PBF过程与Crab脉冲星

华中师范大学

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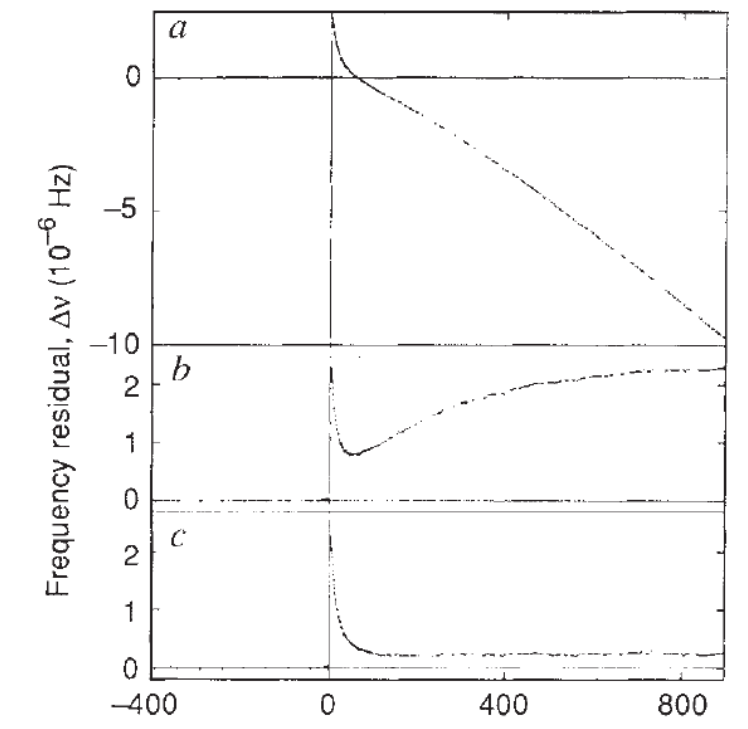
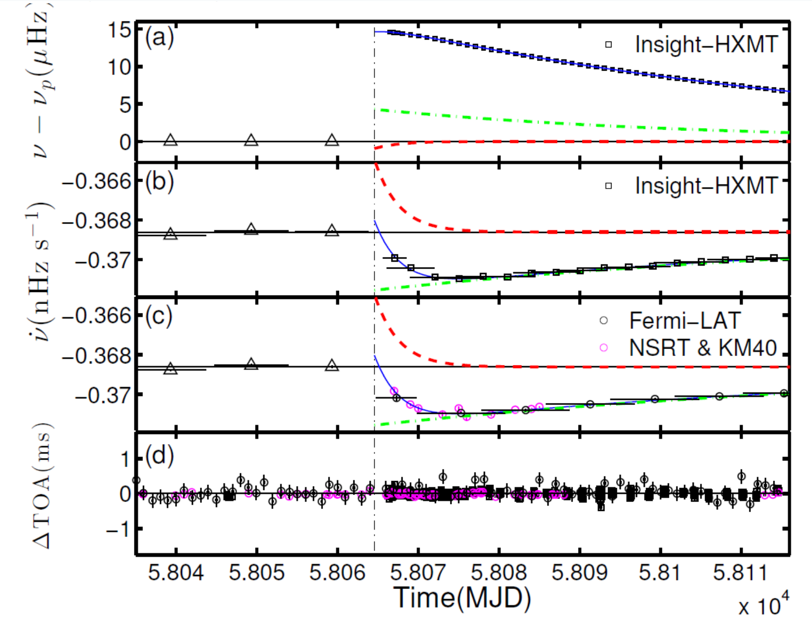
广州，2018,7

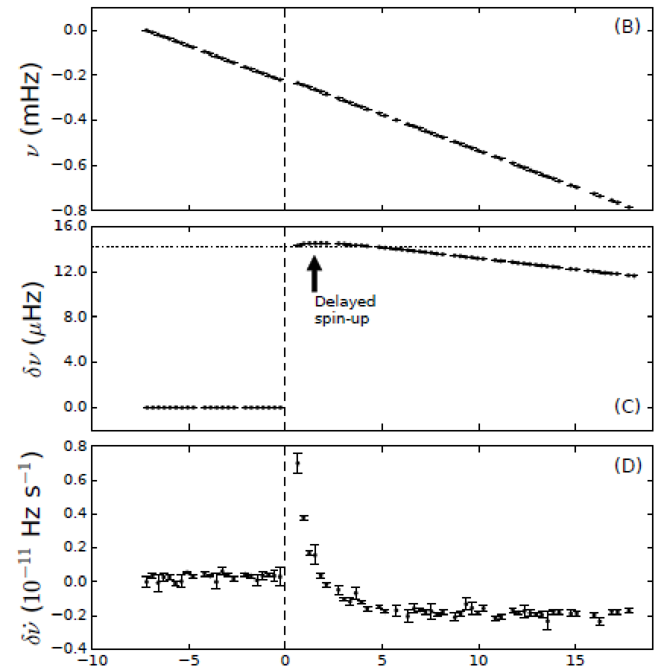
问题



Nature 1992



Insight 2017



MNRAS 2018

- Cassiopeia A 温度快速下降
- 中子星超流与Cooper对形成和破坏（PBF）
- 超流退耦
  - Crab制动指数
  - Post-Glitch 正力矩
- 总结

