Core-Collapse SN detections from Einstein Telescope

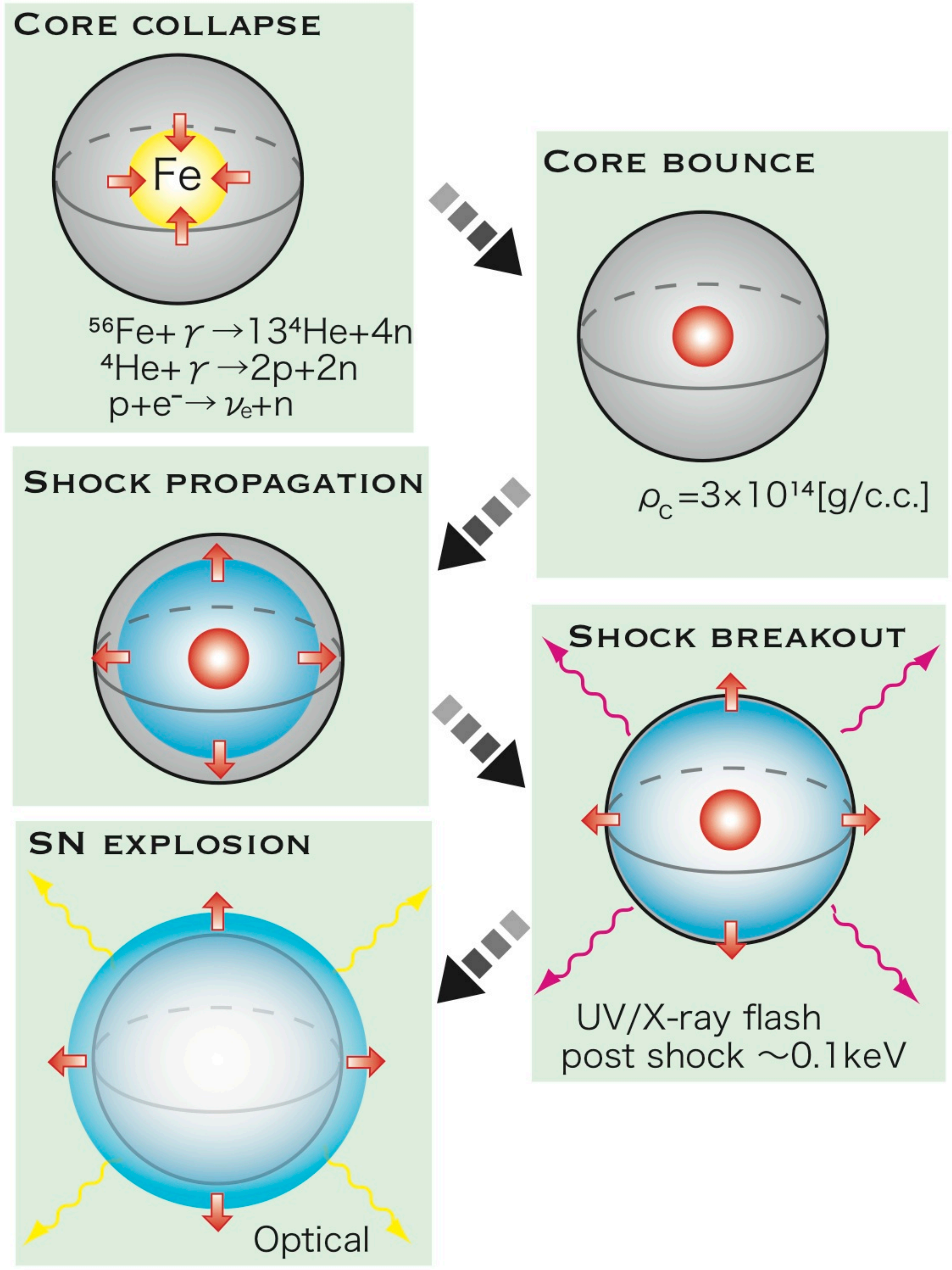
Ines Francesca Giudice

In collaboration with:
ALESSIO LUDOVICO DE SANTIS, MARIA TERESA BOTTICELLA, MARICA BRANCHESI, LUCA IZZO, ENRICO CAPPELLARO

HOT TOPIC FOR TIME DOMAIN ASTRONOMY IN THE NEXT DECADE

CCSNe are key probes of fundamental physics, stellar nucleosynthesis, late evolutionary phases, galaxy star formation rate and chemical evolution.

- **NEUTRINOS AND GWS**
  Direct probe of the core-collapse engine
- **EM COUNTERPART**
  Trace SBO, nucleosynthesis, and remnant formation

