The influence of strong magnetic fields on hybrid stars

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< Flash Talk >

1. Incorporating “2LL” (2nd Landau Level)
2. Critical magnetic field
3. Hybrid star properties

Observed maximum mass of stars

P. Demorest et al. Nature 467 (2010) 1081.

1.97±0.04 Msun

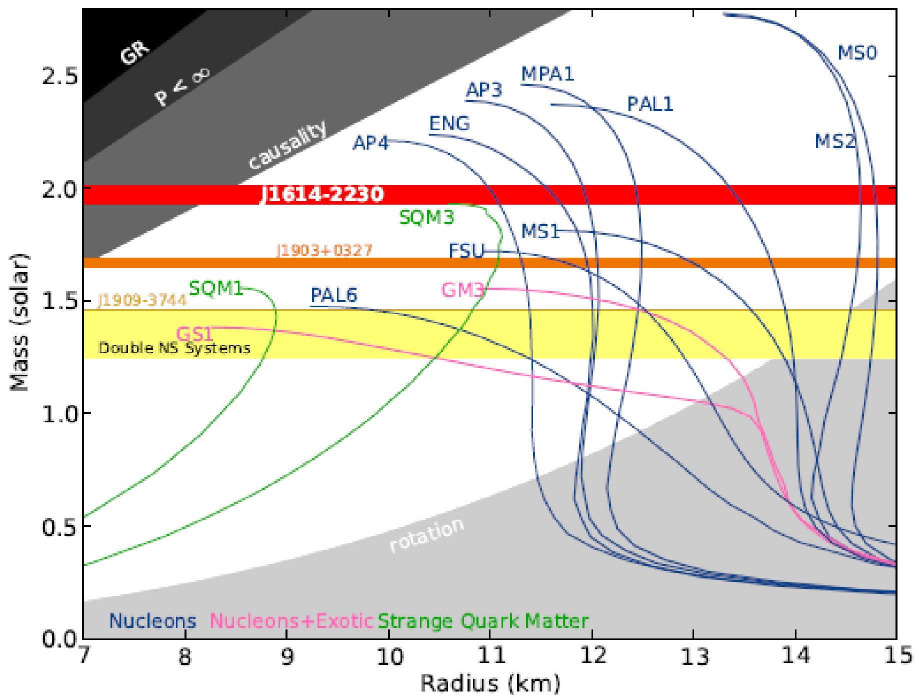


Figure 3: Neutron star (NS) mass-radius diagram. The plot shows non-rotating mass versus physical radius for several typical NS equations of state (EOS)[25]. The horizontal bands show the observational constraint from our J1614−2230 mass measurement of 1.97±0.04 $M_\odot$, similar measurements for two other millsecond pulsars[3, 26], and the range of observed masses for double NS binaries[2]. Any EOS line that does not intersect the J1614−2230 band is ruled out by this measurement. In particular, most EOS curves involving exotic matter, such as kaon condensates or hyperons, tend to predict maximum NS masses well below 2.0 $M_\odot$, and are therefore ruled out.

J. Antoniadis et al., Science 340 (2013) 6131

2.01±0.04 Msun :PSR J0348+0432

Equation of state (EOS)
for high density matter

Hyperon matter

Quark matter

⇒ "soft" EOS

"Hyperon PUZZLE"

