Comparative Magnetic Minima:
Characterizing quiet times in the Sun and stars
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The Ni I lines in the solar spectrum

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Abstract. The stratosphere is the region where the ozone chemistry is important for the balance of energy, and radiation in the near UV plays a fundamental role in the creation and destruction of ozone. However, the radiation in this range of wavelength has not been very well modeled. One of the most important elements, according to its abundance in the solar atmosphere, that contribute to the emission and absorption of radiation in the spectral range between 1900 and 3900 Å, is neutral nickel (Ni I). In this work we improve the atomic model of this element, taking into account 490 lines over the spectrum. We solve these lines in NLTE using the Solar Radiation Physical Modeling (SRPM) program and compare the results with observation of the quiet sun spectrum.

Keywords. radiative transfer, line: profiles, Sun: spectral irradiance

1. Introduction

It is well known that 90 % of the ozone is located and produced in the stratosphere by photodissociation of molecular oxygen by near UV Solar radiation in the Schuman-Runge bands and by ozone photodissociation in the Hartley-Huggins bands (1900 to 3900 Å). A change in the amount of solar radiation reaching this region can affect the production of ozone. Climate changes can be induced by ozone mixing ratio, changes that can affect the biosphere. Changes in ozone affect the amount of solar radiation transmitted through the stratosphere and produce tropospheric effects. Also, these changes affect the amount of biologically harmful radiation reaching the Earth's surface (Brasseur, 1997). For these reasons, there is a need for an accurate calculation of the Solar radiation that reach the top of the Earth atmosphere in the near UV range.

This spectral range has not been well modeled or observed. In order to build a semi-empirical model in the range of interest observations are essential. An important limitation is that observations from ground are difficult because of atmospheric absorption, and observations from space have limited spectral resolution. Also, another problem to obtain a realistic model is the availability of accurate atomic data for NLTE calculation.

Considering its abundance in the solar atmosphere, Ni I is an important species with quite strong lines in this range. A study that computes NLTE populations of this species is the one by Bruls (1993). In this work the author studied the behavior of the Ni I 6769.64 Å line used in MDI on board of SOHO and GONG for observing Doppler velocity and the vector magnetic field. An atomic model with only nineteen levels was built, and the level populations were computed using the model C by Vernazza *et al.* (1981).

To take into account the strong Ni I lines in the near UV range we increased the number of energy levels in the atomic model, and update the atomic data to calculate

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the populations in full NLTE using the latest available semi-empirical models for the Solar atmosphere (Fontenla *et al.* 2011).

In the present work we calculated the Quiet Sun spectrum by these new solar models and compared with observations of several line profiles at various wavelengths.

2. The new Ni I atomic model and spectral synthesis calculations

To carry out the calculations we used the Solar Radiation Physical Modeling code developed by Fontenla *et al.* (2011, and references therein). The code solves the radiative transfer, statistical equilibrium and momentum balance equation, assuming a one dimensional planeparallel atmosphere.

We used the latest semi-empirical models built by Fontenla *et al.* (2011) for features observed on the solar disk. These features were defined by their emitted intensity in Ca II K images taken with Precision Photometric Solar Telescope (PSPT) at Osservatorio Astronomico di Roma (Fontenla *et al.* 2009). The Quiet Sun spectrum was built by weighted averaging the three models listed in Table 1 and intend to reproduce the low solar activity state during 2008-2009.

We built a new Ni I atomic model with 61 energy levels, with the corresponding sublevels. With an energy level we mean the lower energy with the same configuration and term. The atomic data were obtained from NIST atomic spectra database (Ralchenko *et al.* 2011). We selected this number of levels to reproduce most of the near UV lines and strong visible lines present in the Solar spectrum. The populations for the different neutral atoms and ions were calculated in full NLTE. The atomic species taken into account were that from Table 2 in Fontenla *et al.* (2011), and the only change included was the new Ni I atomic model that increased the number of energy levels from 10 to 61.

The observations we used to compare our results are irradiance observations in the spectral range from 1969 to 3100 Å by Hall & Anderson (1991) and Anderson & Hall (1989). These observations are stratospheric balloon measurements, with all the complications to calibrate them correctly because of the atmospheric absorption. For this reason, these observations are here scaled so that the continuum matches the values in the calculated spectra. For comparison with these data the synthetic line profiles were convolved with a Gaussian function to simulate the resolution of the observations.

For comparing lines in the visible spectra, from 3290 to 7000 Å, we use the FTS Solar Atlas by Brault & Neckel (1999). These observations show the solar intensity at disk center obtained at the Kitt Peak Observatory and were calibrated in absolute units by a correction procedure whose accuracy may be questioned. More reliable absolute calibration exists for the Thuilliet *et al.* (2003), and the Harder *et al.* (2010) data. However, these data has much lower spectral resolution.

Figure 1 shows a comparison between several line profiles along the spectra with increasing wavelength. With solid lines we indicate our calculation, with dashed lines the spectra calculated by Fontenla *et al.* (2011) present only in the visible lines, and with doted lines the observations. The differences between the two synthetic profiles are in the NLTE calculations. In our case the populations were calculated in full NLTE with 61 levels. The spectra calculated by Fontenla *et al.* (2011) considered NLTE calculation only for 10 levels, and then they approximated the departure coefficients of the rest of the levels with the value obtained for the last level calculated in NLTE.

The figure shows a better agreement between our synthetic line profiles and the observed ones. It is important to note that several of these lines are quite strong, especially those within the range of interest shown in the first four panels. The last panel shows the Ni I 6769.64 Å line used in MDI on board of SOHO and GONG observations.

