Abstract. The RT-2 Experiment, a low energy gamma-ray telescope, onboard CORONAS-PHOTON satellite is designed to study the temporal, spectral and spatial properties of the hard X-ray solar flares mainly in the energy range of 15 – 100 keV, which is extendable upto 1000 keV. During the operational period of ~ 9 months, it has been able to detect a few solar flares and at least four Gamma-Ray Bursts (GRBs). In this paper, we discuss the properties of the GRBs as observed by RT-2 in the energy band of 15 to ~1000 keV. We will present the results of spectral and timing properties of the GRBs (specially for the GRB 090618) using RT-2 detectors. Temporal analysis suggests that all four GRBs belong to the category of long duration bursts.

Keywords: gamma-ray burst:general – instrumentation:detectors – supernovae:general
1. Introduction

RT-2 (named after Röntgen) Experiment (Debnath et. al. 2011, Nandi et. al. 2011, Kotoch et. al. 2011, Sarkar et. al. 2011, Sreekumar et. al. 2011, Rao et al. 2010, 2011a) is a part of Russian Solar mission satellite named Coronas-Photon. It was launched into \( \sim 550 \) Km polar LEO (Low Earth Orbit) on 30\textsuperscript{th} January, 2009 from Plesetsk Cosmodrome, Russia. The mission was dedicated to study mainly the solar flares in a wide energy band of electromagnetic spectrum ranging from UV to high-energy \( \gamma \)-rays (\( \sim 2000 \) MeV). But the mission has lost its functionality after \( \sim 9 \) months of its successful launch due to the failure of the main power-bus of the satellite.

RT-2 is an Indian Space Research Organization (ISRO) sponsored X-ray and low-energy \( \gamma \)-ray (up to 1 MeV) solar experiment in collaboration with MEPHI, Russia. It consists of an ensemble of three low-energy hard X-ray/gamma-ray payloads (RT-2/S, RT-2/G & RT-2/CZT). RT-2/S & RT-2/G are mainly sensitive in the energy range of \( 15-100 \) keV. They also have extended detection capabilities, up to \( \sim 600 \) keV for RT-2/S and up to \( \sim 1000 \) keV for RT-2/G (Debnath et al. 2011). But, RT-2/CZT is sensitive to the spectral energy range of \( 20-100 \) keV with imaging capability.

The main scientific objectives of the RT-2 experiment were to explore temporal, spectral and spatial behaviors of the Sun and solar events, such as solar flares etc. Due to the large FOV of the RT-2 instruments and having the capability to act as an omni-directional detector in high energy range (\( > 50 \) keV), detectors have been able to detect a few extra-solar events such as Gamma-Ray Bursts (GRBs). During the mission life time, RT-2 has co-discovered four GRBs - GRB 090618 (Rao et al. 2009, 2011a), GRB 090820, GRB 090926A, and GRB 090929A (Chakrabarti et al. 2009a, 2009b, 2009c).

In this paper, we discuss the timing and spectral properties of the first observed GRB 090618 and preliminary results of the other GRBs. The paper has been organised in the following way: in §2, a brief discussion on RT-2 observations and data analysis procedures
is given, in §3 observational results of the GRBs are discussed and in §4 discussion and concluding remarks.

2. Observation and Data Analysis

In this paper, we present the results of the four GRBs as observed by RT-2. During its operational period, RT-2 has successfully co-discovered GRB 090618, GRB 090820, GRB 090926A & GRB 090929A. All these four GRBs were detected by RT-2/S and RT-2/G. However, RT-2/CZT has not been able to image any of these GRBs, because of the long duration commissioning phase of RT-2/CZT operation and the entire payload is shielded with Ta material, which restricts the detection of GRBs as these were observed at high inclination angle. In this Section, we will discuss about the observations and the data analysis procedure in briefly.

