Searching for High Energy Neutrinos from Magnetars with IceCube

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Abstract: Magnetars are neutron stars with very strong magnetic fields on the order of 10^{13} to 10^{15} G. Young magnetars with oppositely-oriented magnetic fields and spin moments may emit high-energy (HE) neutrinos from their polar caps as they may be able to accelerate cosmic rays to above the photomeson threshold **[1]**. Giant flares of soft gamma-ray repeaters (a subclass of magnetars) may also produce HE neutrinos and therefore a HE neutrino flux from this class is potentially detectable **[2]**. Here we present plans to search for neutrino emission from magnetars listed in the McGill Online Magnetar Catalog using 10 years of well-reconstructed IceCube muon-neutrino events looking for significant clustering around magnetars' direction. IceCube is a cubic kilometer neutrino observatory at the South Pole and has been fully operational for the past ten years.

1 - Neutrino Emission Mechanism In Magnetars:

There are two main sources of energy that power a magnetar:

- The **spin-down power** accelerates protons, and
- The magnetic power provides a large amount of near-surface photons.

Assuming **both of these energy sources power the magnetar, and that the magnetar is young enough**, then the criterion for photomeson interactions are satisfied with the dominant interaction resulting in neutrino emission being the Δ-resonance **[1]:**

$$p\gamma \rightarrow \Delta \rightarrow n\pi^+ \rightarrow n\nu_\mu\mu^+ \rightarrow n\nu_\mu e^+\nu_e\bar{\nu}_\mu$$

2 - Neutrino Detection: The IceCube Neutrino Observatory:

The IceCube Neutrino Observatory:

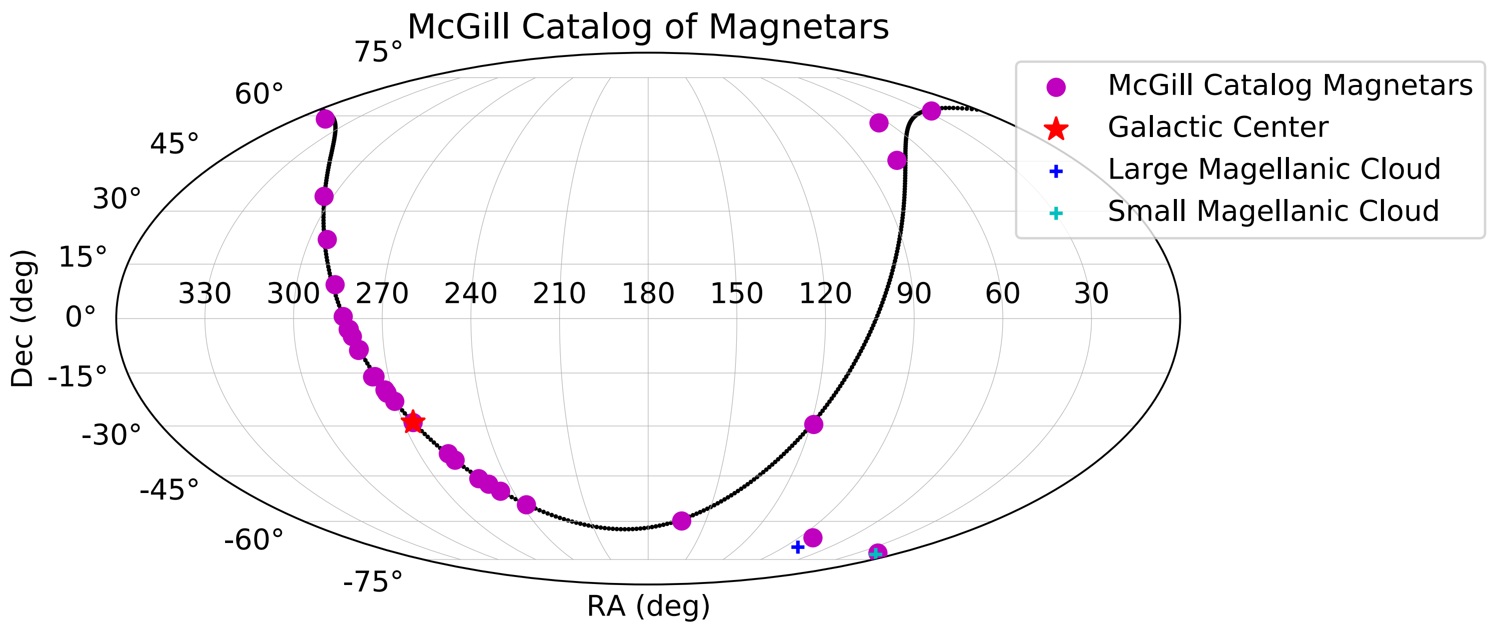
- **Cubic-kilometer neutrino detector** deep inside the Antarctic ice **[3]**
- Operational for the past 10 years, published the **first evidence of High Energy (HE) neutrinos of astrophysical origins** in 2013 **[4]**.
- Charged-current interactions of muon neutrinos produce high-energy muon tracks with an angular resolution of ~1° for energies above 10 TeV.

