Magnetars and Magnetoids

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and

JINR, Dubna

GAISH, May 18, 2007

Estimations

Radiopulsars, magnetars

Magnetoids

Are we sure?

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

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

.

Radiopulsars

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

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

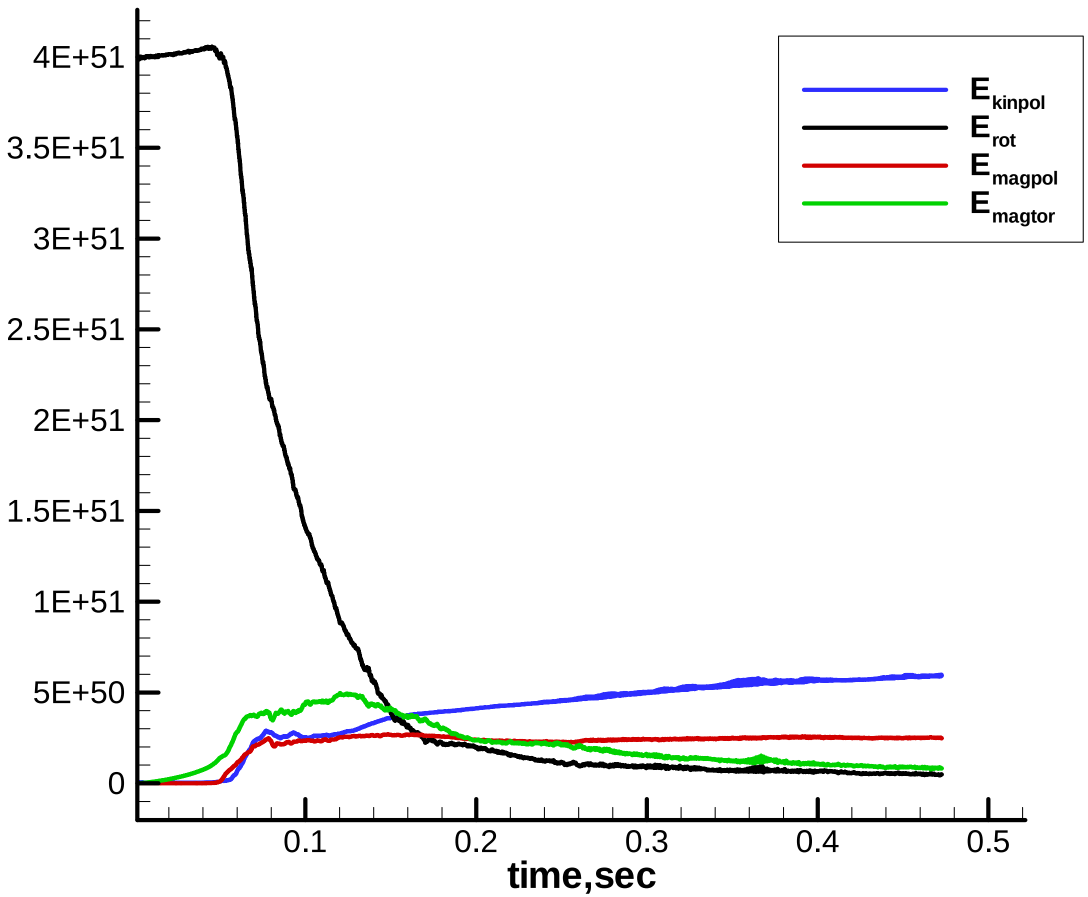
I – moment of inertia of the neutron star

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

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

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

Neutron star formation



N.V.Ardeljan, G.S.Bisnovatyi-Kogan, S.G.Moiseenko MNRAS, 2005, **359**, 333.

B(chaotic) ~ 10^14 Gs

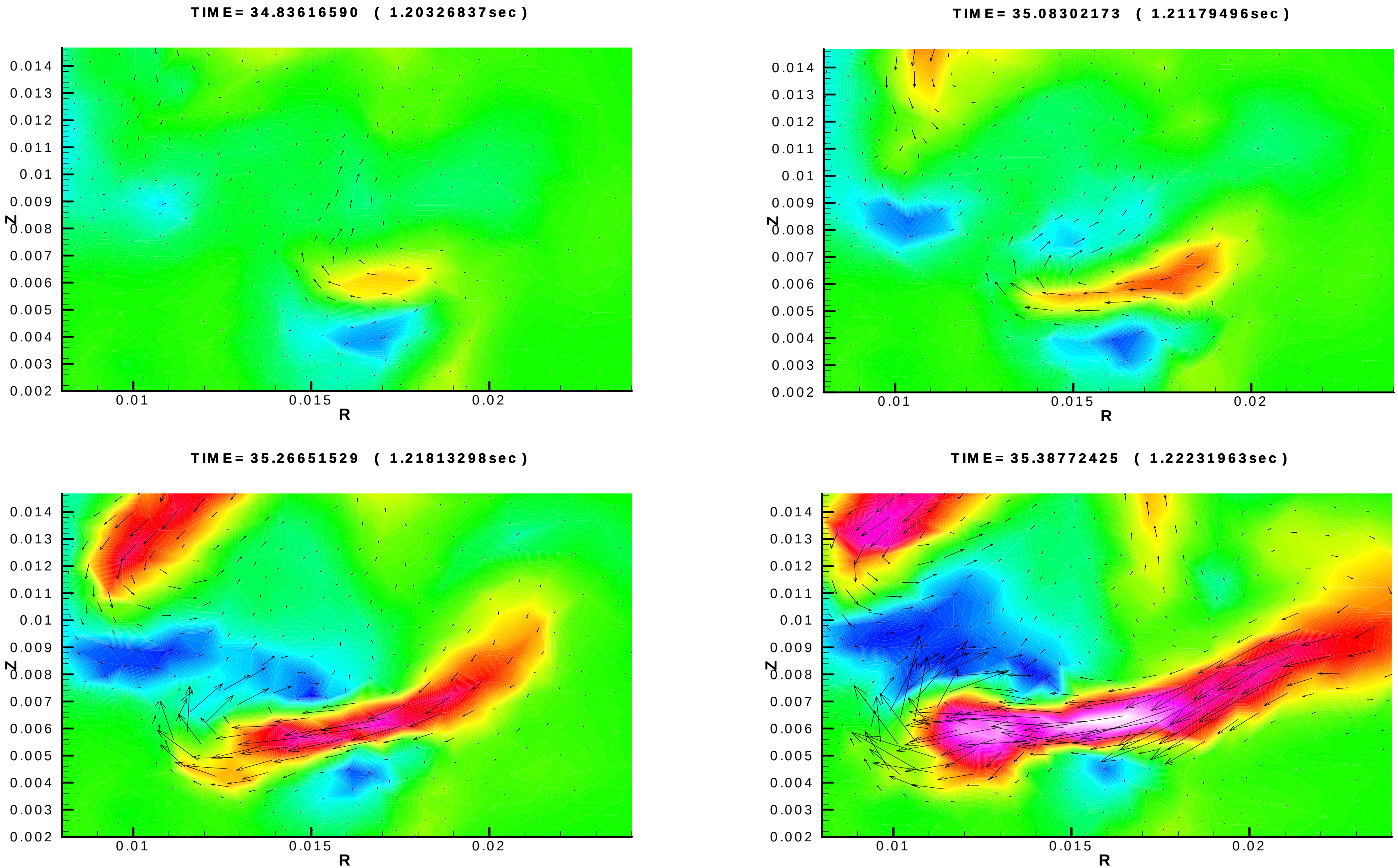
High residual chaotic magnetic field after MRE core collapse SN explosion.

