

Interferometric Survey of Stellar Parameters

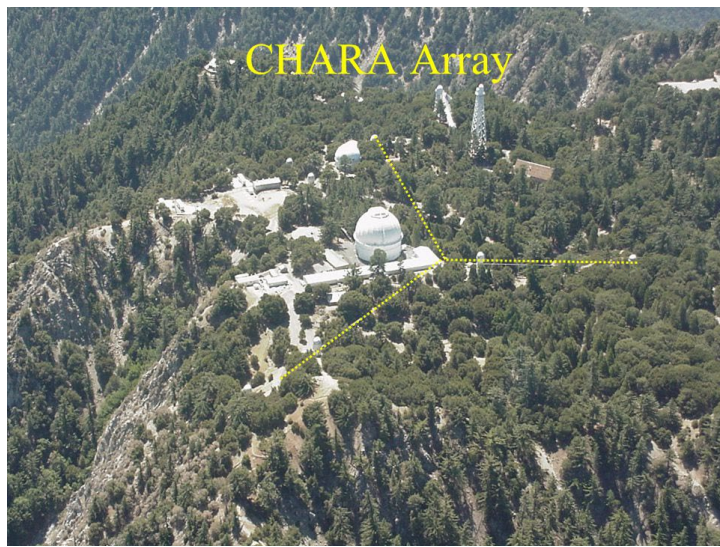
D. Mourard

N. Ebrahikuty, R. Ibanez-Bustos, J. Jonak, R. Ligi, M. Vrad
P. Bério, L. Bourges, O. Creevey, S. Deheuvels, J. Dejonghe, A.
Domiciano, D. Lecron, A. Meilland, G. Mella, F. Morand, N.
Nardetto, K. Perraut, D. Salabert, M. Wittkowski
& the CHARA team (Mount Wilson Observatory)

and

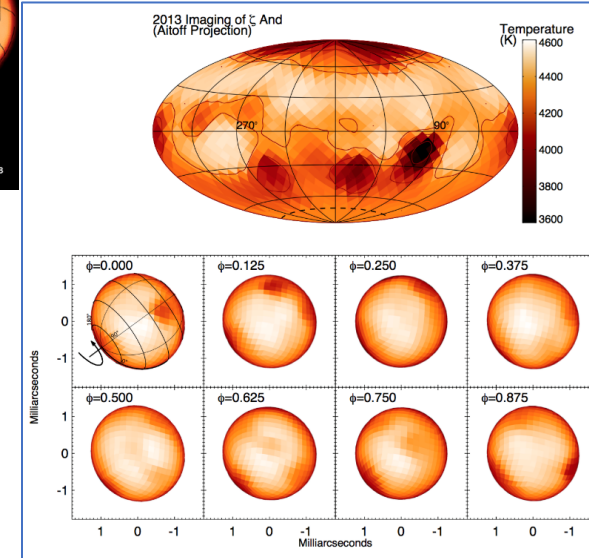
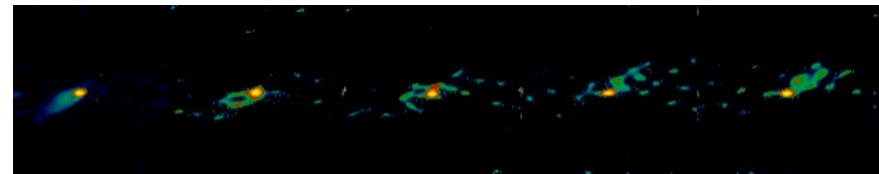
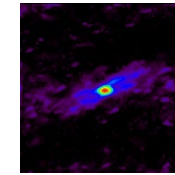
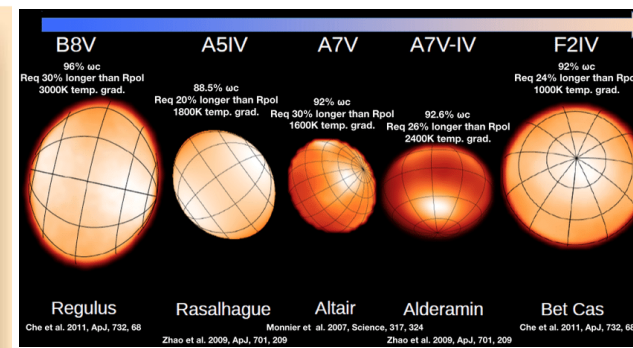
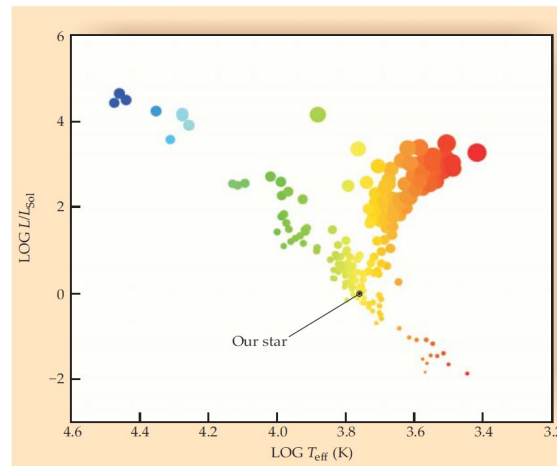
Stellar **P**arameters and **I**mages with a **C**ophased **A**rray

Colloque de prospective du PNPS – Janvier 2024 – Marseille/LAM



CHARA Array

Réseau CHARA, Mt Wilson, CA
6 télescopes de 1m, 330m de base
Instruments infrarouges et visible
OCA: collab depuis 2005, instrument VEGA → SPICA



- Aujourd'hui, pas plus de ~200 étoiles disposent d'une mesure de diamètre angulaire à 1%, (catalogue JMDC, Duvert+16): principalement des géantes, différentes techniques, différents instruments, différentes bandes spectrales...
- Grande opportunité car les missions spatiales, notamment PLATO, se tournent vers des étoiles brillantes pour une meilleure caractérisation. En parallèle progrès en sensibilité et précision en interférométrie optique.
- Bases de 300m sur CHARA and accès au visible → résolution record de 0.1mas (sondage des étoiles MS)

SPICA en quelques mots

- *Senseur de franges 6T bande H pour stabilisation rapide des franges*
- Un recombineur 6T plan image (600-900nm) avec 3 modes de dispersion et alimenté par 6 fibres monomodes.

