Multi-Messenger Transients: From Current Observations to the Prospects of Next-Generation Observatories

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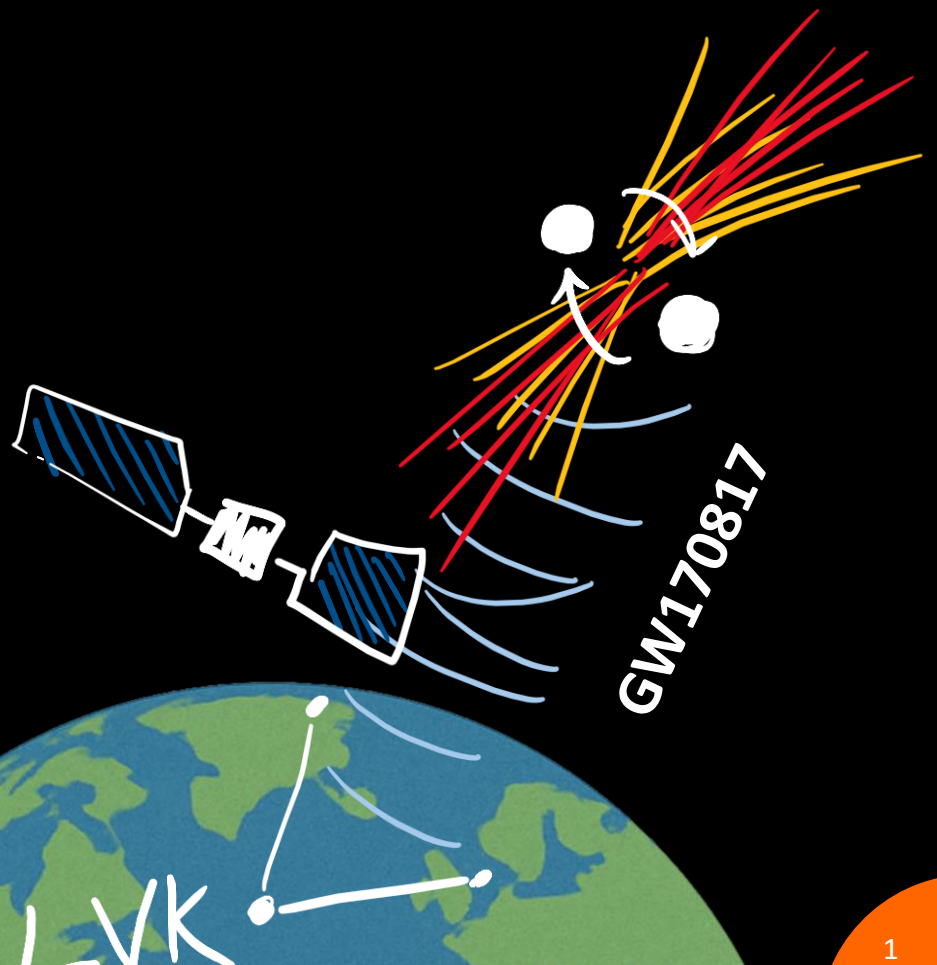
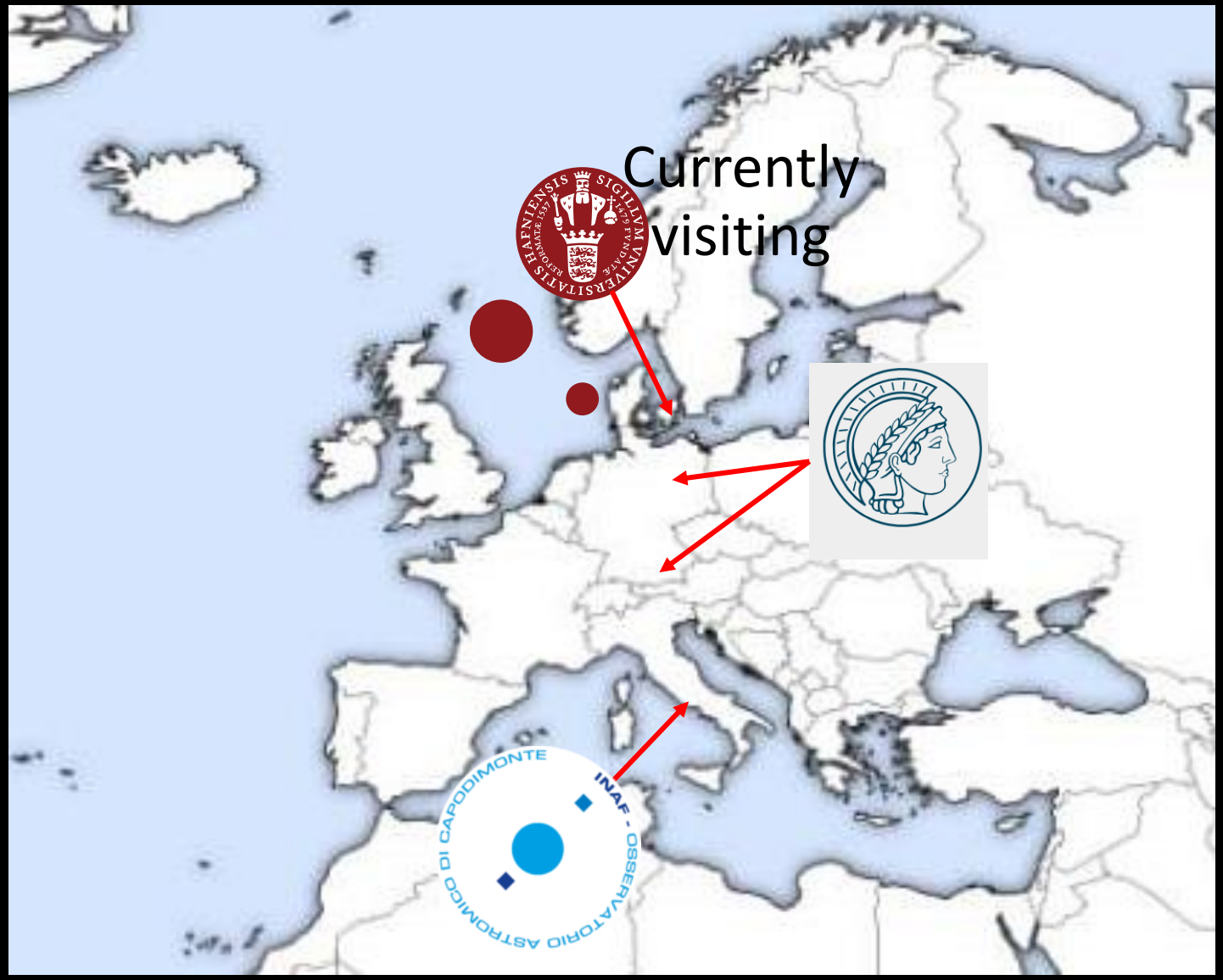


Advisors :
Filippo Santoliquido,
Samuele Ronchini,
and **Marica Branchesi**

Current Collaboration Map (outside of L'aquila)



Multimessenger Transients

Focus on two categories

Core-Collapse Supernovae

SN (optical)

Long GRBs

Previously on …

neutrinos

BNS mergers

GW

Short GRBs

neutrinos

Current and future observatories

Current detectors

~ 100s GRB observations

The Fourth Fermi-GBM Gamma-Ray Burst Catalog: A Decade of Data

A. von Kienlin, C. A. Meegan, W. S. Paciesas, P. N. Bhat, E. Bissaldi, M. S. Briggs, E. Burns, W. H. Cleveland, M. H. Gibby, M. M. Giles Show full author list

LVK bounds and ~ 150 published events

GWTC-4.0: Population Properties of Merging Compact Binaries

The LIGO Scientific Collaboration, the Virgo Collaboration, the KAGRA Collaboration: A. G. Abac, I.

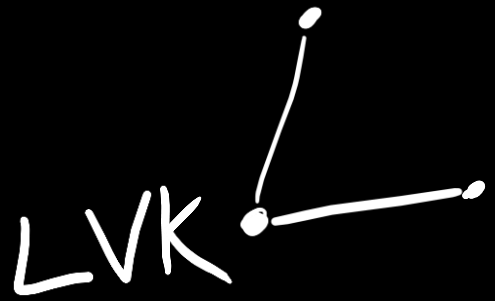
158 mergers from the cumulative Gravitational-Wave Transient Catalog 4.0,

Current and future observatories

Current detectors

~ 100s GRB observations

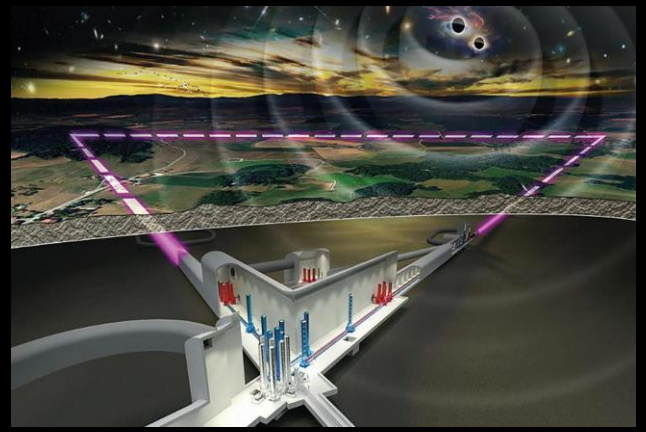
LVK bounds and ~ 150 events



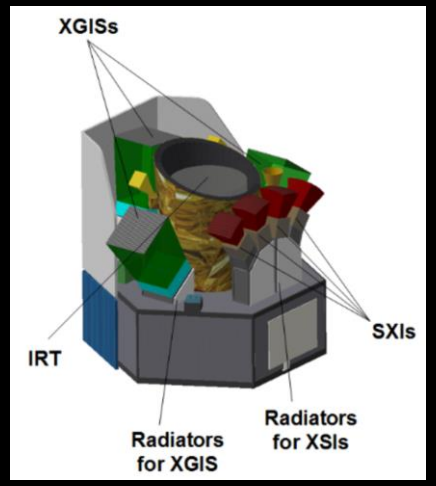
What can we infer on BNS, NS-BH, etc…

Future observatories

Einstein Telescope

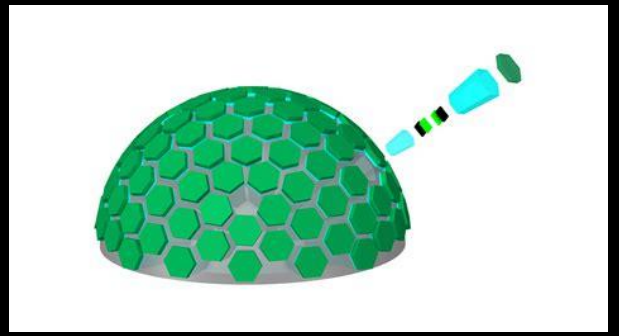


THESEUS



Cosmic Explorer

Crystal Eye



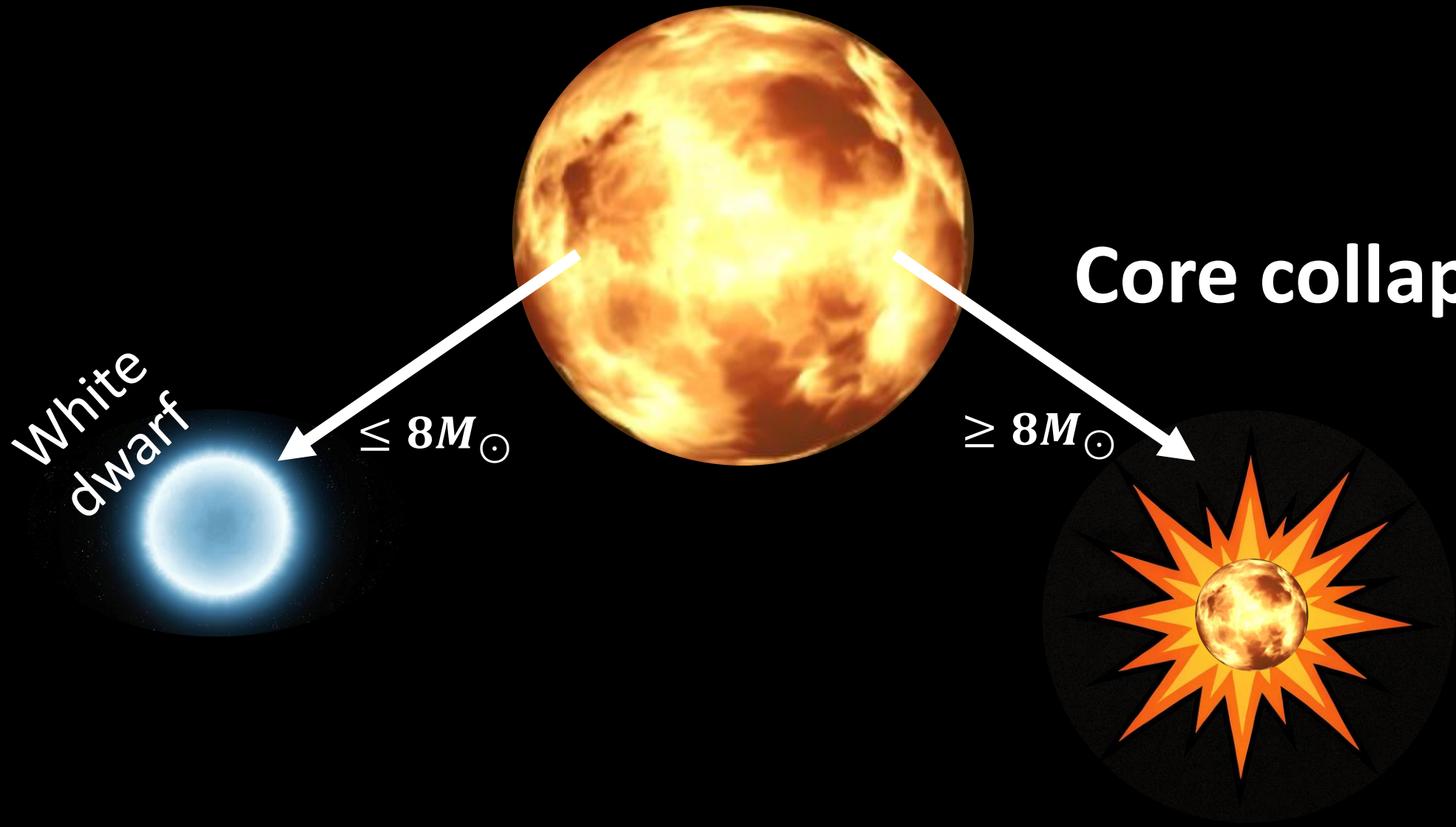
Current and future observatories prepartion

Optimize multi-messenger data analysis?

What **tools** and **frameworks** are needed to enable synergies across messengers and facilities**?**

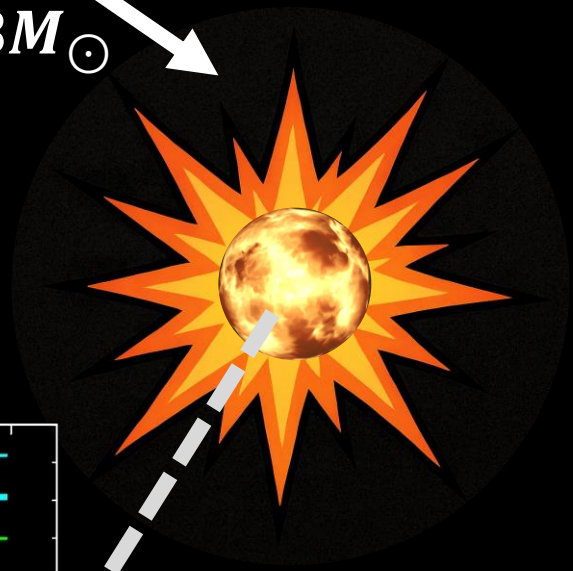
Which observatory **designs** maximize scientific return? What science goals should drive these choices?

