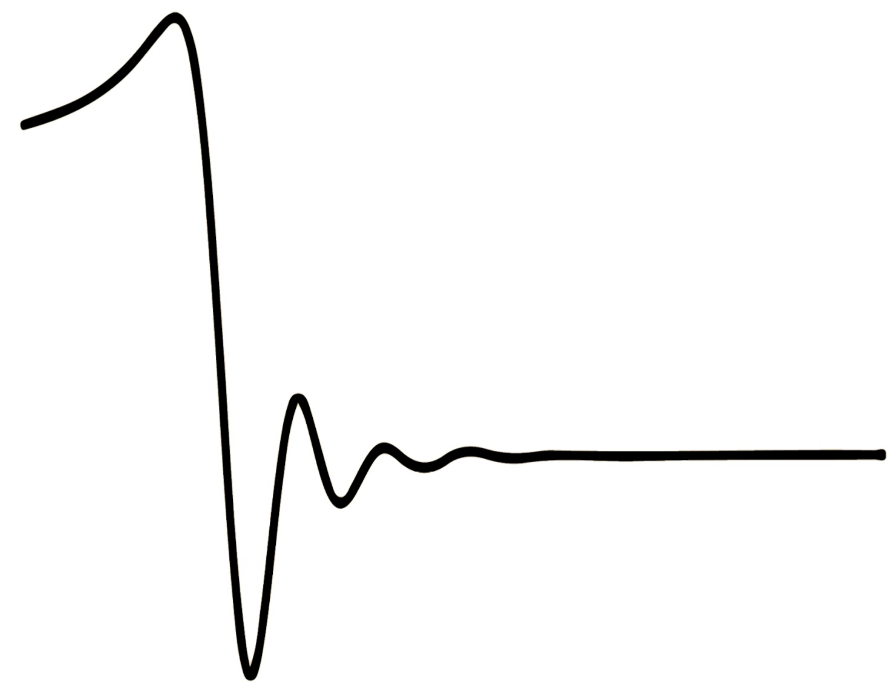
Common Tools for the Einstein Telescope community

