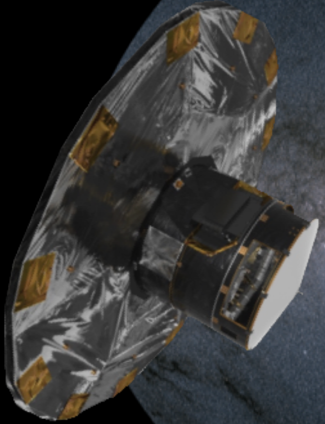
The Gaia-LSST synergy: resolved stellar populations In selected Local Group stellar systems

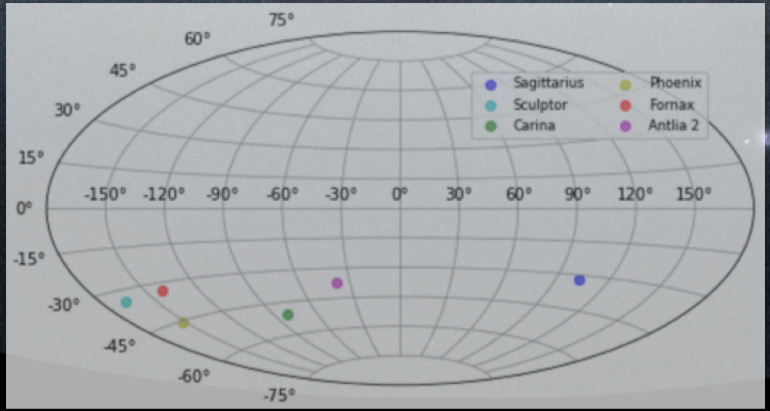
Gisella Clementini

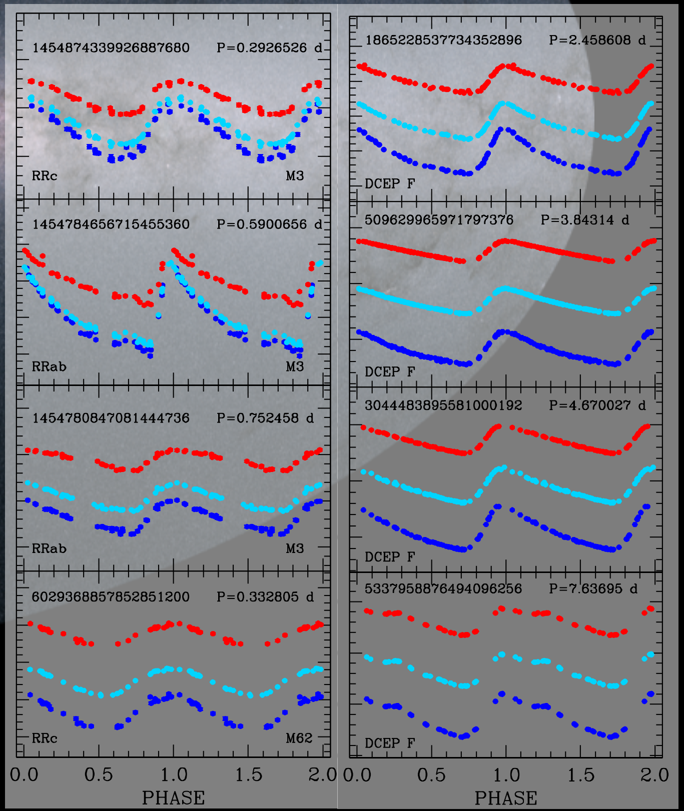
INAF - Osservatorio Di Astrofisica e Scienza dello Spazio di Bologna

PI of The Gaia-LSST Synergy Project

Cepheids & RR Lyrae WP Lead, CU7 - Gaia DPAC







Gaia-RIA Workshop, Barcelona, February 17-19, 2020

1. The Gaia-LSST synergy: from Pulsating Stars to Star Formation History

PI – G.Clementini

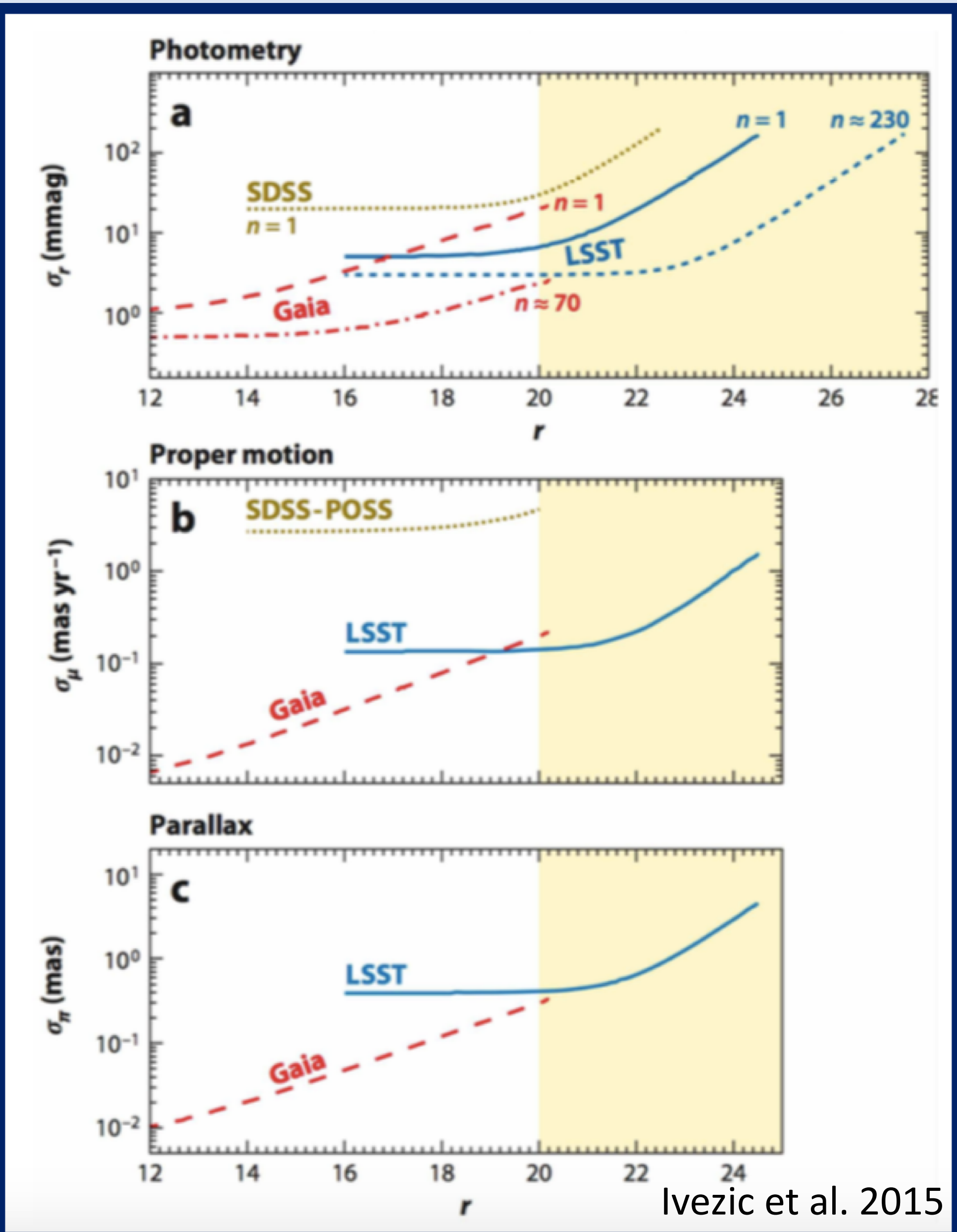
The project develops the synergy between Gaia and LSST in the field of **pulsating variable stars** (particularly RR Lyrae and Cepheids) **as standard candles and stellar population tracers** and in **star formation recovery**.

