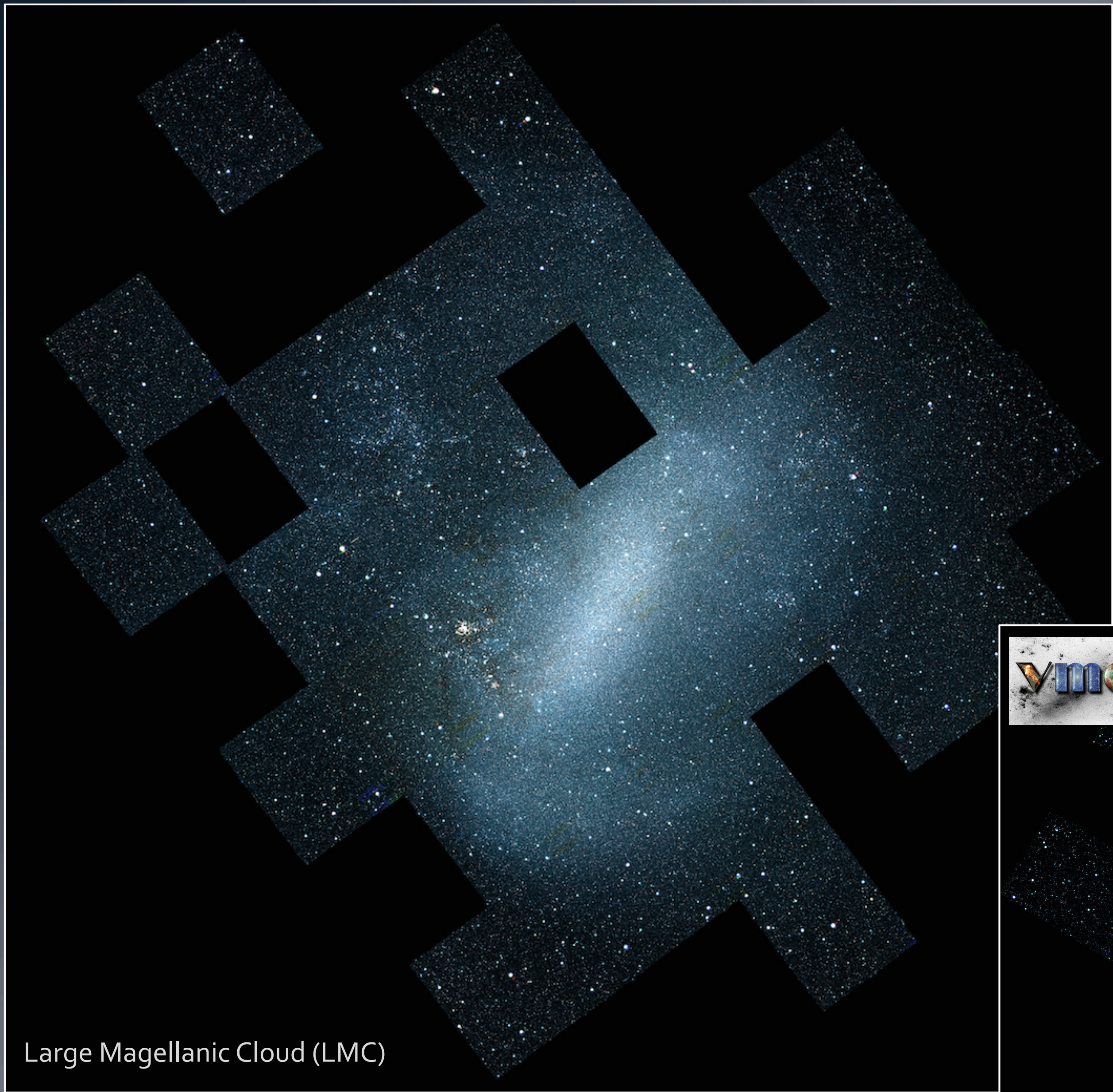
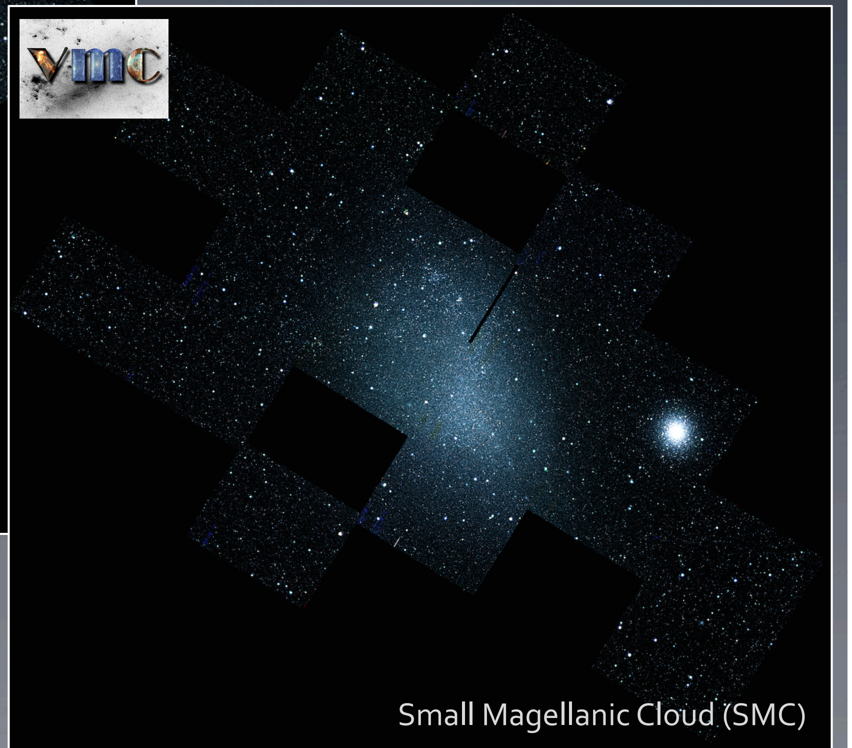
LSST and the Magellanic Clouds

Maria-Rosa Cioni



Large Magellanic Cloud (LMC)



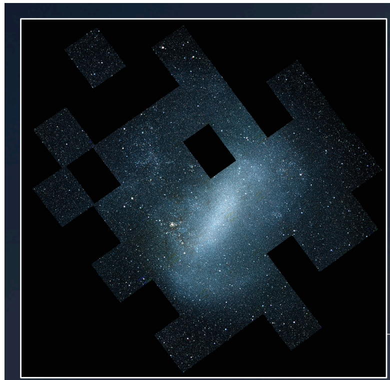
Small Magellanic Cloud (SMC)

Belgrade, 21st June 2016

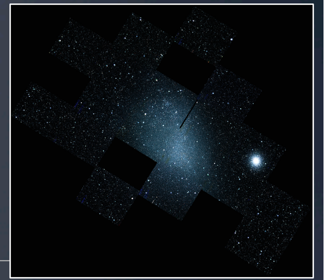
LSST and the Magellanic Clouds

Agenda:

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

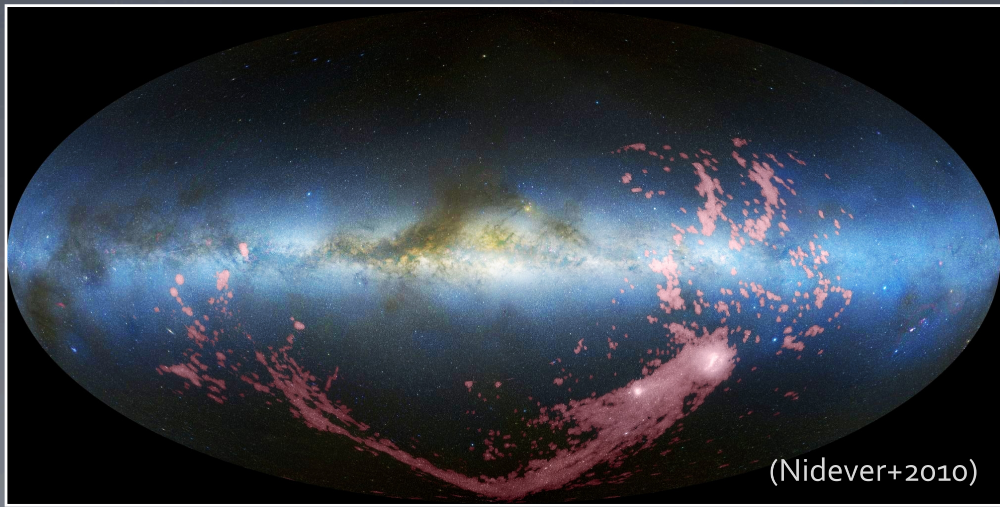


Magellanic Clouds

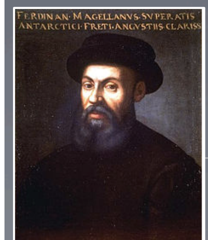


- Most luminous and largest dwarf satellite galaxies of the Milky Way
- Metal poor/ Nearby/ Interacting/ With associate Bridge/ Stream
- Recently arrived / With satellites / With gas
- Early-stage minor merger/ Interactions of dwarfs

