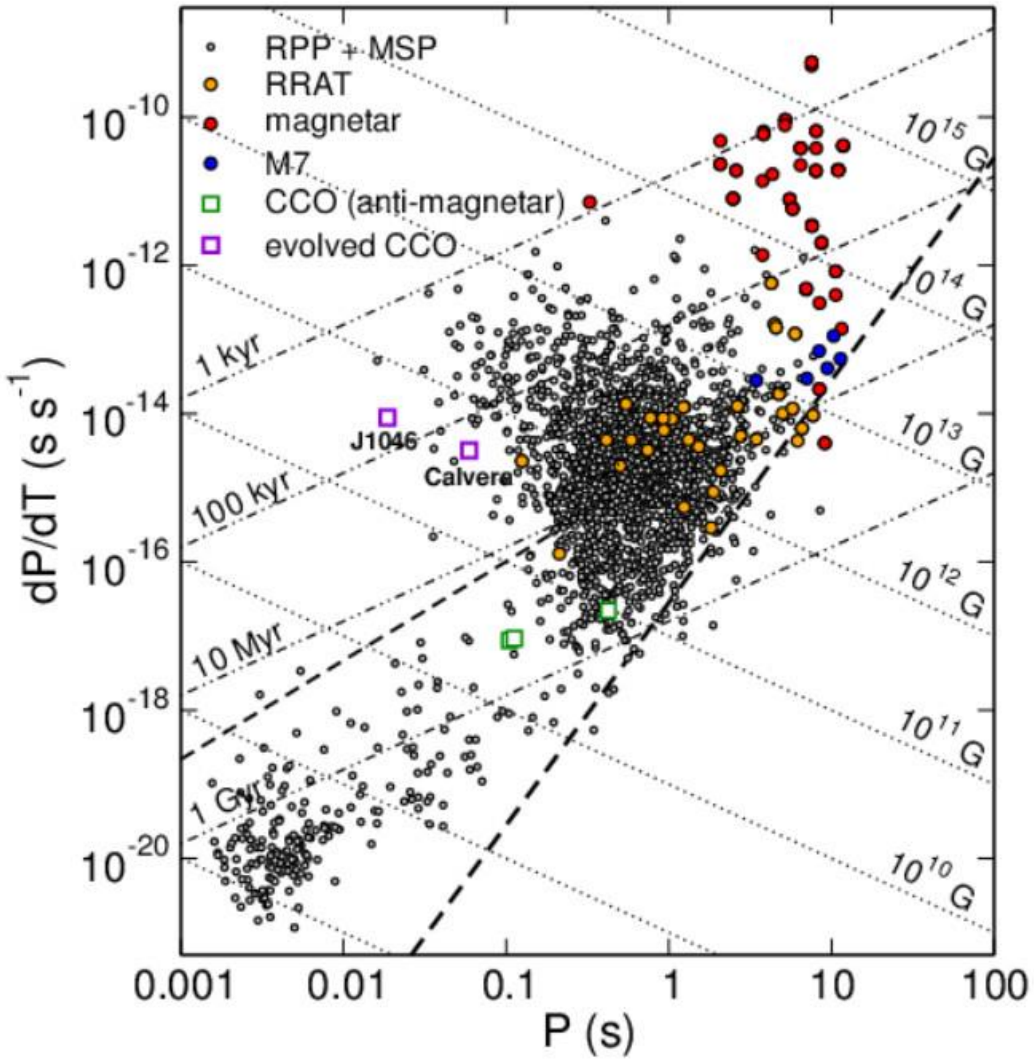
2201.07507

HIGH MAGNETIC fiELD NSS IN BINARY SYSTEMS

Sergei Popov

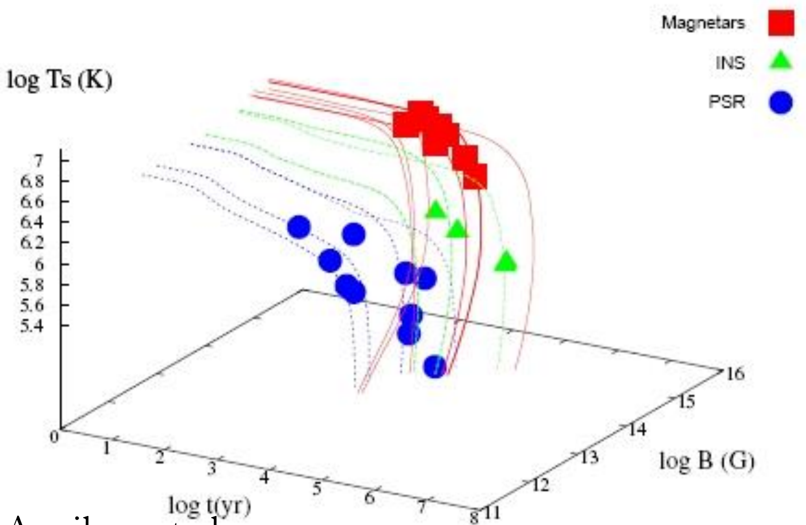
DIVERSITY OF NEUTRON STARS

Pires et al. 2015

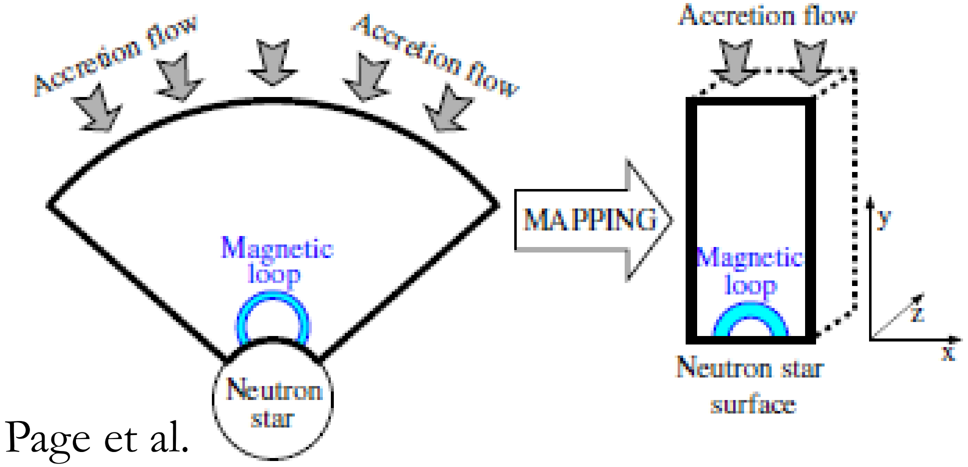


During last ~15 years many attempts have been made to build a model of “GRAND UNIFICATION FOR NEUTRON STARS”.

MAIN INGREDIENTS OF A UNIFIED MODEL: MAGNETIC FIELD EVOLUTION

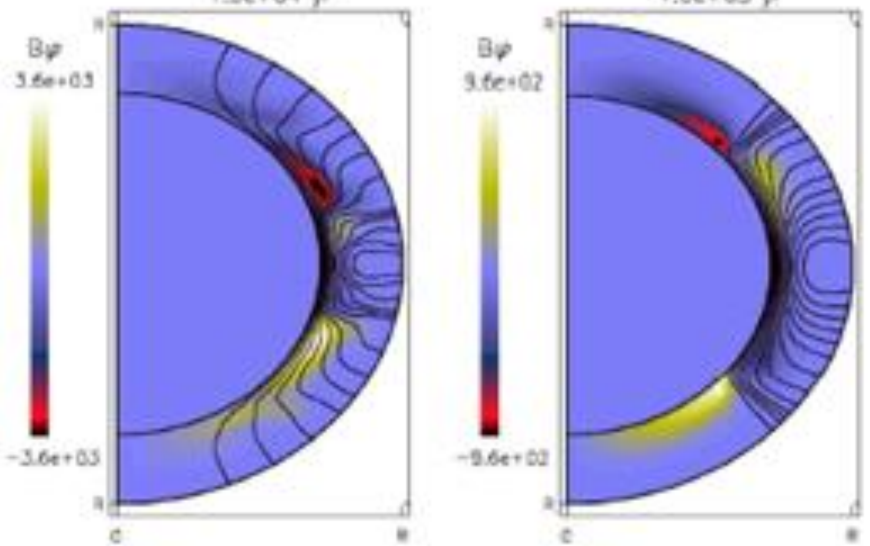


Aguilera et al.

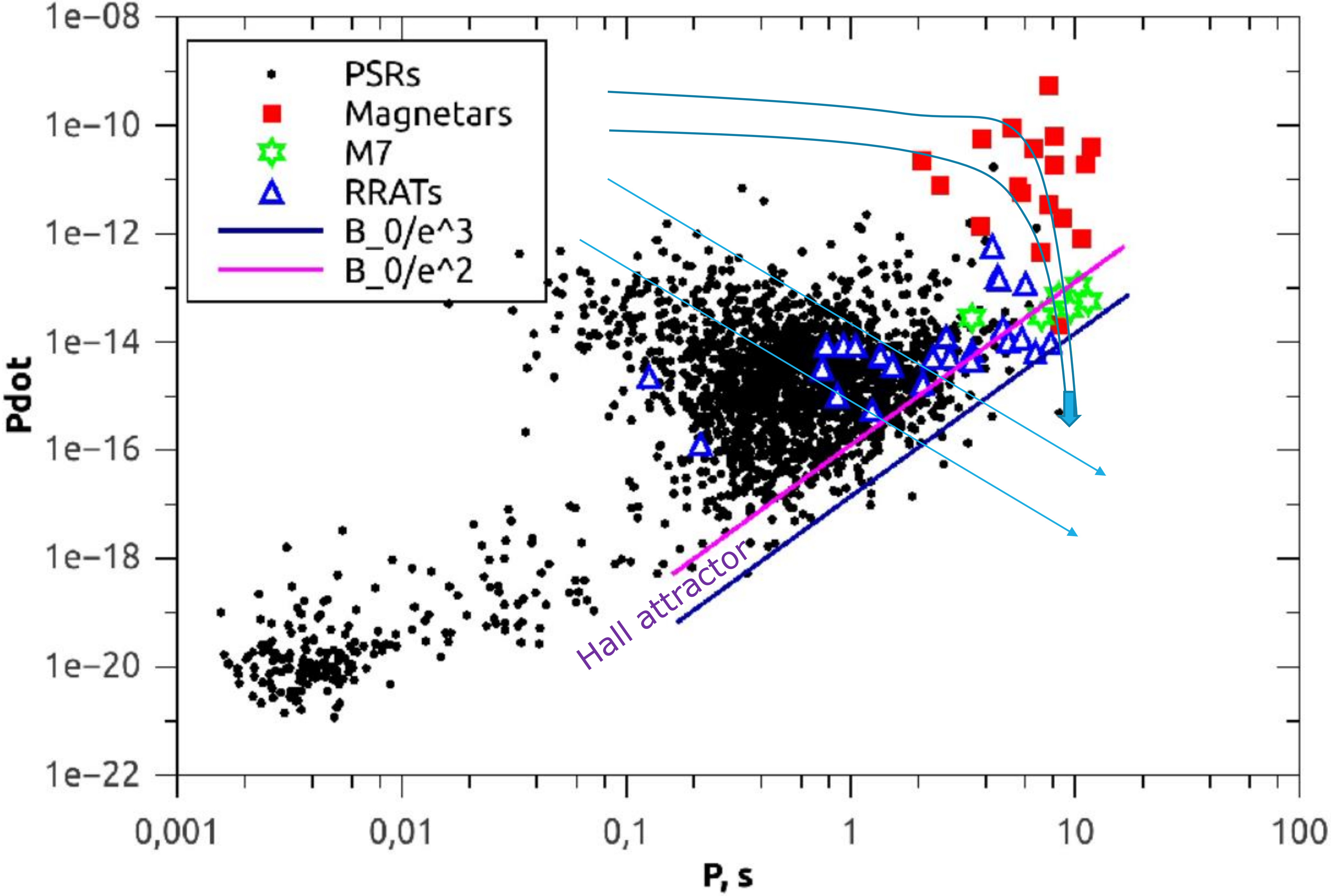


Page et al.

Pons et al.



- Field decay
  - Emerging magnetic field
    - Magnetic field topology

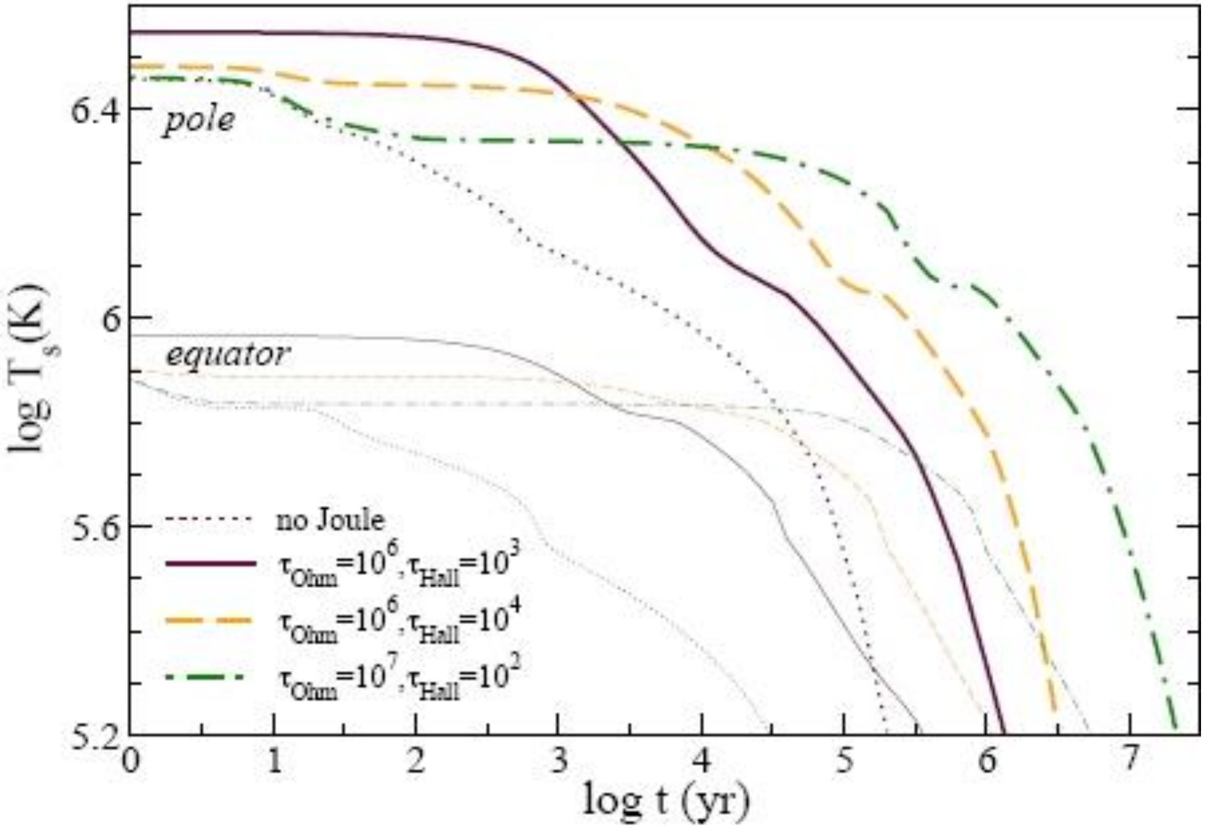


PSRs
Magnetars
M7
RRATs
B_0/e^3
B_0/e^2
Hall attractor
1e−08
1e−10
1e−12
1e−14
1e−16
1e−18
1e−20
1e−22
Pdot
0,001
0,01
0,1
1
10
100
P, s

MAGNETIC FIELD DECAY VS. THERMAL EVOLUTION

Magnetic field decay can be an important source of NS heating.

arxiv:0710.0854 (Aguilera et al.)



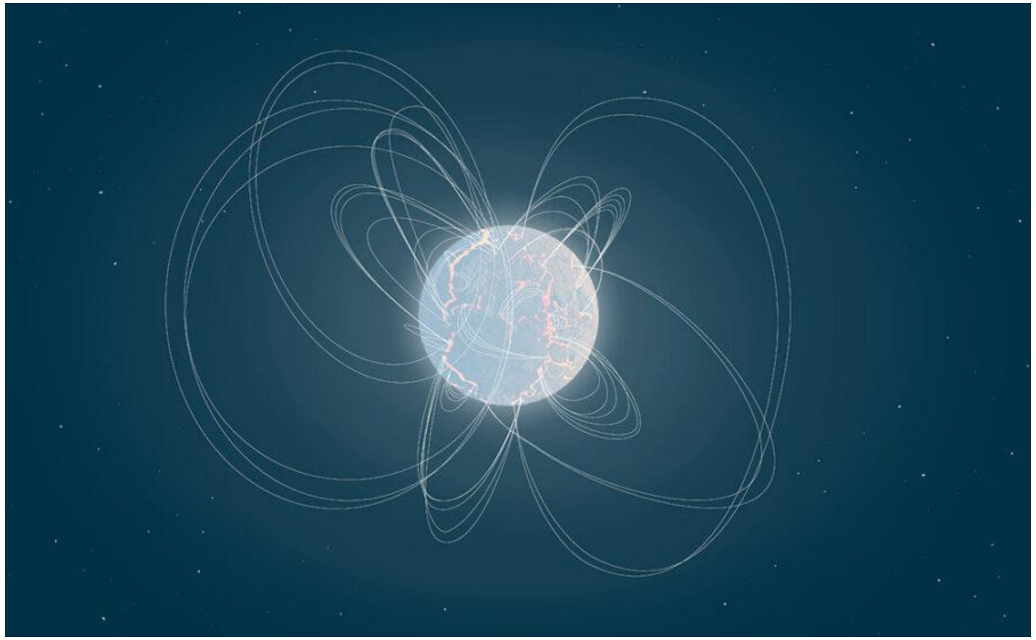
Ohm and Hall decay

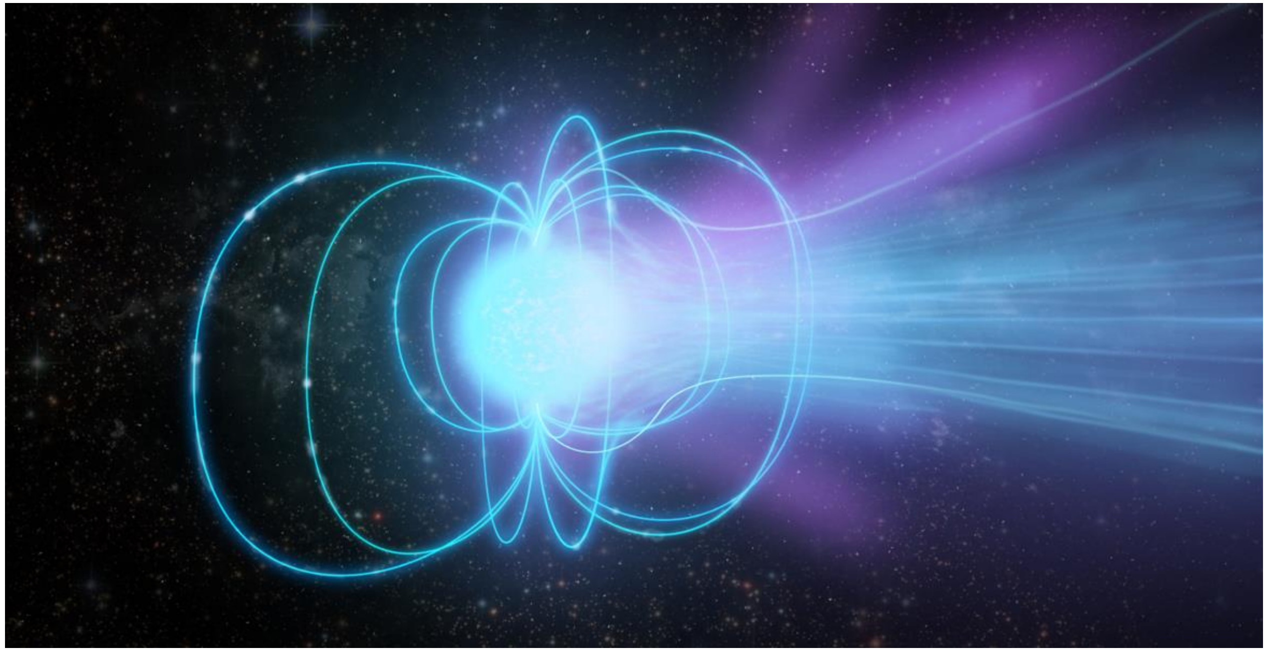
Heat is carried by electrons.
It is easier to transport heat along field lines. So, poles are hotter.
(for light elements envelope the situation can be different).

$$B = B_0 \frac{\exp(-t/\tau_{\text{Ohm}})}{1 + \frac{\tau_{\text{Ohm}}}{\tau_{\text{Hall}}}(1 - \exp(-t/\tau_{\text{Ohm}}))}$$

WHAT DO WE CALL “A MAGNETAR”?

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



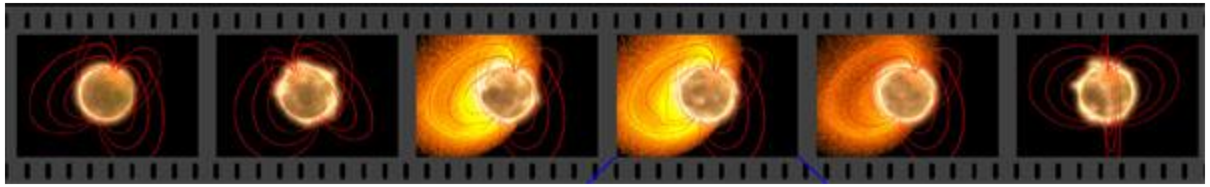


Or it is necessary to have dominance of magnetic energy release in the total energy budget of the source?

<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



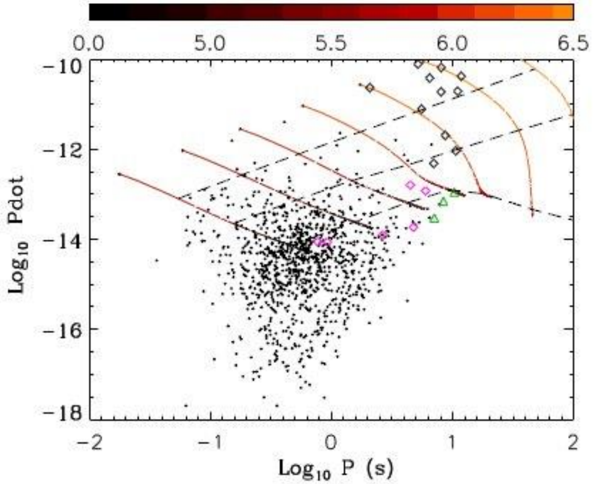
McGill on-line catalogue lists ~30 magnetars.
All of them are isolated objects.
However, an existence of a binary companion (except cases of accretion on a compact object) hardly can prevent detection of an SGR flare, and the expected number of NSs in binaries is not as small as ~3%.

See, however, the talk by A. Chrimes

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.

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

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

advection Ohm Hall

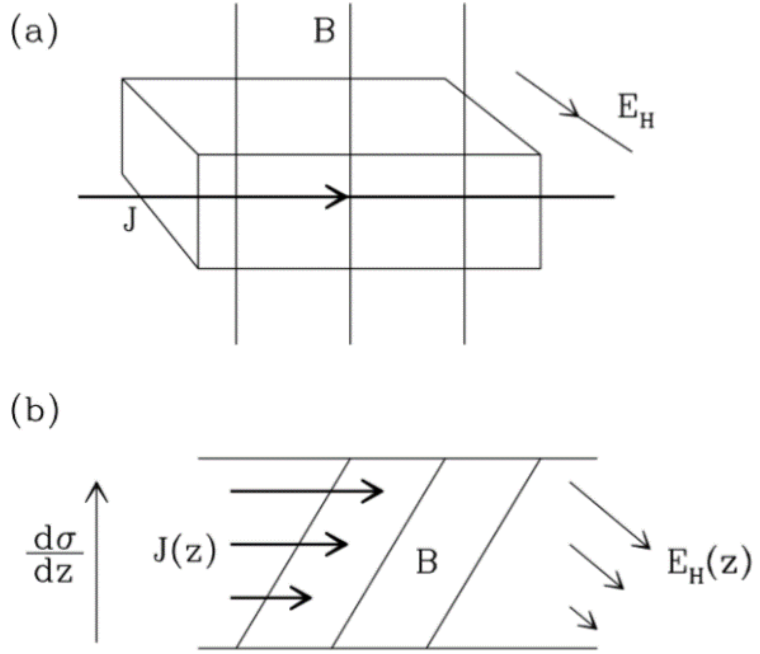
$$E = -\frac{1}{c} v \times B + \frac{J}{\sigma} + \frac{J \times B}{n_e e c},$$

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

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

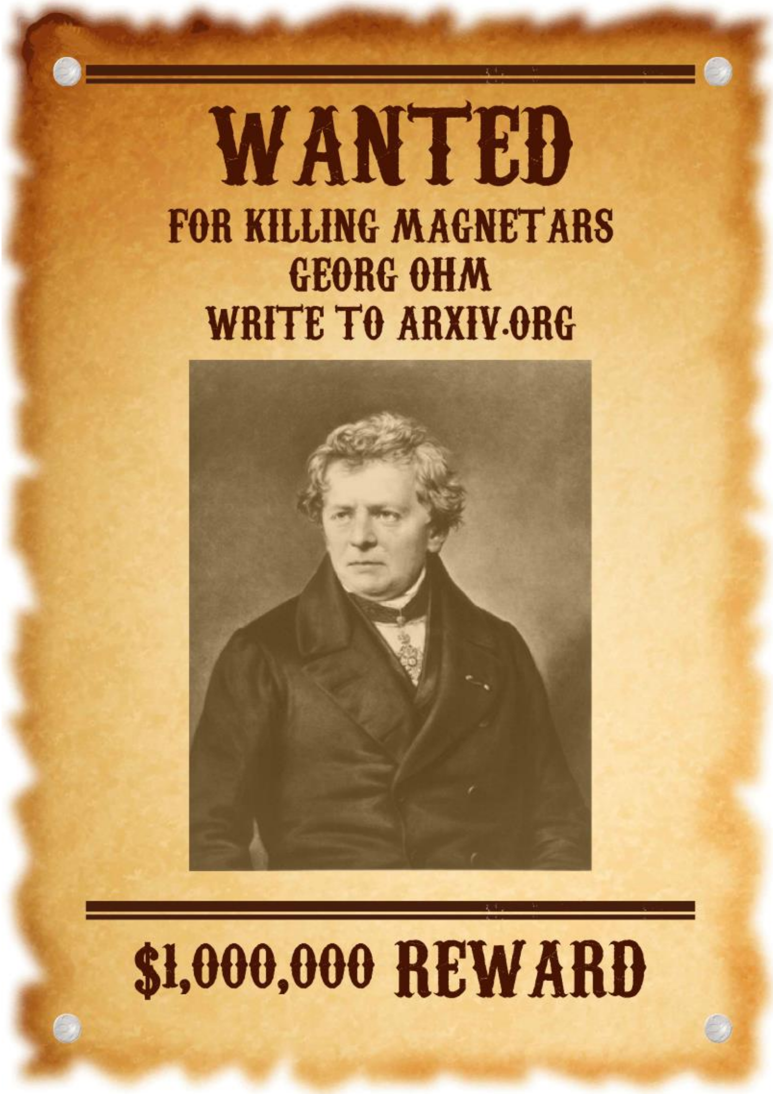
With only Hall term we have:

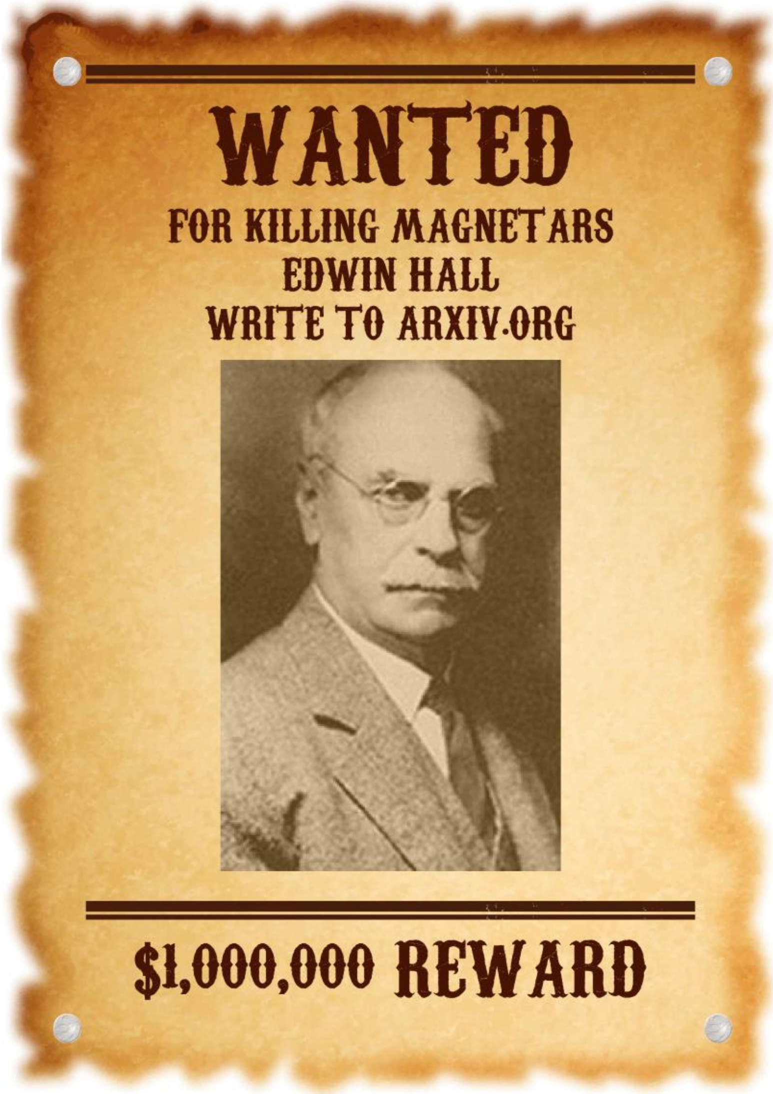
$$\frac{\partial B}{\partial t} = -\nabla \times \left(\frac{J \times B}{n_e e}\right), \qquad t_{\rm Hall} = \frac{n_e e L}{J} = \frac{4\pi n_e e L^2}{cB},$$



astro-ph/0402392

WHO IS KILLING MAGNETARS?

