l'Observatoire de Paris | LESIA
Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique
CNRS

STESCI workshop II

Context and purpose

M.J. Goupil and WP120 office

K.Belkacem, R-M. Ouazzan T. Morel

Milazzo May 22-26 *2018*

Stesci workshops

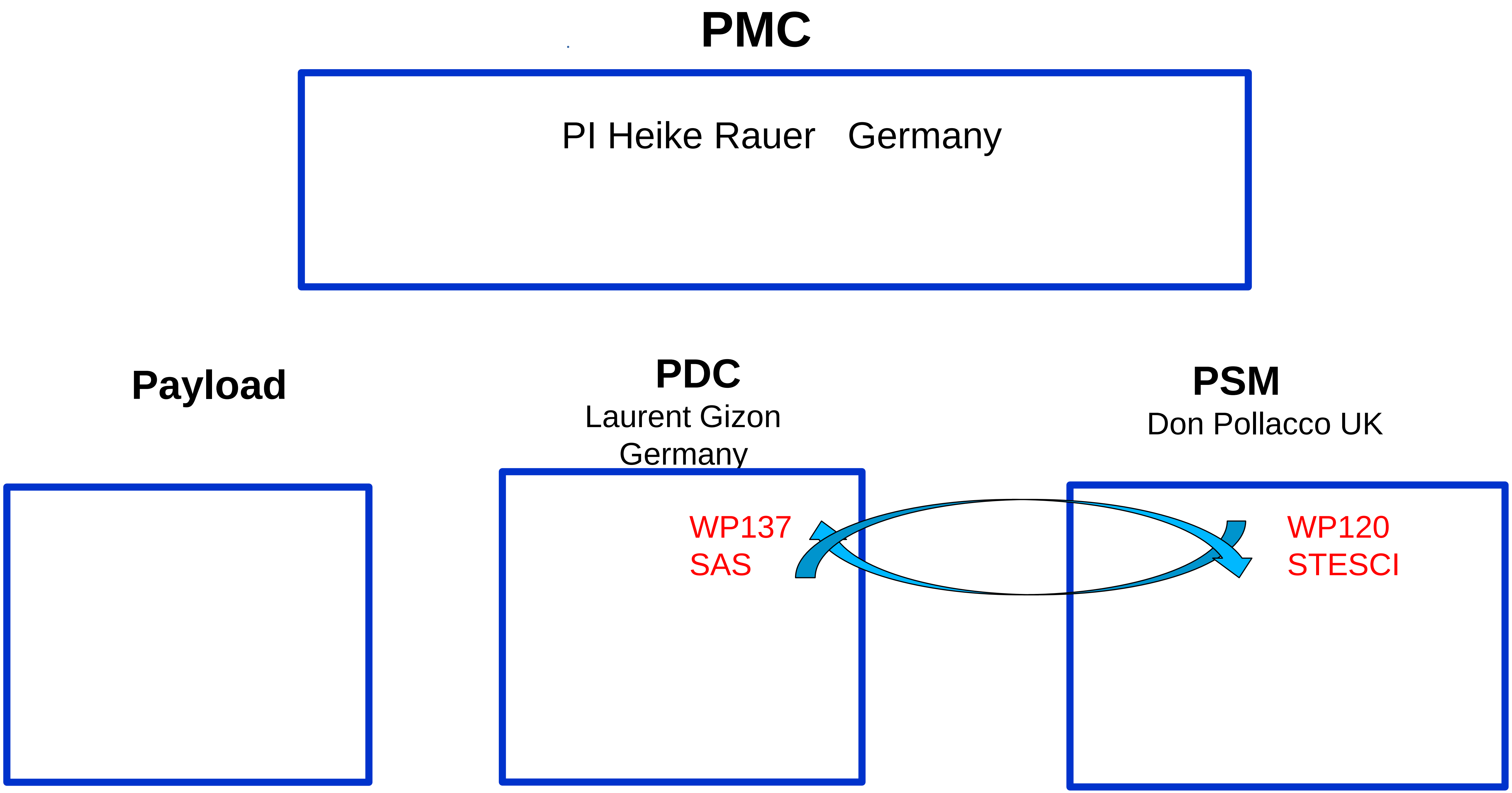
✓ Second of the series :

First one in Paris before selection (date ?

✓General purposes of these meetings :

- Provide information to those not newly arrivals or not 'en première ligne'
    - about the mission : where are we ?
    - about past actions and results from WP120
- Promote discussion for interface needs
- Discuss important and urgent scientific issues
- Define future actions

PLATO consortium structure



Implement
Produce data product

Specify
validate data product

Data Products

Data products : L1 -->L2 :

Validated imagettes, light curves and centroid curves	DP0	L0
Calibrated imagettes, light curves and centroid curves	DP1	L1
Planetary candidate transits and their parameters	DP2	L2
Asteroseismic mode parameters	DP3	L2
Stellar rotation and activity	DP4	L2
Stellar radii, masses, and ages	DP5	L2
Living catalogue of confirmed planetary systems and their characteristics using light curves and transit time variations	DP6	L2
Follow-up ground-based observations		Lg
Living catalogue of confirmed planetary systems and their characteristics using new ground-based follow-up observations (Lg)	DP6+Lg	L3

Stellar science and asteroseismology → must provide data products DP3 to DP5

PLATO requirements for DP5

***PLATO* - main requirements for the stellar core program for DP5 and P1**:

for a G0V star with *V* ≤ 10 *(Reference star :* 1$M_\odot$, 1$R_\odot$, 6000 *K)*

- $\Delta R_{star}/R_{star} \leq 2\%$
- $\Delta M_{star}/M_{star} \leq 15\%$
- ΔAge/Age ≤ 10 %

It translates into ~0.1–0.2 μHz uncertainties around ν_{max}

✓ Precision : already reachable today
(Reese et al. 2015, Silva Aguirre et al. 2015 , …, ; WP120 HH1-HH4)
Still some issues about the way precisions are etimated, about selection criteria

✓ What about accuracy ? How to estimate it ?
✓ What about computing time for a large star ensemble ?

Purpose of the WP120

- Specifications of procedures, methods, algorithms, pipelines in order to provide DP3 to DP5 according to the PLATO requirements

- Provide appropriate tools (grids of stellar models, theoretical oscilation frequencies, tables of spectroscopic parameters, ...)

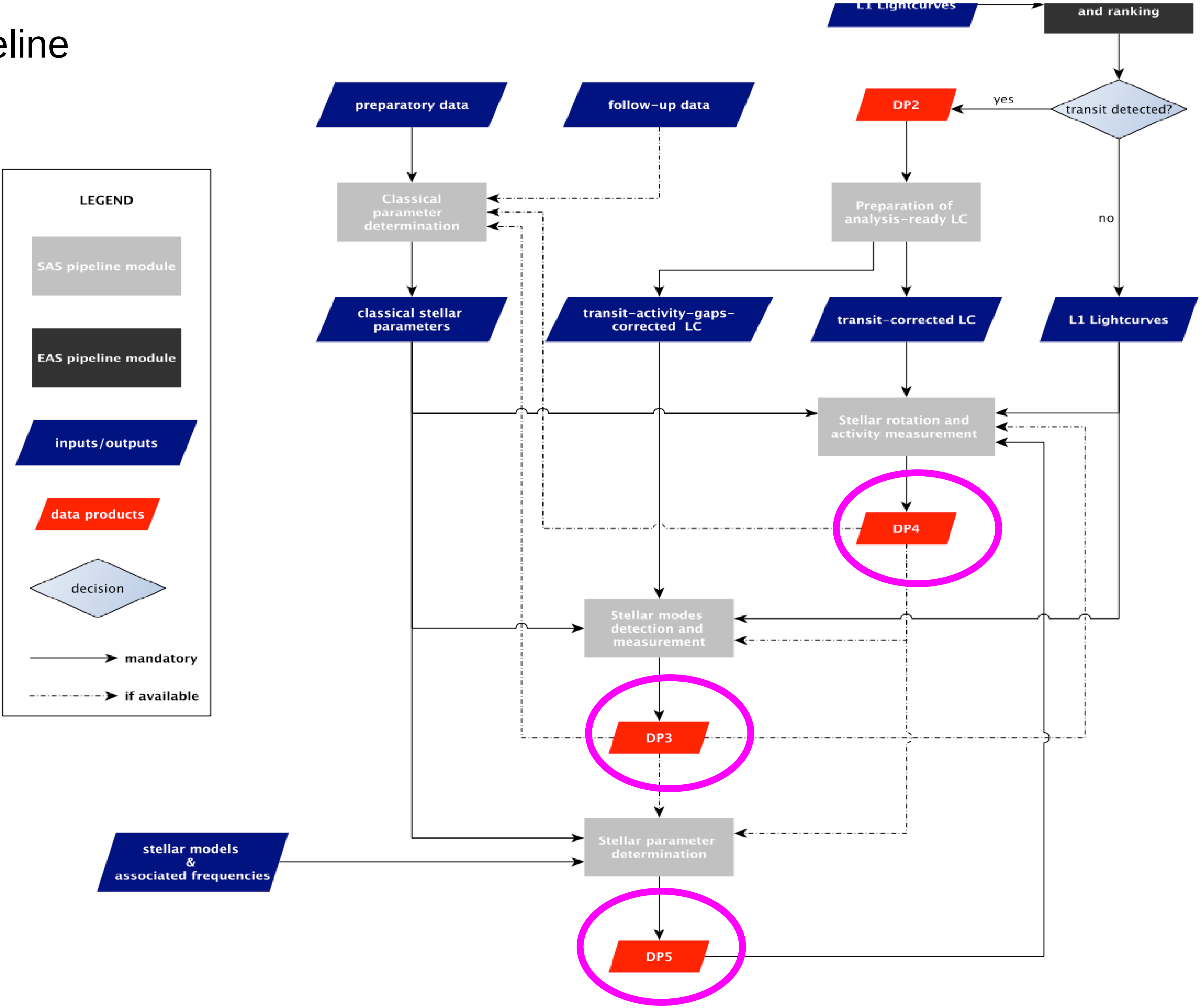
- Updating and validation of the data output during operation and postoperation

Purpose of the WP120 before 2020

- To define the architecture of the **pipelines**
- To describe the methods and tools
- To define the **input, output, intermediate products, interfaces**
- To define the validation tests and benchmarks
- To build validated mock pipelines in order to feed the documents to be transferred to the PDC

Stellar Pipelines

Top level pipeline
to be updated

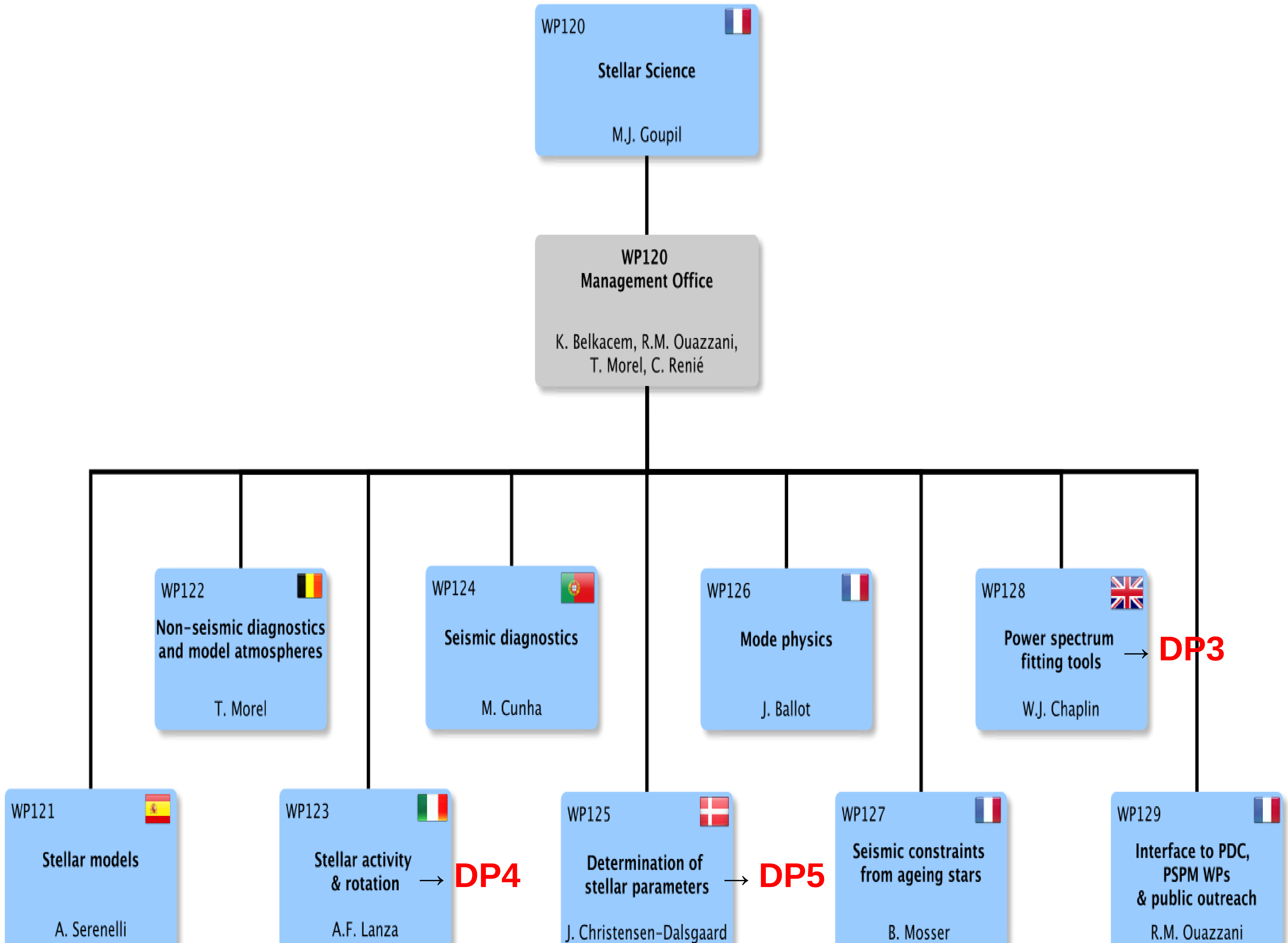


Pipelines

Pipeline branch → DP3 Pipeline branch → DP4 Pipeline branch → DP5

✓ Description of the DP3-DP5 pipeline branches currently being built independently
→ URDs+URJDs : high level pipeline description: stage 1 (done)- stage 2 (in prep)

WP120 : structure and organisation



Pipelines

Pipeline branch → DP3 Pipeline branch → DP4 Pipeline branch → DP5

✓ Description of the DP3-DP5 pipeline branches currently being built independently
→ URDs+URJDs : high level pipeline description: stage 1 (done)- stage 2 (in prep)

✓ but connections exist between the pipeline branches: they appear through the description of
Input/output/interfaces

Input , output and intermediate data

INPUT

1) PLATO light curves

2) Catalogs and follow-up, spectroscopy, interferometry
   * V1 : before launch
   * V2-V3 : during operation and after

Intermediate data products

OUTPUT

DP3 : oscillation mode parameters + seismic mean internal rotation + inclination angle
DP4 : stellar activity and surface rotation measurements
DP5 : mass, radius and age of the (core program) F5-K7 stars + M dwarfs

Input , output and intermediate data

INPUT

1) PLATO light curves

2) Catalogs and follow-up, spectroscopy, interferometry
* V1 : before launch
* V2-V3 : during operation and after (follow up)

- Classical parameters : Teff, log g , log L surface chemical abundances
- Scaling laws
- Stellar models and frequency calculations → grids of stellar models + on the fly for specific cases
- Surface boundary conditions for stellar models (T (tau) laws) and oscillation frequencies
- 3D Model outer layers + convective flux/entropy tables + surface effects
- Stellar activity model → scaling laws for 1D stellar models
- Spot modelling, gyrochronology
- Simulated light curves – Tests cases/benchmarks
  (Plato noise (V, B-V,Ntel) + spots+low freq. Activity + granulation + oscillation)
- Limb darkening
- Inclination of stellar rotation axis, measurement of spin-orbit angle

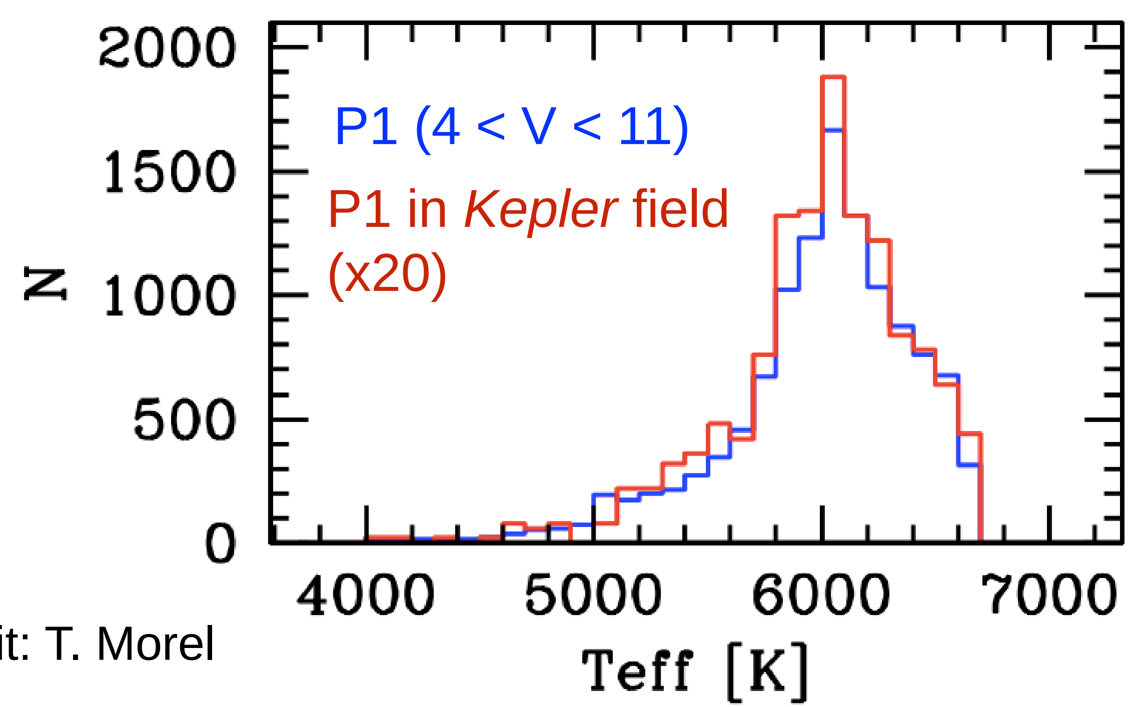
OUTPUT

DP3 : oscillation mode parameters + seismic mean internal rotation + inclination angle
DP4 : stellar activity and surface rotation measurements
DP5 : mass, radius and age of the (core program) F5-K7 stars + M dwarfs

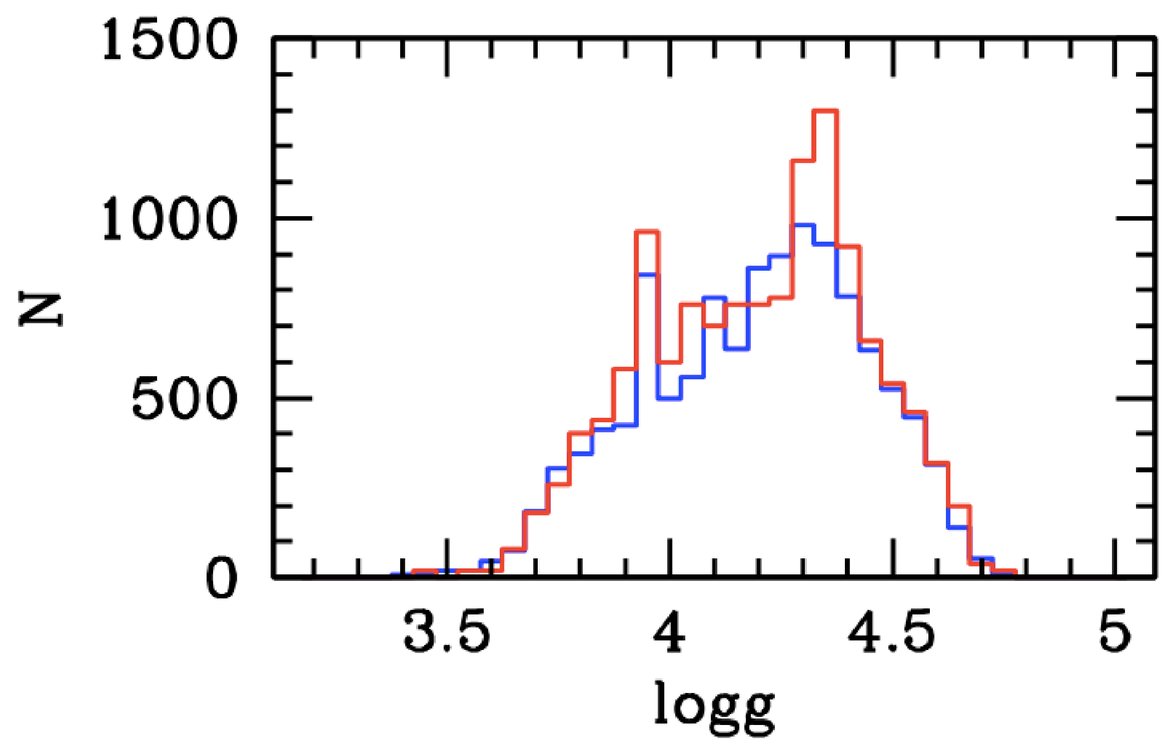
Which stars are we talking about ?

