

# Search for Sub-parsec Binary Supermassive Black Holes (BBHs) with Multi-Epoch Spectroscopy

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### Single-peaked broad line sub-pc BBH candidates

The working scenario:

- 1. Only one BH is active, carrying its own BLR
- 2. The other (inactive) BH is orbiting outside the





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Liu, YS, et al. 2013, Submitted

### **Need multi-epoch spectroscopy for confirmation**

#### **BBH** period

$$P = 2\pi d^{3/2} (GM_{\text{tot}})^{-1/2} = 300 d_{0.1}^{3/2} M_{8,\text{tot}}^{-1/2} \text{ yr}$$

#### los velocity offset

$$V_1 = \frac{M_2}{M_{\text{tot}}} \left(\frac{GM_{\text{tot}}}{d}\right)^{1/2} \sin I \sin \phi = 2000 \left(\frac{M_2}{M_{\text{tot}}}\right) M_{8,\text{tot}}^{1/2} d_{0.1}^{-1/2} \sin I \sin \phi \,\,\text{kms}^{-1}$$

### los acceleration $a_1 = \frac{GM_2}{d^2} \sin I \cos \phi = 44 \left(\frac{M_2}{10^8 M_{\odot}}\right) d_{0.1}^{-2} \sin I \cos \phi \, \mathrm{km \, s^{-1} yr^{-1}}$

# Broad lines with small offset may have large acceleration

### **Two strategies:**

- 1. Targeting quasars with offset broad lines: Eracleous et al. (2012), Decarli et al. (2013), Liu et al. (2013, see poster by Xin Liu)
- Targeting general quasars: Shen et al. (2013), Ju et al. (2013)

### I. The general quasar population

#### Shen et al. 2013 (Hbeta); also see Ju et al. 2013 (MgII)

Free 2-epoch spectroscopy of ~2000 quasars from SDSS DR7 with Hbeta coverage (most have small offsets)
Restframe time separation: ~ 0.01-10 yr (peaks around 1 yr)

#### Luminosity and virial BH mass distributions of the active BH



### Multi-epoch spectroscopy of broad lines I. The general quasar population



### The binary separation must be larger than the BLR size

### I. The general quasar population

- ~ 700 pairs have good measurements of the broad line velocity change between 2 epochs; typical measurement errors in velocity shift: ~ 40 km/s (typical acceleration ~ 40 km/s/yr)
- 28 systems show detected (2.5sigma) velocity shifts between two-epochs



### I. The general quasar population



#### proper error analysis is key



Typical measurement errors in velocity shift: ~ 40 km/s

### I. The general quasar population

#### **Constraints from non-detections**



I. The general quasar population

### Caveat

BBHs versus broad-line-region variability

Typical dynamical time of the BLR is  $\tau_{dyn} = \frac{R_{BLR}}{V_{FWHM}} \approx a \text{ few yrs}$ 

BLR variability should mostly produce stochastic velocity shifts. Additional spectroscopic epochs needed.

# What's next?

- Additional spectra can easily strengthen or rule out the binary scenario
  - More spectroscopic epochs coming in SDSS-III and SDSS-IV (TDSS, 2014-2020) for thousands of quasars
  - Need to understand the BLR better (i.e., through reverberation mapping)

□Continued monitoring could eventually lead to orbit constraints for many candidates