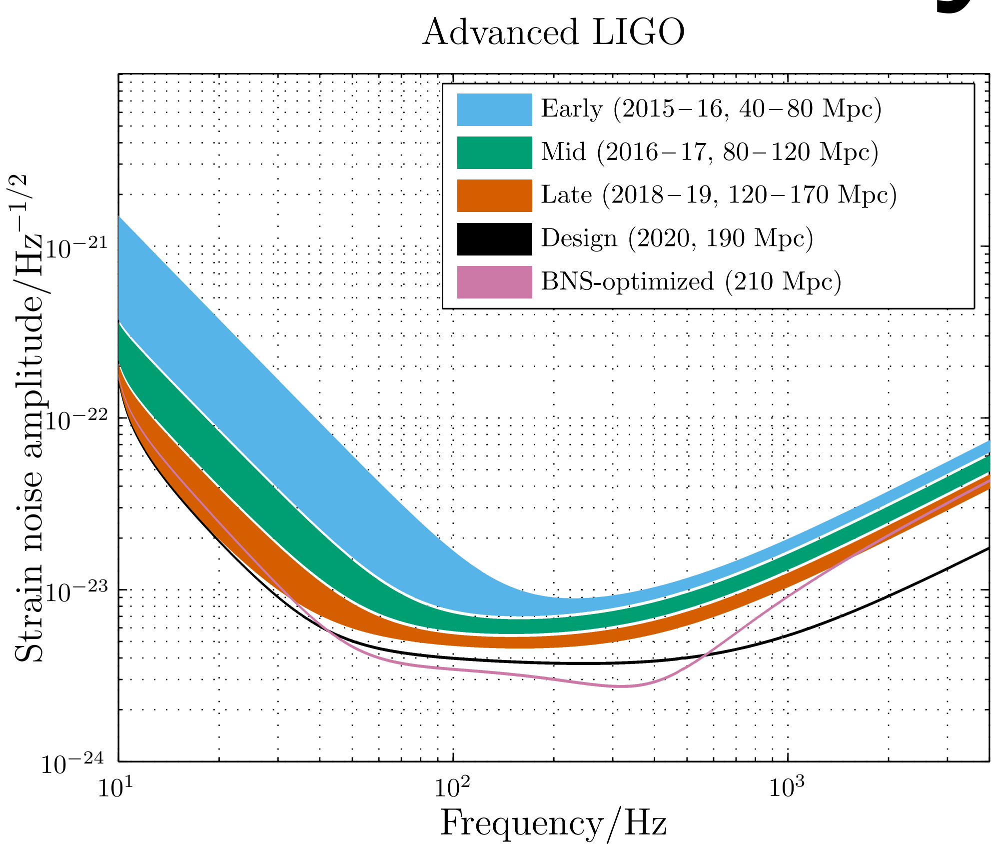
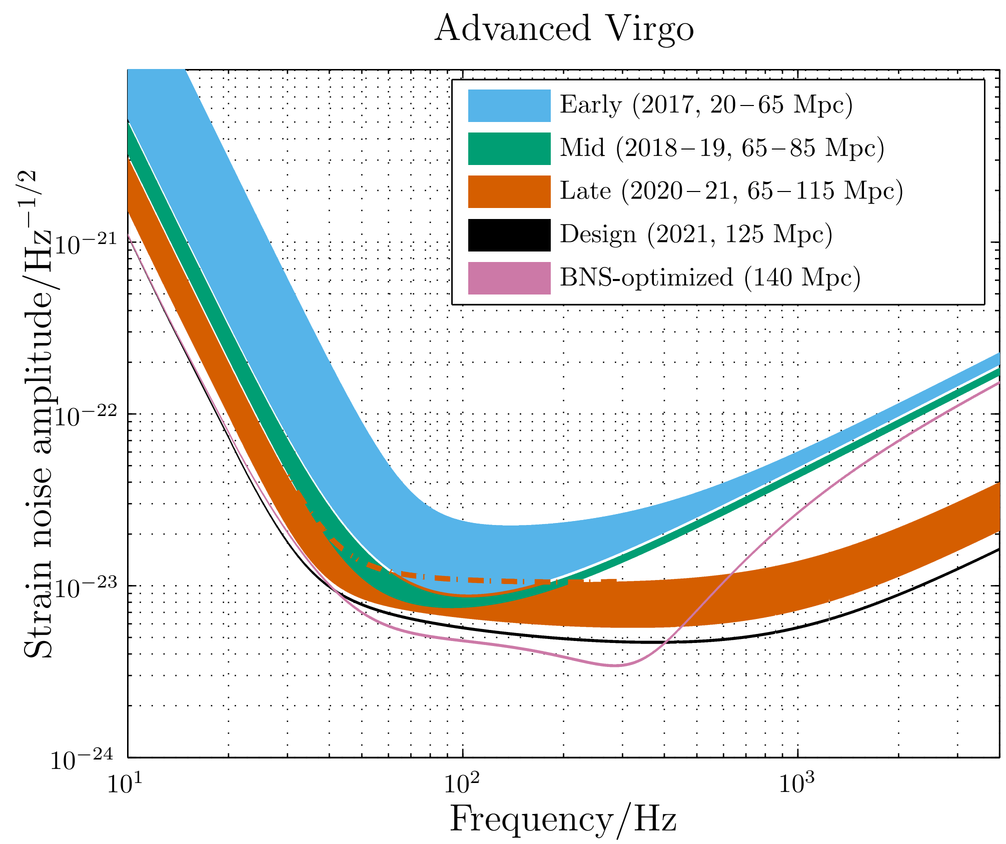
Future Gravitational Wave Observations

