

PAPER • OPEN ACCESS

Spectral evolution of long gamma-ray bursts observed with Konus-Wind

To cite this article: D S Svinkin *et al* 2020 *J. Phys.: Conf. Ser.* **1697** 012003

View the [article online](#) for updates and enhancements.

You may also like

- [X-ray and gamma-ray emission from solar flares](#)

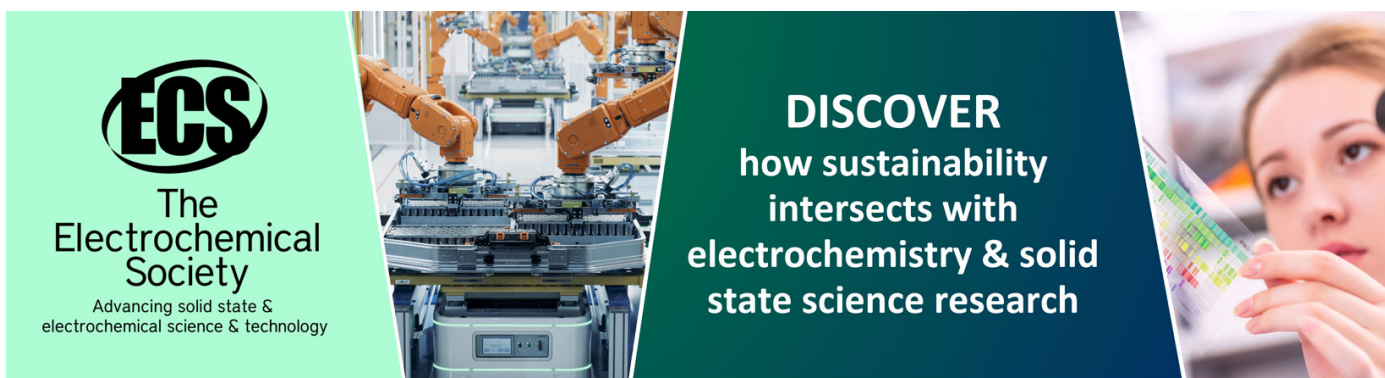
A L Lysenko, D D Frederiks, G D Fleishman et al.

- [Observations of the GRB Afterglow ATLAS17aeu and Its Possible Association with GW 170104](#)

B. Stalder, J. Tonry, S. J. Smartt et al.

- [Energy Budget of Plasma Motions, Heating, and Electron Acceleration in a Three-loop Solar Flare](#)

Gregory D. Fleishman, Lucia Kleint, Galina G. Motorina et al.



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Spectral evolution of long gamma-ray bursts observed with Konus-Wind

D S Svinkin¹, Yu R Temiraev², D D Frederiks¹, A E Tsvetkova¹,
M V Ulanov¹ and A G Demin²

¹ Ioffe Institute, Politekhnikeskaya 26, St. Petersburg 194021, Russia

² Peter the Great St. Petersburg Polytechnic University, Polytechnicheskaya 29, St. Petersburg 195251, Russia

E-mail: svinkin@mail.ioffe.ru

Abstract. We present a preliminary analysis of spectral evolution of 35 long bright gamma-ray bursts (GRBs) detected by Konus-Wind instrument. From the temporal and spectral analyses of the sample, we investigate the evolution of parameters of the smoothly joined broken power-law spectral model (the Band “GRB” function), in particular, we analyse hardness-intensity correlation within a burst. We show that the bulk of bursts exhibit $E_p \propto F^\gamma$ relation with the slope $\gamma \sim 0.3\text{--}0.5$, where E_p is the νF_ν spectrum peak energy and F is the energy flux; while a number of events have the smooth initial phase with strong spectral evolution with $\gamma \gtrsim 1$. Finally, we discuss derived the Band function parameters and their evolution pattern in the framework of GRB emission models.

