Magnetospheric Models of Rotation Powered Pulsar

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After observational constraints on magnetospheric models of the rotation powered pulsar are briefly summarized, a recent issue on the magnetospheric structure is clarified through the Jackson's gedanken experiment.
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§1. Introduction

Rotation powered pulsars are known by their slowing down of rotation, namely by their loss rates of rotational energy $\mathcal{P}_{rot} = I\Omega\dot{\Omega}$, where I is the inertial moment of the star, Ω is the angular velocity, and $\dot{\Omega} = d\Omega/dt$. An issue we discuss in this short review is how the rotational power $\mathcal{P}_{rot}$ is converted into high-energy particle flux and into radiation flux. In §2, we will summarize main observational constraints on magnetospheric models of the rotation powered pulsars. Recent progresses in theory seem to give a new viewpoint for constructing models. We will discuss it in §3.

§2. Observational Constraints

Some fraction of the rotation power $\mathcal{P}_{rot}$ is radiated as a pulsar wind. There are now seven known supernova remnants which are exited by central pulsars and five X-ray synchrotron nebulae detected around ordinary pulsars.

We know a little bit more about the Crab pulsar. More than 99% of the Crab's $\mathcal{P}_{rot}$ is in the pulsar wind. The wind brings about a shock at the inner edge of the nebula. In the post shock region, about a quarter of the wind power is radiated via synchrotron photons, and the remaining power is used to push the gas of the nebula. This fact indicates that most of the wind power is in kinetic energy of a pair plasma in the pre-shock region[1]; the ratio of the kinetic energy to the electromagnetic energy is estimated to be $\sim 3\ 10^3$. The pre-shock flow has a Lorentz factor of $\sim 10^6 - 10^7$ and a particle flux of $\sim 10^{38}$ sec^{-1}. This particle flux requires pair creation in the magnetosphere[2]. Observation of the synchrotron nebulae with central pulsars in X-ray indicates that ratios of X-ray luminosity to the rotational power $\mathcal{P}_{rot}$ decreases as the rotation slows down[3].

X-ray and gamma-ray pulses are detected, e.g., Crab pulsar, PSR0540-69, and PSR1509-58, in X-ray[4], and Crab in 100MeV-GeV gamma-ray[5] and in TeV gamma-ray[6]. Detections of TeV gamma-rays from the Crab pulsar and from other pulsars indicate that the particle accelerating region is near the light cylinder because such high energy photons cannot escape from the inner part of the magnetosphere without creating electron-positron pairs. The outer gap model by Chen *et al.*[7] well explains spectra from optical to 10GeV ranges for the Crab and Vela pulsars.

Radio observations show that the place where the radio emission arises is near the star[8], and a high brightness temperatures (typically 10^{26}K) indicates a dense pair plasma. Therefore, there is another kind of gap in which particles are accelerated and then pairs are created.

The radio emission mechanism dose not operate, and pulses turn off when their periods increase more than the "turnoff period" which is approximately given by $\dot{P}P^{-5} = 5\ 10^{-7}$.

§3. Models

To describe what is the recent issue on the global structure of the pulsar magnetosphere, we shall make a gedanken experiment, which is originally proposed by Jackson[9]. The gedanken experiment is as follows: a magnetized neutron star is supposed to be in a vacuum and not to rotate and then it is spun up quite slowly (adiabatically); the question is what happens around the star as a function of the period.

The first effect of rotation appears as a quadrupolar electric field as shown in Fig. 1. The second phenomenon is emission of charged particles from the star due to the induced electric field. If the magnetic moment is parallel to

