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Proper motions and brown dwarfs with the VVV survey

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Abstract. The Vista Variables in the Vía Láctea survey (VVV) is a near-IR ESO public survey devoted to study the Galactic bulge and southern inner disk covering 560 deg^2 on the sky. This multi-epoch and multi-wavelength survey has helped to discover the first brown dwarfs towards the Galactic center, one of the most crowded areas in the sky, and several low mass companions to known nearby stars. The multi-epoch information has allowed us to calculate precise parallaxes, and put some constraints on the long-term variability of these objects. We expect to discover over a hundred more brown dwarfs.
The VVV survey makes a great synergy with the Gaia mission, as both will observe for a few years the same fields at different wavelengths, and as VVV is more sensitive to very red objects such as brown dwarfs, VVV might provide unique candidates to follow up eventual astrometric microlensing events thank to the exquisite astrometric precision of the Gaia mission.

Key words. Stars: brown dwarfs— methods: observational, techniques: imaging, spectroscopy, surveys, proper motions

1. Introduction

Brown dwarfs (BD) are sub-stellar objects with very low surface temperatures (300<T<2200K, age dependent) that are unable to sustain hydrogen fusion in their interiors. Low temperatures allow molecules to play an important role in shaping the atmosphere spectrum of these objects, making colors at different wavelengths very distinctive. Most of previous successful searches in the field were based on optical to mid IR color selections applied to large area surveys revealing over two thousands of these objects (e.g. Kirkpatrick et al. 2011). An alternative is lo search young young BD in stellar associations, such as the DANCe project (Bouy et al. 2013, 2014, this volume) As BDs are very cold and hence faint, most of the currently discovered BDs are located relatively nearby. An alternative and widespread way to discover these faint objects is searching for high proper motion sources. Up to date several groups have worked in this with successful results (Phan-Bao et al. 2008; Artigau et al. 2010; Lucas et al. 2010; Luhman 2013; Luhman 2014c; Smith et al. 2014) and the most recently catalogs of high proper motion objects based on WISE multiepoch data (Luhman 2014a; Luhman & Sheppard 2014; Kirkpatrick et al. 2014). These efforts have unveiled the third and forth closest systems and the coldest brown dwarf discovered to date, in addition to several other interesting ultra cool dwarfs.

The Vista Variables in the Vía Láctea survey (VVV) is a near-IR multiepoch ESO public survey covering 560 sq. degrees on the sky towards the Galactic bulge and southern disk. (Minniti et al. 2010; Hempel et al. 2014) Although the main goal is to search for variable stars and study the 3-D structure of the Milky Way, it suits the requirements to measure proper motions and particularly the high spatial resolution allow us to spot and characterize new high proper motion sources. Here we describe the methods, first results and perspectives of VVV survey search for high proper motions sources and brown dwarfs and the connection with the observations carried out with the Gaia mission.

2. VVV observations

The VVV survey is being carried out with VIRCAM at the VISTA telescope (Emerson et al. 2006; Dalton et al. 2006) at cerro Paranal observatory. This instrument is made up of 16 detectors of 2048x2048 pixels, with a resolution of 0.34″/pix. Each pointing, covering 0.6 deg^2, is called a ‘pawprint’, and six overlapping pawprints are used to build one final image (Tile) covering twice an area of 1.5 deg^2. The image reduction, astrometric and photometric calibration and source catalog production are done by the Cambridge Astronomy Survey Unit[1] (CASU; Irwin et al. 2004) The total sky area observed by VVV survey is 560 deg^2, and can be seen in Figure 1. The observations started at the end of 2009 and will finish after 2016. The whole area has been observed in the $ZY\ JHK_S$ bands and multiepoch observation in the K_S band have been obtained for every field with different cadence along the time. By the end of the survey the bulge area should be observed around 100 times and the disk region slightly less times. These observations are well suited to calculate proper motion and derive parallaxes for nearby sources. We expect to calculate parallaxes for T0 type BDs up to 25-30 pc, for brighter sources such as early L or late M dwarfs we expect to reach twice as far in the less crowded fields.

3. Methods and current results

We started two searches of high proper motion sources (HPMs). The first one was based on visual inspection of false color images using different K_S epochs to: look for bright (probably saturated)[2] sources that might been hidden before due to chance alignment in previous searches. We also search around previously known HPM stars to look for co-moving companions. We first found a new ’unusually blue’ brown dwarf at 17.5 ± 1.1 pc based on trigonometric parallax (Beamín et al. 2013). We also found 7 new companions to HPM stars and obtain their spectral types. These new findings around HPM stars mean a 4% incompleteness in the census of HPM sources (Ivanov et al. 2013).

