

# Cepheids Pulsation Workshop

02 to 04 February 2005

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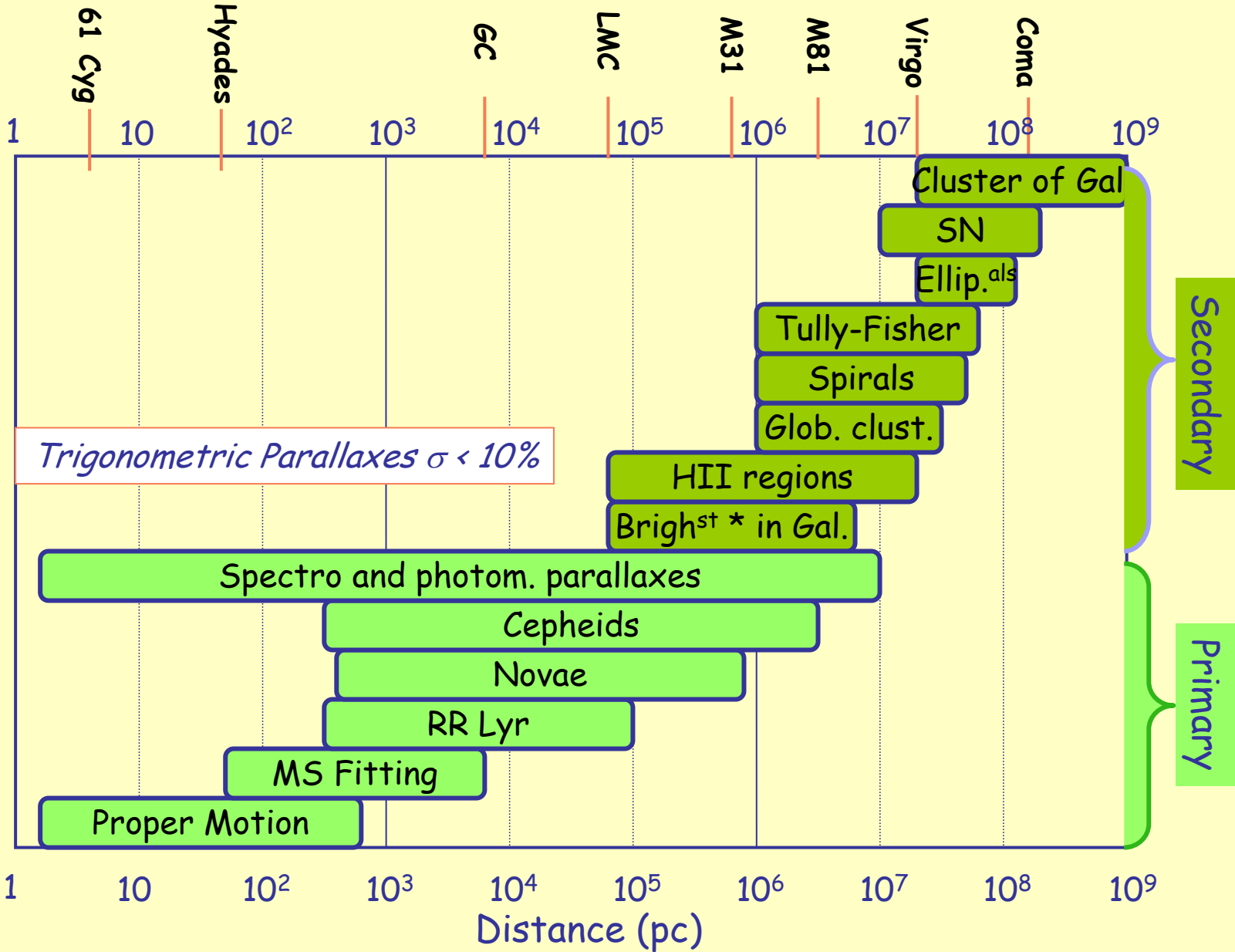
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Long Baseline Interferometry  
Prospects for the Cepheid's program

# Outline

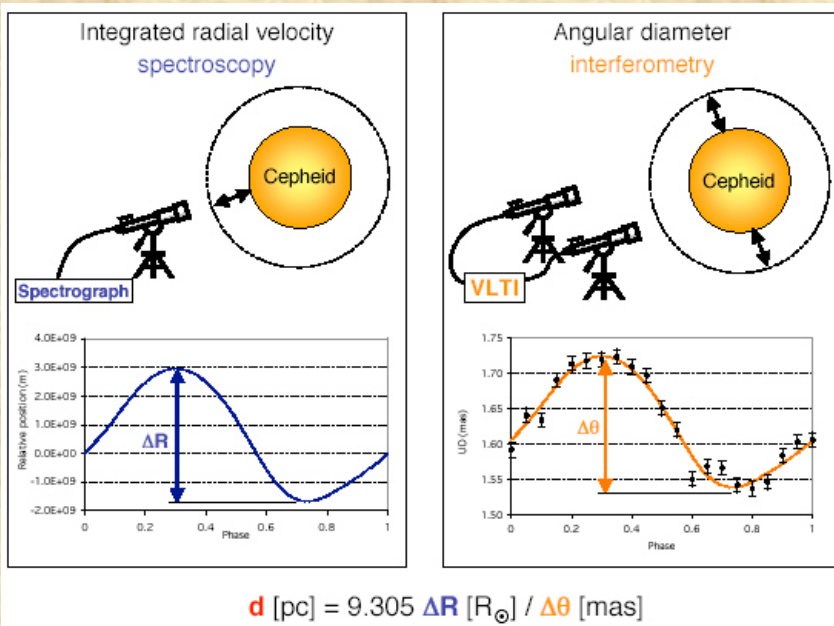
1. Cepheids & LBI: the first lessons
2. How to continue?
3. New possibilities
4. Various ideas

# The Cosmic Distance Ladder



# Cepheids and LBI

- A very old dream...and a very challenging goal:
  - Davis et al., 1979, Proc. IAU Coll. 50, Eds Davis and Tango, Sydney, 1-27
- The main purpose is the distance scale program



