UNIVERSITY OF TURKU

Magnetars!

Kristen E. Gardner

UTU - Department of Physics and Astronomy

What is a Magnetar?

Definition:

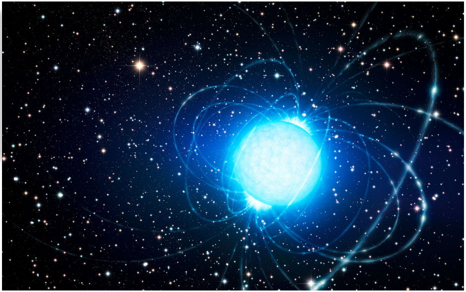

Figure: Artistic depiction of a magnetar [1]

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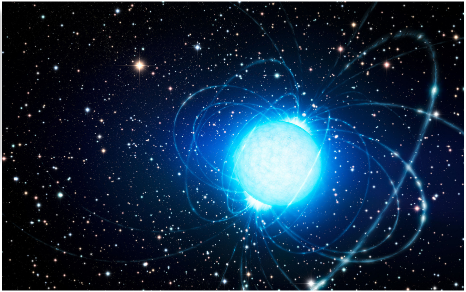

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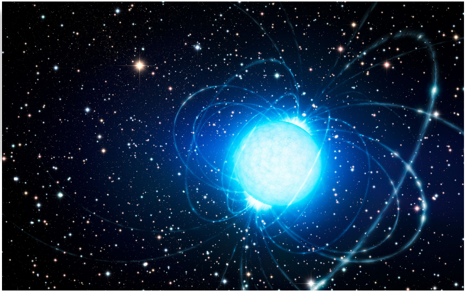
- neutron star
- massive magnetic field ($\geq 10^{13}$ G)



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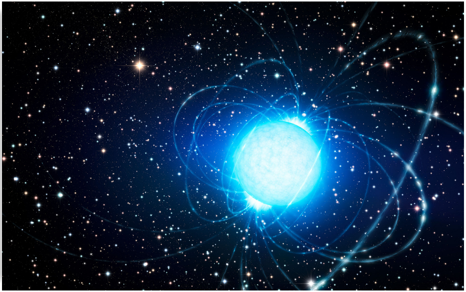

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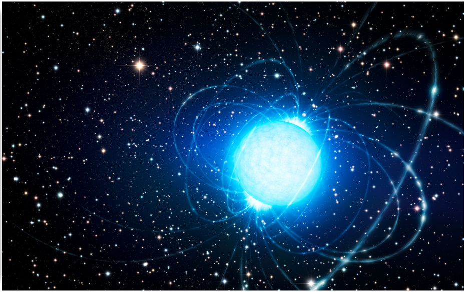

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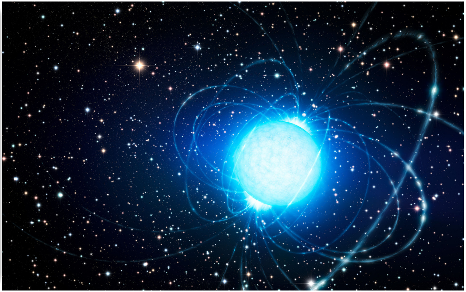

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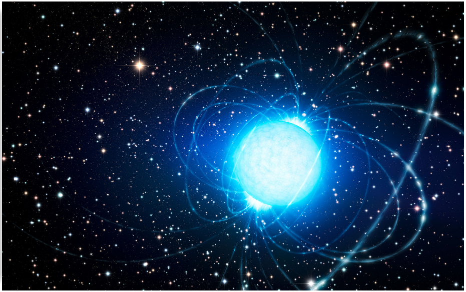

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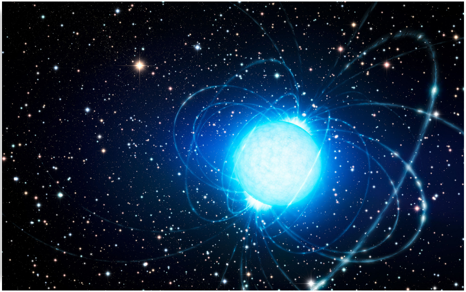

