Spectral Characteristics of the Solar Transition Region

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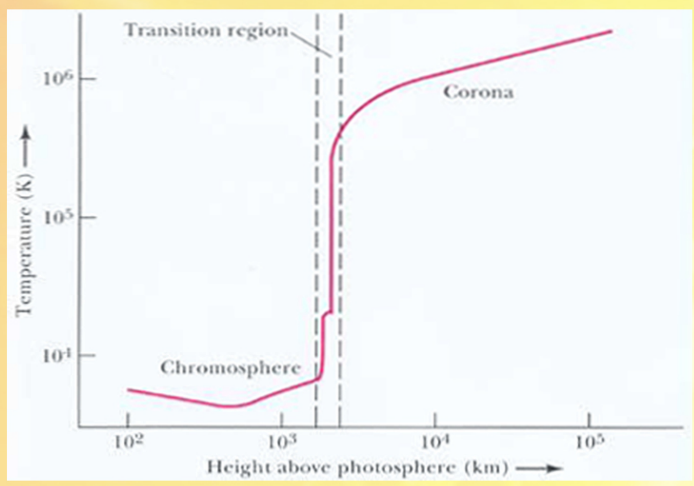
Introduction

An understanding of the solar transition region is crucial to a full appreciation of the Sun's atmosphere. Dynamic structures extending from the underlying chromosphere are likely responsible for the atmosphere's puzzling temperature profile, but the details of these processes are still largely unknown. One possibility is that spicules are the cause of unique transition region spectral profiles and a key mechanism in coronal heating. Recent high resolution images of spicule structures from the Hinode spacecraft have allowed unprecedented research into spicule behavior and effects. We analyze ultraviolet emission lines from the transition region using spectral data from the SUMER instrument aboard SOHO in order to relate long-observed spectral characteristics of these lines to spicule structures. Our investigation is ongoing, but we suspect a correlation of line characteristics and two different spicule types.

Resources

De Pontieu, B., et al. 2007a, PASJ, 59, S655
Dere, K.P., & Mason, H.E. 1993, Sol. Phys., 144, 217
McIntosh, S.W., De Pontieu, B., & Tarbell, T.D. 2008, ApJ, 673, L219
Peter, H. 2000, A&A, 360, 761

Why the solar transition region?

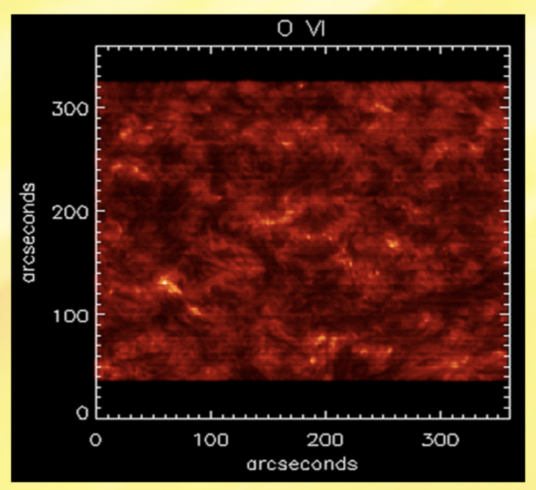


The 'coronal heating problem' refers to the seemingly inversed temperature gradient observed in the solar atmosphere. Rather than the outwardly increasing temperatures expected for a central heating source, the corona is orders of magnitude hotter than inner atmospheric layers. Across the transition region is the most dramatic change, going from 10^4 to 10^6 Kelvin in a small distance. This huge change suggests that important processes for coronal heating reside in the transition region and upper chromosphere. But how can the inverted temperature gradient exist in the first place, in contradiction to the second law of thermodynamics? Plots like the one above are deceiving; they ignore the dynamic, inhomogeneous nature of the solar atmosphere. Non-thermal, mechanical processes must account for the observed heat flow. Spicules are one structure that could propagate the necessary mechanics for coronal heating.

Spicules?

