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Analysis of Hα Observations of High Altitude Coronal Condensations

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Abstract. Preliminary analysis of Hα images of high-altitude coronal condensation known as "coronal spiders" is presented. The kinematics of material seen draining from the coronal spiders are also studied. An estimate of the mass of the object for a range of electron temperatures and electron densities is obtained.

1. Introduction

Coronal spiders are suspended plasma visible in Hα approximately $0.1R_\odot$ above the solar limb, and which may last for hours or days. In the descending phase of the solar cycle, they are quite common, occurring on average once every ten days. Some of the more remarkable observed features of coronal spiders include their height above the limb, the span of the footpoints, and the lack of an observable mechanism of support for the central mass. These characteristics raise interesting questions concerning the topology of the magnetic field in the corona where coronal spiders are observed.

The coronal spiders studied in this paper were seen in Hα images of the High Altitude Observatory's Prominence Monitor. An example of one of the coronal spiders studied is shown in Figure 1. A quantitative description of some of the spiders observed is given in Table 1.

The work presented here is principally descriptive and diagnostic, and has been pursued in the hope that these results will be useful in studying the origin and role of suspended mass in coronal structures. Observations of coronal spiders raise several questions concerning their nature and relevance to coronal dynamics. In particular, one would like to know what the magnetic field structure is like, and if it is possible to use the falling mass to trace the field lines. To this end, an investigation into the kinematics of small knots of material seen draining from the central mass of the spider is discussed in Section 2. Further, since no upwelling of mass from the chromosphere into the spiders has been observed, the question arises of where the emitting plasma originates. As a first approach to this question, Section 3 presents a mass estimate for the coronal spider of January 24, 1992.

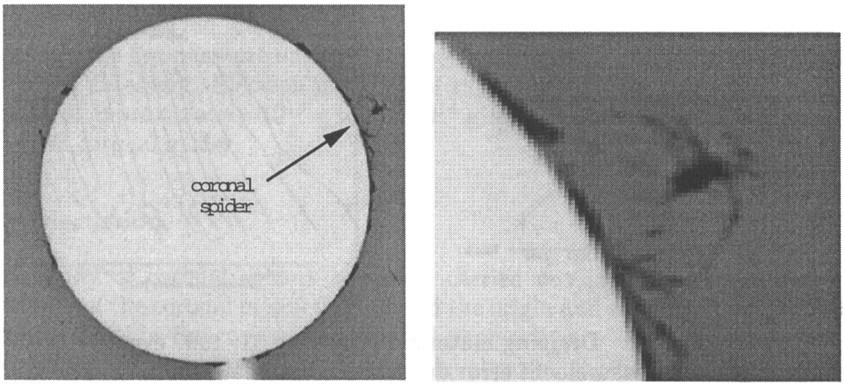


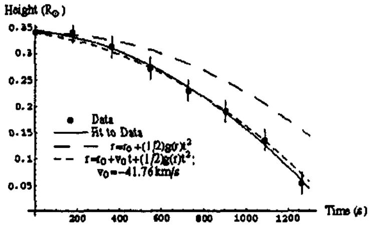
Figure 1. (a) Hα image of the coronal spider (arrow) of January 24, 1992. (b) A close-up of the same coronal spider.

Table 1. Descriptive statistics for seven coronal spiders.

Event	Duration	Height above limb	Width	Length	Footpoint Span
2 January 92	1 day	70,000 km	14,000 km	55,000 km	150,000 km
3 January 92	30 minutes	70,000 km	14,000 km	35,000 km	140,000 km
12 January 92	3 hours	14,000 km	30,000 km	40,000 km	none visible
18 January 92	1 day	83,000 km	20,000 km	70,000 km	180,000 km
24 January 92	1 day	70,000 km	20,000 km	40,000km	180,000 km
29 January 92	2 days	30,000 km	40,000 km	70,000 km	150,000 km
1 March 92	1 day	55,000 km	85,000 km	30,000 km	165,000 km

2. Kinematics

The kinematics of a small knot of falling material were examined in order to ascertain whether the fall might be along a magnetic field line. The event studied, chosen to minimize projection effects, was the January 31, 1997 "tower" event, which looks similar to an earlier stage of some of the spiders described in Section 1. In a movie made from digital Prominence Monitor images taken at three minute intervals, the draining material seemed to be in free-fall, and movement was primarily vertical. Edge-enhanced images of the selected event were used to better indicate the position of the knot of material. The radial position of the falling mass is shown in Figure 2. The estimated error included in the plot is due to the motion of the occulting disk with respect to the limb, as well as to the change in shape of the falling material. Figure 2 shows that the data are fit well by a quadratic. In particular, free-fall in solar gravity with an initial downward velocity of 41.76 km/s fits the data well within the observing error. Such an initial velocity, while large, is not unreasonable, and could be due to a force imparted to the falling mass before it becomes visibly separate from the central mass. Alternatively, had the mass started falling from rest 100 seconds earlier from several thousand kilometers higher, a velocity of 42 km/s could easily have been attained by the time its motion became discernable. These results suggest that, for this event, the mass may be falling along a magnetic field line.