Simulation of the northern field

✓Stellar population computed with the Besançon Model (A. Robin 2017) adapted for a PLATO 2yr long run

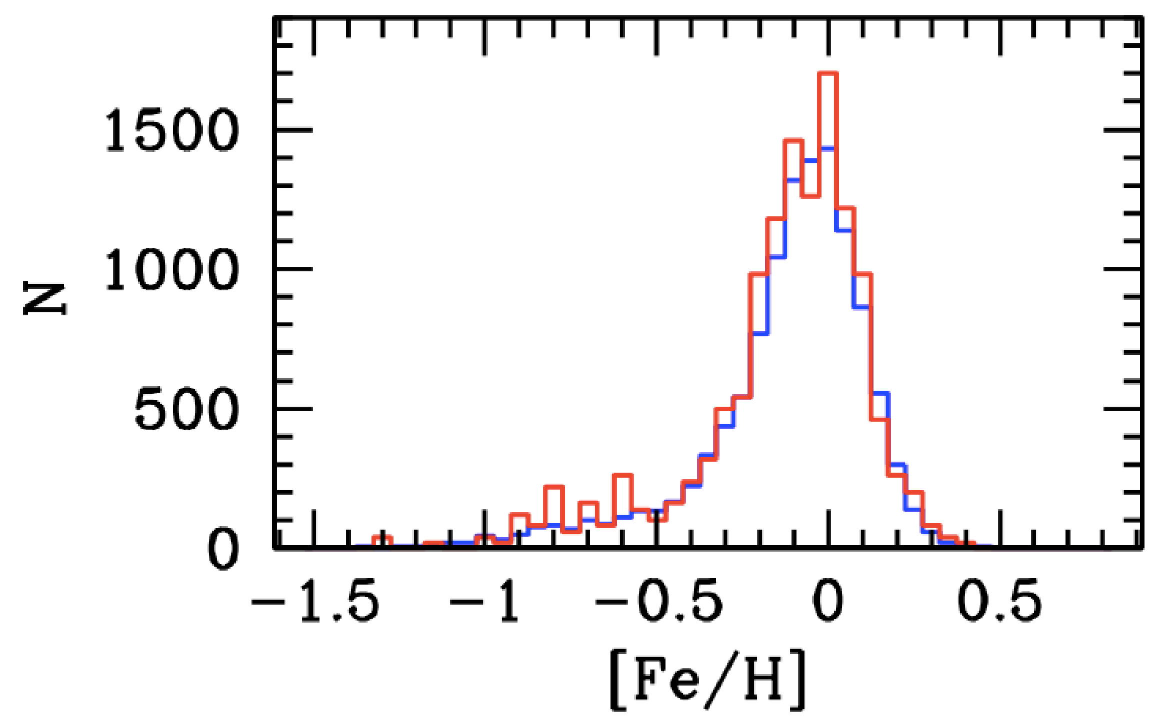


credit: T. Morel



Star distributions from the simulated catalogue: P1 & P2 samples only

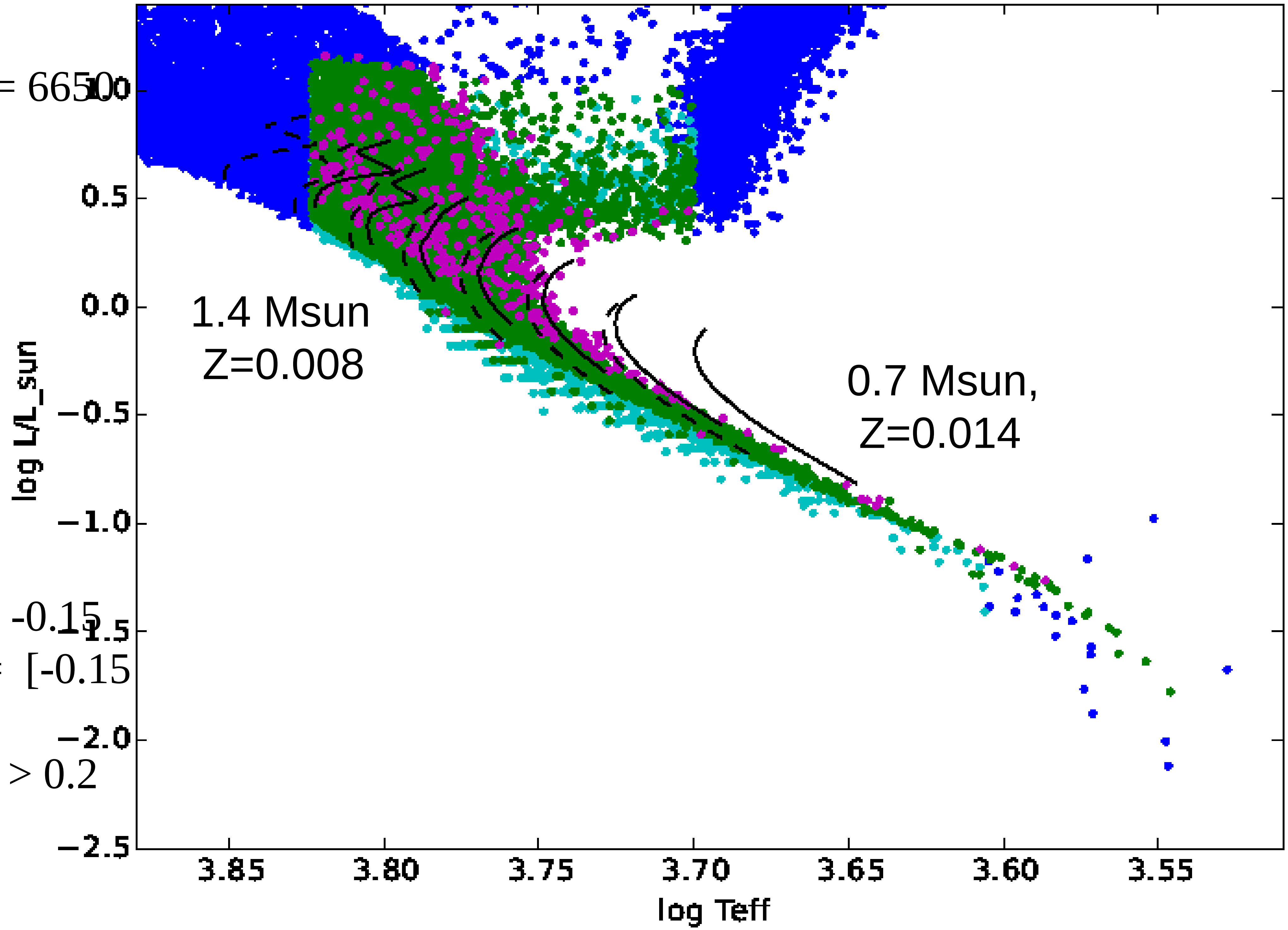
the properties of the Kepler field stars are similar to the properties of the PLATO P1 sample stars



Which stars are we talking about ?
Simulation of the northern field

P1 sample : mass and metallicity ranges

4030 <= Teff <= 6650



cyan [Fe/H] < -0.15
green [Fe/H] = [-0.15 , 0.2]
magenta [Fe/H] > 0.2

Internal WP120 Requirements

✓Current performances/what is requested

- Distinction between what is currectly achieved and what could be expected in > = 2020
- Distinction bewteen precision and accuracy
- Requirements on intermediaite products to be determined

✓ Selection criteria for defining the DP3-DP5 output. Exemple:

which radius with with which uncertainties (pdf)?
which age with which uncertainties (pdf)??

✓ Validation tests and benchmarks

To be discussed at the present workshop

➢**On the science side**

- which issues are important/urgent to settle, priorities ?

- list of foreseen necessary technical notes

➢**On the management side :**

- current and future actions related to the above issues

- Meetings :

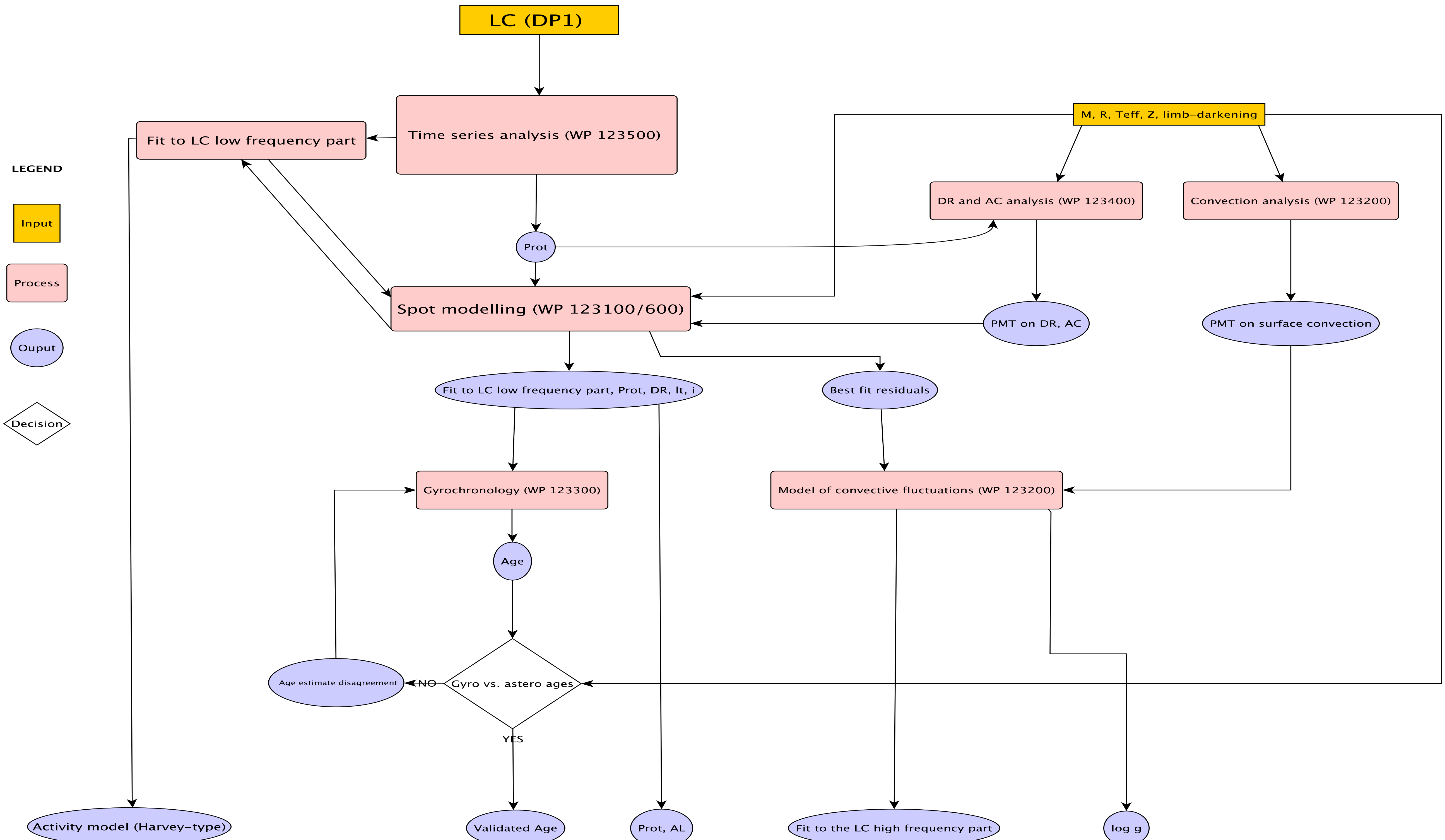
  - WP12X regular meetings (Ex. WP122 Liège April 2018)   or on specific topics
    exemples   : Limb darkening 1 day- meeting   → technical note
    Stellar actrivity 2 day-meeting   → technical note

  - STESCI workshop III : when, where ?

END

Stellar Rotation and Activity → DP4

WP 123 - N. Lanza (Italy)

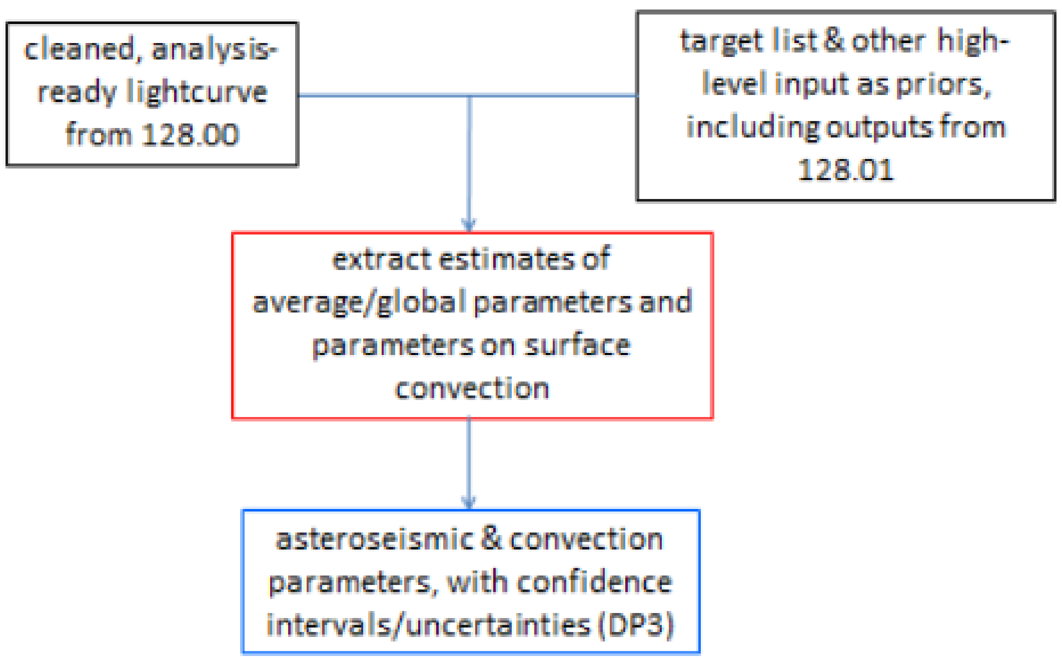


PMT: parameterization
Prot: mean rotation period;
DR: surface differential rotation; AC: activity cycle(s);
It: spot areas and coordinates;
i: inclination of the star spin axis to the line of sight;

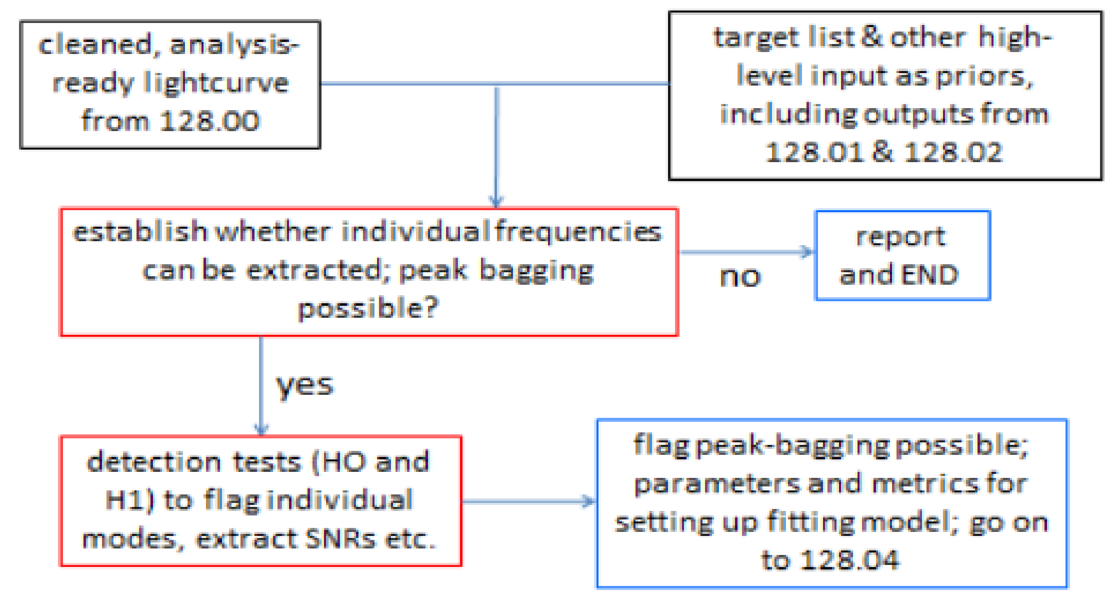
Oscillation mode analysis → DP3

WP128: W. Chaplin (UK)

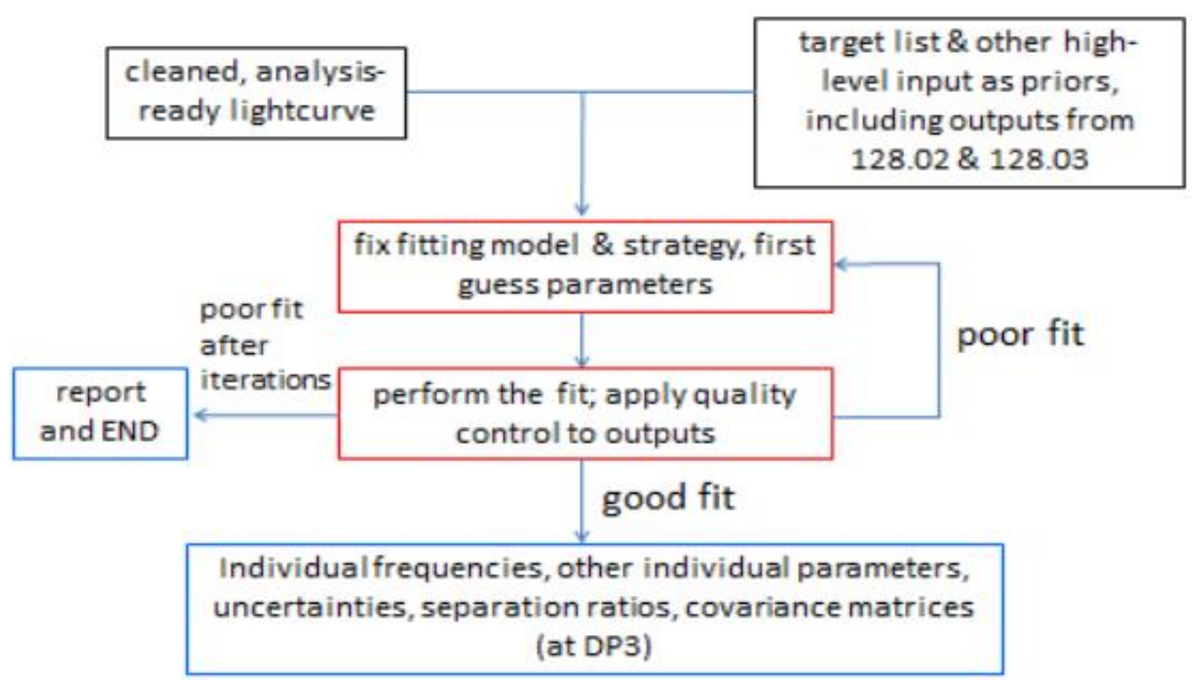
WP128.02: Extraction of average/global asteroseismic parameters



WP128.03: Preparation for peak-bagging

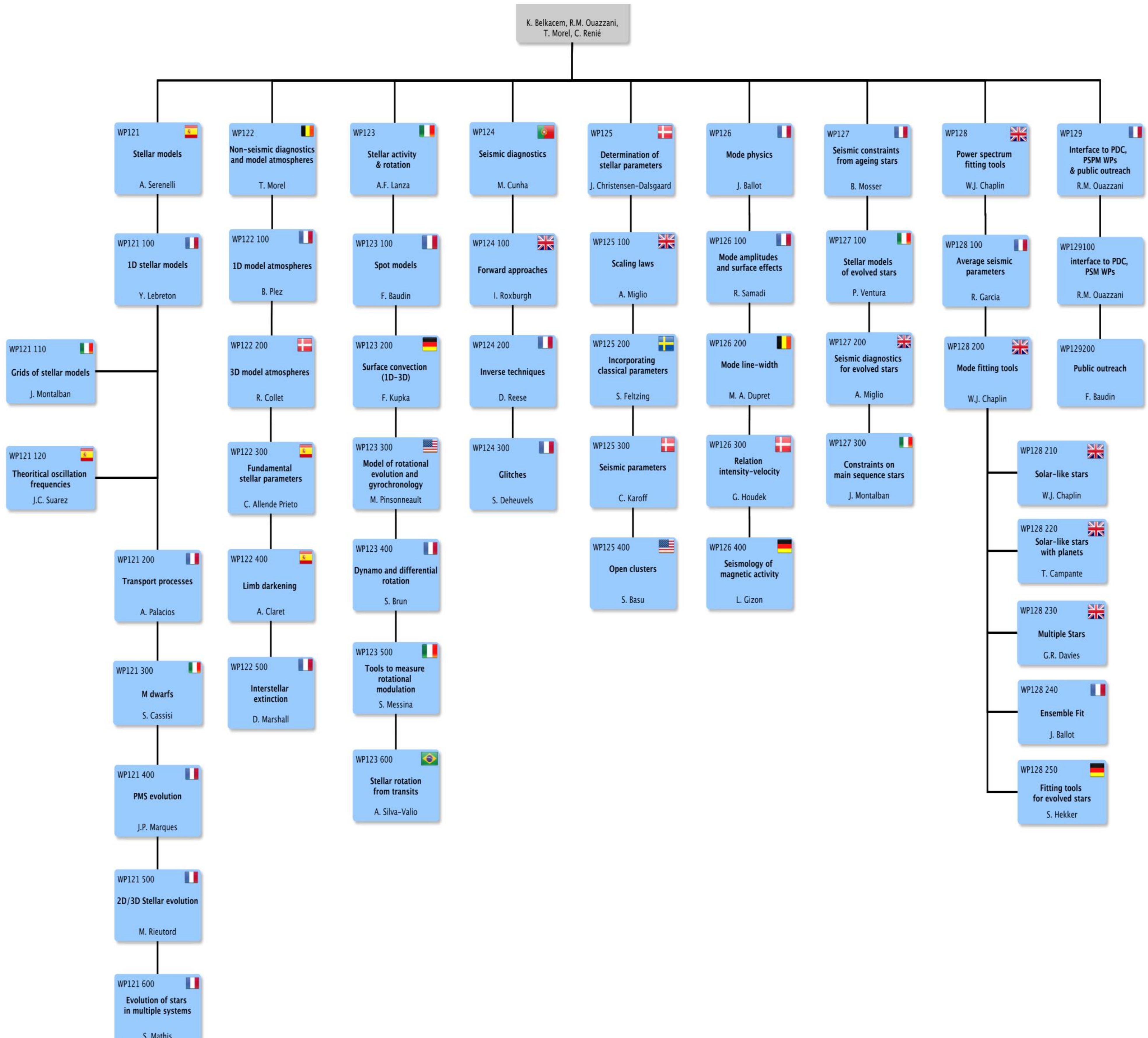


WP128.04: Peak-bagging



23 countries
200 registered participants
… active participants

Complicated architecture :
Need interfaces



Which stars are we talking about ?

The PLATO samples

Samples of target stars with the current baseline observing strategy :

- P1 ≥ 15 000 (goal 20 000) dwarfs and subgiants, spectral type F5-K7, 8 ≤ *mag* ≤ 11, noise ≤ 34 ppm.√h, time sampling 25s
- P2 ≥ 1 000 dwarfs and subgiants, spectral type F5-K7, *V* ≤ 8.2, noise ≤ 34 ppm.√h, (300 stars with 2 colours)
- P4 ≥ 5 000 M dwarfs *V* ≤ 16, time sampling 25s.
- P5 ≥ 245 000 dwarfs and subgiants, spectral type F5-K7, *V* ≤ 13, time sampling 600s and 25s for 9000 stars.