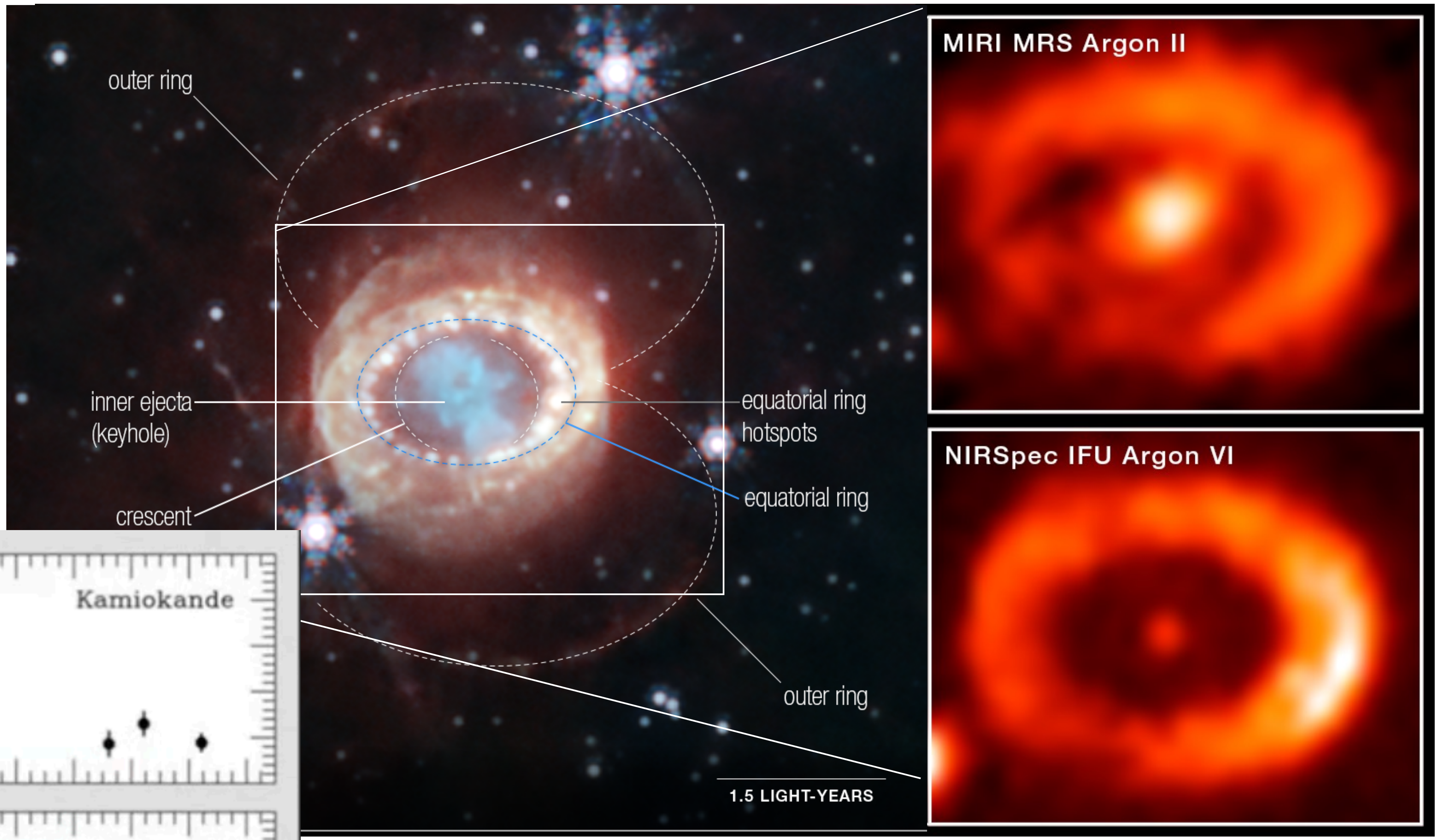


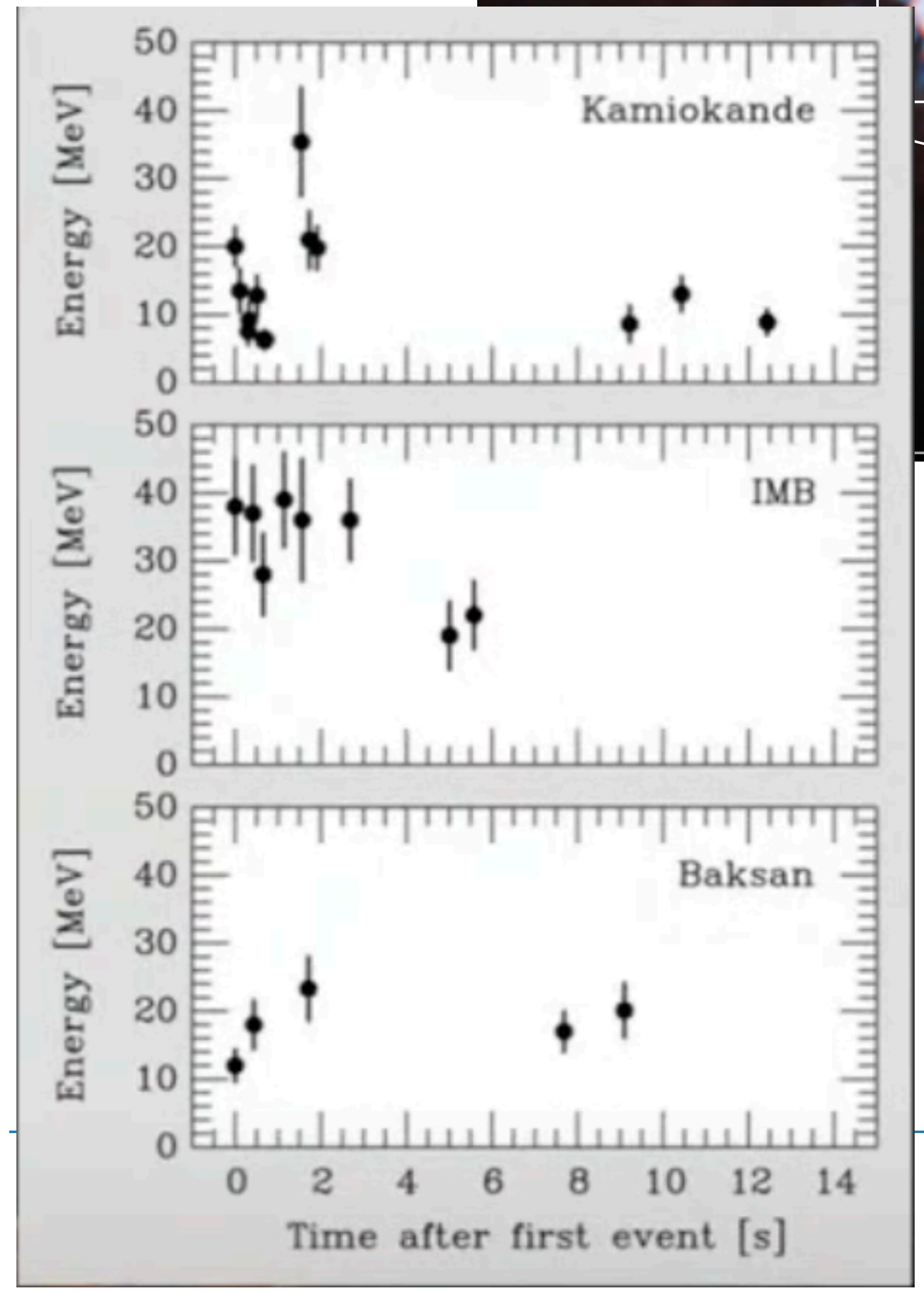
BENEFITS OF THE MM APPROACH:

- **Real time alters** → from neutrinos and GW
- **Early follow-up** for electromagnetic counterparts
- **Improved localization**
- **Joint analysis** → comprehensive overview of CCSNe

