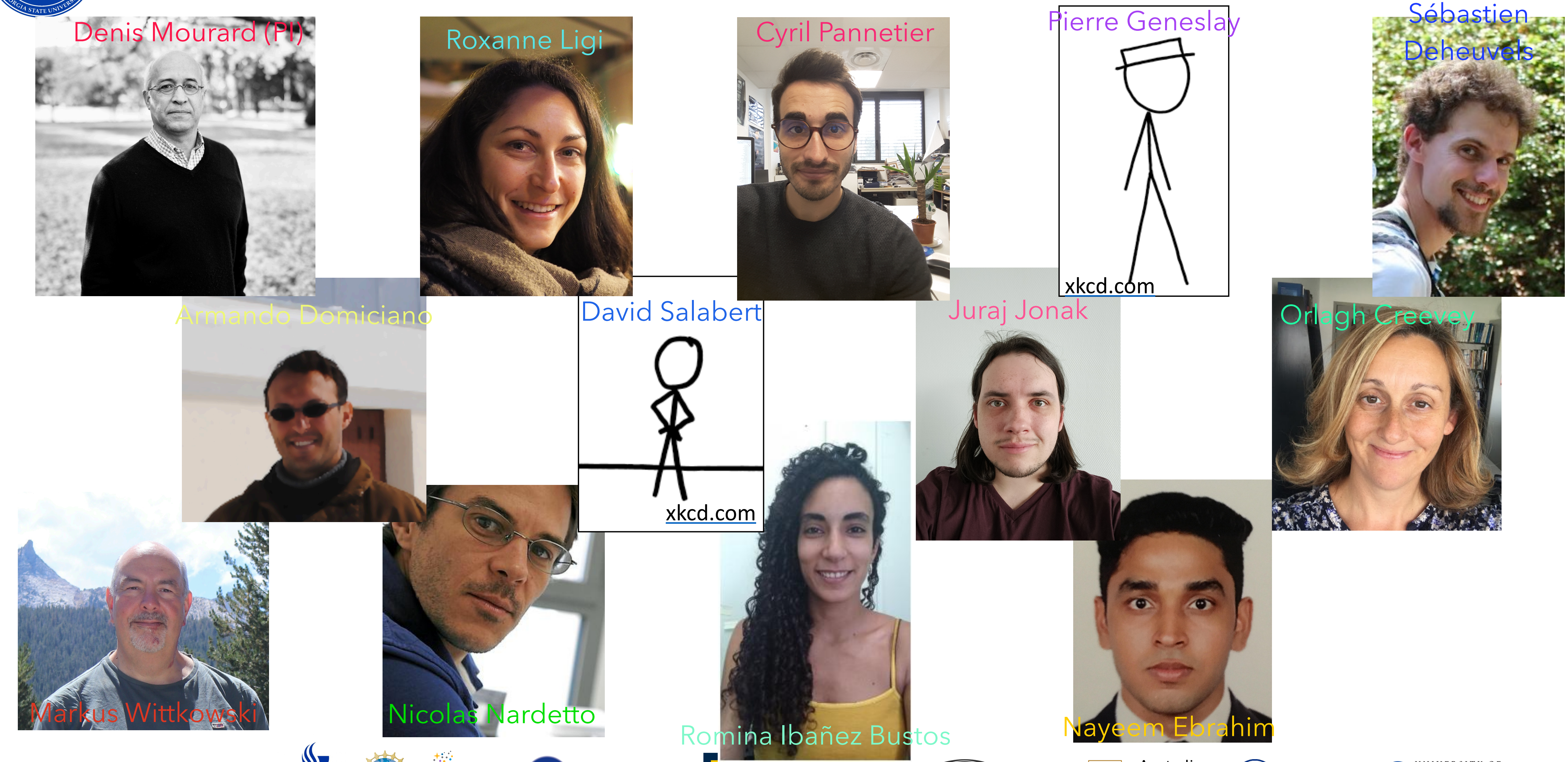
THE SCIENTIFIC PROJECTS OF THE ISSP SURVEY

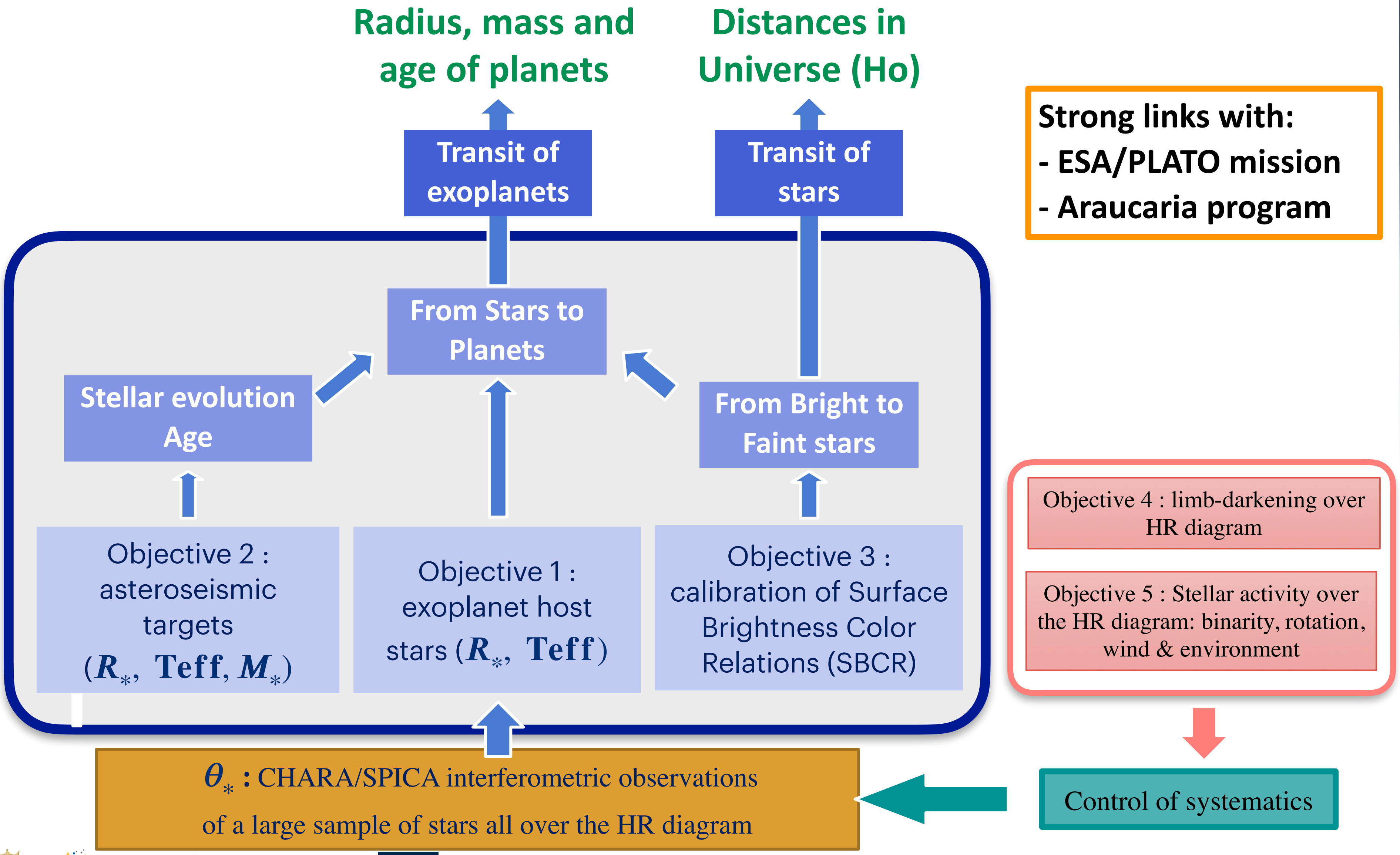
Roxanne Ligi, Denis Mourard, Romina Ibañez Bustos, Armando Domiciano, David Salabert, Orlagh Creevey, Nicolas Nardetto, Sébastien Deheuvels, Juras Jonak, Markus Wittkowski, Cyril Pannetier, Pierre Geneslay, Nayeem Ebrahim, et al.

