ET OSB div 7
Stellar collapse and isolated neutron stars

Coordinators:
Ik Siong Heng, Marco Limongi, Cristiano Palomba

ET Symposium
Maastricht, May 6th, 2024

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Many thanks to previous coordinators:
Marie-Anne Bizouard, Enrico Cappellaro and Pablo Cerda-Duran!

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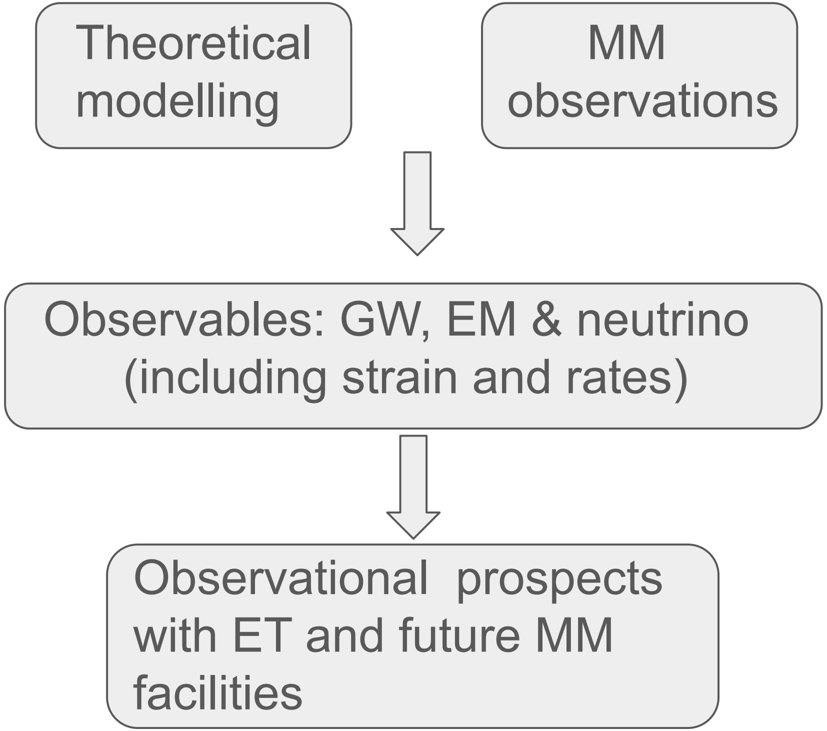
Goals & Scope



Q1: which are the stars that eventually evolve to a collapse?
Q2: which is the stellar collapse mechanism and rates?
Q3: can we predict which compact objects are produced?
Q4: which are the most promising GW emission channels from spinning NSs?
Q5: which are the GW detection perspectives with ET?
Q6: which are the future EM/nu facilities we can exploit for MM?

Connection with DIV4 (MM), DIV6 (nuclear physics), DIV8 (waveforms), DIV10 (DA)

Div 7 activities & organisation

Meetings about every month, most recently to discuss div 7 blue book chapter but, in the long term, we aim to **discuss recent papers from group's members (from modeling to data analysis techniques through observational results)**

Please get in touch with div chairs to volunteer topics!

List of relevant publications: https://wiki.et-gw.eu/OSB/StellarCollapseNS/Publications

Goal:

Assess recent progresses in CCSN and magnetar GW emission modeling. Assess event rates (CCSN, magnetars, SGR, FRB, ...).
Survey future facilities for MMA.
Assess ET capabilities to detect these sources.

Blue book div7 chapter

- Significant efforts in writing from many authors
  - currently ~50 pages (78 with references)
  - some sections require more work
- Still not a complete draft
- We are committed to have a full draft by the end of May
  - Contributors are kindly asked to write/complete their parts

