Metallicity - Basics

- Metallicity as [X:Y:Z]
- X = Hydrogen
- Y = Helium
- Z = „the rest“

$$X \equiv \frac{m_H}{M} \qquad Y \equiv \frac{m_{He}}{M} \qquad Z = \sum_{i>He} \frac{m_i}{M} = 1 - X - Y$$

Metallicity - designations

- In the literature you will find
  - [Z]
  - [Fe/H]
  - [M/H]
  - [Element 1 / Element 2]
- Relations for the transformation are necessary

$$[\mathrm{Fe/H}] = \log_{10}\left(\frac{N_{\mathrm{Fe}}}{N_{\mathrm{H}}}\right)_{\mathrm{star}} - \log_{10}\left(\frac{N_{\mathrm{Fe}}}{N_{\mathrm{H}}}\right)_{\mathrm{sun}}$$

$$[\mathrm{O/Fe}] = \log_{10}\left(\frac{N_{\mathrm{O}}}{N_{\mathrm{Fe}}}\right)_{\mathrm{star}} - \log_{10}\left(\frac{N_{\mathrm{O}}}{N_{\mathrm{Fe}}}\right)_{\mathrm{sun}}$$

$$= \left[\log_{10}\left(\frac{N_{\mathrm{O}}}{N_{\mathrm{H}}}\right)_{\mathrm{star}} - \log_{10}\left(\frac{N_{\mathrm{O}}}{N_{\mathrm{H}}}\right)_{\mathrm{sun}}\right] - \left[\log_{10}\left(\frac{N_{\mathrm{Fe}}}{N_{\mathrm{H}}}\right)_{\mathrm{star}} - \log_{10}\left(\frac{N_{\mathrm{Fe}}}{N_{\mathrm{H}}}\right)_{\mathrm{sun}}\right]$$

Metallicity – designations

$$[\mathrm{M/H}] = \log_{10}\left(\frac{N_{\mathrm{M}}}{N_{\mathrm{H}}}\right)_{\mathrm{star}} - \log_{10}\left(\frac{N_{\mathrm{M}}}{N_{\mathrm{H}}}\right)_{\mathrm{sun}}$$

$$\log_{10}\left(\frac{Z/X}{Z_{\mathrm{sun}}/X_{\mathrm{sun}}}\right) = [\mathrm{M/H}]$$

Table 2. Transformation of [Fe/H] to [Z] using $[\mathrm{Y}] = 0.23 + 2.25[\mathrm{Z}]$ from Girardi et al. (2000) applied in this work.

[Fe/H]	[Z]	[Fe/H]	[Z]	[Fe/H]	[Z]
−0.729	0.004	−0.030	0.018	+0.253	0.032
−0.525	0.006	+0.019	0.020	+0.288	0.034
−0.387	0.008	+0.077	0.022	+0.312	0.036
−0.282	0.010	+0.116	0.024	+0.343	0.038
−0.224	0.012	+0.152	0.026	+0.371	0.040
−0.149	0.014	+0.185	0.028		
−0.086	0.016	+0.225	0.030		

Metallicity - designations

- [dex], e.g. [Fe/H] = -0,5 dex

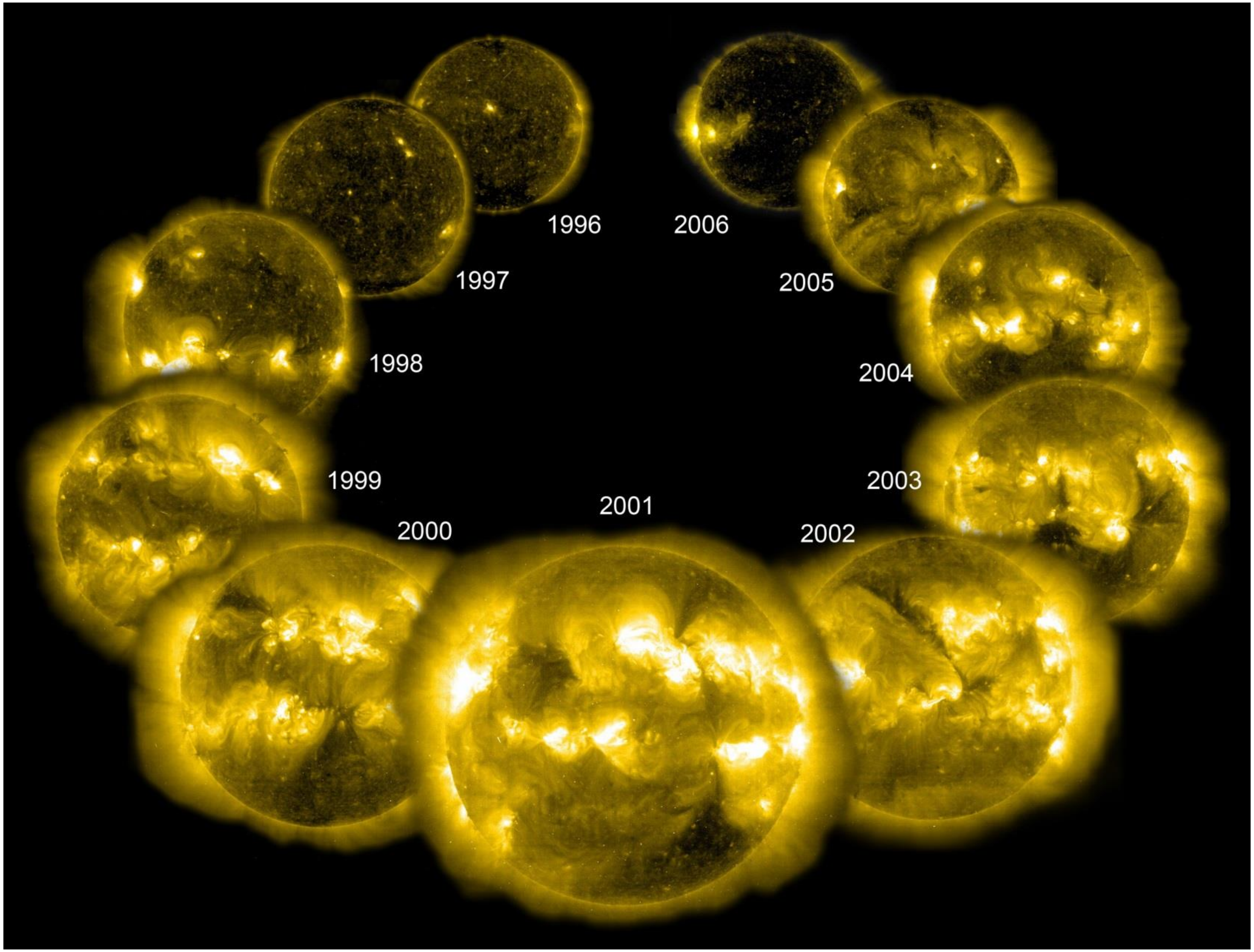
-2	0,01
-1,5	0,03
-1	0,10
-0,9	0,13
-0,8	0,16
-0,7	0,20
-0,6	0,25
-0,5	0,32
-0,4	0,40
-0,3	0,50
-0,2	0,63
-0,1	0,79
0	1,00
0,1	1,26
0,2	1,58
0,3	2,00
0,4	2,51
0,5	3,16
0,6	3,98
0,7	5,01
0,8	6,31
0,9	7,94
1	10,00
1,5	31,62
2	100,00