Heat production during Ohmic damping of the chaotic magnetic field may influence NS cooling light curve

GAISH, May 18, 2007

Inner region: development of magnetorotational instability (MRI)

GAISH, May 18, 2007



Toy model of the MRI development: expomemtial growth of the magnetic fields

$$\frac{dH_\varphi}{dt} = H_r\left(r\frac{d\Omega}{dr}\right);$$ at initial stages $$H_\varphi < H_\varphi^* : \left(r\frac{d\Omega}{dr}\right) = A \approx \text{const},$$

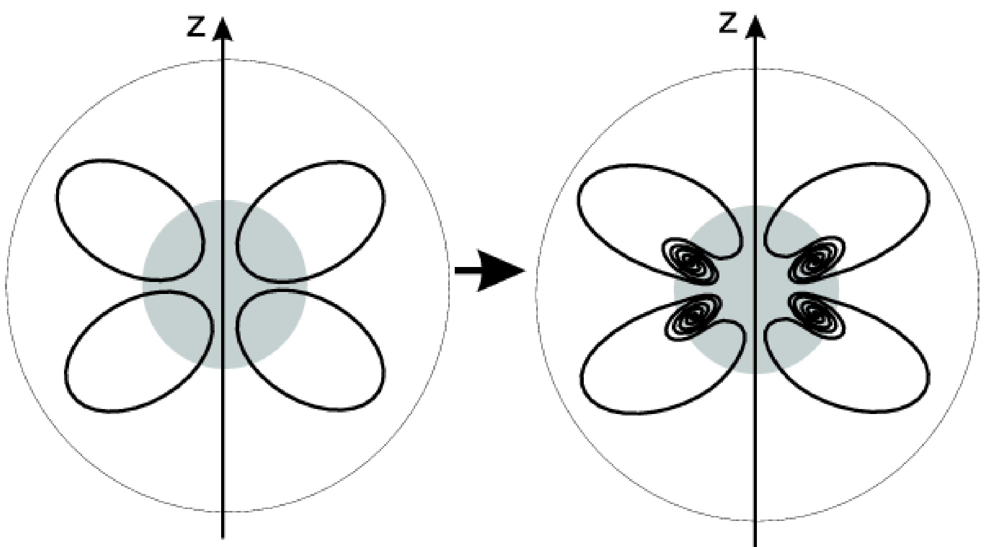
MRI leads to formation of multiple *poloidal* differentially rotating vortexes. Angular velocity of vortexes is growing (linearly) with a growth of H_φ.

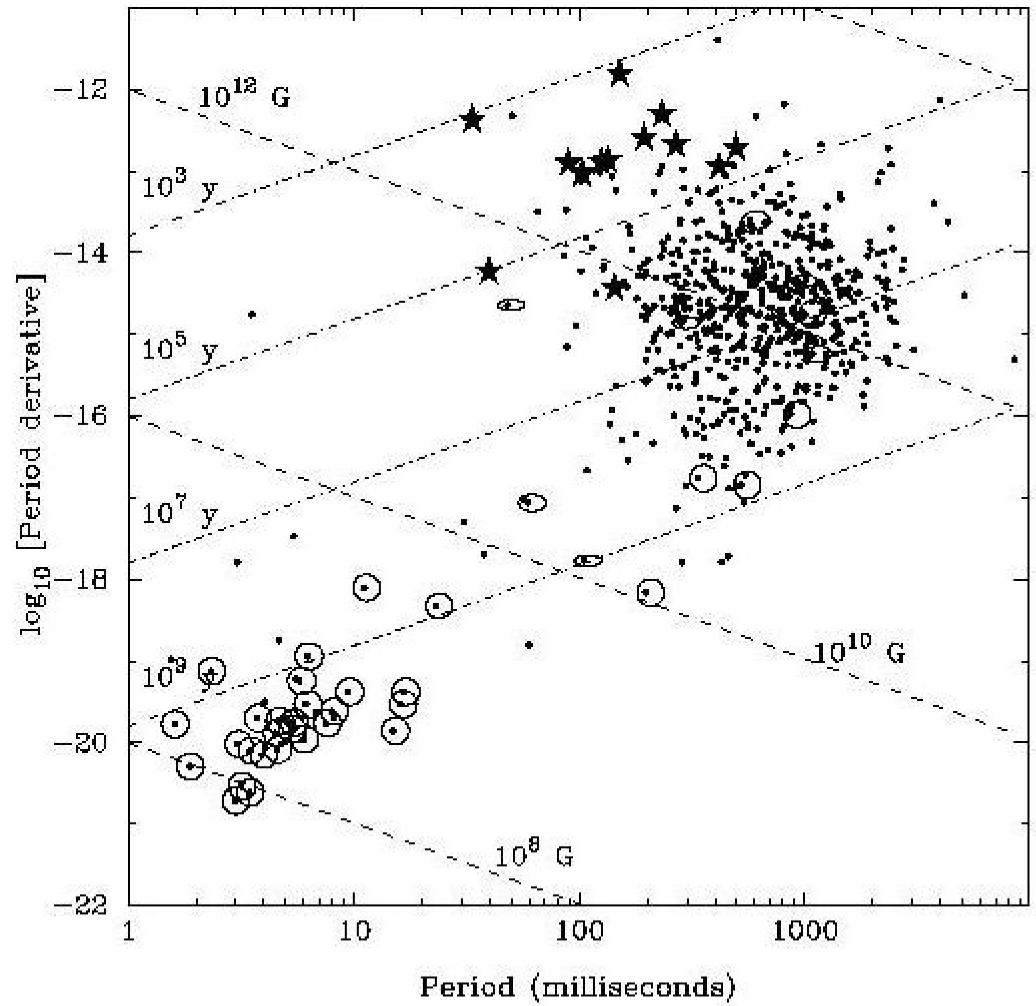
$$\frac{dH_r}{dt} = H_{r0}\left(\frac{d\omega_v}{dl}l\right), \qquad \left(\frac{d\omega_v}{dl}l\right) \approx \alpha(H_\varphi - H_\varphi^*).$$

$$\frac{d^2}{dt^2}\left(H_\varphi - H_\varphi^*\right) = AH_{r0}\alpha(H_\varphi - H_\varphi^*)$$

$$\Downarrow$$

$$\begin{cases} H_\varphi = H_\varphi^* + H_{r0}e^{\sqrt{A\alpha H_{r0}}(t-t^*)}, \\ H_r = H_{r0} + \dfrac{H_{r0}^{3/2}\alpha^{1/2}}{\sqrt{A}}\left(e^{\sqrt{A\alpha H_{r0}}(t-t^*)} - 1\right). \end{cases}$$




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)

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, 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" $\simeq 4.4 \times 10^{13}$ 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.

Soft Gamma Repeaters (SGR)

Mazets et al., AZhLett, **5**, 1979, 641-643

Soft gamma-ray bursts from the source B1900+14

AZhLett, **5**, 1979, 636-640

Recurrent gamma-ray bursts from the flaring source FXP 0520 - 66

Giant bursts in SGR similar to short GRB

19.01

STATISTICAL PROPERTIES OF THE SOFT GAMMA REPEATER(SGR) GB790107

J. G. Laros, E. E. Fenimore, R. W. Klebesadel (Los Alamos), and S. R. Kane (UCB)

The high energy transient GR790107, originally cataloged as a gamma-ray burster by Mazets, et al., has recently been shown to be repetitive, with the highest activity (~80 out of ~100 events) seen in late 1983 (Laros, et al. 1986, Nature, 322, 152). Its mean photon energy of ~30 KeV, together with the repetitive behavior, impel us to place it in a new class, which we tentatively call soft gamma repeaters (SGRs). Other probable SGRs are GB790324 and possibly the "March 5" source GB790305B. Preliminary data on the repetitions of GB790107 were presented at the Toulouse COSPAR meeting and at the Taos Gamma-Ray Stars conference. The repetitions, with $\lesssim 0.2$ S durations and ~30 KeV characteristic energies, appear very similar to the first detected outburst in 1979. Using data from the UCB/Los Alamos experiment on ICE, we have determined other characteristics of the repetitions, namely: (1) The interval between successively observed events ranges from seconds to years, (2) There is little correlation between The interval and the intensity of the preceding or following outburst, (3) No periodicities are evident, (4) The luminosities of the repetitions ranged form $\sim 1 \times 10^{-7}$ (The instrumental threshold) to $\sim 3 \times 10^{-6}$ ergs cm^{-2}, with the distribution monotonically falling with increasing luminosity. We will discuss these and other results on this intriguing new type of repeating high energy transient. This work was supported by the US DOE and NASA.