MODES	Nb of SpCh	SpCh	Spectral Band	MagLim $V^2=0.6$	MagLim $V^2=0.6 + FT$	MagLim Vdiff	MagLim Vdiff+FT
LR: R=140	60	3-7 nm	300nm	8.5	11.5		
MR: R=4400	500	0.17nm	85nm			5.5	9.5
HR: R=13000	500	0.06nm	29nm			4.5	8.5

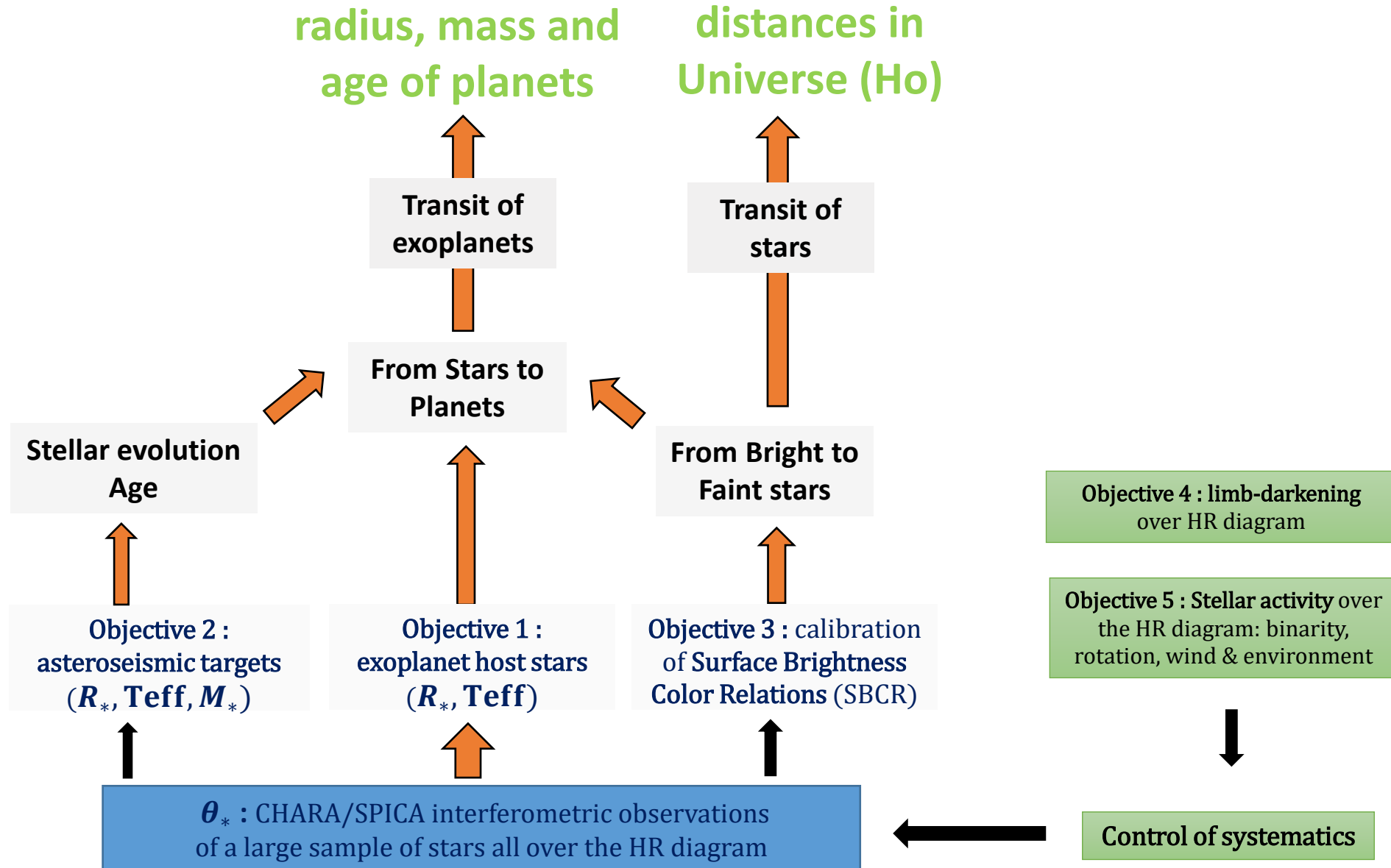
MagLim: V^2 : SNR=10, 10mn d'intégration, 1 canal spectral

Vdiff: [SNR=10, $\sigma\phi < 5^\circ$], $V^2=0.6$ dans le canal de référence, 30mn d'intégration, 1 canal spectral

Estimateur de SNR basé sur les travaux FRIEND (Martinod+2018), CHARA-AO hypothèse (SR=20%)

SPICA (bande 600-900nm) est opéré simultanément avec MIRCX (bande H) et MYSTIC (bande K)

Interferometric Survey of Stellar Parameters



Strong links with:

- ESA/PLATO mission
- Araucaria program

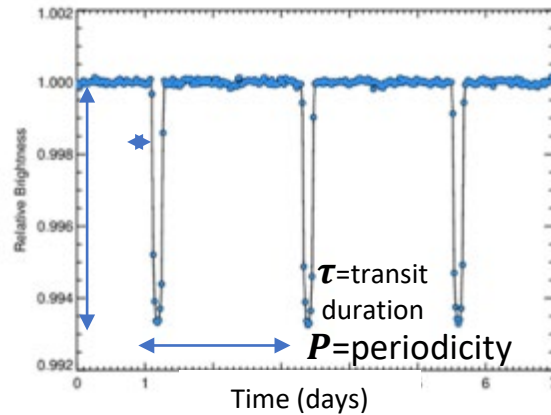
Exoplanet hosts stars *TESS, CHEOPS, PLATO... (S01)*



Transit of exoplanets

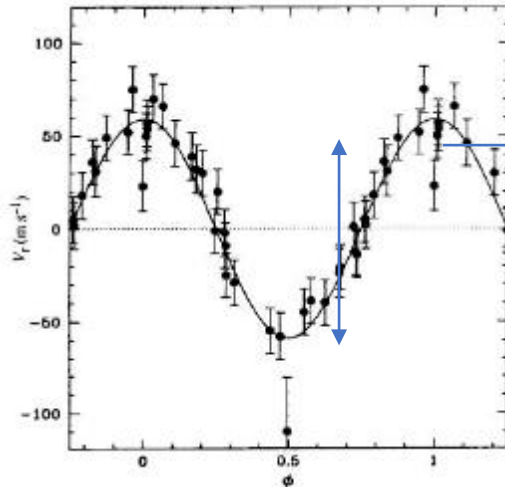
PHOTOMETRY

$\frac{\Delta F}{F}$
transit
depth



RADIAL VELOCITY

Radial velocity
(km/s)



