Studying Cepheids Using Optical Interferometry

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Cepheids distance scale:

Supernovae Ia

Faber–Jackson

Tully–Fisher

Cepheids : P–L

astrometric parallaxe

distance (log10 pc)

0   1   2   3   4   5   6   7   8   9

alpha   delta   Magellanic   M31   Coma galaxy cluster
Centauri Cephei   Clouds
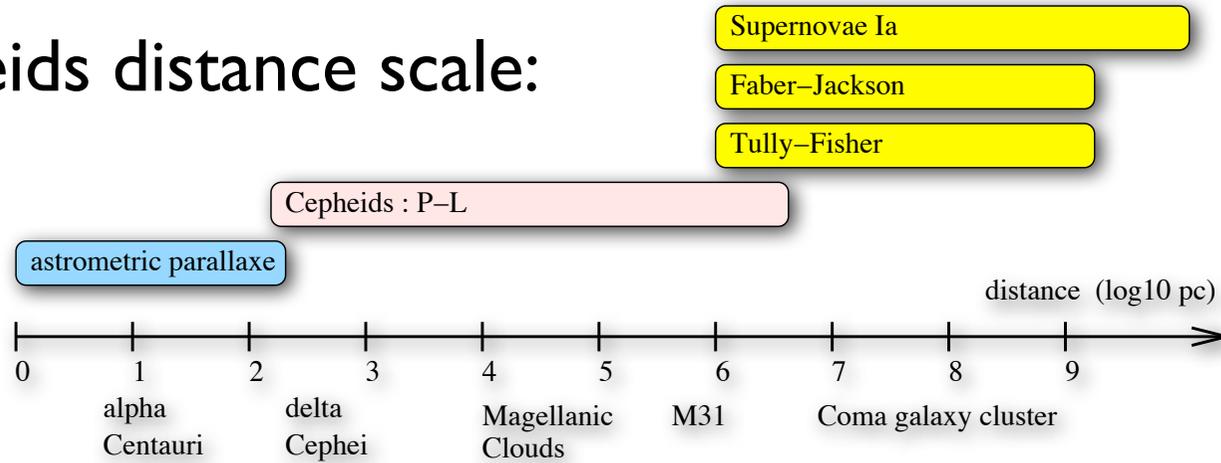
Baade-Wesselink Method:

$$\theta(T) - \theta(0) = -\frac{2}{d} \int_0^T v_p(t)dt$$

Angular diameter   Puls. velocity

Interferometry can reach $\sigma_d/d \sim 1.5\%$
but P-L calibration is 10% right now

Status

- 1% distances need a 1% proofed method

- actual BW relation:

$$\theta_{\mathrm{UD}}(T) - \theta_{\mathrm{UD}}(0) = -\frac{2kp}{d} \int_0^T v_{\mathrm{rad}} dt$$

  - p: spectroscopic factor V_{puls}/V_{rad}

  - k: $\theta_{UD}/\theta_{\star}$

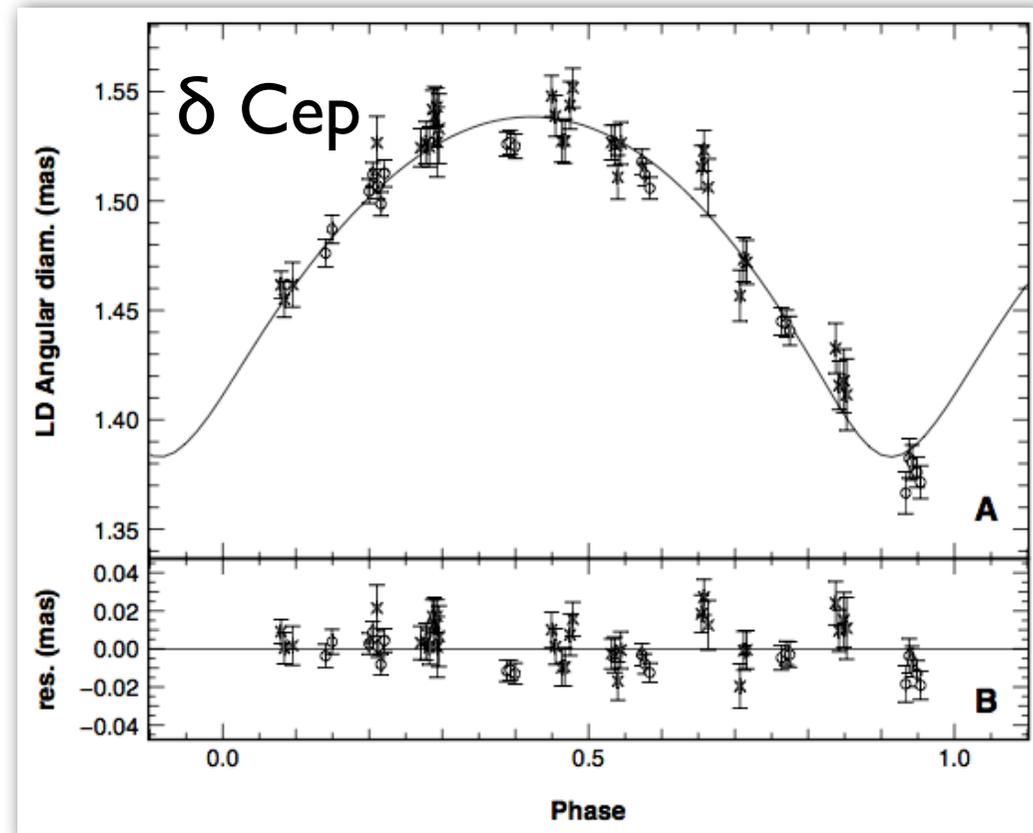Both can be studied / measured using optical interferometry

p-factor

(Mérand et al. 2005)