Our team includes members of the Gaia DPAC directly involved in the processing of variable sources observed by Gaia.

In its multi-epoch, unbiased monitoring of the whole sky, Gaia is measuring positions, trigonometric parallaxes, proper motions and time-series multi-band (spectro-)photometry for about 2 billions stars down to a faint magnitude limit of ∼21 mag. Among them are several thousands of Cepheids, and hundred thousands of RR Lyrae stars and LPVs in the Milky Way and other Local Group systems.

LSST will be Gaia's deep complement in the south hemisphere, as it will provide parallaxes, proper-motions, and photometry with similar uncertainties than at Gaia 's faint end but up to 5 magnitudes fainter than in Gaia.

LSST versus *Gaia*



Ivezic et al. 2015

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In its multi-epoch, unbiased monitoring of the whole sky, Gaia is measuring positions, trigonometric parallaxes, proper motions and time-series multi-band (spectro-)photometry for about 2 billions stars down to a faint magnitude limit of ~21 mag. Among them are several thousands of Cepheids, and hundred thousands of RR Lyrae stars and LPVs in the Milky Way and other Local Group systems.

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By exploiting the Gaia-LSST synergy, we aim at enlarging Gaia's horizon for pulsating variable stars as standard candles and stellar population tracers, as well as the team expertise in properly treating trigonometric parallaxes and star formation recovery into the space/time domain of LSST.

The ultimate goal is to use RR Lyrae stars and Cepheids, together with the CMD of the resolved stellar populations to:

1. Trace the stellar generations in galaxies in and beyond the Local Group;
2. Measure distances to the systems hosting RR Lyrae stars and Cepheids;
3. Map their 3D structures, radial trends, halos, streams and discover new satellites, UFDs in particular;
4. Study their star formation histories;

By combing the above information we will derive hints on how the MW, M31 and galaxies alike, have formed.

2. RR Lyrae, Cepheids and Luminous Bue Variables to constrain theory using LSST observations

PI – I.Musella

This project aims at **exploiting the LSST capabilities** as a fundamental benchmark for **stellar evolution and pulsation theory.** In particular, the distance measurements provided by LSST for Cepheids and RR Lyrae, will permit to:

1. constrain to an unprecedented level of accuracy the relations that make these stars primary distance indicators to evaluate the extragalactic distance scale and the Hubble constant;
2. derive the 3D structure of the investigated systems;
3. constrain the physical and numerical assumptions of pulsation models through the comparison between theoretical light curves and LSST observed light variations.

The project also aims at exploiting the multiband high performance monitoring capabilities of LSST to significantly increase the number of confirmed LBVs. This will enable an accurate determination of :

1. the duration of the LBV phase;
2. the location of these stars in the HR diagram;
3. the total amount of mass lost, either in total and per eruption, as a crucial ingredient in our understanding of the final fate of massive stars, as well as of the interstellar medium chemical enrichment.

LSST Science Collaborations and Task Forces involved

- Stars, Milky Way, and Local Volume Scientic Collaboration
- Transients/variable stars Scientic Collaboration
- Stellar Variability in Crowded Fields Task Force

The Gaia-LSST synergy: resolved stellar populations in selected Local Group stellar systems

Paper submitted in response to the LSST call for white papers issued in fall 2018 in order to optimise the cadence of the LSST observations.

The Gaia-LSST Synergy: resolved stellar populations in selected Local Group stellar systems

G. Clementini[1], I. Musella[2], A. Chieffi[3], M. Cignoni[4], F. Cusano[1], M. Di Criscienzo[5], M. Fabrizio[5,6], A. Garofalo[1,7], S. Leccia[2], M. Limongi[5], M. Marconi[2], E. Marini[5,8], A. Marino[5,9], P. Marrese[5,6], R. Molinaro[2], M.I. Moretti[2], T. Muraveva[1], V. Ripepi[2], G. Somma[2], P. Ventura[5],

with the support of the LSST Transient and Variable Stars Collaboration.