SN1987A - FIRST SN WITH DETECTED ν

THE FIRST PARTIAL-MULTIMESSENGER DETECTION OF A CORE-COLLAPSE SUPERNOVA





Neutrino signature:

- Constraints on the neutrino mass and charge
- Direct probe of a core-collapse in a massive star

Electromagnetic counterpart:

- Tentative identification of the **progenitor star**
- Spectrophotometric evolution of the ejecta for 37 years
- Multi-wavelength analysis of CSM interaction

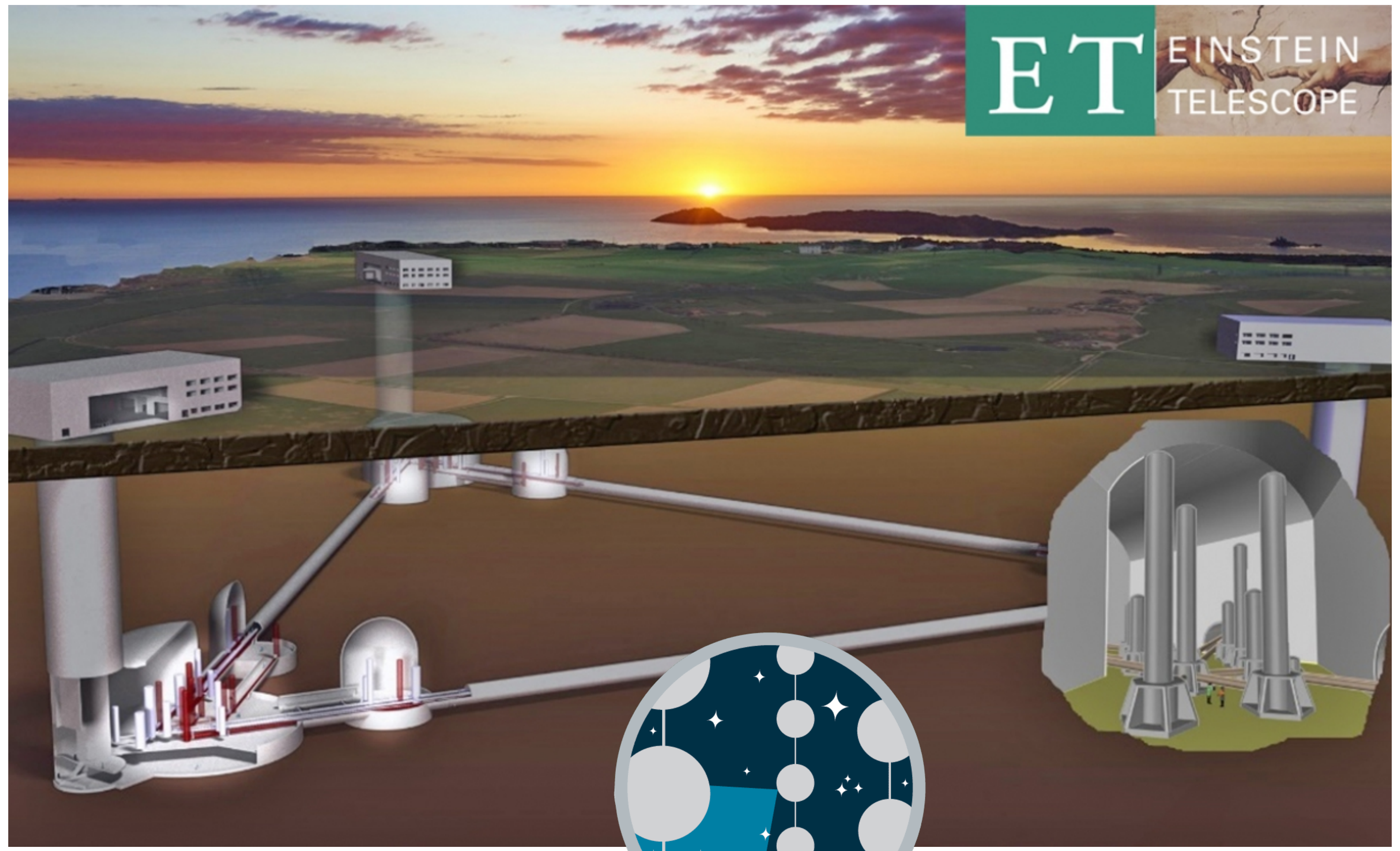
Ongoing remnant observations:

