Searching for Hyper velocity stars
Poster 10

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Summary

A natural consequence of the presence of a super-massive black hole in the centre of our galaxy is the existence of dynamically ejected stars, called Hyper-velocity stars. Up to now six young massive HVS are known that have Galactic rest-frame velocities exceeding the escape velocity of the Galaxy and are therefore unbound. To date no old-population HVS ejected from the Galactic Centre has been discovered except the subluminous O star US 708 (Hirsch et al., 2005). Therefore our search for new HVS is directed to both old subdwarf OB stars like US 708 and young blue main sequence stars like HE 0437−5439 (Edelmann et al., 2005). A survey for hot subdwarf as well as for B-type candidates has been initiated recently at the ESO NTT and the Calar Alto 3.5 m telescope .

Introduction

Kinematical studies in the central Arcsecond of the Galaxy have revealed beyond doubt that our galaxy hosts a central super-massive black hole (Schödel et al., 2002). Hills (1988) predicted that a binary system closely passing the super-massive black hole could be disrupted. While one star is captured by the tidal forces the other could be accelerated up to $4000\,km\,s^{-1}$ and then leave our galaxy.
While no such Hyper-velocity stars (HVS) were discovered firstly, stars with speeds up to $\sim 200\,km\,s^{-1}$ far away from the Galactic plane (e.g. Ramspeck et al., 2001), called *runaway stars* have been found.
No more than two years ago, Brown et al. (2005) discovered the first HVS SDSS J090745.0+024507 (also HVS 1) a faint (B = 19.8) B-type star travelling in ~110 kpc distance through the Galactic halo with a Galactic rest-frame velocity (GRV) of at least $+709\,km\,s^{-1}$. Shortly thereafter Hirsch et al. (2005) discovered the first low mass old population HVS US 708 (also HVS 2), an extremely helium rich subluminous O star (He-sdO) with a Galactic rest-frame velocity of at least $+751\,km\,s^{-1}$ at a distance of $\sim 19\,kpc$ in the halo.
The third HVS discovered is a main sequence B star, HE 0437−5439, found and classified by Edelmann et al. (2005) with a Galactic rest-frame velocity of at least $563\,km\,s^{-1}$.
A wealth of theoretical and observational effort was stimulated by these discoveries. The theoretical work makes progress in understanding the origin of the HVS, exploring the nature and environment of the Super-Massive Black Hole (SMBH) (e.g. Gualadris et al., 2005) and probing the Galaxy's dark matter halo (e.g. Gnedin et al., 2005). Meanwhile further observations led to the discovery of seven HVS total, but a larger sample will be a rich source for new progress in this field.
Remarkably up to now six out of the seven known HVS seem to be young and massive B stars but, with respect to the existing data, could also be Horizontal Branch stars; only US 708 the He-sdO is confirmingly assigned to old-population. But there should exist a much greater number of such old-population stars, still hidden in a much denser background of Galactic halo stars (Kollmeier et al., 2007).
Here we present our search for new HVS directed both to young blue main sequence stars like HE 0437−5439 (also HVS 3) and old subdwarf OB stars like US 708 (HVS 2).

HVS 2 a hot subdwarf star

The second HVS found, US 708 was discovered by our group and classified as hot subdwarf O star. Such stars are believed to be successors of subdwarf B stars, which form the Extreme Horizontal Branch (EHB) (Heber, 1986) and are core helium burning stars ($T_{eff} = 22\,kK - 40\,kK$) with a thin inert hydrogen envelope ($M_{env} \leq 0.02\,M_{\odot}$). As they cannot sustain hydrogen shell burning these stars will evolve directly into white dwarfs avoiding the Asymptotic Giant Branch (AGB). While most sdB stars form a rather homogenous class in terms of helium deficiency, a large diversity is found among sdO stars (Heber et al., 2005). Only a very small fraction of sdO stars is helium deficient while even a large fraction are He-sdOs,

