Origin and evolution of magnetars

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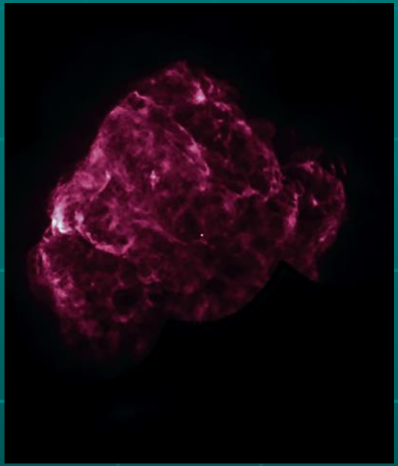
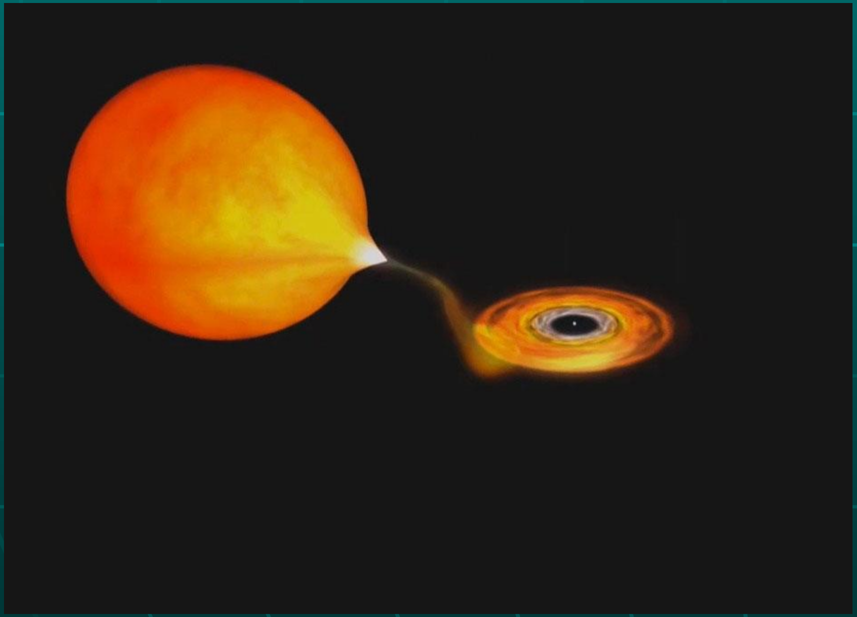
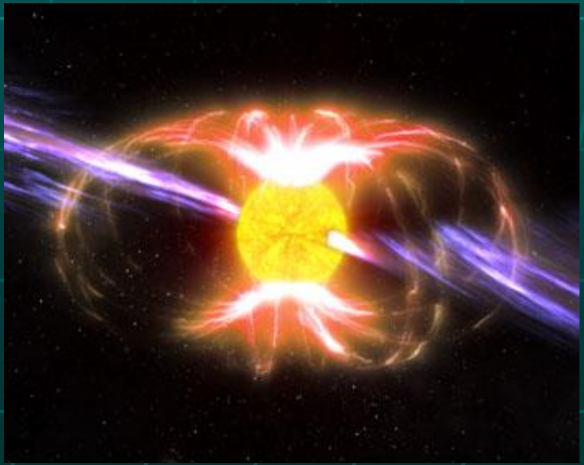
Plan of the talk

- Origin of magnetars. Role of binaries
- Evolution of magnetars. Binaries as probes.
- “Frozen” magnetars in CCOs

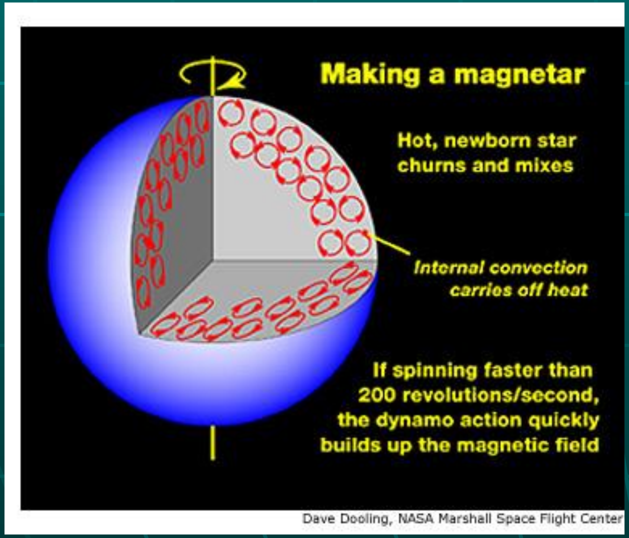






Origin of magnetars field

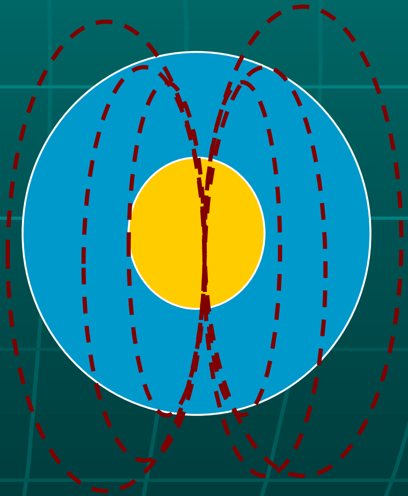
Generated



Dave Dooling, NASA Marshall Space Flight Center

Classical dynamo scenario starting from DT in 90s

Fossil



Critisized by Spruit (2008)

Dynamo mechanism conditions

Rapid rotation is necessary!

P_0~ few msec
This is difficult to achieve due to slowdown of
a stellar core rotation (Heger et al. 2004, Meynet, Maeder 2005).
The same problem appear in GRB scenario.

Stellar rotation can be enhanced only in binaries.

There are different possibilities
to gain additional angular momentum
due to mass transfer or tidal interaction.

We need to to perform population
synthesis calculations.

Binary evolution channels. I.

Among all possible evolutionary paths that result in formation of NSs we select those that lead to angular momentum increase of progenitors.

- Coalescence prior to a NS formation.
- Roche lobe overflow by a primary without a common envelope.
- Roche lobe overflow by a primary with a common envelope.
- Roche lobe overflow by a secondary without a common envelope.
- Roche lobe overflow by a secondary with a common envelope.

This is an optimistic scenario, as it is assumed that angular momentum is not lost in significant amount after it has been gained (astro-ph/0505406)

Products of binaries. I.

