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

Precise Ages, Masses, and Radii for Evolved Stars in Open Clusters

2. Abstract

We propose spectroscopic observations of eclipsing binaries in two rich open clusters (M37 and NGC 1817) to produce precise ages. Masses and radii can be measured very precisely in eclipsing binaries, and when one of the stars is evolving measurably away from the zero-age main sequence, age can be determined precisely and with minimal systematic uncertainty. In the bigger picture, anchoring age measurements to precise standards in this way improves the fidelity of other techniques (like gyrochronology and asteroseismology) that are difficult or impossible to predict theoretically and require calibration. The proposed observations are part of a broader effort provide stellar age standards for this purpose.

3a. Number of requested hours per telescope and instrument

TNG					REM	
DOLORES	DOLOR.+MOS	NICS	HARPS-N	GIANO-B	ROSS	REMIR
			10			

3b. Observing modes

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

4a. Preferred months

first choice: September second choice: April

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

The NGC 1817 target will only be observable toward the end of the semester, while the M37 targets will observable at both ends.

5a. Past and future of the project

a) Hours already awarded to the project:

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

6. Principal investigator

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7. Co-investigators (name and institution)

L. Malavolta, Padova University (Italy),
D. Nardiello, Padova University (Italy),
E. Sandquist, San Diego State University (USA)

8. Status of the project

Telescope	Instrument	Date	Hours	Notes
TNG	HARPS-N	2017gen	63	Due to bad weather and technical problems only 40h collected

Description

Observations were obtained for several binaries, with one (V1178 Tau) overlapping with the current proposal. As discussed in section 12, we are requesting spectra with higher S/N in order to better measure the rapidly rotating stars in V1178 Tau. Results for one binary in the old open cluster M67 have been been published (see below), and two others are in the process of being analyzed.

Publications

- Sandquist, E. et al. 2018, AJ, 155, 152
- Brucalassi, A. et al. 2017, A&A, 603, 85
- Nardiello, Libralato, Bedin et al. 2016, MNRAS, 455, 2337
- Libralato, Nardiello, Bedin et al. 2016, MNRAS, 463, 1780

\+ Press Release: `http://www.media.inaf.it/2016/09/23/a-caccia-di-esopianeti-negli-ammassi-stellari/`
- Nardiello, Libralato, Bedin et al. 2016, MNRAS, 463, 1831
- Brucalassi A. et al. 2016 A&A, 592, L1

\+ Press Release: `https://www.eso.org/public/news/eso1621/`
- Brucalassi A. et al. 2014 A&A, 592, L9.
- Pasquini, L.; Brucalassi, A.; Ruiz, M.T.; Bonifacio, P.; Lovis, C.; Saglia, R.; Bedin L. R. et al.2012, A&A, 545, A139.
- Pichardo, B.; Moreno, E.; Allen, C.; Bedin, L. R.; Bellini, A.; Pasquini, L. 2012AJ....143...73P.
- Yadav, R. K. S.; Bedin, L. R.; Piotto, G.; Anderson, J.; Cassisi, S.; Villanova, S.; Platais, I.; Pasquini, L.; Momany, Y.; Sagar, R. 2008A&A...484..609Y.
- Pasquini, L.; Biazzo, K.; Bonifacio, P.; Randich, S.; Bedin, L. R. 2008A&A...489..677P.

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.

No.

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.

No.

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

A) Scientific rationale Age is the most difficult characteristic to determine for a star, largely because their internal changes leave little observable evidence during most of their lives. Even when a stars characteristics start to evolve more rapidly, the age of the star cannot be measured directly; models are always necessary at some stage in the process (Soderblom 2010). As a result, age determination is subject to systematic uncertainties in our understanding of the physics of stellar interiors. To address this, we can confront theory with measurements that can be made precisely and interpreted with well-understood physics. Mass is a fundamental and precisely measurable property for stars in double-lined spectroscopic binaries (if orbital inclination is known). When one of the stars is at the main sequence turnoff or beyond, the mass in combination with other rapidly-changing properties (like radius or color-magnitude position) precisely constrains age (to better than 5% uncertainty).

Most traditional and newer age measurement methods have substantial observational and theoretical obstacles. Isochrone fitting to color-magnitude diagrams (CMDs) of the most quickly evolving stars in a cluster is extremely common, but there are *many* pitfalls like observational uncertainties in distance, reddening, and chemical composition; and theoretical ones in the physics of convection, and in color-$T_{\rm eff}$ transformations that produce systematic (and sometimes correlated) errors. Asteroseismology is a practical tool for probing the interior structure of giants thanks to Kepler and COROT. However, although a stars mean density can be determined well from simple measures of the oscillation spectrum, estimations of stellar masses and radii (and through them, age) use scaling relations based on solar type stars that require calibration to eliminate systematic errors, and this calibration is continues. Gyrochronology promises to produce ages for individual main sequence stars, but this depends on empirically calibrating how stars of different masses spin down with time.