JWST suggests the presence of a neutron star

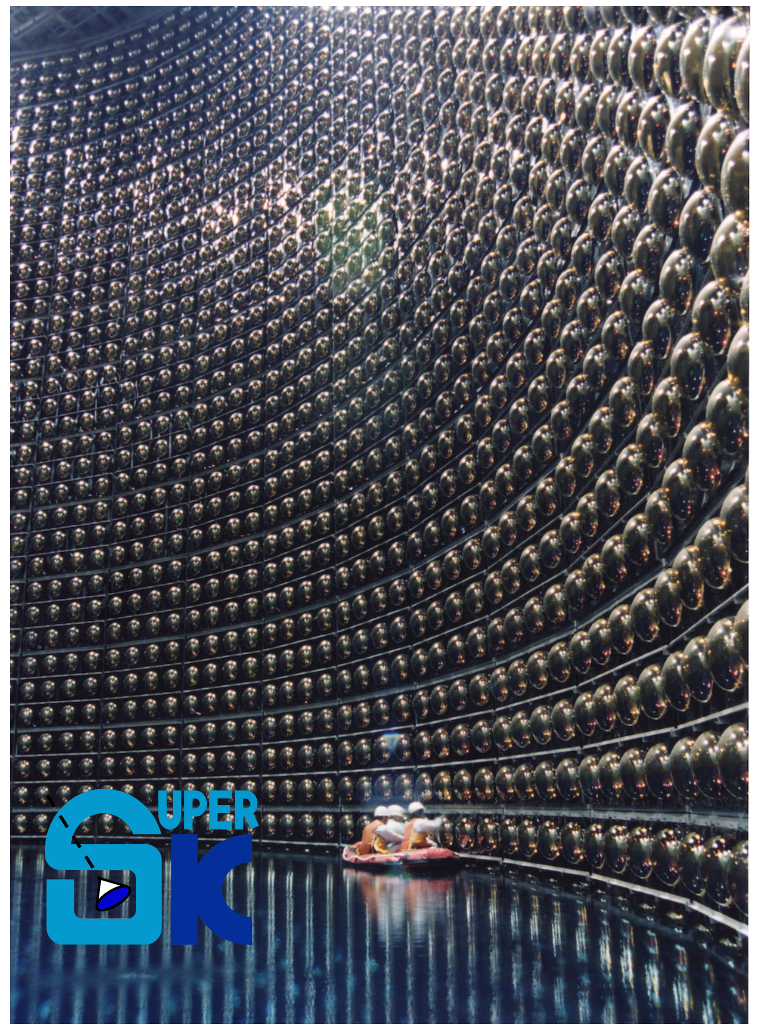
FUTURE SYNERGIES

Messenger	Current Instruments	Future/Upgrades
Neutrinos	Super-Kamiokande, IceCube, Borexino	DUNE, Hyper-Kamiokande, JUNO, IceCube Gen2
Gravitational Waves	LIGO, Virgo, KAGRA	Einstein Telescope, Cosmic Explorer
Optical / NIR	ZTF, Pan-STARRS	Rubin LSST
X-rays / Gamma	Swift, Fermi, INTEGRAL	THESEUS, SVOM, AMEGO-X
TeV / SBO	HESS, MAGIC, VERITAS	CTA, SWGO
Radio	VLA, MeerKAT	SKA

Improved sensititity of 3rd generation GW detector, such as ET, and the **increase of detection** from future neutrino detection will enable **targeted multimessenger searches** for nearby CCSNe.



DUNE
DEEP UNDERGROUND
NEUTRINO EXPERIMENT



ICECUBE
GEN2

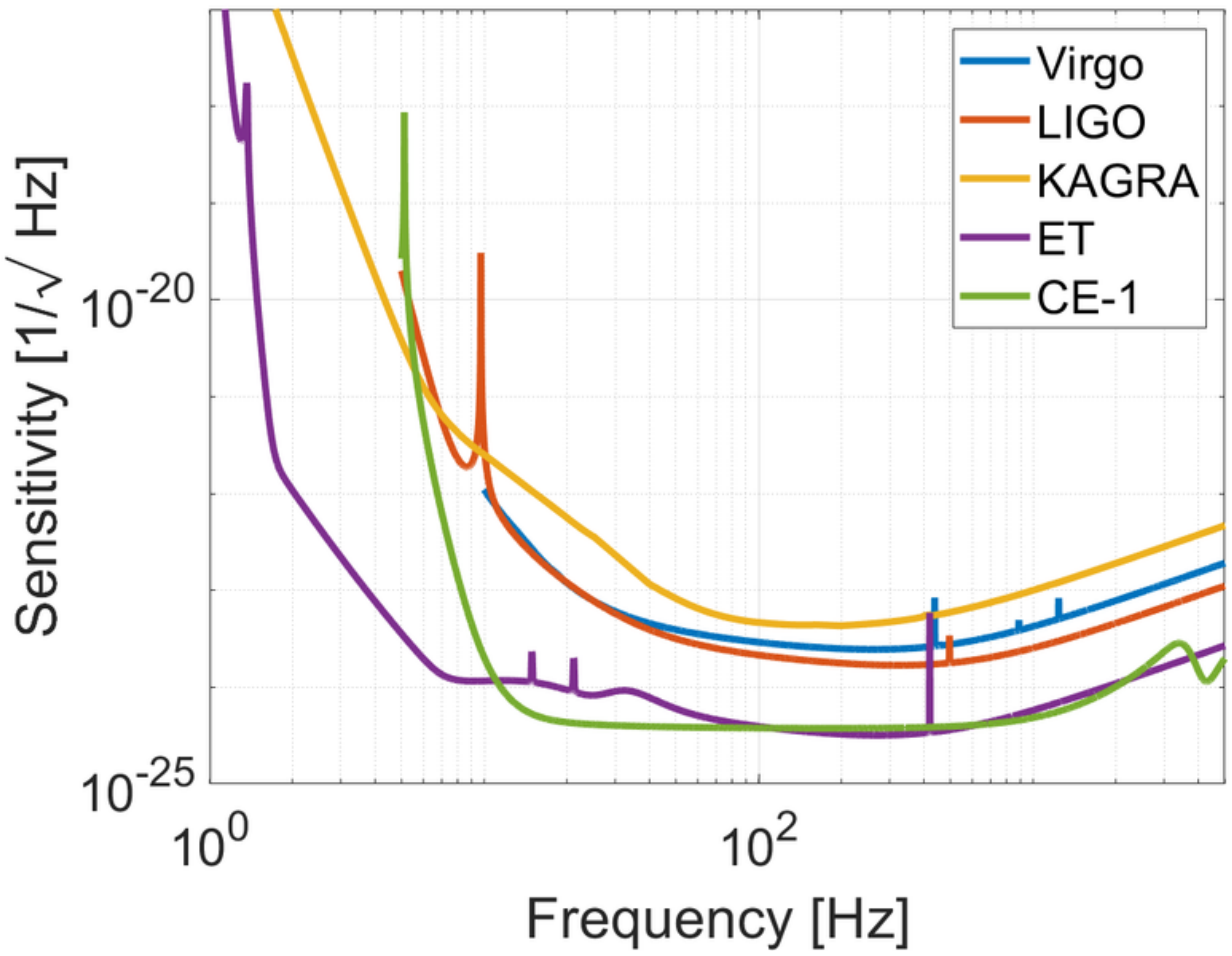
COSMIC
EXPLORER

CCSNE AS GRAVITATIONAL WAVE EMITTERS

GW EMISSION MECHANISM:

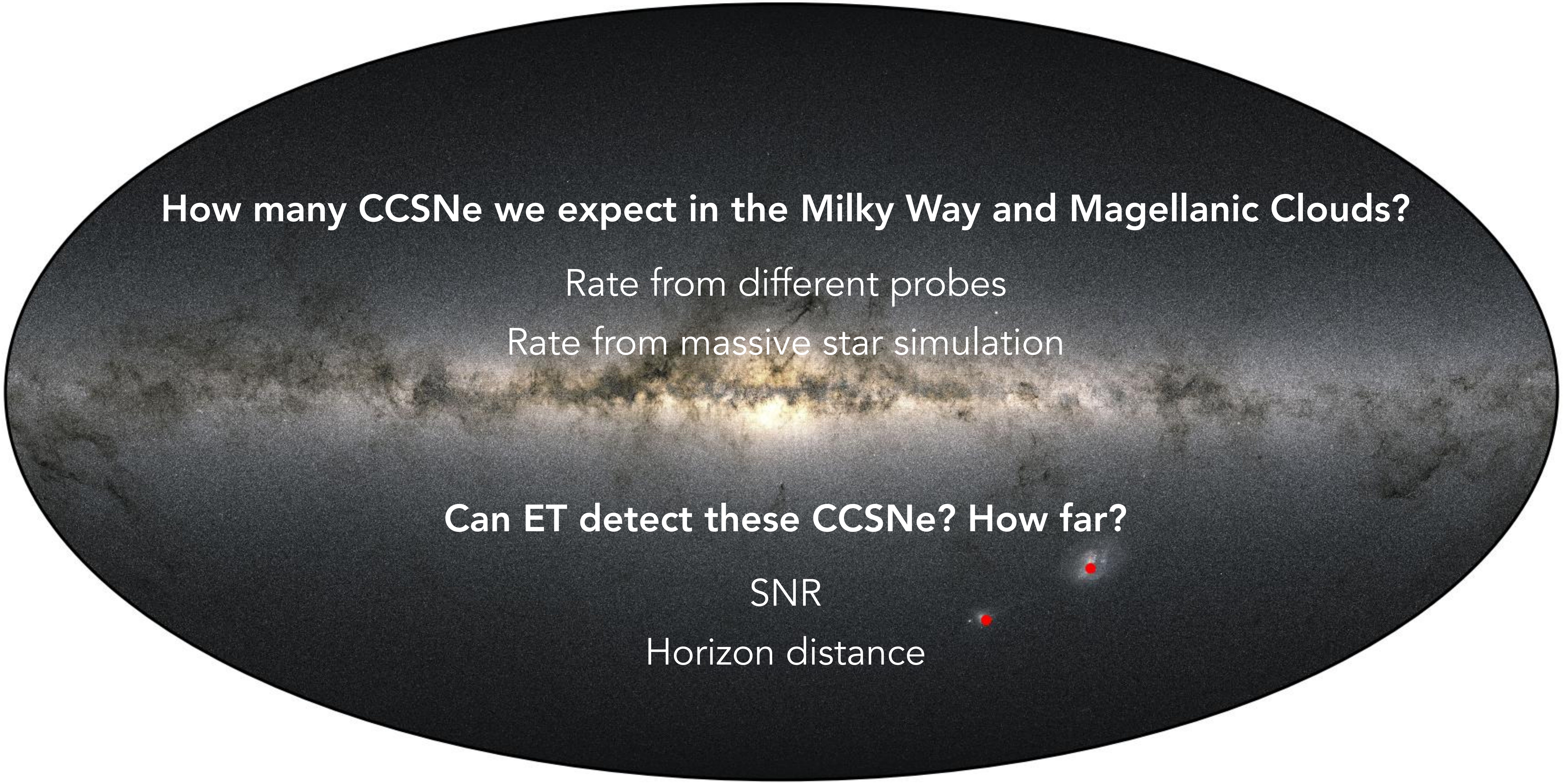
- **Proto-Neutron Star Oscillations**
  G-mode and f-mode oscillations.
- **Standing Accretion Shock Instability & Convection**
  Asymmetric motions in the post-shock region.
- **Prompt Convection**
  Early-stage convection due to negative entropy gradients.

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



P.Rosati et al. (2021)

KEY OBJECTIVE OF OUR PROJECT



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

Rate from different probes

Rate from massive star simulation

Can ET detect these CCSNe? How far?