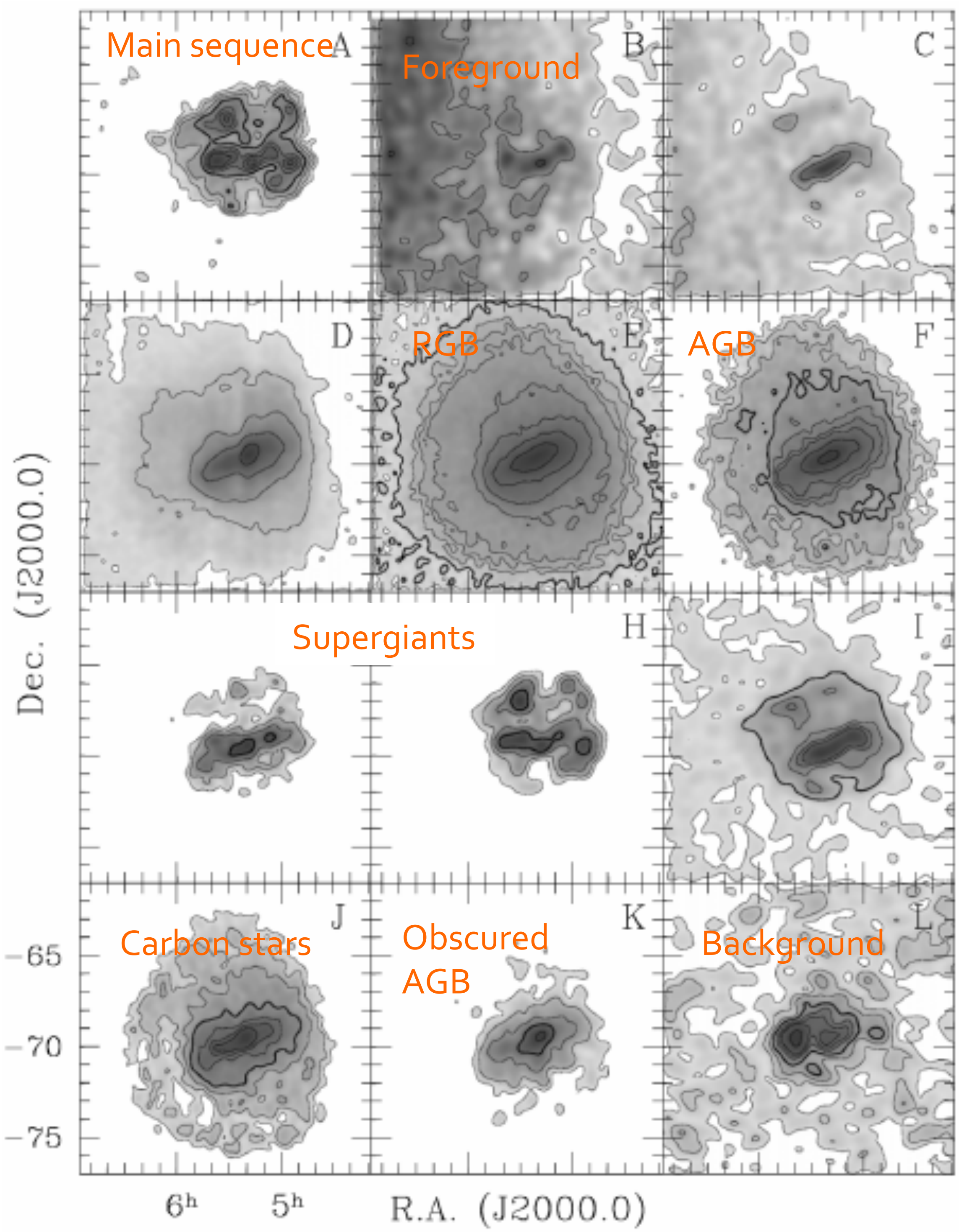
Prototype nearby system.
Unique opportunity!



(Nidever+2010)



Discovered by
Fernão de Magalhães (1480-1521)



Morphology of the LMC*

Distribution of stars as function of stellar population age.

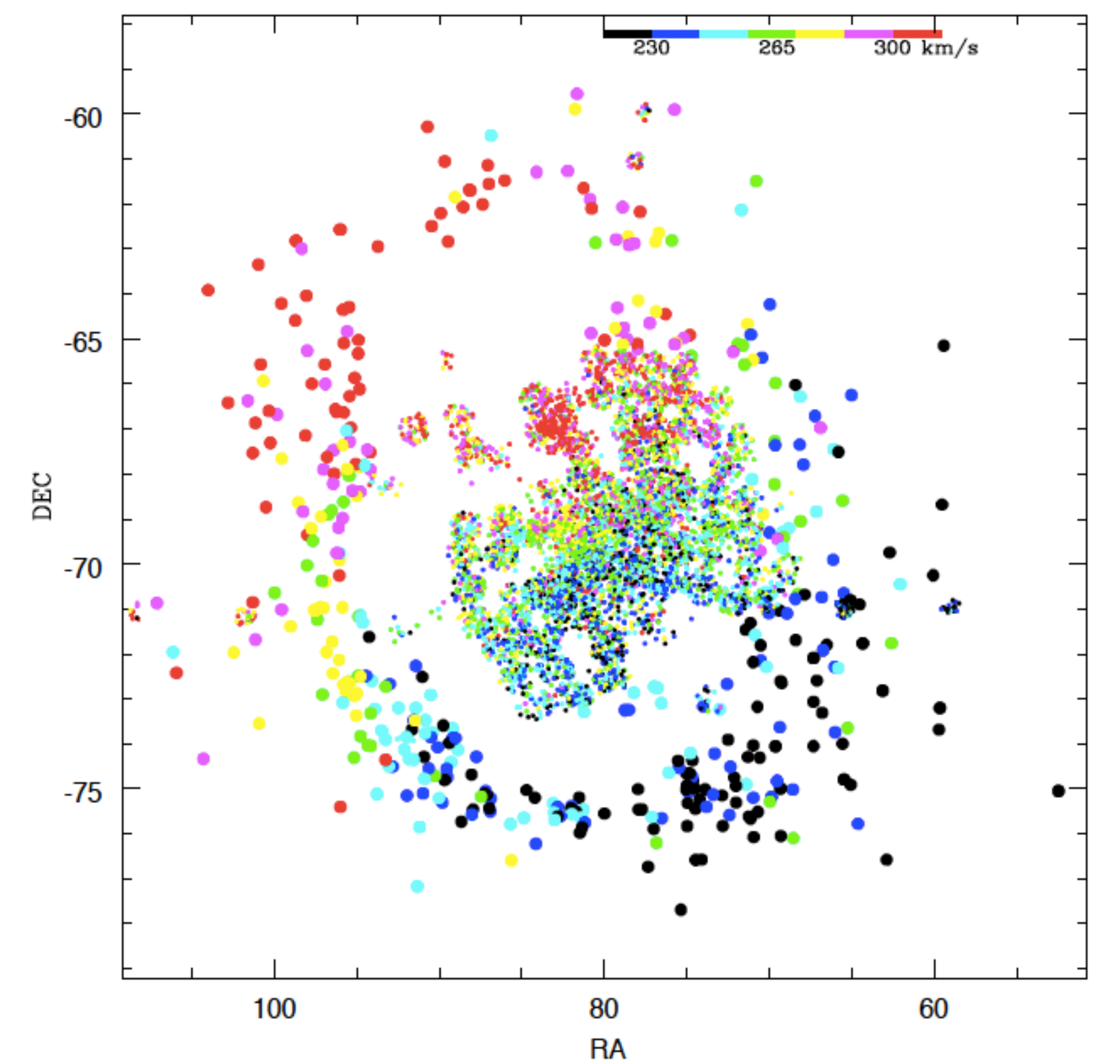
To note:

Bar: thin / thick
Disk
MW contamination
Clumpiness
Smoothness

* Based on 2MASS data

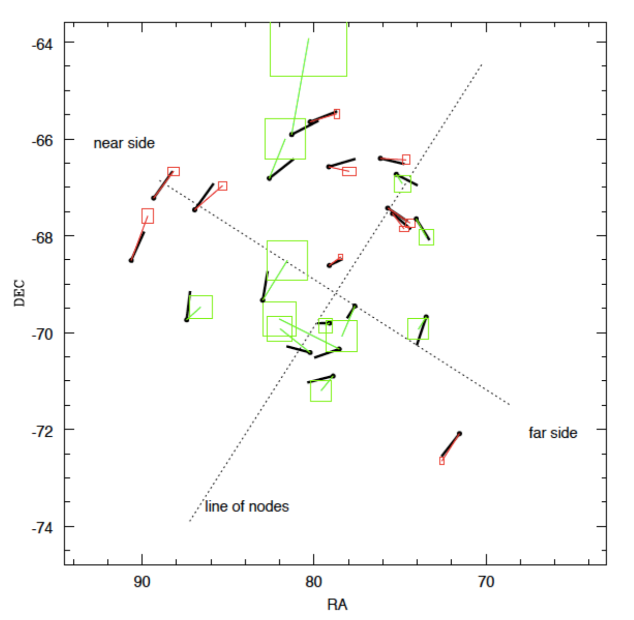
Nikolaev & Weinberg 2000

Radial velocity* & Proper Motion**



* Based on spectroscopic data

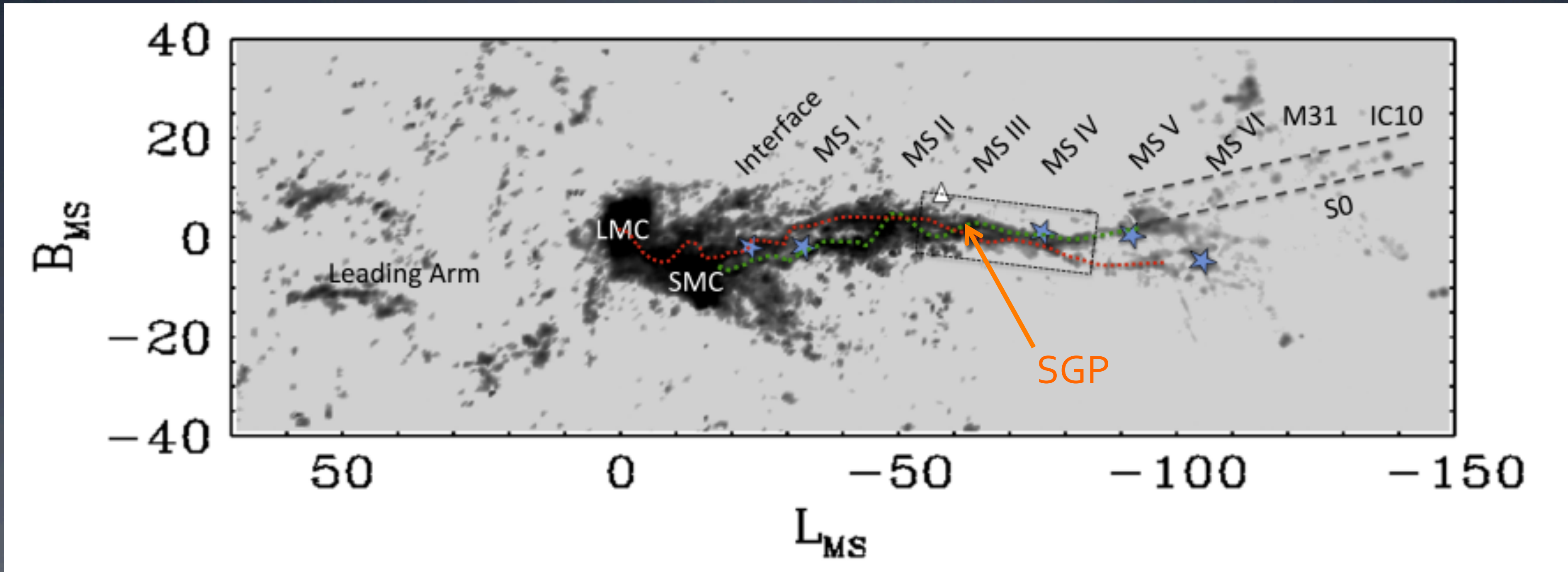
** Based on HST data



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

van der Marel et al. 2014

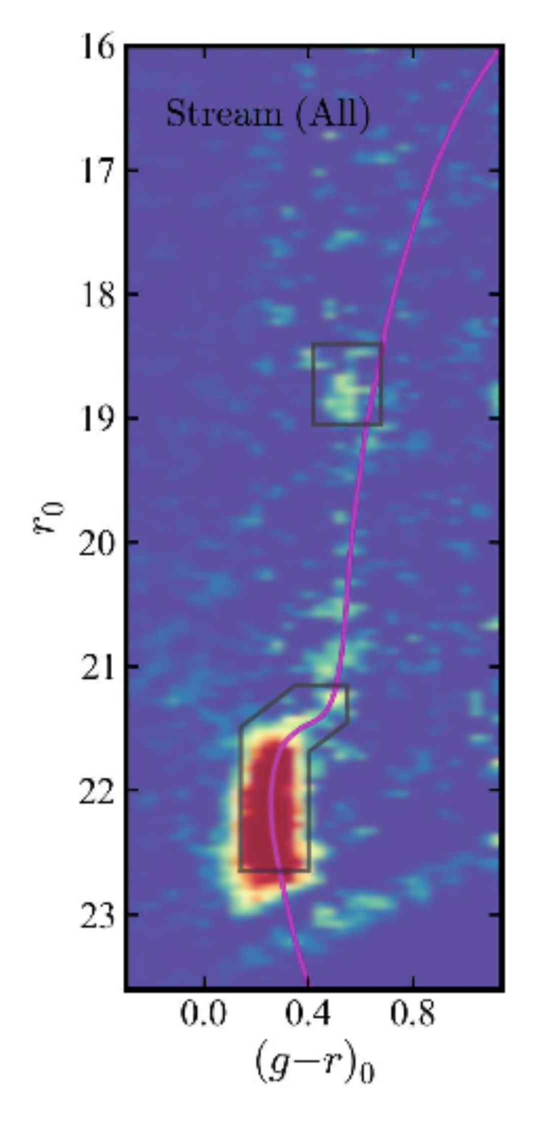
The Magellanic Stream



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.

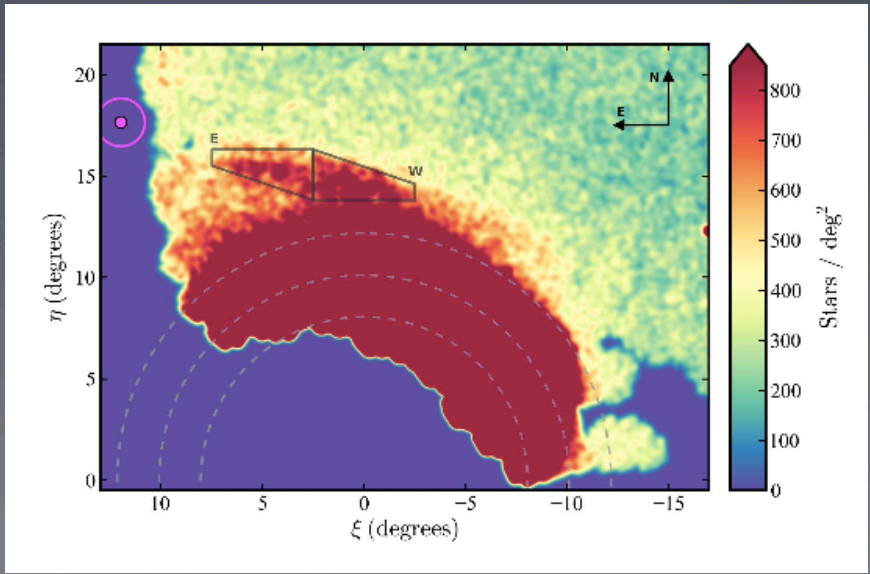
Hammer et al. 2015

Outer substructures



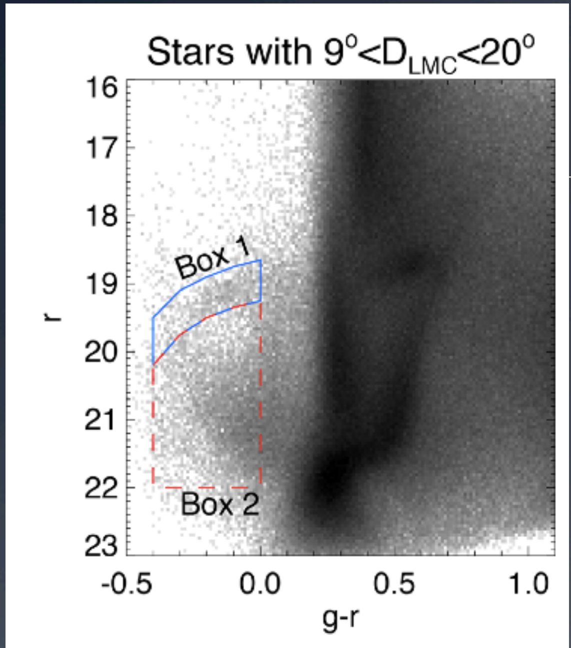
DECAM observations
Substructure in the outer disk of the LMC.

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



Mackey et al. 2016

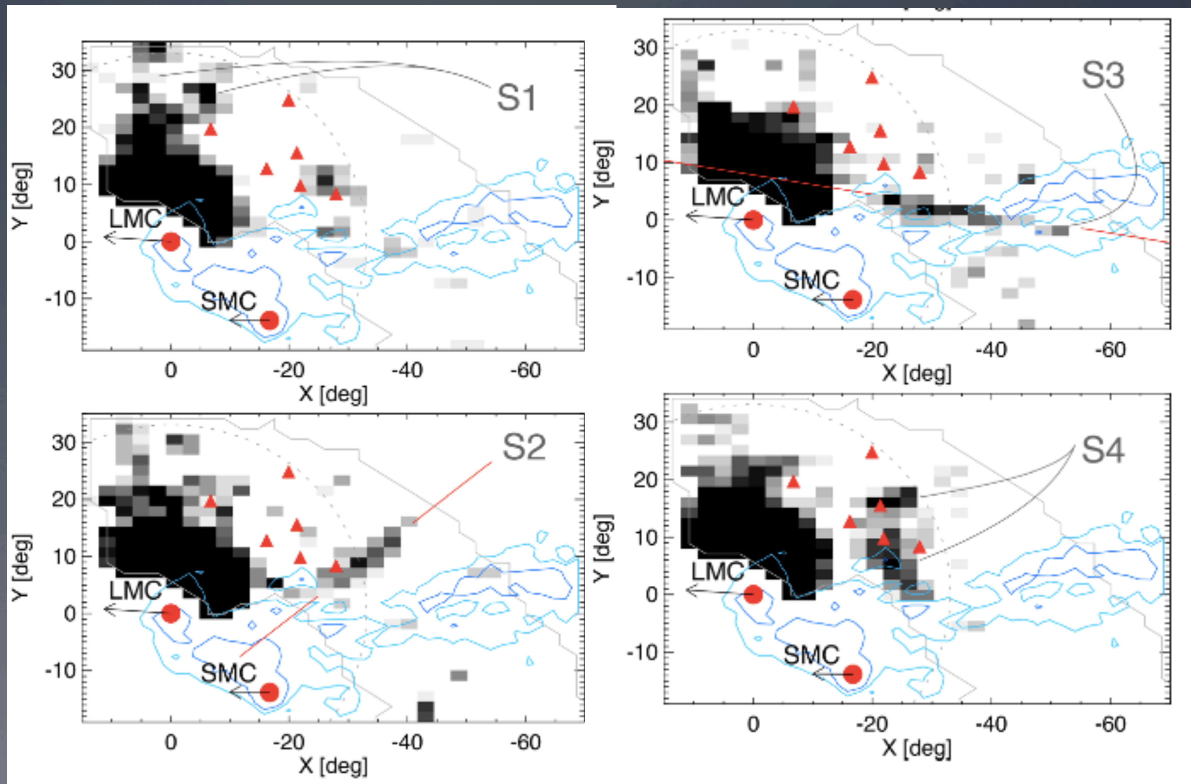
Stellar streams



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

Box 2 contains young LMC disc stars.

DECAM observations



Red triangles are new satellites.

