DIAGNOSTIC LINE RATIOS

VIII
RVS Workshop
Padova 2004

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Why diagnostic lines are important?

They are probes useful to investigate:

Temperature (T)

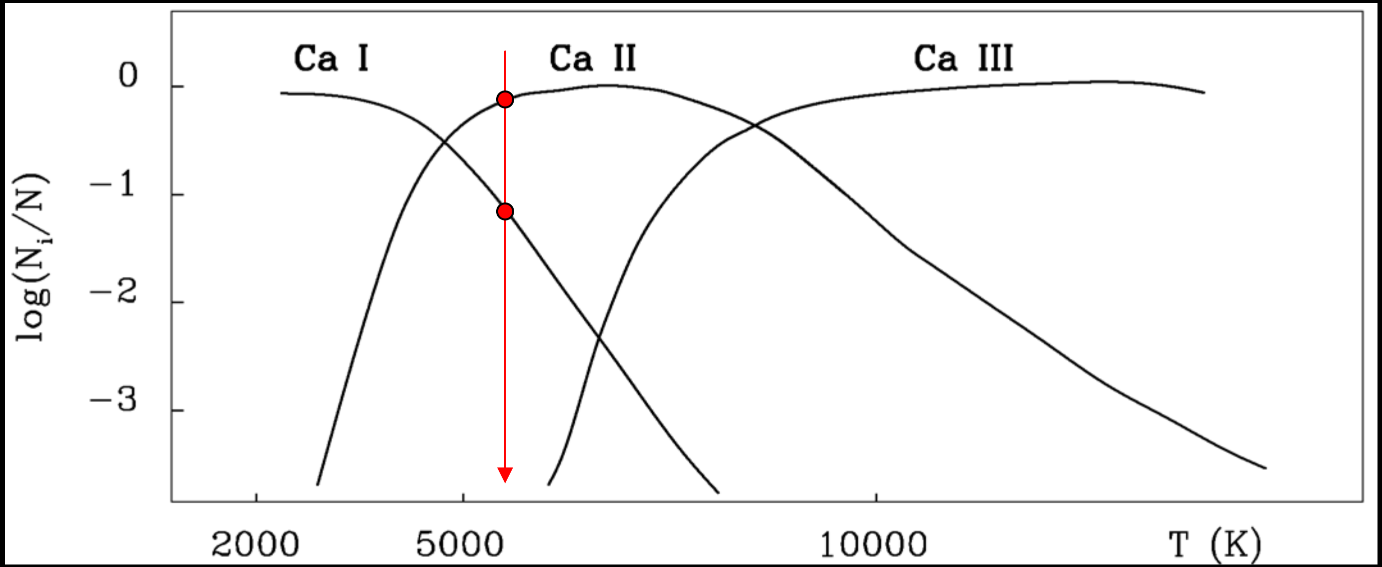
Surface gravity (log g)
Luminosity

CLASSIFICATION (temperature, luminosity)

TEMPERATURE

Best condition: two lines of the same element in two different ionized levels (ex. Ca I and Ca II).

CaI/CaII, Saha equation → Temperature

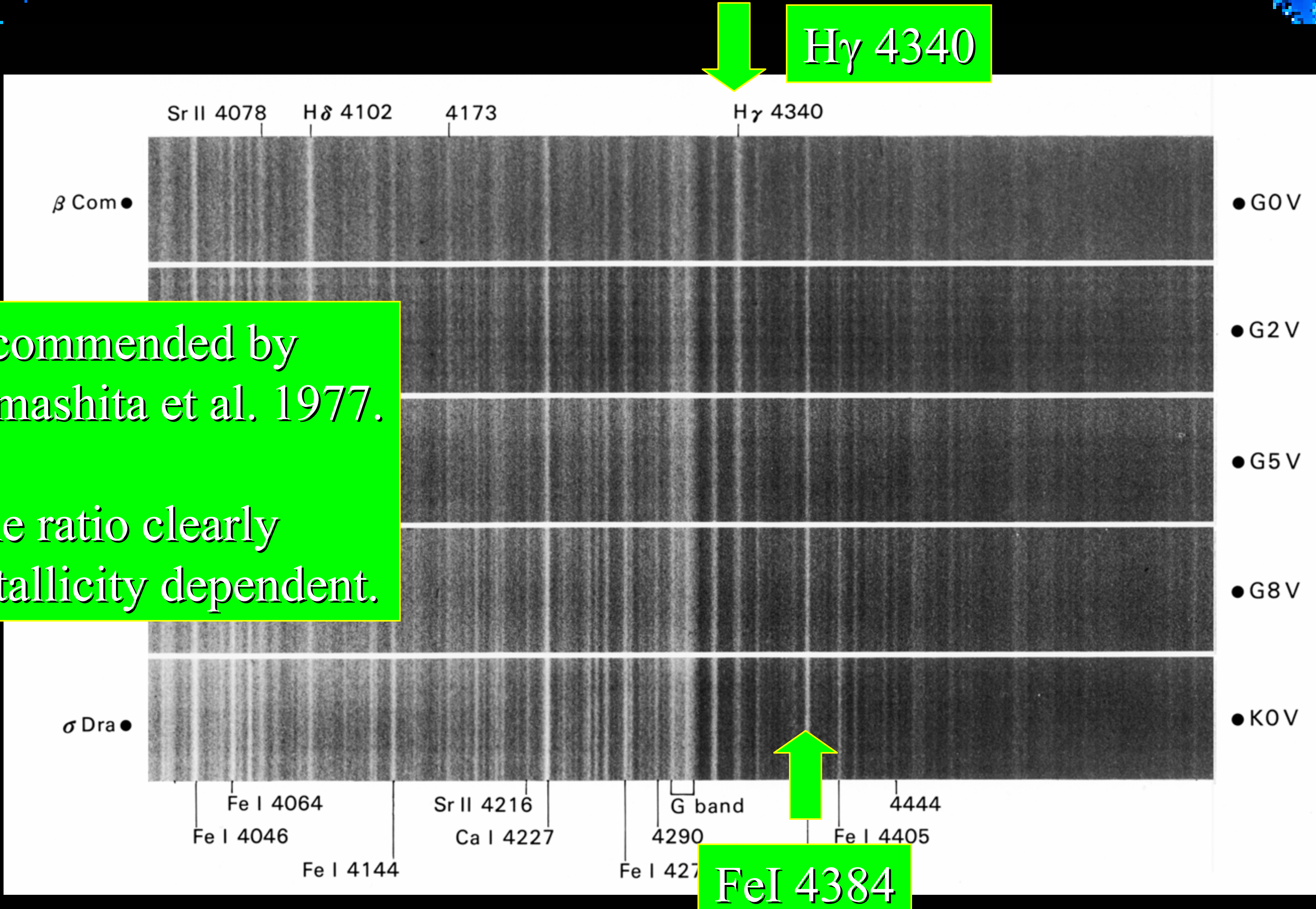


Unfortunately in the GAIA region we can not find two lines with these characteristics.

