Issues from Plato HH exercises

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Goal : to estimate the uncertainties of seismic determination of stellar parameters (radius, mass, age) of Plato target stars. Focuse on stars from the core program*

Core program*: F to K stars i.e. main sequence stars and subgiants with masses below about 1.4 Msol

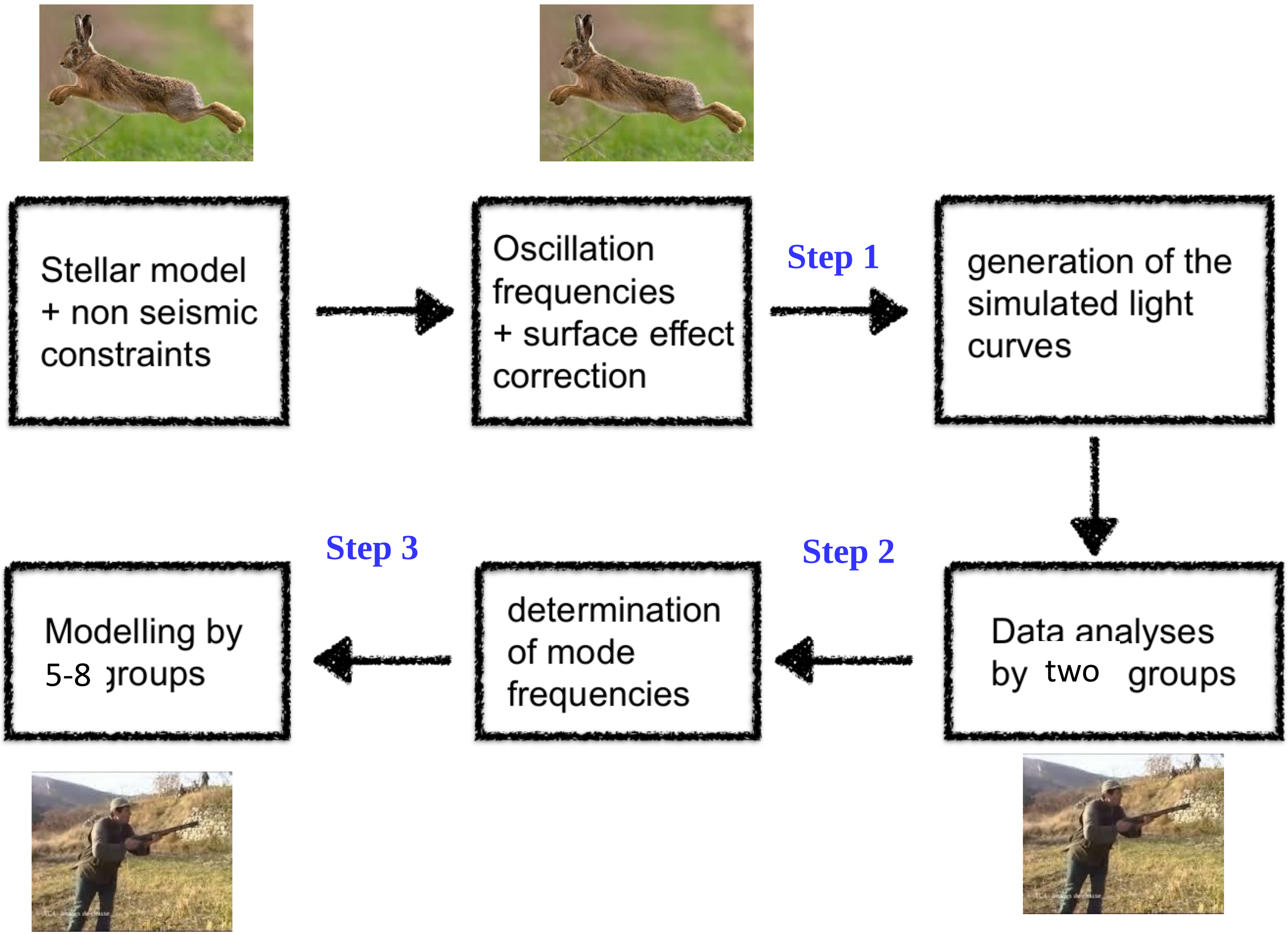
Plato spec: 10% on age
10 % on mass
1% on radius

for the reference star (1Msun, 1Rsun, 6000K) with V=11

In 2015, several successive blind tests : **HH1- HH2a and HH2b, HH3**

'simple' cases : stellar models with low mass and chemical comp. such that no convective core is present
stellar model close to the PLATO 'reference star' (1Msol, 1Rsol, 6000K)

HH schema



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

Input models (hare)

HH1, HH2b, HH3 : 1.12 Msun, 1.20 Rsun, T_{eff} = 6130 K, age = 3.44 Gyr (Xc=0.30)
Z_{ini} = 0.014, Y_{ini} = 0.26, $(Z/X)_{ini}$ = 0.019 AGS09 mixture
V=9, 10 and 10.5
α_{cgm} = 0.65 (CGM prescription)

diffusion, no overshoot

HH2a : 1.182 Msun, 1.34 Rsun, T_{eff} =5954K, age =3.216 Gyr (Xc=0.25),
Z_{ini} = 0.016, Y_{ini} =0.25, $(Z/X)_{ini}$ = 0.022 AGS09 mixture
V=10
α_{cgm} = 0.50 (CGM prescription)

diffusion, no overshoot

Simulated Light curves

- T_{obs} = a two-year run
- a noise level according to the Plato specifications and expectations for Plato data

- In power spectrum , SNR =signal/noise

- **Noise** = photon noise (V) + instrum. Noise

- **Signal** = oscillations ((ν, A_ν , □ $_\nu$,), l-dependent visibility, □ (Teff),) + granulation (Teff)

- **Oscillation frequencies** l=0-3 modes
  surface effects scaled from 3D calculations (Sonoi et al 2015)

HH1, HH2b no splitting
HH2a splittings averaged rotation and inclination angle

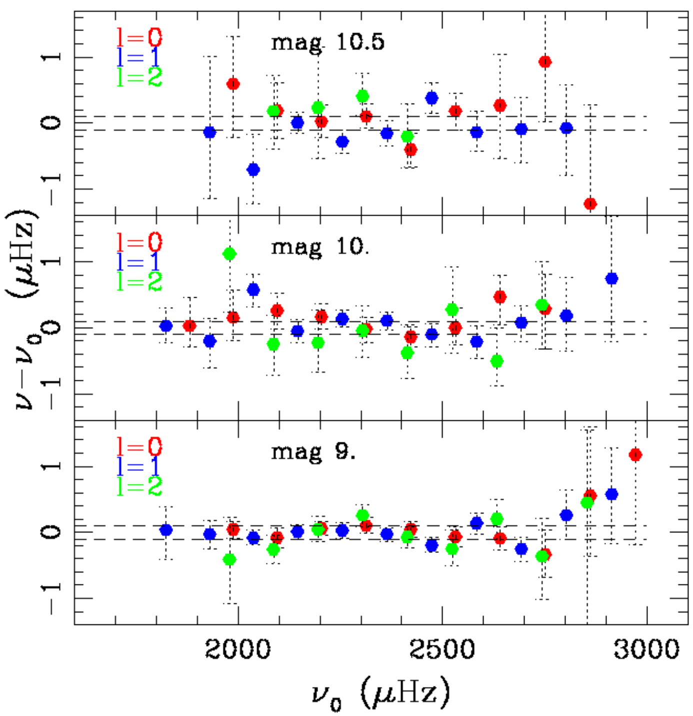
Step 2: Data analyses

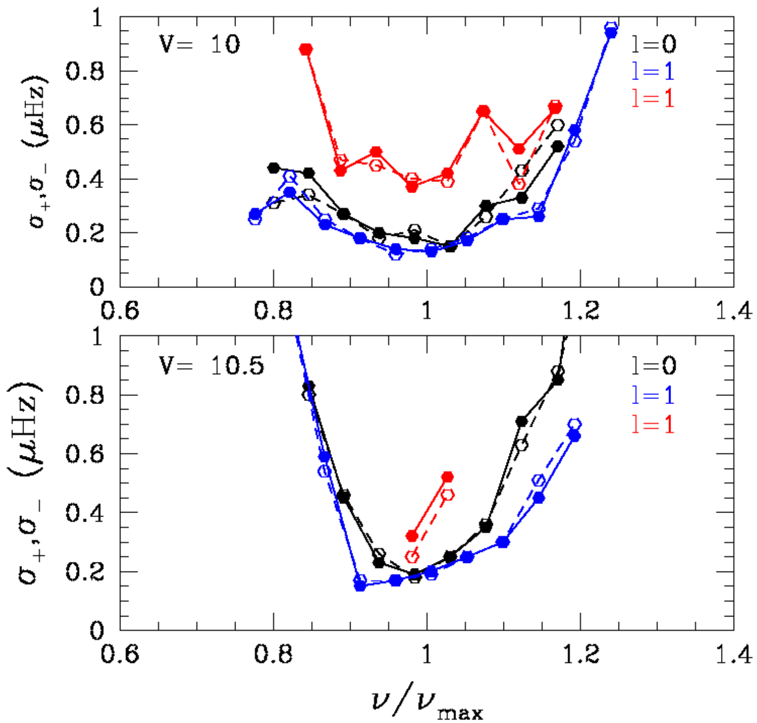
- carried out as blind tests by two independent groups (team 1 : Birm's group and team 2: O. Benomar).

- Accuracy at the level of 0.1 μHz for a large number of frequencies about the frequency at maximum power.

This fulfils the Plato specification.

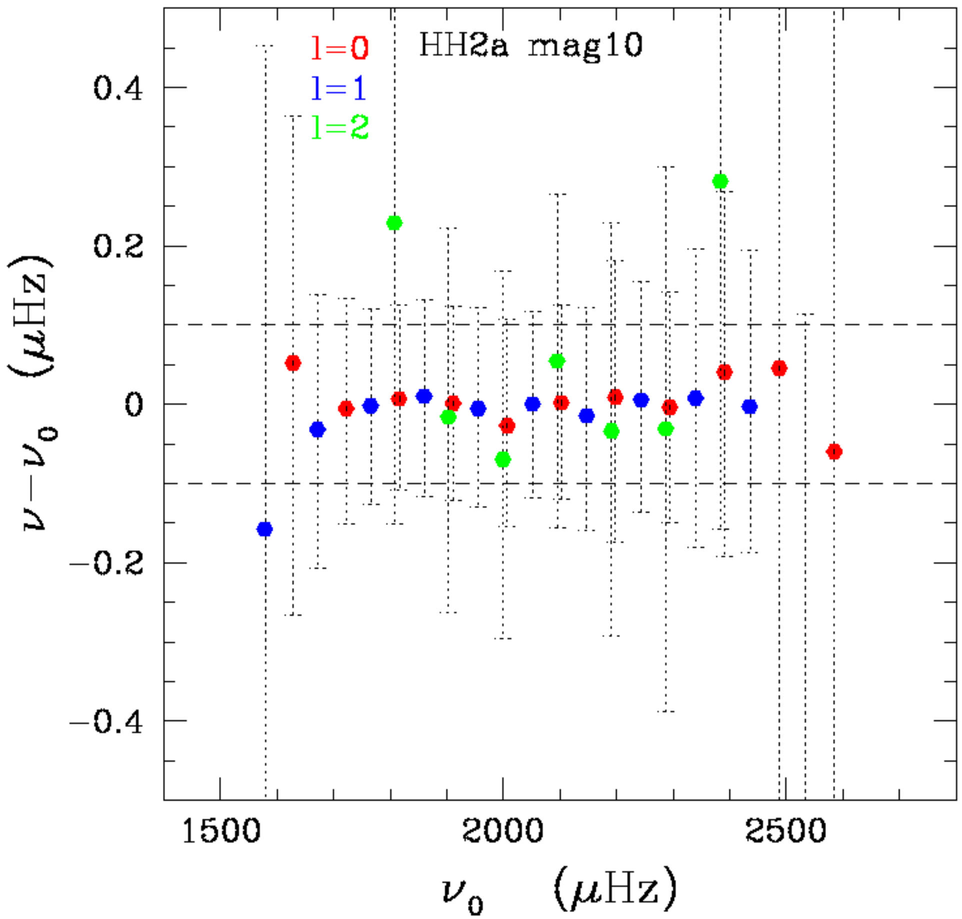
Photon noise : 27 ppm/h at V=11



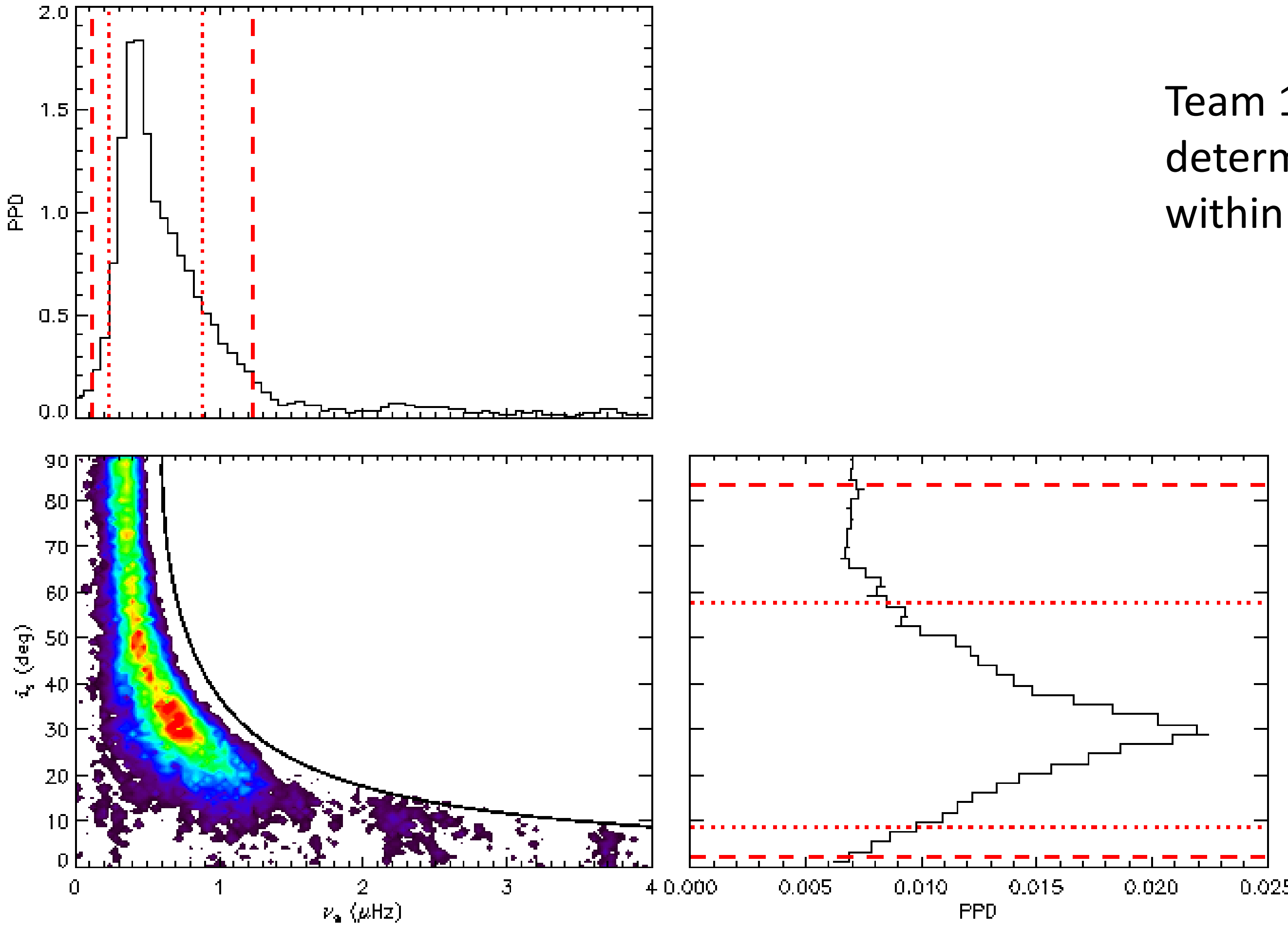


Step 2: Data analyses

Comparison between the results of both teams : team2 –team 1



Determination of the averaged rotation rate and inclination angle



Team 1 : determination within 1 sigma

Step 3 : derivation of mass, radius and age

Non-seismic observational constrains :

HH1 Teff = (5894 ± 80) K; log L/Lsun = 0.318 ± 0.030; [Fe/H] = 0.065 ± 0.051dex

(the constraints on T_{eff} and log L/Lsun are within 1 σ error while the constraint on [Fe/H] is at ~ 2.1 σ from the real value).

HH2b, HH3 cases : T_{eff} = (6100 ± 80) K; log L/Lsun= 0.22 ± 0.03; [Fe/H] =0.04 ± 0.05 dex

(the constraint T_{eff} is within 1 σ- error while the constraint on [Fe/H] is at ~ 1.9 σ from the real value and the constraint log L/Lsun is at 1.3 σ from the real value).

Step 3 : derivation of mass, radius and age

Stellar parameters

M1 : CESTAM+ ADIPLS + Levenberg-Marquard (S .Deuheuvels, **purple: SD**)
M2 : (V. Silva-Aguirre, **blue : SAV**)
M3 : CESTAM+ LOSC + Levenberg-Marquard (Y. Lebreton, **dark green : YL**)
M4 : AMP (ASTEC+ADIPLS+gen. alg.) (O. Creevey, **cyan : OC**)
M5 : ASTFIT (ASTEC+ADIPLS+ grid) (J. Christensen-Dalsgaard, **red : JCD**)
M6 : + grid) (D. Reese, **black : DR**)
M7 : (I. Roxburgh, **magenta:IR**)
M8 : MESA (K. Verma & H. Antia, **light green : AM**)

Glitches
A. Mazumdar

Details in Reese et al 2016, Silva-Agurre et al 2015 and later today

HH1 : Impact of the choice of surface effect modelling

Two experiments were conducted with surface effects added to the frequencies from an oscillation,

- B1 case : the level of surface effects much higher than standard
- B2 case : the level of surface effect level is standart but the way there are modelled are based on 3D simulations

Hound :

❖ Mass and radius within the spec

❖ When included, surface effects

- from an empirical relation such as the currently used Kjeldsen-Bedding one (**M1, M3**)
- from a scaling to the Sun (**M5**)

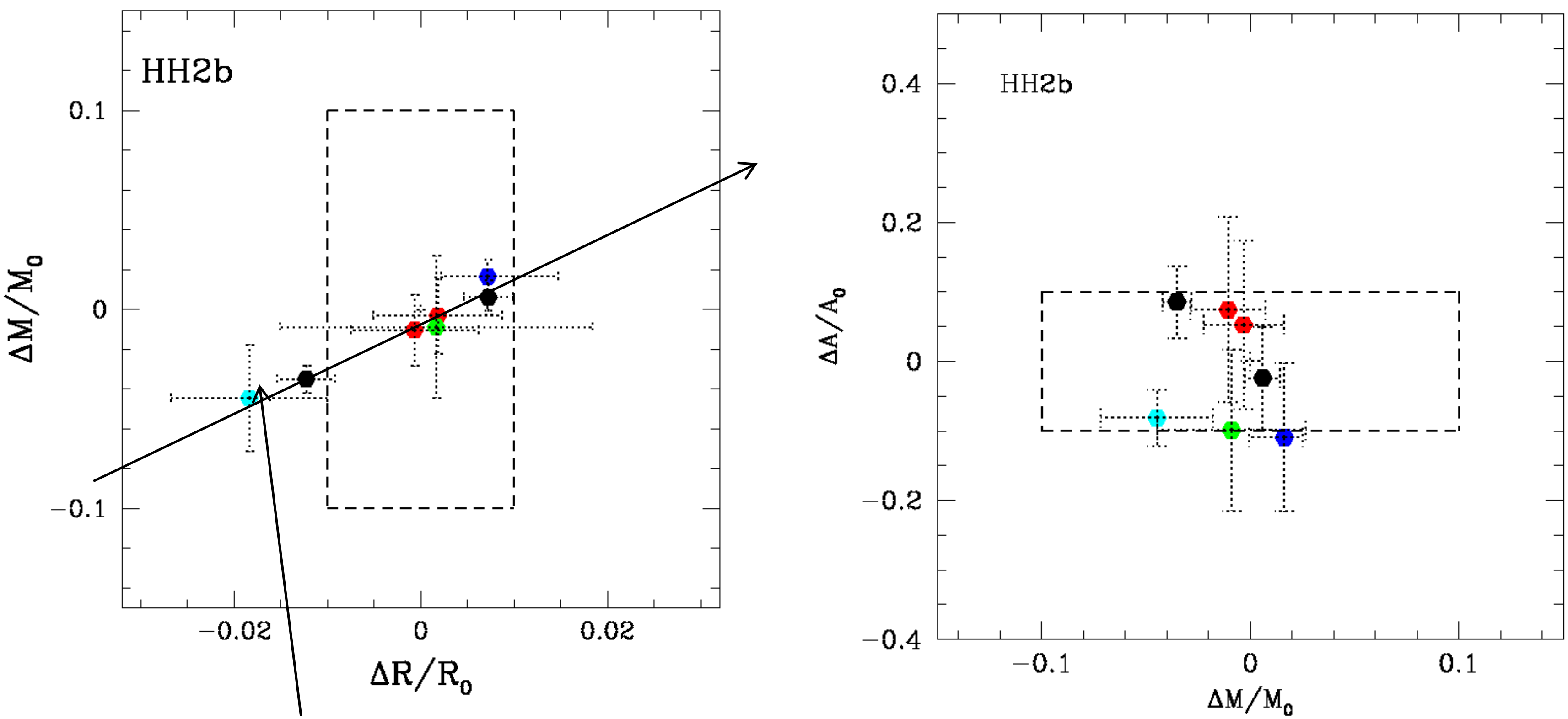
M5 : The results shows that the age is quite underestimated in the B1 case whereas it is slightly surestimated in the B2 case. B2 case provides a better fit than the B1

However for HH1,

- ➢ noise level overestimated
- ➢ Widths of the modes not the correction variaiotn with frequency

Mass, radius and age for HH2b

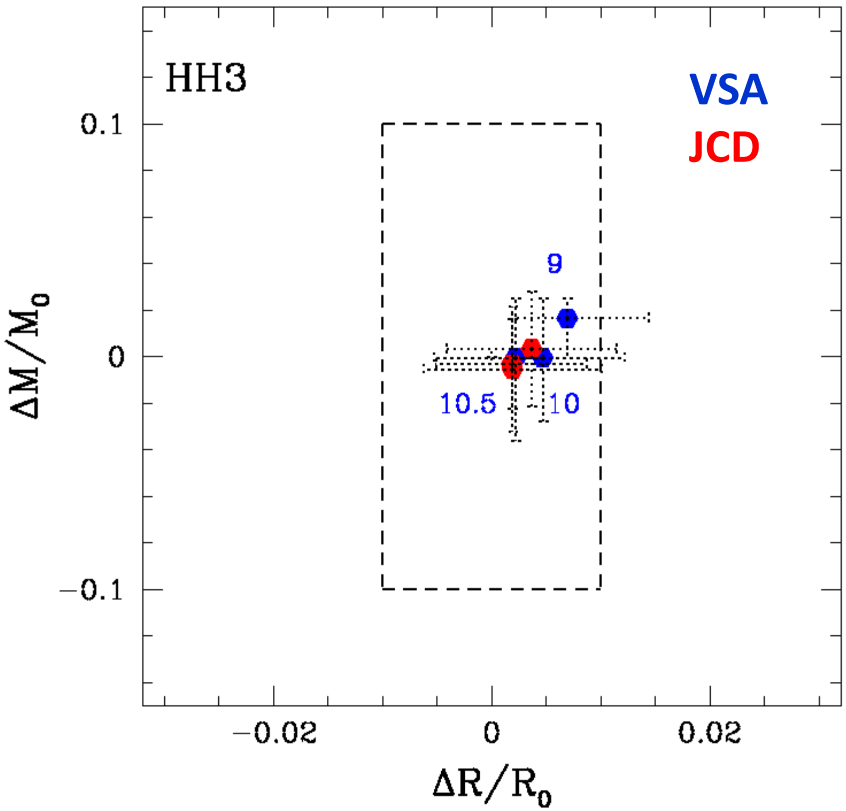
The mass, radius and age are retrieved within 2-4%, 1% and 10 % respectively, that-is within the Plato Specifications.

