重力波天文学による Ia型超新星母天体の同定

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Backgrounds

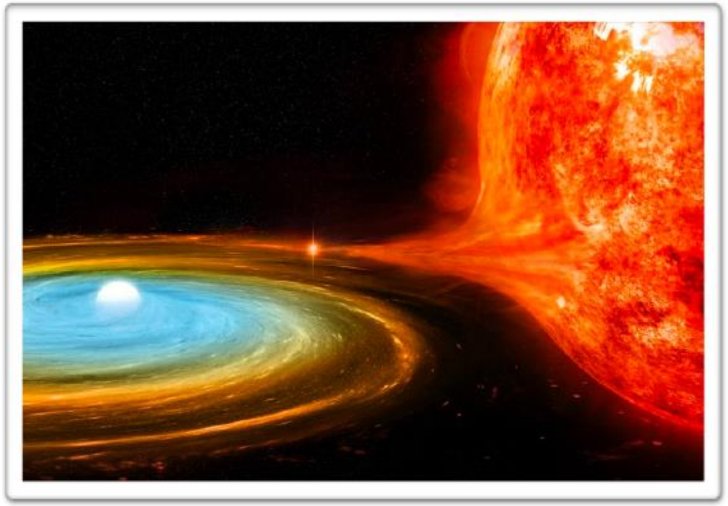
- Type Ia supernova

Thermonuclear explosions of a near Chandrasekhar white dwarf (WD).

- However, currently no consensus regarding the events leading to the explosion.

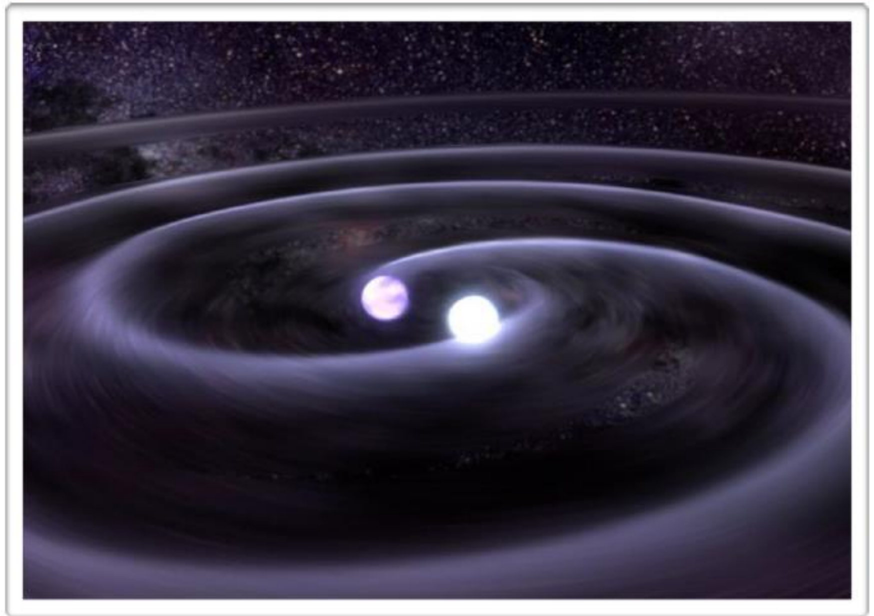
- Single degenerate

Accreting WD?



NASA/CXC/M. Weiss

- Double degenerate (DD) binary WD merger?



(Tod Strohmayer (GSFC), CXC, NASA, Illustration)

Mechanism?

