LSST and the Magellanic Clouds

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Large Magellanic Cloud (LMC)

Small Magellanic Cloud (SMC)
LSST and the Magellanic Clouds

Agenda:

- What is the current view of the Magellanic Clouds?
- What is the contribution of current surveys?
- What will LSST provide?
Magellanic Clouds

- Most luminous and largest dwarf satellite galaxies of the Milky Way
- Metal poor/ Nearby/ Interacting/ With associate Bridge/ Stream
- Recently arrived / With satellites / With gas
- Early-stage minor merger/ Interactions of dwarfs

Prototype nearby system. Unique opportunity!

Discovered by Fernão de Magalhães (1480-1521)

(Nidever+2010)
Morphology of the LMC*

Distribution of stars as function of stellar population age.

To note:

Bar: thin / thick Disk MW contamination Clumpiness Smoothness

* Based on 2MASS data

Nikolaev & Weinberg 2000
Radial velocity* & Proper Motion**

* Based on spectroscopic data

** Based on HST data

2-3 epochs, 3-7 years, 30 stars and 1 QSO per field

van der Marel et al. 2014
The Magellanic Stream

There is as much gas in the Stream as there is in the SMC, and a lot near the SGP. Is the product of LMC/SMC interaction and ram pressure stripping by MW. It contains both LMC and SMC material (there are two filaments). There are stars in the leading arm.

Hammer et al. 2015
Outer substructures

**DECAM observations**
Substructure in the outer disk of the LMC.

Disk stripping or transient feature?
LMC-MW and/ or LMC-SMC interaction.

Mackey et al. 2016
Stellar streams

Extracting blue horizontal branch halo stars (box 1) at large distances and tracing their distribution.

Box 2 contains young LMC disc stars.

Red triangles are new satellites.

Belokurov & Koposov 2016
The current surveys of the Magellanic Clouds
The OGLE-IV survey

- 630 deg²
- VI ~ 21/20 mag
- 400 epochs
- 2010-2015

A long-term variability study on dense stellar regions.

RR Lyrae stars: >45000
Classical Cepheids: >9000

Soszyński et al. 2016b
Udalski et al. 2015
Soszyński et al. 2016a
3D structure from Cepheids

The Clouds are inclined towards each other.

The entire LMC bar is coplanar and as distant as the LMC disc. The classical bar and the northern arm are closer. The Cepheids ages peak at 100 Myr.

The SMC is highly elongated. There are two age peaks at 100 and 220 Myr. Nearer stars are younger.

There are Bridge stars across a wide range of distances.

Assuming no Z gradient.

Jacyszyn-Dobrzonecka et al. 2016
Bridge stellar distribution

Skowron et al. 2014
The VMC survey

- 170 deg²
- YJKs ~ 22 mag
- 12 Ks epochs
- 2008-2018

A near-infrared deep-wide study of history and structure.

Near-infrared colour-magnitude diagrams down to old turn-off stars.

Ks-band light-curves for Cepheids and RR Lyrae stars.

http://star.herts.ac.uk/~mcioni/vmc/

Cioni et al. 2011
LMC is 65% complete; SMC is 95% complete!

Advanced = all YJ and at least 6 $K_s$ epochs have been observed.
Star Formation History

Each tile is 1.65 deg$^2$ in size.

These observed diagrams contain a range of stellar populations that sample the whole history of the SMC galaxy.

Rubele et al. 2015
SMC
Star Formation History

The most detailed map to date (area and resolution)!

Modest star formation rate at ages < 5 Gyr (from 0.15 to 0.5 M☉yr⁻¹).

Peak at 1.5 Gyr like in the LMC.

Young star formation in the centre and to the East.

Ages from top to bottom are:
8/ 25/ 63 Myr – 125/ 200/ 316 Myr – 0.5/0.8/1.2 Gyr – 2/ 3.2/ 5 Gyr – 8/ 12 Gyr.

