SGR/AXP - are they magnetars?

.

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and

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“Ioffe Workshop on GRBs and other transients:
Twenty Years of Konus-Wind Experiment”,
In memory of E.P. Mazets

Neutron stars are the result of collapse.

Conservation of the magnetic flux

$$B(ns)=B(s)\,(R_s/R_{ns})^2$$

$B(s)=10 – 100$ Gs, $R_s \sim (3 – 10)\,R(\mathrm{Sun})$, $R_{ns}=10$ km

$B(ns) = 4\ 10^{11} – 5\ 10^{13}$ Gs Ginzburg (1964)

Radiopulsars

$\mathbf{E = AB^2\,\Omega^4}$ **-** magnetic dipole radiation (pulsar wind)

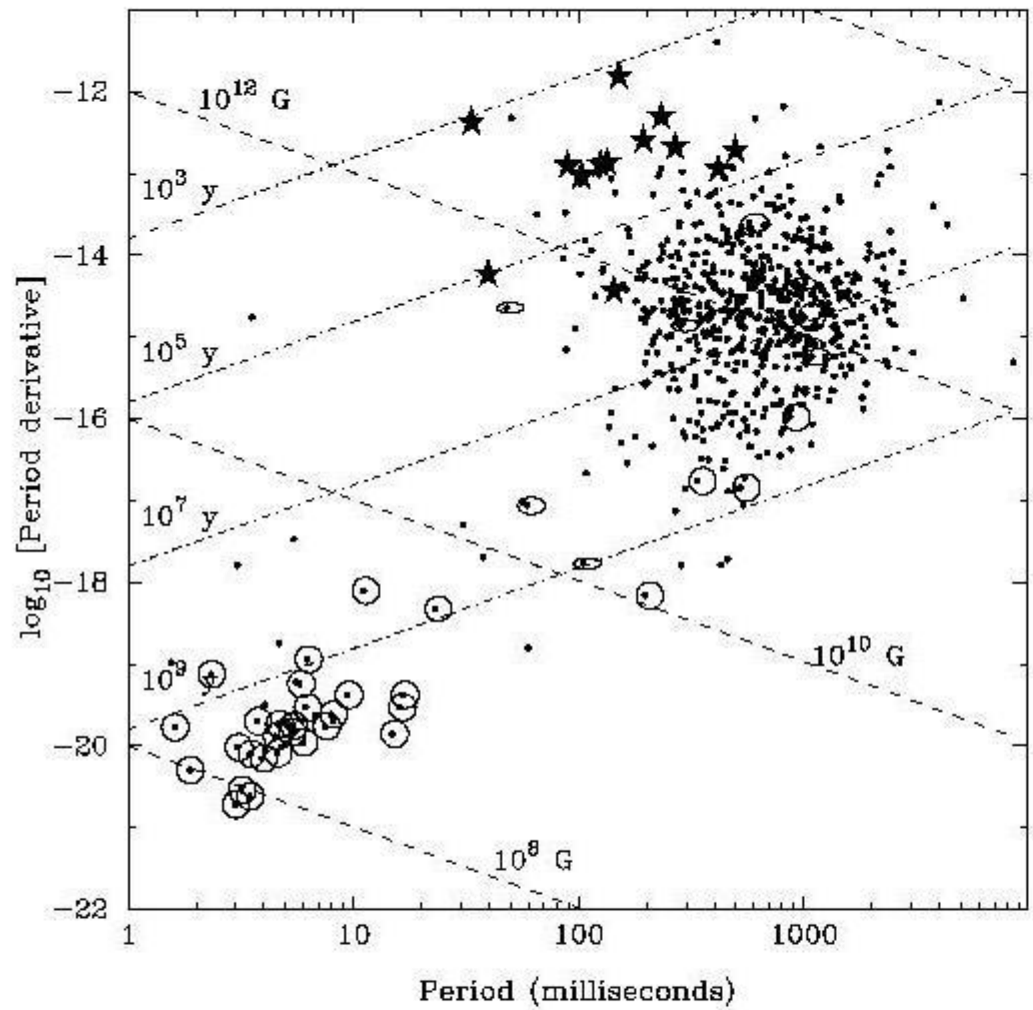
$\mathbf{E = 0.5\,I\Omega^2}$

I – moment of inertia of the neutron star

$\mathbf{B\ =\ IP\dot{P}/4\pi^2 A}$

Single radiopulsars – timing observations
(the most rapid ones are connected with young supernovae remnants)

B(ns) = $2 \cdot 10^{11} - 5 \cdot 10^{13}$ Gs



10^{12} G
10^3 y
10^5 y
10^7 y
10^9 y
10^{10} G
10^8 G
−12
−14
−16
−18
−20
−22
1
10
100
1000
$\log_{10}$ [Period derivative]
Period (milliseconds)

SGR: neutron stars with periods 2 – 8 seconds

Giant bursts, L in the peak increase 5 – 6 orders of magnitude

Slow rotation, low rotational energy, observed average luminosity exceeds rotational loss of energy more than 10 times,and orders of magnitude during giant outbursts

Suggestion: source of energy – magnetic field - magnetars

SGR and short GRB

- **Giant bursts in SGR similar to short GRB**
- Mazets, E. P., et al. 1999b, Astronomy Letters, 25, 73
- Bisnovatyi-Kogan, G. S. 1999, preprint (astro-ph/9911275)

Short GRB, interpreted as giant bursts of SGR

In **M31 (Andromeda)** -1 February, 2007 (**~ 1 E45 erg** **)**
Mazets et al., arXiv:0712.1502

In **M81** - 3 November 2005 (**~ 7 E46 erg**) **Golenetskii et al. (2005) GCN..4197**

Radiopulsars with very High Magnetic Fields and Slow Rotation

THE ASTROPHYSICAL JOURNAL, 541:367–373, 2000 September 20

DISCOVERY OF TWO HIGH MAGNETIC FIELD RADIO PULSARS

F. CAMILO,[1,2] V. M. KASPI,[3,4,5] A. G. LYNE,[2] R. N. MANCHESTER,[6] J. F. BELL,[6] N. D'AMICO,[7,8]
N. P. F. MCKAY,[2] AND F. CRAWFORD[3]

We report the discovery of two young isolated radio pulsars with very high inferred magnetic fields. PSR J1119−6127 has period $P = 0.407$ s, and the largest period derivative known among radio pulsars, $\dot{P} = 4.0 \times 10^{-12}$. Under standard assumptions these parameters imply a characteristic spin-down age of only $\tau_c = 1.6$ kyr and a surface dipole magnetic field strength of $B = 4.1 \times 10^{13}$ G. We have measured a stationary period second derivative for this pulsar, resulting in a braking index of $n = 2.91 \pm 0.05$. We have also observed a glitch in the rotation of the pulsar, with fractional period change $\Delta P/P = -4.4 \times 10^{-9}$. Archival radio imaging data suggest the presence of a previously uncataloged supernova remnant centered on the pulsar. The second pulsar, PSR J1814−1744, has $P = 3.975$ s and $\dot{P} = 7.4 \times 10^{-13}$. These parameters imply $\tau_c = 85$ kyr, and $B = 5.5 \times 10^{13}$ G, the largest of any known radio pulsar.

Both PSR J1119−6127 and PSR J1814−1744 show apparently normal radio emission in a regime of magnetic field strength where some models predict that no emission should occur. Also, PSR J1814−1744 has spin parameters similar to the anomalous X-ray pulsar (AXP) 1E 2259+586, but shows no discernible X-ray emission. If AXPs are isolated, high magnetic field neutron stars ("magnetars"), these results suggest that their unusual attributes are unlikely to be merely a consequence of their very high inferred magnetic fields.