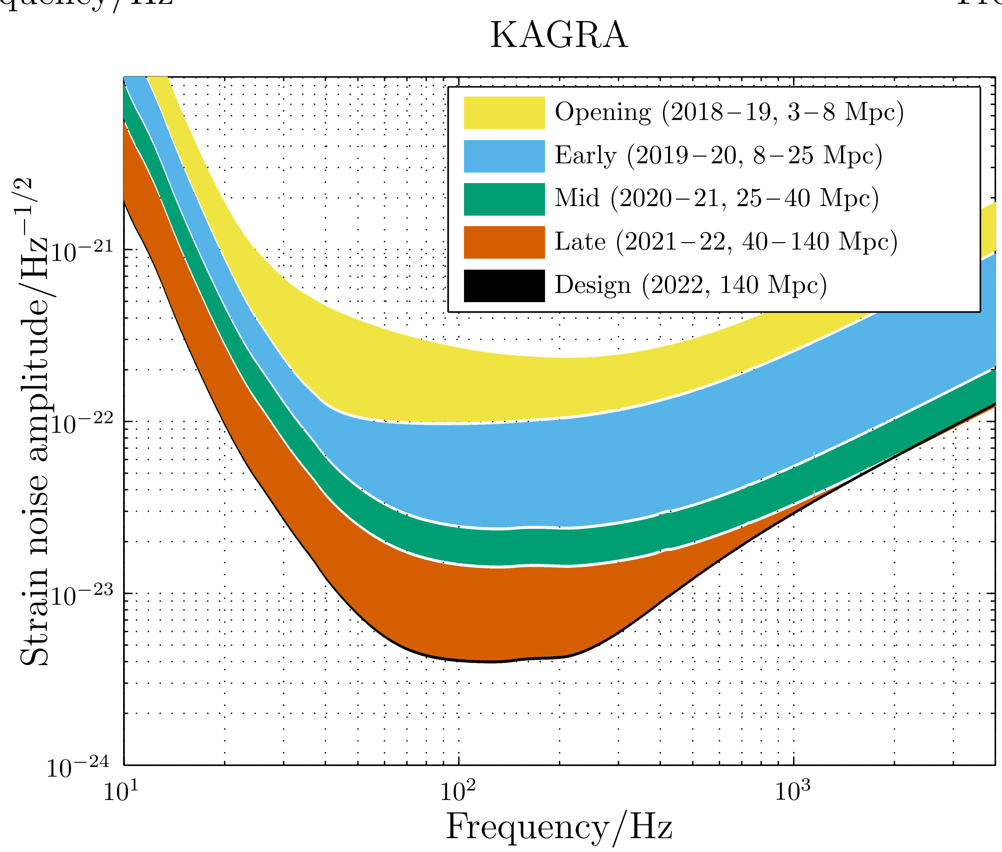
Stephen Fairhurst

GW170817: The First Double Neutron Star Merger
KITP, December 7, 2017

Sensitivity Evolution

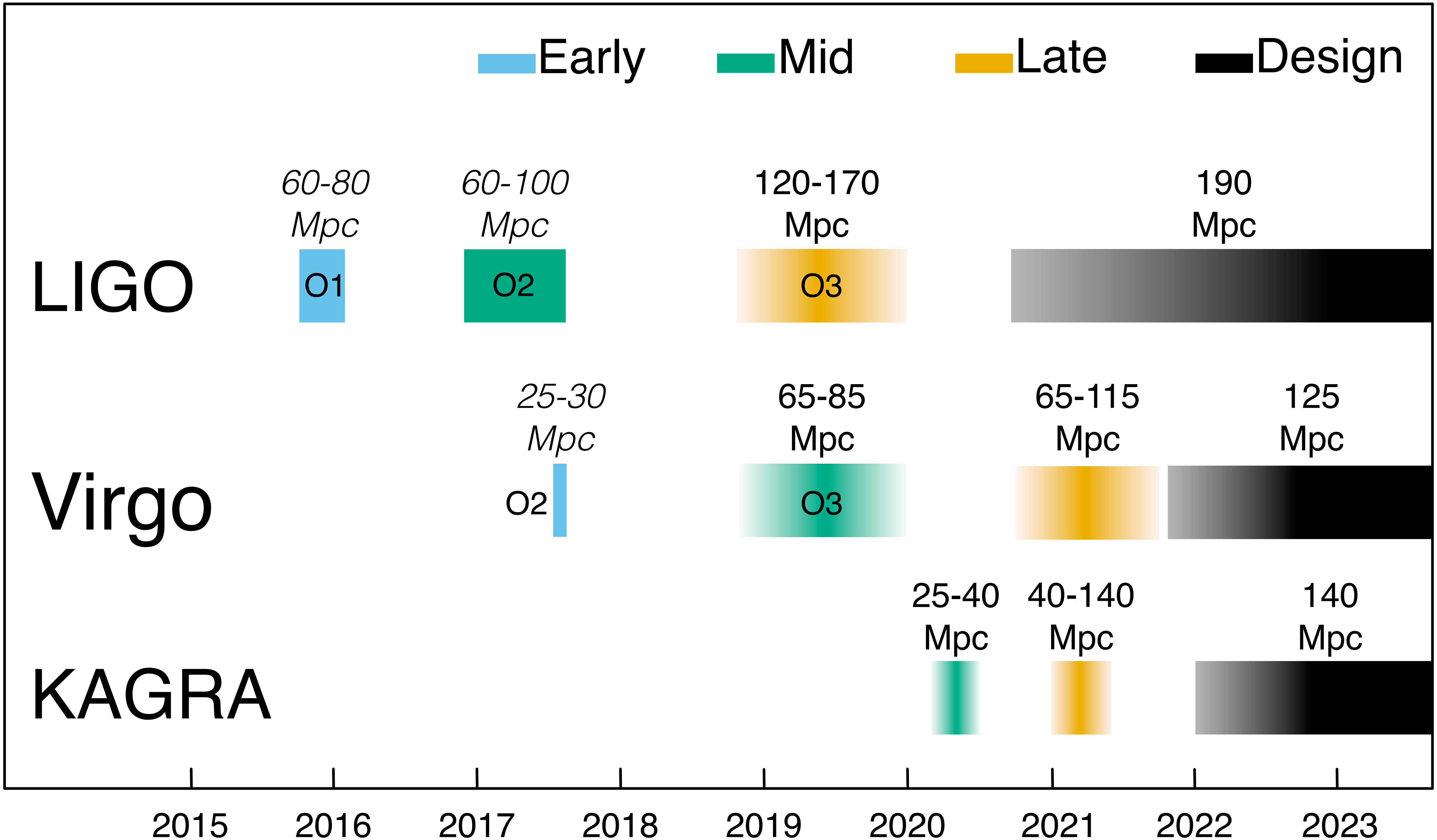






From Abbott et al, arXiv:1304.0670v4

Sensitivity Evolution



From Abbott et al, arXiv:1304.0670v4

Observing scenario

Epoch			2015 – 2016	2016 – 2017	2018 – 2019	2020+	2024+
Planned run duration			4 months	9 months	12 months	(per year)	(per year)