Temperature is derived from a visual comparison between two lines generally of different elements. The comparison is called *line ratio*.

Similar situation of the *Classical region*: 3600-4800 Å (MK Classif.)

MK CLASSIFICATION
diagnostic line ratios for temperature

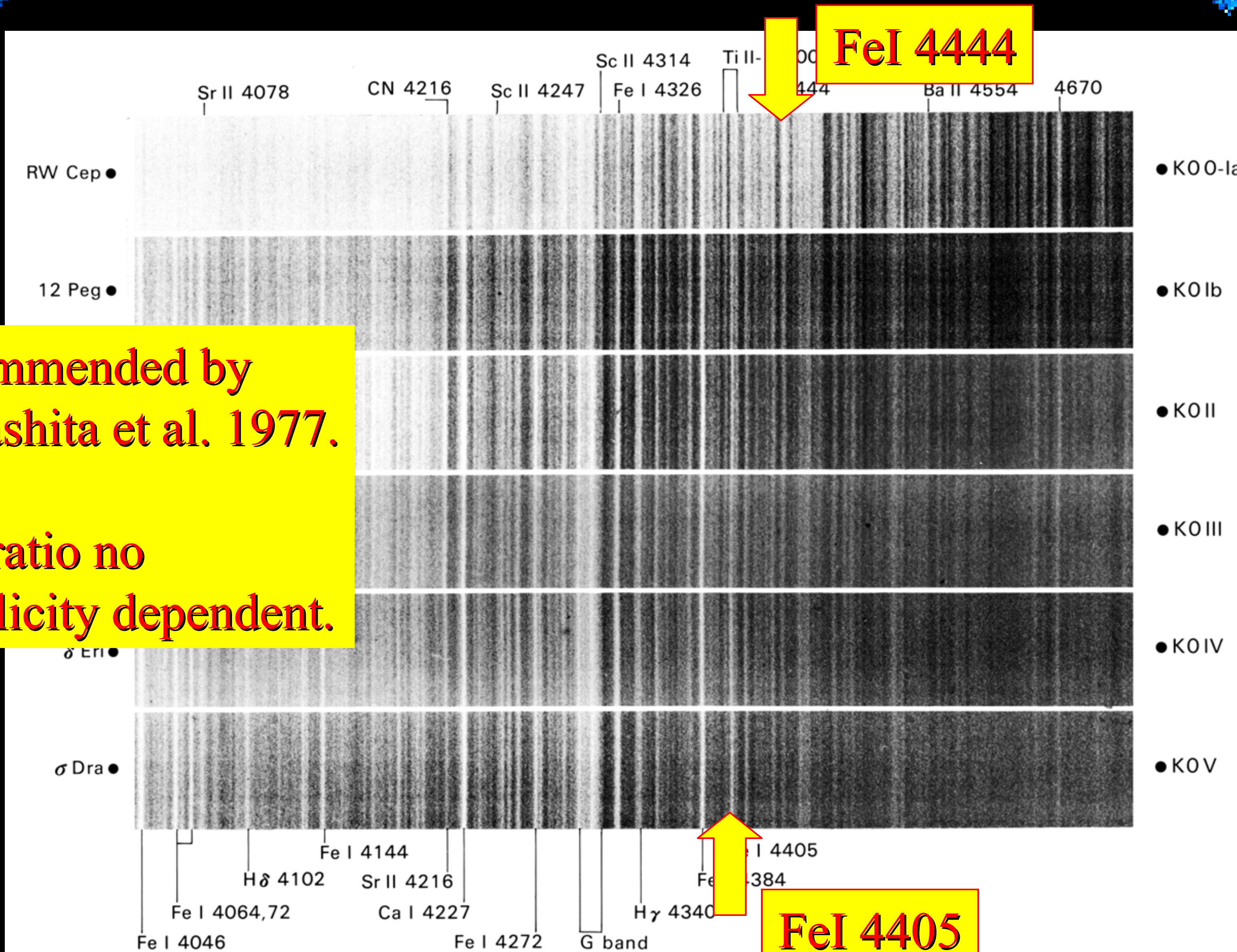


Recommended by Yamashita et al. 1977.

Line ratio clearly metallicity dependent.

MK CLASSIFICATION

diagnostic line ratios for luminosity



Recommended by Yamashita et al. 1977.

Line ratio no metallicity dependent.

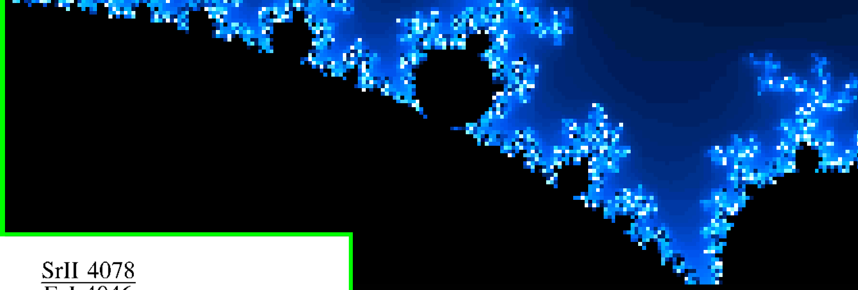
O4-B0	HeII 4542 / HeI 4471		
O7-O9	HeII 4200 / (HeI 4026 + HeI 4144)		
O7-B0	HeII 4686 / HeI 4922		
B0-B0.5	(SiIV 4089 + SiIV 4116) / HeI 4121	HeII 4686 / HeI 4713	
B0-B1	CIII 4068–4070 / HeI 4009	CIII 4647–4651 / HeI 4713	
B0-B2	SiIII 4552 / SiIV 4089		
B1-B5	CII 4267 / MgII 4481		
B3	SiII 4128–4130 / HeI 4121		
B5-B7	CII 4267 / MgII 4481	SiII 4128–4130 / HeI 4144	
B5-A0	SiII 4128–4131 / (HeI 4144 + HeI 4026)	MgII 4481 / HeI 4471	profilo righe di Balmer
B9.5-A5	MnI 4030–4034 / FeI 4271		
A0-A7	MgII 4481 / FeI 4385		
A0-F0	CaII 3934 / (CaII 3968 + HI 3970)		
F0-G0	(FeI 4046 o CaI 4227) / (HI 4102 o HI 4340)	MnI 4030–4034 / SiII 4128–4132	CH4300 / FeI 4385
G0-K0	(FeI 4046 o FeI 4144 o CaI 4227) / HI 4102	FeI 4384 / HI 4340	FeI 4921 / HI 4816
M4-M8	banda CaOH 5500-5600		
M7-M8	bande VO		

