Gaia: Perspectives for determining stellar surface parameters

H.-G. Ludwig

ZAH – Landessternwarte, Heidelberg

Overview

- Interplay between determination of stellar atmospheric parameters and development of model atmospheres in the light of Gaia
  - effective temperature $T_{\rm eff}$
  - surface gravity $\log g$
  - chemical abundances
  - leaving out: rotational velocity

- Application of model atmospheres play a role on many levels of Gaia data analysis
  - e.g., libraries of stellar spectra
  - stellar atmospheres well developed theoretical tool

- Accurate observational constraints necessary to make model shortcomings apparent

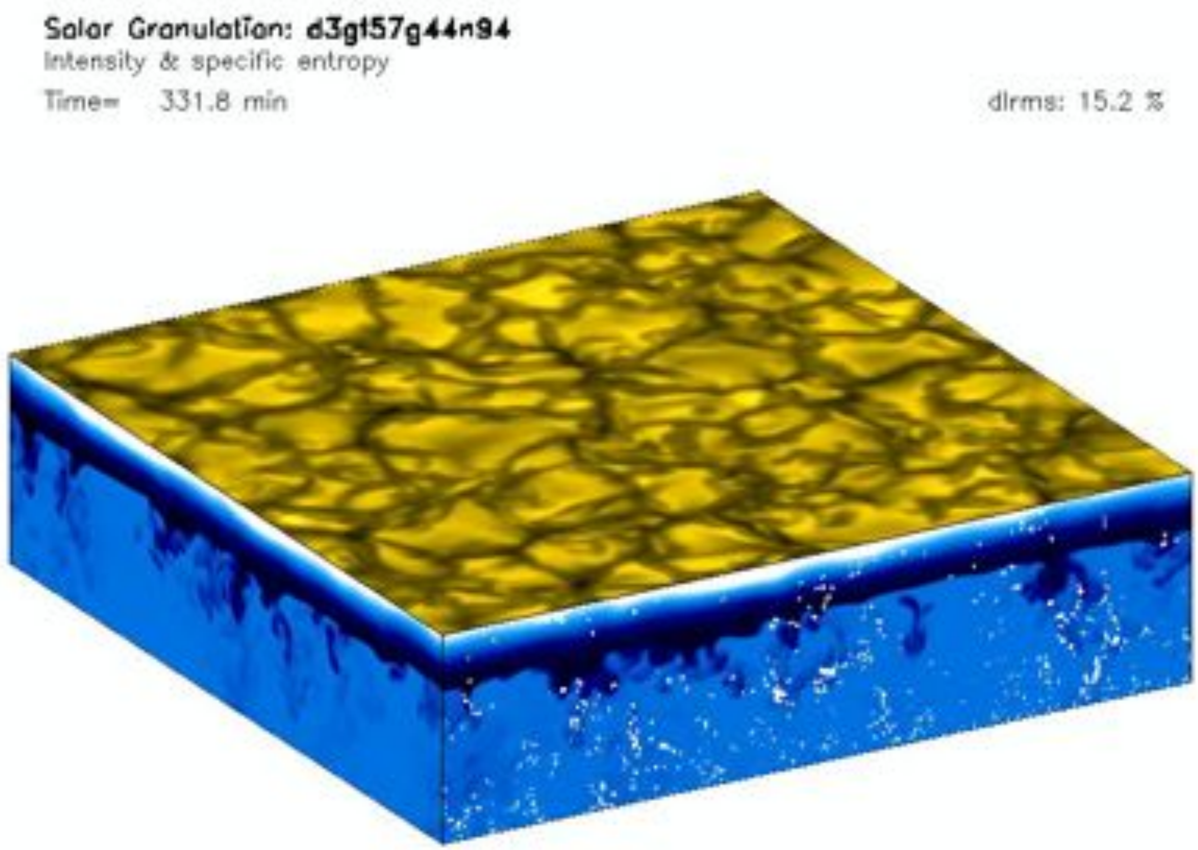
- HIPPARCOS based results and stories from own projects

BIPM ideas of accuracy . . .