✓ Samples of stars will be observed with different numbers of telescopes corresponding to different noise levels

Which stars are we talking about ?
The PLATO samples

✓ For all samples, we are asked to provide DP3 to DP5

✓ Requirements on the precision/accuracy for DP3 to DP5 only on P1-P2 samples

- P1 ≥ 15 000 (goal 20 000) dwarfs and subgiants, spectral type F5-K7, 8 ≤ *mag* ≤ 11, noise ≤ 34 ppm.√h, time sampling 25s

- P2 ≥ 1 000 dwarfs and subgiants, spectral type F5-K7, *V* ≤ 8.2, noise ≤ 34 ppm.√h, (300 stars with 2 colours)

✓ For the other two samples, we wiil do what we can

- P4 ≥ 5 000 M dwarfs *V* ≤ 16, time sampling 25s.

- P5 ≥ 245 000 dwarfs and subgiants, spectral type F5-K7, *V* ≤ 13, time sampling 600s and 25s for 9000 stars.

Which stars are we talking about ?

PIC

Which stars are we talking about ?

The ***Input Catalog*** is being built using existing star catalogues.

A field of reference (TBC) was defined.

For that field, the star count yields :

- about 13 000 dwarfs and subgiants, spectral type F5-K7, 8 ≤ *mag* ≤ 11, noise ≤ 34 ppm.√h, time sampling 25s
- about 29 000 dwarfs and subgiants with V ≤ 11, 34 ppm/h < NSR ≤ 80 ppm/h
- about 80 000 stars dwarfs and subgiants with V < 13, NS R < 80 ppm/h.

The Gaia release DR2 will be used to update/optimise the content of the PIC.

Which stars are we talking about ?

Simulation of the northern field

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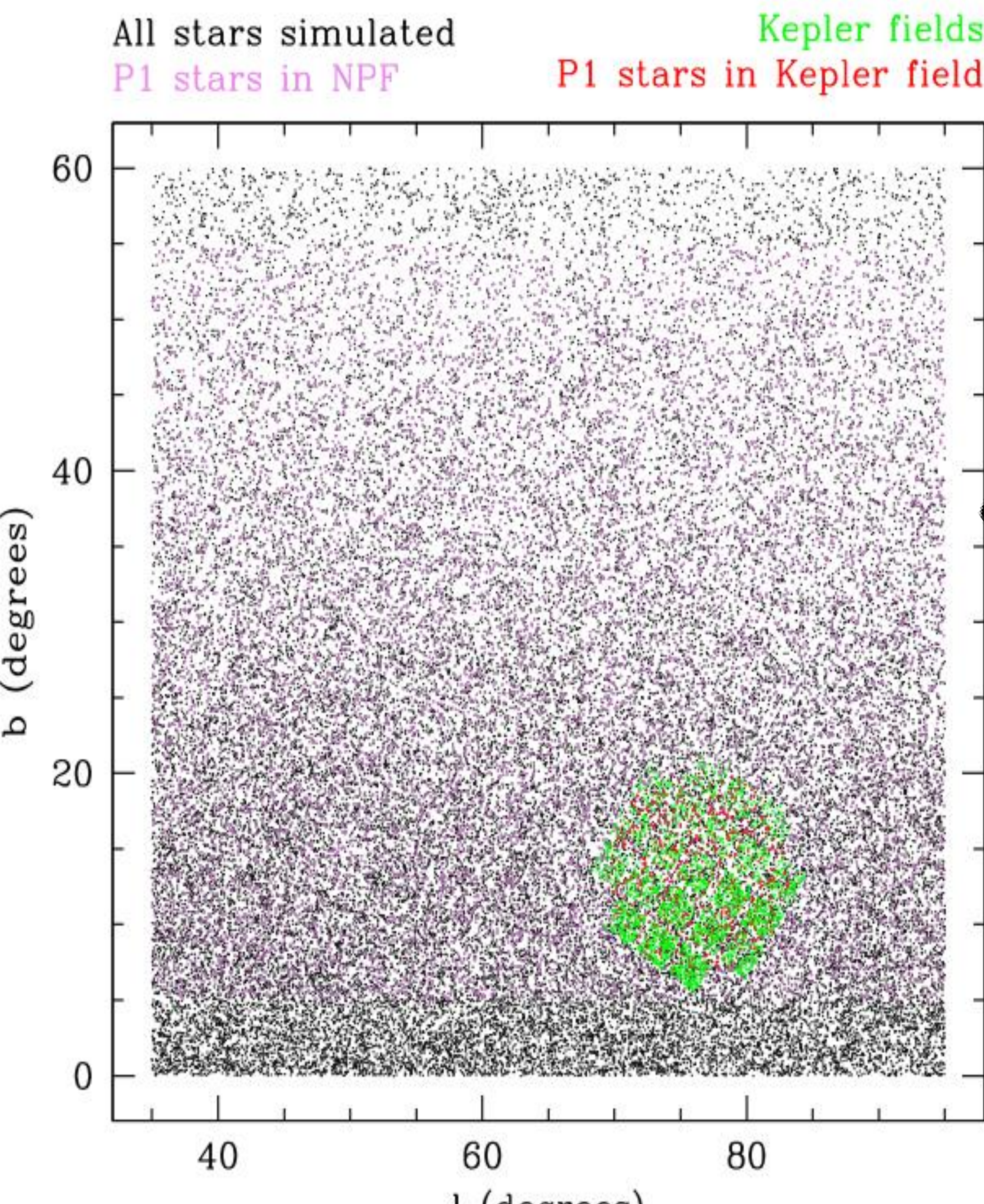
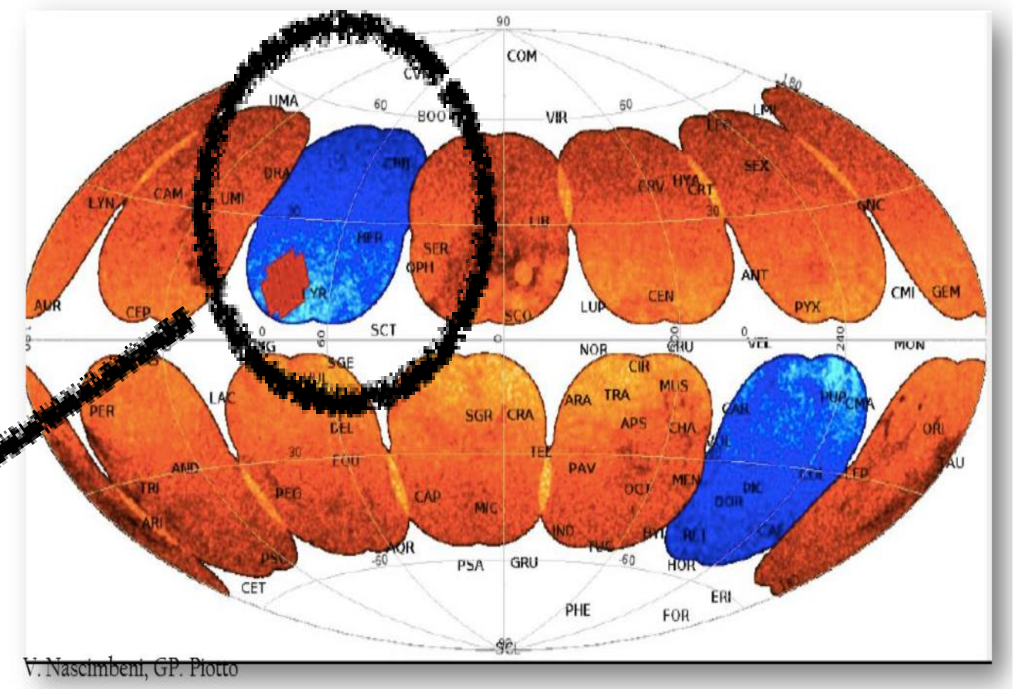




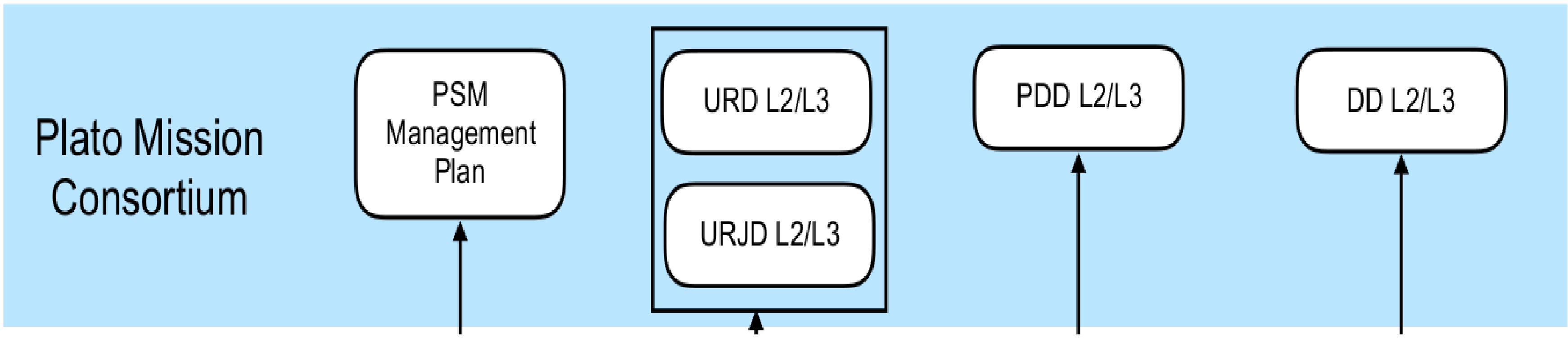
All stars simulated

P1 stars

Kepler field

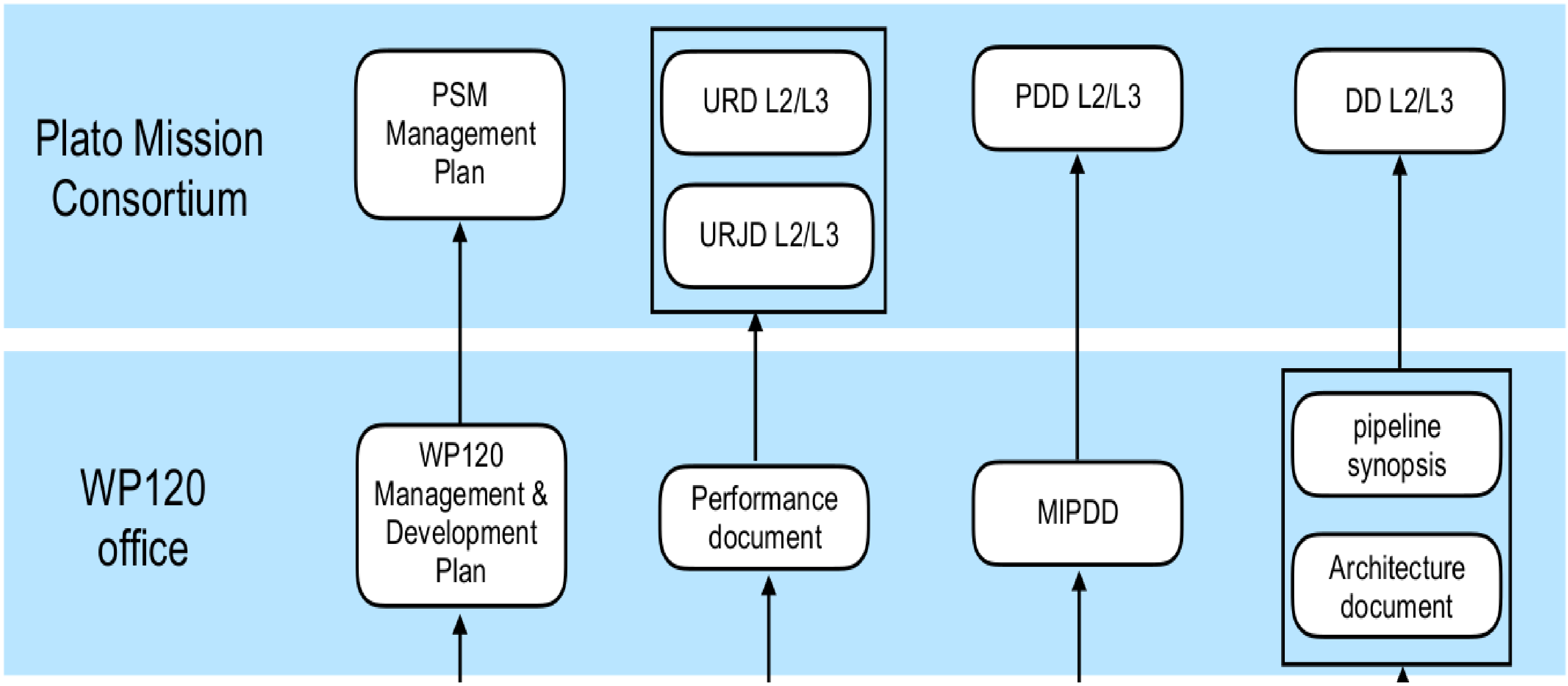
P1 stars in *Kepler* field

Documentation 2017-2020



Acronyms:
- DD: Design document
- URD: User Requirements Document
- URJD: User Requirements Justification Document
- PDD: Product Definition Document
- MIPDD: Mandatory Intermediate Product Definition Document
- ATBD: Algorithm Template Baseline Description
- IP: Intermediate Product

Documentation 2017-2020



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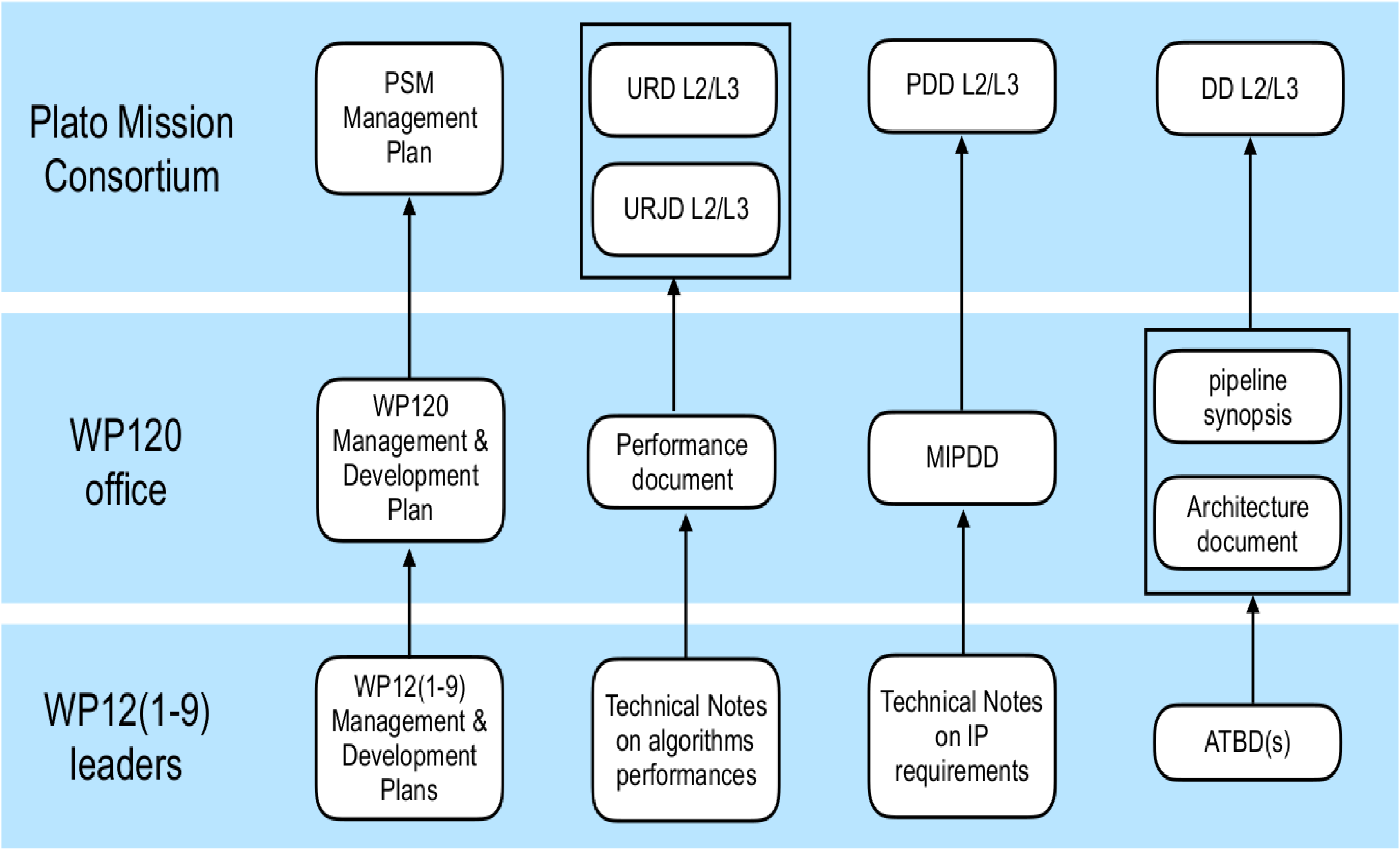

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Documentation 2017-2020

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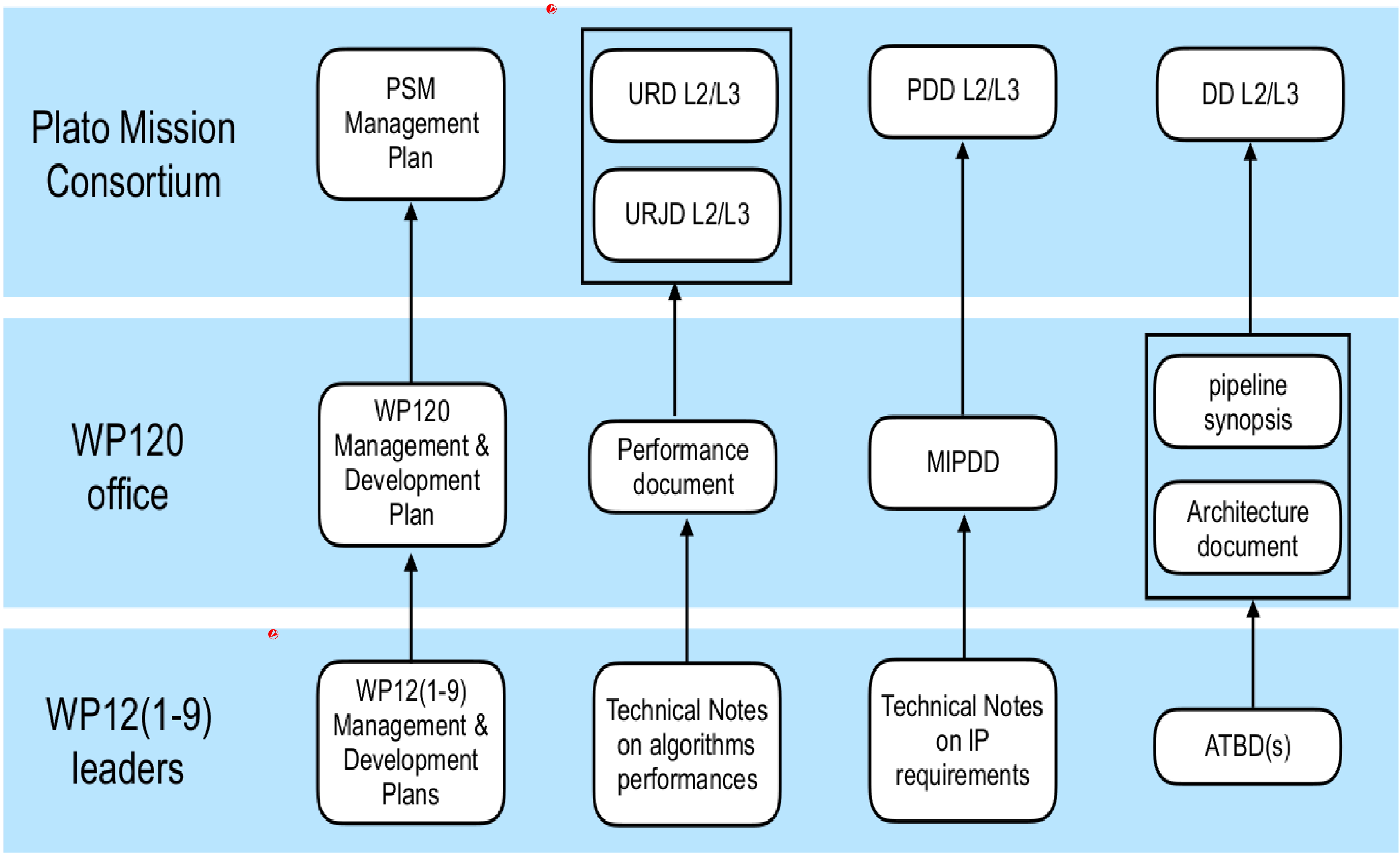

