

# Maximum energy in magnetar magnetosphere

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# 動機(妄想?)

マグネターはどのような天体  $(M, R)$   $M/R$  か

**大質量**  $M = (2 + \alpha)M_{sun}$

**軽い**  $M = (1.4 - \beta)M_{sun}$

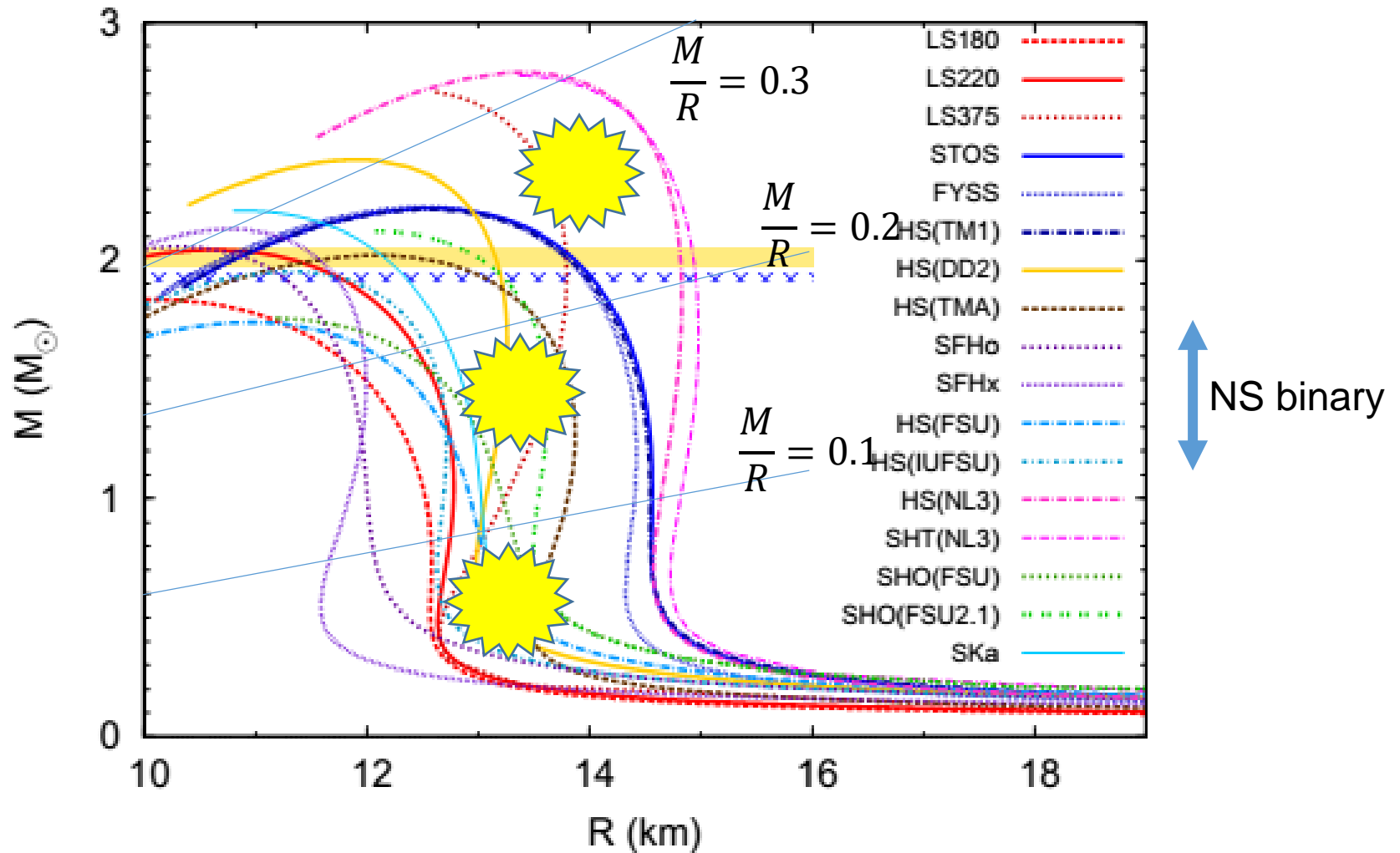
-> **起源(親星  $B$ の増幅の条件)**

**または 無関係か**

**磁気圏の構造(理論)からの  
何らかの示唆がえられたら?**

**観測?**

# Where is magnetar in M-R diagram ?



# M/R を決める

これまでNSで(議論された)内容

**偶然的観測**

1. 放射半径

$$R_{\infty} = R \left(1 - \frac{2M}{R}\right)^{-1/2}$$

2. ライン(赤方偏移)