Classical DD

Webbink 1984; Iben & Tutukov 1984

Violent merger

Pakmor et al. 2010; Sato et al. 2015

D^6 scenario

Woosley, & Kasen 2011;
Shen, & Bildsten 2014

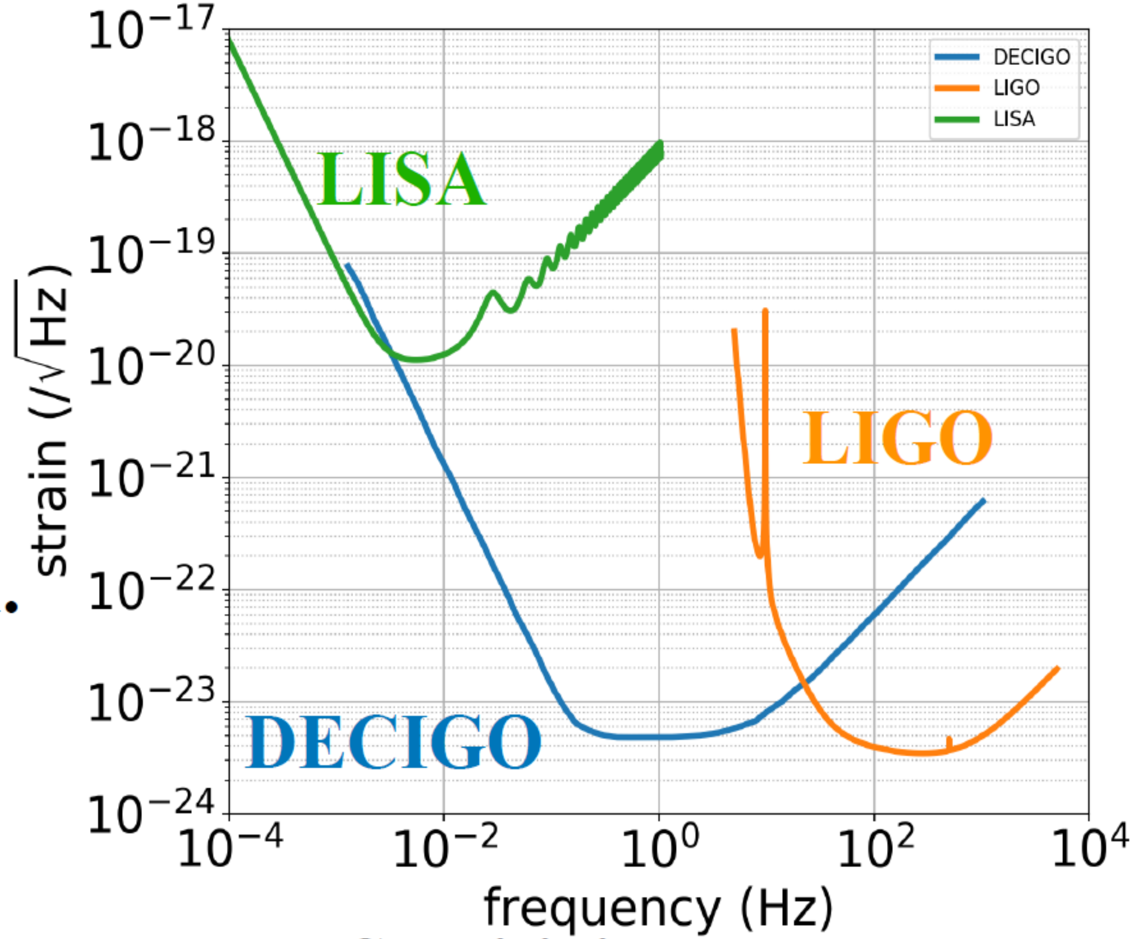
Backgrounds

- Binary WD mergers emit gravitational waves (GWs) with ~ 0.1 Hz.
- Space-based gravitational wave detectors with great sensitivity in the decihertz range can detect the GWs.

e.g. <u>DECIGO,</u> Tiango, Amigo, DO

GWs form WD-WD mergers tell us their masses, direction, distance, and so on.

<u>We are able to constrain the Type Ia SN progenitor and its explosion mechanism.</u>



Sensitivity curves

Event rate

- Type Ia SNe event rate at z~0 from Lick Observatory Supernova Search.

$$(0.301 \pm 0.062) \times 10^{-4} \mathrm{SN\ yr^{-1}\ Mpc^{-3}}, \qquad \text{(Li et al. 2011)}$$

