MODELLING OF LATE TYPE SPECTRA AND ABUNDANCES: NEW OBSERVED DATA AND APPROACHES

Ya.V. Pavlenko[1], J.S. Jenkins[2], H.R.A. Jones[3]

[1] *Main Astronomical Observatory of NASU, Ukraine*
[2] *University of Santyago, Chile*
[3] *University of Hertfordshire, UK*

ABSTRACT. Spectrum of well known solar twins are interested for us in many aspects. We test the use the minimisation procedure to the observed spectrum of the Sun (Kurucz et al. 1996) in the wide spectral region $\lambda\lambda$ 4000 -8700 Å. For the Sun we obtained log N(fe) = -4.40, i.e the reference abundance (Gurtovenko & Kostik 1989), and microturbulence velocity $V_t = 1$ km/s.

Key words: Stars, spectroscopy.

1. Introduction

Studing stars which spectral type pretty close to solar but with a number of differences could help test new analyzing techinques. One of the examples is a work by Willie Soon et al. (1998) who tried gapped wavelet a pproach on studing clustering of surface features on magnetically-active rapidly rotating stars with solar charachteristics in general.

Majority of another research conducted on this and other solar-type stars were focused on itemizing their parameters such as effective temperature, bolometric magnitude, radius, metallicity and color indices using different observational data, photometric and spectroscopic techniques (Glushneva et al 2002). However, the spectrocopic data obtained by instruments allows us to renew existing information to improve our vision of stellar nature through more precise modeling process.

Modern spectrographs (FEROS, HASRPS) provide observational data of the solar quality. New procedures of the data reduction give us the chance to obtain more information of the solar-like stars with the high enough accuracy. However, the amount of the data is huge, traditional methods of the fine analysis of the stellar spectra are too time consumable to be the effective tool managing these data. This topic relates to the many problems of today astrophysics as search planetary systems, chemistry of the solar neighbourhood, chemistry evolution of our Galaxy, etc (see Jenkins et al. 2008, 2009).

The main aim of our work is to test some new approaches developed to get more information from the spectra of solar-like stars using the original minimisation procedure.

2. Observational data

We use Kurucz et al. (1984) spectrum of the Sun. It's worth noting that the atlas contains the low noise, high resolution (R=500000) data. However, some spectral regions are affected by telluric absorption. We excluded these regions from our consideration.

Procedure

2.1 Model atmospheres

We compute plane-parallel model atmospheres of the Sun (5777/4.47) in LTE, with no energy divergence, using the SAM12 program (Pavlenko 2003), which is a modification of ATLAS12 (Kurucz 1993). Chemical equilibrium is computed for molecular species assuming LTE. The opacity sampling approach Sneden et al. (1976) is used to account for absorption of atoms, ions and molecules (see more details in Pavlenko 2003). The 1-D convection mixing length theory modified by Kurucz(1993) in ATLAS12 was used to account for convection. The computed model atmosphere of the solar atmosphere is available ftp://ftp.mao.kiev.ua/pub/users/yp/Results /0.5777.444.ja.

Additionally, we used model atmospheres of the Sun HOLMU (Holveger, Muller 1974) and Kurucz (2010). Comparison of our computed 1D model structures with Kurucz (1993) and HOLMU are shown in Fig. 1.

2.2 Synthetic spectra

Synthetic spectra are computed with the WITA6 program Pavlenko (1997), using the same approximations and opacities as SAM12. To compute synthetic spectra we use line lists from VALD2(Kupka et al. 1999). The shape of each atomic line is determined using the