$$1 + z = \left(1 - \frac{2M}{R}\right)^{-1/2}$$

3. QPO (降着円盤)

4. 光度曲線 hot Spot

マグネターで何かあるでしょうか？

# Astroseismology

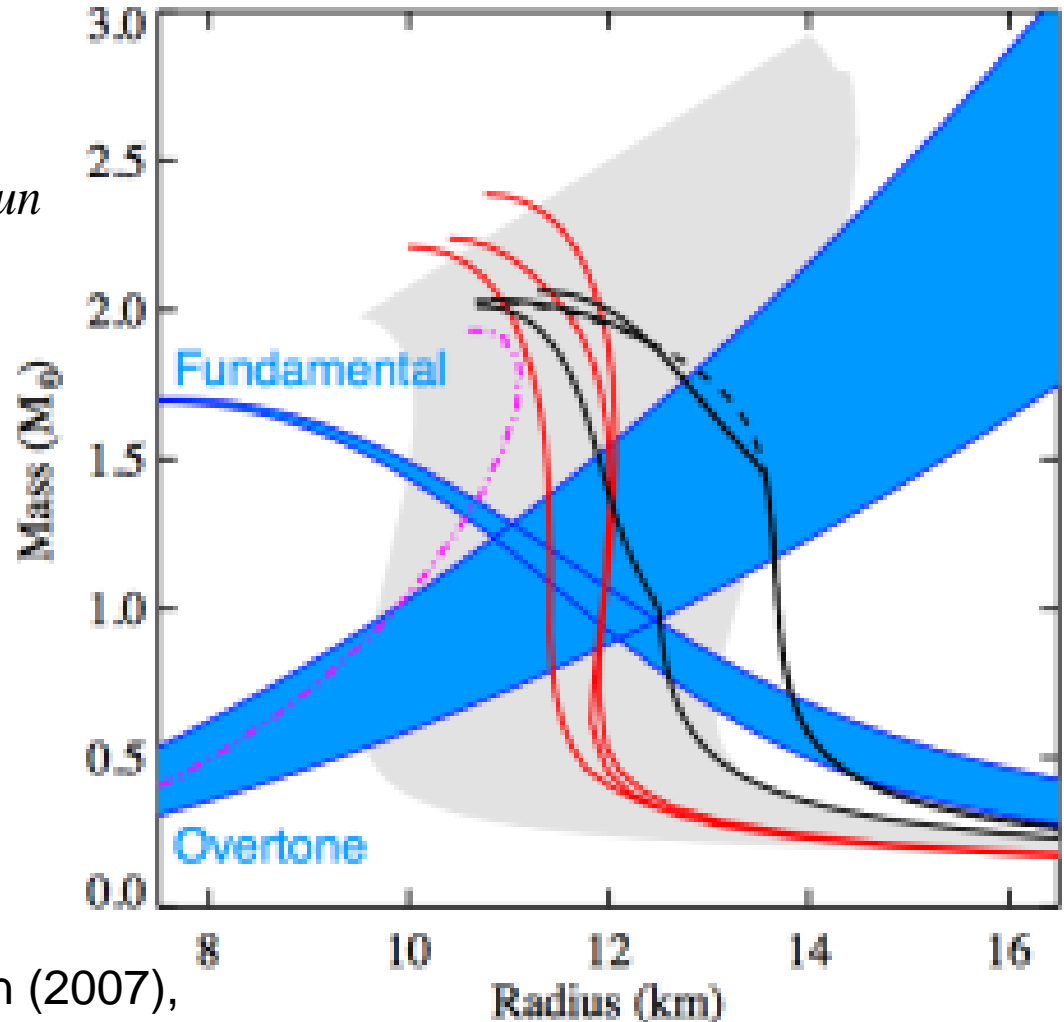
マグネターフレア QPO

SGR 1806-20

$\rightarrow M \approx (1-1.4)M_{sun}$

$R \approx 12km$

比較的軽い方を  
示唆？



Samuelsson and Andersson (2007),

# Energy Storage

## Interior vs Exterior

$$\Delta E_{EM} \approx 10^{46} \text{ ergs}$$

$$E_B \approx 10^{48} \text{ ergs}$$

Two possible sites of energy storage for **magnetar flares**

- Crust/Core
- **Magnetosphere (This talk)**  
-> less effective to GW rad.

Energy stored by twist of magnetic fields  
Sudden eruption, when it exceeds a critical value  