The SPICA core Team



Principal objectives (see Denis's talk)

- Address a large number of problematics in the stellar physics field
- Through a large survey of homogeneous sample: 1000 stars



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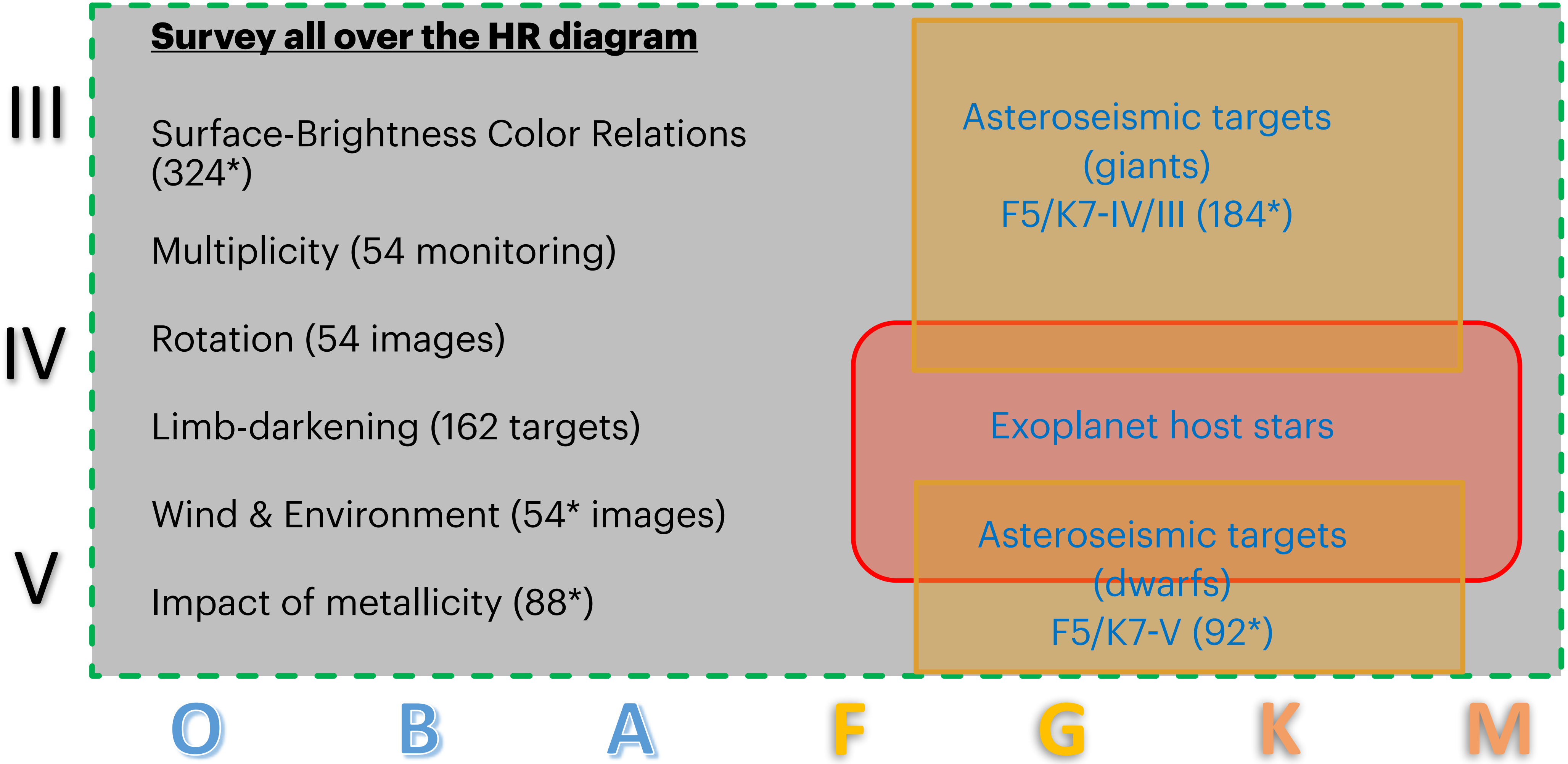
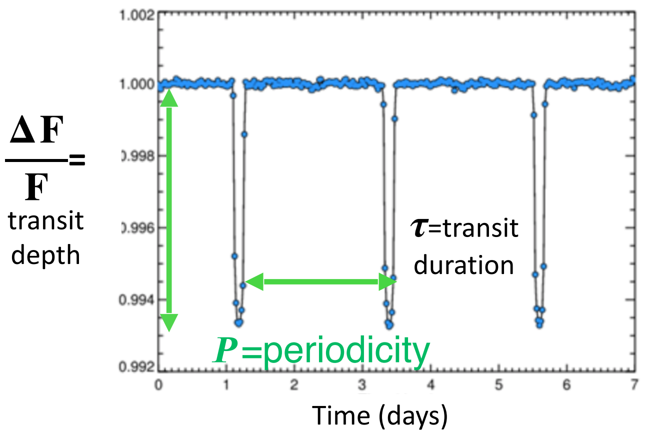


800*+200I➔ ~4000 obs ➔ 200 guaranteed nights (ERC) but efficiency and performance are key issues

S01: Exoplanet host stars

R. Ligi, T. Boyajian, A. Chiavassa, A. Gallenne, R. M. Roettenbacher, D. Mourard, R. Szabò, M. Wittkowski, T. Guillot, A. Crida, S. Albrecht, S. Borgniet

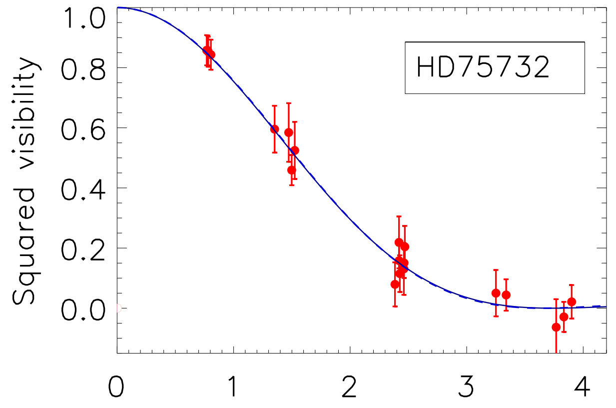
PHOTOMETRY of stars hosting exoplanets in transit: PLATO, TESS, …



Transit duration: $T=2R_\star/a\Omega$

Period: $P = 2\pi/\Omega$

INTERFEROMETRY : θ



$P/T^3 = (\pi^2 G/3)\,\rho_\star$

Measure of stellar density $\rho_\star$

(Maxted et al. 2015, Seager & Mallén-Ornelas 2003)

→

Direct measurement of the stellar mass

$M_\star=(4\pi/3)R_\star^3\rho_\star$

(Ligi et al. 2016)

←

Measure of $R_\star$ by interferometry within the ISSP survey

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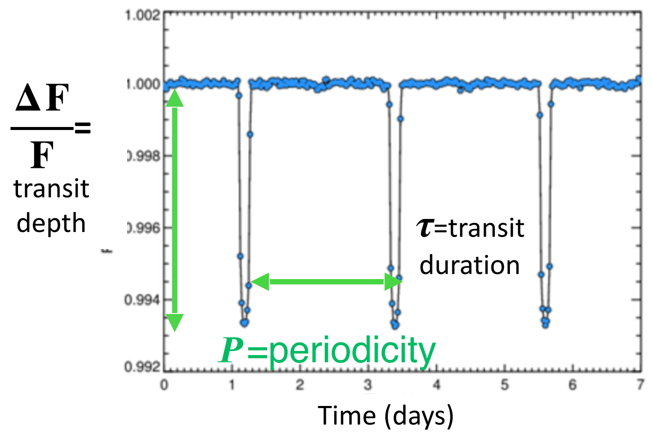


