Radio transients and neutron stars

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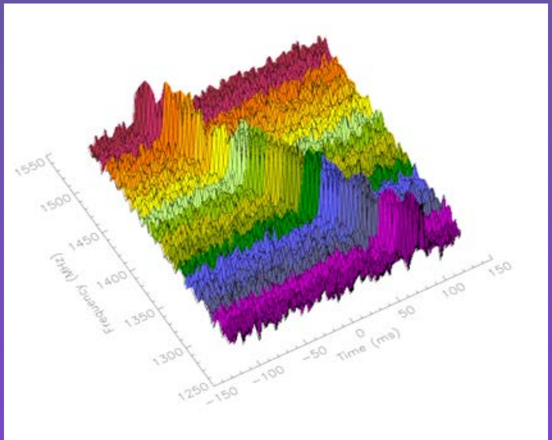
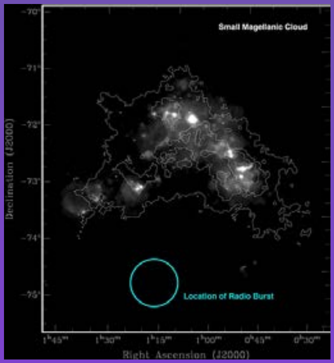
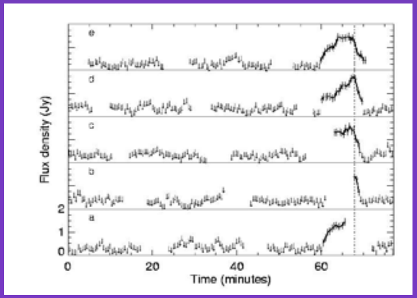
Fast Radio Bursts
(Lorimer et al. 2007, Thornton et al. 2013, …….)

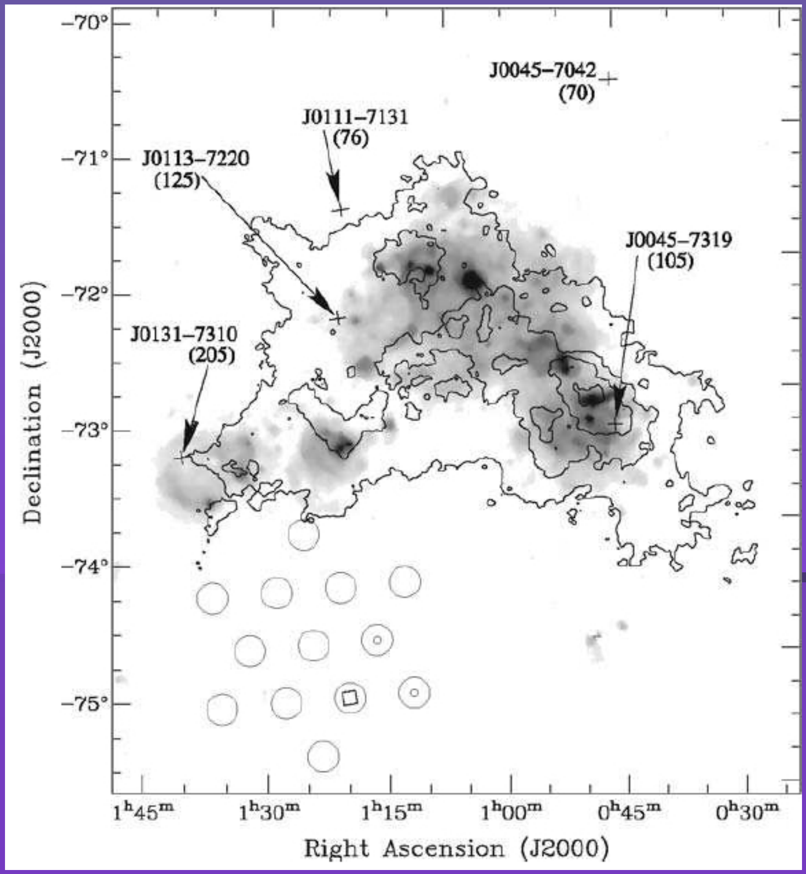




Mysterious radio transient GCRT J1745-3009 (Hyman et al. 2005, …..)