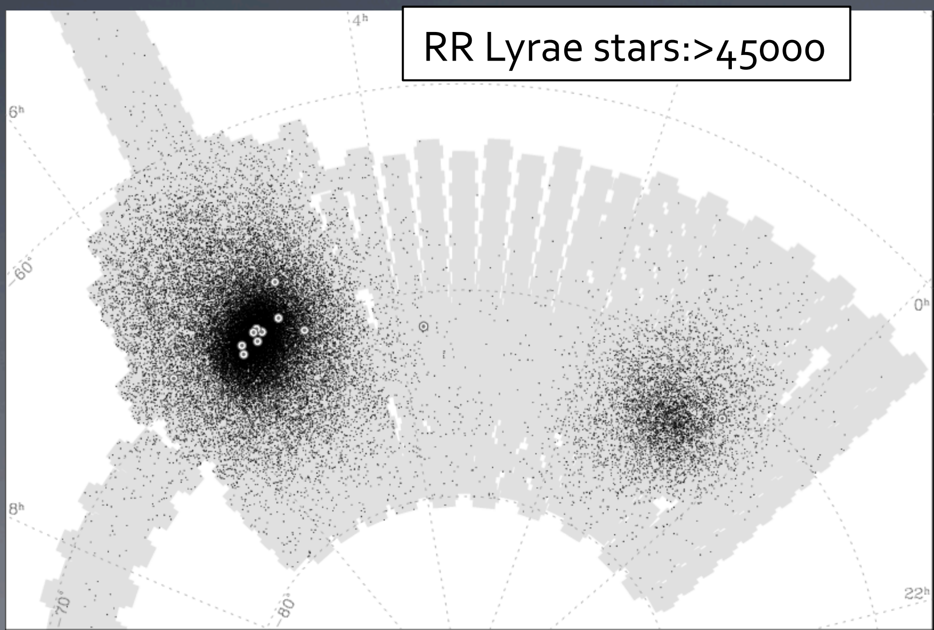
Belokurov & Koposov 2016

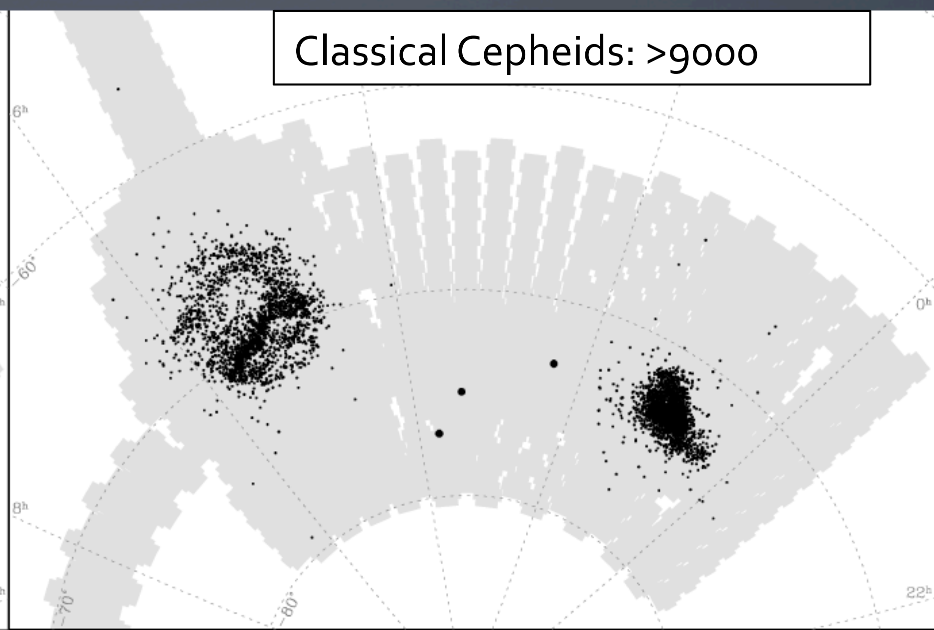
The current surveys of the Magellanic Clouds

The OGLE -IV survey

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

A long-term variability study on dense stellar regions.

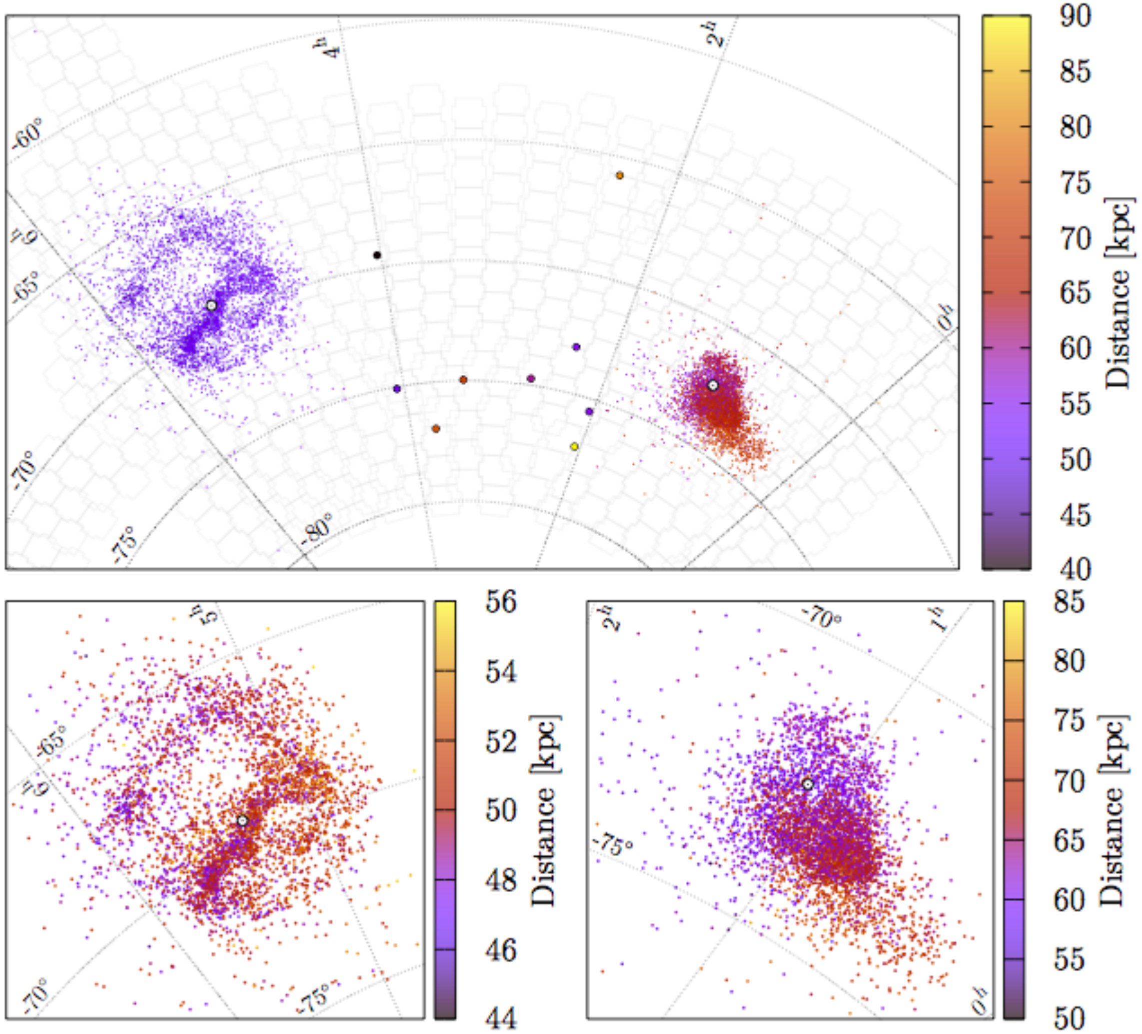




Soszyński et al. 2016b   Udalski et al. 2015   Soszyński et al. 2016a

OGLE

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.

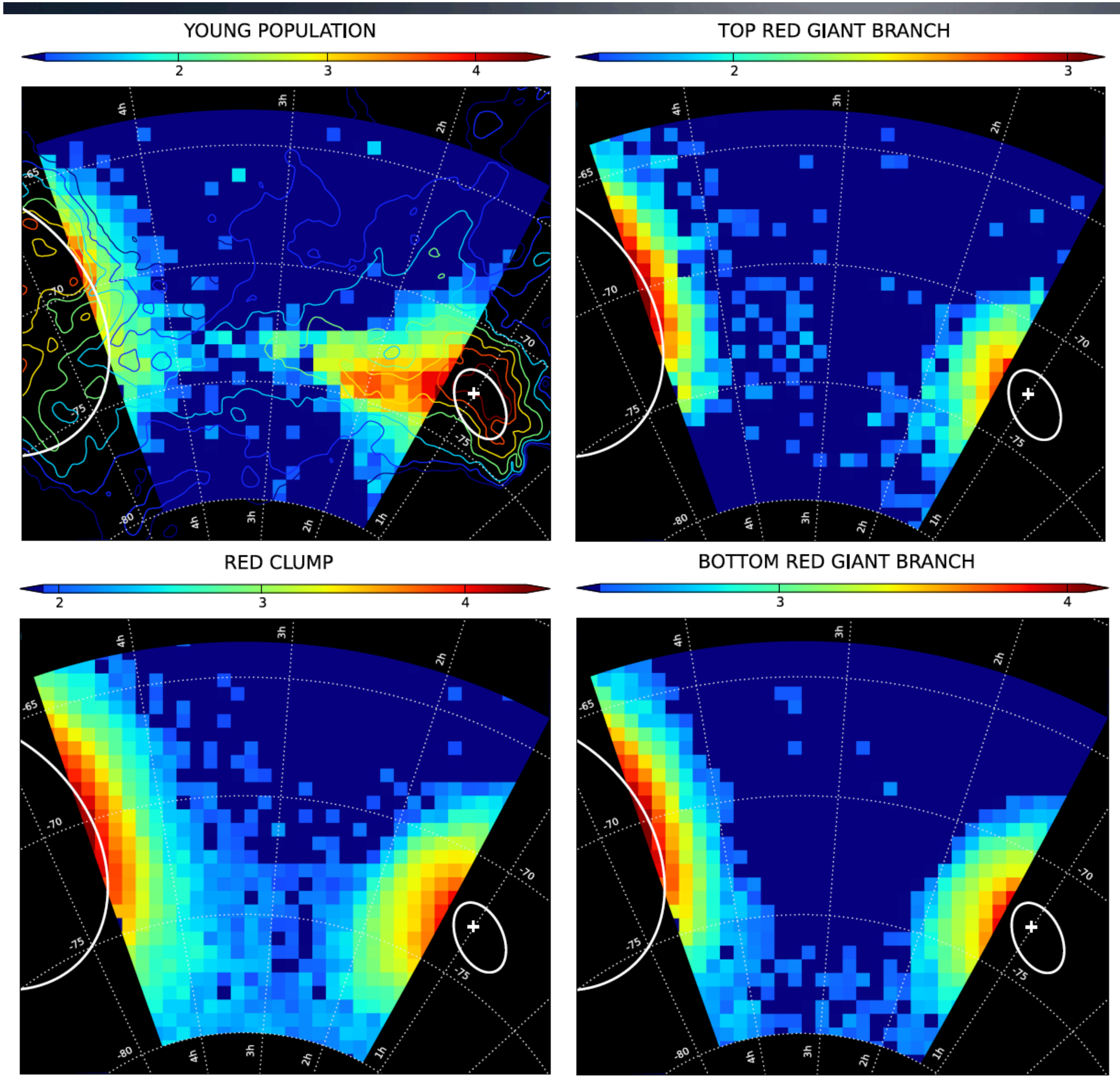
The SMC is highly elongated. There are two age peaks at 100 and 220 Myr. Nearer stars are younger.

There are Bridge stars across a wide range of distances.

Assuming no Z gradient.

