Stellar physics with GAIA

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Action Spécifique Gaia

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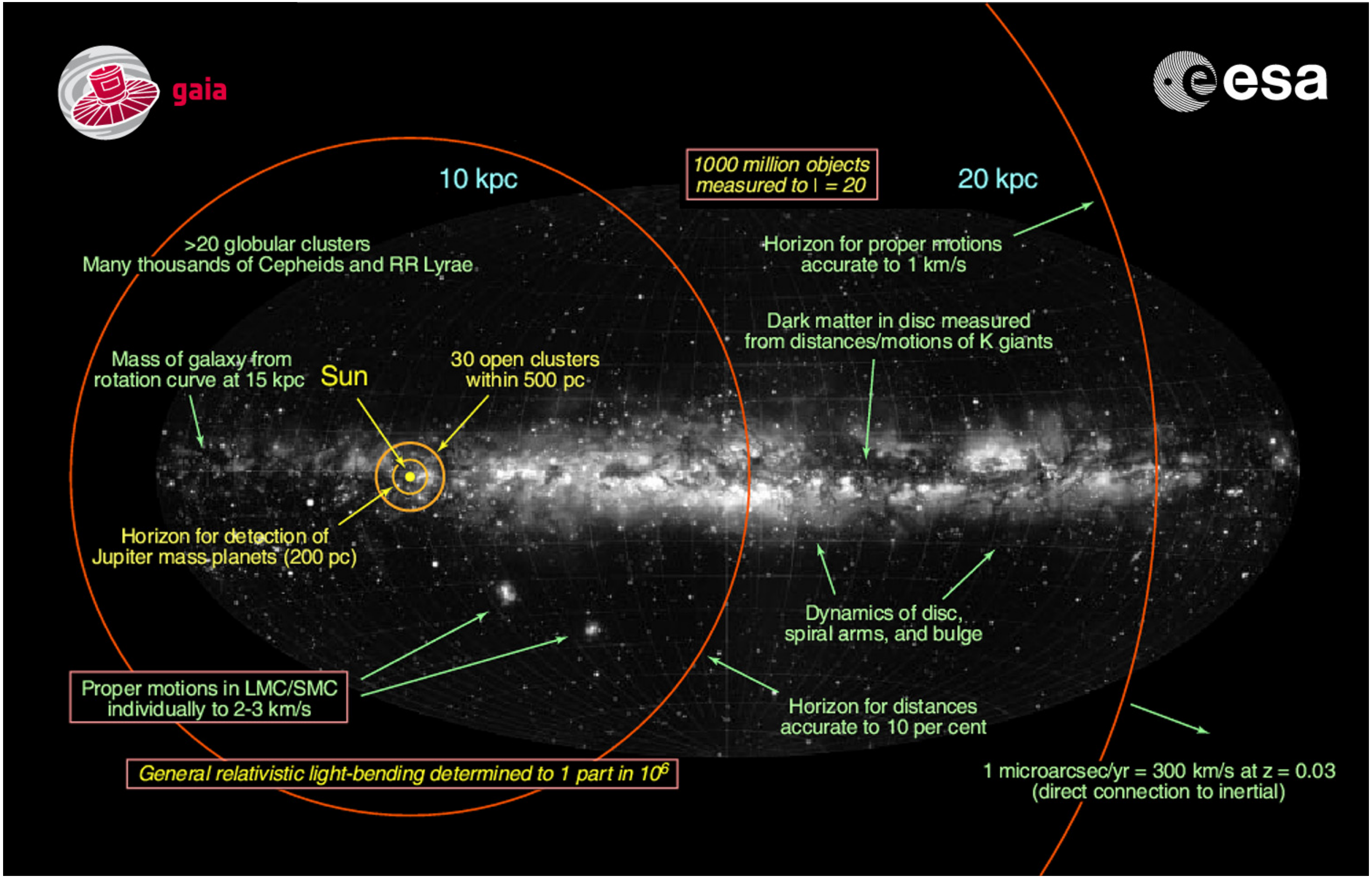


gaia
esa
10 kpc
1000 million objects measured to | = 20
20 kpc
>20 globular clusters
Many thousands of Cepheids and RR Lyrae
Horizon for proper motions accurate to 1 km/s
Dark matter in disc measured from distances/motions of K giants
Mass of galaxy from rotation curve at 15 kpc
Sun
30 open clusters within 500 pc
Horizon for detection of Jupiter mass planets (200 pc)
Dynamics of disc, spiral arms, and bulge
Proper motions in LMC/SMC individually to 2-3 km/s
Horizon for distances accurate to 10 per cent
General relativistic light-bending determined to 1 part in 10^6
1 microarcsec/yr = 300 km/s at z = 0.03
(direct connection to inertial)

GAIA

- Scope of GAIA : Galactic formation and evolution, dynamics

⇒stars are markers (kinematics, chemistry, ...)

- Also, of course: reference frame, cosmological distance scale, exoplanets, fundamental physics, solar system, dark matter, ...

Stars as targets per se

- Stars can be studied with GAIA : we will gain insight into various aspects of stellar physics :
  - Distances -> luminosities, radii, etc
  - Masses, ...
- Preparation of GAIA induces better stellar physics, and new tools

- My talk will illustrate these two points

What will GAIA provide ?

- 10^9 stars to V<20 (300μas) (completeness)
- $26x10^6$ stars to V<15 (20μas)
  - Sun @1kpc: Δd/d=0.02
  - Red Giant @2.5kpc: Δd/d=0.05
  - M-L dwarf @100pc: Δd/d=0.03
- $3x10^6$ stars better than 1%
- $30x10^6$ stars better than 10%

- Proper motions 50% better than parallaxes
- Radial velocities at 1-10km/s to V=16

=> Masses for binaries

- Multiple epochs => stellar variability, rare types of stars/stages of stellar evolution : $18x10^6$ variables (Eyer & Cuypers 2000)

What will GAIA bring us for stellar physics ?

- Good distance => accurate L, the most commonly missing parameter in Galactic star studies
- L combined with T_{eff} (from photometry/ spectrophotometry) => R ($L=4\pi R^2 \sigma T_{eff}^4$)
- M and R => gravity g (difficult to derive from spectroscopy, and often affected by NLTE effects)
- In addition, synergy with seismology which provides, e.g., M/R^3

Stellar evolution (1)

- Modeling of stellar evolution :
  - Good physics : EOS, nuclear reaction rates, opacities, atomic diffusion, atmospheres, ...
  - Special difficulties for cool, dense stars, late stages, and accurate modeling (e.g. Sun)
- Predictions: L(t), R(t), T_{eff}(t), z(t), ...
- Validation with well known systems (Sun, α Cen binary, ...)

Stellar evolution (2)

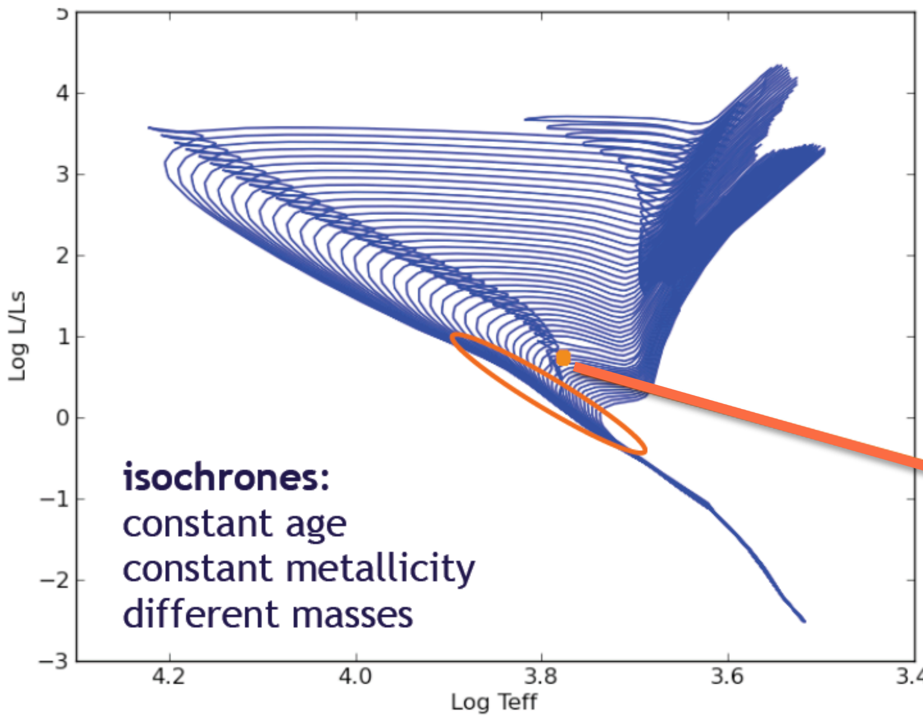
- Atmospheres :
  - Boundary condition
  - Transformation L-T_{eff} => M_V, BC_V, T_{eff} – color
  - Extraction of stellar parameters from observations : T_{eff}, logg, chemical composition, ...

Great recent progress : opacities, 3D, NLTE, ...

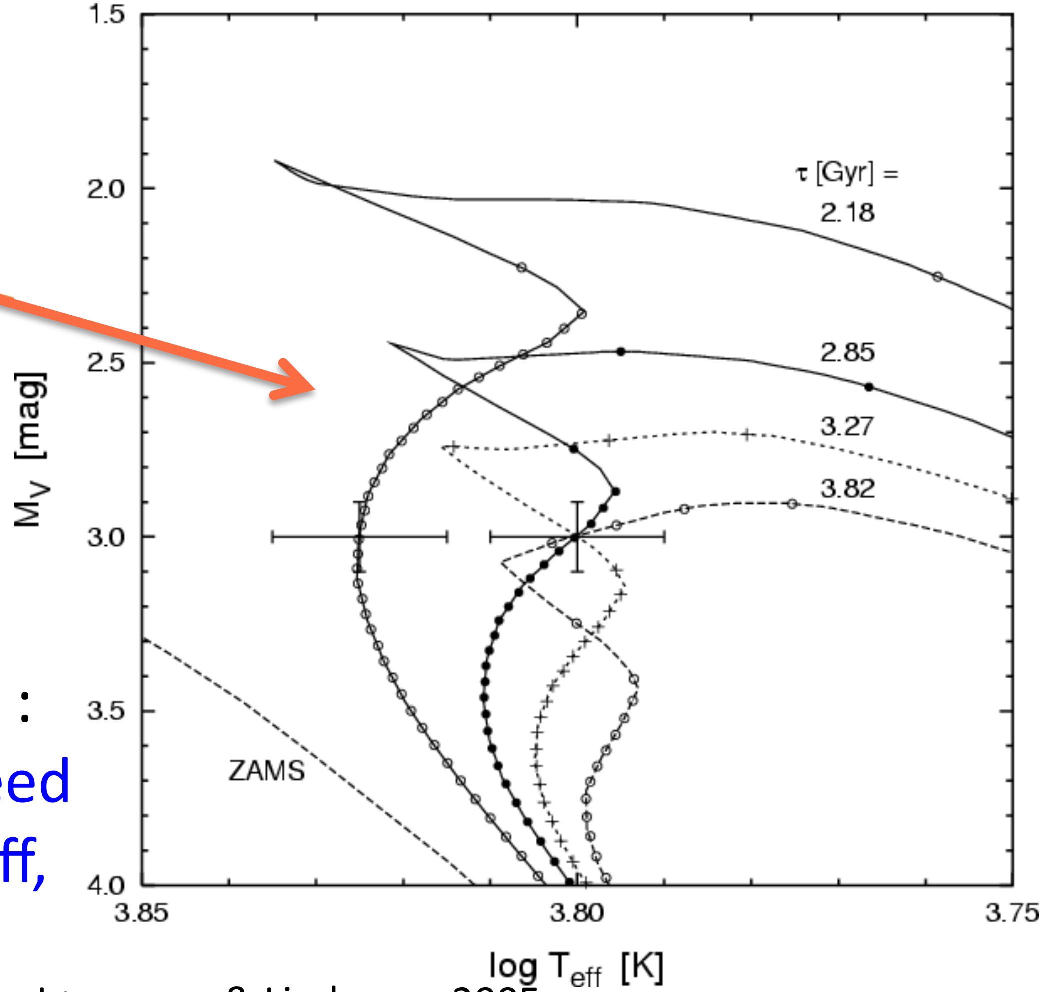
But still relatively large systematic errors for cool giants, hot stars, metal-poor stars

Ages from isochrones

Principle straightforward: place a star T_{eff}, L, [M/H] => age, mass, $[M/H]_0$



Courtesy Y. Lebreton



Jørgensen & Lindegren 2005

Not always easy, nor unambiguous : Isochrones overlap. In any case, need for very precise, and accurate L, Teff, and [Fe/H], (and mass!)

