Effect of the equation of state on the r-mode instability of strange stars

Reporter：YuBin Wang (王榆斌)

Supervisor：XiongWei Liu and Xia Zhou

China West Normal University –
XinJiang Astronomy Observation

2018.07.05

Outline

I. Background

II. R-mode instability window and observational data

III. Conclusion and discussion

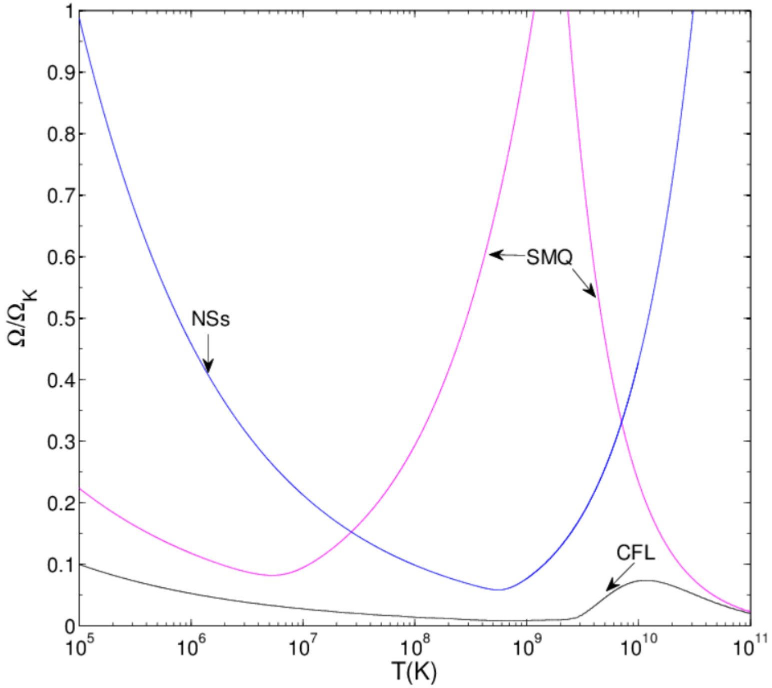
I. Background

II. R-mode instability window and observational data

III. Conclusion and discussion

R-mode instability window

- ✓ The r-modes in a perfect fluid star obey gravitational wave radiation(GWR) driven CFS for all rates of stellar rotation
- ✓ The r-modes grow due to GWR and it is positive feedback increasing GWR
- ✓ The viscosity of stellar matter can effectively suppress the infinite growth of the modes
- ✓ the tug-of-war between the driving effect of GWR and all relevant dissipation mechanisms



the rotating frame

- ✓ The r-modes evolve with $e^{i\omega t-t/\tau}$
- ✓ R-mode energy change $\frac{dE}{dt}=(\frac{dE}{dt})_{\mathrm{gw}}+(\frac{dE}{dt})_{\mathrm{V}}=-\frac{2E}{\tau}>0$, instability, GWR
- ✓ $\frac{dE}{dt}<0$, stability
- ✓ $\frac{dE}{dt}=0$, critical condition, $\frac{1}{\tau_{\mathrm{gw}}}+\frac{1}{\tau_{\mathrm{V}}}=\frac{1}{\tau}=0$

Andersson 1998; Lindblom et al. 1998; Madsen 1998;2000;Owen et al. 1998

Time scale

$$\frac{1}{\tau_{\rm gw}} = -\frac{32\pi G\Omega^{2l+2}}{c^{2l+3}} \frac{(l-1)^{2l}}{[(2l+1)!!]^2} \times \left(\frac{l+2}{l+1}\right)^{2l+2} \int_0^R \rho r^{2l+2} dr \qquad (1)$$