The Astrophysical Journal, 591:L135–L138, 2003 July 10

PSR J1847−0130: A RADIO PULSAR WITH MAGNETAR SPIN CHARACTERISTICS

M. A. McLaughlin,[1] I. H. Stairs,[2] V. M. Kaspi,[3] D. R. Lorimer,[1] M. Kramer,[1] A. G. Lyne,[1] R. N. Manchester,[4] F. Camilo,[5] G. Hobbs,[4] A. Possenti,[6] N. D'Amico,[7,8] and A. J. Faulkner[1]

We report the discovery of PSR J1847−0130, a radio pulsar with a 6.7 s spin period, in the Parkes Multibeam Pulsar Survey of the Galactic plane. The slowdown rate for the pulsar, 1.3×10^{-12} s s^{-1}, is high and implies a surface dipole magnetic field strength of 9.4×10^{13} G. This inferred dipolar magnetic field strength is the highest by far among all known radio pulsars and over twice the "quantum critical field" above which some models predict radio emission should not occur. The inferred dipolar magnetic field strength and period of this pulsar are in the same range as those of the anomalous X-ray pulsars, which have been identified as being "magnetars" whose luminous X-ray emission is powered by their large magnetic fields. We have examined archival *ASCA* data and place an upper limit on the X-ray luminosity of J1847−0130 that is lower than the luminosities of all but one anomalous X-ray pulsar. The properties of this pulsar prove that inferred dipolar magnetic field strength and period cannot alone be responsible for the unusual high-energy properties of the magnetars and create new challenges for understanding the possible relationship between these two manifestations of young neutron stars.

Young Neutron Stars and Their Environments
IAU Symposium, Vol. 218, 2004
F. Camilo and B. M. Gaensler, eds.

M. A. McLaughlin et al.

Two Radio Pulsars with Magnetar Fields

Abstract. PSRs J1847−0130 and J1718−37184 have inferred surface dipole magnetic fields greater than those of any other known pulsars and well above the "quantum critical field" above which some models predict radio emission should not occur. These fields are similar to those of the anomalous X-ray pulsars (AXPs), which growing evidence suggests are "magnetars". The lack of AXP-like X-ray emission from these radio pulsars (and the non-detection of radio emission from the AXPs) creates new challenges for understanding pulsar emission physics and the relationship between these classes of apparently young neutron stars.

Both of these pulsars were discovered in the Parkes Multibeam Pulsar Survey (see e.g. Manchester et al. 2001). PSR J1847−0130 has a spin period of 6.7 s and inferred surface dipole magnetic field[1] of 9.4×10^{13} G. PSR J1718−37184 has a period of 3.4 s and magnetic field of 7.4×10^{13} G. The magnetic fields of both pulsars are well above the "quantum critical field" $\simeq 4.4\times10^{13}$ G above which some models predicted radio emission should not occur (Baring & Harding 1998).

A radio pulsar with an 8.5-second period that challenges emission models

Young, M. D.; Manchester, R. N.; Johnston, S.

Nature, Volume 400, Issue 6747, pp. 848-849 (1999).

Radio pulsars are rotating neutron stars that emit beams of radiowaves from regions above their magnetic poles. Popular theories of the emission mechanism require continuous electron-positron pair production, with the potential responsible for accelerating the particles being inversely related to the spin period. Pair production will stop when the potential drops below a threshold, so the models predict that radio emission will cease when the period exceeds a value that depends on the magnetic field strength and configuration. Here we show that the pulsar J2144-3933, previously thought to have a period of 2.84s, actually has a **period of 8.51s**, which is by far the longest of any known radio pulsar. Moreover, under the usual model assumptions, based on the neutron-star equations of state, this slowly rotating pulsar should not be emitting a radio beam. Therefore either the model assumptions are wrong, or current theories of radio emission must be revised.

Pulsar Astronomy - 2000 and Beyond, ASP Conference Series, Vol. 202; Proc. of the 177th Colloquium of the IAU held in Bonn, Germany, 30 August - 3 September 1999

Young, M. D.; Manchester, R. N.; Johnston, S.

Ha, ha, ha, ha, staying alive, staying alive: A radio pulsar with an 8.5-s period challenges emission models.

SGR with giant bursts

SGR: Soft Gamma Repeaters

SGR 1900+14, discovered by Mazets et al.(1979)
(**Giant burst at 27 August 1998, >7 E43 erg**)

SGR 1806-20, observed by Mazets et al. (1980); identified as SGR by Laros et al. (1986) (**Giant burst at 27 December 2006, ~ 2 E46 erg**)

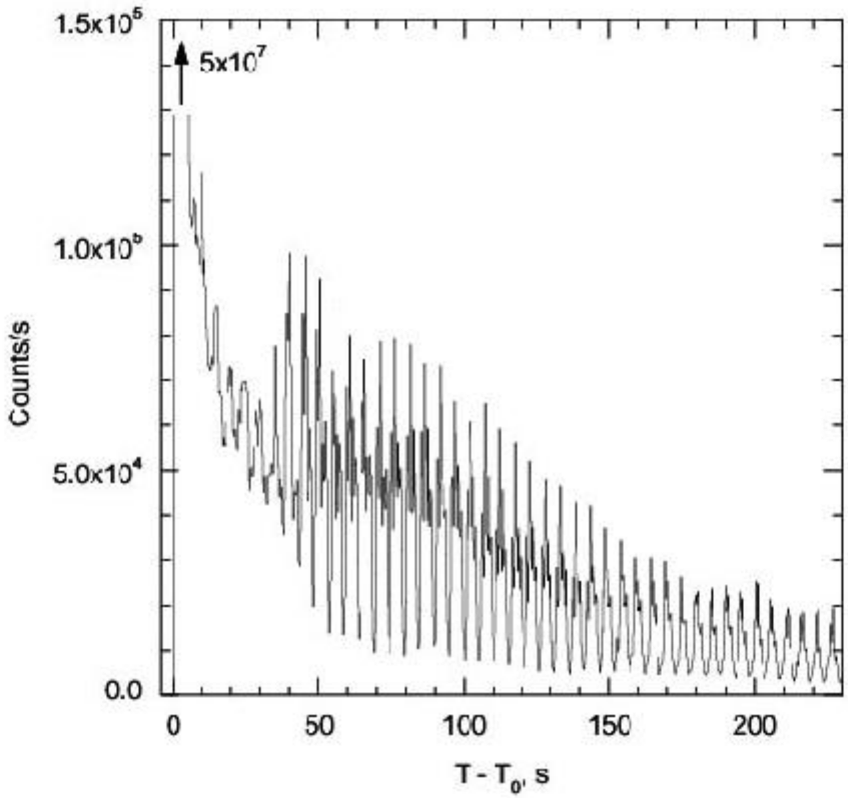
SGR 1627-41, discovered by BATSE
(**semi-giant burst at 18 June 1998, ~1 E43 erg**)

1 in Large Magelanic Cloud: **SGR 0526-66**, discovered by Mazets et al.(1979)
(**Giant burst at 5 March 1979, >2 E44 erg**)

