Interferometry and surface brightness colour relations

PLATO STESCI workshop III

D. Mourard, OCA-Nice

Barcelona, 20 Nov 2019

Basic principles

Interferometry means "*Fringes or Visibility/Closure Phase or Fourier Transform or Aperture Synthesis…*"

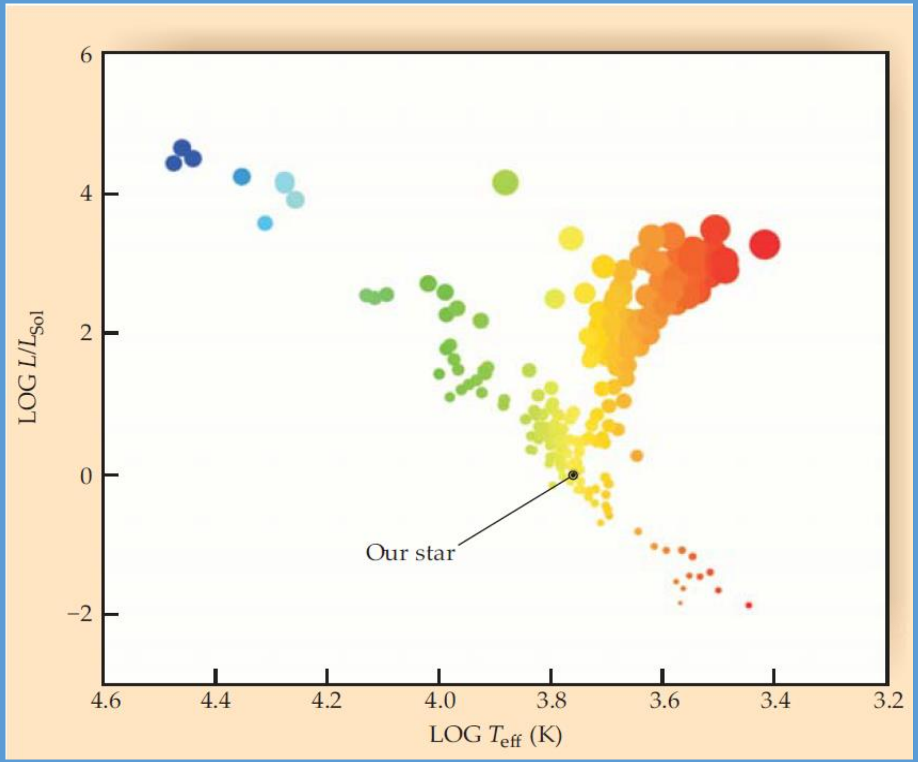
But Interferometry means also "brightness distribution"…

… and it offers a unique angular resolution allowing to 'see' details on stars.

"Brightness distribution" could mean:

- Equivalent uniform disk diameter
- Limb darkened diameter and limb darkening law (or more directly intensity profile)
- Surface of stars and environment

Exemples



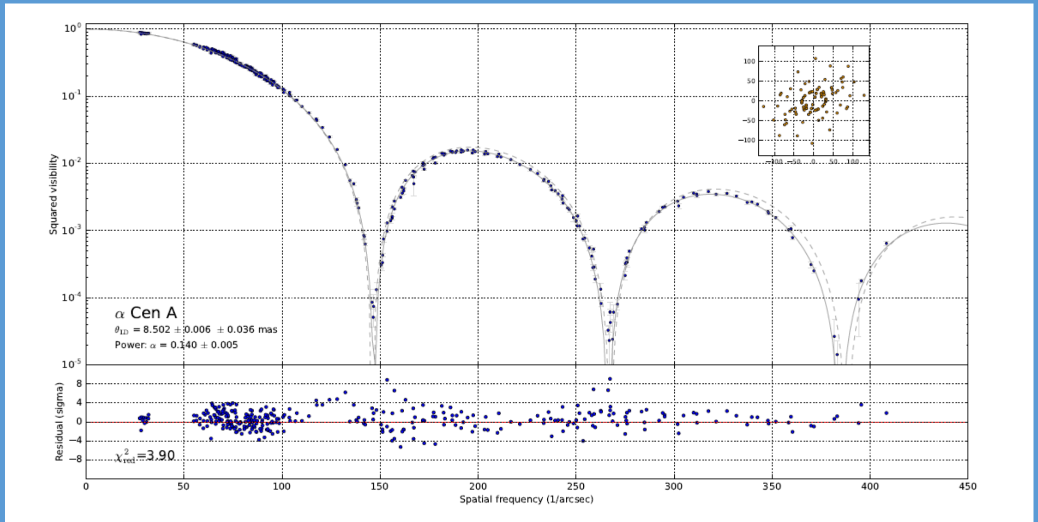
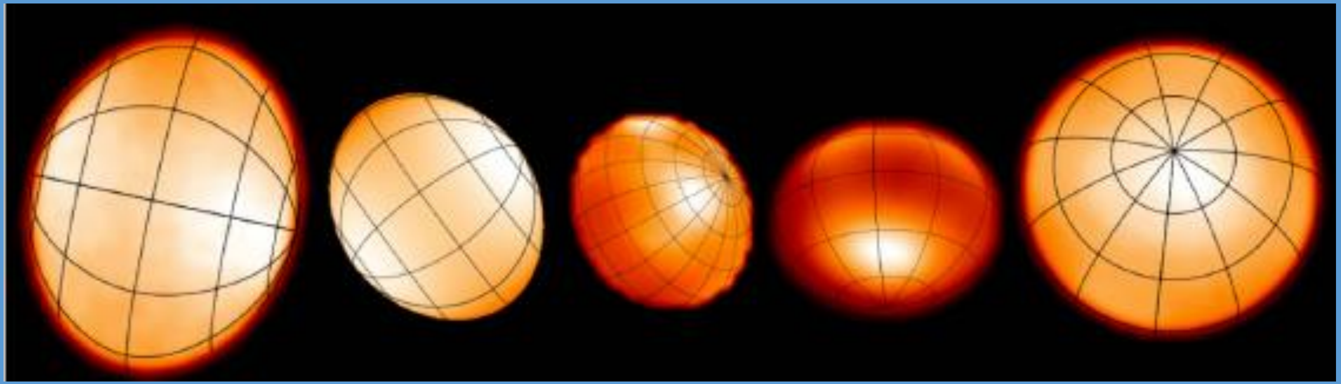


