*Magnetic Fields throughout Stellar Evolution*
*Proceedings IAU Symposium No. 302, 2013*
*P. Petit, M. Jardine & H. Spruit, eds.*

doi:10.1017/S1743921314002695

# Effects of strong magnetic fields in dense stellar matter

**A. Lavagno and F. Lingua**

Department of Applied Science and Technology, Politecnico di Torino, I-10129 Torino, Italy
INFN, Sezione di Torino, I-10125 Torino, Italy

**Abstract.** We study the effects of strong magnetic fields in dense stellar matter within an effective relativistic equation of state with the inclusion of hyperons and $\Delta(1232)$-isobar degrees of freedom. The effects of high magnetic field interactions significantly affect the nuclear equation of state and the macroscopic properties of the star. In this framework we investigate the role of the presence of the $\Delta$-isobars degrees of freedom in structure and in the bulk properties of the compact star.

**Keywords.** Relativistic equation of state, $\Delta$ baryonic resonances, Compact stars

---

Recent observations provided wide evidence that very strong magnetic fields are bound to exist inside and around several neutron stars. Many studies suggest that the magnetic field on the surface of these *magnetar* candidates could rise up to $10^{15}$ G, reaching even grater values as large as $10^{18}-10^{19}$ G in their cores, see, e.g., Duncan & Thompson (1995), Hurley *et al.* (1999), Mareghetti & Stella (1995) and Chakrabarty, Bandyopadhyay & Pal (1997). Such a strong value of magnetic field may widely influence the property of the nuclear equation of state (EOS) and the bulk properties of the neutron star matter, see, e.g., Cardall, Prakash & Lattimer (2001), Rabhi, Panda & Providencia (2011), Dexheimer, Negreiros, Schramm (2012) and Lopes & Menezes (2012).

In this contribution we are going to study the effect of strong magnetic field in dense stellar star matter in the framework of a relativistic EOS with the inclusion of hyperons and $\Delta(1232)$-isobar degrees of freedom. See Lavagno (2010), Lavagno & Pigato (2012) and Lavagno (2013) for details.

The total Lagrangian density $\mathcal{L}$ can be written as $\mathcal{L} = \sum_b \mathcal{L}_b + \mathcal{L}_m + \sum_l \mathcal{L}_l + \mathcal{L}_M$, where the indexes $b$ and $l$ run over all considered baryons (nucleons, hyperons and $\Delta$s) and leptons (electrons and muons) respectively. While $m$ denote the interaction corresponding to the mesons fields ($\sigma$, $\omega$, $\rho$) and the term $\mathcal{L}_M$ corresponds to the lagrangian density of the magnetic field itself. More explicitly, we have

$$\mathcal{L}_b = \overline{\psi_b}\Big[\gamma_\mu\Big(i\partial^\mu - q_b A^\mu - g_{\omega b}\omega^\mu - g_{\rho b} I_{3b}\rho^\mu - (m_b - g_{\sigma b}\sigma)\Big)\Big]\psi_b\,, \tag{0.1}$$

$$\mathcal{L}_l = \overline{\psi_l}\Big[\gamma_\mu\Big(i\partial^\mu - q_l A^\mu - m_l\Big)\Big]\psi_l\,, \tag{0.2}$$

$$\mathcal{L}_m = \frac{1}{2}\Big(\partial_\mu\sigma\partial^\mu\sigma - m_\sigma^2\sigma^2\Big) - \frac{1}{3}bm(g_\sigma\sigma)^3 - \frac{1}{4}c(g_\sigma\sigma)^4 + \frac{1}{2}m_\omega^2\omega_\mu\omega^\mu + \tag{0.3}$$

$$- \frac{1}{4}\Omega_{\mu\nu}\Omega^{\mu\nu} + \frac{1}{2}m_\rho^2\rho_\mu\rho^\mu - \frac{1}{4}\rho_{\mu\nu}\rho^{\mu\nu}\,, \tag{0.4}$$

$$\mathcal{L}_M = -\frac{1}{16\pi}F_{\mu\nu}F^{\mu\nu}\,. \tag{0.5}$$

In this investigation we adopt the so-called GM3 parametrization by Glendenning & Moszkowski (1991), with the same hyperons coupling constants used by Lavagno (2010). The magnetic field contribution is included as an external applied field along the z-axis