RT-2/S and RT-2/G are generally operated in the solar quiet mode (SQM) when the satellite orbits in the “GOOD” regions (i.e., outside the high background regions of Polar Caps and SAA), when count rates in eight channels (for each detector) are stored every second. The spectral data are stored every 100 s. The low energy spectra are stored separately for NaI(Tl) (15 – 100 keV) and NaI(Cs) (25 – 215 keV) detectors based on the pulse shape along with the high-energy spectrum in the energy range of 215 – 600/1000 keV (see, Debnath et al. 2011, for details). The onboard software automatically stores the data in finer time resolution (0.1 s count rates and 10 s spectra) during the solar flare mode (SFM), when the count rates exceed a pre-determined threshold limit. RT-2/CZT operates only in the SQM when 1 s count rates, 100 s spectra, and images are stored. It has no solar flare operation mode. The onboard performance of the RT-2 instruments are discussed in Nandi et al. (2009) and Rao et al. (2011b).

RT-2 light curve and spectral data were extracted from the ‘raw’ data using ground-based software. The data is processed further with the NASA’s software package hea-soft6.8 using FTOOLS and XSPEC.
3. Results

3.1 GRB 090618

The GRB 090618 was discovered with the Swift BAT on 2009 June 18 at 08:28:29 UT (Schady et al. 2009) at a redshift of $z = 0.54$ (Cenko et al. 2009a). The temporal profile of Swift/BAT showed that the GRB was very intense with multi-peak emission in gamma-rays. The GRB was also detected by various observatories in X-ray and gamma-ray energies such as AGILE (Longo et al. 2009), Fermi GBM (McBreen et al. 2009), Suzaku WAM (Kono et al. 2009), Konus-Wind on board the Wind satellite and Konus-RF on board the Coronas-Photon satellite (Golenetskii et al. 2009a), the RT-2 Experiment on board the Coronas-Photon satellite (Rao et al. 2009), etc. The optical afterglow of GRB 090618 was also immediately detected with the ROTSE-IIIb (Rujopakarn et al. 2009), Palomar 60 inch telescope (Cenko et al. 2009b). The Swift X-ray Telescope (XRT) was able to detect the X-ray afterglow (very bright in X-rays), just 121 sec after the BAT trigger. Within a few secs, the X-ray flux decayed rapidly with a slope of $\sim 6$ before breaking at $T_0 + 310 \, \text{s}$ ($T_0 = 08:28:29 \, \text{UT}$) to a almost flatter slope of $0.71 \pm 0.02$ (Beardmore et al. 2009).

GRB 090618 was very intense in hard X-rays and gamma-rays during the prompt emission phase that makes enable to study the time-resolved spectral characteristics of the different peak profiles. The GRB (band) model fitted spectra in the energy range of 20 keV - 2 MeV that obtained from the Konus-RF (from $T_0$ to $T_0 + 142 \, \text{s}$; $T_0 = 08:28:27.060 \, \text{UT}$) detector on board the Coronas-Photon satellite, provided the important parameters of the low-energy photon index ($\alpha$), high-energy photon index ($\beta$), and peak energy ($E_p$) as $-1.28$, $-3.06$, and $220 \, \text{keV}$ (Golenetskii et al. 2009a). The BAT light curve of the GRB in the energy band of 15-150 keV was found to be of a multi-peak structure with a duration of about 130 s. The multi-peaked profile was also observed in the 50 keV - 5 MeV range light curve of the Suzaku Wide-band All-sky Monitor (Kono et al. 2009).
Nature of GRBs observed by RT-2 onboard CORONAS-PHOTON Satellite

20
40
60
GRB 090618                                       Time resolution = 1 sec
RT−2/S Light curve
[59 − 215 keV]
215 − 1000 keV
Counts/sec
200
400
600
−300 −200 −100
0 100 200 300 400 500
Time (sec)   [T0 = 08h 28m 27s (UT)]

20
40
60
80
100
120
140
160
GRB 090618                                       Time resolution = 1 sec
RT−2/G Light curve
[59 − 215 keV]
215 − 330 keV
330 − 1000 keV
Counts/sec
200
400
600
200
300
400
−300 −200 −100
0 100 200 300 400 500
150
200
250
300
350
400
Time (sec)   [T0 = 08h 28m 27s (UT)]

Figure 1. (a-b) Light curves of GRB 090618 in different energy band (marked) of (a) RT-2/S and (b) RT-2/G detectors. Four emission peaks along with the ignition (precursor trigger) pulse at T0 = 08h 28m 27s UT are detected clearly in the energy band of 59 - 215 keV.

