The temporal coincidences of events detected in four neutrino detectors and two gravitational antennas still remain among the most puzzling phenomena associated with SN1987A. The coincidences form a six-hour signal approximately coincident in time with the well-known LSD signal at 2h52m UT on 23/02/1987. After 30 years of research, the characteristics and the shape of the six-hour signal have been studied quite well, but the mechanisms of its formation have not been fully understood as of yet. Here we suggest that data obtained from another technology, radioactive decays, might provide new insights into the origin of signals previously seen in neutrino detectors and gravity wave detectors. On August 17, 2017, at 12h41m UT, the GW170817 signal was detected by LIGO and Virgo. At the same time, an approximately 7-hour long signal coincident with GW170817 was detected in the Si/Cl experiment on precision measurement of the $^{32}$Si half-life. We show that the Si/Cl signal is unexpectedly similar to the six-hour signal from SN1987A. In addition, we establish that the sources of the coinciding events are similar to those of the Si/Cl signal. To explain the surprising similarities in both signals, we present a mechanism which could in principle account for this phenomenon in terms of a local increase in the density of axionic dark matter induced by a gravity wave.

Keywords: neutrino, gravitational waves detections, radioactivity

1. INTRODUCTION

On August 17, 2017, at 12h41m04s UTC (below we assume UTC time to be identical to UT), LIGO and Virgo gravitational detectors both recorded a gravitational wave signal $^{[1]}$, $^{[2]}$ designated as GW170817. The ensuing analysis of its characteristics showed that, most likely, the signal was caused by a merger of two neutron stars (NS) with masses of approximately $1.2M_\odot$ and $\sim 1.6M_\odot$. The object was located in the galaxy NGC4993 of the constellation Hydra at a distance of 40 Mps ($\sim 1.3 \times 10^8$ light years) from the Earth, the closest for any gravitational-wave event ever recorded. A train of nearly flat gravitational waves (GW) reached the southern hemisphere of the Earth in the region of the Fiji islands. Gravitational detectors began to record the signal approximately 30 s before the NS merger, when the GW frequency increased to the lower limits of detectors' sensitivity ranges at about 30 Hz. The subsequent increase in frequency to $\sim 0.5$ kHz (kilohertz) was accompanied by an increase in the GW amplitude. This ended with a peak at the very moment of NS merger that produced a time-frequency spectrogram, which is known as a "chirp". This was the first time that GWs from NS merger were recorded. All signals detected except GW170817 (GW190425 was not marked as a significant event) were identified as coming from black hole (BH) mergers that occur over shorter times, on the order of hundreds of milliseconds. The search for a neutrino flux from GW170817 failed; no detector capable of detecting neutrinos with energies up to $\sim 100$ MeV (Borexino, Daya Bay, HALO, IceCube, KamLAND, LVD, and Super-K) has reported any neutrino signals.

Nevertheless, in the data from $^{[3]}$, an experiment on the precision measurement of the $^{32}$Si half-life ($T_{1/2} \sim 172$ years), a correlation between $^{32}$Si and $^{36}$Cl decay rates was observed and associated with GW170817. This correlation was observed for a $\sim 7$ h period coincident with that of GW170817 (between point 1 and point 7 in Fig. 1).

In Sec. 2, we discuss the relationship between the LIGO signal GW170817 and a correlation in the event rates in a Si/Cl decay experiment found by the authors of the experiment. In Sec. 3 we discuss the relationship of the SN1987a neutrino events and signals in gravitational wave detectors running at the time. This was investigated in the papers cited in this section and established quantitatively in the form of the probabilities of coincidence of detector events (Sec. 3.1). One of the important points is the proof of the muon origin of the signals from the gravitational antennas in Rome and Maryland, including the signals recorded by the antennas during SN1987A (Sec. 3.2). The main objective of our research is the analysis of experimental data taking into account the methodological features of the experiments. We show that two qualitatively different instrumental technologies appear to have seen the same astrophysical signal (Sec. 4).