1. Introduction

The observed energy spectrum of the main phase of gamma-ray bursts, the prompt emission, is significantly non-thermal, with a typical gamma-ray burst photon spectrum described with the Band function [1]. Such a spectrum implies that a large proportion of the energy released in the GRB central engine is converted into non-thermal particles which subsequently emit photons, most likely, by the synchrotron process. It is suggested that the particles are accelerated by the Fermi mechanism in internal shocks in a relativistic outflow (jet) from the central engine (the fireball model [2]). The synchrotron emission model predicts a photon index at low energies to be in between $-3/2$ (fast cooling regime) and $-2/3$ (slow cooling regime) [3]. It is also believed that a fraction of the observed radiation comes from the jet’s photosphere, when the expanding jet becomes transparent to its own radiation (see, e.g., [4]). One of possible ways to constrain parameters of radiation models is to study the time evolution of parameters of the Band model, including the hardness-intensity correlation during the burst. For the first time the hardness-intensity correlation was reported in [5]. For a large number of bursts, it was found that the hardness-intensity correlation has a form of a power law, $E_p \propto F^\gamma$ with a slope $\gamma \sim 0.5$, where E_p is the energy corresponding to the peak of the spectral energy distribution (SED), νF_ν spectrum (see, e.g., [6] for details), and F is the energy flux. It was shown that the correlation is consistent with the standard synchrotron radiation model (see, e.g., [7]). Thus, the study of the spectral evolution of bright bursts may provide a crucial information on the emission mechanism.

During more than 25 years of operation Konus-Wind (KW) [8] has detected more than 3000 GRBs in the wide $\sim 20\text{ keV--}10\text{ MeV}$ energy band which enables the detailed study of the



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

GRB spectral evolution, in particular, for bright bursts with separated smooth emission pulses.

We start with a description of the KW detectors and the GRB sample used in Section 2. In Section 3 we describe the analysis procedures and present the results in section 4. Finally, in Section 5 we conclude with a summary.

2. Konus-WIND

KW consists of two identical NaI(Tl) detectors S1 and S2, each with 2π field of view. The detectors are mounted on opposite faces of the rotationally stabilized *Wind* spacecraft (launched on 1994 November 1), both observing the whole sky. Each detector has an effective area of $\sim 80\text{--}160\text{ cm}^2$ depending on the photon energy and incident angle. The burst lightcurves are recorded in three energy bands G1 (13–50 keV), G2 (50–200 keV), and G3 (200–760 keV), while burst energy spectra are measured in the 13 keV–10 MeV band (nominal). For a more detailed description of KW see [9, 10, 11].

Between 1994 and 2020 KW has detected ~ 3250 GRBs with $\sim 17\%$ of them being short GRBs. For the analysis we selected 35 ($\sim 15\%$) brightest long GRBs in the KW sample in terms of peak count rate in the 50–760 keV band on the 64 ms timescale. We additionally required that prominent features of the burst light curve are reasonably well covered by individual spectra (e.g., at least few spectra were measured during the initial phase of the burst), since the length of the KW spectrum accumulation interval vary during the triggered mode record and it also depends on the count rate.

3. Data analysis

The temporal analysis of the sample was performed in a way similar to [11]. During the analysis we noticed that some GRBs show the distinct, low-amplitude initial phase (IP) similar to one of extremely intense GRB 130427A, see, e.g. [12]. To quantitatively characterize the IP shape, we fitted, using a χ^2 minimization, the initial parts of background-subtracted burst light curves, measured with 16 ms or 64 ms resolution, by a sum of exponential pulse functions [13]

$$A(t) = A_m \lambda \exp\{-\tau_1/(t - t_0) - (t - t_0)/\tau_2\} \quad (1)$$

for $t > t_0$; where t_0 is the pulse start time; A_m is the pulse amplitude; τ_1, τ_2 are time constants characterizing the rise and decay parts of the pulse; and $\lambda = \exp(2\mu)$, $\mu = (\tau_1/\tau_2)^{1/2}$. This pulse peaks at $t_m = t_0 + (\tau_1\tau_2)^{1/2}$ and has a width, measured between two $1/e$ points $w = \tau_2(1 + 4\mu)^{1/2}$.

The spectral analysis was performed using XSPEC version 12.9.0 [14]. The raw count rate spectra were rebinned to have a minimum of 20 counts per channel to ensure Gaussian-distributed count statistics and fitted using the χ^2 statistic as a figure of merit to be minimized. Each spectrum was fitted by two spectral models, the Band function:

$$f(E) \propto \begin{cases} E^\alpha \exp\left(-\frac{E(2+\alpha)}{E_p}\right), & E < (\alpha - \beta) \frac{E_p}{2+\alpha} \\ E^\beta \left[(\alpha - \beta) \frac{E_p}{(2+\alpha)}\right]^{(\alpha-\beta)} \exp(\beta - \alpha), & E \geq (\alpha - \beta) \frac{E_p}{2+\alpha}, \end{cases} \quad (2)$$

where α is the low-energy photon index, β is the high-energy photon index, and E_p corresponds to the peak of νF_ν spectrum; and an exponentially cutoff power-law (CPL):

$$f(E) \propto E^\alpha \exp\left(-\frac{E(2+\alpha)}{E_p}\right). \quad (3)$$

Both spectral model amplitudes were normalized to the energy flux (F) in the 20 keV–10 MeV range.