RT-2 instruments detected the GRB 090618 with a large off-axis angle of 77°, which triggered at T0 = 08 : 28 : 27UT and lasted for almost 150 sec. During the event, the RT-2 payload was completely in the “SHADOW” mode (away from the Sun) with “GOOD” time (away from SAA and polar regions), which started at 08 : 16 : 10.207 UT and ended at 08 : 37 : 35.465 UT. Data from RT-2/S and RT-2/G are used for the present analysis.

3.1.1 Timing analysis results for GRB 090618

GRB 090618 was detected in the different energy bands of RT-2/S and RT-2/G detectors. The 1 sec binned light curves of the GRB, as seen by RT-2/S and RT-2/G are shown in Figure 1. The multi-structured burst profile is clearly seen in the light curve of 59 - 215 keV. The emission peaks are registered at T0+65 s, T0+85 s and at T0+115 s. To find the widths of the peaks, we tried to fit RT-2/G light curve data of 59-215 keV energy band with fast-rise-exponential-decay (FRED) profile developed by Kocevski et al. (2003).
According to the FRED profile GRB photon flux can be defined as:

\[ F(t) = F_m \left( \frac{t}{t_m} \right)^r \left[ \frac{d}{d + r} + \frac{r}{d + r} \left( \frac{t}{t_m} \right)^{(r+1)/(r+1)} \right]^{-(r+d)/(r+1)}, \]

where \( F_m \) is the maximum flux at time \( t_m \), \( r \) and \( d \) are the decaying indices for rising and decaying phases of any pulse (peak) respectively. We first fit individual peaks and then total light curve with the pulse profile of Eqn. (1). This model fitted light curve for RT-2/G detector in the energy band of 59 - 215 keV is shown on Fig. 2. We also fitted this model in the other energy bands of RT-2/G light curves. Finally we calculated widths of each peaks from our fittings. All the fitted parameters and pulse widths are noted in Table 1. We also compared our fitted results with Swift BAT data (Rao et al. 2011a).

3.1.2 Spectral analysis results for GRB 090618

Spectral analysis for the GRB was done by using the RT-2/S and Swift BAT data. We used 15 – 200 keV BAT, 100 – 210 keV RT-2/S G1, and 250 – 600 keV RT-2/S G2 data for our combined spectral fitting analysis. While fitting the combined spectrum of BAT and
Table 1. FRED profile fitted results for RT-2/G light curves of GRB 090618

| Pulse | Energy range (keV) | $F_m$ (s$^{-1}$) | $t_m$ (s) | $r$ (s) | $d$ (s) | Width (s) |
|-------|-------------------|----------------|-----------|--------|--------|-----------|
| 1     | 532.0             | 65.0           | 81.1      | 13.8   | 6.30   |           |
| 2     | 59-215            | 422.0          | 70.0      | 34.5   | 34     | 7.15      |
| 3     | 210.0             | 85.0           | 20.0      | 20.0   | 14.60  |           |
| 4     | 72.0              | 114.0          | 42.0      | 40.0   | 9.49   |           |
| 1     | 315.0             | 65              | 82.5      | 16.4   | 5.59   |           |
| 2     | 215-330           | 200.0          | 70.0      | 41.6   | 34.2   | 6.17      |
| 3     | 76                | 85.0           | 25.0      | 22.0   | 12.17  |           |
| 1     | 330-1000          | 144.0          | 65.0      | 78.3   | 22.5   | 4.77      |
| 2     | 64.0              | 70.0           | 88.0      | 84.0   | 2.93   |           |

RT-2, the relative normalisation factor was kept fixed at 1.30. Detailed spectral analysis is given in Rao et al. (2011a). The combined spectrum is well fitted with the standard BAND model. Spectral fitted results showed that the time averaged peak energy is at $\sim 164$ keV and integrated fluence in $20 - 600$ keV energy band is equal to $2.8 \times 10^{-4}$ ergs/cm$^2$.

Figure 3. The unfolded Swift BAT and RT-2/S combined energy spectrum of GRB 090618 (Rao et al. 2011a).
The GRB spectrum can be well fitted with the double power-law model introduced by Band et al. (1993). In this model, two power-laws join at break frequency \((\alpha - \beta)E_0\), where \(\alpha\) and \(\beta\) are the first and second power-law indices respectively, and \(E_0\) is the break energy. Now one can calculate the peak energy \(E_p\) by the relation \(E_p = E_0(2 + \alpha)\). Figure 3 shows the unfolded BAND model fitted *Swift* BAT and RT-2/S combined energy spectrum of the GRB 090618.