Rubele et al. 2015
We obtain mean magnitudes from the best fitting $K_s$ template of each star. The period is obtained from OGLE III data.

Red, blue and green indicate pulsation in the fundamental, first, and second overtones.

The rms of the relations is about 0.15 mag. There are $\sim 4000$ Cepheids.
Proper motion

VISTA observations: Ks band, 10 epochs, 1 yr.
Reference ~ 40,000 background galaxies.

Stellar populations have distinct PMs.
There are 47 Tuc stars far out.

(red and blue squares are HST values)

Cioni et al. 2016
CTIO and VST surveys

Common goals:
- Star formation history
- Inner and outer structures
- Finding satellites

Outcome:
An homogenous coverage of the area in multiple bands and below the old main-sequence turn-off.

Dark Energy Survey (DES)
Magellanic Satellite Survey (MagLiteS)
Survey of the Magellanic Clouds stellar history (SMASH)

VST GTO surveys:
- STEP
- YMCA
Discovery of a new satellite

Hydra II is old and metal poor. It is a distance \((m-M)_0=20.64 \pm 0.16\) mag. The isochrone corresponds to 13 Gyr and \([\text{Fe/H}]=-2.2\) dex.

Martin et al. 2015
Gaia

Proper motion and substructures:
VISTA – pushing data to the limits (0.05 mas/yr; 10,000 stars; 1 yr; 10 pts.)
Gaia – an extraordinary leap forward (0.01 mas/yr, < 500 stars; 5 yr; 70 pts.)

Improved reference system.

Variable stars:
Complete census
Better light-curves

Sensitive to just below the HB of the SMC

RR Lyrae stars in the Magellanic Clouds
The LSST era
The Thousands and One Magellanic Clouds Survey (2021-2026; PI Cioni)

S#9 Consortium survey (endorsed by SCB)

500,000 stars
Radial velocity
Iron abundance
Multiple stellar populations
Plus a subset with other elements and monitoring.

To the limit of HB stars and then use MOONs.

4MOST: medium resolution (350-950 nm) and high resolution (390-650 nm).
## Present and future surveys

<table>
<thead>
<tr>
<th>Survey</th>
<th>Time scale</th>
<th>Area (deg²)</th>
<th>Repeats</th>
<th>Scale (“/pix)</th>
<th>FWHM (“)</th>
<th>Filters</th>
<th>Sensitivity (AB)</th>
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<td>2011+</td>
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<td>30 (i)</td>
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<td>0.8-1.0</td>
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<td>2010-2014</td>
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<td>~400 (l)</td>
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<td>VI</td>
<td>21, 20 (Vega)</td>
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<td>0.27</td>
<td>1.0</td>
<td>uz + gri</td>
<td>24</td>
<td>10, 20</td>
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<tr>
<td>Skymapper</td>
<td>2010+</td>
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<td>6</td>
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<td>LSST</td>
<td>2021-2031 δ&lt;+34</td>
<td>56-184</td>
<td>&lt;&lt;0.2</td>
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<td>0.8</td>
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<td>-</td>
<td>G band</td>
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<td>Euclid</td>
<td>2020-2026</td>
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<td>1</td>
<td>0.1, 0.3</td>
<td>-</td>
<td>Vis, YJH</td>
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<td>12 (Ks)</td>
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<td>YJKs</td>
<td>22.5-23.4</td>
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LSST survey design

- Magellanic Clouds

Total depth, AB mag, 50.

The LSST Operations Simulation Team 2015
Conclusions

For LSST to be competitive on Magellanic Clouds science in the 2020s we need to:

• Obtain multi-epoch & multi-band observations
• Sample short- and long-time baselines.
• Cover a large area down to -80 deg (1000 deg²; LSST Science book)

Science cases include:

• Identifying substructures (streams/ satellites/ star clusters)
• Study substructures with proper motion
• Mapping extinction
• Studying multiple/ binary systems