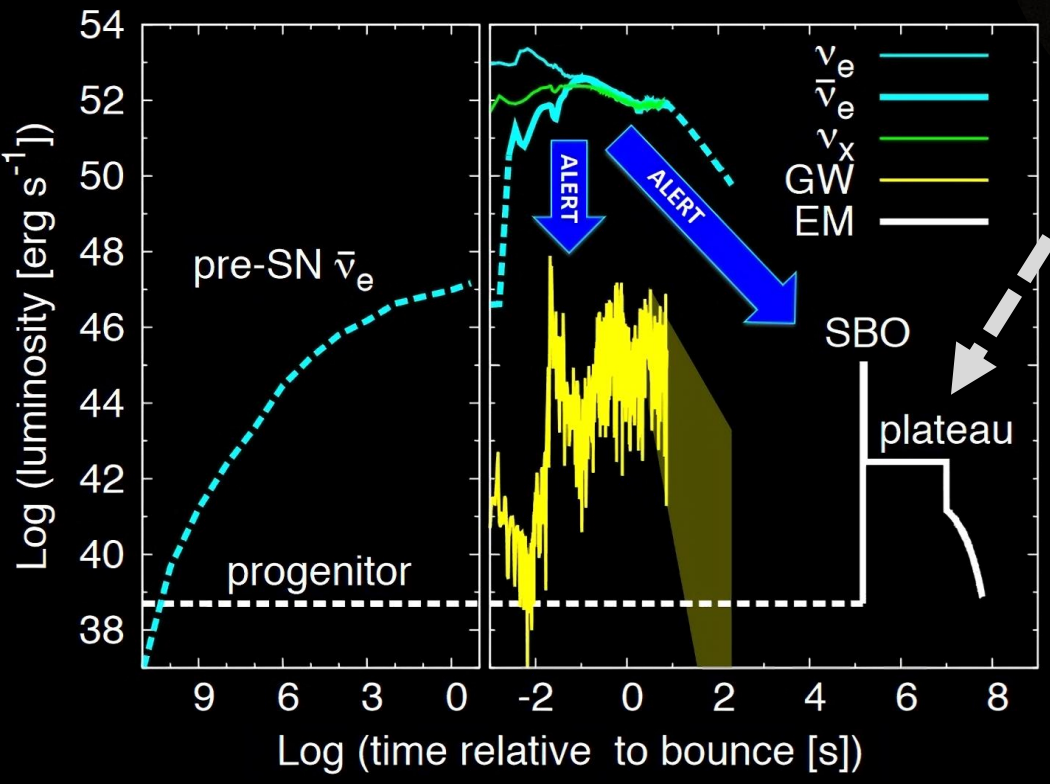
The Fate of stars

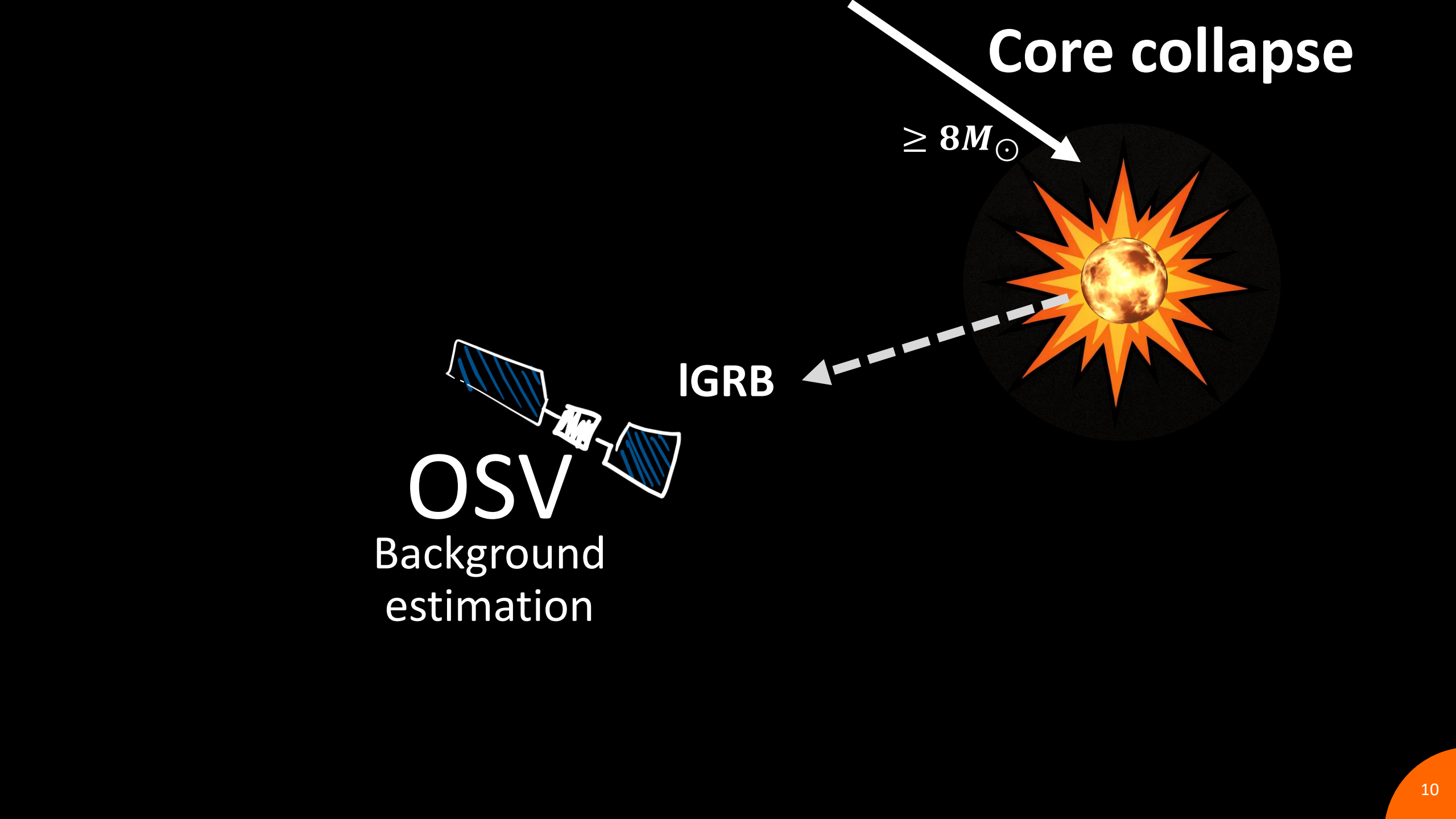


Core collapse

$\geq 8M_{\odot}$

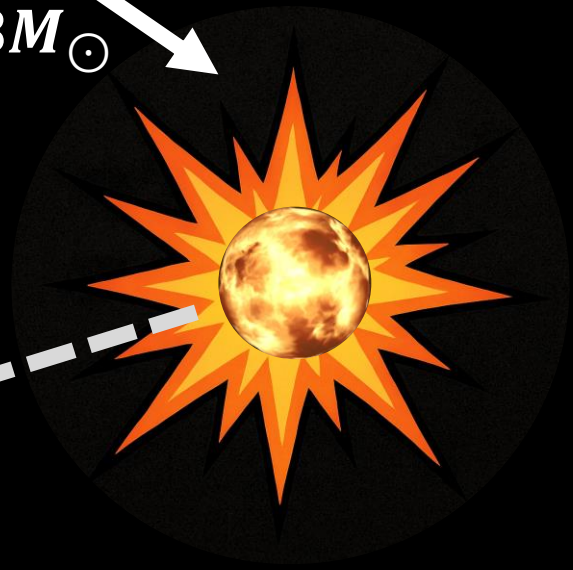




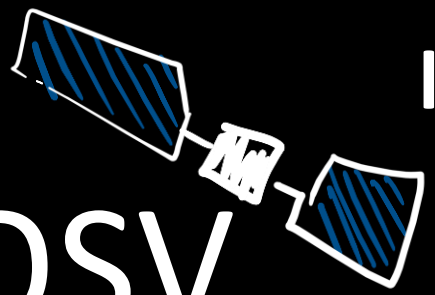

Core collapse
$\geq 8M_{\odot}$
lGRB
OSV
Background
estimation

Core collapse

$\geq 8M_{\odot}$



IGRB



OSV

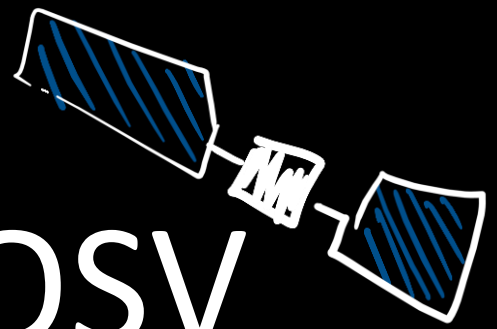
Background estimation

Broadband Modelling of GRB 230812B Afterglow: Implications for VHE γ-ray Detection with IACTs

Shraddha Mohnani[⋆1,2], Biswajit Banerjee[⋆⋆2,3], Davide Miceli[4], Lara Nava[5,6], Gor Oganesyan[2,3], Pawan Tiwari[2,3], Annarita Ierardi[2,3], Alessio L. De Santis[2,3], Samanta Macera[2,3], Amit Shukla[1], Marica Branchesi[2,3], Swarna Chatterjee[1,2], Sushmita Agarwal[1], Abhirup Datta[1], Kuldeep Kumar Yadav[8], and G.C. Anupama[9]

Transient MeV radiation from a relativistic tidal disruption candidate

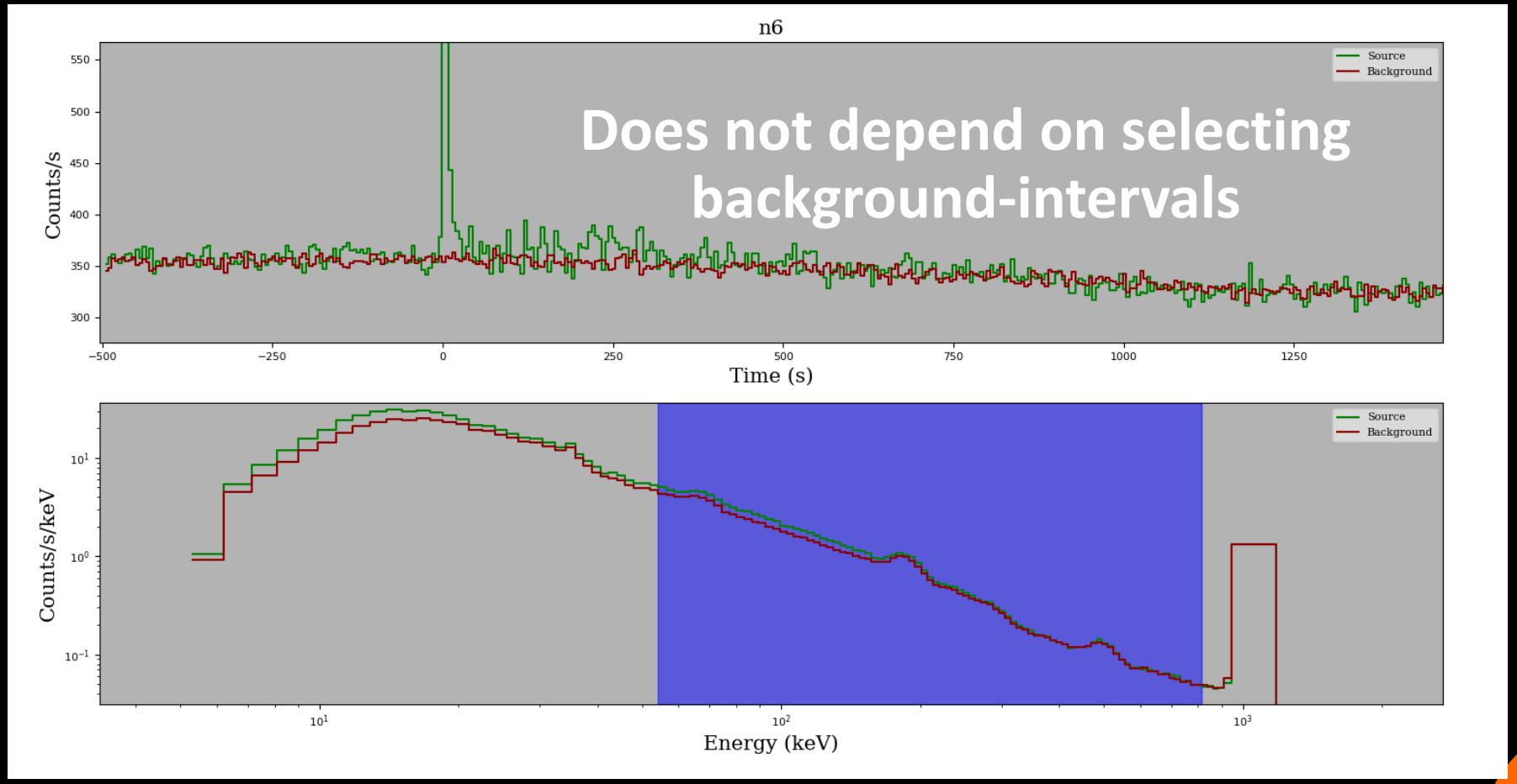
Gor Oganesyan[1,2⋆], Elias Kammoun[3⋆⋆], Annarita Ierardi[1,2⋆⋆⋆], Alessio Ludovico De Santis[1,2], Biswajit Banerjee[1,2], Emanuele Sobacchi[1,2], Felix Aharonian[4,5,6], Samanta Macera[1,2], Pawan Tiwari[1,2], Alessio Mei[1,2], Shraddha Mohnani[7], Stefano Ascenzi[1,2], Samuele Ronchini[8,9], and Marica Branchesi[1,2]

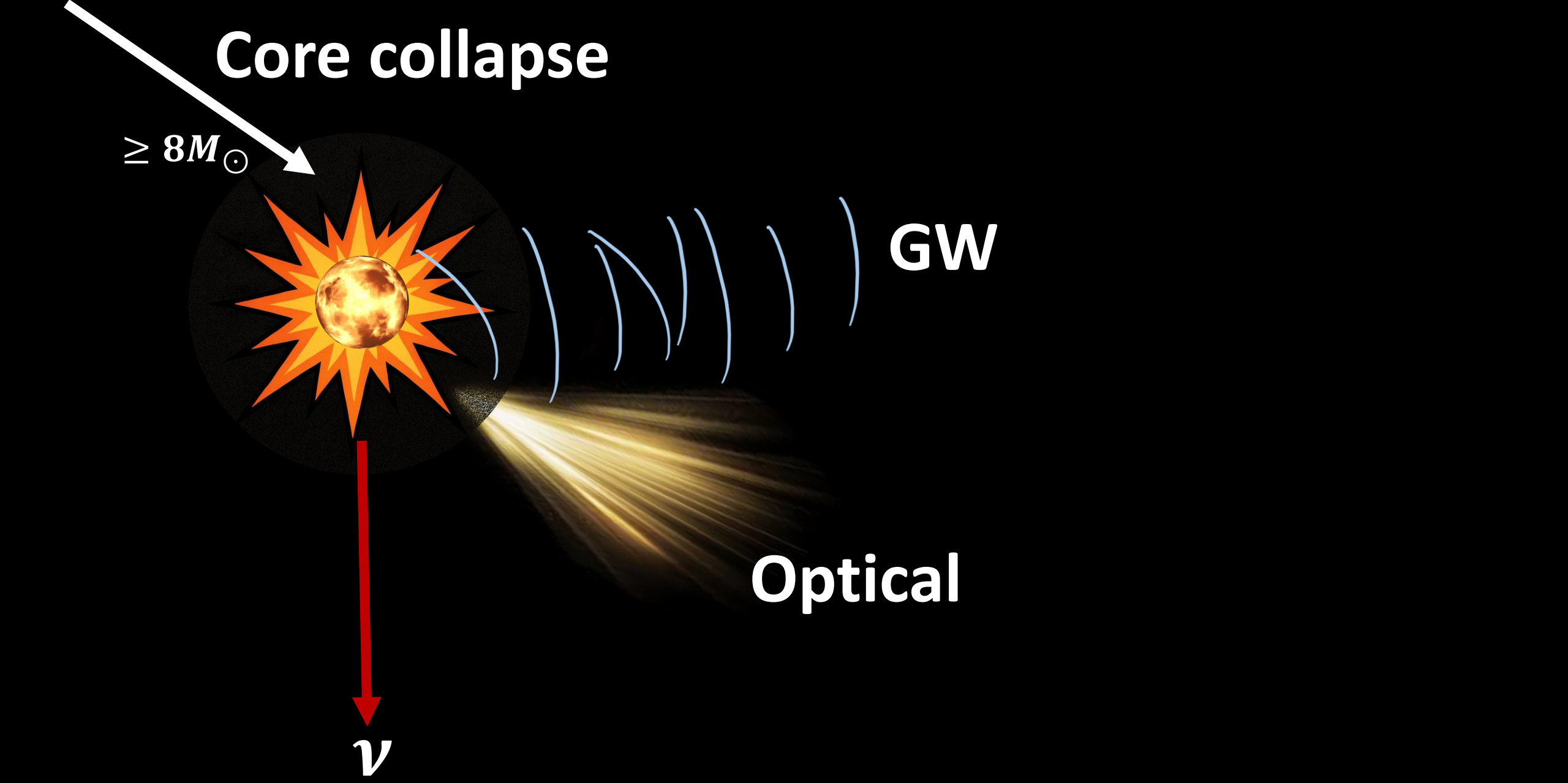


OSV

Background estimation

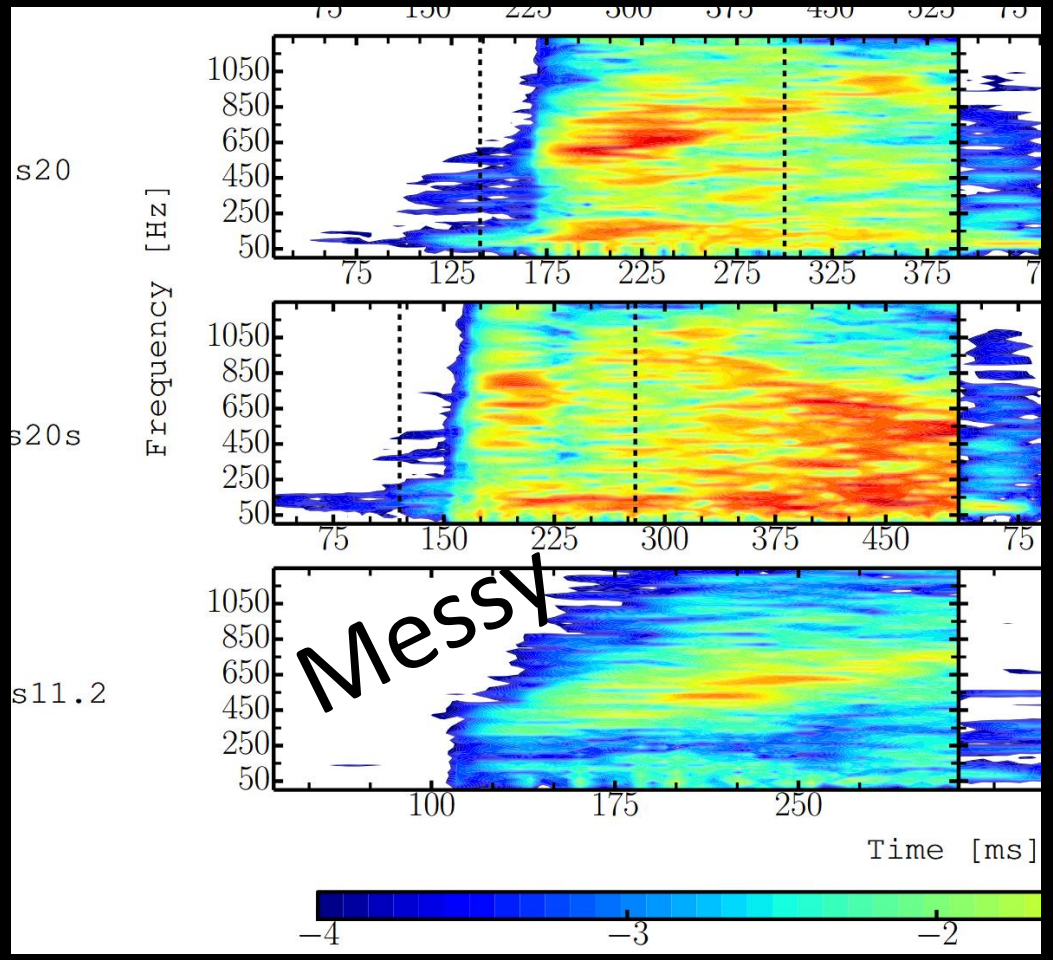
Example I produced



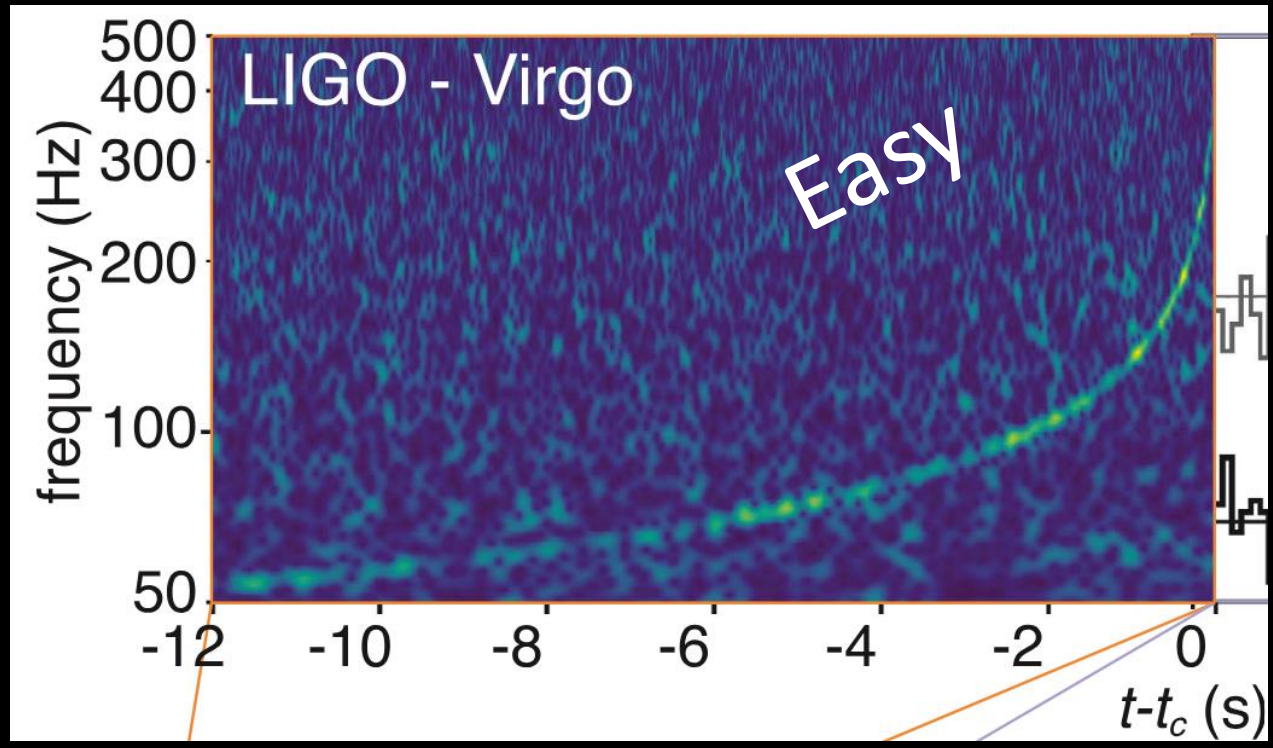

Core collapse
$\geq 8M_\odot$
GW
Optical
ν

Supernova GWs

SN [H. Andresen et al 2017]