Expected burst range/Mpc		LIGO	40 – 60	60 – 75	75 – 90	105	105
		Virgo	—	20 – 40	40 – 50	40 – 70	80
		KAGRA	—	—	—	—	100
Expected BNS range/Mpc		LIGO	40 – 80	80 – 120	120 – 170	190	190
		Virgo	—	20 – 65	65 – 85	65 – 115	125
		KAGRA	—	—	—	—	140
Achieved BNS range/Mpc		LIGO	60 – 80	*60 – 100*	—	—	—
		Virgo	—	*25 – 30*	—	—	—
		KAGRA	—	—	—	—	—
Estimated BNS detections			0.002 – 2	0.007 – 30	0.04 – 100	0.1 – 200	0.4 – 400
Actual BNS detections			0	—	—	—	—
90% CR	% within	5 deg^2	< 1	1 – 5	1 – 4	3 – 7	23 – 30
		20 deg^2	< 1	7 – 14	12 – 21	14 – 22	65 – 73
	median/deg^2		460 – 530	230 – 320	120 – 180	110 – 180	9 – 12
Searched area	% within	5 deg^2	4 – 6	15 – 21	20 – 26	23 – 29	62 – 67
		20 deg^2	14 – 17	33 – 41	42 – 50	44 – 52	87 – 90

From Abbott et al, arXiv:1304.0670v4

Updated Expectations

- Use LIGO-Virgo BNS rate

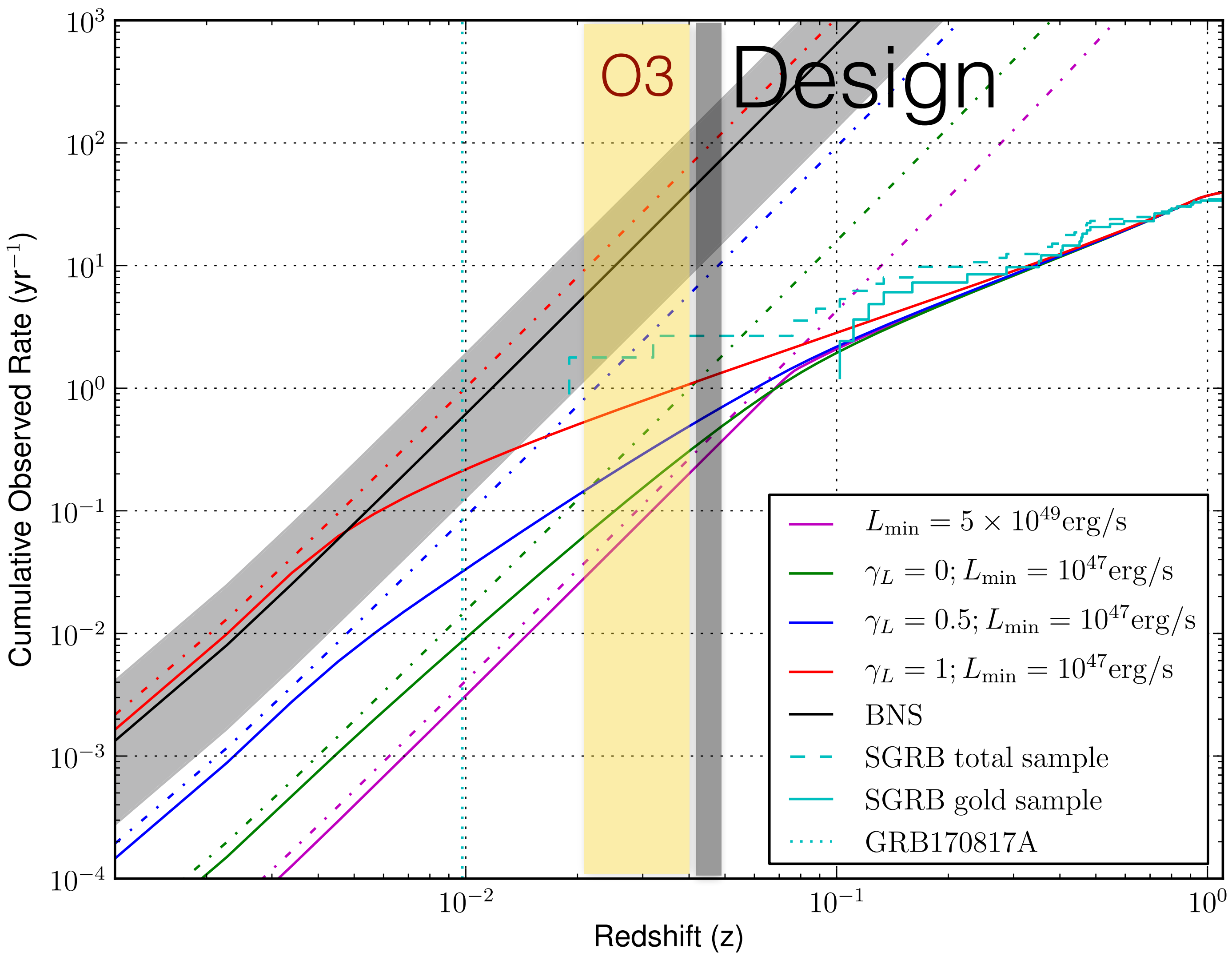
$$R = 1540^{+3200}_{-1220}\ \mathrm{Gpc^{-3}\,yr^{-1}}$$