Figure 4. (a,b) Light curves in different energy band (marked) of (a) RT-2/S and (b) RT-2/G detectors. Emission peaks along with the weak precursor trigger pulse at \(T_0 = 00\text{h} 38\text{m} 16\text{s (UT)}\) are shown (Chakrabarti et al., 2009a).

### 3.2 GRB 090820

The Fermi Gamma-Ray Burst Monitor (GBM) first detected the GRB 090820 by its trigger number 272421498 (Connaughton V. 2009) on 20th August, 2009 at 00:38:16.19 UT. The source location was at RA(J2000) = 87.7 degrees (5h 51m) and Dec(J2000) = 27.0 degrees (+27°0’). The light curve of this bright GRB shows GBM triggered on a weak precursor, followed by a bright pulse beginning 30 sec later and lasting a further 30 seconds. The integrated event fluence is around \(6.6 \times 10^{-5}\) ergs/cm\(^2\) in the energy band of 8-1000 keV.
Both the RT-2 phoswich detectors (RT-2/S & RT-2/G) have detected this bright astrophysical event (Chakrabarti et al., 2009a). The satellite was in the GOOD/LIGHT mode with Earth latitude = -64.09 and longitude = 169.11 with 600 sec duration of GOOD time observation, starting at 00h 29m 16sec (UT) and ending at 00h 39m 16sec (UT). After 30 sec of the event, the satellite completely entered into the BAD mode of high charge particle region.

The 1 sec binned light curves of RT-2 detectors are shown in Figure 4. The GRB light curve shows a simple profile of a strong emission peak at $T_0 + 34$ sec with a weak precursor ($T_0 = 00:38:16$ UT). The time duration of the brightest emission is around 19 sec with $\sim 1100$ counts/sec in the energy band of 59 - 215 keV.

3.3 GRB 090926A

The very bright GRB 090926A was first detected by the Fermi-GBM trigger 275631628 (Bissaldi 2009) on 26th September, 2009 at 04:20:26.99 UT. The source location was at RA(J2000) = 354.5 degrees (23h 38m), DEC(J2000) = -64.2 degrees (-64\degree 12'), with an uncertainty of 1\degree. The GBM light curve consists of single pulse with a duration (T90) of 20 sec. The integrated fluence in the energy range of 10 keV to 10 GeV is around $2.47 \times 10^{-4}$ ergs/cm$^2$.

RT-2 instruments (RT-2/S & RT-2/G) also detected this bright GRB at $T_0 = 04h 20m 27s$ (UT) (Chakrabarti et al., 2009b). The satellite was in the LIGHT mode (pointing towards the Sun) for a short duration at a high latitude in its orbit. During this time, the GOOD time (away from the polar and SAA regions) observation was for 348 sec starting at 04h 16m 55sec (UT) and ending at 04h 22m 43sec (UT). This burst was also detected by KONUS-RF, another instrument onboard CORONAS-PHOTON satellite (Golenetskii et al., 2009b).

The burst light curve consists of multiple peaks of total duration of $\sim 17$ sec, followed
Figure 5. (a,b) Light curves in different energy band (marked) of (a) RT-2/S and (b) RT-2/G detectors. Two emission peaks along with the weak precursor trigger pulse at $T_0 = 04h 20m 27s$ UT are detected in a wide energy band of 15 - 1000 keV (Chakrabarti et al., 2009b).

by a weak tail ending at $T_0 + 30$ sec. The strongest peak count rate is $\sim 1200$ counts/sec in the energy band of 59-215 keV. The 1 sec binned light curves of both the detectors at different energy band are shown in Figure 5.

3.4 GRB 090929A

The Fermi Gamma-Ray Burst Monitor first reported the GRB 090929A by its trigger 275891585 (Rau, A., 2009). The event occurred at 04:33:03.97 UT on 29th September, 2009 in the sky location of RA(J2000) = 51.7 degrees (03h 27m), DEC(J2000) = -7.3 degrees (-7$^\circ$18'), with an uncertainty of 1.3 degrees. The integrated fluence in the energy range of 8-1000 keV is around $1.06 \times 10^{-5}$ ergs/cm$^2$.