Diagnostic line ratios for T_{eff} recommended by Yamashita et al. 1977

A lot of diagnostic line ratios.

Each of them has a very small range of validity.

G0-K0	(FeI 4046 o FeI 4144 o CaI 4227) / HI 4102	FeI 4384 / HI 4340	FeI 4921 / HI 4816



Diagnostic line ratios for log *g* recommended by Yamashita et al. 1977.

O6-O8	HeII 4686 e NIII 4634–4642 in emissione / NIV 3479–3485 in assorbimento				
O9-O9.5	SiIV 4089 / CIII 4068–4070	SiIV 4116 / HeI 4121	CIII 4649 / HeII 4686	HeII 4686 / CIII 4647–4651 + HeI 4713	
B0-B1	SiIV 4119 / HeI 4026,4144,4009	SiIV 4116 / HeI 4121	SiIII 4553 / HeI 4713		
B1	SiIV 408 / HeI 4; OII–CII / HeI 4713				
B2	righe OII e; OII 4415 / HeI 4				
B3	CII 3919 / HeI 3; CII 42 / HeI 4388				
B5-B7	HeI 3965 / HeI 4009; profilo righ				
B7-B8	ali delle ri				
A0-A2	SiII 3856 / CaII 393				
A2-A3	ali delle				
A3-A…	FeII–TiI				

A9-F1	YII 3983 / FeI 4005	FeII–CrII 4002 / FeI 4005	FeII–TiII 4025 / FeI 4005,4046	SrII 4078 / FeI 4046	
	FeII 4179 / FeI 4144	FeII–TiII 4173 / CaI 4227	SrII 4216 / CaI 4227		
F2-F5	YII 3983 / FeI 4005	FeII–CrII 4002 / FeI 4005	FeII–TiII 4025 / FeI 4005,4046	SrII 4078 / FeI 4046	FeII 4179 / FeI 4144
	FeII–TiII 4173 / CaI 4227 + FeI 4144	SrII 4216 / FeI 4144	TiII 4444 / MgII 4481	BaII 4554 / MgII 4481	
F7-F9	YII 3983 / FeI 4005	FeII–TiII 4025 / FeI 4005	SrII 4078 / HI 4102 + FeI4046	FeII 4129,4179 / FeI 4144	
	SrII 4126 + ScII 4247 / FeI 4144	BaII 4554 / MgII 4481			
G0-G2	YII 3983 / FeI 4005	SrII 4078 / HI 4102 + FeI 4046,4064	FeII 4179 / FeII 4173	SrII 4216 / FeI 4144	
G5-G8	SrII 4078 / CaI 4227 + FeI 4046,4064	SrII 4216 / FeI 4144,4272 + CaI4226	TiII 4400,4408 / FeI 4405		
G8-K0	discontinuità di CN a 4216	SrII 4078 / FeI 4046,4064,4072	TiII 4400,4408 / FeI 4405	FeI 4444 / FeI 4405	
K2-K4	discontinuità di CN a 4216	SrII 4078 / …	HI 4012 / …		
K5-M0	… / FeI 4064,4072	… / FeI 4064,4072,4144	… / FeI 4144 + TiI 4186		
M0-M1	SrII 4078 / FeI 4046,4064	HI 4012 / FeI 4144	SrII–FeI 4216 / FeI 4144	FeI 4375,4389 / FeI 4384	
M1-M4	SrII 4078 / FeI 4046,4064,4072,4263	HI 4012 / FeI 4046,4144	SrII–FeI 4216 / FeI 4144,4251	FeI 4375,4389 / FeI 4384	

G8-K0	discontinuità di CN a 4216	SrII 4078 / FeI 4046,4064,4072	TiII 4400,4408 / FeI 4405	FeI 4444 / FeI 4405

MK CLASSIFICATION
the state of the art

- A lot of diagnostic line ratios.
- Small range of validity for each of them.

No numerical relations between diagnostic lines and physical parameters:

"...a line is deeper than the another line..."
"...the line intensity increases with temperature..."