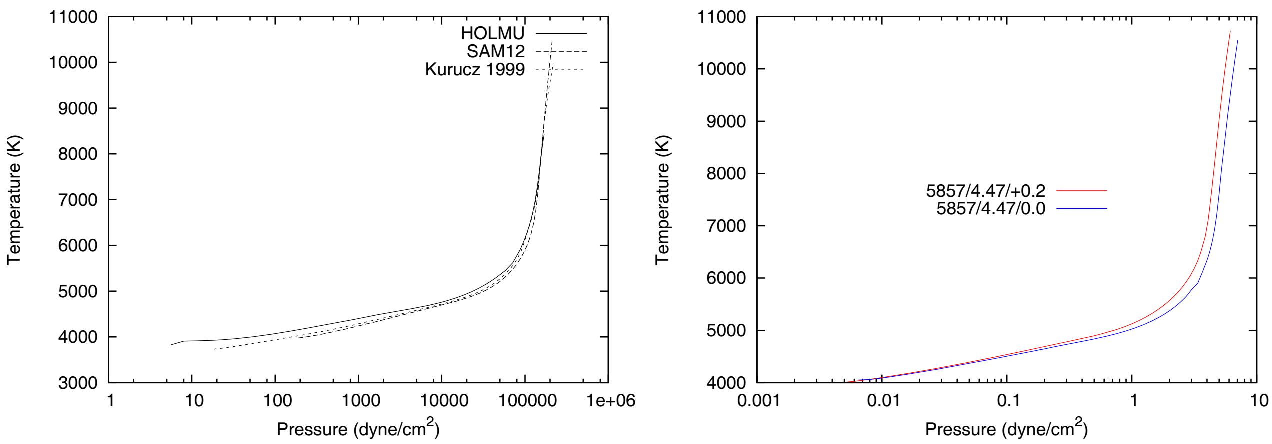

Figure 1: Left: comparison of temperature structures of model atmospheres of the Sun: HOLMU, Kurucz, SAM12. Right: changes of temperature structure of model atmosphere of due to the drop of metallicity by 0.2 dex

Voigt function. Damping constants are taken from line databases, or computed using Unsold's (Unsold, 1955) approach. A wavelength step $\Delta\lambda = 0.025$ Å is employed in the synthetic spectra computations.

It is worth noting that atomic species provide different contribution to the formation of the spectrum of solar-like stars. As example, in Fig. 2 we show a few spectra formed by absorption of a few selected species in the whole spectral region of our interest. Iron lines are dominated across our spectrum.

2.3 Microturbulent velocity

In our computations we determine a microturbulent velocity on the stage of determination of the Fe abundance (see section 3). Afterwards that V_t can be used in the procedure of determination of other elements.

2.. Abundance determination procedures

First of all, we developed our procedure which allows determine a limited number of parameters: V_t , v sin i, abundance Fe(H) from the general fit to the observed spectrum. Absorption of iron dominates in the spectrum, therefore this procedure can be used for estimations of abundances.

From the observed spectral region we choose 11 spectral regions to be used in our analysis. It was done due to the different reasons:

- Synthetic spectra were computed with a fixed step for a limited number of wavelengths points (N=20000).
- We cropped spectral regions of strong telluric absorption.
- In our testing runs we found that a response of spectral regions on abundance variations differs with wavelengths.

Table 1: Spectral region splitting

N	λ_{min}	λ_{max}
1	4000.00	4400.00
2	4400.00	4800.00
3	4800.00	5200.00
4	5200.00	5400.00
5	5400.00	5800.00
6	5800.00	6300.00
7	6300.00	6800.00
8	6800.00	6865.00
9	6940.00	7160.00
10	7300.00	7590.00
11	7800.00	8130.00

In the Table 1 we show the list of our spectral regions.

To determine the best fit parameters, we compare the observed fluxes F_ν with the computed fluxes F_ν^x.

Namely, we find the minima of the 3D function

$$S(f_{\rm s}, f_{\rm h}, f_{\rm v}) = \sum_\nu (F_\nu - F_\nu^x)^2 ,$$

where F_ν and F_ν^x are the observed and computed spectra respectively, and $f_{\rm s}$, $f_{\rm h}$, $f_{\rm v}$ are the wavelength shift, the normalisation factor, and microturbulent velocity, respectively.

The minimisation was done for every adopted abundance, and from the grid of the better solutions we find the log N(Fe) and V_t at min S.

3. Abundance of Fe in atmosphere of the Sun

We determined the iron abundance in the atmosphere of the Sun for model atmospheres shown in Fig. 1.