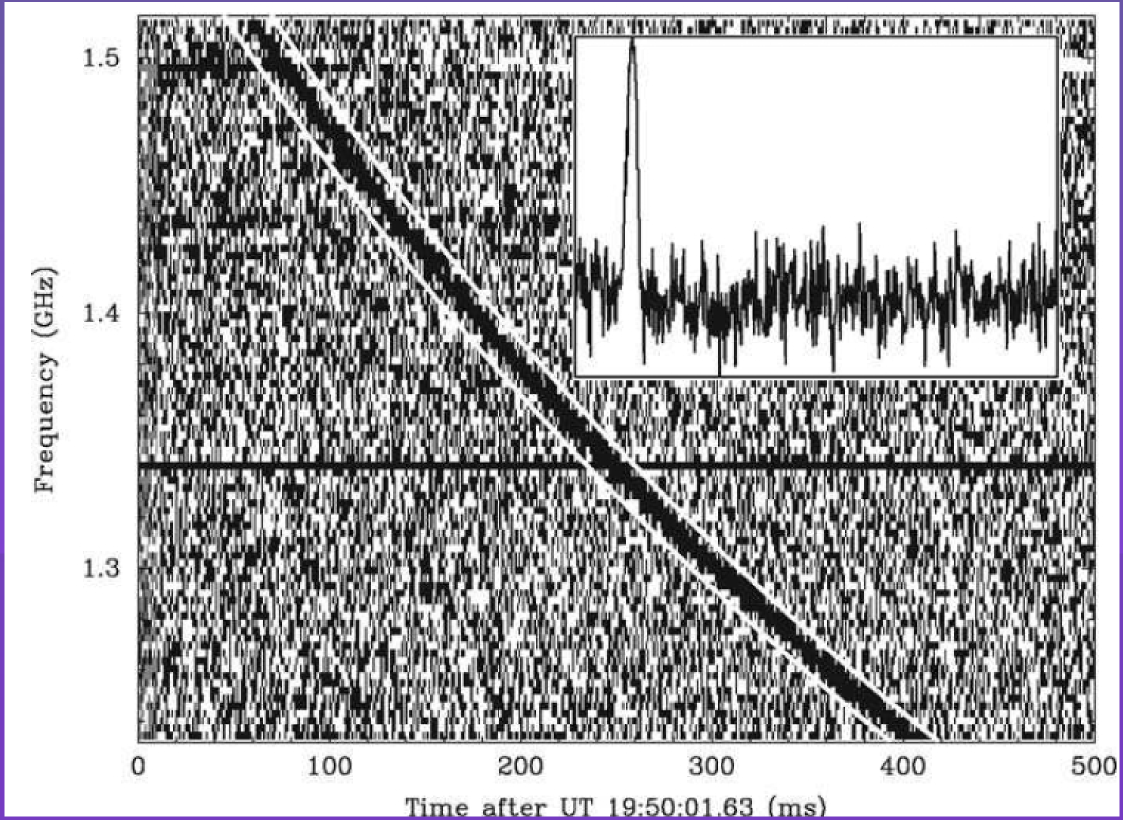
Millisecond extragalactic radio burst



Discovered by Lorimer et al.
[Science 318, 777 (2007)]
1.4 GHz, Parkes

~30-40 Jy, < 5 msec
3 degrees from SMC

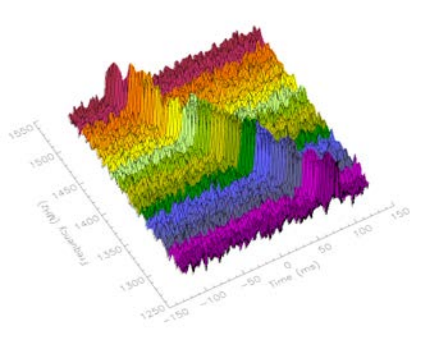
Millisecond extragalactic radio burst



Large DM 375 cm^{-3} pc
Extragalactic
Distance ~< 1 Gpc
(>600 Mpc from optical limits on the host galaxy)

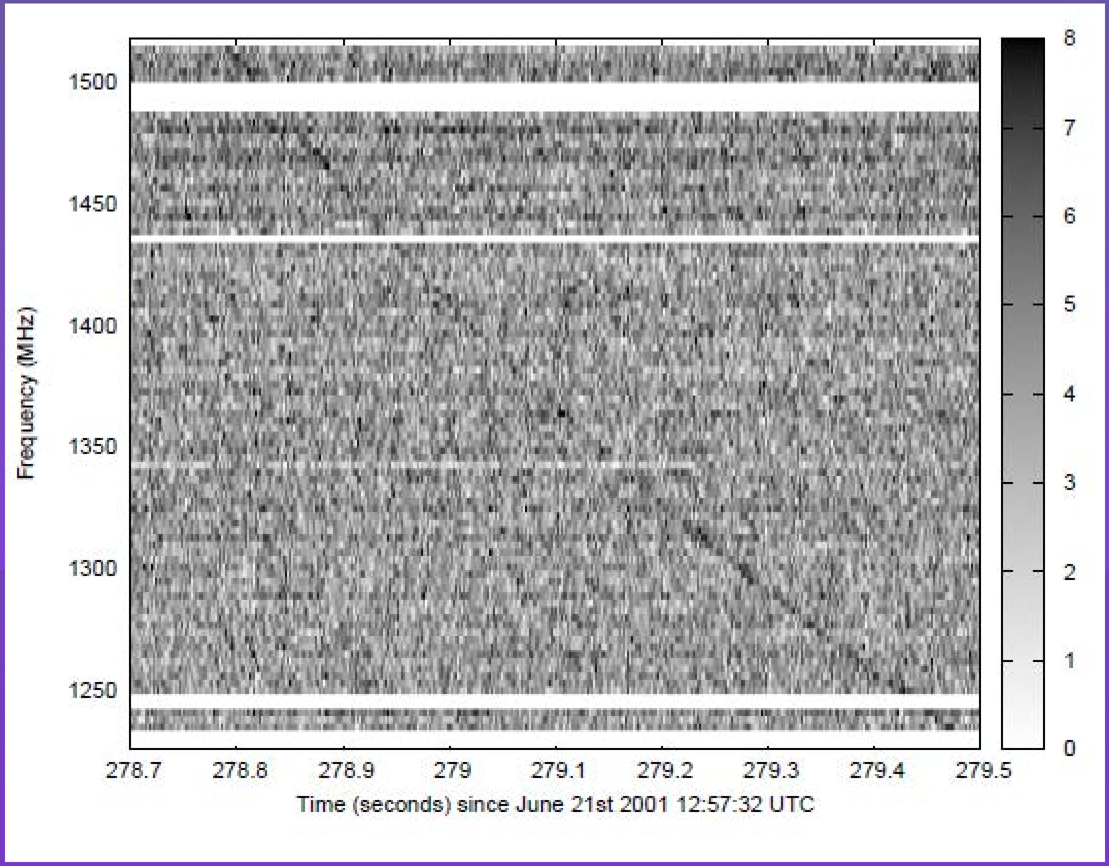
Rate is about 90/day/Gpc^3

This rate is much lower than the SN rate, and much larger that the rate of GRBs.



[Science 318, 777 (2007)]

A second example?



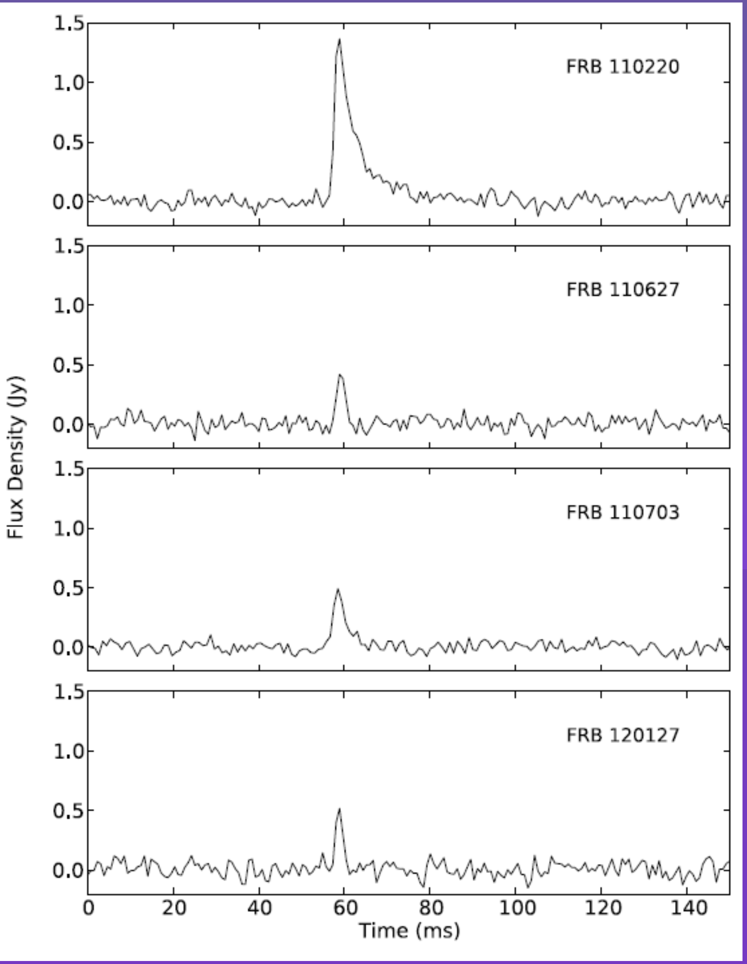
7.8 msec
0.4 Jy

Nearly in the Galactic plane

Keane et al. 1206.4135

New FRBs

Four new bursts discovered.
Now it is clear that we deal with a class of events. Origin – unknown