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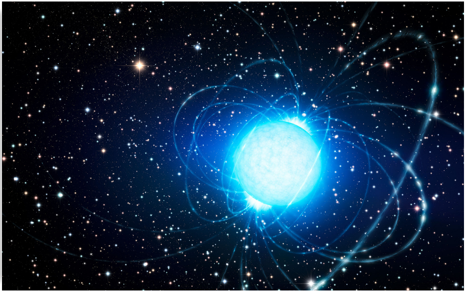

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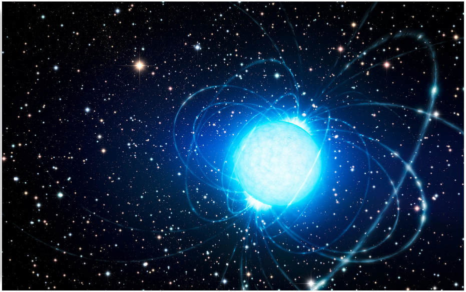

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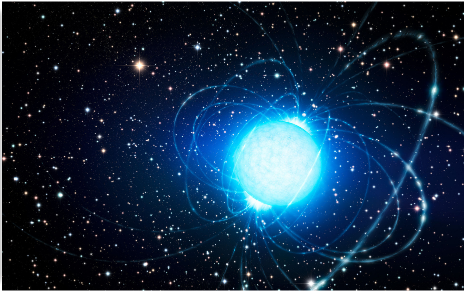

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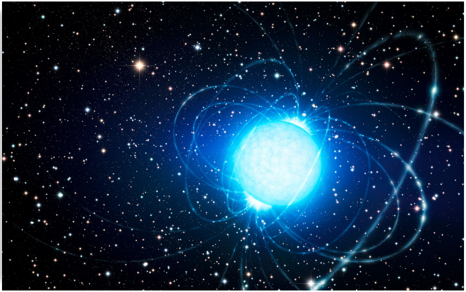

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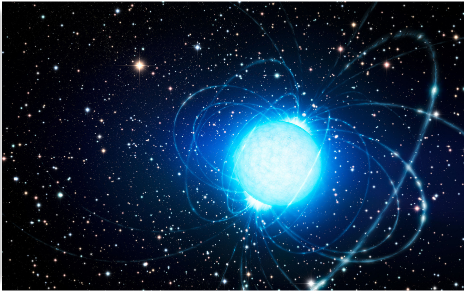

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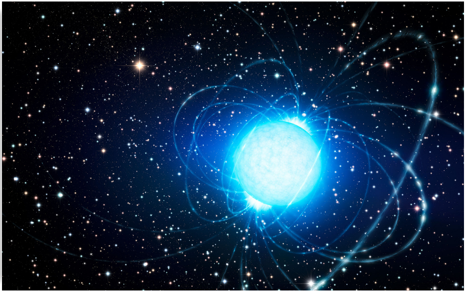

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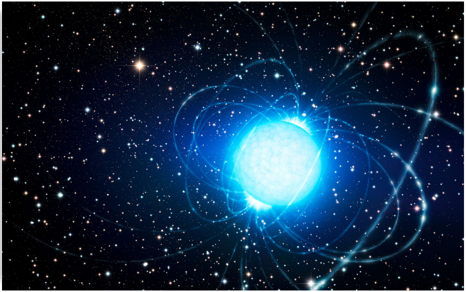
- cross-species magnetar/pulsar



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Distinctions

Neutron Star

- radius on order of 10 km
- 1.1 - 2.16 solar masses
- $10^9 - 10^{13}$ G (for non-magnetars)

Magnetars

Radio Pulsars

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Radio Pulsars

- $\sim$100 ms rotational period
- spin-down $\rightarrow$ radio emission, and non-thermal X/gamma-ray radiation

