UNIVERSITY OF BIRMINGHAM

LIGO Scientific Collaboration

Advanced LIGO

Gravitational-wave astronomy & binary neutron stars

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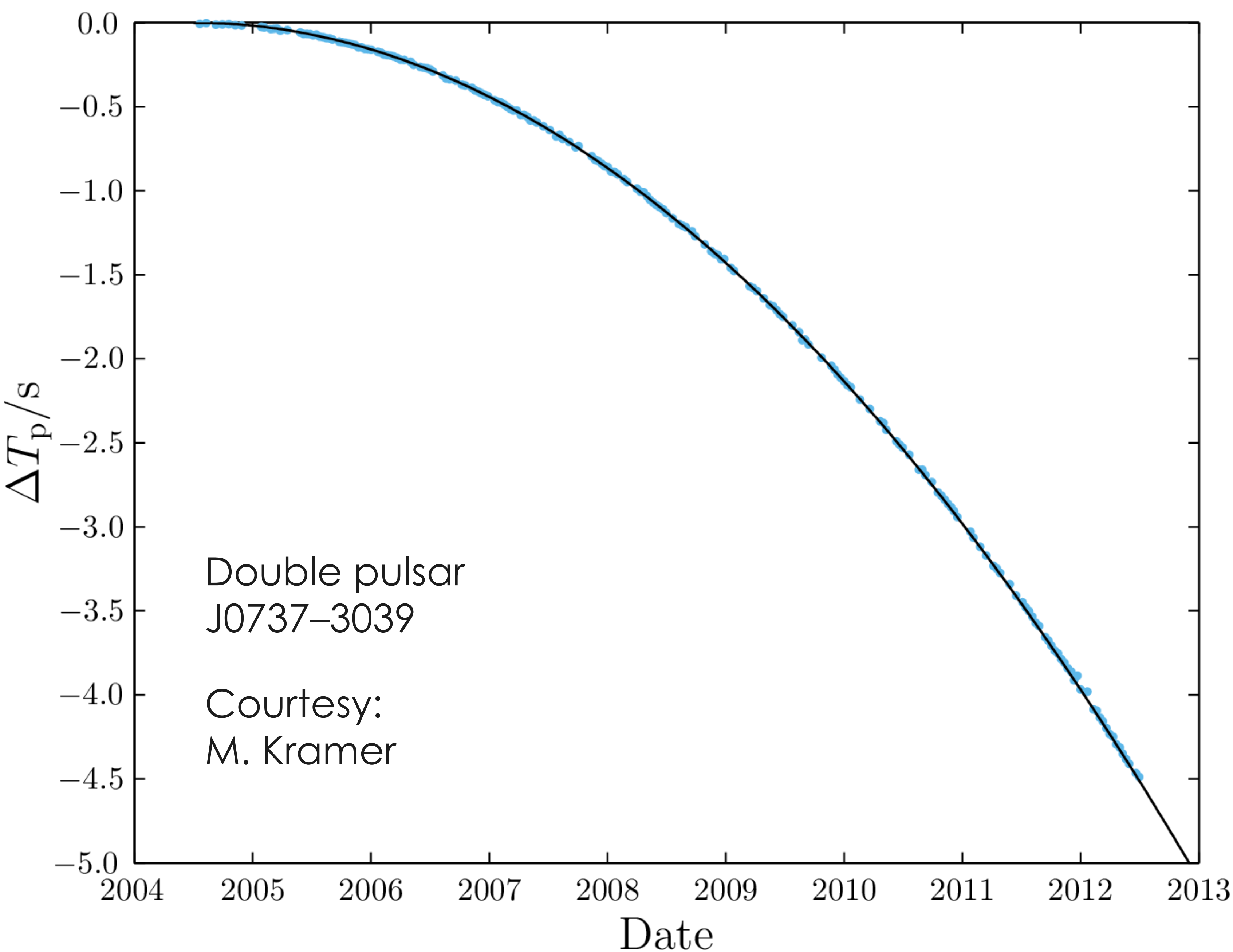
1 June 2015

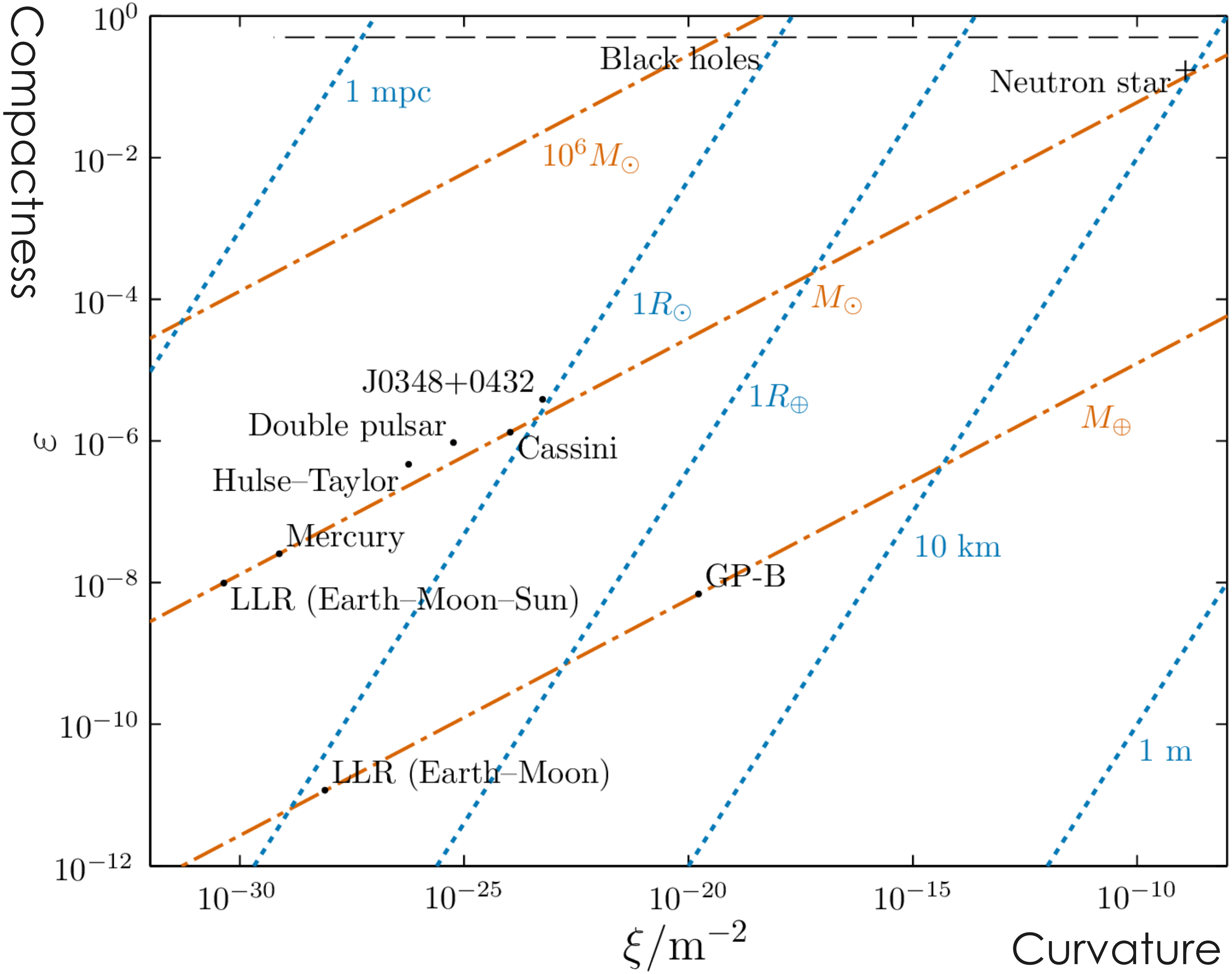
Cambridge Cosmology Lunch

Prospects for gravitational-wave astronomy

What we can learn about binary neutron stars

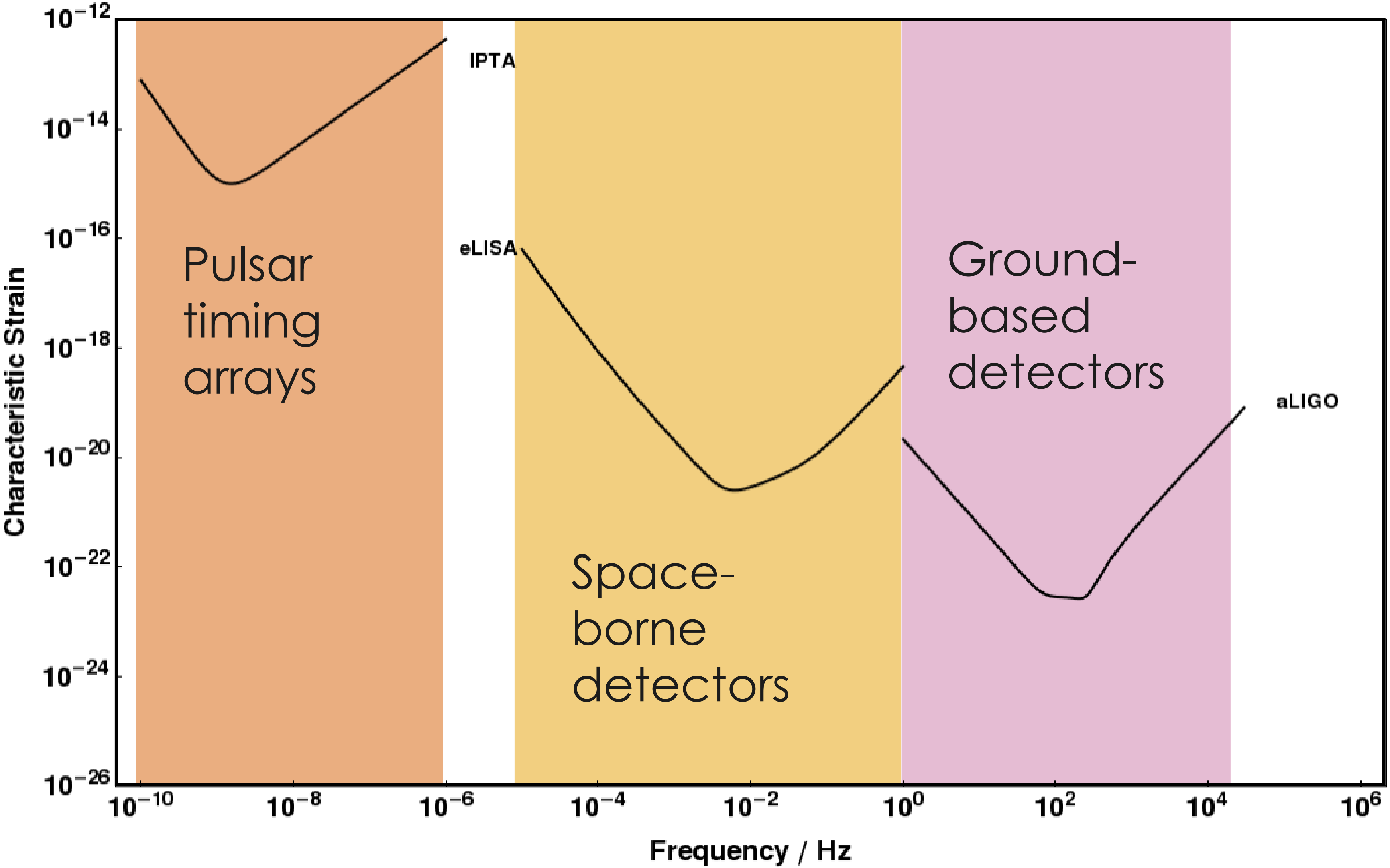


0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
−4.0
−4.5
−5.0
$\Delta T_p/\mathrm{s}$
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Date
Double pulsar
J0737–3039
Courtesy:
M. Kramer