Conclusions

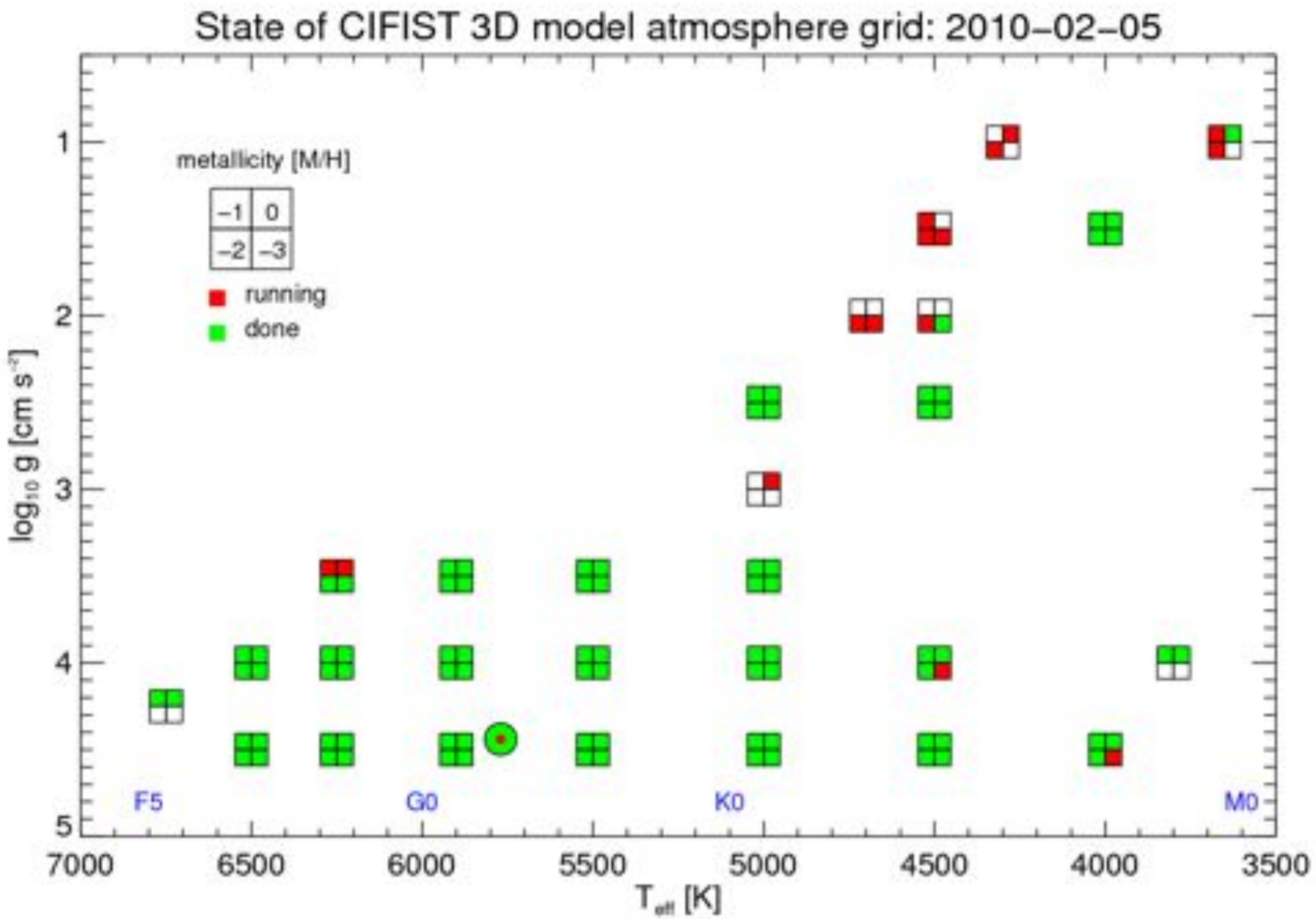
- Gaia will sharpen the constraints model atmospheres have to fulfill
- Desirable improvements on the stellar T_{eff} scale demand for new discoveries – which Gaia will likely make – and accompanying observational and theoretical efforts
- Gaia can help to provide non-standard observables of particular interest to 3D model atmospheres

Personal bias



- Modellist, cool stars, development of 3D hydrodynamical model
  - stellar abundance work, Sun, metal-poor stars
- Member of CU6, WP on radial velocity zero point definition

CIFIST **3D model atmosphere grid**



(Ludwig, Caffau, Steffen, Freytag, Bonifacio, Kučinskas, 2009)

Solar 3D abundances in comparison

EL	N	Caffau et al.	AG89	GS98	AGS05	AGSS09
Li	1	1.02 ± 0.02	1.16 ± 0.10	1.10 ± 0.10	1.05 ± 0.10	1.05 ± 0.10
C	43	8.50 ± 0.11	8.56 ± 0.04	8.52 ± 0.06	8.39 ± 0.05	8.43 ± 0.05
N	12	7.86 ± 0.12	8.05 ± 0.04	7.92 ± 0.06	7.78 ± 0.06	7.83 ± 0.05
O	10	8.76 ± 0.07	8.93 ± 0.035	8.83 ± 0.06	8.66 ± 0.05	8.69 ± 0.05
P	5	5.46 ± 0.04	5.45 ± 0.04	5.45 ± 0.04	5.36 ± 0.04	5.41 ± 0.03
S	9	7.15 ± 0.06	7.21 ± 0.06	7.33 ± 0.11	7.14 ± 0.05	7.12 ± 0.03
Eu	5	0.52 ± 0.03	0.51 ± 0.08	0.51 ± 0.08	0.52 ± 0.06	0.52 ± 0.04
Hf	4	0.87 ± 0.04	0.88 ± 0.08	0.88 ± 0.08	0.88 ± 0.08	0.85 ± 0.04
Th	1	0.08 ± 0.03	0.12 ± 0.06	*0.09 ± 0.02*	*0.06 ± 0.05*	0.02 ± 0.10
K	6	5.10 ± 0.09	5.12 ± 0.13	5.12 ± 0.13	5.08 ± 0.07	5.03 ± 0.09
Fe	15	7.51 ± 0.08	7.67 ± 0.03	7.50 ± 0.05	7.45 ± 0.05	7.50 ± 0.04
Os	3	1.15 ± 0.06	1.45 ± 0.10	1.45 ± 0.10	1.45 ± 0.10	1.25 ± 0.07
Z		0.0154	0.0189	0.0171	0.0122	0.0134
Z/X		0.0211	0.0267	0.0234	0.0165	0.0183

AG89 Anders & Grevesse Geochemica et Cosmochimica acta, 1989 Vol. 53 (6th place)

GS98: Grevesse et Sauval; Space Science Reviews 85: 161-174, 1998

AGS05: Asplund et al.; ASP Conferences Series, Vol. 336, 2205

AGGS09: Asplund, Grevesse, Sauval, & Scott, 2009, ARAA 47, 481

- O-abundance: model atmospheres and spectral synthesis (NLTE) enter on the $0.05 \ldots 0.1$ dex level

Absolute chemical abundances and fundamental atmospheric parameters

- Solar abundances from spectroscopy benchmark demand model atmospheres of highest fidelity
- Differences between Caffau et al. and AGSS09 dominated by systematics in model atmospheres and assumptions in NLTE spectral synthesis
  - same spectra, same atomic parameters used ...
- T_{eff} and $\log g$ obviously well constrained in the case of the Sun
- Constraining physics of atmosphere models (late-type stars) using chemistry in other stars needs
  - T_{eff} to better than 1 %
  - $\log g$ to better than 0.1 dex
- Would make model systematics apparent like in the solar case
  - left out fine print on abundance cross-talk, extinction, rotation, micro-turbulence

High precision atmospheric parameters?

