DARK ENERGY SURVEY

The LMC Geometry and Outer Stellar Population from Early DES Data

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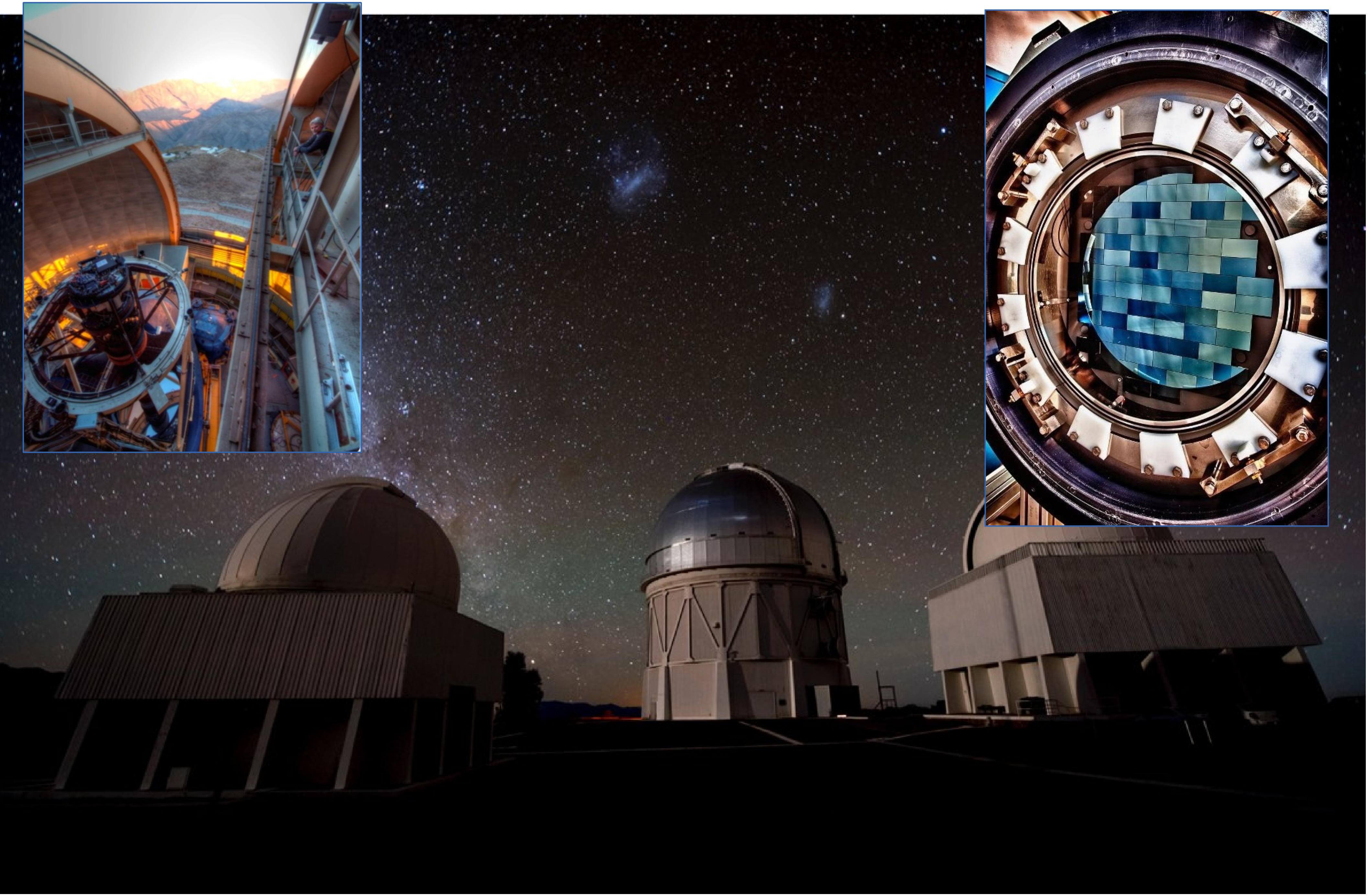
DES News

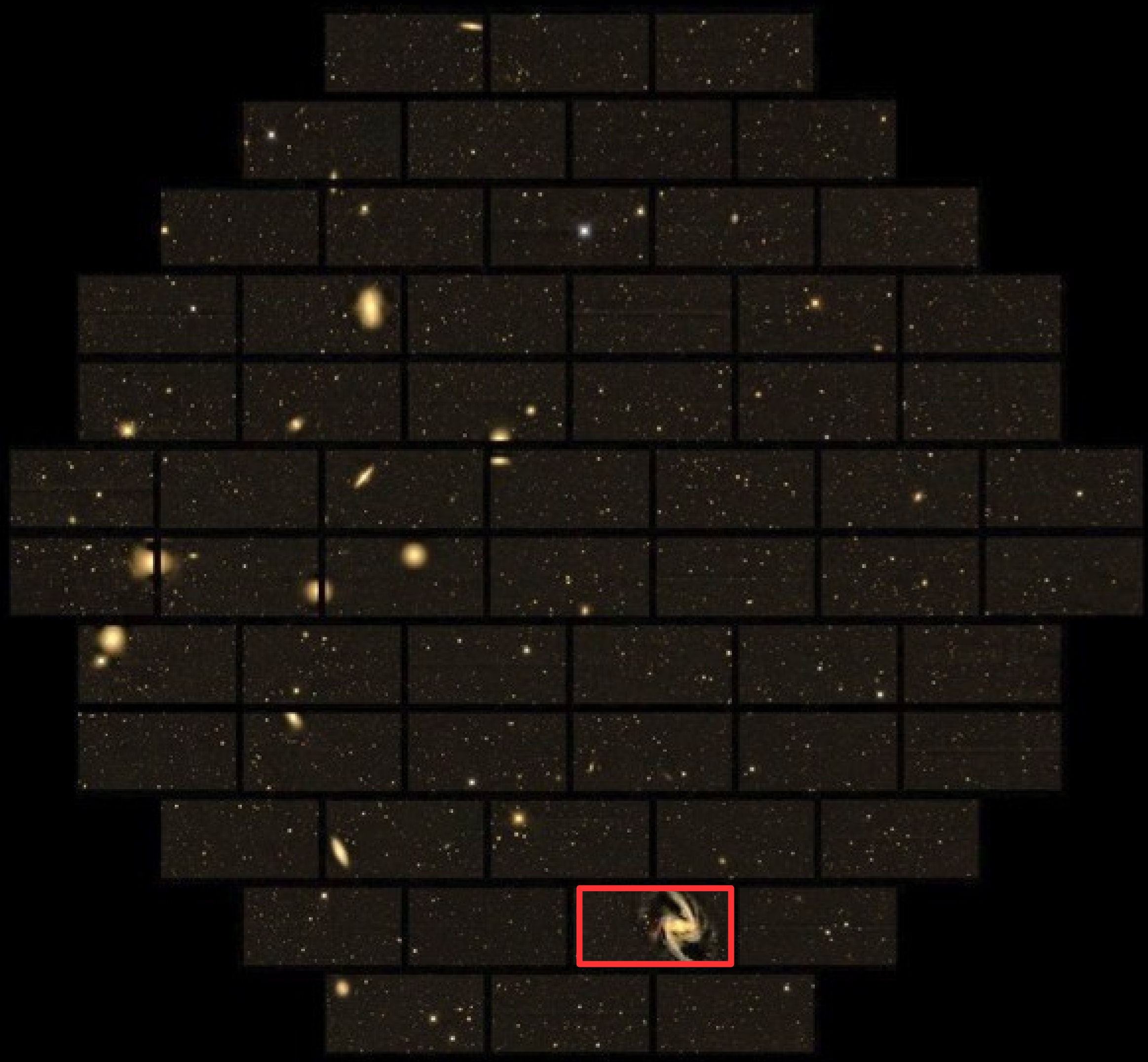
Eduardo Balbinot
for the DES Collaboration

