ELF Q-burst caused by extragalactic gamma ray burst

A.P. Nickolaenko[1] and A.Yu. Schekotov[2]

[1]Usikov Institute of Radio-Physics and Electronics, National Academy of Sciences of the Ukraine, 12, Acad. Proskura st. Kharkov, 61085, the Ukraine, e-mail: sasha@ire.kharkov.ua
[2]Schmidt Institute of Physics of the Earth, Russian Academy of Sciences, 10, B. Gruzinskaya, Moscow D-242, 123995 GSP-5, the Russia, e-mail: checkit@post.ru

Abstract

Experimental results are presented on the electromagnetic pulse associated with the abrupt change in the Earth–ionosphere cavity caused by the intense gamma ray burst of December 27, 2004. Parameters of observed extremely low frequency pulse correspond to expectations: the source bearing points to the epicenter of the ionosphere modification, the pulsed waveform is similar to that computed, and its amplitude exceeds by a few times the level of regular Schumann resonance background. The ELF pulse onset at the Karymshino observatory (52.8° N, 158.3° E) is ~0.16 s prior to the published time of modification in the VLF records.

1. Introduction to parametric Q – burst excitation

We present experimental results on the consequences of the powerful gamma ray burst of Dec. 27, 2004. We also model the 'parametric' extremely low frequency (ELF are the 3–30 Hz frequencies) pulse originating from disturbance of currents in the global electric circuit and compare its parameters with the record at Karymshino Schumann resonance observatory (52.8° N, 158.3° E). Detailed information on the gamma burst might be found in papers [1–4]. The minimum information is following: The burst occurred at 21:30:26.5 UT when a giant gamma ray burst illuminated the dayside of the Earth. The flux was 100 times greater than the 1998 gamma burst from the Magellan Cloud. The center of ionosphere disturbance was positioned over the Pacific Ocean (146.2°W and 20.4°S). Gamma flare reduced the daytime ionosphere by ~20 km, and the disturbance lasted for more than 1 hour in the VLF records [2, 4]. The ELF propagation path parameters were: the distance from observatory to the center of disturbance D_S = 9.7 Mm, and the wave arrival azimuth A_Z = 129.3°.

Abrupt changes of parameters of global electric circuit must cause a 'parametric' electromagnetic pulses having special characteristics facilitating its distinguishing from the casual ELF transients arriving from the powerful lightning strokes [5]. These features are as follows. The arrival time of ELF pulse is close to the detection of gamma burst. Horizontal magnetic field components of radio wave point toward the center of ionosphere modification. Expected pulse amplitude exceeds the Schumann resonance background by a factor of 2–10. Since the ionosphere is positively charged, the source current is "positively" polarized: the pulse onset in the vertical electric field component E_Z is negative. Owing to a great geometrical size of the field source, the pulse contains only the lowest Schumann resonance mode [5, 6]. The field polarization is linear.

2. Experimental setup and results of observations

Monitoring of magnetic field components is performed at the Karymshino observatory (52.8° N, 158.3° E), Kamchatka, Russia [7]. The receiver band-pass is 0.003–40 Hz. Waveforms of *H*, *D*, and *Z* geomagnetic field components are monitored with the 24-bit ADC at sampling frequency of 150 Hz. The GPS time stamp is used with the standard deviation of 5 ms. The magnetic inclination is 6.5° W. We present the 26 to 27 s fragment centered at the time when the disturbances in VLF radio signals were reported [3]. We applied the wavelet transform with the third order complex Gauss wavelet.

Figure 1 illustrates experimental results: upper plot depicts the recorded waveforms, and the middle one shows the polarization. The bottom diagrams show the source bearings for the three intervals marked by black horizontal bars. In the first interval, the maximum amplitude of signal (not shown) is found at the 6–7 Hz frequency, and it shifts to the second Schumann resonance mode (14–15 Hz) afterwards. Ellipticity and polarization were found

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from the coherence matrix [9] computed from the coefficients of wavelet transform [7]. The wave arrival azimuth is measured clockwise from the direction to the north toward the perpendicular to the major axis of the wave polarization ellipse. Its value is increased by the 6.5° local magnetic inclination. The azimuthal circle was divided into sectors of 10° width to plot the source bearing (averaged over 3–20 Hz) corresponding to particular pulse elements. Histograms in form of lobes superimposed on the global map show the number of occurrence in each sector. Signal in the first interval occupies a wide band, has the 6–7 Hz peak, is linearly polarized, and has the wave arrival azimuth of ~120° corresponding to the epicenter of gamma burst (star). The same azimuth is observed in the initial section of the second interval. It re-appears at the very beginning of the third interval. The main lobe of the third interval indicates toward the Australian eastern coast.