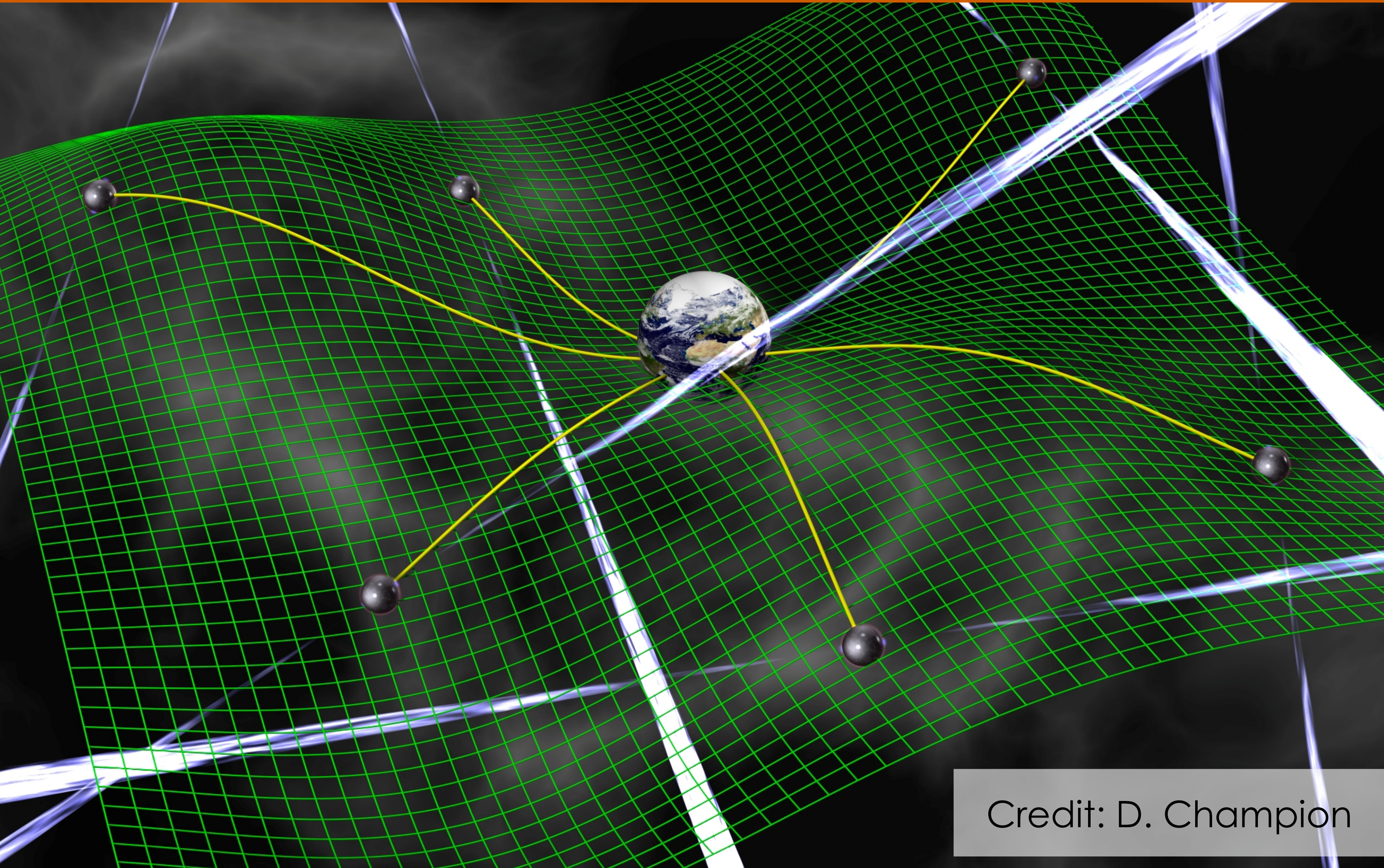
Strong-field gravity

Gravitational-wave spectrum



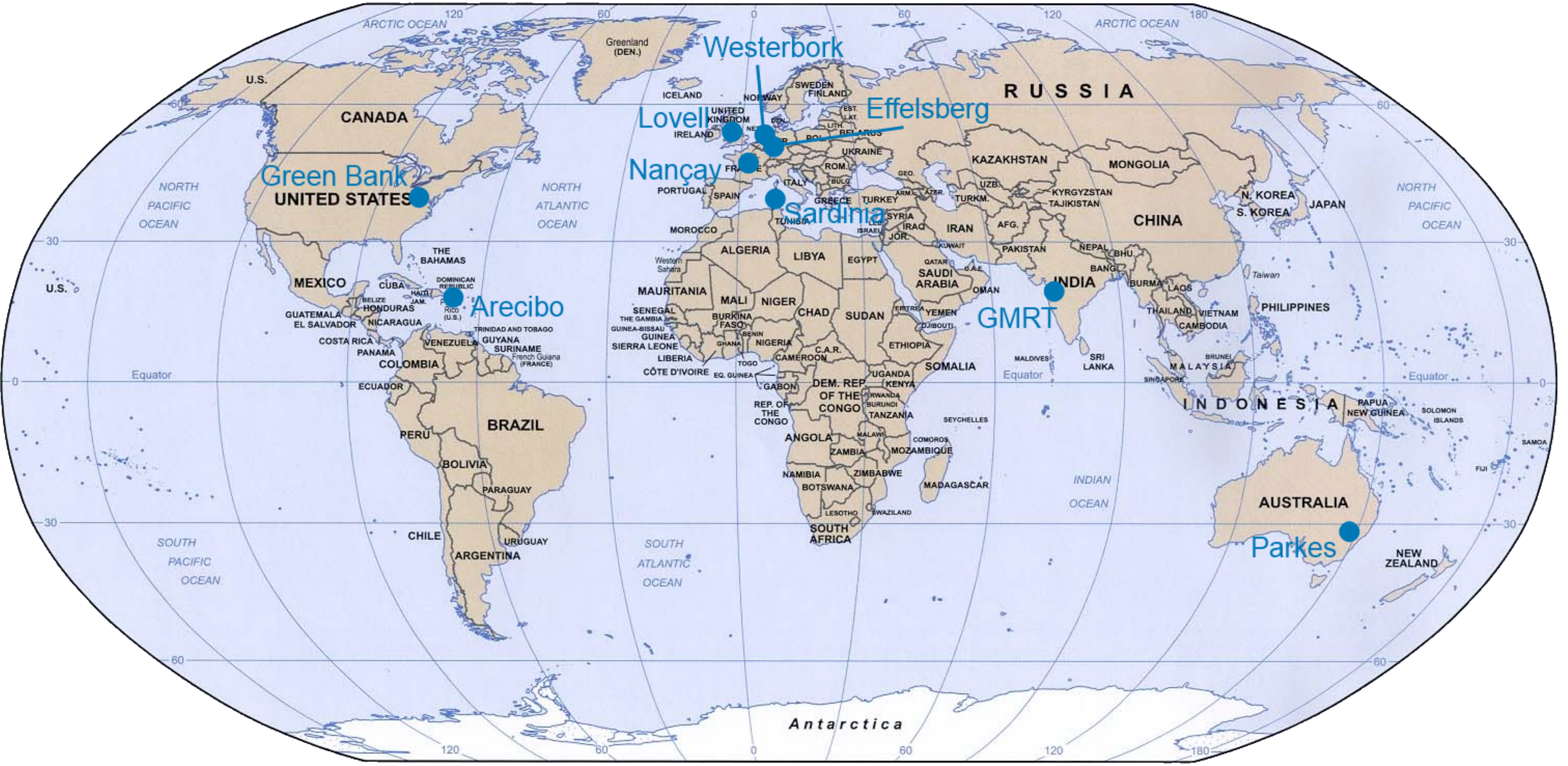
Credit: rhcole.com/apps/GWplotter/

Pulsar timing

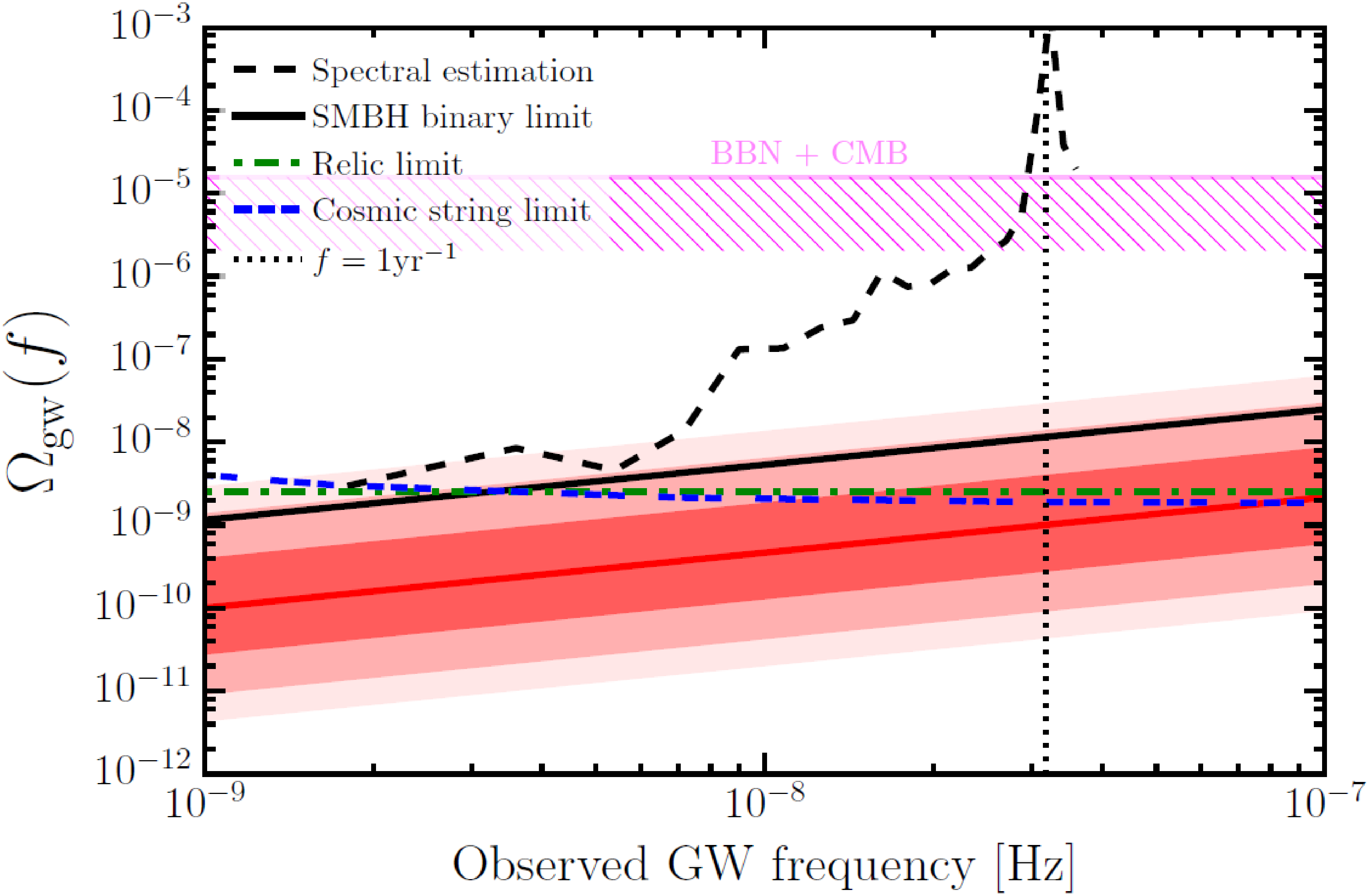


Credit: D. Champion

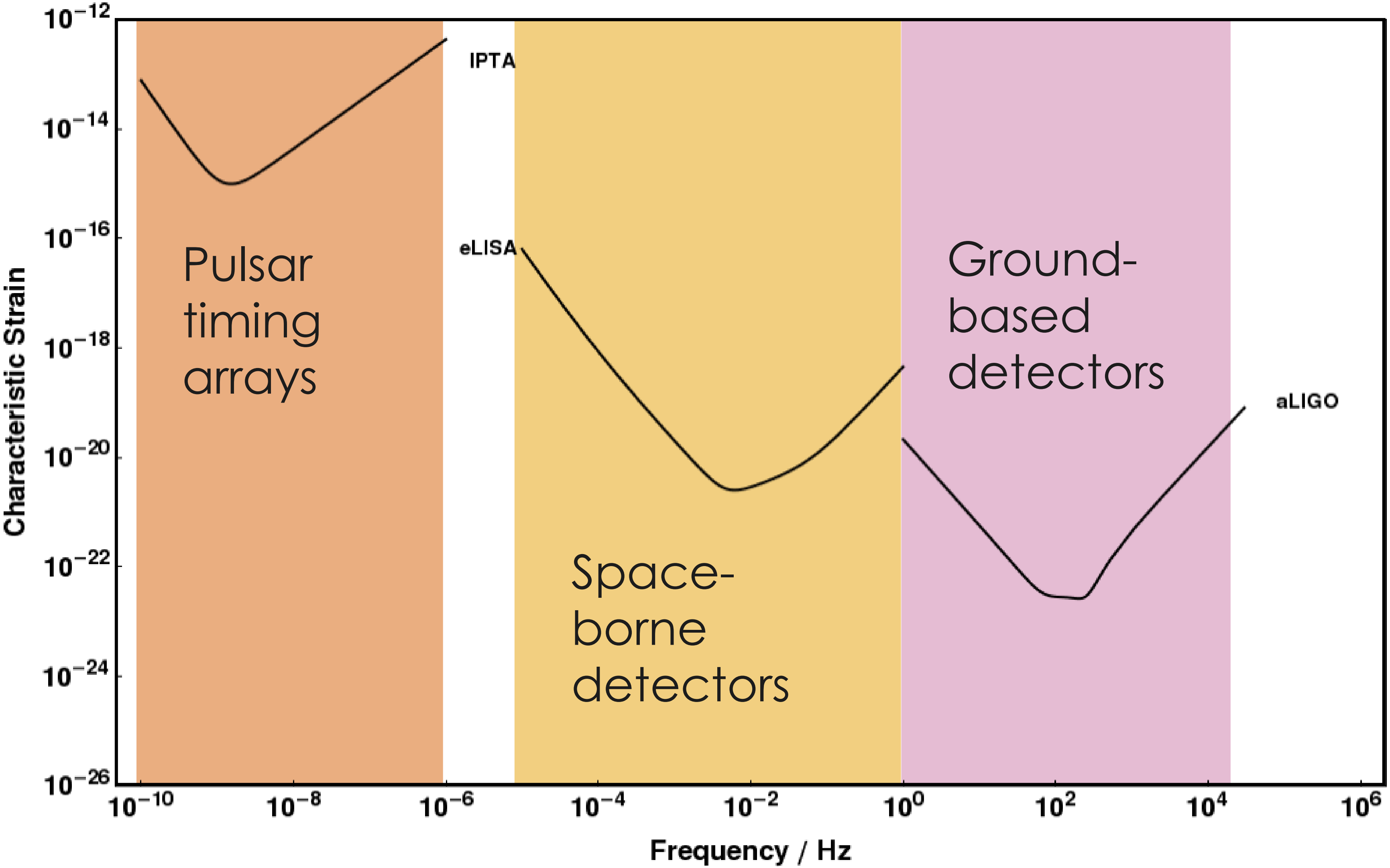
IPTA


Westerbork
Effelsberg
Lovell
Nançay
Green Bank
Sardinia
Arecibo
GMRT
Parkes