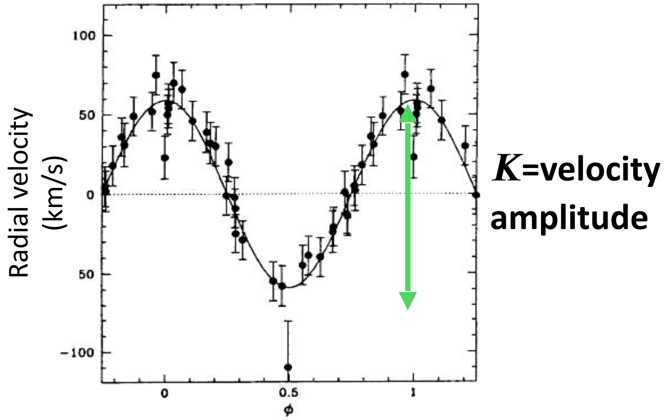
Transit light curve:

$R_p = R_\star \times \sqrt{TD}$

VELOCIMETRY of exoplanets in transit

RV measurements:

$m_p \sin(i) = M_\star K (P/2\pi G M_\star)^{1/3}$



ρ_p

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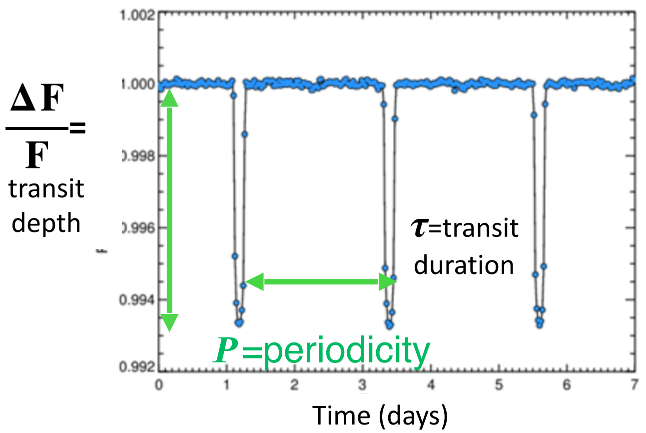

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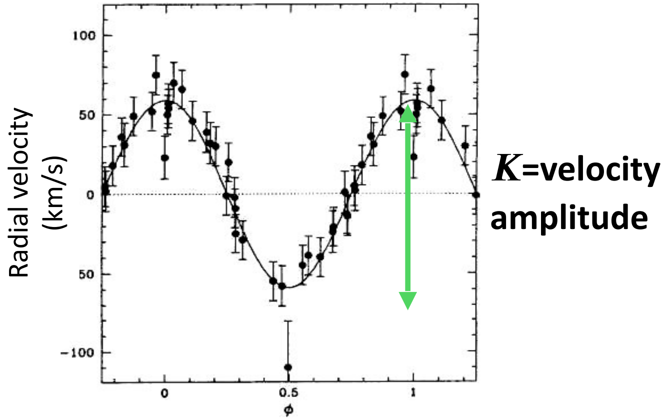
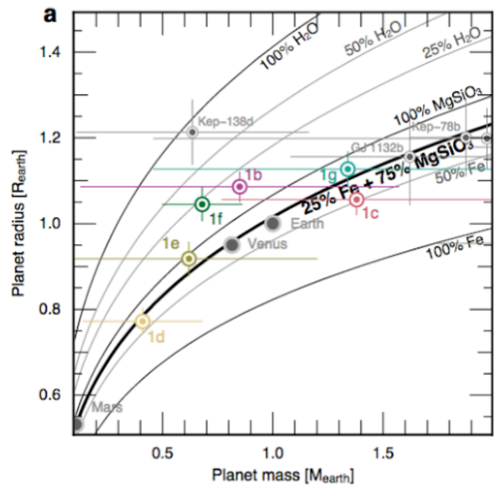


ρ_p



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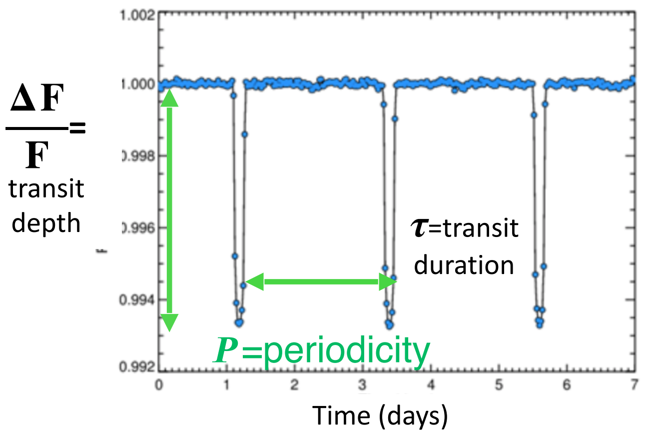

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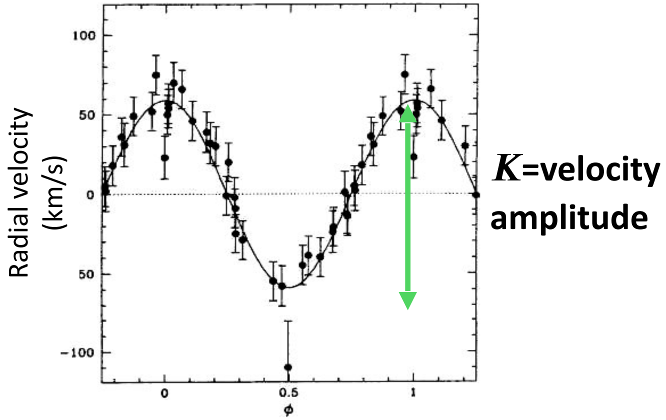
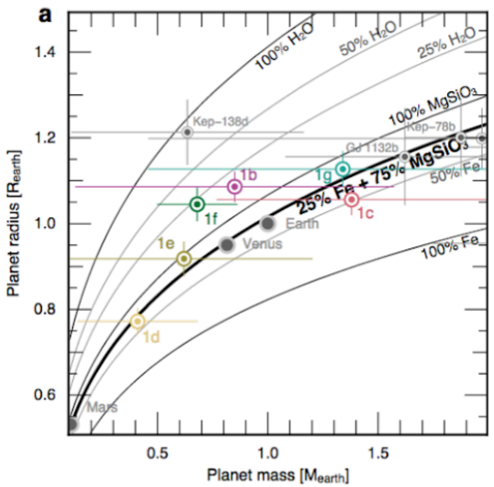