stiff EOS

Three nucleon interaction

Strong magnetic field

B(surface): Radio Pulsars ~10^{12} G
Magneters ~10^{15} G

$$|\mu| = \frac{e\hbar}{2m_e c} = 5.79 \times 10^{-9}\ \mathrm{eV/G}$$

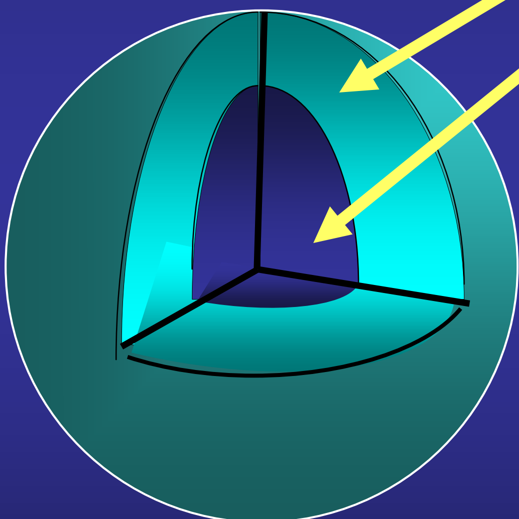
Itzykson & Zuber, QFT

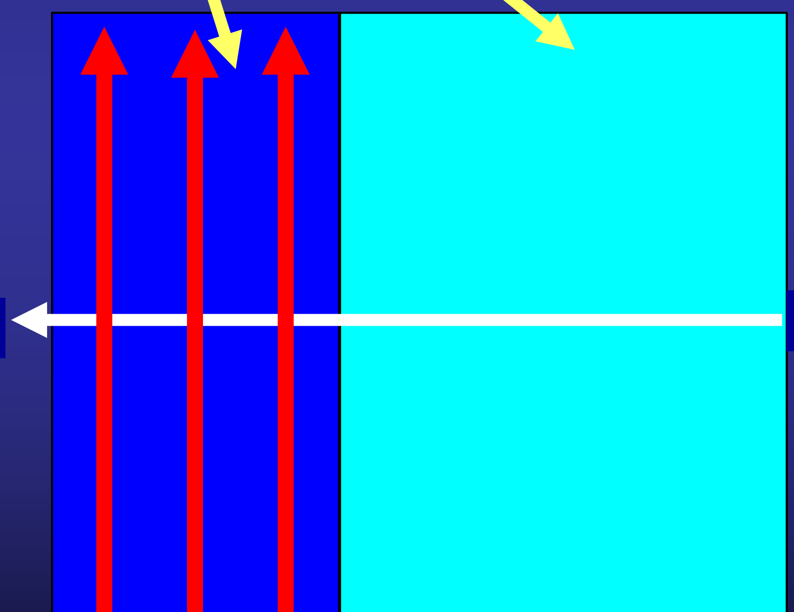
Much stronger field suggested inside the star:~10^{18}G
Lai and Shapiro, ApJ.383(1991)745

1.0×10^{19} G ~ (240 MeV)^2

" hadronic matter"

" quark matter"