Short GRB, interpreted as giant bursts of SGR

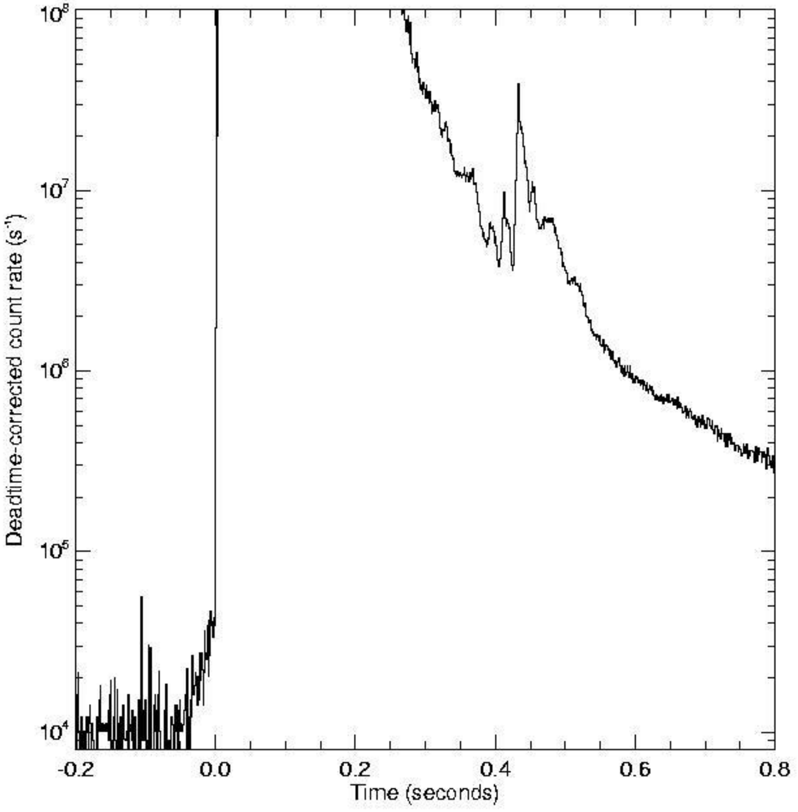
In **M31 (Andromeda)** -1 February, 2007 (**~ 1 E45 erg)** **Mazets et al., arXiv:0712.1502**
In **M81** - 3 November 2005 (**~ 7 E46 erg**) **Golenetskii et al. (2005) GCN..4197**

The giant 1998 August 27 outburst of the soft gamma repeater SGR 1900 + 14. Intensity of the E > 15 keV radiation (Mazets, 1999c).

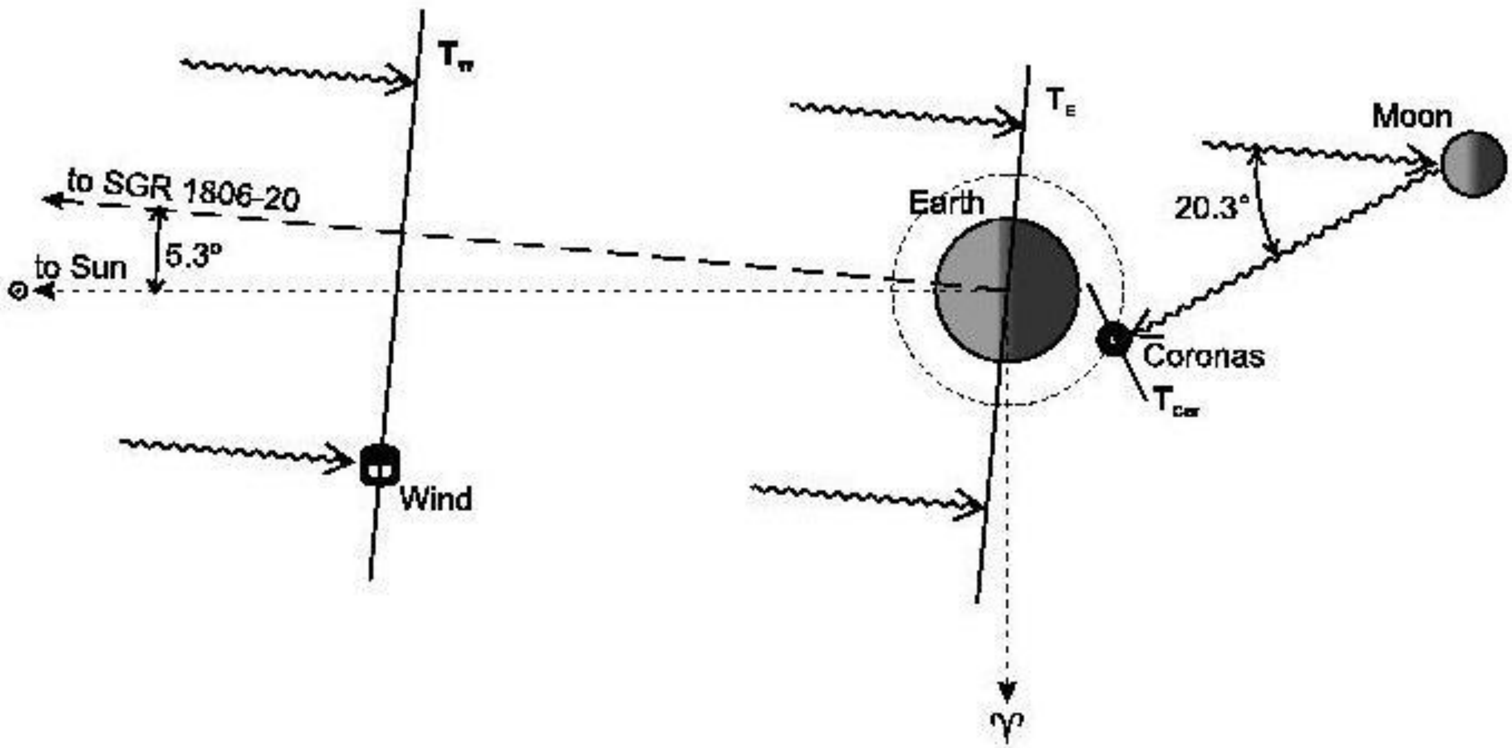


The greatest flare of a Soft Gamma Repeater

- On December 27 2004 the greatest flare from SGR 1806-20 was detected by many satellites: Swift, RHESSI, Konus-Wind, Coronas-F, Integral, HEND, …
- 100 times brighter than ever!



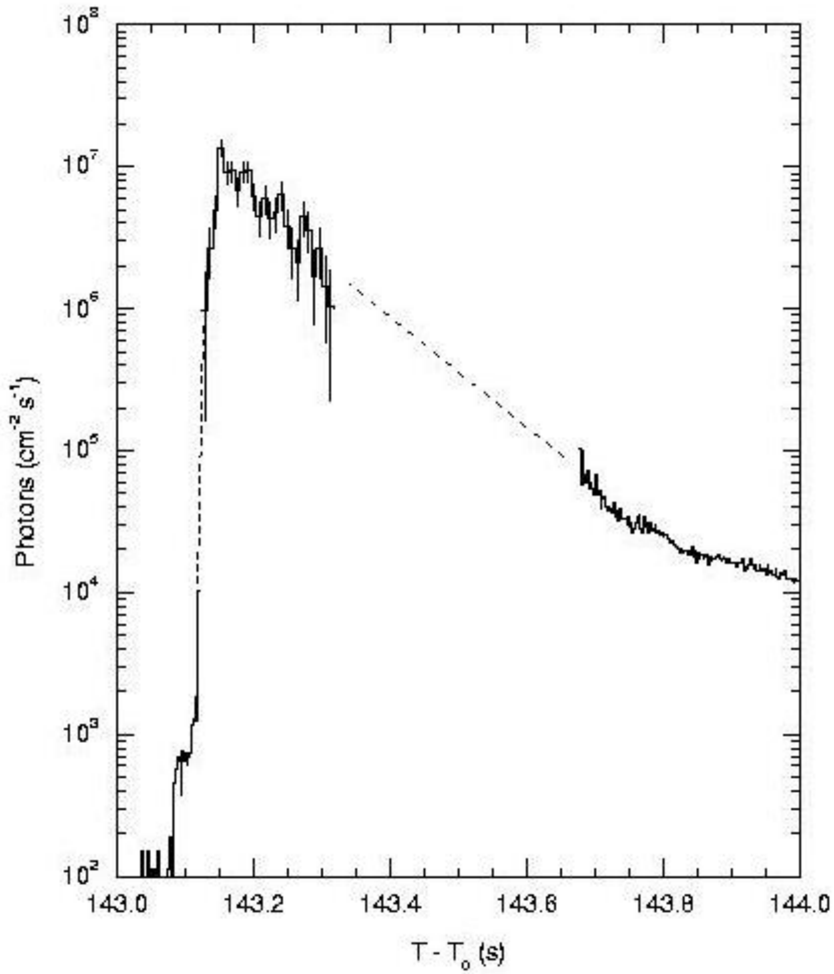
Palmer et al.
Astro-ph/0503030



T_W
T_E
Moon
to SGR 1806-20
Earth
20.3°
5.3°
to Sun
Coronas
T_{Cor}
Wind

2004 December 27 giant outburst.

Reconstructed time history of the initial pulse. The upper part of the graph is derived from Helicon data while the lowerpart represents the Konus-Wind data. The dashed lines indicate intervals where the outburst intensity still saturates the Konus-Wind detector, but is not high enough to be seen by the Helicon.



