Annotated Bibliography

What does the paper say about your phenomenon?

How are the theoretical models constructed?

What assumptions and approximations are being made?

What are the predictions and implications?

What more do you need to know to understand this article?

**Magnetars –** <http://solomon.as.utexas.edu/sciam.pdf>

This article serves as a great overview of what magnetars are, some of their features, how and when they were discovered, and to a lesser extent, what is being done with them today. Magnetars were first conceived of in the early 70’s after a giant pulse of gamma radiation far too powerful to be from an ordinary star sent several satellites and sensors radiation levels off the charts. Theorists and observers soon leaped at the idea that this phenomenon could’ve originated from one of the two most extreme objects in the universe, and after black holes were decided incapable of this deed, they began looking at neutron stars.

The search into gamma ray bursts (GRB), soft gamma repeaters (SGR), and anomalous x-ray pulsars (AXP) led scientists to a handful of discoveries. For one, magnetars are a very particular form of neutron star. If a star had a large enough magnetic field and the fast enough internal gas currents, after a supernova, a neutron star could perhaps spin so incredibly fast (more so than a pulsar) that it matched the rotation speed of the now-condensed internal solar fluid, creating a dynamo, and allowing for the magnetic field to stabilize and dominate the star. These magnetic fields are usually between 10^14 and 10^15 gauss and are capable of changing fundamental physics. **A magnetar’s magnetic field actually polarized the vacuum around it, stretching atoms into “long cylinders thinner than the quantum-relativistic wavelength of an electron.” Even the tiny-but-mighty electron becomes deformed and stretched into an ovular shape. Near the bottom of the magnetar magnetic field spectrum, a hydrogen atom would be stretched over 200 times narrower.** These magnetic fields are also powerful enough to cause damage to the crust of the magnetar, allowing for a release of energy that comes in two forms: a general expulsion of soft gamma rays, typical of a SGR, or occasionally a large-scale event causes a magnetic field rearrangement that releases a violent burst of energy (similar to solar flares). The fact that their magnetic and electric fields in these bursts first produce a giant fireball that decays before producing other electromagnetic radiation is worth looking into.

**Formation of Very Strongly Magnetized Neutron Stars: Implications For Gamma-Ray Bursts -** <http://articles.adsabs.harvard.edu/full/1992ApJ...392L...9D/L000009.000.html>

This article strongly mirrors the one above – I believe it was a heavy influence. It was a fairly easy read from 1992 detailing some characteristics about magnetars and offering multiple solutions for a few theories. They explain that pulsars often differ from magnetars in that their slower rotation speed is caused by either their internal convection not being united enough, but rather spotty and broken, or that the ratio between these internal ionized gas currents and the outer rotation speed was now enough to align the magnetic fields in magnetar fashion. When these celestial beasts are formed, it seems that they are often kicked away from the origin of the supernova that created the as well, with several possible theories. The main theory is that neutron star equivalents to sunspots, caused by contained neutrinos can cause a massive recoil on the neutron-star.

There is also evidence shown that strengthens the argument for a massive slowing down of magnetars due to their large magnetic field, as well as they’re involvement with soft gamma repeaters. **Currently there are no known magnetars with a short rotation period. It is theorized that a magnetar has a short life, no longer than 10,000 years, brought upon by their intense magnetic field. As we learned in class, any change in magnetic flux is met by electrical resistance, and this is true even in the extreme magnetosphere here. With so much magnetism, fluctuating at that, there is so much force acting *against* magnetar rotation that they are doomed to an active life 10,000-100,000 times shorter than their cousin the pulsar (with a magnetic field several orders of magnitude lower.** Over many years, observations of gamma and x-ray pulses from these magnetars has allowed people to track their locations, spin frequencies, emissions. The consensus is that these neutron stars spin down far faster than their pulsar brethren due to their massive magnetic fields pressing against the ionized convection currents (and thus electric fields) from within them, allowing them a relatively short life. It is discussed that these objects not only have links to SGR, but also possibly to gamma ray bursts as discussed in the article above.