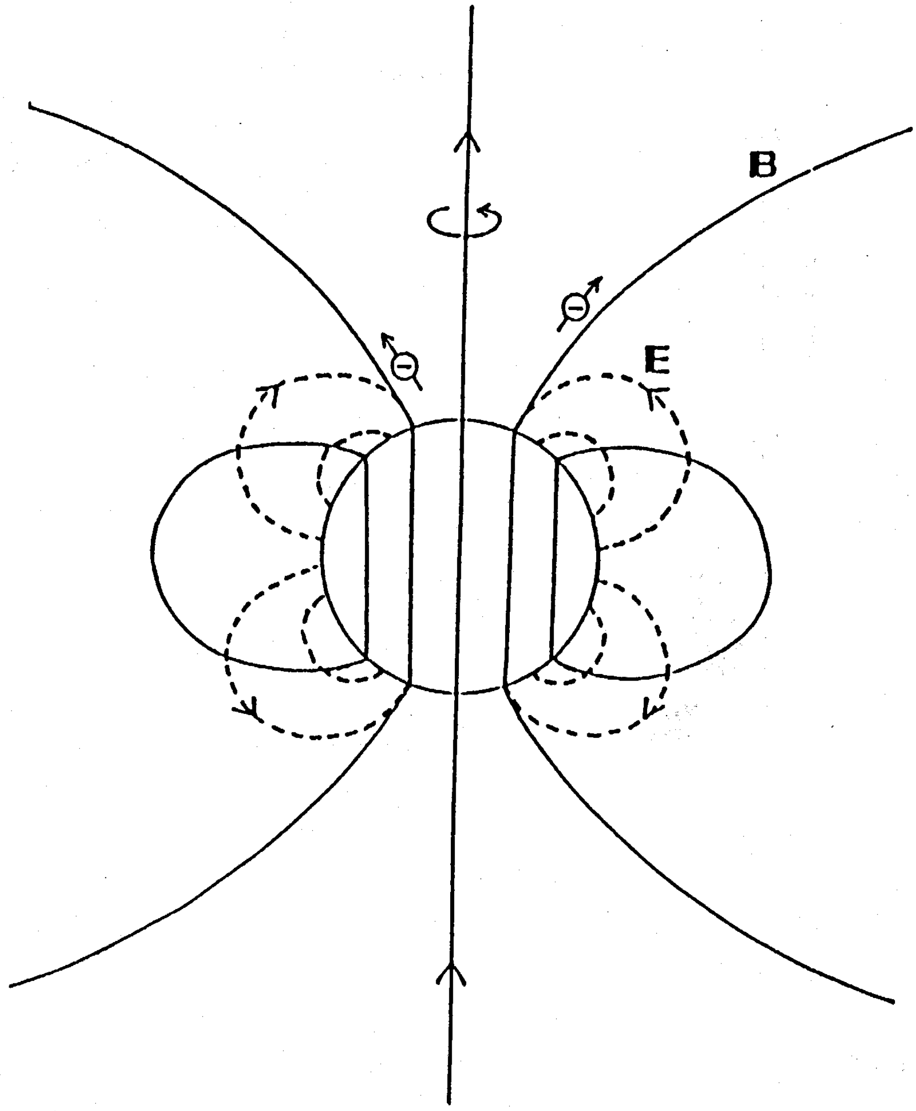

Figure 1: Electric field around the spinning magnetized conductor in a vacuum. The charged particles are pulled out from the polar caps by the field-aligned electric field.

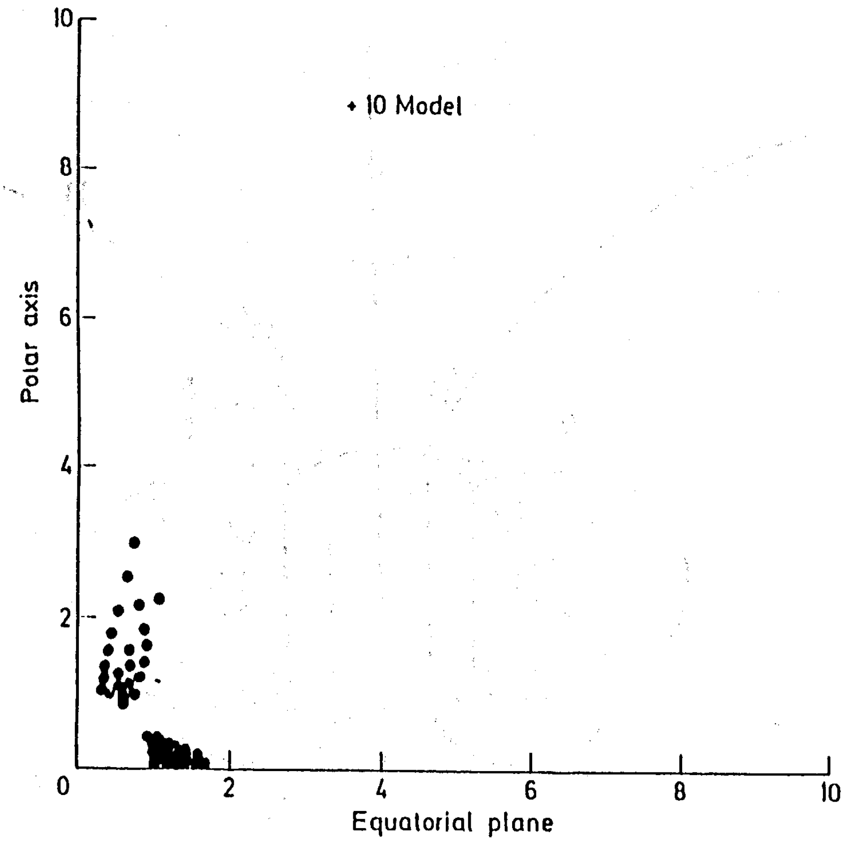

Figure 2: The emitted particles come to an equilibrium to form the polar and equatorial clouds. Krause-Polstorff and Michel[10)] found this numerical solution by a particle code.

the angular velocity, electrons are pulled out, and if it is anti-parallel, ions are pulled out (recent estimates of the ion work function for the neutron star crust imply that ions are emitted freely. The star will charge up because of the emission of charged particles. The particles come to an electrodynamical equilibrium to form charged clouds[10)] as shown in Fig. 2.