中子星温度快速下降

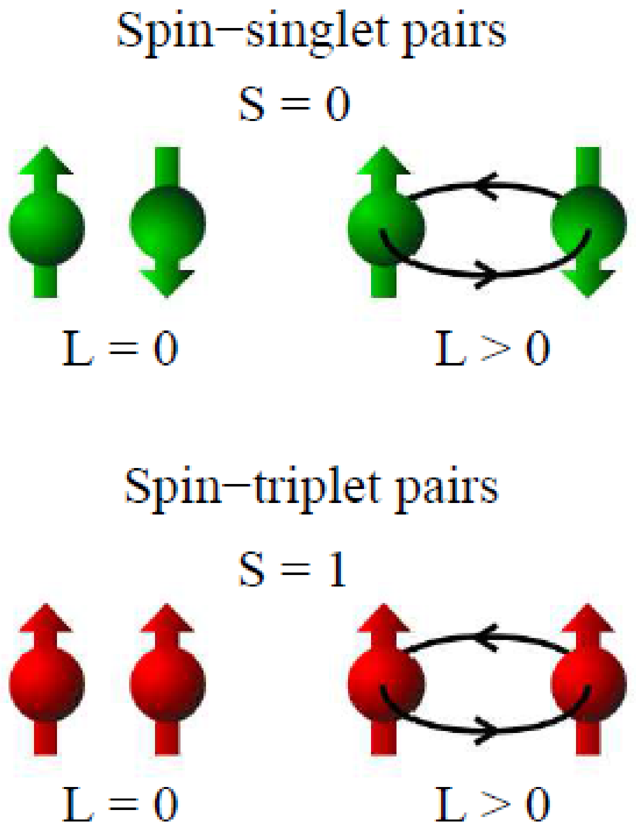
Three types of superfluidity

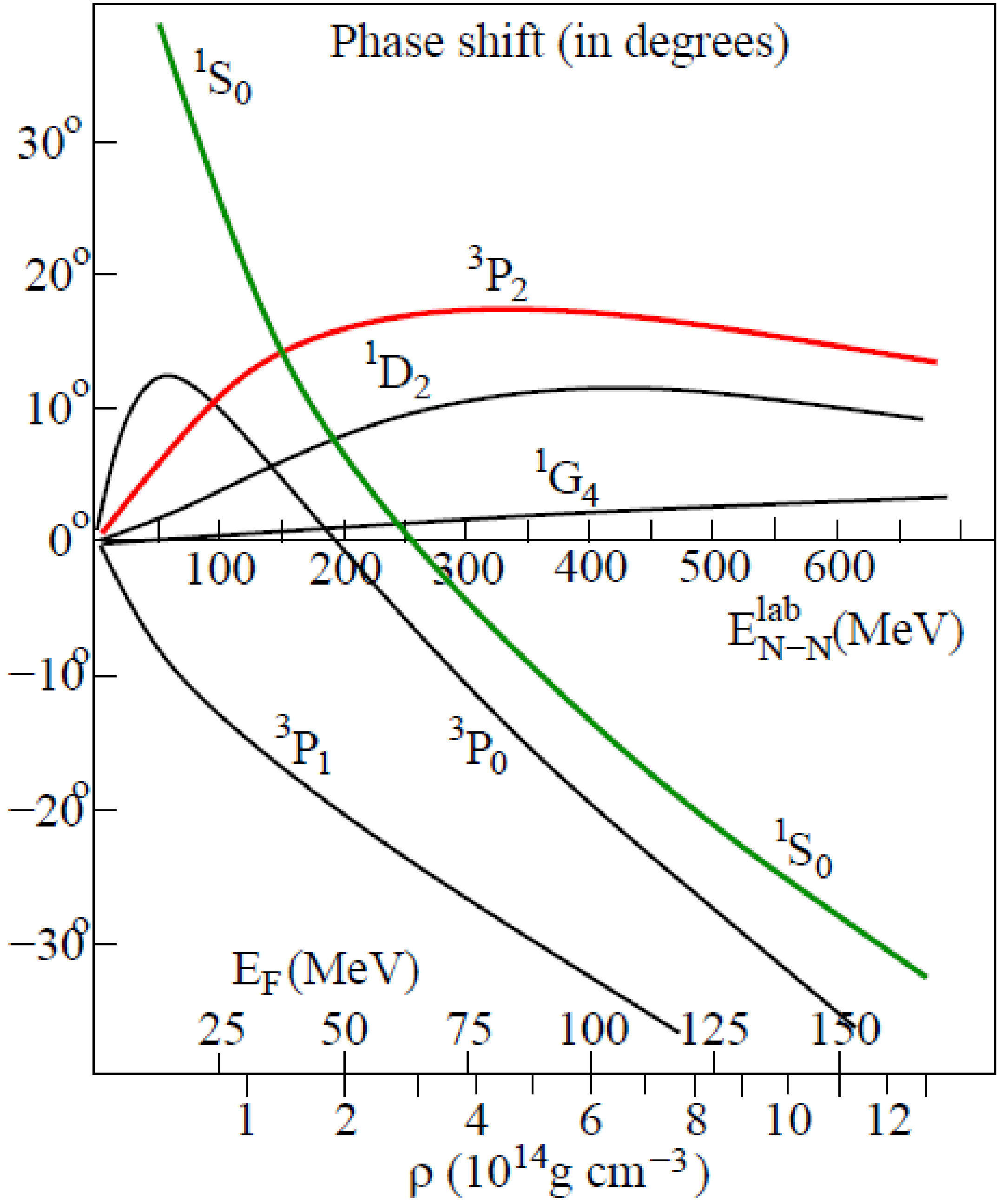
	Superfluidity type	λ	$F(\vartheta)$	$k_B T_c/\Delta(0)$
A	$^1S_0$	1	1	0.5669
B	$^3P_2$ $(m_J = 0)$	1/2	$(1 + 3\cos^2\vartheta)$	0.8416
C	$^3P_2$ $(\lvert m_J \rvert = 2)$	3/2	$\sin^2\vartheta$	0.4926

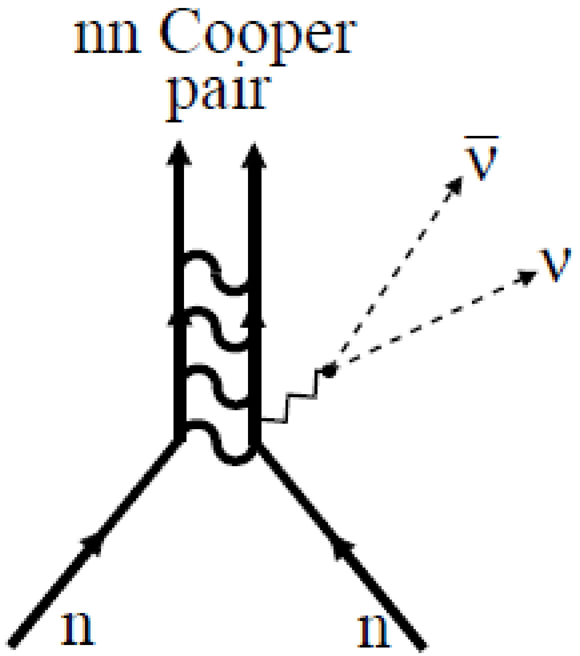
$$\ln\left[\frac{\Delta_0}{\Delta(T)}\right] = 2\lambda \int \frac{d\Omega}{4\pi} \int_0^\infty \frac{dx}{z} f(z) F(\vartheta)$$

