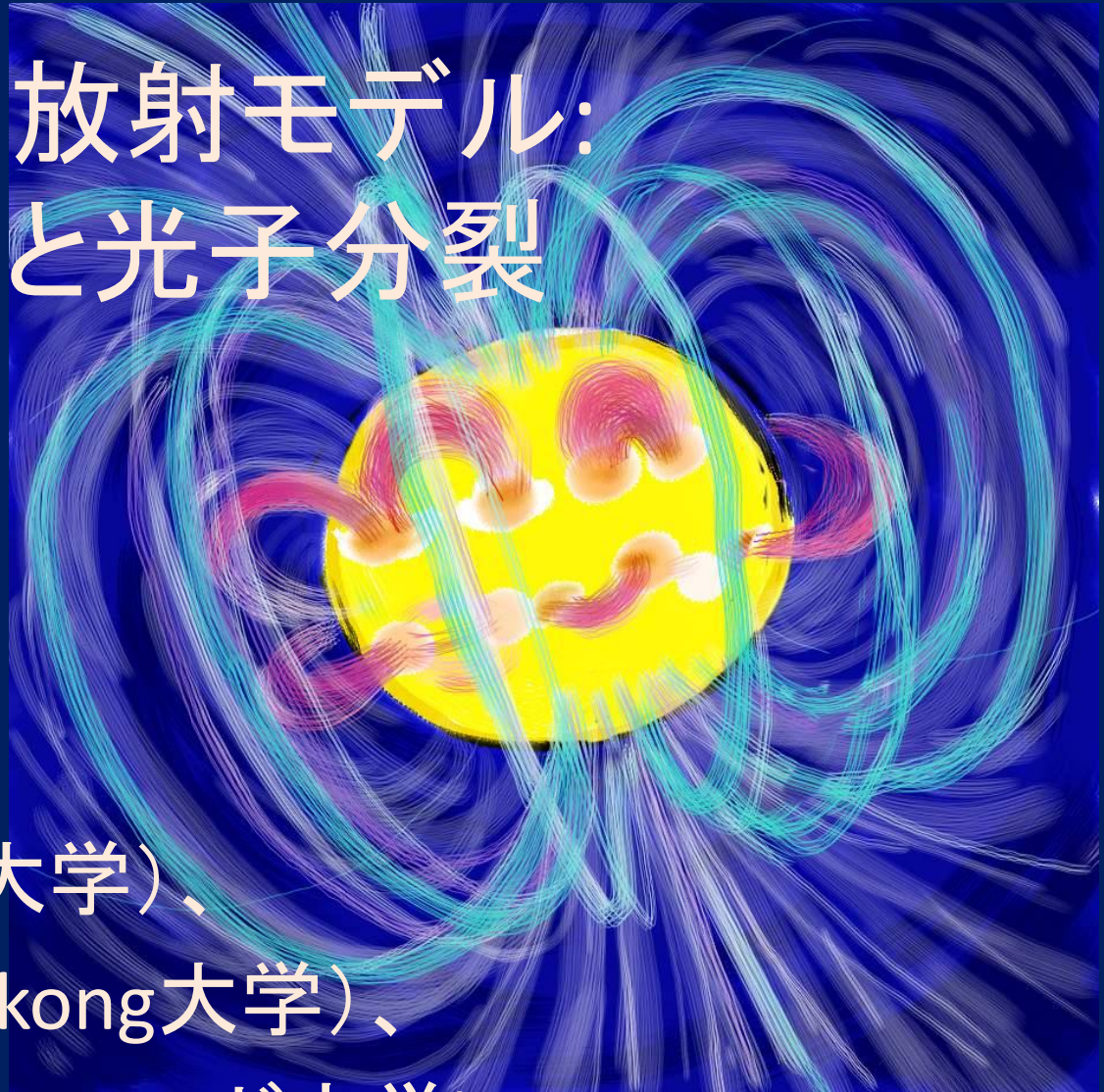


マグネターの放射モデル: すざくの観測と光子分裂



柴田晋平(山形大学)、
高田順平(Hongkong大学)、
榎戸輝揚(スタンフォード大学)

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(Enoto et al. 2010, マグネター大研究: Suzaku key project: Makishima et al.)
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単独の中性子星のスピンダウン