The Sun as standard star

- „Our“ standard star for the normalisation of the metallicity is the Sun
- We define:
  - Mass
  - Luminosity = absolute (bolometric) magnitude
  - Temperature = spectral type = color
  - Age
  - Chemical composition
  - Internal structure (rotation, magnetic field, convection, diffusion, pulsation, …)

Abundance analysis - Sun

- *Review article:* Asplund et al., 2009, Annual Review of Astronomy & Astrophysics, 47, 481
- Ingredients:
  - Stellar atmosphere
  - Atomic line data
  - High resolution spectra
  - Analysis method
  - Starting parameter
- Gray, 2005, The Observation and Analysis of Stellar Photospheres, Cambridge University Press

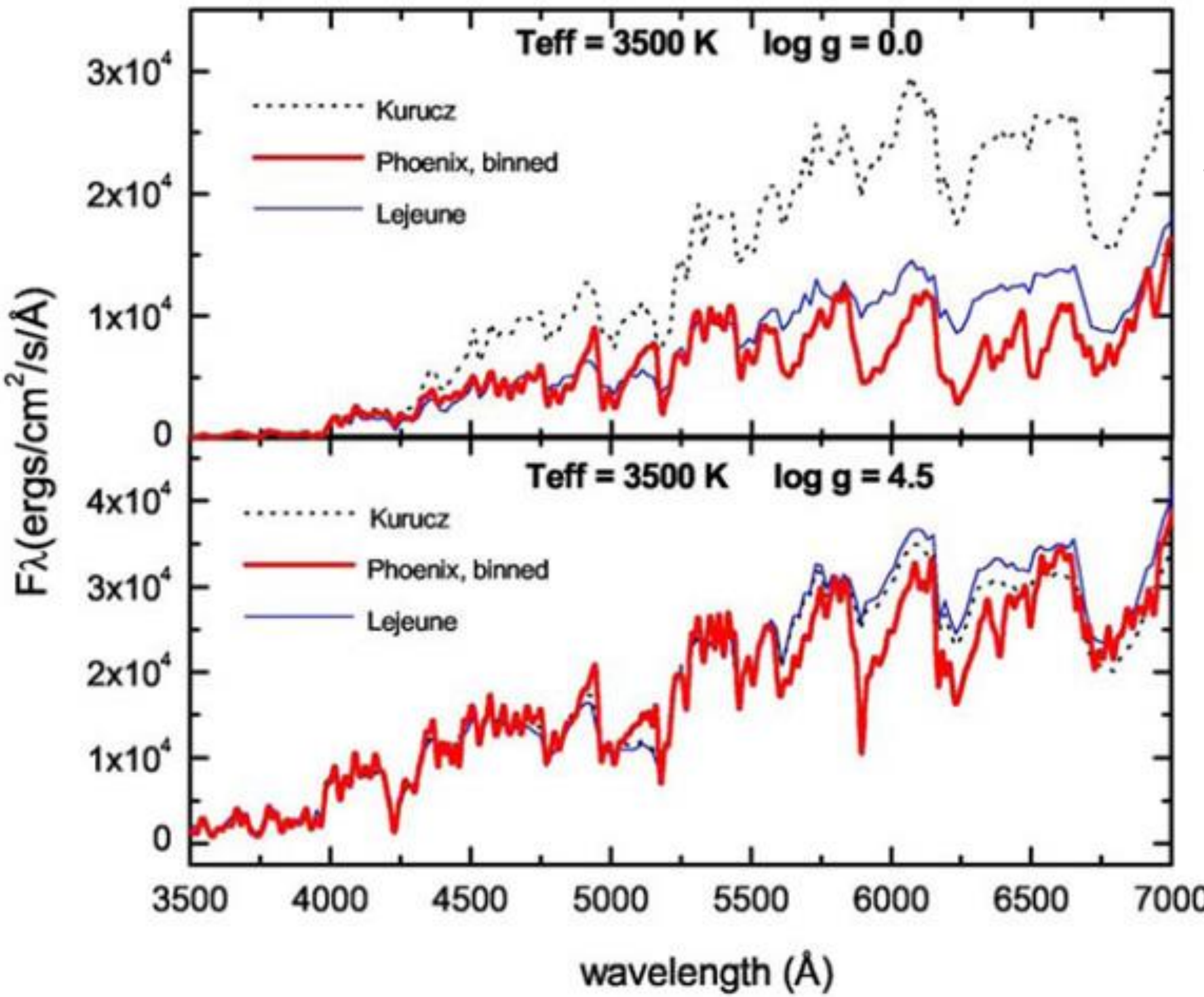


Should we care about it?