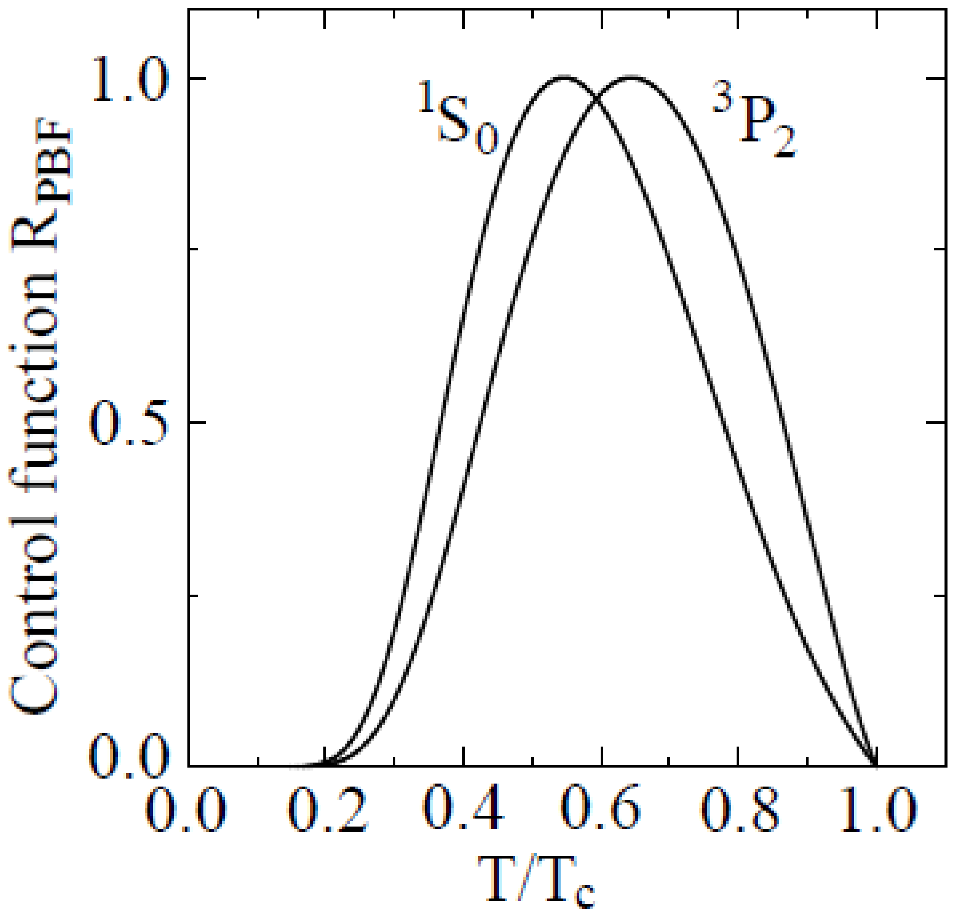
$$z = \frac{\tilde{\varepsilon}}{k_B T} = \sqrt{x^2 + y^2}, \quad x = \frac{v_F(p - p_F)}{k_B T}, \quad y = \frac{\delta}{k_B T}$$

$$\varepsilon - \mu = \pm\tilde{\varepsilon}, \quad \tilde{\varepsilon} = \sqrt{\delta^2 + v_F^2(p - p_F)^2}$$


Spin−singlet pairs
S = 0
L = 0
L > 0
Spin−triplet pairs
S = 1
L = 0
L > 0

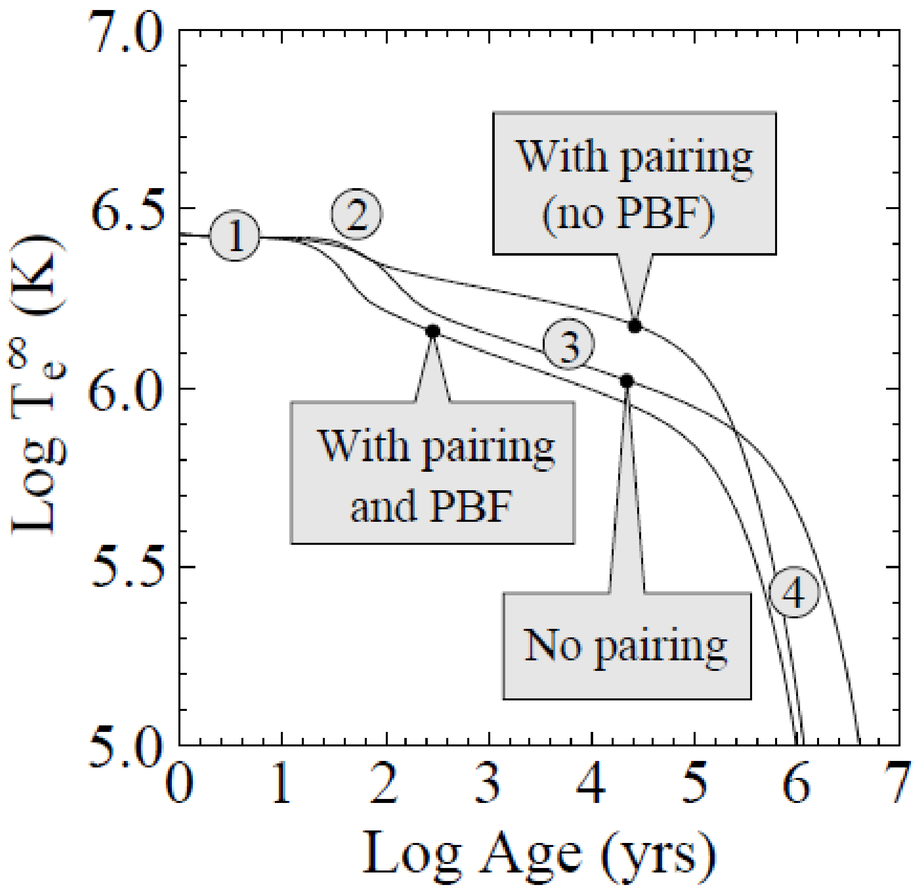

Phase shift (in degrees)
$^1S_0$
$^3P_2$
$^1D_2$
$^1G_4$
$^3P_1$
$^3P_0$
$^1S_0$
30°
20°
10°
0°
−10°
−20°
−30°
100
200
300
400
500
600
E^{lab}_{N-N}(MeV)
E_F(MeV)
25
50
75
100
125
150
1
2
4
6
8
10
12
ρ (10^{14}g cm^{-3})