SNR

Horizon distance

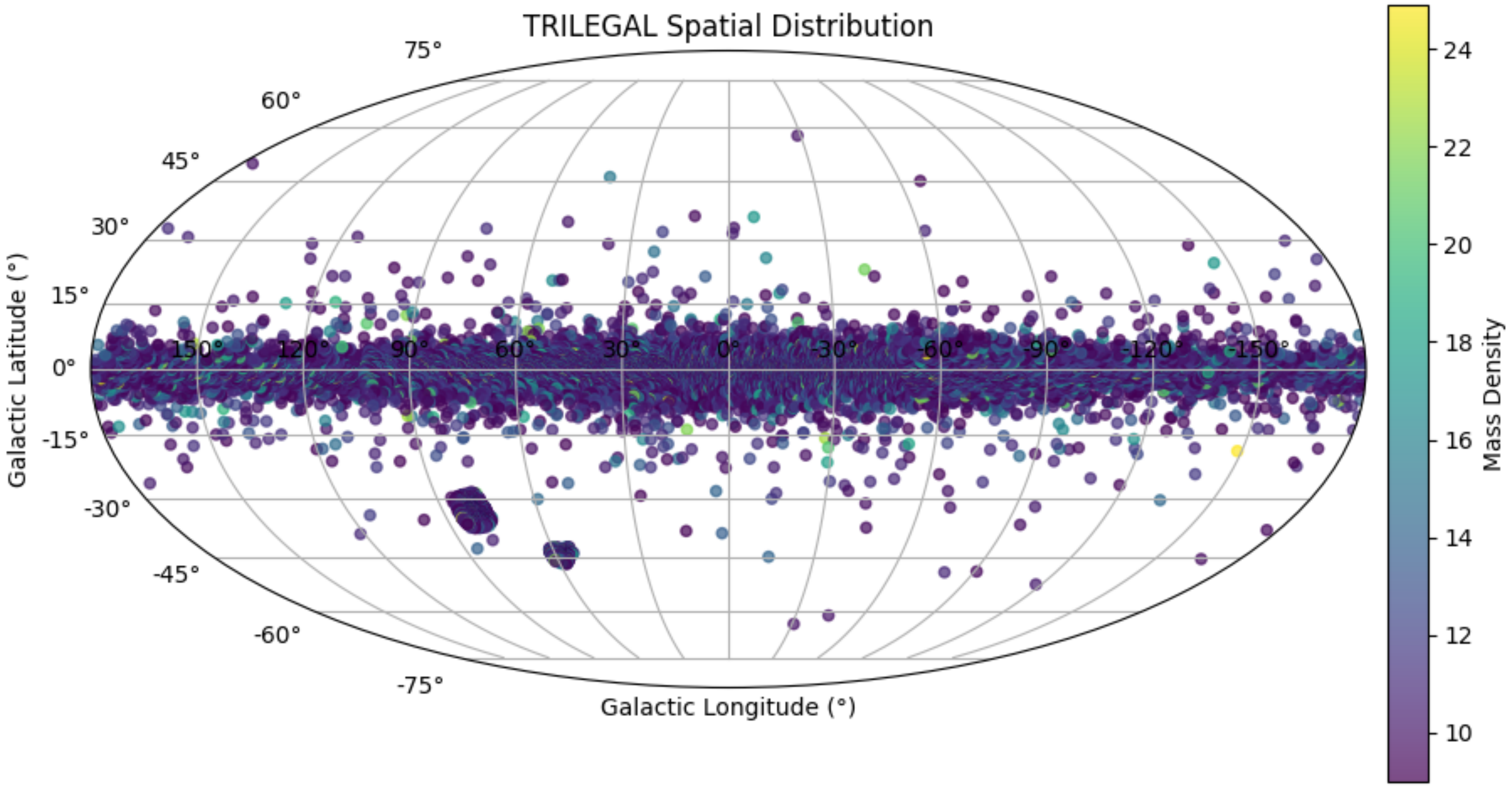
CCSN RATE IN THE MILKY WAY

Observed rate:

- Last observed SN: **SN1604** (Kepler's SN)
- **Detection Challenges:** dust absorption in the Galactic disk
- **Indirect proxies:** Counts of massive stars, SN remnants, elements aboundancies, historical SN..
- Rate from the combination of different proxies: 1.63 ± 0.46 events per century (Rozwadowska et al. 2021)

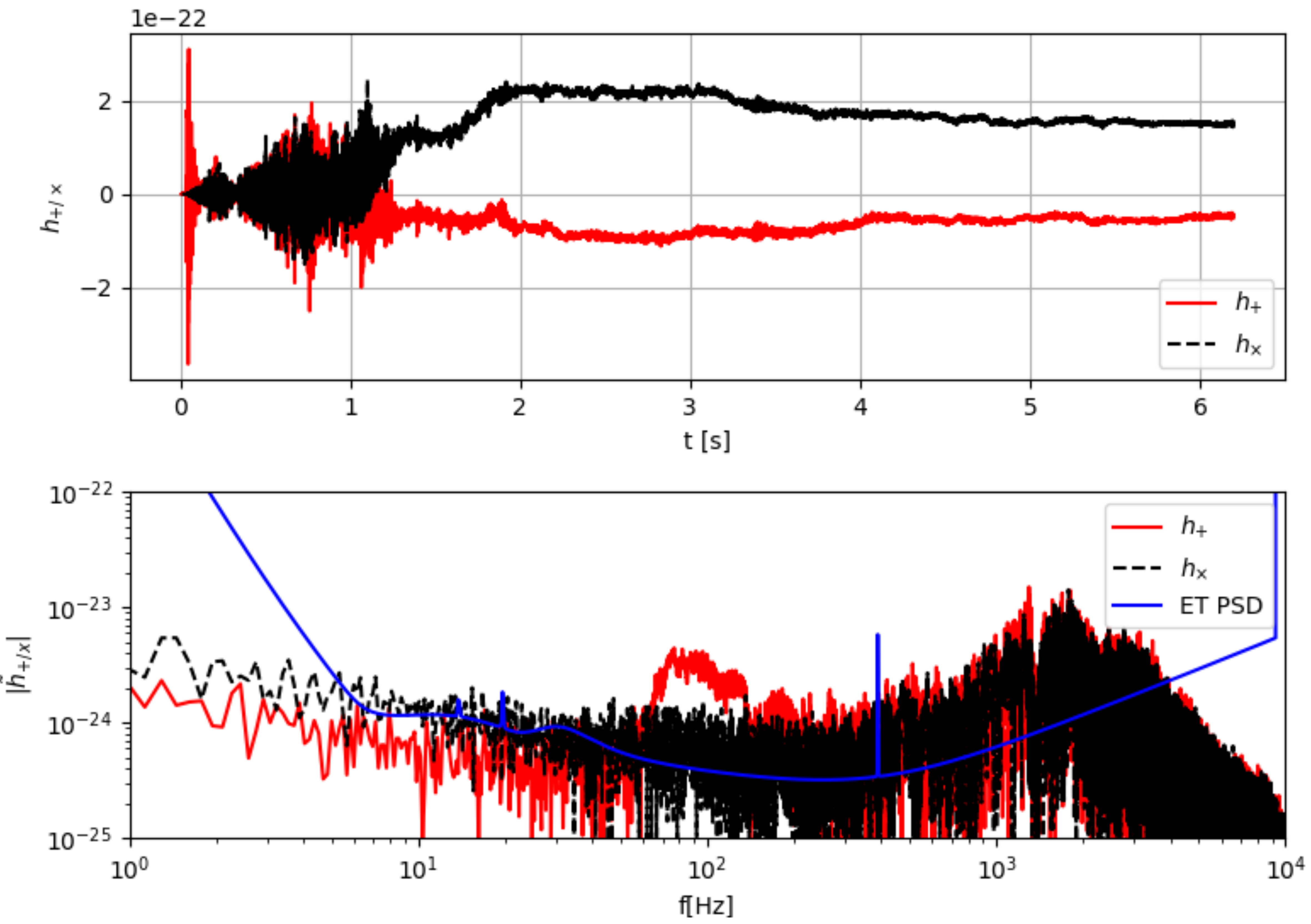
Rate from a massive star distribution:

- **TRILEGAL** spatial distribution of massive stars (Dal Tio et al. 2025)
- **Progenitor mass range**: from 9 to 25 $M_\odot$
- **Preliminary estimate** of core-collapse supernovae rate from simulations: $\sim$ 1 event per century



ET DETECTION CAPABILITY

- **Simulated CCSN waveforms** from D. Radice et al. (2019) a D. Vartanyan et al. (2023)
- Progenitor mass range: from **9** to **25** $M_{\odot}$
- Massive star spatial distribution from **TRILEGAL**
- **GWFISH** adapted for the injection of CCSN waveforms



