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Anomalous Pulsar and Magnetars - General Properties

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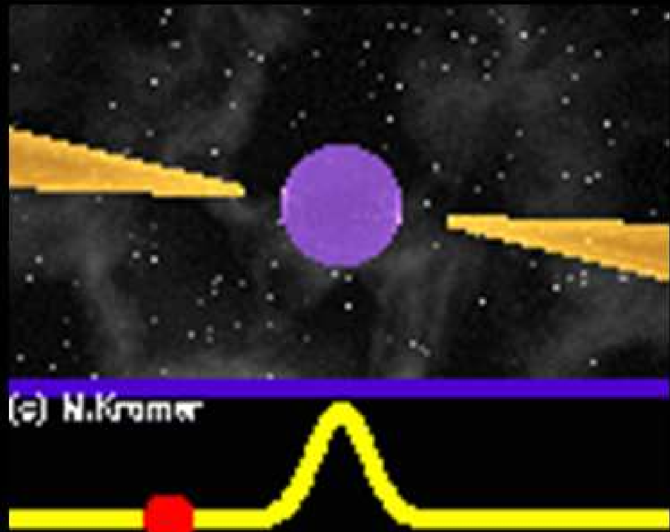
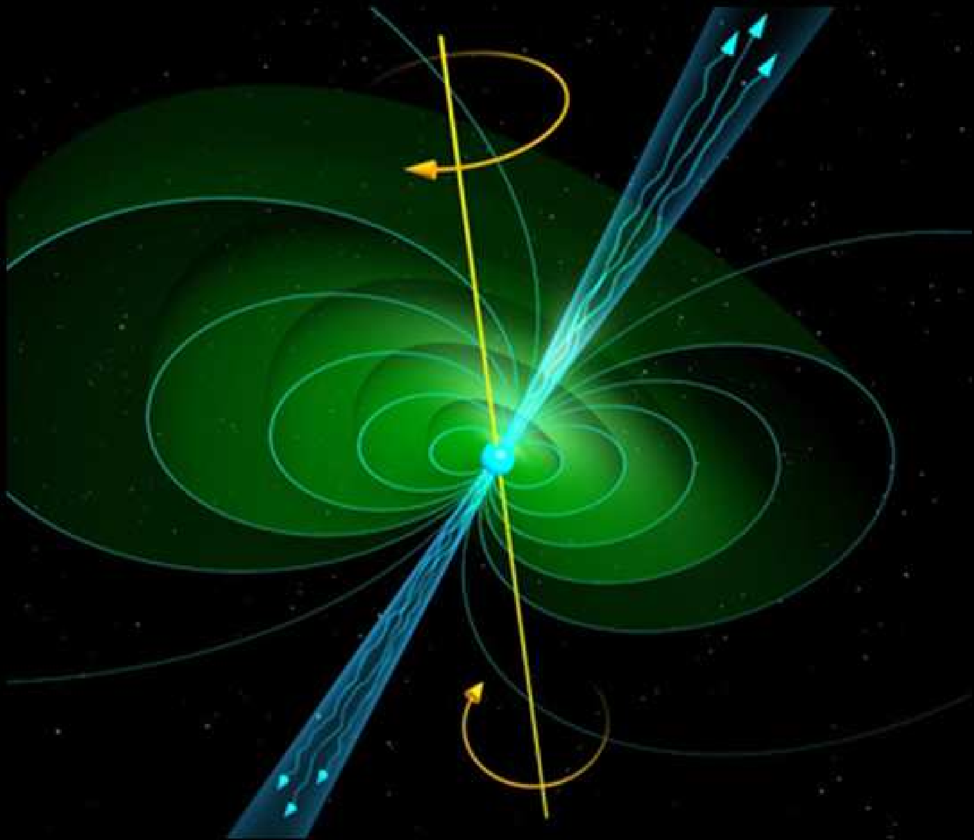
Anomalous Pulsars

http://cta.iliauni.edu.ge/

$$B \sim 10^{12} \div 10^{13}\,\mathrm{G}$$

$$\rho \sim 10^{14} \div 10^{15}\,\mathrm{g\ cm^{-3}}$$





$$W = I\Omega\dot{\Omega} = \frac{4\pi^2 I\dot{P}}{P^3}$$

$$I \approx 10^{45}\,\mathrm{g\ cm^2}$$

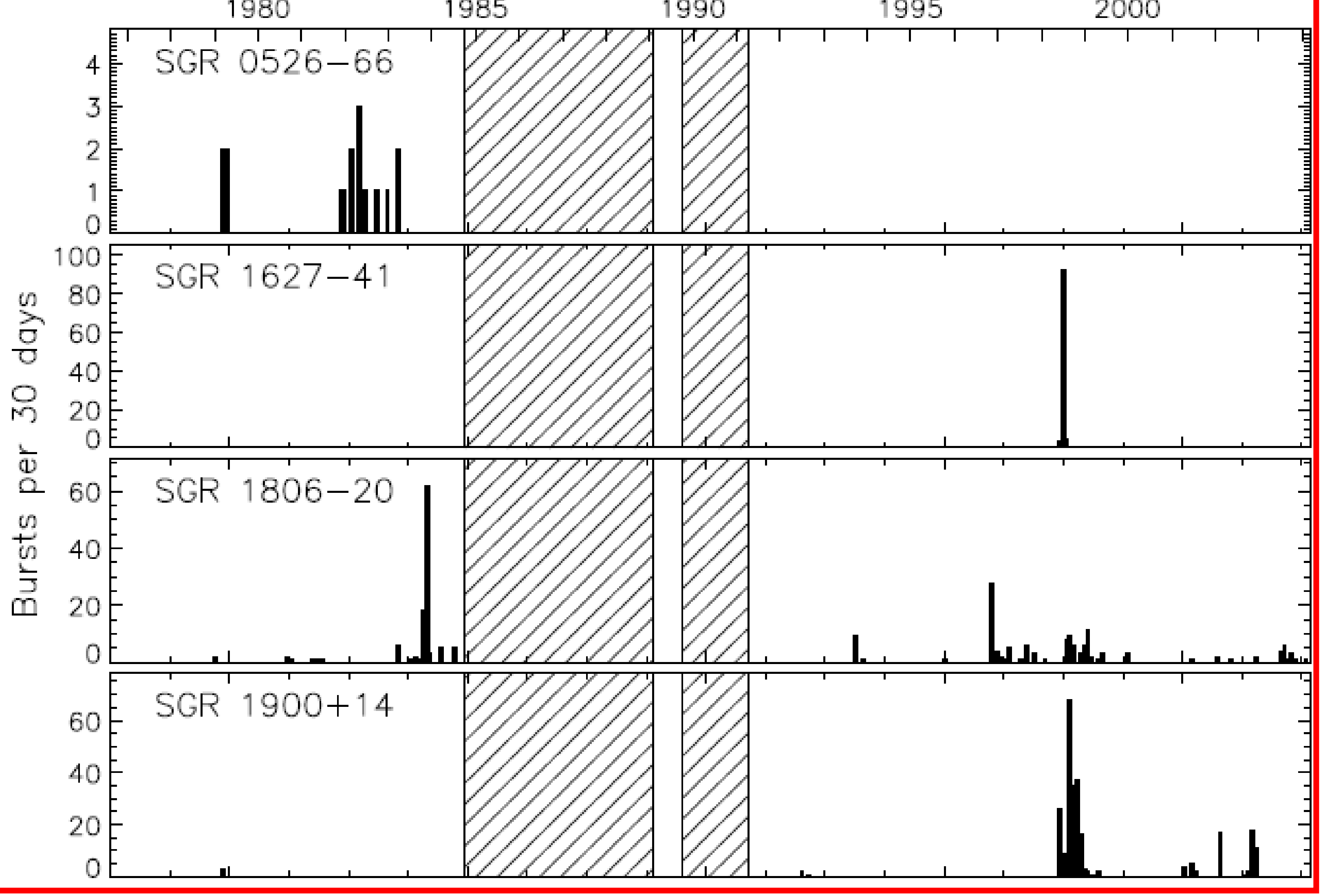
Anomalous Pulsars

- Soft Gamma-Ray Repeaters (SGR)
- Anomalous X-ray Pulsars (AXP)
- Rotational Radio Transients (RRAT)
- Compact Central Objects (CCO)
- X-ray Dim Isolated Neutron Stars (XDINS)

Soft Gamma-ray Repeaters

- *4(+2) known*
- *first observed 30 years ago*
- *emit short (~0.1 s) bursts of soft γ-rays (peak luminosity <10^{41} ergs/s)*
- *emit multiple bursts but might be dormant for years*
- *are quiescent X-ray sources*
- *sometimes emit giant flares ~10^{44-45} ergs/s (per 50-100yr)*
- *rotation periods in the 5-8 s range*

Burst activity history of the four SGRs

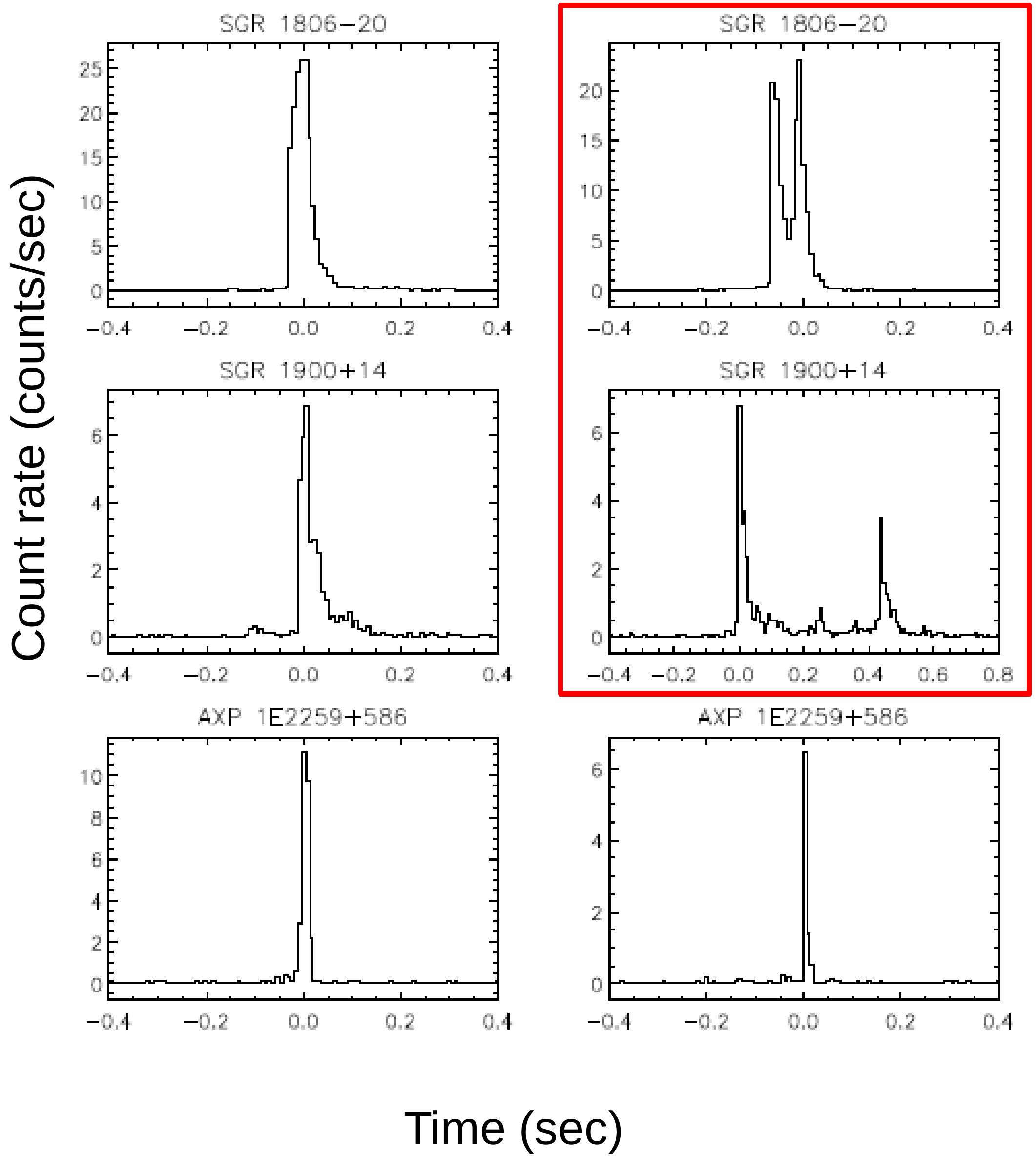


Bursts occur at irregular intervals with variable duration and intensity

Anomalous X-ray Pulsars

- *9(+1) known*
- *first observed about 30 years ago*
- *rotation periods in the 2-12 s range*
- *no binary companions*
- $L_X >> dE/dt$
- *'anomalous' as energy source unclear*
- *AXPs exhibit SGR like bursts*

The common burst morphologies for SGR and AXP



A burst typically has a faster rise than decay, and lasts ~100ms

A number of bursts are multi-peaked

- *From SGR 1900+14 the periodic X-ray emission is detected permanently*

- *In case of SGR 1627-41 and SGR 1806-20 the periodic X-ray emission is detected only during the waiting time*

- *And from SGR 0526-66 the periodic X-ray radiation is detected only during the gamma active period*

