Exploring EUV Spicules Using 304 Angstrom He II Data from SDO/AIA

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Abstract

We present results from a statistical study of He II 304 Å EUV spicules at the limb of the Sun. We also measured properties of one macrospicule; macrospicules are longer than most spicules, and much broader in width than spicules. We use high-cadence (12 sec) and high-resolution (0.6 arcsec pixels) resolution data from the Atmospheric Imaging Array (AIA) instrument on the Solar Dynamic Observatory (SDO). All of the observed events occurred near the solar north pole, where quiet Sun or coronal hole environments ensued. We examined the maximum lengths, maximum rise velocities, and lifetimes of 33 EUV spicules and the macrospicule. For the bulk of the EUV spicules these quantities are, respectively, ~10,000----40,000 km, 20---100 km/s, and ~100--- ~1000 sec. For the macrospicule the corresponding quantities were respectively ~60,000 km, ~130 km/s, ~1800 sec, which is typical of macrospicule measured by other workers. Therefore macrospicules are taller, longer-lived, and faster than most EUV spicules. The rise profiles of both the spicules and the macrospicules match well a second-order (``parabolic'') trajectory, although the acceleration was often weaker than that of solar gravity in the profiles fitted to the trajectories. Our macrospicule also had an obvious brightening at its base at birth, while such brightening was not apparent for the EUV spicules. Most of the EUV spicules remained visible during their descent back to the solar surface, although a small percentage of the spicules and the macrospicule faded out before falling back to the surface. Our sample of macrospicules is not yet large enough to determine whether their initiation mechanism is identical to that of EUV spicules.

Introduction

Various jet-like phenomena occur in the Sun's atmosphere. In the chromosphere, spicules are ever-present, with about a million of these "chromospheric spicules" on the Sun at any time; they shoot up to heights of ~5000 km above the photosphere (e.g., Beckers 1968, 1972; Sterling 2000; De Pontieu et al. 2007; Tsiropoula et al. 2012). In the hotter atmosphere, X-ray jets occur at a rate of ~60/day and extend to ~5 x 10^4 km (e.g., Shibata et al. 1992, Shimojo et al. 1996, Savcheva et al. 2009, Cirtain et al. 2007, Moore et al. 2013). Other coronal jets, similar to the X-ray jets, are visible in relatively ``hot'' EUV images (e.g., in lines formed by Fe ions at wavelengths of 193 and 195 Ang; e.g., Wang et al. 1998, Nisticó et al. 2009).

Here we study study jets seen at cooler temperatures than the coronal jets but hotter than the spicules. These jets are seen in EUV He II 304 Å images, which show emissions of the chromosphere and transition region of temperature ~50,000 K. We use data from the Solar Dynamics Observatory (SDO) Atmospheric Imaging Array (AIA) (Lemen et al. 2012). The "304 Å EUV spicules" dominate the limb in close-up AIA 304 Å images, with about two dozen distinct spicule-like features being discernible in 100'' spans of the polar limb regions at any given time. Movies of such images show the 304 Å spicules to be highly dynamic, similar to the chromospheric spicules. Here we concentrate on these common EUV 304 Å features that jet up ~10'' above the limb as seen in the 304 Å images. Much less frequently there are larger jets visible in the 304 Å images, of size similar to the X-ray jets (~5x10^4 km); we refer to these larger jets as ``macrospicules.'' We examined directly one macrospicule in this work, and we compare its properties with that of the 304 Å spicules. Two questions of interest are: (1) What are the properties of spicules seen at this wavelength, and (2) are macrospicules large-scale versions of the 304 Å spicules?

Data Sets

We examined AIA 304 Å channel data three? different time periods. For each data set, we restricted our field of view to about 100''-spans of the limb in the north polar region. Table 1 lists the observation details. These times and observation fields of view were selected to coincide with Hinode SOT observations of the same regions. (SOT data were not examined in this study). All of the data were of 12 sec cadence and at the full AIA resolution of 0''.6/pixel. Data set 0 is from a polar coronal hole region. Data sets 1---3 were of the polar region, but during a period of the solar cycle when the polar coronal holes were not present, and thus they are polar quiet Sun regions.