Stellar evolution (3)

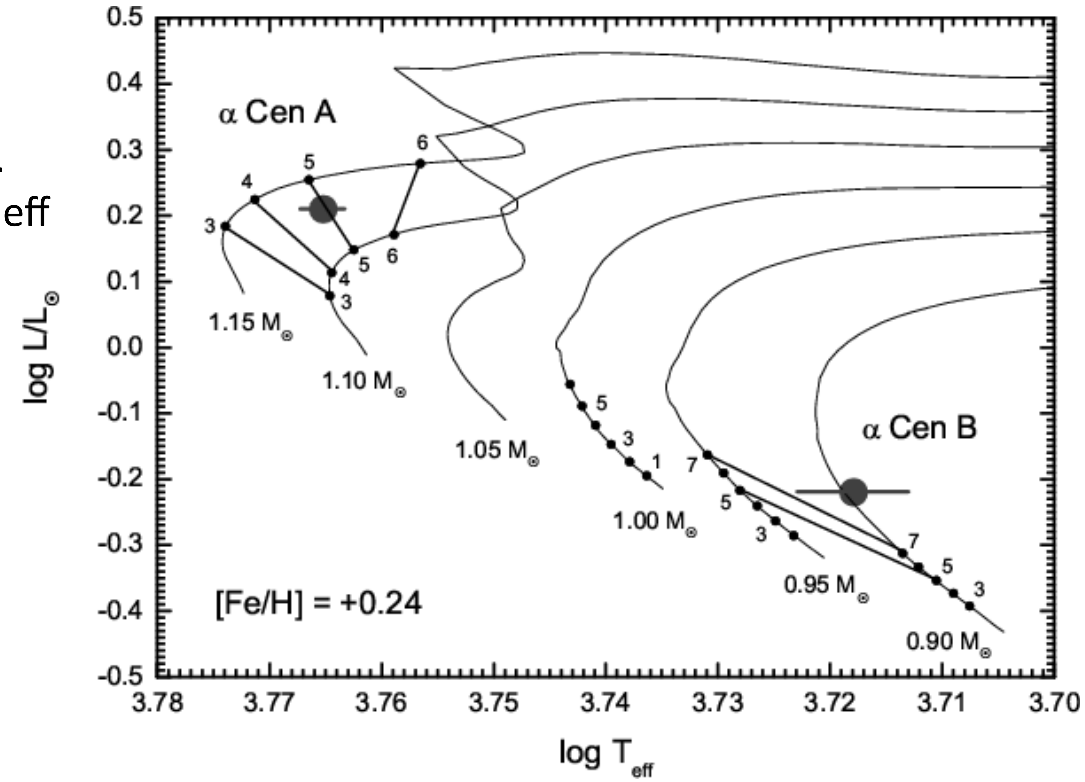
- Validation

Example of α Cen

M_A=1.105±0.007, R_A=1.224±0.003, $\log g_A$=4.307±0.005

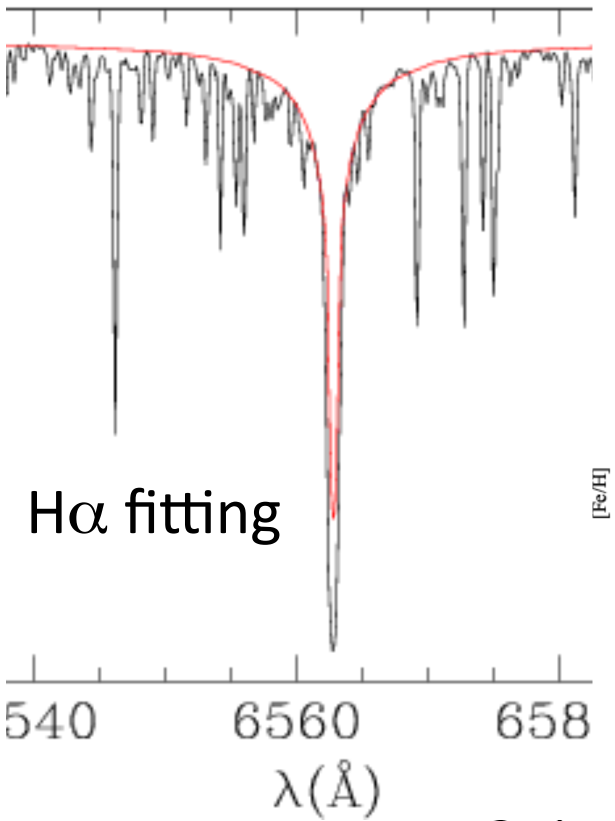
M_B=0.934±0.006, R_B=0.863±0.005, $\log g_B$=4.538±0.008

Spectroscopic determination of T_{eff}

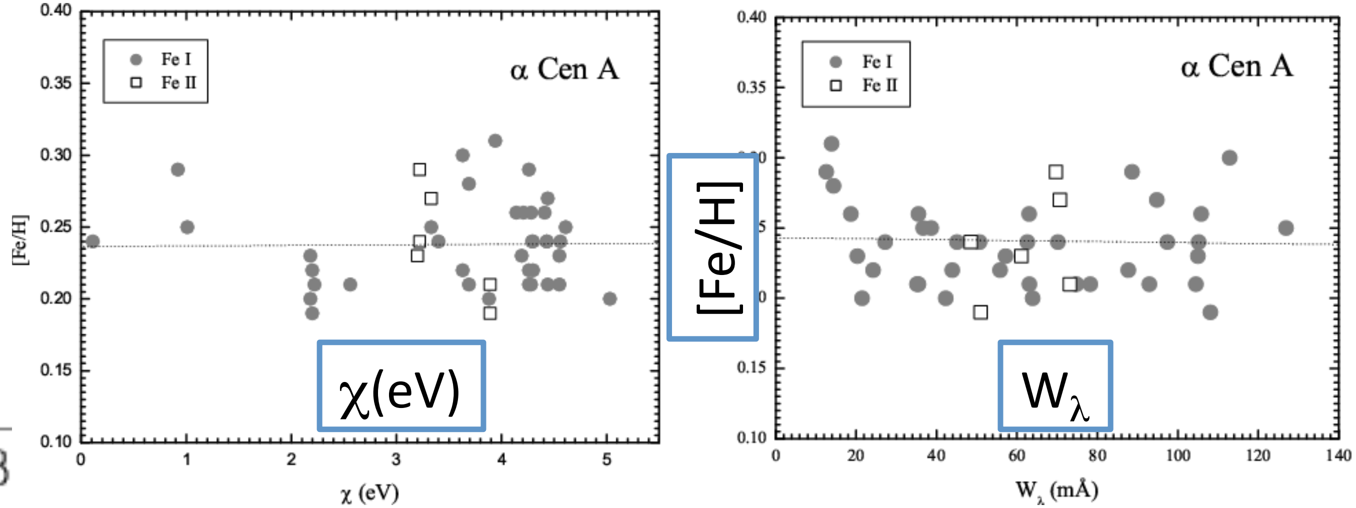


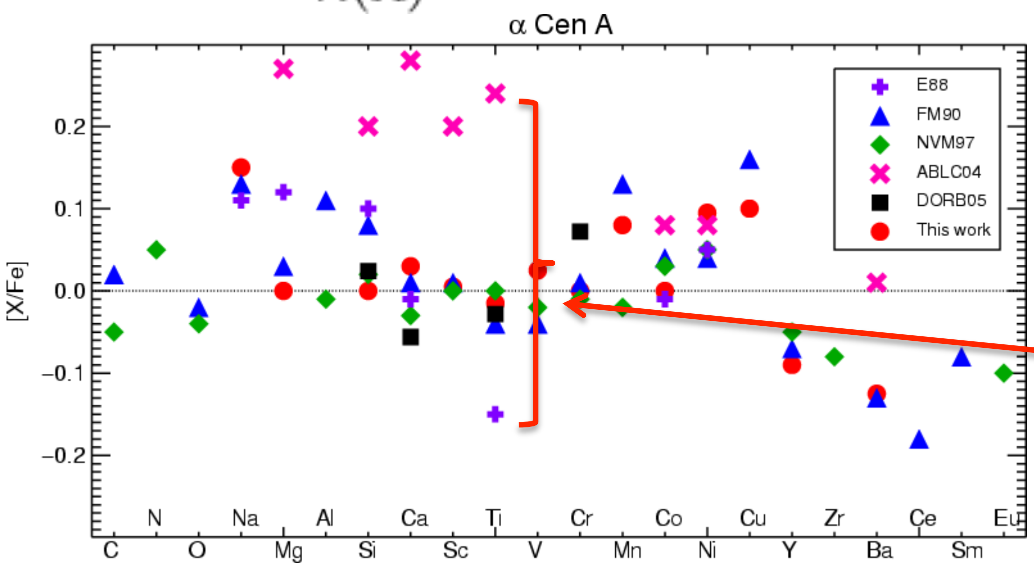
Porto de Mello et al. 2008

Alpha Cen : spectroscopic determination of T_{eff}



FeI and FeII line fitting





But, scatter in T_{eff} from various authors is about 300K !

And abundance scatter is large too!