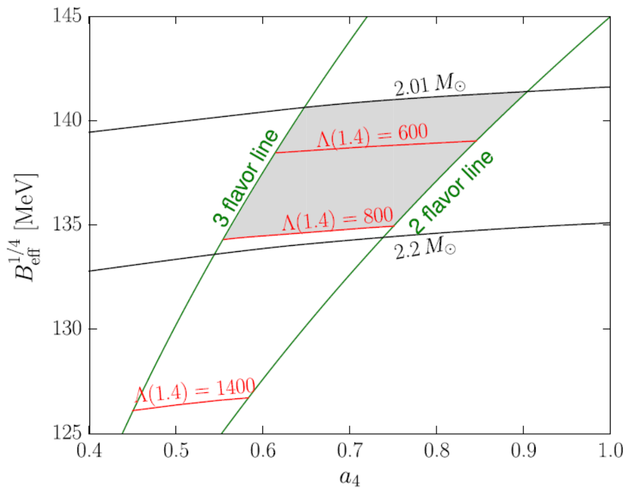
$$\frac{1}{\tau_{\rm sv}} = (l-1)(2l+1)\left[\int_0^R \rho r^{2l+2} dr\right]^{-1} \int_0^R \eta r^{2l} dr \qquad (2)$$

$$\frac{1}{\tau_{\rm bv}} = \frac{4\pi}{690}\left(\frac{\Omega^2}{\pi G\bar{\rho}}\right)^2 R^{2l-2}\left[\int_0^R \rho r^{2l+2} dr\right]^{-1} \times \int_0^R \zeta\left(\frac{r}{R}\right)\left[1+0.86\left(\frac{r}{R}\right)^2\right] r^2 dr \qquad (3)$$

- η and ζ are the efficient of shear viscosity and bulk viscosity respectively
- dependence on the equation of state (EoS)
- R-modes for $l = m = 2$ is the strongest GWR

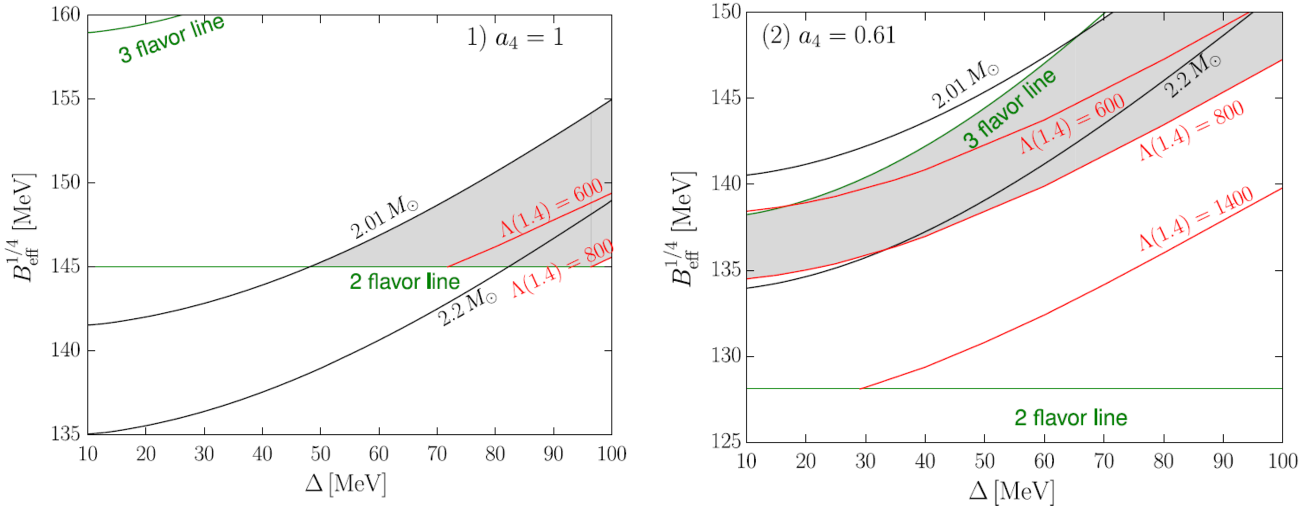
Lindblom et al.1998； Owen et al.1998; Nayyar & Owen 2006