- $d = 274 \pm 11$pc (parallaxe HST)

- No discrepancy between $\theta(t)$ and $\int v_p$

$p = 1.27 \pm 0.06$

$\quad 0.007$ from V_{rad}

$\quad 0.020$ from θ

$\quad 0.050$ from d
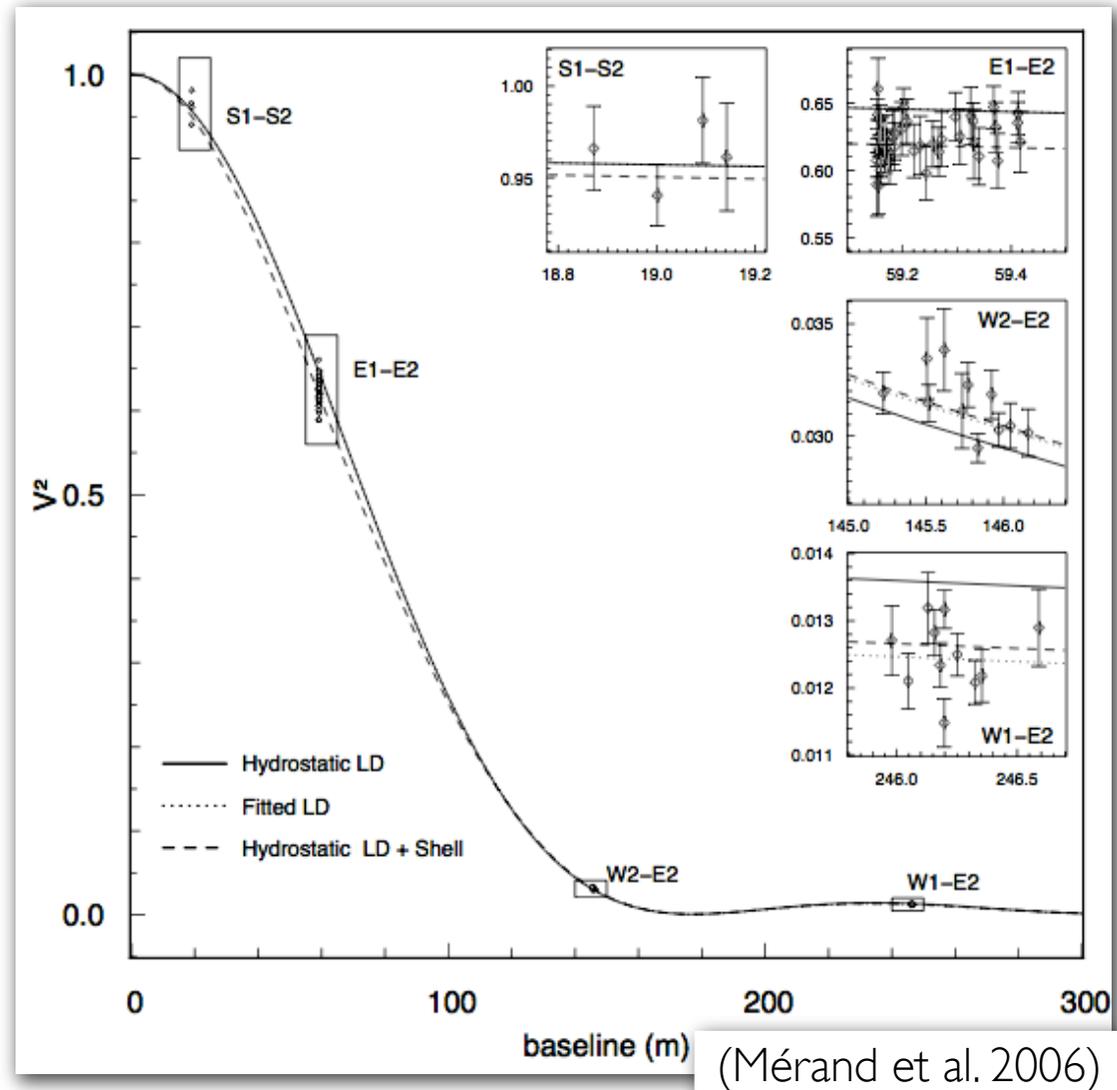
1.27 suggested by Nardetto et al. (2004) models