$$\dot{P} = dP/dt \quad \Omega = d\dot{\Omega}/dt$$



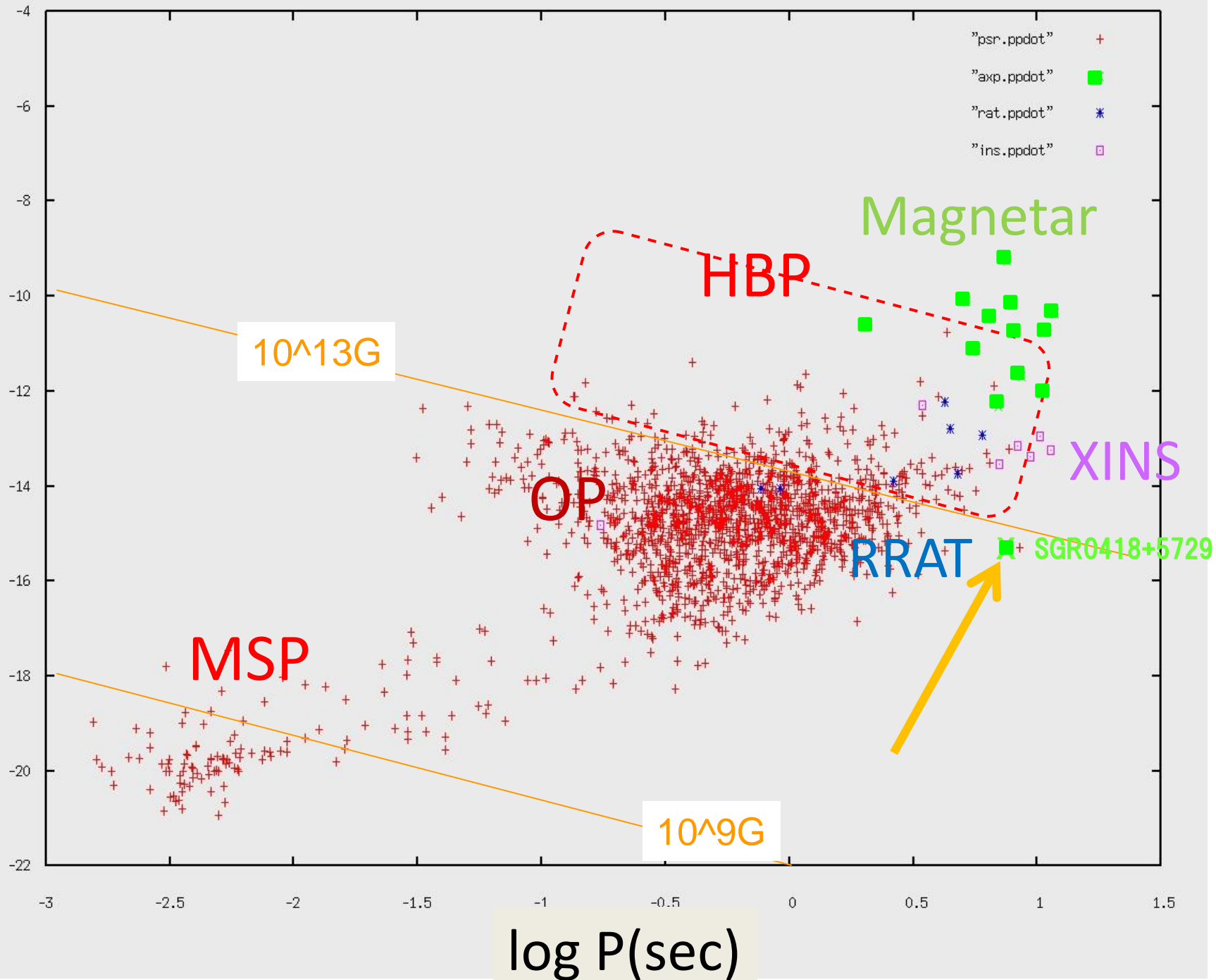
電磁氣的なブレーキ

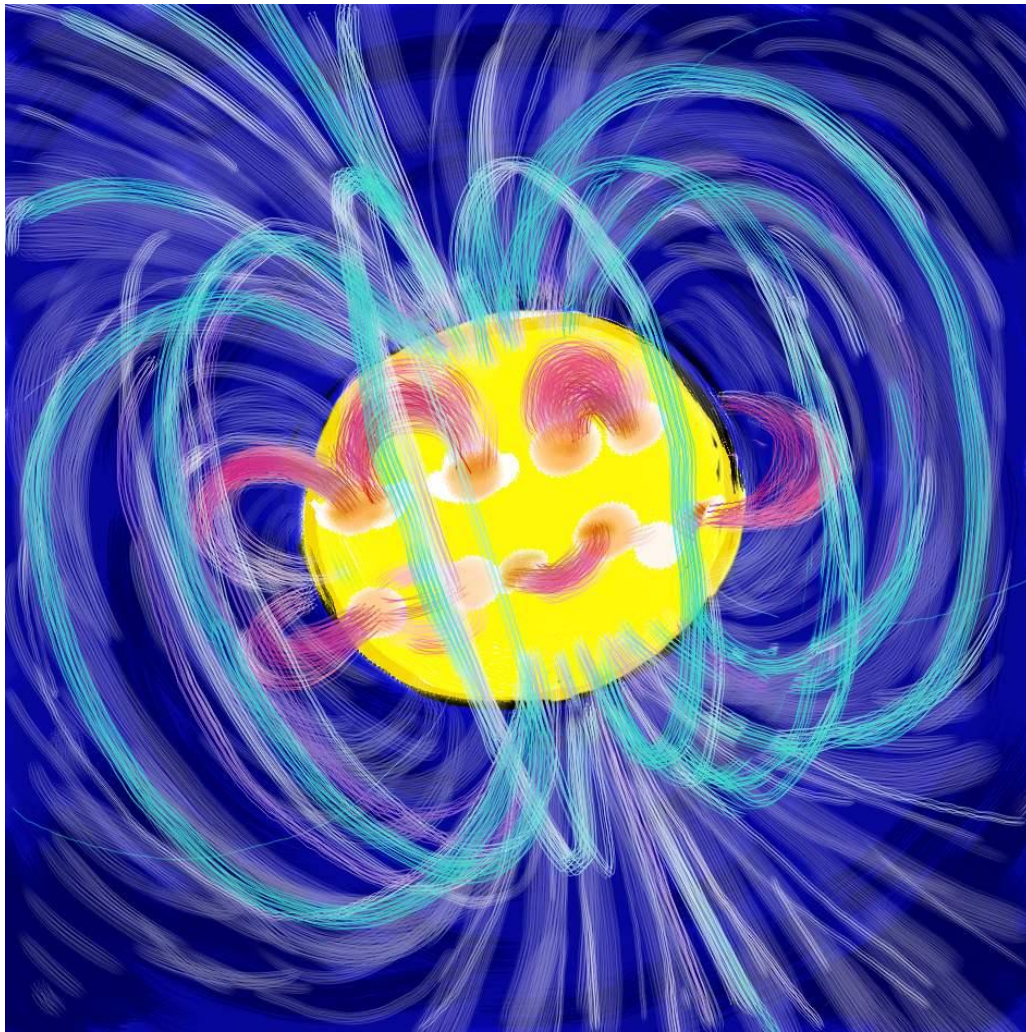
$$\dot{E}_{rot} = \mathfrak{S}\Omega\dot{\Omega} = \frac{\mu^2\Omega^4}{c^3}$$

磁気双極子モーメント $\mu = (1/2)B_d R^3$

双極子磁場強度 $> B_{QED} = 4 \cdot 10^{13} \text{G}$

Log dP/dt (sec/sec)





BdとBaは別成分

Dipole
component

Active region
magnetic field

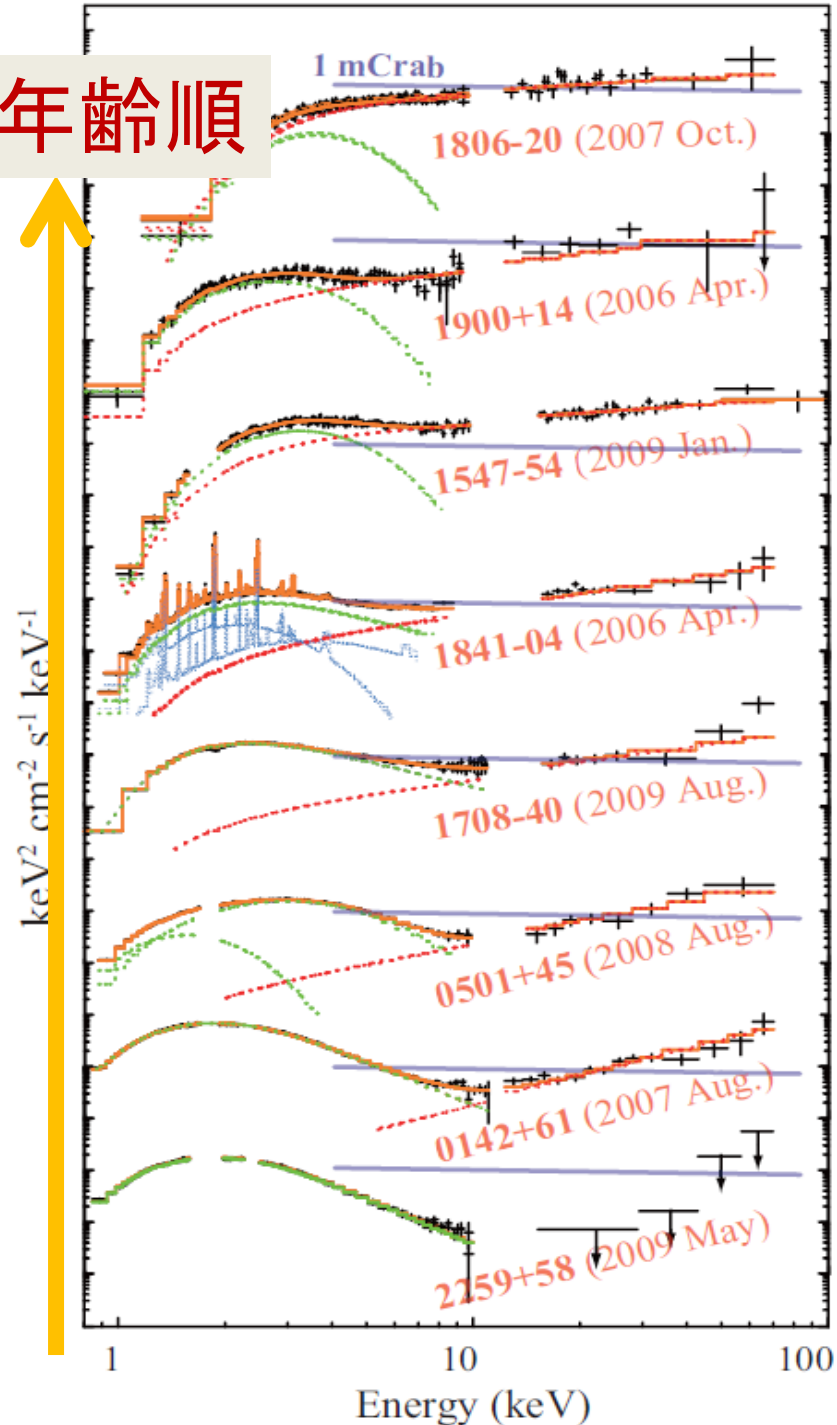
Bdは磁気トルク
(spin-down)を決める
Decayしにくい

Ba はBa より強く
Decayする。

→23b 青木雄太

強磁場電波パルサーにみられるX線光度の超過

年齡順



Soft component

$kT \sim 0.5\text{keV}$

bb

bb+comptonized comp.

Bb+comptonized comp.+bb2

F_s (soft flux)

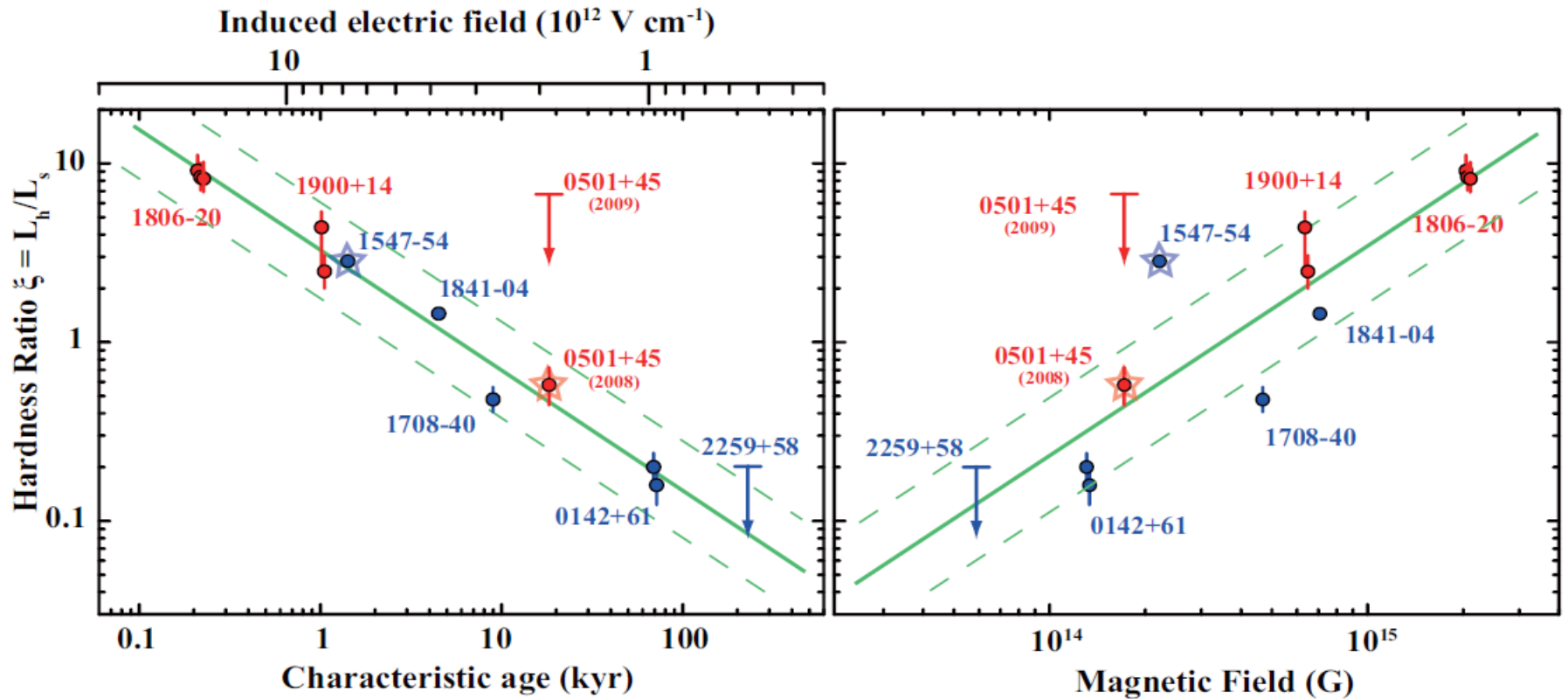
Hard component

Power law

F_h in 1-60keV (hard flux)