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Table 1. Quiet Sun feature components and their respective models. We follow the feature and model index designations as in Fontenla *et al.* (2011)

Feature	Description	Photosphere-Chromosphere Model Index	Relative area on the Solar Disk
B	Quiet Sun inter-network	1001	80 %
D	Quiet Sun network lane	1002	19 %
F	Enhanced network	1003	1 %

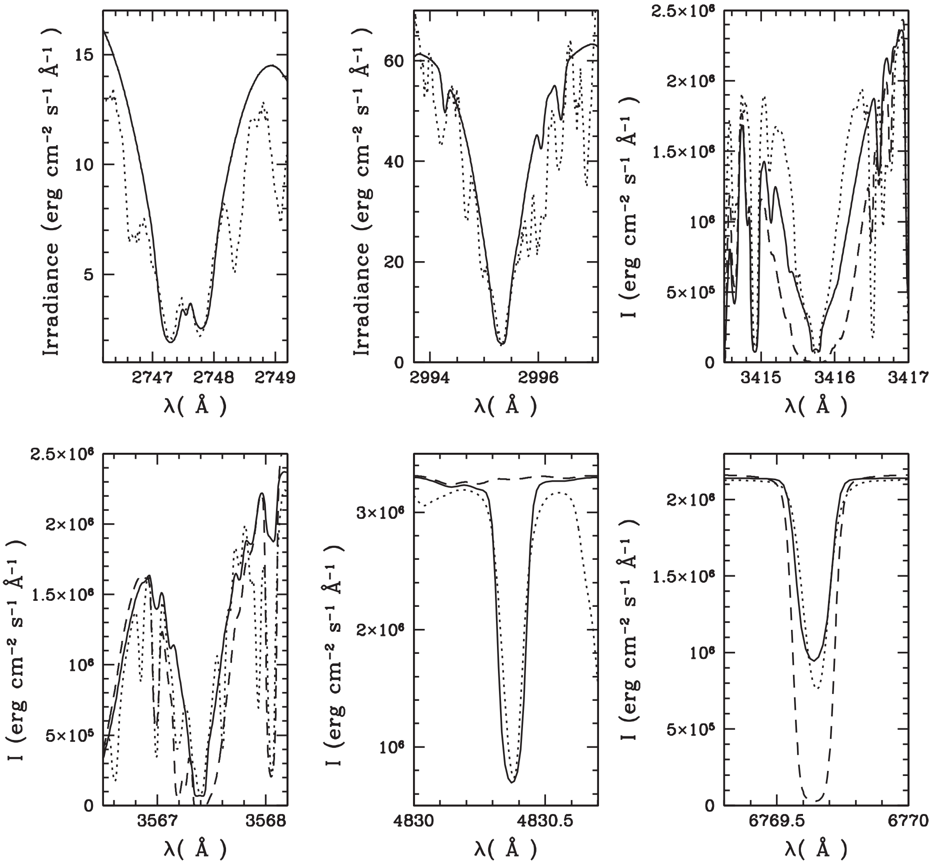

Figure 1. Comparison between observed and synthetic line profiles. With solid lines are shown our calculation, with dashed lines the spectra calculated by Fontenla *et al.* (2011) present only in the visible lines, and with doted lines the observations.

3. Summary

In this work we improved the Ni I atomic model to include the majority of the lines in the near UV range that are listed in the NIST atomic database. Several of these lines are quite strong and have not been taken into account in solar irradiance calculations.

There are large differences in the synthetic line profiles using different approximations. The results shown in this work stress the importance of full NLTE calculation and the use of a sufficient number of levels to obtain a realistic synthetic line profiles.

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We reproduce very well the Ni I 6769.64 Å used in MDI and GONG observations, allowing a deeper study of the line formation, specially in different phases of the solar cycle, to investigate the impact of the solar activity in its behavior.

We do not show in this work details on the line source functions, departure coefficients or depths of formation, but these subjects will be included in a forthcoming paper.

References

Anderson, G. & Hall, L. 1989, *JGR*, 94, D56435

Brasseur, G. (ed.) 1997, *NATO ASI Series: The Stratosphere and its role in the Climate System*, 54, 1

Brault, J. & Neckel, H. 1999, *Sol. Phys.*, 184, 421

Bruls, J. 1993, *A&A*, 269, 509

Fontenla, J., Curdt, W., Haberreiter, M., Harder, J., & Tian, H. 2009, *ApJ*, 707, 482

Fontenla, J., Harder, J., Livingston, W., Snow, M., & Woods, T. 2011, *JGR*, 116, D20108

Hall, L. & Anderson, G. 1991, *JGR*, 96, D712927

Harder, J., Thuillier, G., Richard, E., Brown, K., Lykke, M., Snow, W., McClintock, J., Fontenla, J., Woods, T., & Pilewskie, P. 2010, *Sol. Phys.*, 263, 3

Ralchenko, Yu., Kramida, A. E., & Reader, J., and NIST ASD Team 2011, *NIST Atomic Spectra Database (ver. 4.1.0), [Online]. Available: http://physics.nist.gov/asd [2011, November 4]. National Institute of Standards and Technology, Gaithersburg, MD*

Thuillier, G., Herse, M., Labs, D., Foujols, T., Peetermans, W., Guillotay, D., Simon, P., & Mandel, H. 2003, *Sol. Phys.*, 214, 1

Vernazza, J., Avrett, E., & Loeser, R. 1981, *ApJS*, 45, 635

Discussion

Jeff Linsky: Oxygen abundance in the Sun has been very controversial because of its overlap with NiI line. It would be good to reevaluate the oxygen abundance

Mariela Vieytes: Thanks for your suggestion, I will study this problem with the new calculations we have done to improve the NiI atomic model.

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