Workshop Summary

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Wrapping up a spectacular meeting...

In a nutshell...

1. Spectrum Synthesis Codes
2. Radiation Hydrodynamics Codes
3. Atmospheric Parameters, Abundance, Metallicity, & Chemical Tagging Studies
4. Large Surveys

5. Atomic Database   www.vamdc.eu

1. Spectrum Synthesis Codes

Hot Stars

- ATLAS9/SYNTHE vs. TLUSTY/SYNSPEC or LTE vs. Non-LTE (Przybilla)
- CMFGEN non-LTE, full line blanketing, photosphere & wind in massive OB stars (Groh, Mahy P6)
- FASTWIND non-LTE fitting high-res. spectra of Galactic massive OB stars (de Koter, Stap P7)

Cool Stars

- PHOENIX/1D general purpose model atmosphere code (with non-equil. dust formation in L, M Dwarfs) & PHOENIX/3D mode (Hauschildt)
- MARCS code for cool stars models and spectra (Plez)
- ATLAS9/WIDTH9 & MOOG LTE codes for EW analysis in post-AGB stars (Gorlova)

For the Gaia Mission

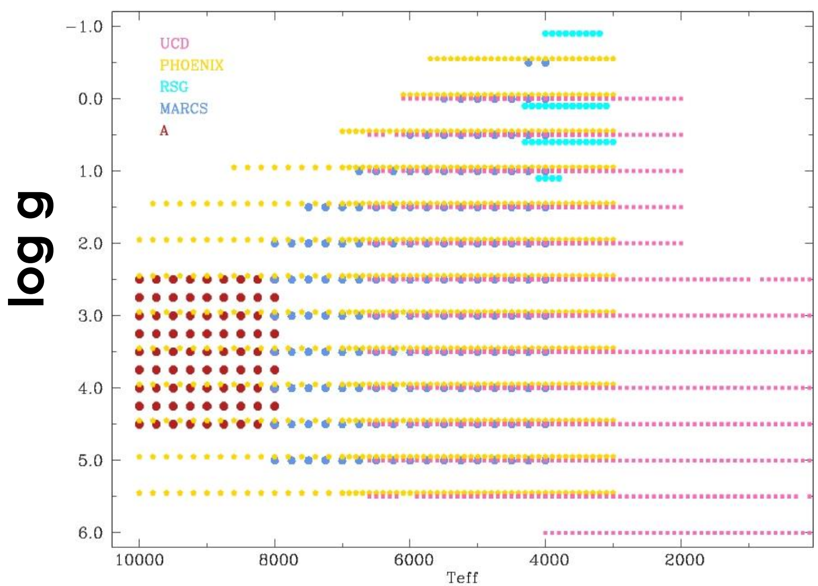
Overview of Libraries of Synthetic spectra for Gaia (Sordo) Implemented in the “Stellar Population Code” to train Gaia algorithms. Stellar spectra computed with PHOENIX/1D, MARCS, TLUSTY/SYNSPEC, CMFGEN, ATLAS, BaSel, ...

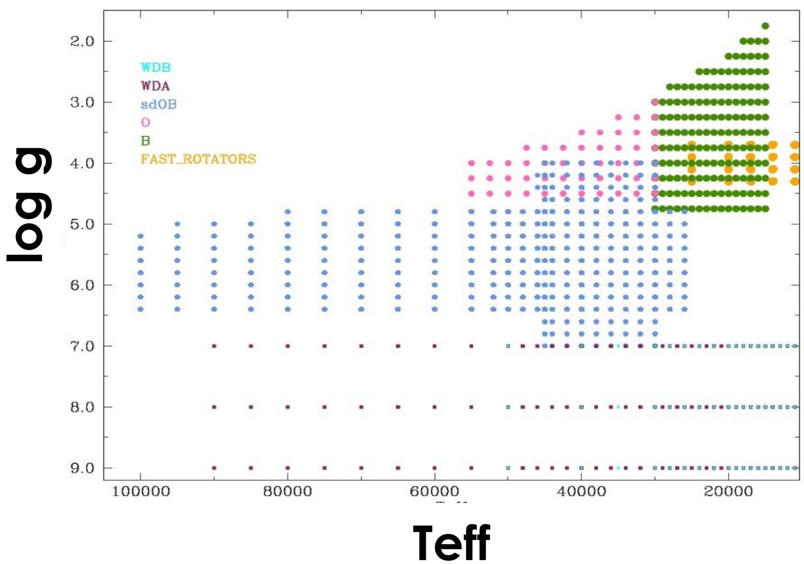
Synthetic Spectral Libraries for Gaia

Stellar type	T_{eff} [K]	logg	[Fe/H]	Provider/code
WD Stars	6,000-90,000	7 - 9		Koester/TMAP
sdOB Stars	26,000-100,000	4.8 - 6.4	+0.0	Heber
OB Stars	15,000-50,000	1 - 5	+0.0-+0.3	Ghost/Tlusty
BAF Stars	6,000-16,000	2.5 - 4.5	-1.5 - +1.0	Kochukhov/LL
Ap Stars	6,500-18,000	1 - 5		Kochukhov/LL
F-M Stars	4,000-8,000	-0.5 - 5.5	-5.0 - +1.0	Gustafsson/Marcs (BP/RP)
F-M Stars	2,800-8,000	-0.5 - 5.5	-5.0 - +1.0	deLaverny/Marcs (RVS)
A-M Stars	3,000-10,000	-0.5 - 5.5	-2.5 - +0.5	Hauschildt/Phoenix
NLTE Cool Stars	4,000-6,000	4.5 - 5.5	+0.0	Korn/Marcs+Multi (RVS)
C Stars	4,000-8,000	0 - 5	-5.0 - +0.0	Plez/Marcs
Emission line stars	25,000-50,000	3 - 5	--	Fremat,Blomme
Ultra Cool Dwarfs	100-4,000	2.5 - 5.5	+0.0	Allard/Phoenix
Fast Rotators	9,000-25,000	3.6-4.2	+0.0	Fremat/Zorec/Martayan
WR	25,000-100,000	3.0-5.2	+0.5	Blomme/CMFGEN
Red Super Giants	3,500-4,200	-1 – 1	+0.0	Josselin/MARCS
O-M stars	3,500-47,500	0 - 5	-2.5 - +1.0	Munari,Sordo /Kurucz

R. Sordo et al. Feb. 2010, Astrophys Space Sci

High-Res. Synthetic Spectral Libraries for Gaia





COOL STARS

Teff < 15,000 K, var. [Fe/H]

MARCS var. indiv. α abund.
PHOENIX var. [α/Fe]
ATLAS LTE
C stars var. [C/Fe]
Ultra-cool dwarfs dust
Ap/Bp non-solar abund.

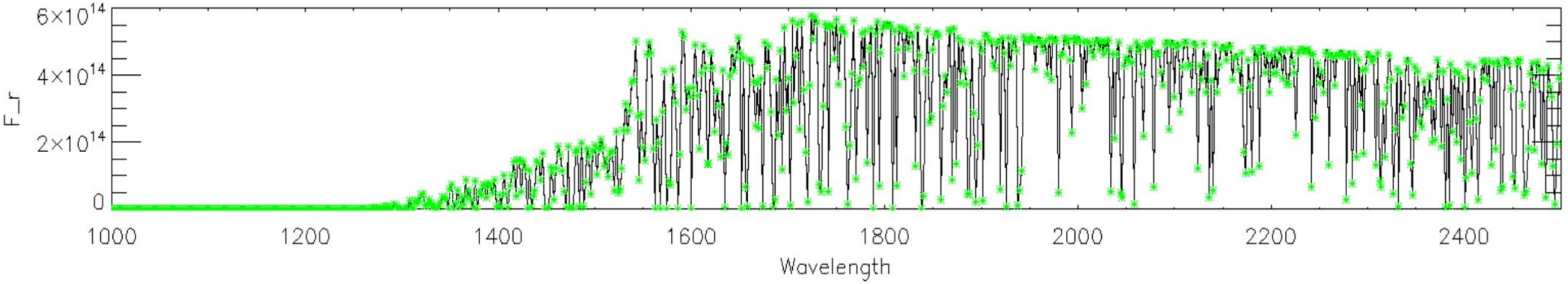
HOT STARS

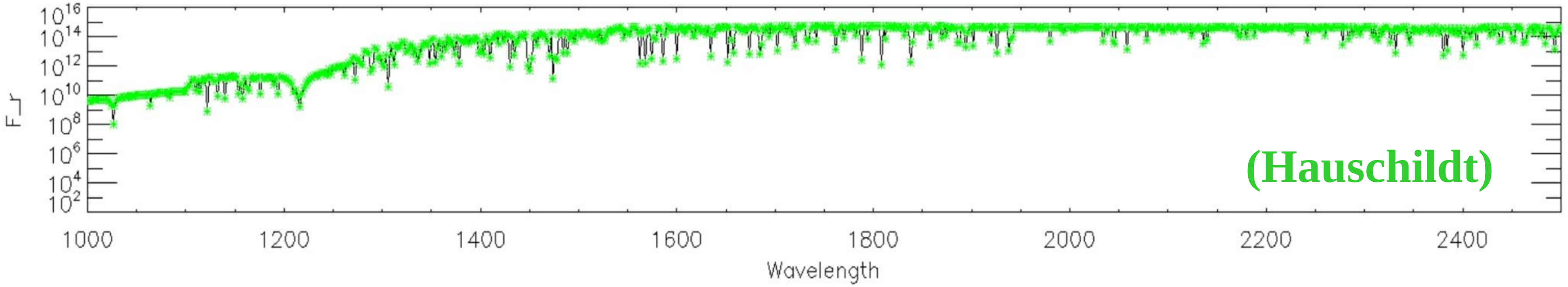
Teff > 15,000 K

O, B non-LTE, mass-loss, winds
Be variable envelope radius
W-R variable mass-loss rates
sdOB non-LTE
WD LTE

Model Grids may overlap and interpolation methods are required

PHOENIX 1D vs 3D: 9000K





- **3-D fully line blanketed stellar spectrum synthesis is a computational challenge!**

In more detail…

HOT DWARFS & GIANTS $15{,}000\ \mathrm{K} \lesssim T_{eff} \lesssim 35{,}000\ \mathrm{K}$

- atmospheric structures: very close to LTE $\Delta T/T(\mathrm{NLTE}-\mathrm{LTE}) \lesssim 1\%$

- SEDs: NLTE modelling required Ly-/He-continua

- line spectra: - LTE assumption highly limited
  - NLTE limited because of model atom implementations

- available LTE & NLTE grids **NOT** suited to reproduce observed spectra over extended wavelength regions, but useful for selected lines

- alternative: hybrid NLTE-modelling with tailored model atoms

- limitations: breakdown of hydrostatic approximation for hotter stars & some supergiants

ATLAS9/SYNTHE & TLUSTY/SYNSPEC (Przybilla, Nieva, & Butler)

Hybrid-NLTE for HOT DWARF

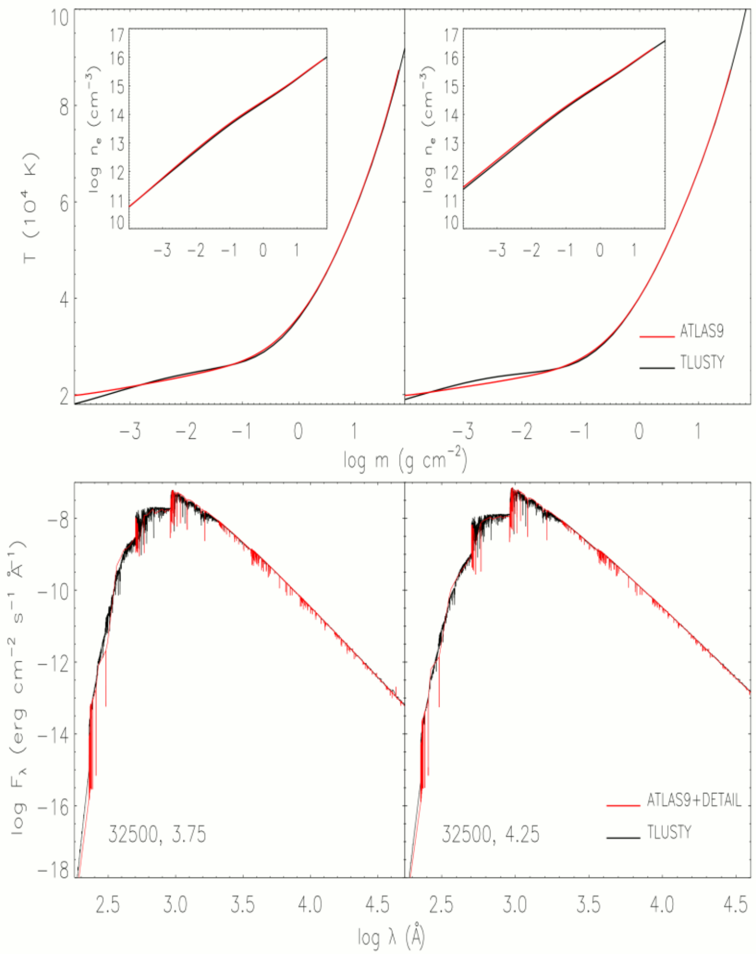


Fig. 9. Upper panel: Comparison of ATLAS9 and TLUSTY temperature structures and electron densities (insets) as function column mass. The computations have been performed for giant and dwarf models. Lower panel: Comparison of spectral ener distributions, the radiation field computed by DETAIL on the basis of the ATLAS9 atmospheric structure vs. TLUSTY.

