WINERED as a Stepping Stone for the Cosmic Distance Scale

Matteo Monelli[1,2], Davide Magurno[3], Giuseppe Bono[3],
Noriyuki Matsunaga[4] and OSIRIS collaboration

1. Instituto de Astrofísica de Canarias, Calle Via Lactea, E-38205, La Laguna, Tenerife, Spain
2. Universidad de La Laguna, Dpto. Astrofísica, E-38206, La Laguna, Tenerife, Spain
3. Departimento di Fisica, Universitá di Roma Tor Vergata, via della Ricerca Scientifica 1, 00133, Rome, Italy
4. Department of Astronomy, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

We present the Oscillating Stars with wIneRed near-Infrared Spectroscopy (OSIRIS) project, aimed at deriving accurate chemical abundances of primary distance indicators covering a wide age range from young Classical Cepheids to intermediate-age Anomalous Cepheids and Miras, old RR Lyrae stars, and Type-II Cepheids. High-resolution near-infrared spectra will be collected with WINERED, a Japanese instrument with the highest available throughput in the range $0.9 - 1.35\,\mu$m. We summarize here the characteristics of the instrument, the data acquisition and reduction, and preliminary results.

1 Introduction

The Data Release 2 of the *Gaia* mission is expected for April 2018. It will release positions, proper motions, and parallaxes for about one billion stars, as well as time series data for a large number of field variable stars. This will represent a breakthrough in many fields of Galactic astrophysics, from Galactic structure, stellar populations, dynamics, formation and evolution of the Bulge, disk, and halo, and have a huge impact in the study of any class of stars. *Gaia* will also have definitive answers concerning variable stars. It will allow the geometrical calibration of the first step of the distance scale: in particular, the calibration of the metallicity-luminosity relation for the RR Lyrae stars (Sandage et al., 1981), and the period-luminosity relations for different classes of stars of both Population I and Population II (RR Lyrae, Classical Cepheids, Anomalous Cepheids, Type-II Cepheids, Miras). This in turn will have strong cosmological implications, as it will allow us to nail down the error bar on the determination of the Hubble constant (Beaton et al., 2016; Riess et al., 2018). However, *Gaia* alone will not be able to provide all the necessary information to accomplish this objective. First, high-resolution spectroscopic metallicities will be crucial to complement the low-resolution estimates provided by *Gaia*. Very little has been done in the literature about the bright field variable stars (Pancino et al., 2015), and this is a very time consuming task, as field stars have to be observed one by one. Second, for most of the brightest RR Lyrae and Cepheids there is little, if any, modern multi-wavelength CCD photometry (Monson et al., 2017).

2 The Project

Our team is running a project aimed at providing a full photometric and spectroscopic characterization of a large number of pulsating variable stars, thus complementing the next *Gaia* data releases as these are bright objects for which parallax will be very accurately measured. The sample includes stars covering all ages, from young tracers (Classical Cepheids, CCs), to intermediate-age ones (Anomalous Cepheids, ACs, and Miras), and old stars such as RR Lyrae (RRL) and Type-II Cepheids (T2C).

i) Optical and NIR photometry is performed with the IAC80 (Teide Observatory, Spain, P.I. Monelli) and the IRSF (InfraRed Survey Facility, a 1.4 m telescope located in the South African Astronomical Observatory, P.I. Matsunaga), respectively. This will allow us to have well-sampled light curves in $UBVRI$ and JHK_s.

ii) High-resolution NIR spectroscopy (P.I. Bono) aimed at deriving a large number of elements, including iron-peak, CNO, α, and s-process elements is performed with the Japanese instrument WINERED.

2.1 WINERED

WINERED (Warm INfrared Echelle spectrograph to Realize Extreme Dispersion and sensitivity) is a high-resolution echelle spectrograph developed by the University of Tokyo (Ikeda et al., 2016; Otsubo et al., 2016). It covers the NIR wavelength range from $0.90 - 1.35\,\mu$m (covering roughly the half of the z band and the entire ranges of the Y- and J-bands), with two possible channels. The low-resolution one (R = 28,000) covers the full wavelength range, while the high resolution one (R = 70,000) covers either the Y $(0.96 - 1.11\,\mu$m) or the J $(1.14 - 1.35\,\mu$m) part of the spectrum.