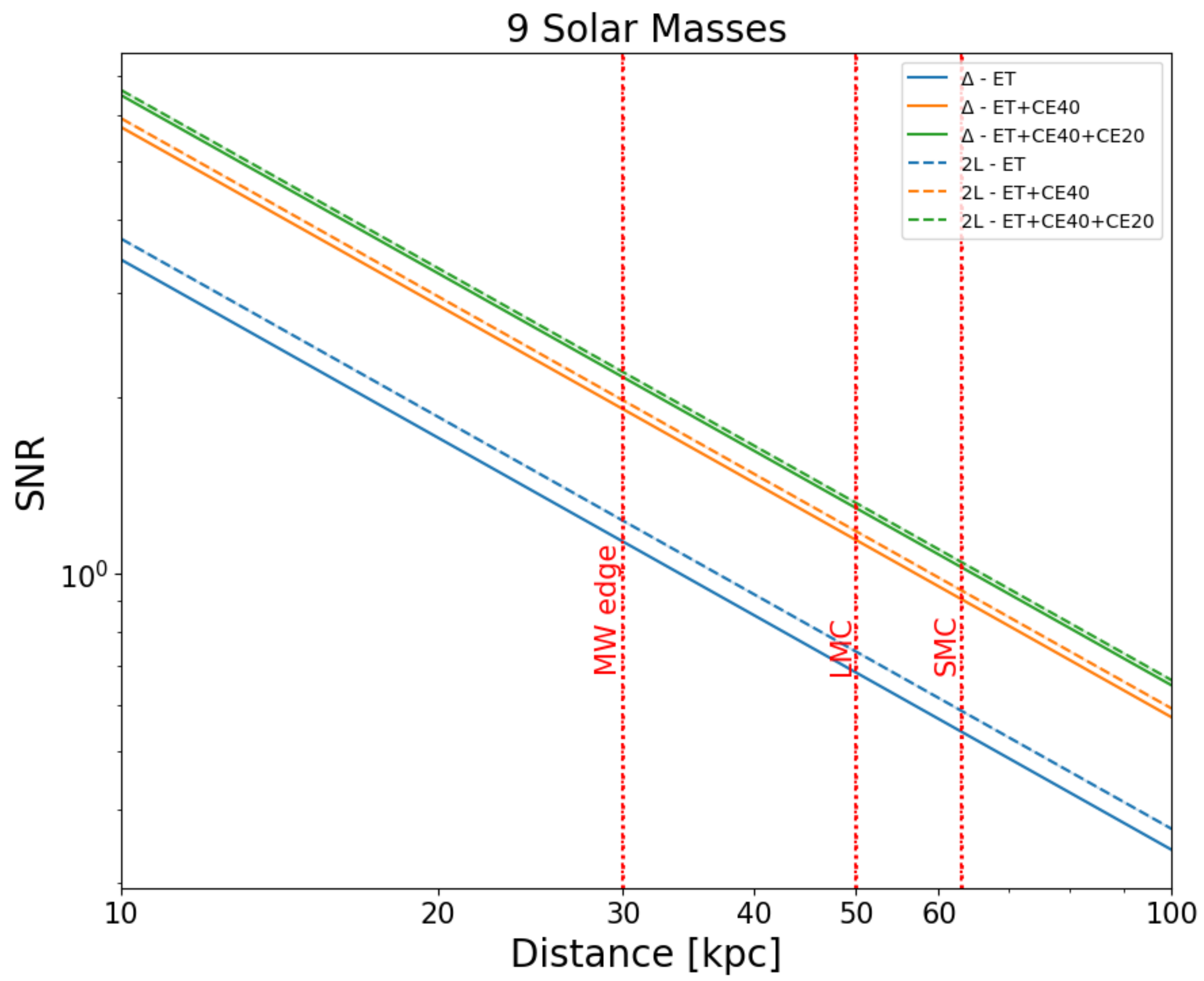
Simulated waveform for 23 $M_{\odot}$ (D.Vartanyan et al. 2023)

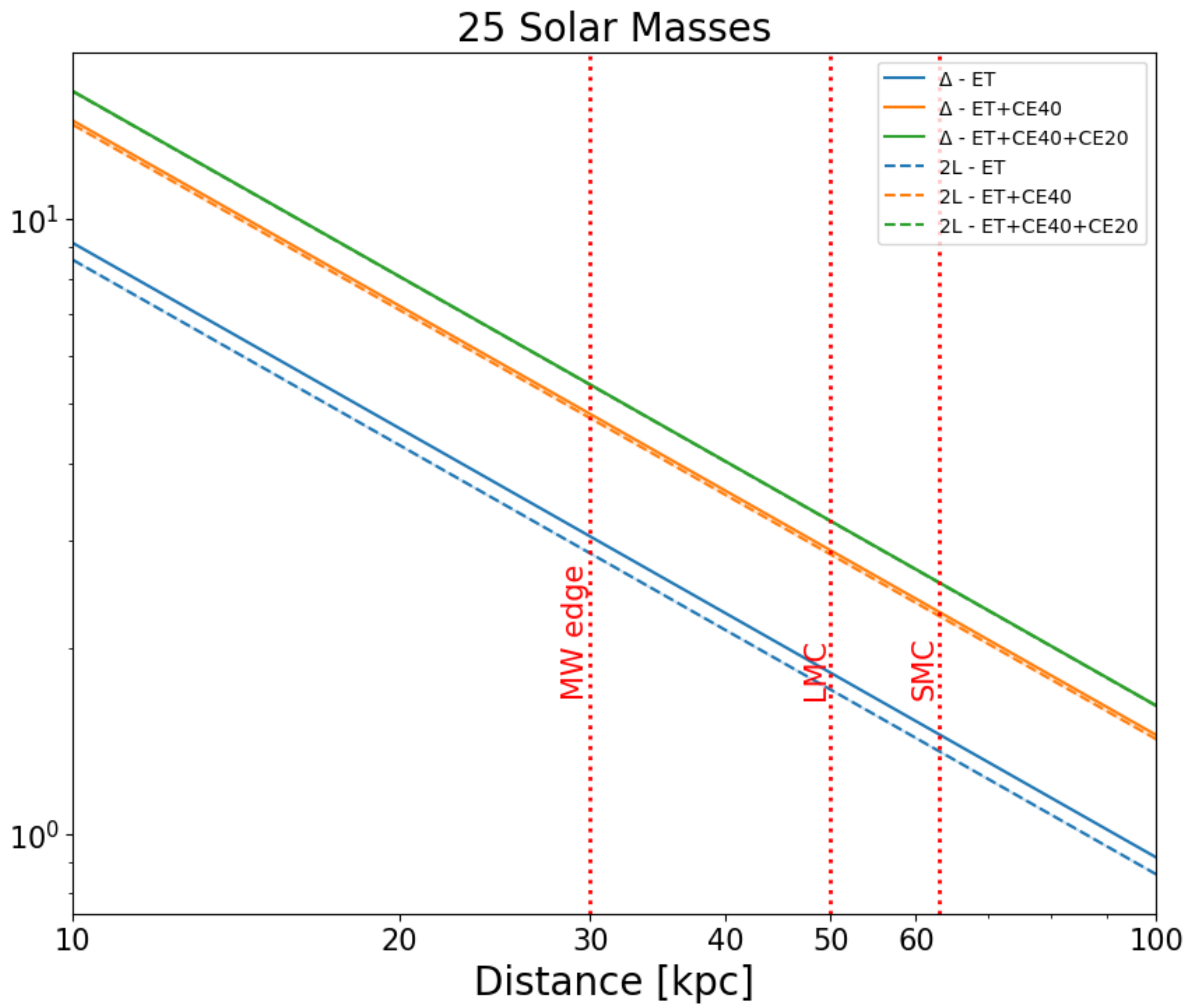
GWFISH (U. Dupletsa et al. 2023) is a simulation software for assessing **detection and parameter estimation** capabilities of future GW detectors, optimized for binary coalescence waveforms (LALsuite-based).