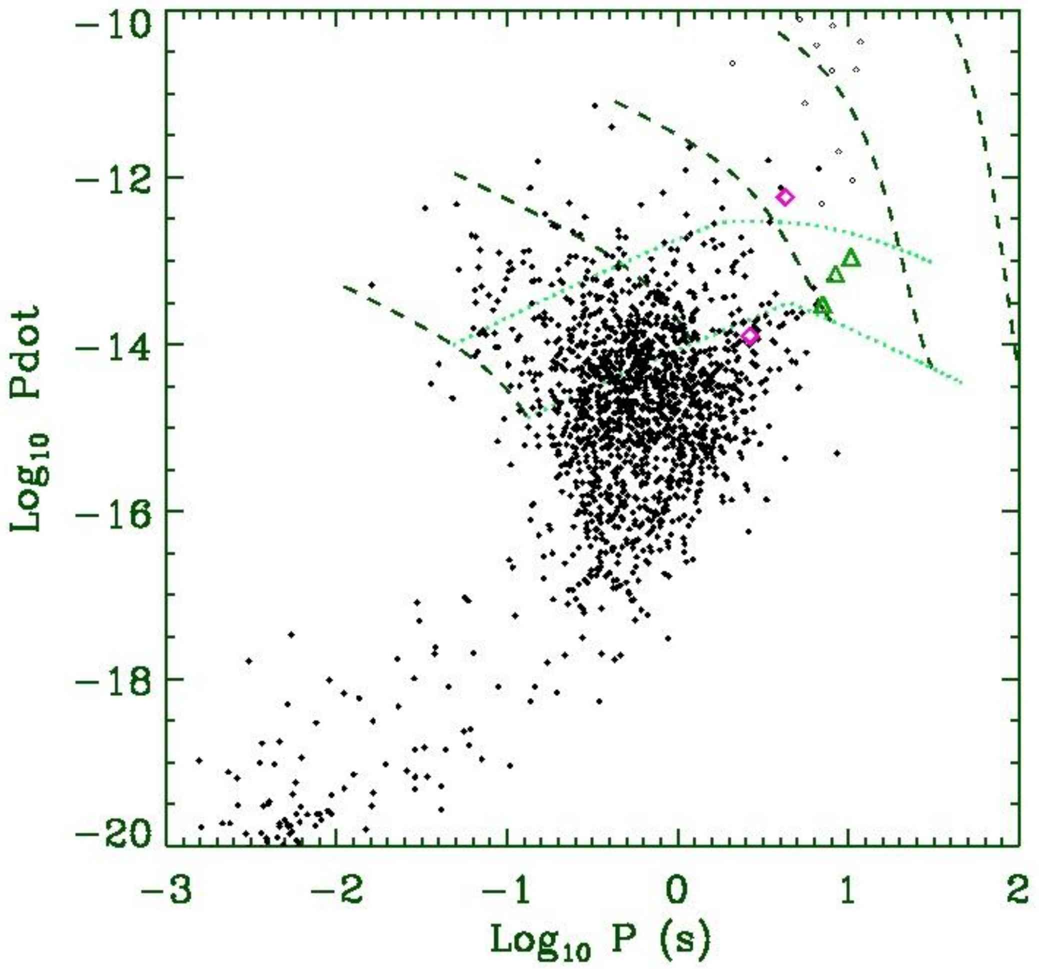




To have reasonable number of magnetars in e.g. X-ray binaries we need to terminated field decay while fields are relatively high, as typical ages of binaries are large in comparison with the decay time scale.

STOP HALL AND SLOW DOWN OHM!

P-PDOT DIAGRAM AND FIELD DECAY



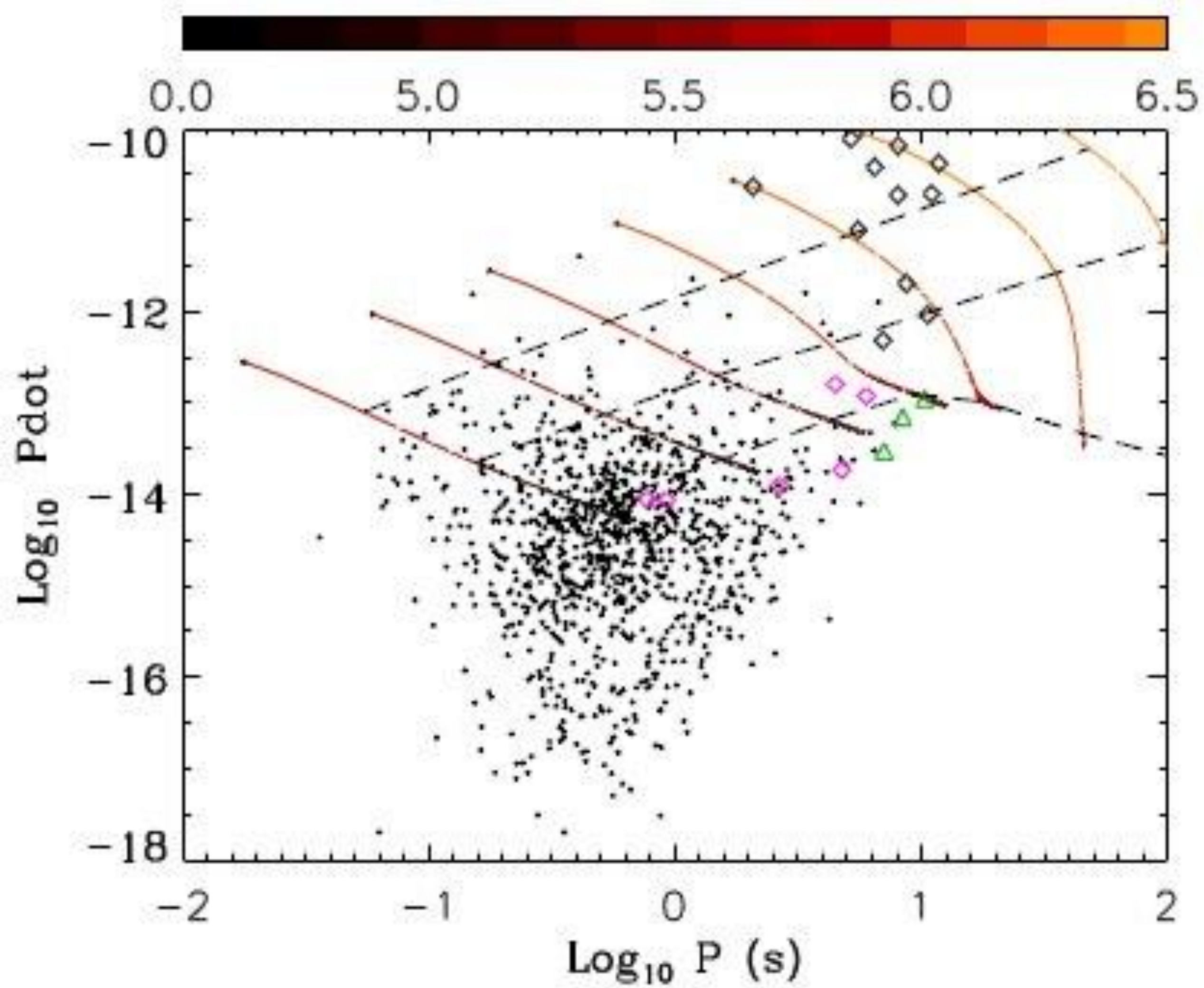
Chashkina, Popov 2012. arXiv: 1112.1123

$$B = B_0 \frac{\exp\left(-t/\tau_{\rm Ohm}\right)}{1 + \frac{\tau_{\rm Ohm}}{\tau_{\rm Hall}}\left(1 - \exp\left(-t/\tau_{\rm Ohm}\right)\right)}$$

$T_{Ohm}=10^6$ yrs
$T_{Hall}=10^4/(B_0/10^{15}\ \mathrm{G})$ yrs

REALISTIC TRACKS

Popov et al. MNRAS 2010



Using the model by Pons et al. (arXiv: 0812.3018) we plot realistic tracks for NS with masses 1.4 Msolar.

Initial fields are:
$3\ 10^{12}$, 10^{13}, $3\ 10^{13}$, 10^{14},
$3\ 10^{14}$, 10^{15}

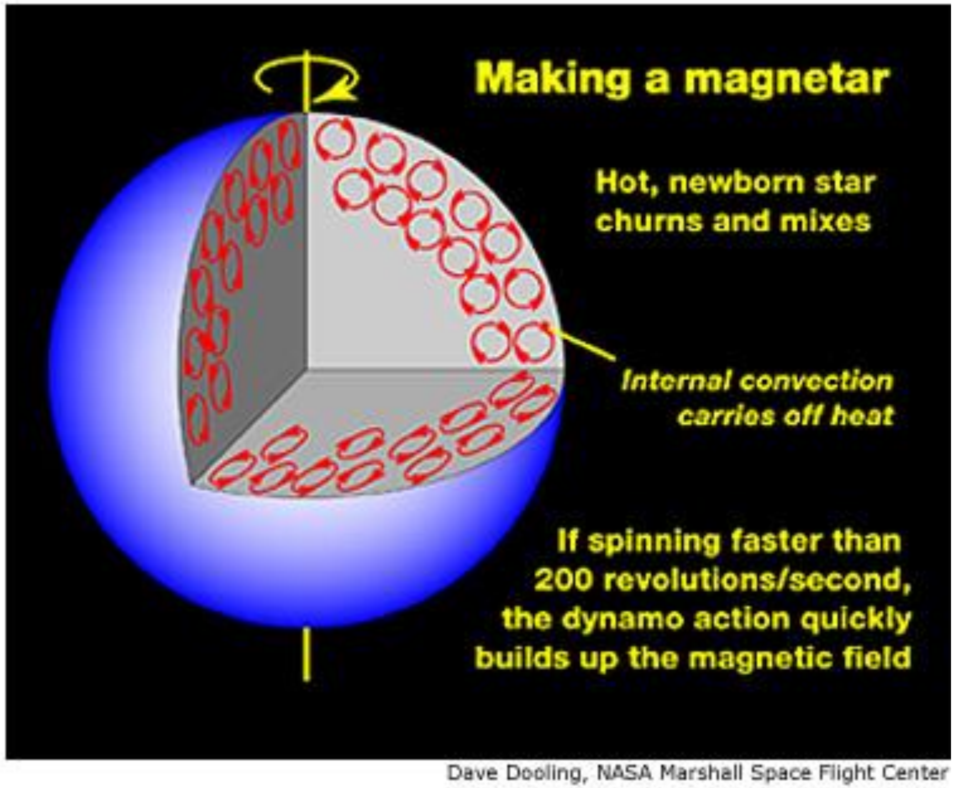
Color on the track encodes surface temperature.

Tracks start at 10^3 years, and end at $2\ 10^6$ years.

See newer calculations in Gullon et al.

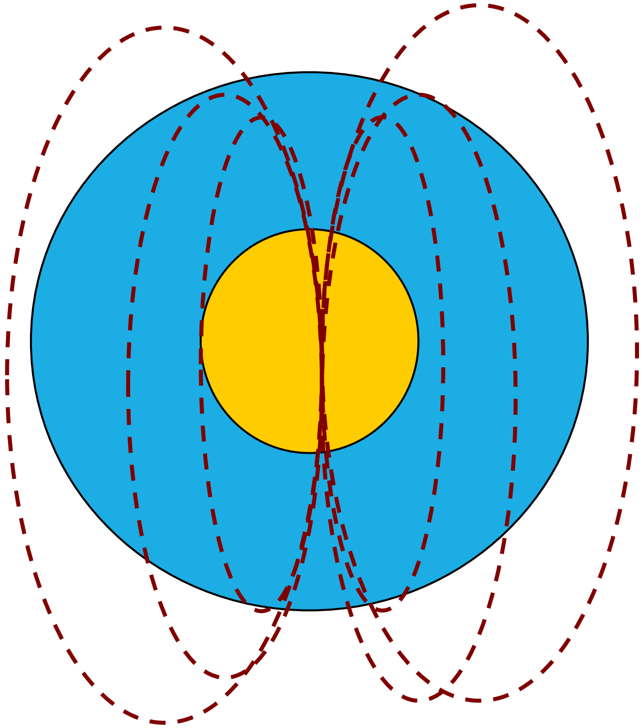
ORIGIN OF MAGNETARS FIELD

Generated



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 perform population
synthesis calculations.

A QUESTION:

Why do all magnetars are isolated?

- 5-10 % of NSs are expected to be binary (for moderate and small kicks)
- All known magnetars (or candidates) are single 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

1405.3109

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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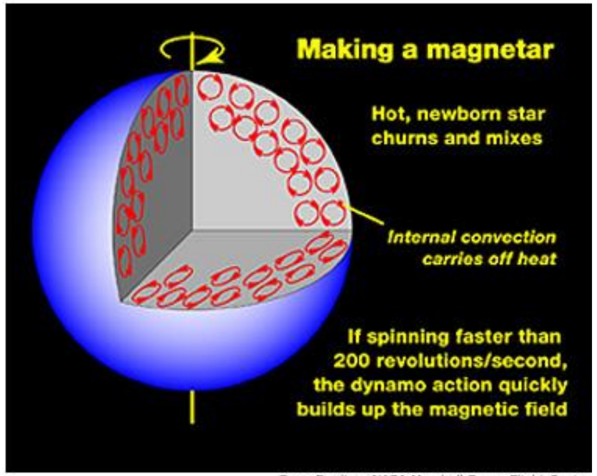
Preprint online version: May 14, 2014

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 $\geq 40 M_\odot$, 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 ($\sim 41 M_\odot + 35 M_\odot$) 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.

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	$\alpha_q = 0$ all	$\alpha_q = 0$ binary magnetars	$\alpha_q = 2$ all	$\alpha_q = 2$ 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%

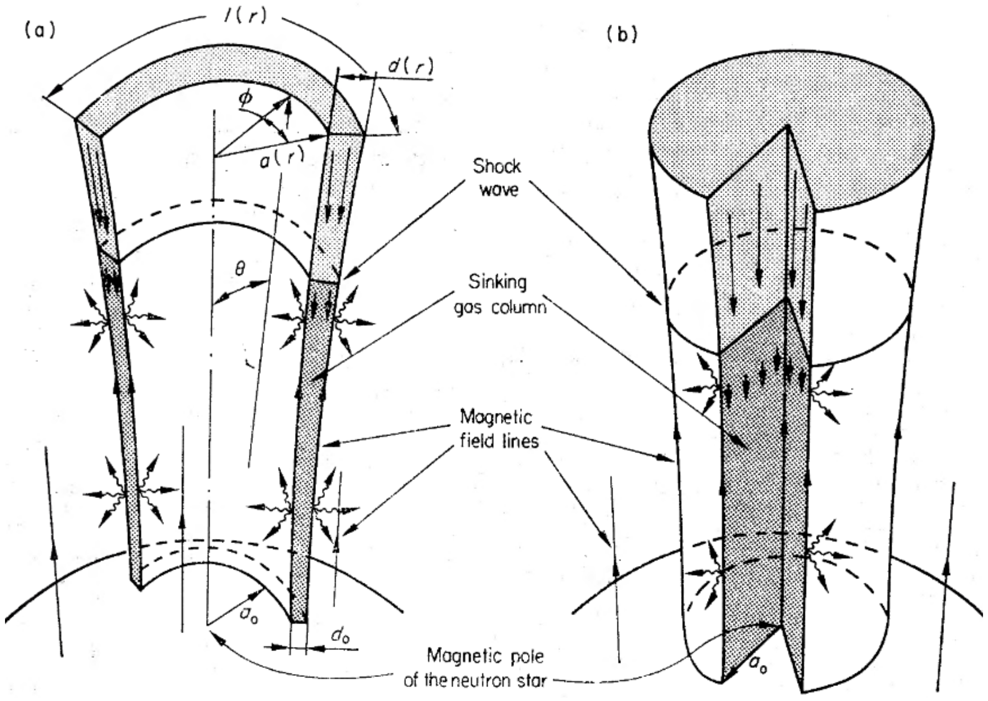
Popov, Prokhorov 2006

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

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

WHY DO WE NEED MAGNETARS, SOMETIMES?

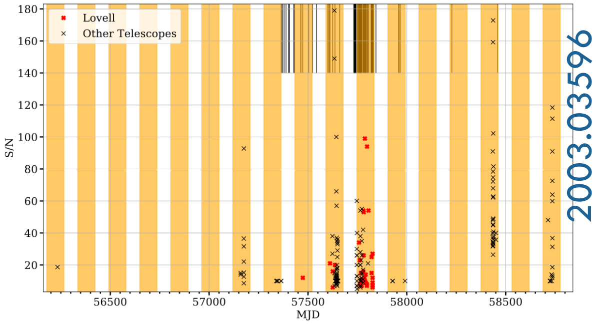
Large luminosity



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

Spin properties

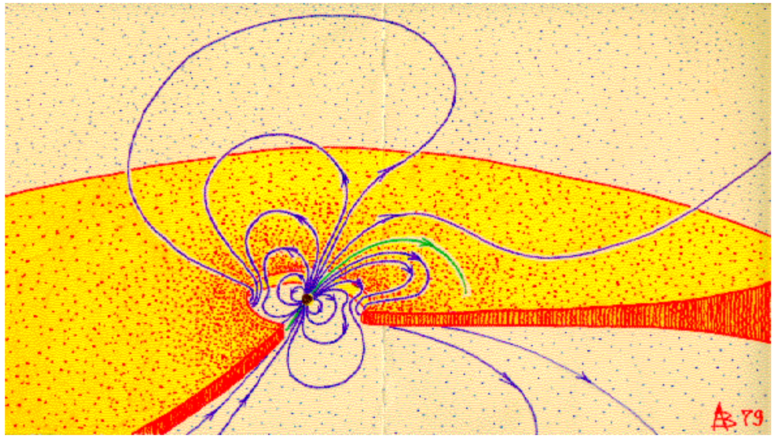
+ FRBs with long periodicity?



2003.03596

Large magnetic fields can result in:

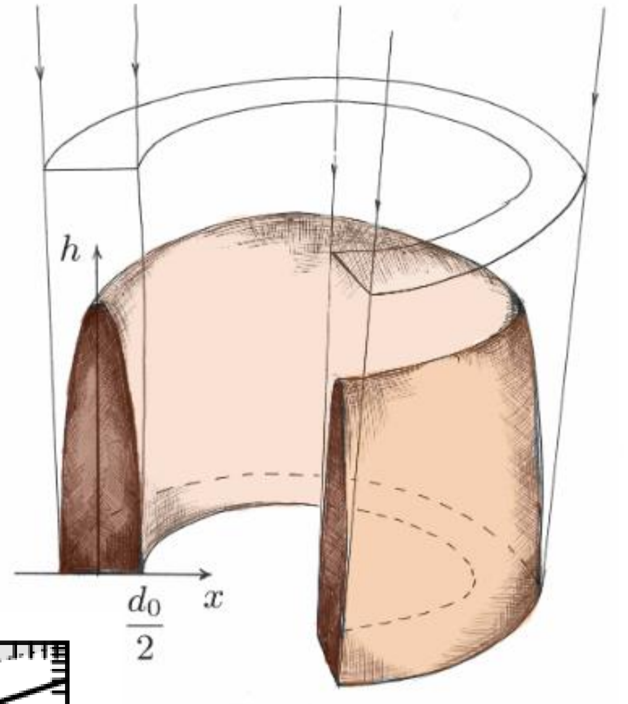
- Long spin periods;
- Rapid spin-down;
- Rapid spin-up;
- Accretor/Propeller transitions
  even for relatively large accretion rates.



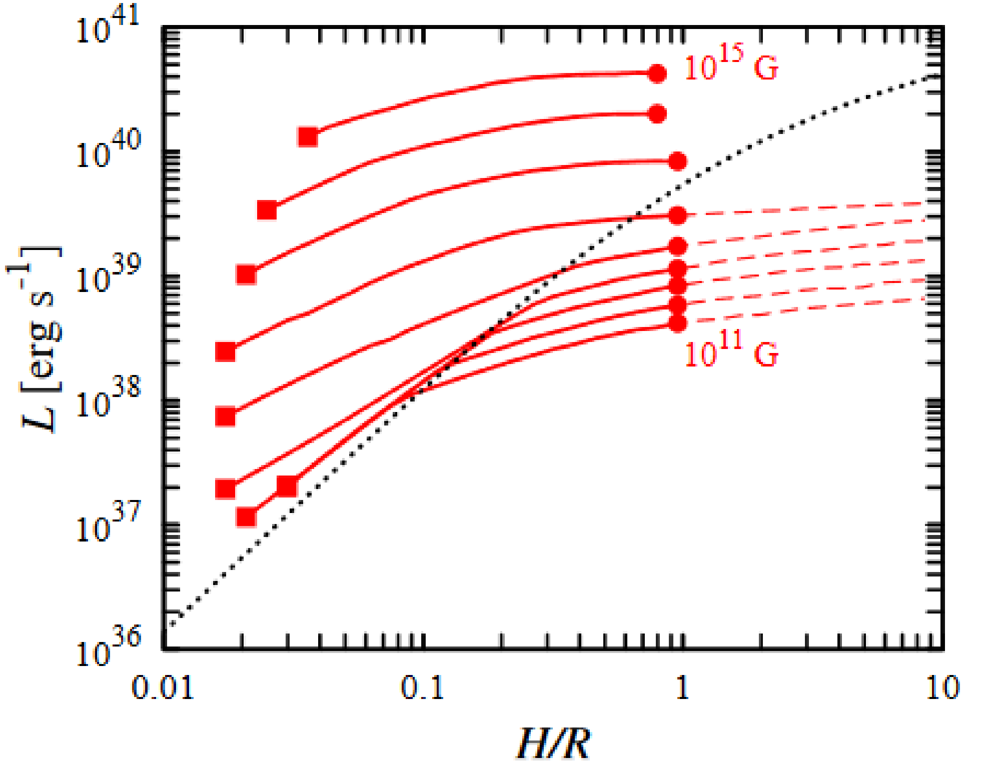
Lipunov

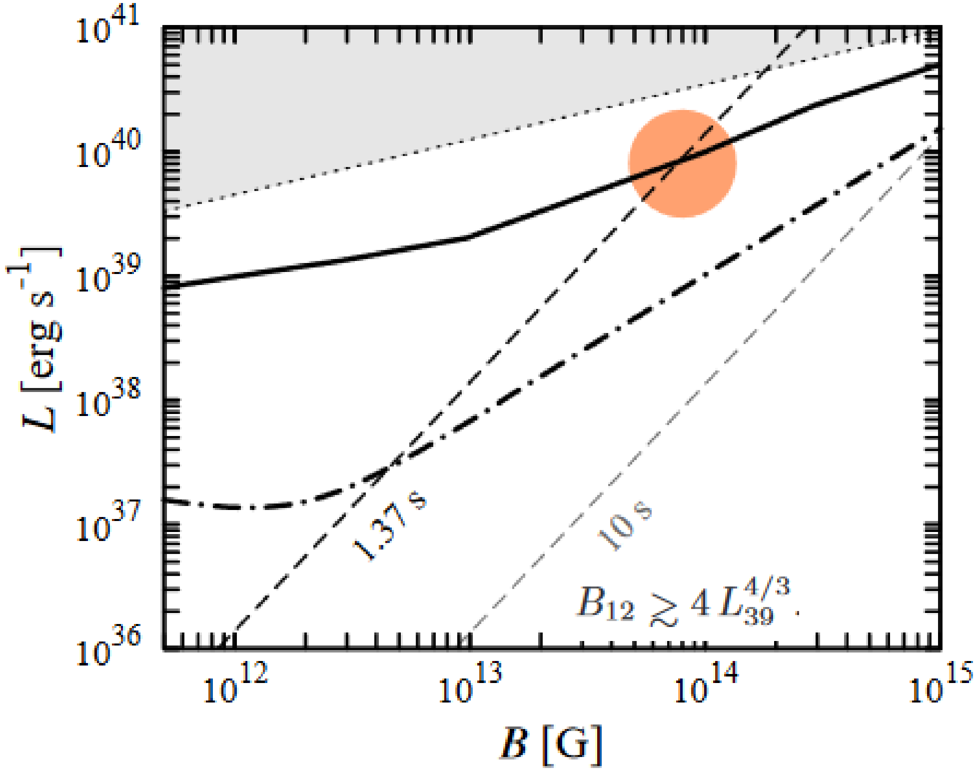
LARGER FIELD – LARGER LUMINOSITY

Strong fields can confine plasma in accretion columns for large luminosities.
In some cases, luminosity can reach super-Eddington values.
Thus, some ULXs can be explained by NSs with magnetar-scale fields.
Still, direct proof is lacking.