Flux ~ 1 Jy, Fluence ~ (0.6-8) Jy ms
E_{radio}~10^{38}-10^{40} erg
DM~550-1100, z~0.5-1, d~1.7-3.2 Gpc
|b|>41^o
Rate ~$10^{4+/-0.5}$ d^{-1} sky^{-1} up to ~3 Gpc
(~100-1000 per cubic Gpc per day)

Thornton et al. 1307.1628

Like an old puzzle ....

GRBs: 1967 – end of 90s

FRBs: 2007 - ....?

Hypotheses

- Supramassive NSs (Falcke & Rezzolla, Zhang)
- WD+WD (Kashiyama et al.)
- Dwarf stars (Loeb et al.)
- GRBs (Zhang)
- NS+NS merger (Totani)
- Primordial BHs (Keane et al.)

In all models it is expected that emission is coherent (see Katz 2013).
Brightness temperature is very high: >~10^{34} K.

Resume:

"Radio Bursts, Origin Unknown"
James Cordes Sci. 341, 40 (2013)

A hyperflare of an extragalactic magnetar

We note that the rate about 100 per day per cubic Gpc is about the expected rate of extragalactic hyperflares of magnetars.

Raising time

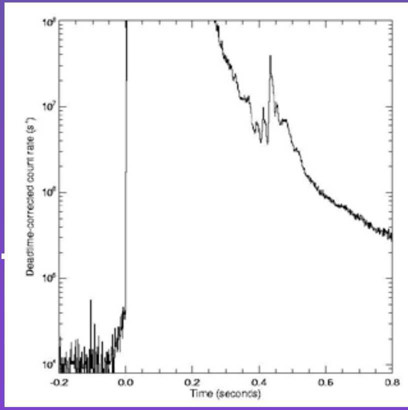
The raising part of the burst 27 Dec 2004 was about 5 msec. This is about what was observed for the mERB.

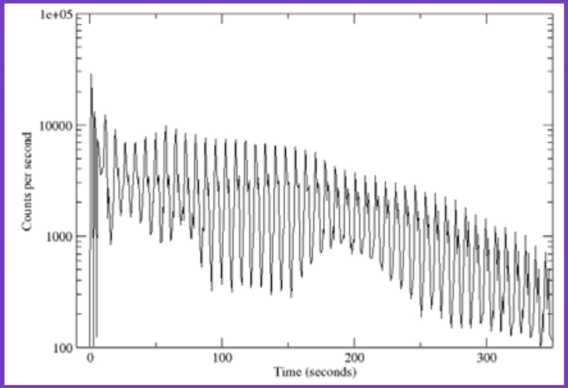
No GRB was detected at the time of mERB

This is natural as a hyperflare is undetectable from ~600Mpc.

Host galaxy

SGRs are expected to be related to starformation sites. So, the host galaxy can be a starforming galaxy with dust.





Popov, Postnov arXiv:0710.2006

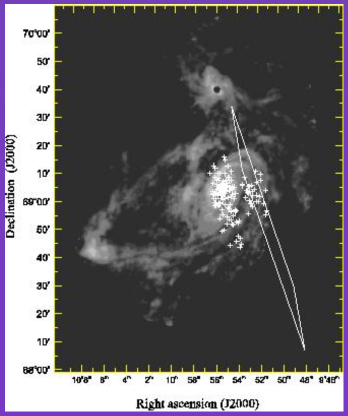
“Hyperflares of SGRs as an engine for millisecond extragalactic radio bursts “

Rate of hyperflares

Popov, Stern (2006) estimated the rate of hyperflares per galaxy ~1/1000 yrs.
Lazzati et al. (2005) provide an estimate somehow larger <1/130 yrs,
But this is an upper limit.
This results are based on no detection of SGR bursts by BATSE
towards local galaxies and Virgo cluster.

These values are 5-50 times lower than the galactic rate of SN.

So, the rate of hyperflares is expected to be ~20-200 per year per cubic Gpc.
This is in good correspondence with the estimate of mERBs rate.



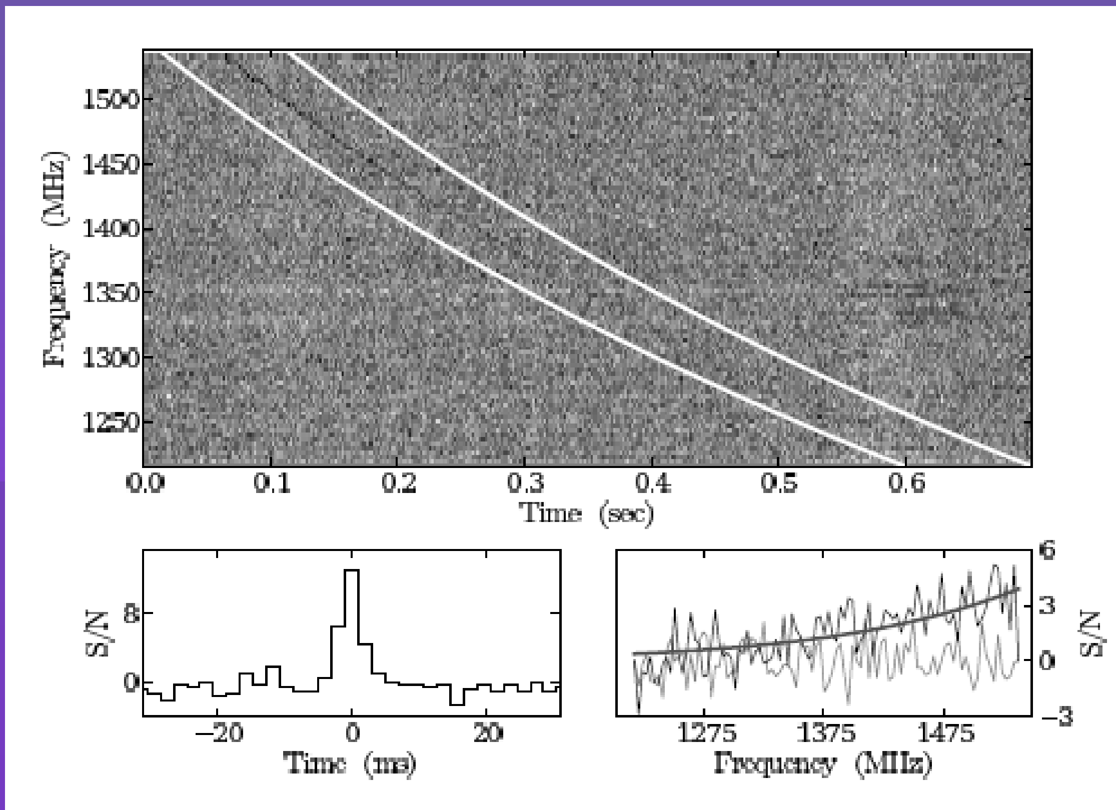
There are candidate bursts in local galaxies:
M81 group of galaxies: M81 itself, M82, M83
(Frederiks et al. 2005)

