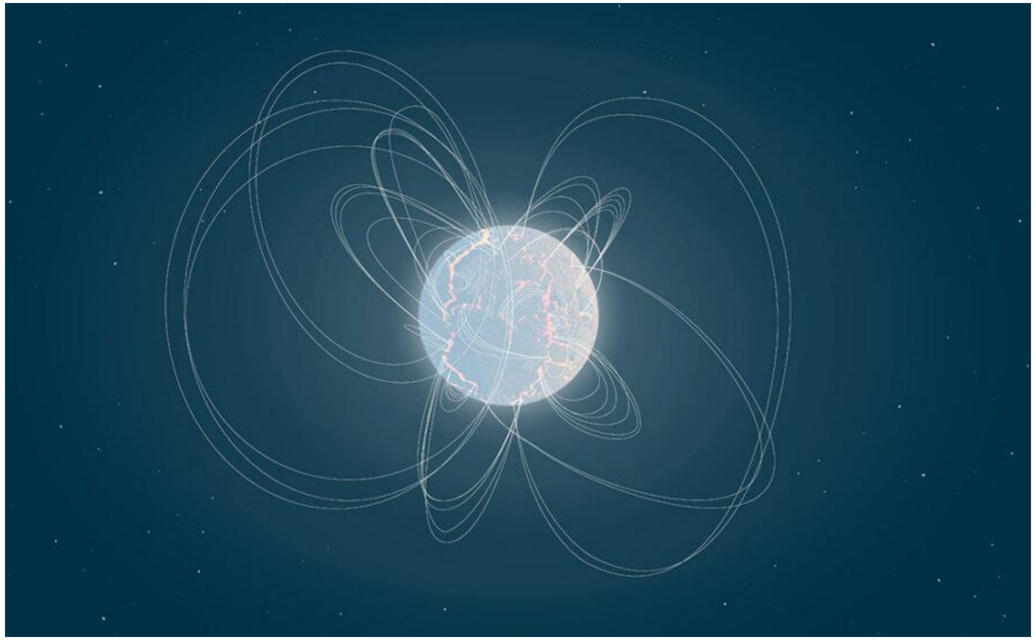
FIELD EVOLUTION AND HIGH MAGNETIC fiELD NSS IN BINARY SYSTEMS

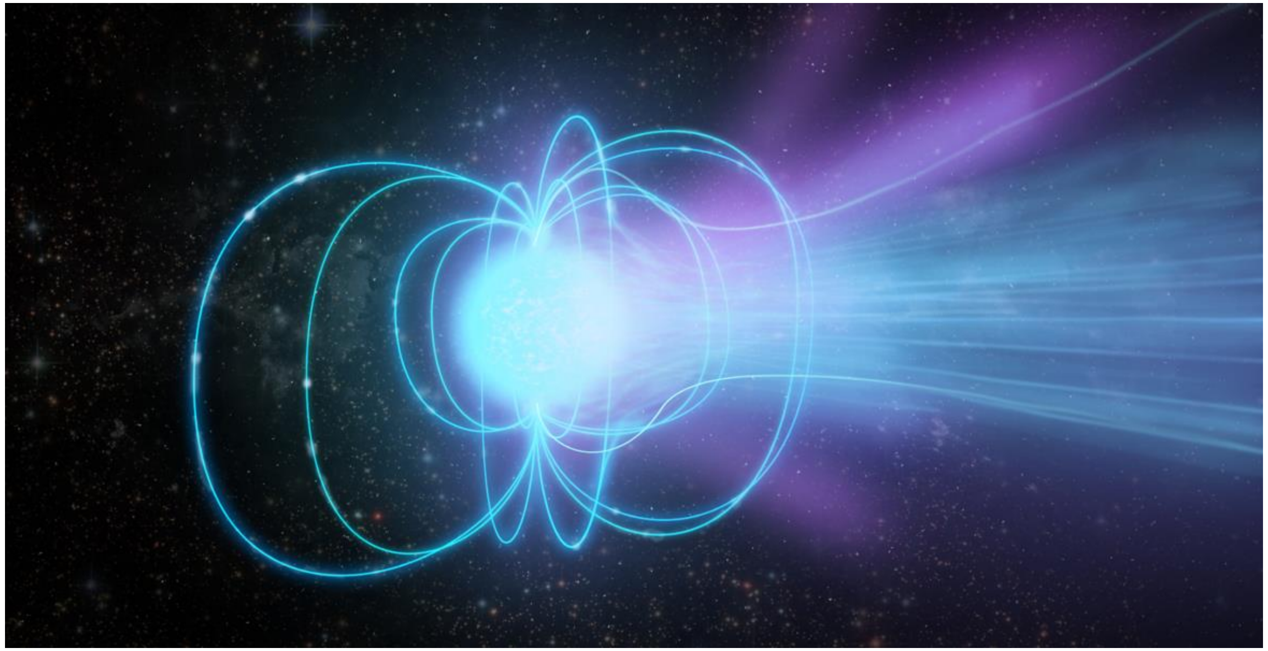
Sergei Popov (ICTP)

2109.05584; 2201.07507

WHAT DO WE CALL “A MAGNETAR”?

Is it just a neutron star with a strong magnetic field?



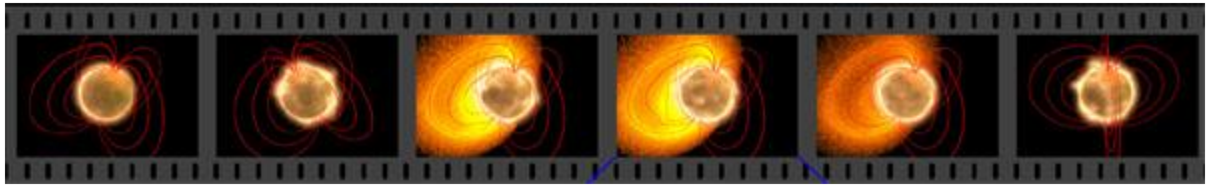


Or it is necessary to have dominance of magnetic energy release in the total energy budget of the source?

<u>Or, we are speaking about the same object, but at different stages of evolution?</u>

DO WE EXPECT MAGNETARS IN BINARIES?

All know Galactic SGRs/AXPs are single sources

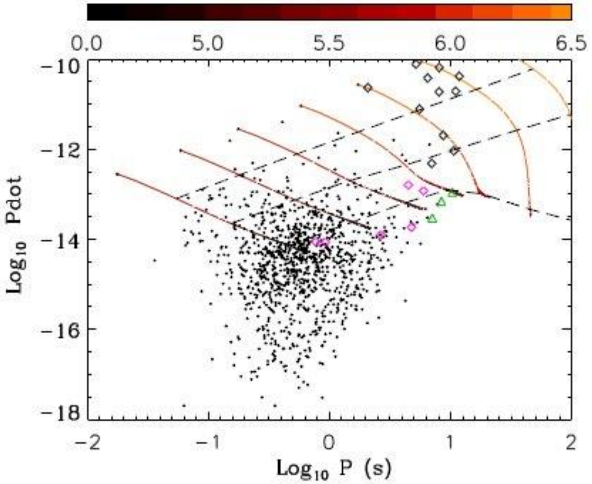


McGill on-line catalogue lists ~30 magnetars.
All of them are isolated objects.
However, an existence of a binary companion
(except probably cases of accretion on a compact object)
hardly can prevent detection of an SGR flare,
and the expected number of NSs in binaries
is not as small as ~3%.

See, however,
2204.09701
2203.14947

Field decay might result in absence of older magnetars

Observations and theoretical models favour magnetic field decay.
Evolution is faster for higher fields due to Hall cascade.

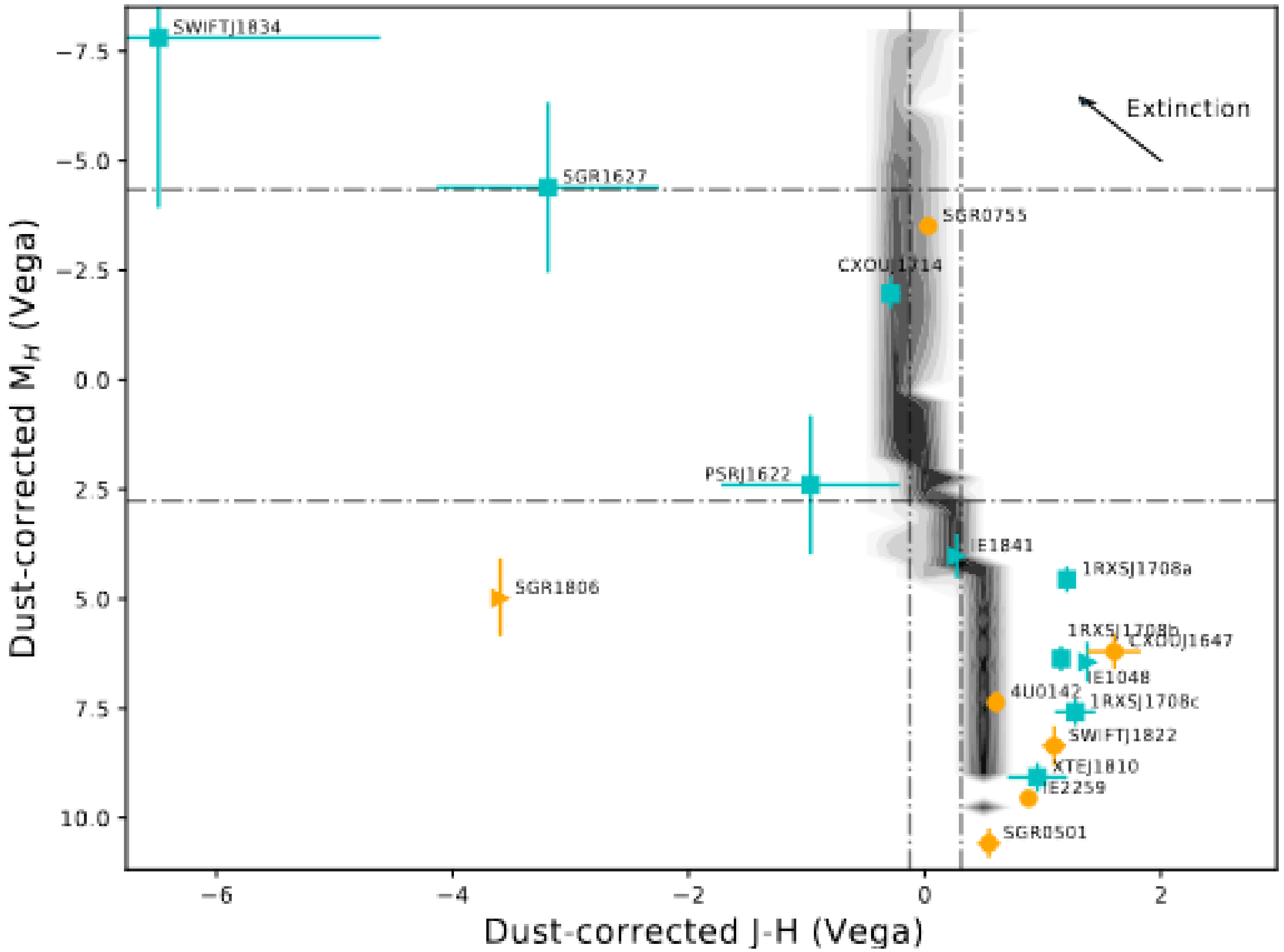


$$t_{\rm Hall} = \frac{n_e e L}{J} = \frac{4\pi n_e e L^2}{cB},$$

Characteristic time scale for decay of magnetars’ field is at least less than ~few thousand years.

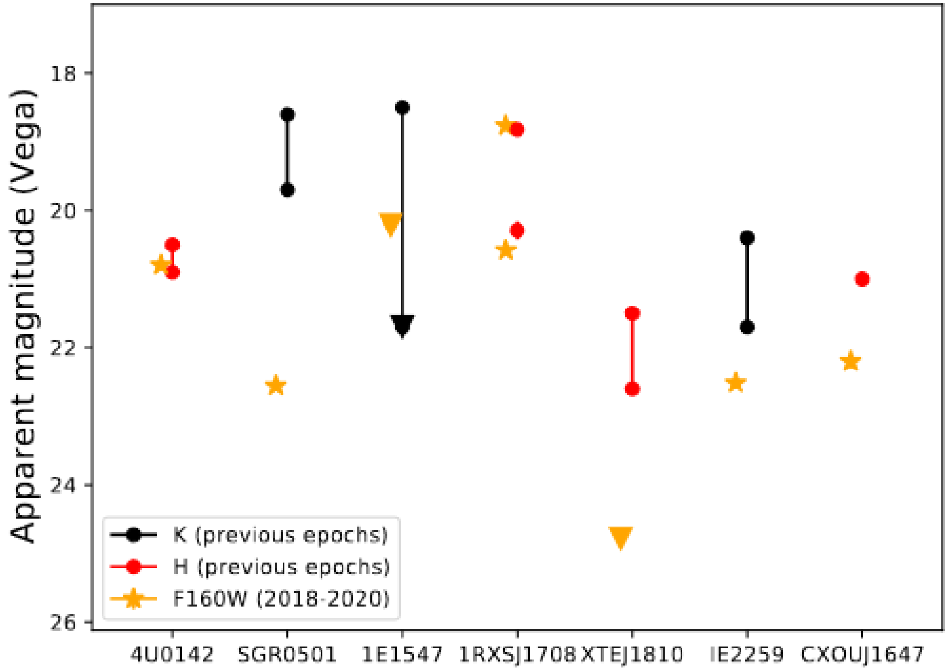
See a review in 2201.07507

CANDIDATES TO OPTICAL COUNTERPARTS OF MAGNETARS



The authors suggest that ~5-10% of magnetars can have bound companions.

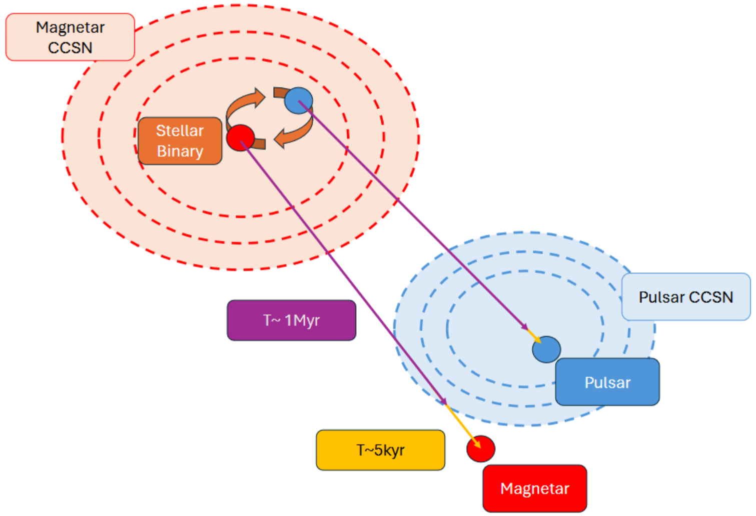
CXOU J171405.7–38103 is probably the best candidate to have a companion (but not recovered in 2404.05135).

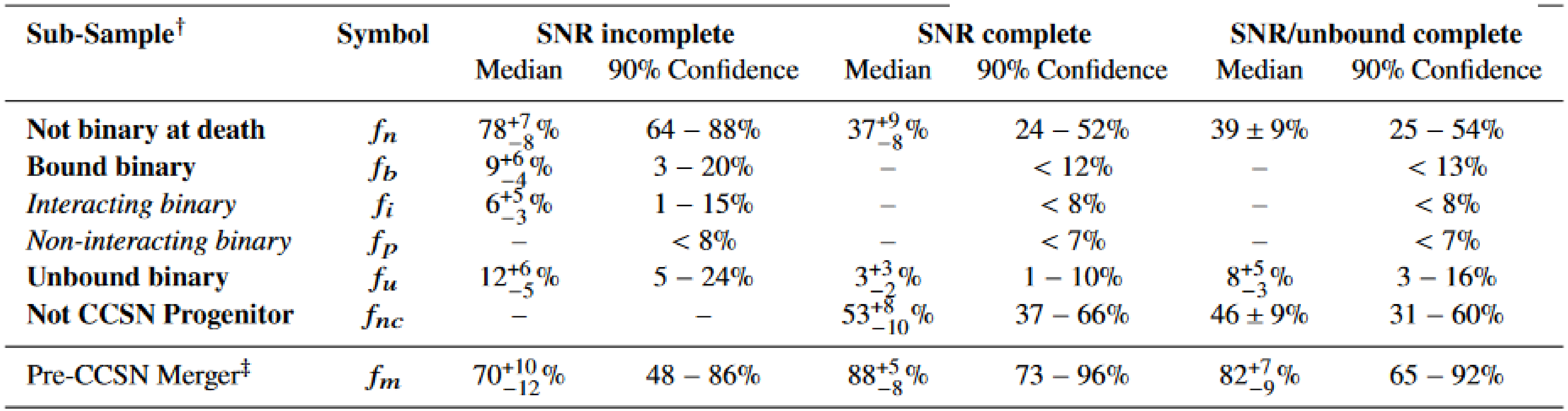


2203.14947, 2204.09701

A SEARCH FOR DESTROYED BINARIES WITH MAGNETARS

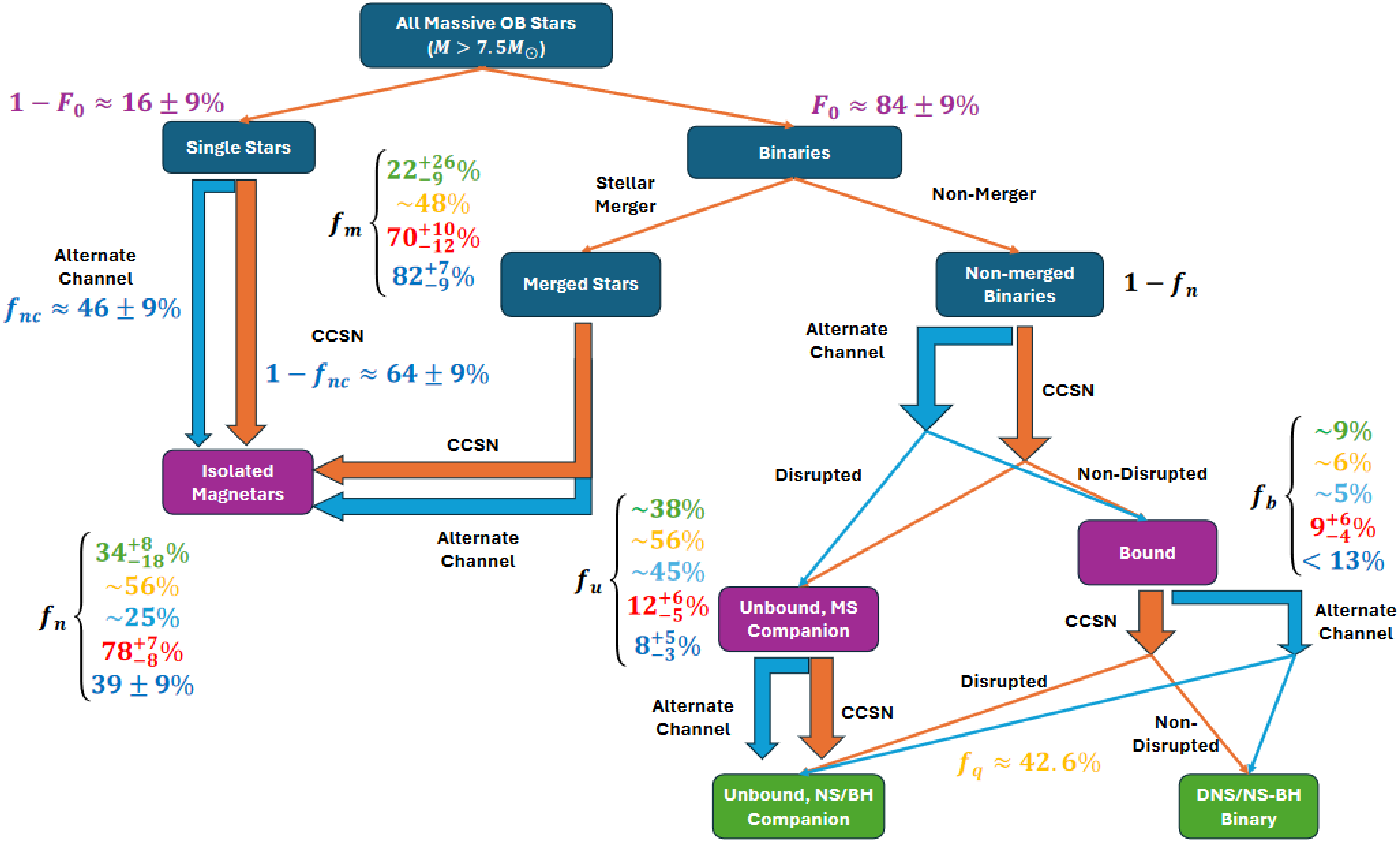
Out of the 31 known magnetars and candidates,
the authors identify two candidates
for unbound magnetar binaries at > 95% confidence:
a massive OB star in association with SGR 1822.3-1606, and
an X-ray pulsar in association with 3XMM J185246.6+003317.
They also recover the proposed Be star companion of
SGR 0755- 2933 and marginally detect the proposed unbound
companion of CXOU J164710.2-455216.





Sub-Sample†	**Symbol**	**SNR incomplete**		**SNR complete**		**SNR/unbound complete**	
		Median	90% Confidence	Median	90% Confidence	Median	90% Confidence
Not binary at death	f_n	$78^{+7}_{-8}\%$	64 – 88%	$37^{+9}_{-8}\%$	24 – 52%	$39 \pm 9\%$	25 – 54%
Bound binary	f_b	$9^{+6}_{-4}\%$	3 – 20%	–	< 12%	–	< 13%
Interacting binary	f_i	$6^{+5}_{-3}\%$	1 – 15%	–	< 8%	–	< 8%
Non-interacting binary	f_p	–	< 8%	–	< 7%	–	< 7%
Unbound binary	f_u	$12^{+6}_{-5}\%$	5 – 24%	$3^{+3}_{-2}\%$	1 – 10%	$8^{+5}_{-3}\%$	3 – 16%
Not CCSN Progenitor	f_{nc}	–	–	$53^{+8}_{-10}\%$	37 – 66%	$46 \pm 9\%$	31 – 60%
Pre-CCSN Merger‡	f_m	$70^{+10}_{-12}\%$	48 – 86%	$88^{+5}_{-8}\%$	73 – 96%	$82^{+7}_{-9}\%$	65 – 92%

2404.05135


All Massive OB Stars
$(M > 7.5M_\odot)$
$1 - F_0 \approx 16 \pm 9\%$
$F_0 \approx 84 \pm 9\%$
Single Stars
Binaries
Stellar Merger
Non-Merger
f_m
$22^{+26}_{-9}\%$
$\sim 48\%$
$70^{+10}_{-12}\%$
$82^{+7}_{-9}\%$
Merged Stars
Non-merged Binaries
$1 - f_n$
Alternate Channel
$f_{nc} \approx 46 \pm 9\%$
CCSN
$1 - f_{nc} \approx 64 \pm 9\%$
Alternate Channel
CCSN
CCSN
Isolated Magnetars
Alternate Channel
Disrupted
Non-Disrupted
f_b
$\sim 9\%$
$\sim 6\%$
$\sim 5\%$
$9^{+6}_{-4}\%$
$< 13\%$
Bound
f_n
$34^{+8}_{-18}\%$
$\sim 56\%$
$\sim 25\%$
$78^{+7}_{-8}\%$
$39 \pm 9\%$
f_u
$\sim 38\%$
$\sim 56\%$
$\sim 45\%$
$12^{+6}_{-5}\%$
$8^{+5}_{-3}\%$
Unbound, MS Companion
CCSN
Alternate Channel
Alternate Channel
CCSN
Disrupted
Non-Disrupted
$f_q \approx 42.6\%$
Unbound, NS/BH Companion
DNS/NS-BH Binary

FIELD DECAY

$$\frac{dB_{\rm p}}{dt} = -\frac{B_{\rm p}}{\tau_{\rm Ohm}(T_{\rm crust})} - \frac{1}{B_0}\frac{B_{\rm p}^2}{\tau_{\rm Hall_0}}.$$

Aguilera et al. 2008

$$\tau_{\rm Hall} = \frac{4\pi e n_e L^2}{cB(t)}, \qquad \tau_{\rm Hall} = \tau_{\rm Hall,0}\frac{B_0}{B(t)}.$$

Hall time scale strongly depends on the current value of the field.

$$\tau_{\rm Ohm} = \frac{4\pi\sigma L^2}{c^2},$$

Ohmic decay depends on the conductivity

$$\frac{\partial \boldsymbol{B}}{\partial t} = -\frac{c}{4\pi e}\nabla\times\left(\frac{\nabla\times\boldsymbol{B}}{n_{\rm e}}\times\boldsymbol{B}\right) - \frac{c^2}{4\pi}\nabla\times\left(\frac{\nabla\times\boldsymbol{B}}{\sigma}\right).$$

$$\sigma = \frac{\sigma_{\rm Q}\sigma_{\rm ph}}{\sigma_{\rm Q}+\sigma_{\rm ph}}. \qquad \tau_{\rm Ohm}^{-1} = \tau_{\rm Ohm,ph}^{-1} + \tau_{\rm Ohm,Q}^{-1}.$$

Resistivity can be due to

- Phonons
- Impurities

$$\sigma_Q = 4.4\times10^{25}{\rm s}^{-1}\left(\frac{\rho_{14}^{1/3}}{Q}\right)\left(\frac{Y_e}{0.05}\right)^{1/3}\left(\frac{Z}{30}\right), \qquad Q = n_{\rm ion}^{-1}\Sigma_i n_i \times (Z^2 - \langle Z\rangle^2).$$

$$\sigma_{\rm ph} = 1.8\times10^{25}{\rm s}^{-1}\left(\frac{\rho_{14}^{7/6}}{T_8^2}\right)\left(\frac{Y_e}{0.05}\right)^{5/3},$$

If these parameters are small the field decays slower.

See Cumming et al. 2004

HALL CASCADE AND FIELD EVOLUTION

$$\frac{\partial B}{\partial t} = -c \nabla \times E,$$

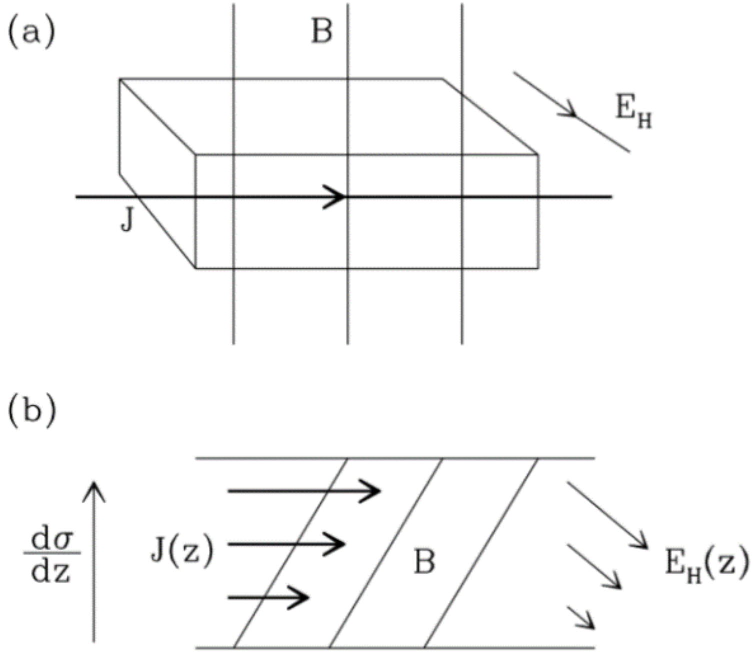
$$\tau_{\text{Ohm}} = \frac{4\pi\sigma L^2}{c^2}.$$

$$E = \overset{\text{advection}}{-\frac{1}{c} v \times B} + \overset{\text{Ohm}}{\frac{J}{\sigma}} + \overset{\text{Hall}}{\frac{J \times B}{n_e e c}},$$

$$J = (c/4\pi)(\nabla \times B)$$

With only the Hall term we have:

$$\frac{\partial B}{\partial t} = -\nabla \times \left(\frac{J \times B}{n_e e} \right), \qquad t_{\text{Hall}} = \frac{n_e e L}{J} = \frac{4\pi n_e e L^2}{cB},$$

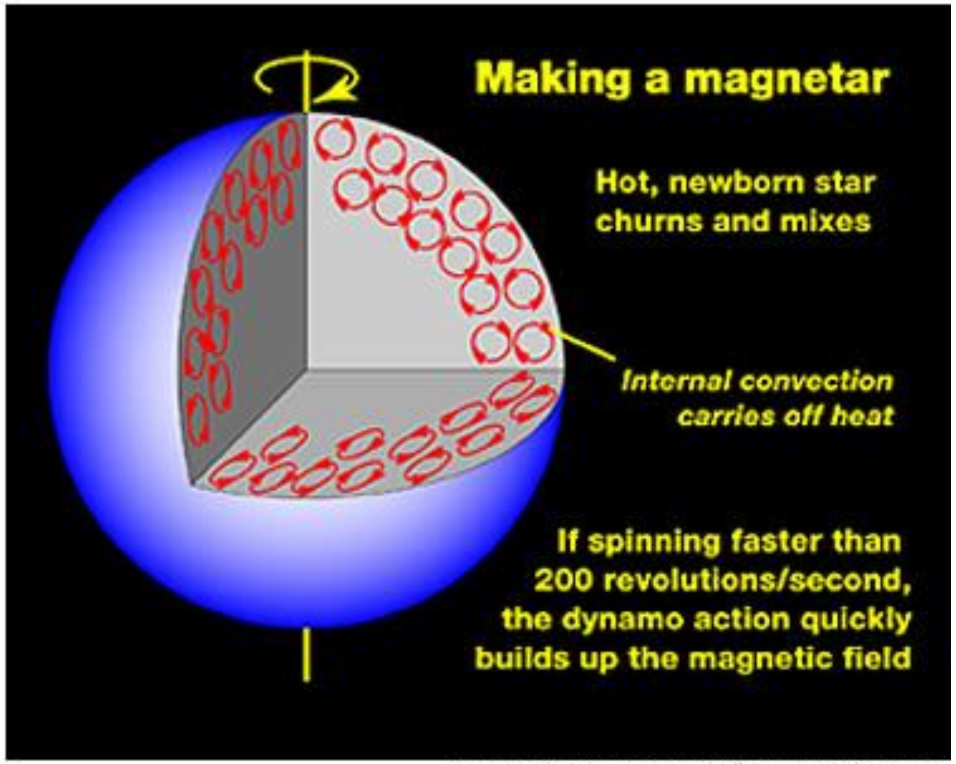


astro-ph/0402392

ORIGIN OF MAGNETARS FIELD

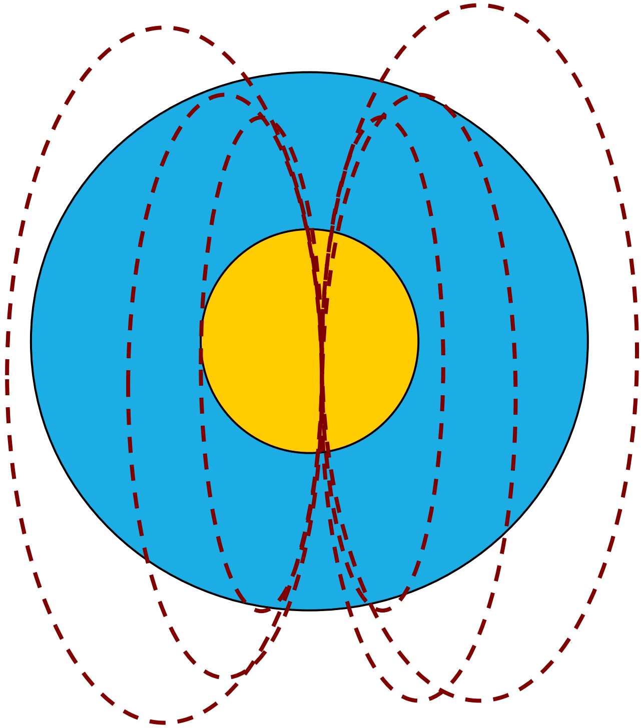
Generated

Fossil



Dave Dooling, NASA Marshall Space Flight Center

Classical dynamo scenario starting from DT in 90s



Criticized by Spruit (2008)

DYNAMO MECHANISM CONDITIONS

Rapid rotation might be necessary to have a large dipolar field!

