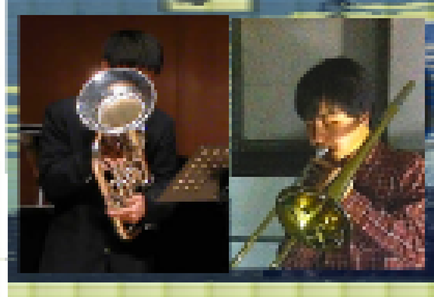
Stationary and Axisymmetric Magnetized Barotropic Stars with Various Field



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Abstract

Analysis of the magnetized star models reveals the requirement for the magnetized star with strong toroidal magnetic field. We consider the total toroidal current density of the magnetized star. If outside the star is vacuum and there is no exterior toroidal fields in the vacuum region, we find there is the upper bound of this total current. This upper bound limits the magnitude of the toroidal magnetic field energy. If the star has the opposite surface current, the total current density inside the star exceeds the upper bound and the toroidal magnetic field energy becomes stronger.

1.Introduction

・What is the origin of the magnetic fields inside the star? If we adopt the fossil fields theory, the magnetic fields of the star must be stable.

・aM/W < Mp/M < 0.8 is stable. (Braithwaite 2009)

・Magnetar model needs hidden strong toroidal fields (Thompson & Duncan 1995)

There would be strong toroidal field inside the star...

However

・Many studies can obtain only weak toroidal(Mp/M > 0.8) configurations. (Lander&Jones 2009, Ciolfi et. al 2009, Fujisawa et. al (IAU274), Lander et. al(2011)...

・Adding surface current (Glampedakis et. al 2011) makes the magnetized star sustain strong toroidal field.

Why? Why? Why?

We consider the current density to answer this question.

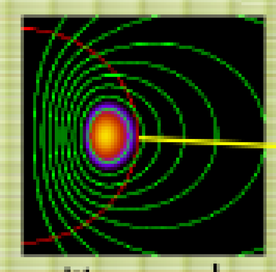
M:magnetic field energy Mp:poloidal magnetic energy W:gravitational energy

2.Formulation & Method

・We use Tomimura&Eriguchi (2005) formulation.

$$\frac{j_\phi}{c} = \frac{1}{4\pi}\kappa(\Psi)B_\phi + \rho r \sin\theta\, \mu(\Psi)$$

・Strong toroidal fields need strong toroidal current density!



B.C : Toroidal fields exit within the last closed poloidal field inside the star.

・We solve the GS eq. to obtain the magnetized equilibria.

$$A_\phi \sin\phi = \frac{1}{c}\int \frac{j_\phi}{|r-r'|}\sin\phi\, dV + \text{surface current}$$

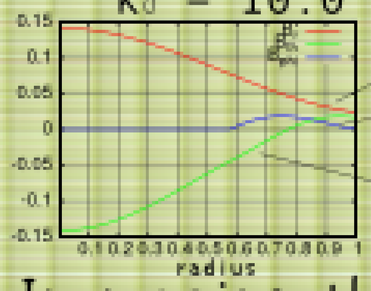
・We use the smae functional forms in Yoshida&Eriguchi(2006)

κ and μ are aribtrary functions

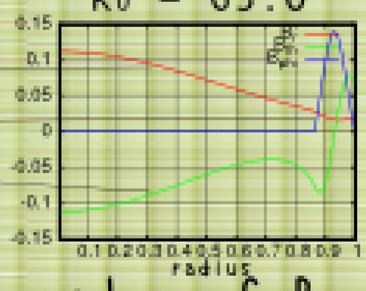
3. Results

・No surface current model

$K_0 = 10.0$



$K_0 = 65.0$



$B_r(\theta=0)$
$B_\phi(\theta=\pi/2)$
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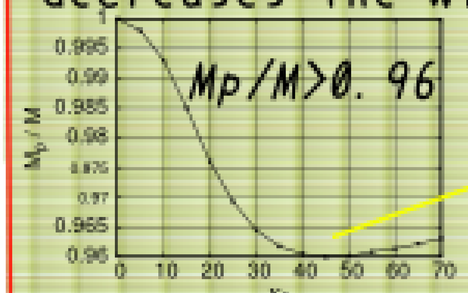
Increasing the maximum value of B_ϕ decreases the width of B_ϕ!