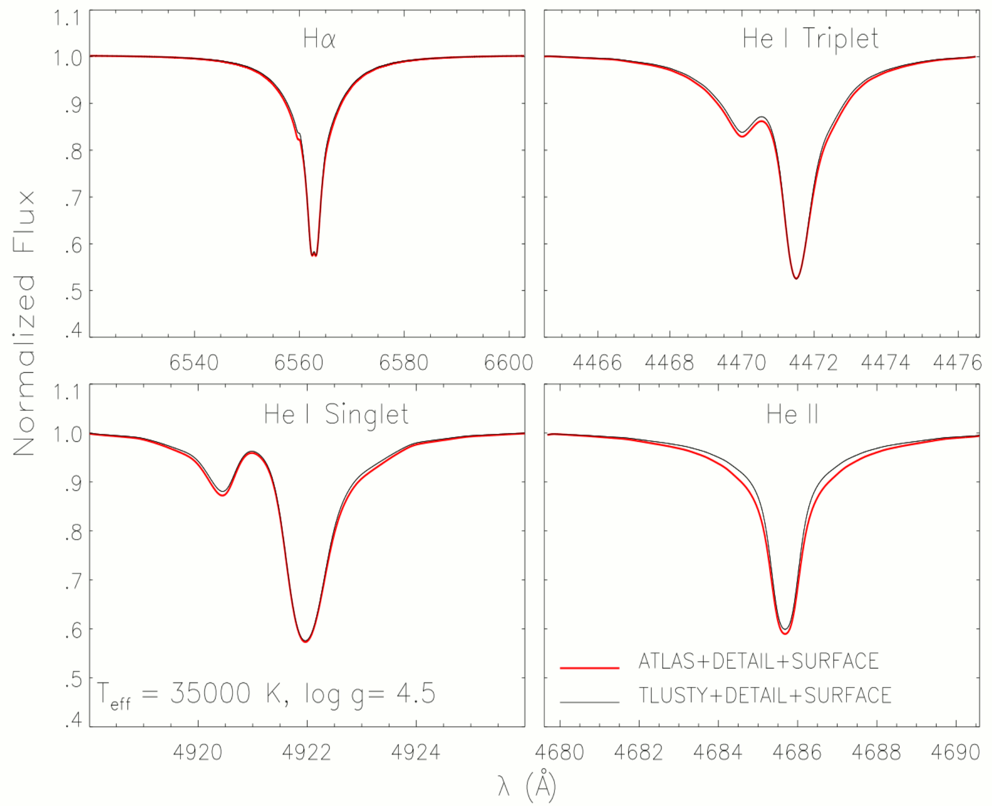


Fig. 10. Comparison of the most discrepant hydrogen and He I/II line profiles from our hybrid non-LTE approach (ADS) and a TLUSTY-DS calculation for a hot main-sequence model. Practically perfect agreement is obtained, with small discrepancies occurring only in the wings of He II λ4686 Å.

MASSIVE OB STARS

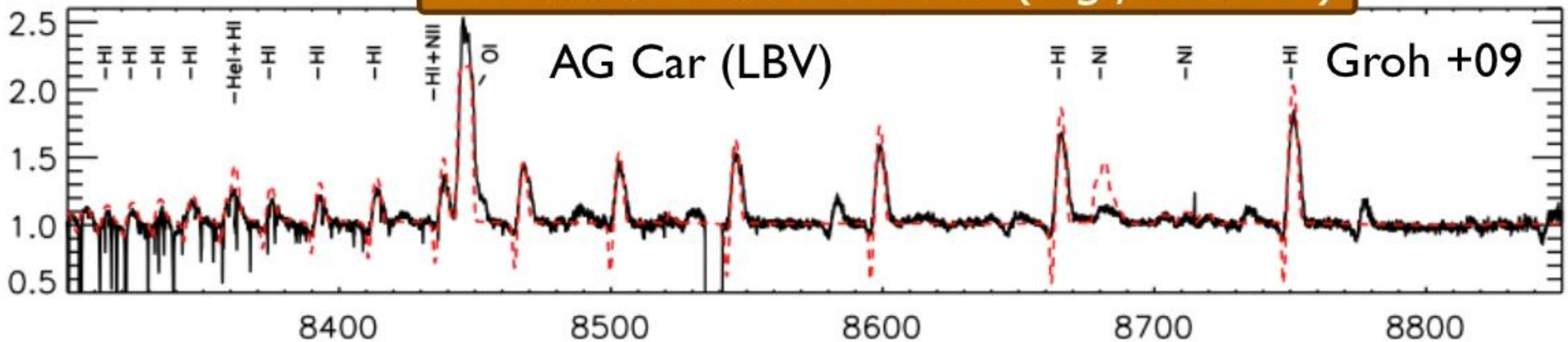
- 1-D, spherically-symmetric, NLTE, simultaneous treatment of photosphere & wind, full line blanketing (large database of atomic data, metals up to Z=30), wind clumping, X-rays.

- *M*ain limitation: momentum balance equation of the wind is not solved; velocity law has to be assumed a priori, but can be constrained from line profiles.

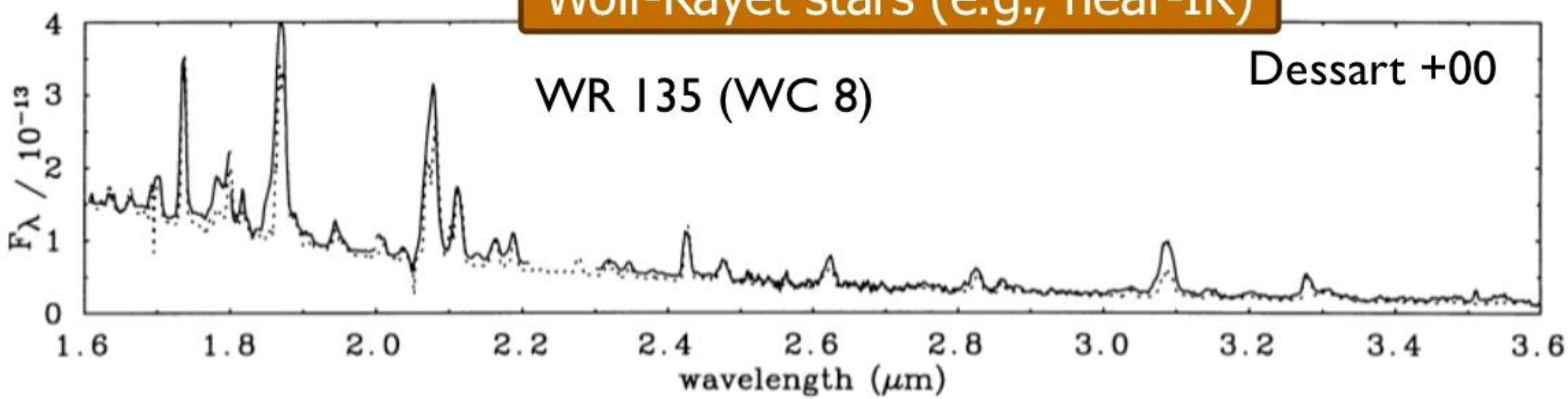
New updates of CMFGEN & time-dependent winds (Groh & Vink 2011)

- **Multi-wavelength analyses of massive hot stars in different evolutionary stages:**

Luminous Blue Variables (e.g., near-IR)



Wolf-Rayet stars (e.g., near-IR)

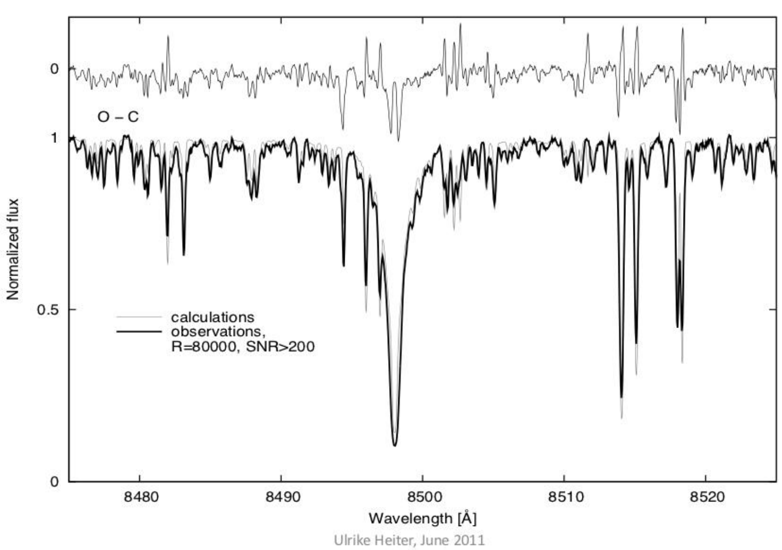


In more detail…

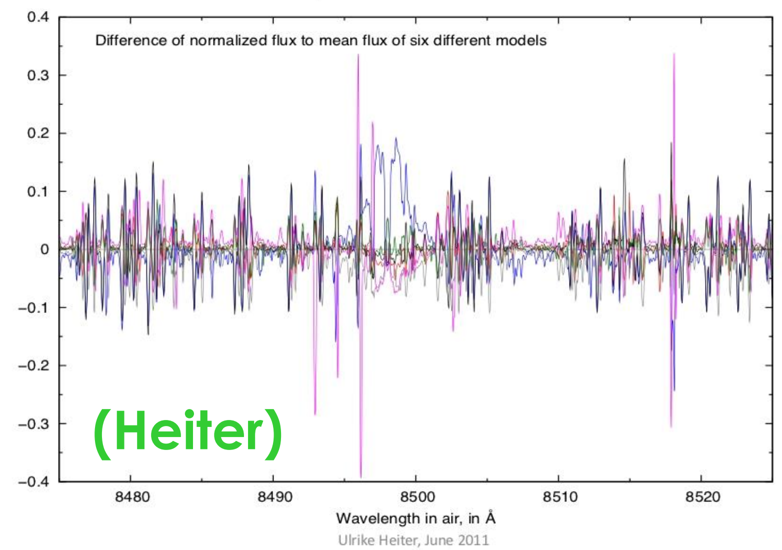
COOL GIANTS

- Observed spectra α Tau and α Ceti modelled by 14 groups with different models and analysis approaches
- Resulting parameters Teff, log g, [Fe/H] vary by 200 K, 0.1, 0.5 dex for α Tau

One of the models (best fit) for α Tau at IR Ca triplet line



Model differences for spectra with equal parameters, but different model atmospheres, line lists, and line formation