Fig. 3. Adjustment of a power law limb darkened disk model to the PIONIER squared visibilities of α Cen A (solid gray curve). The dashed gray curve represents the best-fit uniform disk model. The *bottom panels* show the residuals of the fit in number of times the statistical error bar. The coverage of the (u, v) plane is shown in the *upper right corner.*



The interferometric products

- 'OIFITS' files containing the calibrated measurements (→ OIDB database)

- θ_{LD} from measurement of θ_{UD} and estimation of LD coefficient

- θ_{LD} from combined measurement of θ_{UD} and LD coefficient
- θ_{LD} from adjustment of intensity profile (1D/3D models) and parallax

- Images of surface and/or environment of stars

- Last but not least: from the collection of all these previous direct measurements, absolute calibration of SBC relations to be used for further estimations of angular diameters of faint targets.

Already existing tools

French expertise center: JMMC

- User support
- Preparation of observations
- Data processing
- Data analysis
- Archiving and dissemination

JEAN-MARIE MARIOTTI CENTER
Infrared and Optical Interferometry for Astronomy

LITpro

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Who are we ?
Who was JMM ?
Partners
Structure
Working Groups
Training
Proposal Preparation
ASPRO
GetStar

LITpro: a JMMC model fitting software

subscribe to Modelfitting feed

LITpro is a **model fitting software**, developed and maintained by one JMMC working group (**CRAL**, IPAG and LAGRANGE).
This software has been developed for the model fitting of data obtained from various stellar optical interferometers and written in the OI Exchange Format. It provides a set of elementary geometrical and center-to-limb darkening functions, all combinable together, which allow to fit Visibilities, Square Visibilities or Triple Products, or any combination of previous observables. It allows to visualize by various plots the data as well as the models and the results of the fits. Tools also have been developed to help users to find the global minimums.

AMHRA service

The AMHRA ("Analyse et Modélisation en Haute Résolution Angulaire") WEB service is a working group of MOIO/JMMC. The main objective of the AMHRA is to develop and/or provide astrophysical models and data analysis tools dedicated to the scientific exploitation of high angular and high spectral facilities (in particular ESO-VLTI instruments) by the astronomical community, including non-specialists in interferometry.
Several tools are offered to the user that seeks to prepare, model, and analyze interferometric observations, notably those from the second generation of VLTI instruments (GRAVITY and MATISSE), which provide unprecedented capabilities on high spectral and spatial resolution.
A full desciption of AMHRA and references are provided here.

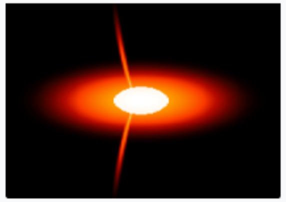
The different types of tools offered or to be offered by AMHRA are:

Polychromatic images from astrophysical models with fast-computation time (real-time models)
Polychromatic images from a pre-calculated grid of astrophysical models
Spectro-interferometric observables from model images (OIFITSModeler)
Analysis and model-fitting tools for spectro-interferometry

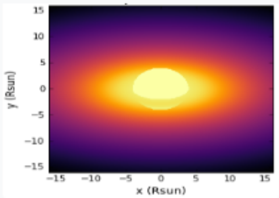
Photo credit : European Southern Observatory

Real Time astrophysical models

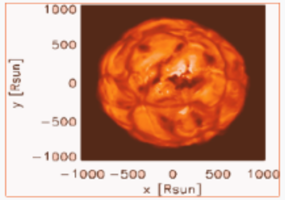
Kinetic Be Disk



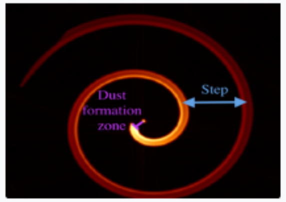
Disc and Stellar Continuum (DISCO)



