The joint search for gravitational wave and low energy neutrino signals from core-collapse supernovae: current status and future plans

Maxim Gromov (SINP MSU, JINR), Z. Bagdasarian, C. Casentini, V. Fafone, W. Fulgione, A. Habig, O. Halim, K. Ishidoshiro, E. Katsavounidis, L. Koepke, G. Pagliaroli, K. Scholberg, A. Sheshukov, M. Szczepanczyk, M. Strait, G. Testera, C. Vigorito, L. Winslow, D. Xu, K. Zuber (the GWNU group)

Abstract

One of the possible scenarios of the multimessenger astronomical studies is the joint search for gravitational wave and low energy neutrino signals from core-collapse supernovae. This activity is pushing forward by the intercollaboration community called the GWNU group. The network includes six neutrino detectors and three gravitational wave observatories. The research is based on two principle approaches. They are an offline analysis of the shared archival data and the online or low-latency alarm system. For the moment the former has been continued since the end of 2014, the latter is under preparation and can be realized within the framework of the SNEWS 2.0 system. Aspects of both approaches are reviewed in the report. In particular, general requirements, common software, data formats, selection and coincidence search algorithms are described briefly. The possibilities of source localization in the sky and determination the distance to the collapsed star are discussed.

GWNU group

ν detectors	IceCube	KamLAND	LVD	Borexino
GW detectors	LIGO	VIRGO		
Accession	NOνA	JUNO		
Prospects	KM3NET	MicroBooNE	XENON1T	

General description and requirements

Propositio maxima: keep as much data as possible after cuts and minimize the misidentification probability. Original idea [1].

Recipe: the detector network allows to reduce the accidental background of the measurement and the study of the characteristics of the events/bursts/signals leads to a decrease in the misidentification probability.

Current method of combining data:

- Every event/burst/signal in any single detector is chosen based on the parameter called the False Alarm Rate or simply the FAR.
  The FAR is a number of accidental background fluctuation above the SN detection threshold per time unit (day or year).
- Search for any coincidences in the network by means of calculation of the Joint False Alarm Rate and classification with this parameter.
  The joint FAR is a number of accidental coincidence of detector signals in the network. The joint FAR R_{joint} is given by

$$R_{\text{joint}} = \prod_{i=1}^{N} R_i \times (2t_{\text{coin}})^{N-1},$$

where R_i – FAR for the i detector, t_{coin} is a coincidence window between GW and ν signals. Conservative approach: $t_{\text{coin}} = 10\,\text{s}$.
The factor "2" appears due to unknown time order of signals.

- Observation reliability: by multiple mutual shifts of the data in time.

Offline and online analyses

Both analyses have a similar methodology [2] but the low-latency search requires fast data processing online. The low-latency GWNU analysis may coincide with the SNEWS analysis differing in trigger levels and, accordingly, in the frequencies of sending alerts as well as in the method of combining data. The joint FAR may not be applied for the SNEWS 2.0. It is better to merge the GWNU analysis within the SNEWS 2.0 but the special processing queue is necessary.

Source localization in the sky

Source localization in the sky can be done by triangulation either within the LIGO–VIRGO subnetwork or within the neutrino detector subnetwork or within the whole GWNU network. The required uncertainty of determining the time is not more than 1 ms [3].

