Stellar Populations - Planning for the Next Decade
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The Dark Energy Survey: perspectives for resolved stellar population studies

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Abstract. The Dark Energy Survey (DES) will cover 5000 sq. deg. in grizY filters. Although its main goals are related to cosmology, it will yield photometric measurements of over 10^8 stars, most of them belonging to the Galaxy. DES will increase the sampling depth of very low-luminosity stellar and sub-stellar species, such as white, red, and brown dwarfs, by a factor of several as compared to SDSS. The structure of the Galactic halo, including its complex sub-structures caused by accretion remnants and globular cluster tidal tails, will also be probed and analyzed. DES will also allow comparison of star counts between Northern and Southern Galactic hemispheres to unprecedented detail. Finally, a significant sample of stars in the outskirts of the Large Magellanic Cloud (LMC) will be studied, providing new light into the debate about the existence of an LMC spheroidal component. These, among other important research goals attainable with the DES stellar data, are discussed in this contribution.

Keywords. Surveys, stars: statistics, Galaxy: stellar content, Galaxy: structure, Local Group.

1. Introduction

The Dark Energy Survey will cover 5000 sq. degrees on the sky, mostly in directions with Galactic latitudes $b < -30^o$. About 20% of the detected sources will be stars, the majority of them located in the thick disk and stellar halo of the Milky Way (MW).

Figure 1 shows an estimate of the MW star counts in the entire DES area. The coloured solid lines show the contribution of different Galactic components as a function of r magnitude. The black solid line shows the total number counts and the dashed line the cumulative values.

The r-band DES magnitude limit is $r \simeq 23.5$. From Figure 1, it is expected that $\simeq 10^8$ stars will be sampled. This large database, with colour information, covering both a wide angle and a large depth will significantly contribute to our understanding of the stellar populations and structure of the thick disk and stellar halo. Below, we detail the main research topics to be addressed.

2. Low luminosity stars in the thick disk and halo

The deep DES images will sample a large number of main sequence M stars, whose mass is slightly above or at the hydrogen burning limit, imposing stronger constraints than previous data on the very faint end of the thick disk and halo stellar luminosity functions. DES will also significantly increase the census of sub-stellar objects such as T and L brown dwarfs, as well as of white dwarfs close to or at the end of the cooling sequence.

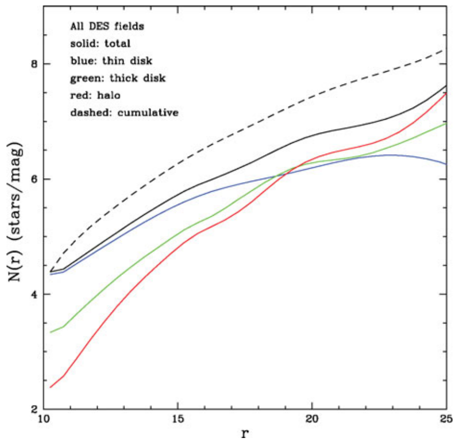

Figure 1. model star counts as a function of r magnitude for the entire DES solid angle. The coloured lines indicate contributions from the thin disk, thick disk and stellar halo, as indicated. The solid black line gives the total star counts. The dashed line gives the cumulative counts, $logN(< r)$. The Galactic model used is described in Santiago *et al.* (1996).

Table 1. Expected DES depths for different stellar samples.

Stellar type	**Abs. Mag.**	DES depth (kpc)
HB	$M_g = 0.9$	240
M0	$M_i = 8.4$	13.3
M9	$M_i = 15.5$	0.5
L5	$M_i = 18.4$	0.13
T0	$M_i = 20.6$	0.05
T4	$M_i = 22.7$	0.018
WD	$M_g = 13.0$	0.9
WD	$M_r = 16.3$	0.26

Table 1 lists the several interesting stellar types whose luminosity function is still relatively unconstrained at the faint end ($M_V > 13$), specially in the thick disk and halo components. The DES depth limits were calculated by taking into account the survey limits in each filter and the requirement that these stars are selected with criteria that combine both magnitudes and colours.

