WAVE–PARTICLE INTERACTIONS: A SOURCE FOR TRAPPED PARTICLES

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1. INTRODUCTION

For 20 years it has been assumed that whistler mode waves can only resonate with electrons above a characteristic energy $E_C = B^2/2\mu_0 N$, the magnetic energy per particle [1]. Since this energy is typically greater than 10 keV in the outer radiation belt, it has then been argued that auroral electrons at energies less that 10 keV could not be diffused in pitch angle by interaction with whistler mode waves. Many authors have since looked for alternative wave mode to be responsible for scattering auroral electrons to produce the diffuse aurora [2], but none has come out with any satisfactory solution.

Johnstone et al.[3] showed that the low energy (a few 100 eV) electrons can, in fact, resonate with the whistler mode waves and their distributions can be unstable to the growth of such waves if there is a loss–cone distribution, i.e. a distribution in which the density decreases towards small pitch angles. This density gradient should be taken, not along a line of constant energy as in "pure" pitch angle diffusion, but along the diffusion characteristic curves given by:

$$v_\perp^2 + (v_\parallel - \omega/k_\parallel)^2 = \text{const.} \tag{1}$$

By using the dispersion relation for whistler mode waves in eqn.(1), they obtained the characteristic curves in energy–pitch angle space along which electrons were scattered by the waves. A set of these curves is shown in Fig.1 as a function of the ratio E/E_C, where E is the total electron energy.

Pitch angle diffusion may then proceed along these curves in either direction: from large to small pitch angle as usually happens (and as is easily understood), or from small to large pitch angles which has not usually been remarked upon. The determining factor is the direction of the particle density gradient. If the highest densities are at large pitch angles (i.e. as in trapped particles with pitch angles near 90°), then the diffusive flow goes towards the loss cone. This is what is normally meant by as pitch angle diffusion. As a result of the shape of the curves in Fig.1, particles diffusing in this direction lose energy which in turn generates wave growth, so the process is unstable or self–driving. An example of such a process is shown in Johnstone et al.[3]. Now if the highest densities are found at small pitch angles, the diffusive flow will go towards large pitch angles. Since the particles will gain energy as they scatter in this case, some external source of energy must be provided. The whistler mode noise, which is resonant with the particles, would be damped. Thus such a process cannot be self–driving. To our knowledge, this later type of pitch angle diffusion has not previously been recognized. I present an example from the Low Energy Plasma Analyzer instrument on CRRES spacescraft which shows such a process clearly taking place.

2. OBSERVATION AND DISCUSSION

The Combined Release and Radiation Effect Satellite (CRRES) satellite had an elliptical orbit of inclination 18°, with perigee of 350 km and apogee at altitude 35,786 km, and covered therefore a wide range of L shells from the inner radiation belt to auroral field lines in the outer belt. The Low Energy Plasma Analyzer instrument measured electrons and positive ions in the energy range 10 eV and 30 keV, with energy resolution of $\Delta E/E = 30\%$. It had complete pitch angle coverage from 0° to 180° every 15 seconds with a resolution of 8° in polar angle, and 5.625° in the perpendicular direction.

