Interferometric observations of benchmark stars

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Introduction

Why interferometric observations on benchmark stars ?

→ Fundamental parameters of stars (angular diameter, effective temperature, etc.): many different methods but strong inconsistencies we can't explain so far

→ White et al. (2018) show strong discrepancies between PAVO and CLASSIC angular diameters measurements : PAVO diameters are 15% smaller than those done with CLASSIC but PAVO consistent with the spectroscopy

→ Karovicova et al. (2018) highlights the disagreement of their new interferometric measurements with the previous effective temperatures of benchmark stars (~ 300 K in difference) :

$$T_{eff} = \left(\frac{4\,F_{bol}}{\sigma\theta^2}\right)^{1/4}$$

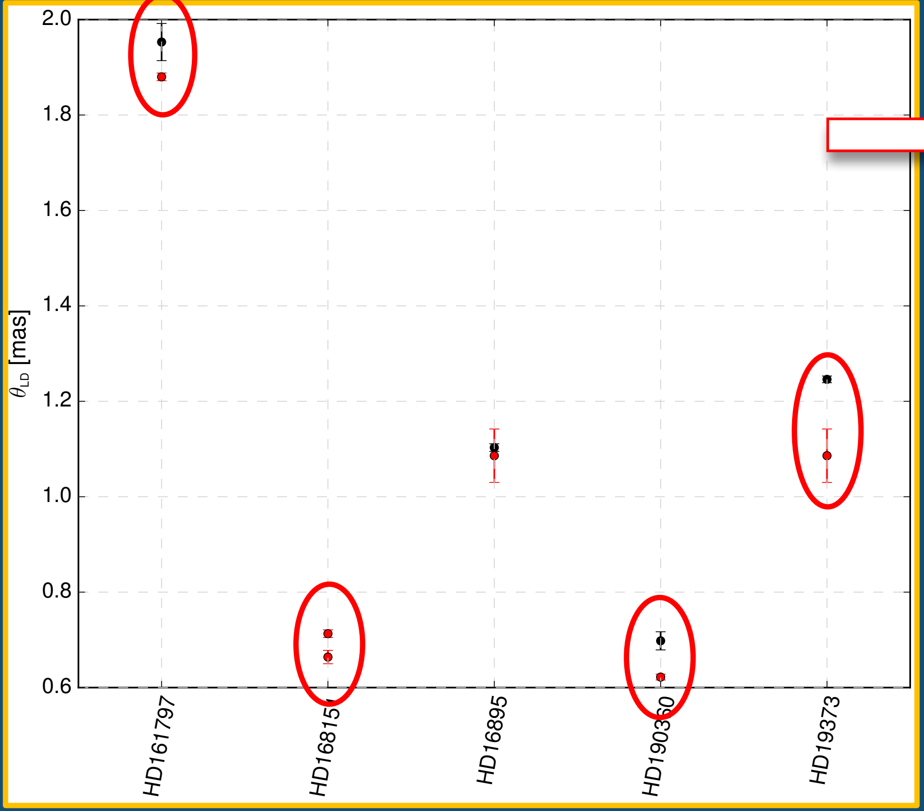
Their measurements are also in agreement with spectroscopy. The two studies agree on the fact that previous measurements were affected by systematic errors exceeding their formal uncertainties. This could come from the estimation of calibrators angular diameters : one needs to observe multiple calibrators as small and as close as possible to the target.

→ We would like to quantify how well we agree on the fundamental parameters of stars

Introduction

Why interferometric observations on benchmark stars ?

→ The JMMC Measured stellar Diameters Catalog (JMDC) Duvert et al. (2016): catalog that lists all interferometric measurements that have been done so far



Many interferometric measurements for a single star that are most of time inconsistent with each other considering the published uncertainties and documented systemtic errors

Instruments ? Visible / infrared problem ?
Underestimation of systematic uncertainties ? Calibrators ?

I already did a work linked with my PhD (for SBCRs) where I implemented criteria to carefully select one measurement among many others. But some redundancies remain unexplained …

Objectives

Surface Brightness-Colour Relations (SBCRs) :

→ Relations between the surface brightness (i.e. the flux density per unit angular area) and the colour of stars : allow to determine distances in the Local Universe

→ PLATO mission : SBCRs used to determine the radius of the exoplanet

Asteroseismology :

→ Most of stars have oscillations : compare diameters from asteroseismology with the interferometric ones : $\theta[mas] = 9.345 \frac{R_*[m]}{d\ [m]}$