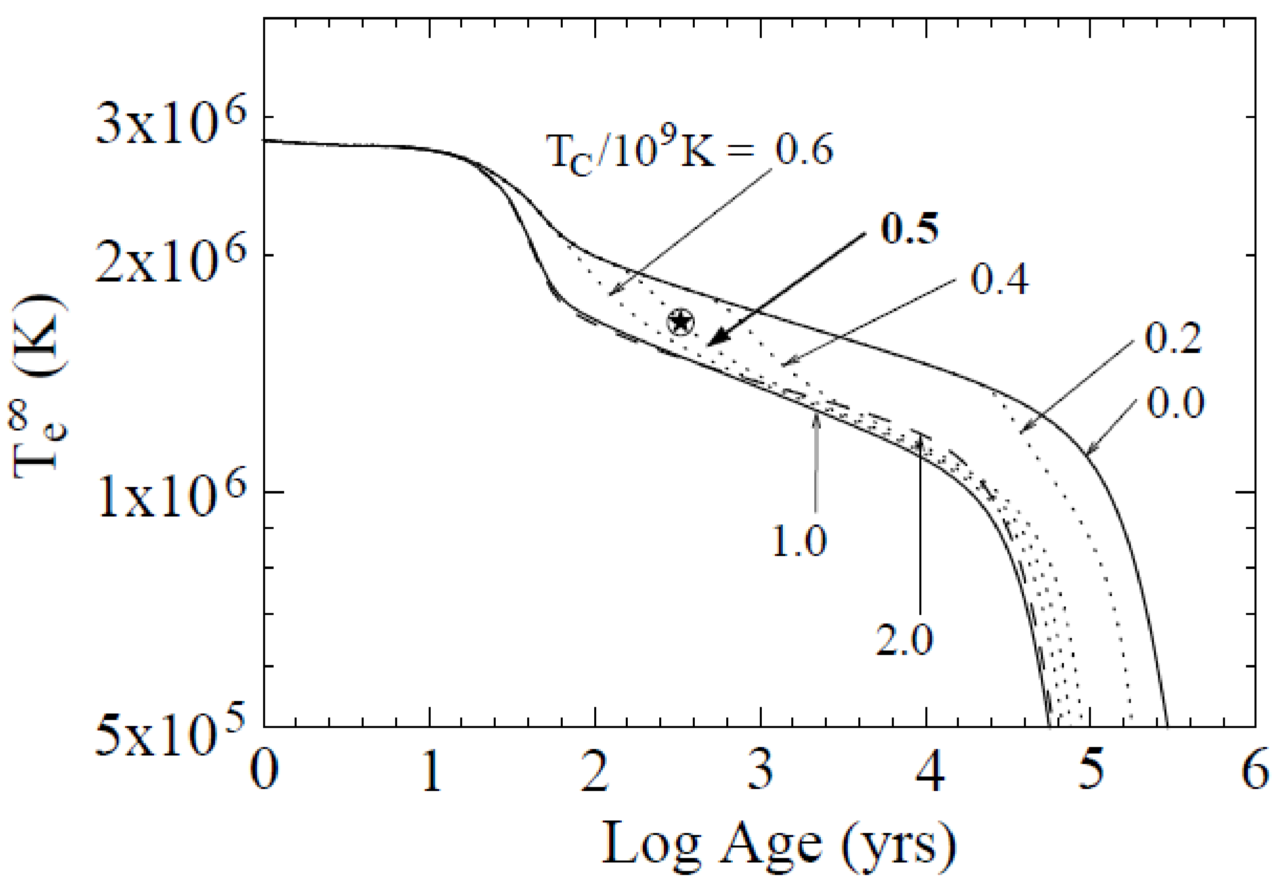




$$\varepsilon^{\rm PBF} = \frac{12 G_F^2 m^*_f p_{F,f}}{15\pi^5 \hbar^{10} c^6} (k_B T)^7 \, a_{f,j} R_j \left[\Delta_j(T)/T\right]$$

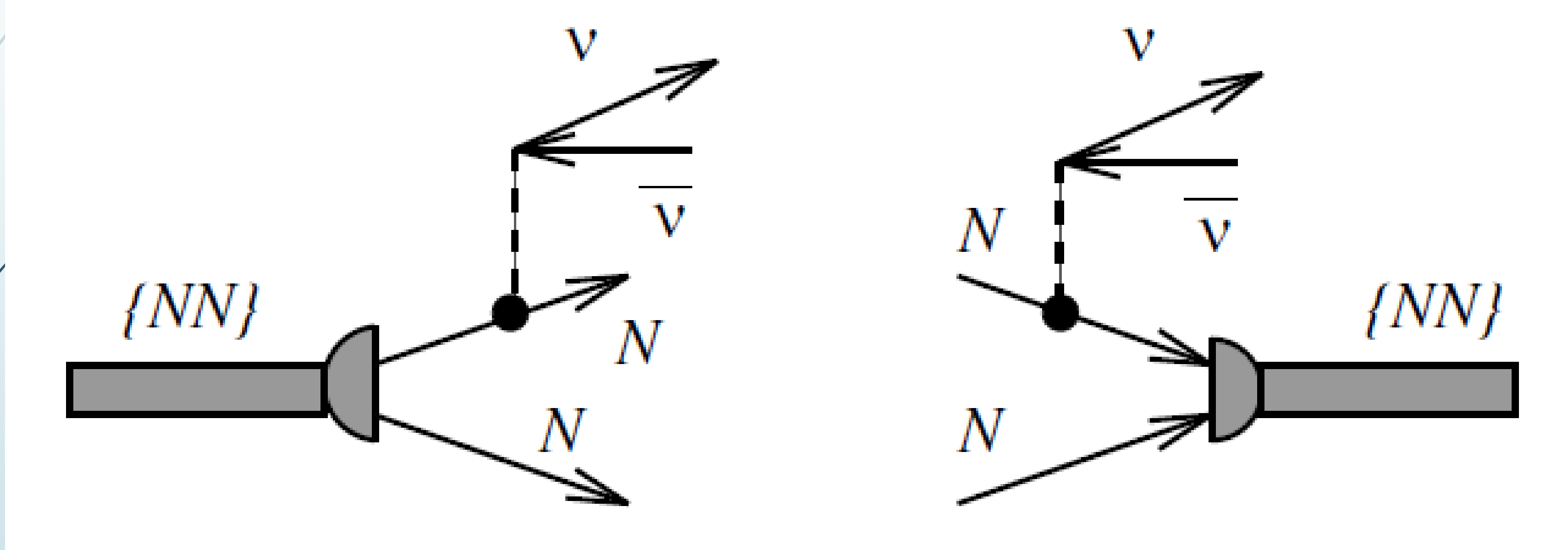
$$= 3.51 \times 10^{21} \, \frac{\rm erg}{\rm cm^3 \, s} \times \tilde{m}_f \, \tilde{p}_{F,f} \, T_9^7 \, a_{f,j} \, R_j \left[\Delta_j(T)/T\right]$$