M dwarfs will be sampled well above the thin disk scale height, even in the case of late M stars. L and T brown dwarfs will still belong to the thin disk. But the depths for these stars are from 2 to 8 times larger than those quoted by Hawley *et al.* (2002) using the Sloan Digital Sky Survey (SDSS).

A population of faint white dwarfs (WDs) in the thick disk and halo will also be observed. Current estimates of the white dwarf luminosity function (WDLF) in the halo are still based on relatively small samples (Harris *et al.* 2006). Additionally, it will be possible to assess variations in the thin disk WDLF peak position, which reflects the end of the white dwarf cooling sequence and is an age indicator, as a function of height above the disk mid-plane at least for $z \leqslant 250$ pc.

3. The global structure of the outer stellar halo

Much of what we know about the halo structure is based on its globular cluster system or on field RR Lyrae. DES will not only increase the number of horizontal branch

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candidates in the halo (see first line in Table 1), but will allow detailed modelling of its structure by using more common stellar tracers, such as main sequence stars.

Recent work by Xu, Deng & Hu (2007) notes evidence for a significant asymmetry in halo stars counts. Unfortunately, the work relied on use photographic plate data in the south, and it was difficult to compare to the deeper, more precise SDSS data in the North. Precise constraints on the halo shape will be possible by combining DES and SDSS data. Any global asymmetry found in the structure of the halo can be used as input into Galactic formation models, and opens the door to quantitatively exploring triaxial dark matter halos as well as possible misalignment between a dark matter halo and the MW stellar disk.

4. Substructures in the halo and thick disk

Several substructures are expected to exist and have been found in the more extended Galactic components.

The Sagittarius tidal stream is the most prominent sub-structure known (see Figure 2). It is also prominent in the South and crosses through the DES survey area. Several other halo sub-structures are known, such as the "Orphan Stream" and the Virgo overdensity. New streams of stars have been detected in the Northern Galactic Cap data of the SDSS. Recently, Grillmair (2009) detected 3 nearby streams at distances of < 10 kpc from the sun.

DES will be able to do a similar survey of streams in the South to even fainter depth. The fundamental physics obtainable from modeling the orbits of these streams are constraints on the shape of the dark matter halo in which the tracer stream stars move. Work on streams in the north indicates that several streams at different inclinations are needed to probe the potential accurately.

In addition to the stellar streams, over one dozen new faint dwarf galaxies (or dissolving globular clusters) have been added to the halo census, beginning with Willman *et al.*

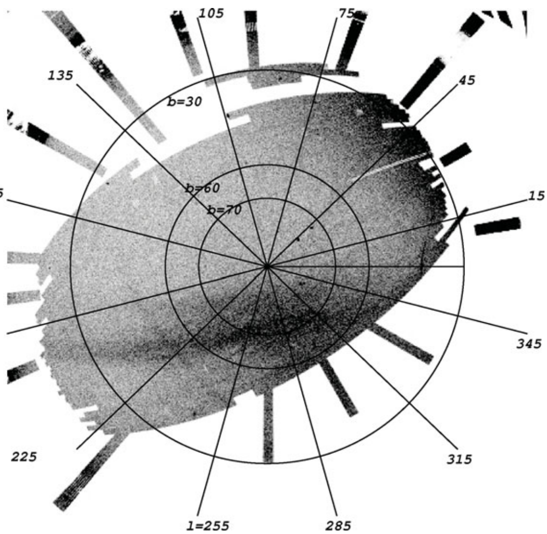

Figure 2. the density of F stars, selected using SDSS, in (l, b) polar coordinates. The stars were selected in $(g - r)_0$ color in the magnitude range $21 < g_0 < 22$. The dominant stream is Sagittarius and its bifurcation. The Orphan stream is also clearly seen, almost perpendicular to Sagittarius. Adapted from Yanny *et al.* (2009).