Ages play a crucial role in the white dwarf initial-final mass relation (IFMR). White dwarf masses can be measured with good precision from spectra, but the WDs have mostly lost the information about their progenitors. For WDs in most clusters, cluster age minus the WD cooling time is related to the star's original mass. Uncertainty in cluster age is frequently the largest contributor to uncertainty in the initial masses (Salaris et al. 2009), and this can be virtually eliminated with well-measured masses of evolved cluster stars. Important parts of this relation are the high mass end ($M_{WD} \geq 1 M_{\odot}$) near the white dwarf/neutron star transition, and the transition from massive to the most common ($\sim 0.6 M_{\odot}$) white dwarfs. With appropriate choice of cluster, these part of the white dwarf IFMR can be targeted and delineated in detail.

B) Scientific aim As eclipsing systems, thorough study of our targets can provide radius measurements of the component stars. The observations we propose are intended to establish precise stellar masses, radii, and ages in clusters where models are tested and *many* age-measurement techniques are calibrated. Typical and realistic targets for "good" mass and radius measurements are less than 1% uncertainties. Age uncertainties are typically amplified mass uncertainties, although the farther a star has evolved from the zero-age main sequence, the smaller the amplification. Our targets contain the most massive stars available in eclipsing binaries in the clusters hosting them - M37 and NGC 1817.

M37 has an age (~ 500 Myr) that puts the bright cluster WDs in the transition between the largest and the most common masses (Cummings et al. 2015). Stellar rotation within the cluster has also been thoroughly studied (Hartman et al. 2009), and the cluster's age places it at the young end of the range when convergent rotational evolution has established a clear period-color relationship. A precise age will improve the reliability of the WD IFMR and improve the age calibration for gyrochronology.

NGC 1817 is extremely rich for an open cluster, and it provides an abundance of giant stars with measured asteroseismic parameters, thanks to an observing campaign during the *Kepler* K2 mission. The giants in this cluster are relatively young (~ 1.1 Gyr) and massive — uncommon giant stars in the field. NGC 1817 gives us the opportunity to calibrate the asteroseismological masses of these stars, but to do that, we need precise mass measurements of other stars in the cluster. The eclipsing system V1178 is our best candidate to do this, in part because it sits right at the cluster turnoff (see Figure 1) with a star evolving off the main sequence. But it is also a relatively close binary ($P = 2.207$ d), and relatively high signal and timed observations are needed to precisely separate the lines of the rapidly rotating stars. Fantastic photometry exists for the binary already (see Figure 2), so that the velocity curve is the only remaining need to derive the age.

Fig. 1. Color-magnitude diagrams of cluster members selected using *Gaia* data, with the eclipsing binary targets shown in red.

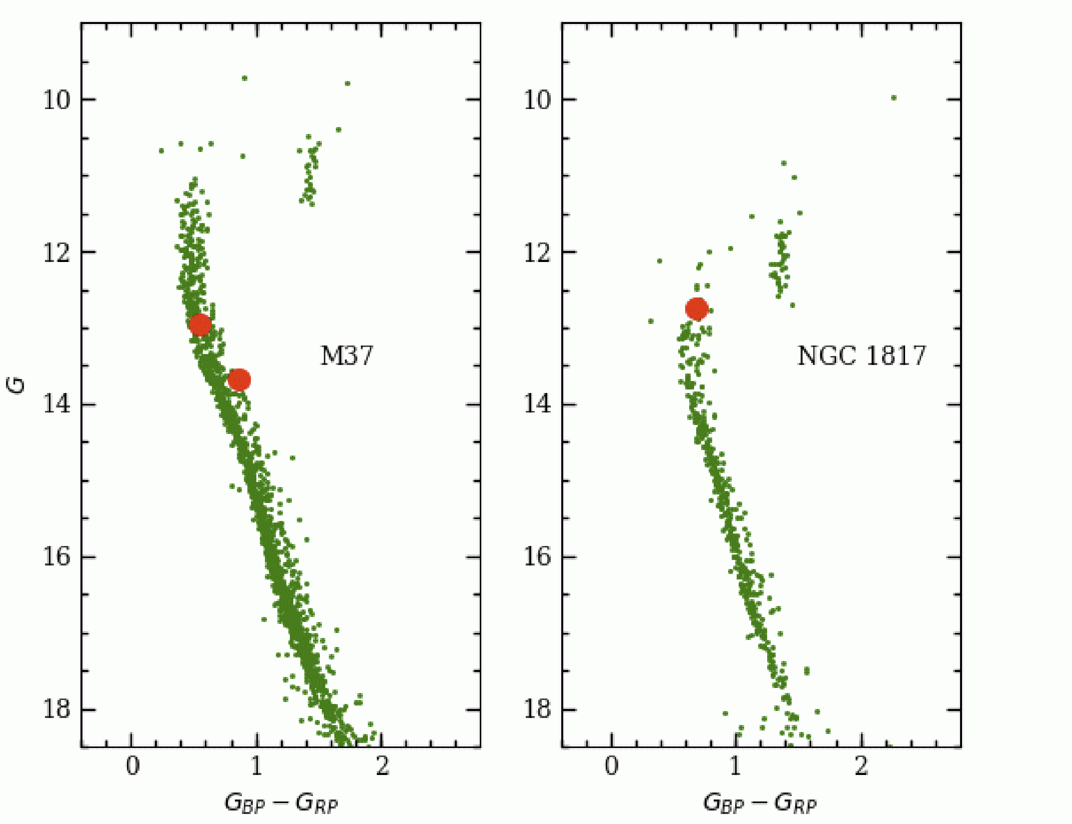
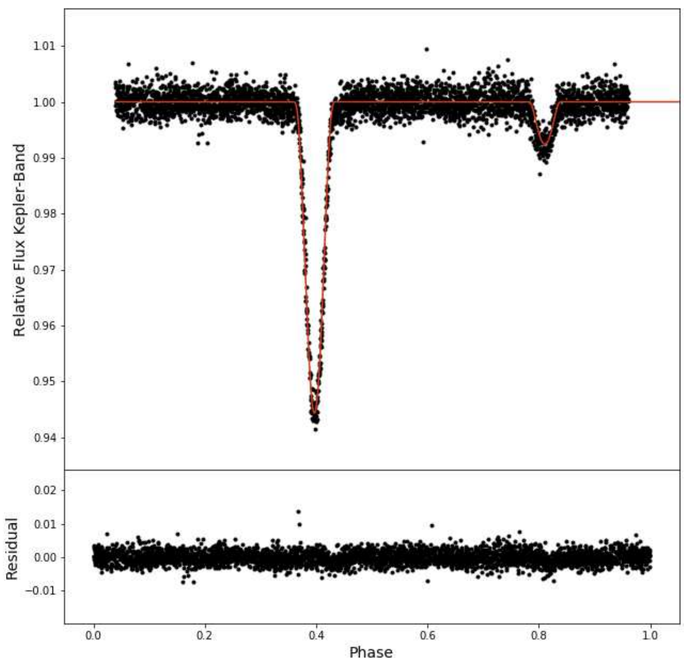