GWFISH

G S S I
GRAN SASSO SCIENCE INSTITUTE

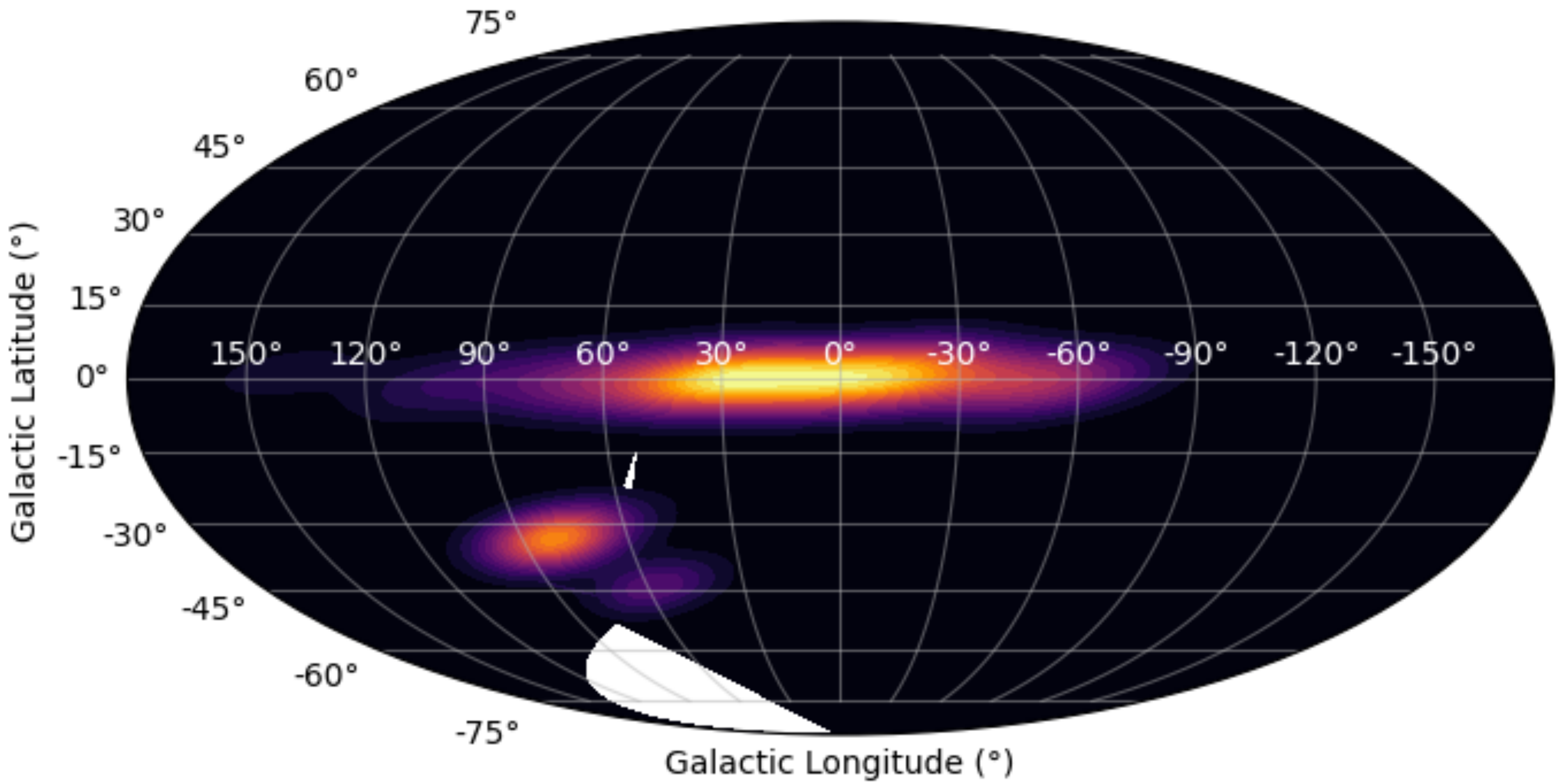
PRELIMINARY RESULTS: HORIZON





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

PRELIMINARY RESULTS: SNR



SNR-weighted density maps: identify the **highest probability region for detection** by the ET.

GWFISH

CONCLUSIONS

CCSNe are promising sources for **multimessenger astrophysics:**

- To date, no CCSN has been through GWs, and only SN 1987A has been observed through neutrino emission.
- Even a single multimessenger event could revolutionize our understanding of CCSNe.

The **Einstein Telescope** will open a new era in GW detection from these events:

- In our work we estimated **expected GW detection rate** and **horizon of ET** for the CCSNe.
- **Preliminary results** suggest possible detection up to the Magellanic Clouds in synergy with Cosmic Explorer.

Future efforts:

- Simulation with waveform models for **rotating progenitor stars** of CCSNe;
- Coordination between **neutrino** and **GW detectors** to maximize detection confidence and sky localization;
- Optimization of **EM follow-up strategies** to capture SBO and probing explosion geometry and nucleosynthesis.