Spectrum synthesis. Introduction to SIU

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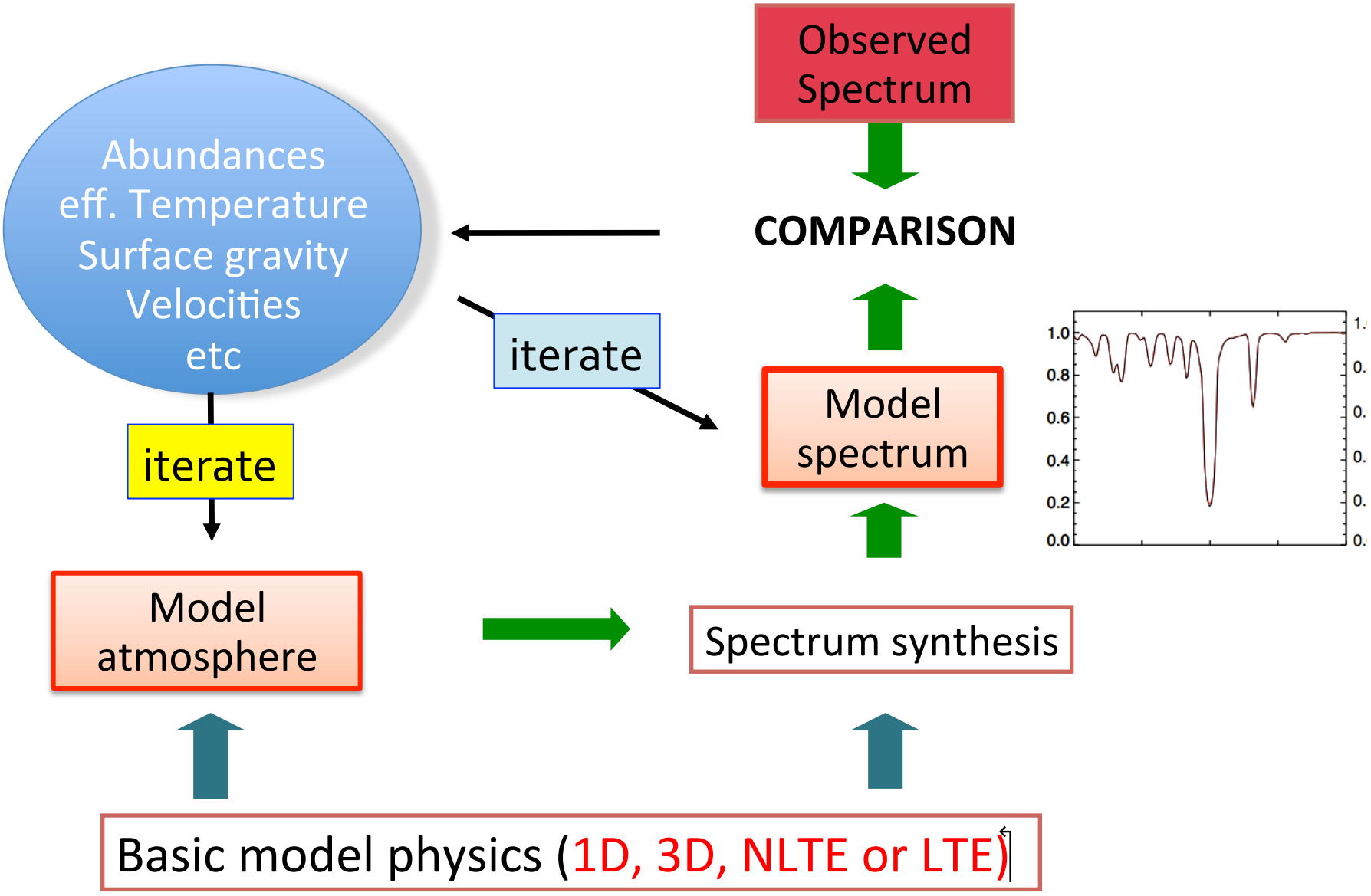
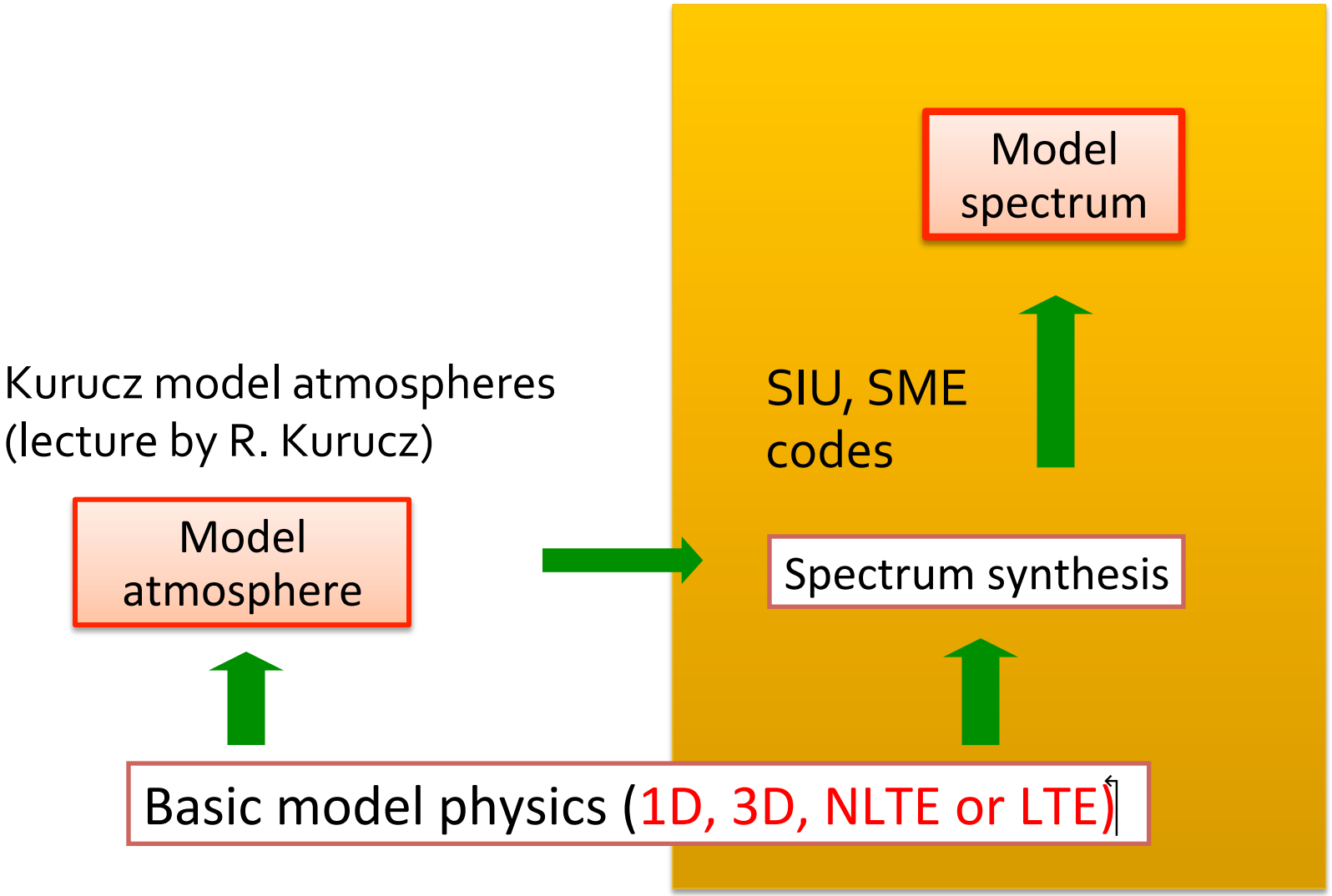
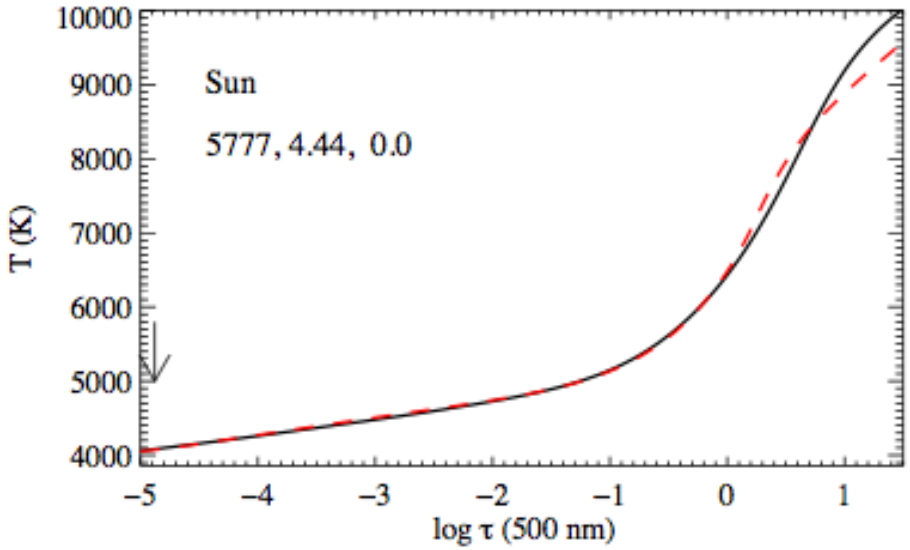
The idea