Now there are few other candidates
(Mazets et al., Frederiks et al., Golenetskii et al.,
Ofek et al, Crider ....),
including one in the direction of M31.

More FRBs

FRB 121102

FRB011025



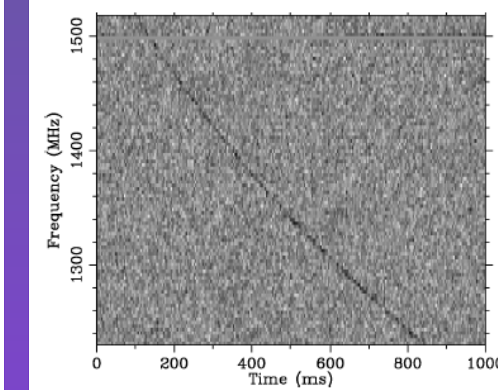
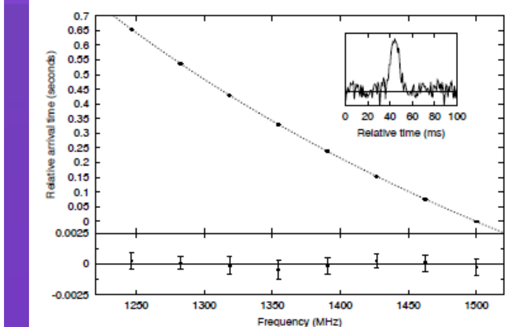


Figure 1. The spectrogram of FRB 011025, with arbitrary power scale plotted in reverse greyscale. One frequency channel containing known narrow-band interference ($f \sim 1500$ MHz) was removed.



Spilter et al. 2014

Burke-Spolaor, Bannister 1407.0400

New data

The new data provide additional support for the magnetar hypothesis.

- The rate is slightly lower than suggested by Lorimer et al.
  (Burke-Spolaor, Bannister 2014; Petroff et al. 2014),
  but still in good correspondence with the magnetar hypothesis.
- New flux measurements are in good correspondence with earlier estimates.

There are questions related to the sky distribution: uniform or not.

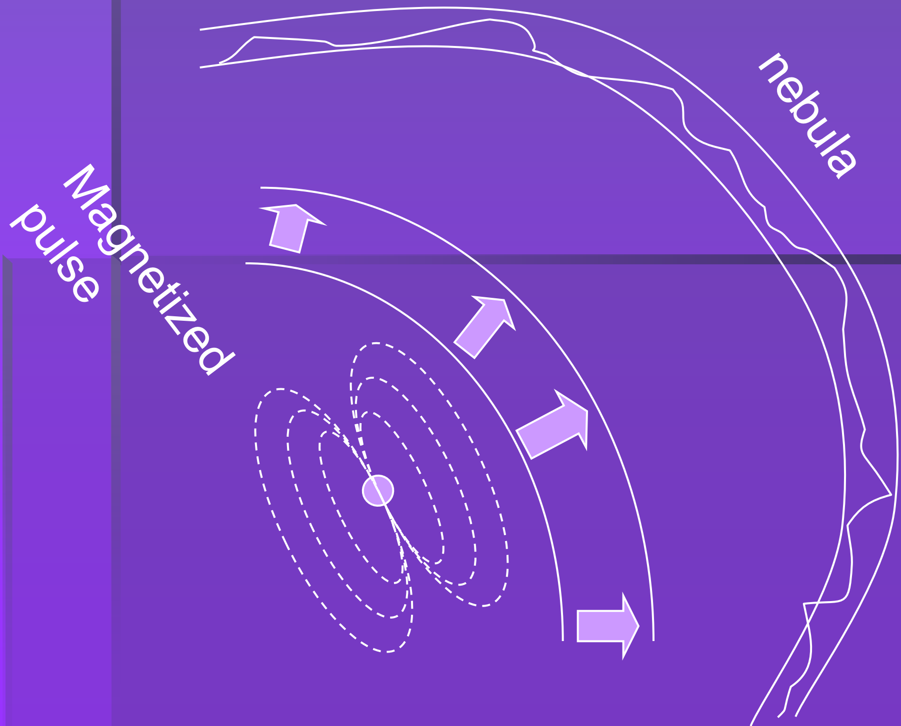
We need a detailed physical model of emission!

1307.4924

Lyubarsky's model

Recently, Yuri Lyubarski proposed a model for FRBs based on magnetars.

The mechanism is:
synchrotron maser emission from relativistic, magnetized shocks



Two shock waves (forward and reverse) are formed after the magnetized pulse reaches the magnetar nebula.
Both shock waves can result in maser emission.

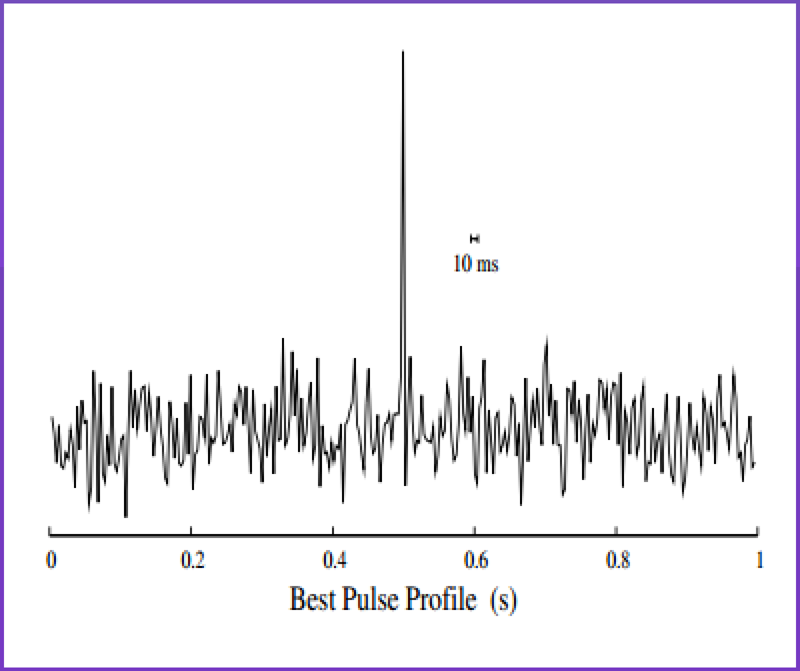
In addition, the forward shock can also produce high-energy (TeV) emission. This prediction can be used to verify the model.