Mushtukov et al. 1506.03600





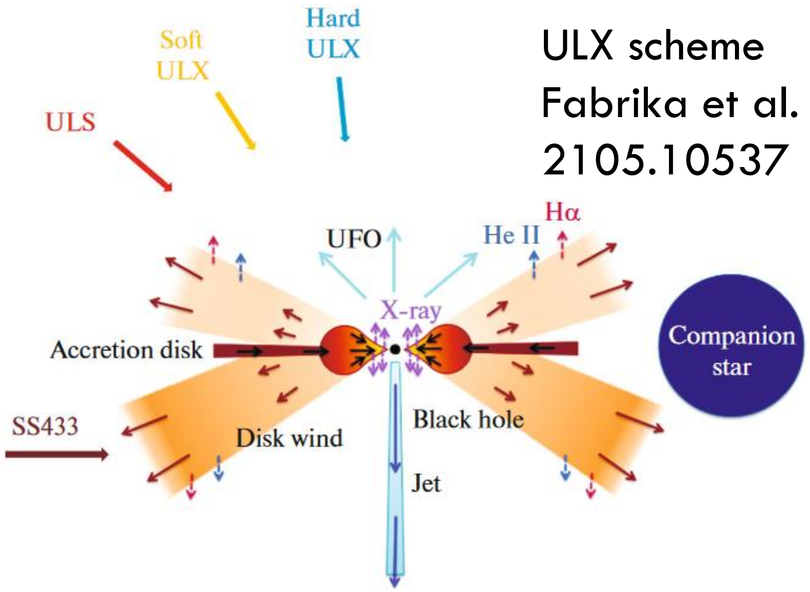
Multipolar field can be important (see the talk by N. Brice).

About electron-positron pairs in accretion columns of ULXs see poster by V. Suleimanov.

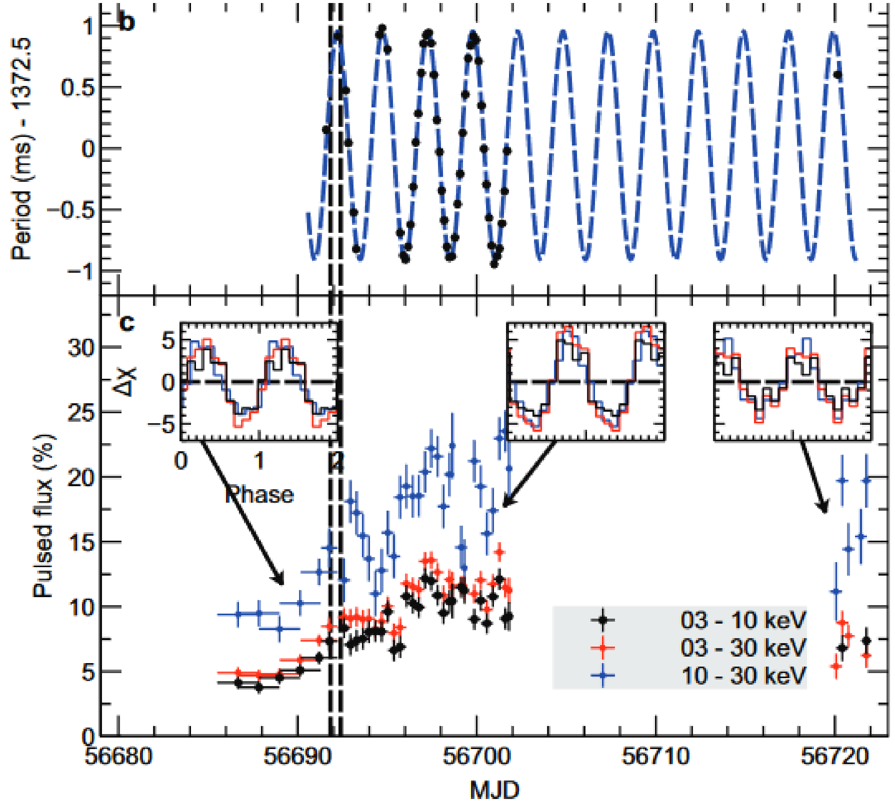
ULTRALUMINOUS X-RAY PULSARS

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

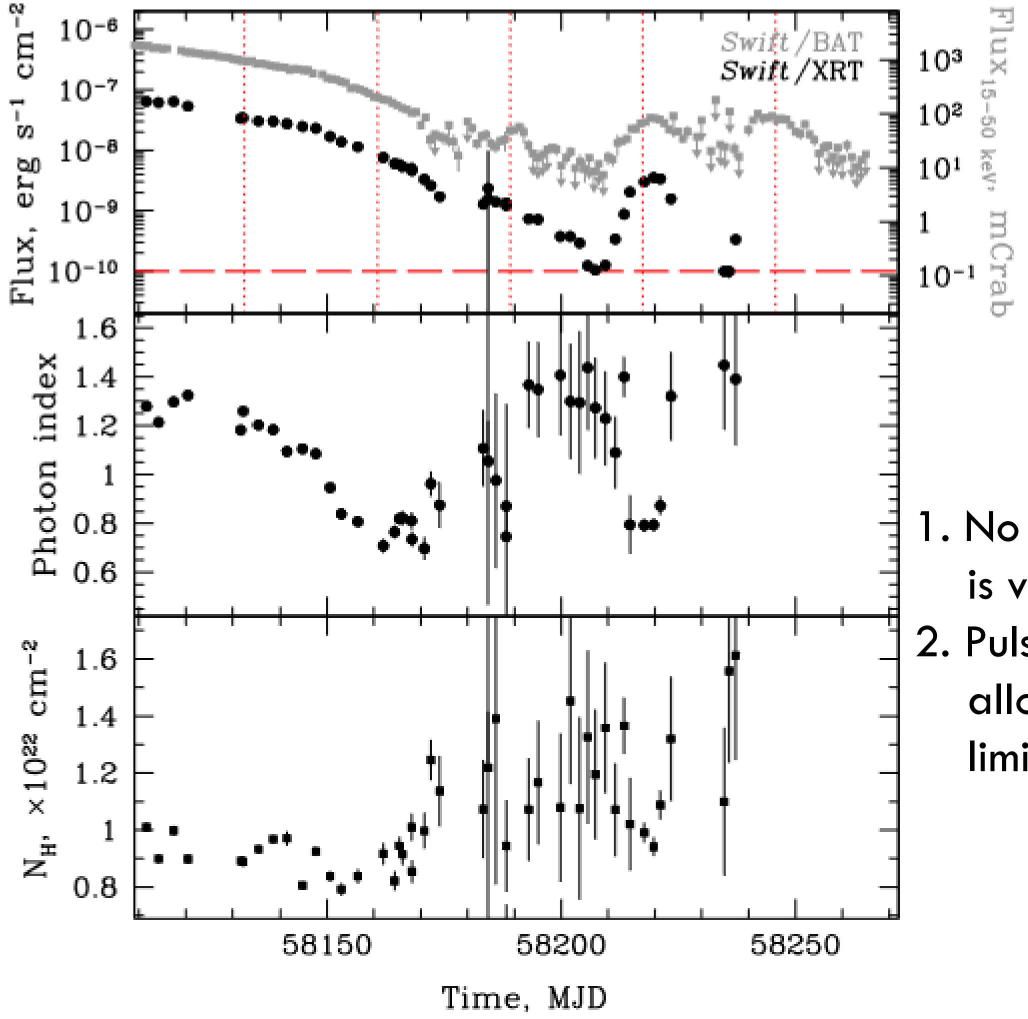


ULX scheme
Fabrika et al.
2105.10537



Bachetti et al. 2014

SOME LOOK NORMAL

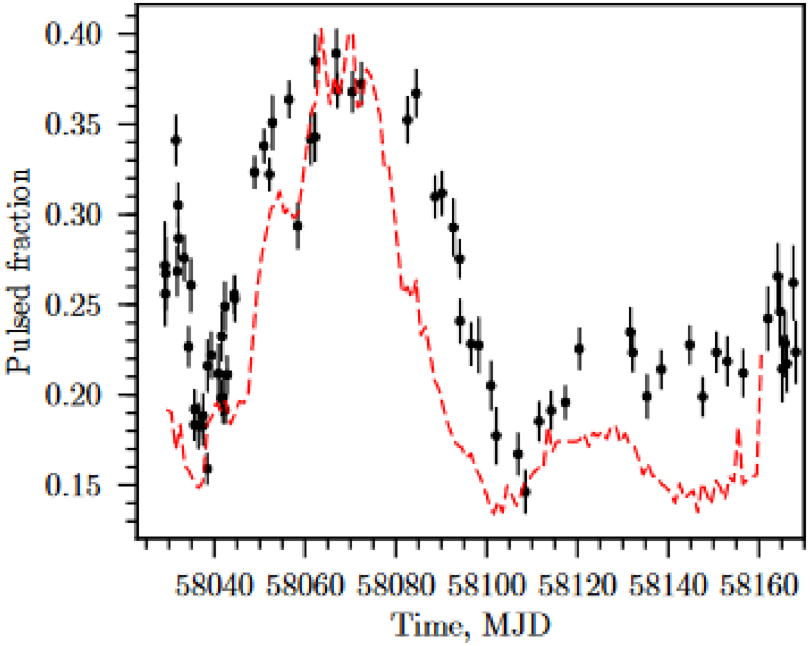


Tsygankov et al. 1806.02283

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

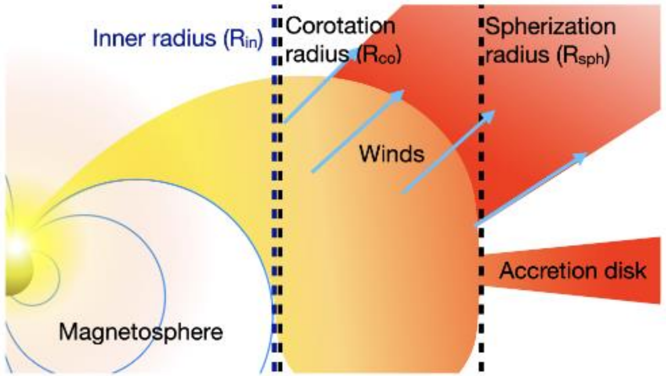
P ~ 10 sec
P_{orb} ~28 days
Be/X-ray
L~$40L_{Edd}$

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

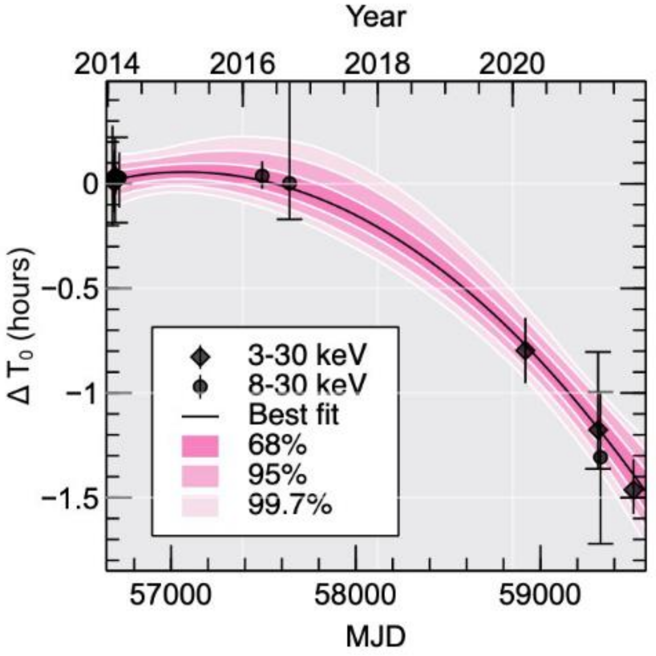
M82 X-2
Orbital decay is measured.
Large mass transfer.
In simple models, large (magnetar scale) field is necessary.

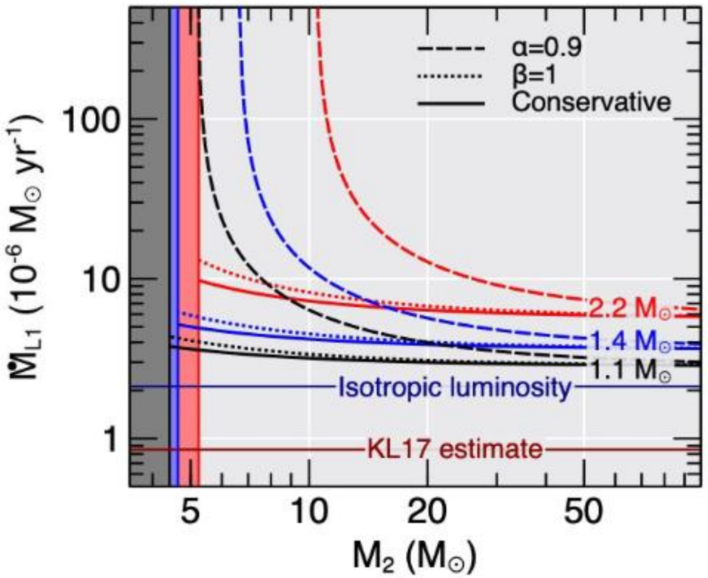


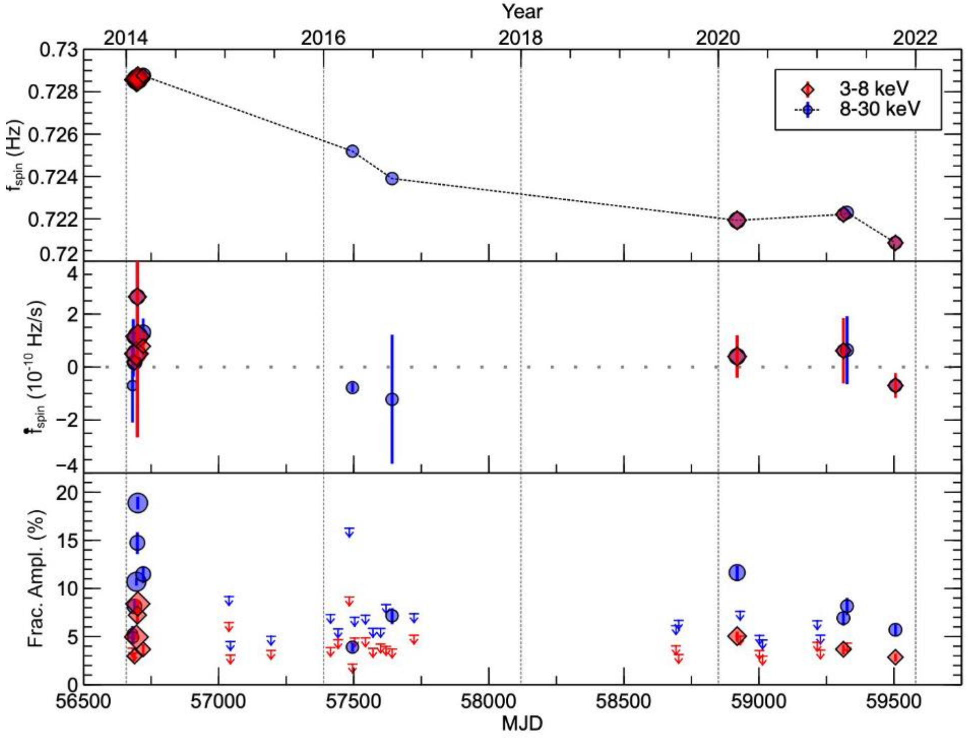
Parameter	Unit	Value (uncert)
$P_{\rm orb}$	d	2.532971(13)
$\dot{P}_{\rm orb}$	$\rm s\ s^{-1}$	$-5.4(1.0)\cdot 10^{-8}$
$\dot{P}_{\rm orb}/P_{\rm orb}$	$\rm yr^{-1}$	$-7.7^{+1.3}_{-1.4}\cdot 10^{-6}$
$a\sin i$	l-sec	22.215(5) (B20)
T_0	MJD	56682.0669(18)

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

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



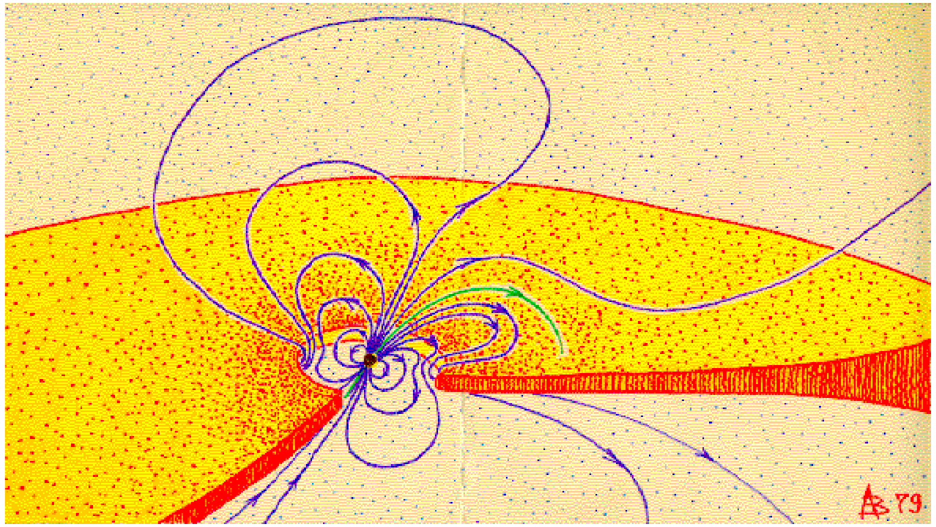




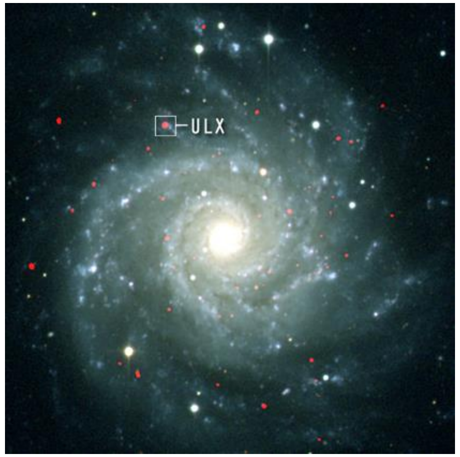
Bachetti et al. 2112.00339

ACCRETING MAGNETARS

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

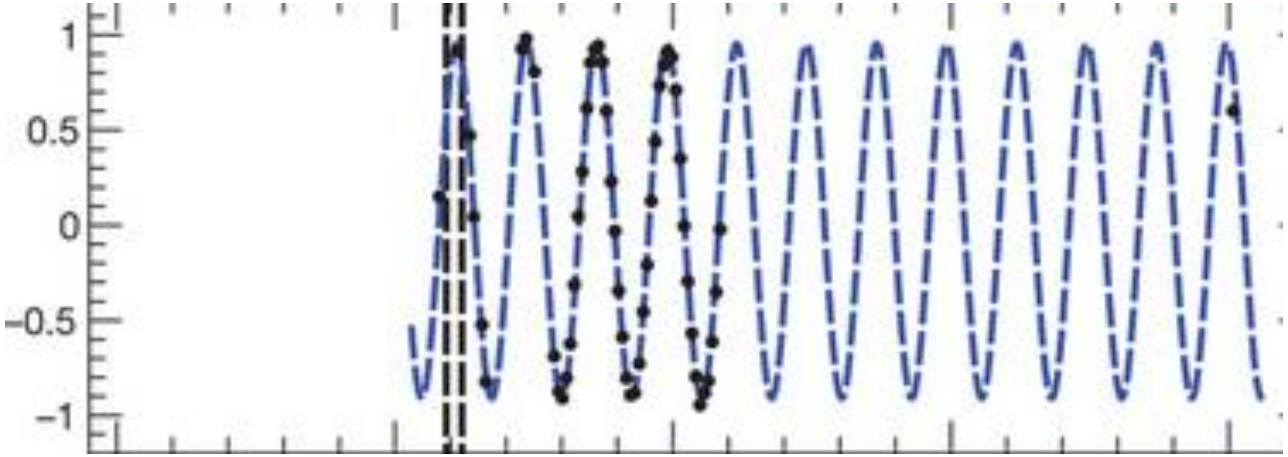


- Spin-up
- Spin-down
- Equilibrium period
- Accretion model
- …….



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 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.

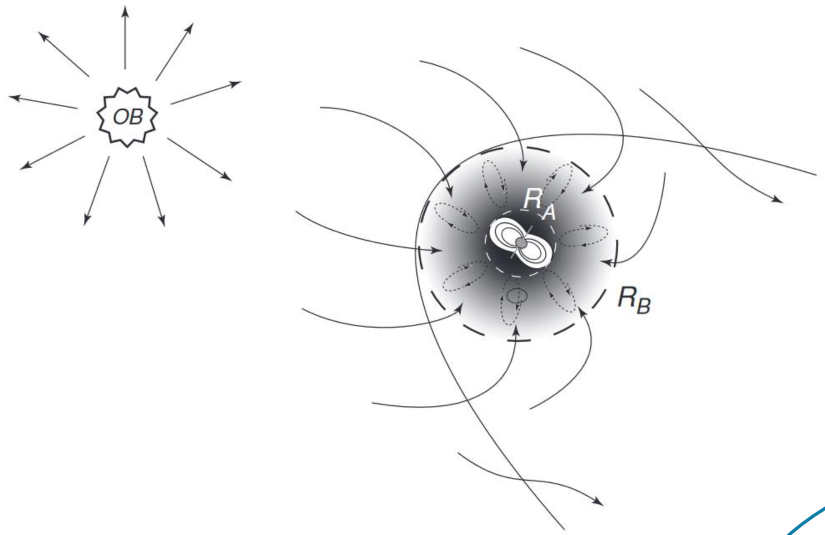
$$B = \frac{2}{R^3}\left(\frac{I\dot{p}GM}{2\pi k_{\rm t}}\right)^{1/2}$$

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

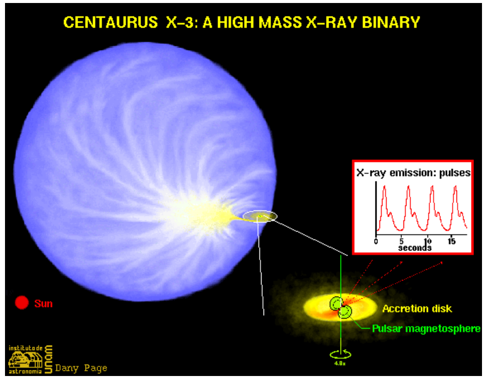
Typically, for wind-accreting systems long spin periods lead to high magnetic field estimates (e.g., Klus et al. 2014):

$$B \approx 1\times10^{14}\,\mathrm{G}\left(\frac{\eta}{\kappa_\mathrm{t}}\right)^{1/2} R_\mathrm{NS6}^{-3}\left(\frac{M}{\mathrm{M}_\odot}\right)^{3/2}\dot{M}_{16}^{1/2} \times\left(\frac{V_\mathrm{rel}}{100\,\mathrm{km\,s}^{-1}}\right)^{-2}\left[\frac{P/100\ \mathrm{s}}{(P_\mathrm{orb}/10\,\mathrm{d})^{1/2}}\right].$$

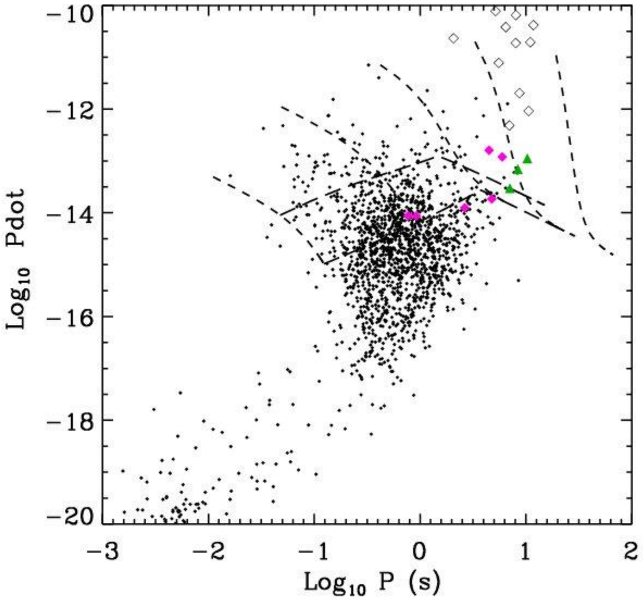
However, for the settling accretion model which is valid for low accretions rates the field estimate is much lower:

$$B = 0.24\times10^{12}\,\mathrm{G}\,\eta_\mathrm{s}\left(\frac{p/100\mathrm{s}}{p_\mathrm{orb}/10\mathrm{days}}\right)^{11/12}\dot{M}_{16}^{1/3}\,(v/(10^8\,\mathrm{cm/s}))^{-11/3}$$

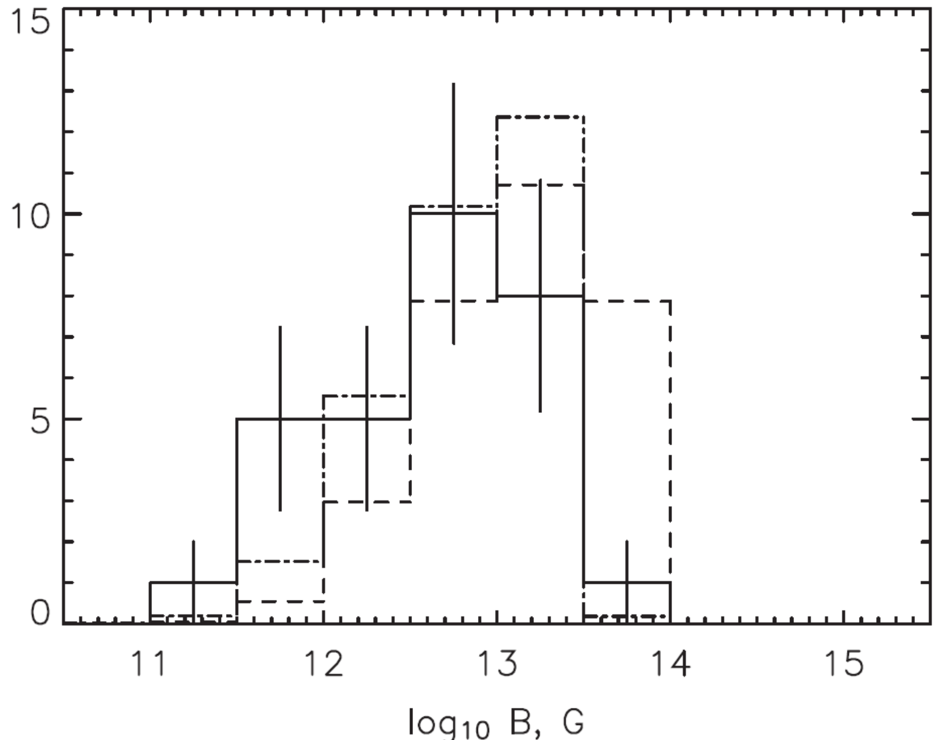
FIELD DECAY IN HMXBS

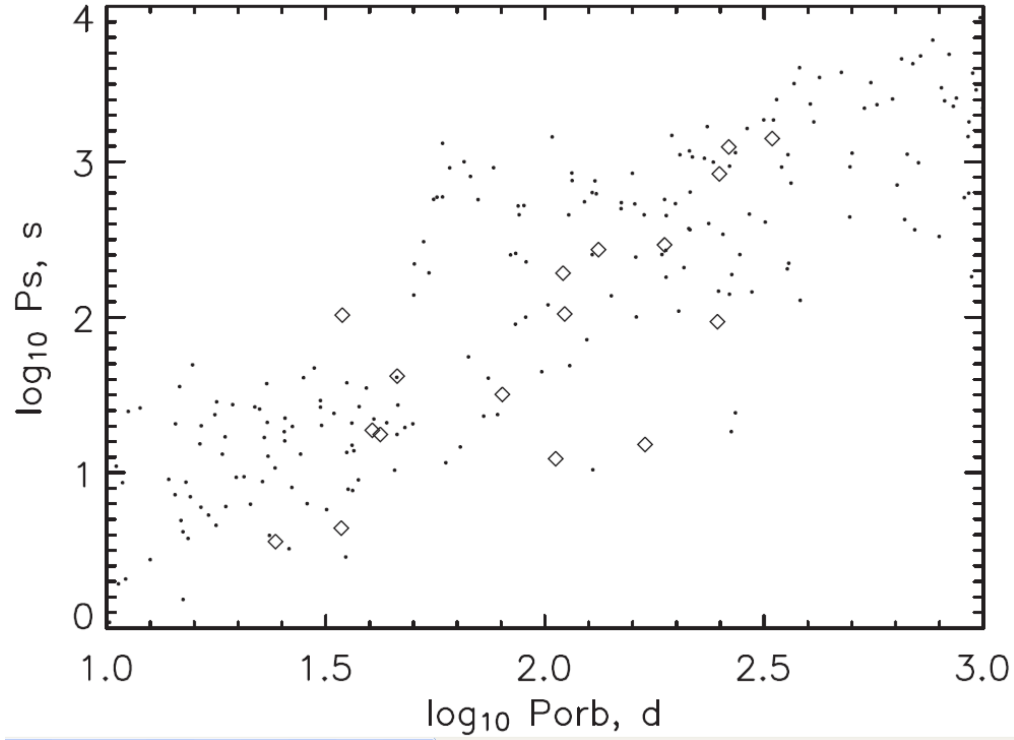


It is possible to use HMXBs to test models of field decay on time scale >1 Myr (Chashkina, Popov 2012).
We use observations of Be/X-ray binaries in SMC to derive magnetic field estimates, and compare them with prediction of the Pons et al. model.