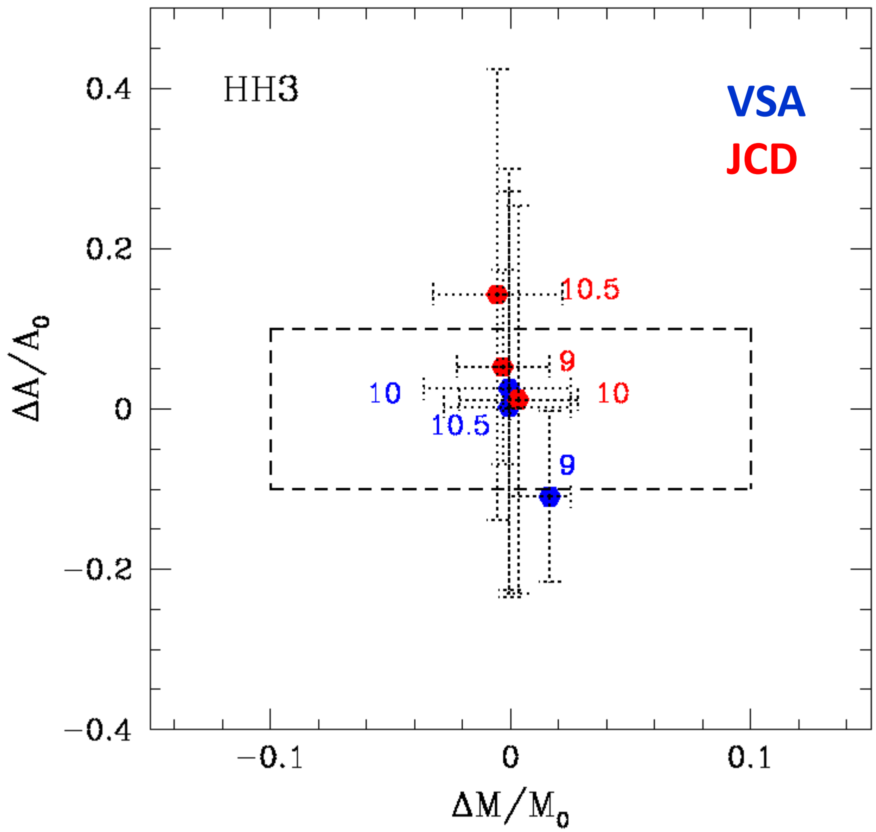


Seismic constrain on the eean density

HH2b, HH3 : impact of the magnittude of the star

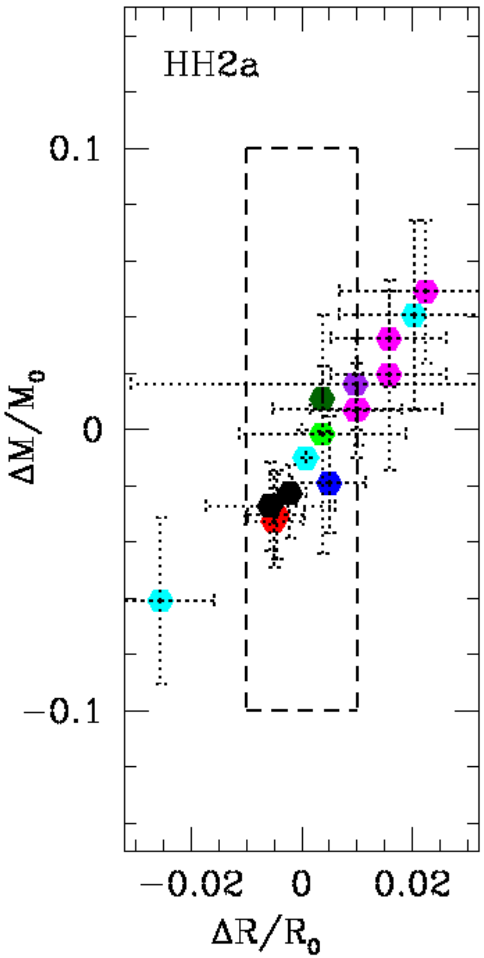
- Small on accuracy (X$_{true}$-X$_{est}$)/X$_{true}$ with X=M, A, R ⁇ within the spec
- Larger for the estimated uncertainties (observational error propagation) > 10% for the age
- for V=10.5

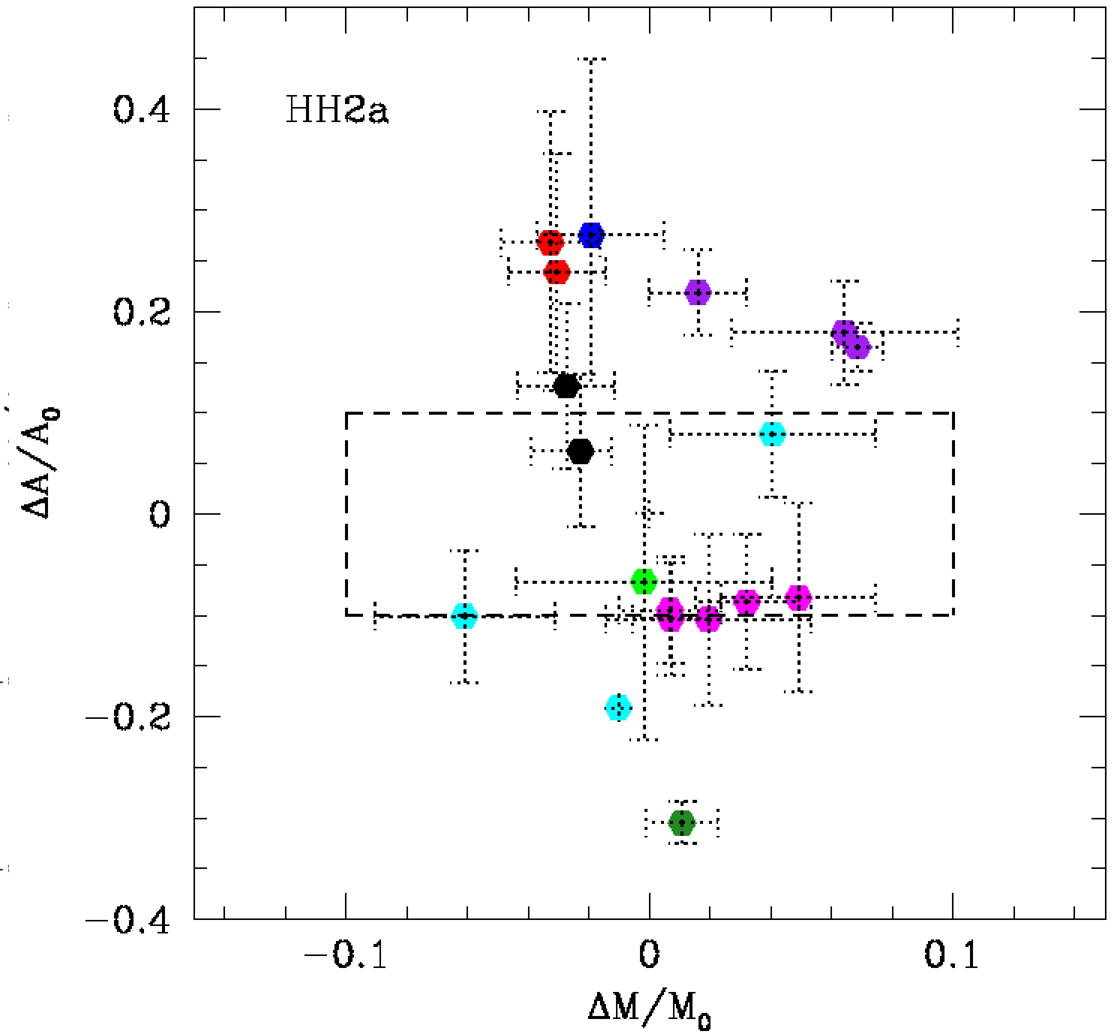




Mass, radius and age for HH2a

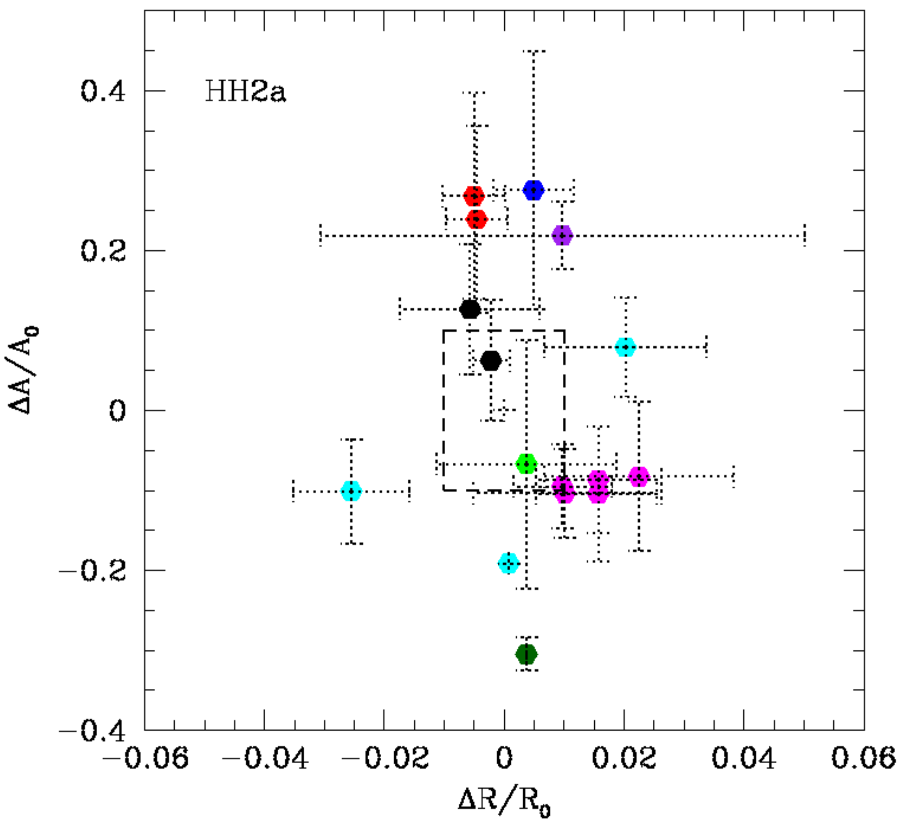
The mass always within the spec; the radius accuracy is at or better than 2%
The age is recovered with an accuracy better than 30 %: 3 modellers are within the spec, the others ar'e at 2 -2.5 sigma





Mass, radius and age for HH2a

- All solution as are within the spec for te mass
- Given a satisfying mass, the radius and the age do not comply with the spec in most cases : either the mass or (exclusively) the radius is within 1 ⍰ of the spec.



Group 1 : satisfy the age spec but NOT the mass nor the radius

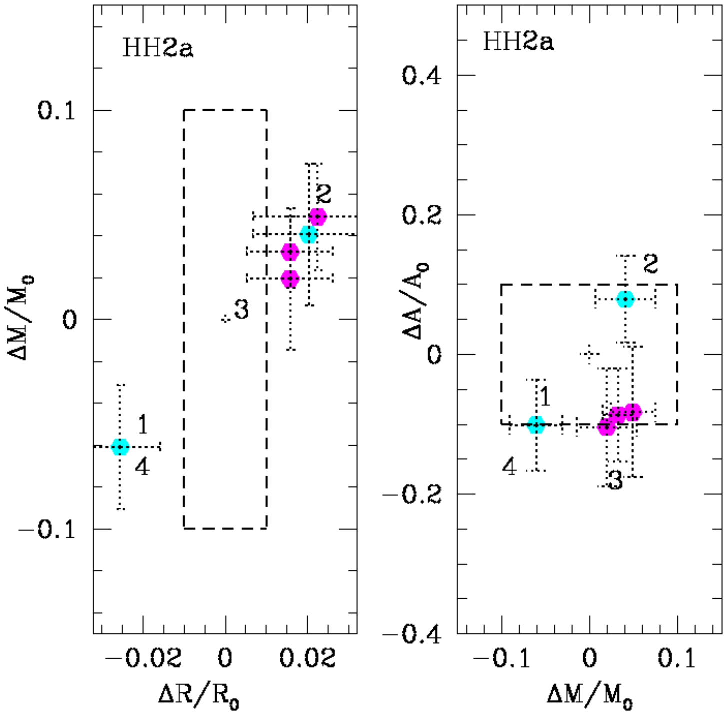
Group2 : satisfy the mass and radius spec but NOT the age

Group3 : satisfy all spec

Group 1 : satisfy the spec for the age but not for the mass nor the radius

M7 :   optimal solutions with fixed alpha_conv et Y_ini.
They ar not adjusted in order to compensate for differeces in the description of convection or other physical content or chemical mixture

OC : only ratios of frequency combination. *They appear to be not sufficient to constrain the mass When a low radial order is added as a constrain, the mass and the radius ten fall within their respective spec but the age no longer does*



Group2 : satisfy the mass and radius spec but NOT the age

These models have all different comp.chim. and different from the true one
These models have a ⍰ smaller than that of the Sun as does the true one.

- **M1, M2, M5** overestimate the age.

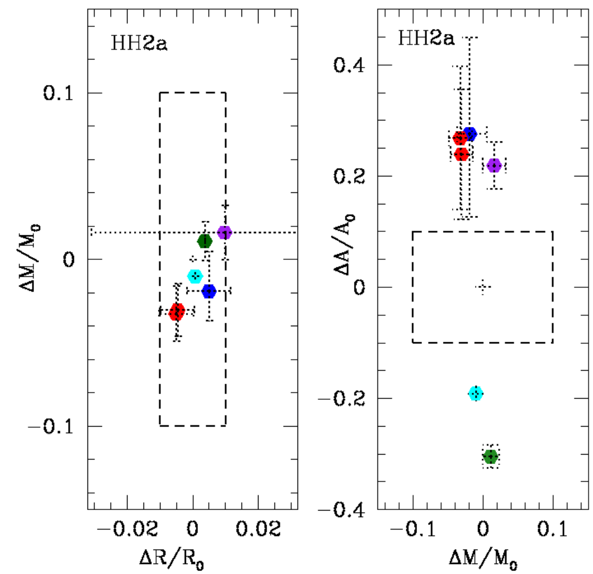
  M2, M5 : a mixture close to the one used for the input model but Yini is determined from a *standart Galactic enrichement law* ⍰ *Y/*⍰ *Z* whereas the input model had a much lower value thn standart

  M1 : same mixture, same convection prescription (CGM), same evolutionary code but *no diffusion included whereas the input includes diffusion.* (see also spacein HH, Reese et al 2016)

  A calculation including diffusion leads to a 4 % error on the age

- **M4, M3** underestimate the age.

They use the solar high metallicity chemical mixture GN93 whereas the low metallicity chemical mixture is used for the input model.

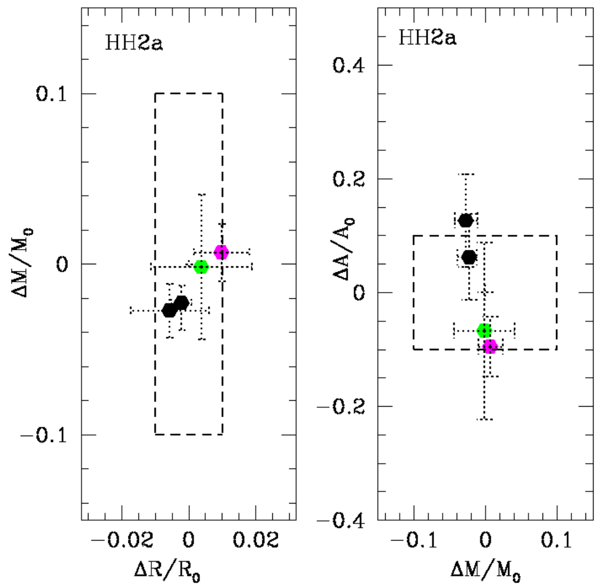


Group3 : satisfy all spec : mass , radius and age

M6,**M7** **M8**

satisfy all spec despite the fact they did not adopt the same chemical mixture, the same convection, than the input model. The reason is that they have more flexibility for the adjustment : no Galactic enrichment law, helum content and metallicity independent

- **M6**,**M7 :** no constraint from [Fe/H]
- **M7**,**M8** an additional parameter alpha_ov (imposed to 0.02 for **M7** and adjusted to 00234 for **M8**) These models have a convective core.
- **M7** several solutions for various imposed (Yini, alpha_conv). No criteria to select the correct one is applied.
- **M6** mass, radius and age are averages over all optimal s *computed independently. The averages set (mass,radius, age correspond to a single stellar model.*



Impact of the choice for the mixing length parameter

M5 carried two computations:

- one with the mixing length fixed to a solar value
- one with the mixing length taken from a grid of values.

The results shows that the mass in unaffected but is slightly off the true value.
The age and the radius are closer to the true values when the mixing length is not fixed to an arbitrary value but is let free to ajust.

HH2a: M1 conducted three computations :

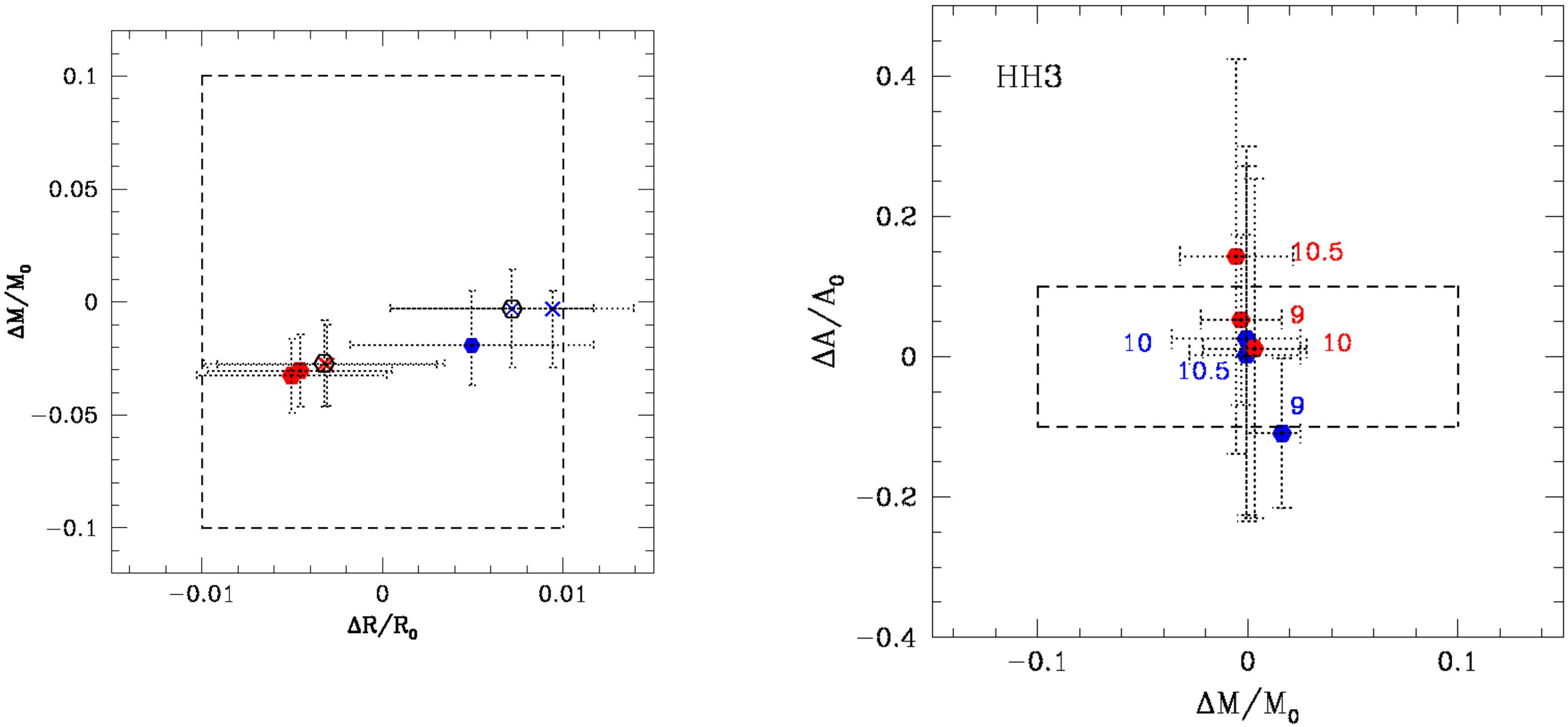
- two assuming the mixing length fixed and set to the calibrated solar value
- one solution obtained by ajusting the mixing length as a free parameter.

The result clearly again shows that letting the alpha parameter free
enables to retrieve correctly the mass and the radius within the Plato specifications.

Propagation of non seimic observational errors

M2 (blue) and M5 (red)

dots : sigma(Teff) = 80 K and sigma([Fe/H])= 0.05 dex
Crosses : sigma(Teff) = 80 K and **sigma([Fe/H])= 0.1 dex**
Circled dot blue : **sigma(Teff) = 120 K** and sigma([Fe/H])= 0.05 dex
Circled dot red : **sigma(Teff) = 120 K** and **sigma([Fe/H])= 0.1 dex**



Individual frequencies or frequency combination

- **HH1** : **M1** carried out two computations:

- one using only individual frequencies (M1a)
- one using ratios of frequency combinations + one low frequency (less sentitive to surface
- effect than higher ones) (M1b)

Unlike the expectation, the case M1a provides a better age whereas M1b provides a perfect mass and radius.
The reason is not clear. Is it due to the method which is a local optimisation or another systematic effect?

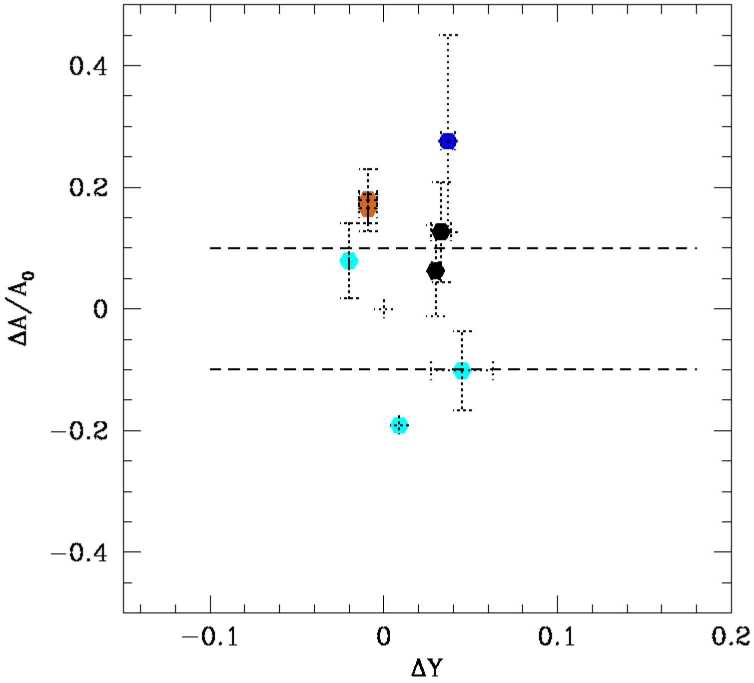
- **HH2** : **M4** carried two computations

- two results are based on the ratios only
- one with the ratios plus one low frequency.

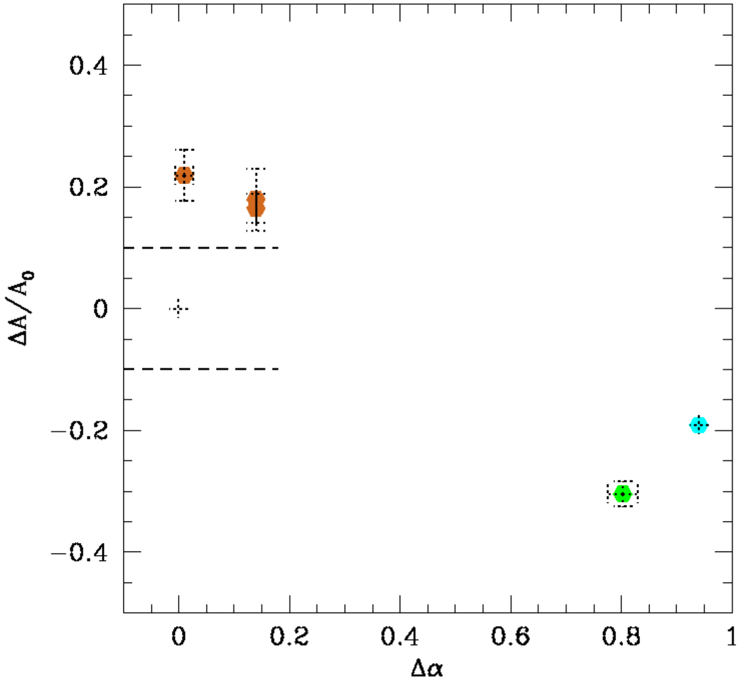
In the case of the ratio only, the mass AND the age are correctly retrieved nut NOT the radius.
When a low frequency is added, the mass AND the radius are correctly retrived but NOT the ag

Why ? Dependency to initial conditions ?