Stellar atmospheres

- **ATLAS** (http://atmos.obspm.fr/)
- **MARCS** (http://marcs.astro.uu.se/)
- **NEMO** (http://www.univie.ac.at/nemo)
- **PHOENIX** (http://www.hs.uni-hamburg.de/EN/For/ThA/phoenix/index.html)
- **TLUSTY** (http://nova.astro.umd.edu/)

Stellar atmospheres



Different synthesized stellar spectra "for the same star"

Abundance - Sun

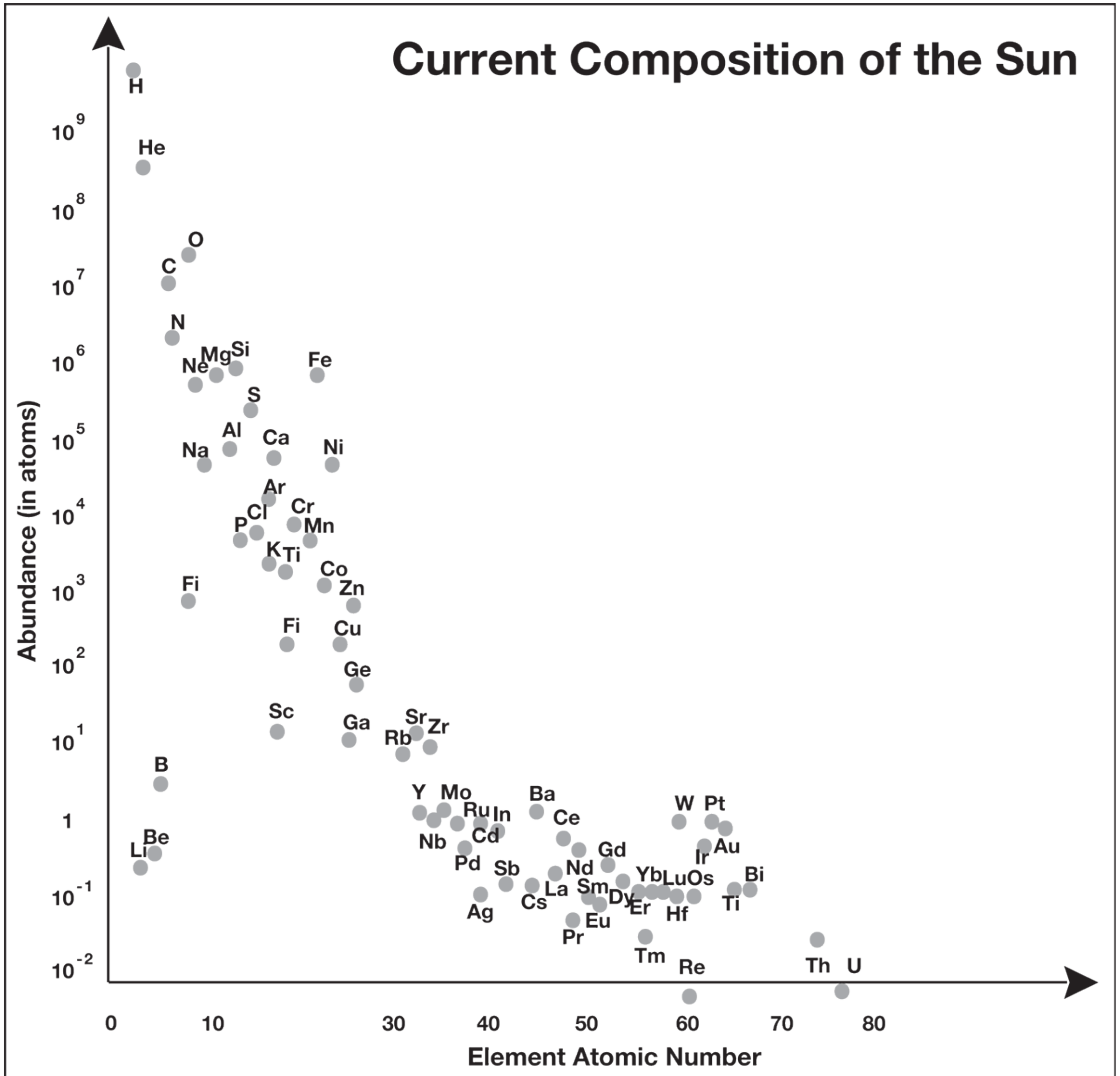
- Problems with
  - Hydrogen
  - Helium
  - Elements with only a few lines
  - Elements with only weak lines
- LTE versus NLTE (Local Thermodynamic Equilibrium)

Abundance - Sun

Asplund et al.