Mazets et al., 2005

SGR/AXP with Low Magnetic Fields and Moderate Rotation

SGR/AXP J1550-5418 (08/10/03, period of 2.1 s is clearly visible)

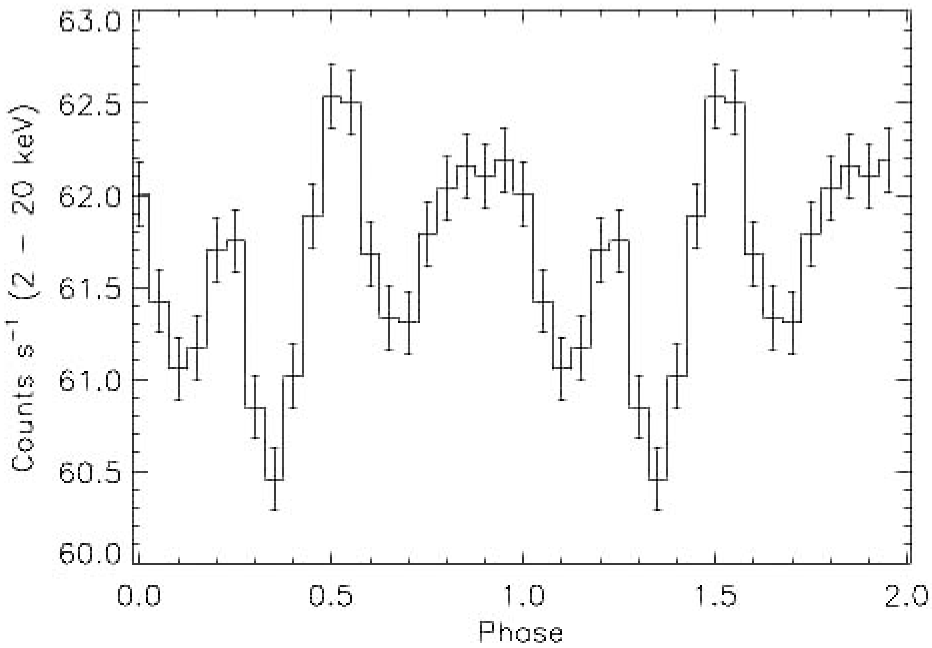
A low-magnetic-field Soft Gamma Repeater (N. Rea et al., 2010)

arXiv:1010.2781 13 Oct 2010 (Fermi gamma monitor)

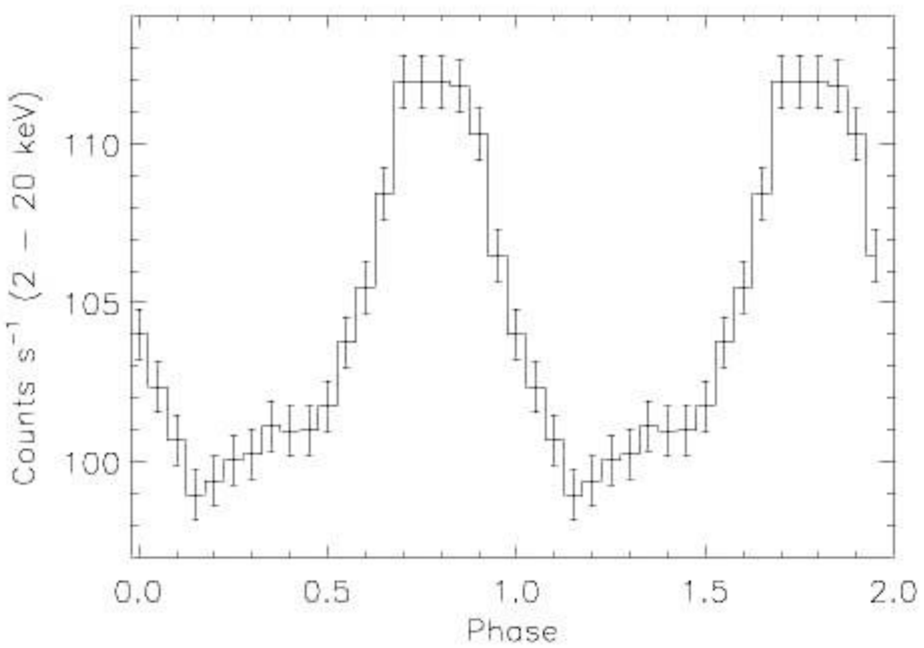
We report on a soft gamma repeater with low magnetic field, **SGR0418+5729**, recently detected after it emitted bursts similar to those of magnetars. X-ray observations show that **its dipolar magnetic field cannot be greater than 7.5 10^12 Gauss**, well in the range of ordinary radio pulsars, implying that a high surface dipolar magnetic field is not necessarily required for magnetar-like activity.

Estimations of the magnetic fields in SGR/AXP

The epoch folded pulse profile of SGR 1900 + 14 (2-20 keV) for the May 1998 RXTE observations (Kouveliotou et al., 1999).

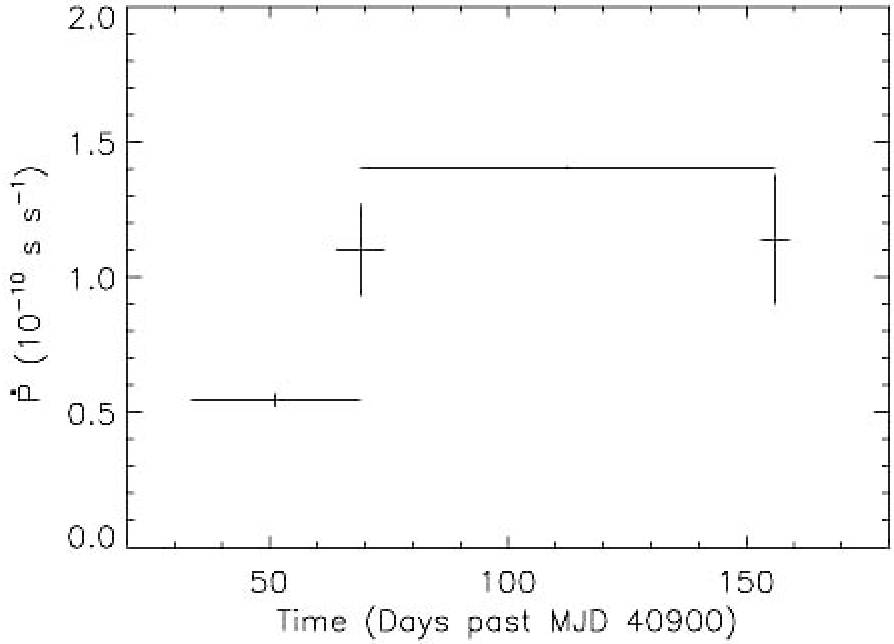


The epoch folded pulse profile of SGR 1900 + 14 (2-20 keV) for the August 28, 1998 RXTE observation. The plot is exhibiting two phase cycles (Kouveliotou et al., 1999).



