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THE MICROWAVE STRUCTURE OF QUIESCENT SOLAR FILAMENTS AT HIGH RESOLUTION

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ABSTRACT

We present high resolution VLA maps of a quiescent filament at three frequencies. The spatial resolution (~15" at 1.45 GHz, ~6" at 4.9 GHz, and ~2" at 15 GHz) is several times better than previously attained. At each frequency, the filament appears as a depression in the quiet Sun background. The depression is measurably wider and longer in extent than the corresponding Hα filament at 1.45 GHz and 4.9 GHz, indicating that the depression is due in large part to a deficit in coronal density associated with the filament channel. In contrast, the shape of the radio depression at 15 GHz closely matches that of the Hα filament. In addition, the 15 GHz map shows enhanced emission along both sides of the radio depression. A similar enhancement is seen in an observation of a second filament obtained 4 days later, which suggests that the enhancement is a general feature of filaments. Possible causes of the enhanced emission are explored.

I. INTRODUCTION

Quiescent solar filaments are clouds of relatively low temperature plasma (6500 K) suspended in and surrounded by plasma at coronal temperatures (> 10^6 K). The observed close proximity of cool and hot gas over a lifetime of many days requires very complete magnetic isolation of the filament plasma. Given this general picture, it seems necessary to postulate the existence of some structure (which we will call the "transition-sheath", in analogy to the chromosphere-corona transition region) that separates these regions of cool and hot gas (Butz et al. 1975; Schmahl et al. 1974). Radio observations at multiple frequencies should be sensitive to the presence of such a filament transition-sheath, especially when a portion of the sheath is seen edge-on.

Microwave observations of filaments with rather poor (a few arcmin) resolution (Rao and Kundu 1977; Raoult et al. 1979) consistently show filaments to be roughly the same size as the filament as seen in Hα, and depressed in brightness relative to the surrounding quiet Sun. The microwave observations of Rao and Kundu (1980), who obtained the best spatial resolution (15" at 5 GHz) prior to the present work, again show the depression to be very similar in size and shape to the Hα filament. In contrast, observations by Bracewell and Graf (1981) with 17" resolution at 10.7 GHz indicate a depression larger than the filament, with a central brightening corresponding to the filament itself. The latter authors suggest that the depression commonly seen at lower resolution is the filament cavity, and that observations at higher resolution would also have shown the filament as enhanced. A model by Straka et al. (1975) supports this suggestion, but observations of a filament depression over several days as it approached the limb (Schmahl, Bobrowsky, and Kundu 1981) were not consistent with the brightening Straka et al. predicted.

Observations in the most compact array configuration of the VLA have been made by Dulk and Gary (1983) at 1.45 GHz, and by Kundu, Melozzi, and Shevgaonkar (1986) at 1.45 and 4.9 GHz. These observations generally support the earlier observations of Rao and Kundu (1980). They show a depression that is somewhat larger than the Hα filament, but do not show an enhancement. The resolution of these observations is still quite poor, however, and at significantly lower frequencies than the observations of Bracewell and Graf (1981).

Here we present new three frequency observations made with the VLA in its hybrid C/D configuration, which gives higher resolution than the D configuration used for previous VLA observations while retaining the short spacings necessary for high quality large-scale maps. In §II we present the observations of one quiescent filament for which the data quality is particularly high, and compare the maps to the corresponding Hα image. A second filament was observed 4 days later, and the 15 GHz map is also presented, verifying that an observed enhancement along the edges of the filaments is a general feature at this frequency. In §III we consider the possible causes for the enhancement. We conclude in §IV with a discussion of the implications of these observations for the structure of the filament.

II. OBSERVATIONS

The Very Large Array of the National Radio Astronomy Observatory * was used in its C/D configuration to observe solar quiescent filaments on 1984 July 16 and 1984 July 20. The array was time-shared among three frequencies—1.45 GHz, 4.9 GHz, and 15 GHz—to produce 12 hour synthesis maps on 16 July, and 6 hour synthesis maps on 20 July. The data were amplitude calibrated against the standard calibrator 3C48. Regrettably, however, the on-line correction for system temperature was incorrect, yielding brightness temperature values that are untrustworthy. Since the required multiplicative factor is as yet undetermined, we will discuss only relative brightness variations in the maps.

The maps at three frequencies for 16 July are shown in Figure 1, along with the corresponding Hα image from Caltech, all to the same scale. In the figure, positive contours are drawn with heavy lines, and negative contours with light lines. The filament is easily seen as a depression (that is, negative contours) at each frequency, where the lowest contours correspond well to the Hα filament. Positive contours in the 1.45 and 4.9 GHz maps correspond to slight brightenings of plage in the Hα image. In contrast, the 15 GHz map shows lanes of bright emission on either side of the filament that seem to have no counterpart in the Hα image.