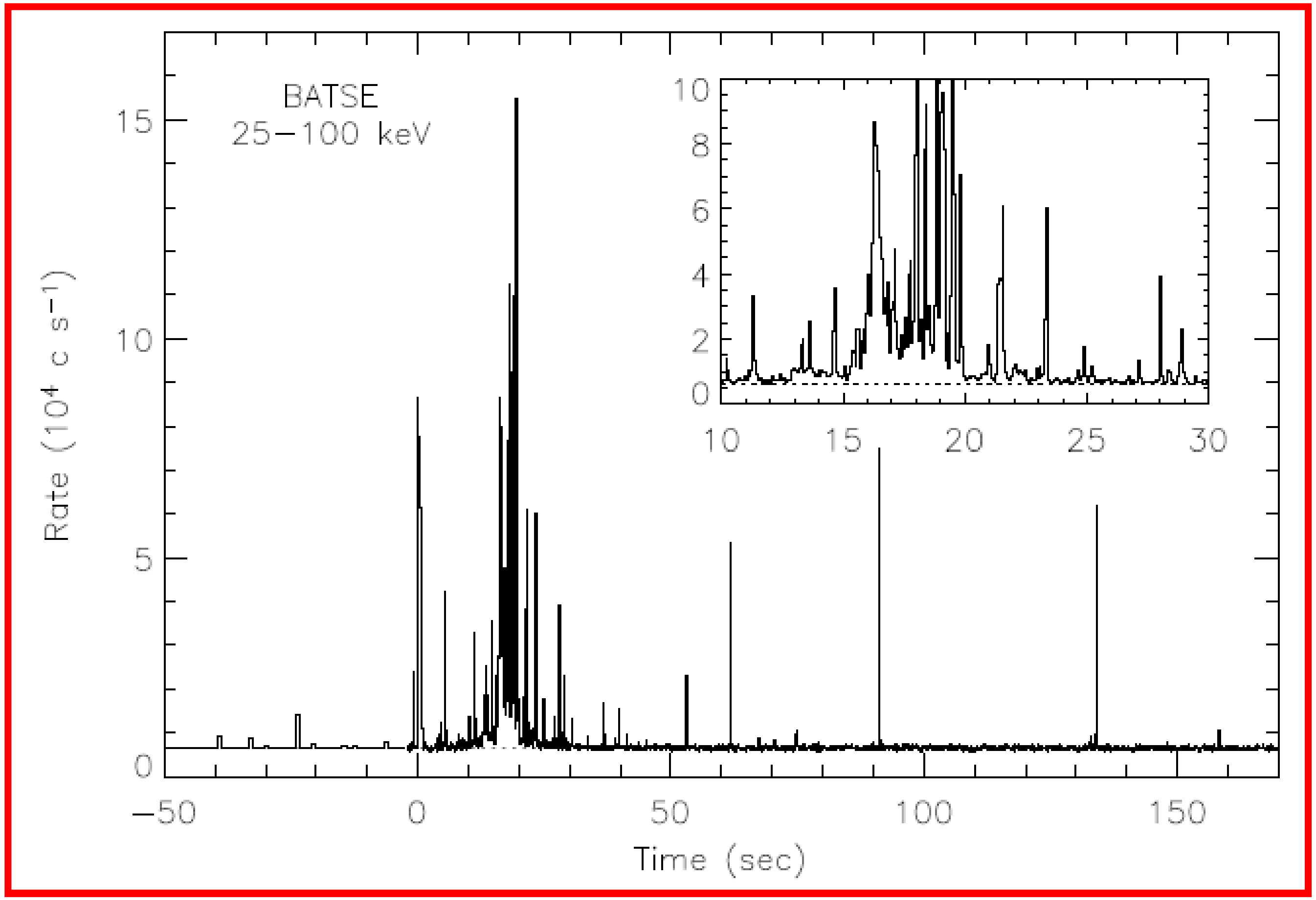
- *The distribution of waiting times between bursts follows a log-normal function.*

- *As pointed out by Cheng et al. (1986) the waiting times between earthquakes show a similar distribution.*

- *The energies radiated during the SGR bursts follows a power-law distribution* $\propto E^{-5/3}$

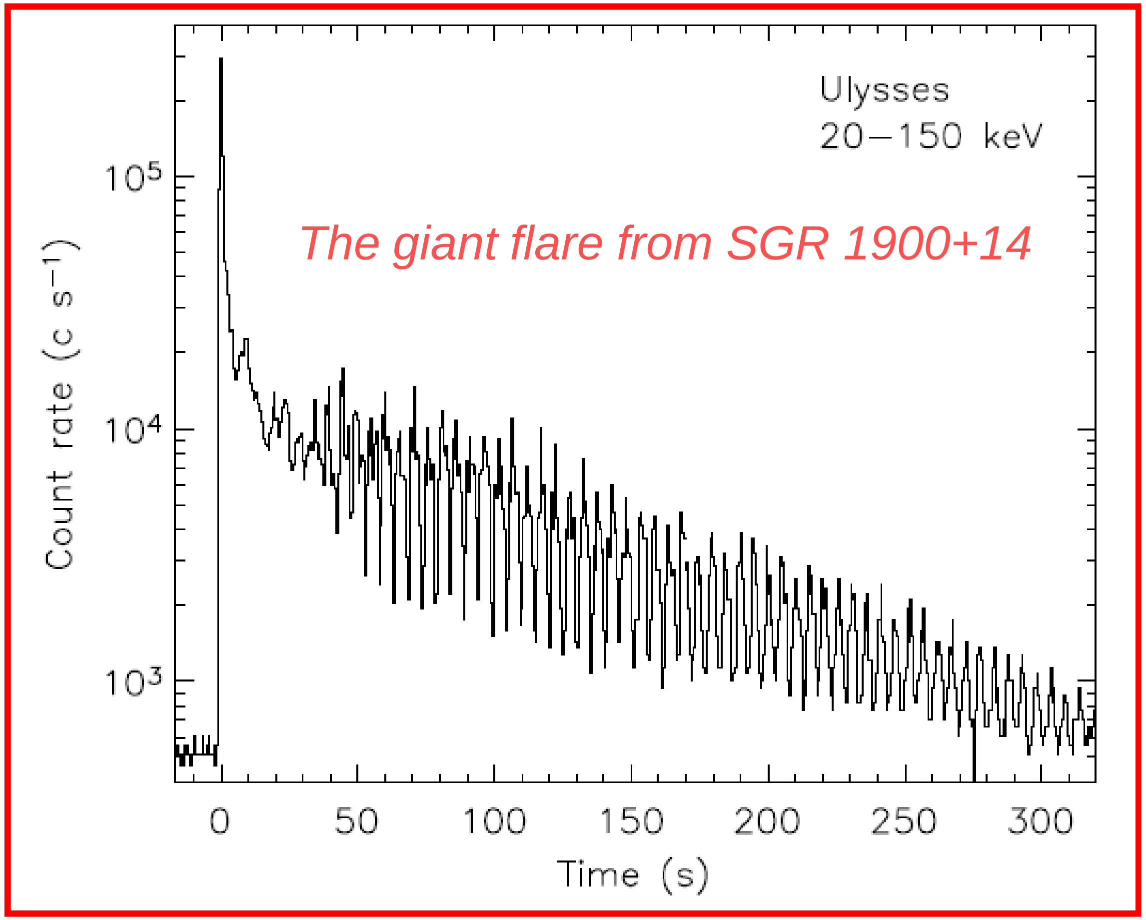
- *Cheng et al. (1996) first pointed out the similarity with the Gutenburg-Richter law for earthquakes*

The time history of the multi-episode burst from SGR 1900+14



Series of many short bursts, with extremely small waiting times are observed on rare occasions and involve several tens of bright bursts that are packed into an interval of a few minutes.

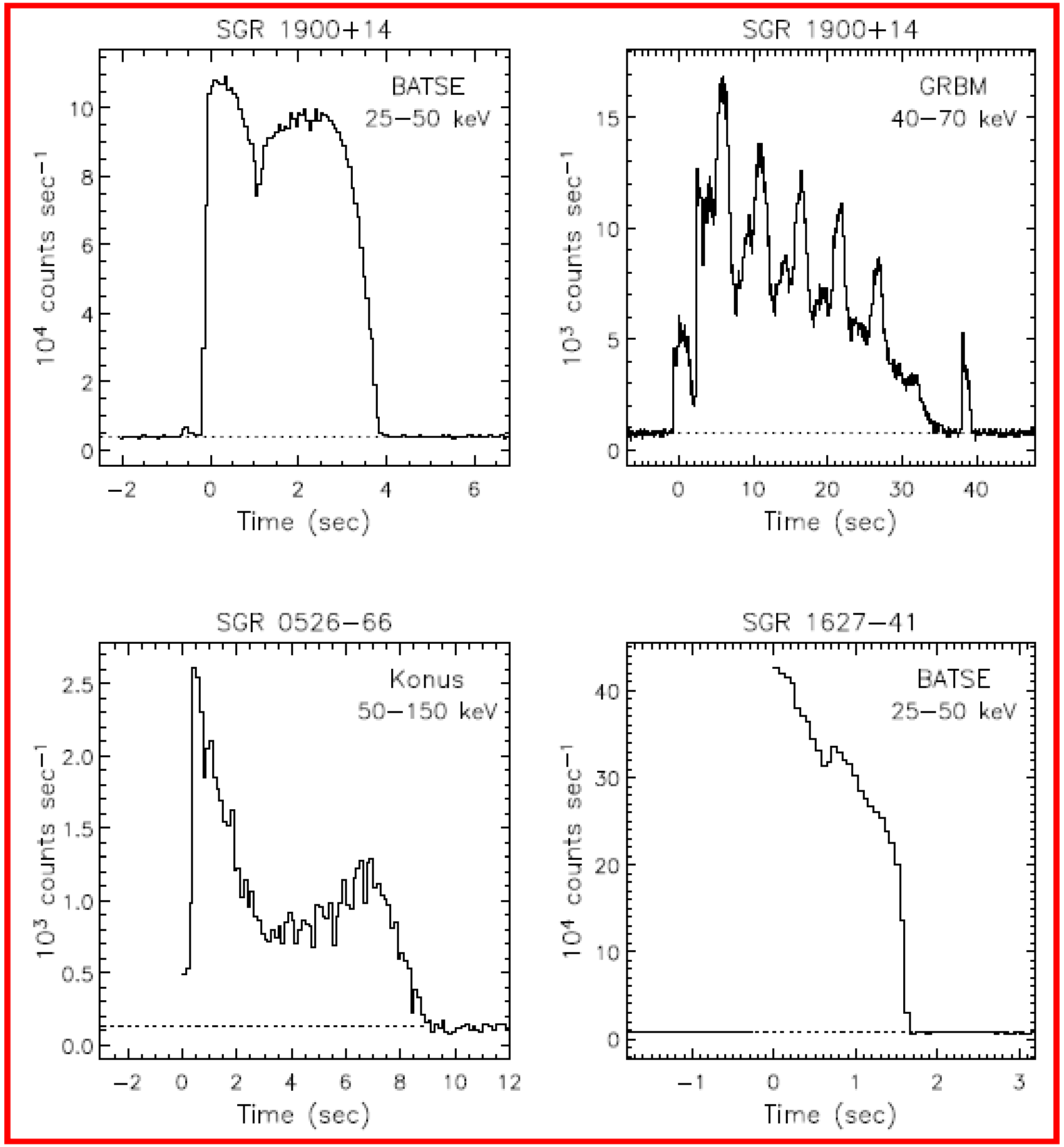
The Giant Flares



The flares begin with ~1s spike of spectrally hard emission which decays rapidly into a softer pulsating tail that persists for hundreds of seconds.

The pulsations clearly visible during the decay are at the spin period of the underlying neutron star.

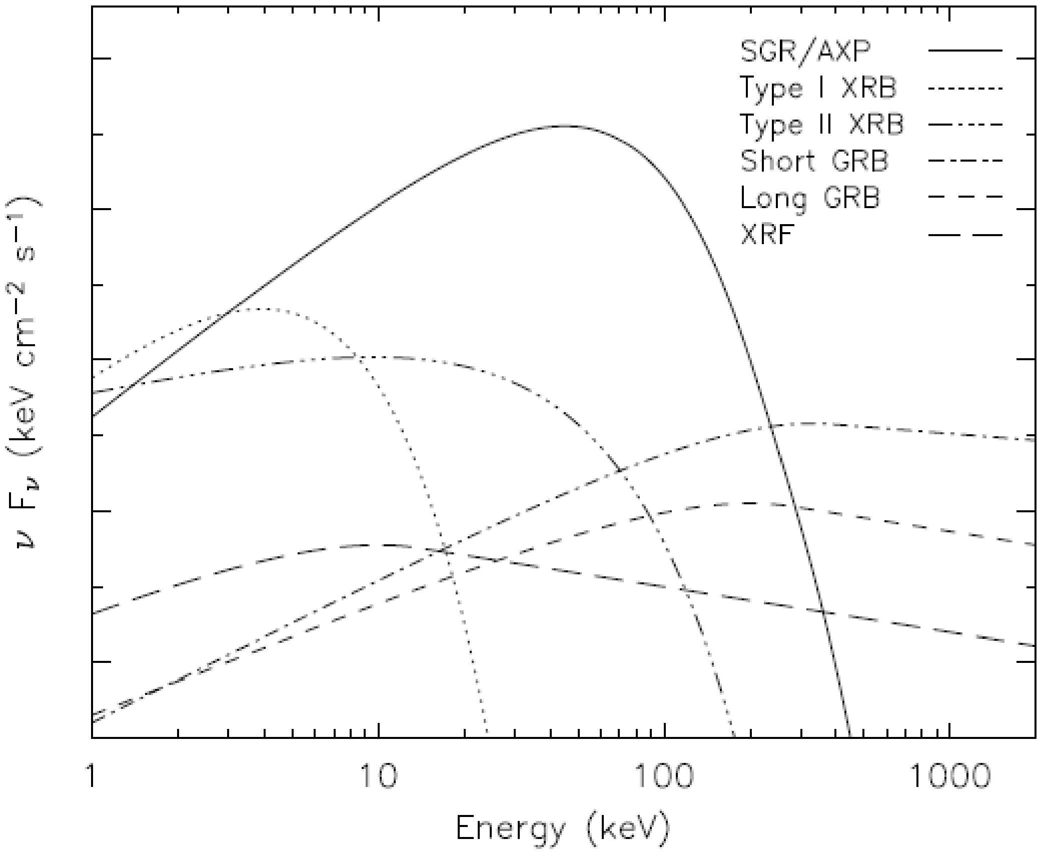
Intermediate Bursts

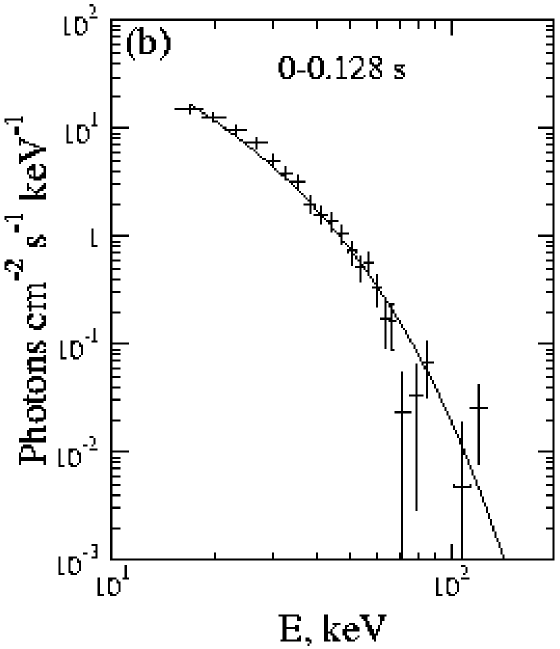


Intermediate bursts are intermediate in duration, peak luminosity and energy between the common recurrent SGR bursts and the giant flares.