Comparison of Atmosphere Models

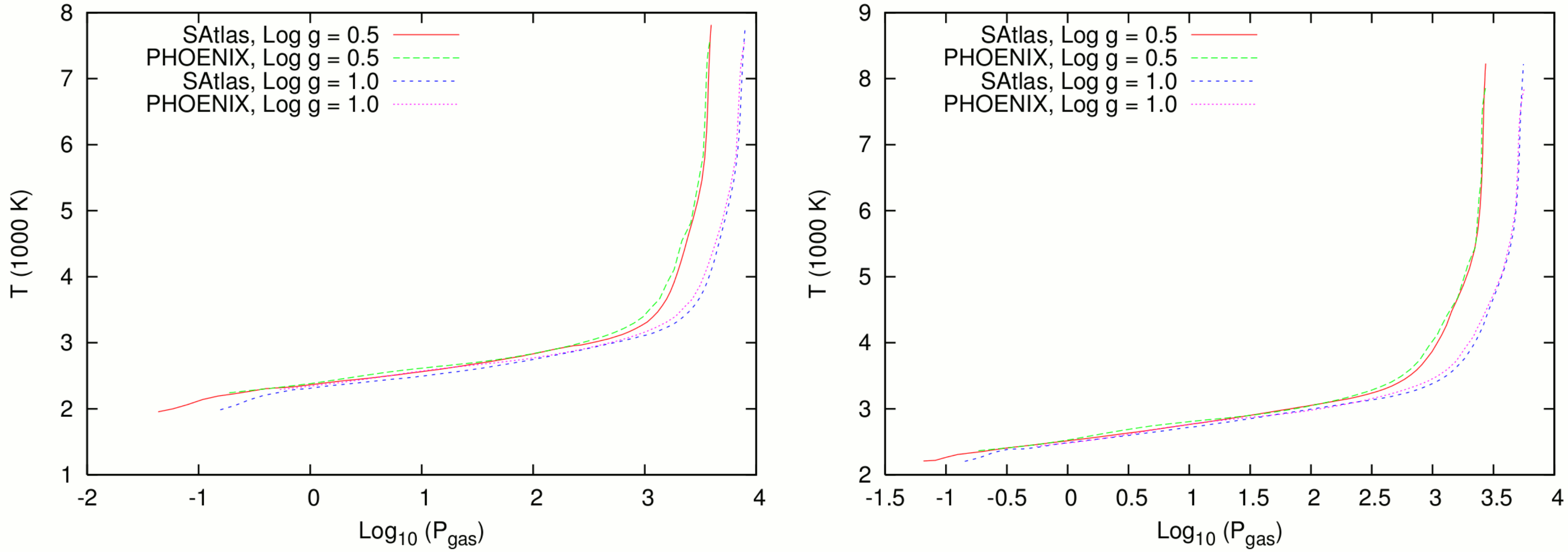
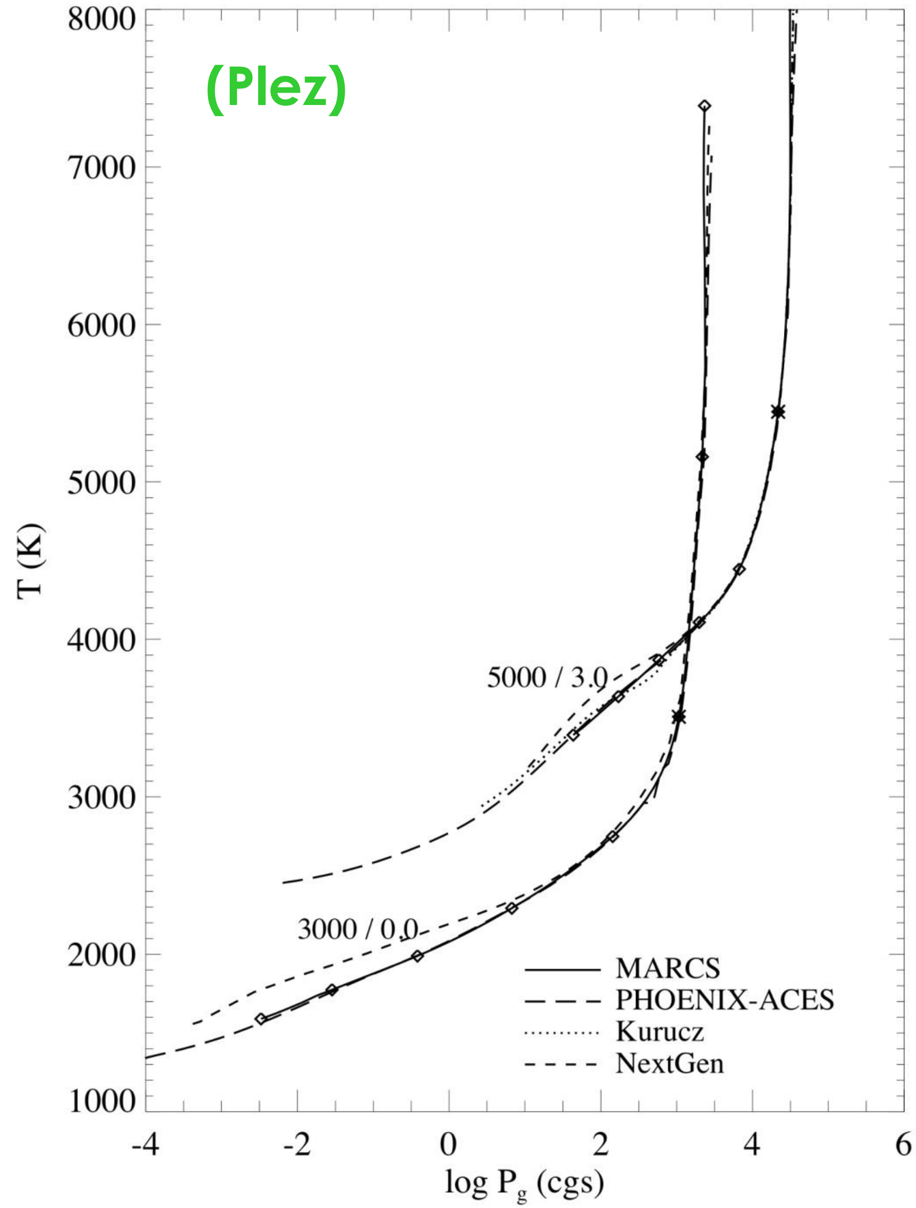


FIGURE 4. Comparison of the temperature structure of model stellar atmospheres computed by the spherical ATLAS code and PHOENIX NextGen models for two gravities $\log g = 0.5, 1.0$. (Left) The models have an effective temperature of 3400 K and mass of $5M_\odot$. (Right) The models have an effective temperature of 3800 K and mass of $5M_\odot$.

- **Comparison of S-ATLAS, PHOENIX/1D, and MARCS spherical symmetry atmosphere models of cool giants show only small differences that do not explain SED differences.**
- **What causes the differences of synthetic fluxes? What assumptions are different?**

MARCS +
Phoenix
(Sph)
ATLAS (PP)



Comparison of Synthetic Spectra in RVS

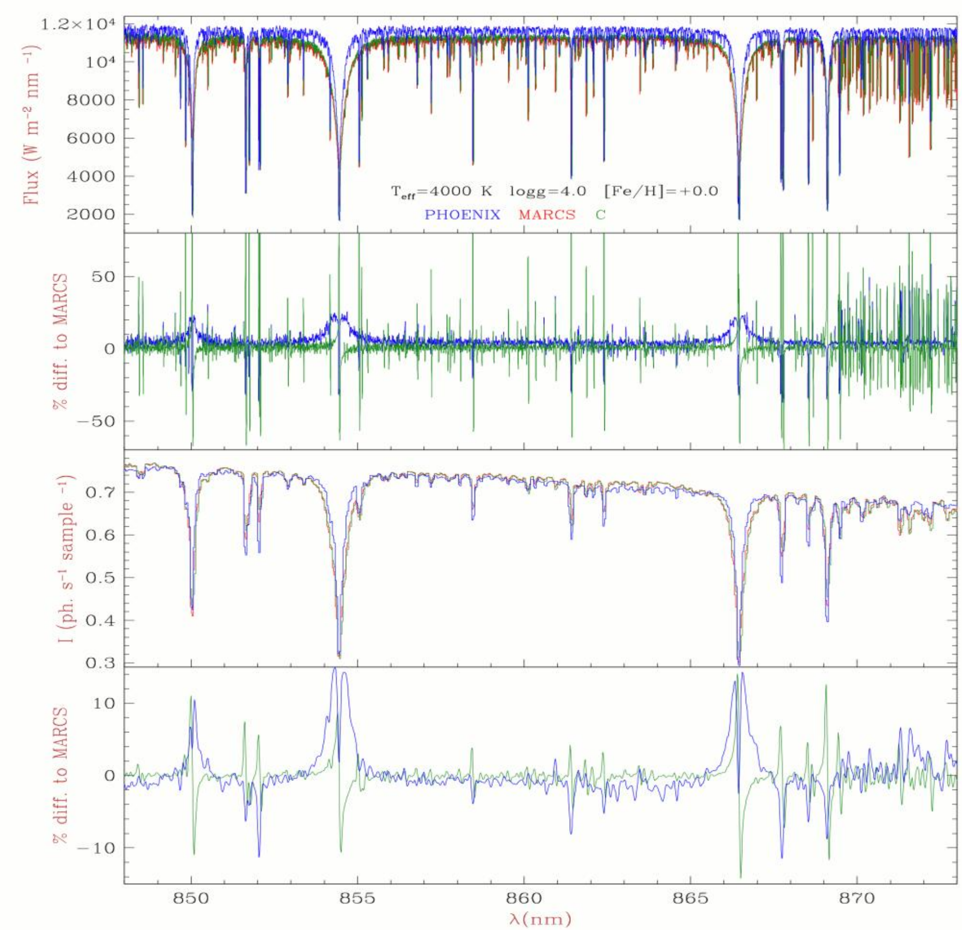


Figure 7: Comparison in the RVS range for PHOENIX, MARCS and C libraries for a star having T_{eff}=4000 K, log g=4.0, [Fe/H]=+0.0. From upper to lower panel: source spectra; residuals of the source spectra (to the MARCS); GOG output spectra; residuals of the GOG spectra to the MARCS.

Vallenari & Sordo, 2008, Gaia-TN

COOL DWARFS

MARCS (Plez)

PHOENIX (Hauschildt)

Differences can be due to:

LTE vs non-LTE

1-D vs 3-D

Sampling meth of opacities and fluxes

but also the Radiative Transfer Input:

Atomic and molecular line lists

Predicted lines vs. observed lines

Equation of state (di+ molecules, TiO, FeH)

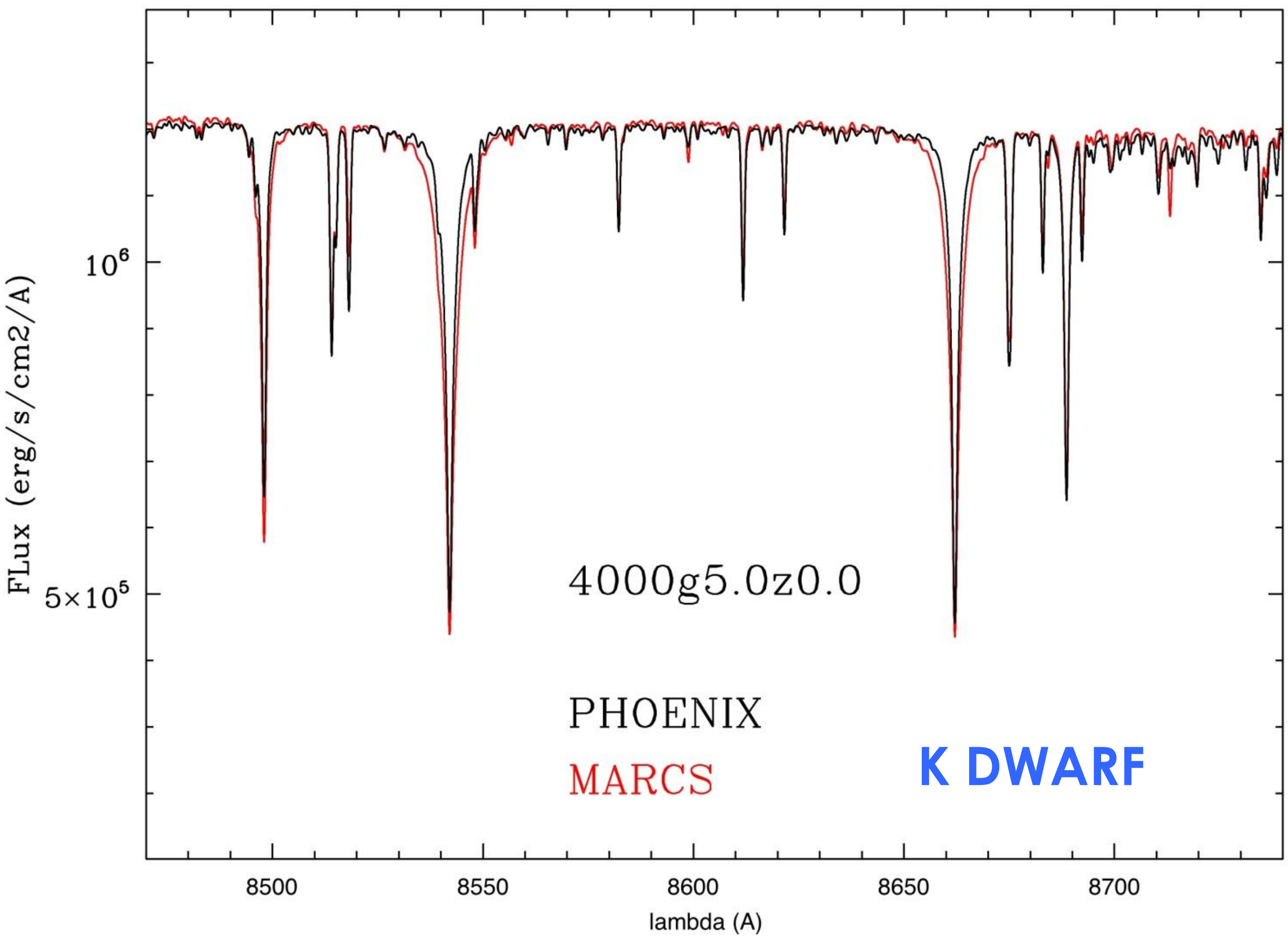
Partition functions (hydrides, ions)

Line oscillator strengths; log(gf)

Line damping coefficients & broadening

Isotopic lines (log(gf) components)

Hyperfine splitting (Mn, Co, etc.)