- Gaia's photometry perhaps up to the task for $G < 15$ and zero extinction? (Bailer-Jones, 2010, MNRAS 403, 96)

- Combine with ground-based measurements

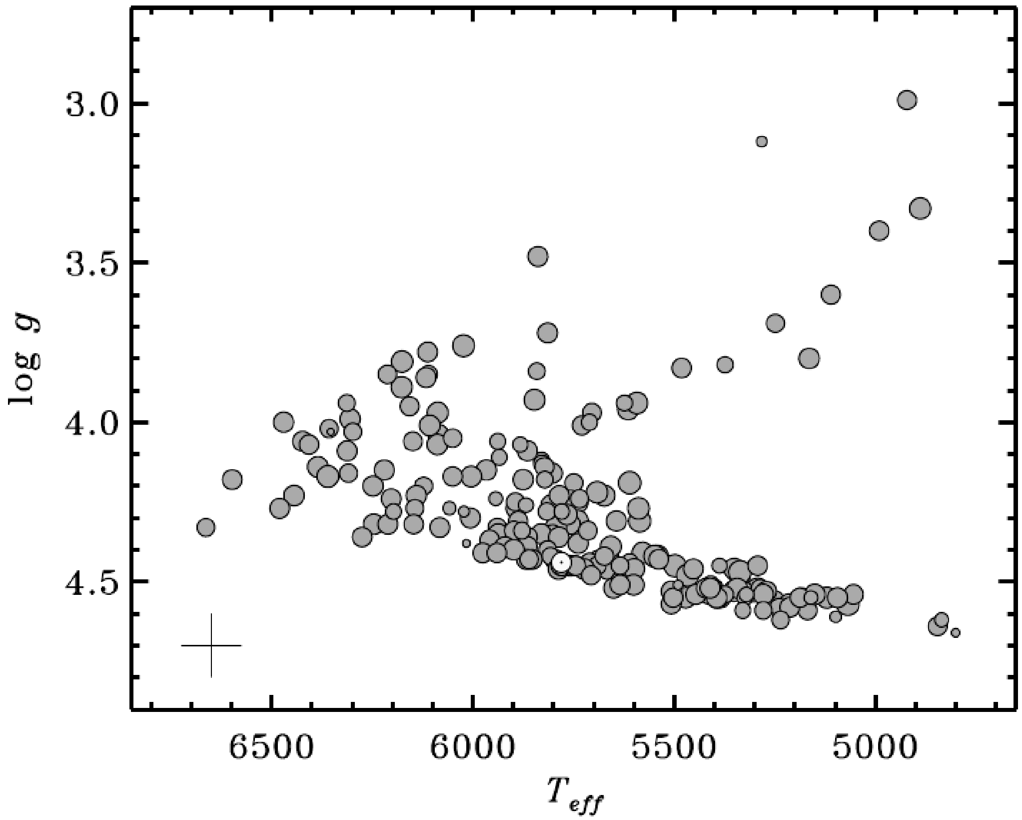
- Effective temperatures from (in order of decreasing model dependence)
  - spectroscopy: (excitation equilibrium), Balmer line profiles
  - photometry: infra-red flux method
  - angular diameters: $T_{\rm eff} \propto \theta_{\rm LD}^{-\frac{1}{2}} f_{\rm bol}^{\frac{1}{4}}$ (weak model dependence)
    rather few measurements, none for very metal-poor stars

- Surface gravities from

$$\log \frac{g}{g_\odot} = \log \frac{M(L, T_{\rm eff})}{M_\odot} + 4 \log \frac{T_{\rm eff}}{T_{\rm eff\odot}} + 0.4\,(M_{\rm bol} - M_{\rm bol\odot})$$

