Direct characterization of limb darkening dedicated to transit measurements and asteroseismology

Roxanne Ligi, PhD student at Observatoire de la Côte d'Azur/CNRS UMR 6525, Nice, France.

The determination of fundamental parameters of stars is essential to constrain their atmosphere and structure, and to understand their evolution. Using VEGA/CHARA interferometer, we have measured the visibility function of distant stars and derived their fundamental parameters.
Particularly, a precise measurement of limb darkening is a powerful tool to derive the temperature, radius and mass of stars. Related to asteroseismology, our knowledge in stellar structure and evolution can be remarkably increased, as limb darkening plays an important role in the pulsation modelling. Besides, the transit method, dedicated to the detection of exoplanets, can also be applied to determine the structure of spots on stars surface, and to measure the radial velocity variations.

LIMB DARKENING

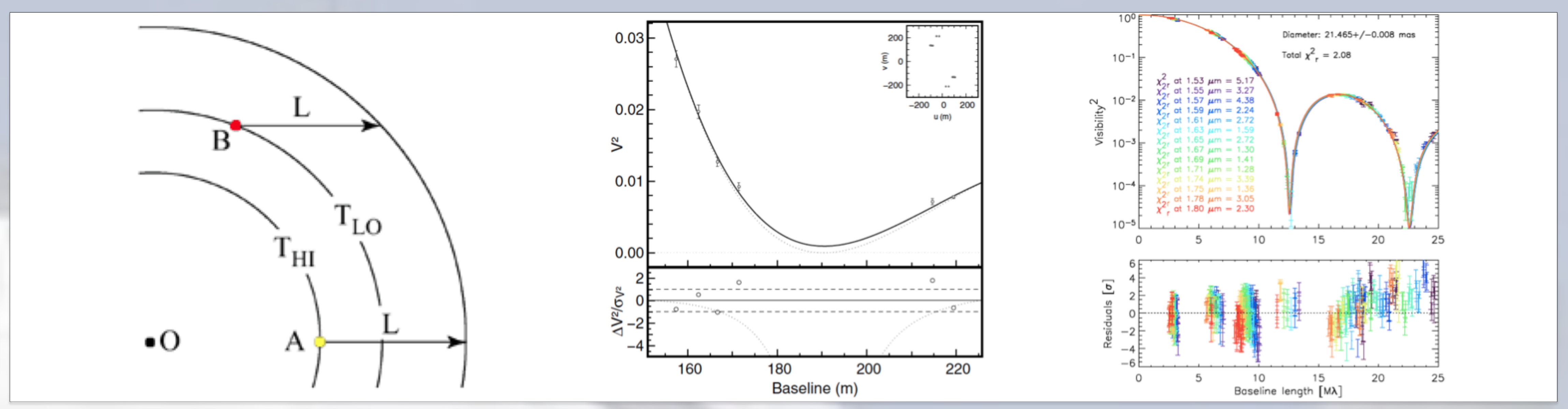

Figure 1: *Left*: illustration of limb darkening. The depth of the atmospheric layer emitting the light detected at the center of or close to the limb of the disk correspond to different effective temperatures. *Middle*: interferometric visibility measurements (top) and fitting residuals (bottom) obtained with FLUOR. *Right*: interferometric observations of Arcturus (Lacour et al., 2008).

The recent development of interferometry allows reaching low visibilities of the observed fringes in the visible wavelengths and thus accessing limb darkening measurements. Using VEGA/CHARA interferometer, we can measure the squared visibilities which is proportional to the first order Bessel function:

$$V^2 = 2J_1(x)/x^2$$

which depends itself on the baseline B, wavelength λ and uniform angular diameter ϑ of the target:

$$x = 15{,}23B(m)\vartheta(mas)/\lambda(m).$$

Using Claret coefficients u, one can derive the limb darkening of a star using Hanbury Brown et al. formula:

$$\rho_\vartheta(\lambda) = [(1-u_\lambda/3)(1-7u_\lambda/15)]^{1/2},$$

from which we derive:

$$\theta_{UD}(\lambda) = \theta_{LD}/\rho_\vartheta(\lambda).$$

Up to now, interferometry gives stars angular diameters with a good precision (less than 2%). Starting from this, a Monte Carlo calculation gives the radius, the mass and the temperature of the star.

RECENT RESULTS

The fundamental parameters of the F4V star 13 Cygnus has been calculated with good accuracy:

ϑ = 0.76 ± 0.014
R = 1.51± 0.03 $R_\odot$
M = 1.60 ± 0.03 $M_\odot$
T_{eff} = 6972 ± 64 K

We could probe the stellar interior starting with these fundamental parameters coupled with asteroseismology and numerical modelling.