To explain the surprising similarities in both signals, we present a mechanism which could in principle account for this phenomenon in terms of a local increase in the
density of axionic dark matter induced by a gravity wave (Sec. 5).

2. Si/Cl SIGNAL

The experiment described in [3], conducted by researchers from various US universities and research organizations, has been in progress since 2014 at Purdue University. The $\beta^-$ decay of $^{32}$Si is identified using electrons from the decay of $^{32}$P ($T_{1/2} \sim 14.28$ days, $Q(\beta^-) = 1709$ keV) that is part of the $\beta$-decay chain $^{32}$Si $\rightarrow$ $^{32}$P $\rightarrow$ $^{32}$S, and occurs in equilibrium with $^{32}$Si. The decay rate of the $^{32}$Si sample is compared with the decay rate of $^{36}$Cl ($T_{1/2} \sim 3.1 \times 10^5$ years) that remains almost constant due to the very long $T_{1/2}$ time and, hence, is used as a calibration standard. The $^{32}$Si half-life is determined from the $^{32}$Si/$^{36}$Cl ratio that changes with time due to the decay of $^{32}$Si.

The experimental setup is based on a scintillation detector, and is protected from electromagnetic noise and supply voltage fluctuations. Measurements are performed under extremely stable pressure, humidity and temperature conditions [3]. A precision mechanical manipulator alternately positions samples of $^{32}$Si and $^{36}$Cl under the detector for measurements. The number of decays for each isotope is measured every hour in half-hour exposures.

The data form two time sequences, in which Cl values in accordance with the measurement method are shifted by 0.5 h relative to Si (Fig. 1). In these sequences a 7-hour long segment was discovered. Within this segment the GW170817 signal is present, and Si and Cl decay counts change synchronously. Changes in decay rates are very small and do not exceed a fraction of a per cent. The Pearson correlation coefficient for decays in this interval was 0.954 [3]. A statistical analysis of the data covering a period from January 1 to October 11, 2017 showed that, firstly, fluctuations in the recorded number of decays for both Si and Cl follow the usual $\sqrt{N}$ rule for statistically uncorrelated data. Secondly, the probability of a random correlation of seven pairs of numbers (counting rates) over a seven-hour interval was no more than $4.3 \times 10^{-4}$, which corresponds to a correlation coefficient of 0.954 [3].

Two more seven-hour segments (May 25 and June 15) with random correlation probabilities of no more than $4.3 \times 10^{-4}$ were identified in the records spanning 9.5 months (from 01/01/17 to 11/10/17) in addition to the seven-hour signal contemporaneous with GW170817.

On the other hand, for the full 13-month period of searching for gravitational wave signals (O1+O2 data sets), 11 signals were identified [3]. Thus, the probability of a random coincidence of the Si/Cl and GW170817 signals is $2.5 \times 10^{-5}$.

Since the probability for a rare background fluctuation to occur at a certain predetermined point in time (same as GW170817) is low, the authors [3] associated the seven-hour Si/Cl signal in August with GW170817, while those for May and June were attributed to statistical fluctuations. The significance of the Si/Cl signal and its connection with GW170817 is now further supported by the observation of a similar correlation signal in $^{44}$Ti and $^{60}$Co decays, the presence of which is shown in Ref. [4], and will be discussed in detail elsewhere.

As follows from Fig. 1, the main features of the Si/Cl signal for 1-hour measurement steps (set based on Si data) are as follows:

a) total duration of approximately 6.5 h (7 pairs of points, from 1 to 7);

b) two-humped signal shape;

c) duration of each peak is approximately 2.5 hours.

The Cl data, shifted by 0.5 h relative to the Si data as discussed above, makes it possible to increase the temporal resolution and refine the signal shape. For this, it is necessary to normalize the Si and Cl decay counts (from point 1 to point 7). This produces a histogram with 0.5-hour bins (Fig. 2). The first peak is then 2-hours wide (from 120 to 240 min) and is preceded by a two-hour baseline. The first peak is followed by an hour-long dip and the second peak, smaller in height and lasting 1 hour (from 300 to 360 min), that may be accompanied by a baseline for approximately an hour (from 360 to 420 min). Thus, with a better time resolution, the total duration of the Si/Cl-signal increases to $\sim 7$ h; both peaks become narrower, and an hour-long dip appears between them.