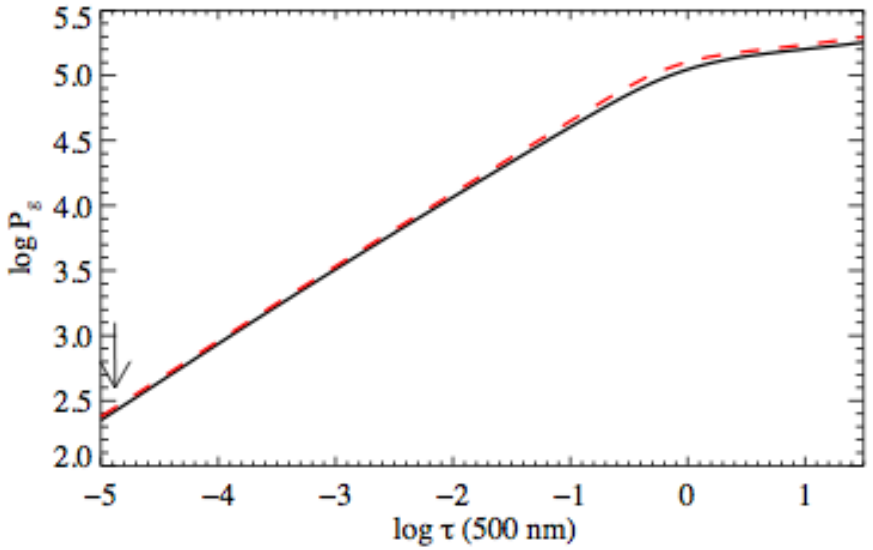

Observed Spectrum
COMPARISON
Abundances
eff. Temperature
Surface gravity
Velocities
etc
iterate
iterate
Model spectrum
Model atmosphere
Spectrum synthesis
Basic model physics (1D, 3D, NLTE or LTE)
1.0
0.8
0.6
0.4
0.2
0.0


Model spectrum
SIU, SME codes
Kurucz model atmospheres (lecture by R. Kurucz)
Model atmosphere
Spectrum synthesis
Basic model physics (1D, 3D, NLTE or LTE)

Model atmosphere

describes the depth-dependence of basic physical quantities: opacity on some reference frequency (optical depth), electron temperature, electron concentration, gas pressure, abundances of different elements





Model atmosphere: Kurucz models

```
 'TEFF   4300.  GRAVITY 1.50000 LTE '
 'TITLE  [0.0] VTURB=1.0 KM/SEC  L/H=1.50 MARCS-OS      ASPLUND ABUNDANCES
' OPACITY IFOP 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 0 0 0 0 0'
' CONVECTION ON   1.50 TURBULENCE OFF  0.00  0.00  0.00  0.00'
'ABUNDANCE SCALE   1.00000 ABUNDANCE CHANGE 1 0.92080 2 0.07837'
' ABUNDANCE CHANGE  3 -10.99  4 -10.66  5  -9.34  6  -3.65  7  -4.26  8  -3.38'
' ABUNDANCE CHANGE  9  -7.48 10  -4.20 11  -5.87 12  -4.51 13  -5.67 14  -4.53'
' ABUNDANCE CHANGE 15  -6.68 16  -4.90 17  -6.54 18  -5.86 19  -6.96 20  -5.73'
' ABUNDANCE CHANGE 21  -8.99 22  -7.14 23  -8.04 24  -6.40 25  -6.65 26  -4.59'
' ABUNDANCE CHANGE 27  -7.12 28  -5.81 29  -7.83 30  -7.44 31  -9.16 32  -8.46'
' ABUNDANCE CHANGE 33  -9.75 34  -8.71 35  -9.48 36  -8.76 37  -9.44 38  -9.12'
' ABUNDANCE CHANGE 39  -9.83 40  -9.45 41 -10.62 42 -10.12 43 -20.00 44 -10.20'
' ABUNDANCE CHANGE 45 -10.92 46 -10.35 47 -11.10 48 -10.27 49 -10.44 50 -10.04'
' ABUNDANCE CHANGE 51 -11.04 52  -9.85 53 -10.53 54  -9.77 55 -10.97 56  -9.87'
' ABUNDANCE CHANGE 57 -10.91 58 -10.46 59 -11.33 60 -10.59 61 -20.00 62 -11.03'
' ABUNDANCE CHANGE 63 -11.52 64 -10.92 65 -11.76 66 -10.90 67 -11.53 68 -11.11'
' ABUNDANCE CHANGE 69 -12.04 70 -10.96 71 -11.98 72 -11.16 73 -12.21 74 -10.93'
' ABUNDANCE CHANGE 75 -11.81 76 -10.59 77 -10.66 78 -10.40 79 -11.03 80 -10.91'
' ABUNDANCE CHANGE 81 -11.14 82 -10.04 83 -11.39 84 -20.00 85 -20.00 86 -20.00'
' ABUNDANC                                                   20.00 92 -12.51'
' ABUNDANC                                                   20.00 98 -20.00'
' ABUNDANC
'READ DECK6 ',dep,' RHOX,T,P,XNE,ABROSS,ACCRAD,VTURB, FLXCNV,VCONV,VELSND'
```

A – abundance of an element, $A = \log N/N_H + 12$

N - total number density of an element

Model atmosphere: Kurucz models

Column mass density m(t)

Gas pressure P(t)

Temperature T(t)

Electron concentration N_e (t)

