Magnetar Oscillations: Observing the Physics of the Neutron Star Crust

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Workshop on Nuclear Astrophysics

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JINA Frontiers 2010

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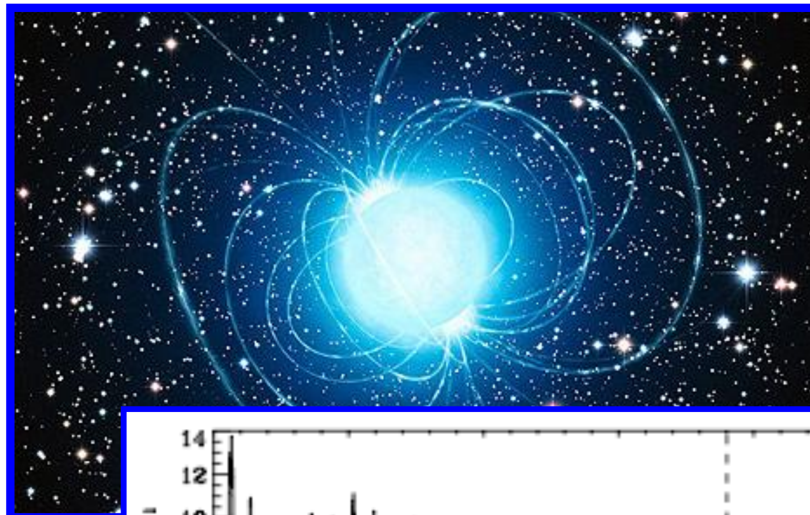
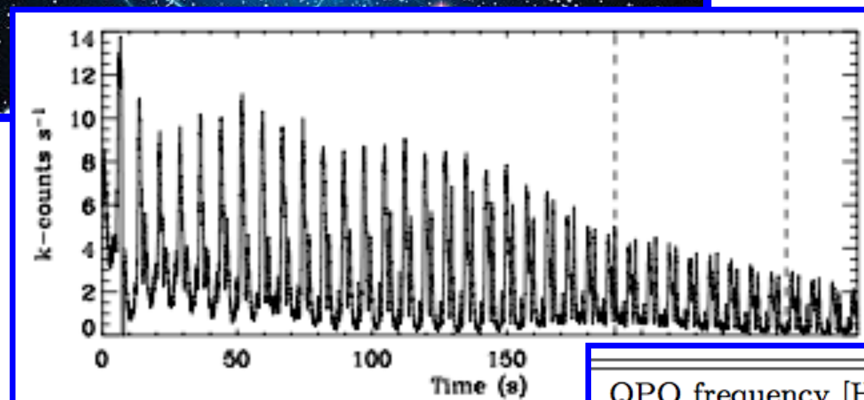
Magnetars Overview

- Highly magnetized neutron stars (>10^{14} G)
- Irregular giant flare emission (3 observed to-date)
- Giant flares triggered by crust reconfiguration
- QPOs in the emission tail are thought to correspond to the torsional modes of the oscillating crust
- QPO frequencies can be predicted with a model of crust composition