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 appears in the GRB scenario.
In several recent studies fallback is used to spin-up the compact object.

Stellar rotation can be enhanced in binaries.

In binaries there are different possibilities to gain additional angular momentum due to mass transfer (including a coalescence) or due to a tidal interaction.

It is necessary to perform population synthesis calculations.

Recently it was proposed that spin-up can happen also due to the fallback accretion (Barrere et al. 2206.01269).

A QUESTION:

Why do all known magnetars are isolated?

- 5-10 % of NSs are expected to be binary (for moderate and small kicks)
- Among all known magnetars (or candidates) there are no robustly identified binary objects.
- At the moment from the statistical point of view it is not a miracle, however, it's time to ask this question.

Two possible explanations

- Large kick velocities
- Particular evolutionary path

BINARY EVOLUTION CHANNELS.

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

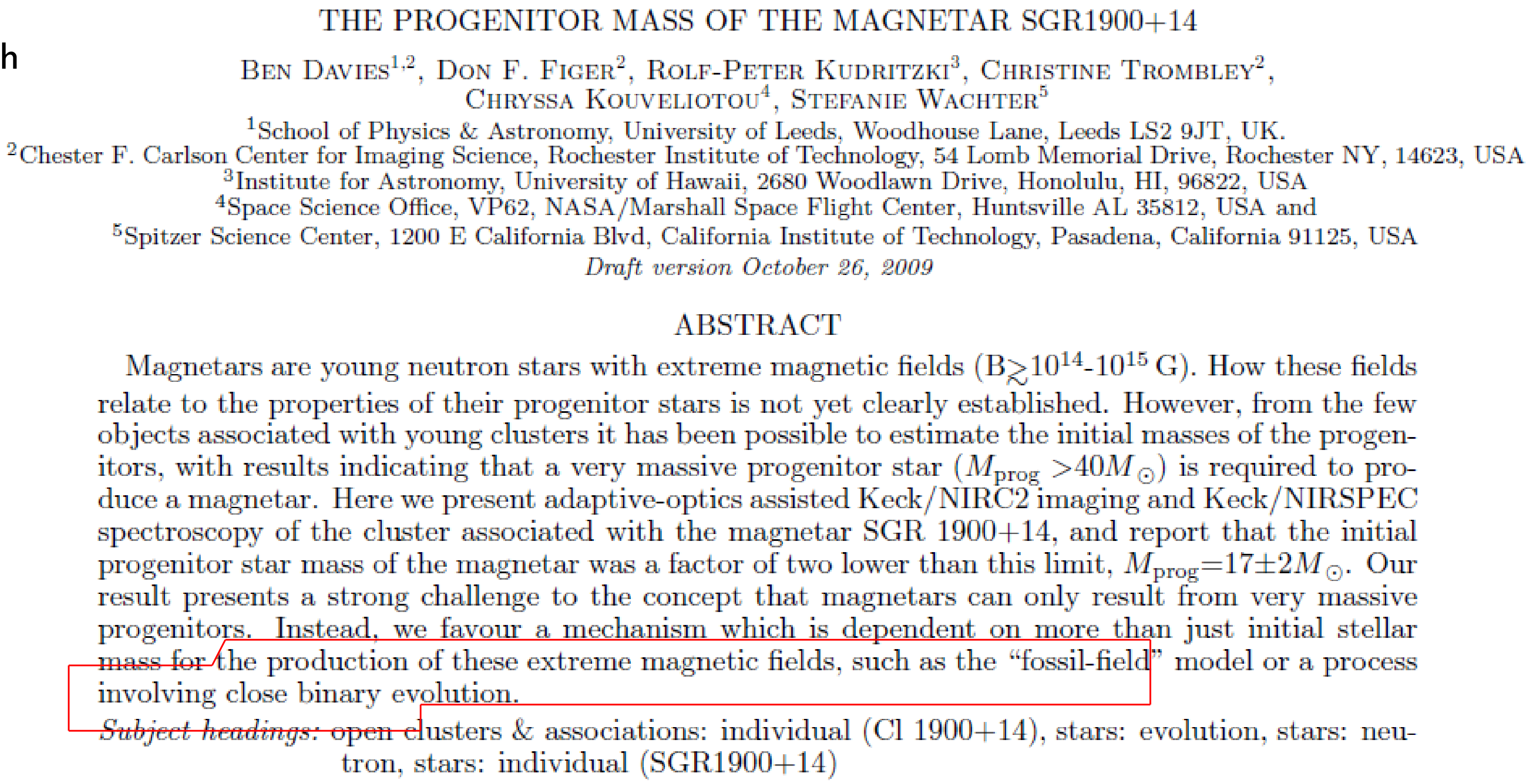
- Coalescence prior to a NS formation.
- Roche lobe overflow by a primary without a common envelope.
- Roche lobe overflow by a primary with a common envelope.
- Roche lobe overflow by a secondary without a common envelope.
- Roche lobe overflow by a secondary with a common envelope.

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

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

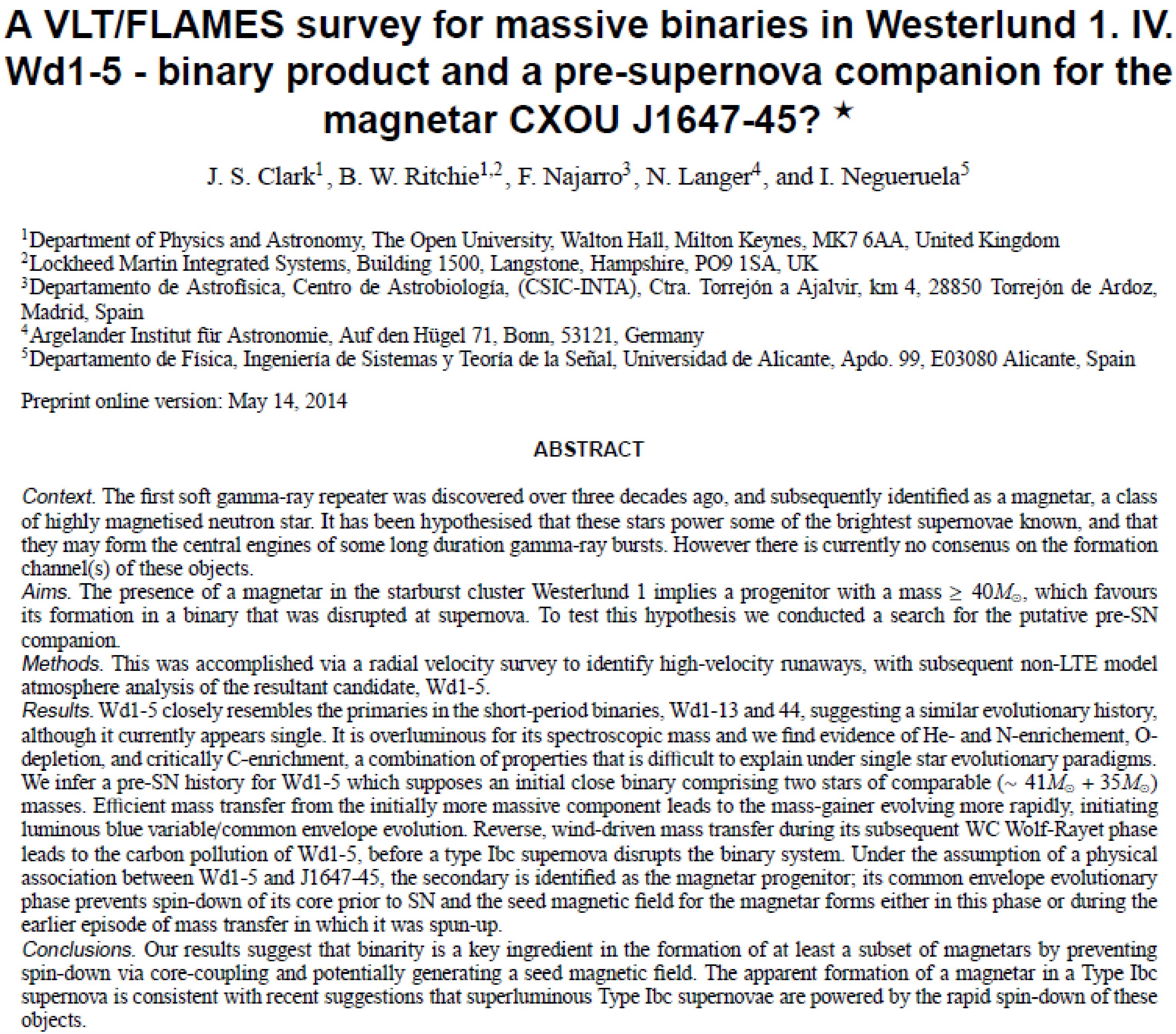
ABSTRACT

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 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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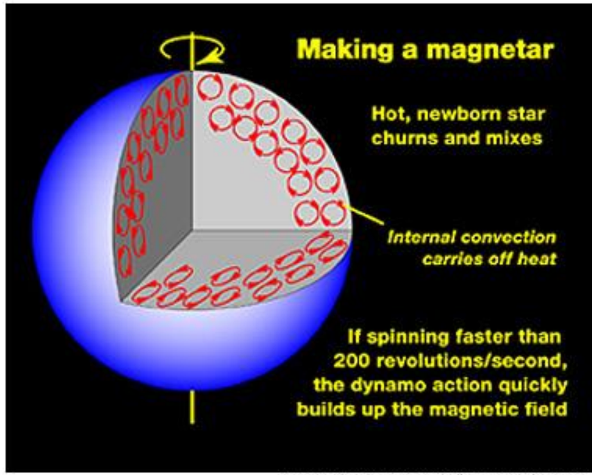
Preprint online version: May 14, 2014

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

ORIGIN OF MAGNETARS IN BINARIES



Dave Dooling, NASA Marshall Space Flight Center

The mechanism of the magnetic field generation is still unknown.

α-Ω dynamo (Duncan,Thompson)
α^2 dynamo (Bonanno et al.)
or their combination

If a dynamo mechanism is operating then it is necessary to have rapid rotation to produce large dipolar field.

Three possibilities to spin-up a star during evolution in a binary:

1) Spin-up of a progenitor star in a binary by accretion;
3) Spin-up of a progenitor star via synchronization;
2) Coalescence of binary companions prior to a compact object formation.

Detalied results of calculations for the bimodal kick and moderate mass loss

Track	$\alpha_q = 0$		$\alpha_q = 2$	
	all	binary magnetars	all	binary magnetars
Merge	60.1%	—	35.7%	—
Primary RLO with CE+Sync.	1.6%	0.2%	0.02%	0.01%
Secondary RLO with CE+Sync.	1.4%	0.3%	2.5%	0.8%
Two RLO w/o CE on Primary	9.4%	0%	19.9%	0%
Two RLO w/o CE on Secondary	0.005%	0%	0.04%	0%
Single RLO w/o CE on Primary	26.1%	0.07%	39.3%	0.08%
Single RLO w/o CE on Secondary	0.7%	0.08%	1.4%	0.06%

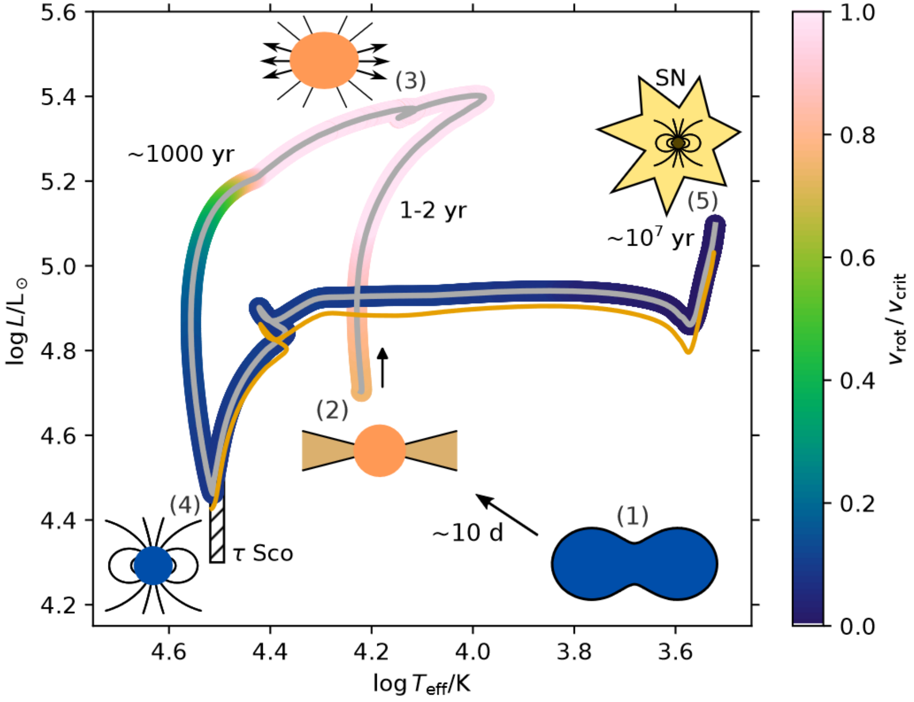
Popov, Prokhorov 2006

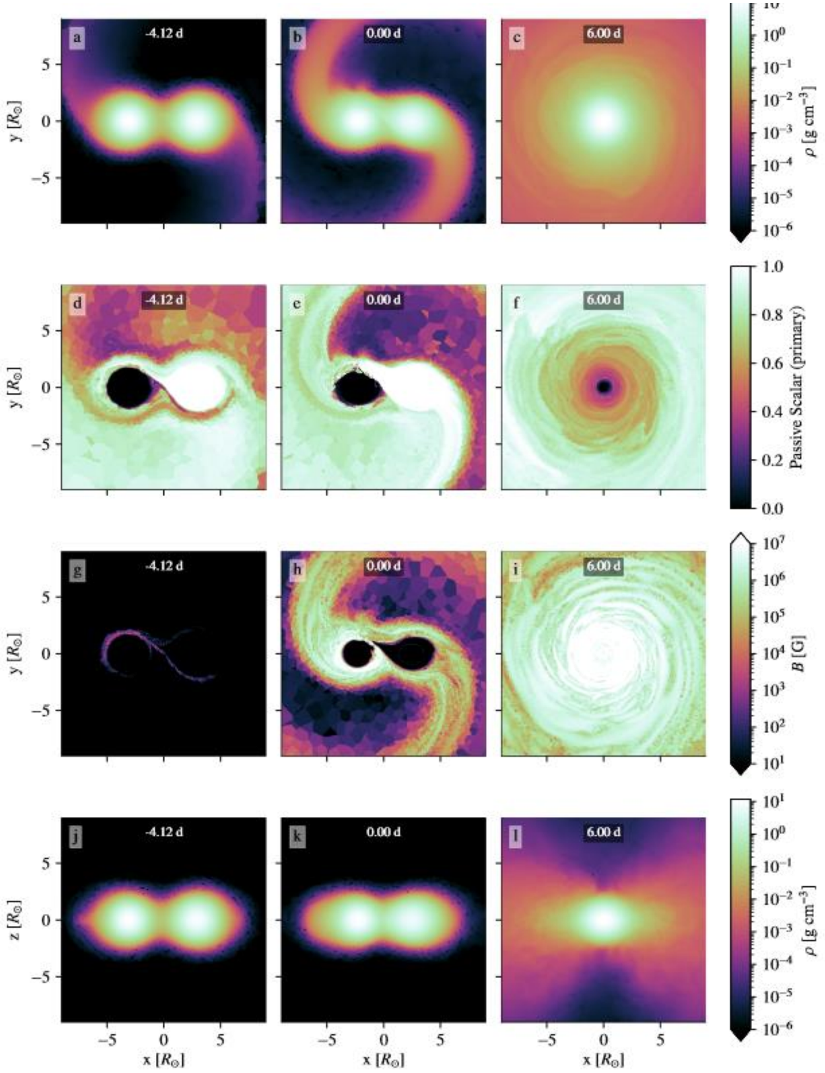
We obtained ~10% of magnetars (i.e., NSs from spun-up progenitors), but among these NSs only ~1% are in survived binaries.

And, of course, all magnetars formed in NS+NS or NS+WD coalescence are isolated.

MAGNETIC FIELD AMPLIFICATION IN BINARIES

magnetic star τ Sco – result of coalescence





If all of the magnetic flux is conserved until core collapse of the merger product,
a resulting neutron star of 10 km radius would have a surface magnetic field strength of about 10^{16} G.

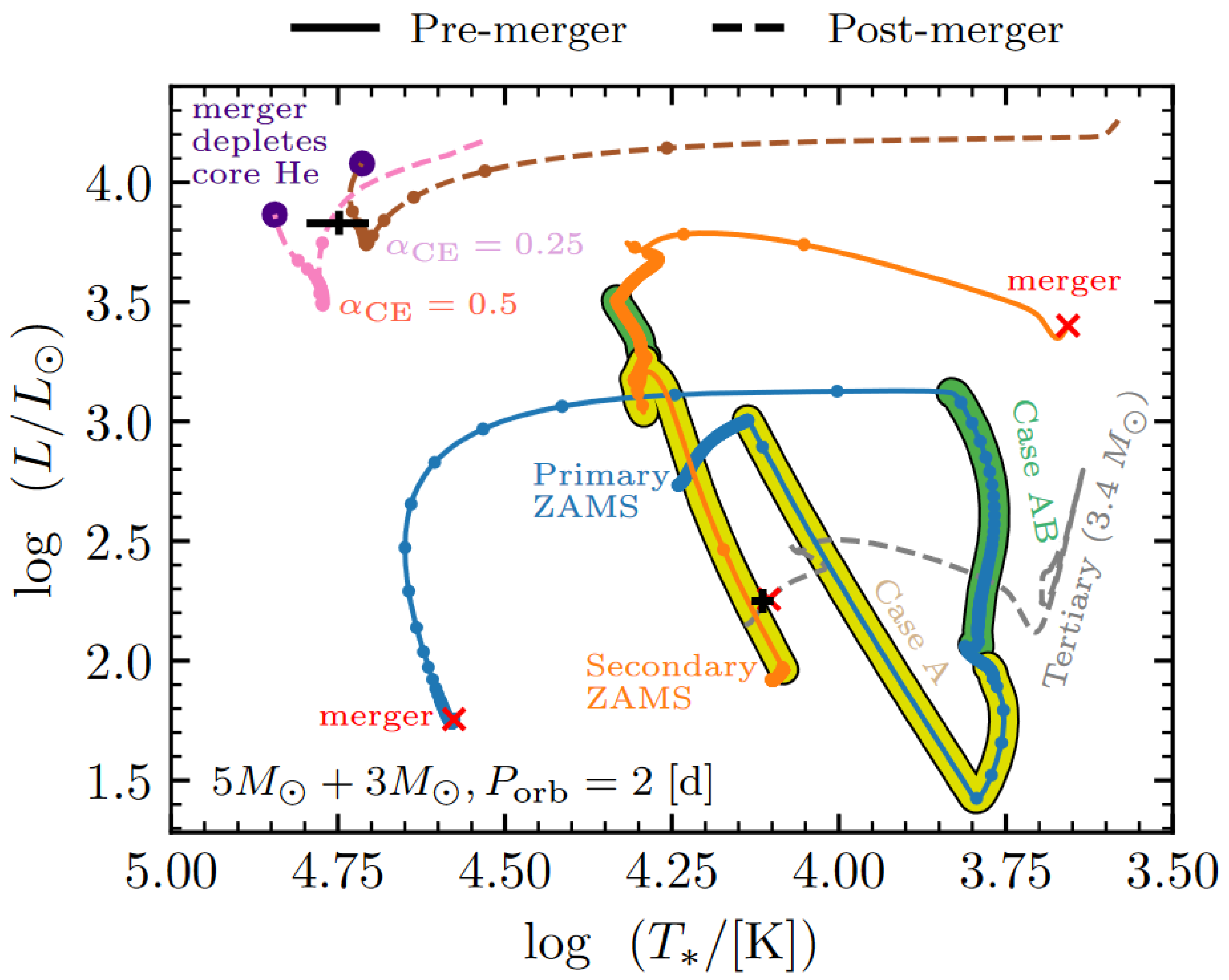
1910.14058

HD45166 – A BINARY WITH A WR STAR

WR + B7V
Orbital period 8200 +/- 200 days
a~9-12 AU

WR: 2 Msun, 43 kGauss
flux conservation will
provide a field >10^{14} G

The authors propose that
the WR star is a result of
a merger of two helium stars.



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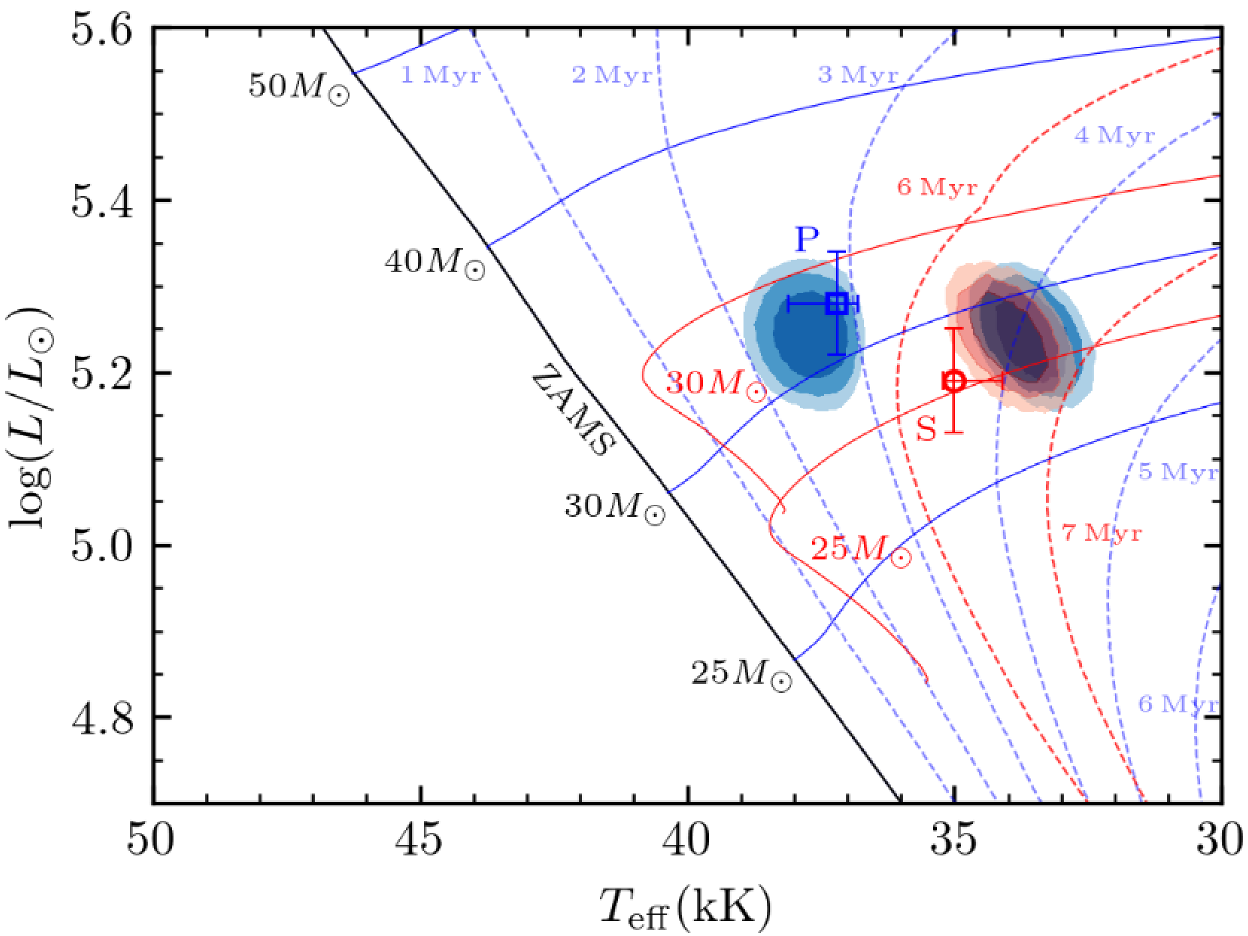
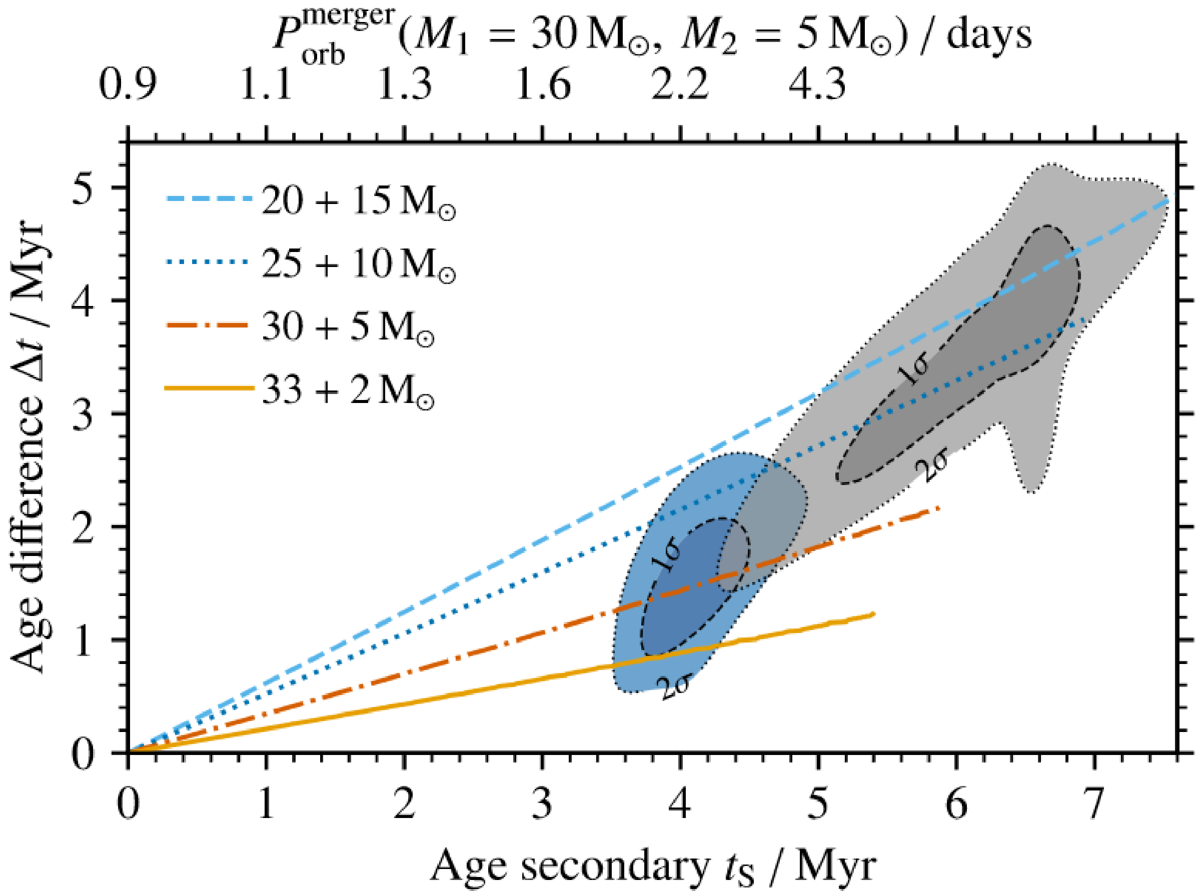
A MASSIVE MAGNETIC STAR IN A BINARY IS A RESULT OF A MERGER





HD 148937 Of?p star

B~ 1000 G

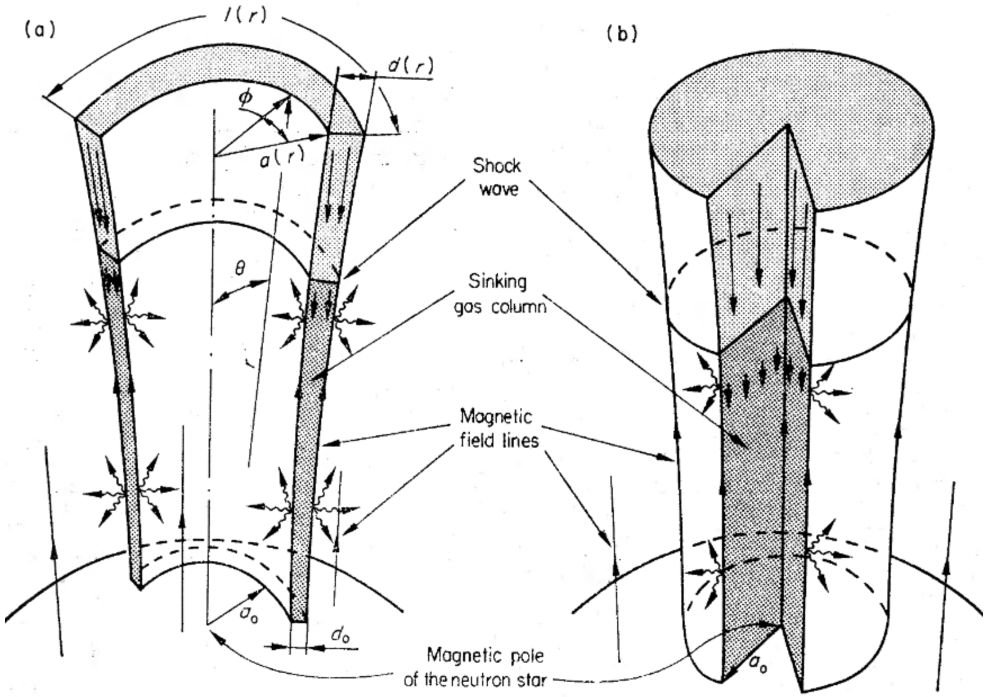
Wide binary ~20 years

Age discrepancy between the two components.

2404.10167

WHY DO WE NEED MAGNETARS, SOMETIMES?