Chashkina, Popov (2012)

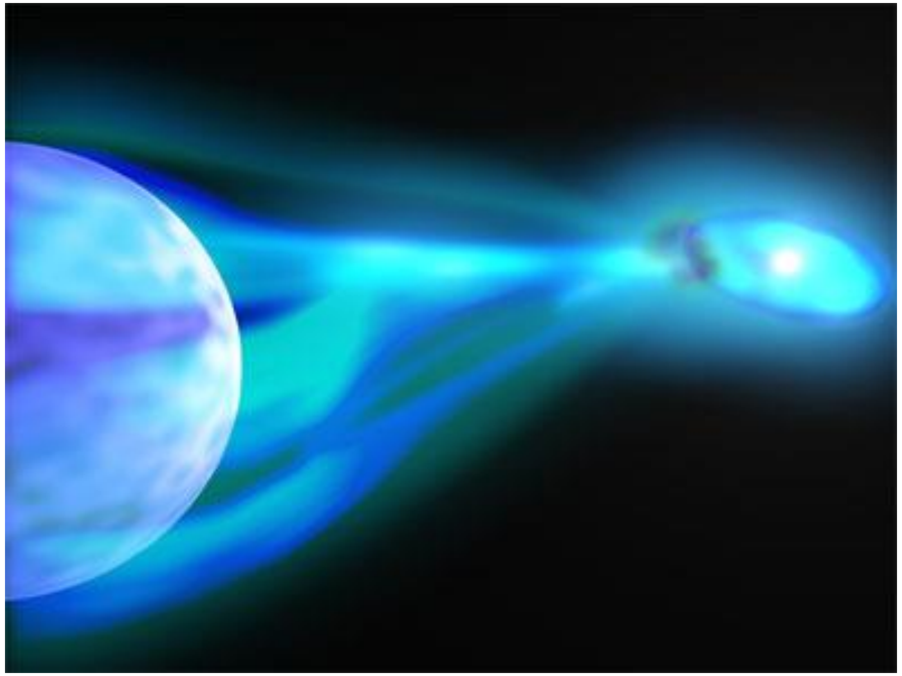


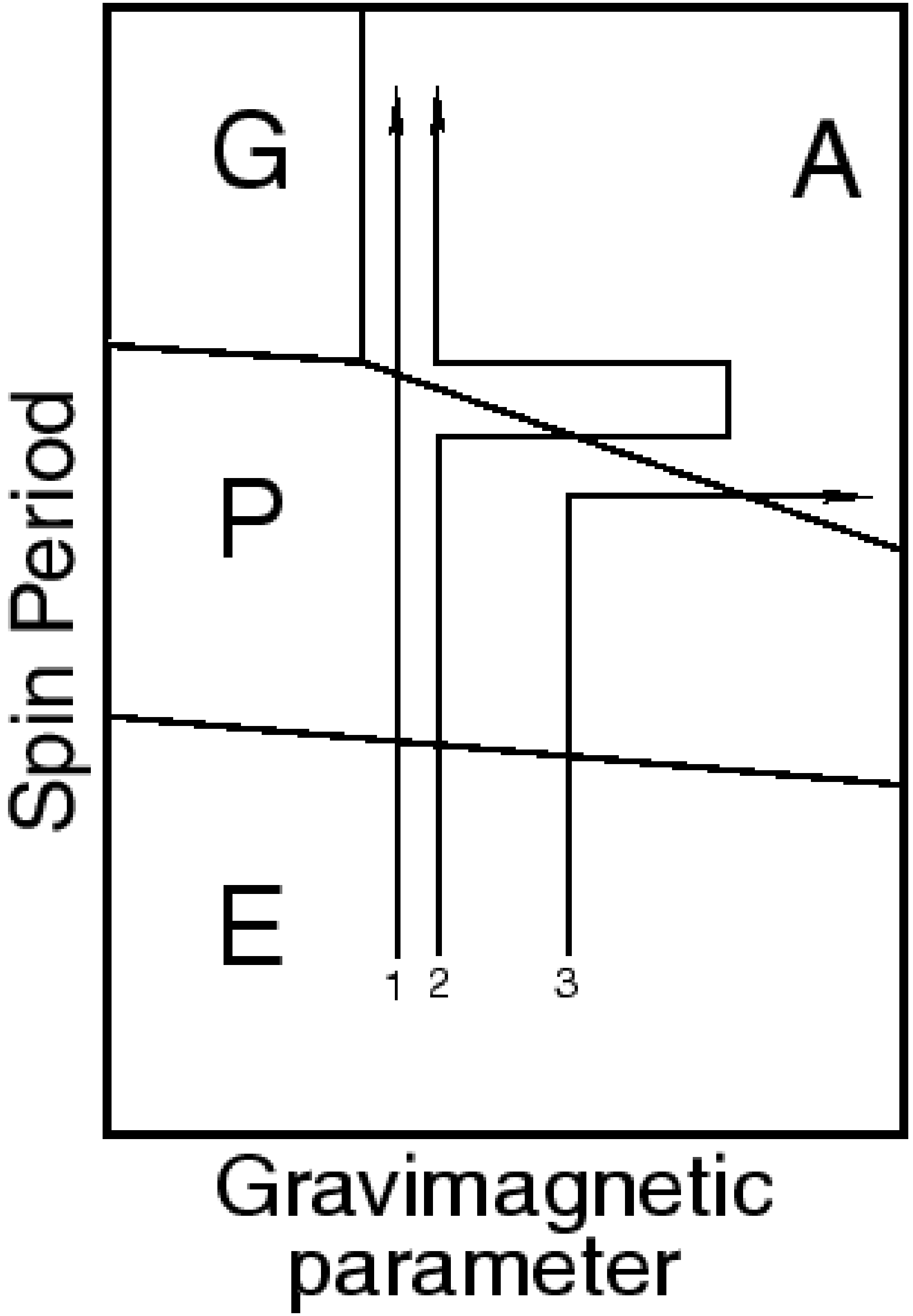


SXP 1062

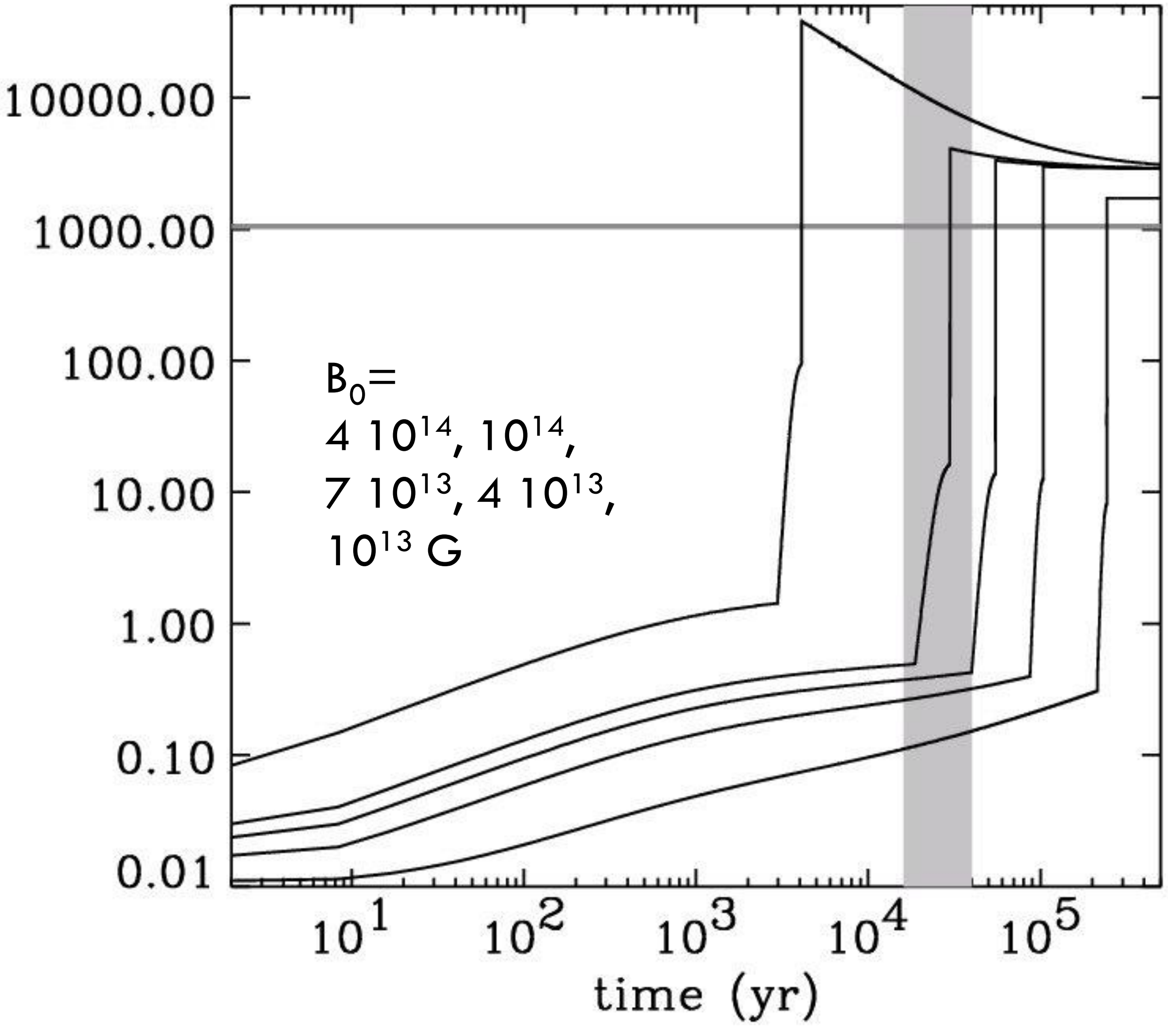
A peculiar source was discovered in SMC.
Be/Xray binary, P=1062 sec.
A SNR is found. Age ~10^4 yrs.
(1110.6404; 1112.0491)

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





SXP 1062



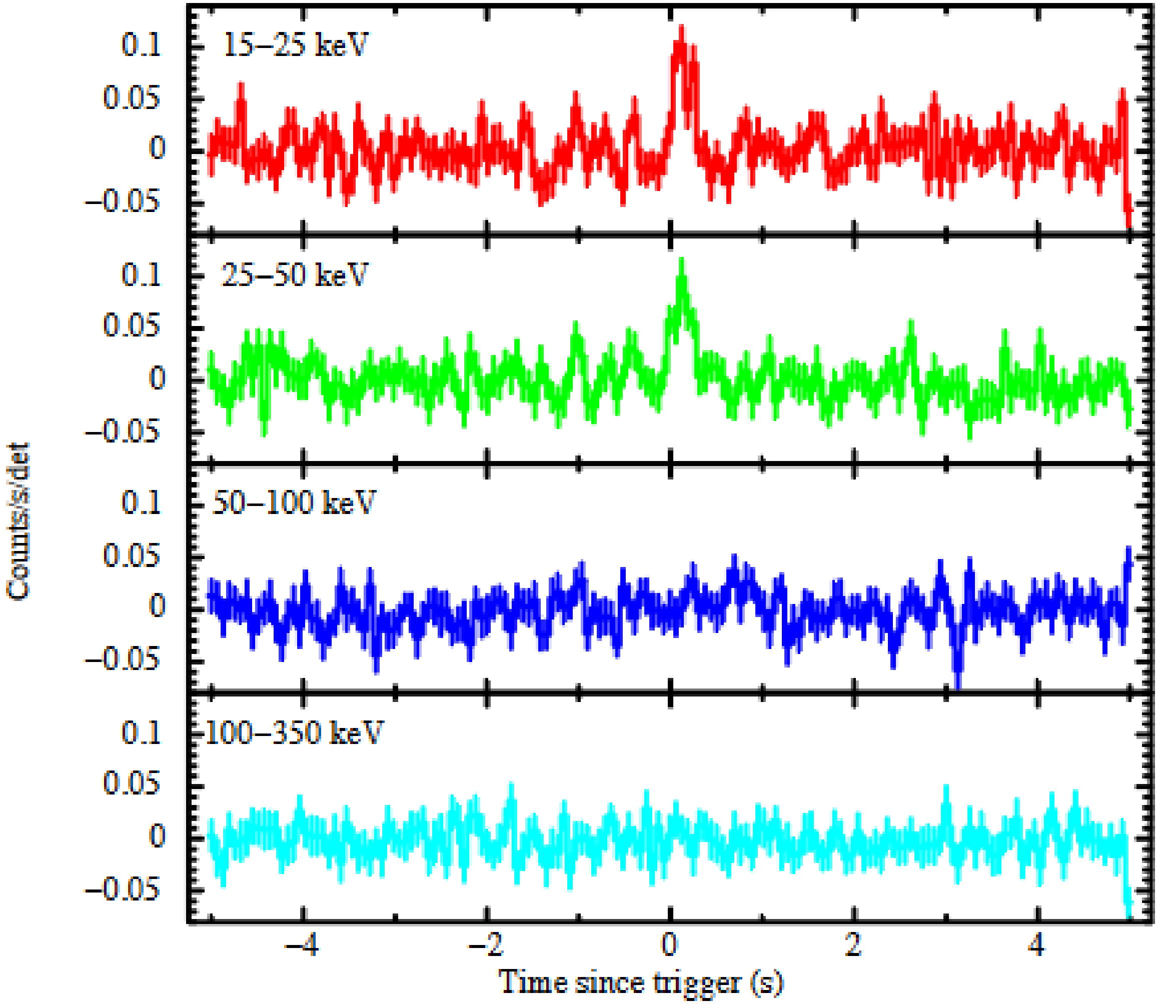
arXiv: 1112.2507

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 (H´enault-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).

BURSTS FROM LS I +61 303



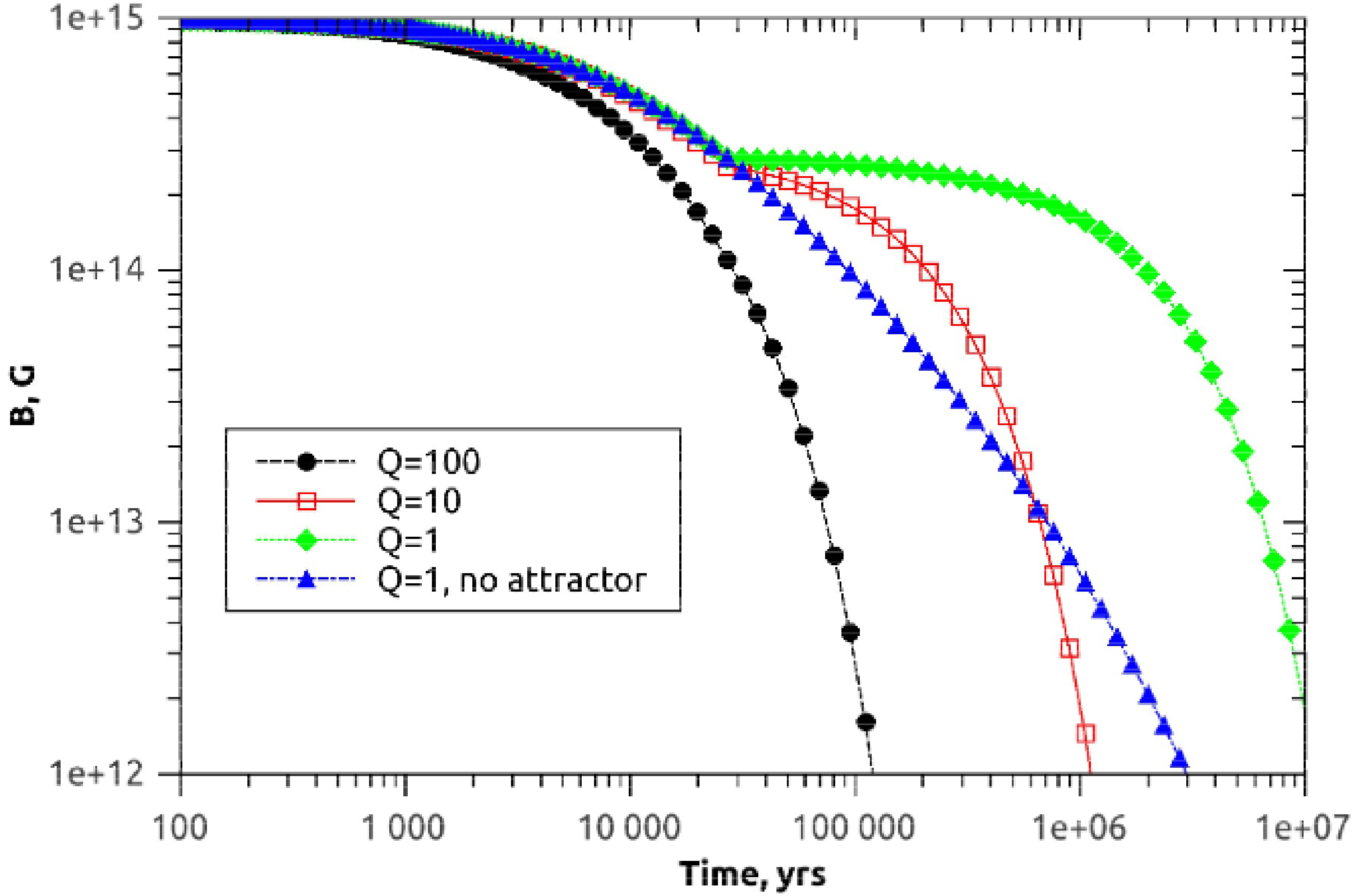
Torres et al. 1109.5008

LS I 62 303 - the only example of
a magnetar-like activity in a binary system.
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).

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.

HOW TO MAKE AN ACCRETING MAGNETAR?

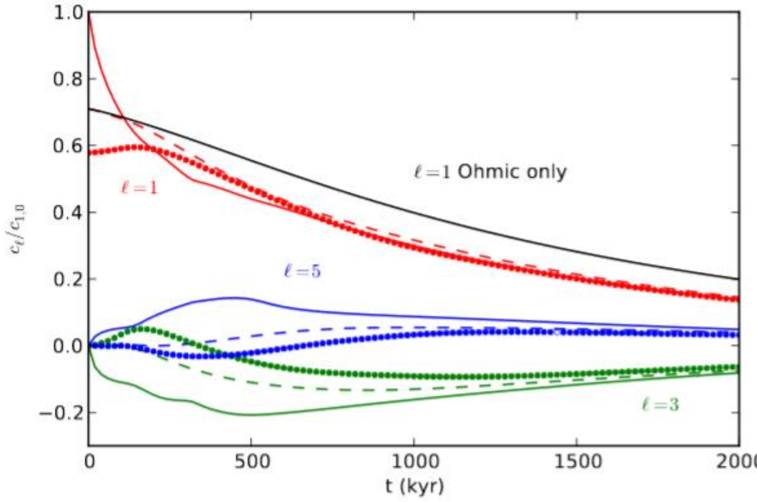


Igoshev, Popov 1709.10385

Three conditions are necessary:

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

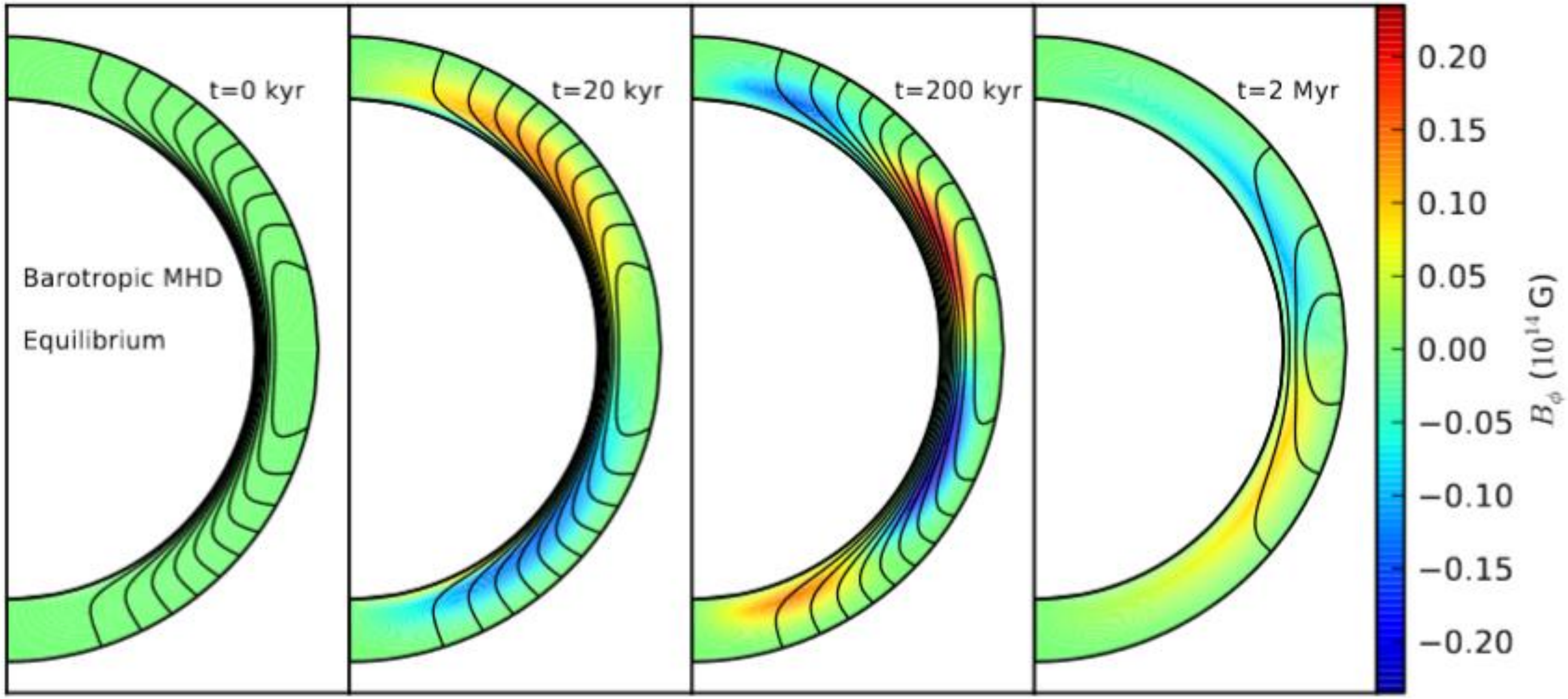
Hall attractor:



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.

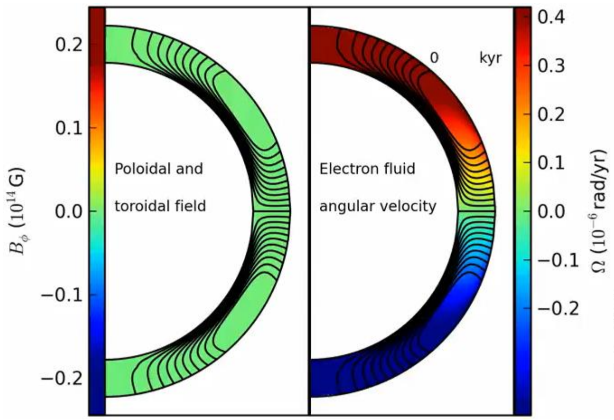


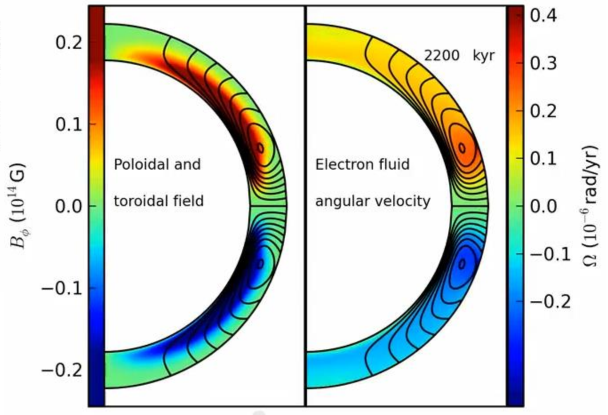
Hall cascade can reach the stage of so-called Hall attractor, where the field decay stalls for some time (Gourgouliatos, Cumming).

