Spectral Line Selection for HMI


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Abstract. We present information on two spectral lines, Fe i 6173 Å and Ni i 6768 Å, that were candidates for use in the Helioseismic and Magnetic Imager (HMI) instrument. Both Fe i and Ni i profiles have clean continuum and no blends that threaten performance. The higher Landé factor of Fe i means its operational velocity range in regions of strong magnetic field is smaller than for Ni i. Fe i performs better than Ni i for vector magnetic field retrieval. Inversion results show that Fe i consistently determines field strength and flux more accurately than the Ni i line. Inversions show inclination and azimuthal errors are recovered to ≈ 2° above 600 Mx/cm² for Fe i and above 1000 Mx/cm² for Ni i. The Fe i line was recommended, and ultimately chosen, for use in HMI.

1. Introduction

The Helioseismic and Magnetic Imager (HMI) needs to accurately measure Doppler velocity and vector magnetic field with limited spectral information, sampling 5 or 6 wavelengths across the line. The spacecraft will have a large velocity range of ±4000 m/s. The line must contain a clean continuum with no blends and no nearby lines. Helioseismology requires the line to be narrow and deep as a steep dI/dλ ensures greater sensitivity to small Doppler shifts. The Ni i line satisfied these requirements and was selected for use with MDI and GONG. Vector magnetic field measurements benefit from a high Landé factor, g_eff, and a simple Zeeman splitting geometry. It is important to minimize the number of blends in umbra where low temperatures allow for molecular absorption. Understanding center-to-limb variations is important because the accuracy of “look-up” algorithms is based on line depth and wing slope parameters.
Table 1. Parameters of Fe\textsuperscript{i} 6173 Å and Ni\textsuperscript{i} 6768 Å.

<table>
<thead>
<tr>
<th>(\lambda) (Å)</th>
<th>(g_{\text{eff}})</th>
<th>Exc.Pot. (eV)</th>
<th>Depth (Å)</th>
<th>FWHM (Å)</th>
<th>H (core) (km)</th>
<th>H (cont.) (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe\textsuperscript{i} 6173.34</td>
<td>2.499</td>
<td>2.22</td>
<td>0.62</td>
<td>0.102</td>
<td>302 (269)</td>
<td>16 (21)</td>
</tr>
<tr>
<td>Ni\textsuperscript{i} 6767.68</td>
<td>1.426</td>
<td>1.83</td>
<td>0.53</td>
<td>0.116</td>
<td>288 (291)</td>
<td>18 (26)</td>
</tr>
</tbody>
</table>

2. General Information of Spectral Lines

Five papers discuss the Fe\textsuperscript{i} line (Stenflo & Lindegren 1977; Auer, House, & Heasley 1977; Simmons & Blackwell 1982; Solanki & Stenflo 1985; Landi Degl’Innocenti 1985), and two the Ni\textsuperscript{i} line (Jones 1989; Bruls 1993). Average values of basic line parameters found in these papers are shown in Table 1. Heights of formation are estimated using VAL-C (Vernazza, Avrett, & Loeser 1981) and Maltby-M umbral models (Maltby et al. 1986) under non-LTE conditions. Umbral heights of formation are shown in parenthesis in Table 1.

Line profiles of Fe\textsuperscript{i} and Ni\textsuperscript{i} in umbrae and quiet Sun scanned by the Kitt Peak McMath telescope and the 1-m Fourier Transform Spectrometer are available at ftp://argo.tuc.noao.edu/pub/atlas. The profiles in the quiet Sun are relatively clean with no blends strong enough to threaten the instrument performance. The Fe\textsuperscript{i} umbral profile shows an obvious blend in the blue wing identified as Eu\textsuperscript{II} 6173.0 Å and there are other two blends nearby. Ni\textsuperscript{i} umbral profiles have shown an obvious blend suggested to be TiO, and two others nearby.

A trade-off exists between a higher \(g_{\text{eff}}\) and a greater velocity range in which the velocity algorithm performs well. A higher \(g_{\text{eff}}\) means greater Zeeman splitting and a smaller effective velocity range in the presence of strong magnetic fields. When the velocity algorithm no longer responds linearly to the Doppler shift due to one wing of the line moving out of spectral sampling range, this is called “saturation”. Fe\textsuperscript{i} saturates at 7 km/s or with a magnetic field of 3 kG. Ni\textsuperscript{i} saturates at 6 km/s or with a field of 4 kG.

