“High Frequency” or What I learned from reading the 3G science case white papers

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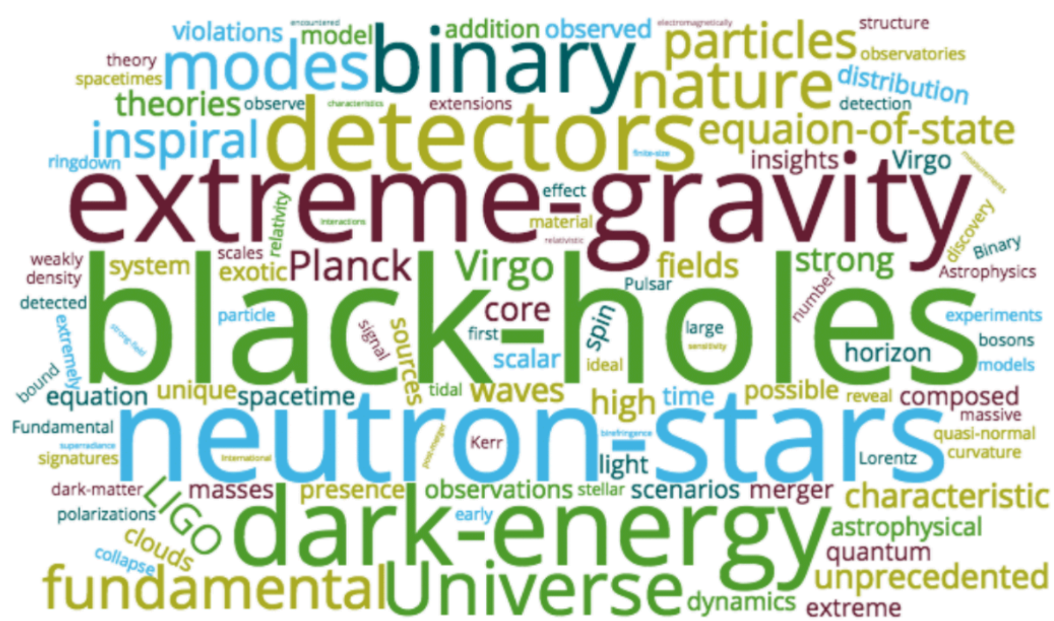
An analogy

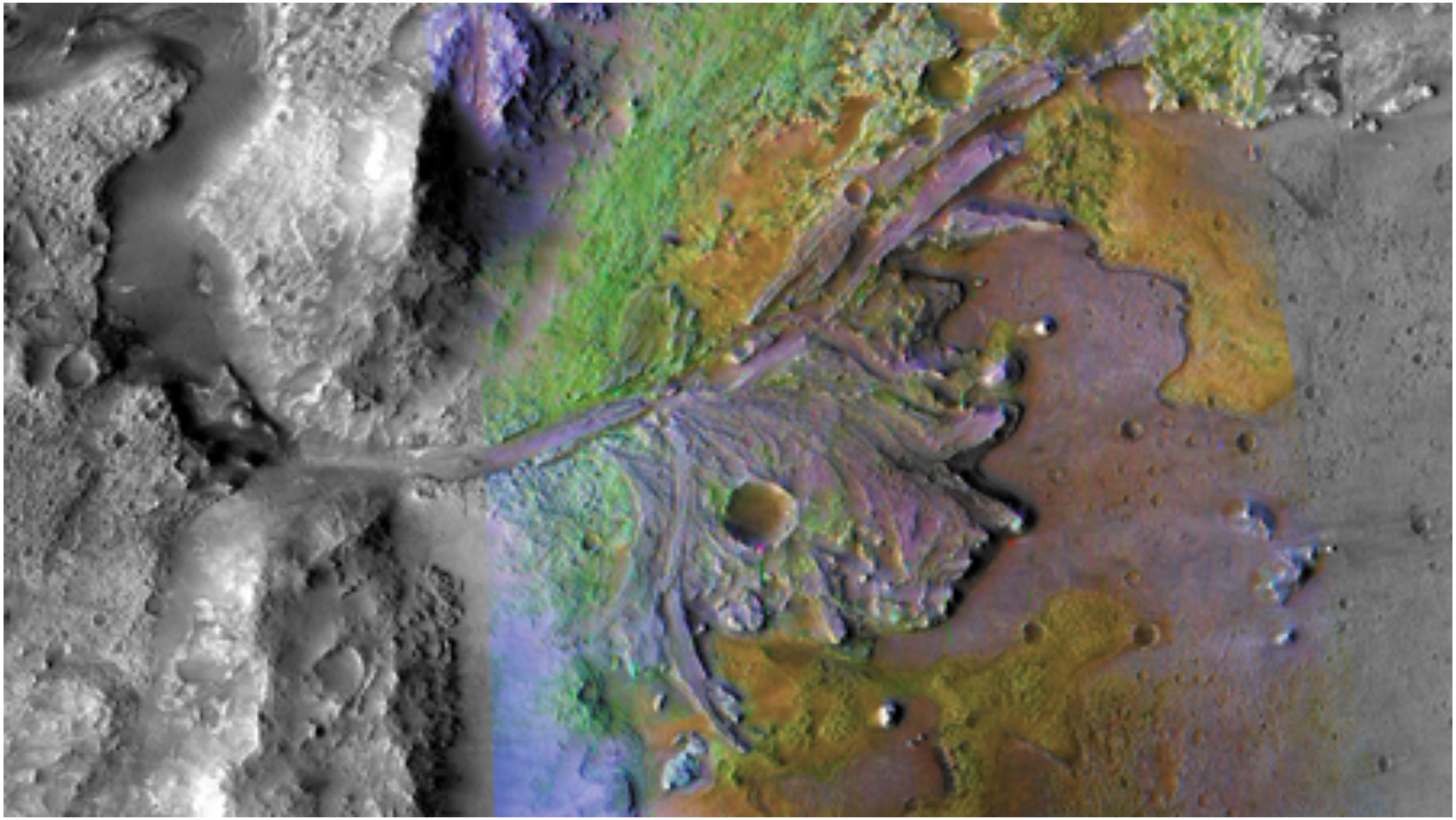
Gravitational-Wave Astronomy with the Next-Generation Earth-Based Observatories

Exploring the Universe from Planck to Hubble Scales



GWIC, GWIC-3G, GWIC-3G-SCT-Consortium

An analogy

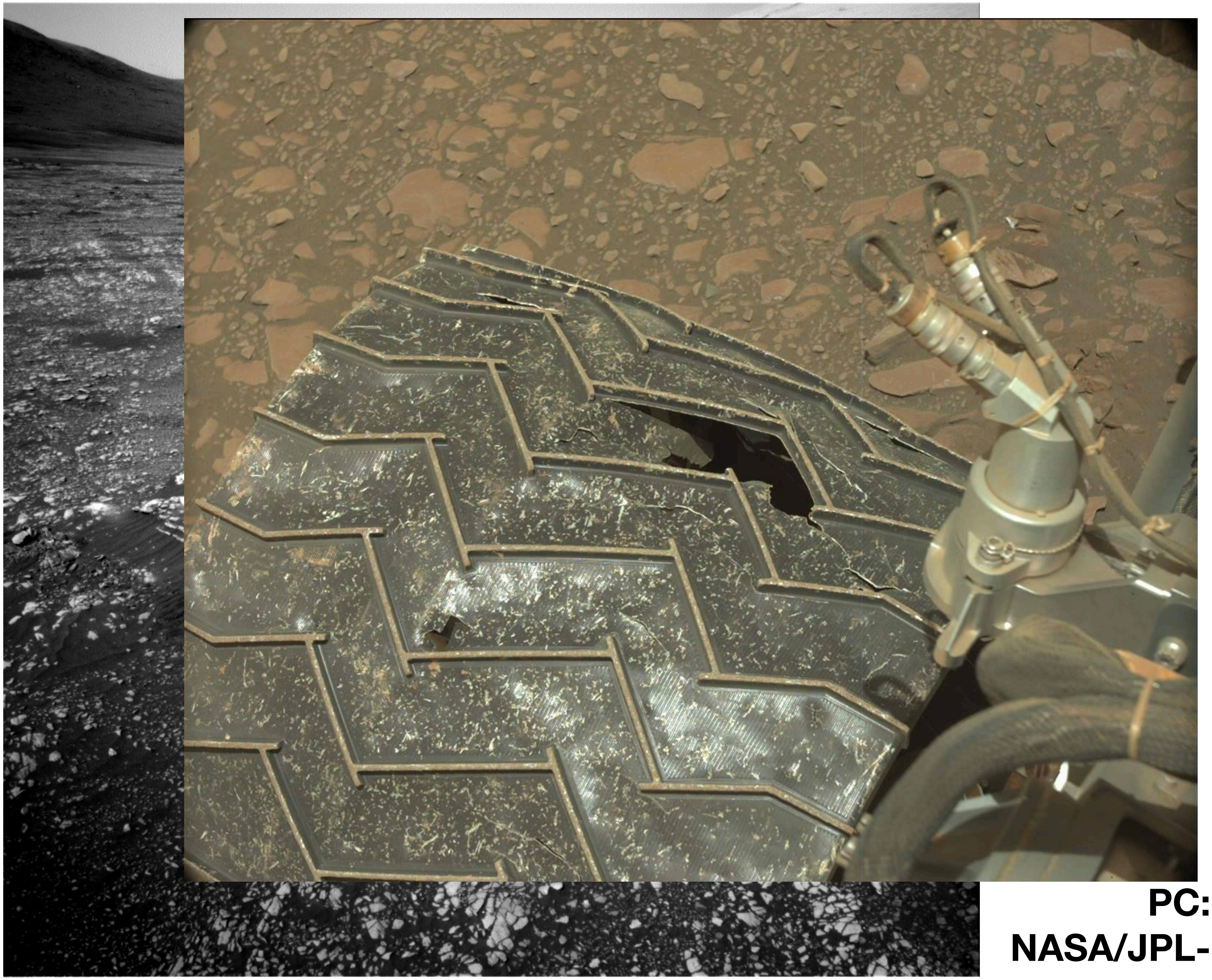


PC:
NASA/JPL/JHUAPL/
MSSS/BROWN UNIVERSITY

An analogy

PC: NASA/JPL-Caltech

An analogy



PC: NASA/JPL-Caltech

The 3G Landscape

- Seed Black Holes
- Neutron Stars
- Compact Binaries
- Cosmology
- Multi-Messenger Observations
- Supernovae
- Extreme Gravity
- Waveform Models
- Detector Networks

Inspired by Vicky and Sathya

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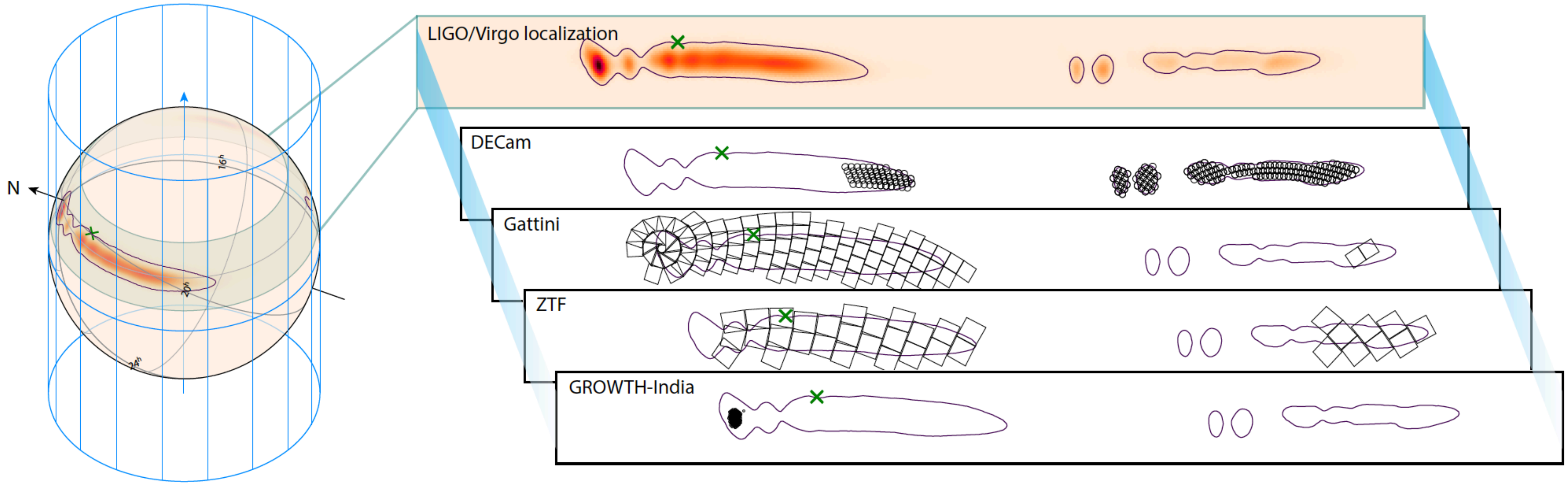
A New Era

DETECTION CAPABILITY OF 3G NETWORK

Table 2.1: Expected BNS detections per year N; number detected with a resolution of < 1, < 10 and < 100 sq. deg. N_1, N_{10} and N_{100}, respectively, and median localization error M in sq. deg., in a network consisting of LIGO-Hanford, LIGO-Livingston and Virgo (HLV), HLV, KAGRA and LIGO-India (HLVKI) and 1 Einstein Telescope and 2 Cosmic Explorer detectors (1ET+2CE).