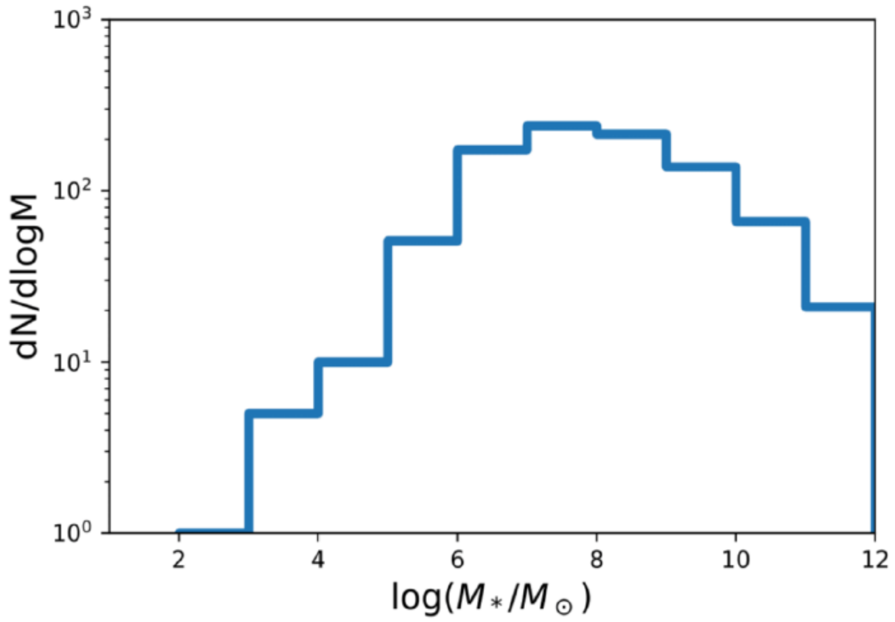
We use this averaged volumetric rate as the fiducial rate.

- From the rate-size relation of Ia supernova host galaxy (Li et al. 2011)

$$\mathrm{SNuM} = \mathrm{SNuM}(M_0) \times \left(\frac{M_*}{10^{10} M_\odot} \right)^{\mathrm{RSS}}$$

and the catalog of nearby galaxies within 11 Mpc (Karachentsev et al. 2013),

we calculated the near event rate. $0.85\ \ \mathrm{yr}^{-1}$



The stellar mass distribution of nearby galaxies.

Range & Localization

- In order to estimate the ability of DECIGO to localize the WD-WD source, we used Fisher analysis.

- **Parameter estimation by Fisher matrix** $\Gamma_{ij} := 4\mathrm{Re}\int_{\mathrm{f_{min}}}^{\mathrm{f_{max}}} df \sum_I \left(\frac{1}{S_{n,I}(f)} \frac{\partial h_I^*(f)}{\partial \lambda^i} \frac{\partial h_I(f)}{\partial \lambda^j} \right),$

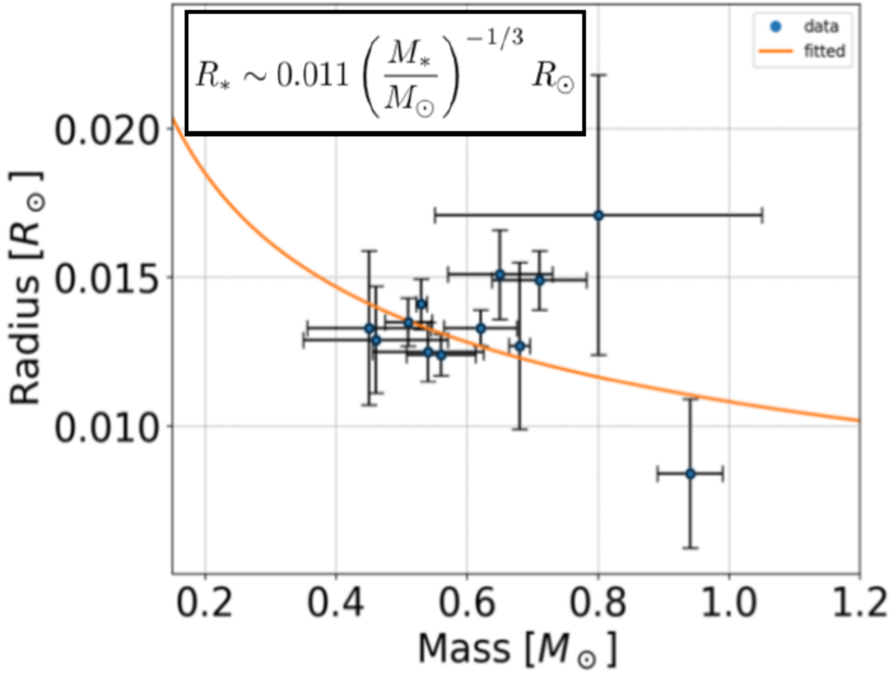
- **Inspiral waveforms up to Newtonian order in amplitude & 3.5 PN in phase**

11 model parameters in GR

$(\log \mathcal{M}, \log \eta, t_c, \phi_c, \log d_L, \chi_s, \chi_a, \theta_s, \phi_s, \cos\iota, \psi_p)$

- **The frequency at the coalescence time can be roughly estimated by mass-radius relation.**

$$f_{\max} \simeq \frac{\omega_s}{\pi} = \frac{1}{\pi}\sqrt{\frac{GM_{\mathrm{tot}}}{(R_1+R_2)^3}}.$$



Mass-radius data (Magano et al. 2017)

Range & Localization

setup

- Sources: (500) binary WD-WD: $0.6,\ 0.8,\ 1M_\odot$ equal mass cases
- DECIGO with designed sensitivity and heliocentric orbit.
- Three-year observation is assumed and observe until the coalescence.