In the "optimistic" scenario we obtain that rapidly rotating cores are mainly produced by mergers and by first RLO (i.e. the secondary companion gains angular momentum).

Mostly, compact objects formed via these channels are isolated.

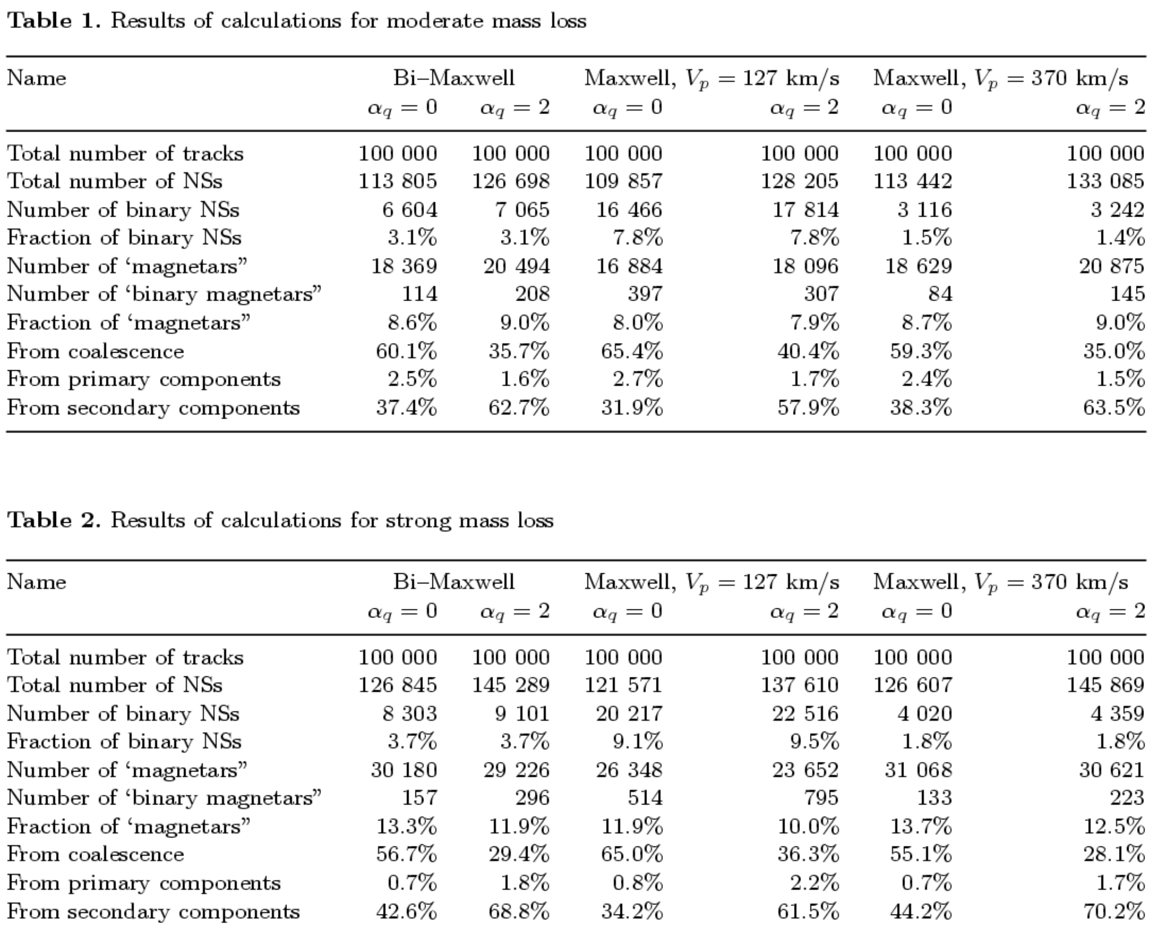


Table 1. Results of calculations for moderate mass loss

Name	Bi–Maxwell		Maxwell, $V_p = 127$ km/s		Maxwell, $V_p = 370$ km/s	
	$\alpha_q = 0$	$\alpha_q = 2$	$\alpha_q = 0$	$\alpha_q = 2$	$\alpha_q = 0$	$\alpha_q = 2$
Total number of tracks	100 000	100 000	100 000	100 000	100 000	100 000
Total number of NSs	113 805	126 698	109 857	128 205	113 442	133 085
Number of binary NSs	6 604	7 065	16 466	17 814	3 116	3 242
Fraction of binary NSs	3.1%	3.1%	7.8%	7.8%	1.5%	1.4%
Number of 'magnetars"	18 369	20 494	16 884	18 096	18 629	20 875
Number of 'binary magnetars"	114	208	397	307	84	145
Fraction of 'magnetars"	8.6%	9.0%	8.0%	7.9%	8.7%	9.0%
From coalescence	60.1%	35.7%	65.4%	40.4%	59.3%	35.0%
From primary components	2.5%	1.6%	2.7%	1.7%	2.4%	1.5%
From secondary components	37.4%	62.7%	31.9%	57.9%	38.3%	63.5%