Unpaired strange quark matter (SQM)



- $\Lambda(1.4) \le 800$ and weak dependence on m_s(100MeV)
- $M_{\rm TOV} \le 2.18 M_\odot$
- $B_{\rm eff}^{1/4}$(134.1,141.4)MeV corresponding a_4(0.56,0.91)

Color-flavor-locked (CFL) phase



- $a_4 = 1, \Delta_{min} \sim 50\text{MeV},\ B_{\rm eff}^{1/4} =$ 145MeV
- $M_{\rm TOV} \le 2.32 M_\odot$
- $a_4 = 0.61,\ \Delta$ is no new limit

Zhou et al. 2018

I. Background

II. R-mode instability window and observational data

III. Conclusion and discussion

- We take into account of bare strange stars for unpaired SQM and crust in the CFL phase, the viscosity is either by shear due to electron-electron scattering or by surface rubbing (Madsen 2000).

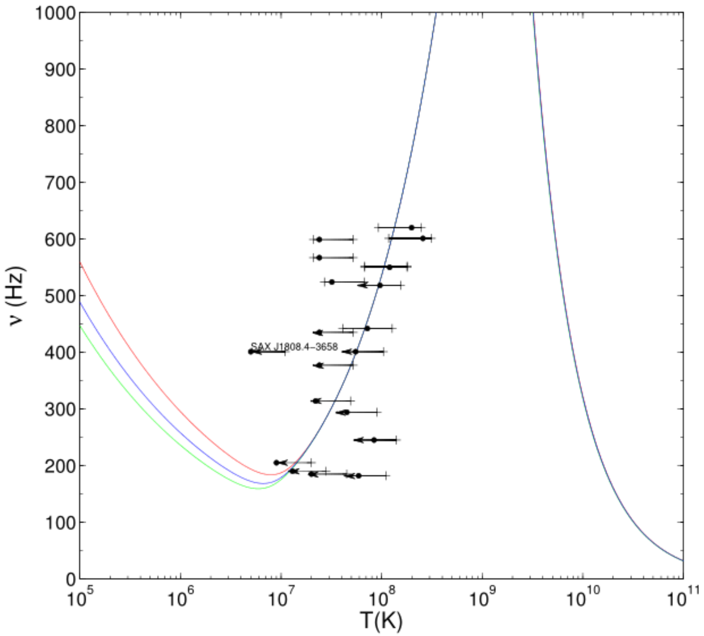
$$\frac{1}{\tau_{\mathrm{gw}}} + \frac{1}{\tau_{\mathrm{sv}}} + \frac{1}{\tau_{\mathrm{bv}}} + \frac{1}{\tau_{\mathrm{sr}}} = 0$$

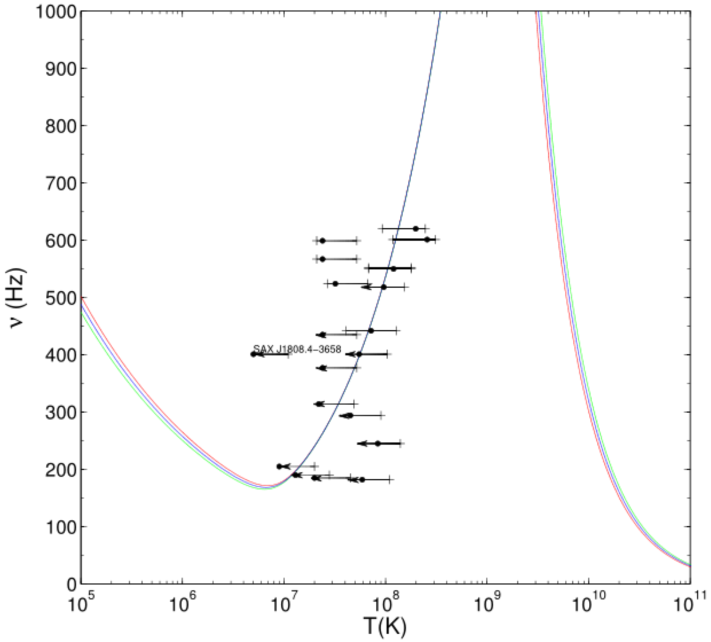
- The internal temperatures for LMXBs refer Gusakov et al. (2014) and partial sources have been update (Chugunov et al. 2017).
- We consider iron envelope for young pulsars (Becker, 2009), and inner temperatures are insignificantly dependent in parameters of EOS and their mass.

