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14. ABSTRACT

Solar prominences are very dynamic objects, showing continuous motions down to their smallest resolvable spatial and temporal scales. However, as macroscopic magnetic structures, they are remarkably stable during their quiescent phase. We present recent ground-based and *Hinode* observations of large-scale bubble-like, dynamic sub-structures that form within and rise through quiescent prominences without disrupting them. We investigate the similarities and differences of the *Hinode* and ground-based observations and discuss their implications for models of prominences.

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Observations of Large-Scale Dynamic Bubbles in Prominences

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Abstract. Solar prominences are very dynamic objects, showing continuous motions down to their smallest resolvable spatial and temporal scales. However, as macroscopic magnetic structures, they are remarkably stable during their quiescent phase. We present recent ground-based and *Hinode* observations of large-scale bubble-like, dynamic sub-structures that form within and rise through quiescent prominences without disrupting them. We investigate the similarities and differences of the *Hinode* and ground-based observations and discuss their implications for models of prominences.

1. Observations of Bubbles within Prominences

Quiescent prominences of the “hedgerow” type are known to have a filamentary structure and downflows. They also often show quasi-stationary, dark, convex regions at their base. The Solar Optical Telescope (SOT) on-board *Hinode* (Tsuneta et al. 2008) provides observations of prominences from space with an unprecedented spatial resolution of about $0.2''$ and temporal cadence of less than 30 s showing that prominences are very dynamic down to their smallest resolvable scale. These new observations led to the discovery of small-scale, continual upflows in the form of dark turbulent plumes (Berger et al. 2008; see also Berger et al. in this volume). At these high spatial resolutions, macroscopic curtain-like prominence structures are seen to be composed of vertically oriented filaments of plasma with widths of only a few hundred kilometers that are separated by dark vertical lanes of comparable widths. Typically, the bright filaments show continual downward motions, while irregular dark plumes are seen to rise upward with velocities of about $10\text{--}20\text{ km s}^{-1}$ (Berger et al. 2008). *Hinode*/SOT has also observed a few cases of large, bubble-like features at the base of quiescent hedgerow prominences. We report on two events on April 25, 2007 and August 16, 2007, when these bubble-like structures in prominences were observed simultaneously in Ca II $\lambda 3968$ and H α for several hours. These large and dark bubbles first grew quasi-steadily, then rose and appeared to push the bright prominence plasma aside in order to travel upward, reaching a significant height within the prominence before losing their round shape. These high-cadence observations are interesting to compare with recent ground-based observations of more dynamic bubble events in quiescent prominences (de Toma et al. 2008).

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1.1. *Hinode* Observations

On April 25, 2007 *Hinode*/SOT observed a relatively dark, arched region rimmed with a thin bright boundary at the base of a quiescent prominence. This bubble-like region was quasi-stationary at first and after 1330 UT started to move upward accelerating up to $\approx 10\text{--}12\text{ km s}^{-1}$. The bubble broke up losing its shape before reaching the prominence top. This bubble had relatively low contrast. Significant sub-structures, including dark upflowing plumes and bright downflows, were noticeable "inside" the bubble. Because these observations are affected by line-of-sight integration, and the full 3-dimensional geometry of the bubbles is not known, we cannot tell whether these sub-structures were part of the bubble itself or simply unrelated structures along the same line-of-sight.