NatGeo



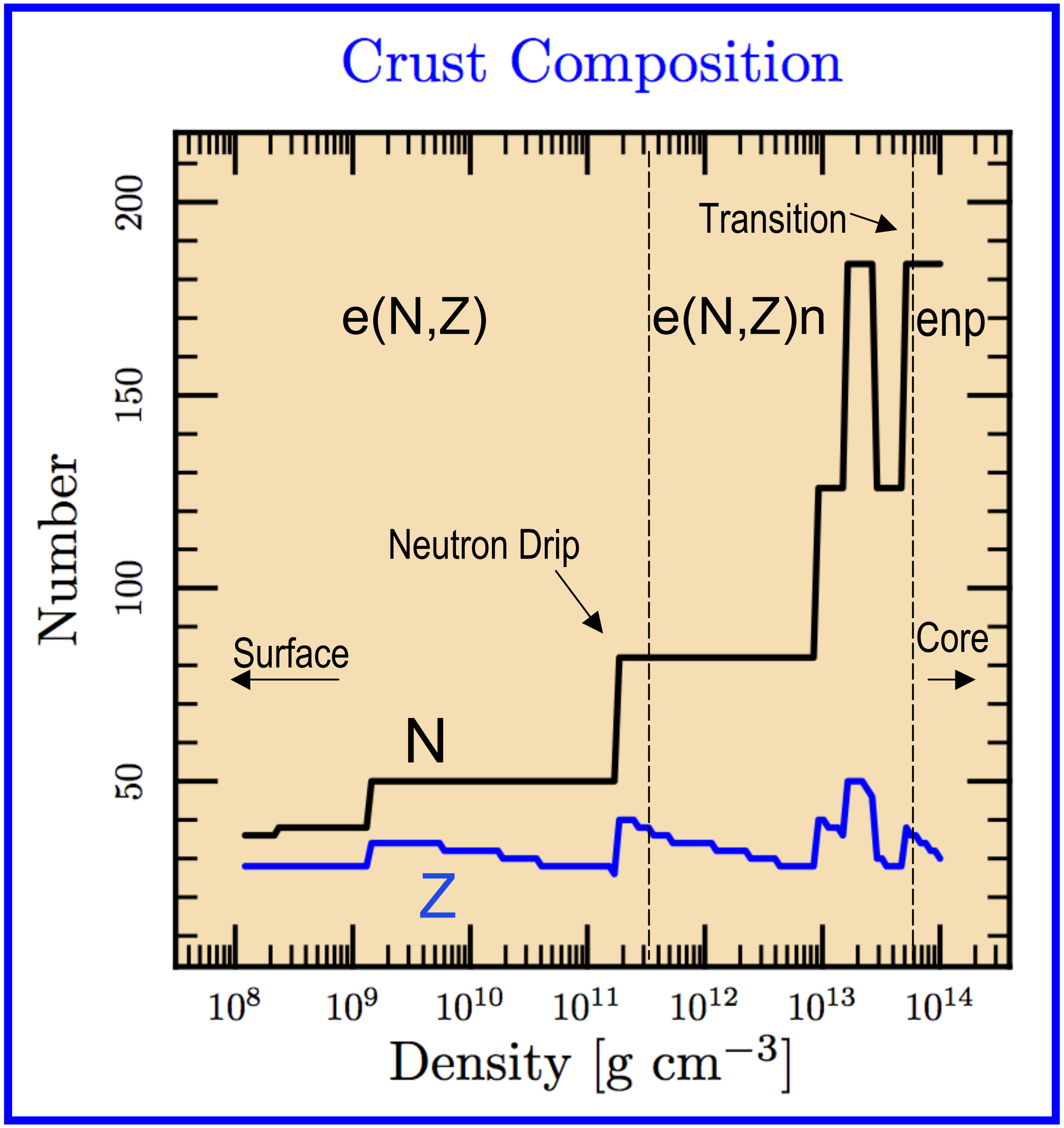
Strohmayer & Watts 2006

QPO frequency [Hz]
29
92.7
150.3
626.46

Neutron star crust composition… $\epsilon(Z, A, n) = \epsilon_{\rm nuc} + \epsilon_l + \epsilon_e + \epsilon_{n,\rm drip}$

Nuclei	$\rho_{\rm max}(\rm g\ cm^{-3})$ $B_* = 0$
$^{64}_{28}$Ni	2.07×10^{7}
$^{66}_{28}$Ni	4.81×10^{8}
$^{68}_{28}$Ni	1.03×10^{9}
$^{84}_{34}$Se	2.68×10^{9}
$^{82}_{32}$Ge	1.12×10^{10}
$^{80}_{30}$Zn	2.90×10^{10}
$^{78}_{28}$Ni	1.10×10^{11}
$^{76}_{26}$Fe	1.33×10^{11}
$^{122}_{40}$Zr	1.95×10^{11}
$^{120}_{38}$Sr	2.86×10^{11}
$^{118}_{36}$Kr	3.80×10^{11}
$^{116}_{34}$Se	5.57×10^{11}
$^{114}_{32}$Ge	7.41×10^{11}
$^{112}_{30}$Zn	9.86×10^{11}
$^{110}_{28}$Ni	1.00×10^{14}

Deibel & Steiner 2010 (in prep)



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$$E_{shell}(Z,N) = a_1 S_2 + a_2 (S_2)^2 + a_3 S_3 + a_{np} S_{np}$$

Dieperink 2009

S_2 = pairing interaction
S_3 = "monopole drift"
S_{np} = deformation
Counting rule of IBM

Shell effects
- Magic Numbers

$$\epsilon(Z,A,n) = \epsilon_{\text{nuc}} + \epsilon_l + \epsilon_e + \epsilon_{n,\text{drip}}$$

Magnetic Field
- Landau Quantization

$$\epsilon_e(Z,A,n;n_e) = \frac{eB}{4\pi^2} \int_0^{k_f} k^2 \sqrt{k^2 + {m_f}^2}\, dk$$