Page et al Phys.Rev.Lett. 2011 ; Proc. Sci. 2011

中子星超流与Cooper对形成和破坏



平衡过程

$$\Gamma^{(\mathrm{CP})} = \frac{4G_{\mathrm{F}}^2 m_N^* p_{\mathrm{F}}}{15\pi^5 \hbar^{10} c^6} (k_{\mathrm{B}} T)^7 \mathcal{N}_\nu a F(v)$$

$$= 1.170 \times 10^{21} \left(\frac{m_N^*}{m_N}\right)\left(\frac{p_{\mathrm{F}}}{m_N c}\right) T_9^7 \mathcal{N}_\nu a F(v)\, \mathrm{erg\,cm^{-3}\,s^{-1}}$$

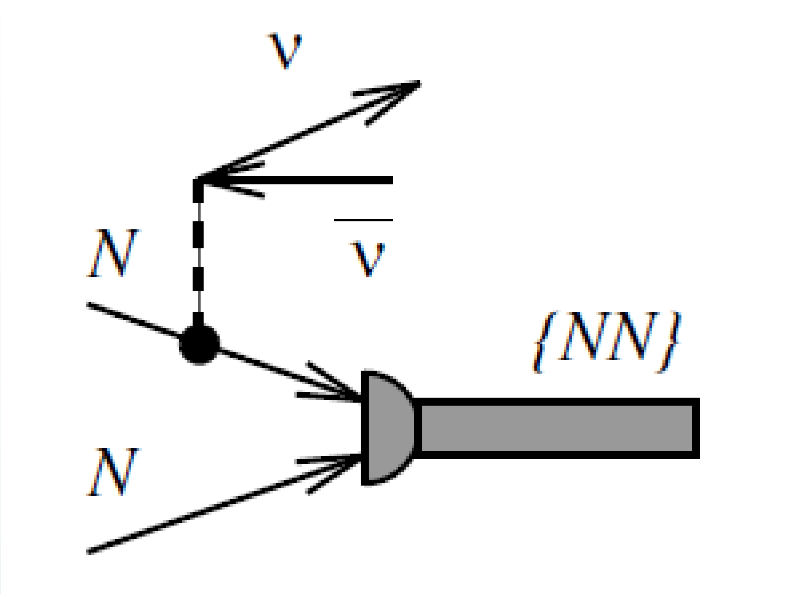
$$F(v) = \frac{1}{4\pi}\int \mathrm{d}\Omega\, y^2 \int_0^\infty \frac{z^3\,\mathrm{d}x}{(\mathrm{e}^z + 1)^2}$$

Voskresensky，Senatorov，Yad. Fiz. 1987；Yakovlev et al Phys. Rep. 2001

偏离平衡

$$\Gamma(\delta\nu) \sim \frac{1}{4\pi}\int d\Omega\, y^2 \int_0^\infty \frac{z^3\,dx}{(e^Z+1)^2}$$

$$Z = z - \delta\nu \qquad \nu = \delta\mu / kT$$



净反应率

$$\Delta\Gamma \propto a\,\delta\mu + b(\delta\mu)^3$$

超流退耦

$$\frac{d}{dt}(I\Omega) = -\beta\Omega^3 - N_{\mathrm{pin}} - N_{\mathrm{mf}}$$

$$\frac{d}{dt}(I_{\mathrm{sf}}\Omega_{\mathrm{sf}}) = N_{\mathrm{pin}} + N_{\mathrm{mf}},$$