The main peculiarities of WINERED are the capability of obtaining high-resolution infrared spectra with high signal-to-noise ratios (SNR=500 or more) and the highest throughput (>50, 32, 42% in z-, Y-, and J-band, respectively) among presently available instruments working at similar wavelengths. WINERED was commissioned in 2013 on the 1.3 m Araki telescope at the Koyama Astronomical Observatory of Kyoto-Sangyo University in Japan. Nevertheless, WINERED is a PI-type instrument, compact and transportable, designed to be attached to various telescopes with a Nasmyth f/11 focus. In January 2017, it was installed at the NTT ESO telescope in La Silla.

Tests performed during the first technical nights have confirmed the performance of WINERED. The measured SNR varies ∼300 (10) for stars of magnitude J=5 (14.0), with integration time of 20 (900) sec. The limiting magnitudes, for an integration time of 3 hr with the wide channel, are J=13.2 (SNR=100) and J=15.2 (SNR=30).

2.2 Spectroscopic data

Data for the OSIRIS project have been collected during a 9-night run between 7 and 15 of February, 2017, under excellent weather conditions. Spectra for about 110 target stars have been collected, using both the low and high resolution modes. Figure 1 shows the spatial distribution of observed variable stars, in Galactic coordinates. Symbols of different colors mark different kinds of pulsators, as labeled.

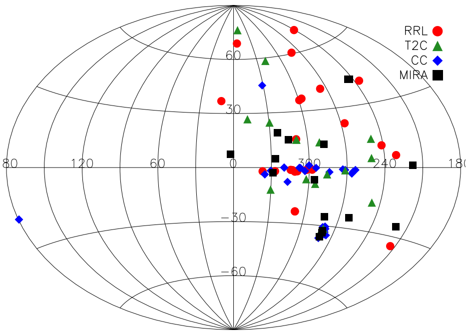

Fig. 1: Spatial distribution in Galactic coordinates of the variable stars already observed with WINERED installed at the ESO NTT telescope. Different symbols and colors indicate different pulsators.

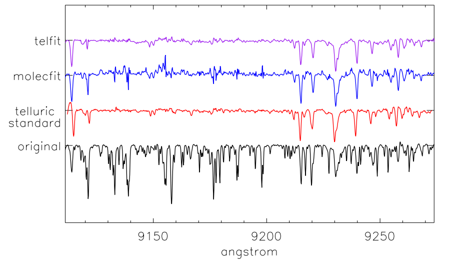

Fig. 2: Comparison of background-subtracted spectrum using different techniques.

The majority of CCs (blue) are concentrated in the Galactic plane, while the other older targets are spread at all latitudes. The clumps of points at coordinate ($\approx$280°, $\approx -30°$) show the LMC targets.

3 Data Analysis

3.1 Background subtraction

NIR bands are highly affected by telluric lines caused by the Earth's atmosphere, and careful subtraction of these features has to be performed before attempting any reliable abundance analysis. The traditional approach relies on the use of a telluric standard star, whose spectrum is subtracted from the target star. However, this approach has two main disadvantages: 1) changes of the atmospheric conditions on short time scale can cause inaccurate subtraction; 2) observation of standard stars can consume a sizable fraction of observing time. For these reasons, we decided to adopt a synthetic sky modeller to compute a proper telluric spectrum for each target star. Figure 2 shows the comparison between background subtraction with the traditional approach (red line) and with the synthetic sky modeled with two different codes, TelFit (Gullikson et al., 2014, purple line) and Molecfit (Kausch et al., 2015; Smette et al., 2015, blue line). The approach based on synthetic sky spectra has residuals of the order of 3%, very close to or better than the standard star approach. We therefore applied the TelFit method to the entire WINERED sample.

3.2 RR Lyrae abundance estimates

As a preliminary check of our data sample, we applied the equivalent width method to two field RRLs, WY Ant ([Fe/H] ~ -2.00) and UV Oct ([Fe/H] ~ -1.80), in order to estimate their metal abundances. These two stars had been already analysed by For et al. (2011) using high-resolution optical spectroscopy, collecting data to