Evolved stars(RSG,AGB) with CO5BOLD



Binary Spiral Model



JMMC - OiDB

Optical interferometry DataBase

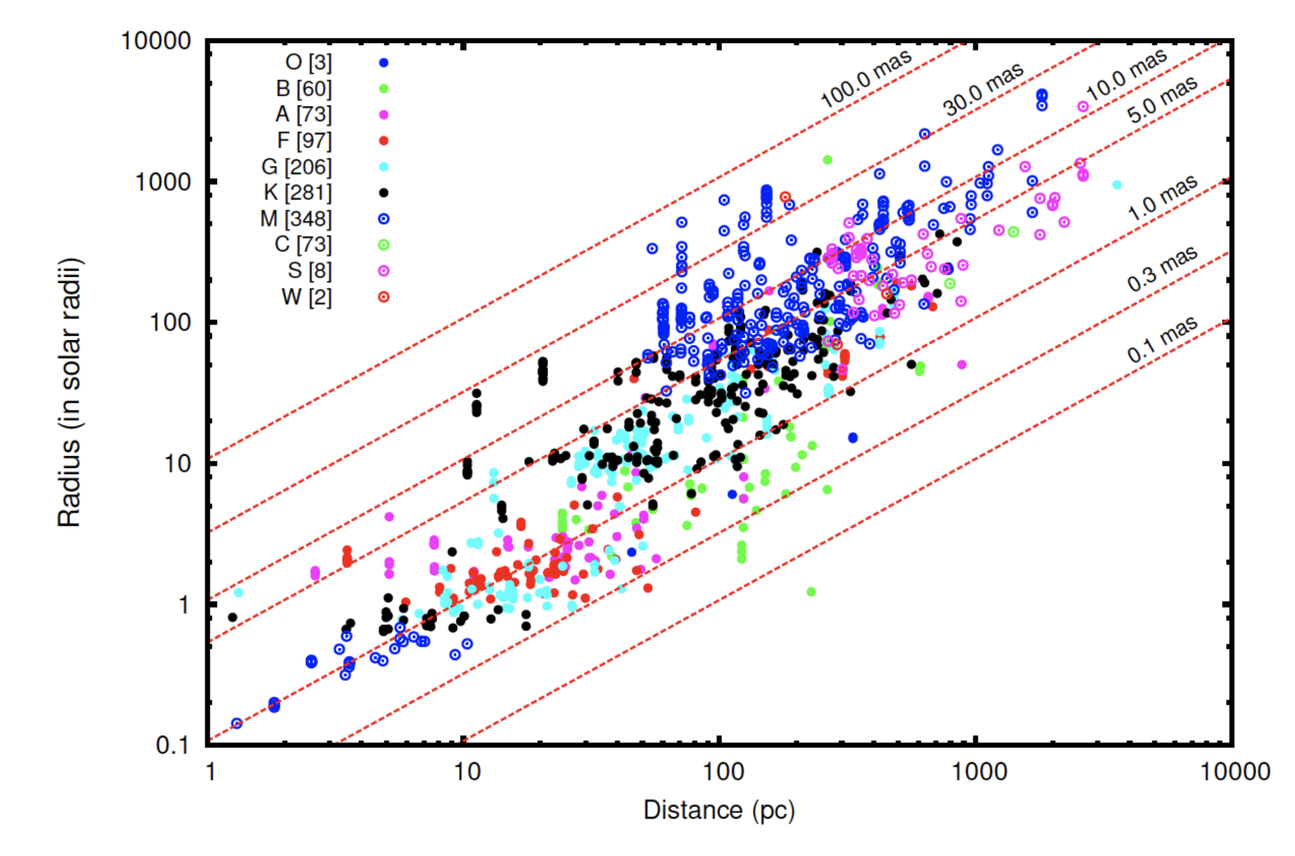
13	11	143	22	8532	9614	37592
FACILITIES	INSTRUMENTS	DATA-PIS	COLLECTIONS	OIFITS	GRANULES	OBS. LOGS

Target name or position

Enter target name or visit the advanced form

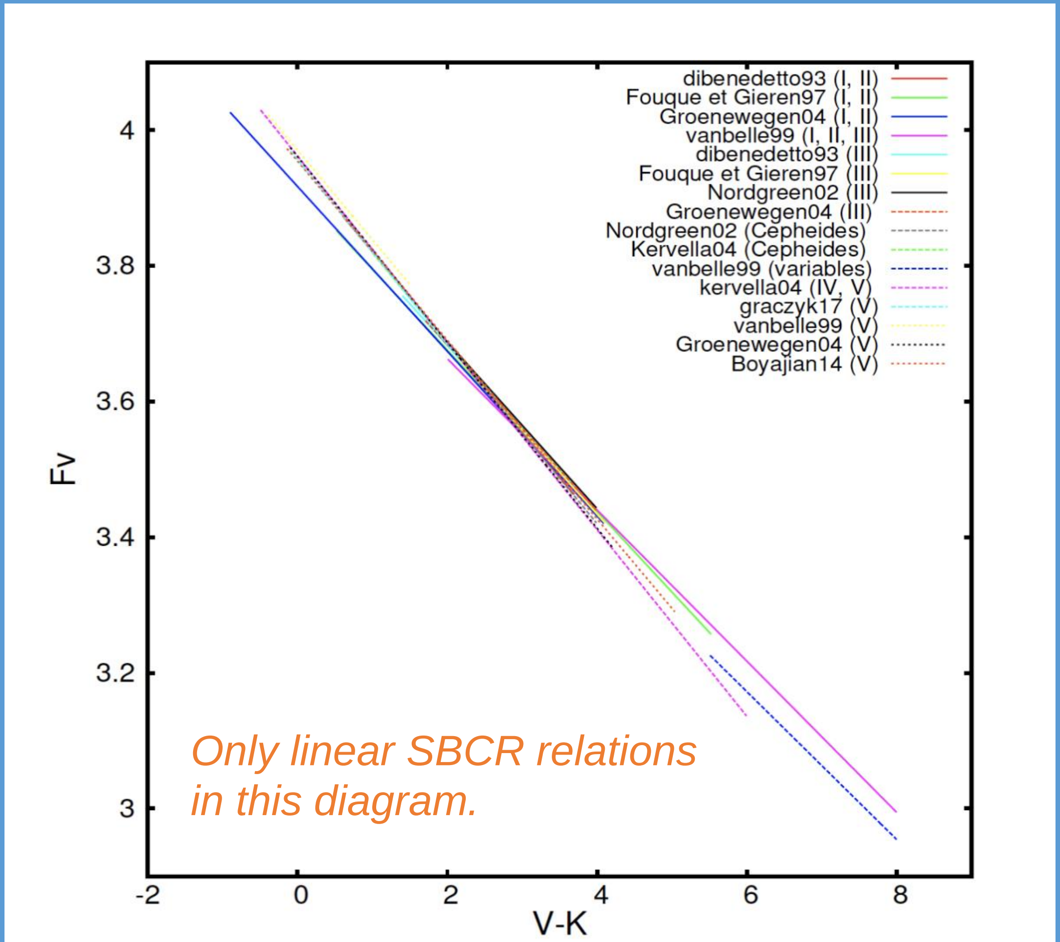
The JMDC catalog (➔Vizier, Duvert+2016)