Age-helium correlation



Age- alpha correlation

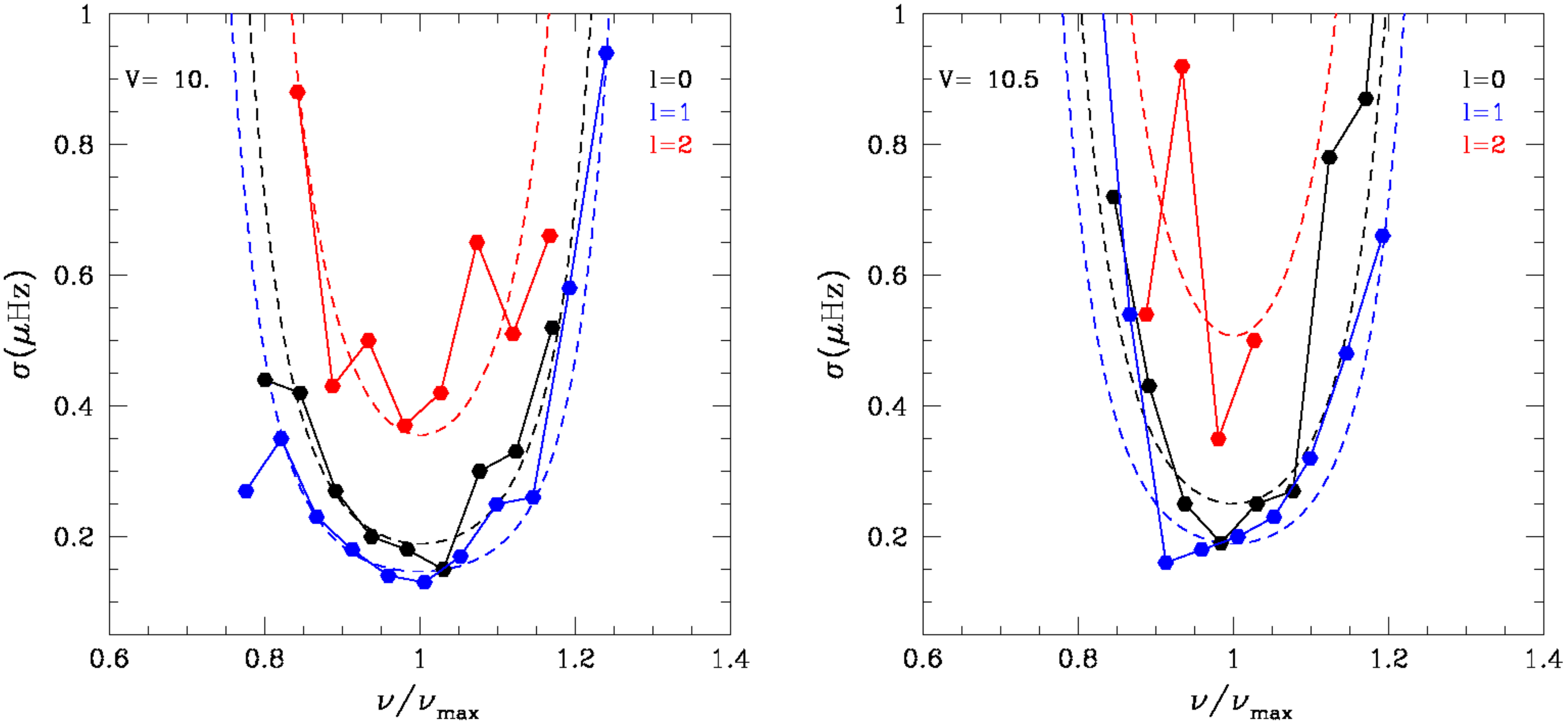


Action : ought to be extended and generalized

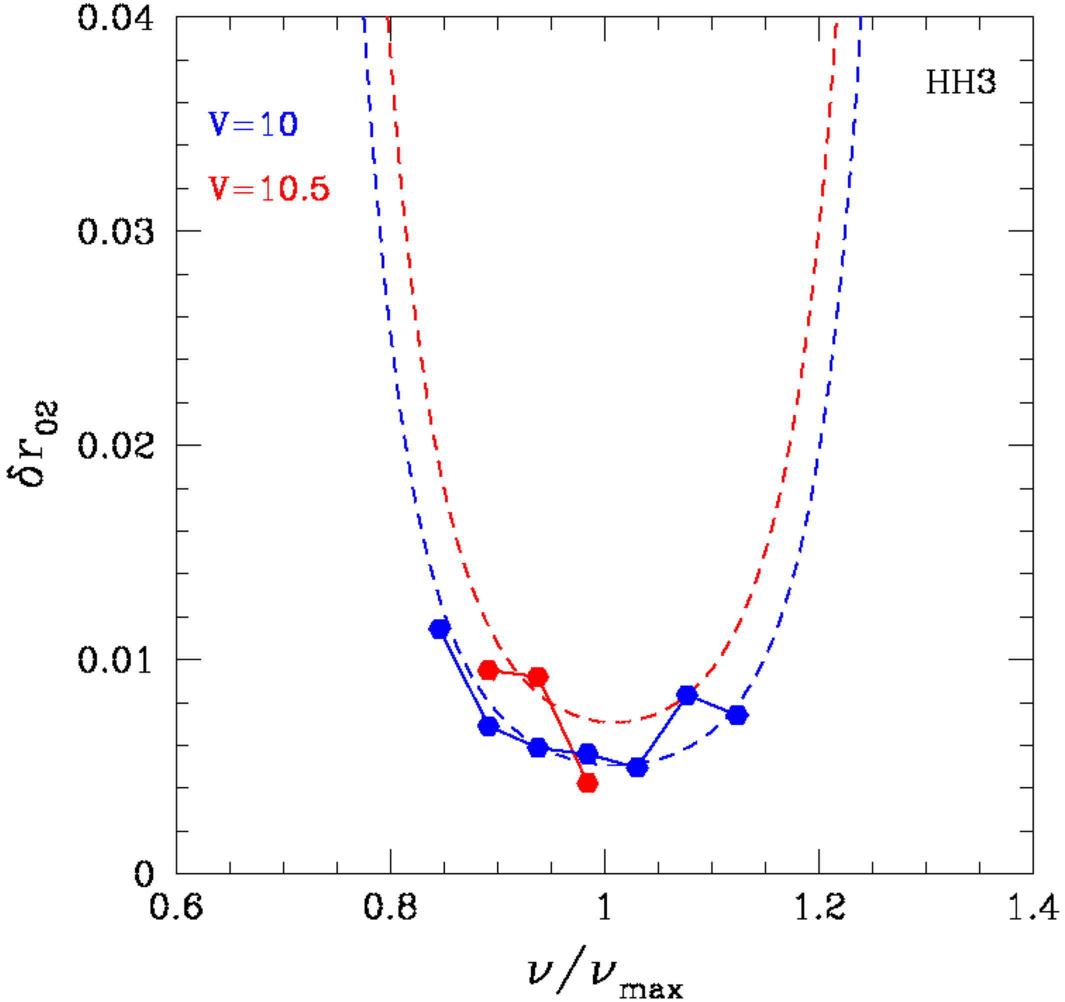
Mitigation from 32 to 28 N-Cam, 24 N-Cam, 20 N-Cam

Validation with a blind experiment HH3

27 ppm/h
wn_ref = 1/3

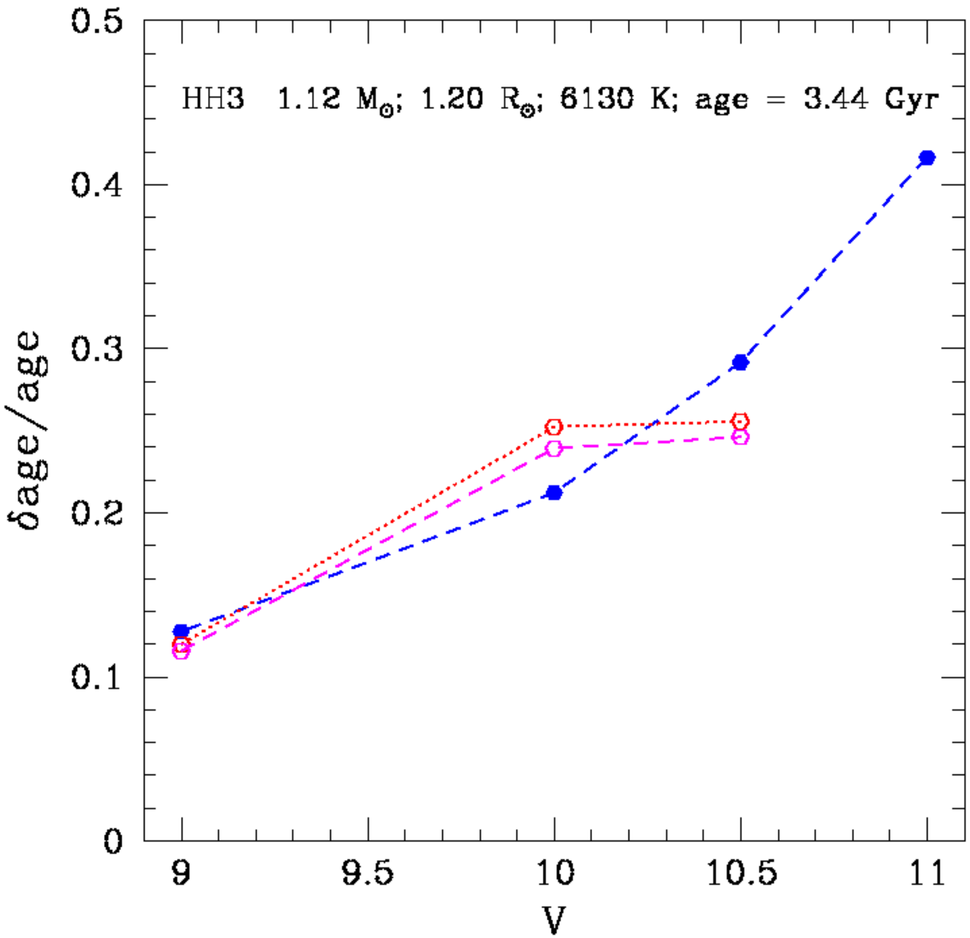


Validation of r02 uncertainty calculation with HH3

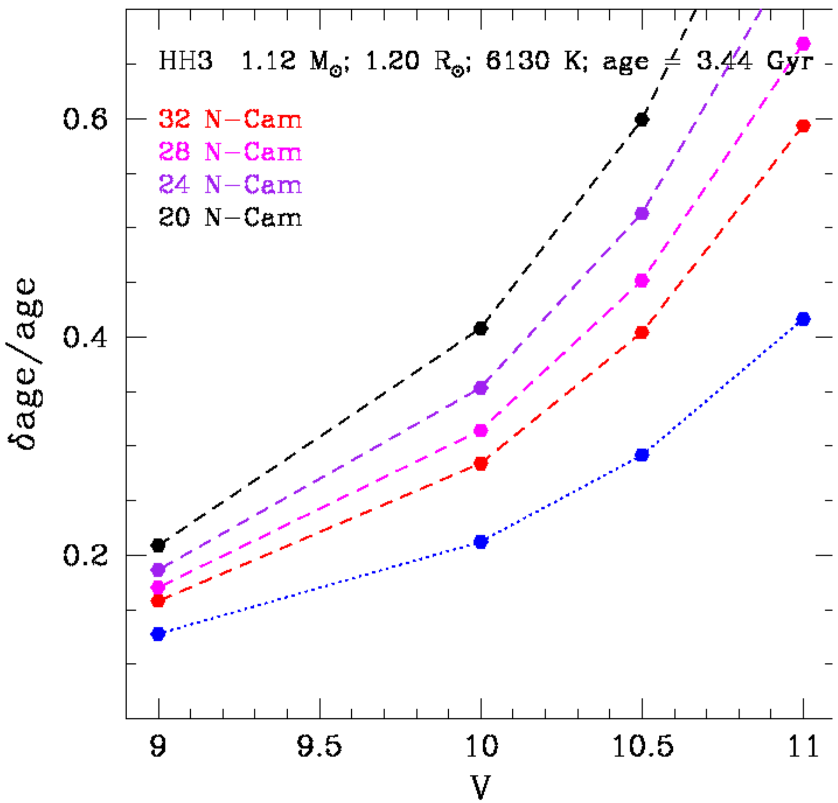


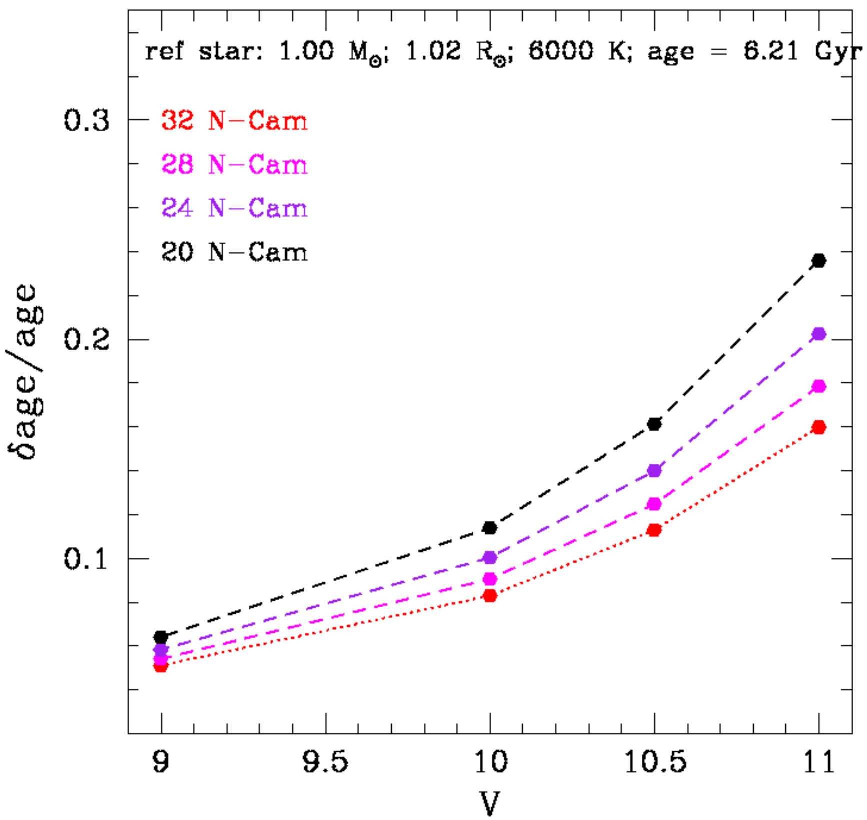
Validation of age uncertainty estimation with HH3

At V=11 with T_obs= 2 years
pn_ref = 27 ppm/h
wn_ref = 1/3 pn_ref
res_ref = 0
Total noise =28.5 ppm/h



Relative age uncertainty due to propagation of observational errors as estimated from optimisation methods : surestimation compared to true error (age_true - age_est)



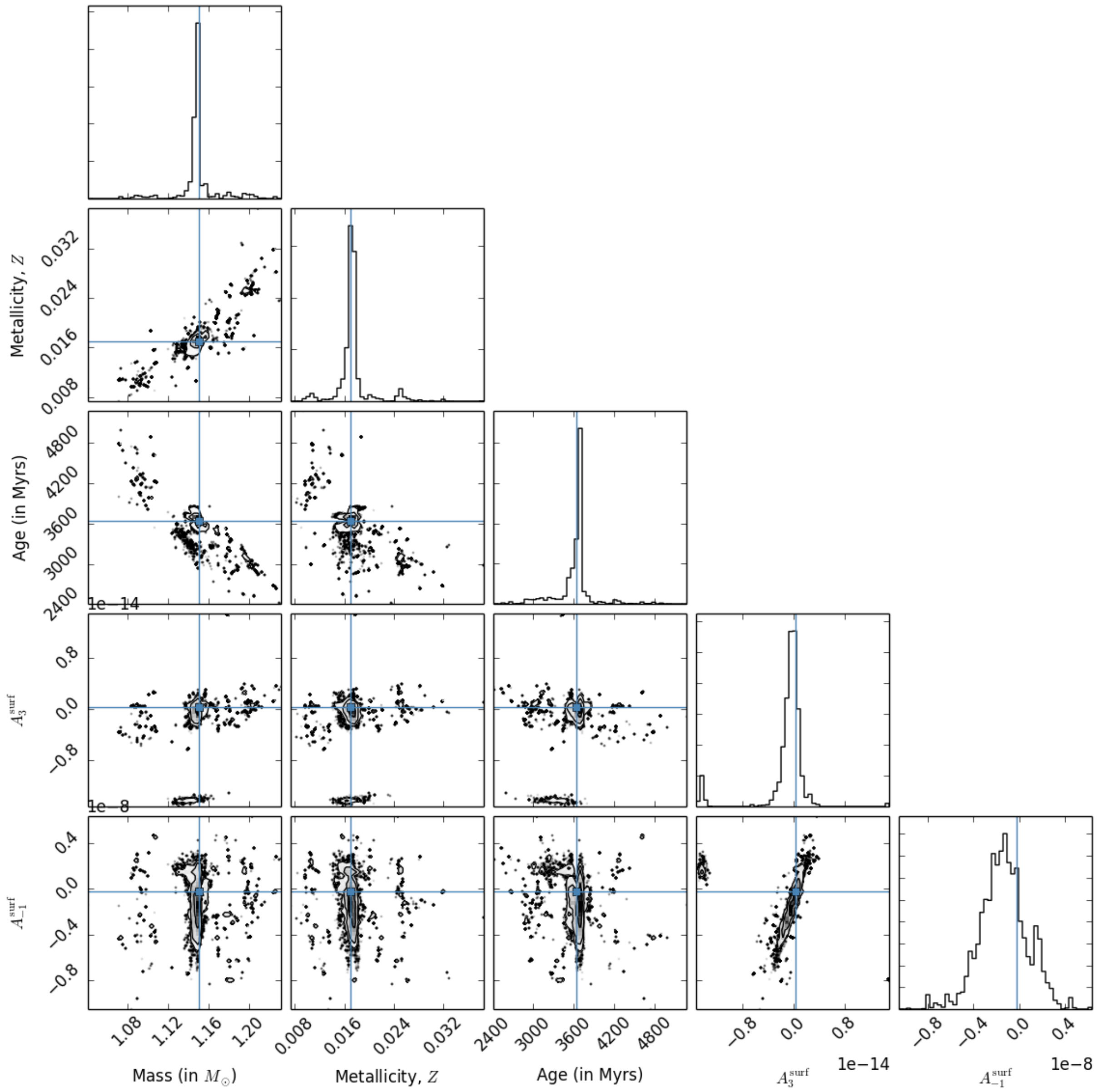


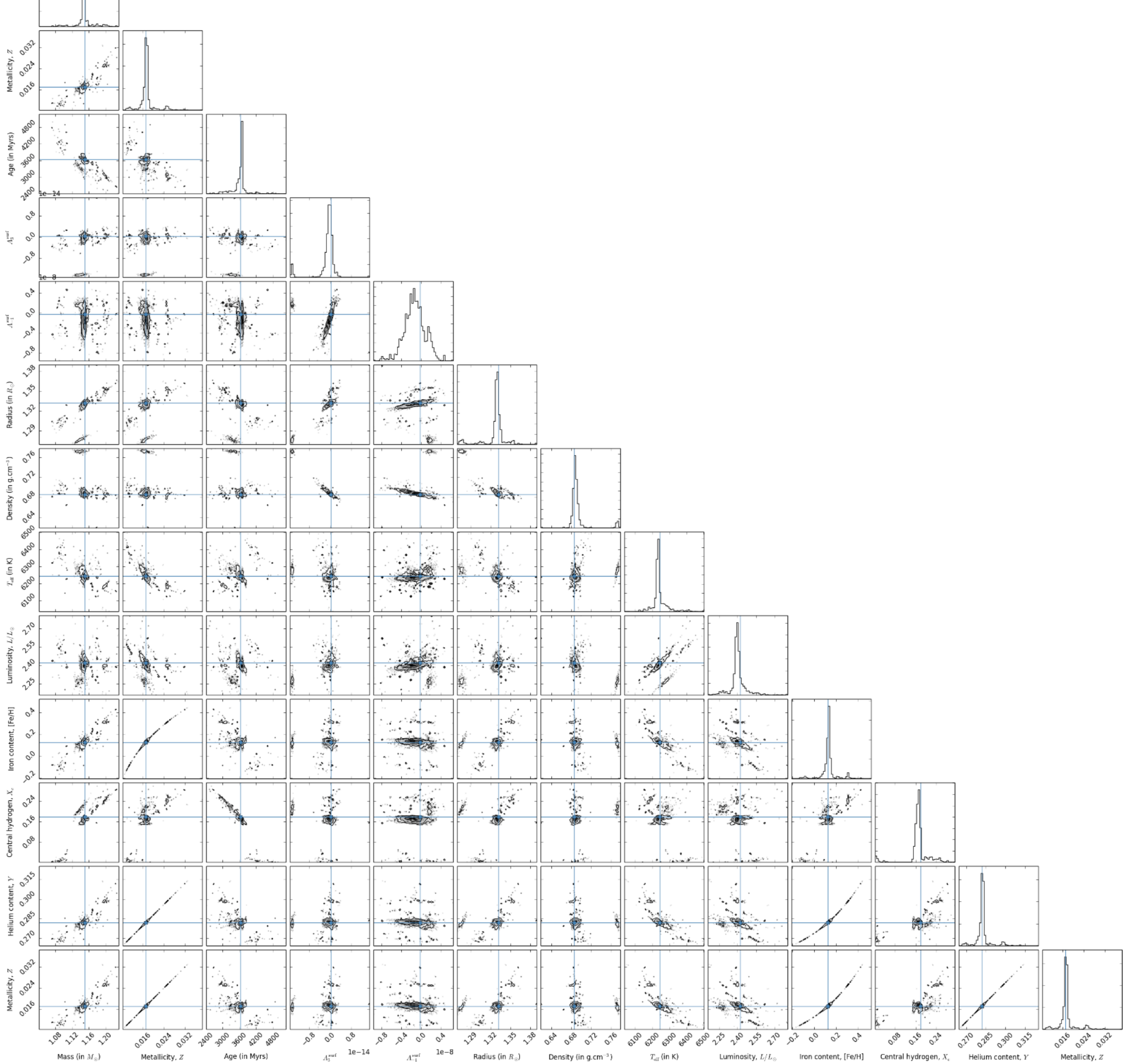
Note : Young stellar model i.e. higher relative age uncertainty than for older stellar models

Note : Differences between true age and estimated age well within error bars

END

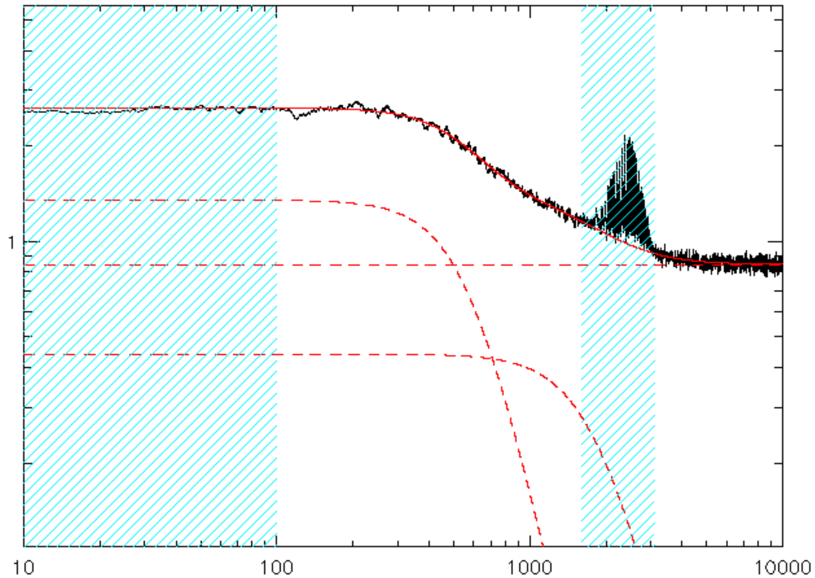
Correlation bewteen stellar parameters



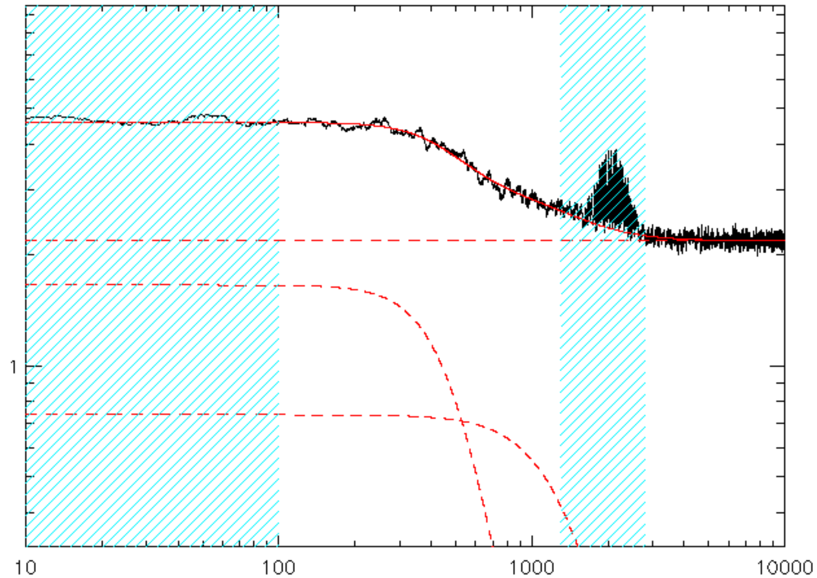


Mass (in $M_\odot$)
Metallicity, Z
Age (in Myrs)
A_1^{surf}
1e−14
A_{-1}^{surf}
1e−8
Radius (in $R_\odot$)
Density (in g.cm^{-3})
T_{eff} (in K)
Luminosity, $L/L_\odot$
Iron content, [Fe/H]
Central hydrogen, X_c
Helium content, Y
Metallicity, Z