VEGA & PAVO instruments on the CHARA array

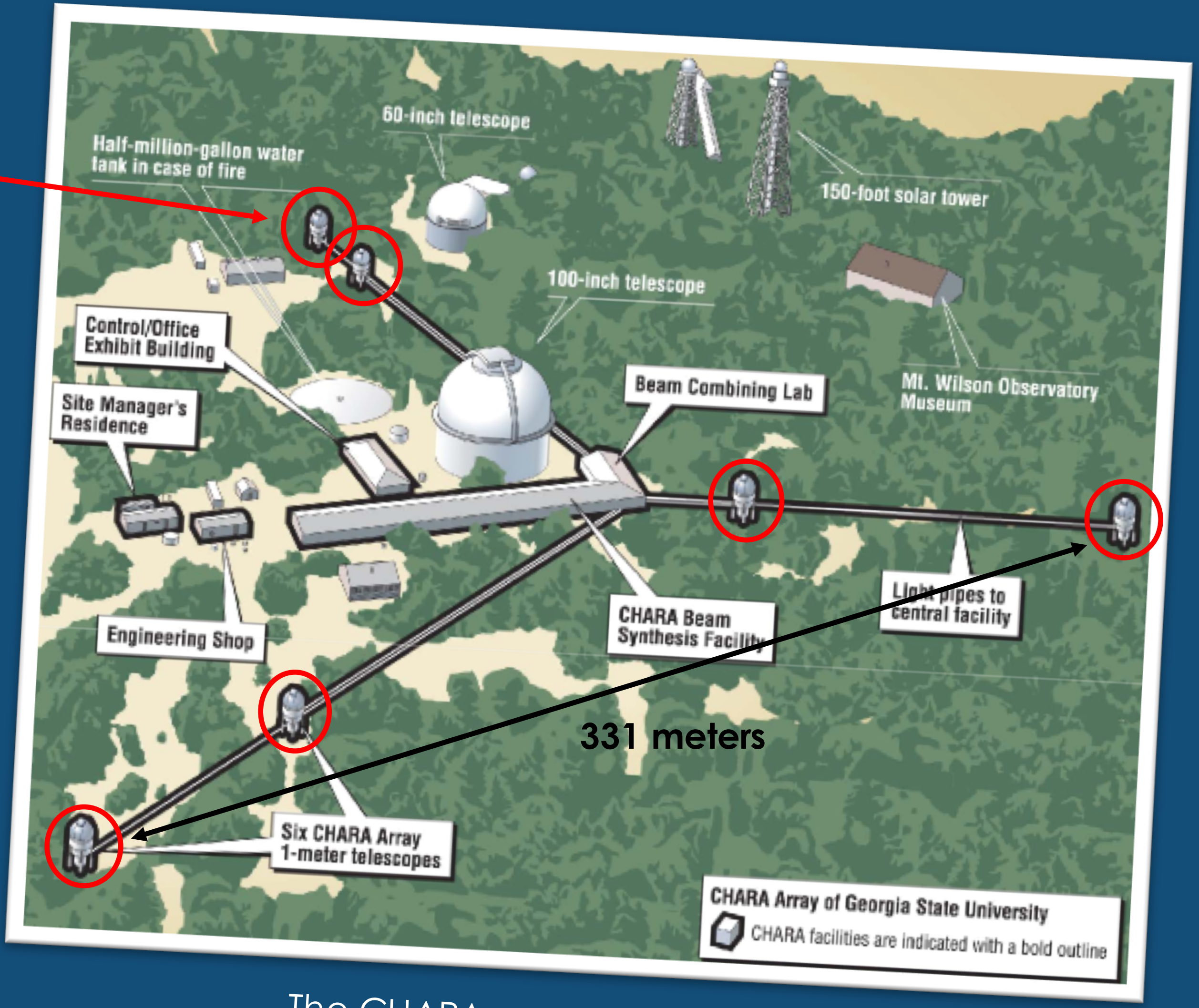
The CHARA array is an optical / near-infrared interferometer located on Mount Wilson, CA
→ 6 telescopes (baselines until 331 meters)

VEGA : Visible sp**E**ctro**G**raph and pol**A**rimeter

→ Optical interferometry (in *R*-band)
→ 0.2 millisecond of arc of spatial resolution and up to 30000 of spectral resolution
→ Up to 4-telescope operations

PAVO : Precision **A**stronomical **V**isible **O**bservations

→ Optical interferometry (in *R*-band)
→ 0.2 millisecond of arc of spatial resolution and up to 30 of spectral resolution
→ Up to 3-telescope operations



The CHARA array at Mount Wilson

VEGA & PAVO targets

Targets observed by both VEGA and PAVO instruments :

→ 10 stars in total for this presentation (but more now to be processed)

→ Goal : compare interferometric measurements from VEGA and PAVO

→ Are they consistent ? Can we identify a problem ?

→ We want angular diameters as precise as possible (to be in agreement with PLATO objectives of 2% in precision on the radius, depending on the distance of the star and its uncertainty)

Star HD	Sp_type	VEGA data*	PAVO data*	N VEGA cals	N PAVO cals	Common cals
HD185657	G6V	6 nights (N = 17)	4 nights (N = 207)	3	6	2
HD182896	K0	4 nights (N = 5)	3 nights (N = 115)	1	5	0
HD178208	K3III	7 nights (N = 23)	3 nights (N = 69)	2	5	1
HD181069	K1III	6 nights (N = 11)	2 nights (N = 92)	4	4	1
HD180756	G8III	3 nights (N = 8)	3 nights (N = 69)	3	3	1
HD21467	K0IV	8 nights (N = 20)	1 night (N = 36)	3	3	0
HD73665	G8III	3 nights (N = 14)	3 nights (N = 110)	3	4	0
HD181597	K1III	3 nights (N = 15)	2 nights (N = 115)	2	3	0
HD175740	G8III	4 nights (N = 12)	2 nights (N = 138)	3	3	0
HD167042	K1III	5 nights (N = 5)	3 nights (N = 207)	2	3	0

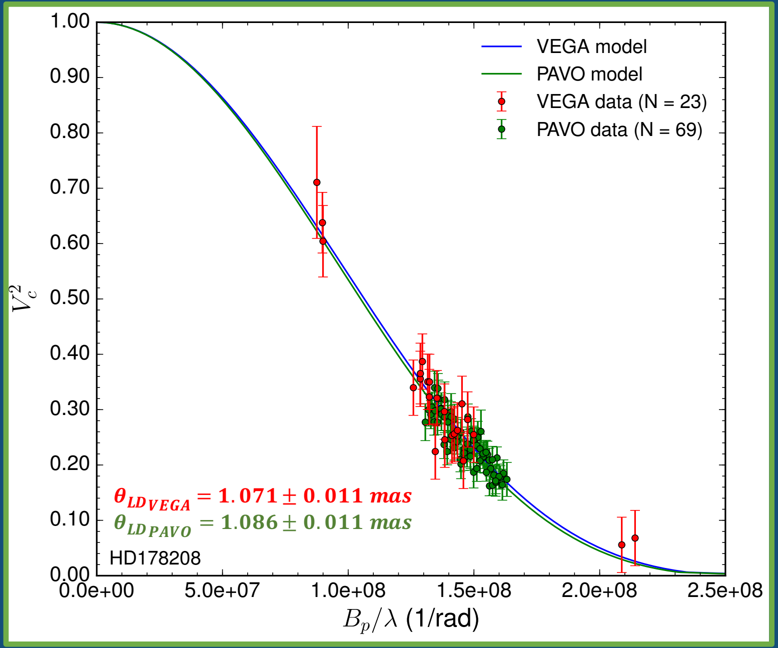
*N is the number of data remaining after processing (V^2 for one single spatial frequency)