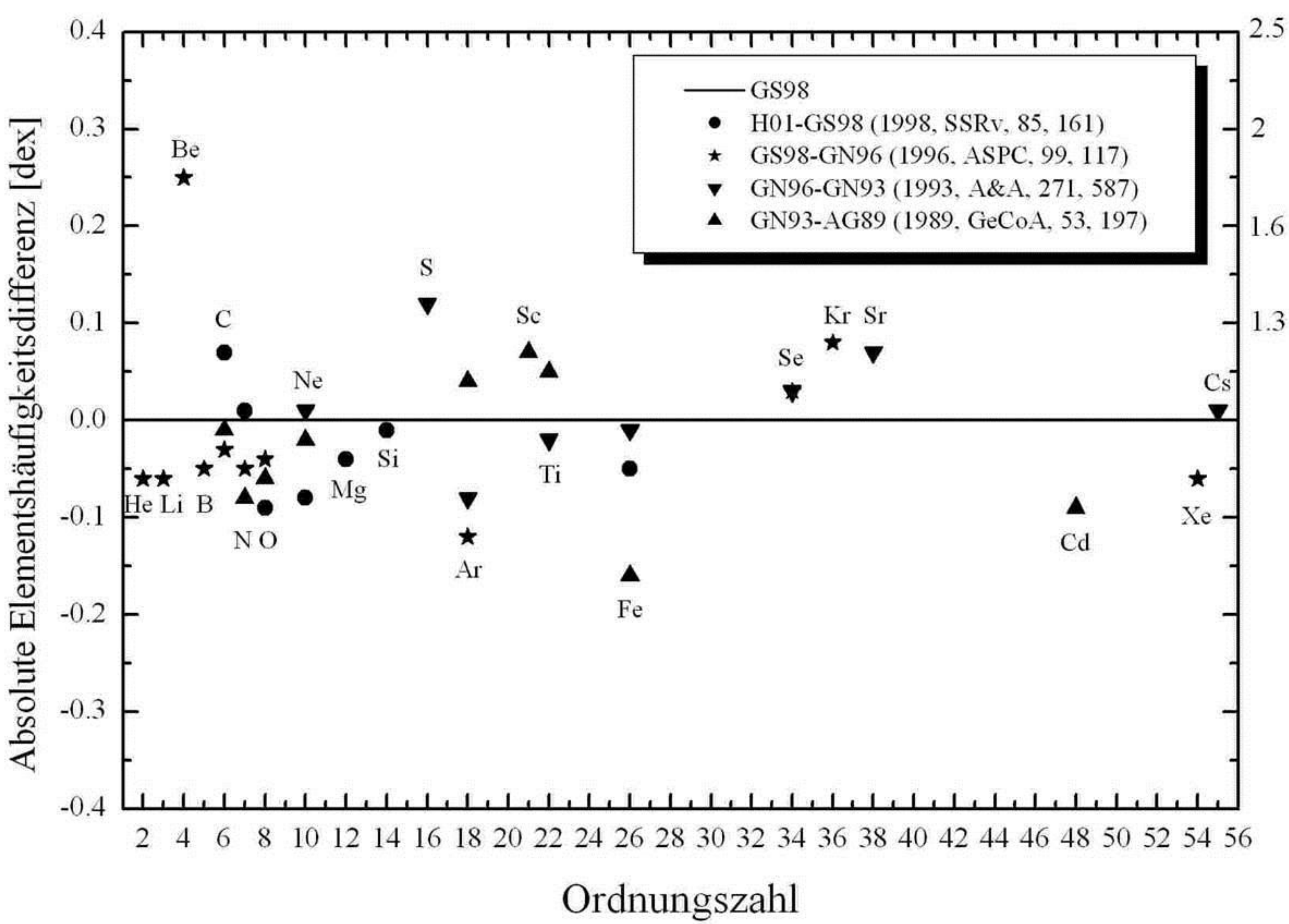
	Elem.	Photosphere	Meteorites		Elem.	Photosphere	Meteorites
1	H	12.00	8.22 ± 0.04	44	Ru	1.75 ± 0.08	1.76 ± 0.03
2	He	[10.93 ± 0.01]	1.29	45	Rh	0.91 ± 0.10	1.06 ± 0.04
3	Li	1.05 ± 0.10	3.26 ± 0.05	46	Pd	1.57 ± 0.10	1.65 ± 0.02
4	Be	1.38 ± 0.09	1.30 ± 0.03	47	Ag	0.94 ± 0.10	1.20 ± 0.02
5	B	2.70 ± 0.20	2.79 ± 0.04	48	Cd		1.71 ± 0.03
6	C	8.43 ± 0.05	7.39 ± 0.04	49	In	0.80 ± 0.20	0.76 ± 0.03
7	N	7.83 ± 0.05	6.26 ± 0.06	50	Sn	2.04 ± 0.10	2.07 ± 0.06
8	O	8.69 ± 0.05	8.40 ± 0.04	51	Sb		1.01 ± 0.06
9	F	4.56 ± 0.30	4.42 ± 0.06	52	Te		2.18 ± 0.03
10	Ne	[7.93 ± 0.10]	−1.12	53	I		1.55 ± 0.08
11	Na	6.24 ± 0.04	6.27 ± 0.02	54	Xe	[2.24 ± 0.06]	−1.95
12	Mg	7.60 ± 0.04	7.53 ± 0.01	55	Cs		1.08 ± 0.02
13	Al	6.45 ± 0.03	6.43 ± 0.01	56	Ba	2.18 ± 0.09	2.18 ± 0.03
14	Si	7.51 ± 0.03	7.51 ± 0.01	57	La	1.10 ± 0.04	1.17 ± 0.02
15	P	5.41 ± 0.03	5.43 ± 0.04	58	Ce	1.58 ± 0.04	1.58 ± 0.02
16	S	7.12 ± 0.03	7.15 ± 0.02	59	Pr	0.72 ± 0.04	0.76 ± 0.03
17	Cl	5.50 ± 0.30	5.23 ± 0.06	60	Nd	1.42 ± 0.04	1.45 ± 0.02
18	Ar	[6.40 ± 0.13]	−0.50	62	Sm	0.96 ± 0.04	0.94 ± 0.02
19	K	5.03 ± 0.09	5.08 ± 0.02	63	Eu	0.52 ± 0.04	0.51 ± 0.02
20	Ca	6.34 ± 0.04	6.29 ± 0.02	64	Gd	1.07 ± 0.04	1.05 ± 0.02
21	Sc	3.15 ± 0.04	3.05 ± 0.02	65	Tb	0.30 ± 0.10	0.32 ± 0.03
22	Ti	4.95 ± 0.05	4.91 ± 0.03	66	Dy	1.10 ± 0.04	1.13 ± 0.02
23	V	3.93 ± 0.08	3.96 ± 0.02	67	Ho	0.48 ± 0.11	0.47 ± 0.03
24	Cr	5.64 ± 0.04	5.64 ± 0.01	68	Er	0.92 ± 0.05	0.92 ± 0.02
25	Mn	5.43 ± 0.05	5.48 ± 0.01	69	Tm	0.10 ± 0.04	0.12 ± 0.03
26	Fe	7.50 ± 0.04	7.45 ± 0.01	70	Yb	0.84 ± 0.11	0.92 ± 0.02
27	Co	4.99 ± 0.07	4.87 ± 0.01	71	Lu	0.10 ± 0.09	0.09 ± 0.02
28	Ni	6.22 ± 0.04	6.20 ± 0.01	72	Hf	0.85 ± 0.04	0.71 ± 0.02
29	Cu	4.19 ± 0.04	4.25 ± 0.04	73	Ta		-0.12 ± 0.04
30	Zn	4.56 ± 0.05	4.63 ± 0.04	74	W	0.85 ± 0.12	0.65 ± 0.04
31	Ga	3.04 ± 0.09	3.08 ± 0.02	75	Re		0.26 ± 0.04
32	Ge	3.65 ± 0.10	3.58 ± 0.04	76	Os	1.40 ± 0.08	1.35 ± 0.03
33	As		2.30 ± 0.04	77	Ir	1.38 ± 0.07	1.32 ± 0.02
34	Se		3.34 ± 0.03	78	Pt		1.62 ± 0.03
35	Br		2.54 ± 0.06	79	Au	0.92 ± 0.10	0.80 ± 0.04
36	Kr	[3.25 ± 0.06]	−2.27	80	Hg		1.17 ± 0.08
37	Rb	2.52 ± 0.10	2.36 ± 0.03	81	Tl	0.90 ± 0.20	0.77 ± 0.03
38	Sr	2.87 ± 0.07	2.88 ± 0.03	82	Pb	1.75 ± 0.10	2.04 ± 0.03
39	Y	2.21 ± 0.05	2.17 ± 0.04	83	Bi		0.65 ± 0.04
40	Zr	2.58 ± 0.04	2.53 ± 0.04	90	Th	0.02 ± 0.10	0.06 ± 0.03
41	Nb	1.46 ± 0.04	1.41 ± 0.04	92	U		-0.54 ± 0.03
42	Mo	1.88 ± 0.08	1.94 ± 0.04				