Depth t

```
READ DECK6  72 RHOX,T,P,XNE,ABROSS,ACCRAD,VTURB,  FLXCNV,VCONV,VEL
 1.11438611E-03   4303.3 1.114E+01 1.188E+09 1.197E-04 5.762E-03
 1.46933430E-03   4325.0 1.469E+01 1.499E+09 1.309E-04 5.781E-03
 1.90642161E-03   4338.1 1.906E+01 1.806E+09 1.404E-04 5.788E-03
 2.44338350E-03   4355.4 2.443E+01 2.200E+09 1.541E-04 5.798E-03
 3.09334096E-03   4372.8 3.093E+01 2.664E+09 1.704E-04 5.816E-03
 3.87393779E-03   4391.0 3.874E+01 3.217E+09 1.900E-04 5.851E-03
 4.80510076E-03   4409.4 4.805E+01 3.867E+09 2.128E-04 5.891E-03
 5.91112062E-03   4428.0 5.911E+01 4.629E+09 2.393E-04 5.939E-03
 7.22091430E-03   4446.5 7.221E+01 5.515E+09 2.698E-04 5.995E-03
 8.76903374E-03   4464.8 8.769E+01 6.544E+09 3.046E-04 6.061E-03
 1.05970558E-02   4482.7 1.060E+02 7.729E+09 3.440E-04 6.141E-03
 1.27556538E-02   4500.1 1.276E+02 9.088E+09 3.885E-04 6.240E-03
 1.53040028E-02   4517.4 1.530E+02 1.066E+10 4.389E-04 6.356E-03
 1.83113451E-02   4534.4 1.831E+02 1.246E+10 4.961E-04 6.489E-03
```

… 72 depth points - t

LTE line formation

- the profile function

$$\psi(\nu-\nu_0)=\phi(\nu-\nu_0)=\frac{H(a,v)}{\sqrt{\pi}\Delta\nu_D} \quad \text{with} \quad a=\frac{\gamma_R+\gamma_3+\gamma_4+\gamma_6}{4\pi\Delta\nu_D} \qquad v=\frac{\nu-\nu_0}{\Delta\nu_D}$$

- line absorption coefficient

$$\kappa_\lambda^l=\frac{\pi e^2}{m_e c}\frac{\lambda}{c}b_i\frac{N_i^{\mathrm{LTE}}}{N_{\mathrm{El}}}N_{\mathrm{H}}\log\varepsilon f_{ij}\frac{H(a,v)}{\Delta\lambda_D}\left(1-\frac{b_j}{b_i}\mathrm{e}^{-hc/\lambda kT}\right)$$

$$\kappa_\lambda=\kappa_\lambda^l+\kappa_\lambda^c,$$

$$S_\nu\equiv\frac{2hc^2}{\lambda^5}\frac{1}{\mathrm{e}^{hc/kT\lambda}-1}=B_\nu$$

line source function, in **LTE** set equal to Planck function

$$I_\lambda(\tau_\nu=0,\mu)=\int_0^\infty S_\lambda(\tau_\lambda)e^{-\tau_\lambda/\mu}d\tau_\lambda/\mu$$

Emergent intensity

$$F_\lambda(0)=2\pi\int_0^\infty S_\lambda(T(\tau_\lambda))E_2(\tau_\lambda)d\tau_\lambda$$

Surface flux

NLTE line formation

$$b_i(\tau_0) = \frac{n_i(\tau_0)}{n_i^*(\tau_0)} \ ,$$

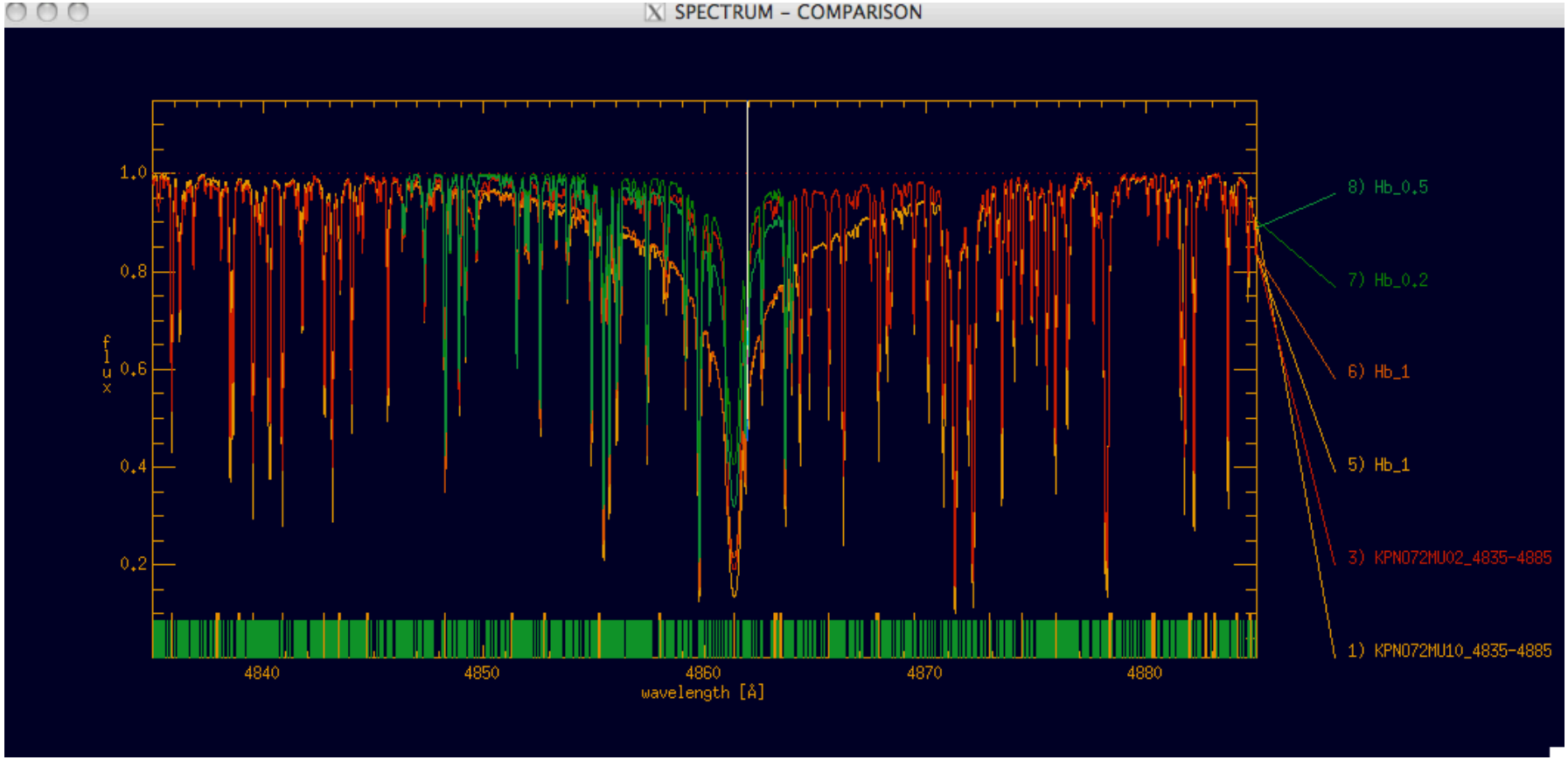
$$\kappa_\nu^l = b_l \kappa^{*l} \frac{1 - \frac{b_u}{b_l} \mathrm{e}^{h\nu/kT}}{1 - \mathrm{e}^{h\nu/kT}} \ .$$

