OB stars in the Leading Arm of the Magellanic Stream

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Abstract. We present our spectroscopic program aimed to study some new interesting features recently discovered in the Magellanic Cloud System. These were revealed by the spatial distribution of OB-type candidate stars, selected based on UV, optical and IR photometry and proper motions from existing large-area catalogs. As a pilot study of our project, we are studying OB-star candidates in the Leading Arm (LA) of the Magellanic Stream, a gaseous tidal structure with no stellar counterpart known so far. Our targets group in three clumps near regions of high HI density in the LA. If confirmed, these young stars would evidence recent star formation in the LA, and they would help better understand and constrain the formation of the LA and its interactions with the Milky Way.

1. OB stars in the Magellanic Cloud System

The Magellanic Cloud System comprises a complex ensemble of gaseous tidal structures originating from the Magellanic Clouds, such as the extended Magellanic Stream (MS), encompassing ~200 degrees across the sky (Nidever et al. 2010), the Bridge, and the Leading Arm (LA). The presence of these structures reveals the complex gravitational interplay between the Clouds and the Milky Way, but their formation is still largely unclear.

In a recent study, Casetti-Dinescu et al. (2012) listed 567 OB star candidates in a wide area including the periphery of the Clouds, the Bridge, the LA, and part of the MS. These stars were selected from cuts in magnitude, colors, and proper motions, after merging the UV photometry from the Galaxy Evolution Explorer survey (GALEX, Bianchi et al. 2011), the IR data of the Two Micron All Sky Survey (2MASS, Skrutskie et al. 2006), the optical photometry of the American Association of Variable Star Observers All Sky Photometric Survey (APASS, Henden et al. 2011), and...
proper motions and photometry from the Southern Proper Motion Program 4 (SPM4, Girard et al. [2011]). The spatial distribution of these candidates revealed various interesting features, namely: 1) a well-populated wing of the Small Magellanic Cloud (SMC), continuing westward with two branches; 2) a narrow path from the SMC wing toward the Large Magellanic Cloud (LMC), offset from the ridge in the Bridge; 3) a well-populated periphery of the LMC; 4) a few scattered candidates in the MS and some overdensities in the LA.

Figure 1. The spatial distribution in Magellanic coordinates of our OB candidates (black circles). Filled black circles show the stars observed spectroscopically, filled green circles show those candidates with velocities larger than 150 km s$^{-1}$. The HI distribution for LSR velocities between 150 and 400 km s$^{-1}$ from the GASS survey (Kalberla et al. 2010) is also shown. The dashed line represents the Galactic plane.

We have recently started an extensive spectroscopic investigation, to study in detail the structures outlined by Casetti-Dinescu et al. (2012). The first aim of our project is the collection of intermediate-resolution spectra to derive the radial velocity (RV) and the stellar parameters of the OB candidates, to confirm their membership to the Magellanic System and study their kinematics. Follow-up high-resolution studies, aimed at a detailed chemical analysis, are planned for confirmed members of the Magellanic System.

The magnitude and color selections of Casetti-Dinescu et al. (2012) provided type O and B candidates; the proper-motion selection provided likely distant candidates. Thus, the aim was to search for hot, young main sequence (MS) stars that are too
distant to be Galactic stars. Nevertheless, intrinsically fainter foreground white dwarfs (WDs) and subdwarf B- and O-type stars (sdB’s) can contaminate the sample. RVs can help identify the Magellanic System members because, as indicated by the kinematics of the related gas (Figure 3 of Venzmer et al. 2012), high values in excess to 150 km s$^{-1}$ are expected. Halo stars may have such high RVs, however, these stars are expected to be early A type, or blue horizontal branch stars, thus redder than our color selections. Since, via proper motions, we eliminate nearby stars (i.e., WDs), we believe our major source of contamination is from subdwarf O and B stars.

