Prospects for Gravitational Waves Searches for Core-Collapse Supernovae within the Local Universe

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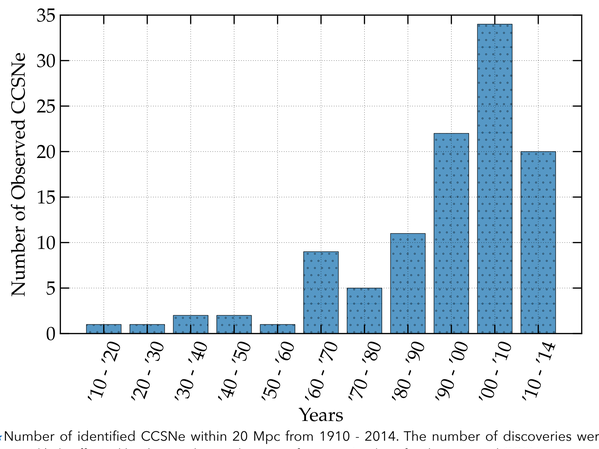
We present an updated estimate of the intrinsic (vs observed) core collapse supernovae (CCSNe) rate within 20 Mpc from Earth, which is roughly the largest distance of interest for the searches for gravitational waves (GWs) from CCSNe with laser interferometers in the near future. The estimate is based on recognizing that CCSN galactic rates are morphologically dependent and take into account all known biases such as the obscuration by the galactic plane. The improved estimation of the CCSNe rate within 20 Mpc is 455.01 ± 83.85 CCSNe Century. In order to estimate the benefits of having multiple CCSNe triggers during the laser interferometer science runs, we compare the performance of two collective detection methodologies (the Feldman-Cousins counting method and the local probability method currently used for GW searches from gamma-ray bursts) with the standard single trigger detection methodology. Implications for the standard candle model exclusion probabilities for CCSNe are also discussed. Illustrative examples of the sensitivity improvement with respect to the single-event current approaches show that the detectable 50% efficiency average range of a CCSNe GW population is about five times larger than the 50% efficiency detectable range for a single CCSN GW. And, are provided for phenomenological and ad-hoc astrophysical waveforms, multi-dimensional first principle CCSN simulations, and analytic and semi-analytic GW emission models of more extreme scenarios.

Observed CCSNe from 1910 - 2014

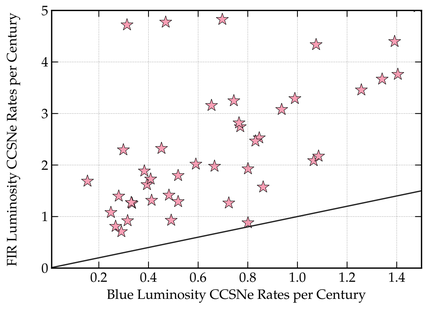


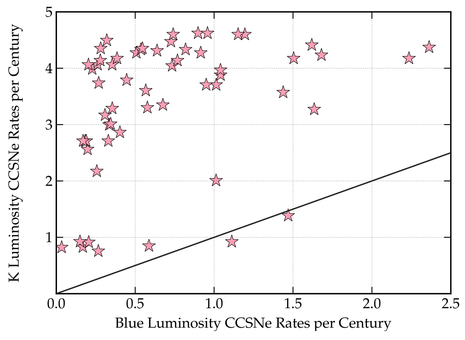
★Number of identified CCSNe within 20 Mpc from 1910 - 2014. The number of discoveries were most likely affected by the number and nature of surveys in place for the targeted CCSNe.

20 Mpc Catalog Database

Catalogs	Information Extracted
GWGC	Sky position, distance, B-magnitude, morphology, major & minor diameters, position angles
VCC	Identification of Virgo Cluster galaxies
IRAS	K magnitudes
2MASS	FIR magnitudes
NBG	Identification of Starburst Galaxies

