

SOLAR RADAR OBSERVATIONS

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Abstract

Radar observations of the sun have been made extensively at decimeter and low meter wavelengths (Eshleman et al., 1960, and James, 1966). Their interpretation by specular reflection on high density structures with "corner reflector" shape is unlikely from the echo spectral broadening and range depth. Gordon's (1973) interpretation of the scattering by a 4 wave interaction between radar and coronal Langmuir waves requires a level of $10^{-2}nKT$ (thermal energy density) of the Langmuir waves. A radar experiment in microwaves with the 300 m dish in Arecibo*) is described, which was able to test this hypothesis. It was based on the idea of scattering radar waves on Langmuir waves by the much more efficient 3 wave interaction. The echo at the beat frequency of the radar (2380 MHz) and the Langmuir wave (170 -270 MHz) is then to be expected at 2600 MHz. The results, however, show the absence of echos, from which an upper limit of $6.10^{-4}nKT$ for the level of Langmuir waves is derived. First results will soon be published (Benz and Fitze, 1979).

Here I report from an other microwave radar experiment in Arecibo which was receiving at the transmitted frequency, similar as the decametric radar observations. We have probed a coronal streamer, a coronal hole, and an active region (emitting noise storm radio bursts).

No echo has yet been detected. Previously, radar observations have been suggested to be possible only at low frequencies, since the optical depth of the plasma layer increases rapidly with frequency, absorbing any echo mirrored at this plasma. However, James' result clearly shows that the reflection occurs well above the plasma layer.

I propose that decametric and low metric radar echos are produced by interactions of the radar wave with ion acoustic waves. Such low frequency electrostatic waves have been suggested by Benz and Wentzel (1979) to be present in type I radio burst sources due to a current-

driven instability, which dissipates free magnetic energy. The requirement of this model on magnetic flux into the corona, 10^{15} gauss cm^2s^{-1} , fits very well the observations. The absence of an echo from Langmuir waves is then due to their low level, and the difficulty to detect echos at high frequency due to the high collisional damping of ion acoustic (and radar) waves at lower heights.

References

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*) The Arecibo Observatory is part of the NAIC which is operated by Cornell University under contract with the US National Science Foundation.

DISCUSSION

Degaonker: How accurately can the height or level of reflection of radar echoes be determined? I would like to know the height from the photosphere from which these decametric echoes are received? I am interested in knowing the height of the transition region from closed to open field lines and its variation.

Benz: The accuracy of the height of reflection is determined by the change in group velocity of the radar waves near the plasma level and the unknown position of the scattering center on the sun. Its distance from the plane through the center of the sun is typically 1.4 solar radii with a maximum range from 0.6 to 2.0. The mean value (1.4 solar radii) may well correspond to the transition you refer to.

Dryer: Is it possible to indicate any possible relevance of the radar observations of wave activity above active regions to the observations of the (so-called) solar flare precursors?

Benz: In principle, this is possible. One would not do this by an experiment like mine with high spatial resolution (and therefore low probability to hit the target), which is more appropriate to a stable source. J. C. James has observed extremely strong echoes during the passage of a coronal shock (type II solar radio burst).

Kuperus: Concluding that a large level of low frequency turbulence exists in a more steady situation could well be interpreted as good evidence for anomalous conductivity in large parts of the active corona.

Benz: Note that the very high level of ion acoustic waves in our noise stress level is very localized in space and time. The low frequency turbulence responsible for the decametric radar echo may be

much weaker. Nevertheless, it would enhance the resistivity above Spitzer's in a large region.

Bratenahl: Low level, low frequency could still represent anomalous resistivity if current path is very narrow with high current density.

Benz: Indeed, I have assumed a source volume V of 10^{28} cm³ for the radar scatterer and the value for the energy density of Langmuir waves scales like $10^{-4} \left(\frac{10^{28}}{V} \right)$. Furthermore, I have assumed that in the average, one source was present during the integration time of 15 min, and that the electron temperature in these sources is 5×10^6 K.

Moore: You seem to favor ion acoustic waves as the basic phenomenon for generating the echo. How do you select this non-magnetic mode over others in which the magnetic field is directly involved?

Benz: I do not. The Benz and Wentzel noise storm model suggests ion acoustic waves as the cause of the bursts. For the radar reflection process lower hybrid or ion cyclotron waves may well be more important.

Gergely: I believe that reconnection related to noise storms cannot be a primary dissipation mechanism. There are active region complexes which are seen on the disk for seven or eight rotations. They sometimes produce a storm during one rotation, no storm during the next, and a storm again during the third. So there must be something in the field geometry which determines if there is or is not a storm. Some of the strongest storms are related to old, decaying regions, not young regions.

Benz: The energy release in the Benz and Wentzel type I model is less than 10% of the energy input into an active region. The density in noise storm sources is between 10^7 and 10^9 cm⁻³, which makes it difficult to detect them in X-rays. The fact that noise storms also occur in decaying regions may simply be explained by coronal field rearrangements, which are also necessary in the decay phase of a spot.

Bhonsle: In your presentation you have mentioned two extreme frequencies for solar radar echoes, namely, at 38 MHz and 2380 MHz. In the former case one obtains strong echoes and in the latter case no echo is observed. I would like to know whether there have been attempts to obtain echoes at other intermediate frequencies. I think it should be of considerable theoretical interest to determine "transition" frequency at which a change over from "echo" to "no echo" condition occurs.

Benz: Note that the microwave radar experiment probes Langmuir waves between 170 and 270 MHz; the decametric radar, however, works at places with plasma frequencies above 38 MHz. These are the numbers you have to compare. The attempt to find echoes from the 408 MHz level has been made in Arecibo. Since it was done during a sunspot minimum, its negative result is no surprise.

Stewart: Why did you choose a radar frequency about 10 times the plasma frequency?

Benz: The coupling between radar and Langmuir waves is proportional to the square of the wave number, k_L , of the Langmuir wave. The largest possible k_L is about one third of the inverse Debye length. Using the resonance condition ($k_L \approx 2k_r$), one finds $\omega_r \approx 10\omega_L$ as optimal condition.

Stewart: Your radar experiment only puts an upper limit on plasma turbulence because you did not receive an echo. So any talk of a high level of turbulence is speculative.

Benz: The microwave radar experiment has practically ruled out the old interpretation of decametric radar echos in terms of Langmuir turbulence. A new theory for decametric echos is necessary. The presence of low frequency turbulence is more evidently suggested by the good association of strong radar echos with noise storms.