The duration of the Si/Cl signal (as well as the signal itself), combined with the presence of a two-hour segment preceding GW170817, is a great challenge to any interpretation based on the current understanding of the mechanisms for catastrophic astrophysical phenomena (mergers of BH and NS, gravitational collapses).
3. SIGNALS RECORDED BY DETECTORS DURING THE SN1987A BURST

To begin, it is necessary to point out that the 7-second LSD signal at 2h52m UT on February 23, 1987, as an example of a possible precursor signal approximately 5 h ahead of the neutrino flux detection by KND, IMB, and BST at 7h35m UT.

The most detailed correlation analysis, covering the range from 0h00m to 8h00m UT on 23/02/1987, has been reported in [20]. One of the important results of this work are the correlation curves for the LSD-RGA/MGA and KND-RGA/MGA setup combinations (Fig. 3). For these combinations, \( p_i(t) \) is the probability of a triple coincidence of their background pulses in the number \( N_{cor} \) observed within the time window \( \Delta T \). A method for calculating \( p_i \) of triple coincidences of setup events within the interval \( \Delta t = \pm 0.5 \) s has been described in [14] and [18], from which the relation \( N_{cor} \propto 1/p_i \) follows. A good illustration of how \( N_{cor} \) and \( p_i \) are related may be found in Fig. 1 of [17] that provides an analysis of correlation for the LSD and BST setups (double coincidences). In the analysis, the same parameters were used as in the determination of triple coincidences: coincidence time \( \Delta t = \pm 0.5 \) s, time window \( \Delta T = 1 \) h, window shift along the time axis \( t_{sh} = 0.1 \) h.

The correlation curves for different combinations of setups [15], [16], [17], [18] have the same feature: a large two-hour long peak from 1h30m to 3h30m. In combinations LSD-RGA/MGA and KND-RGA/MGA, it is followed by a one-hour dip to \( \sim 4h30m \), and a group of small peaks up to \( \sim 6h30m \). Due to the similarity of the correlation curves for different combinations of detectors, we have combined them under a common label 6D/6h signal that reflects the number of detectors (6D) and duration of the correlation region (6h) in the vicinity of the LSD signal at 2h52m UT.

The analysis of correlations leads to the following conclusions:
(a) the existence of time correlations of the events of all detectors in the six-hour neighborhood of the LSD signal is an experimental fact supported by statistics;
(b) correlations are observed on an intercontinental scale, and are independent of experiment conditions and signal detection techniques;
(c) correlations are observed from 0h30m to 6h30m UT on 23/02/1987, and the number of coincidences is the greatest between 1h45m and 3h45m;
(d) time shifts applied to KND (+7.7 s) and BST (−29 s) events to make adjustments to KND and BST clocks lead to the highest number of coincidences between their events and the events of other detectors;
(e) no correlations within a one-hour vicinity of the KND–IMB–BST neutrino signal at 7h35m UT on
### TABLE I: Characteristics of neutrino detectors

|        | LSD     | KND     | BST     | IMB     |
|--------|---------|---------|---------|---------|
| Coordinates | 45.8°N 6.9°E | 36.4°N 137.3°E | 42.4°E | 41.7°E 81.3°W |
| Depth (flat overburden), m w.e. | 5200 | 2700 | 850 | 1570 |
| Altitude, m | +1380 | +370 | +1950 | 200 |
| Effective Volume Mass, t | 90 | 2140 | 200 | 3300 |
| Muon average energy, GeV | 385 | 260 | 140 | 190 |
| Muon counting rate, h⁻¹ | 4.2 | 1.3 × 10⁵ | 10 | 9.7 × 10⁵ |
| Energy threshold, MeV | 5 (int.) 7 (ext.) 10 | 25 (24 hits) | 25% 10 MeV,e⁻ | 25% 12-20 MeV |
| Background counting rate, h⁻¹ | 43 | 86 | 2 × 10¹ | 8.1 × 10³ |
| Accuracy of detector clock | ± 2 ms | ± 60 s | ± 54 s | ± 50 ms |
| Resolution time (no worse) | 0.2 μs | 0.2 μs | 0.2 μs | 0.2 μs |