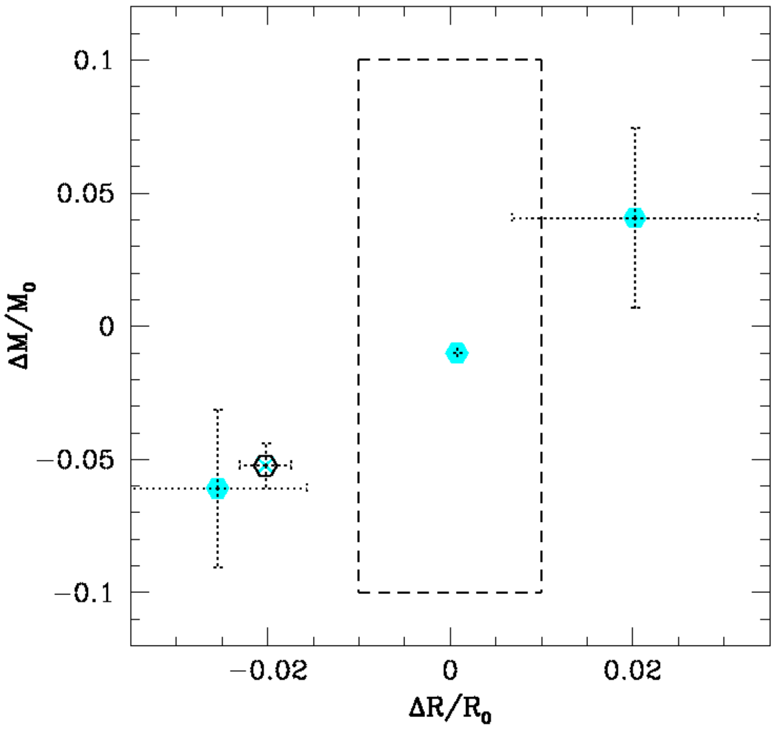
V=9



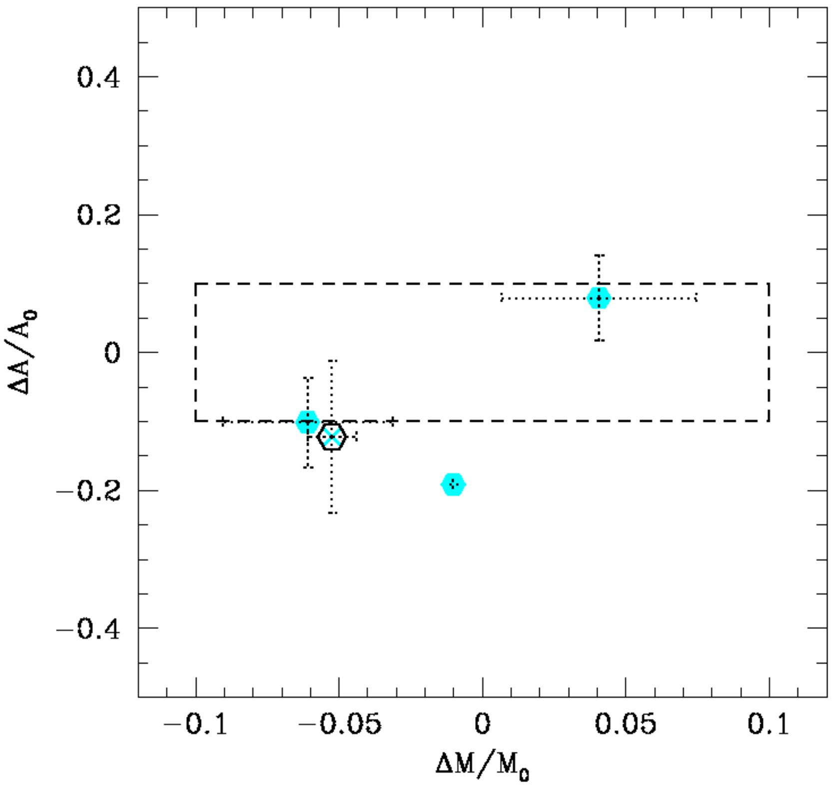
V=10



M4 tests



0.1
0.05
0
−0.05
−0.1
ΔM/M₀
−0.02
0
0.02
ΔR/R₀



0.4
0.2
0
−0.2
−0.4
ΔA/A₀
−0.1
−0.05
0
0.05
0.1
ΔM/M₀

With or without the luminosity constraint

IR

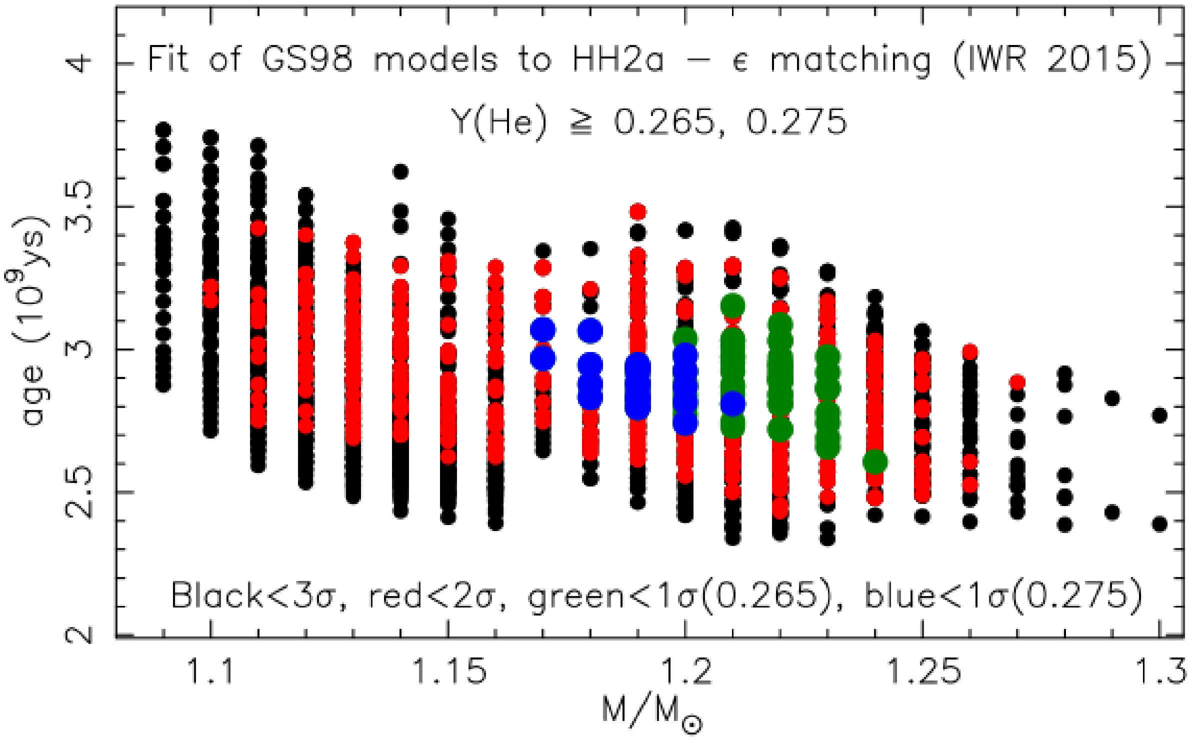


Figure 1: Model fitting using ϵ matching, 1, 2, 3 σ fits to HH2a data

For HH2a, the masses and radii are retrieved within 2-4 % and 1%, respectively, provided the proper seismic diagnostics are used. The ages are retrieved within 10% for several modellers and within a maximum of 30% uncertainty for the others. The larger uncertainty on the age for HH2a than for HH2b is
due to the chemical composition - the initial helium content, the metallicity, and the relative abundances of
the heavy chemical elements were assumed non-standard in the input model.

This can easily corrected by extended the grids of stellar models and the parameter space to explore : a posteriori tests were
performed and showed that by doing so the PLATO specifications are satisfied.

Conclusion, most of the tools are already available and quite efficient to accurately estimate masse radii, and ages of solar-like stars. However, improvements are expected during the development ph fully meet the Plato specifications on the age determination. An important part of the effort must ar concentrate on taking advantage of the appropriate seismic diagnostics for deriving constrains on th helium abundance and the relative abundance of the heavy elements.

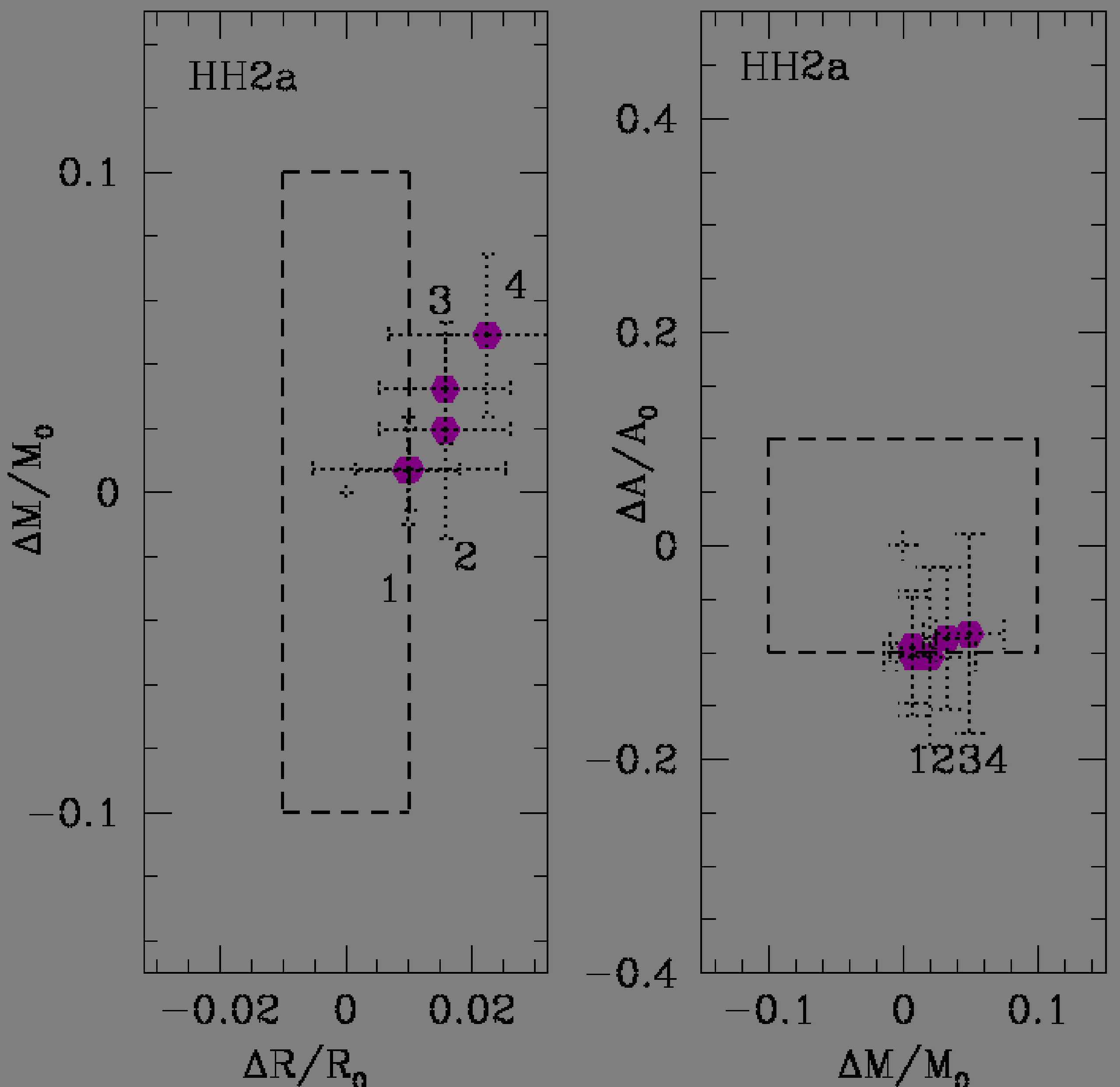
Issues

Summary and Conclusion for HH2a

These results show that the correct solution for the M, R, A can be found despite the fact that the physical input and the chemical composition are different from those of the input model. Adjustment of free parameters enable to build a model satisfying what the seismic diagnostics impose. With the adopted seismic diagnostics, the adjustments allowed to compensate the differences with the input model for the structure to give the proper age at the correct mass and radius Of course the value of the initial helium content used in the best fitting solutions does not correspond to the original value of the input model, nor the luminosity and in some cases the surface metallicity.
This characterization of a planet host star may be sufficient, unless information on the luminosity and/or the T_{eff} and/or the metallicity of the host star is needed, which will then require a model with the correct structure.

the impact of changing the number of cameras on the relative stella
age uncertainty. The relative age uncertainty is plotted as a funct

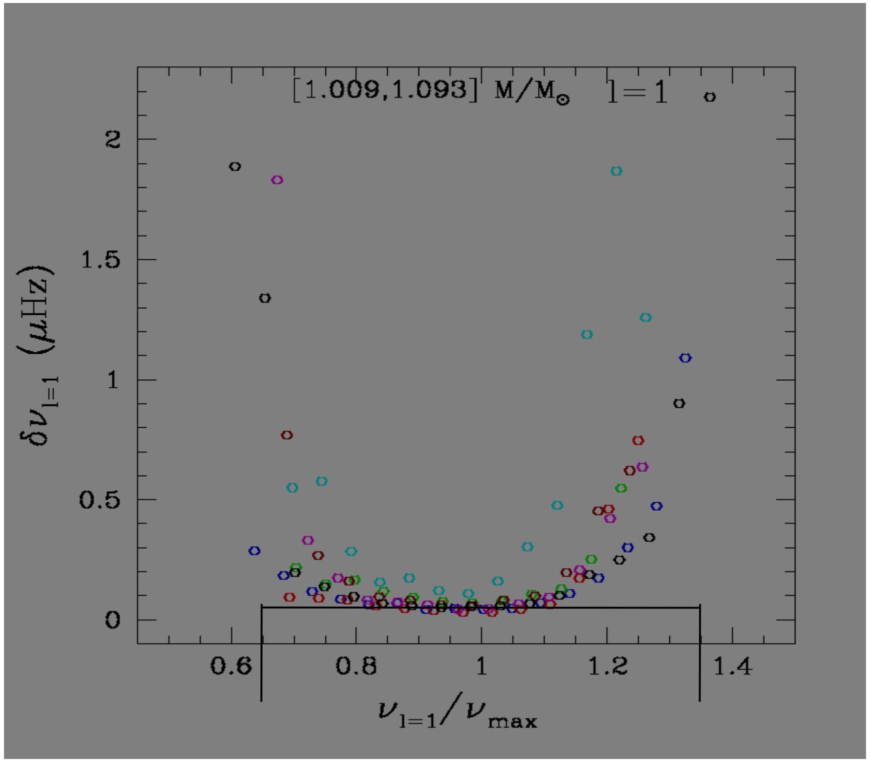
On the bad side, the calculation takes into account ONLY the chang
On the good side, here for sake of rapidity, I used only averaged

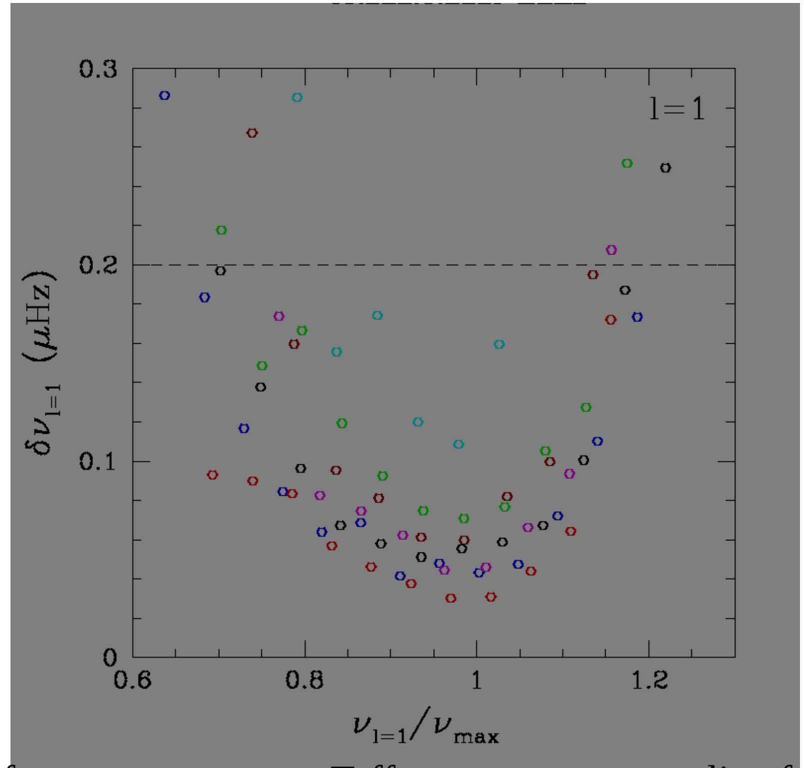

HH2a
0.1
0
−0.1
ΔM/M₀
−0.02
0
0.02
ΔR/R₀
1
2
3
4
HH2a
0.4
0.2
0
−0.2
−0.4
ΔA/A₀
−0.1
0
0.1
ΔM/M₀
1234

Consequences of mitigation (32 Ncam to 28, 24, 20 N-Cam) on age determination

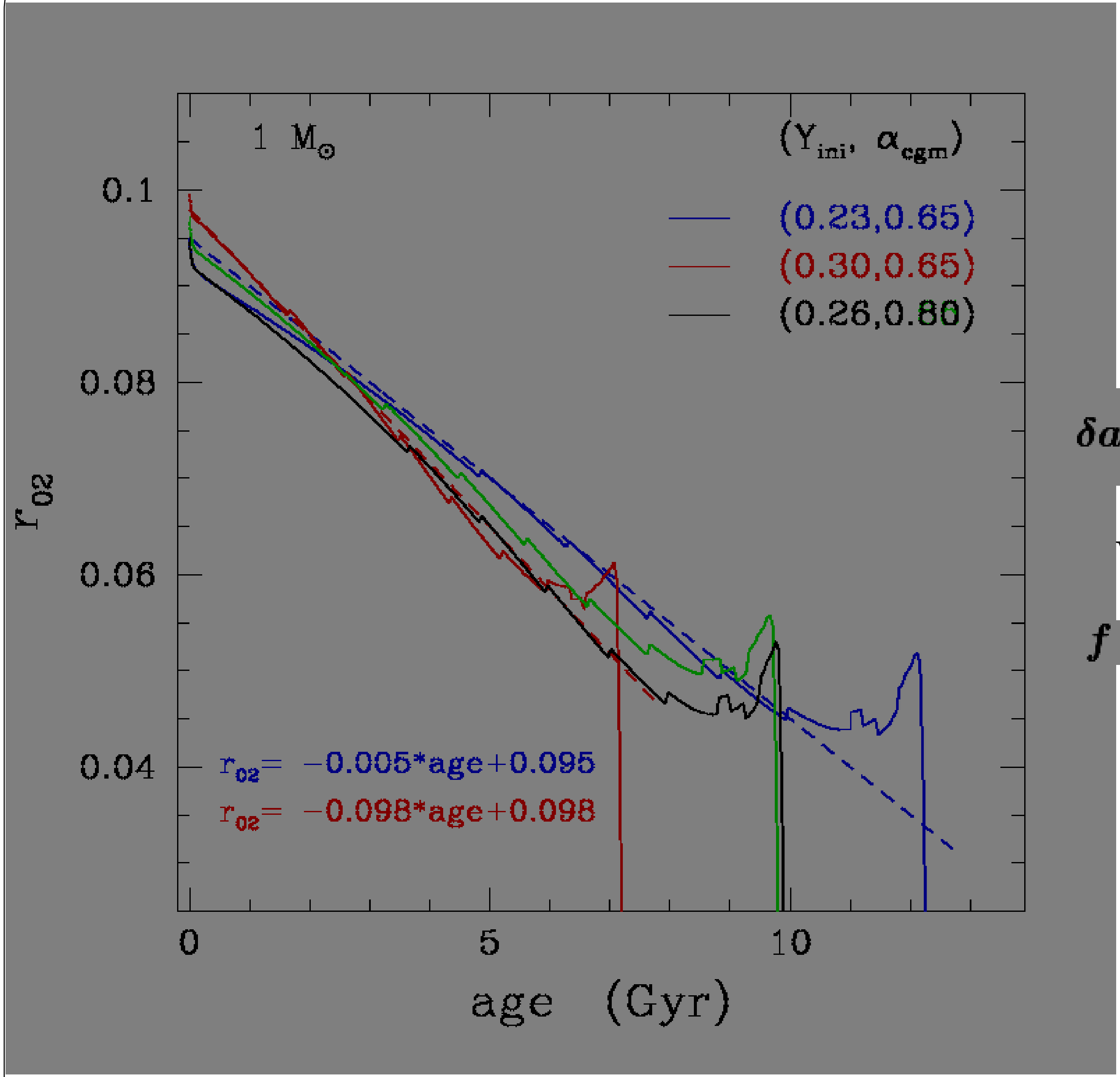
Age determination requires the use of stellar models and optimisation methods due to degeneracy in the set of constraints

Validation : Kepler data 1 year observation





Magnitude and teff		nb of frequency with <0.2 muHz	Teff	rescaling for Plato
V = 9.19 (0.02) red		11	5674	
V= 6.20 blue	16 Cyg B	12	5750	
V = 5.95 black	16 Cyg A	11	5825	
V = 9.55 (0.02) magenta		8	5668	
V =10.15 (0.04) chocolate		8	5811	
V = 9.91 (0.03) green		8	5852	
V = 10.78 (0.06) cyan		5	6047	

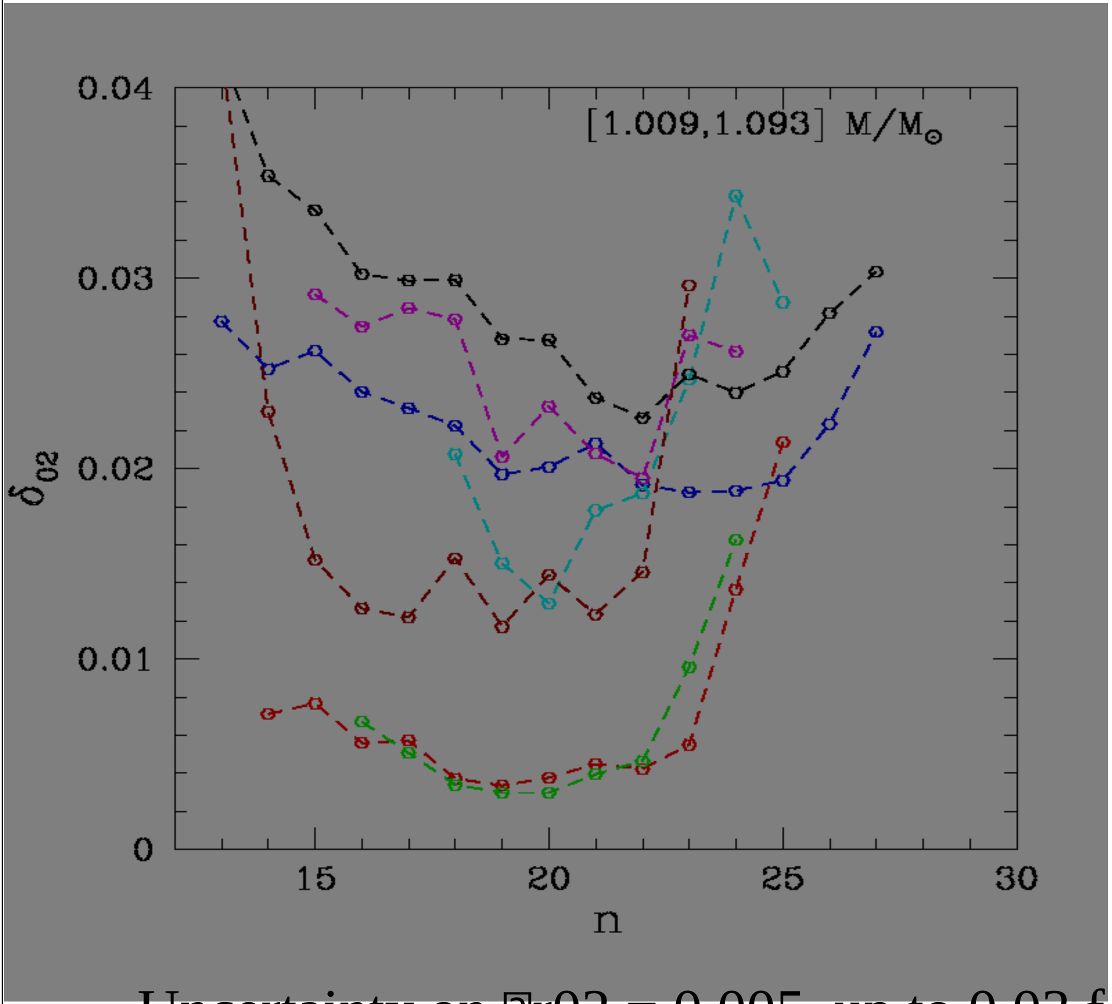


$$\delta age = \frac{1}{f} \ \delta r_{02}$$

with

$$f \in [0.005, 0.01]$$

Kepler data

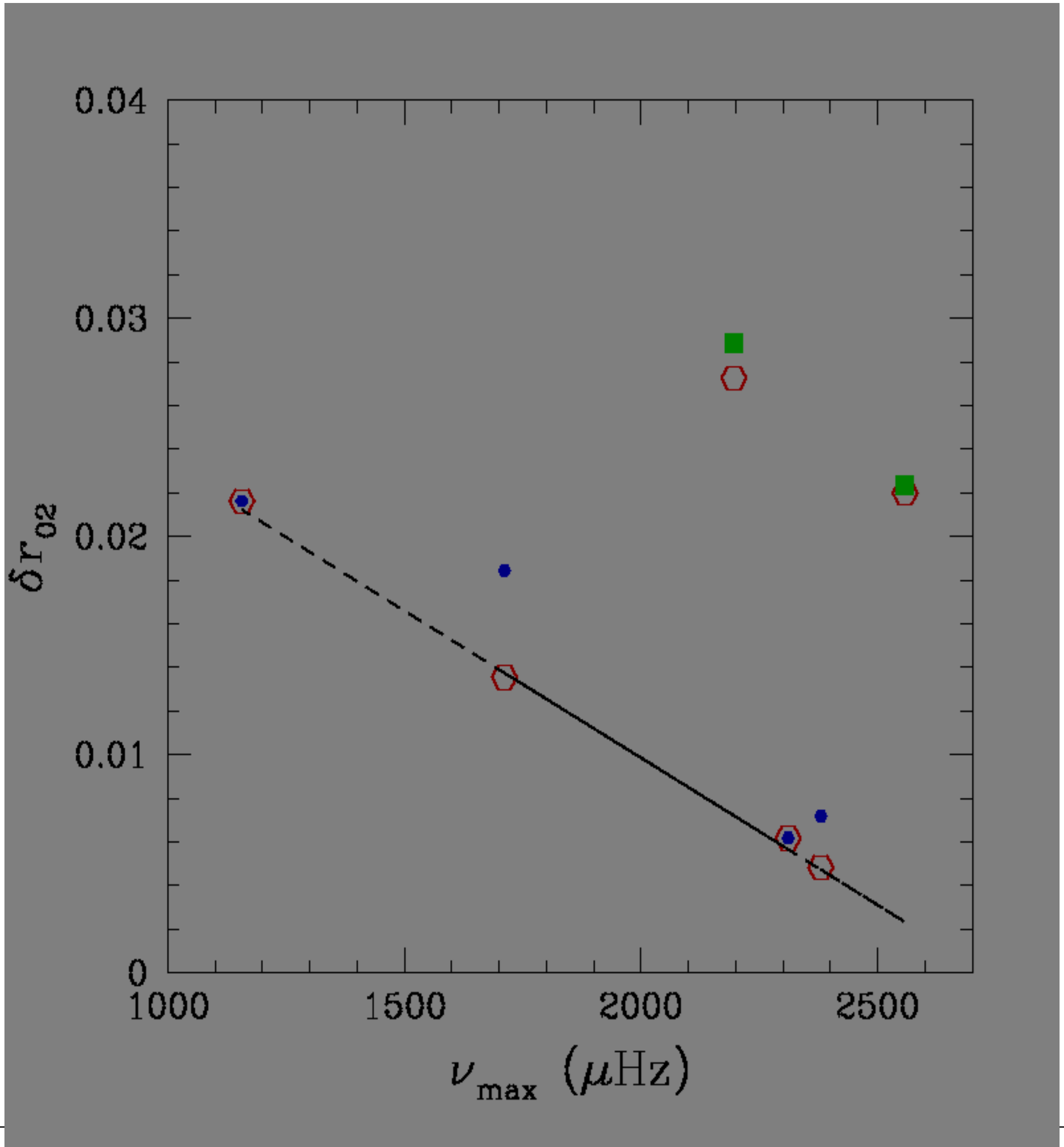


Mass Magnitude Teff ��r02>

Uncertainty on �r02 = 0.005 up to 0.03 for individual
Ie too large ie needs mean value over as many modes as possible

