MODERN TREND OF THE GRAVITATIONAL WAVE DETECTION

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ABSTRACT. A brief review of the gravitational wave detection is presented and some modern approach in the gravitational wave experiment is considered. In addition to the old method of searching for coincident reactions of two separated gravitational antennae it was proposed to seek perturbations of the gravitational detector noise background correlated with astrophysical events such as neutrino and gamma ray bursts which can be relaibly registered by correspondent sensors. The problem of optimal algorithms for this approach is discussed. The importance of the question is demonstrated in reanalysis of the old data concerning the phenomenon of neutrino-gravity correlation registered during of SN1987A explosion.

Key words: Gravitational waves

A conventional scheme of the gravitational wave experiment on searching for stochastic bursts of gravitational radiation from astrophysical sources supposes a registration of coincident reactions of two or more spatially separated gravitational detectors. It was considered as only way to establish a global nature of the detected signal which probably could be a metric perturbation associated with gravitational wave if the detector's isolation was good enough (Weber, 1960). A realization of this scheme requires at least two identical gravitational antennae located in different points of the globe with good synchronized clocks, good communication etc. Although this ideology is known already thirty years the coincident experiment in automatic regime was performed only by J.Weber during his first observation with room temperature bar detectors located in Chicago and Maryland (Weber, 1969, 1970). Later the "coincidence searching" episodically have been done by several groups as a rule in the form of joint data analysis of the electronic records of both setups *a posteriori* but not on line. The recent example of such procedure with cryogenic antennae EXPLORER and ALLEGRO is presented in the paper (Astone et.al., 1994). A reason why the detection of coincidences "on line" was replaced with analysis *a posteriori* is obvious. The "on line" regime (although it's very convenient and effective) requires an additional electro- communication equipment. Besides it could be easy realized if the same research group would have two equivalent detectors in disposal (like it was in "time of room temperature bar detectors") but a complication and large cost of modern cryogenic and interferometrical set up makes it difficult in general. In nearest future the automatic selection of coincidences probably will be realized with two large scale interferometric antennae which are under construction now in the LIGO project (Abramovici et.al., 1992). At present however the coincidence analysis *a posteriori* is considered as the only way of investigation stipulated by a presence of two gravitational antennue in simultaneous operation with equivalent sensitivity.

In last years another type of gravitational wave experiment was discussed. The idea is to search weak perturbations of the gravitational detector's noise background correlated with some astrophysical events such as neutrino and gamma ray bursts (Bemporad, 1995; Michelson, 1995; Modestino & Pizzella; Gusev et.al., 1998). The reason of this approach lies in the understanding that last stages of star evolution (such as supernova explosion, binary coalescence, collapse etc.) traditionally considered as the gravitational burst sources have to be accompanied also by neutrino and very likely gamma radiation. It means in general that a detection of neutrino or gamma ray bursts by appropriate sensors defines time marks around which one might hope to find also exitations of the gravitational detectors. An advatage of this method consists first of all in a remarkable reduction of the observational time interval and second in a potential opportunity to accumulate weak signals. The last point is especially interesting taking into account a deficit of required sensitivity of the gravitational detectors available at present in the world laboratories.