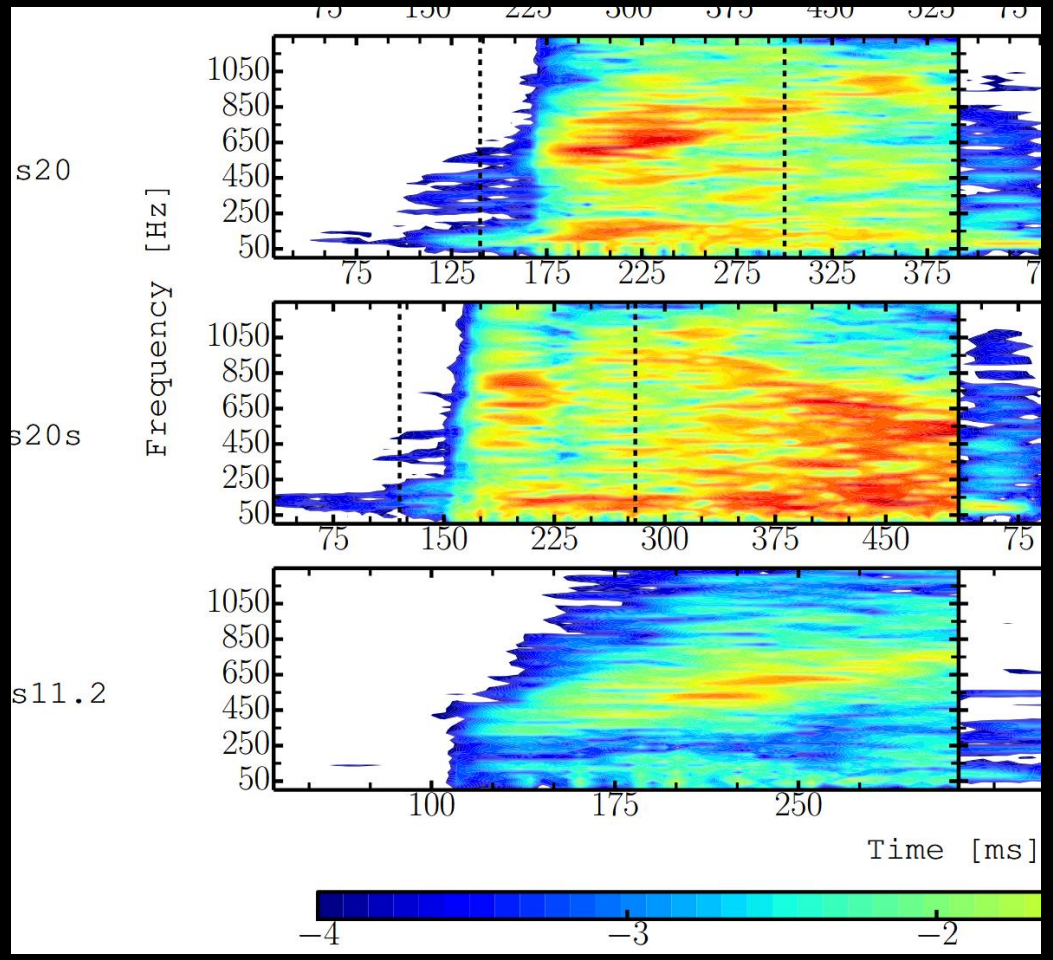
BNS



Abbott BP, et al. (LIGO, Virgo and other collaborations) 2017

Supernova GWs

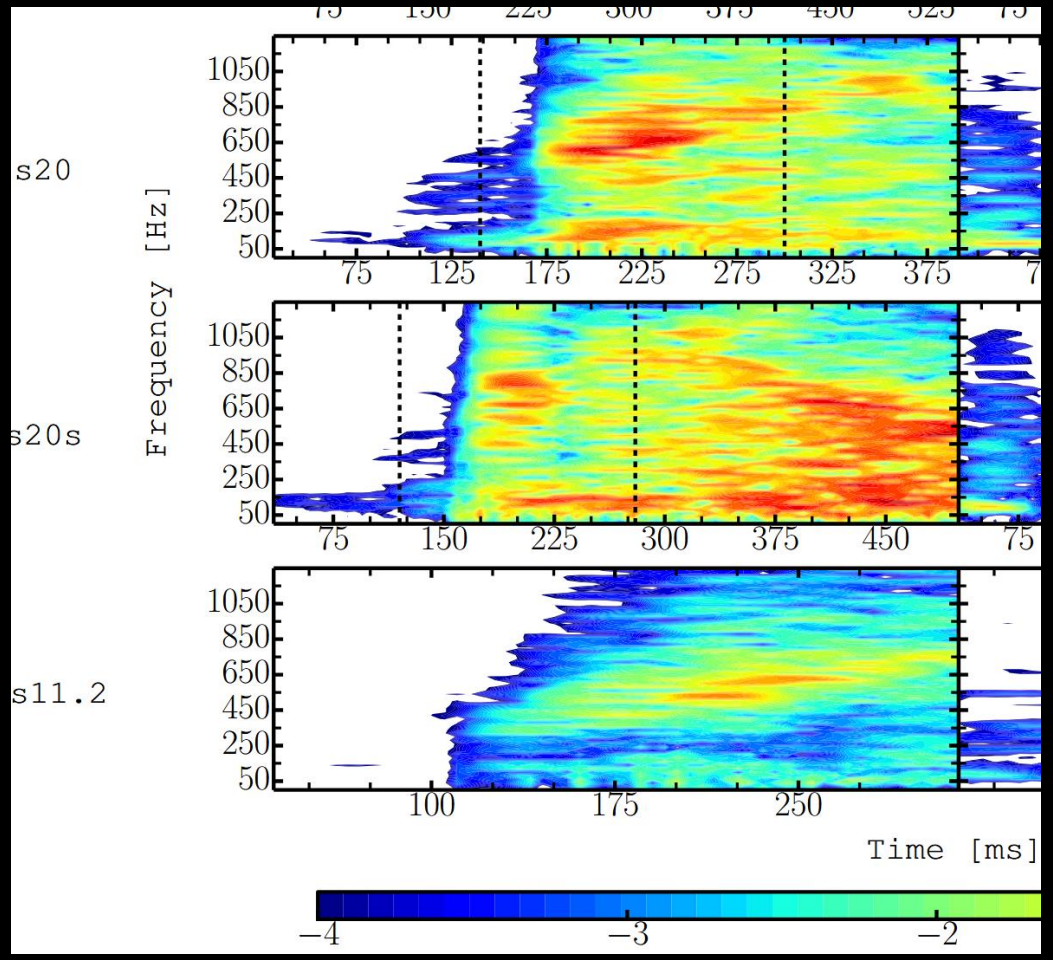
SN [H. Andresen et al 2017]



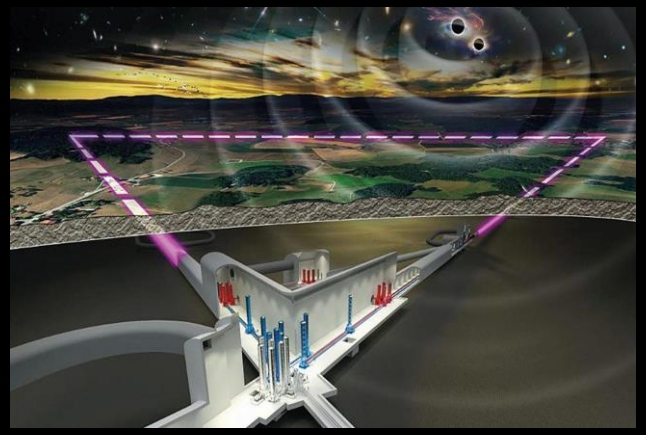
No templates

Very faint

Supernova GWs



Can ET see them ?



GWFish

Simulates GW detector networks → measurement uncertainties based on the Fisher-matrix approximation

Detector motion

Multiband detection

U. Dupletsa et al 2023

U. Dupletsa et al 2025

GWFish

U. Dupletsa et al 2022

BUT

Only compact object mergers

No time/frequency series

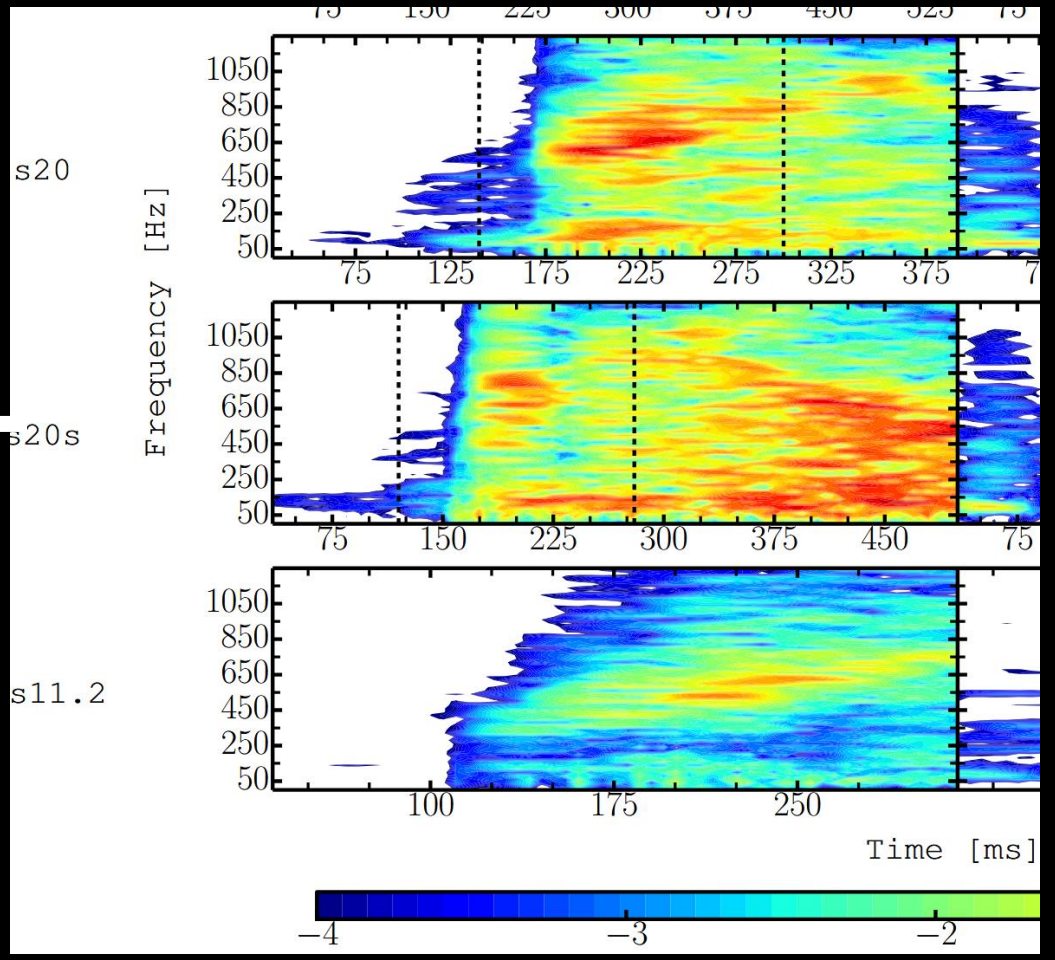
No Supernova

GWFish

I Modified

GWFISH

New possible input



GWFish

GWFish

The Science of the Einstein Telescope

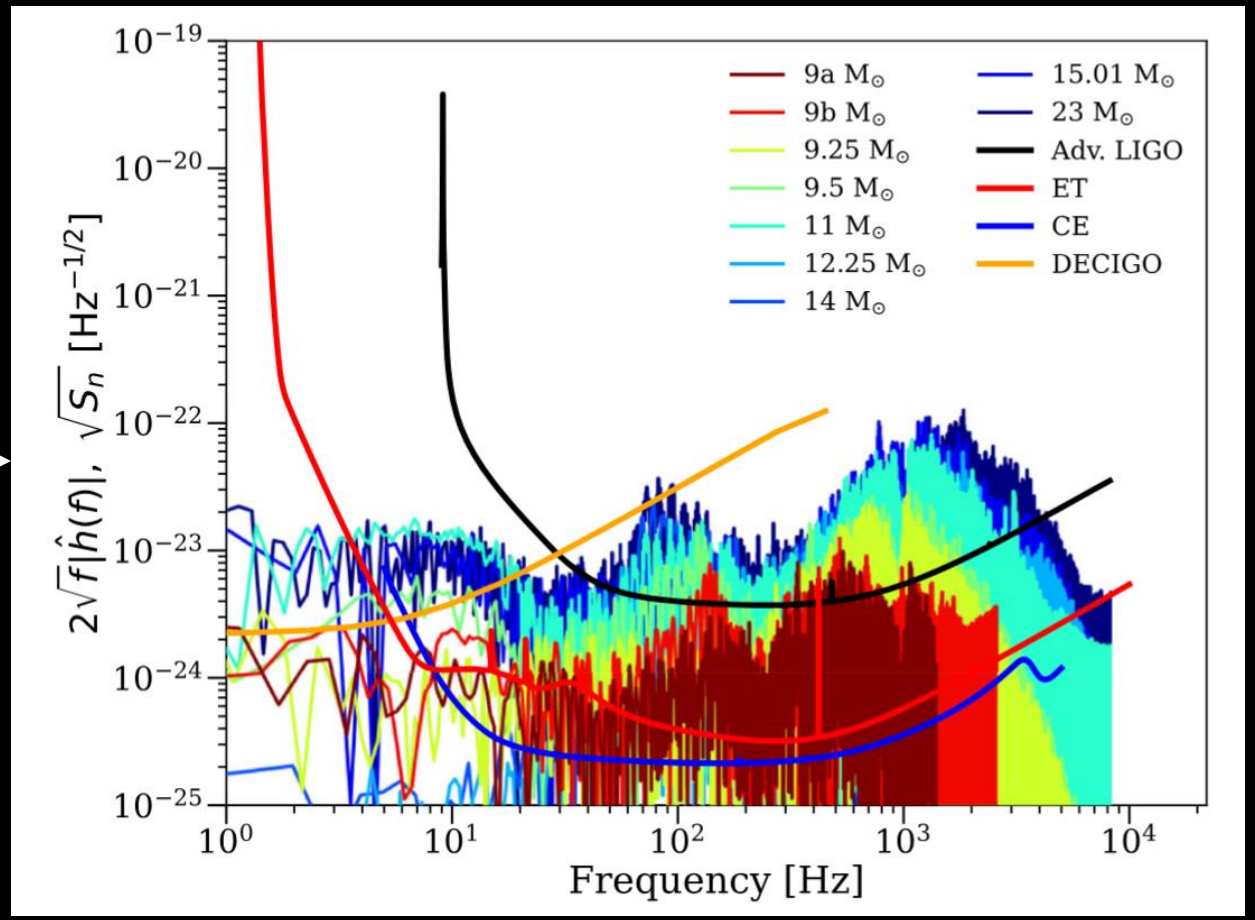
Einstein Telescope collaboration

Handled SN SNR calculations

GWFish

State of the art 3D simulations

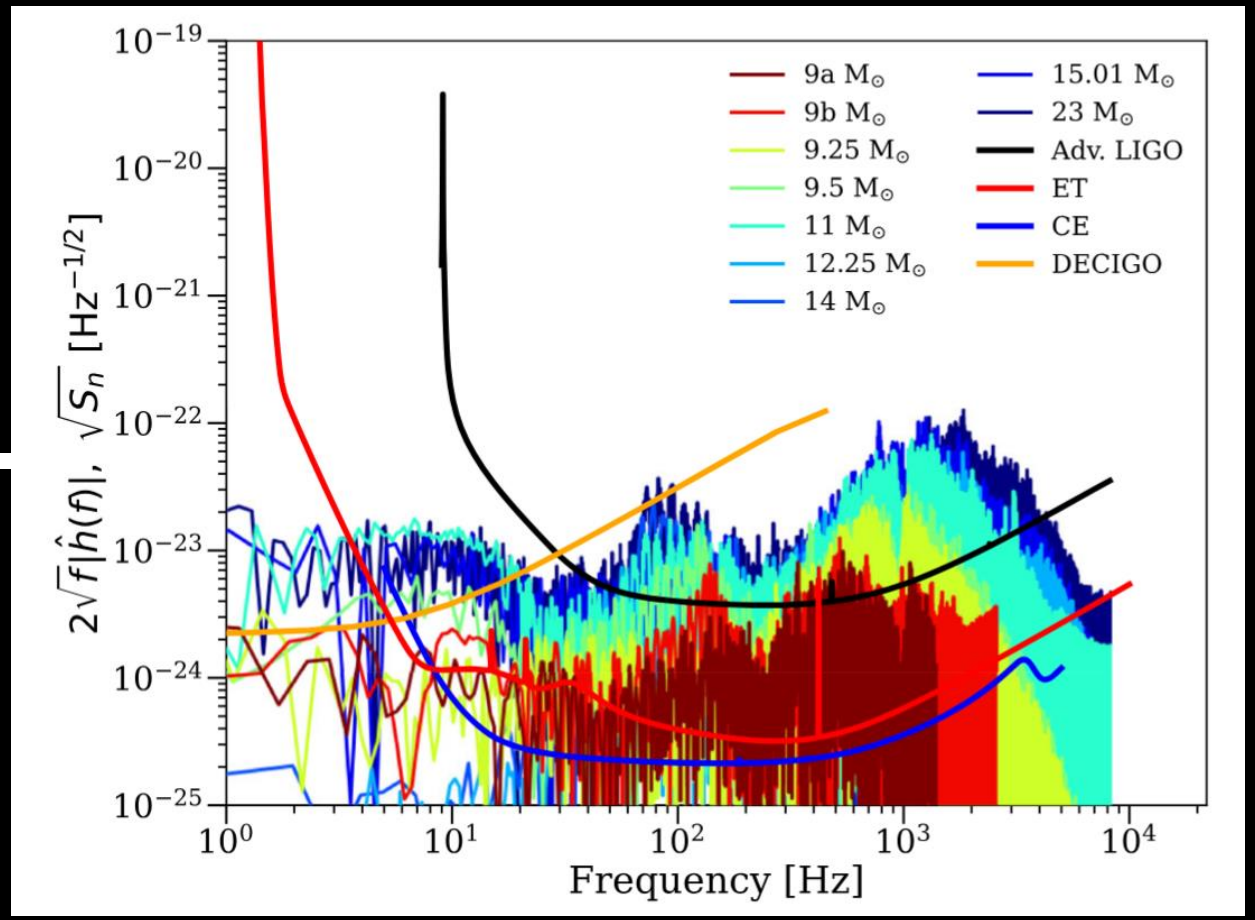
(A. Burrows group archive https://www.astro.princeton.edu/~burrows/)