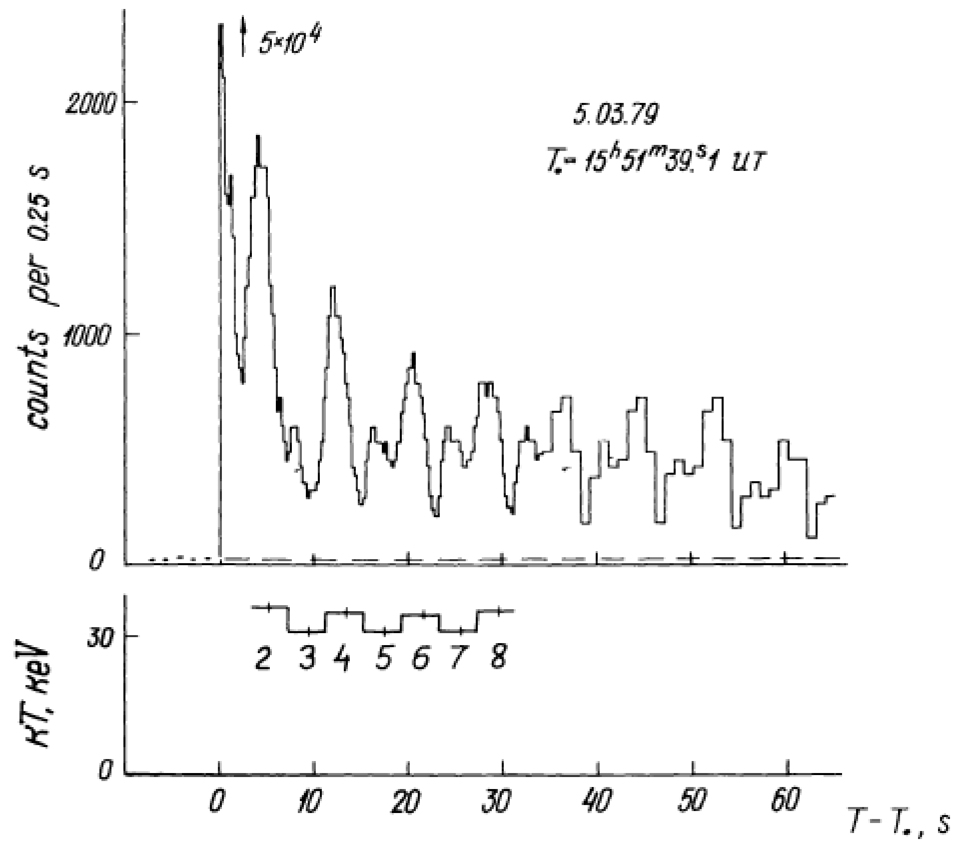
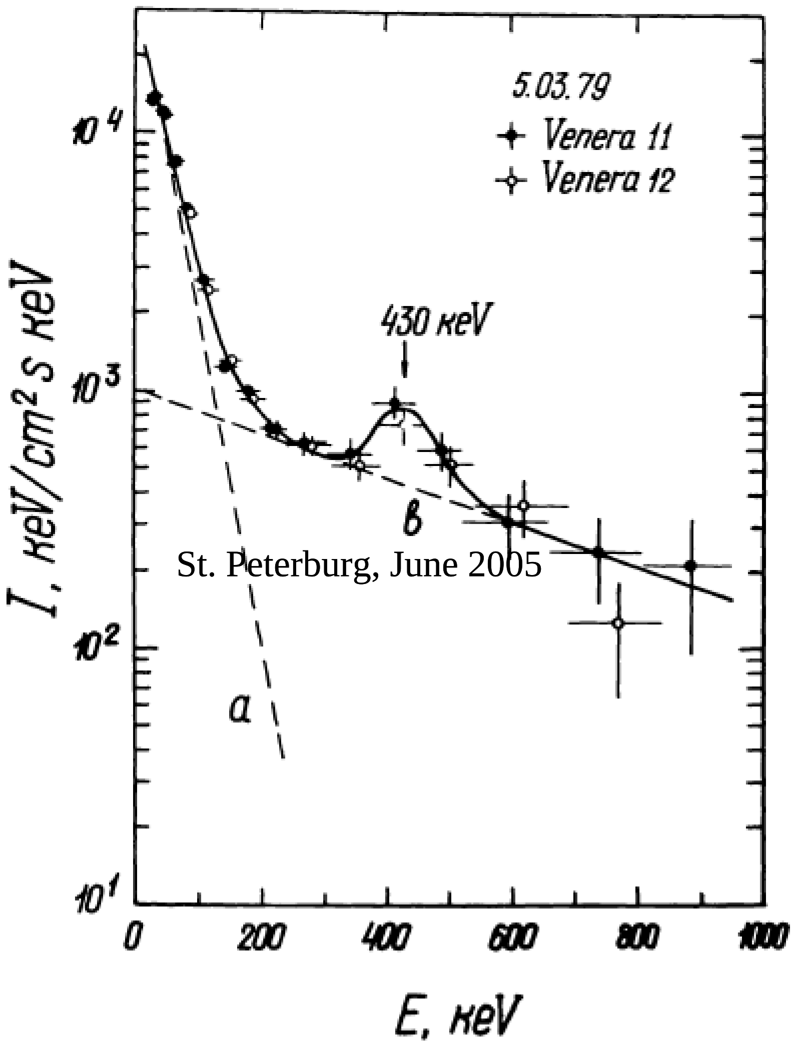


Fig. 1. 5 March 1979 gamma-ray burst. Top: time profile; narrow initial pulse and pulsations, resolution 0.25 s. Bottom: temperature variations for the thermal bremsstrahlung spectra in the pulsating stage of the burst, $I \propto \exp(-E/kT)$, time taken to measure each spectrum 4 s.

Mazets et al., 1981



Mazets et al., 1981

Fig. 2. A reconstructed spectrum of the narrow initial pulse in the 5 March 1979 gamma burst. (a) soft component ($kT = 35 \pm 5$ keV); (b) hard component with a redshifted annihilation line ($kT = 520 \pm 100$ keV).

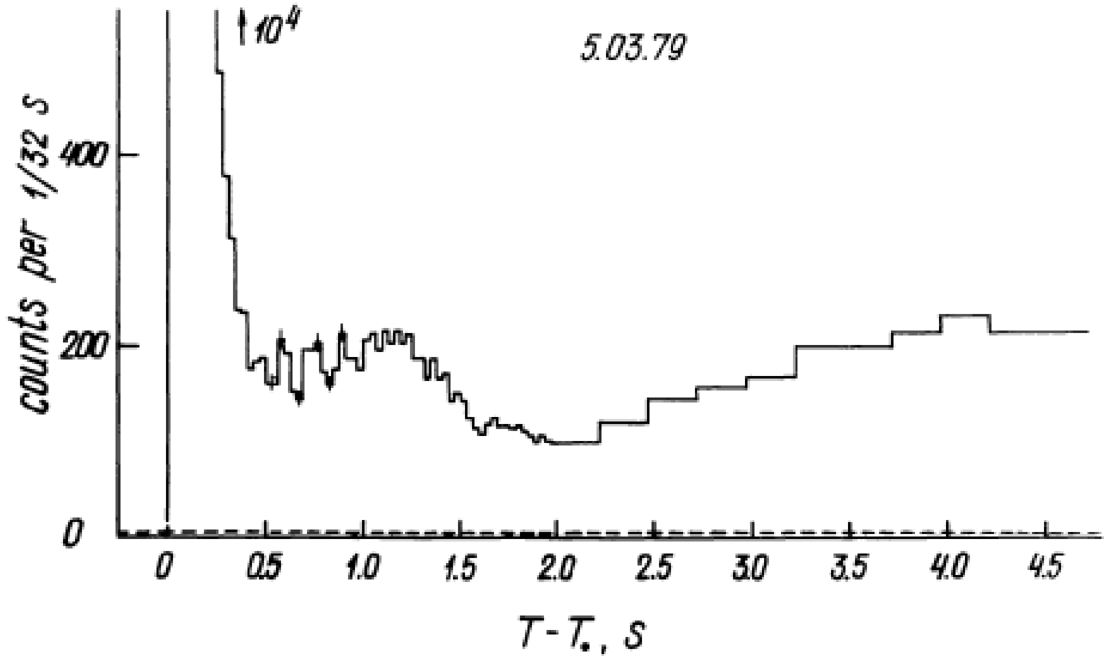
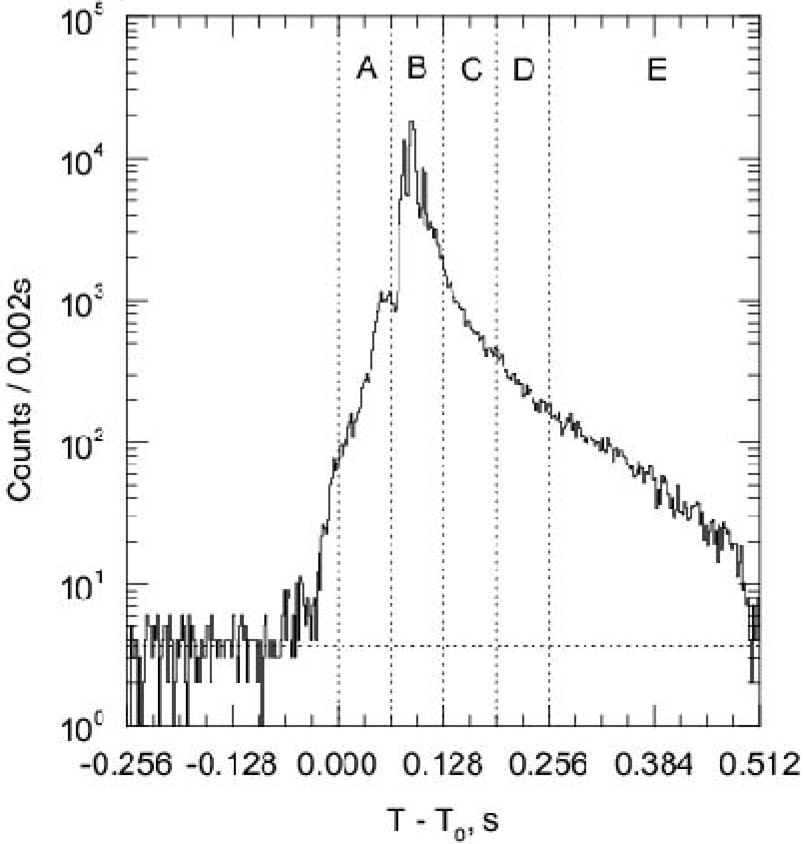