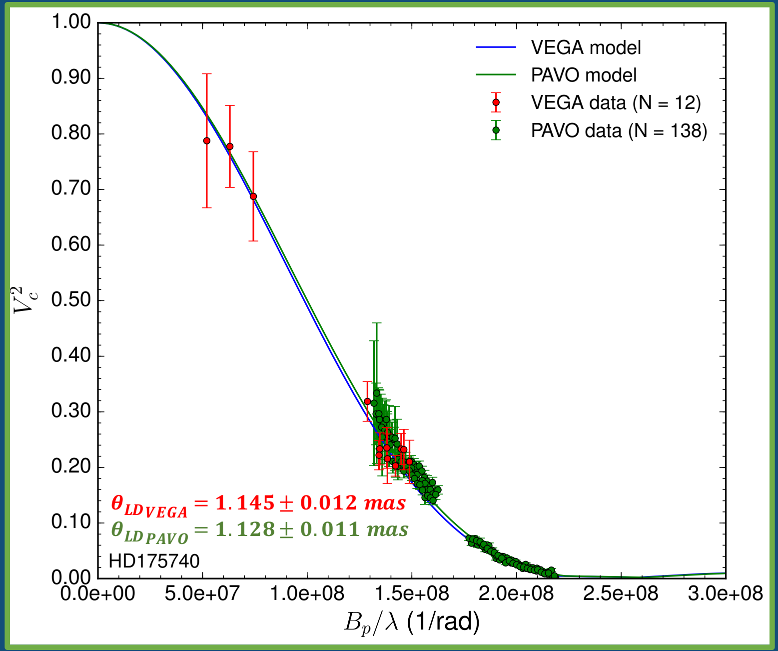
Log of VEGA and PAVO observations of the 10 benchmark stars

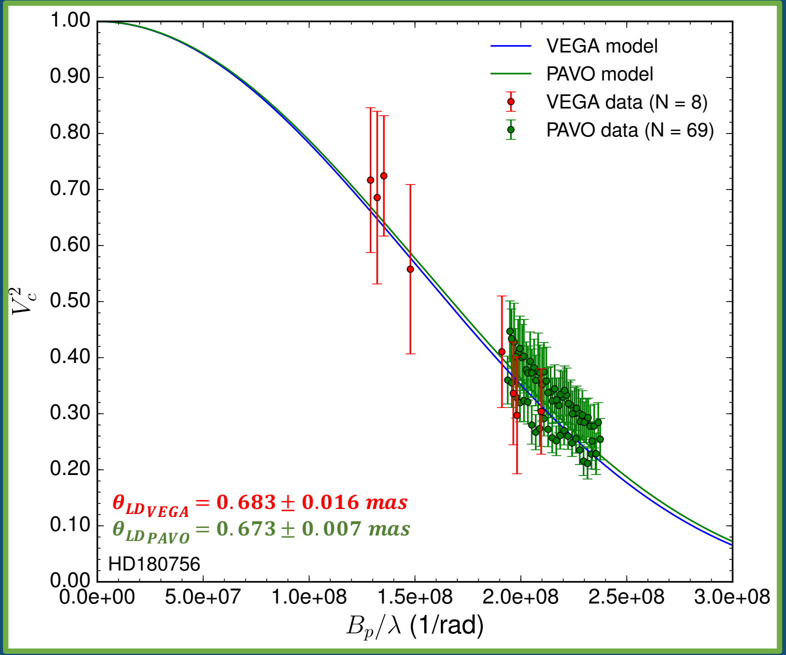
! → Almost no common calibrators between PAVO and VEGA

Results from VEGA & PAVO measurements

Consistent results







ⓘ Limb darkened angular diameter model from Hanbury et al. (1974)

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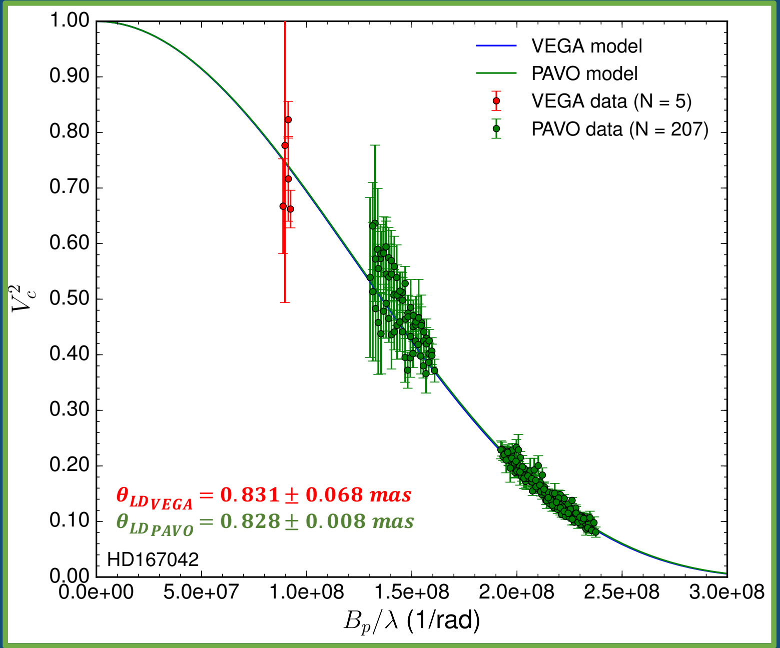

