaxy pair. Only ~1400 galaxies met this criterion.
- *WISE* color cut selections (Satyapal et al. 2014):
  - Selected only galaxies with mid-infrared signatures indicative of AGNs (*W1-W2* > 0.5 color cut; Stern et al. 2012; Assef et al. 2013). This narrowed our sample down to ~120.
- Include only interacting galaxies with at least two distinct nuclei separated by <10 kpc. This left us with ~90 galaxies.
- Follow up with *Chandra X-ray Observatory* of the fifteen brightest (Satyapal et al. 2017; Pfeifle et al. 2019).
- We present here analysis of near-IR spectroscopy of all the *Chandra* detections.





Line of sight velocities of components in all fifteen interacting galaxy systems relative to their systemic velocities measured at optical wavelengths



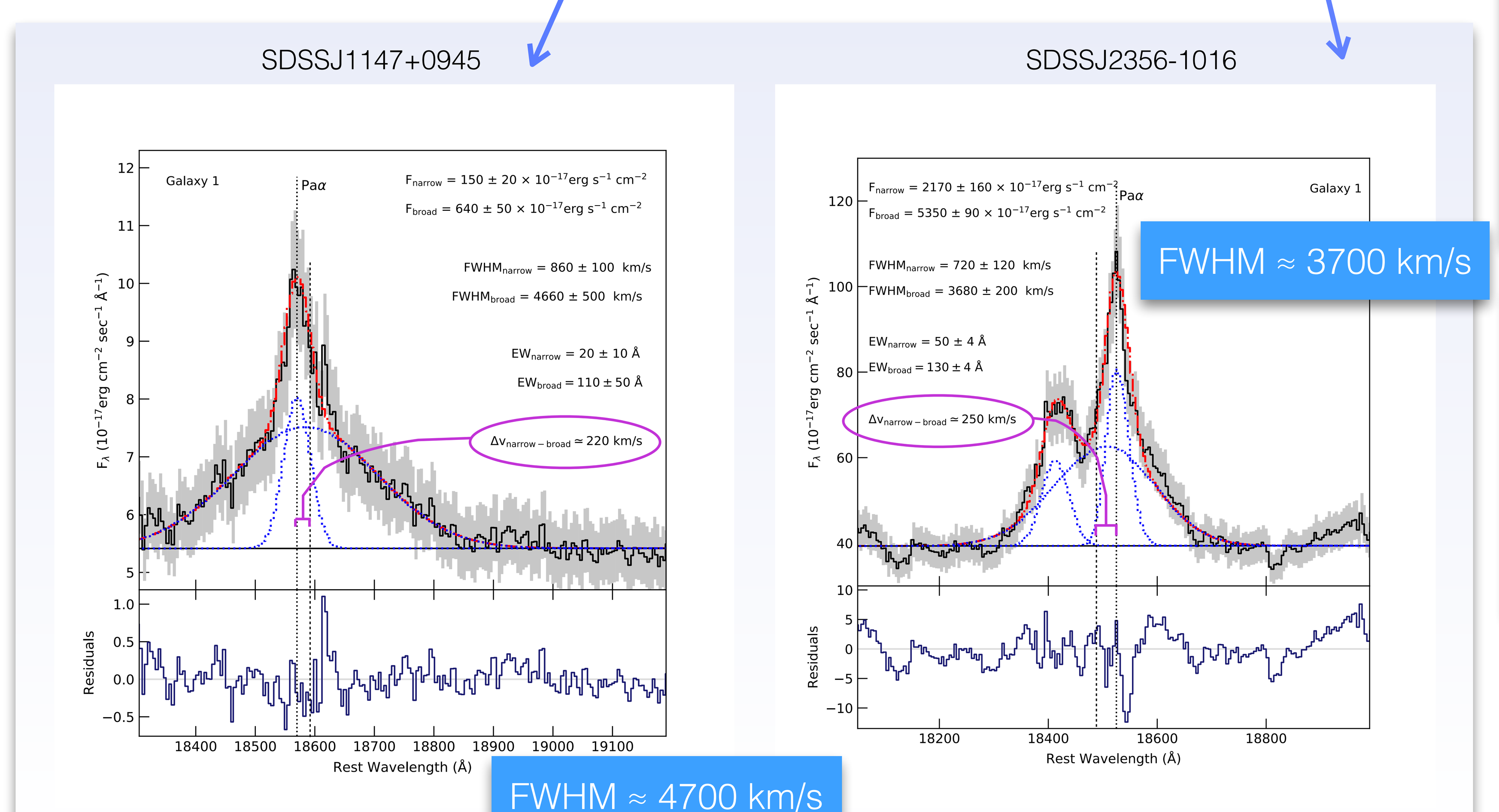
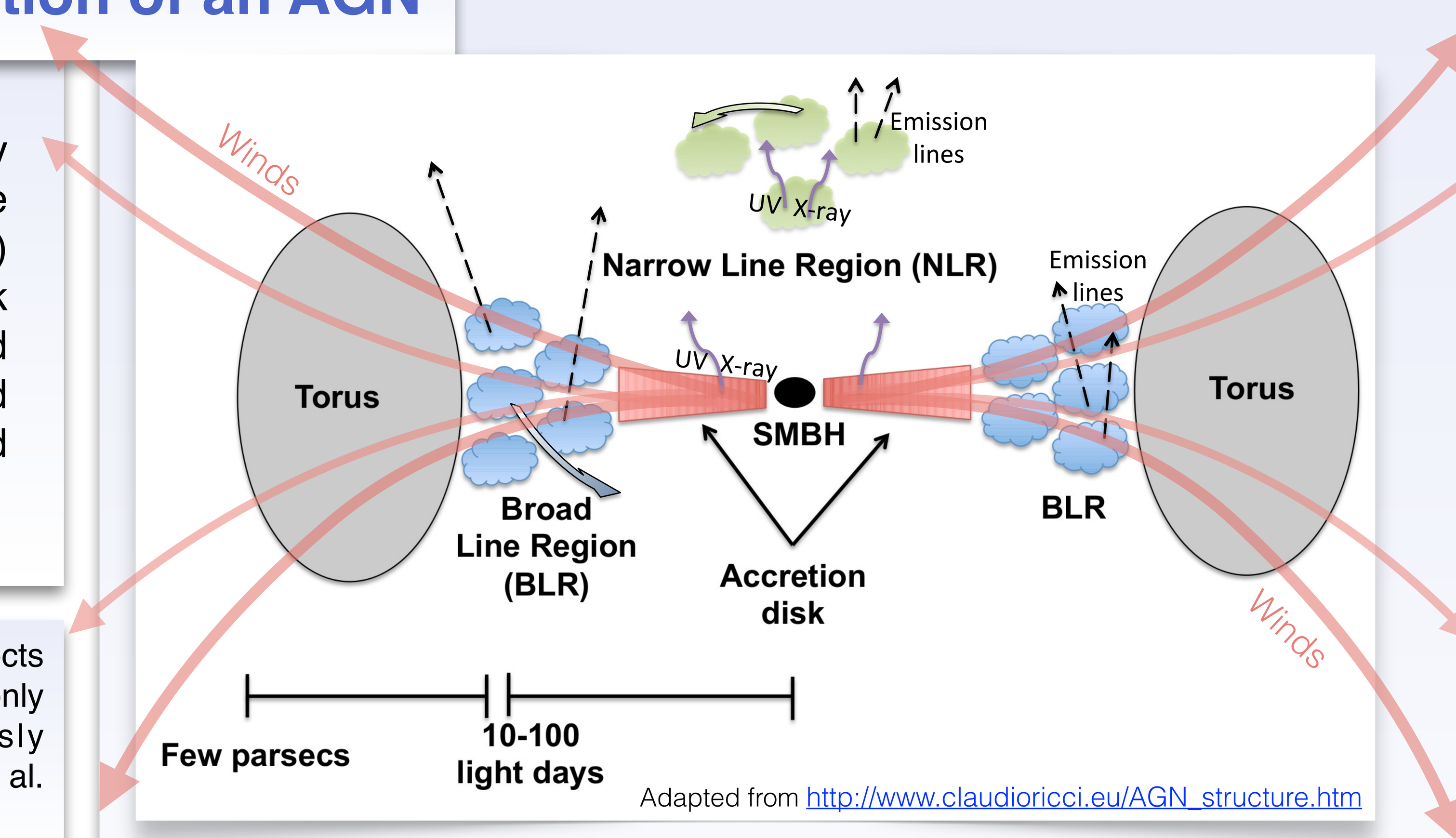


Illustration of an AGN

Depiction of how dusty toroidal material can obscure the broad line region (BLR) emission. The accretion disk emits high energy X-ray and UV photons which ionize and excite gas in the BLR and narrow line region (NLR).