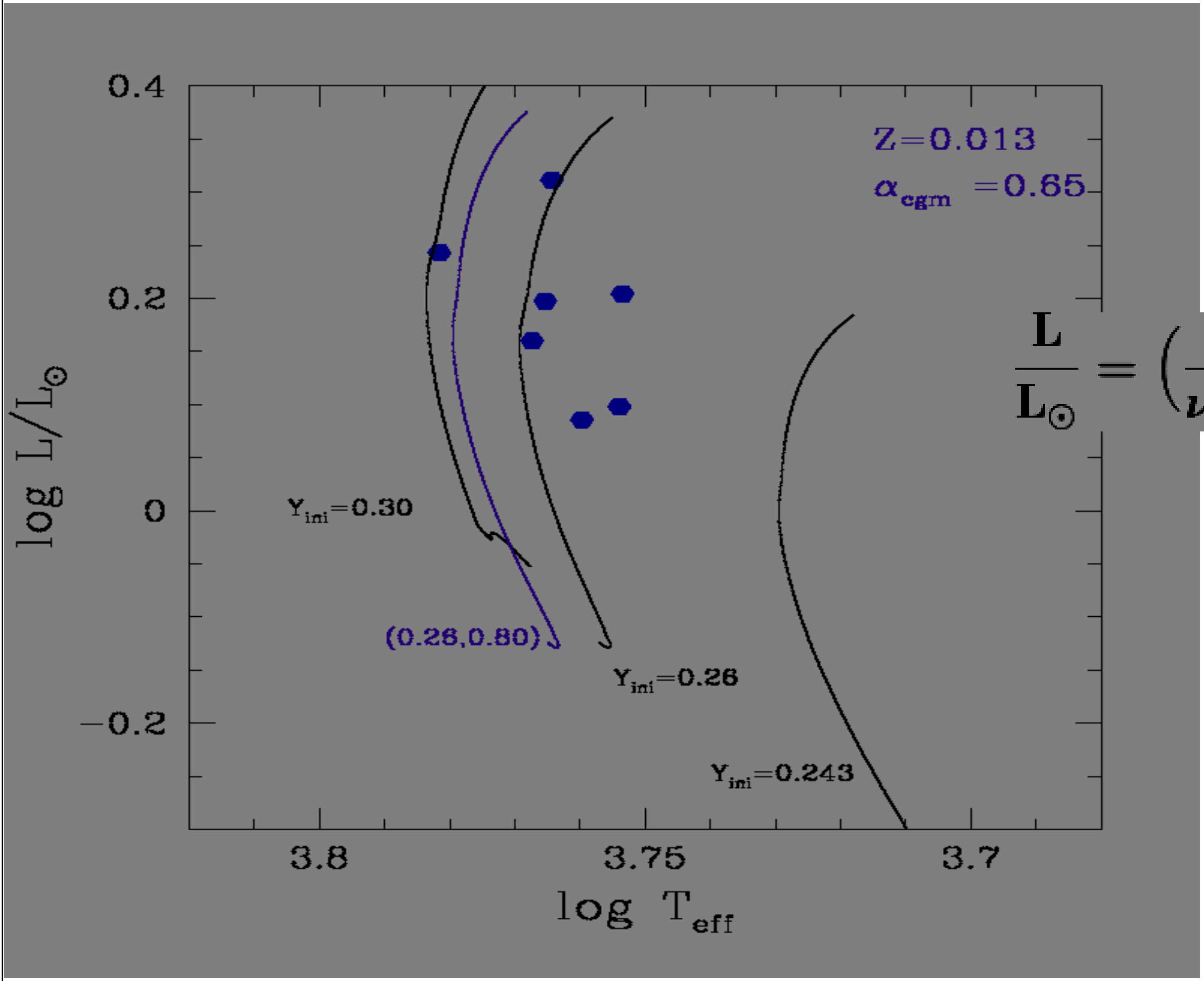
Kepler data with 1 yr observation

$$\delta r_{02} = -0.0135\ \nu_{max} + 0.03685 \qquad (\nu_{max}\ \text{in mHz})$$



Stellar models with 1 Msol

Kepler stars with masses between 1.00 and 1.10



Luminosities derived from seismic averaged quantities

$$\frac{L}{L_\odot} = \left(\frac{\nu_{max}}{\nu_{max,\odot}}\right)^2 \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4} \left(\frac{T_{eff}}{T_{eff,\odot}}\right)^5$$

In that mass range, given the mass, Yini, Z and alpha, the age is univocally related to the luminosity rather than Teff

Several issues

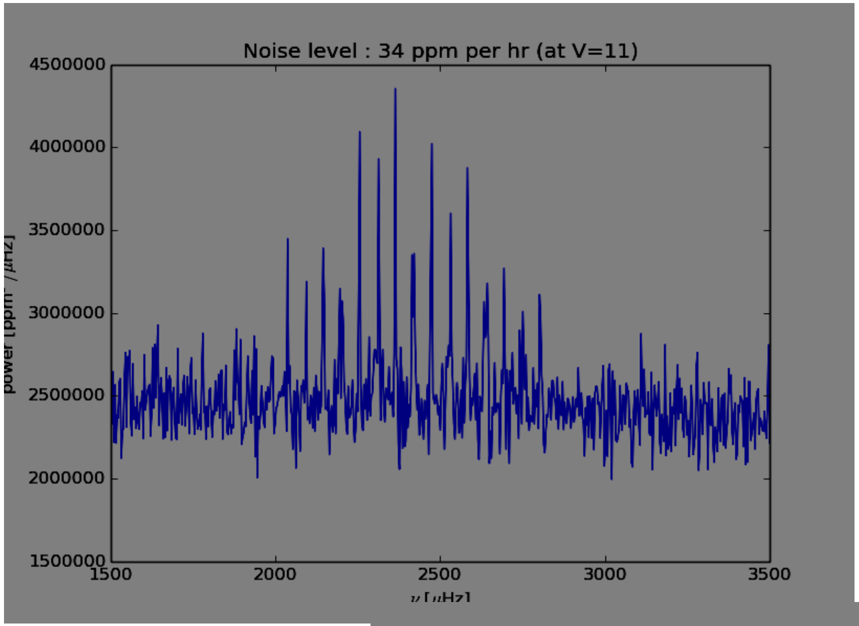
1- How many stars with 10 % max for age uncertainty ?
What type of stars : V, Teff or spectral type

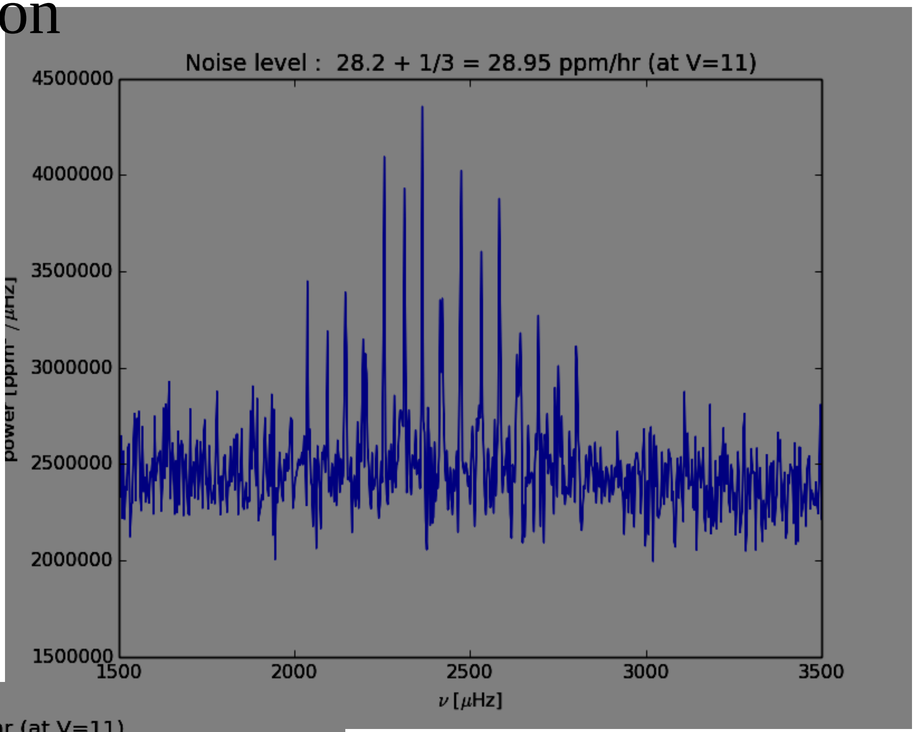
2- What age uncertainty for 28 N-Cam at given V ?
How brighter must it be for an equivalent uncertainty than 32 N-Cam ?

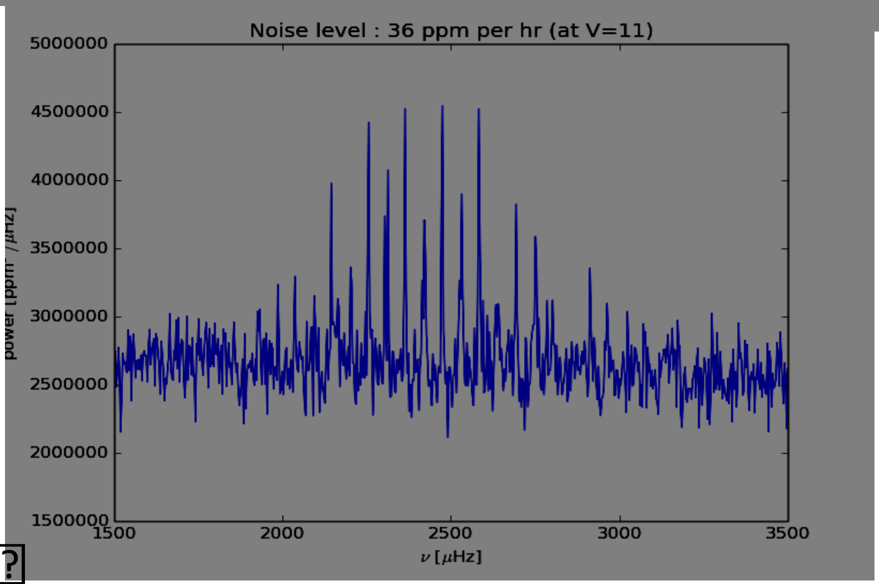
3- 24N-Cam and 20 N-Cam : what do we lose ?

4- Good cases : 26 ppm/h

Introduction

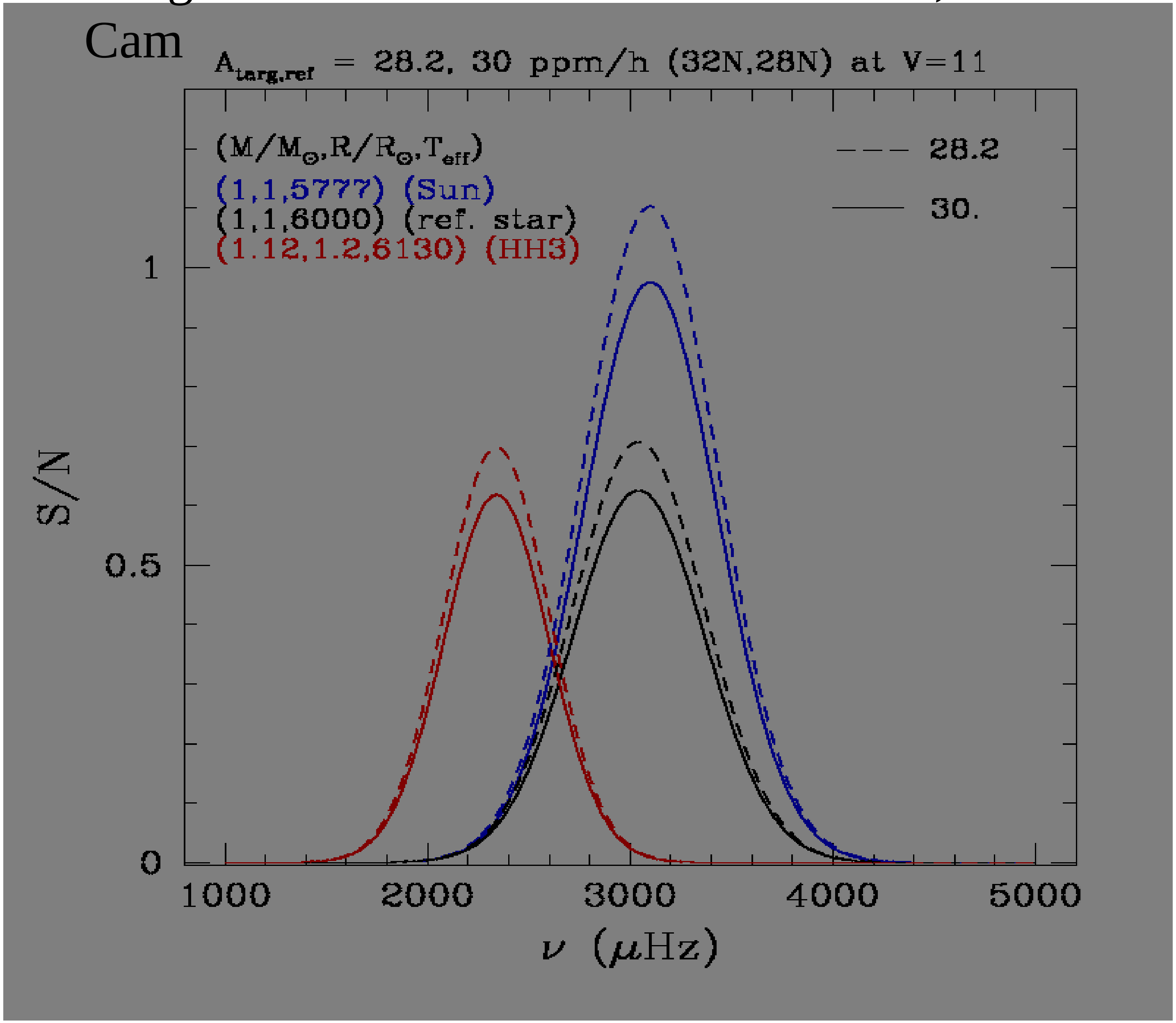






? max

1.Signal-to-noise ratio as a function of V, Teff for xN-Cam



Star : Oscillation height (in power spectrum) → S

V mag (target photon noise) → N1

Granulation (for osc. Freq. range 10 ?Hz-40 ?Hz) → N2

Instrument :

Random noise → N3=2/3 N1

Residual after correction → N4=1/3 N1

Total noise N = N1+N2+N3+N4 (in power spectrum)

↓

S/N → beta =1/SNR

→ frequency uncertainty sigma (Libbrecht formula 1992)

→ 1) light curve simulation+ data analysis + stellar modelling+optimisation → age uncertainty

→ 2) scaling (after validation) → age uncertainty

S/N → beta =1/SNR

→ frequency uncertainty sigma (Libbrecht formula 1992)

→ 1) light curve simulation+ data analysis + stellar modelling+optimisation → age uncertainty

→ 2) scaling (after validation) → age uncertainty

Delta N(1,2,3,4) or Delta S ((M,Y,Z), Teff or spectral type) or

→ Delta SNR → Delta numax

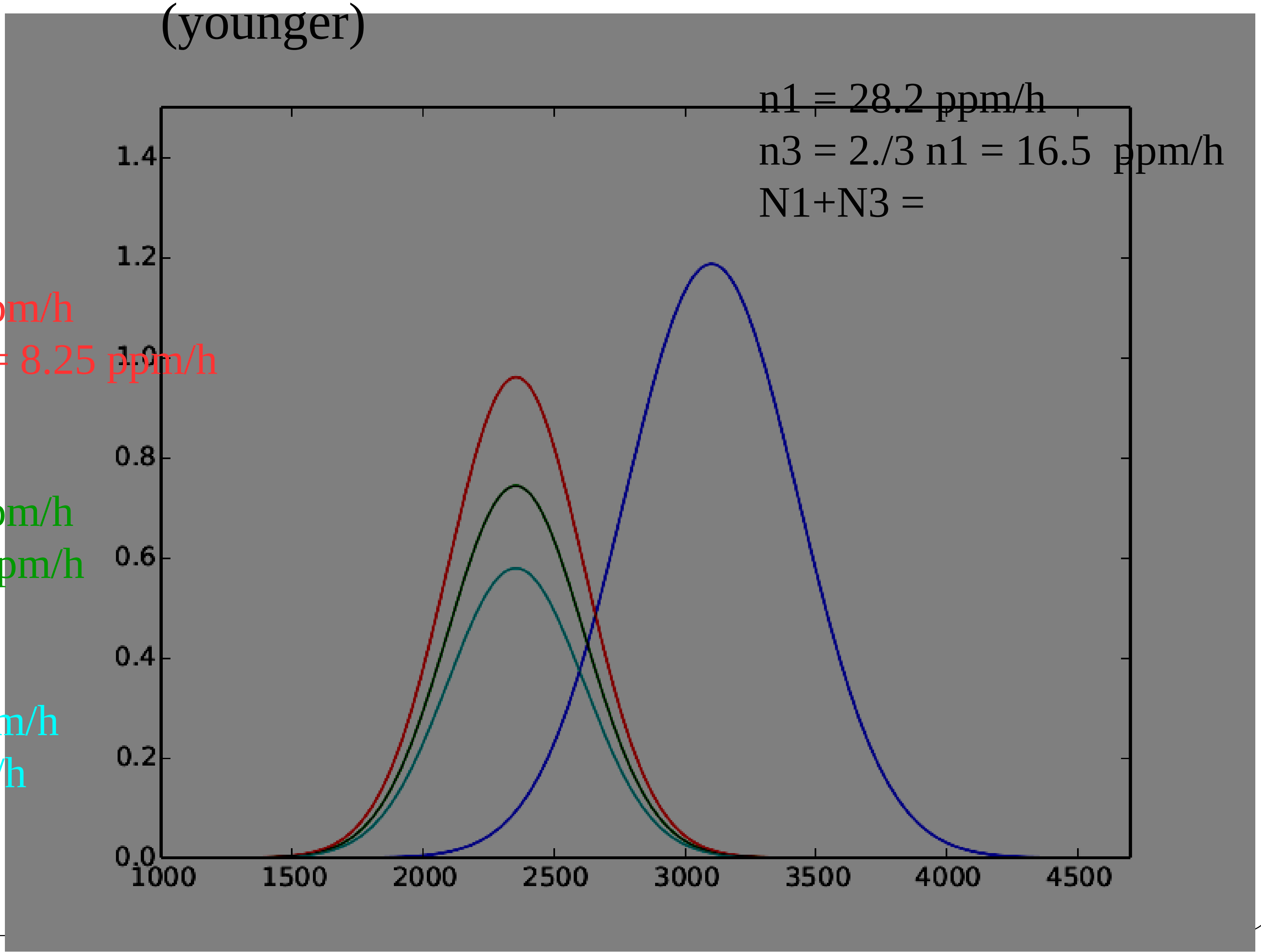
mag = 11

HH3 teff =6250 K (younger)

Sun teff=5777 K

SNR (power spectrum)

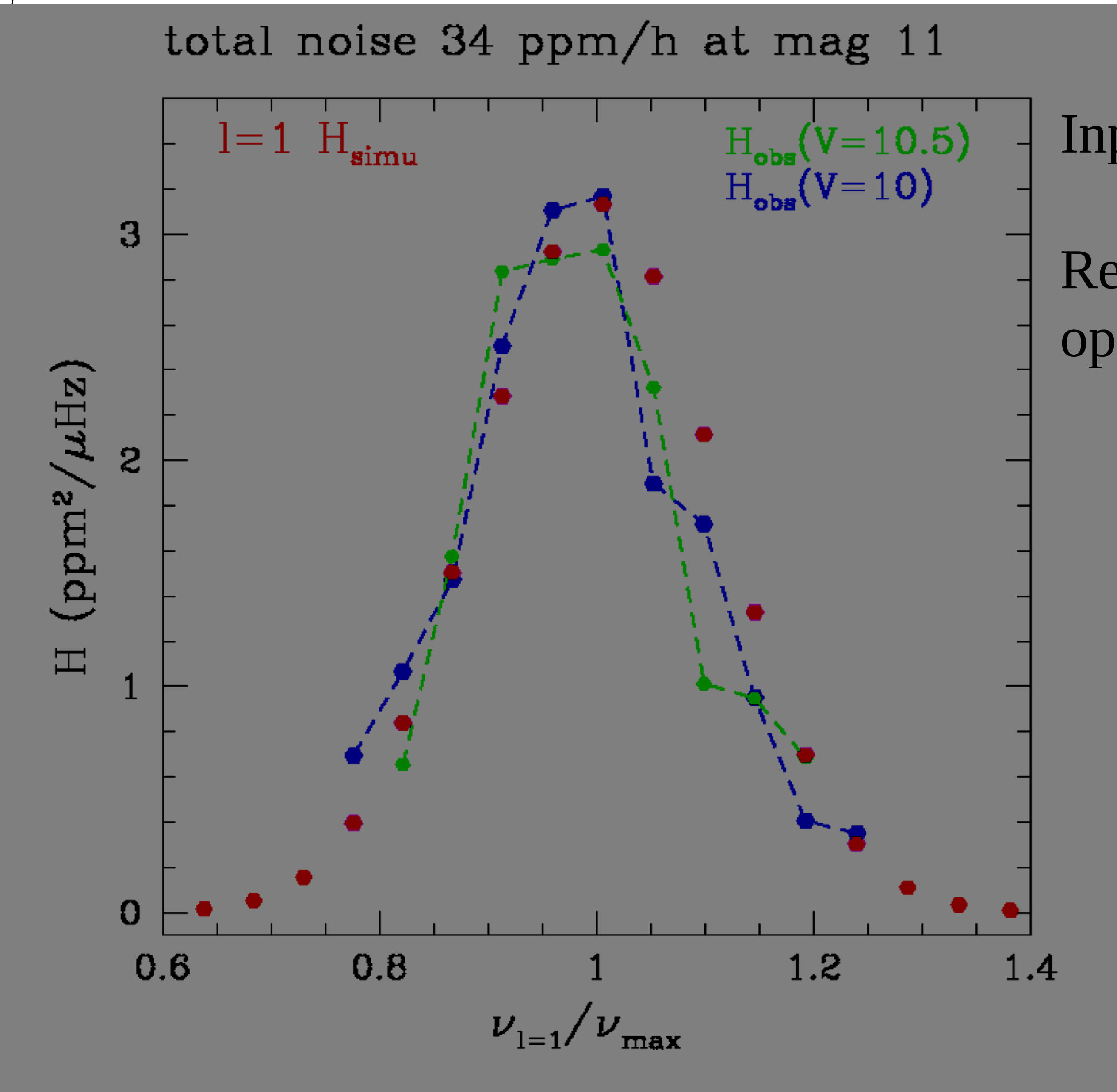
n1 = 28.2 ppm/h
n3 = 2./3 n1 = 16.5 ppm/h
N1+N3 =



n1 = 28.2 ppm/h
n3 = 1/3N1= 8.25 ppm/h
N1+N3 =

n1 = 28.2 ppm/h
n3 = 16.5 ppm/h
N1+N3 =

n1 = 28.2 ppm/h
n3 = 26 ppm/h
N1+N3 =



Input spectrum +simu : red

Results of data analysis + optimisation : blue and gree

Photon noise n1 = 34*10**(0.2*(V-11) ppm/h in amplitude spetral densit

In power spectral density :

N=n**2

N = N1+N2+N3+N4

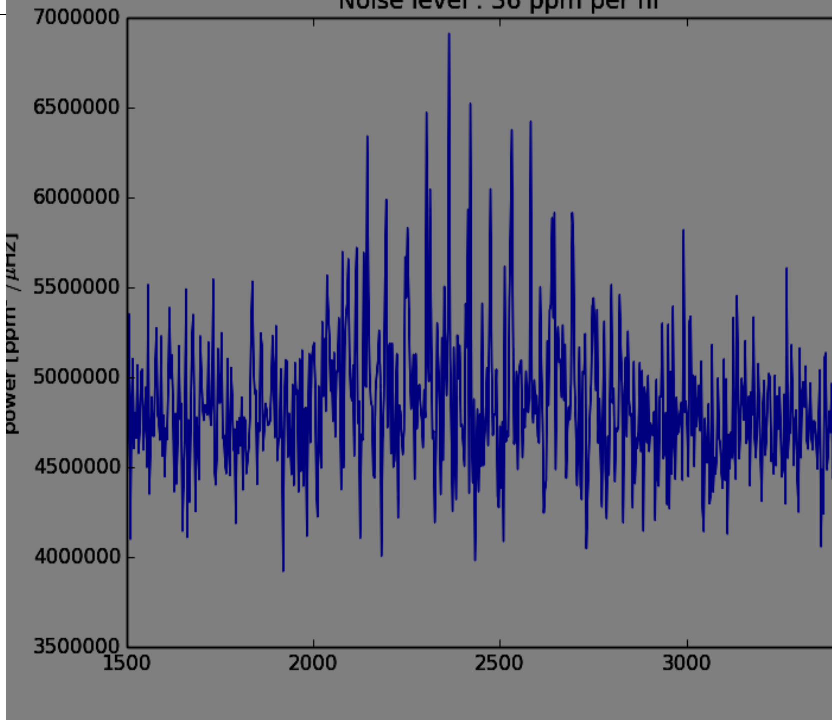
N1(V=10.5) = 36*10**(0.2*(V-11))= 34 *10**(0.2*(10.5-11))