UNIVERSITY OF SURREY

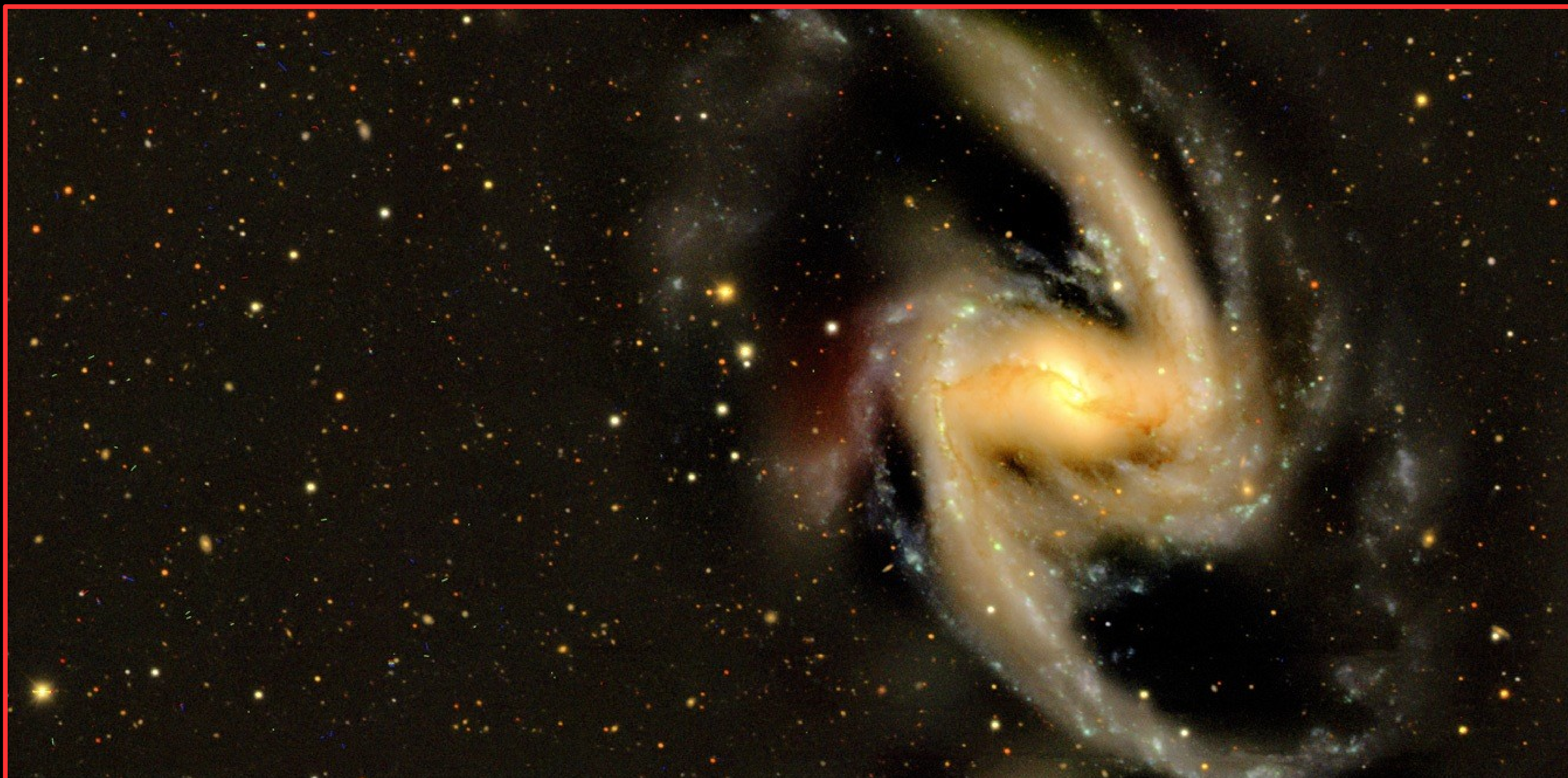
e.balbinot@surrey.ac.uk



First light



Fornax cluster



The Dark Energy Survey (DES)

- Photometric survey
  - » 5000 deg^2
  - » 5 years planned operation
  - » Nominal photometric depth
    - – $g = 24.7$
    - – $r = 24.5$
- So far two main internal releases
  - » SVA1
    - – Science verification data
    - – ~ 300 deg^2 at full survey depth
  - » Y1A1
    - – Regular annual release
    - – ~ 1200 deg^2 at "half" survey depth

The LMC on SV-A1

- The SV-A1 SPT-E footprint covers the North edge of the Large Magellanic Cloud (LMC)
  - » Closest angular separations of ~ 4° from the LMC centre
- Photometry reaches g ~ 1.5 mag fainter than the old Main Sequence Turn-Off
- Complete and homogeneous for stars
  - » Tests made with DAOPHOT as truth table