Inclusion FIR and K Luminosities as tracers for CCSNe rate



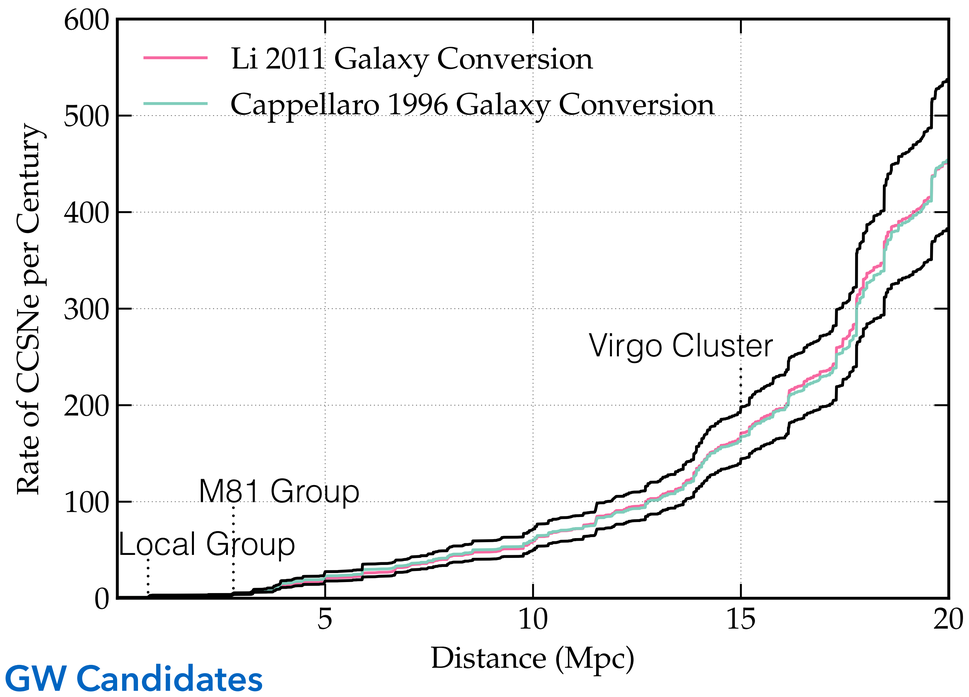


Past SNe Rate Methods in Comparison to our Methodology

Past Approaches	Limitations	Corrections
All Sky Survey[2,3]	Obscuration by the galactic plane	The contribution of a 28.8 degrees band around the galactic plane was included by rescaling the rest of the sky
Observed part of the sky & counted the number of SN observed[1-4]	Surveys are flux limited - limiting magnitude thresholds produce a deficit of low-luminosity CCSNe	Introduced a factor that took into account the potential number of dimly occurring CCSNe
Normalized CCSNe rates to either B-band, K-band, or FIR luminosity of host galaxies[2-4]	Starburst regions with high dust content possess underestimated SNe rates	Introduced combination of blue and FIR luminosity as indicators of star formation
Measured SNe rate at higher redshift distances[2,3]	Luminosity functions and relative fractions of SNe evolve with redshift	Incomplete morphology info was corrected by separating and defining galaxies by absolute magnitude

Low Redshift Extrapolation (within 20 Mpc) from High Redshift Published SN Rates

Reference	Rate of SNe/yr
Li et al. 2011(c)	2.35 ± 0.27
Cappellaro et al. 1999	1.44 ± 0.17
Cappellaro et al. 2015	3.79 (+2/-1.8)
Gill et al. 2017	4.45 ± 1.18



LIGO SN GW Candidates

Scientific Run	Name	Discovery Time [UT]	On-Source Window	Host Galaxy	Distance	Type
ER8	SN 2015aq	2015-09-21.072	0.528 days	UGC 5015	23.8 Mpc	IIP
O1	SN 2015as	2015-11-15.778	1.47 days	UGC 5460	19.588 Mpc	II
O1	SN 2016B	2016-01-3.62	4.03 days	PGC 037392	22.7 Mpc	IIP
O1	SN 2016C	2016-01-03 20:10:14	0.424 days	NGC 5247	22.2 Mpc	IIP
O1	SN 2016X	2016-01-19.487	2.86 days	UGC 08041	15.8 Mpc	IIP

Interested? Check out my other poster!

Finding the Optimal CCSNe Detection Strategy

Implementation of Counting Techniques within CCSNe-Data Analysis-Methodology

determine if the efficiency of detecting a collective population of GWs was larger than the single injection efficiency at a distance equal to the average distance of the population of injections

Feldman-Cousins Test

★ Detection of a population with a background of rare events following a Poisson distribution is performed by counting the number of events in the foreground and comparing it to the expected number of background events

"GRB" Strategy

★ The GRB approach is based on calculating how the largest separation between a local probability of a data point and the expected local probability is compatible with the foreground containing only noise events.

★ The probability of a given separation between the foreground and the background can be computed with the binomial probability. If a binomial probability below 0.05 is achieved, then we can claim a 95% detection confidence.

aLIGO CCSNe Distance Detectability

Waveform	cWB Distance (Mpc) @ 50% hrss	FC Distance (Mpc)	GRB Distance
LB1	0.732	5	5
LB2	2.252	5	5
LB3	0.191	5	5
LB4	3.292	5	5
LB5	11.511	15	15
Piro1	0.891	5	5
Piro2	4.409	15	15
Piro3	2.445	5	5
Piro4	12.569	15	15

3G CCSNe Distance Detectability

Waveform	cWB Distance (Mpc) @ 50% hrss	FC Distance (Mpc)	GRB Distance (Mpc)
Muller1-N20-2	0.38	1	5
Muller1-L15-3	0.47	1	1
Muller1-W15-4	0.99	N/A	1
Yak1	0.002	0.5	0.1
Yak2	0.001	0.5	0.5
Yak3	0.002	0.1	0.1
Yak4	0.004	0.5	0.5

Immediate Data-Analysis Applications

Currently, we are implementing a plugin that focuses on the spatial distribution of CCSNe sources within 20 Mpc, *derived from this work*, into the Coherent Waveburst (cWB) pipeline

References

[1] Li et. al 2011
[2] Cappellaro et. al 1999
[3] Cappellaro et. al 2015
[4] Van den Bergh et. al 1988

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