Both the phoswich detectors (RT-2/S & RT-2/G) of the RT-2 Experiment, have also detected this GRB (Chakrabarti et al., 2009c). During the time of GRB, the satellite was in the LIGHT mode (pointing towards the Sun) with GOOD time (i.e., away from the polar charge particle and SAA regions) observation of 1537 sec starting at 04h 21m 20sec
The 1 sec binned burst light curves show double peak profile of a total duration of just around 5 sec. The strongest peak count rate is \( \sim 310 \) counts/sec in the energy band of 59-215 keV. In Figure 6., the light curves are plotted at various energy bands for both the detectors.

4. Discussions and Concluding Remarks

In this paper, we have discussed briefly about the instruments of RT-2 Experiment onboard Russian CORONAS-PHOTON mission and discuss the observational results obtained from the four GRBs, observed by RT-2.

Immediately after the commissioning phase of RT-2 payloads, GRB 090618 was co-observed by RT-2 along with other X-ray and gamma-ray satellites. A complex, multiple
peaks were observed in the light curve of GRB 090618. Spectro-timing analysis showed a systematic softening of the spectrum for the successive pulses which is associated with the variations in the timing parameters. The measured isotropic energy ($E_{\text{iso}}$) and intrinsic peak energy ($E_{p,i}$) of this GRB are around $2.2 \times 10^{53}$ ergs and 252 keV. The results suggest that the GRB 090618 closely follows the ‘Amati’ relation. It has been recently suggested that GRB090618 has a multiple components, possibly even the signatures of the black holes (Izzo et al. 2012).

Timing analysis of other GRBs show that the burst width decreases with the increase of the energy ranges and also show the nature of the energy dependence of the gamma-ray variations. The GRBs that are detected by RT-2, belong to the category of long-duration bursts.

**Acknowledgments**  The RT-2 project was made possible in part from a grant from Indian Space Research Organization (ISRO). We also acknowledge other scientific and technical team members of the RT-2 project.

**References:**

1. Beardmore, A. P., et al., 2009, GCN Circ., 9528, 1
2. Bissaldi, E., GCN Circ., 9933, 1
3. Cenko, S. B., et al., 2009a, GCN Circ., 9513, 1
4. Cenko, S. B., et al., 2009b, GCN Circ., 9518, 1
5. Chakrabarti, S. K., et al., 2009a, GCN Circ., 9833, 1
6. Chakrabarti, S. K., et al., 2009b, GCN Circ., 10009, 1
7. Chakrabarti, S. K., et al., 2009c, GCN Circ., 10010, 1
8. Connaughton, V, 2009, GCN Circ., 9829, 1
9. Debnath, D., et al., 2011, Exp. Astron., 29, 1
10. Golenetskii, S., et al., 2009a, GCN Circ., 9553, 1
11. Golenetskii, S., et al., 2009b, GCN Circ., 9959, 1
12. Golenetskii, S., et al., 2009c, GCN Circ., 9968, 1
13. Izzo, L. et al, 2012, A&A, 543A, 10
14. Kocevski, D., & Liang, E. 2003, ApJ, 594, 385
15. Kono, K., et al. 2009, GCN Circ., 9568, 1
16. Kotoch, T. B., et al., 2011, Exp. Astron., 29, 27
17. Longo, F., et al. 2009, GCN Circ., 9524, 1
18. McBreen, S., et al. 2009, GCN Circ., 9535, 1
19. Nandi, A., et al., 2009, ICST Conf. Proc. (arXiv:astro-ph/0912.4126)
20. Nandi, A., et al., 2011, Exp. Astron., 29, 55
21. Rao, A. R., et al. 2010, ApJ, 714, 1142
22. Rao, A. R., et al. 2011a, ApJ, 728, 42
23. Rao, A. R., et al. 2011b, SoSyR, 45, 123
24. Rao, A. R., et al. 2009, GCN Circ., 9665, 1
25. Rau, A., 2009, GCN Circ., 9962, 1
26. Rujopakarn, W., et al. 2009, GCN Circ., 9515, 1
27. Sarkar, R., et al., 2011, Exp. Astron., 29, 85
28. Schady, P., et al. 2009, GCN Circ., 9512, 1
29. Sreekumar, S., et al., 2011, Exp. Astron., 29, 109