# `MAGNETARS', SOFT GAMMA REPEATERS & VERY STRONG MAGNETIC FIELDS - <https://web.archive.org/web/20130517180957/http://solomon.as.utexas.edu/~duncan/magnetar.html>

# Here, we see much review of the history and theory of the previous two articles, but I will go over the additional content here. We examine that crust of a magnetar undergoes extreme pressure and shear strain primarily from the magnetic field and an induced current brought from Ampere’s Law:

# ∮B●dl = 4πI/C

# When the magnetic field, flowing from two parts of the star, experiences fluctuations from a changing pole on the star (as in the crust shifts and changes the magnetic field), this creates a current of charged particles in the field above the magnetar. The current forces protons to one pole of the star and electrons to the other and since electrons are so light, they impact the crust very hard and heat it up. All the while, these current-driven electrons also collide with some soft X-ray radiation near the outside of the star, transferring energy to said X-rays and possibly contributing to the hard and soft X-ray signatures we observe from these extreme places.

# We also find that a current computational technique for modeling the inner workings of a magnetar resemble a pan of boiling water. Inside a newly formed neutron star, the dense fluid of neutrons inside the star undergo convection, where hot patches rise and cool ones fall. The previously mention dynamo effect (previous articles) comes to light here. As this hot, dense fluid is circulating, the free electrons and protons within it and any magnetic fields wandering around (perhaps already in place before the star reached this stage of its life (death?)) get caught up and carried by these currents. In a star that was initially rotating fast enough with a perhaps-stronger-than-usual magnetic field, these currents serve to amplify the magnetism of the object. This is dynamo action, and it is also the reason why the Earth and Sun have magnetic fields (but we spin nowhere near as fast).

# Here we also shed light on the unimaginable strength of these magnetars: their magnetic fields generally lie between 1014 -1015 G. The strongest magnetic fields that humans have yet created (with large explosion mind you) were 107 G. These lasted 4-8 microseconds… and we cannot make them any stronger or last longer because we do not have instruments capable of *not being completely destroyed* be these fields.

# Pulsars and Magnetars – <https://link.springer.com/article/10.1007/s13538-013-0137-y#Sec9>

# Examined here, is the similarities and differences between pulsars and magnetars in an attempt to draw a clearer line between the two and to walk through a few theories of magnetar properties. Immediately, it becomes clear that the main process of measuring the magnetic field of a neutron star (of any kind) is with

# Bd=3.2×1019√PṖ G

# where P is the period of the star, measured with collected data on gamma and X-ray emissions from these objects. This has discovered magnetic fields, however, that exceed the Eddington limit – limiting how much luminosity a star can emit. This is corrected by observing that the intense magnetic field changes the properties of electron scattering, making it more dependent on the polarization of light. This, coupled with the fact that the cross section of a photon is reduced, is able to surpass the Eddington limit without breaking any rules.

# This article also brings to light that not every accepted theory of magnetar characteristics are perfect, but they are rather the best models we have. For example, it is generally accepted that a magnetar emission, born of a starquake, is caused by the crust of the star cracking. What is unsure is *how* that crust cracks. The leading theory is that as the awesome magnetic field does all of the work: as it decays, it pumps heat into the magnetar. As the magnetic fields twist and bend and become unstable, this produces a current on the crust of the star and also pumps heat into it. These two heating factors, along with a space-bendingly-strong magnetic field puts enough shear damage on the crust that it cracks and releases X-ray and gamma radiation. Another, lesser theory, posits that these fissures could be the result of a large energy deposition inside the star, perhaps from internal ionic winds. Additionally, the article adds that the X-ray portion of these bursts is most likely due to the field decay depositing additional heat into the star. The other semi-complete explanation that arises is what actually causes the strong magnetic fields. One explanation is simple: the strong magnetic fields are simply remnants of the most magnetically active stars, amplified by the compression into a neutron star. As mentioned in a previous article, however, the leading theory is close but more complicated (including ionized fluids spinning inside the star, amplified magnetization, and a dynamo effect).

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# Personal note: P&Ms

# Magnetic field decay provides a source of internal heating which can play an important role in the X-ray emission from the surface of magnetars.

# This is due to the self-regulating effect resulting from the strong temperature-dependence of neutrino emission and might explain why persistently bright AXPs/SGRs do not undergo outbursts, but change their luminosity by, at most, of a factor of a few.