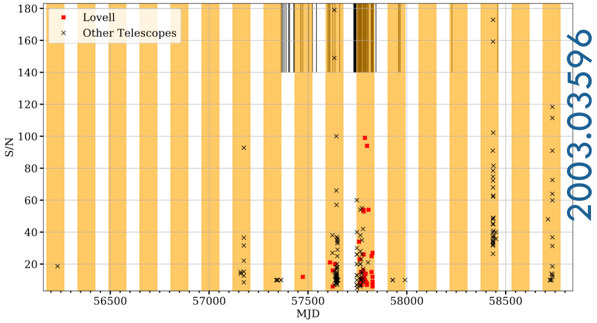
Large luminosity



If an accretion column is formed than the luminosity can exceed the Eddington (Basko, Sunyaev 1975, 1976).

Spin properties

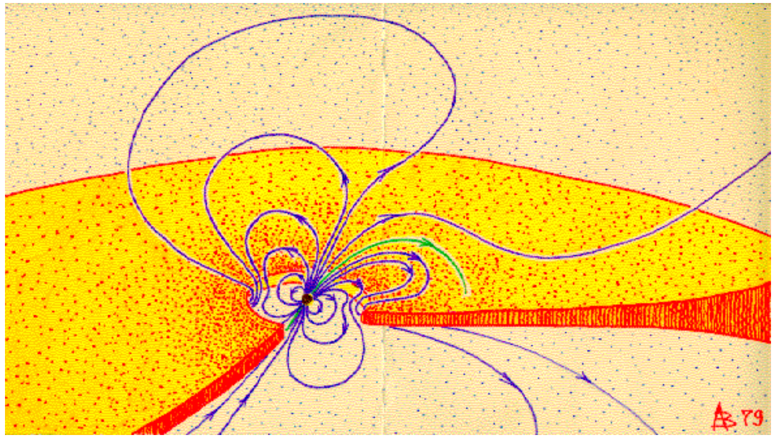
+ FRBs with long periodicity?



2003.03596

Large magnetic fields can result in:

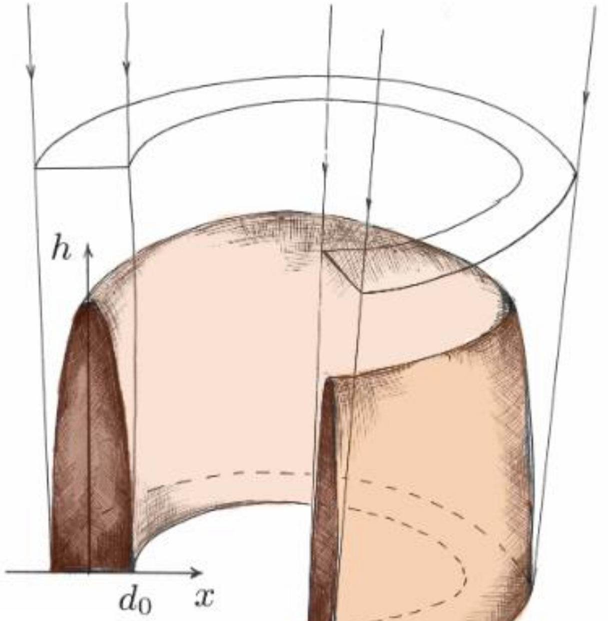
- Long spin periods;
- Rapid spin-down;
- Rapid spin-up;
- Accretor/Propeller transitions even for relatively large accretion rates.



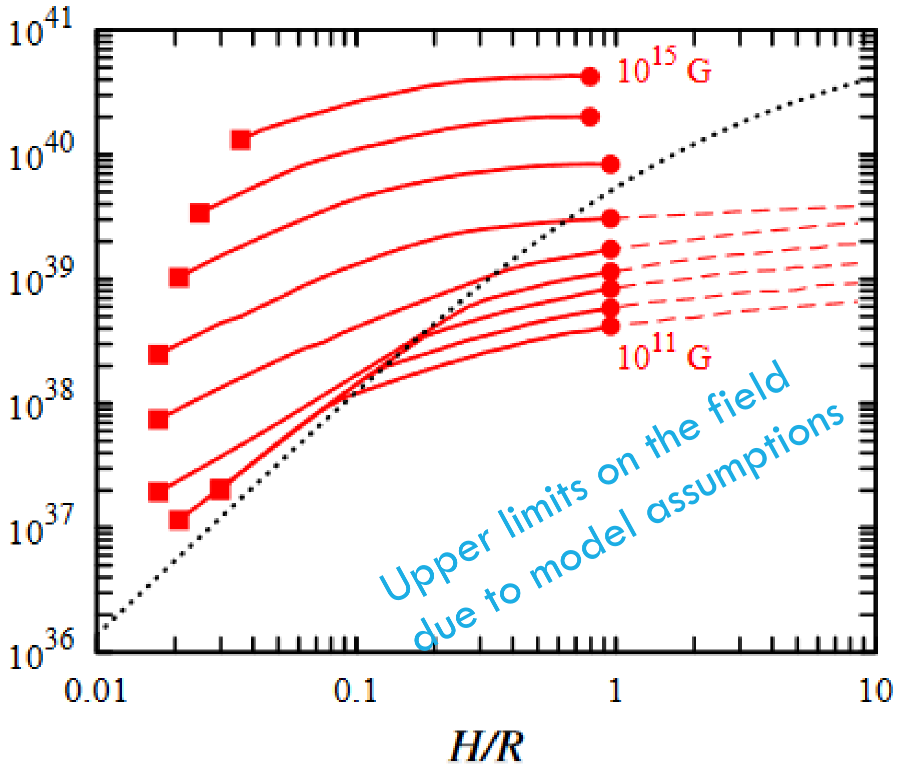
Lipunov

LARGER FIELD – LARGER LUMINOSITY

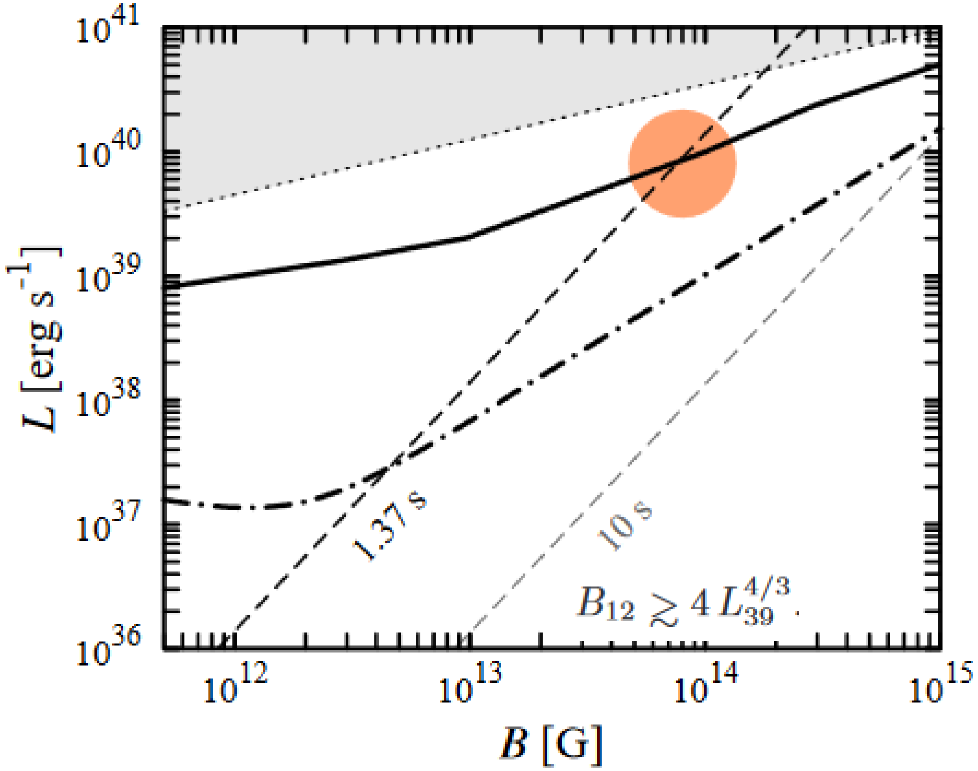
Strong fields can confine plasma in accretion columns for large luminosities.
Luminosity can reach super-Eddington values: the interaction cross-section can be much below the Thomson value.
Thus, some ULXs can be explained by NSs with magnetar-scale fields.



Mushtukov et al. 1506.03600



Upper limits on the field due to model assumptions

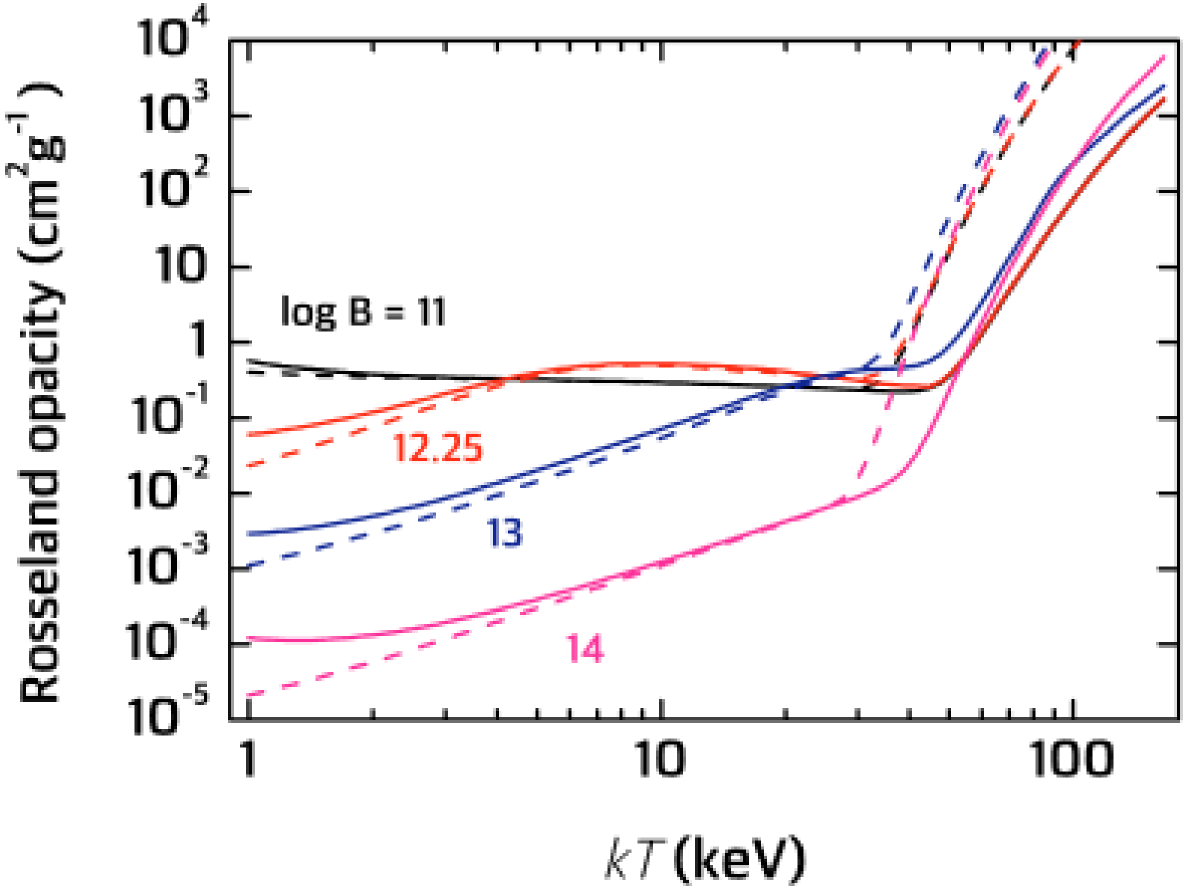


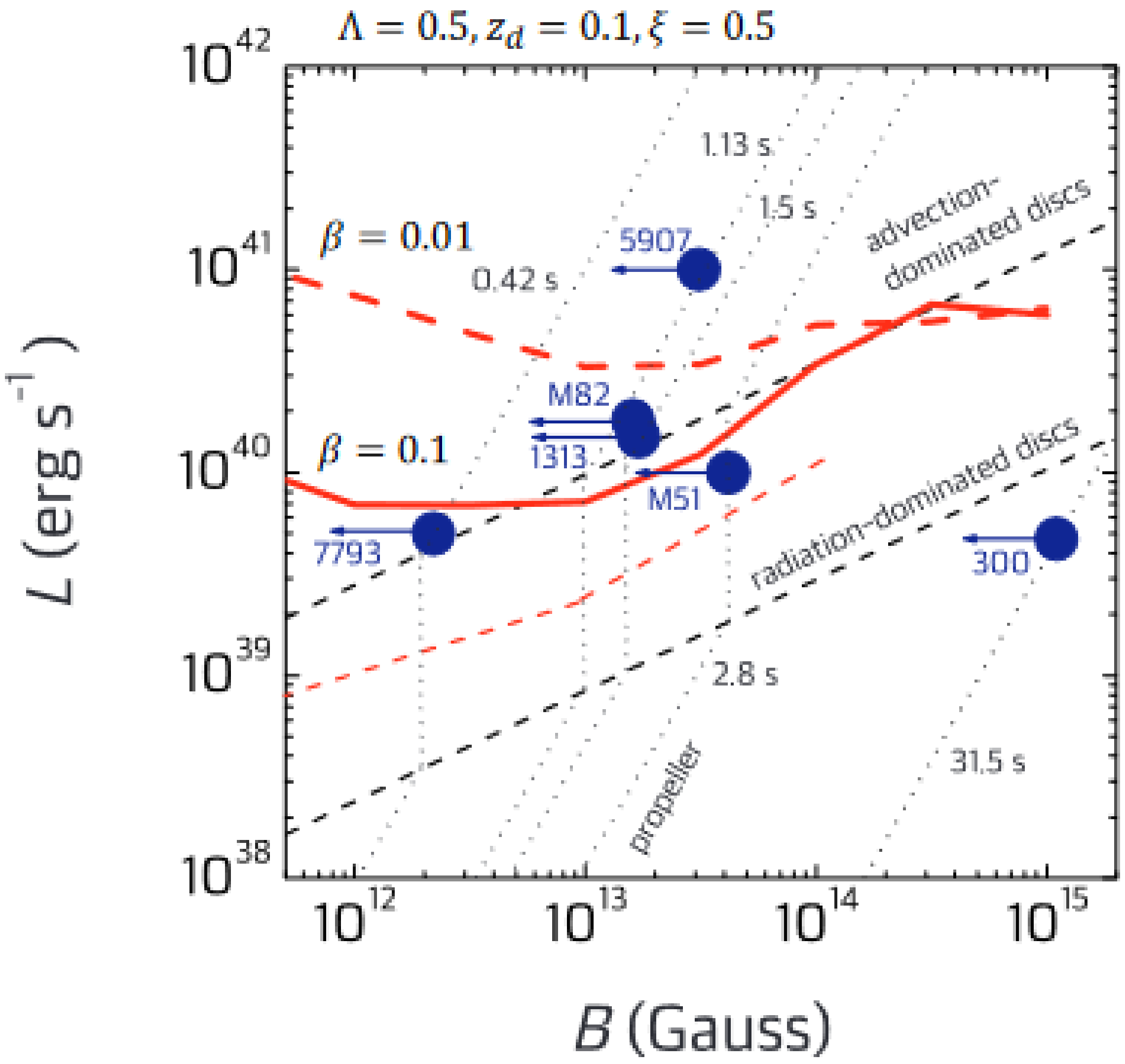
Strong fields can be due to multipoles to avoid the propeller (2104.06138).

About electron-positron pairs in accretion columns of ULXs Suleimanov et al. 2210.09995.
So, the results are modified, see 2208.14237.

NEW CALCULATIONS

High luminosities of accreting NSs can be explained even with normal magnetic fields.





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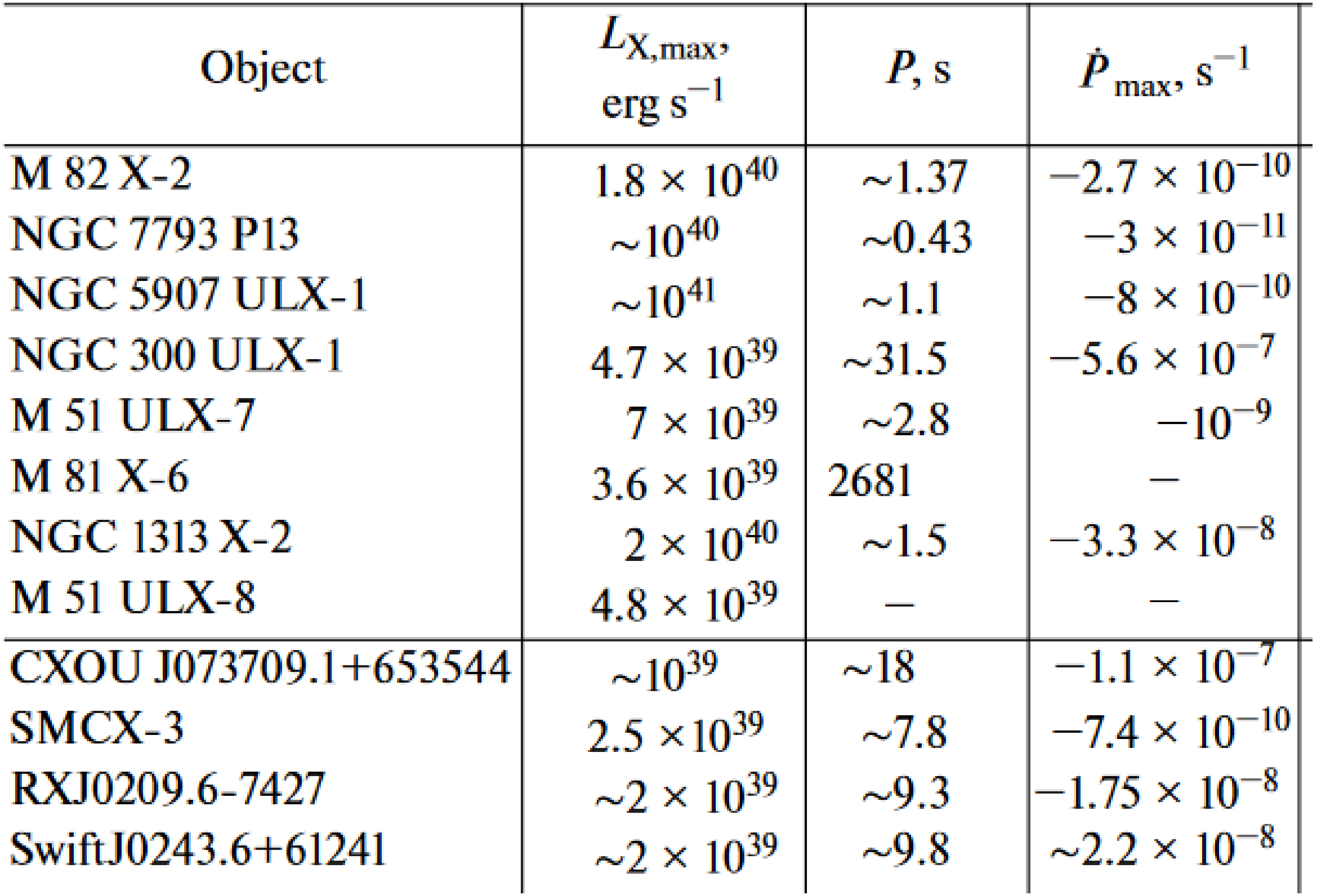
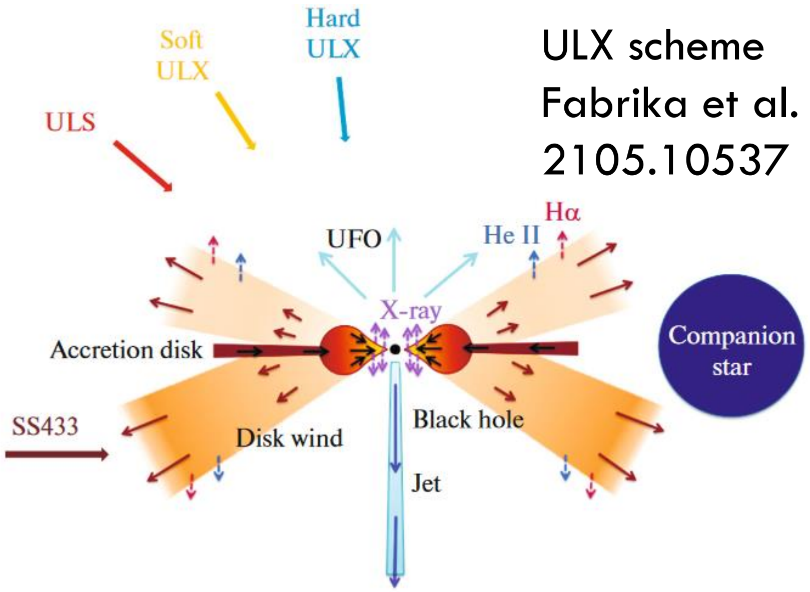
ULTRALUMINOUS X-RAY PULSARS

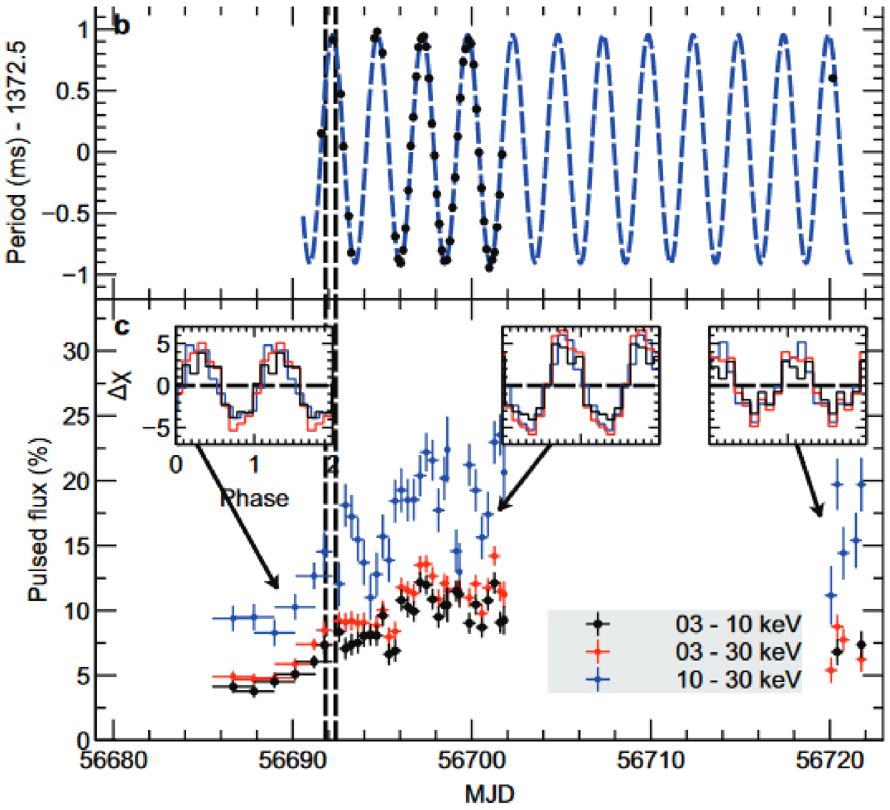


Object	$L_{X,\max}$, erg s^{-1}	P, s	$\dot{P}_{\max}$, s^{-1}
M 82 X-2	1.8×10^{40}	~1.37	-2.7×10^{-10}
NGC 7793 P13	$\sim 10^{40}$	~0.43	-3×10^{-11}
NGC 5907 ULX-1	$\sim 10^{41}$	~1.1	-8×10^{-10}
NGC 300 ULX-1	4.7×10^{39}	~31.5	-5.6×10^{-7}
M 51 ULX-7	7×10^{39}	~2.8	-10^{-9}
M 81 X-6	3.6×10^{39}	2681	–
NGC 1313 X-2	2×10^{40}	~1.5	-3.3×10^{-8}
M 51 ULX-8	4.8×10^{39}	–	–
CXOU J073709.1+653544	$\sim 10^{39}$	~18	-1.1×10^{-7}
SMCX-3	2.5×10^{39}	~7.8	-7.4×10^{-10}
RXJ0209.6-7427	$\sim 2 \times 10^{39}$	~9.3	-1.75×10^{-8}
SwiftJ0243.6+61241	$\sim 2 \times 10^{39}$	~9.8	$\sim 2.2 \times 10^{-8}$

2105.10537



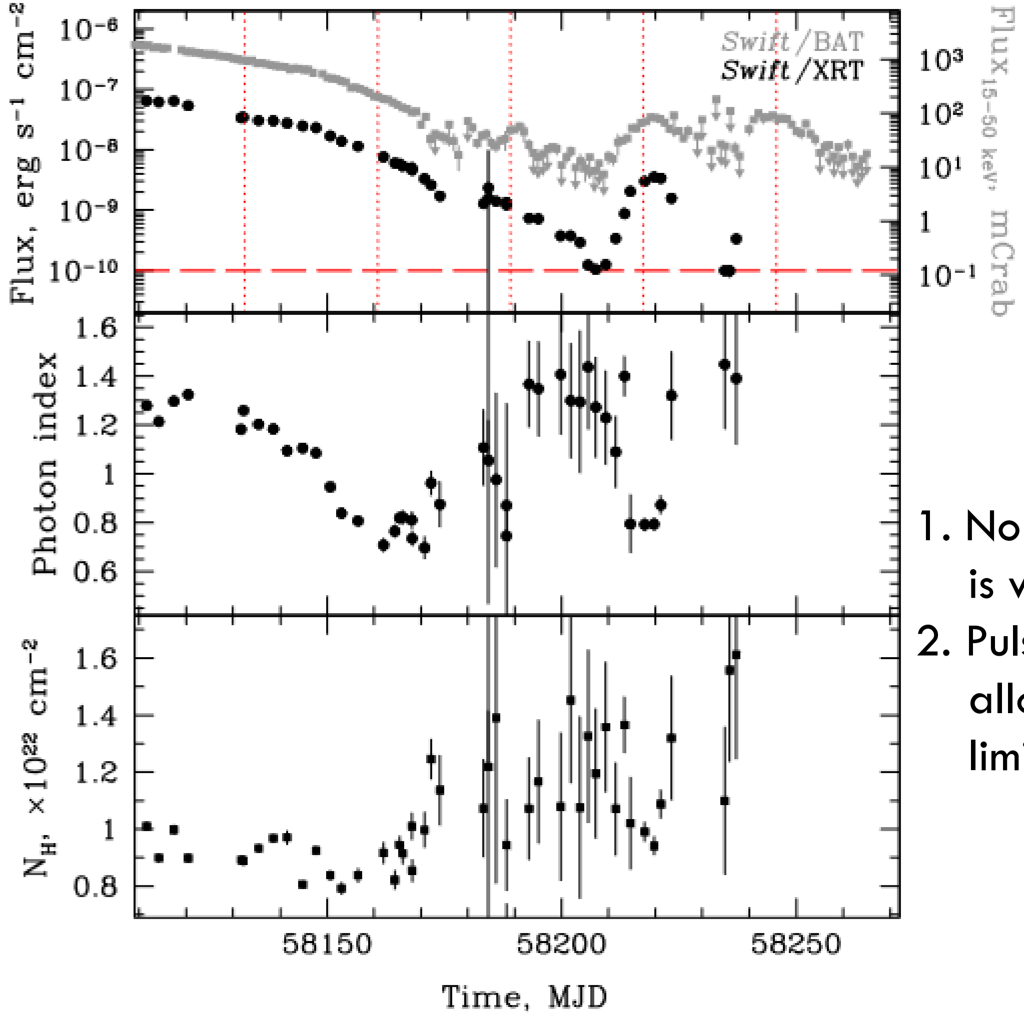
ULX scheme
Fabrika et al.
2105.10537



Bachetti et al. 2014

SOME LOOK NORMAL

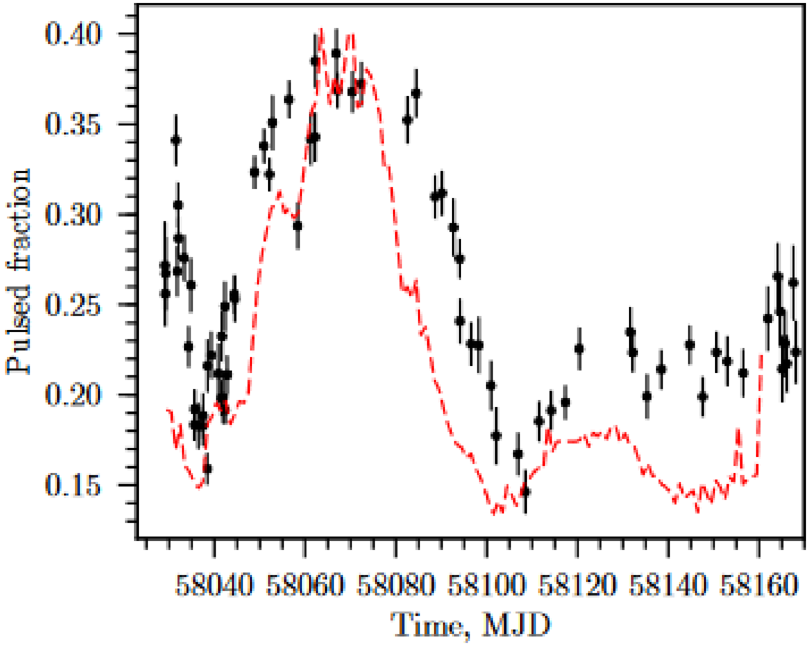
Tsygankov et al. 1806.02283



Normal (~10^{13} G) magnetic field in the Galactic ultraluminous X-ray pulsar Swift J0243.6+6124.

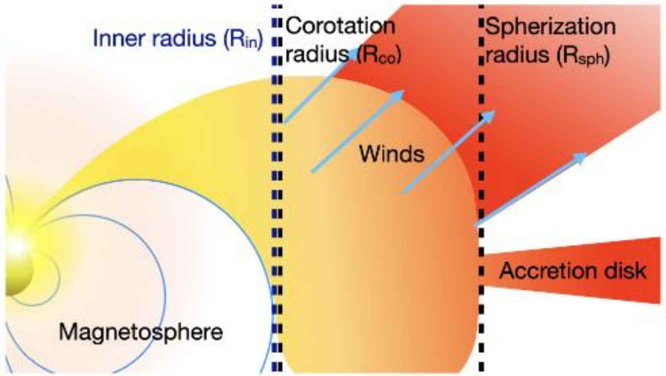
P ~ 10 sec
P_{orb} ~28 days
Be/X-ray
L~$40L_{Edd}$

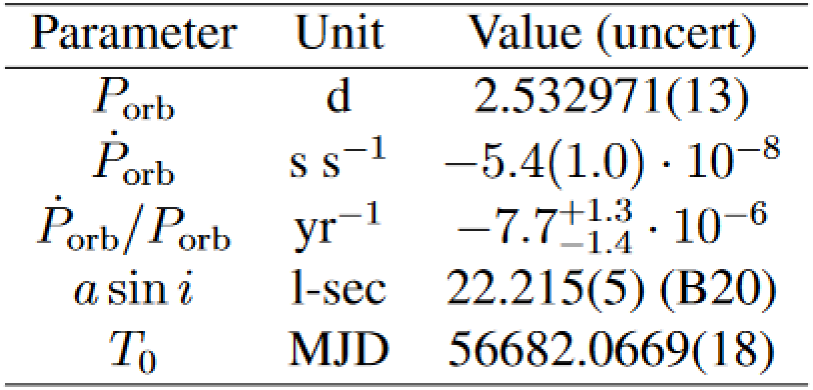
1. No propeller transition is visible. Thus, B<~6 10^{12}G
2. Pulsed fraction variation allow to obtain a lower limit B>~10^{13}G



SOME - NOT

M82 X-2
Orbital decay is measured.
Large mass transfer.
In simple models, large (magnetar scale: few 10^{13} G) field is necessary.