[1]INAF - Osservatorio di Astrofisica e Scienza dello Spazio di Bologna; [2]INAF - Osservatorio Astronomico di Capodimonte; [3]INAF - Istituto di Astrofisica e Planetologia Spaziali, Roma; [4]Dipartimento di Fisica, Università di Pisa; [5]INAF - Osservatorio Astronomico di Roma; [6]Space Science Data Center - ASI; [7]Dipartimento di Fisica e Astronomia, Università di Bologna; [8]Dipartimento di Matematica e Fisica, Università degli Studi di Roma Tre, Roma; [9]Dipartimento di Fisica e Astronomia, Università La Sapienza, Roma.

P.Is.: Gisella Clementini & Ilaria Musella

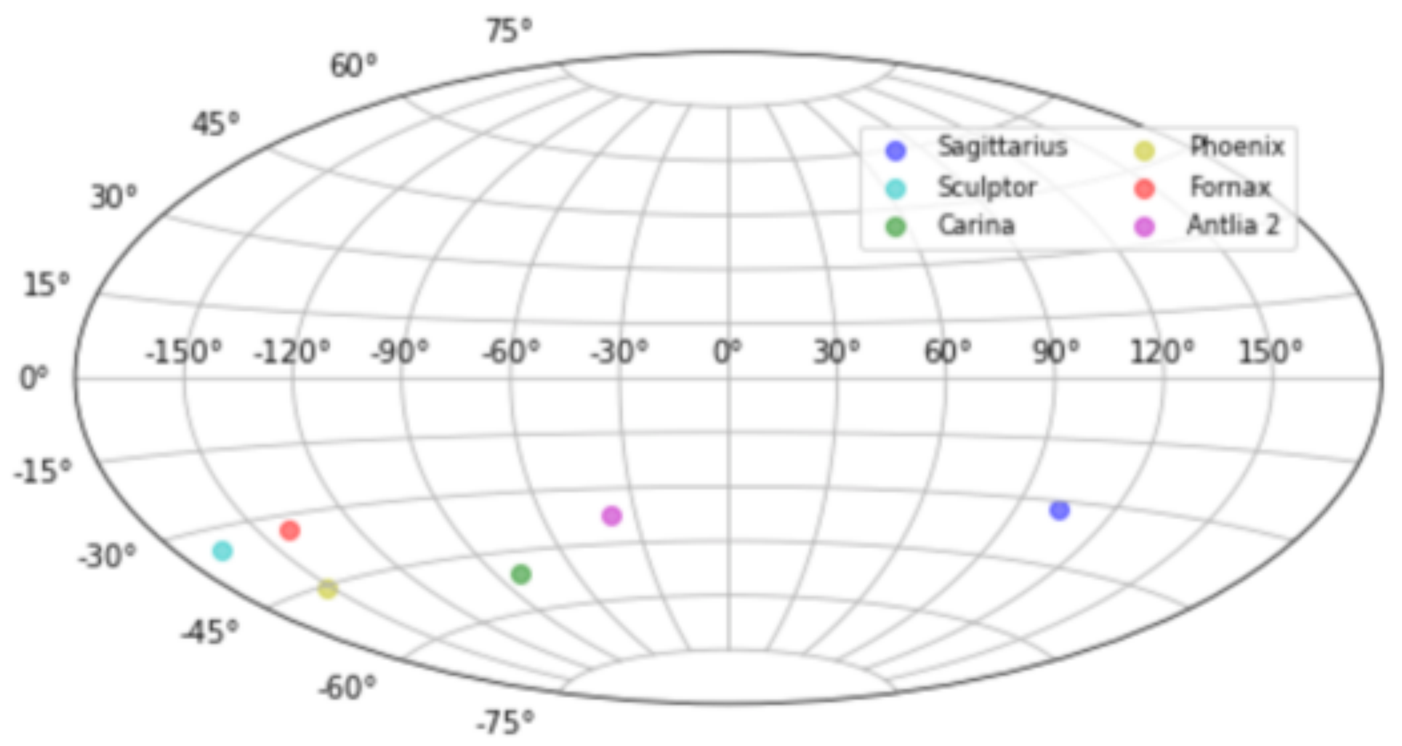
Project

Fully characterize the resolved stellar populations in/around six Local Group stellar systems of different morphological type that are located from ~30 to ~400 kpc from us.

dSphs: Sagittarius, Sculptor, Fornax, Carina

dIrr: Phoenix

''ultra-diffuse'' dwarf: Antlia 2



All our targets are included in the LSST main ''Wide-Fast-Deep survey'' (WFD)

Target selection

Table 1: Information on our selected stellar systems

Target	RA(J2000)	DEC(J2000)	$(m-M)_0$	E(B-V)	Ng	Nr	Ni
M54/Sagittarius	$18^h55^m03.3^s$	$-30°28^m43.0^s$	17.13	0.15	13	33	37
Sculptor	$01^h00^m09.35^s$	$-33°42^m32.5^s$	19.57	0.016	26	44	47
Carina	$06^h41^m36.7^s$	$-50°57^m58.0^s$	20.08	0.05	14	33	31
Fornax	$02^h39^m59.33^s$	$-34°26^m57.1^s$	20.70	0.02	28	50	56
Phoenix	$01^h51^m06.3^s$	$-44°26^m41^s$	23.10	0.014	14	23	24
Antlia 2	$9^h35^m32.64^s$	$-36°46^m02.28^s$	20.56	0.19	26	57	58