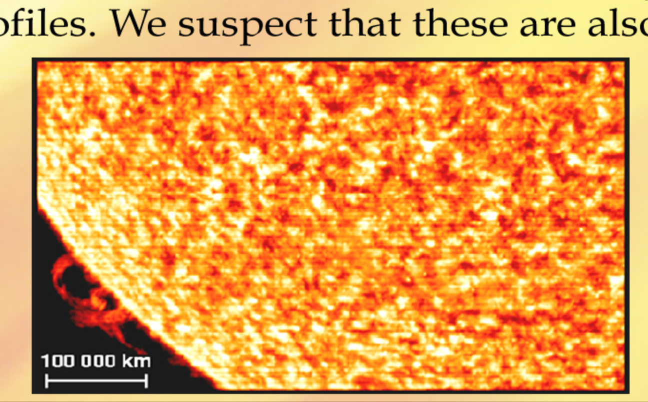
Spicules are short-lived 'jets' of plasma extending from the photosphere into the chromosphere. They act as tracers, allowing us to observe wave motions and magnetic structure. We observe two types: Type-I spicules, which have lifetimes from 3 to 7 minutes, and Type-II spicules, which only last around 45 seconds but are much more dynamic and exhibit faster upward velocities. We suspect that Type-II spicules are pivotal to coronal energy transport.

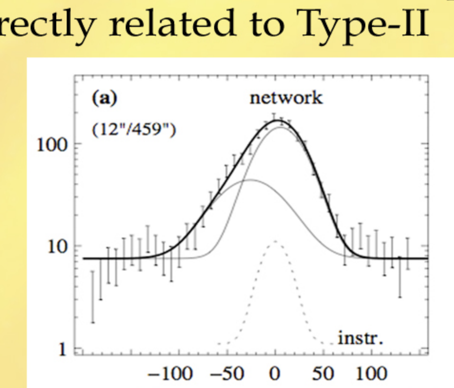
Non-thermal Spectral Profiles



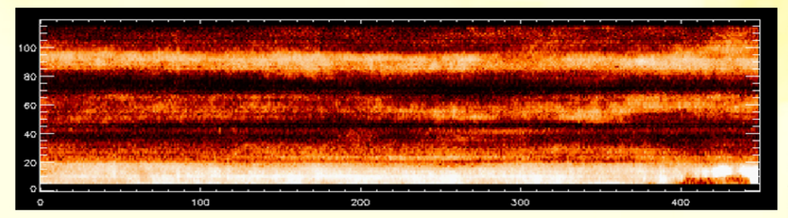
The chromosphere and transition regions appear as a patchwork of bright 'network' regions of high magnetic activity and darker 'inter-network' regions. For about 25 years it has been observed that transition region spectra in the active network regions deviate from a single Gaussian shape; they are instead better fit by the combination of a single Gaussian 'core' curve and a less intense, broader 'second component' Gaussian curve.

These two curves are believed to be caused by two different unresolved processes or structures in the solar atmosphere. There have been many hypotheses about what non-thermal mechanical motions are responsible for these 'two-component' spectral profiles. We suspect that these are also directly related to Type-II spicules.





SUMER Data

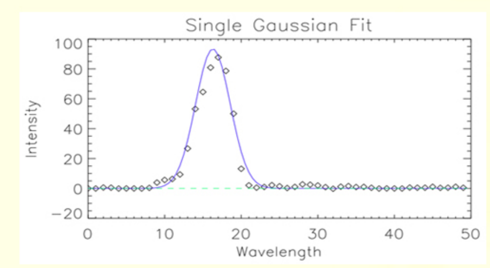


'Sit and Stare' image of Ne VIII
x axis = time
y axis = space

The SUMER (Solar Ultraviolet Measurements of Emitted Radiation) spectrograph instrument aboard SOHO observes the Sun through a slit, producing images with 1 spatial dimension and 1 spectral dimension. We use the SUMER slit to produce two types of data sets. The first is a 'raster' image, which sequentially captures adjacent slit images to produce a 3-dimensional image (two spatial and one spectral). The second is a 'sit and stare' image, which keeps the slit on the same area of the sun through time to again create a 3-dimensional image (spatial, temporal, and spectral). The result is spatially (and temporally) resolved images that have spectral data for every pixel. We have these images for several ultraviolet transition region emission lines.