The problem is similar to solar flare

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*Reconnection in Three Dimensions*

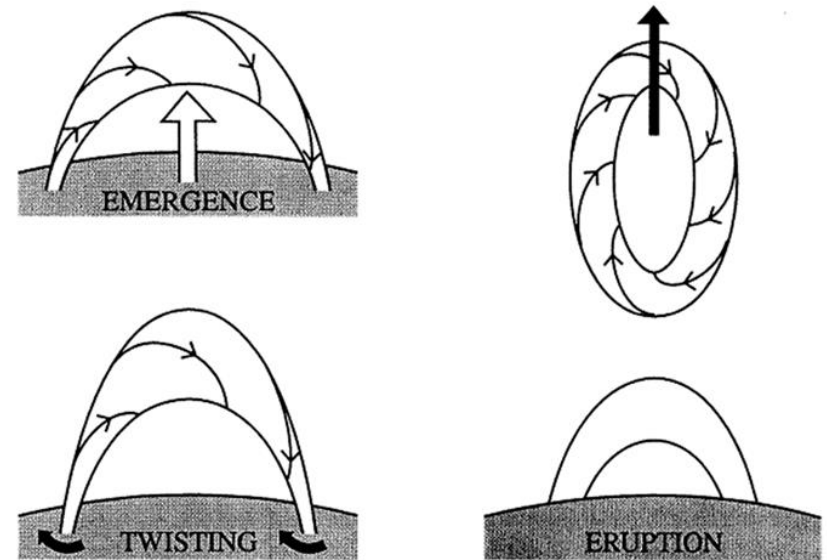


Fig. 8.17. Magnetic helicity changes associated with emergence of flux through a boundary or twisting motions at the boundary or a magnetic eruption.

Priest & Forbes "Magnetic reconnection" (2000)

**Emergence/Twisting -> Magnetic eruption**

# Force-Free Magnetosphere

## Low-beta-plasma in magnetosphere

$$(B_{15})^2 \approx 10^8 \text{ g / cm}^3 > \rho \gg p$$

Force-free cond.  $\vec{j} \times \vec{B} = 0 \Rightarrow \vec{j} \parallel \vec{B}$

Nonlinear partial diff eqn. (GS eqn.)