The line depth, width, equivalent width, and slopes for the red and blue wings for both lines in quiet Sun have been measured from Mt. Wilson data. The line depths for both lines linearly decrease with the cosine of the center-to-limb angle, the line widths linearly increase, and the equivalent widths slightly increase. The line depth of Fe\textsuperscript{i} is generally 2% deeper than that of Ni\textsuperscript{i}, and the line width of Fe\textsuperscript{i} is 15% narrower than that of Ni\textsuperscript{i}. The equivalent width of Fe\textsuperscript{i} is 6% smaller than that of Ni\textsuperscript{i}. The slopes for the red wings of the lines are generally greater than those for the blue, while the Fe\textsuperscript{i} slope is greater than for Ni\textsuperscript{i}. Plots from Mt. Wilson observations relating to this material can be found at http://www.astro.ucla.edu/SolarData/MWOLineProfiles.

3. Line Comparisons Using ASP Data

Comparisons of inverted data from the Advanced Stokes Polarimeter (ASP) for Ni\textsuperscript{i} and Fe\textsuperscript{i} show how well the lines perform for the purpose of vector magnetometry. On March 9, 2002, a map of a active region NOAA 9856 was made by scanning the ASP slit across the sunspot observing the Fe\textsuperscript{i} 6302/6301 Å.
Figure 1. Comparison of spectral line performance for Fe I 6173 Å from NOAA 9856 (○), Fe I 6302 Å from NOAA 9856 (△), Fe I 6302 Å from NOAA 9866 (□), and Ni I 6768 Å from NOAA 9866 (×). Panels from top left plot errors of velocity, velocity, magnetic field, inclination, azimuth, filling factor, longitudinal flux, and transverse flux. These are results for simulated profiles representing a 68% confidence level.

in Channel A and Fe I 6173 Å in Channel B. On March 10, 2002, a map of another active region, NOAA 9866, was made observing with the Fe I 6302/6301 Å in Channel A and Ni I 6768 Å in Channel B. Scatter plots (not reproduced due to page limitations) show Fe I 6173 Å to perform better as a vector field diagnostic than Ni I 6768 Å.
4. Comparing Line Performance Using Simulated Profiles

To estimate line performance, we apply filter profiles to simulated line profiles. The simulated line profiles use Milne-Eddington (ME) parameters recovered by the inversion of ASP observations of NOAA 9856 and NOAA 9866 (see §3). Meaning, the field strengths, filling factor, etc., inferred from ASP observations are used to simulate line profiles. The simulated profiles mimic the observed profiles but lack effects such as molecular blends, nearby lines, and asymmetries.

We apply HMI filters to the simulated Stokes profile and add anticipated noise. The noise level indicates we can recover a polarization signal with a sensitivity of $2.2 \times 10^{-3}$ of $I_c$. We use a Levenberg-Marquardt least-squares minimization to fit the profiles (del Toro Iniesta & Ruiz Cobo 1996). The statistical difference between fitted and true parameters provides a measure of the information content contained in the filtered spectral line.

Performance comparisons, shown in Fig. 1, are made by binning results by the input ME parameter on the horizontal axis and plotting the differences between input and output on the vertical axis. The values represent the 68% confidence level. Both lines perform similarly for velocity for weak fields and small input velocities. The saturation effect is evident for Fe i for stronger fields and larger velocities, as expected for a higher $g_{\text{eff}}$ line. For magnetic field strength and inclination we note nearly a factor of 2 better performance for the Fe i lines than the Ni i line. Errors decrease as apparent flux density, and therefore polarization signal strength, increases. In Fig 1, while all lines have azimuth errors < 5° for strong polarization, Ni i is less accurate than Fe i for low flux density. While Fe i has a better magnetic performance and similar velocity performance for weak fields, it will be necessary to chase the line or suffer a less accurate velocity performance in umbra.

5. Summary

We recommend the Fe i 6173 Å spectral line for HMI due to performing better for magnetism diagnostics while not sacrificing velocity information excepting when high field strengths and velocities move the line beyond effective sampling range. A more extensive version of this paper detailing the analysis of the Ni i and Fe i lines for use in HMI is forthcoming (Norton et al. 2006).

References

Jones, H. 1989, Solar Phys., 120, 211