For bursts with rather smooth rise and decay phases, we fitted the time-resolved E_p - F relation with a simple power law.

4. Results

All spectra of the analysed bursts are well described by the Band or CPL models with P-value of the χ^2 statistics $\gtrsim 1\%$. The time resolved fits show strong variations of α , E_p , and β with the flux. Bright bursts typically show hard $\alpha > -2/3$ inconsistent with the simple synchrotron emission model.

The results of the analysis of a typical long GRB 960924 are presented in figure 1.

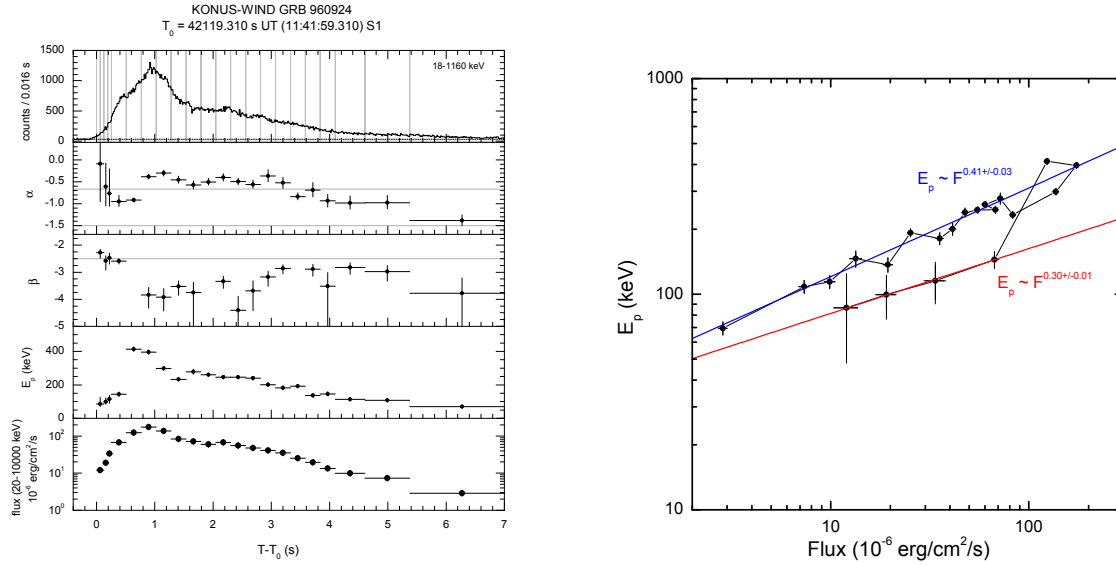


Figure 1. Lightcurve of bright smooth GRB 960924 along with the evolution of Band function and CPL (where β is not presented) parameters (left). Vertical gray solid lines denote spectrum accumulation intervals, horizontal dashed line corresponds to background count rate. The gray lines in the α panel denote synchrotron lines of death of $-3/2$ and $-2/3$. The gray line in the β panel denotes typical value of -2.5 . The time resolved E_p - F relation (right). The relations during smooth leading (red) and trailing (blue) fronts are well described by a power law with slopes of ~ 0.4 and ~ 0.3 , respectively.

We have found 13 GRBs with the initial phase well fitted by a single model pulse or a sum of two pulses. The burst properties are listed in table 1, which contains the following columns. Burst detection date, burst detection time (UT, not corrected for Wind-Earth light travel time), T_{90} — the interval containing 90% of burst counts in the energy band ~ 50 –750 keV. The next two columns contain the initial pulse spectral lags, the difference of the pulse peak times in a softer and a harder band. The penultimate column contains the slope of E_p - F relation of the burst initial phase, calculated for burst with good enough spectral coverage. The last column contains a comment on the light curve fit. The uncertainties are given at 68% confidence level. GRB 190305A with $T_{90} \sim 1.5$ s may be attributed to long GRBs due to a long tail seen up to ~ 15 s after trigger time.

In six cases IP shows a significant hard-to-soft evolution which is governed by both α and E_p . For these bursts, the slope of the E_p - F relation is significantly steeper ~ 0.8 –3. Figure 2 and figure 3 show the initial phases and the spectral evolution of GRB 950822 and GRB 131014A with pronounced spectral evolution.