- Extend GRB luminosity distribution down as

$L_{\star\star} = 5 \times 10^{49}$ erg s^{-1}:

$$\phi_o(L_{\rm iso}) = \begin{cases} \left(\frac{L_{\rm iso}}{L_{\star\star}}\right)^{-\gamma_L}\left(\frac{L_{\star\star}}{L_{\star}}\right)^{-\alpha_L} & L_{\rm iso} < L_{\star\star} \\ \left(\frac{L_{\rm iso}}{L_{\star}}\right)^{-\alpha_L} & L_{\star\star} < L_{\rm iso} < L_{\star}, \\ \left(\frac{L_{\rm iso}}{L_{\star}}\right)^{-\beta_L} & L_{\rm iso} > L_{\star} \end{cases}$$

- Fit GRB rate to 40 per year observed in Fermi GBM



From "Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger"

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		Virgo	—	*25 – 30*	—	—	—
		KAGRA	—	—	—	—	—
Estimated BNS detections			0.002 – 2	0.007 – 30	**1 - 50**	**6 - 120**	0.4 – 400
Actual BNS detections			0	**1**	—	—	—
90% CR	% within	5 deg^2	< 1	1 – 5	1 – 4	3 – 7	23 – 30
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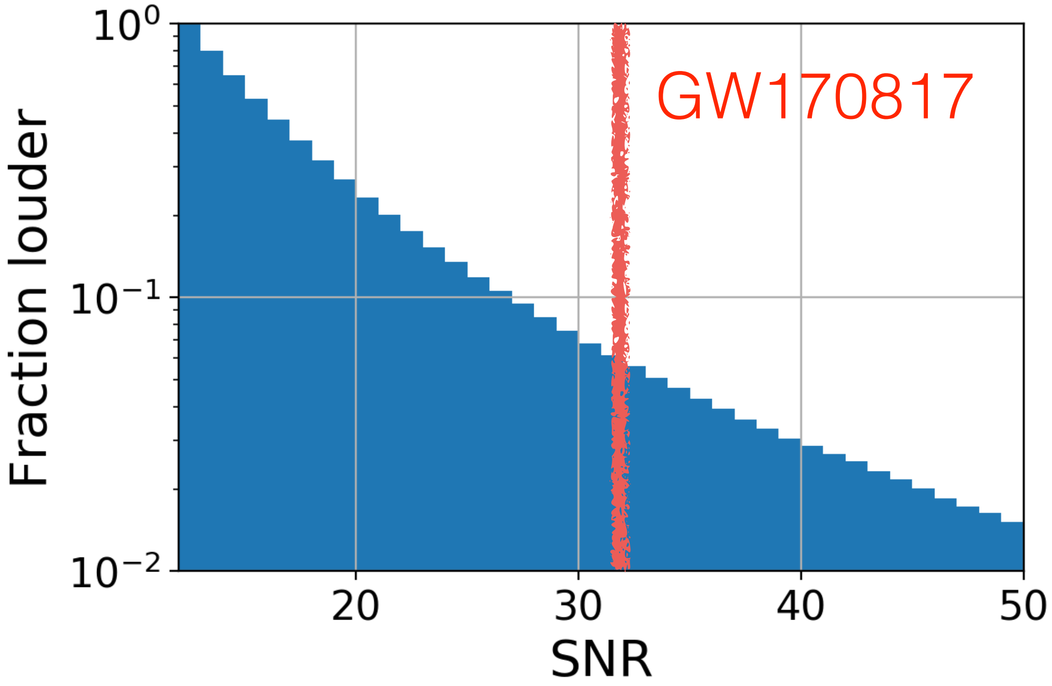
Searched area	% within	5 deg^2	4 – 6	15 – 21	20 – 26	23 – 29	62 – 67
		20 deg^2	14 – 17	33 – 41	42 – 50	44 – 52	87 – 90
Estimated GW-GRB					**0.1 - 1.4**	**0.3 - 1.7**	
Actual GW-GRB				**1**	-	-	