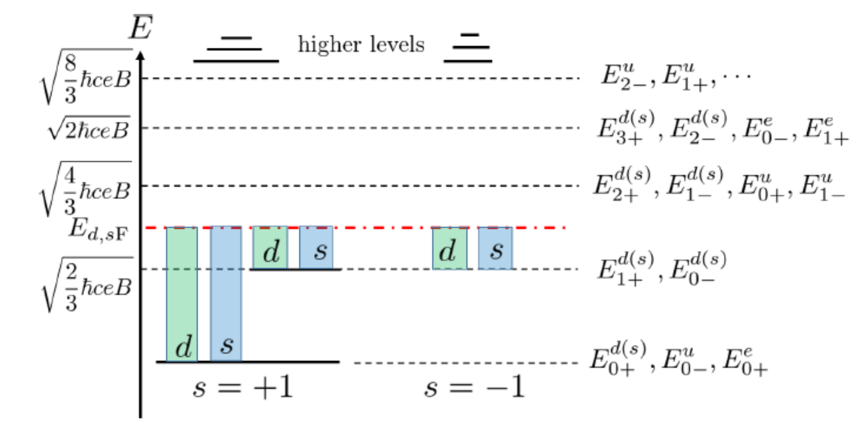
Center

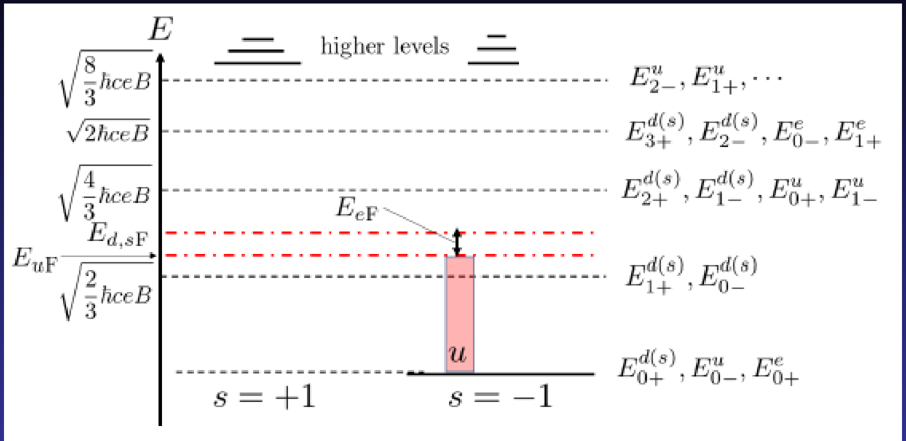
Surface

" Hybrid star"

B: Magnetic Field

② 2LL+β equilibrium





Energy density(2LL)

$$\varepsilon_f = \frac{3|e_f B|}{4\pi^2\hbar^2}\left[p^{(1)\,2}_{\mathrm{dF}} + 2p^{(1)}_{\mathrm{dF}}p^{(2)}_{\mathrm{dF}} + \frac{4\hbar|e_f B|}{c}\ln\left|p^{(1)}_{\mathrm{dF}} + p^{(2)}_{\mathrm{dF}}\right| - \frac{2\hbar|e_f B|}{c}\ln\left(\frac{2\hbar|e_f B|}{c}\right)\right]$$