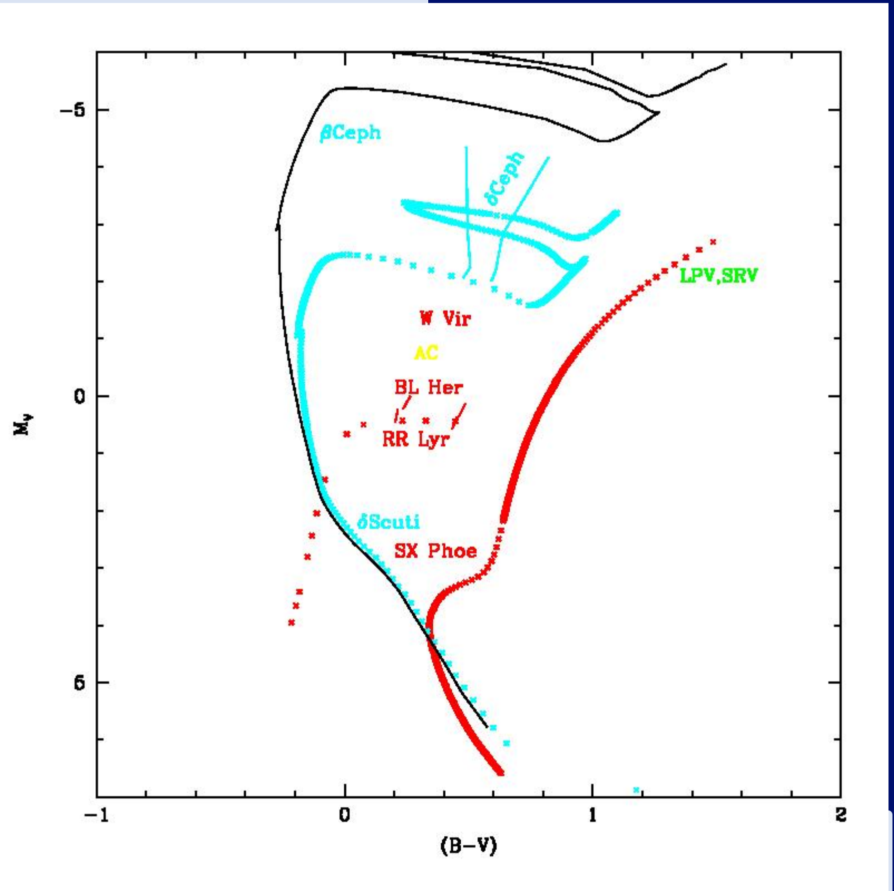
- To exploit the wide-field and deep limiting-magnitude capabilities of the LSST
- Sinergy and complementarity with *Gaia* → selected systems with an RGB within the reach of Gaia and not yet (all) saturated by the LSST
- In five of them (all but Phoenix) we will reach at least one magnitude below the TO of the oldest stellar component (t ≥ 10 Gyr) with the LSST

Project

TOOLS:

✓ pulsating variable stars populating the whole classical instability strip (obs-teo)

✓ the colour-magnitude diagram (CMD)



FINAL AIMS:

✓ to provide a complete picture of these nearby stellar systems all the way through to their periphery

✓ to directly link and cross-calibrate the Gaia and LSST projects

Tools

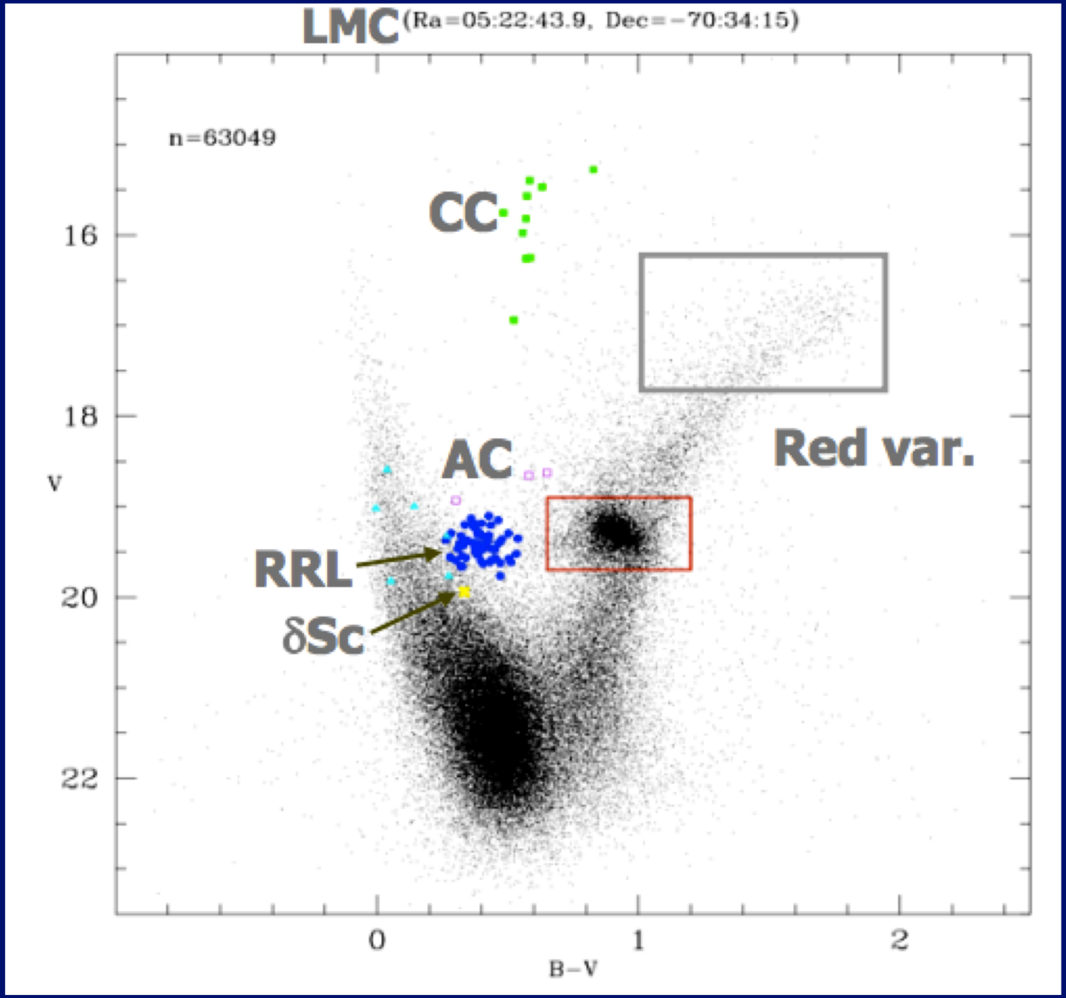
- **Pulsating variables** as tracers of the different stellar generations