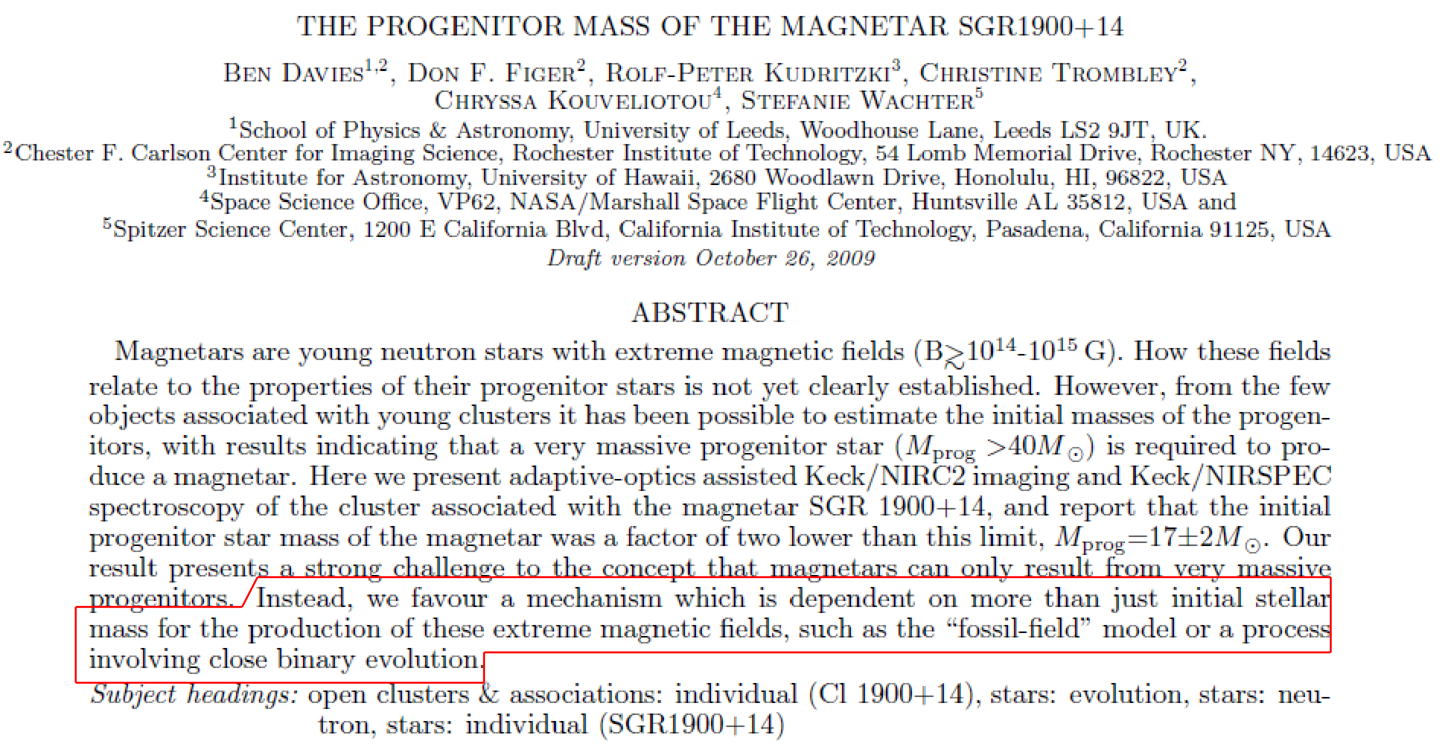
Table 2. Results of calculations for strong mass loss

Name	Bi–Maxwell		Maxwell, $V_p = 127$ km/s		Maxwell, $V_p = 370$ km/s	
	$\alpha_q = 0$	$\alpha_q = 2$	$\alpha_q = 0$	$\alpha_q = 2$	$\alpha_q = 0$	$\alpha_q = 2$
Total number of tracks	100 000	100 000	100 000	100 000	100 000	100 000
Total number of NSs	126 845	145 289	121 571	137 610	126 607	145 869
Number of binary NSs	8 303	9 101	20 217	22 516	4 020	4 359
Fraction of binary NSs	3.7%	3.7%	9.1%	9.5%	1.8%	1.8%
Number of 'magnetars"	30 180	29 226	26 348	23 652	31 068	30 621
Number of 'binary magnetars"	157	296	514	795	133	223
Fraction of 'magnetars"	13.3%	11.9%	11.9%	10.0%	13.7%	12.5%
From coalescence	56.7%	29.4%	65.0%	36.3%	55.1%	28.1%
From primary components	0.7%	1.8%	0.8%	2.2%	0.7%	1.7%
From secondary components	42.6%	68.8%	34.2%	61.5%	44.2%	70.2%

astro-ph/0505406

Observational evidence

There are several cases where observations favour magnetar birth in binary systems



THE PROGENITOR MASS OF THE MAGNETAR SGR1900+14

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Draft version October 26, 2009

ABSTRACT

Magnetars are young neutron stars with extreme magnetic fields ($B \gtrsim 10^{14}$-10^{15} G). How these fields relate to the properties of their progenitor stars is not yet clearly established. However, from the few objects associated with young clusters it has been possible to estimate the initial masses of the progenitors, with results indicating that a very massive progenitor star ($M_{\rm prog} > 40 M_\odot$) is required to produce a magnetar. Here we present adaptive-optics assisted Keck/NIRC2 imaging and Keck/NIRSPEC spectroscopy of the cluster associated with the magnetar SGR 1900+14, and report that the initial progenitor star mass of the magnetar was a factor of two lower than this limit, $M_{\rm prog} = 17 \pm 2 M_\odot$. Our result presents a strong challenge to the concept that magnetars can only result from very massive progenitors. Instead, we favour a mechanism which is dependent on more than just initial stellar mass for the production of these extreme magnetic fields, such as the "fossil-field" model or a process involving close binary evolution.

Subject headings: open clusters & associations: individual (Cl 1900+14), stars: evolution, stars: neutron, stars: individual (SGR1900+14)

0910.4859

Another recent case

A VLT/FLAMES survey for massive binaries in Westerlund 1. IV. Wd1-5 - binary product and a pre-supernova companion for the magnetar CXOU J1647-45? *

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Preprint online version: May 14, 2014

ABSTRACT

Context. The first soft gamma-ray repeater was discovered over three decades ago, and subsequently identified as a magnetar, a class of highly magnetised neutron star. It has been hypothesised that these stars power some of the brightest supernovae known, and that they may form the central engines of some long duration gamma-ray bursts. However there is currently no consenus on the formation channel(s) of these objects.
Aims. The presence of a magnetar in the starburst cluster Westerlund 1 implies a progenitor with a mass $\geq 40M_{\odot}$, which favours its formation in a binary that was disrupted at supernova. To test this hypothesis we conducted a search for the putative pre-SN companion.
Methods. This was accomplished via a radial velocity survey to identify high-velocity runaways, with subsequent non-LTE model atmosphere analysis of the resultant candidate, Wd1-5.
Results. Wd1-5 closely resembles the primaries in the short-period binaries, Wd1-13 and 44, suggesting a similar evolutionary history, although it currently appears single. It is overluminous for its spectroscopic mass and we find evidence of He- and N-enrichement, O-depletion, and critically C-enrichment, a combination of properties that is difficult to explain under single star evolutionary paradigms. We infer a pre-SN history for Wd1-5 which supposes an initial close binary comprising two stars of comparable ($\sim 41M_{\odot} + 35M_{\odot}$) masses. Efficient mass transfer from the initially more massive component leads to the mass-gainer evolving more rapidly, initiating luminous blue variable/common envelope evolution. Reverse, wind-driven mass transfer during its subsequent WC Wolf-Rayet phase leads to the carbon pollution of Wd1-5, before a type Ibc supernova disrupts the binary system. Under the assumption of a physical association between Wd1-5 and J1647-45, the secondary is identified as the magnetar progenitor; its common envelope evolutionary phase prevents spin-down of its core prior to SN and the seed magnetic field for the magnetar forms either in this phase or during the earlier episode of mass transfer in which it was spun-up.
Conclusions. Our results suggest that binarity is a key ingredient in the formation of at least a subset of magnetars by preventing spin-down via core-coupling and potentially generating a seed magnetic field. The apparent formation of a magnetar in a Type Ibc supernova is consistent with recent suggestions that superluminous Type Ibc supernovae are powered by the rapid spin-down of these objects.