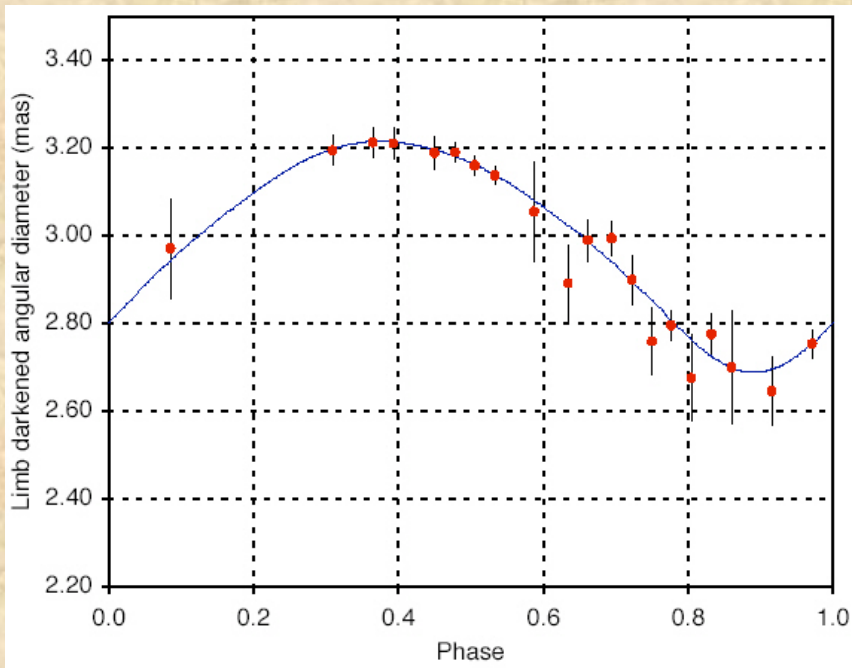
Kervella et al., 2004

## Limitations:

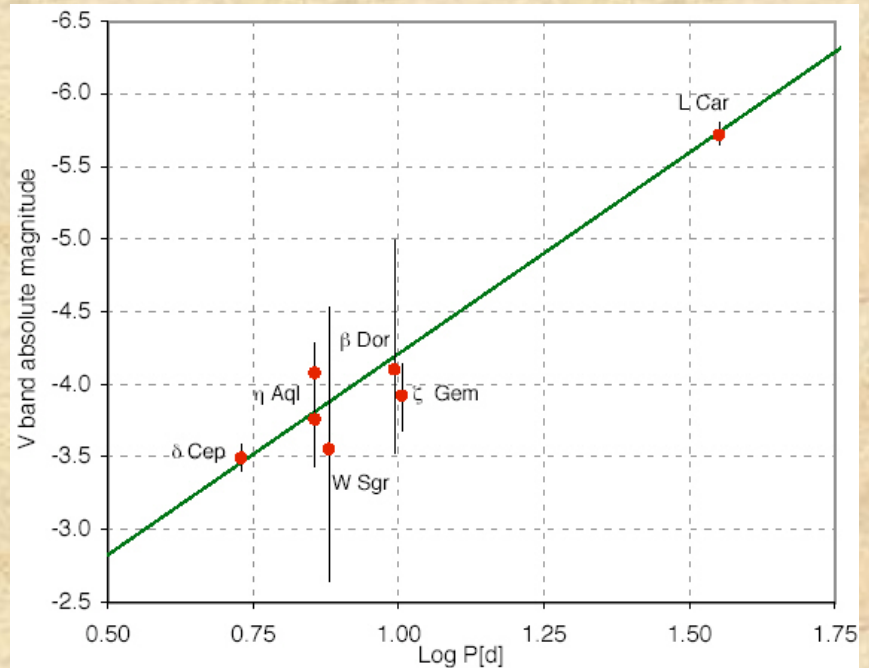
- Accuracy of  $V^2$  measurements
- Validity of the LD disk representation?
- Accuracy of RV measurements
- From RV to  $\Delta R$  estimations
- Relation between  $\theta(\lambda_i)$  and  $R(\lambda_s)$
- Limited sampling of the measurements

# State of the art

Pulsation of L Car with VLT/VINCI



PL relation with interferometric cepheids

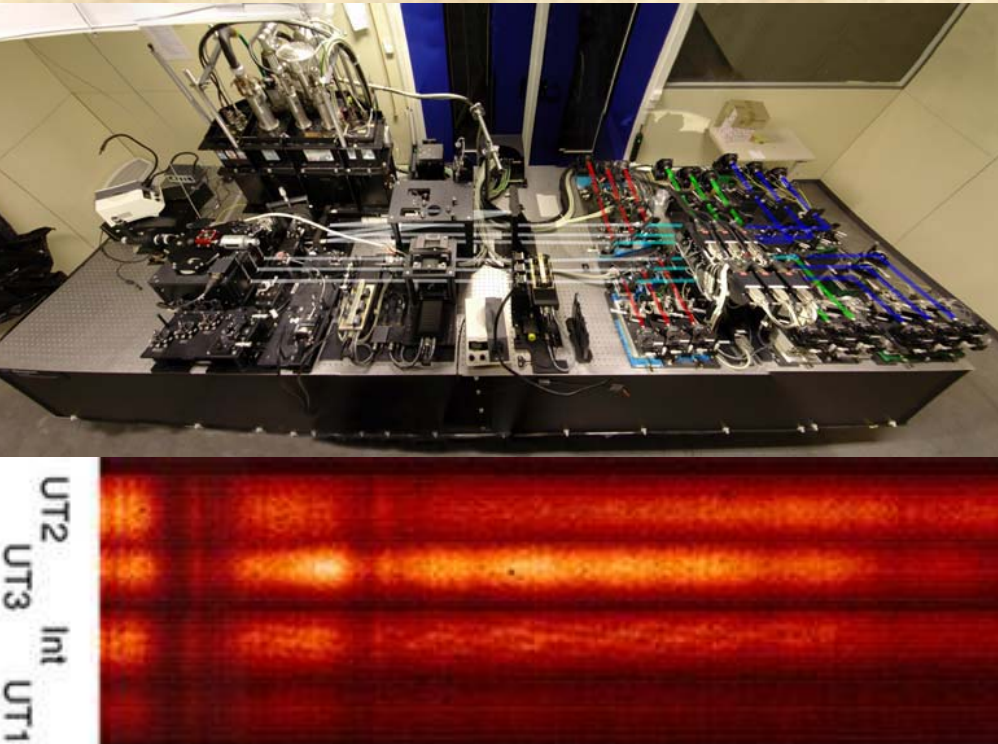


Kervella et al., 2004abcd

# First lessons

- The IBW method is a good one...
- ...but we need more stars and better accuracy
  - New instruments
  - Increase the angular resolution
    - Increase the baseline
    - Decrease the wavelength
  - Use other interferometric observables
  - Better understanding of the pulsating atmosphere, of the atmospheric motions (as a function of  $\lambda$ )...

# AMBER on the VLTI



- Commissioning under progress
- First GTO observations in dec. '04.
- Opening: 1st october 2005: LR HK ( $K < 7$ ) and MR HK ( $K < 5$ ) with UTs
- ATs will be ready this year!

# Preparation of the cepheid program on AMBER/VLTI

- 1) Selection of stars using the Simbad database:
- Declination  $[-80^{\circ}; +30^{\circ}]$  (lat:  $-25^{\circ}$ )
  - Apparent magnitude  $V < 10$
  - Object type "Cepheid"

+ cross-check with the catalog:  
Caldwell, J.A.R., AJ 93, 5, (1987)

- 2) Determination of the V-K indexes using the Johnson table as a function of the mean spectral type.