  - Old (t > 10 Gyr) → RR Lyrae, Population II Cepheids, (SX Phoenicis)

  - Intermediate age → Anomalous Cepheids

  - Young (t< 100 Myr) → Classical Cepheids, (dScuti)

- **CMD** of the resolved stellar populations



Adapted from Clementini et al. 2003

LSST versus *Gaia*

Gaia:

Sagittarius → δScuti

Sculptor, Carina → RR Lyrae

Fornax, Phoenix → bright Cepheids and RGB stars

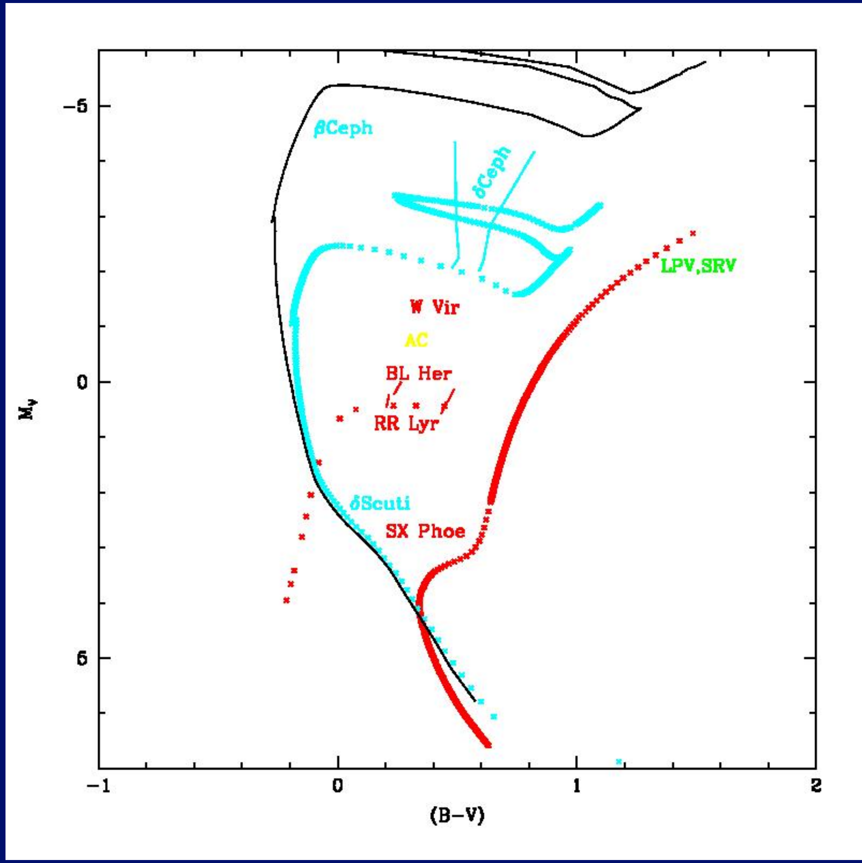
Antlia 2 → ? (depending on the system actual distance)

LSST:

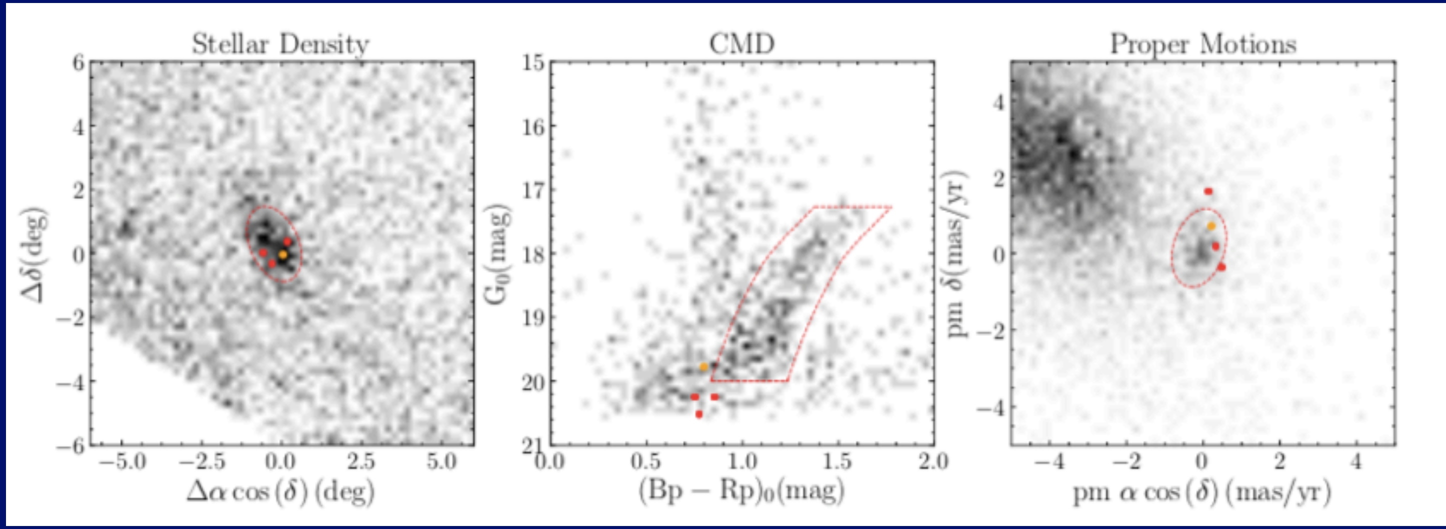
Sagittarius, Sculptor, Carina, Fornax → δScuti