u, e : LLL, d,s : 2LL

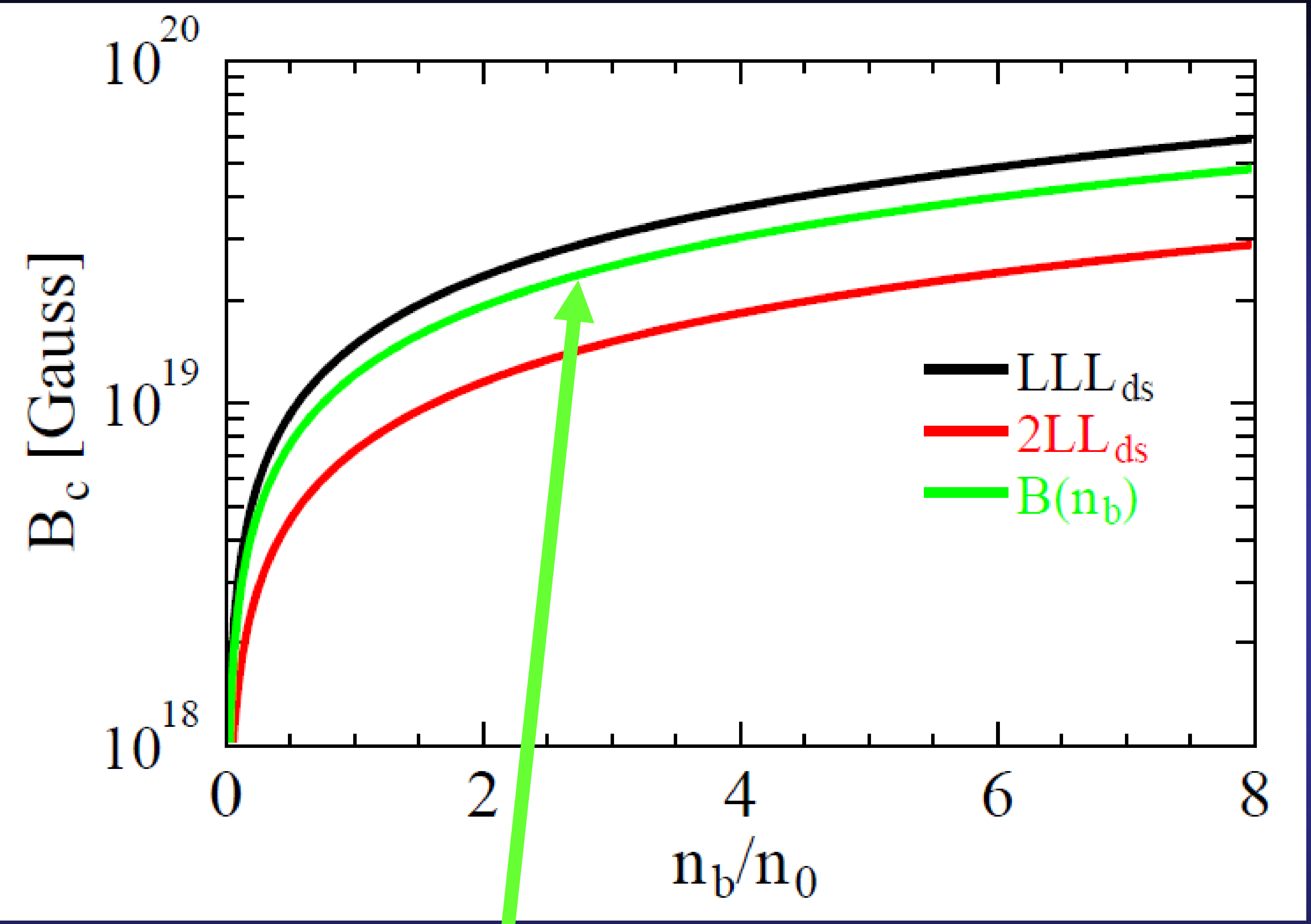
$$\begin{aligned}\varepsilon_{2\mathrm{LL}\beta} = a&\left\{\frac{3n_\mathrm{b}}{2a} - \left(p^{(1)}_{\mathrm{dF}} + 2\sqrt{p^{(1)\,2}_{\mathrm{dF}} - \frac{2}{3}eB}\right)\right\}^2 \\ +a&\left[p^{(1)\,2}_{\mathrm{dF}} + 2p^{(1)}_{\mathrm{dF}}p^{(2)}_{\mathrm{dF}} + \frac{4eB}{3}\ln\left|p^{(1)}_{\mathrm{dF}} + p^{(2)}_{\mathrm{dF}}\right| - \frac{2eB}{3}\ln\left(\frac{2eB}{3}\right)\right] \\ +\frac{a}{2}&\left\{\frac{2}{7}\left(p^{(1)}_{\mathrm{dF}} - 2\sqrt{p^{(1)\,2}_{\mathrm{dF}} - \frac{2}{3}eB}\right)\right\}^2 + \mathcal{B}\end{aligned}$$

$$P = n_\mathrm{b}^2\frac{\partial(\varepsilon/n_\mathrm{b})}{\partial n_\mathrm{b}}$$

2LL(ds) $B_\mathrm{c} = 7.27 \times 10^{18} \times \left(\frac{n_\mathrm{b}}{n_0}\right)^{\frac{2}{3}}$ G