References

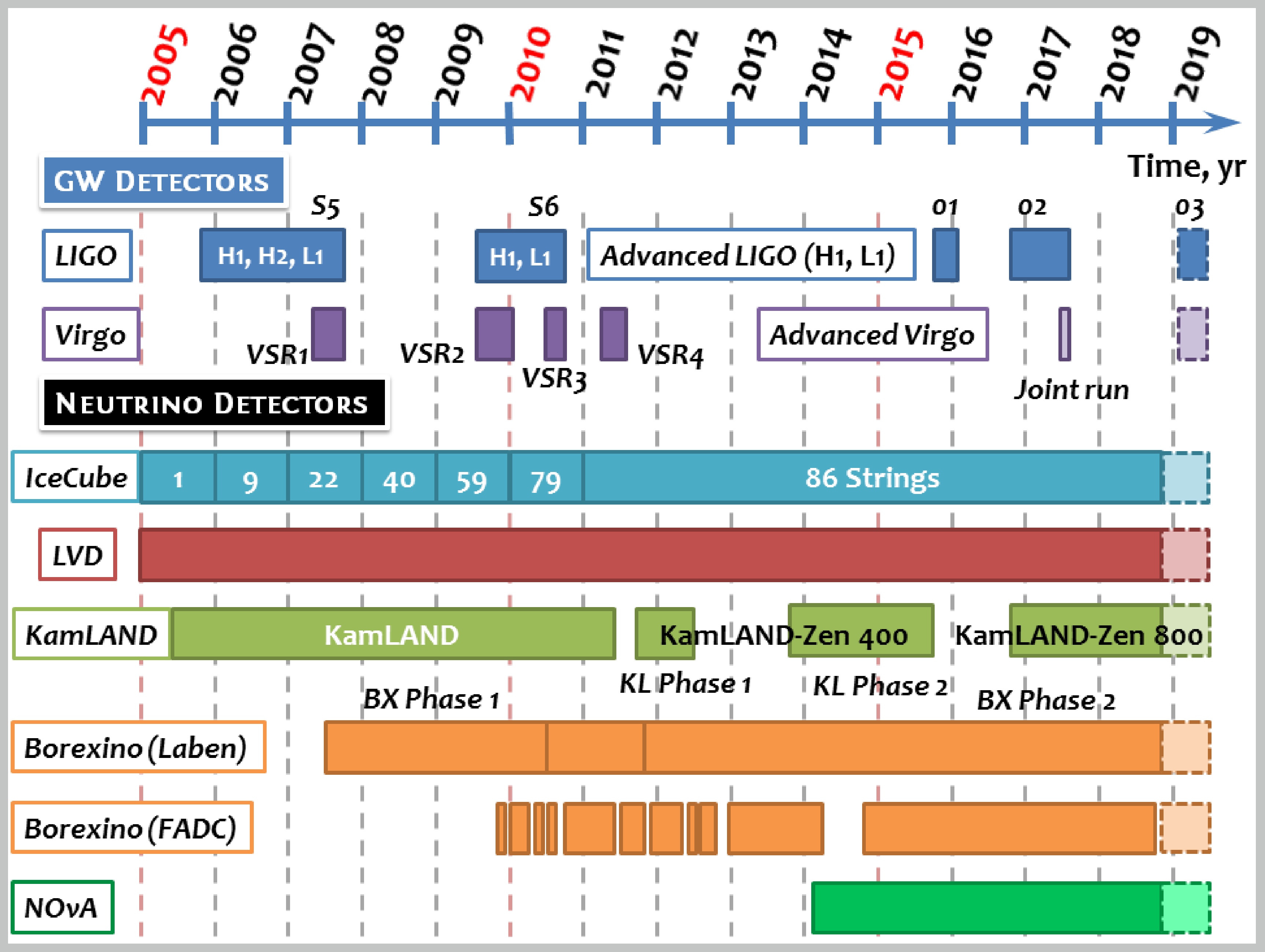
[1] Leonor I *et al.* 2010 *Class. Quant. Grav.* **27** 084019 (*Preprint* 1002.1511)

[2] Gromov M B and Casentini C 2017 *J. Phys. Conf. Ser.* **888** 012099

[3] Pagliaroli G *et al.* 2009 *Phys. Rev. Lett.* **103** 031102 (*Preprint* 0903.1191)

[4] Casentini C *et al.* 2018 *JCAP* **1808** 010 (*Preprint* 1801.09062)

Data collected by experiments



Data formats for sharing

Before sharing: processing at the level of each detector
Only information about selected events/bursts/signals
Every detector must provide **two types of data lists**

- for the coincidence search

GPS time of the burst start (s)	FAR (events/day)

- extra information for further investigation

For LVD, Borexino, KamLAND, JUNO		
multiplicity	FAR (ev/day)	GPS start time (s)
GPS start time (ns)	duration (s)	real duration (s)
ξ (ev/s)	mean energy (MeV)	after muon?
energy (MeV)	time (us)	

For IceCube and NOνA	under discussion

For LIGO and VIRGO		
SNR	FAR (ev/day)	GPS start time (s)
GPS start time (ns)	duration (s)	frequency band (Hz)
strain range ($10^{-21}\,\text{Hz}^{-1/2}$)		

Common software and repositories

LNGS Linux Cluster and JINR GitLab

- Coincidence code (for any network configuration)
- Burst selection for a Borexino-like detector
- Adding ξ parameter
- Time conversion
- GWNU Makefile example
- Shared data