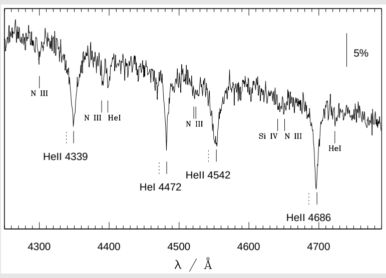

Figure 1: Spectrum of US 708 obtained with LRIS at the Keck I telescope (Hirsch et al., 2005). Shifted wavelenghts are marked with full lines while laboratory wavelenghts are marked with dotted lines.

in which the He II lines dominate the line spectrum.
Figure 1 shows a section of the spectrum of HVS 2, which served as verification observed at the Keck I telescope with LRIS (Low Resolution Imaging Spectrometer). Note the high redshift of the spectral lines. From this measurement the resulting heliocentric radial velocity is $708 \pm 15\,km\,s^{-1}$.
While the He-sdO stars cluster near $T_{eff} = 45000\,K$, the sdOs and sdBs (short: sdOBs) are spaciously spread. Also about half of the sdOB's were found in short period binaries (Maxted et al., 2001; Napiwotzki et al., 2004), but until now only one system including a He-sdO was discovered (fraction of 5 %). This implies that sdOBs and He-sdOs belong to different populations (Heber et al., 2005). As for the formation of sdB stars binary evolution obviously plays an important role, the same may hold for the sdO stars. Han et al. (2003) provided a population synthesis study, which is in good agreement with the observed parameter range, but fails to reproduce the spreading of the parameter region in detail. Three formation channels have been proposed: stable Roche lobe overflow, common envelope evolution and a merger of two helium white dwarfs which could explain the single sdBs. The mostly single He-sdO stars may have developed from such mergers as well.
An excellent starting point to search for HVS is the work of Hirsch (in prep.), who performs a search for sdO stars in the enormous data base of the Sloan Digital Sky Survey (SDSS). Through the procedure of classification a number of sdOB HVS candidates can be sieved. Figure 2 shows the Galactic rest-frame velocity distribution of the (He-)sdO stars and some of the sdOBs.

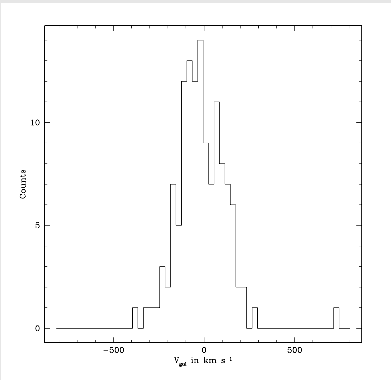

Figure 2: Galactic rest-frame velocity distribution of the sdOBs in DR5 (Hirsch, in prep.) with a binning of $20\,km\,s^{-1}$ including HVS 2.

The bin size of $20\,km\,s^{-1}$ is in accord with the accuracy of the SDSS data. From this distribution it is obvious that we expect to find more candidates by increasing the size of the sample. Another interesting point based on Figure 2 is that one could not only expect to find highly redshifted HVS but also highly blueshifted ones.

HE 0437 - A young massive HVS

Unlike HVS 2 the third HVS discovered is the young massive main sequence star HE 0437−5439, found and classified by Edelmann et al. (2005). Its atmospheric parameters have been determined to be $T_{eff} = 20354 \pm 116\,K$, $\log g = 3.77 \pm 0.02$ (cgs) and $\log(n_{He}/n_H) = -0.94 \pm 0.02$. Figure 3 shows HVS 3 in a $T_{eff}-\log g$-diagram.
From comparing its position to the evolutionary tracks they were able to estimate its mass to $8.4 \pm 0.5\,M_{\odot}$ for solar metallicity and a slightly lower mass of $8.0 \pm 0.5\,M_{\odot}$ resulting for a LMC metallicity.
The evolutionary lifetime of HVS 3 is short for the star to originate from our Galactic Centre (GC). However, Edelmann et al. (2005) showed that it could have been ejected from the Large Magellanic Cloud. Calculating trajectories for HVS 3 from the centre of the LMC they derived $\sim 2\,mas\,yr^{-1}$ for its proper motion.
If this theory holds, we would expect to find more HVS like HE 0437−5439.