I.
GAIA WAVELENGTH RANGE
8500-8750 Å

ANOVA + SYNTHETIC SPECTRA

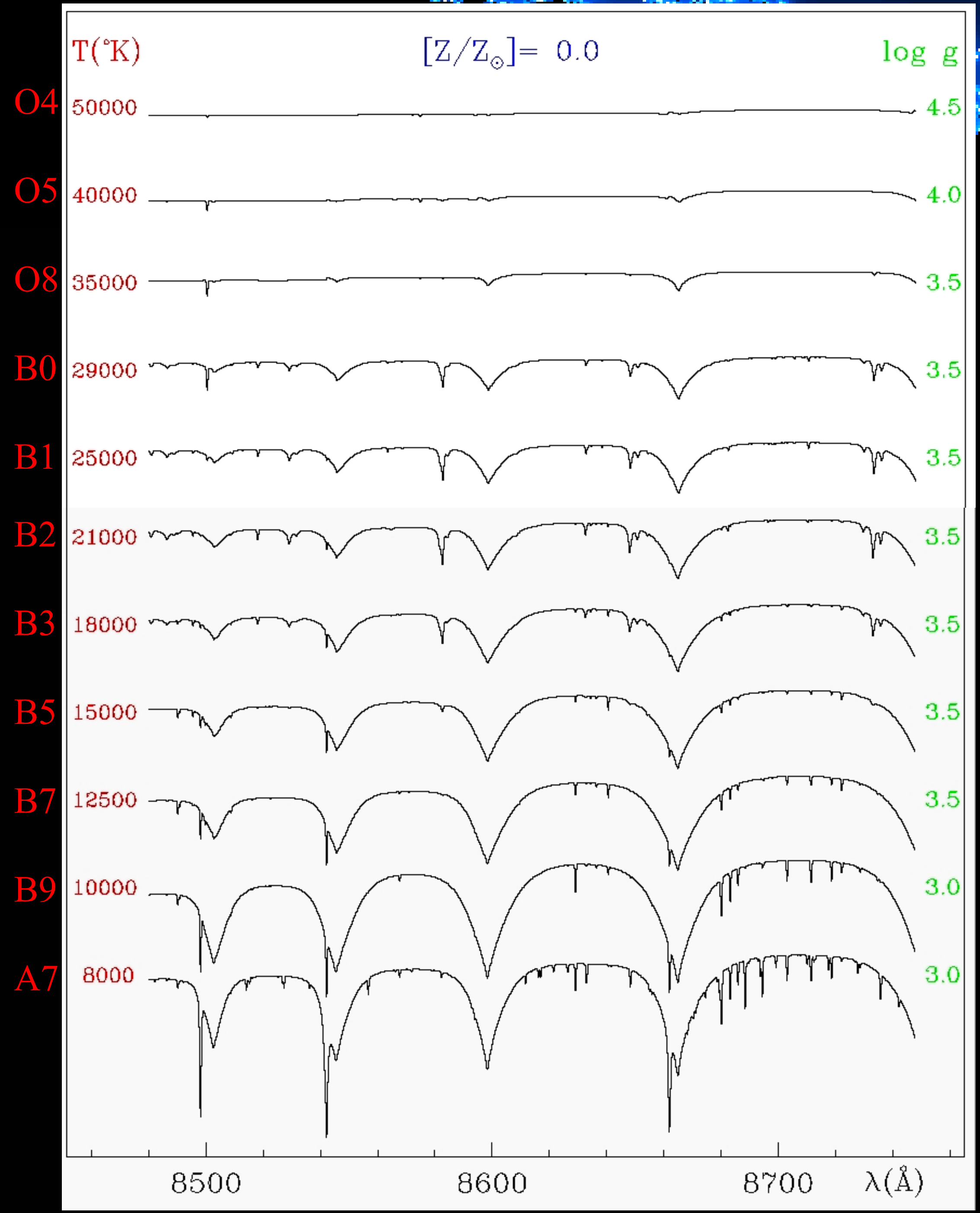
To identify the lines sensitive to the physical parameters (temperature and log g) we used a statistical method ANOVA + Synthetic Kurucz Spectra (solar metallicity).

$$\text{Line depth} = A(T) + B\,(\log g) + AB\,(T, \log g) + W(\text{costant})$$

Behaviour of 170 lines depending on temperature and/or luminosity.

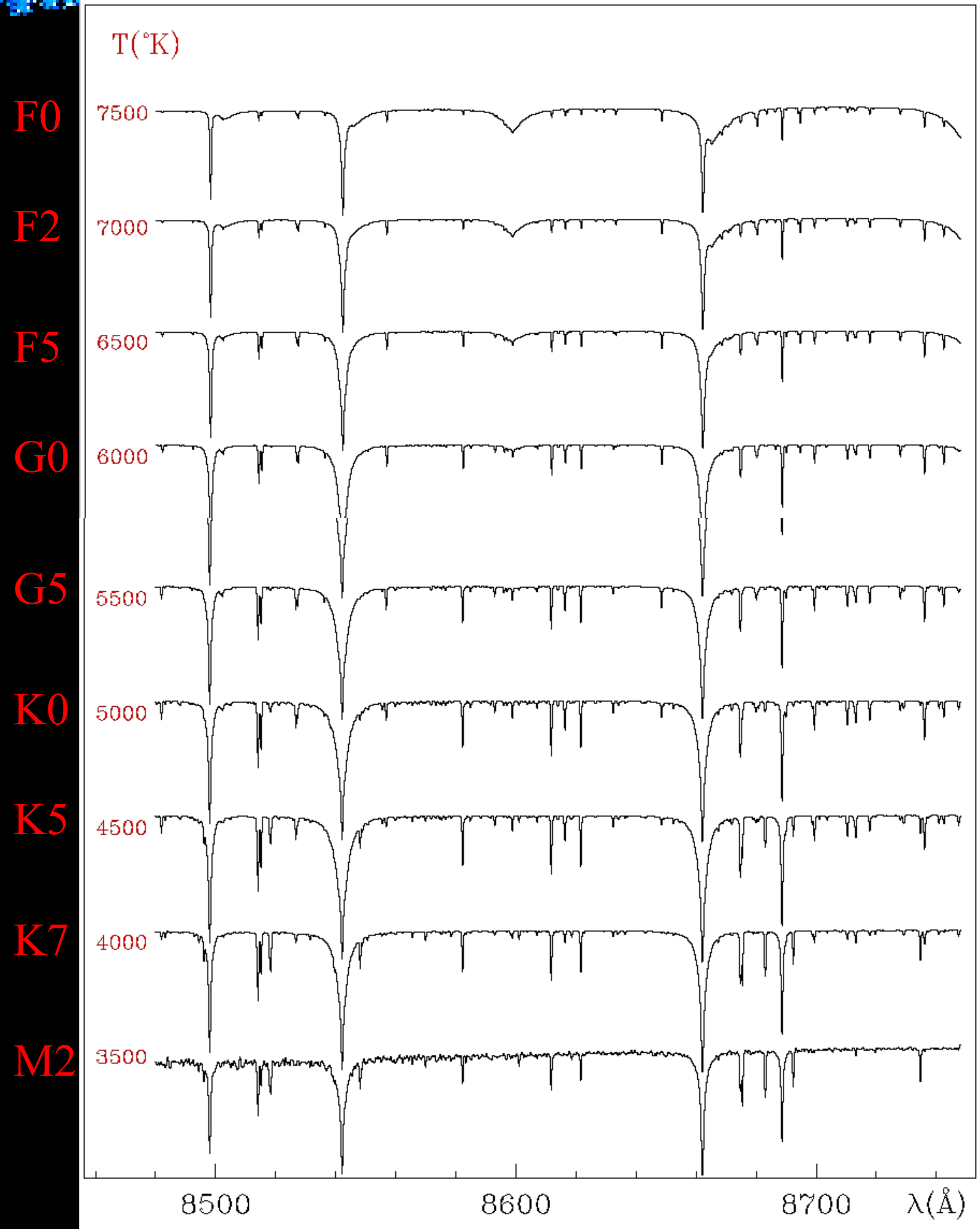
Synthetic spectra in the GAIA region for stars O4-A7.