δ Cep
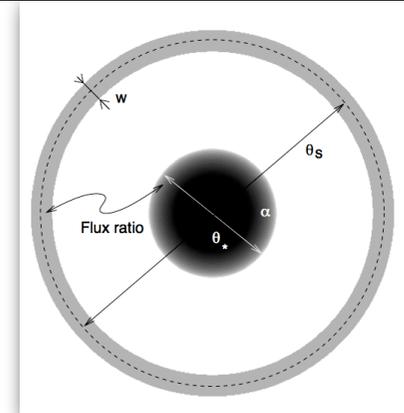
formal precision on the distance: 1.6%
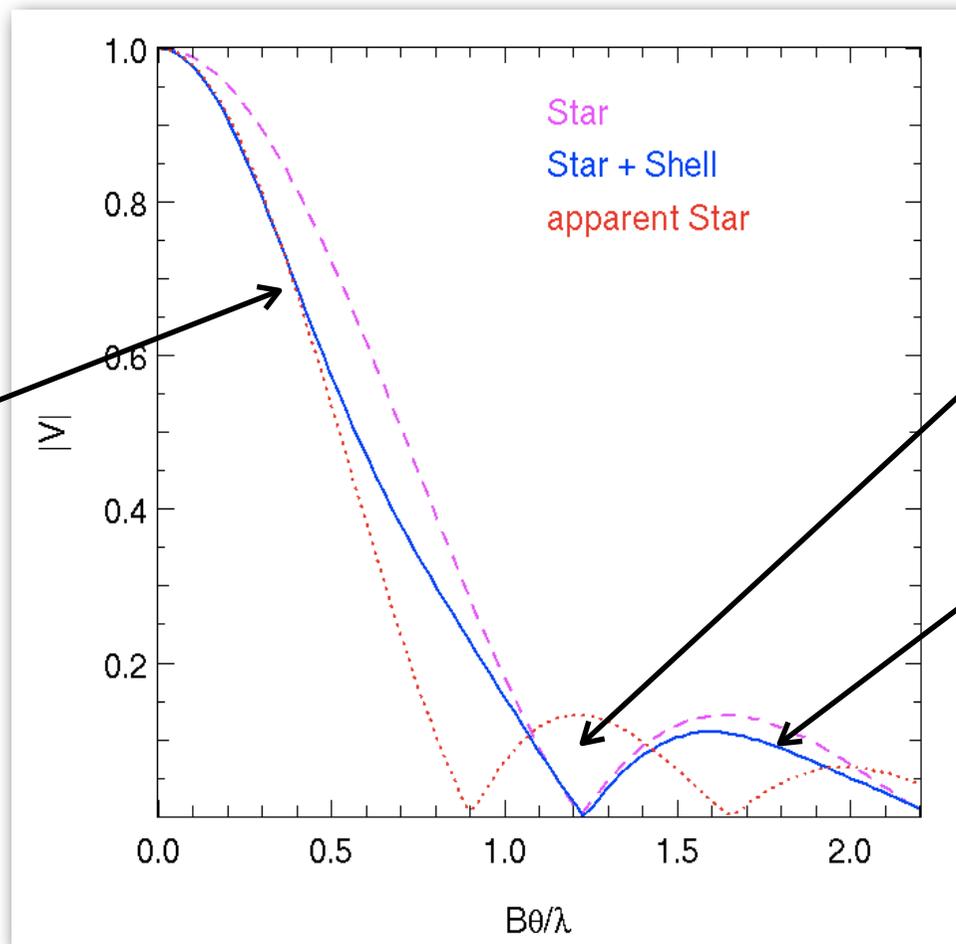
k = θ_UD/θ★ : limb darkening?

- Polaris:
  - very small amplitude
  - first overtone
- Strange data set:
  - LD much stronger than models
  - deficit around V^2=65%
- Presence of a larger component explains the deficit AND the apparent stronger LD

(Mérand et al. 2006)

CSE Effects:

1) Object looks larger at small angular resolution

Effect 1 vanishes near first null

2) Lower 2nd lobe, as if CLD was stronger

CSE around Cepheids

- Detected so far (visibility deficit):

  - Polaris: 4 baselines with CHARA/FLUOR

  - δ Cep: 3 baselines with CHARA/FLUOR

  - l Car: 3 baselines with VLTI/VINCI and in mid infrared using VLTI/MIDI

- No non-detection for similar stars

New Material (2006)

- July Run → B~250m

  - 3 Cepheids with resolved pulsation (η Aql, Y Oph, Y Sgr)

  - 1 with unresolved pulsation (FF Aql)

  - Y Oph and η Aql offer interesting comparison with VLTI (and PTI)

