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THE SEARCH FOR NEW MILKY WAY DWARF GALAXIES IN THE PAN-STARRS 1 PANOPTIC SURVEY

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Abstract. We present the latest results of the on-going search for faint dwarf galaxies in the surroundings of the Milky Way within Pan-STARRS 1 data. Covering three quarters of the sky the on-going Pan-STARRS 1 survey is a photometric survey in optical and near-infrared bands. Applying a convolution method to identify overdensities, followed by a preliminary analysis of the object detection significance led to no obvious dwarf galaxy candidates in regions of the sky not previously surveyed by the Sloan Digital Sky Survey. This result questions the isotropy of the Milky Way dwarf galaxy satellite system.

Keywords: Dwarf Galaxies, Pan-STARRS

1 Introduction

Over the course of the last forty years, Local Group dwarf galaxies (DGs) have been a source of increasing interest for a variety of reasons. Such galaxies are the faintest and smallest galaxies known, with large mass to light ratios. They are probes of both the dark matter (DM) on the galactic scale, and of the faint end of galaxy formation. The first eight Milky Way (MW) DGs were found through visual inspection of photographic plates, making up the MW 'Classical' DGs. Aside from the serendipitous discovery of Sagittarius through spectroscopy (Ibata et al. 1994), a veritable explosion of DG discoveries was made with the advent of deep photometry from the Sloan Digital Sky Survey (SDSS) bringing the total census of MW DGs to 25 (see Walker 2013 for a review).

Milky Way dwarf galaxies, as well as those orbiting M31 have been of increasing interest given their apparent tension with two tenets of galaxy formation in a ΛCDM universe. The number of DGs that we observe is at least an order of magnitude lower than the number of DM haloes predicted from simulations. Why is only a fraction of the DM haloes populated? The so-called Missing Satellite Problem (Klypin et al. 1999; Moore et al. 1999) can be solved by several mechanisms linked to galaxy formation physics (re-ionisation, supernova feedback,... e.g. Macciò et al. 2010). Secondly, observations as early as Lynden-Bell (1976) suggest the anisotropic orientation of DGs around the MW, another aspect not generally accepted by simulations. Indeed recently it was shown by Ibata et al. (2013) that ~ 50 % of M31's DGs lie in 'a vast thin plane'. Similar recent results re-emphasise this observation around the MW, in the form of the Vast Polar Structure of Satellite Galaxies (VPOS) (Pawlowski et al. 2012).

The Panoramic Survey Telescope And Rapid Response System 1 (Pan-STARRS 1 or PS1) has the major advantage of providing a homogeneous coverage of three quarters of the night sky. Even though its depth is similar to that of the SDSS, its spatial extent is at least double that of the SDSS data release used for DG searches, thereby opening up a sizeable new area to the search for faint MW companions. In particular, and contrary to the SDSS, PS1 covers a sizeable region outwith the plane of satellites, thereby allowing for a clear test of the validity of the VPOS. Here, we report on our on-going search for unknown DGs around the MW within the single-epoch data of the survey.

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2 The Pan-STARRS 1 Survey

Pan-STARRS 1 is a 3.5 year survey targeting three quarters of the total sky, northwards of $\delta = -30^o$, hence it is also known as the PS1 3π Survey. Using a 1.8 metre telescope in Haleakala, Hawaii, in combination with a 1.4 GPixel camera and field of view of 3.3 degrees, data is collected in five optical and near-infrared bands: g_{P1}, r_{P1}, i_{P1}, z_{P1} and y_{P1}. The sky is observed four times per year per filter over the course of the survey's duration. In these proceedings, only data produced from the individual images are used, yielding photometric depths that are ~ 1 magnitude shallower than the SDSS.

3 Dwarf Galaxy Detection Algorithm

To find DGs over large areas of sky, an automated detection algorithm is necessary, allowing for spatial overdensities of rightfully coloured stars, potentially corresponding to new DGs, to be extracted from the 2 billion stars of the survey. Such methods have successfully been applied in the past and identified new DGs in the SDSS (Koposov et al. 2008; Walsh et al. 2009). Therefore, a similar technique as described in the aforementioned Koposov et al. (2008) paper is applied in these proceedings, but modified and adapted to the intricacies of the PS1 data.

