Coincident search for gravitational-wave and neutrino signals from core-collapse supernovae

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Proposal for joint neutrino-GW search for nearby core-collapse supernovae

"Propose multi-stage collaborative work among gravitational-wave and stellar collapse neutrino communities that will put both in a better position to detect and extract the science of nearby core-collapse events in the immediate and near future."

Neutrino community

- S D'Antonio
- A Di Credico
- V Fafone
- W Fulgione
- K Scholberg

Theory/Phenomenology

- C D Ott
- G Pagliaroli
- F Vissani

LIGO-Virgo community

- L Cadonati
- E Coccia
- R Frey
- E Katsavounidis
- I Leonor
- C D Ott
- G Pagliaroli
- E Thrane

Motivations for joint neutrino-GW nearby supernova search

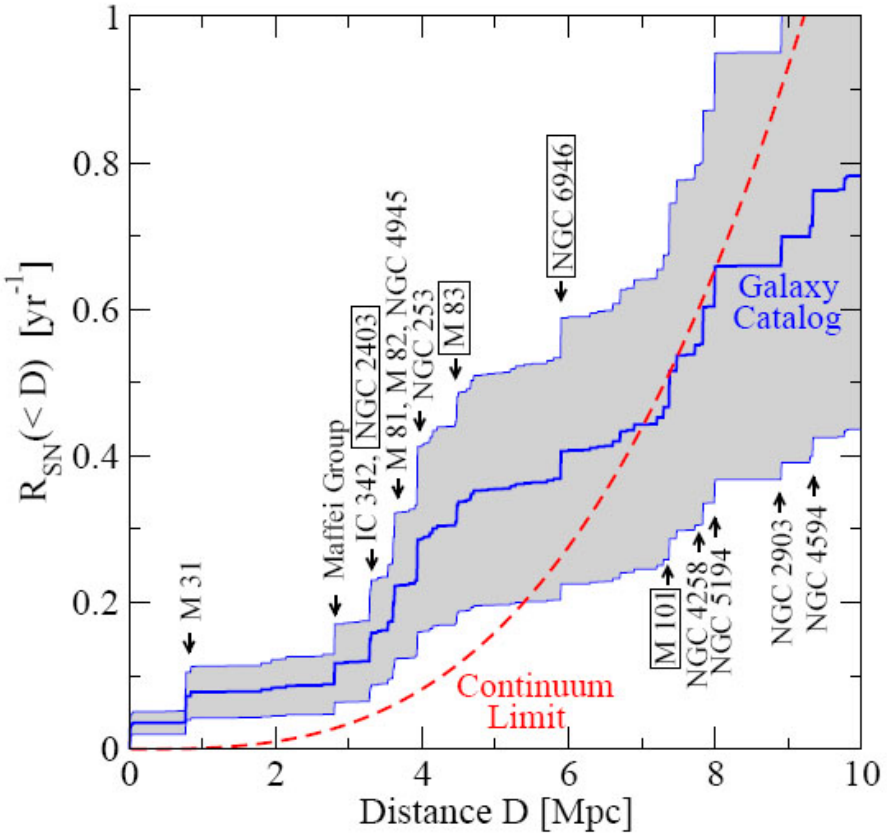
- neutrino signal and gravitational-wave signal from core-collapse supernova are expected to be prompt and occur within a short time window (~seconds) of each other
  - onset of optical signal would be detected ~hours later
- both neutrino and GW signals would probe the innermost region of a SN core
- some supernovae might be optically dim but would still be seen in neutrinos and gravitational waves
- current generation of neutrino and GW detectors are expected to be sensitive to signals from Galactic/nearby supernova
- joint search will allow for shorter time windows and will tolerate higher single-detector false alarm rates, i.e. detection thresholds can be lowered
- use of worldwide network of neutrino and GW detectors will increase detection live time

