Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PEM27-09 Room:301A Time:May 24 11:15-11:30

Sigma problem of the Crab Nebula & energy dissipation by parametric instability of large amplitude electromagnetic wave

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The Crab Nebula is one of the supernova remnants known best. Today a theoretical model for the nebula is established by Kennel&Coroniti(1983). First, the central star (a pulsar) rotates and creates pair plasmas (electron-positron plasmas). Then the plasmas blow outward accompanying a certain wave as pulsar wind. The wind forms a shock wave and its downstream side is observed as the nebula. Although there must be a energy dissipation of extremely high efficiency from the field to plasmas in pulsar wind region, this mechanism is unknown (sigma problem).

By the way, in space plasmas, especially for solar wind, shock or magnetic reconnection, nonlinear wave-wave interactions are important. Parametric instability is one of these processes, where an incident nonlinear wave decays into several different wave modes satisfying the matching conditions for both frequency and wavenumber.

In this study, we analyze a parametric instability of relativistically intense circularly polarized electromagnetic waves, considering application on sigma problem. Following Max (1973), Lee&Lerche (1978), we analyzed the instability of these waves in a cold relativistic electron-ion plasma. We then extend the analysis to an electron-positron plasma including the effect of relativistically hot temperature. For simplicity, we use 2-fluid equations and get self-consistent equilibrium solutions. Furthermore, we also consider direct-current magnetic field and derive dispersion relation of the instability.

We also discuss an efficiency of energy dissipation by the instability, using a Particle-In-Cell (PIC) simulation code.

Keywords: relativistic plasma, electron-positron plasma, parametric instability, crab nebula, pulsar, particle simulation