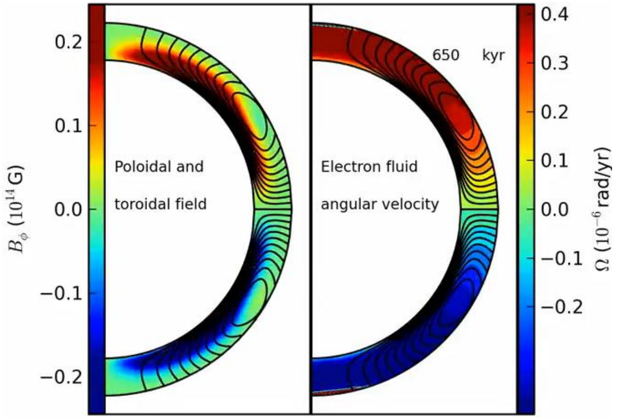
HALL CASCADE AND ATTRACTOR

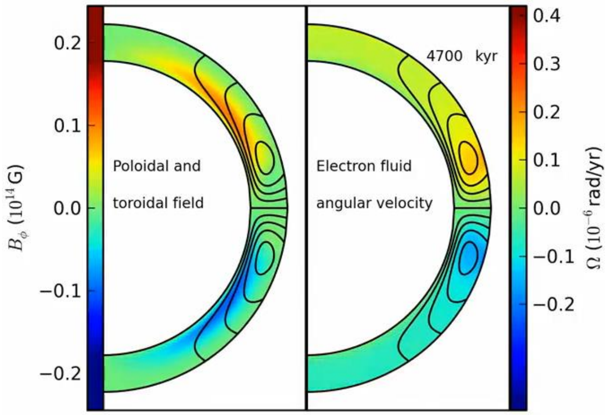
Gourgouliatos and Cumming 2013

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.







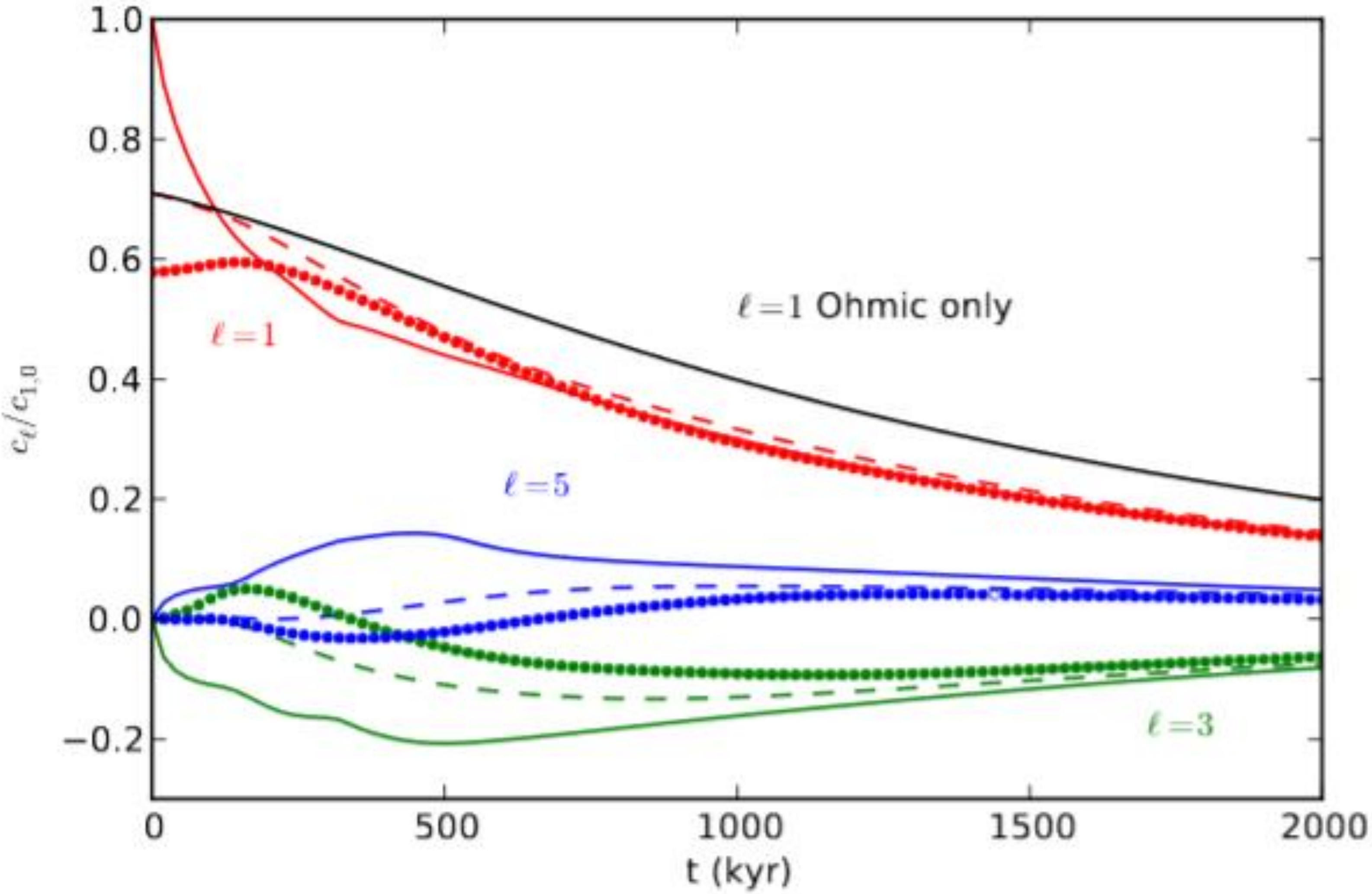


Hall cascade can reach the stage of so-called Hall attractor,
where the field decay stalls for some time (Gourgouliatos, Cumming).

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

EVOLUTION OF DIFFERENT COMPONENTS

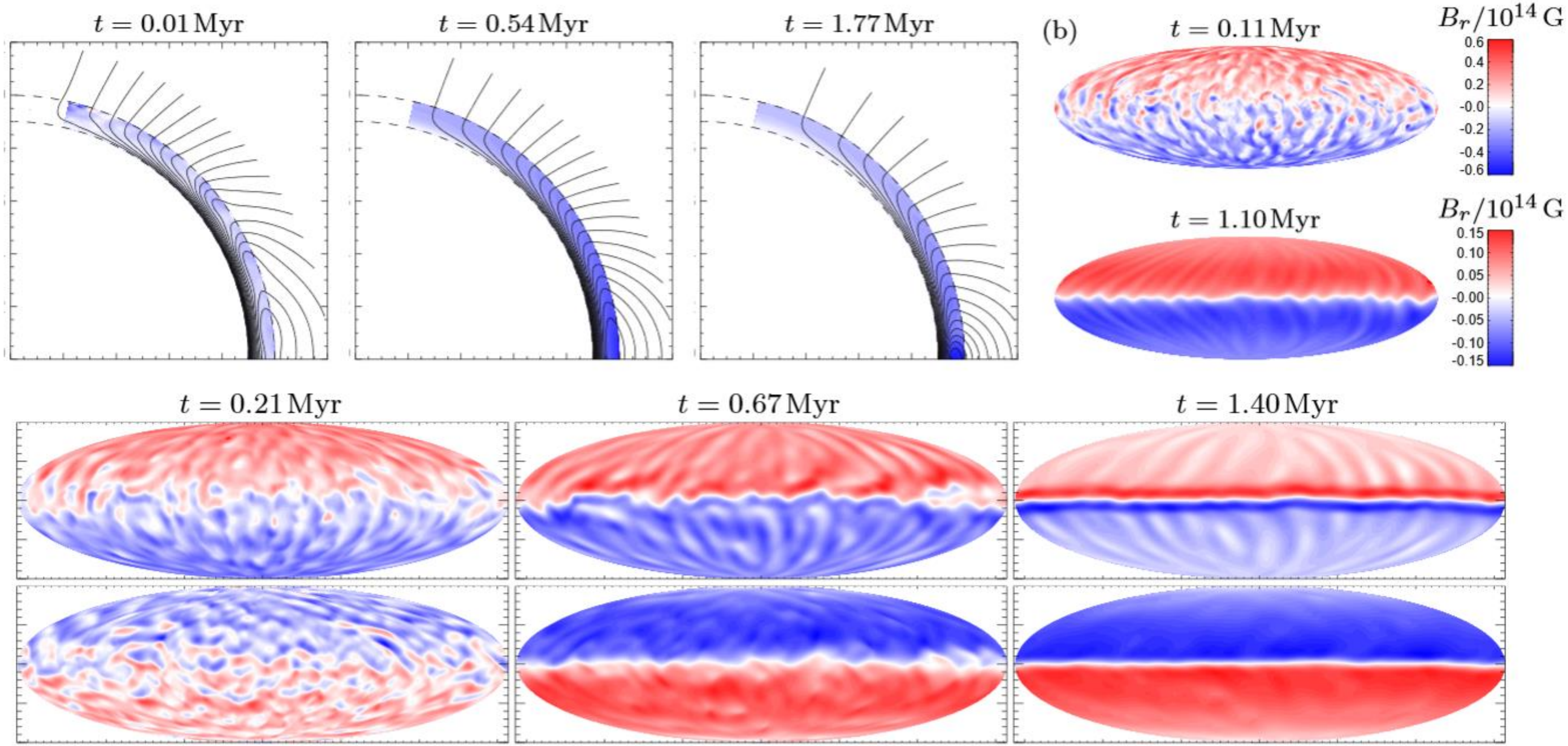
1311.7004



Hall attractor mainly consists of dipole and octupole

INDEPENDENT STUDIES OF THE HALL CASCADE

1501.05149

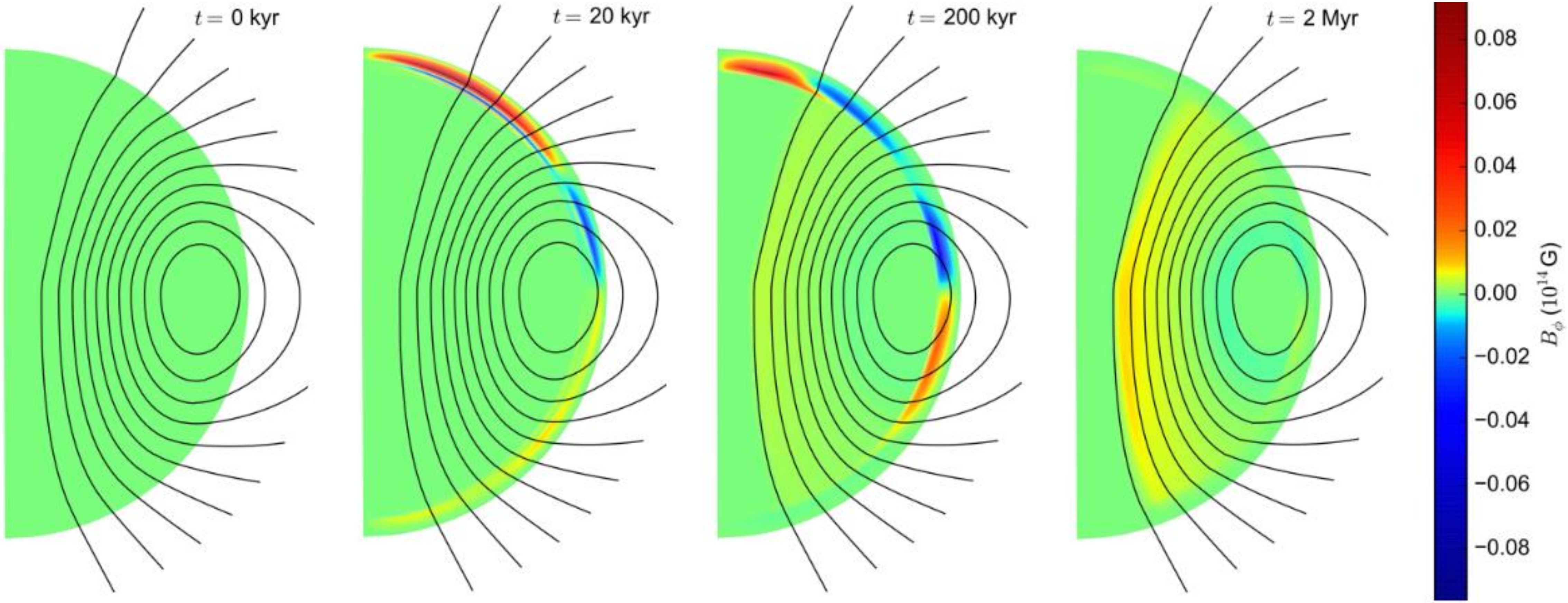


New calculations support the idea of a kind of stable configuration.

See also 1604.01399

CORE AND CRUST FIELD EVOLUTION

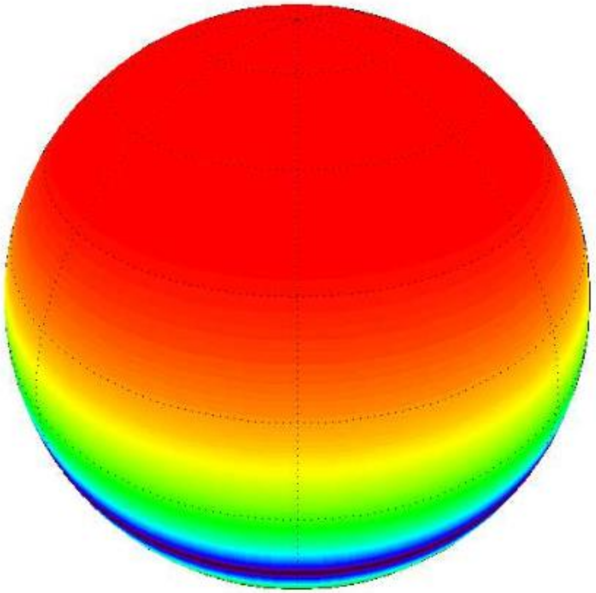
1709.09167



Hall attractor is confirmed.

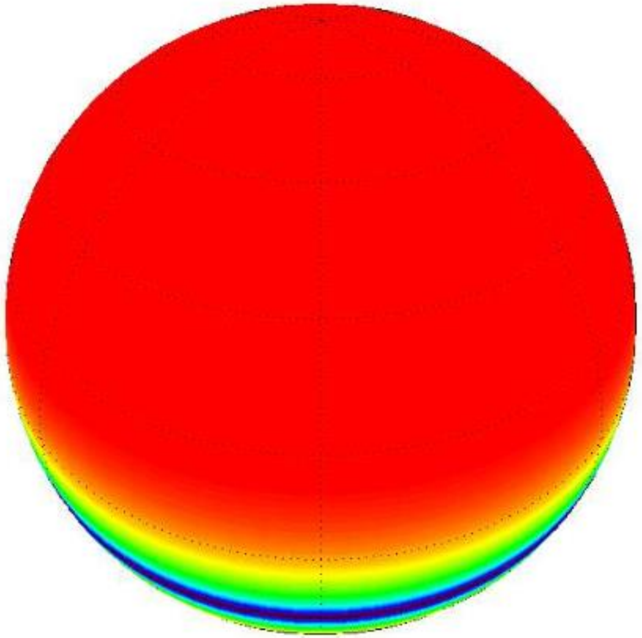
TEMPERATURE MAPS

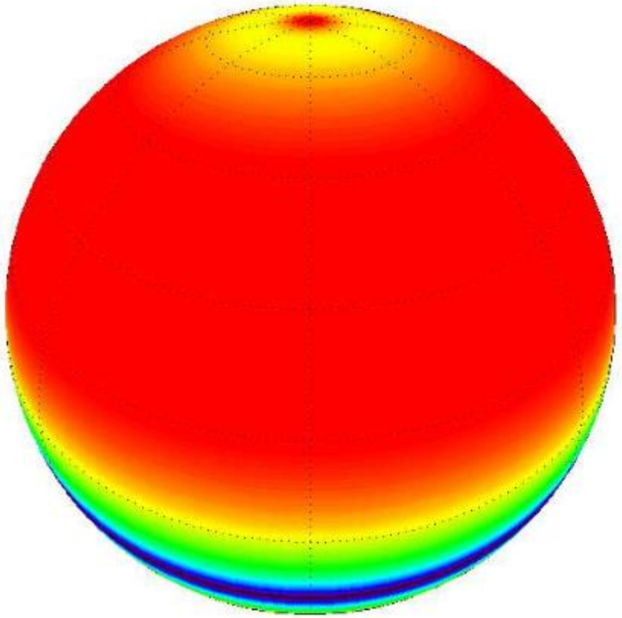
arXiv: 1610.05050



Pure dipole

Dipole+octupole+l5

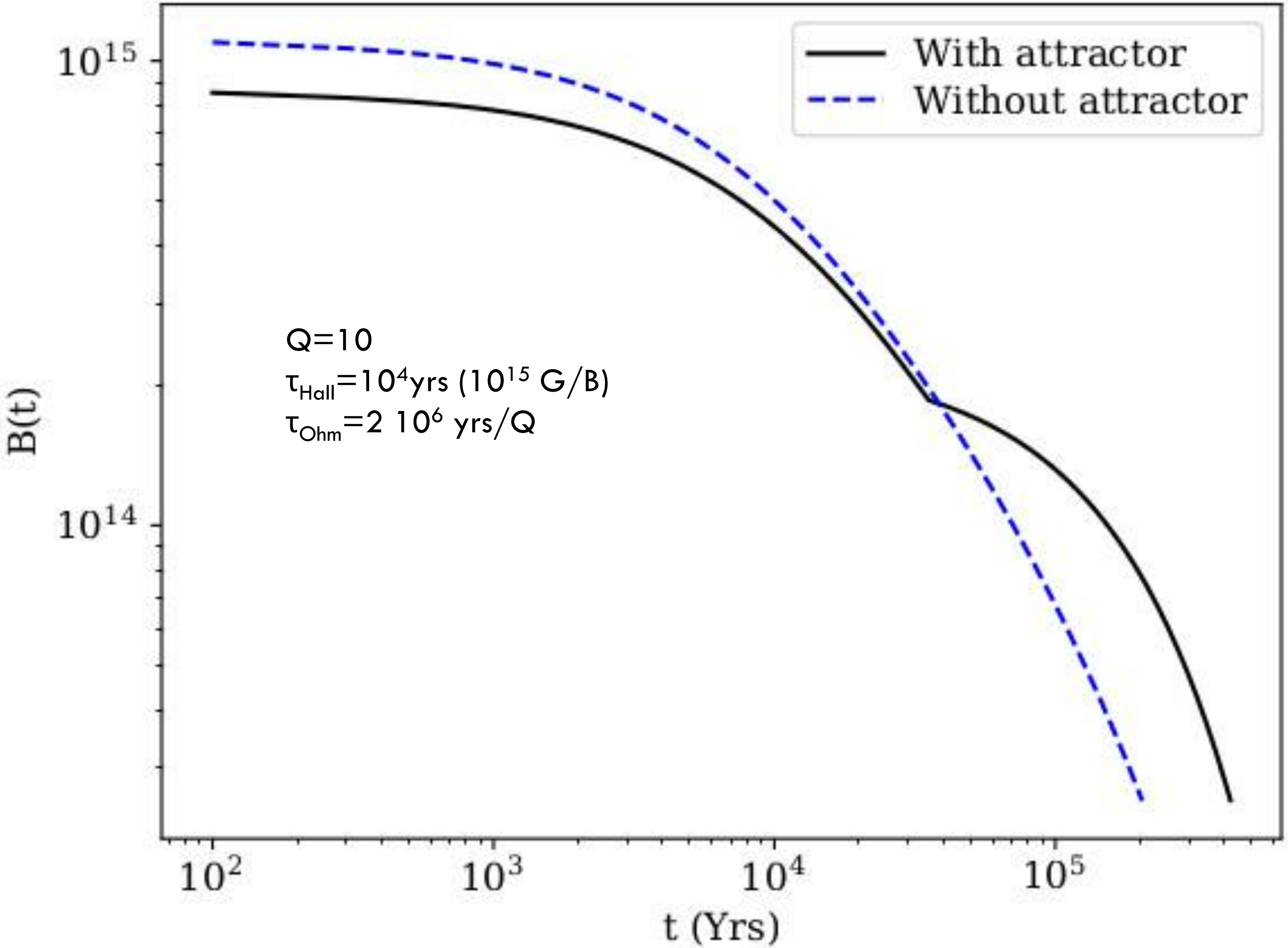




Dipole + octupole (Model 1)

	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

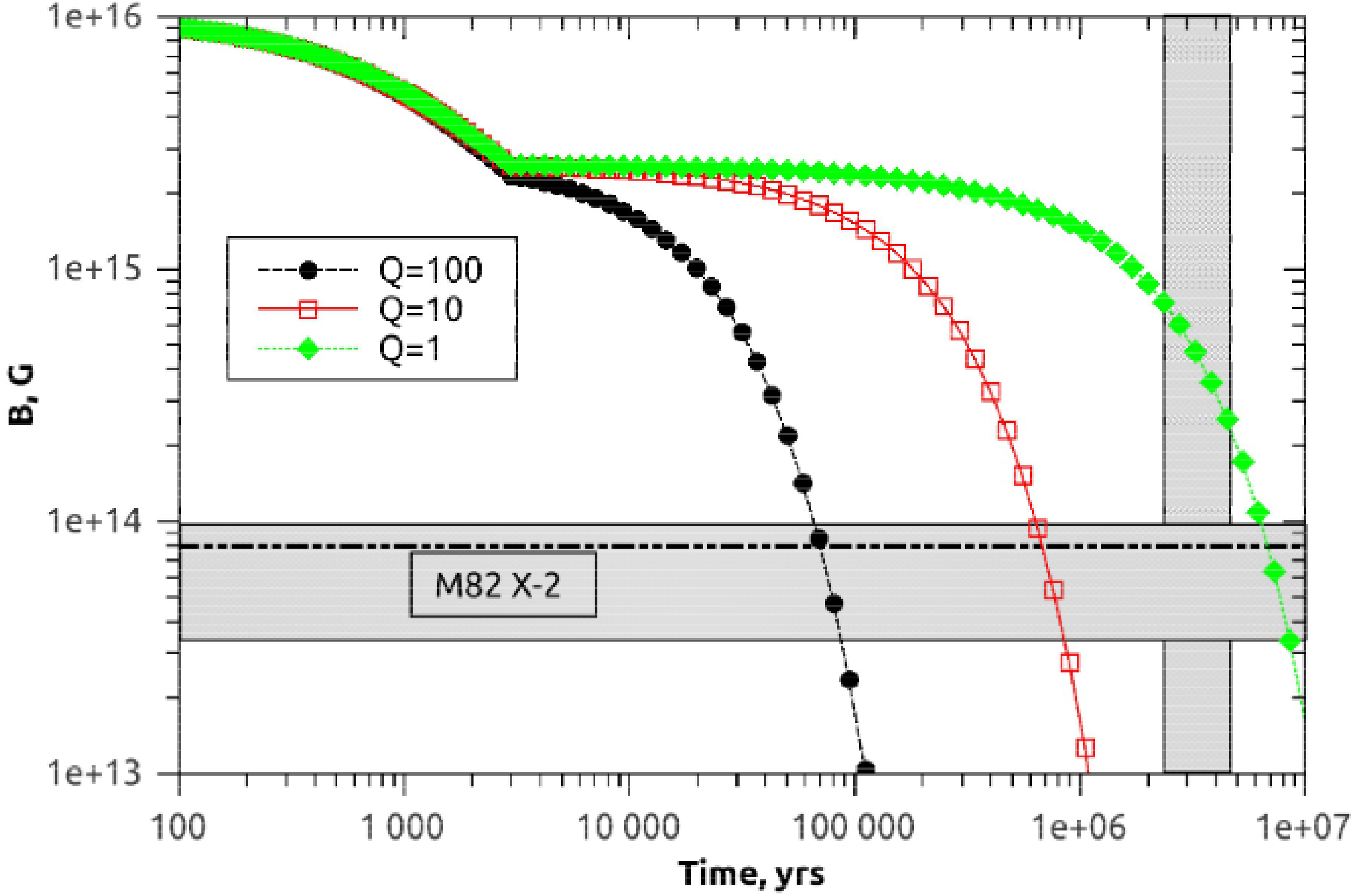
New results in 2009.04331



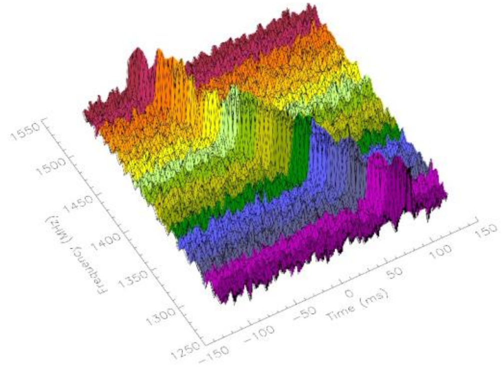
With attractor
Without attractor
Q=10
$\tau_{Hall}=10^4$yrs (10^{15} G/B)
$\tau_{Ohm}=2\ 10^6$ yrs/Q
B(t)
10^{15}
10^{14}
10^2
10^3
10^4
10^5
t (Yrs)

PARAMETERS OF ULX M82 X-2

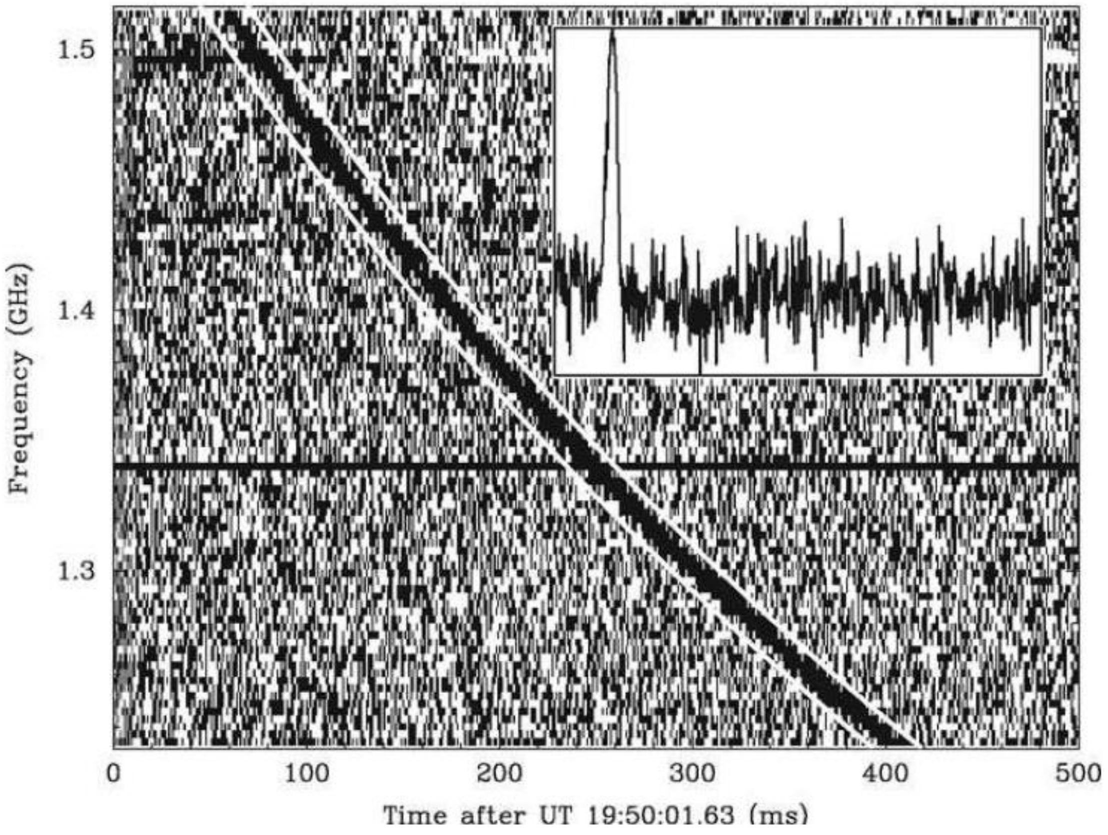
1709.10385



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]

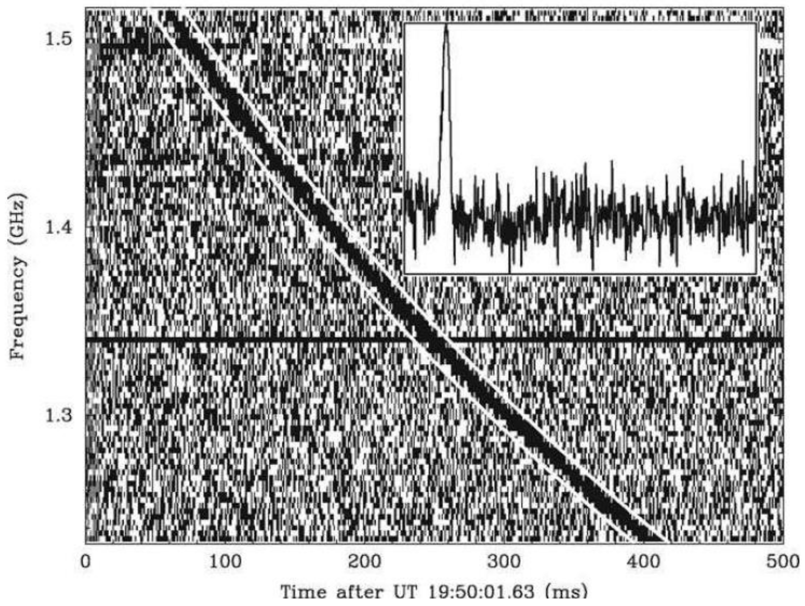
Large dispersion measure.
If dispersion is due to intergalactic medium
then radio luminosity is ~10^{43} erg/s.