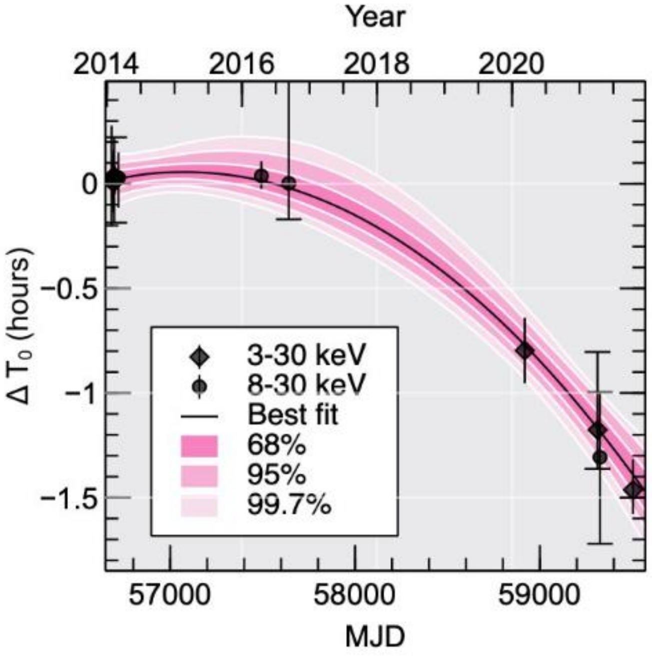


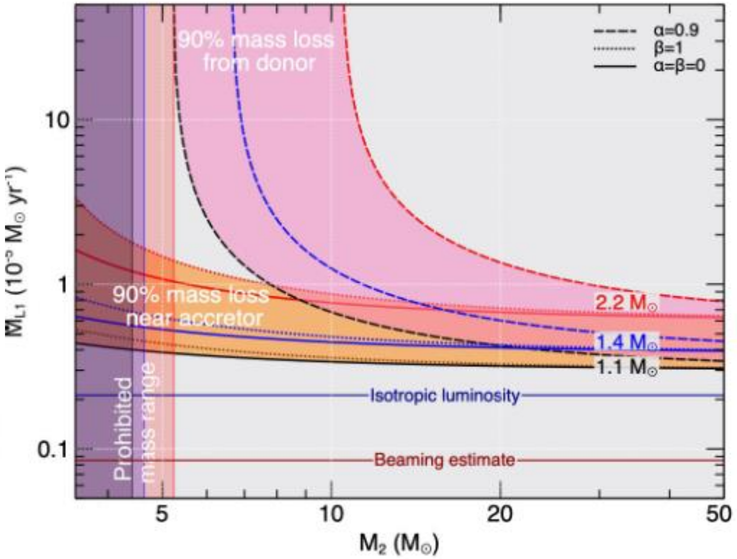


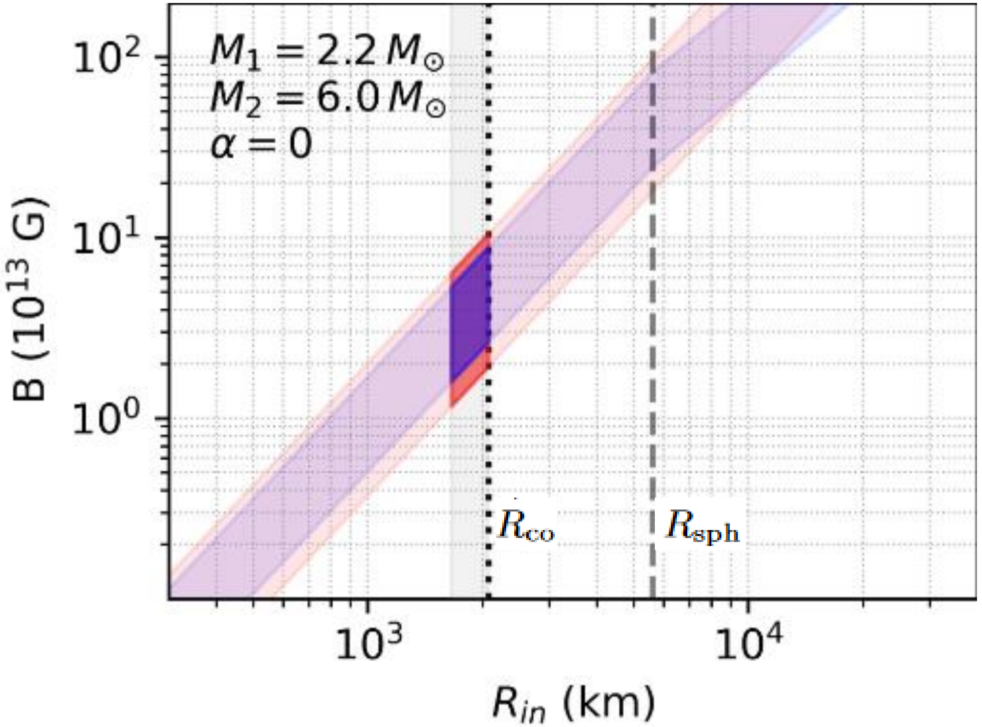
Parameter	Unit	Value (uncert)
$P_{\rm orb}$	d	2.532971(13)
$\dot{P}_{\rm orb}$	s s^{-1}	$-5.4(1.0)\cdot 10^{-8}$
$\dot{P}_{\rm orb}/P_{\rm orb}$	yr^{-1}	$-7.7^{+1.3}_{-1.4}\cdot 10^{-6}$
$a\sin i$	l-sec	22.215(5) (B20)
T_0	MJD	56682.0669(18)

$$T_n = T_0 + n\,P_{\rm orb} + \frac{1}{2}n^2\,P_{\rm orb}\,\dot{P}_{\rm orb} + \frac{1}{6}n^3 P_{\rm orb}^2\,\ddot{P}_{\rm orb}^3 + \ldots$$

$$\delta T_n(t) = \delta T_0 + \frac{t-t_0}{P_{\rm orb}}\delta P_{\rm orb} + \frac{1}{2}\frac{\dot{P}_{\rm orb}}{P_{\rm orb}}(t-t_0)^2$$



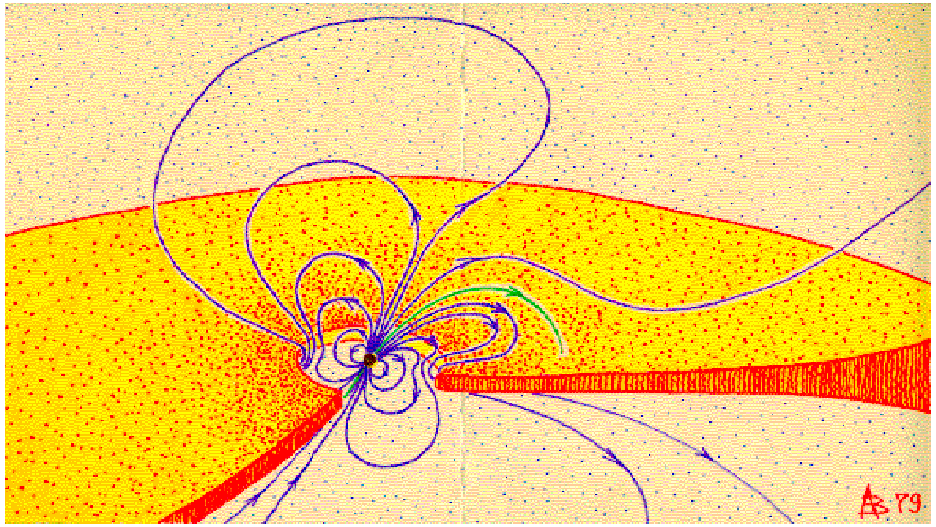




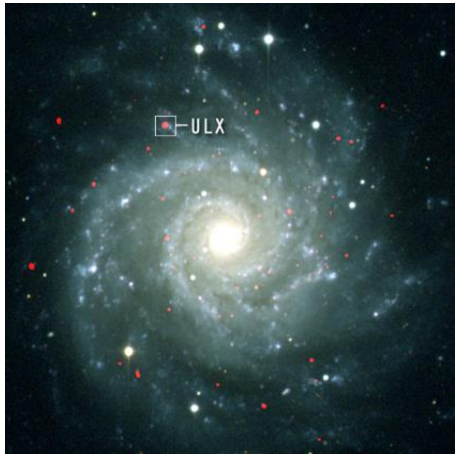
Bachetti et al. 2112.00339

ACCRETING MAGNETARS

Typically magnetic fields of neutron stars in accreting X-ray binaries are estimated with indirect methods.

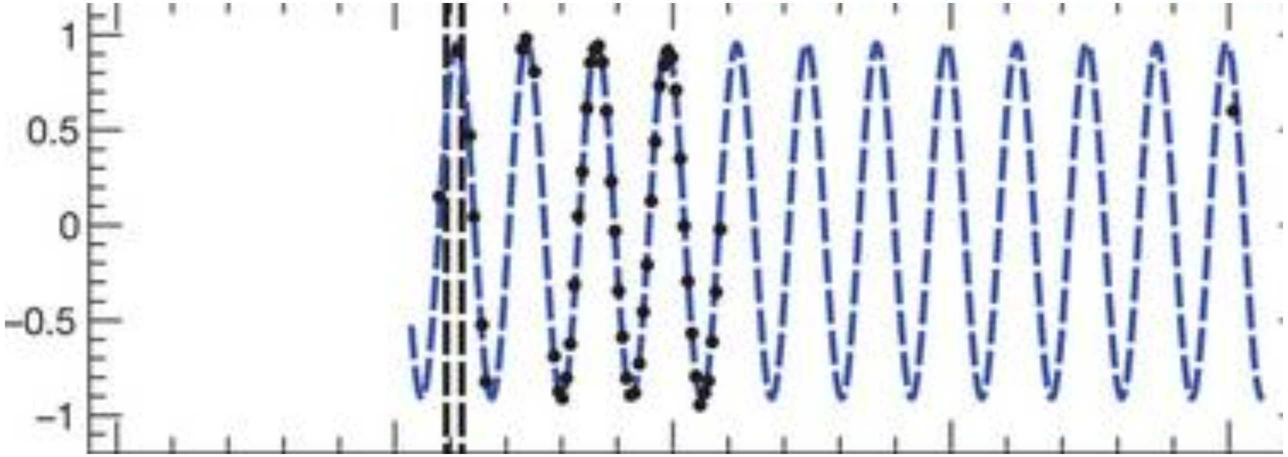


- Spin-up
- Spin-down
- Equilibrium period
- Accretion model
- …….



1709.10385

- ULX. NuSTAR J095551+6940.8 (M82 X-2). Ekşi et al. (2015).
- ULX. NGC 5907. Israel et al. (2017a)
- ULX. NGC 7793 P13. Israel et al. (2017b).
- 4U0114+65. Sanjurjo et al. (2017).
- 4U 2206+54. Ikhsanov & Beskrovnaya (2010).
- SXP1062. Fu & Li (2012)
- Swift J045106.8-694803. Klus et al. (2013).



FIELD ESTIMATES BASED ON SPIN PROPERTIES

There are many classical and modern approaches to estimate NS’s magnetic field from spin properties.

[See, eg. Chashkina&Popov 2012, Klus et al. 2014, Ho et al. 2014, Shi et al. 2015, Igoshev&Popov2018, Chen et al. 2021, and references to classical papers by Ghosh&Lamb, Davidson&Ostriker and many others therein.]

1. Equilibrium.

A) disc accretion

$$B = 2^{-1/4}\pi^{-7/6}k_{\rm t}^{-7/12}\epsilon^{7/24}p^{7/6}\dot{M}^{1/2}(GM)^{5/6}R^{-3}.$$

B) wind accretion

$$B = 2\sqrt{\frac{2\eta}{k_{\rm t}\pi}}p_{\rm orb}^{-1/2}v^{-2}(GM)^{3/2}\dot{M}^{1/2}pR^{-3}.$$

2. Spin-up.

$$B = \frac{2^4\pi^{7/2}}{\epsilon^{7/4}}\frac{(I\dot{p})^{7/2}}{R^3p^7\dot{M}^3(GM)^{3/2}}$$

3. Spin-down.

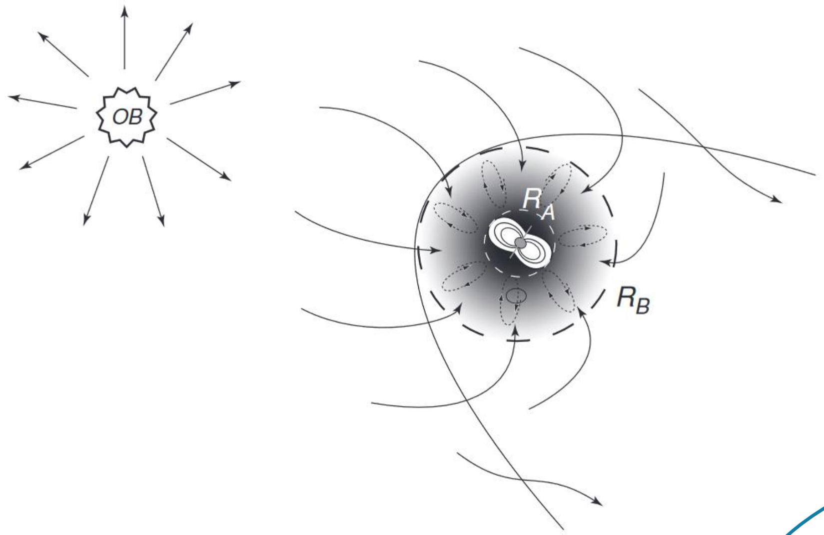
$$B = \frac{2}{R^3}\left(\frac{I\dot{p}GM}{2\pi k_{\rm t}}\right)^{1/2}$$

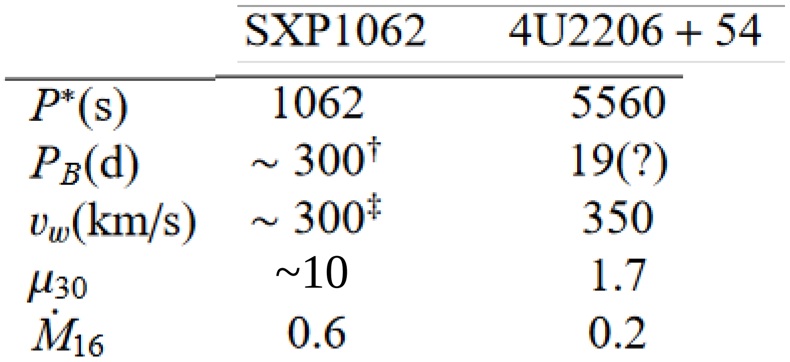
Many more equations exist to estimate magnetic fields using spin and its derivatives (e.g. Shi et al. 2015). Typically, only dipolar component can be estimated.

E.g., 4U 0114+65, 4U 2206+54, SXP 1062, Swift J0451 were proposed as accreting magnetars.

SETTLING ACCRETION HELPS AGAINST MAGNETARS

Shakura et al. 1302.0500





	SXP1062	4U2206 + 54
P^*(s)	1062	5560
P_B(d)	$\sim 300^\dagger$	19(?)
v_w(km/s)	$\sim 300^\ddagger$	350
μ_{30}	~10	1.7
$\dot M_{16}$	0.6	0.2

Postnov, Shakura et al. 1307.3032

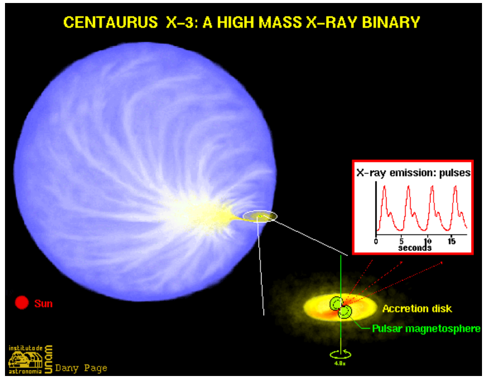
Typically, for wind-accreting systems long spin periods lead to high magnetic field estimates (e.g., Klus et al. 2014):

$$B \approx 1\times 10^{14}\,\mathrm{G}\left(\frac{\eta}{\kappa_\mathrm{t}}\right)^{1/2} R_\mathrm{NS6}^{-3}\left(\frac{M}{\mathrm{M}_\odot}\right)^{3/2}\dot M_{16}^{1/2} \times\left(\frac{V_\mathrm{rel}}{100\,\mathrm{km\,s^{-1}}}\right)^{-2}\left[\frac{P/100\,\mathrm{s}}{(P_\mathrm{orb}/10\,\mathrm{d})^{1/2}}\right].$$

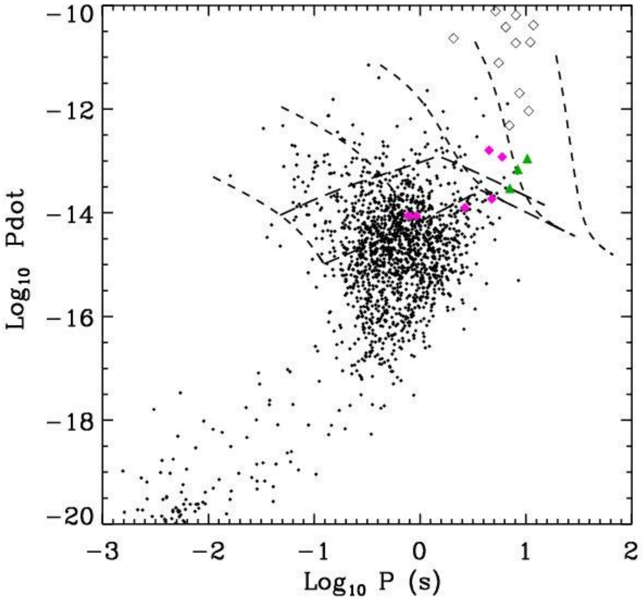
However, for the settling accretion model which is valid for low accretions rates the field estimate is much lower:

$$B = 0.24\times 10^{12}\,\mathrm{G}\,\eta_\mathrm{s}\left(\frac{p/100\mathrm{s}}{p_\mathrm{orb}/10\mathrm{days}}\right)^{11/12}\dot M_{16}^{1/3}\,(v/(10^8\,\mathrm{cm/s}))^{-11/3}$$

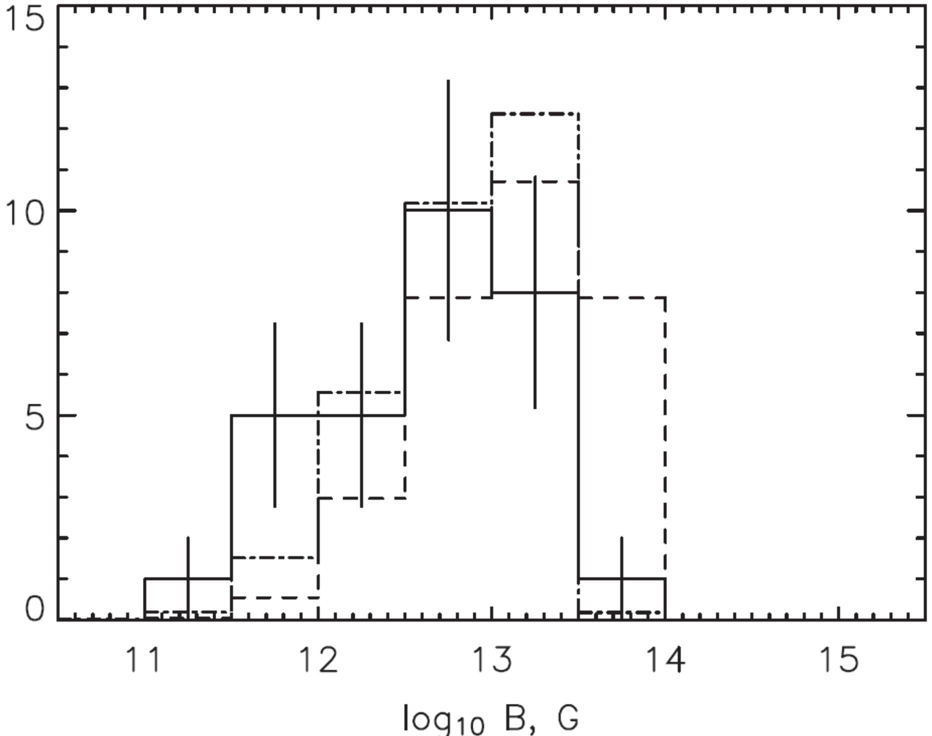
FIELD DECAY IN HMXBS

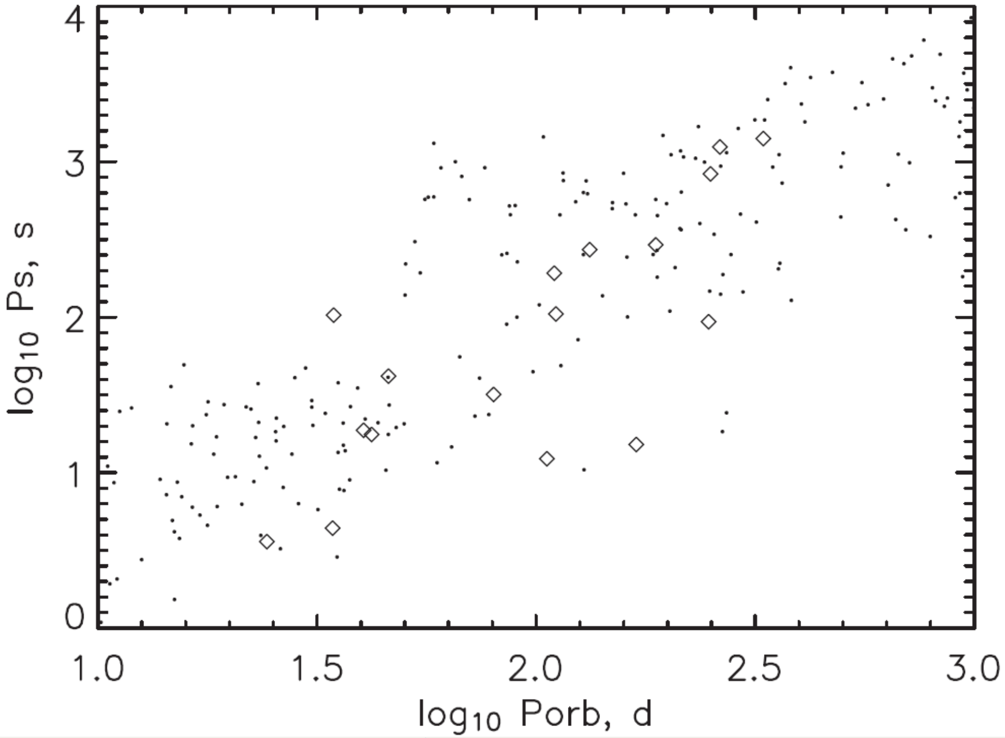


It is possible to use HMXBs to test models of field decay on time scale >1 Myr (Chashkina, Popov 2012).
We use observations of Be/X-ray binaries in SMC to derive magnetic field estimates,
and compare them with prediction of the Pons et al. model.



Chashkina, Popov (2012)

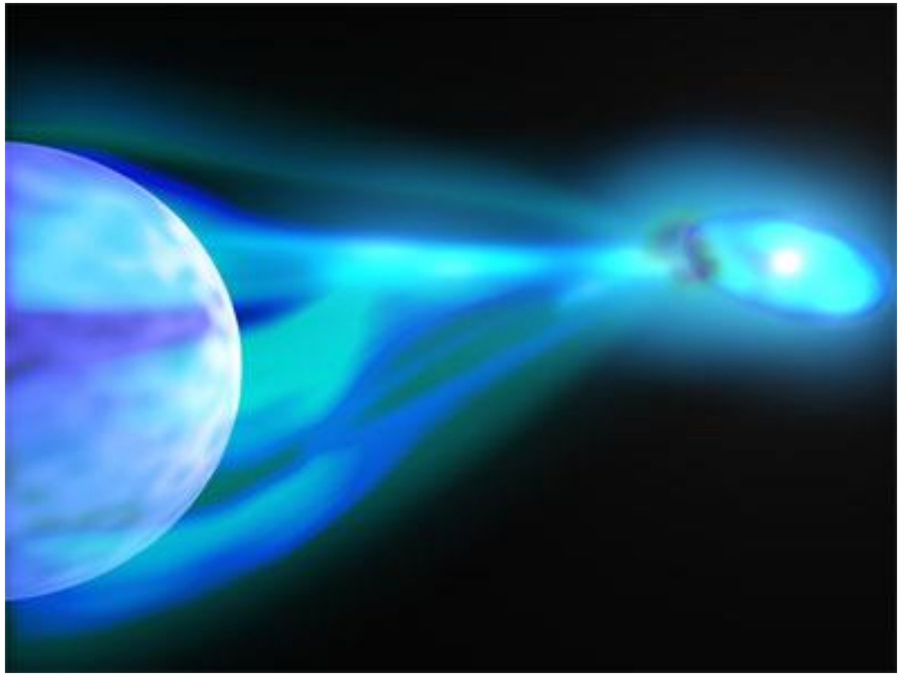


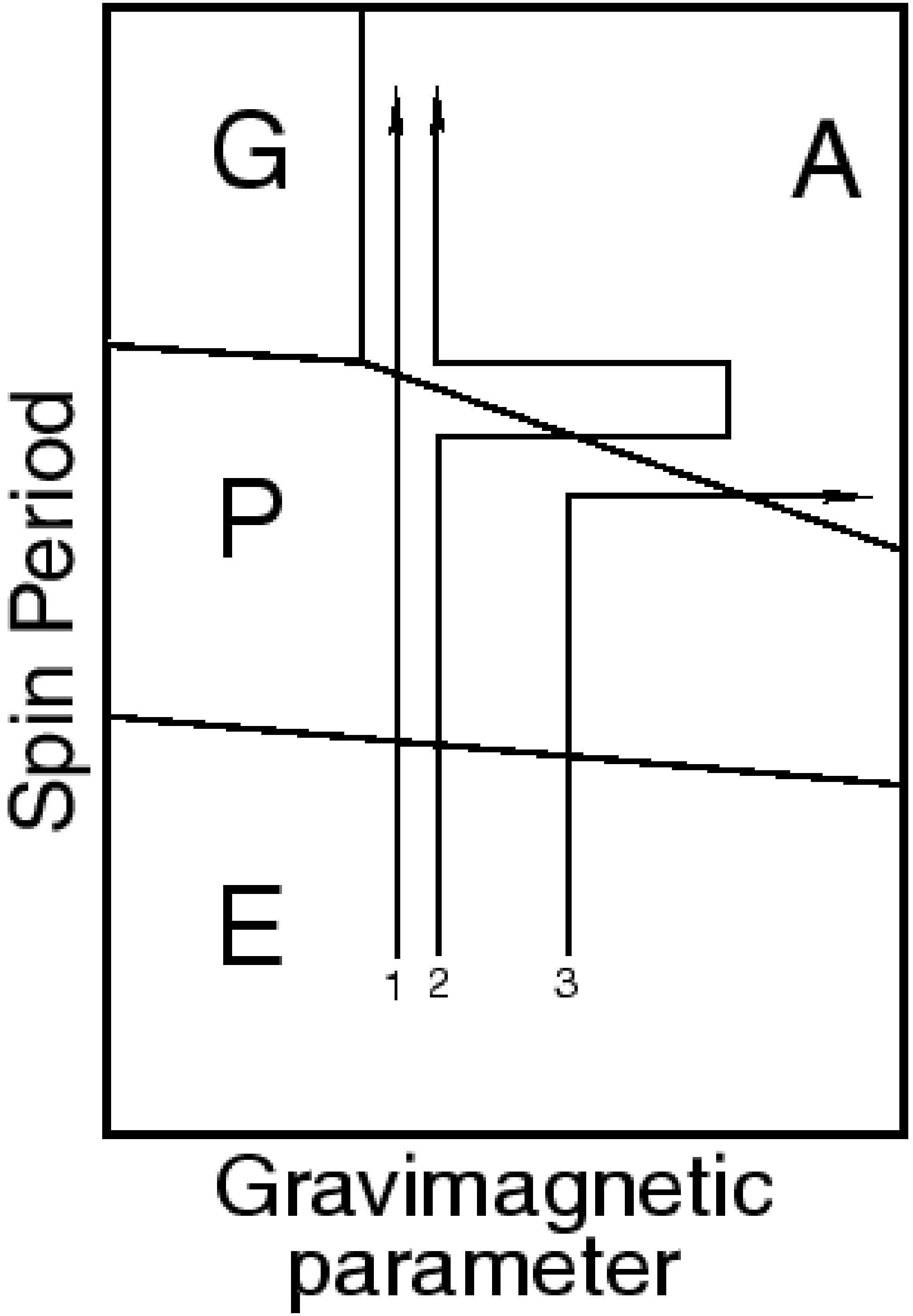


SXP 1062

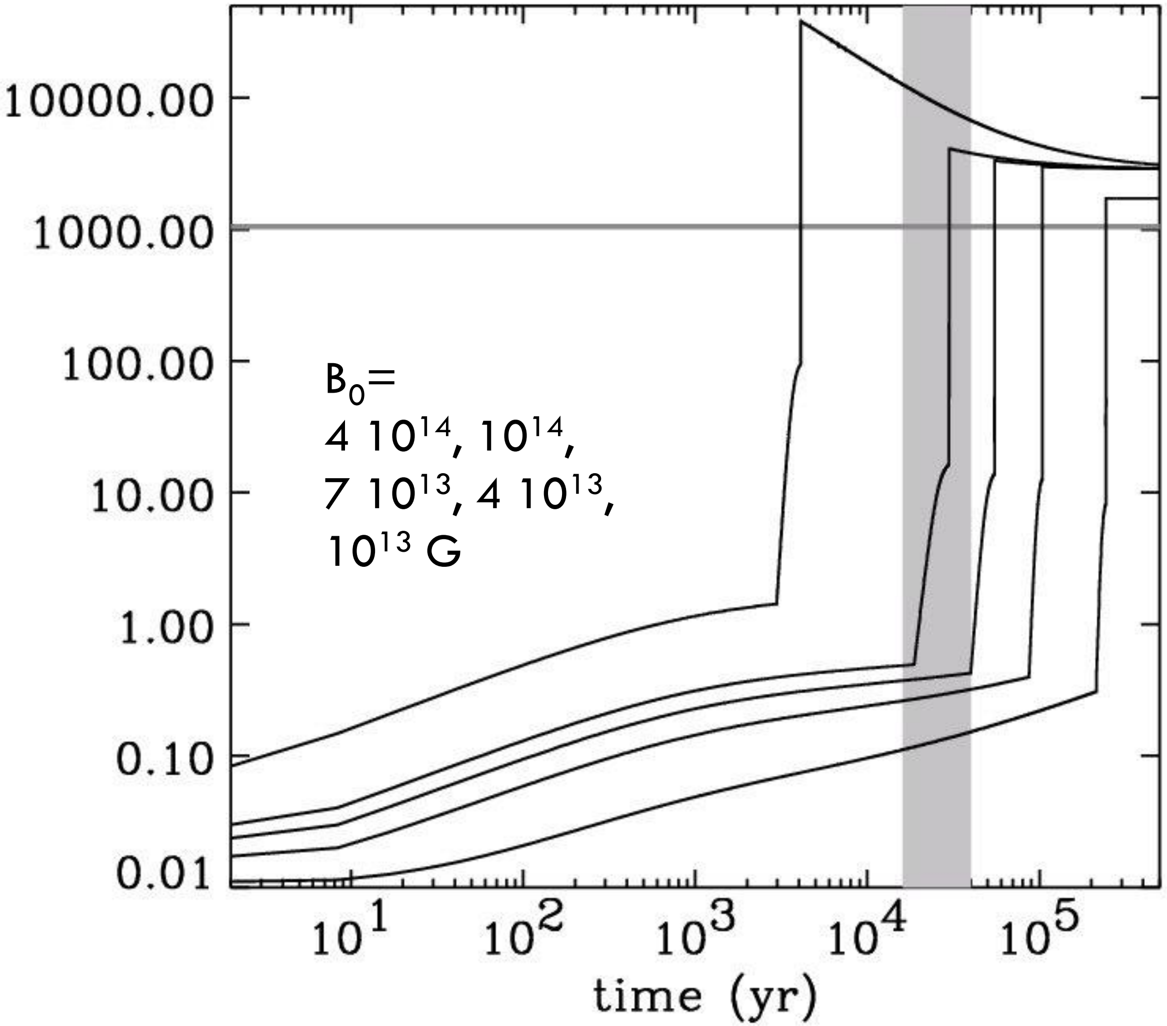
A peculiar source was discovered in SMC.
Be/Xray binary, P=1062 sec.
A SNR is found. Age ~10^4 yrs.
(1110.6404; 1112.0491)

Typically, it can take ~1 Myr for a NS with B~10^{12} G to start accretion.