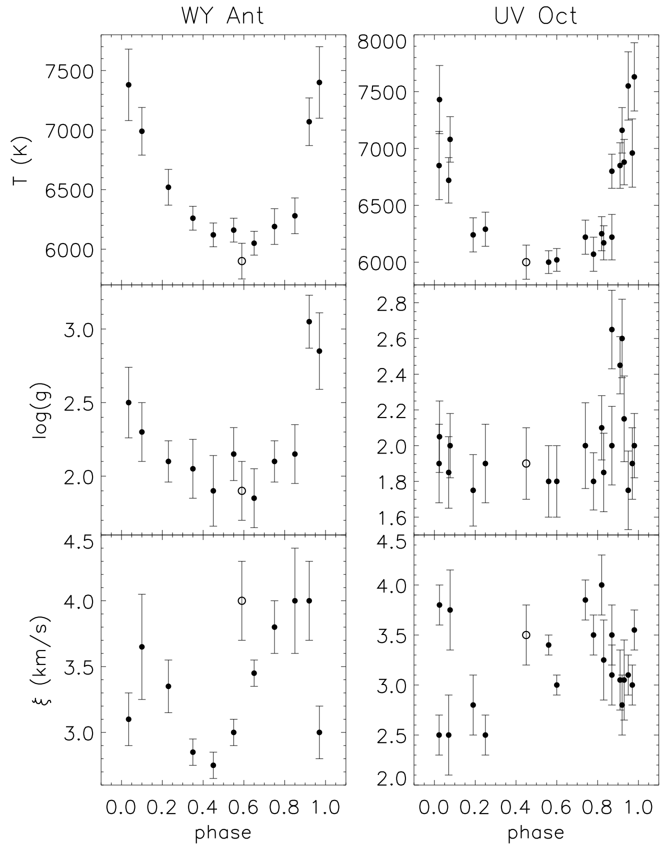

Fig. 3: Comparison of the atmospheric parameters estimated from a preliminary analysis on WINERED spectra of two RRLs (open) with the results from For et al. (2011) (black).

fully cover the pulsational period. Figure 3 shows the comparison between the spectroscopically estimated atmospheric parameters ($T_{\rm eff}$, $\log g$, microturbulence) for our sample (open symbols) and the multiphase sample of For et al. (2011) (black dots). The agreement between the two samples is extremely good within the error bars. Good agreement, within the error bars, can also be found in the estimated abundances of [Fe/H], α-elements (Mg, Si, Ca) and Sr II. Preliminary abundances agree with For et al. (2011) within about 0.2 dex, which is a good result if we consider that only few lines ($\leq$4, with the exception of Si) where observed and measured for each atomic species.

4 Conclusions and Future Work

We have presented the first results of the OSIRIS project, aimed at collecting high-resolution NIR spectra for a large sample of stellar pulsators. Targets have been selected to sample the most important families of fundamental distance indicators, for which *Gaia* will provide accurate parallaxes (CCs, ACs, Miras, RRLs, T2Cs).

Our data reduction strategy has been tested, and we have verified that:

- optical and NIR spectra provide consistent values for different chemical elements;
- abundance estimates are largely independent of pulsation phase.

The full data analysis of the ~ 150 stars observed is currently in progress.

Acknowledgements. This research has been supported by the Spanish Ministry of Economy and Competitiveness (MINECO) under the grant AYA2014-56795-P

References

Beaton, R. L., et al., *ApJ* **832**, 210 (2016), arXiv: 1604.01788

For, B.-Q., Sneden, C., Preston, G. W., *ApJS* **197**, 29 (2011), arXiv: 1110.0548

Gullikson, K., Dodson-Robinson, S., Kraus, A., *AJ* **148**, 53 (2014), arXiv: 1406.6059

Ikeda, Y., et al., in Ground-based and Airborne Instrumentation for Astronomy VI, *Proc. SPIE*, volume 9908, 99085Z (2016)

Kausch, W., et al., *A&A* **576**, A78 (2015), arXiv: 1501.07265

Monson, A. J., et al., *AJ* **153**, 96 (2017), arXiv: 1703.01520

Otsubo, S., et al., in Ground-based and Airborne Instrumentation for Astronomy VI, *Proc. SPIE*, volume 9908, 990879 (2016)

Pancino, E., et al., *MNRAS* **447**, 2404 (2015), arXiv: 1412.4580

Riess, A. G., et al., *ApJ* **853**, 126 (2018), arXiv: 1710.00844

Sandage, A., Katem, B., Sandage, M., *ApJS* **46**, 41 (1981)

Smette, A., et al., *A&A* **576**, A77 (2015), arXiv: 1501.07239