The CHARA/SPICA Science Overview

The CHARA/SPICA Science Group

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.... bout 65 other colleagues (see https://lagrange.oca.eu/fr/spica-team)

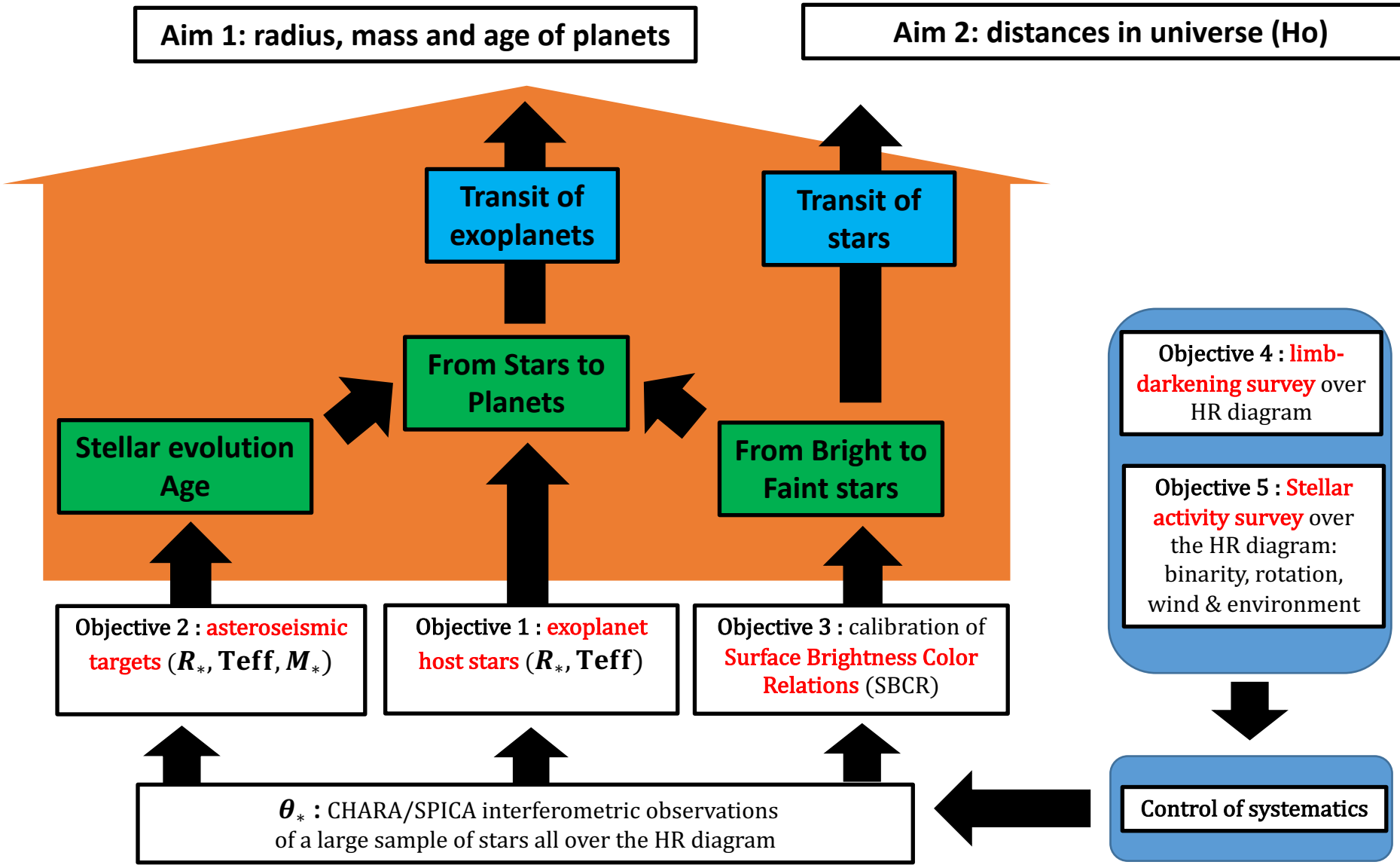
CHARA/SPICA capabilities *in a nutshell*

- **Facts:** Up to now, ~220 different stars have their angular diameter precise at the 1% level based on different instruments (JMDC catalogue, Duvert+16): O (0), B (3), A(9), F(22), G(38), K(89), M(35 mostly giants), C(25).

- **CHARA/SPICA is an « angular diameter machine »:**
  - In 3 years (80 nights per year), we plan to derive the angular diameter of 800 stars with a 1% precision and do images of about 200 stars.
  - In several years, CHARA/SPICA will multiply by ten the number of stars with high precision angular diameter.
  - Importantly, CHARA/SPICA can provide a homogeneous set of data for a large amount of stars all over the HR diagram from O to M stars.