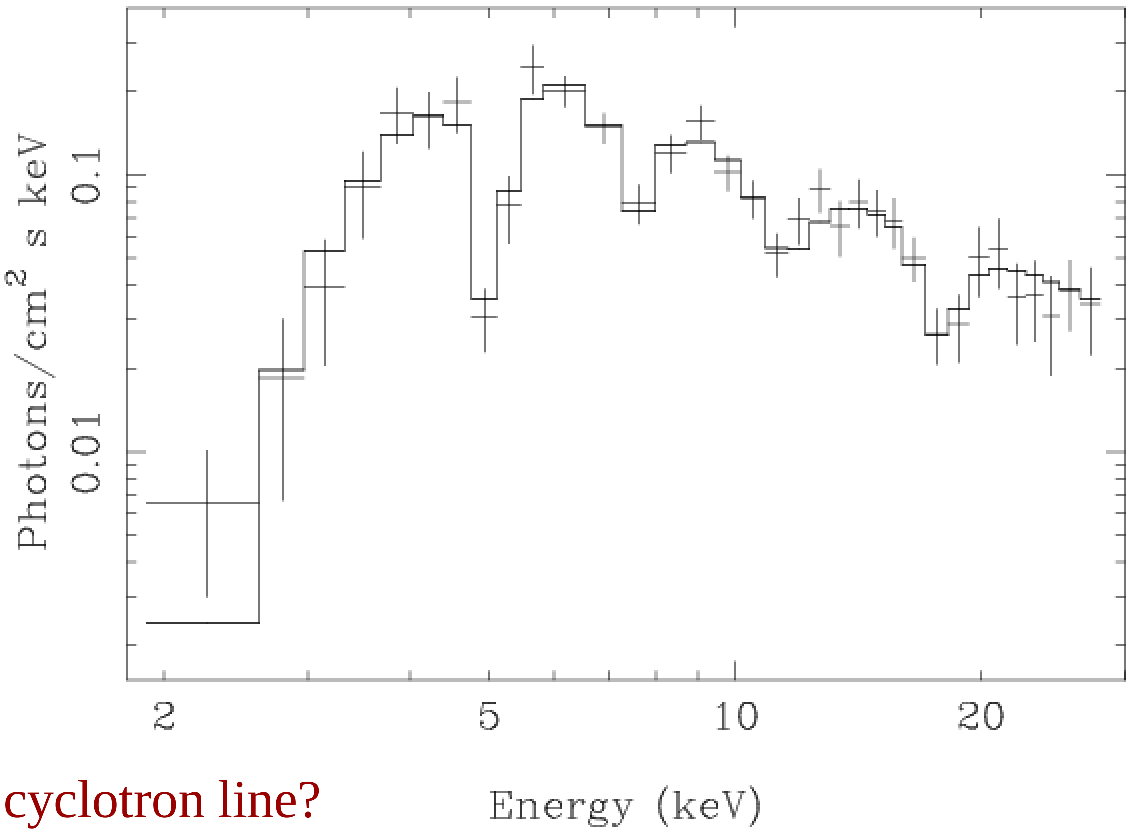
Pulse shape is changing, making errors in finding derivative of the period.

The evolution of "Period derivative" versus time since the first period measurement of SGR 1900+14 with ASCA. The time is given in Modified Julian Days (MJDs) (Kouveliotou et al., 1999)



SGR 1806-20:

spectrum and best-fit continuum model for the second precursor interval with 4 absorption lines (RXTE/PCA 2-30 keV), Ibrahim et al. (2002)



Proton or electron cyclotron line?

The Magnetar Model

The soft gamma repeaters as very strongly magnetized neutron stars - I. Radiative mechanism for outbursts

Duncan, Robert C.; Thompson, Christopher

MN RAS, Volume 275, Issue 2, pp. 255-300 (1995) .

A radiative model for the soft gamma repeaters and the energetic 1979 March 5 burst is presented. We identify the sources of these bursts with neutron stars the external magnetic fields of which are much stronger than those of ordinary pulsars. Several independent arguments point to a neutron star with B_dipole~5x10^14 G as the source of the March 5 event. A very strong field can (i) spin down the star to an 8-s period in the ~10^4-yr age of the surrounding supernova remnant N49; (ii) provide enough energy for the March 5 event; (iii) undergo a large-scale interchange instability the growth time of which is comparable to the ~0.2-s width of the initial hard transient phase of the March 5 event; (iv) confine the energy that was radiated in the soft tail of that burst; (v) reduce the Compton scattering cross-section sufficiently to generate a radiative flux that is ~10^4 times the (non-magnetic) Eddington flux; (vi) decay significantly in ~10^4-10^5 yr, as is required to explain the activity of soft gamma repeater sources on this time-scale; and (vii) power the quiescent X-ray emission L_X~7x10^35 erg s^-1 observed by Einstein and ROSAT as it diffuses the stellar interior. We propose that the 1979 March 5 event was triggered by a large-scale reconnection/interchange instability of the stellar magnetic field, and the soft repeat bursts by cracking of the crust.

Rotation energy losses are much less than observed (magnetic ?), so

B estimations using dP/dt are not justified:

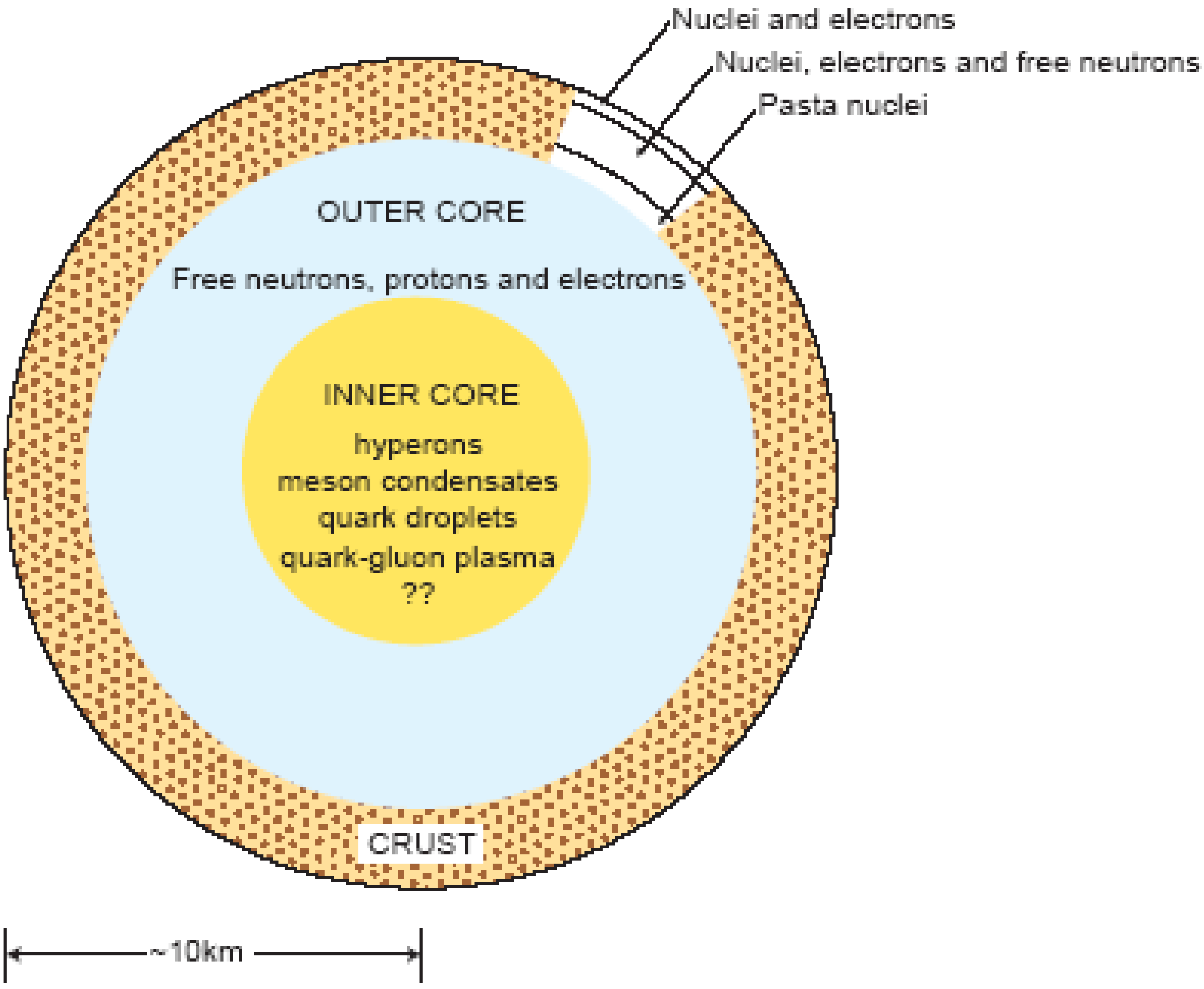
Magnetic stellar wind as a mechanism of angular momentum losses.