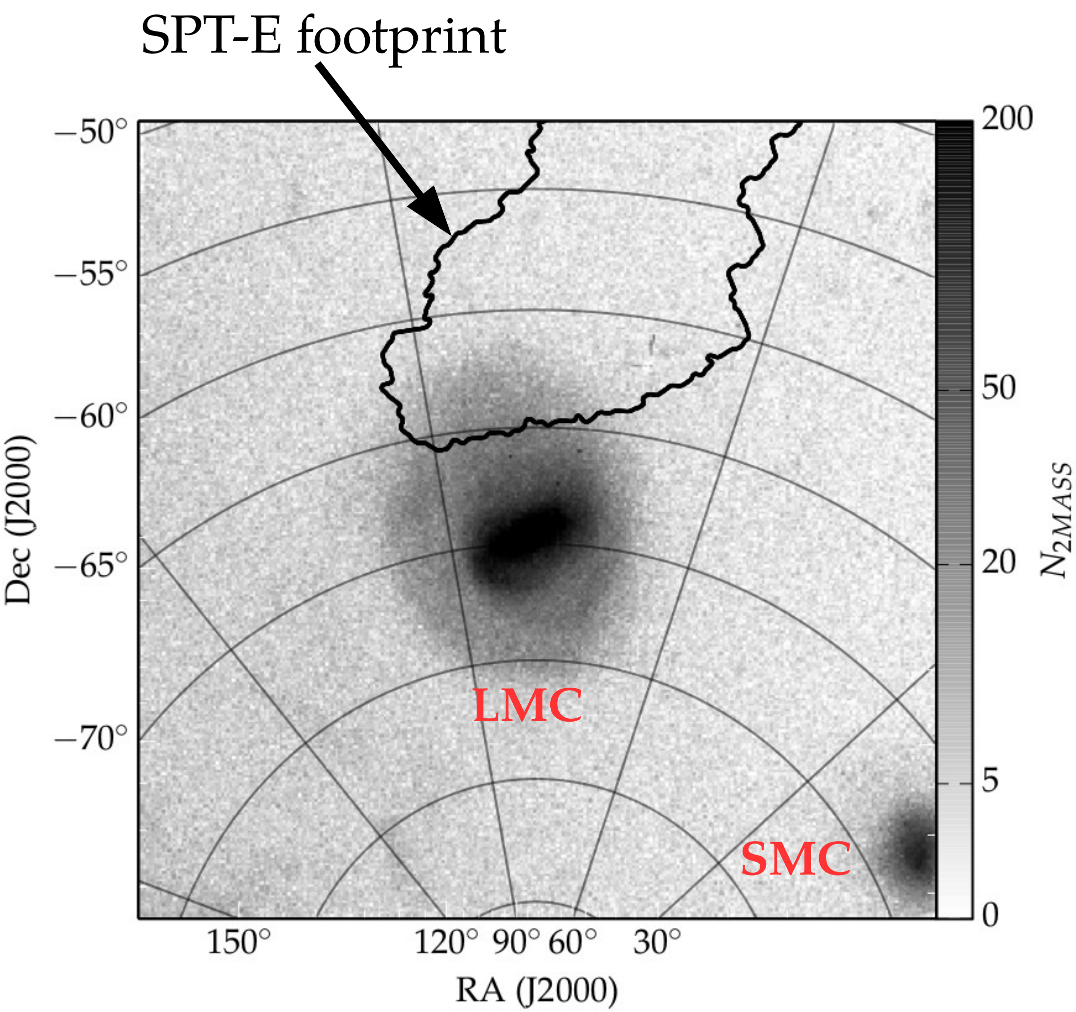


Figure 1: number of 2MASS stars in the vicinity of the Magellanic Clouds. The solid line shows the SPT-E footprint.

Data selection

- `|SPREAD_MODEL_I| <= 0.002`
- Mask
  - Approximate pixelization of Mangle masks
  - `MAG_LIM >= 23`
  - Not in a hole
  - Not near a star cluster
    - Added holes centred on LMC star clusters
- `Flags <= 3` (not near bright objects or CCD features)
- Extinction corrected using Schelegel+98 dust maps

Hess diagrams in all colours

- » Clearly distinguishable old from intermediate-young LMC stars
- » Milky Way stars dominate only on redder colours

  (g-r) > 1.2
- » Very complex Red Clump (RC) in (g-r)

We define colour-magnitude boxes to isolate a given stellar type or population

Age < 3 Gyrs

Red Clump

Age > 3 Gyrs

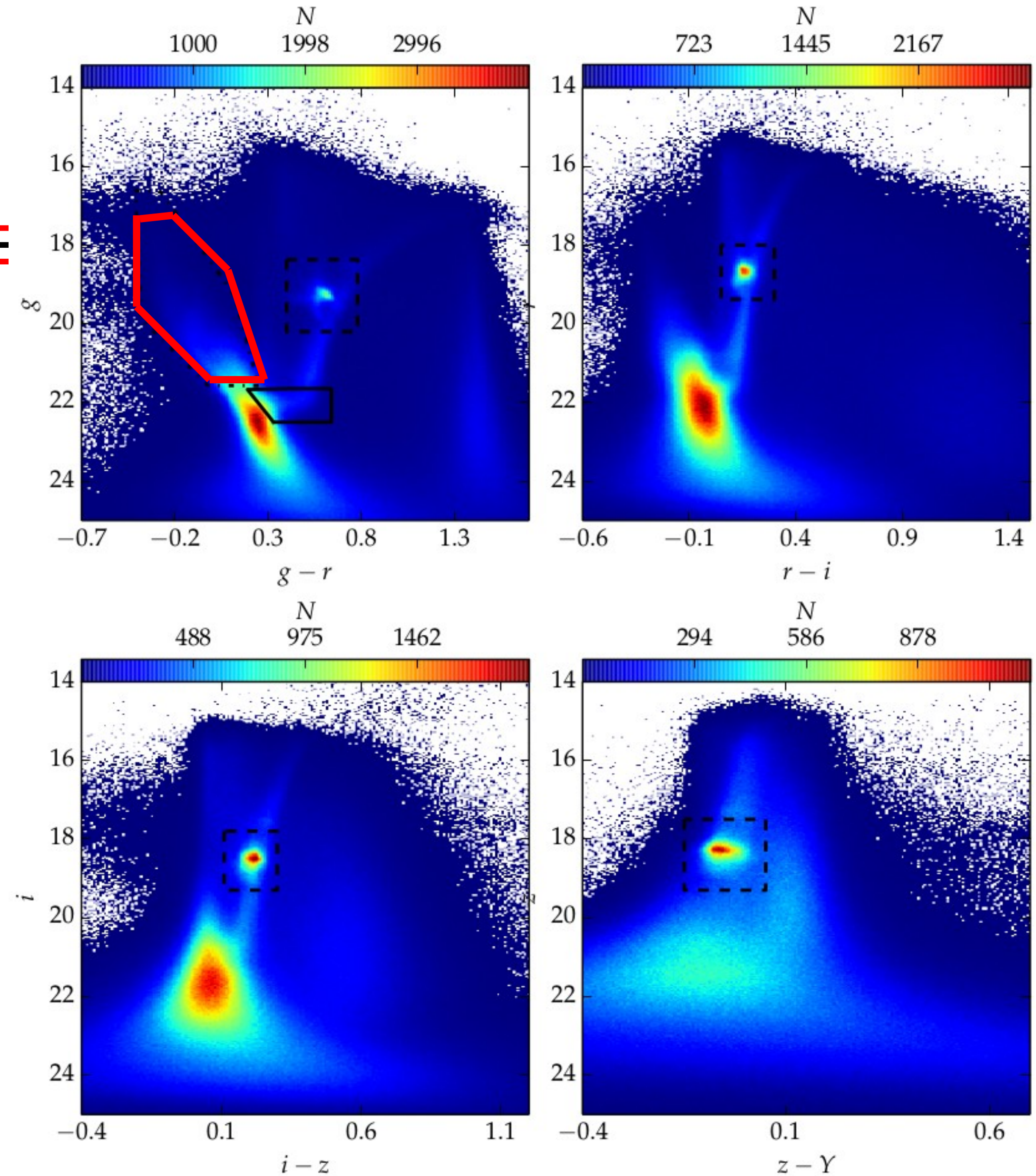


Figure 2: Hess diagrams for all colours available for DES. Boxes mark different colour-magnitude cuts. Legend shown in the bottom left of the slide.