The intermediate bursts are most commonly observed in the days and months following the giant flares.

Burst spectral properties





Burst spectra modeled by thermal Bremsstrahlung.

AXPs show persistent X-ray emission which is variable.

- *some of the observed variability is clearly driven by burst activity.*

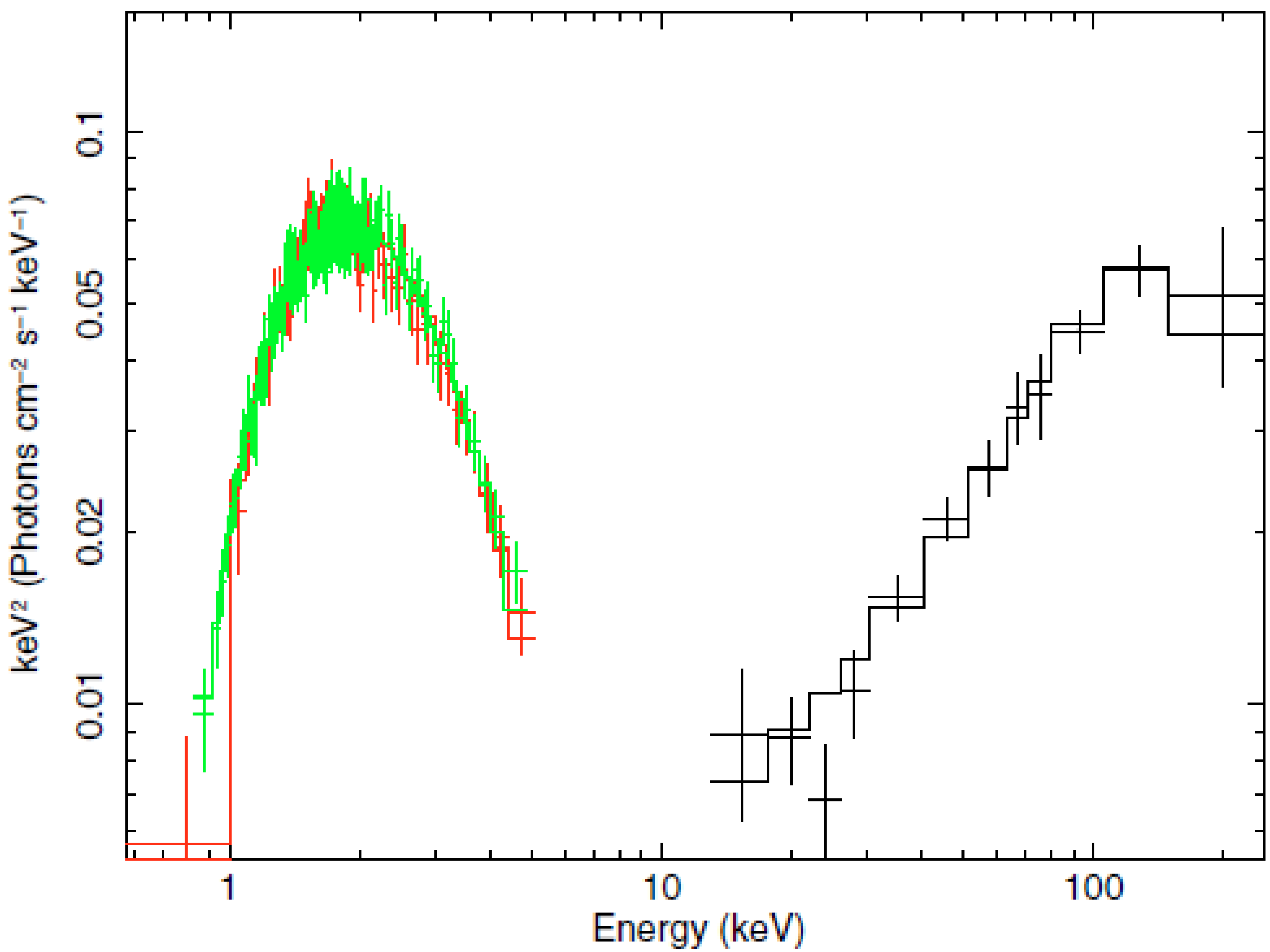
- *other sources show large changes in luminosity (~10-100) with no or little burst activity.*

X-ray spectra

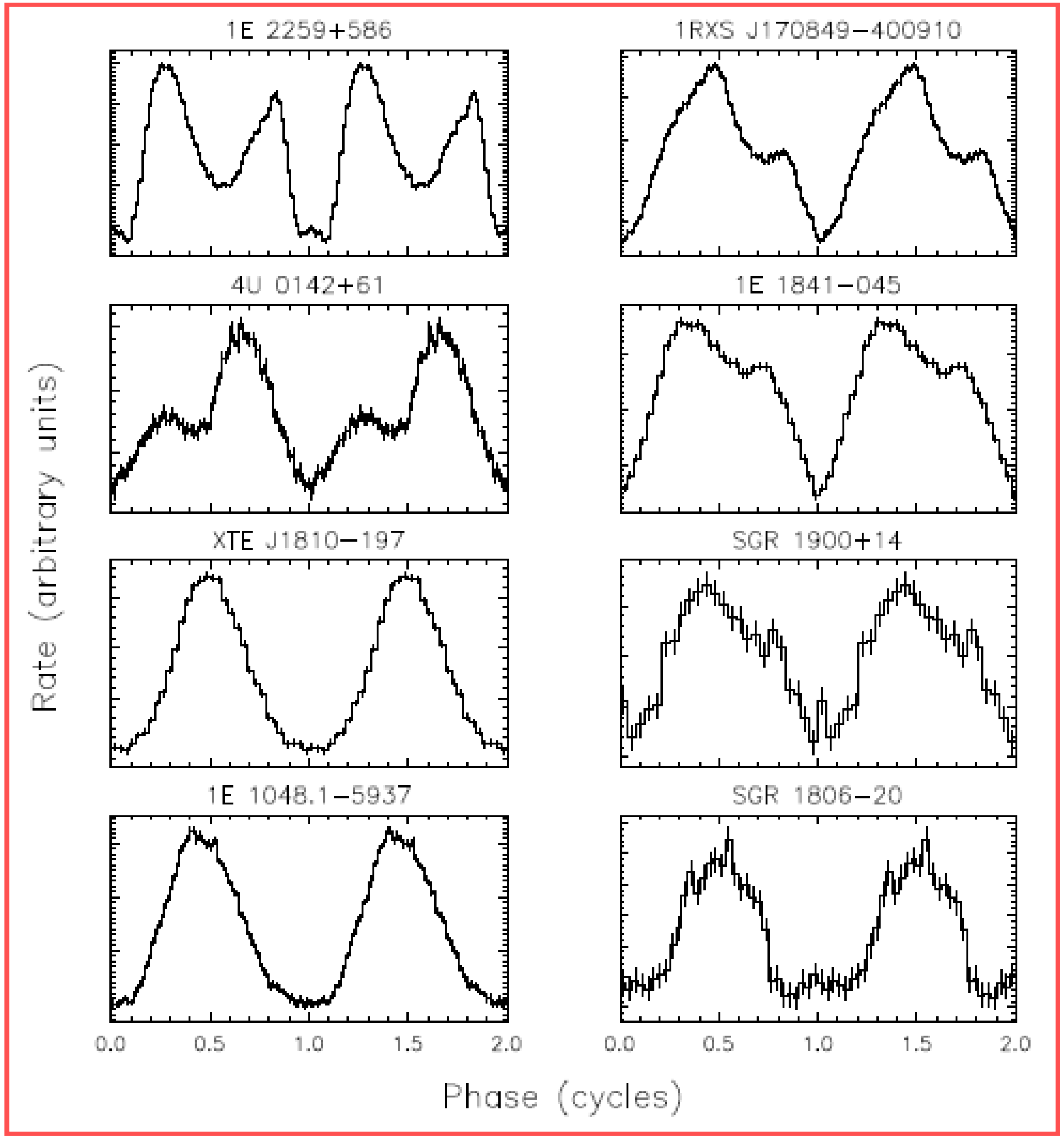
The X-ray spectra of SGRs and AXPs (0.5−10 keV) are usually well fit by a two-component model, a blackbody plus a power law, modified by interstellar absorption.

Source[a]	N_H 10^{22} (cm^{-2})	Blackbody Temperature (keV)	Photon Index	Unabsorbed[b] Flux 10^{-11} (ergs cm^{-2} s^{-1})	Luminosity[c] 10^{35} (ergs s^{-1})
SGR 0526−66	0.55	0.53	3.1	0.087	2.6
SGR 1627−41	9.0	–	2.9	0.027−0.67	0.04−1.0
SGR 1806−20	6.3	–	2.0	1.2−2.0	3.2−5.4
SGR 1900+14	2.6	0.43	1.0−2.5	0.75−1.3	2.0−3.5
CXOU 010043.1−721134	0.14	0.41	–	0.010	0.39
4U 0142+61	0.91	0.46	3.4	8.3	0.72
1E 1048.1−5937	1.0	0.63	2.9	0.41−2.3	0.053−0.25
1RXS J170849−400910	1.4	0.44	2.4	6.4	1.9
XTE J1810−197[d]	1.1	0.67	3.7	0.01−2.2	0.01−2.6
1E 1841−045	2.5	0.44	2.0	1.9	1.1
AX J1845−0258	9	–	4.6	0.04−1.0	0.05−1.2
1E 2259+586	1.1	0.41	3.6−4.2	1.6−5.5	0.17−0.59

X-ray spectrum of 4U+ 0142+62



Pulse profiles



The X-ray pulse profiles range from simple sinusoids to more complex profiles showing (typically) two maxima per cycle, but the SGRs sometimes have more complicated pulse profiles.

Burst Induced Variability

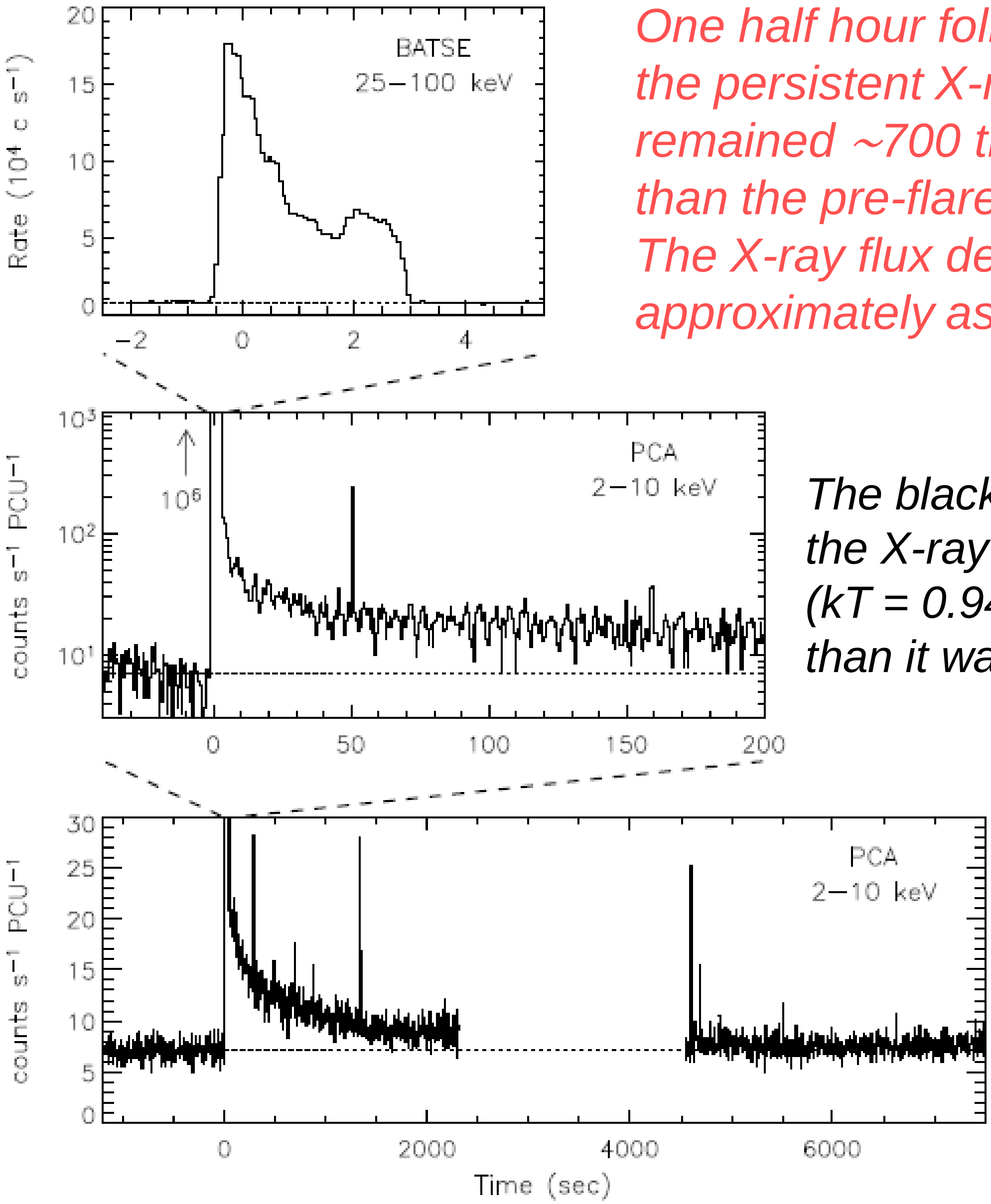
It has become evident that burst activity in the SGRs can have a persistent effect on the underlying X-ray source.