Identification with SNR is not firm.

Jumps in dP/dt, in pulse form -- not seen in other pulsars

Cyclotron lines: proton radiation (?)

Model of Nuclear Explosion



Schematic cross section of a neutron star.

Cooling of hot dense matter (new born neutron star)

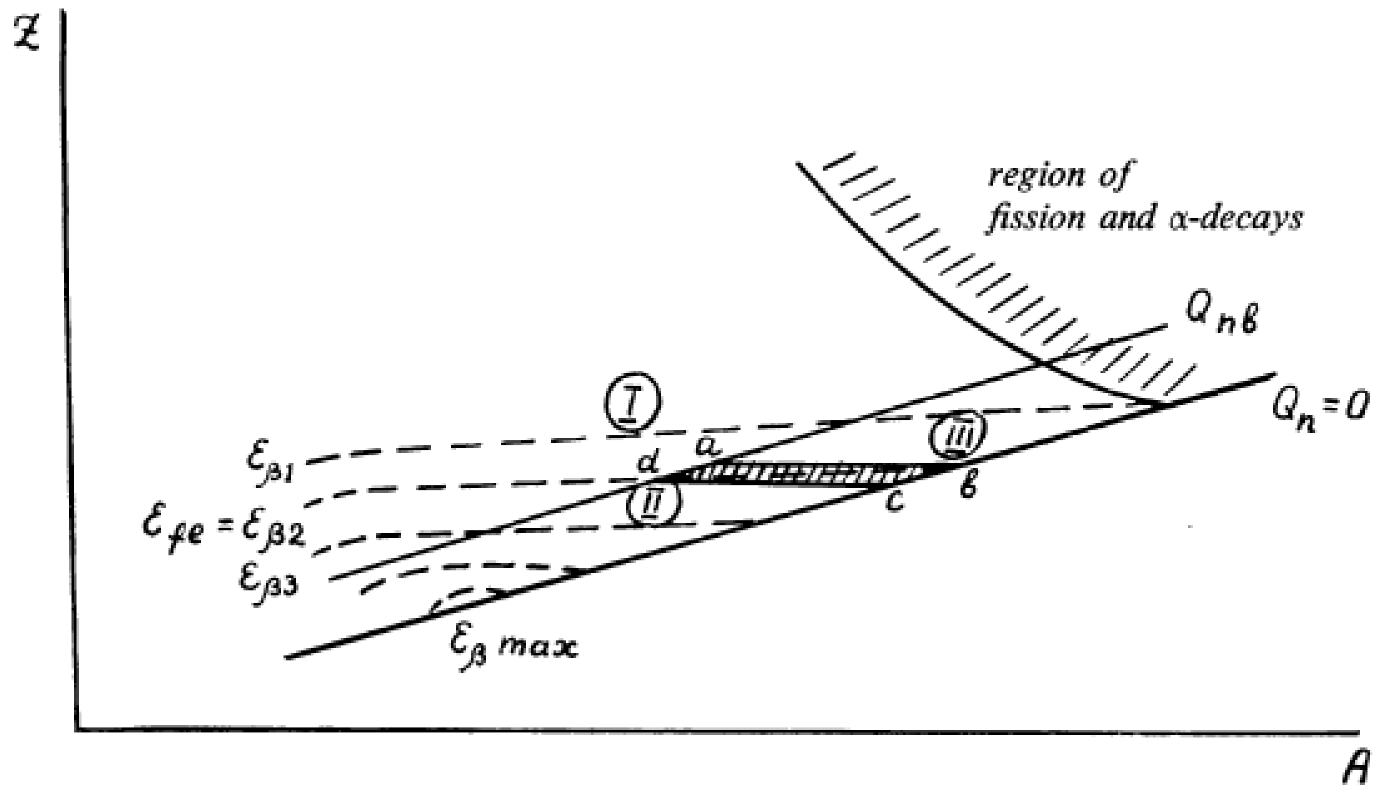


Fig. 4. The formation of chemical composition at the stage of limiting equilibrium. The thick line $Q_n = 0$ defines the boundary of the region of existence of nuclei, the line Q_{nb} separates region I, where photodisintegration of neutrons is impossible from regions II and III. The dashed lines indicate a level of constant $\varepsilon_\beta = Q_p - Q_n$; $\varepsilon_{\beta 1} < \varepsilon_{\beta 2} < \ldots < \varepsilon_{\beta \max}$. In region I – $Q_n > Q_{nb}$; in region II – $Q_n < Q_{nb}$, $\varepsilon_{fe} < \varepsilon_\beta$; and in region III – $Q_n < Q_{nb}$, $\varepsilon_{fe} > \varepsilon_\beta$. The line with the attached shading indicates a region of fission and α-decay. The shaded region *abcd* determines the boundaries for the values of (A, Z) with a limited equilibrium situation, at given values of $Q_{nb}(T)$ and $\varepsilon_{fe}(\varrho)$.

G. S. BISNOVATYI-KOGAN and V. M. CHECHETKIN

Astrophysics and Space Science **26** (1974) 25–46.

Nonequilibrium layer of maximal mass

$$M_{od} = \frac{4\pi R^4}{GM}(P_2 - P_1) \simeq 0.1\,(P_2 - P_1).$$ =2 10^29 g=10^-4 M Sun

$$\varrho_1 \simeq \mu_e\, 10^6 \left(\frac{8}{0.511}\right)^3 \simeq 3.8 \times 10^9 \mu_e \text{ gm см}^{-3}.$$

$$\varrho_2 \simeq \mu_e\, 10^6 \left(\frac{33}{0.511}\right)^3 \simeq 2.7 \times 10^{11} \mu_e \text{ gm см}^{-3}$$

$$E_n \approx 4 \times 10^{17} (P_2 - P_1) \text{ эрг} \approx 10^{48} \text{ эрг}$$

$$P_1 = 7.1 \times 10^{27} \text{ in cgs units},$$

$$P_2 = 2.1 \times 10^{30} \text{ in cgs units}.$$

Astrophysics and Space Science **35** (1975) 23–41

PULSED GAMMA-RAY EMISSION FROM NEUTRON AND COLLAPSING STARS AND SUPERNOVAE*

G. S. BISNOVATYI-KOGAN, V. S. IMSHENNIK, D. K. NADYOZHIN,
and V. M. CHECHETKIN

and the spectrum of emission. In case (3) ejection of chemically non-equilibrium matter from the neutron star leads to an intensive emission which is produced due to fission of superheavy nuclei, β-decay of radioactive elements and radiative capture of free neutrons. Ejection of matter from the neutron stars may be related to the observed jumps of periods of pulsars. From the observed gain of kinetic energy of the filaments of the Crab Nebula ($\sim 2\times 10^{41}$ erg) the mass of the ejected material may be estimated ($\sim 10^{21}$ g). This leads to energies of the γ-ray bursts of the order of 10^{38}–10^{39} erg, which agrees fully with observations at the mean distance up to the sources 0.25 kpc. As distinct from the outbursts of supernovae it would seem that no difficulties concerning the burst frequency and the spectrum of emission are encountered. From the mechanisms of γ-ray emission examined here the