Table 1: EUV 304-Ang Spicule and Macrospicule Observations

Data Set	Start Time (UT)	End Time (UT)	X-range (arcsec)	Y-range (arcsec)
0	2011 Sep 11 09:38	2011 Sep 15 11:00	-50---+50	+935---+1035
1	2014 Apr 4 00:19	2014 Apr 4 01:33	-30---+70	+935---+1035
2	2014 Apr 13 23:30	2014 Apr 14 00:45	-65---+35	+935---+1035
3	2014 Apr 14 23:15	2014 Apr 15 00:19	-75---+45	+935---+1055

Procedure

We examined the AIA 304 Å movies over the regions and times of Table 1. We looked for spicules that were isolated enough to follow their entire evolution, from emergence above the limb "surface" seen in the 304 Å images until they returned to that surface or faded from view. From each of the data sets 0---2 we were able to identify ~10 spicules that satisfied these criteria. From movie 3 we only identified 4 spicules, because much of the time a large, wide macrospicule dominates that movie, obscuring the smaller spicules along the same line-of-sight.

For each selected spicule, we measured the projected length from the photospheric limb, with the white-light limb being calculated from the Sun-Earth distance at the times of the observations. Typically the limb seen in 304 Å images is ~10''---15'' above the photospheric limb, and so the minimum-observable length (height) for the 304 Å spicules is ~7000 km. We measured the top of the spicules visually, after verifying that the apparent top location of the features was not significantly influenced by the intensity scaling of the displayed images. We derived velocities from the derivative of the length-time trajectories (after applying a running box-car smoothing to the trajectories), and fit first- and second-order polynomials to the trajectories. From the second-order fits we could obtain an acceleration term, which we could compare with the solar gravitational acceleration.

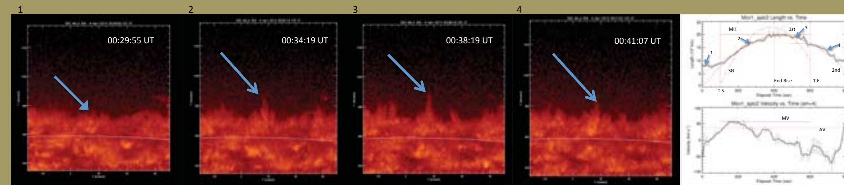

Figure 1. The above series of panels shows the rise and fall of a 304 Å spicule on April 4, 2014, from 00:29:55-00:41:07 UT. Blue arrows point to the approximate location that was chosen as the top of the spicule for each frame. The white curve shows the white-light photospheric limb. The panel to the far right shows the trajectory of the spicule as a function of time on top and the velocity of the spicule over time at the bottom, where error bars are 1 σ uncertainties from three independent measurements. In the trajectory plot, the dotted line (denoted by "1st") is the first-order fit to the rise; the dashed line ("2nd") is the 2nd-order fit to the rise and fall of the spicule; the vertical dashed line ("T.S") denotes the beginning of the fit; the vertical dashed line ("T.E.") denotes the end of the fit; the vertical dotted line ("end rise") is the end of the spicule's rise and the end of the 1st order fit; the dashed and dotted line ("SG") shows the solar gravity fit; and the solid horizontal line ("MH") shows the max height. In the velocity plot, the solid line ("MV ") is the max velocity and the dotted line ("AV") is the average velocity.

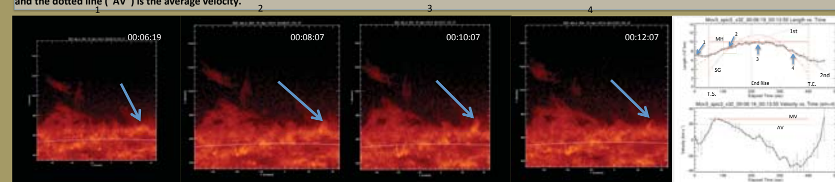

Figure 2. Same as Figure 1, except for the spicule on April 15, 2014, from 00:06:19-00:12:07 UT.

