AN EXTRAORDINARY JOURNEY INTO THE TRANSIENT SKY - PADOVA 4/04/2025

Core-Collapse SN detections from Einstein Telescope

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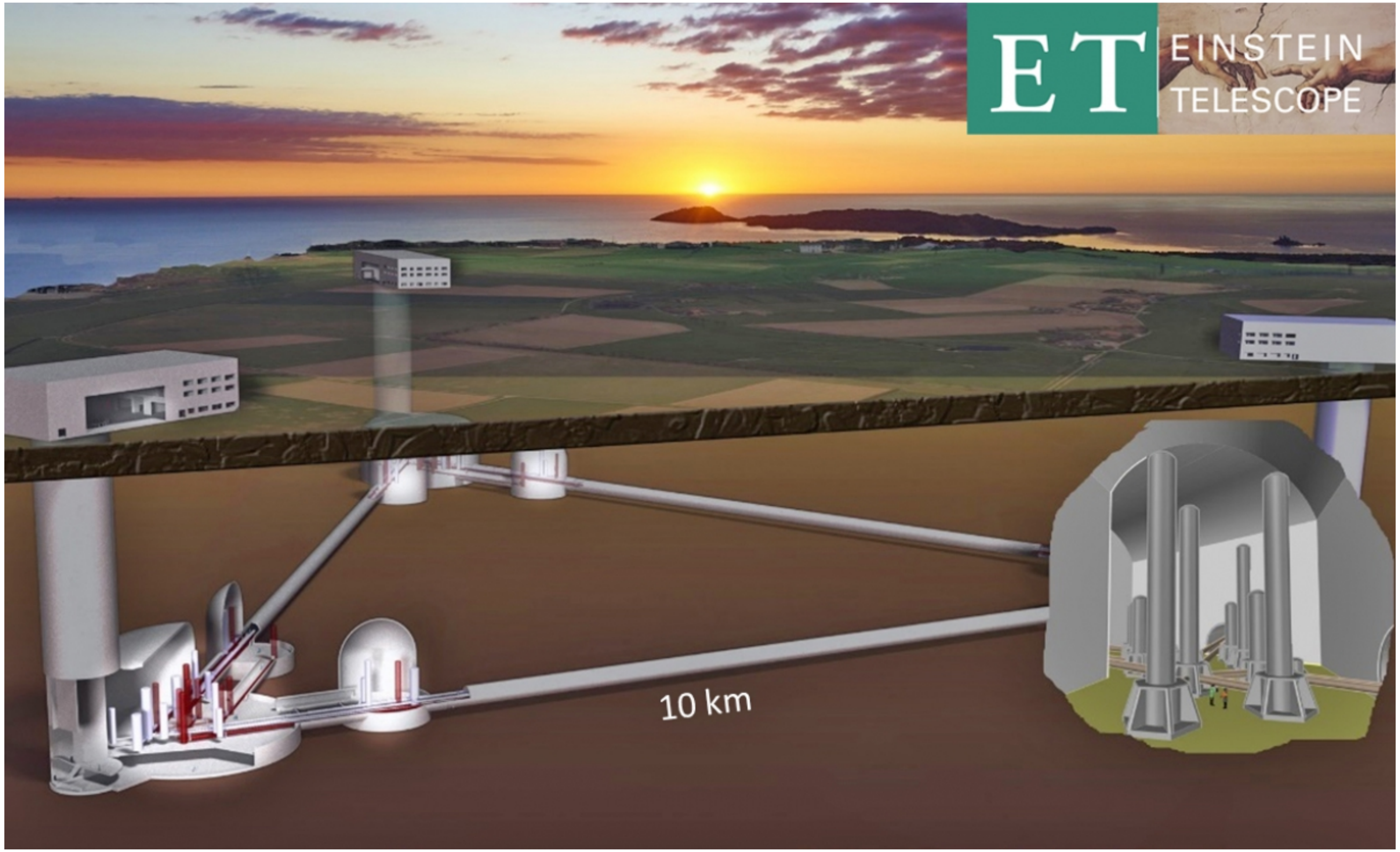
EINSTEIN TELESCOPE



- Third generation detector;
- Sensitivity improvement;
- 3 pairs of laser interferometers: **low-frequency** interferometer and a **high-frequency** interferometer;
- Study of the early universe evolution;
- Physics near black holes;
- Possible applications in the study of dark matter;
- Detection of weaker signals from expected new sources: isolated neutron stars, **core collapse supernovae**.