Neutron Star Types

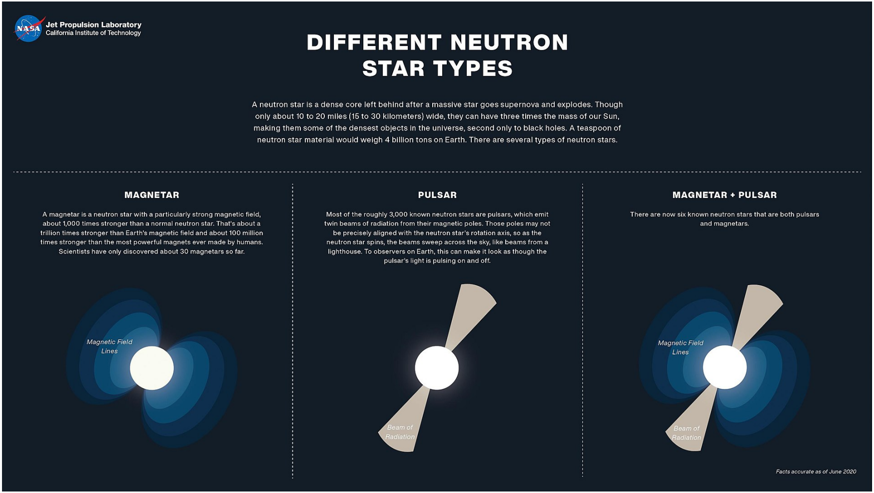

Figure: Neutron star types, courtesy of JPL [3]

Distribution in Space

Observations:

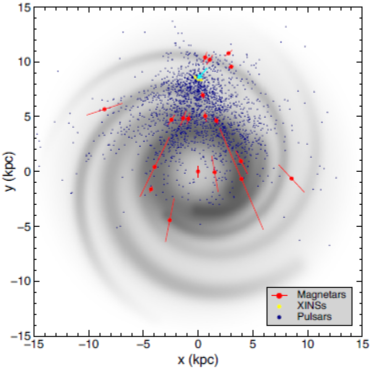

Figure: Top down view of the Milky Way with known Magnetars (and distance uncertainties) in red. [4]

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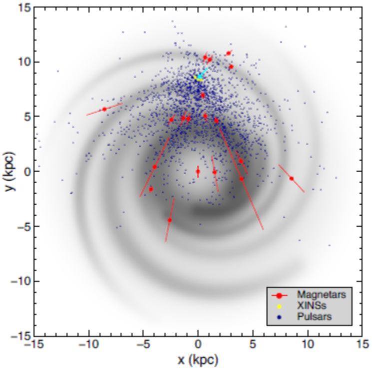
- generally within the galactic plane



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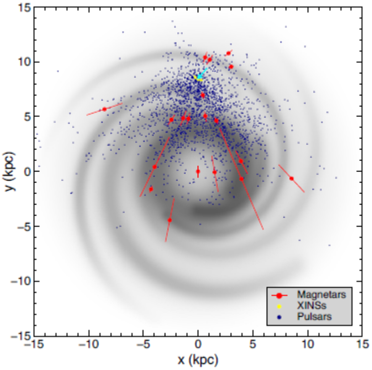

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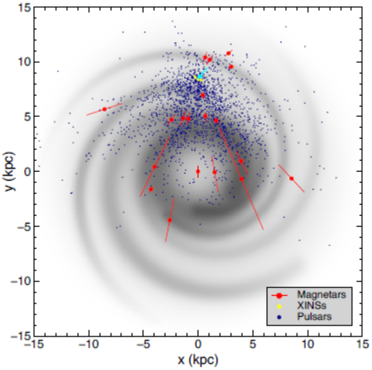

