Spectroscopic Search for Binary Supermassive Black Holes

by Mike Eracleous

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The Elusive, Bound Binaries
In the beginning...

0945 + 076

3C 227

-2100 km s$^{-1}$

figure from Gaskell (1983)
Double-Peaked Emitters

Figure from Eracleous et al. (1997)

Figure from Gaskell (1996)

Figure from Shen & Loeb (2010)
figures from Eracleous et al. (1997)

~30 cases now; see Gezari et al. (2007); Lewis et al. (2010); Flohic (2009)
figures from Shen & Loeb (2010)
SDSS J1536+0441: old ideas resurrected


$z=0.3727$

$\lambda (10^{-17} \text{ erg/s/cm}^2/\text{Å})$

$H\beta$

$[\text{O III}]$

Rest Wavelength (Å)
A Systematic Search for Close, Bound Binaries
The hypothesis: only one BH is “active”

Figure from Cuadra et al. 2009, MNRAS, 393, 1423
see also Hayasaki et al. 2007, PASJ, 59, 427

Figure from Artymowicz & Lubow 1996, ApJ, 467 L77

$\lambda$ (10$^{-17}$ erg/s/cm$^2$/Å)

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$H_\beta$

$[O \, \text{III}]$

$z=0.3727$

$U_2$
We observe:

\[ u_2 = V_2 \sin i \sin \phi \]

\[ u_{2,3} = \frac{V_2 \sin i \sin \phi}{10^3 \text{ km/s}} \]

\[ P = \frac{332 M_8}{(1 + q)^3 u_{2,3}^3} \left( \frac{\sin i}{\sin 45^\circ} \right) \left( \frac{|\sin \phi|}{\sin 45^\circ} \right)^3 \text{ yr} \]

\[ a = \frac{0.11 M_8}{(1 + q)^2 u_{2,3}^2} \left( \frac{\sin i}{\sin 45^\circ} \right) \left( \frac{|\sin \phi|}{\sin 45^\circ} \right)^2 \text{ pc.} \]

\[ \left| \frac{du_2}{dt} \right| = 19 \frac{u_{2,3}^4 (1 + q)^3}{M_8} \frac{(\sin 45^\circ)^3}{\sin i} \frac{(\sin 45^\circ)^4}{\sin \phi} \frac{|\cos \phi|}{\cos 45^\circ} \text{ km/s/yr} \]
Selection of Candidates from SDSS

- Spectroscopic PCA used to find quasars with “oddball” Hβ profiles.
  - start with $z < 0.7$ quasars from SDSS DR7
  - tune of PCA technique to find offset line peaks
  - ~900 candidates ➔ final filtering by visual inspection
  - at the end of the day: 88 candidates

- Volonteri et al 2009 predict ~130 such binaries in the SDSS DR7 spectroscopic sample (~17,000 quasars)
Reconstruction of Line Profiles Using First 5 Eigenspectra

$\chi^2 = 0.91$

$\chi^2 = 0.90$
Reconstruction of Line Profiles Using First 5 Eigenspectra

\[ \chi^2 = 5.83 \]

\[ \chi^2 = 3.12 \]
Distribution of Velocity Offsets

![Graph showing the distribution of velocity offsets with peak velocity shift in km s\(^{-1}\)](image-url)
Correlation between skewness and shift

![Graph showing correlation between skewness and shift. The x-axis represents Peak Shift (km/s) ranging from -4000 to 4000. The y-axis represents Pearson Skewness Coefficient ranging from -0.4 to 0.4. There are two regions labeled blueshift and redshift. The graph includes a scatter plot with points indicating the correlation.](image URL)
Followup Observations

- “2nd epoch”
  Dec 2009 - Mar 2011
  MDM 2.4m Hiltner
  KPNO 4m Mayall
  Palomar 5m Hale
  9.2m Hobby-Eberly

- “3rd epoch”
  just completed
Caveats: Pandora’s Box
Displaced Peaks Do NOT Always Mean Binaries!

from Gezari, Halpern & Eracleous (2007)
from Eracleous et al. (1997)
Nor Do Displaced Peaks that Move!

from Eracleous et al. (1997) including data from Gaskell (1996)

Gezari, Halpern & Eracleous (2006) see also Marziani et al. (1996)
from Lewis, Eracleous, & Storchi-Bergmann (2010)
So far, so god, so what?
Theoretical predictions of population size in broad agreement with observed numbers.

We can pick out the short-period binaries \((P\sim 10–20 \text{ yr})\) from repeating patterns, even though these will be short-lived.

We will learn a lot about the dynamics of the gas in the broad-line region in the process.

Therefore, we push on...
Continue monitoring observations
verify velocity variations
check for monotonic velocity changes: 3 epochs can constrain a sinusoid $\Rightarrow$ lower bound on the mass

Simulations of the population properties and assessment of impostors

Optical and radio imaging: test for recoiling BHs
HST and EVLA + VLBI

Spectroscopic Test for Perturbed Accretion Disks
Involves comparison of Balmer and Lyman line profiles.
End of story

for now...