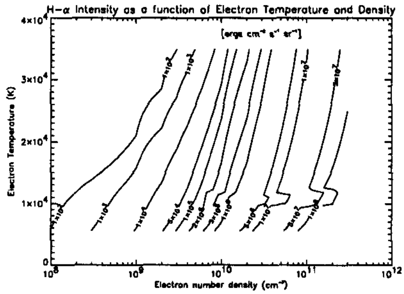


Figure 2. Left: Draining material in January 31, 1997 event. Error bars indicate measurement error due to observational problems such as motion of the occulting disk.

Figure 3. Right: Contour plot showing Hα intensity as a function of electron density and electron temperature (deviations near 10^4K are due to slow convergence of the code and should be ignored).

3. Mass Estimate

In order to better understand the formation of coronal spiders, it is desirable to obtain an estimate of the mass. From the Hα intensity observed in the Prominence Monitor data, the population of the n=3 level of hydrogen can be obtained, assuming a suitable length dimension and optical thinness. A radiative transfer code is then used to determine what range of electron temperatures and electron densities could produce the observed Hα intensity, following the method of Athay and Illing (1986). A mass estimate for the spider is obtained from the total density, the two observed dimensions of the spider, and the unobserved third dimension which is assumed comparable to the two observed dimensions.

The radiative transfer code used to predict the n=3 population for various electron temperatures and electron densities was developed by P. Judge at the High Altitude Observatory. The model consists of a uniform layer 30,000 km thick of neutral and ionized hydrogen. Hydrogen is modeled as a six-level atom, with five bound states and a continuum. The statistical equilibrium equations are then solved numerically to obtain ratios of bound state populations to protons.

For the January 24, 1992 coronal spider, the intensity observed in the Hα image was $2.19 \times 10^9\, erg\, cm^{-2}\, sr^{-1}\, s^{-1}$. If a linear dimension of 30,000 km is assumed, then the observed intensity yields a value for the n=3 population of 6.87 cm^{-3}, since

$$I(H\alpha) = \left(\frac{h\nu_{32}}{4\pi}\right) n_3 A_{32} L \tag{1}$$

where L is the linear dimension of the spider, and $A_{32} = 4.4 \times 10^7\, s^{-1}$ is the transition rate out of the n=3 level.

A contour plot (Figure 3) shows the range of electron densities which can give rise to the observed Hα intensity for electron temperatures between 5,000 K and 40,000 K. Electron densities between 3×10^9 cm^{-3} and 2×10^{10} cm^{-3} will

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produce the observed Hα intensity for electron temperatures in this range. To constrain the temperature or density range, measurements in other wavelengths would be necessary. Electron densities of this range yield a range of estimated masses of approximately 10^{13} g to 5×10^{14} g for the dimensions of the January 24, 1992 coronal spider.

4. Discussion

This study of coronal spiders has been carried out in order to examine the structure of the coronal magnetic field and the origin and support of mass density enhancements in the corona from a novel perspective.

While the observational difficulties involved in the field-tracing technique described in Section 2 limit its applicability to other events, it is hoped that such a technique will permit the magnetic field topology to be more confidently traced. In addition, the draining of mass from the central body of the spider is of interest in establishing the source of the spider mass, as well as the reasons for its disappearance.

The mass estimate of the coronal spider shows that a significant mass – approximately one-hundredth of the mass involved in a typical coronal mass ejection – is suspended high in the corona for an extended period of time. Ten to one hundred times more dense than the surrounding corona (Athay 1976), the plasma would require 10^{28} erg to be raised from the photosphere to a height typical of spiders. Observation seems to suggest, however, that mass of chromospheric temperature and density is not lifted to the spider, but that coronal plasma condenses to form the spider. Questions yet to be answered in the study of coronal spiders include what kind of magnetic field structure might support them, and what kind of conditions in the corona favor their formation.

Acknowledgments. We wish to acknowledge the assistance of Phil Judge in the application of the radiative transfer code, developed to solve a somewhat different problem, to coronal spiders.

References

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