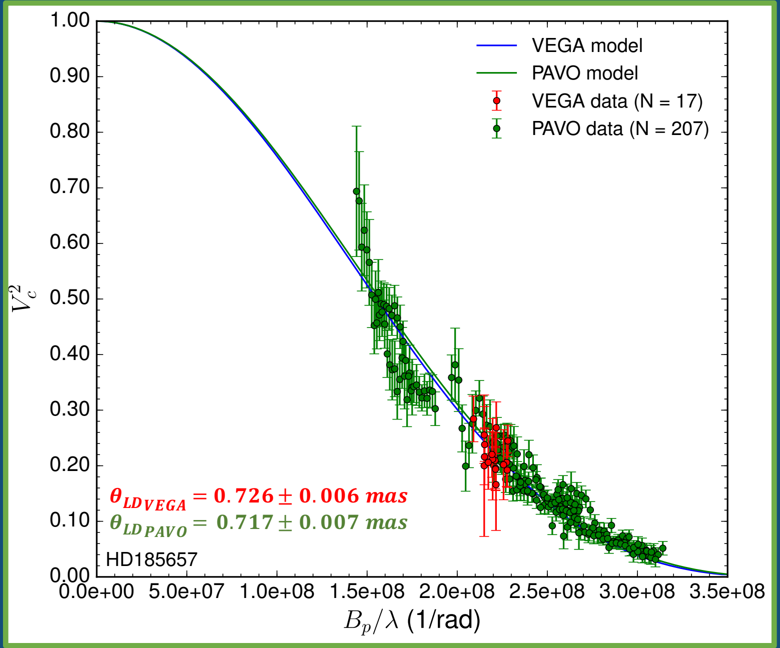

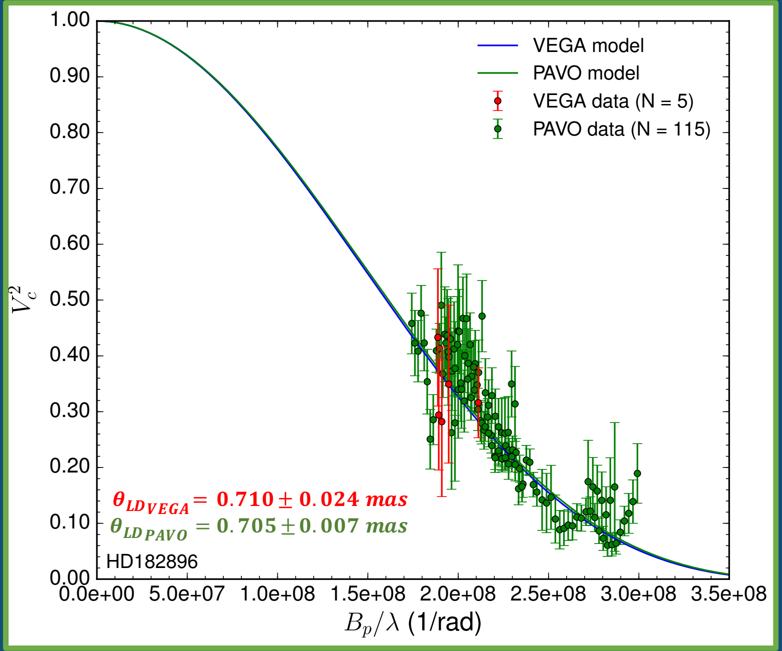

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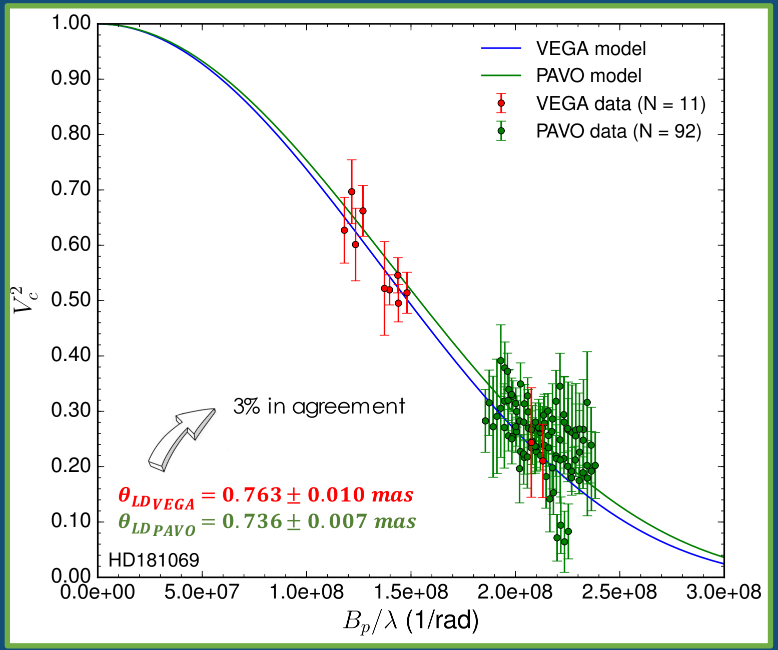
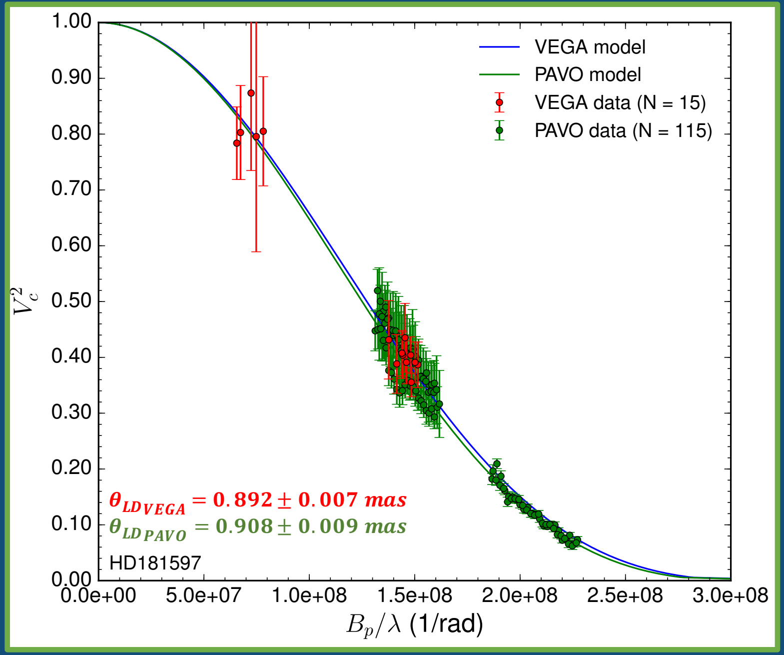
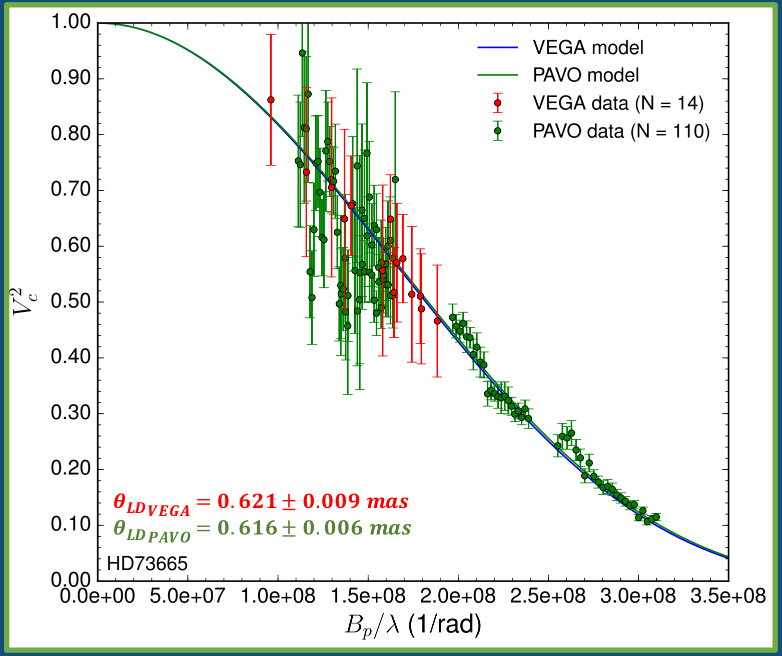


