

# Interferometric detection of Cepheid pulsation

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# Reminder:

## Interferometric diameter measurements

### Interferometric diameter estimations are model dependant

- Suffer from bias (e.g. Uniform Disk / Limb Darkened Disk)
- Use of photosphere models to take into account Center to Limb Variations (ATLAS, MARCS, PHOENIX, ...)
- CLV can be measured: interferometric measurement is difficult (low visibility, large baselines, bandwidth smearing: we're working on it...)

# Pulsating stars: Cepheid

- Evidence for diameter variations (~15%):
  - *Radial velocity, luminosity...*
- Evidence for changes in the photosphere within a period:
  - Teff: from ~5000K to 6400K (typical)
  - Log g: from 1.2 to 1.7 (typical)
  - Micro turbulence (*spectroscopic evidences, see Breitfellner & Gillet 1993*)
- *Expected differential effects due to CLV variations...*

# Problems

- For Cepheid interferometric observations (converting  $V^2$  to angular diameters):
  - A single static model, representing the average photosphere?
  - Grid of static models, computed for different phases?
  - A complete model from an hydrodynamic code?
- For what applications?
  - Need for a **realistic** model to avoid bias (mean diameter, mainly)
  - Need for a good **dynamical** model to avoid differential effects

# Interferometric detection of the pulsation

- First *clear* detections mainly used for distance measurements

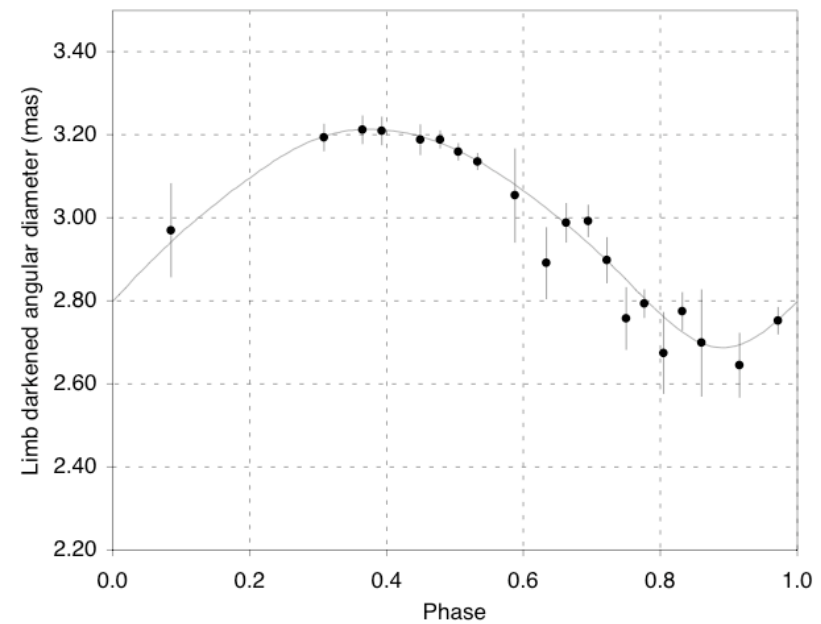
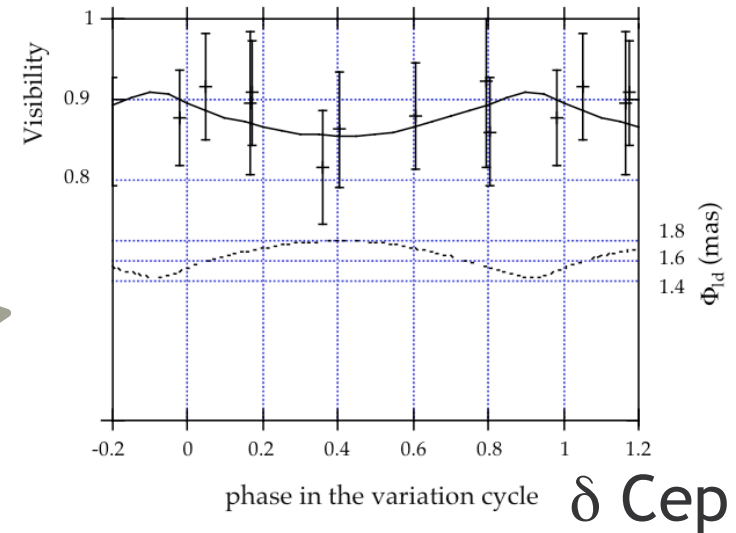
Baade-Wessenlink method:

$$\theta(t) = \theta_0 + \frac{\int_0^t p(\phi) V_{\text{rad.}}(\phi) d\phi}{\text{distance}}$$