- Fall Run → Visibility profile of a non pulsating yellow supergiant: α Per
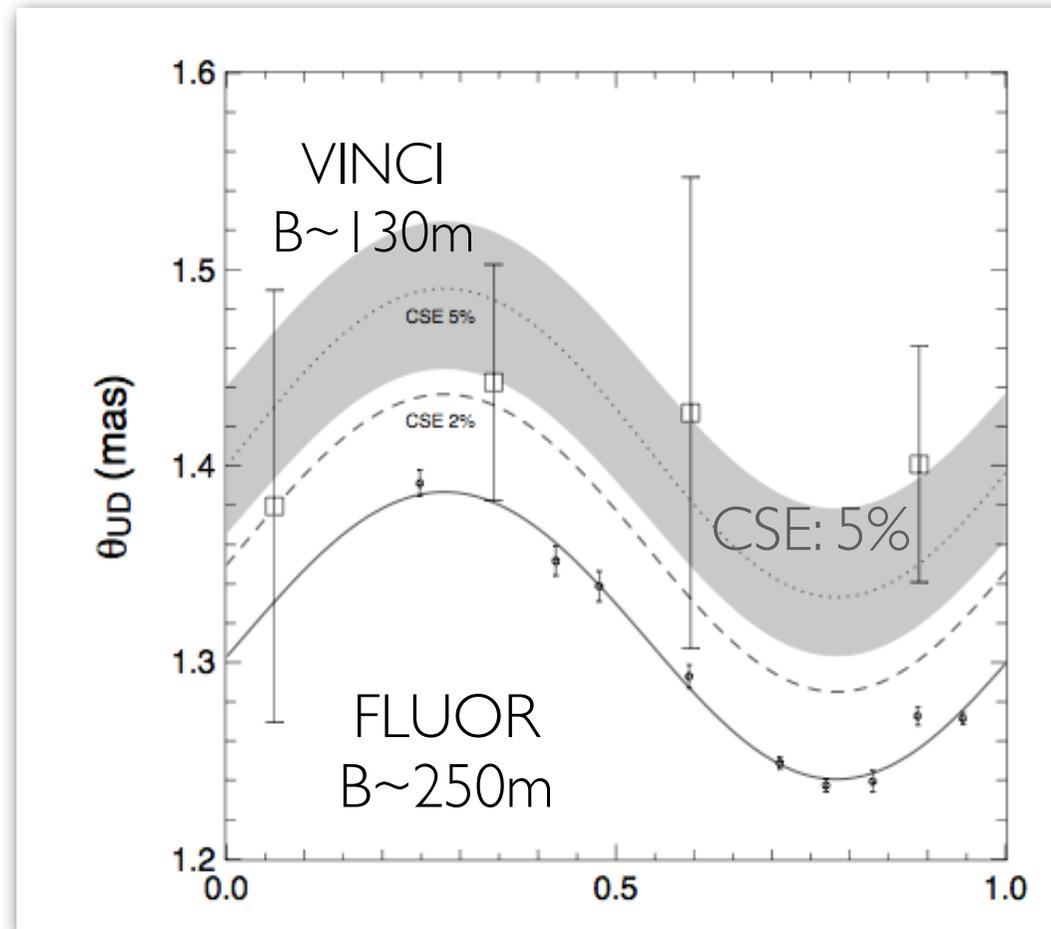
CSE everywhere?

NO: check star checked out

- α Per: non pulsating SG in instability strip