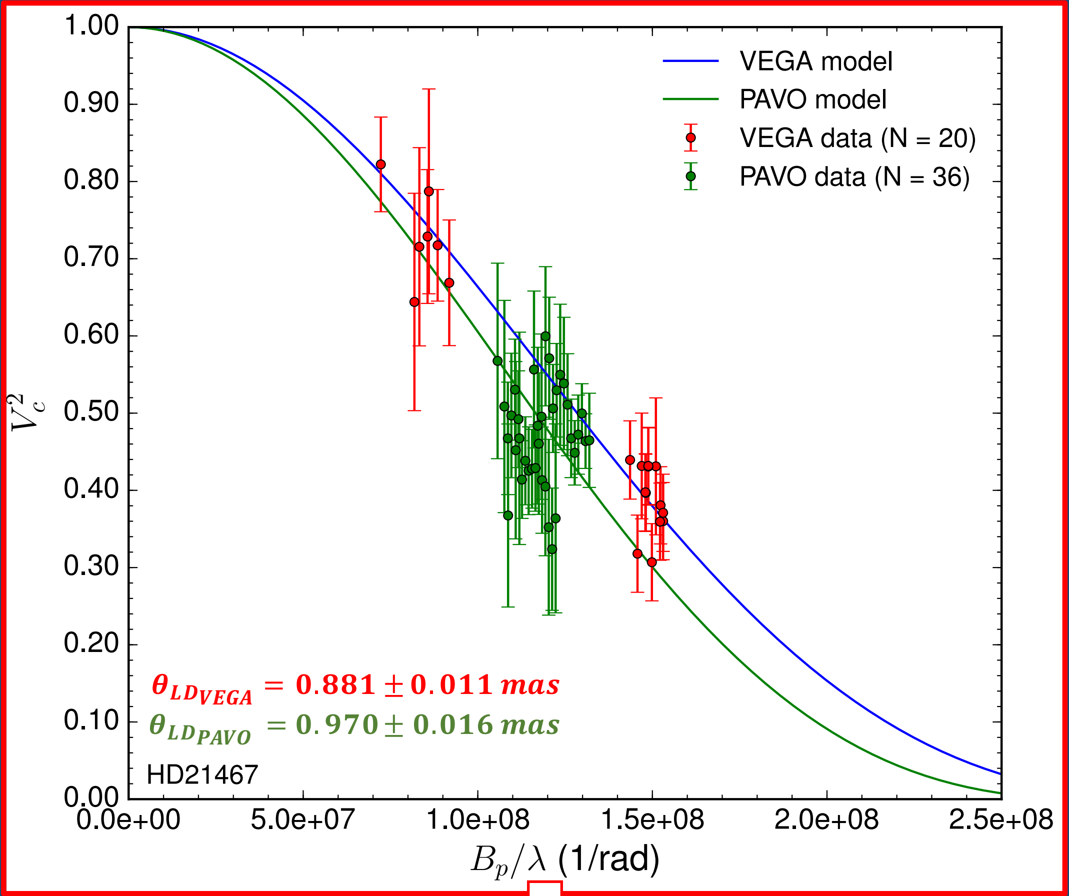




Limb darkened angular diameter model from Hanbury et al. (1974)

Results from VEGA & PAVO measurements

Inconsistent results



PAVO night of bad quality (wind, humidity, bad seeing ...), but small uncertainties
→ Deeper study on the estimation of individual uncertainties when bad conditions

To be checked in detail ...