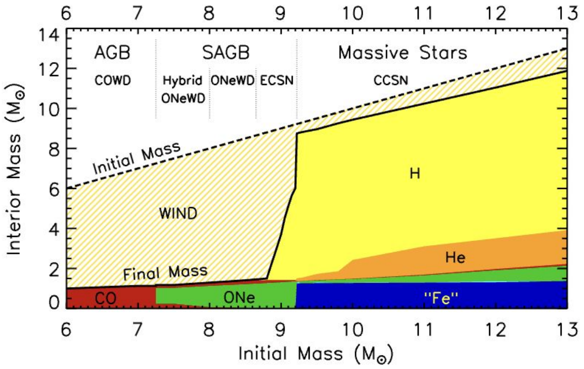
Sec. 2 - Stellar Collapse

Sec. 2 - Stellar evolution toward stellar collapse

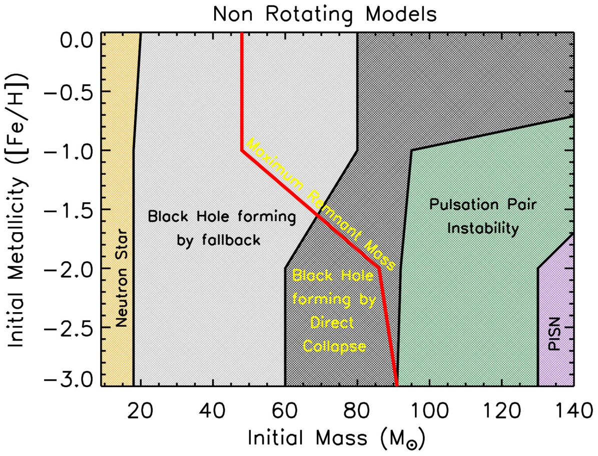
Expected final fate and remnants of stars in the various initial mass interval as a function of the initial metallicity and initial rotation velocity. Expected maximum mass of BH (red line, see Ugolini's Talk)

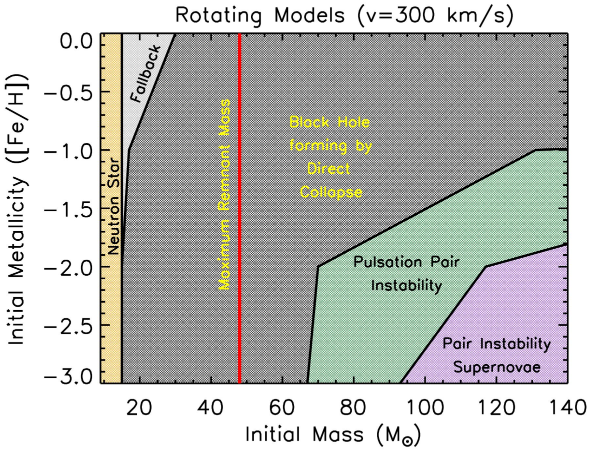
M_{ECSN}: Minimum mass of stars exploding as Electron Capture Supernovae

M_{ECSN}: Minimum mass of stars exploding as Core Collapse Supernovae



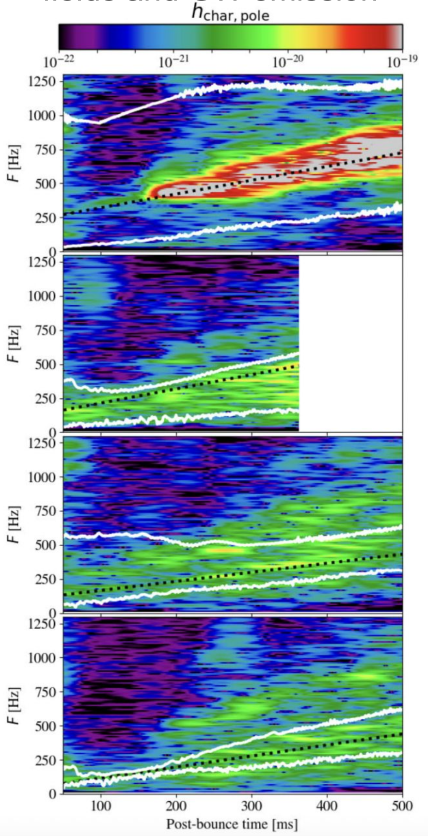
Limongi+ 2024





Sec. 2 - Modelling, explosion mechanisms and dynamics

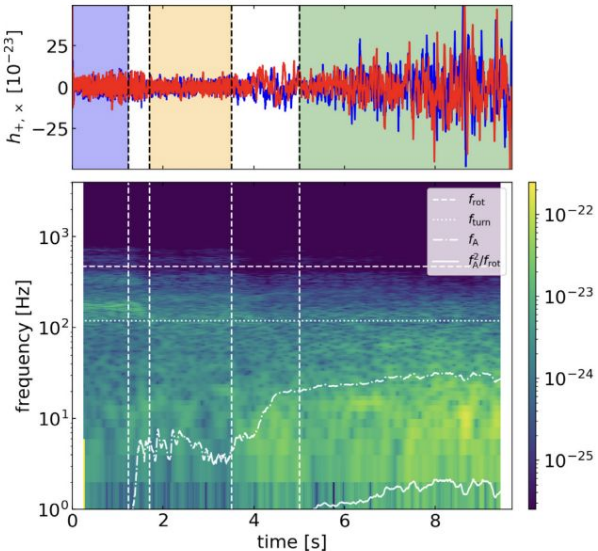
Bugli+ (2023): rotational instabilities, magnetic fields and GW emission



