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# Variables as stellar tracers and distance indicators

M. Marconi

Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Napoli, Via Moiariello 16, I-80131 Napoli, Italy, e-mail: marcella.marconi@oacn.inaf.it

**Abstract.** The importance of pulsating stars as stellar population tracers and primary distance indicators is briefly reviewed. In particular, we discuss several approaches based on the comparison between the predictions of nonlinear convective pulsation models and observations, to constrain the intrinsic stellar parameters.

**Key words.** Stars: variables –Stars: distances – Stars: fundamental parameters

## 1. Introduction

Pulsating stars are intrinsic variables showing cyclic or periodic variations on a time scale of the order of the free fall time. In the simplest case they are radial pulsators, with typical oscillation period from few seconds to several months and pulsation amplitudes that range from a minimum set by the instrument capability to a maximum of 2-3 mag (e.g. MIRA variables). The various classes of pulsating stars map a wide range of periods and luminosities and cover different evolutionary phases. For this reason they can trace stellar populations of different age in the same galaxy. In particular RR Lyrae, Pop. II Cepheids and SX Phoenicis are typical tracers of the old (> 10 Gyr) stellar populations; Anomalous Cepheids can be interpreted as belonging to an intermediate-age (1-5 Gyr) stellar population, whereas Classical Cepheids are typical tracers of young (< 100-200 Myr) stellar populations. As Classical pulsators share approximatively the same effective temperature range in the Color-Magnitude disgram, they are expected to share the same driving mechanism too. Dating back to the pioneeristic investigations by (Zhevakin 1958) the mechanism driving pulsation is associated to a valve effect produced by opacity ($\kappa$ mechanism) and adiabatic exponent ($\gamma$ mechanism) variations in the ionization regions of the most abundant elements of stellar envelopes, namely $H$, $He$ and $He^{+}$. In particular, the $\gamma$ mechanism is the effect of temperature variations on luminosity variations, while the $\kappa$ mechanism is the effect of opacity variations on luminosity variations. The main reason for studying these pulsating stars is based on the well known relation between pulsation and intrinsic stellar parameters (van Albada & Baker 1971; Bono et al. 1997, 2000, see e.g.). On the basis of the simplest linear adiabitic theoretical approach a period density relation is obtained, that combined with the Stephan-Boltzman law implies a Period-Luminosity-Color-Mass relation (see e.g. van Albada & Baker 1971; Bono et al. 1999; Di Criscienzo et al. 2004). Observed periods and colours can be used to constrain the mass and/or the luminosity. The existence of these relations is the basis of the use of variable stars as distance indicators, through the luminosity information derived from the analysis of pulsation properties. At the same time the ML relations predicted by stellar evolution can be independently tested. To study the pulsation properties of the investigated variable stars we need to adopt pulsation models solving the hydrodynamical equations in the stellar envelope (the core is excluded; see Cox 1980, for details). In particular nonlinear convective pulsation models (Gehmeyr 1992; Bono & Stellingwerf 1994; Bono et al. 1999; Szabó et al. 2004) are able to predict all the relevant pulsation observables: periods, pulsation amplitudes, detailed lightcurves, blue and red edges of the instability strips for the selected pulsation mode.

## 2. Pulsating stars and their role of distance indicators and stellar population tracers

The most common distance indicators among pulsating stars are Classical Cepheids and RR Lyrae stars, that are intermediate and low mass central He burning stars, respectively.

### 2.1. RR Lyrae stars

These low mass pulsating stars have typical periods ranging from 0.3 to 1.0 days, a visual absolute magnitude from 0 to 1 mag and belong to the so called horizontal branch (HB) evolutionary phase. The traditional standard candle associated to RR Lyrae stars is the relation between their absolute visual magnitude and their iron content [Fe/H]. This relation is usually adopted in the linear form

$$M_V(RR) = a[Fe/H] + b$$

even if evolutionary and pulsation models suggest a change in the slope at [Fe/H]≃-1.5 (see e.g. Caputo et al. 2000; Cassisi et al. 1998; Lee et al. 1990).

A number of values determined in the literature for the slope and the zero point of the $M_V$-$[Fe/H]$ relation, in the linear approximation, are reported in Table 1.