Lentati *et al.* (2015) arXiv:1504.03692



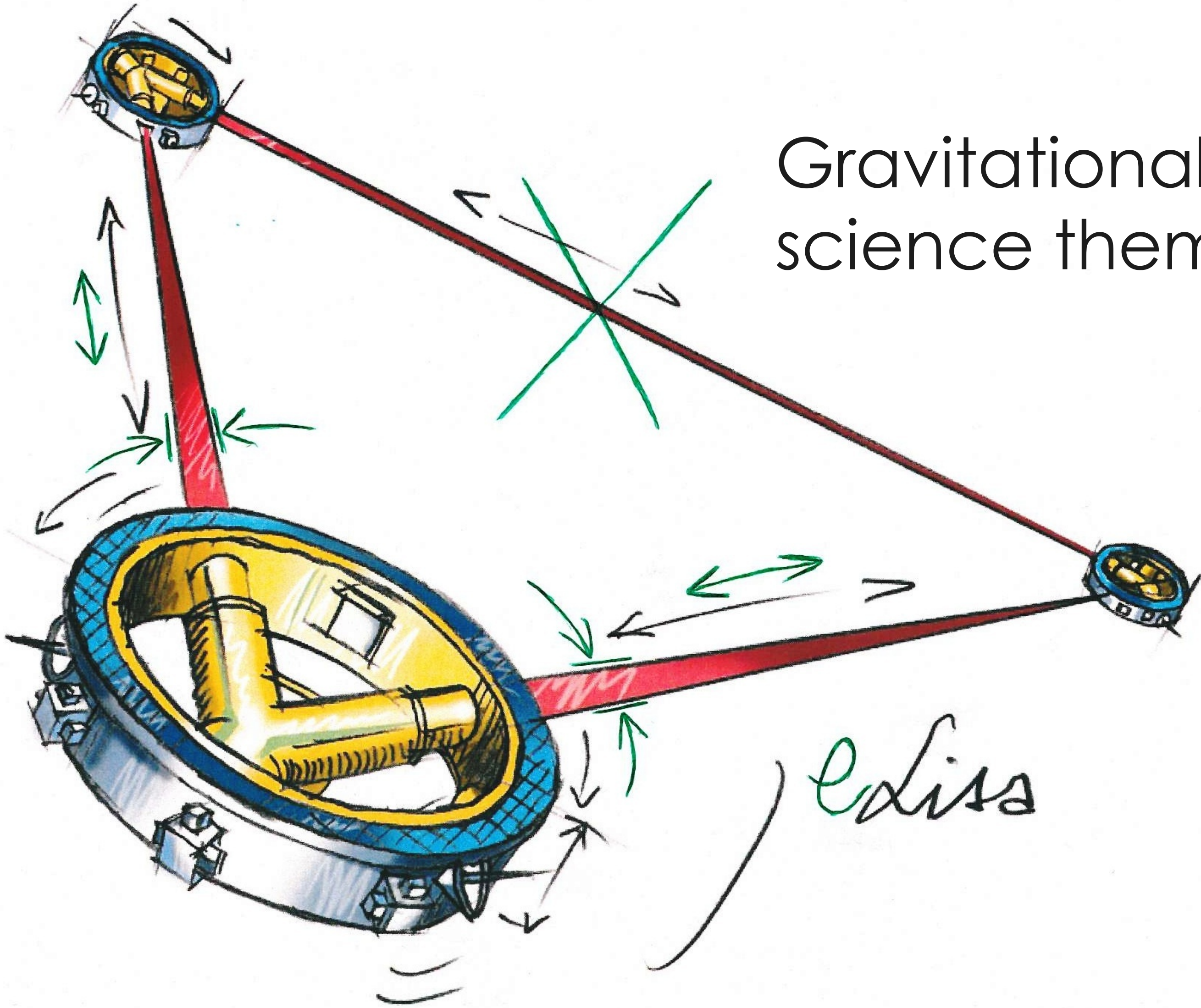
Gravitational-wave spectrum



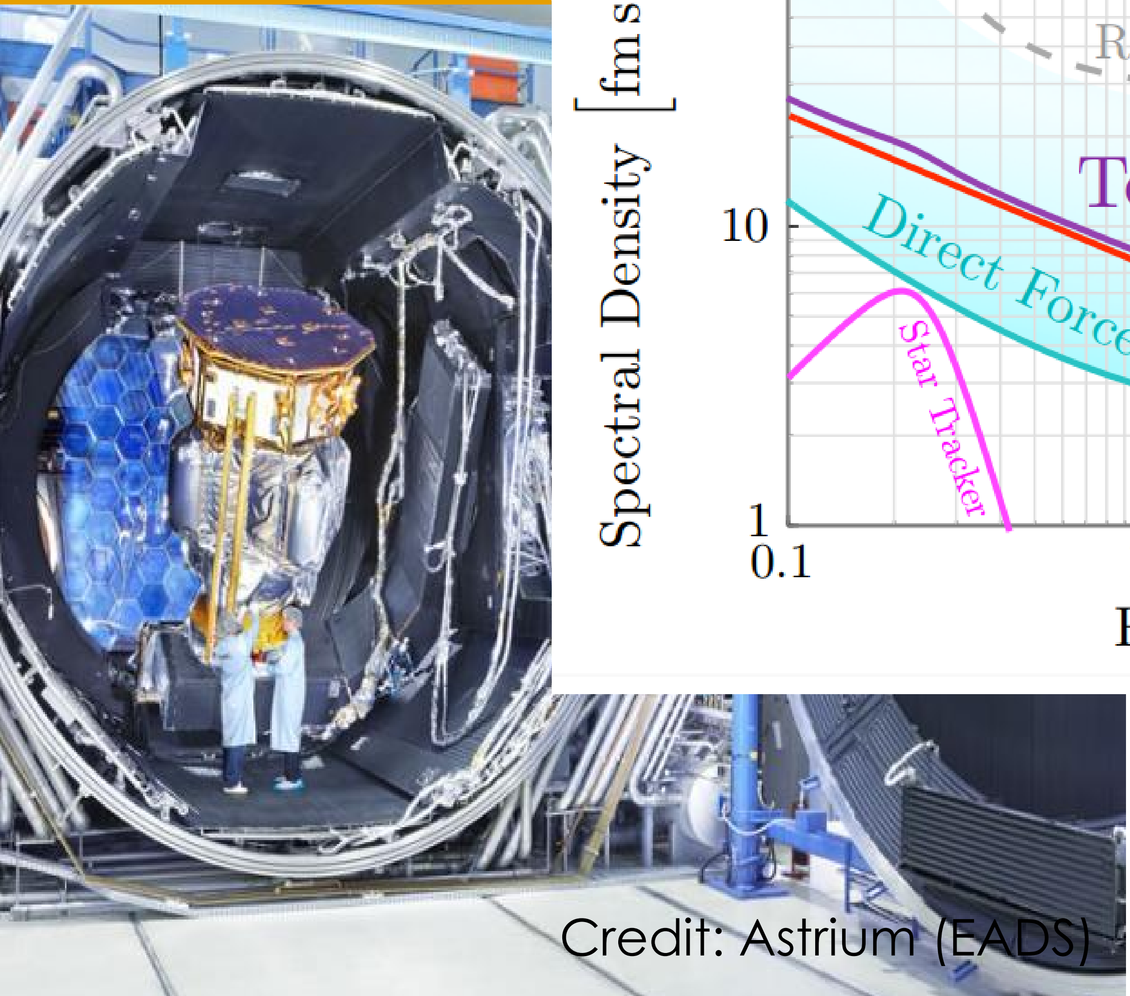
Credit: rhcole.com/apps/GWplotter/

L3 mission concept

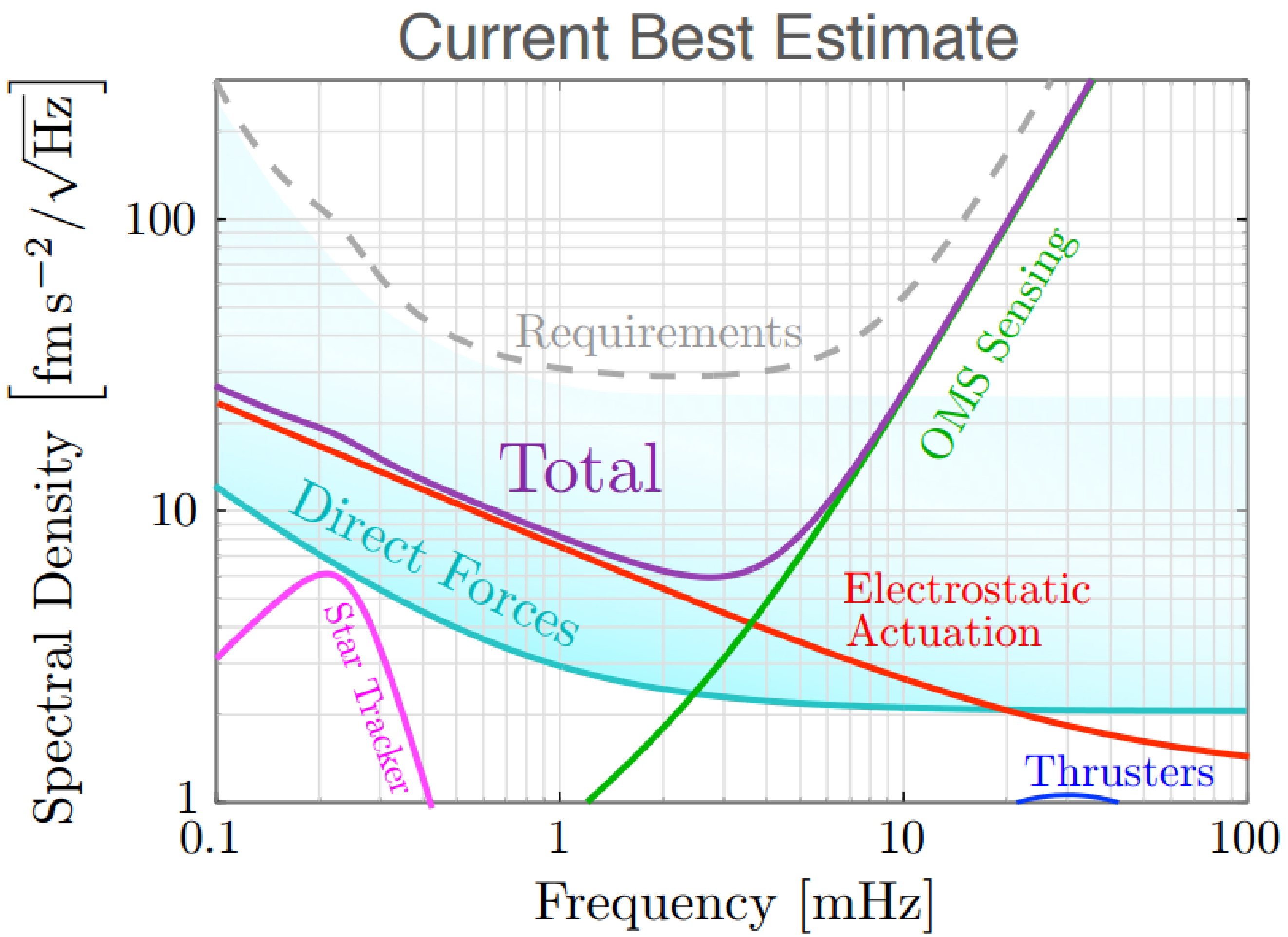
Gravitational Universe
science theme chosen



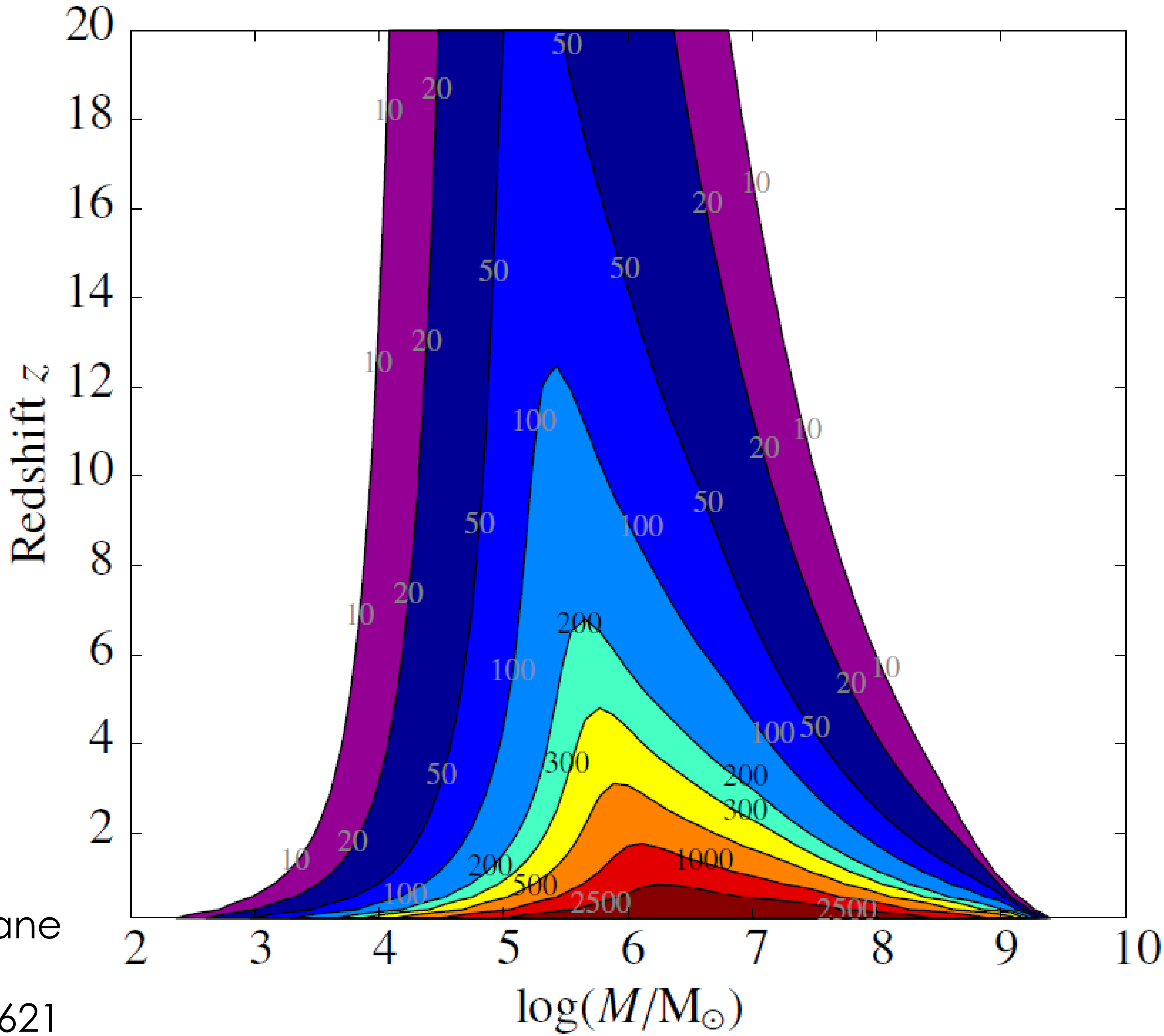
LISA Pathfinder



Credit: Astrium (EADS)