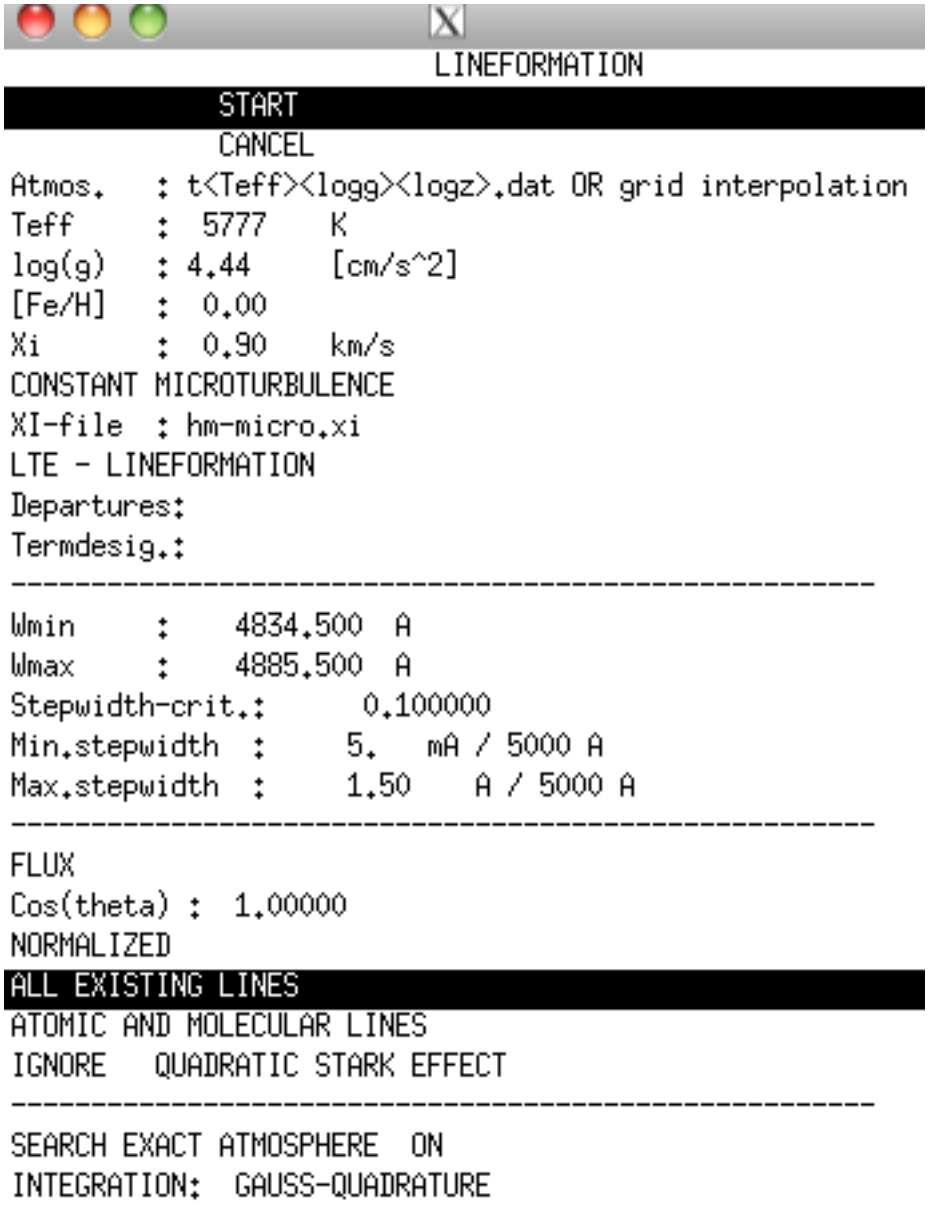
$$S_\lambda = \frac{2h\nu_0^3}{c^2} \frac{1}{\frac{b_l}{b_u} \mathrm{e}^{h\nu_0/kT} - 1} \ .$$

correction to opacity and to the line source function using the **departure coefficients b(t)**