- ~1500 stellar angular diameter measurements from different techniques (lunar occultation, intensity interferometry and optical interferometry).
- 11% (resp. 22%) of stars have their angular diameter measured with a precision better than 1% (resp. 2%). It corresponds to 159 and 323 measurements, respectively.



But issues are remaining…

Indeed, the JSDC (Chelli+16) provides the angular diameter of 453000 stars with a median statistical uncertainties of 1.1%
But, if we consider the 23 surface-brightness color relations (SBCR) available in the literature, we have inconsistencies



1. $S_V = V - 5\log\theta_{LD} = \sum a_k (V-K)^k$
2. $F_V = 4.2207 - 0.1 S_V = \alpha + \beta (V-K)$
3. $\log\theta_{LD} = d_1 + c_1 1(V-K) - 0.2V$
4. $\theta_{LD}(V=0) = 10^{A+B(V-K)}$
5. $\Phi_V = \frac{\theta}{9.305 * 10^{\frac{-V}{5}}} = \sum z_k (V-K)^k$

If we apply the 23 SBCR to an hypothetic star of mV=6; we obtain a dispersion of :

- 2% if V-K=3
- 9% if V-K=0 (early-type stars)
- 9% if V-K=5 (late-type stars)

Conclusion: We are probably far from being able to estimate the angular diameter of stars with a 1% precision and accuracy.

Definition of the main objectives of CHARA/SPICA

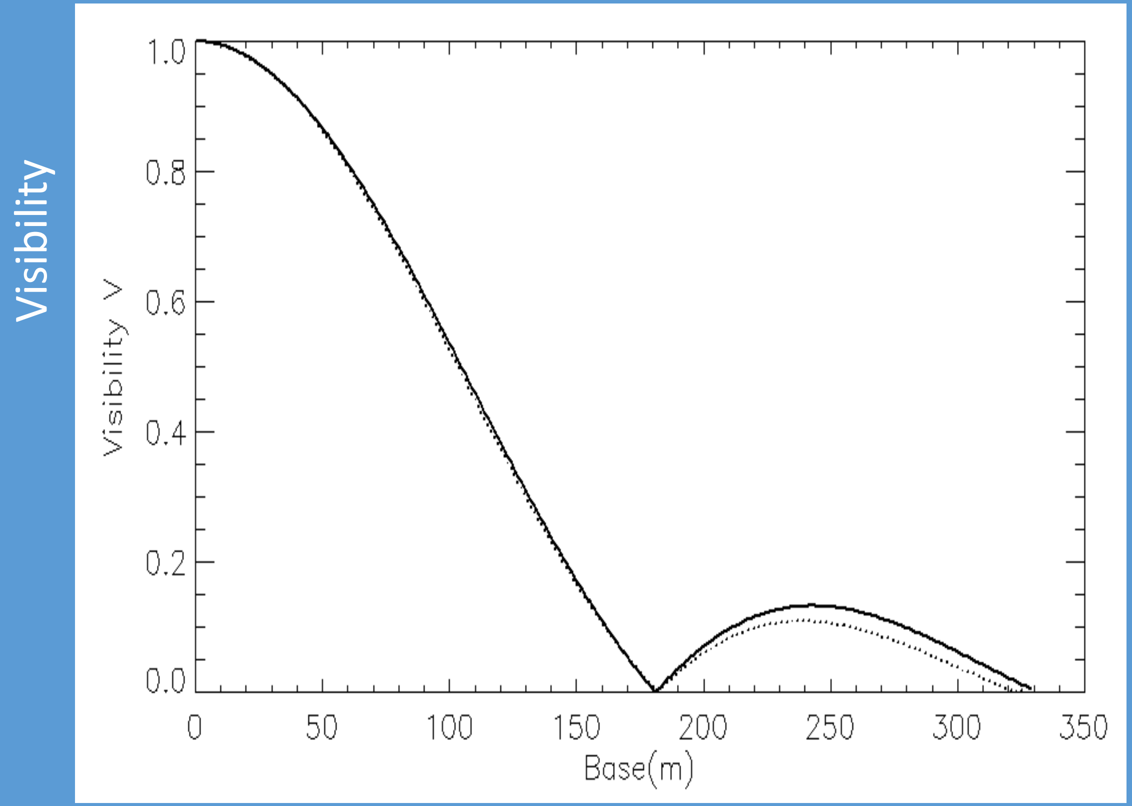
Measuring a large number of angular diameters