Improve Ca II collisional broadening data in PHOENIX?

FGK STARS

- **NLTE abundance corrections for Fe I lines in large-scale simulations**

- **NLTE corrections increase with smaller [Fe/H] and log g.**
  LTE assumption may underestimate gravities and metallicities.

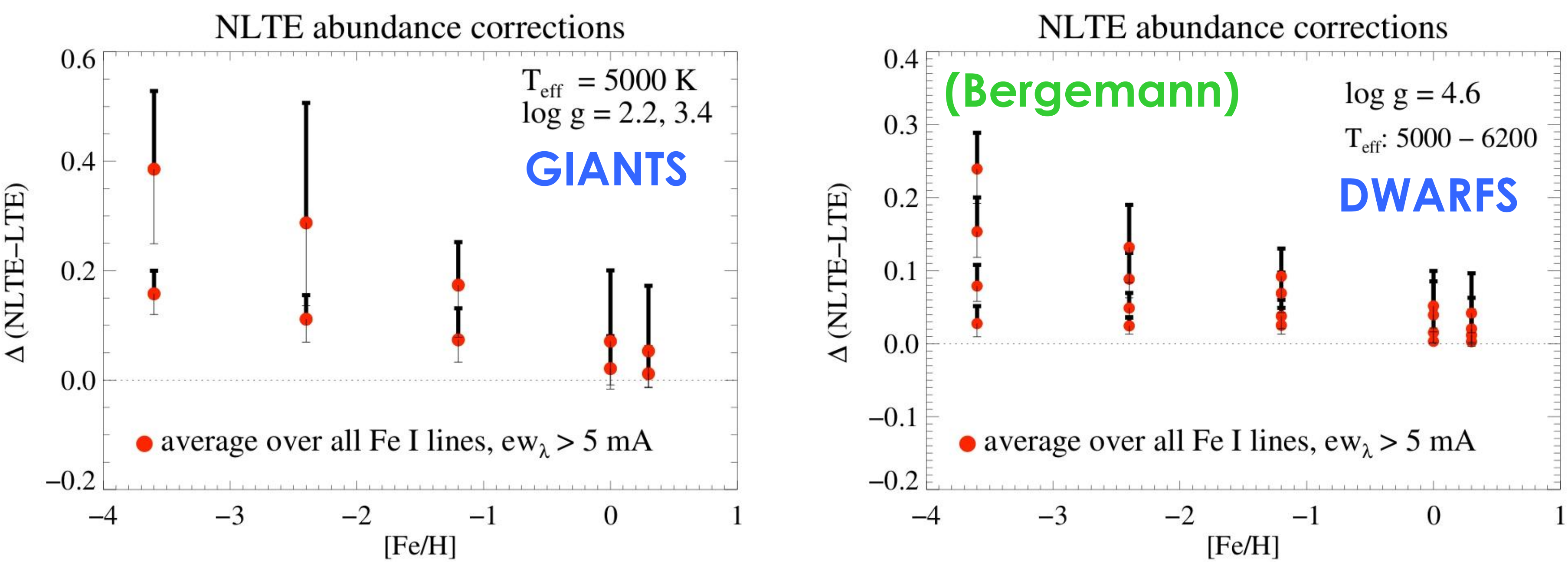
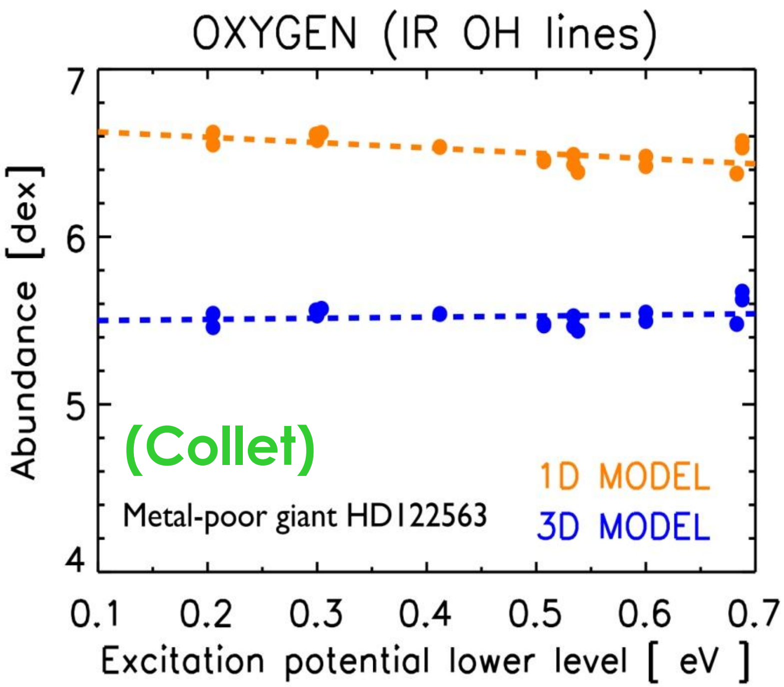


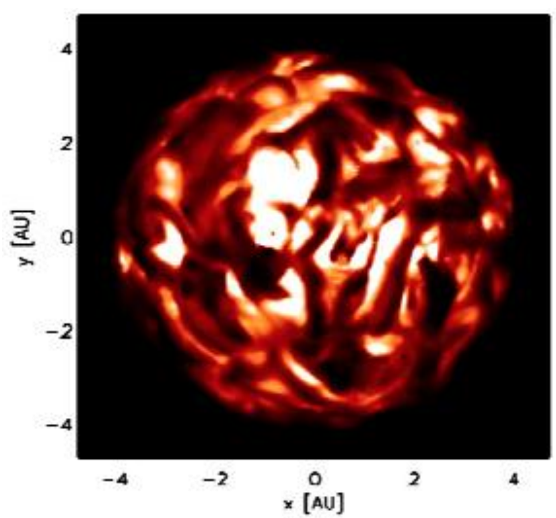
Figure 1: NLTE abundance corrections as a function of [Fe/H] for different model atmospheres. Left panel: $T_{\rm eff} = 5000$ K, and $\log g = 2.2, 3.6$. Right panel: $T_{\rm eff} = 5000, 5400, 5800, 6200$ K, and $\log g = 4.6$.

2. Radiation Hydrodynamics Codes

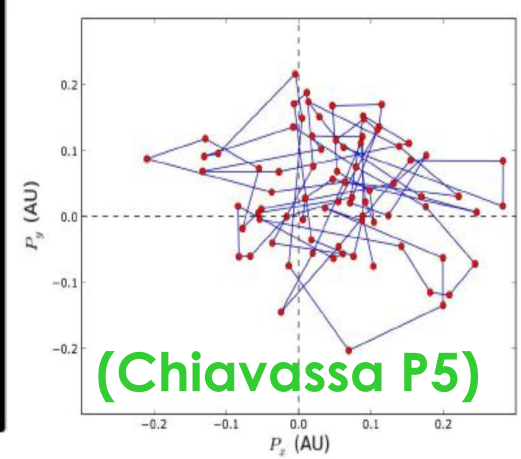
- **Stagger-Code** (StaggerGrid project) grids of time-dep, 3-D, hydro model atmospheres and applied to line formation calculations without micro- and macroturbulence. In cool metal-poor stars of [Fe/H] = -3 3-D oxygen abundance is 0.5 dex smaller than in 1-D.
- **CO5BOLD** code for time-dep, 3-D, hydro convective envelope effects on parallax and ΔRad Vel ~1 km/s in K Giants, < 4 km/s in Red SG)



Red supergiant image computed in Gaia – G band



Predicted photocenter shifts over 5 yr



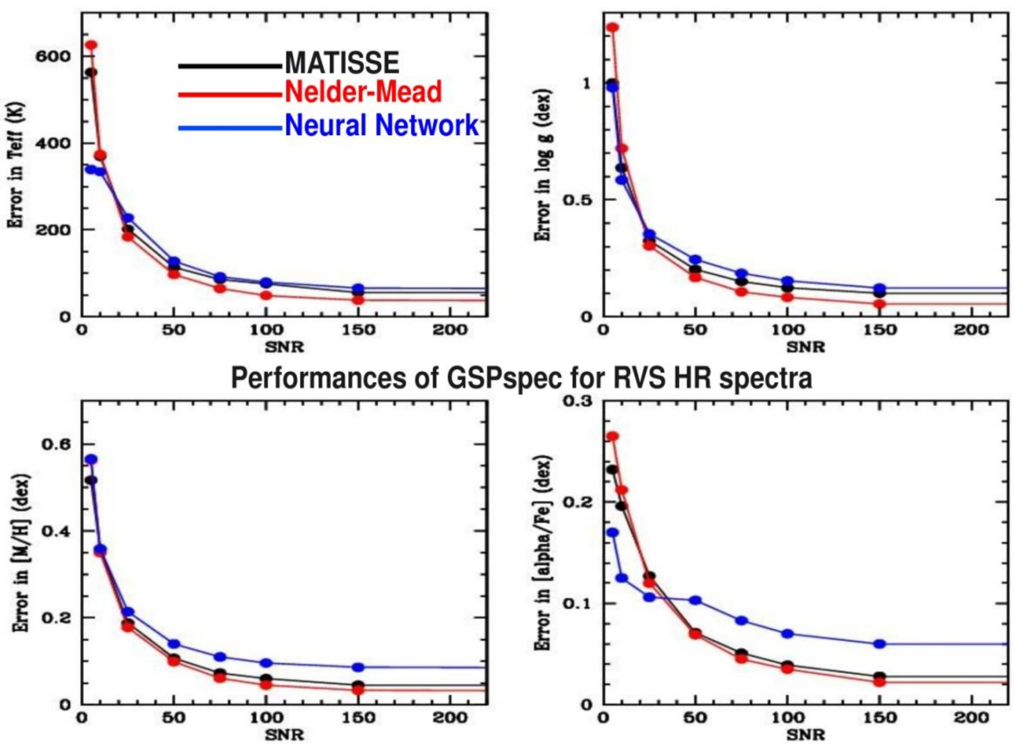
3 % of R∗

3. Atmosph. Parm. & Adundance Studies

FGK STARS

- Gaia Data Processing and Analysis Consortium — DPAC
  Group: Generalized Stellar Parametrizer spectroscopy — GSP-Spec

- Automated determination of Teff, log g, [M/H], and elm. abundances using **MATISSE** & **DEGAS** codes



Performance in RVS for R=11500

SNR = 50

- Δ Teff ~ 100 K
- Δ log g ~ 0.2-0.3 dex
- Δ [M/H] ~ 0.15 dex
- Δ [α/H] ~ 0.1 dex