How do different populations behave in the LMC

LMC density models assuming a **circular exponential disk.**

- » Line of nodes PA $\theta_0 \sim 120°$
- » Inclination $i \sim 30°$
- » Scale radius $R_s \sim 1$ kpc

- Models were degraded using the pixelized masks
- Spatially dependent MW foreground contamination
  - » Using AddStar in the DES Science Portal
- MCMC was used to find the best model

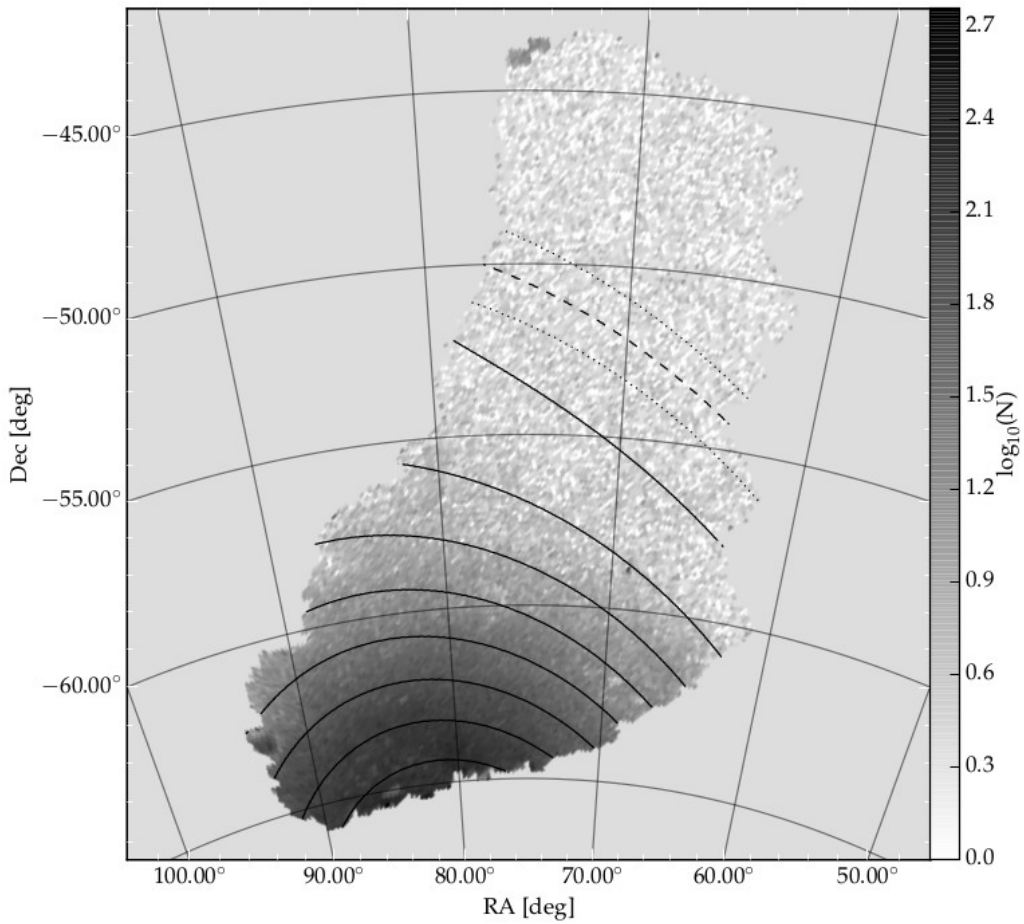


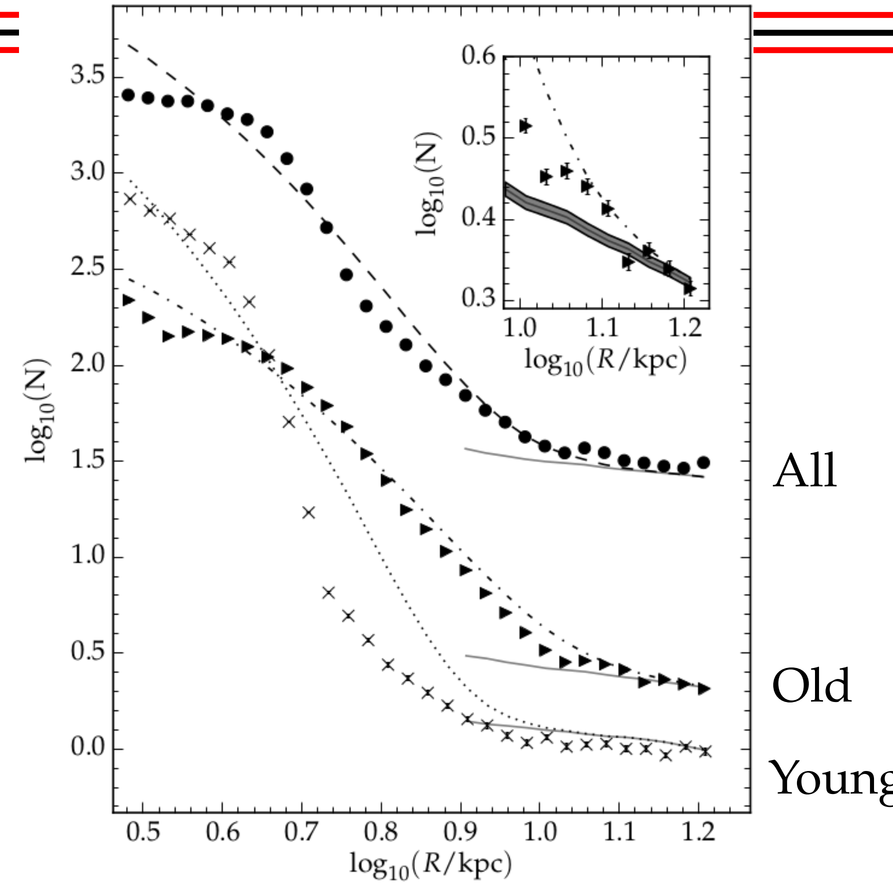
Figure 3: HEALpix density map of the SPT-E region. Contours show the best fit disk model for the LMC. This map was constructed using only **old** LMC stars.

Outside-in formation?

- Young population has a 50% smaller scale radius
- Other geometric parameters remain within the limits of what is found in the literature
- Truncation (tidal?) radius of about 14 kpc for the old population

$$R_t = d_{LMC}\left(\frac{M_{LMC}}{2M_{MW}(d < d_{LMC})}\right)^{\frac{1}{3}}$$

$$M_{\rm MW}(d < d_{\rm LMC}) = 24.5^{+8.8}_{-6.4} \times M_{\rm LMC}$$



Population	Age Gyr	θ_0 deg	i deg	R_s kpc
All	–	$129.27 \pm 0.17(\pm 1.08)$	$-38.65 \pm 0.08(\pm 1.59)$	$1.11 \pm 0.01(\pm 0.02)$
Young	0 - 3	$125.91 \pm 0.20(\pm 0.09)$	$-44.23 \pm 0.13(\pm 1.80)$	$0.72 \pm 0.01(\pm 0.00)$
Old	3 - 13	$127.15 \pm 0.95(\pm 0.59)$	$-33.54 \pm 0.38(\pm 1.25)$	$1.43 \pm 0.01(\pm 0.00)$

Red Clump

- Fit of the peak of the RC magnitude
  - Gaussian plus 2nd order polynomial
- Repeated ~ 200 times for **`HEALpix`** pixels
  - Central peak is a standard candle
  - Width gives information about the thickness of the LMC disk