- To support the exoplanet researches through direct characterization of the host star.
- To support, e.g., the direct determination of extragalactic distances through accurate and homogeneous SBC relationships, but also to permit precise and accurate angular diameter estimations for many different purposes.
- Many other projects

Very timely with the new space missions (TESS, CHEOPS, PLATO) and their objectives of measuring brighter stars than with the first generation of space missions (CoRoT, KEPLER)

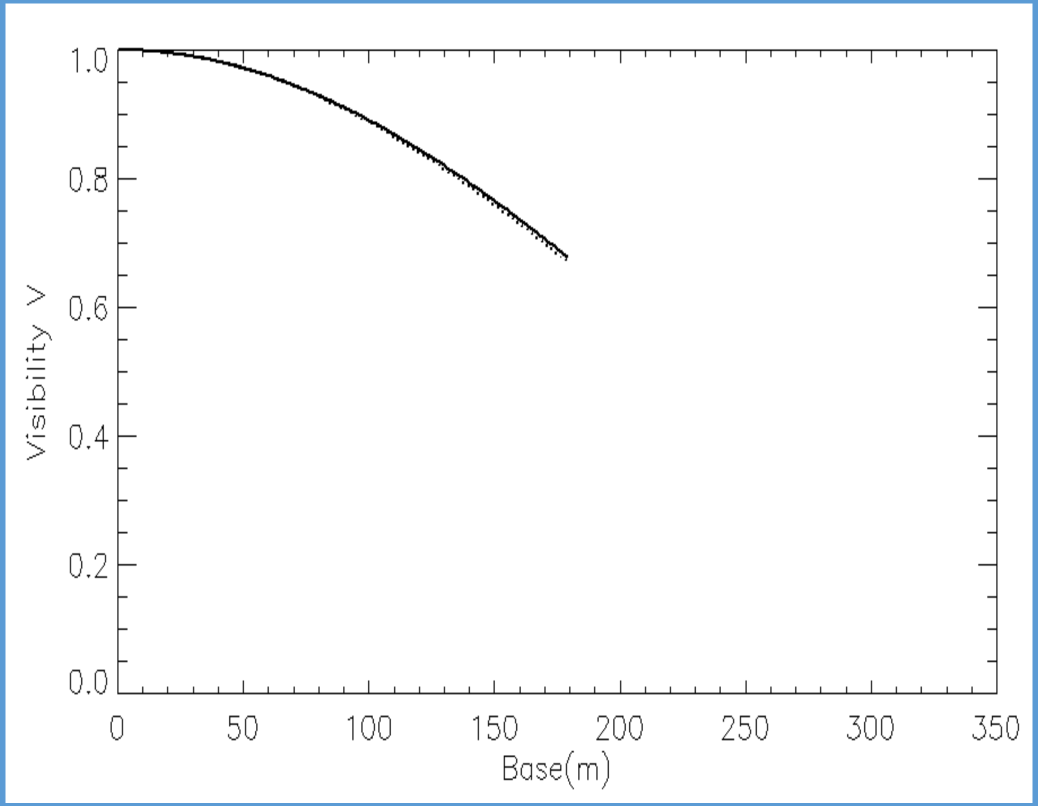
Visibility function of a star θ_{UD}=1mas

CHARA, 330m, λ=700nm + θ_{LD}(0.5)



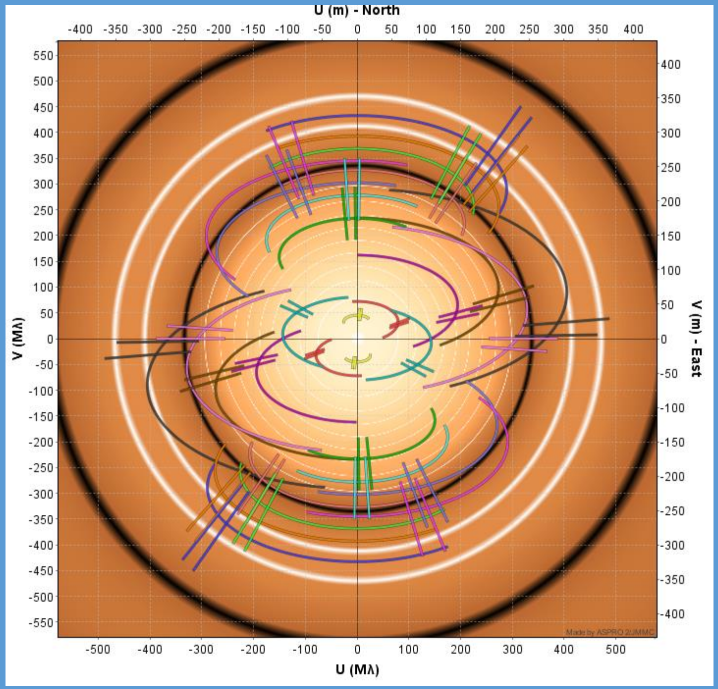
ΔV=1% ➔ $\Delta\theta/\theta$=1%
Sensitive to LD