➔ **Increased sensitivity to supernova event**

Estimates of Galactic and nearby core-collapse supernova rate

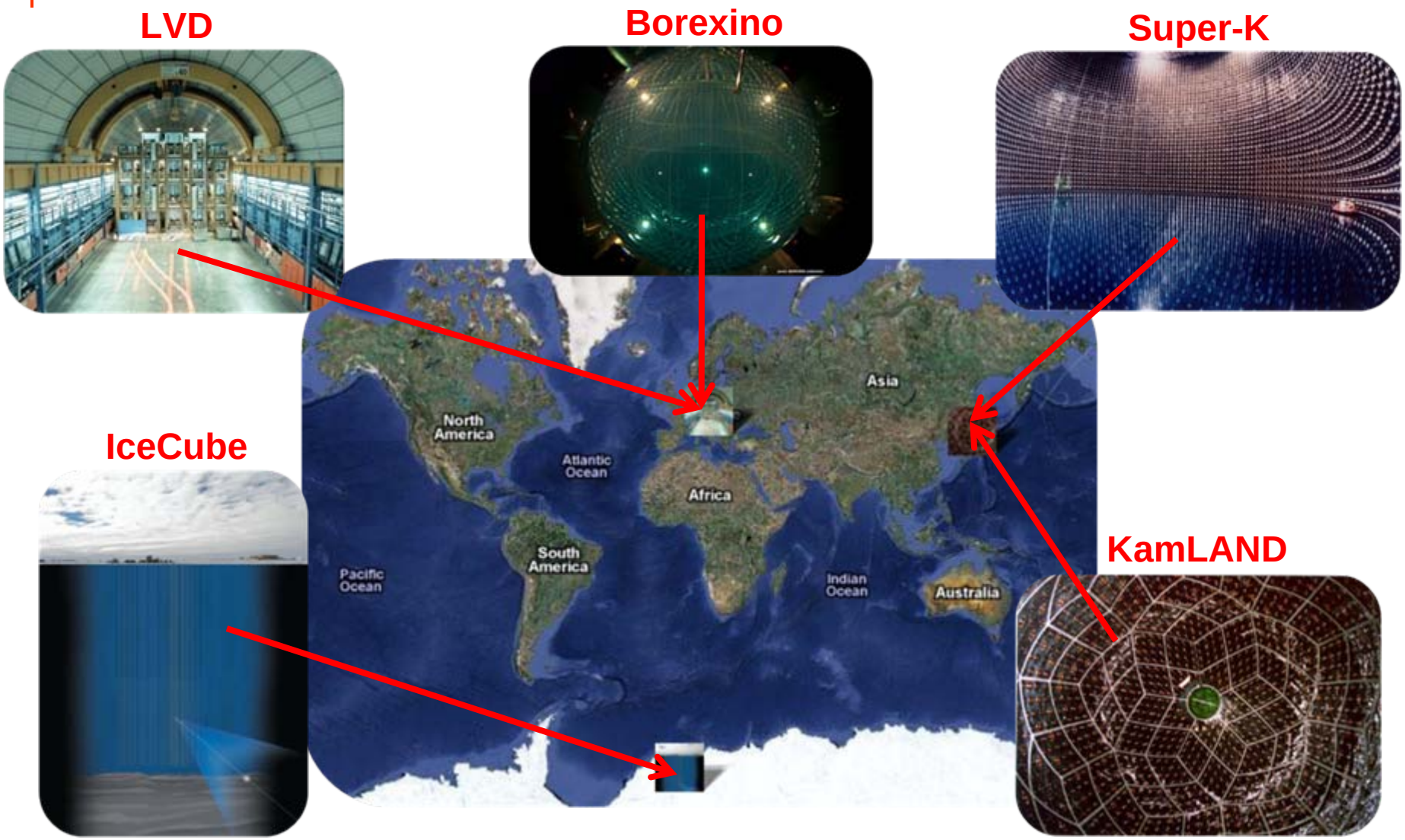
- estimated Galactic rate is a few (~3) per century
- estimated rate in Local Group (out to ~1 Mpc) ~twice the Galactic rate
- ~1 per year out to the Virgo cluster
- observations indicate that the true nearby SN core-collapse rates could be higher than these estimates (e.g. ~3 times higher, using observed SN in 2002-2005)
- electromagnetically dark or obscured SN would also bring uncertainties to these rates