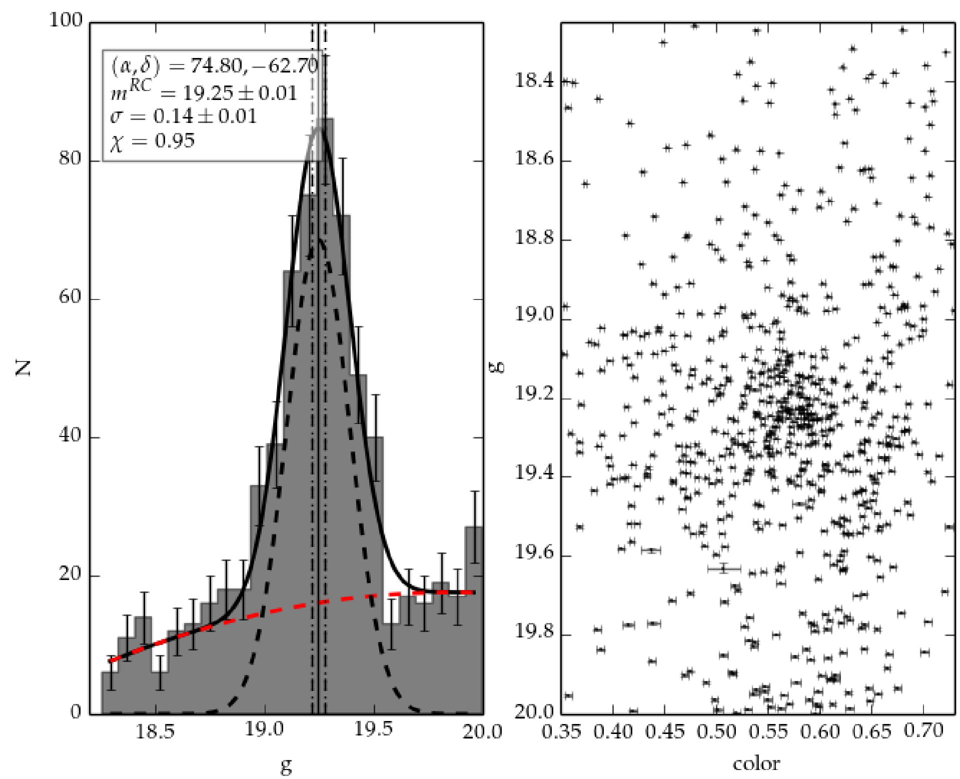


Figure 4: (*right panel*) Red Clump CMD region blow-up; (*left panel*) number counts and the best fit (solid line). We also show only the Gaussian (dashed) and the polynomial (red dashed). The vertical lines show the peak (solid) and uncertainty (dot-dashed).

Distance modulus map

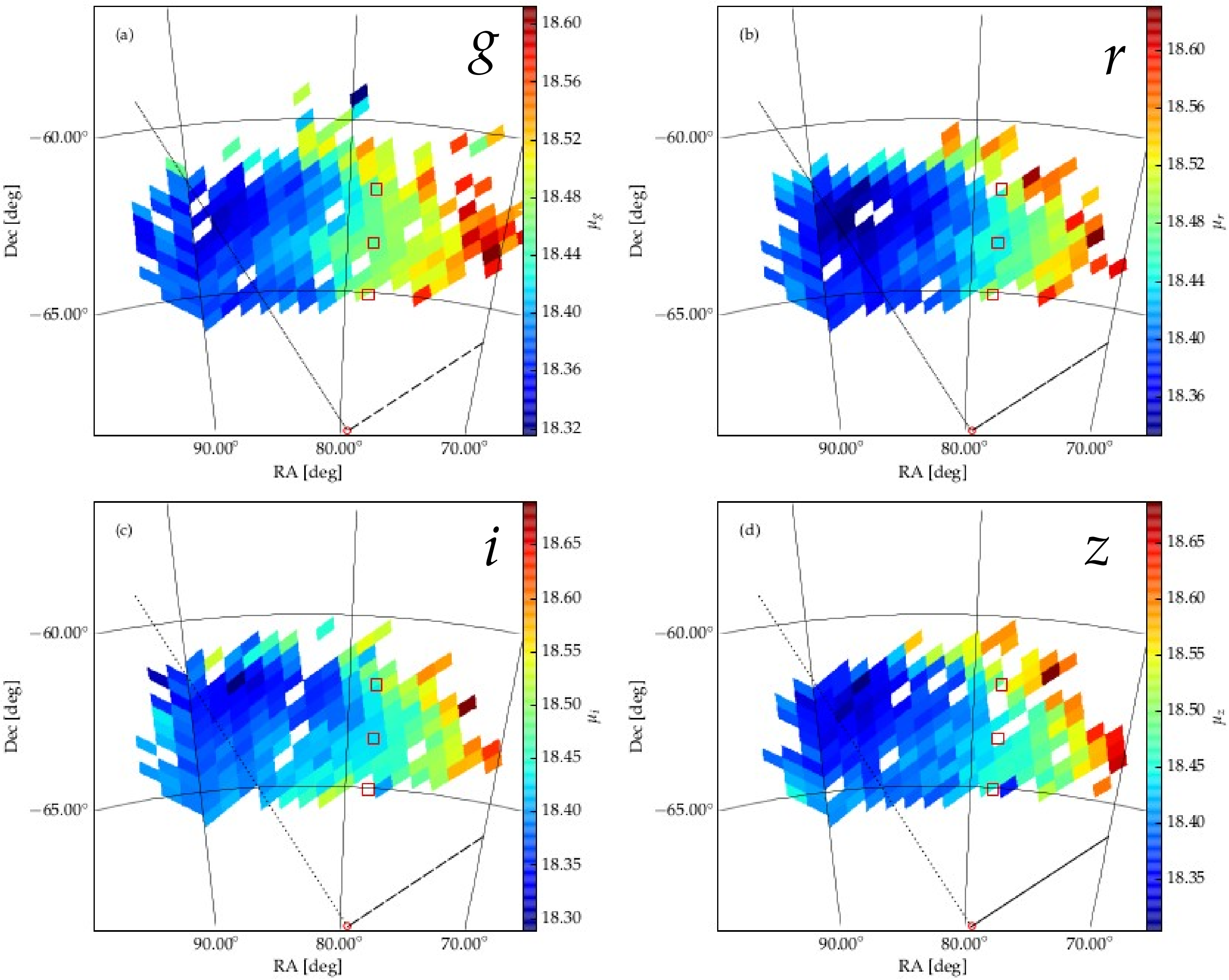


Figure 5: distance modulus shown in colour code. Each panel shows the estimate in a DES filter. The dotted line shows the direction of maximum distance variations from the LMC centre according to our best fit disk model. The dashed line shows the line of nodes.

Distance and thickness

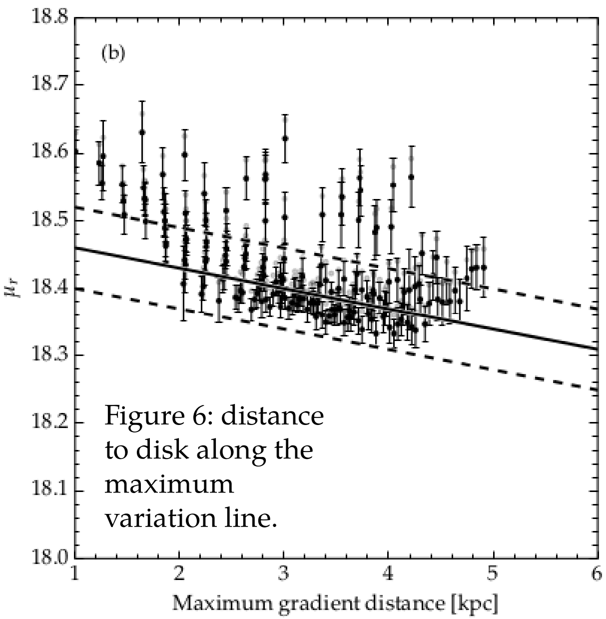


Figure 6: distance to disk along the maximum variation line.

- Distance modulus distribution along the line of maximum gradient follows very closely the disk model we found
- Small deviations at large distances may be present
  - » These deviations make the disk more distant to what is expected
  - » *Warp* in the LMC disk!

