INAF – TIME ALLOCATION COMMITTEE

Application for observing time **Category: D**

Period AOT39 (April 2019 – September 2019) **Submit using: www.tng.iac.es/submit.html**

1. Title

Following-up Gaia newly discovered Cepheid variables

2. Abstract

Classical Cepheids are the most important primary indicators for the extragalactic distance scale. Establishing the precise zero points of their Period-Luminosity and Period-Wesenheit (PL/PW) relations has profound consequences on the estimate of H_0. The recent Data Release 2 (DR2) of the *Gaia* Spacecraft includes photometry and parallaxes for thousands of classical Cepheids. However follow up observations to obtain Near-Infrared (NIR) photometry as well as spectroscopic data are needed to fully exploit *Gaia* results. With the present proposal we aim at observing 50 Cepheids possessing *Gaia* parallaxes better than 20% in relative error and with a wide spread of periods. A companion proposal presents the complementary part of the project to obtain high-resolution spectroscopy with HARPS-N for a sample of 12 objects observable from both hemispheres.

3a. Number of requested hours per telescope and instrument

TNG					REM	
DOLORES	DOLOR.+MOS	NICS	HARPS-N	GIANO-B	ROSS	REMIR
					100	100

3b. Observing modes

TNG:		Visitor		Service		ToO
REM:		Rapid Response	X	Queuing		ToO

4a. Preferred months

first choice: Apr second choice: Sept

4b. Other scheduling constraints (use also box 14)

5a. Past and future of the project

a) Hours already awarded to the project:

b) Hours foreseen to complete the project: 100
(not including this request)

6. Principal investigator

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8. Status of the project

Telescope	Instrument	Date	Hours	Notes

Description

Publications

9a. If this proposal is a part of a PhD thesis, write here the name of the student, the thesis title and briefly describe the relevance of these observations for the thesis goals.

G. De Somma, *The theoretical calibration of the H_0 from Classical Cepheids.* The proposed observations will be crucial to test theoretical predictions concerning the use of multi-filter Period-Luminosity and Period-Wesenheit relations and their dependence on chemical composition.

9b. Is this, or a similar application submitted to other time allocation committees (e.g. ESO, TNG-CAT, ITP)? If yes, please specify which and explain if and why the proposals should be considered complementary.

10. Description of the programme (max. 3 pages, including references, tables, and figures.)

A) Scientific rationale Classical Cepheids (DCEPs) are young (50-500 Myrs) Population I stars commonly found in disks of late-type galaxies as well as in the irregular ones. DCEPs are the most important primary distance indicators for the cosmic distance scale (Riess+2016,Riess+2018a), due to their characteristic Period-Luminosity (PL) and Period-Wesenheit (PW - reddening-free) relations (Leavitt 1912,Madore 1982,Caputo+2000). In conjunction with secondary distance indicators such as SNIa, the DCEPs provide an estimate of $\mathrm{H}_0 \sim 73.48 \pm 1.66$ km/sec/Mpc with 2.3% of claimed uncertainty (Riess+2018b). However, there is a tension at 3.4-3.7 σ with $\mathrm{H}_0 \sim 66.93 \pm 0.62$ km/sec/Mpc obtained from the analysis of the cosmic microwave background plus ΛCDM model (Planck Collaboration+2016,Riess+2018a,Riess+2018b).

To reconcile the inconsistency between these values, we need more accurate calibrations of the different steps of the cosmic distance ladder. In first place we have to check locally (in the Milky Way) the calibration of slopes/zero points of the PL/PW relations used for CCs that at moment rely on a handful of objects with accurate Hubble Space Telescope (HST) parallaxes (Riess+2018a).

In this context a great help can be given by the measures of the astrometric spacecraft *Gaia* (Gaia Collaboration, Prusti+2016). Indeed, the recent Data Release 2 (Gaia Collaboration Brown+ 2018) includes accurate photometry and astrometry (including parallaxes) for more than 1000 DCEPs (Holl+2018,Clementini+2018). In a recent paper (Ripepi+2018) we have re-analised the sample of *Gaia* DCEPs, removing the existing contaminants, remaining with about 800 DCEPs, among which 143 are new discoveries. Gaia parallaxes are crucial to calibrate PL and PW relations. The slope and the zero points of these relations depend on a number of systematic effects. As the combination of the period-mean density relation, the Stefan-Boltzmann law and the evolutionary mass-luminosity relation lead to Period-Luminosity-Color (PLC) relations, the commonly adopted PL relations result from an averaging operation of the finite color width of the instability strip. As the intrinsic dispersion of the PL relation, due to the strip topology, strongly decreases as the adopted filter wavelength increases, Near-Infrared (NIR: JHK_S bands) PL are commonly used for the distance scale. NIR bands are also much less affected by reddening with respect to the optical, even if Cepheids especially towards the Galactic center, can show large extinctions also in the NIR. On the other hand, both in the optical and NIR, the use of PW relations has many advantages, indeed they are reddening free by definition and the color term included in their definition take partially into account the width of the instability strip, thus reducing significantly the intrinsic dispersion of these relations. However, both PL and PW relations show a dependence on metallicity that is smaller at NIR but has to be taken into account to avoid systematic effects in the determination of the distances (e.g. Romaniello+2008, Bono+2010, Gieren+2018 and references therein). An additional issue in the determination of PL/PW relations for DCEPs is the presence of companions. Indeed, it is estimated that at least half of the DCEPs are part of binary systems (e.g. Anderson & Riess 2018). This occurrence can alter significantly both the photometry (wrong average magnitudes, especially in the optical) and the astrometry (wrong distances) of DCEPs and it needs to be taken into account in the determination of PL/PW relations.