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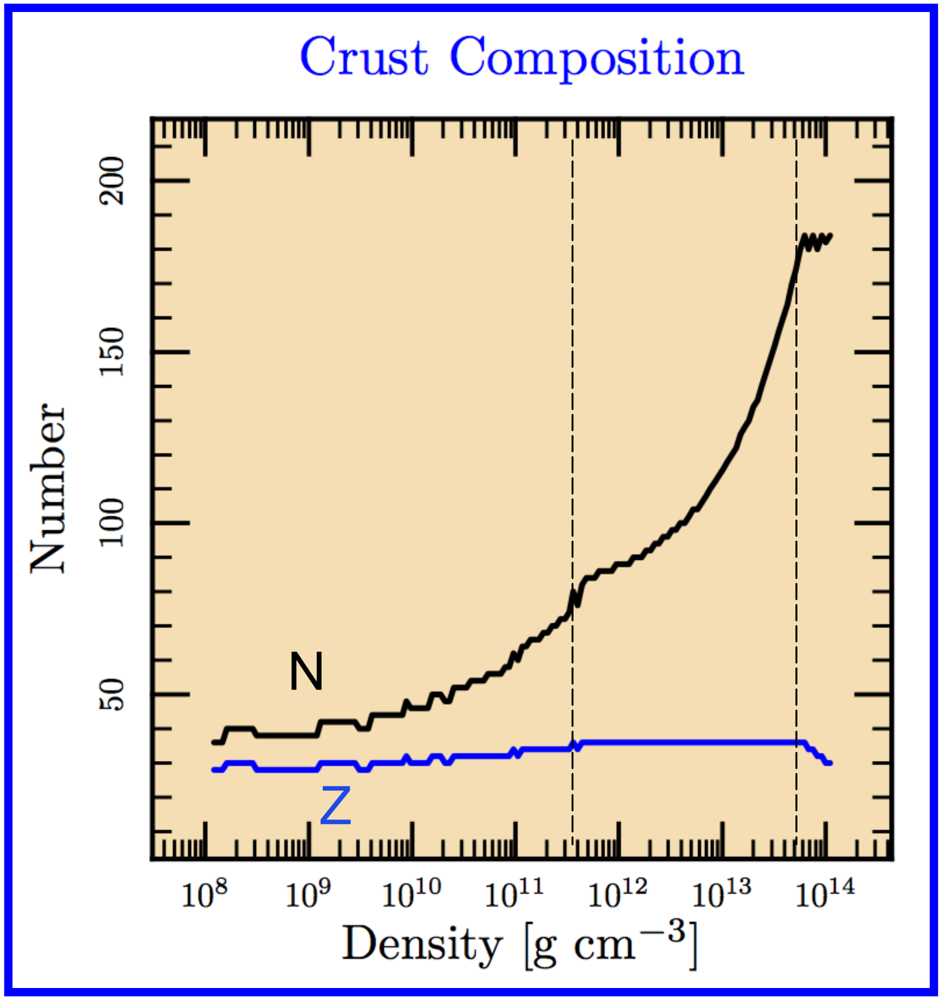
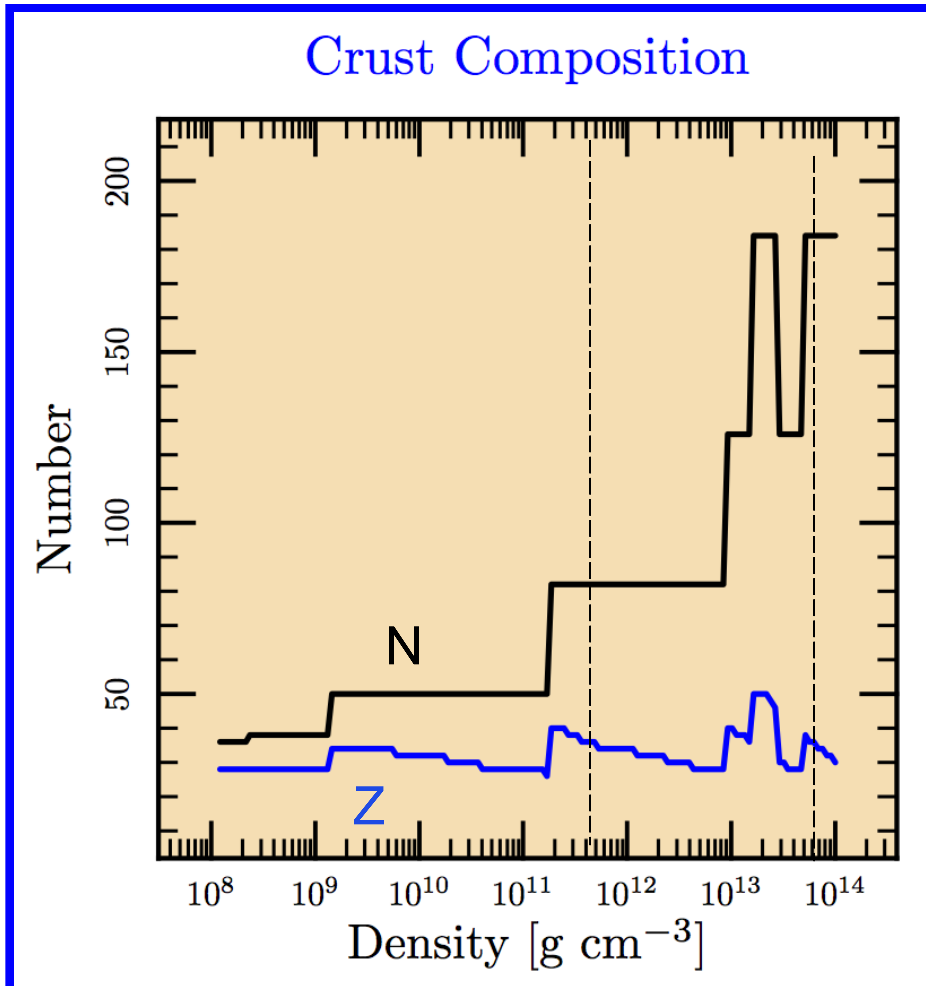
Model Addition (1)