HVS of late B-type

Except from US 708 and HE 0437 all other HVS, recently found in survey performed by Brown et al. (2006), are of late B spectral type. The velocity distribution they found was clearly Gaussian, like ours in Figure 2, but slightly shifted in positive direction and therefore asymmetric. So they proposed to speak of a bound population with rest-frame velocities between 300 and $450\,km\,s^{-1}$ (Brown et al., 2007). Although such a broad spectrum of HVS based on its formation mechanism has been predicted (f.e. Yu & Tremaine, 2003; Gualadris et al., 2005) a high ejection rate can only be achieved by additional encounters with e.g. an Intermediate Massive Black Hole (IMBH) or massive star clusters (Perets et al., 2006). Remarkably until now we do not know any blueshifted HVS with velocities $\sim 400\,km\,s^{-1}$. Although from the Three-body

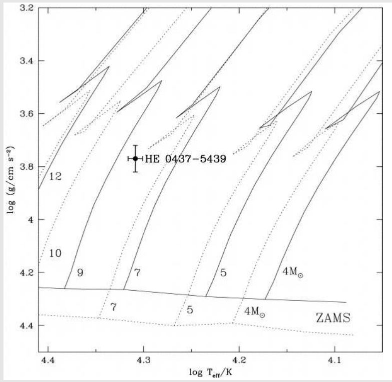

Figure 3: Position of HVS 3 in a $T_{eff}-\log g$-diagram with evolutionary tracks for solar (Schaller et al., 1992; *solid lines*) and LMC metallicity (Schaerer et al., 1993; *dotted lines*).

scatter scenario there should also exist HVS with such high velocities, which are still bound and forced to fall back to the galactic plane.

Kinematics

For a discovered star with high radial velocity it is absolute essential to estimate its Galactic rest-frame velocity. In order to make a accurate estimation we need at least two medium resolution spectra to rule out radial velocity variablility, hence an indication for binarity. In the first step we calculate the spectroscopic distance of the star. This is done by determining the atmospheric parameters as exact as possible using the *FITPROF* procedure by Napiwotzki et al. (1999). With this input, together with the observed luminosity and the estimated stellar mass (e.g. by evolutionary tracks) the absolute luminosity can be calculated leading to an approximate spectroscopic distance relative to the observer. Combining this distance with the coordinates and, if available, a proper motion of the star, we determine Galactic coordinates and finally the demanded Galactic rest-frame velocity.
By calculating the trajectories from the GC we derive information about the formation region of the discovered stars as well as information about the SMBH in the GC and the mass distribution in the Galaxy.
This procedure led to the discovery that HVS 3 is too young to be originated in the GC. Therefore trajectories from the centre of the LMC were calculated and resulted a proper motion of $\sim 2\,mas\,yr^{-1}$, easily verifiable e.g. with the ESO GAIA satellite, which is a very promising astrometry project.
But so far these estimations are rather crude but as the interest in HVS is still growing we expect to see fast progress in this field.

The search project

The discovery and analysis of HVS is an important aim in modern stellar astronomy. Our search is not only tageted on young B-type stars but also on the old population subdwarfs as there may be a remarkable number of them still hidden. With two medium resolution spectra we would be able to give an estimation of the GRV as well as to calculate possible trajectories from the star's place of birth. Our first observing run was scheduled for February 2007 at the Calar Alto 3.5 m telescope and was clouded out completely. Observations at the ESO NTT have recently finished and are currently analysed. In addition we applied to continue our search for HVS at the Calar Alto observatory.

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