$$\rightarrow D(G) = -SS' \quad (= -\gamma G^n)$$

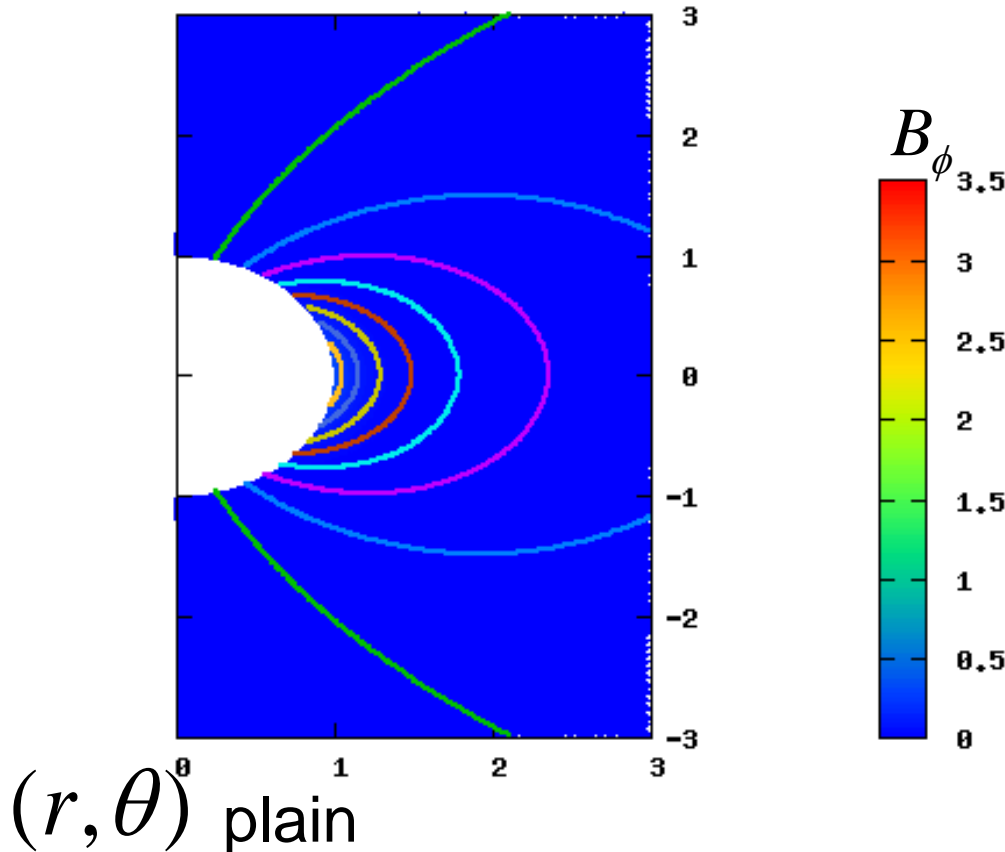
Present model

G: Magnetic flux/Poloidal comp.  $A_\phi \Leftrightarrow (B_r, B_\theta)$

S: Current stream/Toroidal comp  $B_\phi \Leftrightarrow (j_r, j_\theta)$

# Quasi-static evolution

## A sequence of equilibrium solutions



G Magnetic field lines

Model of  $n=7$  and  $M/R=0.25$

Axisymmetric model

YK(2017) arXiv:1703.02273  
:MNRAS 468

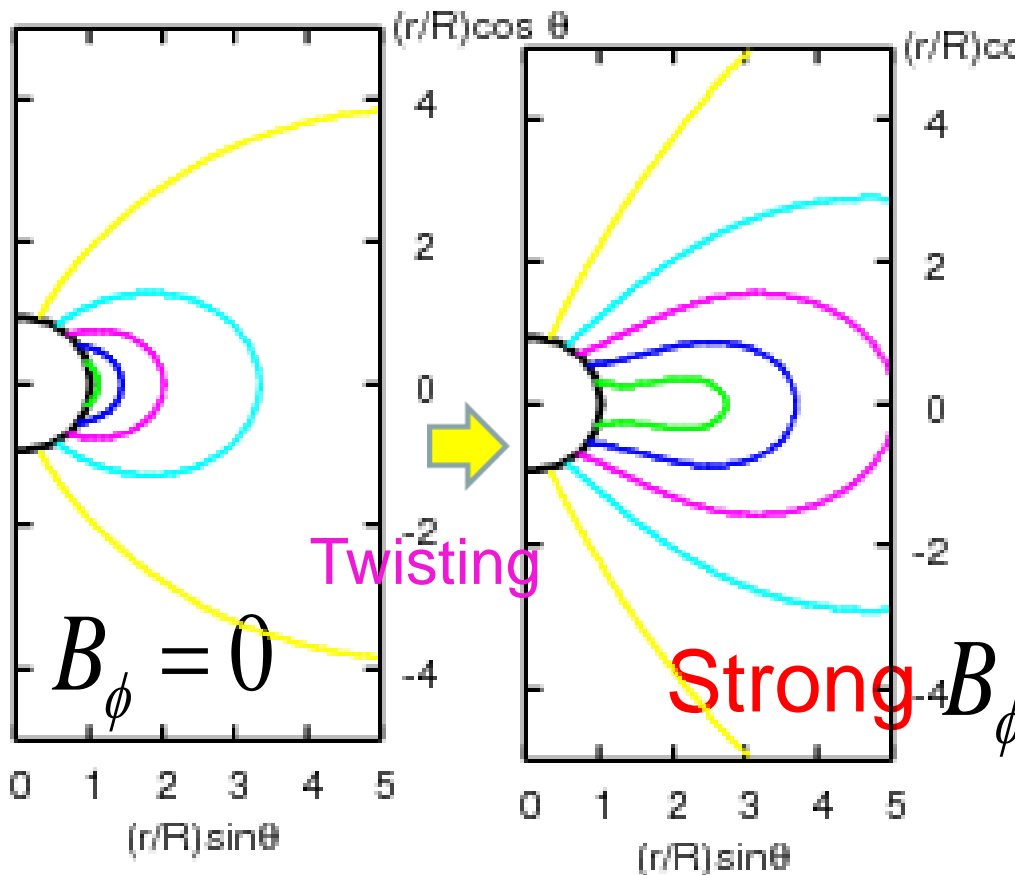
Increasing twist  
in a long timescale  
 $\gg$  dynamical one