### TABLE II: Characteristics of gravitational antennas in Rome (RGA) and Maryland (MGA)

|        | RGA     | MGA     |
|--------|---------|---------|
| Coordinates | 42.0°N 12.5°E | 39.0°N 77.0°W |
| Altitude, m | 40 | 20 |
| Substance, form | Al, cylinder, L=3.0m, D=0.6m | Al, cylinder, L=1.55m, D=1.0m |
| Mass, t | 2.3 | 3.1 |
| Eigen vibration frequency, Hz | 858 | 1660 |
| Orientation | 29° E-W | 0° E-W |
| Accuracy of detector clock | ± 0.1 s | ± 0.1 s |
| Effective temperature | 29 K | 31 K |

![FIG. 3: Correlation curves obtained at ∆t = ± 0.5 s, ∆T = 0.5 h, tsh = 0.1 h for the LSD–RGA/MGA and KND–RGA/MGA setup combinations. The ordinate scale represents the probability pᵢ scaled up 10⁶ for the LSD–RGA/MGA and 10⁵ for KND–RGA/MGA curve.](image)

23/02/1987 in the data from all detectors were found.

3.1 Origins of 6D/6h Signal Events in Particle Detectors LSD, KND, BST, IMB

The origin of the coincident events of the detectors will be estimated based on a comparison of the average values of their amplitudes with the average background pulse amplitudes within the range from 1h45m to 3h45m (Table III), taking into account the distribution of events throughout a detector.

Background pulses of LSD and KND detectors, which had low detection thresholds (Table I), should be grouped by energy near the threshold due to the steeply decreasing power spectrum of the background $N_{bg} \propto E^{-\alpha}$, where $\alpha \approx 3$ is within the energy range of 5 to 10 MeV [21]. The background pulses come mainly from the radioactivity of detector materials and surrounding rock.

The main background of the BST setup (single 10 to ∼50 MeV pulses picked up by counters) at a threshold of 10 MeV is produced by muons (∼10⁵ μ/h), causing one-time signals in single counters, and noise pulses from photomultipliers [22].

The values given in Table III show that the average amplitudes of all LSD events correlating with KND and BST events, and KND events correlating with LSD events, are near the detection threshold, taking into account the energy resolution of 20–25% (Table I). In addition, the mean energy $\bar{E} = 6.7$ MeV of the LSD signal at 2h52m (5 pulses) is almost the same as the mean energy $\bar{E}_{bg} = 6.8$ MeV of LSD background events.

On the basis of the BST–LSD correlation analysis in [17], we can draw a conclusion concerning the origin of the correlating events of the BST detector. The results of the analysis show that the spatial distribution of the BST events correlating with LSD events (in the period of 1h45m to 3h45m) is consistent with the distribution of background pulses within the BST setup. Herewith, the number of correlating events in 650 outer counters (7 events total) is 3.2 times greater than the number of events in 1,200 inner counters (4 events), when expressed on per-counter basis. This value practically coincides with the ratio of 3.1 per counter per hour for background pulses. The energy of the correlating pulses
TABLE III: Background $N_{bg}$ and correlating $N_{cor}$ events of the LSD, KND, BST detectors in the period of 1h45m to 3h45m UT 23/02/87

| Characteristics of all detector events | Characteristics of detector events correlating with events of other detectors |
|----------------------------------------|--------------------------------------------------|
| LSD $N_{bg}=230$, $\mu_{bg}=9.2$ MeV, $T_{bg}=9.2$ MeV | $N_{cor}=19$, $\mu_{cor}=7$ MeV, $T_{cor}=7.2$ MeV |
| KND $N_{bg}=190$, $\mu_{bg}=7$ MeV, $T_{bg}=9.2$ MeV | $N_{cor}=10$, $\mu_{cor}=7$ MeV, $T_{cor}=7.2$ MeV |
| BST $N_{bg}=212$, $\mu_{bg}=13$ MeV, $T_{bg}=13.6$ MeV | $N_{cor}=10$, $\mu_{cor}=7$ MeV, $T_{cor}=7.2$ MeV |