CCSNE AS GRAVITATIONAL WAVE EMITTERS

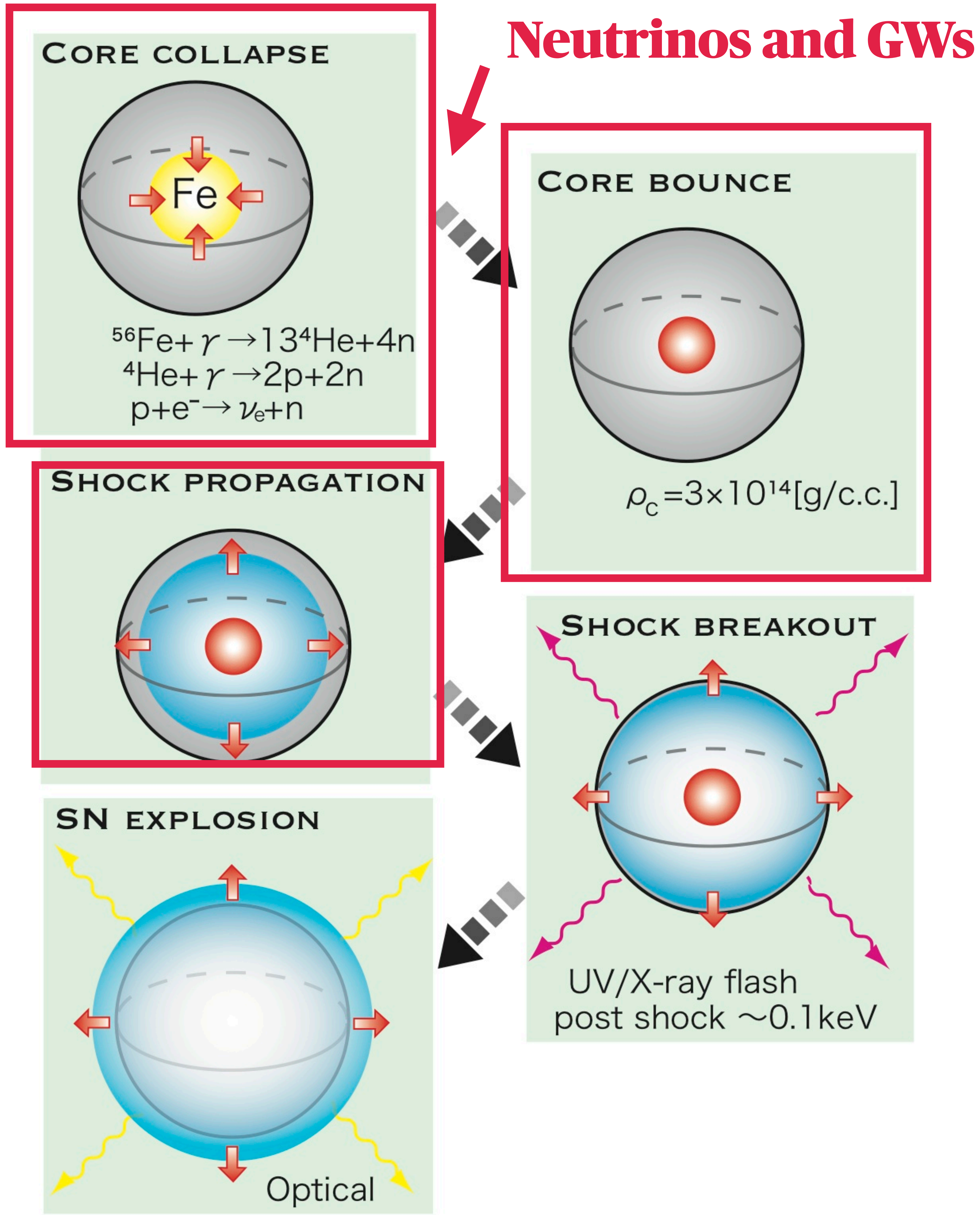
Current Limitations:

Our knowledge is primarily based on electromagnetic observations.

Direct insight into the collapsing core requires **neutrinos** and **GWs.**

GW Emission Mechanisms:

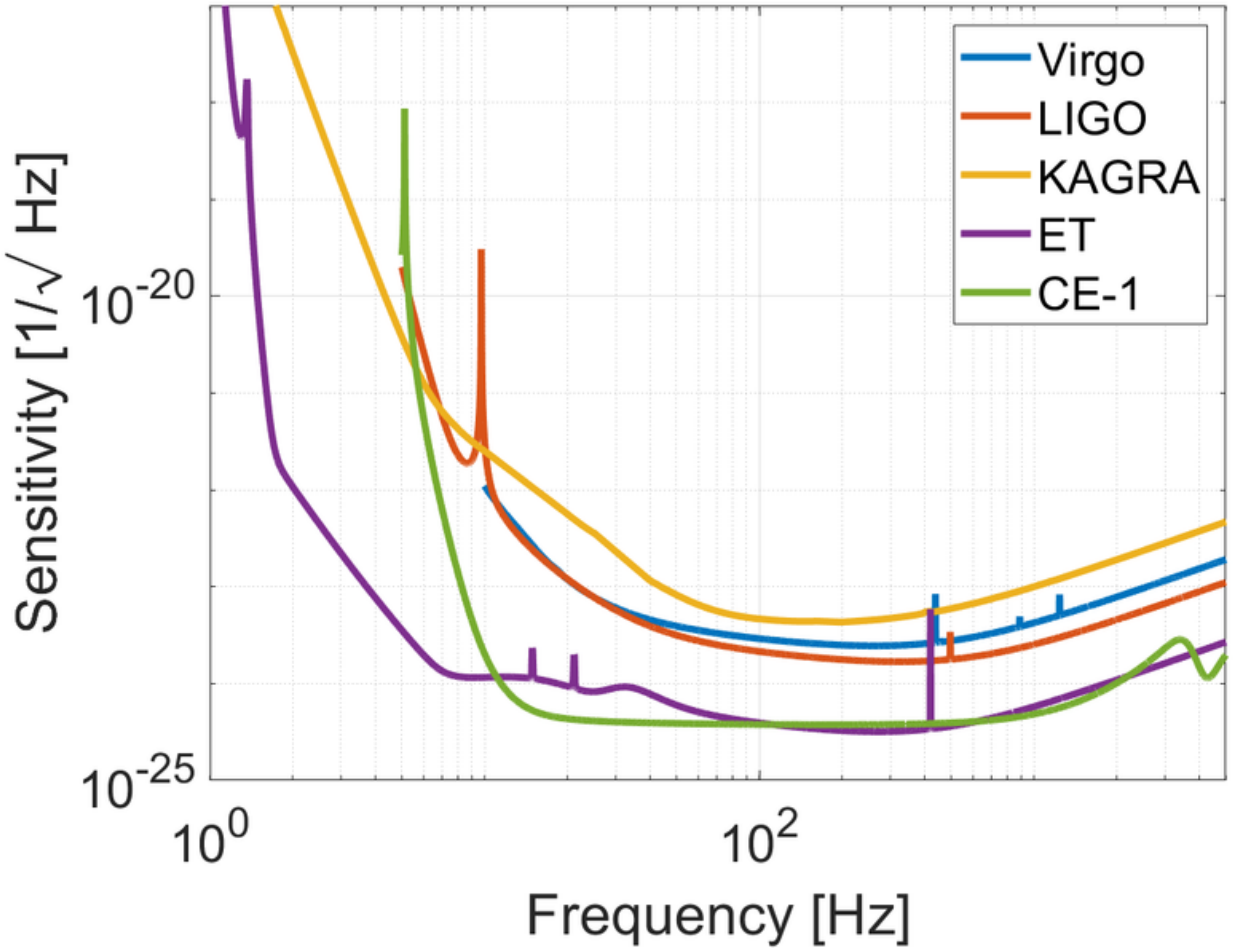
- **Proto-Neutron Star (PNS) Oscillations**
  g-mode and f-mode oscillations of the PNS.
- **Standing Accretion Shock Instability (SASI) & Convection**
  Asymmetric motions in the post-shock region, leads to time-varying mass flows, generating GWs.
- **Prompt Convection**
  Early-stage convection due to negative entropy gradients, contributes to the initial GW burst.