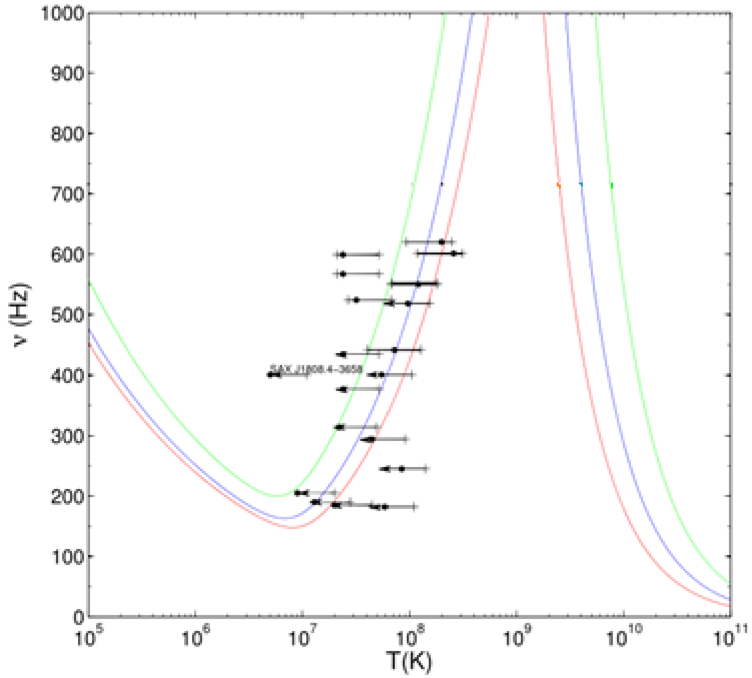
Unpaired SQM

M	$1.4M_\odot$	m_s	100MeV		
a_4	$B_{\rm eff}^{1/4}$(MeV)	Color	a_4	$B_{\rm eff}^{1/4}$(MeV)	Color
0.61	138	Green	0.72	136	Green
0.72	138	Blue	0.72	140	Red
0.83	138	Red			

$B_{\rm eff}^{1/4}$(MeV)	138	a_4	0.72
Mass	Color	Mass	Color
$1.0M_\odot$	Green	$1.5M_\odot$	Blue
$2.0M_\odot$	Red		