- 3) Prediction of the mean angular diameter (DiBenedetto, 1993)

$$\log \Phi = 0.5334 - 0.2V + 0.266(V-K)$$

then  $\frac{\Phi_{ld}}{\Phi_{ud}} = \sqrt{\frac{1 - \frac{u}{3}}{1 - \frac{7u}{15}}}$  gives  $\Phi_{ud}$

- 4) Determination of the optimum interferometric baseline, ie when the variation of V is maximum for a given variation of the angular diameter

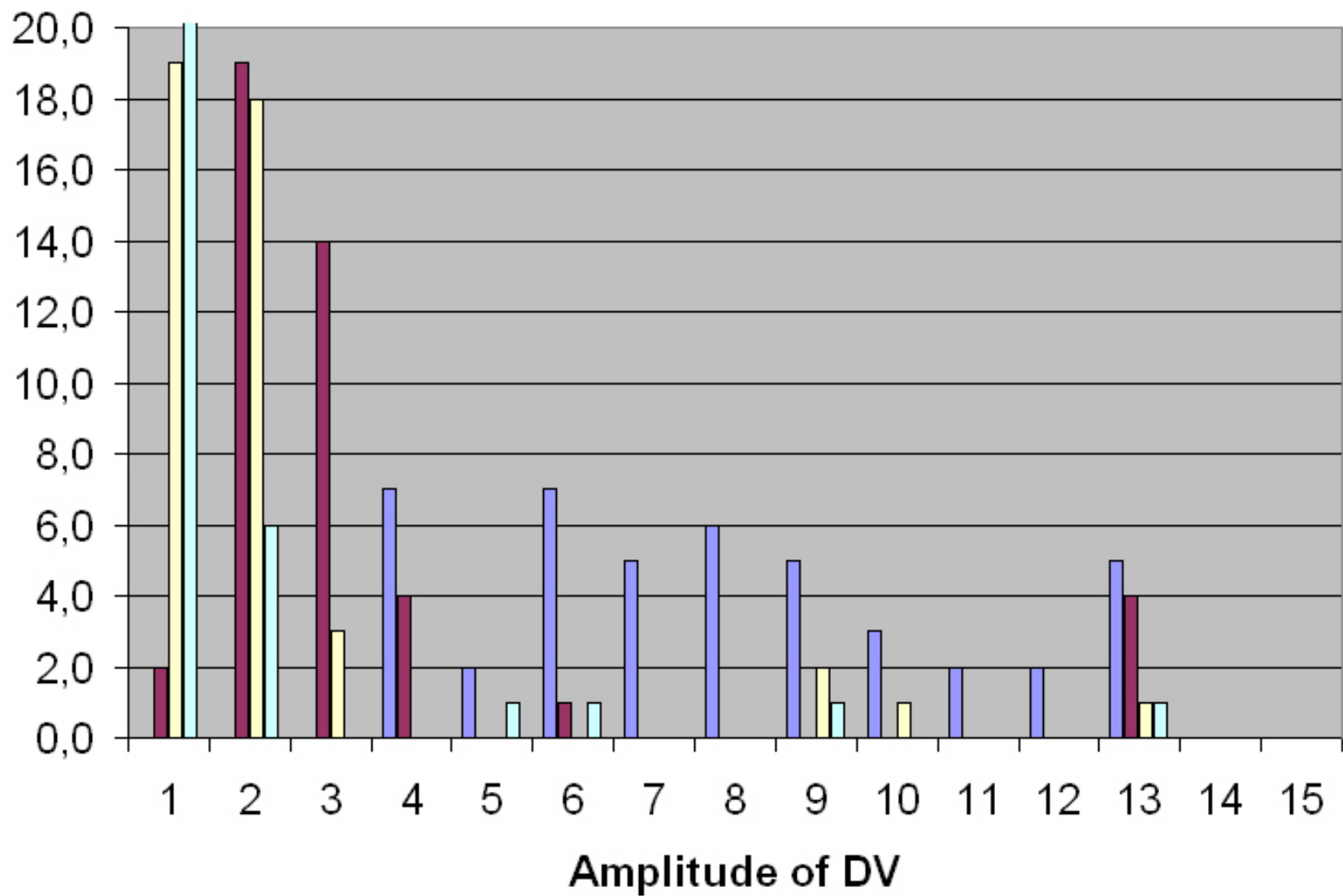
$$V(z) = \frac{2|J_1(z)|}{z} \quad \text{with } z = 15.23 \frac{B_{(m)} \Phi_{(max)}}{\lambda_{(m)}}$$

The baseline B is determined by the equation  $z=2.3$  and is limited to the maximum physical baseline of the VLTI array ( $200\text{m} * \cos(\delta - \text{lat})$ ).

- 5) Computation of the mean Visibility and Amplitude of variation of the visibility, assuming  $\frac{\Delta \Phi}{\Phi} = 15\%$ .

- 6) Selection of stars with  $\Delta V \geq 3\%$ :  $\implies 44$  stars.