The observation of a second filament 4 days later gives us an opportunity to check whether these bright features at 15 GHz are structures generally associated with filaments, or are peculiar to the filament in Figure 1. The map of a quiescent filament, observed on 20 July, was synthesized over 6 hours, rather than the twelve hours used for the maps in Figure 1, but otherwise the observations are similar. A flare occurred in an active region to the north of the filament on 20 July, which adversely affected the observations at lower frequencies. The 15 GHz observations, however, were not affected due to the smaller field of view at the higher frequency. The map is shown in Figure 2, where the filament stretches diagonally across the map in nearly the same orientation as the filament in Figure 1. Again the filament appears as a depression similar in shape to the corresponding Hα filament (not shown), and again the bright lanes of emission appear flanking the filament. We now turn to a discussion of the origin of these bright lanes of emission.

III. POSSIBLE CAUSES OF THE ENHANCED EMISSION AT 15 GHZ

A. Instrumental Effects

There are two effects that could cause an apparent enhancement along the edges of a depression in VLA data. The first is the effect of bad or improperly calibrated data samples. In radio synthesis, a data sample from a pair of antennas represents a measurement of a single fourier component of the sky brightness distribution. An abnormally high amplitude measurement for a single antenna pair results in linear "stripes" of alternating bright and dark features in the map. From an examination of plots of amplitude versus baseline over the duration of the observations, we conclude that no abnormally high amplitudes are included in the maps.

The second instrumental effect is the VLA response to a sharp edged, broad-topped feature. Because the VLA does not measure low and zero spatial frequency fourier components, a depression shaped like a rectangle function (*cf.* Bracewell 1978) might appear with bright edges. However, since we know the smallest spacing of the VLA in the C/D configuration, we can predict how broad such spurious bright features would be. The smallest spacing corresponds to a spatial scale of more than 150", which implies that missing spacings can cause features only of order this size, whereas the features we are discussing are more than an order of magnitude smaller (10" in size). We conclude that the bright emission features cannot be due to missing spatial frequencies.

We further note that the fidelity of the map is sufficiently high, as demonstrated by the comparison of the negative contours with the Hα filament in Figure 1, that the bright features must be regarded as real solar features. Possible identification of these features is discussed in the next subsection.

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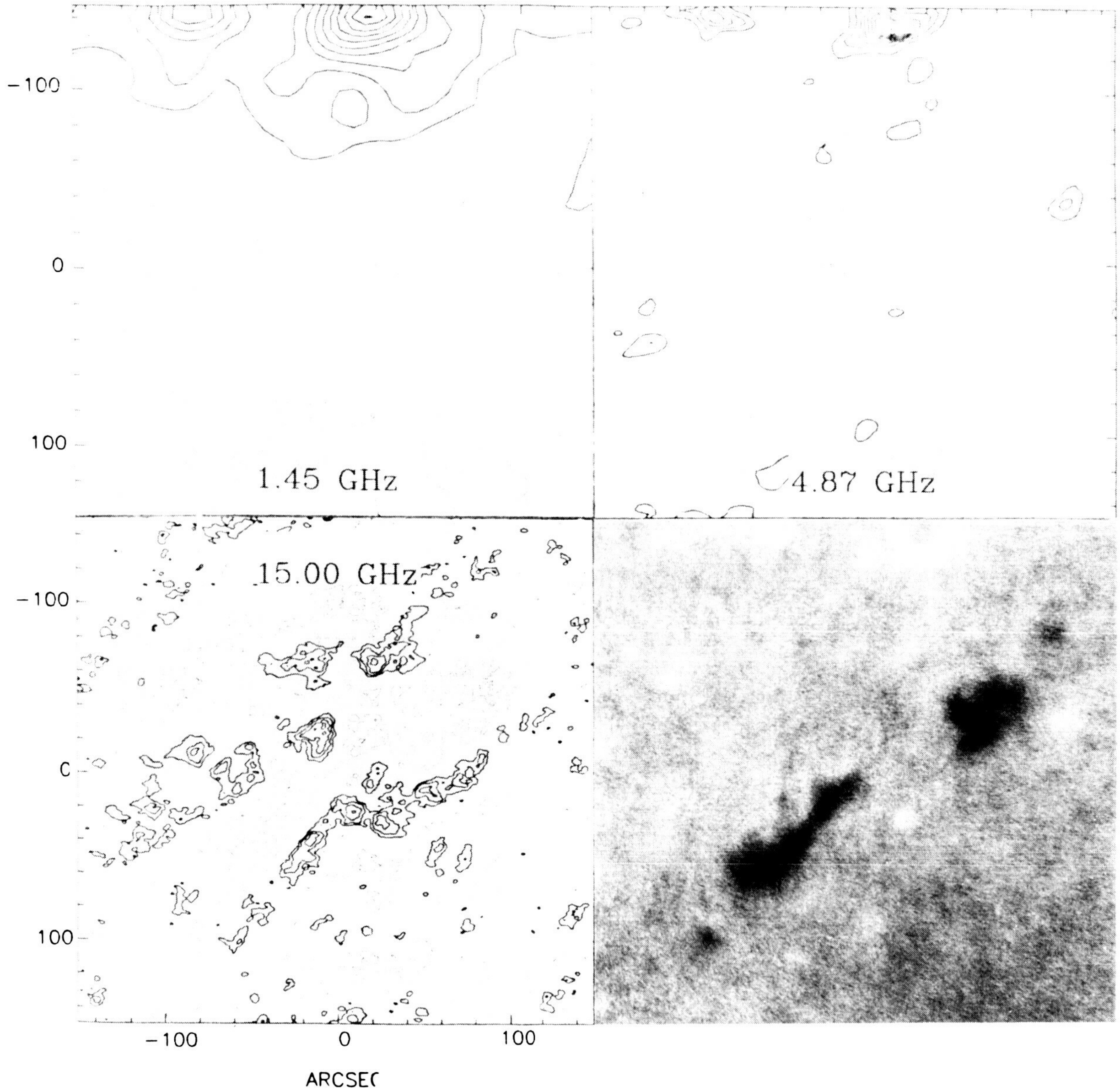