Abundance - Sun



Asplund et al.

Abundance - Sun



PhD thesis – U. Heiter

Abundance - Sun

Table 4: The mass fractions of hydrogen (X), helium (Y) and metals (Z) for a number of widely-used compilations of the solar chemical composition.

Source	X	Y	Z	Z/X
Present-day photosphere:				
Anders & Grevesse (1989)[a]	0.7314	0.2485	0.0201	0.0274
Grevesse & Noels (1993)[a]	0.7336	0.2485	0.0179	0.0244
Grevesse & Sauval (1998)	0.7345	0.2485	0.0169	0.0231
Lodders (2003)	0.7491	0.2377	0.0133	0.0177
Asplund, Grevesse & Sauval (2005)	0.7392	0.2485	0.0122	0.0165
Lodders, Palme & Gail (2009)	0.7390	0.2469	0.0141	0.0191
Present work	0.7381	0.2485	0.0134	0.0181
Proto-solar:				
Anders & Grevesse (1989)	0.7096	0.2691	0.0213	0.0301
Grevesse & Noels (1993)	0.7112	0.2697	0.0190	0.0268
Grevesse & Sauval (1998)	0.7120	0.2701	0.0180	0.0253
Lodders (2003)	0.7111	0.2741	0.0149	0.0210
Asplund, Grevesse & Sauval (2005)	0.7166	0.2704	0.0130	0.0181
Lodders, Palme & Gail (2009)	0.7112	0.2735	0.0153	0.0215
Present work	0.7154	0.2703	0.0142	0.0199

[a] The He abundances given in Anders & Grevesse (1989) and Grevesse & Noels (1993) have here been replaced with the current best estimate from helioseismology (Sect. 3.9).

Table 2. Transformation of [Fe/H] to [Z] using [Y] = 0.23 + 2.25[Z] from Girardi et al. (2000) applied in this work.

[Fe/H]	[Z]	[Fe/H]	[Z]	[Fe/H]	[Z]
−0.729	0.004	−0.030	0.018	+0.253	0.032
−0.525	0.006	+0.019	0.020	+0.288	0.034
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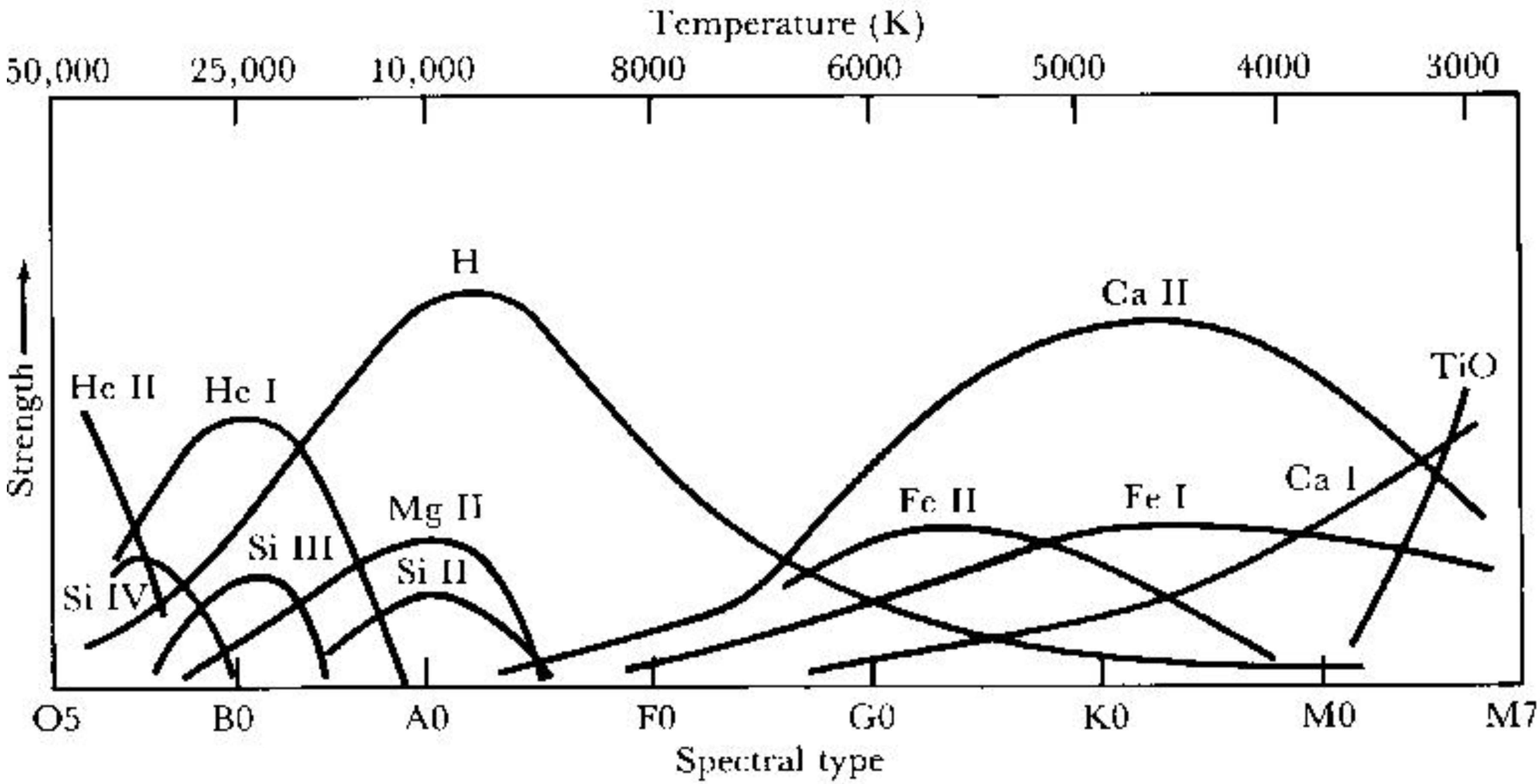
−0.282	0.010	+0.116	0.024	+0.343	0.038
−0.224	0.012	+0.152	0.026	+0.371	0.040
−0.149	0.014	+0.185	0.028		
−0.086	0.016	+0.225	0.030		