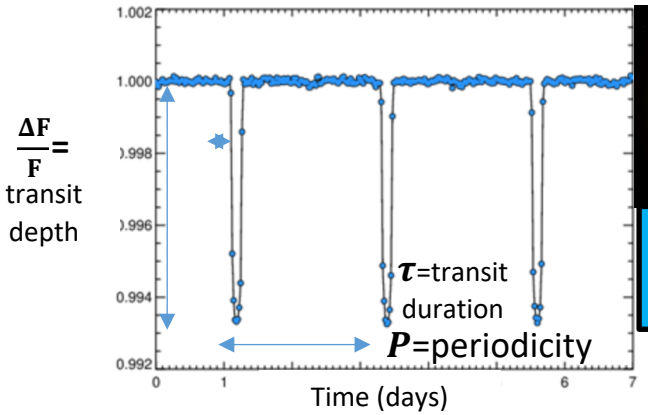
- **CHARA/SPICA is an « image box »:** CHARA/SPICA can study stellar activity (i.e. binarity, rotation, wind/environment, chromosphere) and limb-darkening all over the HR diagram

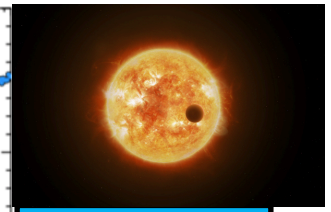
The CHARA/SPICA survey (core program)



Objective 1: Radius and Effective Temperature of a large sample of exoplanet host stars (~50 targets)

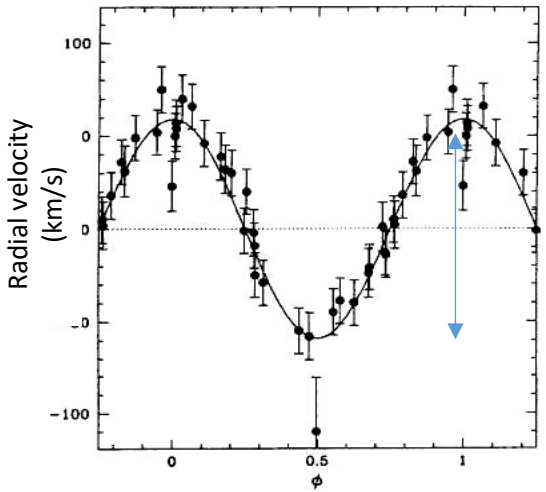
PHOTOMETRY of Exoplanets in transit: PLATO, TESS, ...





Transit of exoplanets

VELOCIMETRY of exoplanets in transit



K=velocity amplitude

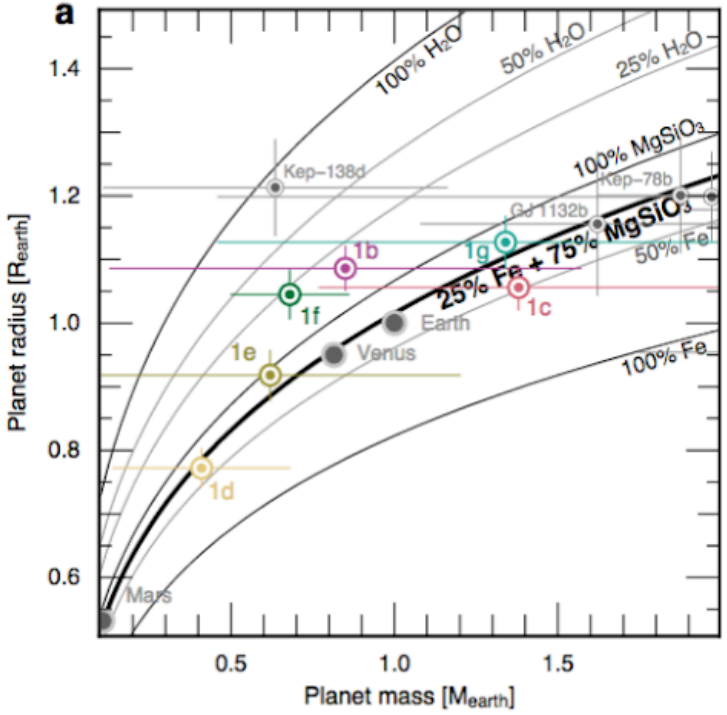
Gaia parallax ← **WP1: INTERFEROMETRY : θ**