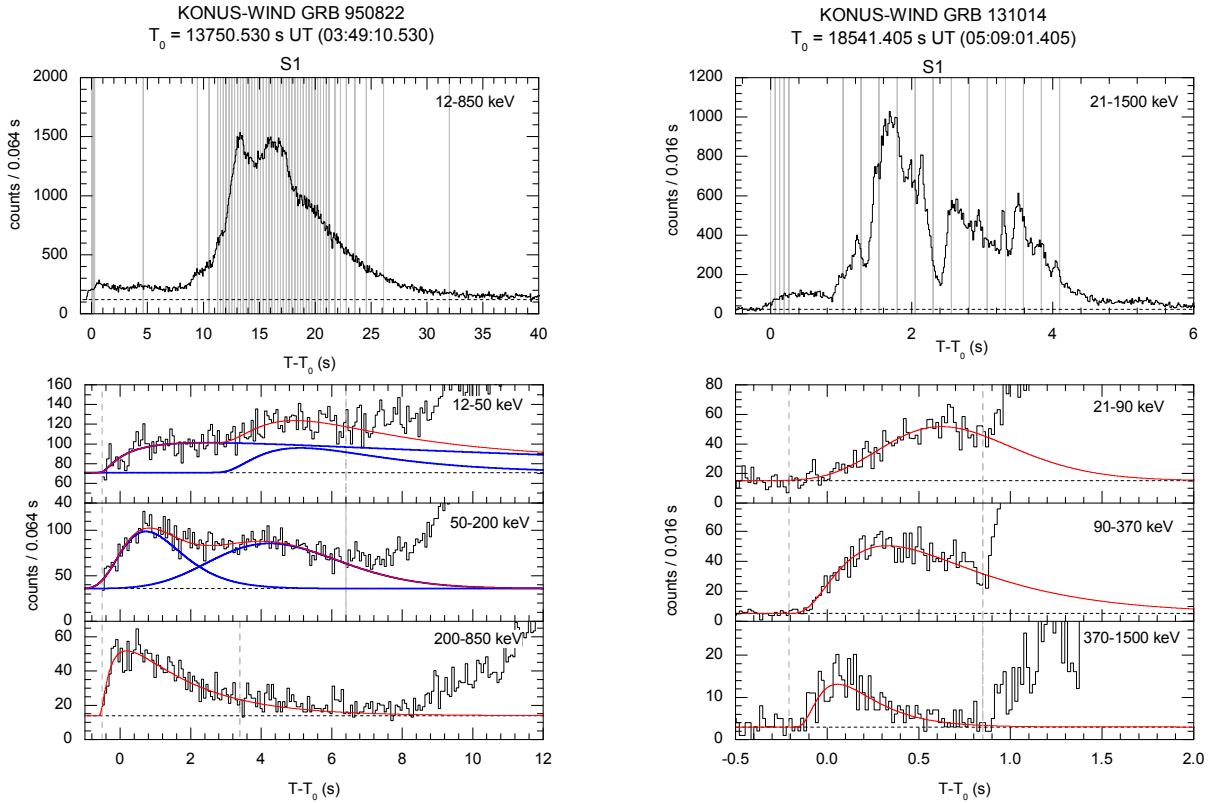


Figure 2. Lightcurves of GRB 950822 (left) and GRB 131014A (right). The top panels show the entire prompt emission phase. The bottom panels show the initial phase fit results in the three energy bands. Vertical solid lines denote spectrum accumulation intervals, horizontal dashed lines correspond to background count rate. The vertical dashed lines denote the lightcurve fit interval.