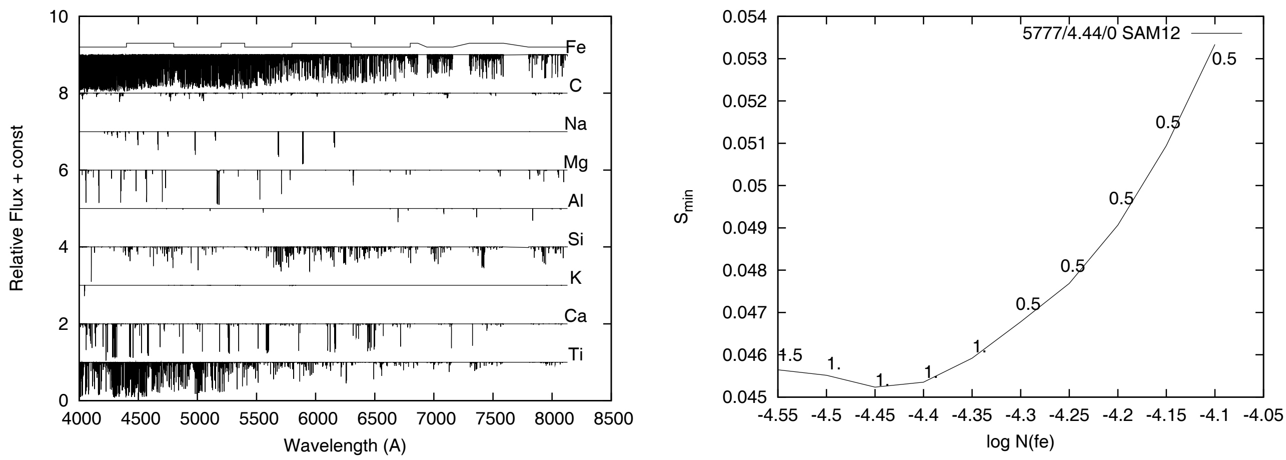

Figure 2: Left: absorption lines of a few atomic species in the theoretical solar spectrum. Computations were carried out for SAM12 model atmosphere and lines from the VALD database. Right: determination of V_t for the SAM12 model atmosphere of T_{eff}=5777 K, log g =4.44.

Table 2: Iron abundance determines for different model atmospheres of the Sun.

Model atm. (K)	Min S	log N(Fe)	V_t (km/s)
The Sun			
HOLMU	0.0465	-4.45	1.5
SAM12	0.0457	-4.50	1.0
Kurucz	0.0452	-4.45	1.0

Our procedure of the iron abundance determination in atmospheres of the Sun and HD1835 was carried out in the following steps:

1. we compute a small grid of synthetic spectra for log N(Fe) from -4.9 with step 0.1 and 5 values of V_t from 0.5 with a step 0.5.

   Only abundance on iron changes other abundances are adopted to be solar.

2. for every computed spectrum S was computed, min S determines a pair of parameters: log N(fe) and V_t .

In Fig. 2 we show the dependence of the computed S_{min} with different V_t on log N(Fe). The found iron abundances for three 1D model atmospheres of the Sun are shown in Table 2.

Theoretical model atmospheres show similar results agreed well with known values of the iron abundance and microturbulent velocity in the solar atmosphere.

4. Conclusions

We obtained a reference solar Fe abundance from analysis of all Fe I and Fe II lines ib the atmodsphere of the Sun. The procedure can be used to determine abundances of other elements in atmospheres of solar twins. However, the procedure shows rather weak dependence of the minimisation factor on the iron abundance. Definitely it can be used in some specific cases:

– we know abundances of other elements in stellar atmosphere. Differences of observed and computed strengths of lines of other elements affect the S value for the element of our interest.

– the procedure does not distinguish lines if different ions of the element of our interest.

– the procedure is sensitive to the level of noise in the observed spectrum. In this paper we used well calibrated solar spectrum. Stellar spectra in most cases are more noisy.

However, the procedure works well for the determination of microturbulent velocity in stellar atmospheres. To determine V_t we use information about strong and weak lines which show different sensitivity on the parameter.

Now we develop new procedure of the automatic analyses of stellar spectra which separately analyses lines of different ions.

Acknowledgements. The work was partially supported by the Program of Comomicrophysics of NASU of Ukraine and PF7 Program Rocky Planets around cool stars (ROPACS PITN-GA-2008-213646).