Result

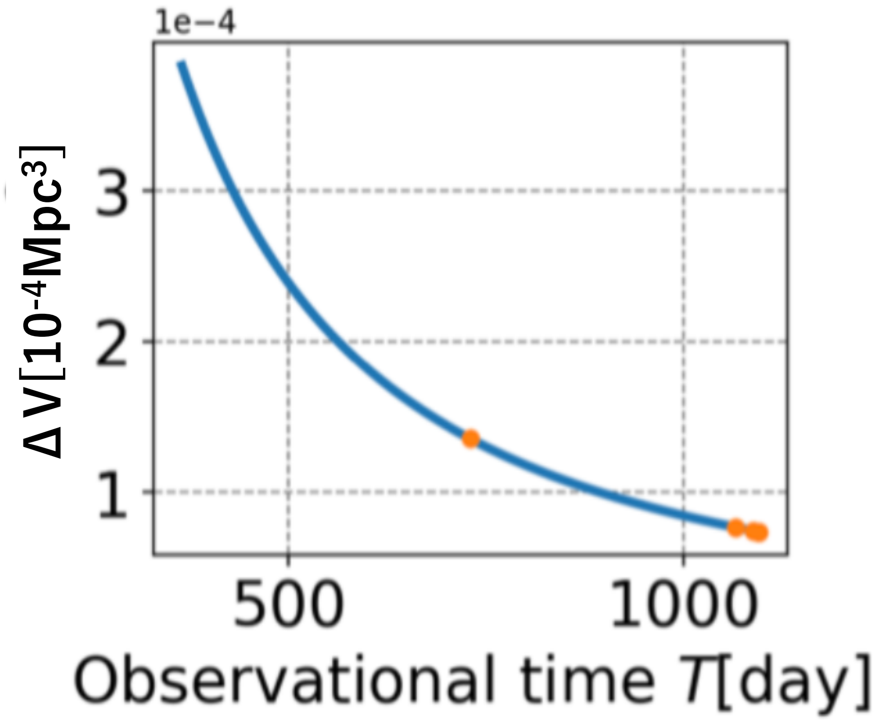
parameter	WD-WD($1M_\odot$, z=0.115)	WD($0.8M_\odot$, z=0.049)	WD($0.6M_\odot$, z=0.016)
SNR	8.14	8.12	8.02
$\Delta \ln d_L$	3.25×10^{-1}	3.80×10^{-1}	5.11×10^{-1}
$\Delta\Omega_s[\mathrm{deg}^2]$	3.11×10^{-2}	4.47×10^{-2}	7.02×10^{-2}
$\Delta \ln \mathcal{M}$	1.83×10^{-7}	1.03×10^{-7}	7.91×10^{-8}

- SNR = 8 when 71 Mpc, 224 Mpc, and 550 Mpc for $0.6,\ 0.8,\ 1M_\odot$ equal mass binaries.

➡ 50-2000 Type Ia SNe are expected within the distance.

➡ Localization volume < $500\ \mathrm{Mpc}^3$. Many their host galaxies could be identified.

Range & Localization



Result

- For multimessenger astronomy,

- Sources: (500) $1M_\odot$ equal mass binary WD-WD at 43 Mpc.