Without shell effects…

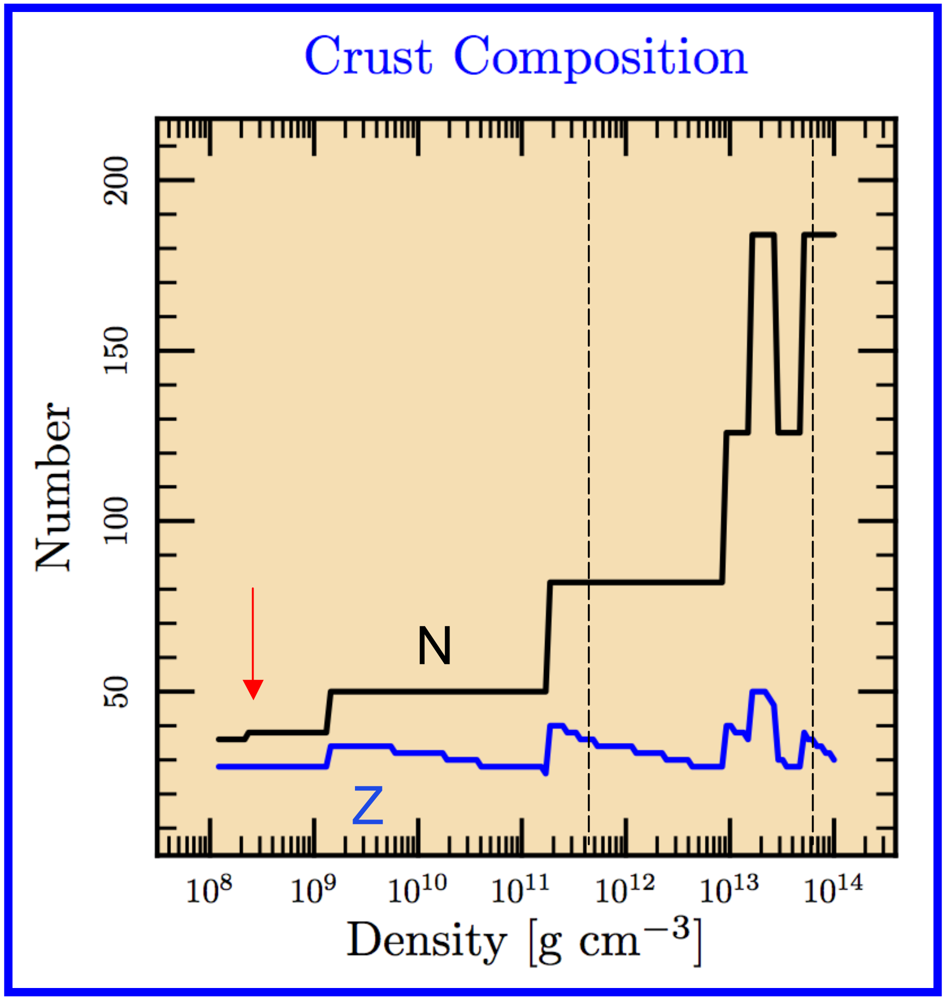


With shell effects…

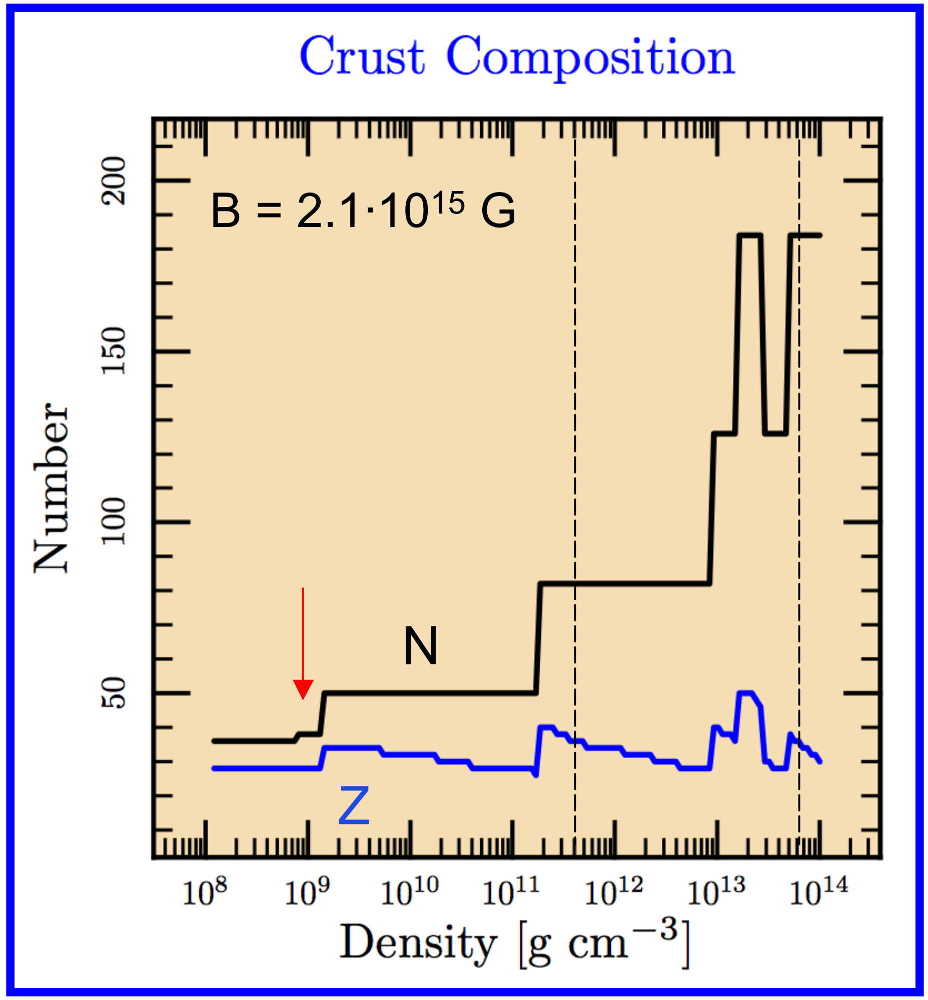


Model Addition (2)

Without magnetic field…



With magnetic field…



Assigning Crust Modes to QPO frequencies

Equilibrium Nuclei →

$$v_s = \sqrt{\frac{\mu}{\rho_i}}$$

$$v_A = \frac{eB}{\sqrt{4\pi\rho_i}}$$

$$n\pi = \int_{R_c}^{R} F(v_s, v_A, \omega)dr$$ *

(WKB approximation)

R = ~ 11.67 km

R_c = ~ 10.81 km

SGR 1806−20	
f [Hz]	mode
29	${}_0t_2$
92.7 ± 0.1	${}_0t_6$
150.3	${}_0t_{10}$
626.46 ± 0.02	${}_1t_l$

**

- magnetars = neutron stars (>10^{14} G)
- giant flares triggered by seismic events
- use crust model to match crust modes to QPO frequencies in giant flares
- added shell effects and a magnetic field

* Steiner & Watts 2009
** Samuelsson & Andersson 2007

Extra

$$S_2 = \frac{n_v \bar{n_v}}{D_n} + \frac{z_v \bar{z_v}}{D_z}$$

$$m_f^2 = m_e^2 + 2\left(x + \frac{1}{2} - \frac{1}{2}\nu\right) eB$$

$$B = \frac{e^{2\lambda}}{({v_S}^2 + {v_A}^2)} \left[e^{-2\nu}\omega^2(1 + {v_A}^2) - \frac{(l^2 + l - 2){v_S}^2}{R^2} \right]$$

10^44 - 10^47 erg/s