

Molecular hydrogen in the chromosphere

IRIS observations and a simple model

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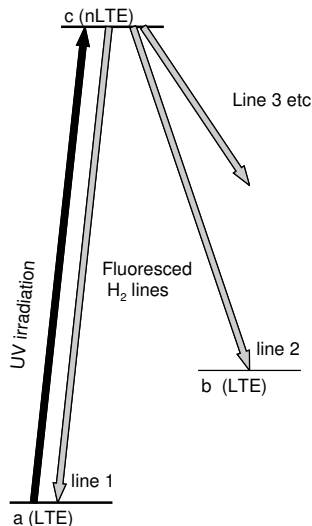
Introduction

The formation of the fluorescent lines of molecular hydrogen (H_2) in the ultraviolet is a careful balance between temperature, pressure, opacity, and irradiation from the transition region. While cool temperatures promote the formation of molecules, the pressure rapidly decreases with height from the photosphere to the chromosphere, making the formation of H_2 increasingly unlikely. In order to produce emission, UV photons of sympathetic wavelength must excite H_2 into upper levels, the depth to which H_2 can be irradiated is limited by the UV opacity, which is dominated by the photoionization of Si I and C I. Due to this sensitivity in their formation, the lines of H_2 have the potential to tell us about the conditions at the very base of the chromosphere. We are currently developing partial NLTE treatment of the H_2 abundance and level populations in order to perform spectral synthesis within the framework of the Rybiki-Hummer (RH) radiative transfer and chemical equilibrium code. In this poster I will present the first results using this treatment and its comparison with IRIS observations.

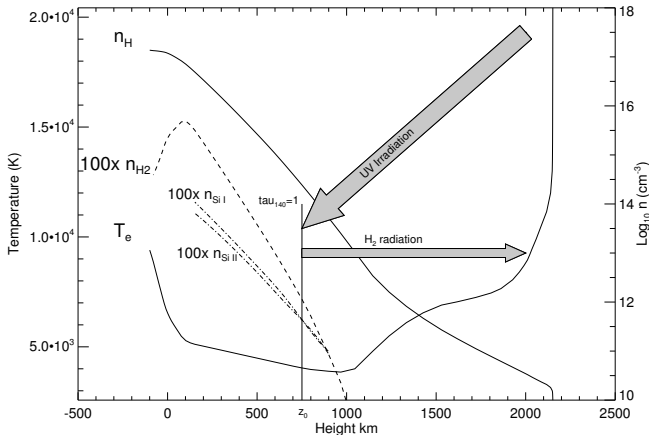
Fluorescence model

Transitions of H_2 with similar wavelengths to strong chromospheric and transition region lines are excited, populating an upper level (a to c). Downward transitions occur with different branching probabilities (c to a, b, ...), producing a fluorescence spectrum.

The absorbed flux depends strongly on the intensity and velocity of the exciting line. Velocity shifts or broadening can provide significantly more flux to the H_2 transition.



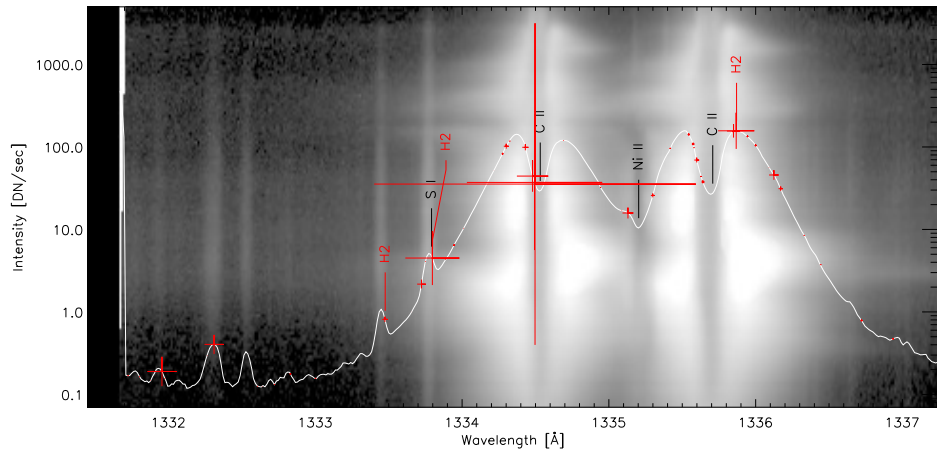
With a simple look at a model of the stratified chromosphere, we can see that relatively little H_2 participates in fluorescence. The largest fraction of H_2 occurs near the height of line formation ~ 150 km above $\tau[5000\text{\AA}] = 1$. The greatest contribution to fluorescence should be from the $\tau[1400\text{\AA}] = 1$ depth which is determined by ionization of Si I.