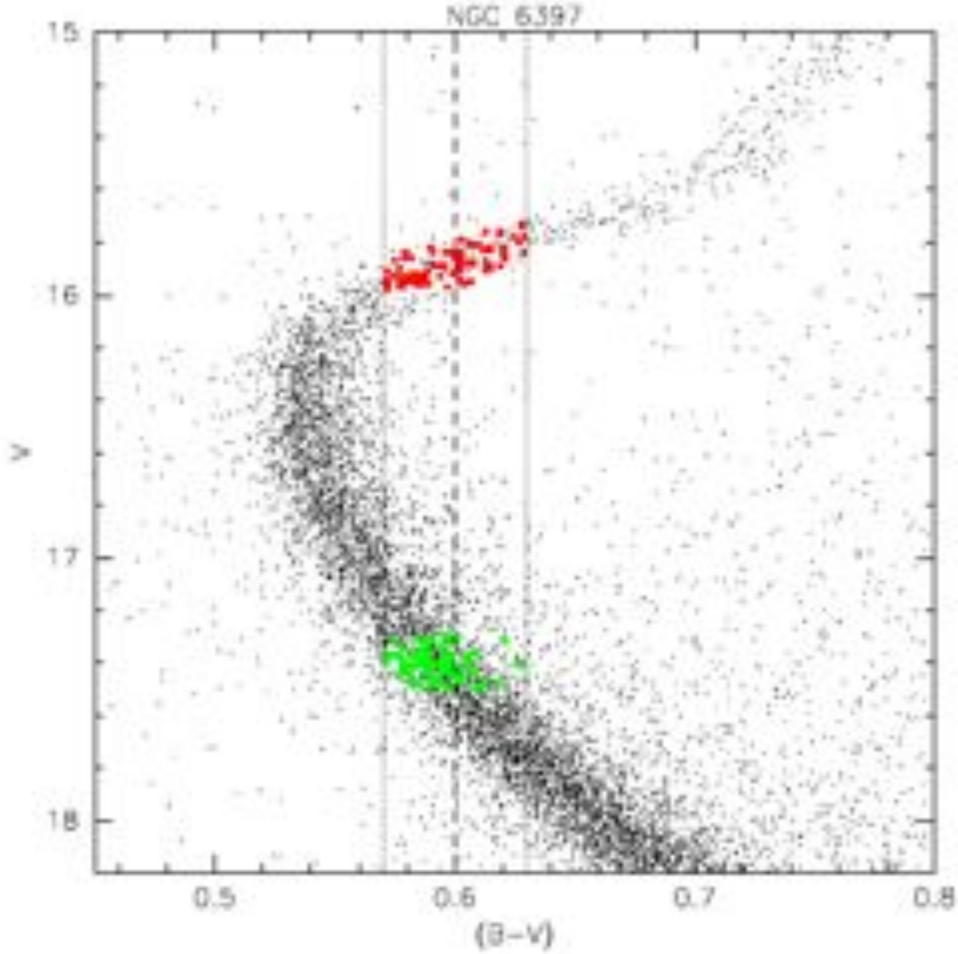
- Gaia provides accurate distances and and estimates of the extinction

Fuhrmann 2004: mid-F to K stars within 25 pc



- $T_{\rm eff}$ from Balmer lines, $\log g$ from HIPPARCOS distances
- Uncertainty in $T_{\rm eff}$ 1.3 %, $\log g$ 0.1 dex
- Error budget on gravity dominated by distance error

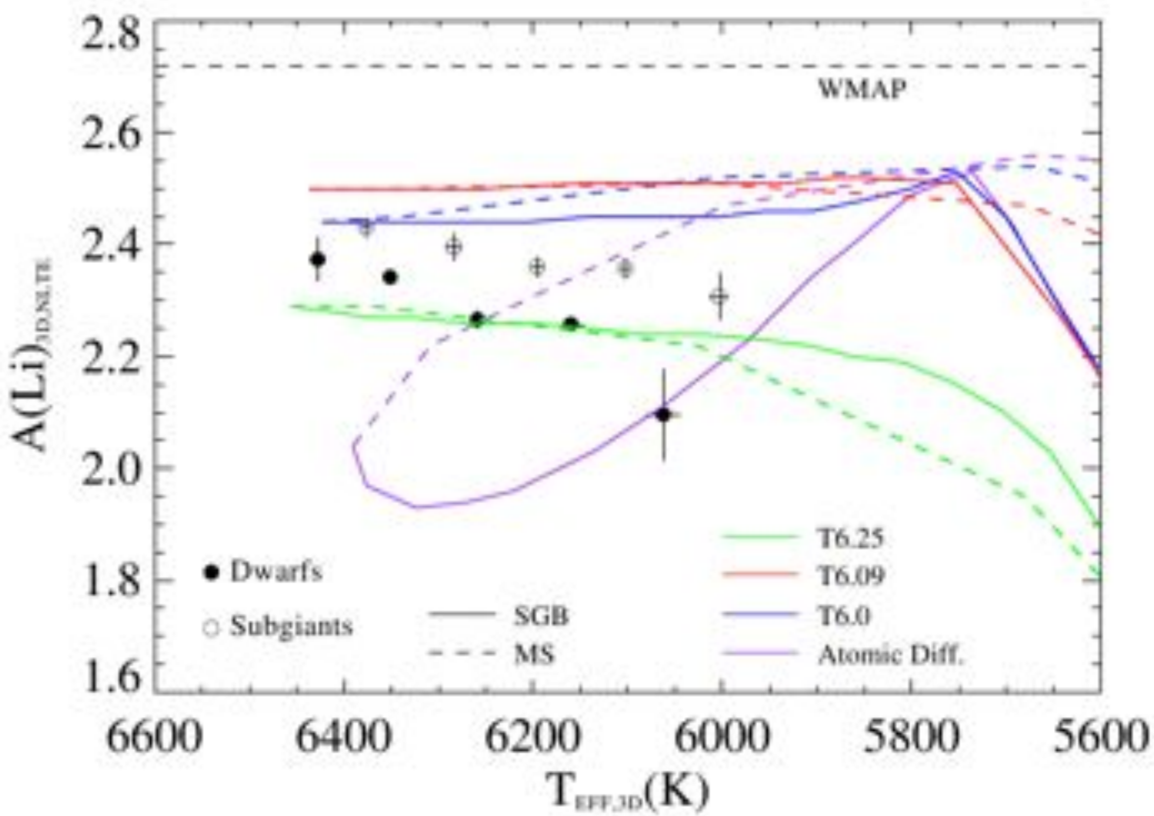
Metal-poor stars: lack of fundamental $T_{\rm eff}$



(González Hernández et al. 2010)

- Colour-magnitude diagram globular cluster NGC6397, $[\mathrm{M/H}] \approx -2$
- 80 MS + 80 SG stars with FLAMES/GIRAFFE