The theoretical presentation of the neutrino bursts produced by collapsing stars at the end of stellar evolution is well known, see for example (Nadezhin & Otrochenko, 1980; Browers & Wilson, 1982; Bethe, 1982). According to the theory a total energy released in the form of neutrino radiation of all flavors has the order of value $0.1M_{\odot}c^2$ and a time scale of several seconds (2-20 s) This radiation can be detected (mainly due to the inverse β-decay reaction) if a source is located not too far from the Earth $(10 \div 100)kpc$. Correspondent experimental programms ("Supernova Watcher") are accepted and carried out by the all neutrino groups having appropriate liquid scintillation detectors (Aglietta et.al.1986; Alexeyev, 1988) or water cherenkov detectors (Bienta et.al, 1983; Hirata et.al., 1988). Moreover the first registration of neutrino flux from supernova as it believes was fixed during of SN1987A explosion (Aglietta et.al.1987; Hirata et.al., 1987; Bionta et.al.1987; Alexeyev et.al.1989). All this programms are orientated on the search of collapsing stars in the Galaxy and close local groups i.e. expected average rate of events is 3 per 100 years (Aglietta et.al., 1987). It is unlikely to wait a large increasing of penetrating power from the neutrino telescopes in nearest future. So Super Kamiokande detector with effective mass in ten times larger allows a detection of 150 neutrino events per year from LMC but only one event from Andromeda (Takita, 1993). It is unrealistic to relay on a detection neutrino from supernova in the Virgo Claster $(15 - 20Mpc)$ which considered as one of the principal sources of a signal for gravitational detectors. Thus a search of correlations between noise backgrounds of neutrino and gravitational wave detectors is limited by the condition of very low event rate $(3 - 10)10^{-2}y^{-1}$ and an opportunity of "signal-noise enhancing" through some integrating procedure practically is absent. Although an expected amplitude of a solitary gravitaional pulse signal might be relatively large up to 10^{-18} in term of metric perturbation from a source in the center of Galaxy.

The other astrophysical phenomenon of our interest, gamma-ray bursts, looks more propitious although it still remains to be confused (Fishman 1993). The main attractive feature of this phenomenon is a relatively high event rate, on average one per day. The large energy emission evaluated for some registered gamma bursts up to the $0,1M_{\odot}c^2$ together with amplitude short time variations on order of $0,1s$ implies to relativistic stars as burst sources. In process of study of this phenomenon two principal scenarios have been considered in respect of the gamma-ray bursts nature. The first one suggests its galactic origin associated with high velocity pulsars distributed not only in the galactic disc but also in the Halo (Belli, 1997). The second scenario appeals to a cosmological picture in which gamma bursts are produced during catastrophic processes with relativistic stars such as collapses, binary coalescences, supernova explosions in distant galaxies (Wijers, 1998). Thus the both scenarios deal with objects that have been considered also as sources of gravitational radiation. Galactic pulsars could produce only very weak GW-bursts as a result of "starquakes" with equivalent metric perturbation on the Earth of order of $10^{-23} \div 10^{-24}$ (Thorn, 1995) for a source in center of Galaxy. However authors of the papers (Bisnovatyi-Kogan, 1995; Komberg & Kompanets, 1997) believe that even a more close pulsar population in vicinity $100pc.$ might provide an observable rate of gamma events ~ 5 per month through mechanizm of "starquake". Then a correspondent GW burst amplitude would be awaited on the level of $10^{-21} \div 10^{-22}$. In the cosmological picture, if one includes into consideration binaries with back hole components the astrophysical forecast gives the GW-burst event rate up to 30 per year at a metric amplitude level of 10^{-21} in the solar vicinity of 50-100 Mpc (Lipunov et.al. 1995; Lipunov et.al, 1997). This estimation was found supposing that only 10^{-4} part of stellar rest mass energy could be converted into gravitational radiation. A more optimistic value of the convertion coefficient 10^{-2} used in the other papers (Sazhin et.al. 1996; Imshennik, 1992) would increase the expected metric amplitude up to 10^{-20}. The recent results obtained with BeppoSAX satellite and Keck II telescope permitted to confront the gamma-ray burst GRB971214 with a galaxy having the redshift of $z = 3.4$. The other case is the burst GRB970508 with an optical counterpart at $z \geq 0.835$ (Kulkarni et.al., 1998). That is the strong evidence of the cosmological nature at least for a part of the registered bursts. Along with these very far sources (1-10) Gpc. more close events were registered. For example the burst GRB980425 probably was associated with an optical object type of supernova explosion at the distance 40 Mpc. $(z = 0,08)$ (Galama et. al., 1998). It is not completely clear how the gamma radiation could penetrate through envelope of supernova, how the black hole coalescence could release the gamma burst, but the energetic of observable events definitely requires scenarios with a crash of relativistic stars and therefore an expectation of the gravitational radiation accompaniment seems reasonable. Moreover the energetic estimation of the GRB971214 burst $\sim 2 \cdot 10^{53}erg$ even exceeds a conventional theoretical electromagnetic energy release $10^{51}erg$ for supernova or neutron star binary merging (Ramprakas, 1998). It makes the models of black hole binary mergers or rapidly rotating massive black hole with accretion, so called "hypernova" (Pachinski, 1998), more attractive and at the same time they are more promissing in respect of the gavitational wave output.