36/34 = 10**(0.2*(10.5-V))

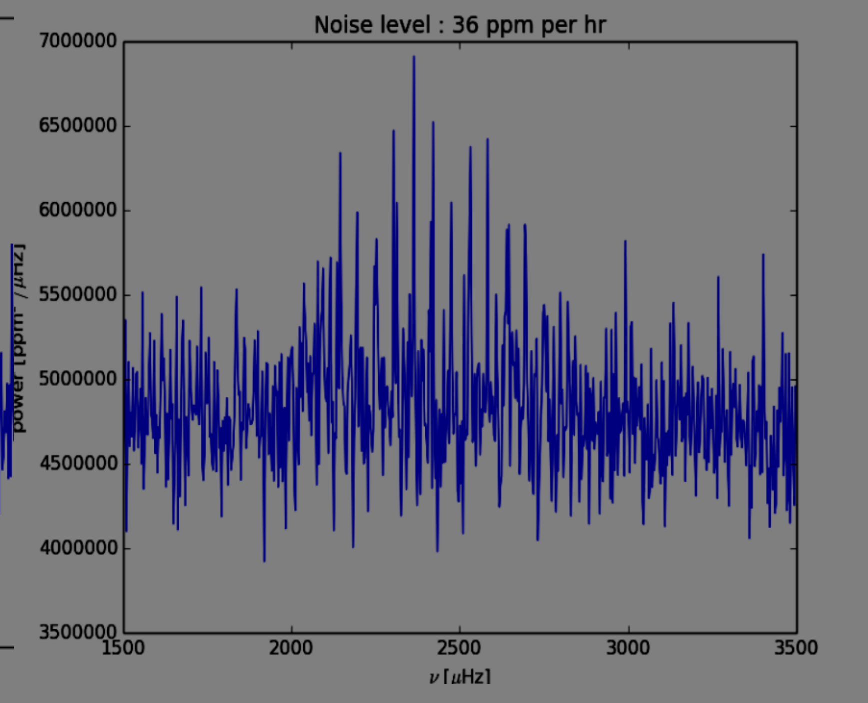
10.5-V = log_10(36/34) = 0.0248 → V= 10.475

For 40 ppm/h, V=10.43

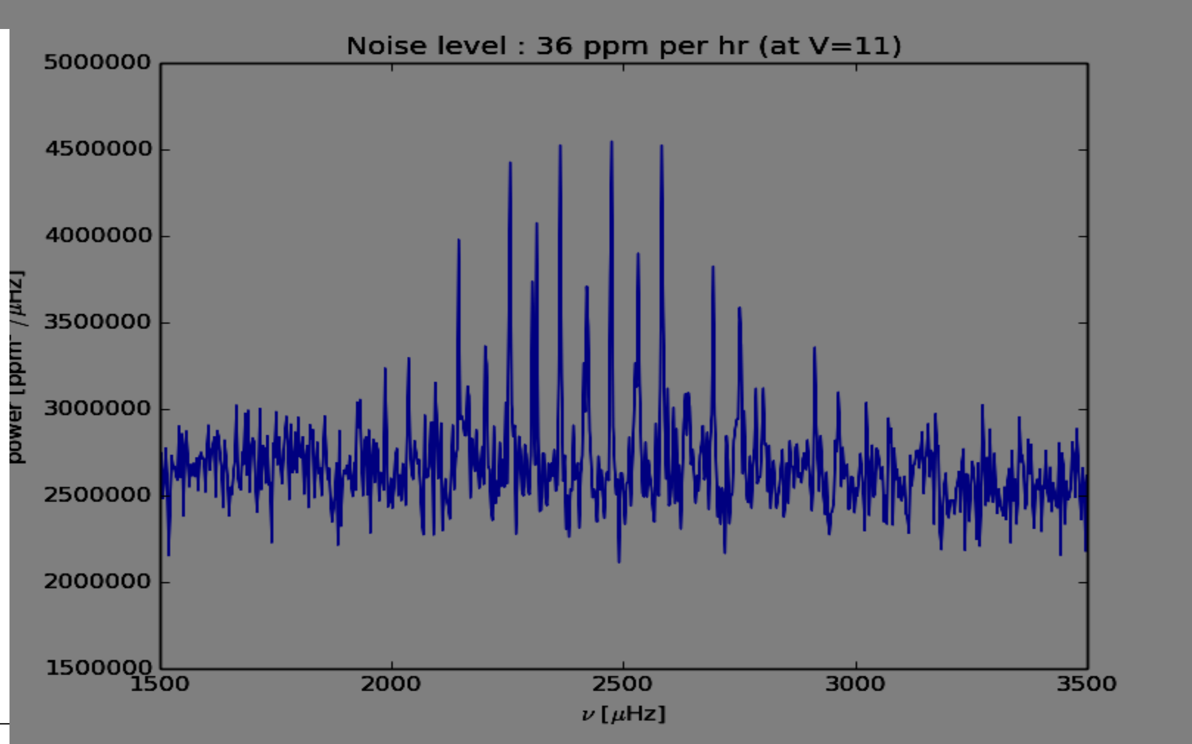
From V=10.5 to V=10 → 42.8 ppm/h



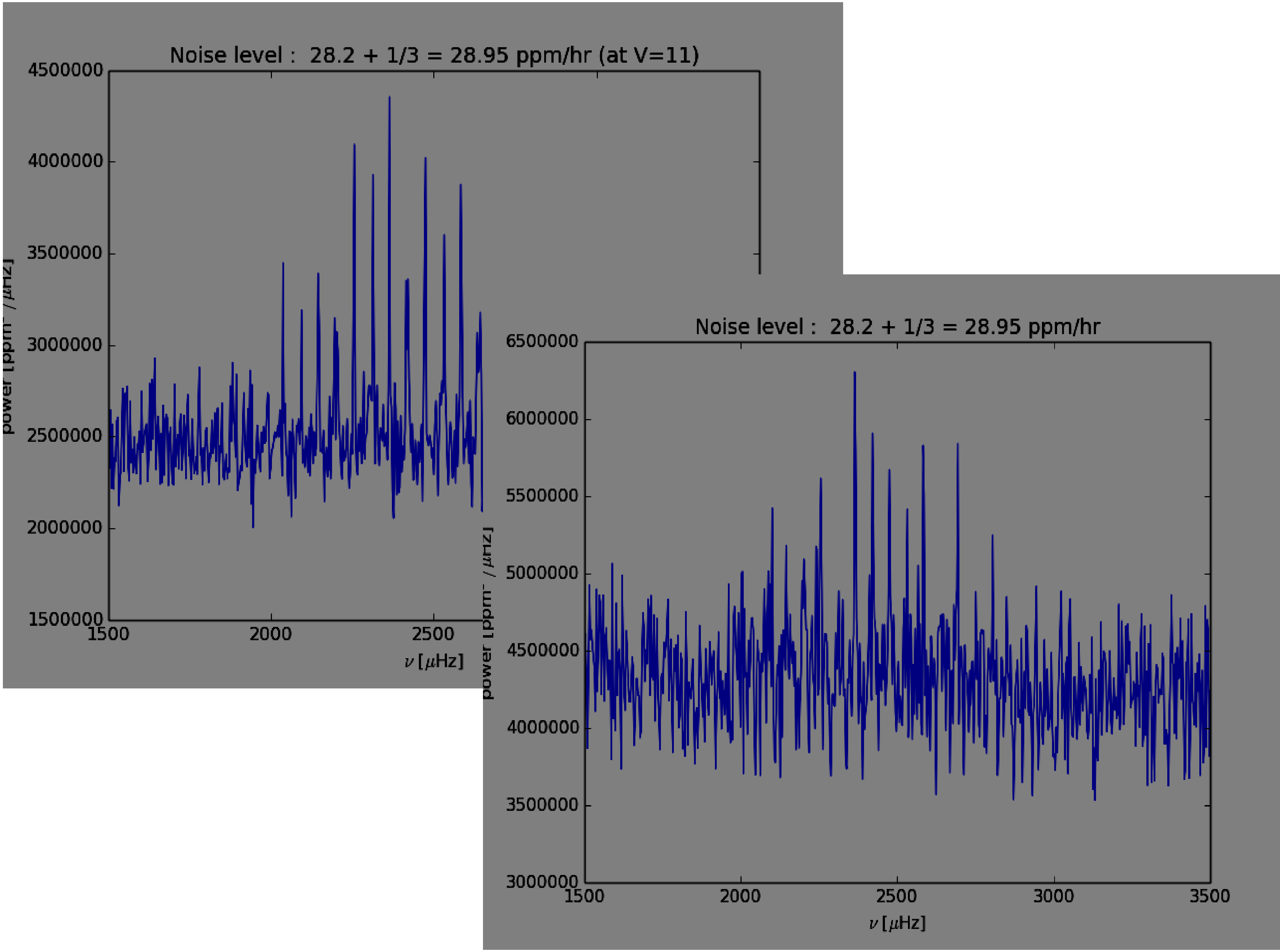
7000000
6500000
6000000
5500000
5000000
4500000
4000000
3500000
1500
2000
2500
3000

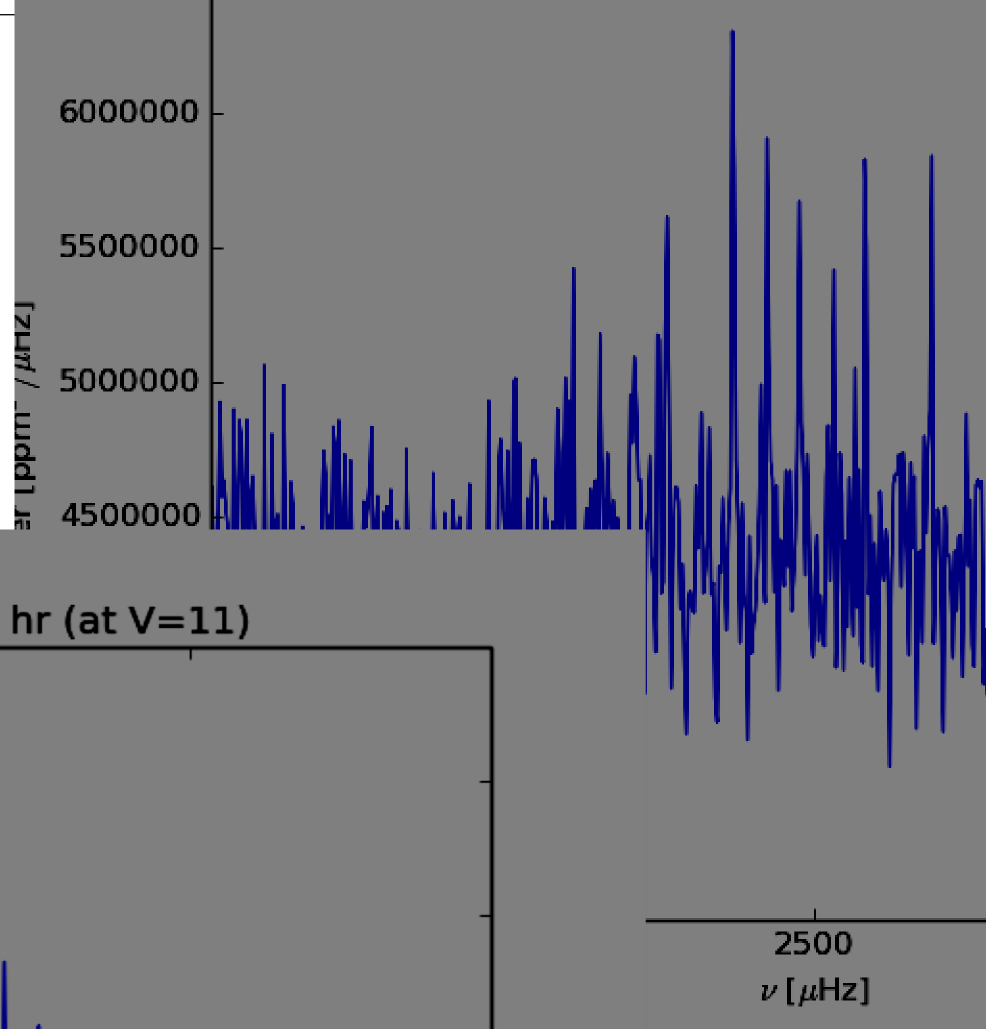


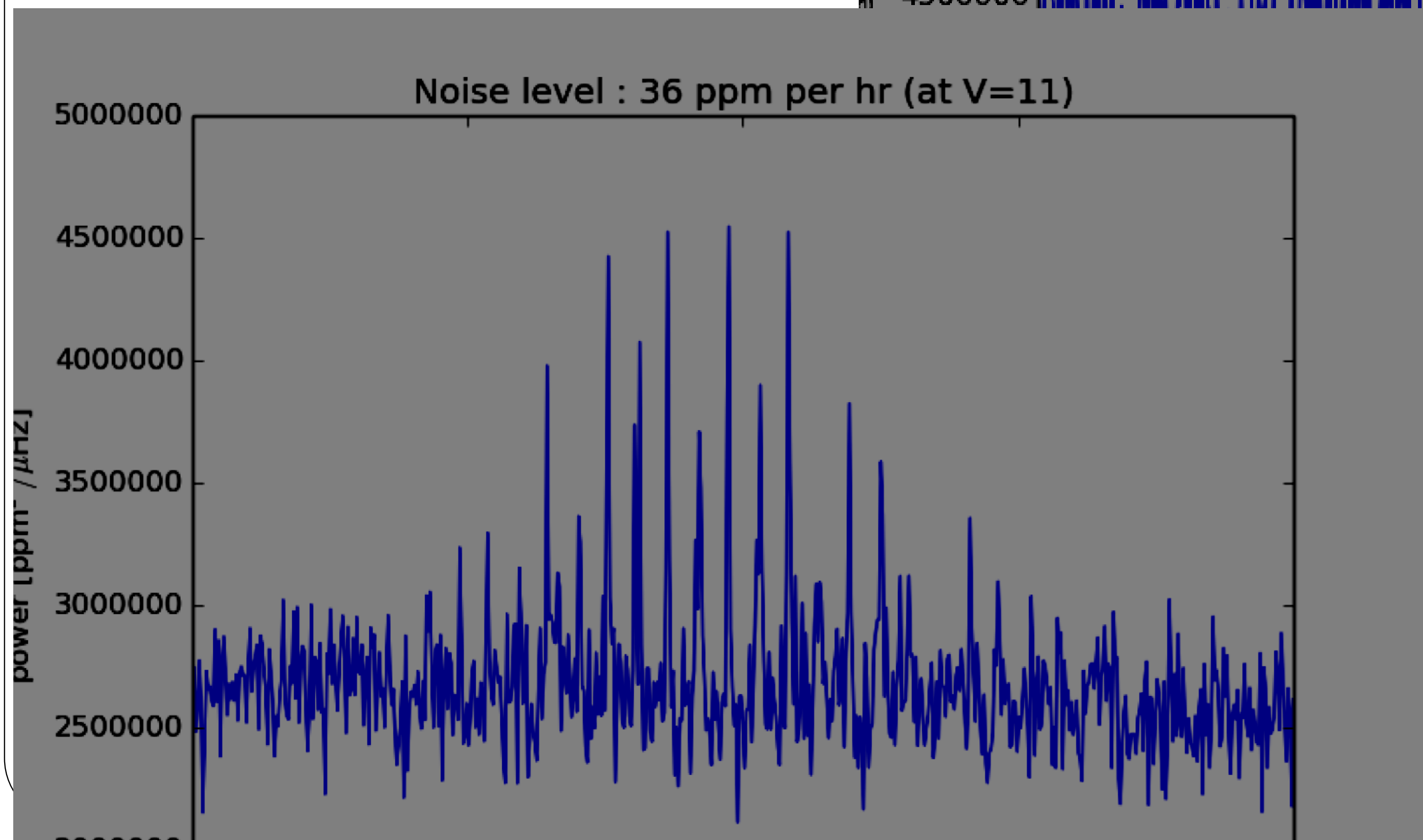
Noise level : 36 ppm per hr
7000000
6500000
6000000
5500000
5000000
4500000
4000000
3500000
1500
2000
2500
3000
3500
ν [μHz]

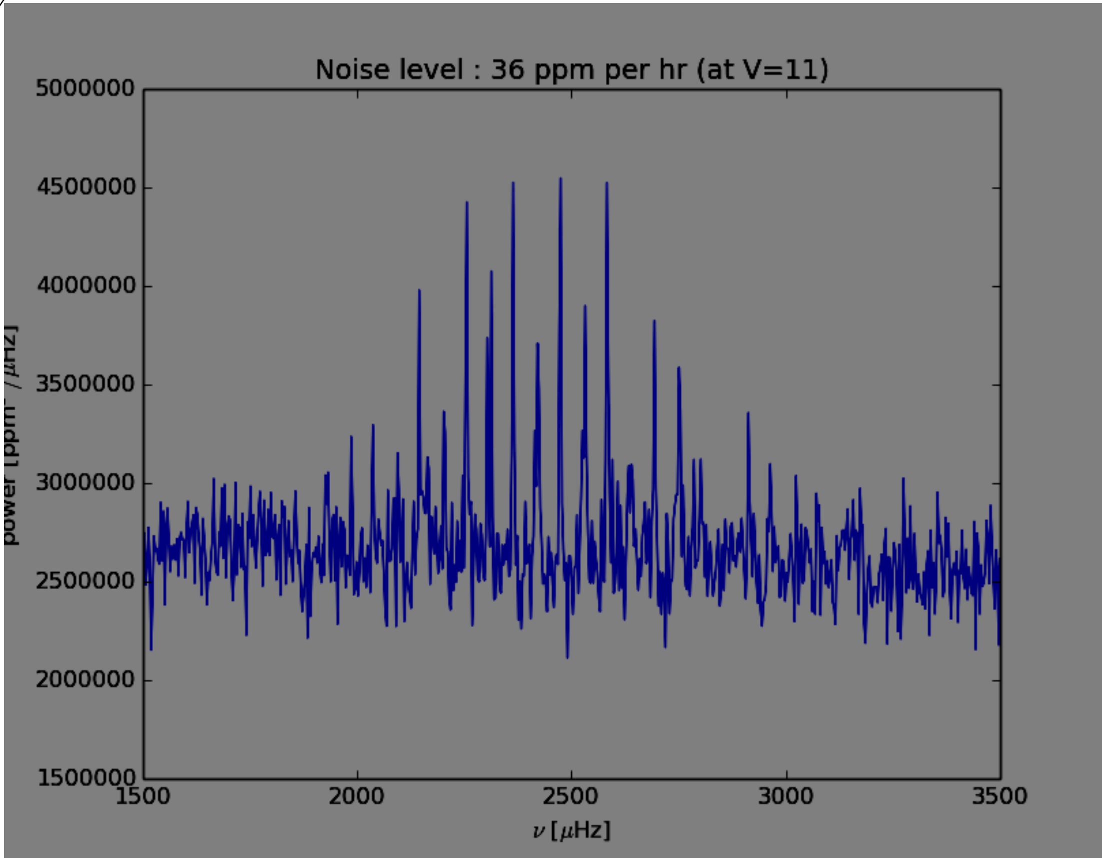
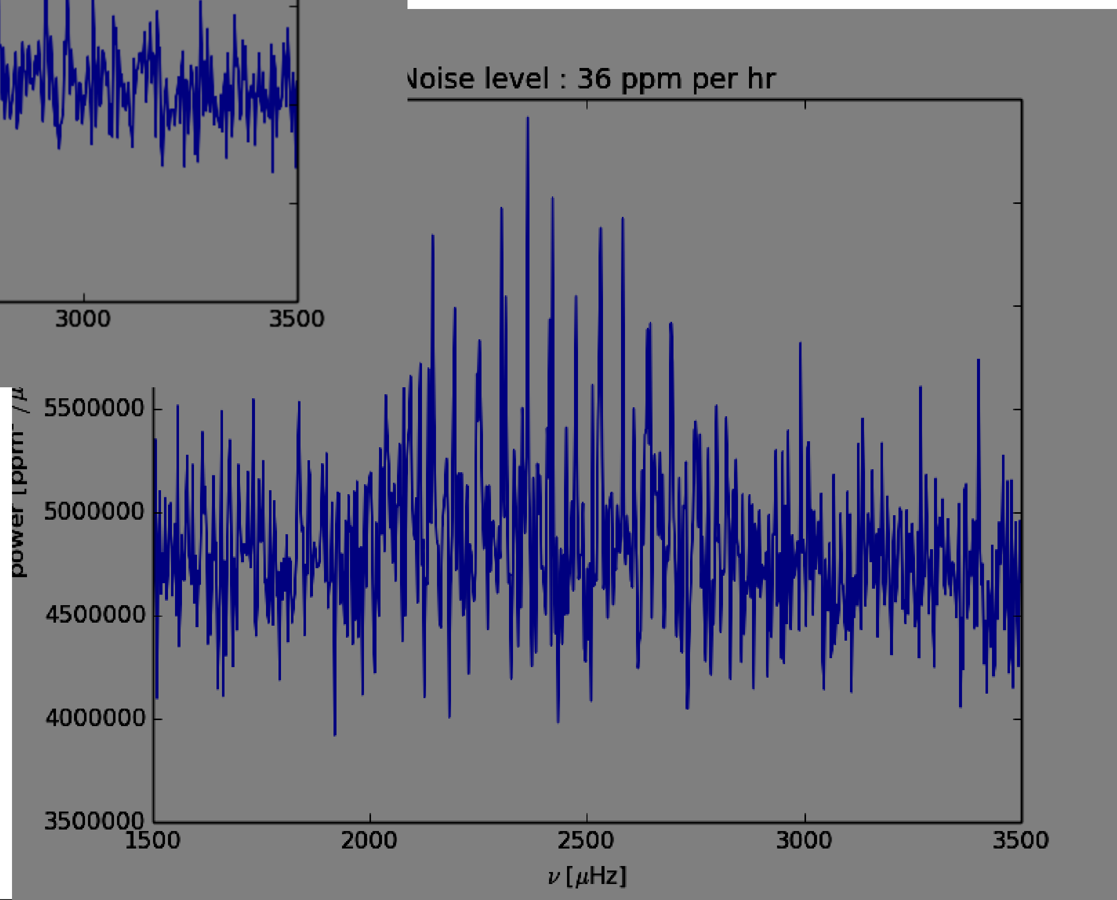


Noise level : 36 ppm per hr (at V=11)
5000000
4500000
4000000
3500000
3000000
2500000
2000000
1500000
1500
2000
2500
3000
3500
ν [μHz]


Noise level : 28.2 + 1/3 = 28.95 ppm/hr (at V=11)
4500000
4000000
3500000
3000000
2500000
2000000
1500000
1500
2000
2500
ν [μHz]
Noise level : 28.2 + 1/3 = 28.95 ppm/hr
6500000
6000000
5500000
5000000
4500000
4000000
3500000
3000000
1500
2000
2500
3000
3500
ν [μHz]


6000000
5500000
5000000
4500000
2500
ν [μHz]


Noise level : 36 ppm per hr (at V=11)
5000000
4500000
4000000
3500000
3000000
2500000


Noise level : 36 ppm per hr (at V=11)
5000000
4500000
4000000
3500000
3000000
2500000
2000000
1500000
1500
2000
2500
3000
3500
ν [μHz]

Noise level : 36 ppm per hr
5500000
5000000
4500000
4000000
3500000
1500
2000
2500
3000
3500
ν [μHz]

1. Current status of PLATO

ESA divides the timeline in phases:

• Phases B1, B2, C/D/E

B1/B2 : definition phases

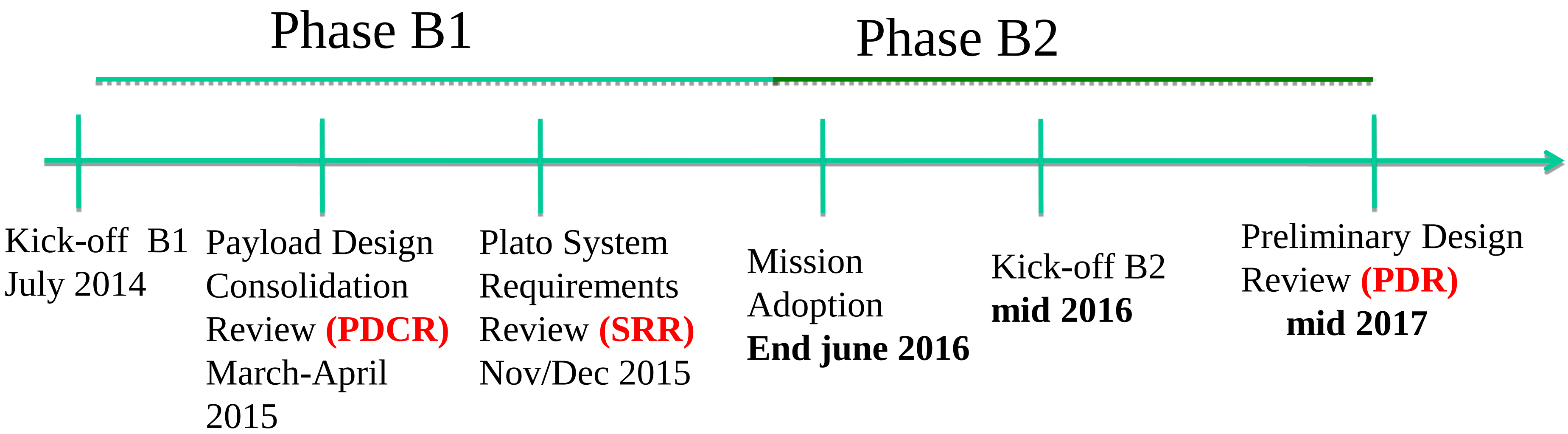
C/D/E: implementation phases

• Launch 2024

• Exploitation: 2024 – 2029 exploitation- updating

• Post OPS : 2030 -2032 exploitation- updating

Important dates and deadlines



PLATO Phase B1 objective is the adoption of the PLATO mission by SPC in March 2016.