Effectif



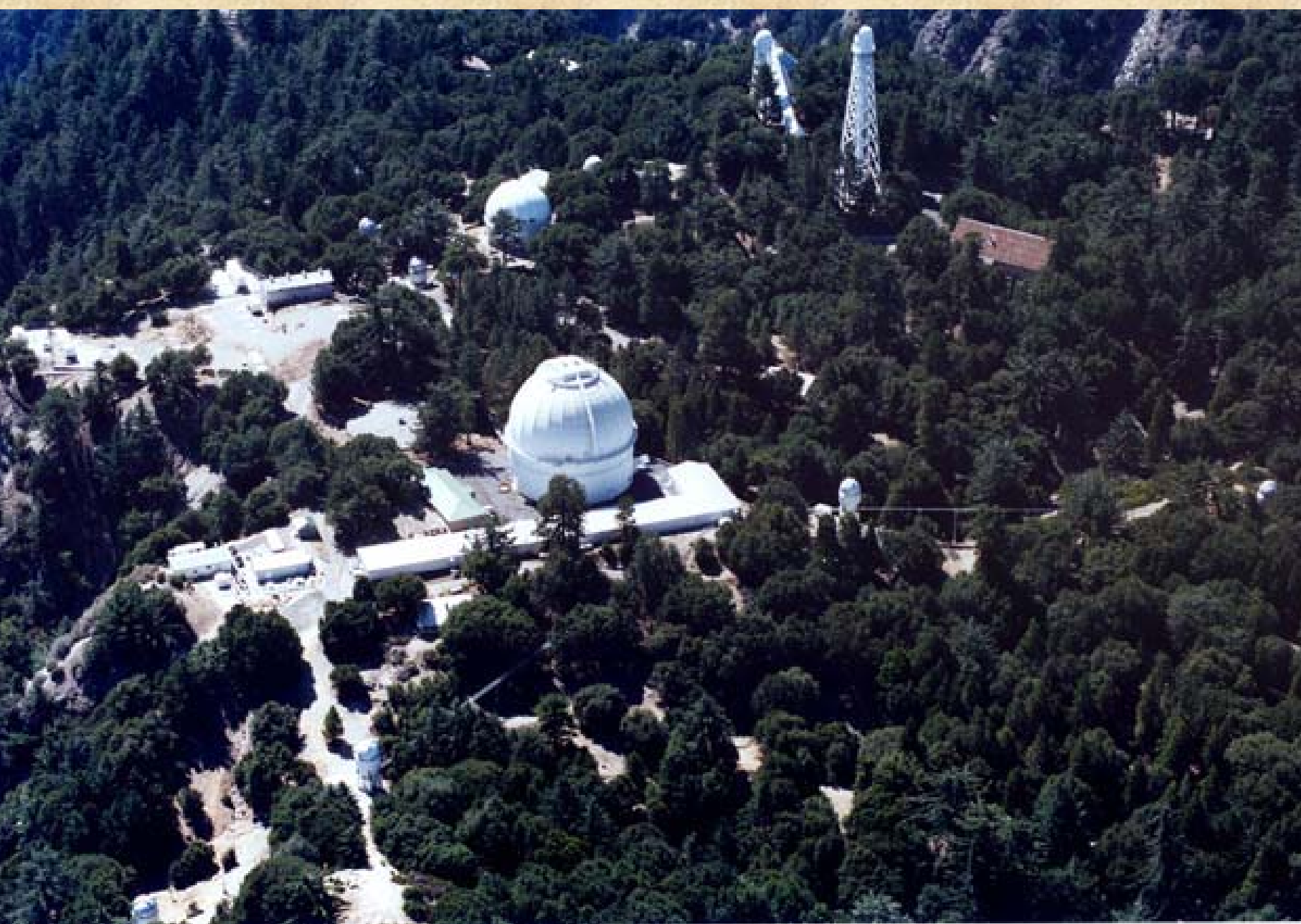
# The Amber program

1. Mainly oriented with the ATs for a correct pulsation sampling  
... (after april 2006...)
2. Simultaneous Low Resolution observations in (J) H and K bands
3. For the brightest (and largest) ones: high resolution observations in J or H  
for the p factor study (see Nardetto this morning): use of well chosen  
spectral lines
4. Also some propositions for the dynamic of the atmosphere and the study of  
the shock wave passage
5. GTO and open time questions...
6. The limit of AMBER program:  
more stars → fainter stars → smaller stars

# First lessons (reminder)

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The CHARA Array at Mount Wilson

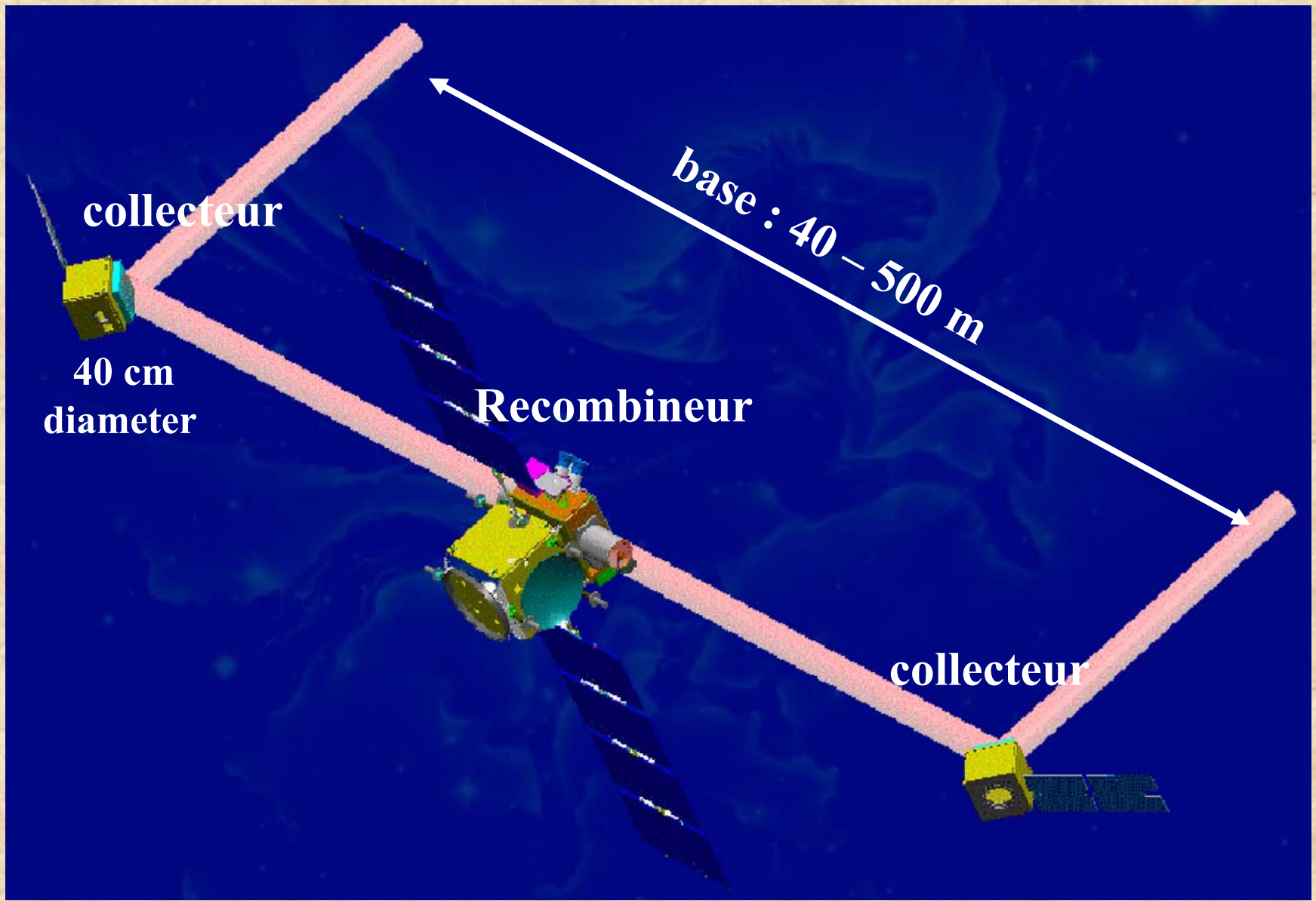


# Le site du Mauna Kea



- Plus grand site astronomique optique de qualité du monde
- 3 télescopes de classe 4m et 4 télescopes de classe >8m équipés d'optique adaptative

*Possibilité de réaliser l'interféromètre le plus résolvant et le plus sensible sans concurrence avant au moins une décennie*