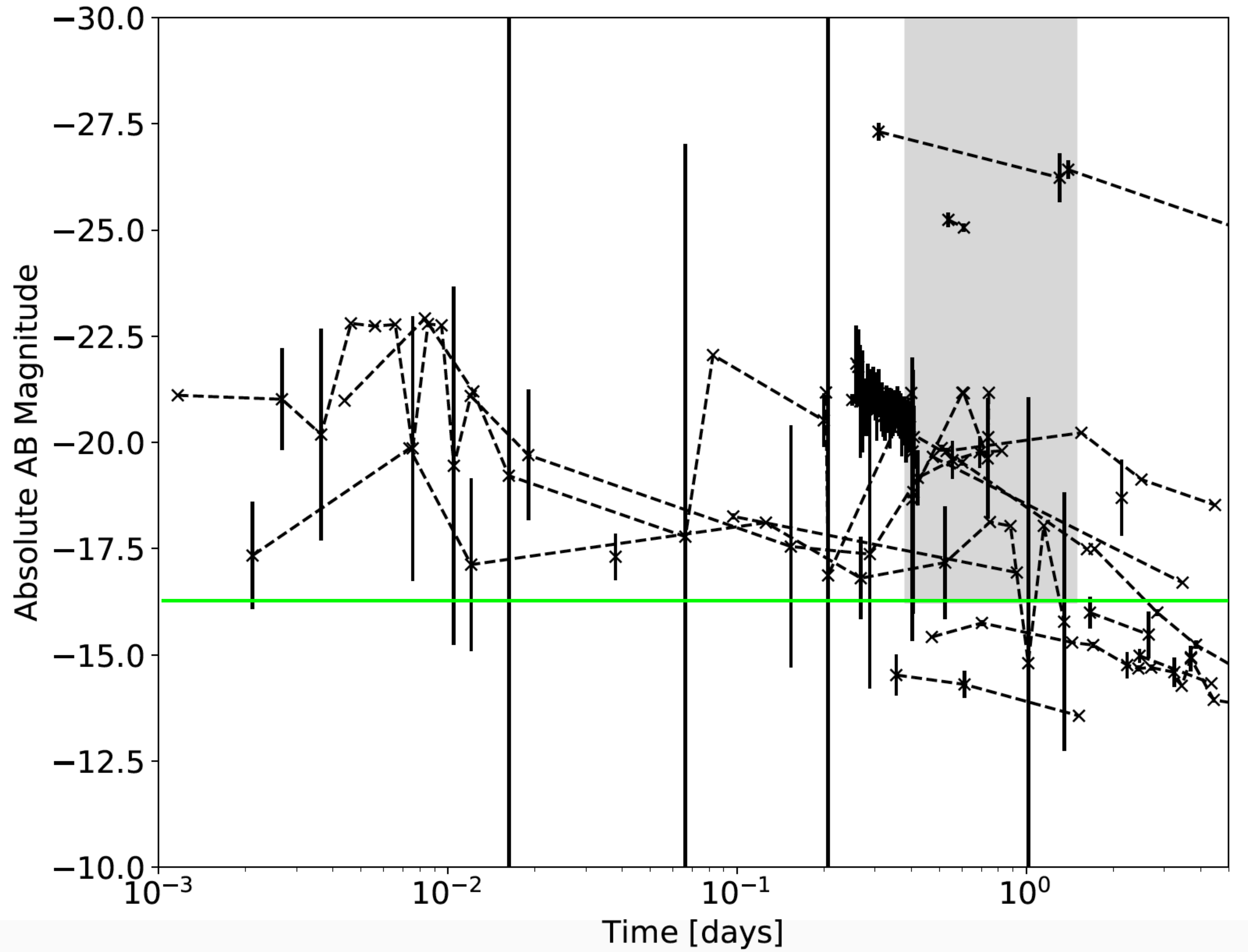
Network	N	N_1	N_{10}	N_{100}	M
HLV	48	0	16	48	19
HLVKI	48	0	48	48	7
1ET+2CE	990k	14k	410k	970k	12

The last few weeks…



with Ahumada, Andreoni, De, Kasliwal, Singer, and others

Non-detection limits



with Ahumada, Cenko, Ghosh, Kaplan and others

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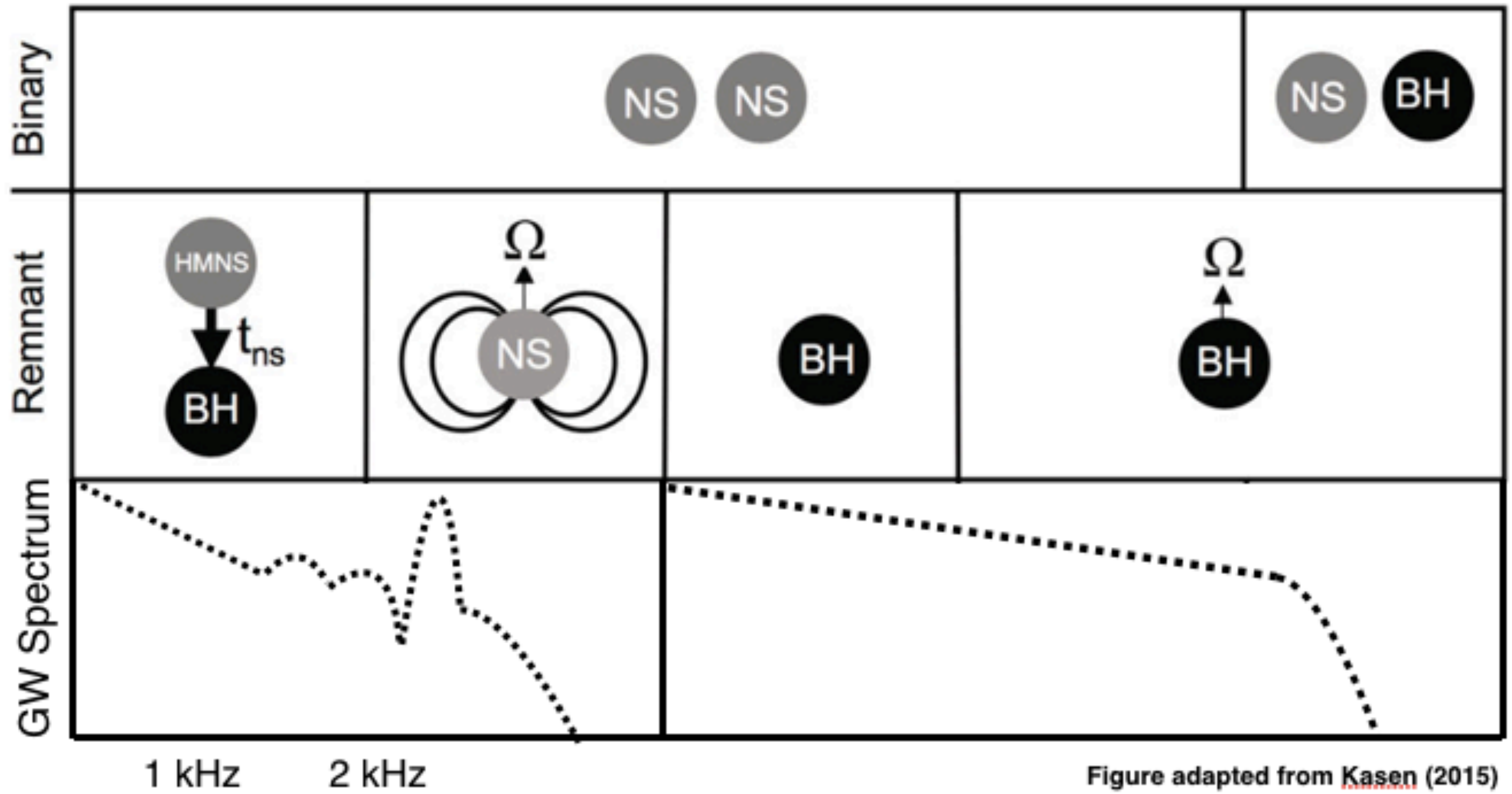
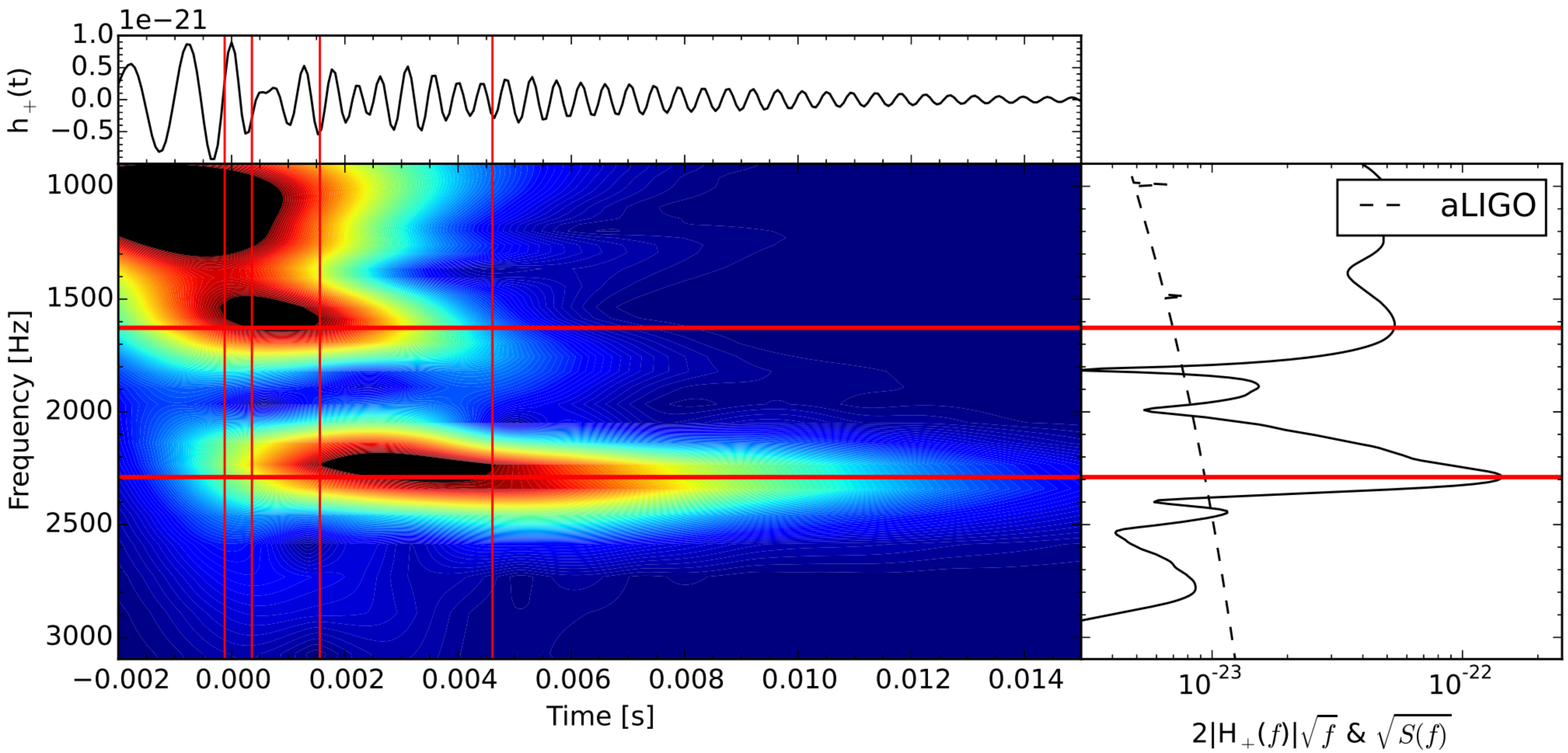
Neutron Star Remnants

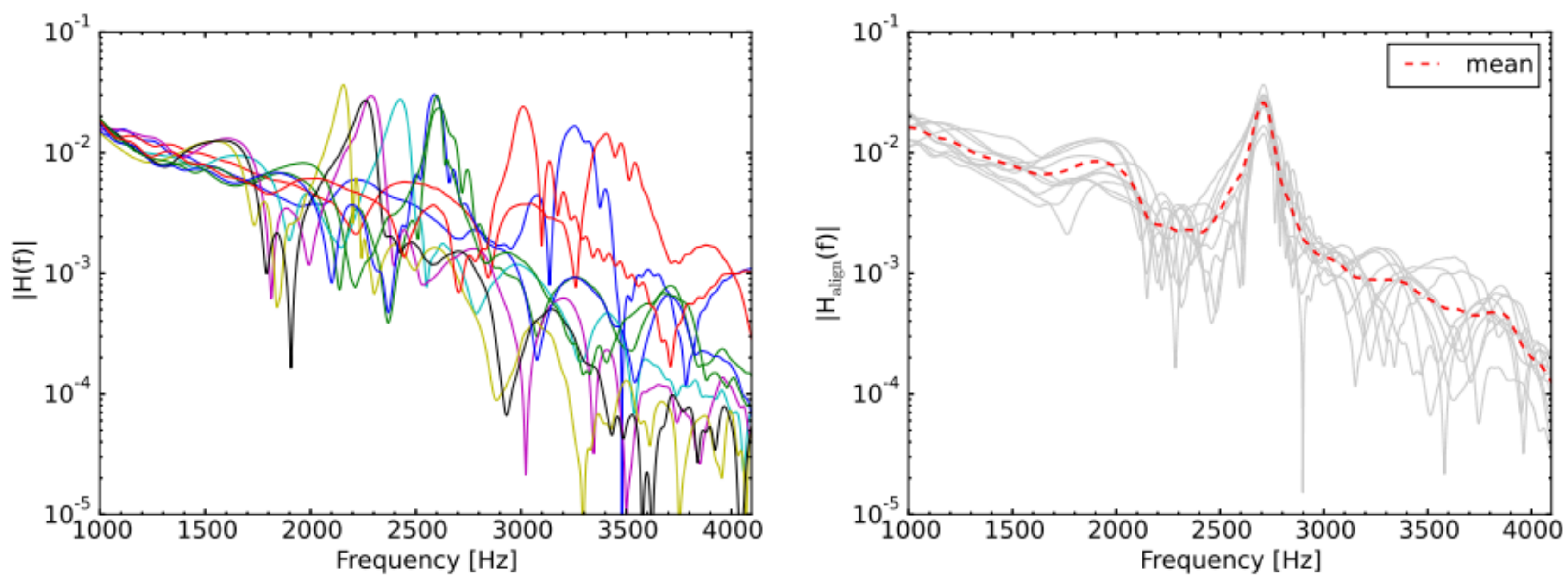
There are a variety of possibilities for post-merger scenarios, depending on the remnant mass and equation of state!



Can constrain the neutron-star equation of state as well as the initial compact binary that created the post-merger NS.