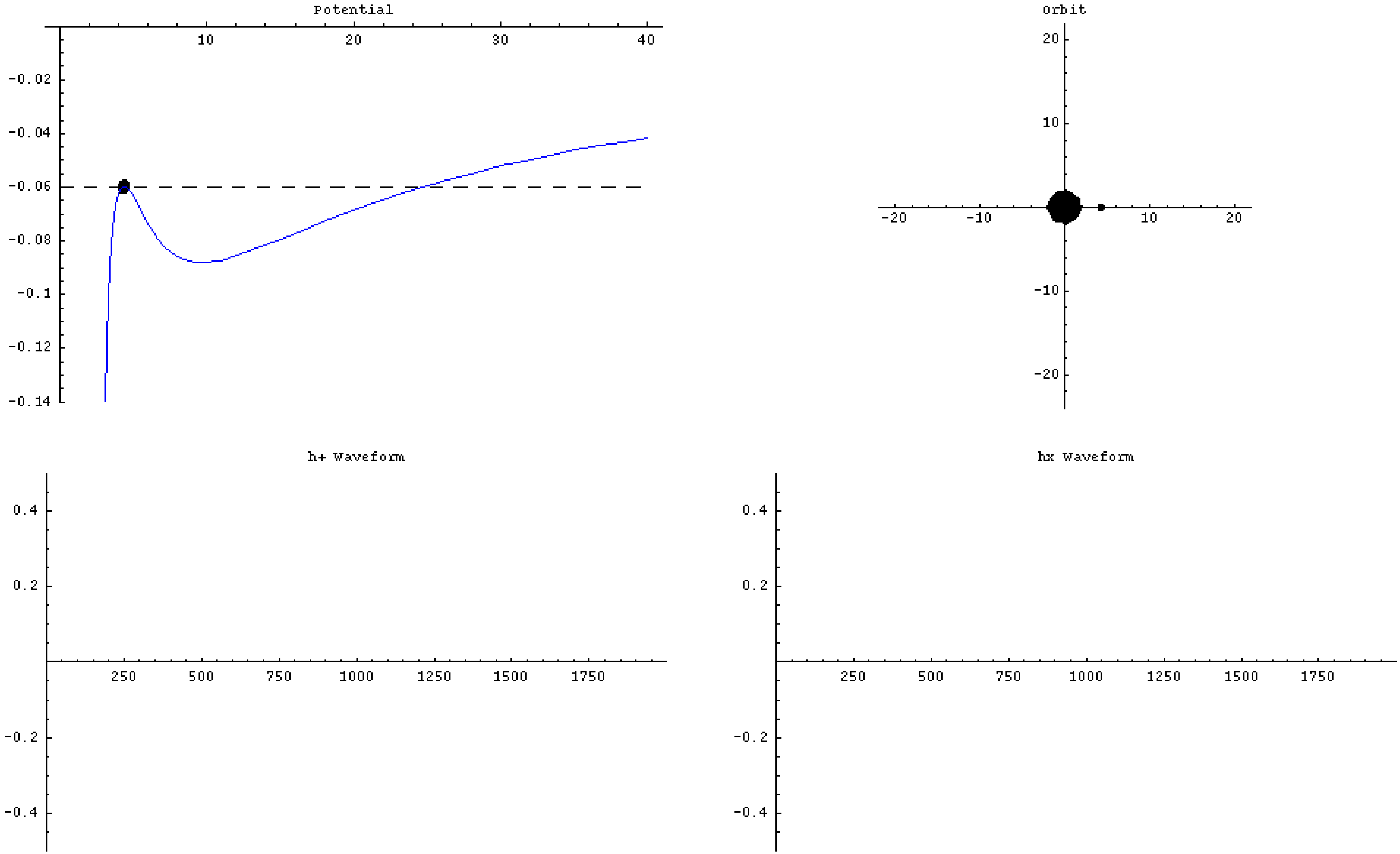


Credit: M. Hewitson



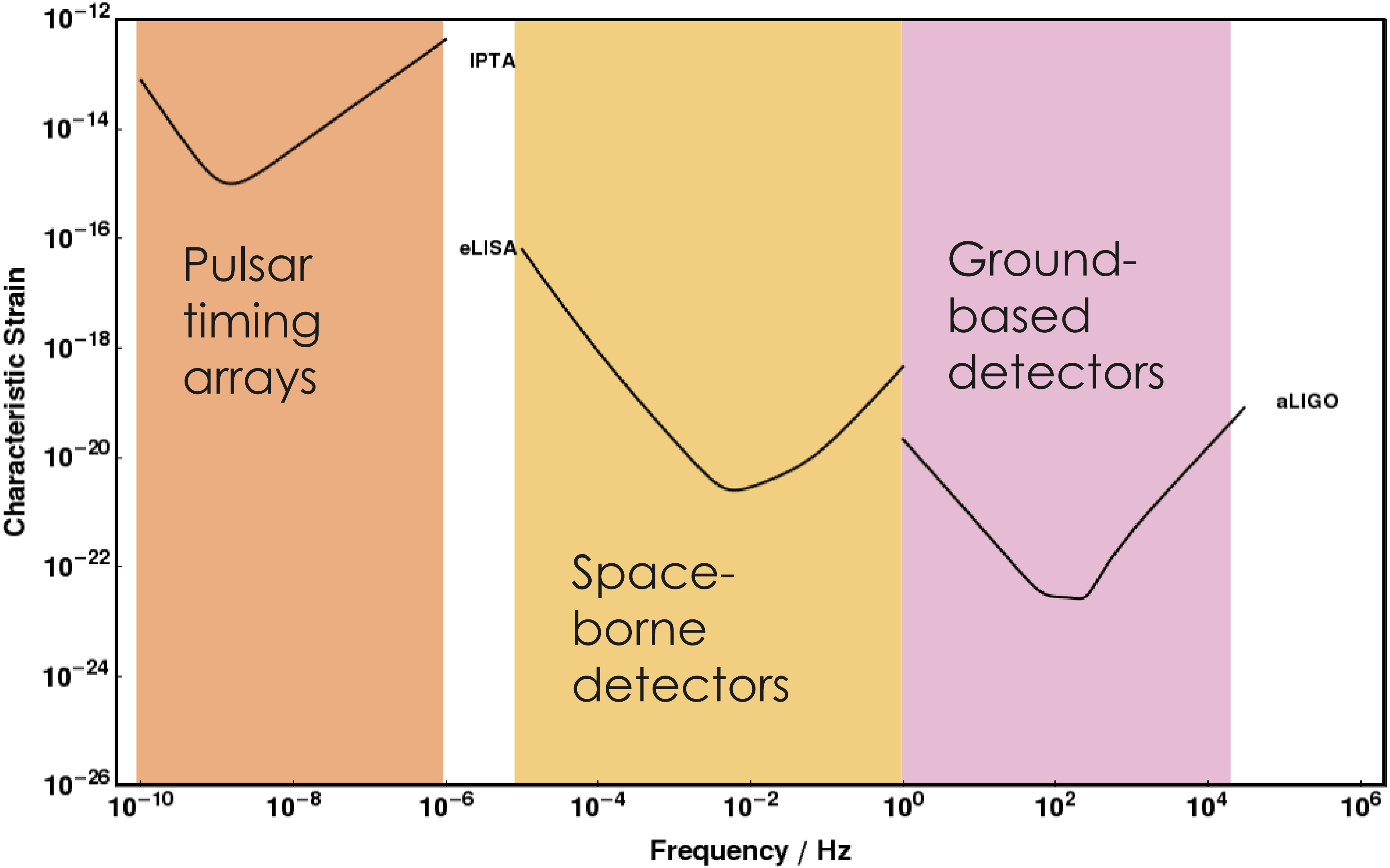
Amaro-Seoane *et al*. (2012) arXiv:1201.3621