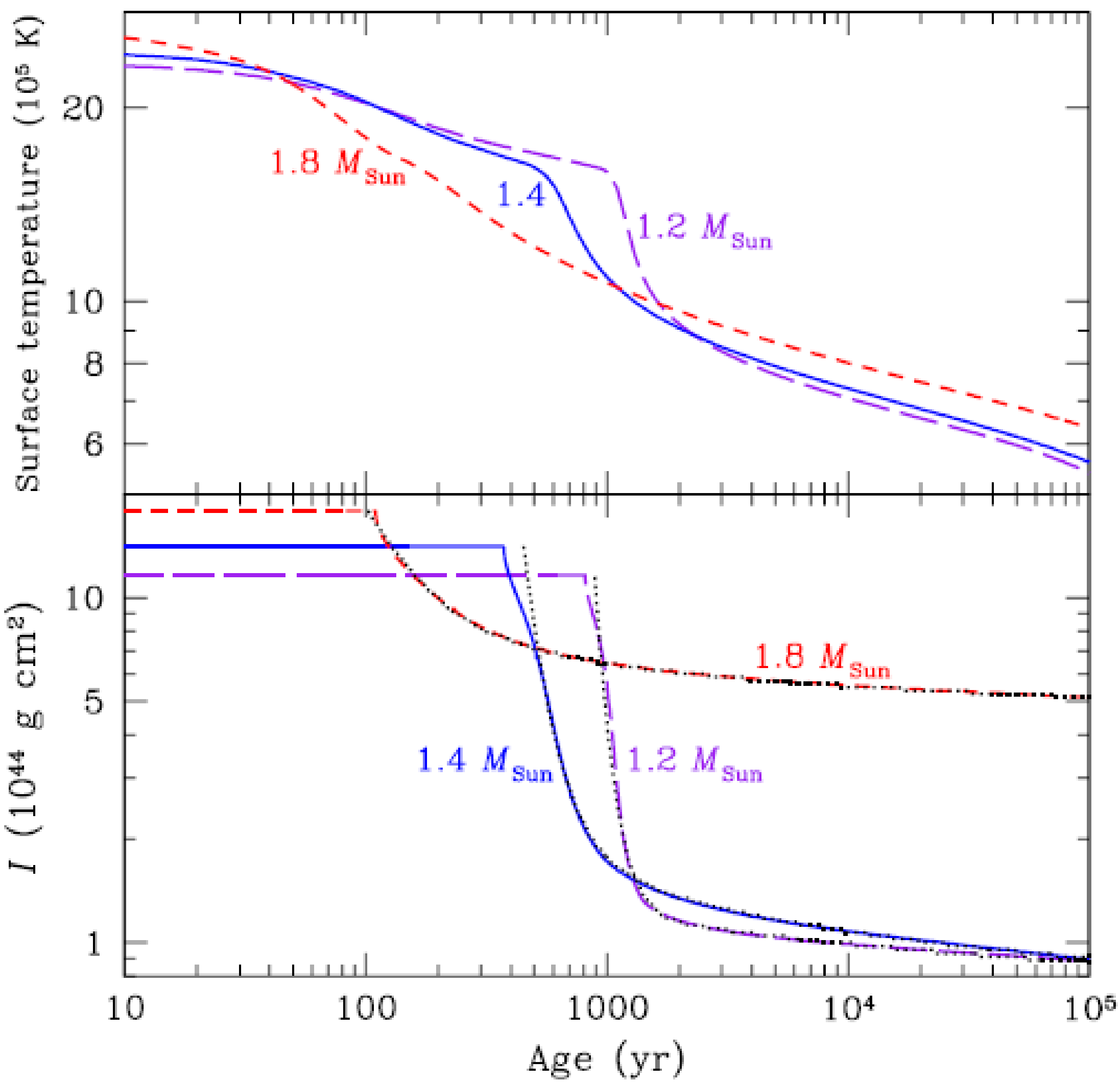
$$\frac{d\Omega}{dt} = (\Omega_{\mathrm{sf}} - \Omega)\frac{1}{I}\frac{dI}{dt} - \beta\frac{\Omega^3}{I}$$

超流退耦

- Crab制动指数

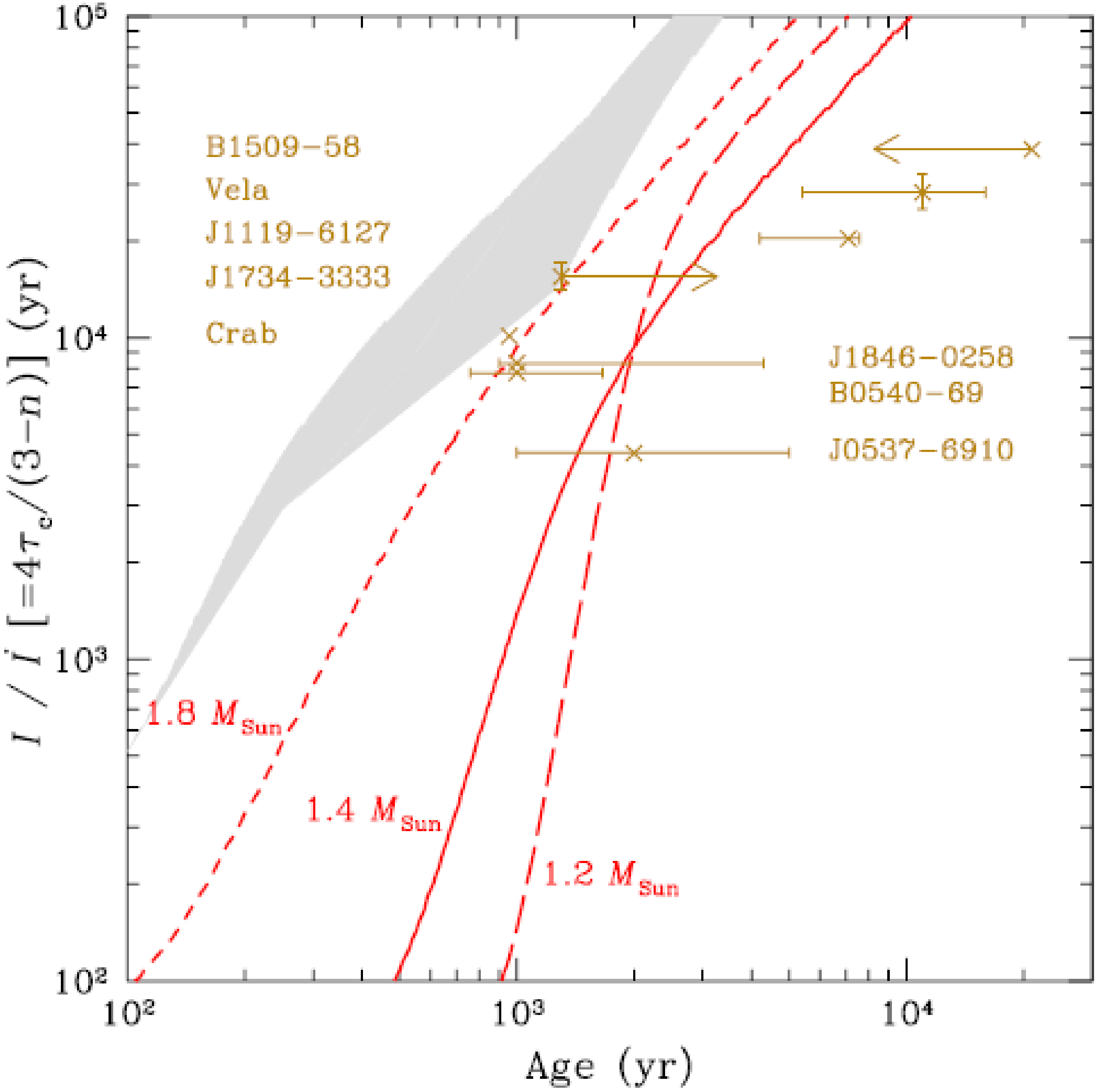
$$\frac{d\Omega}{dt} = (\Omega_{sf} - \Omega)\frac{1}{I}\frac{dI}{dt} - \beta\frac{\Omega^3}{I}$$