Hardness ratio

$$\xi = F_h / F_s$$



Enoto et al. 2010

$$\xi = \frac{F_h}{F_s} = (3.3 \pm 0.3) \times \left(\frac{\tau_c}{1 \text{ kyr}} \right)^{-0.67 \pm 0.04}$$

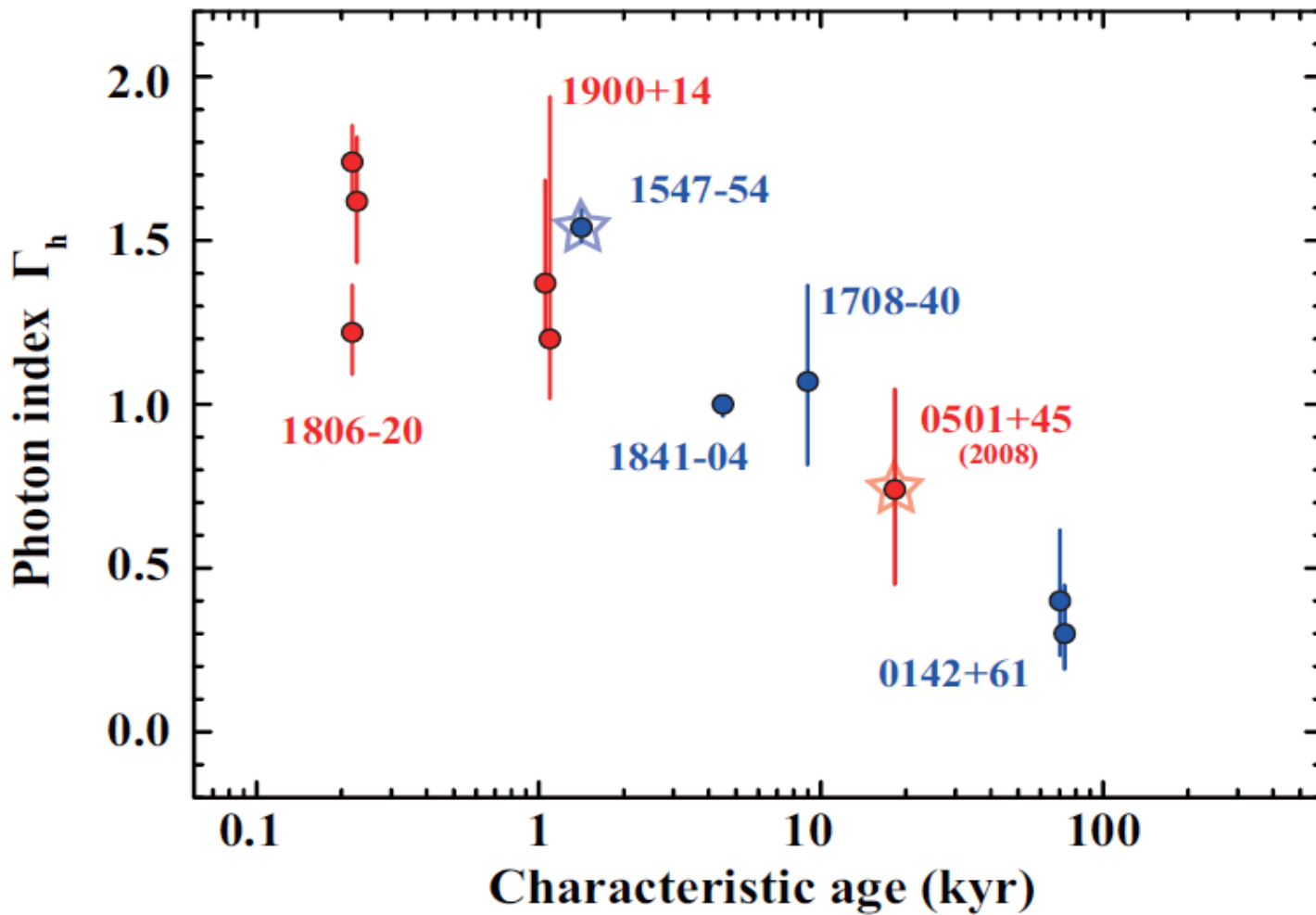
$$= (0.09 \pm 0.07) \times \left(\frac{B_s}{B_{\text{QED}}} \right)^{1.2 \pm 0.2}$$

相関係数

(Spearman's rank order test)