Ando, S. et al. 2005, PRL, 95, 171101



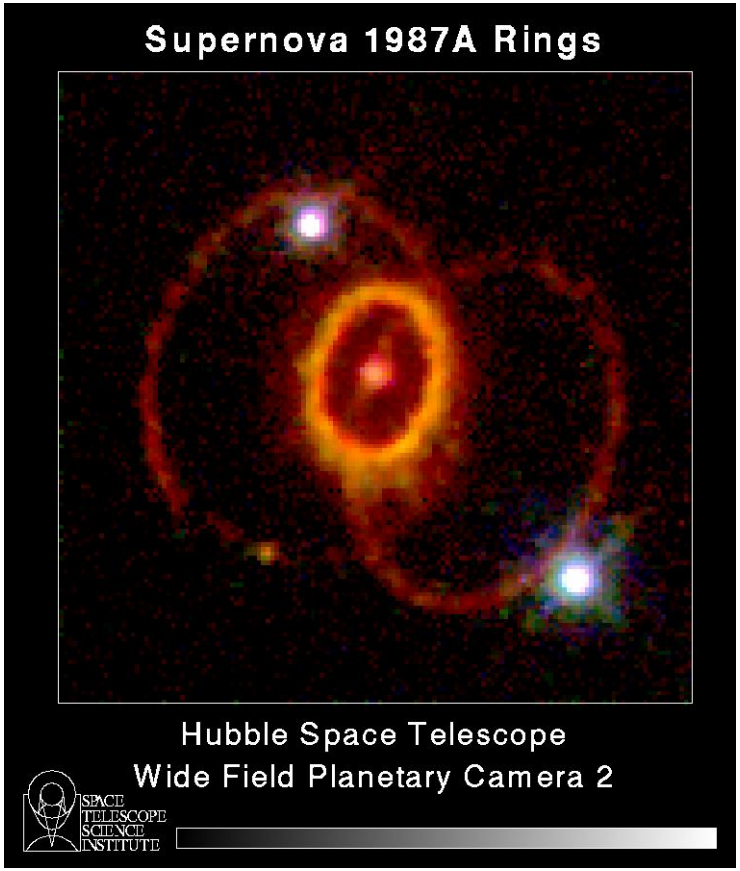
Global network of GW detectors

Some neutrino experiments with SN detection capability



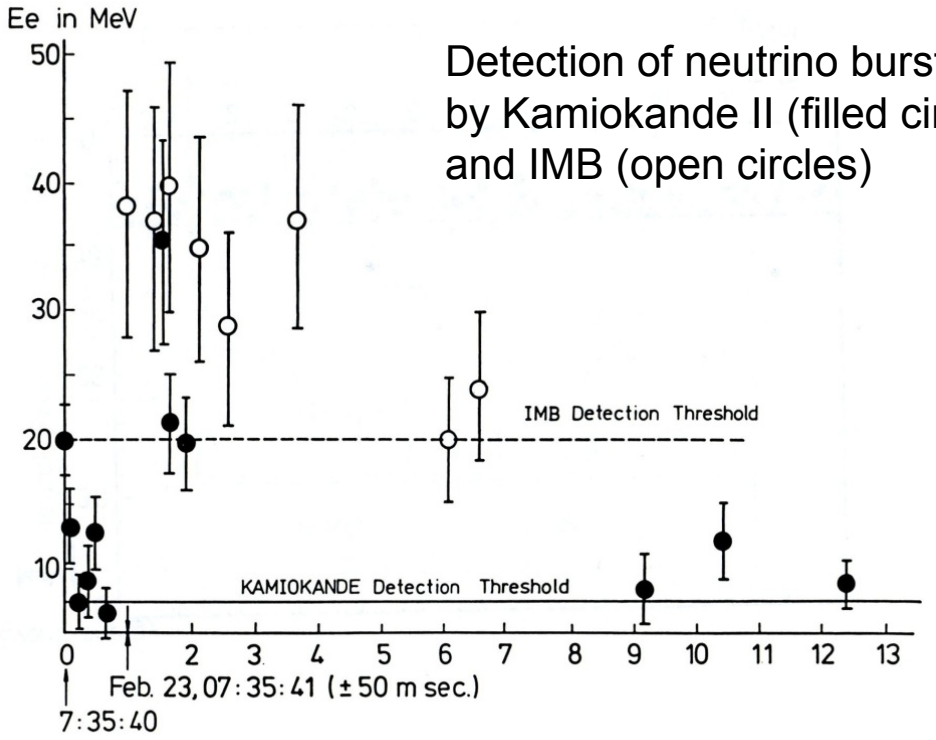
Neutrino signal from supernovae: SN 1987A