R_*

From Stars to Planets

$$R_p = \frac{R_*}{9.2984}\sqrt{\frac{\Delta F}{F}}$$

$$M_P = c.M_*^{2/3}P^{1/3}$$



The tools already exist: θ* of 55 Cnc with VEGA/CHARA at 1.6% (Ligi+16)

Objective 2: Observation of a large and homogeneous sample of asteroseismic and interferometric targets (~275 targets)

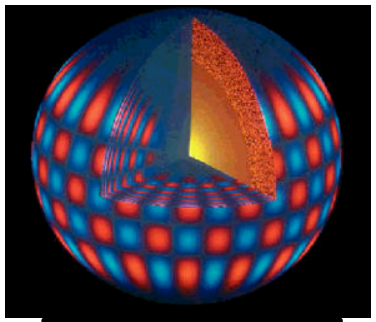
Scaling Relations (SR) in the litterature
Teff from spectroscopy

$R_{*[SR]}, M_{*[SR]}$

Comparison

'full' frequencies analysis of benchmark (b) stars

$R_{*[b]}, M_{*[b]}$



Calibration

Contraints

Stellar evolution Age

$R_{*[I]}$

Gaia parallax

WP2/WP3: INTERFEROMETRY : θ

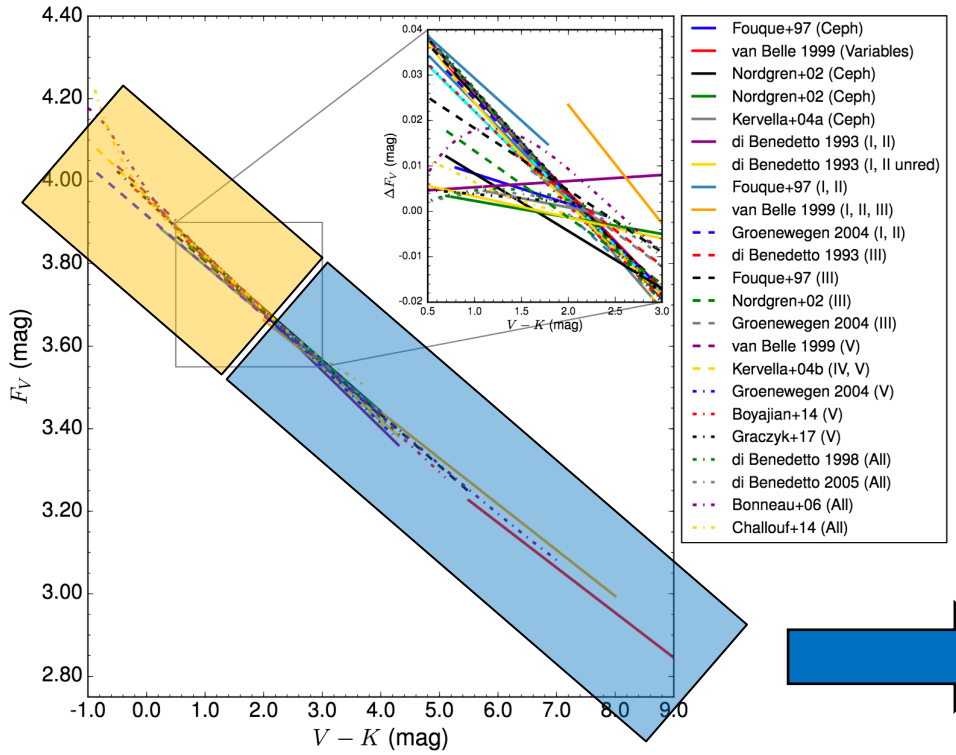
Examples of analysis:

- VEGA/CHARA θ* of the CoRoT target at 2.7% of precision (Bigot+11)
- VEGA/CHARA θ* of the roAp target at 2.1% of precision (Perraut+13)

Objective 3: Calibration of Surface Brightness Color Relations (SBCR) all over the HR diagram (~325 targets)

From bright to faint stars

$$F_V = 4.2207 - 0.1S_V = \alpha + \beta(V-K)$$



SBCR of early-type stars:
- **distance determination of M31/M33**

Synergy with Araucaria project: (ERC Synergy)
Ho at 1%

PhD of A. Salsi
- SBCR for late-type stars based on JMDC and CHARA/VEGA; difference of SBCR between type and classes (Salsi+19)
- SBCR for early-type stars based on CHARA/VEGA (Salsi+20, submitted)
- Theoretical study on-going.