@ XII Einstein Telescope Symposium

Hungarian Academy of Science

June 2022

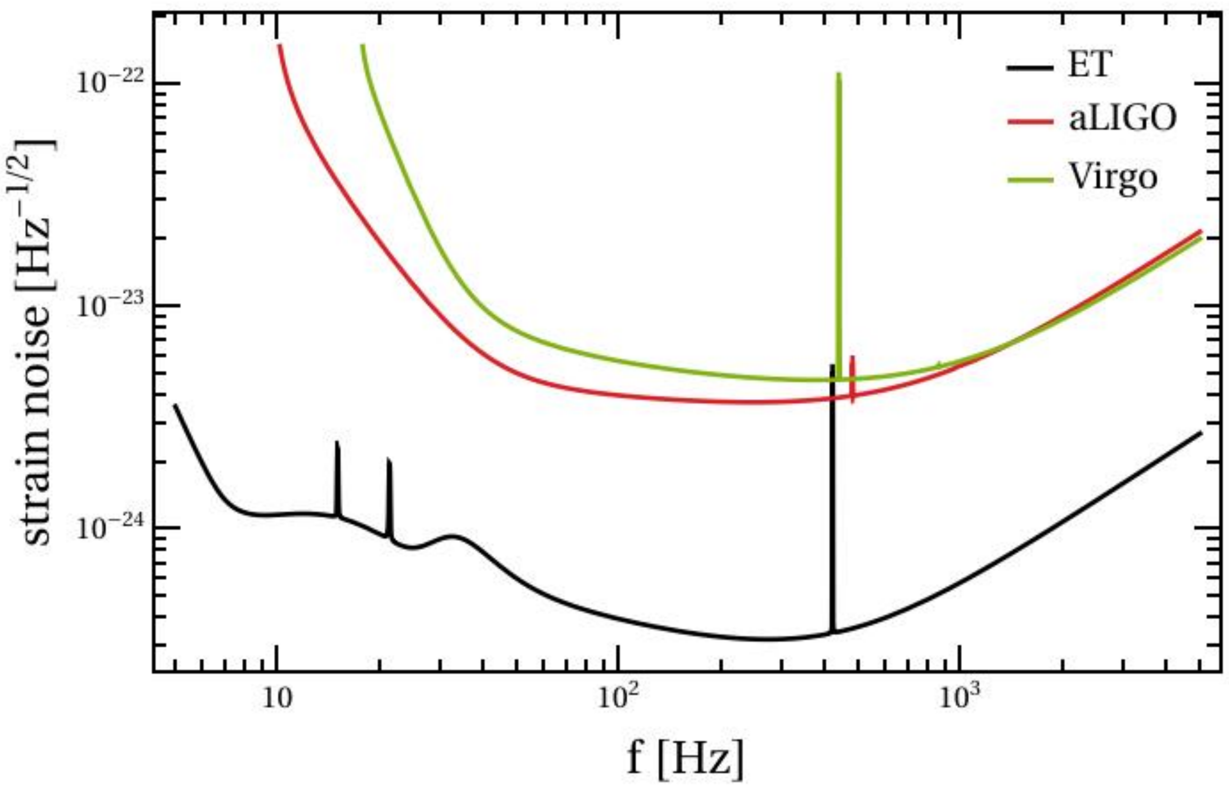


GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

ET EINSTEIN TELESCOPE

Andrea Maselli
Siong Heng
Michal Bejger

ET sensitivity



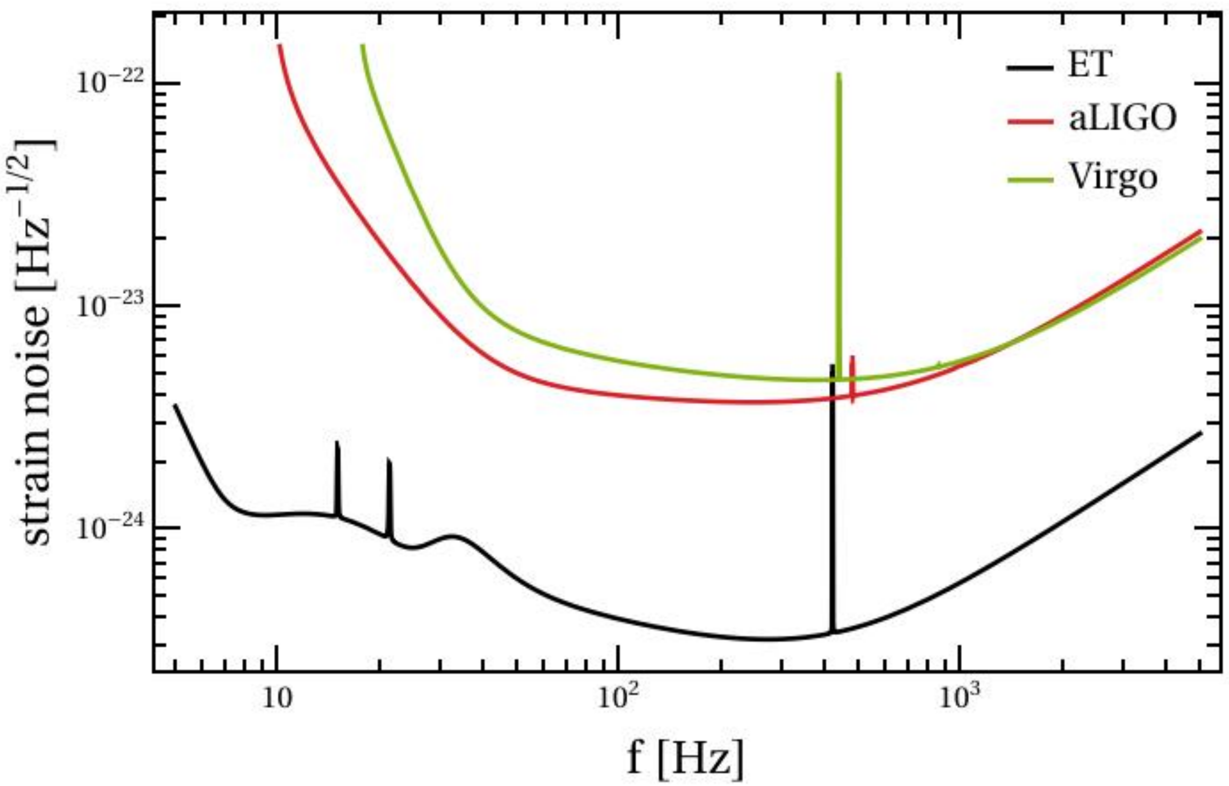
$\mathcal{O}(10^4 - 10^5)$ *BBH/yr*

$\mathcal{O}(10^4 - 10^5)$ *BNS/yr*

- *Longer inspiral signals*
- *More sensitive at high-frequencies*
- *High signal-to-noise ratios*

Evans & Hall Class. Quant. Grav. 36, 22 (2019)

ET sensitivity



$\mathcal{O}(10^4 - 10^5)$ *BBH/yr*

$\mathcal{O}(10^4 - 10^5)$ *BNS/yr*

more science cases

exploit populations

- *Longer inspiral signals*
- *More sensitive at high-frequencies*
- *High signal-to-noise ratios*

Evans & Hall Class. Quant. Grav. 36, 22 (2019)

ET science cases

ET does not only improve current physics, but opens for new science windows

- *Develop such science cases and assess ET ability to chase for them is key to support the project and the community (Obsevational Science Board X)*

Full posterior sampling (MCMC...) $\xrightarrow{\text{Gaussian approximation}}$ *Fisher approach*

Sathya & Tania Talk

Fast calculations
Population studies
Multi-band/messenger analysis
Detector(s) configurations
....