ρ_p

➔ Composition of exoplanets



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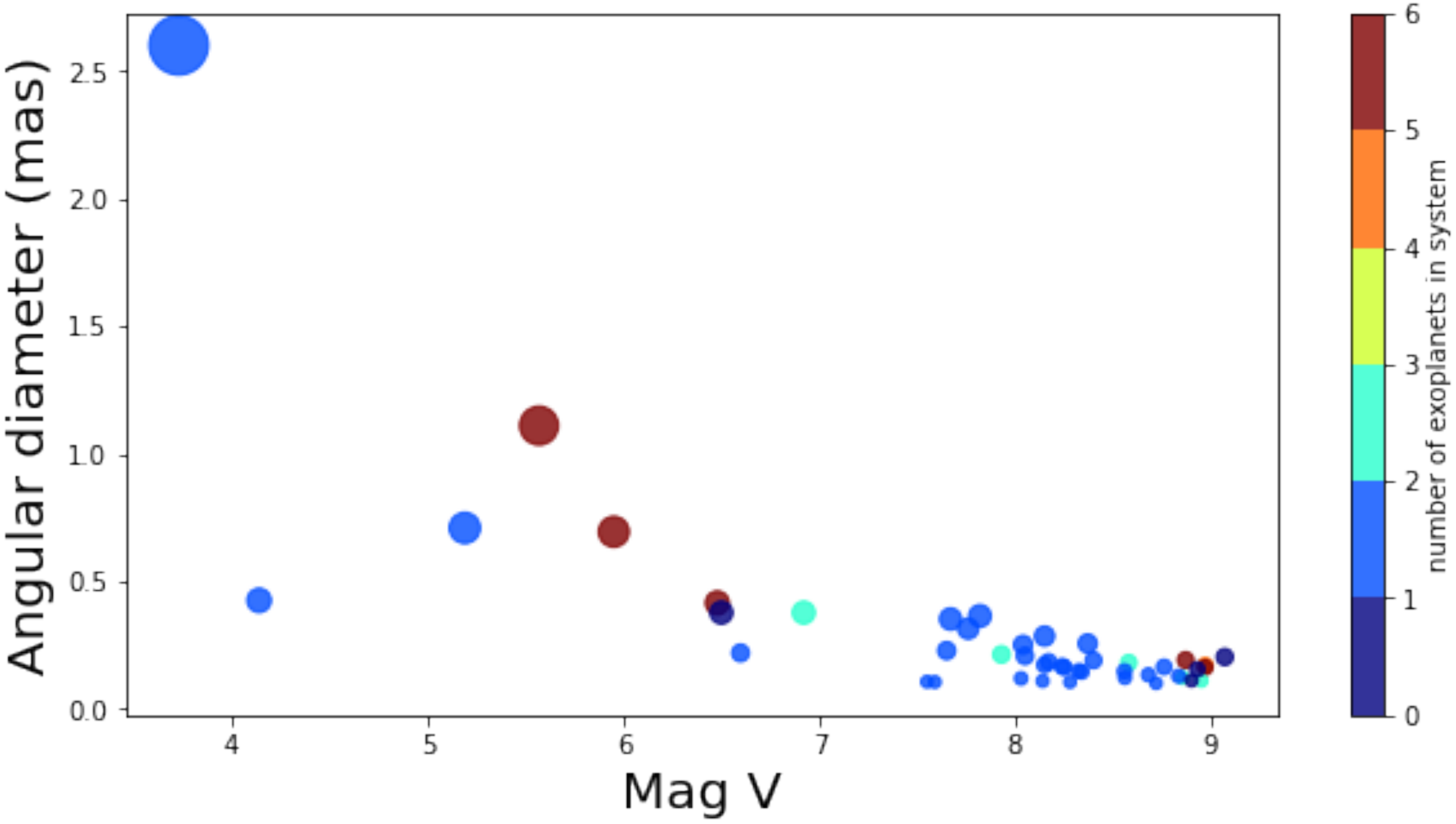
45 stars

42 with transiting exoplanets
3 detected by direct imaging
(for LD and imaging)

MagV < 8.5
$\theta_\star > 0.1$ mas

(Remember with VEGA: 5 targets)



S02: Asteroseismic FGK dwarfs

O. Creevey, R. Ligi, D. B. Palakkatharappil, T. Morel, R. M. Roettenbacher, R. Szabò, T. Boyajian, N. Nardetto, D. Mourard, M. Bazot, W. J. Chaplin

Three subsamples:

- S0: stars with detected global seismic quantities
- S1: stars with detected individual frequencies
- S2: stars with detected individiual frequencies with enough precision to infer differential rotation

The objectives:

S0: (a) calibrating the radius seismic scaling relation covering a range of masses and metallicities (b) model-independent masses using Delta nu and R_interferometric

S1: detailed seismic analysis for (a) high precision stellar parameters (b) testing of different physical ingredients in stellar models

S2: "Butterfly diagrams" ➔ needs imaging (this point has not had moved forward much)

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spicawp2db_v1.4

	ID_string	RA_float	Dec_float	Bibref_string	Seismic_integer	Activity_integer	Activit_type_strir	DataFile_string	Dnu_float	eDnu_float	Numax_float	eNumax_float
2	HIP 58093	178.7164989	-1.45151956	https://ui.adsabs.harvard.edu/abs/2015	0				65.7	0.7	1176	58
3	HIP 58191	179.0052387	-1.44221601	https://ui.adsabs.harvard.edu/abs/2015	0				51.5	1.01	890	46
4	HIP 55778	171.4289355	5.74789509	https://ui.adsabs.harvard.edu/abs/2015	0				66.6	0.8	1196	72
5	HIP 57676	177.435715	6.523228357	https://ui.adsabs.harvard.edu/abs/2015	0				57.1	1.3	1000	46
6	HD 89345	154.6710833	10.12903056	https://arxiv.org/pdf/1805.01860.pdf	1			HD89345_FreqData.txt	67	1.87	1300	58
7	KIC 6106415	285.4153333	41.49009167	https://iopscience.iop.org/article/10.108	1		high-proper moti	KIC6106415_FreqData.txt	10.4	0.5	2210	50
8	KIC 12009504	289.4408333	50.480075	https://iopscience.iop.org/article/10.108	1	2	rotationaly varial	KIC12009504_FreqData.txt	88	0.6	1833	40
9	KIC 10513837	280.8679333	47.70363456	https://iopscience.iop.org/article/10.108	1	1	red giant branch	BD+472682_FreqData.txt	14.6	0.2	191	7
10	KIC 8006161	281.1463301	43.83327475	https://iopscience.iop.org/article/10.108	1		high proper-moti	HD173701_FreqData.txt	149.3	0.4	3570	96
11	KIC 7940546	283.0687447	43.70994327	https://iopscience.iop.org/article/10.108	1			HD175226_FreqData.txt	58.9	0.2	1081	34
12	KIC 5939450	283.5598312	41.22579437	https://iopscience.iop.org/article/10.108	1			HD175576_FreqData.txt	30.5	2.4	605	25
13	KIC 9139151	284.0886021	45.51478694	https://iopscience.iop.org/article/10.108	1		high proper-moti	BD+452796_FreqData.txt	117.3	0.3	2695	74
14	KIC 9139163	284.0921957	45.5070442	https://iopscience.iop.org/article/10.108	1	2	eruptive variable	HD176071_FreqData.txt	81.1	0.2	1685	45
15	KIC 10454113	284.1526994	47.65643422	https://iopscience.iop.org/article/10.108	1	2	rotationally varia	HD176153_FreqData.txt	105.1	0.3	2310	68
16	KIC 6106415	285.4153258	41.49009044	https://iopscience.iop.org/article/10.108	1		high proper-moti	HD177153_FreqData.txt	104.3	0.3	2219	60
17	KIC 9206432	285.9380663	45.60838577	https://iopscience.iop.org/article/10.108	1			HD177723_FreqData.txt	84.7	0.3	1859	50
18	KIC 5774694	286.0682393	41.00317867	https://iopscience.iop.org/article/10.108	1			HD177780_FreqData.txt	140.2	4	3442	274

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	ID_string	RA_float	Dec_float	RadRef_float	eRadRef_float	Mass_float	eMass_float	Age_float	eAge_float	Teffref_float	eTeffref_float	[Fe/H]_float	e[Fe/H]_float	AngDiam_meas	errAngDiam_me	Density_float
2	HIP 58093	178.7164989	-1.45151956	1.71	0.03	1.14	0.05			5695	77	0.19	0.1	0	0	
3	HIP 58191	179.0052387	-1.44221601	2.08	0.04	1.28	0.05			6125	77	-0.04	0.1			
4	HIP 55778	171.4289355	5.74789509	1.77	0.03	1.35	0.06			6417	77	0	0.1			
5	HIP 57676	177.435715	6.523228357	1.87	0.04	1.14	0.05			5852	77	-0.08	0.1			
6	HD 89345	154.6710833	10.12903056	1.657	0.017	1.11	0.04	8.3	1.2	5480	100			0.117		2.21
7	KIC 6106415	285.4153333	41.49009167	1.23	0.02	1.1	0.07	6	2	6000	200			0.28		
8	KIC 12009504	289.4408333	50.480075	1.42	0.03	1.22	0.08	3.5	2	6200	200			0.097		
9	KIC 10513837	280.8679333	47.70363456	4.788	0.093	1.29	0.074			4955	95			0.171	0.009	
10	KIC 8006161	281.1463301	43.83327475	0.927	0.014	0.959	0.036			5355	107			0.324	0.016	
11	KIC 7940546	283.0687447	43.70994327	1.944	0.0275	1.38	0.0835			6287	74			0.236	0.006	
12	KIC 5939450	283.5598312	41.22579437	2.916	0.061	1.625	0.1015			6380	70			0.241	0.008	
13	KIC 9139151	284.0886021	45.51478694	1.178	0.018	1.218	0.046			6141	114			0.106	0.004	
14	KIC 9139163	284.0921957	45.5070442	1.571	0.01	1.405	0.0305			6525	111			0.142	0.005	
15	KIC 10454113	284.1526994	47.65643422	1.251	0.017	1.165	0.045			6134	113			0.14	0.006	
16	KIC 6106415	285.4153258	41.49009044	1.24	0.018	1.11	0.0345			6061	89			0.279	0.008	
17	KIC 9206432	285.9380663	45.60838577	1.544	0.015	1.482	0.044			6614	135			0.097	0.007	
18	KIC 5774694	286.0682393	41.00317867	1	0.0155	1.079	0.043			5911	106			0.173	0.008	
19	KIC 3733735	287.2581	38.89985666	1.427	0.0195	1.454	0.0415			6824	131			0.132	0.006	
20	KIC 3632418	287.3618131	38.7140153	1.911	0.0255	1.396	0.0745			6286	70			0.164	0.006	