**collecteur**  
40 cm  
diameter

**Recombineur**

**collecteur**

base : 40 - 500 m

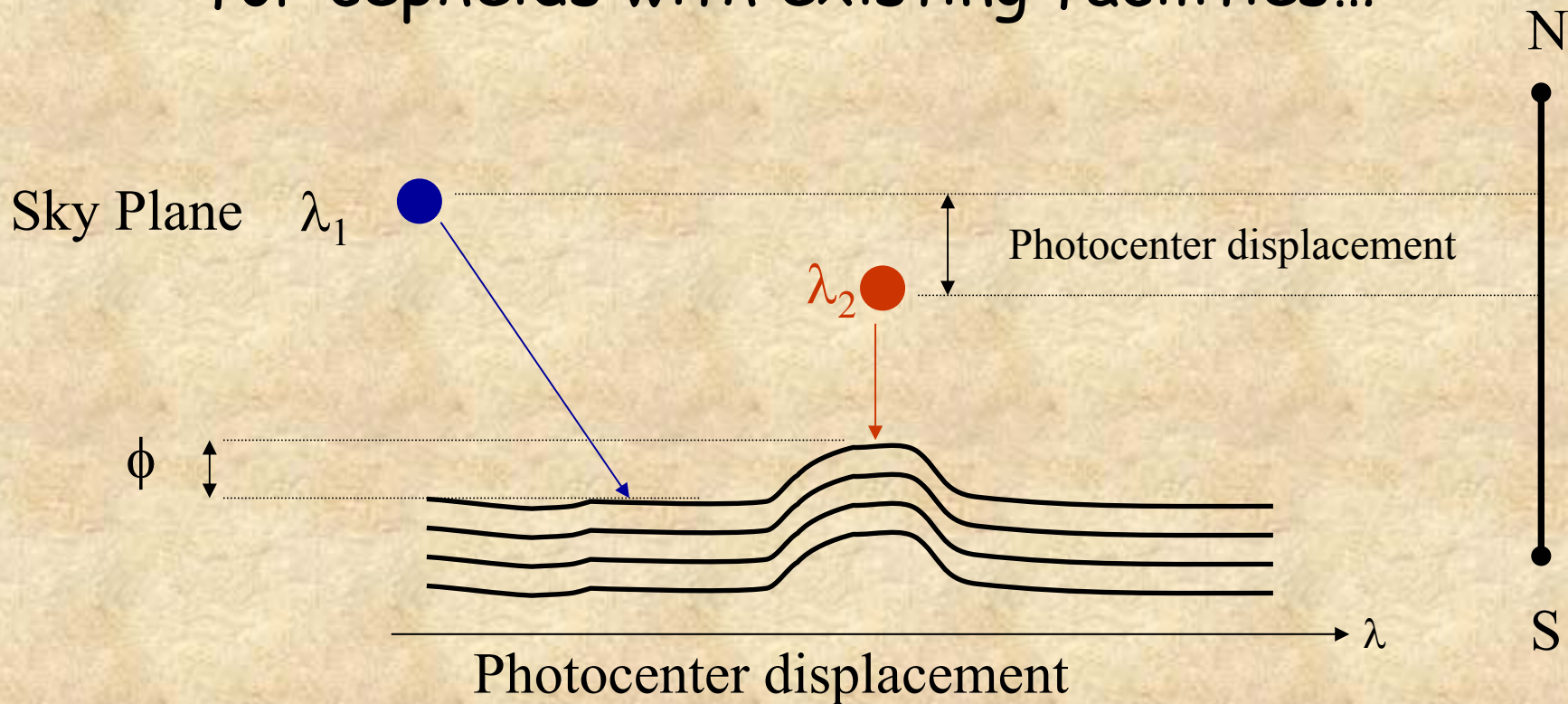
# Other ideas...

- Visible spectrograph of *GI2T/REGAIN* on the VLT I
- KEOPS: a kilometric array in antarctic
  - But mainly oriented for imaging purposes
- DARWIN
  - Mainly oriented for nulling interferometry and spectroscopic characterization of exo planets
- OVLA, hyper telescopes...
- Very long baselines
  - very large number of telescopes
  - very ambitious projects!!

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Differential interferometry could help us a lot for cepheids with existing facilities...



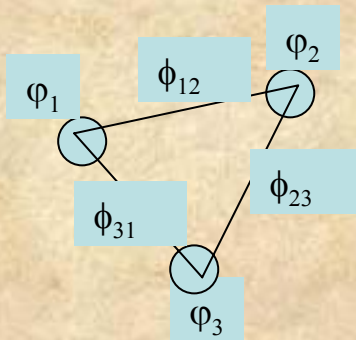
Shift of the fringes ( $\phi$ )



Change in the visibility phase

# Phase measurements in LBI

## Phase closure



Ligne de base 12 :  $\Psi_{12} = \Phi_{12} + \varphi_1 - \varphi_2$

Ligne de base 23 :  $\Psi_{23} = \Phi_{23} + \varphi_2 - \varphi_3$

Ligne de base 31 :  $\Psi_{31} = \Phi_{31} + \varphi_3 - \varphi_1$

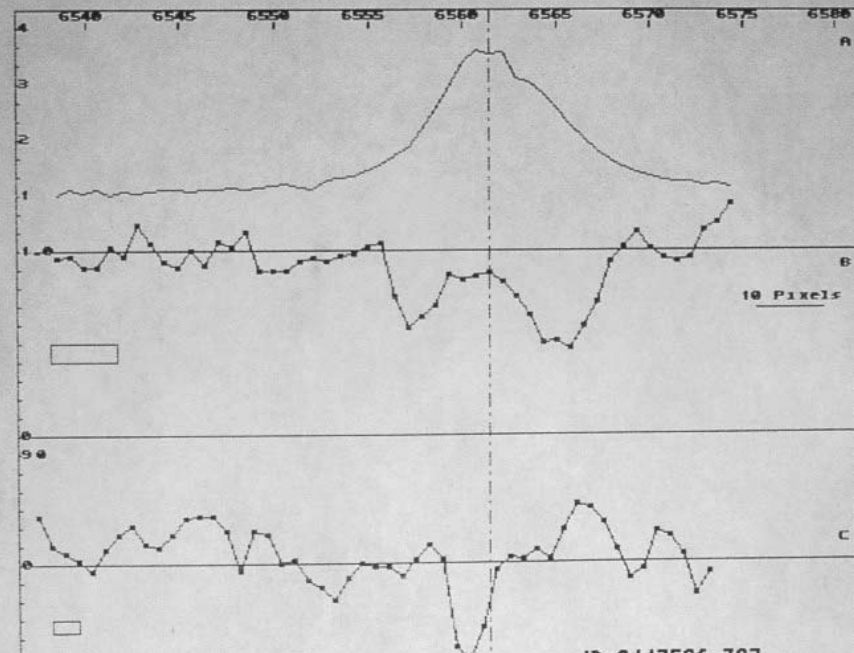
Equation de clôture :  $\Psi_{12} + \Psi_{23} + \Psi_{31} = \Phi_{12} + \Phi_{23} + \Phi_{31}$