1405.3109

Binary evolution channels. II.

“Easy come – easy go”. Angular momentum can be lost
after it was increased in a binary.

Here we consider only tidal synchronization on late stages
(end of helium burning, or carbon burning).
I.e. a core gets additional momentum not long before the collapse.
(can work also for GRB progenetors)

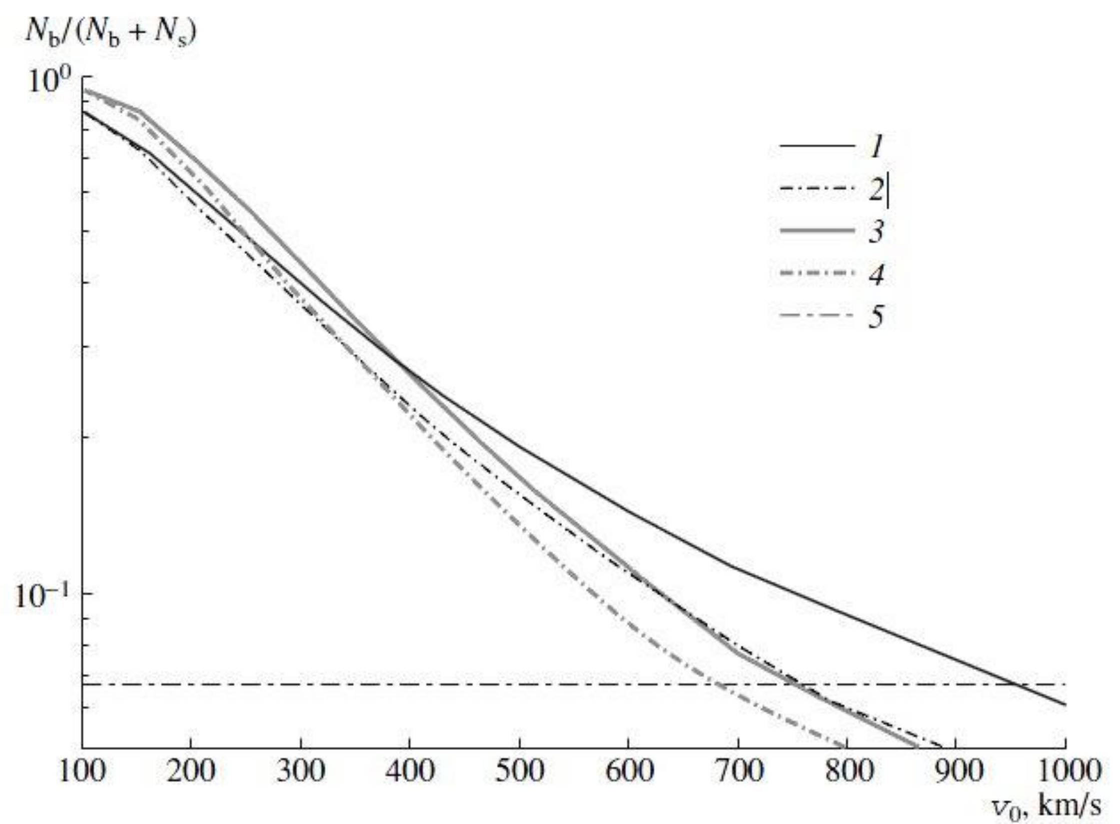
This is possible only in very narrow systems (P_{orb}<10 days).
So, this is a “pessimistic” scenario (arXiv: 0905.3238).

The trick is also to explain the fact that all know well-established
magnetars (SGRs, AXPs) are isolated objects.

Different kicks and mass loss

(1) isotropic kick,
type A wind scenario;
(2) isotropic kick,
type C wind scenario;
(*3*) Kick along the spin axis,
type A wind scenario;
(*4*) Kick along the spin axis,
type C wind scenario

(arXiv: 0905.3238)

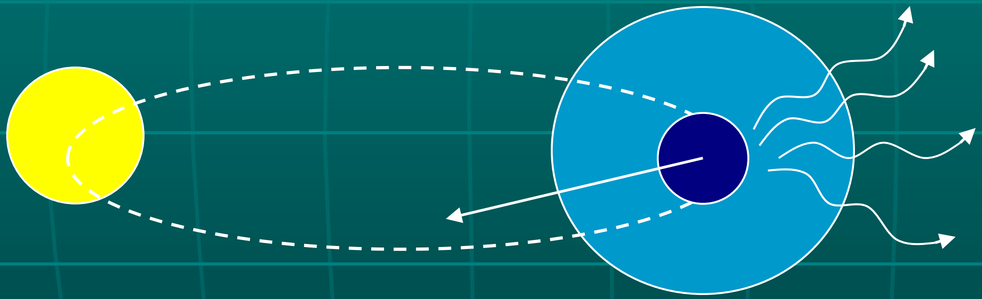


$$f(v) \sim \frac{v^2}{v_0^3} e^{-\frac{v^2}{v_0^2}},$$

Single maxwellian
distribution

Products of binaries. II.

We can easily reproduce the fraction of magnetars among NSs, however, to make them all isolated we need kick velocities larger than average for NSs.