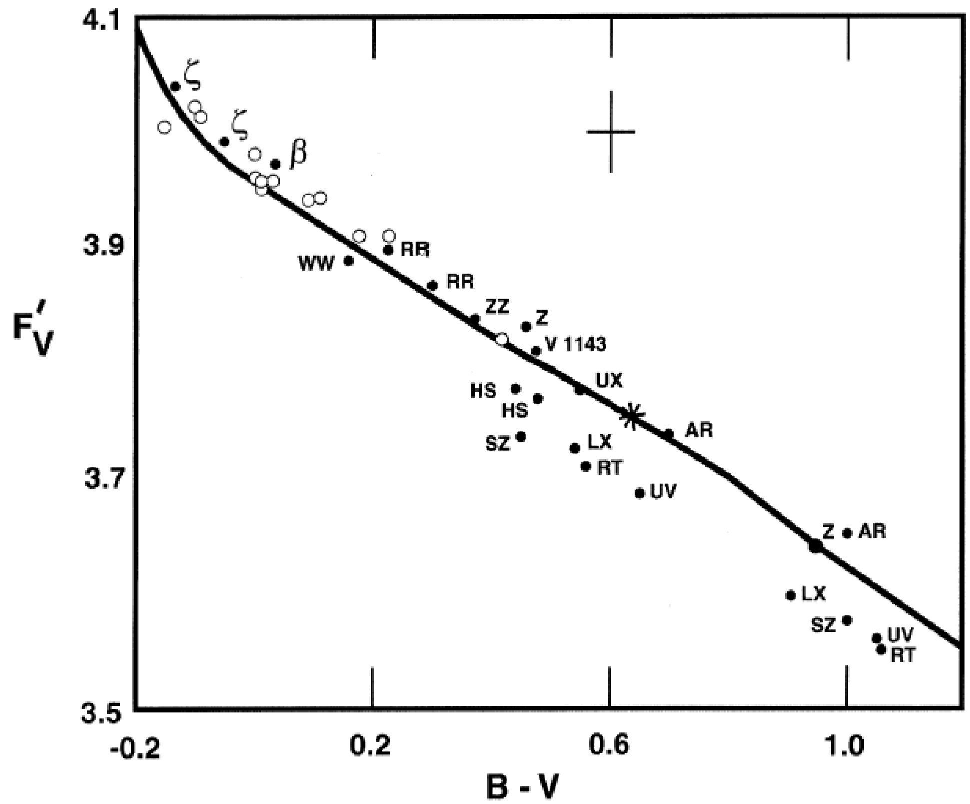
Metal-poor stars: lack of fundamental $T_{\rm eff}$



(González Hernández et al. 2010)

- $T_{\rm eff}$ from Balmer lines in 3D, $\log g$ from colours and cluster isochrone
- ΔA(Li)$/\Delta T_{\rm eff} = 0.07\,{\rm dex}/100\,{\rm K}$, apparent trends real?
- Fuhrmann-like precision for metal-poor population for model calibration?

Instead of one take two – detached eclipsing binaries



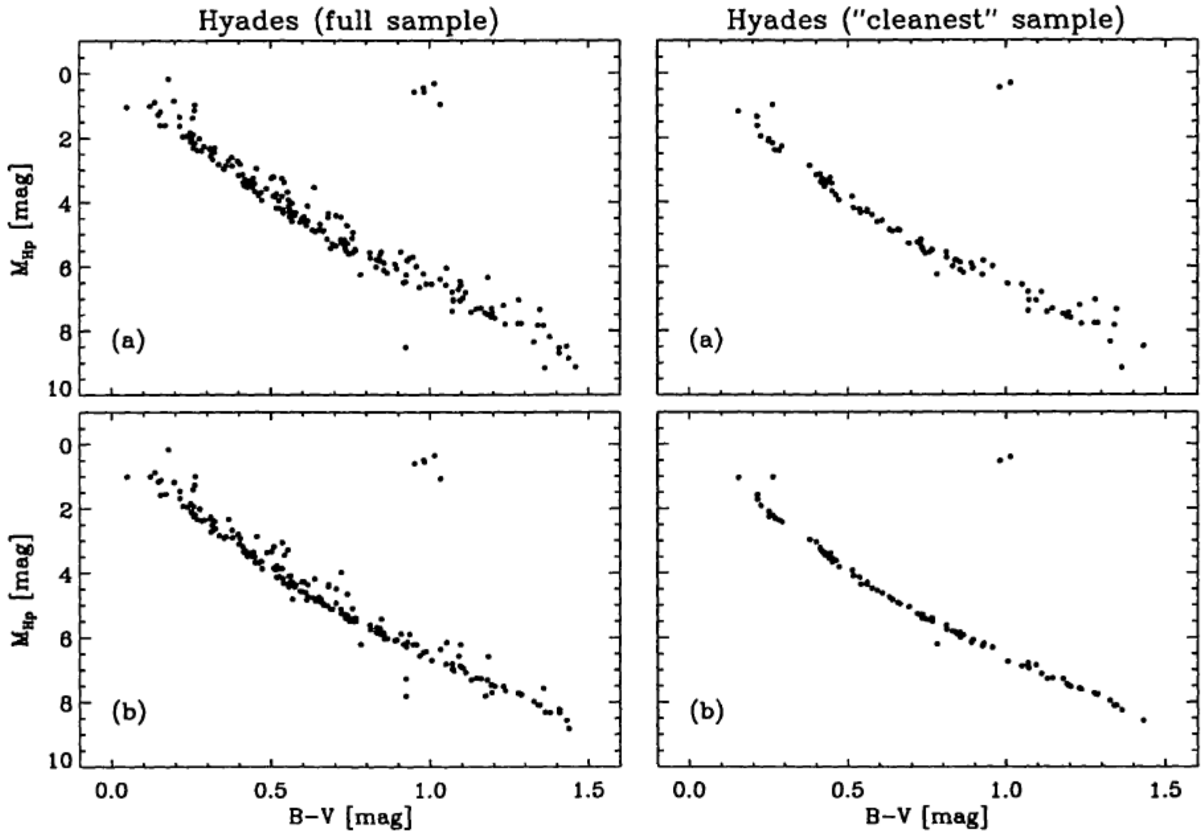
(Popper 1998)