Thus there are serious theoretical prerequisites to search for gravitational bursts around time marks defined by correspondent events of neutrino and gamma-ray detectors. Now lists of desirable events can be provided by the four world neutrino telescops and cosmic CGRO (BATSE) and BepoSAX satellites. In this situation the key question is a sensitivity of the gravitational detectors which are in operation at present. In fact this is only supercryogenic resonance detector "NAUTILUS" (INFN, Frascati) and similary set up "AURIGA" (INFN, Legnaro) could achieve the sensitivity level 10^{-21} for short bursts $\sim 10^{-3}sec$ (Astone et.al., 1997). The two cryogenic detectors mentioned above "ALLEGRO" and "EXPLORER" have the short burst sensitivity $6 \cdot 10^{-19}$ i.e. of 2, 5 orders less the desirable value. However it worth to note here that for more long signals the estimation of its sensitivity must be increased up to 10^{-21} for burst duration close to $1 sec$ due to accumulation of signal cycles (see detailes in Gusev et.al. 1997).

Generally an improvement of detection sensitivity depends on our knowledge of the signal structure, arrival time etc. In this sense a theory does not provide us a large assortiment of models for gravitational signal. Mostly its energetic part might be presented by a short pulse with several cycles of carrier frequency ($10^2 - 10^3$) Hz (Thorn, 1995). There is a deficit of models with joint description of the gravitational, neutrino, and gamma radiation output. Some examples one can find in the papers (Thorn, 1995; Sazhin et.al. , 1996; Imshennik, 1992; Zakharov, 1996) where multistage scenarios of gravitational collapse were considered in the processes of neutron star formation and star remnants coalescence. In such approach a packet of the neutrino pulses separated by time intervals from few seconds up to several days accompanied by gravitational bursts was predicted with a total energy release up to one percent of the rest mass. The multi-stage scenario is also typical for collapse of massive star with large initial angular momentum (Thorn, 1995). A radial matter compression there might be interrupted by repulsing bounces, fragmentation, fragments mergers or ejection of one of them etc. In principle each of these stage could produce gravitational, electromagnetic and neutrino bursts but a detaile description of such models has not yet been developed. Entirely inspite of obvious uncertainty of joint scenarios and unknown event rate of complex collapses in the Universe an expectation of the multi-pulse structure for a gravitational signal associated with a packet of neutrino and gamma ray bursts is enough grounded at present.

The argumentation above stimulates one to define an optimal data processing of the gravitational detector output in parallel with a record of astrophysical events registered by neutrino or gamma ray observatories. A simple comparison with an attempt to find coincidences is insufficient due to an inevitable unknown time delay between events of different nature but mainly due to a deficit of gravitational and neutrino detector sensitivity. Partly for this reason the attepmts of searching for correlation between neutrino-gamma data (Aglietta et.al., 1995) and gamma-gravity data (Astone et.al., 1999) were not successful. It has to be done according to the optimal filtration theory taking into account all available information concerning of noise background and conceivable model of signal (Helstrom, 1968).

Thus the one actual problem of GW-experiment is to formulate some optimal algorithm of searching for a correlation of neutrino as well as gamma-ray events with stochastic background of gravitational detectors. The example of solution this problem was given by the RTM-collaboration when this group reported about the "neutrino-gravity correlation effect" registered by two room temperature bar detectors in Roma and Maryland and Torino neutrino scintillator under Mont Blanc (Amaldi et.al., 1987; Aglietta et.al., 1989, 1991).