Asplund et al.

Determination of the metallicity

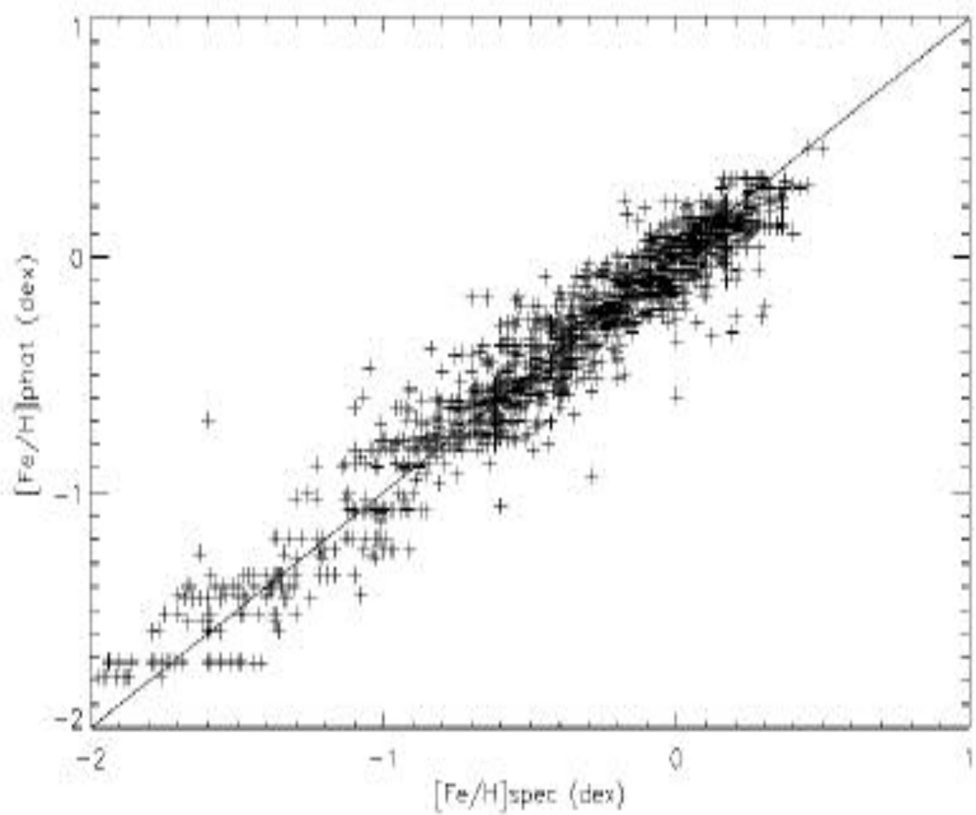
- The determination of the metallicity can be done in three ways:
  1. Spectroscopic abundance analysis
  2. Fitting of isochrones
  3. Photometric calibrations