SBCR of late type stars:
- **distance determination of SMC/LMC (Ho)**
- **faint PLATO targets**

Synergy with PLATO space mission

Objective 3 : calibration of SBCR *all over the HR diagram*

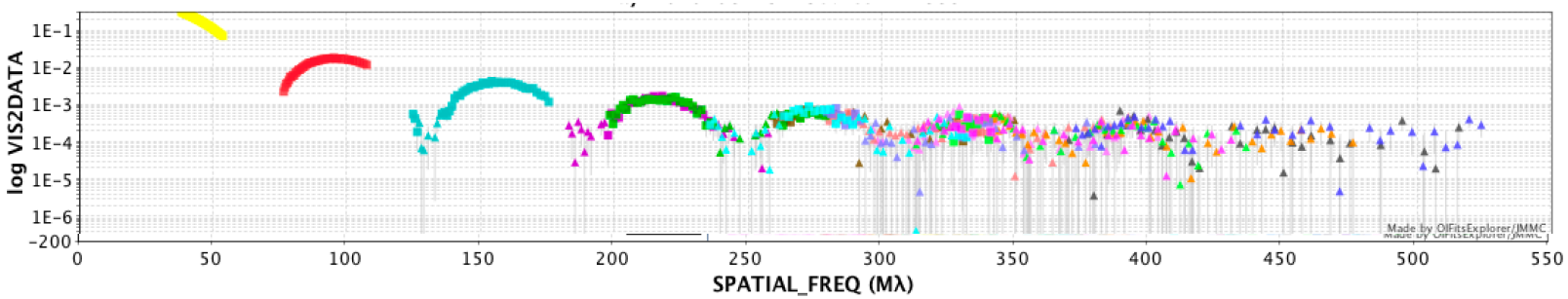
WP7: INTERFEROMETRY θ

Objective 4: Limb-darkening survey over the HR diagram

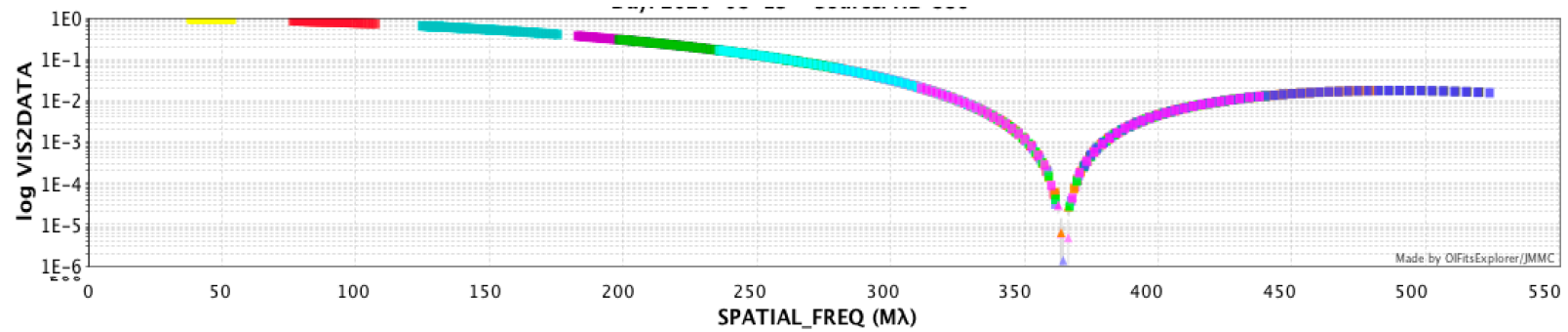
WP11 (~160 targets)

- *for more precision/accuracy on the derived angular diameters*
- *for studying the stellar atmosphere models*

Example 1: K4, mV=4, θ=3.53 mas (1 observation)



Example 2: B0, mV=1, θ =1.1mas (1 observation)



Example:
- PIONIER observations (Kervella+17)

Dwarfs	Challouf			Salsi-1			Salsi-2		
SpTy	O	B0	A0	F5	G7	K4	M0	M3	M4
V // V-K	-2	-1	0	1	2	3	4	5	6
0	0,10	1,00	3,35	6,28	11,82	22,25	39,94	70,70	125,14
1	0,06	0,63	2,11	3,96	7,46	14,04	25,20	44,61	78,96
2	0,04	0,40	1,33	2,50	4,71	8,86	15,90	28,14	49,82
3	0,02	0,25	0,84	1,58	2,97	5,59	10,03	17,76	31,43
4	0,02	0,16	0,53	0,99	1,87	3,53	6,33	11,20	19,83
5	0,01	0,10	0,33	0,63	1,18	2,23	3,99	7,07	12,51
6	0,01	0,06	0,21	0,40	0,75	1,40	2,52	4,46	7,90
7	0,00	0,04	0,13	0,25	0,47	0,89	1,59	2,81	4,98
8	0,00	0,03	0,08	0,16	0,30	0,56	1,00	1,78	3,14
9	0,00	0,02	0,05	0,10	0,19	0,35	0,63	1,12	1,98
10	0,00	0,01	0,03	0,06	0,12	0,22	0,40	0,71	1,25