1401.6674

Bursts from M31

Also (Rubio-Herrera et al. 2013) bursts from M31 have been reported.

~1-4 Jy, millisecond duration. In one case, probably, repetitions.
Compatible with magnetar activity in M31



It is necessary to assume that one of magnetars in M31 was in active phase during observations. If so, the rate of bursts will be much different in future observations.

Kulkarni et al. analysis

This authors discuss all proposed explanations for FRBs
starting with *perytons* – local events. Still, they can be an option.
It is necessary to have more observations, in particular to have
simultaneus observations of flares by (at least two) different telescopes.

The Galactic origin is absolutely ruled out (see also Tuntsov 2014).

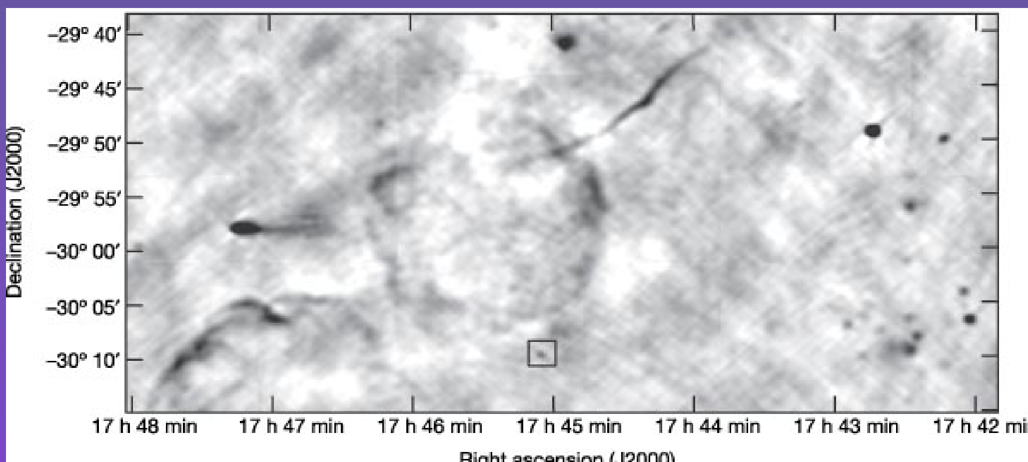
Finally, extragalactic origin seems to be more natural.

After careful analysis of different possibilities, the authors favour
the model related to giant flares of magnetars.

We have situation similar to that with GRBs in 70s-90s!

1402.4766

GCRT J1745–3009

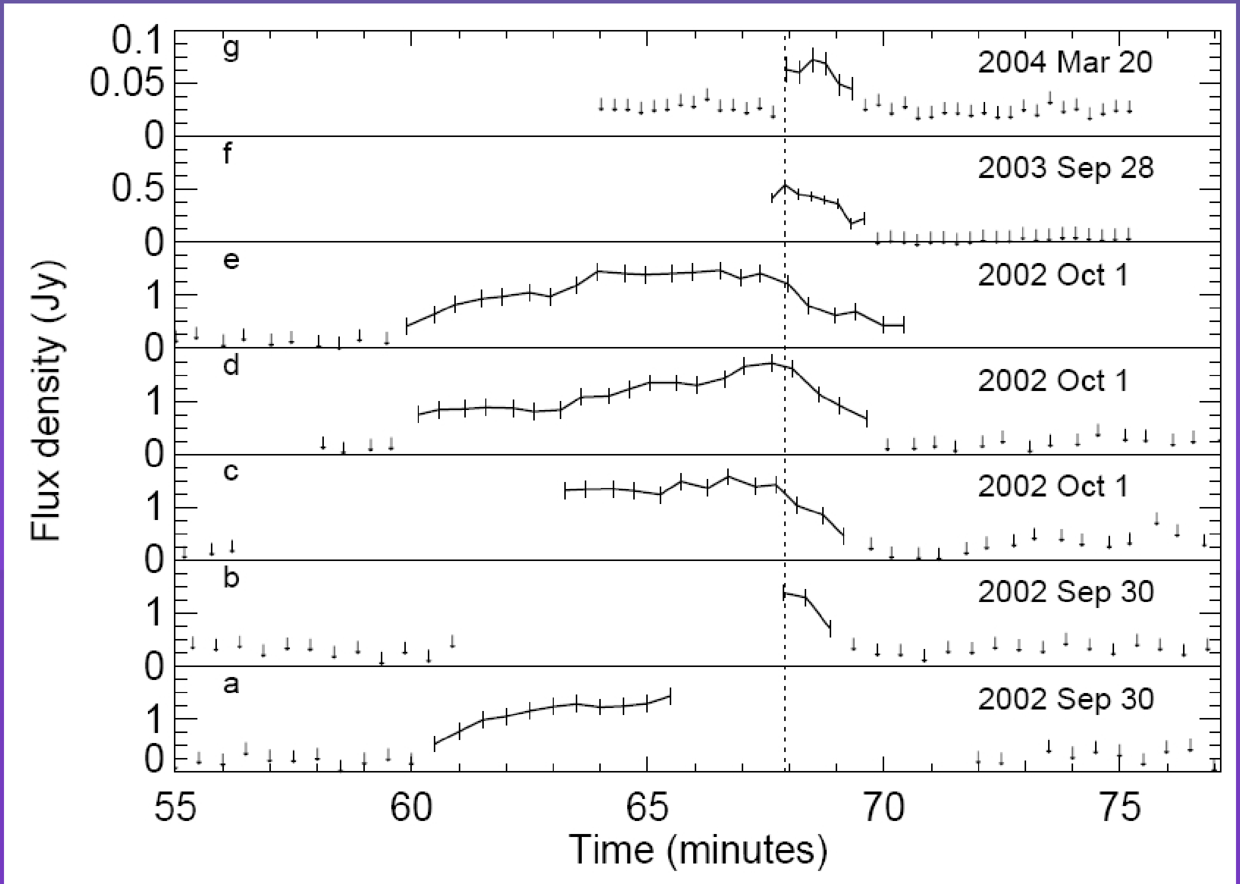


GCRT J1745–3009
is located at right ascension
17 h 45 min 50.8 s,
declination -30° 09' 52"   10",
indicated by the small box
below the 20'-diameter shell
of the supernova remnant,
SNR 359.1–00.5.