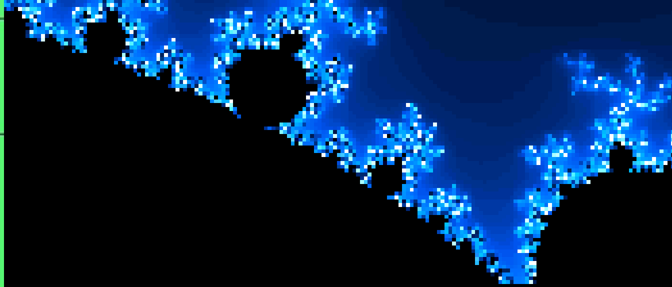
From Castelli & Munari, 2001, A&A 366, 1003 and Zwitter, Castelli & Munari 2004, A&A 417, 1055



Synthetic spectra
in the GAIA region
for stars F0-M2.

From Munari & Castelli,
2000, A&AS 141, 141
and
Zwitter, Castelli & Munari
2004, A&A 417, 1055





n° pix	λ(Å) □	ID	n° mult.	thesis	A ■	B □	AB	W
5859	8601.052	FeI			0.2302	0.0905	0.0376	0.0145
5859	8601.079	TiI			0.2302	0.0905	0.0376	0.0145
6507	8713.187	FeI	400/1267	g	0.2423	0.0233	0.0710	0.0092
6507	8713.210	FeI			0.2423	0.0233	0.0710	0.0092
6249	8668.440	SI			0.2457	0.1264	0.0245	0.0128
5534	8545.387	HI	10 (P15)	❶; a	0.2521	0.7051	0.1916	0.0372
5550	8548.098	TiI	150		0.2763	0.2238	0.0307	0.0215
6213	8662.141	CaII	2		0.3064	0.2067	0.0026	0.0116
5829	8595.960	SiI	80		0.3136	0.0893	0.0342	0.0115
5277	8501.544	SiI			0.3432	0.2609	0.1075	0.0182
5374	8517.971	TiI	182		0.3720	0.0485	0.0264	0.0175
5283	8502.487	HI	10 (P16)		0.3754	0.8509	0.1569	0.0394
5284	8502.668	FeI			0.3806	0.7968	0.1566	0.0389
5846	8598.825	FeI	1153		0.4076	0.4968	0.1187	0.0299
5279	8501.799	NiI			0.4220	0.3637	0.1475	0.0234
6630	8734.707	TiI	68	dh	0.4388	0.0125	0.0389	0.0227
6211	8661.898	FeI			0.4585	0.2476	0.0042	0.0166
5836	8597.050	SiI	80		0.4675	0.2109	0.0693	0.0211
5281	8502.219	SiI			0.5009	0.5386	0.1755	0.0296
5357	8515.110	FeI			0.5451	0.0460	0.0369	0.0126
5750	8582.257	FeI	401	e	0.5555	0.0333	0.0458	0.0127
5376	8518.349	TiI	150	❺; b	0.5645	0.0416	0.0230	0.0195
6387	8692.326	TiI	68		0.5821	0.0118	0.0417	0.0203
6286	8674.743	FeI	339		0.6130	0.0238	0.0420	0.0133
6230	8665.022	HI	9 (P13)		0.6274	0.5752	0.1553	0.0370
5978	8621.598	FeI	401		0.6374	0.0221	0.0515	0.0129
5921	8611.795	FeI	339		0.6875	0.0308	0.0597	0.0166
6333	8682.988	TiI	68	❷; f	0.8372	0.0170	0.0321	0.0196
5844	8598.396	HI	9 (P14)	❶; a	1.0008	0.6333	0.2313	0.0402
6289	8675.374	TiI	68	❼	1.0124	0.0198	0.0297	0.0207
5351	8514.069	FeI	60	❺; b	1.0297	0.0331	0.0276	0.0174
5842	8598.191	TiI			1.0413	0.5302	0.2349	0.0393
6366	8688.621	FeI	60	❸❹; c	1.6252	0.0006	0.0286	0.0268

RESULTS from ANOVA for temperature

Lines arranged in order of sensitivity to T_{eff} (A coefficient).

The most sensitive lines are FeI, TiI and Paschen lines.