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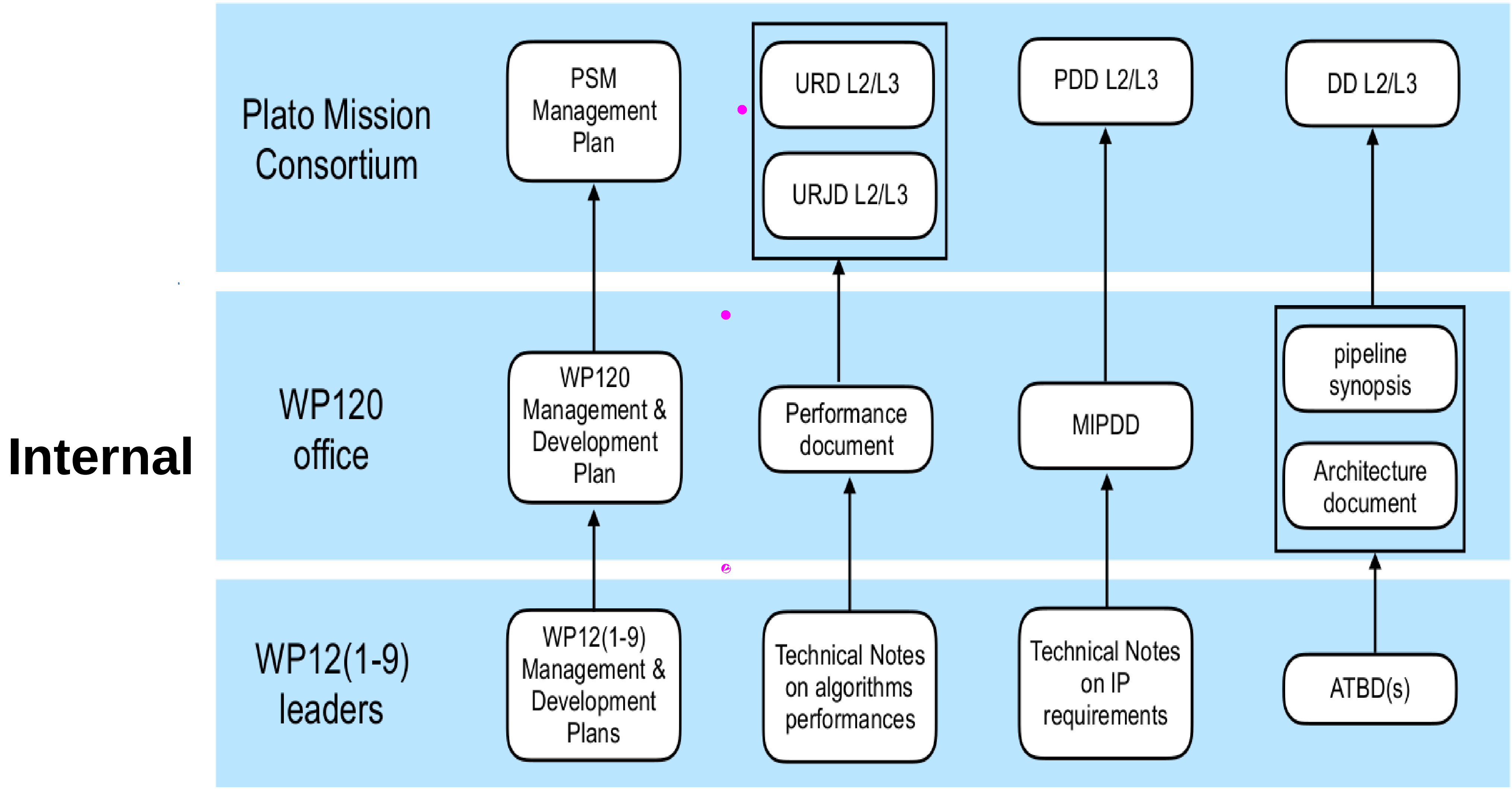
done

Documentation 2017-2020



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Next to be done

Agenda
up to the first internal review (Q3/2019)

July 2018: First draft of Technical Notes on IP (Internal products) requirements

Requirements on

- Non-seismic parameters (Gaia radius, bolometric luminosity, Teff, spectroscopic logg, vsini, [Fe/H] and [X/Fe])
- Grids of 1D atmosphere models
- Grids of 3D atmosphere models
- Grids of limb- and gravity-darkening coefficients

→ Exact and complete definition of the above-mentioned internal products
→ What are the needs to comply with the expectations in terms of precision, accuray?
(e.g. expected precision on non-seismic parameters versus magnitude, spectral type, etc…)
→ What is/are the expected pipeline(s), performances?
(e.g. how 1D and 3D atmosphere models will be used, in which cases, etc…)

Credit. K. Belkacem

Agenda
up to the first internal review (Q3/2019)

Janv. 2019: First drafts of Technical Notes on algorithms performances

→ For each each internal products, the notes provides the results of the tests and validation procedures

→ These documents must justify selected algorithms and the expected performances (they justify the requirements)

Janv. 2019: Update of Technical Notes on IP requirements

July 2019: First set of ATBDs, algorithms, and IP + Delivery of the first set of algorithm prototypes

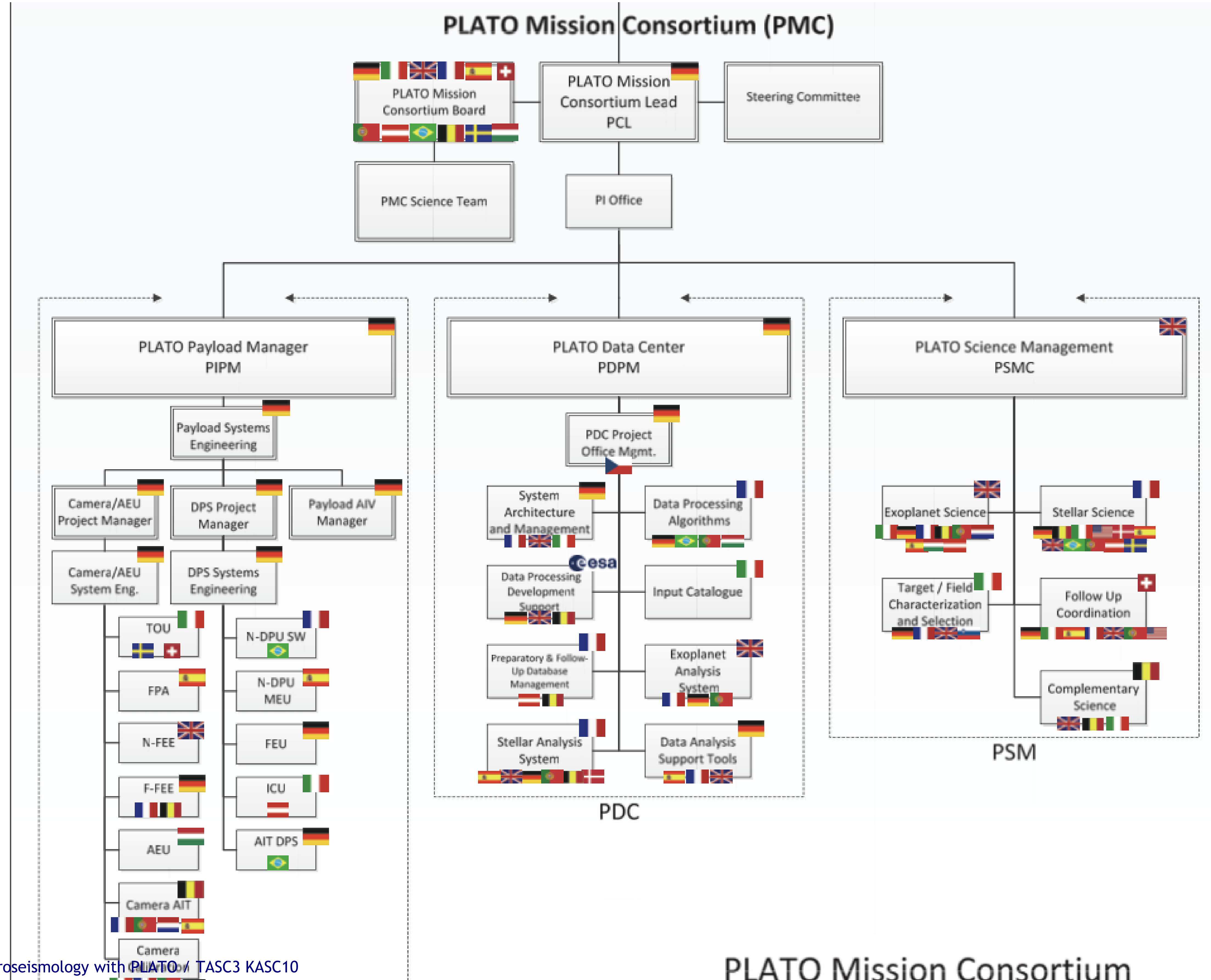
ATBD = *Algorithm Template Baseline Descriptions*

→ We must use these prototypes to consolidate and justify the global requirements on the WP120 pipeline for the first internal review (L2 & L3 UDRs internal review Q3 2019)

→ This will be completed and updated for the second internal review (Q4 2020)

Credit. K. Belkacem

PLATO Mission Consortium



WP122 technical notes

For benchmarks doc

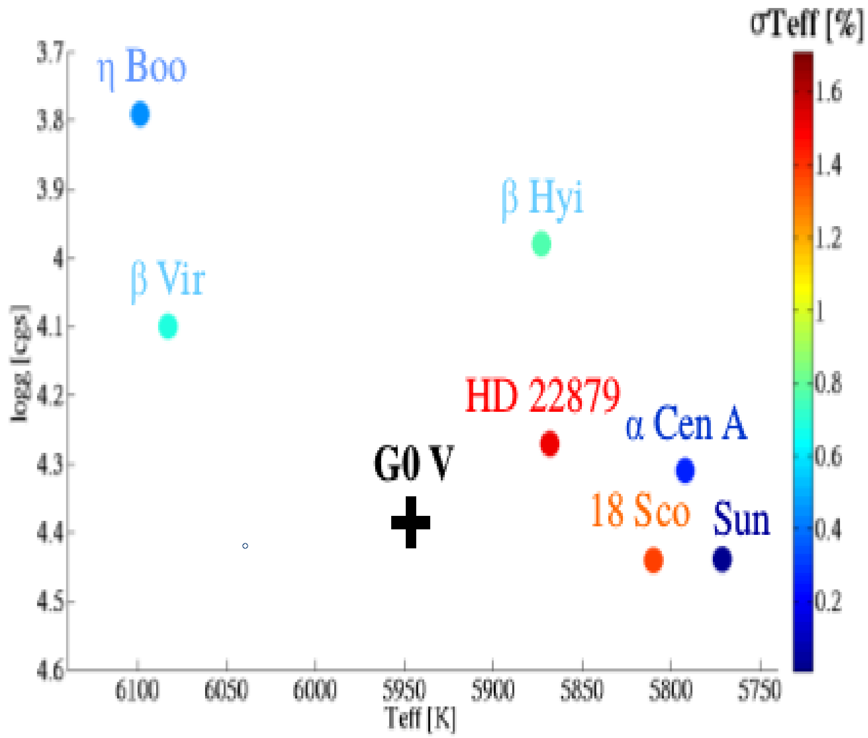
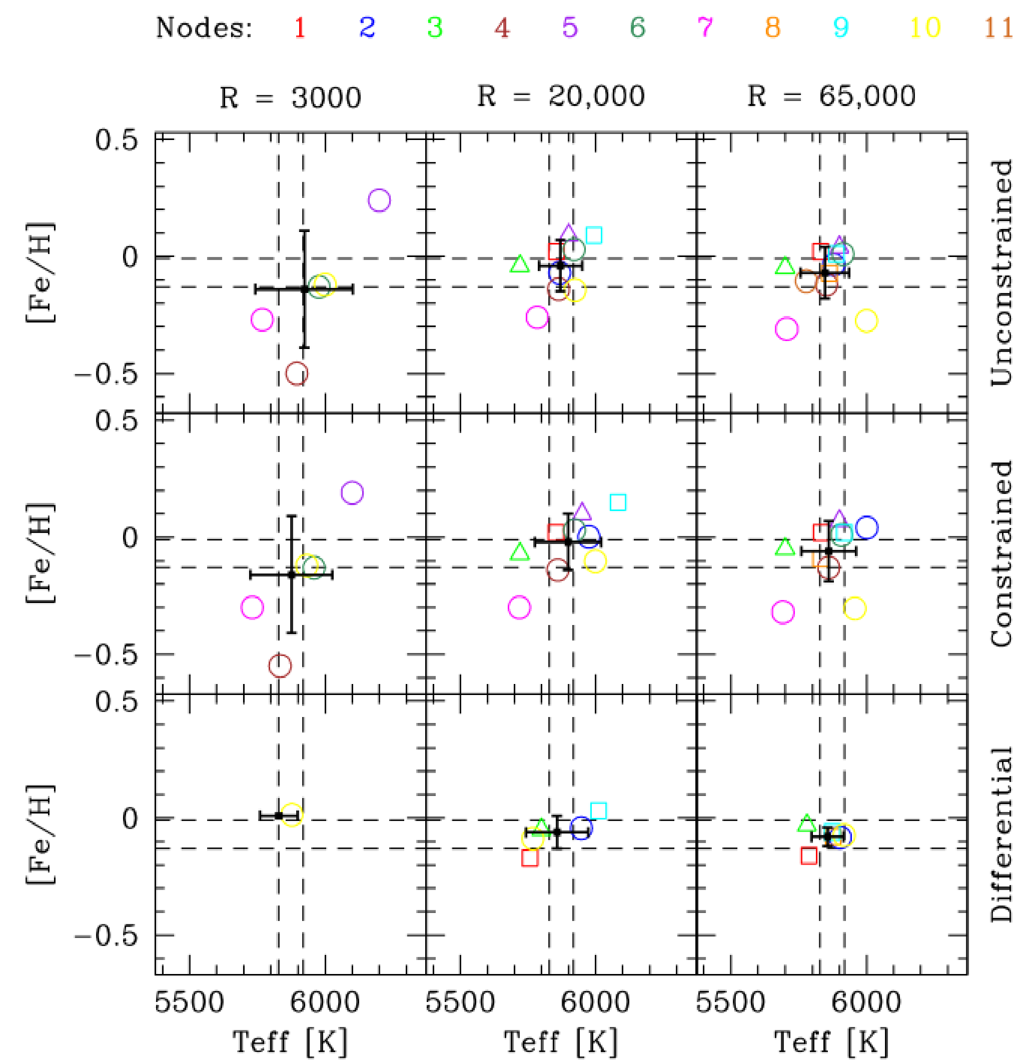


Figure 1: *Position of the Gaia benchmark stars in the relevant region of the ($T_{\rm eff}$, $\log g$) plane (i.e., around G0 V). The points are colour coded according to their relative $T_{\rm eff}$ uncertainties. The two stars eventually selected are α Cen A and β Hyi.*

Table 1: Properties of the two targets selected (Heiter et al. 2015). The recommended LTE [Fe/H] values are taken from Jofré et al. (2014). The uncertainties take into account the various sources of error reported in their table 3. Namely, we added in quadrature σ (Fe I), $\Delta T_{\rm eff}$, $\Delta \log g$, $\Delta v_{\rm mic}$, and Δ (ion).

Name	$T_{\rm eff}$ [K]	$\log g$	[Fe/H]
α Cen A	5792±16	4.31±0.01	+0.24±0.08
β Hyi	5873±45	3.98±0.02	−0.07±0.06

For justification doc URJD



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THEORY

Stellar evolution code

+

Oscillation code

OBSERVATIONS

- Classical observables
  (Teff, L, [Fe/H], logg)
- Seismic observables

OPTIMIZATION

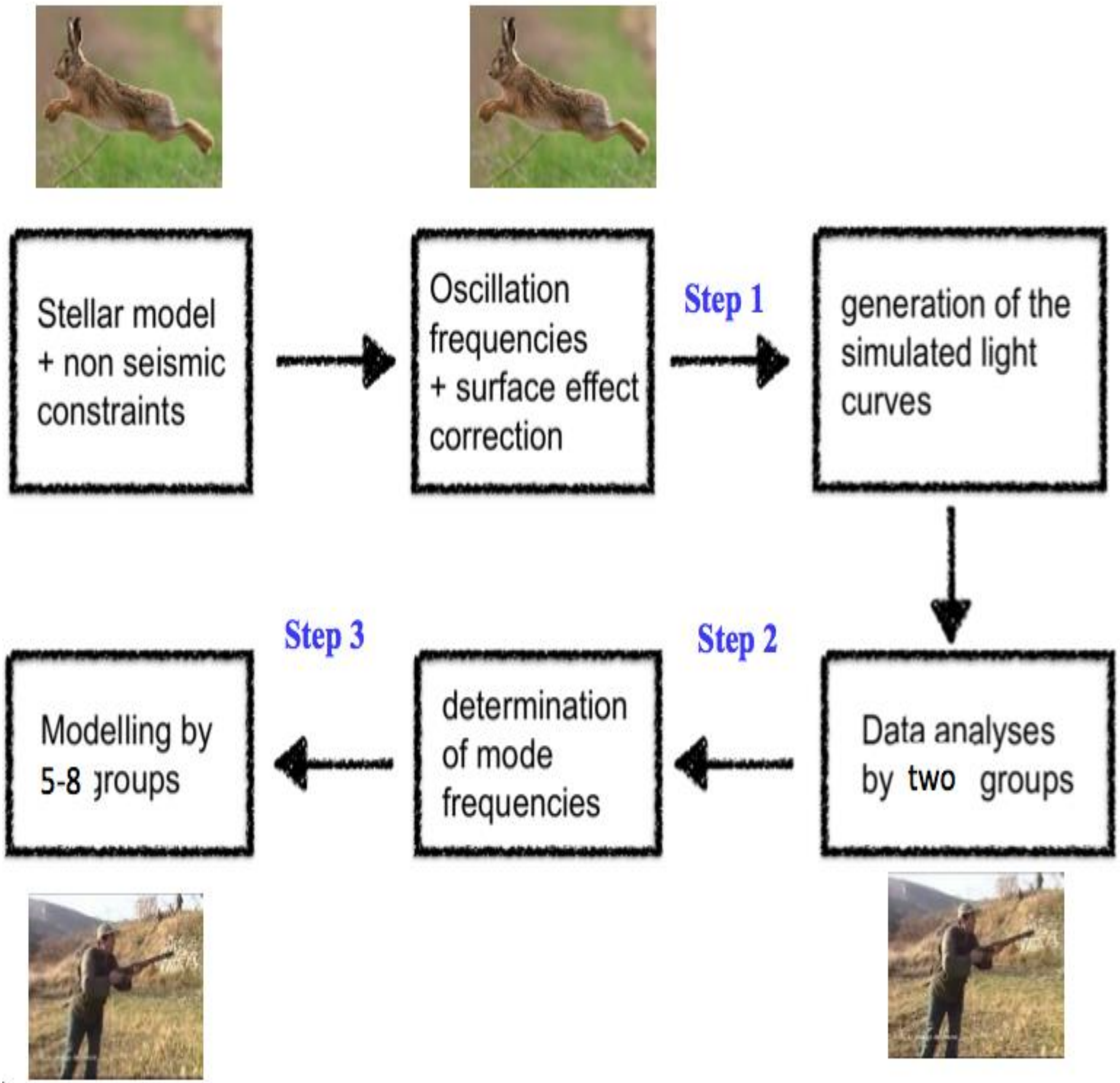
Search for a model that matches both classical and seismic observables

Disagreement

Information about lacking or wrong physics in the theory

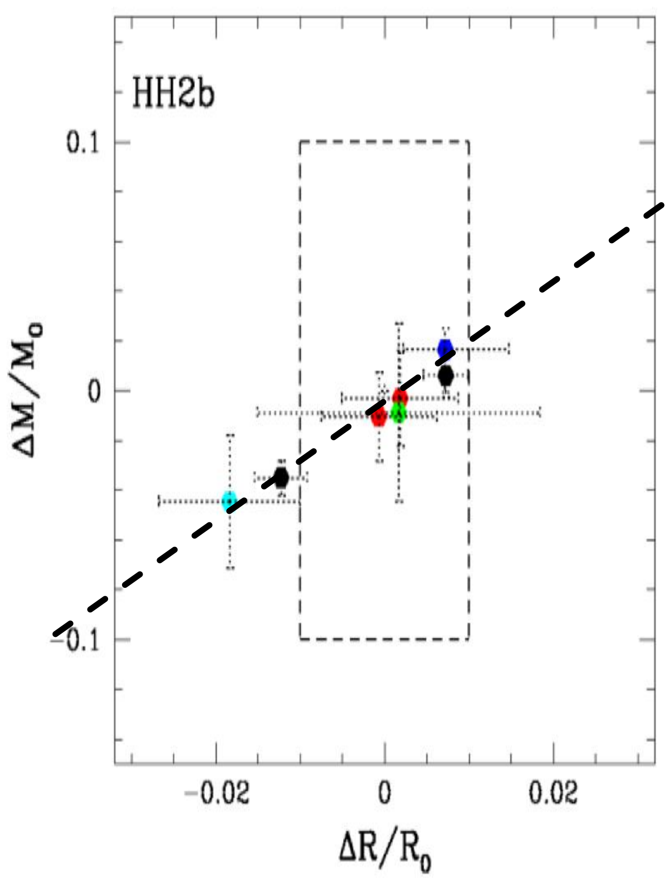
Agreement

Better estimates of model parameters

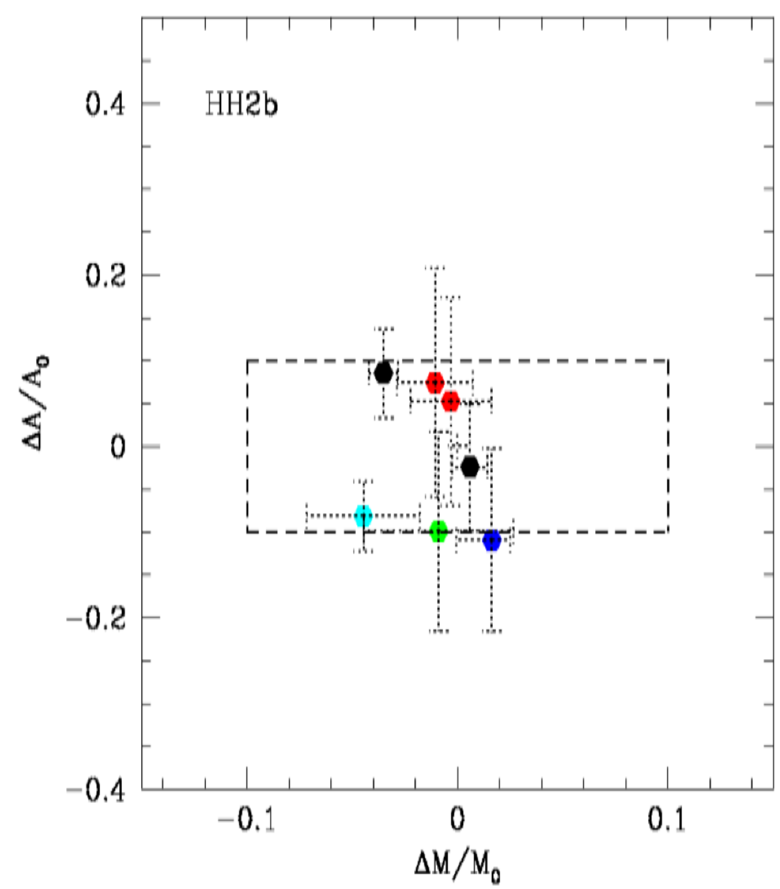

Stellar model
+ non seismic
constraints
Oscillation
frequencies
+ surface effect
correction
Step 1
generation of the
simulated light
curves
Data analyses
by two groups
Step 2
determination
of mode
frequencies
Step 3
Modelling by
5-8 groups