Fig. 2. *Kepler* K2 light curve and preliminary fit for V1178 Tau.



References:

Cummings et al. 2015, ApJ, 807, 90
Hartman et al. 2009, ApJ, 691, 342
Salaris et al. 2009, ApJ, 692, 1013
Soderblom 2010, ARA&A, 48, 581

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
WEBDA 486	05 52 45.6	32 33 38	J2000	V13.04	12000s	M37 member; eclipsing
V541 Aur	05 52 20.4	32 33 20	J2000	V13.41	10800s	M37 member; eclipsing
V1178 Tau	05 12 32.3	16 44 52	J2000	V12.59	9600s	NGC 1817 member; eclipsing

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

For two of the eclipsing binaries (V541 Aur and V1178 Tau), the orbital ephemerides are known, and we request observations near the radial velocity extremes in order to best determine the velocity amplitude and thus, stellar mass. For this reason, the flexible scheduling of TNG is especially important. The large collecting area of the TNG, along with the high resolution, wide wavelength coverage, and stability of HARPS-N will make it possible to disentangle the spectra of the two stars in these relatively faint targets. Because the targets are stellar eclipsing binaries with relatively short orbital periods, the velocity amplitudes are tens of km s^{-1}, and will be easily detectable with enough signal for the fainter star. We have calculated exposure times for individual visits to have S/N near 30 for an airmass of 1.2 and $1''$ seeing.

For V1178 Tau, the orbital period (2.207 d) makes it so the times to observe velocity extremes are typically on successive nights. Our calculations of the best nights for observation at TNG are: August 28, September 7, 17 and 18 (although the 18th may have large contamination from the Moon nearby), 27 and 28. We request four visits of 2400 s each. The two stars are nearly equal in brightness, and have both been detected in previous spectra, but their large rotational velocities make relatively high S/N necessary to separate their line contributions.

For V541 Aur, the orbital period (5.34785 d) is longer, and good dates are less common. Our calculations indicate that observations on April 8, and September 24 and 27 will be closest to the velocity extremes. We require exposures of 3600 s for each visit, broken into 30 minute sub-exposures for an update of the atmospheric dispersion corrector and telescope focus.

For the remaining eclipsing binary (WEBDA 486), the orbital period is not known, and we request visits on some of the same nights that the other targets are observed in order to identify the orbital period. Exposures of 2400 s should allow us to reach S/N near 30 in the spectra, and we request 5 visits (on most nights when the other targets are observed).

13. Requested instrument(s) setup

Id	Instrument	Binning	Filter(s)	Slit	Grism	Time	Additional Information

14a. Moonlight constraints

Max. # of days from new moon 7

14b. Scheduling constraints, special requirements and other remarks

(please include justification of constraints in 14a)

Because we are requesting observations of binary stars with different orbital periods, our request would have to be filled on distinct nights. Other observations could be obtained for other programs on the same nights. The best nights for our observations are given in section 12.

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