Jacyszyn-Dobrzenecka et al. 2016

Bridge stellar distribution



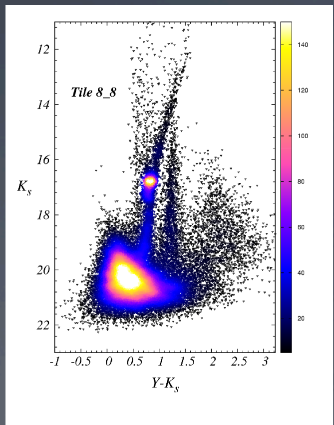
Skowron et al. 2014

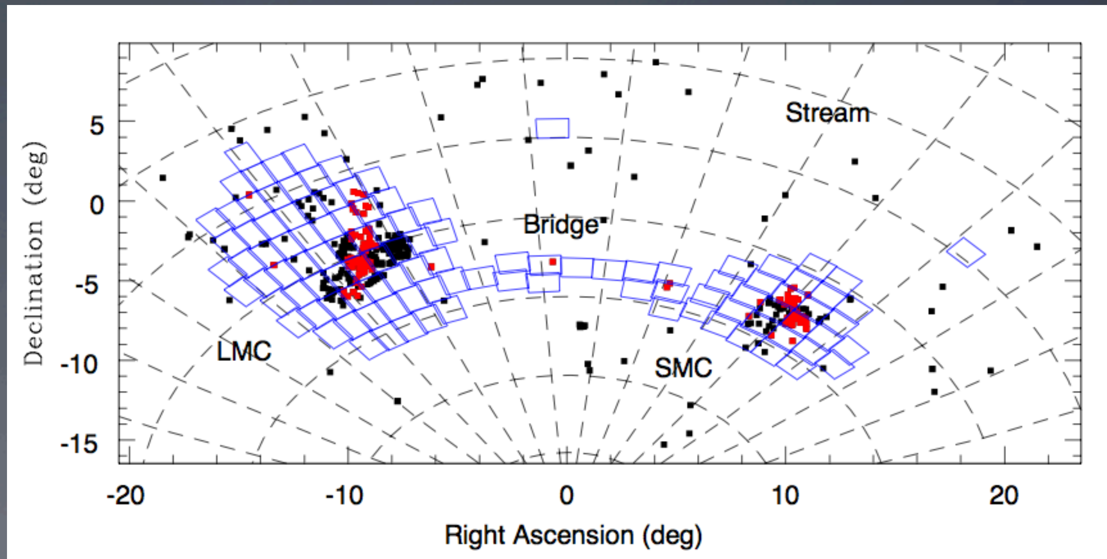
The VMC survey

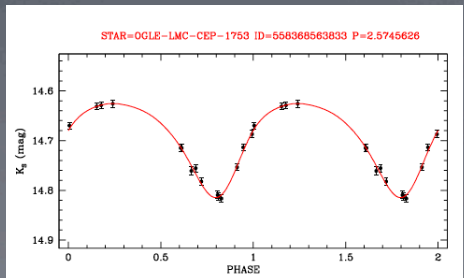
- 170 deg²
- YJKs ~ 22 mag
- 12 Ks epochs
- 2008-2018

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

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





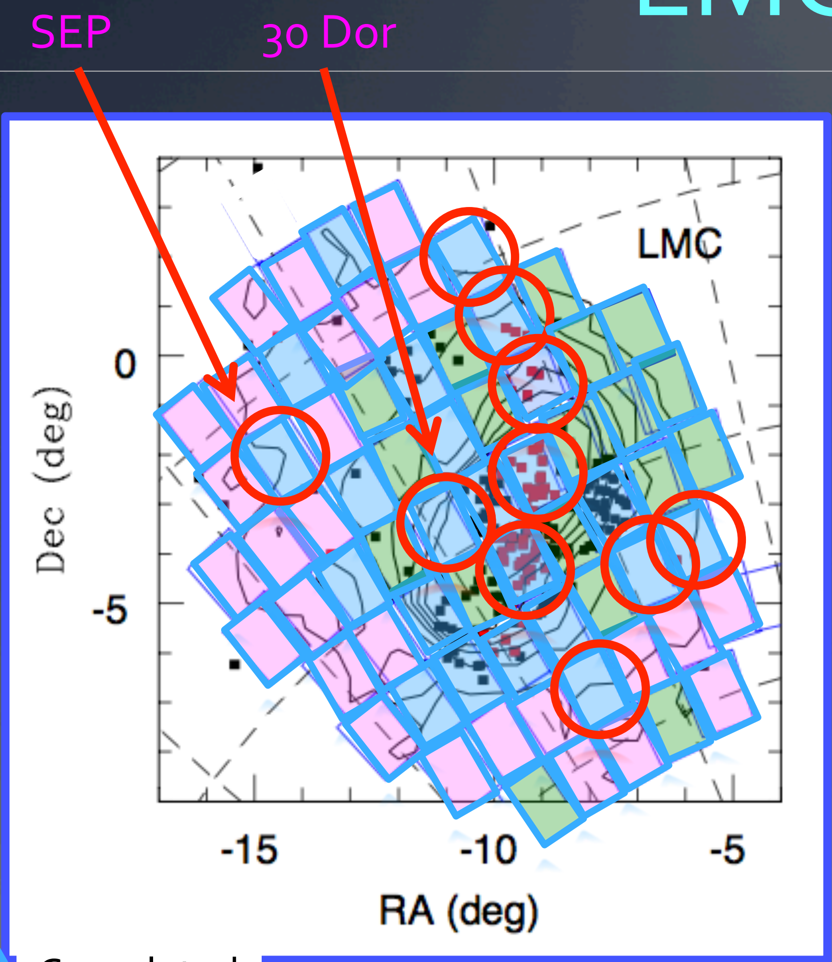


Ks-band light-curves for Cepheids and RR Lyrae stars.

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

Cioni et al. 2011

Survey progress LMC & SMC



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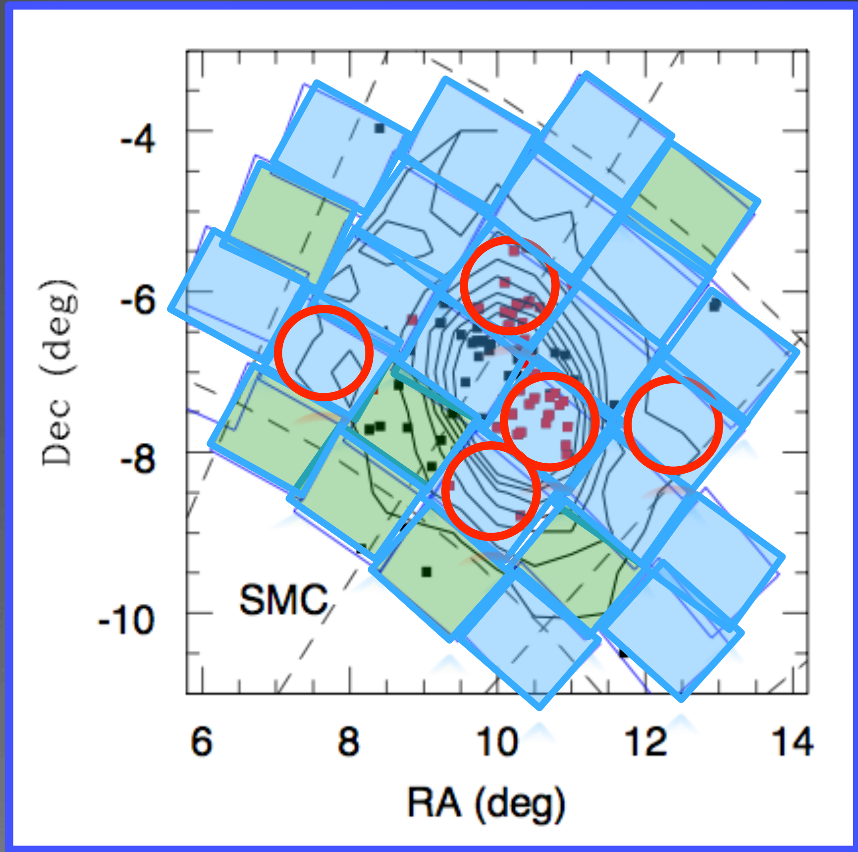


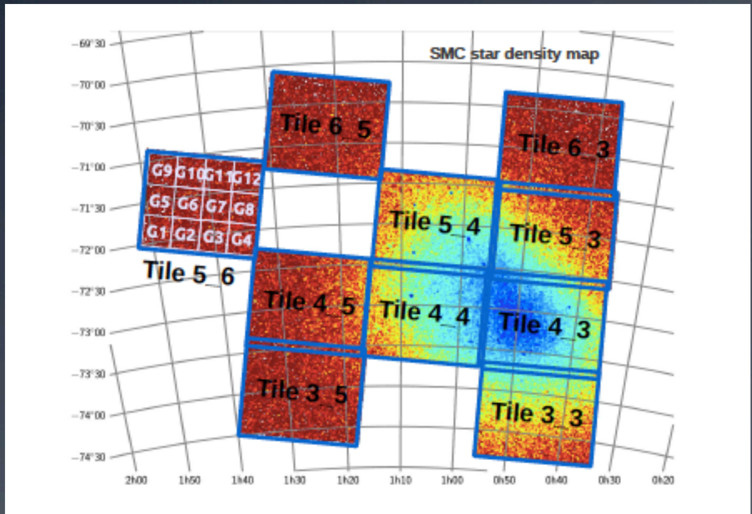
Completed
Advanced
Started

Public

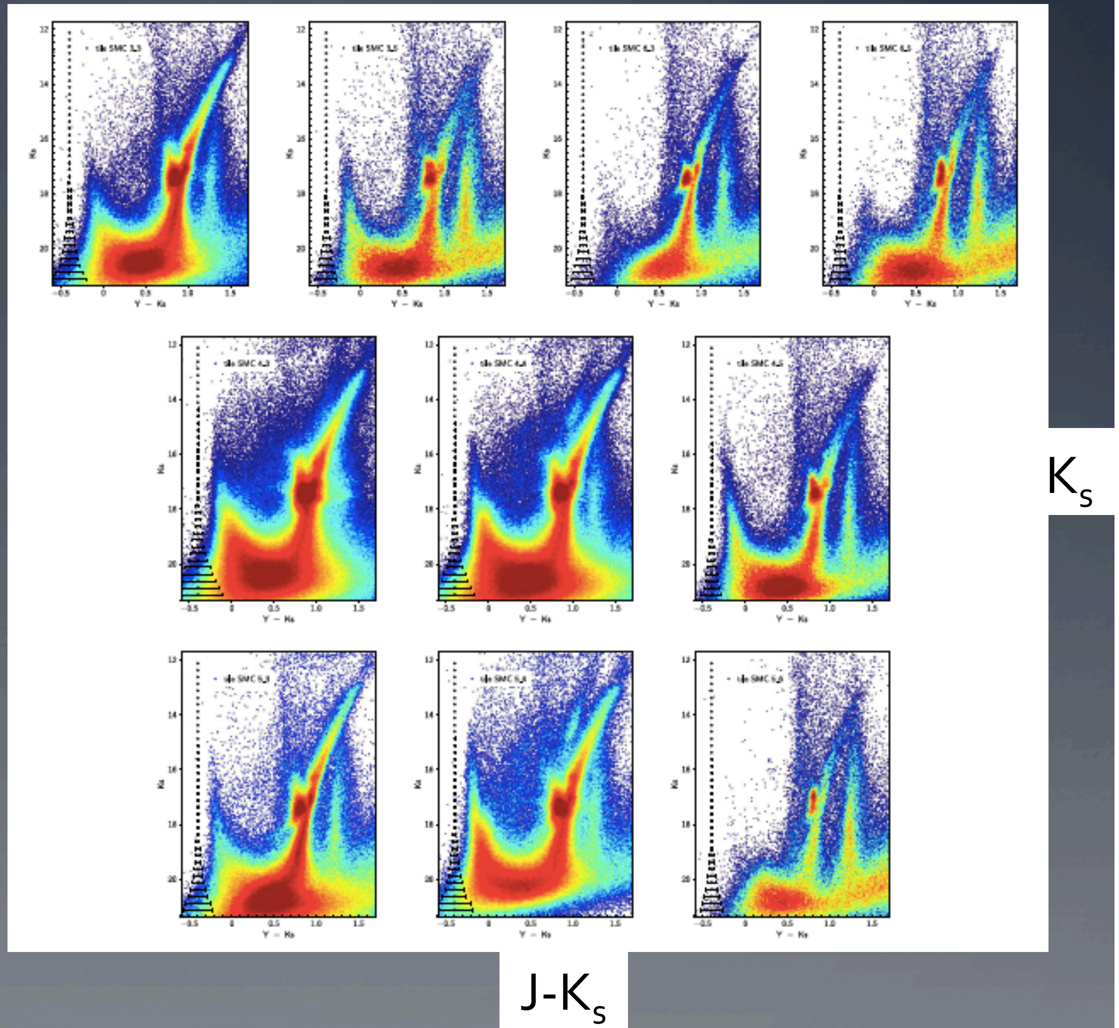
LMC is 65% complete; SMC is 95% complete!