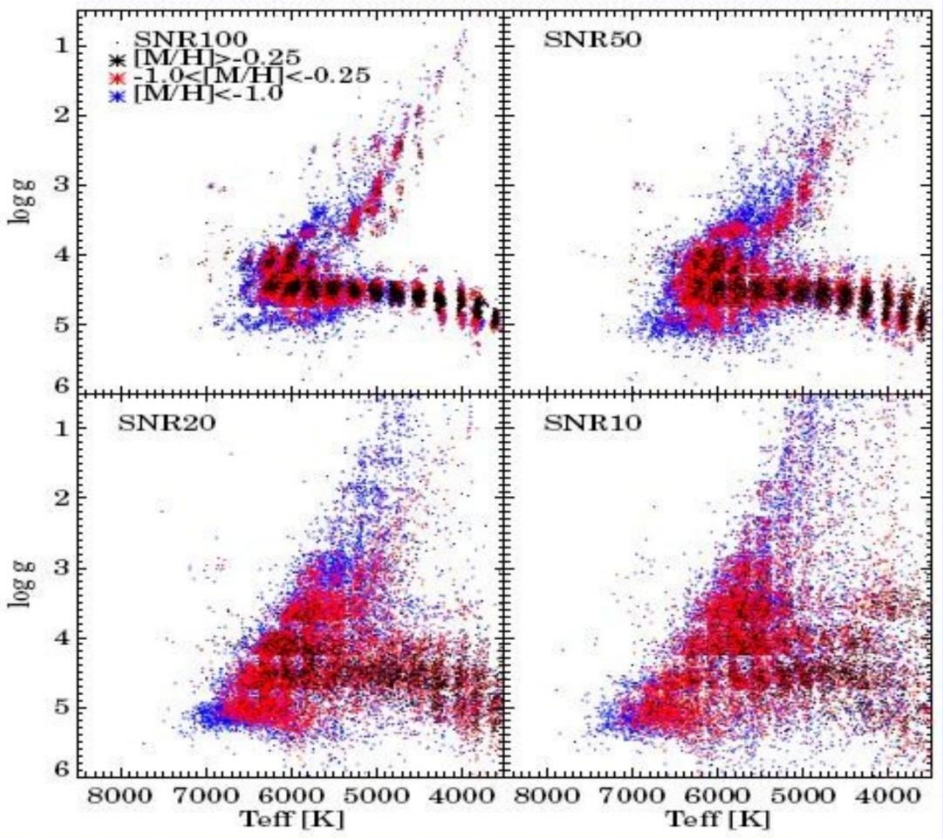
(Recio-Blanco)

Chi square method of synth. spectra & Classification decision tree

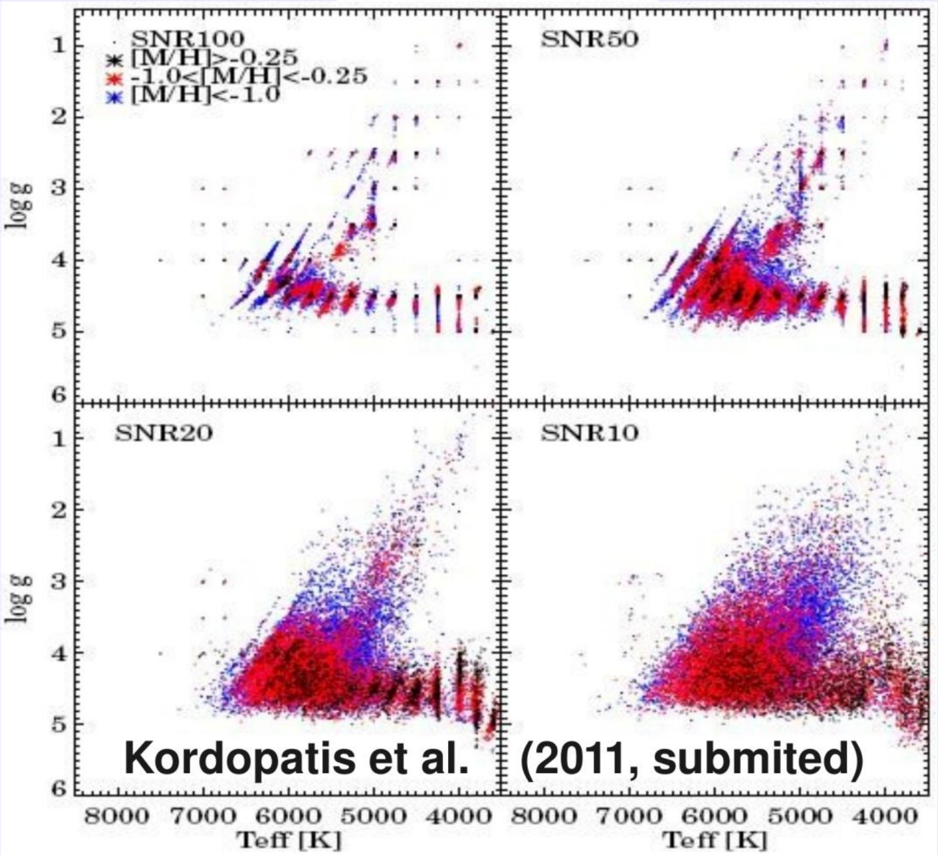
Generalized Stellar Parametrizer-spectroscopy and the CaII range :

Internal errors : Different methods depending on the SNR.

MATISSE

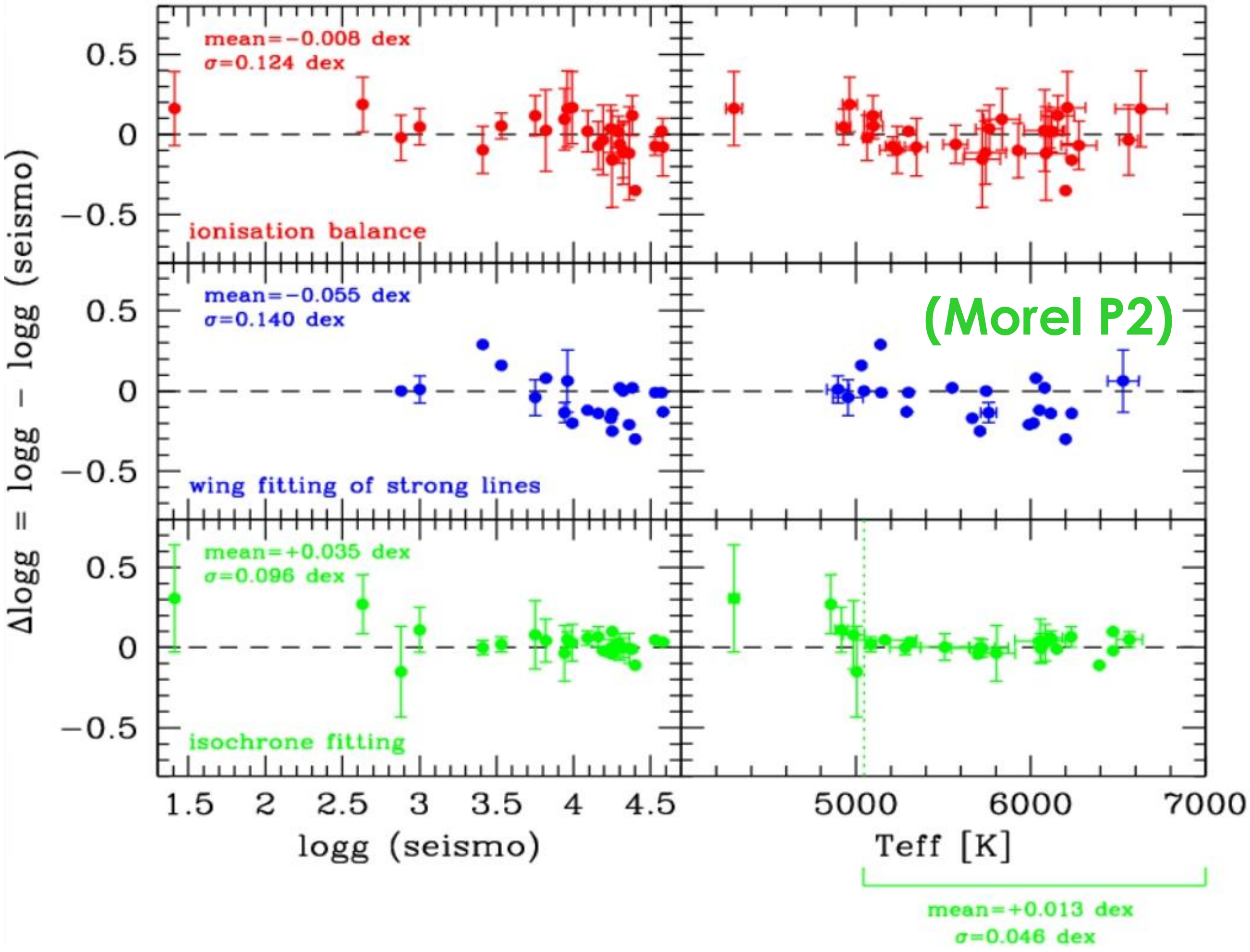


DEGAS



FGK STARS accurate determination of log g

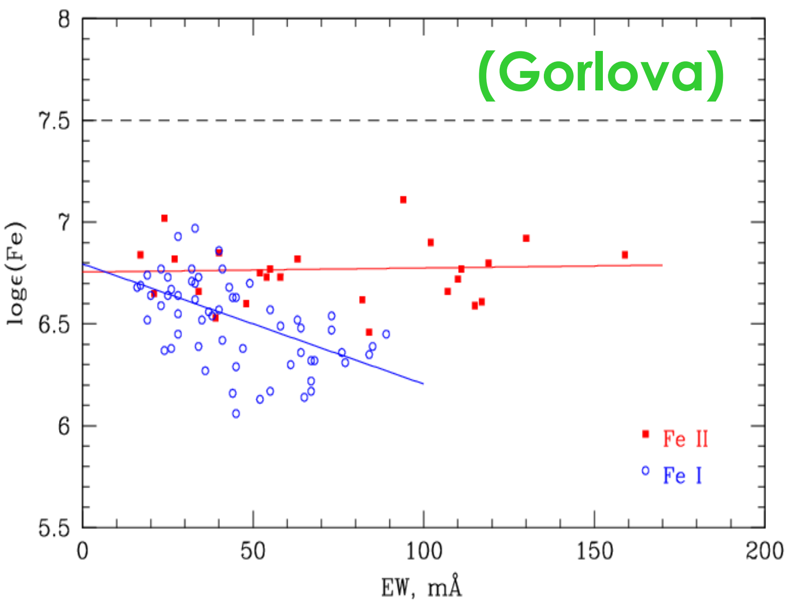
- CoRoT & Kepler sample of 30 G Dwarfs & Red Giants with SEISMIC log g
- log g from fitting strong lines agree within 0.06 dex, but $\sigma < 0.14$ dex

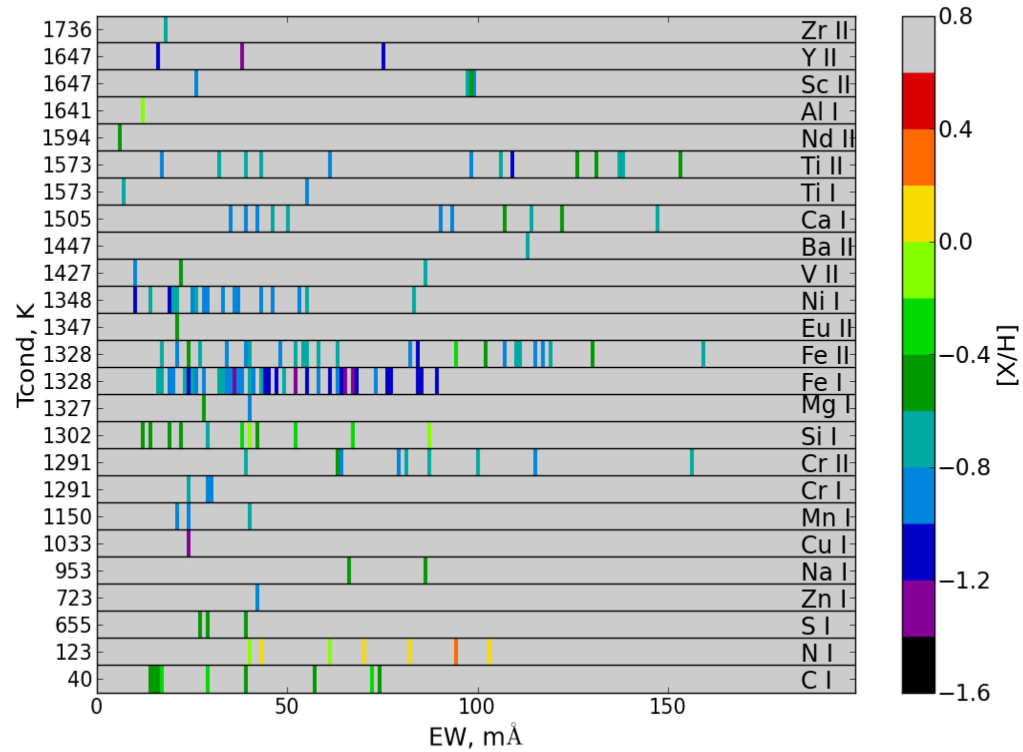


POST-AGB STARS determination of elm. abundances

- individual abundances from WIDTH9 and MOOG codes using EW of weak and strong lines in high-res. Mercator-HERMES spectra

- NLTE effects in Fe I and Fe II lines yield different microturbulence velocity in F-G supergiants. Abundance values agree for weaker lines.