## Differential phase

$$\left\langle \tilde{I}_{\lambda_1} \tilde{I}_{\lambda_2}^* \right\rangle_{\vec{B}/\lambda} \Rightarrow \frac{\left| \tilde{O}_{\lambda_1} \left( \frac{\vec{B}}{\lambda} \right) \right|}{\left| \tilde{O}_{\lambda_2} \left( \frac{\vec{B}}{\lambda} \right) \right|} \text{ et } \text{Arg} \left( \tilde{O}_{\lambda_1} \left( \frac{\vec{B}}{\lambda} \right) \right) - \text{Arg} \left( \tilde{O}_{\lambda_2} \left( \frac{\vec{B}}{\lambda} \right) \right)$$



figure 1.4



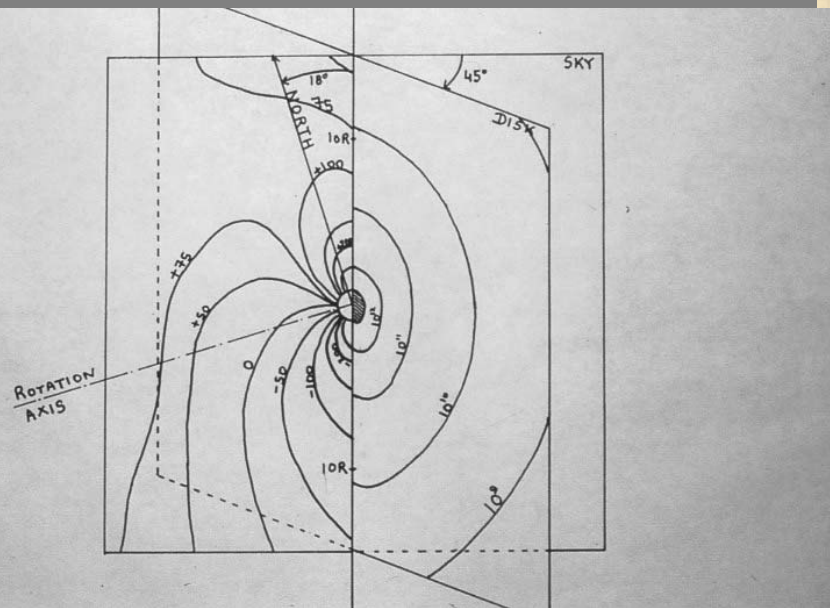
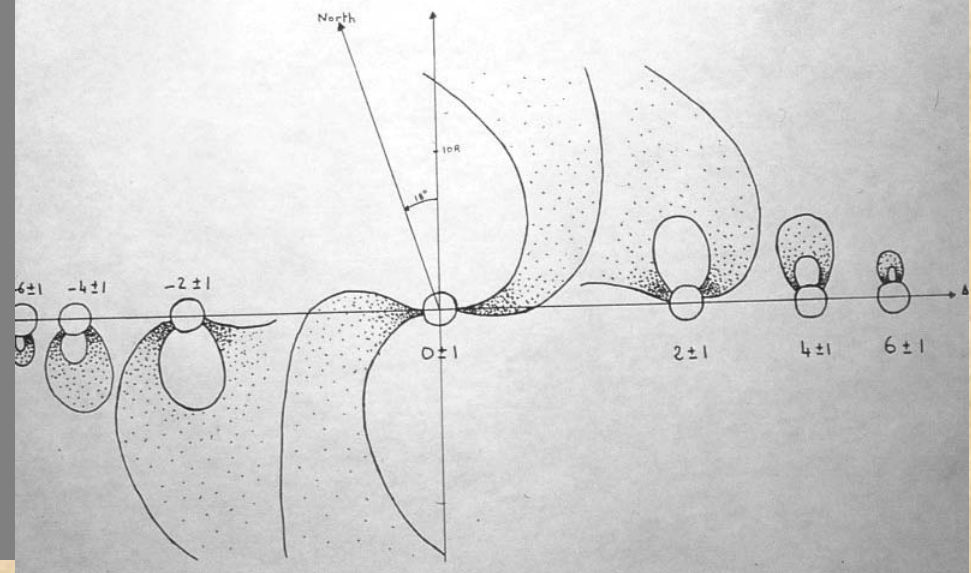


Figure 2. b



# Photocenter displacement (1)

- **Non resolved object:**  $\Phi(u=B/\lambda) = 2\pi (B/\lambda) \varepsilon(\lambda)$

- Photocenter:

$$\varepsilon(\lambda) = \int r o(r, \lambda) dr / \int o(r, \lambda) dr$$

- yields the first order moment of the brightness distribution  $o(r, \lambda)$ , interesting parameter for any object showing spectral features possibly due or connected to "large scale" spatial features.

# Photocenter displacement (2)

- Some numbers:
- $B=200\text{m}$ ,  $\lambda=2\mu\text{m}$ ,  $\sigma(\phi)/\phi=10^{-3}$  → sensitivity of a few  $\mu\text{as}$ !
- For a cepheid
  - Preliminary calculations for a simple rotating stars (Mourard, 1990)
  - Extension to rotating+pulsating stars (Lagarde&Petrov, 1996)
  - Typical phase effect: **+20% of the diameter**
  - Typical phase effect due to the change of diameter:  $\pm 20\%$  of  $10\%$  =  **$\pm 2\%$**
  - These numbers will be confirmed on the basis of spectrally resolved intensity maps
- A 1 mas cepheid could be detected with a SNR of 20
- If we go to  $0.5\mu\text{m}$ , a  $250\mu\text{as}$  cepheid could be measured
- If we increase the number of lines simultaneously observed, we can reduced the sensitivity by a factor of 10 and go to  $20\mu\text{as}$  diameter

# LMC Cepheids with AMBER and PRIMA facilities

Statistical studies (*preliminary work...*):

- Based on the informations found in Persson et al., *Astron.J.*, 128, nov. 2004
- Use of the H and K magnitudes
- The spectrophotometric relation

$$\Phi_{JK} = (a_0 + a_1(J-K) + a_2 (J-K)^2 + a_3(J-K)^3 + a_4 (J-K)^4 + a_5(J-K)^5) 9.306 \cdot 10^{-0.2J}$$

avec  $\Delta\phi / \phi = 9,1 \%$

$$\Phi_{JH} = (a_0 + a_1(J-H) + a_2 (J-H)^2 + a_3(J-H)^3 + a_4 (J-H)^4 + a_5(J-H)^5) 9.306 \cdot 10^{-0.2J}$$