Gamma-ray bursts as a manifestation of the inherent activity of neutron stars

G. S. Bisnovatyi-Kogan and V. M. Chechetkin

Institute for Space Research, USSR Academy of Sciences

(Submitted April 16, 1980)

Astron. Zh. **58**, 561–568 (May–June 1981)

A model of a γ-ray burst is developed on the basis of a nuclear explosion in the envelope of a neutron star owing to a chain reaction of fission of superheavy nuclei. It is shown that most of the emission in a γ-ray burst should be thermal, but a nonthermal component and γ-ray lines can be present. The parameters of the powerful burst of March 5, 1979, are estimated on the basis of the emission spectra and the present model. The distance to the burst is $\lesssim 100$ pc and the total energy of the burst is $\lesssim 2 \cdot 10^{39}$ erg.

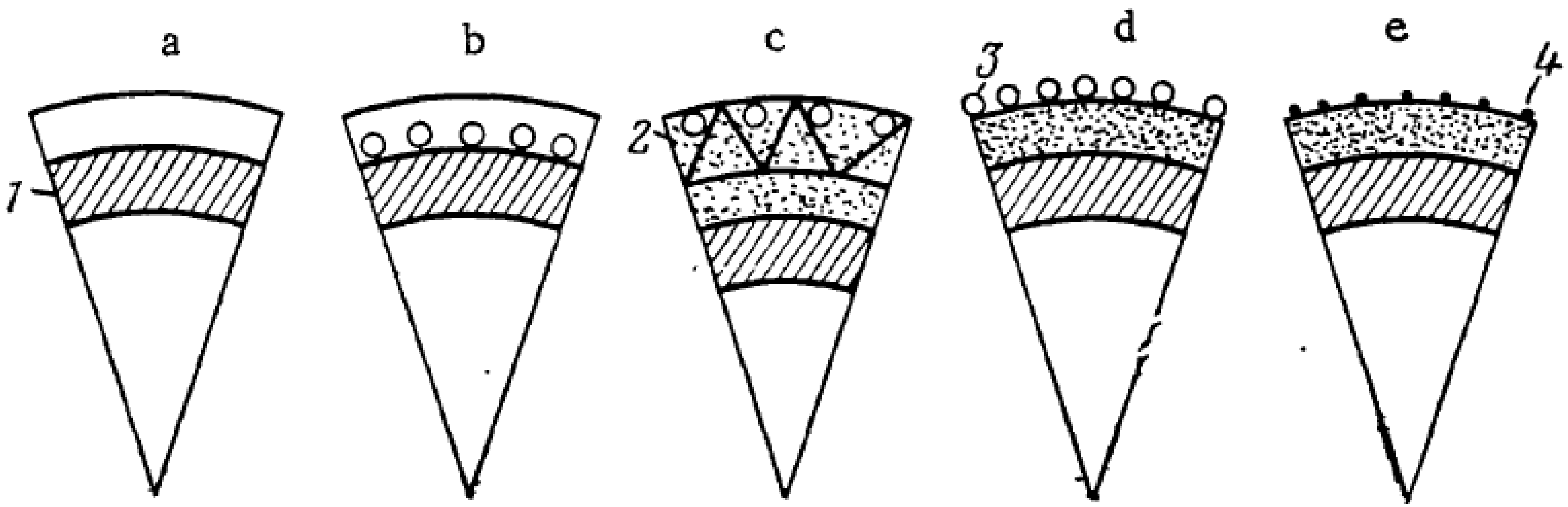


FIG. 1. Schematic model of formation of the γ-ray burst of March 5, 1979: a) equilibrium state of a section of the neutron star; 1) nonequilibrium layer; b) state after a starquake; c) explosion of the main mass, formation of a shock wave; ejection of material and formation of a hot spot; emission of the initial powerful pulse; 2) shock waves; d) explosion of ejected remnants of the nonequilibrium layer, formation of hard radiation; 3) region of formation of hard radiation and γ-ray lines; e) pulsar stage, structure of heated part of the surface, locally $L \simeq 0.1 L_{ed}$; 4) corona. Material of the nonequilibrium layer is denoted by circles.

b) Parameters of the emitting region.

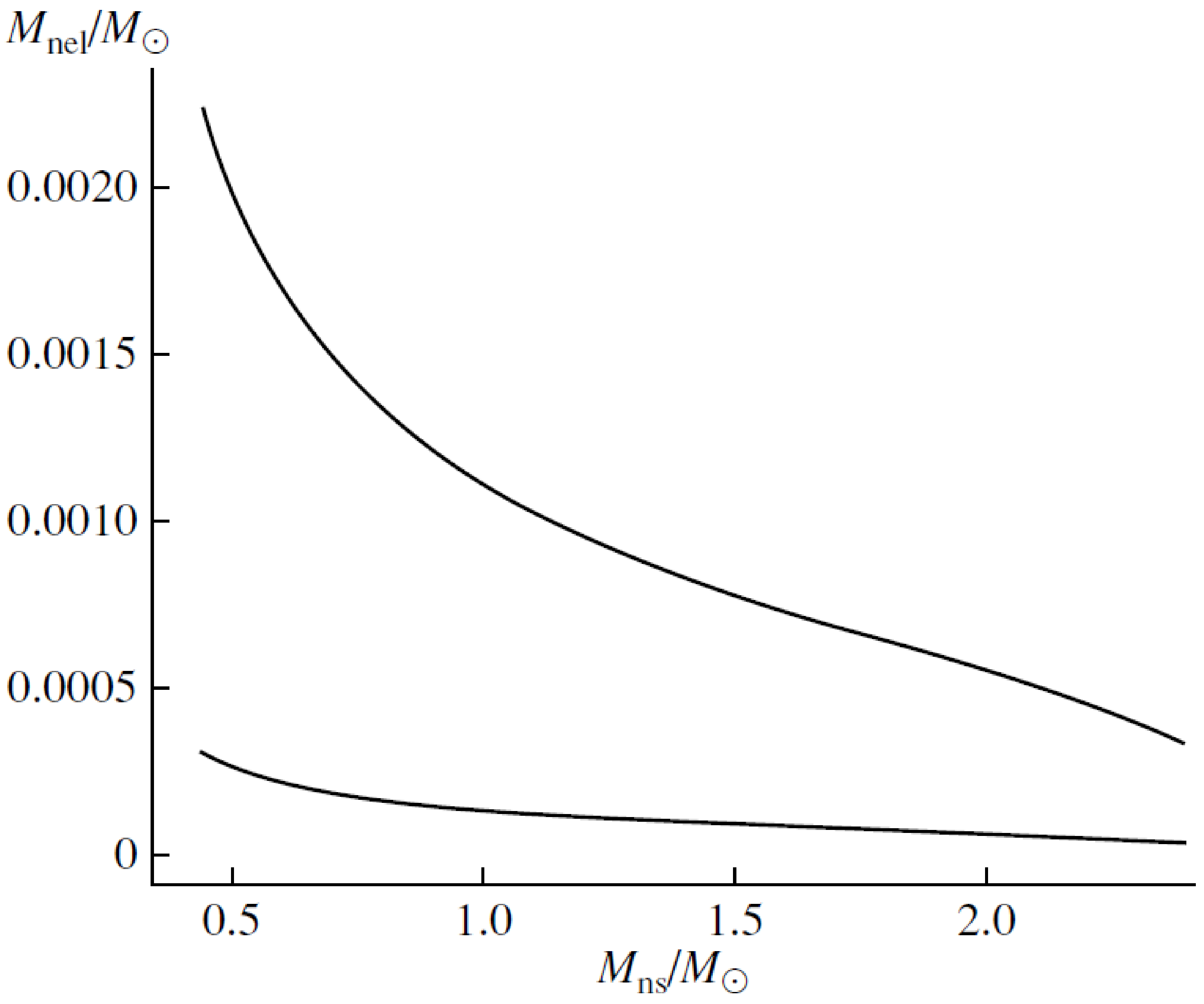
The spectrum of a burst in the pulsar stage in the range from 30 to 260 keV is well approximated by the bremsstrahlung of a transparent gas with $T \simeq 4.2 \cdot 10^{8}$°K (35 keV) forming a corona. Because of the fact that the Planckian spectrum of the cooler surfaces is not observed, the coronal emission exceeds the luminosity of the photosphere. In this case mechanical flow of energy through the photosphere predominates over thermal flux. This is evidently connected with convective motions with participations of the magnetic field in the stellar envelope generated as a