Post-merger searches

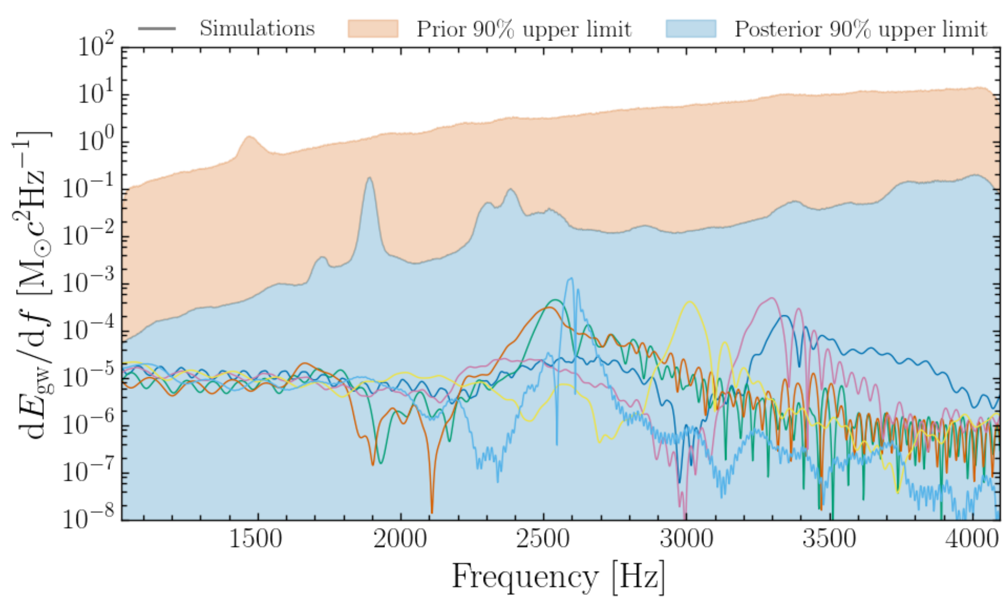




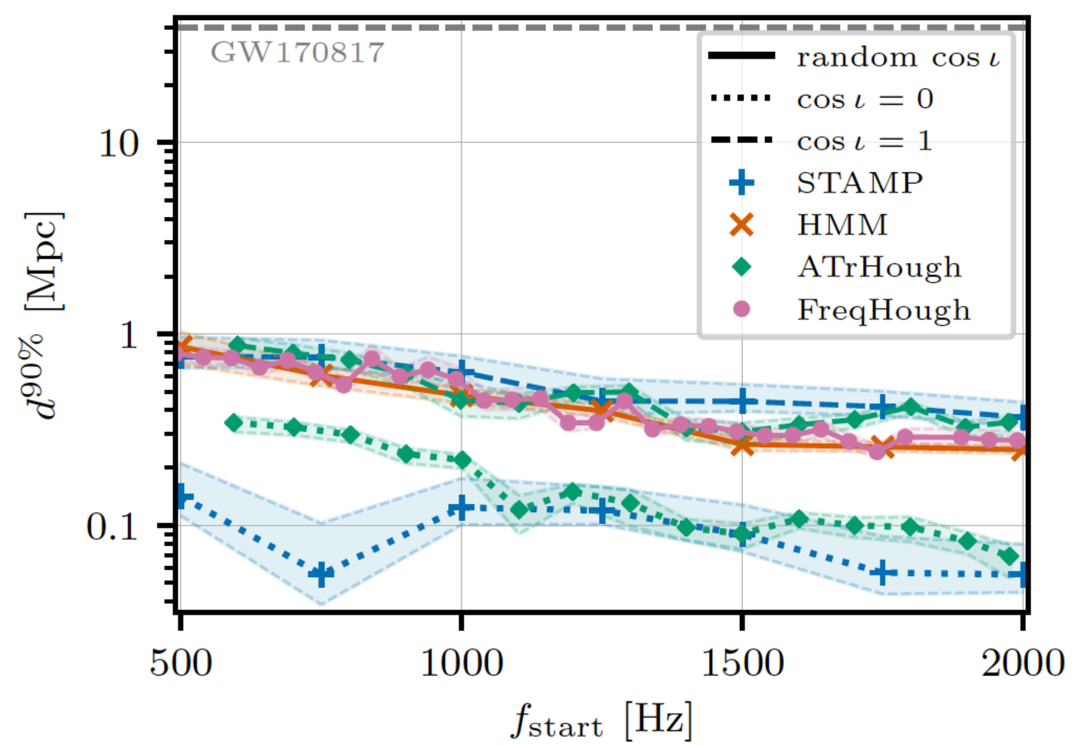
Clark et al. 2015

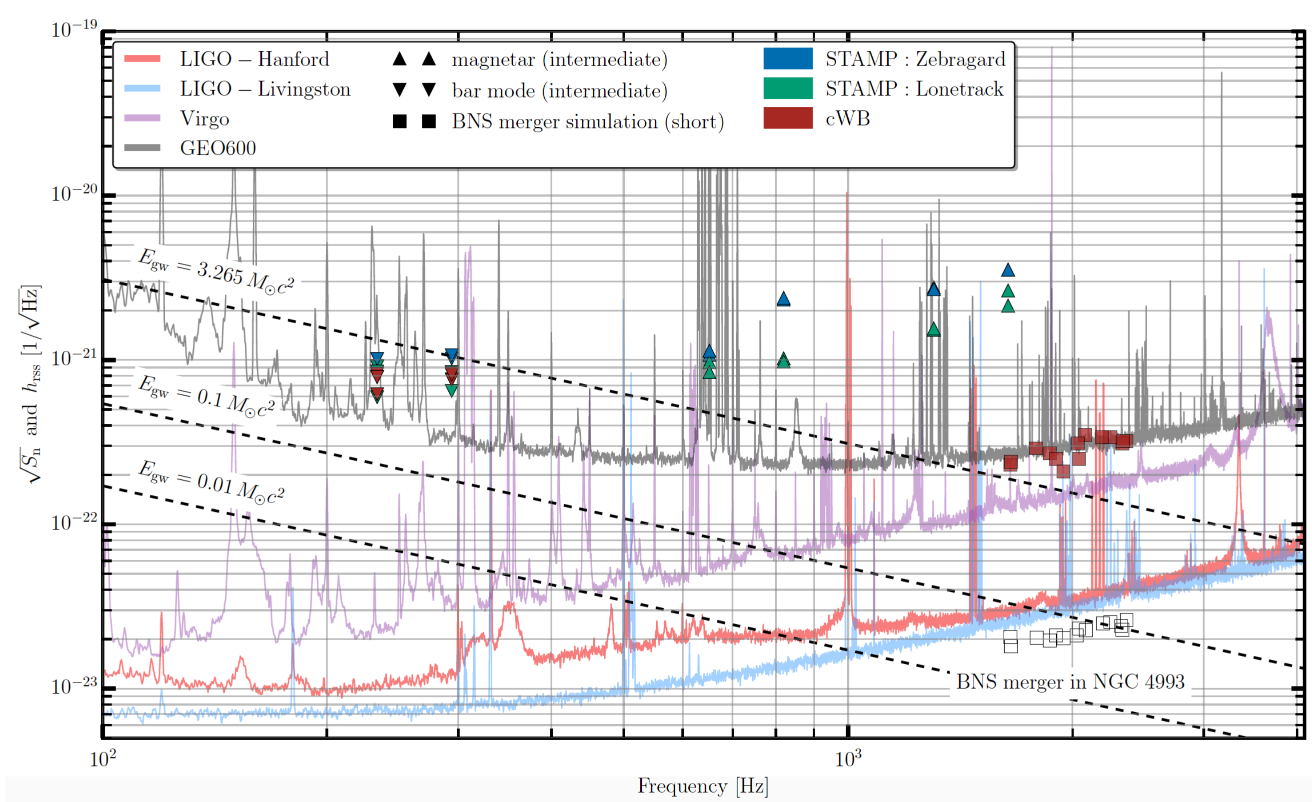
Post-merger searches

Short Duration: 10 - 100 ms



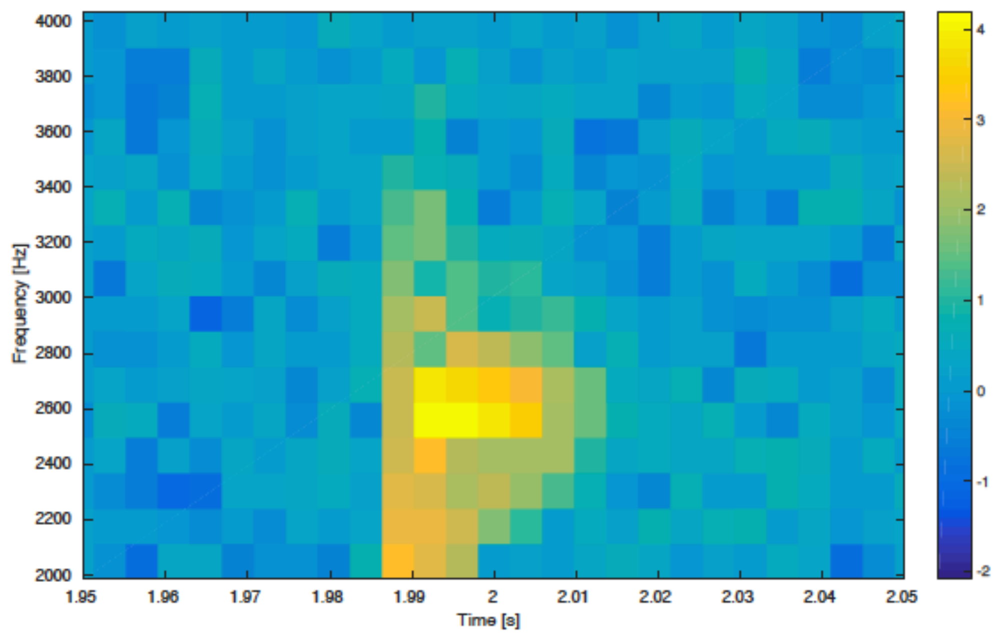
Long duration: 100 - 10,000 s

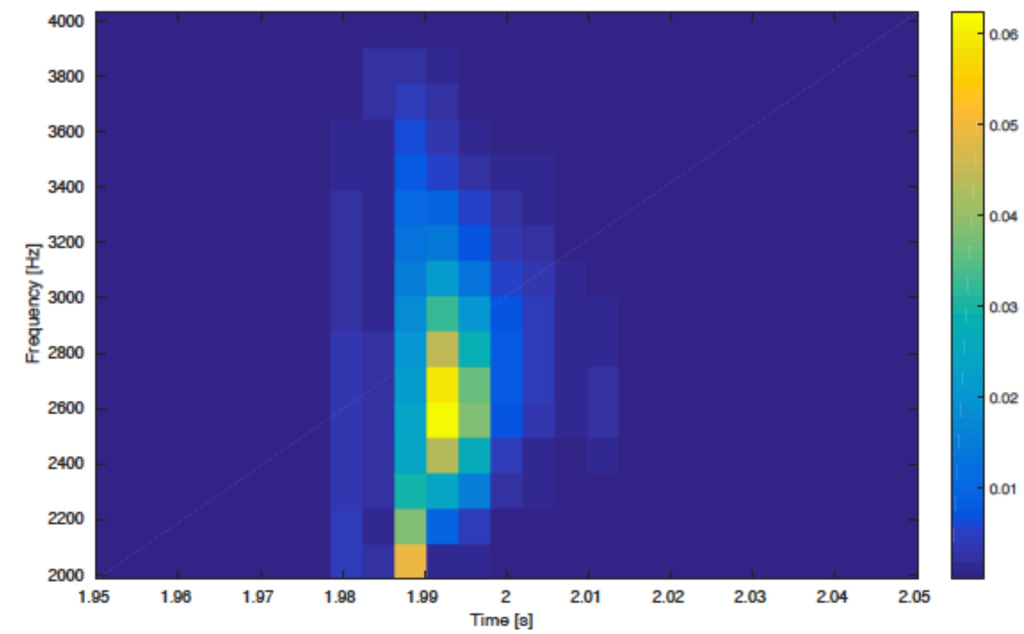




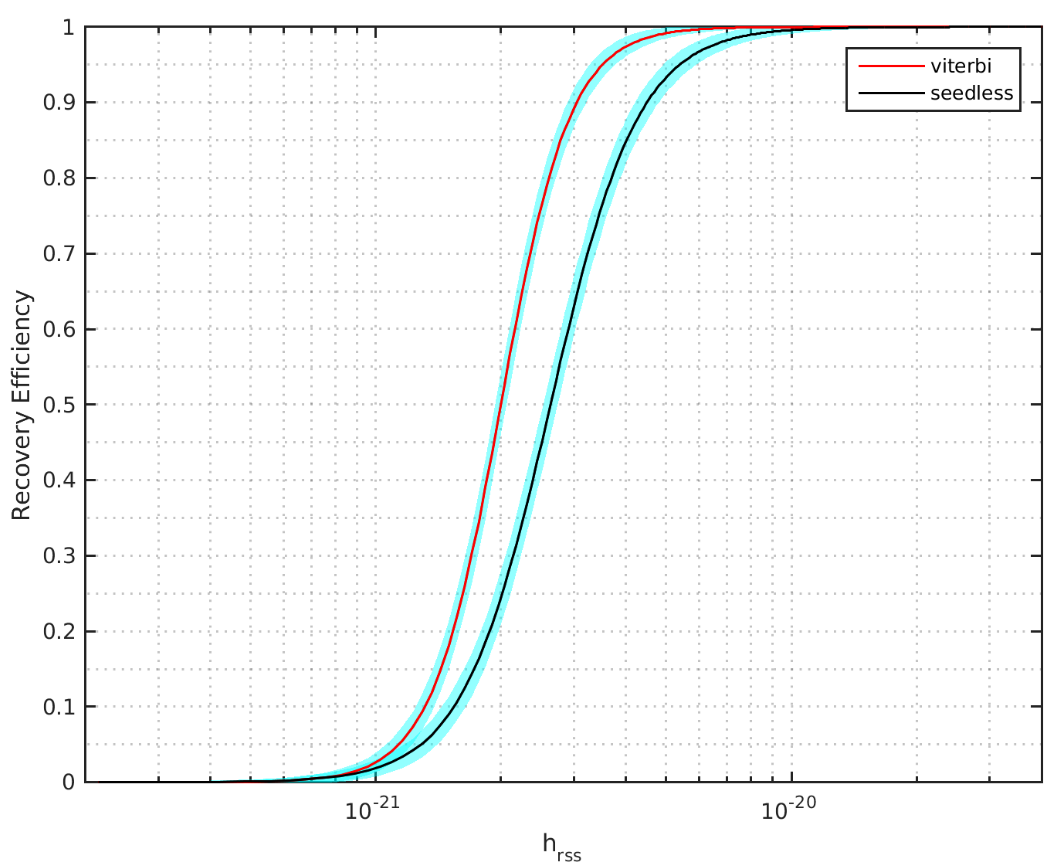
Intermediate Duration: 1 - 1000 s

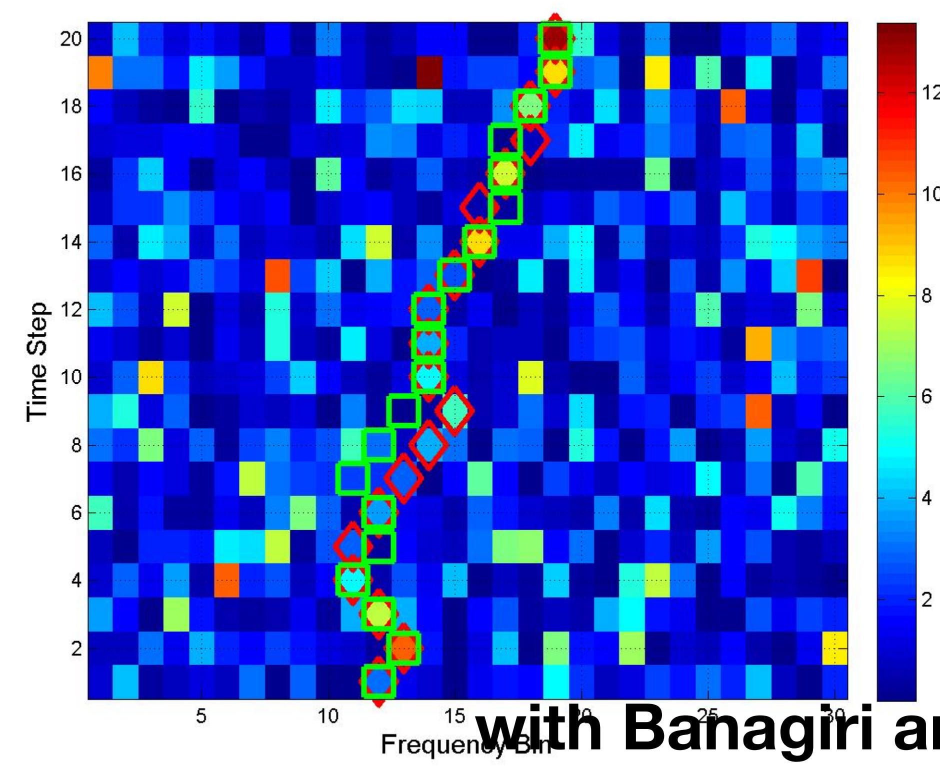
Improving the clustering





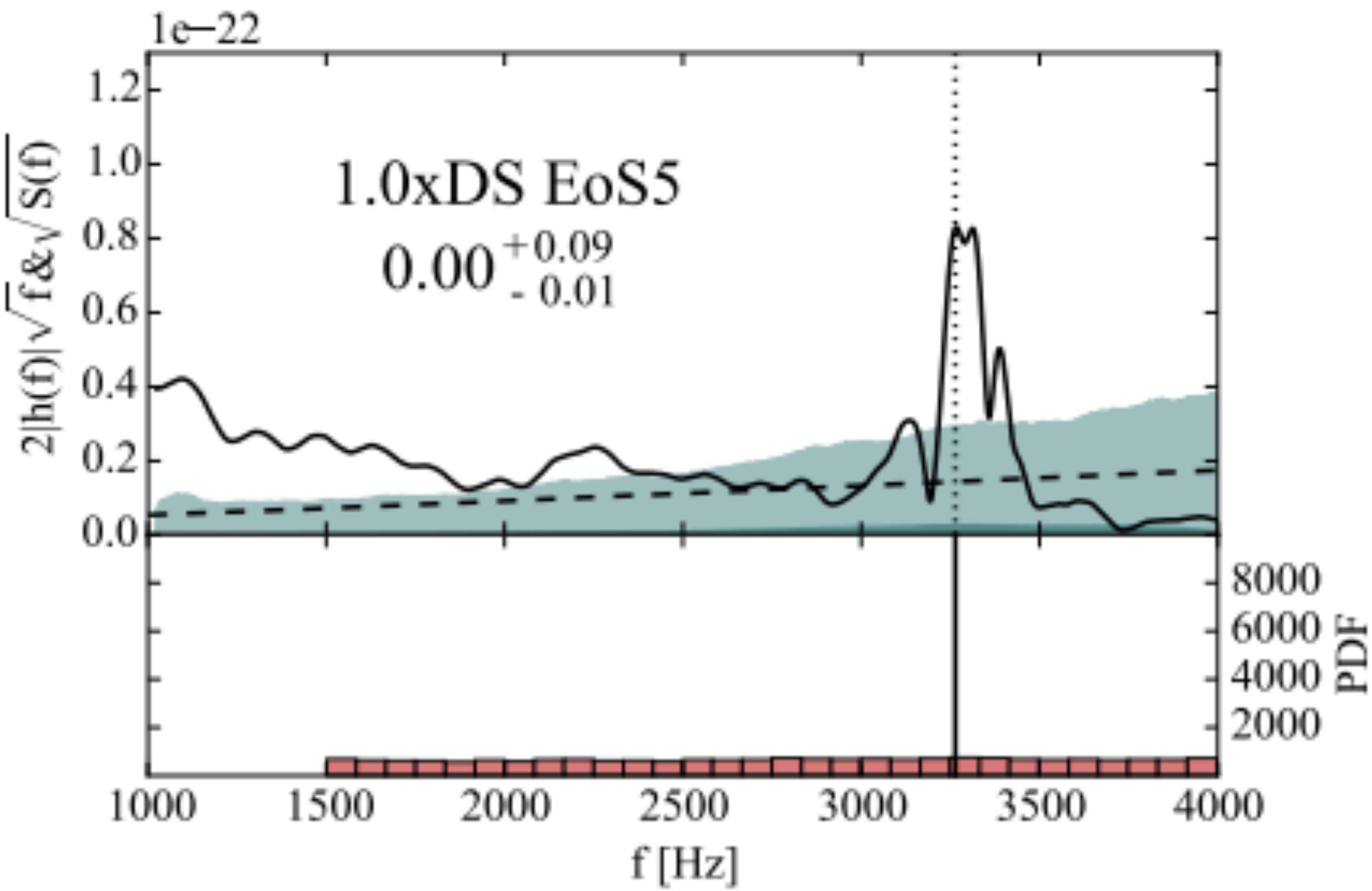