We plan to use a sample of events **from both the northern and southern sky using 10 years of IceCube data optimized for point source searches.**

3 - The Magnetar Catalog

We use the **McGill Online Magnetar Catalog [5]** which contains 30 magnetars:

- **14 Anomalous X-ray Pulsars (AXPs)**
- **16 Soft Gamma-ray Repeaters (SGRs)**



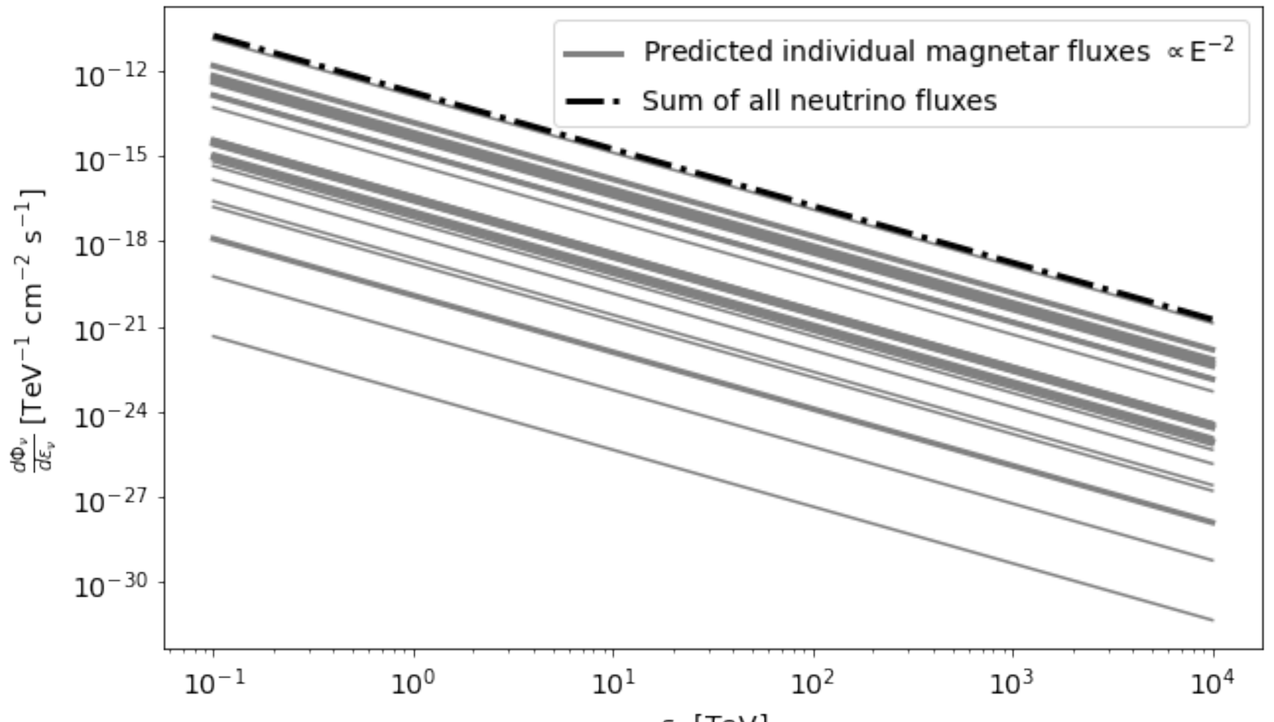
In addition to the McGill catalog:

- The two newly discovered magnetars, **Swift J1555.2-5402** and **SGR 1830-0645** will be included in all 3 phases discussed in details in Section 4.
- γ-ray burst GRB 200415A is believed to be a giant flare of a magnetar in the starburst galaxy NGC 253 **[6]**. We will include **NGC 253** in our time-dependent and individual analyses described in Section 4.

4 - Analysis Plan:

There are **three phases** in our search for neutrinos from magnetars with IceCube.

1. **Time-integrated Stacked Search:** Time-integrated stacked unbinned likelihood analysis for increased sensitivity.
   - A. The weights in this analysis are **1. Equal:** No models are taken into account; **2. Energy flux:** Direct correlation between the neutrino flux and the unabsorbed X-ray energy flux ; **3. Inverse period:** Young magnetars are more likely to emit high energy neutrinos.
   - B. **Testing the Neutrino Emission Model in Zhang, et al. [1]:** We will compare the differential neutrino flux derived from Zhang et al. to the sensitivity and discovery potentials obtained from our time-integrated stacking analysis.
2. **Time-dependent Search:** Test the hypothesis that the baryon-rich flare of a SGR 10^{-3} times smaller than that of SGR 1086-20 can produce about one event in IceCube, and the rate of such flares is about 1/10 year **[2]**. We will perform a **time-dependent light curve analysis using the method in [7].** We will search for neutrinos in IceCube around the time of increased X-ray activity of the magnetars using the data from MAXI/Riken and Swift BAT.
3. **Study of Individual Sources:** Look at individual sources such as SGR 1935+2154, **associated with a fast radio burst (FRB) [7]**, without stacking to set upper limits on the neutrino flux.



The differential neutrino flux given in [1] plotted using the data in the McGill magnetar catalog [5].

5 - Summary and Future Work:

Here we presented a proposed search for neutrino emission from magnetars using 10 years of IceCube data outlining the three phases of this analysis and discussed the rationale behind each.

We are now in the process of generating sensitivities and discovery potentials for the time-integrated stacking analysis. If no significant signal is identified, we will set constraints on magnetars as a whole class of objects contributing to the all-sky astrophysical neutrino flux.

Following the time-integrated stacking analysis, we will move on to probing magnetars as transient sources by performing a time-dependent analysis. Finally we will look at individual magnetars that are of special interest, such as SGR 1935+2154 which has been associated with a FRB **[8]**.

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References

[1] B. Zhang, Z. G. Dai, P. Meszaros, E. Waxman, and A. K. Harding *The Astrophysical Journal* 595 no. 1, (Sep, 2003) 346–351.
[2] K. Ioka, S. Razzaque, S. Kobayashi, and P. Meszaros *The Astrophysical Journal* 633 no. 2, (Nov, 2005) 1013–1017.
[3] IceCube Collaboration *Journal of Instrumentation* 12 no. 03, (Mar, 2017) P03012–P03012.
[4] IceCube Collaboration *Science* 342 no. 6161, (2013)
[5] S. A. Olausen and V. M. Kaspi *The Astrophysical Journal Supplement Series* 212 no. 1, (Apr, 2014) 6.
[6] Svinkin, D., Frederiks, D., Hurley, K. *et al.* Nature **589,** 211–213 (2021)
[7] IceCube Collaboration *arXiv e-prints* (Dec., 2020) arXiv:2012.01079
[8] C. D. Bochenek, V. Ravi, K. V. Belov, G. Hallinan, J. Kocz, S. R. Kulkarni, and D. L. McKenna *Nature* 587 no. 7832, (Nov, 2020) 59–62.