The second search was done using the catalogs alone. We cross matched four VVV K_S epochs as evenly spaced in time as possible, then search for any object with motion larger than 0.07″/yr, we used four epochs to clean some spurious detections. We restricted our search to objects brighter than K_S=13.5 (more details in Gromadzki et al. 2013). Around 1500 HPM sources have been found and a final catalog describing these sources is being prepared (Kurtev et al. in prep.)

Also VVV data allow us to keep track of the long term photometric variability and the possibility to detect BD companions and planets around M dwarfs and BD, this is a path we

[1] `http://casu.ast.cam.ac.uk/surveys-projects/vista`

[2] If the source is saturated the object might not be detected or might produce multiple detections or the accuracy of the centroid is compromised

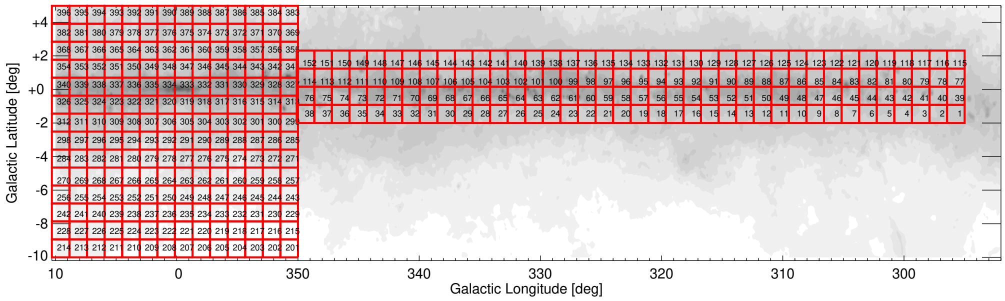

Fig. 1. VVV Survey area and tile numbering. The tile names start with "b" for bulge and "d" for disk tiles, followed by the numbering as shown in the figure. (Credit: Saito et al. (2012) A&A 537, A107, reproduced with permission ©ESO.)

are now also exploring (Rojas-Ayala et al. submitted)

The final precision of the parallax measurements obtained with VVV data after the six years of observations, will be in the mili(sub-mili) arcsec regime, comparable to the results of other ground based astrometric measurements (Faherty et al. 2012; Marocco et al. 2013; Manjavacas et al. 2013; Smart et al. 2013, among others).

4. VVV and Gaia synergy

The VVV deeper near IR images and the new HPM objects found towards very crowded regions provide an excellent opportunity to find targets for astrometric microlensing that could be followed up with Gaia. In some cases the superb astrometric precision of the Gaia mission will provide accurate independent estimates of the masses and probe the existence of companions, planets or moons around these new objects and/or also presence of discs (Dominik & Sahu 2000; Di Stefano et al. 2013; Sahu et al. 2014). The VVV also provide a unique complement to Gaia in the most crowded regions of the sky, as the number of sources that Gaia mission can analyze in those regions is limited by crowding. Gaia will reach ~18-19 mag (Gaia optical magnitudes) near the galactic disk and bulge, VVV has reached K_S 17-18.5 depending on the crowding level. Taking into account the intrinsic red colours of very low mass stars and BDs and VVV will observe deeper and would complete most of other searches for proper motions and BD carried out by now. there is also a huge synergy in other fields of astrophysics such as galactic structure and bulge studies where VVV can go deeper and through most of the dust that would not allow Gaia to prove inner regions of the Milky Way. Gaia will provide a deeper absolute astrometric reference frame with an exquisite precision for the proper motions studies carried out with the VVV observations.

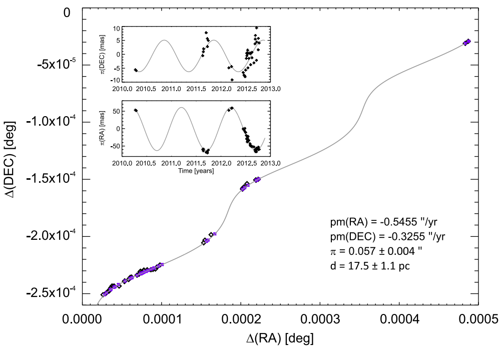

Fig. 2. Parallax of VVV BD001, the distance was measured based on relative astrometry with a precision of a few mas (π=0.057 ± 0.004 ″), as more data become available, increasing the time baseline and number of observations, the astrometric precision will improve to become close to 1 mas. Explained in Beamín et al. (2013)

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