nº pix	λ(Å) □	ID	nº mult.	*thesis*	A □	B ■	AB	W
6317	8680.282	NI	1		0.1297	0.1167	0.0041	0.0064
6318	8680.411	SI			0.1941	0.1172	0.0132	0.0072
6249	8668.440	SI			0.2457	0.1264	0.0245	0.0128
5245	8496.108	TiI			0.1521	0.1338	0.0116	0.0151
5555	8548.877	CrI			0.0667	0.1535	0.0217	0.0124
5247	8496.483	FeI			0.0204	0.1610	0.0145	0.0123
6243	8667.363	FeI			0.1428	0.1892	0.0311	0.0166
6243	8667.380	SiI			0.1428	0.1892	0.0311	0.0166
6213	8662.141	CaII	2		0.3064	0.2067	0.0026	0.0116
5836	8597.050	SiI	80		0.4675	0.2109	0.0693	0.0211
5491	8538.014	FeI			0.0442	0.2153	0.0213	0.0177
5515	8542.091	CaII	2	❶❸; a	0.2142	0.2200	0.0022	0.0096
5550	8548.098	TiI	150		0.2763	0.2238	0.0307	0.0215
5266	8499.606	FeII			0.0410	0.2262	0.0331	0.0157
5492	8538.175	FeI			0.0609	0.2362	0.0232	0.0191
6211	8661.898	FeI			0.4585	0.2476	0.0042	0.0166
5277	8501.544	SiI			0.3432	0.2609	0.1075	0.0182
5250	8496.984	FeI			0.0307	0.2647	0.0269	0.0192
5256	8498.023	CaII	2		0.1679	0.2918	0.0024	0.0122
5498	8539.127	FeI			0.0745	0.2956	0.0268	0.0211
5500	8539.468	TiI			0.1608	0.3420	0.0257	0.0245
5279	8501.799	NiI			0.4220	0.3637	0.1475	0.0234
6222	8663.716	FeI			0.0128	0.3826	0.0379	0.0230
5521	8543.151	SiI			0.1309	0.4149	0.0083	0.0205
5525	8543.734	CrI			0.0602	0.4799	0.0332	0.0254
5846	8598.825	FeI	1153		0.4076	0.4968	0.1187	0.0299
5842	8598.191	TiI			1.0413	0.5302	0.2349	0.0393
5281	8502.219	SiI			0.5009	0.5386	0.1755	0.0296
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5844	8598.396	HI	9 (P14)	❶; a	1.0008	0.6333	0.2313	0.0402
5534	8545.387	HI	10 (P15)	❶; a	0.2521	0.7051	0.1916	0.0372
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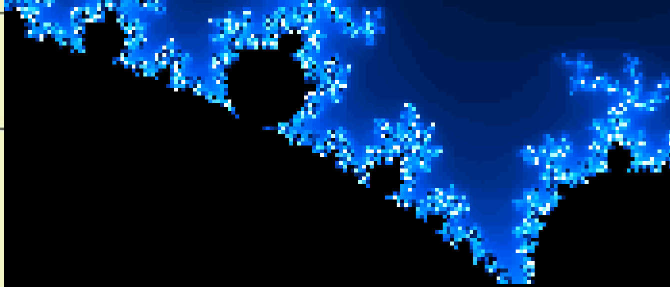


RESULTS from ANOVA for log *g*

Lines arranged in order of sensitivity to log *g* (B coefficient).

The most sensitive lines are Paschen lines, FeI and SiI.

RESULTS FROM ANOVA

We identified the most sensitive lines to T_{eff} and log *g*…

But

Line depth is directly connected to the physical parameters only if the line is optically thin, not for core-saturated lines.

Synthetic spectra can not match the cosmic spread (nature has much more imagination than synthetic spectra!).

Synthetic spectra of cooler, larger stars differ from observed spectra.

II.
GAIA WAVELENGTH RANGE
8500-8750 Å

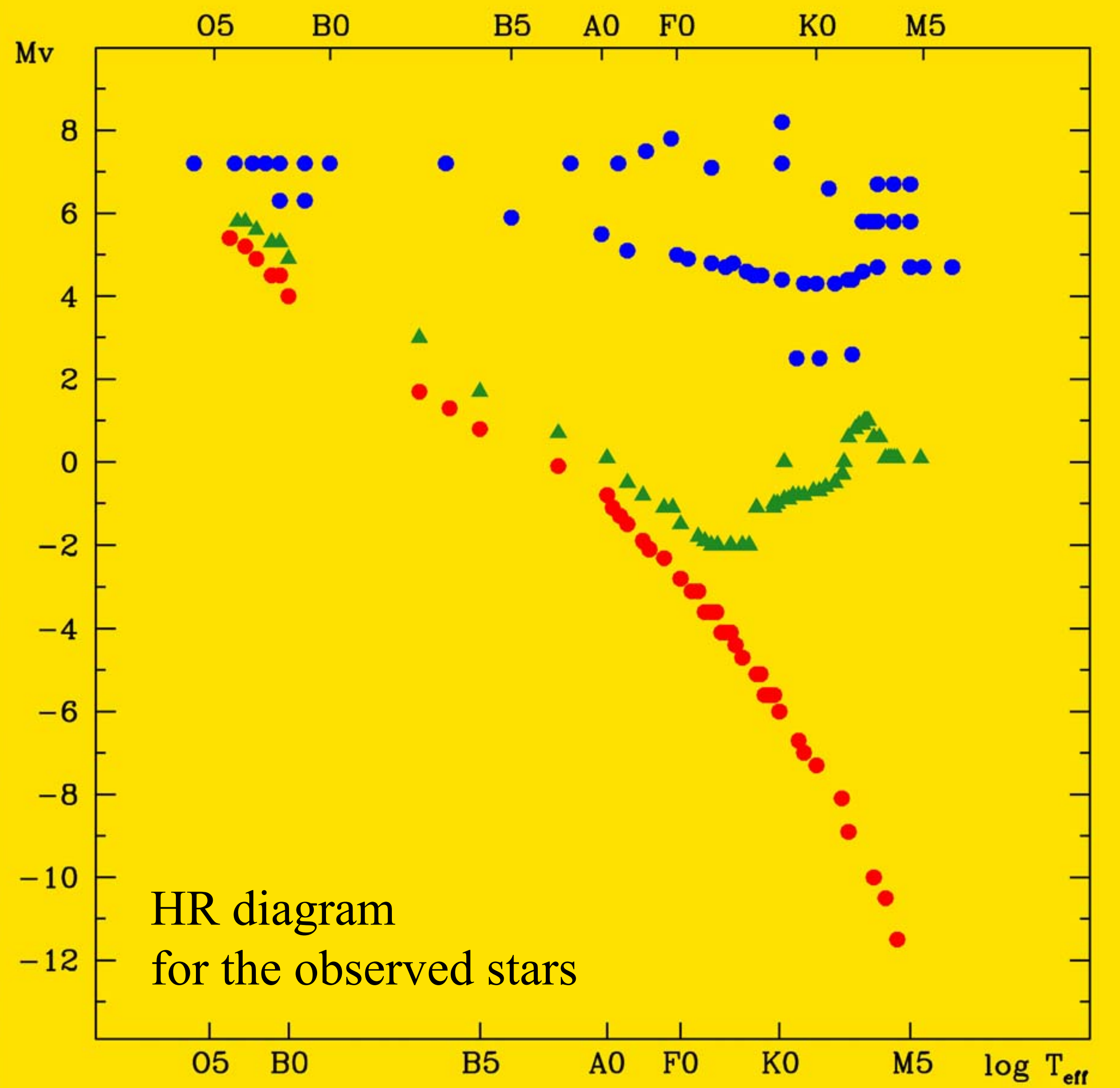
OBSERVED SPECTRA

To identify directly diagnostic line ratios we analized the behaviour of the lines in the observed spectra.