SXP 1062



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

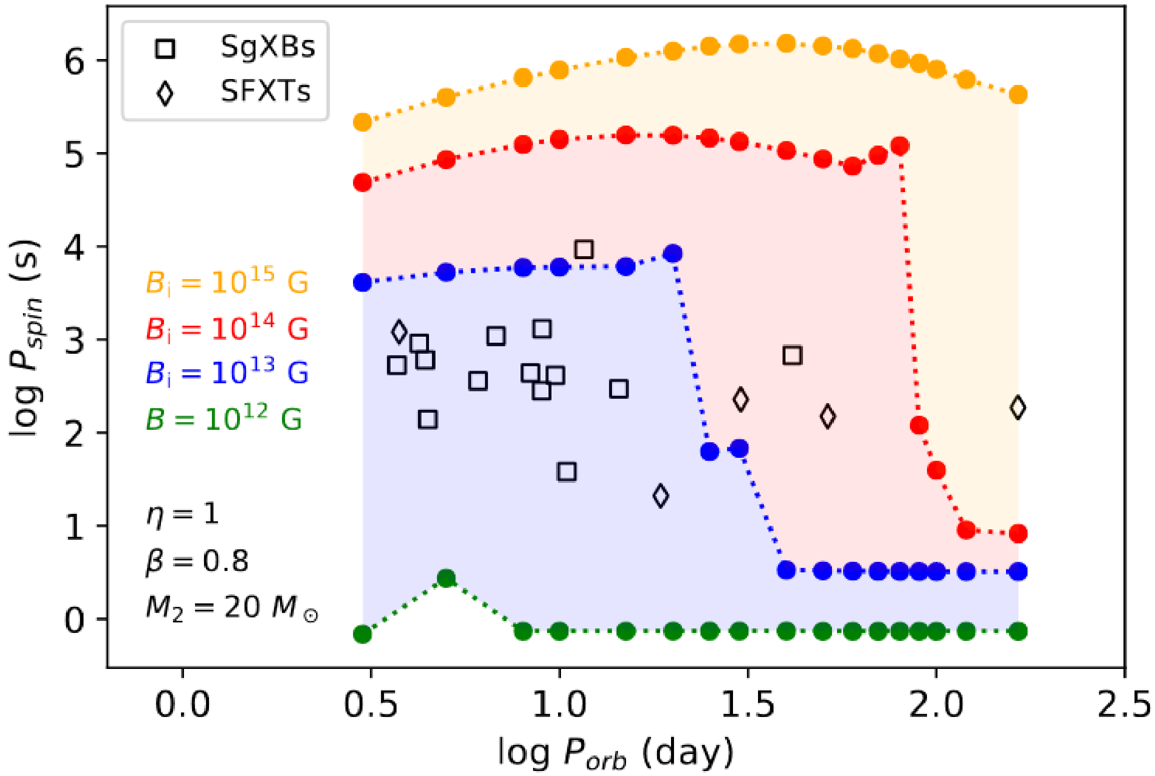
arXiv: 1112.2507

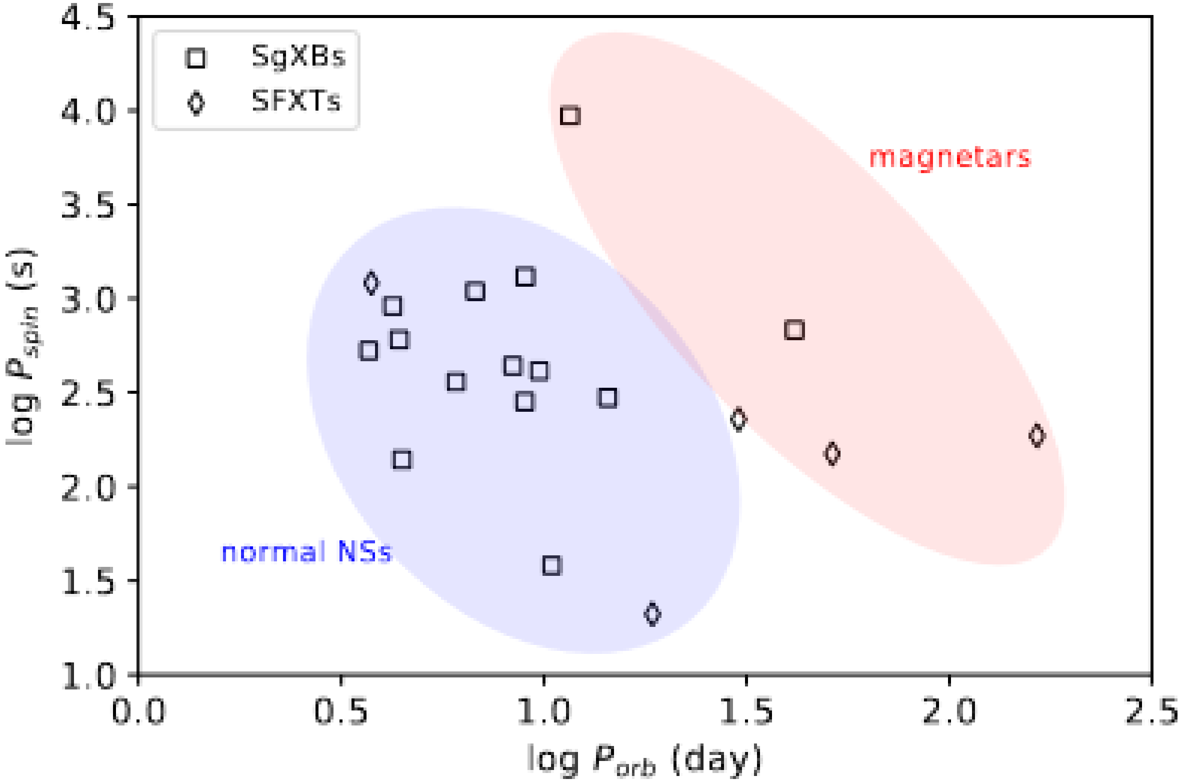
A crucial thing for studying magneto-rotational evolution is to have an independent age estimate. In the case of HMXBs an interesting source with known age is SXP1062 (Henault-Brunet et al. 2012, Haberl et al. 2012).

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).

FORMER MAGNETARS AMONG WIND-ACCRETING HMXBS





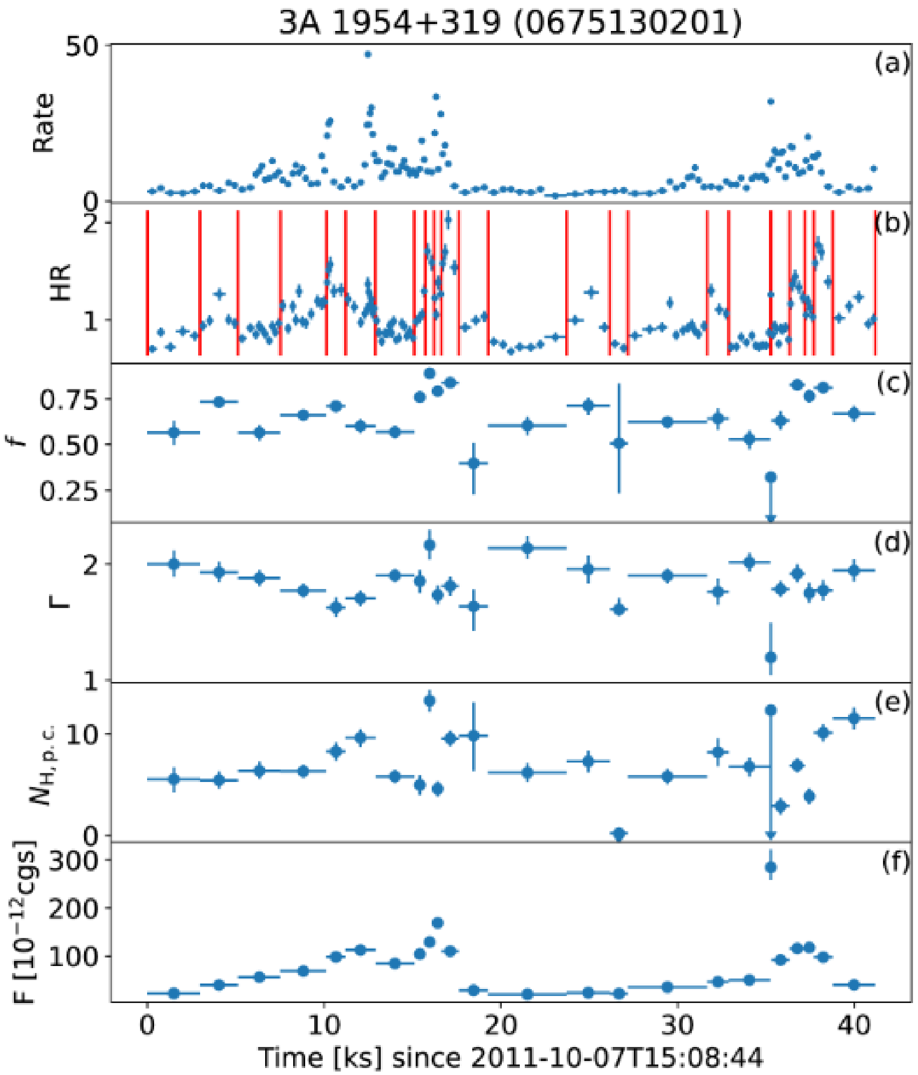
2110.10438

Large initial magnetic fields are necessary either to reach long spin periods or to start accreting from the wind in the case of wide binary systems.

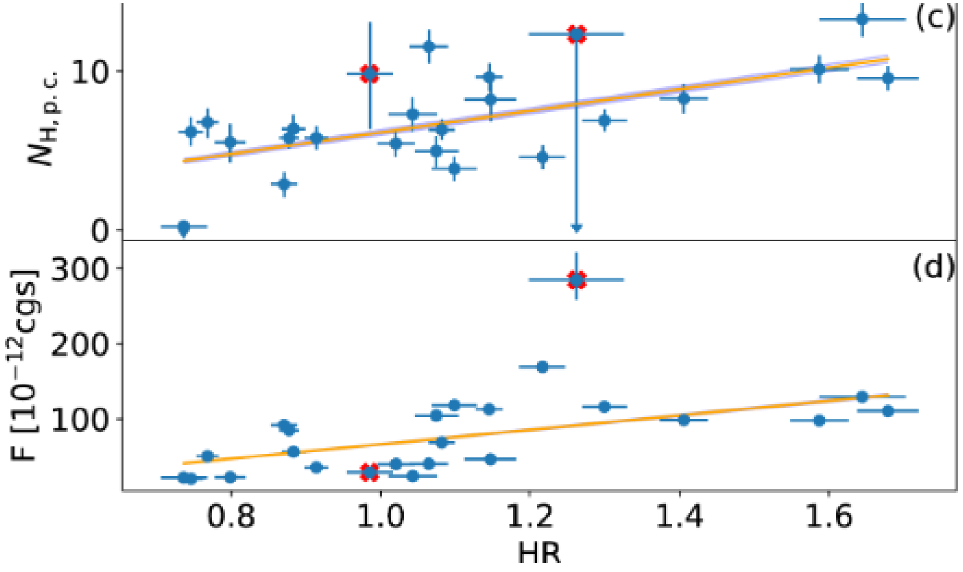
A RED SUPERGIANT AND A MAGNETAR IN 3A 1954+319?

3A 1954+319
P ~5 hours

Red supergiant
M=9 Msun
Porb ~few years



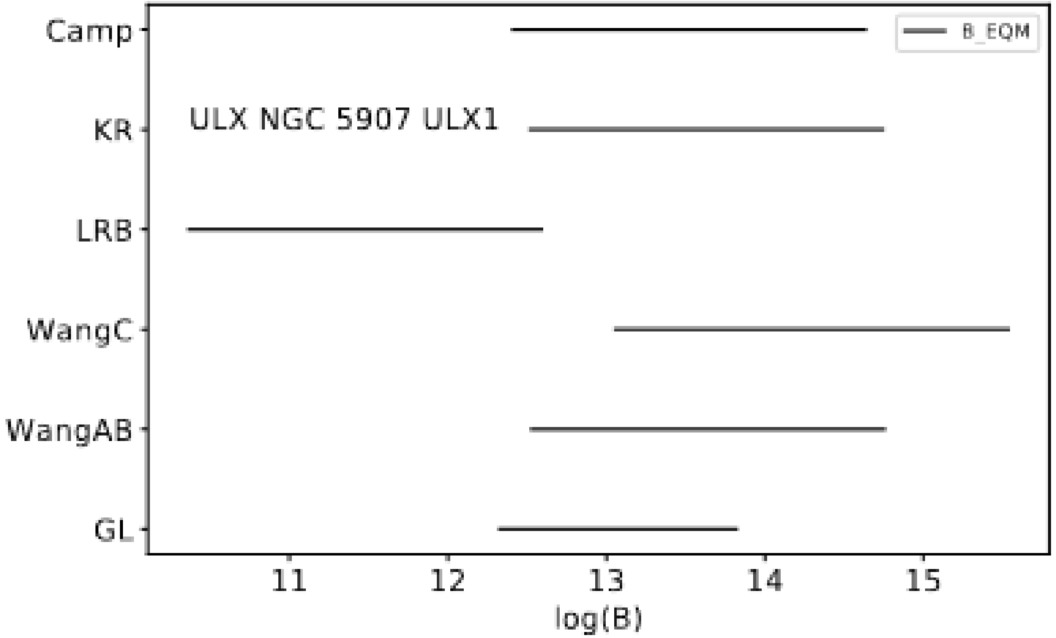
Points corresponding to spikes in the HR, especially during the intervals of the brightest emission are generally characterized by an increase of the covering fraction (by up to about 60%) and the partial covering absorption column density.

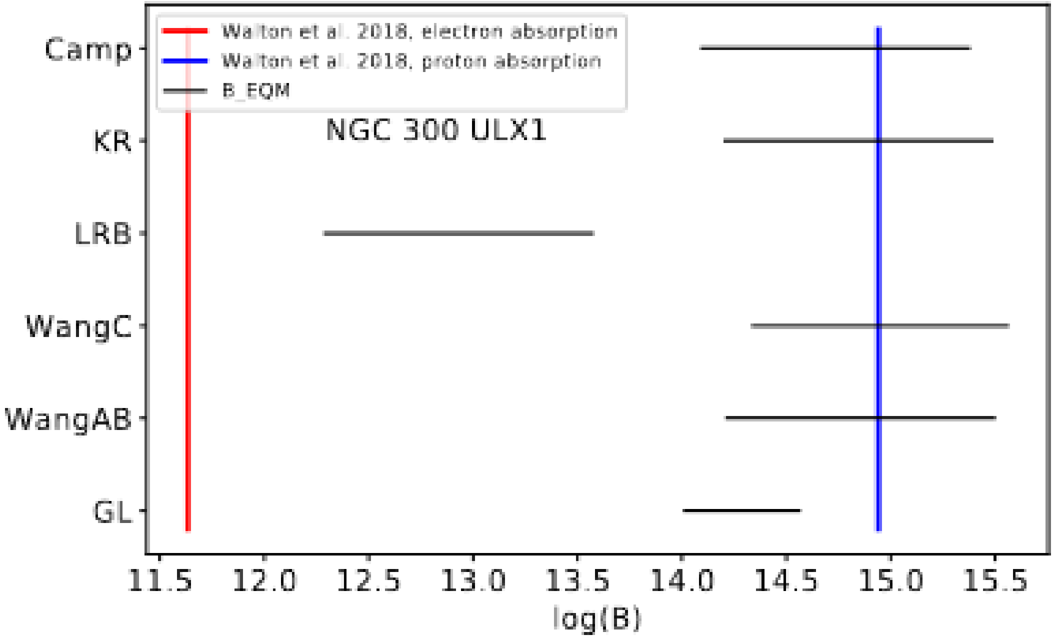


2112.08517

FIELD ESTIMATES FOR ULXS

6 different torque models used.
8 sources analyzed.

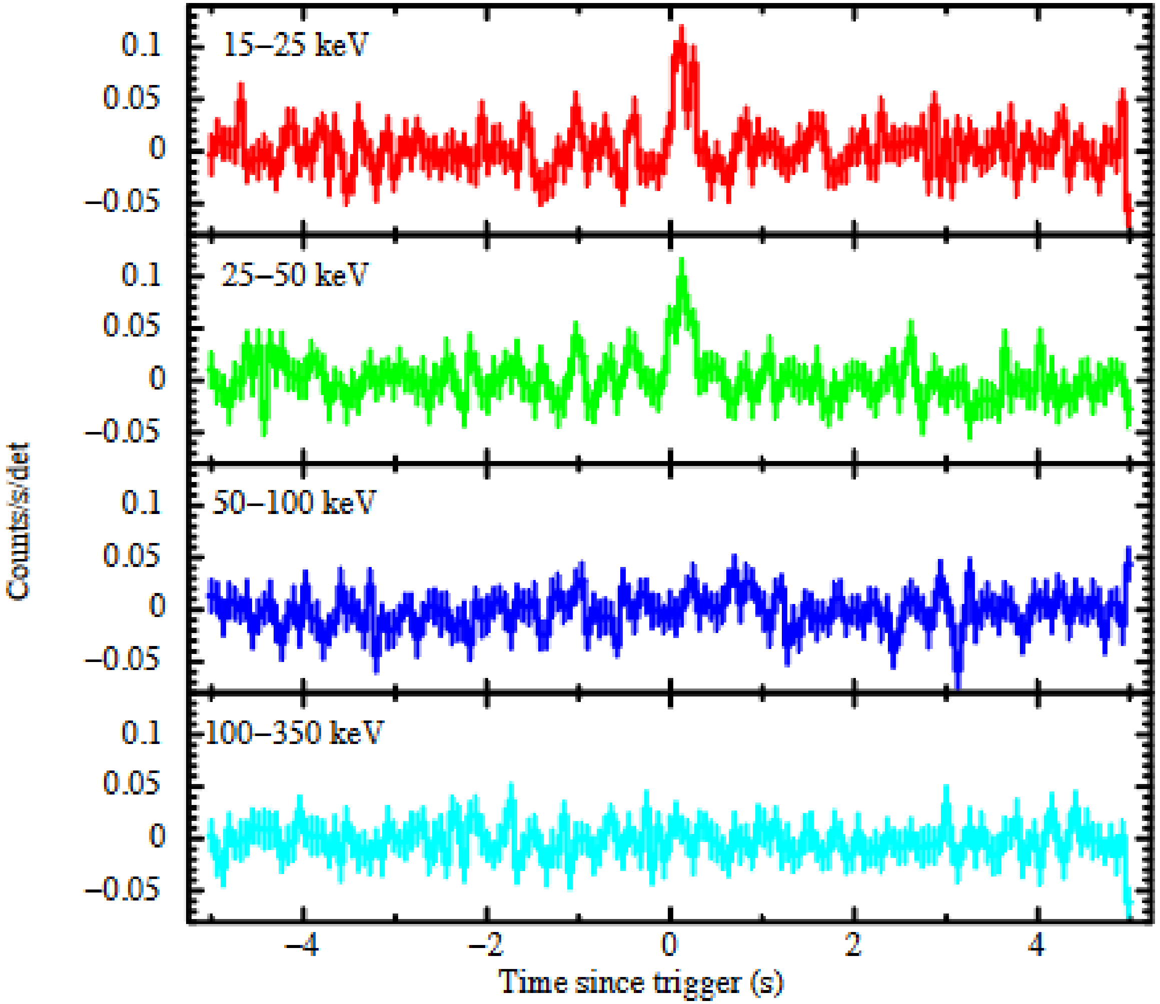




2104.09076

About NGC 300 ULX1 see also arXiv:2205.09293.
The authors obtain B~3 10^{14} G.

BURSTS FROM LS I +61 303



Torres et al. 1109.5008

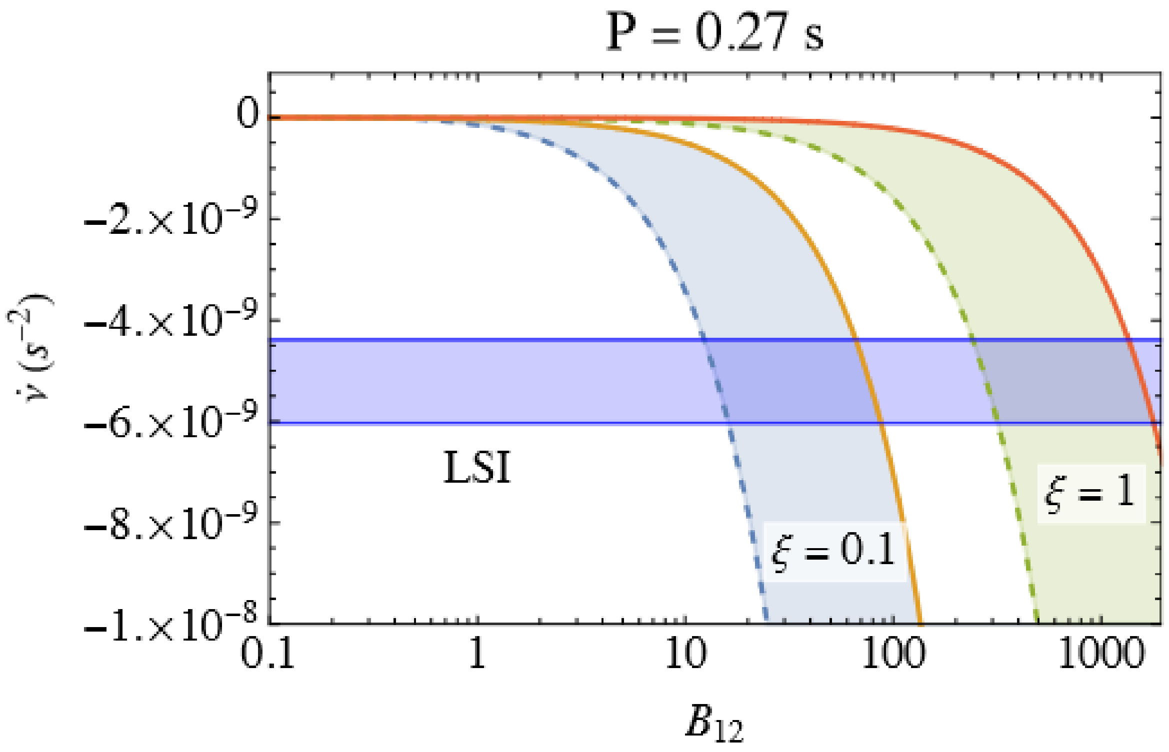
LS I 62 303 - the only example of a magnetar-like activity in a binary system. HMXB. Be-star 10-15 Msun. Porb~27 d. Low luminosity (2 10^{37} erg/s) can point towards relative low field (<10^{14}G).

Another burst was detected by Swift in 2012 (Burrows et al. 2012).

Spin period 0.27 s (2203.09423)

LS 5039 can be another magnetar in a gamma-ray binary if pulsations and the Pdot value are confirmed (Yoneda et al. 2009.02075). No bursts, but system similar to LS I +61 303.

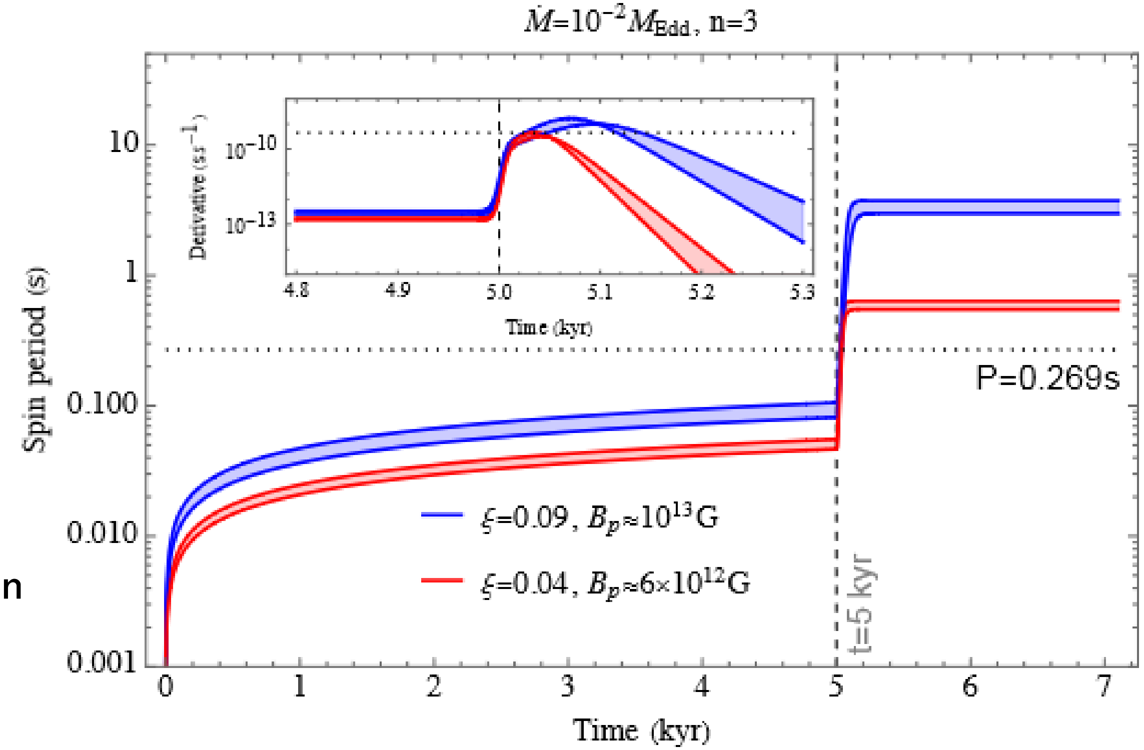
OR IS LS I +61 303 A LOW-FIELD PROPELLER?



The neutron star’s age and spin evolution are theoretically difficult to reconcile unless a strong propeller torque is in operation. This torque could be responsible for the bulk of even the maximum allowed spin-down, potentially weakening the inferred magnetic field by more than an order of magnitude.

$$R_A = \xi \frac{B_p^{4/7} R_\star^{12/7}}{(GM_\star)^{1/7}\dot{M}^{2/7}},$$

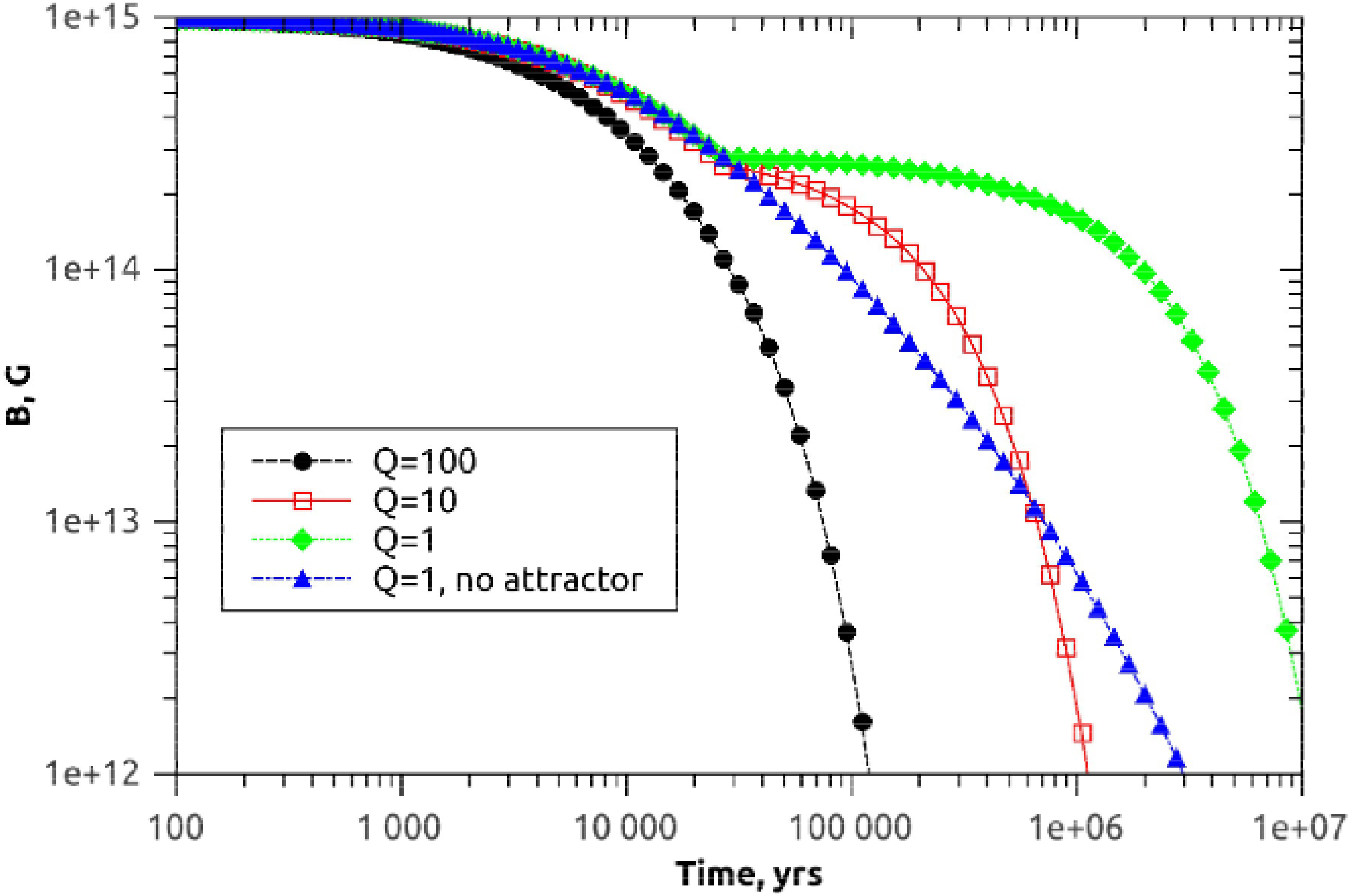
$$\frac{R_A}{R_{co}} \approx 289\,\xi \frac{R_6^{12/7} B_{14}^{4/7}}{M_{1.4}^{10/21}\dot{M}_{-10}^{2/7}P_{-1}^{2/3}},$$



2210.09471

HOW TO MAKE AN ACCRETING MAGNETAR?