- Isolating the contribution of the disk thickness to the spread of the RC we find that
  - » Fairly constant thickness from 2-4 kpc from the LMC centre $\sigma \sim 0.08$ mag (1.8 kpc @ R_{LMC})
  - » Increase of the thickness in the outskirts $\sigma \sim 0.14$ mag (3 kpc @ R_{LMC})

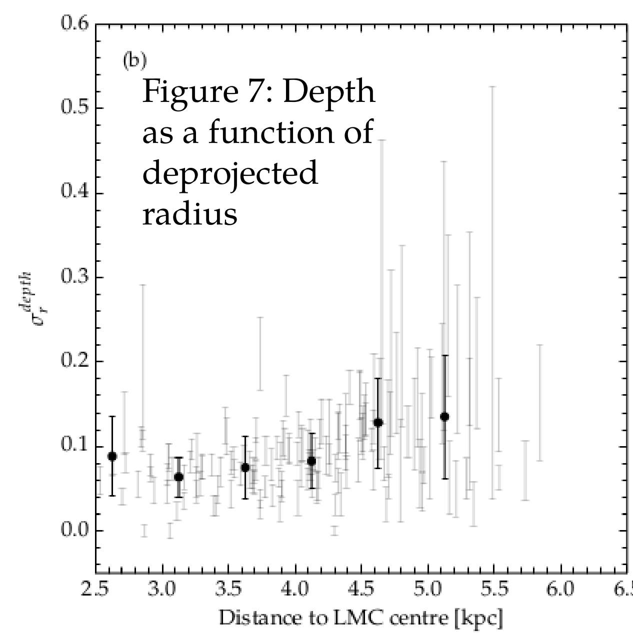


Figure 7: Depth as a function of deprojected radius

Warp or Halo?

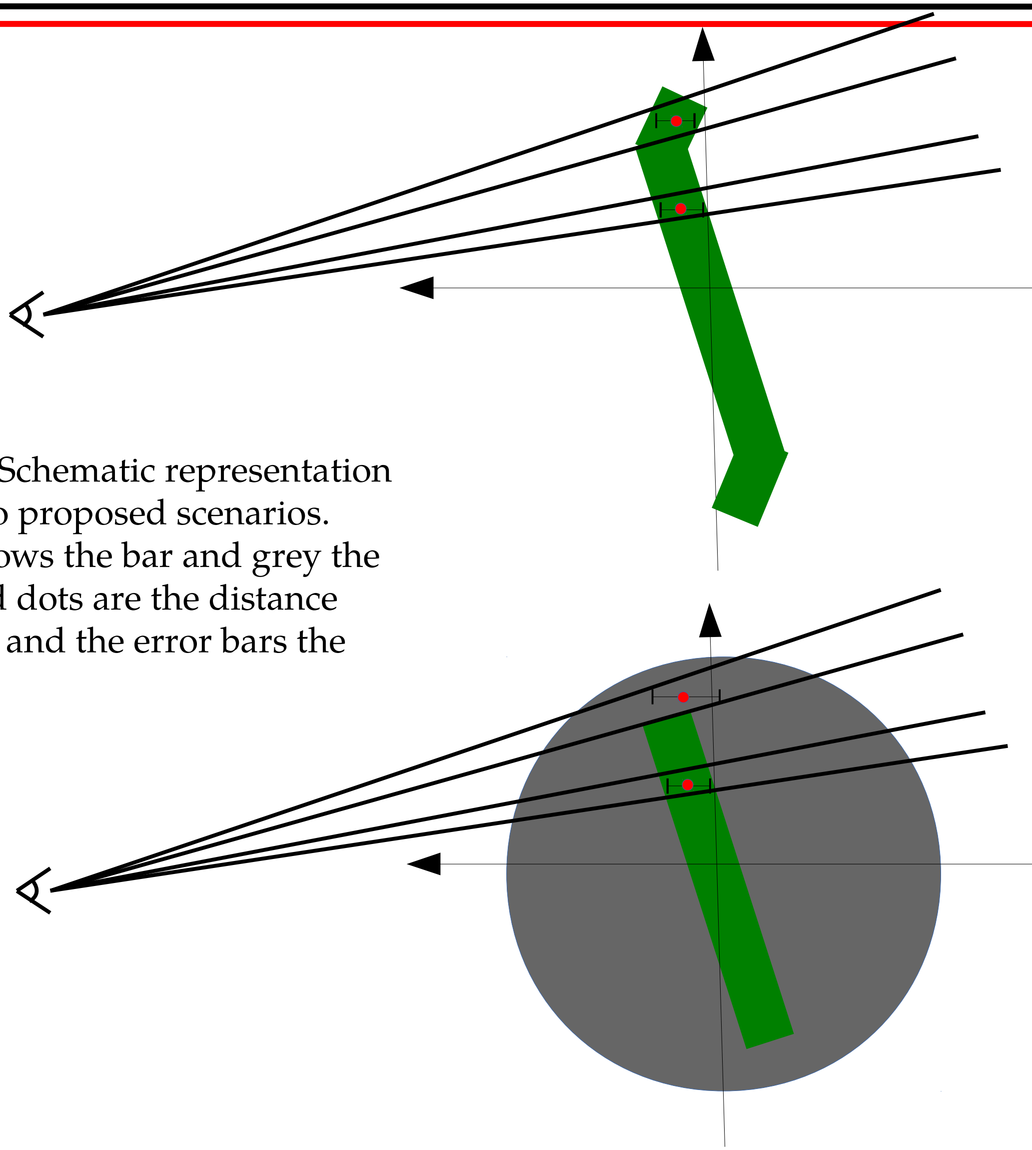


Figure 8: Schematic representation of the two proposed scenarios. Green shows the bar and grey the Halo. Red dots are the distance estimates and the error bars the depth.

- Warp
  - » Young populations should be present in warp region
  - » Little or no increase in thickness
- Halo
  - » Typically old population
  - » Distance shift towards the LMC centre
  - » Increased thickness

Results

for more see Balbinot et al. 2015

- The LMC disk has different scale radius for different stellar populations
  - This points to a scenario where star formed in an **outside-in** mode
- The young population is not well described by a simple exponential disk
- Red Clump distance points to warping
- Marginal increase in thickness in the outskirts (*flare*)
- LMC-MW mass ratio favours a first passage scenario (i.e. Magellanic Clouds are in their first pericentric passage)
- LMC mass in good agreement with HST velocity field mass determination

$$M_{LMC} = 2.3^{+0.8}_{-0.6} \times 10^{10} M_{\odot}$$ This work

$$M_{LMC} = (3.5 \pm 1.4) \times 10^{10} M_{\odot}$$ van der Marel 2014 (HST)

