A new study of Cepheids $p$-factor: application on $\kappa$ Pav and RS Pup

**Advisors**

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1. Measuring distances: why and how?
2. Cepheids and the parallax-of-pulsation method
3. The projection factor
4. Two examples: kappa Pav and RS Pup
5. And after?
1929: E. Hubble discovers the expansion of the Universe

$\begin{align*} v &= (H_0) \cdot d \\ 
\text{Virgo cluster} \\
\text{Velocity} &= \text{Hubble's Constant} \times \text{distance} \\
\text{Hubble's Law} \\
\text{Velocity of Recession} \\
\end{align*}$
Measuring distances: why?

$H_0$

- It represents the
- Gives the age of the Universe
- Constrains the values of cosmological parameters

$\rightarrow$ But we need to reach the

State of the art: 3.1% measurement from Riess et al. (2011)

Nobel Price 2011 to Riess, Perlmutter and Schmidt for the acceleration of the expansion.
How to reach the Hubble Flow?

...By building a “cosmic scale”
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Extragalactic Distance Ladder
How to reach the Hubble Flow?

...By building a “cosmic scale”

Planck Collaboration (Ade et al. 2013)
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Cepheids as standard candles

1912

\[ M = a \log P + b \]

Slope \( a \): Cepheids in the Magellanic clouds

Need of

\[ \rightarrow \text{Parallax, light echoes, binary systems...} \]
The Interferometric Parallax-of-Pulsation

$\Delta R$ and $\Delta \theta$ are the linear and angular variations of diameter: $d \propto \frac{\Delta R}{\Delta \theta}$
Interferometric data

Large observing program in both hemispheres

- **CHARA** (Mont Wilson observatory - California)
- **VLTI** (Cerro Paranal - Chile) - PIONIER
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Main limitation of the parallax-of-pulsation method

\[ V_{\text{puls}} = \rho \cdot V_{\text{rad}} \]

\( \rho \) includes:
- Geometry
- Limb-darkening
- Atmospheric effects
- Way of deriving the \( V_{\text{rad}} \)
- ...

Tricky parameter!
The projection factor

Main limitation of the parallax-of-pulsation method

Main equation of the parallax-of-pulsation (PoP) method:

\[ \theta(T) - \theta(0) = -2 \left( \frac{p}{d} \right) \int_0^T \left( V_{\text{rad},t} - V_\gamma \right) \, dt \]

- Degeneration between \( p \) and the distance
- Dispersion of the values in the literature: 10%!
- If we know the distance, we can measure the \( p \)-factor via an invert use of the PoP method
Observational values of the p-factor:

First result on Delta Cep (Merand et al. 2005)

The 4% HST parallax measurement of Benedict et al. 2002 leads to a p-factor of $p = 1.27 \pm 0.06$
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Application on the type II Cepheid kappa Pavonis

- Low metallicity
- Representant of the galactic halo
- Irregular variations in the pulsation period
- 5% parallax measurement from the HST

12 diameter measurements obtained with PIONIER
The 5% HST parallax (Benedict et al. 2011) leads to $p = 1.267 \pm 0.072$ (Breitfelder et al. 2014).

We checked as well:
- A small K excess (CSE detected by Gallenne et al. 2012)
- No obvious signal of a companion (although predicted in precedent studies)
The projection factor

RS Pup and the light echoes...

- Cepheid in a reflecting nebula
- Propagation of light echoes
- Long period (~41.5 days)

HST/ACS color composite image of RS Pup
The projection factor

RS Pup and the light echoes...
The distance can be derived from the light echoes, but only if we know the geometry of the scattering material.

- Polarimetric imaging from the HST → Degree of linear polarization
- Degree of linear polarization → Scattering angle
- Scattering angle → Geometry of the nebula

\[ d = 1910 \pm 80 \text{ pc} \] (Kervella et al., 2014)
Now that we know the distance, we can derive the p-factor!

More complicated than what we thought:
- Amplitude variations in the radial velocity curve
- Tricky period variations (over 40 years of data!)

Cycle-to-cycle amplitude variations

(Anderson 2014)
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Next step:
Measuring the p-factor of a larger sample of Cepheids

- Observational values important to help constraining models
  - A lots of values will allow us to study the dependancies of the p-factor
  - Cepheids with an HST parallax (~10), and in a near future GAIA
Thanks for your attention!

Questions?