$E_{cor} = 23.6$ MeV (Table III), which significantly exceeds both the threshold energy ($E_{th} = 10$ MeV) and the background pulse energy $E_{bg}$, suggests a significant contribution made by muon crossings of only one counter to the total number of correlating events.

The origin of IMB events is obvious: given the 20 MeV energy threshold of the detector, all of them are produced by muons and products of their interactions.

The energy distributions of the background pulses and correlating events in the LSD, KND, and BST experiments plotted in Fig. 11, 13, and 14 in [18] show that, in general, these distributions in all setups are consistent with one another. These facts suggest that all correlating events in the LSD, KND, BST, and IMB detectors were the physical background pulses, not only within the time interval from 1h45m to 3h45m, but also for the entire duration of the 6D/6h signal.

3.2 Origin of Events in Gravitational Antennas RGA and MGA

The solid-state resonant antennas RGA and MGA (Table III) were operated indoors, at room temperature, near sea level [12], [13]. The antenna excitation energy was determined within a set time interval; for RGA the interval was 1 s, and for MGA is was 0.1 s, followed by summation to 1 s. Thus, any event in the antenna reflects its energy state within a 1-second interval. Each event has an almost constant noise (thermodynamic) component, which is in equilibrium with room temperature and noise of the electronics [24].

The sequences of 55 events received in the RGA and MGA experiments between 2h51m56s and 2h52m51s UT on 23/02/1987 are characterized by average temperatures of $\langle T_{R} \rangle = 29$ K for RGA and $\langle T_{M} \rangle \approx 30$ K for MGA [12].

Let us consider the energy characteristics of RGA events using the differential and integral amplitude distributions shown in Fig. [4]. Despite the conclusion made in [25] on the lack of influence of extensive air shower particles on MGA (and, therefore, on RGA), one cannot exclude the possibility of the formation of the distribution shown in Fig. [4] under the action of atmospheric muon flux. This follows since the authors of [25] have studied coincidences between gravitational antenna signals and instantaneous antenna intersections by showers, while every RGA (and MGA) event was produced by the total excitation energy of the antenna over one-second period.

When positioned horizontally, the RGA was impacted by 290 muons per second on average: $N_{\mu} = SI_{\mu}F = 1.8 \text{ m}^2 \times 130 \mu \text{m}^{-2} \text{s}^{-1} \times 1.24 = 290 \mu \text{s}^{-1}$; where $S$ is a horizontal cross-section of the RGA, $I_{\mu}$ is a total muon flux at sea level, $F$ is a geometric factor taking into account the RGA shape and the angular muon distribution $I_{\mu}(\theta) \propto \cos^{2}\theta$.

Within the framework of the hypothesis of the muon origin of the events, the histogram $N(\geq T)$ for a detector temperature $T$ shown in Fig. [4] is shaped by fluctuations in the total energy release by muons ($\varepsilon_{\mu}$) crossing GA over a one-second interval: $\varepsilon_{\mu} = N_{\mu} \varepsilon_{l}$, where $N_{\mu}$ is the number of muons crossing RGA per second; $\varepsilon$ is specific energy loss of muons $\mu\text{eV} \text{g}^{-1} \text{cm}^{-2}$; and $l_{\mu} = 2RL/(R + L) \times \rho_{SI} \approx 0.55m (R = 0.3m, L = 3m) \times 2.7 \text{ g/cm}^{3}$ is the mean path of muons crossing GA. Given the average ionization loss $\varepsilon \approx 2 \text{ MeV} \text{g}^{-1} \text{cm}^{-2}$, we find the total energy release of muons, $\varepsilon_{\mu} \approx 80$ GeV.