Extreme-mass-ratio inspirals



Credit: J Gair

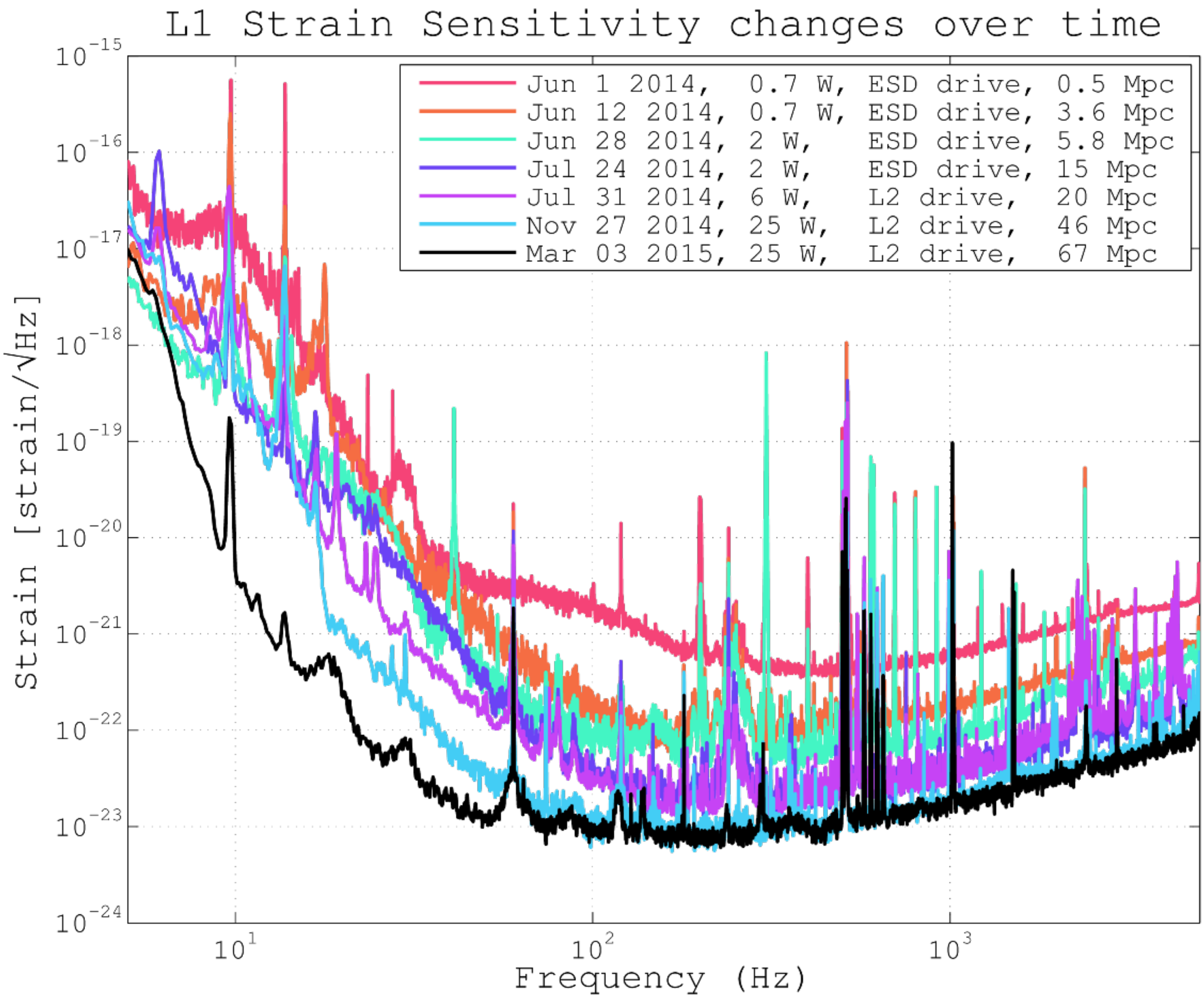
Gravitational-wave spectrum



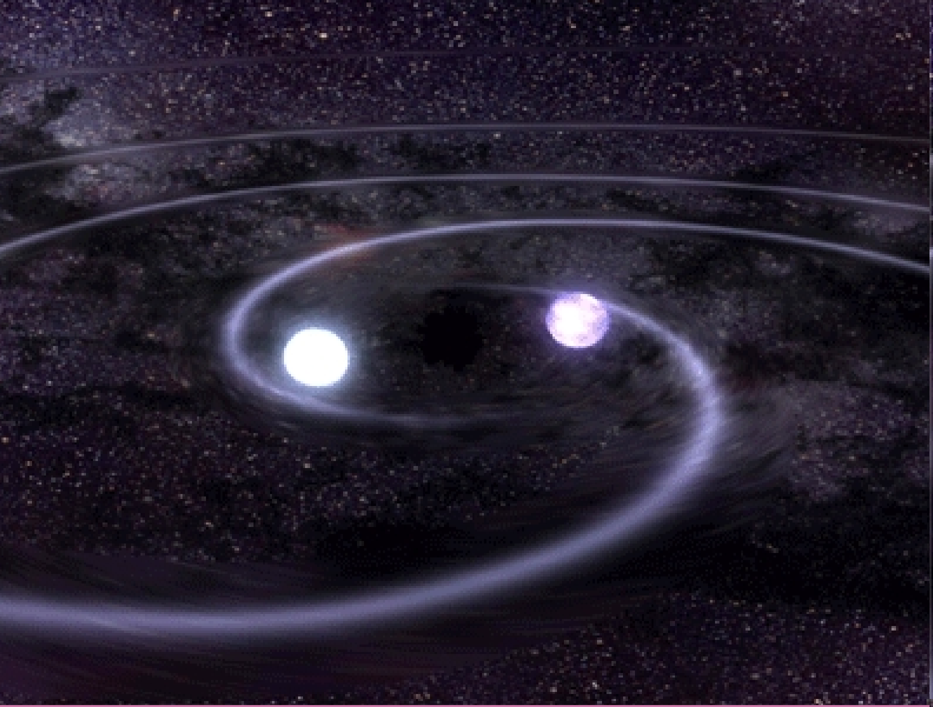
Credit: rhcole.com/apps/GWplotter/

Ground-based interferometer

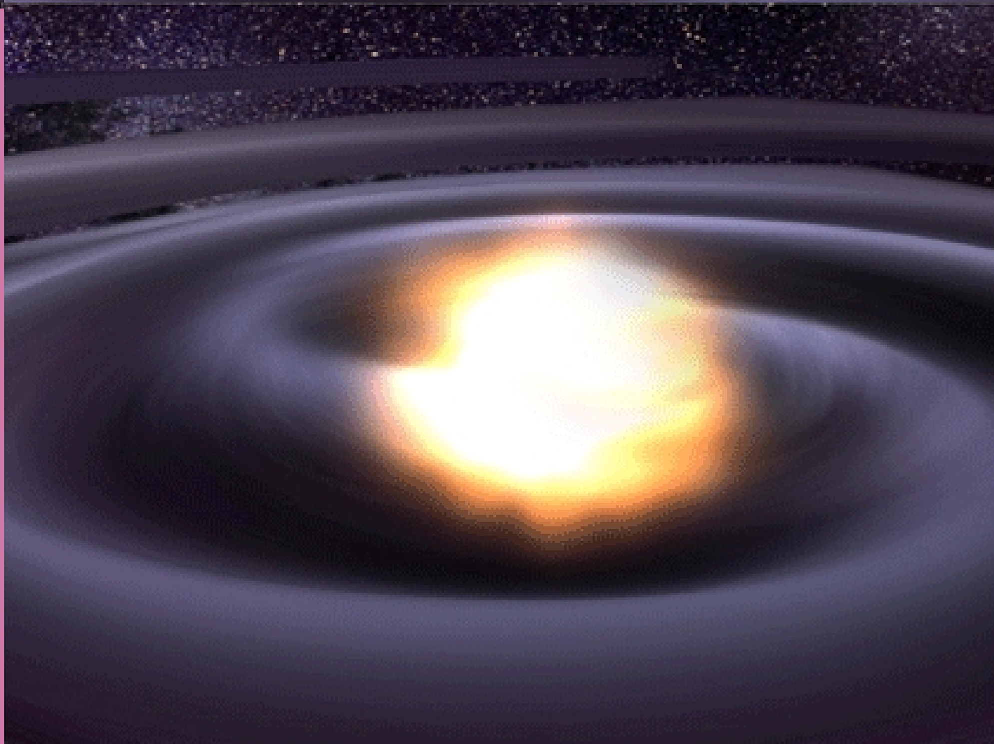
Detector network



Credit: LIGO Document G1401390-v8



Binary neutron stars

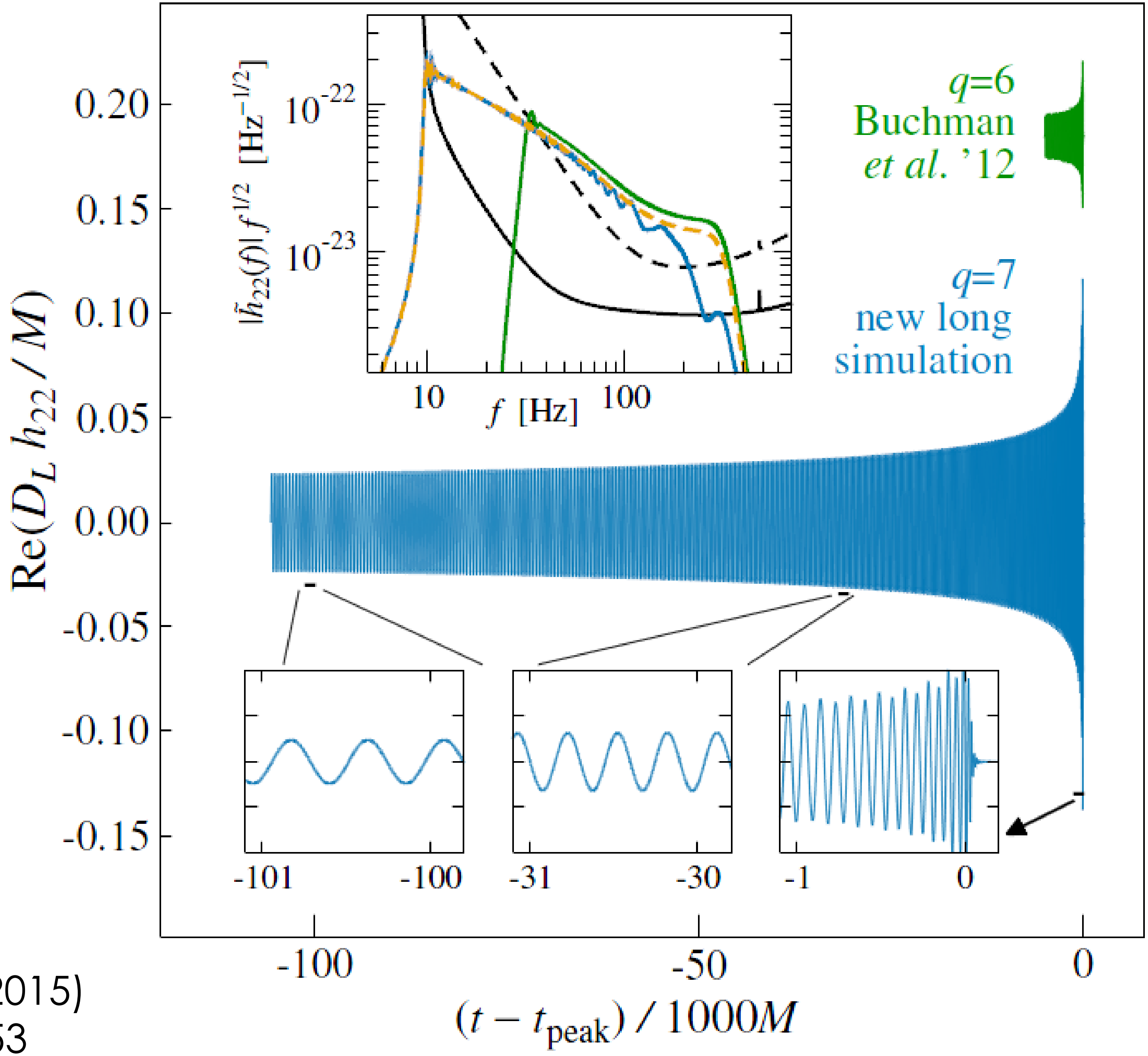


Credit: NASA

Detectors cover a range of potential sources

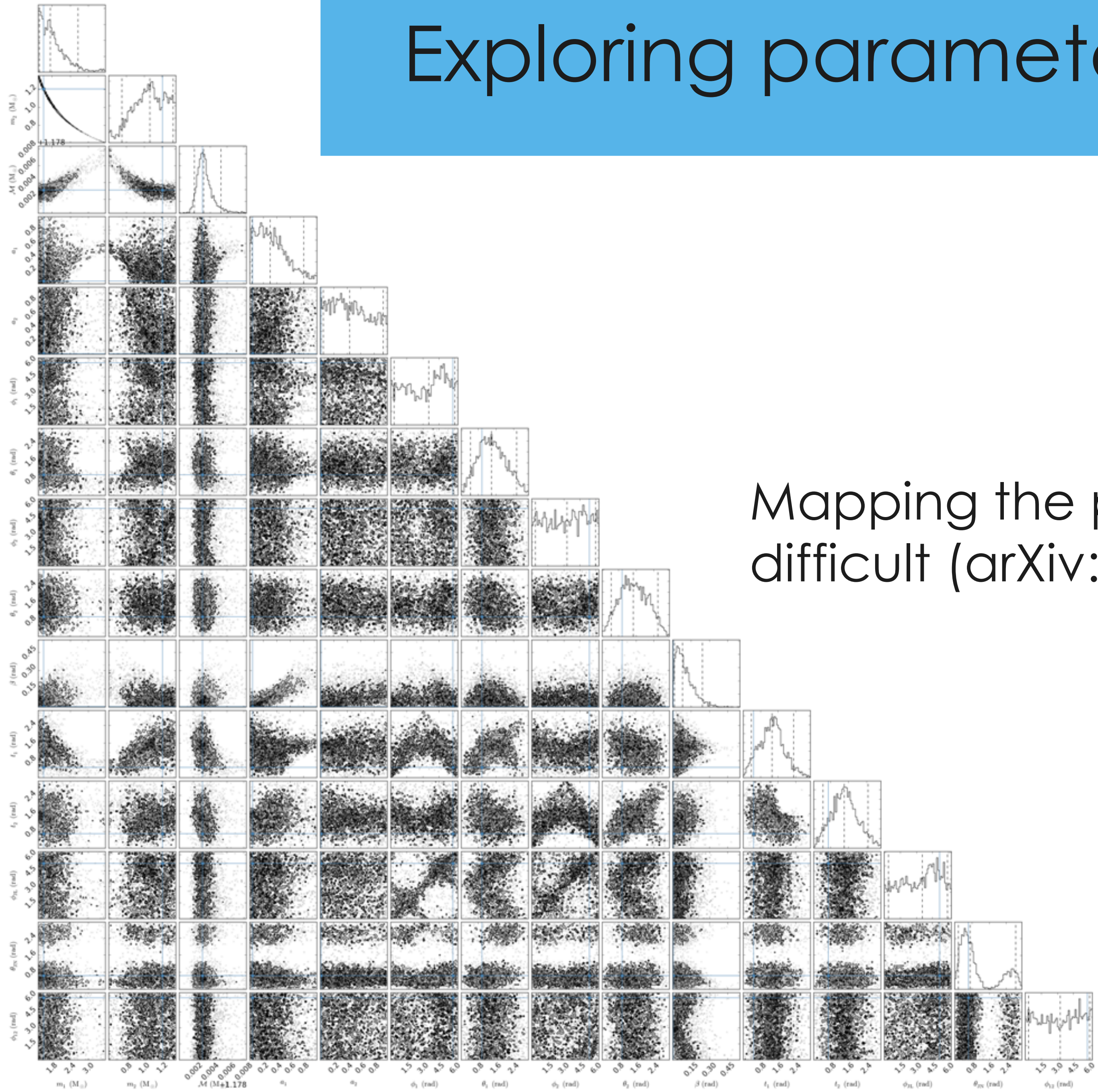
Binary neutron stars may be the main source for Advanced LIGO

Inspirals are well under-stood



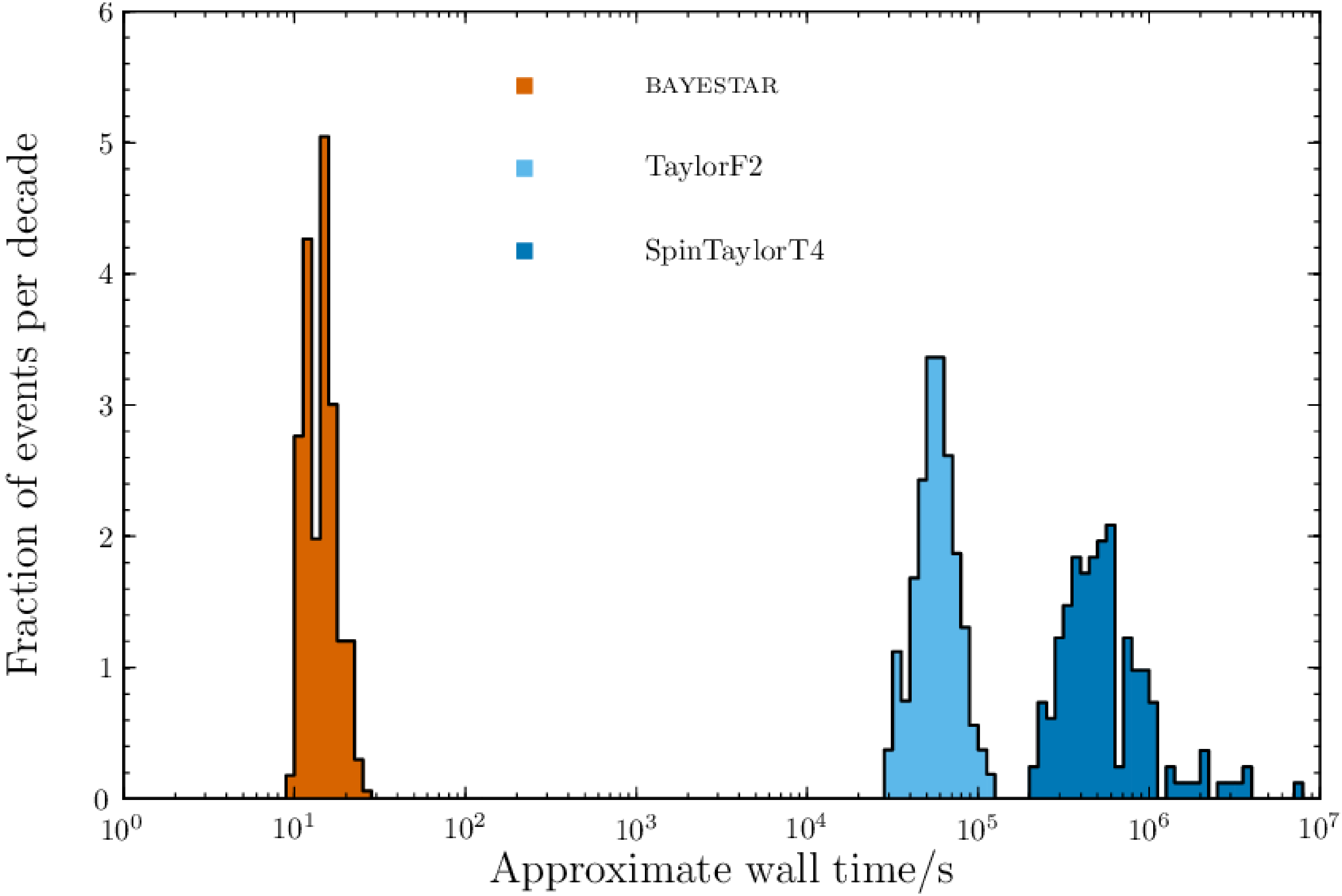
Szilagyi *et al.* (2015)
arXiv:1502.04953

Exploring parameter space



Mapping the posterior is difficult (arXiv:1409.7215)

Time taken



BAYESTAR
TaylorF2
SpinTaylorT4
Fraction of events per decade
Approximate wall time/s
0
1
2
3
4
5
6
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7

Data release | 2015, HL | 2016, HLV | new 2015, recoloured | Show/hide columns

The First Two Years of Electromagnetic Follow-Up with Advanced LIGO and Virgo

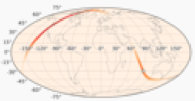
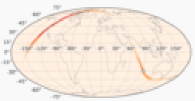
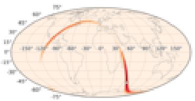
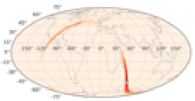
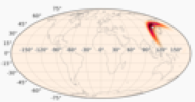
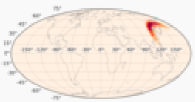
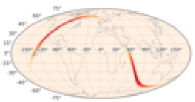
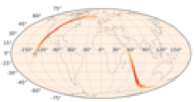
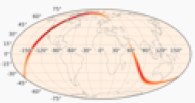
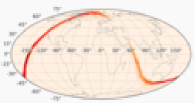
Singer et al. 2014 arXiv:1404.5623 | Berry et al. 2015 arXiv:1411.6934

www.ligo.org/scientists/first2years/

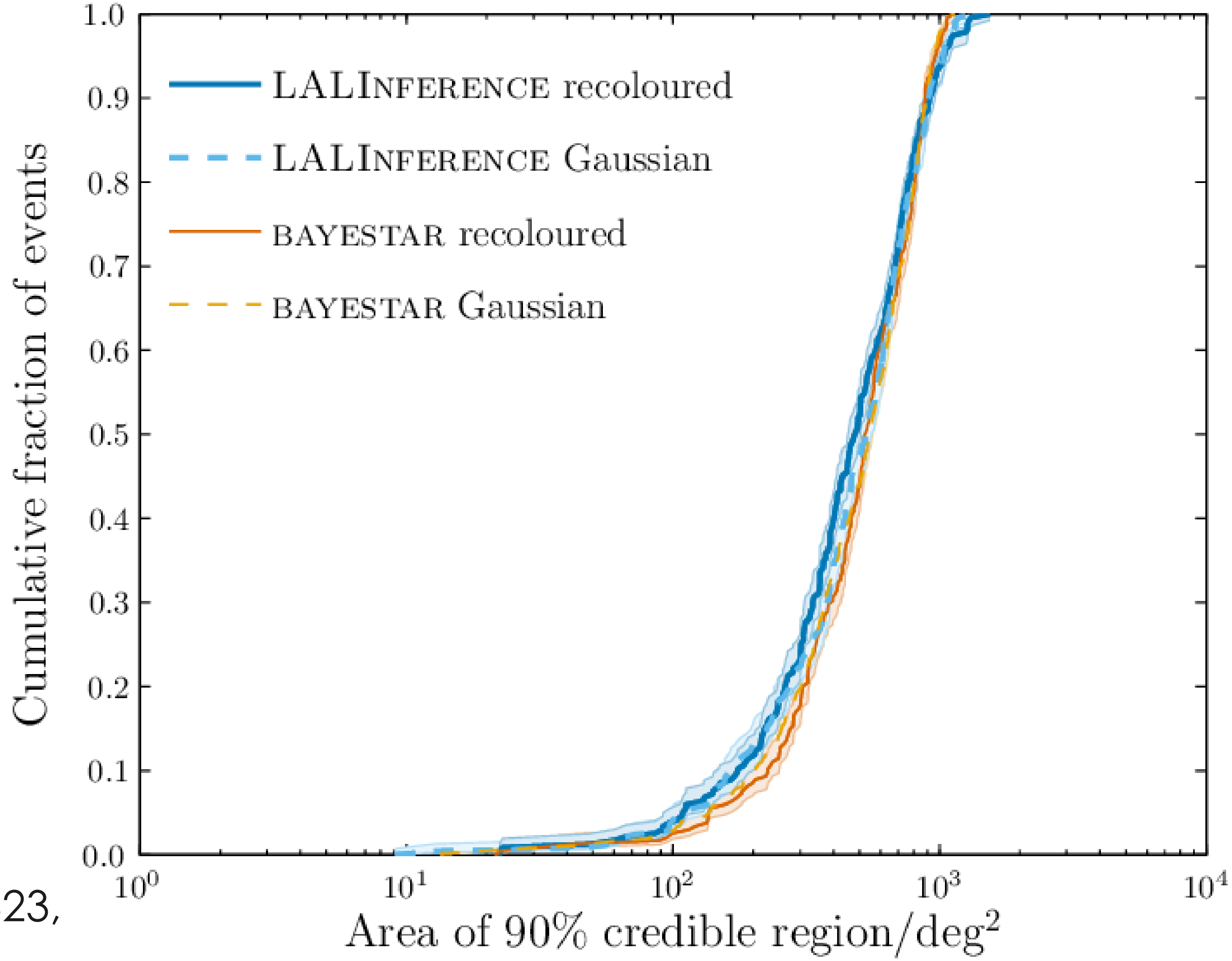
This web page
additional onli
related to the
Two Years of
Follow-Up with
and Virgo" and
paper "Parame
for Binary Neu
Coalescences

Data release | 2015, HL | 2016, HLV | new 2015, recoloured | Show/hide columns

Catalog of simulated events and sky maps for two-detector, HL, 2015 configuration. This is the same configuration as the 2015 tab, except that the simulated detector noise is data from initial LIGO's sixth science run, recoloured (filtered) to have the same PSD as the early Advanced LIGO configuration. See also ASCII tables of simulated signals, detections, and parameter-estimation accuracies in Machine Readable Table format.