The RTM-algorithm consisted in composing the following variable

$$Z = \sum_{k=1}^{n} (1/2)(R^2(t_k + \tau)/\sigma^2) \qquad (1)$$

which was the sum of quadratic values of the overlope of output antenna process (in fact the detector energy variations) taken in times of astrophysical events i.e. registered neutrino time marks t_k, with some small shift τ ; the sum was accumulated on the interval of observation which *aposteriori* contained n events. (A physical sense of this variable becames clear after normalization (1) on the total number of the events: then it is a "selected mean value" of the detector energy variations corresponded to the astrophysical events.) Thus the RTM group having deal with Z-variable (1) have found under a special shift $\tau = 1.2 sec$ the relatively large experimental value $Z/n = 72.3K$ fixed in the night Feb 22-23 when SN1987A was exploded. To estimate a chance probability this value was compared with an empirical statistics extracted from the gravitational data according to simulated neutrino piossonian time marks. This procedure resulted in the extremely small chance probability for the registered Z-value on order of 10^{-6}. It was interpreted as a fixation of the remarkable (νg)-correlation produced by SN1987A.

However later in our paper (Rudenko et.al., 1999) it was shown that a formal application of the Maximum Likelihood Principal to the problem leaded to some correction of the optimal variable. It was recommended to find an absolute maximum of Z through variation of the shift τ , i.e. to get over a new so called "absolute maximum -variable"

$$Z_{max} = max_\tau Z(\tau), \quad \tau \in [\tau_{min}, \tau_{max}] \qquad (2)$$

A value of τ_{opt} which provides a maximum of $Z(\tau)$ should be taken as MLP-evaluation of the real time shift between astrophysical event and gravitational signal (in our simple approach the shift is supposed to be the same for all events, - a hypothesis of "homogenity of events"). It was remarked in [44] that there was no a definition of the τ-interval limits inside of the statistical model; it has to be choosed on a base of additional physical arguments, astrophysical scenarios etc.

In our reanalysis of the RTM data we confirmed the same experimental value of Z variable (72.3 K). However according to the developed MLP-algorithm the estimation of the chance probability now had to be done on the base of Z_{max} statistics (2) instead of Z.

Such method takes into account an increase the chance probability due to selection of the "optimal time shift" between gravitation and astrophysical (neutrino) data. As we found a new estimation of the chance probability was reduced to the value 10^{-3} which was also not too large. Unfortunately a reliabilty of this estimation occasionally was suffered from the fact that sampling times of gravitational (1 sec) and neutrino (0.01 sec) data were different and neccessity of some interpolation procedure introduced an additional uncertainty resulted in the value 10^{-2} for the chance probability. Thus our MLP-algorithm have shown that the available experimental data of RTM group were insufficient to make a robust conclusion in favour of (νg)-correlation effect.

The example with SN1987A gave enough presentation how the MPL-algorithm could work exhibiting clearly at the same time its weak point: a dependence on the unknown range of time shift between astrophysical and "gravitational" events. An *apriori* estimation of it on physical arguments is desirable to provide an efficiency of the algorithm. Any attepmts to limit this range appealing to specific of the experimental data or particular manner of opreator behaviour under searching for the "signal exitation Z_{exp}" do not lead to "objective boundaries" for time shift variations and thus a correspondent evaluation of the chance probability remains to be suspended. Only an apriori knowledge of the time shift range could introduce some certainty (deterministic elements) in this ill posed problem. In the extremely favourable case when the value of shift is known exactly the estimation of chance probability can be taken just from Z-distribution which is much more robust then Z_{max}-distribution.

In the case of gamma ray bursts the problem of "optimal algorithm" probably will be more difficult due a complex structure of gamma pulses, uncertaties in its time position, duration , unhomogenious form etc. and unclear nature of this phenomenon itself. Nevertheless as a final remark we should like to emphasize that the modern approach to gravitational wave experiment discussed in this talk stimulates a research activity in two directions: the first is a development of more detailed joint scenarios for neutrino-gamma-gravity radiation sources, the second is an elaboration of more robust filtering data processing procedures which could be free from subjective elements in estimation of statistical errors.

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