As recently discussed by Caputo (2012) this relation is based on the assumption that everything is constant, apart from metallicity. However, the ZAHB luminosity dramatically depends on the helium abundance Y, and a significant fraction of observed RR Lyraes are generally evolved from the ZAHB. This evolutionary effect, at fixed chemical composition, is ∼0.10 mag for RR Lyrae evolving from the red side of the instability strip, but can be as large as ∼0.40 mag for those evolving from the blue side. Moreover, the transformation from the global metallicity Z to the measured [Fe/H] value, adopted to compare theory with observations, depends on the enhancement of $\alpha$-elements with respect to iron (Salaris et al. 1993). All these factors contribute to make the $M_V$-$[Fe/H]$ relation far from a sound standard candle, as exemplified by the wide ranges spanned by coefficients in Table 1.

On the other hand, since the first investigations by (Longmore et al. 1986, 1990), it is evident that RR Lyrae are standard candles also because they obey to a K band PL relation. Indeed, as both the period and the (V-K) color are strictly related to the effective temperature and the RR Lyrae visual magnitude is not period dependent, models predict a correlation between the absolute K magnitude and the pulsation period, in the sense that longer periods correspond to brighter pulsators in the K band. It has been demonstrated (Bono et al. 2001) that the intrinsic dispersion is significantly reduced when metallicity differences and evolutionary effects are corrected. Indeed, the relation holding for RR Lyrae stars is not a simple $M_K$-log $P$ but a $M_K$-log $P$-$[Fe/H]$ relation. Several authors have investigated the near infrared properties of RR Lyrae stars in order to constrain the coefficients of this relation, but in the literature are still present significant differences among the various determinations of the metallicity term coefficient (Bono et al. 2003; Dall'Ora et al. 2006; Sollima et al. 2006, see e.g.). An additional aspect to be taken into account when using RR Lyrae as distance indicators is the debated He enhancement that could affect a fraction of pulsators in selected Galactic globular clusters (see e.g. Norris 2004; Lee et al. 2005; D'Antona & Caloi 2008; Piotto et al. 2007). Stellar evolution models predict brighter stars within the RR Lyrae instability strip as Y in-

**Table 1.** Some determinations of the oefficients of the $M_V$-$[Fe/H]$ relation, in the linear approximation $M_V(RR) = a([Fe/H] + 1.5) + b$

| Source | $a$ | $b$ |
|---|---|---|
| Sandage et al. 1993 | 0.30 | 0.94 |
| Fernley et al. 1998 | 0.20 ± 0.04 | 0.98 ± 0.05 |
| Clementini et al. 2003 | 0.214 ± 0.047 | 0.54 ± 0.09 |
| Benedict et al. 2011 | 0.214 ± 0.047 | 0.45 ± 0.05 |

creases at fixed Z. But higher luminosity levels imply longer pulsation periods and, according to pulsation models, all the predicted properties change with an Y increase, more as a consequence of the brighter luminosity than for a real dependence on this parameter (see Marconi et al. 2011, for a discussion of the He abundance effect on pulsation models).

## 2.2. Classical Cepheids

Classical cepheids are the intermediate mass counterpart of RR Lyrae stars, associated to a blueward excursion in the HR diagram, called blue loop, with periods ranging from $\sim$ 1 to above 100 days and absolute visual magnitudes ranging from -2 to -7 mag. Since the pioneering study by Miss Leavitt, at the beginning of past century, in the Small Magellanic Cloud, Classical Cepheids are known to obey to a well defined relation between Period and Luminosity (PL). This occurrence is again related to the combination of the period-density relation and the Stephan-Boltzman law with the addition of a Mass-Luminosity relation predicted by stellar models in the blue loop evolutionary phase. In this way one gets a Period-Luminosity-Color (PLC) relation, that holds for each individual pulsator. The PL relation is then obtained by averaging over the color extension of the instability strip and, for this reason, it is a statistical relation, requiring a statistically significant sample of pulsators to be accurately determined. Indeed the PL relations reflect the instability strip topology and due to the strip finite width, the intrinsic dispersion of PL relations is significant, reaching 0.2-0.3 mag in the optical bands.