- Use angular diameter variations
  - *That's a differential measurement!*
  - If angular diameter biased, does not matter... (really?? will surely affect the mean diameter)

# Interferometric Measurements...

- Mourard et al. 1997 (GI2T), Kervella et al. 2001 (FLUOR/IOTA), ...
  - « Marginal » detections
- Lane et al. 2000 (PTI), Kervella et al. 2004 (VINCI/VLTI)
  - Clear detection
  - Distance measurement (BWM)



# Interferometric Measurements II

- Best precision on distances derived by BWM : 4%  
*(corresponds to the best characterisation of the amplitude)*
- Best angular diameter uncertainty for individual interferometric measurements (up to now):

*l Car*, (VINCI/VLTI *near Infra Red*) : 1-2%

Differential effects not yet detectable if  
they account for less than a few percent  
in term of angular diameter

# Hydrodynamic Models

(from an interferometrist point of view...)

From Marengo et al. 2003

- Mean diameter changed drastically (several sigmas)
- Distance did not changed
- In Near-IR:
  - « An accuracy of the order of 0.2% in the diameter is required to be sensitive to [variations in the LD corrections induced by the hydrodynamics] »
- Quite different in visible

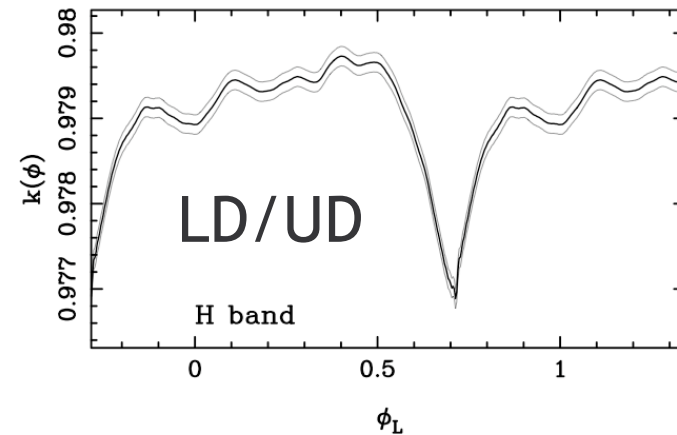


TABLE 1  
BW BEST FIT OF  $\zeta$  GEM PTI H-BAND LD DATA

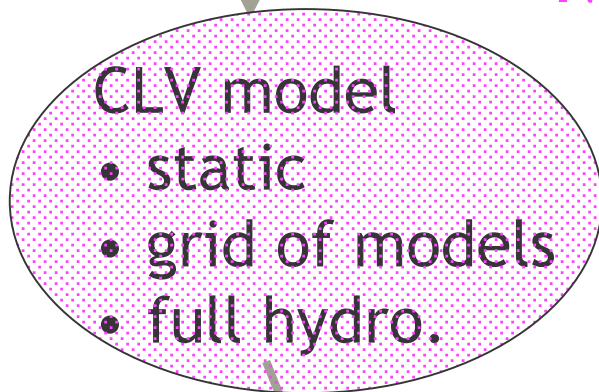
Fit Parameter (1)	$k(\phi)$ (model) (2)	$k = 0.96$ (3)
$R_0 (R_\odot)$ .....	$67.0^{+8.7}_{-6.9}$	$66.2^{+8.3}_{-6.6}$
$D$ (pc).....	$372^{+49}_{-39}$	$361^{+46}_{-36}$
$\Theta_0$ (mas).....	$1.665 \pm 0.007$	$1.698 \pm 0.007$
$\chi^2$ .....	28.1	29.5