„Metalls“ in stars



Photometric calibrations

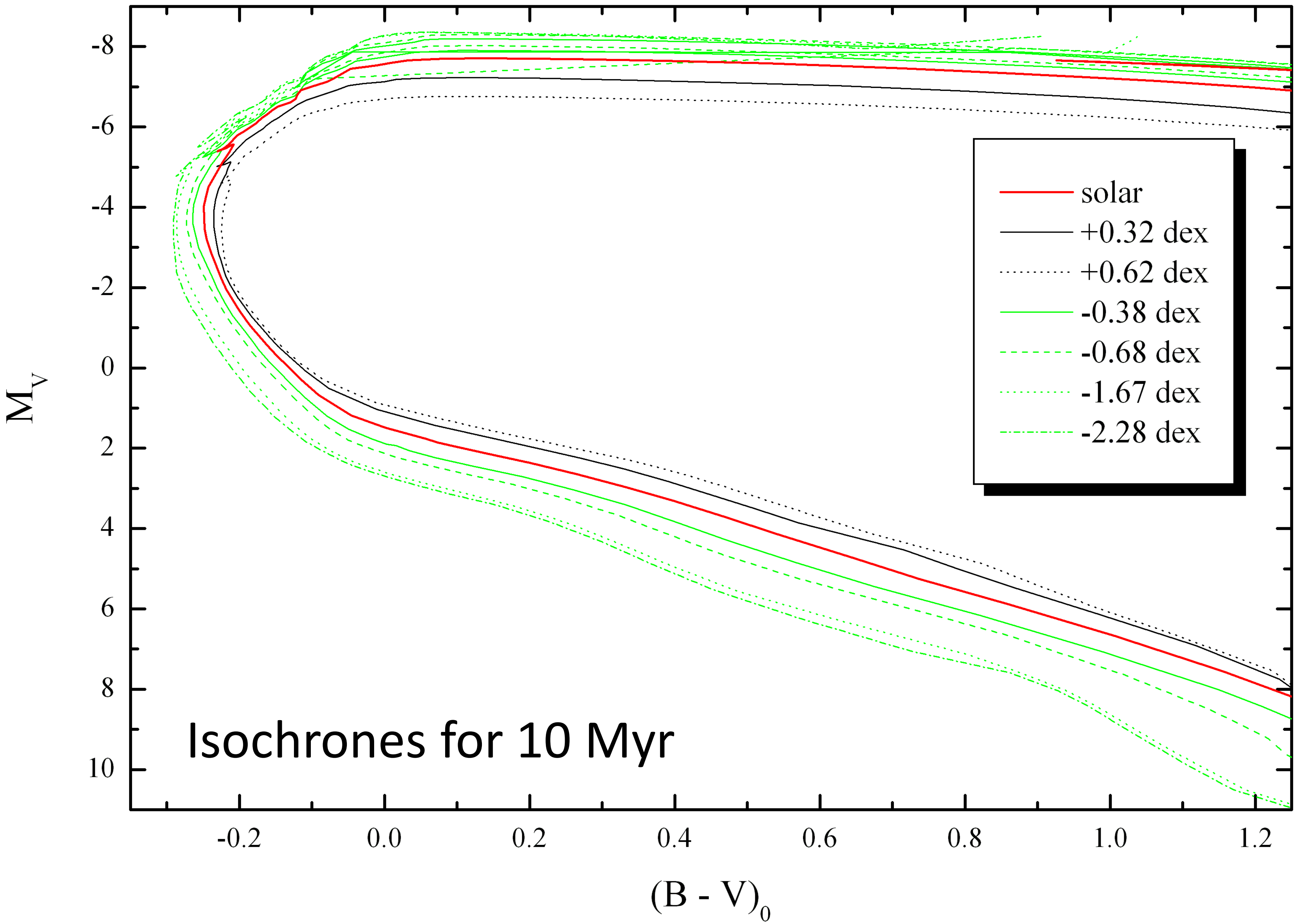
Error: +-0.10 dex

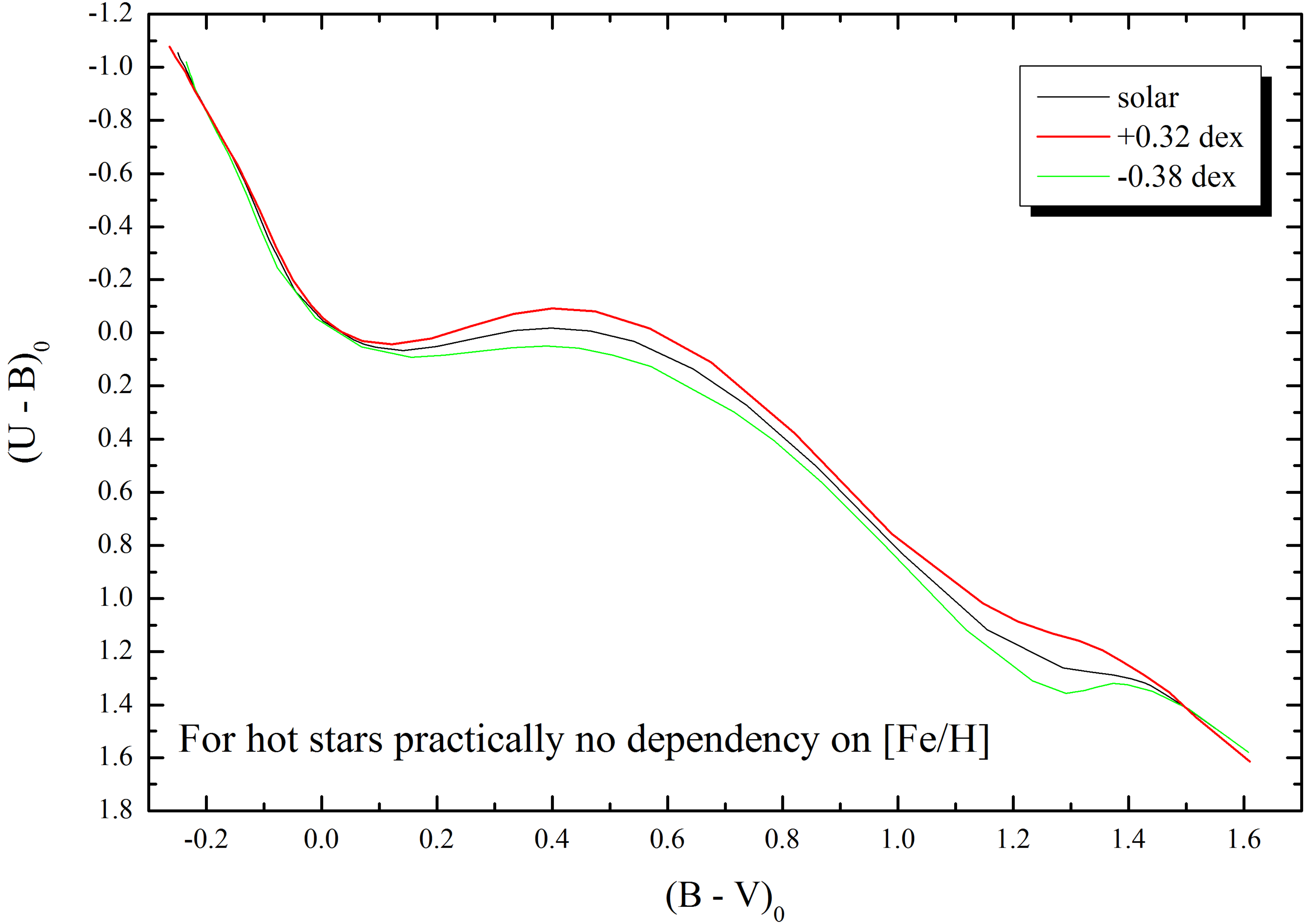


$$
\begin{aligned}
[\mathrm{Fe/H}]_{phot} = & -10.424602 + 31.059003(b-y) \\
& + 42.184476 m_1 + 15.351995 c_1 \\
& - 11.239435(b-y)^2 - 29.218135 m_1^2 \\
& - 11.457610 c_1^2 - 138.92376(b-y)m_1 \\
& - 52.033290(b-y)c_1 + 11.259341 m_1 c_1 \\
& - 46.087731(b-y)^3 + 26.065099 m_1^3 \\
& - 1.1017830 c_1^3 + 138.48588(b-y)^2 m_1 \\
& + 39.012001(b-y)^2 c_1 \\
& + 23.225562 m_1^2(b-y) - 69.146876 m_1^2 c_1 \\
& + 20.456093 c_1^2(b-y) - 3.3302478 c_1^2 m_1 \\
& + 70.168761(b-y) m_1 c_1 .
\end{aligned}
$$