Stellar evolution (3)

- Validation

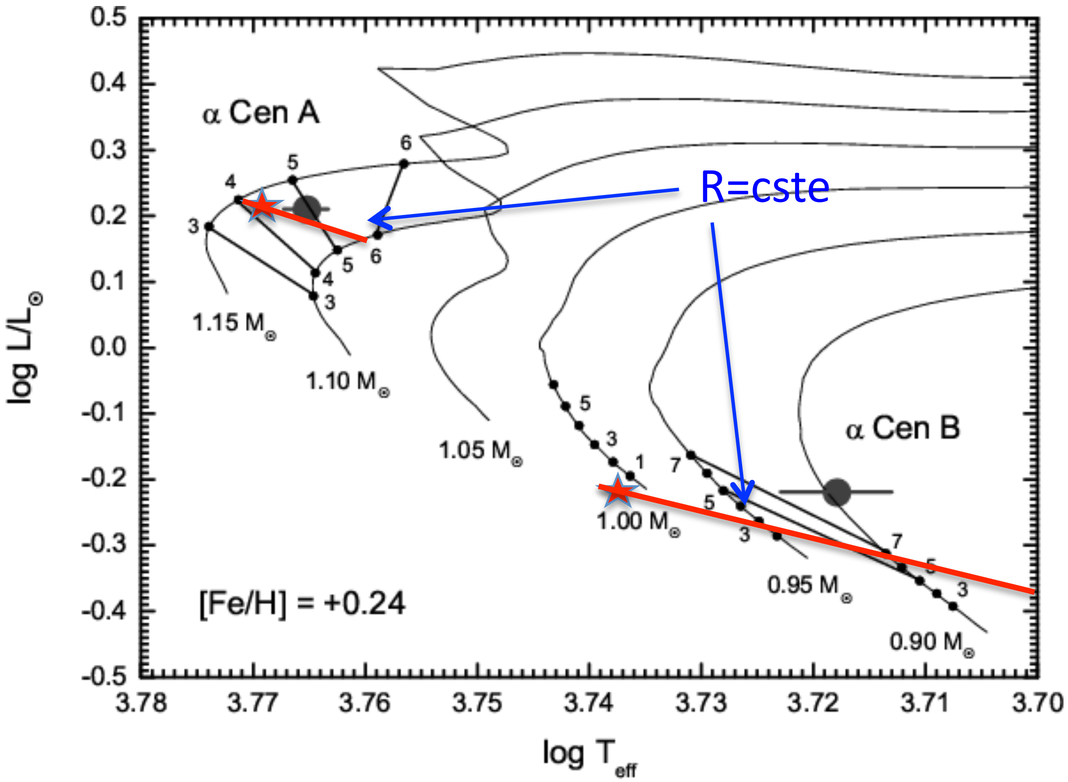
Example of α Cen

M_A=1.105±0.007, R_A=1.224±0.003, $\log g_A$=4.307±0.005

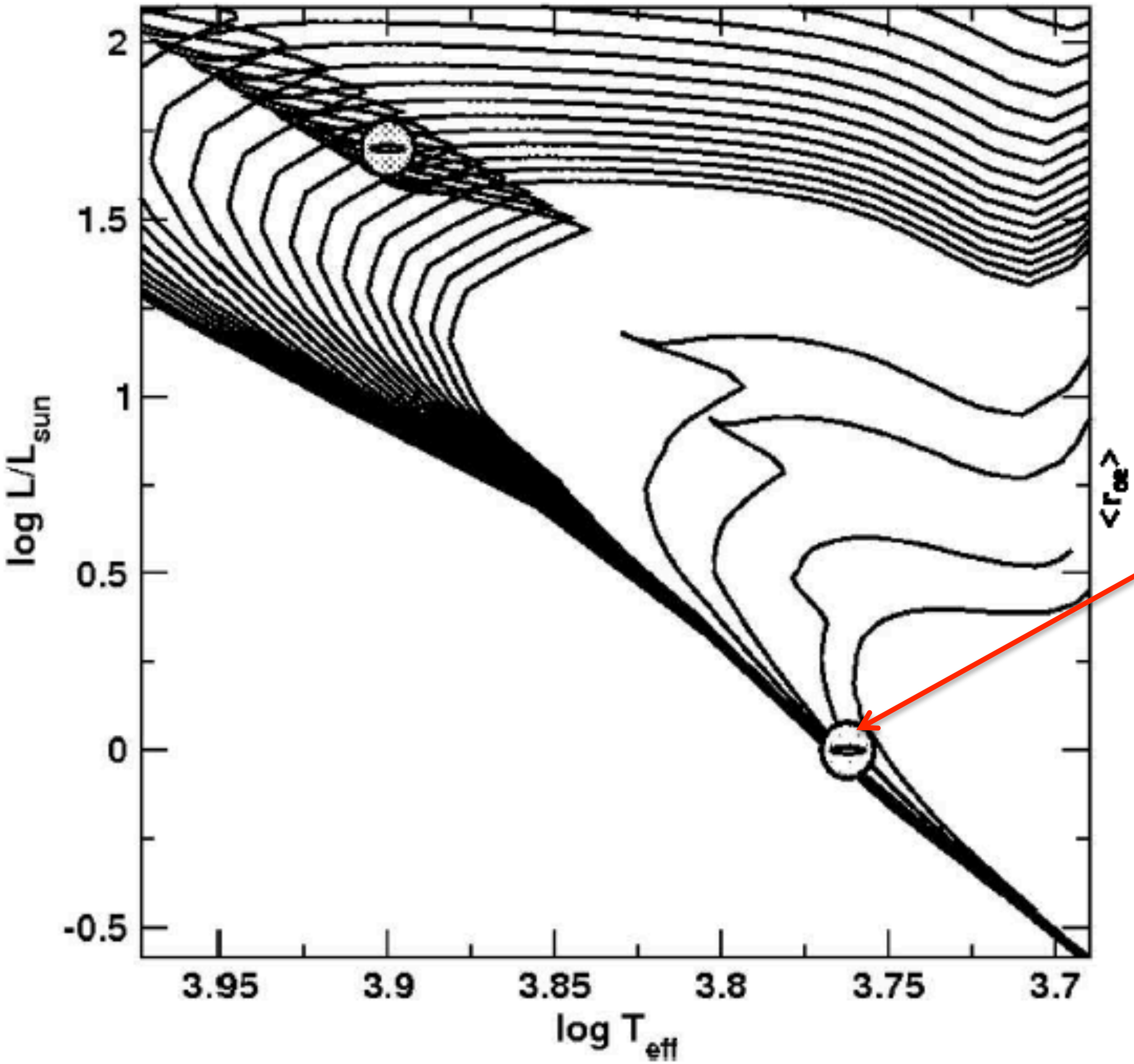
M_B=0.934±0.006, R_B=0.863±0.005, $\log g_B$=4.538±0.008

Note that $\log T_{eff}$ from L and R are : 3.77 and 3.74
⇒L is wrong?
⇒T_{eff} from spectroscopy not good ?

⇒Find a consistent solution = constraint for atmosphere and evolution models
i.e. L, g, T_{eff}, M_V, BC, etc from atmos., and then test evolutionary tracks
Remaining difficulty : abundances!



GAIA and stellar parameters



GAIA will bring tight constraints on L, T_{eff} for many stars.

But, degeneracy is still a problem : MS and TO.

Seismology is very complementary !

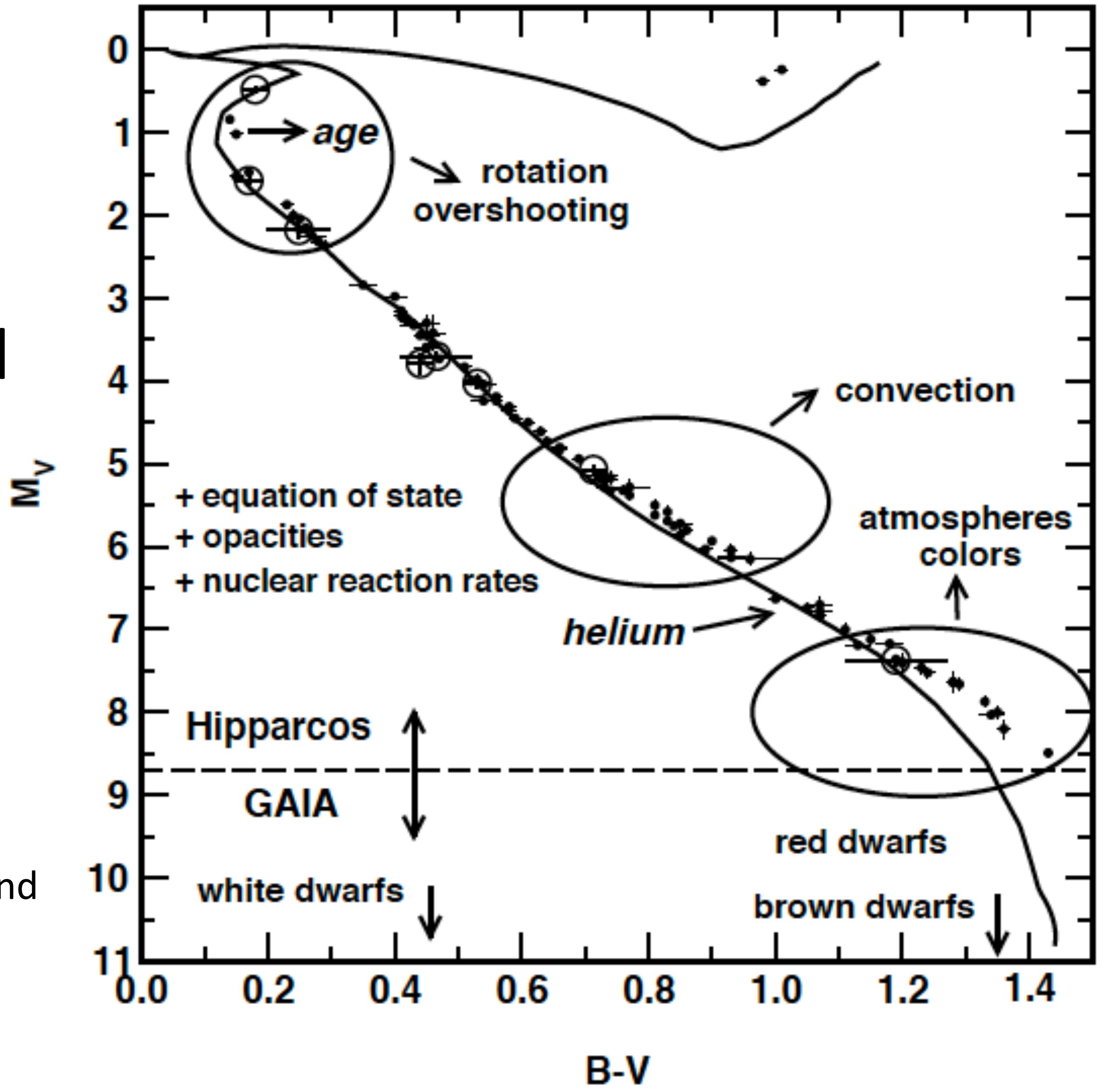
Lebreton & Montalbán 2010

Clusters

- HR diagrams of clusters

=> same ages, and initial chemical composition

Hyades (de Bruijne et al. 2001,and Lebreton et al. 2001)



Clusters and He abundance

Hyades M-L diagram:

vB22A & B allow to determine the He abundance.