Therefore, to safely use DCEPs for the distance scale, we need NIR photometry and information about their reddening, metallicities and possible duplicity. Accurate estimates for these quantities are already present in the literature (e.g. Genovali+2015) for a subsample of about 1/3 of the DCEPs observed by *Gaia*. Hence, to fully exploit the *Gaia* astrometry for the DCEP pulsators it is crucial to carry out follow-up observations, to obtain accurate: i) light curves in the JHK_s bands and ii) high resolution spectra

In this context, the instruments available to our community are perfect for our purposes. Indeed, the target DCEPs are bright enough to be imaged by REM in the NIR (and Optical) and to obtain high-resolution spectra with HARPS-N@TNG. In this proposal we concentrate on the NIR photometry, whereas a parallel proposal is devoted to the spectroscopy with HARPS-N.

B) Scientific aim We aim at collecting 15 epochs in $g'r'i'z'$ and JHK' for 50 DCEPs with *Gaia* parallaxes with relative errors better than 20% with ROSS2 and REMIR instruments at REM telescope, respectively. The main aim of the proposal is to secure accurate light curves in the NIR bands, however REM is able to observe simultaneously in the optical, so that the $g'r'i'z'$ photometry comes for free. Less reliable average magnitudes in the NIR bands can be obtained with a smaller number of epochs, but, since *Gaia* final release will provide distance moduli to better than 1-2% for hundreds of DCEPs, there is no point in being limited by the precision of the photometry. Moreover also optical photometry will be useful as detailed below. The sample of target DCEPs includes the 12 objects observable from both hemispheres also proposed for HARPS-N observations. The remaining 38 objects have been chosen among the DCEPs observed by *Gaia* with the following characteristics: 1) absence of NIR photometry in the literature; 2) relative error in parallax better than 20%; 3) wide spread in period. In particular we included objects with short (<1 d) and long (> 30 d) periods, very important to better constrain PL/PW DCEP relations, but present in the literature (NIR photometry) in poor numbers. The sample of DCEPs proposed here will enhance the number of such objects with good JHK' light curves by ∼13%, thus representing an enlargement of the sample capable of influencing the derived PL/PW relations. These numbers can be doubled in the next semester, when we plan to apply for a similar number of targets.

As an additional benefit of the proposed observations, the optical photometry will be extremely useful, as we will adopt the multi-wavelength fitting of the reddening law (Freedman+1991) to estimate individual reddening values with precision of 1-2% by using 10 filters, i.e. $g'r'i'z'JHK'$ from REM plus G, G_{BP}, G_{RP} from *Gaia*.

Summarising, the proposed observations will allow us to: i) increase the sample of DCEPs with accurate *Gaia* parallaxes and NIR photometry by 13% (+13% next semester); ii) estimate individual reddening values for all targets; iii) determine more accurate NIR PL/PW relations for DCEPs using *Gaia* parallaxes.

Anderson, R. I.; Riess, A. 2018, ApJ, 861, 36
Bono et al. 2010, ApJ, 715, 277
Caputo et al. 2000, A&A, 354, 610
Clementini et al. 2018, arXiv:1805.02079
Freedman, W. L., Wilson, C. D., & Madore, B. F. 1991, ApJ, 372, 455 Gaia Collaboration et al. 2016 2016, A&A, 595, A1
Gaia Collaboration et al. 2018, A&A, 616, A1
Genovali et al. 2015, A&A, 580, A17
Gieren et al. 2018, arXiv:1809.04073
Holl et al. 201818, arXiv:1804.09373
Leavitt & Pickering 1912, Harvard College Observatory Circular, 173, 1
Madore 1982, ApJ, 253, 575
Riess et al. 2016, ApJ, 826, 56
Riess et al. 2018a, ApJ, 855, 136
Riess et al. 2018b, ApJ, 861, 126
Ripepi et al. 2018, arXiv181010486R
Romaniello et al. 2008, A&A, 488, 731