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.

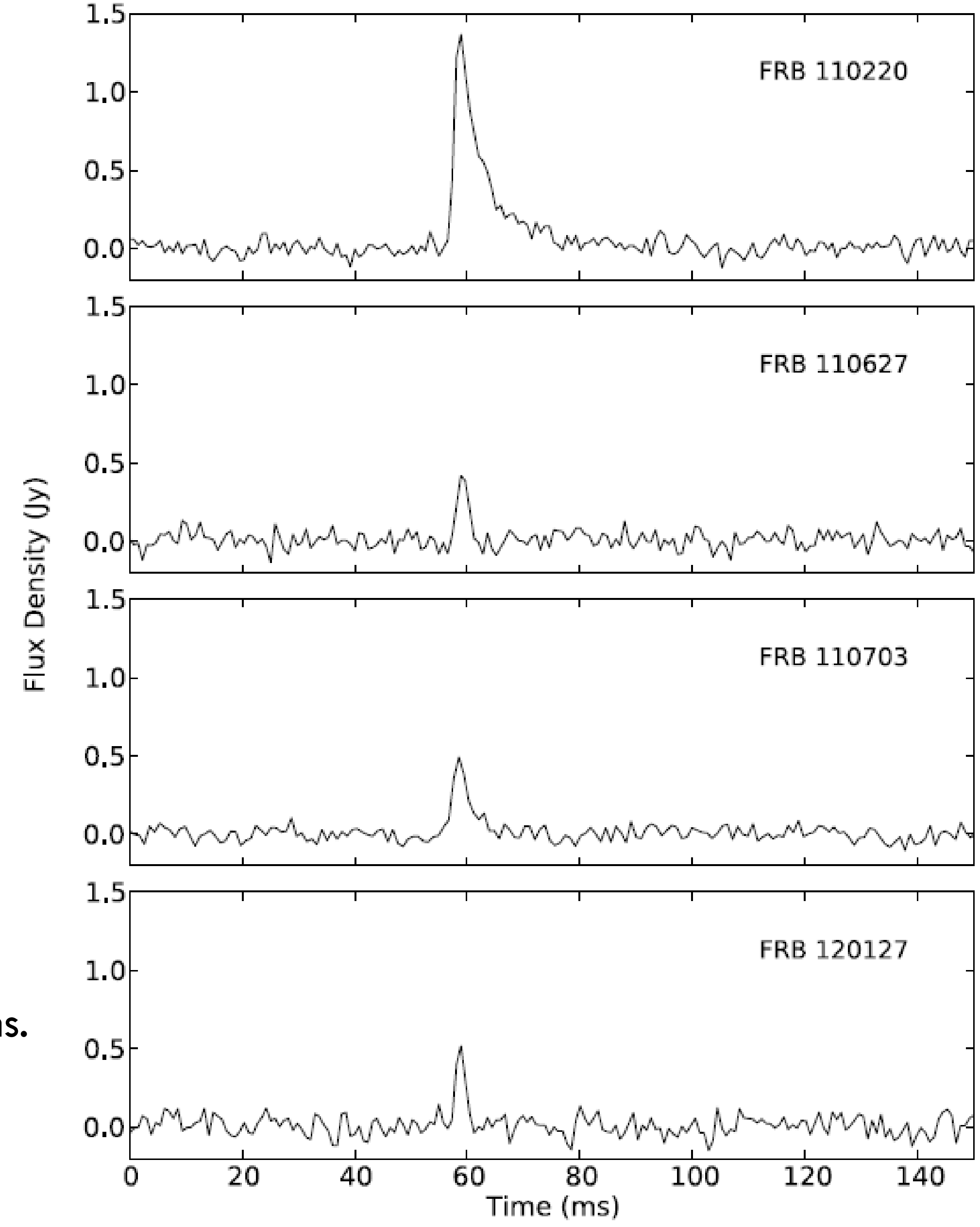
2016 Spitler et al. The first repeating source.
Chatterjee et al. Identification of the host galaxy

Lorimer et al.



Large dispersion measure points to extragalactic origin.

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



1307.1628

REPEATING BURSTS

Repeating bursts are detected firstly from FRB 121102.

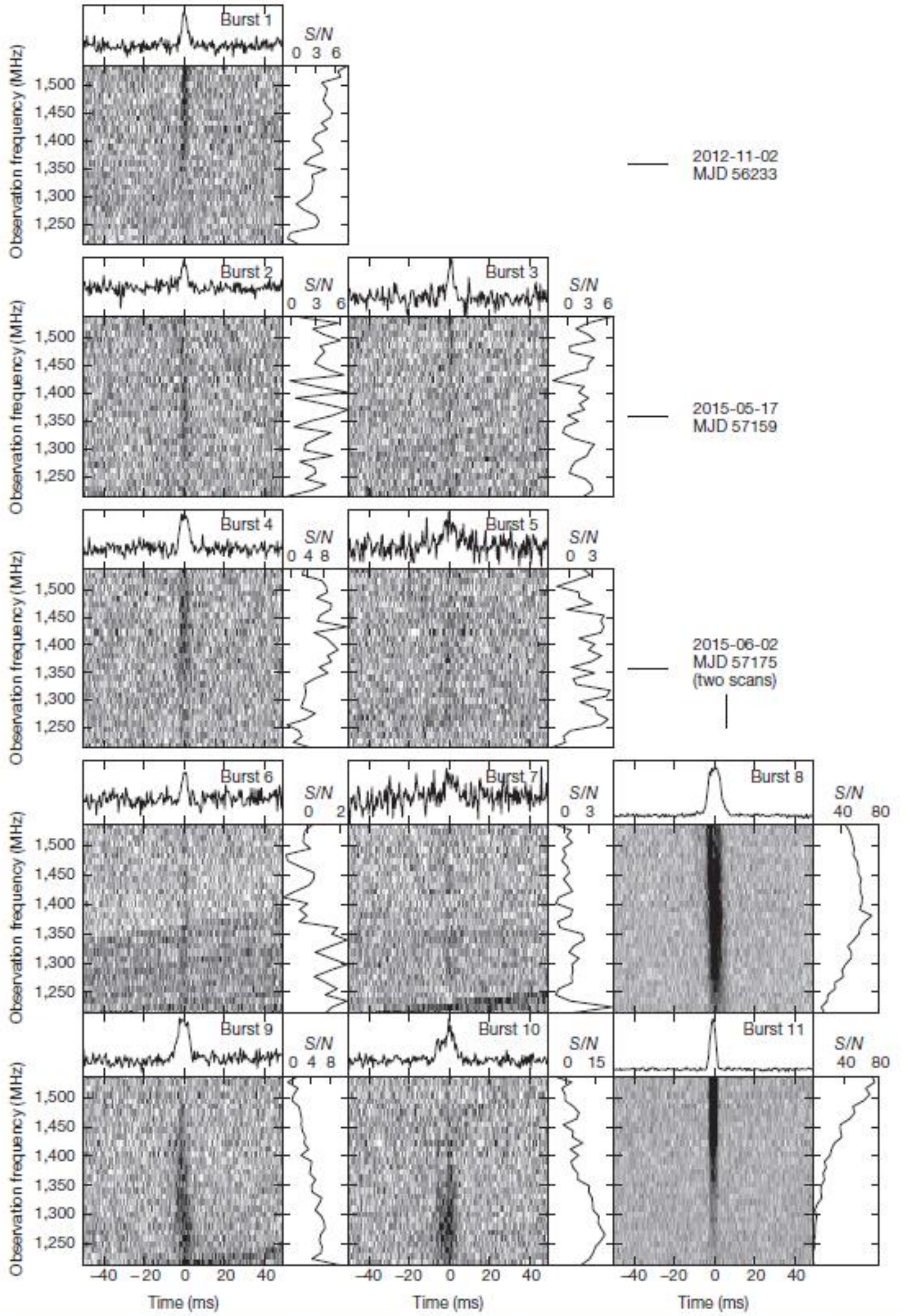
The source was found at Arecibo.

Initially 10 events reported.
Rate ~ 3/hour
Weak bursts (<0.02-0.3 Jy)

Variable spectral parameters.

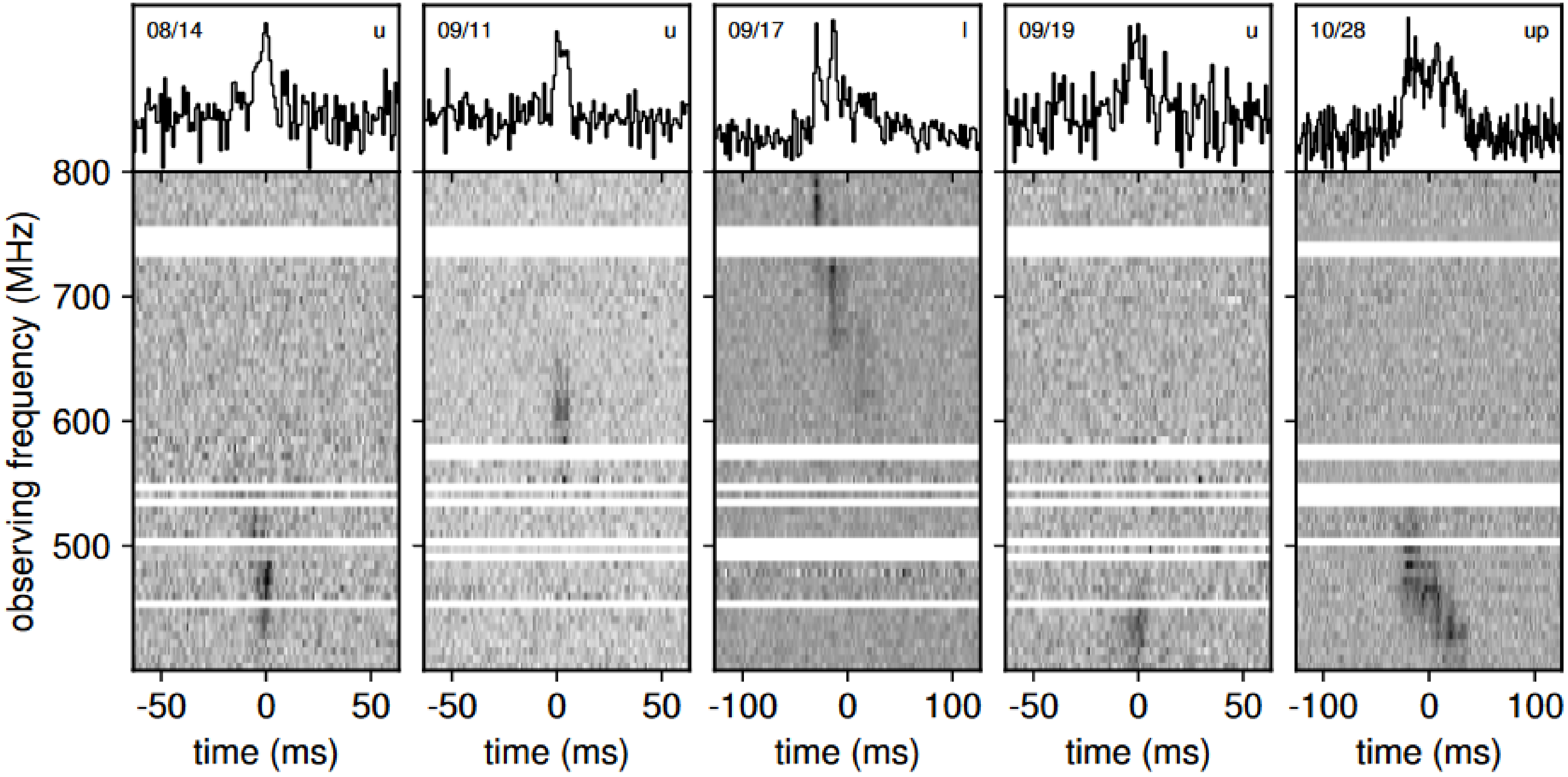
Unclear if it is a unique source,
or it is a close relative of other FRBs.

1603.00581



THE SECOND REPEATER

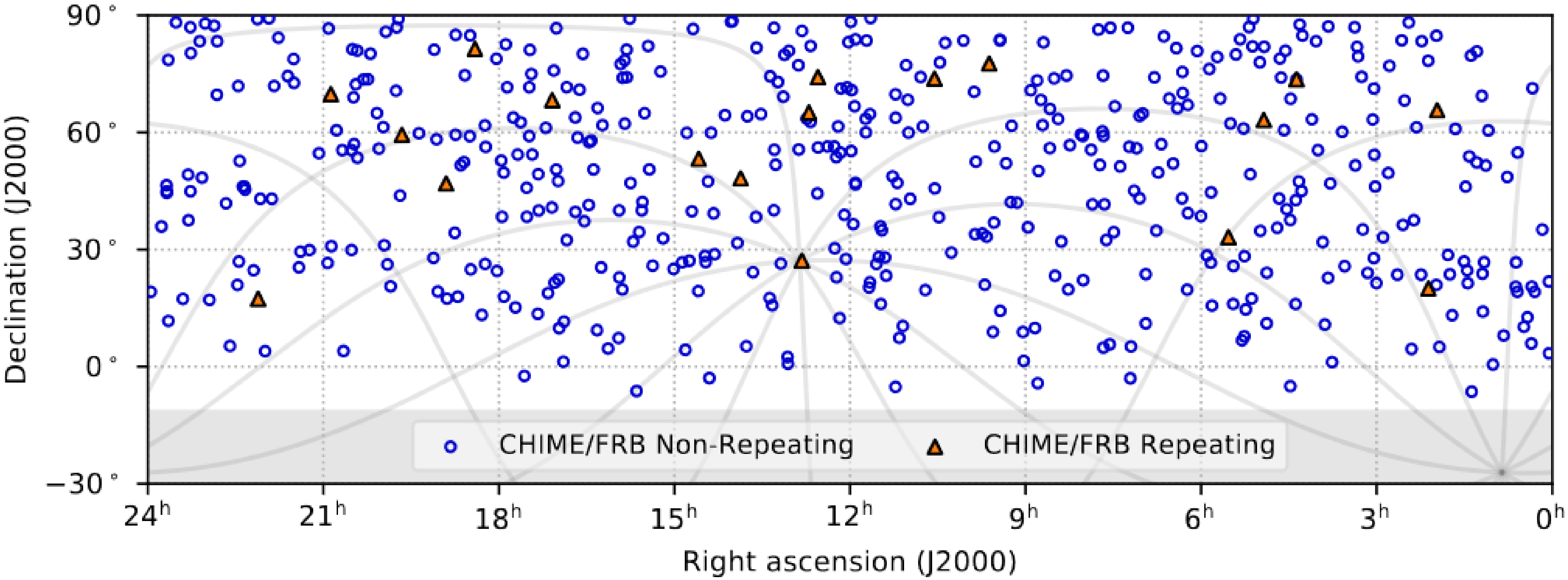
FRB 180814
CHIME



1901.04525

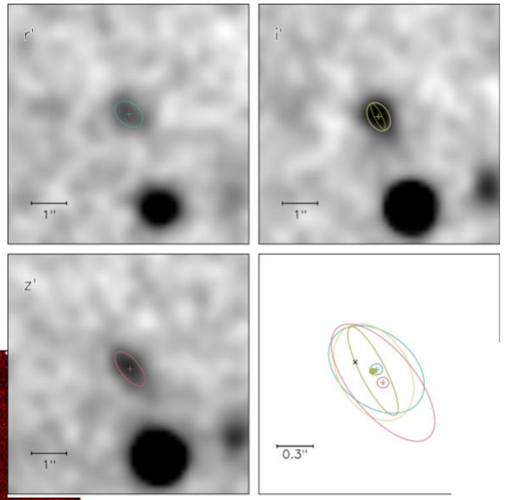
CHIME CATALOGUE

www.chime-frb.ca/catalog

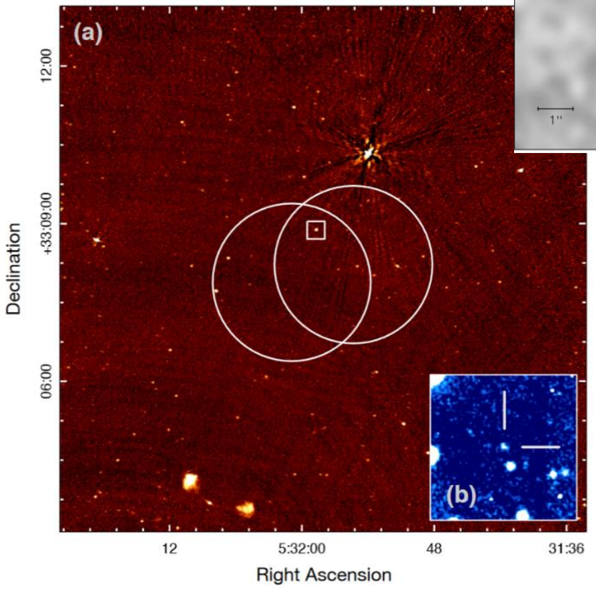


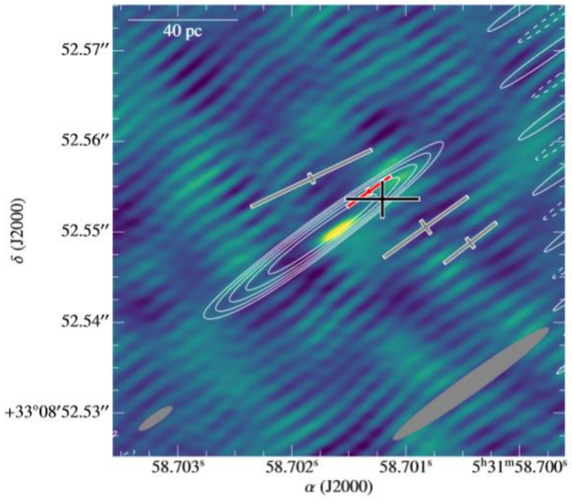
2106.04352

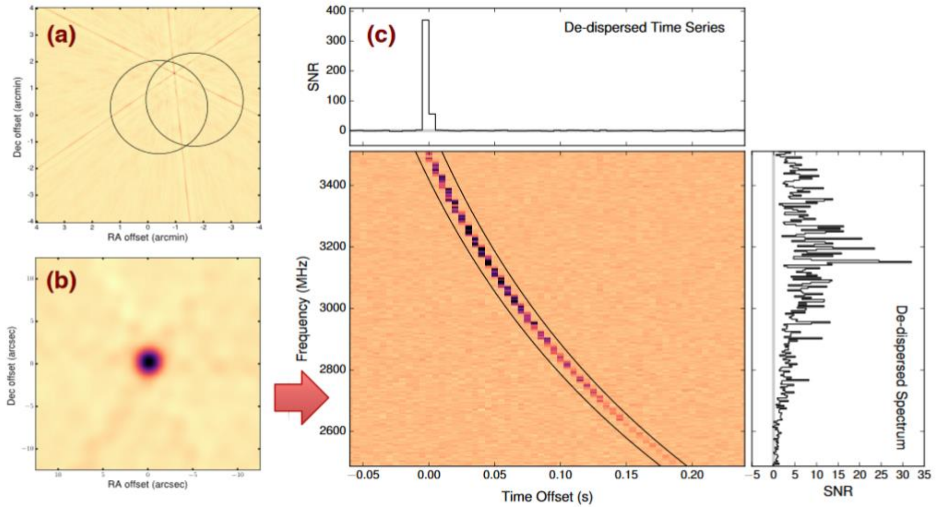
HOST GALAXY OF THE FRB



Thanks to precise localization of FRB 121102
it became possible to identify a host galaxy.
This a dwarf galaxy with high starformation rate
at z~0.2 (~1 Gpc).

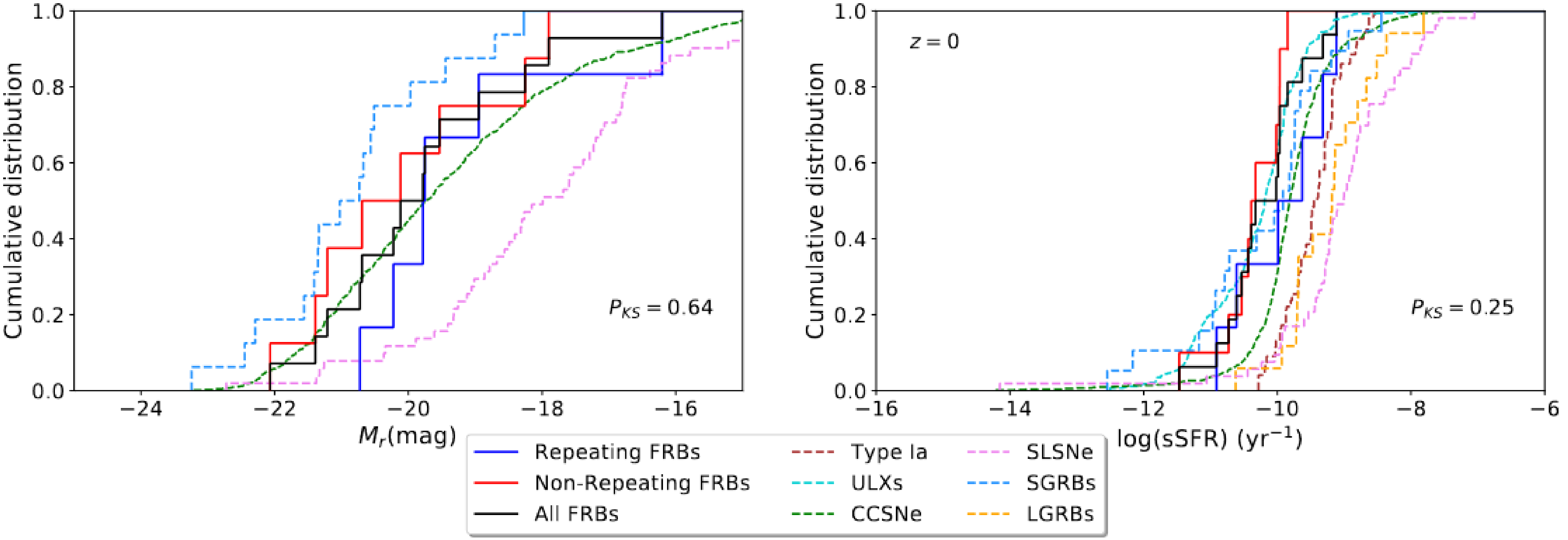






1701.01098, 1701.01099, 1701.01100

FRB HOST GALAXIES

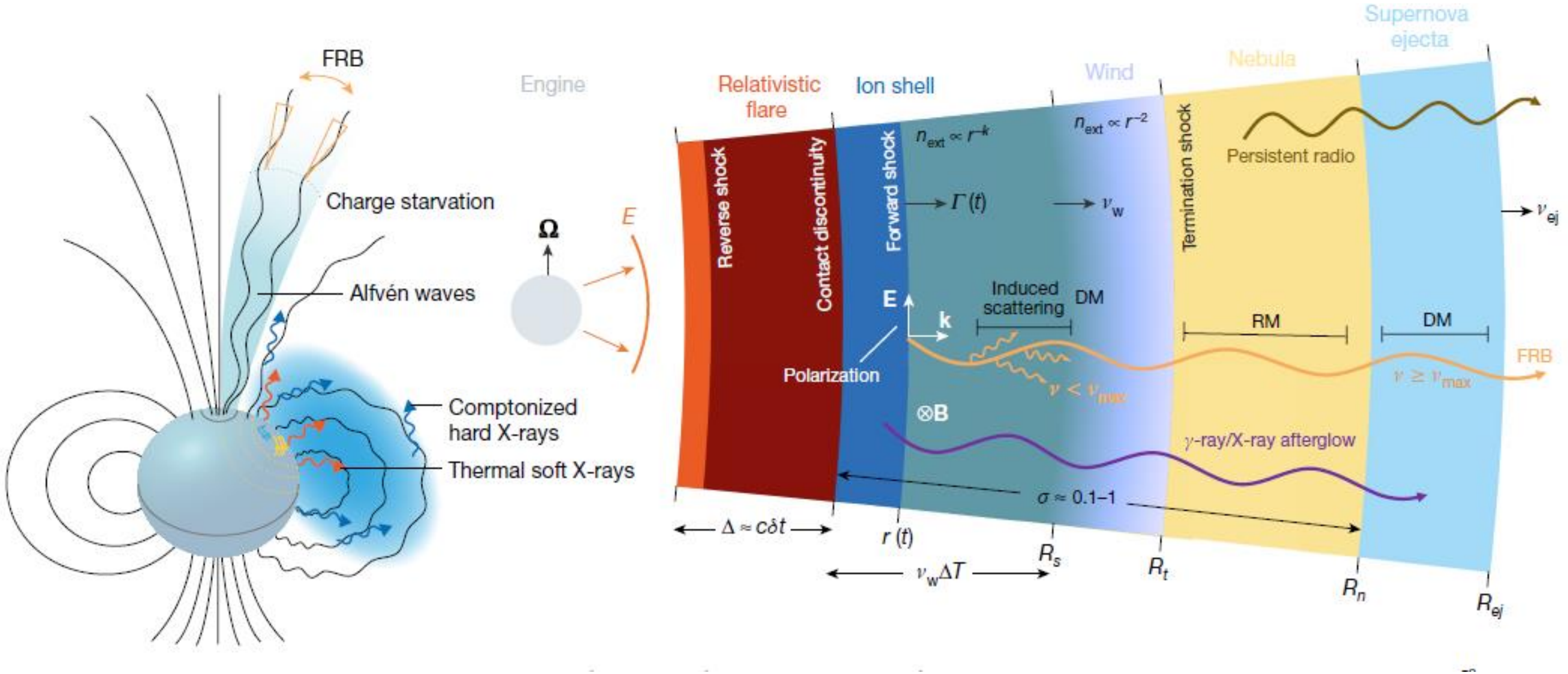


CCSN and sGRB host galaxies look similar.