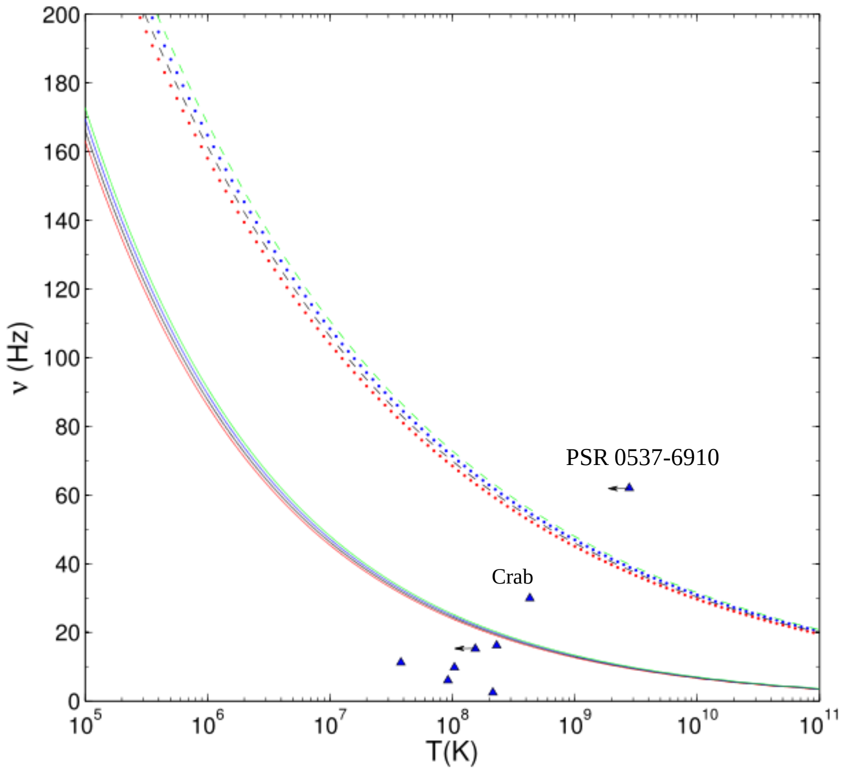




CFL quark phase

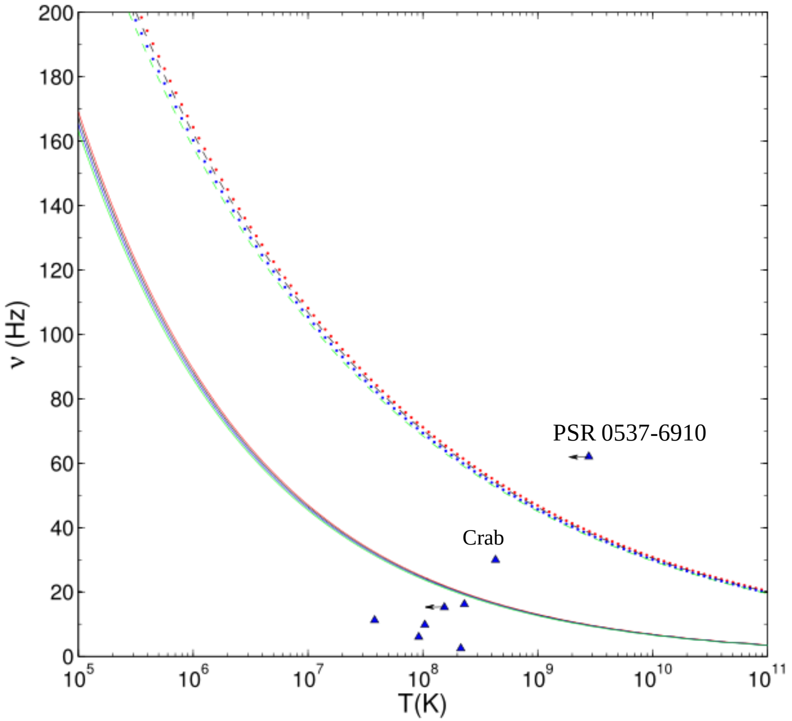
$\Delta = 100 MeV$

Mass	$1.4M_\odot$	a_4	1	
Δ(MeV)	$B_{\rm eff}^{1/4}$(MeV)	Δ(MeV)	$B_{\rm eff}^{1/4}$(MeV)	Color
70	146	100	146	Red
80	146	100	148.5	Black
90	146	100	151	Blue
100	146	100	153.5	Green



Dashed and dotted (solid) curves represent shear due to surface rubbing (electron-electron scattering)