11. List of targets (note that the absence of a proper object list and information may weaken the proposal)

Name	α	δ	Epoch	Mag.	Time	Additional Information
431901873...	19 20 06.95	+12 47 43.0	J2000	G9.38	360s	Target also for HARPS-N
410485778...	18 31 19.75	-13 06 29.5	J2000	G9.48	360s	Target also for HARPS-N
406988778...	18 03 41.74	-22 10 58.7	J2000	G9.54	360s	Target also for HARPS-N
434461141...	16 23 26.40	-09 40 59.5	J2000	G9.57	360s	Target also for HARPS-N
409634104...	18 21 05.54	-18 27 19.7	J2000	G9.80	360s	Target also for HARPS-N
415475802...	18 39 04.03	-10 49 21.3	J2000	G9.97	360s	Target also for HARPS-N
425646446...	18 33 46.85	-04 48 32.9	J2000	G10.07	360s	Target also for HARPS-N
427857059...	18 48 16.32	+00 49 03.5	J2000	G10.21	360s	Target also for HARPS-N
409578265...	18 09 46.69	-18 22 38.3	J2000	G10.31	360s	Target also for HARPS-N
182519033...	19 35 44.75	+18 56 42.5	J2000	G10.60	360s	Target also for HARPS-N
415555094...	18 36 52.36	-09 07 04.8	J2000	G10.62	360s	Target also for HARPS-N
414569787...	18 11 30.60	-15 55 33.5	J2000	G10.73	360s	Target also for HARPS-N
589110816...	14 23 45.69	-58 29 25.0	J2000	G11.27	360s	
406388359...	17 52 28.41	-26 42 12.6	J2000	G11.91	360s	
585789287...	13 17 13.75	-66 04 59.5	J2000	G11.51	360s	
426819862...	19 13 50.71	+02 51 19.9	J2000	G10.93	360s	
434461141...	16 23 26.40	-09 40 59.5	J2000	G 9.57	360s	
428916637...	19 32 07.18	+03 00 45.5	J2000	G13.73	360s	
598081442...	15 58 46.91	-53 41 47.3	J2000	G 9.45	360s	
593439871...	16 28 11.23	-51 11 56.4	J2000	G 9.76	360s	
410390193...	18 38 48.40	-13 24 46.0	J2000	G 8.75	360s	
586338940...	13 11 04.45	-61 37 37.4	J2000	G11.21	360s	
406368942...	17 52 58.15	-27 36 00.4	J2000	G 9.46	360s	
598144513...	16 01 25.31	-51 50 20.4	J2000	G11.14	360s	
415778009...	18 14 15.83	-09 20 20.6	J2000	G10.73	360s	
406382655...	17 54 17.60	-26 45 29.6	J2000	G10.82	360s	
586252934...	13 14 00.15	-62 29 54.4	J2000	G11.82	360s	
409578265...	18 09 46.69	-18 22 38.3	J2000	G10.31	360s	
585390185...	14 07 42.00	-63 15 15.6	J2000	G11.76	360s	
597480367...	17 32 53.11	-35 54 41.1	J2000	G11.48	360s	
414569787...	18 11 30.60	-15 55 33.5	J2000	G10.73	360s	

12. Observational strategy and justification of requested time, including overheads.

The proposed targets have all $Gaia$ G mag comprised between about 9 and 15 mag (see target list), but in large majority they are brighter than 12 mag in G. Using the REMIR ETC, we estimated that we can reach very high SNR (>100) with DIT=5,10,15 s (repeated 5 times) for bright, intermediate and faint objects, respectively. On average, including the overheads (about 300s estimated on past similar observations with REM), we calculate that each epoch will take about 480s. Since we aim at observing 15 epochs for 50 objects, the total time required by present proposal is 480s x 15 epochs x 50 objects = 100 h.
Simultaneous photometry in $g'r'i'z'$ will be obtained tuning the exposure times in order to avoid saturation. Special reduction techniques will be adopted to treat stray light contamination in the optical, which represents a serious problem for the observations with ROSS2. Overall, including all the effects other than photon noise, we estimate that we will reach a photometric precision for few % both in the optical and in the NIR bands. The photometric calibration will be easily secured by the 2MASS survey in the NIR and APASS in the optical. The monitoring nature of REM observing strategy is ideal to our purposes since we aim at obtaining well sampled light curves for variables displaying a variety of periods, from 1 to about 50 days, with RA that makes it possible to image the targets for several months from La Silla.

11a. Additional list of targets

Name	α	δ	Epoch	Mag.	Time	Additional Information

13. Requested instrument(s) setup

Id	Instrument	Binning	Filter(s)	Slit	Grism	Time	Additional Information
1	ROSS2	1x1	$g'r'i'z'$			100h	
2	REMIR	1x1	JHK'			100h	

14a. Moonlight constraints

Max. # of days from new moon $\boxed{10}$

14b. Scheduling constraints, special requirements and other remarks
(please include justification of constraints in 14a)

Given the problems of stray light in the optical bands, it is preferable to avoid full moon.

It would be preferable to not obtain more than one epoch per night per target, in order to obtain an approximately even sampling of the light curve also for target DCEPs with periods larger than a few days.

Note that we inserted the complete list of 50 targets in the box 11 and 11a (note also that the target names are truncated as the *Gaia* IDs are too long), but those targets supposed to fall in the box 11a - i.e. the extrapage 4a - for unknown reasons are not displayed. In any case the full list is present in the .tex file.

15. Observational background of the applicants

Name of the observer(s) at TNG:

Experience of the observer(s) with the requested TNG instrument(s)

Experience of the observer(s) with other telescopes/instruments

FGG-INAF complies with the Spanish law for sensible data management (LOPD). Please read the page www.tng.iac.es/info/lopd/lopd-aot.html

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