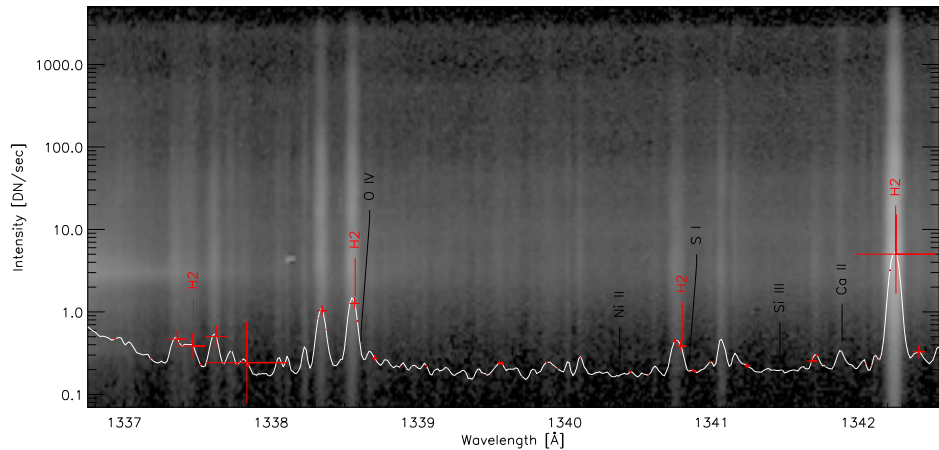
Physically motivated H₂ line identification

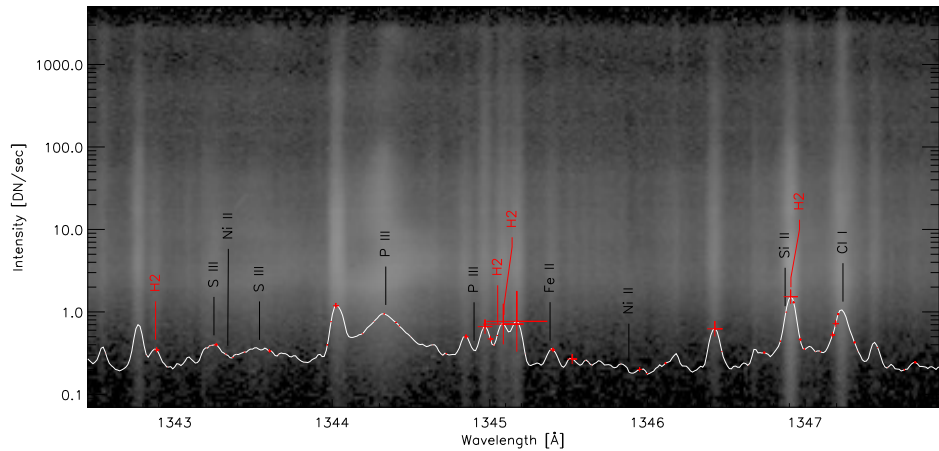
Only a subset of all possible transitions are excited, so determining which lines are strong is easy with a good line list. Matching the emission probabilities from Abgrall et al. (1993a) and Abgrall et al. (1993b) with the oscillator strengths from the Kurucz line list, we calculate the flux absorbed to the upper level based on the SUMER atlas spectrum of the quiet-Sun, the relative strengths of the output emission based on the branching ratios for each transition that is a member of the upper level.