Ho, Andersson Nature Phys. 2013



•Crab制动指数

$$n = 3 - \frac{2\dot{I}}{I}\frac{\Omega}{\dot{\Omega}} - \left(\frac{3\dot{I}}{I}\frac{\Omega}{\dot{\Omega}} - \frac{\ddot{I}}{I}\frac{\Omega^2}{\dot{\Omega}^2}\right)\left(\frac{\Omega_{sf}}{\Omega} - 1\right) = 3 - 4\tau_c \left|\frac{\dot{I}}{I}\right|$$



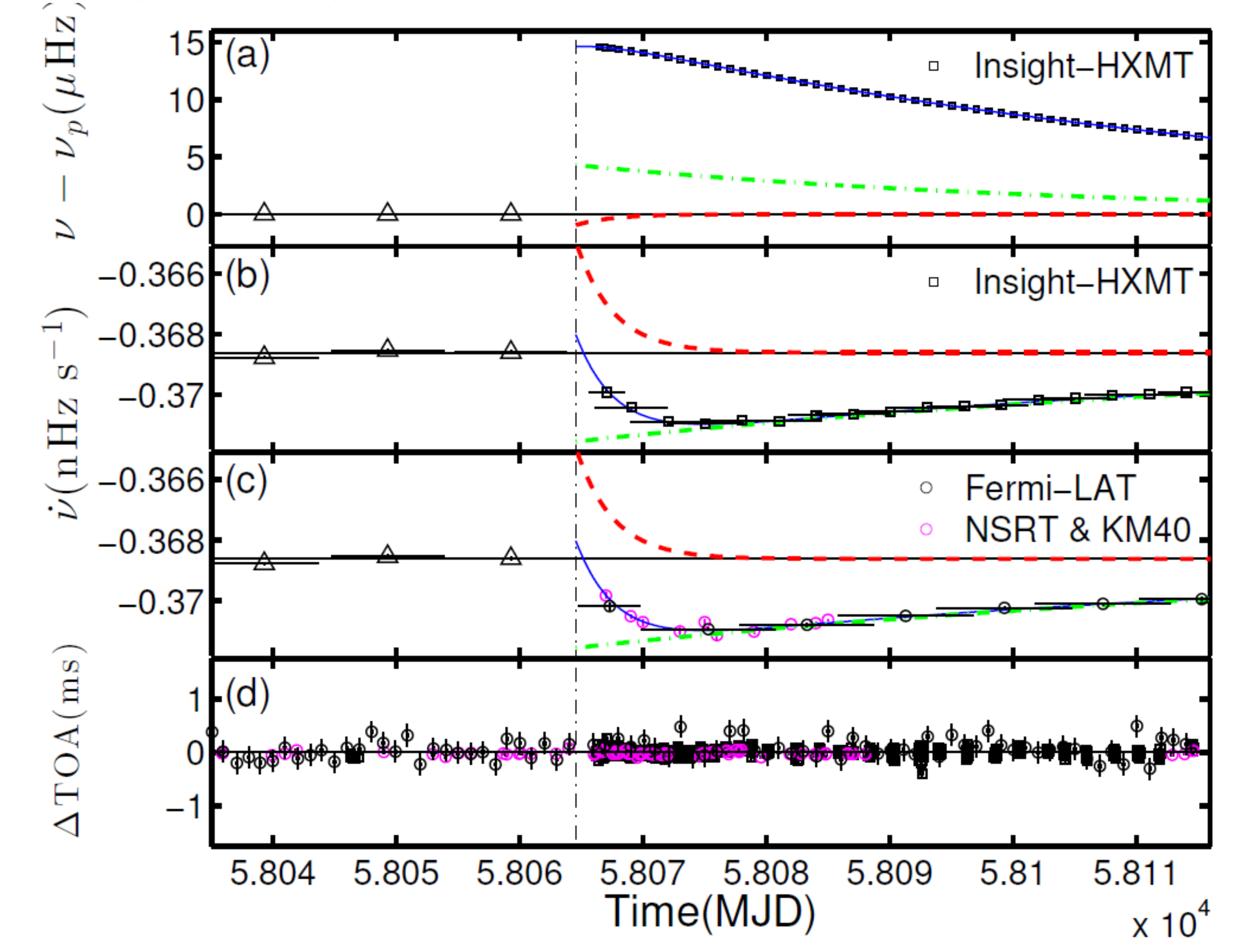
超流退耦

- Post-Glitch 正力矩

$$\frac{d\Omega}{dt} = (\Omega_{\rm sf} - \Omega)\frac{1}{I}\frac{dI}{dt} - \beta\frac{\Omega^3}{I}$$

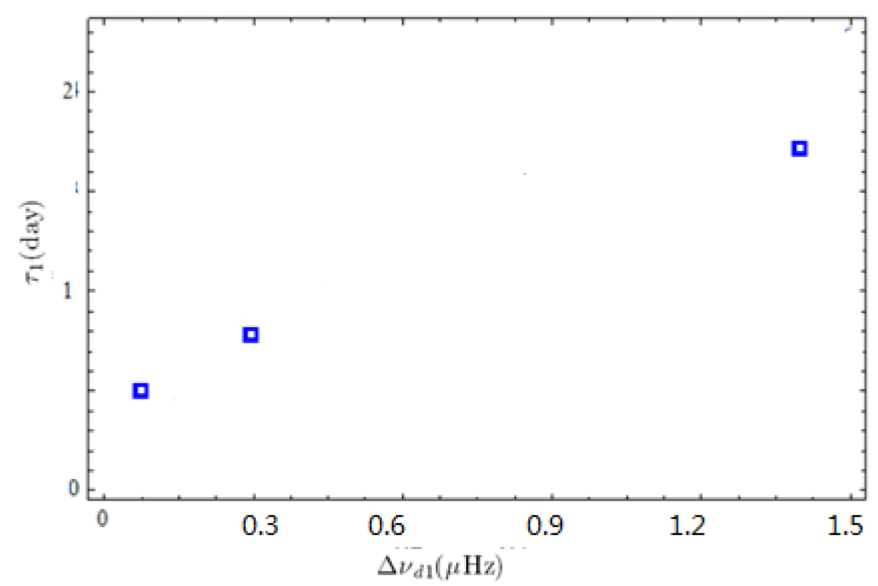
$$\frac{dI}{dt} = (\partial I/\partial\delta\mu)\delta\dot{\mu}$$