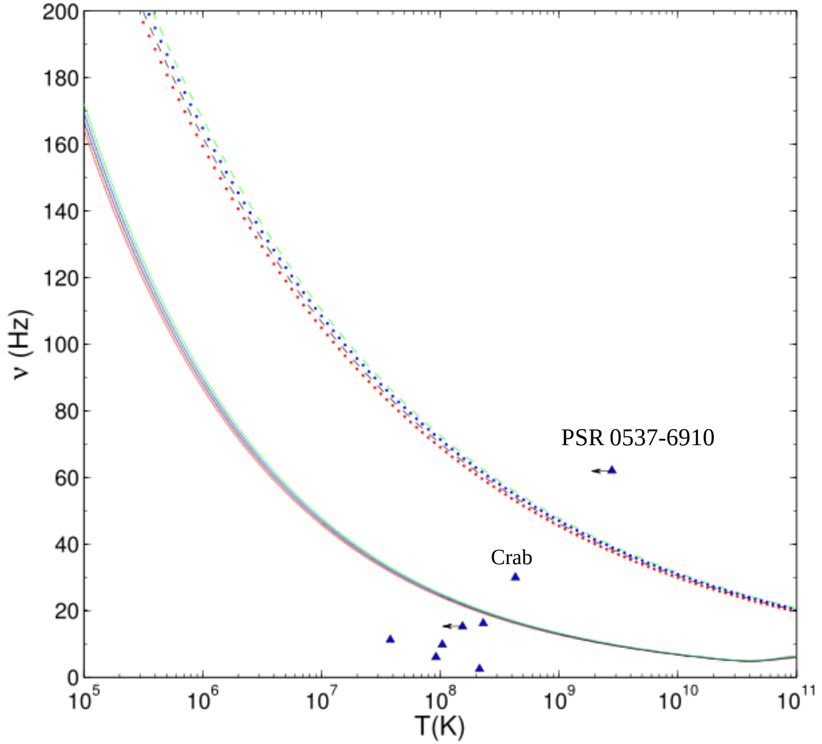
$$B_{\rm eff}^{1/4} = 146 \mathrm{MeV}$$



CFL quark phase

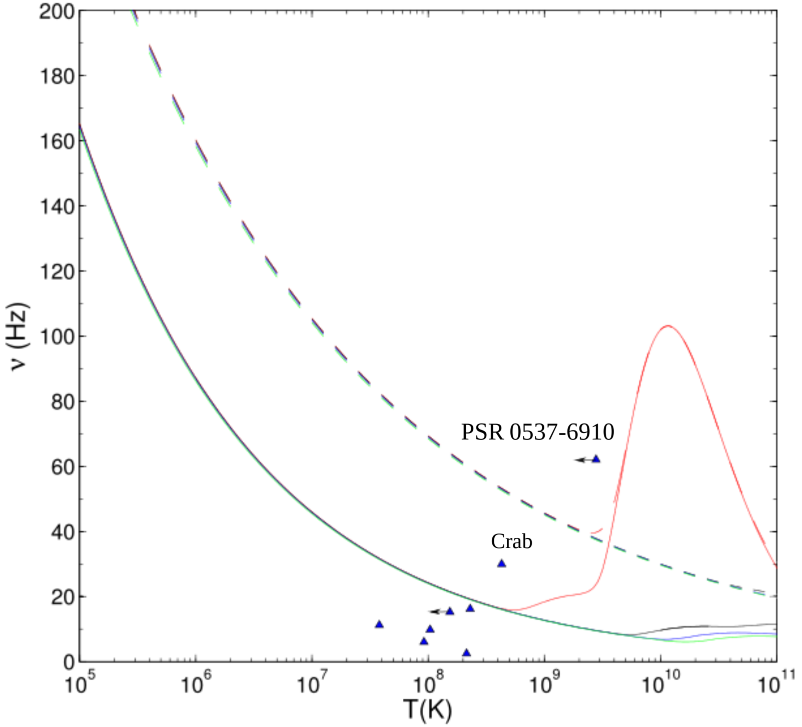
Mass	$1.4M_{\odot}$	a_4	0.61	
Δ(MeV)	$B_{\rm eff}^{1/4}$(MeV)	Δ(MeV)	$B_{\rm eff}^{1/4}$(MeV)	Color
1	136.5	75	144	Red
10	136.5	75	146	Black
20	136.5	75	148	Blue
30	136.5	75	150	Green