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Gaussian approximation

Fisher approach

Sathya & Tania Talk

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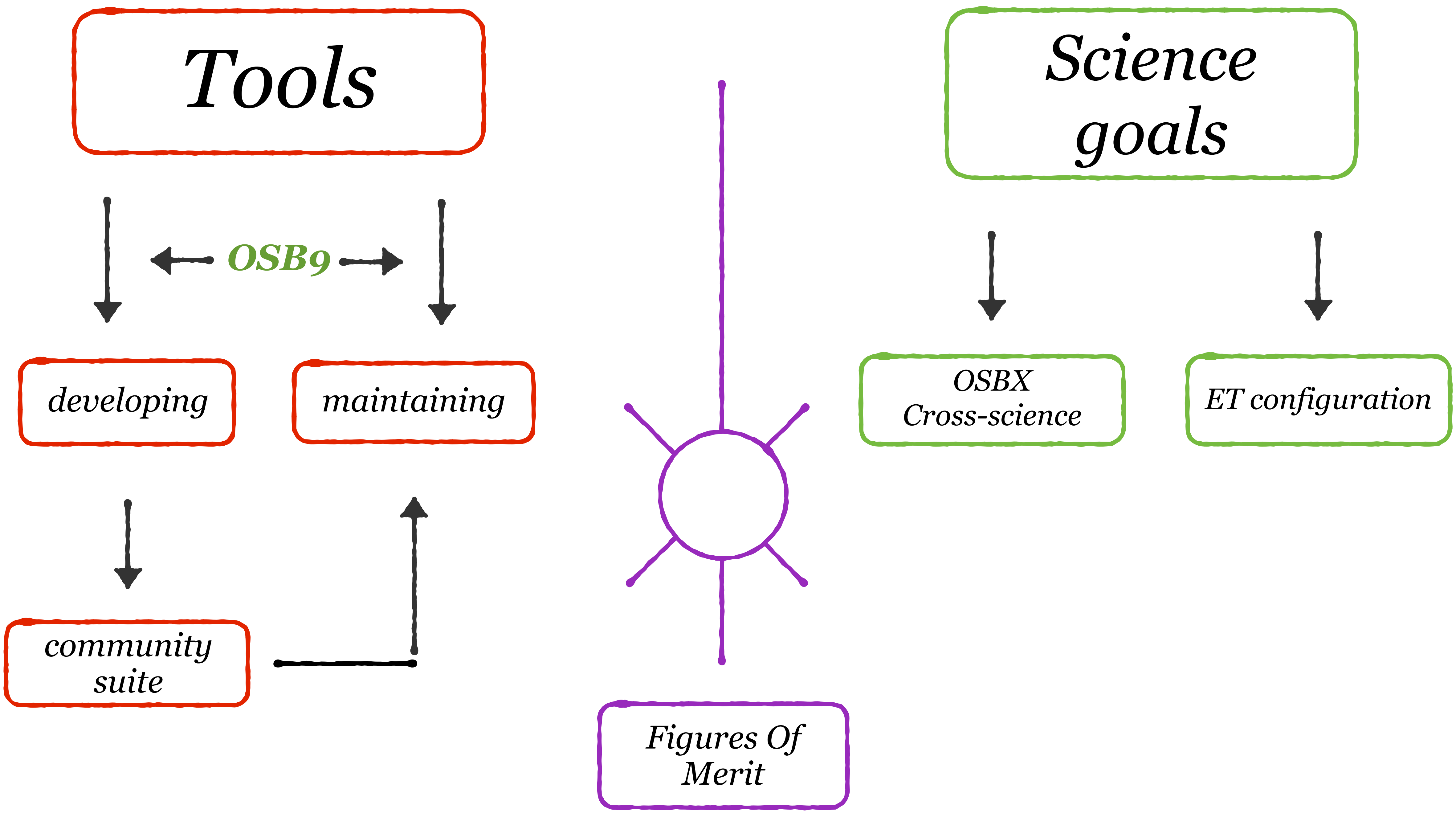
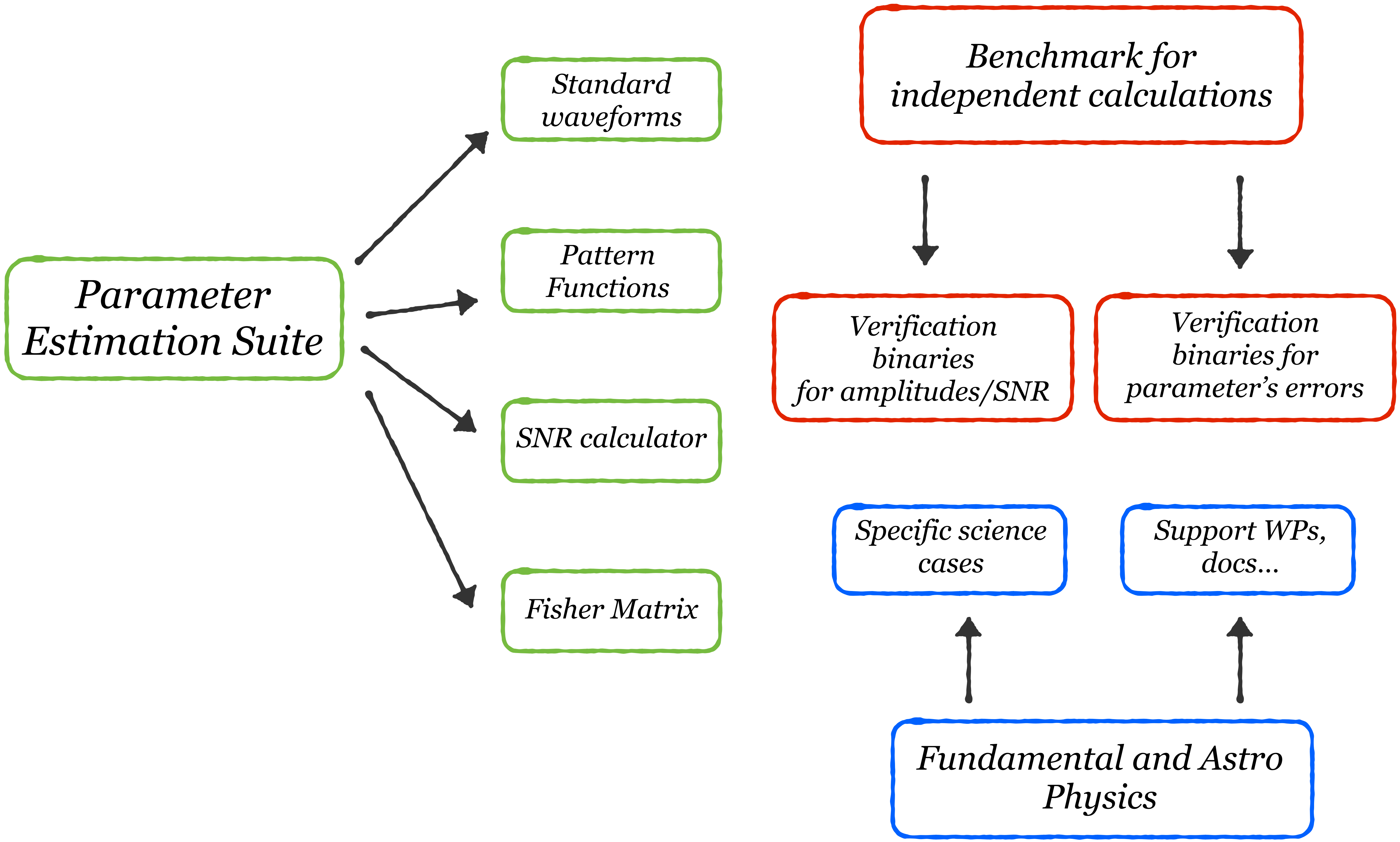
Common Tools