SIU

Spectrum Investigation Utility (Reetz, 1999, PhD)





- define a model atmosphere or provide

T_{eff}

logg

[Fe/H]

Xi: microturbulence

- Min wavelength
- Max wavelength

- Flux or Intensity

$\cos\theta$ = 0..1 (for intensity)

- **Linelist**

LINELIST – atomic data for each line

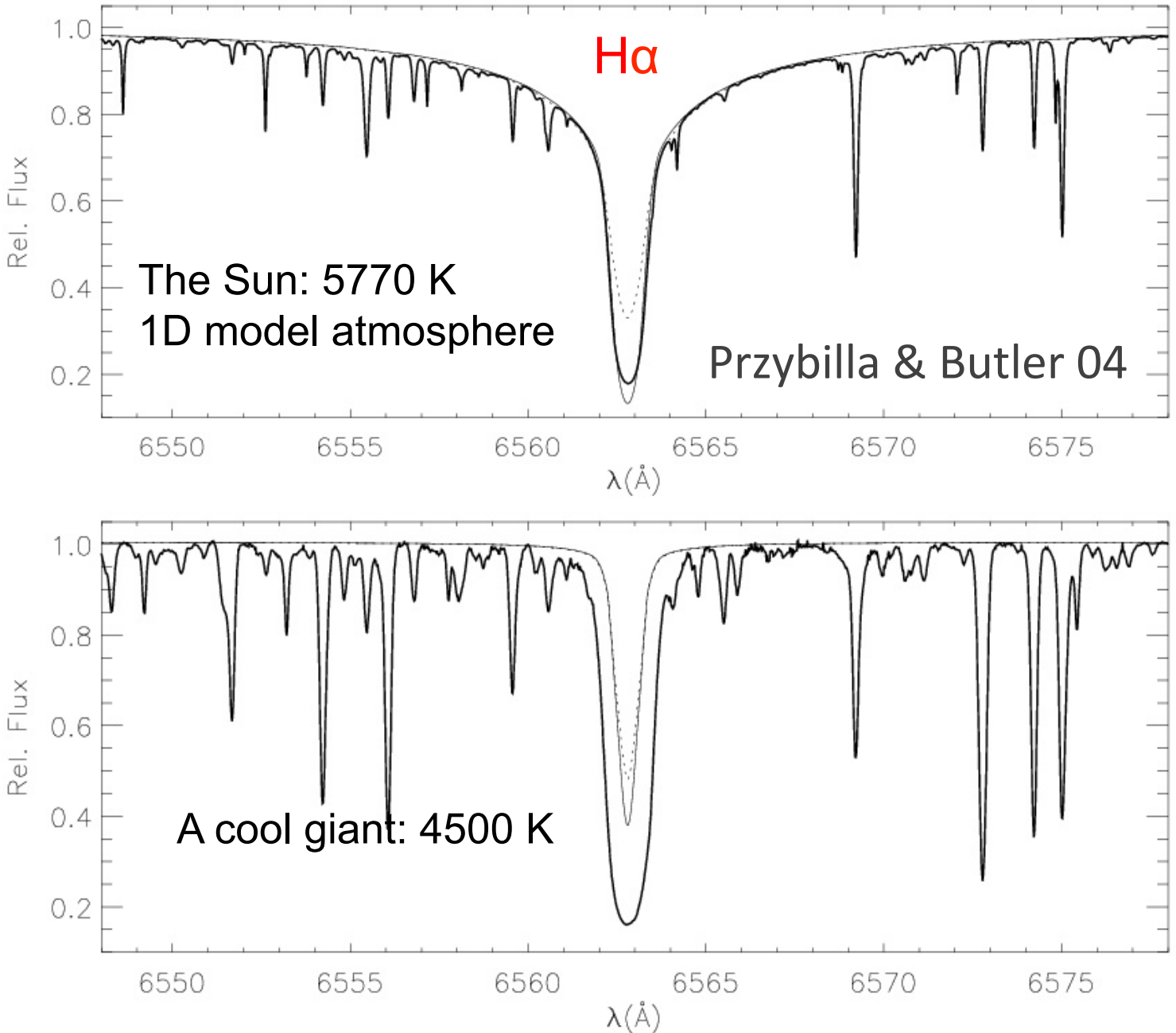
STAT	ION	LAMBDA	MPT	E-LOW	LABU	LABL	JU	JL	DW	GAMRAD	LOG(GF)	GF-REF	LOG(C6)	C6-REF	NEW GF	NEW C6	LOG(C4)
DEL	Mn II	4861.701					10.181	3G 5G(5.0 5.0)	0.20	6.47E+08	-2.412	KUC	-31.652	KUC	0.000	0.000	-14.862
	Cr I	4861.734					3.375	5D 3P(2.0 2.0)	0.20	1.95E+08	-0.398	KUC	-31.936	KUC	0.000	0.000	-15.020
	MgH I	4861.779	24,1		0.206		B,v X,v(0.0 0.0)		0.20	9.40E+07	-3.851	KUC	-32.957	STD	-3.851	0.000	0.000
	MgH I	4861.779	24,1		0.206		B,v X,v(0.0 0.0)		0.20	9.40E+07	-3.914	KUC	-32.957	STD	-3.914	0.000	0.000
	CH I	4861.828	12,1		0.090		B,v X,v(0.0 0.0)		0.20	9.40E+07	-3.805	KUC	-32.526	STD	-4.159	0.000	0.000
	Cr I	4861.845	31		2.530		5F 5G(3.0 4.0)		3.50	3.61E+08	-0.951	KUC	-31.910	KUC	-0.736	0.000	-15.604
	>Fe I	4861.953			4.638		i5D 5P(2.0 1.0)		0.20	2.88E+08	-2.053	KUC	-30.358	UNS	-1.353	0.000	-13.836
DEL	SiH I	4861.964	28,1		0.518		A,v X,v(0.0 0.0)		0.20	9.40E+07	-4.937	KUC	-32.922	STD	0.000	0.000	0.000