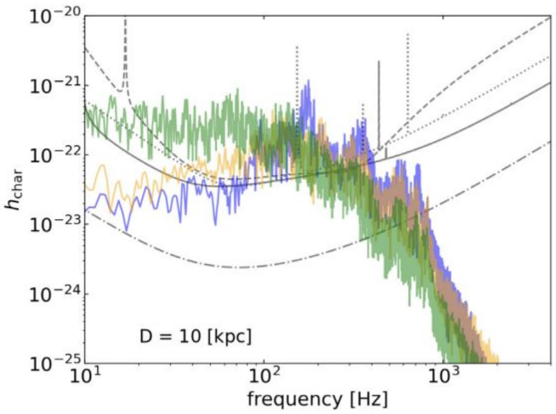
Recent advances on:

- waveforms from 3D core collapse simulations with/without rotation and magnetic field
- Neutron-MHD code comparison
- Detectability and parameter inference of SN waveforms

Credit for slide content: Martin Obergaulinger

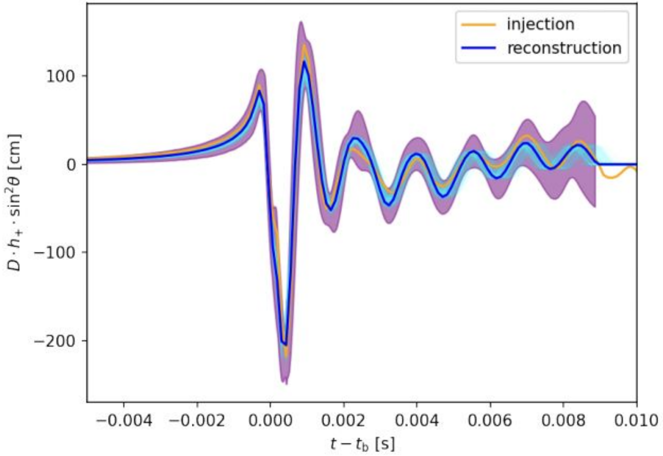


Raynaud+ (2022): PNS dynamo and GW emission

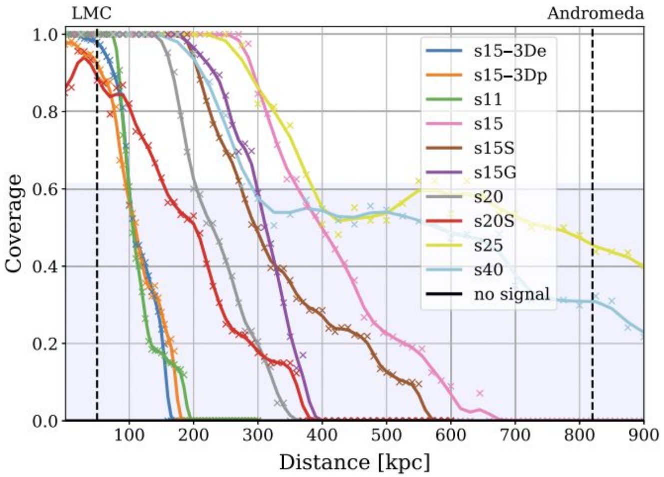


Credit for slide content: Martin Obergaulinger

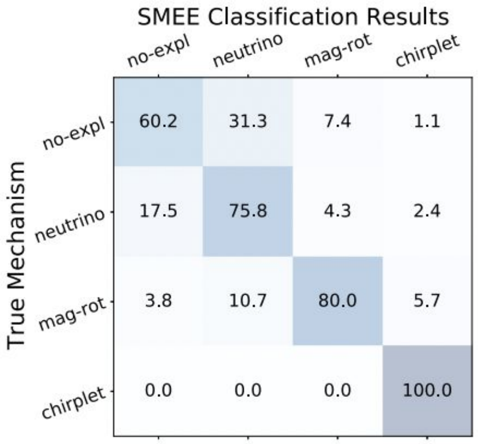
Pastor-Marcos+ (2023): Bayesian inference for rapid rotation