CCSNE AS GRAVITATIONAL WAVE EMITTERS

Detectability: Limited to a few seconds
Energy Range: $10^{-10} - 10^{-7} M_{\odot} c^2$
Frequency Range: $100Hz - 1kHz$

The **CCSN rate** at different distances can help to optimize GW detection and its analysis.



P.Rosati et al. (2021)

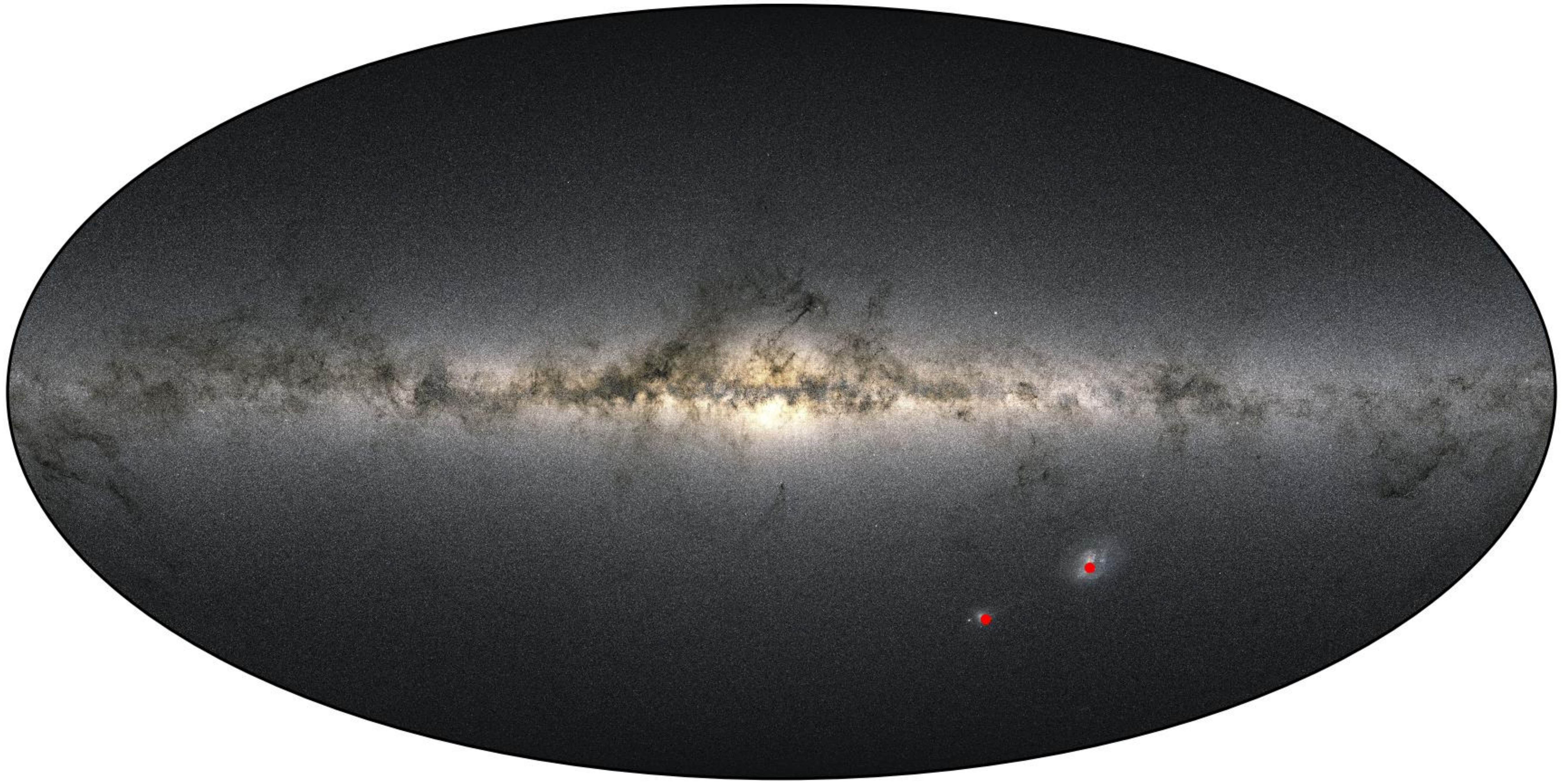
ET DETECTION CAPABILITY IN THE MW

How many CCSNe can we expect in the Milky Way and Magellanic Clouds?