2108.01282

http://frbhosts.org/

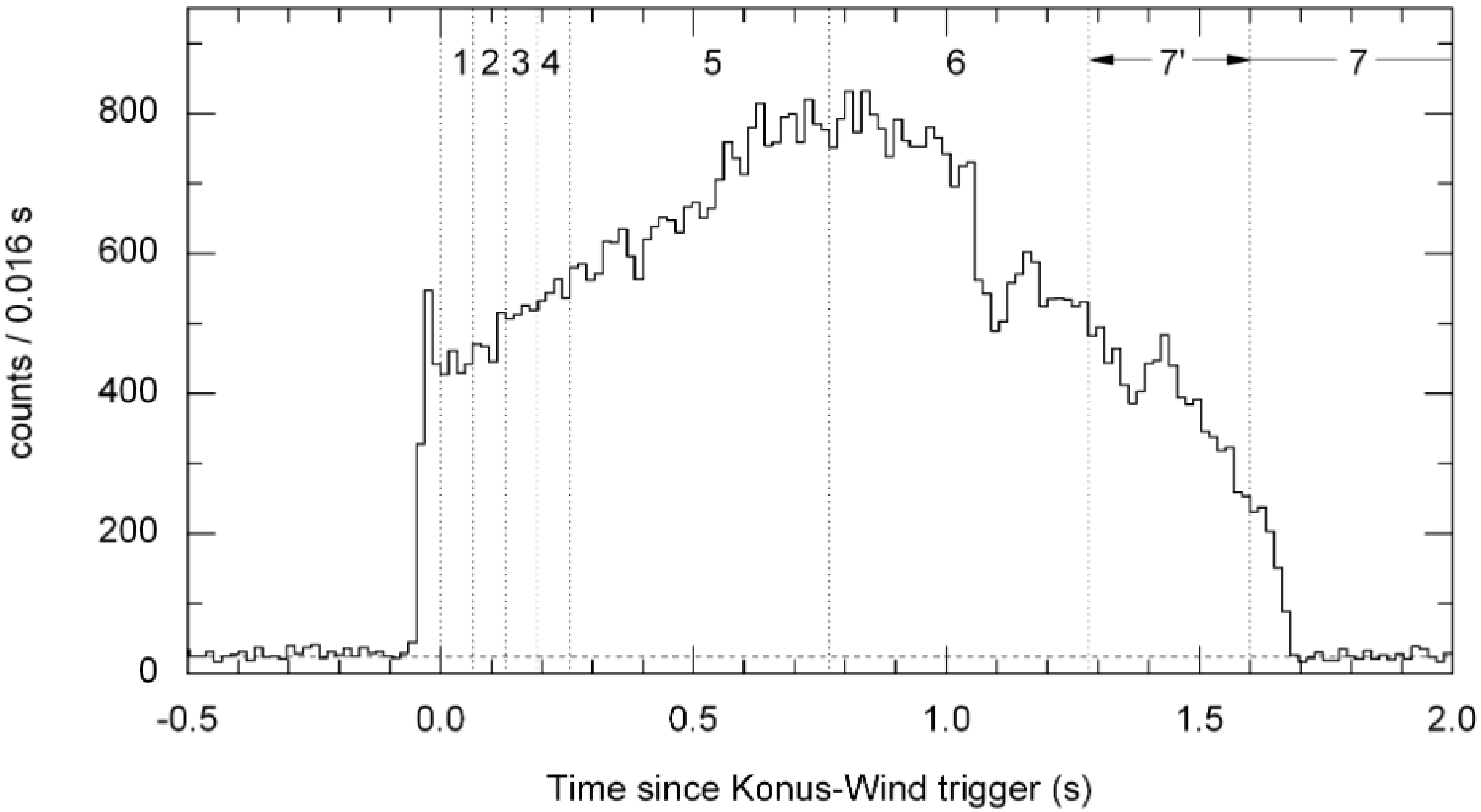
MAGNETOSPHERE OR OUTER SHOCKS?



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)

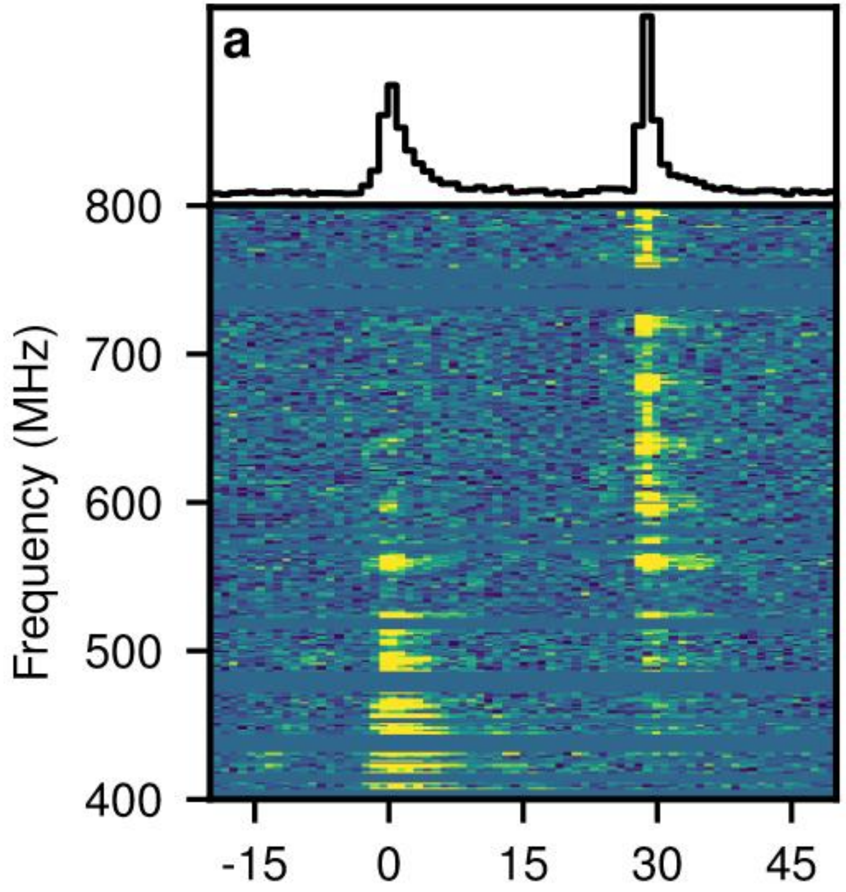


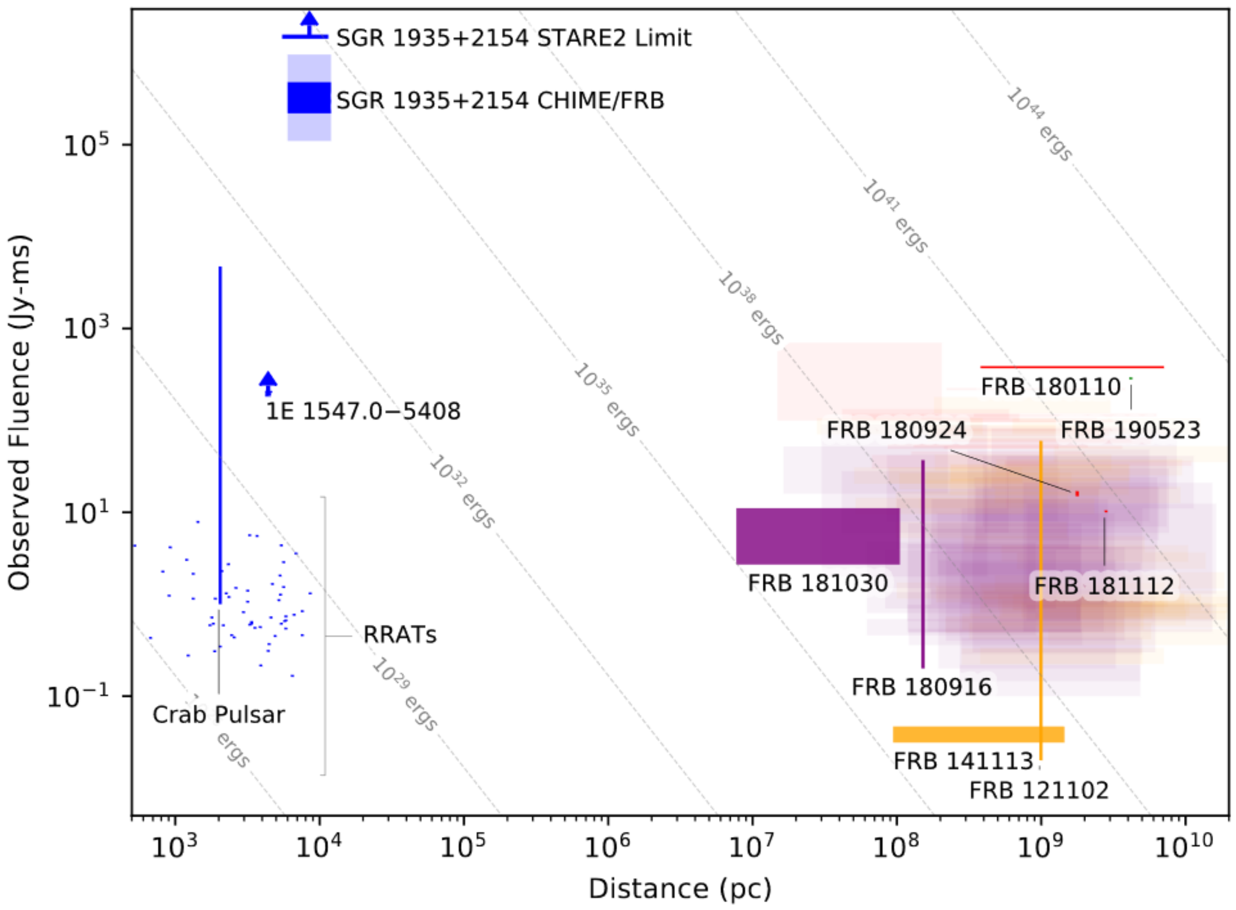
Activated in April 2020.
Finally, on April, 28 2020
A simultaneous burst
in radio and X/gamma
was detected.

astronomerstelegram: 13681-13769

GCN: 27666-27669

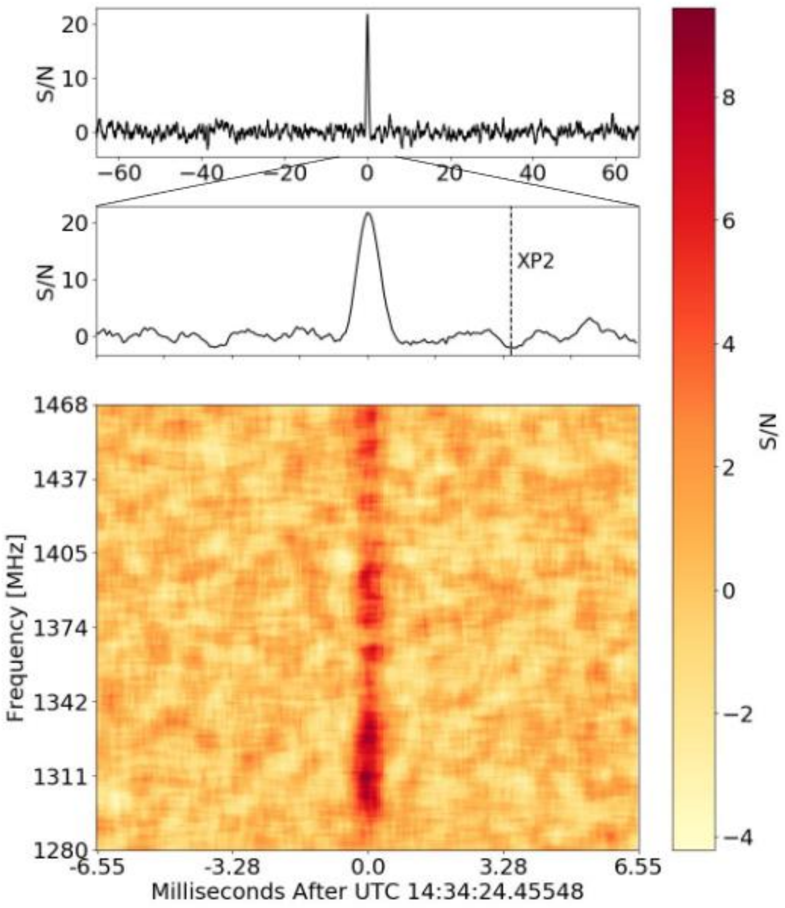
CHIME DATA

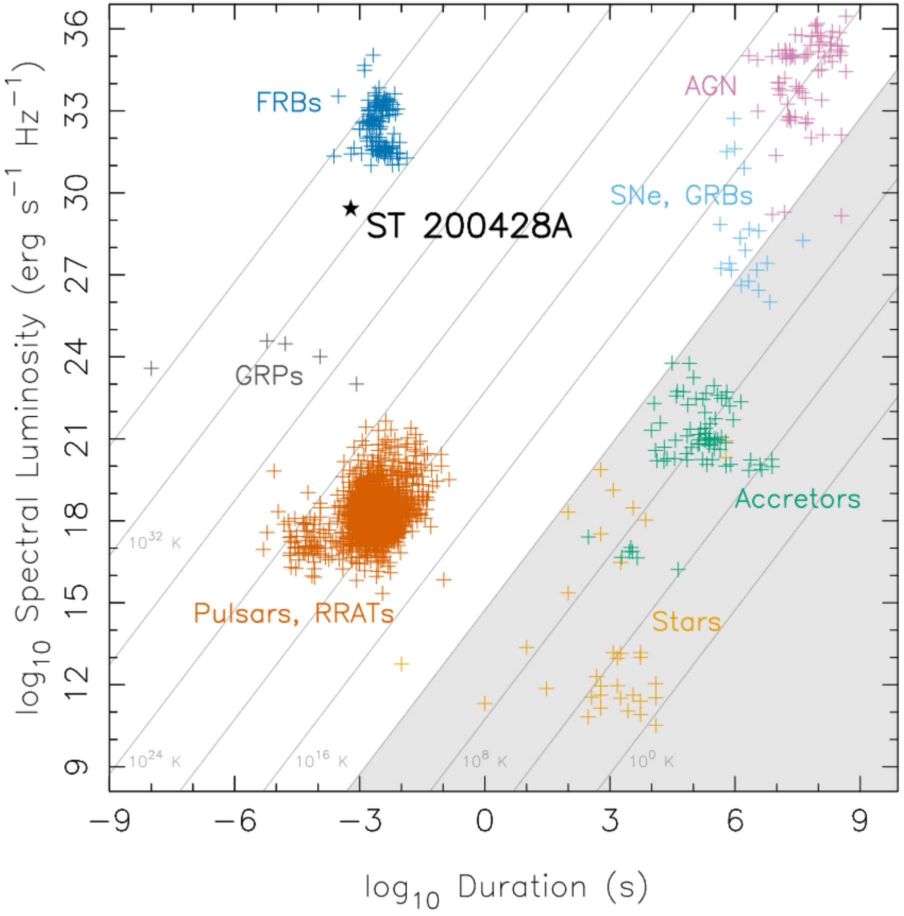




2005.10324

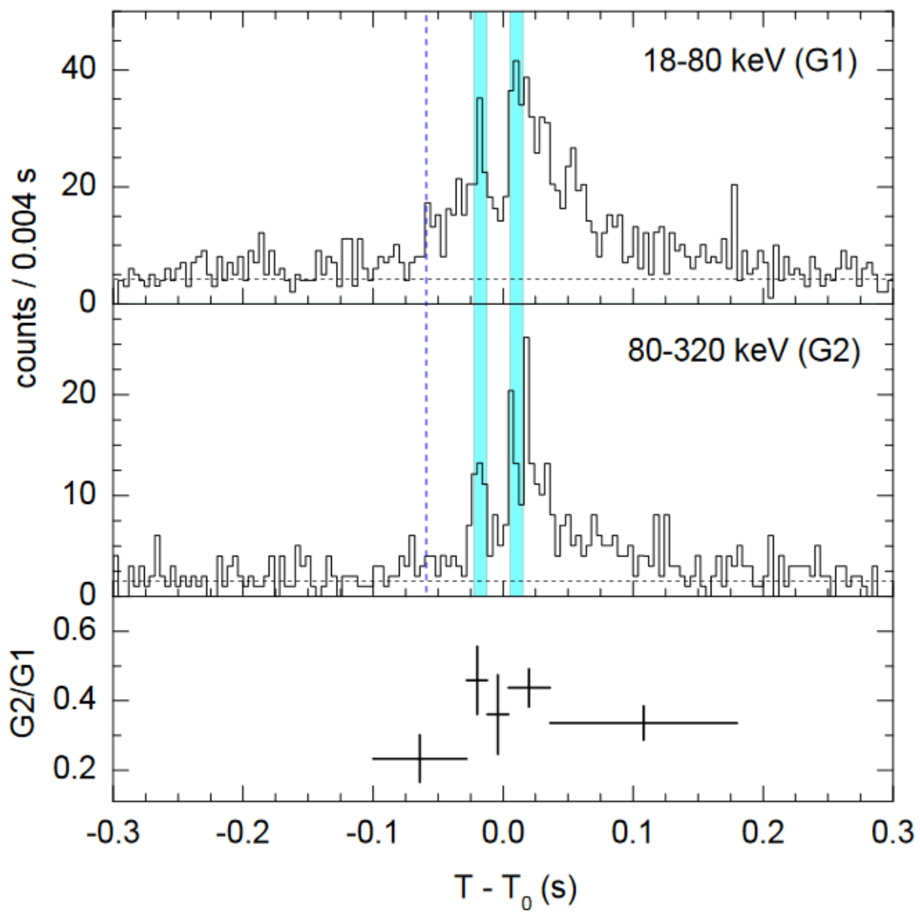
STARE2 DATA

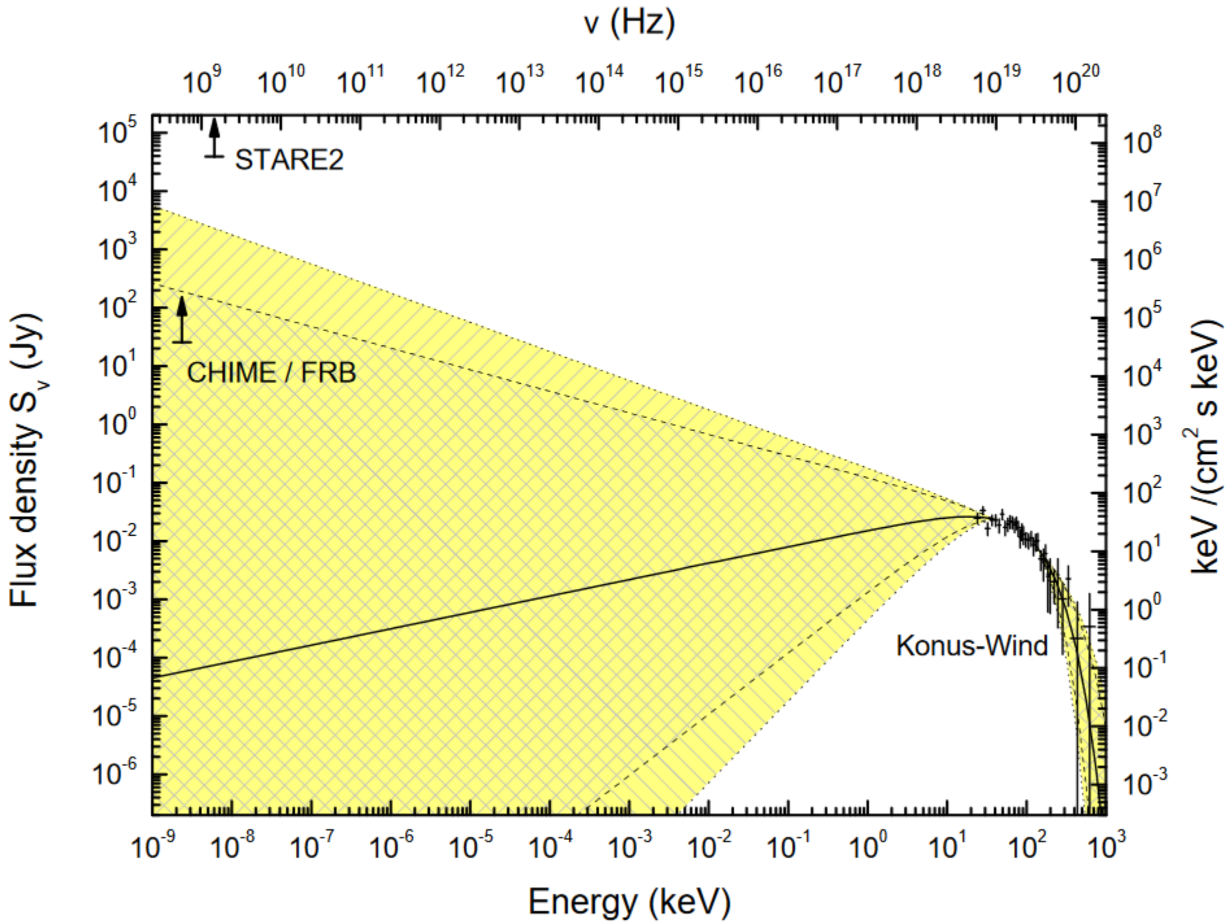




2005.10828

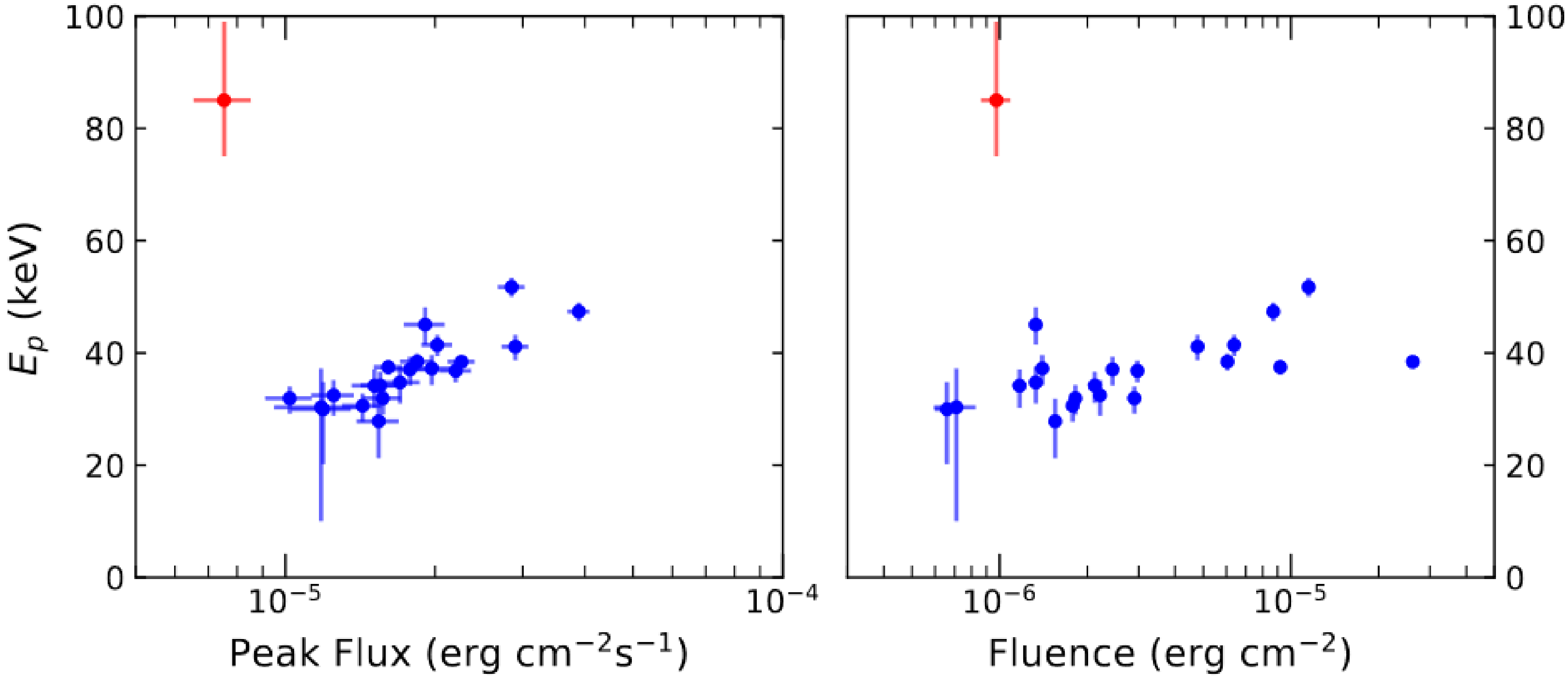
KONUS-WIND DATA





2005.11178

KONUS-WIND DATA

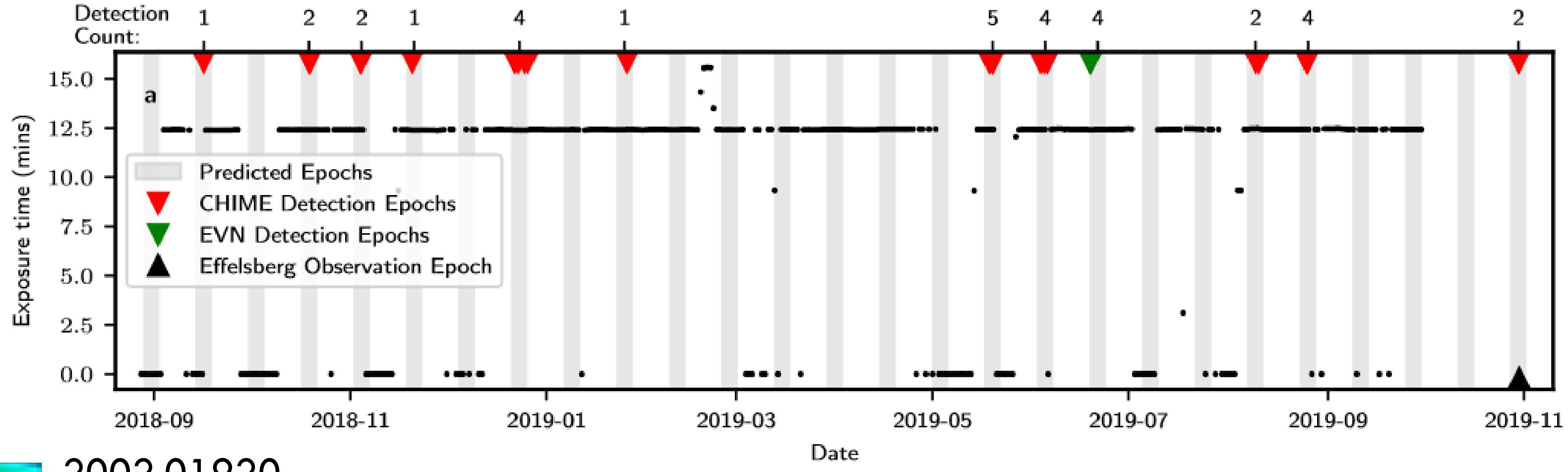


2005.11178

FRBS IN BINARIES?