- “**Easy**” target: M = 1.12 $M_\odot$, R = 1.20 $R_\odot$, Age = 3.44 Gyr (X_c = 0.3)
  - Mass recovered within
  - Radius recovered within for most modelers
  - Age recovered within

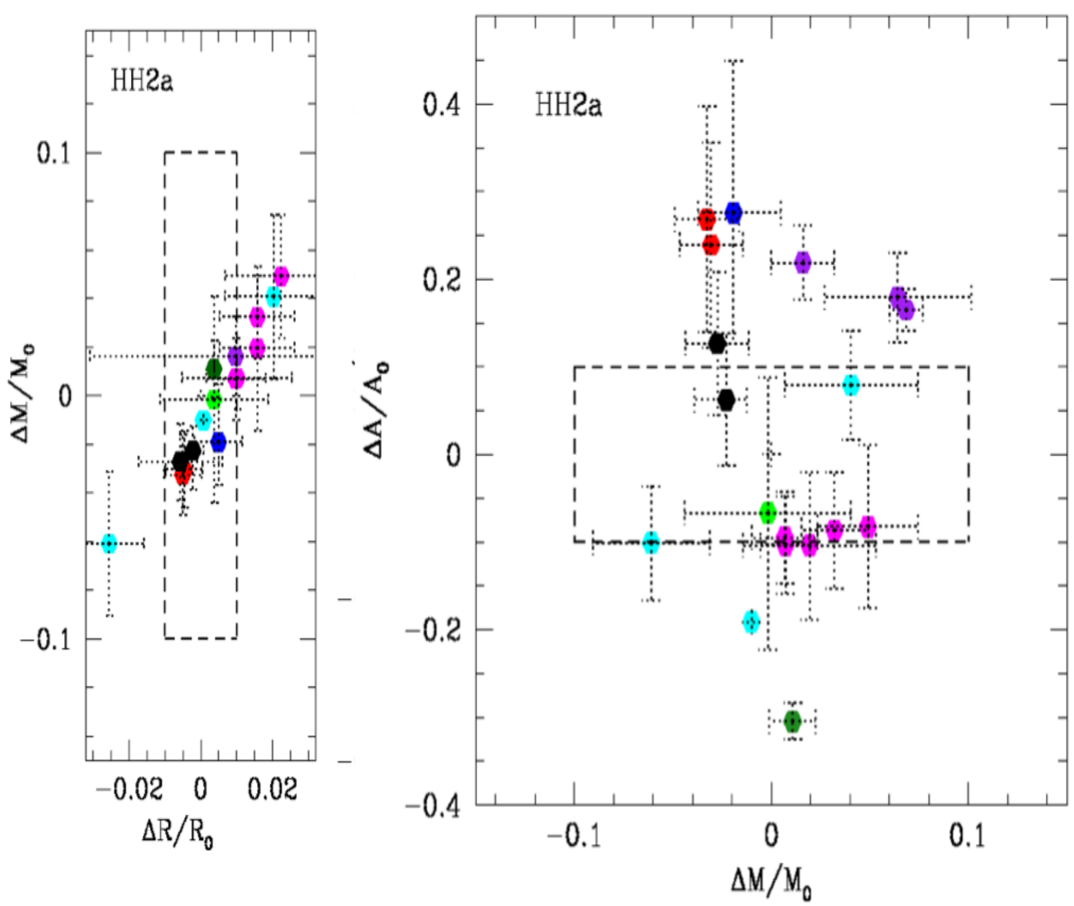
⇒ Stellar parameters within PLATO requirements, in spite of different choices of input physics, seismic observables, and optimization techniques



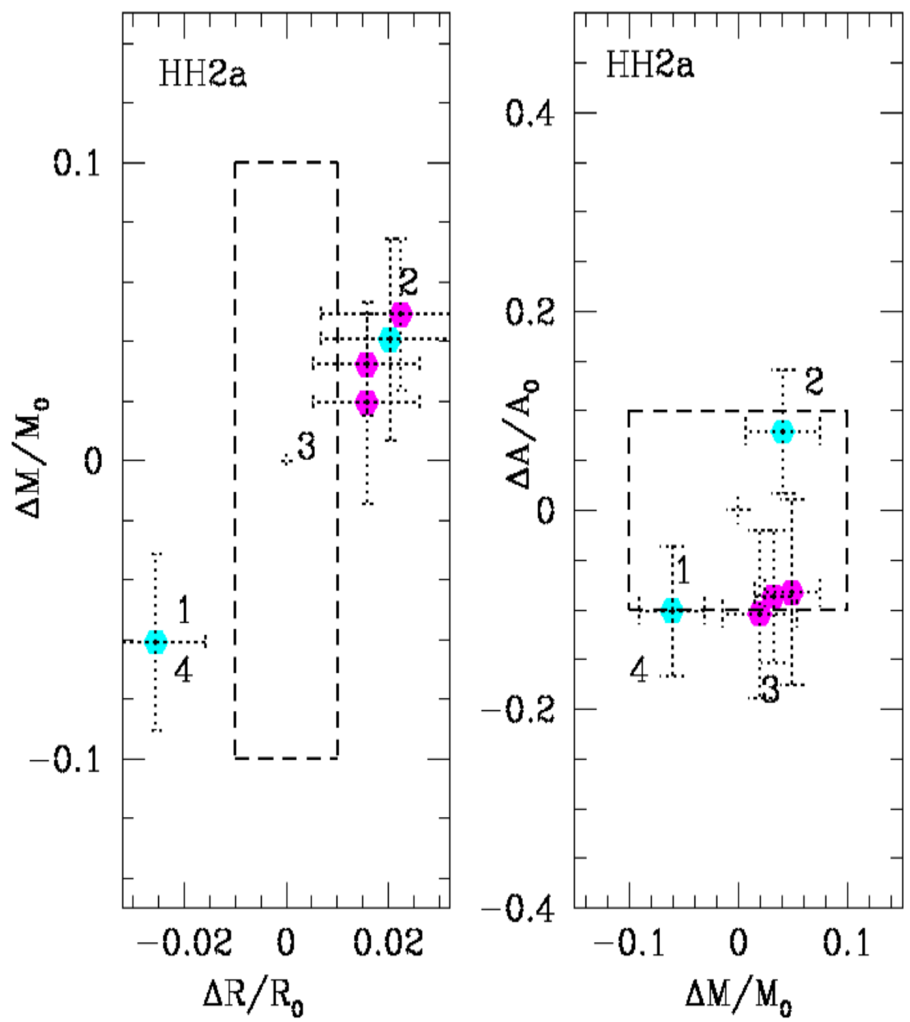
Seismic constraint on mean density (slope ~ 3)



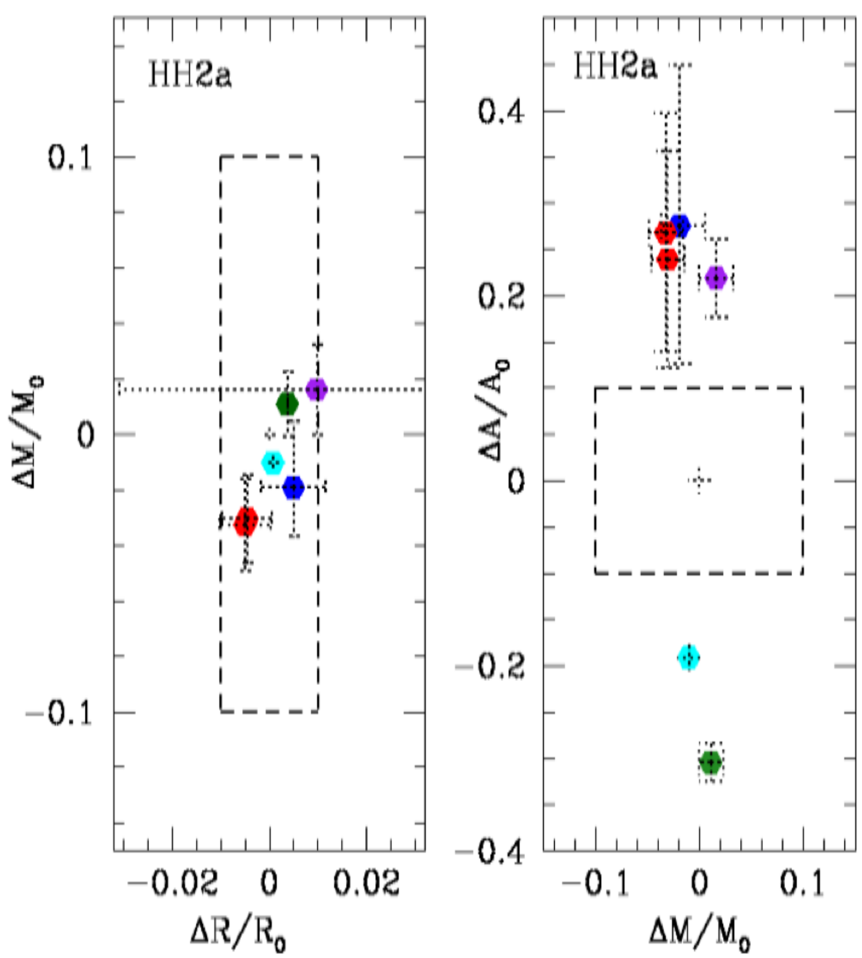
- "**Tricky**" target: M = 1.18 $M_\odot$ (convective core), unusual physics (sub-solar value of α_{conv}, low initial helium abundance)
  - Mass recovered within
  - Radius recovered within for most modelers
  - Age recovered within
  - ⇒ Recovered radii and ages outside PLATO requirements



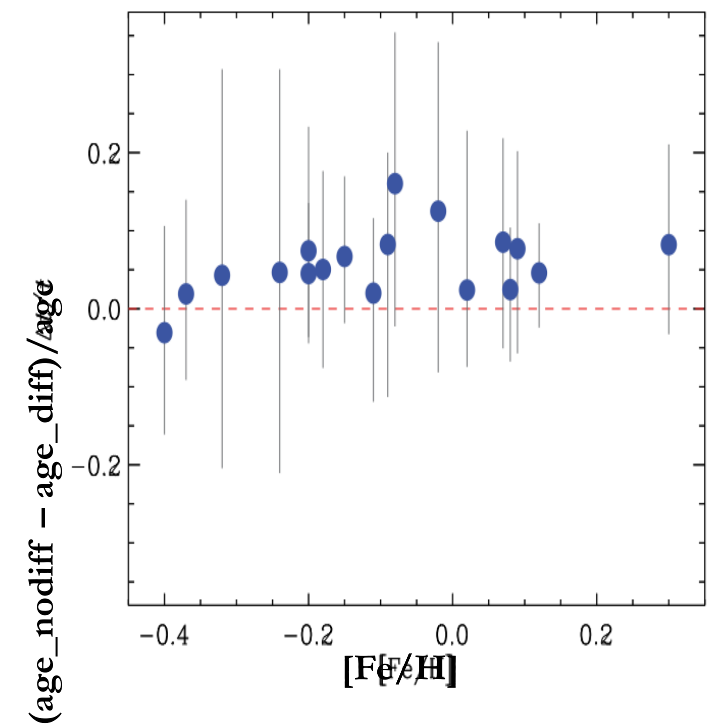
- “**Tricky**” target:
  - Models with **ages** within spec, but **radius** out of spec
    - Not enough flexibility for α_{conv}
    - Use of the frequency ratios, which are sensitive to stellar age but lose information on the mean stellar density (solution: add low-frequency modes in the fit)



- “**Tricky**” target:
  - Models with **radius** within spec, but **age** out of spec
    - **Chemical mixture** (GN93 instead of AGS09)
    - Fixed **chemical enrichment law** differs from that of the input model
    - **Microscopic diffusion** (ages without diffusion are overestimated)



Effects of diffusion on age estimates



Silva-Aguirre et al. (2015)

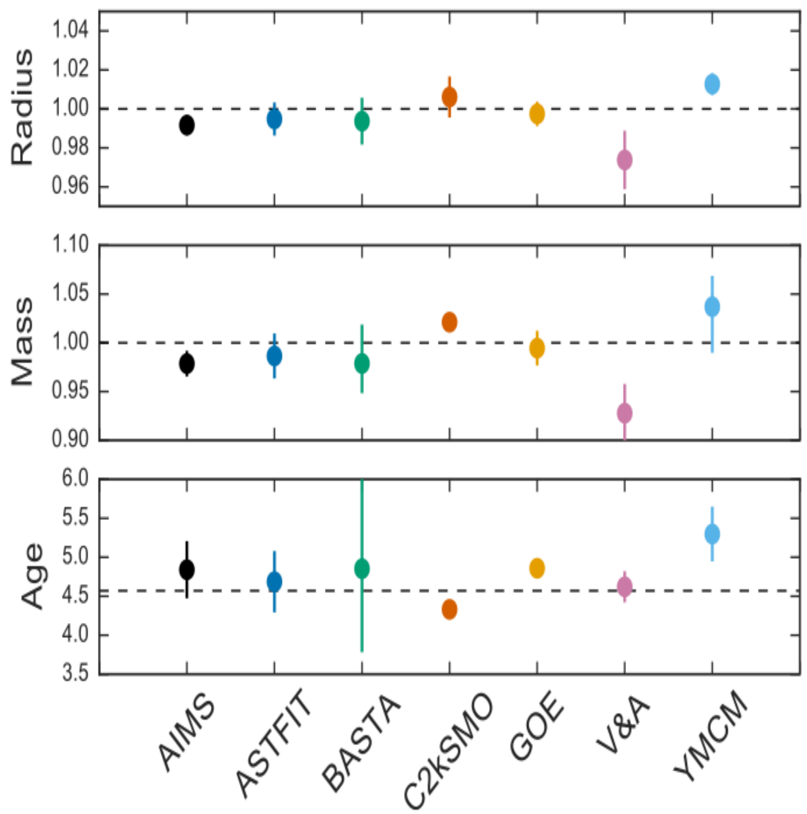
Seismic modeling of Kepler LEGACY

Testing the accuracy

Benchmark stars

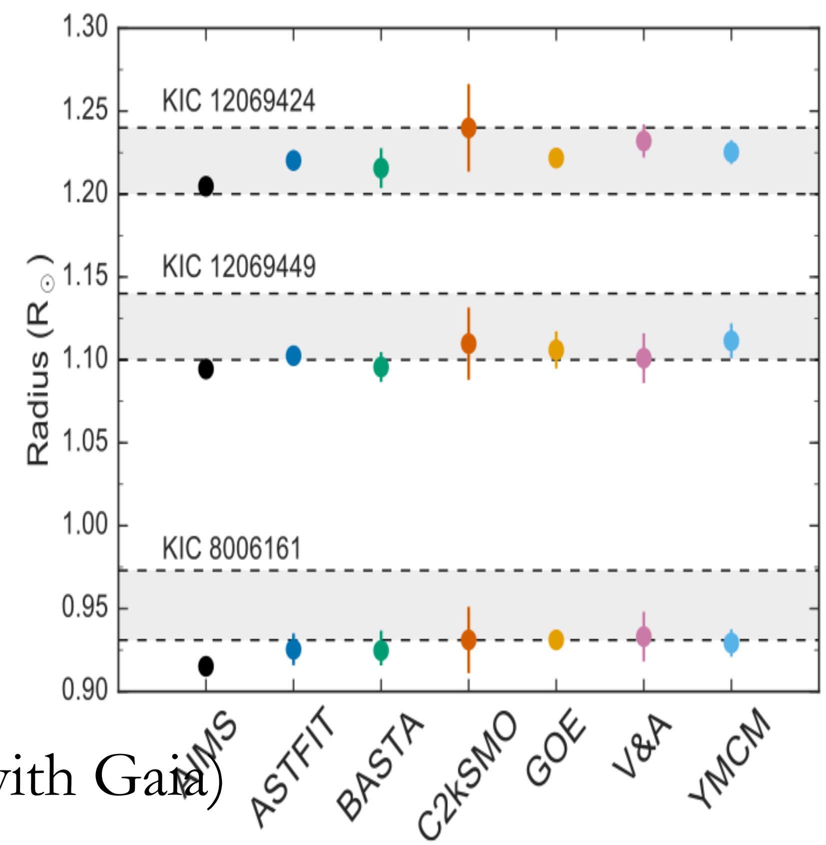
✓The Sun

(Silva Aguirre et al. 2017)



✓Interferometric radii (comparison with radii measurement from CHARA interferometer)

(Silva Aguirre et al. 2017)

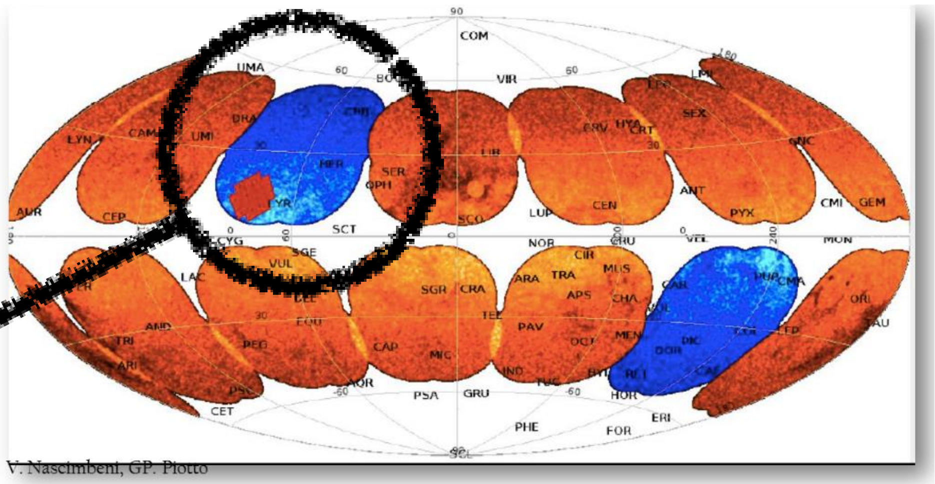


✓Parallaxes (**Silva Aguirre et al. 2012**, more to come with Gaia)

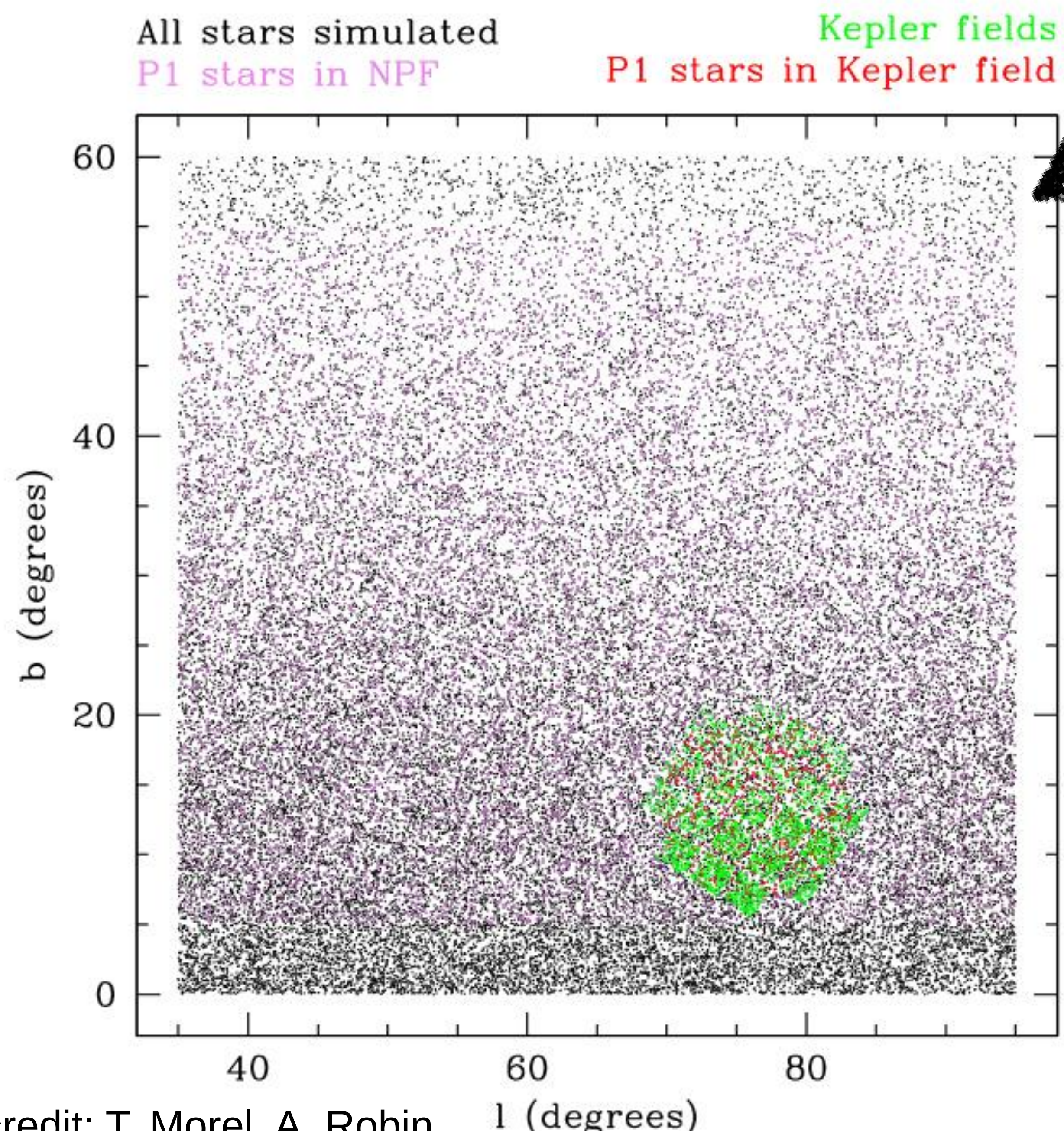
✓Binary systems

Credit.S. Deheuvels

The PLATO noise



Stellar population computed with the Besançon Model (A. Robin 2017) adapted for a PLATO 2yr ✓ long run