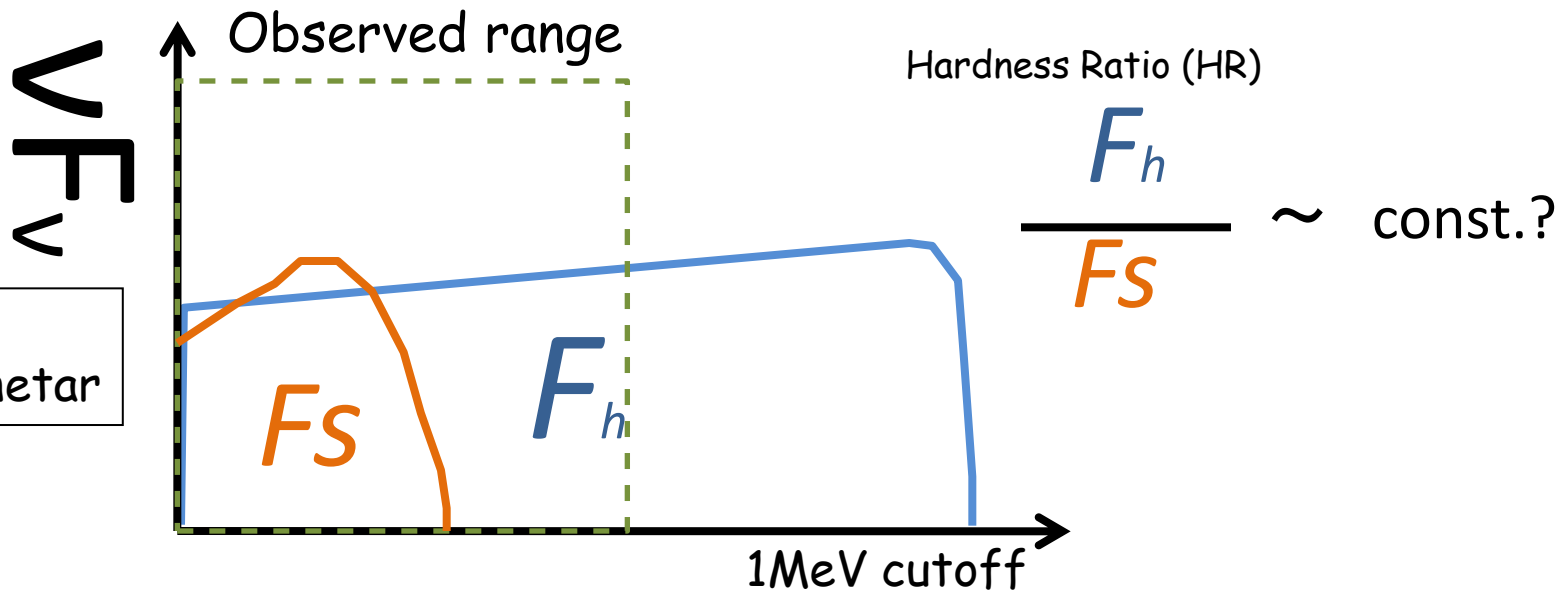
0.96

0.87

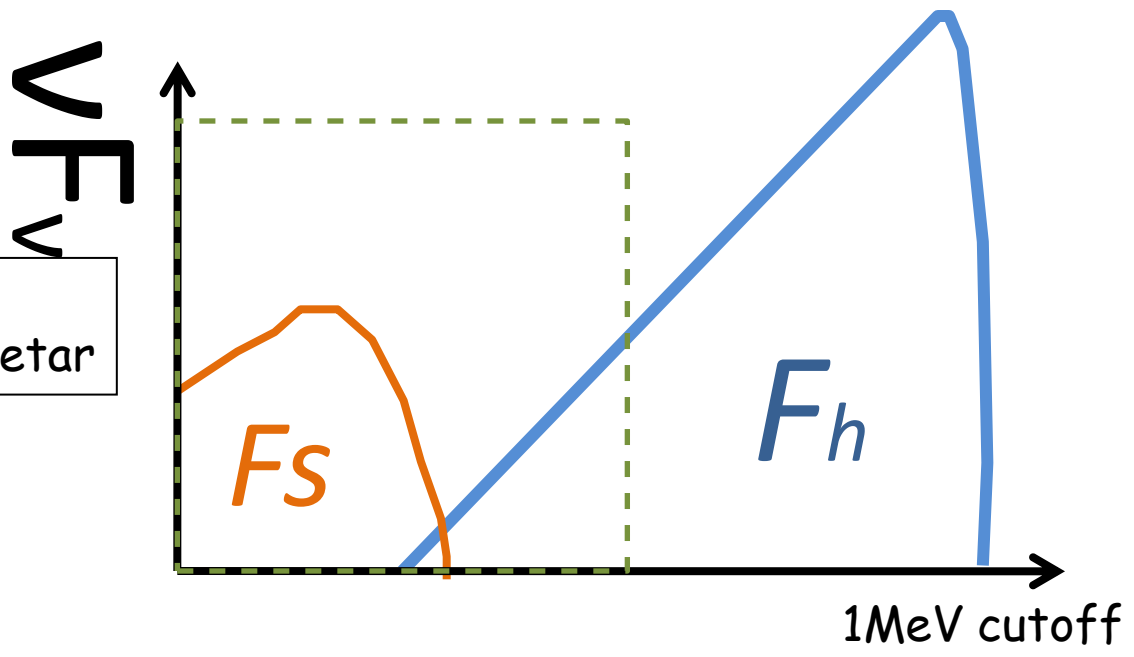


Enoto et al. 2010

High field
Young magnetar



Low field
Old magnetar



ほとんどすべて放射になる

磁場のエネルギー開放:

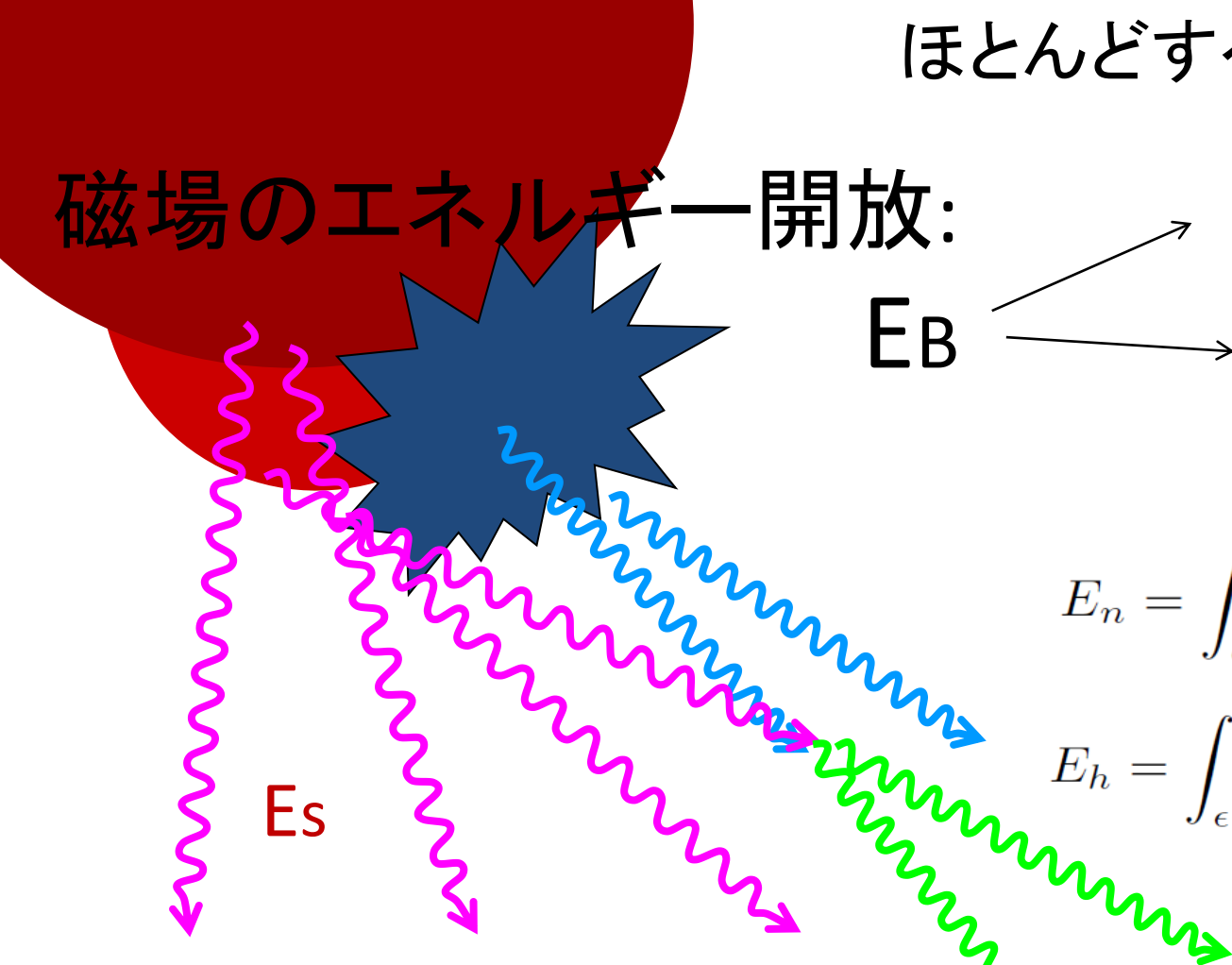
$$E_B \begin{cases} \rightarrow \eta E_B = E_n \\ \rightarrow (1-\eta)E_B = E_s \\ \qquad \qquad \qquad \propto F_s \end{cases}$$

$$E_n = \int_{\epsilon_1}^{\epsilon_0} K \epsilon^{\Gamma+1} d\epsilon$$

$$E_h = \int_{\epsilon_1}^{\epsilon_2} K \epsilon^{\Gamma+1} d\epsilon \propto F_h$$

$$HR = \frac{\eta}{1-\eta} \frac{\epsilon_2^{2-\Gamma} - \epsilon_1^{2-\Gamma}}{\epsilon_0^{2-\Gamma} - \epsilon_1^{2-\Gamma}}$$

$$\eta = 0.9, \epsilon = 2m_e c^2$$



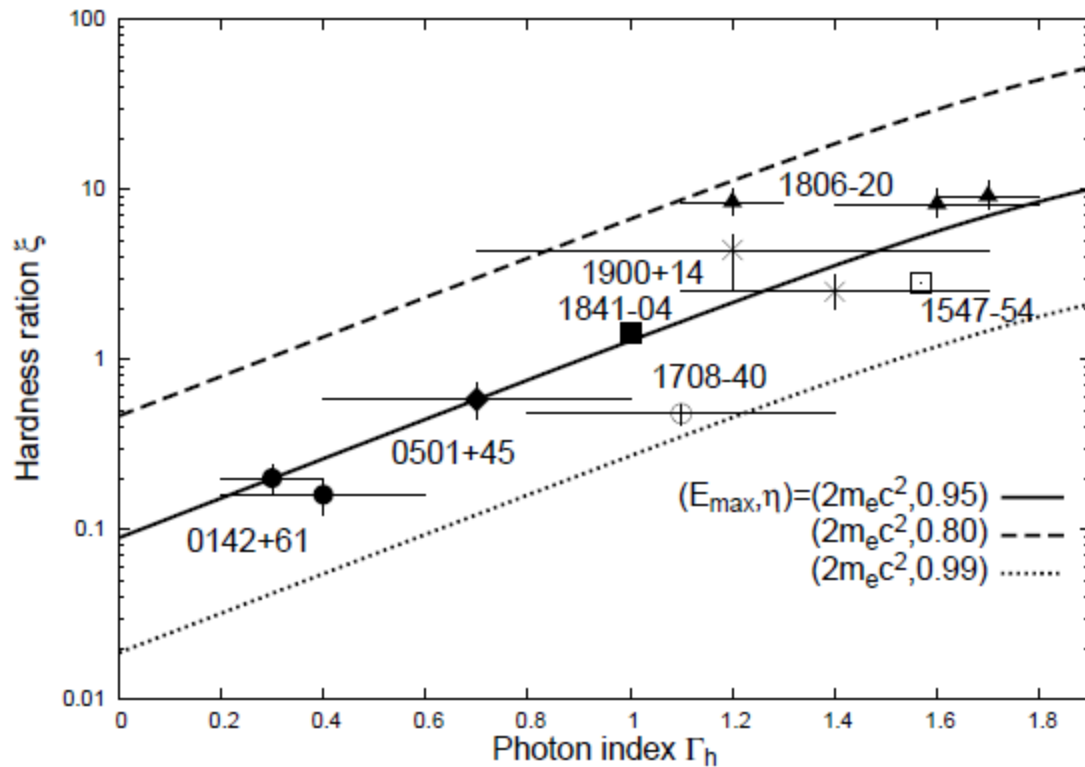


Fig. 1. Hardness ratio as a function of the photon index. The lines represents the model prediction expressed by equation 3 with $E_{max} = 2m_e c^2$, $E_{o,min} = 1$ keV and $E_{o,max} = 70$ keV. The solid, dashed and dotted lines are results for $\eta = 0.95, 0.8$ and 0.99 . The observational data are taken from Enoto et al. (2010b).