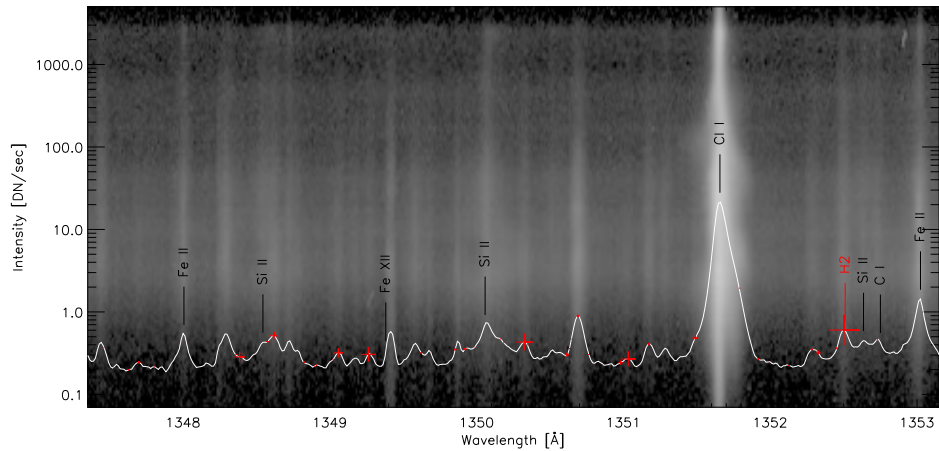
The following plots of a bright flare spectrum show a bright flare spectrum from the IRIS FUV1 and FUV2 channels. Previously identified atomic and molecular lines from Sandlin et al. (1986); Jordan et al. (1978); Jordan et al. (1979); Bartoe et al. (1978); Bartoe et al. (1979) are labeled. The possible H₂ transitions are indicated by blue crosses, where the predicted strength of the line is indicated by the size of the symbol.

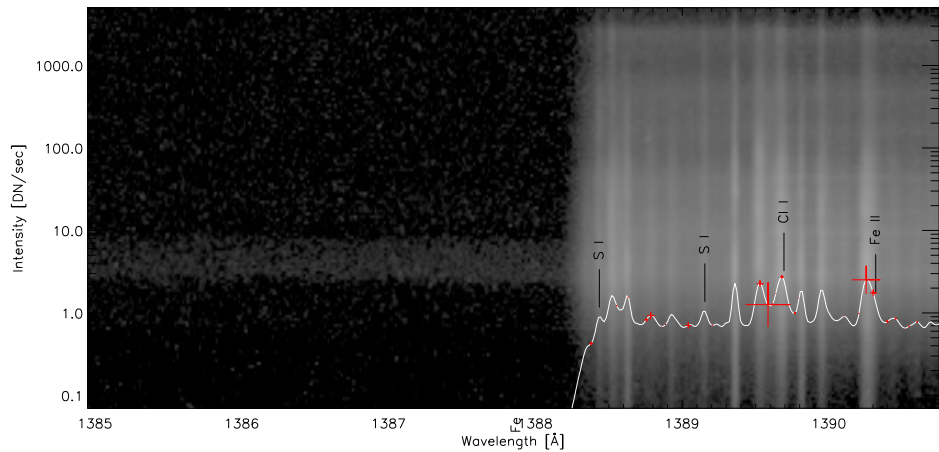


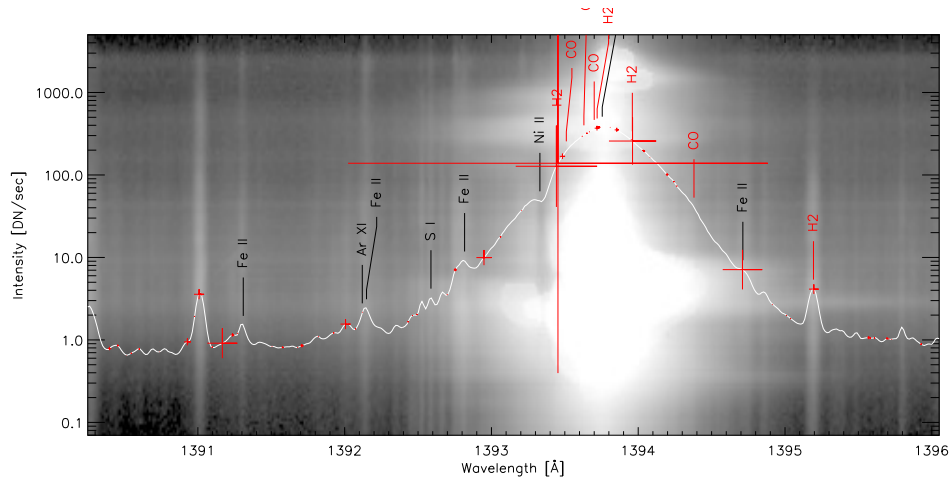
*With few lines available in the typical FUV1 spectrum, the wavelength correction is inaccurate on the blue side of the spectrum which results in some systematic shifts here. Detailed line identification for low-temperature, low-velocity species like H₂ should greatly improve the relative accuracy of the wavelength solution.