- *During the 1998 burst activation of SGR 1900+14, the X-ray counterpart became brighter, its energy spectrum was altered, and the pulse shape changed dramatically.*

- *The X-ray counterpart of SGR 1627−41 has become progressively dimmer since the outburst in 1998.*

- *The AXP 1E 2259+586 showed a broad array of spectral and temporal changes coincident with its outburst in 2002.*

The time history of SGR 1900+14 burst and its afterglow

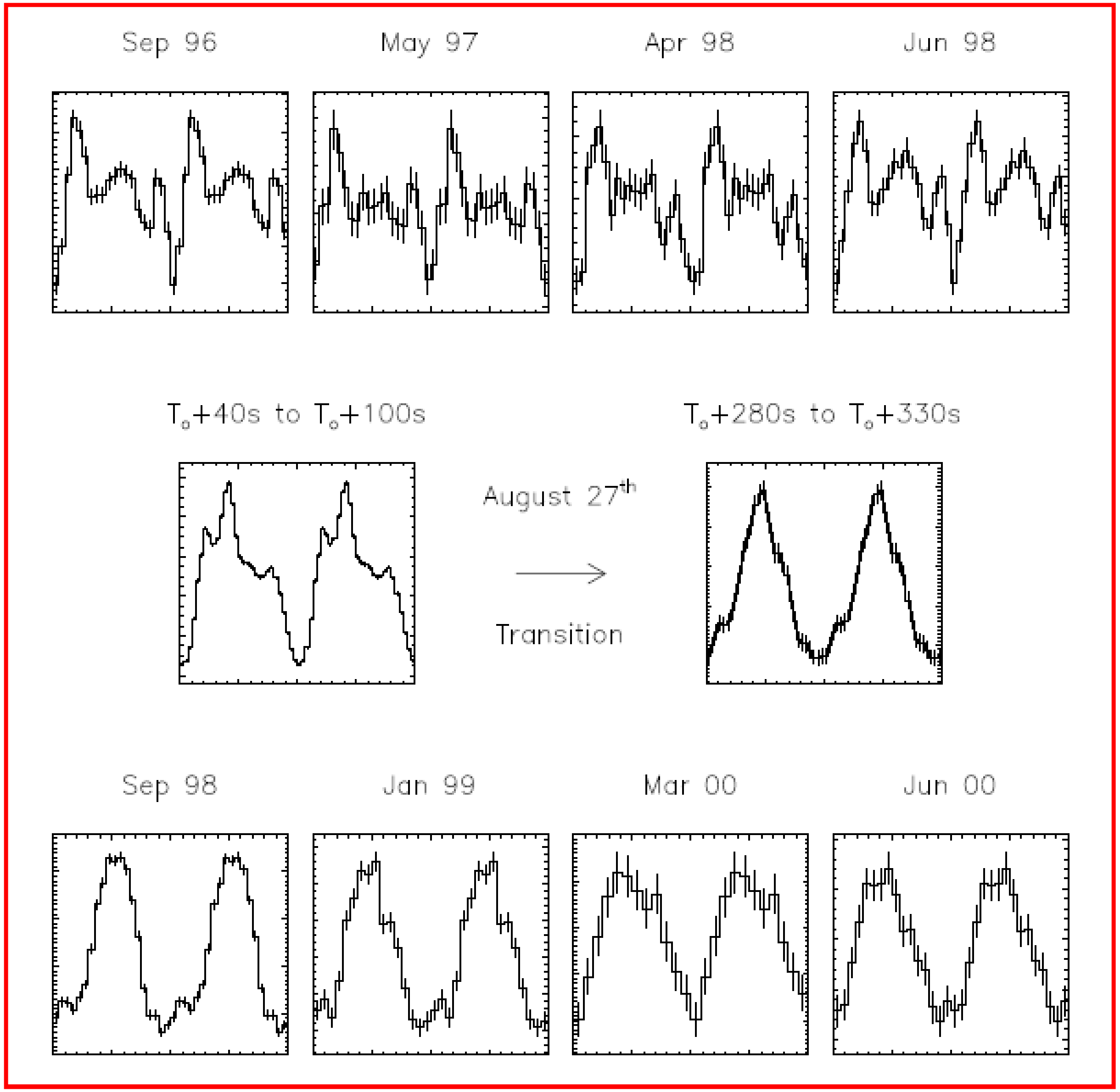


One half hour following the flare,
the persistent X-ray flux from SGR 1900+14
remained ~700 times brighter
than the pre-flare level.
The X-ray flux decayed over the next 40 days
approximately as a power law in time.

The blackbody component of
the X-ray spectrum was hotter
($kT = 0.94$keV) one day in the afterglow phase
than it was before the burst ($kT = 0.5$keV).

There is a sharp discontinuity
in the energy spectrum when the
high-luminosity burst emission
terminates indicating
the transition from the burst
to the afterglow.

Changes in X-ray Pulse Shape and Pulsed Fraction



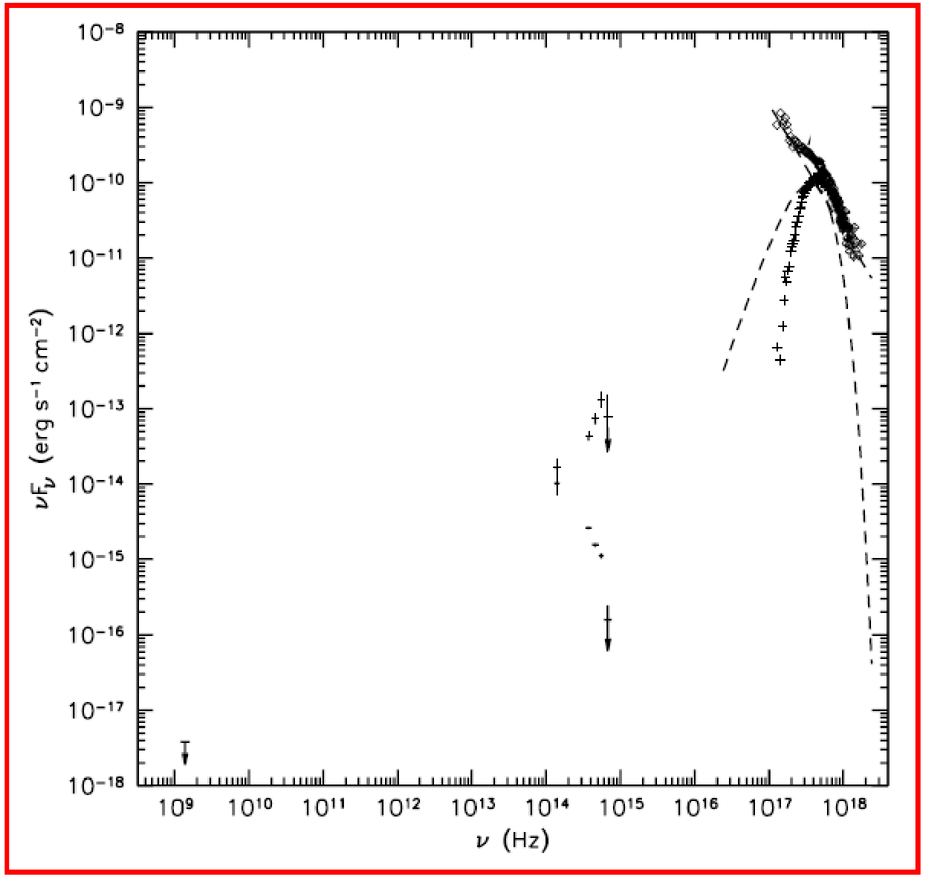
Evolution of the pulse profile of SGR 1900+14.

Counterparts at other wavelengths

During the giant flare of SGR 1900+14 was detected the radio emission at 111MHz pulsating with the same period as its X-ray emission.

Four AXPs (1E 2259+586, 1RXS J1308.6+212708, 4U0142+61 and XTE J1810+187) emit in the radio domain.

Some of AXPs and SGRs have the optical and/or infrared counterparts.



The spectral distribution for 4U 0142+61

Soft Gamma-ray Repeaters

Source	Period (s)	Period Derivative $(10^{-11}\ \mathrm{s\ s^{-1}})$	Magnetic Field $(10^{14}\ \mathrm{Gauss})$	dE/dt $(10^{33}\ \mathrm{erg\ s^{-1}})$	L_x $(10^{35}\ \mathrm{erg\ s^{-1}})$
SGR 1900+14	5.1	~7.8	6.4	100	~0.031
SGR 1627-41	2.6	<0.6	<12	1.2	~0.39
SGR 1806-20	7.6	54.9(9)	21	3.9	0.054
SGR 0526-66	8.0	6.5(5)	7.3	…	<0.24
SGR 1801-23	…	…	…	0.056	0.18
SGR 0501+4516	5.8	0.5(1)	1.7	1.4	~0.78

Anomalous X-ray Pulsars

Source	Period (s)	Period Derivative (10^{-11} s s^{-1})	Magnetic Field (10^{14} Gauss)
1E 1547.0-5408	2.0	2.3	2.2
XTE J1810-197	5.5	0.8	1.7
1E 1048.1-5937	6.5	~2.7	4.2
AX J1845-0258	6.97	…	…
1E 2259+586	6.98	0.05	0.59
CXOU J010043.1-721134	8.0	1.8(8)	3.9
4U 0142+61	8.7	0.2	1.3
CXO J164710.2-455216	10.6	0.25	1.6
1RXS J170849.0-400910	11.0	1.9	4.7
1E 1841-045	11.8	4.1	7.1

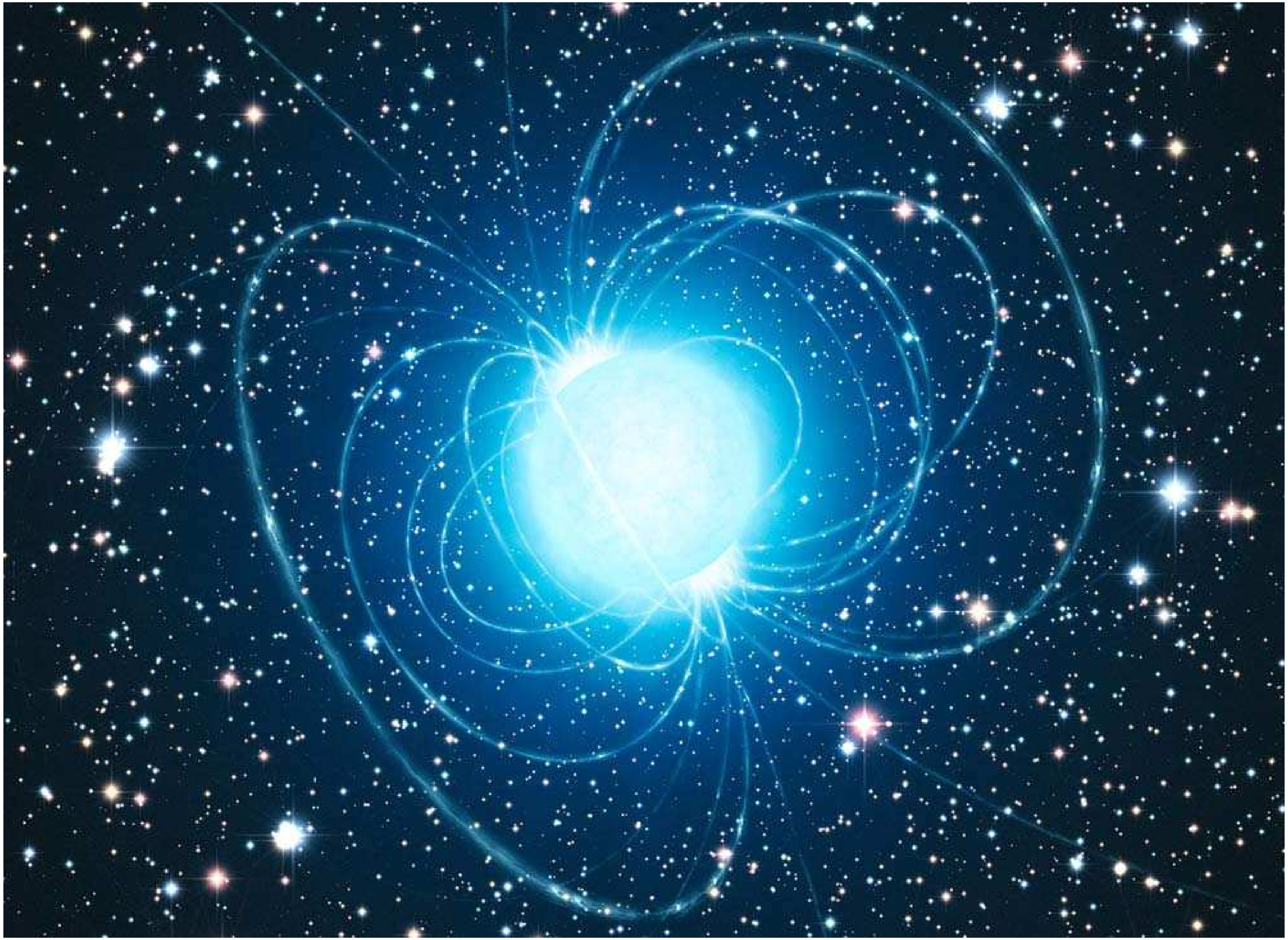
Anomalous X-ray Pulsars

Source	dE/dt (10^{33} erg s^{-1})	L_x (10^{35} erg s^{-1})
1E 1547.0-5408	100	~0.031
XTE J1810-197	1.2	~0.39
1E 1048.1-5937	3.9	0.054
AX J1845-0258	…	<0.24
1E 2259+586	0.056	0.18
CXOU J010043.1-721134	1.4	~0.78
4U 0142+61	0.12	>0.53
CXO J164710.2-455216	0.078	~0.26
1RXS J170849.0-400910	0.57	~1.9
1E 1841-045	0.99	~2.2

AXP and SGR

- first discovered about 30 years ago
- *$P \sim 2\text{-}12$ s*
- *$B_S \sim 10^{14}\text{-}10^{15}$ G*
- *$L_X >> dE/dt$*
- *'anomalous'*

Magnetar Model



Magnetar Model

$$B_{\mathrm{dipole}} = 3.2 \cdot 10^{19} \sqrt{P\dot{P}} \ \mathrm{Gauss} \quad \Rightarrow \quad B_{\mathrm{surface}} \sim 10^{14} - 10^{15} \ \mathrm{Gauss}$$

The pulsars with such strong surface magnetic fields are called the 'magnetars'.