SDSS images show that these objects are highly disturbed systems with only one system, Mrk 463, previously identified as a dual AGN (Bianchi et al. 2008).

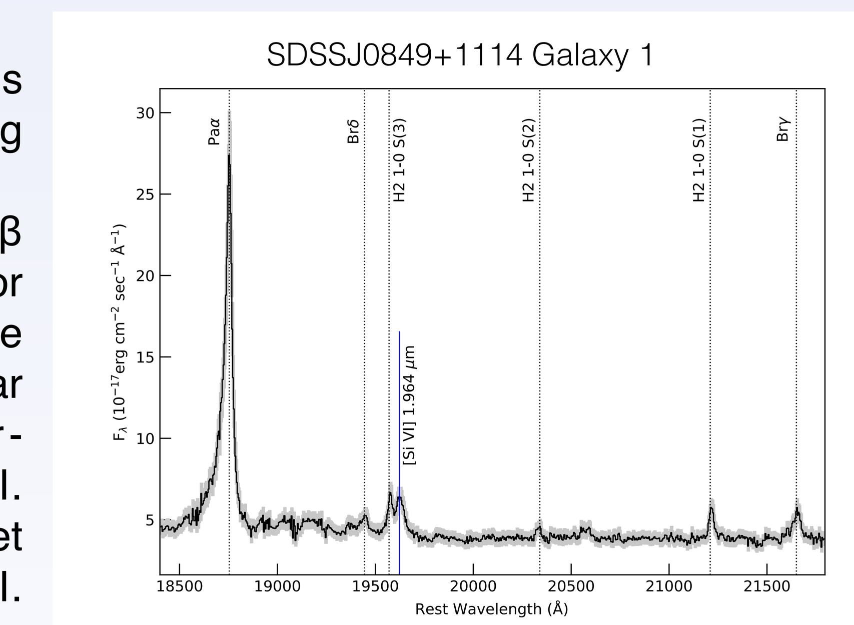
Results

Modeling the near-IR spectra of all interacting galaxies reveals the presence of broad hydrogen emission lines (Paα) of widths > 2400 km/s, which are the staple of ionization by accretion onto a supermassive black hole. Interestingly all these components are found to be blue shifted relative to the systemic velocity of their hosts, suggesting the presence of strong cosmic outflows caused by AGN activity.

Future Work

Pursue other AGN diagnostics for the galaxies that do not display broad emission components, to include:

- Near-IR line ratios diagnostic diagrams using $H_2$1-0S(1)/Brγ and [Fe II] 1.257 μm/Paβ which are useful tools for separating emission-line objects by their nuclear activity in the near-infrared (Larkin et al. 1998; Rodríguez-Ardila et al. 2005; Riffel et al. 2013).



- Coronal line emission detection (indicated above in blue), which results from forbidden transitions that cannot be produced by stellar processes, are strong indications of the presence of an AGN (Marconi et al. 1994).
- Comparison of H_2 and [Fe II] kinematics which will test the relative role of thermal excitation in AGN versus star forming regions in these galaxies (Riffel et al. 2013).

References: Assef, R. et al. 2013, *ApJ*, **772**, 26; **Bianchi, S.** et al. 2008, *MNRAS*, **386**, 105; **Larkin, J.E.** et al. 1998, *ApJ*, **114**, 59; **Lintott, C. J., Schawinski, K., Slolsar, A.** et al. 2008, *MNRAS*, **389**, 1179; **Marconi, A.** et al. 1994, *A&A*, 291; **Pfeifle, R.** et al. 2019, *ApJ*, **875**, 117; **Riffel, R.** et al. 2013, *MNRAS*, **430**, 2002; **Rodrigeuz-Ardila, A.** et al. 2005, *MNRAS*, **364**, 1041; **Satyapal, S.** et al. 2017, ApJ, **848**, 126; **Satyapal, S.** et al. 2014, *MNRAS*, **441**, 1297; **Seifert, W.** et al. 2003, *SPIE*, **4841**, 962; **Seifert W.** et al. 2010, *SPIE*, **7735**, 7; **Stern, D.** et al. 2012, *ApJ*, **753**, 30

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