Bc of d,s quark at LLL ⇔ 2LL: C_B=14.8

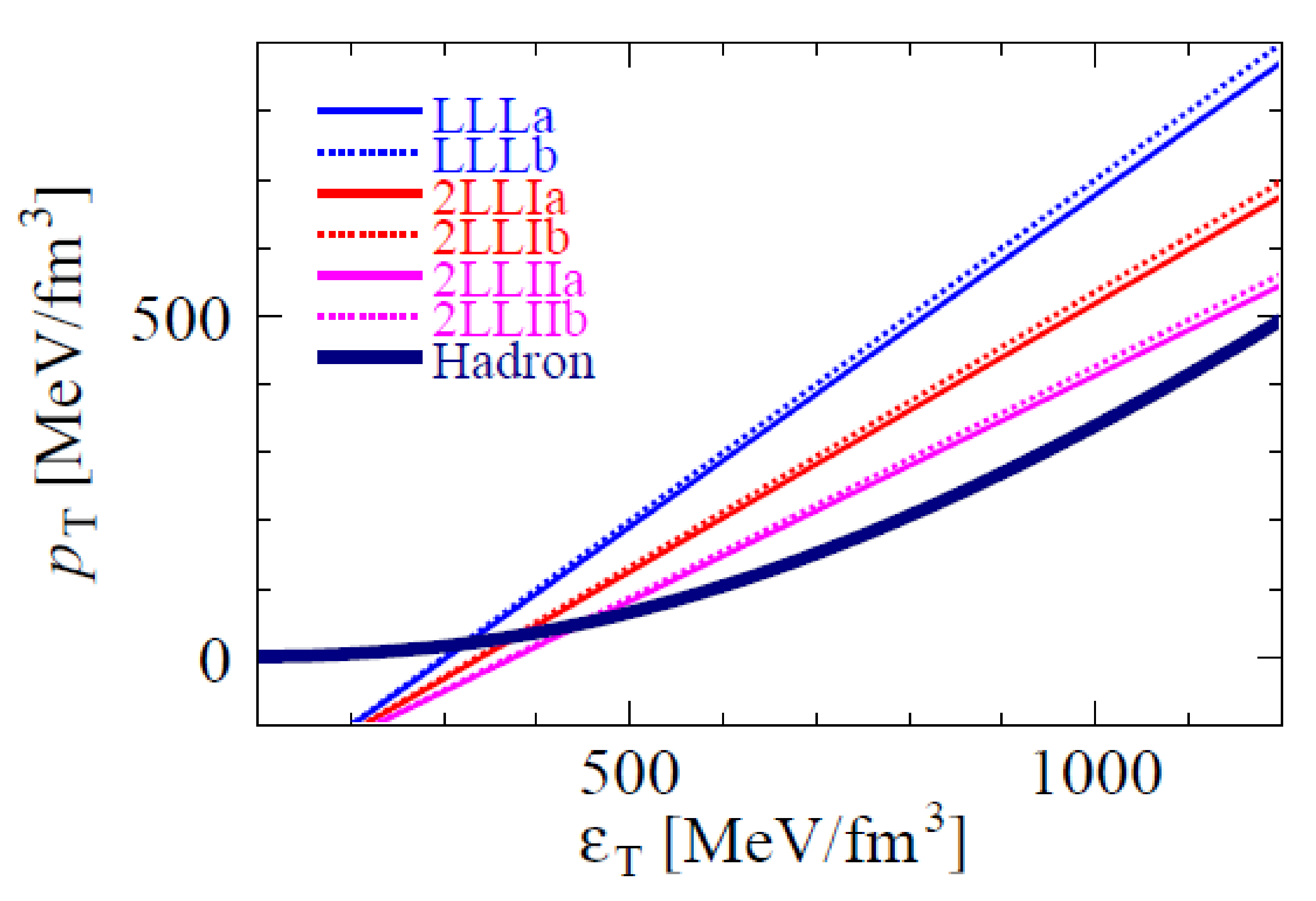
Density dependent magnetic field



"u,e in LLL"
&
"d,s in 2LL"

$$B(n_{\rm b}) = \underline{C_B} \times 10^{18} \times \left(\frac{n_{\rm b}}{n_0}\right)^{\frac{2}{3}} \text{G}$$