- LD consistent with hydrostatic models (not the case for Polaris)

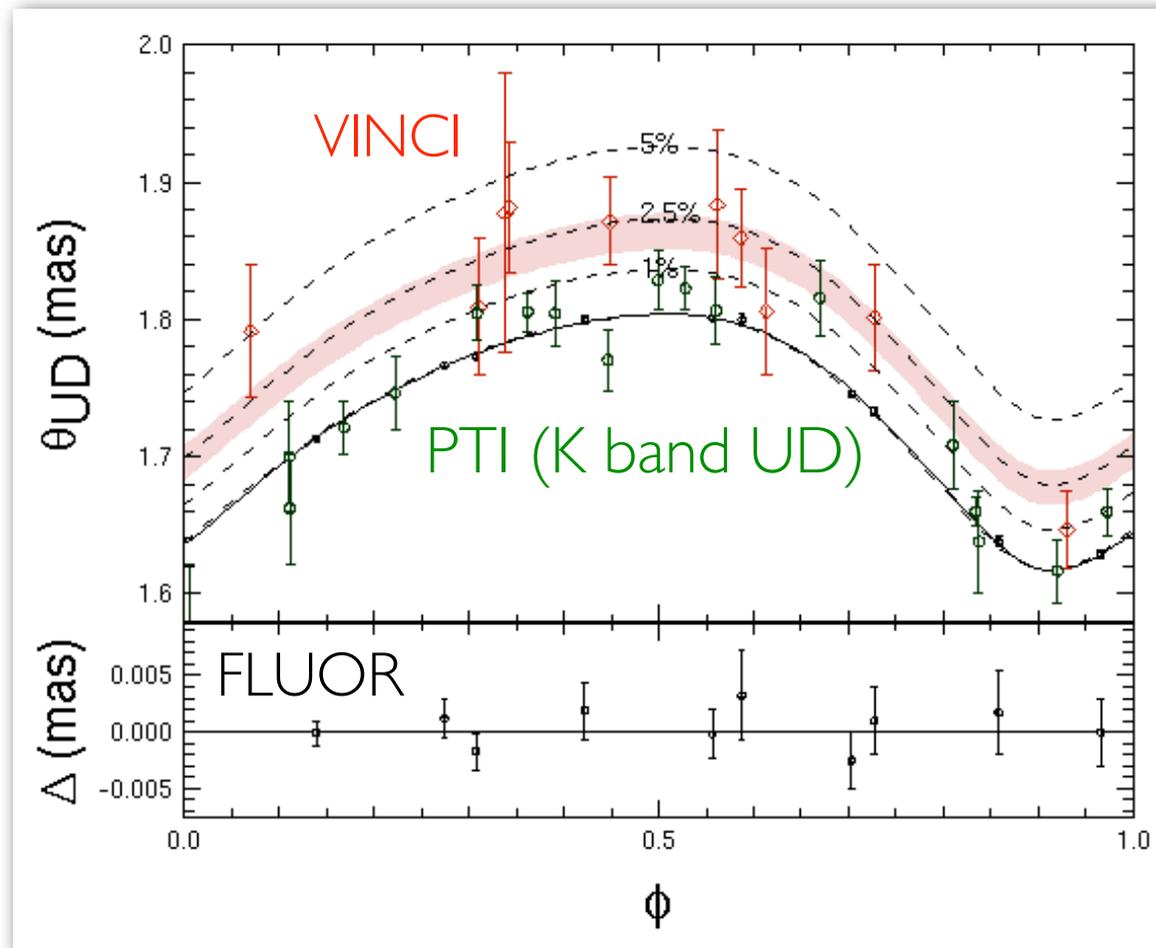- $F_{CSE} < 0.26\%$
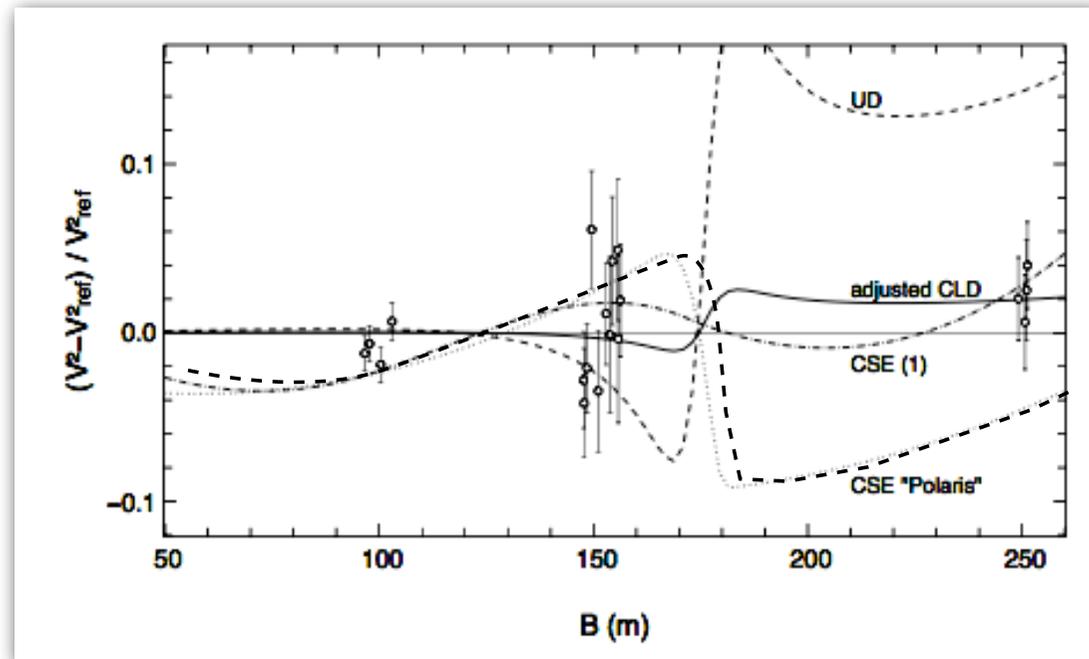
(Mérand et al. accepted)