$\Delta = 75\mathrm{MeV}$



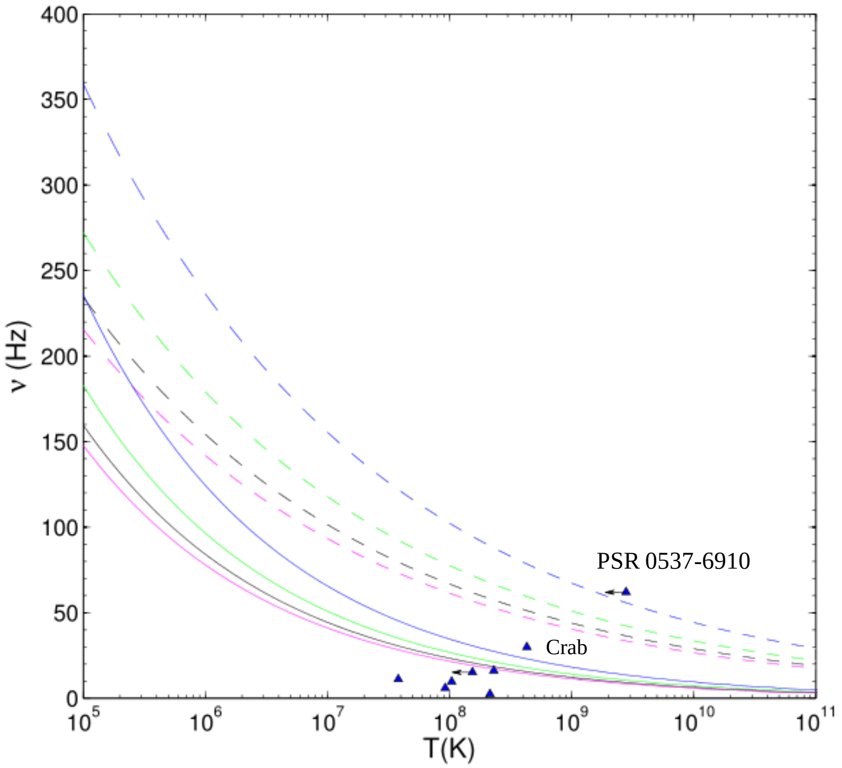
Dashed and dotted (solid) curves represent shear due to surface rubbing (electron-electron scattering)