- **Rate from different probes** (historical SNe, counts of massive stars, Al^{26} distribution..)
- **Rate from massive star distribution**

Can ET detect these CCSNe? How far?

- **SNR**
- **Horizon distance**



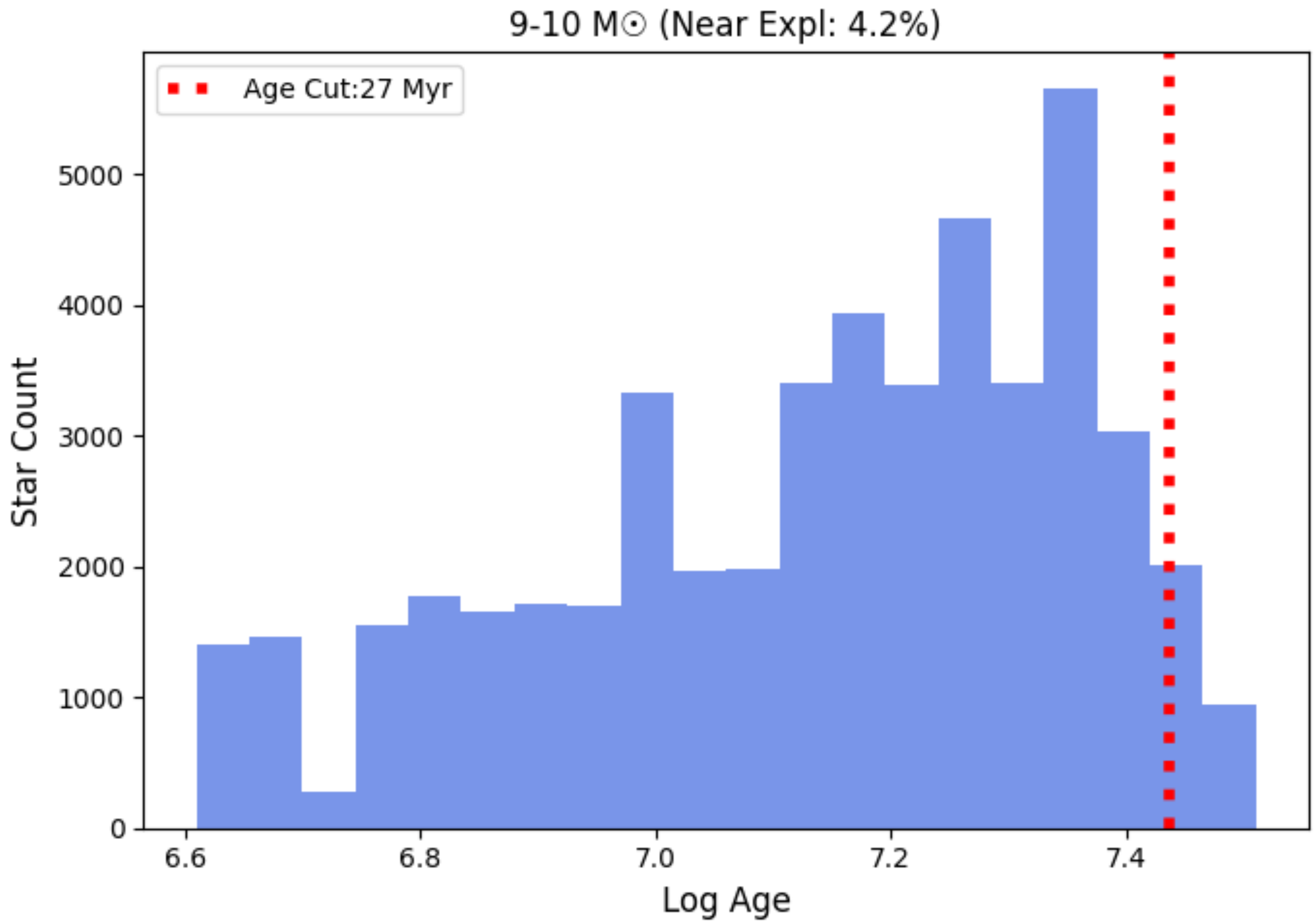
CORE COLLAPSE SUPERNOVA RATE

- **Last observed SN: SN1604 (Kepler's SN)**
- **Detection Challenges:** dust absorption in the Galactic disk.