Y Oph

- VINCI @ 130m

- FLUOR @ 250m

- very similar instruments (K band)

- Y Oph appears larger for a small baseline than for a large one

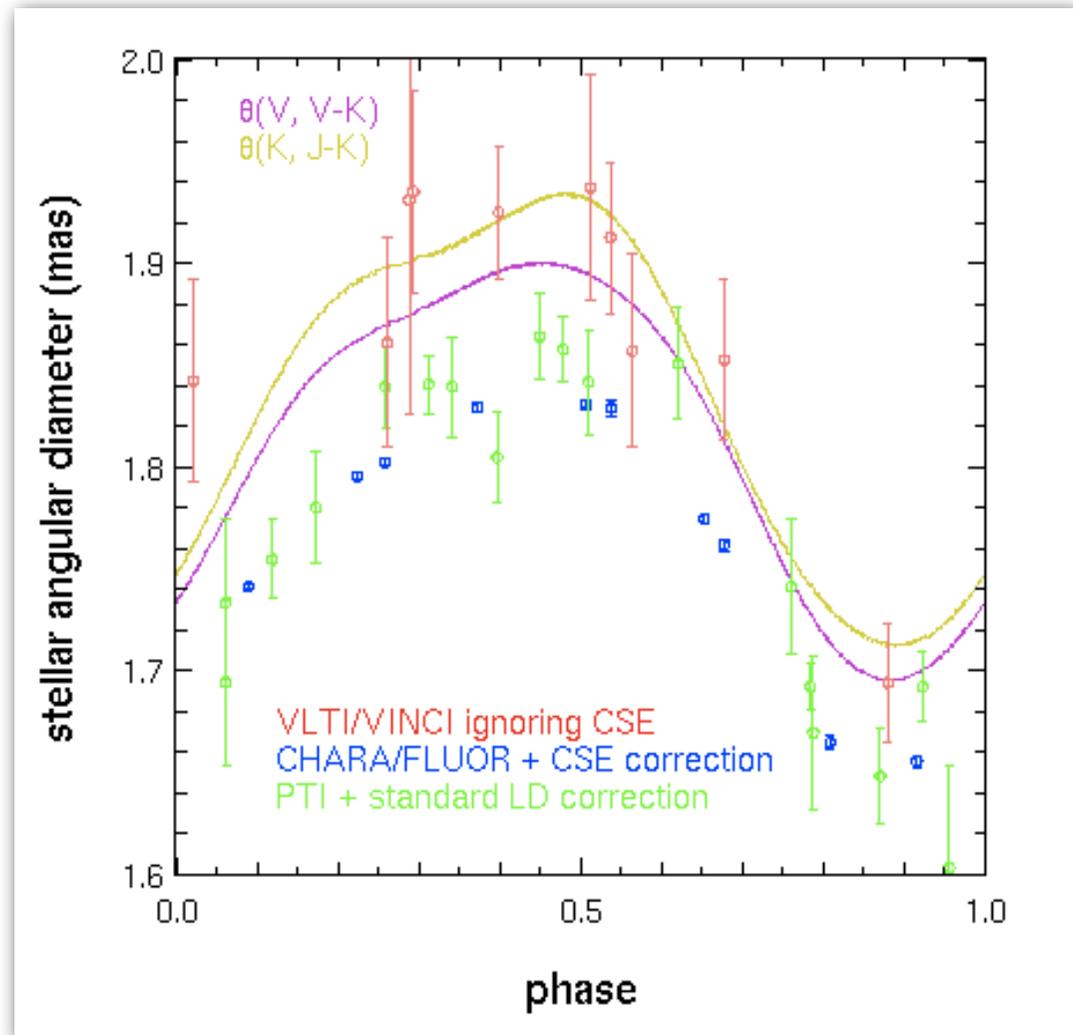- interpreted as a CSE effect

(Mérand et al. accepted)

η Aql

- VINCI shows larger diameters

- PTI data to compare with

  - B~100m

  - H band

- FLUOR and PTI data within 1 σ

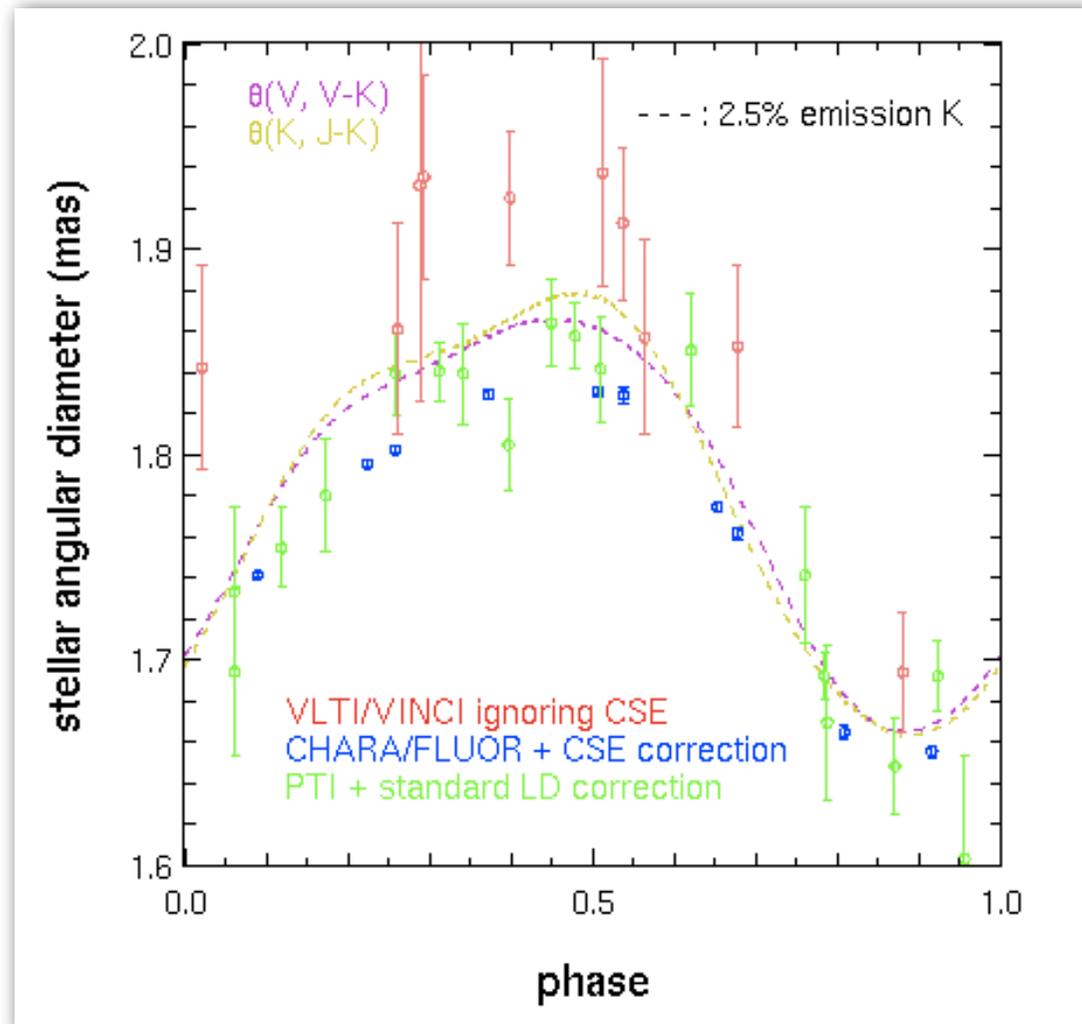- CSE not seen in H Band ?

