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This Week's Citation Classic

Kennel C F & Petschek H E. Limit on stably trapped particle fluxes.
J. Geophys. Res. **71**:1-28, 1966.
[Avco-Everett Research Laboratory, Everett, MA]

When the electron pitch angle distribution is anisotropic, whistler mode waves can be unstable. Atmospheric losses create an unstable distribution of electrons in the earth's radiation belts. The condition that whistler waves efold ten times in propagating through their amplification region near the geomagnetic equator sets a limit on the fluxes that can be stably trapped. Above this limit the whistler mode turbulence scatters electrons into the atmosphere. The observed fluxes are near or below the stably trapped limit, in agreement with theory. [The *SCI®* indicates that this paper has been cited over 510 times since 1966.]

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"In 1960-1961, I took a leave of absence from the department of astronomy at Princeton University to work for the Avco-Everett Research Laboratory. It was unclear what to do with a very young (21) employee. Finally Harry Petschek spoke up for me. At our first serious meeting he told me: 'I am working on a theory of collisionless shocks (whatever those were!); we have tried to make them in the laboratory but have failed because we couldn't eliminate particle collisions; however, there is a collisionless solar wind and it *will* form a collisionless bow shock ahead of the earth. I know little about space physics, but I want to apply my theory to the shock when it is discovered. You read the *Journal of Geophysical Research* and teach me space physics; in return, *I* will teach *you* plasma physics.'

"In addition to working on shocks, we got interested in the auroral Xrays that Kinsey Anderson and others[1] were measuring. We knew they represented a drain on the earth's electron radiation belts that required a turbulent scattering mechanism involving waves near the electron cyclotron frequency. We rediscovered Roald Sagdeev's theory of the whistler mode,[2] and we developed our own version of the quasi-linear theory to describe the turbulent whistler-electron scattering. We finally hit on the idea that there would be a limit to the stably trapped electron fluxes in the radiation belts, above which they would be lost to the atmosphere. The trouble was, the *measured* fluxes exceeded our limit by a factor thousand! All seemed lost, and Harry advised me to return to Princeton, which I did in 1961; I changed from an astronomy to a plasma physics thesis with Edward A. Frieman. Frieman taught me how to do a serious physics calculation and never let me reason sloppily (for long!).

"With the end of the thesis in sight, I gave Harry a call. 'The fluxes have come down,' I said; 'the experimentalists recalibrated their instruments.' 'In that case, you have a job.' At Princeton, I had learned it is not sufficient to be clever, you must prove your ideas, and so Harry and I settled down to the nuts and bolts of comparing our theory with experiment. By that time (1964), N.M. Brice, J.M. Cornwall, and J.W. Dungey had entered the field,[3-5] so we knew we had formidable competition. Everything worked out well, and our paper was published in the January 1, 1966, *Journal of Geophysical Research*. I had always wanted an academic career, so that date found me working at the International Center of Theoretical Physics, Trieste, with Roald Sagdeev; but that is another story. The collaboration with Petschek was the pivotal point in my scientific life.

"I am pleased to report that our paper played no small role in implanting plasma physics in space physics."

1. **Anderson K A & Milton D W.** *J. Geophys. Res.* **69**:4457-80, 1964.
2. **Sagdeev R Z & Shafronov V D.** *Sov. Phys.-JETP Engl Trans.* **12**:130-2, 1961.
3. **Brice N.** *J. Geophys. Res.* **69**:4515-22, 1964.
4. **Cornwall J M.** *J Geophys. Res* **69**:1251-8, 1964.
Dungey J W. *Planet. Space Sci* **11**:591-5, 1963.