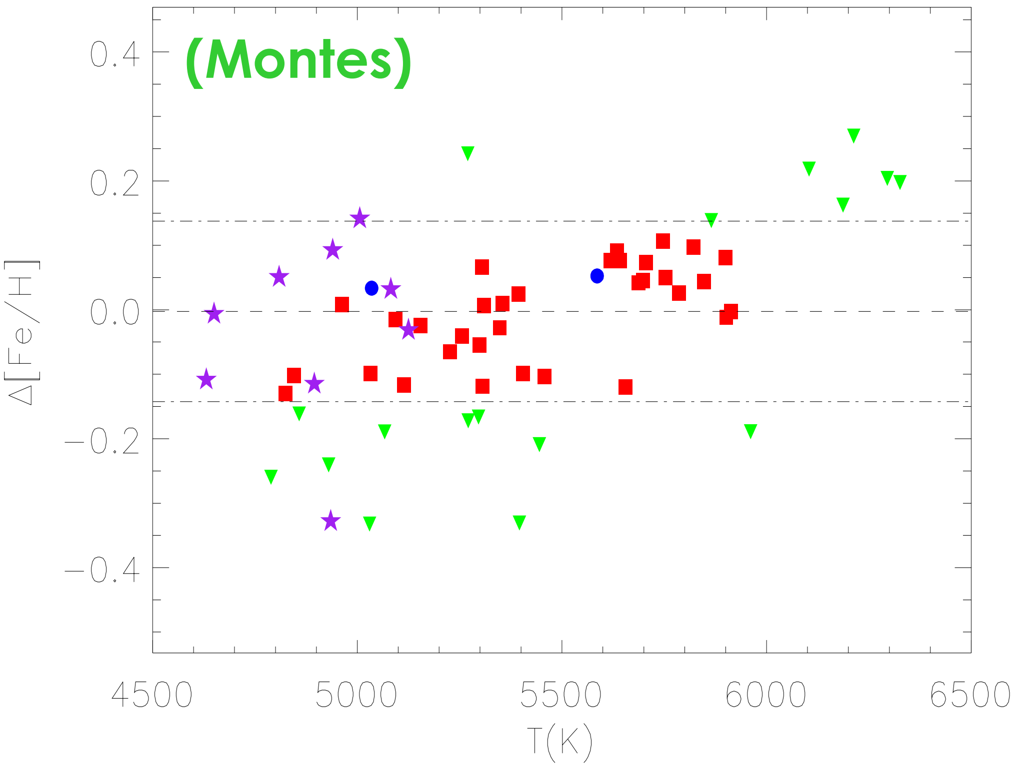


Metallicity diagram without averaging = 'abundogram'

FGK STARS membership to Moving Groups

- atmospheric parameters Teff, log g, microturbulence velocity, & [Fe/H] from StePar code using EW values and imposing ionization equilibrium with log(ϵ(Fe I)) = log(ϵ(Fe II)).

- [Fe/H] used for studying candidate membership of Hyades Supercluster with respect to [Fe/H] of known cluster member



Study of metallicity and Li abundance of Hyades Stream compared to Hyades Cluster

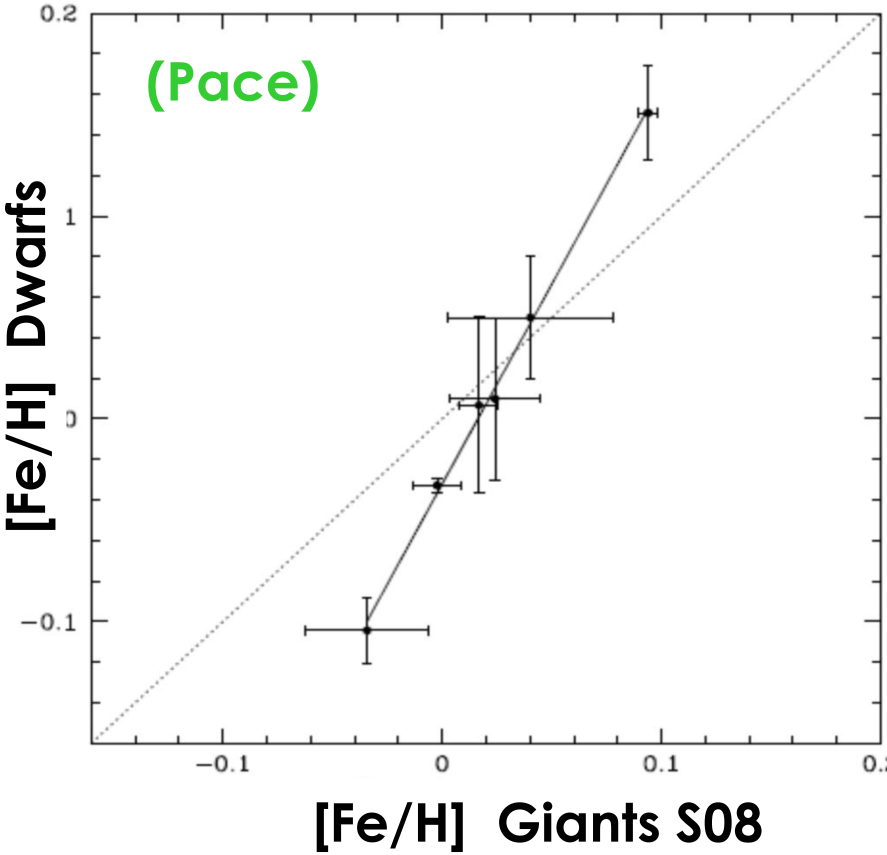
Stream has metallicity excess 0.2 dex compared to thin disc

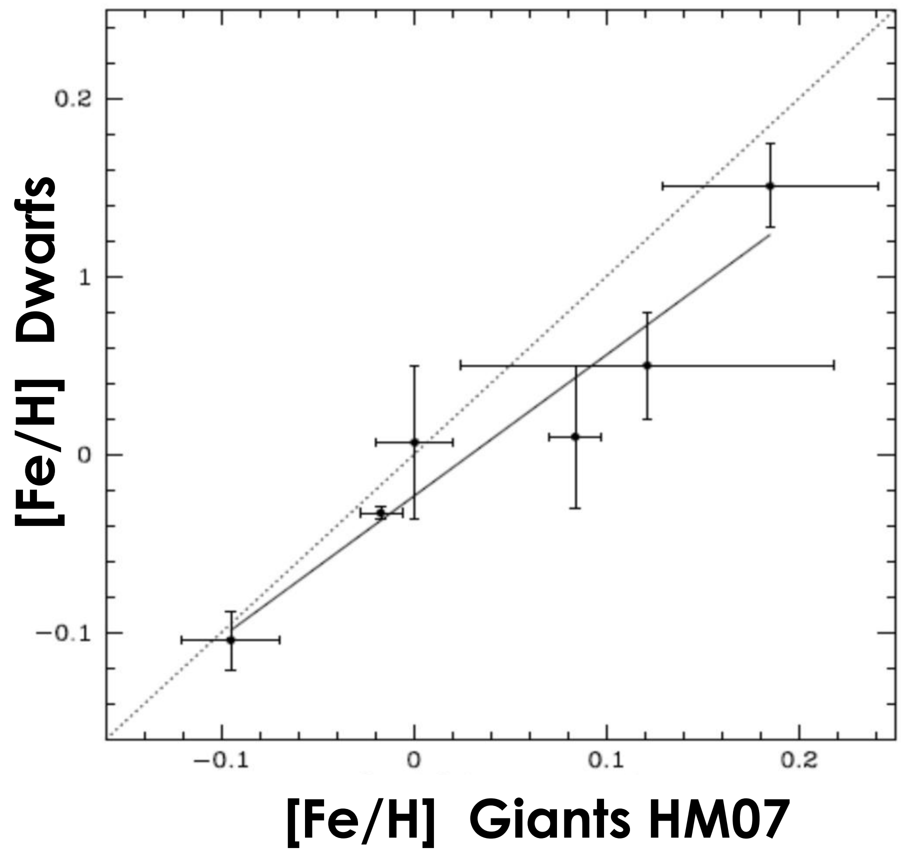
Stream is a 4:1 resoncance of the spiral pattern? (Jorissen P11)

[Fe/H] of Cool Dwarfs vs Giants in Clusters

- Are there effects of stellar evolution and input line lists on metallicity, or clear example of important NLTE effects between dwarfs and giants?

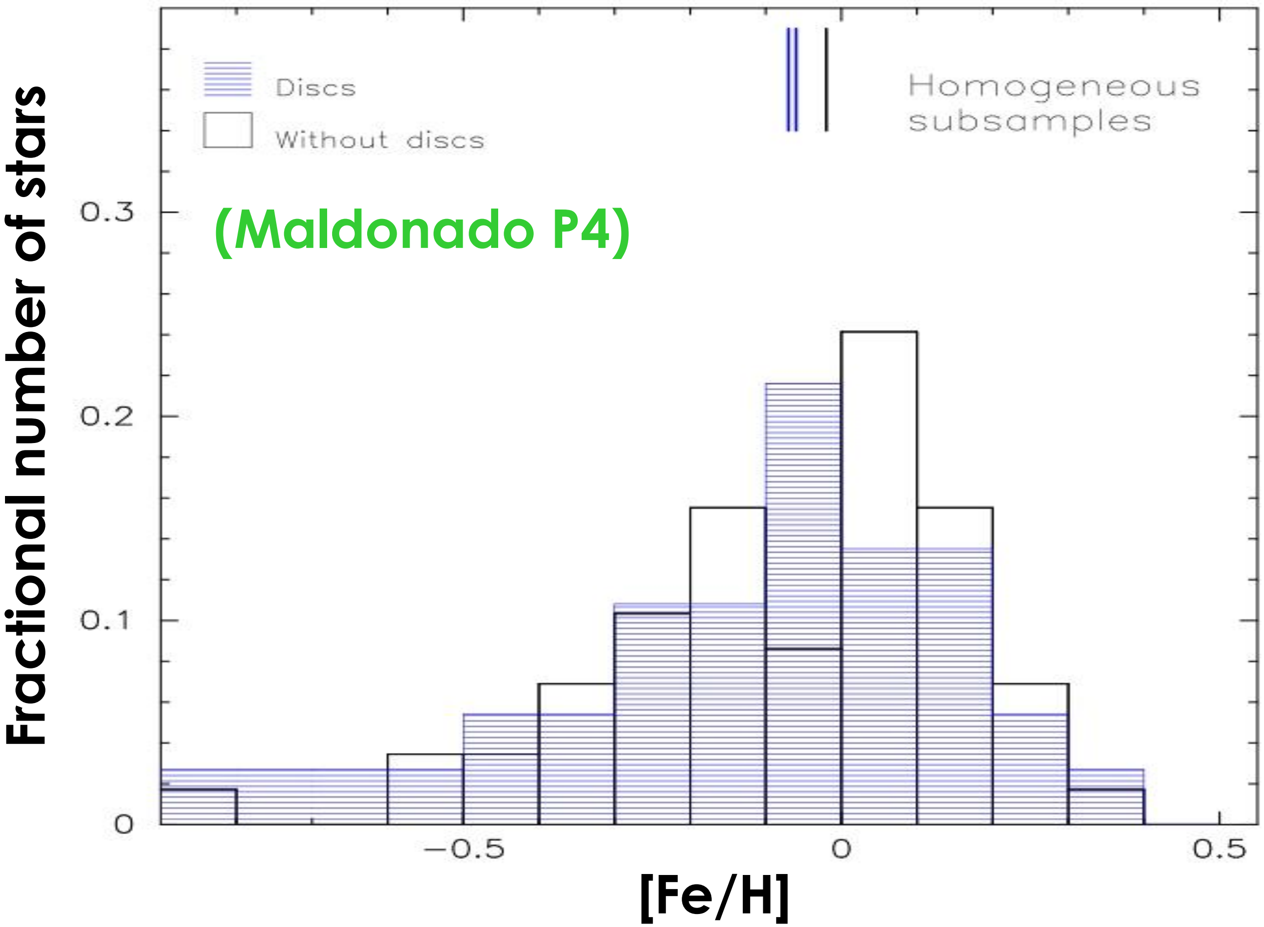
- May influence Galactic chemical evolution, planet formation rate, ...