Martell & Laughlin, 2002, ApJ, 577, L45

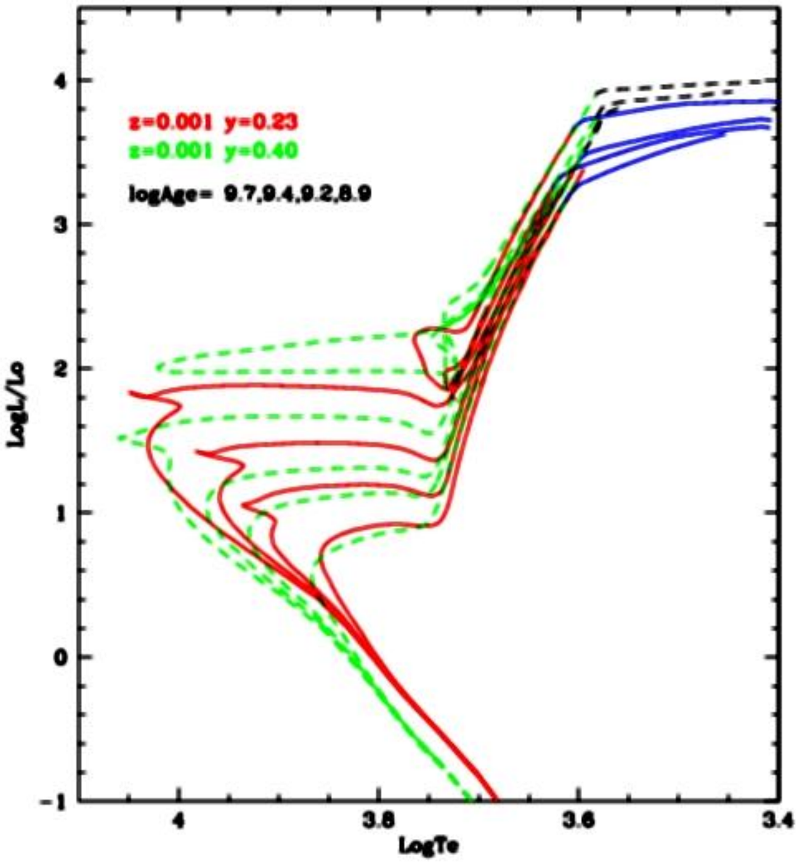
Metallicity => different opacity



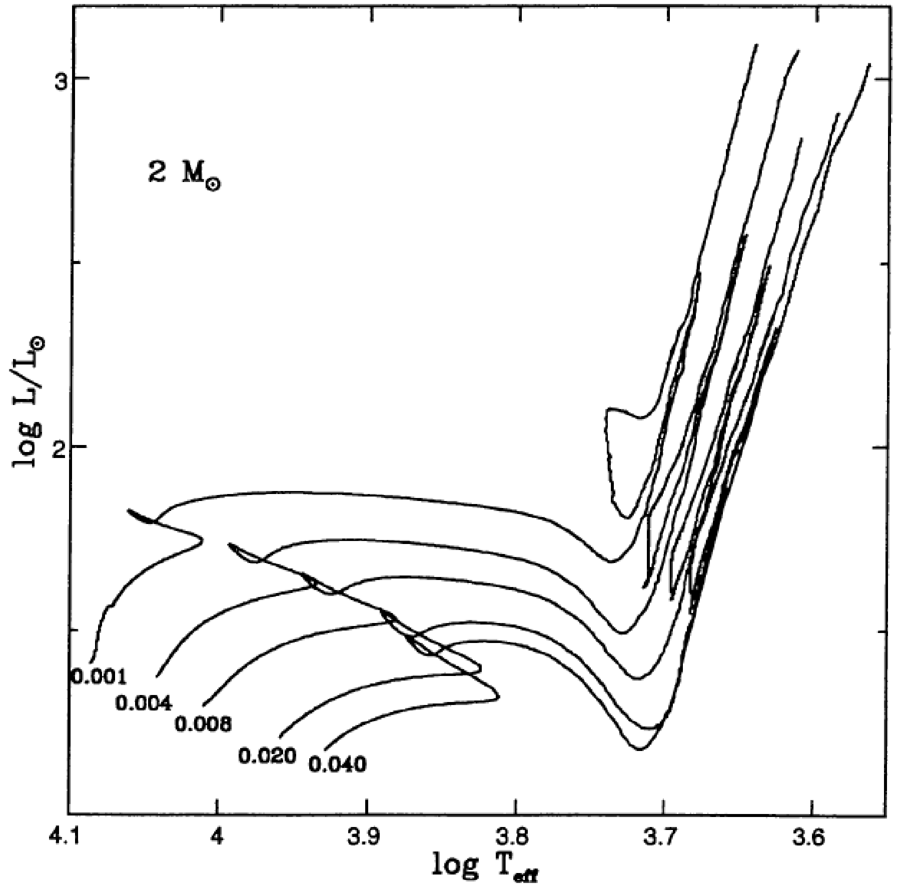


solar
+0.32 dex
-0.38 dex
For hot stars practically no dependency on [Fe/H]
(U - B)0
(B - V)0
-1.2
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

Metallicity - isochrones



Different He abundances – [Z] constant



Schaller et al., 1993, A&AS, 101, 415