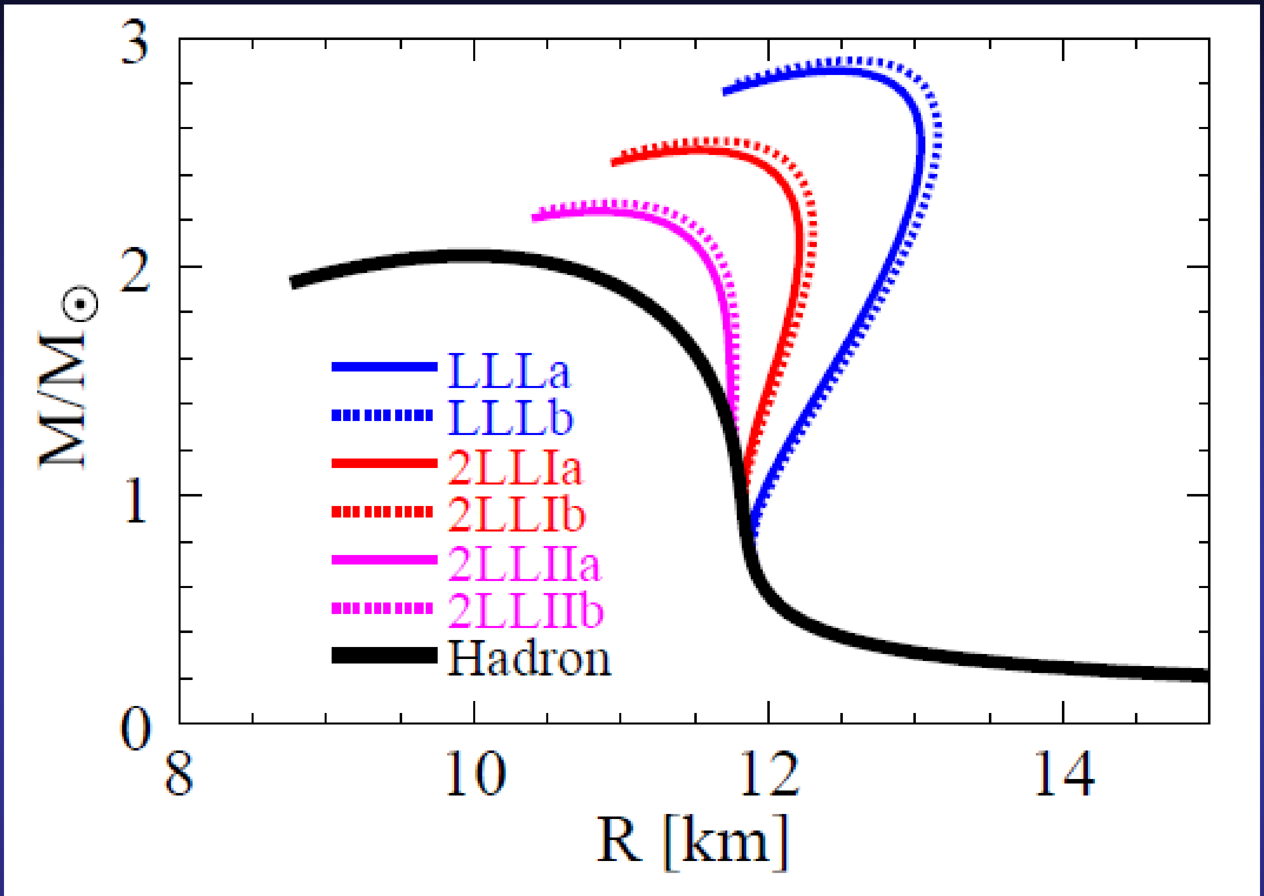
Quark EOS for various magnetic field strength



label	C_B	pressure term
LLLa	14.83	$B^2/(24\pi)$
2LLIa	13.44	$B^2/(24\pi)$
2LLIIa	12.06	$B^2/(24\pi)$
LLLb	14.83	$B^2/(8\pi)$
2LLIb	13.44	$B^2/(8\pi)$
2LLIIb	12.06	$B^2/(8\pi)$

Solid line(a) : anisotropic
Dotted line(b) : Isotropic

Mass-radius relation of hybrid stars with different magnetic field strength



preliminary

label	C_B	pressure term
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2LLIb	13.44	$B^2/(8\pi)$
2LLIIb	12.06	$B^2/(8\pi)$

Maximum mass of hybrid stars

LLLa: 2.86 $M_\odot$ **LLLb: 2.90** $M_\odot$
2LLIa: 2.51 $M_\odot$ **2LLIb: 2.55** $M_\odot$
2LLIIa: 2.24 $M_\odot$ **2LLIIb: 2.28** $M_\odot$