The most debated issues in the study of Classical Cepheids are:

1. **The dependence of Cepheid properties and PL on chemical composition.** In the past literature, Cepheid PL relation was often considered universal: the LMC PL has been used to measure the distance to extragalactic Cepheids often independently of their chemical composition (see e.g. Madore & Freedman 1991; Freedman et al. 2001; Saha et al. 2001). Any dependence of the PL relation on chemical composition introduces systematic effects on the extragalactic distance scale. In spite of the great effort both on the observational and theoretical side to constrain this effect (see e.g. Macri et al. 2006; Bono et al. 2008, and references therein), a general consensus on the universality of the P-L relations has not been achieved yet. From the theoretical side, nonlinear convective models predict a non negligible dependence of the metal content, with predicted PL relations getting flatter as $Z$ increases. This effect decreases toward longer wavelenghts, as extensively discussed in Caputo et al. (2000); Fiorentino et al. (2002); Marconi et al. (2005). Models also predict a simultaneous effect of $Z$ and $Y$ variations on the instability strip topology and the PL relation, with a sort of turnover of the metallicity correction at $Z \approx 0.02$ and a simultaneous dependence on the helium to metal enrichment ratio for higher metallicities (Marconi et al. 2005). This result was supported by Romaniello et al. (2005, 2008) on the basis of spectroscopic $[Fe/H]$ measurements of Galactic and Magellanic Cepheids.

2. **The linearity of the PL over the whole observed period range**. Several investigations (see e.g Caputo et al. 2000; Tammann et al. 2003; Ngeow & Kanbur 2006, and references therein) disclosed the nonlinearity of the PL in BVRI. The proposed mechanism that may cause this effect is the interaction between the hydrogen ionization front and the stellar photosphere (Kanbur & Ngeow 2006). Significant advantages for what concerns both the metallicity dependence and the nonlinearity effect are obtained working in the Near-Infrared (NIR) bands (see e.g. Ripepi et al. 2012a,b; Inno 2012, and references therein).
3. **The origin of the mass discrepancy between evolutionary and pulsational mass estimates.** Stobie (1969); Cogan (1970); Rodgers (1970) discovered that the pulsational estimates of Cepheid masses did not agree with the evolutionary ones, with the former being smaller by 20%-40%. The discrepancy was then reduced by about 10%-15% in mass (see e.g. Keller & Wood 2002, 2006; Caputo et al. 2005, and references therein), thanks to the adoption of new radiative opacities in stellar models, even if mass loss and core overshooting continued to be invoked to further reduce the discrepancy. Recently, Pietrzyński et al. (2010) provided the first accurate determination of the dynamical mass (to an unprecedented 1% precision) of a classical Cepheid in a well-detached, double-lined, eclipsing binary in the LMC (OGLE-LMC-CEP0227). This result was found to be in agreement both with the pulsational mass based on the Period-Mass-Radius relation and with the evolutionary estimates based on updated stellar models (see discussion in Cassisi & Salaris 2011; Prada Moroni et al. 2012). Moreover, updated nonlinear convective pulsation models allow us to accurately reproduce the light, radial velocity and radius curves of CEP0227 (Marconi et al. 2013 in preparation) for values of the instrinsic stellar parameters in excellent agreement with the dynamical estimates. These pulsation models are also providing theoretical constraints to the chemical composition of CEP0227. In fact the model fitting technique allows us to discriminate not only the mass, the luminosity and the effective temperature, but also the metal and helium abundance of the investigated pulsator. An example is shown in Fig. 2, where the best fit models reproducing the light and radial velocity curves of the Cepheid HV12197 in the LMC cluster NGC1866 are plotted for various assumptions of the chemical compositions(we refere the interested reader to Marconi et al. 2013, and references therein).

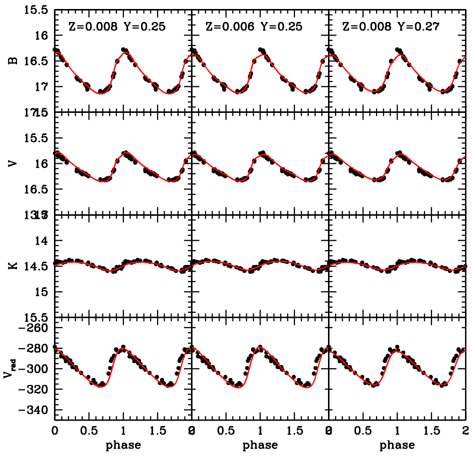


**Fig. 1.** Model fitting of the observed light and radial velocity curves of variable HV12197 (symbols) using nonlinear convective pulsation models (solid lines) for Z=0.008 Y=0.25 (left panel), Z=0.006 Y=0.25 (middle panel) and Z=0.008 Y=0.27 (right panel).

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