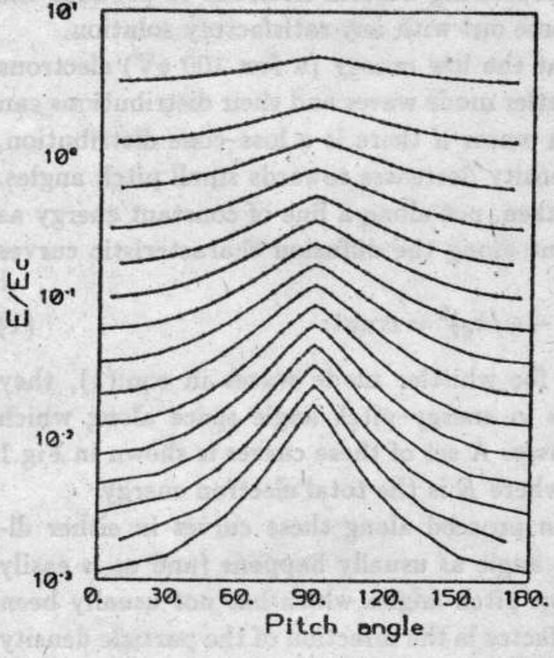

Fig.1. Plot of the characteristic diffusion curves in energy–pitch angle space. Only along these curves can electrons diffuse, either from 90° pitch angle towards the loss cone or from field–aligned position towards 90° pitch angle, when in resonance with parallel propagating whistler mode waves.

The data shown here are electron measurements from CRRES Orbit 77 on 26 August 1990. It was first selected for study because a persistent field–aligned (counter–streaming) pitch angle distribution could be seen at energies below 1 keV in the summary data plot. The field–aligned electron event occurred at 1543 UT, 0605 LT, 6.7 L–shell, 15° magnetic latitude, and lasted for about 10 min. Similar pitch angle distributions have been found over a wide range of local time in the CRRES lifetime dawn to dusk on the nightside magnetosphere.

Fig.2 show the color–coded energy–pitch angle distributions of Orbit 77 during 1540–1556 UT, for an energy range of 100 eV to 30 keV. The frames in each figure are numbered consecutively. The colour shows the count rate after subtraction of the background noise and normalization by the geometric factors of the sensor. The data shown in each frame are integrated over 4 spins (about 2 minutes) of the spacescraft.