But :

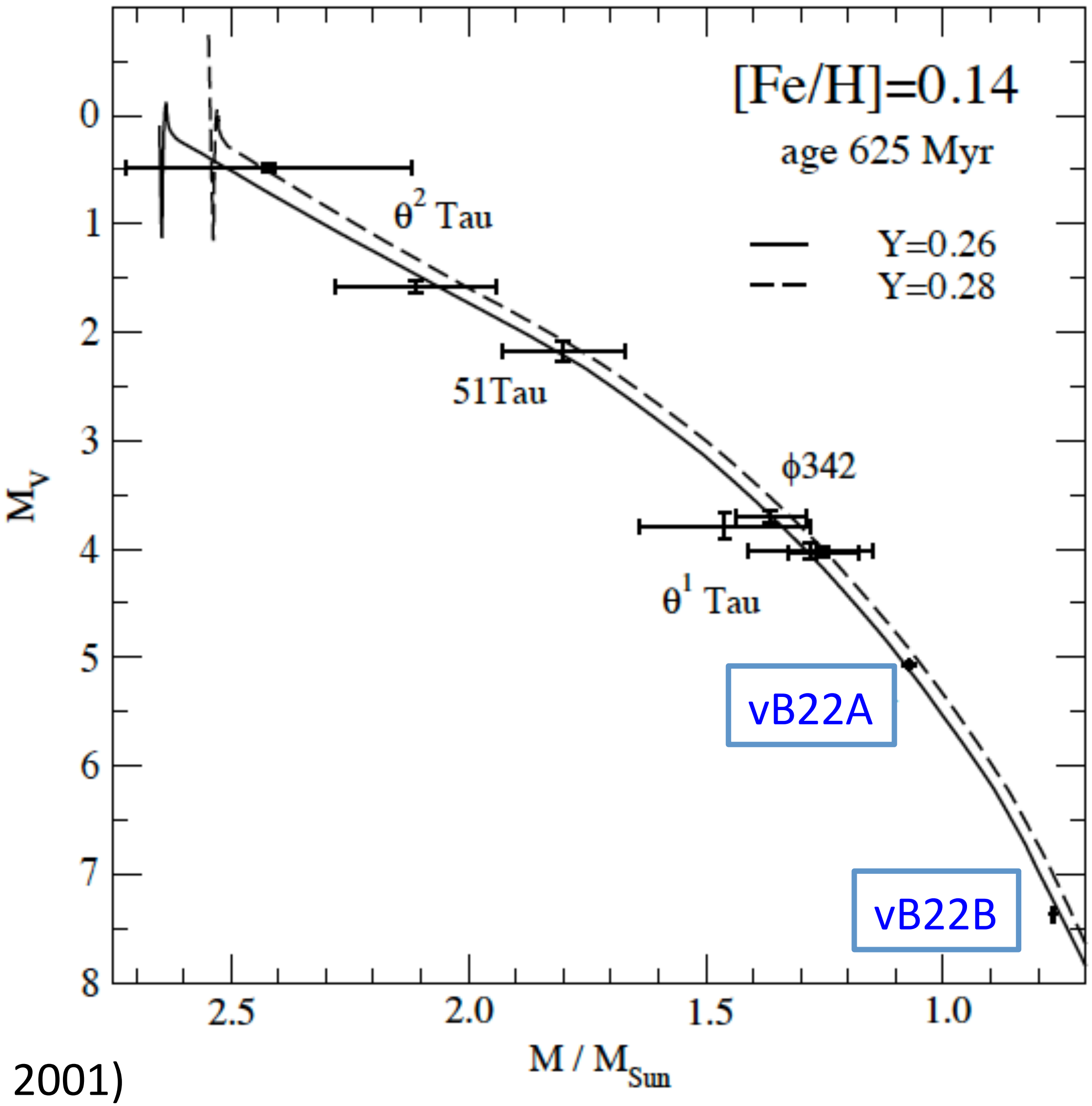
degeneracy [Fe/H], He

(0.09,0.25) (0.14,0.26) (0.19,0.27)

...and

Mixing-length, EOS, ...

=> **Need more data!**

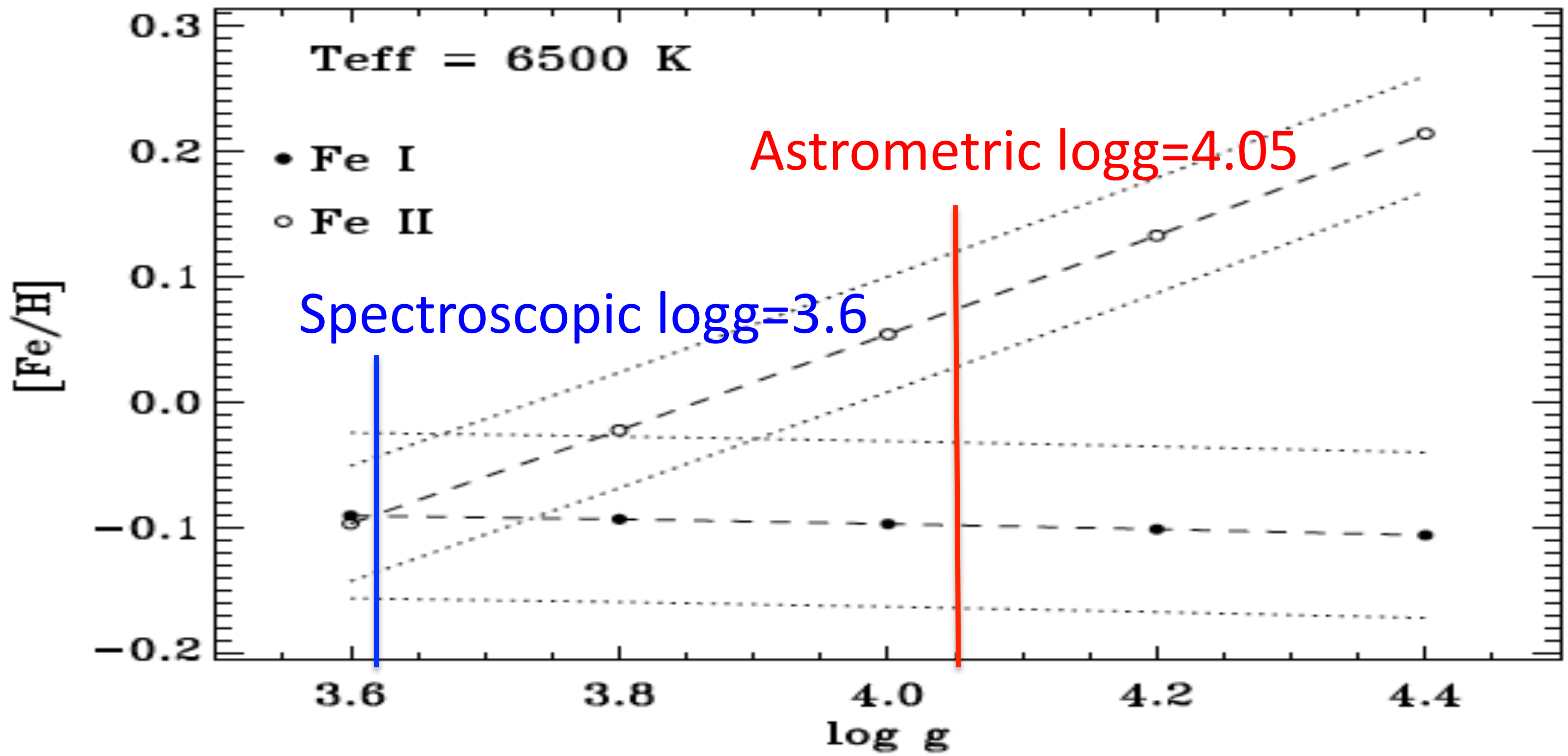


(Torres et al. 1997, Lebreton et al. 2001)

Abundances : NLTE effects

Requiring ionization equilibrium (LTE) => gravity g

Fuhrmann et al. 1997 (Procyon)

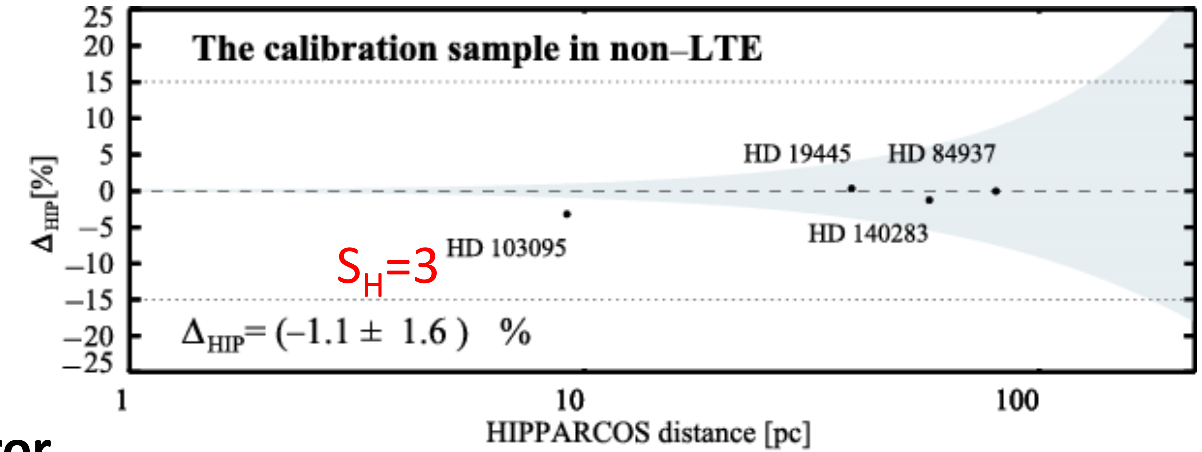


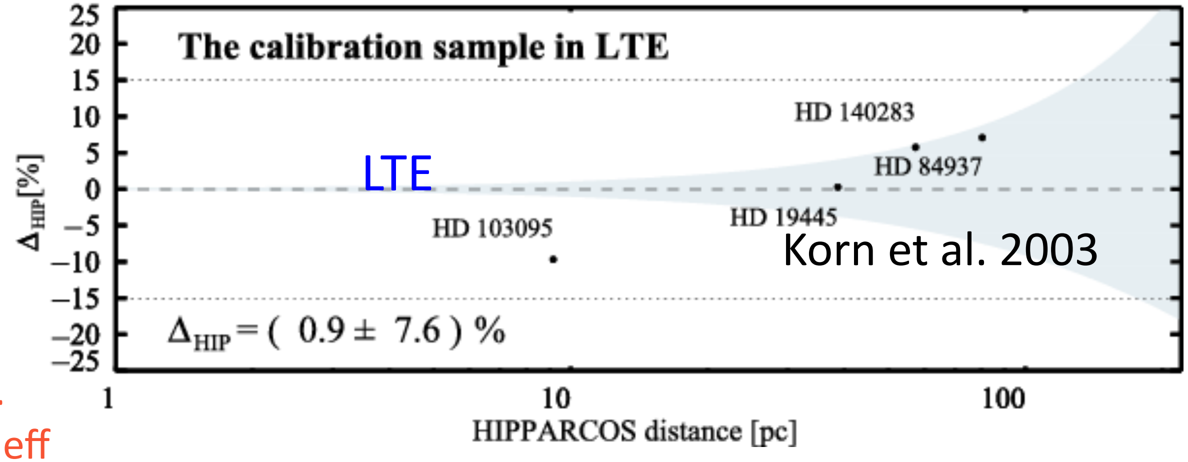
NLTE effects

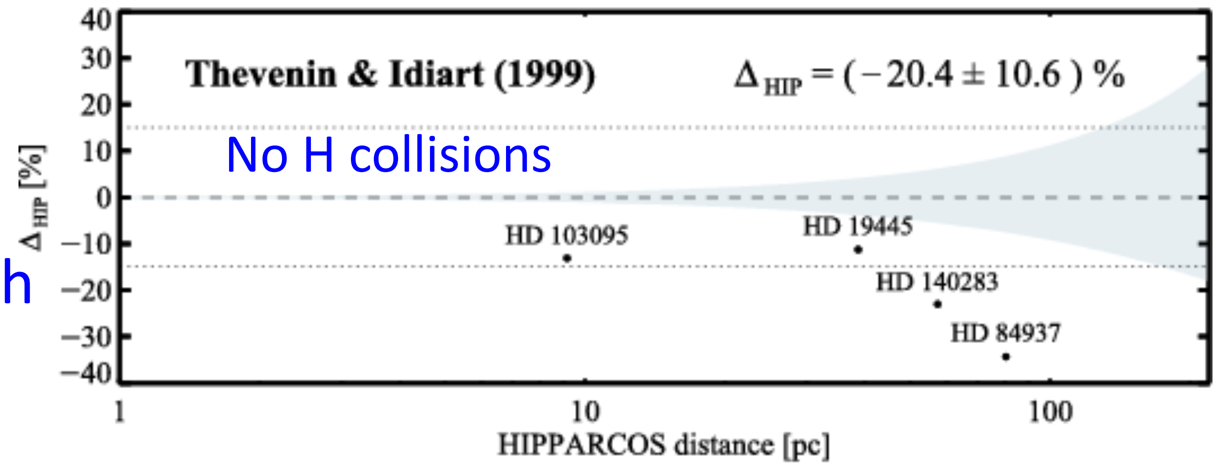
- In fact FeI/FeII or CaI/CaII depend on collisions (e- and H), and photo-ionization.
- Collisions with H not well known. Drawin aproximation with factor S_H between 0 (no collisions) and 1-3 (closer to LTE)