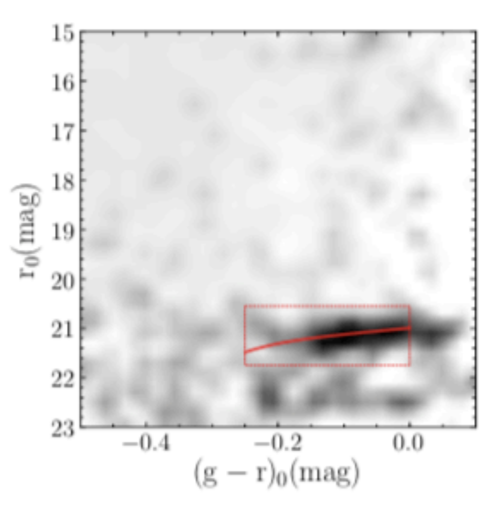
Phoenix → RR Lyrae

Antlia 2 → ? (depending on the system actual distance)



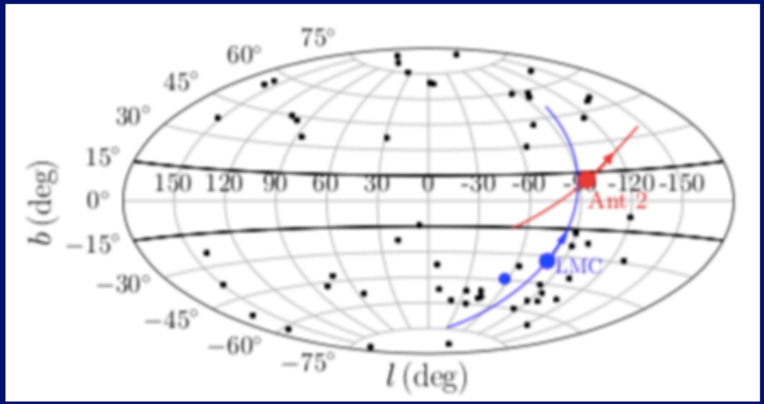
ANTLIA2



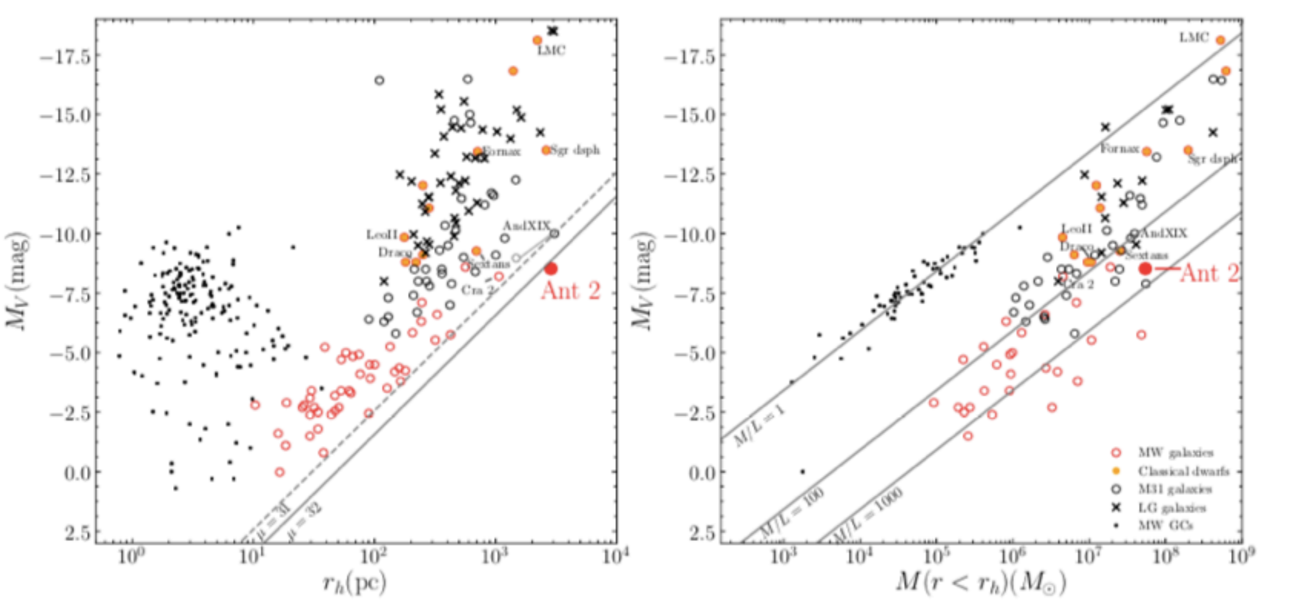


DECam

Gaia DR2

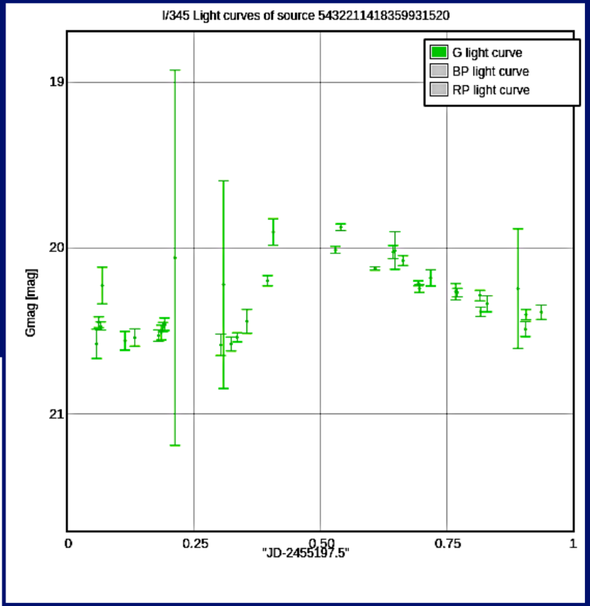


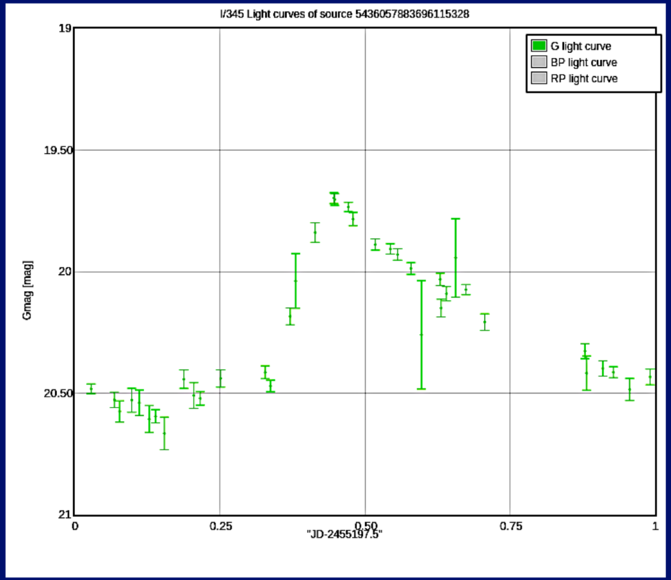
D ~ 130 kpc

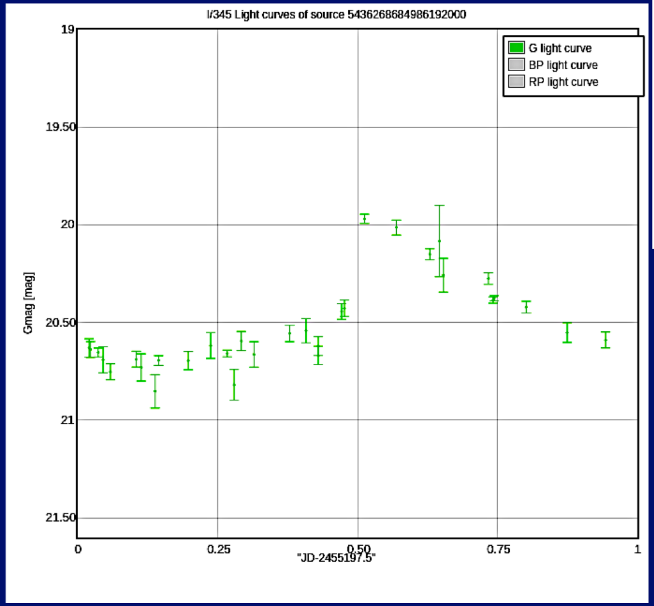


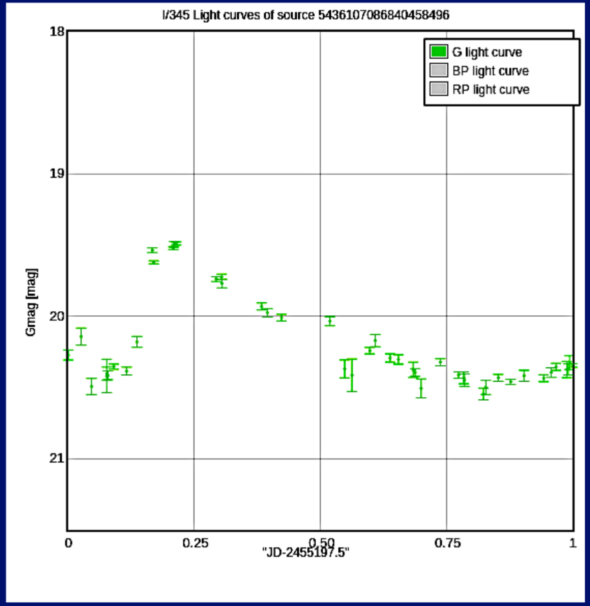
Torrealba et al. 2018, MNRAS, 488, 2743

ANTLIA2









Gaia DR2 RR Lyrae stars

D ~ 80-90 kpc

Scientific project

FINAL AIMS:

- ✓ to provide a complete picture of these nearby stellar systems all the way through to their periphery
- ✓ to directly link and cross-calibrate the Gaia and LSST projects.

Intercalibration *Gaia*-LSST

i) Intercalibrate the LSST and Gaia datasets using primarily variable stars, but also constant RGB/MS stars.

ii) Translate into the LSST passbands different theoretical and empirical diagnostic tools developed for the processing and characterization of the variable stars, as members of Coordination Unit 7 (variability) in the Gaia Data Processing and Analysis Consortium (DPAC) (Clementini et al. 2016, 2019; Ripepi et al. 2019);

iii) Test the quality assurance of products for the pulsating stars (light curves, pulsation parameters etc.);

iv) compare the LSST magnitude limits and performance with respect to Gaia in regions of high crowding/absorption;

Scientific steps

i) Trace their different stellar generations over the large spatial extension and magnitude depth allowed by the LSST;

