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ORIGINAL ARTICLE

Bragg diffraction and the iron crust of cold neutron stars

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Abstract If cooled-down neutron stars have a thin atomic crystalline–iron crust, they must diffract X-rays of appropriate wavelength. If the diffracted beam is to be visible from Earth (an extremely rare but possible situation), the illuminating source must be very intense and near the reflecting star. An example is a binary system composed of two neutron stars in close orbit, one of them inert, the other an X-ray pulsar. (Perhaps an "anomalous" X-ray pulsar or magnetar, not powered by gas absorption from the companion or surrounding space, would be the cleanest example.) The observable to be searched for is a secondary peak added (quasi-) periodically to the main X-ray pulse. The distinguishing feature of this secondary peak is that it appears at wavelengths related by simple integer numbers, $\lambda, \lambda/2, \lambda/3, \ldots, \lambda/n$ because of Bragg's diffraction law.

Keywords Bragg diffraction · Neutron stars · Crystalline iron · Bragg peaks

1 Introduction

Current theories of Neutron Stars (Bombaci 2007) imply that as pressure builds up towards the interior of the star there are successive phase transitions from an iron crust (Chamel and Haensel 2008; de Young 1991), to a nuclear medium with high neutron density, to a neutron Fermi liquid, to more exotic forms of matter. It has proven difficult to make empirical progress on the star's composition. For example, very information-rich equations of state (Huber et al. 1994; Klahn et al. 2006) have to be tested with few numbers (mass, size, pulsar period and time dependence, etc.)

That the outer-most layer of the star contains iron is known from the characteristic absorption lines of Fe (Cottam et al. 2002). In recently formed stars or in stars that are heated by accretion, a hot iron "ocean" is likely to cover the surface (Haensel et al. 2006). However, if the star is not accreting material, it cools rapidly; the star stops emitting X-rays after about a million years (Chamel and Haensel 2008). At about 2×10^7 years (a small time in galactic scale) the star is believed to have reached 1000 K simply by radiation (Yakovlev and Pethick 2004; Imshennik et al. 2002), a temperature which is well below the solidification of iron.

The hypothesis that this iron layer is in crystalline form has only been indirectly tested by observations of the initial cooling in quasi-persistent soft X-ray transients. These seem to be consistent with the neutron star crust having the structure of a perfect crystal, while models based on an amorphous crust cannot fit the data (Shternin et al. 2007).

We here propose a direct test that might be performed as the catalog of X-ray sources expands, requiring the existence of a binary system composed of one such cooled-down neutron star with certain minimal assumptions that will be spelled out shortly, and an X-ray emitting companion.

The canonical way of ascertaining the crystalline structure in a laboratory material is by exposing it to X-rays and studying the resulting diffraction pattern (it is not possible to directly observe neutron diffraction from Earth due to the neutron's short lifetime of about 15 min). This textbook method works well even for fragmented crystals, for example a dust sample made of microcrystals can be made to produce a diffraction pattern that appears as characteristic diffraction rings (Cullity and Stock 2001).

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