Development and maintenance of the codes for ET science cases

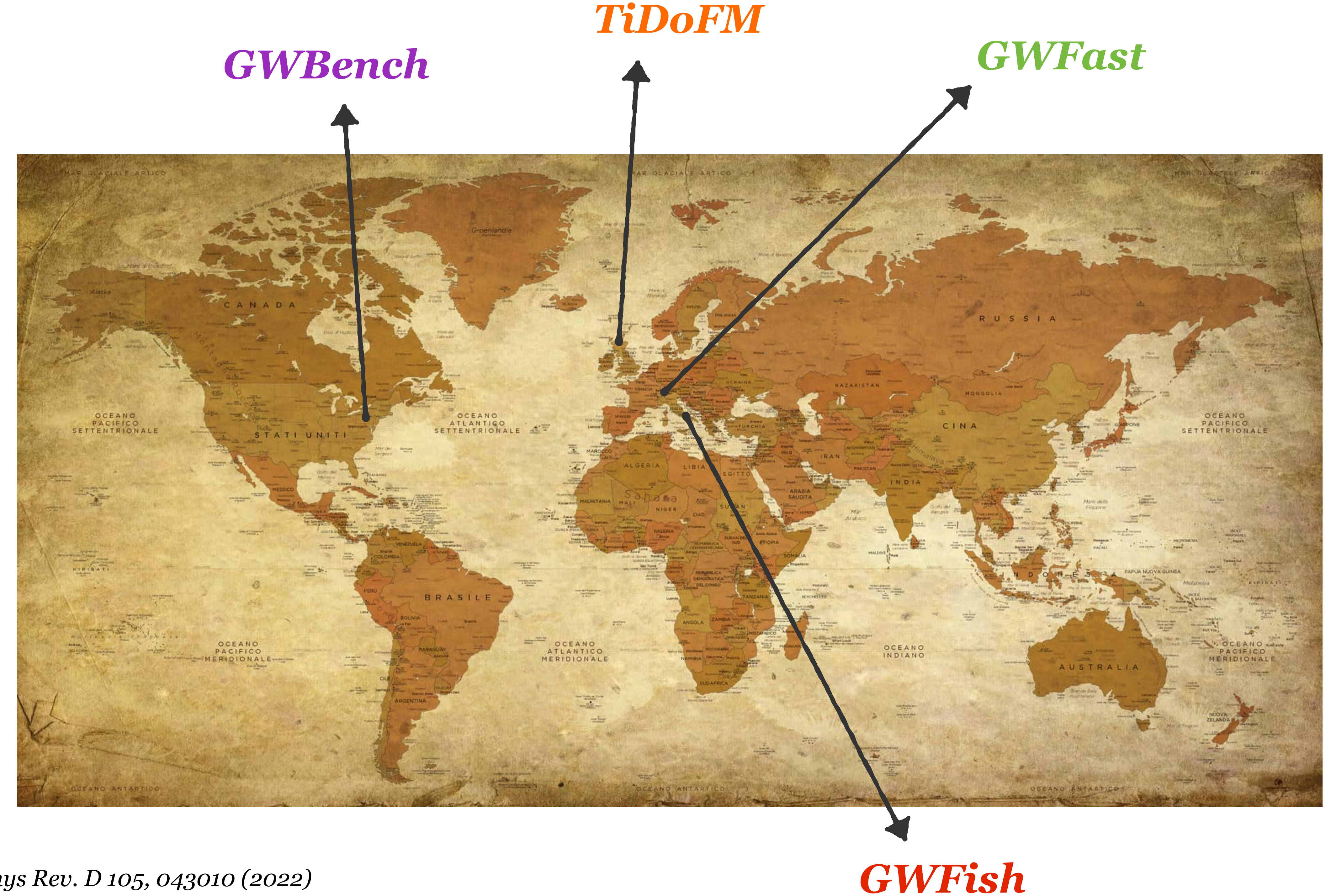


Common Tools

Development of the infrastructures



Common effort



Li +, Phys Rev. D 105, 043010 (2022)
Harms +, 2205.02499 (2022)
Borhanian +, 2202.11048 (2022)
Iacovelli +, to appear (2022)

Common effort

GWFast

M. Mancarella,
F. Iacovelli, M. Maggiore

GWBench

S. Sborhanian,
B. Sathyaprakash

TiDoFM

Y. Li, M. Chan,
C. Messenger,
X. Fang, S. Heng

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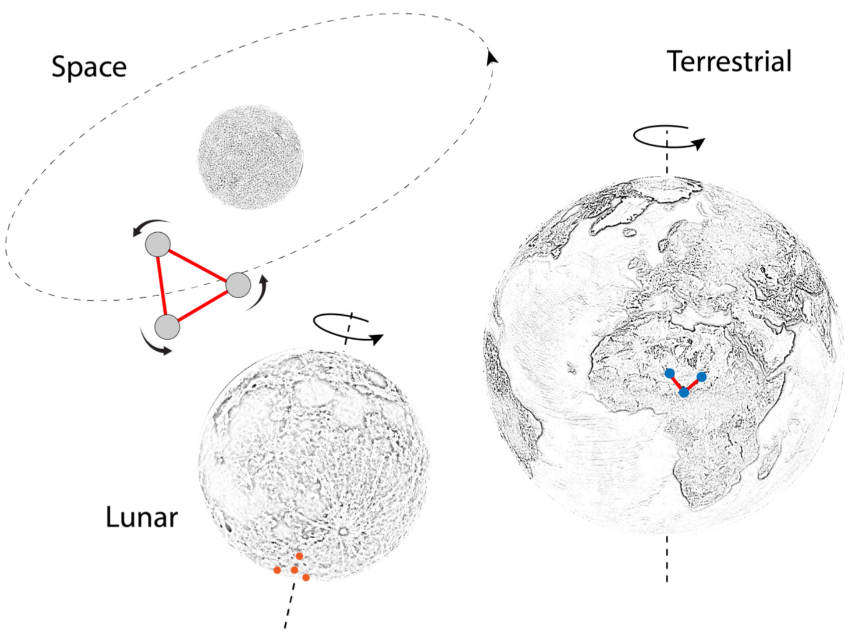
Join In!