A flux rope  
detached

Dynamical simulation  
e.g, Parfrey et al 2013

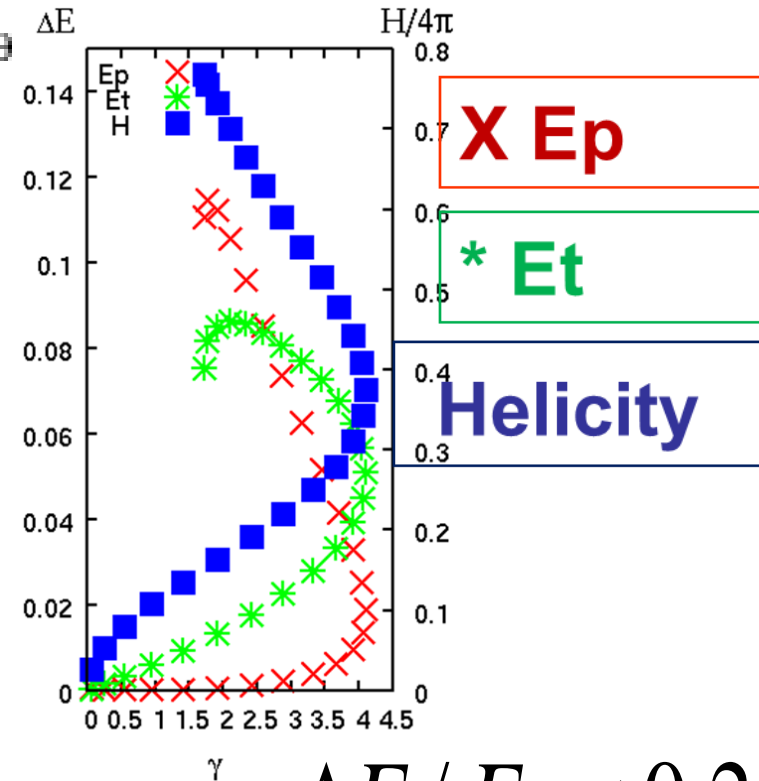


# Results in flat spacetime



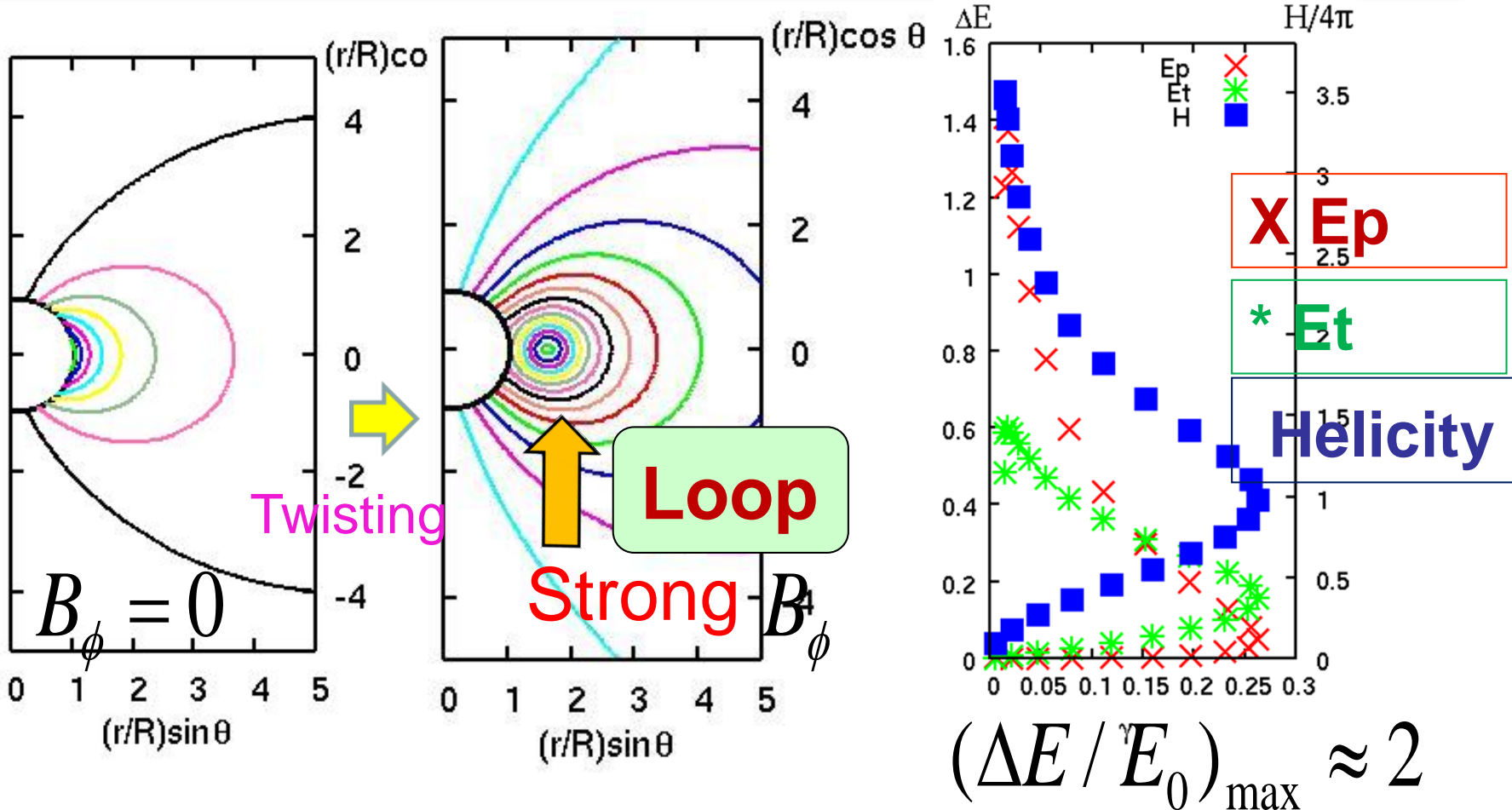
Pure dipole

Highly twisted structure with  $n=7$   
Flat spacetime