with Schale, Coughlin, Clark and Bauswein





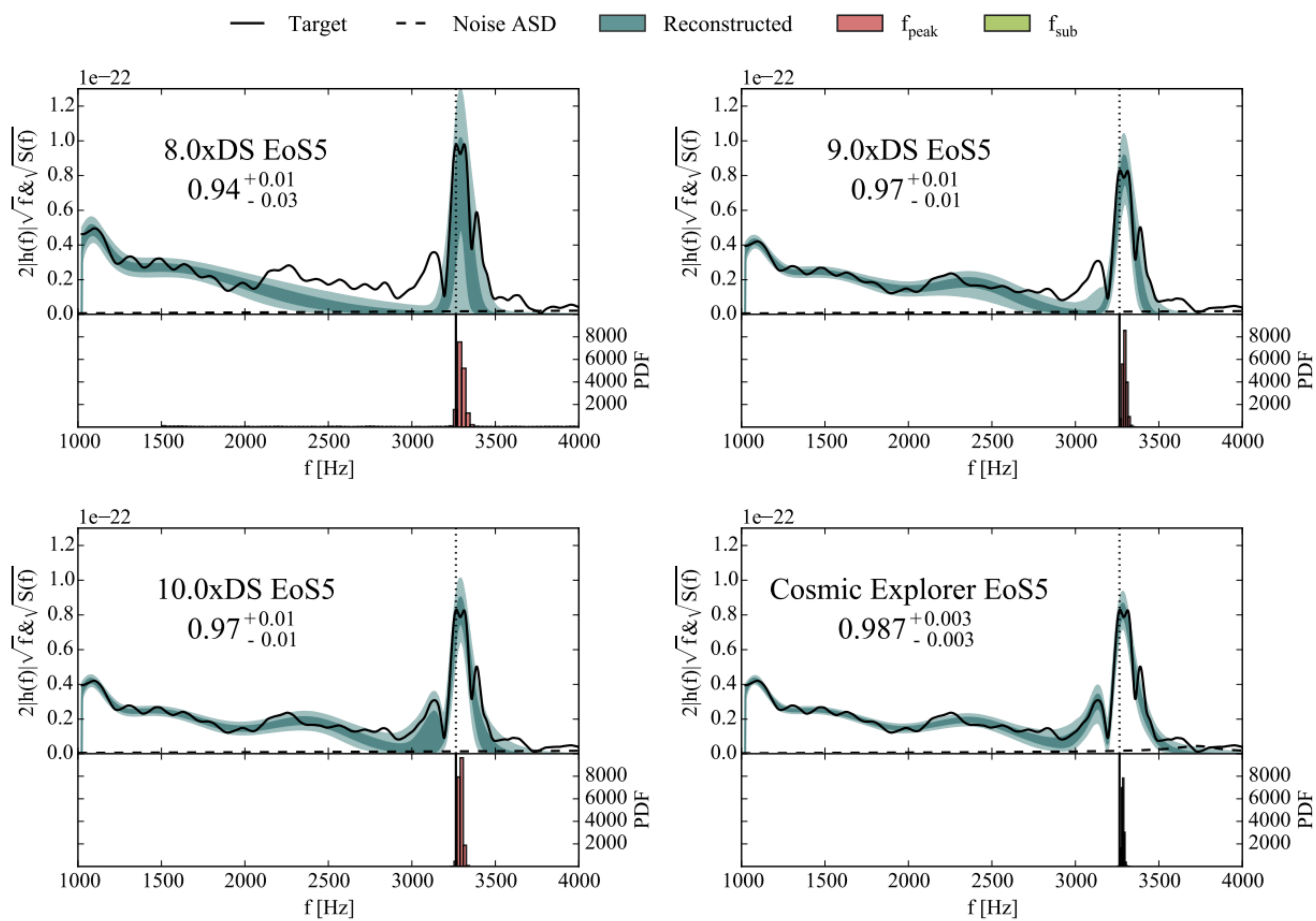
with Banagiri and Sun

Improving the detector



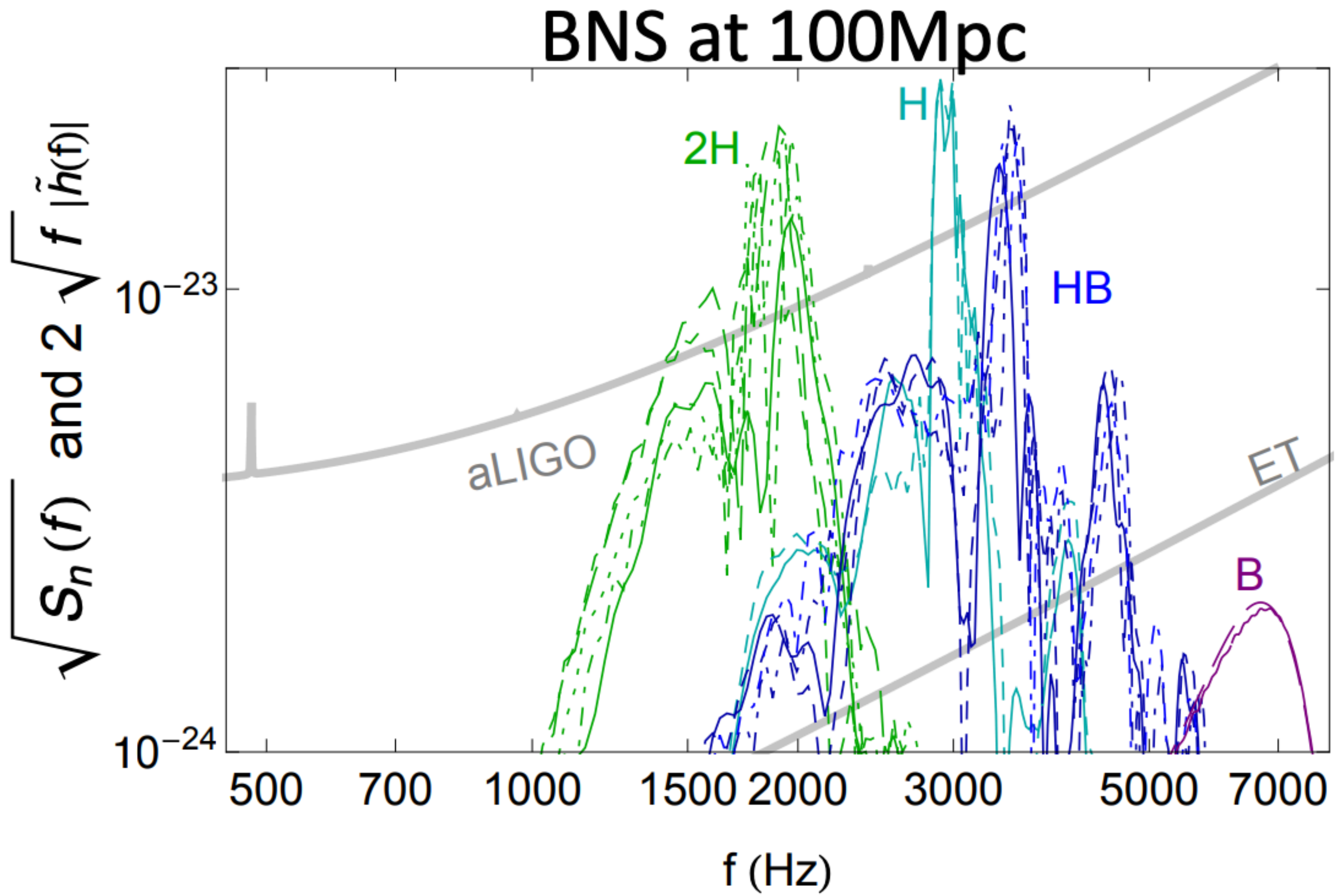
Torres-Rivas et al. 2019

Improving the detector



Torres-Rivas et al. 2019

Why GWs + NSs



3G detectors will…

- **Will constrain masses to about 0.1 M**
- **Will constrain radius to less than a kilometer**

Read et al. 2013

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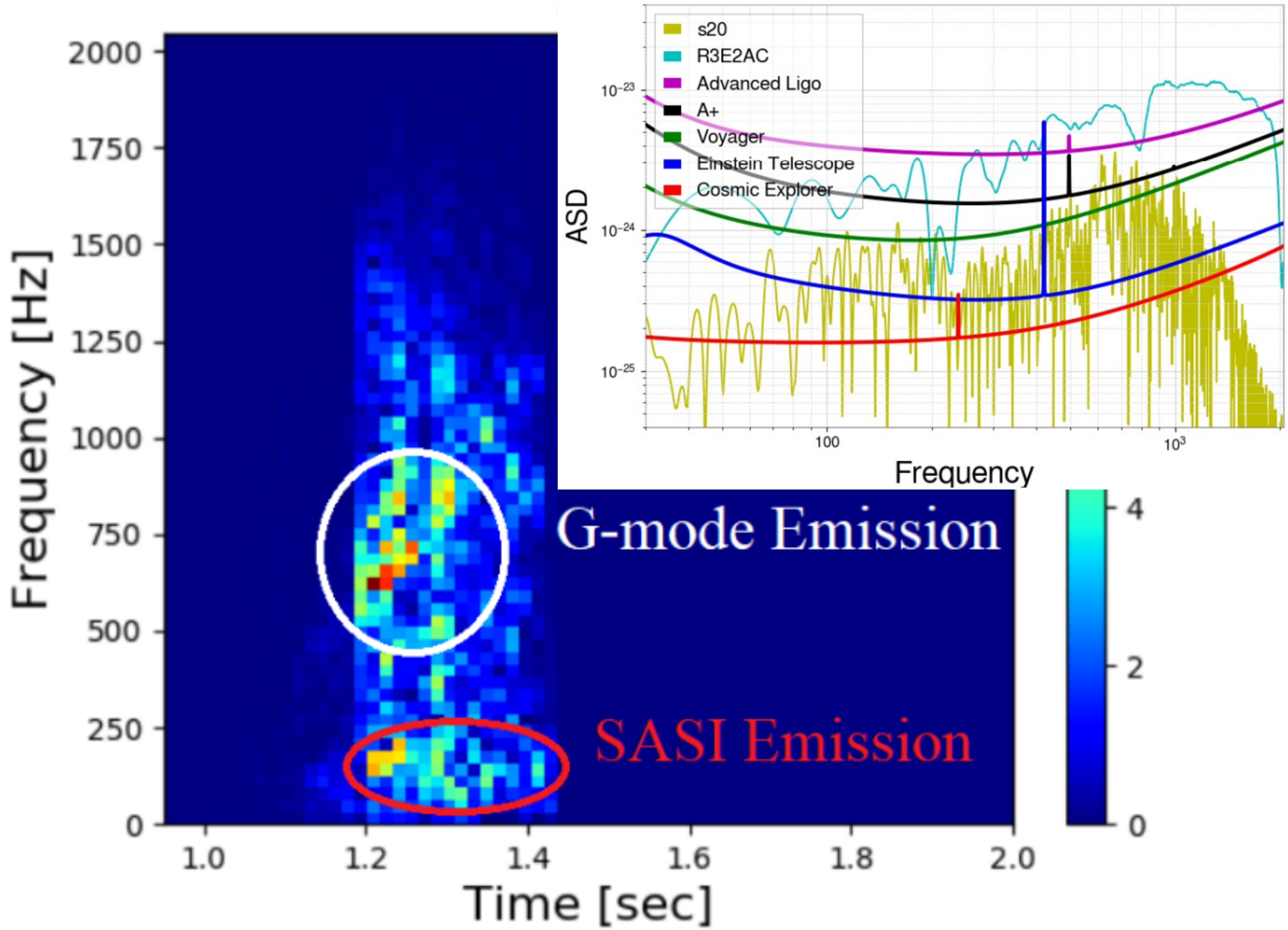
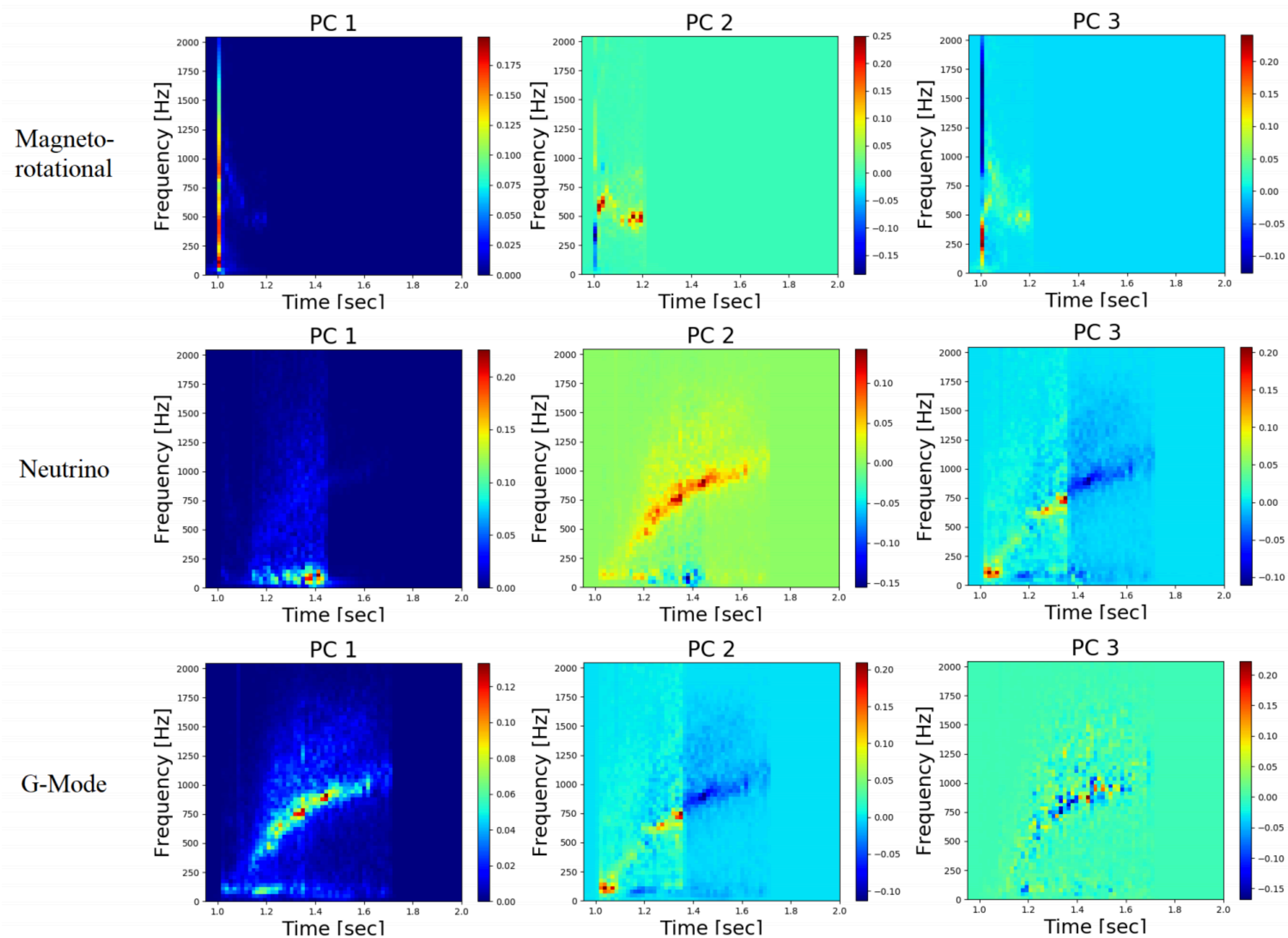
Inspired by Vicky and Sathya