OBSERVED SPECTRA
to take into account the real conditions of the stars.

EQUIVALENT WIDTHS
are more correlated with the physical parameters.

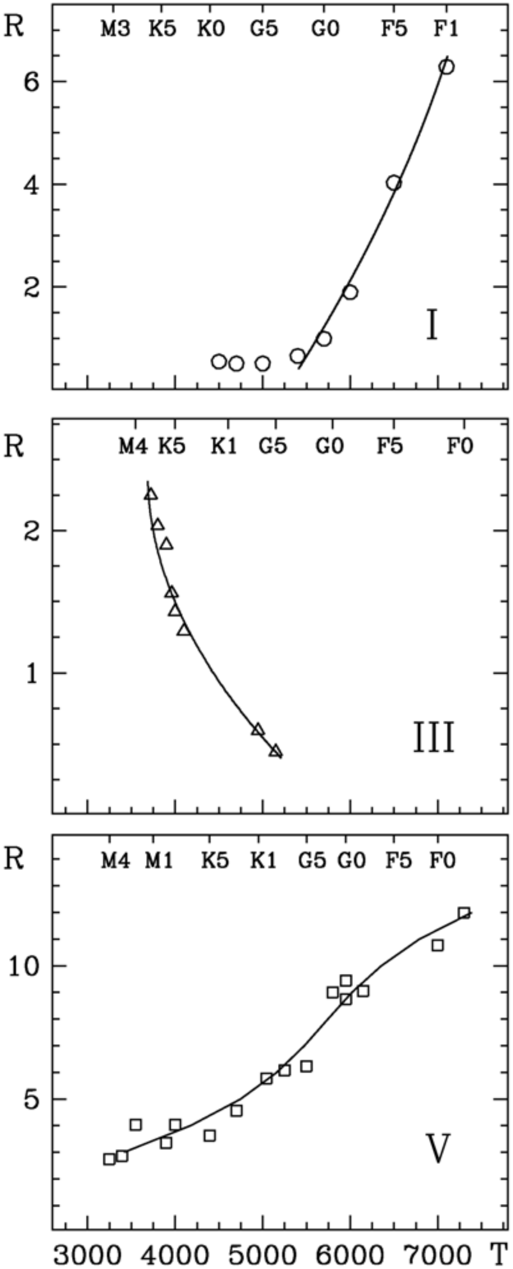
MK STANDARD STARS



We needed a great deal of standard stars observed at resolutions similar to that of the GAIA spectrograph.

222 MK standard stars with the 1.82m of Cima Ekar (Asiago).

Munari & Tomasella, 1999 A&AS, 137, 521
Marrese et al. 2003 A&A, 406, 995



$$R = \frac{\text{Blend } 8680}{\text{FeI } 8675}$$ → FeI 8679.6

$$T = 5257.3 + 380.1\ R + -14.6\ R^2$$

$$R = \frac{\text{TiI } 8683}{\text{Blend } 8680}$$

$$T = 5883.6 - 1826.3\ R + +379.6\ R^2$$

$$R = \frac{\text{CaII } 8542}{\text{FeI } 8688}$$

$$T = -607.8 + 1876.0\ R + -204.0\ R^2 + 8.6\ R^3$$

From Boschi et al. 2003, PASP 303, 535

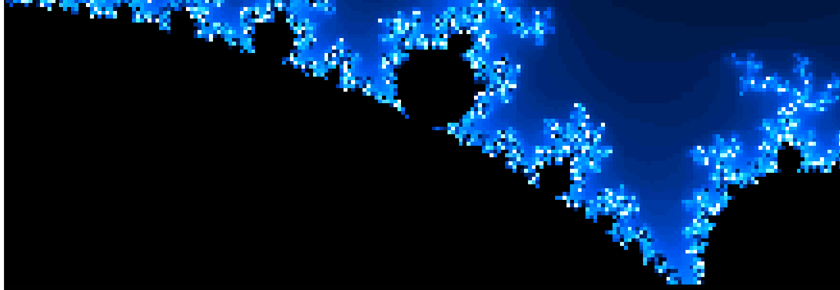
RESULTS FROM OBSERVED SPECTRA for T_{eff}

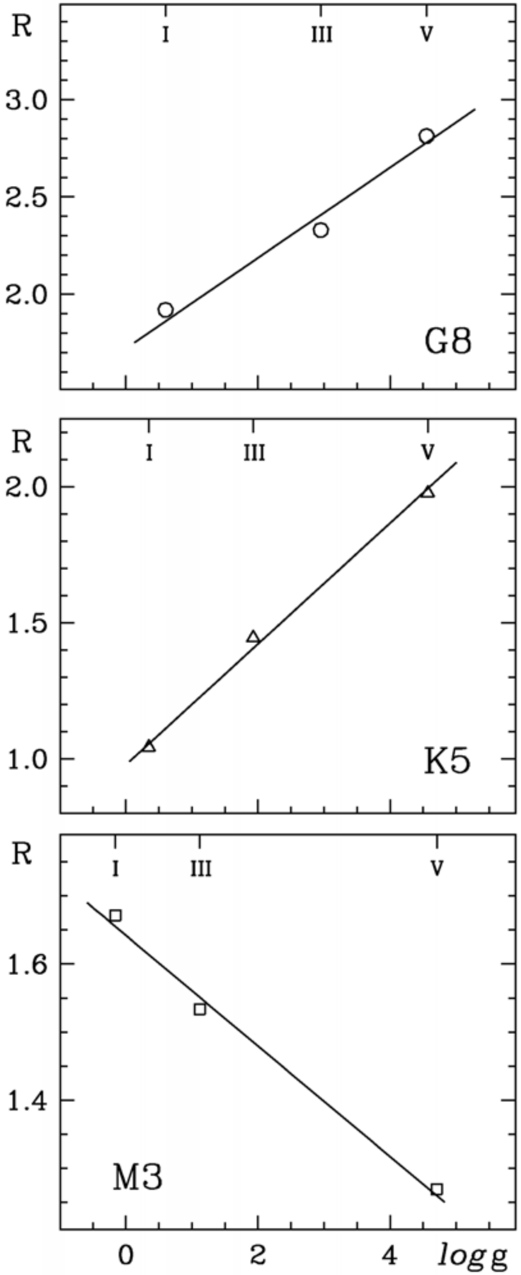
Simple numerical relations between R (ratio of EWs) and T_{eff}.