Figure 1. Contour plots of a filament observed on 1984 July 16 at three frequencies, together with an Hα image obtained at Caltech, all to the same scale. The heavy contours outline regions enhanced relative to the background brightness, while light contours represent regions depressed in brightness. The 1.45 and 4.9 GHz maps show the typically observed depression associated with, but somewhat larger than the filament. The unique 15 GHz observation, however, shows a previously unreported feature, enhanced emission along the edges of the filament depression. See text for possible explanations of this phenomenon.

B. Solar Features

There are at least three possible solar origins for the emission: 1) emission from chromospheric plage, unassociated with the filament, that is coincidentally aligned with the filament axis, 2) emission from chromospheric plage that marks the footpoints of the magnetic loops that support the filament, and 3) emission arising well above the chromosphere, unassociated with plage, that marks the edges of the filament transition sheath. We discuss each of these possibilities in turn.

Coincidental Alignment of Plage

Undoubtedly some of the areas of enhanced 15 GHz radio emission arise from plage regions, since there is occasional correspondence between some of the bright radio features and slight enhancements in Hα in Figure 1. However, it seems unlikely that the plage associated regions will appear *coincidentally* along the edges of the filament in such a way as to give the impression of a nearly continuous lane of emission, as appears especially along the lower edge of the filament in Figure 1. Further, there is a clear absence of enhanced emission away from the edges of the both filaments in Figures 1 and 2.

Enhanced Plage Associated with the Filament

The bright lanes of enhanced emission are reminiscent of the two ribbon flares sometimes seen associated with erupting quiescent filaments (Tang 1986). Certainly the supporting magnetic field lines required in any filament model will intersect the chromosphere somewhere along the edges of the filament channel, and perhaps be the site of local heating. However, this scenario would seem to require enhanced Hα plage along the edges of filaments, whereas such plage is not generally seen, nor is it visible in Figure 1. In addition, the radio enhancement is not seen at lower frequencies, even though both the 1.45 and 4.9 GHz maps show bright features at the other sites of plage. It remains possible that some heating is taking place that is visible at 15 GHz, but does not affect the region of the chromosphere where the Hα spectral line is formed. If this is the case, enhanced emission in some UV lines would be expected. Confirmation must await more complete observations, including UV observations of filaments at the required 10" resolution.

Emission From a Transition Sheath

If a transition sheath surrounds the cool filament material, it should be visible as optically thin emission at 15 GHz. This emission would be expected to be brightest where the line of sight depth of the transition sheath is greatest, *i.e.* along the edges of the filament, in agreement with the observations. The breadth of the lanes of emission in Figures 1 and 2 is about 10", or about 7000 km. This is probably much broader than the transition sheath itself, but increased breadth can be accounted for by irregularities in the shape of the sheath. This possibility also requires confirmation from more complete observations, however.

IV. IMPLICATIONS OF THE ENHANCED EMISSION AT 15 GHZ

We have argued that the bright lanes of emission seen in the 15 GHz map of Figures 1 and 2 are solar features associated with the filament. We are left with two contending possibilities: emission either from the footpoints of the magnetic loops supporting the filament or from a transition sheath surrounding the filament. In either case, these new observations give an indication of a filament associated structure never before directly observed. (It is possible, however, that the report by Bracewell and Graf (1981) of a brightening associated with a filament at 10.7 GHz refers to the same phenomenon as shown here.)