Core-Collapse Supernovae



Roma et al. 2019

Core-Collapse Supernovae



Roma et al. 2019

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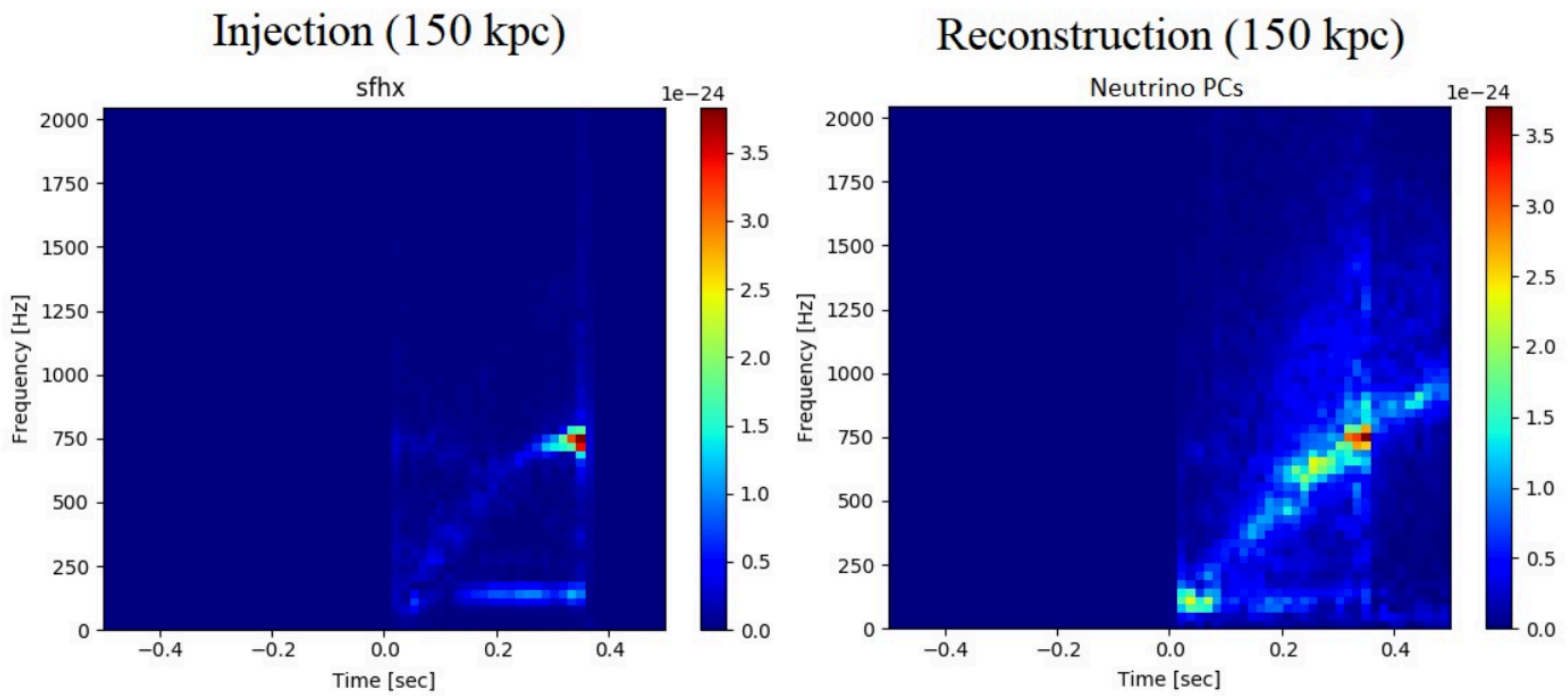

Roma et al. 2019

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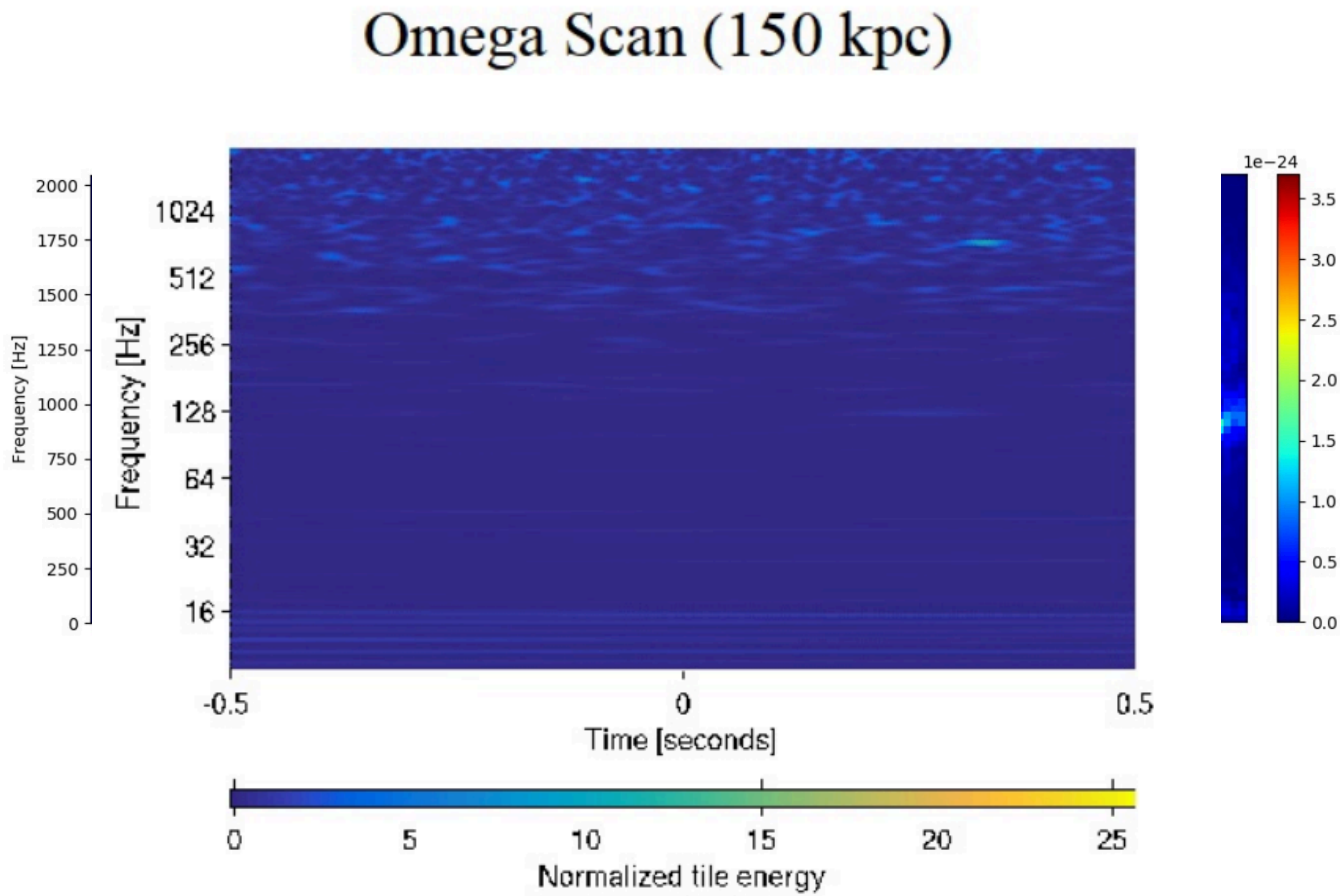

Roma et al. 2019

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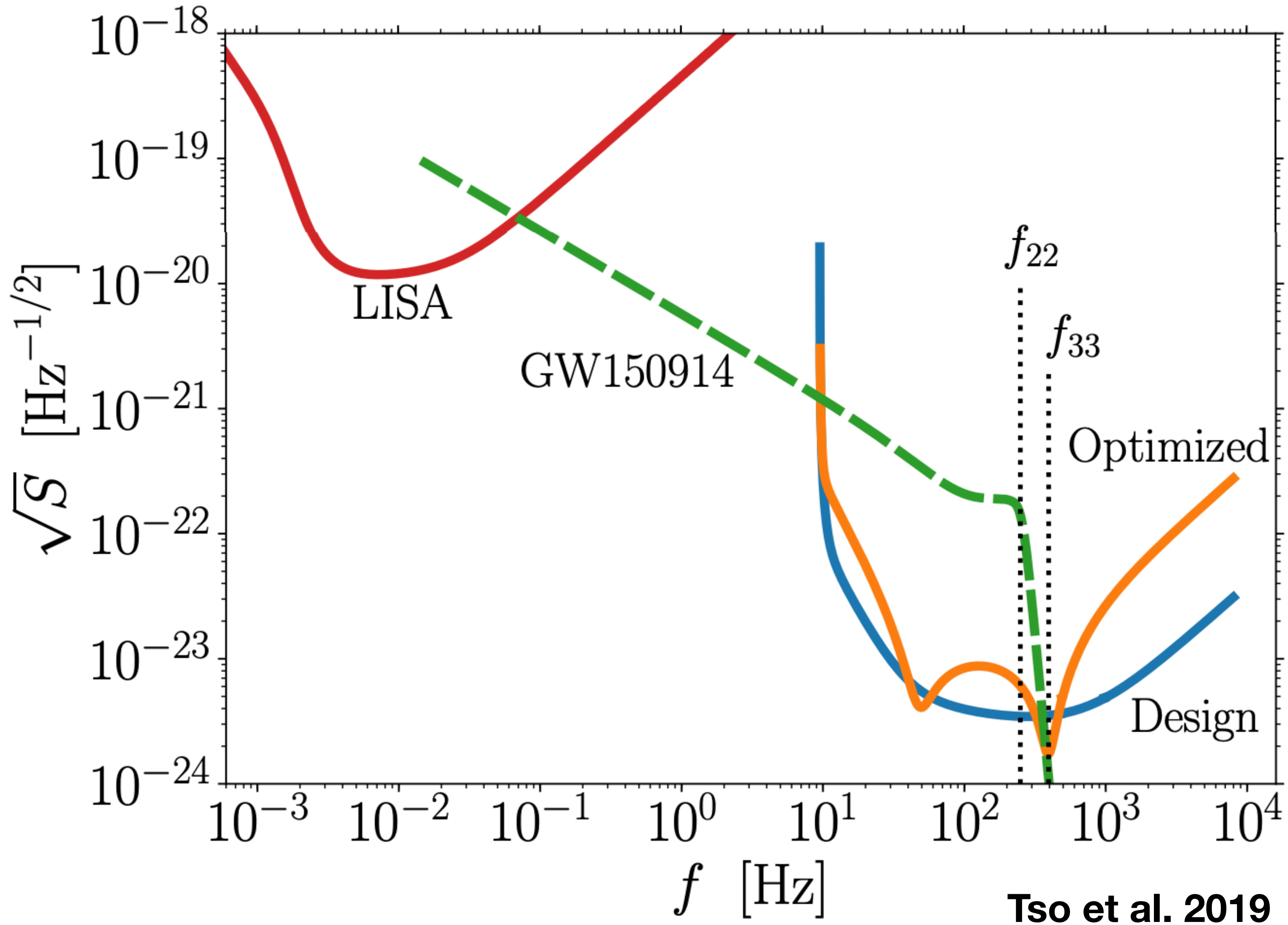
Black-Hole Spectroscopy