A powerfull tool to study this type of host star is the limb darkening, which can be determined with low visibilities.

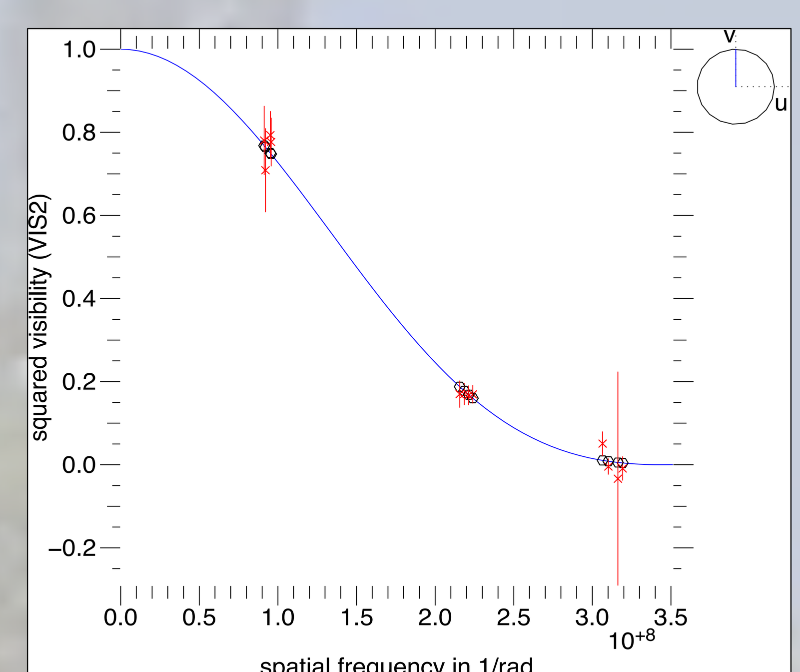

Figure 2: Model of limb darkening squared visibility obtained with JMMC LITpro software, from 13 Cyg data obtained with June and October observations.

PROSPECTIVE

With VEGA, we will be able to measure the second lobe of squared visibility and thus precisely characterize the limb darkening of stars.

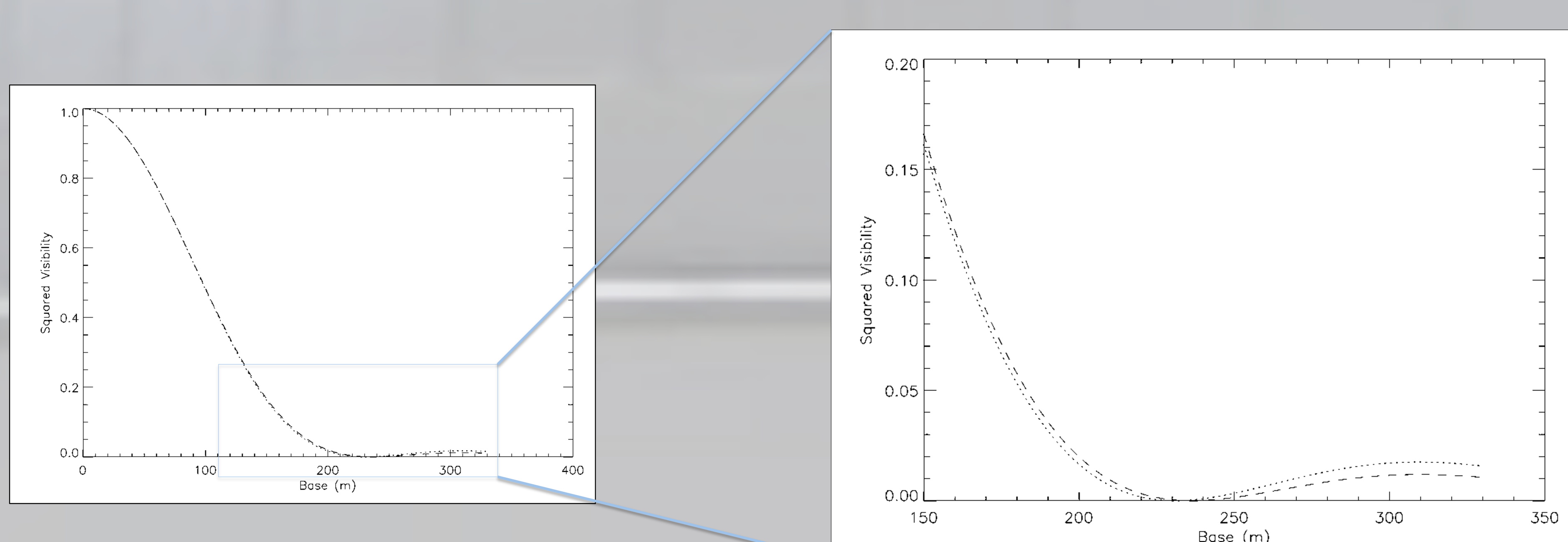

Figure 3 : *Left:* Squared visibility of 13 Cyg for a uniform disk (dotted line) and a limb darkening disk (dashed line). *Right:* zoom of the squared visibility. The difference between the two curves is obvious from a base of 150 m.