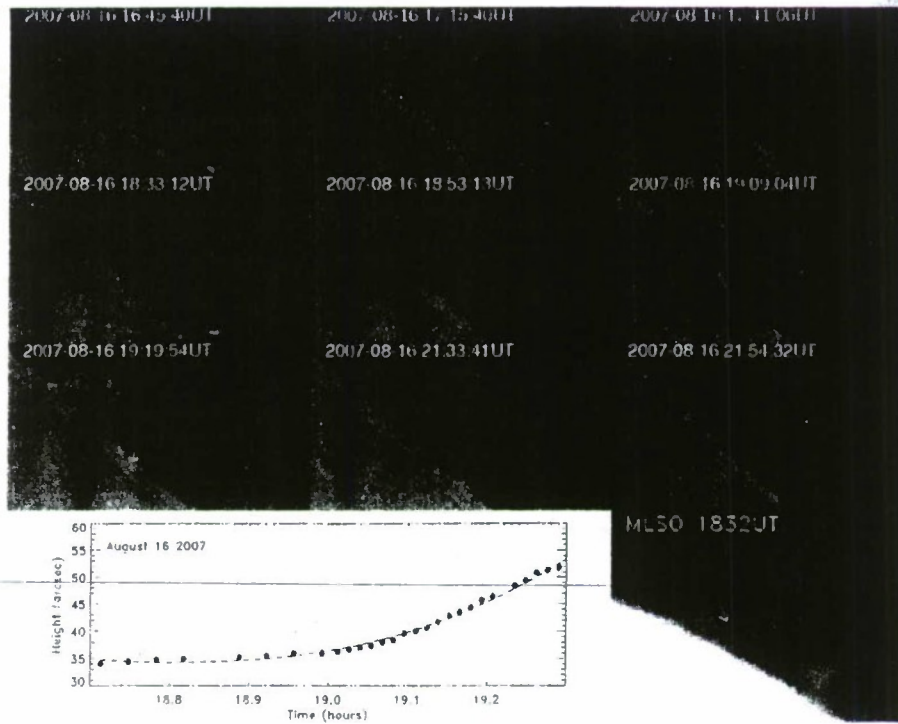


Figure 1. $H\alpha$ images taken with *Hinode*/SOT, showing the rise, break-up, and subsequent reformation of the bubble on August 16, 2007 (top three rows). Note that the bubble shape changed as it moved upward. We also show the trajectory of the bubble during its fast ascent (bottom left), and a lower-resolution image of the bubble taken at MLSO (bottom right).

The bubble observed on August 16, 2007 (Fig. 1) was longer lived, wider, and had higher contrast than the one of April 25. The bubble was seen to slowly grow in size and rise. During its ascent, its apparent width increased from less than $40''$ to about $55''$. The bubble's bright boundary at times lost definition, and the bubble appeared to be at the point of break-up, but then restructured itself to its original shape. Around 1900 UT the southern end started to acceler-

ate reaching a velocity of about 20 km s^{-1} and a height of $\approx 56''$ before breaking up at $\approx 1923 \text{ UT}$. Interestingly, the bubble was seen to reform at about the same location about 90 min after it broke, and started to slowly rise and grow again reaching up to $65''$ in width.

1.2. Ground-Based Observations

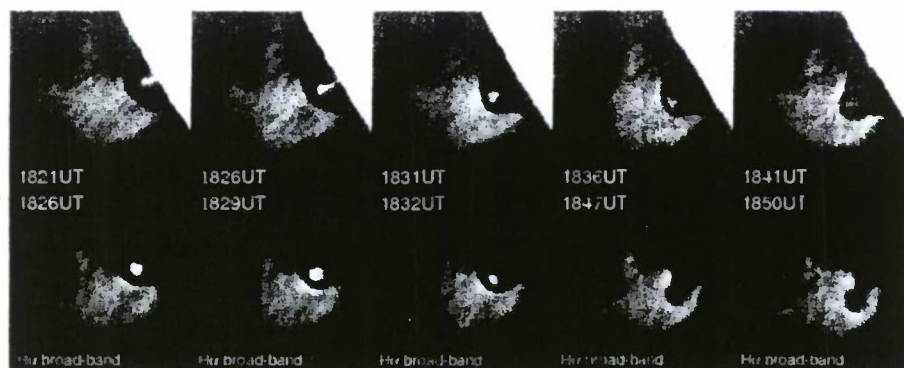


Figure 2. $H\alpha$ images taken with the Improved Solar Observing Optical Network (ISOON) at NSO/SP (top) and with the Polarimeter for Inner Coronal Studies (PICS) at MLSO (bottom) on November 8, 2007. The top images, taken 5 min apart, show the details and evolution of the bright core inside the bubble as it approached the bubble top. The bottom images, taken during the early (left three panels) and late (right two panels) phase of the event, clearly show the bright front and the necking of the bubble.