The magnetosphere of the charged clouds surrounded by a cacuum space is electrodynamically stable. However, if the star is spun up further, the magnetosphere becomes unstable against a pair creation avalanche; if a charged particle is put in the vacuum space, it brings about a pair creation avalanche because of a strong field-aligned electric field in the vacuum space around the clouds. Our recent issue is what is the next steady state of the magnetosphere with successive pair creation avalanches, maybe with a quasi-periodicity.

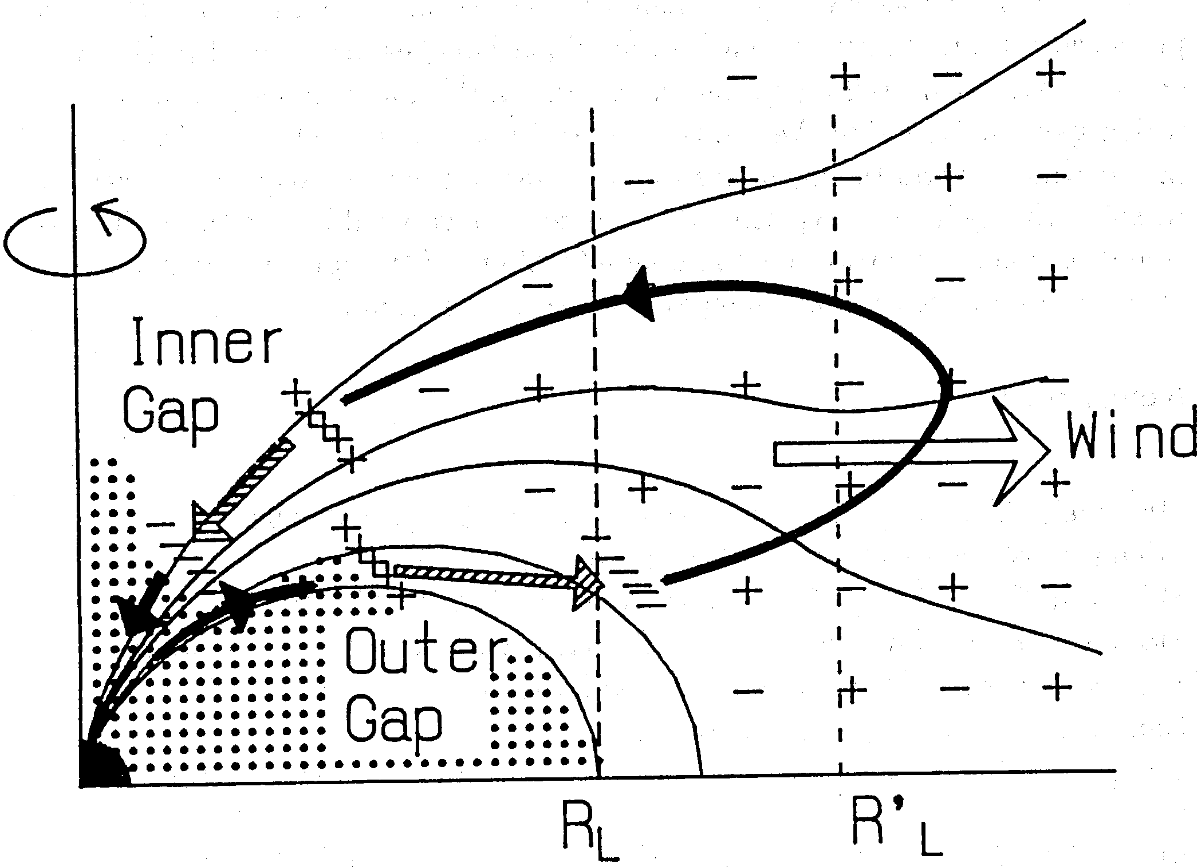

Figure 3: Schematic picture of the pulsar model proposed by Shibata[12]. The model has two gaps producing pairs and the inner and outer magnetosphere. The inner magnetosphere corotates with the star and essentially thought to be the charged clouds in Fig. 2. The outer magnetosphere, the base of which rotates more slowly than the inner one, consists of pairs.

Not many works have been done on this issue. Recently Michel[11] has proposed a radio pulsar mechanism in which banches are formed in the pair creation avalanche falling to the star. Shibata[12] has proposed a model in which gaps just outside the electric clouds create pairs and the pairs form a pulsar wind beyond the gaps (see Fig. 3). One of the most attractive strategy to solve the gedanken experiment discussed above would be a three dimensional particle simulation for the magnetosphere of the spun-up neutron star where the pair creation avalanches is taken into account.

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