different SBCRs dwarfs/giants

Giants	Challouf			Salsi-1			Salsi-2		
SpTy	O	B0	A0	F5	G7	K4	M0	M3	M4
V // V-K	-2	-1	0	1	2	3	4	5	6
0	0,24	1,09	3,16	6,72	11,79	20,68	36,41	62,26	106,46
1	0,1	0,69	1,99	4,24	7,44	13,05	22,97	39,28	67,17
2	0,10	0,44	1,26	2,68	4,69	8,23	14,49	24,79	42,38
3	0,06	0,27	0,79	1,69	2,96	5,20	9,15	15,64	26,74
4	0,04	0,17	0,50	1,07	1,87	3,28	5,77	9,87	16,87
5	0,02	0,11	0,32	0,67	1,18	2,07	3,64	6,23	10,65
6	0,02	0,07	0,20	0,42	0,74	1,30	2,30	3,93	6,72
7	0,01	0,04	0,13	0,27	0,47	0,82	1,45	2,48	4,24
8	0,01	0,03	0,08	0,17	0,30	0,52	0,91	1,56	2,67
9	0,00	0,02	0,05	0,11	0,19	0,33	0,58	0,99	1,69
10	0,002	0,011	0,032	0,067	0,118	0,207	0,364	0,623	1,065

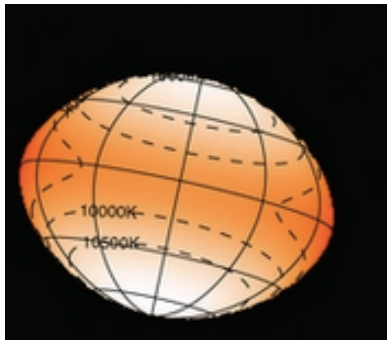
Objective 5: Stellar activity survey over the HR diagram binarity (WP8), rotation (WP9), wind & environment (WP12)

Stellar activity over the HR diagram ~ ~200 **images**

Binarity (~ 54 targets)

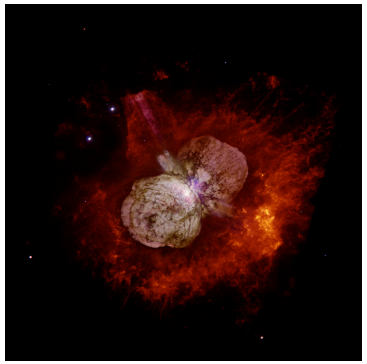
- study of dynamical masses over the HR diagram
- Hierarchical binaries (ksi tau, Nemravova+16)

Rotation (~ 54 targets)



- study the gravity darkening over the HR diagram (mainly O to F stars)
- Impact rotation SBCR (Challouf+14), alpha Cep (Delaa+13)