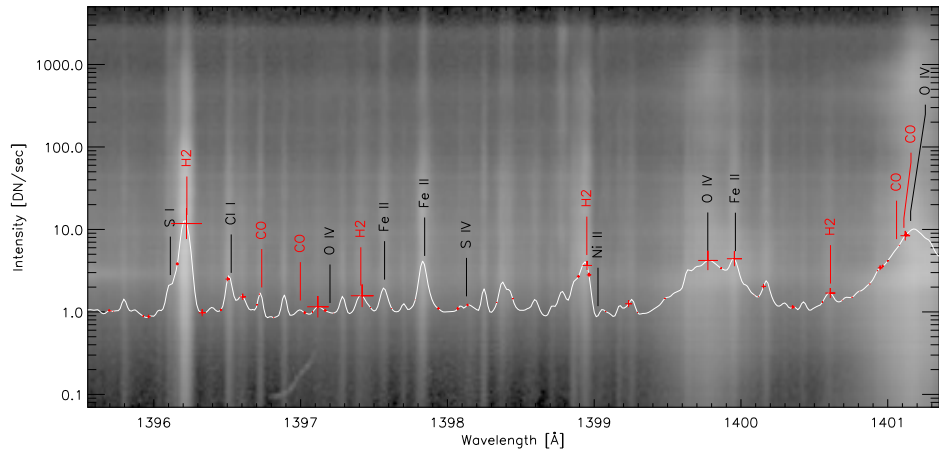


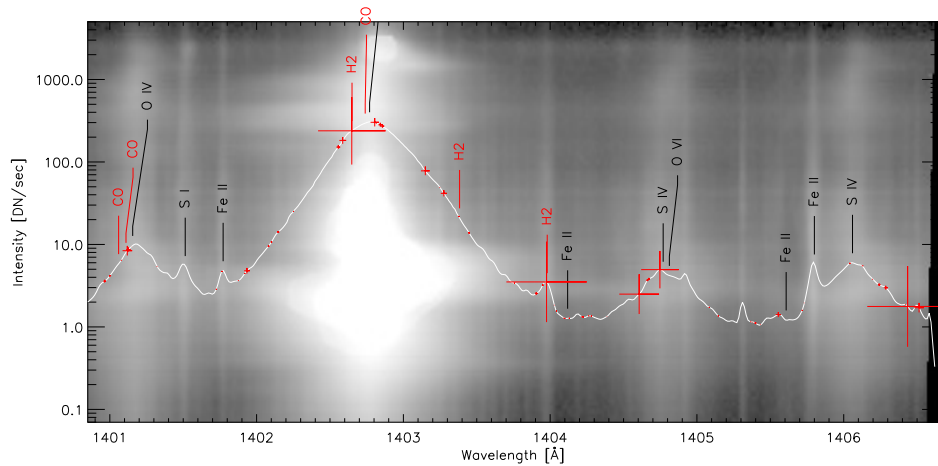










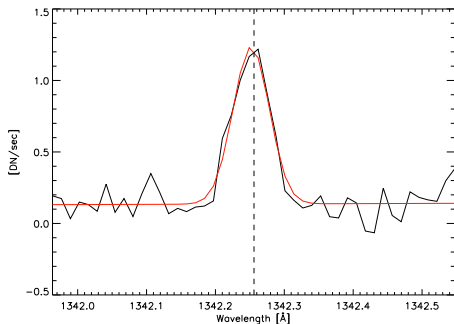


Measuring consistence of excitation and emission

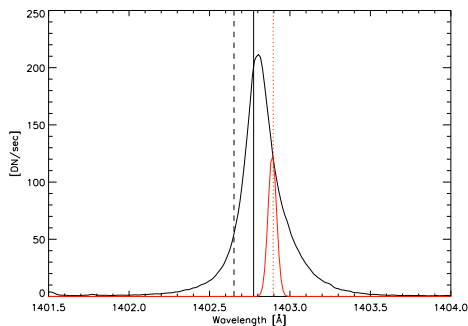
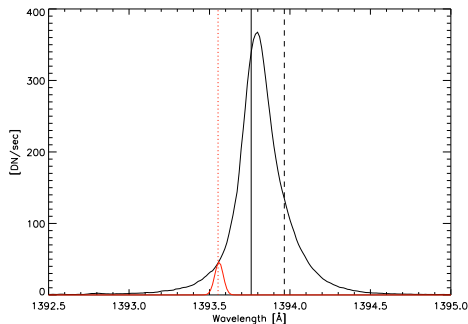
By measuring the H_2 fluorescent emission and the transition region line responsible for their excitation we can tell something about the physical state of the lower chromosphere. In a perfectly uniform atmosphere we would expect the emission to track linearly with excitation, but if there is non-uniformity (in H_2 abundance or opacity, i.e. temperature and density changes), or if the radiation field is non-local, there will be some scatter about a linear relation.

