A hypervelocity star from the LMC

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Introduction

We study the acceleration of the star HE0437-5439 to hypervelovity and discuss its possibile origin in the Large Magellanic Cloud (LMC). The star has a radial velocity of 723 km/s and is located at a distance of 61 kpc from the Sun [R1]. With a mass of 8 solar masses, the travel time from the Galactic centre is of about 100 Myr, much longer than its main-sequence lifetime. Given the small distance (18 kpc) to the LMC, it that the star originated in the cloud rather than in the Galactic centre. The minimum ejection velocity required to travel from the LMC to its current location is 500 km/s. Such a high velocity can only be obtained in a dynamical encounter with a massive black hole [R2-R3]. We perform scattering experiments in which a stellar binary encounters a massive black hole and constrain the minimum black hole mass required to produce the observed space velocity.

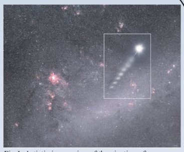

Fig 1. Artistic impression of the ejection of a hypervelocity star from the LMC.

Method

We perform numerical simulations of three-body scatterings with a massive black hole. We consider interactions in which a binary containing a 8 solar masses main-sequence star (representing HE0437-5439) encounters a single black hole of 10^2-10^4 solar masses. The simulations are carried out using the SIGMA3 package, which is part of the Starlab software environment. For each simulation we select the masses of the three stars, the semi-major axis of the binary and the relative velocity at infinity. All other parameters are randomly sampled from known distributions. The black hole is assumed to be a point mass while the stars are assigned zero-age main sequence radii.

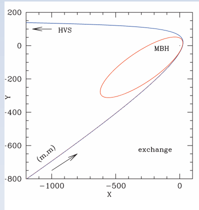

Fig 2. Example of a three body encounter involving a stellar binary and a massive black hole. In the encounter of the binary components is ejected with large velocity while the companion star remains bound to the black hole in a wide and eccentric orbit (exchange) [R4].

Results: ejection probability

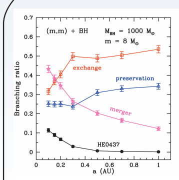

Fig 3. Branching ratios for encounters between an equal mass (8 solar masses) binary and a black hole of 1000 solar masses.

Fig.3 shows the probability of different outcomes (branching ratios) in encounters between an equal mass binary (m_1=m_2=8 solar masses) and a 10^3 solar masses black hole. The encounters are classified as preservation, exchange or merger. In an exchange one of the stars is captured by the black hole while the other is ejected, possibly with large velocity. If the velocity exceeds 500 km/s, we regard the star as a possible candidate for HE0437-5439. This occurs in about 10% or fewer of all encounters for semi-major axes in the range 0.1-1.0 AU [R4].

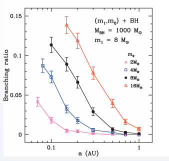

Fig 4. Fraction of exchange encounters between an unequal mass stellar binary and a black hole of 1000 solar masses.

Fig.4 shows the branching ratios for high velocity ejections in encounters involving a 10^3 solar masses black hole and unequal mass stellar binaries. The mass of one star is fixed to 8 solar masses while the mass of the companion varies in the range 2-16 solar masses. While the 8 solar mass main-sequence star is ejected, the companion is captured by the black hole. Exchange encounters with fast escapers are most likely in the case of binaries with larger companion masses and/or shorter orbital periods.

Results: velocity distribution

We compute velocity distributions for the escaping single star in the case of equal mass binaries and for different values of the black hole mass. While it appears possible to achieve the required ejection velocity for a 10^2 solar masses black hole, the smallest semi-major axis is needed for this to happen, and only in about 10% of all exchanges. We conclude that a black hole mass larger than about 10^3 solar masses is favored for typical values of a. In our systematic study of the effect of the initial semi-major axis of the interacting binary we adopt a homogeneous sampling in log a and we superpose the results of these experiments to obtain the total velocity distribution of the ejected star. Fig. 5 presents such a superposed velocity distribution for a binary consisting of 8 solar masses stars. The three histograms give the distribution for a black hole mass of 10^2 (black), 10^3 (blue),10^4 (red) solar masses.