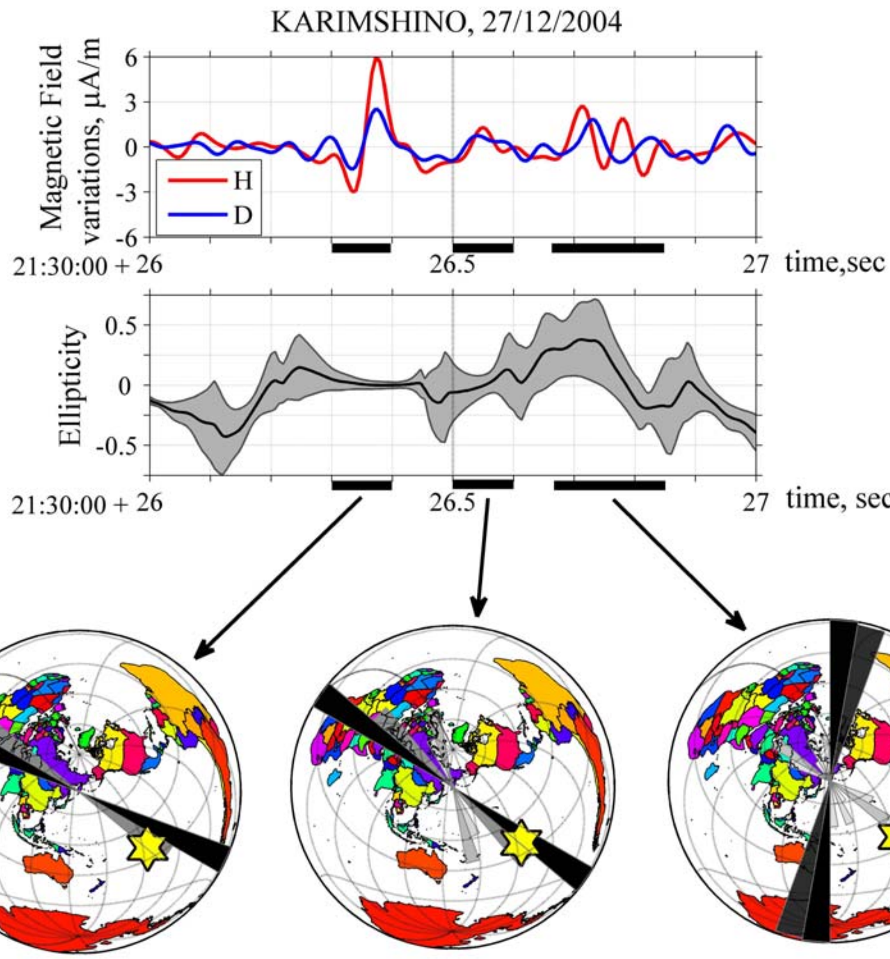

Figure 1. Wave arrival angles for different fragments of experimental record.

We interpret the record as a radio wave from the parametric source shown by star in the maps. The first interval corresponds to the direct wave, and the second interval is the "antipode" wave. Since the observatory–source distance is 9.7 Mm, and the peak frequency of the pulse in the first interval ~7 Hz, the time delay of antipode wave must be equal to 142 ms×20.6 Mm/20 Mm = 147 ms. This value perfectly agrees with the observed waveform.

Experimental and model pulses were compared showing exceptional similarity in the field components. Their reciprocity was quantified by using the cross-correlation coefficient $R(\tau)$. The $R(\tau)$ maximum value reached 0.75, and its position corresponds to the pulse arrival time. We found that the ELF pulse onset was shifted toward the "pre-history" of gamma ray burst by ~0.16 s in respect to modifications reported for the VLF band.

3. Discussion

A number of reasons might be suggested explaining the lead of ELF pulse against the VLF modifications.