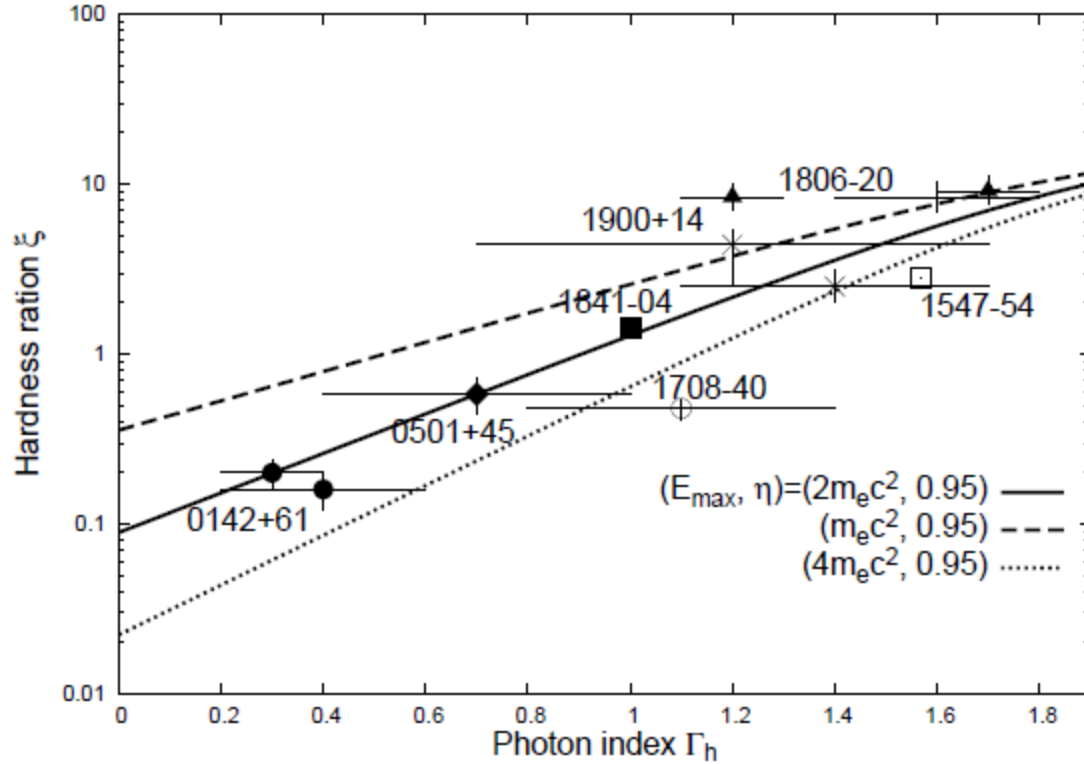
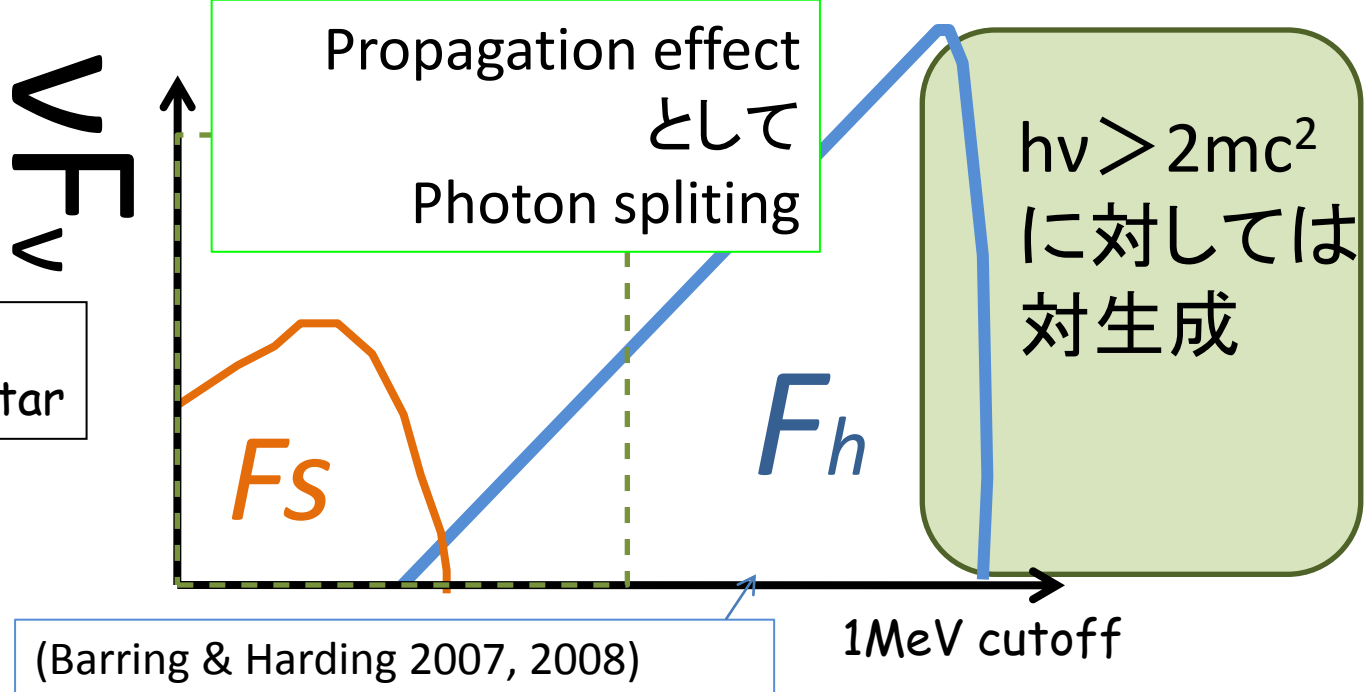
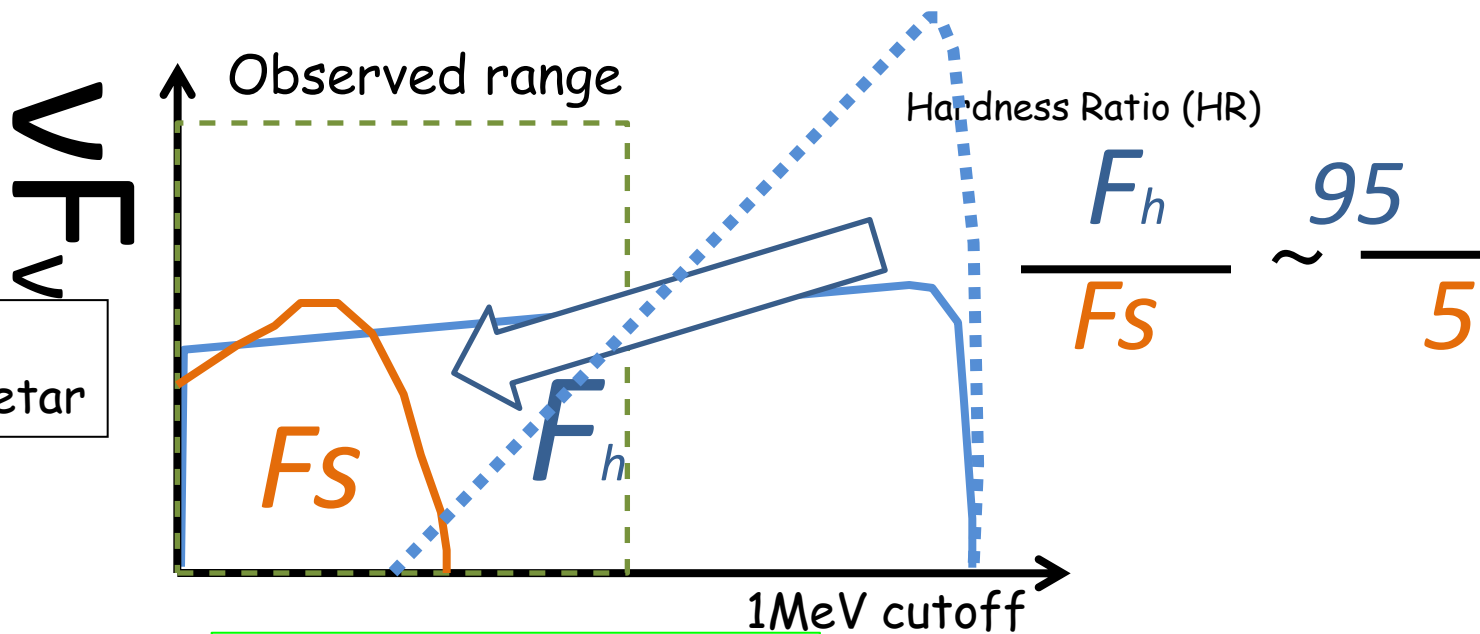
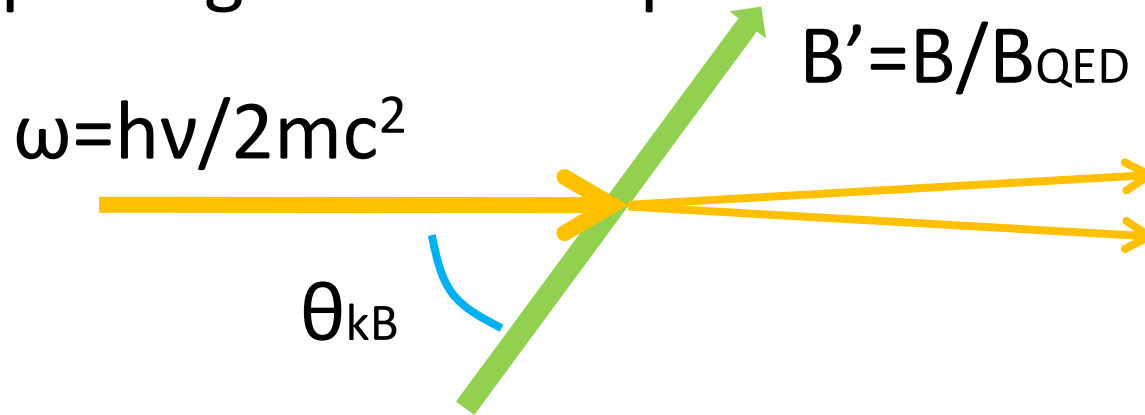


Fig. 2. Hardness ratio as a function of the photon index. The lines represent the model prediction expressed by equation 3 with $\eta = 0.95$, $E_{o,min} = 1$ keV and $E_{o,max} = 70$ keV. The solid, dashed and dotted lines are results for $E_{max} = 2m_e c^2$, $m_e c^2$ and $4m_e c^2$. The observational data are taken from Enoto et al. (2010b).



