Report of the LSST Italy project: "The Gaia-LSST synergy: from pulsating stars and star formation history to WD planets"

G. Clementini, M. Cignoni, F. Cusano, A. Garofalo,
T. Muraveva, V. Ripepi, R. Silvotti, F. Faedi

December 2018

Abstract

Our 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. Our team includes also experts in star formation recovery and in the White Dwarf (WD) exoplanet domain. Members of this project are currently involved in the processing of variable sources observed by the ESA mission *Gaia*, which is observing and measuring positions, trigonometric parallaxes, proper motions and multi-band time-series photometry for more than one billion sources among which thousands of Cepheids and hundred thousands of RR Lyrae stars down to a faint magnitude limit of V $\sim$ 21 mag. 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 ($V \sim 21$ mag) but up to $\sim$5 magnitudes fainter than in *Gaia*. By exploiting the *Gaia*-LSST synergy, our main aim is to enlarge *Gaia*'s horizon for pulsating variable stars as standard candles and stellar population tracers and in star formation recovery into the space/time domain of LSST. To this end we have reviewed the tools and pipelines we developed for the processing, validation and characterization of pulsating stars observed by *Gaia* in order to verify their adaptability to the cadence of the LSST observations. We built catalogues of pulsating variables stars that will allow us to test the performance of the LSST pipeline for variable stars and are developing a database of images based on LBT observations that will allow us to test the LSST imaging performance. Our custom code for star formation recovery was also further developed and tested on HST images, in order to have it ready for the analysis of the LSST data on dwarf galaxies. The Gaia-LSST synergy is being developed also in the WD exoplanet domain: LSST will produce $\sim$800 photometric measurements in 10 years for $\sim$ 110,000 WDs with G<21 mag identified from *Gaia* DR2, that fall in the fields of the LSST Wide-Fast-Deep survey. These 6-band light curves will allow us to detect the first WD planetary transits, adding a fundamental step for understanding the late-stage evolution of >95% of planetary systems.

1 Quintuplet Information 2018

Please provide names, position and affiliation of the current members of the quintuplet.

- Gisella Clementini, first researcher, INAF - Osservatorio di astrofisica e scienza dello spazio di Bologna, project PI
- Michele Cignoni, fixed-term researcher, Dipartimento di Fisica, Università di Pisa, quintuplet member
- Felice Cusano, fixed-term researcher, INAF - Osservatorio di astrofisica e scienza dello spazio di Bologna, quintuplet member
- Tatiana Muraveva, PostDoc, INAF - Osservatorio di astrofisica e scienza dello spazio di Bologna, quintuplet member
- Alessia Garofalo, PhD student, University of Bologna, quintuplet member
- Vincenzo Ripepi, researcher, INAF - Osservatorio Astronomico di Capodimonte, Napoli - project Co-PI
- Roberto Silvotti, researcher, INAF - Osservatorio Astrofisico di Torino - project Co-PI
- Francesca Faedi, PostDoc, INAF - Osservatorio Astronomico di Catania - associate member

2 Quintuplet Information 2019

To be discussed at the LSST Meeting of December 18-19 in Rome, and finalised afterwards.

1. **Scientific Collaborations and/or the Task Forces joined during the last year**
    - Stars, Milky Way, and Local Volume Scientific Collaboration
    - Transients/variable stars Scientific Collaboration
    - Deep Drilling Fields (DDF) and Minisurvey (MS) proposals planning Task Force
    - Stellar Variability in Crowded Fields Task Force

3 Scientific Activity

Gisella Clementini reviewed the tools for the classification, validation and characterization of pulsating stars developed within the work package devoted to the specific processing and characterization of Cepheids and RR Lyrae stars observed by *Gaia*, that she leads in the Coordination Unit 7 (Variability) of the Gaia Data Processing and Analysis Consortium (DPAC), in order to verify their adaptability to the cadence of the LSST data flow. She prepared the White Paper "The Gaia-LSST Synergy: resolved stellar populations in selected Local Group stellar systems", which was done jointly with the LSST project: "RR Lyrae, Cepheids and Luminous Blue Variables to constrain theory using LSST observations" **PI I. Musella**, specifically taking care of defining the scientific case and selecting targets as to guarantee an optimal synergy between the *Gaia* and LSST observations and their mutual detection/saturation limits.

Michele Cignoni has been working at improving the proprietary genetic code SFERA (Star Formation Evolution Recovery Algorithm), which will be used to recover the SFH of the LSST dwarf galaxies, by testing it on several galaxies of the HST treasury program LEGUS, as well as nearby ultra faint dwarfs (UFDs) and very deep Large Magellanic Cloud fields. The aim was to make the code working in all possible conditions of stellar crowding, differential reddening, metallicities and star formation regimes. He has also implemented in the code two sets of stellar models, the Padova PARSEC 2018 and latest MESA MIST.

Alessia Garofalo performed a search for RR Lyrae variables and SX Phoenicis in Milky Way classical dwarf spheroidals (dSphs), UFDs and globular clusters (GCs), using external databases (e.g. Gaia, ViZier, ADS, OGLE IV). These databases will be used in the future to select targets for the LSST DDT minisurvey proposals and to test the performance of the LSST pipeline for variable stars. Figure 1 shows in the upper panel 148 GCs and, in the lower panel, 55 Local Group dSphs (including the 6 systems selected for observation in the LSST-Gaia synergy White Paper) and UFDs. The systems containing RR Lyrae stars were marked with different colours (see legend).