Results from VEGA & PAVO measurements

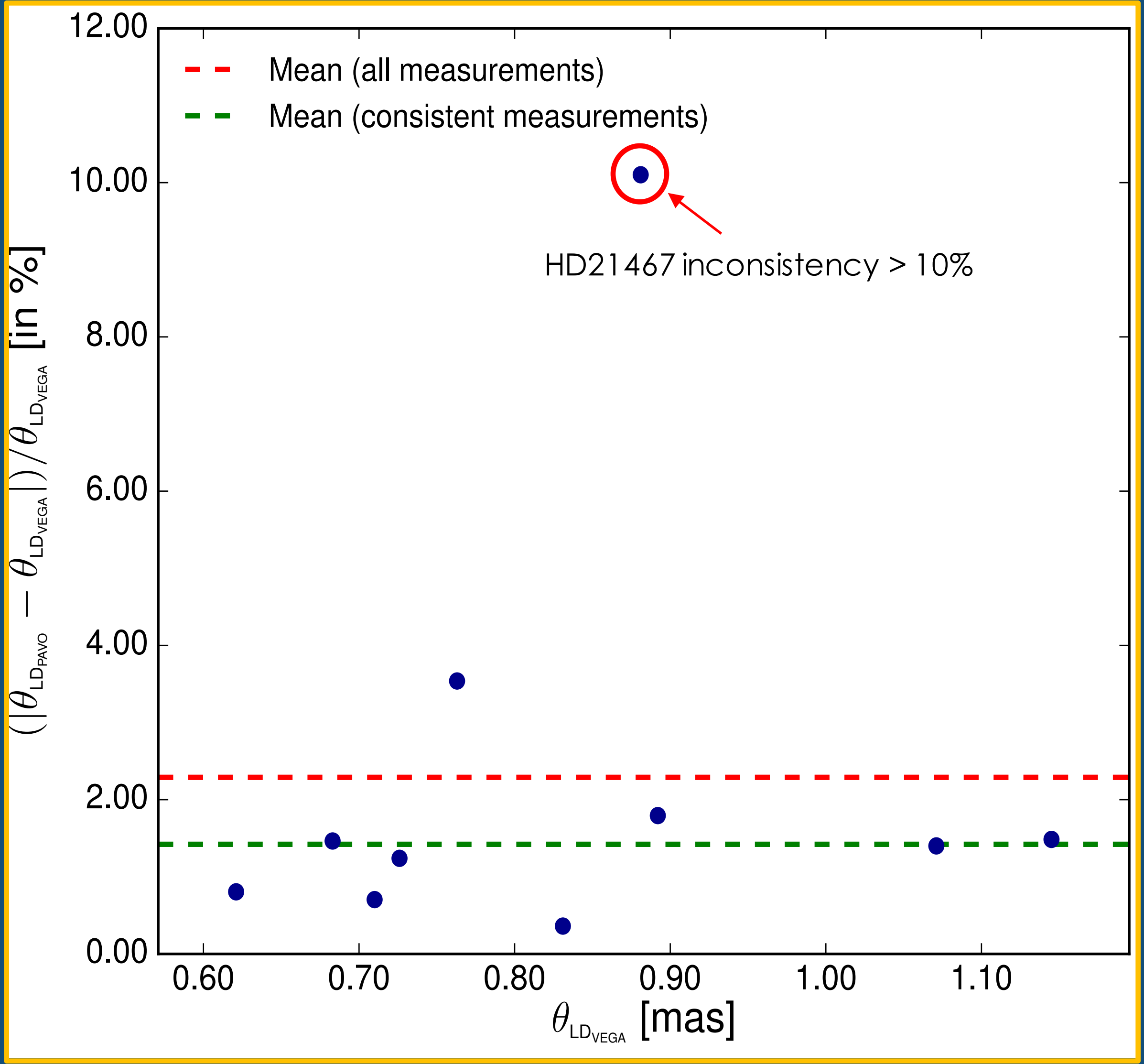
1. Considering all measurements :

$$\frac{|\theta_{LD_{PAVO}} - \theta_{LD_{VEGA}}|}{\theta_{LD_{VEGA}}} \approx 2.29\%$$

2. Considering consistent measurements :

$$\frac{|\theta_{LD_{PAVO}} - \theta_{LD_{VEGA}}|}{\theta_{LD_{VEGA}}} \approx 1.42\ \%$$

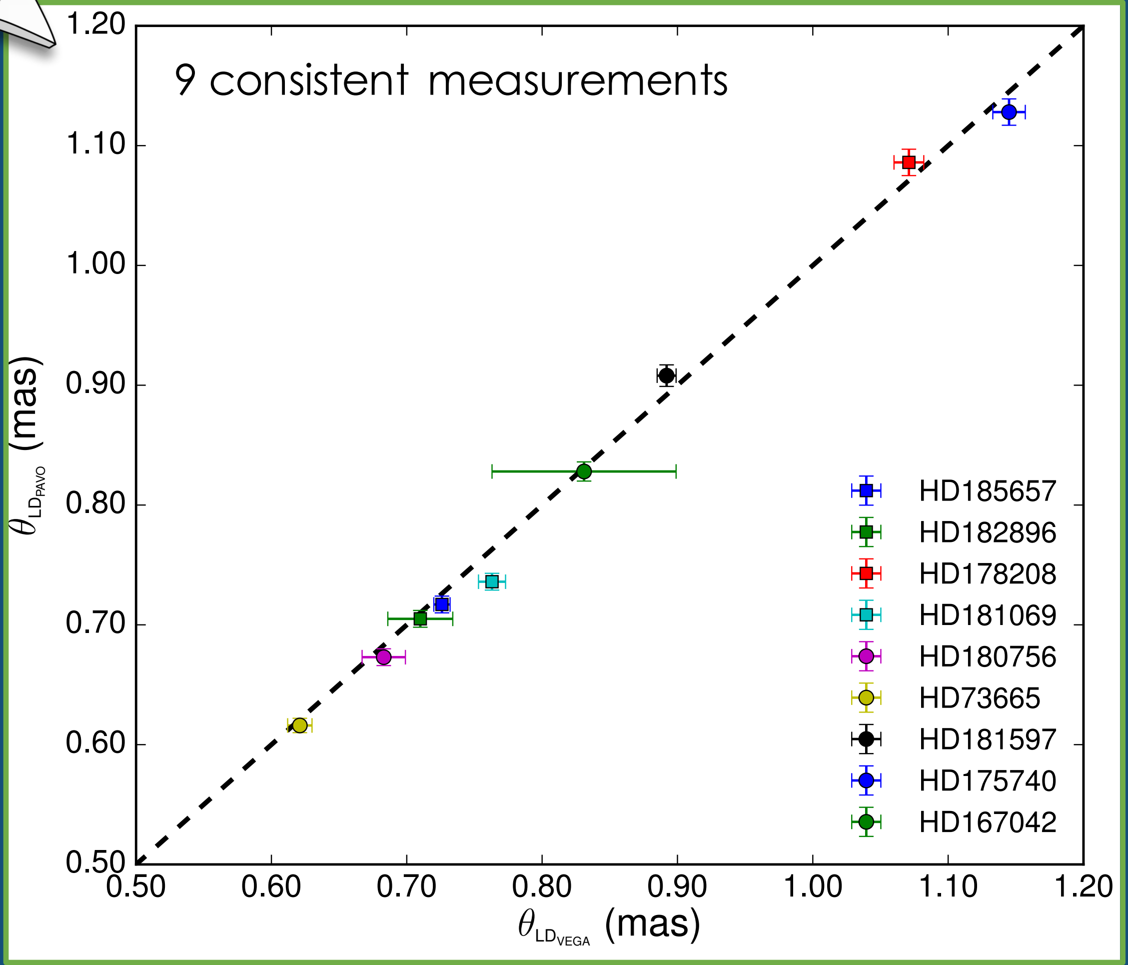
Diameters are in very good agreement, up to 1.42 %
Even if there are no common calibrators !