SPICA

Parallax Gaia
Bolometric flux

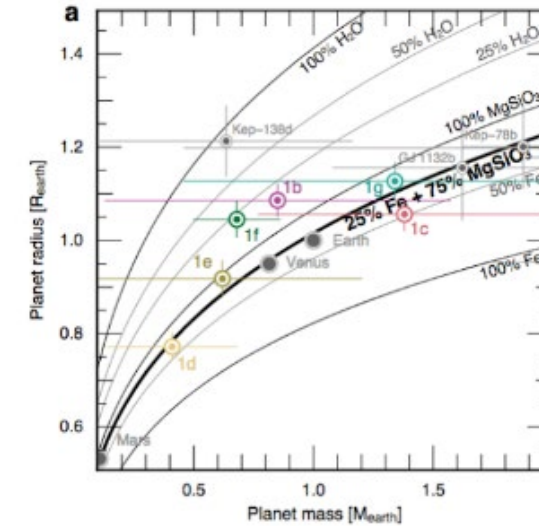
$R_* - T_{eff}$

e.g.: Ligi+16

From stars to
planets

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

$$M_p = c \cdot M_*^{2/3} P^{1/3}$$



Needs: extraction of angular diameter, T_{eff} -logg probably by hypothesis for LD, bolometric flux for T_{eff} , parallax, stellar evolution modelling, planet modelling, ...

Asteroseismology and interferometry

PLATO preparation/follow-up (S02 and S03)

Scaling relations from
the frequencies

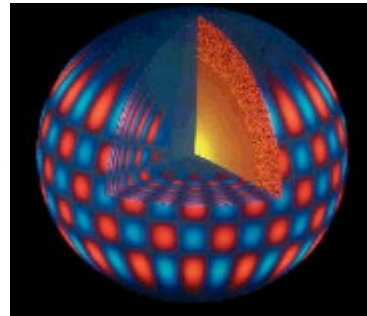
$R_*[SR], M_*[SR]$

Comparison

Full analysis on benchmark stars

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

Calibration



Constraints

Mass, Age
Stellar evolution

$R_*[I], R_*[SBCR]$

Gaia parallax

CHARA/SPICA angular diameters θ

Needs: extraction of angular diameter, Teff-logg probably by hypothesis for LD but also some direct measurements are possible (stellar atmosphere models), bolometric flux for Teff, parallax, stellar evolution modelling, seismic parameters, ...

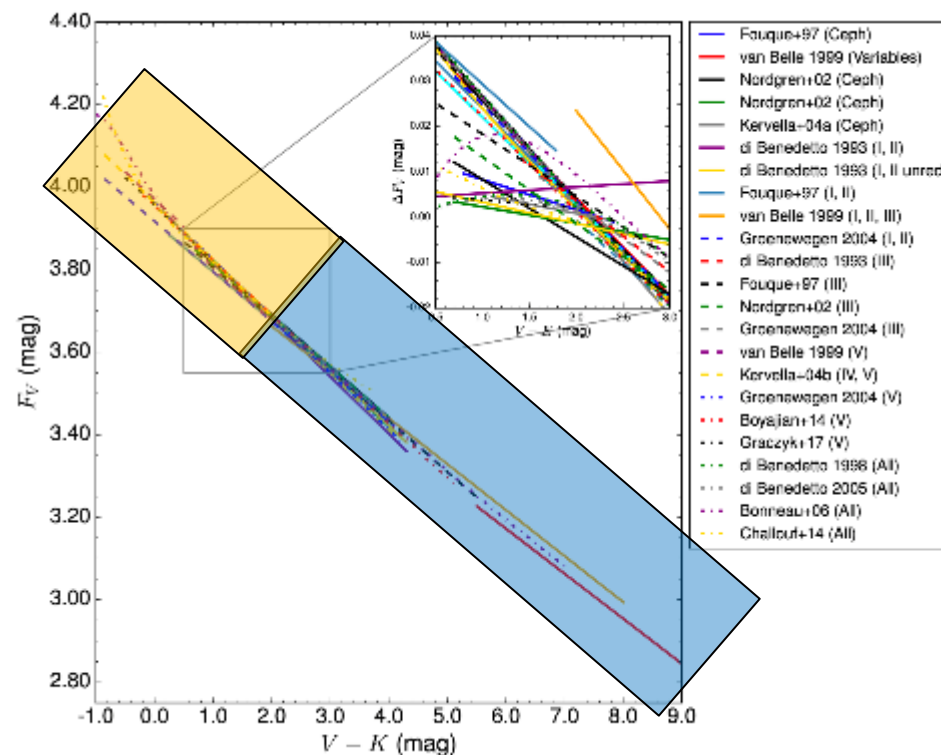
Calibrations of SBCR across the HR diagram (S04)



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

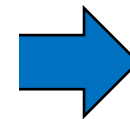
$$S_\lambda = m_{\lambda_0} + 5 \log \theta_{LD}$$