- Photometric and spectroscopic analysis of eclipsing system provides radii
- Known distances and extinction provide luminosities $\rightarrow T_{\rm eff}$
- Popper 1998: 14 analysed systems with HIPPARCOS distances to better than 10 %

Instead of one take two – detached eclipsing binaries

- Gaia expected to discover eclipsing binaries
  - photometry $0.5 \ldots 7 \times 10^6$ (Laurent Eyer),
  - RVS 25 000 SB2s (David Katz)
  - good chances for metal-poor systems
  - substantial ground-based follow-up work necessary
- Certainly also helpful for the less well-charted regions of the HRD
  - temperature scale of very late M-type and substellar objects uncertain
  - atmospheric and atomic physics complicated due to molecular and dust formation

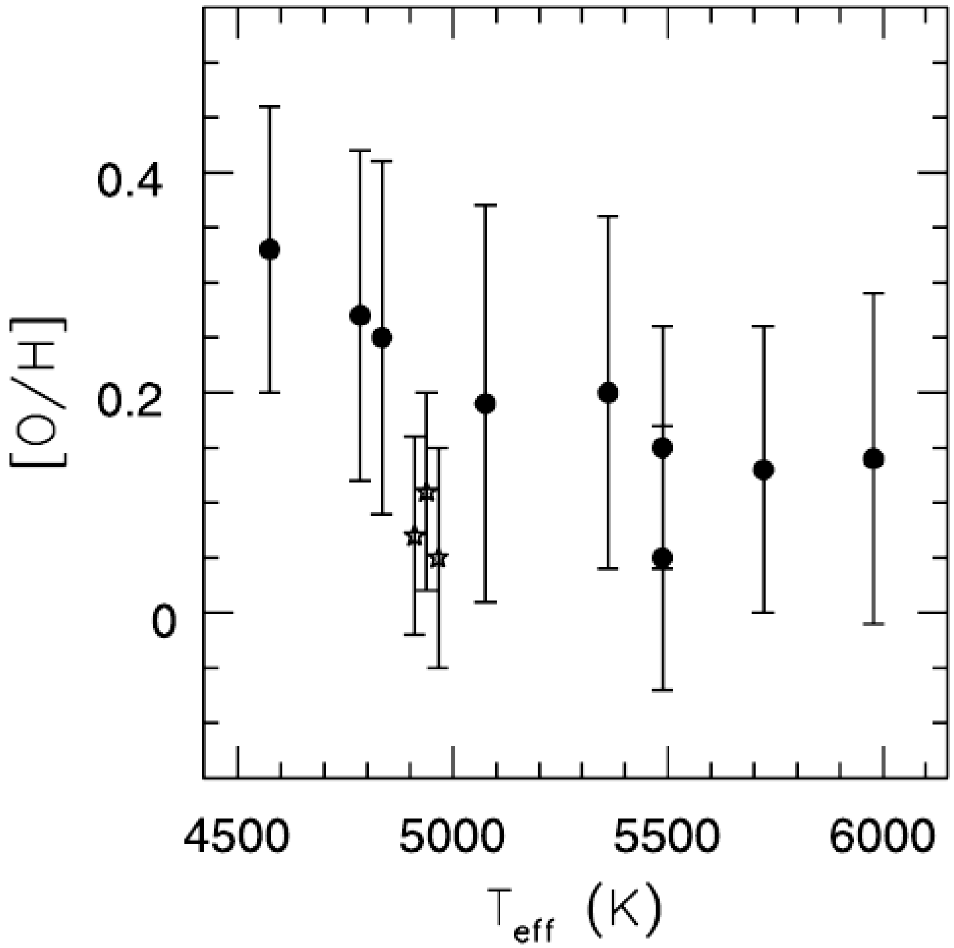
Clean populations – example from HIPPARCOS & Hyades



(from Madsen, Lindegren, & Dravins 2000)

- Inclusion of proper motion information improved parallaxes 1.5 mas (top panels) to 0.3. . .0.5 mas (bottom panels)
- Cleaned for binaries (right panels) with available kinematics and distances
- Reveals fine features in the cluster main-sequence – interpretation?