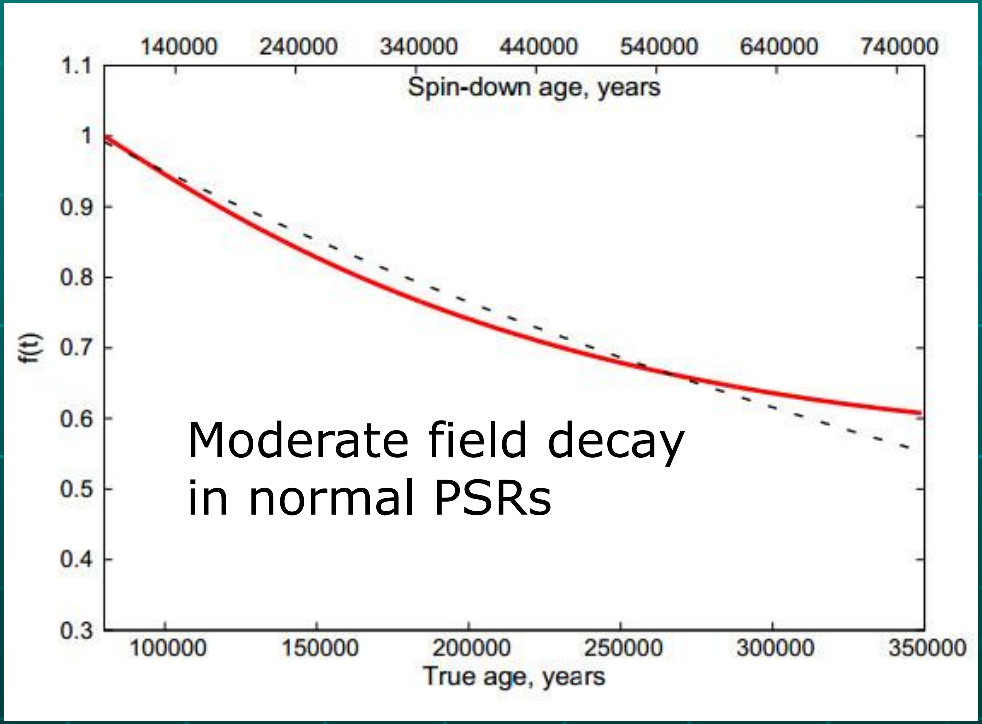


Here we come to the question:
if there are magnetars in binary systems?
I.e., shall we assume that most of them are isolated?

Binaries and field evolution

It is important to probe field evolution on different time scales and for different values of the initial magnetic field.

- standard fields, < few Myrs
  Normal PSRs
- large fields, ~ tens kyrs
  SGRs AXPs
- large fields, ~hundred kyrs
  Magnificent seven (?)
- All fields, Gyrs
  Accreting isolated NSs
  (in future?
  See arXiv: 1004.4805)



Moderate field decay in normal PSRs

Binaries provide an additional possibility to probe the time scale unavailable for INSs.

Preliminary arXiv:1309.4917
Final results: arXiv: 1407.6269

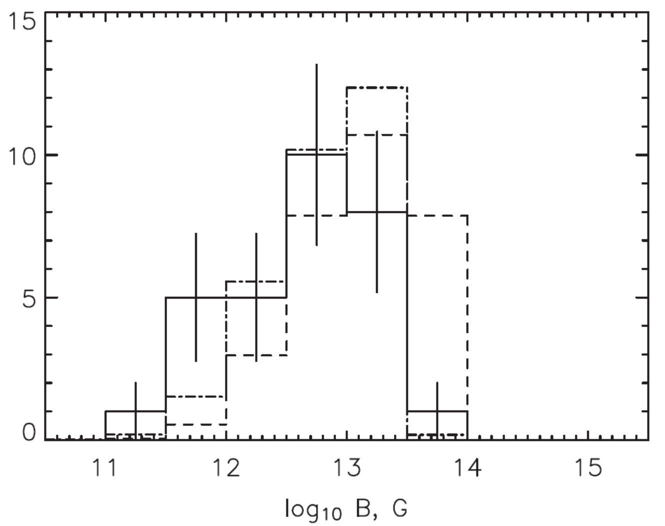
Accreting magnetars in binaries

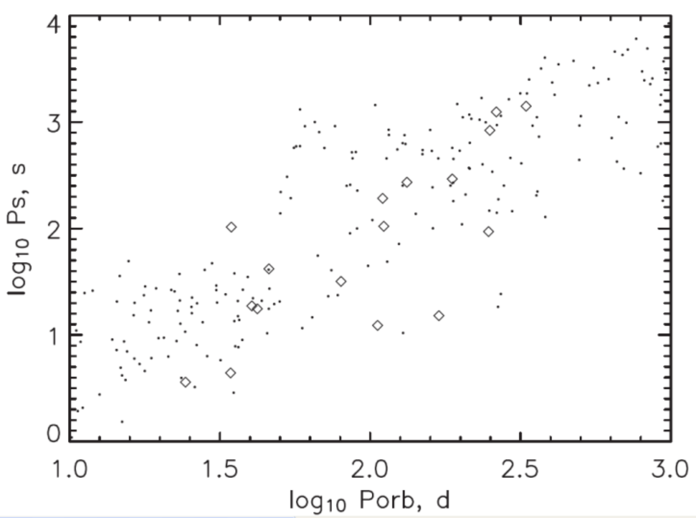
HMXBs are good probes of NS evolution on the time scale up to few 10^7 yrs.

It is possible to estimate the magnetic field of a NS in a binary **IF** you know the correct model of accretion (see a list, for example, in Postnov et al. 2013).

Some authors (see Klus et al. 2013, Ho et al. 2013 and references therein) claim that only large magnetic fields can explain properties of several objects.

Some studies can explain the data without large fields.

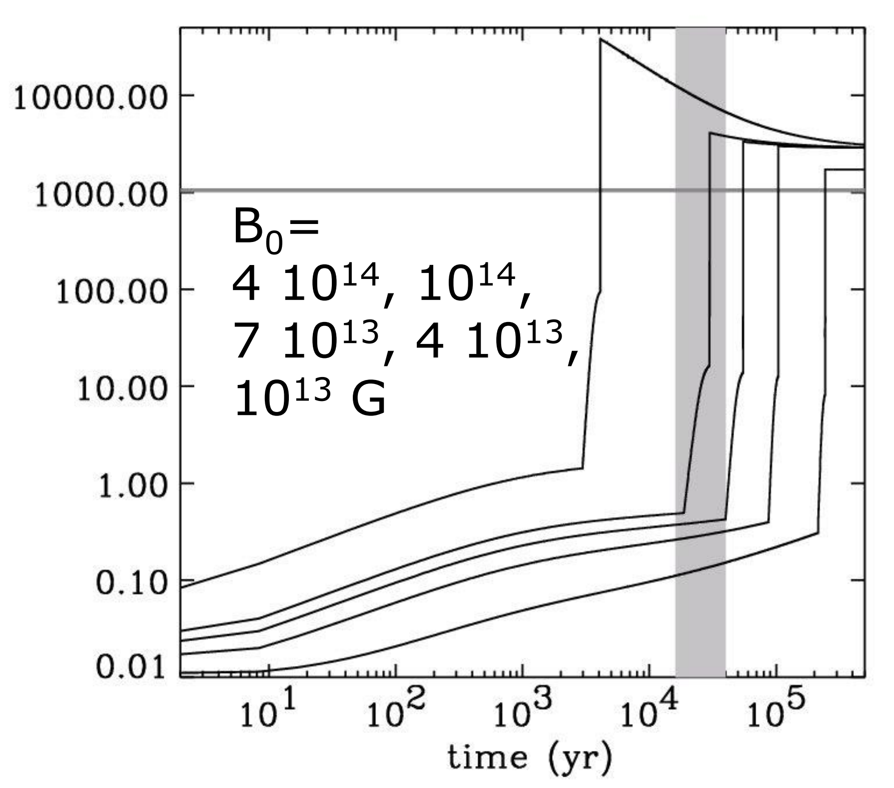




Set of 42 Be/Xray binaries in SMS can be explained in the framework of decaying field model of Pons et al. (arXiv: 1112.1123)