Other sources in the image include the sources to the west which are part of Sagittarius E, the linear feature, 'The Snake', to the north, and 'The Mouse' to the northeast of GCRT J1745–3009.

Discovered by Hyman et al. Nature 434, 50-52 (3 March 2005)
See a recent review in Ray et al. arXiv: 0808.1899

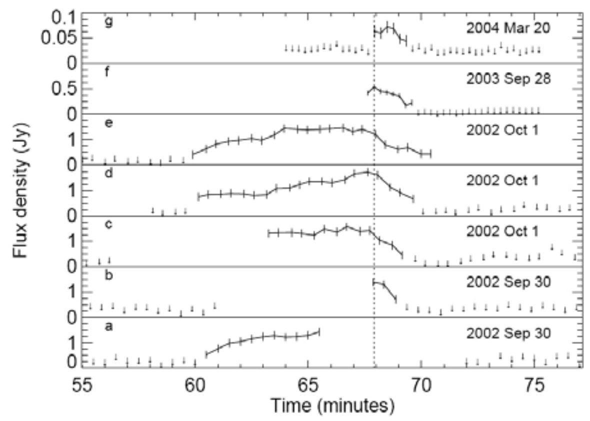
Detected bursts



(Hyman et al. 2007)

Bursts

Altogether 7 bursts detected.



- 5 bursts in 2002.
  VLA 330 MHz
  Duration of each ~ 10 minutes
  Flux ~ 1Jy
  Periodicity ~ 77 minutes
  Between bursts limit <75 mJy

- a burst in 2003.
  GMRT 330 MHz
  The maximum was not detected.
  Probably the burst is similar to 2002 bursts

- a burst in 2004
  GMRT 330 MHz
  Different from earlier.
  Weaker ~0.05 Jy
  Shorter ~2 minutes

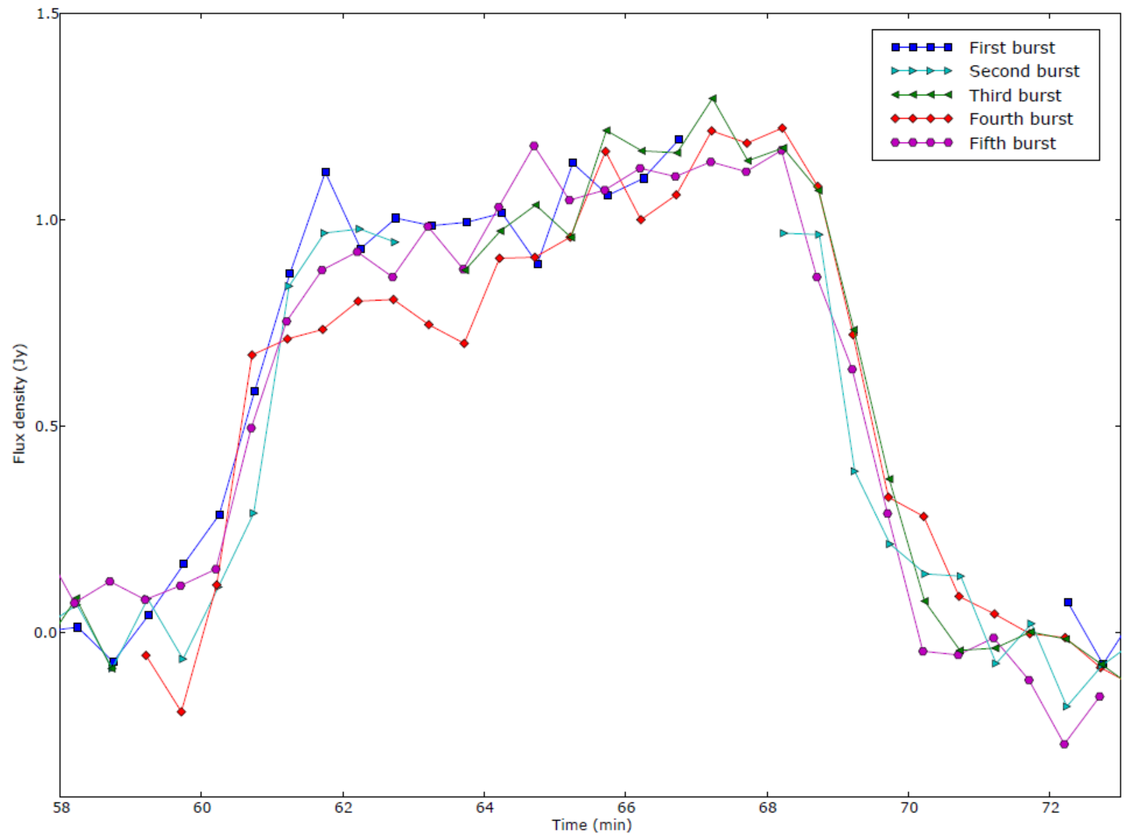
Duty cycle <7% (~ 120 hours of observations altogether)

Five first bursts look similar to each other

Three stages can be distinguished:

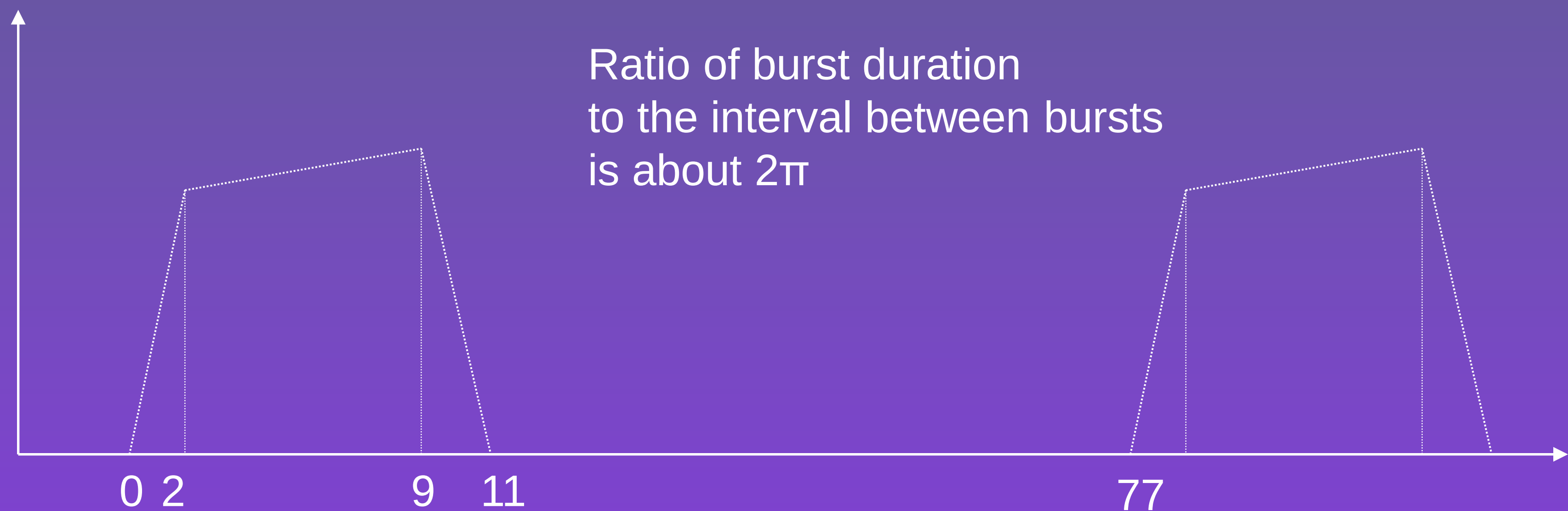
1. Rising – 2 min
2. Slow growth – 7 min
3. Rapid decay – 2min