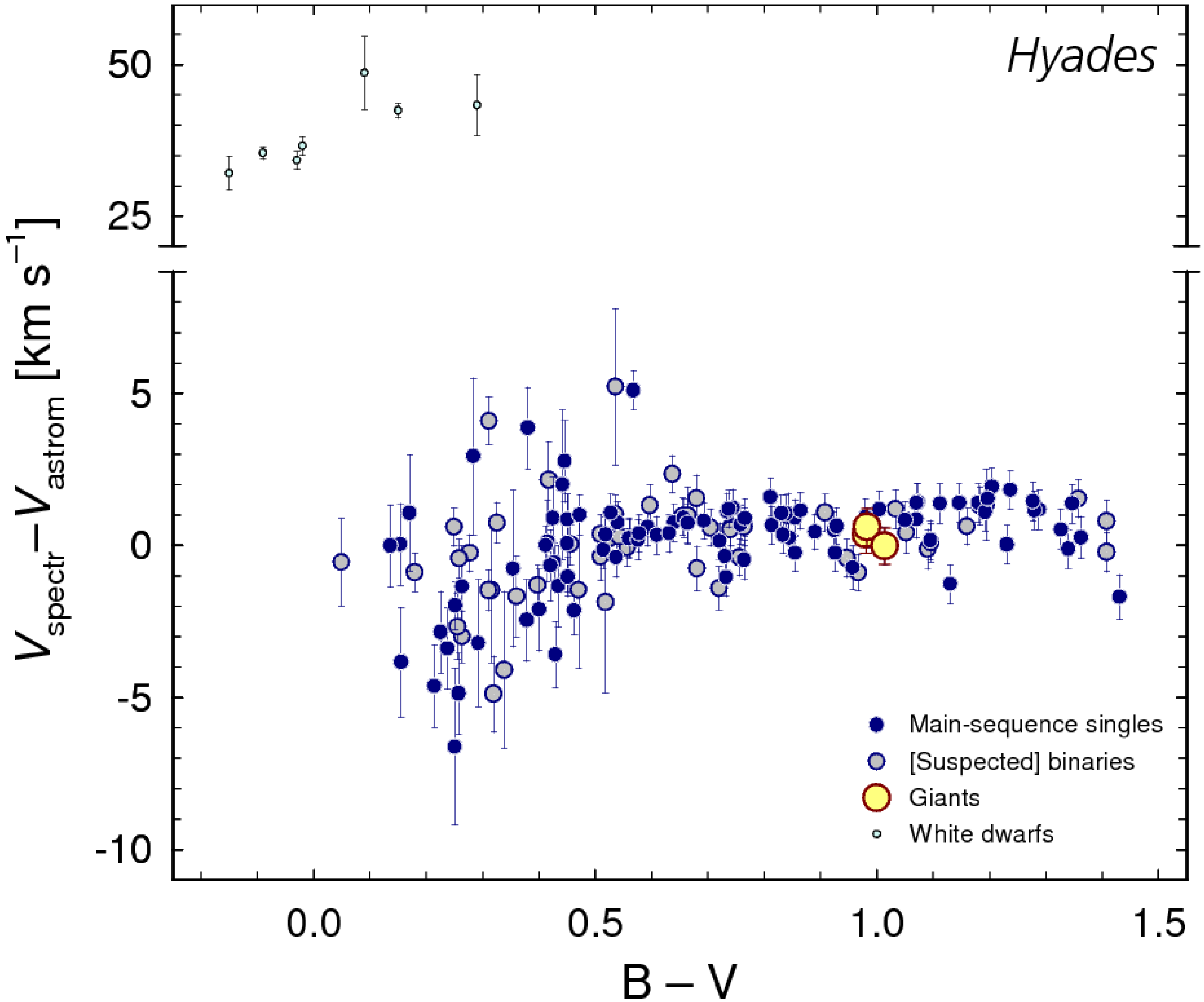
Hyades: chemical homogeneity versus model problems



(from Schuler et al. 2006), dwarfs dots, giants stars

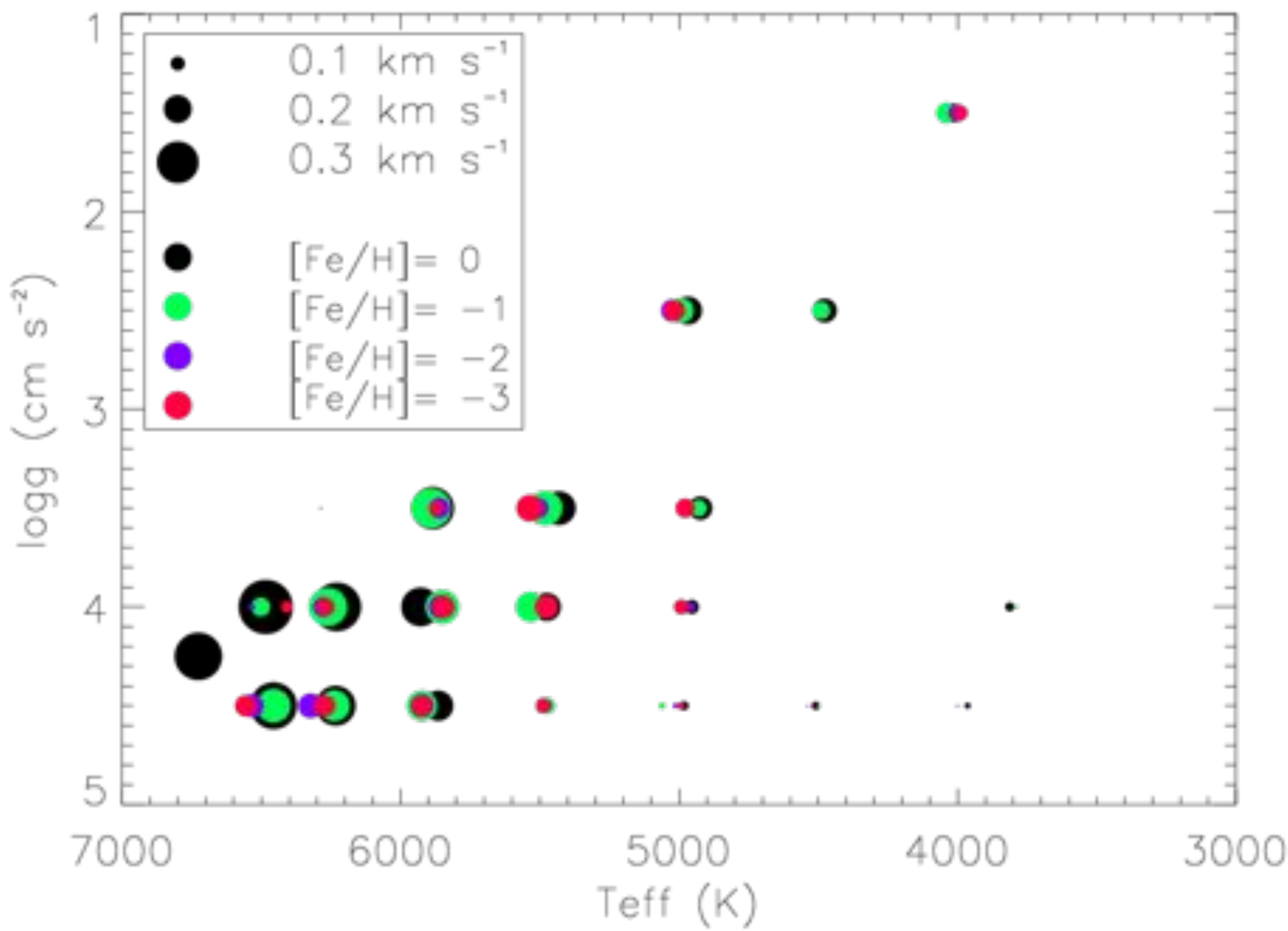
- Oxygen from forbidden 6300 Å line (no NLTE effects!) in Hyades
- Chemical inhomogeneous or modelling deficit? Chemical tagging?