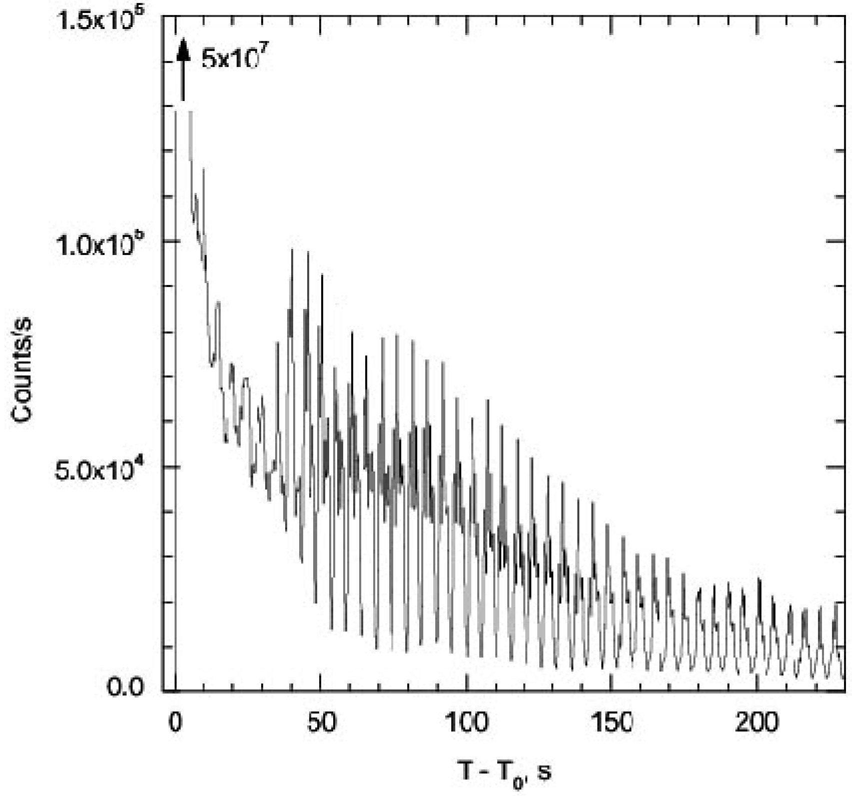
Fig. 4. The initial stage in the 5 March 1979 gamma burst. The maximum in the region $T - T_0 =$ 0.5–1.5 s does not belong to the pulsation series with the period 8.1 ± 0.1 s. In the interval 0.4–1.2 s, fast oscillations are superimposed on a relatively-smooth intensity profile.

Mazets et al., 1981

The time history of the giant burst from the soft gamma repeater SGR 1627-41. on June 18, 6153 s UT corrected for dead time. Photon energy E > 15 keV. The rise time is about 100 ms (Mazets, 1999a).

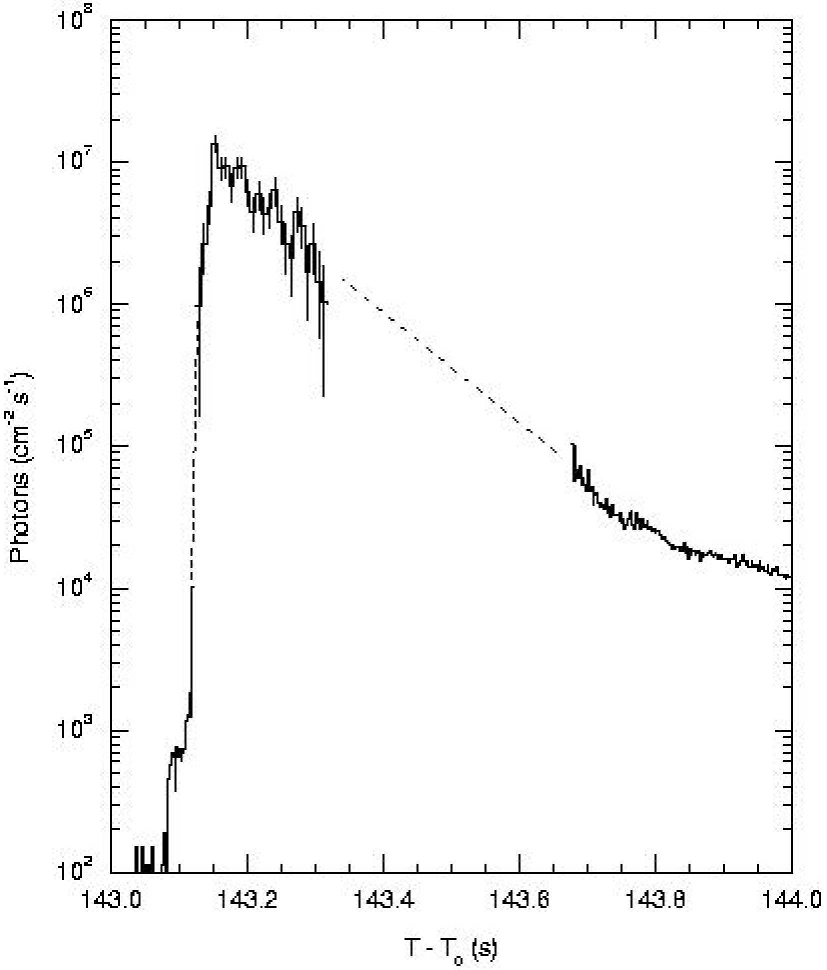


The giant 1998 August 27 outburst of the soft gamma repeater SGR 1900 + 14. Intensity of the E > 15 keV radiation (Mazets, 1999c).