The H_2 lines at 1333.797 and 1342.256 Å are a good pair of lines for the measurement of consistency. They share the upper level ($J=2$, $v=0$) which is excited exclusively by Si IV through the 1393.961 and 1402.648 Å H_2 lines in the red and blue wings of the Si IV 1393.755 and 1402.770 Å lines. Large branching ratios of 0.10 and 0.15 make these some of the brightest H_2 lines that IRIS observes.

The 1333.797 Å line is coincident with a S I line, but comparison with other unblended H_2 and S I lines has shown the S I component is insignificant (Jaeggli et al., 2014).

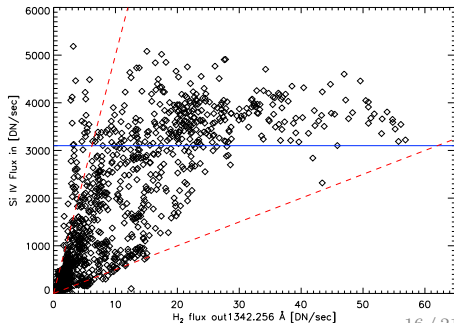
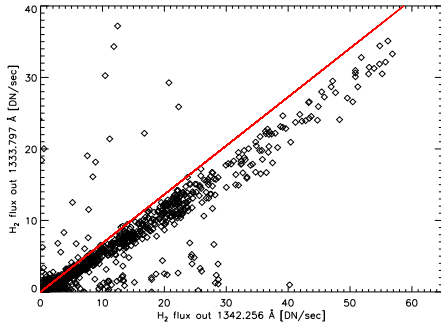


Here's an example of how the consistence is measured. The H_2 line is fitted with a Gaussian profile (top left). The intensity integrated over the line is the “flux out.” The measured velocity of the profile is used to determine the standard of rest of the Si IV lines, and the profile is reversed about this standard of rest. The Si IV profile is multiplied by a Gaussian profile with the same width as the H_2 profile and integrated (as in the right plots), this is the “flux in.”



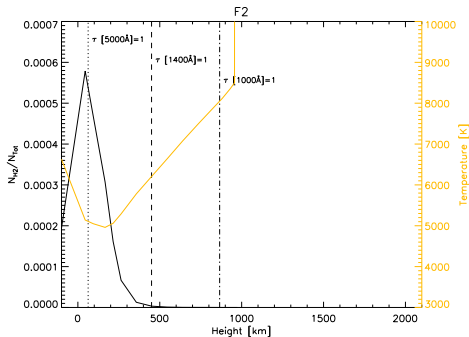
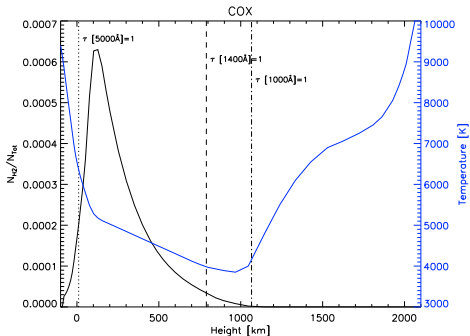
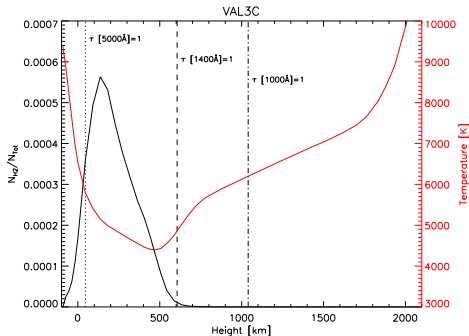
The consistency of H_2 and Si IV emission has been measured for a small segment of the Oct 11 data. The top figure shows the flux in the two H_2 lines compared. The red line shows the slope we would expect for the branching ratio values quoted above.

The bottom figure shows the flux measured in the 1342.256 \AA H_2 line vs. the total estimated flux provided by the Si IV lines. The blue line indicates the saturation threshold, the red dashed lines are meant to guide the eye, and represent a slope of 50 and a slope of 500. Multiple behaviors are apparent in the plot which may represent contributions from distinctly different atmospheres.