The great majority of hot MS stars are found in binaries (Sana et al. 2012), with preference to equal-mass close systems. Close binaries are extremely common even among sdB’s (Maxted et al. 2001), although they could be less frequent among older halo objects (Moni Bidin et al. 2008). Hence, RVs are not conclusive to assess the membership of the targets to the Magellanic System. The measurement of temperature and gravity can easily identify WDs but, as shown by Salgado et al. (2013), these parameters cannot distinguish MS stars from sdB’s in the interval $T \approx 13 \, 000$–$17 \, 000$ K. However, as discussed by the same authors, other indicators may be used. For example, the surface helium abundance can be very indicative, because the atmosphere of sdB’s in this temperature range is depleted of helium by more almost a factor of 100 (O’Toole 2008, Moni Bidin et al. 2012) due to gravitational settling (Greenstein 1967; Baschek 1975). The rotational velocity is also indicative, because fast rotators are common among early-type MS stars, but not among sdB’s (Geier & Heber 2012). However, given the large difference in distance between the genuine members and the foreground contaminants, the spectroscopic mass is probably the most efficient discriminant among them (see, e.g., Moehler et al. 2000, for a successful analysis based on this criteria).

As a pilot study of our extensive program, we have recently started the analysis of the overdensities of OB star candidates found by Casetti-Dinescu et al. (2012) in the direction of the LA. In Figure 1, we show the spatial distribution of our OB candidates in the LA region. The HI distribution for velocities between 150 and 400 km s$^{-1}$ is also shown, from the GASS survey (Kalberla et al. 2010).
2. Star formation in the Leading Arm

The LA is a complex gaseous feature preceding the LMC in its orbit, whose origin is likely tidal, but its morphology cannot be explained by purely tidal models (Diaz & Bekki 2011). It comprises four sub-structures (Venzmer et al. 2012), with no known stellar counterpart. It has been suggested that the LA is hydrodynamically interacting with both the gaseous Galactic disk (McClure-Griffiths et al. 2008) and the hot halo (Diaz & Bekki 2011). The discovery of OB stars in the LA would demonstrate that recent star formation occurred possibly as a consequence of these interactions, opening a new insight into the complex dynamical environment of the Magellanic System.

The spectra of forty-two OB star candidates from the Casetti-Dinescu et al. (2012) sample in three LA overdensities above and below the Galactic plane, were collected. This was done during two observing nights with the IMACS spectrograph at the 6.5m Baade telescope at Las Campanas Observatory. The 1200 l/mm grating at the f/4 camera was employed at first order, with a blaze angle of 17° and a 0.75″-wide slit, for a resulting resolution of 1.3 Å (R≈3500) in the range 3650–5230 Å. The average seeing during observations was 0.7”, and the resulting spectral signal-to-noise ratio was higher than 50 for all the stars. The spectra were reduced and extracted with standard IRAF\footnote{IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.} routines.

Classical cross-correlation techniques (Tonry & Davis 1979), as implemented in the IRAF fxcor task, were employed to measure RVs. In absence of a prior knowledge of the exact temperature and gravity of the targets, the synthetic spectrum of a MS B-type star drawn from the library of Munari et al. (2005) was adopted as template. However, a mismatch between the parameters of the template and object spectra enhance the uncertainties but does not affect the results, especially for hot stars (Morse et al. 1991; Moni Bidin et al. 2011). The RVs of three standard stars from Chubak et al. (2012) and two spectrophotometric standard hot stars from Hamuy et al. (1994) were inspected to estimate and correct a zero-point offset of ≈5 km s⁻¹ in both nights. The final error, taking into account the relevant sources of uncertainties (wavelength calibration, cross-
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correlation, and zero-point correction) resulted between 3 and 14 km s$^{-1}$, depending on
the star, but close to $\approx$5 km s$^{-1}$ for most of the targets.

The RV distribution of the observed targets is shown in Figure 2. These preliminary
results evidence that the sample is highly contaminated by foreground Galactic
stars, because most of the stars have RV< 140 km s$^{-1}$, incompatible with the motion of the LA (Venzmer et al. 2012). Nevertheless, eight stars are found at RV> 140 km s$^{-1}$. However, as discussed in Section 2, RVs alone are not sufficient to establish LA membership. The spectra are currently being fitted with the routines developed by Bergeron et al. (1992) and Saffer et al. (1994), as modified by Napiwotzki et al. (1999), to derive the stellar parameters (temperature, gravity, and surface helium abundance) of the targets. In Figure 3 we show the spectrum of a very promising star, whose RV ($\sim$170 km s$^{-1}$) excellently agrees with the expectation for a LA member, and whose broad helium lines visible in the Figure point to a fast rotating MS star.

Acknowledgments. This investigation is based on data gathered with the 6.5-meter Baade telescope, located at Las Campanas Observatory, Chile (program ID: CN2013A-152).

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