	CH I	4861.969	12,1		0.558		A,v X,v(0.0 0.0)		0.20	9.40E+07	-2.700	KUC	-32.608	STD	-3.050	0.000	0.000
	CH I	4862.002	12,1		0.558		A,v X,v(0.0 0.0)		0.20	9.40E+07	-4.680	KUC	-32.[illegible]	STD	-5.030	0.000	0.000
	MgH I	4862.018	24,1		0.868		B,v X,v(0.0 0.0)		0.20	9.40E+07	-2.207	KUC	-32.881	STD	-2.207	0.000	0.000
	MgH I	4862.018	24,1		0.868		B,v X,v(0.0 0.0)		0.20	9.40E+07	-2.247	KUC	-32.881	STD	-2.247	0.000	0.000
	CH I	4862.025	12,1		1.090		B,v X,v(0.0 0.0)		0.20	9.40E+07	-3.782	KUC	-32.526	STD	-4.132	0.000	0.000
DEL	SiH I	4862.043	28,1		0.518		A,v X,v(0.0 0.0)		0.20	9.40E+07	-4.937	KUC	-32.922	STD	0.000	0.000	0.000
	Mn I	4862.050	43		3.840		4P 4P(2.5 1.5)		0.20	8.89E+06	-1.383	KUC	-32.021	KUC	0.000	0.000	-15.487
	Co I	4862.086			4.064		2D 2F(1.5 2.5)		0.20	6.27E+07	-0.901	KUC	-31.516	KUC	0.000	0.000	-14.129
DEL	Ni II	4862.152			12.475		2G(4.5 4.5)		0.20	8.65E+08	-2.413	KUC	-31.738	KUC	0.000	0.000	-14.183
DEL	V I	4862.159			2.865		4H 4F(2.5 1.5)		0.20	1.82E+08	-3.619	KUC	-31.495	KUC	0.[illegible]	0.000	-12.475
	CH I	4862.178	12,1		0.558		A,v X,v(0.0 0.0)		0.20	9.40E+07	-4.780	KUC	-32.608	STD	-5.130	0.000	0.000
	CH I	4862.212	12,1		0.558		A,v X,v(0.0 0.0)		0.20	9.40E+07	-2.662	KUC	-32.608	STD	-3.012	0.000	0.000