NLTE effects

Plot of **spectroscopic distance error**







Use reference stars, with known distances (thus L), T_{eff} (thus R), and masses (thus g) to **calibrate NLTE corrections** !

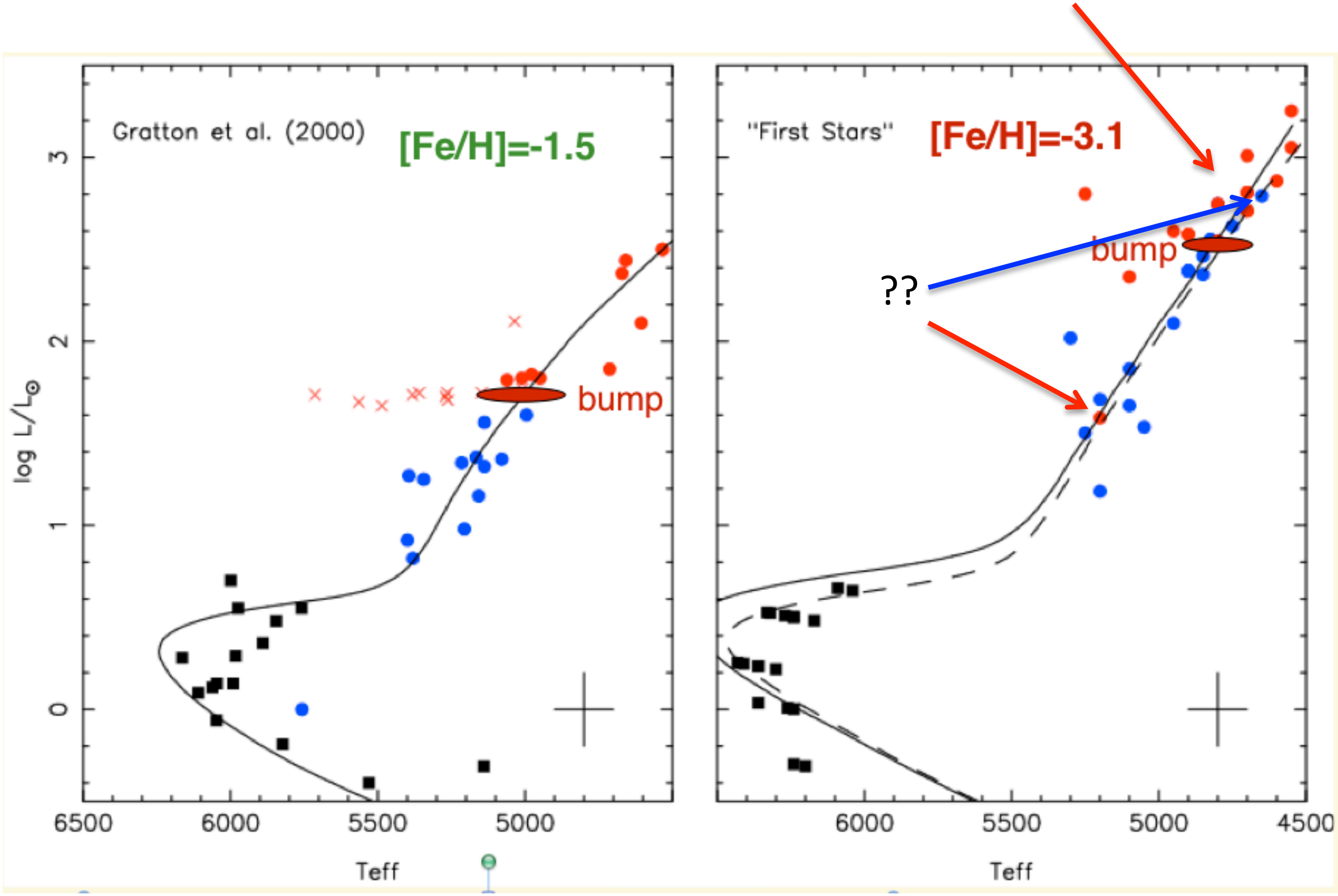
GAIA will provide large such samples

Transport processes ; abundance anomalies

CN processed RGs with high N/C, low $^{12}C/^{13}C$, no Li

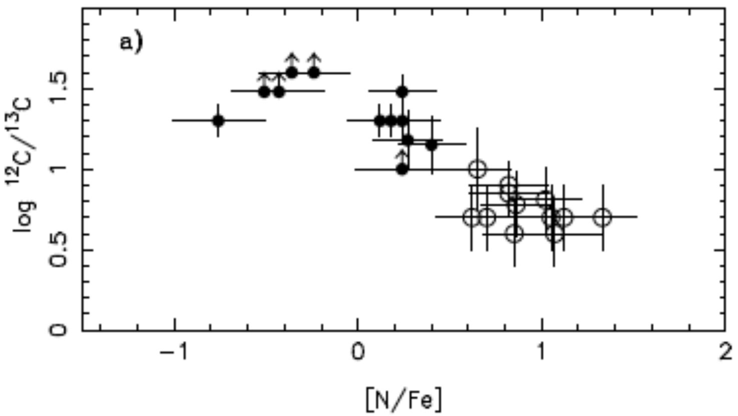
Thermohaline mixing ?

Charbonnel & Zahn (2007), Cantiello & Langer (2010)



Spite et al. 2007

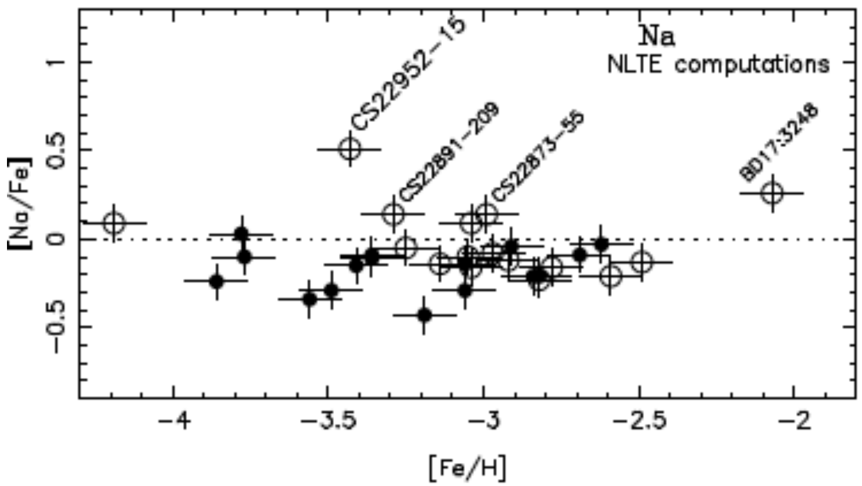
Mixing

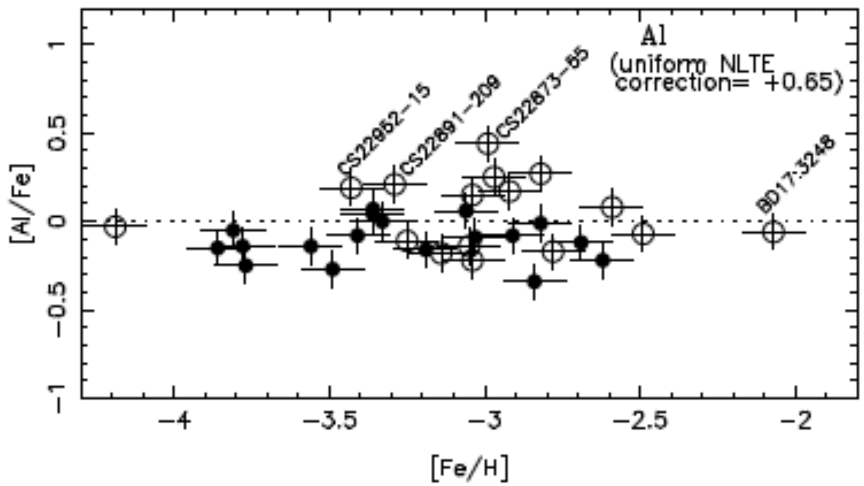


Na-Al overabundance for field stars, as seen in globular cluster stars. But are these AGBs?