SBCR for early type:
➤ distance M31/M33
ARAUCARIA



From bright to faint
stars

SBCR for late type:
➤ distance SMC/LMC (Ho)
➤ PLATO targets



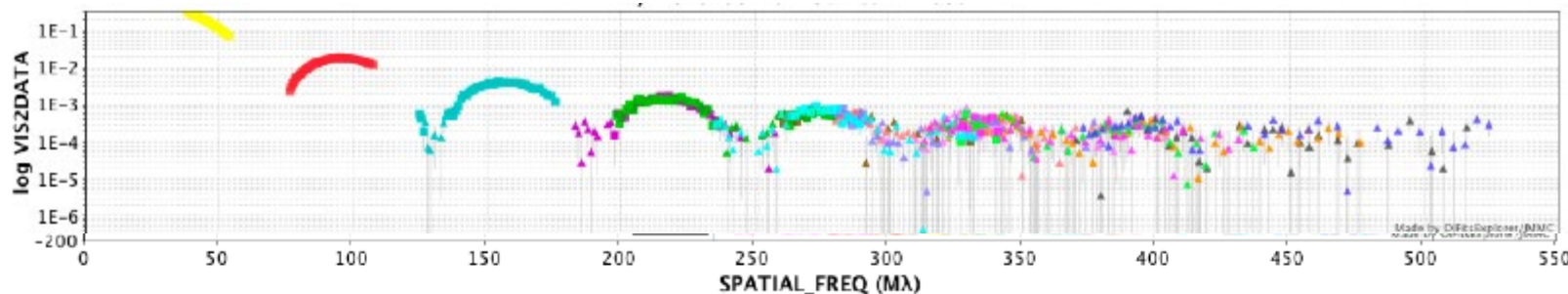
Needs: extraction of angular diameter,
Teff-logg probably by hypothesis for LD but
also some direct measurements (stellar
atmosphere models), bolometric flux for
Teff, parallax, stellar evolution modelling,
accurate photometry, variability indexes,
extinction correction, ...

Objective 4: Limb-darkening survey over the HR diagram

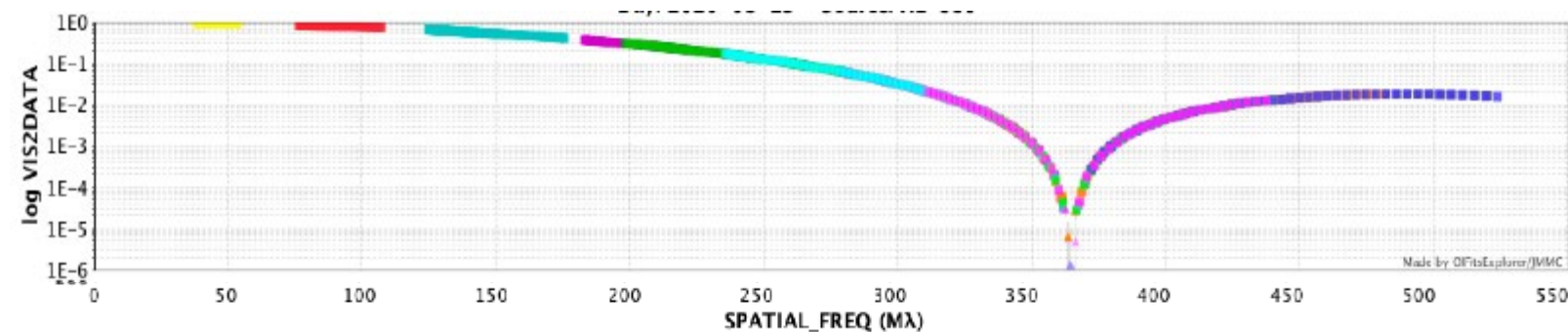
S05 (~160 targets)

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

Example 1: K4, mV=4, $\theta=3.53$ mas (1 observation)



Example 2: B0, mV=1, $\theta=1.1$ mas (1 observation)



Needs: extraction of angular diameter through stellar atmosphere models, bolometric flux for Teff, parallax, stellar evolution modelling, variability indexes,...

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

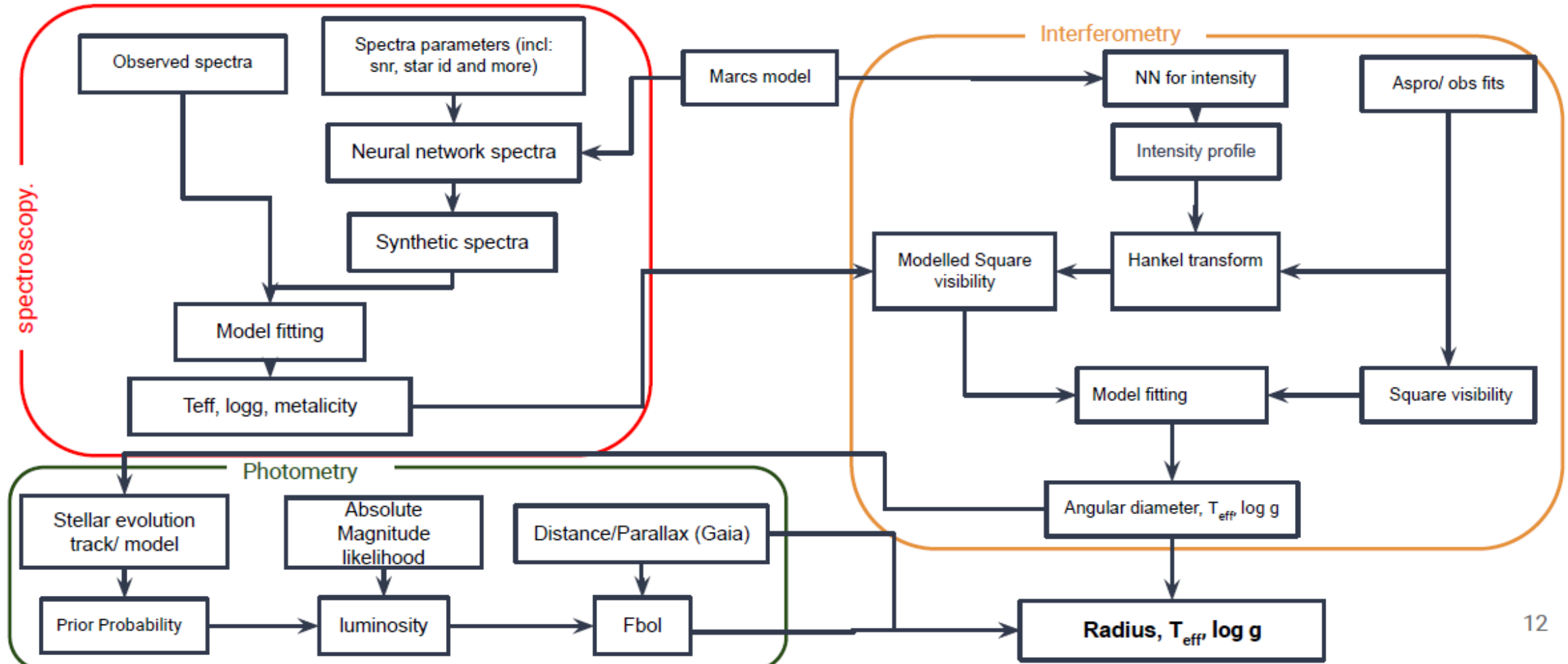
Giants	Challouf			Salsi-1			Salsi-2		
SpTy	O	B0	A0	F5	G7	K4	M0	M3	M4
V // V-K	-2	-1	0	1	2	3	4	5	6
0	0,24	1,00	3,16	6,72	11,79	20,68	36,41	62,26	106,46
1	0,15	0,69	2,99	4,24	7,44	13,05	22,97	39,28	67,17
2	0,10	0,40	1,26	2,68	4,69	8,23	14,49	24,79	42,38
3	0,06	0,27	0,79	1,69	2,96	5,20	9,15	15,64	26,78
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