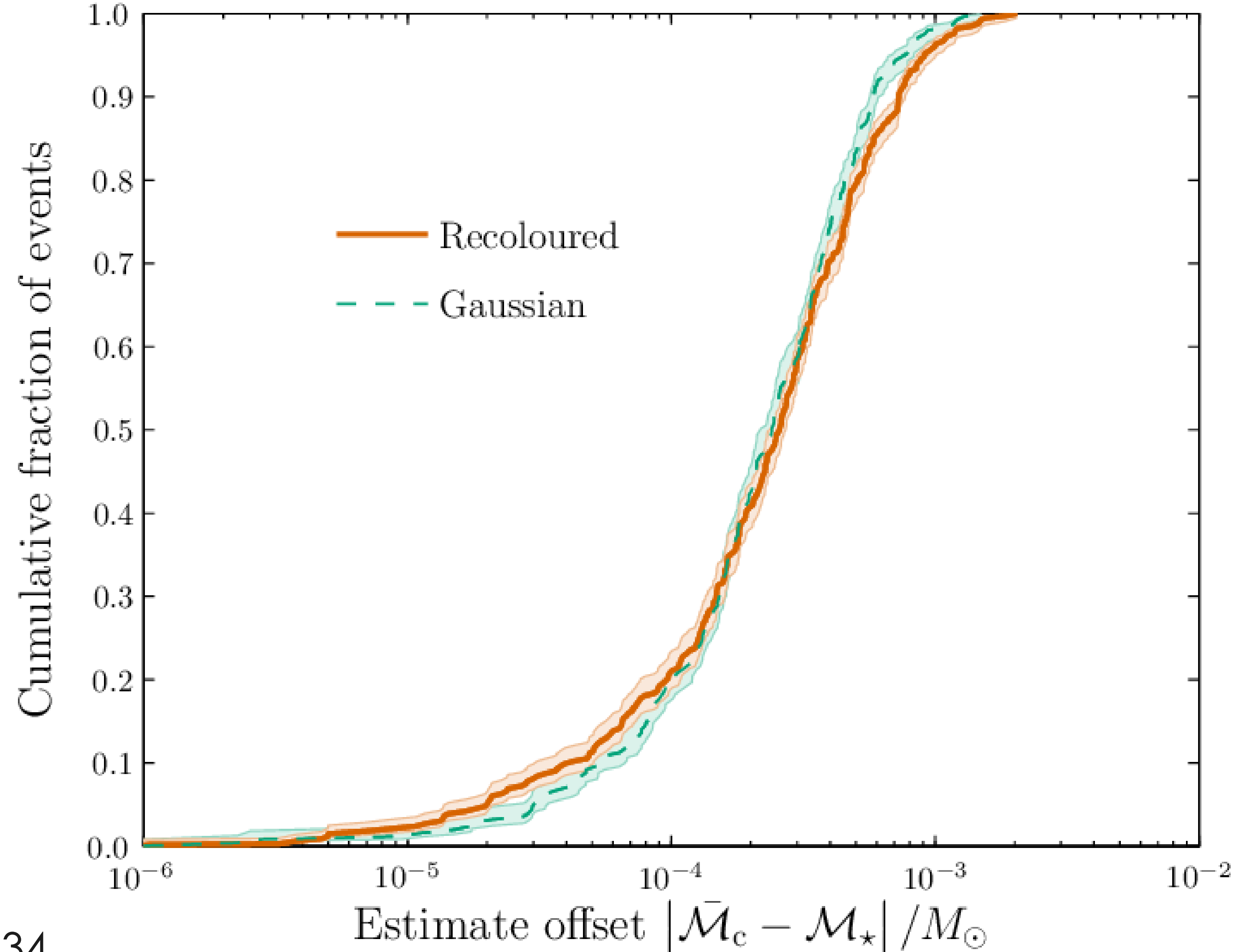
event ID	sim ID	network	SNR			BAYESTAR			LALINFERENCE_NEST			sky maps	
			net	H	L	50%	90%	searched	50%	90%	searched	BAYESTAR	LALINFERENCE_NEST
4532	899	HL	13.9	10.1	9.5	180	750	190	170	790	150		
4572	1243	HL	13.2	10.0	8.7	230	830	45	200	920	33		
4618	1768	HL	10.8	8.0	7.3	160	540	220	130	440	280		
4647	1964	HL	12.4	8.6	9.0	260	890	1200	190	780	780		
4711	2704	HL	10.7	8.0	7.1	370	1200	300	450	1600	520		

Sky localization



arXiv:1406.5623, 1411.6934

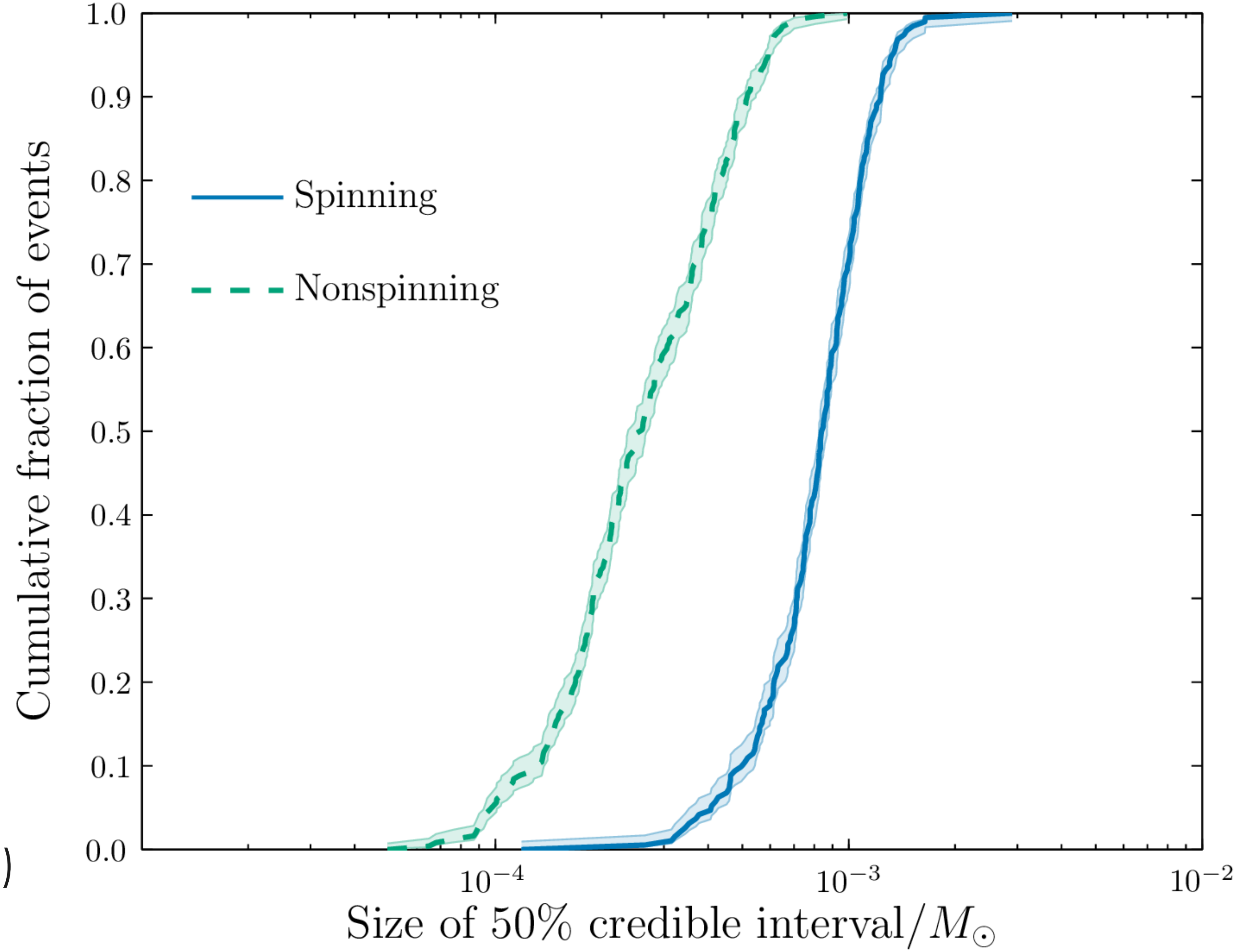
Chirp mass



arXiv:1411.6934

Chirp mass

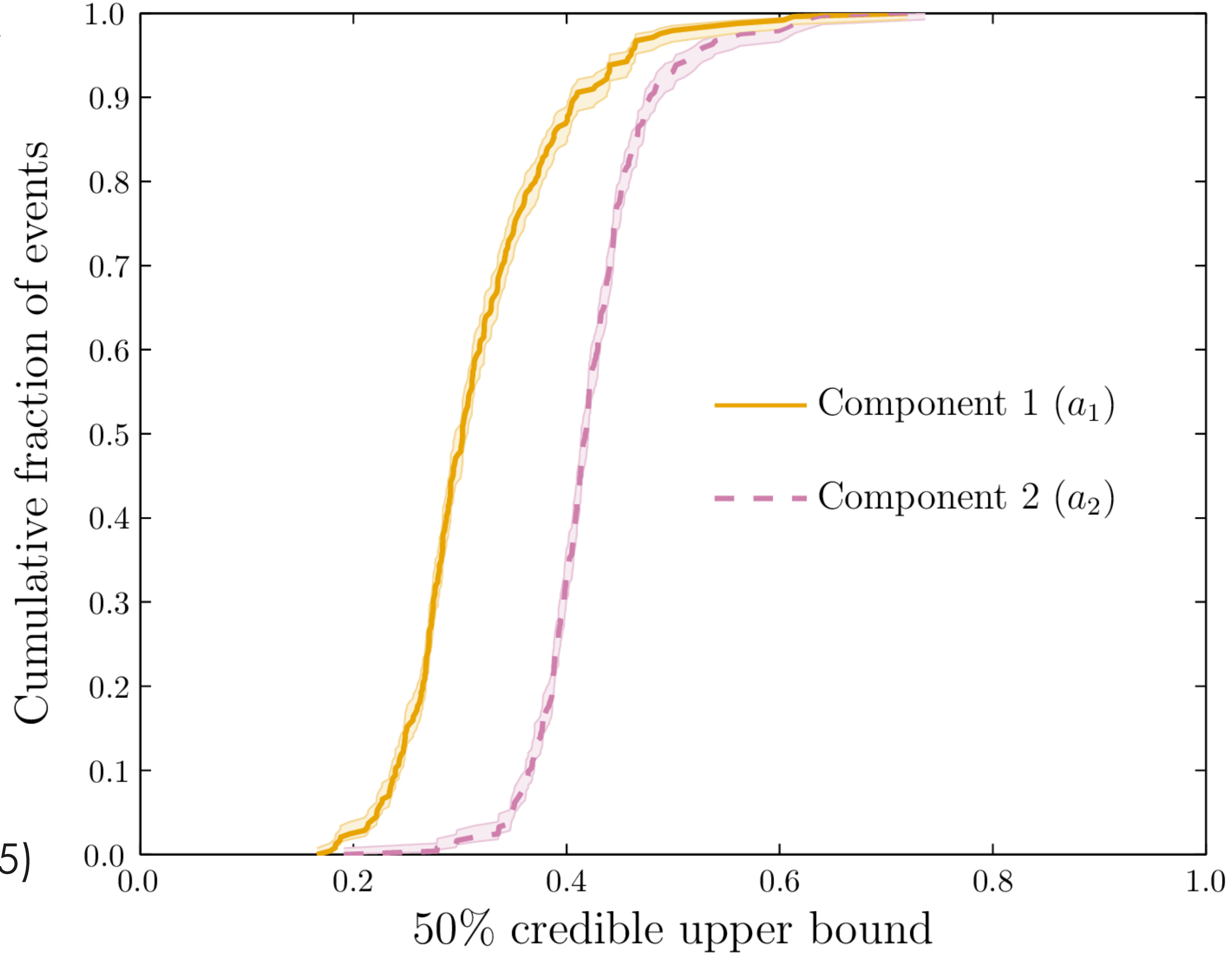
Preliminary



Farr *et al*. (2015) in prep.

Spin

Preliminary



Farr *et al*. (2015) in prep.

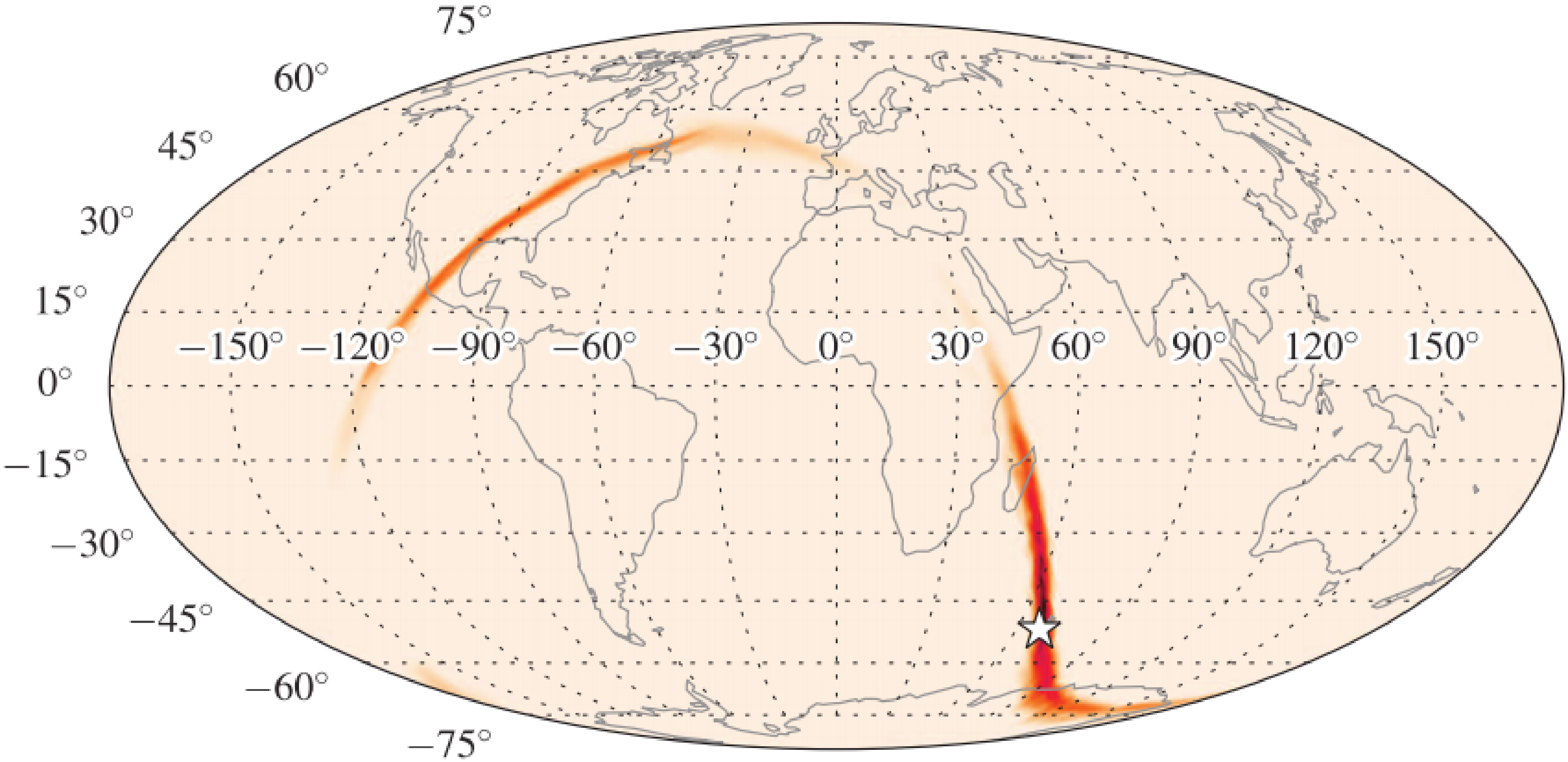
Summary

Gravitational-wave astronomy spans a range of frequencies and sources.

Advanced LIGO starts observations this year.
Binary neutron stars may be main source.