SXP 1062

A crucial thing for studying magneto-rotational evolution is to have an independent age estimate.
In the case of HMXBs a unique source with known age is SXP1062 (H´enault-Brunet et al. 2012, Haberl et al. 2012).



B_0=
4 10^{14}, 10^{14},
7 10^{13}, 4 10^{13},
10^{13} G

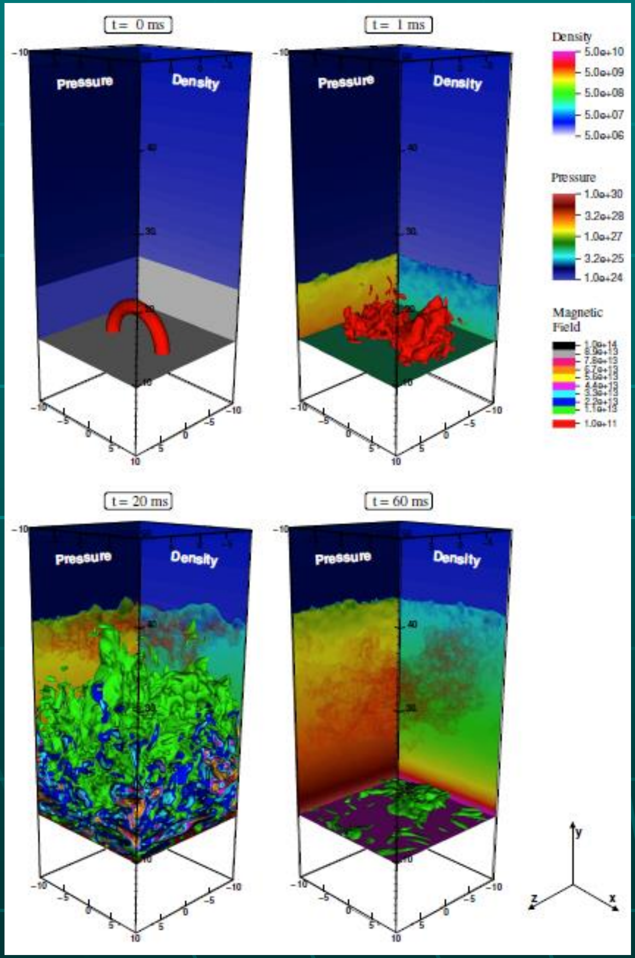
We were able to reproduce properties of SXP 1062 assuming a magnetic field decay.

I.e., initially the NS was a magnetar but now it has s standard magnetic field.
The crucial element of this model is the new accretion model by Shakura et al. (2013).

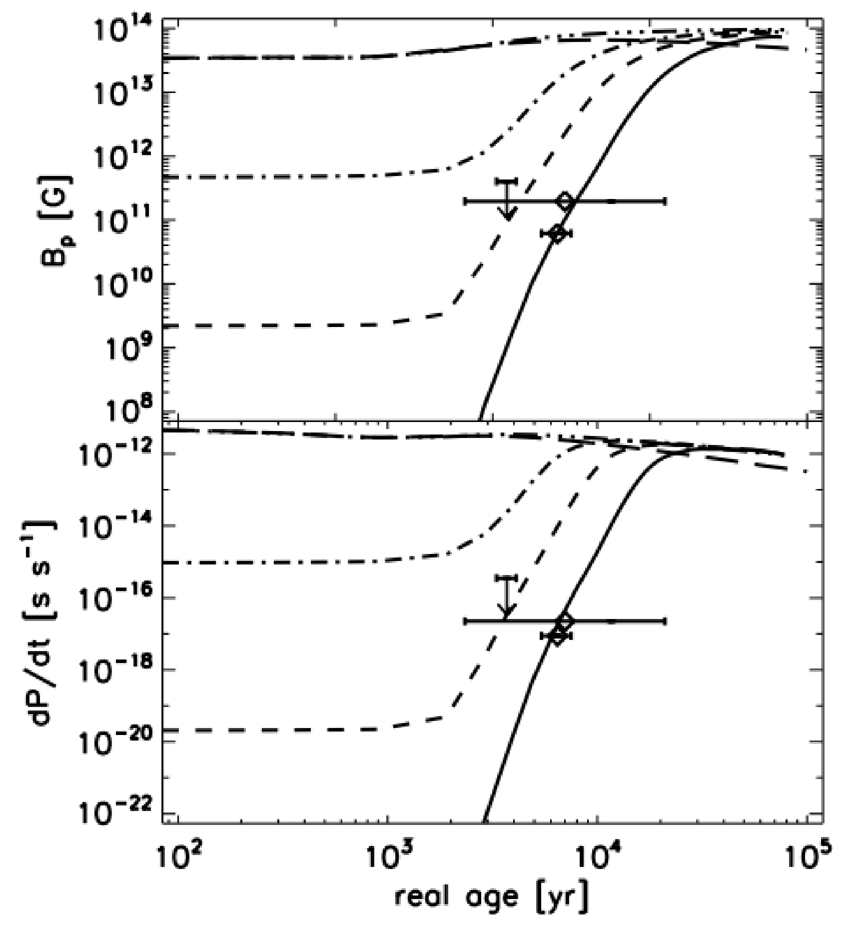
arXiv: 1112.2507

The final element for the GUNS?

The field is buried by fall-back, and then re-emerges on the scale ~10^4 yrs.