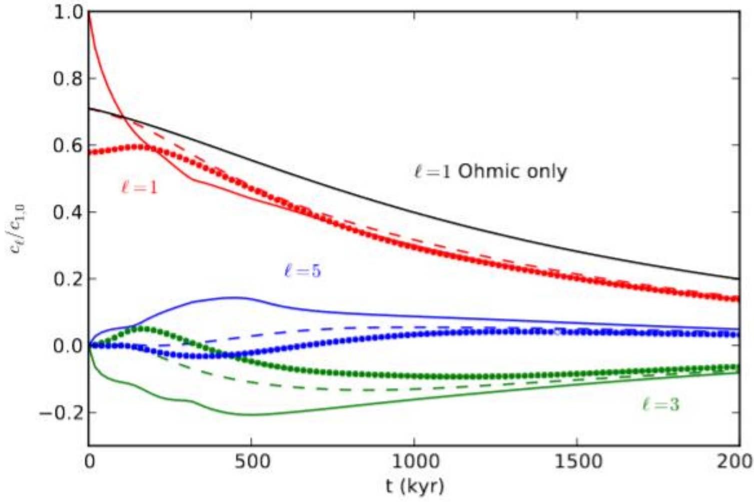
Igoshev, Popov 1709.10385



Three conditions are necessary:

1. Hall attractor;
2. Rapid cooling of the crust;
3. Low values of Q.

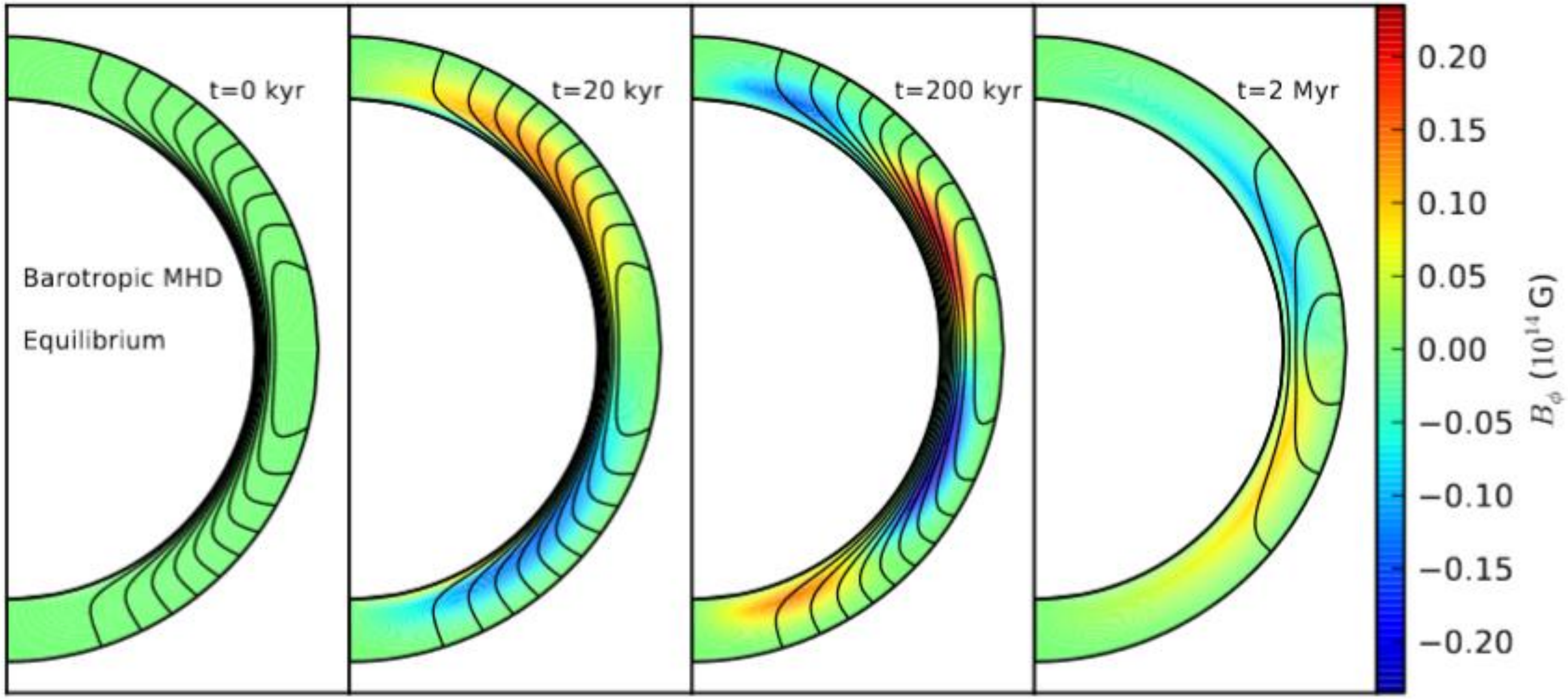
Hall attractor:



Gourgouliatos, Cumming 1311.7004

HALL CASCADE AND ATTRACTOR

The system is trying to relax towards a state of isorotation, with the electron fluid having the same angular velocity on a poloidal field line.

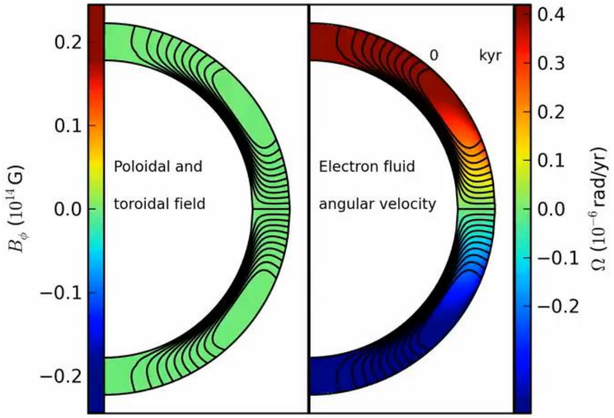


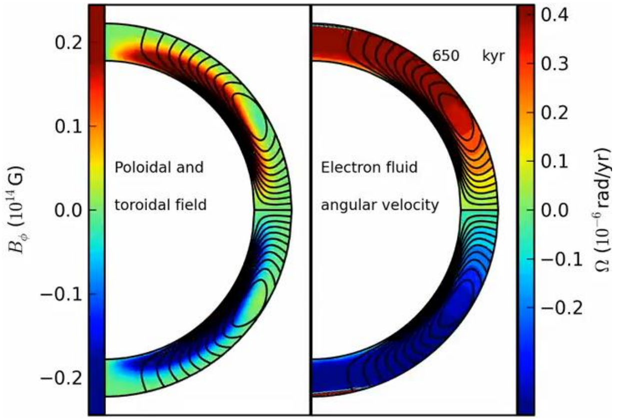
Hall cascade can reach the stage of so-called Hall attractor,
where the field decay stalls for some time (Gourgouliatos, Cumming).

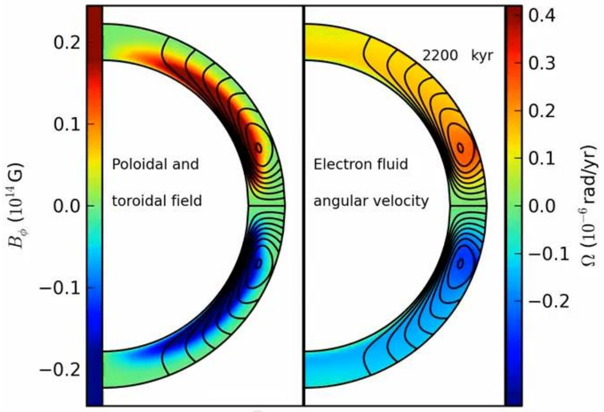
HALL CASCADE AND ATTRACTOR

Gourgouliatos and Cumming 2013

The system is trying to relax towards a state of isorotation,
with the electron fluid having the same angular velocity on a poloidal field line.







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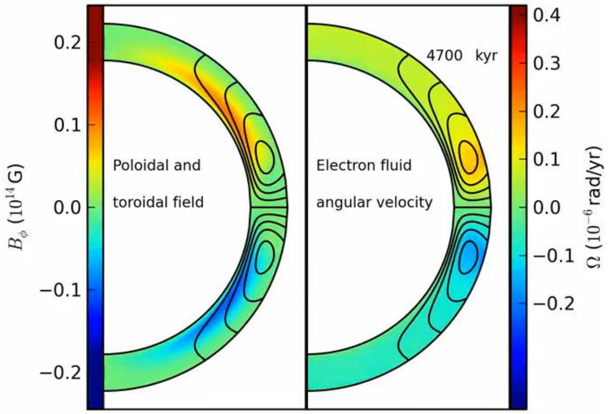
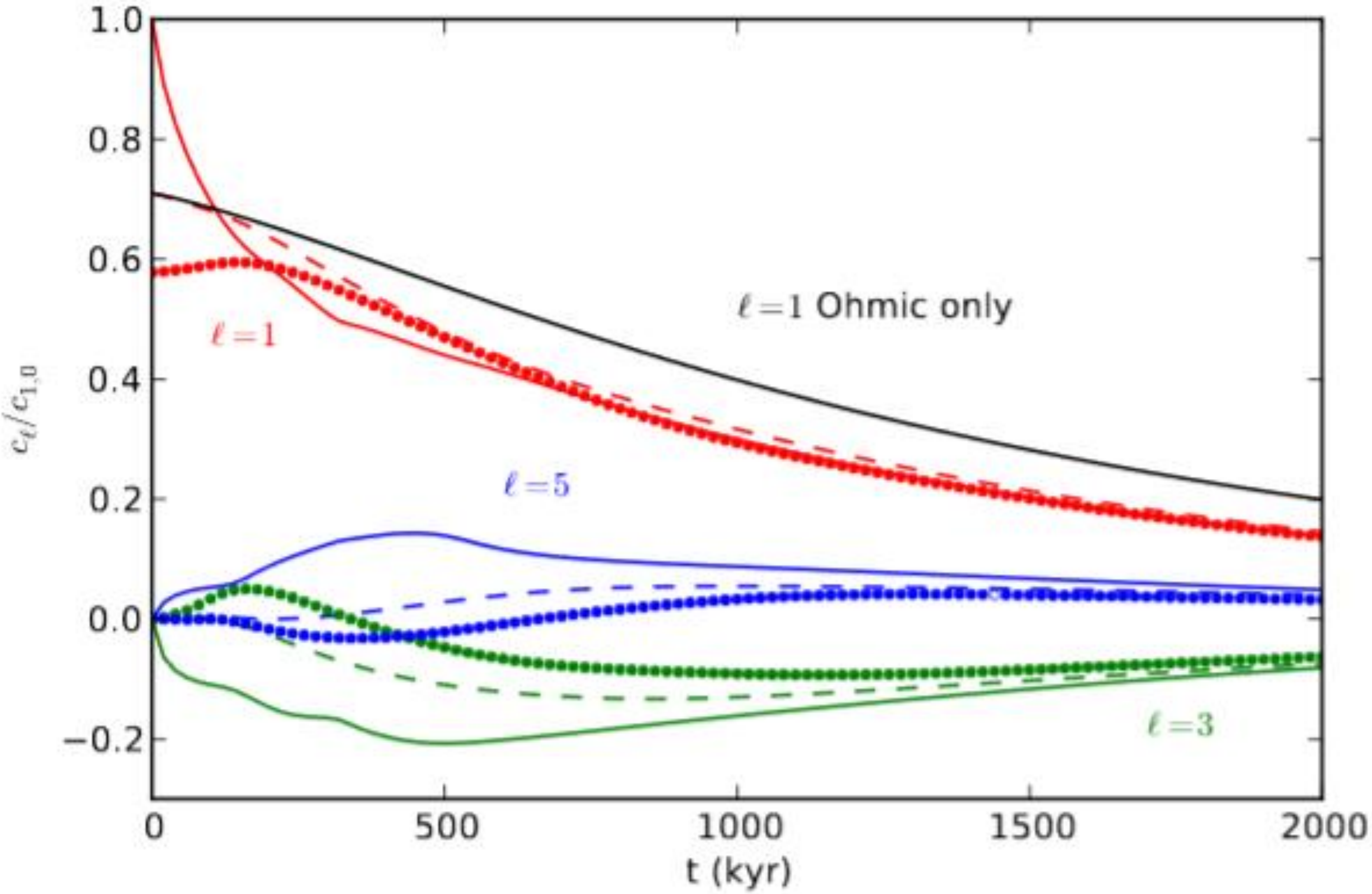


http://www.physics.mcgill.ca/~kostasg/research.html

EVOLUTION OF DIFFERENT COMPONENTS

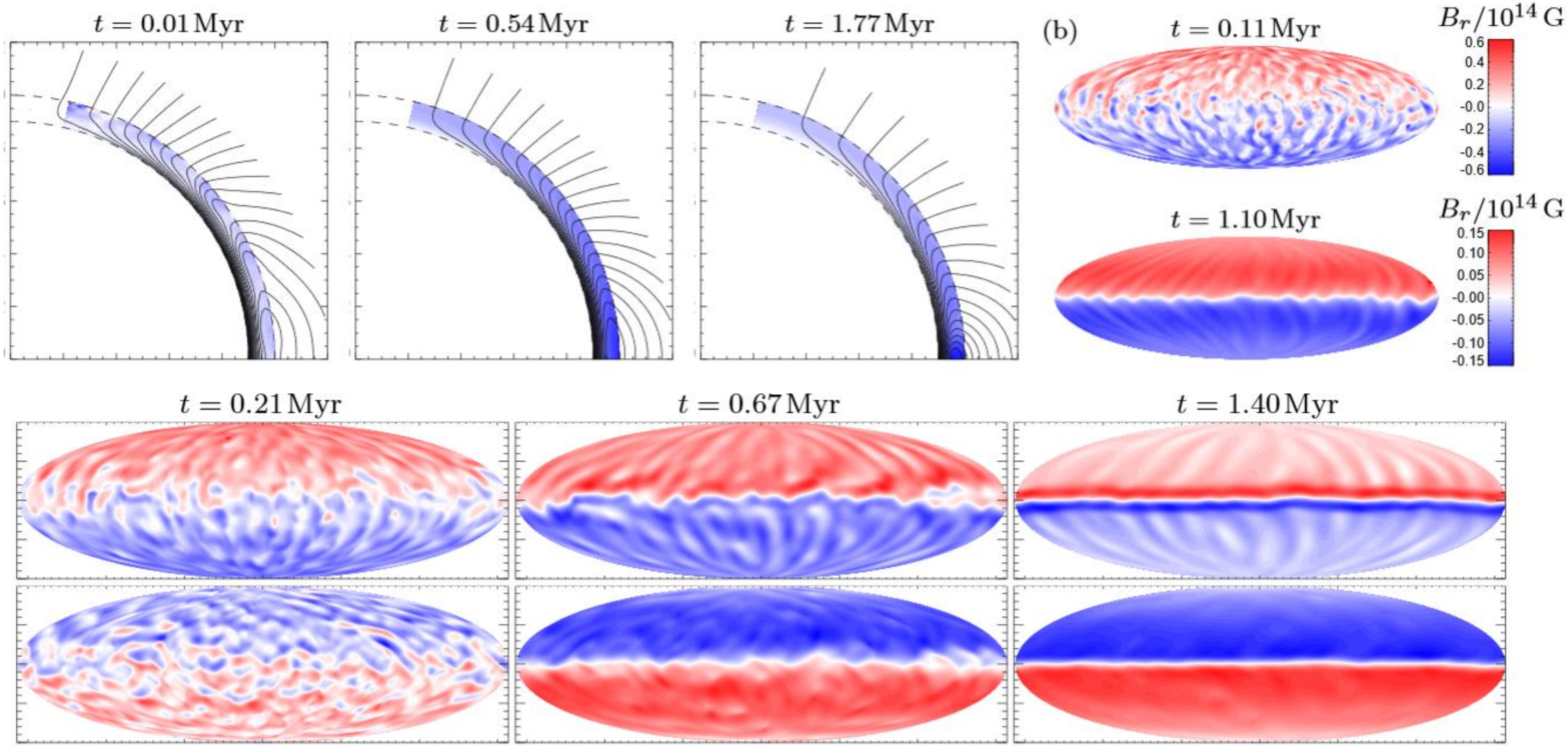
1311.7004



Hall attractor mainly consists of dipole and octupole

INDEPENDENT STUDIES OF THE HALL CASCADE

1501.05149

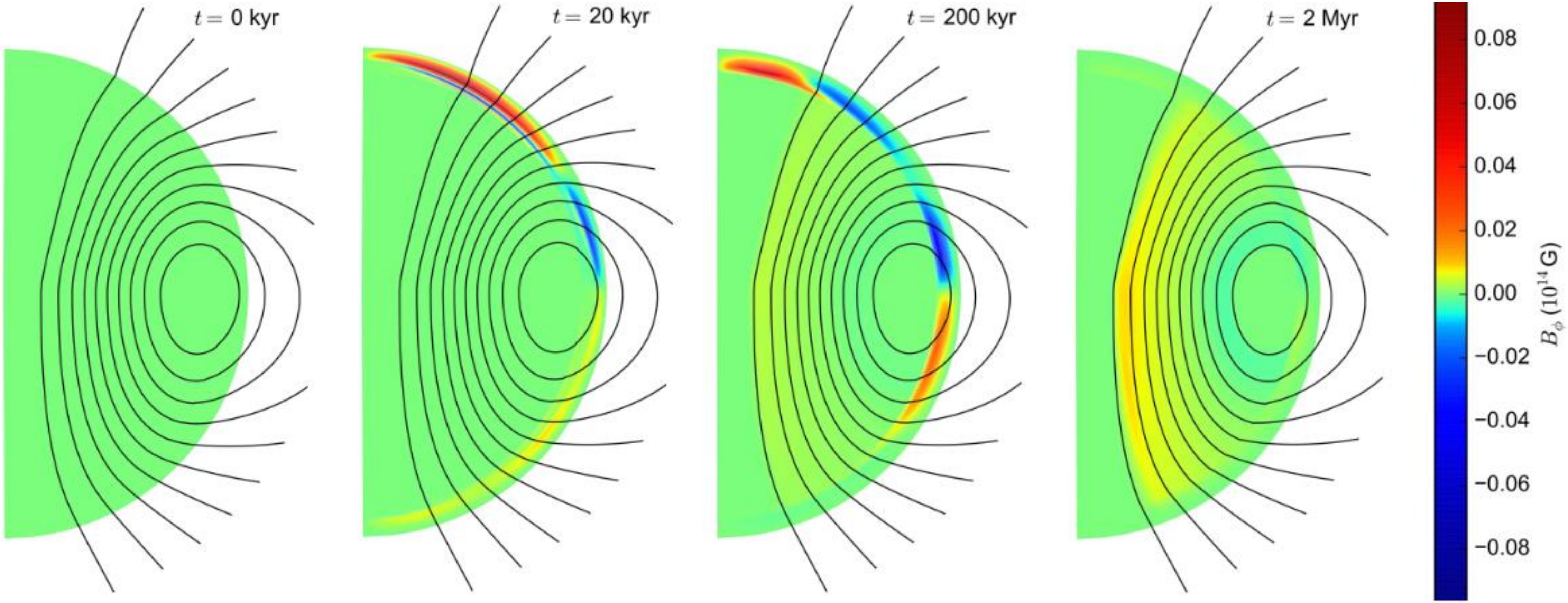


New calculations support the idea of a kind of stable configuration.

See also 1604.01399

CORE AND CRUST FIELD EVOLUTION

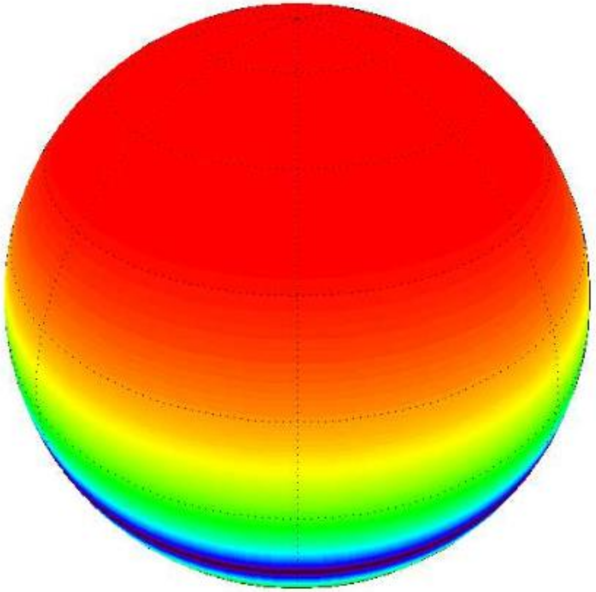
1709.09167



Hall attractor is confirmed.

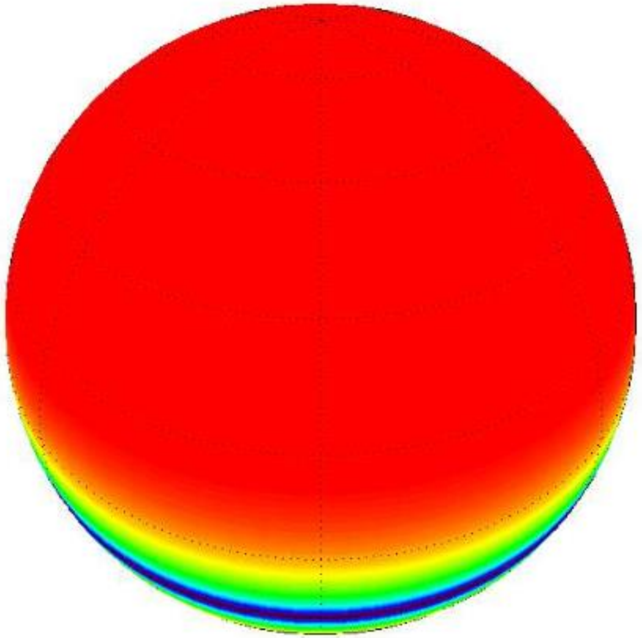
TEMPERATURE MAPS

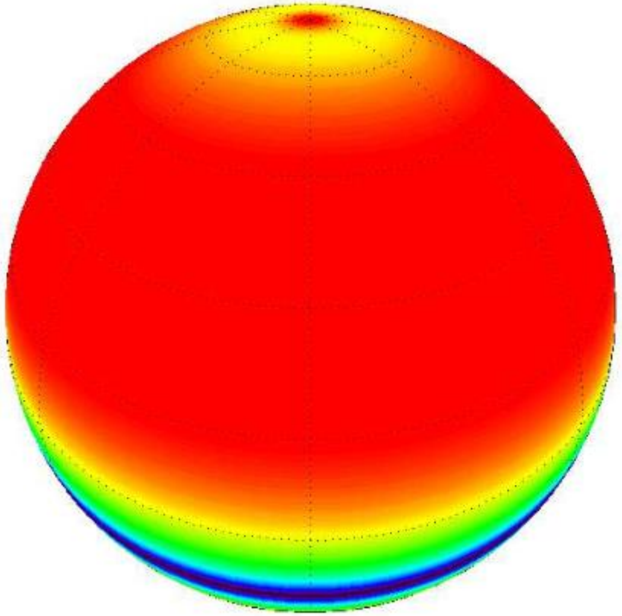
arXiv: 1610.05050



Pure dipole

Dipole+octupole+l5

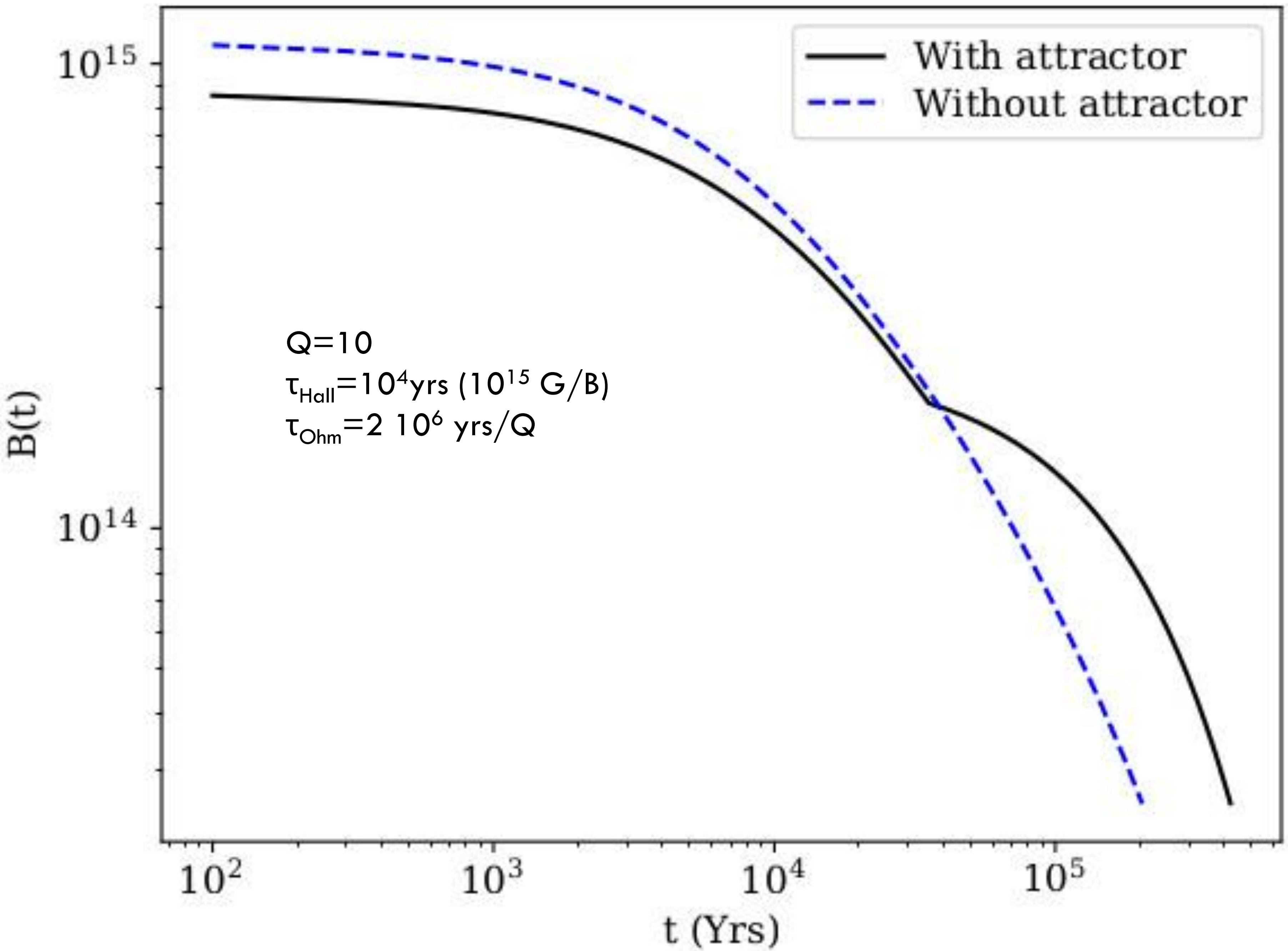




Dipole + octupole (Model 1)

	χ	ξ	T_1 (eV)	T_2 (eV)	A_2/A_1
Pure dipole	15°	80°	72.0	57.8	1.27
Model 1	20°	80°	73.0	59.4	0.76
Model 2	25°	80°	73.5	58.1	0.36

New results in 2009.04331



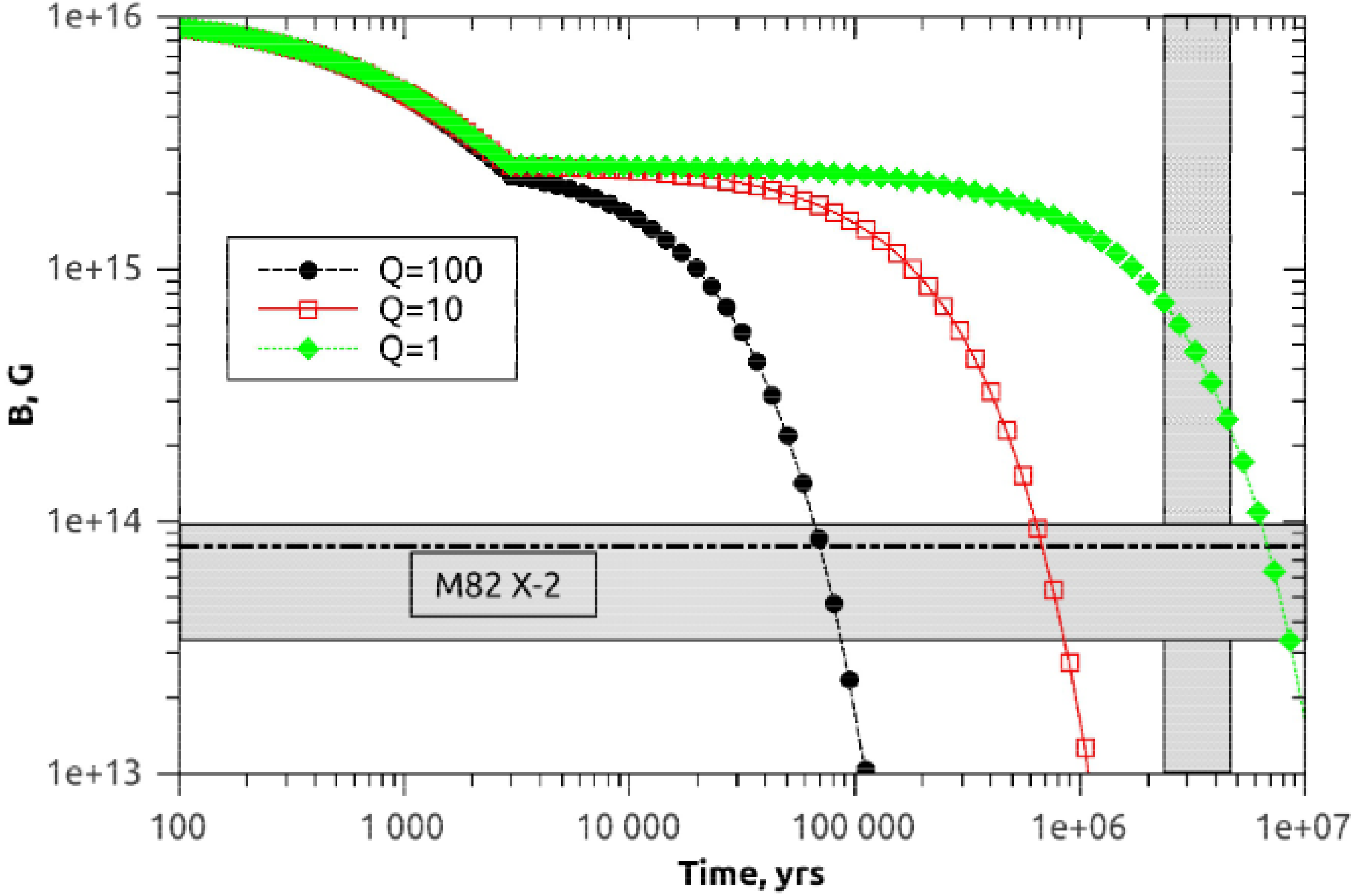
Q=10

τ_{Hall}=10^4yrs (10^{15} G/B)

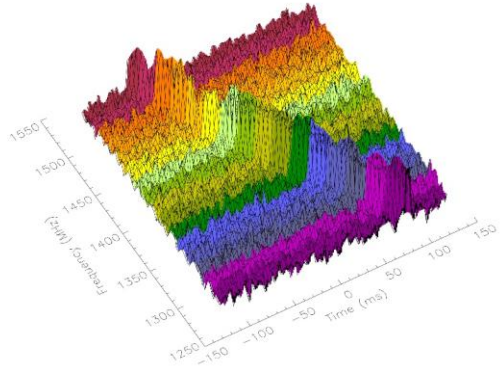
τ_{Ohm}=2 10^6 yrs/Q

PARAMETERS OF ULX M82 X-2

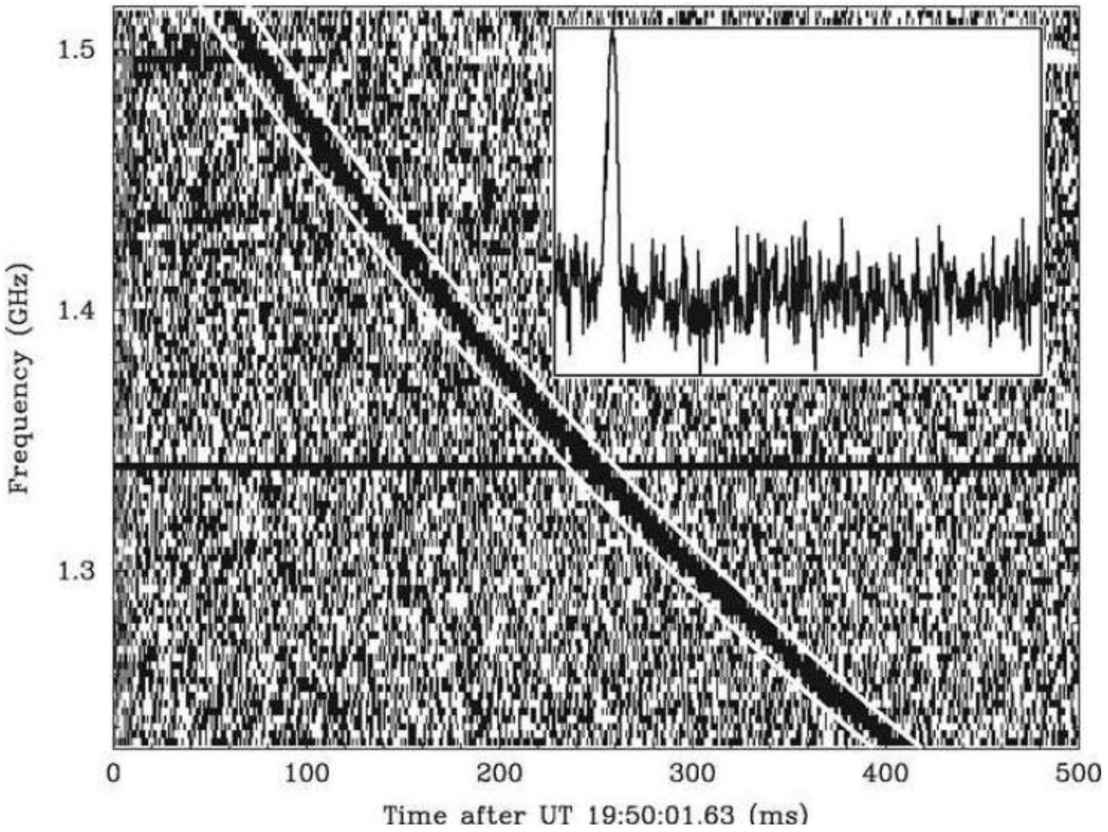
1709.10385



MILLISECOND EXTRAGALACTIC RADIO BURSTS



Science 318, 777 (2007)



Discovered in 2007.