# Method to derive distances

Interferometric  $V^2$   
Data set

Radial Velocities  
Data set

*Need for Models!!*



Angular diameter

Photospheric displacement

$$\theta(t) = \theta_0 + \int_0^t p(\phi) V_{\text{rad.}}(\phi) d\phi$$

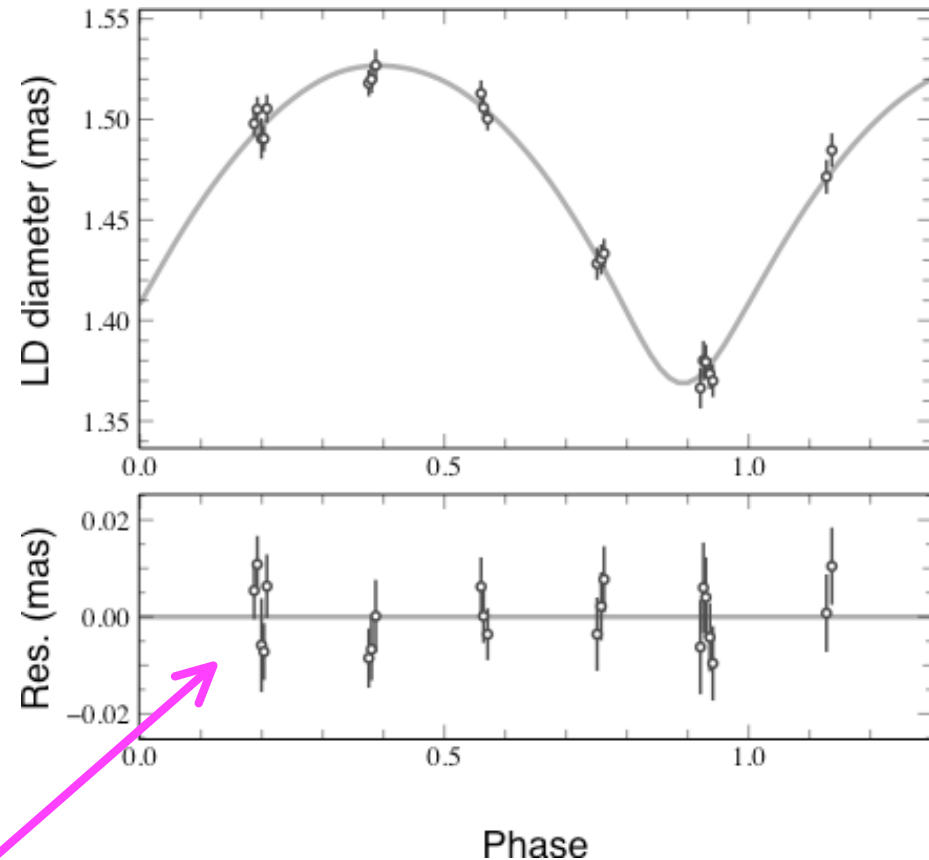
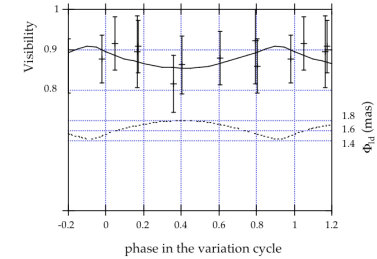
distance

# Latest results on $\delta$ Cep

## 2004 observations using FLUOR/CHARA

### Characteristics:

- Average static CLV
- Near IR (K band)
- **Ind. Precision < 0.5%**  
(angular diam.)
- Gray line = radial velocities (Bersier 1994) integrated using constant p-factor



*no departure in shape  $V^2/V_{rad}$*

# $\delta$ Cep width FLUOR/CHARA

- Known Distance (HUBBLE/FGS parallax, Benedict et al. 2002)  $d=273.5\pm 11pc$
- BWM to determine average  $p$ -factor

- Preliminary results:  $\theta(t) = \theta_0 + \frac{\bar{p} \int_0^t V_{\text{rad.}}(\phi) d\phi}{\text{distance}}$

$V_{\text{rad}}$  from cross-correlation (2 sets):

$$p = 1.30 \pm 0.01_{V_{\text{rad}}} \pm 0.04_{\text{interf}} \pm 0.05_{\text{distance}}$$

$V_{\text{rad}}$  from Gaussian-Fit (3 sets):

$$p = 1.34 \pm 0.01_{V_{\text{rad}}} \pm 0.04_{\text{interf}} \pm 0.05_{\text{distance}}$$

# Conclusion

- Interferometric measurement of the pulsation is easy, for the closest cepheids, to a great precision
- Distance estimation (BWM) requires models (*CLV*, *p*-factor)
- First constraints are coming ( $\delta$  Cep and its *p*-factor)
- Interferometry is about to be model-limited
  - No departure between angular diameter and photospheric displacement variations *shape*
  - Bias on distance? Need independent estimations.
  - Going toward smaller wavelength will increase differential effects

# Elements for discussion

- *Benedict et al.* are about to measure the distance to more cepheids (FGS parallax)
  - More avg. p-factor estimation feasible
- CLV measurements (center-to-limb darkening) will be soon possible for cepheids (VLBOI), at high spectral resolution (e.g. AMBER/VLTI,  $R=10000$ )
  - New constraints for models
- $p$ -factor remains a strong limitation to the Baade-Wessenlink method (*It hides every thing we master the less...*)