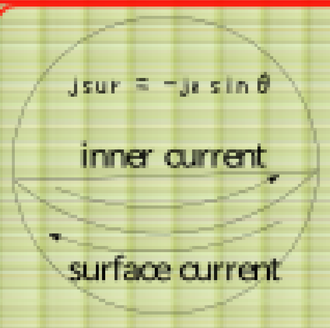


There is the minimum value of Mp/M(see Lander&Jones 2009, Ciolfi et. al 2009)

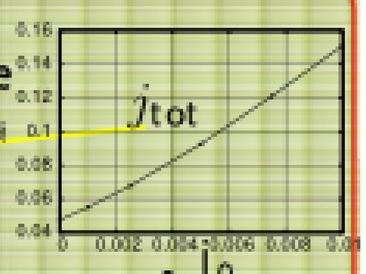
We define the total current $j_{tot} = \int_V j_\phi dV$

There is the upper bound of j_{tot}. This bound limits B_ϕ!!!

・Surface current models



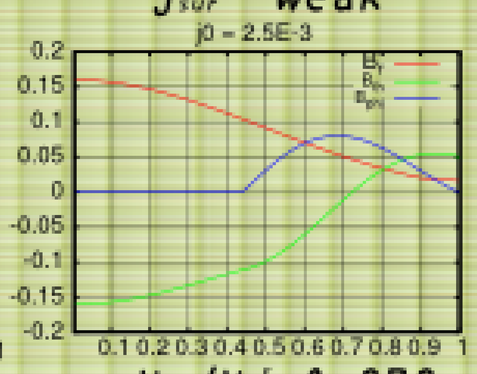
Adding the opposite surface current, j_{tot} increases and Mp/M decreases!!!



Surface current sustains strong B_ϕ

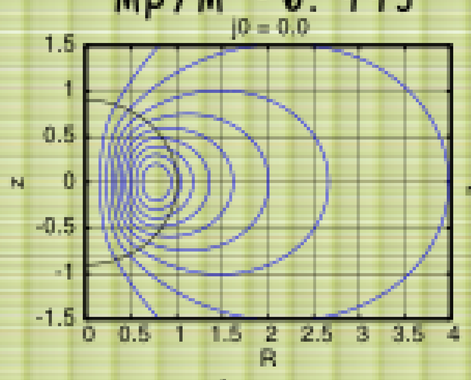
$j_{sur} \sim 0$

$j_{sur} \sim$ weak

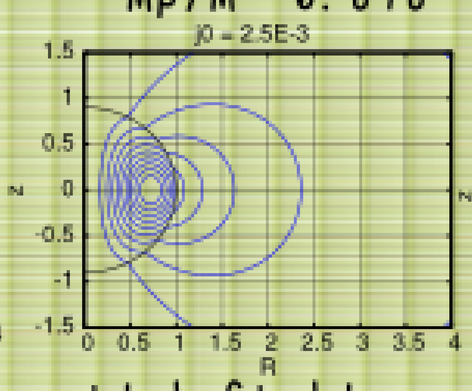


$j_{sur} \sim$ strong

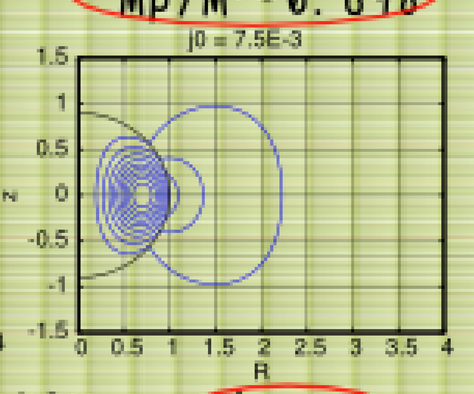
Mp/M ~ 0.993



Mp/M ~ 0.878



Mp/M ~ 0.698



weak ~ toroidal field energy ~ strong

4. Discussion

・If the magnetized stars have strong toroidal magnetic field, there are two possibilities.

1. They have opposite surface current.
2. They have magnetosphere which makes toroidal current near the stellar surface.

We need to consider both interior field and magnetosphere simultaneously!

References

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