(Mérand et al. in preparation)

η Aql: surface brightness

- Take Fouque et al. (1997) surface brightness + V, J, K photometry
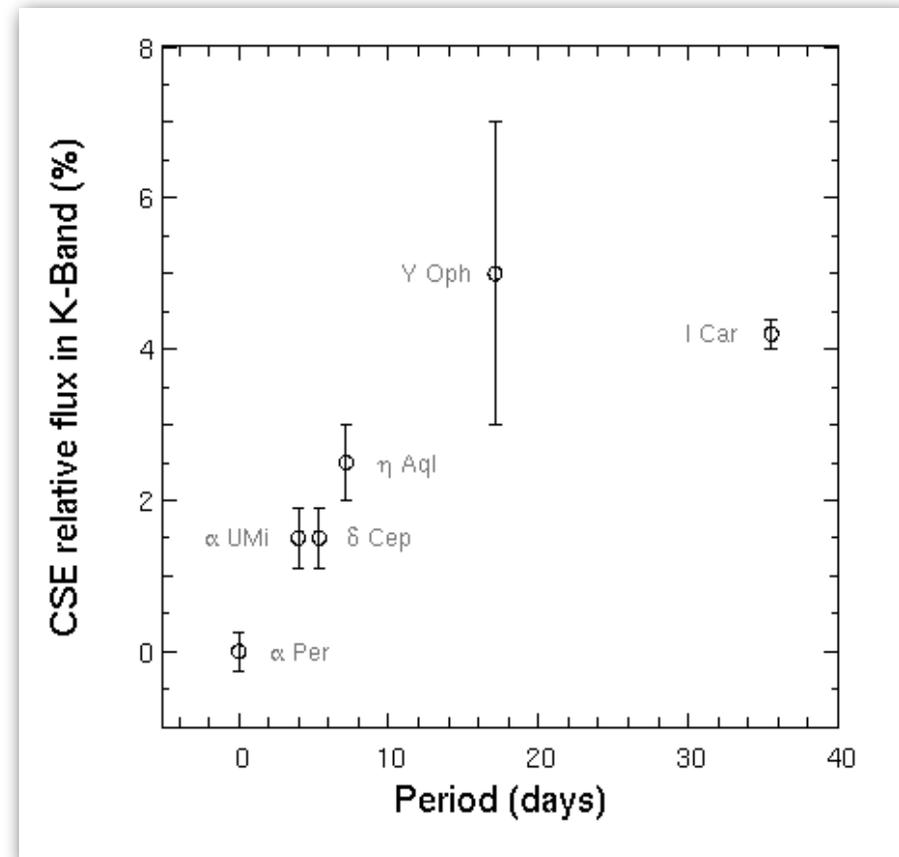
- agree with VINCI

- disagree with PTI and CHARA

- ...

One Possible explanation

- K band photometry correction for the CSE 2.5% "emission"

- Better agreement

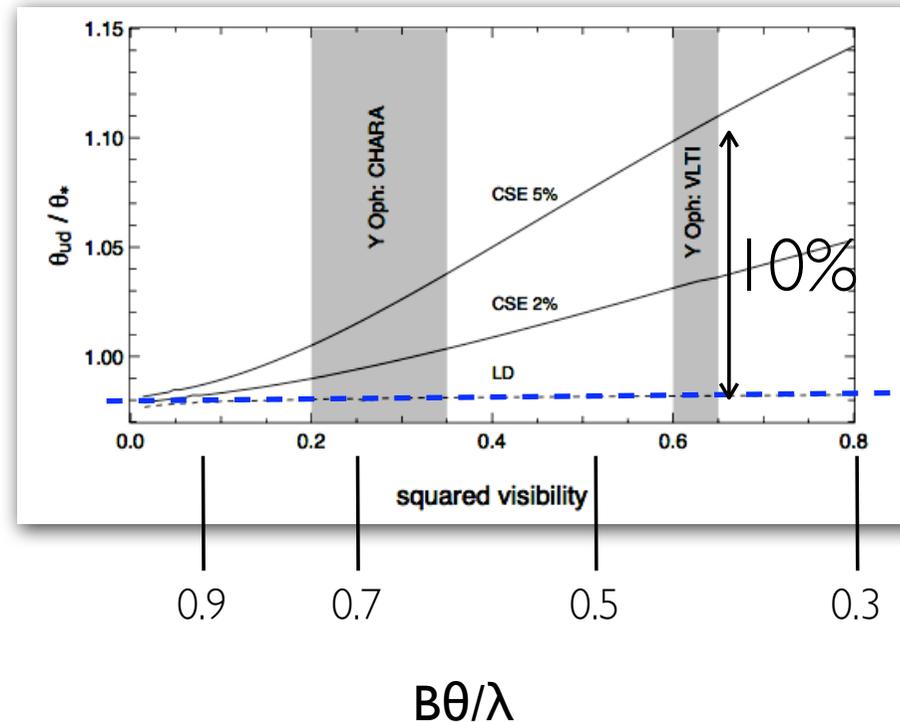# A correlation with pulsation period?

- The larger P, the brighter the CSE ?

- M, L, R ↗

- T_{eff}, g ↘

- pulsation driven mass loss?

