The BLR Profile Signature of a Binary BH
Ari Laor & Yohai Meiron
Evidence for Binary BHs

3C 75

0402+379

NGC 6240

Mrk 463
**A new compact binary BH revealed?**

( March 2009) *Nature*

**A candidate sub-parsec supermassive binary black hole system**  Todd A. Boroson & Tod R. Lauer

The **BLR profile** reveals a compact 0.1 pc massive binary BH

\[ \Delta V=3500 \text{ km/s}, \quad \text{FWHM}(r)=6000 \text{ km/s}, \quad \text{FWHM}(b)=2400 \text{ km/s} \]

\[ \rightarrow \quad M(r)=10^{8.9}, \quad M(b)=10^{7.3} \quad M_{\odot} \]
Actually an old idea

**A test of the massive binary black hole hypothesis:**

**Arp 102B**

J. P. Halpern & Alexei V. Filippenko


The H-alpha line profile of Arp 102B has been measured for 5 yr without detecting any change in velocity.

Compact binary massive BH **ruled out.**
The rotating frame potential in a binary system

At the $L_1$ point $M_1/R_1^2 = M_2/R_2$.

Therefore $R_1/R_2 = \sqrt[4]{(M_1/M_2)}$

since $\sigma^2 = GM/R$ near each BH

$\sigma_1/\sigma_2 = \sqrt[4]{(M_1/R_1) / (M_2/R_2)}$

or $\sigma_1/\sigma_2 = (M_1/M_2)^{1/4}$

For a mass ratio $M_1/M_2 = q$

it is simple to show that

$\sigma_1^2/V_{rot}^2 = 2(q + \sqrt[4]{q})/(1+q) > 1$ for $q > 1$

The dispersion around the more massive object always > binary rotation velocity

One BLR line is always broader than the line velocity separation.

What about that BLR line from the other companion?
Calculation of the velocity distribution near a binary BH

Initial condition for $M_1:M_2 = 3:1$

Uniform phase space distribution within the common Hill sphere.

\[ t=0 \]

Integrate test particle orbits

\[ t=800t_{\text{period}} \]
A 1:1 binary observed at different angles

*spherical* configuration

[Graph showing flux density vs. velocity for different angles φ and θ]

Cloud
A 1:1 binary observed at different angles

**Disk-like configuration**

![Graphs showing flux density vs. velocity for different angles](image)

- $\phi=0^\circ$, $\theta=0^\circ$
- $\phi=0^\circ$, $\theta=45^\circ$
- $\phi=45^\circ$, $\theta=0^\circ$
- $\phi=45^\circ$, $\theta=45^\circ$
A 1:1 binary, different radial gas distribution

Disk-like configuration

Radial distributions

\[ \rho \propto \text{const.} \]

\[ \rho \propto r \]

\[ \rho \propto r^{-1} \]

\[ \rho \propto r^{-2} \]
Different binary BH mass ratio

*Spherical* configuration

![Graph showing different binary BH mass ratios with spherical configuration.](image)
Different binary BH mass ratio

*Disk* configuration

![Graphs showing different binary BH mass ratios in Disk configuration](image)
A binary BH fit to the B&L Quasar

Even at 1:300 the line is too broad. May come from larger scales.

FWHM(r) = 10,000 km/s   FWHM(b) = 2,000 km/s

$$\frac{M(r)}{M(b)} = \left(\frac{\sigma(r)}{\sigma(b)}\right)^4 \Rightarrow \frac{M(r)}{M(b)} = 5^4 = 625$$

Highly unlikely given the similar luminosity.
Further developments with SDSS J1536+0441

Candidate Binary Black-Hole System

VLA image at 8.5 GHz, Wrobel & Laor (2009)

A 5 kpc binary quasar?
K-band image by HAWK-I at the ESO/VLT

Decarli et al. 2009, ATel 2061
Source B is 1/30 of source A \(\rightarrow\) Elliptical galaxy?

but K-mag/L(8.5GHz) as in the primary quasar.

Lauer & Boroson 2009 (arXiv:0906.0020)
A Double Peaked Emitter
+ source B does not emit component b
→ A 5 kpc binary quasar ruled out
+ No velocity shift
→ A 0.1 pc binary BH ruled out

The narrow cores varies.

What produces the double peaks?

What is the companion object?
Conclusions

A binary BH produces highly blended BLR lines, and generally an asymmetric profile (detectable?)

Well separated narrow components cannot be produced by a binary BH.

SDSS J1536+0441 not a binary, but remains a mystery.