(Barrington & Harding 2007, 2008)

Photon splitting mean free path



$$T_{sp}(\omega) \sim \frac{\alpha^3}{120\pi^3} \frac{1}{\lambda} B'^6 \omega^5 \sin^6 \theta_{kB} (3\mathcal{M}_1^2 + \mathcal{M}_2^2), \quad (6)$$

$$\begin{aligned} \mathcal{M}_1 &= \frac{1}{B'^4} \int_0^\infty \frac{ds}{s} e^{-s/B'} \\ &\times \left[\left(-\frac{3}{4s} + \frac{s}{6} \right) \frac{\cosh s}{\sinh s} + \frac{3 + 2s^2}{12 \sinh^2 s} + \frac{s \cosh s}{2 \sinh^3 s} \right], \\ \mathcal{M}_2 &= \frac{1}{B'^4} \int_0^\infty \frac{ds}{s} e^{-s/B'} \\ &\times \left[\frac{3 \cosh s}{4s \sinh s} + \frac{3 - 4s^2}{4 \sinh^2 s} - \frac{3s^2}{2 \sinh^4 s} \right], \end{aligned} \quad (7)$$

Photon splitting mean free path

$$\omega = \hbar\nu / 2mc^2$$

$$B' = B / B_{\text{QED}}$$

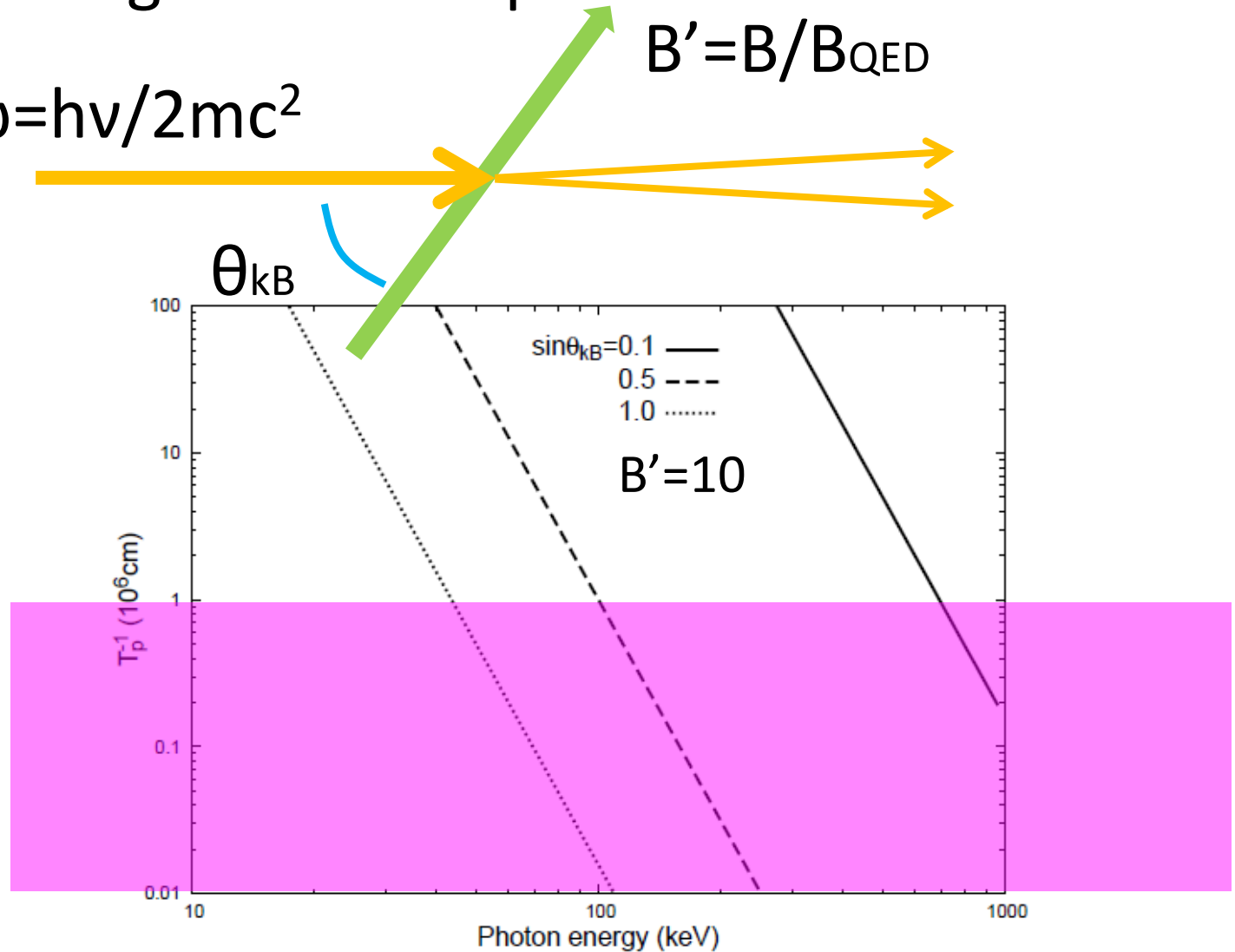
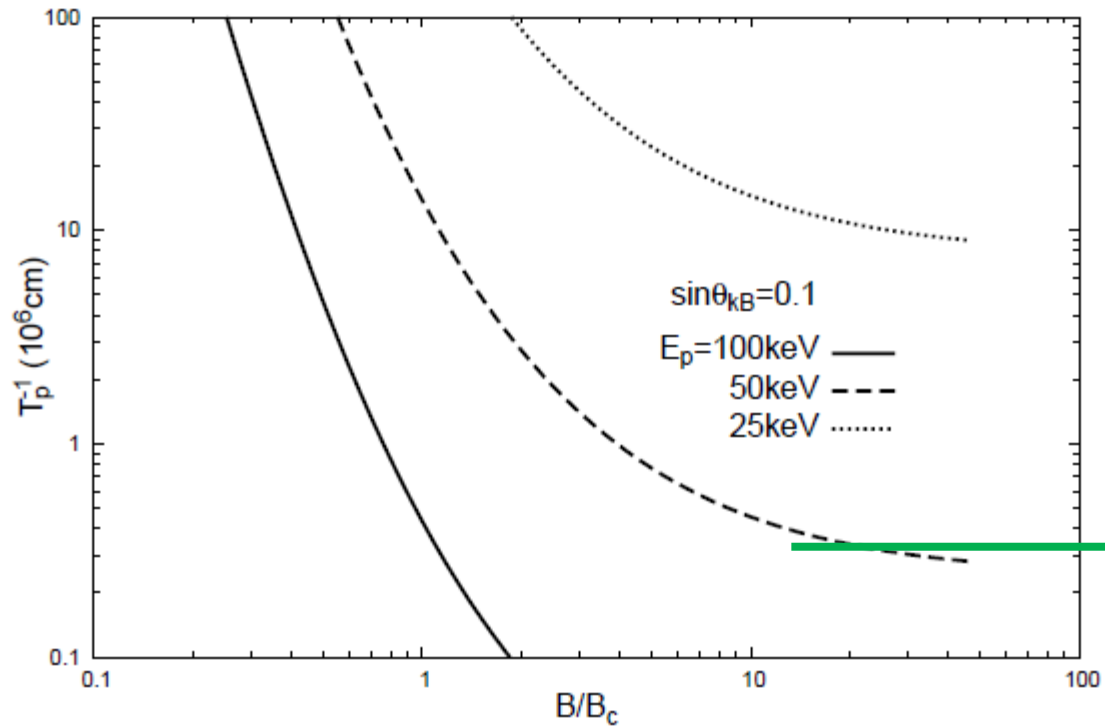


Fig. 4. Attenuation length of the photon-splitting as a function of the photon energy. The solid, dashed and dotted lines are results for the collision angle corresponding to $\sin \theta_{kB} = 0.1, 0.5$ and 1.0 . We assume the magnetic field $B = 10B_c$.