- *The pulsar emission is powered by its rotational energy.*

- *The observed X-ray luminosity of SGR and AXPs Lx are much bigger than the pulsar's rotational energy dE/dt .*

- *Alternatively the observed emission might be powered by the decay of the star's magnetic field.*

Magnetar Model

The magnetic energy supply of the neutron star ➡

$$\boxed{\varepsilon = \frac{B^2}{8\pi}\frac{4\pi R_*^3}{3} + \int_{R_*}^{r_{LC}} \frac{B^2}{8\pi} 4\pi r^2 dr}$$

$R_* = 10^6$ cm - is the radius of the neutron star

$r_{LC} = cP/2\pi$ is the light cylinder radius (the hypothetical surface where the rotation speed equals the speed of light)

$B_s = 10^{15}$ G surface magnetic field is needed to supply an output luminosity $\sim 10^{35}$ erg/s extending over 10^5 years

Magnetar Model

$$\boxed{B_{cr} = 2\pi m^2 c^3 / eh = 4.41 \cdot 10^{13}\,\mathrm{Gauss}} \Rightarrow$$ *The critical value of the magnetic field*

If we equal the energy of a quantum emitted through the transition between Landau levels to its rest energy for nonrelativistic electron we will get the Schwinger limit for the magnetic field value.

If B>>Bcr on any quantum energy level the motion of electron is relativistic

$$E = mc^2 (1 + 2nB / B_{cr})^{1/2}$$

$$n = 0,1,2,\ldots$$

Magnetar Model

The Larmor radius of the relativistic electron

$$R_L = c\gamma / \omega_B = cp_\perp / eB, \text{ where } \omega_B = eB / mc$$

$$\gamma = (1 + p_\perp{}^2 / m^2c^2)^{1/2}$$

If we write the Heizenberg uncertainty principle

$$\Delta x \cdot \Delta p \geq \hbar$$

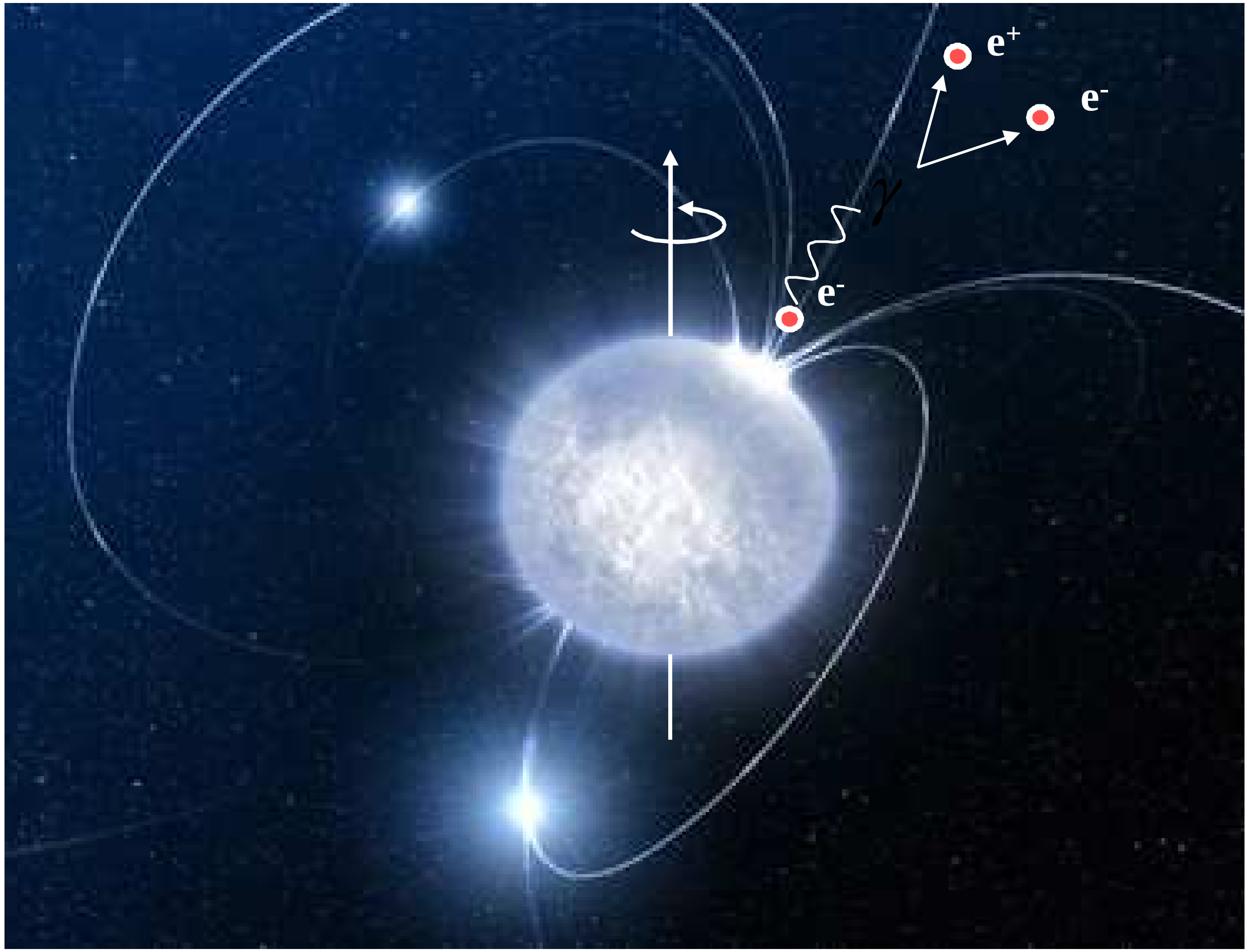
assuming that $\Delta x \approx R_L$ and $\Delta p \approx p_\perp$

$$R_L \sim (\hbar / mc)(B / B_{cr})^{-1/2} << \lambda_{compton}$$

$\lambda_{compton}$ is the characteristic quantum size of an electron

According to the results the electron should be rotating with the radius that is less than its quantum size.

Magnetar Model



$$\varepsilon > mc^2$$

$$B_\perp \varepsilon > 10^{18} GeV$$

$$\boxed{\gamma + B \rightarrow e^+ + e^- + B}$$

If $B >> B_{cr}$ $\gamma + B \rightarrow \gamma_1 + \gamma_2 + B$

Magnetar Model

Magnetars must be radio quiet!

Later the pulsed radio emission at 111MHz was detected from SGR 1900+14 which pulsated with the same period as its X-ray emission.

The AXPs 1E2259+586, 1RXS J1308.6+212708, 4U0142+61 and XTE J1810-187 emit the pulsed radiation in the radio domain.

The question appears is the pulsar radio emission theory incorrect? Or the super-strong magnetic fields does not exist in SGRs and AXPs.

The alternative explanation might be that farther in the pulsar magnetosphere where the value of the magnetic field will reach $B<B_{cr}$ might develop the cascade processes that will produce the electron-positron plasma filling the pulsar magnetosphere.

Magnetar Model

The pulsar braking index

$$n = \frac{\Omega d^2\Omega / dt^2}{(d\Omega / dt)^2} = 2 - \frac{P d^2 P / dt^2}{(dP / dt)^2}$$

From SGR 1900+14 observations

$P = 5.16 s \quad dP/dt = 1.23 \cdot 10^{-10} \quad d^2P/dt^2 = 0.53 \cdot 10^{-20}$

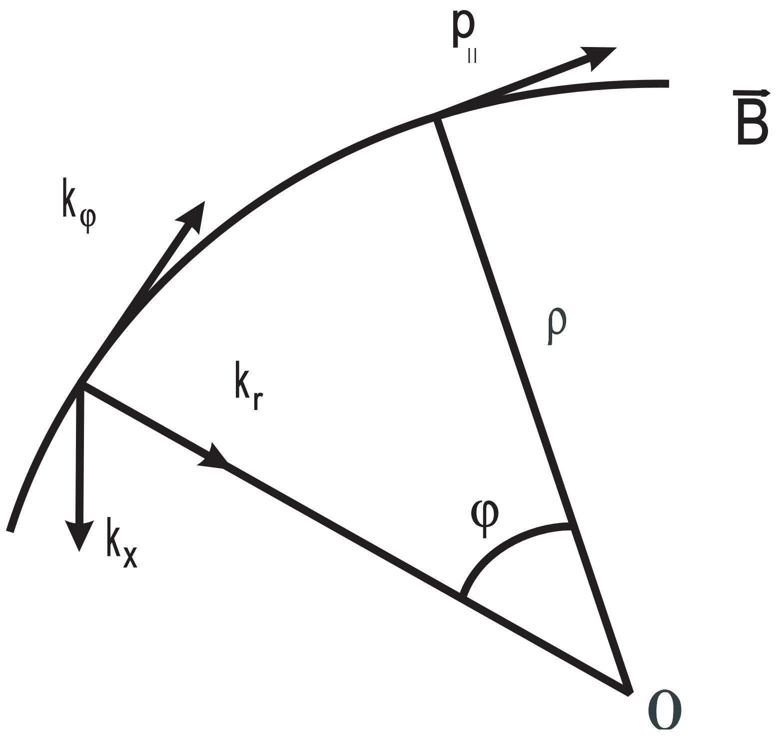
Thus $n = 0.19$, but for magnetic dipole radiation n must be equal to 3

$$B_{\text{dipole}} = 3.2 \cdot 10^{19} \sqrt{P\dot{P}} \text{ Gauss}$$

The Drift-Wave Model

The real spin period of the pulsar might differ from the observable one, as a consequence of the existence of very low frequency drift waves in the region of generation of the pulsar emission.

$$\boxed{\frac{\Delta\rho}{\rho} \approx k_\varphi r \frac{\Delta B_r}{B_\varphi}}$$



The cylindrical coordinate system

The Drift-Wave Model

$\omega_{dr} \approx k_x u_b$ - the frequency of the drift waves

$$P_{dr} = \frac{2\pi}{\omega_{dr}} = \frac{2\pi}{k_x u_x} = \frac{\lambda_{\max}}{u_x} = \frac{e}{4\pi^2 mc} \frac{BP^2}{\gamma}$$

where $\lambda_{\max} \sim r_{LC} = cP / 2\pi$

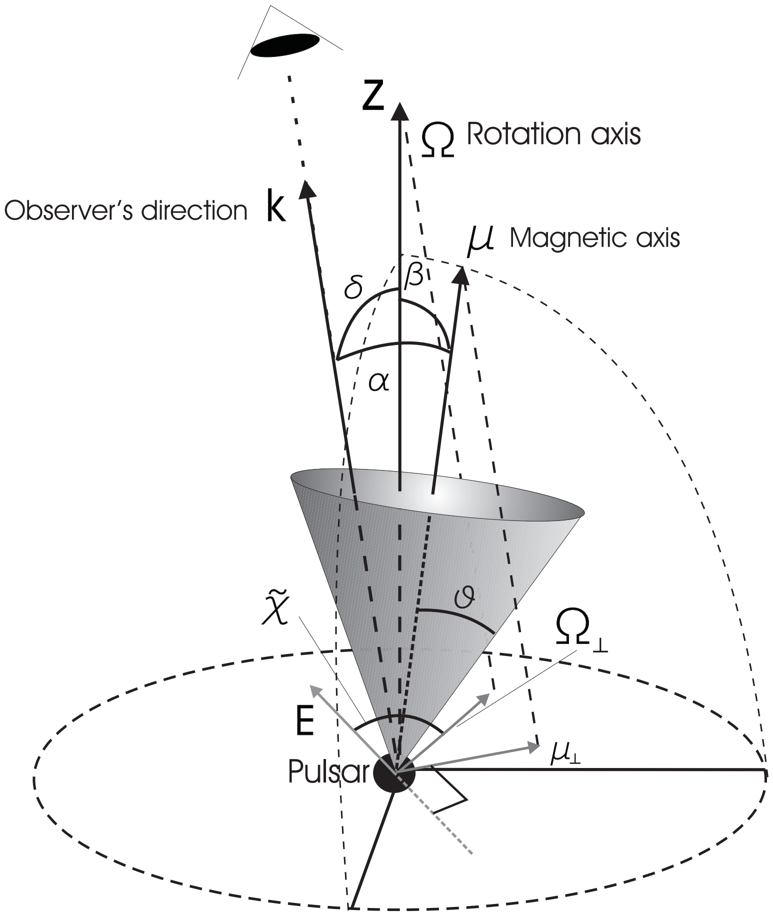
$$\dot{P}_{dr} = \frac{eB}{2\pi^2 mc\gamma} P\dot{P}$$

$$\boxed{\text{Consequently } B_{\text{dipole}} = 3.2 \cdot 10^{19} \sqrt{P_{real} \dot{P}_{real}} \text{ Gauss}}$$

$$\Downarrow$$

$$B_{surface} \sim 10^{12}\, Gauss << B_{cr}$$

The Drift-Wave Model



$$\alpha = \arccos[\sin\delta \sin\left(\beta_0 + \Delta\beta \sin\left(\omega_{dr} t + \varphi\right)\right)\cos\Omega t$$
$$+\cos\delta \cos\left(\beta_0 + \Delta\beta \sin\left(\omega_{dr} t + \varphi\right)\right)]$$

The Drift-Wave Model

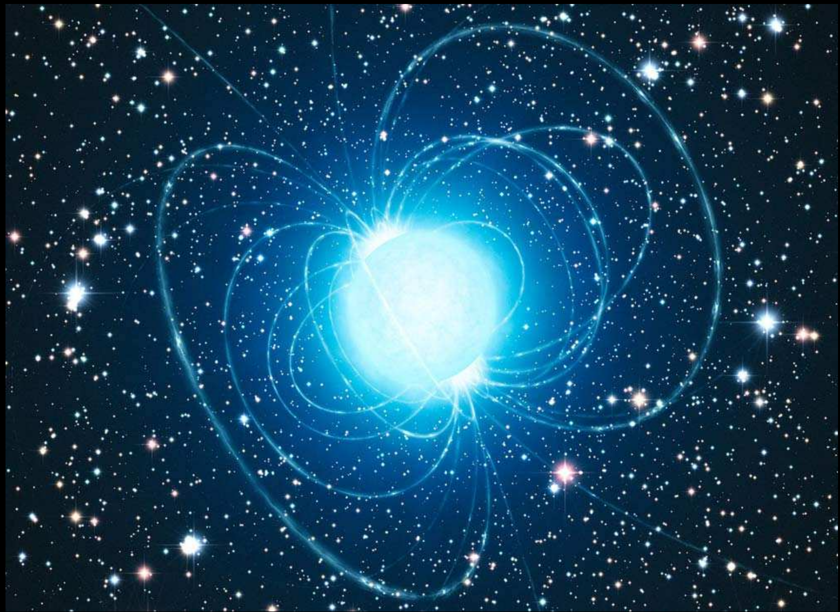
The emission frequency in the observer's frame ν
and ν_0 the frequency in the frame where $V = 0$
are related to each other as follows:

$$\nu = \nu_0 \frac{\left(1 - V^2/c^2\right)^{1/2}}{1 - V\cos\alpha/c},$$ here α is the angle between the observer and the emitting particle's velocity.