- in core-collapse supernova most (~99%) of the gravitational binding energy (~3E+53 ergs) is released in the form of neutrinos of all flavors
- neutrino energies are in the ~few tens of MeV range
- ~1E+58 neutrinos are emitted over a time scale of ~few tens of seconds
- neutrino burst from SN 1987A in LMC (~50 kpc) was detected by neutrino experiments



Neutrino signal from supernovae: SN 1987A

Koshiba, M. et al. 1988, in "SN 1987A in the LMC"



Detection of neutrino burst
by Kamiokande II (filled circles)
and IMB (open circles)

~13 seconds

Anglo-Australian Telescope
(~1 month after SN)

first optical sighting occurred
~a few hours after time of neutrino burst

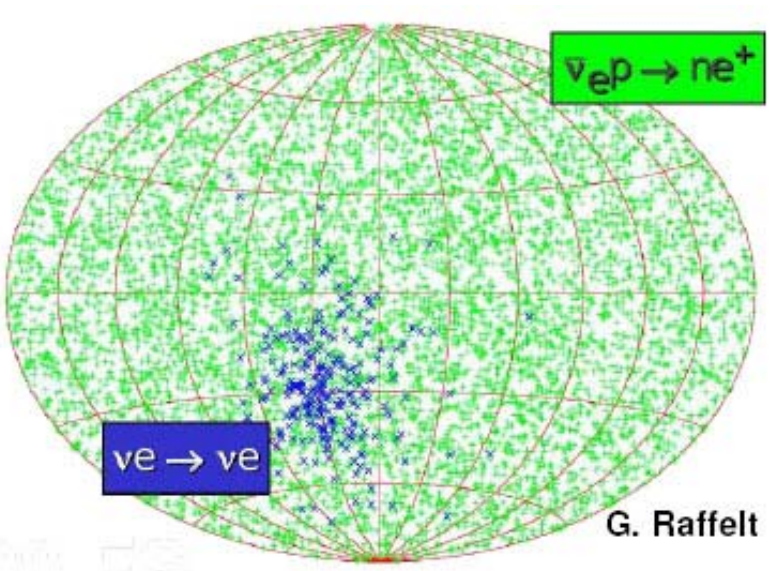
Rough estimates of sensitivity of some neutrino detectors to core-collapse SN at 8.5 kpc

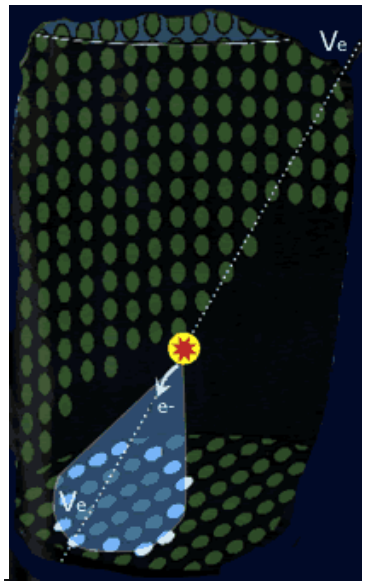
Detector	Type	Mass (kton)	Location	Events at 8.5 kpc	Live period
Super-K	H_2O	32	Japan	8000	1996-present
SNO	D_2O	1 (D_2O)	Canada	400	1999-2006
		1.4 (H_2O)		450	
LVD	C_nH_{2n}	1	Italy	300	1992-present
KamLAND	C_nH_{2n}	1	Japan	300	2002-present
Borexino	C_nH_{2n}	0.3	Italy	100	2005-present
AMANDA	Long string	0.4/PMT	South Pole	N/A	1998-2009
IceCube	Long string	0.4/PMT	South Pole	N/A	2007-present

these detect Cherenkov light from charged particles produced or scattered due to neutrino interactions in the medium