Results from VEGA & PAVO measurements : summary

Star HD	theta_LD VEGA [mas]	theta_LD PAVO [mas]
HD185657	0.726 +/- 0.006	0.717 +/- 0.007
HD182896	0.710 +/- 0.024	0.705 +/- 0.007
HD178208	1.071 +/- 0.011	1.086 +/- 0.011
HD181069	0.763 +/- 0.010	0.736 +/- 0.007
HD180756	0.683 +/- 0.016	0.673 +/- 0.007
HD21467	0.881 +/- 0.011	0.970 +/- 0.016
HD73665	0.621 +/- 0.009	0.616 +/- 0.006
HD181597	0.892 +/- 0.007	0.908 +/- 0.009
HD175740	1.145 +/- 0.012	1.128 +/- 0.011
HD167042	0.831 +/- 0.068	0.828 +/- 0.008

Results from the comparison



Conclusions :

- PAVO / VEGA angular diameters are in good agreement
- Visible / infrared problems ?

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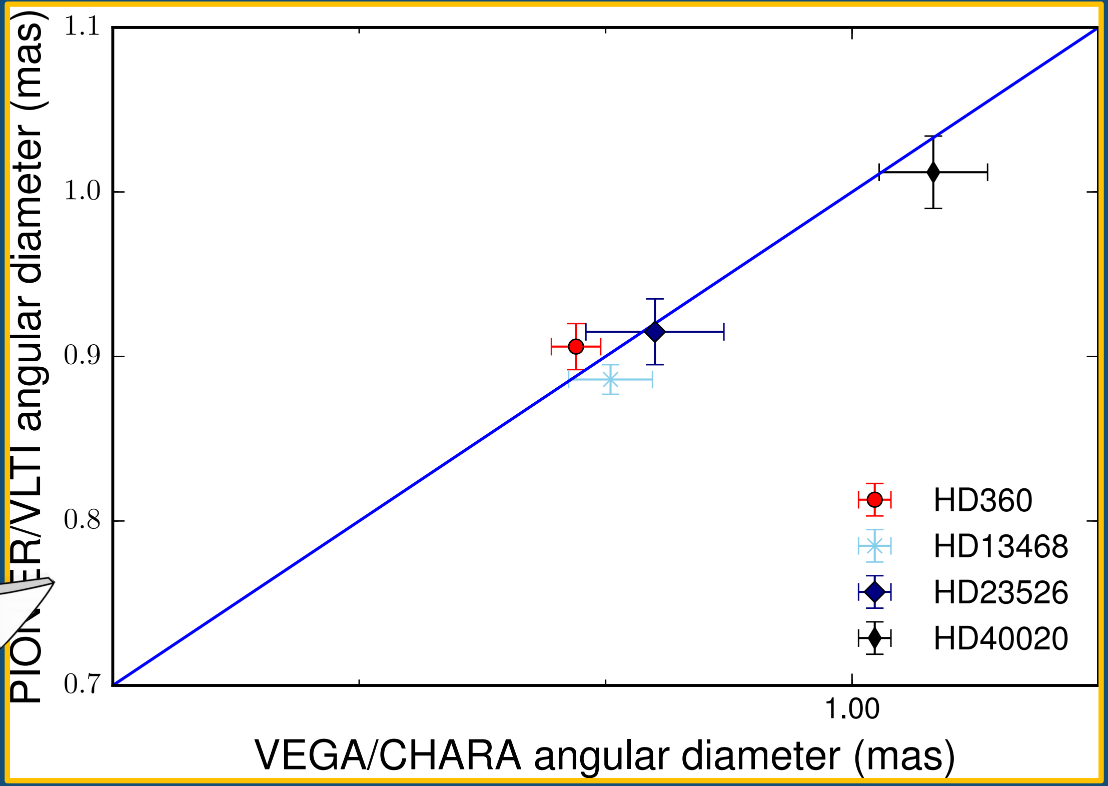

Nardetto et al. (2019, in prep.) : comparison between PIONIER (*H*-band) and VEGA