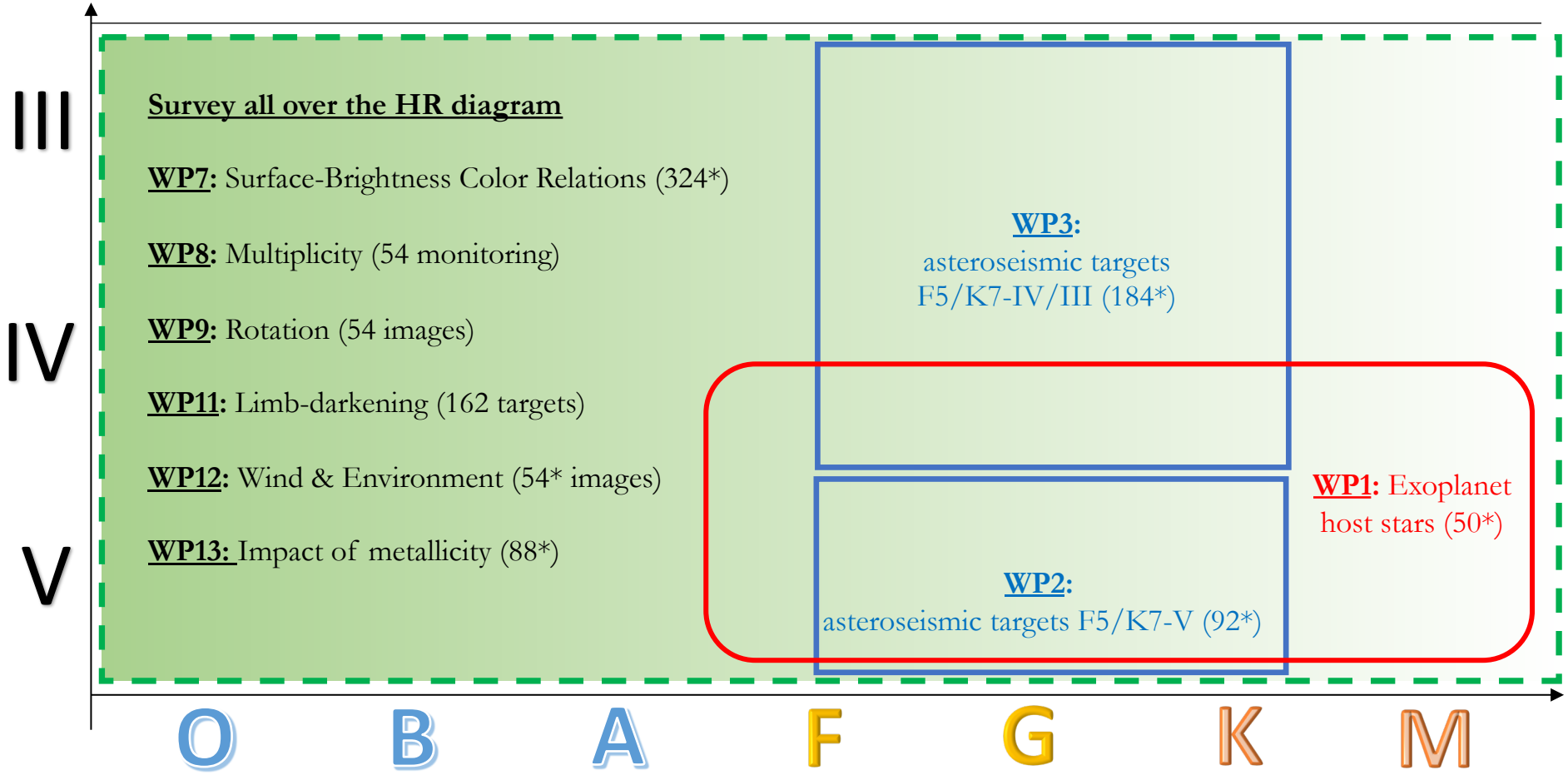
Wind & environment (~ 54 targets)



- study the wind & environment for hot and cold stars
- Wind on Deneb and Rigel (Chesneau+10), Chromosphere of K giants (Berio+11), environment of delta Cep (Nardetto+16)

- for more precision/accuracy on the derived angular diameters. Improve the quality control of CHARA/SPICA
- quantify the impact of stellar activity on the SBCR
- constraints on stellar evolution models

The CHARA/SPICA survey: summary



➡ Synergy CHARA/SPICA survey /Araucaria Project

➡ Synergy CHARA/SPICA survey / PLATO space mission

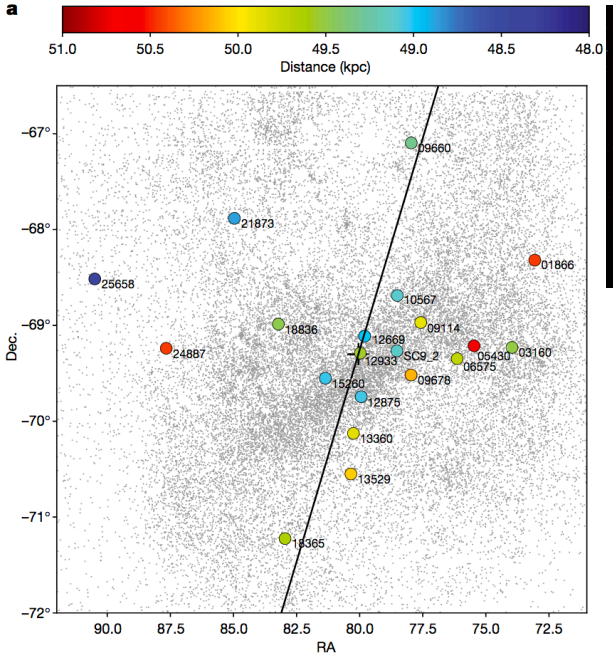
Synergy between CHARA/SPICA and the Araucaria Project of distance determination in the local group

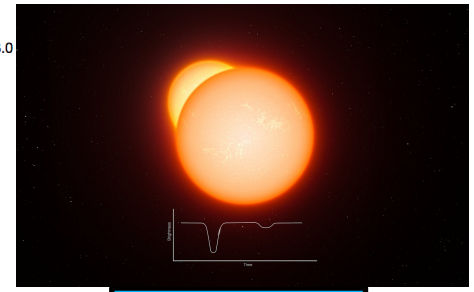
A distance to the Large Magellanic Cloud that is precise to one per cent