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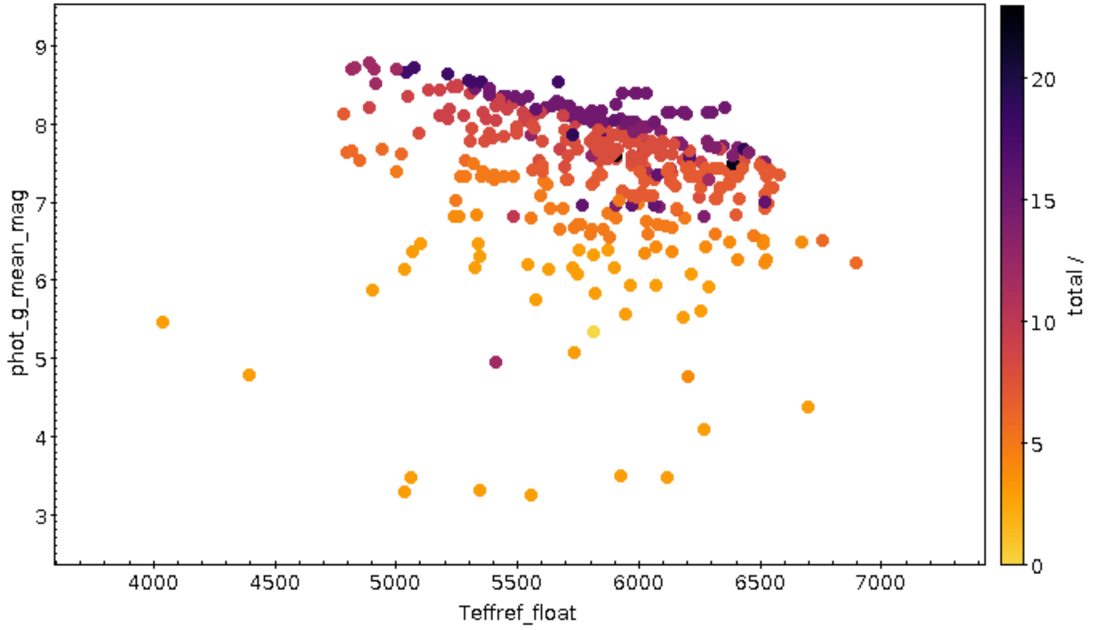


S03: Subgiants and Giants with asteroseismic data

S. Deheuvels, O. Creevey, R. M. Roettenbacher, R. Szabò, W. J. Chaplin, D. Mourard, T. Morel, Y. Lebreton, N. Nardetto, M. Bazot

- Objective 1: Place constraints on stellar physics through detailed modeling using simultaneously seismology (mixed modes) + interferometry (precise radius)

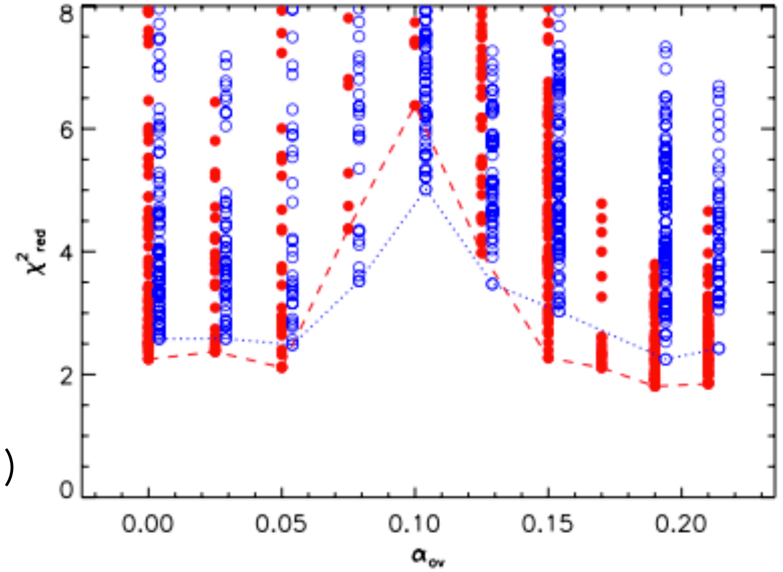
  ➔ Need bright stars with excellent seismic data

For subgiants, this could be used to gain insight on the extent of main-sequence convective cores (which remains an open question in stellar physics).

Ex. for CoRoT subgiant HD49385:

Deheuvels & Michel (2011)

	AGS05	
	low α_{ov}	high α_{ov}
α_{ov}	$0.00^{+0.01}$	0.19 ± 0.01
$M/M_\odot$	1.264 ± 0.013	1.210 ± 0.021
Age (Gyr)	4.88 ± 0.11	5.10 ± 0.18
$R/R_\odot$	1.947 ± 0.007	1.917 ± 0.011
T_{eff} (K)	5940 ± 40	6080 ± 60
$\log g$	3.960 ± 0.002	3.954 ± 0.002
α_{conv}	0.52 ± 0.01	0.56 ± 0.03
Minimum χ^2_{red}	2.11	1.81



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- Objective 2: To test so-called "seismic scaling relations", which provide estimates for stellar masses, radii, and surface gravity using global seismic parameters

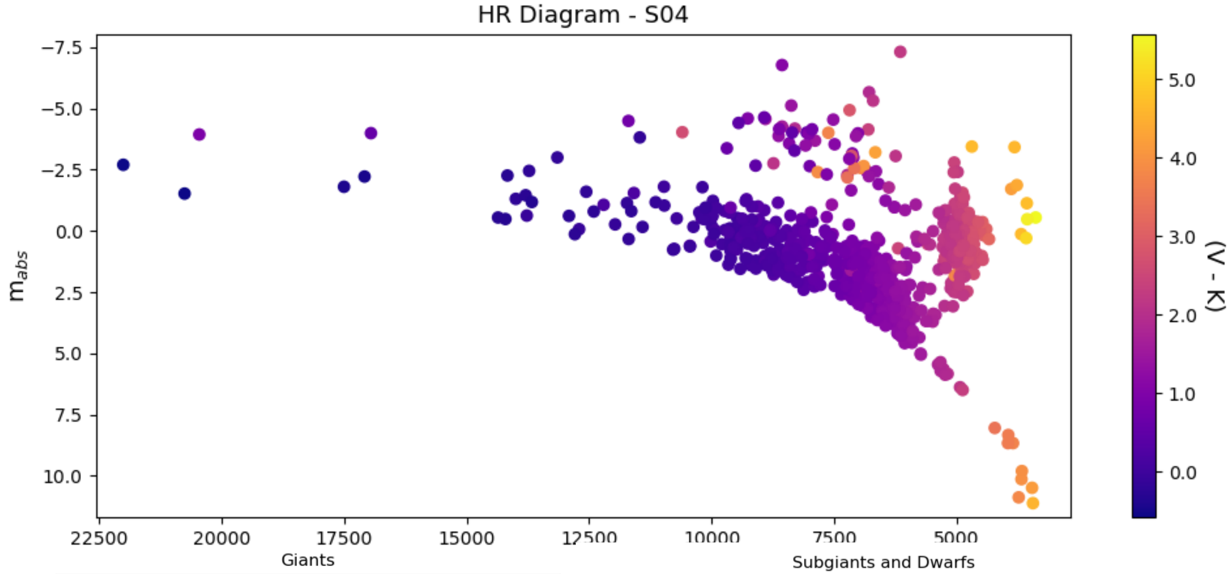
➔ Requires interferometric radii for stars with:

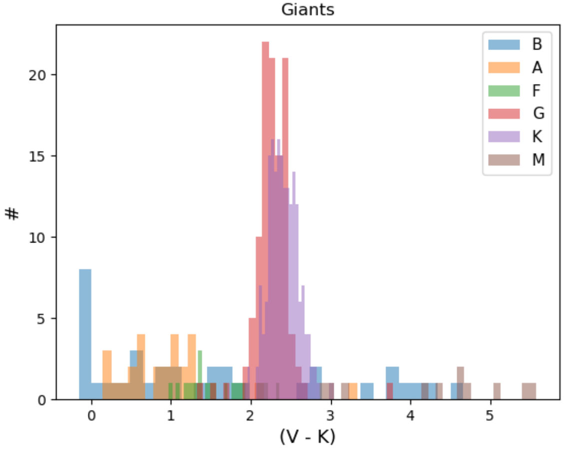
- different evolutionary stages (subgiant phase, red giant branch & core-He burning phase)
- different masses
- different metallicities

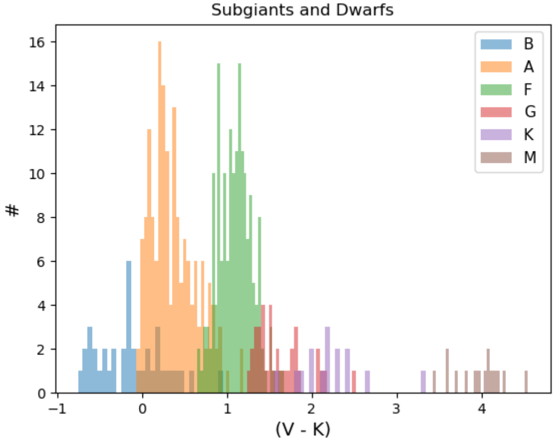
- Choice of targets: Subgiants & red giants from CoRoT, Kepler and TESS missions showing (i) good seismic data and (ii) large enough predicted angular diameter

S04: Calibration of Surface Brightness Color Relations over the HR diagram

R. Ibañez Bustos, N. Nardetto, D. Graczyk, T. Boyajian, A. Gallenne, P. Kervella, A. Domiciano, F. Martins, R. Ligi, T. Morel, A. Chiavassa, R. Szabos, M. Wittkowski, D. Mourard





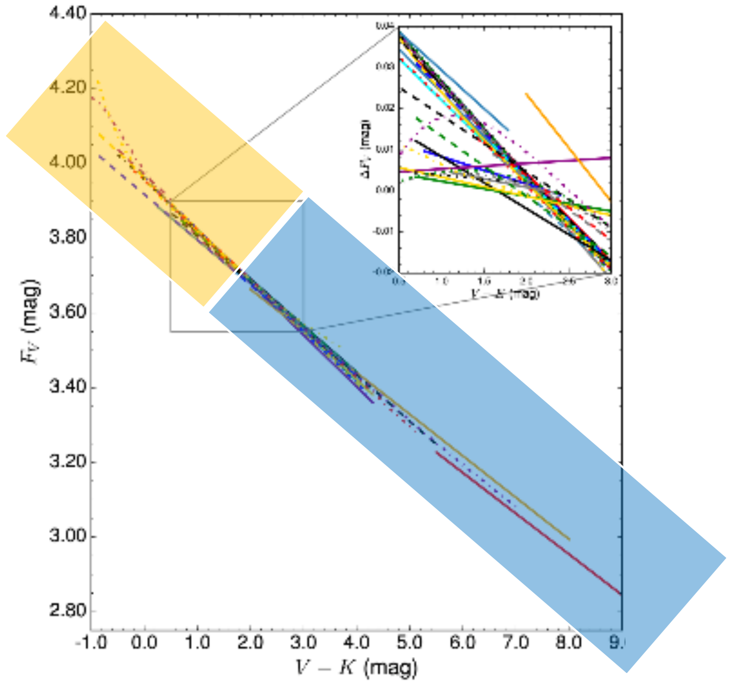


Most targets are unactive with good photometry:
eG <0.003 and eKs < 0.02

$$F_V = 4.2207 - 0.1\, m_{V0} - 0.5 \log \vartheta_{LD}$$

INTERFEROMETRY → θ

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



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SBCR calibration:

- For late-type stars based on JSDC and CHARA/VEGA: difference of SBCR between types and classes (Salsi+ 2019)
- For early-type stars based on CHARA/VEGA (Challouf+ 2014, Salsi+ 21).
- Theoretical study (Salsi+ 22).

Most targets are unactive with good photometry: eG <0.003 and eKs < 0.02

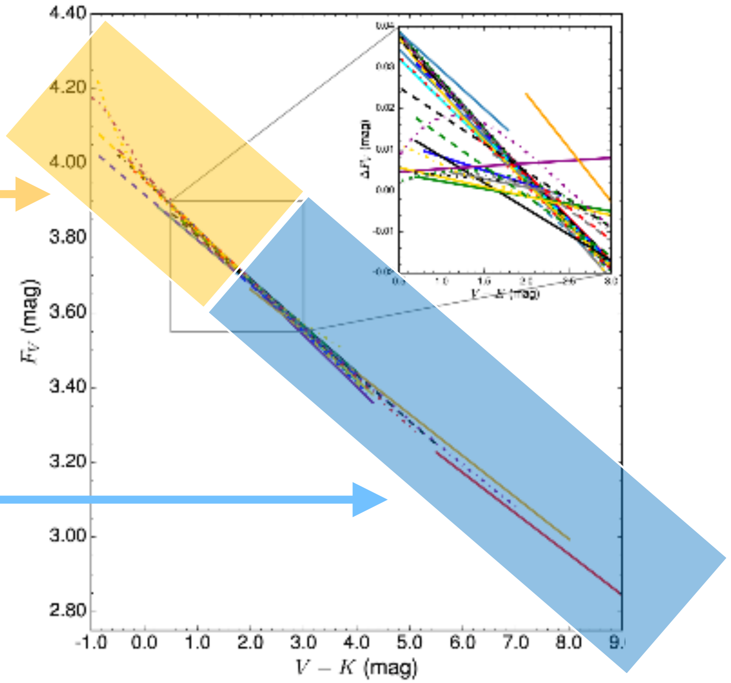
$$F_V = 4.2207 - 0.1\, m_{V0} - 0.5 \log \vartheta_{LD}$$

INTERFEROMETRY ➔ θ

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

SBCR of early type stars:
➔ distance determination of M31/M33 ARAUCARIA
Synergy with the Auraucaria project: H0 at 1% precision

SBCR of late-type stars:
➔ distance determination of SMC/LMC
➔ Faint PLATO targets
Synergy with PLATO space mission



S05: Limb-darkening over the HR diagram

D. Mourard, A. Claret, P. Kervella, N. Nardetto, A. Domiciano

- ~160 targets
- for more precision/accuracy on the derived angular diameters
- for studying the stellar atmosphere models ➔ see talk Nayeem Ebrahim