Bernal, Page, Lee 2013

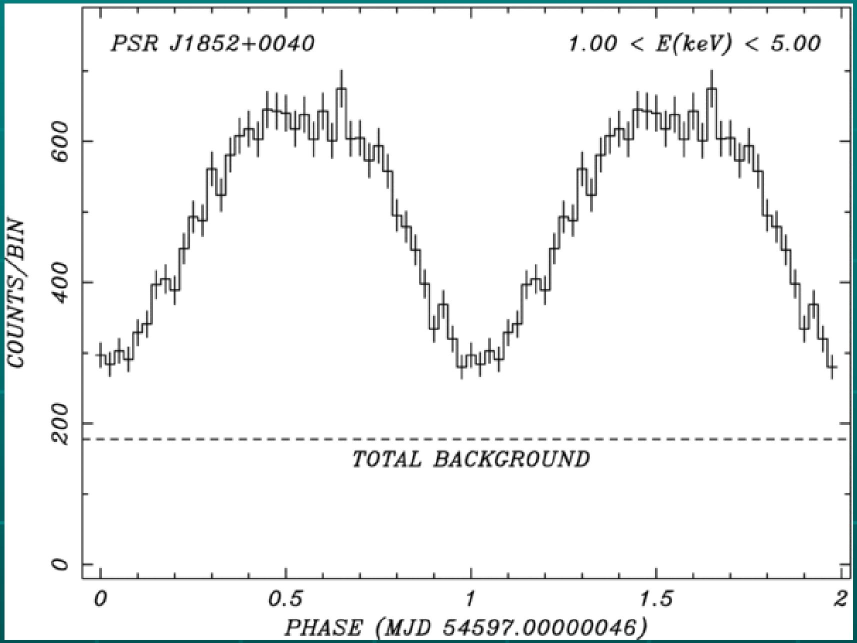


Vigano, Pons 2012

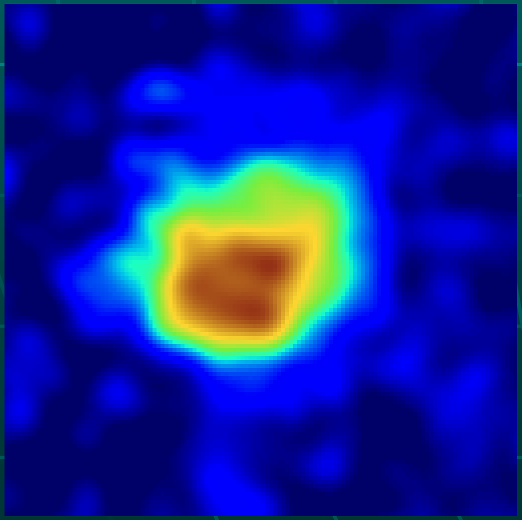
"Frozen" magnetars

Kes 79. PSR J1852+0040. P~0.1 s

Shabaltas & Lai (2012) show that large pulse fraction of the NS in Kes 79 can be explained if its magnetic field in the crust is very strong: few ×10^{14} G.



Halpern, Gotthelf 2010

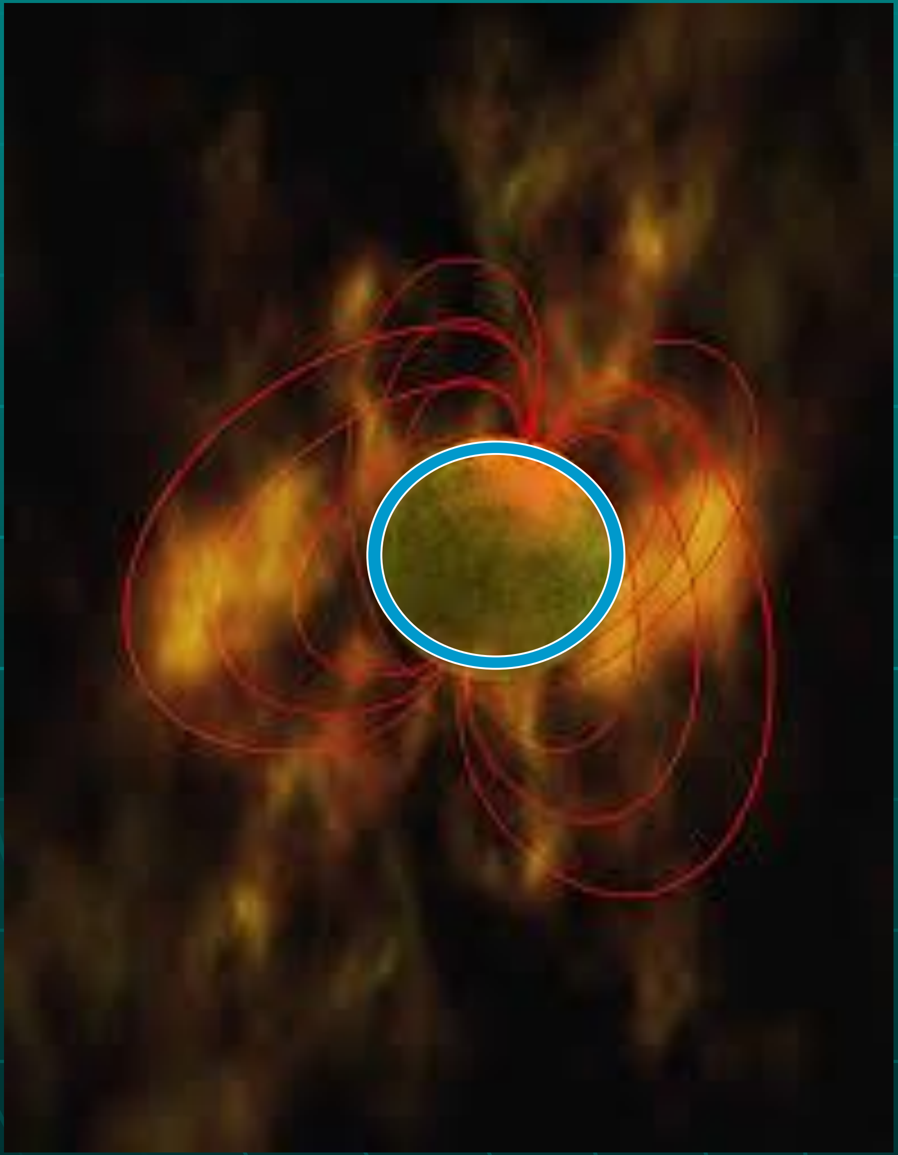


Kes 79

- If submergence of the field happens rapidly, so the present day period represents the initial one
- Then, the field of PSR 1852 was not enhanced via a dynamo mechanism
- Detection of millisecond "frozen" magnetars will be a strong argument in favour of dynamo.

arXiv: 1307.3127

What causes what?