Starting from the measured visibilities, we aim at adjusting the model of squared visibility V_λ^2. This limb linear model was built with the following equation:

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

(H.R. Brown, 1974)

with $\alpha=1-u_\lambda$, $\beta=u_\lambda$ *and* $x = 15{,}23B\vartheta_{LD}/\lambda$.

It is now depending on two parameters, and not one anymore: the limb darkened diameter, and the limb darkening coefficient u_λ.

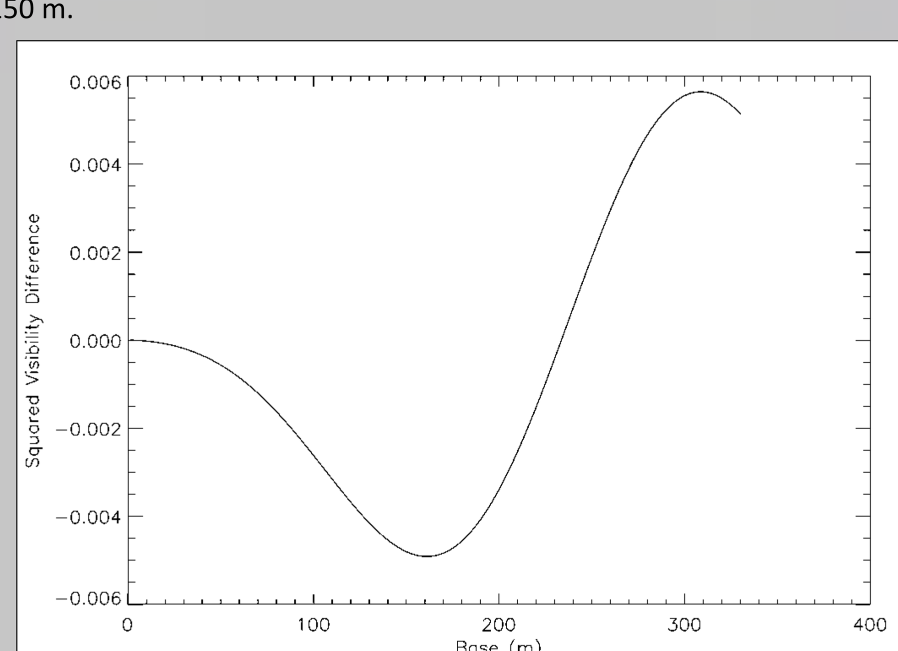

Figure 4: Difference between the squared visibility of 13 Cyg uniform disk and limb darkening. It is higher in the second lobe of visibility, that is why it is usefull to reach it.

APPLICATIONS

Asteroseismology

The goal of asteroseismology is to study the interior of stars by probing their surface pulsations. Acoustic waves propagate in stars, with variable speed and amplitude according to the temperature and chemical composition of the interior. Combined with asteroseismology, stellar parameters can be constrained in an accurate way. This allows a good description of stellar interiors, their evolution and chemical composition. As an example, Bigot et al. recently used the p-mode frequency of HD49933 to derive its atmospheric parameters, as the effective T_{eff}, log g and [Fe/H].

Transit measurements

Interferometry could also bring valuable information for stars observed by the transit method. Indeed, the geometrical structure of spots and the effects of rotation can be deduced from interferometric measurements. Many numerical codes have been developped to better understand the stellar surfaces and atmospheres, for which limb darkening is a key parameter (Desort et al. (2007)).

References

Bigot L., Mourard D., Bériot P. et al. 2011, A&AL, submitted
Baines E. K., van Belle G. T., ten Brummelaar T. A., et al. 2007, ApJL, 661, 195
Baines E. K., McAlister H.A., ten Brummelaar T. A., et al. 2008, ApJ, 680, 728
Bonneau D., Clausse J.-M., Delfosse X. et al. 2006, A&A, 456, 789
Brown R. H., Davis J., Lake R. J. W. et al. 1974, MNRAS, 167, 475
Creevey O. L., Monteiro M. J. P. F. G. et al. 2007, ApJ, 659, 616
Desort M., Lagrange A.-M., Galland F. et al. 2007, A&A, 473, 983
Aerts C., Christensen-Dalsgaard J., Kurtz D. W., 2010, Asteroseismology, A&A Library