Method	CCSNR $(100\ \text{yr})^{-1}$	Reference
Galaxy models and historical records	2.1	Tammann et al. [1994]
	$3.2^{+7.3}_{-2.6}$	Adams et al. [2013]
	$1.4^{+1.6}_{-0.9}$	Murphey et al. [2021]
CCSNR measurements in the local Universe	1.7 ±1.1	Cappellaro et al. [1993]
	2.4-2.7± 0.9	van den Bergh and McClure [1994]
	2.30 ±0.48	Li et al. [2011]
Counts of massive stars	1 - 2	Reed [2005]
NSs	7.2	Rozwadowska et al. [2021]
SN remnants	0.43	Leahy et al. [2020]
^{26}Al distribution	1.9 ± 1.1	Diehl et al. [2006]
Combination of different methods	1.63 ± 0.46	Rozwadowska et al. [2021]

The Science of Einstein Telescope, arXiv 2503.12263

CORE COLLAPSE SUPERNOVA RATE



- Stellar distribution of massive stars from **TRILEGAL** (Dal Tio et al. 2022) within the Milky Way and the Magellanic Clouds.
- **IMF** Chabrier
- **Progenitor mass range**: 9 to 25 $M_{\odot}$.
- **Stars near explosion**: cut at last 5 Myr for each mass bin.
- **Estimated core-collapse supernovae rate from simulations: $\sim$ 2 per century**

ET DETECTION CAPABILITY IN THE MW

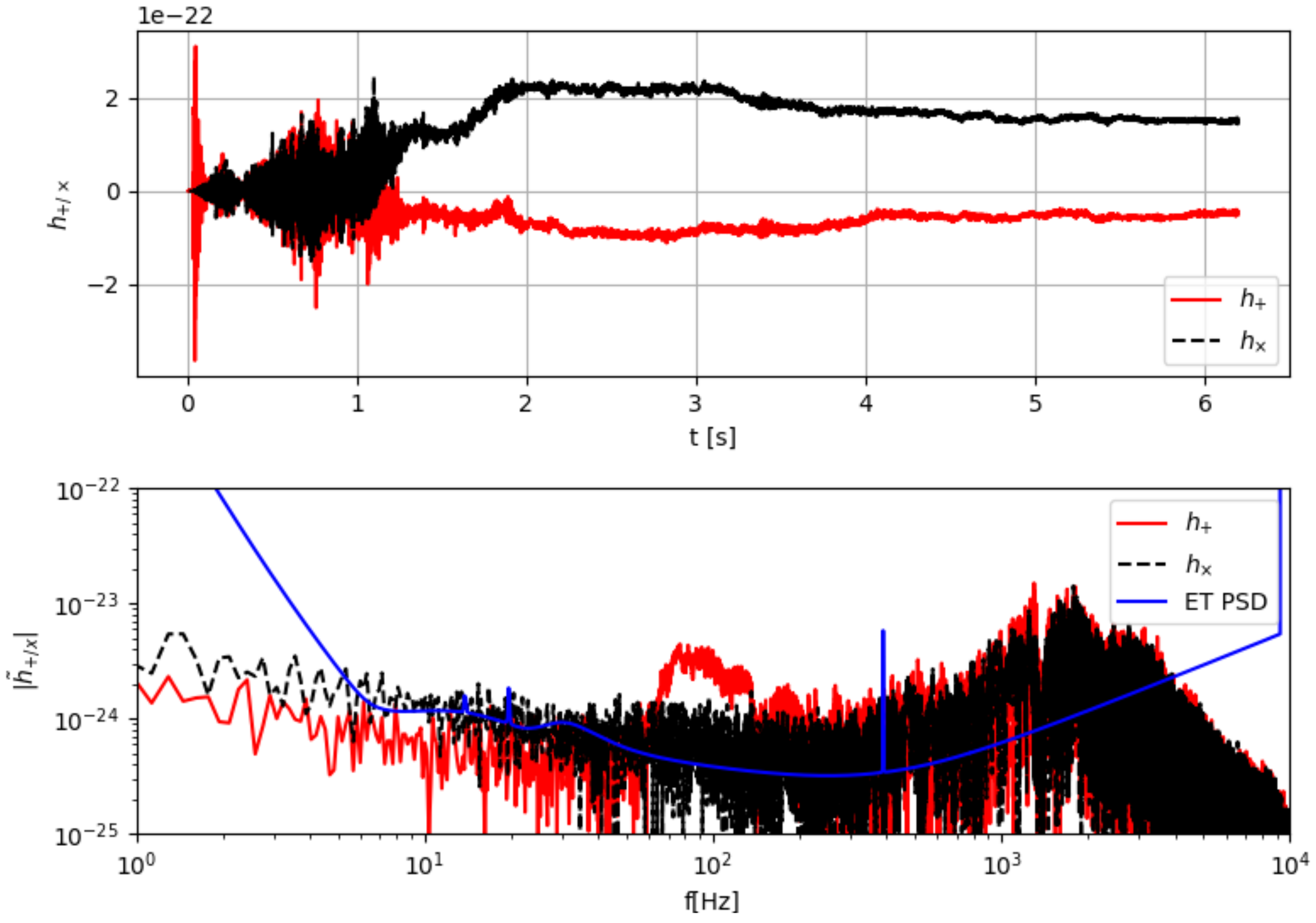
- GWFISH is a simulation software for assessing **detection and parameter estimation (PE)** capabilities of future GW detectors, optimized for binary coalescence waveforms (LALsuite-based)
- We adapted GWFISH for the injection of **CCSN waveforms**.
- **Aim:** Evaluating the **detection capability of the Einstein Telescope,** also as a network working with **Cosmic Explorer**

GWFISH

GSSI
GRAN SASSO SCIENCE INSTITUTE

*U.Dupletsa et al. (2023)