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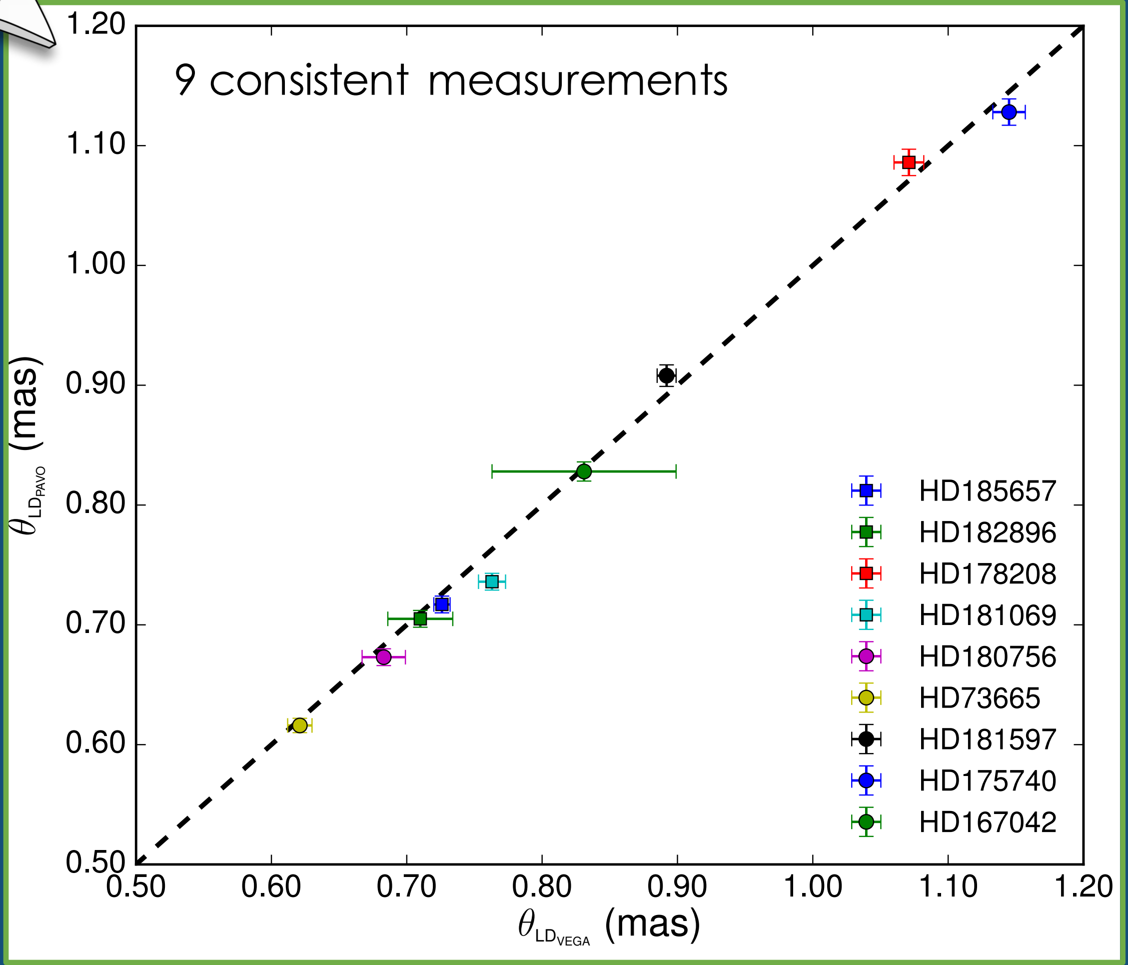


Conclusions :

- PAVO / VEGA angular diameters are in good agreement
- Visible / infrared problems ? → No …
- Inconsistent data for HD21467 : suffers from calibration issues (bad PAVO night, scans are systematically offsets)

→ Karovicova et al. (2018) demonstrate the importance of the determination of calibrators angular diameters

Perspectives

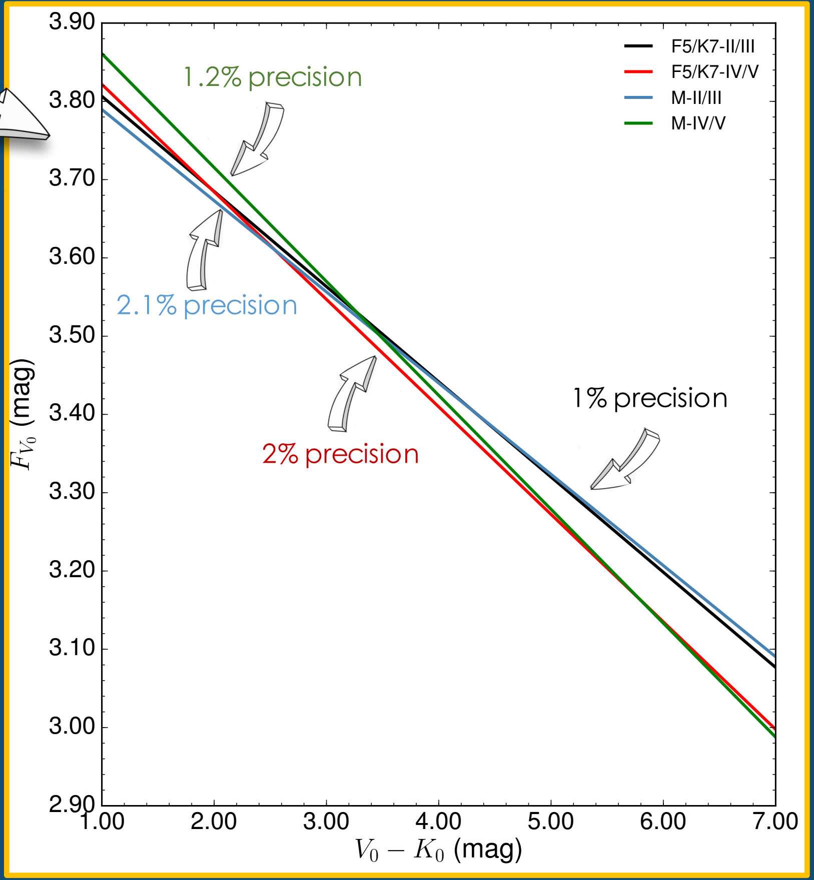
Measuring angular diameters are of high importance for calibrating Surface Brightness-Colour Relations (SBCRs)

→ Salsi et al. (2019), in prep : 4 new precise SBCRs that allow to deduce angular diameters with 1-2% of uncertainty

→ Disagreement between subgiants/giants and subdwarfs/dwarfs stars

→ Include VEGA/PAVO measurements in the sample of stars : are they consistent with the SBCRs ?

→ Need to resolve these discrepancies : theoretical SBCRs using models



Salsi et al. (2019), in prep : newly developed SBCRs linked to the PLATO mission

Thank you !

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Method for determining an limb-darkened angular diameter

1. We compute visibilities from both VEGA and PAVO instruments

2. We fit a model of Bessel functions (visibility curve) above measurements :

$$\Gamma_\lambda{}^2(d) = (\alpha/2+\beta/3)^{-2}[\alpha J_1(x)/x+\beta(\pi/2)^{1/2}\, J_{3/2}(x)/x^{3/2}]^2 \quad (4)$$

where $\alpha = 1-u_\lambda$, $\beta = u_\lambda$, $x = \pi\theta_{\rm LD}\, d/\lambda_0$, $\theta_{\rm LD}$ is the true angular diameter of the limb-darkened star, and it is assumed that $\Delta_\lambda = 1$.

Fitting this model using a χ^2 minimization strategy returns a θ_{LD} estimate

NB : The standard error of the angular diameter is determined in the following way :

$$\chi^2(p_i+\sigma_i) = \chi^2(p_i)+1$$

Thus the standard error is an uncertainty which corresponds to an increase of χ^2 by 1