2004 December 27
giant outburst.

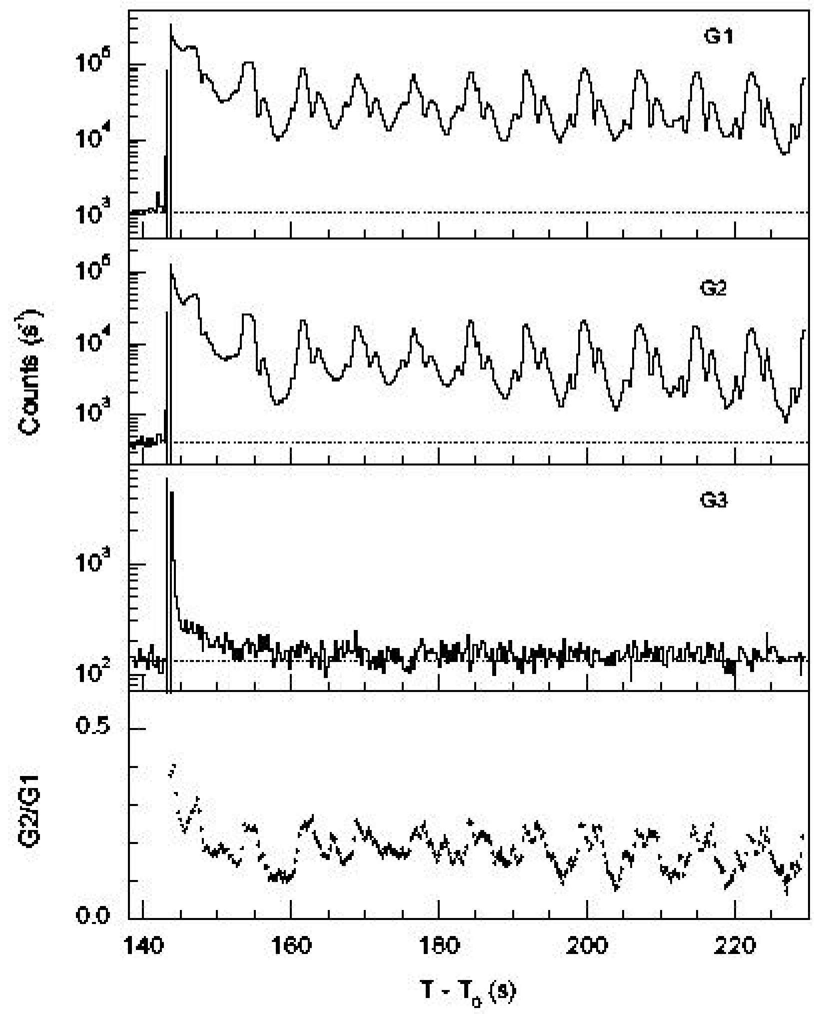
Reconstructed time history of the initial pulse. The upper part of the graph is derived from Helicon data while the lowerpart represents the Konus-Wind data. The dashed lines indicate intervals where the outburst intensity still saturates the Konus-Wind detector, but is not high enough to be seen by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



Mazets et al., 2005

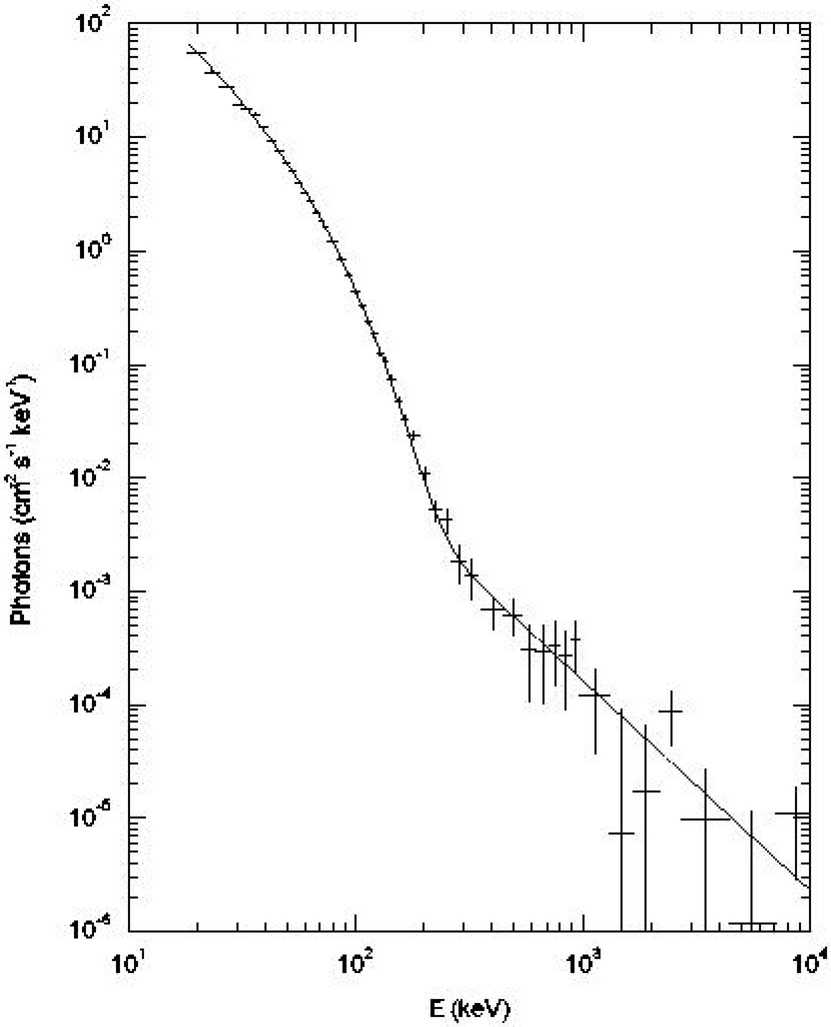
GAISH, May 18, 2007

Time history of the 2004 December 27 giant outburst recorded by the Konus-Wind detector in three energy windows G1 (16.5--65~keV), G2 (65--280~keV), and G3 (280--1060~keV), and the hardness ratio G2/G1. The moderate initial count rate growth to 10^2--10^3~counts~s^{-1} transforms rapidly to an avalanche-type rise to levels >5 \times 10^7~counts~s^{-1}, which drives the detector to deep saturation for a time \Delta T \simeq 0.5~s. After the initial pulse intensity has dropped to \sim 10^6~counts~s^{-1}, the detector resumes operation to record the burst tail.



Mazets et al., 2005

A spectrum of the burst tail averaged over the pulsation period. The low-energy component is similar to spectra of SGR's recurrent bursts with $E_0 \simeq 30$~keV. At high energies it exhibits a hard power-law component with $\alpha = -1.8 \pm 0.2$. This two-component model is shown by the solid line.



Mazets et al., 2005

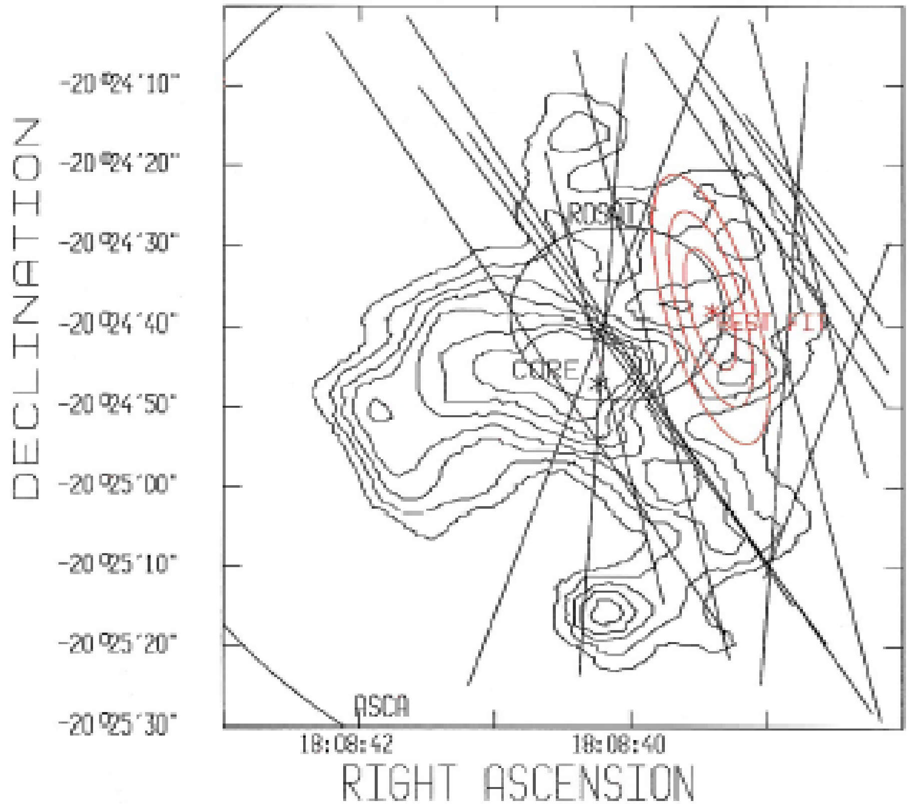


FIG. 2.—Eight IPN annuli (*black lines*) and the 1, 2, and 3 σ equivalent confidence contours (*red annuli*) for SGR 1806−20. The best-fit position and the position of the nonthermal core are indicated. The *ASCA* error circle is just visible in the lower left-hand and upper left-hand corners; its radius is 1′, quoted as a systematic error, with no confidence limit given (Murakami et al. 1994). The *ROSAT* PSPC error circle is at the center; its radius is 11″, with no confidence limit quoted (Cooke et al. 1993). We have reanalyzed the *ROSAT* data and confirm the presence of a weak source at this position, but we are unable to establish confidence limits for its position. The 3.6 cm radio contours of G10.0-0.3 are also shown, from Vasisht, Frail, & Kulkarni (1995).