Pointing

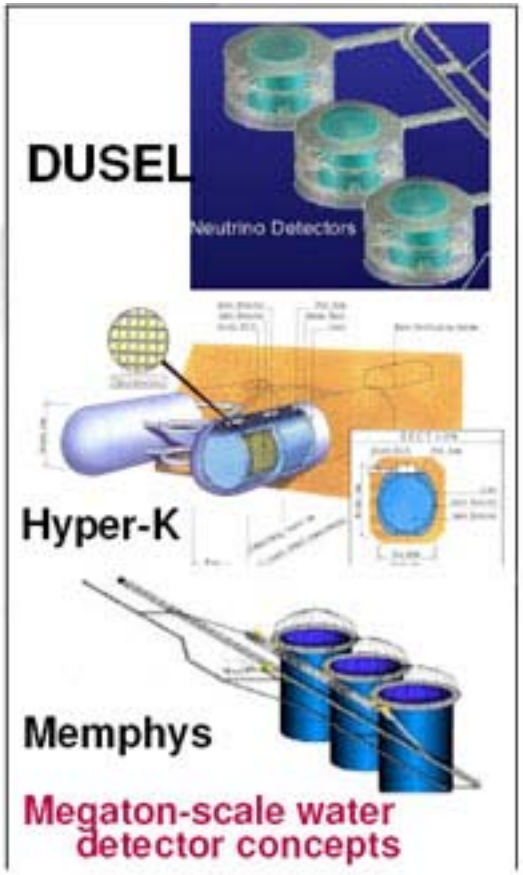
- if there are enough events, electrons from elastic scattering with neutrinos can be used to reconstruct direction
- events from dominant absorption interaction would be approximately isotropic
- with Super-K, expect a pointing accuracy of ~4 degrees for a SN at 8.5 kpc

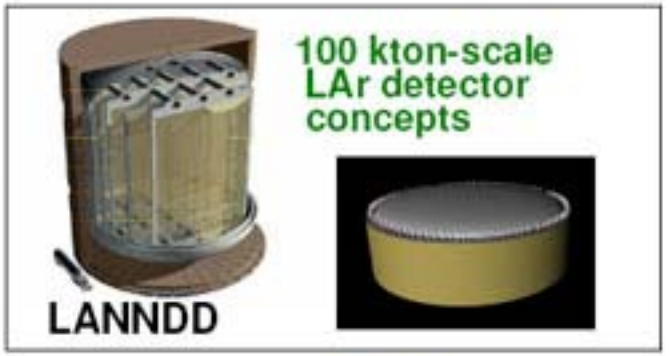


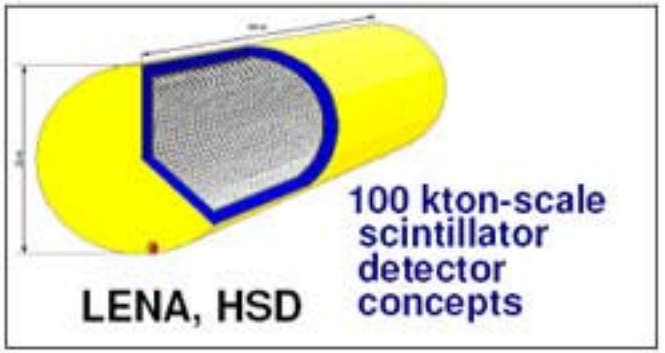


Next generation neutrino mega-detectors (10-20 years)