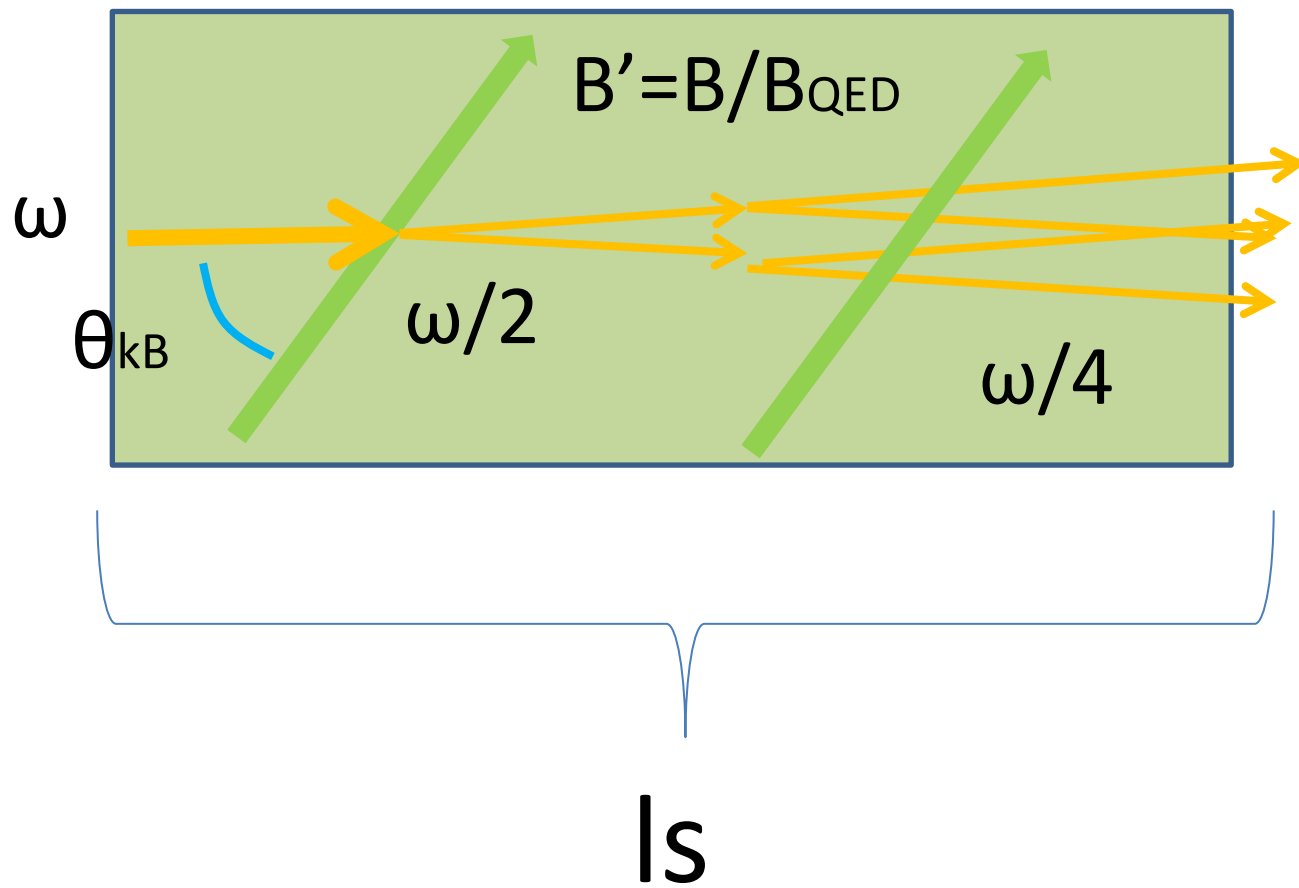


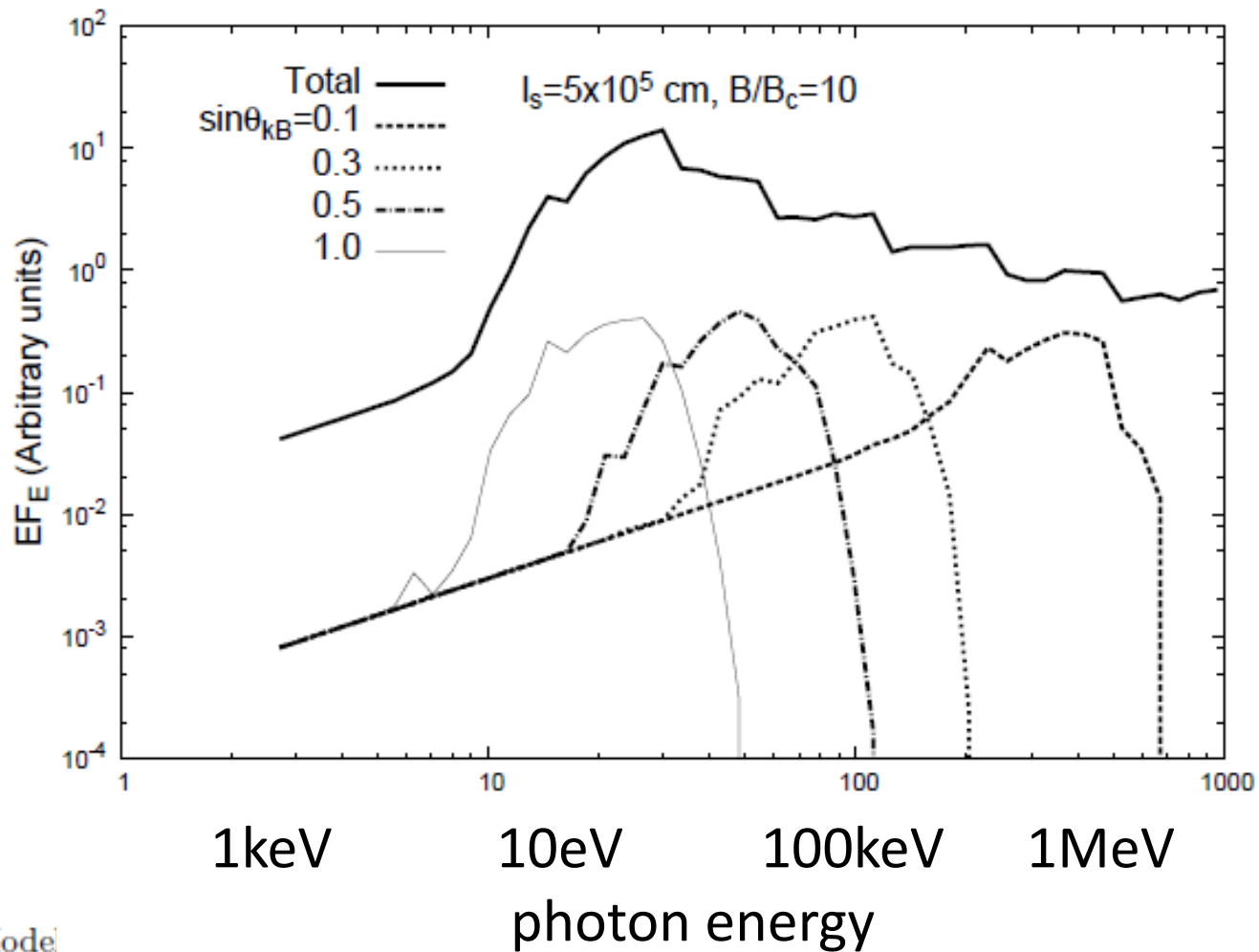
磁場が強ければ
おおざっぱに一定

Fig. 5. Attenuation length of the photon-splitting as a function of the magnetic field strength. The solid, dashed and dotted lines are results for the photon energy $E = 100$ keV, 50 keV and 25 keV. We assume the collision angle corresponding to $\sin\theta_{kB} = 0.1$.



$B_a=4 \times 10^{14}$ G





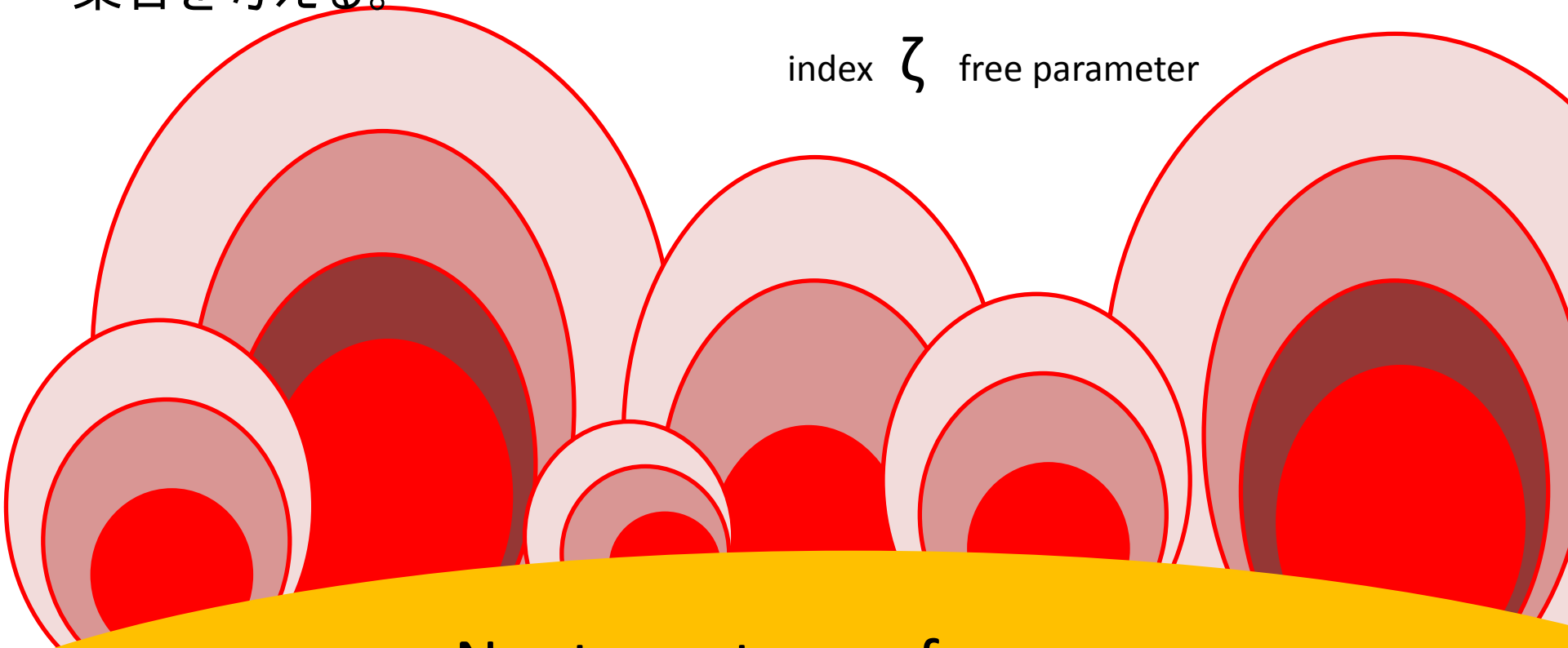
B' given
 l_s given
 では
 何世代まで
 落ちるかが
 決まるので
 ピークが出る。
 l_s で
 ピークの位置が
 決まる。