Tso et al. 2019

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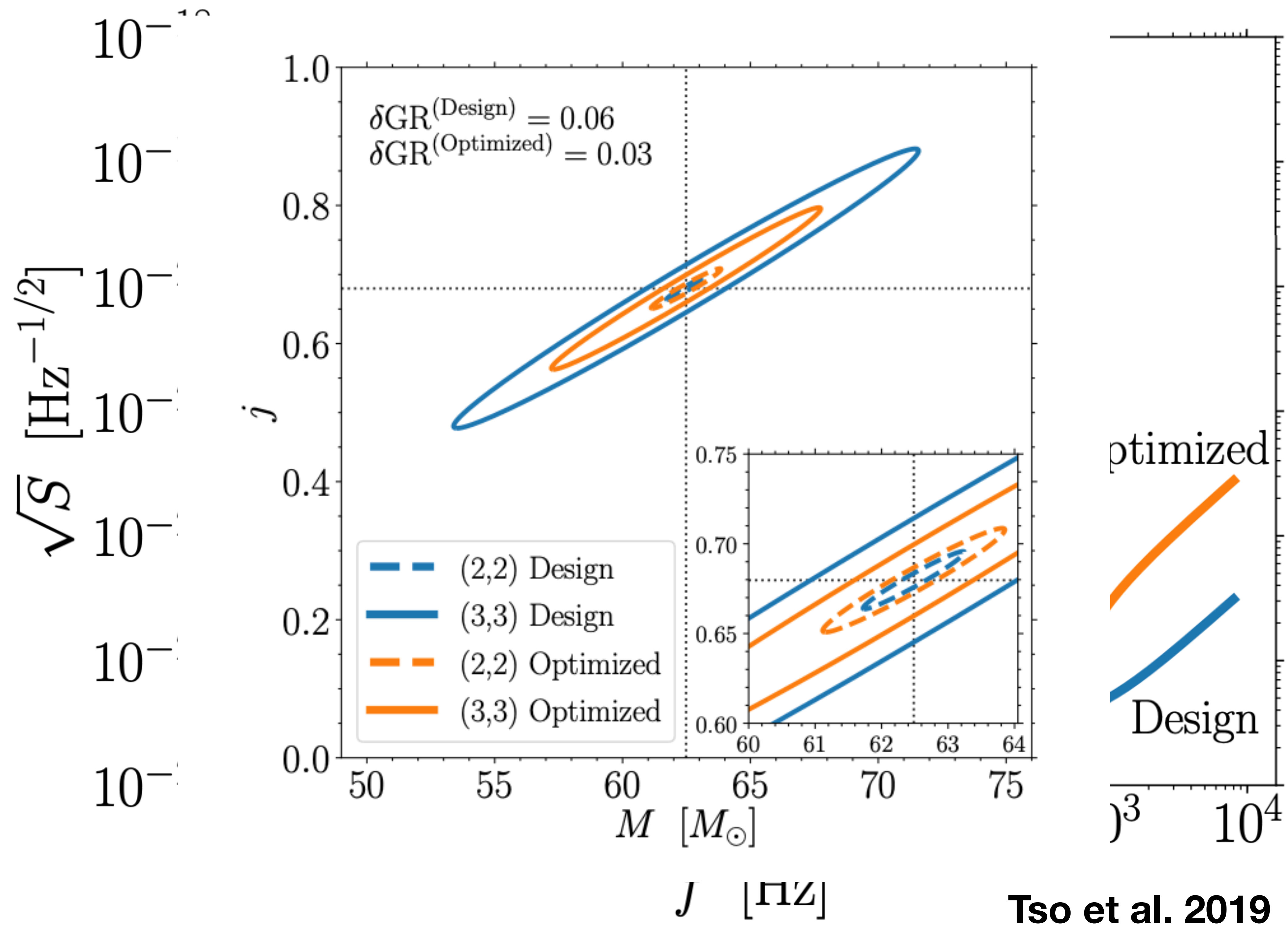
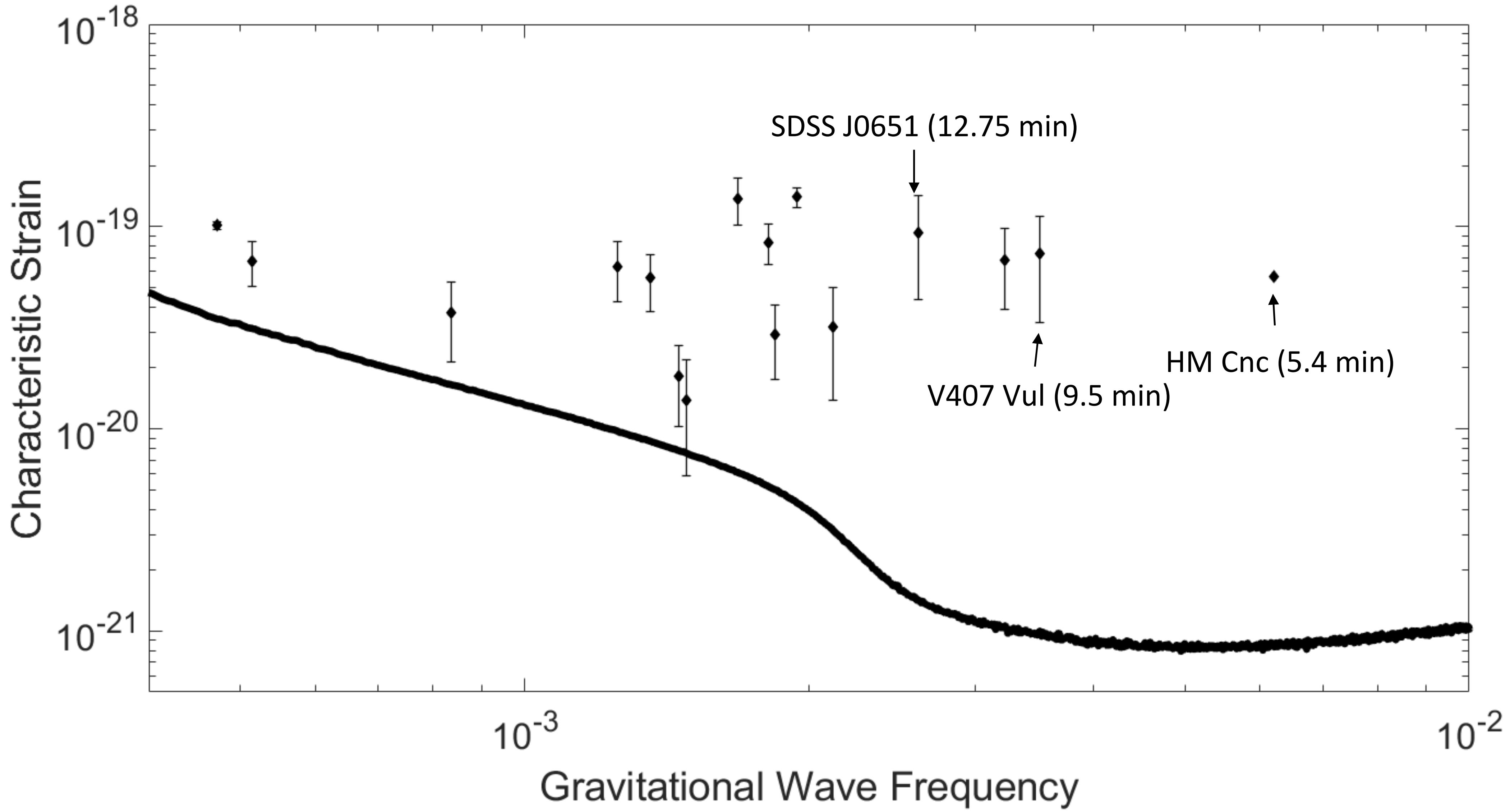


Tso et al. 2019

Another Analogy



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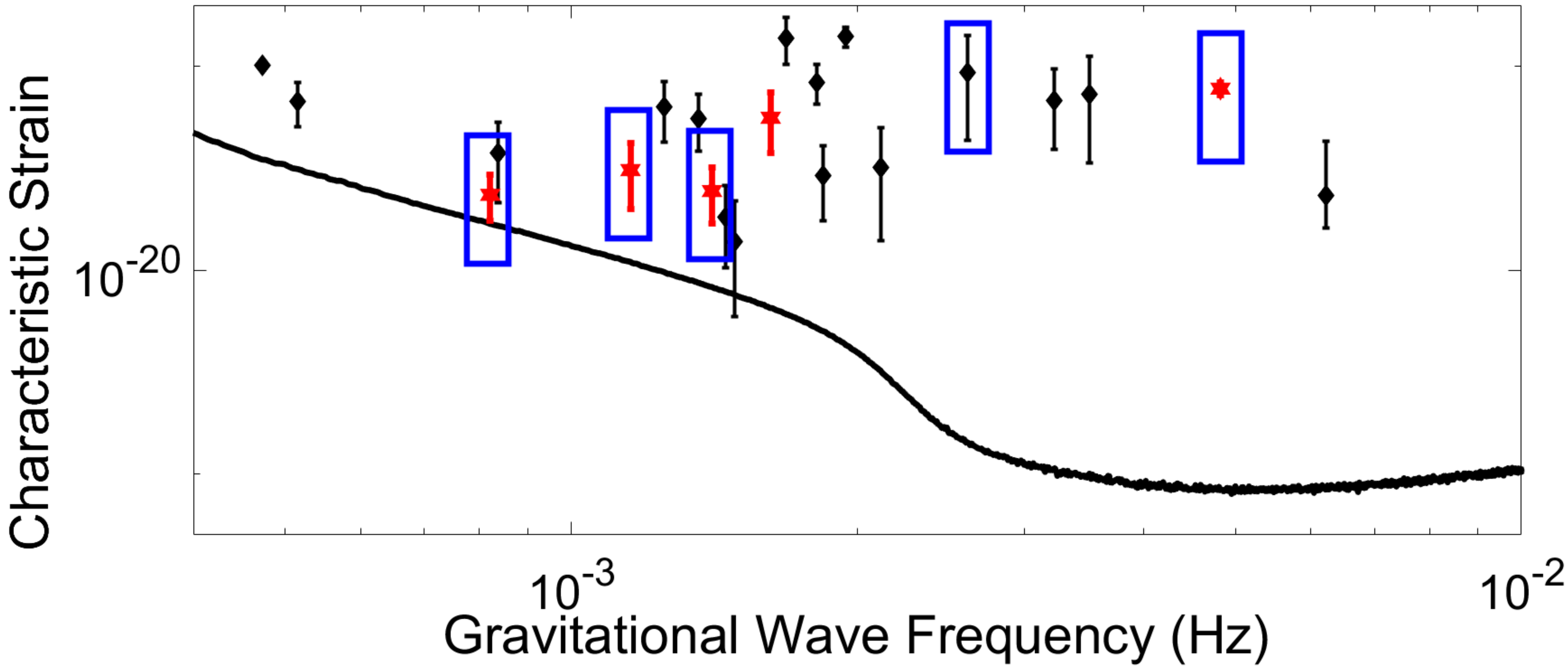

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The 3G Landscape

- Seed Black Holes
- Neutron Stars
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- Cosmology
- Do we know how to combine EM-GW data to extract the physics?
- Supernovae
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Inspired by Vicky and Sathya

The 3G Landscape

- Seed Black Holes
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- Large-scale parameter estimation , subtraction, and projection?
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The 3G Landscape

Seed Black Holes

Neutron Stars

Large-scale parameter estimation , subtraction, and projection?

Can unambiguous counterparts/hosts be *efficiently* identified?

Do we know how to combine EM-GW data to extract the physics?

Supernovae

Extreme Gravity

Waveform Models

Detector Networks

Inspired by Vicky and Sathya

The 3G Landscape

Seed Black Holes

Neutron Stars

Large-scale parameter estimation , subtraction, and projection?

Can unambiguous counterparts/hosts be *efficiently* identified?

Do we know how to combine EM-GW data to extract the physics?

More sophisticated analysis framewoks for GW bursts + astrophysical sources?

Extreme Gravity

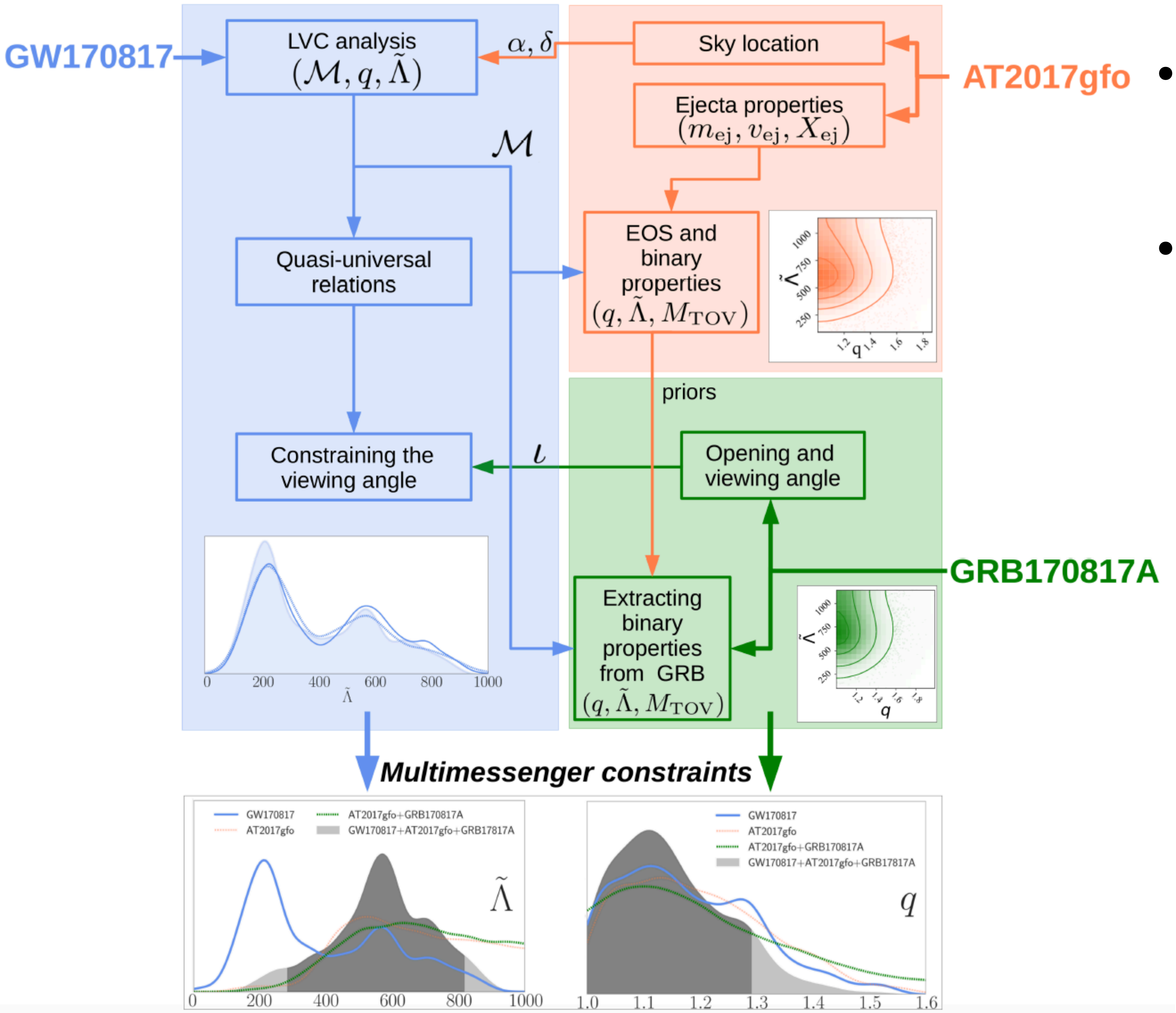
Waveform Models

Detector Networks

Inspired by Vicky and Sathya

Thank you!