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The Magnetars

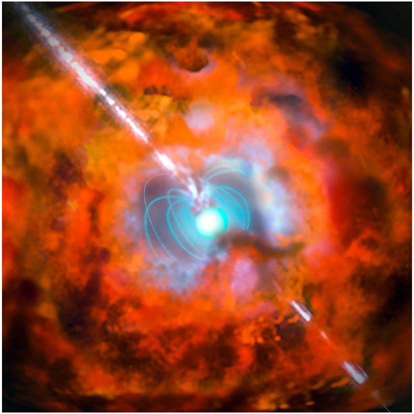
Name	P (s)	B (10^{14} G)	Age (kyr)	E (10^{33} erg s^{-1})	D (kpc)	L (10^{33} erg s^{-1})	Band
CXOU J010043.1-721134	8.02	3.9	6.8	1.4	62.4	65	...
4U 0142+61	8.69	1.3	68	0.12	3.6	105	OIR/H
SGR 0418+5729	9.08	0.06	36000	0.00021	2	0.00096	...
SGR 0501+4516	5.76	1.9	15	1.2	2	0.81	OIR/H
SGR 0526-66	8.05	5.6	3.4	2.9	53.6	189	...
1E 1048.1-5937	6.46	3.9	4.5	3.3	9.0	49	OIR
(PSR J1119-6127)	0.41	4.1	1.6	2300	8.4	0.2	R/H
1E 1547.0-5408	2.07	3.2	0.69	210	4.5	1.3	O?/R/H
PSR J1622-4950	4.33	2.7	4.0	8.3	9	0.4	R
SGR 1627-41	2.59	2.2	2.2	43	11	3.6	...
CXOU J164710.2-455216	10.6	<0.66	>420	<0.013	3.9	0.45	...
1RXS J170849.0-400910	11.01	4.7	9.0	0.58	3.8	42	O?/H
CXOU J171405.7-381031	3.82	5.0	0.95	45	13	56	...
SGR J1745-2900	3.76	2.3	4.3	10	8.3	<0.11	R/H
SGR 1806-20	7.55	20	0.24	45	8.7	163	OIR/H
XTE J1810-197	5.54	2.1	11	1.8	3.5	0.043	OIR/R
Swift J1822.3-1606	8.44	0.14	6300	0.0014	1.6	>0.0004	...
SGR 1833-0832	7.56	1.6	34	0.32	...	...	...
Swift J1834.9-0846	2.48	1.4	4.9	21	4.2	<0.0084	...
1E 1841-045	11.79	7.0	4.6	0.99	8.5	184	...
(PSR J1846-0258)	0.327	0.49	0.73	8100	6.0	19	...
3XMM J185246.6+003317	11.56	<0.41	>1300	<0.0036	7	< 0.006	...
SGR 1900+14	5.20	7.0	0.9	26	12.5	90	H
SGR 1935+2154	3.24	2.2	3.6	17	...	...	...
1E 2259+586	6.98	0.59	230	0.056	3.2	17	OIR/H
SGR 0755-2933	...	...	...	...	...	...	...
SGR 1801-23	...	...	...	...	...	...	...
SGR 1808-20	...	...	...	...	...	...	...
AX J1818.8-1559	...	...	...	...	...	...	...
AX J1845.0-0258	6.97	...	...	...	...	2.9	...
SGR 2013+34	...	...	...	...	...	...	...

Figure: So far... [4]

Supernova Remnant Associations

Basics:

Consequences:



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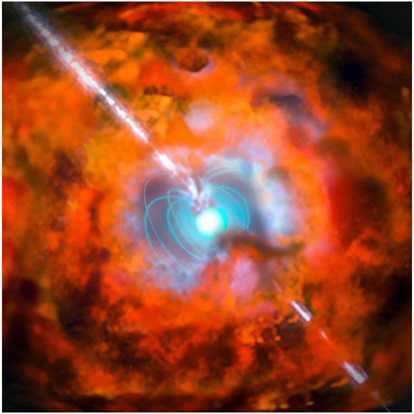

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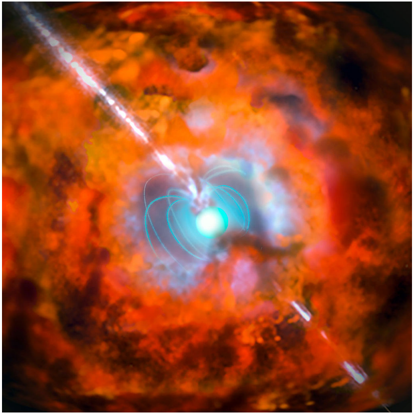