Dwarves

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

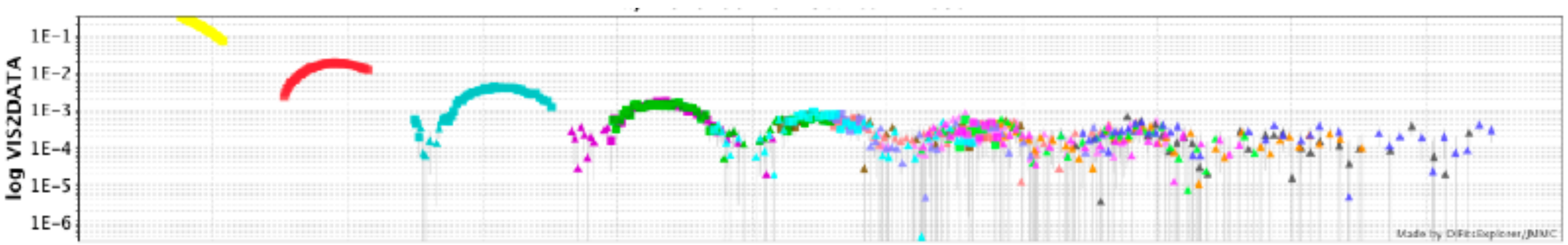
Giants

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	0,15	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

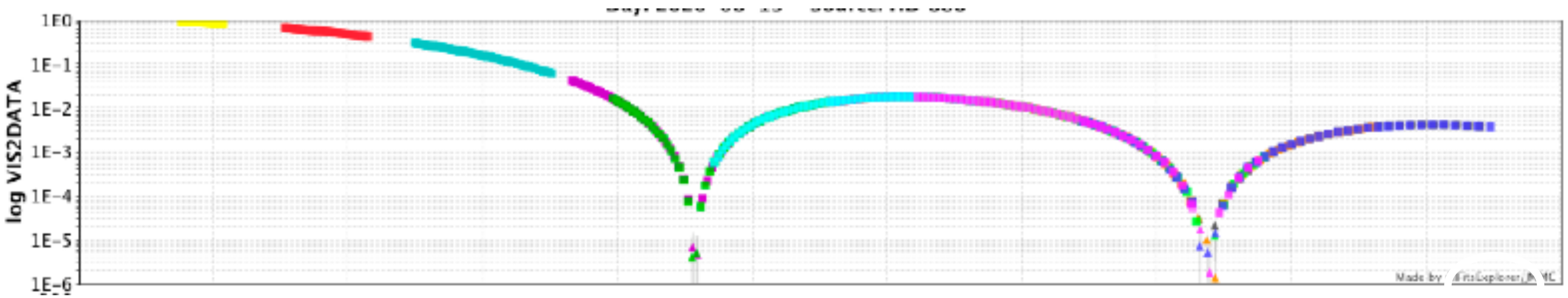
S05: Limb-darkening over the HR diagram

D. Mourard, A. Claret, P. Kervella, N. Nardetto, A. Domiciano

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



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



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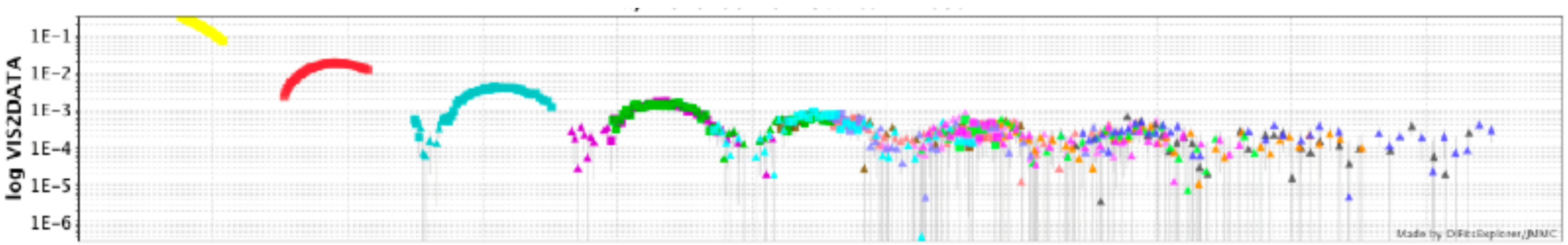

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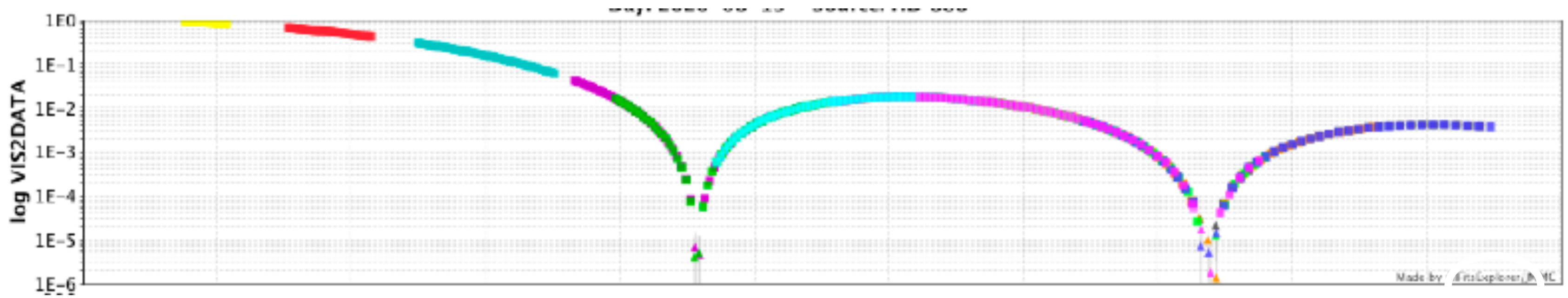

Needs: extraction of angular diameter through stellar atmosphere models, bolometric flux for Teff, parallax, stellar evolution modelling, variability indexes,…

S06: Binaries

J. Jonak, D. Mourard, O. Creevey, A. Gallenne, P. Kervella, G. Schaefer, N. Nardetto, P. Harmenec, A. Oplistilova

~50 detached binaries in the sample (mainly EB or SB) on different orbital phases:

- spectral type no later than G
- 0.15 mas < separation < 10 mas
- Monitoring over the HR diagram, including hierarchical binaries (ksi tau, Nemravova+16)

- Goal: Combine with spectroscopic and photometric data
  - ➔ obtain precise masses and distances
  - ➔ Constrain on evolution models

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

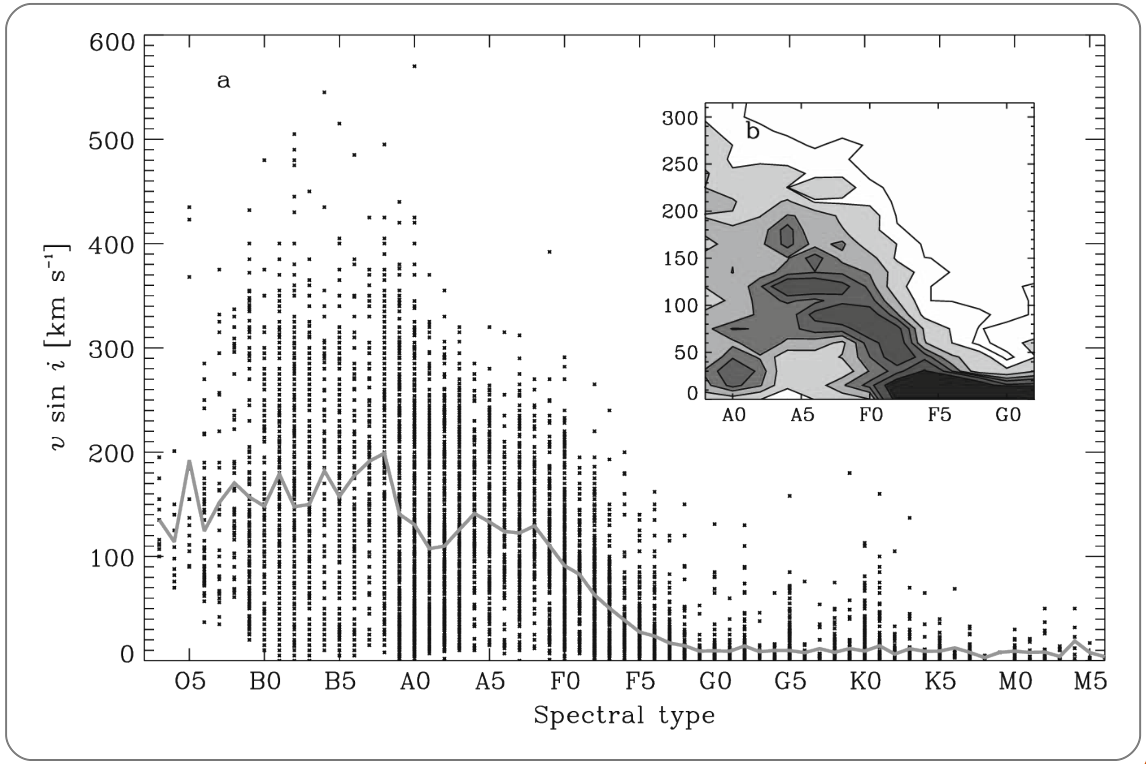
S07: Rotation

A. Domiciano de Souza, S. Albrecht, A. Claret, A. Gallenne, P. Kervella, A. Meilland, N. Nardetto, M. Rieutord, R. M. Roettenbacher, P. Stee, D. Mourard

