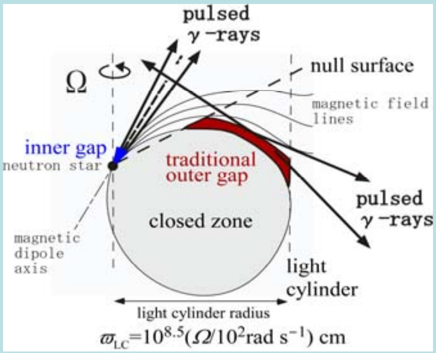
Time-dependent simulations of Particle Accelerator in Pulsar Outer Magnetospheres

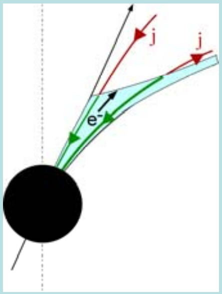
Pei-Chun Hsu[1], Kouichi Hirotani[2], and Hsiang-Kuang Chang[1]

1 Department of Physics and Institute of Astronomy, National Tsing Hua University, Taiwan
2 ASIAA/National Tsing Hua University - TIARA, Taiwan

Abstract We investigate the non-stationary particle acceleration and pair-creation cascade in a rapidly rotating neutron-star magnetosphere. Solving the Poisson equation for the electrostatic potential together with the Boltzmann equations for positrons, electrons, and γ-rays on the two-dimensional poloidal plane, and evaluating the blackbody temperature of the heated polar-cap surface by the bombardment of back-flowing particles, we demonstrate that a stationary, self-sustained particle accelerator is formed in the outer magnetosphere for typical millisecond pulsar parameters. We also present a preliminary result of the deathline of millisecond pulsars.

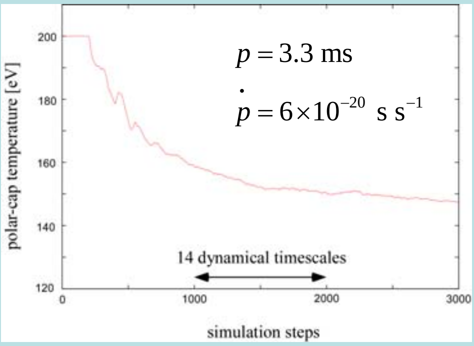
Introduction Pulsar magnetosphere can be divided into two zones: The closed zone filled with a dense plasma co-rotating with the star, and the open zone in which plasmas flow along the magnetic field lines to escape through the light cylinder (fig.). The last-open field lines form the border of the two zones. Attempts to model the particle accelerator (in the open zone) have concentrated on two scenarios: Inner-gap (IG) model with emission altitude within several neutron-star radii over a pulsar polar cap, and outer-gap (OG) models with acceleration occurring between the null surface and the light cylinder. Both models predict that e^-'s/e^+'s are accelerated by the electric field, $E_{\|}$, along the magnetic field lines to emit γ-rays via curvature radiation.

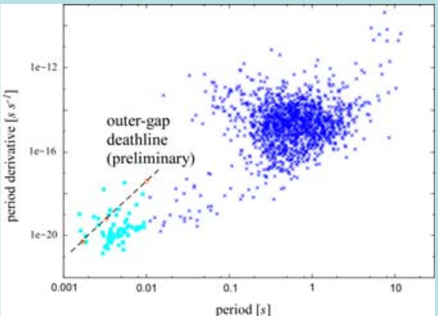




Self-consistent electrodynamics Traditional OG models have had success in explaining the observed light curves. However, it was demonstrated by Hirotani et al. (2003) that an active gap must extend toward the star, not the null surface. Therefore, it is essential to merge the OG and IG models, which have been separately considered. Since recent slot-gap model, an outward extension of the IG model into the outer magnetosphere, induces the electric current that is opposite to the global requirement (fig.), it is straightforward to extend the OG model into the inner magnetosphere. To this aim, Takata et al. (2006) and Hirotani (2006) solved the Poisson equation for the electrostatic potential on the poloidal plane, together with the stationary Botzmann equations for particles and γ-rays.

Non-stationary simulation of particle accelerator In the present work, we first solve the time-dependent Boltzmann equations for e^+/e^- and γ-rays, self-consistently with the Poisson equation. The Lorentz-factor and pitch-angle dependences of particle distribution functions, as well as γ-ray propagation and the distribution of the created pairs on the poloidal plane, are correctly computed. We apply the method to millisecond pulsars, considering that the pair creation takes place due to the collisions between the γ-rays and the thermal photons emitted from the heated polar cap, and evaluating the blackbody temperature by the bombardment of created particles. We find that self-sustained, stationary solutions exist for representative parameters of milli-second pulsars (fig.).





Millisecond pulsar death line We examined the condition for a gap to be self-sustained by the X-rays emitted from the heated polar-cap surface for millisecond pulsars. A preliminary result of the outer-gap deathline obtained by our time-dependent simulation, is presented in the figure. By developing this method, we are going to examine the deathline of class-I (less luminous, soft, broad X-ray pulsation) millisecond pulsars as well as the crass-I and –II dichotomy.