FLARE OF 1970 MARCH 01
A REVIEW AND FURTHER EVIDENCE FOR ADIABATIC HEATING

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Summary. The microwave and hard-X-ray burst of 1970 March 01, 11:27 UT was found to originate from a common thermal plasma with a maximum temperature of 57 keV. The low coronal plasma with an average electron density of about $3.10^8 \mathrm{cm}^{-3}$ covered a projected area of 5.10^{18} cm^2. In Fig. 1 the time profiles of the emission measure and the temperature are compared with the 10.5 GHz flux while Fig. 2 shows the reversible relationship between the hard X-ray emission measure and temperature during the impulsive phase. The arrows indicate the direction of increasing time. The dashed-dotted line, representing an adiabatic process with an index $\varkappa = 5/3$, agrees well with the observations showing a compression followed by an expansion (Mätzler et al. 1978).

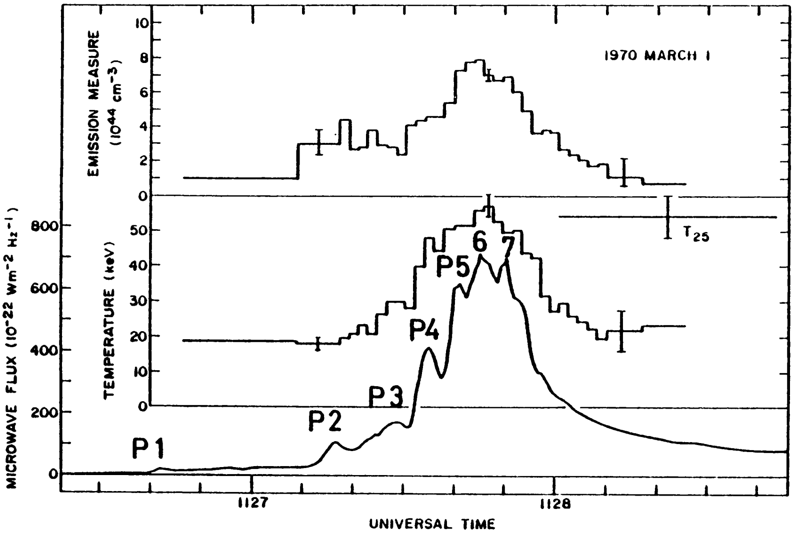

FIGURE 1. Time profiles of the emission measure and temperature compared with the 10.5 GHz flux.

In such a high-temperature plasma the microwave radiation is strongly

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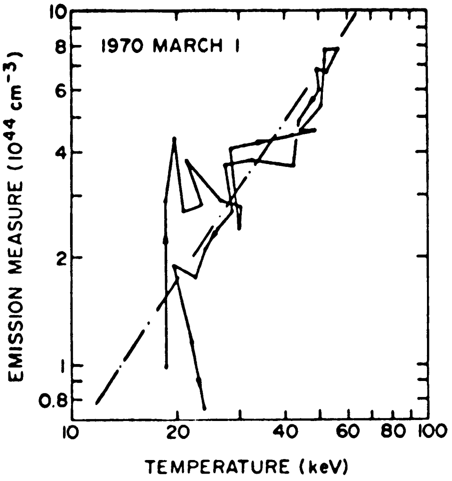
self-absorbed by the gyrosynchrotron process leading to a black-body spectrum at low frequencies up to high harmonics of the cyclotron frequency. Because the optically thin part of the radiation can be neglected the microwave flux is given by

$$I(f,t) = 0.16 \cdot f^{2} \cdot T(t) \cdot A(f,T(t)) \qquad \text{(SFU)} \qquad (1)$$

where A(f,T(t)) is that area of the source which is optically thick at frequency f in GHz and temperature T in keV.
The function A(f,T(t)) was investigated for serveral processes and it was found (Mätzler 1978) that only for a compression along magnetic field lines could agreement between observed and calculated flux be found.

The hard X-ray and the 10.5 GHz microwave time profiles are modulated during the rise phase but exhibit a smooth decay. Seven distinct peaks are identified (Fig. 1) and their peak to peak time seperations are called quasi-period τ which decreases with increasing flux. Particularly a strong correlation was found between τ and T as shown in Fig. 3.



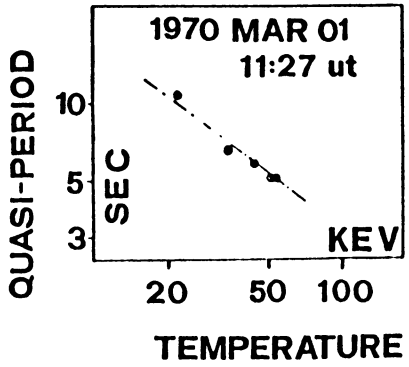


FIGURE 2. Correlation diagram between emission measure and temperature. The dashed-dotted line represents the relationship for an adiabatic process with index $\varkappa = 5/3$.

FIGURE 3. Correlation diagram between quasi-period τ and temperature T. The dashed-dotted line represents $\tau \propto T^{-0.75}$.

Under the assumption that the modulations are caused by a disturbance travelling along the magnetic field lines at the Alfvén speed V_A the quasiperiod is given by the ratio of the length of the compressed region to V_A . For an adiabatic index $\varkappa = 5/3$ the quasi-period τ can be calculated (Wiehl and Mätzler, 1979)

$$\tau = \tau_0 \cdot \left(\frac{T_{max}}{T} \right)^{0.75} \tag{2}$$

For the parameters of the burst of 1970 March 01 τ_0 was estimated to 8.5 sec which agrees well with the observed value of 5.3 sec while the best fit of the data yielded an exponent of 0.83 again very close to the predicted value of 0.75.