77 min between bursts

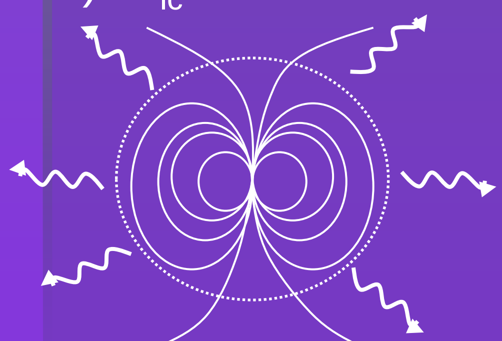


Spreeuw et al. 2009 A&A

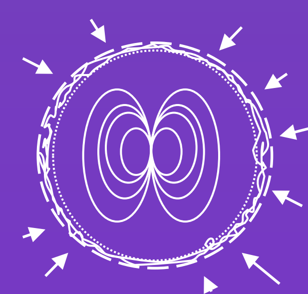
Timing properties



a) R_{lc}/c vs. P



b) R_{co}/v_{ff} vs. P



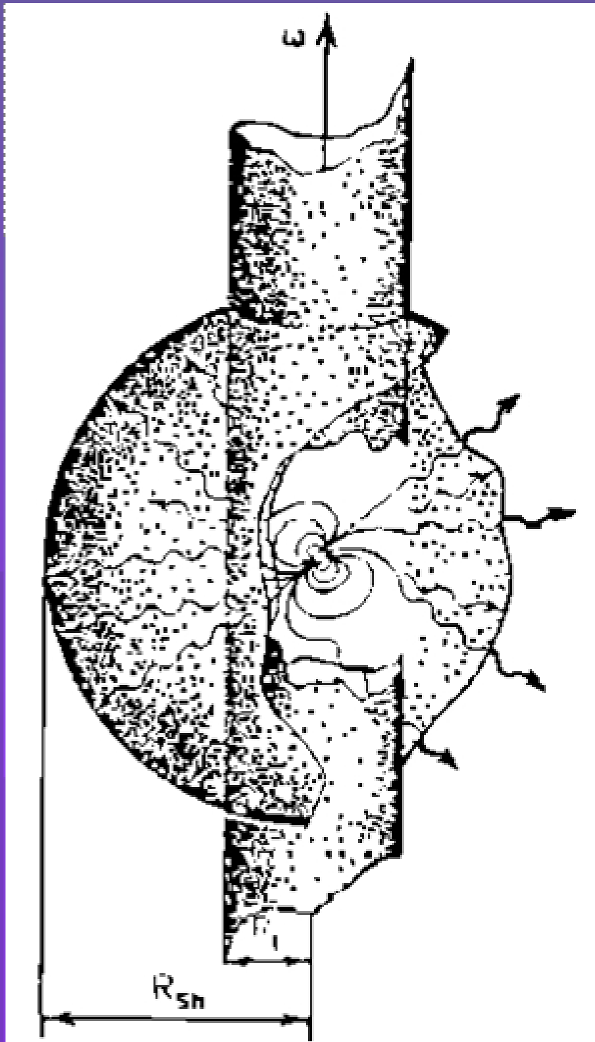
Proposed models to explain the source

- Near-by objects (brown dwarf, low-mass star, exoplanet,...). Hyman et al. (2005)
- Nulling pulsar. Kulkarni, Phinney (2005)
- Double pulsar. Turolla et al. (2005)
- Transient white dwarf pulsar. Zhang, Gil (2005)
- Precessing pulsar. Zhu, Xu (2005)

If the source is at the Galactic center, then the total energy release in a flare is about 10^{34} erg/s.

We discussed (0812.4587) a set of possibilities
related to less explored stages of
isolated and accreting neutron stars:
Propellers, Superejectors,
mixed phases for isolated neutron stars,
pulsar wind caverns in binaries, ...

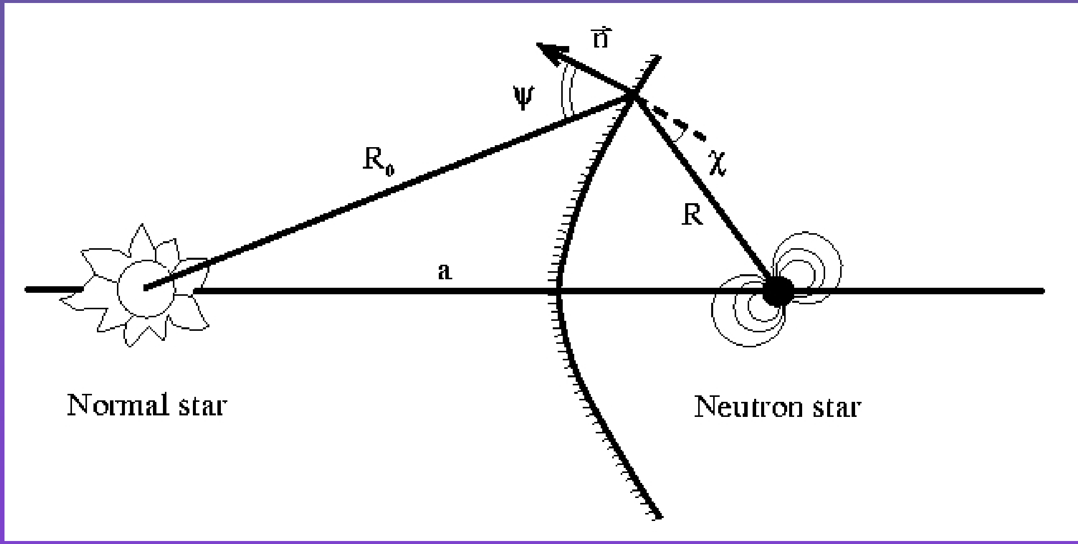
Ejector stage



Matter cannot approach a NS due to large pressure of relativistic particles wind and electro-magnetic radiation

$$R_{\rm Sh} = \left(\frac{8\kappa_t \mu^2 G^2 M^2 \omega^4}{\dot{M}_c v_\infty^5 c^4}\right)^{1/2}, \qquad R_{\rm Sh} > R_G$$