In case when $\gamma >> 1$ and $\alpha \rightarrow 0$ $\nu \sim 2\gamma\nu_0$.

$$P_\nu = P_{\nu_0} \frac{1}{1 - V\cos\alpha/c},$$ and when $\gamma >> 1, \alpha \rightarrow 0$ $P_\nu \approx 2P_{\nu 0}\gamma^2$

Conclusions



The SGRs and AXPs are normal pulsars and their long observed spin periods are the periods of the drift waves that are not directly observable but cause the periodic change of the magnetic field lines.

Thus the standard pulsar emission theory is applicable to the anomalous pulsars, and the open topic in the 'magnetar' model of the recently observed radio emission from AXPs and SGRs becomes clear.

X-ray Dim Isolated Neutron Stars

• *Seven X-ray dim isolated neutron stars are known,
despite extensive searches after 2001 their number remained constant,
thus often are called 'The Magnificent Seven' (M7).*

• *They are nearby isolated neutron stars r~100pc*

• *M7 stars exhibit very similar properties*

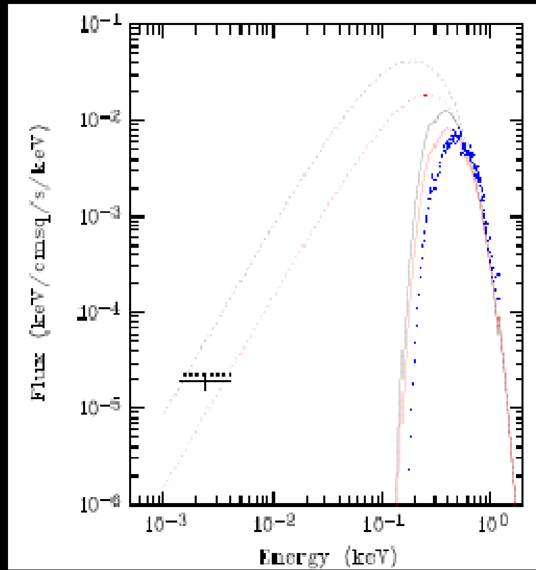
• *Their soft X-ray emission is well represented by Planckian shape,
thus they are supposed to be pure thermal sources*

• *Some of them have confirmed optical counterparts and emit optical spectrum
With the Rayleigh-Jeans slope*

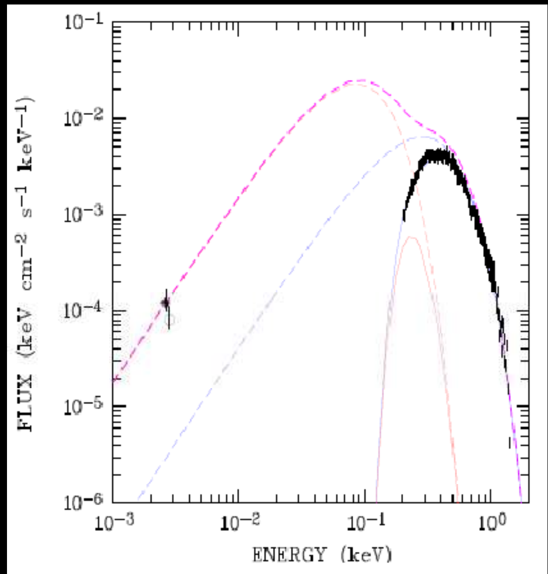
• *Six of M7 have show spectral features, which are believed to be
the proton cyclotron lines*

X-ray Dim Isolated Neutron Stars

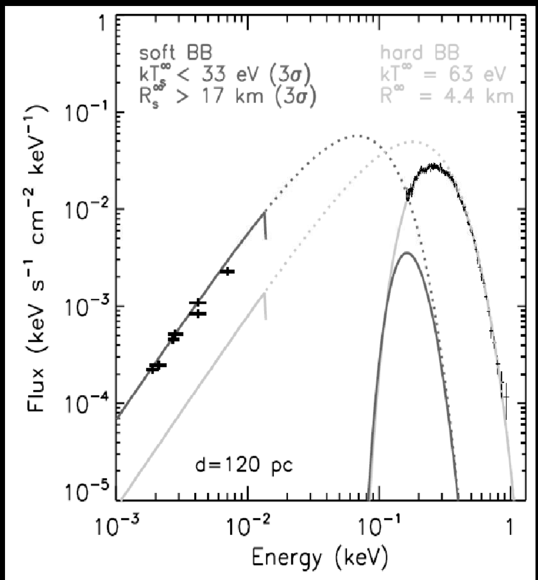
RX J1308.6+2127

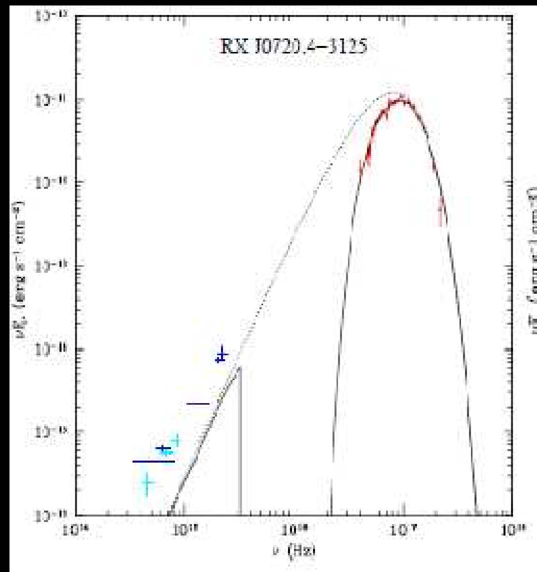


RX J0720.4+3125



RX J1856.5-3754





RX J2143.0+0654

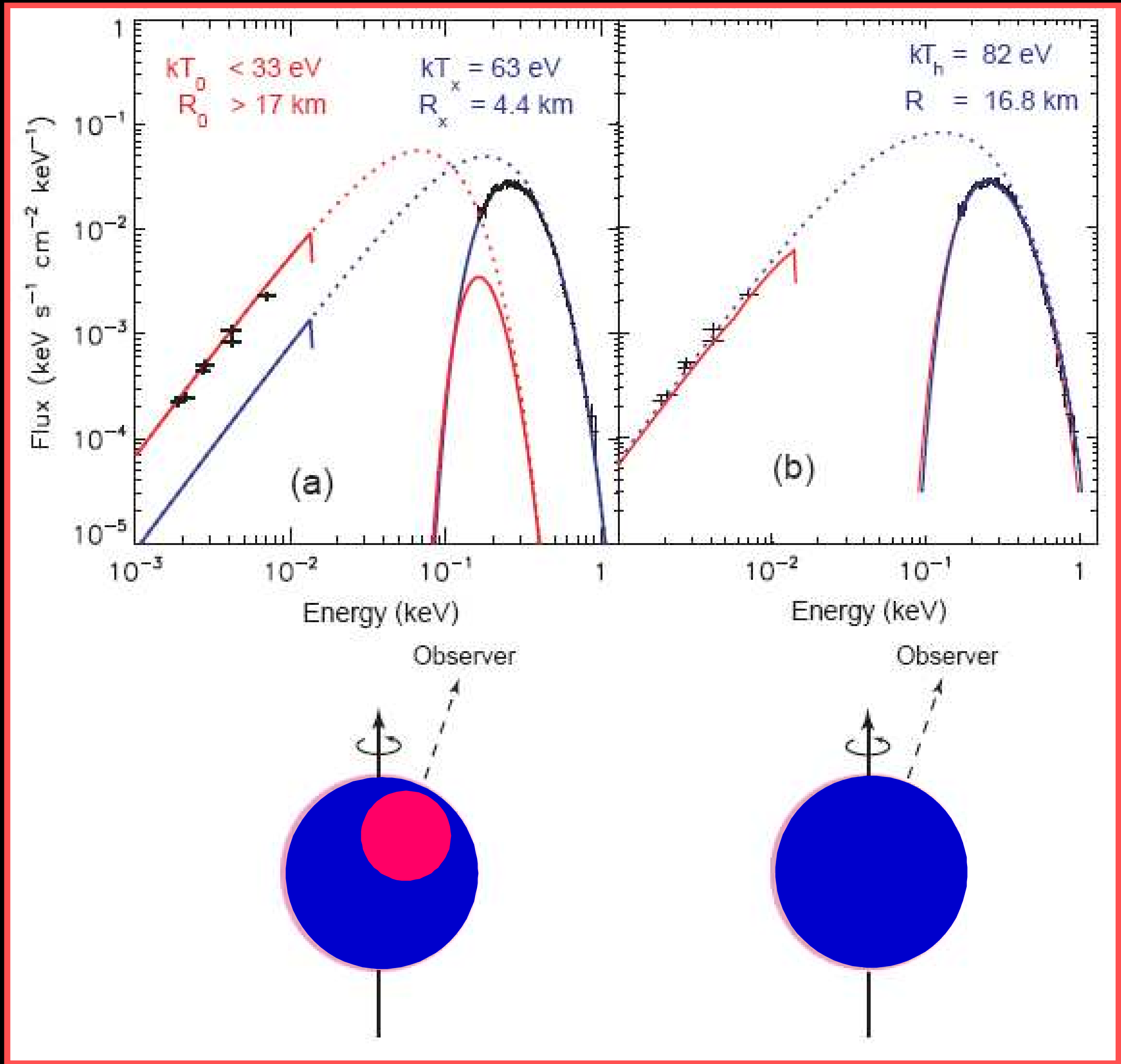
X-ray Dim Isolated Neutron Stars

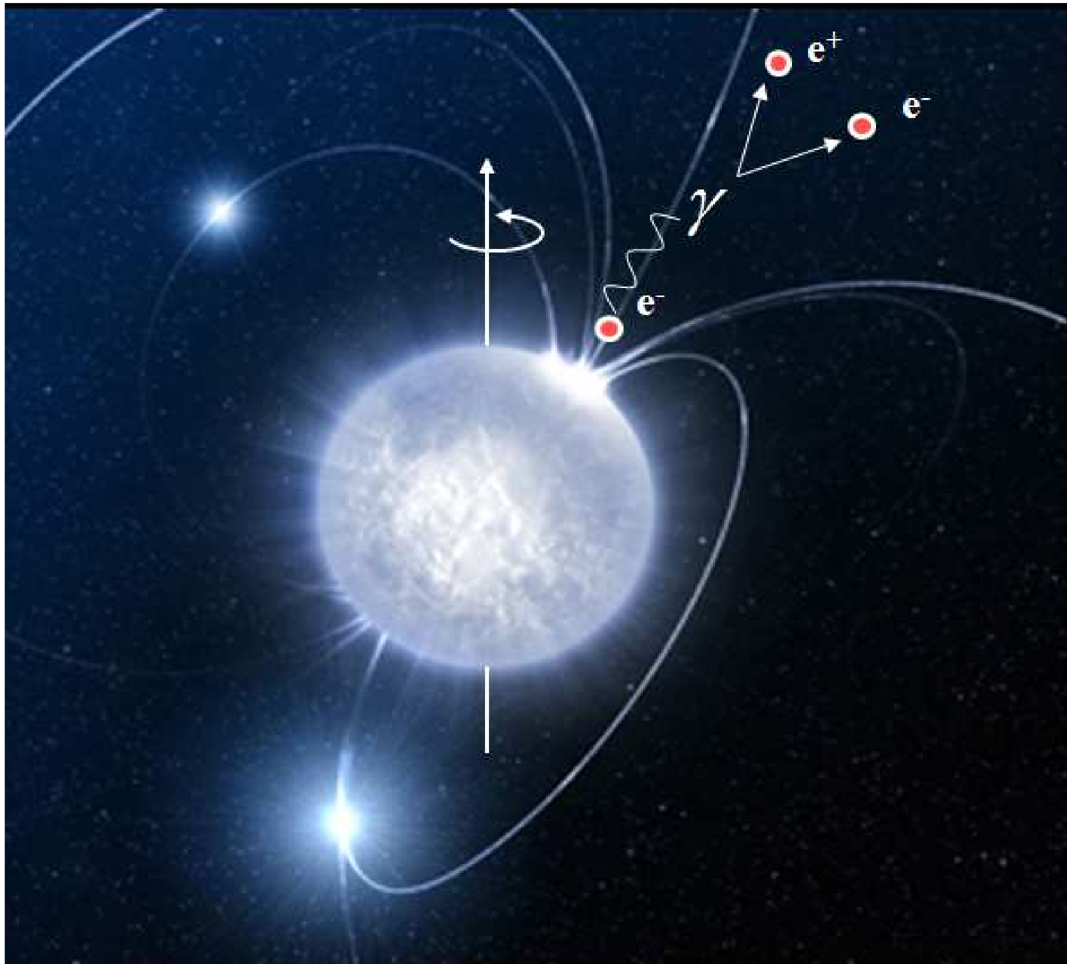
Object	Period s	dP/dt $10^{-13}ss^{-1}$	Pulse Fraction	B_{dip} $10^{13}G$
RX J1856.5-3754	7.06	0.3	1	1.5
RX J0720.4-3125	8.39	0.69	11	2.4
RX J0806.4-4123	11.37	<18	6	<14
RBS 1223	10.31	1.12	4	3.4
RX J1605.3+3249	6.88?		<3	
RX J0420.0-5022	3.45	<92	17	<18
RBS1774	9.44	< 60	18	2

$$B_{dip} = 3.2 \cdot 10^{19} \left(P\dot{P}\right)^{1/2} G$$

X-ray Dim Isolated Neutron Stars

RX J1856.5-3754





$$\varepsilon > 2mc^2$$

$$B_\perp \varepsilon > 10^{18}\,\mathrm{G\,eV}$$

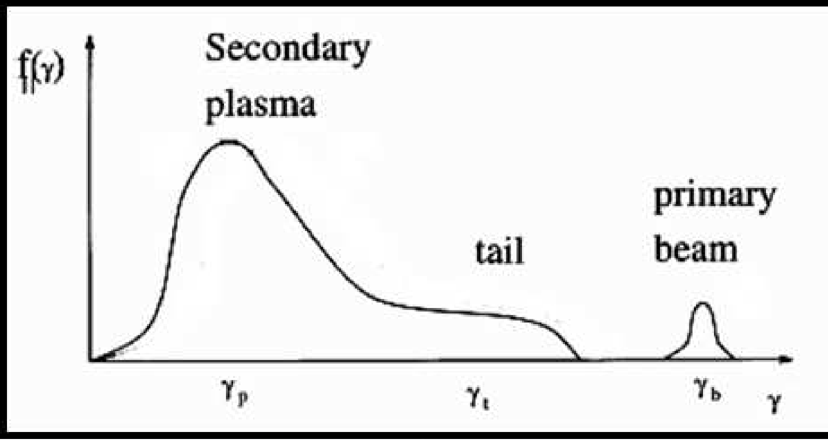
$$\gamma + B \rightarrow e^+ + e^- + B + \gamma'$$