D. Vartanyan et al. 2023

D. Radice et al. 2019

GWFish

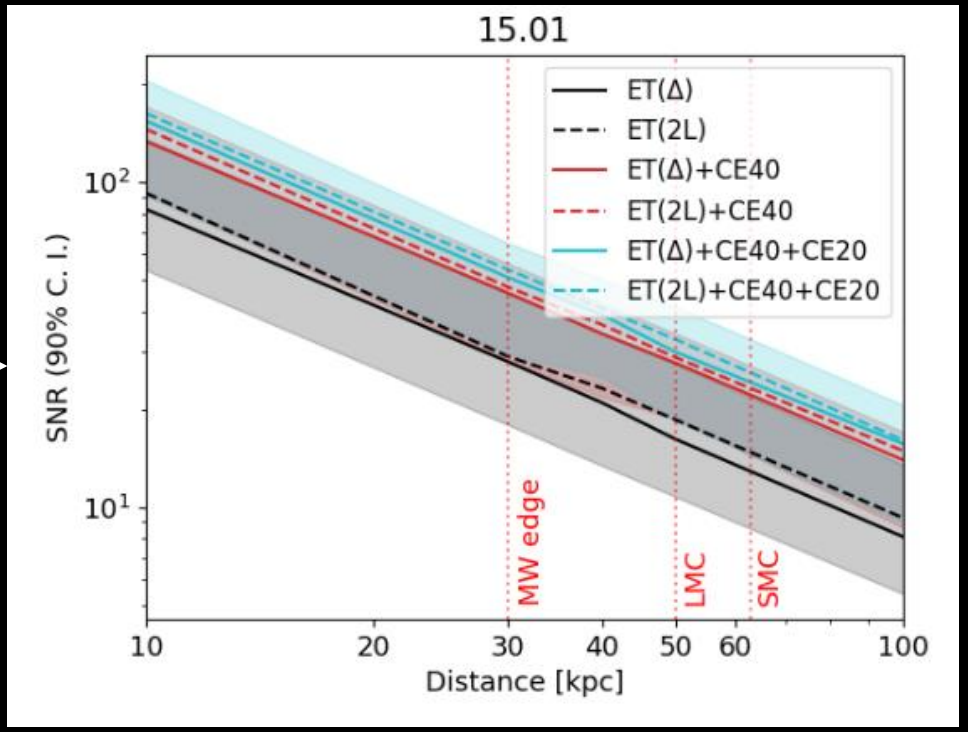


D. Vartanyan et al. 2023

D. Radice et al. 2019

GWFish

15 Solar masses progenitor

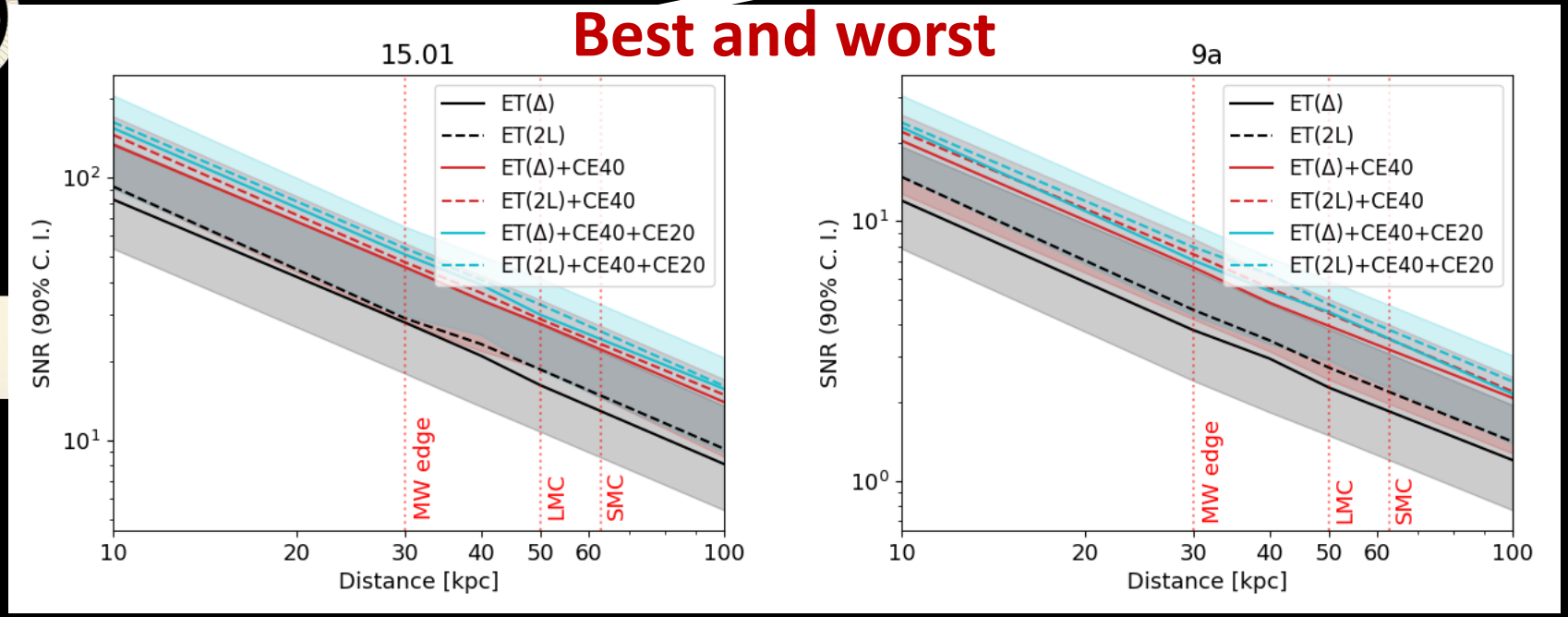


GWFish

The Science of the Einstein Telescope

Einstein Telescope collaboration

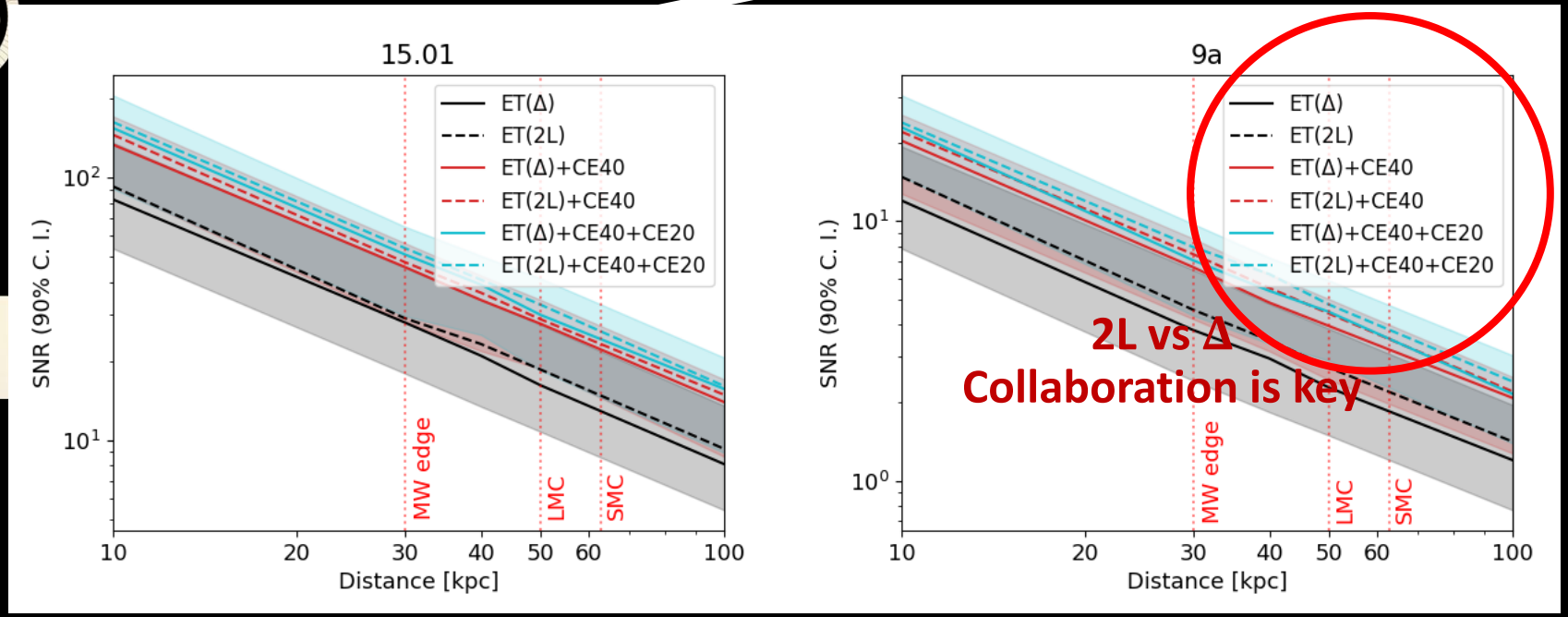
Best and worst



GWFish

The Science of the Einstein Telescope

Einstein Telescope collaboration



GWFish

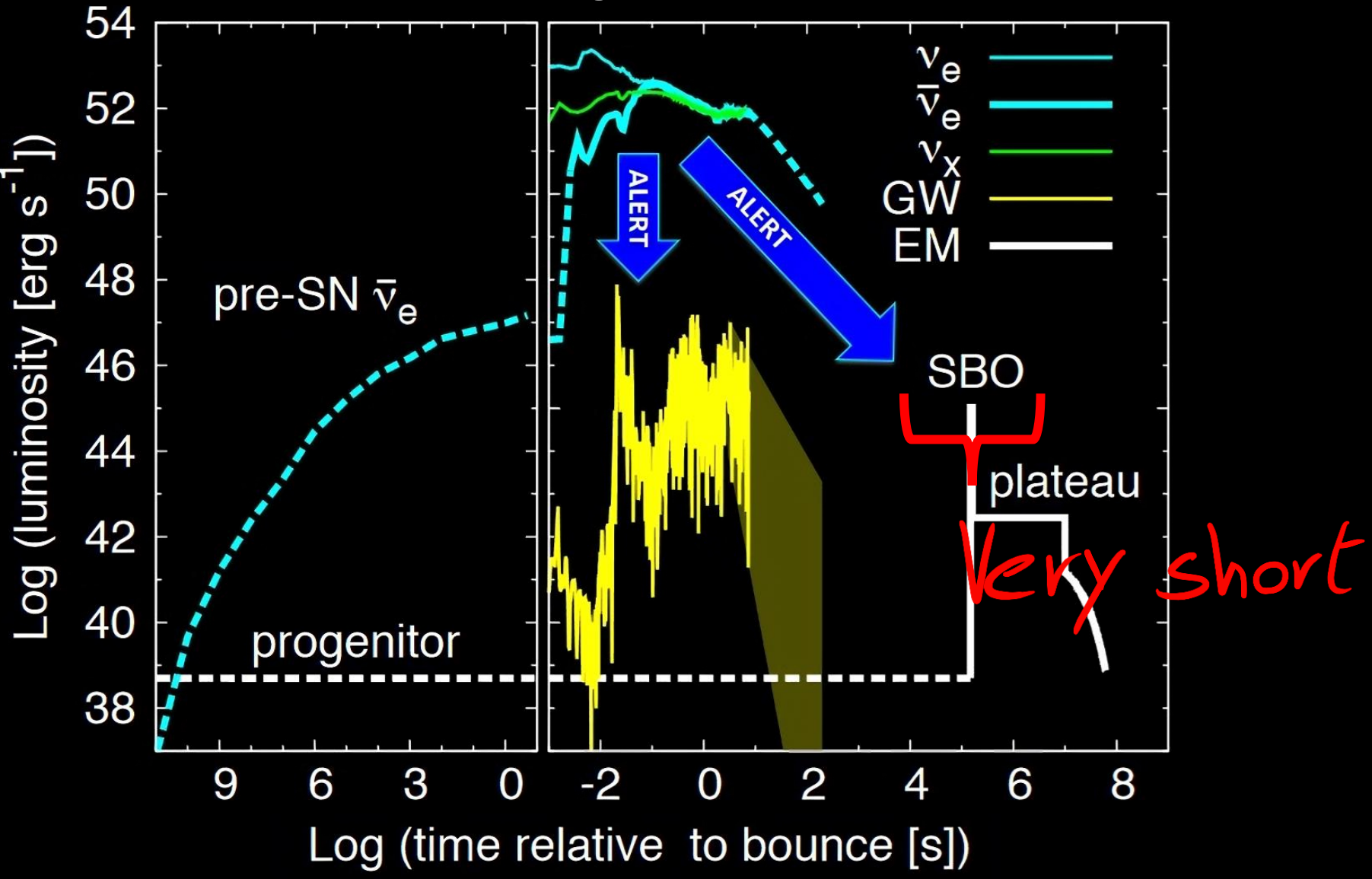
The Science of the Einstein Telescope

Einstein Telescope collaboration

Working on optimizing SN detection prospects

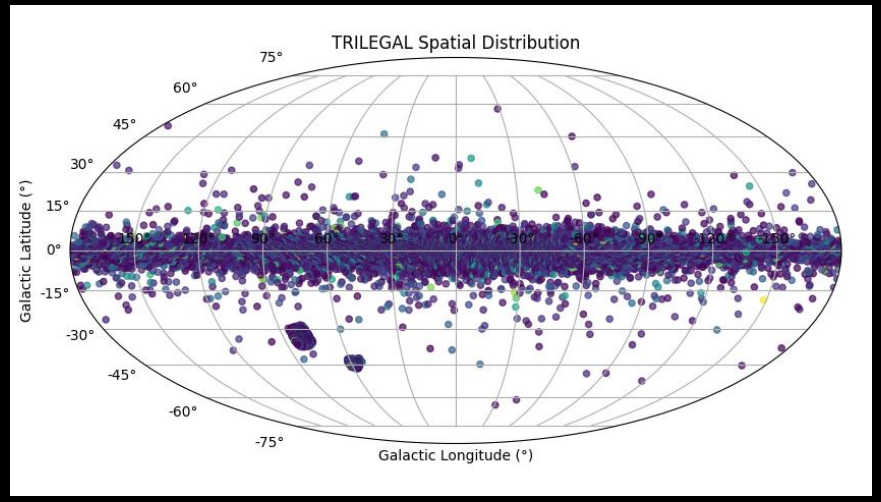
In preparation : Studying instrument optimization for ET

GW + Optical



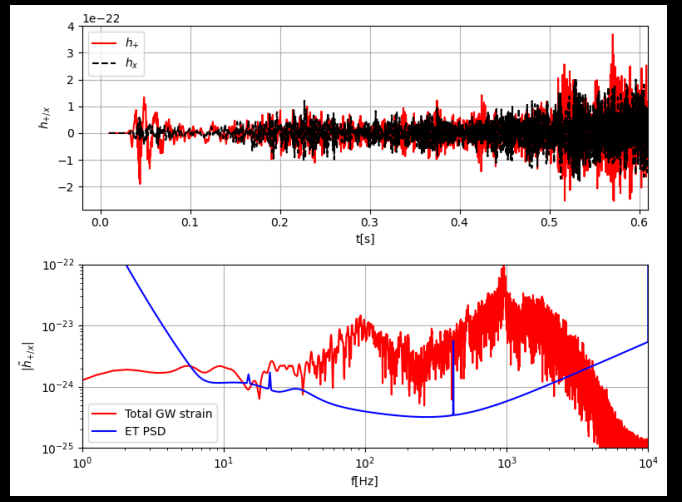
very short

GW + Optical (in preparation)

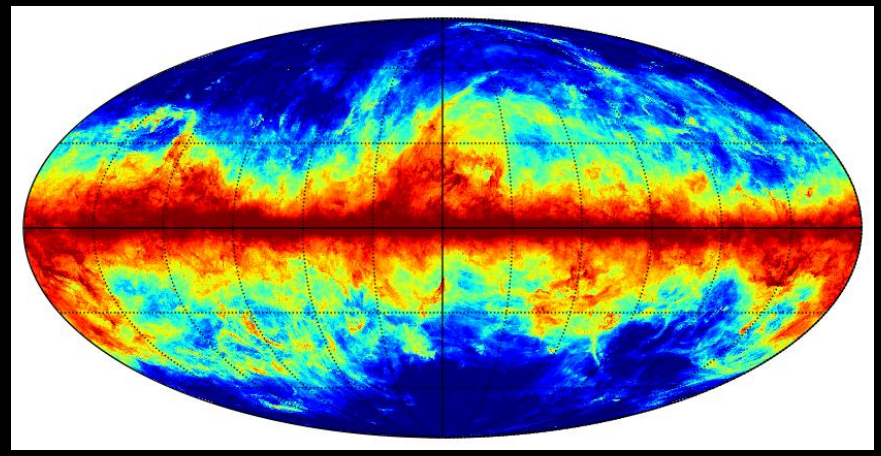


Star mass distribution

(in preparation)
I. Giudice, A. L. De Santis et al.
(202?)



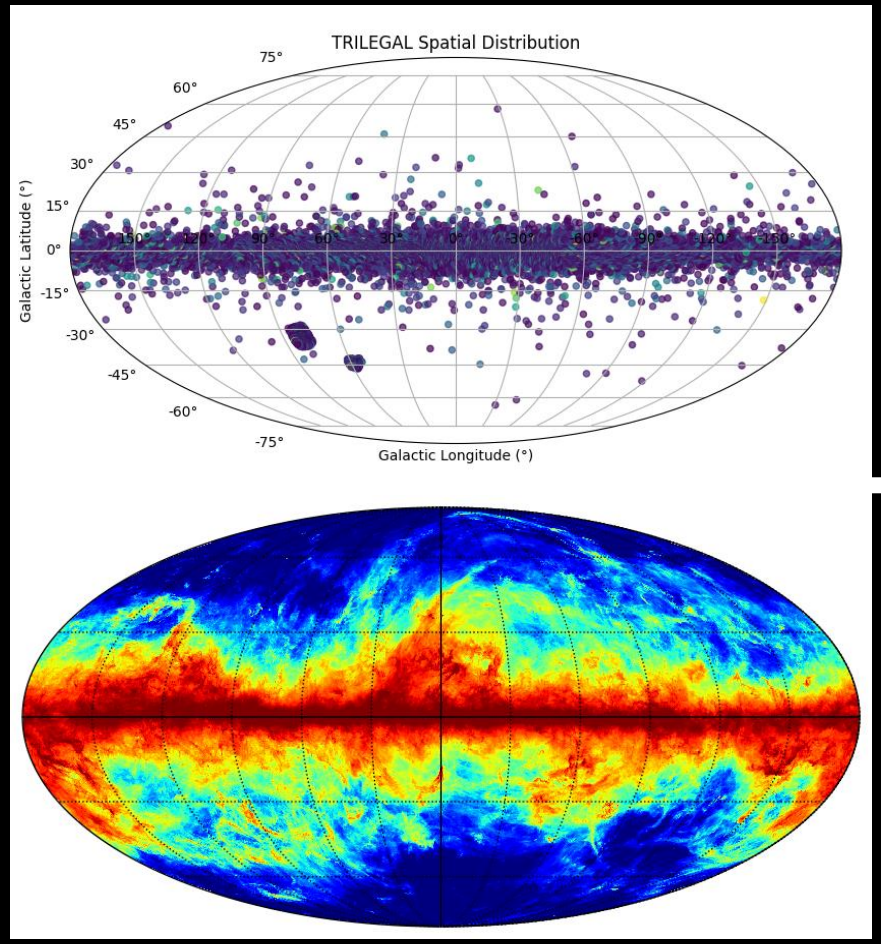
Waveforms



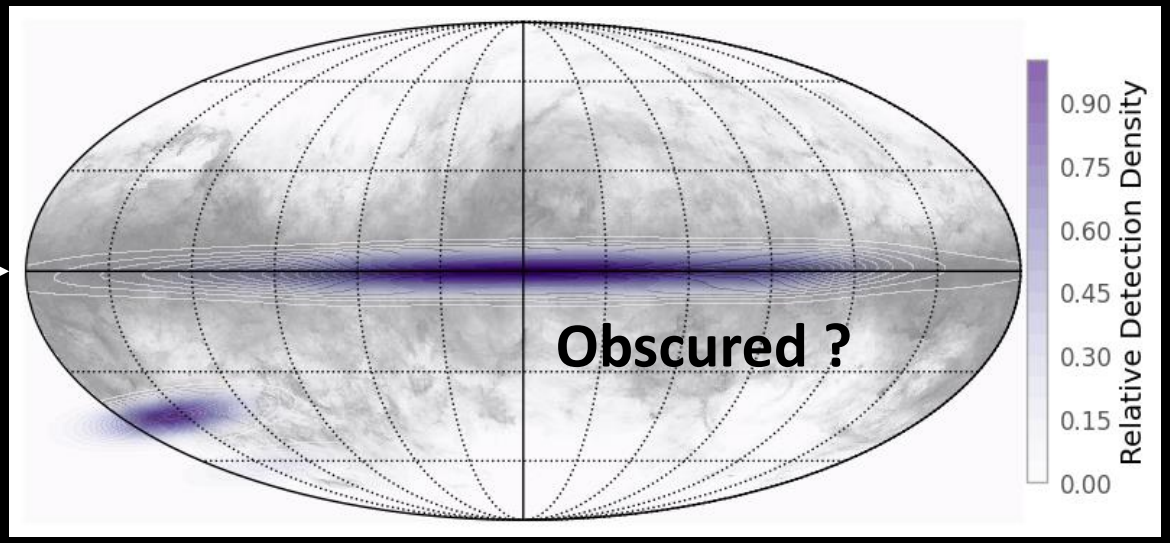
Dust distribution

Dr. Maria Teresa Botticella
Ines Giudice

GW + Optical (in preparation)