1. The simplest explanation is the systematic error in the time stamps. However, data of other observatories (we hope that detailed comparison of records is due) show an outstanding similarity with Karymshino record. Hence, the failure in the time marks, if any, occurred within the GPS system itself. This is improbable.

2. The time lead is not connected with the arrival of gamma rays because the transient is an ordinary Q–burst. This signal might arrive from a terrestrial lightning stroke and casually coincide with the gamma burst. In this case we must explain why the other independent parameters also match: (i) – the pulse arrived from the "correct" angular sector; (ii) – its spectrum (waveform) contains only the lowest Schumann resonance mode, as the model predicted; (iii) – the wave is linearly polarized and has an appropriate amplitude. Correspondence of all these features supports the idea of parametric excitation of pulse.

3. In case of the recorded ELF pulse is linked with the gamma quanta, one has to explain the origin of 0.16 s lead. One explanation is that EM radiation originates in the "electrosphere", the layer having the thickness of a single atmosphere scale height (6–7 km) and positioned near the tropopause (~15 km). The fair weather potential varies here with the highest rate. We know that the night ionosphere D region is maintained by the galactic background radiation: the long-term VLF monitoring confirms this. The D region lifts with the increase of solar activity, as it "sweeps out" the galactic rays. Galactic background might explain the origin of precursory ELF pulse. If we accept that the gamma burst passes through the "continuous medium" of galactic background rays (similarly to solar ionizing radiation), the advancing hard gamma rays might form at its front a "bunch" in the background. The lead of such a bunch will be of 0.16 s when positioned 50,000 km ahead of the hard gamma ray burst.

4. There might be another explanation. The Dec. 27, 2004 gamma ray burst had a 120 s precursor detected by space observatories [1]. Besides, the record shown in Fig. 3 of paper [3] shows a small increase in counts just ahead of the major gamma burst. We only have to suggest that such an increase (possibly, the softer rays) has provoked modifications in the electrosphere and caused the ELF transient. Simultaneously, it could have a minor effect on the ionosphere and the VLF records. The "soft" radiation preceding the hard one seems quite acceptable, especially, in the context that interaction altitude of ionizing radiation with the atmosphere strongly depends on its energy. Just recall that the long-wave portion of solar UV radiation has minor effect on ionosphere, but it forms the ozonosphere.

We can suggest that parametric Q–burst splits in two parts. The first one, precursor, appears prior to the major gamma burst. The second one coincides with the burst. It could be delayed from VLF records owing to electrosphere height and its reaction time. The "secondary" parametric source is produced by interaction of gamma rays with already modified electrosphere. This interaction and relevant currents might have different characteristics, e.g., the center of secondary source can loss its symmetry, or have different spectrum, etc.

4. Conclusion

Experimental data confirm existence of transient ELF signal associated with exceptional gamma ray burst of December 27, 2004. Time of registration is close to the arrival of gamma rays. Simultaneously detection of transient pulse experimentally 'confirms' the concept of the global electric circuit and the modification of its current by the gamma burst. We list the major results of the work below.

- Continuous ELF records at Karymshino observatory (Russia) show a discrete pulse associated with the extra-terrestrial gamma ray burst. Its amplitude exceeds the Schumann resonance background by a factor of 6, as might be expected from the model disturbances in the global electric circuit.

- Owing to great size of parametric field source, the waveforms and spectra of ELF pulse contain a single maximum of the first Schumann resonance mode in accord with model predictions.

- Wave has the expected linear polarity. The source bearing indicates on the epicenter of ionosphere modification. The error of 10° agrees with the pulse-to-background ratio.

- Delay of the second sub-pulse in respect t the pulse onset is consistent with the concept of direct and antipodal waves arriving from the parametric source to observatory.

- The cross correlation coefficient of experimental and computed waveforms reached the 0.75 level.

- The discrete ELF pulse was recorded at Karymshino observatory 0.16 s prior to the onset of modifications reported in the VLF band. The lead might be explained by the origin of ELF pulse in the electrosphere modulated by galactic background or by a precursory "soft" component of the gamma ray burst.

- It is desirable to compare Karymshino data with records of other Schumann resonance observatories. The comparison would improve the accuracy of interpretations.

5. References

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