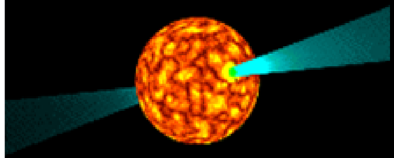
The parallel distribution of the electron-positron plasma near the star surface

$$\gamma_p \sim 1 \div 10$$

$$\gamma_t \sim 10^4 \div 10^5$$

$$\gamma_b \sim 10^6 \div 10^7$$





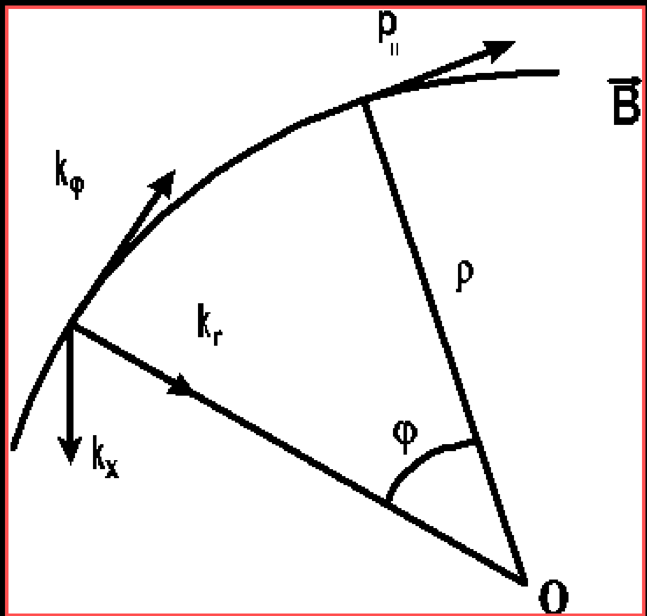
The plasma emission model of the pulsar

Generation of waves is possible

far from the star surface

if the condition of the cyclotron resonance is fulfilled

$$\omega - k_\varphi V_\varphi - k_x u_x + \frac{\omega_B}{\gamma_{res}} = 0$$

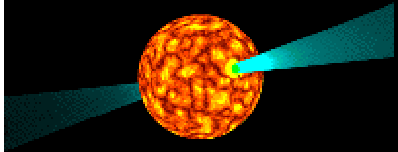


$$V_\varphi = c\left(1 - \frac{u_x^{\,2}}{c^2} - \frac{1}{2\gamma_{res}^{\,2}}\right)$$

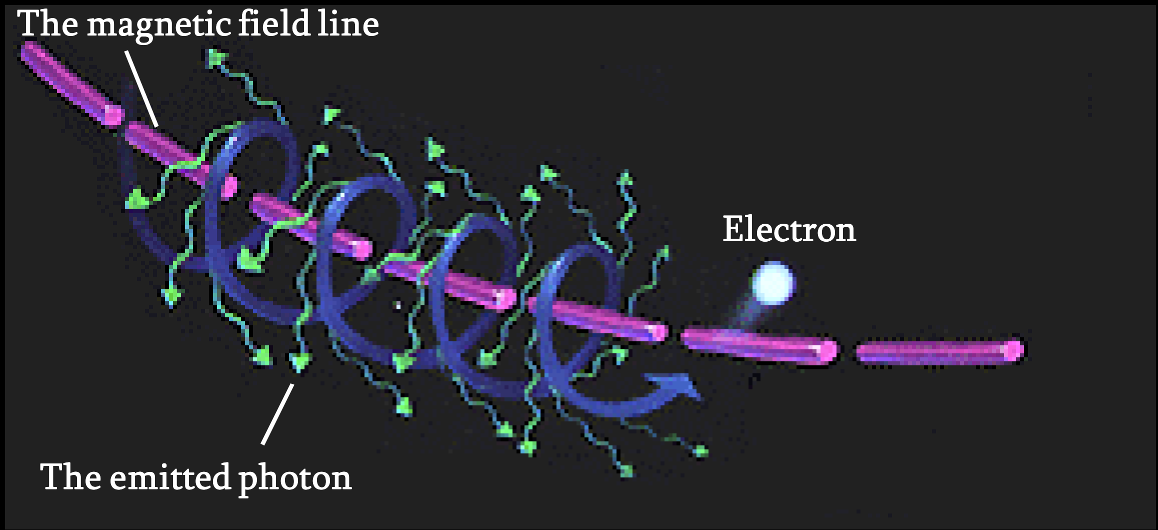
$$k_\varphi^{\,2} + k_\perp^{\,2} = k^2$$

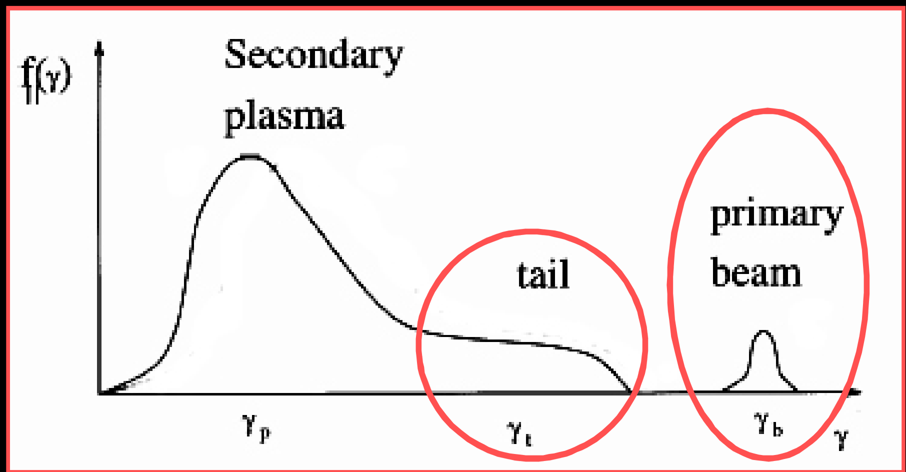
$$k_\perp^{\,2} = k_x^{\,2} + k_r^{\,2}$$

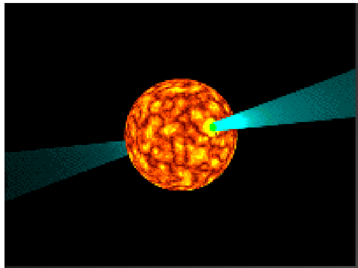
$$u_x = \frac{c V_\varphi \gamma_{res}}{\rho \omega_B}$$



The plasma emission model







The plasma emission model

$$\frac{\partial f}{\partial t}+\frac{1}{p_\perp}\frac{\partial}{\partial p_\perp}\{p_\perp(G_\perp+F_\perp)f\}=\frac{1}{p_\perp}\frac{\partial}{\partial p_\perp}\left\{p_\perp D_{\perp,\perp}\frac{\partial f}{\partial p_\perp}f\right\}$$

$$G_\perp=-\frac{mc^2}{\rho}\gamma\psi \qquad D_{\perp,\perp}=\frac{e^2}{8c}\delta\left|E_k\right|^2{}_{k=k_{res}}$$

$$F_\perp=-\frac{2e^2\omega_B{}^2}{3c^2}\psi\left(1+\gamma^2\psi^2\right) \qquad \delta=\frac{\omega_p{}^2}{4\omega_B{}^2\gamma_p{}^3}$$

For the primary beam electrons $|G_\perp| << |F_\perp|$

for the tail particles $|G_\perp| >> |F_\perp|$

$$f(p_\perp)=C\exp\left(\int\frac{F_\perp}{D_{\perp,\perp}}\right)=Ce^{-\left(\frac{p_\perp}{p_{\perp 0}}\right)^4}$$

$$p_{\perp_0}\approx\frac{\pi^{1/2}}{B\gamma_p{}^2}\left(\frac{3m^9c^{11}\gamma_b{}^5}{32e^6P^3}\right)^{1/4}$$

Chkheidze, N., Machabeli, G., Osmanov, Z., 2011, ApJ, 730, 62

The synchrotron emission

$$\boxed{\frac{\partial f_{II}}{\partial t} = \frac{\partial}{\partial p_{II}}\left(\left[\frac{2e^2\omega_B{}^2}{3m^2c^4\pi^{1/2}}p_{\perp_0} + \frac{2e^2}{3\rho^2}\gamma^4 - \frac{e^2}{4mc^2\gamma}\left|E_k\right|^2\right]f_{II}\right)}$$

0

$$f_{\rm II} \propto \frac{1}{\left|E_k\right| p_{II}{}^{1/2}}$$

$$\boxed{\frac{\partial\left|E_k{}^2\right|}{\partial t} = 2\Gamma_c\left|E_k{}^2\right| f_{II}}$$

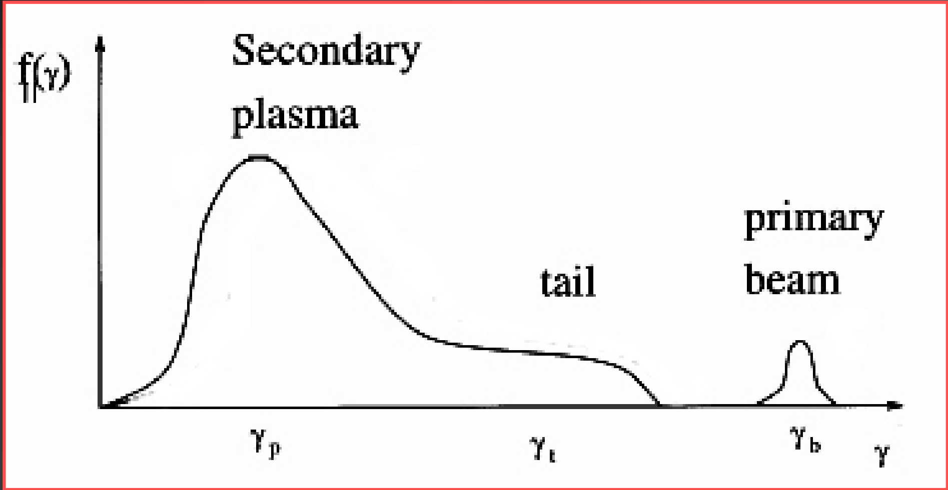
$$\boxed{\frac{\partial f_{II}}{\partial t} = \frac{\partial}{\partial p_{II}}\left(\left[\frac{2e^2\omega_B{}^2}{3m^2c^4\pi^{1/2}}p_{\perp_0}\right]f_{II}\right)}$$

$$\Gamma_c = \frac{\pi^2e^2}{k_{II}} f_{II}\left(p_{res}\right)$$

$$\alpha\frac{\partial}{\partial p_{II}}\left(\frac{\left|E_k\right|}{p_{II}{}^{1/2}}\right) + f_{II_0} = 0$$

$$\alpha = \mathrm{const}$$

The synchrotron emission



$$f_{\mathrm{II}_0} \propto p_{II}^{\;-n}$$

The spectral distribution of the synchrotron emission

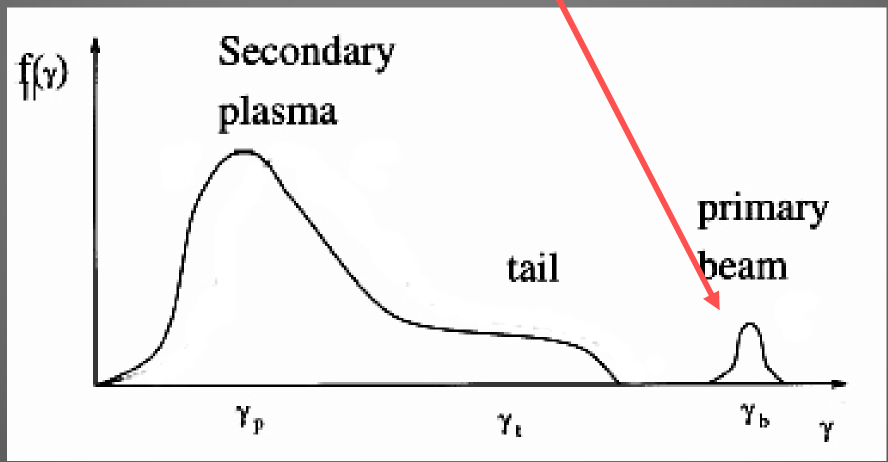
$$F_\varepsilon \propto \varepsilon^{-\frac{2-n}{4-n}} \times \int_{x_{\min}}^{x_{\max}} x^{\frac{2-n}{4-n}} \left[\int_x^\infty K_{5/3}(z)dz \right] dx$$

$$x = \varepsilon / \varepsilon_m$$

Chkheidze, N., Machabeli, G., Osmanov, Z., 2011, ApJ, 730, 62

X-ray Dim Isolated Neutron Stars

The resonance particles are the primary beam electrons



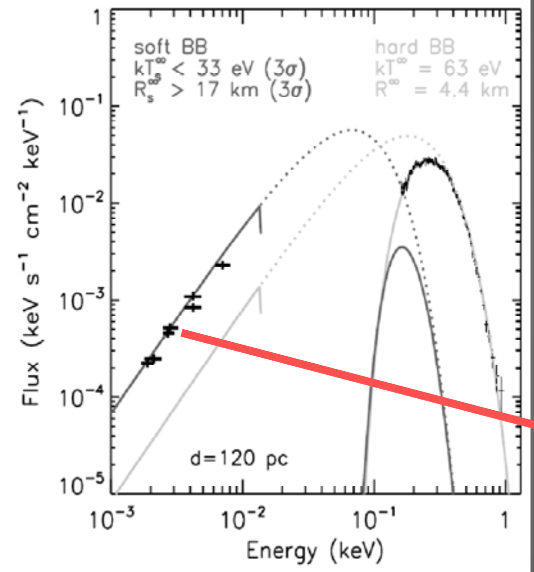
$$\gamma_b \sim 10^7$$

Osmanov, Z., Rieger, F. M., 2009, A & A, 502,15

X-ray Dim Isolated Neutron Stars

$$\boxed{\omega - k_\varphi V_\varphi - k_x u_x + \frac{\omega_B}{\gamma_{res}} = 0}$$