~few to tens of events from M31





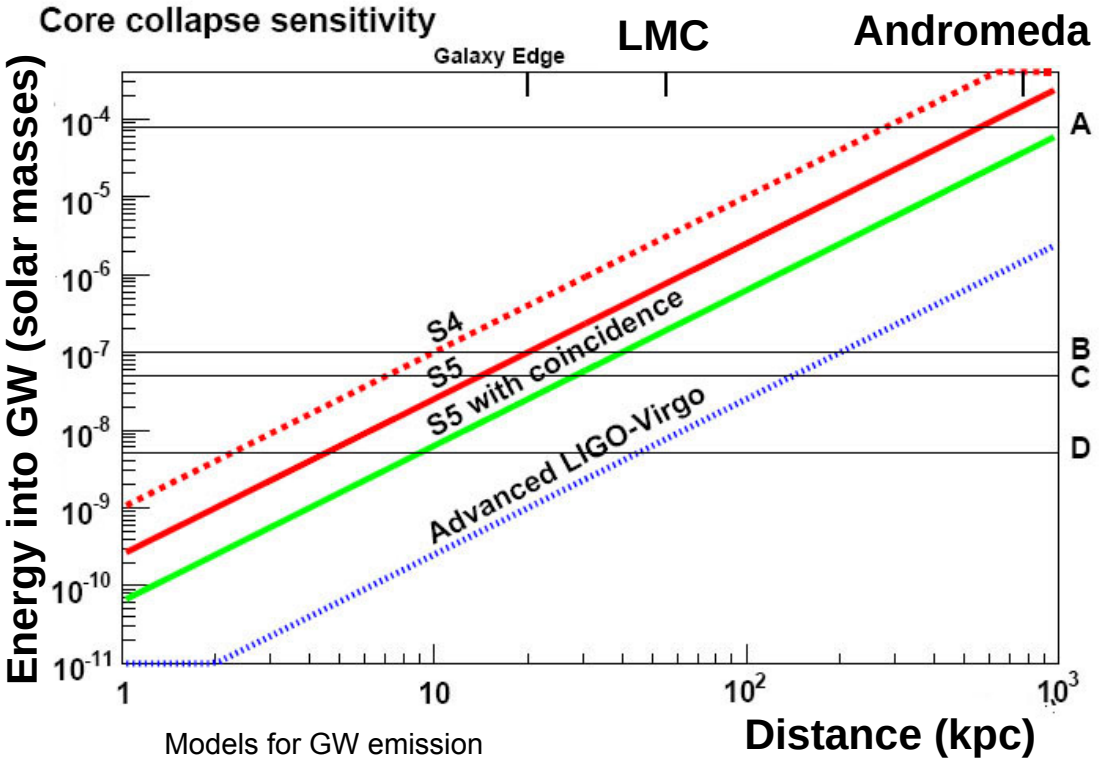


LIGO-Virgo sensitivity and expected improvement with joint neutrino search

$$E_{GW} \approx \frac{\pi^2 c^3}{G} D^2 f_0^2 h_{rss}^2 \qquad 153 \text{ Hz}$$

- in contrast to neutrino signal, energy emitted as GW radiation is expected to be small
- currently, there are large uncertainties in models of core-collapse SN, e.g. simulations have difficulty making a SN explode
- like neutrino signal, GW signal would probe the innermost region of SN core
- requiring coincidence of GW and neutrino signals to within a short time window of ~few seconds would allow lower detection thresholds