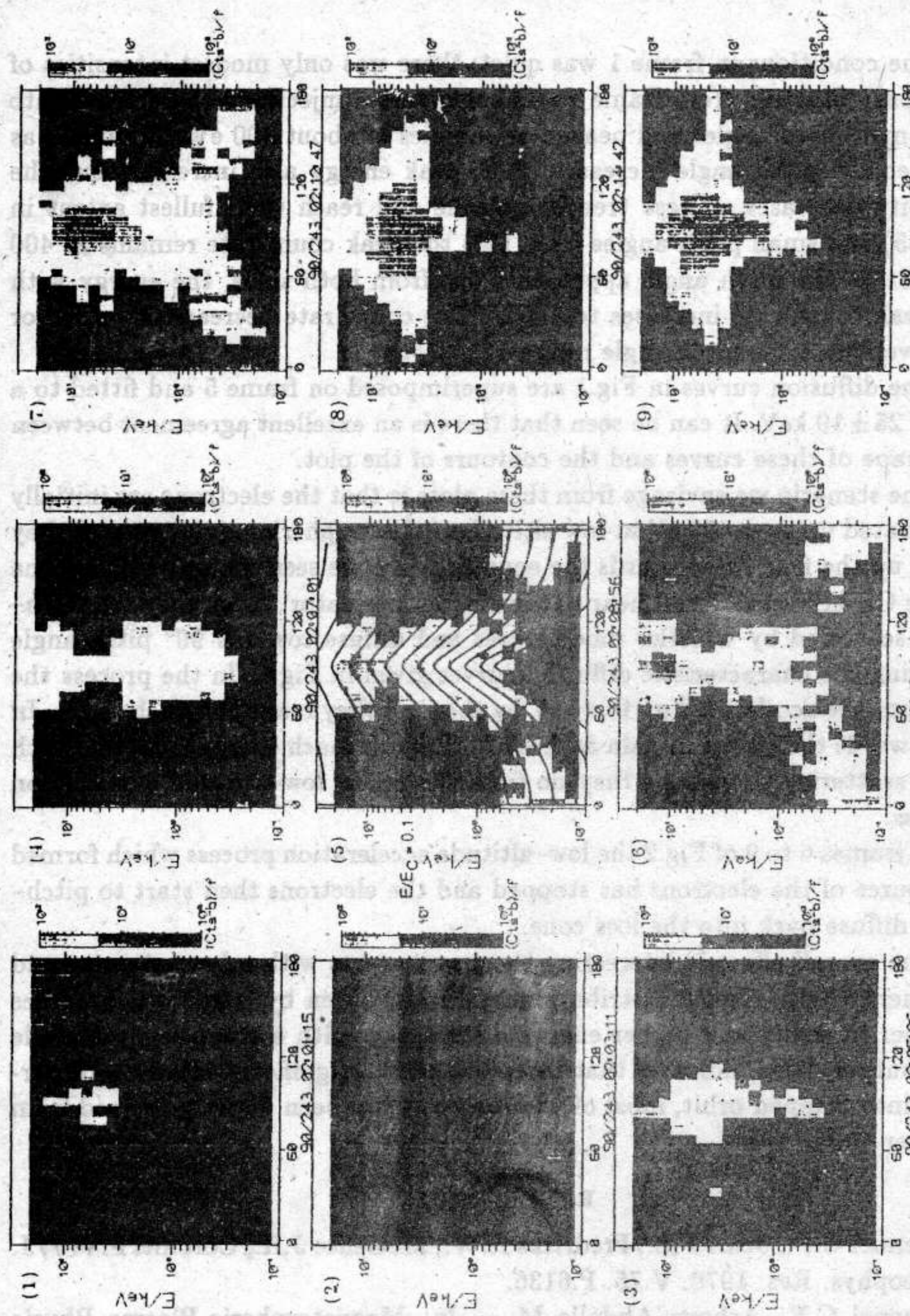

Fig.2. Color–coded plots of energy–pitch angle distributions of the event in Orbit 77. The color shows the electron count rate after substraction of the background noise and normalization by the geometric factors of the sensor. The frames are numbered in time sequence and the starting time each frame is listed at the bottom of the frame. The data shown in each frame has been averaged over ~ 2 min. The diffusion curved from Fig.1 (with only position for $E/E_C = 1$ marked) are superimposed on frame 5 and fitted to the spectrum with a characteristic energy $E_C = 25$ keV.

The conditions in frame 1 was quiet; there was only modest intensities of electrons. Starting from frame 2, we begin to see injections of electrons into very small pitch angles and peaked at energies of about 400 eV. Gradually as the electron pitch angle increases, their peak energy also increases, but the intensity decreases. These trends continue and reach their fullest extent in Fig.2(5). At small pitch angles ($\alpha < 12^{\circ}$) the peak count rate remains at 400 eV, but as the pitch angle approaches 90^{o} from both sides, the energy with the peak count rate increases to 4 keV. The count rate decreases by a factor of 3 over the same pitch angle range.

The diffusion curves in Fig.1 are superimposed on frame 5 and fitted to a E_C of 25 ± 10 keV. It can be seen that there is an excellent agreement between the shape of these curves and the contours of the plot.

The scenario we envisage from these plots is that the electrons are initially accelerated up to ~ 400 eV at low altitudes (of ionospheric origin), and as they travel up the field line towards the equator, they are seen within the loss cone by the CRRES spacescraft near to the magnetic equator. Then they are pitch–angle scattered by whistler mode waves and diffuse towards 90^{o} pitch angle following the characteristic diffusion curves given in Fig.1. In the process the electrons are accelerated up to 4 keV by the time they reach 90^{o} pitch angle. In other words the electrons gain at least 10 times as much energy from the pitch angle scattering process as they do from the initial low–altitude acceleration process.

In frames 6 to 9 of Fig.2 the low–altitude acceleration process which formed the source of the electrons has stopped and the electrons then start to pitch–angle diffuse back into the loss cone.

The overall effect is interesting because it starts with a low intensity and low energy field–aligned distribution in frame 1, then by frame 8 it becomes a higher intensity and higher energy distribution with a trapped pitch angle distribution. This indicates that there has been a significant injection of particles into trapped orbit, most of whose energy has been directly derived from whistler–mode noise.

REFERENCES

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