RX J1856.5-3754



$$\omega_t \approx kc(1-\delta)$$

$$\boxed{\nu \approx 2\pi \frac{\omega_B}{\delta\gamma_b} \sim 10^{14}\,\mathrm{Hz}}$$

$$F_\nu \propto \nu^2$$

$$|E_k|^2 \propto \nu^{3-2n}$$

$$f_{II_0} \propto p_{II}^{-5/2}$$

X-ray Dim Isolated Neutron Stars

$$\boxed{F_\varepsilon \propto \varepsilon^{-\frac{2-n}{4-n}} \int x^{\frac{2-n}{4-n}} \left[\int_x^\infty K_{5/3}(z)dz \right] dx}$$

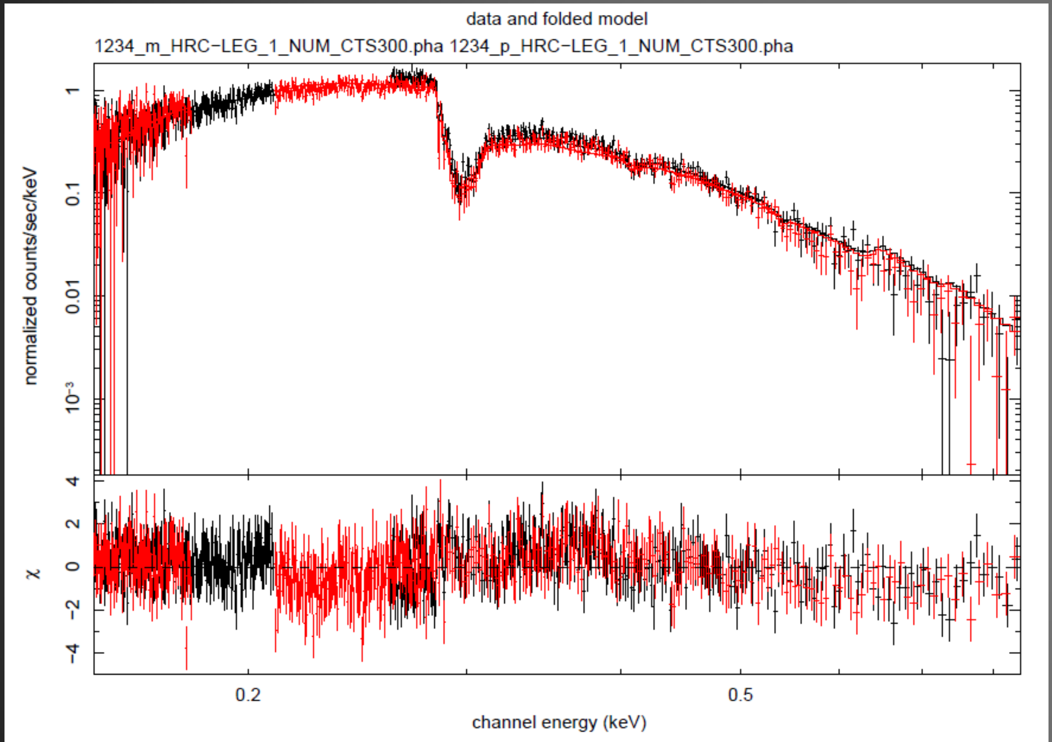
$$\downarrow$$

$$F_\varepsilon \propto \varepsilon^{0.3} \int x^{-0.3} \left[\int_x^\infty K_{5/3}(z)dz \right] dx$$

$$\boxed{F_\varepsilon \propto \varepsilon^{0.3} \exp\left(-\frac{\varepsilon}{\varepsilon_m} \right)}$$

X-ray Dim Isolated Neutron Stars

RX J1856.5-3754



For the plasma emission model

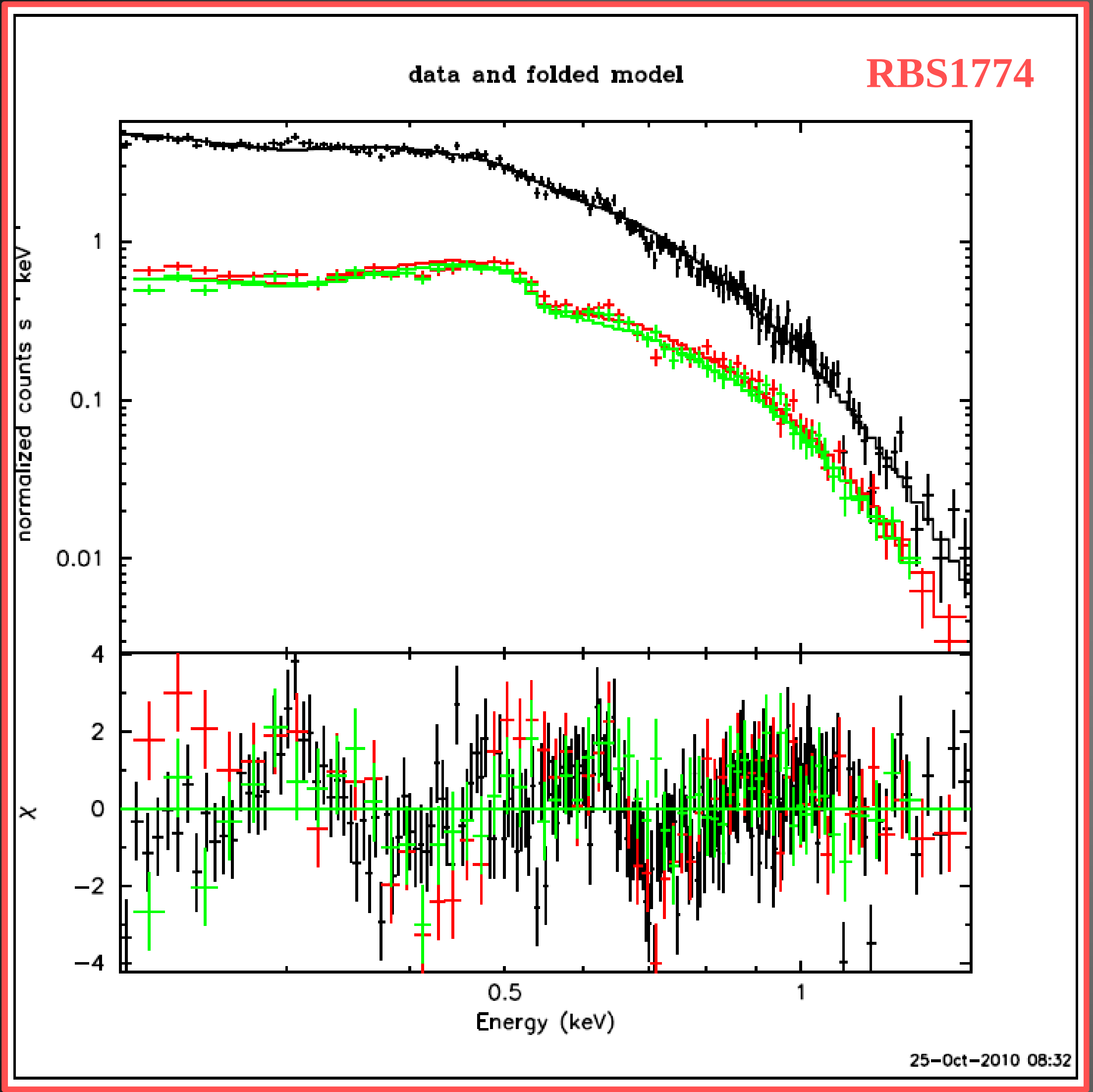
$$\chi^2 = 1.00\ (970 \text{d.o.f})$$

For the thermal emission model

$$\chi^2 = 1.20\ (970 \text{d.o.f})$$

Chkheidze, N., Machabeli., G, 2007, A&A, 471, 599
Chkheidze, N., Xiaoling, X. L., 2011, MNRAS (submitted)

X-ray Dim Isolated Neutron Stars



The plasma emission model gives

$$\chi^2 = 1.63\,(311 \mathrm{d.o.f})$$

The thermal emission model gives

$$\chi^2 = 1.81\,(311 \mathrm{d.o.f})$$

Chkheidze, N., 2011, A&A, 527, 2

X-ray Dim Isolated Neutron Stars

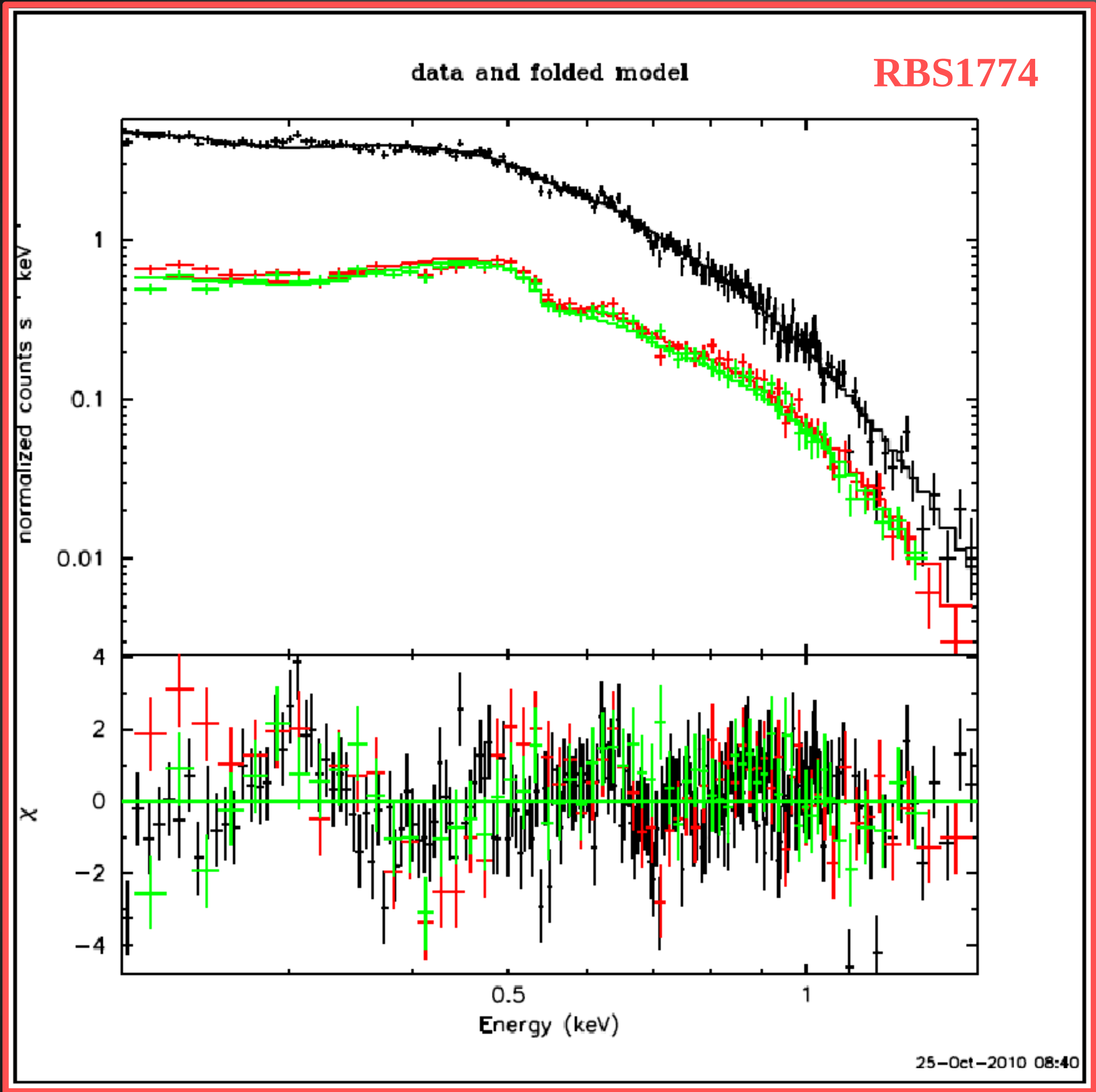
The condition for the cyclotron damping

$$\omega - k_\varphi V_\varphi - k_x u_x - \frac{\omega_B}{\gamma_{res}} = 0$$

$$\omega \approx kc$$

$$\omega_d \approx \frac{2\omega_B}{\psi^2 \gamma_b} \qquad \varepsilon_\mathrm{d} = (h/2\pi)\omega_d \approx 0.7\mathrm{keV}$$

X-ray Dim Isolated Neutron Stars



The plasma emission model

$$\chi^2 = 1.50\,(309\text{d.o.f})$$

The thermal emission model

$$\chi^2 = 1.50\,(309\text{d.o.f})$$

Chkheidze, N., 2011, A&A, 527, 2

X-ray Dim Isolated Neutron Stars

Model	n_H ($10^{20} cm^{-2}$)	ϵ_m^{-1} (eV)	kT_{bb}^{∞}	χ^2(dof)
plasma	$1.20^{+0.03}_{-0.03}$	11.54 ± 0.78		1.00(970)
bbody	$0.95^{+0.03}_{-0.03}$		63.5 ± 0.2	1.20(1145)

Model	n_H ($10^{20} cm^{-2}$)	ϵ_m^{-1} (eV)	kT_{bb}^{∞} (eV)	$E_{edge/line}$ (eV)	σ_{line} (eV)	$\tau_{edge/line}$	χ^2(dof)
plasma	$3.36^{+0.20}_{-0.20}$	7.0 ± 0.2					1.63(311)
plasma*edge	$3.30^{+0.12}_{-0.12}$	6.9 ± 0.1		679^{+13}_{-13}		$0.20^{+0.03}_{-0.03}$	1.50(309)
bbody	$1.85^{+0.17}_{-0.17}$		103.5 ± 0.8				1.81(311)
bbody*gabs	$1.84^{+0.20}_{-0.17}$		105.1 ± 0.9	731^{+8}_{-13}	27^{+16}_{-4}	$6.5^{+1.2}_{-1.0}$	1.50(308)