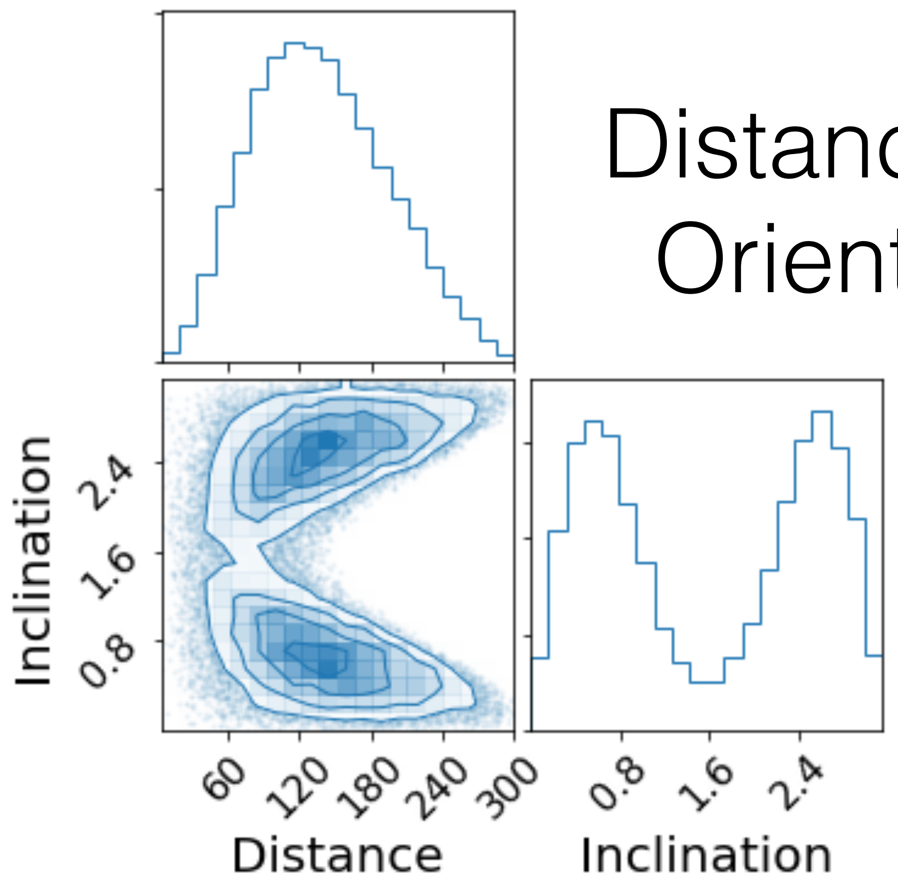
From “Gravitational Waves and Gamma-Rays from a Binary Neutron Star Merger”

