Cepheids and Gaia's second data release

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THE DISTANCE SCALE

PARALLAX OF PULSATION

Radial velocity

Expansion
Max radius
Contraction
Min radius

Angular diameter

θ max
θ min
The distance $d$ is given by the relation:

$$d = \frac{2\delta R(T)}{\delta \theta(T)} = \frac{-2(k+p) \int_0^T v_{\text{rad}}(t) \, dt}{\theta_{\text{UD}}(T) - \theta_{\text{UD}}(0)}$$

where $\delta R(T)$ and $\delta \theta(T)$ are the variations of radius and angular diameter, respectively, $v_{\text{rad}}(t)$ is the radial velocity, $k$ is the limb darkening correction, and $p$ is the projection factor.
THE P-FACTOR

- Pure geometry = 1.5
- Limb darkening component < 1
- Atmosphere dynamics = ?


Fig. 3. Cep data fit. Various panels show pulsation and radial velocities with spline model and residuals (panel a); angular diameters and residuals, with the baseline color-coded for the data and CSE-biased model – as a dash line, based on the model shown in Fig. 2 – (panel b); effective temperatures (panel c); photometric measurements and models (panels d to k) for different photometric bands or colors. Typical error bars are shown on the right side of the plot, below the reduced $\chi^2$ values.

For example, the slow (compared to the pulsation time) evolution of the star’s interior leads to a first-order period change. The amount of linear change is an indicator of the evolutionary stage of the Cepheids and can be computed theoretically (see, for example, Fadeyev 2014). We allowed the period to change linearly in our model.

3. Prototypical stars

Note that the observational data, and best fit model are available as FITS tables at the CDS.

3.1. Cep Cep is the prototypical Cepheid and has been observed extensively, in particular by optical interferometer. We took the photometry from Mockett & Barnes (1984), Barnes et al. (1997), Kiss (1998), Berdnikov (2008) and Engle et al. (2014). We also added photometric observations from Tycho and Hipparcos from van Leeuwen et al. (1997) and ESA (1997). We took the cross-correlation radial velocities from Bersier et al. (1994) and Storm et al. (2004). The angular diameters are the ones published in Mérand et al. (2005) and Mérand et al. (2006). In addition, to properly interpolate the photospheric models, we adopted a metallically of $[\text{Fe/H}] = 0.06$, based on Andrievsky et al. (2002).

We note that the metallicity has a very weak effect on surface brightness values and is undetectable with our data set. For the $2\sigma$ averaging, we used four groups of observables: radial velocities (91 measurements) angular diameters (67 measurements), photometric magnitudes (483 measurements), and colors (421 measurements). Error bars for each of these groups were multiplied by $\sim 0.59$, $\sim 0.50$, $\sim 1.26$, and $\sim 1.35$, respectively.

We show the fit in Fig. 3, and the most important parameters are listed in Table 3.

It is interesting to compare the result we obtain here with that of our previous study, which did not include photometry.
RS Puppis

- Long-period Cepheid
  $P = 41.5$ days

- $\pi = 0.524 \pm 0.022$ mas
  (4.2%) from its light echoes

RS Pup (P~41.4d) d=1910.0pc E(B-V)=0.496 Kesan=0.027mag H$_{\alpha}$=0.016mag

Radial velocity
Angular size (interferometry)
Photometry

p=1.25 ± 0.06

• Measurement of p-factor through comparison of observed cross-correlation functions to synthetic CCF profiles

• Post-doc of Simon Borgniet (LESIA)

Interferometric observations of Cepheids

- More than 1000 individual epochs
- 42% VLTI, 39% CHARA, 19% others
Galactic Cepheids with Gaia

Full sample

- ~35 stars with optical interferometry (full SPIPS) > PhD thesis of Boris Trahin (supervisors Pierre Kervella & Antoine Mérand)
- ~200 stars with radial velocities (SBC)
- ~500 stars with Gaia (+other) photometry + limited RV

Selected sample

- 225 stars

No data (125)
Data (100)
Binarity: V1334 Cyg

Pulsation period = 3.3 days
Orbital period = 5.3 years

Circumstellar envelopes

- PhD student **Vincent Hocdé** (Nice) supervised by Nicolas Nardetto
- Detection of CSEs in the visible with VEGA

### δ Cep

![Graph of δ Cep](image)

**Included in SPIPS modeling**


![Graph of T Mon](image)

**Photosphere**
- Fe
- 80% Fe + 10% W-S + 10% Al₂O₃
- 90% Fe + 10% W-S
- 90% Fe + 10% Al₂O₃
- 90% Fe + 5% W-S + 5% Al₂O₃

**E1E2**
- S1S2

**Final adopted parameters.** See Sect. 3.4.2.