Why GWs + NSs

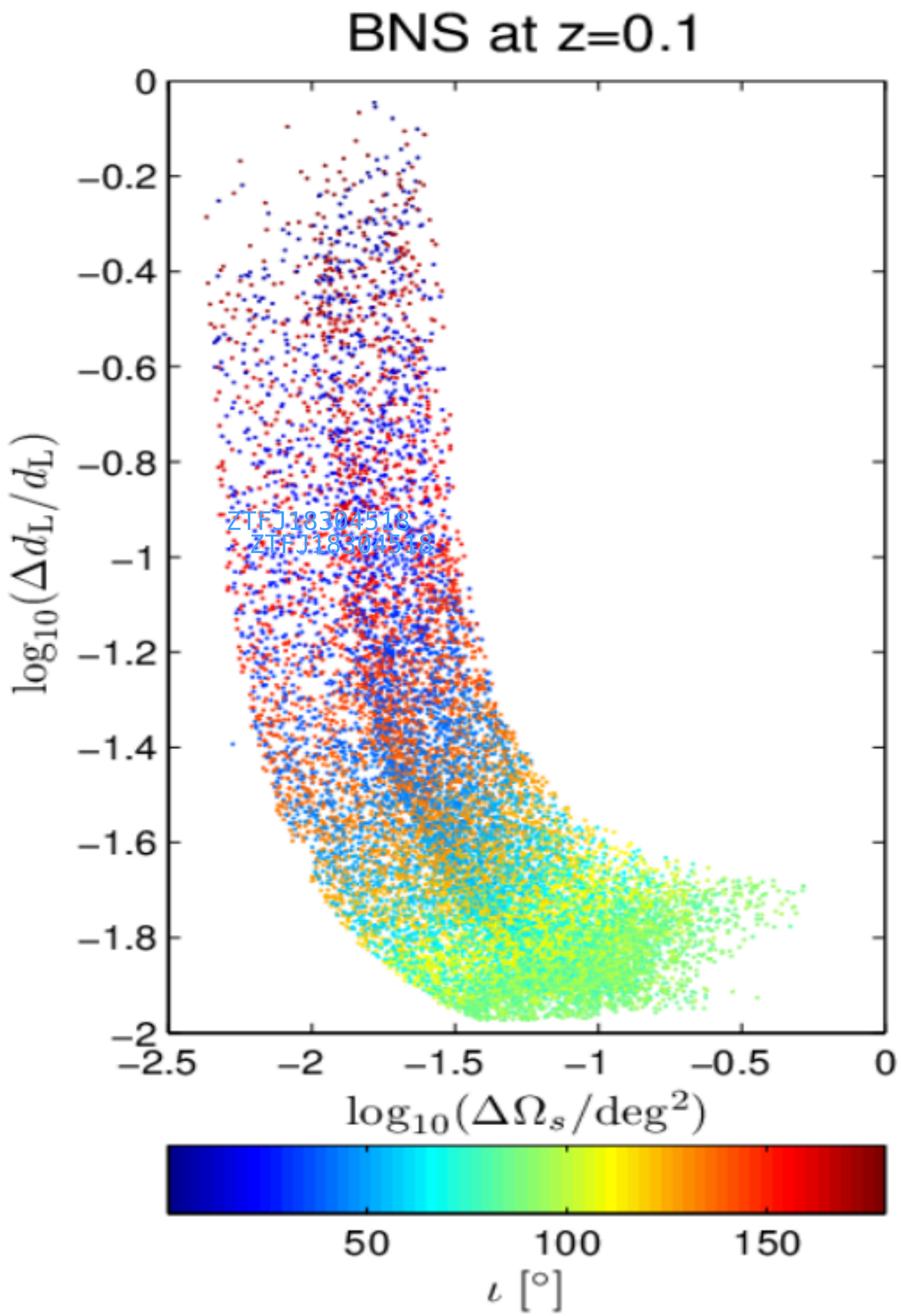


- $q \lesssim 1.29$ with 90% confidence.
- $279 \lesssim \Lambda \lesssim 822$ with 90% confidence

with Dietrich, Margalit and Metzger

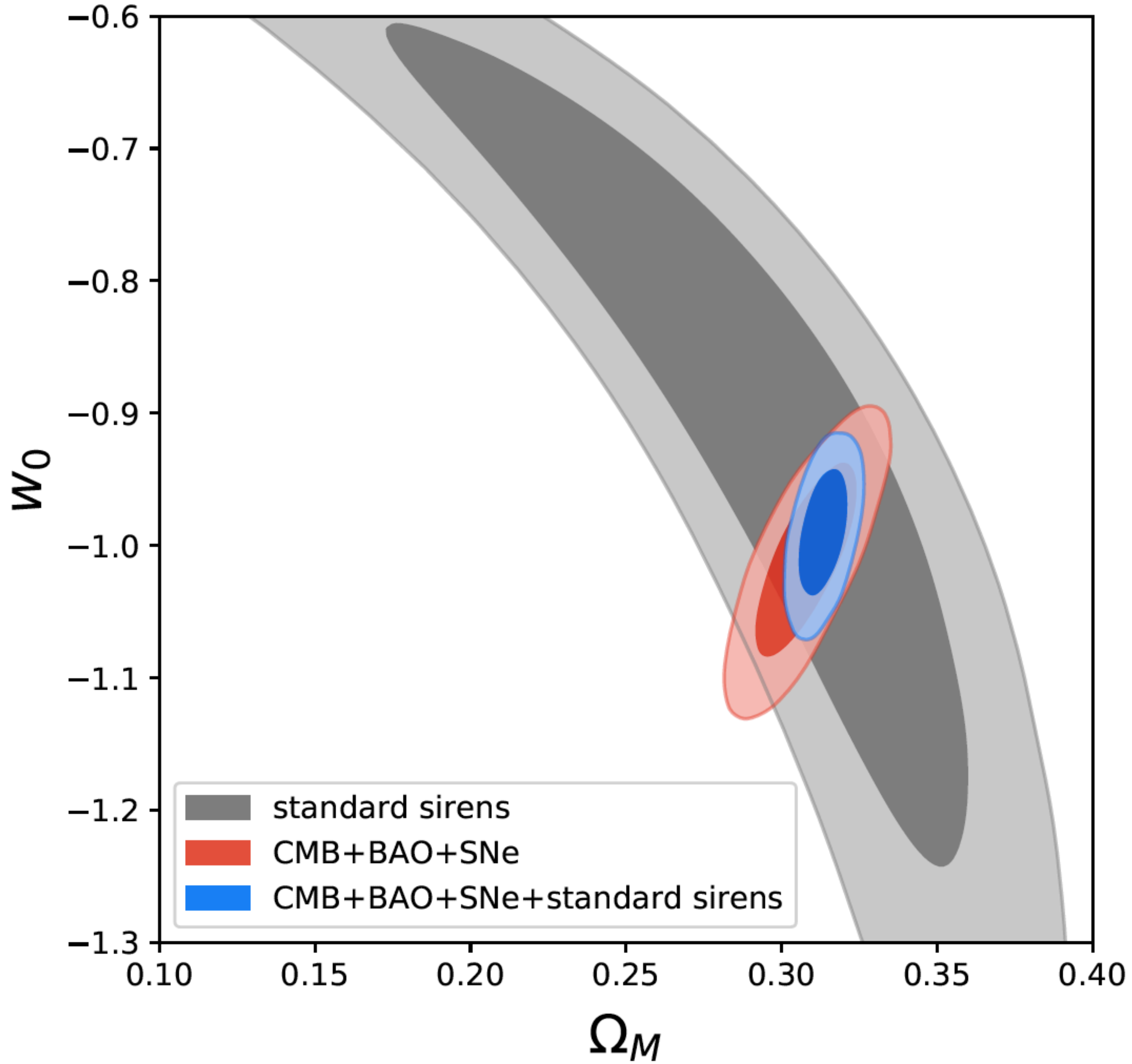
Localization Prospects

Network	CE-ET	3CE
Detected	34000	47000
Localized	12000	40000
Within 1 de	920	1400
Within 10 d	7800	16000
Within 100 (	11000	36000
Median Area (	-	17
Single Pat	97%	89%



Zhao and Wen 2018

Localization Prospects



WP: COSMOLOGY AND THE EARLY UNIVERSE 2019

Localization Prospects

Table 2: Present (*P*) and future (*F*) electromagnetic facilities that are able to observe faint/distant counterparts to GWs. Detection Limit (**DL**, 1 hr exposure time) for UV, optical, and near-IR facilities are expressed in AB magnitudes, for X-rays in $10^{-16}\,\mathrm{erg\,s^{-1}\,cm^{2}}$, and for radio in μJy. Distance reach (**D** in Mpc) of facilities for GW170817-like events are shown.

	Facility	**DL**	**D**
Gamma-rays	*Fermi P*	S/N 5	80
	AMEGO *F*	S/N 5	130
X-rays	*Swift P*	S/N 5	~80
	Chandra P	30	150
	ATHENA *F*	3	480
	Lynx F	6	450
	STROBE-X *F*	S/N 5	120
UV	HST (im) *P*	26	2000
	HST (spec) *P*	23	400
Optical Imaging	Subaru *P*	27	3200
	LSST *F*	27	3200
Optical Spec.	Keck/VLT	23	500
	GMT *F*	25	1265
	TMT *F*	25.5	1592
	E-ELT *F*	26	2005
Infrared Imaging	WFIRST *F*	27.5	4800
	Euclid *F*	25.2	1700
Infrared Spec.	Keck/VLT	21.5	481
	GMT *F*	23.5	762
	TMT *F*	24	960
	E-ELT *F*	24.5	1208
Radio	VLA (S) *P*	5	91
	ATCA (CX) *P*	42	51
	ngVLA (S) *F*	1.5	353
	SKA-mid (L) *F*	0.72	634

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The white paper by Margutti et al, "Target of Opportunity Observations of Gravitational Wave Events with LSST", estimates that effective follow-up of LIGO-Virgo events with LSST will require roughly 85 hours per year, about 2% of the total available time. The SAC recommends that an OpSim experiment incorporate ToOs from gravitational wave triggers as outlined in Margutti et al. We note that this white paper was written prior to LIGO-Virgo's third observing run. Given the success of the first month of this new run, including two neutron star merger alerts within 30 hours, estimates of the kilonova rates, luminosity, timescales, colors, and positional uncertainties could change substantially over the next year. The SAC recommends re-visiting the assumptions made in this white paper in six to twelve months.

	HST (spec) P	23	400
Optical Imaging	Subaru P	27	3200
	LSST F	27	3200

Radio	VLA (S) P	5	91
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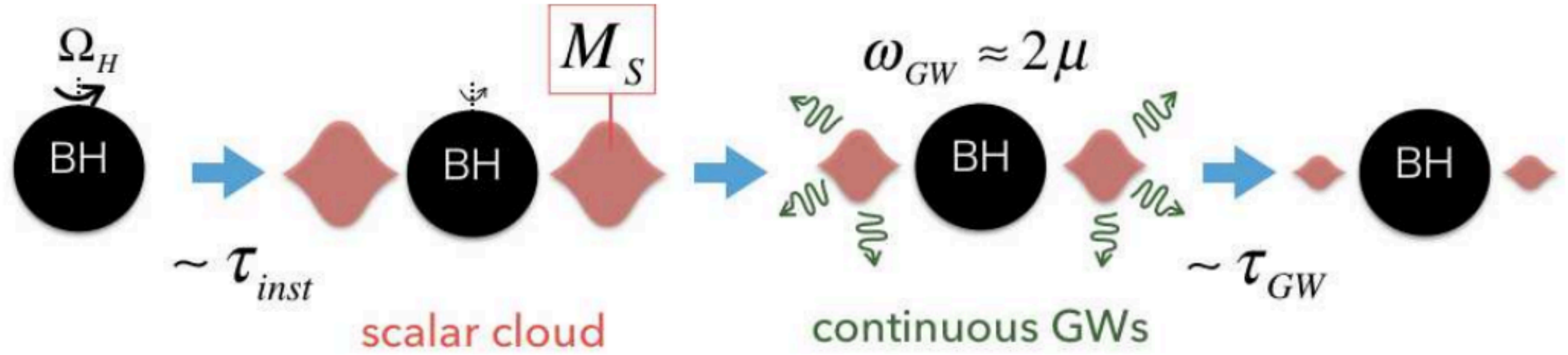
Axions

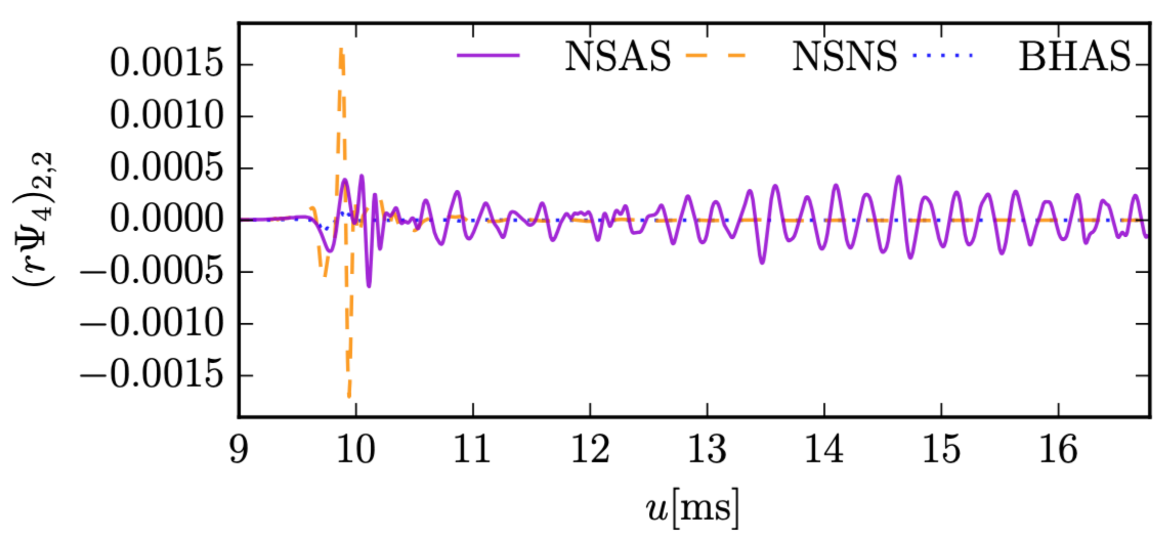
Axions are proposed ultralight bosons that can extend the standard model and could be viable dark-matter candidates