ET DETECTION CAPABILITY IN THE MW

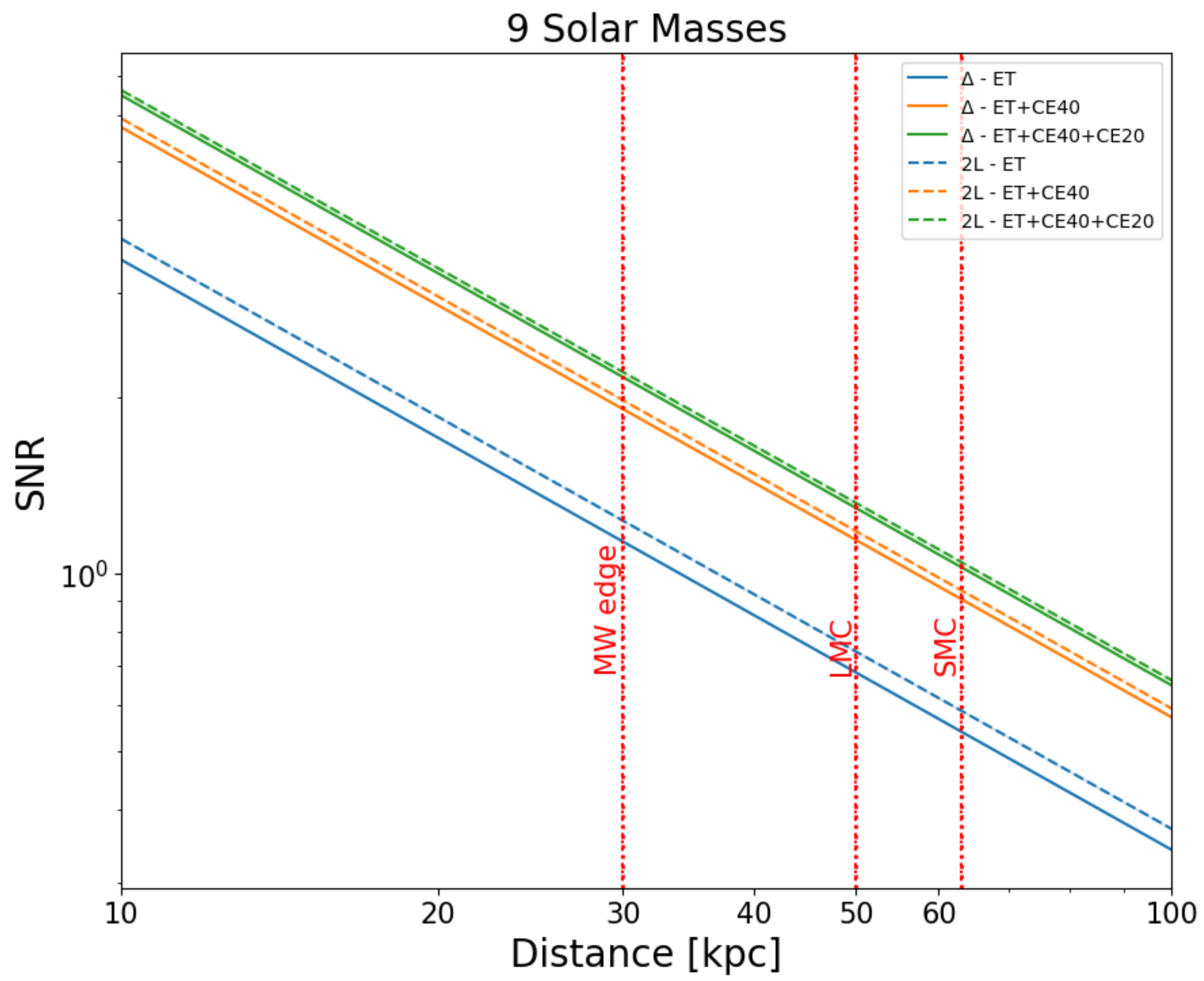


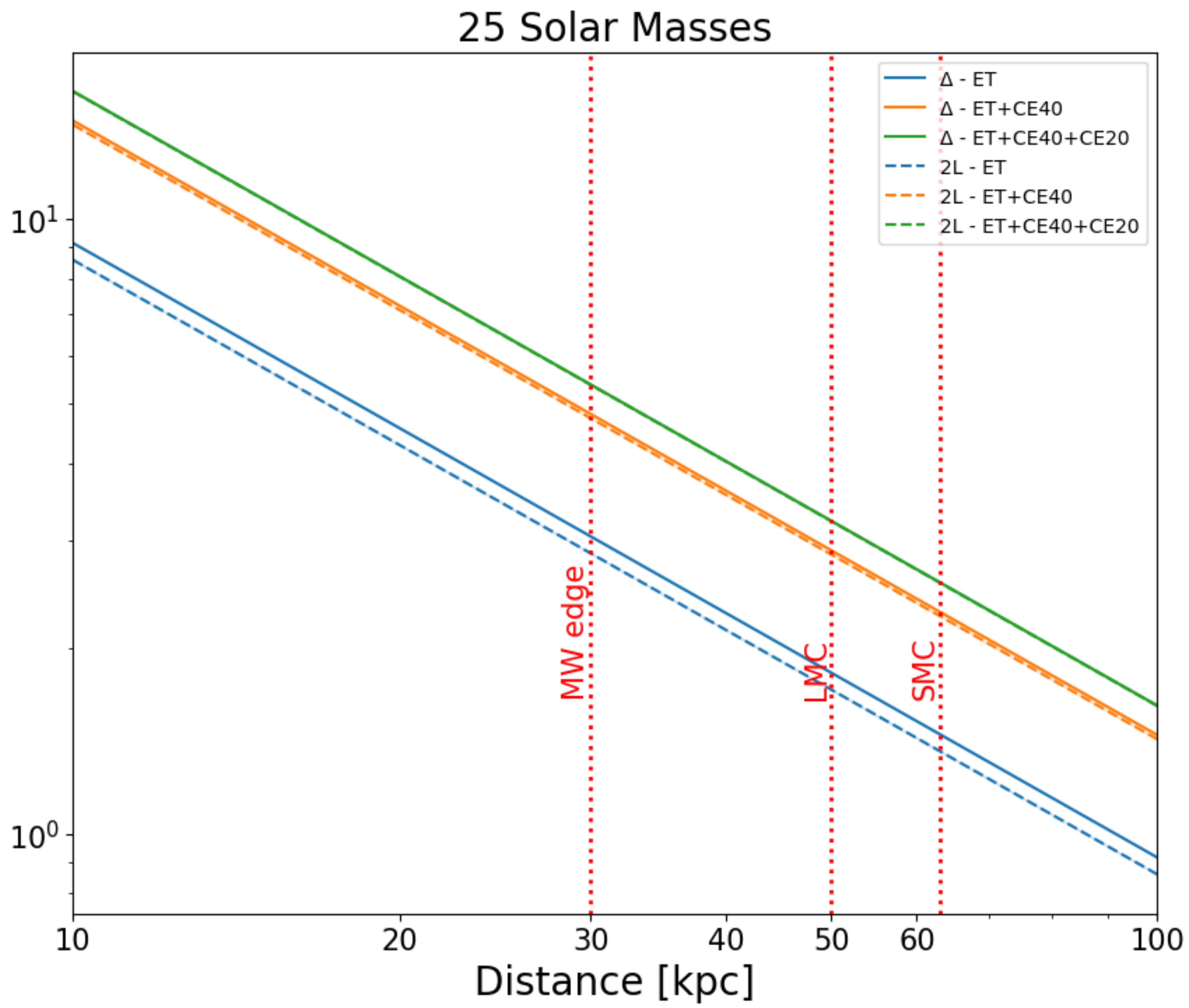
Simulated waveform for 23 $M_\odot$ (D.Vartanyan et al. 2023)