All stars simulated

P1 stars

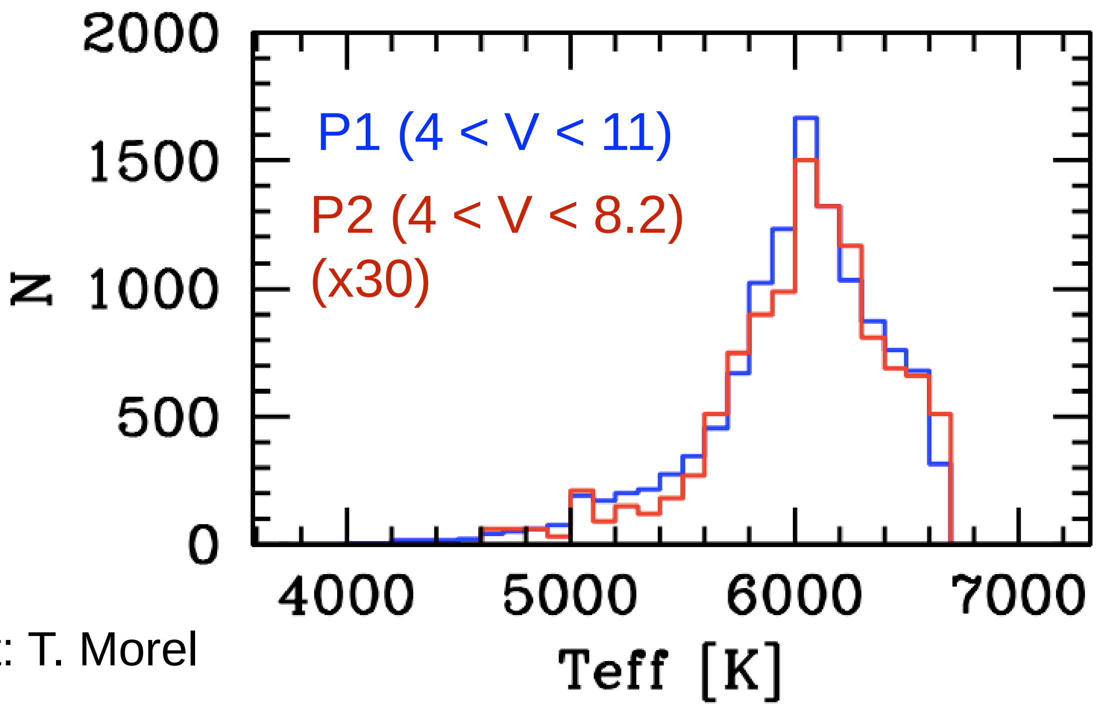
Kepler field

P1 stars in *Kepler* field

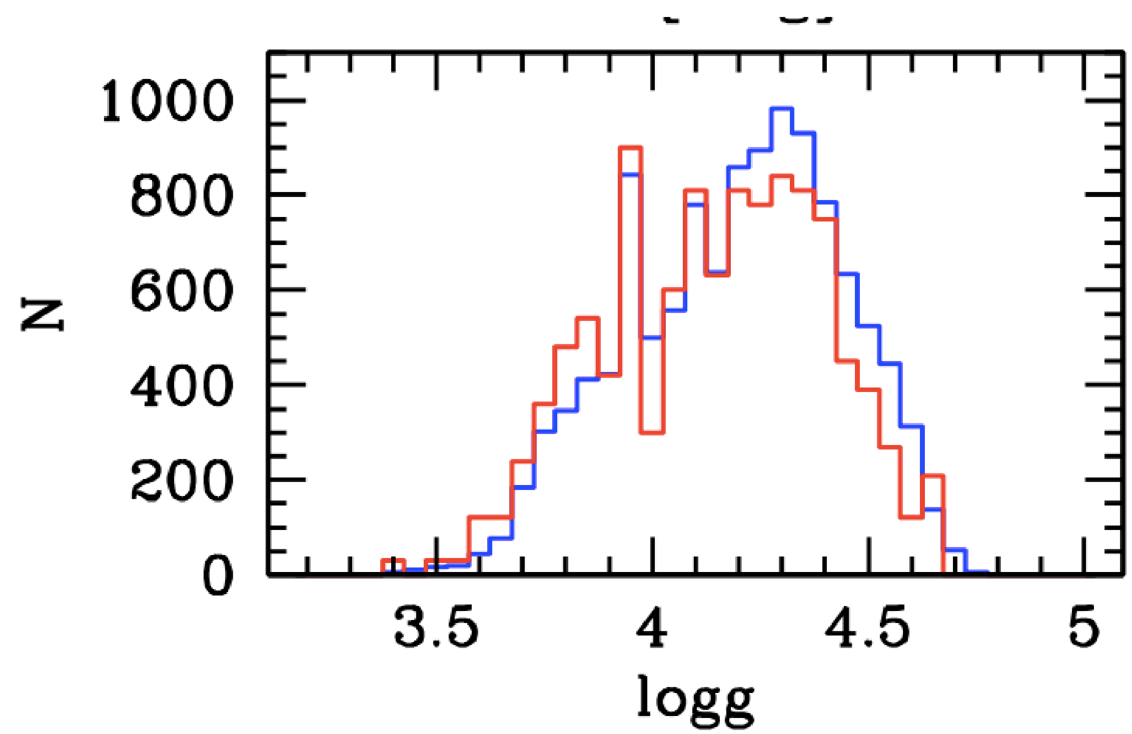
credit: T. Morel, A. Robin

The PLATO noise

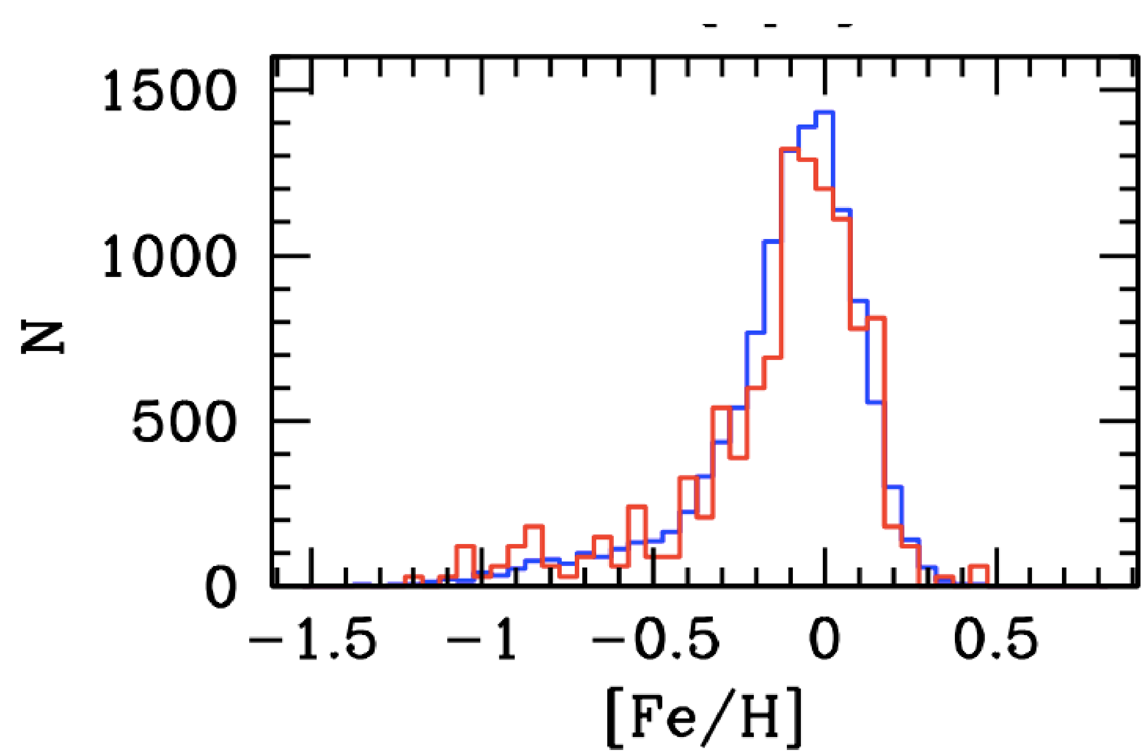
✓Stellar population computed with the Besançon Model (A. Robin 2017) adapted for a PLATO 2yr long run



credit: T. Morel



Star distributions from the simulated catalogue:
P1 & P2 samples only



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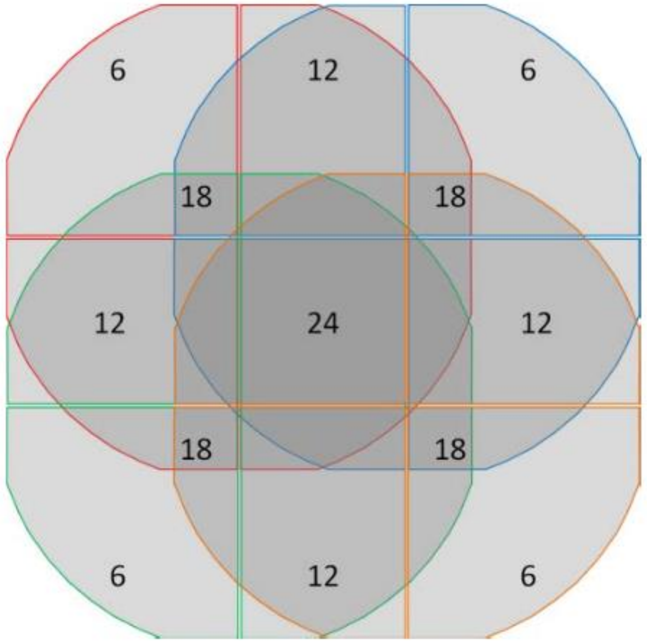
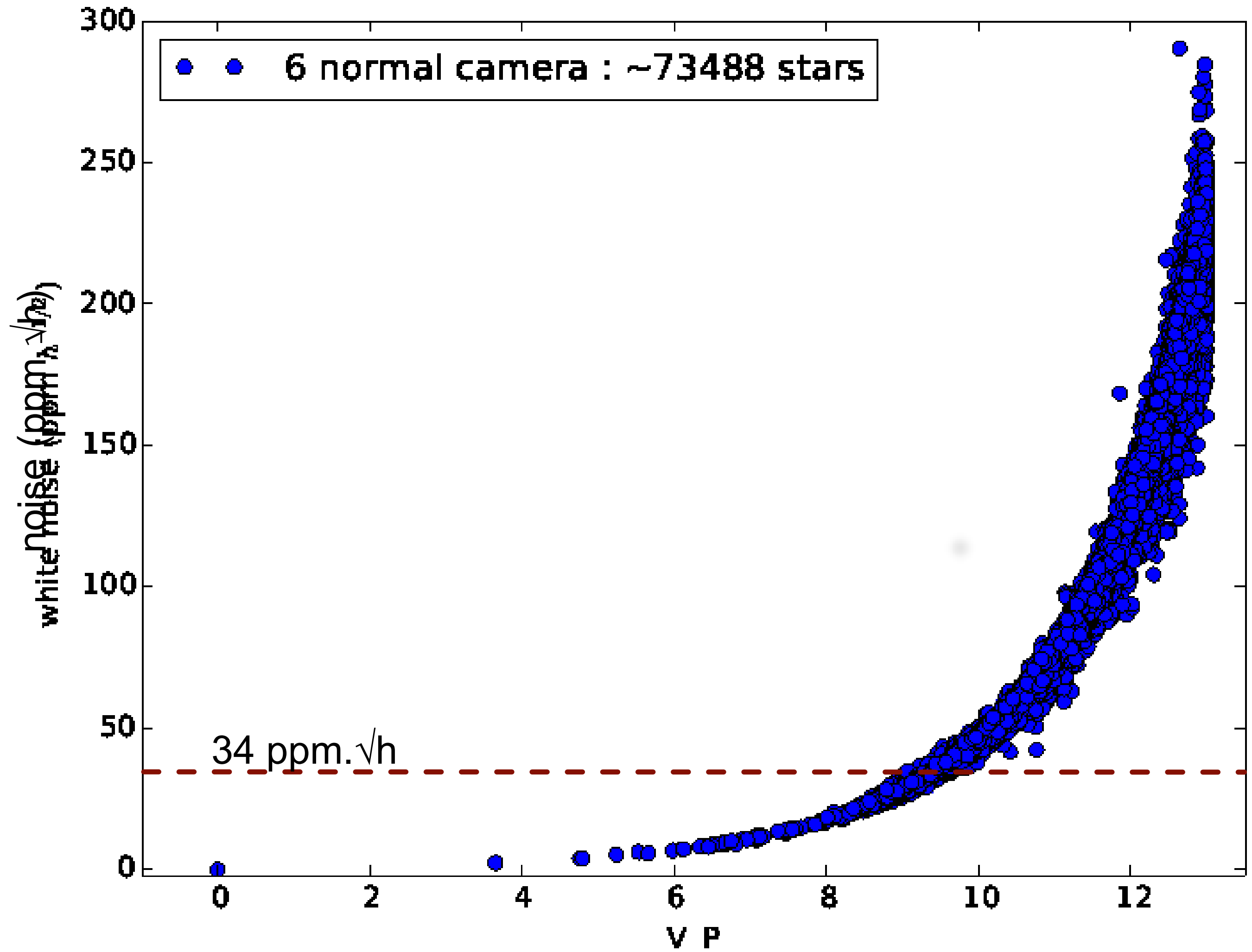


✓ Plato noise including :

- Target photon noise
- Random noise from the instrument
- Residual noise after correction from systematics



✓ the noise level for a target depends on the number of cameras

credit: M.J. Goupil, J. Cabrera

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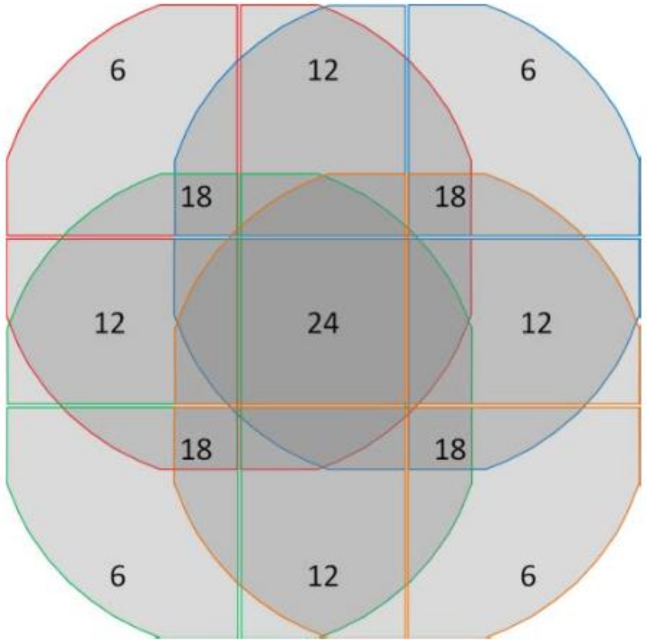

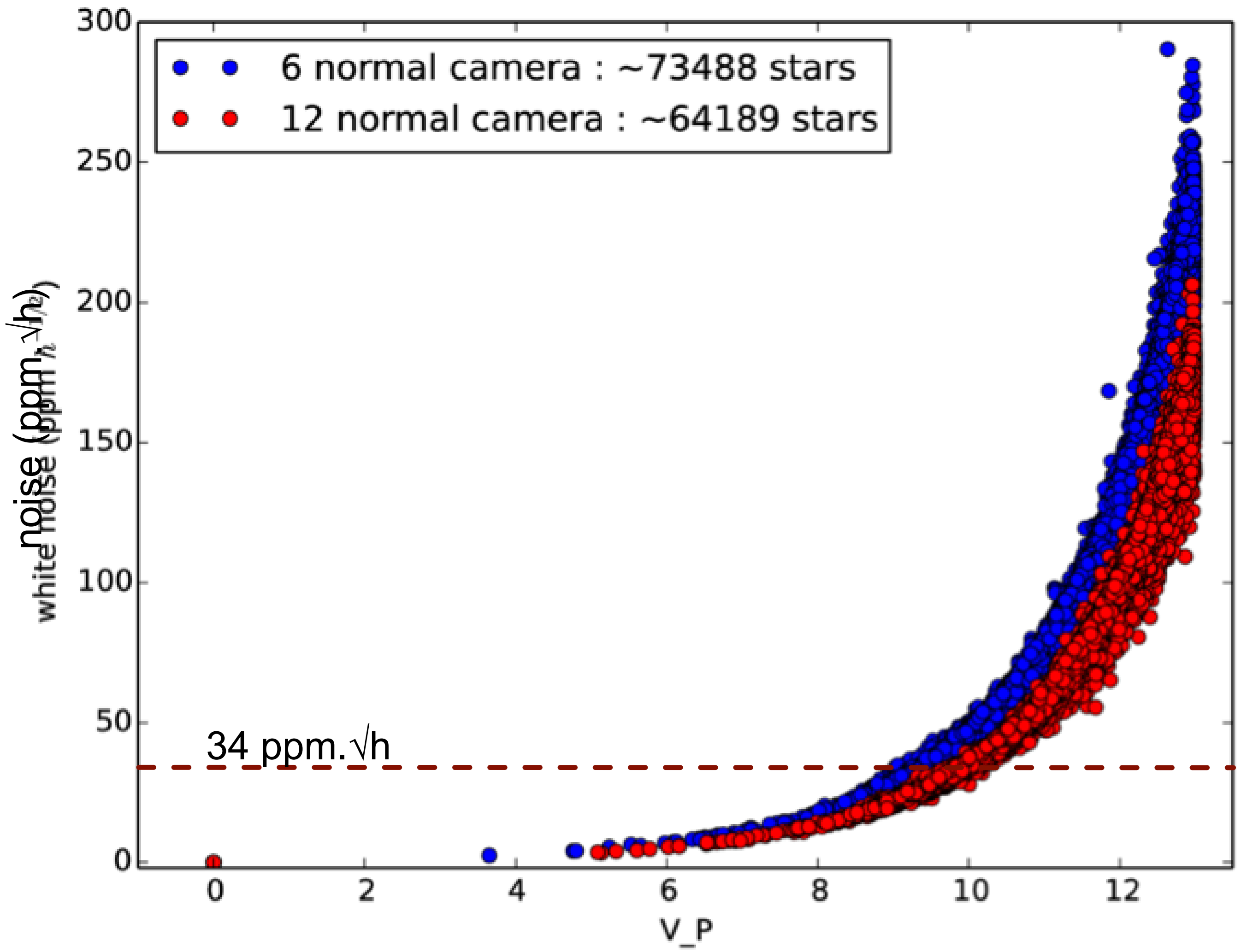

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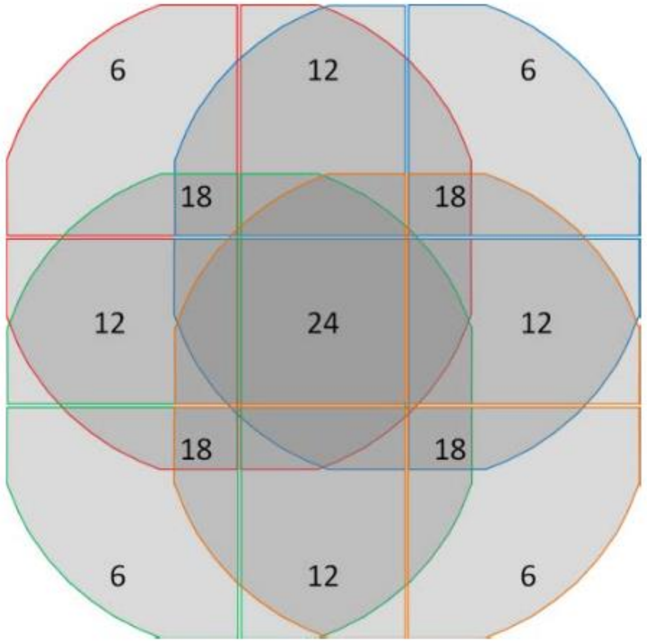

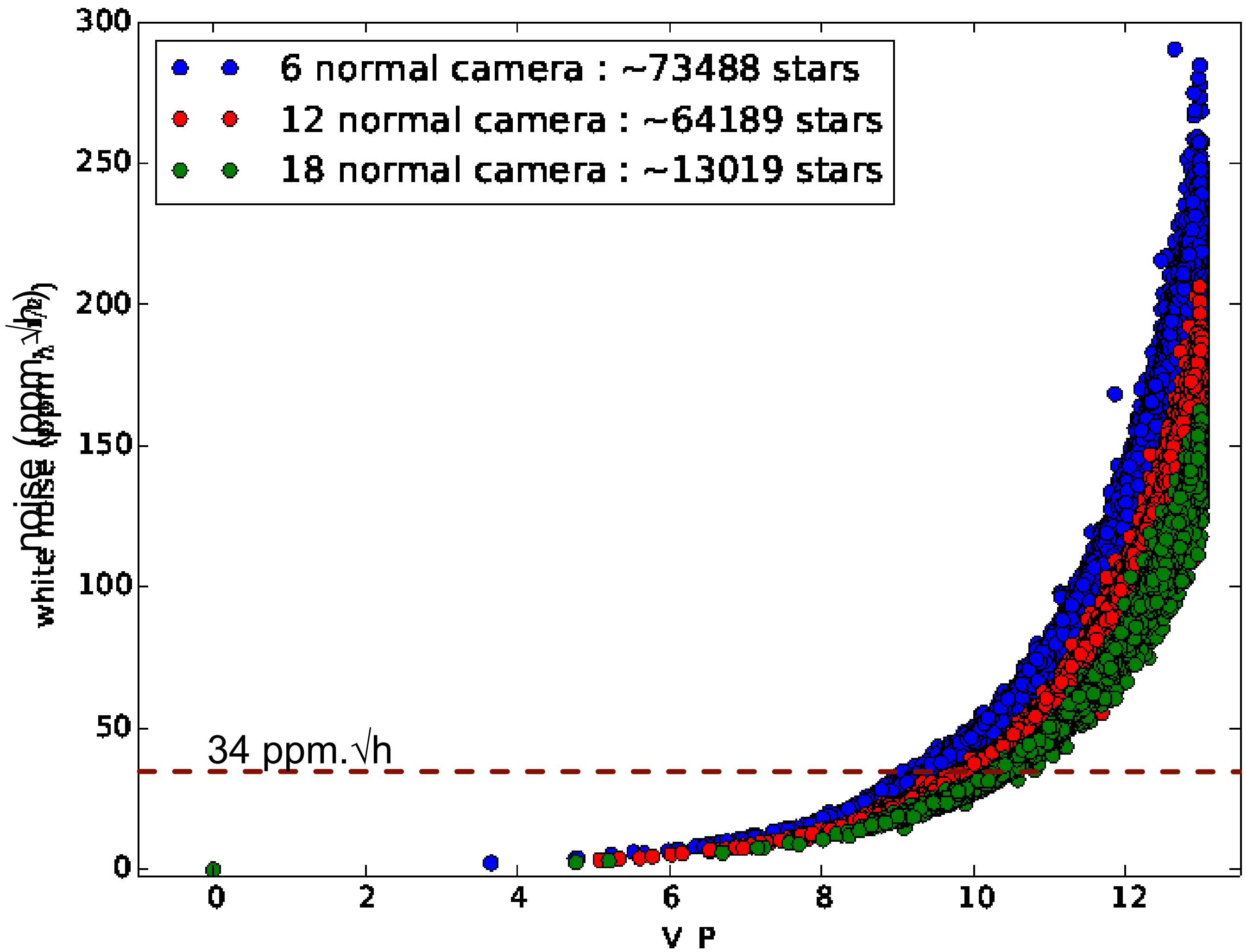

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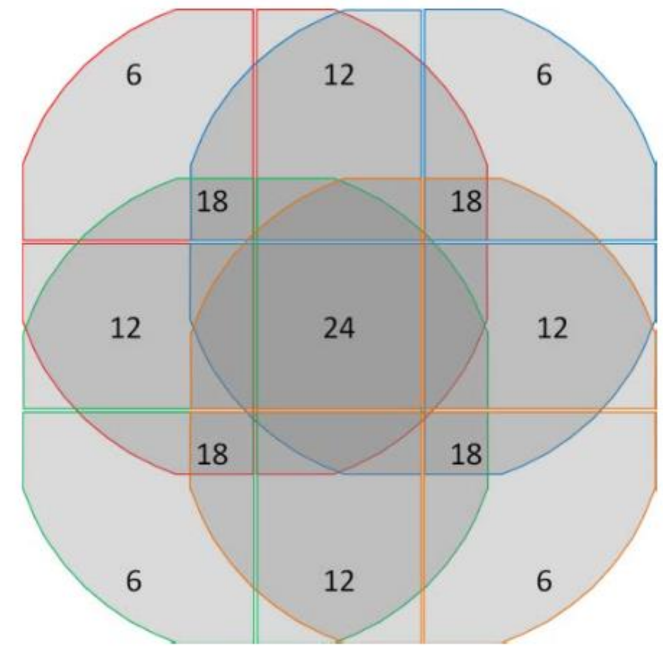