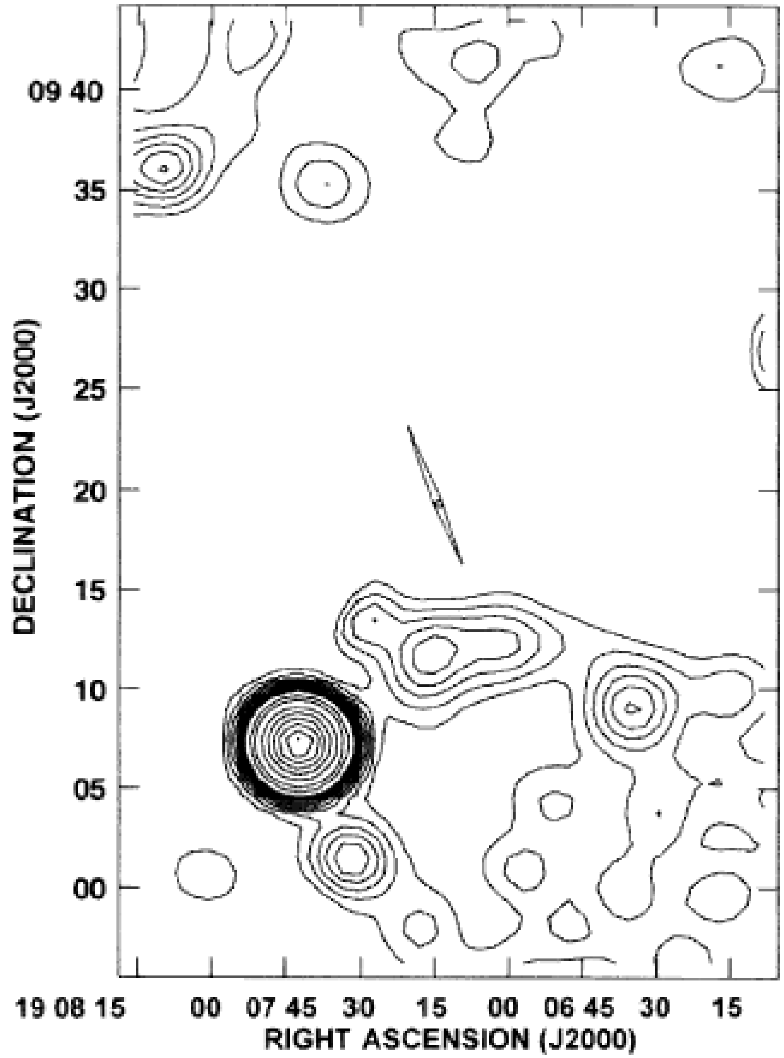


FIG. 2.—Error box for SGR 1900+14 superposed on a radio map of this region. The radio continuum image was taken at the VLA on 1994 February 7 at a frequency of 327 MHz (Vasisht et al. 1994). The synthesized beam size is approximately 3′. The contour levels progress in steps of 20–200 mJy beam^{-1}. The higher contour levels progress in steps of 20 mJy beam^{-1} to the peak of 1.6 Jy. The position of the ROSAT source within the error box is indicated.

SGR model: **Magnetar** B=10^14 – 10^15 Gs

Magnetic Field Limit on SGR 1900+14
Rothschild, R. E.; Marsden, D.; Lingenfelter, R. E.
preprint arXiv:astro-ph/9911238

Astrophysical Journal, Volume 520, pp. L107-L110

We measured the period and spin-down rate for SGR 1900+14 during the quiescient period two years before the recent interval of renewed burst activity. We have shown that the spin-down age of SGR 1900+14 is consistent with a braking index of ~1 which is appropriate for wind torques and not magnetic dipole radiation. We have shown that a combination of dipole radiation, and wind luminosity, coupled with estimated ages and present spin parameters, imply that the magnetic field for SGR 1900+14 is less than 6 x 10^13 G and that the efficiency for conversion of wind luminosity to x-ray luminosity is <2%.

Formation of very strongly magnetized neutron stars - Implications for gamma-ray bursts

Duncan, Robert C.; Thompson, Christopher

Astrophysical Journal, Part 2 - Letters, vol. 392, no. 1, June 10, 1992, p. L9-L13.

It is proposed that the main observational signature of magnetars, high-field neutron stars, is gamma-ray bursts powered by their vast reservoirs of magnetic energy. If they acquire large recoils, most magnetars are unbound from the Galaxy or reside in an extended, weakly bound Galactic corona. There is evidence that the soft gamma repeaters are young magnetars. It is argued that a convective dynamo can also generate a very strong dipole field after the merger of a neutron star binary, but only if the merged star survives for as long as about 10-100 ms. Several mechanisms which could impart a large recoil to these stars at birth, sufficient to escape from the Galactic disk, are discussed.

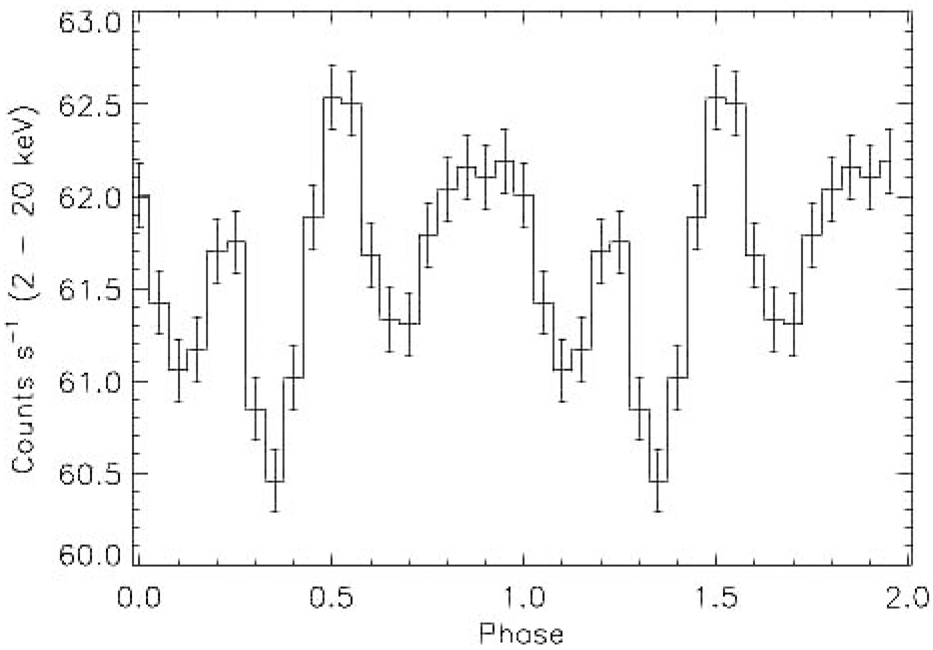
The soft gamma repeaters as very strongly magnetized neutron stars - I. Radiative mechanism for outbursts

Duncan, Robert C.; Thompson, Christopher

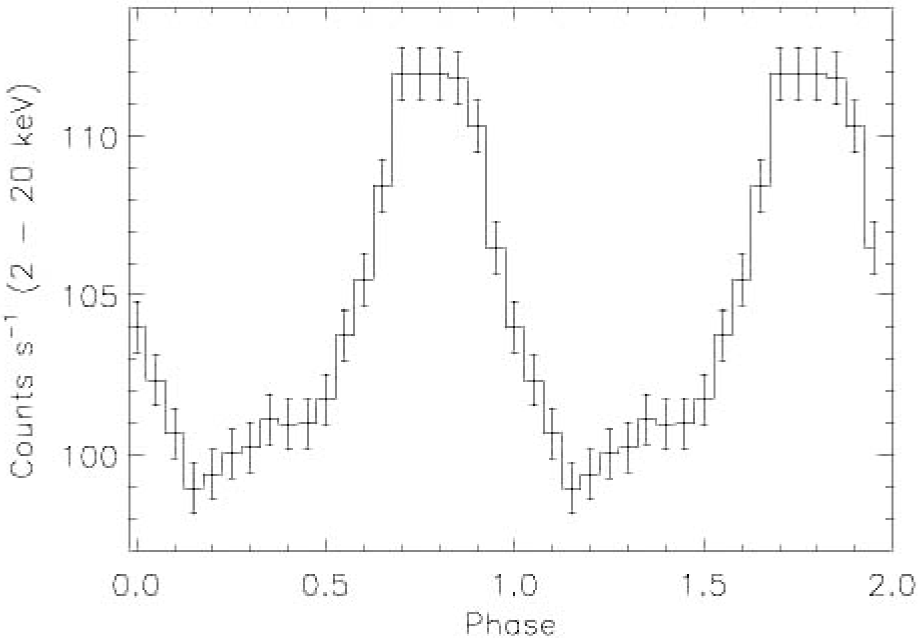
MN RAS, Volume 275, Issue 2, pp. 255-300 (1995) .