The integral distribution $N_{\mu}(\geq \zeta)$ and the integral distribution RGA-events $N_{R}(\geq T)$, MGA-events $N_{M}(\geq T)$ have the same features:

- Energy (temperature) values for almost all events (53 out of 55) are between 0 and 100 K, and their distribution agrees with the exponent $\exp(-T/(\langle T \rangle))$; In the range of $\Delta T = 100K$ (from 0 to 100K), the $\langle T \rangle/\langle T \rangle$ ratio decreases by a factor of 3.3 at $\langle T \rangle = (29 \pm 1)K$ and $\langle T \rangle = (31 \pm 4)K \approx 30K$.
- There is an exponential segment of ionization loss distribution with the exponent $\zeta/\langle \zeta \rangle = 0.41$ in the range $\Delta \zeta = 1.35$ (from 0.85 to 2.2); the vast majority (about 96%) of all events $N_{\mu}$ for the entire interval $\zeta \geq 0.85$ is within this range: the $\Delta \zeta/\langle \zeta \rangle$ ratio in the range $\Delta \zeta = 1.35$ decreases 3.3 times.

Therefore, the temperature range $\Delta T = 0$ to 100K corresponds to $\Delta \zeta = 1.35$; so, we can determine the coefficient $k = (\Delta T / \Delta \zeta) = 74$ that connects $\zeta$ and $\langle T \rangle$: $\langle T \rangle = \zeta \cdot k = 0.41 \cdot 74 = 30 K$.

The equality $\langle T \rangle = \langle T \rangle$ is a consequence of the muon origin of the antenna signals. This is due to the fact that, firstly, the total energy release of a large number of muons crossing the antenna during 1 second is proportional to its mass, regardless of its size and spatial orientation, and secondly, the heat capacity of an antenna is also proportional to its mass. Therefore, if characteristics of the muon flux are identical (RGA and MGA were located at almost the same altitude, see Table III), the antennas made of the same material should display the same temperature characteristics associated with muon energy release.
The total signal duration is about 6 hours.

FIG. 4: Left: Differential and integral energy distributions of 55 RGA and MGA events in the vicinity of the LSD signal at 2h52m UT 23/02/1987. Right: Differential spectrum of muon ionization losses \( N_\mu(\zeta) \) measured at sea level and its integral \( N_\mu(\zeta \geq \zeta) \). The abscissa scale \( \zeta \) represents the ratio \( \zeta = \varepsilon / \varepsilon_{pr} \), where \( \varepsilon_{pr} \) is the probable loss of energy; and the ordinate values are arbitrary units.

4. RELATIONSHIP BETWEEN THE Si/Cl AND 6D/6h SIGNALS

The correlation curve shown on the top panel in Fig. 5 (plot derived from Fig. 1 of [20]), is a graphic presentation of the 6D/6h signal at the time window \( \Delta T = 1 \) h. The curve represents the probability \( P_i \) that the correlation curves \( p_i(t) \) for two different setup combinations (LSD–RGA/MGA and KND–RGA/MGA, Fig. 3) are similar to each other; that is, they have the same probability for a fixed time \( t \) (RGA/MGA are coincidences of the events of RGA and MGA antennas with amplitudes above a certain value [16], [18]).

The main characteristics of the 6D/6h signal mentioned above (total duration of about 6 h, the presence of two peaks, and the ratio of their durations) reveal an unexpected similarity with the Si/Cl signal. This similarity between Si/Cl and 6D/6h signals is illustrated by the bottom panel in Fig. 5. The ordinate scale on the left is defined by the function \( N_{cor} = \log(10/P_i) \), where \( P_i \) are the probability values at the selected points of the curve on the top panel in Fig. 5 that match the interval (1 h) between measurements and the their duration (0.5 h) in the Si/Cl experiment. The right scale represents the value of \( \log N_{Si} \), where \( N_{Si} \) is the number of Si decays at points 2 to 7 in Fig. 1; the number \( N_{Si} \) at point 2 is assigned to the time 1h30m of the 6D/6h signal. As indicated above, the interval between measurements for both curves was 1 h. Analysis with a better time resolution at 0.5 h intervals (Fig. 3 in [20]) allowed us to refine the shape of the 6D/6h signal as follows: beginning at \( \sim 0h40m \), duration of the first peak of about 1.5 h (from 2h00m to \( \sim 3h30m \)); then one-hour long dip to \( \sim 4h30m \), followed by a group of peaks during \( \sim 2h \). The total signal duration is about 6 hours.