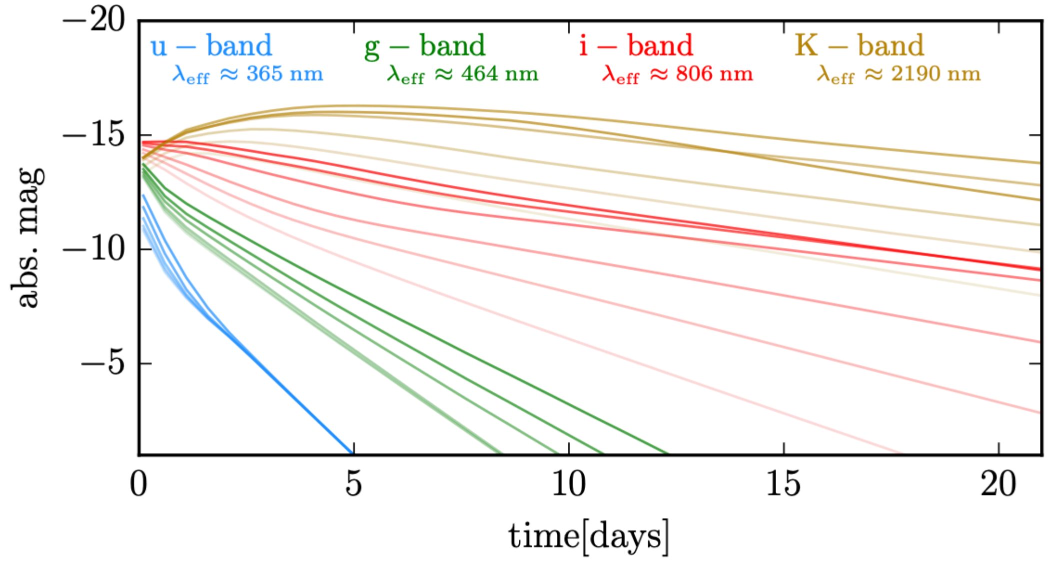
Clouds



Tsukada et al. 2019

Mergers

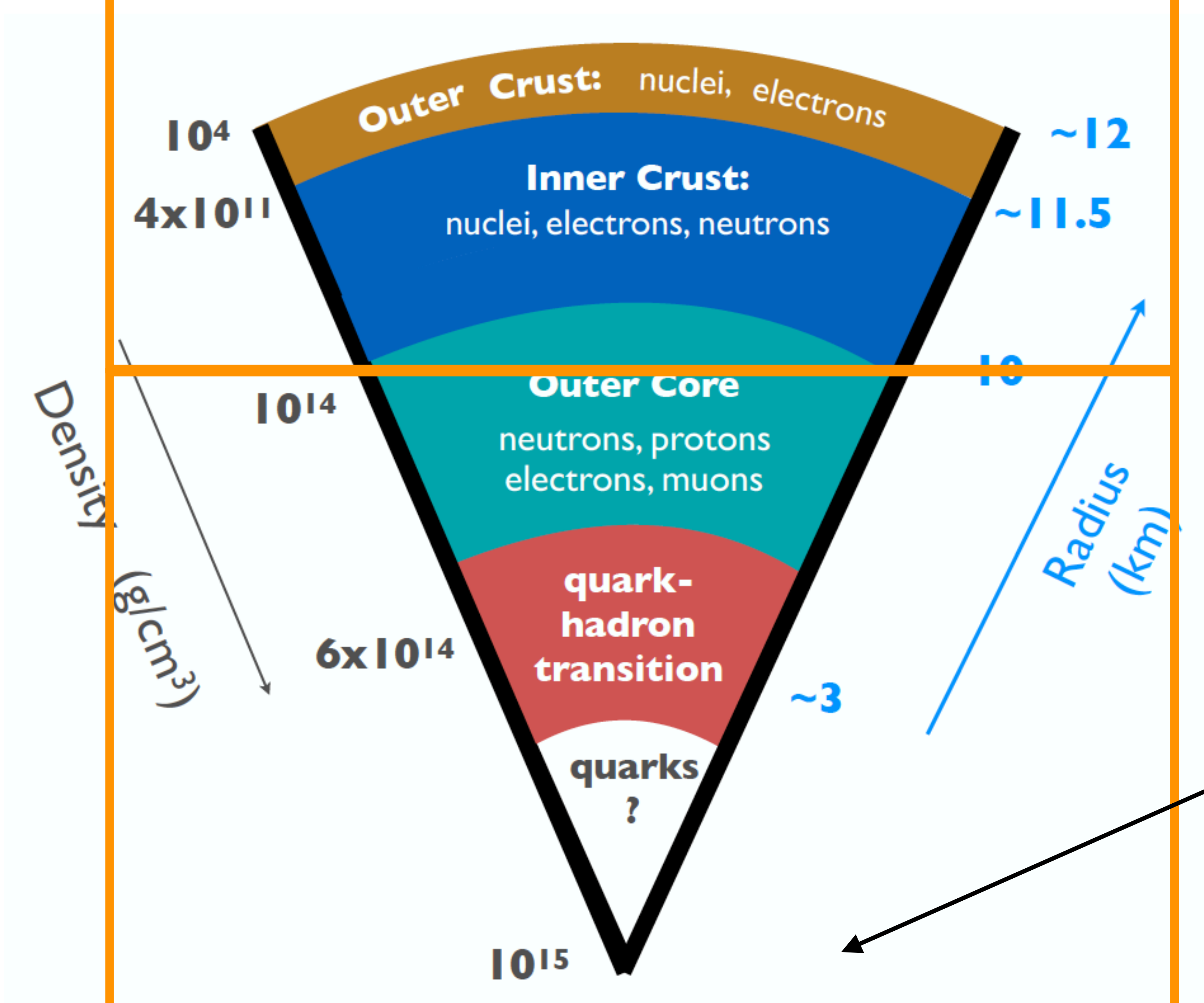




Dietrich et al. 2019

NS Matter

Low Mass NSs



High Mass NSs

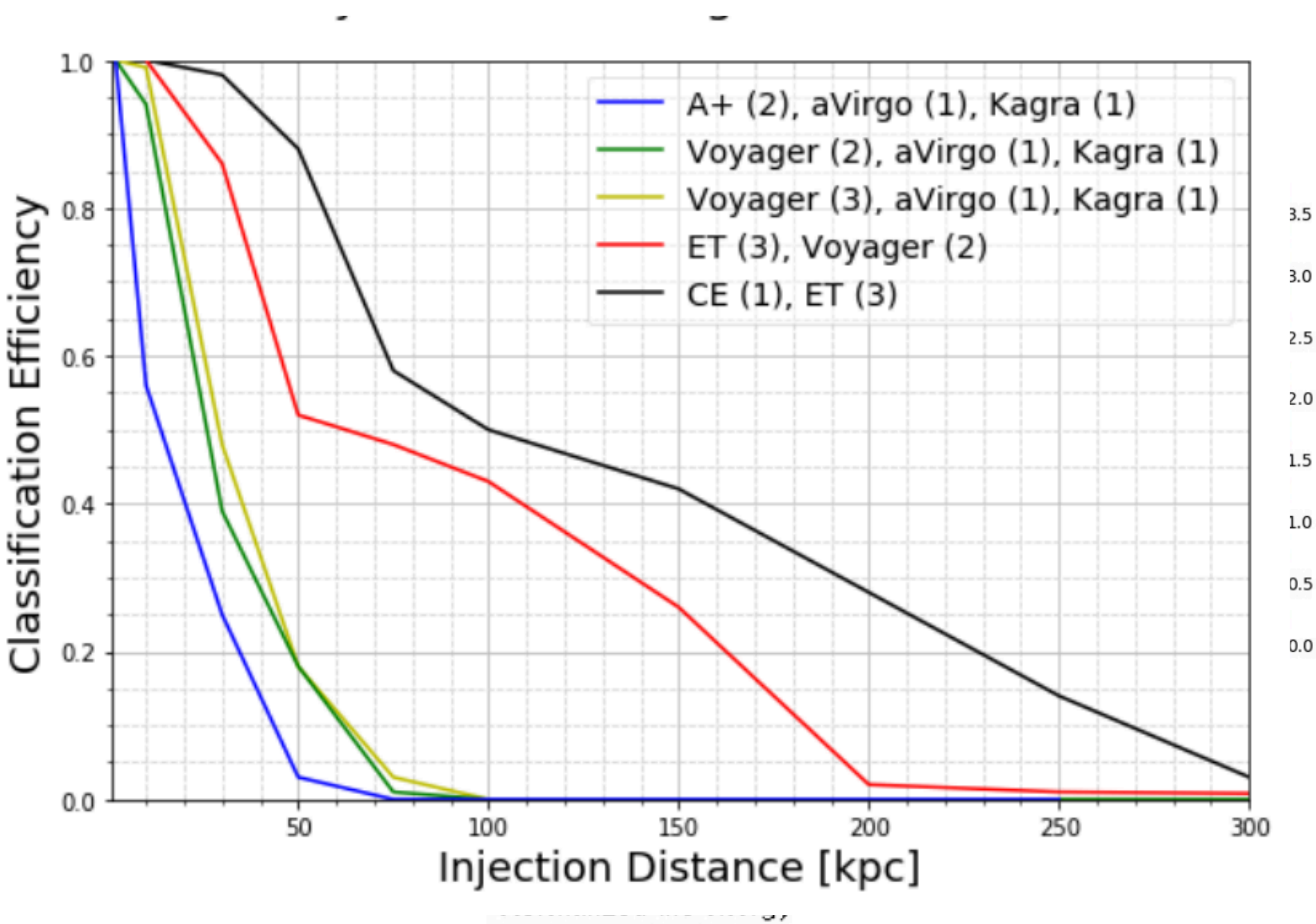
Effect of EOS on GWs

- rotational deformations
- various kinds of tidal interactions including the excitation of internal oscillation modes
- spin-tidal couplings
- the presence of a hard surface / crust

NS J0348+0432:
M about 2 solar masses
BUT…
X-rays are hard to model so not much radius information.

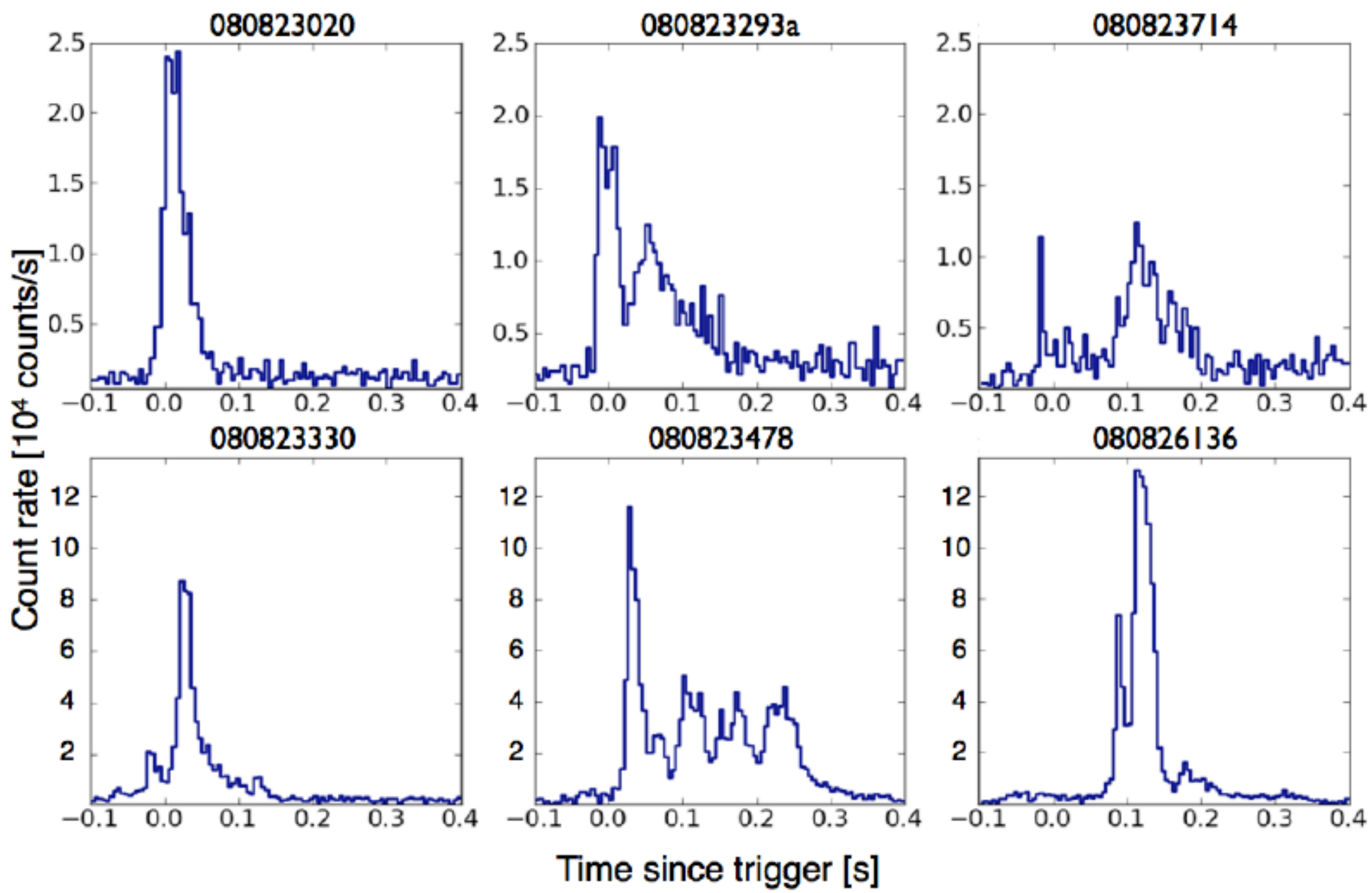
3G Science Case Document

Core-Collapse Supernovae



Roma et al. 2019

Bursts from Magnetars and Other Pulsars



Huppenkothen et al. 2012

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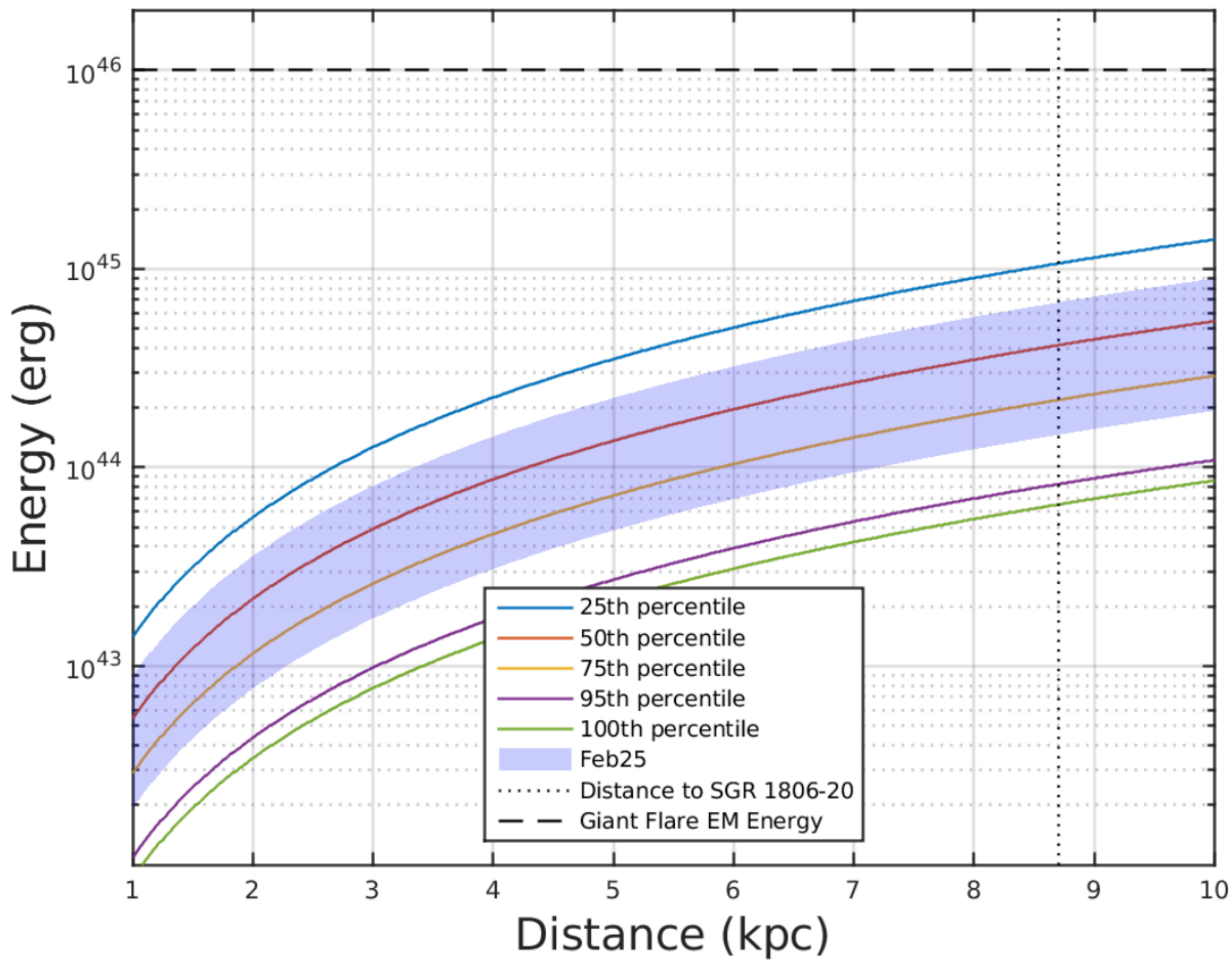

Abbott et al. 2019