Fig. 6. Model ed-dot-
 ted and thin-solid lines are results for $\theta_{kB} = 0.1, 0.3, 0.5$ and 1.0 . $10^2 \text{ cm}, 10^4 \text{ cm}$ and 10^6 cm . The thick line represents the spectrum integrated over $0 \leq \theta_{kB} \leq \pi/2$. The results are for the propagating distance of $l_s = t \times 10^5 \text{ cm}$ and the magnetic field of $B/B_c = 10$.

Power law分布のいろいろなサイズの磁気ループの集合を考える。

$$\frac{dN_{l_s}}{dl_s} \propto l_s^{-\zeta} \quad 1 \text{ cm} \leq l_s \leq 10^6 \text{ cm},$$

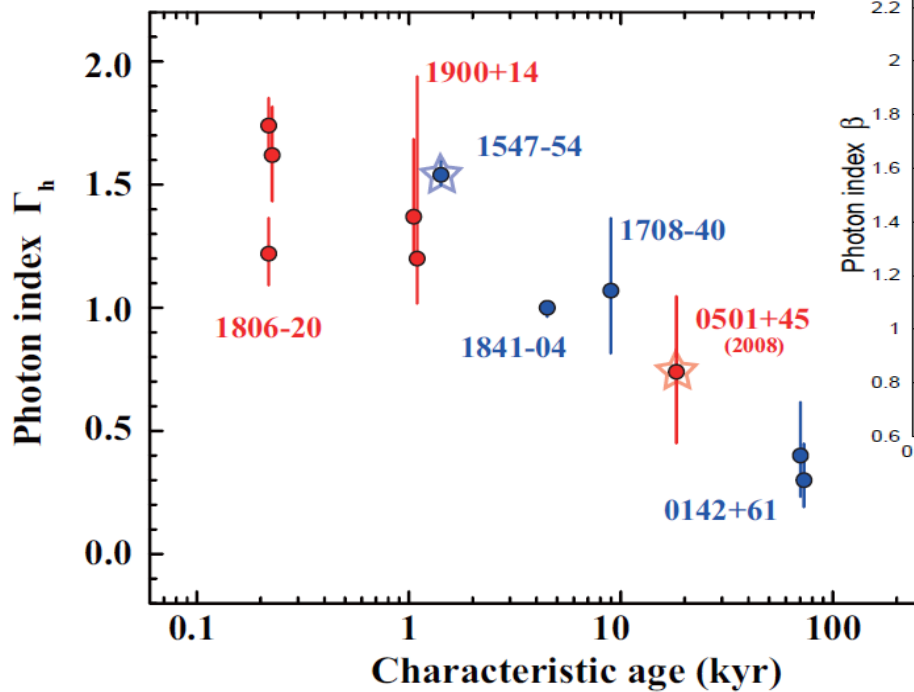
index ζ free parameter



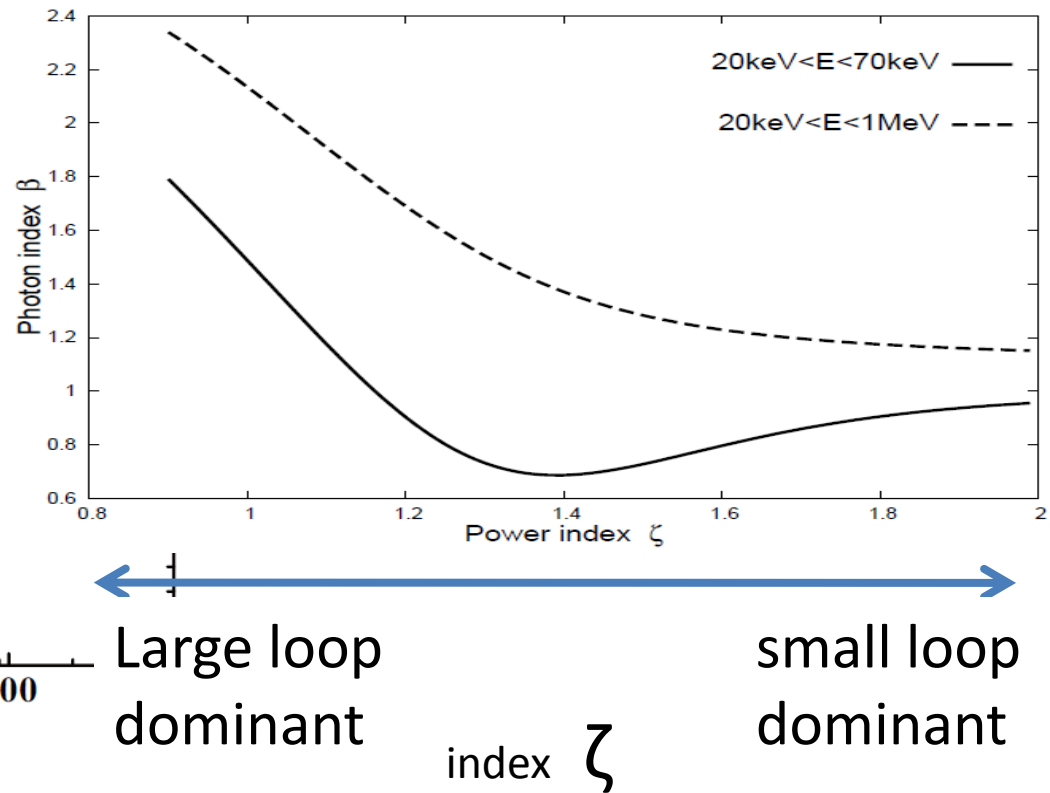
Neutron star surface

Ageとともに大きなループから無くなっていく:
decay of active regions

Observation (Enoto et al. 2010)



Present model



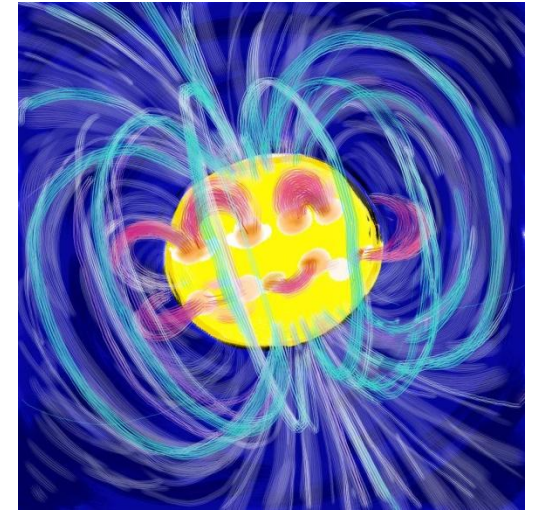
問題点

●モードロックのため連続的な光子分裂が起こらないのでないか。

→磁気糸になっいて $B < B_q$ の空間がいっぱいある、磁気糸の交差により磁気中性面と真空ギャップが多数存在、コンプトン散乱などの効果？

●95%が non-thermal だとエネルギー的には $B_a = 10^{15} \text{G}$ あったほうが嬉しい。 $B_a = 10-100$
 B_d

全エネルギー(the magnetar)



$$L_x(\text{thermal}) \sim 2 \times 10^{34} \text{ erg/s}$$

$$L_{\text{tot}} = L_x(\text{thermal}) / 0.05 = 4 \times 10^{35} \text{ erg/s}$$

$$\tau = 100 \text{ kyr} = 3 \times 10^{12} \text{ s}$$

$$L_{\text{tot}} \times \tau = 10^{48} \text{ erg}$$

$$\begin{aligned} B_a^2 R^3 &= (10^{15} \text{ G})^2 (10^6 \text{ cm})^3 \\ &= 10^{48} \text{ erg} \end{aligned}$$

$$\text{Maybe } B_a = 10^{15} \text{ G} = 10 - 100 \text{ Bd}$$