ML for Stellar Atmosphere Models

Part of MSteSci1 pipeline (PLATO PDC)



Ebrahimkuty et al., A&A in prep





Objective 5: - Stellar activity survey over the HR diagram **binarity** (S06), **rotation** (S07), **wind & environment** (S08)

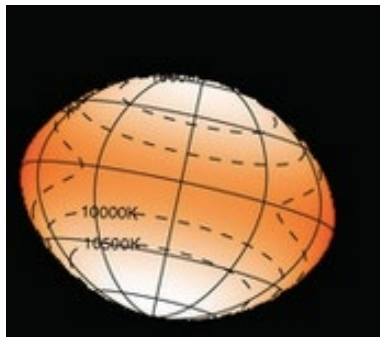
Binarity (~ 54 targets)



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

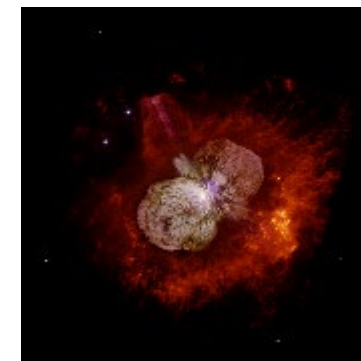
Stellar activity over
the HR diagram ~
~200 images

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)

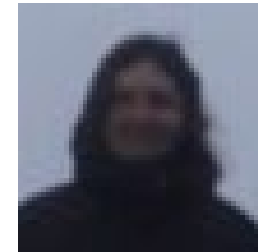
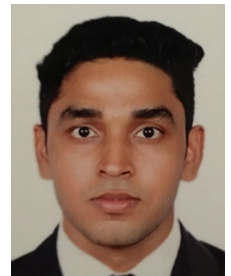


- study the wind & environment for hot and cold stars
- Wind on Deneb and Rigel (Chesneau+10), Chromosphere of K giants (Berio+11), environment of delta Cep (Nardetto+16)

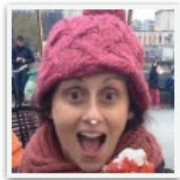
Needs: specific adjustments of visibilities (pysHELLspec, amhra,),
complementary spectroscopic and photometric data, ...

The science team of ISSP

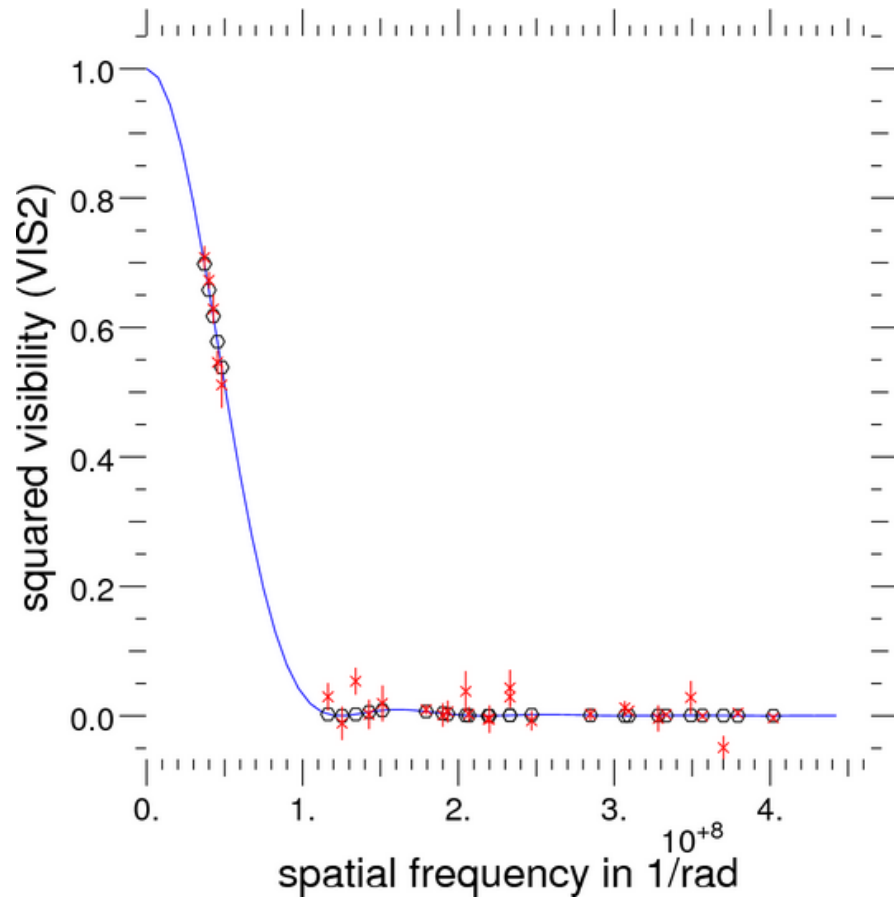
- Roxanne Ligi: 3-year postdoc (1/12/2022) – exoplanet host stars
- Mathieu Vrad: 3-year postdoc (1/11/2022) – interferometry and asteroseismology
- Romina Ibañez-Bustos: 3-year postdoc(1/04/2023) –SBCR
- Nayeem Ebrahimkutty: PhD (1/07/2023) – Limb darkening
- Juraj Jonak: PhD (1/12/2022) – binaries and stellar masses