Common features

All around suite's specifications

- *Time and frequency domain codes for waveform generation and statistical errors on source parameters*
- *A variety of GW templates already available (TaylorF2, Phenom,...)*
  - *Ready-to-include more sophisticate models*
  - *Ready-to-use standard GR tests*
- *Easy to include post-merger templates for ringdown analysis*
- *Tidal Love numbers to study neutron star physics*
- *Interface with LAL suite*
- *Time dependent pattern functions with detector localization*
  - *Detector orbital motion included*
- *Multi-detector platform*



Science goals

Study of detector configurations and impact on science cases

- *Site location and orientation, arm-length, geometry*
- *Interplay with current and future 3G detectors, e.g. **C**osmic **E**xplorer*
- *Interplay with EM facilities for **multi-messenger** astronomy*
- *Interaction with all science divisions to study ET capabilities*

Key questions with fast tools supplied by population of sources

- *BNS and BBH horizon*
- *Efficiency and detection rates*
- *Joint bounds on source parameters (e.g. stellar equation of state)*
- ....

Where are we?

After an initial independent development of each group, we have teamed up for a community effort

- *Defined a set of BNS injections to test the suites and have common agreement on the parameter estimation*

	Mc	eta	dL	dec	ra	iota	psi	tcoal	Phicoal	chi1z	chi2z
0	1.15	0.24900	0.1	0.785398	0.785398	0.785398	0.785398	0.290958	0.785398	0.01	-0.005
1	1.15	0.24900	0.1	0.785398	0.000000	0.785398	0.785398	0.290958	0.785398	0.01	-0.005
2	1.15	0.24900	0.1	0.785398	1.570796	0.785398	0.785398	0.290958	0.785398	0.01	-0.005
3	1.15	0.24900	0.1	1.570796	0.785398	0.785398	0.785398	0.290958	0.785398	0.01	-0.005
4	1.15	0.24900	0.1	0.000000	0.785398	0.785398	0.785398	0.290958	0.785398	0.01	-0.005
5	1.15	0.24900	0.1	0.785398	0.785398	0.000000	0.785398	0.290958	0.785398	0.01	-0.005
6	1.15	0.24900	0.1	0.785398	0.785398	1.570796	0.785398	0.290958	0.785398	0.01	-0.005
7	1.15	0.24999	0.1	0.785398	0.785398	0.785398	0.785398	0.290958	0.785398	0.01	-0.005
8	1.15	0.25000	0.1	0.785398	0.785398	0.785398	0.785398	0.290958	0.785398	0.01	-0.005

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- *Work in progress, with suites already matching on the majority of the fundamental benchmark metrics*

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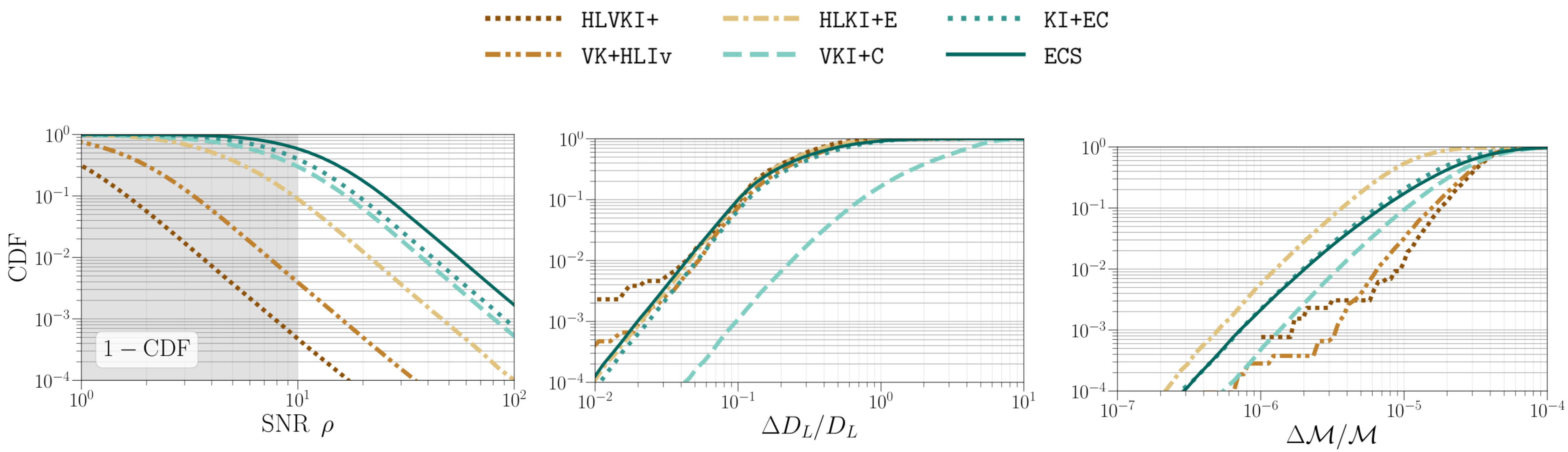
Join In!