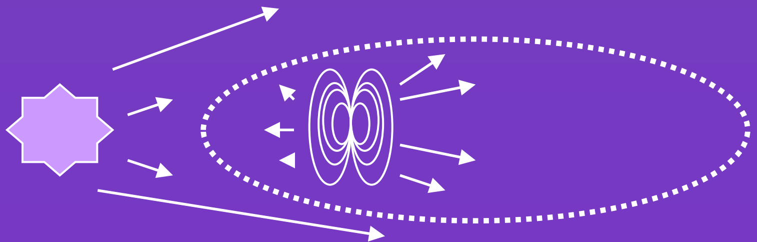
Pulsating cavern



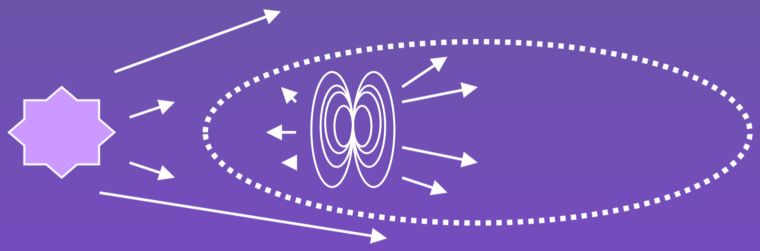
Lipunov, Prokhorov 1984

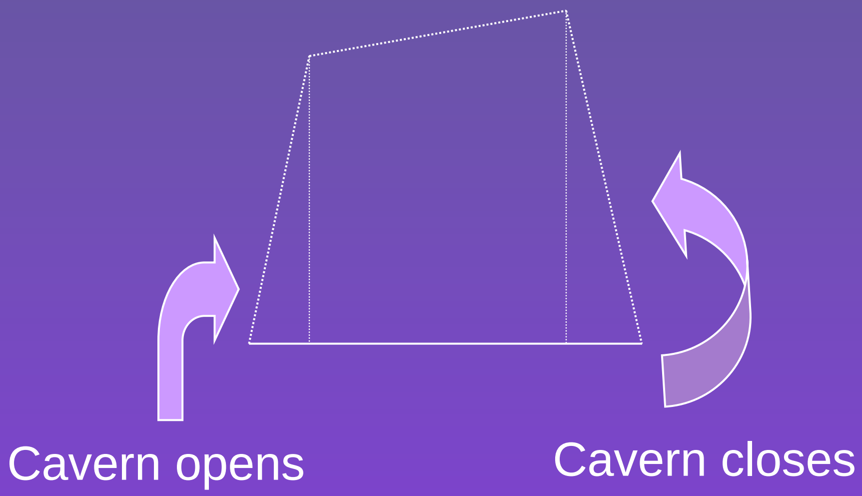
$$\frac{\dot{M} V_{\mathrm{w}}}{4\pi R_0^2} \cos^2\psi + P_{\mathrm{g}} = \frac{L_{\mathrm{m}}}{4\pi R^2 c} \cos^2\chi + \frac{\delta L_{\mathrm{m}} t}{3V}$$

A cavern can form around the NS.
The cavern grows with time
till it breaks.



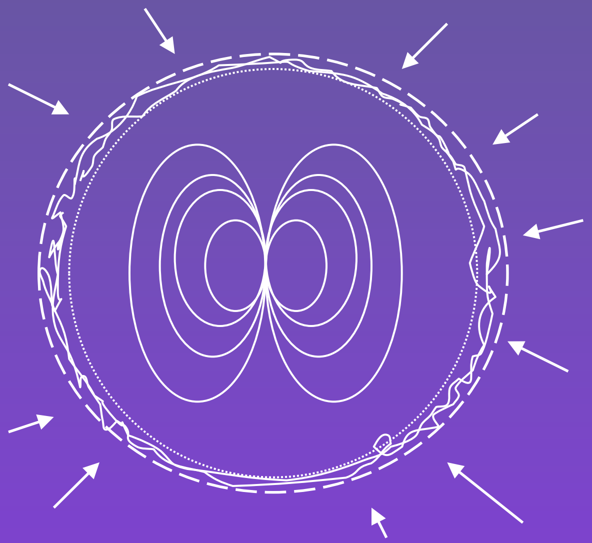
Burst profile for a cavern





Problems: stability of the cavern walls, how to make regular pulsations with identical bursts

Transient propeller



If cooling is efficient enough, then it is possible to form an envelope around a NS at the stage of Propeller.
The envelope grows in mass and contract till it reaches the corotation radius, then it collapses to a NS, there is a flash and ejection is possible.

$$\mu^2/8\pi R^6 = GM_{\rm sh}M/4\pi R^4$$

$$\Delta t_{\rm b} = R_{\rm co}/v_{\rm ff} = P/2\sqrt{2}\pi$$

$$B^2(R_{\rm co})/8\pi = (M_{\rm sh}/4\pi R_{\rm co}^2)(GM/R_{\rm co}^2)$$

$$\Delta t = M_{\rm sh}/\dot{M} = 10^8\,{\rm s}\,\mu_{30}^2 P^{-4/3}\rho_{-24}^{-1}v_{100}^3$$

Problem: energetics

Energetical considerations

Flux 1Jy (at 92 cm) during ~12 min.
This corresponds to ~10^{34} erg for Galactic center.

If "pumping" happen during 77 min,
then it is necessary to have a source
with radio luminosity 10^{30} erg/s.

If no "pumping" – then 10^{31} erg/s.

A radio pulsar (in a cavern?) can provide necessary amount of energy.

Conclusions

- A new class of fast radio bursts is now established.
- Origin is unknown, Galactic is excluded
- Extragalactic origin seems to be the most natural
- Statistical properties are in good correspondence with the magnetar hypothesis
- A theoretical model exists for the magnetar hypothesis

- The nature of GCRT J1745-3009 is still unknown
- Can be related to a rare stage of a neutron star
- A pulsar in a cavern in a stellar wind is one of posible models.