Advanced = all YJ and at least 6 K_s epochs have been observed.

Star Formation History

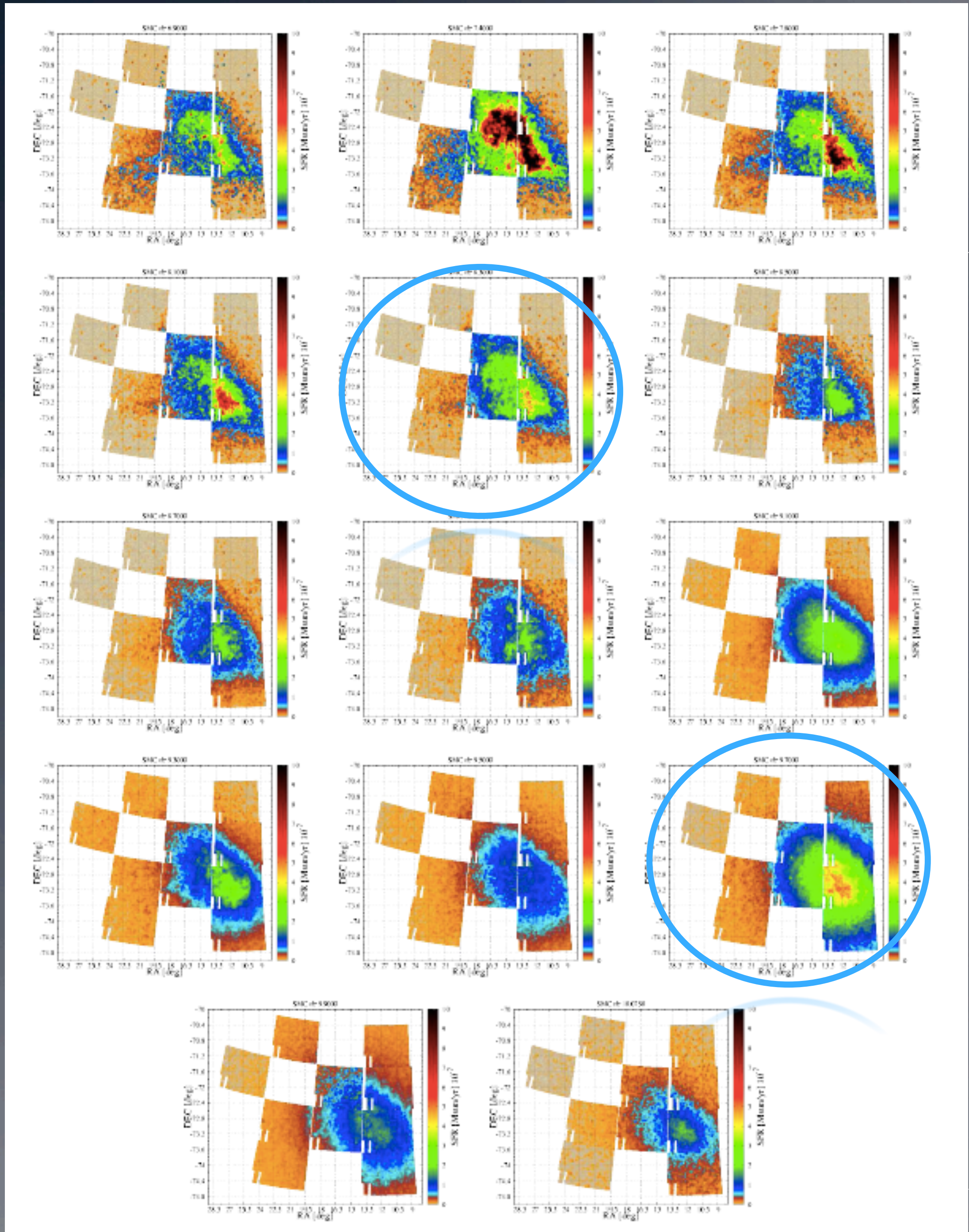


Each tile is 1.65 deg^2 in size.



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 $M_{\odot} yr^{-1}$).

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

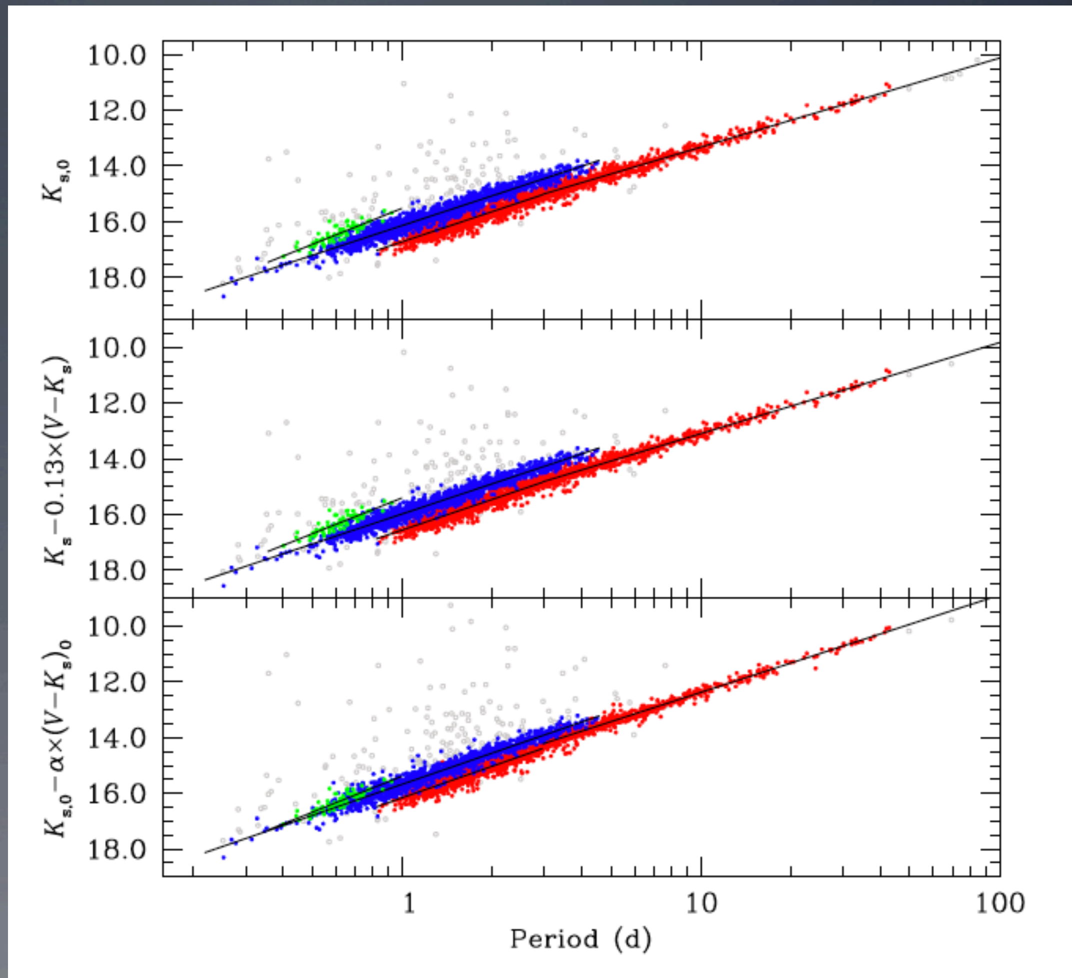
Cepheids relations

We obtain mean magnitudes from the best fitting Ks template of each star.

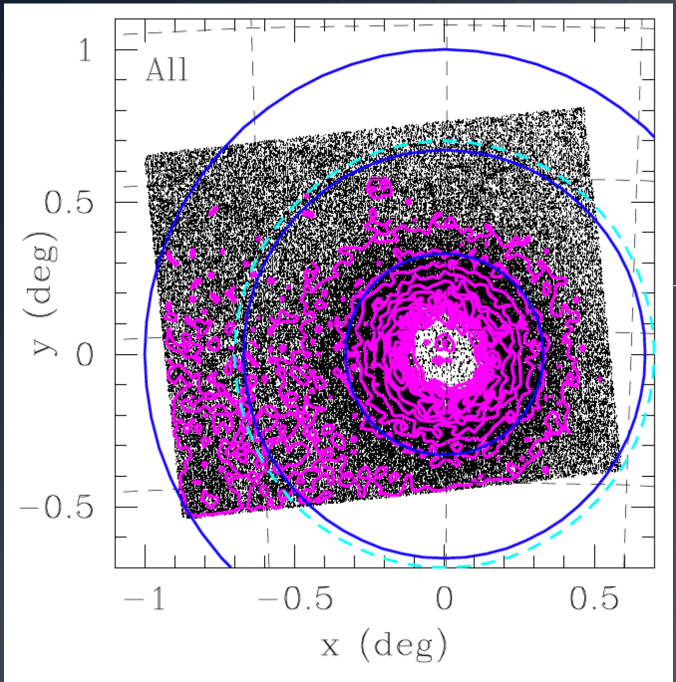
The period is obtained from OGLE III data .