Some results

BNS parameter estimation for different network configurations

Borhanian +, 2202.11048 (2022)



Change in the z-reach between A+ and 3G detectors [0.11->2.3]

	BNS		
Cosmic rate	4.7×10^5		
SNR ρ	≥ 10	≥ 30	≥ 100
HLVKI+	220	7	0
VK+HLIv	1,800	71	2
HLKI+E	42,000	1,700	46
VKI+C	140,000	8,900	250
KI+EC	190,000	13,000	340
ECS	270,000	28,000	780

	BNS			
SNR ρ	≥ 10		≥ 100	
	z_r	z_h	z_r	z_h
HLVKI+	0.11	0.42	0.011	0.041
VK+HLIv	0.22	0.9	0.022	0.087
HLKI+E	0.64	3.3	0.06	0.27
VKI+C	1.2	8.1	0.1	0.46
KI+EC	1.5	9.5	0.13	0.51
ECS	2.3	16	0.17	0.67

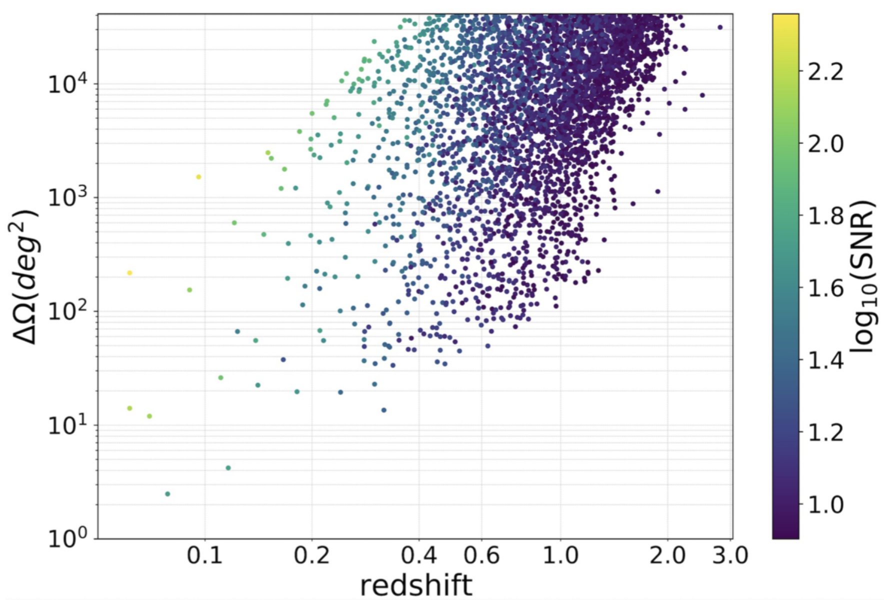
Some results

Localisation of BNS with multi-messenger observations

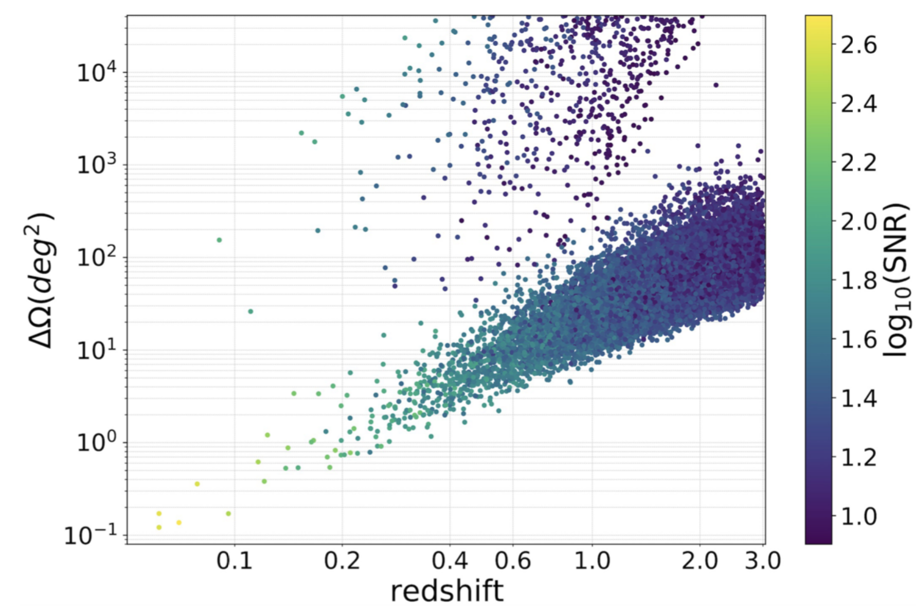
Ronchini +, 2204.01746 (2022)