- Mass loss in known around Cepheids from UV/IR photometry

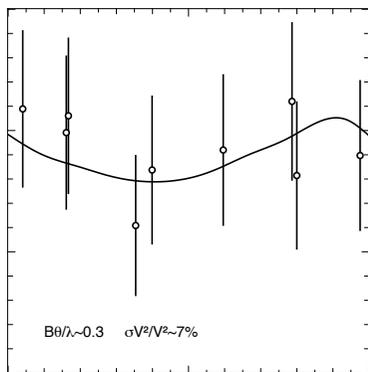(Mérand et al., in preparation)

Why is this important?

- $\theta_{UD}/\theta_\star$ is now a function of spatial resolution $B\theta/\lambda$

- IBW distance can be biased: up to 10%
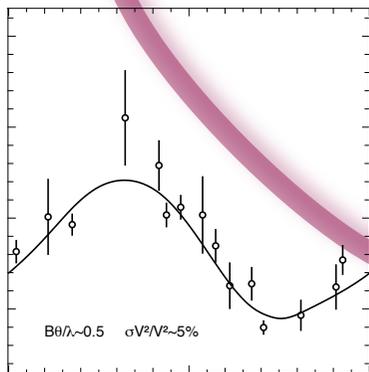
- safe side: $B\theta/\lambda \geq 0.9$

To Do

- Keep working on data I already acquired

- Observe Y Oph and η Aql with FLUOR and B~100m to confirm FLUOR ↔ VINCI

- Observe other stars, including ζ Gem and others...

- 1% P-L calibration is getting closer

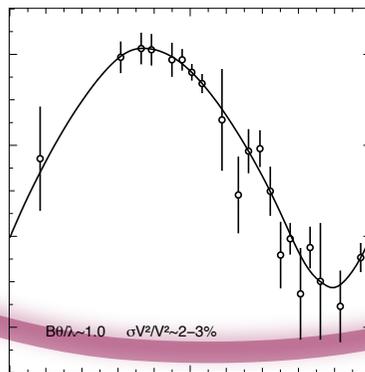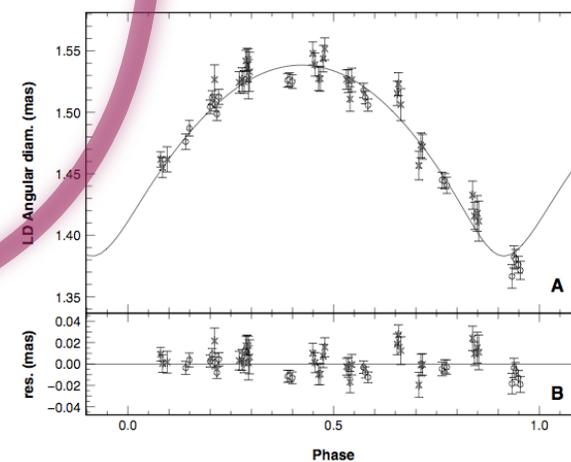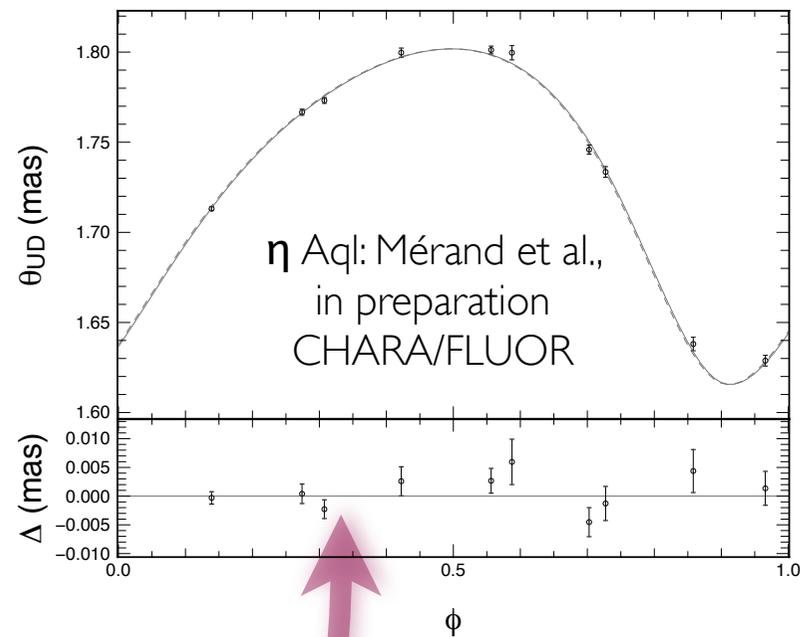10 years of interferometric Cepheids observations

δ Cep: Mourard et al. (1997) GI2T

η Aql: Mérand et al., in preparation CHARA/FLUOR

θ_{UD} (mas)

Δ (mas)

ϕ

ζ Gem: Lane et al. (2000) PTI

I Car: Kervella et al. (2004) VLTI/VINCI

δ Cep: Mérand et al. (2005) CHARA/FLUOR

$B\theta/\lambda{\sim}0.3$ $\sigma V^2/V^2{\sim}7\%$

$B\theta/\lambda{\sim}0.5$ $\sigma V^2/V^2{\sim}5\%$

$B\theta/\lambda{\sim}1.0$ $\sigma V^2/V^2{\sim}2{-}3\%$

phase

phase

phase

LD Angular diam. (mas)

res. (mas)

Phase

A

B