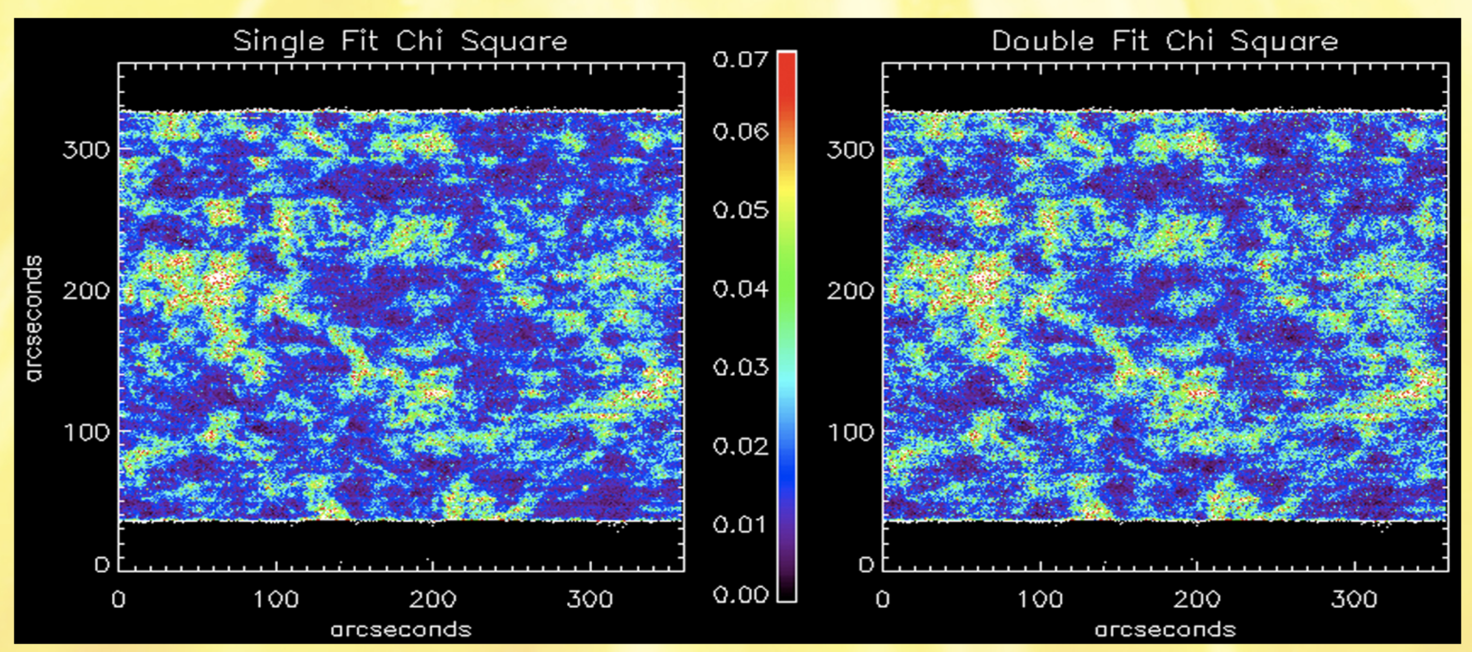
Spectral Profile Fitting

$$\chi^2 = \frac{\sum_{i=1}^{ndata} \frac{(real_i - model_i)^2}{\sigma_i^2}}{ndata - nparameters}$$



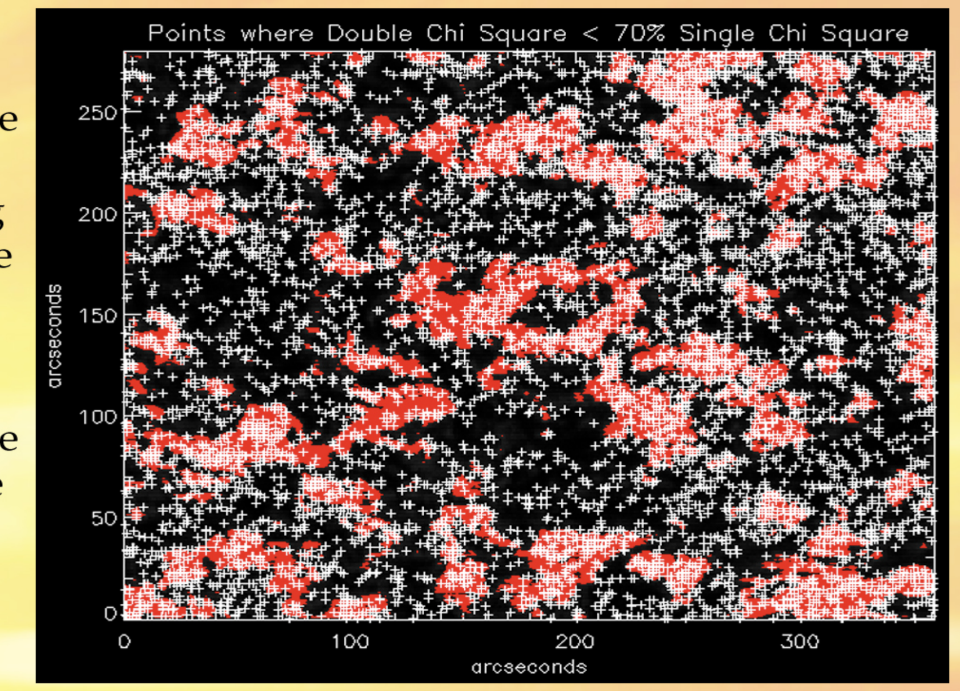
We use the genetic algorithm PIKAIA to fit single and double component Gaussian curves to the spectra in every pixel of the SUMER data sets. Genetic algorithms (GA) mimic natural selection to evolve randomly generated Gaussian parameters until an acceptable fit to the real data is reached. The measure of fit we use is a reduced chi square value (shown right), which is weighted by the number of parameters involved. After the robust GA finds an acceptable fit, we allow the much faster IDL routine MPFIT to slightly tweak the parameters and perfect the fit. (See http://www.hao.ucar.edu/Public/models/pikaia/pikaia.html for more info on GA's and PIKAIA)