$$B_{\rm eff}^{1/4} = 136.5\mathrm{MeV}$$

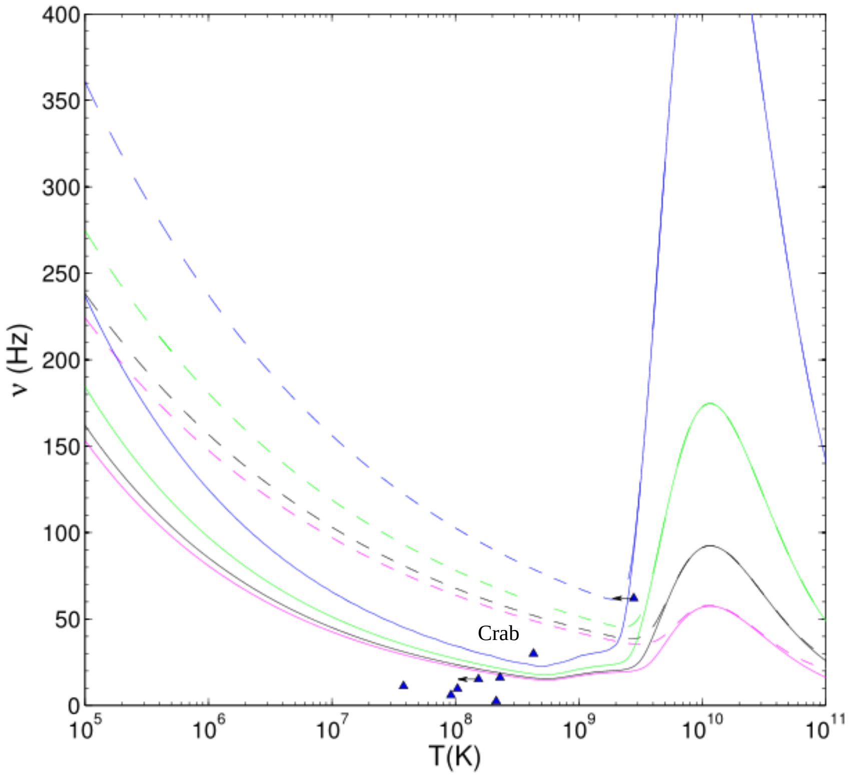


CFL quark phase

- $a_4 = 1$, $\Delta = 100\text{MeV}$, $B_{\text{eff}}^{1/4} = 146\text{MeV}$, $0.5M_{\odot}$(Blue), $1.0M_{\odot}$(Green), $1.5M_{\odot}$(black), and $2.0M_{\odot}$(Red)



- $a_4 = 0.61$, $\Delta = 1\text{MeV}$, $B_{\text{eff}}^{1/4} = 136.5\text{MeV}$, $0.5M_{\odot}$ (Blue), $1.0M_{\odot}$(Green), $1.5M_{\odot}$(black), and $2.0M_{\odot}$(Red)



I. Background

II. R-mode instability window and observational data

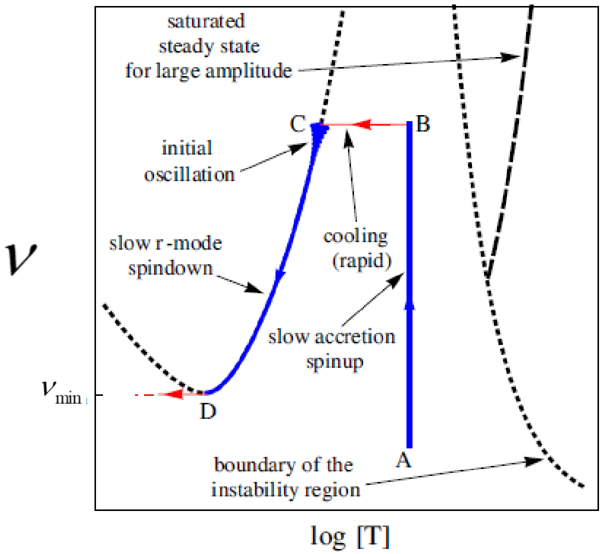
III. Conclusion and discussion

Conclusion

- The effect of EoS for unpaired SQM only is significant influence on the temperature $T \leq 10^7\mathrm{K}$.
- Most of LMXBs are around right boundaries of instability window in low temperature, several sources, especially SAX J1808.4-3658, are located in the instability window.
- The dissipations enhanced by crust are important, the effect of EoS for CFL phase modestly acts on the instability window, except for lower gap($\Delta \sim 1\mathrm{MeV}$) and gap $\Delta < 1\mathrm{MeV}$ (Zhou et al. 2018).
- PSR J0537-6910 is located in the instability window, the Crab pulsar is uncertain.

Discussion

- Results conform to the boundary-straddling scenario of thermal evolution (Andersson et al, 2002).
- SAX J1808.4-3658 may be either a massive star and excites the direct Urca processes (Alford et al., 2008; Schwenzer, 2012; Salmi et al., 2018) or GWR, MXB 1659-298 has identified the direct Urca processes (Brown et al., 2018).
- PSR J0537-6910 is possibly detected by advanced LIGO.
- Newly formed pulsars.



Thank you