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Astrometry of X-ray Binary GRS 1915+105

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Abstract. A velocity of 75±15 km s^{-1} has been measured by VLBA astrometry, for this black hole of 14 $M_{\odot}$. Such data for a larger sample may clarify the origin and evolution of microquasars.

1. Introduction

GRS 1915+105 is a famous X-ray binary with superluminal ejecta (Mirabel & Rodriguez 1994), and spectacular X-ray variability from an unstable accretion disk (Greiner, Morgan, & Remillard 1996) . For nearly a decade, its nature was obscured by A_v >25 at D$\sim$12 kpc. Finally, IR spectroscopy with the VLT (Greiner et al 2001) gave a mass of 14±4 $M_{\odot}$ for the primary, with companion of $\sim$1.2±0.2 $M_{\odot}$ in a 33.5 days orbit. VLBA imaging (Dhawan et al 2000), in addition to the ejecta during outbursts, revealed an AU-sized radio jet coupled to the accretion disk activity. The jet is located within 1AU (0.1 mas) of the black hole.

2. Observations and Results

Observations spanned $\sim$7 years at intervals set by the flare activity. Standard VLBA phase-referencing was used, with cycle time 3 min, and 1 min on the ICRF reference source, J1924+1540. A second reference J1922+0840 served as quality check. Wavelengths of 3.6 and 2 cm were alternated every 20min, at 256Mb/s recording. Position *rms* is $\sim$1 mas at each epoch, dominated by tropospheric variations. Positions at the two wavelengths on a given observation date agreed, and were averaged together for that date.

As seen in Fig. 1, the black hole velocity lies primarily in the Galactic plane. Using our measured proper motion and the known V_{radial}, we remove the expected Galactic rotation at 12 kpc, and find a peculiar motion of the BH of 75±15 km/s, equivalent to the energy (momentum) of a pulsar moving at 240 km/s (750 km/s). A Galactocentric orbit, computed assuming a smooth potential, gives a maximum height above the disk of 230 pc, eccentricity 0.29, and mean velocity 79 km/s.

3. Discussion

The formation of black holes of 14 $M_\odot$ challenges stellar evolution theory. Belczynski & Bulik (2002) conclude that standard models can work only if: (a) Wind mass loss for very massive stars is half that commonly assumed; and (b) Black holes $\geq$10 $M_\odot$ form by direct collapse, without SN explosion, hence without any birth kick. Less massive black holes form through partial fallback, with nearly symmetric SN and little or no kick. Neutron stars form in asymmetric SN, and receive substantial birth kicks, seen in the measured velocities of young pulsars, (Arzoumanian et al 2002). We estimate (using eq. 1 of Nelemans et al 1999) that mass unbound from the binary in a symmetric SN explosion imparted at most 23-44 km/s, for allowable mass ratios. For the most likely D$\sim$12 kpc, an *additional* kick of 30-50 km/s from an asymmetric SN is required to explain the measured velocity.

Alternatively, the parent molecular cloud, and $\sim$15 subsequent spiral arm passages, (Weilen 1977), could impart as much as 40 km/s, assuming the binary is as old the donor, a red giant of 1.2 $M_\odot$ aged $\sim$4 Gyr. This explanation for the velocity requires no birth kick. It is consistent with the low velocity out of the plane, and with the velocity dispersion of old disk stars, observed by Hipparcos to be 40 km/s (Dehnen & Binney 1998).

Interestingly, of the BH binaries with accurate astrometry, one has low velocity, two others do not: Cyg X-1 is 10.1 $M_\odot$ with v= 9 km/s away from its birthplace, the Cyg OB association (Mirabel & Rodrigues 2003). GRO 1655-40 is a runaway binary (Mirabel et al 2002) of 5.4 $M_\odot$ with v= 120 km/s. XTE 1118+48 is 7 $M_\odot$ with v= 145 km/s - either it is on a halo orbit, or it received an extreme kick out of the plane (Mirabel et al 2001).

4. Conclusions

a. The most massive known stellar black hole moves at (45-75)$\pm$15km/s with respect to its regional standard of rest, for the range of distances 6-12 kpc.
b. At the most likely distance of 12 kpc, the velocity may exceed that allowable by stellar evolution models for the formation of massive black holes.
c. Alternatively, GRS 1915 is 3-5 Gyr old and acquired its peculiar velocity by dynamic diffusion, as do old disk stars. An asymmetric supernova is not required.
d. VLBA astrometry can help determine space velocities, and clarify the origin and evolution of microquasars - e.g. Is their velocity distribution similar to that of (accretion spun-up) millisecond pulsars? Do they get a birth kick as do young pulsars? Are they disk, bulge or halo objects?

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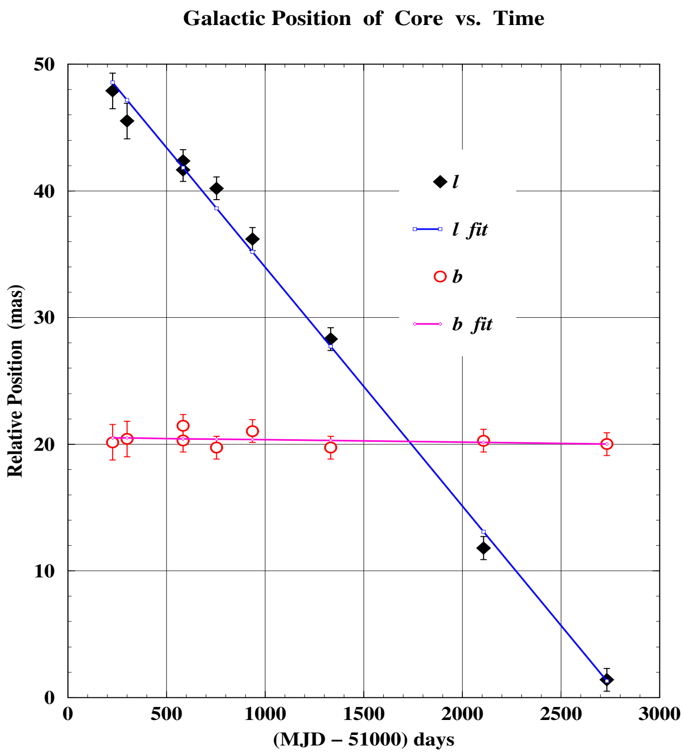

Figure 1. Proper motion of the black hole in b=–0.08±0.2 mas/yr, and l=–6.8±0.2 mas/yr.

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