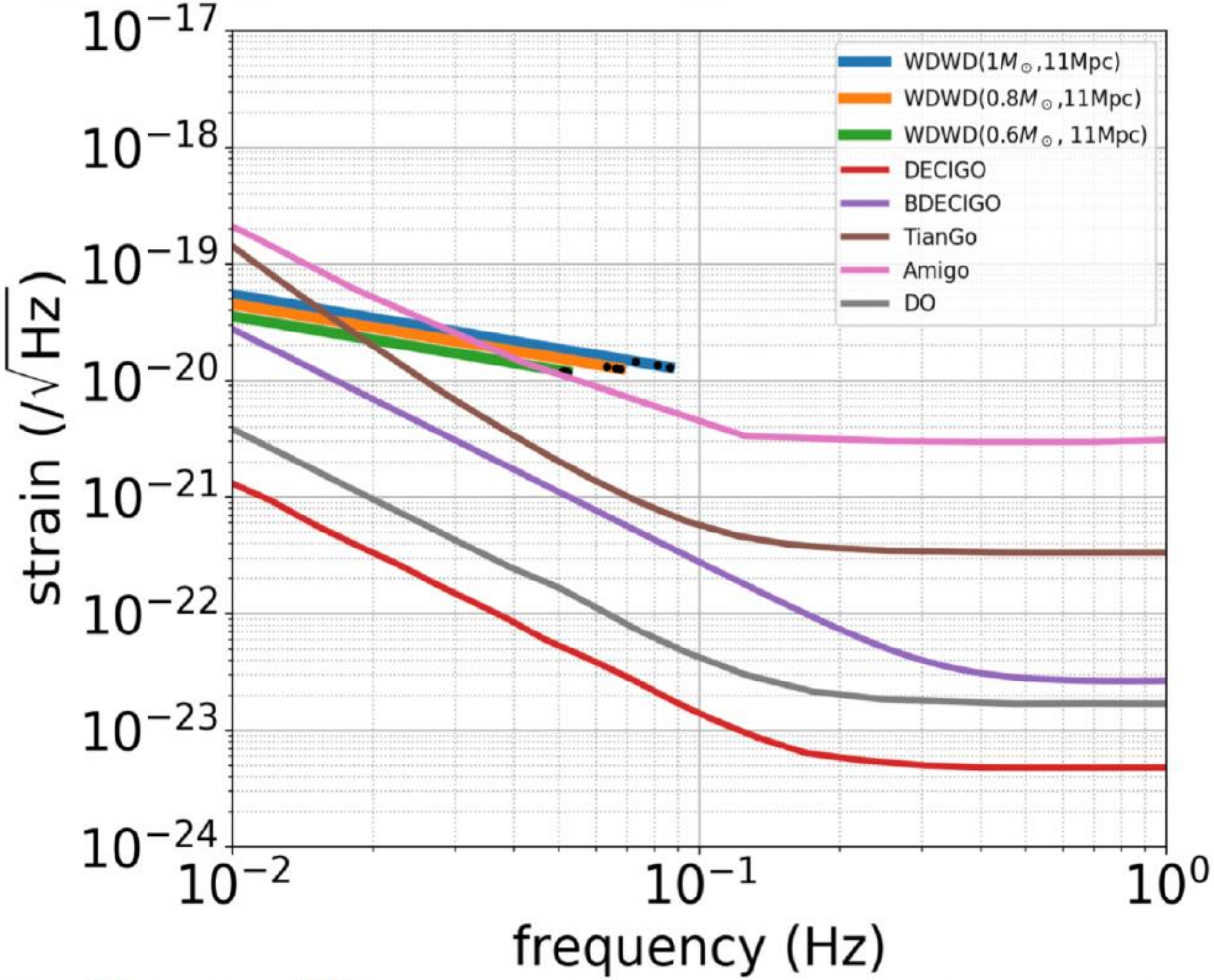
- Observational time dependence fixing $f_{\rm min}$ to 3 year before merger.

- Orange dots denote 1 year, 1 week, 1 month and 1 day before merge.

→ **The near source can be localized one year before merger in advance so that the host galaxy is identified.**

Range & Localization

- 11 Mpc, within which about one event is expected…
  black dots denote 10 year, 3 year before merge, and the coalescence time.



A detector with $h \sim 10^{-20}$ [$\text{Hz}^{-1/2}$] around 0.1 Hz can observe binary WD-WD.

Conclusion & outlook

arXiv:1910.01063

- Probe for binary white dwarf (WD-WD) mergers as a possible progenitor of Type Ia supernovae with decihertz gravitational-wave detectors.

- ~1 event is expected within 11 Mpc by detector with $h \sim 10^{-20}$ [$\mathrm{Hz}^{-1/2}$] at 0.1 Hz.

- It is expected that DECIGO observe 50-2000 events per year and identify their host galaxies even in advance.

- We will investigate WD-WD mergers with different explosion mechanism including non-equal mass binary cases and effects of tidal deformation.