Predictions /observation strategies

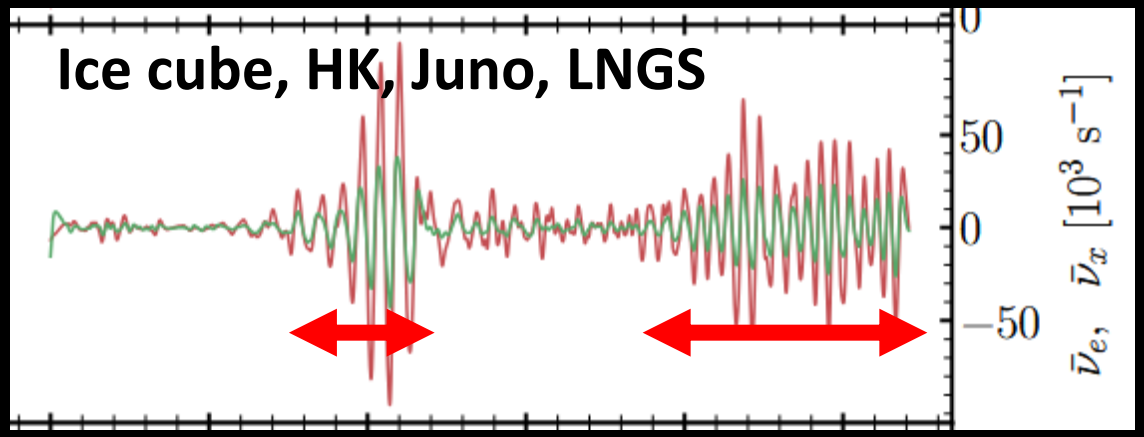


GW + neutrinos (work in progress)

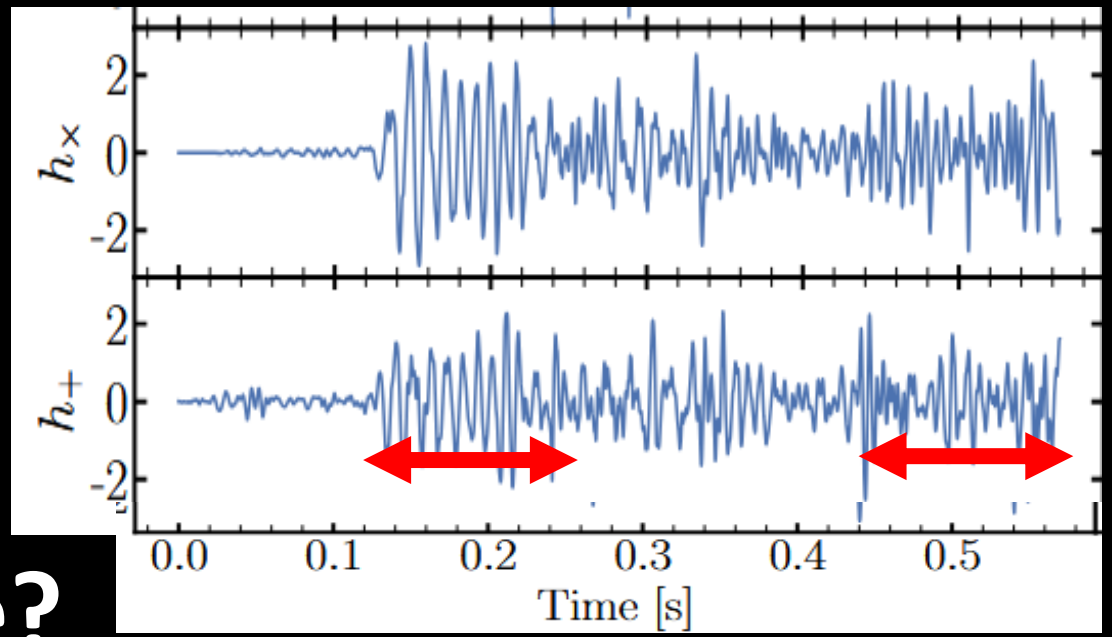
ν

Pattern ?

GW

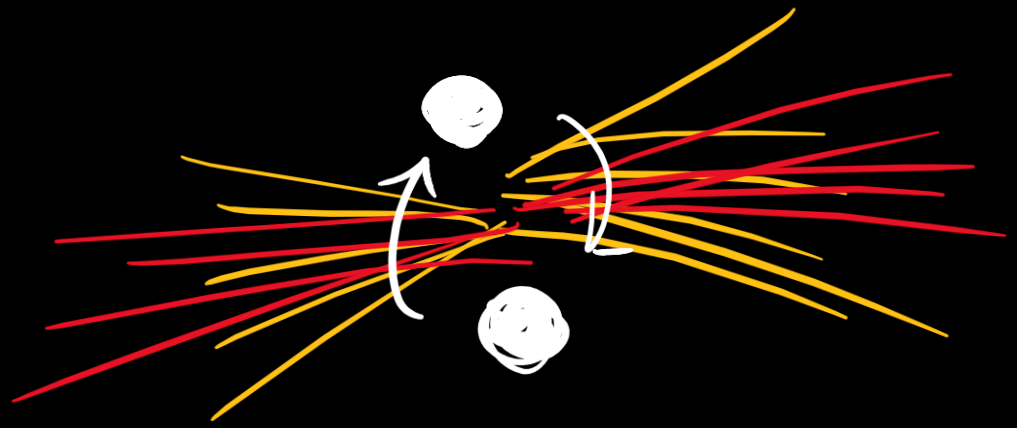


M. Drago et al 2023

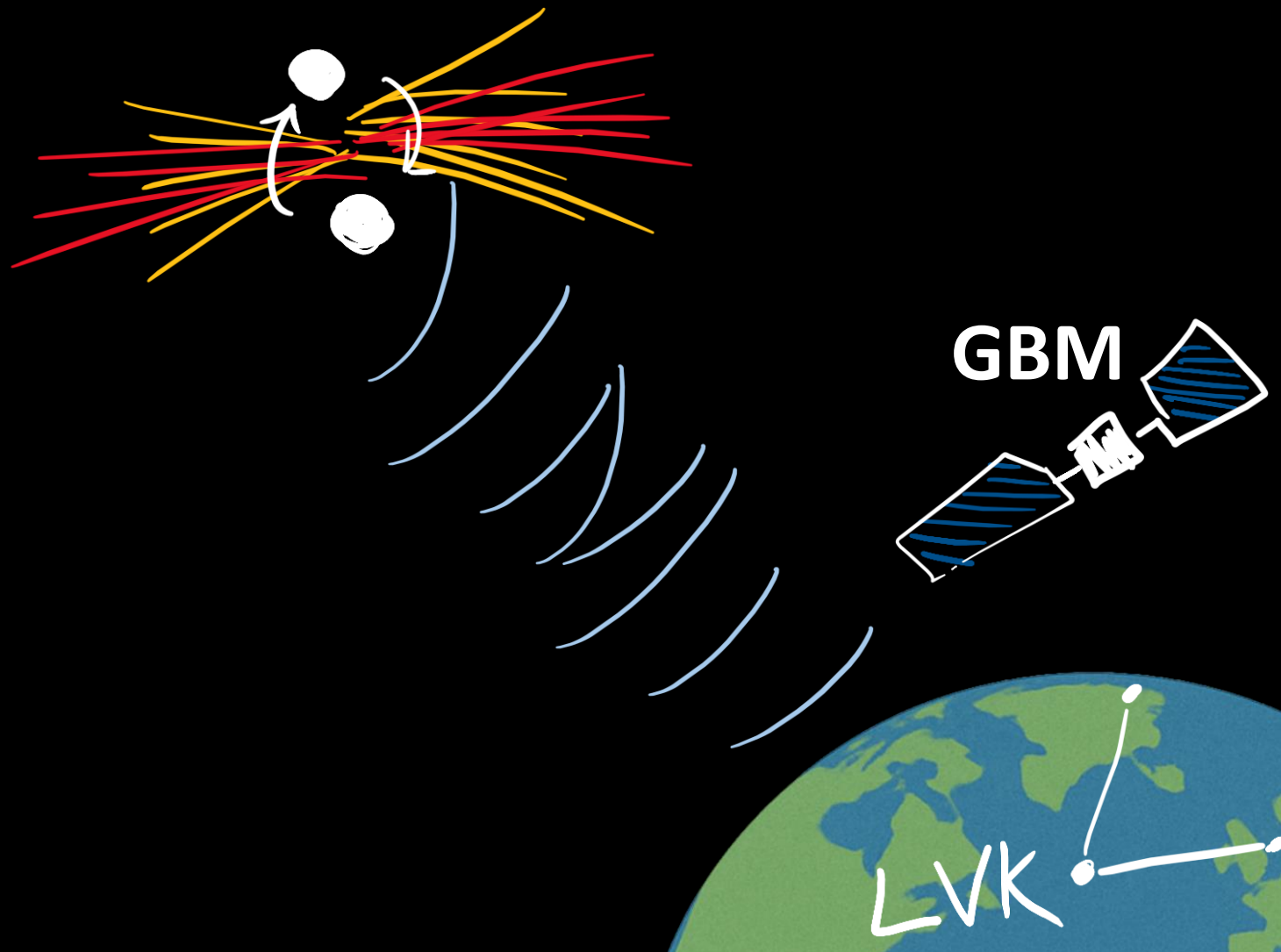


Template?

Binary neutron stars

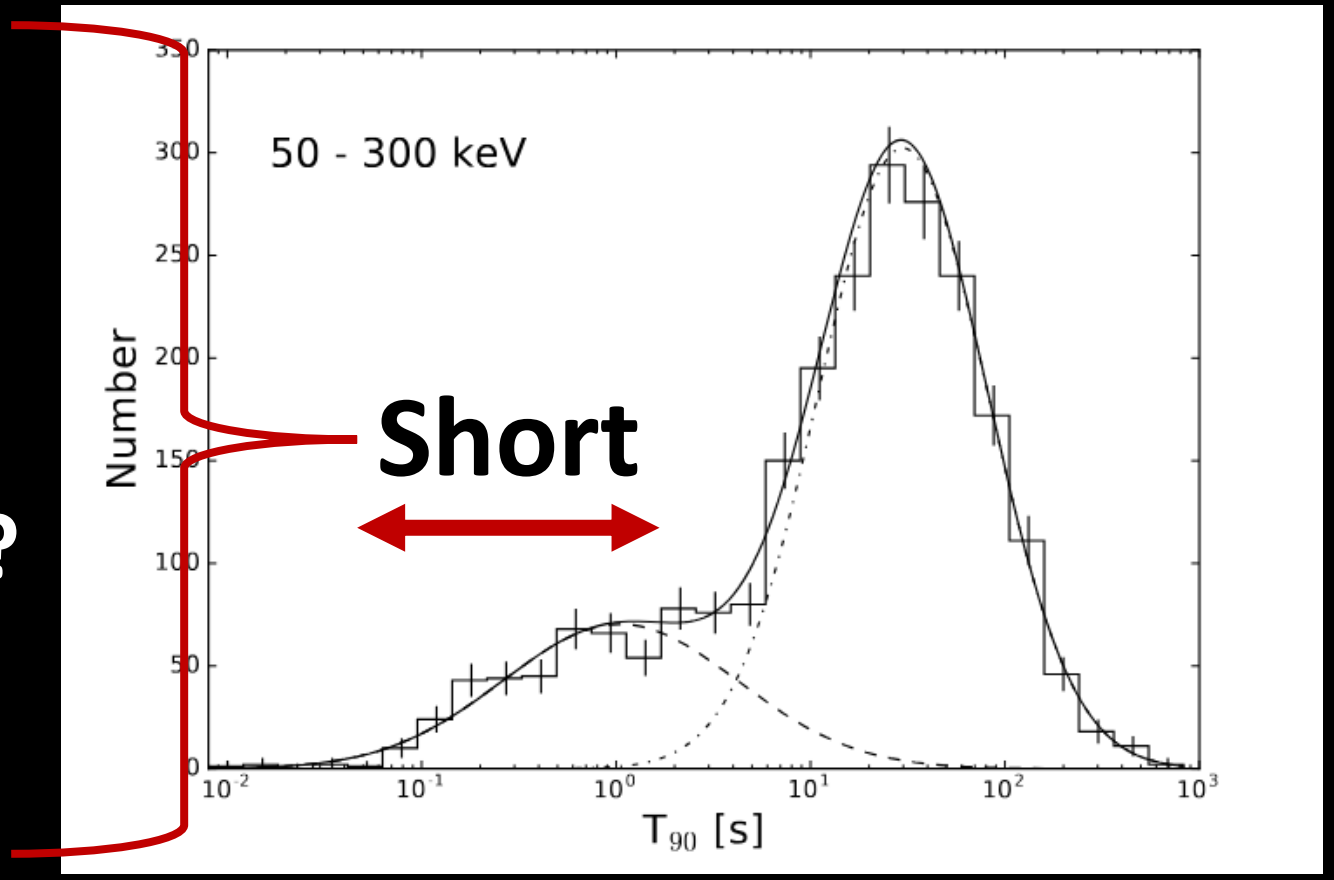


GW170817/GRB170817A

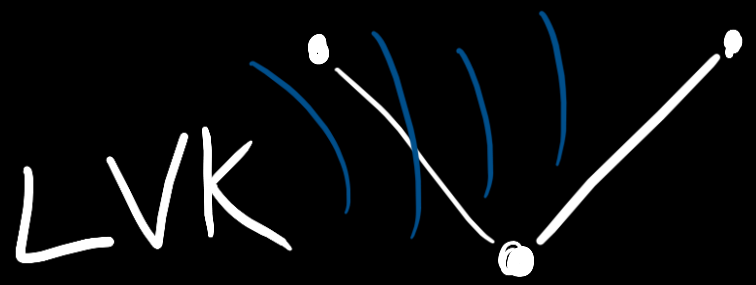


Binary Neutron Stars

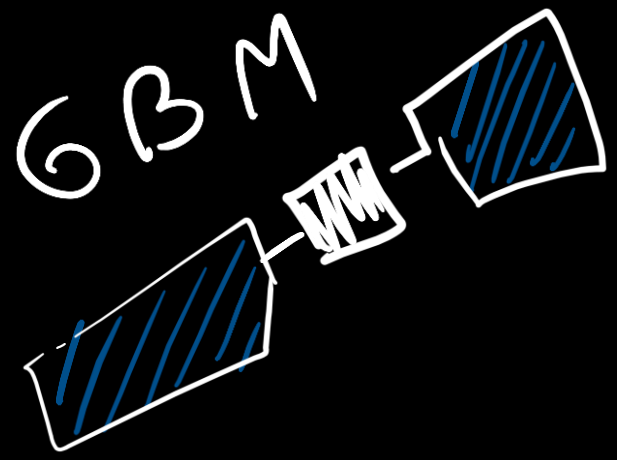
Binary neutron Star mergers?



Tensions

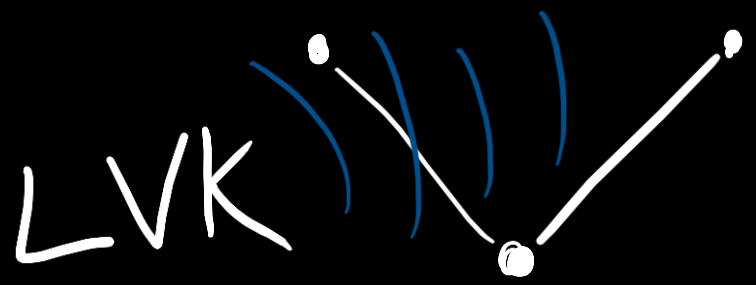


2 BNS mergers in 4 observation runs

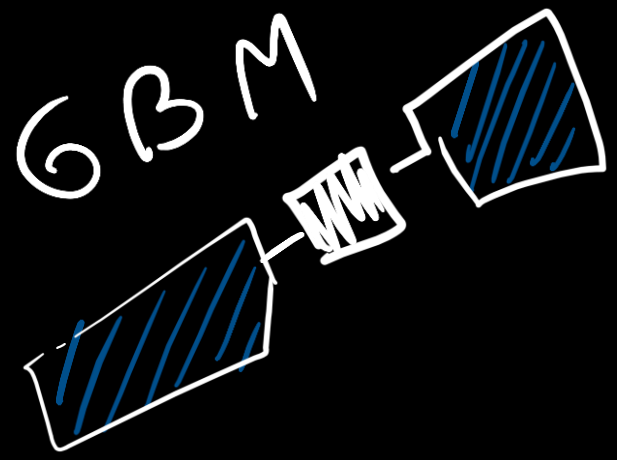


40 sGRBs / yr

Tensions

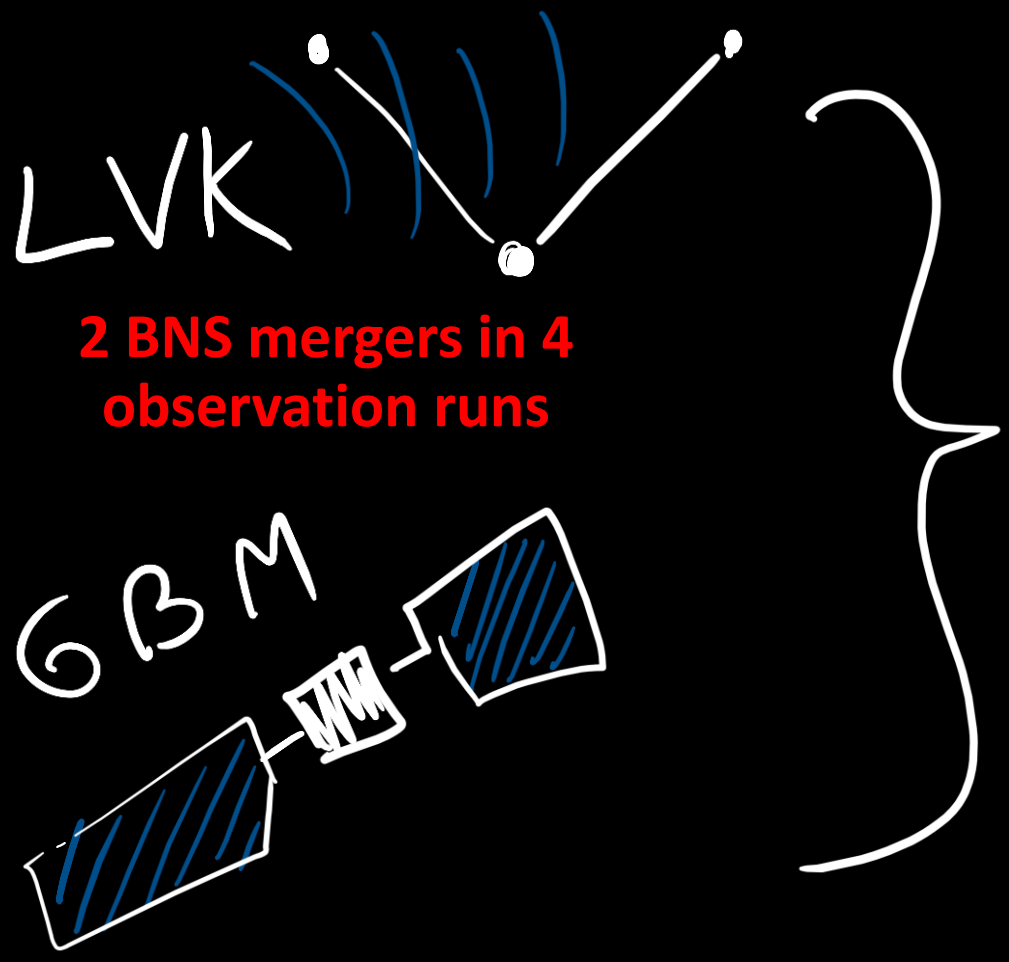


2 BNS mergers in 4 observation runs



40 sGRBs / yr ← A lot

Tensions



What are the compatible astrophysical BNS merger rates?

How many mergers successfully launch a sGRB?