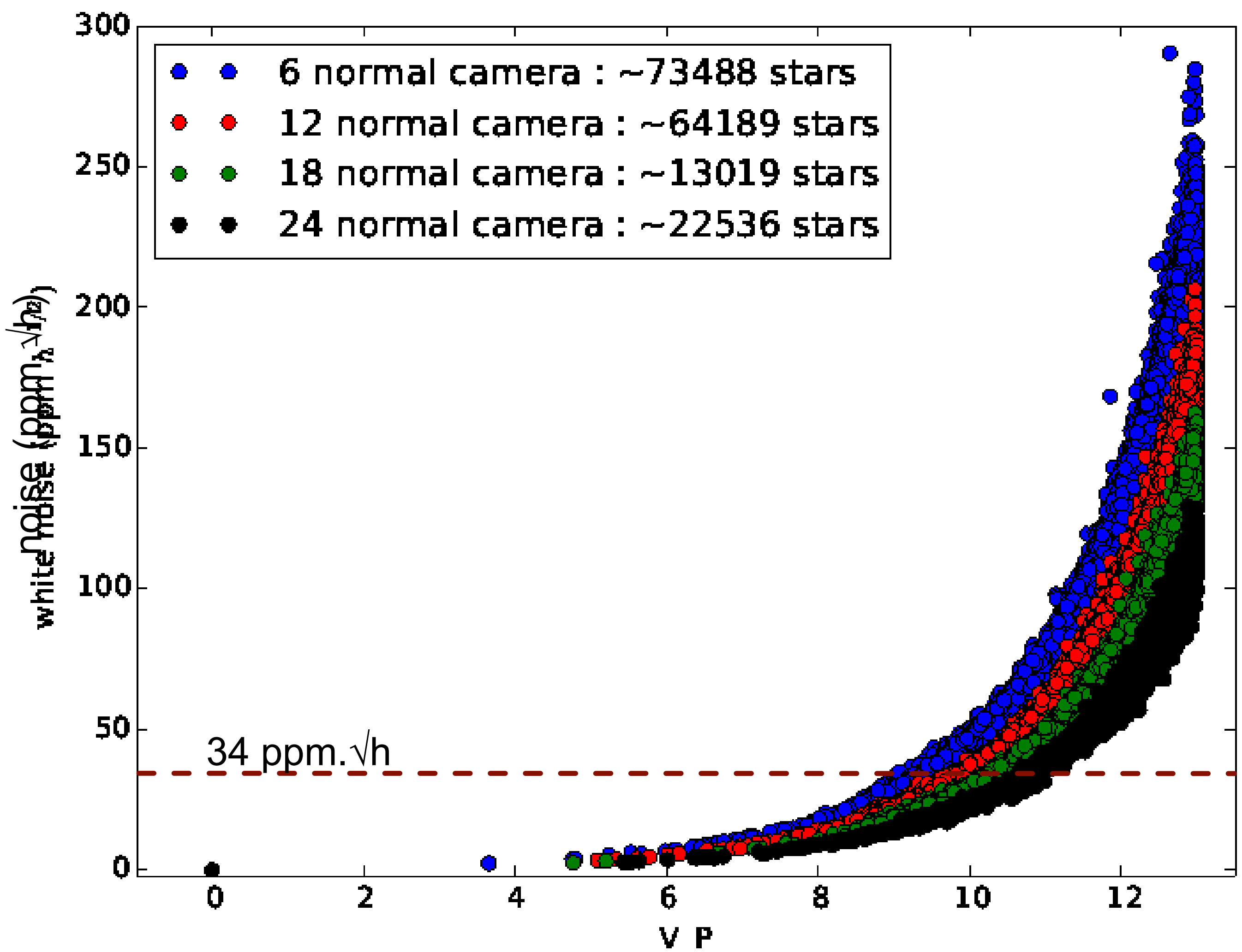

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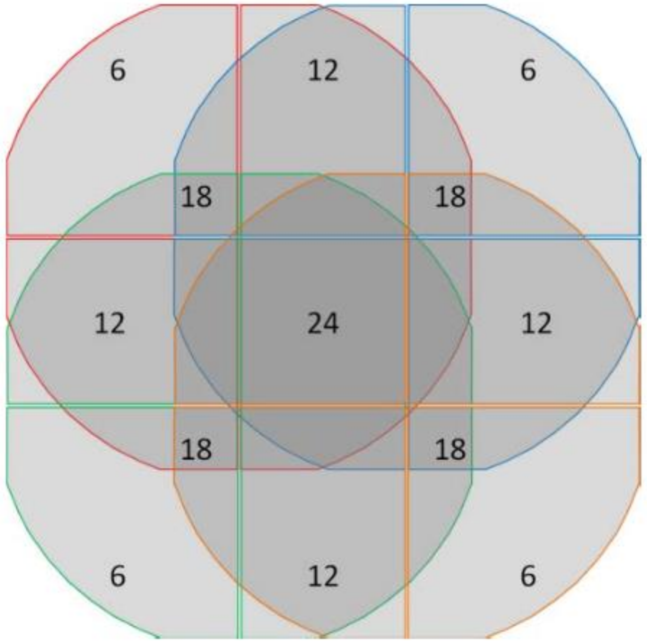

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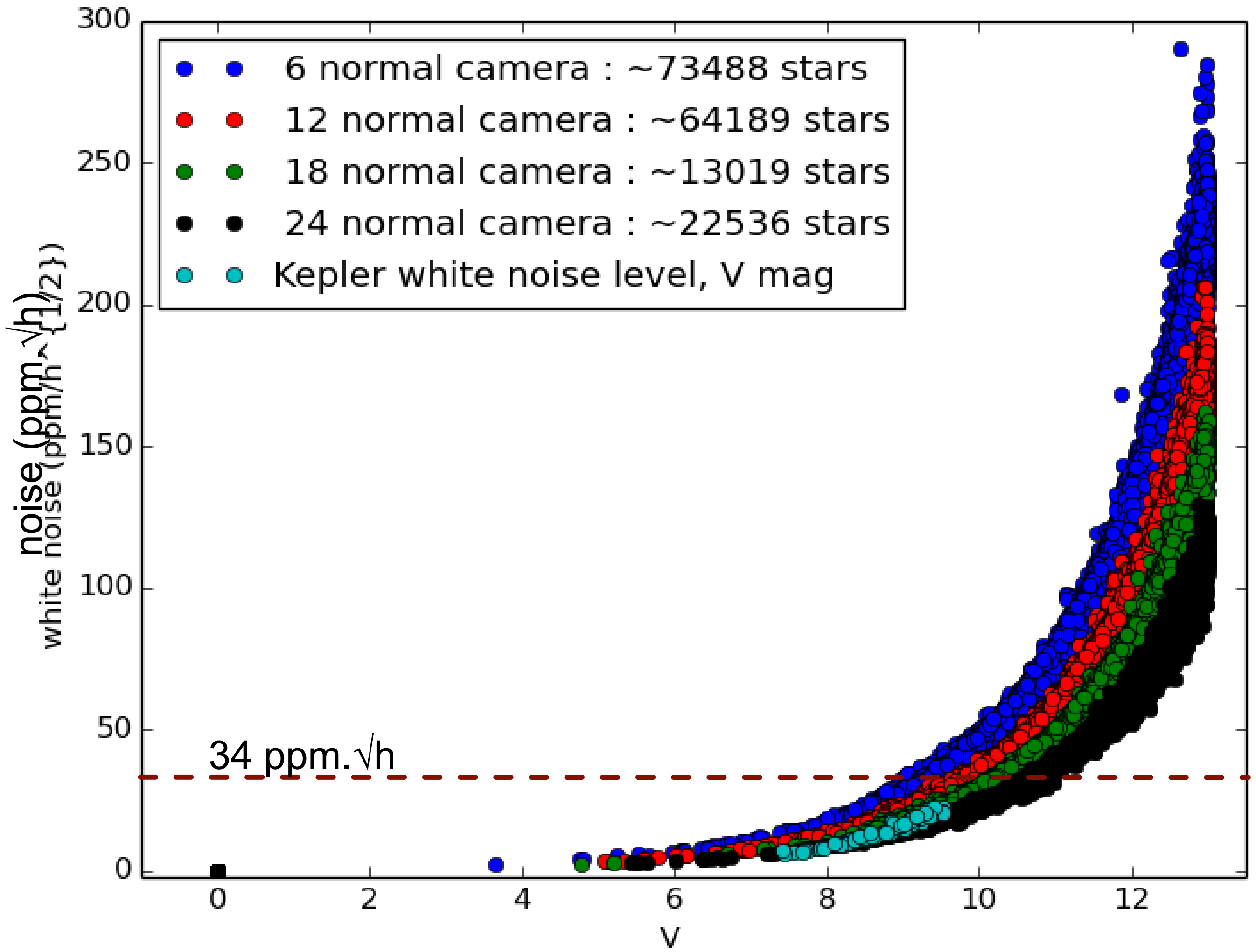

Kepler white noise as derived by M. Lund provided by V. Silva Aguirre

credit: M.J. Goupil, J. Cabrera

✓ the noise level for a target depends on the number of cameras

✓ for 24 cameras, the noise level is comparable to the Kepler Legacy sample

Kepler Legacy sample is an excellent benchmark for PLATO

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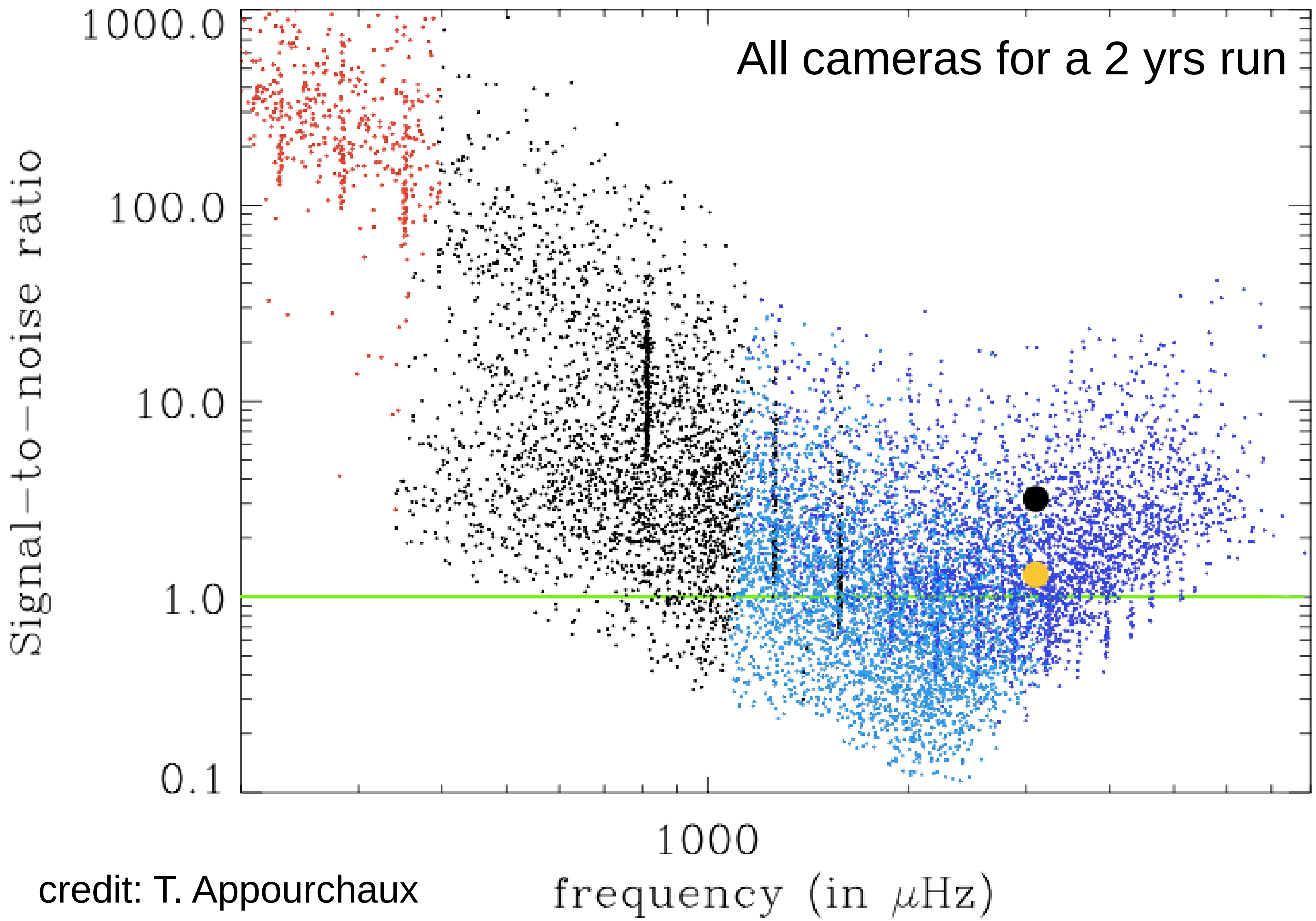
Detectability of solar-like oscillations

granulation are derived from scaling relation using CoRoT and Kepler observations (Corsaro et al. 2012,20

oise : photon noise, random noise from the instrument, residual noise after correction from systematics



credit: T. Appourchaux

main-sequence stars (Deep blue, M < 1.1M⊙; light blue M > 1.1M⊙)

subgiant stars

redgiant stars

the black and orange points are the reference star at 6000 K at V = 8.5 and V = 10, respectively.

PLATO will be able to detect solar-like stars from the main-sequence to the red giant branch

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PLATO main requirements for seismology

✓ Requirements for DP5 and P1:

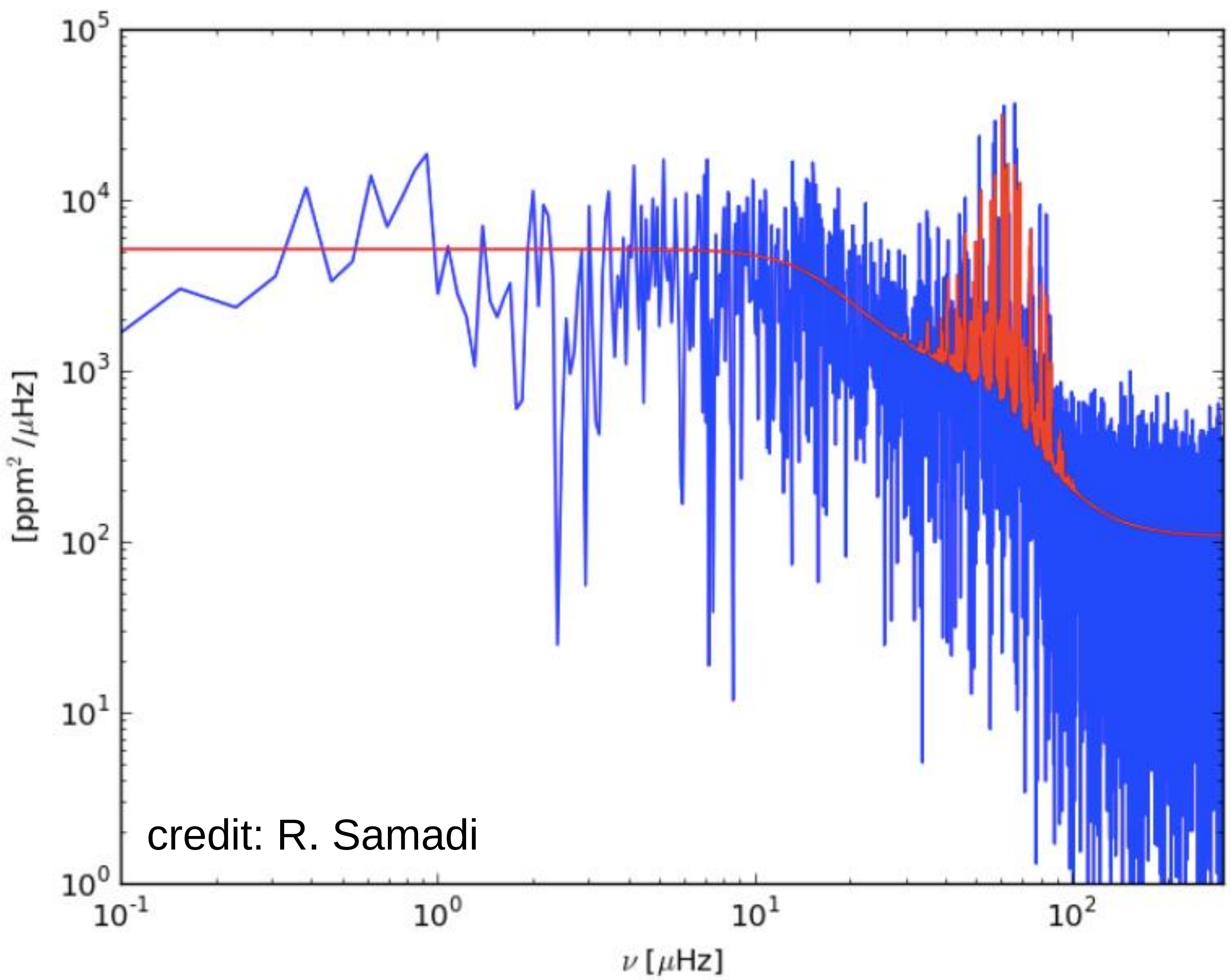
- $\Delta R_{star}/R_{star} \leq 3\%$ for a G0V star with $V \leq 10$
- $\Delta M_{star}/M_{star} \leq 10\%$ for a G0V star with $V \leq 10$
- $\Delta Age/Age \leq 10\%$ for a G0V star with $V \leq 10$ *(Reference star : 1$M_\odot$,1$R_\odot$,6000 K)*

➔ It translates into ~0.1–0.2 μHz uncertainties around ν_{max}

First H&H exercices are encouraging
see Goupil et al. 2016 for details)

✓ Simulated light-curve (R. Samadi) for a star at
- mag 9, 10, 10.5

$M/M_\odot$ = 1
log $L/L_\odot$ = 0.22 ± 0.03
[Fe/H] = 0.04± 0.05
Teff = 6100 ± 80 K



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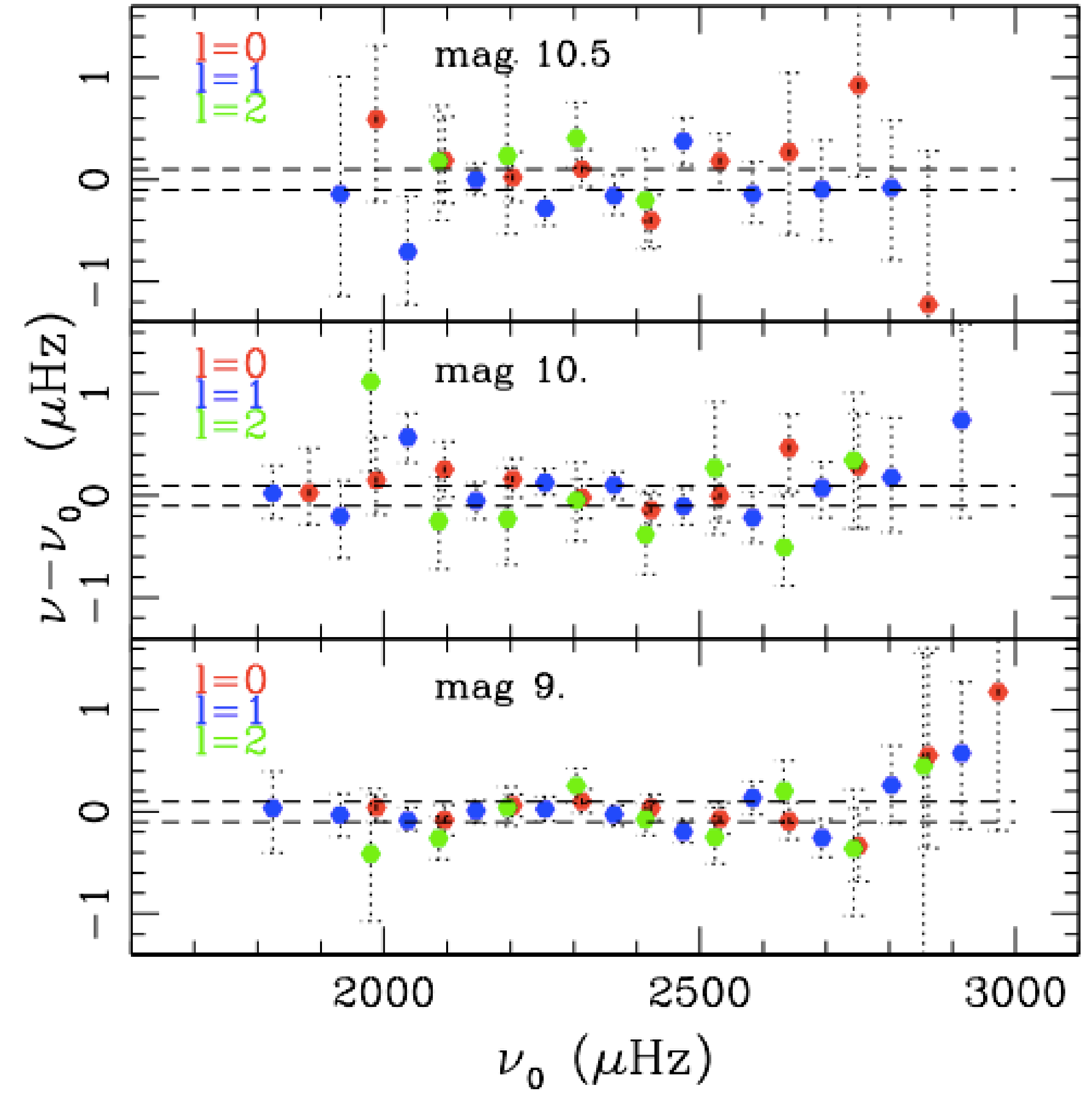
Data analysis performed by several groups among
- which the results of the Birmingham group are shown