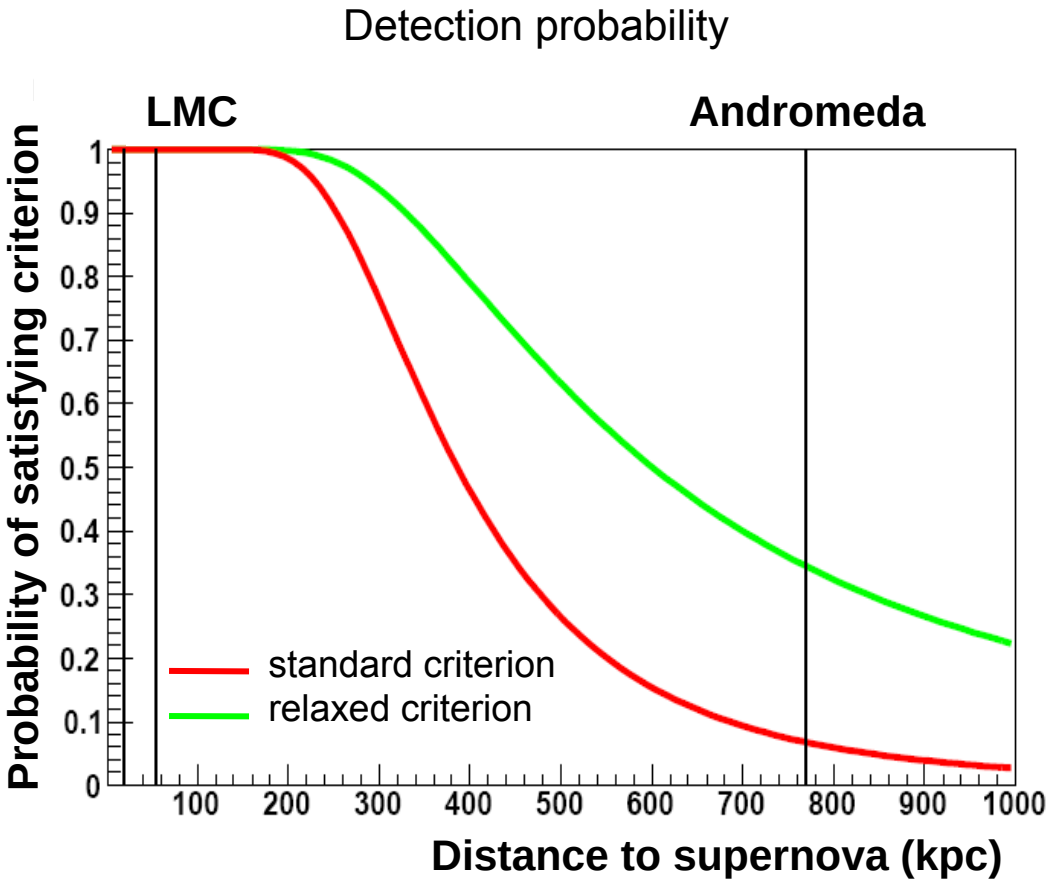
➔ **improvement in sensitivity**



Models for GW emission
(from Ott, C. 2009, CQG, 26, 063001)
A: PNS pulsations
B: rotational instability
C: rotating collapse and bounce
D: convection and SASI

Joint search could benefit neutrino search as well

- criterion for neutrino search can be relaxed
- example: for Super-K distant SN search, criterion is at least 2 neutrino events per 20 seconds and high energy threshold of 17 MeV
- if coincidence with GW signal is used, then criterion can be relaxed to a single neutrino event; odds will increase that distant core-collapse will satisfy this criterion
- energy threshold could also be lowered



Supernova early warning system (SNEWS)

http://snews.bnl.gov

- alert system which would send out notification of high-confidence SN to astronomical community a few minutes after detection of neutrino burst by multiple detectors
- LIGO-Virgo is signed up to get these alerts in the control rooms
- low-latency search for a GW signal coincident with a SNEWS trigger is planned for the LIGO-Virgo S6/VSR2 run
- the proposed joint GW-neutrino search will complement the existing infrastructure and procedures which are in place in the event of a SNEWS alert

Data sets and status of proposal

- past runs--sufficient overlapping data exists
  - **LIGO-Virgo S5/VSR1 run** (Nov 2005 to Sep 2007; ~70% to ~80% duty cycle depending on interferometer)
  - **SK-III run** (Aug 2006, continued past S5)
  - **LVD run 8** (Feb 2005 to May 2007; >99% duty cycle), **LVD run 9** (June 2007 to Dec 2008; >99% duty cycle)
- future runs
  - LIGO-Virgo S6/VSR2 run
  - neutrino detectors expected to be online during S6/VSR2
- LIGO-Virgo collaborations have reviewed the proposal; awaiting final approval
- neutrino collaborations (currently Super-K, LVD, Borexino) are examining the proposal and discussions are ongoing
- Join us if you are interested in this proposal!

Summary

- A proposal for a joint neutrino-GW search for nearby core-collapse supernovae has been presented
- The proposed search is scientifically well motivated, with experimental benefits to both neutrino and GW communities
- This is also a good avenue for establishing a robust working relationship between the two communities
  - would complement the work done for the joint GW and high-energy neutrino searches