Origin - unknown.

One of the most interesting discoveries in XXIc.

No coincident bursts in other wavelengths.

No source identification.

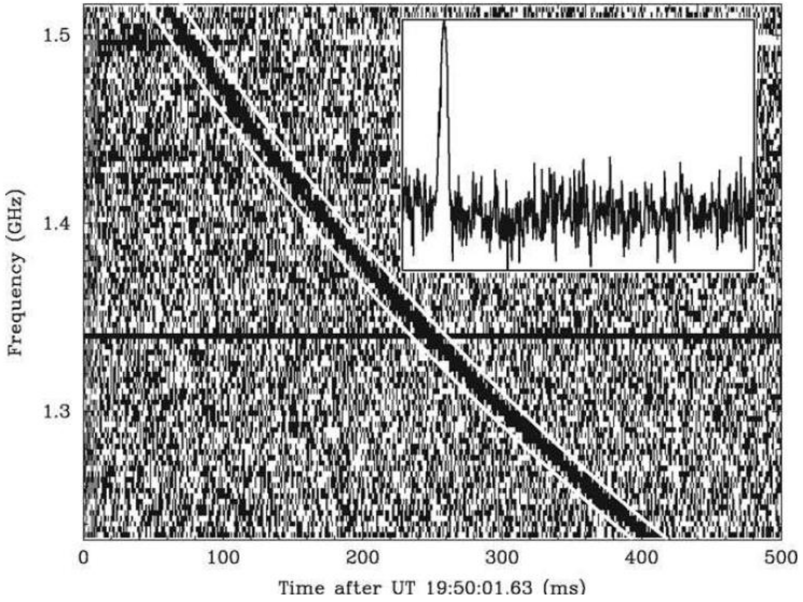
[About the difference between RRATs and FRB
see 1512.02513]

Large dispersion measure.
If dispersion is due to intergalactic medium
then radio luminosity is ~10^{43} erg/s.

BRIEF HISTORY OF FRBS

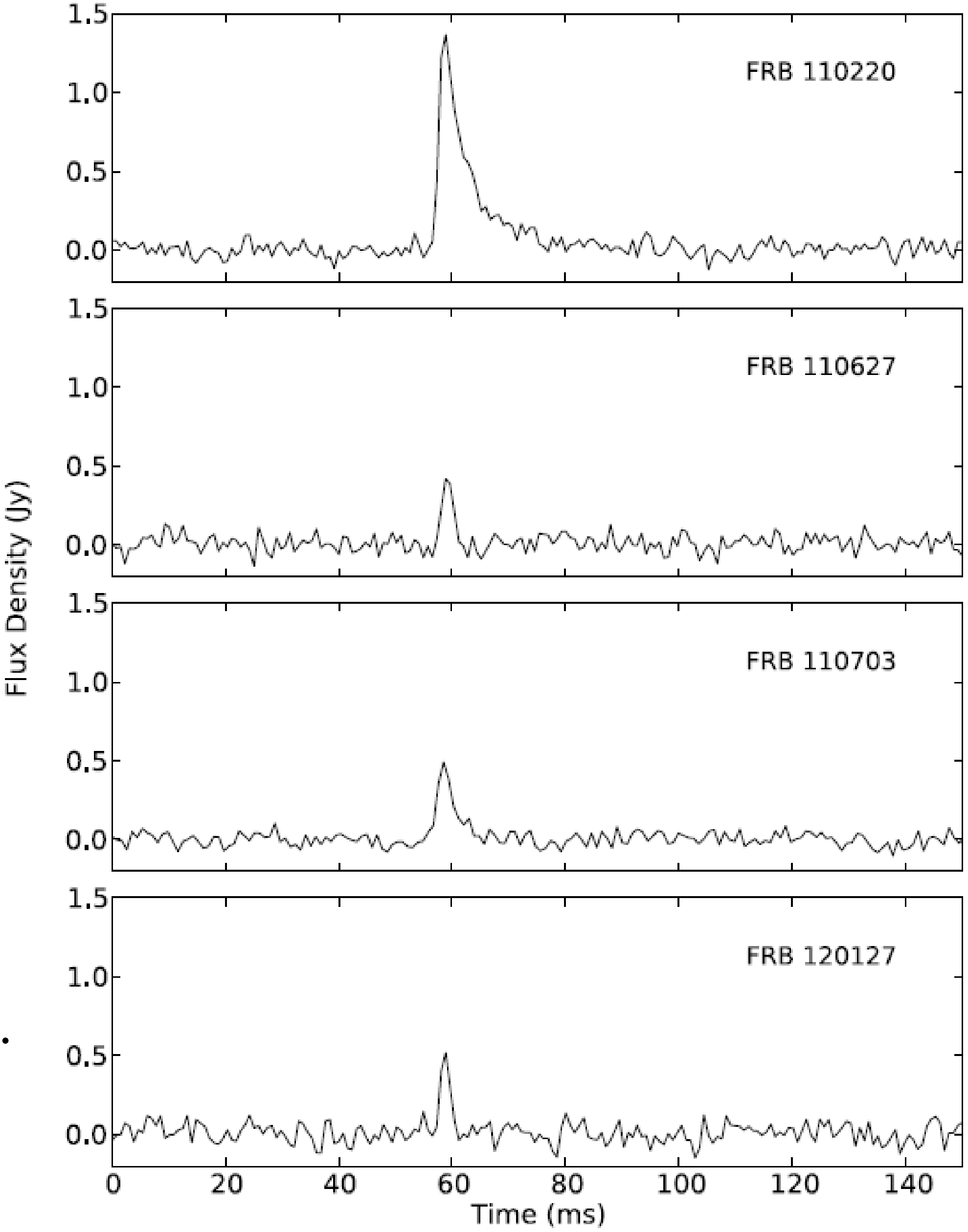
2007	Lorimer et al.	The first event announced.
2012	Keane et al.	The second event.
2013	Thornton et al.	Four events. The story really starts.
2016	Spitler et al.	The first repeating source.
	Chatterjee et al.	Identification of the host galaxy

Lorimer et al.



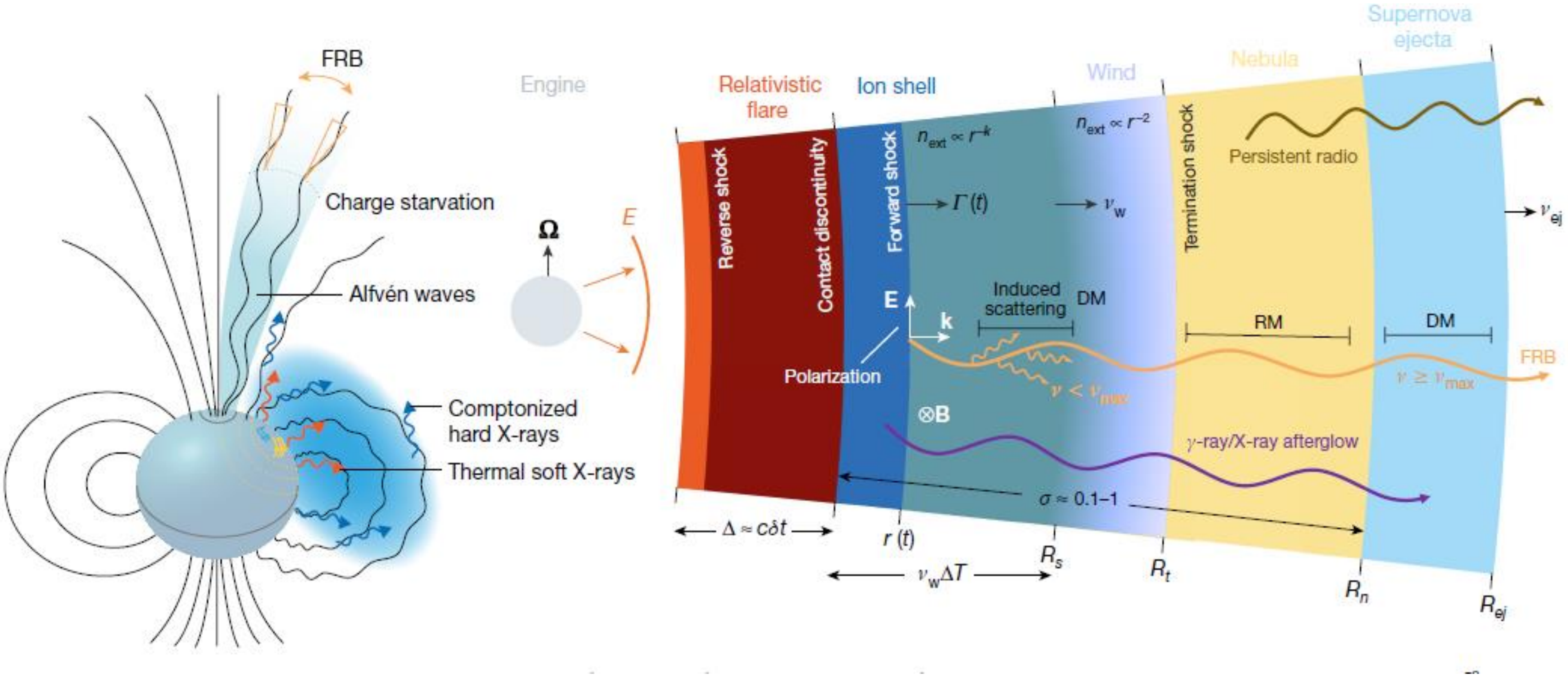
Large dispersion measure points to extragalactic origin.

This is supported by isotropic sky distribution and many other considerations.



1307.1628

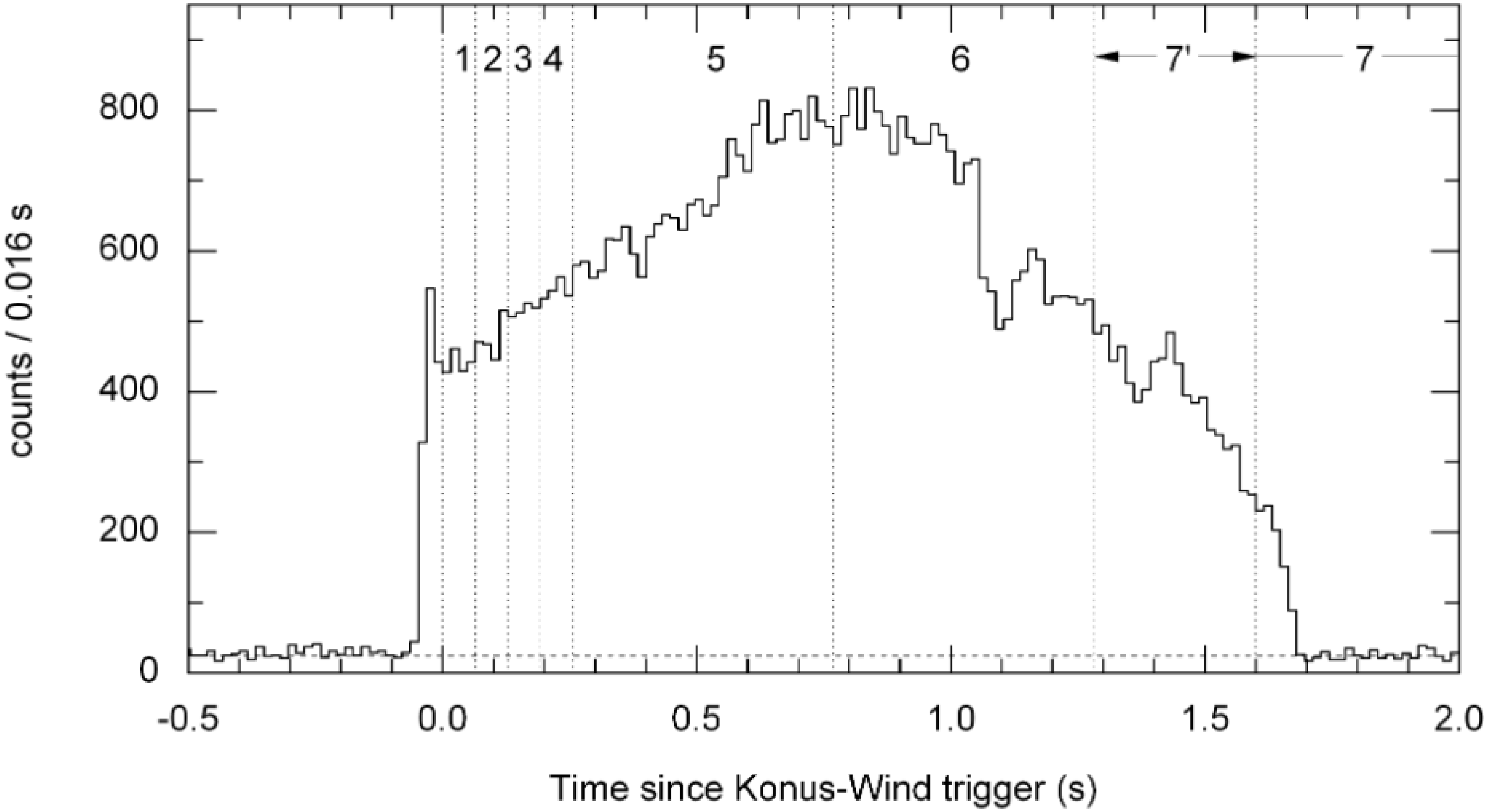
MAGNETOSPHERE OR OUTER SHOCKS?



Zhang 2020 (Nature)

SGR 1935+2154

Discovered in 2014 (see, Israel et al. 2016).
P=3.25 sec
Distance ~7-12 kpc (2005.03517)
Intermediate flare (Kozlova et l. 2016)



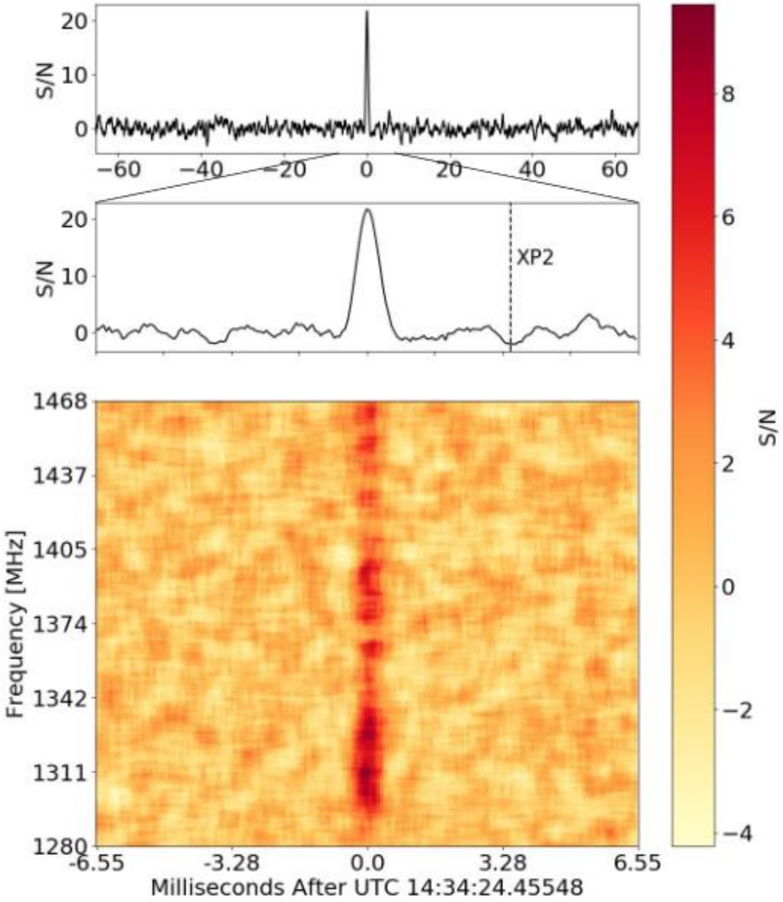
Activated in April 2020.
Finally, on April, 28 2020
A simultaneous burst
in radio and X/gamma
was detected.

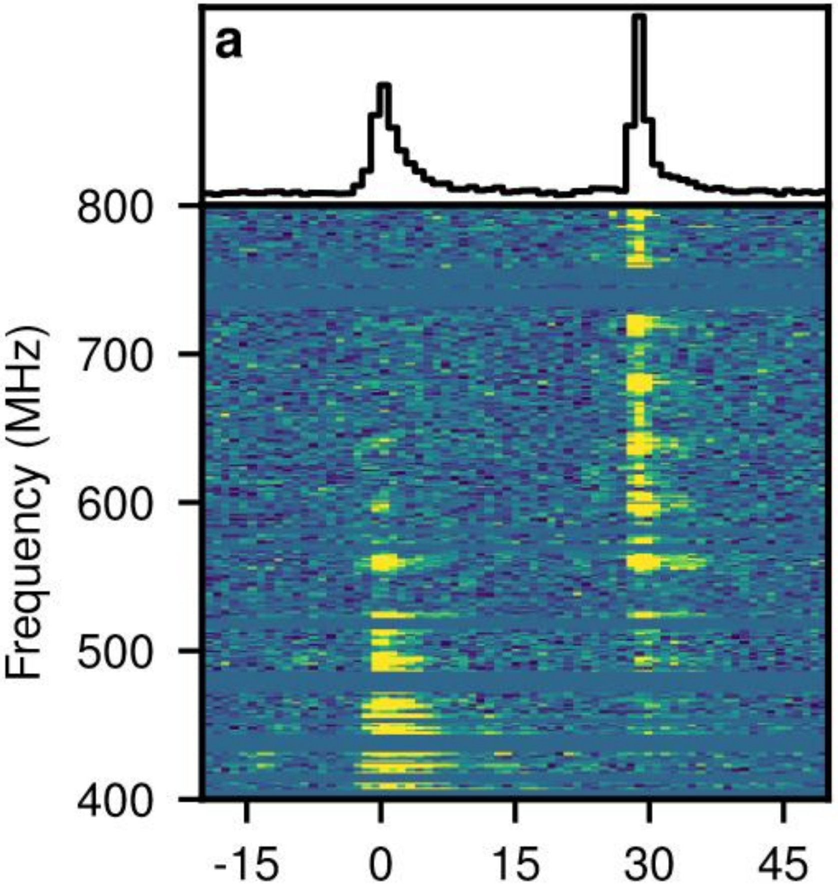
astronomerstelegram: 13681-13769

GCN: 27666-27669

STARE2 AND CHIME DATA

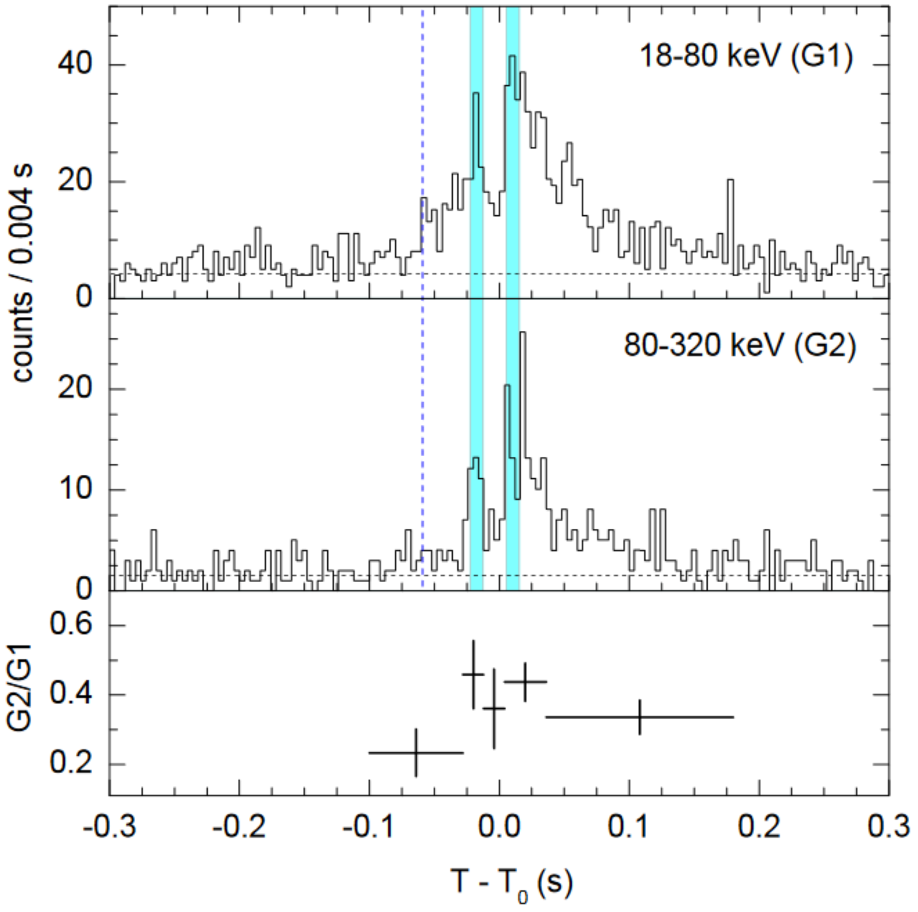
2005.10828

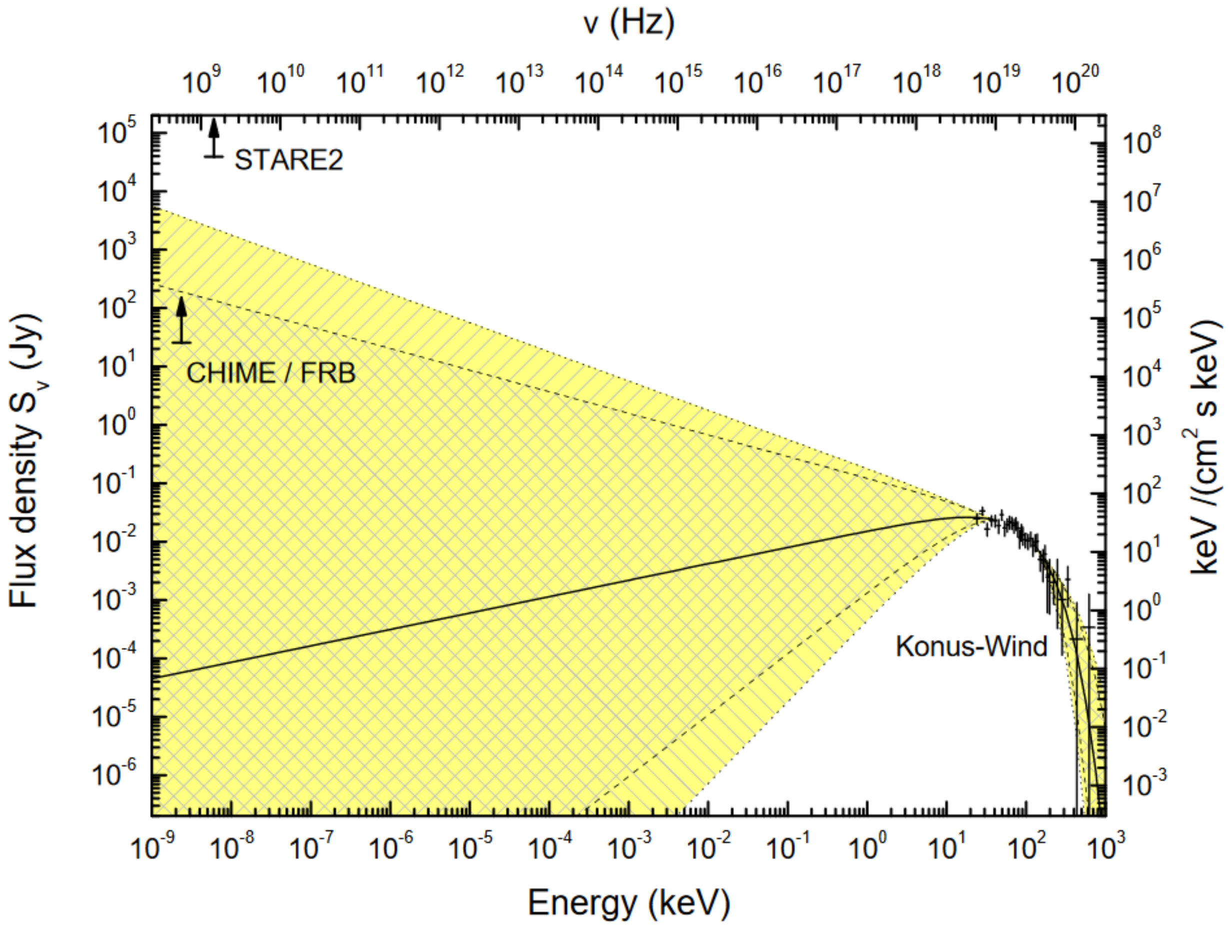




2005.10324

KONUS-WIND DATA



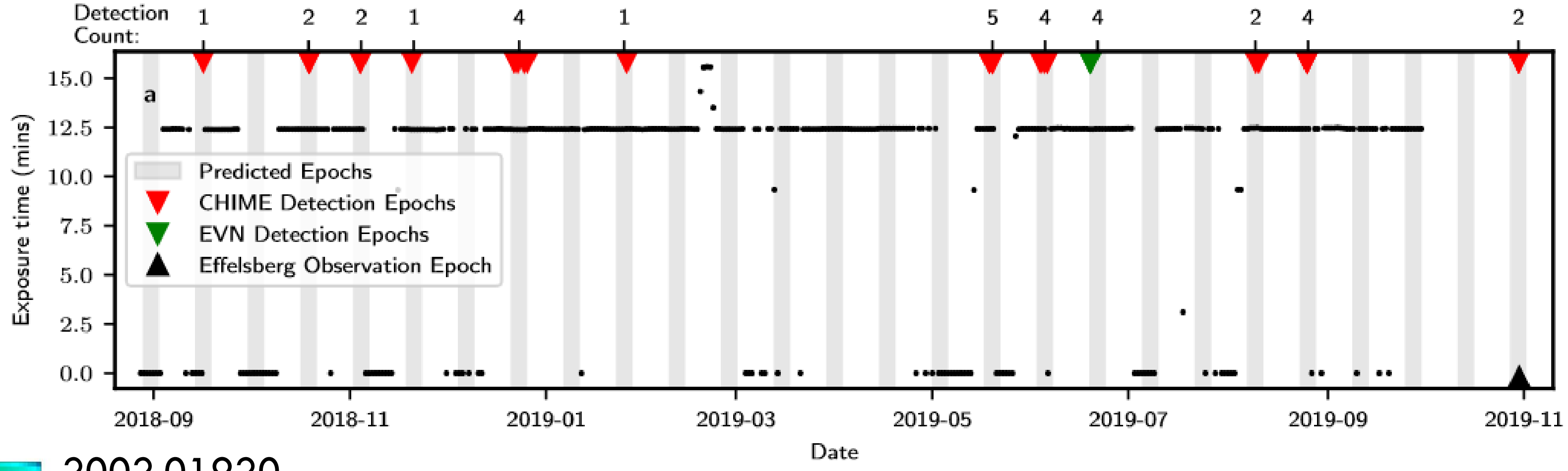


2005.11178

FRBS IN BINARIES?