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see Goupil et al. 2016 for details)
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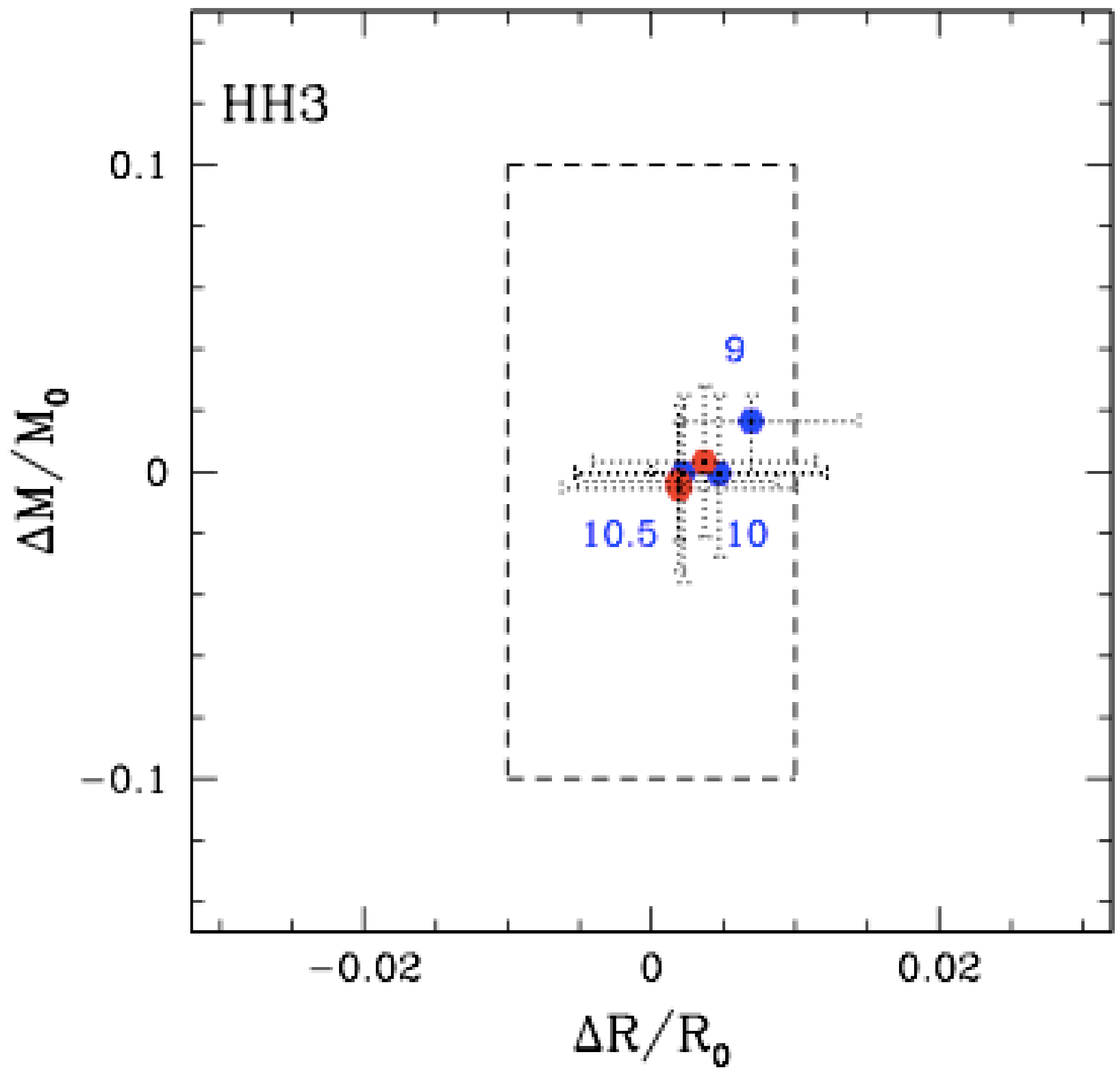
- Modeling performed by several groups among which the results of J. Christensen-Dalsgaard and V. Silva Aguirre are shown

→ Results compliant with the requirements in mass and radius



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First H&H exercices are encouraging
(see Goupil et al. 2016 for details)

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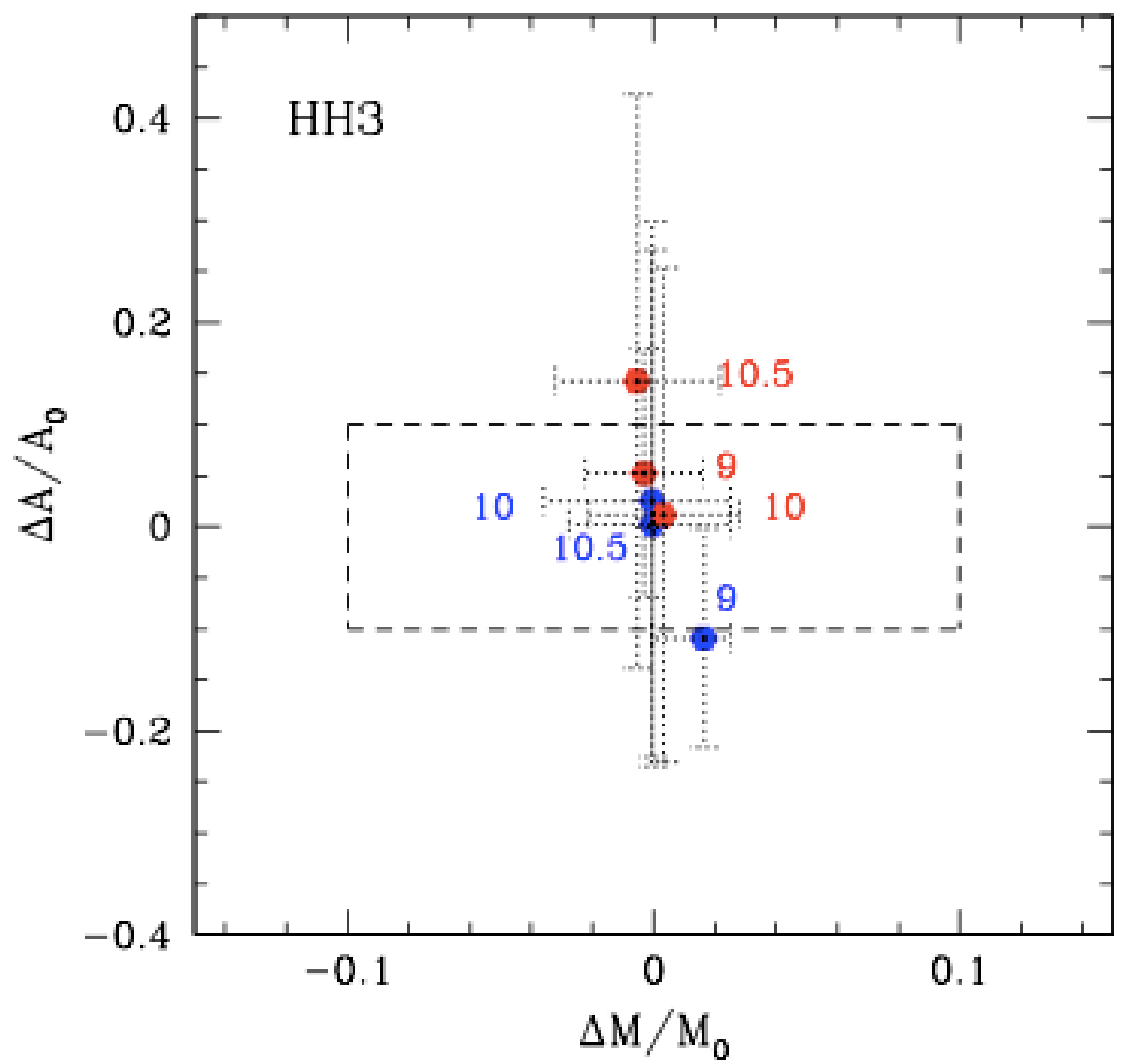
➔ Almost compliant with the requirements in age



What can be done with long cadence data?

oscillations detectable

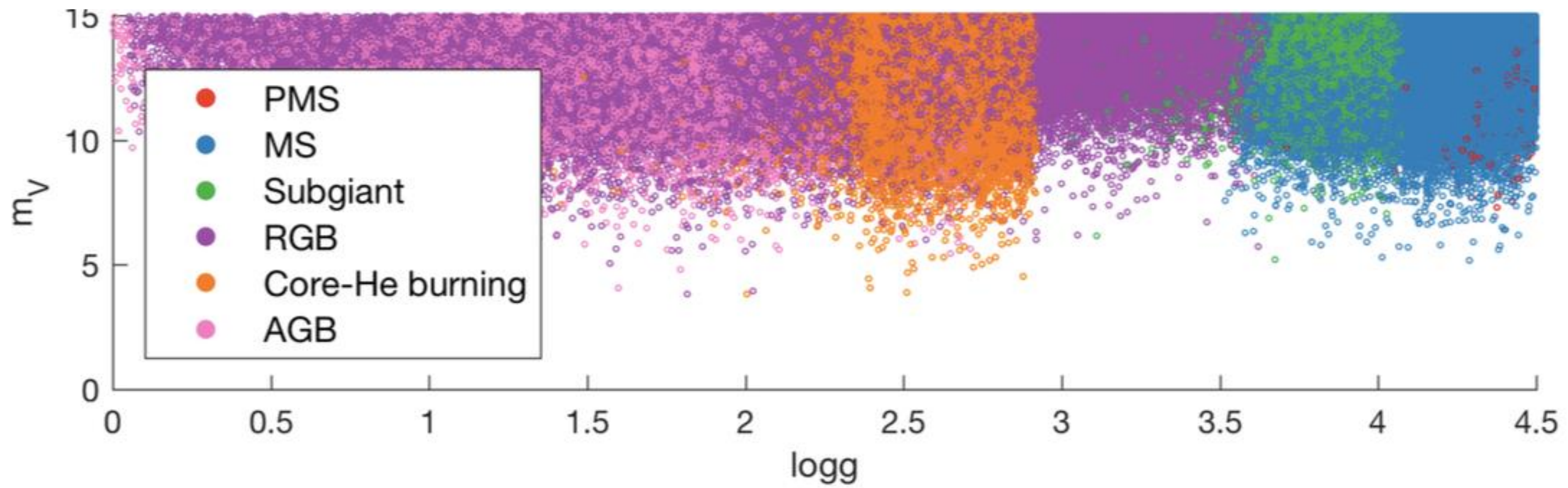
$$\langle\Delta\nu\rangle\,,\ \nu_{\rm max}$$

+ evolutionary state

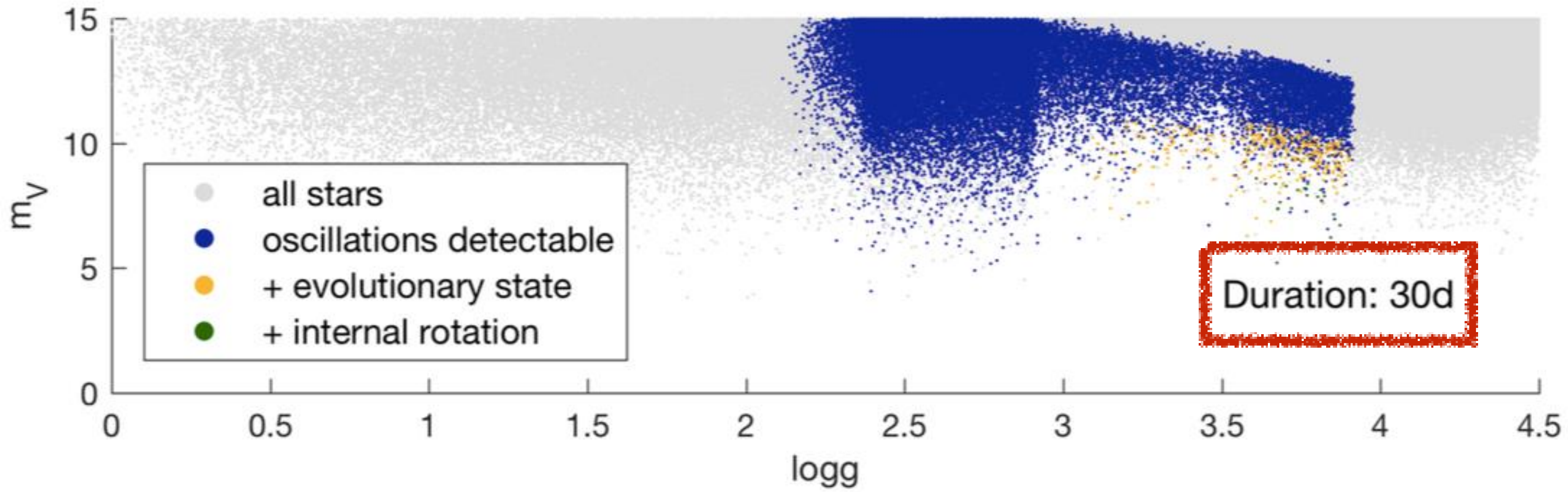
$$\Delta\Pi$$

+ internal rotation

$$\delta\nu_{n,\ell}$$



Miglio et al. (2017)



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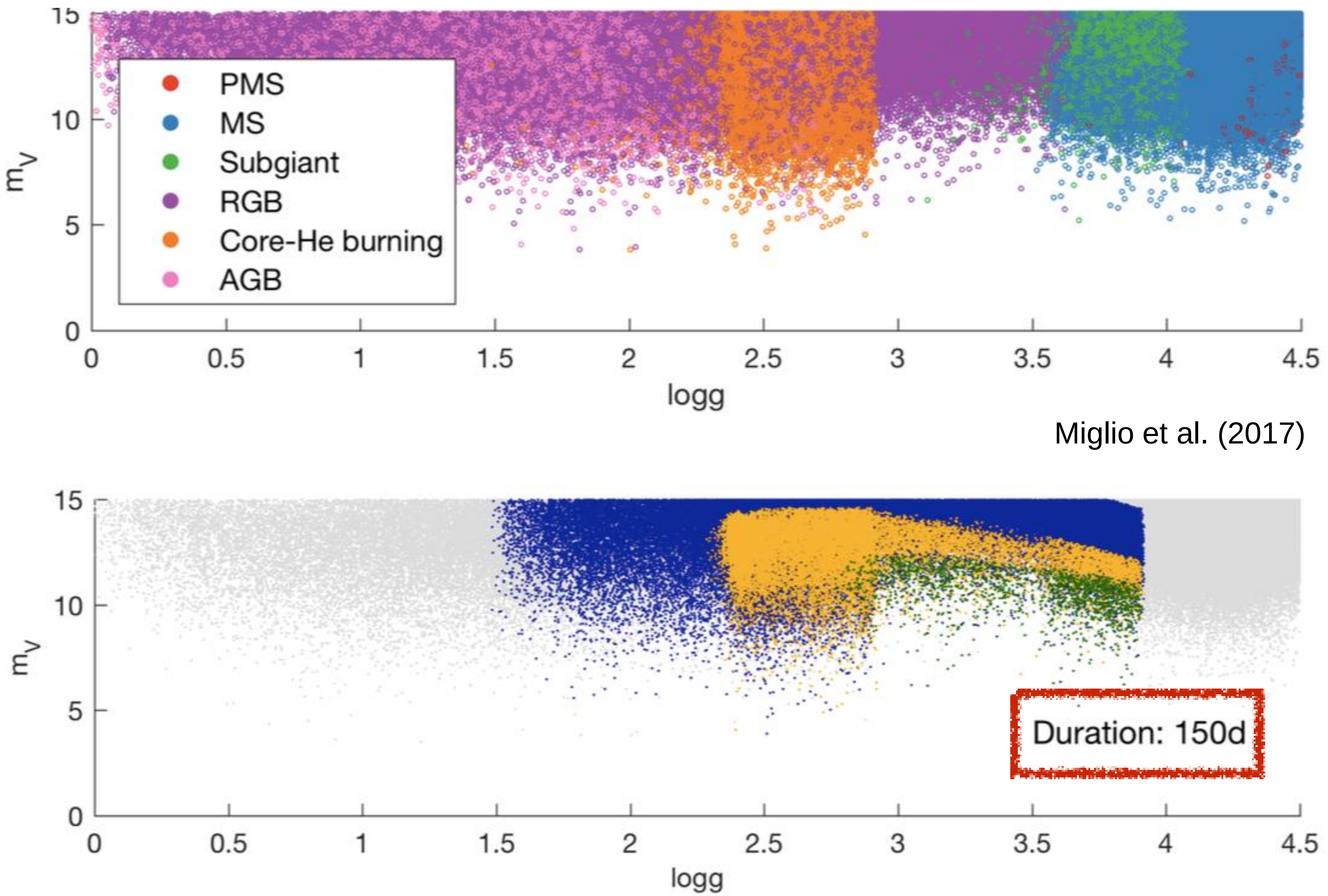

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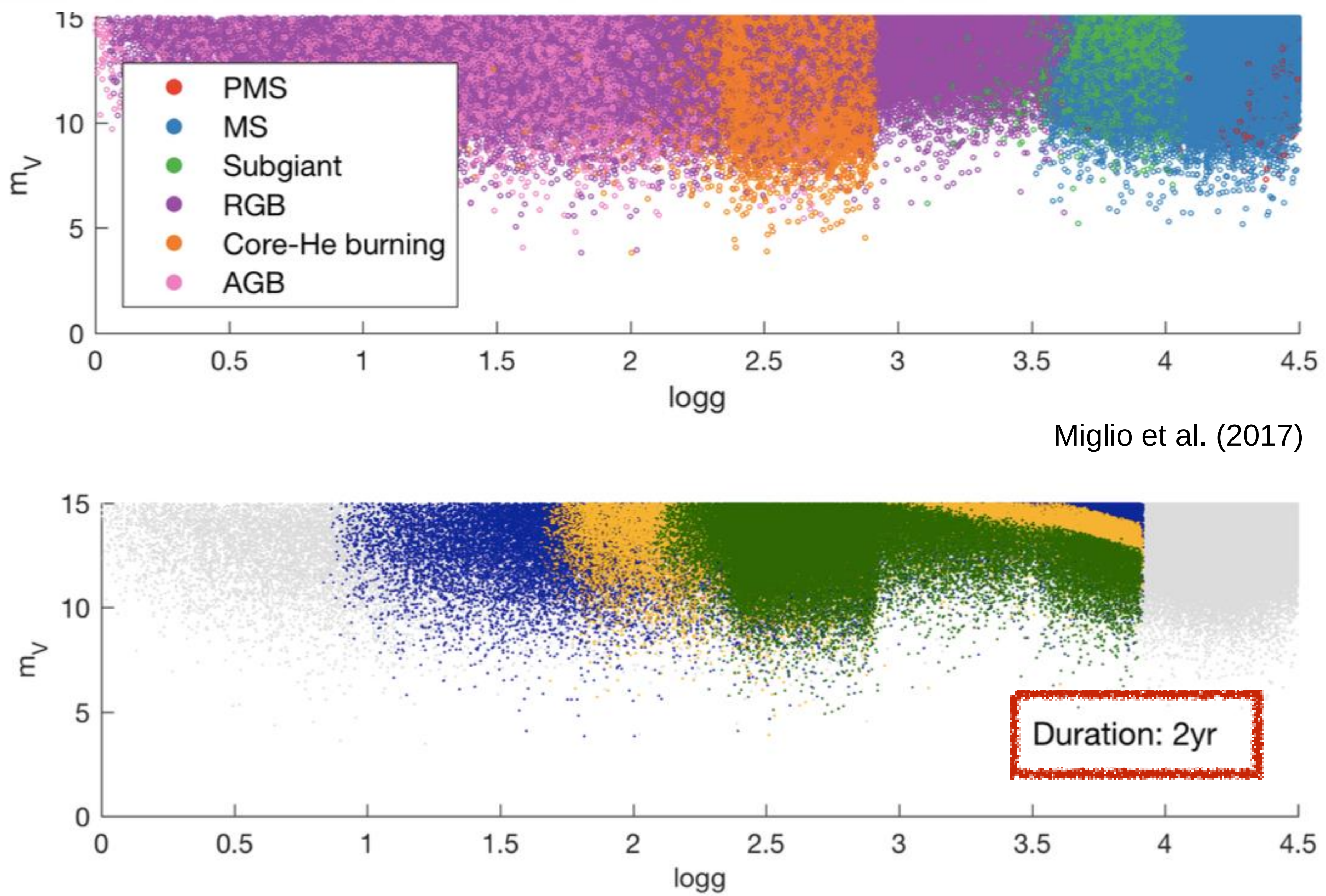

Miglio et al. (2017)

→ *it shows that the asteroseismic yields of PLATO are potentially enormous*

→ *but still a lot of work is to be done to reveal all PLATO potentialities*

What's next?

✓ Up to now, the performance work mainly focused on the main objectives of PLATO (e.g. a terrestrial planets in the habitable zone of solar-like stars.)

✓ With the adoption, the scientific preparation of the mission will accelerate, for instance the assessment of the seismic performances for:

- a larger diversity of planet-host stars and the stars without planets
- solar-like oscillating red giants, F5 to K7 stars in clusters, eclipsing binaries, etc…
- the particular case of bright stars

↓

to that end, the *Kepler* Legacy sample as well as TESS observations will be extensively used for performance calculation but also as benchmarks