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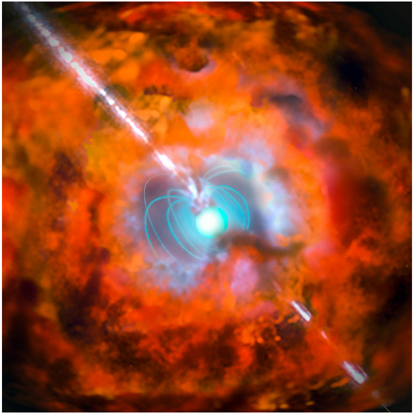

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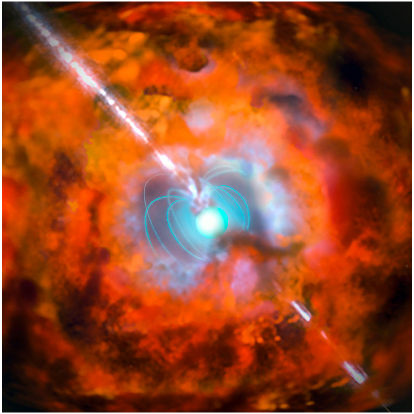

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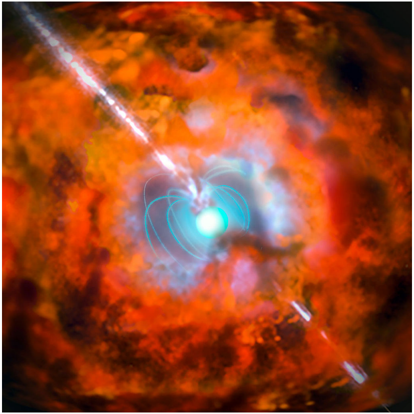

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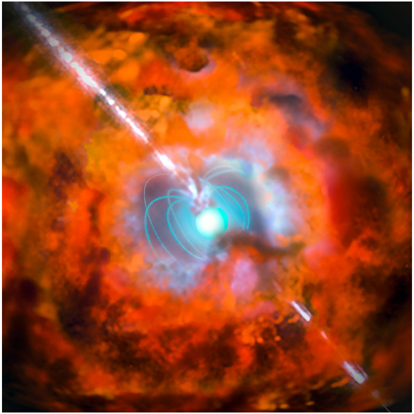
- no conclusive theory of formation as of yet



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- B-Field is created via convective mass-flows leading to a dynamo effect post supernova [6]

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Magnetic Braking

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- cause of quiescent x-ray radiation
- linked to star quakes

Summary and Conclusions

What we know

- Magnetars exist, are a class of neutron star
- Strong magnetic fields ($> 10^{13}$ G)
- Lifetime of 1-10 kyr
- Supernovae remnants are common
- Generally confined to galactic plane
- There are different kinds of Magnetars

What we don't know

- A definitive model for the formation of magnetars
- Cause of increased magnetic field
- True abundance in MW
- Any in other galaxies

Questions?

References

1. Magnetar Image 1 http://www.eso.org/public/images/eso1415a/
2. Duncan RC, Thompson C. 1992. ApJ 392:L9-L13
3. Neutron Star Types https://photojournal.jpl.nasa.gov/figures/PIA23863.jpg
4. Kaspi, V. M., & Beloborodov, A. M. (2017). Magnetars. Annual Review of Astronomy and Astrophysics, 55(1), 261-301. https://doi.org/10.1146/annurev-astro-081915-023329
5. Magnetar Remnant http://www.eso.org/public/images/eso1527a/
6. R. Raynaud, J. Guilet, H.-T. Janka, T. Gastine "Magnetar formation through a convective dynamo in protoneutron stars." Science Advances 6, eaay2732 (2020).