Spectral Runway: An Analysis of Solar Balmer Lines through both Observations and Models

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1. Introduction

Motivation: We are interested in the variation of stellar magnetism, which affects the atmospheres of their orbiting planets may determine their habitability.

Background: Spectral analysis provides a glimpse into the physical properties of stellar atmospheres. This understanding relies heavily on models, as spatially resolved spectra of stars are not available. The Sun offers an excellent opportunity for detailed observations of the effects of magnetic features on spectral irradiance and further validation of state-of-art models.

Objective: We utilize high spatial resolution spectroscopic solar observations to investigate how surface magnetism affects the atmospheres of their orbiting planets.

2. Data

Observations: Observations were obtained on November 4th and 5th of 2019 at the Richard B. Dunn Solar Telescope (DST) upon Sacramento Peak in New Mexico. We specifically examine high spatial resolution spectroscopic observations obtained with the HSG spectrograph of the Balmer absorption lines of Hα and Hγ. The data consists of two sets (each describing different types of regions) of one-dimensional atmosphere models using two sets (each describing different types of regions) of one-dimensional atmosphere models published in Fontenla et al. 1999 and Fontenla et al. 2011, respectively. Said models are listed below in Table 2.

Models: The theoretical spectra were obtained with the RH synthesis code (Uitenbroek, 2001) using two sets (each describing different types of quiet and active regions) of one-dimensional atmosphere models published in Fontenla et al. 1999 and Fontenla et al. 2011, respectively. Said models are listed below in Table 2.

3. Methodology

Spectral Reduction: The HSG spectral observations were dark and flatfield corrected. The resulting spectra were flux calibrated using the FTS Quiet Sun reference spectrum (Brautl & Neckel 1977). After the initial reduction, the spectra were averaged over space and time, yielding the final, mean spectra used in the analysis.

Convolution: To account for observational error, each model is convolved with a Point Spread Function (PSF) determined by the standard deviation, σ, and the percentage of scattered light, κ, from the convolution of the FTS reference spectrum (Brautl & Neckel 1977) to the HSG observations. As given in Cabrera Solana et al. 2007:

\[ I_{\text{model}}(\lambda) = I_{\text{PSF}}(\lambda) \times G(\lambda) \]

Where \( I_{\text{model}} \) is the intensity of the FTS spectrum, and \( I_{\text{PSF}} \) is the PSF generated from the standard deviation between the observed spectra and the FTS spectrum. Table 3 provides the κ and σ values for both Hα and Hγ observations.

4. Results

Observations: The resulting masks (see e.g. Figure 1) indicate what type of feature to expect to observe in the DST field of view.

Table 1: Observations and Models

<table>
<thead>
<tr>
<th>Time Observed</th>
<th>μ Value</th>
<th>μ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>November 4th</td>
<td>0.0847232</td>
<td>0.82</td>
</tr>
<tr>
<td>November 5th</td>
<td>0.120080</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Table 2: Observation parameters for gaussian PSF generated for Hα and Hγ spectral regions. This includes the standard deviation, σ, and the percentage of scattered light, κ.

Table 3: Results of state-of-the-art models compared with theoretical spectra.

<table>
<thead>
<tr>
<th>Model</th>
<th>Active Network (1003)</th>
<th>Facula (1004)</th>
<th>Quiet Sun (1001)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hα</td>
<td>0.0760507</td>
<td>0.0473649</td>
<td></td>
</tr>
<tr>
<td>Hγ</td>
<td>0.0847232</td>
<td>0.120080</td>
<td></td>
</tr>
</tbody>
</table>

5. Conclusions

Analysis: After the initial analysis of comparing and contrasting all 16 models against the 5 observations, our final results of the best fitting models are listed in section 3.

General Conclusions: All of the observations listed in section 4 show that the 1999 models expect a much more active region than observed. The 2011 models correlate to our expectations for the observations, including the depth of the line and somewhat of its width and wings. This is in agreement with the AIA masks for these regions.

Active Region Observations: As can be seen in Figure 1, the northeast region observation crosses several points of active region (namely network and facula). This causes certain pixel regions of the observations to skew the mean spectra to be shallower than expected, due to the increase of the magnetic signature.

As stated above, the observations are underestimated by the 1999 models, and correctly represented by the 2011 models. For the active regions, we should have obtained that network and facula models best fit the observations as according to the AIA masks (Figure 1). Therefore, this means that the 2011 models correctly represent active regions as well.

6. Moving Forward

Continue Analysis of Other Models | Repeat Analysis for Other Observations | Apply Findings to Big Data

7. Acknowledgements

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8. References


Figure 1: Hα observations at disk center (top) and southwest region (bottom). Both observations were best fit with models 1003 (Active Network) and 1004 (Facula). Figure 2: Hγ observation at disk center. The best models were model 1001 (Quiet Sun) and model 1004 (Facula).

Figure 3: Hα observation at disk center and the southwest region. The SRPM segmentation algorithm (Fontenla & Harder, 2005) was applied to AIA 1700 A images acquired close in time to DST observations. The resulting masks (see e.g. Figure 1) indicate what type of feature to expect to observe in the DST field of view.

Figure 4: Hγ observation at the northeast region, divided into regions of active sun (blue) and quiet sun (orange). When compared with 1999 models (top), it can be seen that the profiles match much more active models, namely models 1001 (Quiet Sun) and 1004 (Facula). When compared to 2011 models (bottom), the quiet region is best represented by model 1001 (Quiet Sun) and the active regions are characterized by a combination of models 1003 (Active Network) and 1004 (Facula).