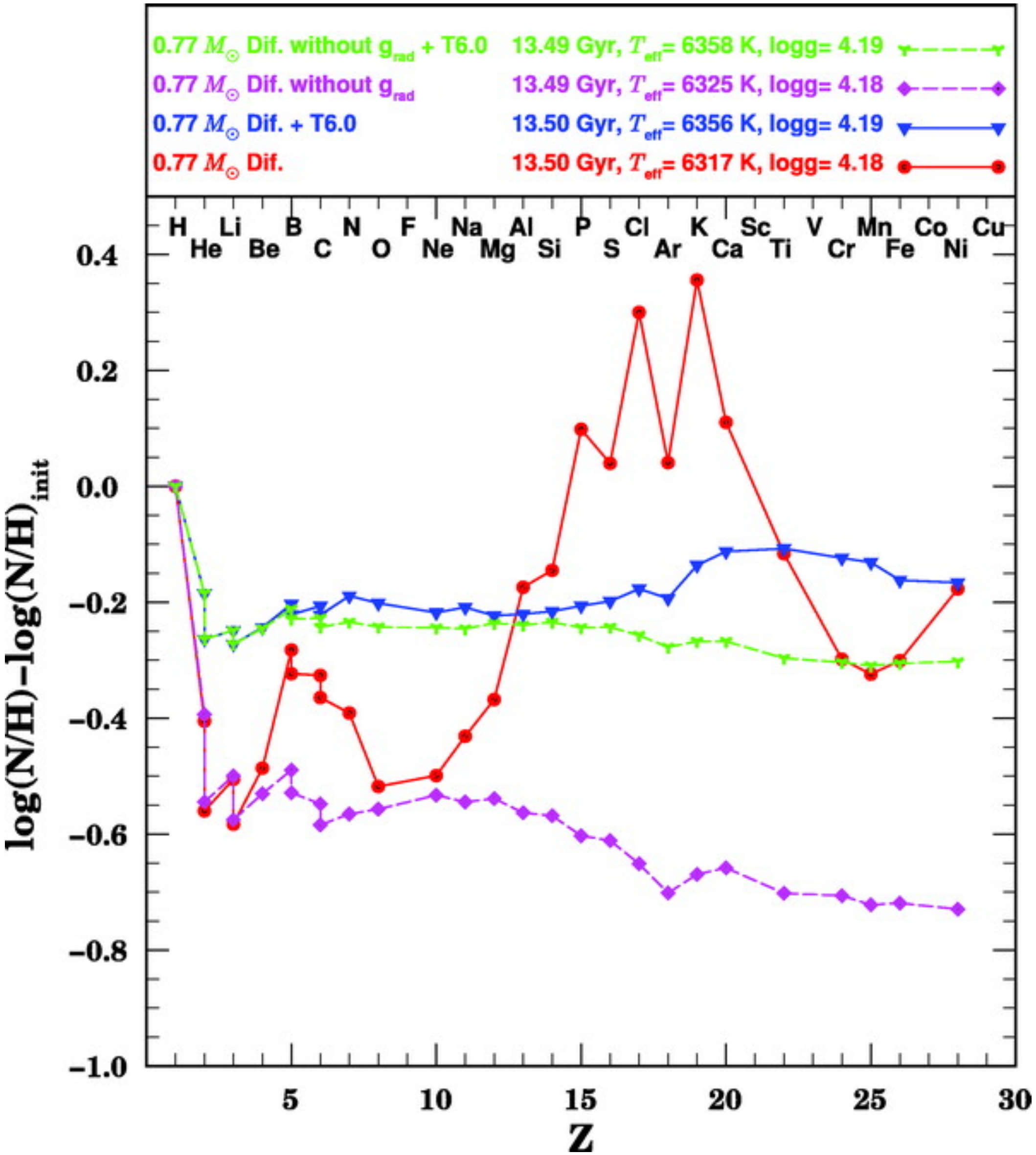
=> Need for **better L, and logg**

Spite et al. 2007





Diffusion and turbulent mixing



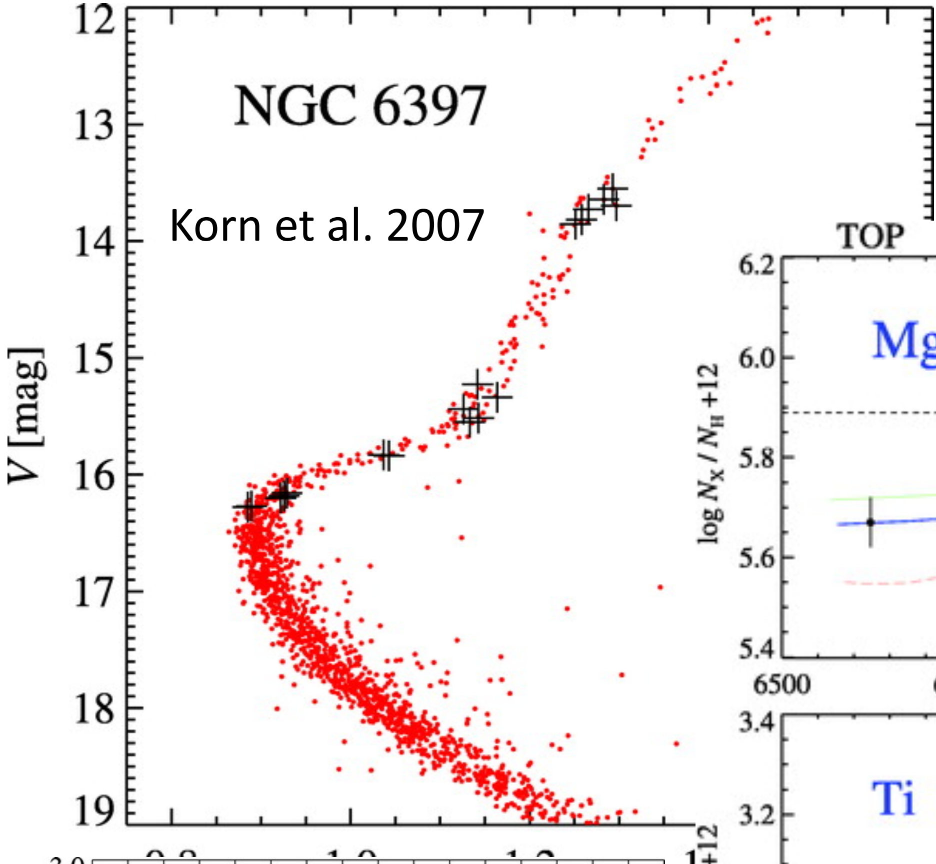
Element diffusion inside stars, with unknown amount of turbulent mixing

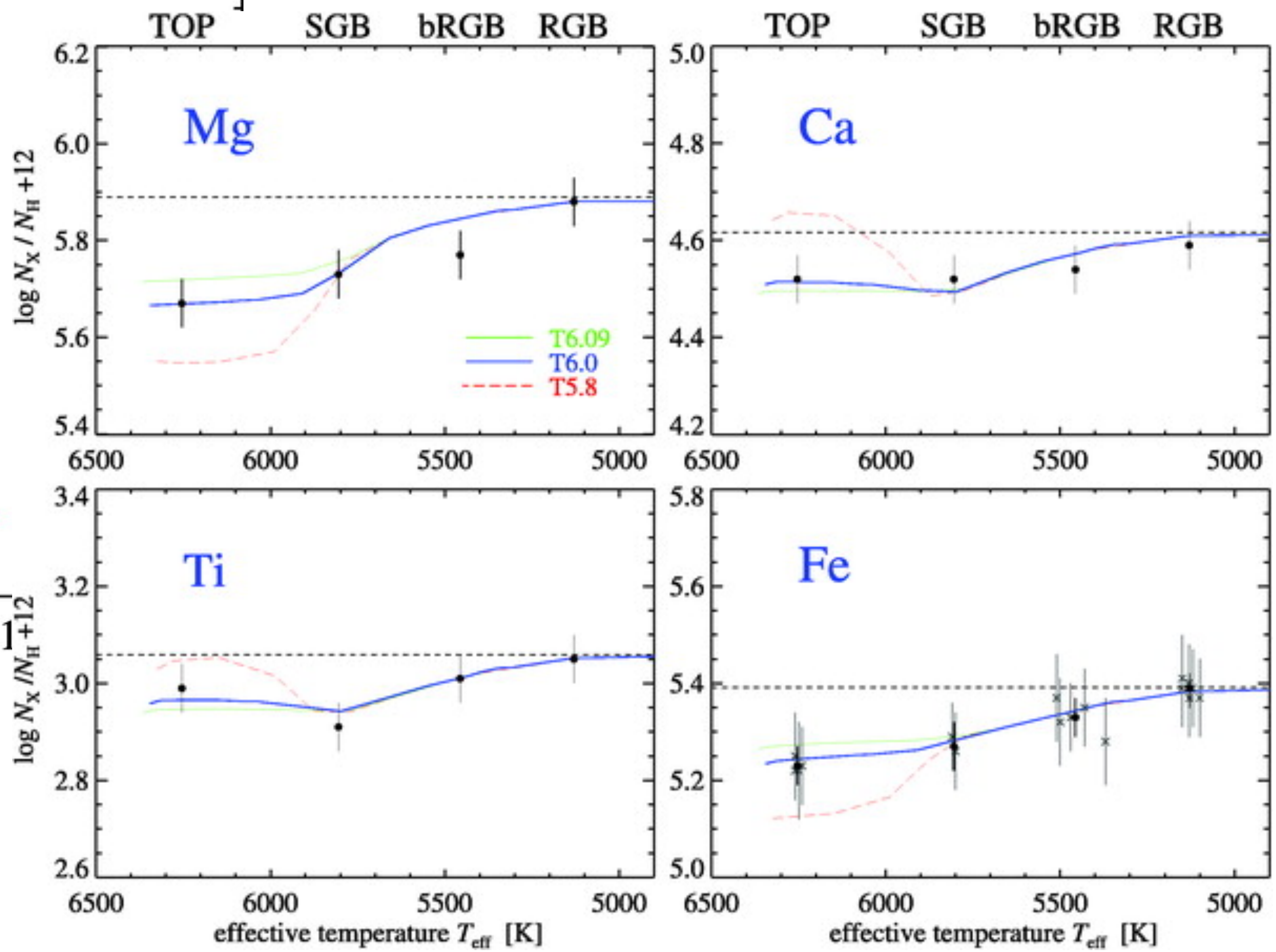
Impact on determination of "real" abundances from surface abundances (Li, ...)

