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Models of magnetized neutron star atmospheres

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Abstract

We present a new computer code for modeling magnetized neutron star atmospheres in a wide range of magnetic fields (10^{12}–10^{15} G) and effective temperatures (3×10^5–10^7 K). The atmosphere is assumed to consist either of fully ionized electron-ion plasmas or of partially ionized hydrogen. Vacuum resonance and partial mode conversion are taken into account. Any inclination of the magnetic field relative to the stellar surface is allowed. We use modern opacities of fully or partially ionized plasmas in strong magnetic fields and solve the coupled radiative transfer equations for the normal electromagnetic modes in the plasma. Using this code, we study the possibilities to explain the soft X-ray spectra of isolated neutron stars by different atmosphere models. In particular, the outgoing spectrum using the "sandwich" model (thin atmosphere with a hydrogen layer above a helium layer) is constructed. Thin partially ionized hydrogen atmospheres with vacuum polarization are shown to be able to improve our understanding of the observed spectrum of the nearby isolated neutron star RBS 1223 (RX J1308.8+2127).
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1. Introduction

At present several classes of neutron stars (NSs) with strong magnetic field are known. They include X-ray dim isolated NSs (XDINSs, Haberl, 2007), central compact objects (CCOs) in supernova remnants (Pavlov et al., 2004), anomalous X-ray pulsars and soft-gamma repeaters (AXPs and SGRs; see reviews by Kaspi, 2007; Mereghetti et al., 2007; Mereghetti, 2008). The NSs in these classes have superstrong magnetic fields up to $B \geqslant 10^{14}$ G (SGR and AXP) and $B \sim$ a few $\times 10^{13}$ G in XDINSs, evaluated from period changes and from absorption features in the observed spectra, if they are interpreted as ion cyclotron lines (see reviews by Haberl, 2007; van Kerkwijk and Kaplan, 2007).

These NSs are sufficiently hot ($T_{\rm eff} \sim 10^6$–10^7 K) to be observed as thermal soft X-ray sources. Some of the XDINSs and CCOs have one or more absorption features in their X-ray spectrum at the energies 0.2–0.8 keV (Haberl, 2007), and the central energies of these features appear to be harmonically spaced (Sanwal et al., 2002; Bignami et al., 2003; Schwope et al., 2007; van Kerkwijk and Kaplan, 2007; Haberl, 2007). The optical/ultraviolet fluxes of the known XDIN optical counterparts are a few times larger than the blackbody extrapolation of the X-ray spectra (Burwitz et al., 2001; Burwitz et al., 2003; Kaplan et al., 2003; Motch et al., 2003; Mignani et al., 2007).

The XDINs are nearby objects, and parallaxes of some of them have been measured (Kaplan et al., 2002a). Therefore, they give a good possibility to measure the NS radii, yielding useful information on the equation of state (EOS) for the NS inner core (Trümper et al., 2004; Lattimer and Prakash, 2007). For a sufficiently accurate evaluation of NS radii, a good model of the NS surface radiation is necessary for the observed X-ray spectra fitting.

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