CURSOR: (4861.934, 0.18) LINE-POS.: 4861.951 54.62% PLOT DEL UNDEL EDIT SELECT UNSELECT LINFOR

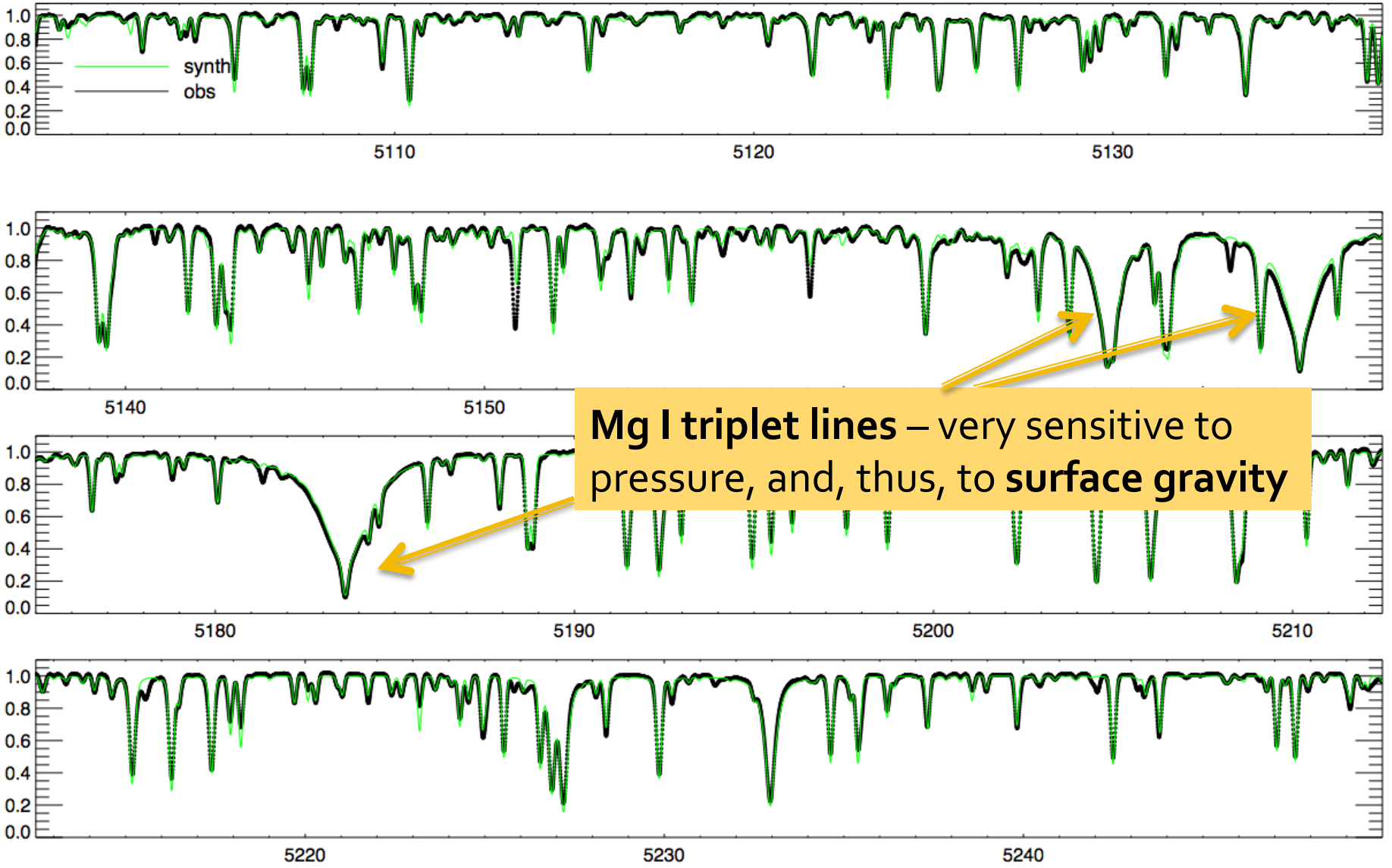
STAT	ION	LAMBDA	MPT	E-LOW	LABU	LABL	JU	JL	DW	GAMRAD
DEL	Mn II	4861.701					10.181	3G 5G(5.0 5.0)	0.20	6.47E+08
	Cr I	4861.734					3.375	5D 3P(2.0 2.0)	0.20	1.95E+08
	MgH I	4861.779	24,1		0.206		B,v X,v(0.0 0.0)		0.20	9.40E+07
	MgH I	4861.779	24,1		0.206		B,v X,v(0.0 0.0)		0.20	9.40E+07
	CH I	4861.828	12,1		0.090		B,v X,v(0.0 0.0)		0.20	9.40E+07
	Cr I	4861.845	31		2.530		5F 5G(3.0 4.0)		3.50	3.61E+08
	>Fe I	4861.953			4.638		i5D 5P(2.0 1.0)		0.20	2.88E+08
DEL	SiH I	4861.964	28,1		0.518		A,v X,v(0.0 0.0)		0.20	9.40E+07
	CH I	4861.969	12,1		0.558		A,v X,v(0.0 0.0)		0.20	9.40E+07
	CH I	4862.002	12,1		0.558		A,v X,v(0.0 0.0)		0.20	9.40E+07
	MgH I	4862.018	24,1		0.868		B,v X,v(0.0 0.0)		0.20	9.40E+07
	MgH I	4862.018	24,1		0.868		B,v X,v(0.0 0.0)		0.20	9.40E+07
	CH I	4862.025	12,1		1.090		B,v X,v(0.0 0.0)		0.20	9.40E+07
DEL	SiH I	4862.043	28,1		0.518		A,v X,v(0.0 0.0)		0.20	9.40E+07
	Mn I	4862.050	43		3.840		4P 4P(2.5 1.5)		0.20	8.89E+06
	Co I	4862.086			4.064		2D 2F(1.5 2.5)		0.20	6.27E+07
DEL	Ni II	4862.152			12.475		2G(4.5 4.5)		0.20	8.65E+08
DEL	V I	4862.159			2.865		4H 4F(2.5 1.5)		0.20	1.82E+08
	CH I	4862.178	12,1		0.558		A,v X,v(0.0 0.0)		0.20	9.40E+07
	CH I	4862.212	12,1		0.558		A,v X,v(0.0 0.0)		0.20	9.40E+07

CURSOR: (4861.934, 0.18) LINE-POS.: 4861.951 54.62% PLOT DE

Hydrogen lines – T_{eff} diagnostics



Mg I lines – **log g** diagnostics



Mg I triplet lines – very sensitive to pressure, and, thus, to **surface gravity**