The chicken or the egg?
Crust or magnetosphere?

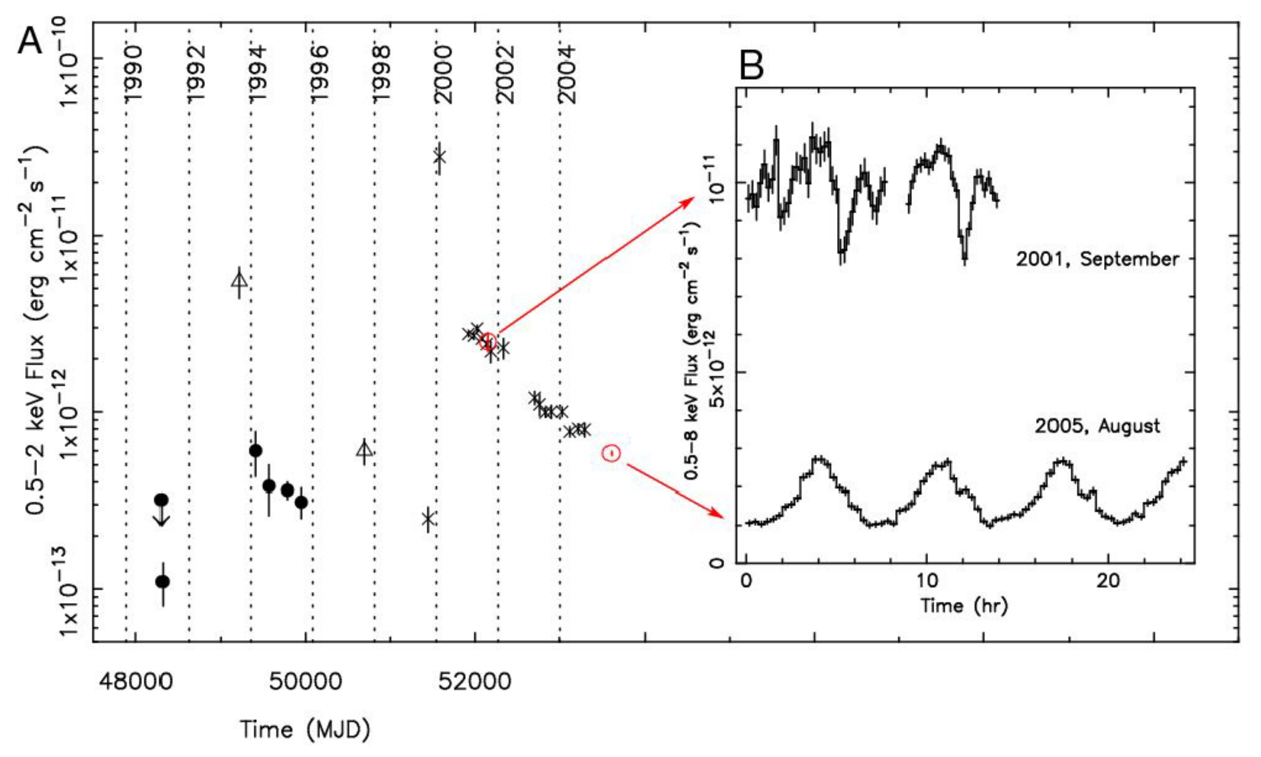
It would be nice to have magnetars without crust, and magnetars without magnetospheres.

Hypothetical highly magnetized quark stars can be the first of them, and “frozen” (aka “hidden”) magnetars – can be testbeds to study crustal processes without magnetospheric phenomena.

RCW 103 as a “frozen” magnetar with active crust. And Kes 79 as …. ?

Kes 79 looks very quiet, stable ….

…but RCW 103 – not.

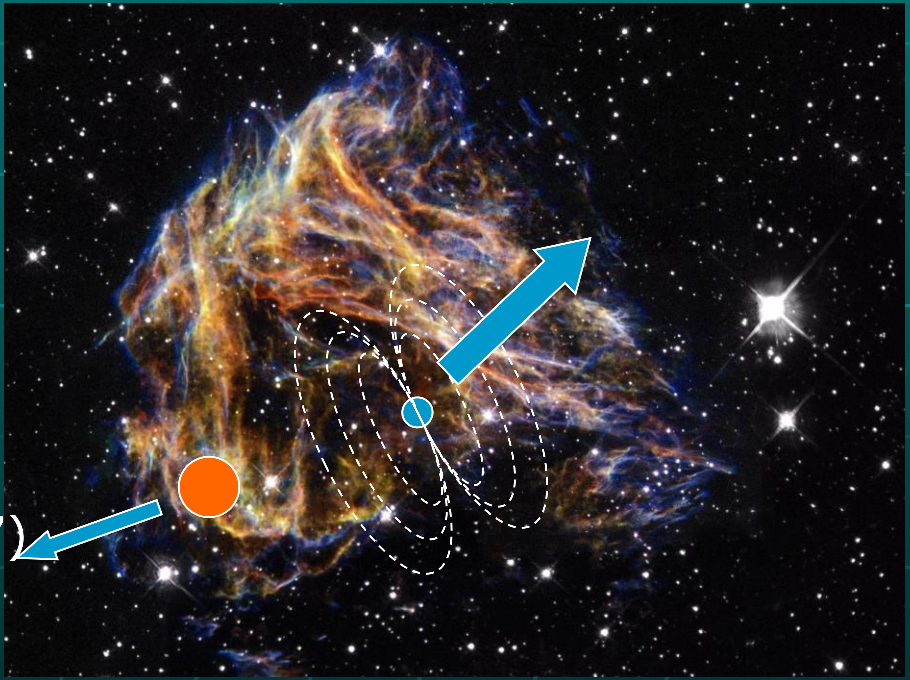


- Fluxes
- Temperatures
- Variability
- Pulse profile changes

De Luca et al. (2006)

Conclusions

- Binary systems can provide evolutionary channels to produce progenitors with enhanced rotation
- Studies of NSs in binaries can be used as a probe of magnetic field evolution on the time scale 1-20 Myrs
- Studies of "frozen" magnetars can shed light on the initial properties of this type of NSs
- In addition, "frozen" magnetars can be used to probe processes in the crust of strongly magnetized NSs.



A compact object in SN1987A can be ``hidden" magmetar, as it was born soon after a coalescence (Morris, Podsiadlowski 2007) and strong fall-back has been proposed to explain its properties (Chevalier 1989, Bernal et al. 2010).