6. References

Gurtovenko E.A., Kostik R.I. 1989, Fraunhofer spectrum and solar system of oscillator strengths, *Kiev, Naukova dumka*, 1

Jenkins J. S., Jones H.R.A., Pavlenko Y., Pinfield D.J., Barnes J.R., Lyubchik Y., 2008, *A&A*, **485**, 571.

Jenkins J. S.; Ramsey L. W., Jones H. R. A.,

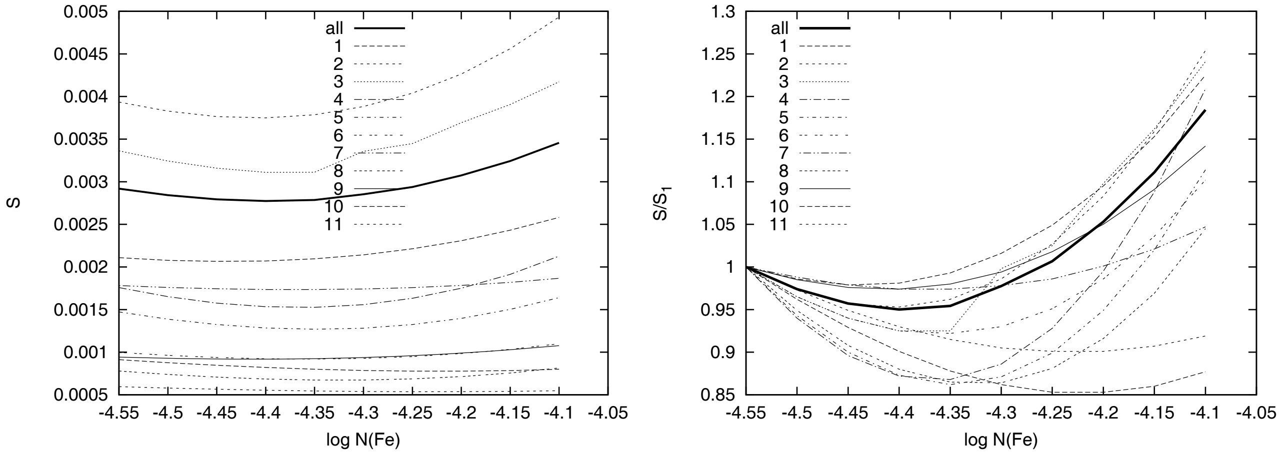

Figure 3: Left: dependence of S on log N(Fe) computed for different spectral regions from the Table 1. Right: the same dependences shown in normalised S, i.e S=1 in the first point of the abundance grid.

Pavlenko Y., Gallardo J., Barnes J. R., Pinfield D. J. 2009, *ApJ*, **704**, 975.

Glushneva I. N., Shenavrin V. I., Roshchina I. A. 2002, *A&AT*, *21*, 317.

Holweger H., Muller E.A. 1974, *Solar Phys.*, **39**, 19.

Kupka F., Piskunov N., Ryabchikova T.A., Stempels H.C., Weiss W.W,. 1999. *Astron. Astrophys. Suppl.*, **138**, 119.

Kurucz R.L. 1993, in "Peculiar versus Normal Phenomena in A-type and Related Stars", eds. M.M. Dworetsky, F. Castelli, and R. Faraggiana, A.S.P. Conference Series vol. **44**, 87.

Kurucz R. L., Furenlid I., Brault J., Testerman L. 1984, Solar flux atlas from 296 to 1300 nm, *National Solar Observatory Atlas, Sunspot,* New Mexico: National Solar Observatory, 198

Pavlenko Ya. V. 1997, *Astron. Astrophys. Sci.*, **253**, p. 43

Pavlenko Ya.V. 2003. *Astron. Rept.*, **47**, 59.

Sneden C., Johnson H.R., Krupp B.M. 1976, *ApJ*, **204**, 218.

Willie S., Peter F., Sallie B. 1982, 1999, *ApJ*, **510L**, 135.

Unsold A. 1955, *Physics der Sternatmospharen*, Springer: Berlin, 1.