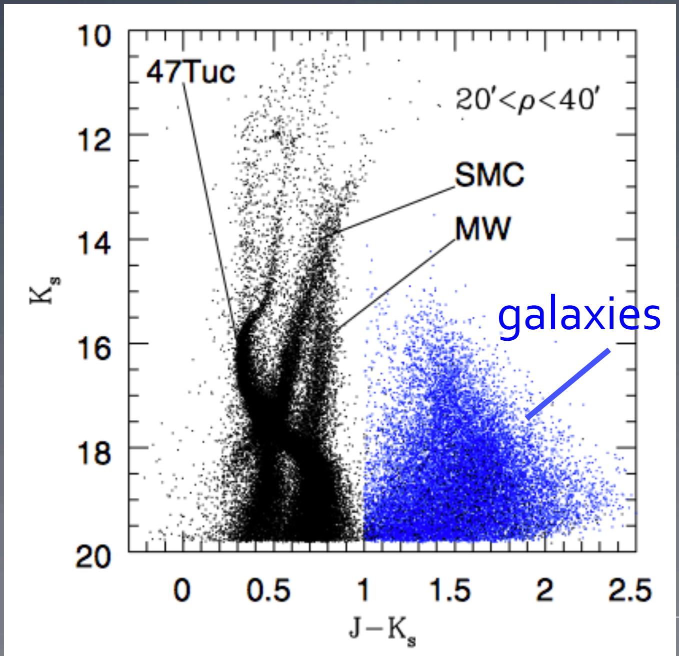
Red, blue and green indicate pulsation in the fundamental, first, and second overtones.

The rms of the relations is about 0.15 mag.
There are ~4000 Cepheids.



Ripepi et al. 2016

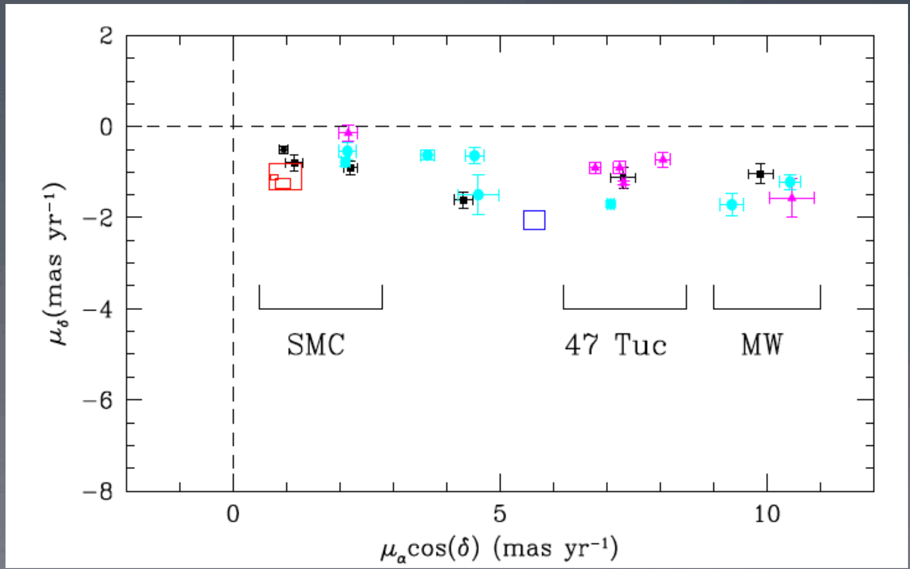




Proper motion

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

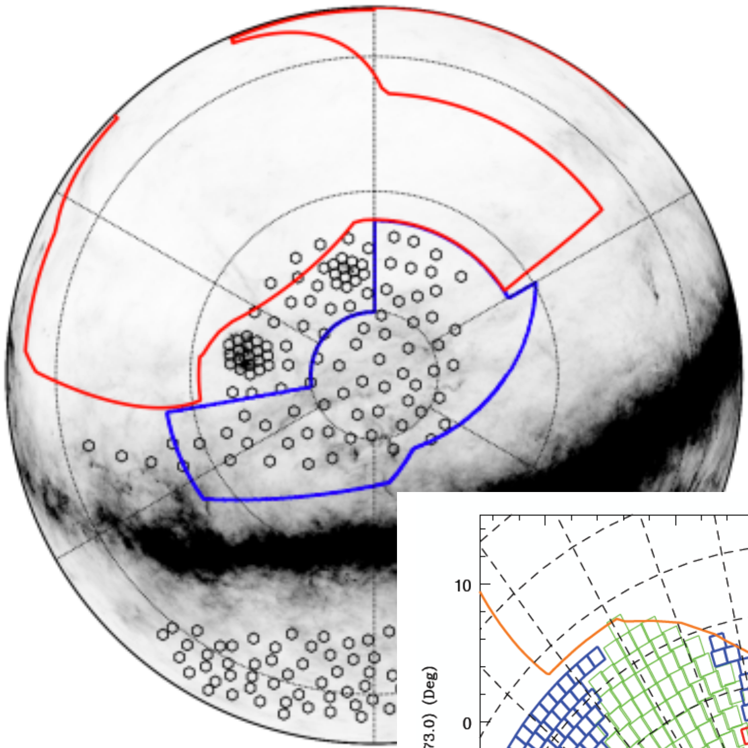
Stellar populations have distinct PMs.
There are 47 Tuc stars far out.



(red and blue squares are HST values)

Cioni et al. 2016

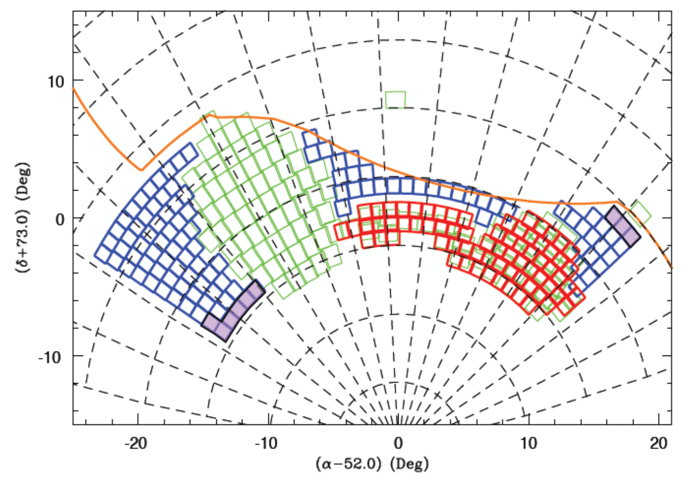
CTIO and VST surveys



Dark Energy Survey (DES)

Magellanic Satellite Survey (MagLiteS)

Survey of the Magellanic Clouds stellar history (SMASH)



VST GTO surveys:
STEP and YMCA

Common goals:

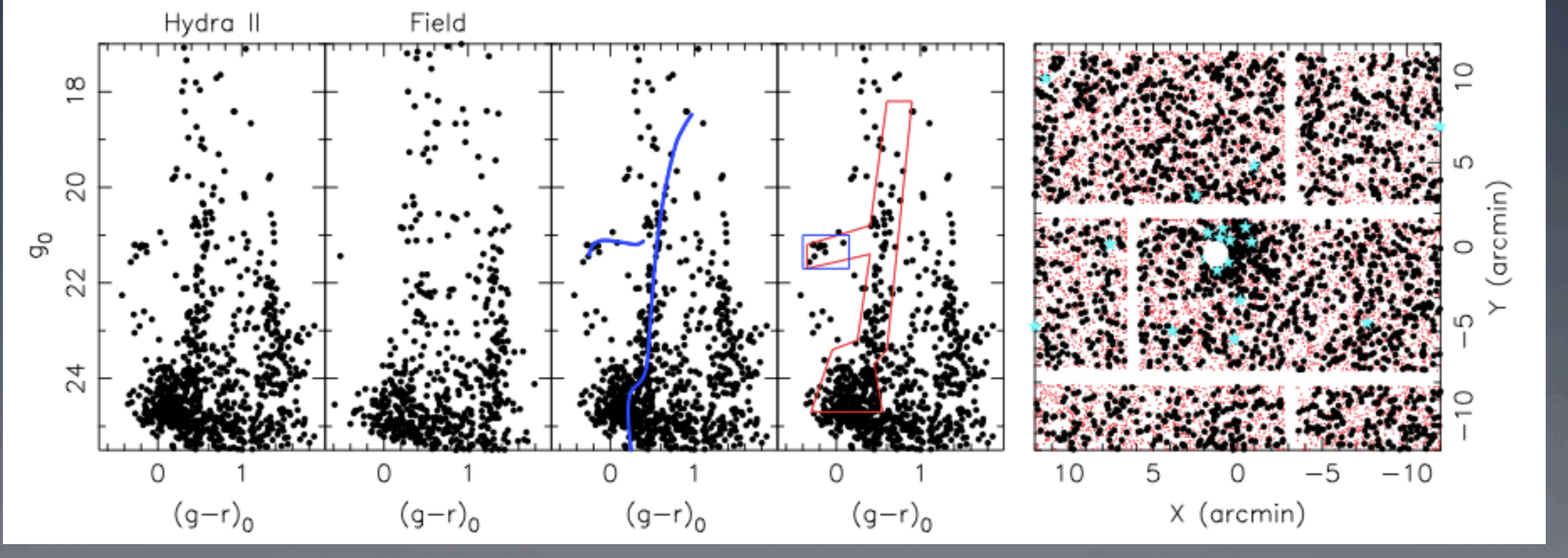
Star formation history
Inner and outer structures
Finding satellites

Outcome:

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

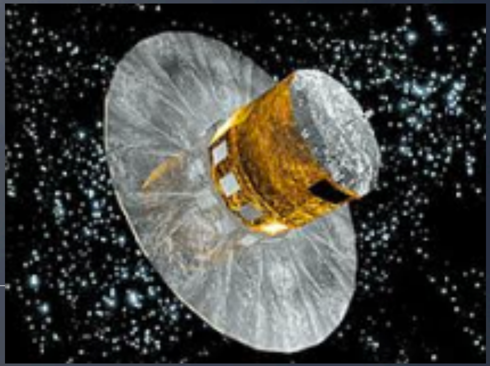
Discovery of a new satellite

Hydra II is old and metal poor. It is a distance (m-M)o=20.64+/-0.16 mag.
The isochrone corresponds to 13 Gyr and [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.)