The accuracy of time bounds determination is \( \pm 15 \) min. The time span of the central coincidence region in this picture agrees with the range of 1h45m to 3h45m in [15], [18] within the margin of error.

5. CONNECTION OF Si/Cl AND 6D/6h SIGNALS WITH GRAVITATIONAL WAVES

We can establish a connection between the Si/Cl and 6D/6h signals if we assume that the 6D/6h signals arise from the response of the local axionic dark matter distribution to a gravity wave.

By hypothesis, axionic dark matter (DM) can directly interact with nuclei, and hence the modified DM distribution can in principle modify nuclear decay rates locally. This mechanism thus provides a natural explanation for time-varying nuclear decay rates as a connection between the Si/Cl and 6D/6h signals.

Non-statistical variations in the intensity of radioactive decays have been reported repeatedly, most recently in [28], [29], [30], [31], [32], [33]. One of the first reliable indications of the possibility of variations (seasonal) has been obtained in an experiment aimed at measuring the half-life of \( ^{32}\text{Si} \) in 1982 – 1985 [34]. The mechanism of these variations remains unknown.

At the time of the Si/Cl and 6D/6h signals, neutrino detectors did not detect any neutrino fluxes. Other than neutrinos from known radiations, gravitational waves would be the only other possible cause of these sig-
nals. Therefore, we consider the possibility of coupling Si/Cl and 6D/6h signals with gravitational radiation. Given the temporal coincidence of the Si/Cl signal with GW170817, along with the Si/Cl and 6D/6h coupling with GW, we consider the effect of gravitational waves on the probability of radioactive decays.

We now demonstrate that the above similarity of the Si/Cl and 6D/6h signals can be explained in terms of a mechanism that is supported by the axion-based model of dark matter Ref. [35].

Following Ref. [35], we consider a generic axion model where “axion” denotes a light pseudoscalar (or scalar) particle with a mass in the range of $\sim 10^{-6}$ eV. On cosmological scales, such particles behave as non-relativistic candidates for dark matter. As noted in Ref. [35], an oscillating pressure arising from axions can induce oscillations in the gravitational potential, which could be detected in principle. In what follows we demonstrate that the preceding mechanism can be inverted to establish that a gravity wave arising from SN1987A or GW170817 can lead to a fluctuation in the local axionic field. This fluctuation can, in turn, couple to the nuclei of radioisotopes such as $^{22}$Si and $^{36}$Cl, and perturb them in such way as to produce the fluctuations observed in the respective decay rates.

Returning to Ref. [35] we consider a class of theories in which the action $S$ is given by

$$S = \frac{1}{2} \int d^4x \sqrt{-g} R + f(R) + S_m$$

(1)

where $R$ is the Ricci scalar, $f(R)$ is a model-dependent function of $R$, and $S_m$ is the matter field arising from axions. To illustrate how this formalism applies to the present work, we follow Ref. [35] and consider a model in which $f(R) = R^2/6M^2$, where $M$ is a constant mass scale. The field equation arising from Eq.(1) can be solved to express the Ricci scalar $R$ in terms of the dark matter density $\rho_{DM}$, as was done in Ref. [35]. However, for present purposes we are interested in how a changing gravitational field arising from SN1987A can influence the local dark matter density $\rho_{DM}$, through a time-dependent contribution from the Ricci scalar. From Ref. [35] this time-dependence is given by

$$\rho_{DM} = R(t) \frac{1 - (2m/M)^2}{[1 - (2m/M)^2] + 3\cos(2mt)},$$

(2)

where $m$ is the axion mass. We note from Eq.(2) that a time-dependence of $\rho_{DM}$ can arise from both a change in the gravitational field given by $R(t)$, and an explicit time-dependence of the axionic field arising from $\cos(2mt)$.