On November 8, 2007 an unusual and dynamic event in a solar quiescent prominence was observed in $H\alpha$ (656.3 nm) and He I (1083 nm) with the instruments of the Mauna Loa Solar Observatory (MLSO) and at the National Solar Observatory/Sacramento Peak (NSO/SP). A large-scale, dark bubble with a bright core rose vertically through the prominence without causing it to erupt (Fig. 2). The bubble had an approximate width of $40''$, and moved upward from the prominence base at an average speed of 12 km s^{-1} . It formed a bright front, likely due to compression of prominence material, as it traversed the prominence up to the top. A compact and bright core developed inside the bubble and was seen to accelerate from 12 km s^{-1} to about 20 km s^{-1} , leaving a thin trail of material behind. The bubble changed its shape during the rise, assuming a "keyhole" shape before fading from view. A second elongated, dark bubble was also seen to rise at the north edge of the prominence almost simultaneously to the first one. Also in this case, we could see filamentary downflows similar to those observed in the *Hinode* events described above.

A similar dynamic bubble, but with a much fainter core, was observed at MLSO on April 6, 2008. As in the previous event, a dark bubble was seen to rise upward, traversing most of the prominence, and finally evolving into a key-hole shape before fading.

2. Discussion

The events described above—a large-scale, bubble-like disturbance moving through a quiescent prominence without causing its eruption—pose several interesting physical questions on the nature of prominences. In spite of the fact that these dark bubbles were comparable in size to the prominences, their only effect was to displace the prominence plasma leaving the overall shape of the prominence very similar to that before the event. *What is the hydromagnetic nature of this remarkable stability of quiescent prominences?* The continuous presence of rising, vertically elongated dark plumes amidst generally descending, narrow vertical bright filaments make us wonder if the stability of the macroscopic structure is distinct from the one that permits the unstoppable rise of a larger-scale, dark bubble up through the entire prominence.

It is not clear if the bubbles observed by *Hinode* and at MLSO are the same physical phenomenon. They have several similarities: their sizes (20–60"), round shapes, relative darkness, and velocities (10–20 km s⁻¹). They also have significant differences: the *Hinode* bubbles were relatively more stationary, longer-lived, and, in one case, the bubble reformed at the same location. The MLSO bubbles were more dynamic, had higher contrast, a bright core, and a bright front that suggests the effect of dynamical compression. *What is the physical nature of these bubbles?* One possibility is that they are organized, closed magnetic structures whose stronger magnetic pressure makes up for the lower gas pressure of its low-density interior. Such structures may persist in quasi-static evolution until a large-scale reconfiguration is necessary for the prominence to find the next available quasi-static equilibrium, as suggested by hydromagnetic models (e.g., Forbes and Isenberg 1991). Alternatively, these bubbles can be high-temperature plasmas, produced by some dynamical heating, that rise convectively through the macroscopic magnetic structure (Berger et al. 2008).

We believe these phenomena merit further observational and theoretical investigation. The answers to these questions are needed for a complete physical understanding of quiescent prominences, from their birth, through quasi-steady evolution, to eventual eruption in association with a coronal mass ejection. Spectro-polarimetric observations are essential to understand the magnetic nature of prominences and their sub-structures. In the case of the fast evolving events described here, imaging spectro-polarimetry is to be preferred. While still challenging, this type of measurements are within reach of present-day instrumentation (e.g., with Arcetri/NSO/IBIS), and should actively be pursued. For this purpose, HAO is proposing the construction of a dedicated instrument (ChroMag) to measure chromospheric magnetic fields and flows.

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References

- Berger, T. E., et al. 2008, *ApJ*, 676, L89
- de Toma, G., Casini, R., Burkepile, J. T., and Low, B. C. 2008, *ApJ*, 687, L123
- Forbes, T. G., and Isenberg, P. A. 1991, *ApJ*, 373, 294
- Tsuneta, S., et al. 2008, *Solar Phys.*, 249, 167