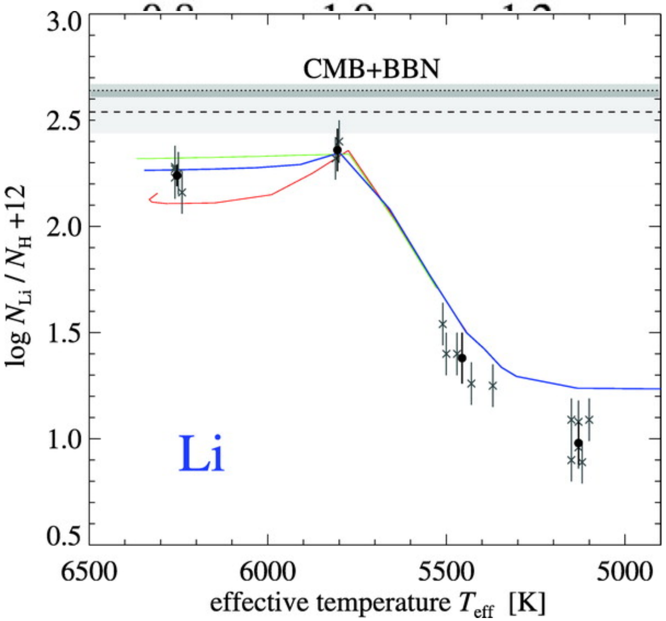
=> Test on clusters

Korn et al. 2007

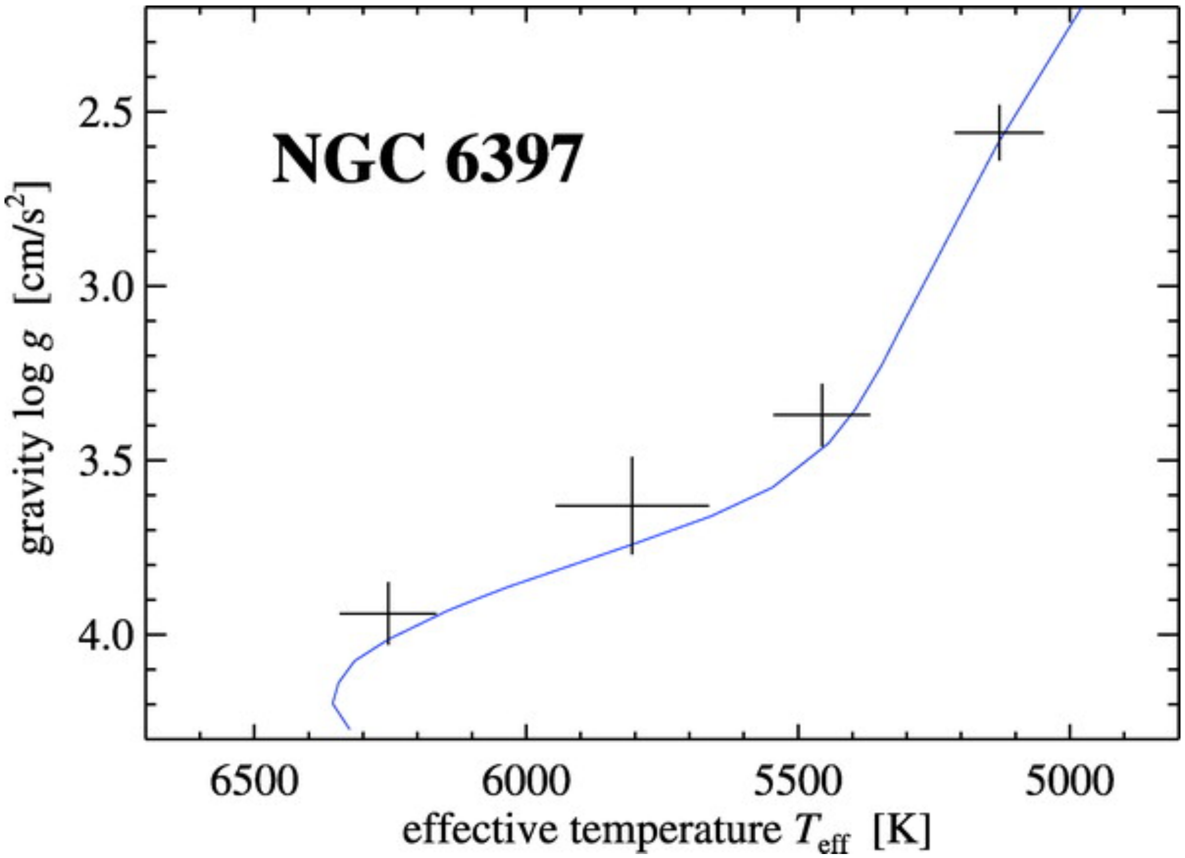
Diffusion and Li







Diffusion; further validation

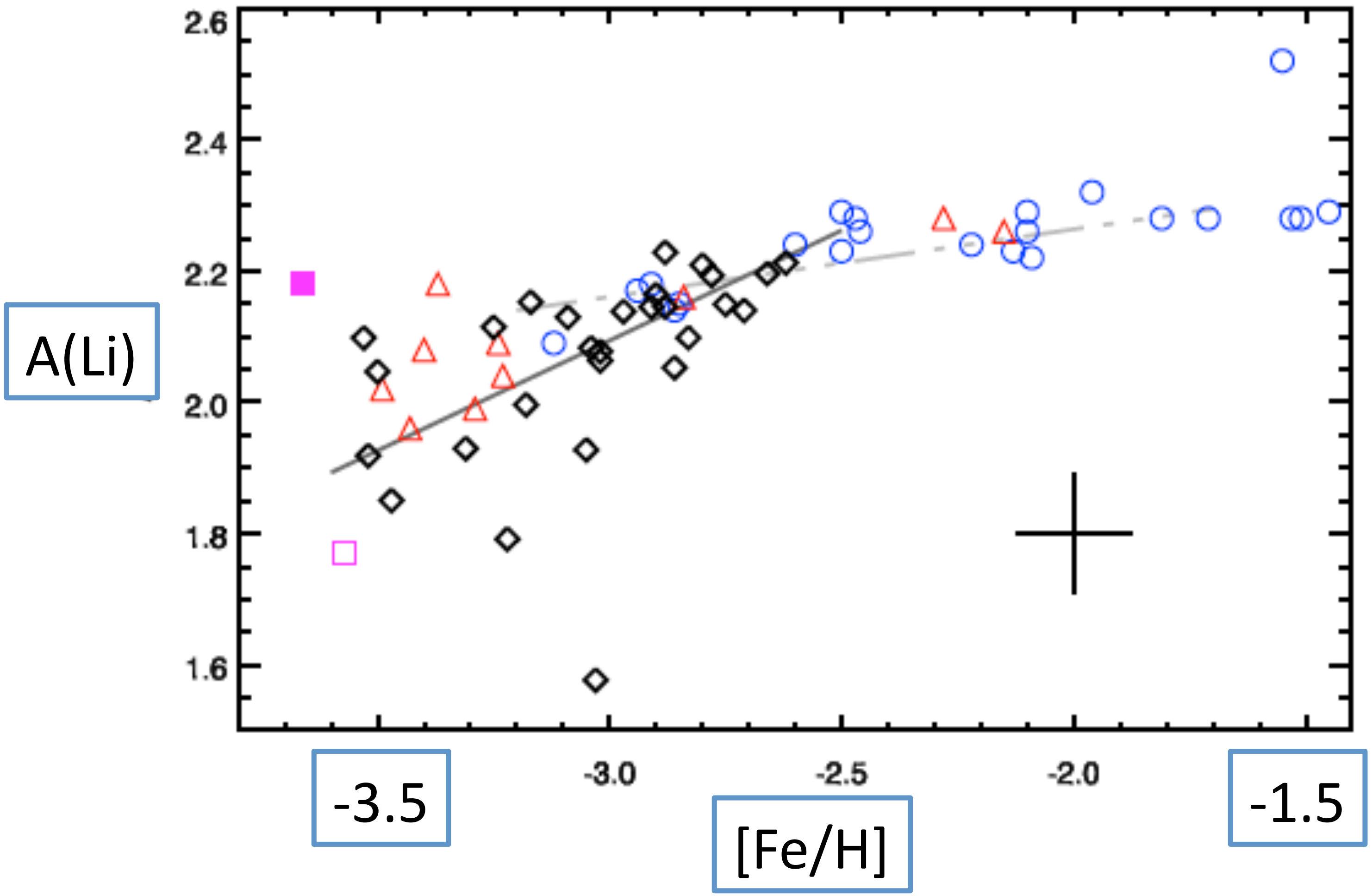


Isochrone computed using the same diffusion model.

Good stellar parameters needed!

Do it on field stars?
=> know precisely their evolutionary stage!

Explain Li in EMP stars?



Sbordone et al. 2010

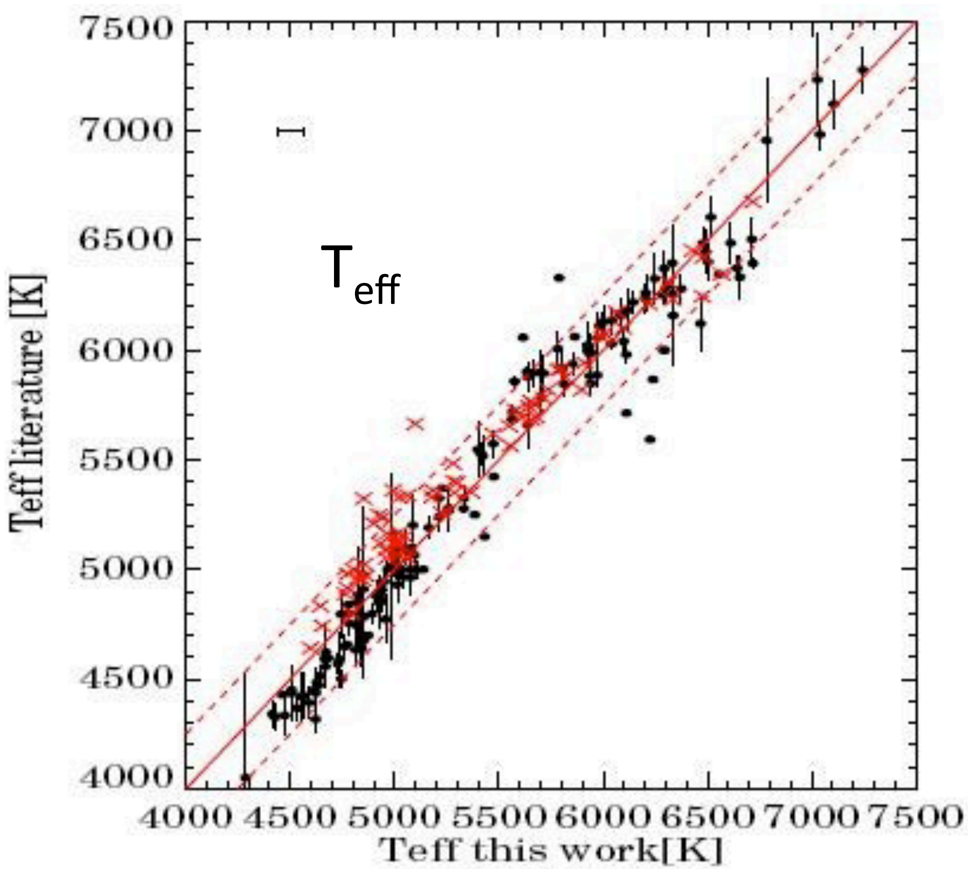
GAIA preparation: Global Stellar Parametrizers

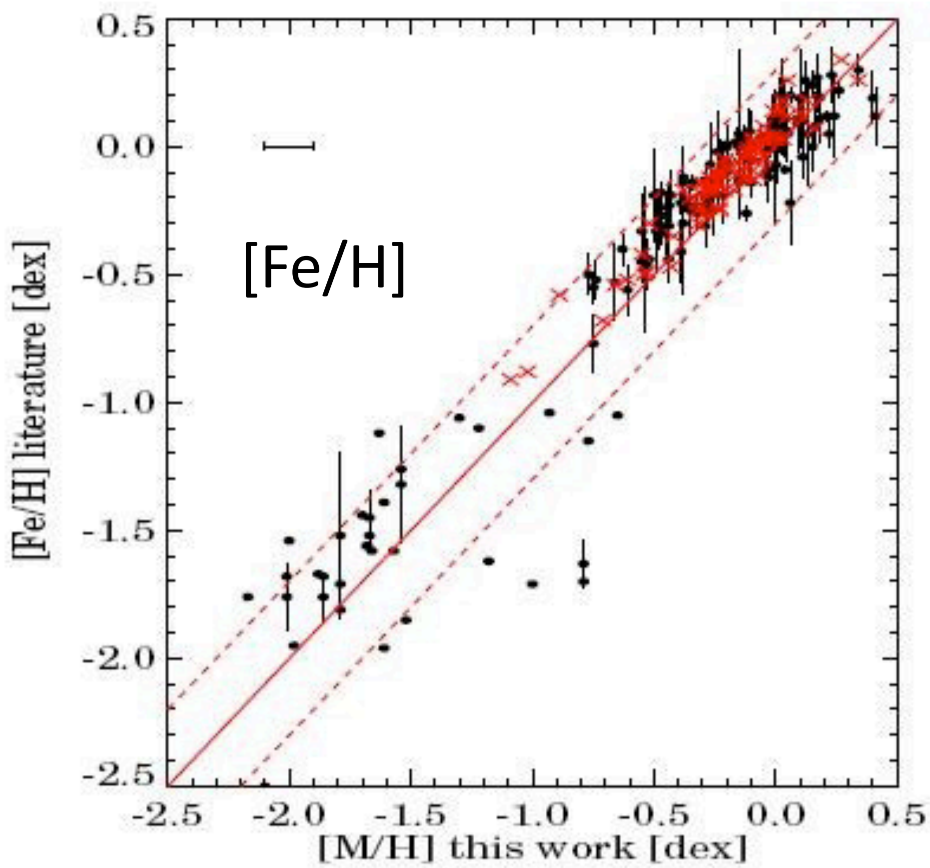
- Powerful algorithms to quickly extract APs from large number of spectra (GSP-spec)
  - Optimization : APs derived from distance minimization
  - Projection : observations projected on a set of vectors defined during learning phase -> MATISSE (Nice)
  - Classification : pattern recognition-> DEGAS (Nice)

GSP-spec : Matisse & Degas

Test on S^{4}N (Allende Prieto et al. 2004) and CFLIB spectral libraries (Valdes et al. 2004)

Kordopatis et al. 2011





GAIA preparation: large homogeneous samples of stars

WP "provide calibration of training data" CU8 (C. Soubiran)

General Stellar Parametrizers are trained on synthetic spectra

⇒ systematic errors in AP's

⇒ Need for external calibration with reference stars.