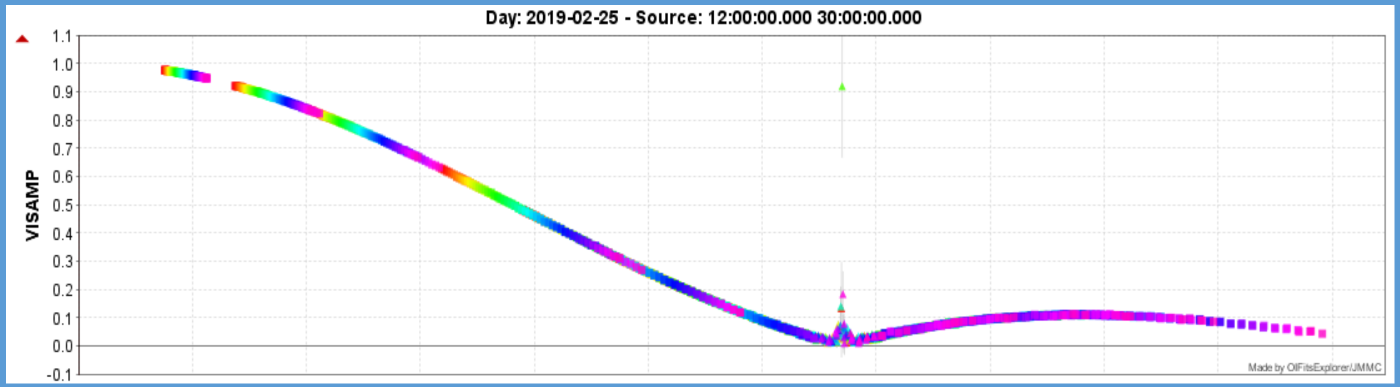
VLTI, 180m, λ=1600nm + θ_{LD}(0.5)



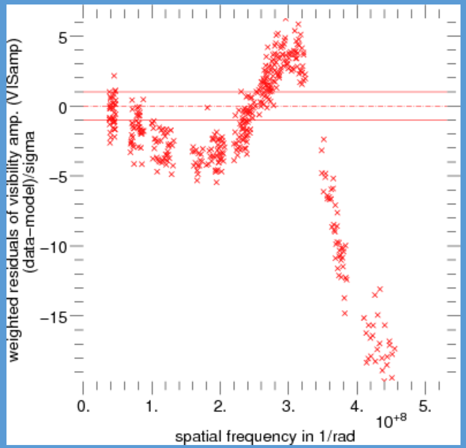
ΔV=1% ➔ $\Delta\theta/\theta$=2.5%
Unsensitive to LD

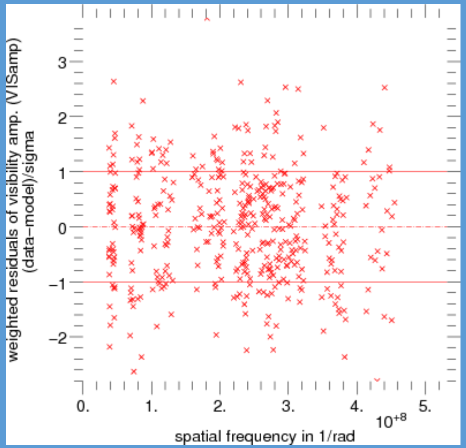
End2End modelling





θ_{LD}=0.8mas, u=0.5 *(ASPRO2 & LITpro tools JMMC)*

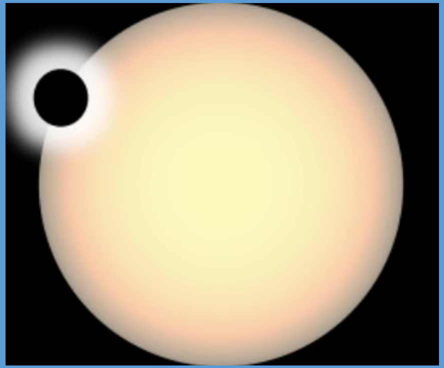




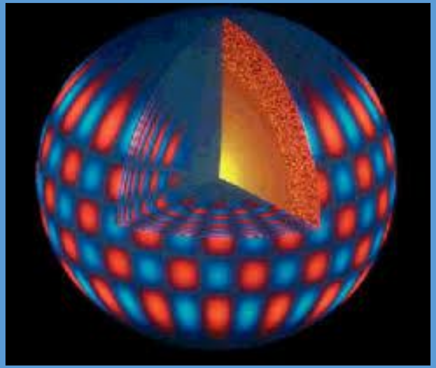
θ_{UD}= 0.7611 +-0.0002   but **chi²=38**!