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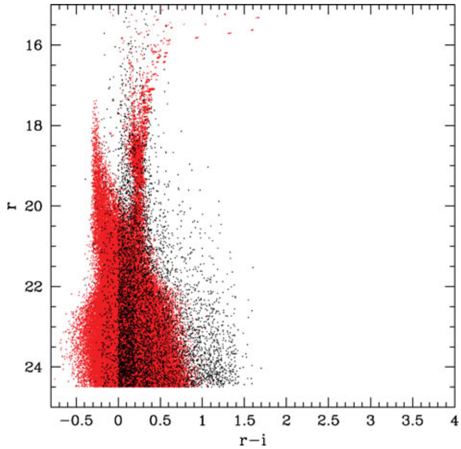

Figure 3. simulated $(r, r-i)$ CMD of a DES field located 7^o north of the LMC centre. The black dots are simulated stars belonging to the Galaxy, whereas the red dots are LMC stars.

(2005) and continuing through Belokurov *et al.* (2007) and Koposov *et al.* (2007). The techniques for finding new dwarfs and clusters are now well established, and can be applied in a straight-forward fashion to the DES imaging data in the South.

5. Tidal Tails from Globular Clusters

Apart from the remnants of accretion events of MW satellites, the stellar halo also displays stellar streams caused by the Galactic tidal field on globular clusters (GCs). As in the case of satellite remnants, globular cluster tidal tails have been previously identified and usually span many degrees across the sky, thereby requiring wide angle surveys to be adequately studied. The lengths and knottiness of these tails can yield detailed information on the past orbit of the clusters and on the potential of the Milky Way.

Several GCs located inside the DES limits have small or intermediate concentration parameters, similar to most globular clusters which so far have been found to display tidal streams such as Pal 5 (Koch *et al.* 2004), NGC 7492 (Lee *et al.* 2004) and NGC 5466 (Grillmair & Johnson 2006). They are therefore excellent candidates for tidal tail searches using the DES stellar sample.

6. Stellar populations in the outermost regions of the LMC

The DES limits will miss the LMC bar and main star formation regions. However, DES will sample regions 5 deg from the LMC centre. Thus, a significant number of LMC stars will be identified in DES colour-magnitude diagrams (CMDs), superposed onto the Galactic field. The observed CMDs of outer LMC stars will allow the reconstruction of the star formation history (SFH) and enrichment history in the LMC outskirts, which, in turn, can be confronted to those obtained in the inner regions (Javiel *et al.* 2005).

Figure 3 below shows an artificial $r, r-i$ CMD of a 1 sq. deg. field located at 7 deg. away from the LMC centre, inside the DES footprint. The LMC stars make up about 80% of the total number in the field. The LMC CMD was created assuming a uniform SFH and a constant metallicity of $Z = 0.08$.

7. Photometric metallicity calibration via cluster fiducial sequences

The DES GC sample is made up of 12 objects. It will allow calibration of stars in the metallicity range typical of the halo, $-2.1 \leqslant [Fe/H] \leqslant -1.2$. The techniques used will be similar to those used by An *et al.* (2008). This sample may also be increased by adding reference clusters with the metallicity of the thick disk, currently estimated at [Fe/H] ~ -0.7.

8. Astrometric proper motion catalog of DES footprint

The DES, either alone, or by using earlier surveys to obtain greater time baselines, can be used to generate a deep, precise proper motion catalog. The UCAC survey, done by the USNO, has an astrograph telescope in Chile, from which the South was surveyed to about $g \sim 19$. The data are public and available now. Proper motions accurate to about 3 mas/yr are available to $g \sim 18$ for most stars. This enables important science projects, including the search for halo white dwarfs, and further stream and dwarf/cluster kinematic constraints.

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