$$\Delta E / E_0 < 0.2$$

# Magnetosphere in relativistic model



Pure dipole

Highly twisted structure with  $n=7$

In curved spacetime  $M/R=1/4$

# Open field

Preliminary  
In preparation

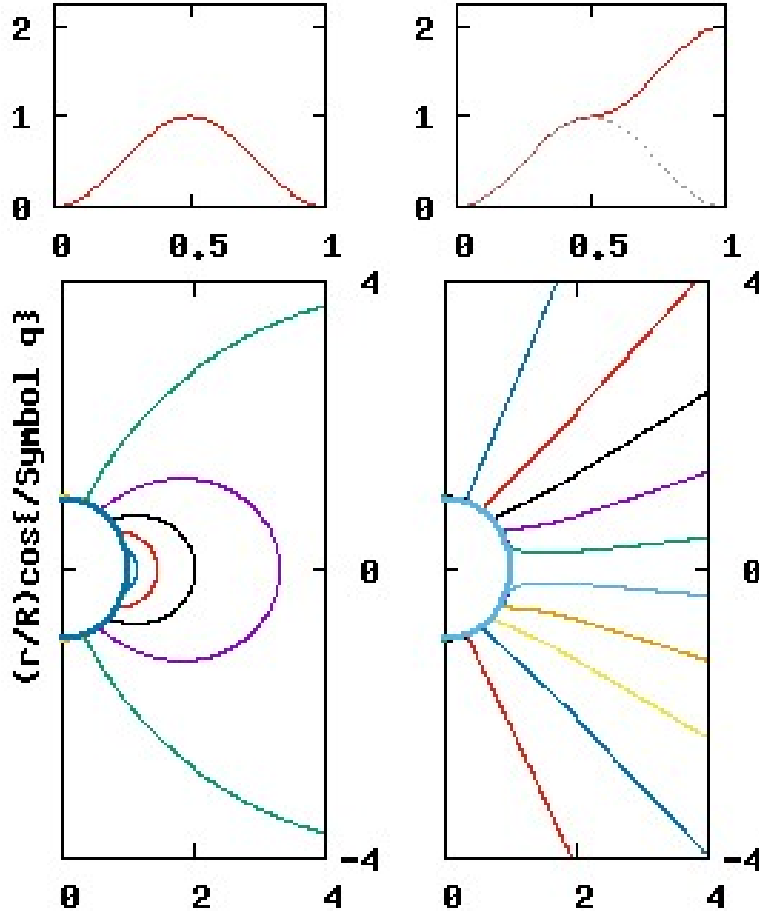
Problems

Stability?