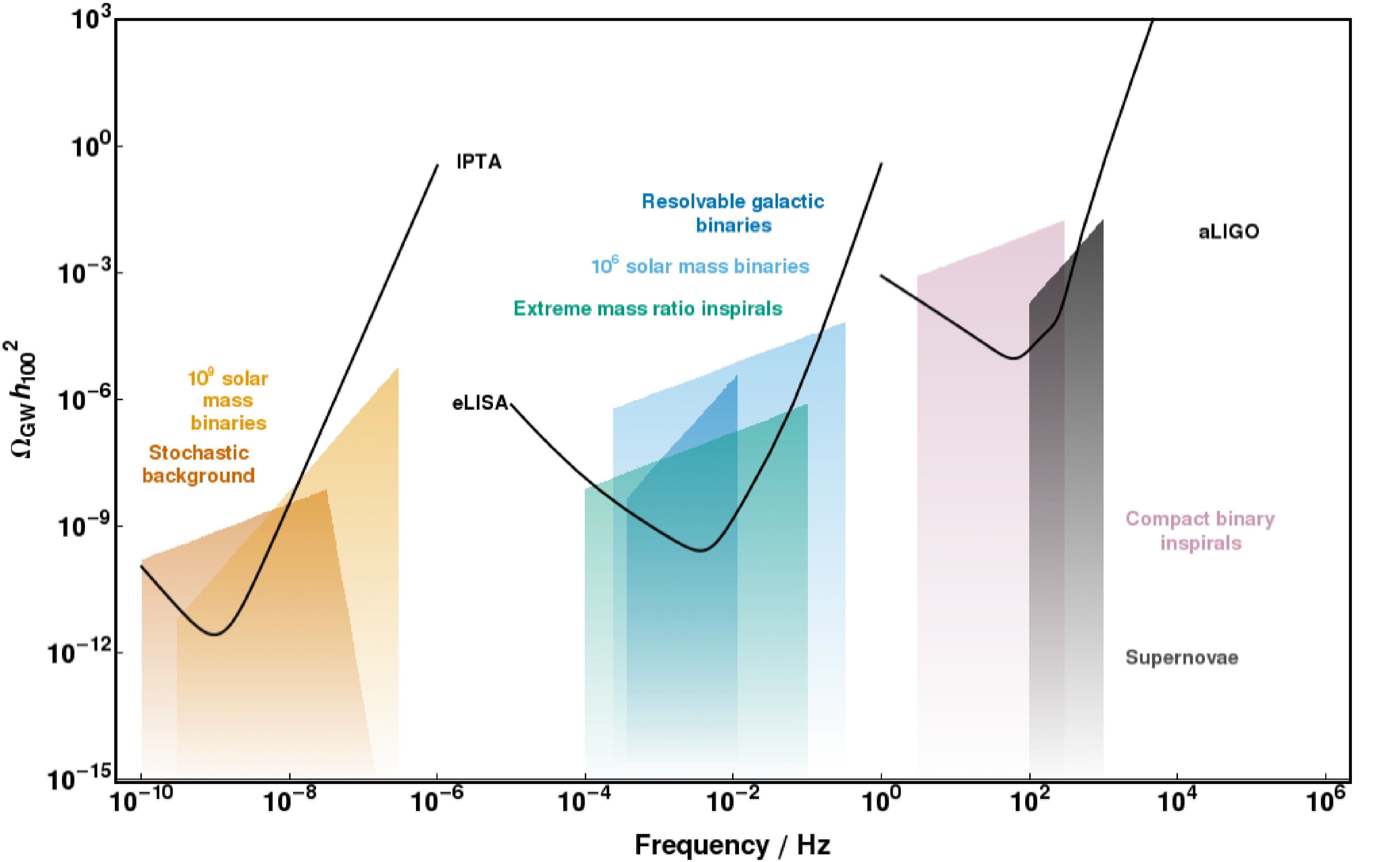
Measure sky position at low latency & chirp mass at medium latency.
Individual masses and spins may not be well measured.

Gravitational-wave astronomy: coming soonish



arXiv:1411.6934
www.ligo.org/scientists/first2years/

Sources



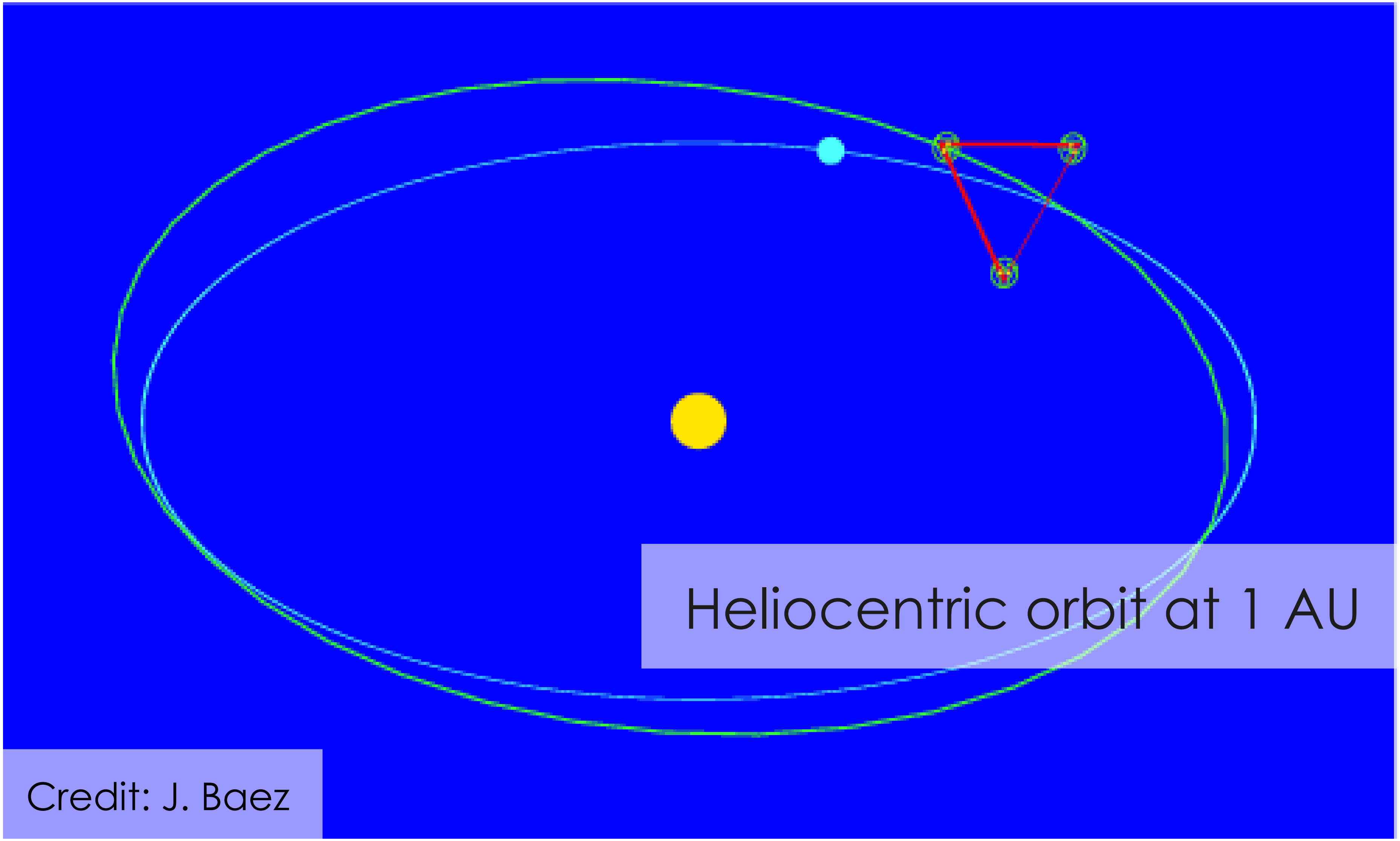
IPTA
eLISA
aLIGO
Resolvable galactic binaries
10^6 solar mass binaries
Extreme mass ratio inspirals
10^9 solar mass binaries
Stochastic background
Compact binary inspirals
Supernovae
$\Omega_{GW} h_{100}^2$
Frequency / Hz
10^3
10^0
10^{-3}
10^{-6}
10^{-9}
10^{-12}
10^{-15}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^0
10^2
10^4
10^6

Outlook

An **approximate** timeline for detector advances:

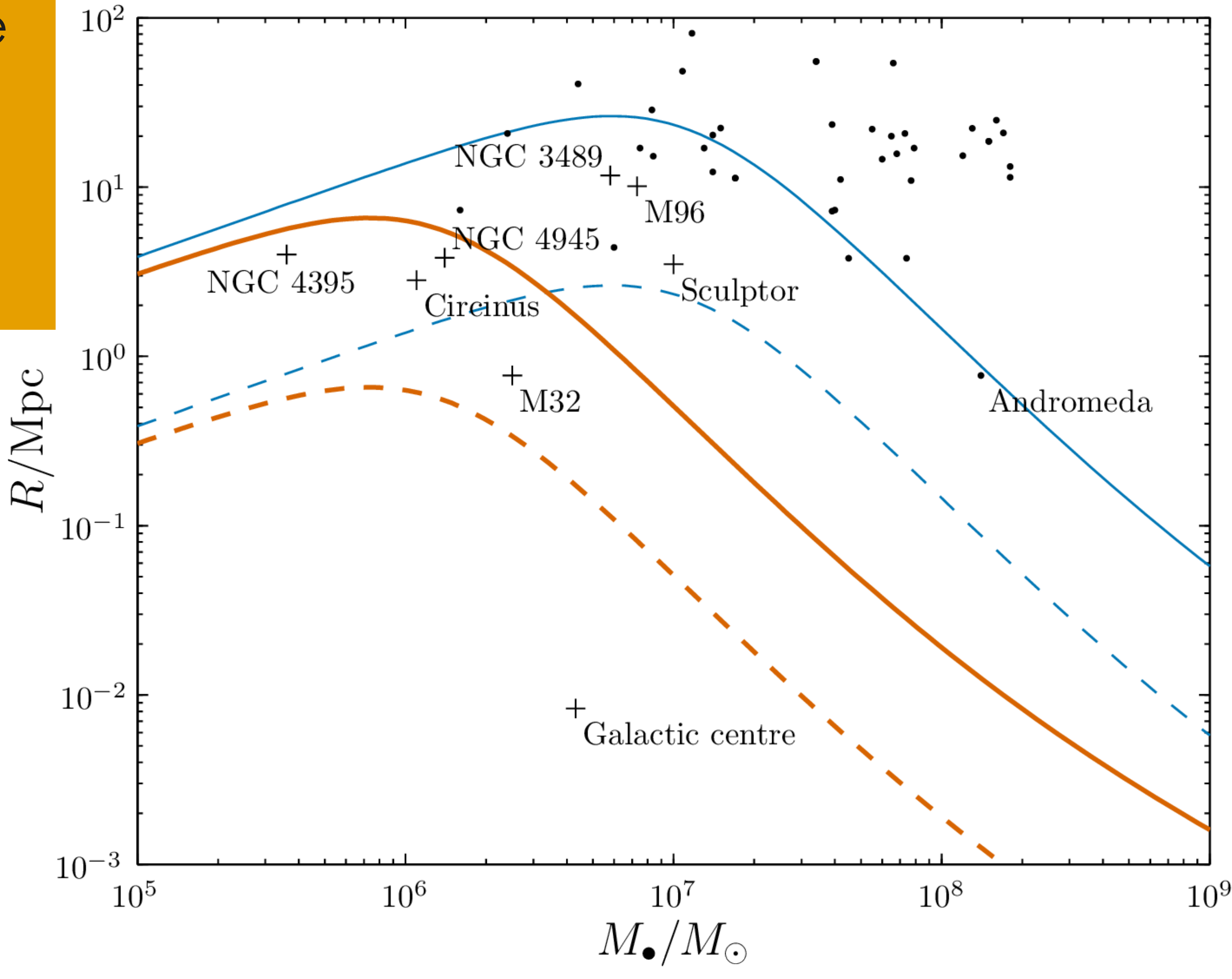
Now IPTA
2015 LISA Pathfinder
2015-2020 Advanced LIGO & Advanced Virgo
2018 KAGRA
2022 LIGO India
2023 SKA
2034 eLISA

Space-based interferometer



Bursts are detectable from nearby galaxies

Berry & Gair (2013)
arXiv:1306.0774

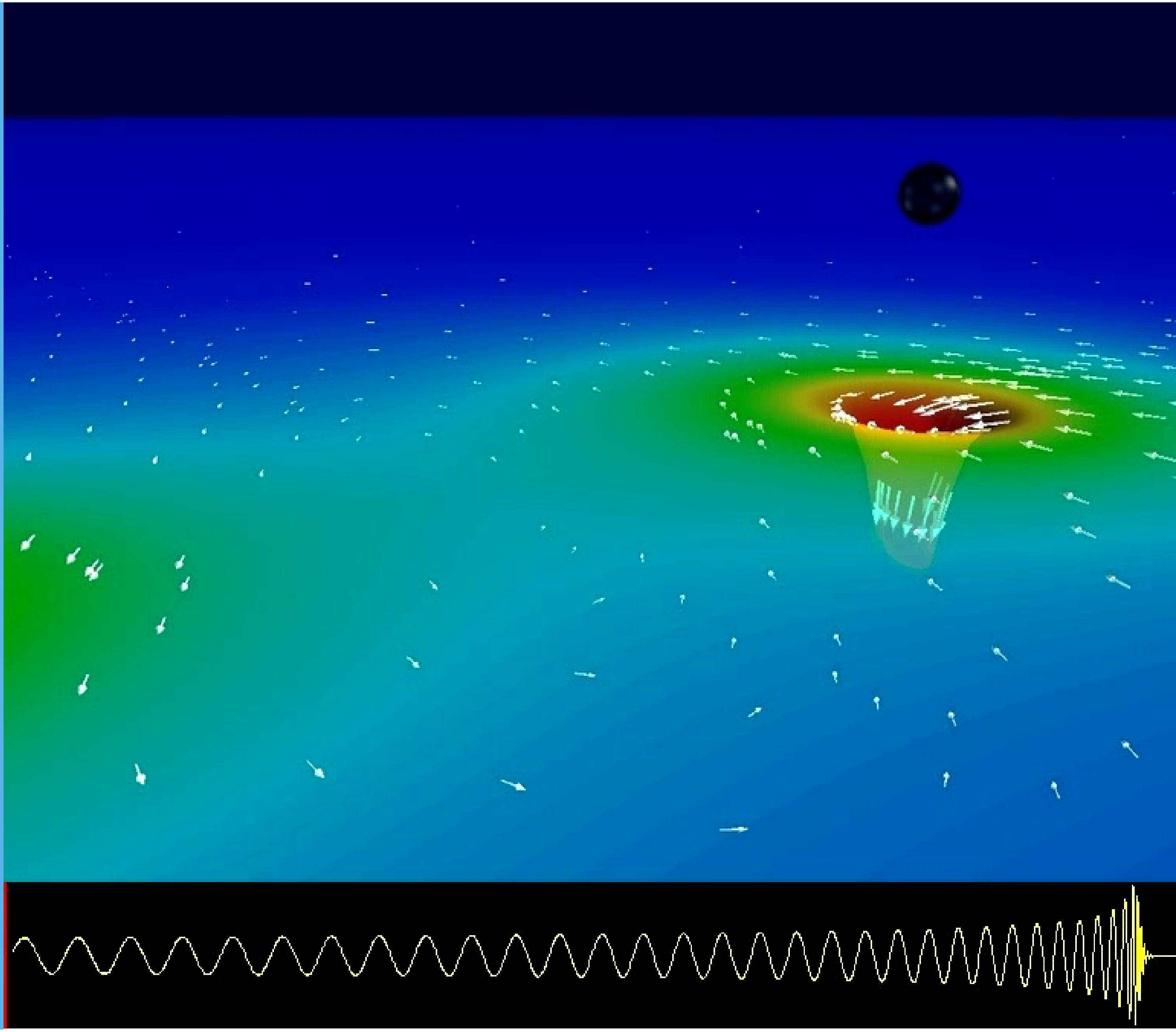


Advanced-detector era

Epoch			2015	2016 – 2017	2017 – 2018	2019+	2022+ (India)
Estimated run duration			3 months	6 months	9 months	(per year)	(per year)
Burst range/Mpc		LIGO	40 – 60	60 – 75	75 – 90	105	105
		Virgo	—	20 – 40	40 – 50	40 – 80	80
BNS range/Mpc		LIGO	40 – 80	80 – 120	120 – 170	200	200
		Virgo	—	20 – 60	60 – 85	65 – 130	130
BNS detections			0.0004 – 3	0.006 – 20	0.04 – 100	0.2 – 200	0.4 – 400
90% CR	% within	5 deg^2	< 1	2	*1 – 2*	*3 – 8*	*17*
		20 deg^2	< 1	14	*10 – 12*	*8 – 28*	*48*
	median/deg^2		481	235	—	—	—
searched area	% within	5 deg^2	6	20	—	—	—
		20 deg^2	16	44	—	—	—
	median/deg^2		88	29	—	—	—