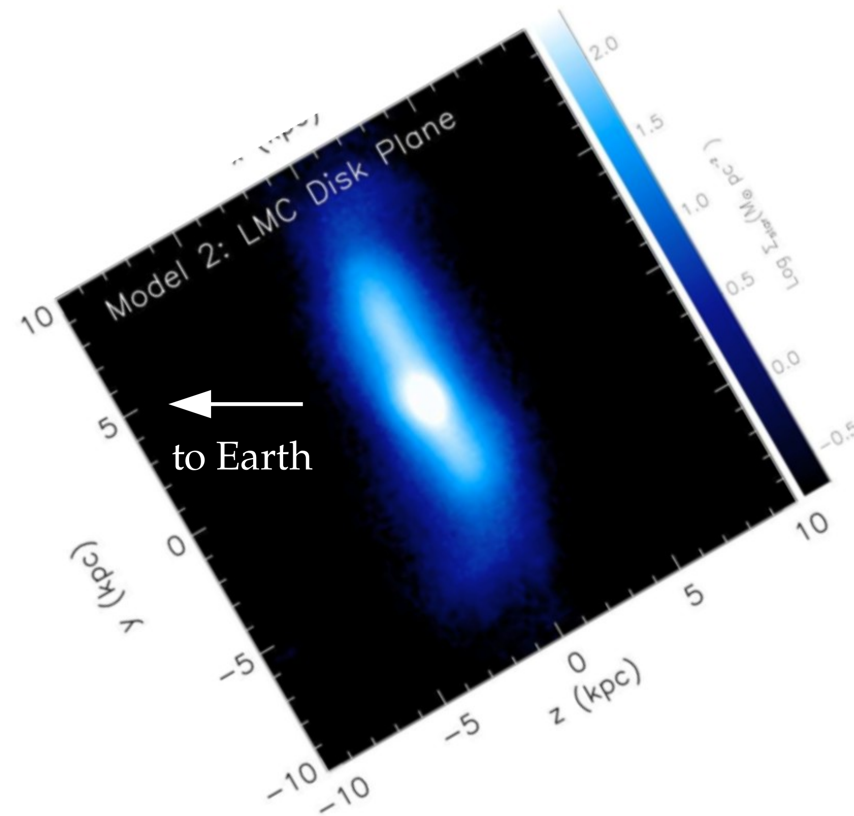


Figure 9: simulated distribution of LMC stars on an edge-on view. (Besla et al 2013; modified)

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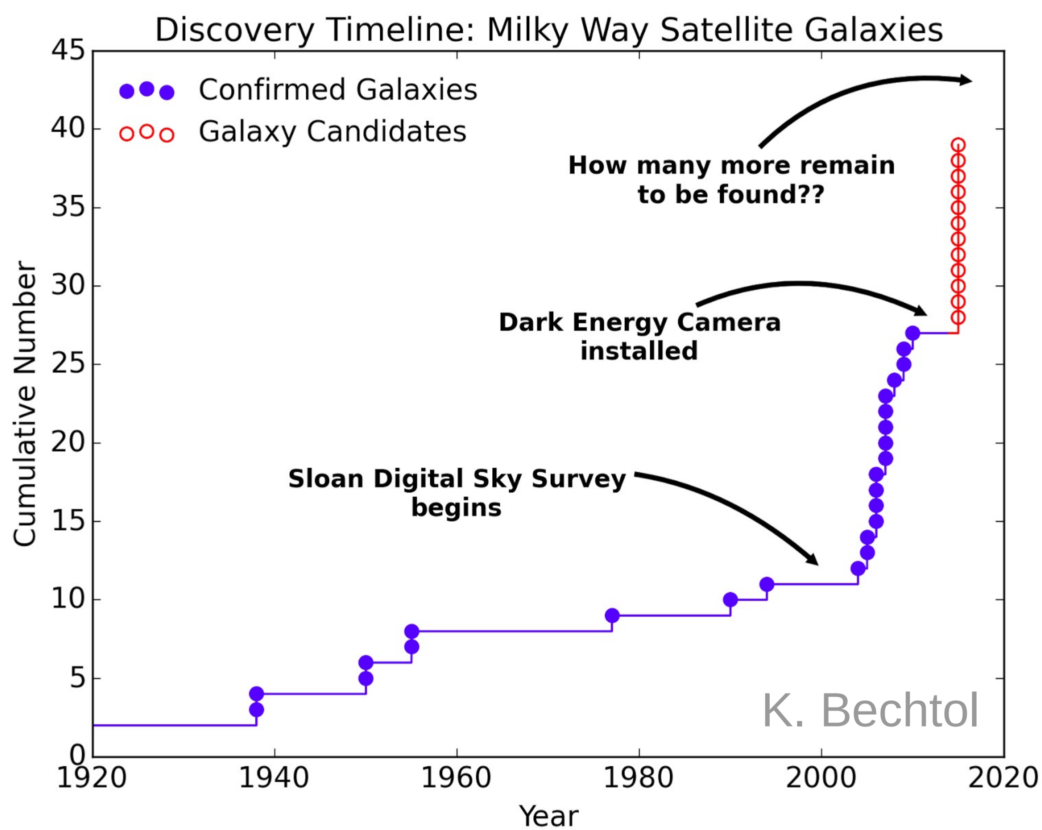

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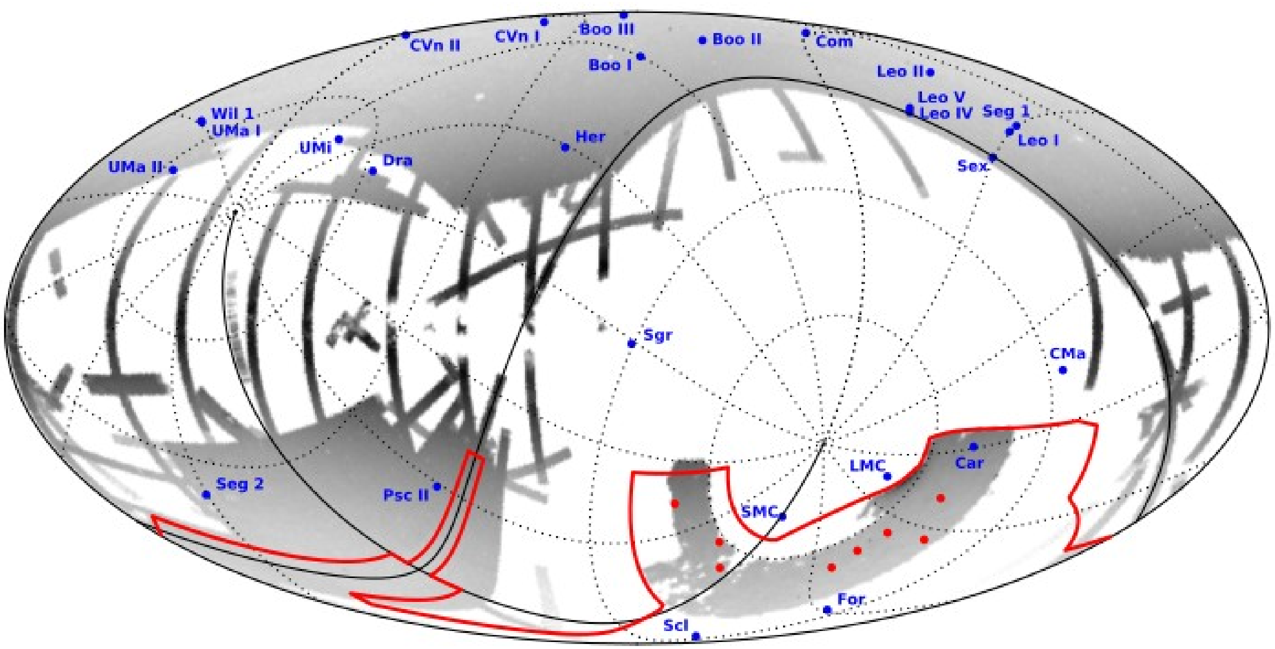
Milky Way Satellites