Opening magnetic  
field lines

Maximum  $E > \text{Opening } E.$   
in a relativistic model

-> Opening magnetized  
flux rope as flare

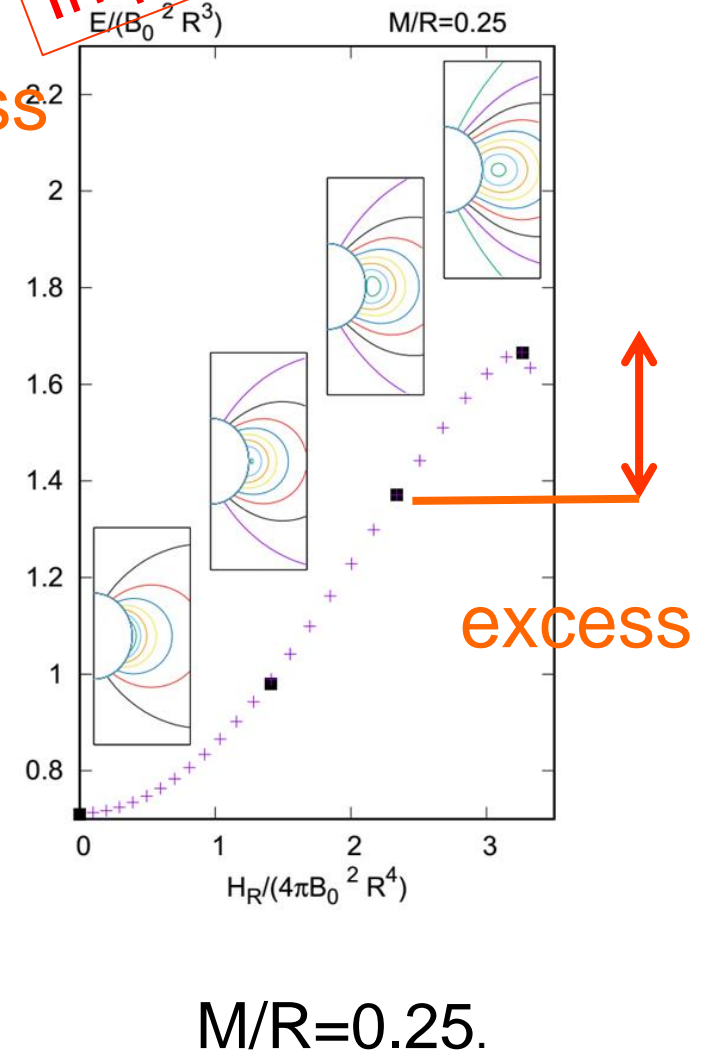
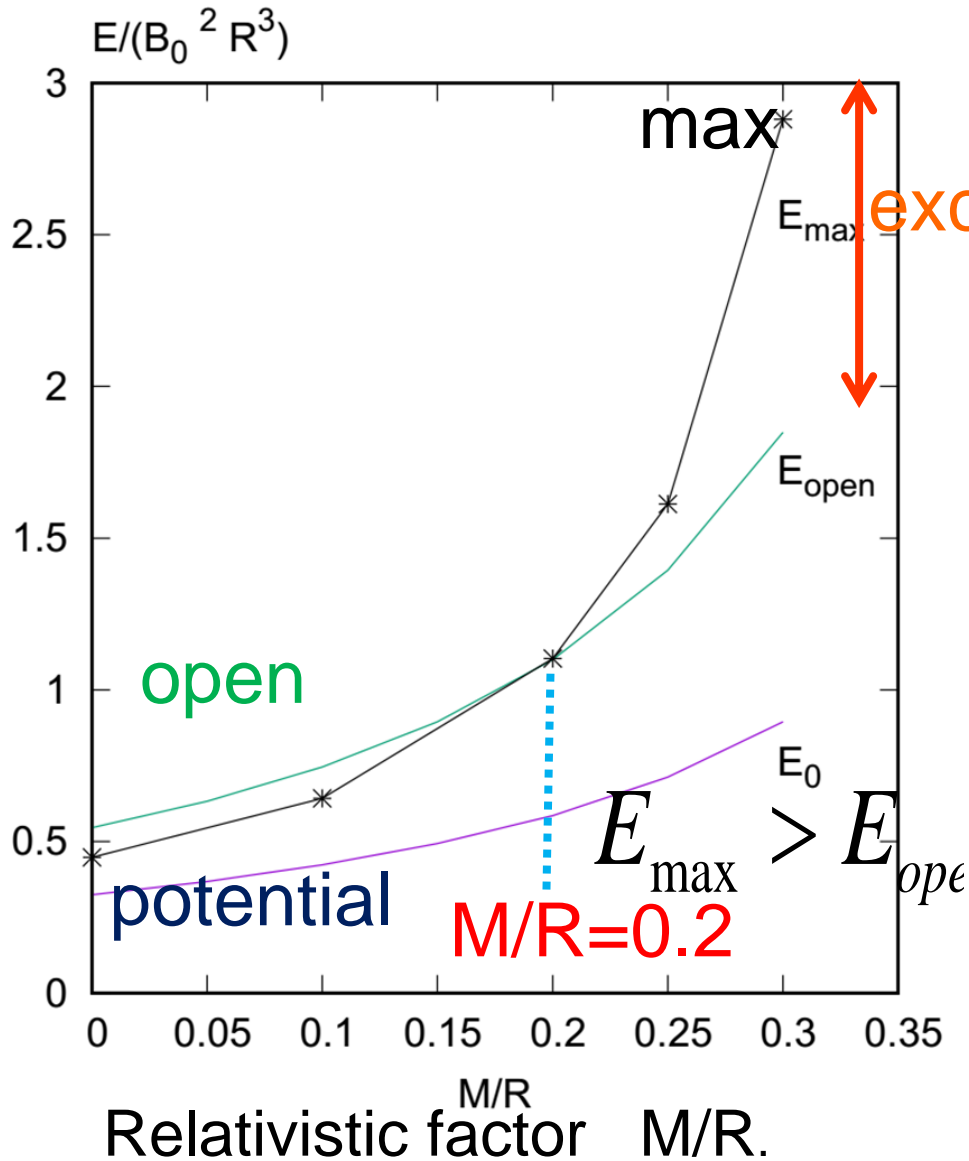


potential  
current-free

open

# Results

Preliminary  
In preparation



# まとめ

**マグネターのM/Rを知りたい**

**殻の磁場の変動 → 磁気圏 → 突然の解放**

**Internal (crust)**

-> **Elastic deformation**

**Plastic**

**External (magnetosphere)**

-> **Reconnection**

**エネルギーの貯蓄**

**M/Rが大 ほど E は大**