θ_{LD}= 0.8004 +-0.0002, u=0.504+-0.002 chi2=1.1

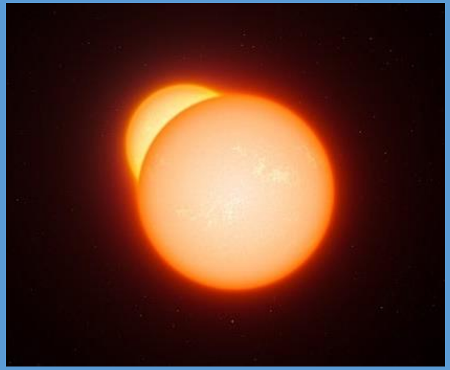
The three main objectives of CHARA/SPICA



1. Exoplanet Host Stars



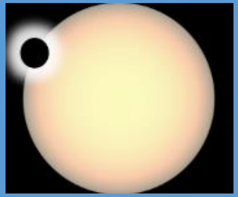
2. Asteroseismology

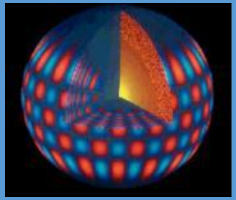


3. SBCR: Araucaria and PLATO

Three objectives:

1. Exoplanet Host Stars
2. Asteroseismology
3. SBCR for distances of EB and PLATO

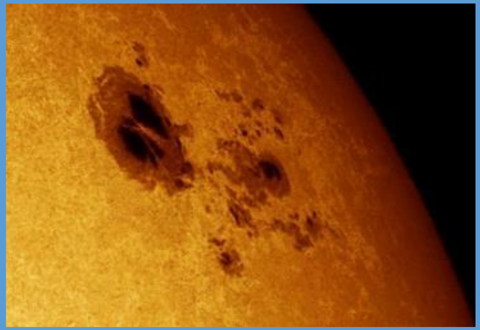




For these three objectives, stellar activity has to be taken into account:

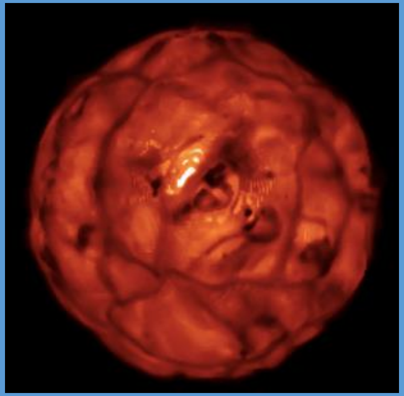
Stellar Activity

1 – Spots

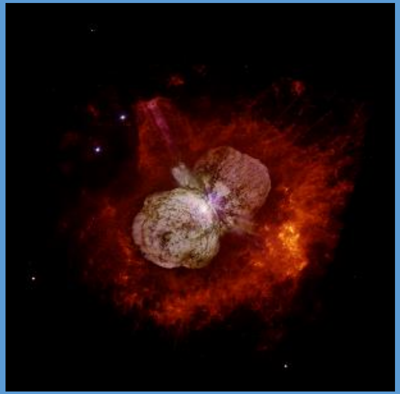


5 – Binarity

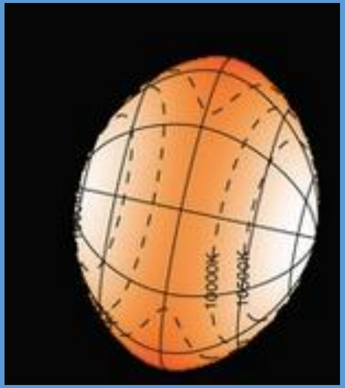
2 – Convection



3 – Wind & environment



4 – Rotation



The CHARA/SPICA products

Level 1: thetaUD + conversion factor ➔ 0.2mas < thetaLD < 0.8mas

Many thousands of stars accessible, δ>-30°, V<9-10

Level 2: thetaLD + limb-darkening coefficient: theta>0.8mas

➔ on CHARA, V=4.2 for F V, V=5.1 for G V, and V=5.9 for K V

➔ ~ 100 F stars, 200 G stars, and 800 K stars.

➔ ThetaLD (+Fbol) ➔ Teff (ΔT<30K)

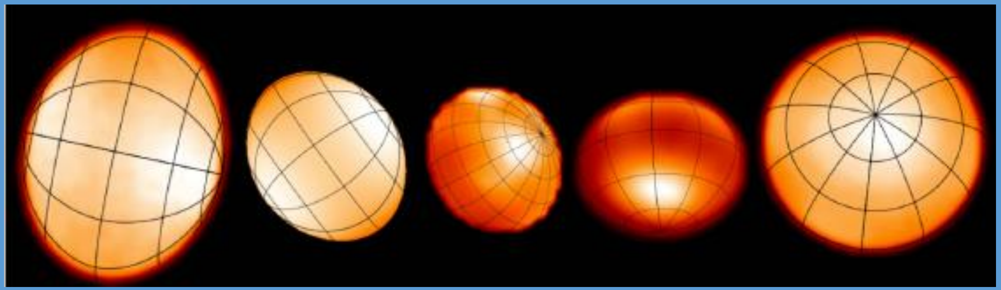
magV	F	G	K
4	0,892	1,332	1,935
5	0,563	0,840	1,221
6	0,355	0,530	0,770