The preceding discussion is a model of how a time-dependent gravitational field arising from SN1987A or GW170817 could produce the time-dependent signals discussed above, through changes in the local axionic dark matter density $\rho_{DM}$. Axionic dark matter can influence unstable nuclei through a variety of mechanisms, particularly those with a relatively small $Q$-value. As shown in Ref. [36], a perturbation as small as 50 eV would induce a change of $\pm 1\%$ in tritium decay, which is typical of changes detected in other radionuclides, undergoing $\beta$-decay. For $\alpha$-decays, the results can be even more dramatic. As will be shown elsewhere [37], an increase in the $Q$-value of $^{222}$Rn by a few eV can change its decay rate by several orders of magnitude. These observations raise the prospect of using fluctuations in $\alpha$- and $\beta$-decays to study astroparticle phenomena, as well as a means of predicting solar storms.

6. CONCLUSION

We have discussed effects with manifest themselves against the background of weak statistical fluctuations in the rates of decay of nuclei in samples. In two samples the effect appears as a decay synchronization, rather than a change in the overall decay rate. An indication of the conservation of the decay constant in the presence of short-term (seasonal) variations in the decay rate follows from the precision measurement of the lifetime of the long-lived $^{32}$Si isotope [34].

The connection of the Si/Cl and GW170817 signals is confirmed by the extremely low probability of their random coincidence. This relationship indicates the possibility of the influence of GW on the probability of decays by means of a fluctuation in the local axionic field.

On the other hand, the existence of a 6D/6h signal is an established experimental fact. Assuming that the 6D/6h signal is associated with the SN1987A burst, and based on the similarity of the shape and origin of the Si/Cl and 6D/6h signals, we can conclude that the 6D/6h signal is caused by the GW from the merger of the compact binary mass system.

Since no neutrino radiation was detected in the vicinity of the LSD signal at 2h52m, we propose that GWs were emitted by a system of two fragments of the star iron core that had disintegrated at the initial stage of collapse. Fragments of the precollapsar were losing energy mainly due to GR and then, after the merger, collapsed into NS, producing the neutrino burst recorded at 7h45m UT. A similar scenario following the disintegration of the newborn neutron star and subsequent merging of its fragments is discussed in [38].

The possibility of inducing a signal which reaches the Earth depends on the distance to the source, the inclination of the binary mass system rotation plane relative to the direction to the Earth, and the GR energy. The availability of the Si/Cl signal shows that, in the case of GW170817, a combination of these conditions and the sensitivity of the Si/Cl experiment contributed to detection, despite the distance to the galaxy NGC4993, which
is three orders of magnitude greater than the distance to SN1987A. It is difficult to say anything about the sensitivity of other detectors that could have detected weak indications of variations in the radioactive background at the time of the GW170817 signal. This is because the coincidences of the background events in the detectors were not analyzed in the temporal vicinity of the signal according to the method employed in [14, 15, 16, 17, 18, 19, 20].

The sequence of events considered above, which admits the action of gravitational field variations on the probability of radioactive decays, indicates the possibility of an additional channel for obtaining information about catastrophic astrophysical phenomena.

We have now demonstrated that signals from catastrophic phenomena such as SN1987A and GW170817 can also be detected via synchronous changes in locally measured radioactive decay rates, along with traditional technologies such as neutrino detectors and gravity wave detectors. Given the availability of a large number of $\alpha$-decay and $\beta$-decay radioisotopes, with a wide variety of half-lives and Q-values, it seems likely that suitable candidates can be found to constitute a new useful detection system.

We conclude this discussion by noting that one implication of the present work is that the similarity of the SN1987A and GW170817 signals lends further support to currently popular models of dark matter based on light axions.

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* Electronic address: Agafonova@inr.ru

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