Astrophys Space Sci (2012) 342:79–85
DOI 10.1007/s10509-012-1143-1

ORIGINAL ARTICLE

Adjustment of the electric current in pulsar magnetospheres and origin of subpulse modulation

Yuri Lyubarsky

Received: 5 May 2012 / Accepted: 6 June 2012 / Published online: 15 June 2012

Abstract The subpulse modulation of pulsar radio emission goes to prove that the plasma flow in the open field line tube breaks into isolated narrow streams. I propose a model which attributes formation of streams to the process of the electric current adjustment in the magnetosphere. A mismatch between the magnetospheric current distribution and the current injected by the polar cap accelerator gives rise to reverse plasma flows in the magnetosphere. The reverse flow shields the longitudinal electric field in the polar gap and thus shuts up the plasma production process. I assume that a circulating system of streams is formed such that the upward streams are produced in narrow gaps separated by downward streams. The electric drift is small in this model because the potential drop in narrow gaps is small. The gaps have to drift because by the time a downward stream reaches the star surface and shields the electric field, the corresponding gap has to shift. The transverse size of the streams is determined by the condition that the potential drop in the gaps is sufficient for the pair production. This yields the radius of the stream roughly 10 % of the polar cap radius, which makes it possible to fit in the observed morphological features such as the "carousel" with 10–20 subbeams and the system of the core–two nested cone beams.

Keywords Stars · Pulsars: general

1 Introduction

The nature of pulsar emission is still a subject of debate. The conventional wisdom is that the pulsar activity is associated with relativistic plasma flows along the open magnetic field lines. According to the commonly accepted picture, the polar cap cascade produces electron-positron pairs (see, e.g., reviews by Grenier and Harding 2006; Arons 2007, and references therein), which stream along the open magnetic field lines with relativistic velocities. The pulsar radio emission is believed to be generated in this outflow.

Because of strong relativistic beaming, the basic morphological features of the pulsar radiation are dictated by the geometry of flow. It is generally accepted that the width of the mean pulse is determined by the width of the open field line tube in the emission region so that narrow pulses imply low emission altitude. The subpulse structure is commonly attributed to a systems of narrow streams of plasma, each stream radiating a subbeam tangentially to the magnetic field lines. These subbeams exhibit pretty regular behavior. It was found that pulsars have attractors in the form of two nested cones (Rankin 1983, 1993). Within the cone, the subpulse behavior also exhibits substantial regularity such as stationary drifting (Rankin 1986; Weltevrede et al. 2006, 2007). In a couple of cases, a careful analysis of the data reveals a remarkable circular "carousel" of emitting subbeams (Deshpande and Rankin 2001; Mitra and Rankin 2008). We are still lacking of a firm model unequivocally explaining why the flow in the open field line tube breaks into isolated streams.

According to Ruderman and Sutherland (1975), the electric field is unable to extract ions from the surface of the neutron star therefore electron-positron pairs are produced in local gap discharges (sparks). Each spark gives rise to a narrow plasma stream responsible for a subpulse. The sparks are isolated one from another because the potential drop in the space between them remains below that necessary for the plasma production. This model remains the most popular (see, e.g., recent paper by van Leeuwen and Timokhin

Y. Lyubarsky (✉)
Physics Department, Ben-Gurion University, P.O.B. 653,
Beer-Sheva 84105, Israel
e-mail: lyub@bgu.ac.il