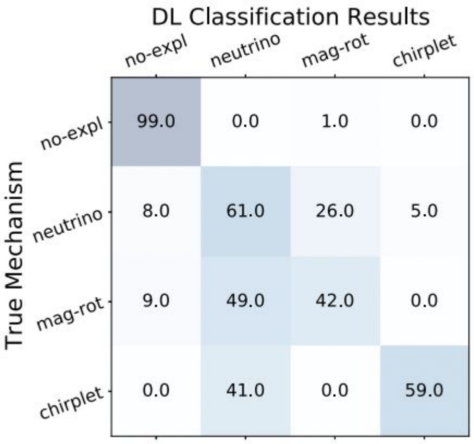


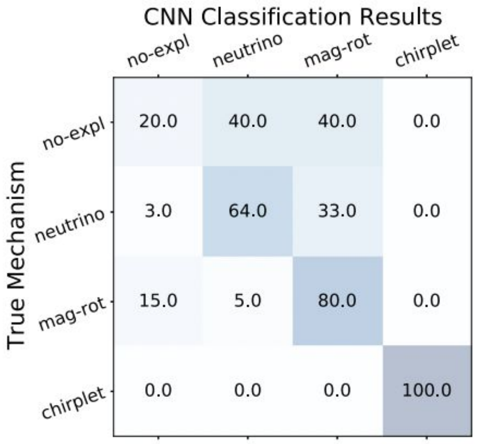
Bruel+ (2023): inference of PNS parameters (M/R^2) with ET + 2CE (plot refers to a favorable orientation)



Powell+ (2024): ML classification of explosion mechanisms using ET







Sec. 2 - Predicted and observed core collapse SN rates

	10 Mpc		50 Mpc		100 Mpc	
	SFR ($M_\odot$ yr^{-1})	CCSNR (yr^{-1})	SFR ($M_\odot$ yr^{-1})	CCSNR (yr^{-1})	SFR ($M_\odot$ yr^{-1})	CCSNR (yr^{-1})
LOSS		$0.29^{+0.05}_{-0.04}$		$37.0^{+5.8}_{-5.7}$		295^{+47}_{-46}
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	9420±602	45±3	75360±4814	362±23
Hopkins & Beacom	65	0.3	8836	42	76121	365
Madau & Dickinson	63	0.3	8059	39	66568	319
Observations		$1.1^{+1.7}_{-0.6}$		38.0±2.5		153±5

See Giudice's Talk

Table 3: The expected CCSNe per year within 10 Mpc, 50 Mpc and 100 Mpc from the volumetric rate measured by LOSS and from different estimates of the total SFR in the same volumes and the number of observed CCSNe per year estimated from archive reports.

- **Sec. 2 status**
  - Most material is there, need to be better shared among the various subsections
  - MM signatures is to be written

Sec. 3 - Spinning Neutron Stars

Sec. 3 - Neutron star populations

- Classes of NSs represents the outcome of different evolutionary paths or different stages (i.e different times) of a given evolutionary path

- NSs can emit GWs essentially through two different mechanisms:
  - persistent emission due to “mountains” or long-lived oscillation modes (e.g. r-modes) [Gittins’ talk]
  - Burst-like emission due to glitches or short-lived oscillation modes

- Different GW search methods depending on the emission mechanism and knowledge of source parameters

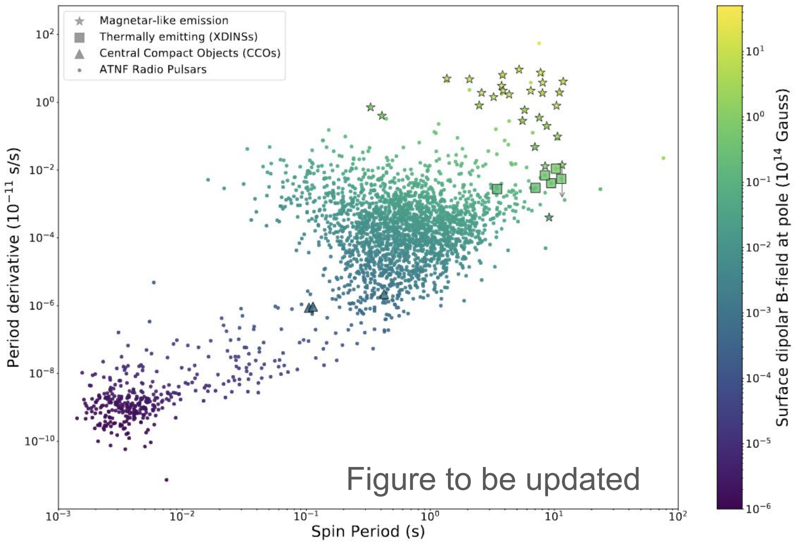


Figure 8: Period versus period derivative of different classes of pulsars. The colour bar reports on their surface dipolar magnetic field at the pole. NR:

Sec. 3 - Spinning Neutron Stars

- **Status**
  - Populations: still some work to be done but overall in good shape
  - GWs emission:
    - reduce overlap with div 6;
    - focus more on what is not covered in div 6: LMXBs, newborn magnetars, pulsar glitches.
    - Outline CW searches depending on GW mechanism/parameter knowledge

Sec. 4 - Observational prospects

Sec. 4 - Continuous waves and long-transients

Prospects for the known pulsar population

Configuration	n_1	n_2	n_3
Δ 10km	866 (2.5×10^{-10}, 1.3×10^{-4})	180 (2.5×10^{-10}, 4.4×10^{-9})	19 (2.5×10^{-10}, 7.5×10^{-10})
Δ 10km HF-only	398 (2.5×10^{-10}, 6.2×10^{-6})	178 (2.5×10^{-10}, 4.4×10^{-9})	19 (2.5×10^{-10}, 7.5×10^{-10})
Δ 15km	983 (2.1×10^{-10}, 1.1×10^{-4})	214 (2.1×10^{-10}, 4.4×10^{-9})	33 (2.1×10^{-10}, 7.9×10^{-10})
2L 15km	959 (2.0×10^{-10}, 1.2×10^{-4})	206 (2.0×10^{-10}, 4.2×10^{-9})	29 (2.0×10^{-10}, 8.1×10^{-10})
2L 15km HF-only	451 (2.0×10^{-10}, 5.6×10^{-6})	203 (2.0×10^{-10}, 4.0×10^{-9})	29 (2.0×10^{-10}, 8.1×10^{-10})
2L 20km	1035 (1.8×10^{-10}, 1.1×10^{-4})	227 (1.8×10^{-10}, 4.3×10^{-9})	33 (1.8×10^{-10}, 7.3×10^{-10})

Table 38. Expected number of detectable sources, assuming three different conditions for the ellipticity: $\epsilon = \epsilon_{sd}$ (n_1), $\epsilon = min(\epsilon_{sd},\ 10^{-6})$ (n_2), $\epsilon = min(\epsilon_{sd},\ 10^{-9})$ (n_3), assuming a total observation time $T_{\rm obs} = 1$ year and a duty cycle of 85%. For each case, we give in parentheses the minimum and median value of ellipticity for detectable signals.

The 2L-15km configuration is used as a reference (for the triangle results are only mildly worse)

Sec. 4 - Continuous waves and long-transients

Differently from “standard” CWs, stronger signals but shorter duration (hours-days) due to fast spin-down

In newborn magnetars the asymmetry is induced by the strong inner magnetic field (if not aligned with the star’s rotation axis)