Table 1. Bursts with smooth initial pulses

Date	Time (UT)	T_{90} (s)	$\tau_{\text{lag,G1-G2}}$ s	$\tau_{\text{lag,G2-G3}}$ s	E_p - F slope	Note
19950822	03:49:10.530	18.9(-0.3,+0.3)	1.78 ± 0.84	0.55 ± 0.11	~ 1.5	two pulses in G1 and G2
19960114	12:15:04.737	30.8(-1.0,+1.1)	0.20 ± 0.17	—	~ 0.5	
19960710	00:11:02.014	27.3(-0.6,+0.8)	-0.36 ± 0.29	0.15 ± 0.27	—	two pulses in G2
19980516	11:23:57.217	15.4(-0.2,+0.3)	0.04 ± 0.13	1.06 ± 0.32	~ 0.4	
19991216	16:07:18.085	14.5(-0.1,+0.2)	0.52 ± 0.51	-0.30 ± 0.49	—	two pulses in G2
20001225	07:09:20.336	26.0(-1.3,+1.4)	0.05 ± 0.05	0.14 ± 0.12	~ 0.3	
20021008	07:00:50.599	14.0(-0.1,+0.1)	0.67 ± 0.09	0.56 ± 0.15	~ 0.8	two pulses in G1, G2, and G3
20090408	19:46:38.539	4.3(-0.2,+0.2)	0.31 ± 0.04	0.13 ± 0.05	~ 3.0	
20130427	07:47:09.501	11.4(-0.2,+0.2)	0.05 ± 0.15	0.18 ± 0.04	~ 1.5	two pulses in G1 and G2
20131014	05:09:01.405	3.0(-0.1,+0.1)	0.30 ± 0.16	0.27 ± 0.11	~ 2.4	
20140320	20:21:38.804	23.1(-0.6,+0.8)	—	0.36 ± 0.32	—	
20190305	13:05:15.900	1.5(-0.1,+0.1)	-0.07 ± 0.65	—	~ 2.6	two pulses in G3
20190530	10:19:06.000	20.8(-0.8,+1.0)	0.24 ± 0.06	0.18 ± 0.17	—	