G. Pietrzyński[1,2*], D. Graczyk[1,2,3], A. Gallenne[4,5], W. Gieren[2], I. B. Thompson[6], B. Pilecki[1], P. Karczmarek[7], M. Górski[2], K. Suchomska[7], M. Taormina[1], B. Zgirski[1], P. Wielgórski[1], Z. Kołaczkowski[1,8], P. Konorski[7], S. Villanova[2], N. Nardetto[5], P. Kervella[9], F. Bresolin[10], R. P. Kudritzki[10,11], J. Storm[12], R. Smolec[1] & W. Narloch[1]

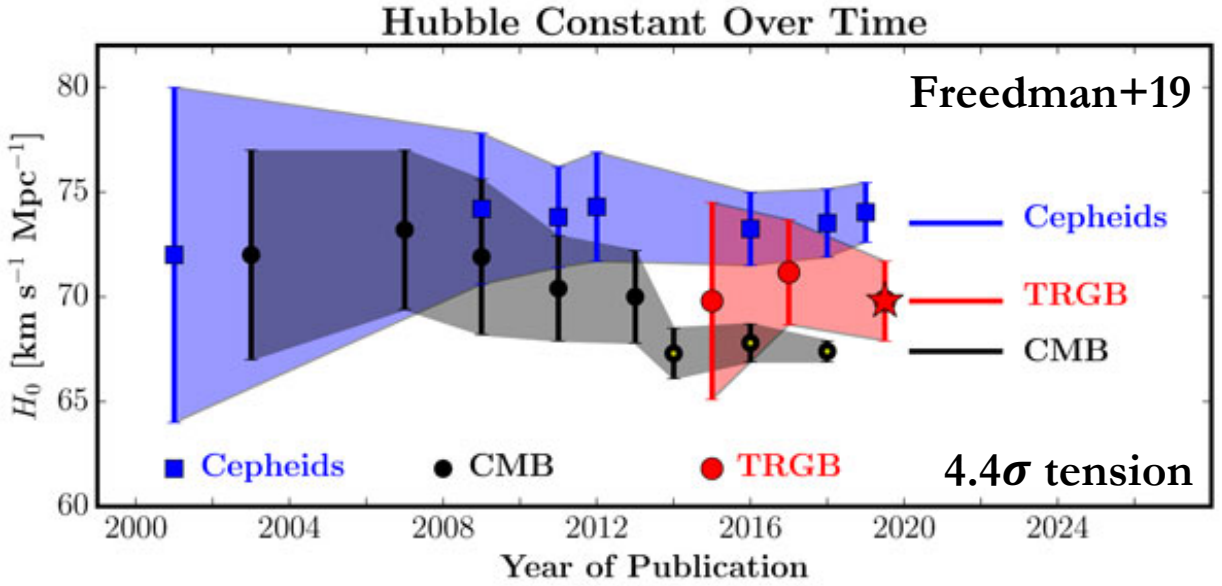
Nature, 2019, 567, Issue 7747, p.200-203

20 late-type eclipsing binaries in LMC





Transit of stars



Related results:

- Distance to SMC at the 2% level (Graczyk+2020)
- Result used by SHOES project: 1.8% on Ho (Riess+2021)

Aim of CHARA/SPICA:

- provide a SBCR for early-type stars with a 2% precision and accuracy (i.e. taking into account stellar activity effects)

Aim of Araucaria Project (ERC Synergy 2020-2025):

- derive the distance to M31/M33 with a few percents precision
- derive Ho independently from SHOES project **at the 1% level**

Synergy between CHARA/SPICA and the PLATO space mission

Direct CHARA/SPICA contribution into ***WP122300*** *« Fundamental stellar parameters » (leader M. Bergemann, Germany)* ***part of WP122*** *« Non-Seismic diagnostics and model atmospheres » (leader T. Morel, Liège)* ***part of WP120*** *« Stellar Science » (leader Marie Jo Goupil, Paris).*

Implication of CHARA/SPICA into ***WP125500*** *« Benchmark stars for PLATO » (leader O. Creevey)*

Direct measurements of CHARA/SPICA
WP122300-WG3
Resp. D. Mourard

Before operation: implementation of CHARA/SPICA measurements into the PLATO pipeline (SAPP); validation of the methodology

During operation: CHARA/SPICA follow-up (currently at least 400 targets in PIC catalogue observable by CHARA/SPICA)