- **Simulated CCSNe waveforms** from D. Radice et al. (2019) and D. Vartanyan et al. (2023).
- Progenitor mass range: **9** to **25** $M_\odot$
- **TRILEGAL** massive star distribution

GWFISH

ET DETECTION CAPABILITY IN THE MW

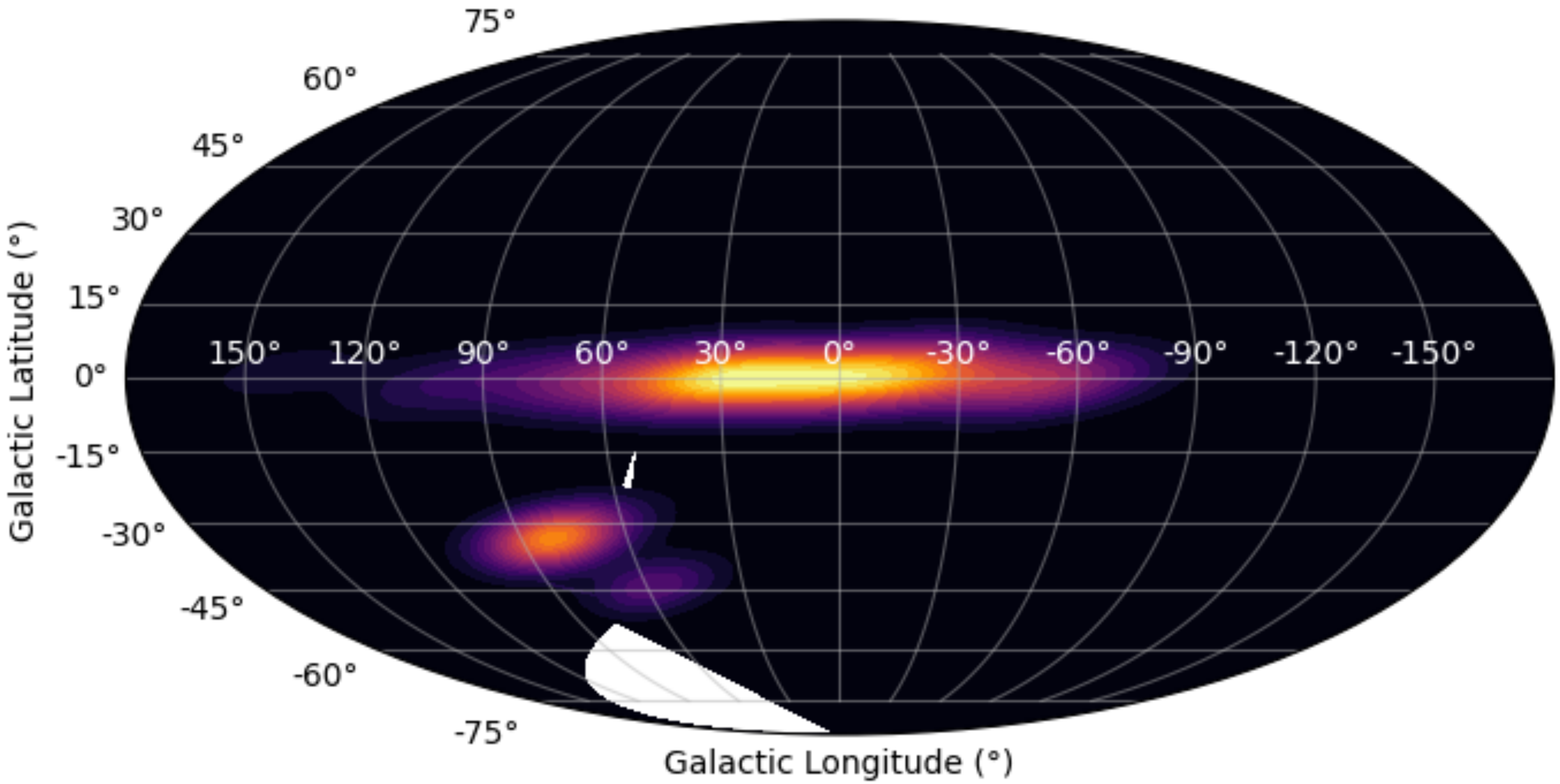




Supernova signals may be detected in **nearby galaxies** with ET+CE, expanding CCSN multi-messenger astronomy **beyond the Magellanic Clouds**.