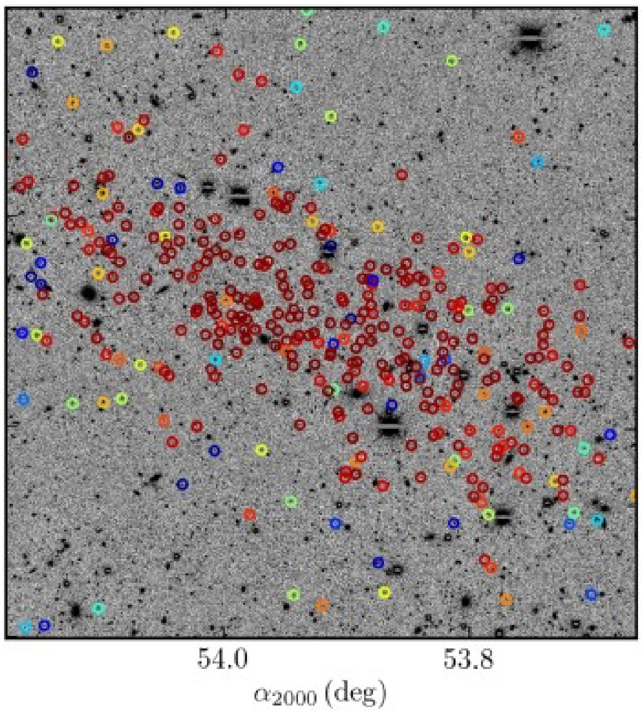
Bechtol et al. (2015)

- 8 new dwarf satellites!

Locations of Milky Way Satellites



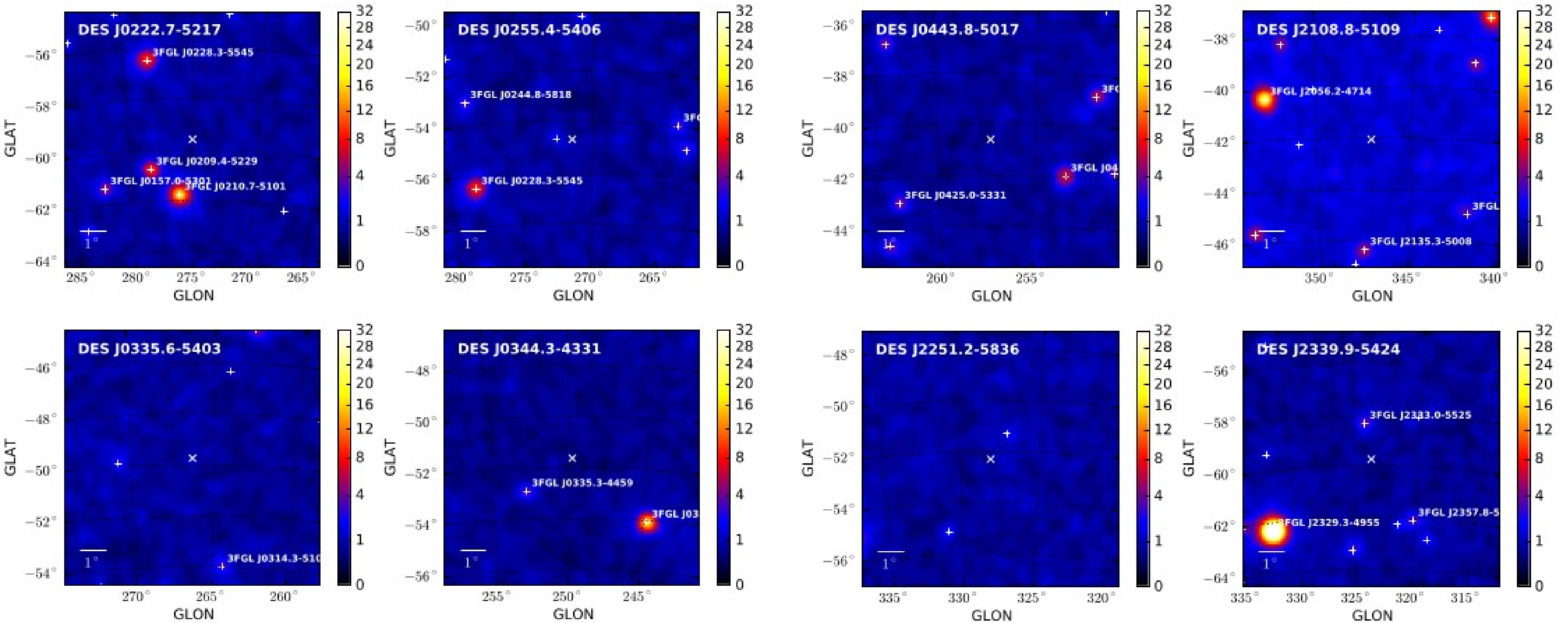
DES J335.6



Milky Way Satellites

Drlica-Wagner et al. (2015)

- No detection of dark matter



Milky Way Satellites

on arXiv today!

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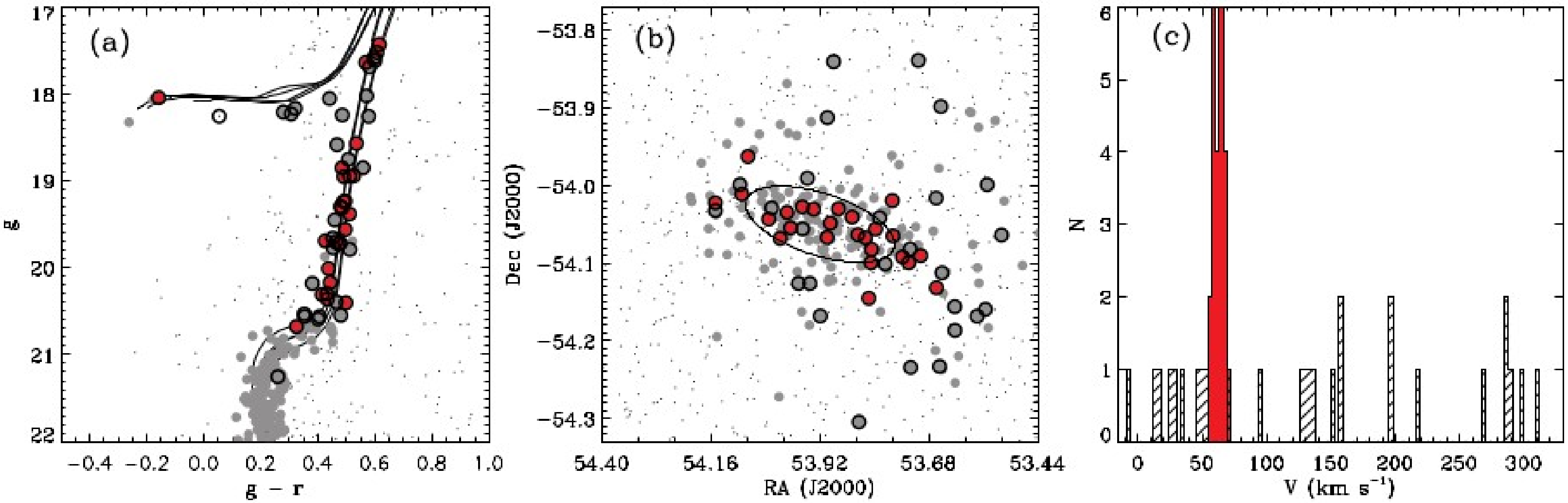
Simon et al. (2015)

- ✦ Spectroscopic follow-up of Reticulum II



- ✦ Confirms it is a Milky Way satellite
- ✦ Unlikely bound to the LMC

More to come in the remaining **4** years of DES!