Study the problem

Observations

- **$\sim$ 100s GRB catalogue**

Study the problem

Observations

$\sim$ 100s GRB catalogue

Interface

Simulations

→BNS pop synthesis

Iorio et al 23

Study the problem

Observations

~ 100s GRB catalogue

+ Interface

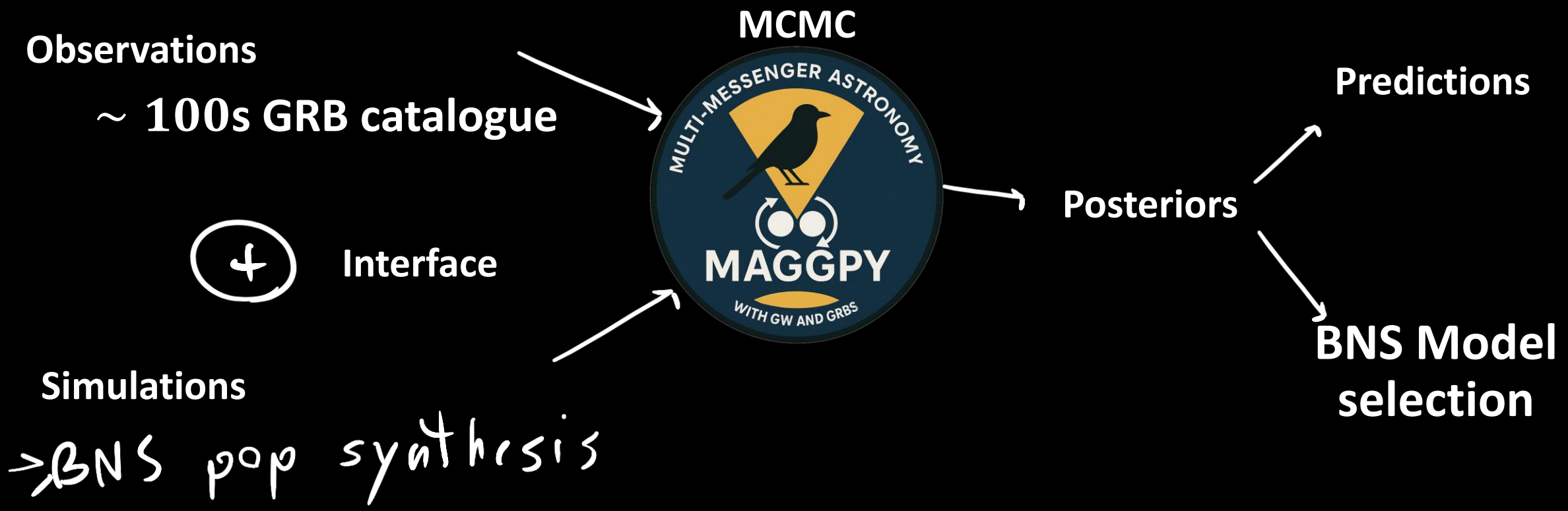
Simulations

→BNS pop synthesis

MCMC

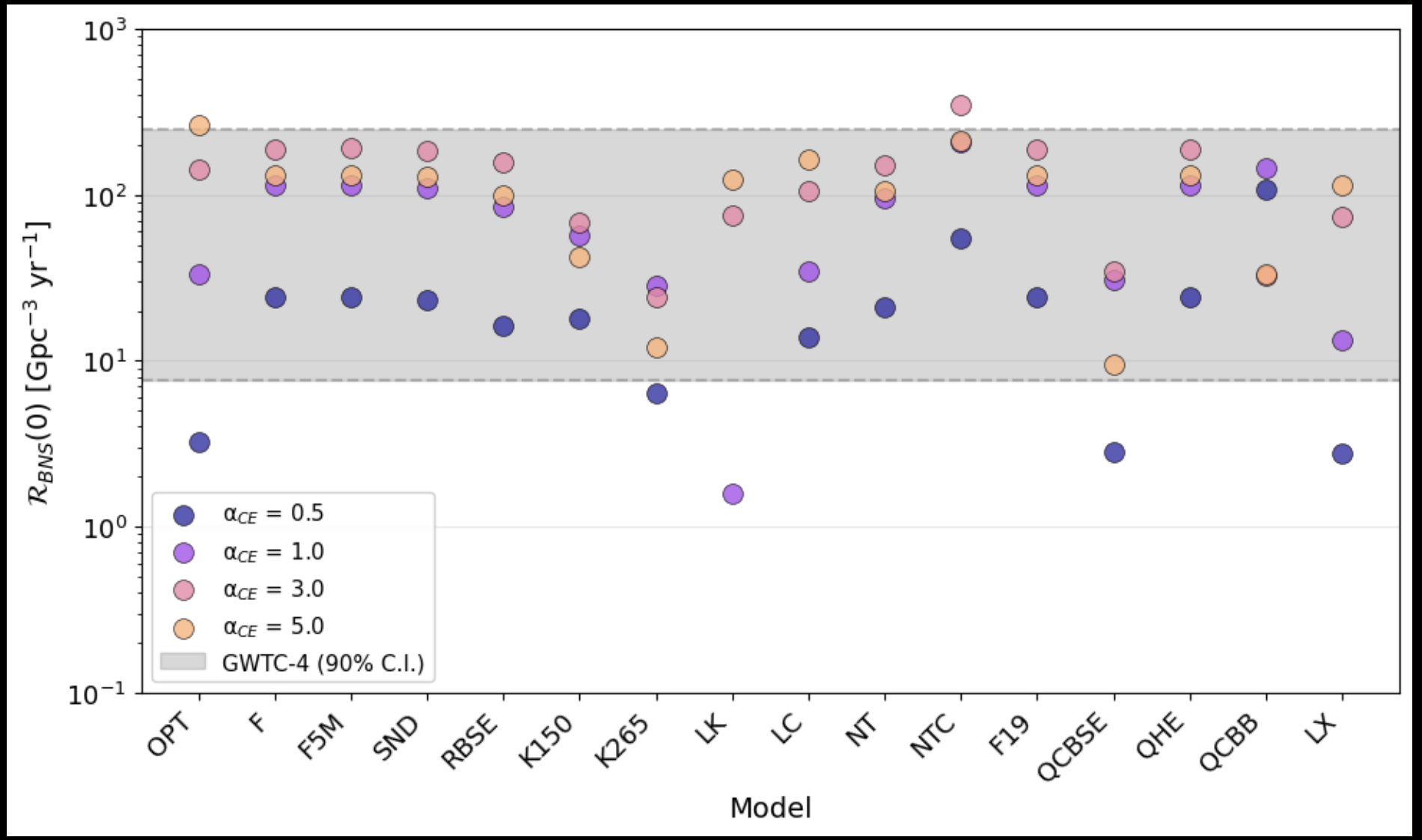
Iorio et al 23

Study the problem



Iorio et al 23

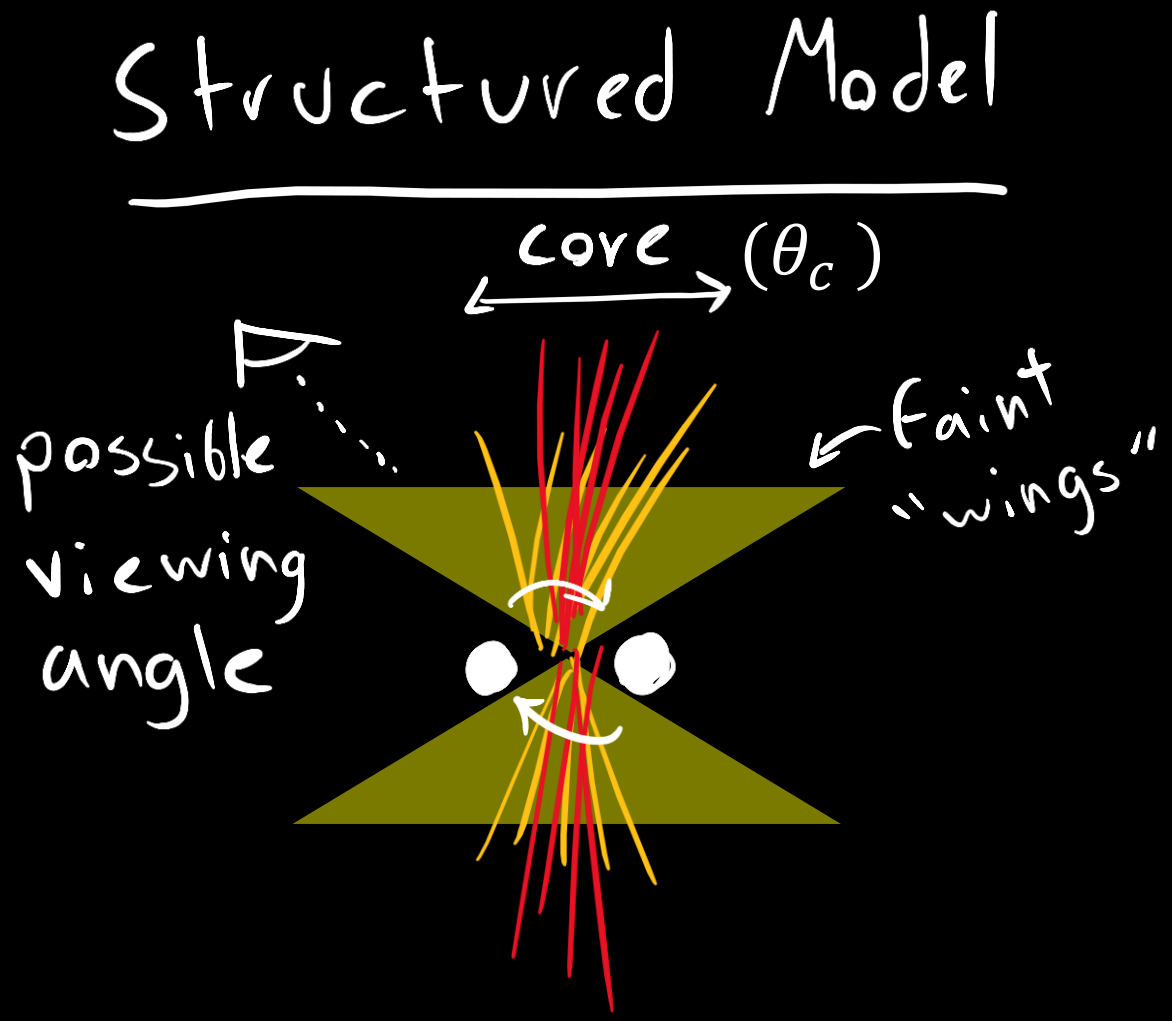
Models studied



Iorio et al 23

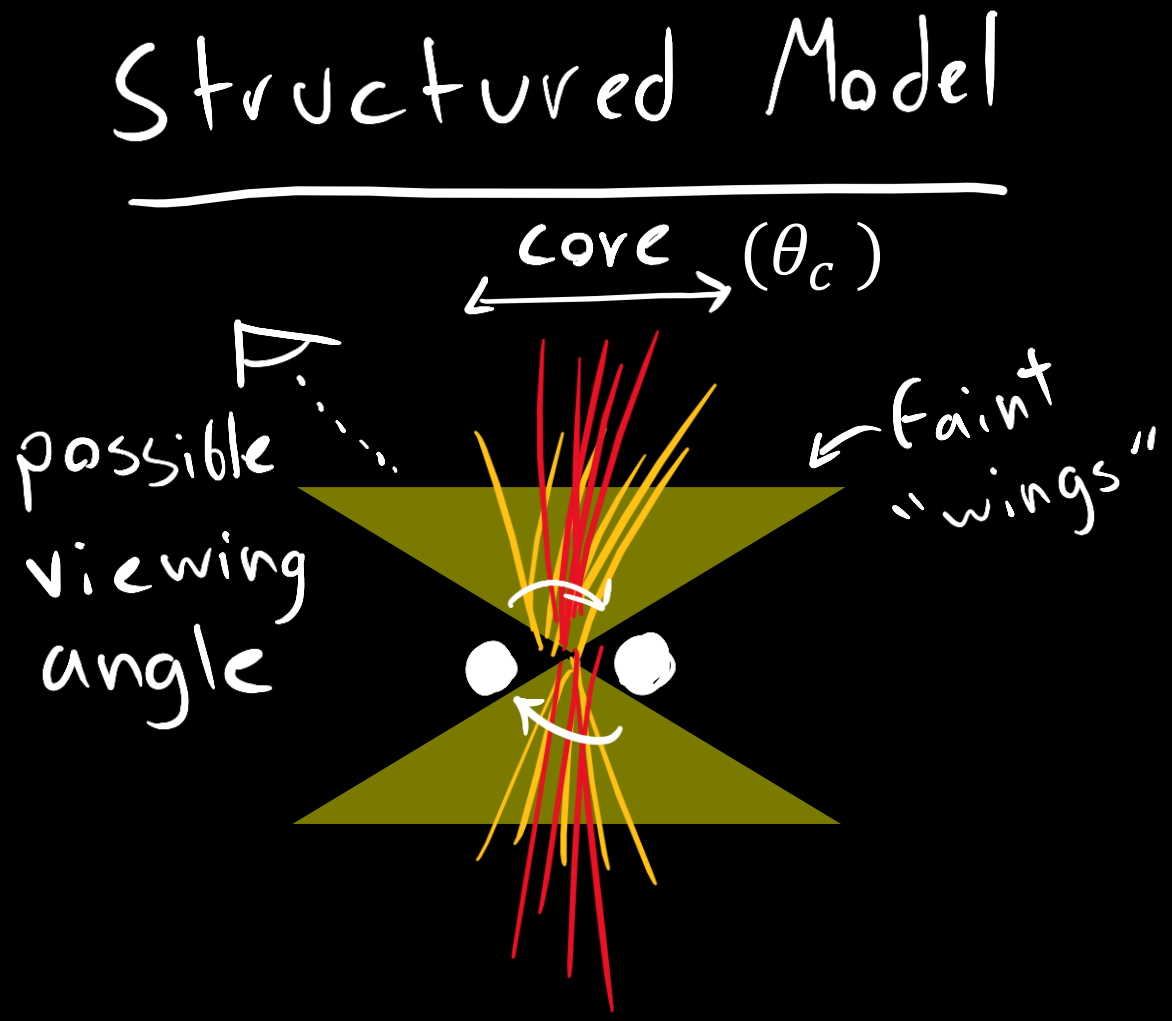
A. L. De Santis et al (202?) (in preparation)

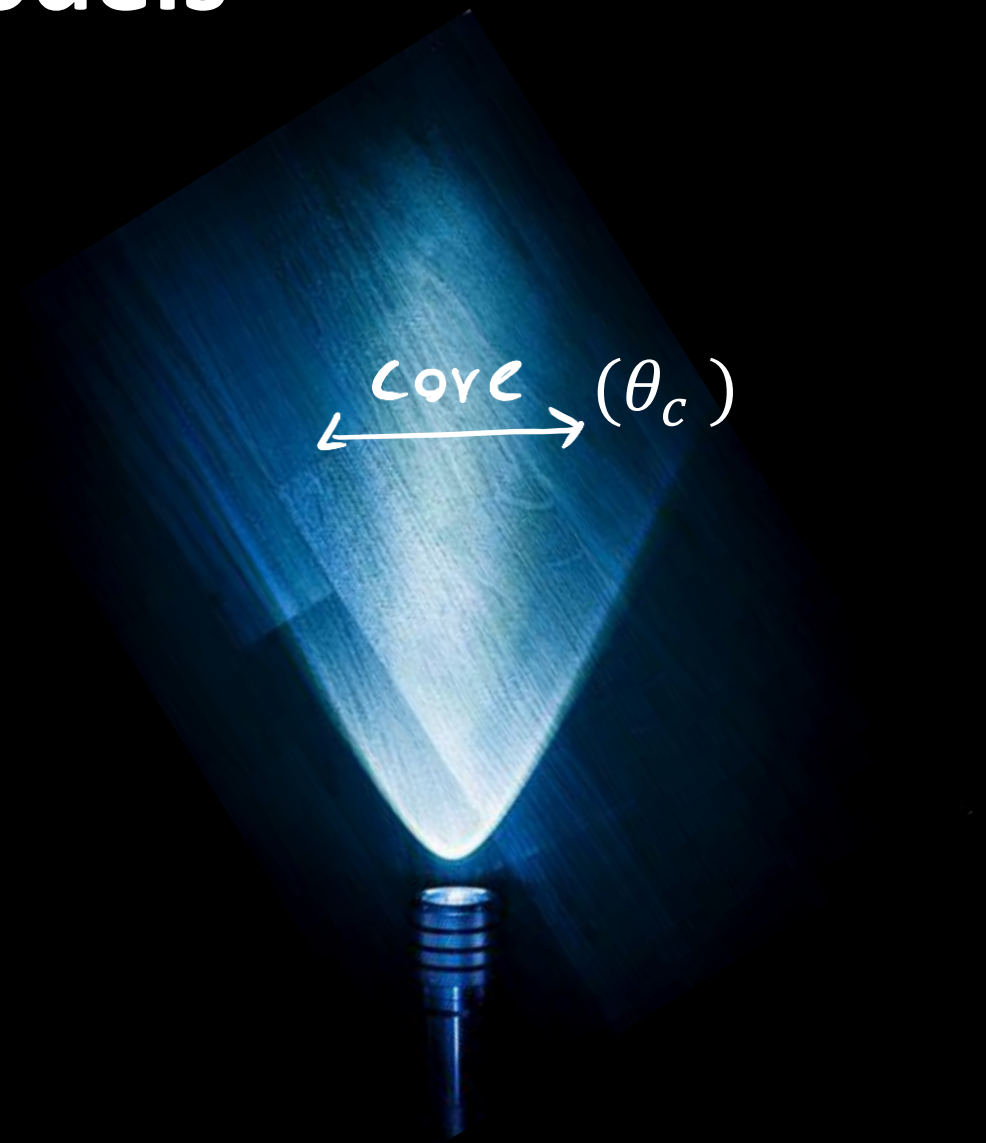
GRB models



Ronchini et al 22.

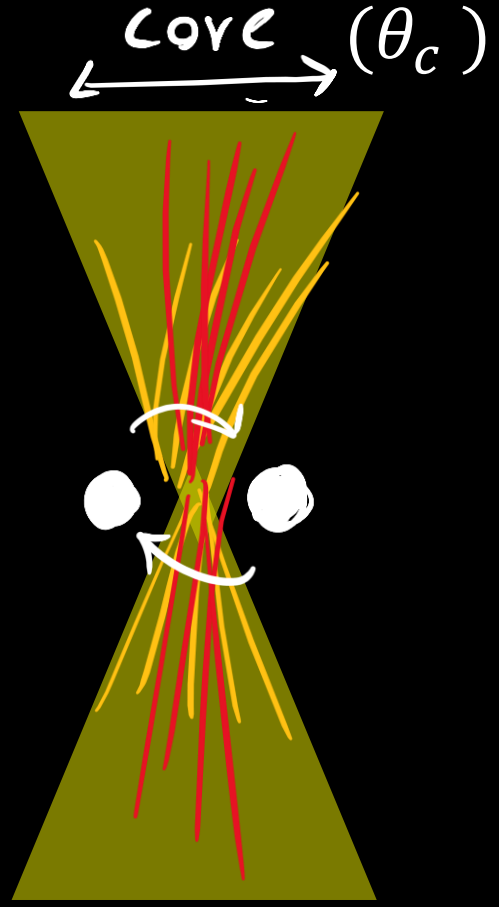
GRB models



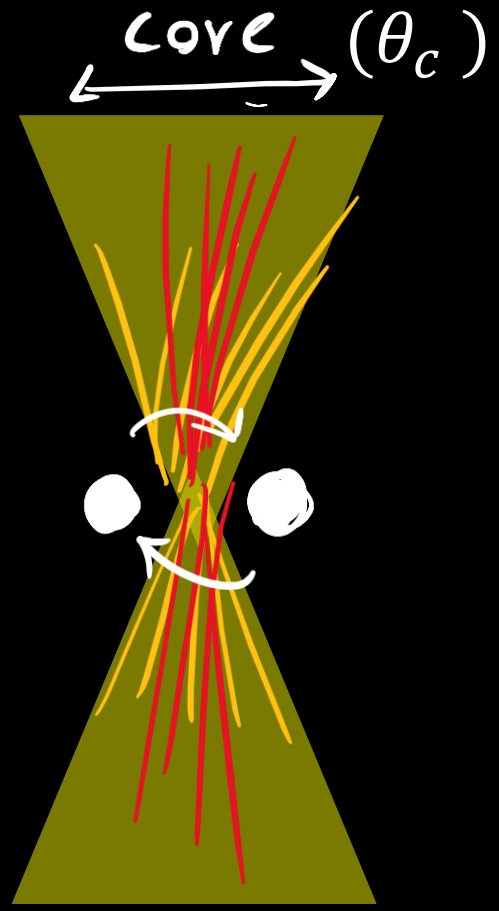


Ronchini et al 22.