JINR GitLab

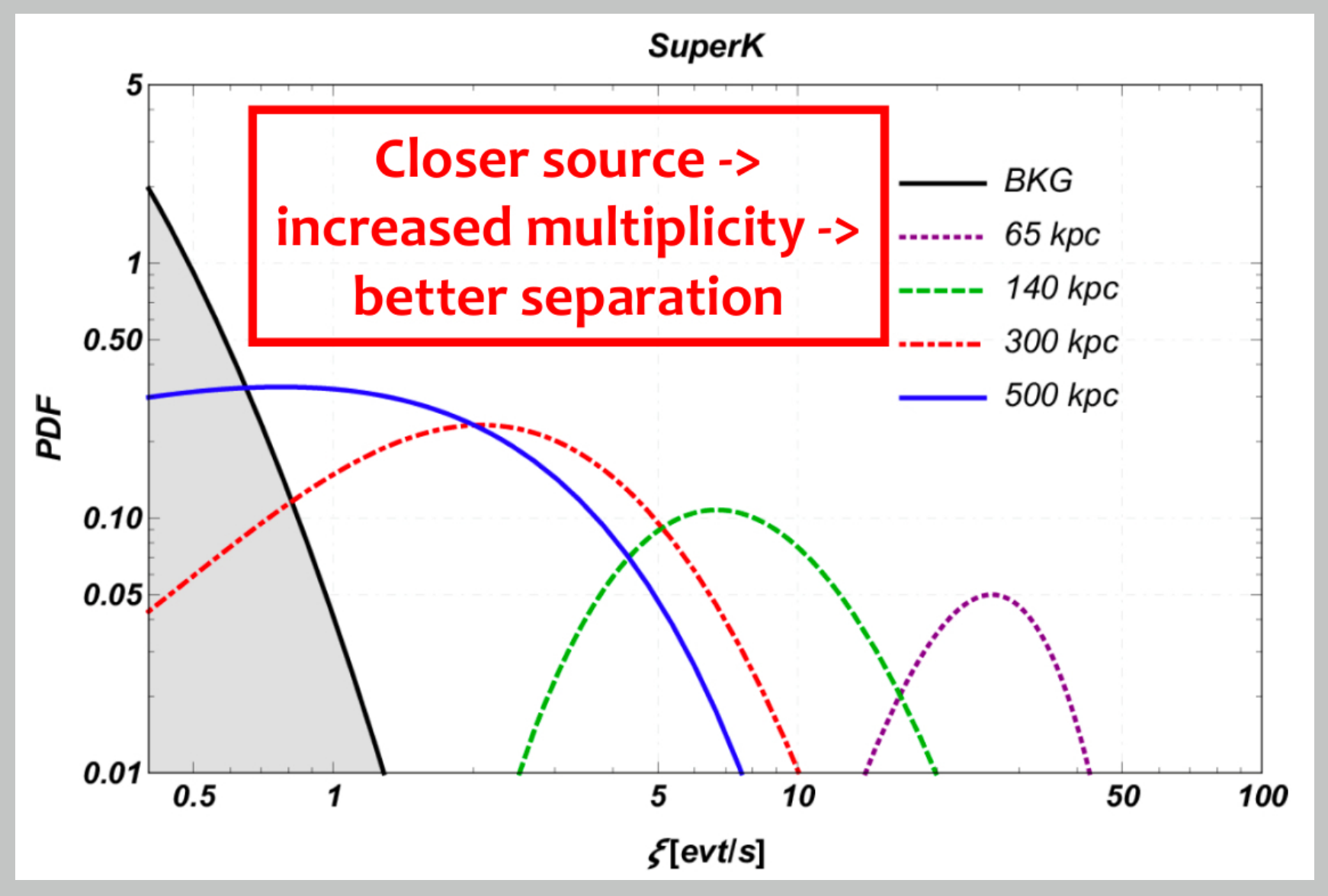
Distance determination to a supernova using neutrino detectors

Toy study [4]
(blemish: model-dependent)

For a particular detector i

$$\xi_i = \frac{m_i}{\Delta t_i},$$

where m_i - event burst multiplicity,
Δt_i - real duration of the burst.



Distributions of pure background and background plus signal clusters in terms of Probability Density Functions (PDFs):

$$\Xi[\xi]_i(D) = \int_0^{\bar{\xi}_i} \text{PDF}_i^{\text{bkg}} d\xi + \int_{\bar{\xi}_i}^{\infty} \text{PDF}_i^{\text{sig+bkg}}(D) d\xi$$

Looking for the $\bar{\xi}_i$ that maximises this function for the distance D.
Also possible to reduce the misidentification probability. See details [4]

Common software and shared data: `https://git.jinr.ru/gwnu-and-snews/gwnu/`

`gromov@physics.msu.ru`