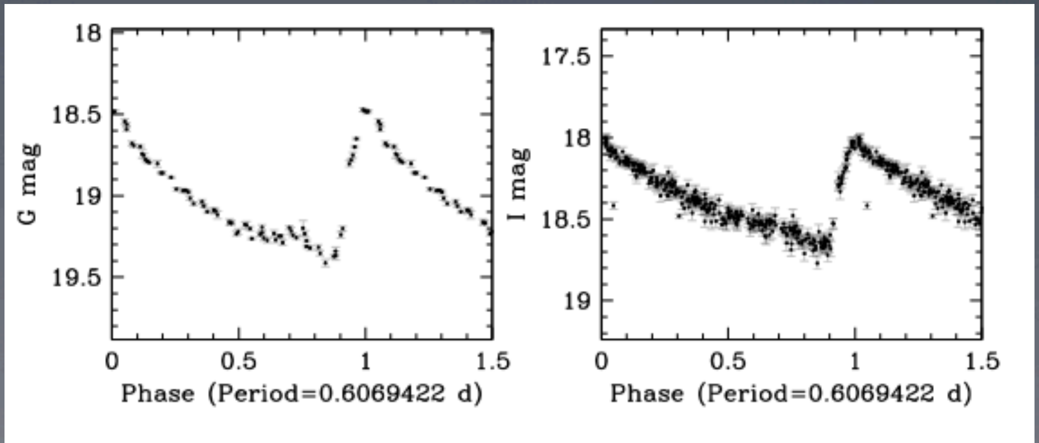
Improved reference system.

Variable stars:

Complete census

Better light-curves

Sensitive to just below the HB of the SMC

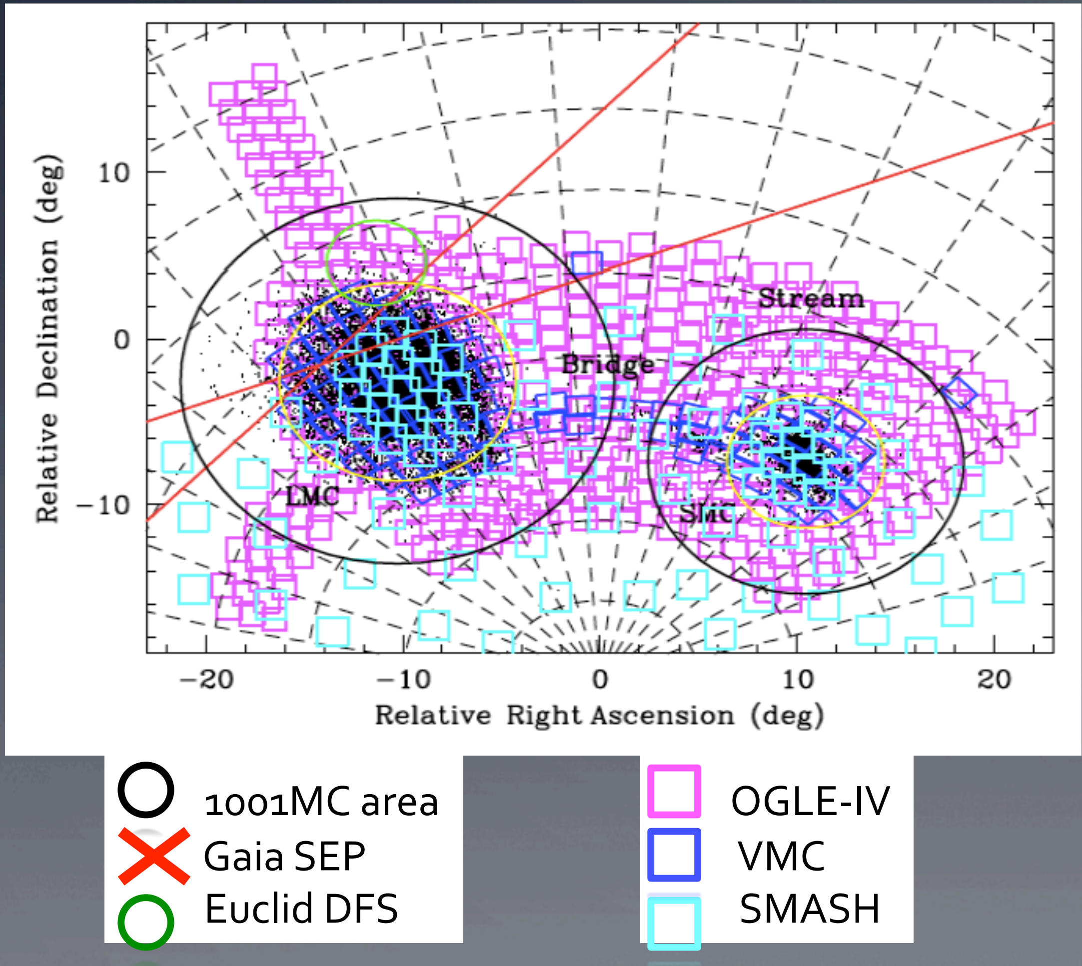


RR Lyrae stars in the Magellaic Clouds

The LSST era

1001MC@

Mid-high res. spectrograph
2400 fibres/ optical regime
To be mounted on VISTA



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.

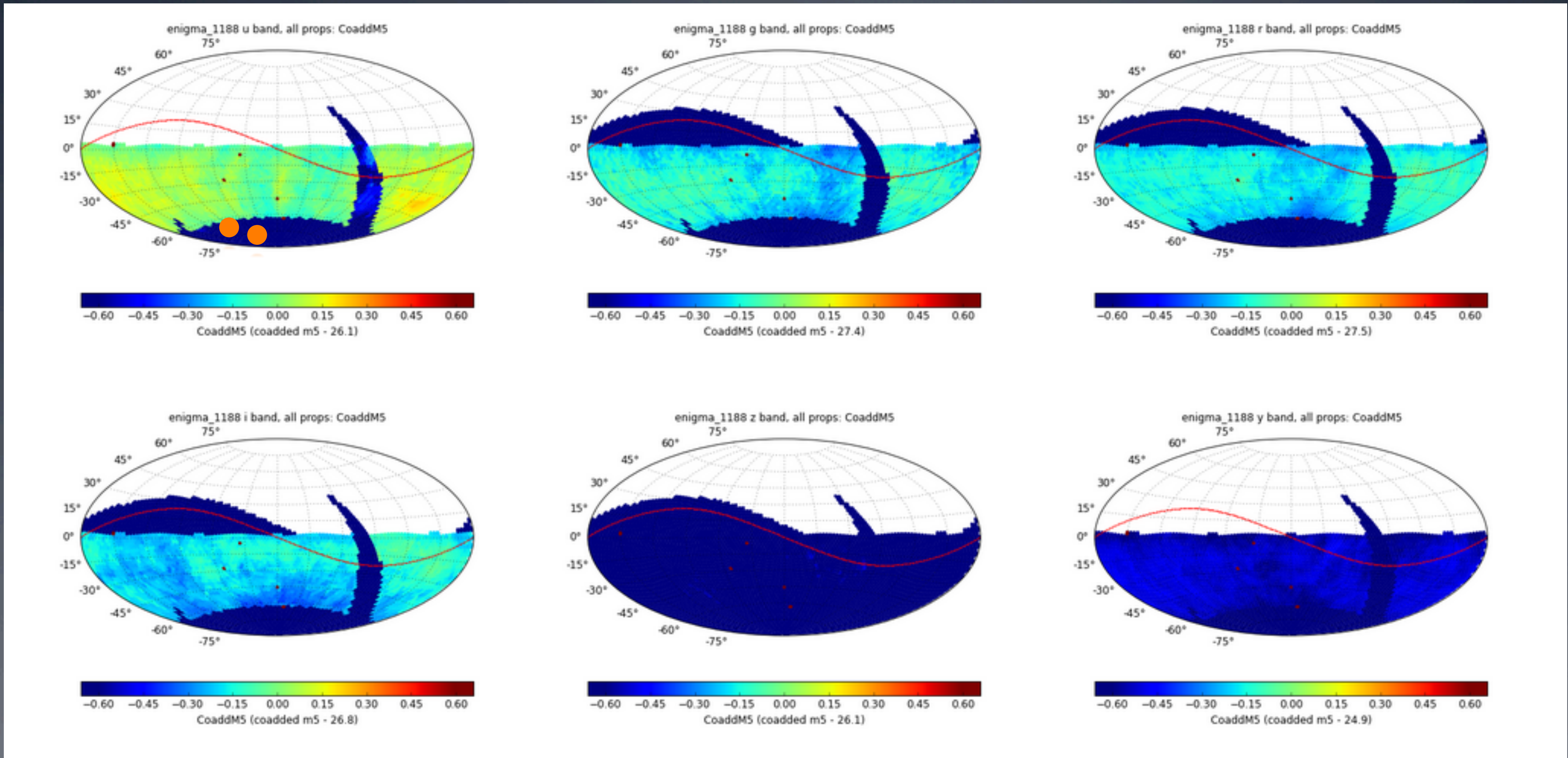
To the limit of HB stars and then use MOONs.

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

Present and future surveys

Survey	Time scale	Area (deg²)	Repeats	Scale ("/pix)	FWHM (")	Filters	Sensitivity (AB)	S/N
STEP	2011+	35	30 (i)	0.21	0.8-1.0	gi	23.5	7
OGLE-IV	2010-2014	540	~400 (I)	0.26	1.0	VI	21, 20 (Vega)	10
SMASH	2013-2016	480	1	0.27	1.0	uz + gri	24	10, 20
Skymapper	2010+	All	6	0.34	1.5	uvgriz	22-20	5
MSS	2016-2019	1300 ext.	1	0.27	1.0	gr	23	20
LSST	2021-2031	$\delta<+34$	56-184	0.2	0.8	ugrizy	22-27.5	5
Gaia	2013-2018	All	70	<<0.2	-	G band	20 (Vega)	>10
Euclid	2020-2026	$\|b\|<30$	1	0.1, 0.3	-	Vis, YJH	24	5
VMC	2009-2018	170	12 (K_s)	0.34	0.9	YJK_s	22.5-23.4	5

LSST survey design



- Magellanic Clouds

Total deph, AB mag, 5σ.

For LSST to be competitive on

Magellanic Clouds science

in the 2020s we need to:

Conclusions

- Obtain multi-epoch & multi-band observations
- Sample short- and long-time baselines.
- Cover a large area down to -80 deg (1000 deg^2; LSST Science book)

Science cases include:

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