From bright to faint stars

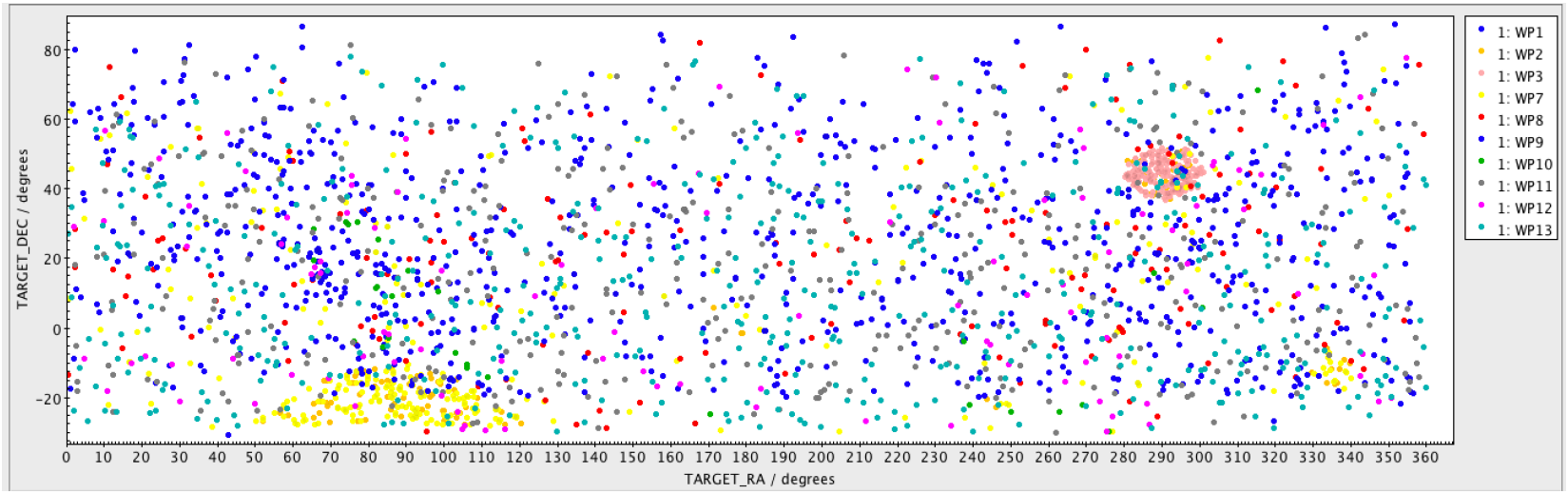
CHARA/SPICA SBCR
WP122300-WG4
Resp. Nardetto

Before operation: Calibration of CHARA/SPICA SBCR. Implementation of SBCRs into the PLATO pipeline (SAPP); validation of the methodology using PIC catalogue or benchmark stars (Gent+21 in prep)

During operation: use of CHARA/SPICA SBCR in the PLATO pipeline

Status of SPICA-database

- list of stars almost ready
- *on-going:* definition of priorities
- *on-going:* definition of the strategies
- *on-going:* management of redundancies/synergies
- *on-going:* implementation of the SPICA database and associated tools



TARGET_PROGNAME	WP01	WP02	WP03	WP07	WP08	WP09	WP10	WP11	WP12a	WP12b	WP13
str5	int64	int64	int64	int64	int64	int64	int64	int64	int64	int64	int64
WP01	31	1	0	5	0	0	0	2	0	0	1
WP02	1	285	0	151	0	0	0	0	0	0	2
WP03	0	0	200	4	0	0	0	0	0	0	1
WP07	5	151	4	474	0	2	0	0	0	0	145
WP08	0	0	0	0	254	24	0	0	1	0	4
WP09	0	0	0	2	24	901	0	13	21	3	4
WP10	0	0	0	0	0	0	29	0	0	0	0
WP11	2	0	0	0	0	13	0	583	10	39	75
WP12a	0	0	0	0	1	21	0	10	26	0	0
WP12b	0	0	0	0	0	3	0	39	0	88	7
WP13	1	2	1	145	4	4	0	75	0	7	488

Reminder:
WP1: exo
WP2: astero/dwarfs
WP3: astero/(sub)-giants
WP7: SBCR
WP8: binaries
WP9: rotation
WP10: YSOs
WP11: LD
WP12: wind & environment
WP13: metal poor stars (Galactic Archeology)

Take home message

- CHARA/SPICA survey is in preparation :

~1000 stars observed in 2022/2023/2024

- 2 main objectives:
  - Fundamental parameters of stars and planets
  - Distance Scale (Ho)
- In parallel, development of new tools (SPICA database, different tools to manage the survey)
- Need of about ~80 nights per year during 3 years
- CHARA/SPICA will have many additional programs (NOAO)
- Interested ? Contact us !