- *Population of* $N = 10^5$ *events with* $0^\circ \leq \theta_v \leq 15^\circ$

ET



ET + CE



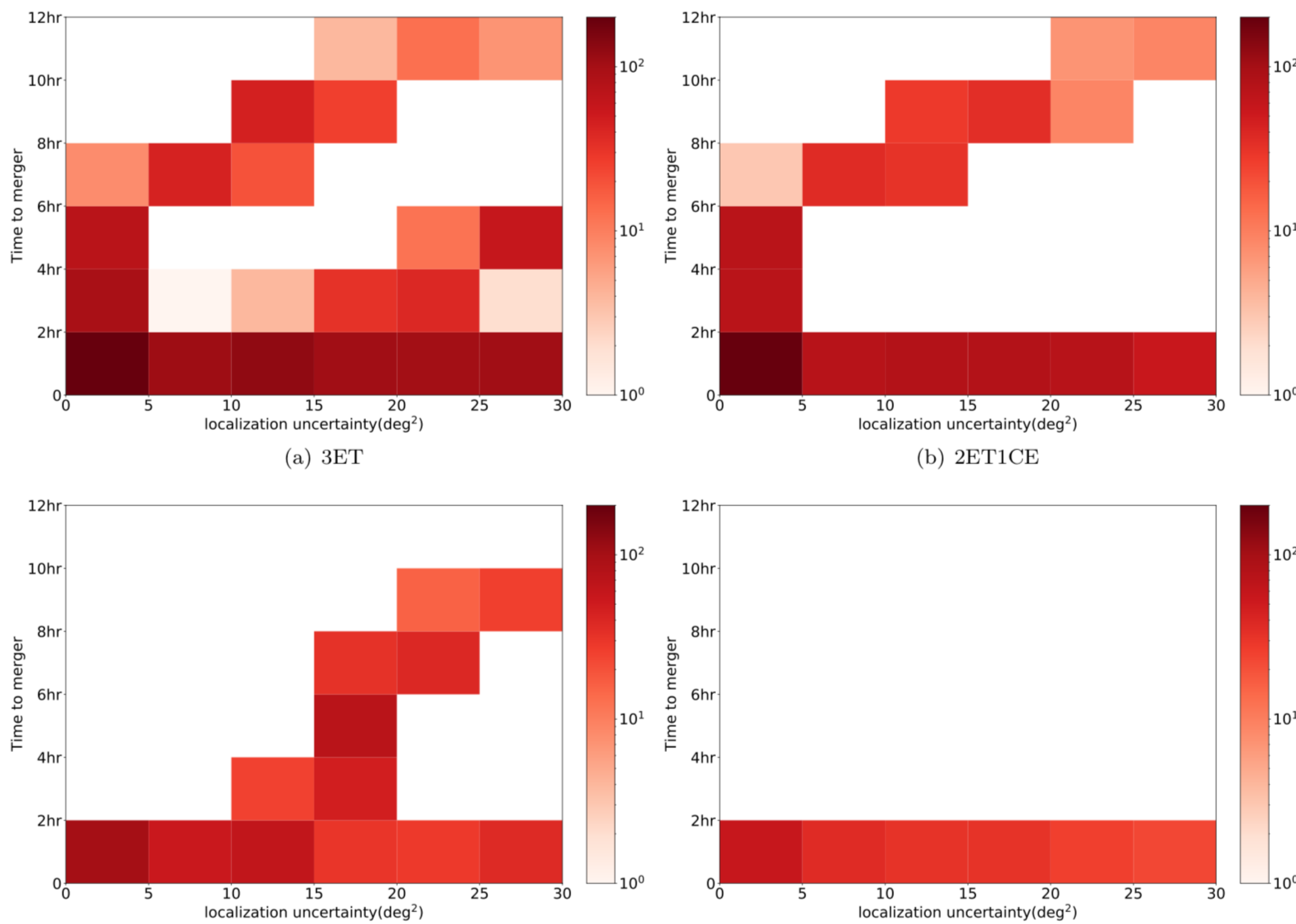
- *Large fraction @ z< 1 with* $\Delta\Omega \lesssim 10\ deg^2$ *which allows multi wavelength EM searches*

	ET	ET+CE
N_{det}	12970	23600
$N_{\mathrm{det}}(\Delta\Omega < 1\ \mathrm{deg}^2)$	0	20
$N_{\mathrm{det}}(\Delta\Omega < 10\ \mathrm{deg}^2)$	2	845
$N_{\mathrm{det}}(\Delta\Omega < 100\ \mathrm{deg}^2)$	69	17049
$N_{\mathrm{det}}(\Delta\Omega < 1000\ \mathrm{deg}^2)$	526	21564

Some results

Time to the merger distribution for BNS @ with $\Delta\Omega \lesssim 30\ deg^2$

Li +, Phys Rev D 105, 043010 (2022)



(a) 3ET (b) 2ET1CE (c) 1ET2CE (d) 3CE

- *BNS detected ~ 10 hours before the merger with mixed network*