Magnetar Seismology

Soft gamma-ray repeaters (SGRs) are characterized by their short (0.1 sec) recurrent bursts of soft gamma-rays. They have been successfully explained as neutron stars with super-strong magnetic fields (10^{15} G); the magnetar model of C. Thompson and R. Duncan. In addition to their normal bursts that release approximately 10^{41} ergs of energy, there have been three "giant flares" that released 10^{44}-10^{46} ergs in a matter of minutes. Not only do these bursts show large pulsations at each SGR's spin period (5-8 sec), but they also show multiple higher frequency oscillations in the range of 18-155 Hz. The thrilling implication is that these oscillations may be shear modes, excited from crustal deformations during the flare (as hypothesized by R. Duncan). If true, they would be the first modes ever seen from a neutron star, initiating a new era where seismology is used to learn about neutron star crusts.

We performed detailed calculations of toroidal oscillations in the crusts of magnetized neutron stars. These demonstrate that the observed pulsations are well explained by low-order oscillations, and show how these waves depend on the neutron stars' mass, radius, and crustal composition. Oscillations with shorter radial wavelengths have higher frequencies (~600-2000 Hz), and would be useful for further investigation of the crust. In fact, subsequent analysis of the December 2004 flare using the RHESSI satellite found a pulsation with a frequency of 626.5 Hz (A. Watts and T. Strohmayer), consistent with our predictions for the next higher order shear wave.

These calculations are just an initial step using seismology to learn about these exotic environments. Future studies should consider more realistic magnetic field geometries since they can act on the modes in surprising ways. A calculation of the transmission of waves through the ocean and into the magnetosphere would be key for understanding the emission mechanism. Relating this to the observed coherence of the oscillations, could provide an additional, powerful constraint.

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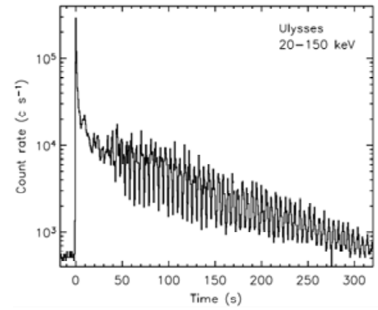
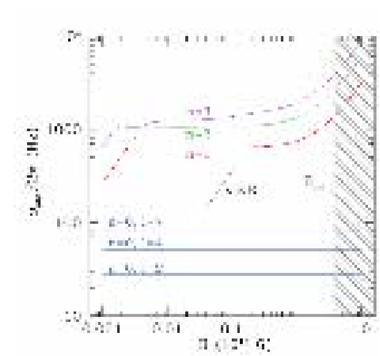


Magnetar giant flares release 10^{44}-10^{46} ergs in just a few minutes. In addition to the spin period, which can clearly be seen just by eye, the light curves contain higher frequency oscillations believed to be seismic shear waves.



Low frequency shear waves are a good match to the observed oscillations, and are largely independent of magnetic field strength. The higher frequency waves are useful for probing the thickness of the crust, and in addition, are more sensitive to the magnetic field.

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