At d~10 Mpc we expect ~1 event every one–few years

Room for DA algorithms improvements

Prospects for long-transient emission from newborn magnetars

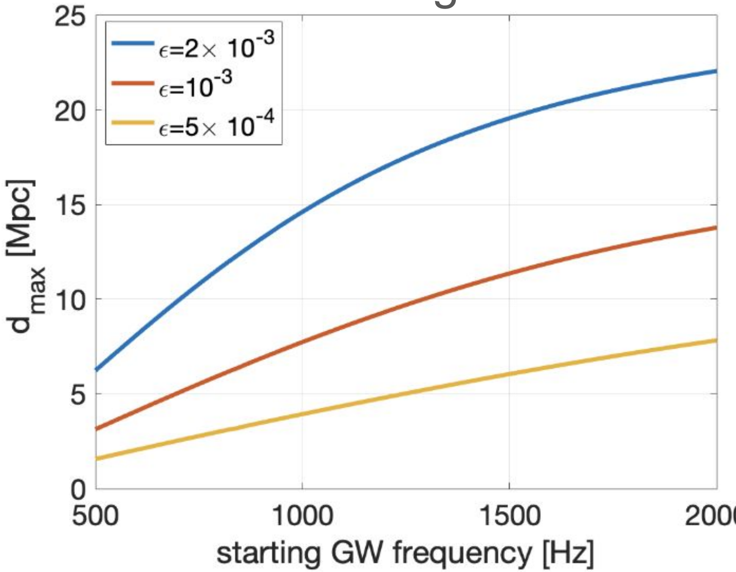
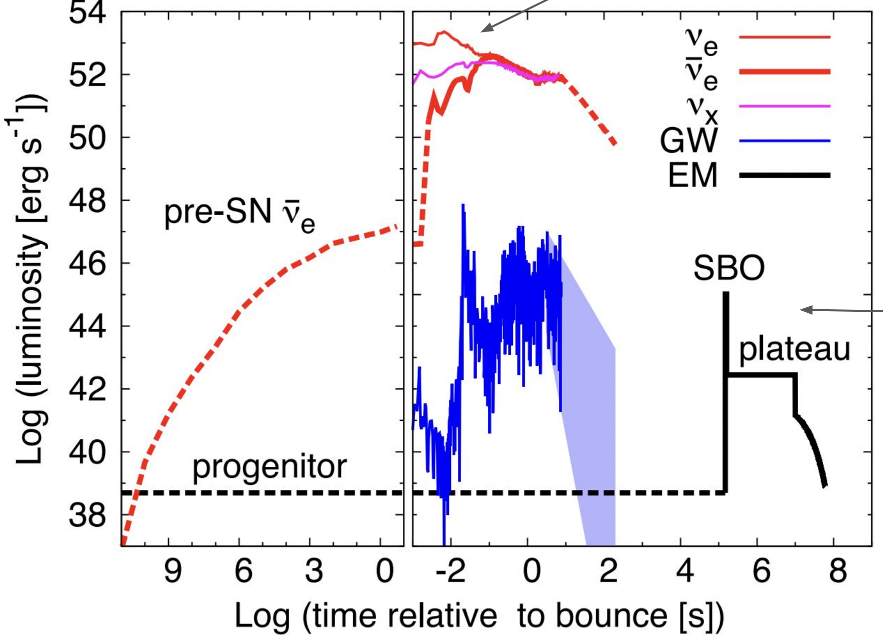


Figure 9: Maximum distance at which long-transient GW emission from a newborn magnetar could be detected by ET for three different plausible values of the ellipticity (and realistic analysis setup). A configuration consisting of two L-sphape 15km arms detectors is considered. Similar results would be obtained for other realistic configurations.

Sec. 4 - Future MM facilities

Nu can provide a temporal trigger



EM alert

Time evolution of multi-messenger signals from a CCSN explosion (nu-driven explosion of a non-rotating 17M_sun progenitor (Nakamura+ MNRAS 2016)

Sec. 4 - Future MM facilities

*EM facilities …. **an incomplete** map*

Astrophysical scenarios

Astrometry

GAIA

Optical/infrared Photometry Spectroscopy

VLT

Search counterparts

Optical variability / transients search

ZTF/ATLAS

RUBIN

Optical / infrared counterpart sort out

NTT+EFOSC2

SOXS

mm/radio

ALMA EVN/VLBI

SKA

Follow-up

VLT X-Shooter JWST

ELT WST

High-energy

Fermi/SWIFT/XMM/ CHANDRA/Einstein Probe

THESEUS

present
future

Slide credit: S. Piranomonte

Sec. 4 - Observational prospects

- **Status**
  - Text needs to be expanded, some subsections to be completed
    - Add prospects for GW-burst signals
    - Additional prospects for CW (all-sky searches, LMXBs)
    - EM population studies
  - Add some explicative figures

Summary

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- Web site : https://wiki.et-gw.eu/OSB/StellarCollapseNS/WebHome
- Mailing list : https://mail.ego-gw.it/mailman/listinfo/et-osb-stellarcollapse-ns
- Blue book : https://www.overleaf.com/project/608ada23f2139b57d696cab4
- Meetings : https://wiki.et-gw.eu/OSB/StellarCollapseNS/Meetings

Talks of this session

Andrew Miller "**Localizing binary neutron star inspirals and constraining primordial black hole abundance using continuous wave methods in ET"**

Xiaoyi Xie **"Bridging Relativistic Jets from Black Hole Scales to Long-Term Electromagnetic Radiation Distances: a Moving-Mesh General Relativistic Hydrodynamics Code with HLLC Riemann Solver"**

Fabian Gittins **"How to make a neutron-star mountain out of a molehill"**

Cristiano Ugolini "**The initial mass – remnant mass relation for core-collapse supernovae"**

Ines Giudice "**Theoretical prediction and observed rates for CCSNe"**