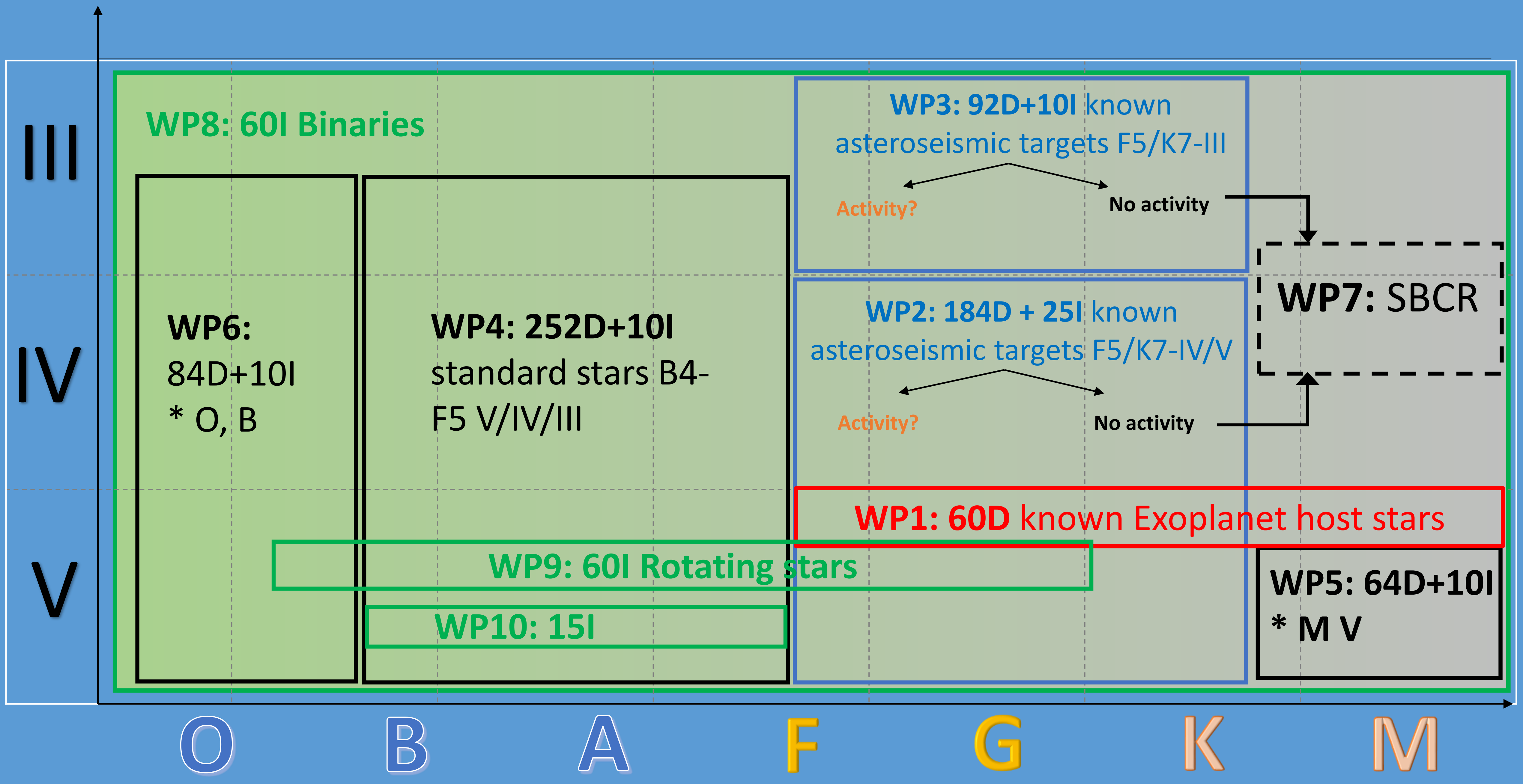
Level 2bis: direct fit of intensity profile from Stellar Atmosphere models

➔ always possible but degeneracy for 'small' stars

Level 3: image reconstruction V<5, theta>1mas

a few hundreds of stars





III
IV
V
WP8: 60I Binaries
WP3: 92D+10I known asteroseismic targets F5/K7-III
Activity?
No activity
WP6:
84D+10I
* O, B
WP4: 252D+10I
standard stars B4-F5 V/IV/III
WP2: 184D + 25I known asteroseismic targets F5/K7-IV/V
Activity?
No activity
WP7: SBCR
WP1: 60D known Exoplanet host stars
WP9: 60I Rotating stars
WP5: 64D+10I
* M V
WP10: 15I
O
B
A
F
G
K
M

CHARA/SPICA and PLATO timelines

Objectives

Determination of angular diameter throughout HR diagram

Application of previous determinations to PLATO targets

Focus on exoplanet host stars and detected binaries

2022 — Start of the CHARA-SPICA survey

2024 — PLATO fields are known

2027 — First PLATO data

Sample

- COROT, SONG and TESS observable targets
- Core sample focused on F, G, K IV-V stars
- Extension to giants and earlier types
- Explore various metallicities

- Extension of the CHARA-SPICA sample to PLATO targets
- Follow-up detected binaries

Methods

Precise and **accurate** T_{eff} and θ
SBCR

Calibration of seismic scale relation

Provide R and T_{eff} for preparation pipeline

Binary detection:
- FLAG (CHARA-SPICA and GAIA complementarity in separation)
- Radius of the component(s)

Binary : mass ratio
radii of components

The plan in relation to PLATO

1. Contributing to **non seismic parameters** and **benchmarking** for fundamental stellar parameters
   1. CHARA/SPICA data in IODB
   2. Linking OIDB to PDC-DB and implementation of St-Pa-Extraction softwares

2. Establishment of accurate and unbiased **SBC relations**
   1. Criteria for selecting homogeneous and unbiased samples
   2. New relations with clear range of applications (colour, index of activity…)

3. **Ground follow-up** of PLATO targets
   1. Access to the CHARA Internal Collaboration time (~50/60n per year)
   2. Guaranteed time through community funding (~20n/year?)
   3. Open Time (~20n?)