The spatial location of stars with appropriate colours and magnitudes is convolved with a composite kernel that include a peaked positive Gaussian of the expected size of a DG, and a negative contribution of a much wider Gaussian that subtracts the contribution of the contaminating sources in the surrounding field to the signal measure. Varying the size of the positive part of the kernel allows us to search for stellar overdensities of varying sizes.

Before conducting the convolution, the data are prepared in the following way: all magnitudes are de-redenned using the Schlegel et al. (1998) maps, in combination with the extinction coefficients for PS1 (Schlafly & Finkbeiner 2011), accounting for the presence of dust; likely extended objects are weeded out by requiring similar aperture and psf magnitudes for an object; and colour and magnitude cuts are applied. In detail, only stars bluer than $r - i = 0.8$ are considered as observable stars from a MW satellite at tens to a few hundred kiloparsecs and are unlikely to be redder than this limit. Furthermore, to avoid the presence of faint artifacts in the data, we cull the catalogue to only keep stars with r_0<21.5 and i_0<21.5.

Due to the nature of the single epoch PS1 data, this work also accounts for the lack of data in the form of holes present in the survey. These holes are mainly due to chip gaps and bad weather. To this end, for a given band, the sky is binned into 0.5x0.5 arcmin^2 pixels. For each pixel, the closest star that appears in two other bands is determined. If this star is also present in the band of interest, then that pixel is deemed to be complete, else not. The completeness mask thereby inferred is folded in the convolution calculation.

4 Detection Significance

The convolution algorithm is applied to the whole PS1 sky for a grid of centres separated by only 2 arcminutes. It yields a fine-scale image of the local stellar under- or overdensities in the shape of the chosen Gaussian. In order to determine the significance of a given pixel, we compare its value to the rms value of all neighbouring pixels within a box of four square degrees. We consider only detections of overdensities that are at least 4-sigma above the background and produce a list of candidates to investigate further. A Colour-Magnitude Diagram (CMD) of the identified candidate is compared to a neighbouring field region to check for the presence of CMD features expected for a DG (main sequence turn-off, red giant branch, horizontal branch,) Artifacts in the data catalogue available at the time of this search generate artificial detections that can easily be sieved out of the candidate list. Nevertheless, known faint dwarf galaxies discovered in the SDSS are recovered, as examplified in Figure 1 for Canes Venatici I (CVnI). The left panel shows the convolution map for the patch of the sky that includes CVnI, while the right panel shows the significance map of the same region. Figure 2 shows two CMDs containing the CMD for CVnI and a field region. All CMD objects are ones that satisfy the colour-box criterion discussed in section 3.

Applying the detection algorithm along with the significance analysis allows for the most booming and obvious SDSS satellites to rediscovered. Amongst those detected are Böotes I, CVnI and Ursa Major II. No new DG is