avec  $\Delta\phi / \phi = 10.7 \%$

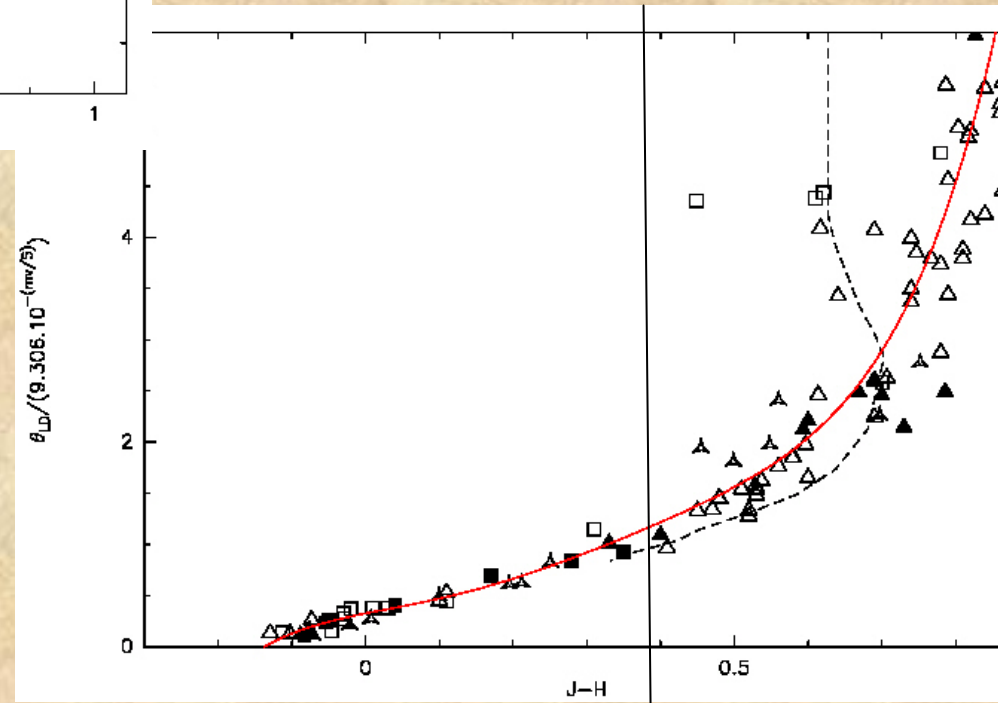
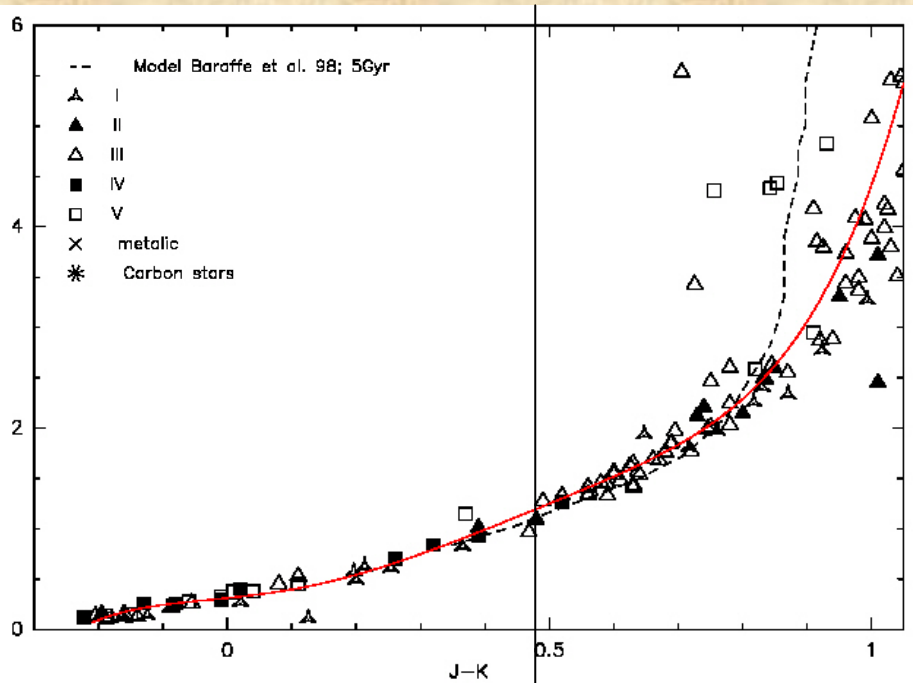
en utilisant le tableau :

Delfosse, Bonneau, 2004

coul	domaine	a <sub>0</sub>	a <sub>1</sub>	a <sub>2</sub>	a <sub>3</sub>	a <sub>4</sub>	a <sub>5</sub>
J-H	[-0.20;1.05]	0.32264301	1.16345012	-2.35793495	4.59855961	-3.99170613	1.6884892
J-K	[-0.20;1.4]	0.31137016	0.72685874	-0.082882155	-0.6358744	0.96504903	-0.28185570

- Estimation of photocenter displacements
- Estimation of signal to noise ratio
  - K=10, UTs, R=1000, 5h  $\sigma_\varepsilon(\lambda) = 1 \mu\text{as}$
  - With the use of the Phase Reference mode of PRIMA and the multiplexing of spectral lines, we should have the sensitivity.