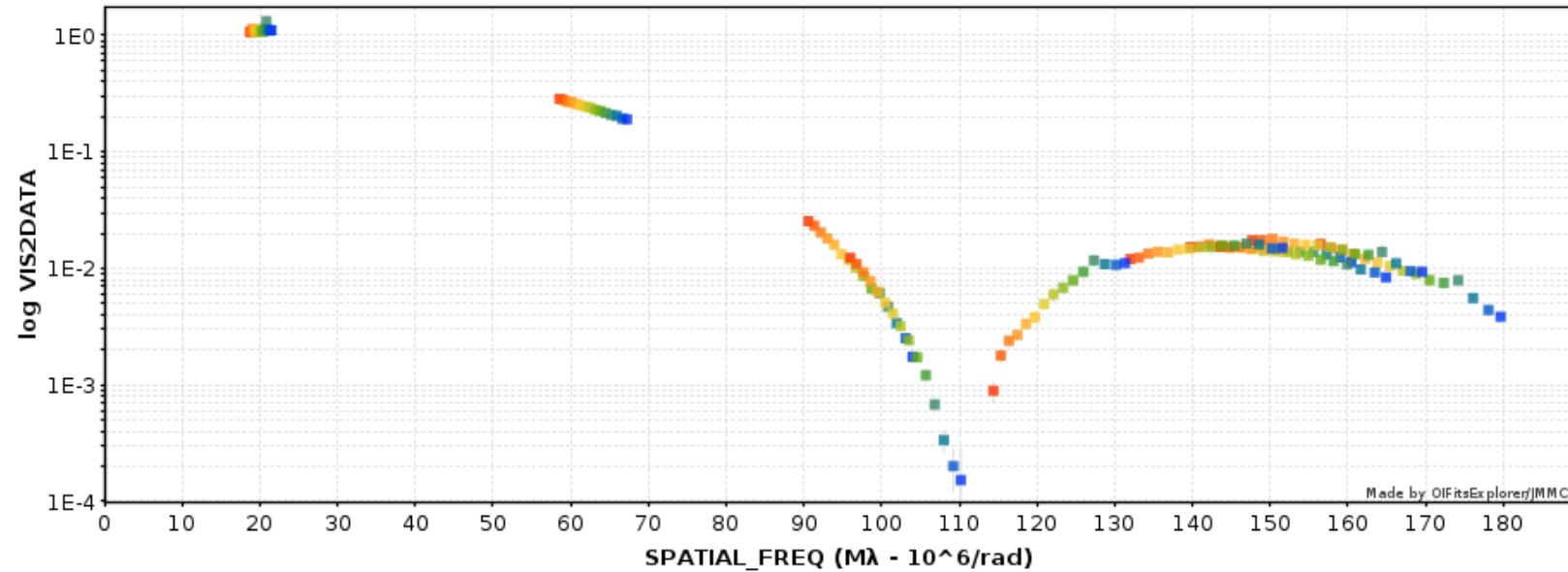
Associated col of the survey: Orlagh Creevey (astero-dwarfs), Sébastien Deheuvels (astero-giants), Armando Domiciano (rotating stars), Nicolas Nardetto (SBCR), Markus Wittkowski (winds and environnements), and Karine Perraut



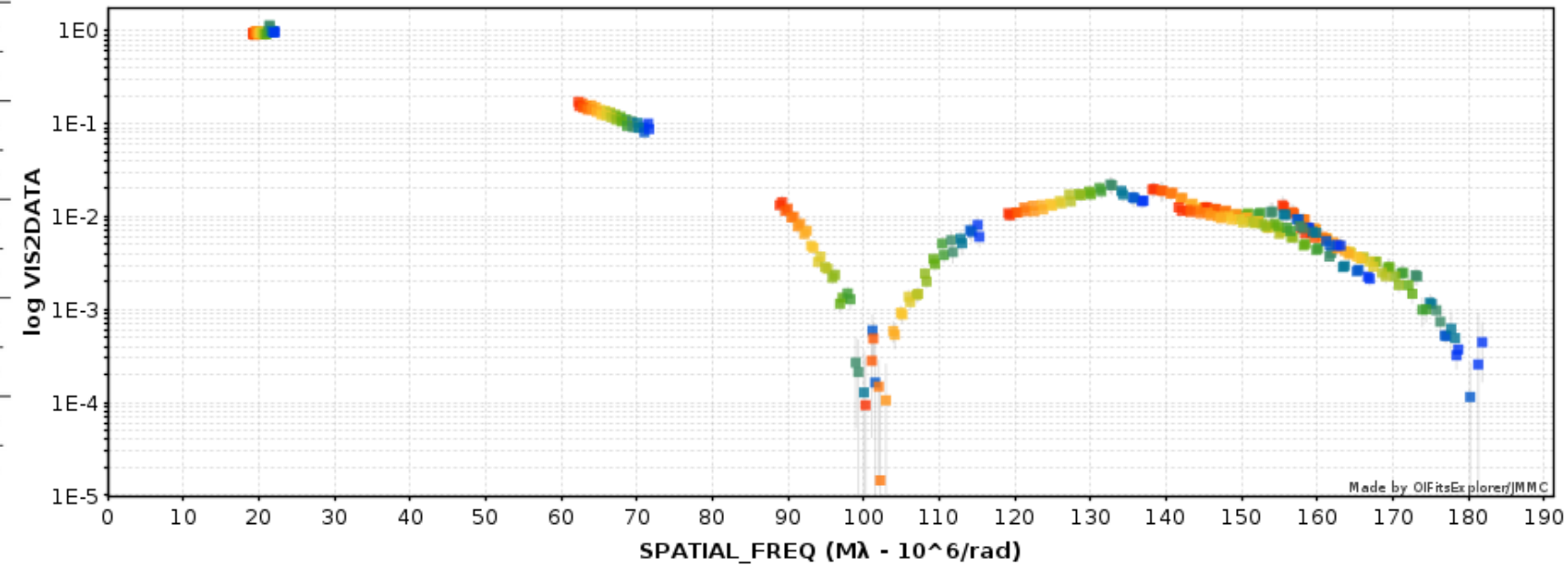
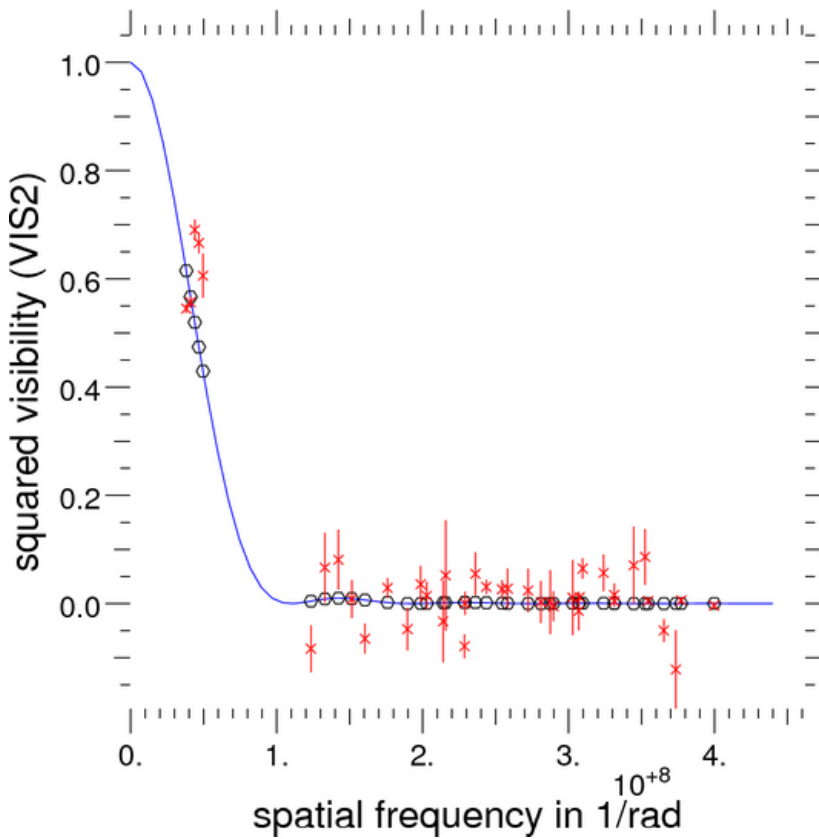
A few examples of recent measurements