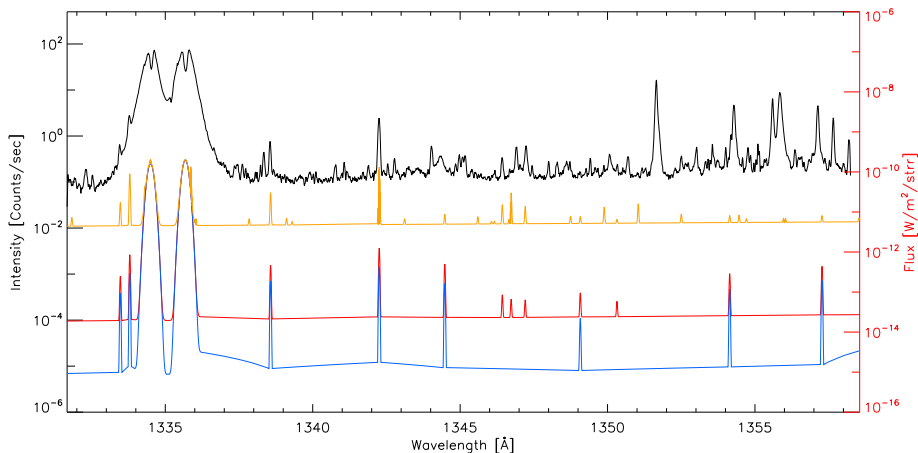


Spectral synthesis with RH

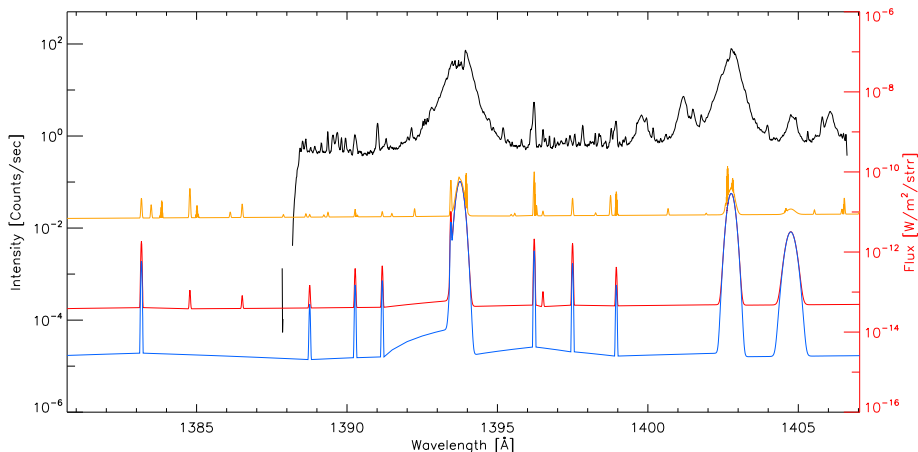
We are using the Rybiki-Hummer (RH) radiative transfer and chemical equilibrium code (Uitenbroek, 2000), which is a flexible tool for investigating molecular populations and radiation in a model of the solar atmosphere. The RH code does not yet have the formalism to treat H₂ fluorescence. We have developed a simple add-on to the RH code which takes the output opacity as a function of wavelength and height, and LTE molecular populations from the RH calculation for a given input model atmosphere, and calculates the propagation of a scaled radiation field down through the top of the atmosphere. The current radiation field is a SUMER spectrum that can be scaled to simulate different conditions (e.g. $\times 100$ for a flare). The emitted H₂ radiation is propagated upward and added to the input spectrum to produce a synthetic fluorescence spectrum.



These plots show the temperatures and partial pressures calculated from the VAL3C, COX, and F2 atmospheres for H_2 in chemical equilibrium and LTE. The vertical lines indicate important opacities. The $\tau[1400\text{\AA}] = 1$ is the deepest that exciting photons can penetrate, and responsible for the largest contribution to fluorescence. H_2 is susceptible to photo-dissociation by photons shorter than $\sim 1000 \text{ \AA}$ (van Dishoeck & Visser, 2011).



The relative strengths of some H_2 lines in the synthetic spectra seem accurate, but the match is not universal.



The strong H_2 line at 1403.9 Å and several other lines are suspiciously missing, however this line is excited by a line outside of the IRIS range, so the subset of the lines currently used in the spectral synthesis may not be sufficient.

References and Acknowledgements

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