Top-hat Model



Top-hat Model



Universal

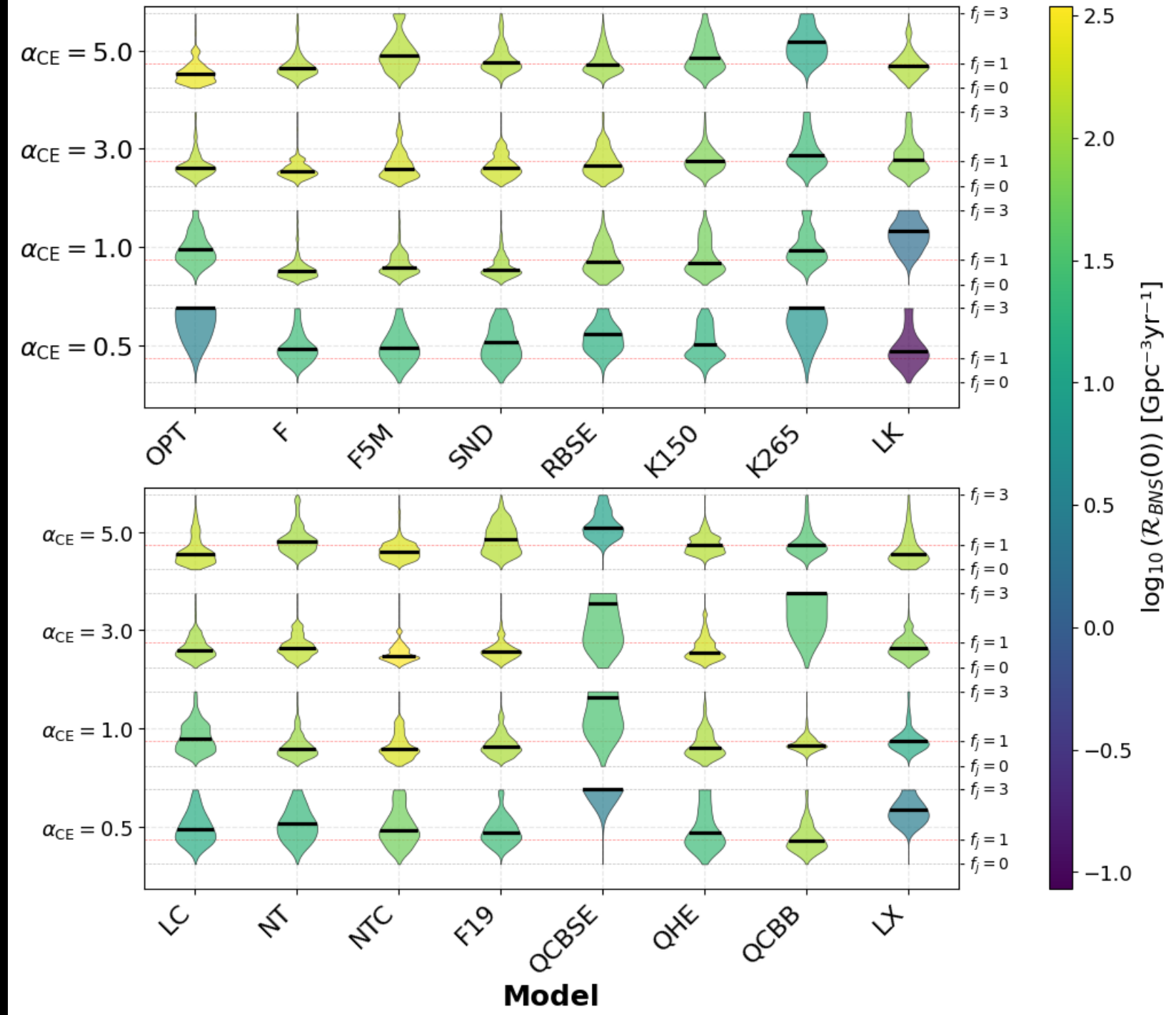
+

Non-Universal

Flat distribution and Log-Normal

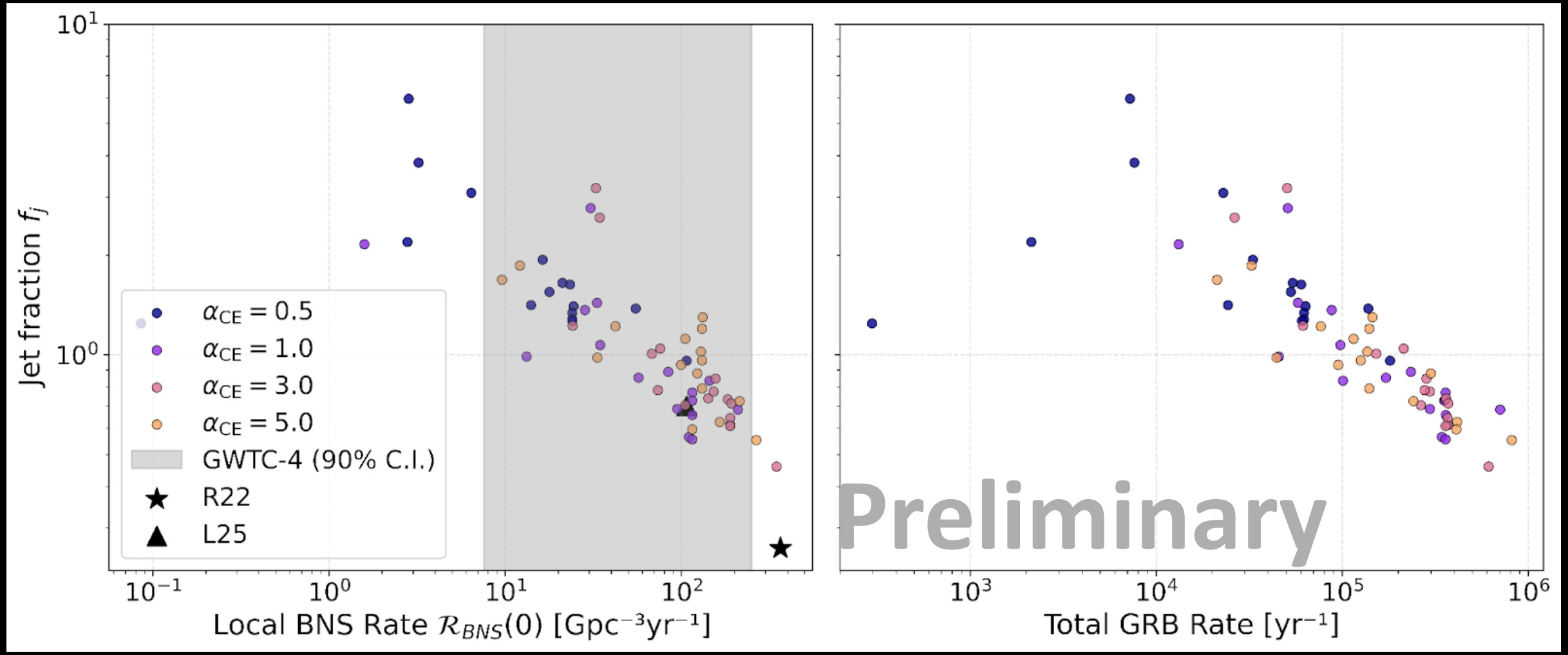
After convergence

Structured Jet Posteriors

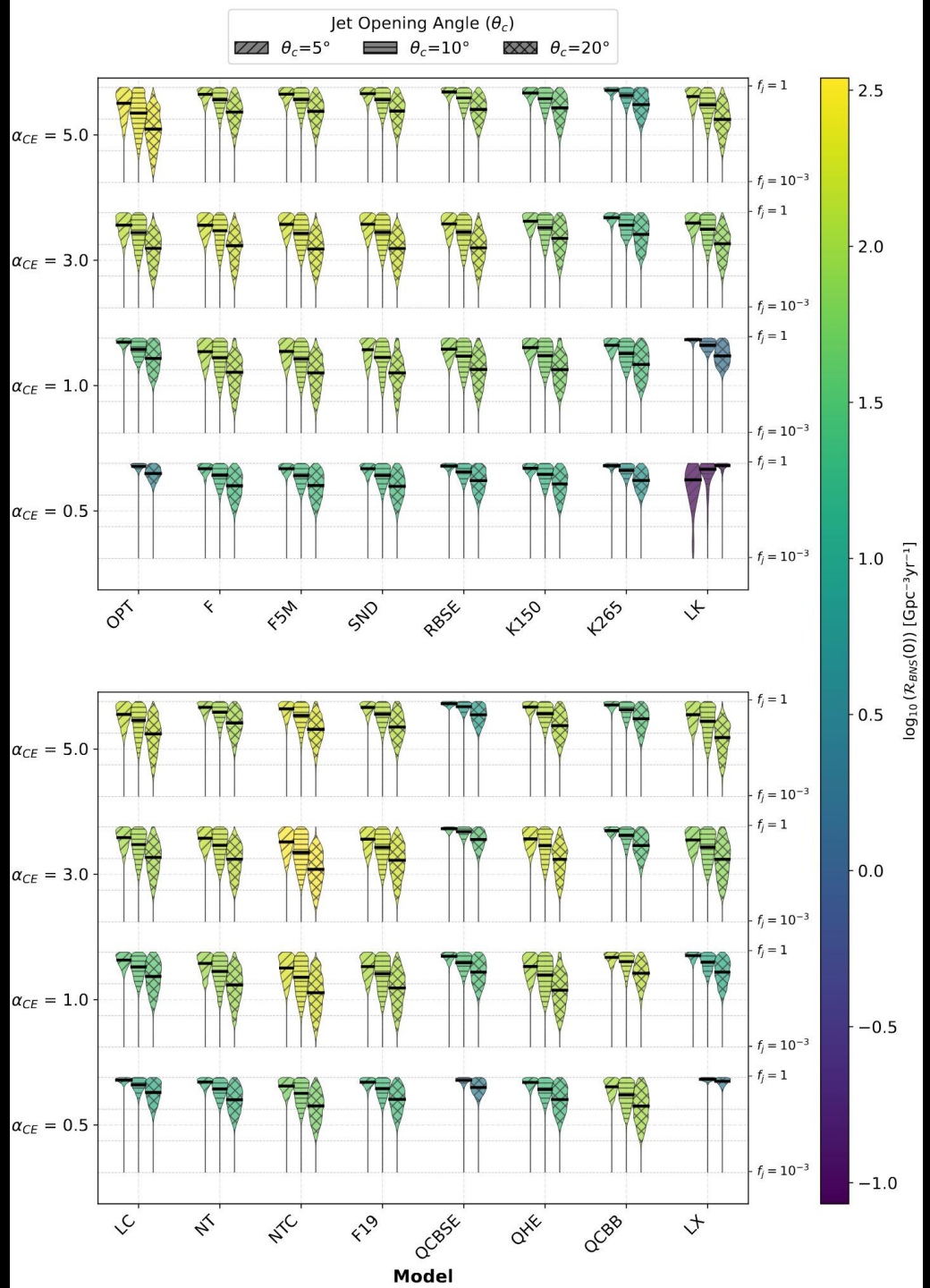


A. L. De Santis et al (202?) (in preparation)

Structured jet Posteriors



Top hat Jet Posteriors



Degenerate with geometry

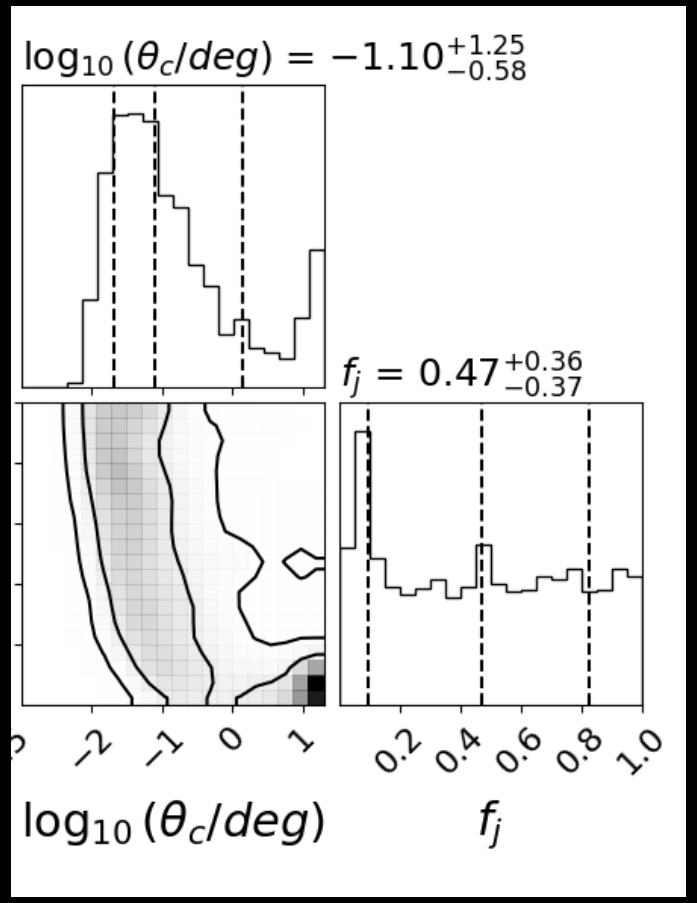
$$\epsilon = f_j \times (1 - \cos(\theta_c))$$