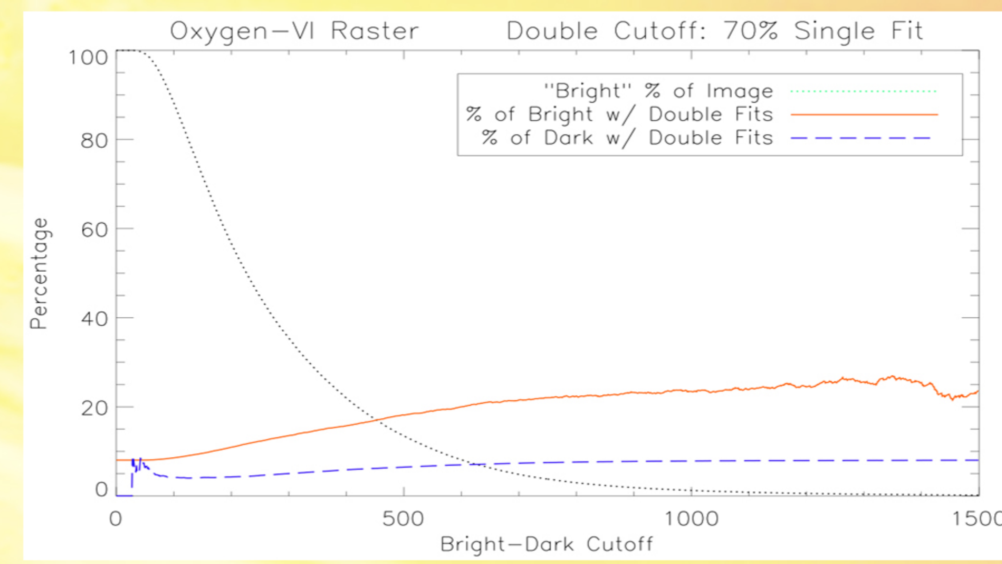
After fitting spectra, we obtain several parameters describing the resulting Gaussians, such as intensity and position. However, to compare between single and double component fits, we are most interested in the X^2 values for every pixel. Below are maps of X^2 for single and double Gaussian fits for a large raster of the Oxygen-VI emission line. The original data intensity map is shown on the left. It is very clear that the X^2 values are much better for both fits in the brighter regions. This is due to much higher signal to noise ratios as intensities increase, and is one of many considerations when deciding whether a single or double component fit is more appropriate for a given pixel.



Spatial Dependence of Second Components

Here we distinguish double component spectra of the same raster as those that have a lower double fit X^2 than a fraction of the corresponding single fit X^2. The red areas are the bright network regions. There is a visible concentration of double fits in the network, but a more quantitative approach is taken below. The % of double fit bright and dark regions is plotted as a function of the minimum 'bright' intensity.





Conclusions

This Oxygen-VI example analysis is fairly representative of the numerous datasets we have looked at: while there are definite trends relating double-component spectra to bright network regions, there is also a noticeable amount of outliers. More work is needed to determine which of these outliers are a product of data noise and fitting algorithms and which represent a constant background population of double-component spectra throughout the transition region, regardless of network and inter-network regions. What is clear is that previous work on the subject (Peter 2000) has been misleading in its representation of double-component spectra as being 'basically restricted' to the bright network. Our findings challenge this over-simplified assumption and call for new interpretations of the phenomena (possibly spicules).

Ongoing Work

Once we have finished analyzing a sufficient number of SUMER data sets, including many wavelengths spanning the transition region and sets from both the disk and the limb, our next step will be to look at matching Hinode data. The Solar Optical Telescope (SOT) aboard Hinode is able to image spicule structures in very high detail, which will allow us to make comparisons between spicule locations and fitted SUMER spectral profile data. We will be looking both at on-disk spatial structure and terminal elevations of spicules and double-component fits.