# $\theta(J, J-H)$ and $\theta(J, J-K)$ relations

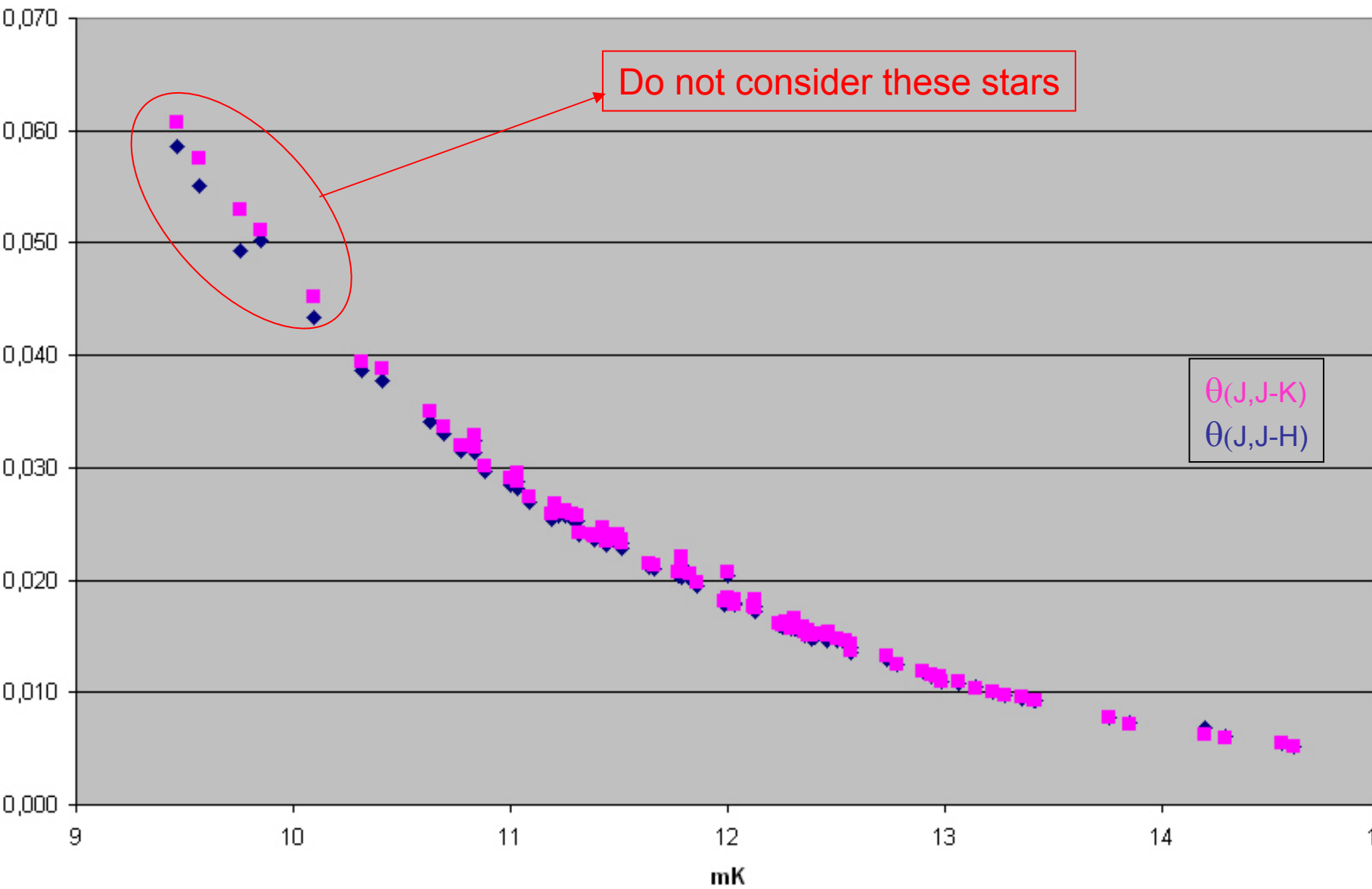


For this LMC sample:

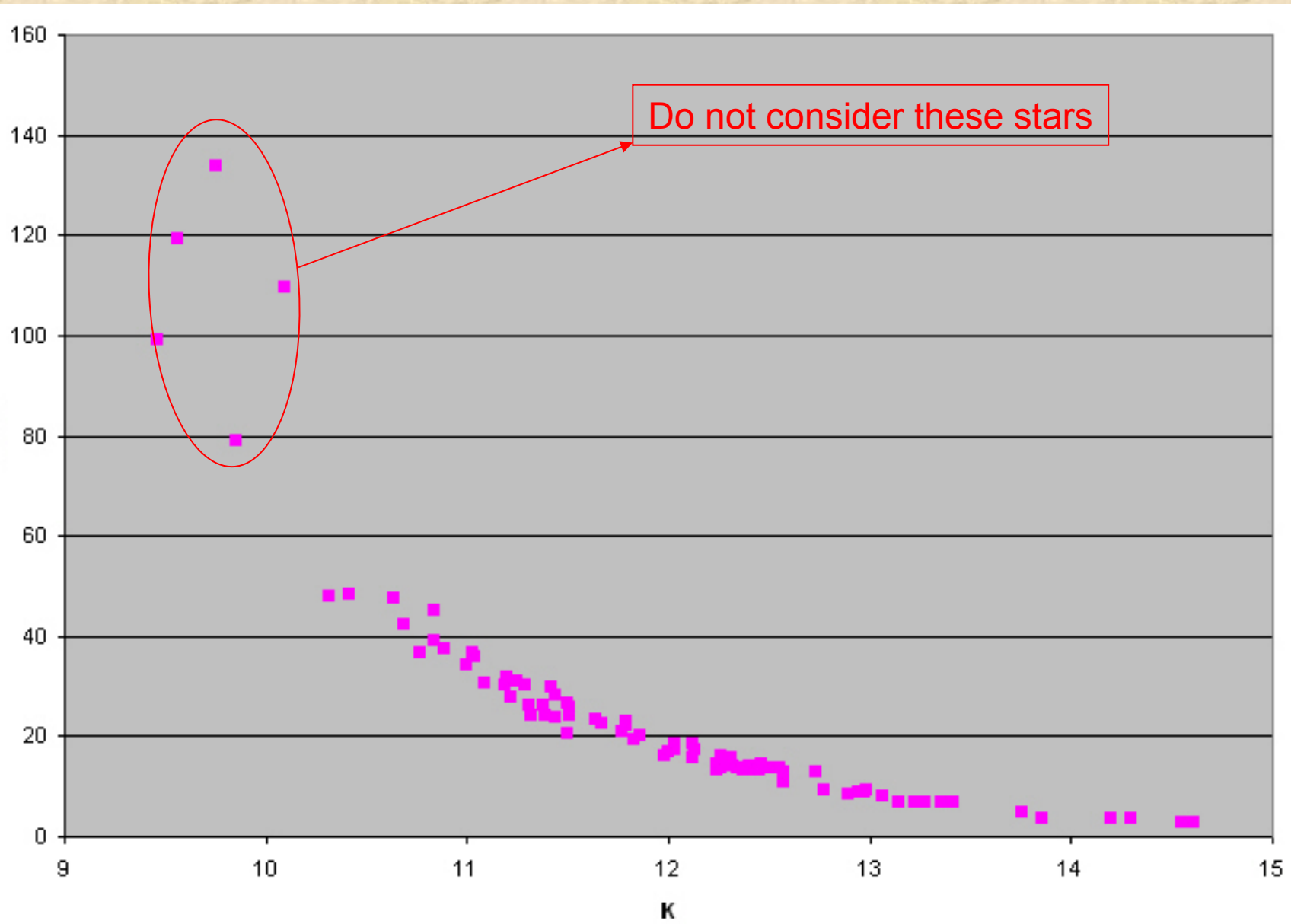
$\langle J-H \rangle = 0.38$

$\langle J-K \rangle = 0.48$

# Angular diameter for a sample of LMC cepheids



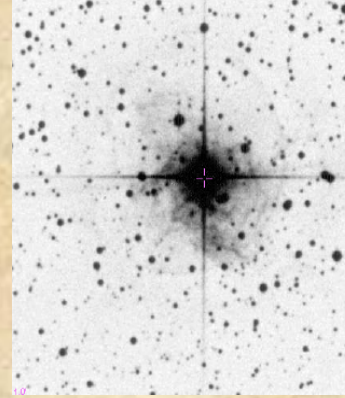
# Periods of the LMC cepheids sample



# First lessons (reminder)

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# Various ideas to conclude



Circumstellar study of cepheids: mass loss?

Stellar surface structure by going to surface imaging (kilometric baseline and large (15) number of telescopes...)

Cepheids as member of binary systems → mass determinations?

Other types of variables (RV Tauri, double mode cepheids, long periods...)

High spectral resolution

- 10000 with AMBER in the infrared
- Up to 30000 in the visible with REGAIN/VLTI
- Direct probe of the contribution functions (weak or strong lines)
- Differential phase delays should be measurable
- Strong constraints on the Limb Darkening Coefficient in spectral lines but only a few cepheids will be correctly reachable on the VLTI (magnitude and spatial resolution).

Differential interferometry could give us access to the LMC cepheids but also to a lot of faint and small galactic cepheids!

- It is just a question of time!