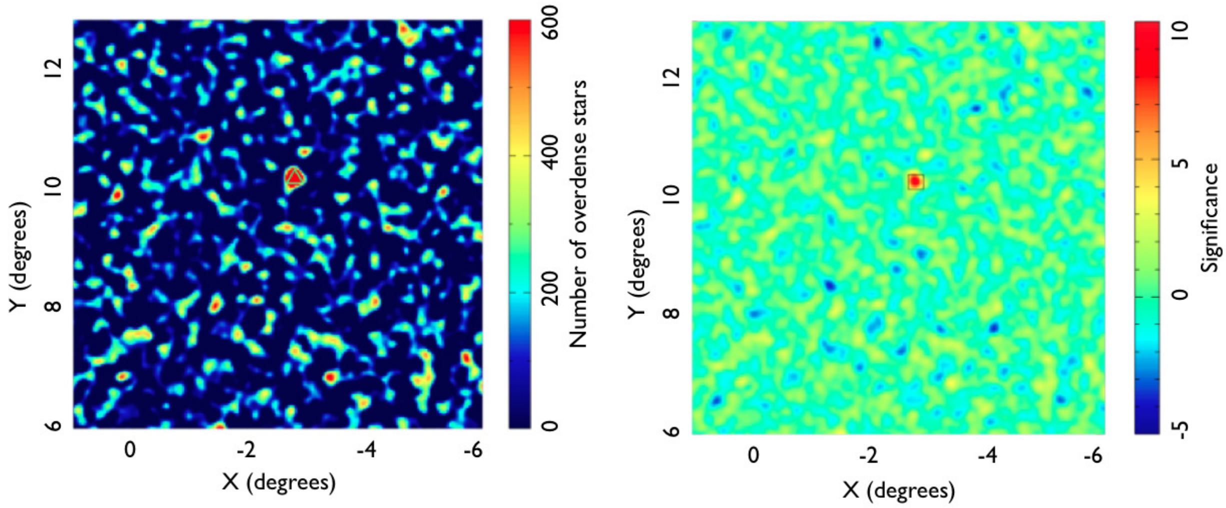

Fig. 1. Left: Differential Image Map representing the integrated counts under the kernel after convolving data with a kernel of positive/signal Gaussian width 4' and negative/background Gaussian width 20'. The green triangle shows the location of CVnI at $X = -2.8^o$ and $Y = 10.2^o$ **Right:** The corresponding significance map, highlighting CVnI as a detection with a signal-to-noise ratio above 10.

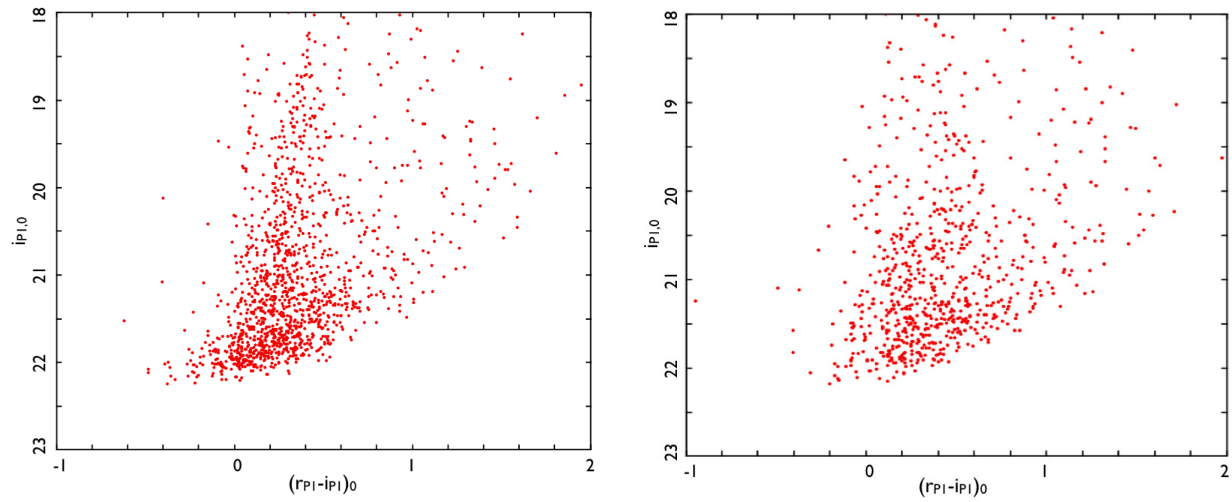

Fig. 2. Left: PS1 CMD of CVnI. The red giant branch stars of CVnI are clearly visible and produce the high-significance detection visible in Figure 1 **Right:** PS1 CMD of field region in the vicinity of CVnI.

confidently identified, even in the large regions that were not covered by the latest SDSS-based DG searches.

5 Results and Conclusion

We report on our on-going search for the presence of new MW DGs in the panoptic PS1 survey. Candidate detections are identified by convolving the stellar catalogue generated from the single epoch PS1 data, accounting for the spatial inhomogeneity of the survey's footprint. However, despite the detection of some of the faint DGs found in the SDSS, no obvious new DG candidate can be identified.

This preliminary result could partly stem from the use of the shallow single epoch PS1 data and we are currently conducting a more in-depth analysis based on the full depth catalogues, However, if it holds true , this result would certainly question the isotropy of MW satellites around their host.

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