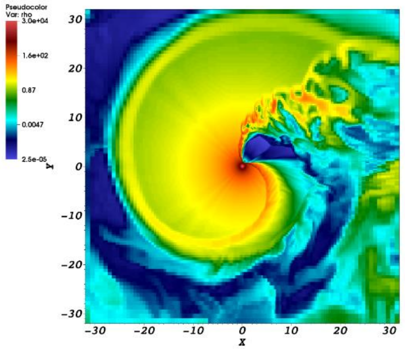
FRB 180916.J0158+65
CHIME (+Effelsberg)

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

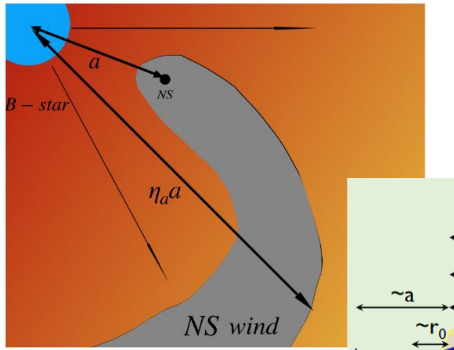


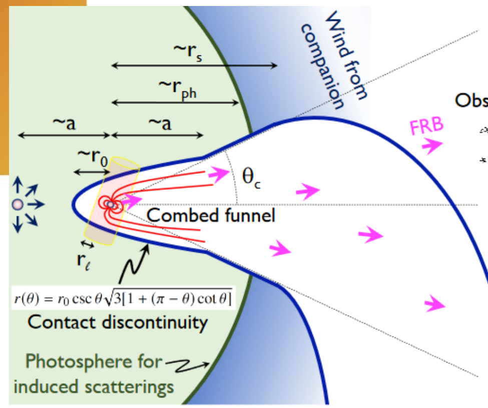
2001.10275

Ideas:
- Binary system
- Precession
- Long spin periods

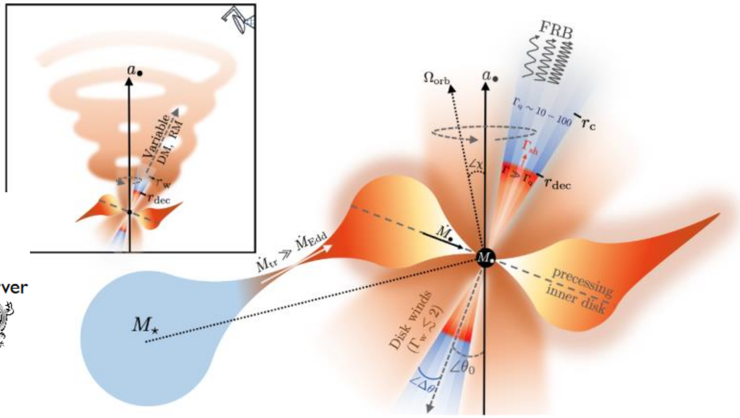


2002.01920





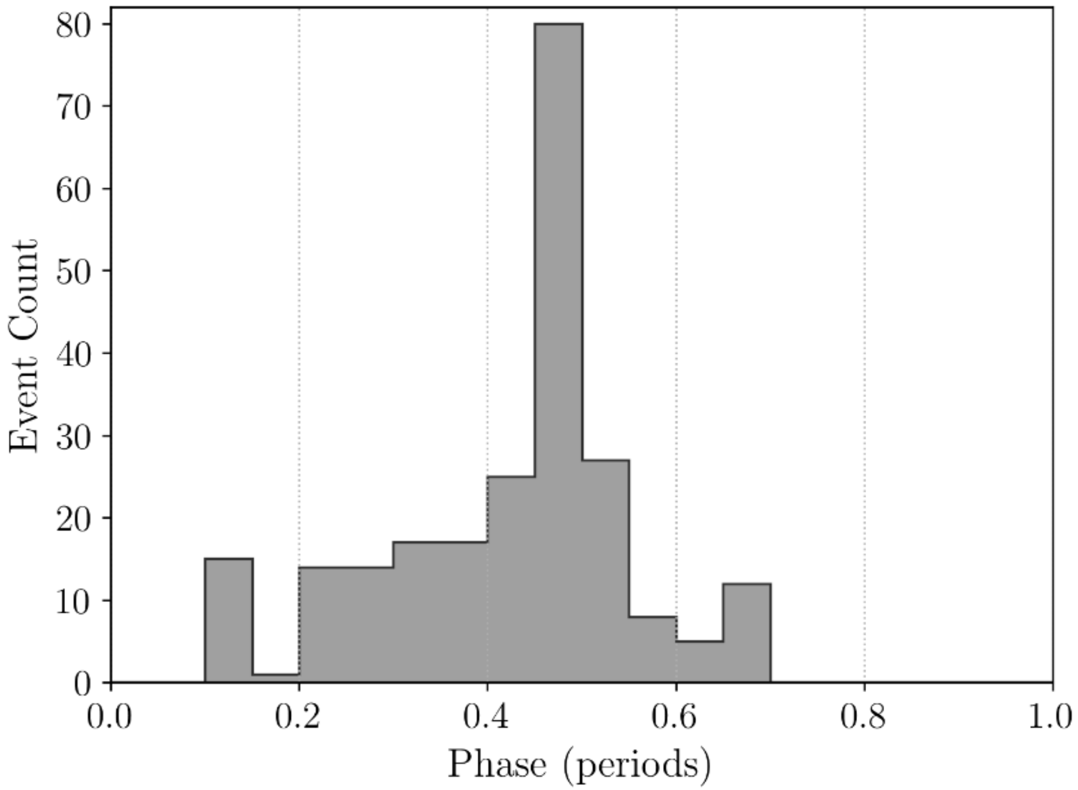
2002.08297

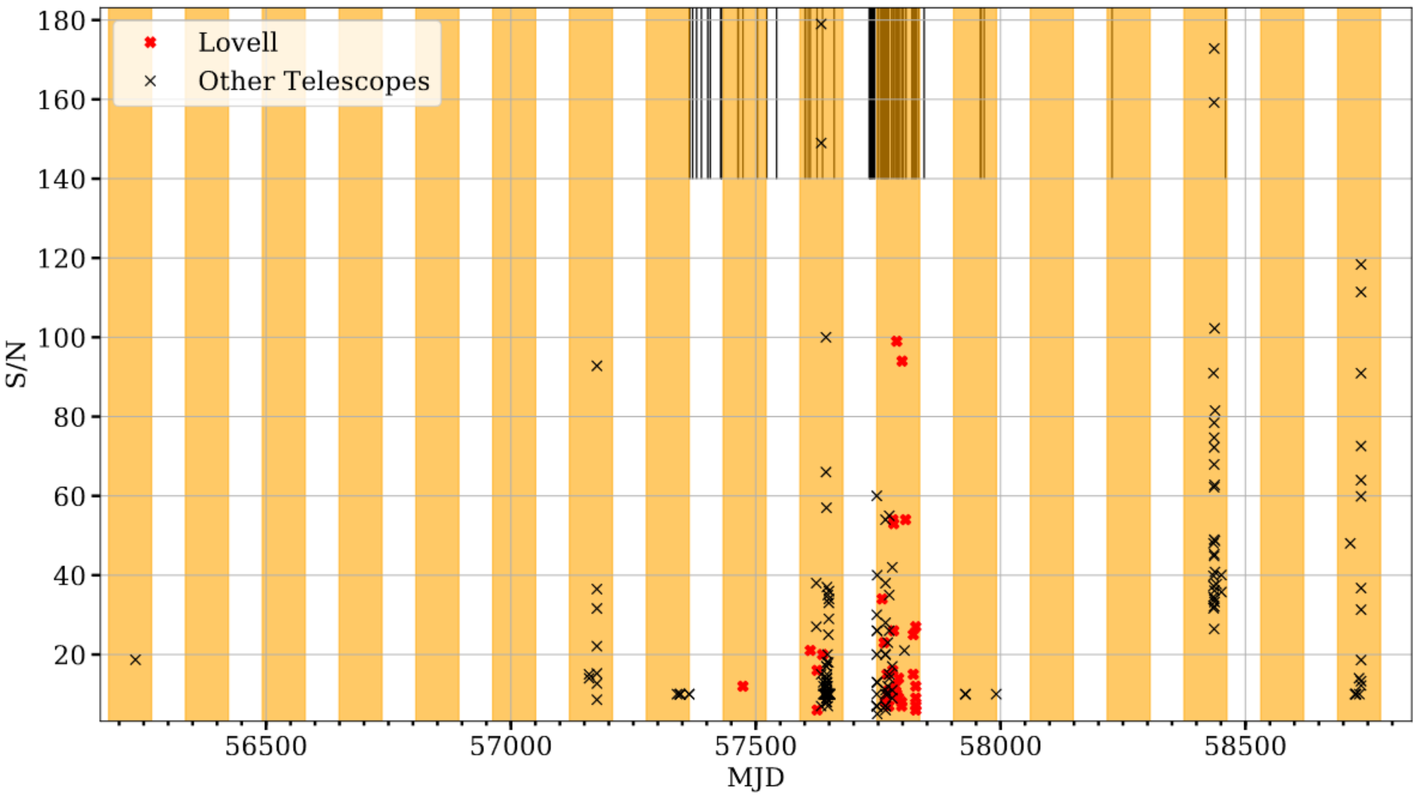


2102.06138

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



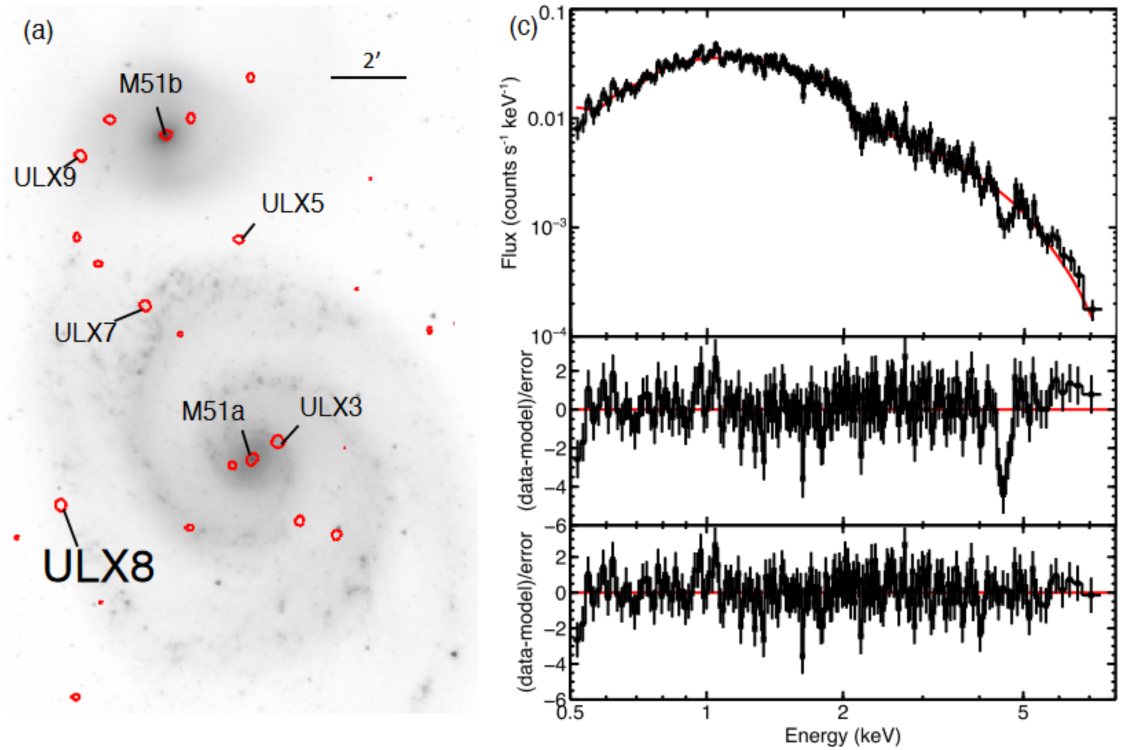


2003.03596, see also 2008.03461

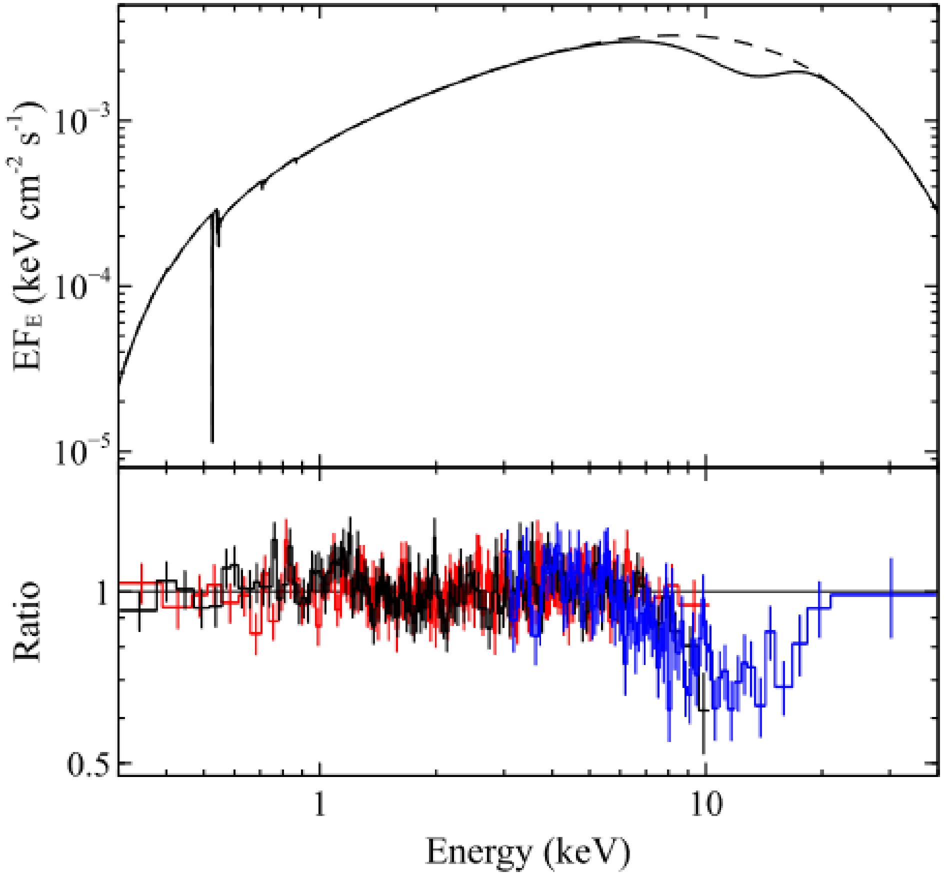
SEARCHING FOR EVIDENCE. I. CYCLOTRON LINES

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



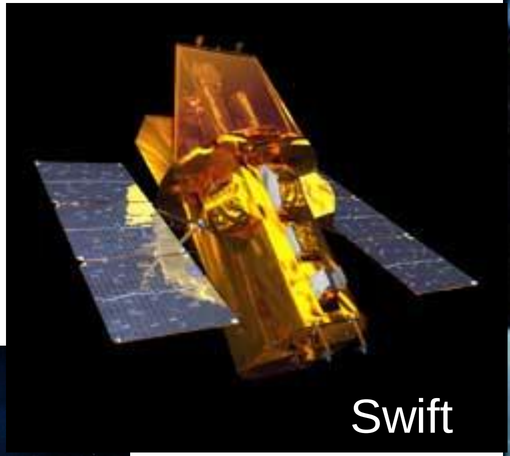
NGC 300 ULX
Electron cyclotron lime: B~10^{12} G.

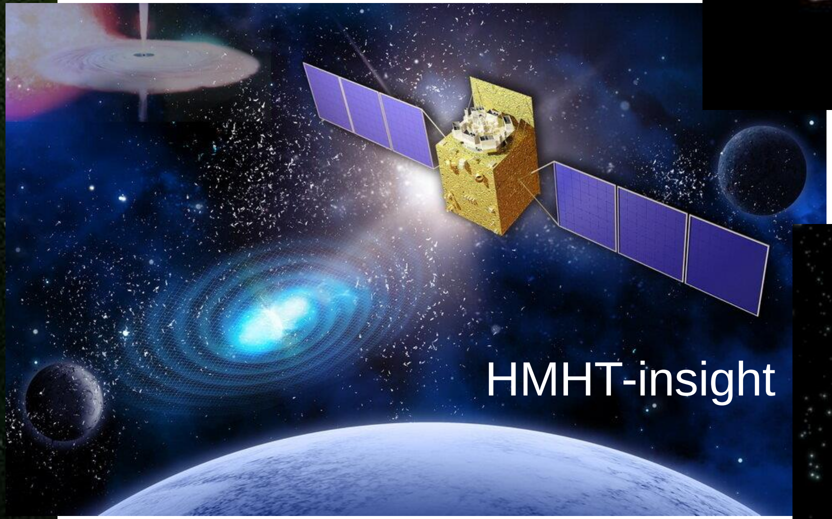


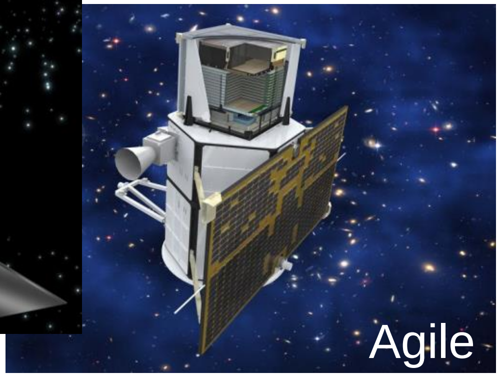
Walton et al. 1803.07571

SEARCHING FOR EVIDENCE. II. MAGNETAR ACTIVITY

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

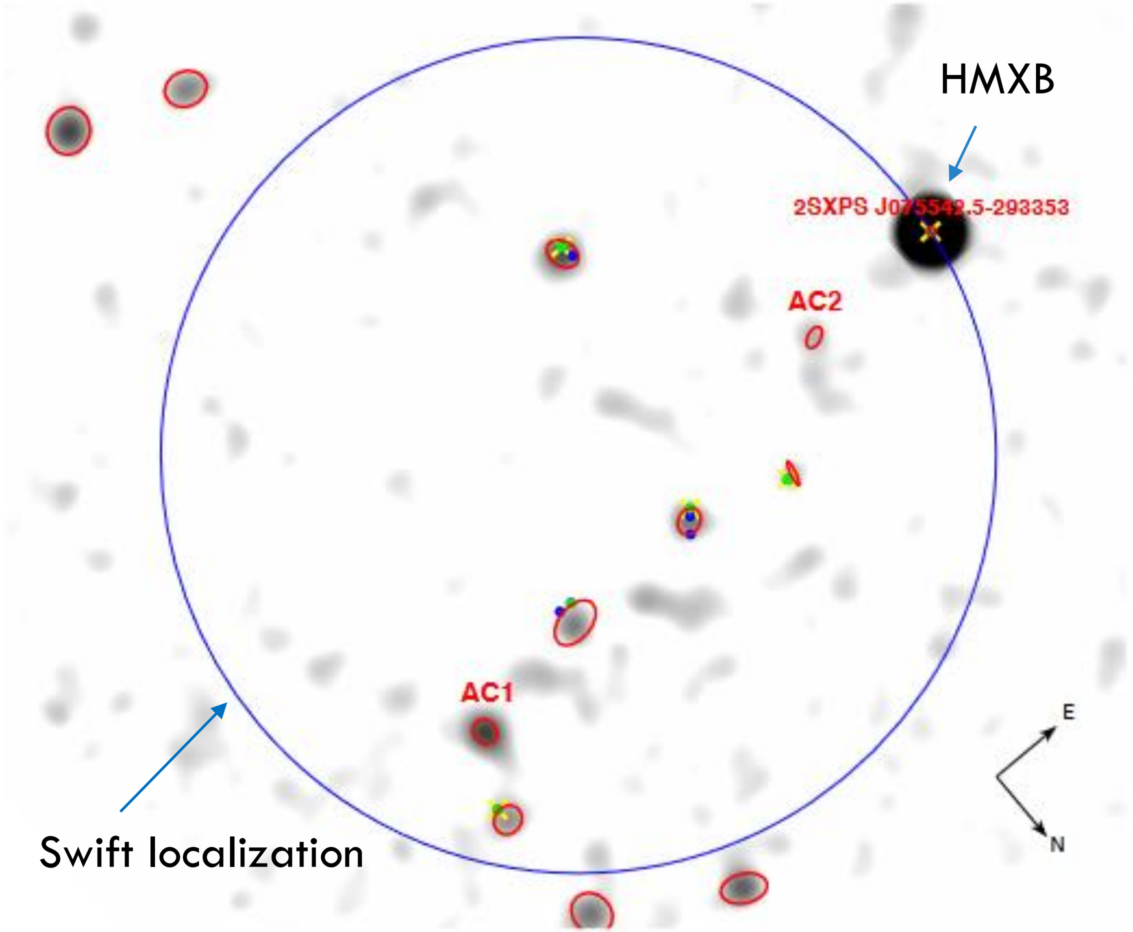




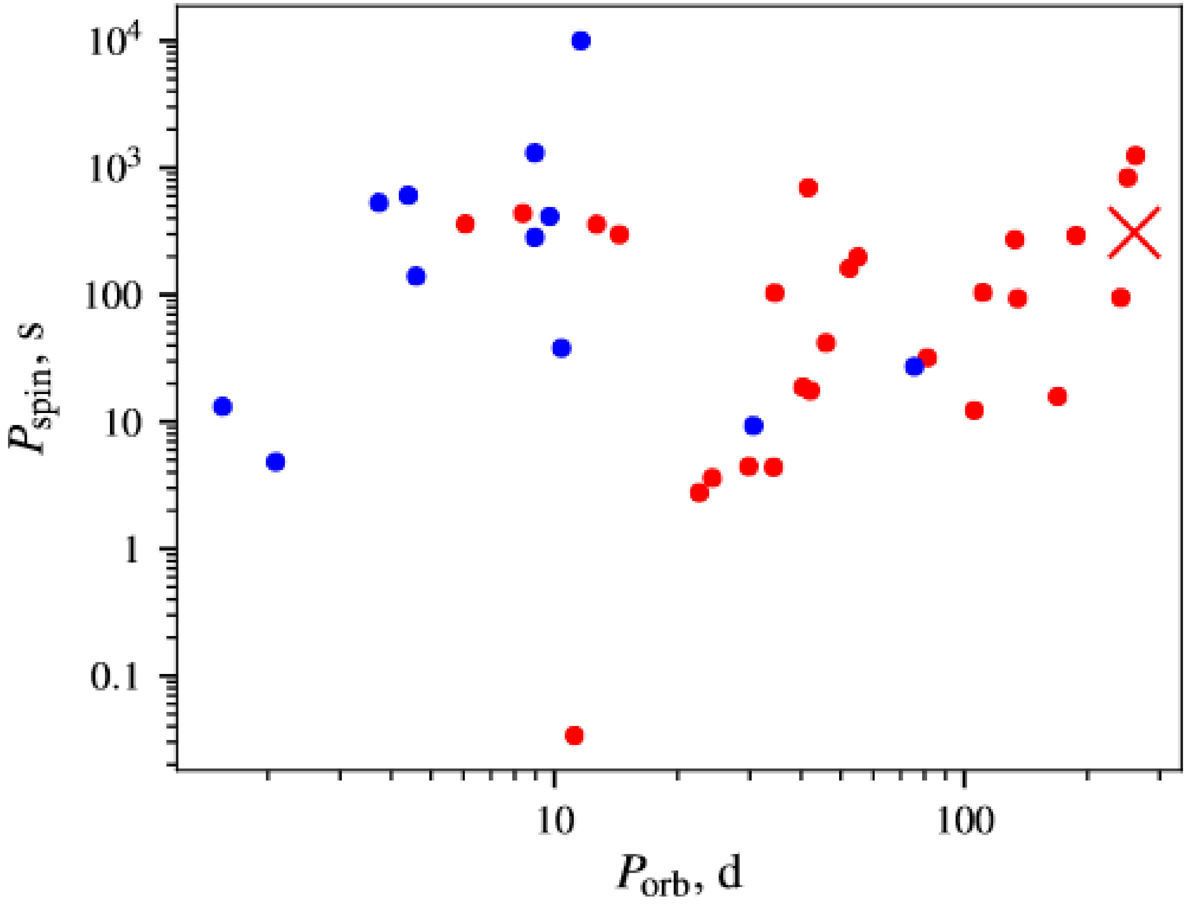


THE FIRST EXAMPLE?

SGR 0755−2933



One 30 msec burst detected by Swift in 2016
Coincident with a HMXB.



Doroshenko et al. 2101.10834

(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