Shown is

$$f_j < 1$$

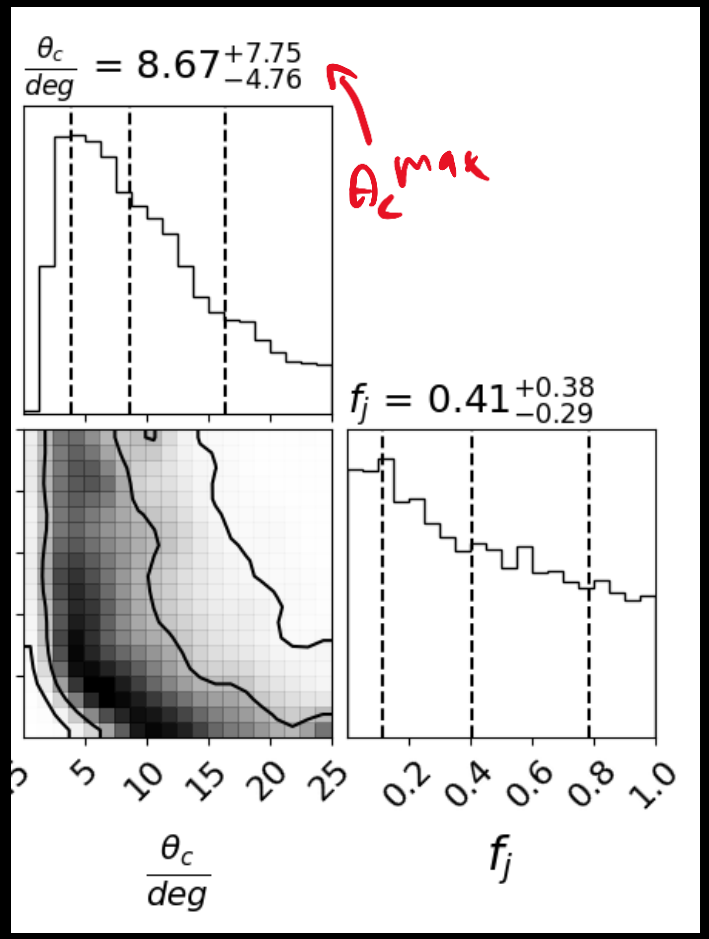
Additional finds

Log-Normal

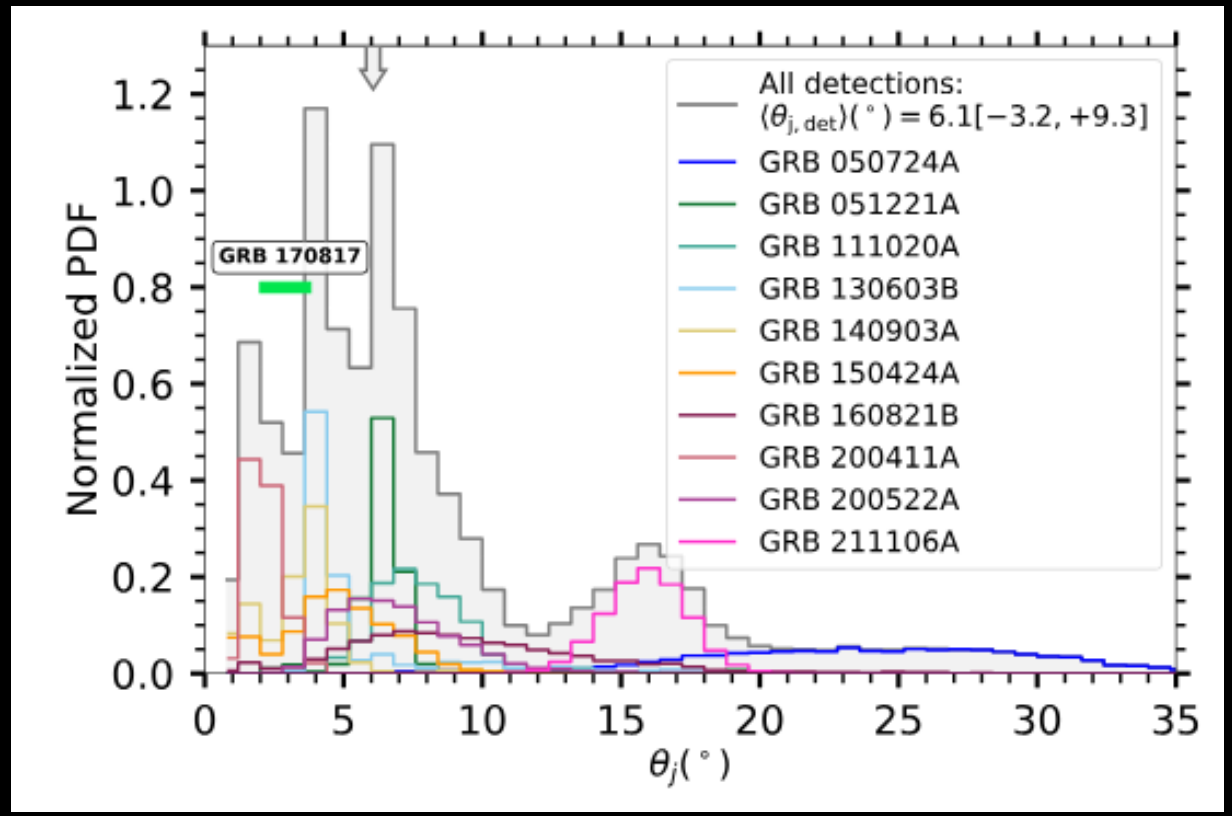


Small

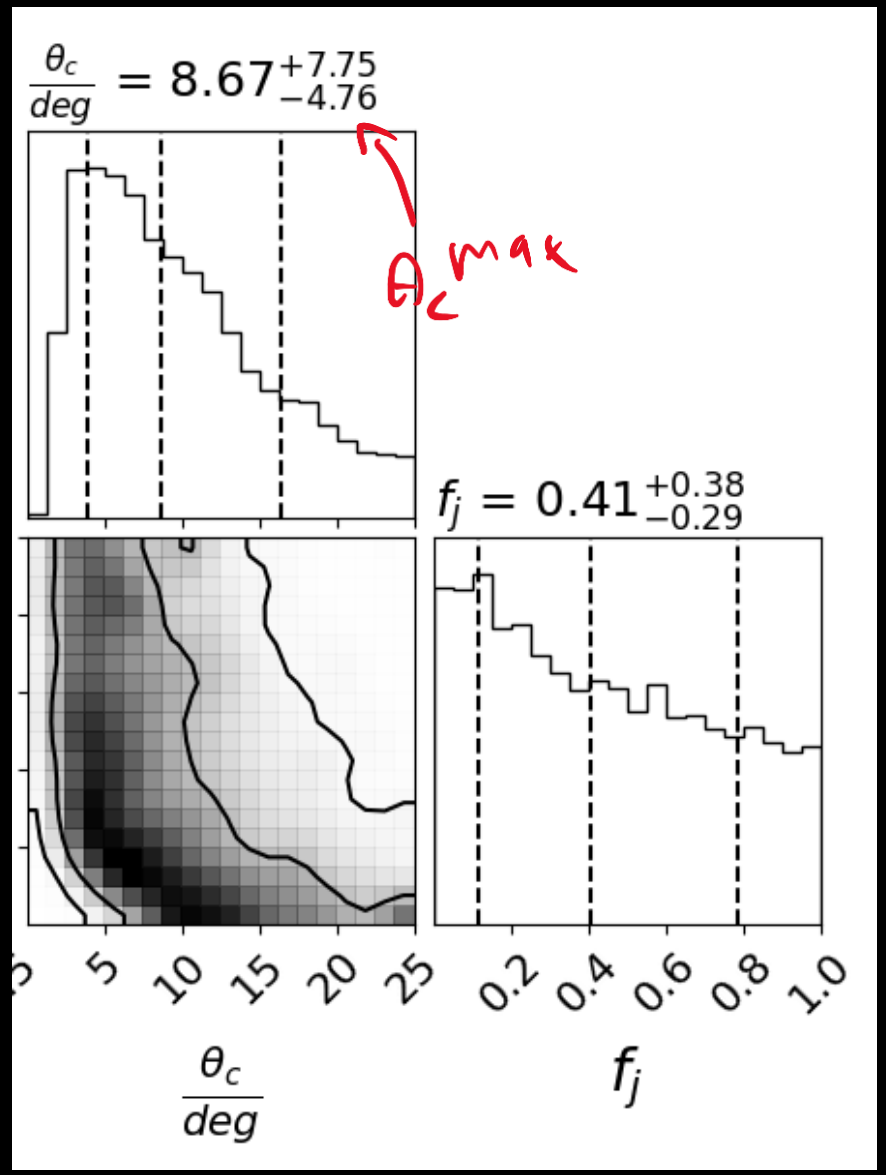
Flat



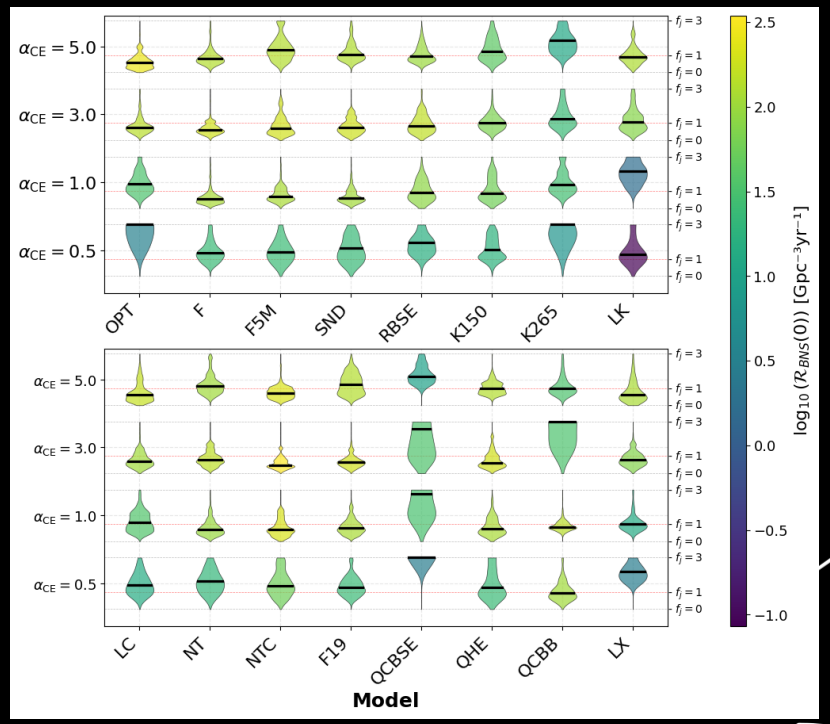
Comparison to other works



Rouco Escorial et al. 23

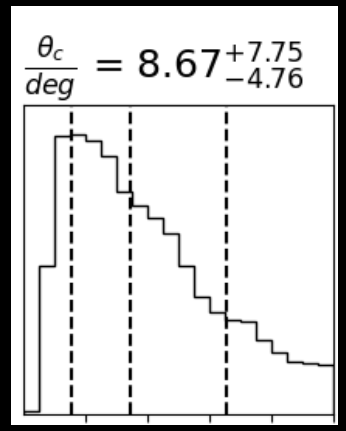


GRBs and BNS



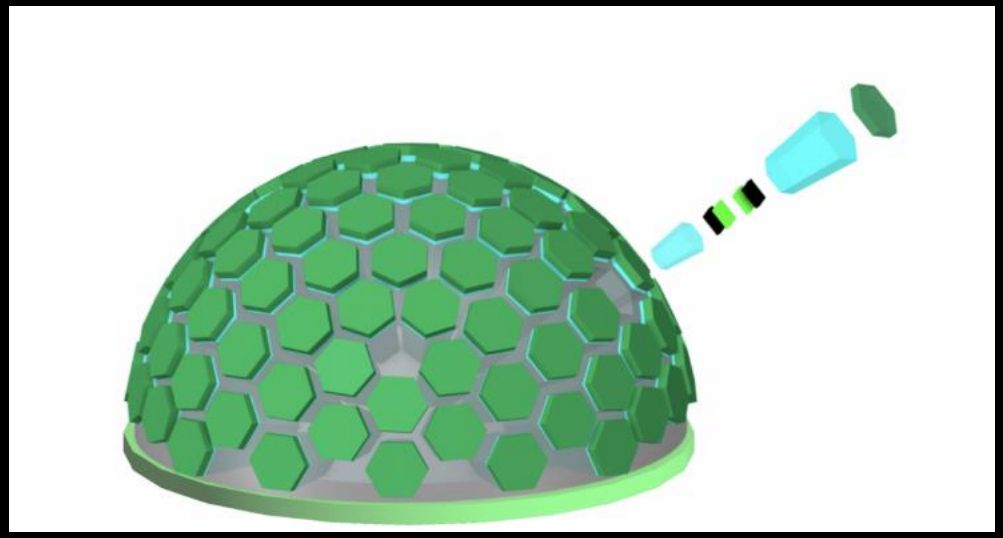
GRB data → Bounds on GW data

θ_c small



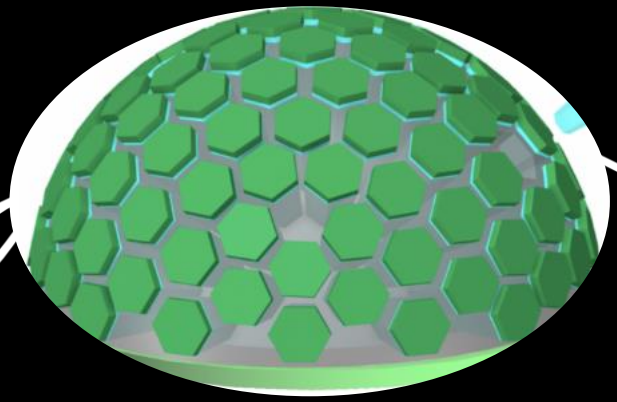
Framework for connecting
Model <-> Predictions

Predictions



Crystal eye

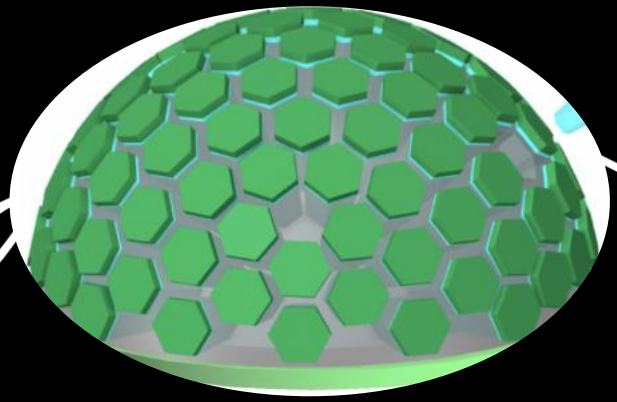
Crystal eye



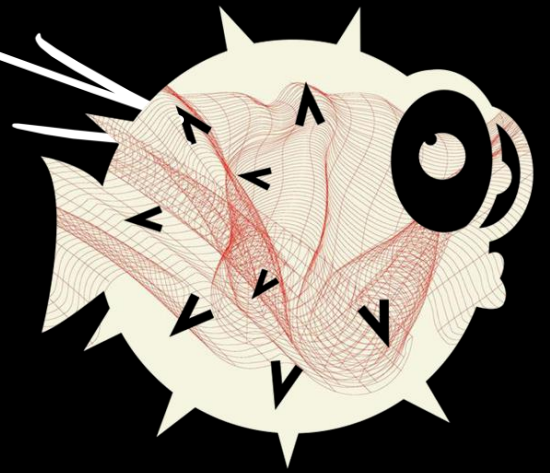
Joint detections

Mock catalogue

Crystal eye



Joint detections



GWFISH

MULTI-MESSENGER ASTRONOMY WITH GW AND GRBS

MAGGPY

Mock catalogue

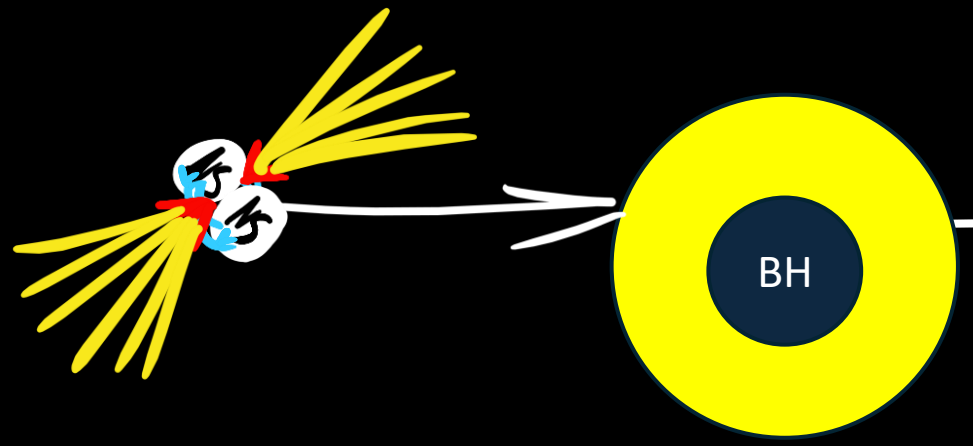
	Fermi-GBM	Crystal Eye
High SNR Threshold (SNR>25)	4.0 ph/cm²/s	1.8 ph/cm²/s
"Golden Sample" (SNR>25) sGRBs/year	16.13	20.55

with

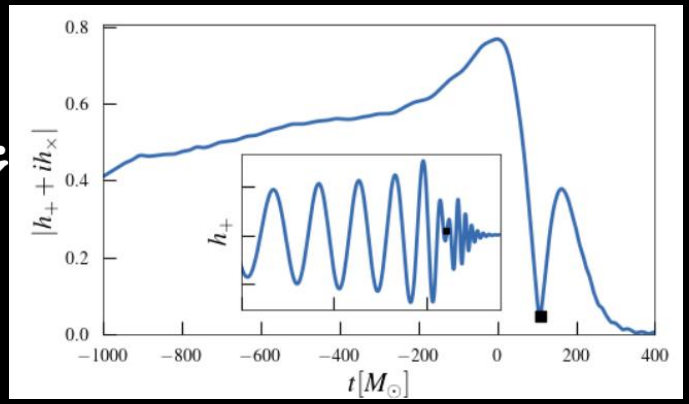
Direct Measurement of the Accretion Disk Formed in Prompt Collapse Mergers with Future Gravitational-Wave Observatories

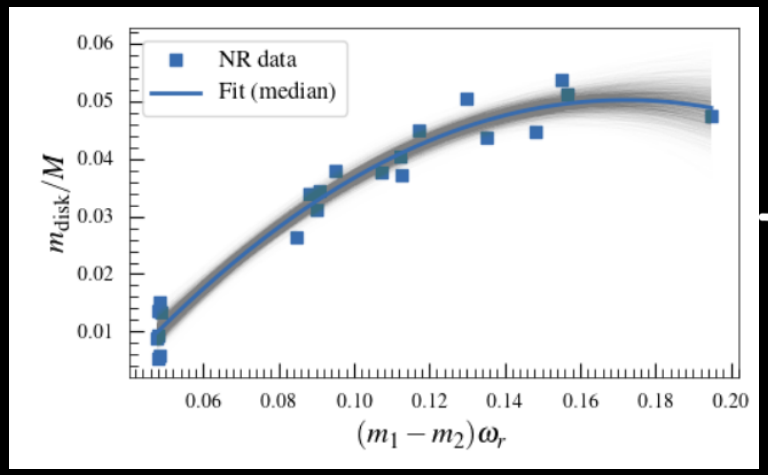
Arnab Dhani,[1,*] Alessandro Camilletti,[2,3,4] Alessio Ludovico De Santis,[5] Andrea Cozzumbo,[5] David Radice,[6,7,8] Domenico Logoteta,[9,10] Albino Perego,[2,3] Jan Harms,[5,11] and Marica Branchesi[5,11]

High frequency



Accretion disk





ONE measurement to calibrate

GRB emission mechanism

Kilonova ejecta

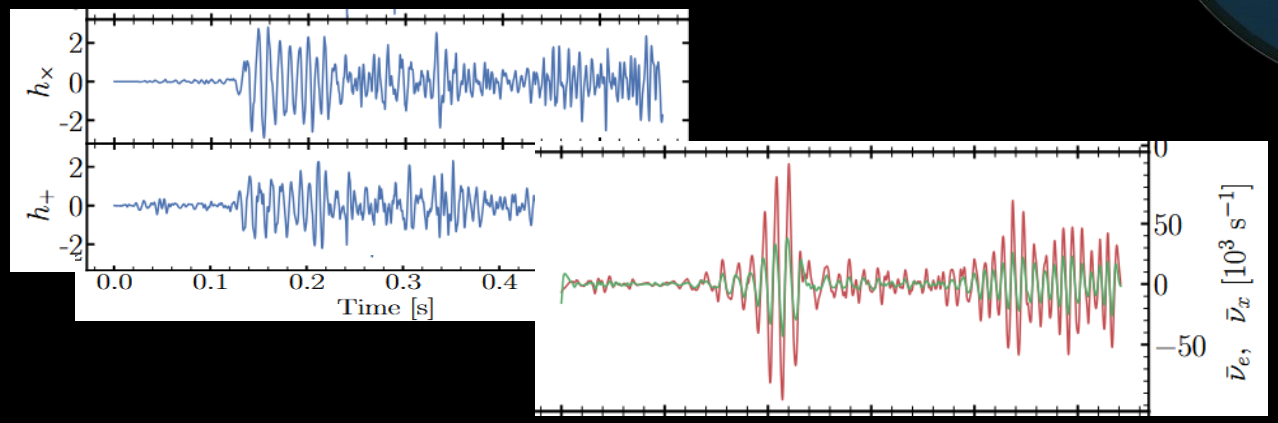
Pubblications

- *Constraining Binary Neutron Star Population Synthesis Models using Short Gamma-Ray Burst Data* (**De Santis** in preparation)
- *Direct Measurement of the Accretion Disk Formed in Prompt Collapse Mergers* (Dhani, Camilletti, **De Santis**, Cozumbo et al. 2025, preprint; arXiv:2507.14071).
- *Transient MeV radiation from a relativistic tidal disruption candidate* (Oganesyan, Kammoun, Ierardi**, De Santis**, Banerjee et al. 2025, accepted in A&AL ,preprint; arXiv:2507.18694).
- *Broadband Modelling of GRB 230812B Afterglow* (Mohnani et al. 2025, submitted to A&A, preprint; arXiv: 2507.18697).
- *The Science of the Einstein Telescope* (2025, accepted in JCAP, preprint; arXiv:2503.12263).
- *Crystal Eye: All sky MeV monitor with high precision real-time localization* (2026, Astroparticle Physics 174, 103171).
- *Optimal Optical Layout of the Einstein Telescope* (in preparation).
- *An Observation Strategy for the Optical Counterpart of a Galactic Supernova* (Giudice, **De Santis** et al. in preparation).
- *Forecasting Short GRB Detections for the THESEUS Mission* (in preparation).

Next steps

Supernovae Detectability & ET Era

- Complete work on GW-optical detectability of SN
- Finalize the visiting project by producing SN templates.
- Implement SN templates into the detectability analysis for GW observations.



Compact Object Population & Short GRBs

MULTI-MESSENGER ASTRONOMY
MAGGPY
WITH GW AND GRBS

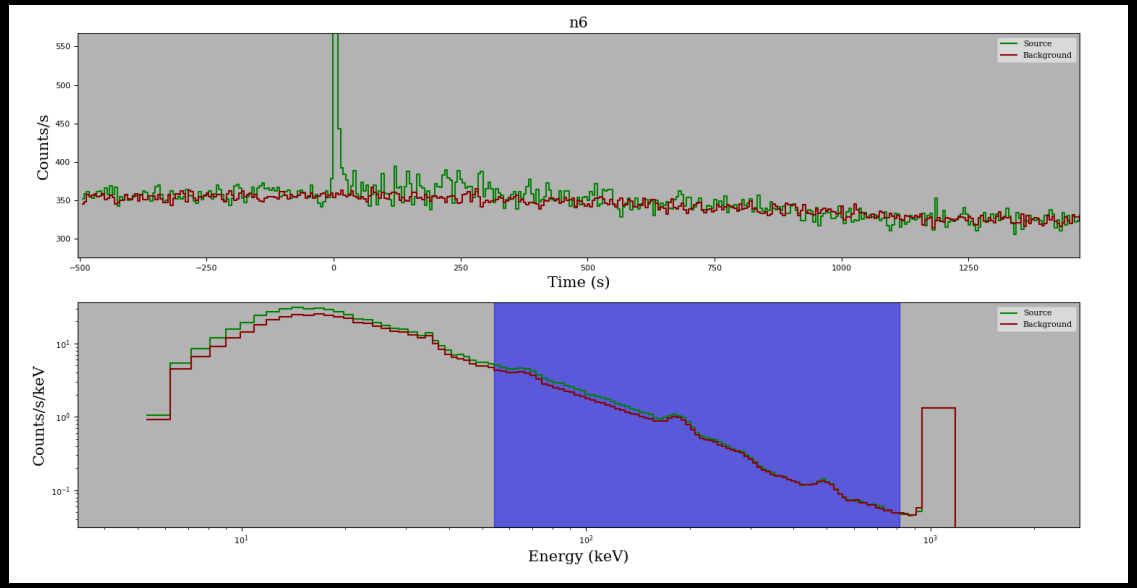
Complete the editing of the paper on BNS populations and their connection to short GRBs

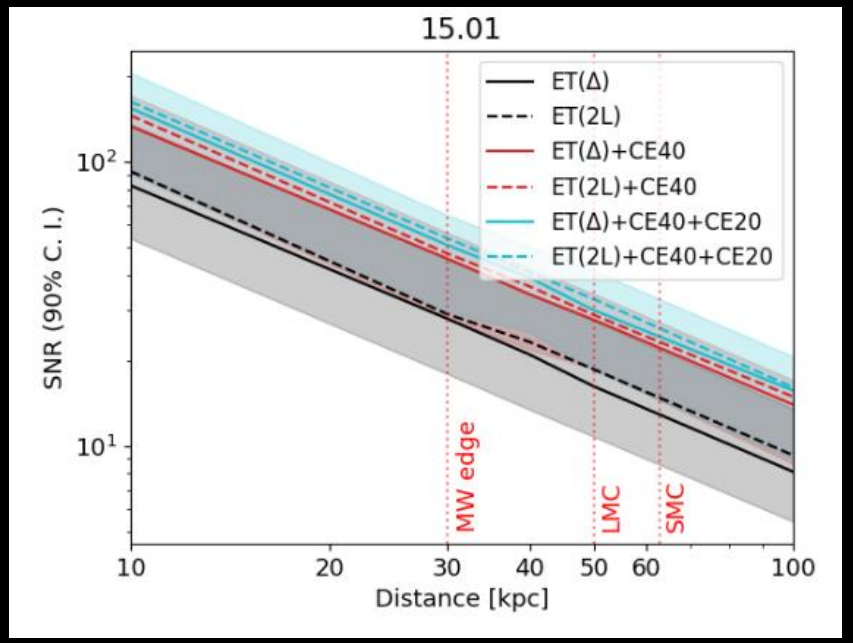
Add afterglow modeling for joint GW/sGRB detection scenarios

Investigate the role of the neutron star–black hole (NSBH) population

Make MAGPPY publicly available.

Summary





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