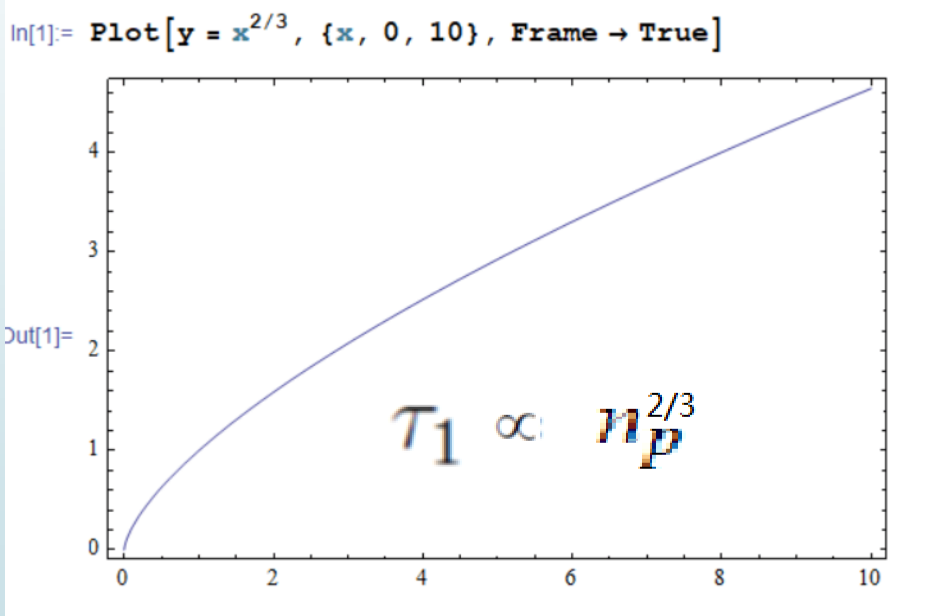
$$\delta\dot{\mu} = (\partial\delta\mu/\partial x)\dot{x} = -\chi\Delta\Gamma$$

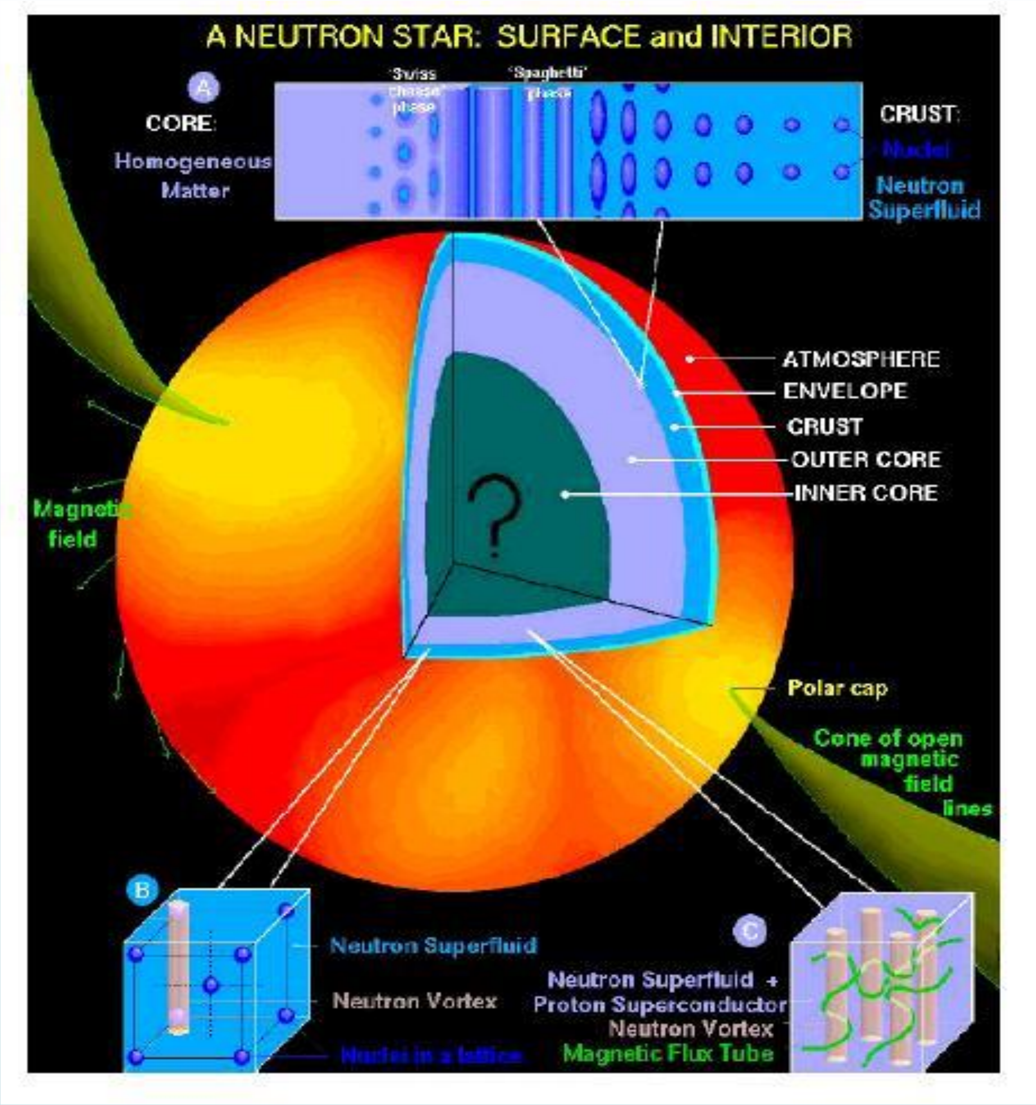


$$\delta\dot{\mu} \propto \exp\left(-\frac{\Delta t}{\tau_1}\right) \qquad \tau_1 = \frac{\delta\mu_0}{\delta\dot{\mu}_0}$$

- Post-Glitch 正力矩







超流成分、区域、结构、超流耦合范围

总结

- 核子超流存在于中子星并且年轻中子星正处于超流发生期
- Cooling、Glitch、制动指数等与超流相关
- 超流影响中子星状态方程？
- 超流激发某种引力波辐射？