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.

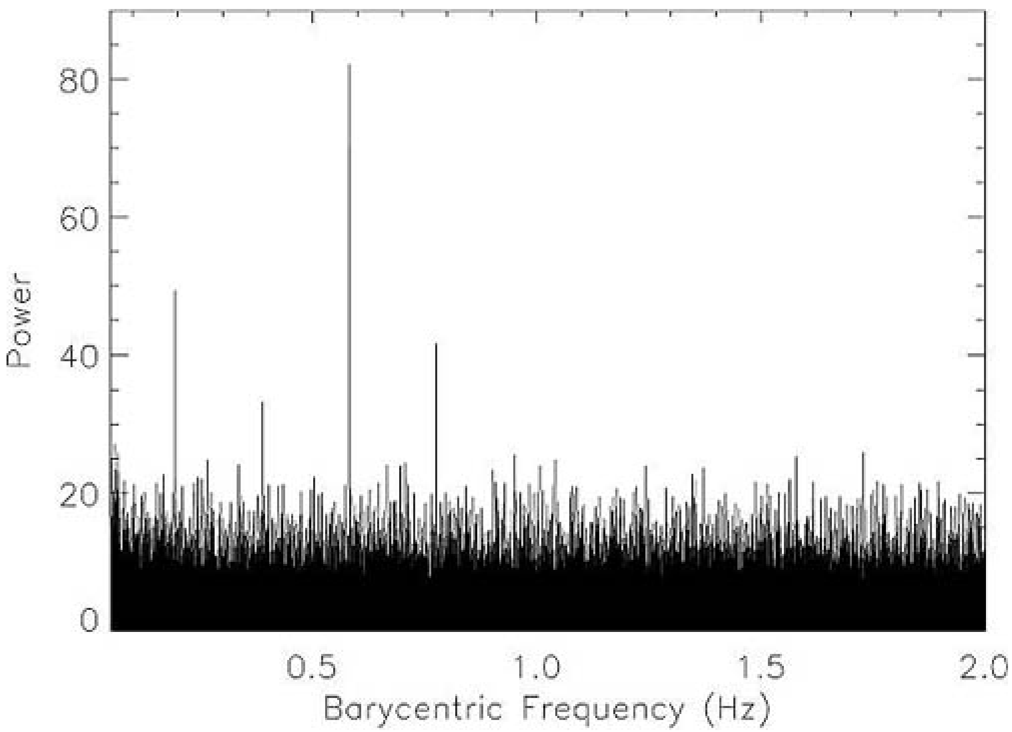
The epoch folded pulse profile of SGR 1900 + 14 (2-20 keV) for the May 1998 RXTE observations (Kouveliotou et al., 1999).



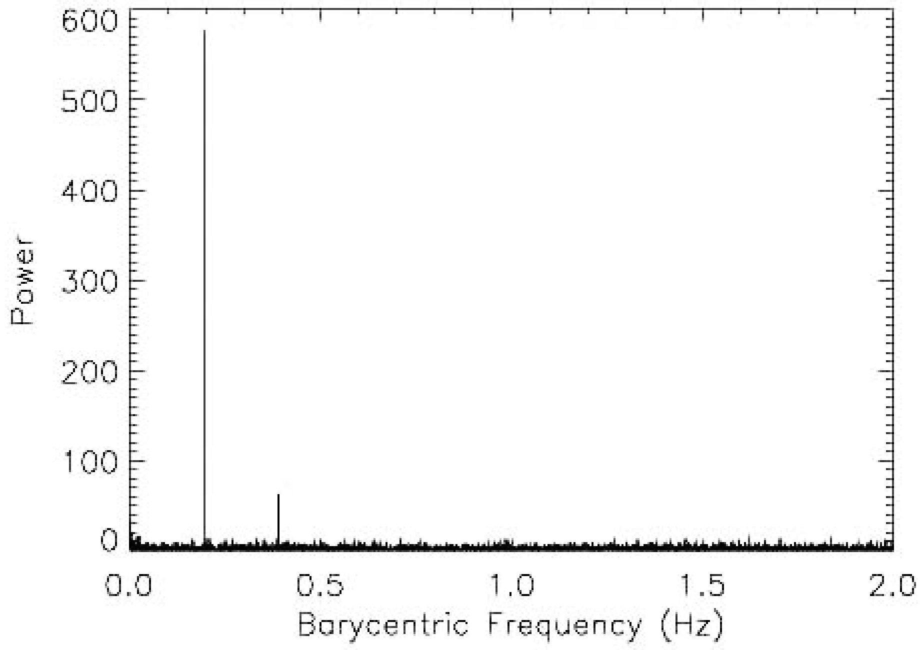
The epoch folded pulse profile of SGR 1900 + 14 (2-20 keV) for the August 28, 1998 RXTE observation. The plot is exhibiting two phase cycles (Kouveliotou et al., 1999).



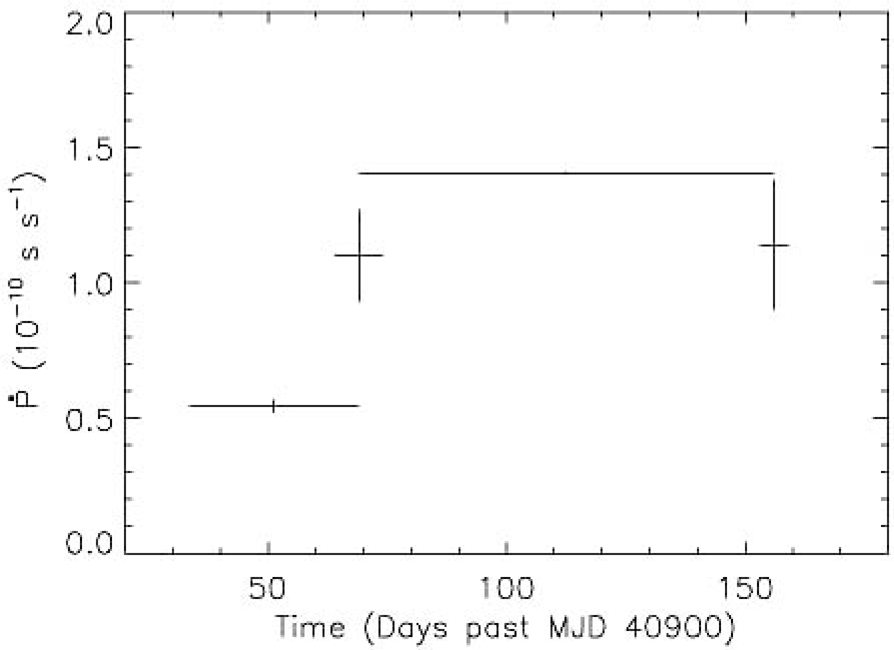
The Power Density Spectrum of the May 1998 RXTE observations of SGR 1900 + 14 . The highest peak in the spectrum corresponds to the fundamental period of 5.159142 s; the three less intense peaks are the harmonics (Kouveliotou et al., 1999)