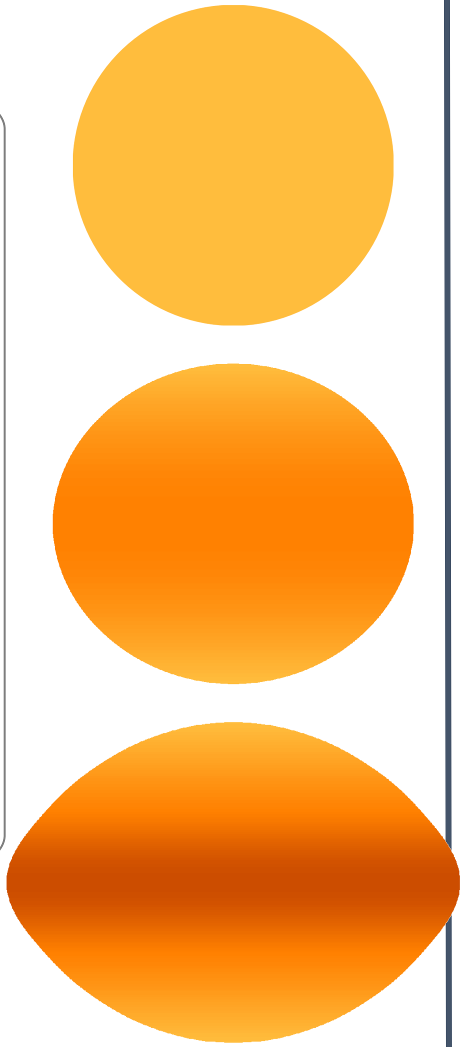
- Flattening → $R_{eq} > R_p$ (centrifugal force)

$$\epsilon \equiv 1 - \frac{R_p}{R_{eq}} = \frac{V_{eq}^2 R_p}{2GM} = \left(1 + \frac{2GM}{V_{eq}^2 R_{eq}}\right)^{-1}$$

- Gravity darkening (GD)
- Baroclinicity → differential rotation & meridional circulation



F. Royer 2009



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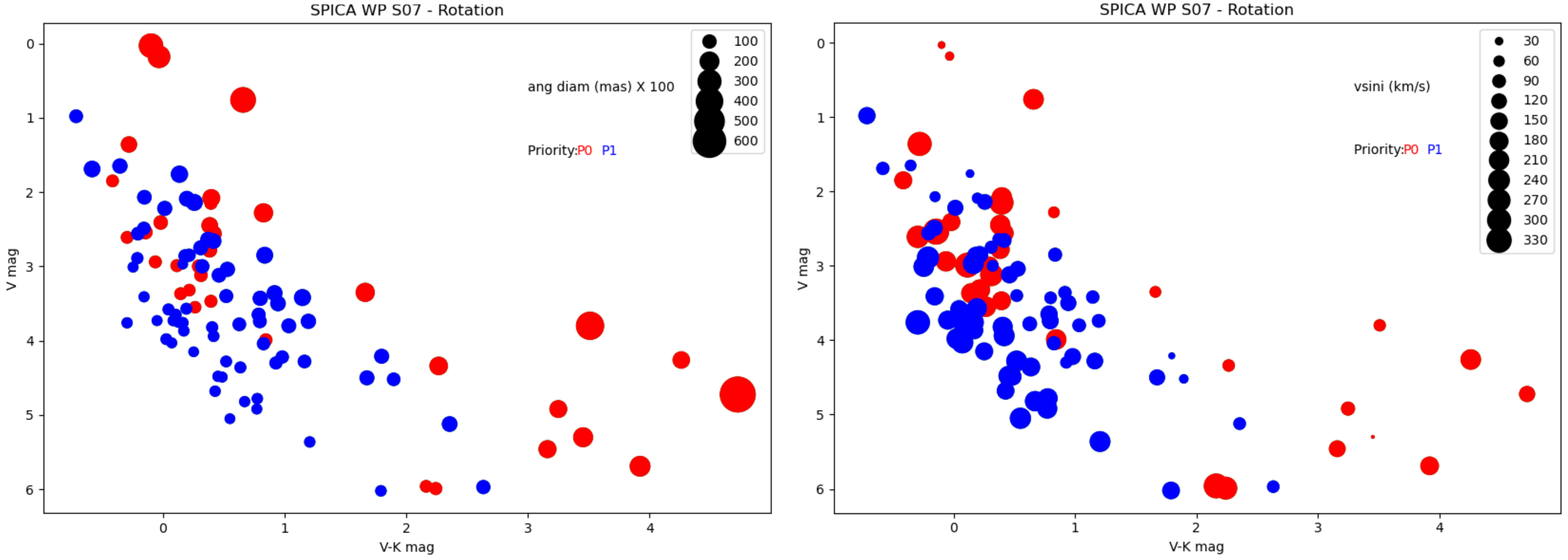
101 targets



S08: Winds & environments for hot and cool stars

M. Wittkowski, N. Nardetto, G. Rau, F. Martins, D. Mourard,
A. Chiavassa, C. Paladini, F. Millour, A. Meilland, V. Hocde

- **Direct support of ISSP**:
  - Better understand winds and circumstellar environment all over the HR diagram
  - How will the presence of winds & environments affect SPICA angular diameters, SBCR, and fund. stellar parameter estimates (R, Teff, M)?
- Winds of hot and cool stars have different underlying physical mechanisms, but diagnostics are similar:
  - High spectral resolution observations of Halpha (656.2 nm), probing winds of hot stars and cool stars
  - For cool stars, high spectral resolution observations of the CaII triplet (849.8, 854.2, 866.2 nm) probing the presence and extension of the chromosphere of cool giants & supergiants as a function of spectral type and luminosity
  - Low spectral resolution observations to constrain the visibility function and the fundamental stellar parameters

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A. Chiavassa, C. Paladini, F. Millour, A. Meilland, V. Hocde

- **Selection criteria**:
  - V<4-5 for high spectral resolution observations
  - 0.7 (hot stars) /2 (cool stars) < θ < 11
  - Declination >-30
  - Spectral types OBA/KM of lum. Class I/II/III
  - Spectral types FG not considered here. Cepheids and rotators covered by other programmes
  - 20 high-priority targets covering different spectral types & luminosities
- Complementary data with VLTI instruments (PIONIER, GRAVITY, MATISSE) well underway for some high-priority targets

Summary and Perspectives

- **ISSP**
  - Big sample (1000 stars), homogeneous reduction, homogeneous model for LD
  - SBCR: direct link to the Araucaria project
  - Exoplanets:
    - Complementarity with the PLATO mission
    - Complementarity with TESS, Kepler, CHEOPS, targets.
  - Complementarity with seismic data → very precise and accurate stellar parameters.
  - Take into account perturbations (winds, binary… S05 → S08)
- **Compementary data**
  - Need data from spectroscopy, photometry, models to fulfill the scientific goals.
  - On-going work: collection and obtention of spectra, database search (HARPS, CFHT, …), idea of an IR photometer in Calern, Armazones (through the Araucaria project), proposals to come…

THANK YOU FOR YOUR ATTENTON