[Fe/H] for a sample of cool stars w/o dusty debris discs

- atm. parms. from high-res. spectra forcing Fe I/Fe II ionization balance
- distribution helps understanding of planet formation. Gaia will detect 10,000 exoplanets

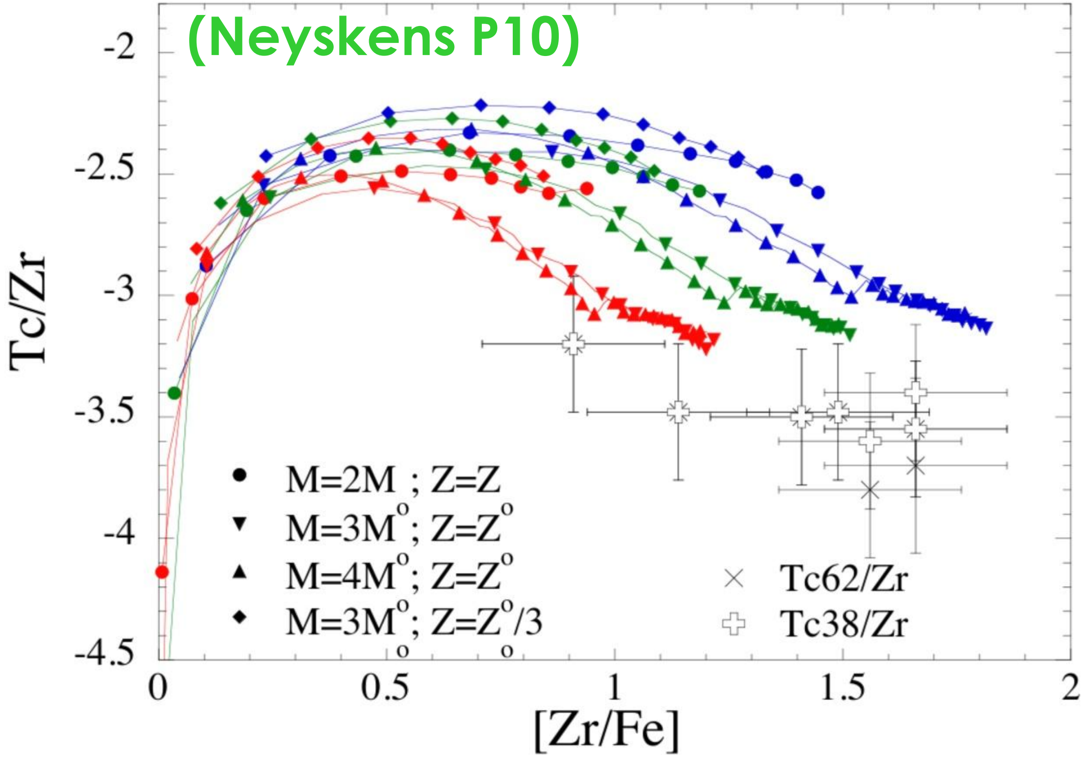


[Tc/Zr] in S-type AGB STARS (0.5 < C/O < 1.0)

- to constrain nucleosynthesis & evolutionary models w STAREVOL code

- envelope model of S-process enrichment over AGB phase compared to Tc abundances from optical Tc I lines

- size of partial mixing zone varied to fit observations with [Zr/Fe]~1 dex



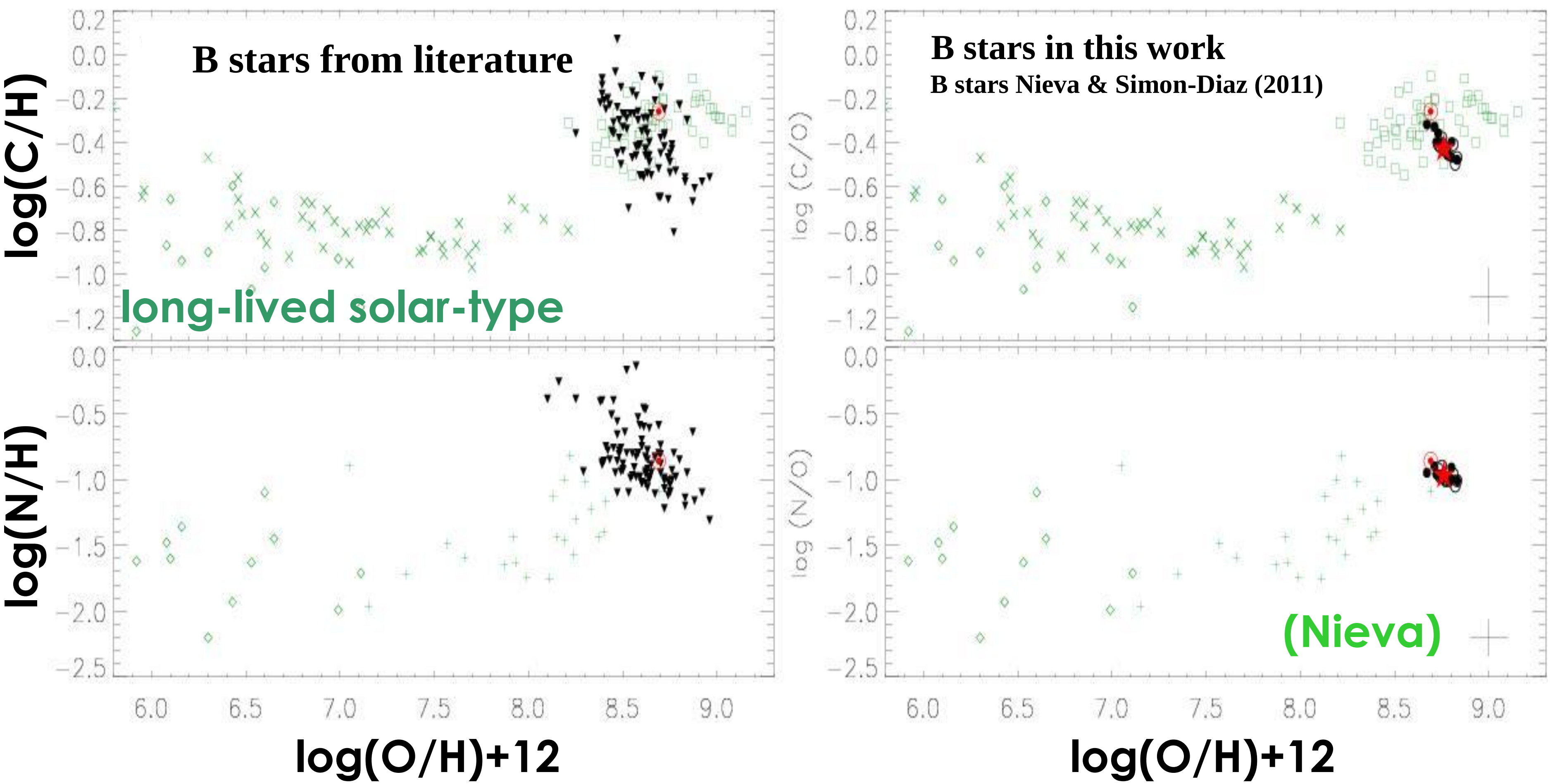
- Grid of S-stars MARCS models to find Teff, [C/O], [s/Fe] with VJHKL photo-metry & spectroscopy

- Teff scale for M-stars from V-K not valid for S stars and gives errors < 400 K

(Van Eck P1)

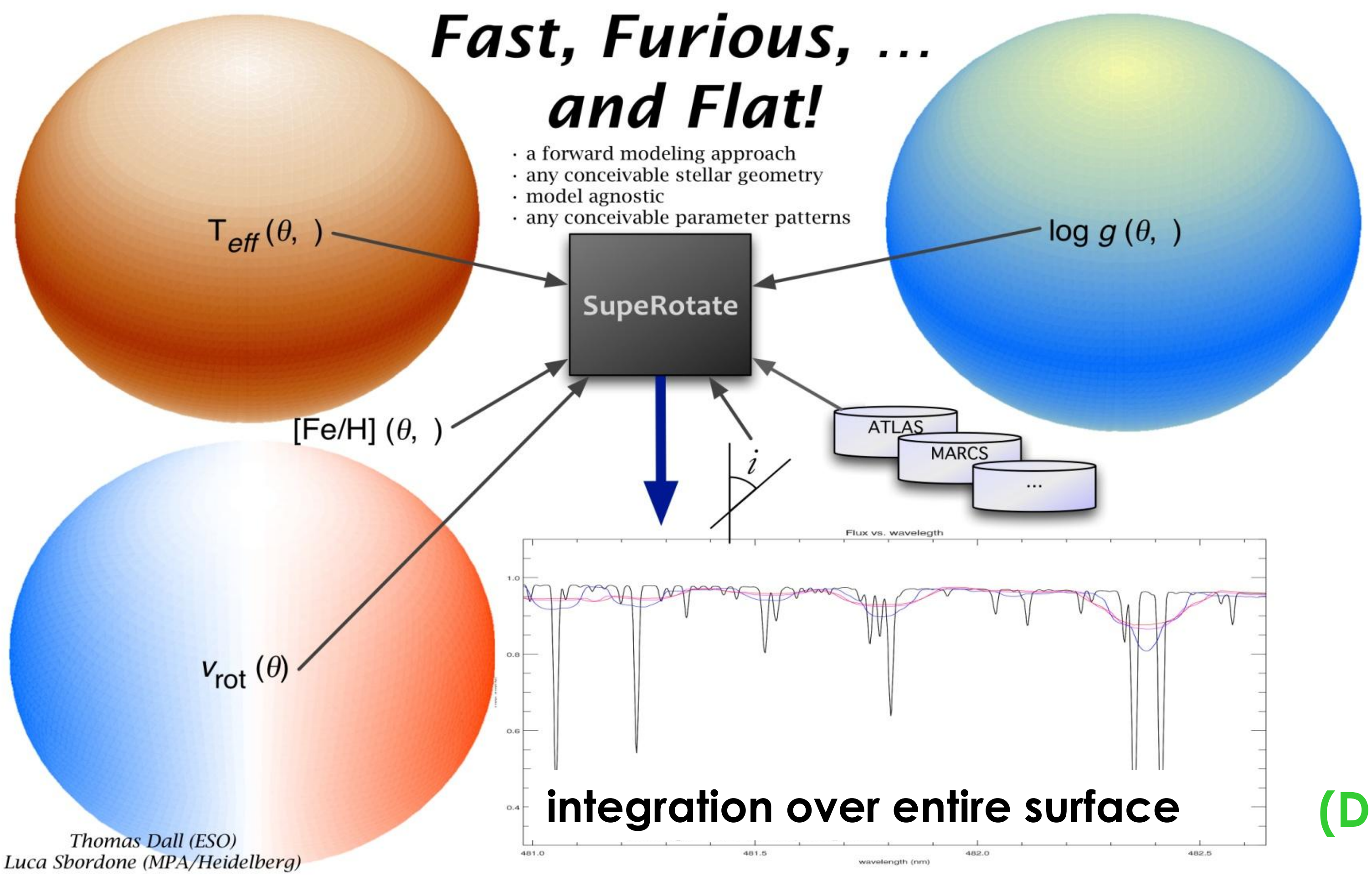
HOT STARS   OB DWARFS

- increase of surface C & N abundance over time with [O/H]
- smaller spread in abundances of B-stars with better spectral modelling



HOT STARS   O STARS

- N surface abundance in young open cluster NGC 2244 consistent with ages of 1 to 5 Myr from CMFGEN models (Mahy P6)