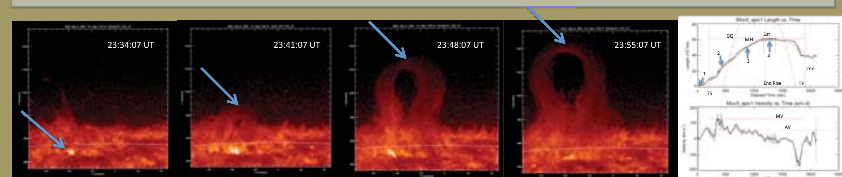

Figure 3. Same as Figure 1, except for the macrospicule on April 14, 2014, from 23:34:07-23:55:07 UT. The brightening indicated in the first frame is unique to the macrospicule observed and is not evident in the other "normal" spicules.

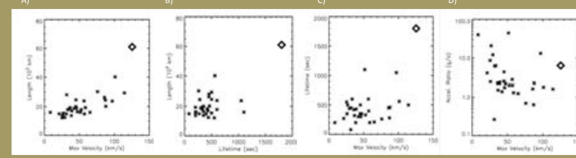

Figure 4. Panel A shows the max heights of the spicules plotted as a function of max velocity, panel B shows the max heights plotted as a function of lifetime, panel C shows lifetimes plotted as a function of max velocity, and panel D shows the acceleration ratio (acceleration of gravity to that derived from the best-fit 2nd-order parabola) of the spicules plotted on a log scale as a function of max velocity.

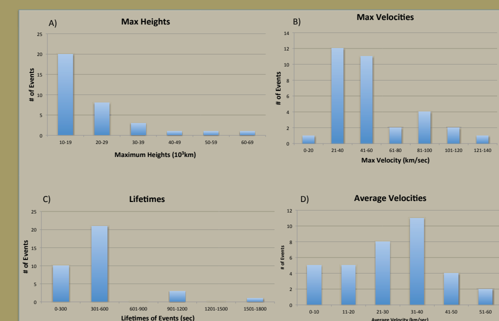

Figure 5. Panel A shows a histogram of the maximum heights of the events, panel B shows a histogram of the maximum velocities, Panel C shows a histogram of the lifetimes, and panel D shows a histogram of the average velocities.

Summary and Discussion

We found the EUV 304 Å spicules to have lengths ~10,000----40,000 km, maximum rise velocities of ~20---100 km/s, and lifetimes of ~100--- ~1000 sec. Velocities averaged over the rise of the spicules were ~5---50 km/s. These lengths and lifetimes are grossly in agreement with earlier EUV and UV observations (e.g., Cook et al. 1991, Dere et al. 1989) Our lengths are much longer than those of the majority of chromospheric spicules, and as such they may represent the longer extensions of chromospheric spicules. A good possibility is that they are the more-extended material of chromospheric spicules after it has become heated and has faded from wavebands where the chromosphere is observable (e.g., Pneuman and Kopp 1978, Sterling 1998, De Pontieu et al. 2011).

We found many of the EUV spicules to fit quadratic trajectories, with effective gravity often significantly smaller than that of solar gravitation. This is consistent with the possibility that they form and further develop due to a prolonged deposition of energy at their base, or due to a rapid heating of chromospheric material that expands to form the spicule. The pressure increase at the base resulting from such an energy input would oppose and thereby weaken the influence of gravity.

This study only included one macrospicule, which was longer (~60,000 km), faster (max velocity ~130 km/s), and longer-lived (~1800 sec) than the bulk of the 304 Å spicules. Our measured values are comparable to some of the macrospicules measured by Moschou et al. (2013). Further studies are required to determine whether the EUV 304 Å spicules and the macrospicules have the same driving mechanism.

A.C.S. and R.L.M. were supported by funding from the Heliophysics Division of NASA's Science Mission Directorate through the Living With a Star Targeted Research and Technology Program, and the Hinode Project. I.R.S. was supported by NSF's Research Experience for Undergraduates Program.

Acknowledgements

I would like to sincerely thank Alphonse Sterling for introducing me to the fascinating science of solar physics and offering me constant support and guidance throughout the summer. A special thanks to David Falconer for all the coding assistance and Ron Moore for all the advice to improve my presentation. Also, my genuine appreciation to Samaiyah Farid and Jacob Heerikhuisen for offering me this phenomenal opportunity. I would finally like to recognize the University of Alabama in Huntsville for the comfortable housing, and all my fellow REU interns for making this the summer of a lifetime. This work was supported by the National Science Foundation under Grant No. AGS1157027.

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