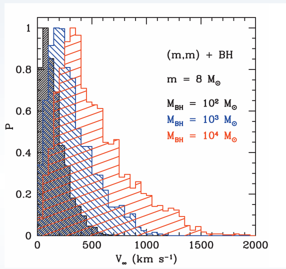

Fig 5. Velocity distribution for the ejected star after an interaction between an equal mass binary and a black hole of 10^2 (black), 10^3 (blue), 10^4 (red) solar masses. These velocity distributions are integrated over the entire range of orbital separations for the initial binary.

Results: parent cluster

The previous analysis suggests the intriguing idea that HE0437-5439 was ejected by an encounter with a > 1000 solar masses IMBH in the LMC. Such an IMBH would most likely be found in a young dense cluster containing stars coeval to HE0437-5439.

Name	M $M_\odot$	r_c pc	r_c/r_h	Age Myr	T_{rlx} Myr	T^0_{rlx} Myr	M_{bh} $M_\odot$
R136	35 000	0.32	0.29	3	7–17	6–14	1000
NGC 2004	27 000	1.57	0.50	20	71–170	41–98	1600
NGC 2100	30 200	1.22	0.62	16	51–120	31–73	2200

Table 1. List of young (< 35Myr) LMC clusters with an initial relaxation time smaller than 100Myr.

The star clusters catalogue by Mackey & Gilmore 2003 [R5] lists the structural parameters for 53 LMC clusters. Nine of these clusters are younger than 35 Myr. Out of these nine clusters, three are both young and with sufficiently large densities to have produced an IMBH (see Table 1).
The first cluster, R136, appears too young to have produced an IMBH and have experienced a gravitational encounter with a binary. The best candidate clusters to host an IMBH are therefore NGC 2004 and NGC 2100. We estimate the mass of a possible black hole by adopting the relation between the cluster structural parameters and the mass of a central black hole by Heggie et al. (2006) [R6]. We find that, given the structure of these clusters, a 1600-2200 solar masses IMBH could be present.

Results: ejection rate

We now compute the rate of ejection of hypervelocity stars from these clusters using the parameters in Table 1 and the cross-section for exchange encounters derived from the scattering experiments. Assuming a central density of 2×10^4 pc^{-3}, a W_0=9 initial King profile and a semi-major axis of 2 AU, we find a rate of one per 20 Myr. Since we do not take into account the effects of a mass function in the core and a semi-major axis distribution, this value represents a lower limit to the rate. It is therefore conceivable that NGC 2004 or NGC 2100 has produced one hypervelocity escaper, in which case an IMBH must be present.

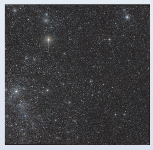

Fig 6. The open cluster NGC 2004 in the LMC (Astrosurf - Antille (Chile)).

Fig 7. The open cluster NGC 2100 in the LMC (ESO PR 2006).

Conclusions

* We study the acceleration of HE0437-5439 to hypervelocities as a result of a gravitational encounter with a massive black hole in the LMC.

* We find that an IMBH with mass > 1000 solar masses is necessary to accelerate the star to a velocity of 500 km/s.

* We look for possible parent clusters for HE0437-5439 and find that NGC 2004 and NGC 2100 are young enough to host stars coeval to HE037-5439 and dense enough to produce an IMBH able to eject a massive star with hypervelocity.

References

[R1] Edelmann, Napiwotski, Heber, Christlieb, Reimers, 2005, ApJ, 634, L181.

[R2] Hills, 1988, Nat, 331, 687.

[R3] Yu & Tremaine, 2003, ApJ, 599, 1129.

[R4] Gualandris & Portegies Zwart, 2007, MNRAS, 376, L29.

[R5] Mackey & Gilmore, 2003, MNRAS, 338, 85.

[R6] Heggie et al. 2006, astro-ph/0611950.