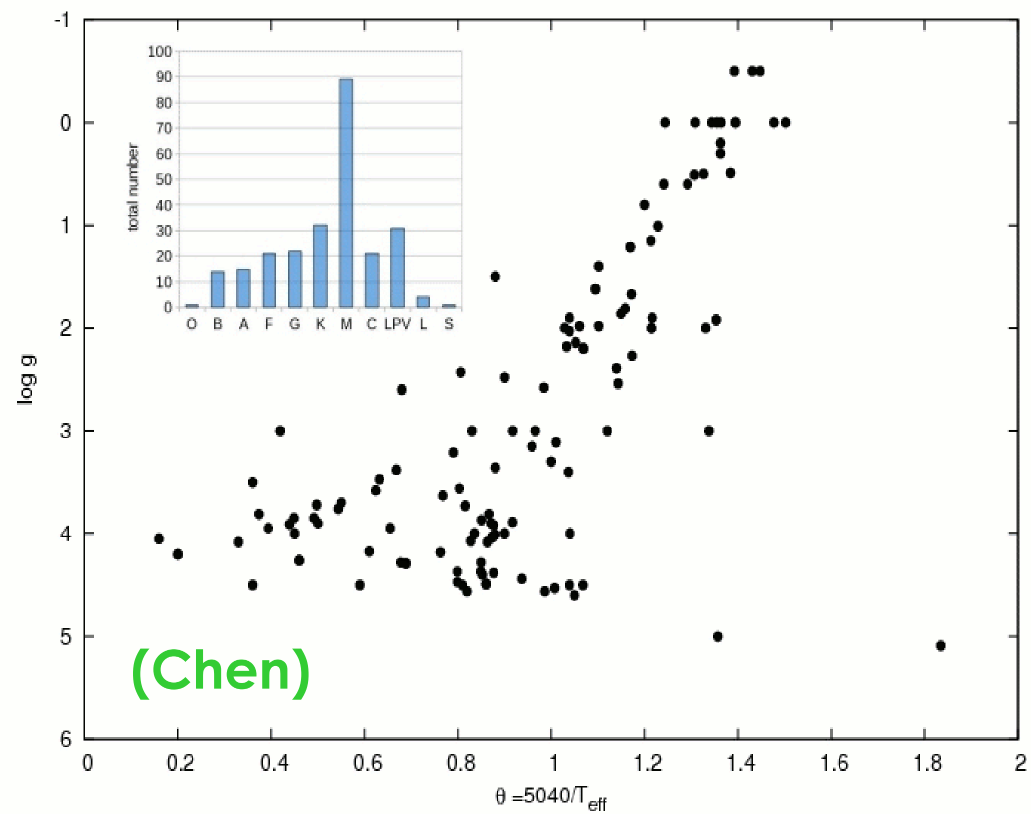


integration over entire surface (Dall)

4. Large Surveys

- Gaia-ESO Survey with VLT FLAMES will observe spectra of 200k stars with hot massive stars in selected clusters
- 300 nights over 5 yr to support/complement Gaia data
- WP definition busy for calibrating, analysis, & interpretation of hot stars

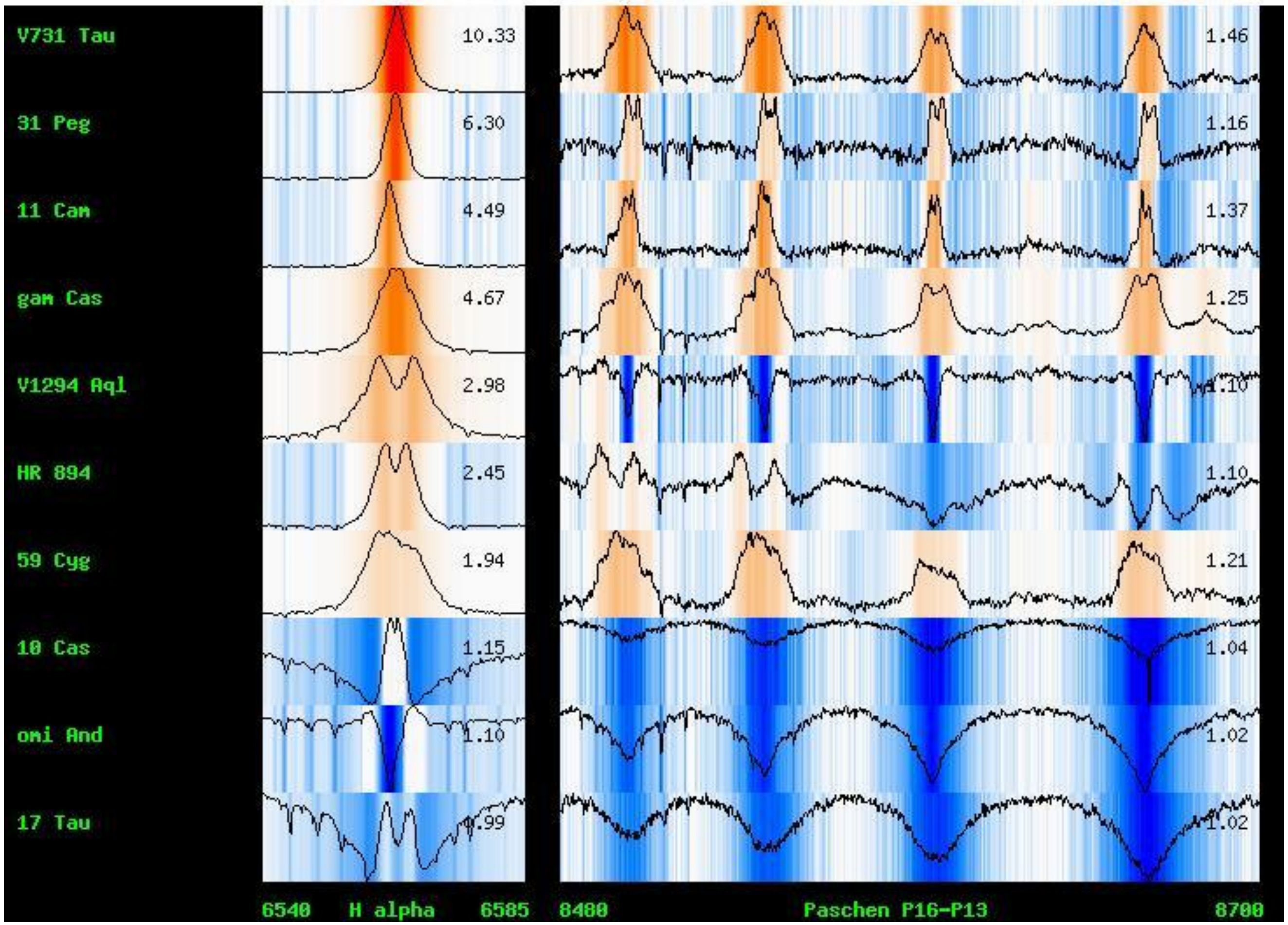
(Blomme)



- VTL X-SHOOTER spectral survey of 600 hot & cool stars with known Teff and log g

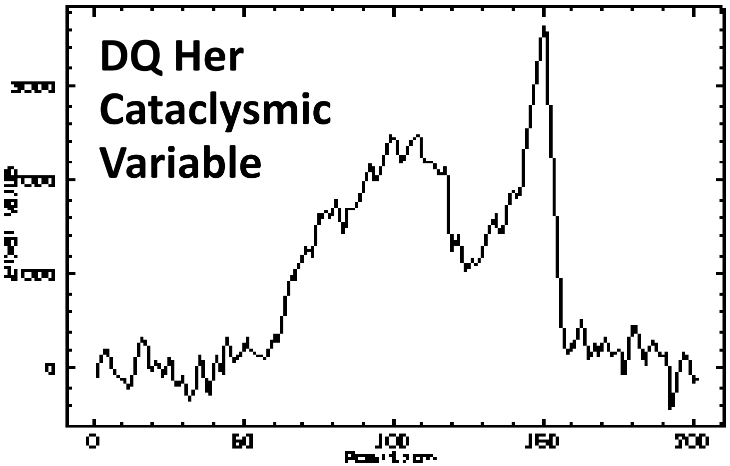
- R~10,000 from optical to near-IR

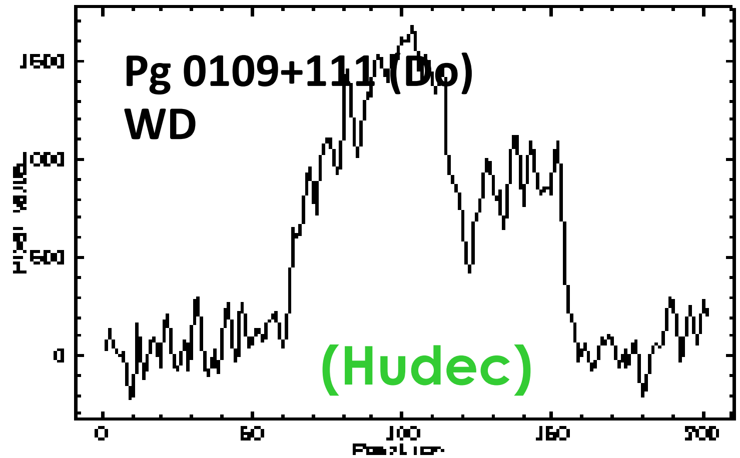
- Survey of 150 Be stars shows that P13 - P16 emission are proxies of Hα emission stronger than 1.5. Paschen line with RVS, while Hα only observed with Rp.

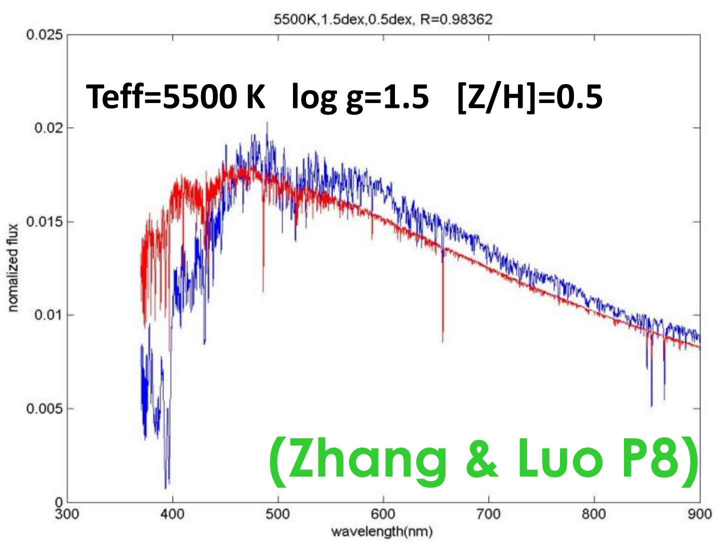


(Koubsky P9)

- Surveys on plates (Low Dispersion Sky) can be used as true simulators of Bp/Rp data. Many objects with prominent spectral features.







- LAMOST Survey will observe a 10^6 stars.
- Teff, log g, metallicity determined from libraries of model spectra from MAFAGS code and KURUCZ ODF spectra.
- ALHAMBRA Photometric System for stellar classification

(Aparicio Villegas)

- Survey of 150 – 200 Galactic O stars in IACOB project for automated finding of Teff log g, Y(He) with high-res. spectra using the FASTWIND code in non-LTE.

(Simon-Diaz)

- Tarantula Survey with VLT-FLAMES of 800 massive stars in LMC to study stellar and cluster evolution. Modelling of O-stars with FASTWIND code for classification and quantitative analyses.

(de Koter)

- near-IR VLT-CRIRES spectra (JHKL bands) of nearby massive stars. Quantitative analysis with FASTWIND for stellar & wind properties.

(Stap P7)

- 4MOST proposed as large int. collaboration to go 2 -3 mag. fainter than Gaia with multi-fiber ground-based spectroscopy of millions of stars of SNR=20 for large facilities NTT, VISTA. Approved for study by ESO.
  High-res R=20000 & 300 fibers;
  Low-res 1500 fibers R=3000 (red) to R=5000 (blue).
  Role of stellar migration for the formation of the thick and thin disc.

(Quirrenbach)

CONCLUSION

- GET READY FOR GAIA, A TREMENDOUS BOOST FOR STELLAR PYHSICS!
- WE HAVE IMPORTANT WORK TO DO AND TO SHOW THE SCIENTIFIC COMMUNITY WE ARE HANDLING IT
  ALL TOGETHER
- GET INVOLVED AND GET TO WORK

Proceedings:

Submission deadline: 31 Aug

Use online JPCS LaTeX template

Submit PDF to Great.esf@oma.be

Invited: **12 pages**

Contributed: **8 pages**

Posters: **8 pages**

Expected publication date: Dec 2011

Thanks Bedankt Merci Danke

Goodbye Tot ziens Au revoir Auf Wiedersehen

Many thanks to all participants and ...

GREAT

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