HD27371 : G9 III, S03, seismic target – Mathieu VRARD

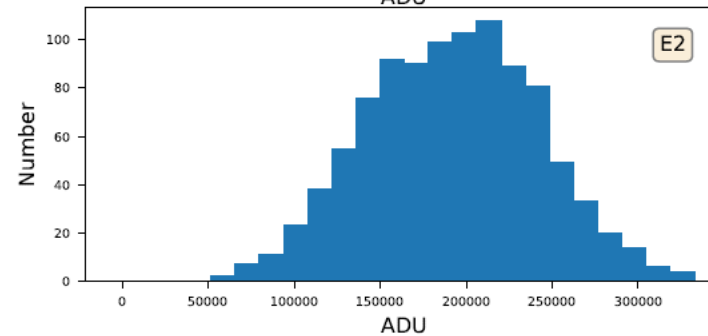
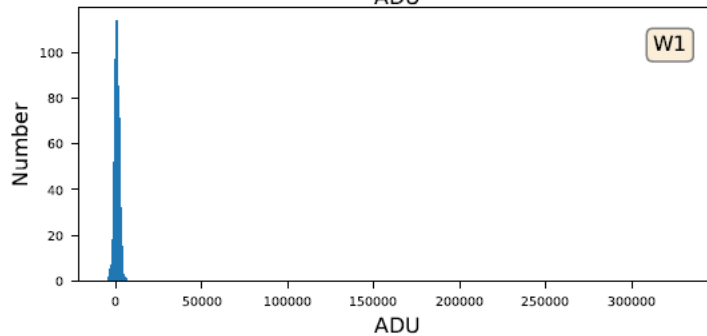
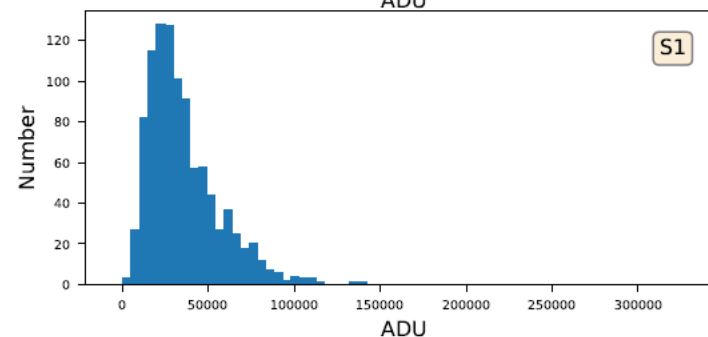
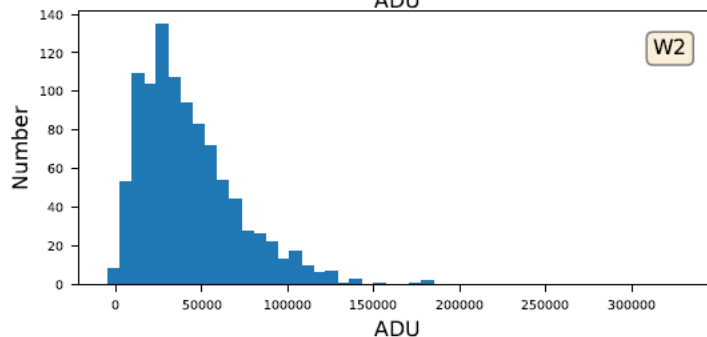
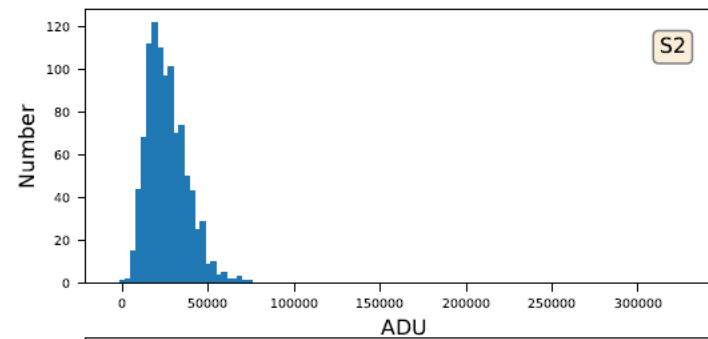
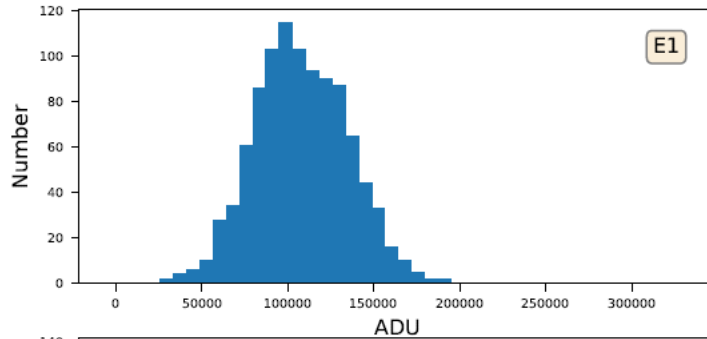