GWFISH

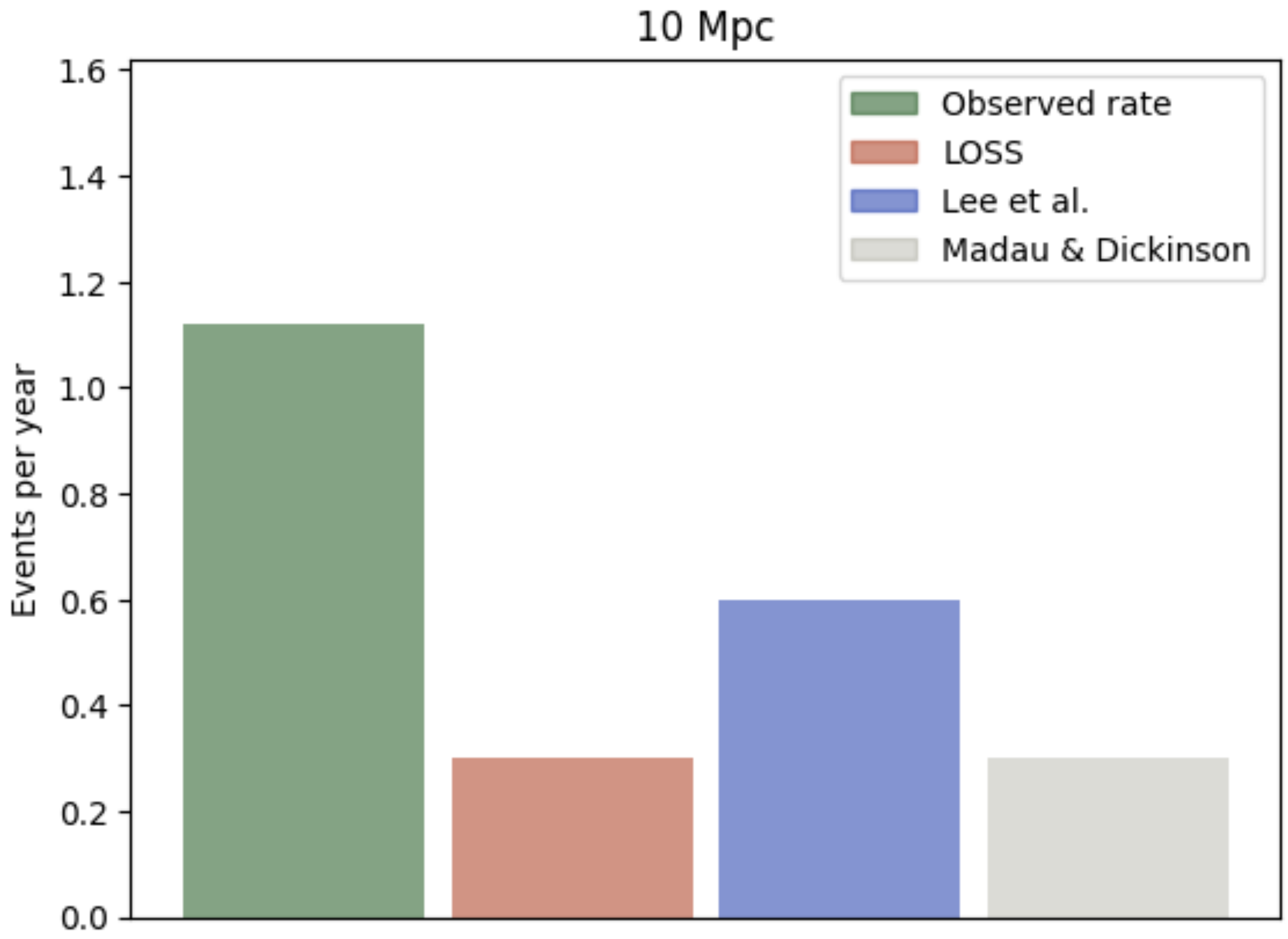
ET DETECTION CAPABILITY IN THE MW



- **SNR-weighted density maps.**
- Identifying key regions where the Einstein Telescope has the **highest detection capability.**

GWFISH

ET DETECTION CAPABILITY



	10 Mpc	
	SFR ($M_\odot$ yr^{-1})	CCSNR (yr^{-1})
LOSS		$0.29^{+0.05}_{-0.04}$
Kennicutt et al.	87±4	0.40±0.02
Lee et al.	123±8	0.59±0.04
Bothwell et al.	75±5	0.36±0.02
Hopkins & Beacom	65	0.3
Madau & Dickinson	63	0.3
Observations		$1.1^{+1.7}_{-0.6}$

Results from The Science of Einstein Telescope, arXiv 2503.12263

THANK YOU
FOR YOUR ATTENTION