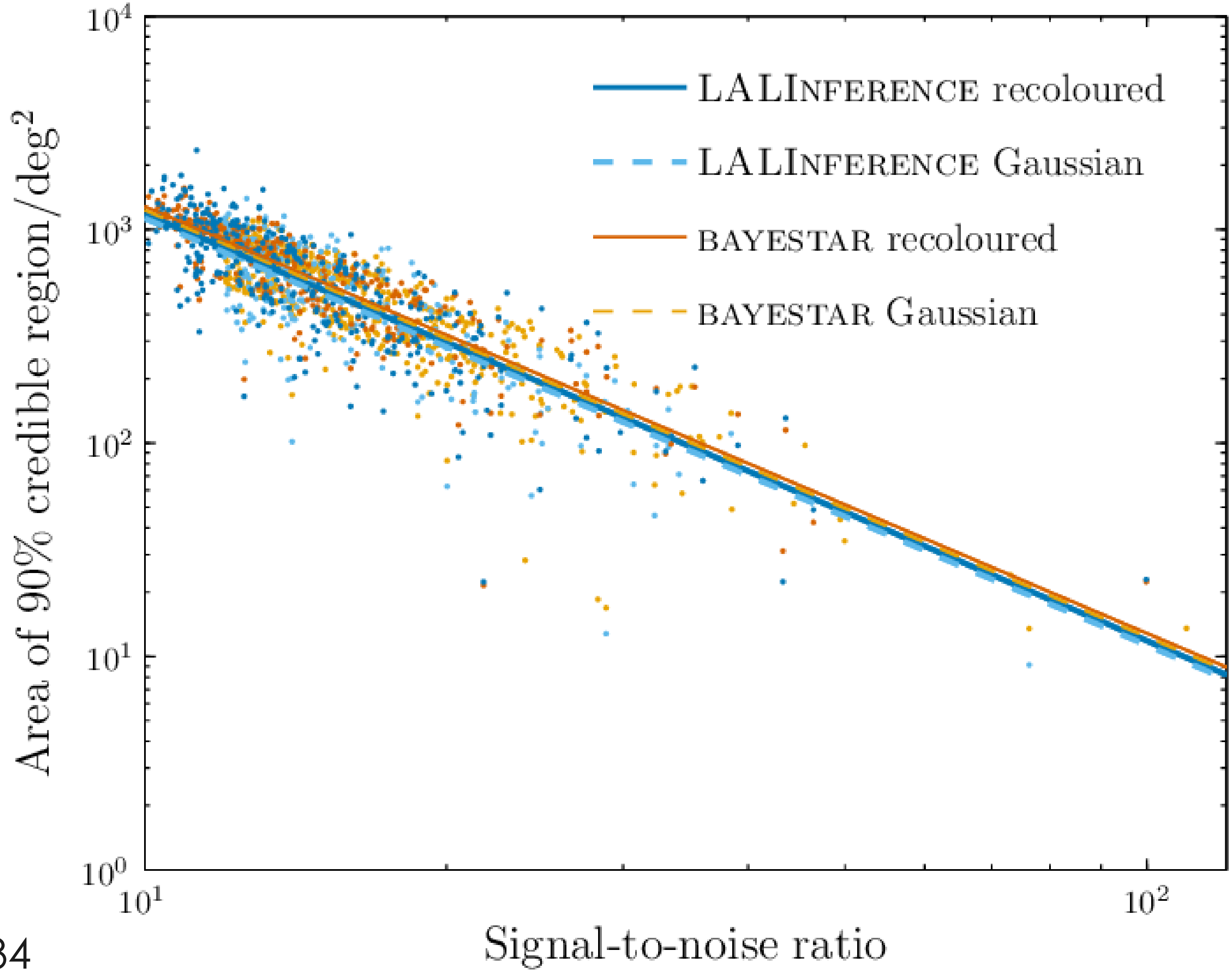
See arXiv:1304.0670

Binary black holes



Credit: Caltech-Cornell

Sky localization



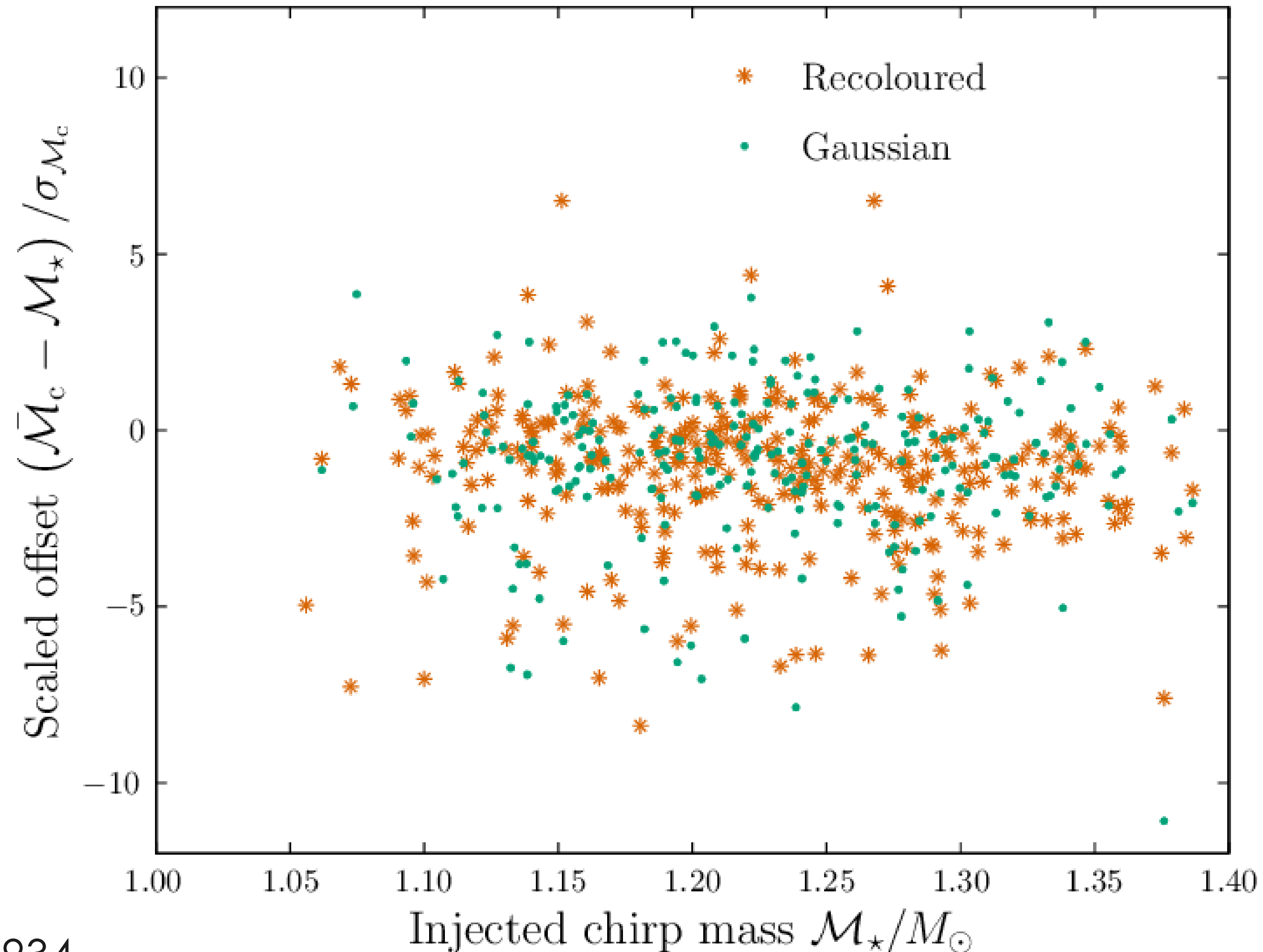
arXiv:1411.6934

Chirp mass

$$\mathcal{M}_{\mathrm{c}} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

Chirp mass gives leading-order amplitude and phase evolution (arXiv:0903.0338)

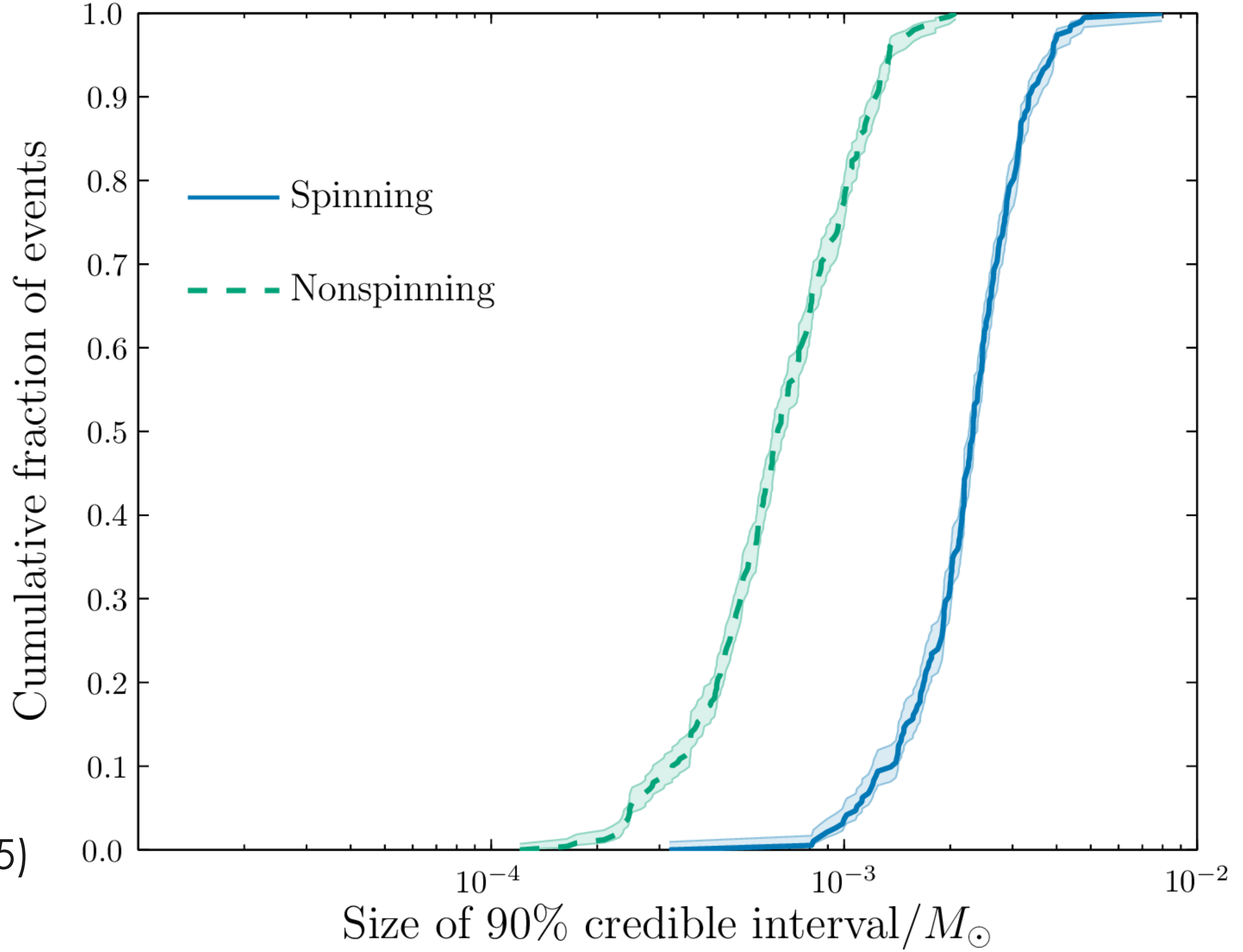
Chirp mass



arXiv:1411.6934

Chirp mass

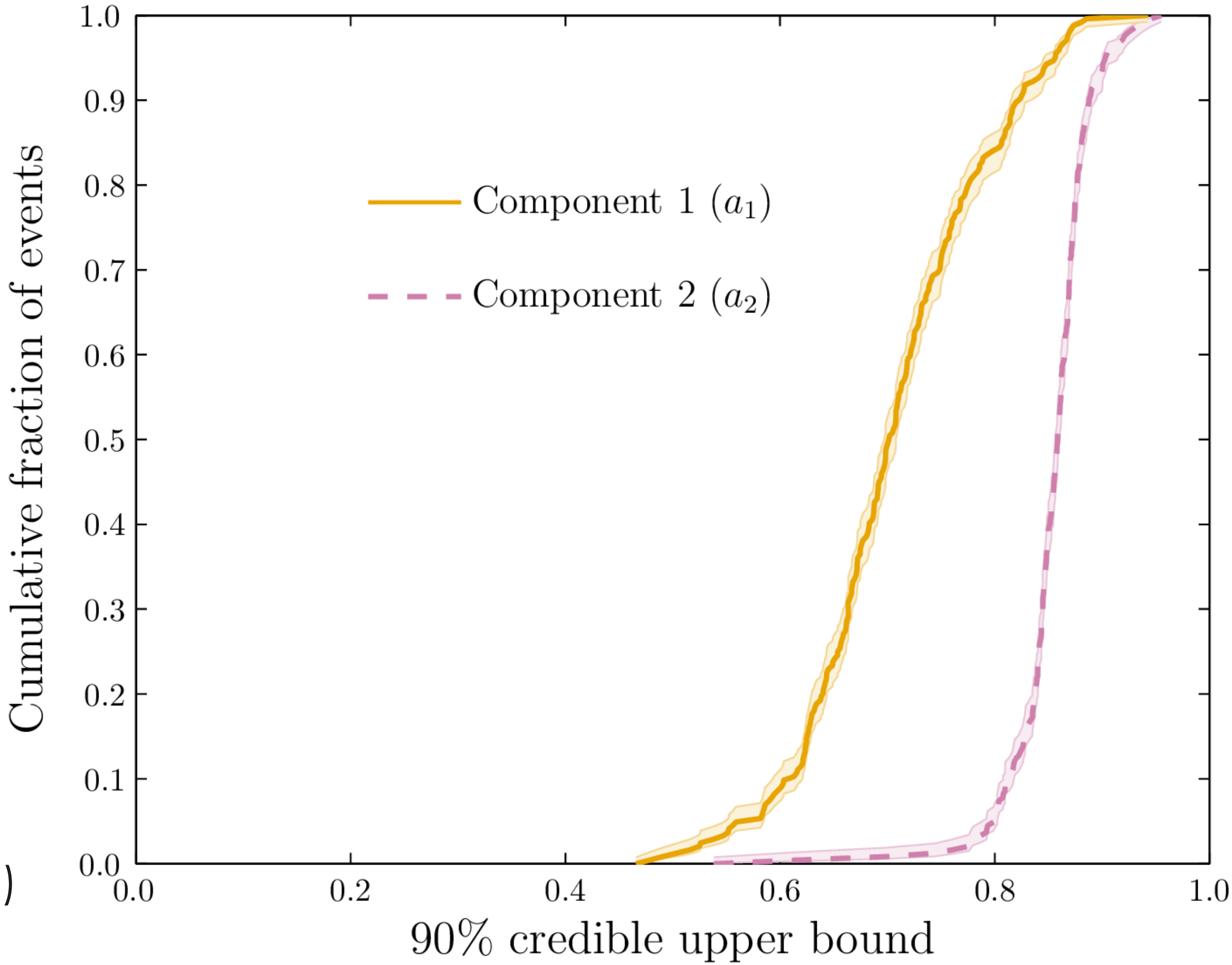
Preliminary



Farr *et al*. (2015) in prep.

Spin

Preliminary



Farr *et al*. (2015) in prep.