- The **PLATO System Requirements Review (SRR)** is a major input to PLATO mission adoption.

The **PLATO System Requirements Review (SRR)** is a major input to PLATO mission adoption.

October 2015: Plato B1 data package delivery for **SRR**

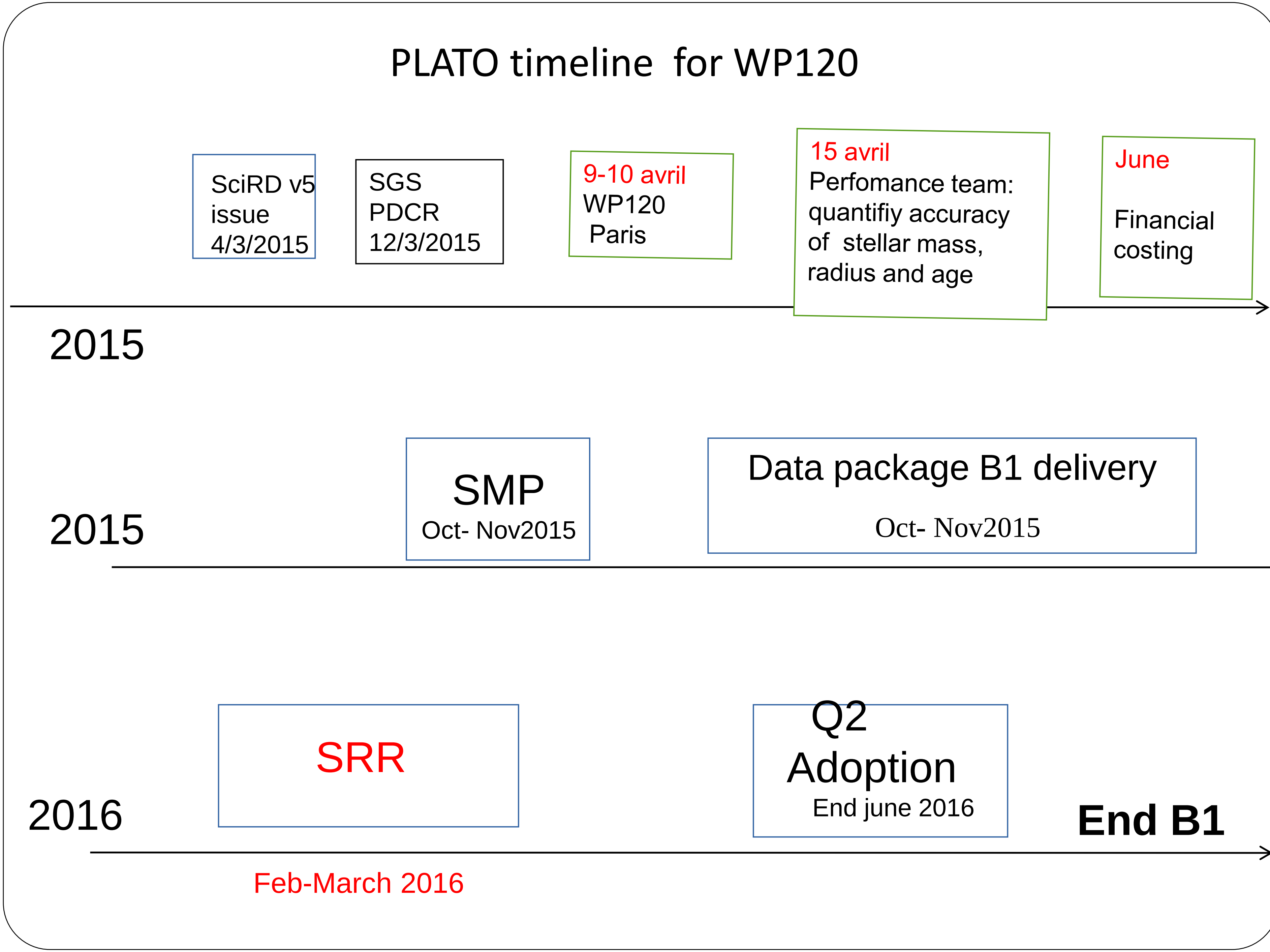
Documents by the consortium:

- PDC Work Breakdown Structure (WBS)
- PDC Work Package Descriptions (WPDs)
- PLATO Consortium Financial Plan
- PLATO Mission Consortium Science Implementation Plan (PMC-SIP)

Documents by ESA:

- Science Requirements Document *(now issue 5.0, to be updated after the PCDR and for the Instrument-SRR and SRR)*
- Science Requirements Justification Document *(it will be issued after the PDCR, and updated before Instrument-SRR and SRR)*
- Science Management Plan *(to be ready by mid September)*

- Definition study report *(to be ready by March 2016)*


PLATO timeline for WP120
SciRD v5 issue 4/3/2015
SGS PDCR 12/3/2015
9-10 avril WP120 Paris
15 avril Perfomance team: quantifiy accuracy of stellar mass, radius and age
June Financial costing
2015
2015
SMP Oct- Nov2015
Data package B1 delivery Oct- Nov2015
2016
SRR
Feb-March 2016
Q2 Adoption End june 2016
End B1

Phase B1 (définitions of spécifications) till the SRR (mid 2016)

- Design of the procedures with existing tools, data and methods
- Estimations of current performances
- Definition of future improvments and associated tests of performance

Phase B2 (consolidation of définitions) till the PDR

- Optimisation of the procedures description
- First tests of performance of these procedures with Plato simulations

Phase C After PDR

- Delivery of a first set of specifications to the PDC for dimensioning and test of the PDC implementation to be discussed with Thierry
- Validation of the first test implementation tests du PDC to be discussed with Thierry

Two levels of document to be produced

1)The first document must show that we will achieve what we promise. Let call ‘WP120 Definition document’

First draft on April 15th (hence with whatever material we already have)- Final version for the B1 datapackage delivery fall 2015

2) A document containing the first set of specifications to be delivered to the PDC: let call it ‘Specification to SSI’ (S3I) document
Deadline to be discussed with Thierry

This second document will require an intermediate document which will provide the details which led to the S3I document

2. Responsabilities of WP120

Or what do we have promised ?

Delivrables PDC

Calibrated 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 masses and ages	DP5	L2
Confirmed planetary systems and their characteristics	DP6	L2

Specifications from WP120

Responsabilities of WP120 :

•Commitments written in the document SciRD v5 delivered to ESA
(*will be made available* on *the WP120 web site when authorized*, *soon)*

WP120 web site : http://www.ias.u-psud.fr/PLATO_STESCI/

- Structure
- Documents
- Events (meetings):

http://www.ias.u-psud.fr/PLATO_STESCI/PLATO_STESCI_Events.html

For more general and detailed information

sci.esa.int/plato/53450-plato-yellow-book

http://www.oact.inaf.it/plato/PPLC/Home.html

- Rauer et al. 2014, A&A

Responsabilities of WP120 :

•Commitments written in the document SciRD v5 delivered to ESA *(will be made available* on *the WP120 web site when authorized, soon)*

•Justifications written in the Sci Justification Document *(coming soon)*

•Concerns only the core program: stars later than F5 with masses up to 1.4-1.5 Msun i.e. showing solar oscillations

•Reference star : a G0V star with 6000 K, 1Rsun, 1Msun

Responsabilities of WP120

1.to provide specifications to determine all possible characteristics **of stars of the core program**

•*stellar mass, radius and age*
•*stellar activity, rotation, limb darkening, ...*

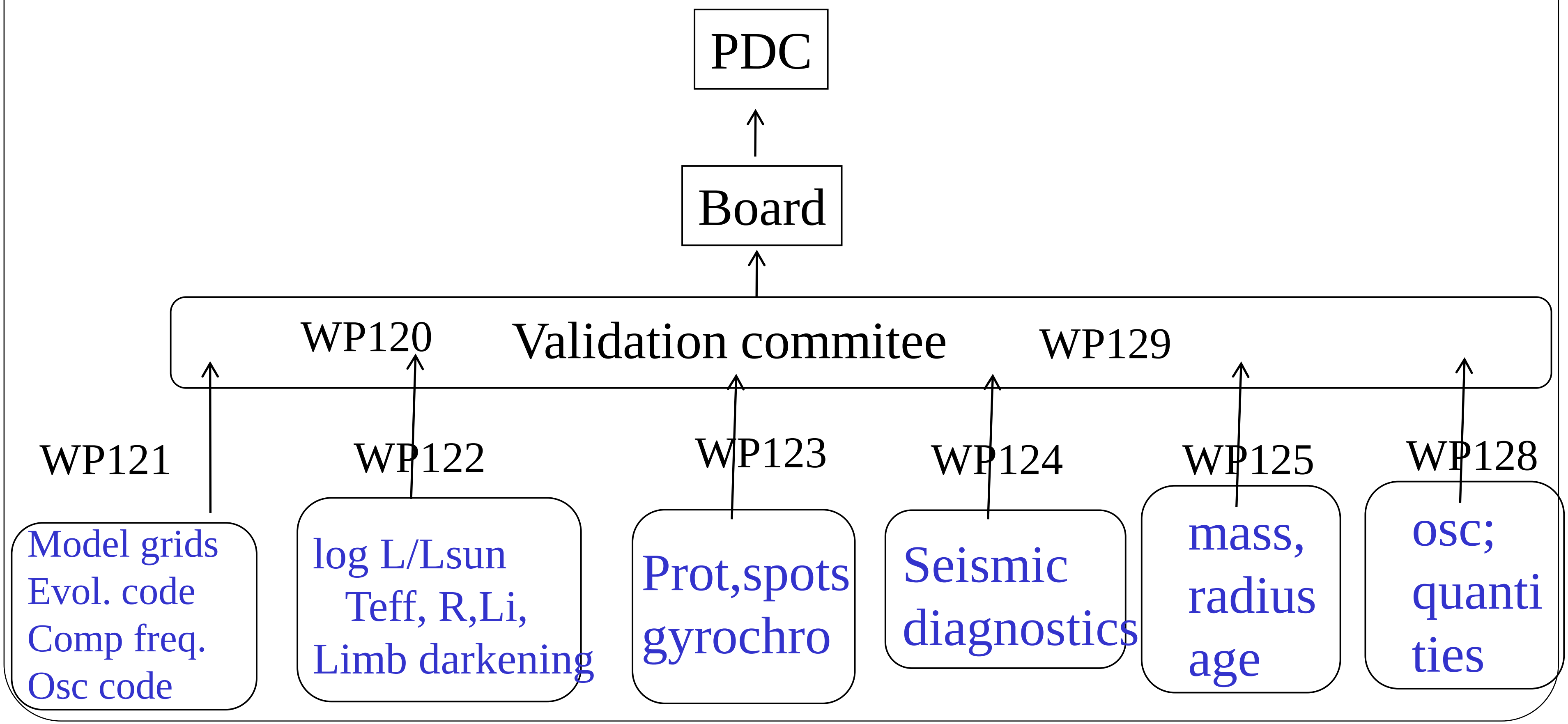
2. Grids of stellar models, evolutionary and oscillation code(s)

3. Validation of PDC implementation

Interfaces with PDC

•Requested by consortium head : validation of PSPM documents by the Board before delivary to PDC. In practice, this will concern the final documents

•In practice also, direct interface between STESCI and SAS



Responsabilities of WP120

WP124, WP125 : to provide specifications of stellar mass, radius and age **with an accuracy of:**

- Radius ~ 1% for the reference star of mv=10 (goal mv=11) (R-SCI-L0-55)
- Age ~ 10% for the reference star of mv=10 (goal mv=11) (R-SCI-L0-12)
- Mass of a planet orbiting a reference GOV (bright enough) star : 10% or better (R-SCI-L0-15)

for the stars of the core program

Input for WP124-125

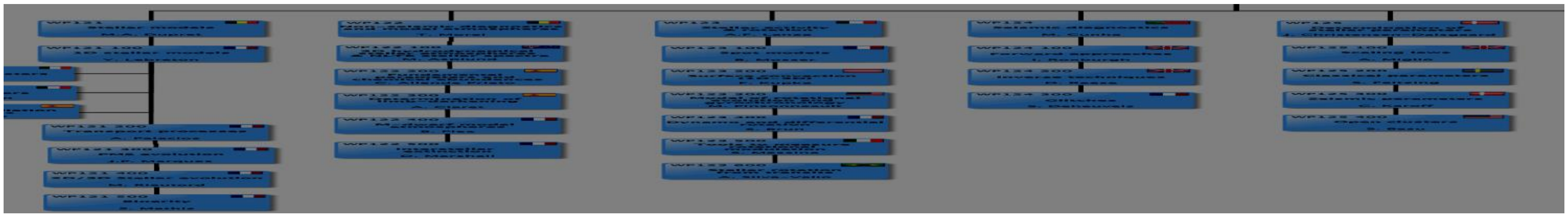
- (*) Measurements of normal modes in main sequence with precisions ~ 0.1 muHz for several mode frequencies below and above the frequency of the mode with maximum amplitude (R-SCI-LO-67) (WP128)

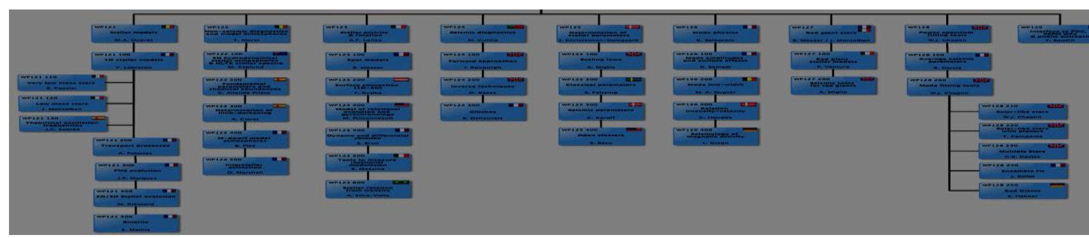
- Teff, log g, chemical composition (WP122)

- Surface Prot (WP123)

- Surface effects (WP126)

(*) optimal case. One must prepare also for data with lower quality level





Interfaces within WP120 will be necessary

Stellar samples

Stars of the core science

Later than F5; mass up to 1.4-1.5 Msun

Planet host dwarfs and subgiants

F5-K7 spectral type

Stellar ensembles, binaries, clusters and low mass red giants
Foas tools to improve the description of physical processes used in stellar models

Perfomances attendues

Number of Light Curves

For the baseline observing strategy:

Noise level	Magnitude limit	4300 deg^2 (long stare fields)	20,000 deg^2 (plus step and stare fields)
(ppm/√hr)	m_V	Number of cool stars	Number of cool stars
34	11	**22,000**	**85,000**
80	13	**267,000**	**1,000,000**

Detection of Earth-sized planets
+
asteroseismology
+ radial velocity

Requires some automatized pipelines

Sample 1

34 ppm in 1h (0.1 mu Hz) for a star with 11 mag
(2 years observation with 32 telescopes)

Sample 2

Sample 3

Sample 4

Sample 5

Document for PDCR (april 2015)

Quantify accuracy of stellar mass, radius and age determination *(requested by the performance team)*

Objective: to show that we know how to achieve the PLATO specifications 9 years from now , with mode details than is written in the red book and with justifications

This will constitue the first draft of WP120 Definition document.
The document will be part of the B1 datapackage (likely as an appendix)

WP120 definition document

1)Definition of tools and methods allowing us to determine the properties of the stars belonging to the core program:

- Identification/list of possible stellar model grids

- Identification/list of appropriate evolutionary and oscillation codes.

- Definition of seismic diagnostics used to derive stellar masses, radii and ages (most importantly from seismic measurements) **WP124**

- Definition of procedures **:** first proposal for a description/flowchart of a possible pipeline : from input to output **WP125**

based on our experience today

2) Performances (efficiency, robustness, rapidity)

Justification with exemples based on simulations and real stars.

- littérature
- Kepler on going project
- HH results Daniel and co workers (Spacein project)
- HH PLATO simulation

Estimation of the impact of the

- incertainties on the non seismic observational parameters (Teff …)
- incertainties on the (computed and measured) oscillation frequencies (for instance observational error 0.1 -0.5 … muHz)
- number of detected oscillation frequencies
- quality of the stellar model grids

on the precision of the output.

Estimation of the impact of the identified incertainties of the physical description of th stellar models on the accuracy of the output

3 PLATO specific needs

- Identify the most impacting biases and the necessary improvments to achieve the required PLATO specifications

- Define tests and validations procedures of the 'final' tools to be delivered

- Define the appropriate simulations, observations of benchmark stars (CoRoT, Kepler) …

4 Expertise on stellar science : exemples

- What is the gain of going from 2 months to 3 months step and stare phases?

- 80 ppm/sqrt(hr): is seismology possible?

5 Expected timeline

6 Description of interfaces within WP120 and with SSI (PDC)

The content must be adapted depending on the specificities of the WPxxx

WP124

WP124

Objective : validated seismic forward and inversion techniques specifically adapted to PLATO data in order to reach the requested level of accuracy

The document should include:

1- model independent method:

•What are the model independent methods (relevant for Plato data) to determine seismic stellar masses and radii ?
(averaged seismic quantities and scaling laws …, inverse methods…)

Advantages : automatic algorithms- rapid then adapted for immediat release for a large sample of stars. Accuracy level 1

1.a) Current methods :

•Estimation of precision, accuracy based on CoRoT and Kepler data and simulations

•Do they satisfy the Plato spec?

•Set of reference stars ?

•Identification of biaises- recommandation to remove them:
exemple: scaling laws and coherence of definition, measurement and computation of of delta nu

1.b) What about 9 years for now ?

• Which expected improvments?

•Which (Plato) simulations to test what ?

•Which stars or ensemble of stars can be used as referenced stars ?

⇒ *More detailed list of of more precise questions for each item*

2- Model dependent methods : age , mass, radii

•For model <u>dependent</u> methods, are specific seismic diagnostic more efficient for the determination of

- mass (individual frequencies, ? …)
- radius
- age (frequency ratios, ?, …)
- log g (model independent, ?, …)
- helium abundance (glitches: are they really efficient?)

?

Description, precision, accuracy, biases…

Should one include them all simulatneously ?

2.a) Current methods :

- Estimation of precision, accuracy based on CoRoT and Kepler data and simulations
- Set of reference stars ?
- Do they satisfy the Plato spec?
- Identification of biaises

2.b) What about 10 years for now ?

- Which expected improvments?
- Which (Plato) simulations to test what ?
- Which stars or ensemble of stars can be used as referenced stars ?

 More more detailed list of of more precise questions for each item

•How to deal/lift parameter degeneracy (mass-helium; alpha_conv-R-age, others ..) ?

•Inversion methods with individual frequencies or frequency combinations/ratios?

WP125

Objective : validated procedure(s) specifically adapted to PLATO data in order to reach the requested level of accuracy

- Choice of model dependent method (s)?: Model grid based methods- Fitting methods

- Choice of optimisation (likelyhood, Levenberg-Marquaard, iterative …)
  - definition of fitting criterium (chi2)

- Exploration of initial parameter space ? Sensitivity ot initial guess ?

Description : advantages, precision, accuracy, biases

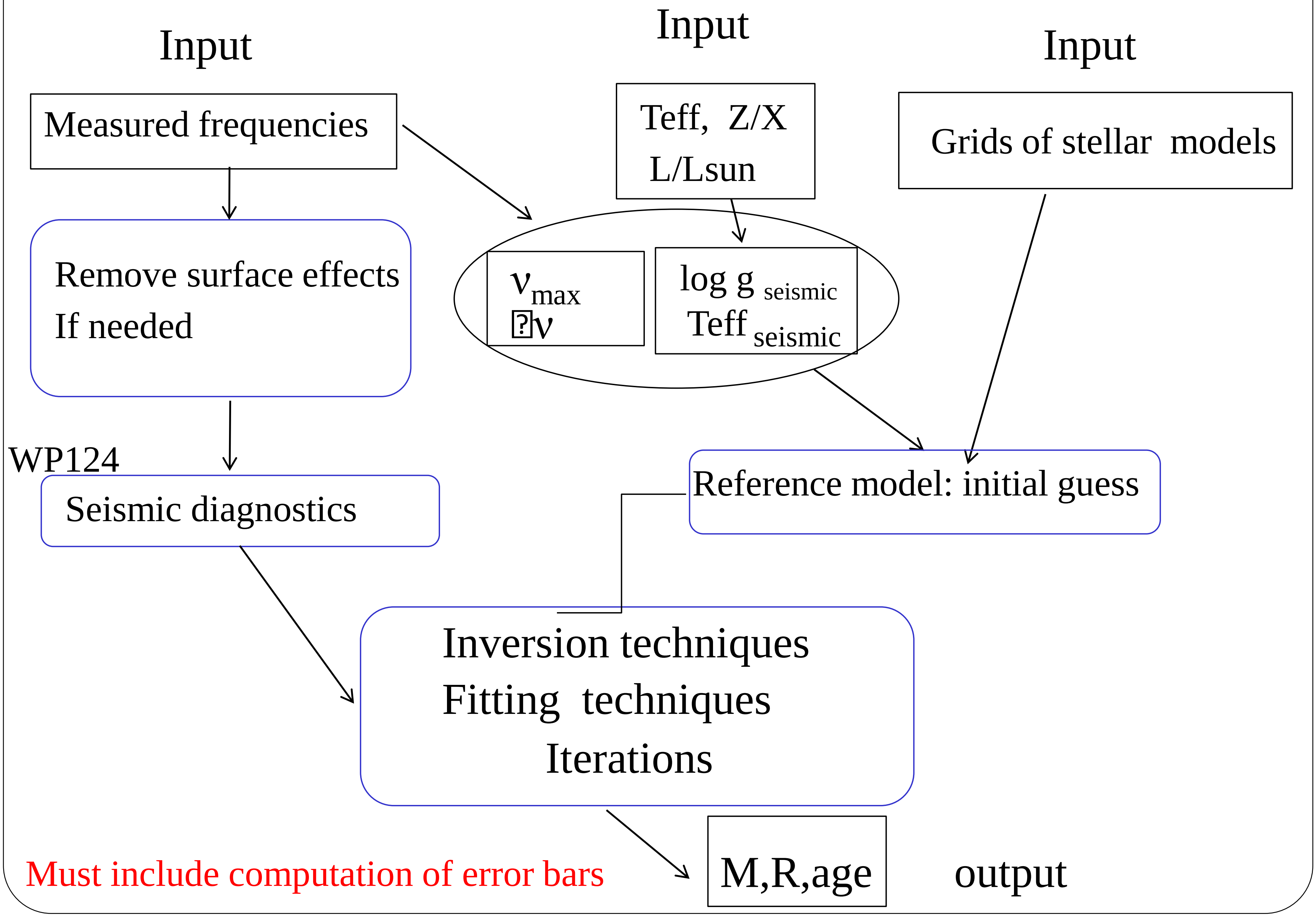
- Pipelines already exist. Options: to choose one and adapt it to Plato objectives or to build one

- Inclusion of constraints (cluster membership, binary, interferometric radius, surface rotation period, surface lithium …) ?

- Several (seismic/non seismic) procedures can provide the stellar mass, radius and ages. They must give coherent results

- Flow chart from input (Teff, freq., …) to output (M,R,age,error bars)
  Description and a organigram for visual convenience

Exemple : description of procedure : WP125



Must include computation of error bars

Perfomances (status today)

Ratio time/ quality	model grids	optimisation methods
Seismic averaged quantities	sample of stars rapidity accuracy level 1 Automatic method	
Individual frequencies	sample of stars rapid accuracy level 2 Automatic method	Individual stars Slower Precision - accuracy level 3

Time estimation for each item - advantages and drawbacks

WP124 and WP125

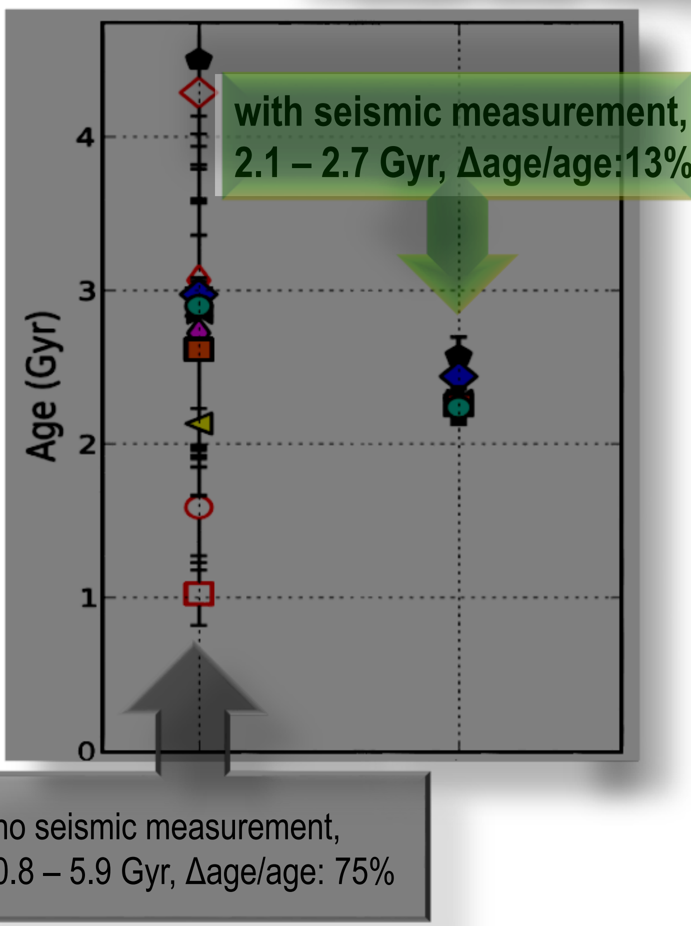
- Need to build prototypes and test them with hare and hound exercises (simulated data) and available data (CoRoT and KEPLER legacy) with PDC

- What minimal precision on input observational data is needed (on frequencies, Teff, chemical comp) as a function of accuracy level (for long runs and step and stare phases)?