Alessia Garofalo and **Tatiana Muraveva** actively participated in the TVS Task Force (TF) on Stellar variability in crowded fields (chair M. Dall'Ora) dedicated to creating metrics aimed at testing the LSST pipeline in crowded fields by recovering main parameters (periods, magnitudes, etc.) and distances of variable stars. DECam archive calibrated images (PI: Saha) of fields observed also by the OGLE IV survey were chosen as a test dataset. Members of our quintuplet attended the TF weekly telecons, contributed to the analysis of the DECam images, the cross-match of the identified variables with the Gaia dataset and to study the under-development de-blender for the LSST stack, Scarlet.

Felice Cusano is developing a database of images based on LBT observations. The plan is to build a big photometric catalog with all possible information based on these images. As a first step of the project we are querying the LBT INAF archive to collect a sample of LBC images in the range of LSST visibility, e.g. with declination lower than dec $< +15°$. The LBC images will permit the first comparison at a similar depth of the first LSST images, allowing the detection of early transients and candidate long period variable. Furthermore, the LBC images will allow us to determine first-epoch positions for faint star ($V > 22$ mag) in the Milky Way and in dwarf satellite galaxies beyond 100 kpc, thus permitting a first LSST measure of accurate proper motion for thousand of stars.

Vincenzo Ripepi used the wide experience gathered in the preparation of the pipeline to characterize and classify classical pulsators (e.g. RR Lyrae, Cepheids and δ Sct variables) in the

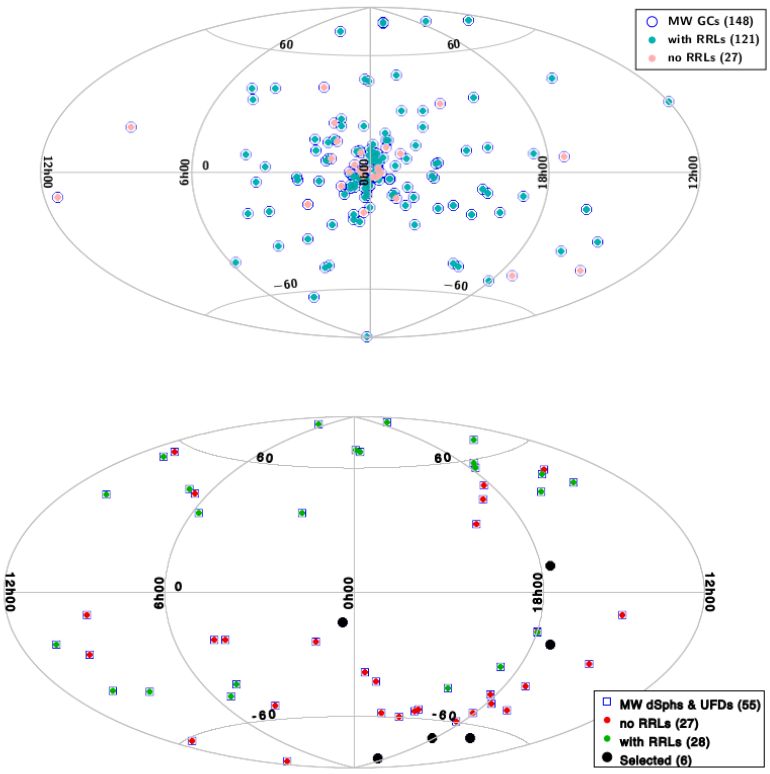

Figure 1: *Upper panel:* Distribution on the sky of 148 Galactic GCs, blue filled circles mark GCs which are known to contain RR Lyrae stars. *Lower panel:* Sky distribution of 55 Local Group dSphs and UFDs. We have highlighted in green the galaxies containing RR Lyrae stars, and with black filled circles 6 systems that we selected for observation in the LSST-Gaia synergy White Paper.

context of the Coordination Unit 7 of the *Gaia* DPAC, to contribute to the definition of the target list (galaxies, type of variables), feasibility and choice of the best observing strategy (e.g. cadence, number of visits, filters) for the White-Papers of which he is a co-author: 1) "The Gaia-LSST Synergy: resolved stellar populations in selected Local Group stellar systems" (P.I. G. Clementini, I. Musella); 2) "unVEil the darknesS of The gAlactic buLgE" (VESTALE, P.I. G. Bono); 3) "Mapping the Periphery and Variability of the Magellanic Clouds" (P.I. K. Olsen-P. Szkody).

Roberto Silvotti extracted a catalogue of *Gaia* DR2 white dwarfs falling in the LSST Wide-Fast-Deep (WFD) survey and he started preliminary simulations to estimate the efficiency in detecting WD transits when using different observing strategies (2x15^s vs 1x30^s exposures per visit). Along with **Francesca Faedi** he prepared the White Paper "Searching for white dwarf transits with LSST".

4 Scientific and technical deliverables

- White Paper "The Gaia-LSST Synergy: resolved stellar populations in selected Local Group stellar systems"
- White Paper "Searching for white dwarf transits with LSST"
- White Paper "unVEil the darknesS of The gAlactic buLgE (VESTALE)"
- White Paper "Mapping the Periphery and Variability of the Magellanic Clouds"

5 List of attached documents

1. White Paper "The Gaia-LSST Synergy: resolved stellar populations in selected Local Group stellar systems"
2. White Paper "Searching for white dwarf transits with LSST"

6 Other information

- LSST TVS Workshop, Naples, 9-11 April 2018. **Gisella Clementini, Tatiana Muraveva, Vincenzo Ripepi**.
- Weekly telecons "Stellar Variability in Crowded Fields Task Force". **Alessia Garofalo, Tatiana Muraveva**.
- Telecons of the "DDF and MS proposals planning Task Force". **Gisella Clementini, Felice Cusano**.
- LSST Special Programs Workshop, Palermo, 8-10 October 2018. **Roberto Silvotti**.