The separation of the bright lanes is about 70" for both filaments, suggesting that this size scale is not uncommon. Comparing the 15 GHz map in Figure 1 with the 4.9 GHz map, it can be seen that the bright lanes at 15 GHz lie at the outer edges of the filament channel. Note that there is a gap in the Hα filament, while the filament channel marked by the depression at 1.45 and 4.9 GHz shows no gap. While the depression at 1.45 and 4.9 GHz results partly from a deficit in coronal material in the filament channel (Kundu, Melozzi, and Shevgaonkar 1986), probably there is also some opacity contributed by the cool material within the Hα filament itself, especially at higher frequencies.

The fact that the filament extends upward for some distance into the corona suggests an observational test of the two possible origins for the 15 GHz enhanced emission. If the emission is located at footpoints, the

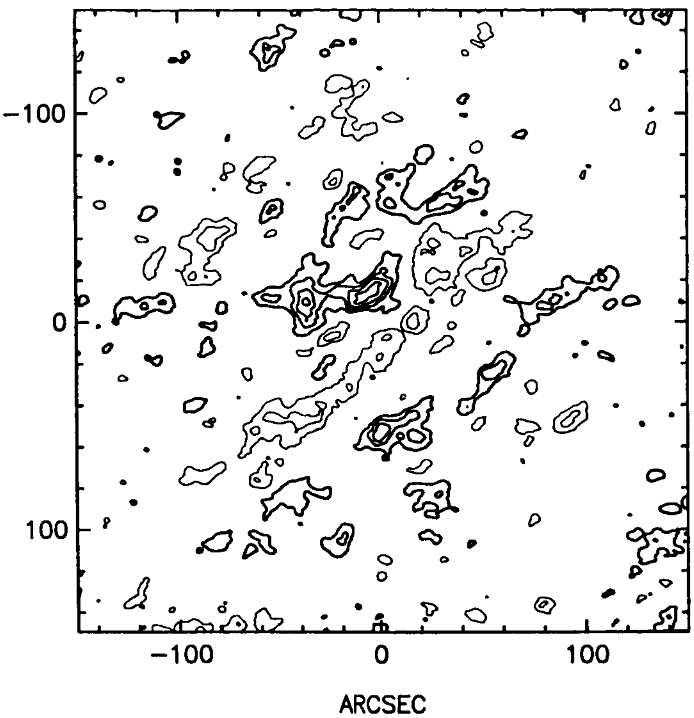

Figure 2. The 15 GHz map of a second filament observed on 1984 July 20. A comparison with the 15 GHz map in Figure 1 shows that the bright lanes of emission along the edge of the filament depression are similar in the two maps. This suggests that the phenomenon is a general one.

lane of emission on the limbward side of the filament will be occulted as the filament approaches the limb. If the emission arises from a transition sheath, on the other hand, the limbward edge of the filament should remain while the other edge becomes less apparent, reflecting a more irregular sheath on the underside of the filament. VLA observations over several days as a filament approaches the limb would allow this question to be resolved.

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REFERENCES

Bracewell, R. N. 1978 *The Fourier Transform and Its Applications*, McGraw-Hill, New York, p52..

Bracewell, R. N. and Graf, W. 1981, *Nature*, **290**, 758.

Butz, M., Fürst, E., Hirth, W., and Kundu, M. R. 1975, *Solar Phys.*, **45**, 125.

Dulk, G. A. and Gary, D. E. 1983, *Astron. Astrophys.*, **124**, 103.

Tang, F. 1986, *Solar Phys.* in press..

Kundu, M. R., Melozzi, M., and Shevgaonkar, R. K. 1986 *Astron. Astrophys.* in press..

Rao, A. P. and Kundu, M. R. 1977, *Solar Phys*, **55**, 161.

Rao, A. P. and Kundu, M. R. 1980, *Astron. Astrophys.*, **55**, 161.

Raoult, A., Lantos, P., and Furst, E. 1979, *Solar Phys.*, **61**, 335.

Schmahl, E. J., Foukal, P. V., Huber, M. C. E., Noyes, R. W., Reeves, E. M., Timothy, J. G., Vernazza, J. E. and Withbroe, G. L. 1974, *Solar Phys.*, **39**, 337.

Schmahl, E. J., Bobrowsky, M., and Kundu, M. R. 1981, *Solar Phys.*, **71**, 311.

Straka, R. M., Papagiannis, M. D., and Kogut, J. A. 1975, *Solar Phys.*, **45**, 131.