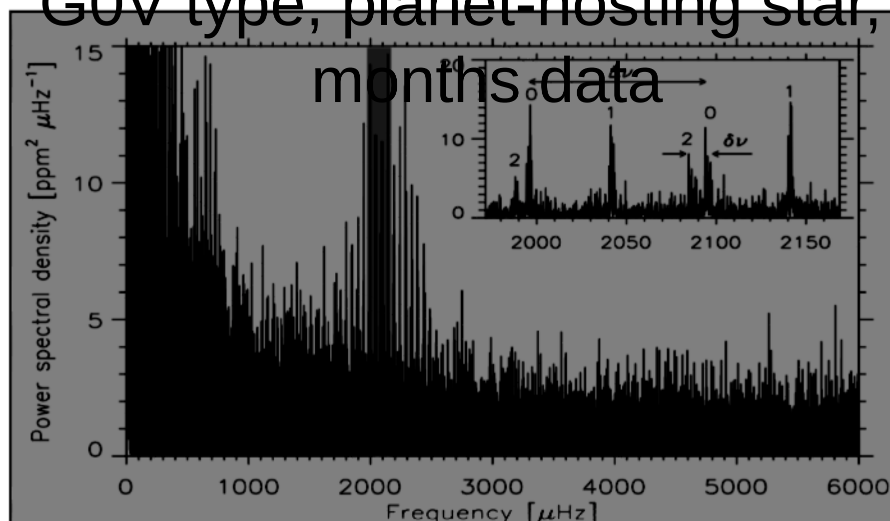
END

Asteroseismology

CoRoT and Kepler have demonstrated that the required accuracies can be met



Example: HD 52265 (CoRoT), a G0V type, planet-hosting star, 4 months data



(Gizon et al. 2013)

Seismic parameters: Radius: 1.34 ± 0.02 R_{sun}, Mass: 1.27 ± 0.03 M_{sun}, Age: 2.37 ±

Determination of the stellar radius

SB law: needs L (distance(Gaia), BC, interstellar redenning) and Teff
Spectrophotometric: needs model atmosphere
Interferometric: needs distance (Gaia) and limb darkening

Determination of the mass:

HR diagram and isochrones, model fitting
Mean density from transit and radius

Determination of the age:

HR diagram and isochrones, model fitting

Document intermediaire à SI3

- l’identification des outils et méthodes permettant de déterminer aujourd’hui les PECP
- l’identification des précisions et biais associés aux PFDE.
- définition des tests, des observations disponibles et des simulations à réaliser permettant la quantification des performances des outils et méthodes ci-dessus, l'identification des biais dans la détermination des PECP.
- Premières conclusions concernant les solutions pour éliminer les biais dans la détermination des PECP.
- Propositions de format des livrables à fournir au PDC tels que les grilles de modèles stellaires.
- Agenda de livraison des spécifications de la responsabilité du WP120 au PDC

Determination of stellar radius : conclusion
(from Morel 2010)

From non-seismic diagnostics *alone*, achieving accuracy of 2% for radius quite challenging:

- 'Classical' method: T_{eff} must be known to within 50 K for solar like and 35 K for M stars (unrealistic in latter case). Accurate knowledge of A_V and BC also necessary (to within 0.015 mag).
- From spectrophotometry: most promising method, but sensitive to reddening and availability of space data a serious issue: currently only STIS, PHASES microsatellite in future (del Burgo et al. 2010)?
- From interpolation in isochrones: strongly model dependent.

Non-seismic analysis expected to eventually provide T_{eff} to within 60 K and [Fe/H] to within 0.1 dex for the bright solar-like PLATO targets (M stars a concern).

Note: the above uncertainties are internal

Determination of stellar radius : interferometry

Kervella et al 2003   bright star alpha Cen A
binary   alpha Cen B fainter
both with solar like oscillations

- *Uniform angular diameter determined within 0.2 % for alpha CenA and 0.4 % for alpha Cen B*

- *With limb darkening (using Claret (2000) 's tables, angular diameter determined within 0.2 % for alpha Cen A and 0.4 % for alpha Cen B*
0.1% has been added to take into account some intrinsic errors on the limb darkening coefficients (possibly LD law not fully appropriate)

- *Hence linear diameters derived within 0.3 % for alpha CenA and 0.5 % for alpha Cen B*

Systematic errors due to the physics of the stellar models which the LD calculat ion relie on (cf Barban et al 2002 for instance) are not included

October 2015: Plato B1 data package delivery for **SRR**

✓ Documents by the consortium for Phase B1 PDCR-SRR

- ~~PDC/PSPM Work Breakdown Structure (WBS~~) done
- ~~PDC/PSPM Work Package Descriptions (WPDs~~) done
- ~~PLATO Mission Consortium Science Implementation Plan (PMC-SIP)~~ done
- PLATO Consortium Financial Plan

✓ Documents to be released by ESA

- Science Management Plan (SMP, highest level document)

(to be ready by mid September)

- Science Requirement Document (SciRD)

(now issue 5.0, to be updated after the PCDR and for the Instrument-SRR and SRR)

- Science Requirement Justification Document (SRJD)

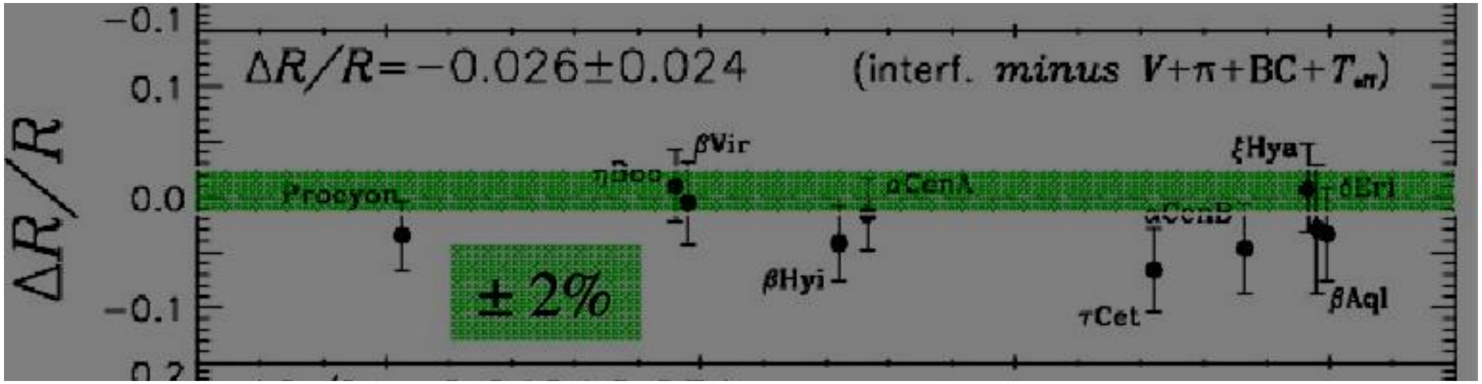
(it will be issued after the PDCR, and updated before Instrument-SRR and SRR)

- Science Implementation Requirements Document (SIRD)
- Science Operations Concept Document (SOCD)
- Definition study report *(to be ready by March 2016)*

Determination of stellar radius : interferometry

(from Morel 2010)

Comparison between photometric and interferometric determinations



Does not include systematic errors (model atmosphere, limb darkening)

Overall Conclusion

Assuming that the star is bright enough that precise observational (non seismic) constraints are available (not warranted):

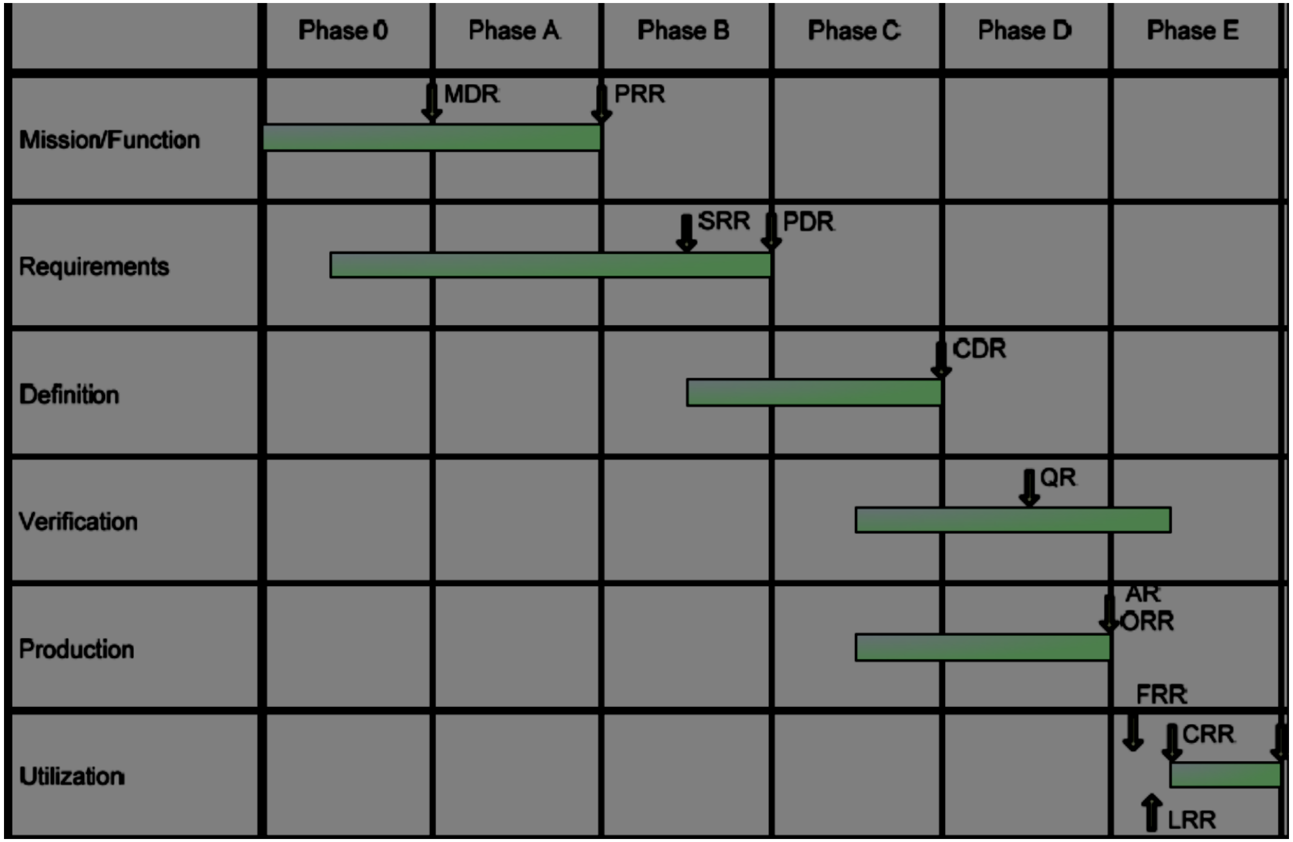
- in 2020 after Gaia, the major source of uncertainty on stellar parameter (mass, age) might then come from uncertainties in stellar model atmosphere and stellar internal structure and evolution (20-30 % on age determination; 6 to 10% on mass).

- before 2020, improvements in stellar physics will partly come from interpretation of Kepler and CoRoT seismic data. However:

  - most stars observed by Kepler are rather old (end of PMS and subgiants) and sited in a single location in the sky.
  - CoRoT observes in two locations so that some impact of the environment on the structure and evolution of stars can be learned. CoRoT also includes younger stars. But CoRoT observes only a limited number of stars.

  This will definetly not be enough to cover the whole region of model parameter space and physical processes conditions encountered in stars (environment, metallicity, rotation, etc…). Furthermore the improvements made available in 2020 may not be applicable to individual target stars (with their own specificities)

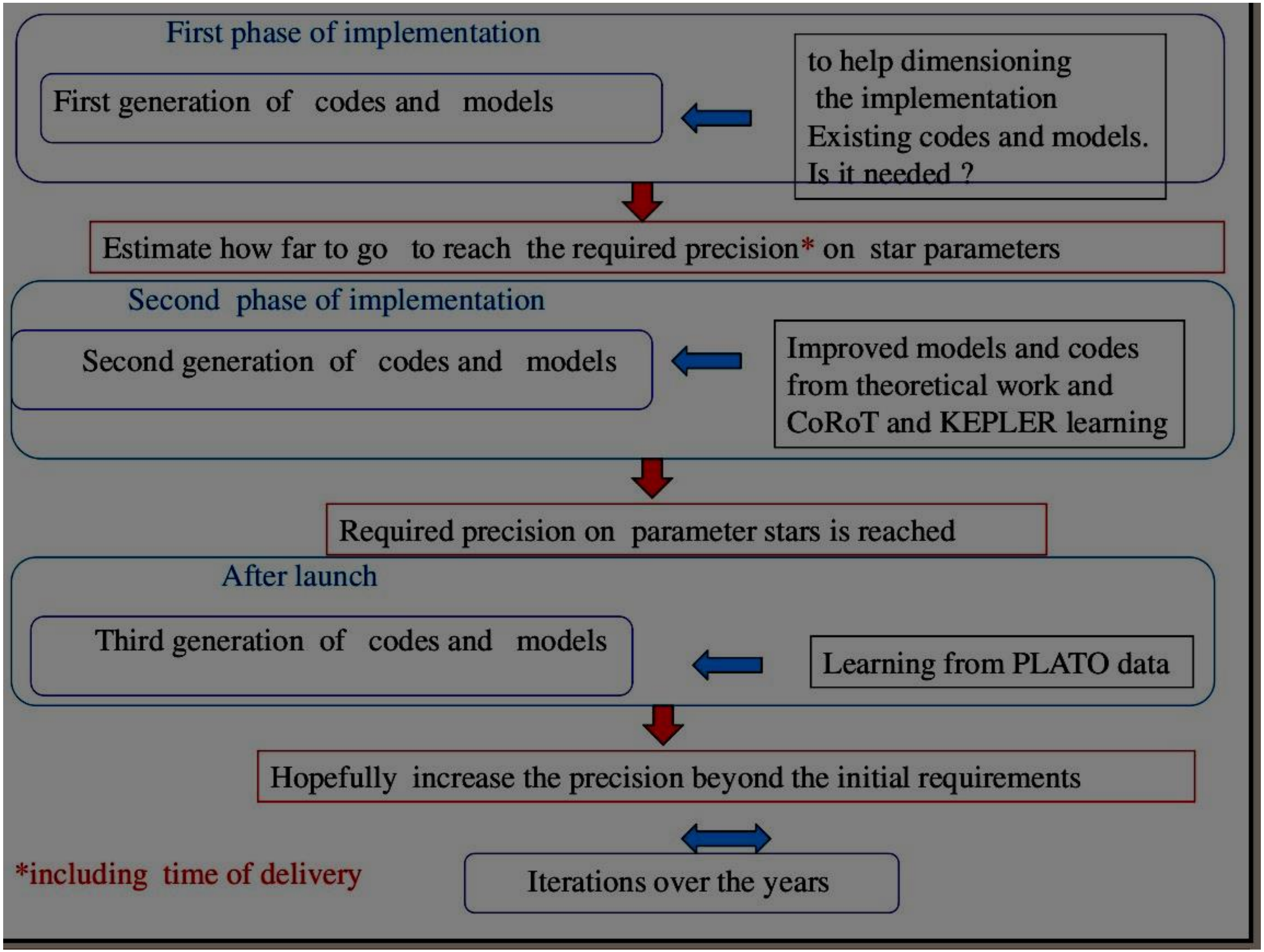
- 10 years from now is short to provide improvements significant enough to bring the age for instance to a satisfying level of accuracy (particularly improvements in the treatment of hydrodynamical processes and their consequences in stellar interiors)



Phase B1: from October 2014 till April 2016

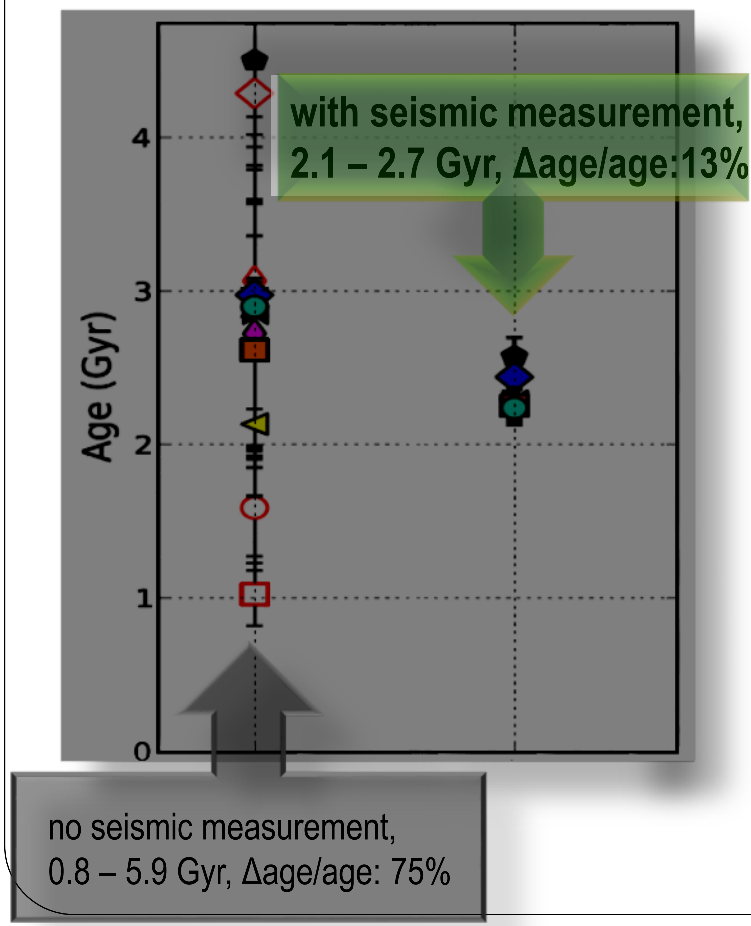
-Payload FM delivery: Jan 2021 – Jan 2022

-PLATO launch: January 2024


First phase of implementation
First generation of codes and models
to help dimensioning the implementation
Existing codes and models.
Is it needed ?
Estimate how far to go to reach the required precision* on star parameters
Second phase of implementation
Second generation of codes and models
Improved models and codes from theoretical work and CoRoT and KEPLER learning
Required precision on parameter stars is reached
After launch
Third generation of codes and models
Learning from PLATO data
Hopefully increase the precision beyond the initial requirements
Iterations over the years
*including time of delivery

Stellar seismology (together with classical parameters Teff...)

CoRoT and Kepler have shown that the requirements in term of precision can be achieved



Example: HD 52265 (CoRoT), a G0V type, planet-hosting star, 4 months data

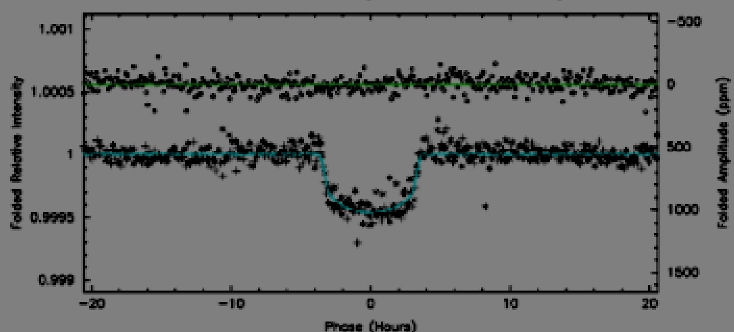
Seismic parameters:

Radius: $1.34 \pm 0.02\ R_{sun}$,

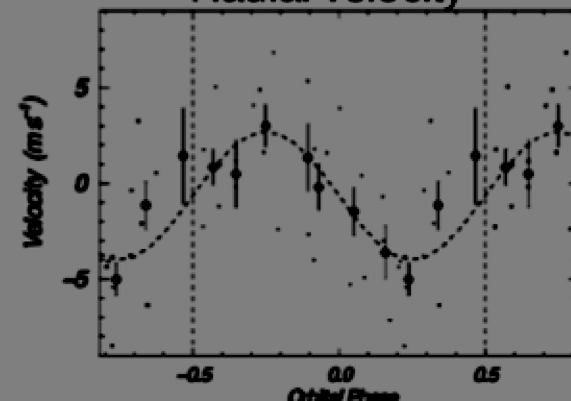
Mass: $1.27 \pm 0.03\ M_{sun}$,

Age: 2.37 ± 0.29 Gyr

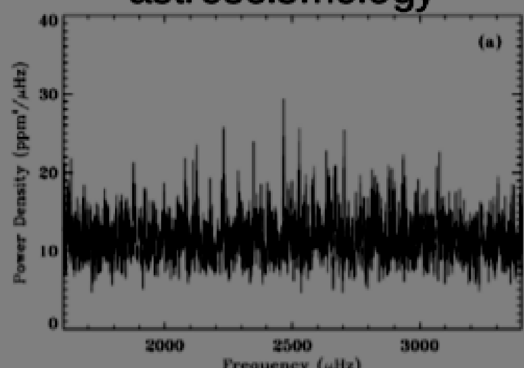
Transit photometry



Radial velocity



astroseismology



Proof of concept for a bright host star by Kepler mission:

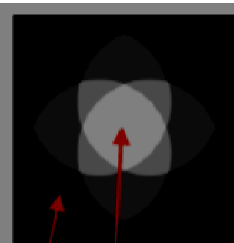
Kepler 10b (Batalha et al. 2011) (10.96 mag star):

$r_p=1.416 \pm 0.03$ R_{Earth}, (2% accuracy)

$m_p=4.56 \pm 1.2$ M_{earth} (25% accuracy)

age: 11.9 ± 4.5 Gyrs (38% accuracy)

as a function of noise level



	PLATO (4300 deg^2)		20,000 deg^2	KEPLER (100 deg^2)	
noise level (ppm/√hr)	nb of cool dwarfs & subgiants 2 long monitoring	m_V	nb of cool dwarfs & subgiants incl. step&stare	nb of cool dwarfs & subgiants	m_V
34	22,000	9.8 - 11.3	85,000		
80	267,000	11.6 - 12.9	1,000,000	25,000	13.6
	>1000	8	>3000	30	8
	>60,000	11	180,000	1,300	11

Spécification (définitions-tests) and Validation

La spécification des outils à implémenter au sein du PDC afin d'estimer avec précision les paramètres fondamentaux des étoiles du core program

L'activité se décomposera en trois étapes :

- une étape de définition avancée (phase B1/B2)
- une étape d'implémentation   (validation)
- une étape de mise à jour

•The documents that the PLATO-SAT is involved before adoption are:

- **Science Requirements Document**
- (now issue 5.0, to be updated after the PCDR and for the Instrument-SRR and SRR)

- **Science Requirements Justification Document**
- (it will be issued after the PDCR, and updated before Instrument-SRR and SRR)

- **Science Management Plan** (to be ready by mid September)
- **Definition study report** (to be ready by March 2016)

For the Science Group Segment, ESA is responsible for
- the Science Operations Concept Document (SOCD),
- the Science Implementation Requirements Document (SIRD)
- the ESA Science Implementation Plan (ESA SIP).

For the definition of the SOCD and the SIRD, ESA+ Consortium.
The Consortium is responsible for the PMC SIP.

All these documents will be updated after the SGS PDCR, before the SGS SRR and for adoption.

In addition, the PMC has to deliver the documents related to payload and performance. OHB has produced the Instrument Document Delivery List with the documents that the Consortium has delivered for the PDCR and that will be updated for the Instrument SRR and before adoption.

Time lines:

1) sample of stars : rapid and precision and accuracy level 1
Automatic algorithms
Exemple averaged seismic quantities - scaling laws

2) sample of stars still rapid and better accuracy
Automatic method
Exemple averaged seismic quantities- model grids

3) sample of stars still rapid and better accuracy
Automatic method
Exemple individual frequencies- model grids

4) sample of stars still rapid and better accuracy
Automatic method
Exemple individual frequencies- model grids

5) individual studies : accurate, less rapid

HH2a

M5

#1 erroneous mode order, L not included sigma([Fe/H]) = 0.05, sigma(T_eff) = 80 K

#2: corrected mode order, L not included sigma([Fe/H]) = 0.05, sigma(T_eff) = 80 K

#3: corrected mode order, **L included in chi^2**

#6: corrected mode order, L not included **sigma([Fe/H]) = 0.10**, sigma(T_eff) = 80 K

#7: corrected mode order, L not included sigma([Fe/H]) = 0.10, **sigma(T_eff) = 120 K**

#8: 'truth' from obs_HH2a_150616_truth, L not included

#9: 'truth' from obs_HH2a_150616_truth_nosurf, L not included

Impact of changes at the level of 1.2% on the estimated uncertainties for the age and 1.6% on the u

Impact on the accuracy at the level of 2-3 % on delA = (A-A0)/A0 and 2-4 % on delM =(M-M0)/M

Impact on the accuracy at the level of 0.3-0.5 % on delR= (R-R0)/R0 and 0.5-0.7% on delRpp, del

Only for the radius, are the impact of the same magntitude thant the biais