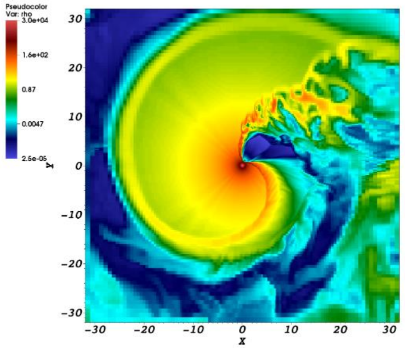
FRB 180916.J0158+65
CHIME (+Effelsberg)

The source is localized
in a near-by massive spiral galaxy.
Period ~16.35 days.

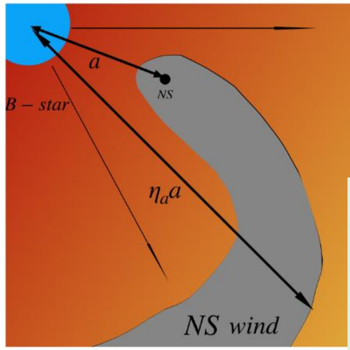


2001.10275

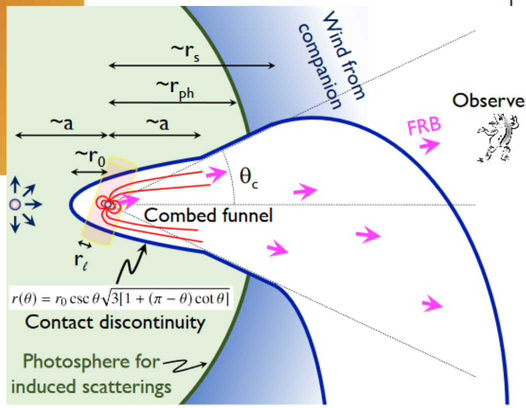
Ideas:
- Binary system
- Precession
- Long spin periods

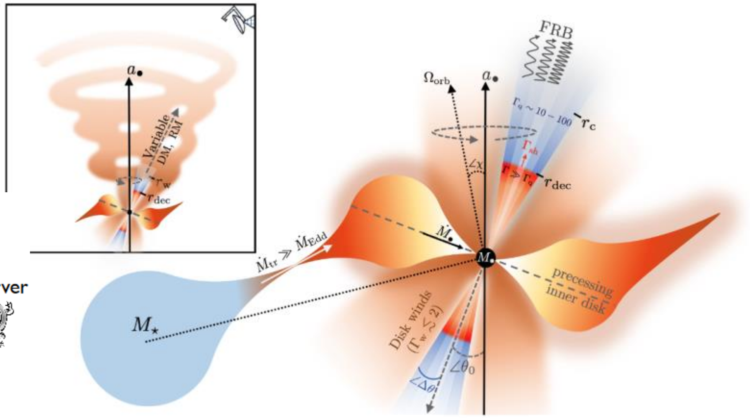


2002.01920



2002.08297

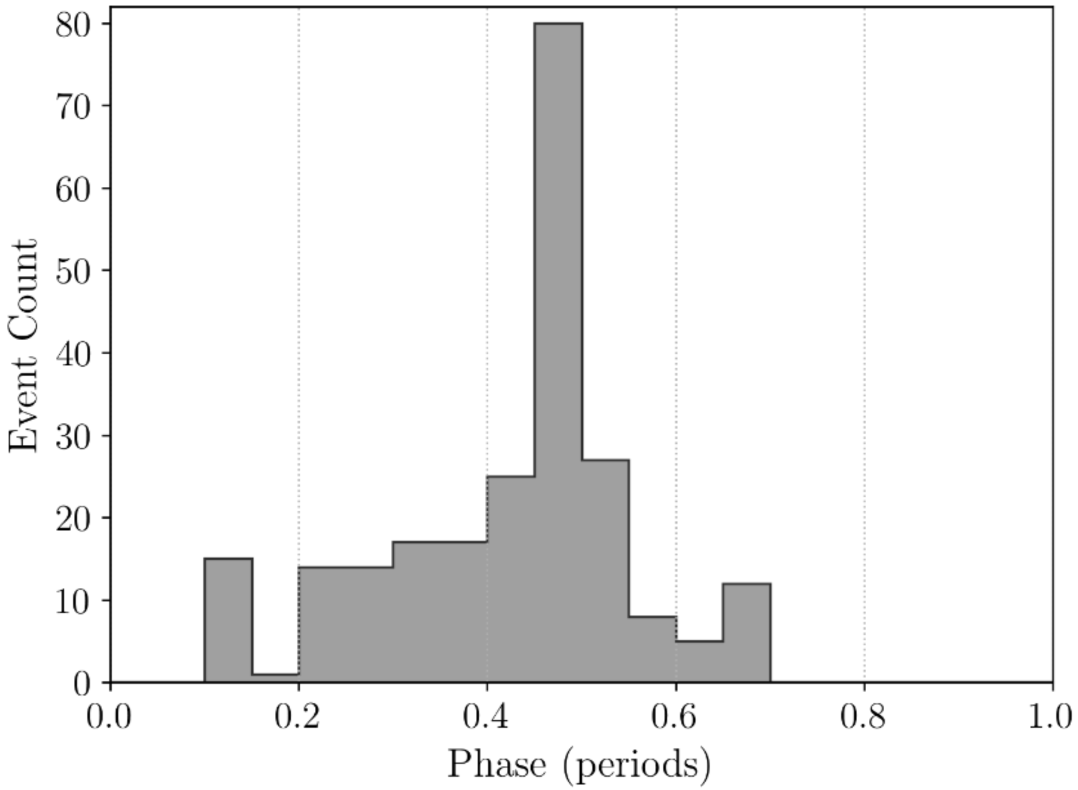


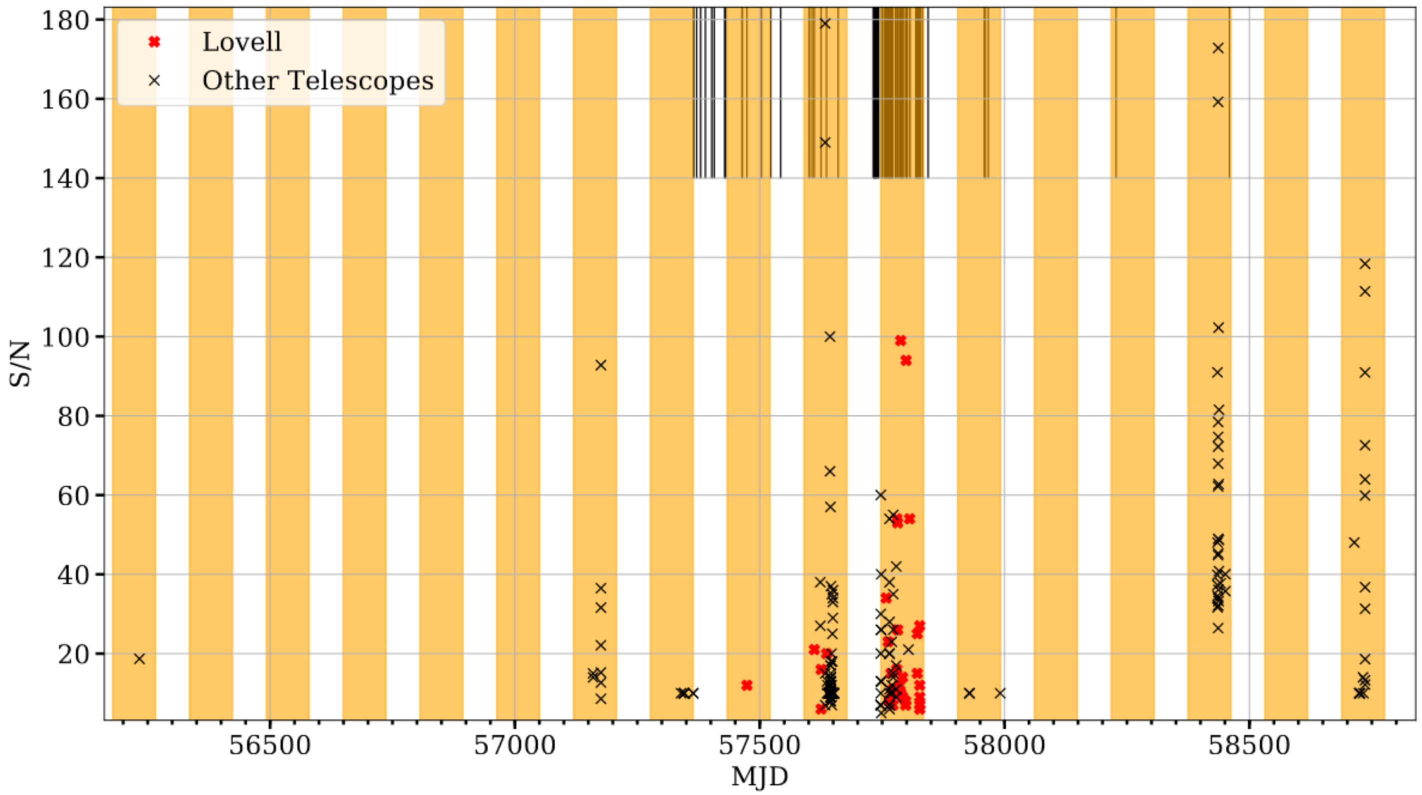


2102.06138

Extreme magnetars in periodic FRBs
with high rate or repetition can be formed from
rapidly rotating cores which have been tidally synchronized
on very late stages of the progenitor evolution (2006.13037).

157 DAY PERIODICITY OF FRB 121102



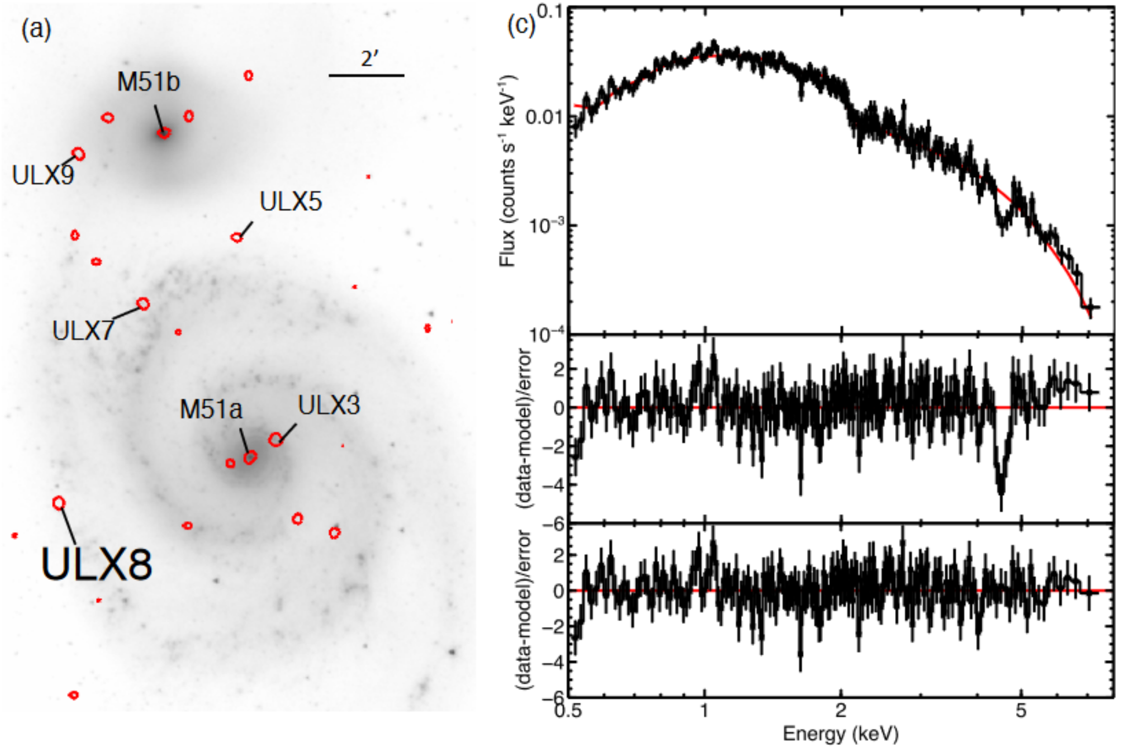


2003.03596, see also 2008.03461

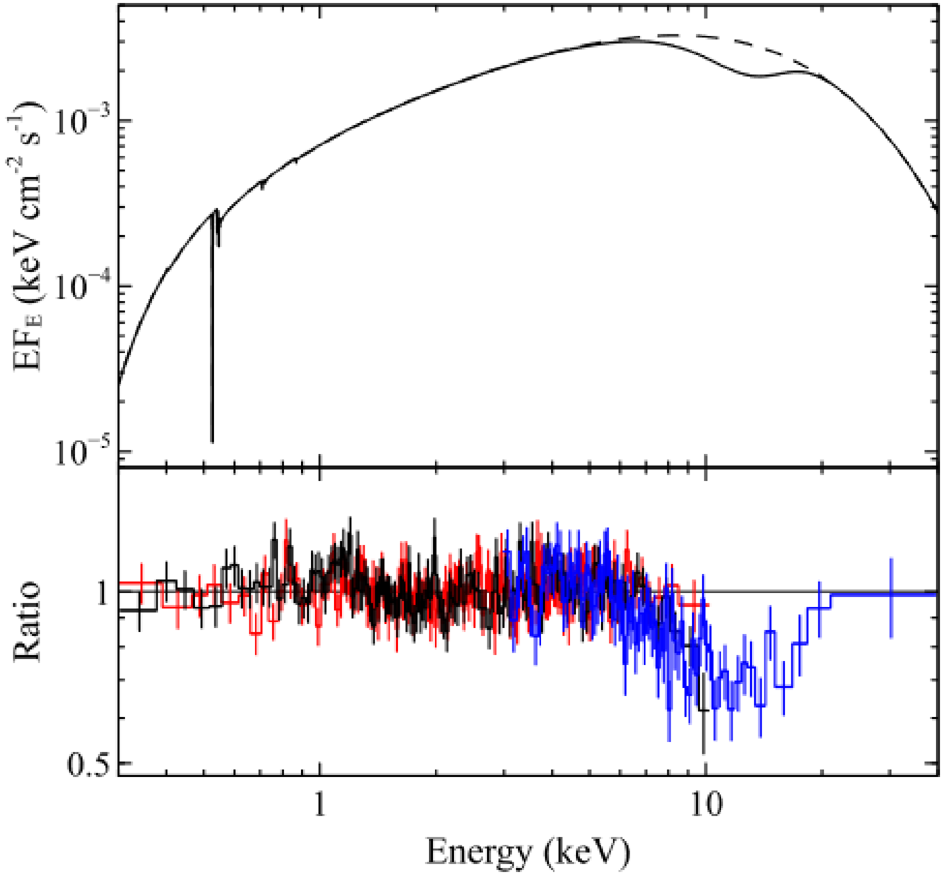
SEARCHING FOR EVIDENCE. I. CYCLOTRON LINES

ULX in M51
If electrons cyclotron – then B~ 6 10^{11} G.
But the line is too narrow.
If proton cyclotron – then B~ 7 10^{14} G.

Brightman et al. 1803.02376



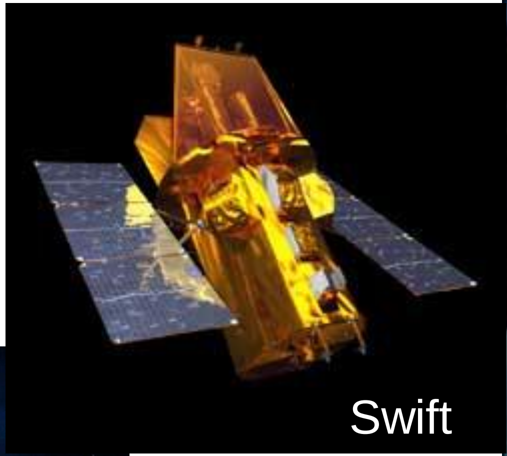
NGC 300 ULX
Electron cyclotron lime: B~10^{12} G.

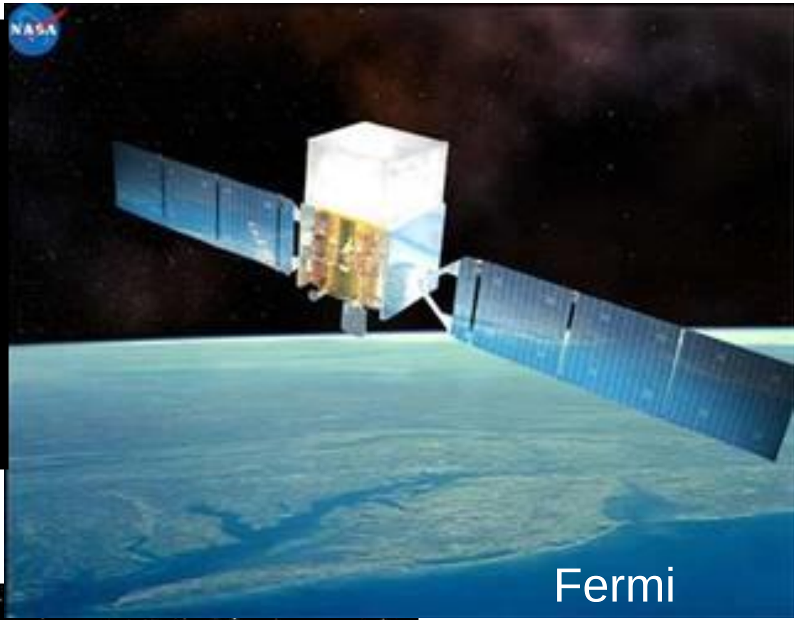


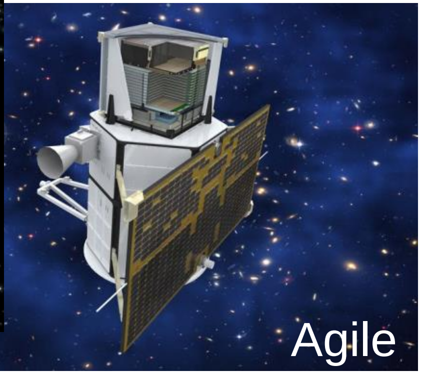
Walton et al. 1803.07571

SEARCHING FOR EVIDENCE. II. MAGNETAR ACTIVITY

Continuous monitoring of high energy flares is going on thanks to many space detectors.

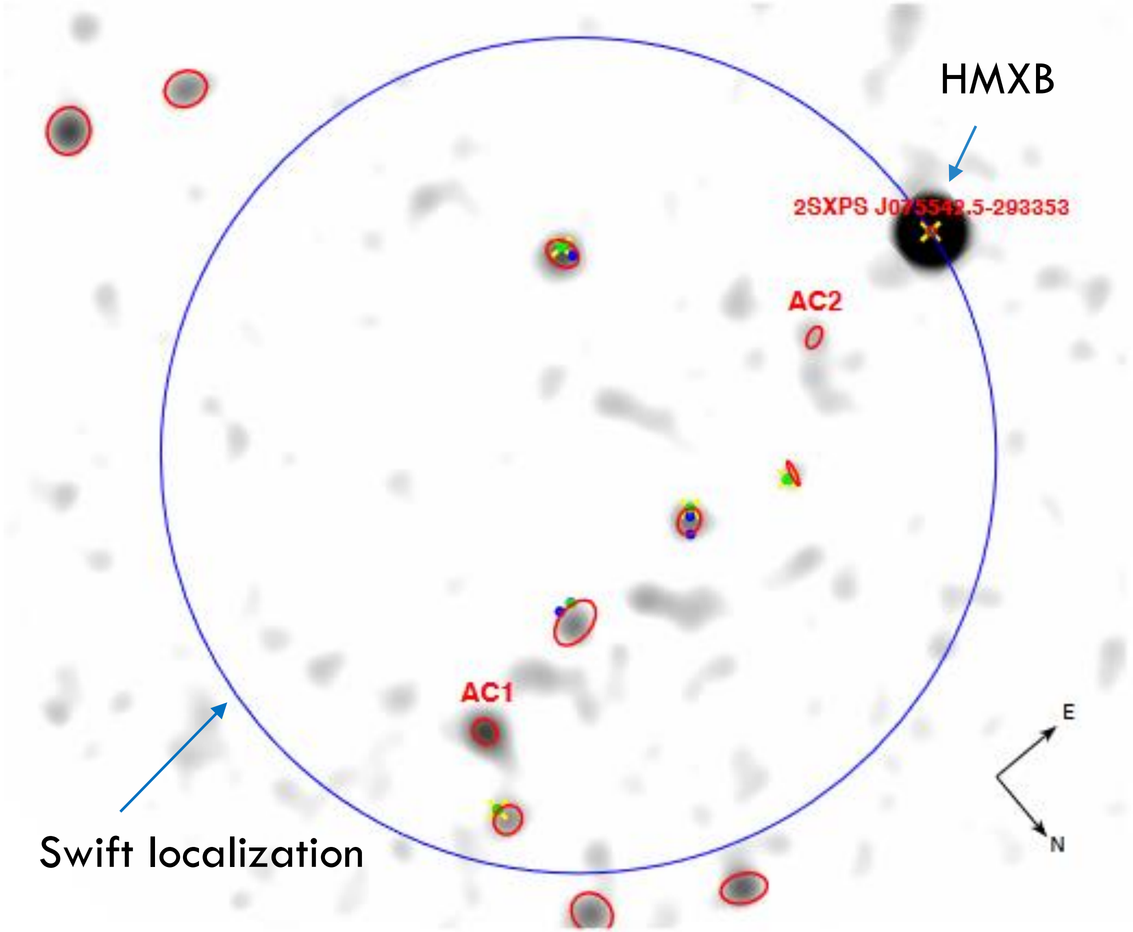






THE FIRST EXAMPLE?

SGR 0755−2933

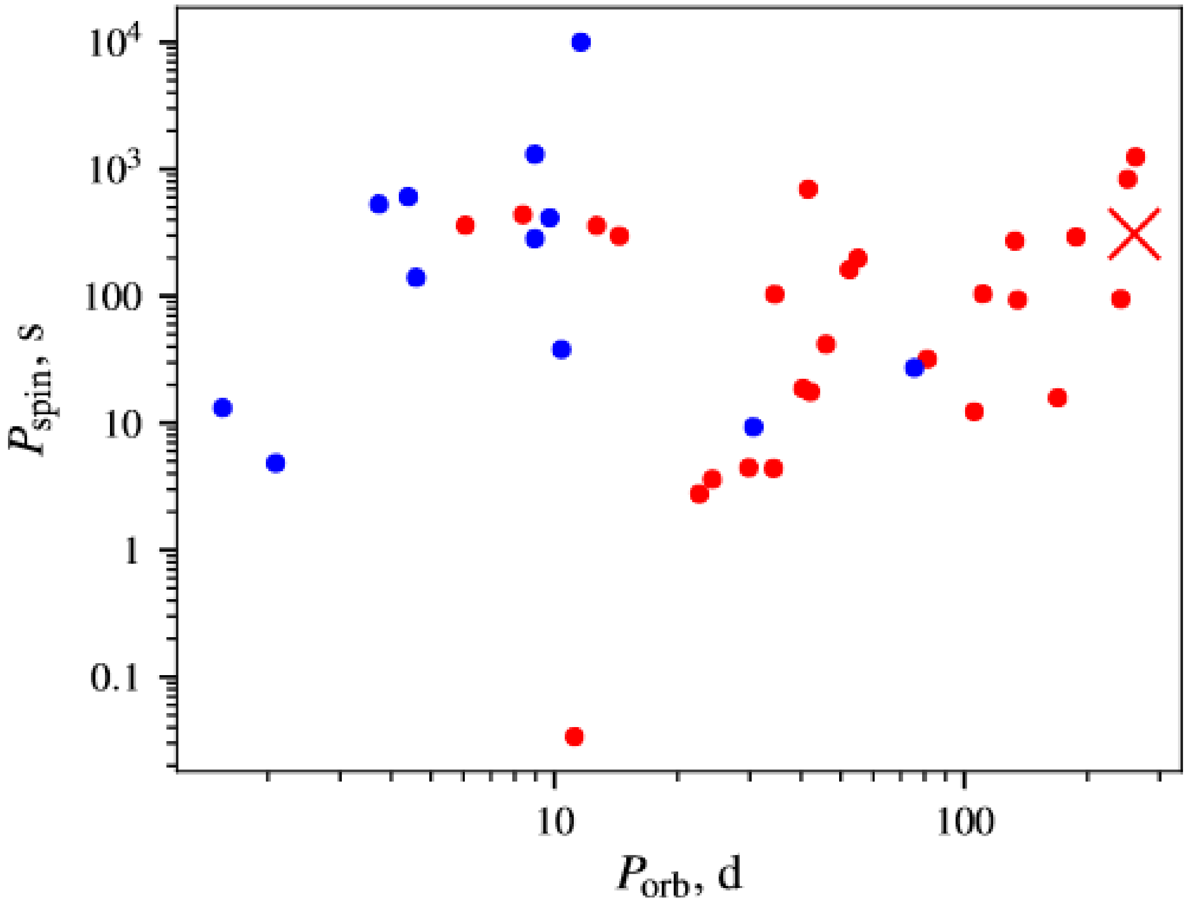


HMXB

Swift localization

One 30 msec burst detected by Swift in 2016

Coincident with a HMXB.

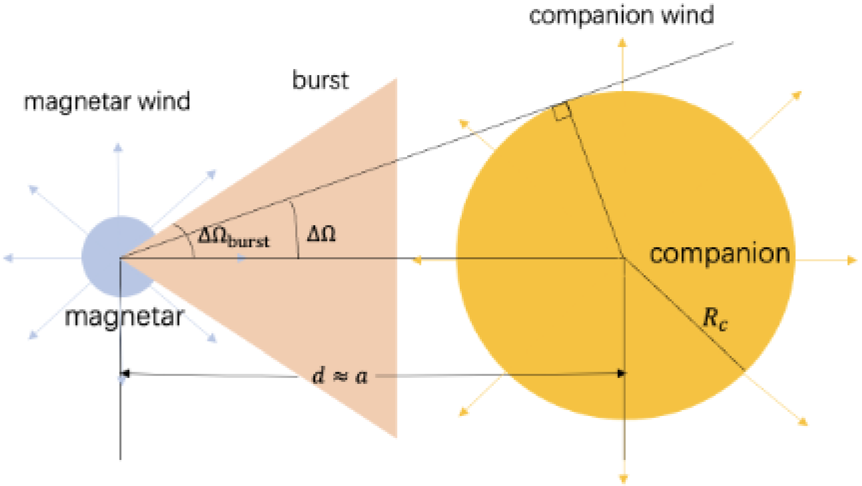


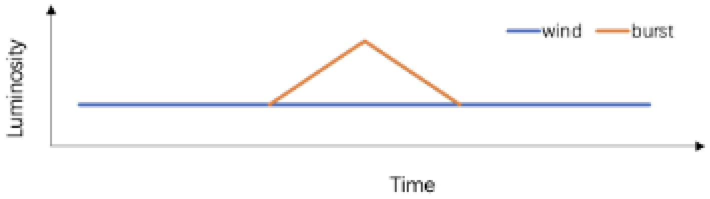
See 2302.00027 about the evolution of this system

Doroshenko et al. 2101.10834

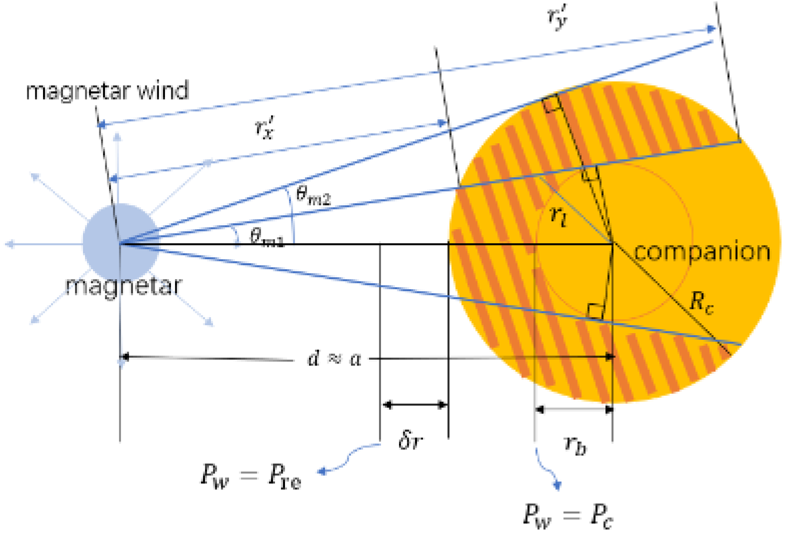
2405.10791

INFLUENCE ON THE COMPANION

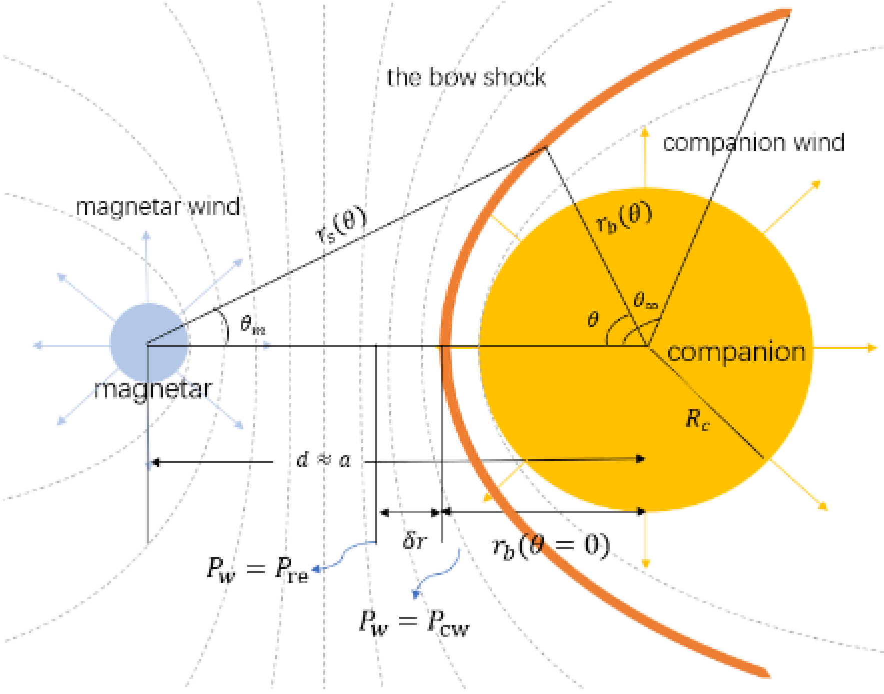




- Young magnetars: persistent wind
- Old magnetars: bursts



(a)



(b)

LSST can detect optical emission due to magnetar bursts from the Galactic sources.
For giant flares: ~ 1-day “afterglow”
For weak bursts: ~ fraction of a second only.

(UNCERTAIN) CONCLUSIONS

Still, we are not sure
if there are magnetars
in binary systems.

Some evidence exists,
but definite proof is lacking.
Also, formation mechanism and
evolution are uncertain.

Important for:

- origin of magnetars;
- field evolution;
- accretion physics;
- FRBs.

Perspectives:

Detection of activity – ultimate proof
for REAL magnetars in binaries.

Are there relatively old (few Myrs) NSs
with large fields, but no magnetar-like activity?

2201.07507