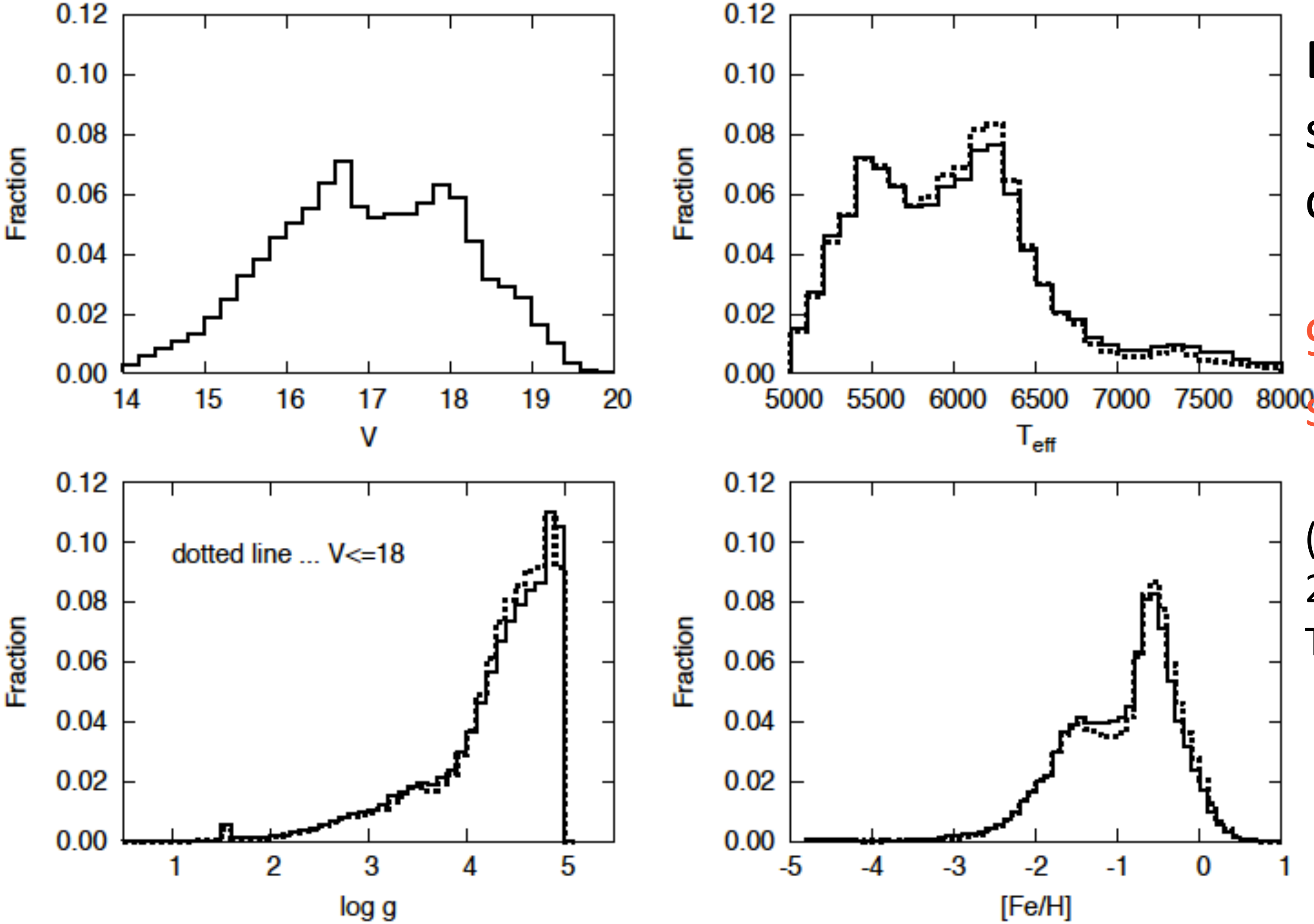
Determine high quality AP's on homogeneous scale

- A few 10's fondamental calibrators (too bright for GAIA)
- 500 to 5000 primary calibrators, with differentially determined AP's
- 1000's of secondary calibrators for large scale validation

In recent years many large samples analyzed by various authors. Analyses will be homogenized.

Challenge! Huge effort! Also important to validate stellar models!

Large samples of stars



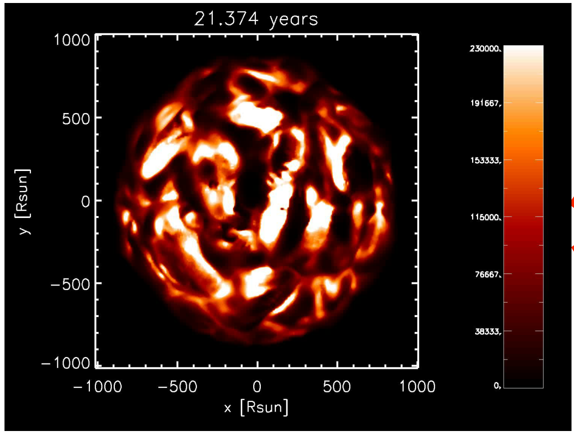
Example for secondary calibrators:

90000 SDSS spectra

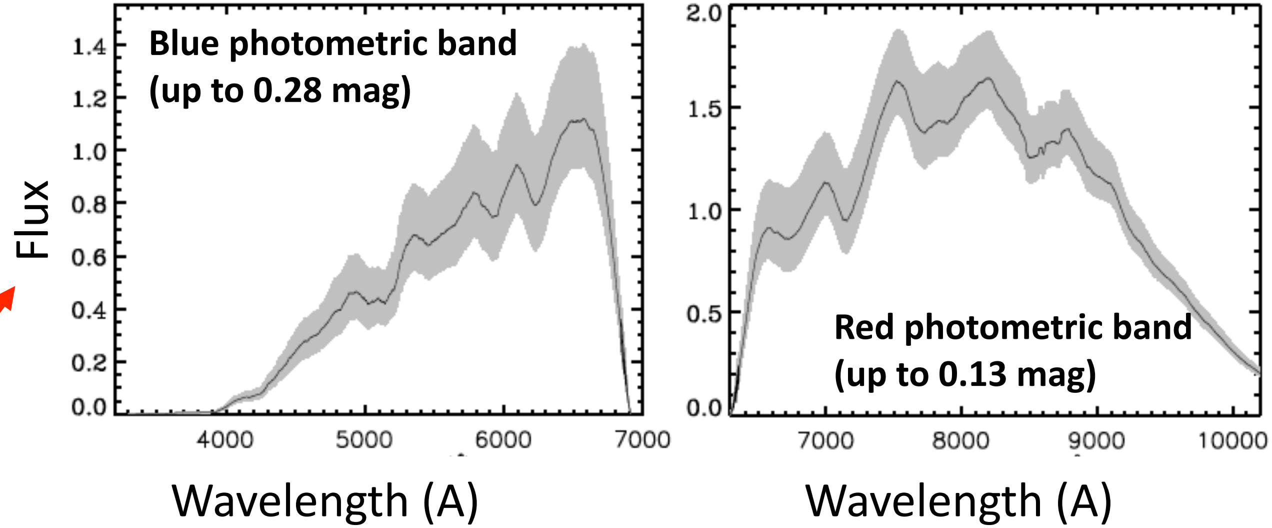
(allende Prieto et al. 2007, and GAIA-C8-TN-UAO-UH-001-1)

GAIA preparation:
3D models, photo-center and parallax accuracy

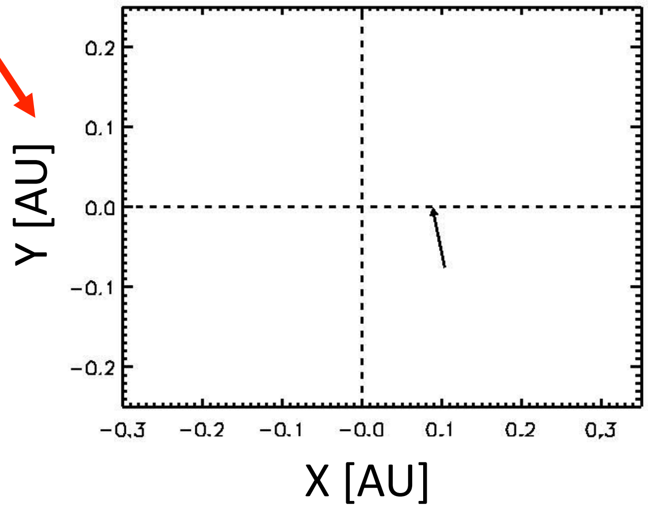
Images computed in Gaia – G band

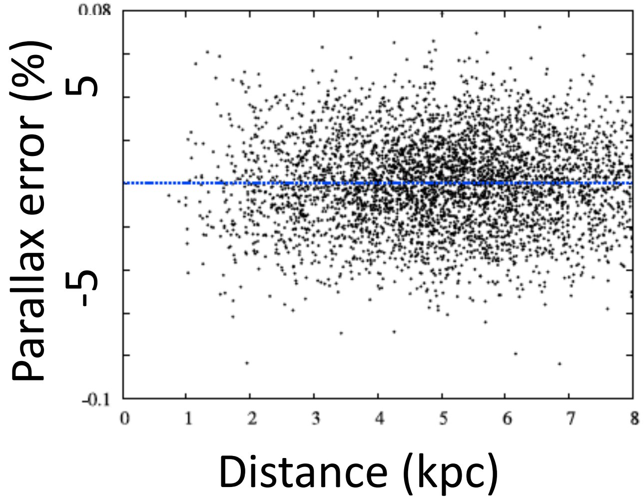


Predicted photometric variability over 5 years



Predicted photocenter variability over 5 years





Consequences of Gaia measurements

Chiavassa, Pasquato, Jorissen, et al.
2011 A&A, 528, id.A120

Hipparcos => GAIA

- 100 binary system with M at 1% => 17000
- 200 stars with π at 1% => 21×10^6, and 7×10^5 at 0.1%
- 120 clusters (d<1kpc) precision better than Hyades now
- Parallaxes for subdwarfs, subgiants, ...
- Distance to stars in 20 globular clusters at <10%

- This unprecedented data set, combined with interferometry (R/d), and asteroseismology (f(M, R, T_{eff})) will allow stringent tests of models (atmospheres and evolution), and quantitative understanding of physical processes (mixing, rotation, ...)