No/Yes metallicity depend.

GAIA resolution is appropriate

Simulation with blind test gives temperature with error: 70÷200 K.





$$R = \frac{FeI\ 8688}{FeI\ 8675}$$

$$\log g = -7.4 + 4.3\ R$$

$$R = \frac{TiI+MgI\ 8735}{SiI+FeI\ 8728}$$

$$\log g = -4.4 + 4.5\ R$$

$$R = \frac{FeI\ 8514}{TiI\ 8518}$$

$$\log g = 20.2 - 12.3\ R$$

From Boschi et al. 2003, PASP 303, 535

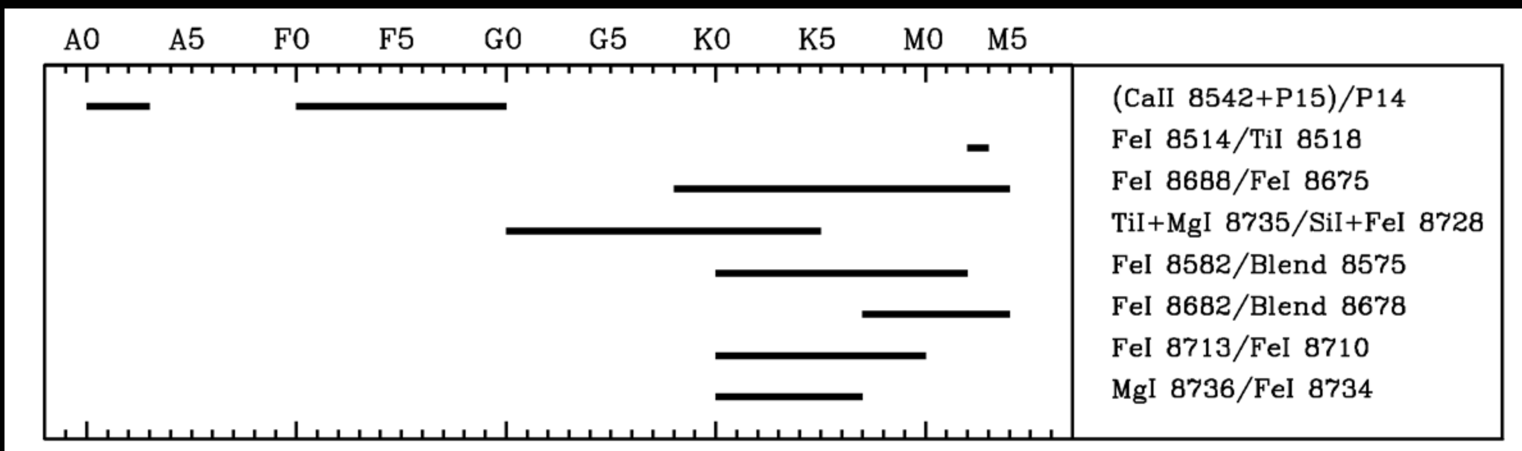
RESULTS FROM OBSERVED SPECTRA for log *g*

Simple Numerical relations between R (EWs ratio and log *g*).

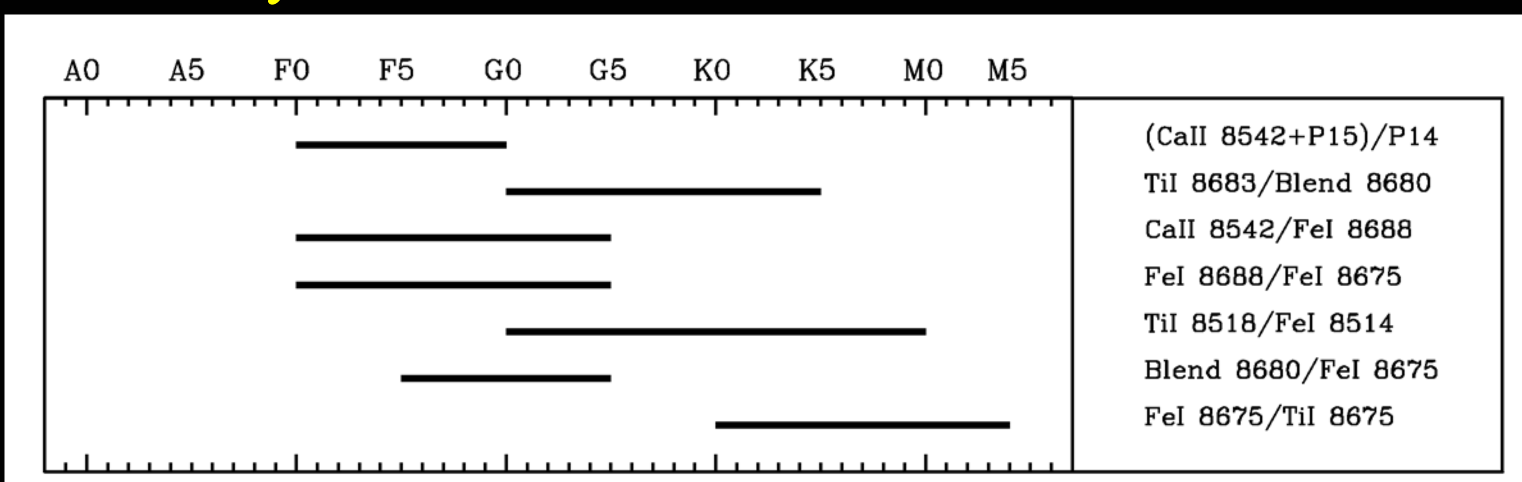
RANGES OF VALIDITY

Temperature

From very small to good ranges. Overlap. Cover entire range.



Luminosity



Summary

Possible line ratios for temperature:

22 relations for supergiants;
14 for giants;
9 for main sequence stars.

Possible line ratios for log g:

identified some line ratios
work in progress.

Diagnostic lines ratios are useful tools:

- To derime cases in which photometry and Kurucz analysis are in disagreement (binary stars in which the companion is undetectable).

- To increase the velocity of the automatic analysis of spectra via Kurucz model (previous information about T and log *g*).


THE END