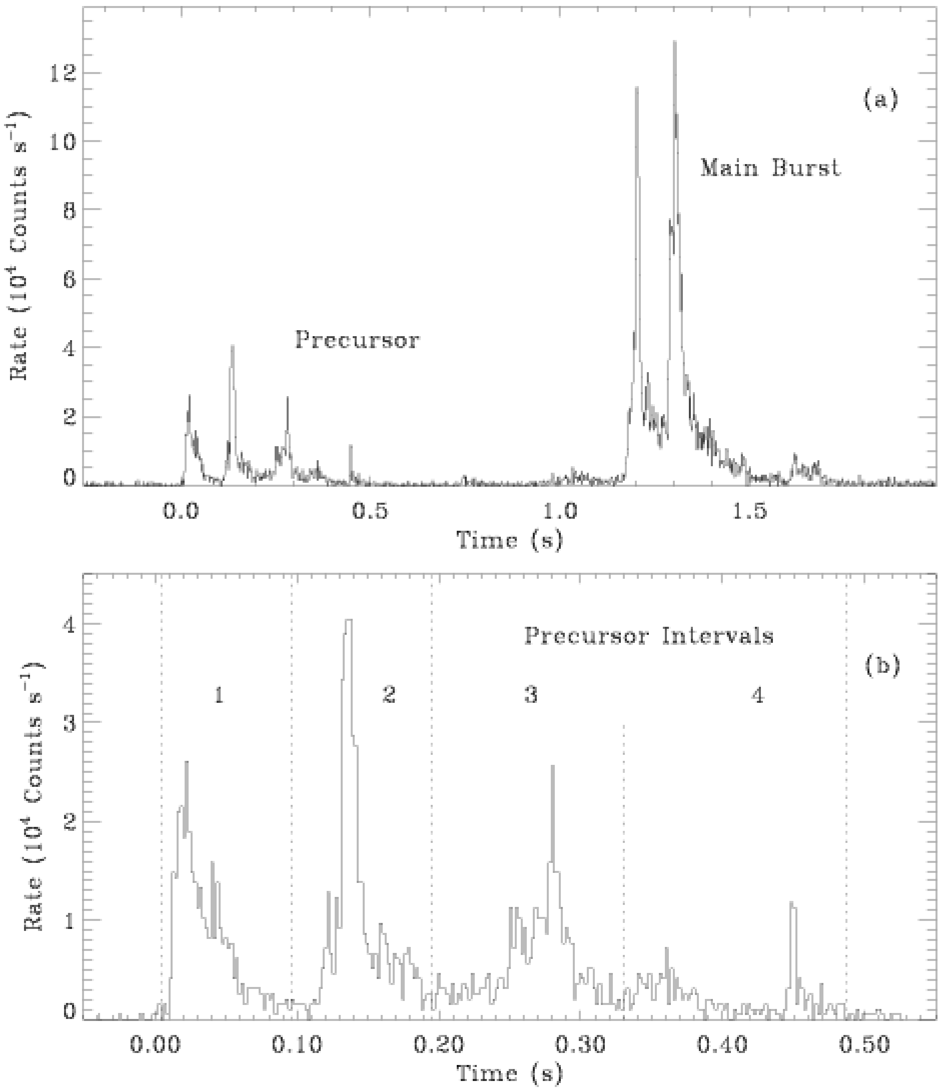
PDS of the August 28, 1998 RXTE observation. The two highest peaks are the fundamental period at 5.160199 s, and its second harmonic (Kouveliotou et al., 1999).



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)

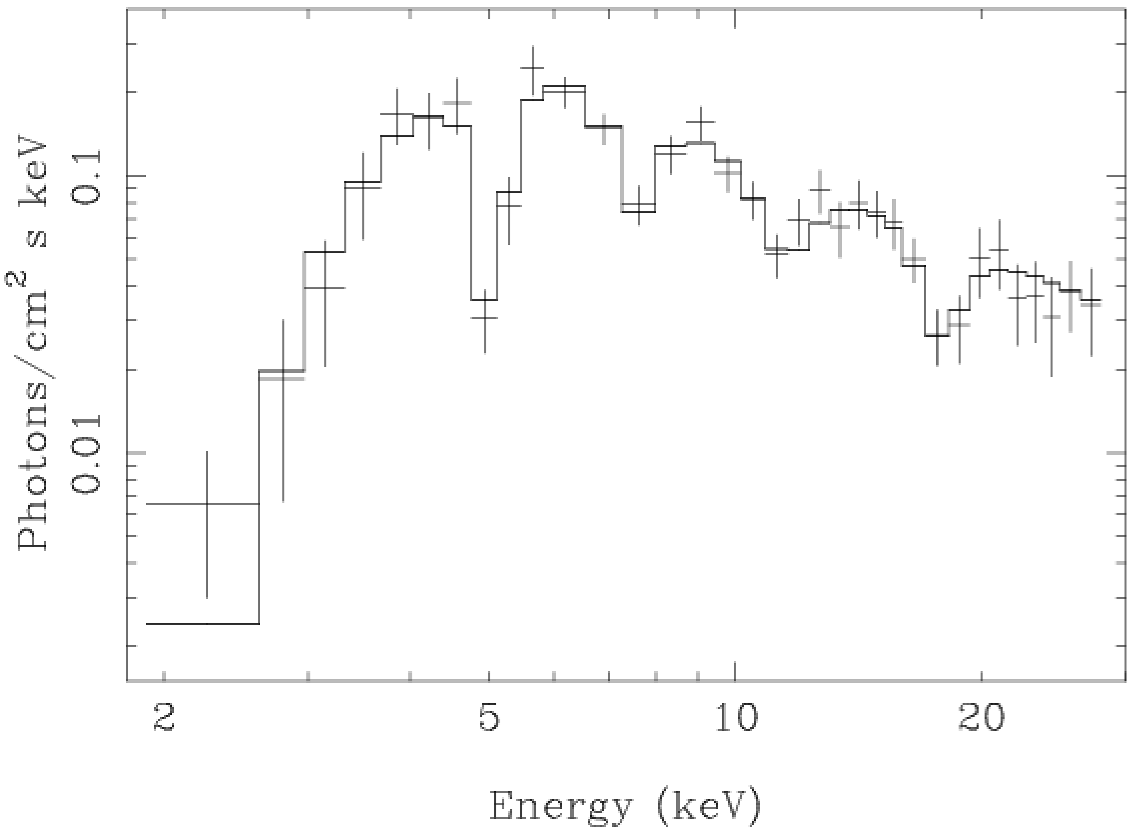


The hystory of the outburst from SRG 1806-20 (RXTE/PCA 2-60 keV). The top panel (a) shows aq bright burst preceded by a long, complex precursor. The bottom panel (b) shows the precursor intervals used in the spectral analysis (Ibrahim et al., 2002).



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)



Rotation energy losses are much less than observed (magnetic ?), so B estimations using dP/dt are not justified.

Giant bursts in nearby galaxies (short GRB): NOT seen at all! (statistically should be see about 10 short GRB)

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

Cyclotron lines: proton radiation (?)

SOVIET ASTRONOMY—AJ VOL. 10, NO. 2 SEPTEMBER-OCTOBER, 1966

A THEORY FOR THE FORMATION AND STRUCTURE OF QUASISTELLAR RADIO SOURCES*

L. M. Ozernoi

Several problems regarding the nature of quasars are examined qualitatively. At a certain evolutionary stage galactic nuclei and the central parts of quasars may be massive diffuse formations with strong magnetic fields and violent internal motions. This little-understood stage, with its severe departures from thermodynamic equilibrium, may well evolve into a state of random motion where equilibrium is efficiently achieved by turbulent transfer processes. A "magnetoid," a quasistationary configuration whose equilibrium is governed by a magnetic field, provides an idealized representation of many effects occurring in galactic nuclei and especially in the central parts of quasars. The gravitational energy released through secular contraction of the nucleus is the ultimate source of the intense quasar radiation. The magnetic field is an important intermediary. An exact solution is obtained for the magnetohydrodynamic equations describing stable fluid rotation along the lines of force of a toroidal magnetic field. This solution, one realization of a magnetoid, yields a characteristic time for repetition of the plasma circulation pattern in more complex magnetoid models. If quasar nuclei do experience such quasiperiodic motions a variable energy flux may result. The observed optical variability (the flux probably varies at other wavelengths also) supports the treatment suggested. Local jets and streams of matter connected with active regions may occur when quasar nuclei reach global quasiequilibrium. Although the magnetoid approach furnishes a unified explanation for the basic property of quasistellar radio sources—an intense and variable flux emitted over a fairly long period—many aspects necessarily remain speculative. This paper summarizes recent work by the author [10-12].

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)