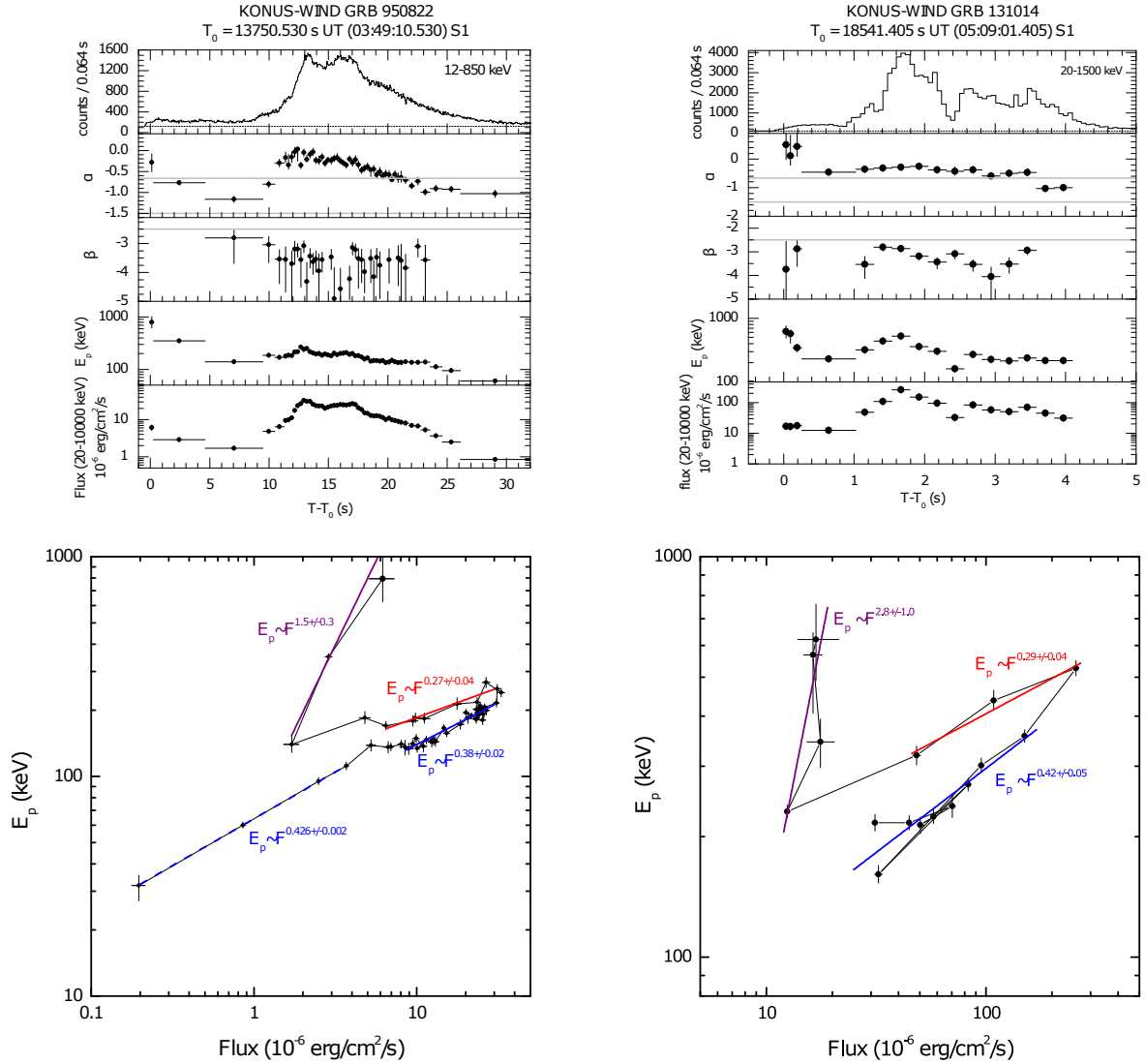


Figure 3. Lightcurves of GRB 950822 (left) and GRB 131014A (right). The top panels show evolution of Band function and CPL parameters. The gray lines in the α panel denote synchrotron lines of death of $-3/2$ and $-2/3$. The gray line in the β panel denotes typical value of -2.5 . The bottom panels show E_p - F relations. The relations during leading (red solid line) and trailing (blue solid and dashed lines) fronts of the main episode are well described by a power-law with slope of ~ 0.4 . During the initial phase the slope of the relation is significantly steeper.

5. Summary and discussion

We analysed 35 bright long Konus-Wind gamma-ray bursts and found a dozen events with smooth IP, a half of which show significant spectral evolution with a steep slope of E_p - F relation during IP. The slopes of E_p - F relation for the most of the bursts without smooth IP are ~ 0.3 – 0.5 which is consistent with “Amati” and “Yonetoku” relations derived for Konus-Wind GRBs [10]. The slope of ~ 0.5 may arise due to the variation of the bulk Lorentz factor of the ejecta or the characteristic random Lorentz factor of the emitting electrons [12, 15]. The observed hard low-energy spectral indexes $\alpha > -2/3$ may be produced by a number of mechanisms, e.g., by the

emission of relativistic electrons in a non-uniform magnetic field or photospheric emission [16].

The observed slopes of E_p - F relation for a fraction of bursts with smooth IP are much steeper than observed for the bulk of GRBs [7]. Such a strong spectral evolution of the IP may be explained assuming a distribution of the Lorentz factor in the outflow, see, e.g. [17].

We plan further detailed analysis of the spectral evolution of the bursts with smooth IP using KW three channel spectral analysis and *Fermi*-GBM data.

References

- [1] Band D, Matteson J, Ford L *et al.* 1993 *Astrophys. J.* **413** 281–292
- [2] Rees M J and Meszaros P 1994 *Astrophys. J.* **430** L93
- [3] Preece R D, Briggs M S, Giblin T W *et al.* 2002 *Astrophys. J.* **581** 1248–1255
- [4] Pe’Er A and Ryde F 2017 *Int. J. Mod. Phys. D* **26** 1730018–296
- [5] Golenetskii S V, Mazets E P, Aptekar R L and Ilinskii V N 1983 *Nat.* **306** 451–453
- [6] Gehrels N 1997 *Nuovo Cimento B Serie* **112B** 11–15
- [7] Lu R, Wei J, Liang E *et al.* 2012 *Astrophys. J.* **756** 112
- [8] Aptekar R L, Frederiks D D, Golenetskii S V *et al.* 1995 *Space Sci. Rev.* **71** 265–272
- [9] Svinkin D S, Frederiks D D, Aptekar R L *et al.* 2016 *Astrophys. J., Suppl. Ser.* **224** 10
- [10] Tsvetkova A, Frederiks D, Golenetskii S *et al.* 2017 *Astrophys. J.* **850** 161
- [11] Svinkin D S, Aptekar R L, Golenetskii S V *et al.* 2019 *J. Phys. Conf. Ser.* **1400** 022010
- [12] Preece R, Burgess J M *et al.* 2014 *Science* **343** 51–54
- [13] Norris J P, Bonnell J T, Kazanas D *et al.* 2005 *Astrophys. J.* **627** 324–345
- [14] Arnaud K A 1996 *Astronomical Data Analysis Software and Systems V (ASPC vol 101)* p 17
- [15] Ghirlanda G, Nava L and Ghisellini G 2010 *Astron. Astrophys.* **511** A43
- [16] Ghirlanda G, Celotti A and Ghisellini G 2003 *Astron. Astrophys.* **406** 879–892
- [17] Bošnjak Ž and Daigne F 2014 *Astron. Astrophys.* **568** A45