Astrometric versus spectroscopic radial velocities



(from Dravins 2003 base on HIPPARCOS data)

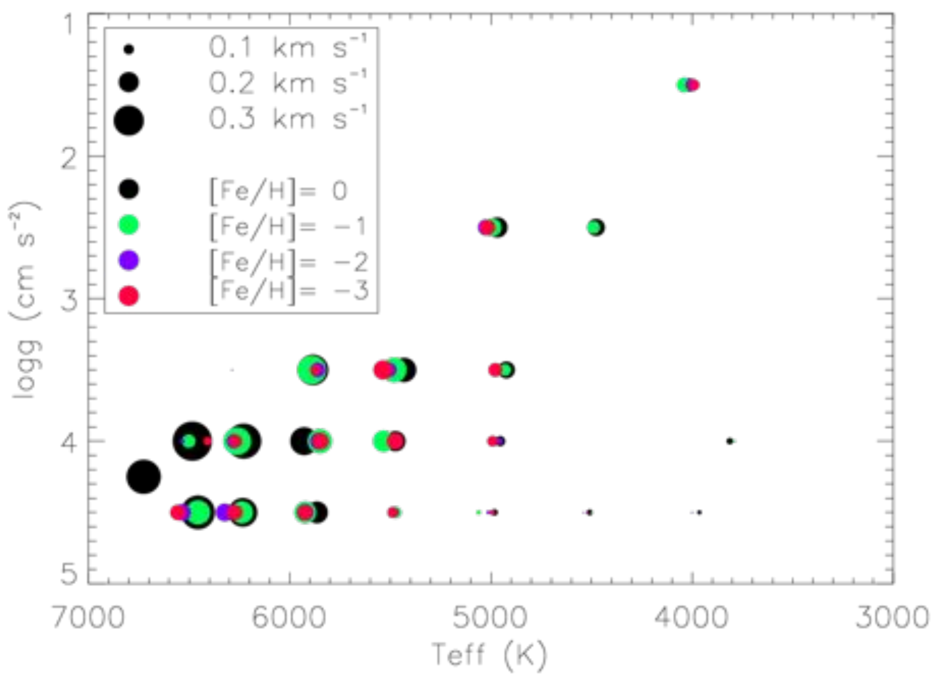
Testing dynamics predicted by 3D model atmospheres

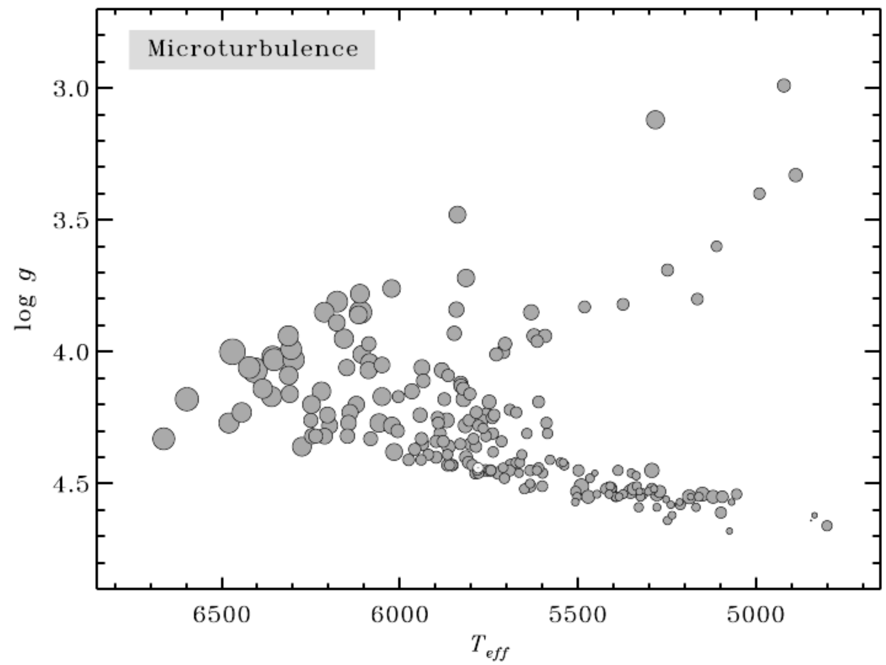


- CIFIST 3D grid plus ASSET spectral synthesis (Koesterke, Allende Prieto, Ludwig)
- RANGER 65 000 core machine at Texas Advances Computing Center (USA)

FIN

Testing dynamics predicted by 3D model atmospheres





- Micro-turbulent velocities from Fuhrmann (2004)
  - micro-turbulence and line shifts both of convective origin