ii) measure their distances using variable stars of different type/parent stellar population and the Tip of the Red Giant Branch (TRGB);

iii) map their 3D structures all the way through to the farther periphery of their halos;

iv) search for tidal streams which are supposed to connect some of these systems

v) study their Star Formation Histories (SFHs) over an unprecedented large fraction of their bodies.

Additional Scientific aims

i) define period-luminosity relations based on statistically significant samples of delta Scuti and SX Phoenicis stars, in different environments (see, e.g. Poretti et al. 2008, for a first example);

ii) test and validate our nonlinear convective pulsation models for several classes of pulsating stars, including in particular, δScuti, SX Phoenicis and LPVs

Data

We need time-series photometry in (at least) three passbands (*g*, *r* and *i*) in order to:

1. built multi-band light curves and deep CMDs from which to infer the properties of the stellar populations of variable and constant stars

2. to derive crucial information on extinction and chemical composition

3. the *g* band is particularly important for low amplitude light curves (δScuti have amplitudes ranging between 0.02 and 0.2 mag)

Data

All our targets are included in the main "**Wide-Fast-Deep survey**"

- ❖ >800 visits over 10 years
- ❖ Time allocation baseline2018: *u*: 8%; *g*: 10% *r*: 22%; *i*: 22% *z*: 19%; *y*: 19%