The analysis of the quasi-period in terms of equations (1) and (2) shows that τ can be related to the microwave flux I

$$\tau = \tau_0 \cdot \left(\frac{I_{max}}{I} \right)^{\frac{0.75}{\gamma_T + 1}} \tag{3}$$

where γ_T depends on the microwave spectral index, the temperature and the plasma beta. The similarity of the time variations of the temperature and the microwave flux leads to a small value of γ_T , which then can be used to calculate the plasma beta quite accuratly. For this burst we found $\beta = 0.30$.
This well investigated burst belongs to an entire class of events that exhibit modulations during the rise phase only and show a smooth decay. An investigation on other members of this class supports the hypothesis that the modulations occur simultaneously with an adiabatic compression.

REFERENCES

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DISCUSSION

Kundu: I have a couple of questions:
1) You said that in your adiabatic model, pulsations should occur only on the rising phase of the microwave. In the literature, there are plenty of spectacular evidences, especially by Janssens that show periodic pulsations (∿ 10 sec) superposed on the peak of the impulsive phase.

2) You have totally neglected the post-burst phase that usually follows the impulsive phase. The post-burst is unpolarized and of much larger size than the impulsive phase -- I'd not expect it to be explained by your model.

Wiehl: There are at least two classes of quasiperiodic bursts. One class consists of bursts that can be decomposed entirely into a number of individual spikes. However there is also a class of events that exhibit modulations during the rise phase only (Parks and Winkler, 1969, Ap. J. 155, L117; Frost 1969, Ap. J. 158, L159; Wiehl and Matzler, 1979 to appear in Astron. and Astrophys). The work presented here describes only the last class of events. The former class of bursts might be explained by sequential flaring of separate kernels in a complex source.

We explained the polarization associated with the impulsive phase as being due to the fact that the absorption coefficient for the extraordinary mode is always larger by a factor of 2 to 20 than the ordinary mode (Matzler 1978, Astron. and Astrophys. 70, 181). Unless both modes are in the optically thick portion of the spectrum, a high-degree of circular polarization is expected. Our model deals only with the impulsive phase. The post-burst phase may be due to a variety of other mechanisms including second-stage acceleration accompanied by escape of energetic particles into a larger source volume.

Spicer: Are you discussing axial compression or radial compression? If it is axial compression $T_{final} = T_{initial} (V_{initial}/V_{final})^2$ so to go from say 0.5 kev to 20 kev you require $V_{final} \sim 10 V_{initial}$. You also say you start at 20 kev and go to 50 kev. What gives you 20 kev to start with?

Wiehl: The compression is along the magnetic field. The observed change in the emission measure is about a factor of 5, corresponding to an adiabatic index of 5/3. The observed initial temperature of 20 keV clearly requires a preheating mechanism.

Vlahos: Could you give us a schematic configuration of the magnetic field structure around the compressed gas. If any particles escape where do these particles go? What drives the piston which drives the compres sion? Is your interpretation unique?

Wiehl: There are no spatial observations available that would give us direct informations on the geometry of the source. However, our interpretation suggests that the source is primarily a confined one. Escape of a small fraction of electrons might be responsible for the post-burst increase observed at 10.5 GHz. Mass motions as observed in conjunction with the Skylab events, have been suggested as a possible source of the compression force (Matzler et al., 1978). The simple compression-expansion mechanism is the only one proposed to date which yields a Maxwellian distribution of electrons with energies $E \geq 30$ keV together with time profiles of the x-ray and microwave emission consistent with the spike-burst observations. We, of course, do not suggest that more elaborate posibilities have been ruled out.

Kane: In the event you described, the temperature and emission measure increased and decreased simultaneously. However, in many events the emission measure seems to stay constant, or continues to increase even though the temperature is decreasing (cf. Elcan, 1979). What could be happening in such events?

Wiehl: The observations you describe might be from a lower energy range. Our x-ray observations are restricted to $E \geq 30$ keV. You might be seeing the hot source expanding and thereby heating up the previously cold surrounding plasma.

Degaonkar: Could your adiabatic compression model explain quasi-periodicity in microwave burst intensity of the order of 1-5 minutes, although you have considered quasi-periodicity of 1-3 secs?

Wiehl: The quasi-period is dependent on the length of the compressed region, the magnetic field and the electron density. A different set of these parameters will yield a different quasi-period.

Benz: Oscillations of fluxtubes are strongly damped by the coronal medium that surrounds them. They can only persist if something drives them. For periodic fluctuations in metric type IV bursts protons have been suggested. Do you know of any energy reservoir for your pulsations?

Wiehl: The modulations in this class of bursts are indeed strongly damped, as is clearly evidenced by the lack of features on the falling portion of the bursts. On the rising part of the events, the driving mechanism seems to be the compression of the flare plasma.

Crannell: With respect to the comparisons between the March 1 burst, which is the subject of this talk, and the multiple-impulsive events, reported by Janssens, it is important to note the differences in the time scales. The duration of the March 1 burst is only a few tens of seconds, so that it is highly unlikely that the observed features did arise from separate source regions.