HD28305 : G9 III, S03, seismic target – Mathieu VRARD



Difficultés alignement, performances de l'Opt.Adap., qualité d'image

HD184006 statistique du flux injecté



Flux E1 = 106926 +/- 25916

Flux W2 = 36468 +/- 28361

~~Flux W1 = 517 +/- 1493~~

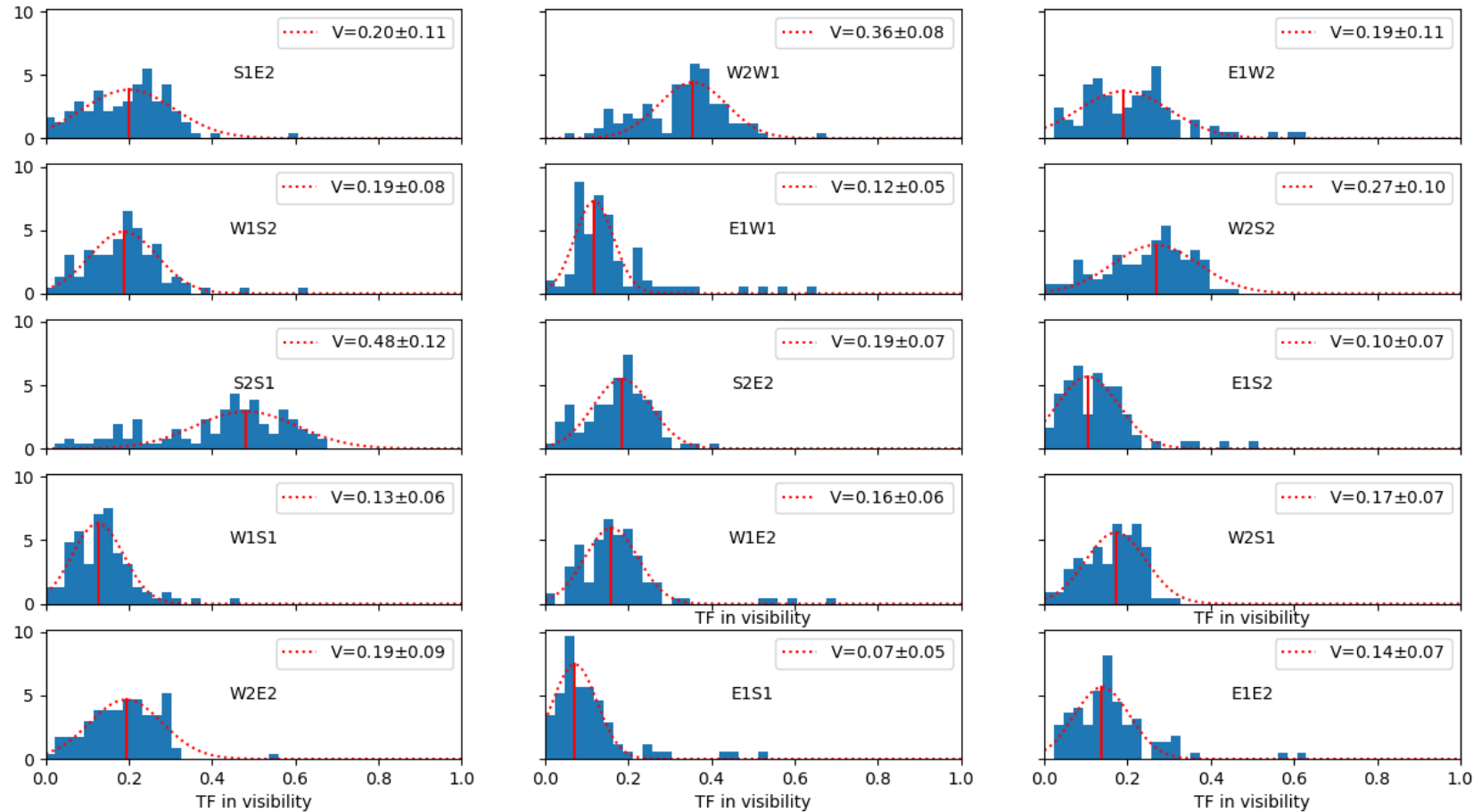
Flux S2 = 24012 +/- 11437

Flux S1 = 30198 +/- 20333

Flux E2 = 194001 +/- 49489

Strehl Ratio autour de 5-8% au lieu du 20-25% attendu. Perte de flux d'un facteur 4 à 5 → 2mag

Difficultés avec la fonction de transfert instrumentale



Niveau de vibration non acceptable identifié au niveau des lignes à retard

$\langle V \rangle = 0.19 \rightarrow \langle V^2 \rangle < 0.04 \rightarrow$
Perte de SNR d'un facteur 25!

Conclusion



- Bons progrès pour les opérations et les performances de SPICA
- Mais des limites identifiées en sensibilité et précision → Groupe de travail mis en place entre CHARA et SPICA pour résoudre ces questions. Raisons objectives claires donc optimisme!
- Premiers résultats du grand relevé; collecte de données d'archives (spectro, photométrie) en bonne progression. Préparation des premières publications.
- 4 programmes externes temps ouvert en 2024B (hors groupe ISSP)
- CHARA couvert par ANO2/CHARA → soutien de la communauté française sur le temps ouvert.
- Lien fort PLATO très motivant. Discussion ARIEL en cours (25 cibles communes)
- Coté Araucaria, encore des choses à construire mais opportunité pour photométrie IR sur étoiles brillantes (critique pour SBCR, notamment)
- Besoins anticipés autour des modèles d'atmosphère (description des profils d'intensité) - impact à voir sur les modèles d'évolution.