result of explosion (convection).

[1)] The projection of this burst against supernova remnant N 50 in the Large Magellanic Cloud[7] seems accidental to us. This is indicated by observations of remnant N 50 in the optical range before and after the γ-ray burst.[23] With allowance for aberration it turns out that nebula N 50 only grazes the edge of the error box of this γ-ray burst.[22]

but

STRONG COLLIMATION COULD CHANGE THIS CONCLUSION



Prepared by S.O. Tarasov

Figure caption

Dependence of the mass of the non-equilibrium layer on the neutron-star mass. The lines show the top and bottom boundaries of the layer mass measured from the stellar surface. The equation of state of the equilibrium matter was used to construct the model of the neutron star, with the boundaries of the layer specified by the densities. Using a non-equilibrium equation of statewill increase the mass of the layer, but should not fundamentally change the values given in the figure.

From

A New Look at Anomalous X-Ray Pulsars.

G. S Bisnovatyi-Kogan and N. R. Ikhsanov

Astronomy Reports, 2014, Vol. 58, No. 4, pp. 217–227.

Nonequilibrium layer of NS mass = 2 Solar (1974)

$$M_{od} = \frac{4\pi R^4}{GM}(P_2 - P_1) \simeq 0.1\,(P_2 - P_1)\,. = 2\ 10\text{^}29\ \text{g} = 10\text{^-}4\ \text{M Sun}$$

$$E_n \approx 4 \times 10^{17}(P_2 - P_1)\ \text{эрг} \approx 10^{48}\ \text{эрг}$$

$$P_1 = 7.1 \times 10^{27}\ \text{in cgs units}\,,$$
$$P_2 = 2.1 \times 10^{30}\ \text{in cgs units}\,.$$

For M=0.45 the mass of the nonequilibrium layer is 7 times larger. The energy store reaches 10^49 erg, what is enough for 1000 giant bursts

Observations of the binary pulsar system J1518-4904 indicated the masses of the components to be
$m_p = 0.72(+0.51 - 0.58\ M_{Solar})$
$m_e = 2.00(+0.58\ -0.51)\ M_{Solar}$ with a 95.4%probability.

Low mass neutron stars could be formed in the scenario of the off-center explosion

Numerical investigation is needed

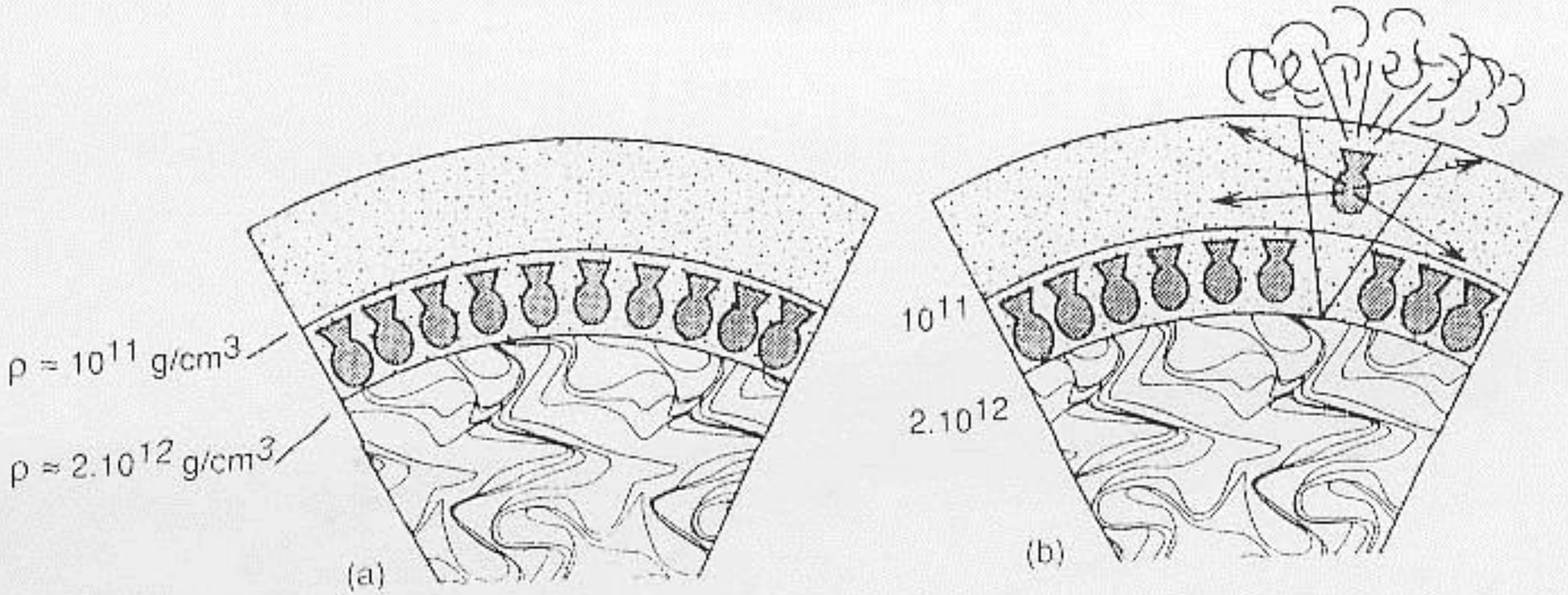


Fig. 1—The schematic picture of nonequilibrium layer in the neutron star: a) in quiescent stage; b) after starquake and nuclear explosion.

Gamma-ray bursts from nuclear fission in neutron stars

G.S. Bisnovatyi-Kogan

In: Gamma-ray bursts - Observations, analyses and theories (A93-20206 06-90), p. 89-98.

Proc Conf. Taos (USA), 1990

Conclusions

1. SGR – highly active, slowly rotating neutron stars

2. Nonequilibrium layer is formed in the neutron star crust, during NS cooling, or during accretion onto it. It may be important for NS cooling, glitches, and explosions connected with SGR

3. The mass and the energy store in NL increase rapidly with decreasing NS mass

4. NL in low mass NS may be responsible for explosions, producing SGR

Solar Physics **121**: 187–196, 1989.

SOLAR AND STELLAR MAGNETIC FIELDS AND STRUCTURES: OBSERVATIONS

JEFFREY L. LINSKY

Joint Institute for Laboratory Astrophysics, National Institute of Standards and Technology, and the University of Colorado, Boulder, CO 80309–0440, U.S.A.

"If the Sun did not have a magnetic field, it would be as uninteresting a star as most astronomers believe it to be."

attributed to ROBERT B. LEIGHTON

"Magnetic fields are to astrophysics what sex is to psychoanalysis."

HENK VAN DE HULST (1988)