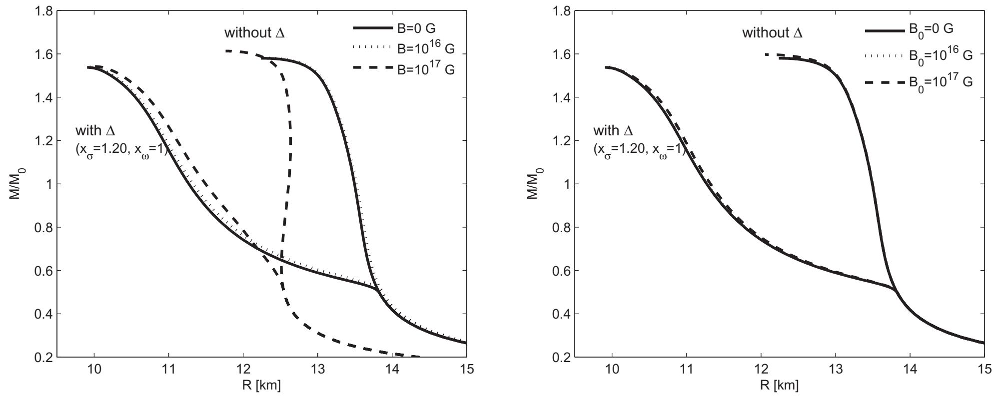


**Figure 1.** Mass radius relationship with and without Δ-isobars and for different values of uniform (left panel) and density dependent magnetic fields (right panel). A $B_{\rm surf} = 10^{15}$ G is used for different values of the central magnetic field $B_0$.

through the vector four potential $A^\mu = (0, 0, Bx, 0)$. We are going to study two different configurations of the magnetic field related to its variation with the baryon density. First, we study the EOS with a constant magnetic field strength as a function of baryon density. Second, we introduce the same profile used by Lopes & Menezes (2012) in order to explain the observed difference in strength of magnetic field between the neutron star surface and its core. The general effect of the magnetic field is to introduce a new source of degeneracy for those particles that have an electric charge $q_{b,l} \neq 0$. This degeneracy factor is due to the formation of the so called Landau levels and influences the computation of both energy and particle density.

In Fig. 1, we show the mass-radius relationships without and in presence of the Δ degrees of freedom, with a constant value of magnetic field (left panel) and a density dependent value of B (right panel). The Δ degrees of freedom implies smaller values of radii with respect to the case in which Δs are not taken into account. This effect is totally independent from the value of the magnetic field and the star assumes slightly smaller values of the maximum mass. Moreover, let us observe that the magnetic field contribution seems to be relevant only for field strength greater than $10^{17}$ G. For this reason, when a density dependent magnetic field is used, only central layers of the star are allowed to assume greater values of B and the mass-radius curves become more similar to the one in absence of magnetic field.

## References

Cardall, C. Y., Prakash, M., & Lattimer, J. M. 2001, *Astrophys. J.*, 554, 322
Chakrabarty, S., Bandyopadhyay, D., & Pal, S. 1997, *Phys. Rev. Lett.*, 78, 2898
Dexheimer, V., Negreiros, R., & Schramm S. 2012, *Eur. Phys. J. A*, 48, 189
Duncan, R. & Thompson, C. 1995, *Mon. Not. R. Astron. Soc.*, 275, 255
Glendenning, N. K. & Moszkowski S. A. 1991, *Phys. Rev. Lett.*, 67, 2414
Hurley, K. *et al.* 1999, *Astrophys. J.*, 510, L111
Lavagno, A. 2010, *Phys. Rev. C*, 81, 044909
Lavagno, A. & Pigato, D. 2012, *Phys. Rev. C*, 86, 024917
Lavagno, A. 2013, *Eur. Phys. J. A*, 49, 102
Lopes, L. L. & Menezes D. P. 2012, *Braz. J. Phys.*, 42, 428
Mareghetti, S. & Stella, L. 1995, *Astrophys. J.*, 442, L17
Rabhi, A., Panda, P. K., & Providencia C. 2011, *Phys. Rev. C*, 84, 035803

https://doi.org/10.1017/S1743921314002695 Published online by Cambridge University Press