Over 10 years we do not have problems: number of visits allow us to obtain an accurate determination of their period(s), classification in types and characterization

…but our proposal aims at obtaining results in 2 years

MAF Simulations

We developped two notebooks (in collaboration with M. Di Criscienzo) based on baseline2018

- https://bit.ly/2QuNieS Very simple notebook that chooses the fields around the selected dwarf galaxies and counts the planned visits in each filter

In the first 2 years the number of planned visits are

- $15<g<25$ $23<r<57$ $24<i<58$ for the fields including the targets
- and about half for the external fields

MAF Simulations

https : //bit.ly/2Quvcd1

A very simple notebook that use PeriodicStarMetric for a number of selected galaxies (with different distances) to compute the recovery fraction of ab-, c-type RR Lyrae and δScuti stars at varying mean magnitudes, periods and amplitudes

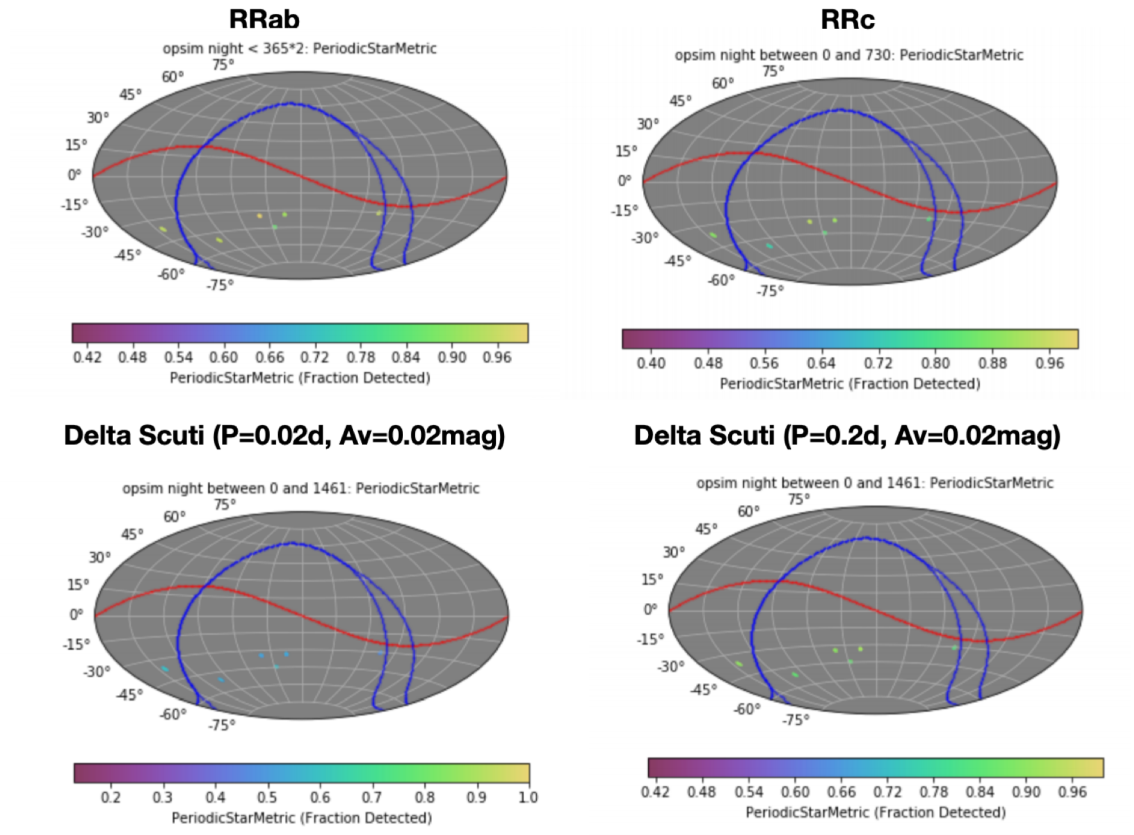


Figure 2: Recovered fraction of different types of RR Lyrae and delta Scuti stars detected in the first two years. See text for details.

Simulation results

- High amplitude RRab stars are recovered at 100% in all systems except Phoenix (with 67%), but for the low amplitude ones the recovery level goes down to 90% for Sculptor and Carina, 80% for Fornax and Antlia and to 56% for Phoenix.

- For δScuti stars the recovery level is much lower because they are significantly fainter. For low amplitude δScuti stars, in all the systems but M54, we have a maximum recovery level of 10-20% and even much lower in Phoenix, whereas for the high amplitude δScuti stars, the level increases to 30%-50%.

This metrics represents only a first approximation

Requested Cadence

Based on the above MAF simulations and the expertise gained from the processing of variable stars observed by *Gaia*, to measure accurate periods, amplitudes and mean magnitudes, we need

- at least about 30 phase-points for RR Lyrae stars
- 60 epochs for δScuti stars.

Therefore, we have proposed to double the scheduled cadence on our targets in the first two years at least in the g, r and i bands. The two possible strategies are:

1. to double the number of visits on the selected systems in the first 2 years by reducing the number in subsequent years

2. to add the necessary visits on these systems in a minisurvey framework.

Conclusions

- ✓ The two proposed strategies allow us to optimize the coverage of short period (P<1d) variables such as RR Lyrae, δScuti and SX Phoenicis stars in the selected stellar systems.

- ✓ We also need the observations provided in subsequent years in the main WDF survey to study secondary modulations on a timescale longer than main oscillations (e.g. the Blazko effect in the RR Lyrae stars, Blazhko 1907) and also to detect and characterise longer period variables.

Conclusions & latest news

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- ✓ New LSST cadence simulations were released recently that cover a wide range of science investigations → check whether they ensure the feasibility of our project.

- ✓ Over the last year the National Science Foundation (NSF) and Department of Energy (DOE) have developed new Data Access Rights and Operations Funding model for LSST in which the international participant model is focussed on in-kind contributions instead of monetary contributions.

Thank you