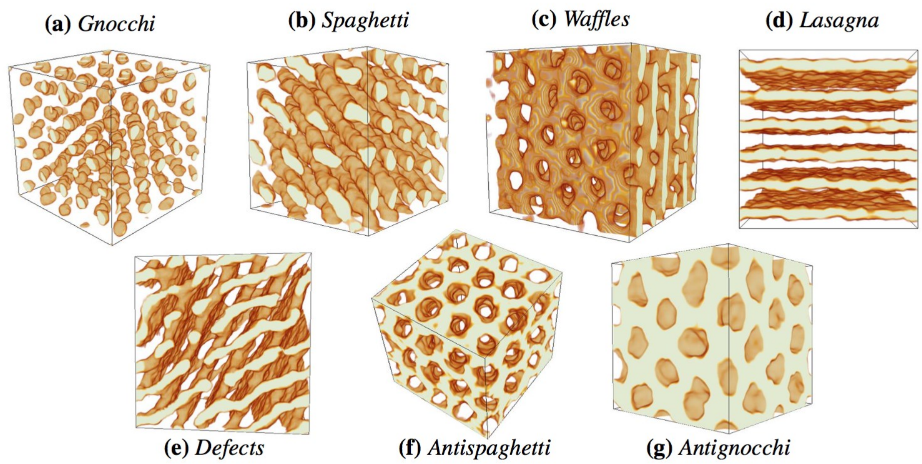
Investigating the thermal properties of nuclear pasta with neutron stars

Cooling neutron star transients provide a unique opportunity to probe the thermal properties of dense matter, in particular, the thermal conductivity of nuclear pasta. Nuclear pasta appears in the deep neutron star crust and consists of nuclei distorted into complex structures by the high density environment. A project led by MSU astronomy graduate student Alex Deibel has modeled the cooling of the neutron star MXB 1659-29 to investigate the effect of nuclear pasta on the long-term cooling behavior of this source [1]. This neutron star had been accreting gas from a companion star for about 2.5 years before accretion halted. Since then, the neutron star has been steadily cooling for over 10 years in quiescence. The surface temperature of the neutron star has been monitored over this time by the X-ray satellites Chandra, XMM-Newton, and Swift.



Molecular dynamics simulations of nuclear pasta from [2]. Nuclear pasta may have a low thermal conductivity due to presence of topological defects [3]; see panel (e) of the figure.

Crust cooling models of MXB 1659-29 predict that the neutron star's crust will cool entirely in approximately 1000 days. Recent observations of MXB 1659-29, however, show that cooling continued for over 2500 days after accretion halted. Because the cooling light curve reveals successively deeper layers of the crust, the observed late time cooling behavior of MXB 1659-29 is consistent with a low thermal conductivity pasta layer deep in the crust. A nuclear pasta layer remains hotter than the surrounding crust during quiescence. As a result, the crust temperature may be above the critical temperature for neutron superfluidity and a layer of normal neutrons forms alongside the pasta. Cooling models that include heat release from a normal neutron layer in the inner crust are consistent with the late time cooling of MXB 1659-29. The late time cooling of another transient KS 1731-260 was also modeled and is also consistent with late time heat release from a normal neutron layer.

The authors also find that the cooling magnetar SGR 1627-41 may indicate the presence of nuclear pasta. Although many uncertainties remain in the thermal relaxation of magnetars, cooling magnetars are useful in that multiple outbursts may observed in the same source on a shorter timescale than in accreting neutron star transients. In the case of SGR 1627-41, the observed cooling following its 2008 outburst shows some evidence for late time cooling from a normal neutron layer. Further cooling observations of this source are needed to delineate between model predictions of the inner crust thermal properties.

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Further Reading:

[1] Deibel, A., Cumming, A., Brown, E. F., and Reddy, S. 2016, submitted to ApJ, arXiv: 1609.07155
[2] Caplan, M E and Horowitz, C. J. 2016, arXiv: 1606.03646
[3] Horowitz, C. J. et al. 2015, Physical Review Letters, 114, 031102