Expected O3 Observations

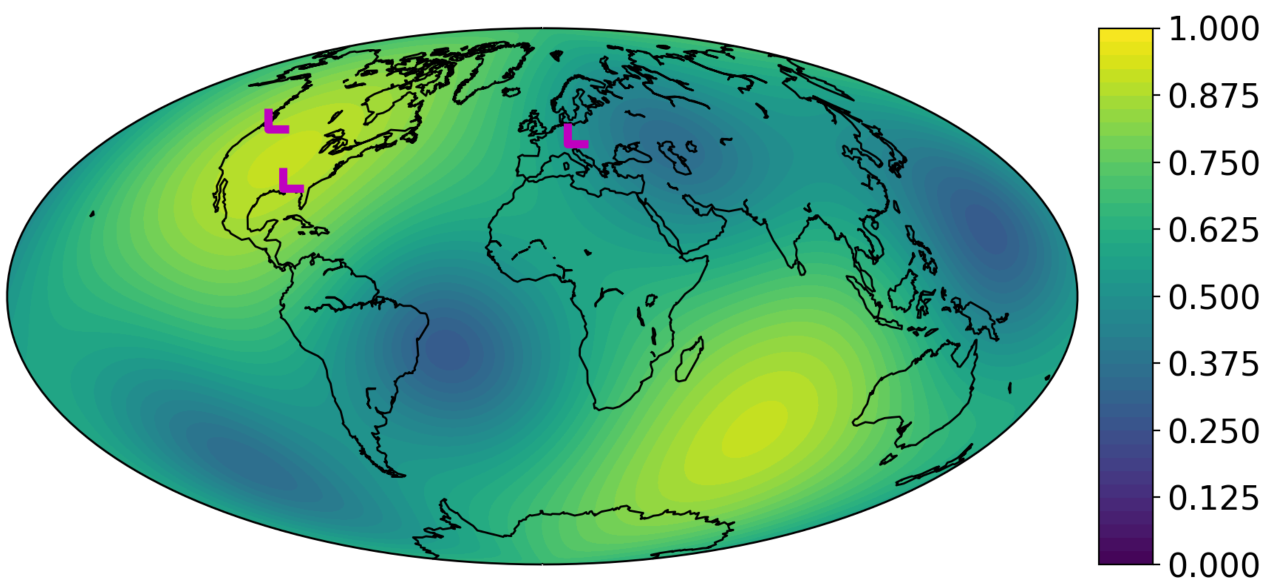
Signal to noise ratio



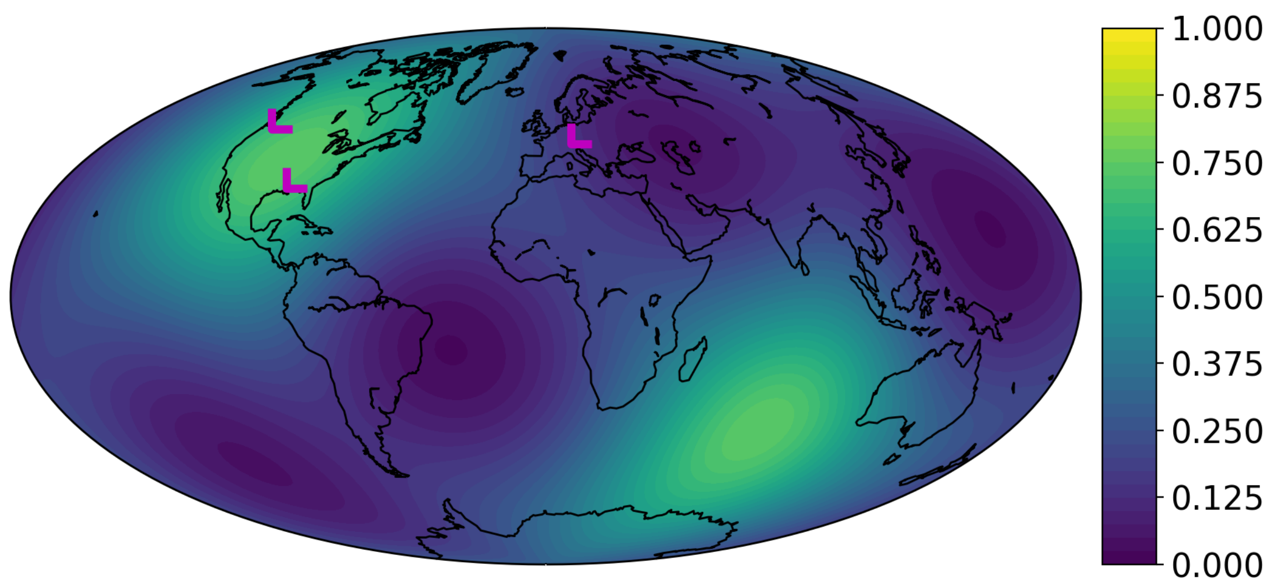
Distance and Orientation



Relative Sensitivity

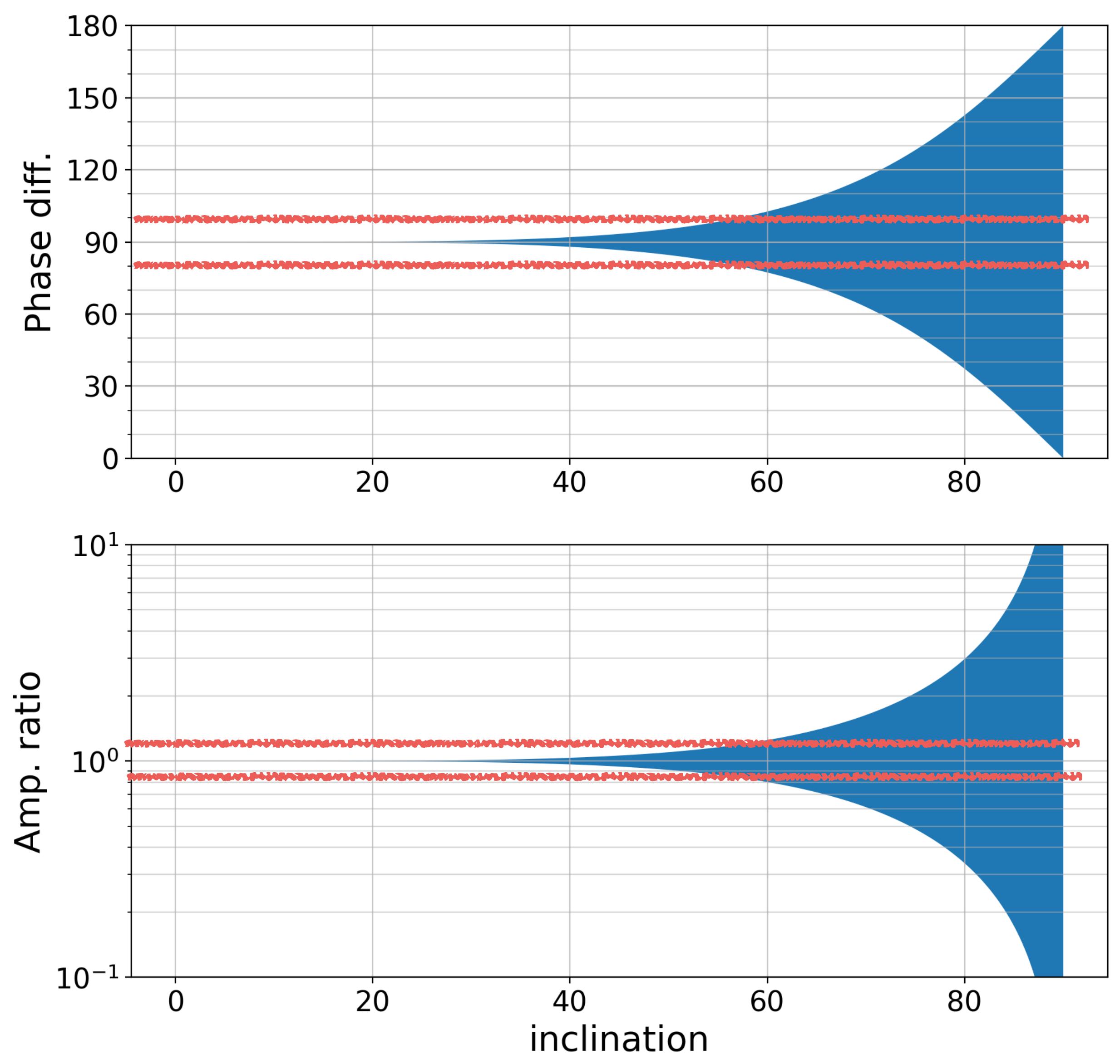


Rate density



Measuring Inclination

- Face-on signals are left/right circularly polarized
- To bound inclination, need to observe difference from circular polarization
- Require good sensitivity to both GW polarizations



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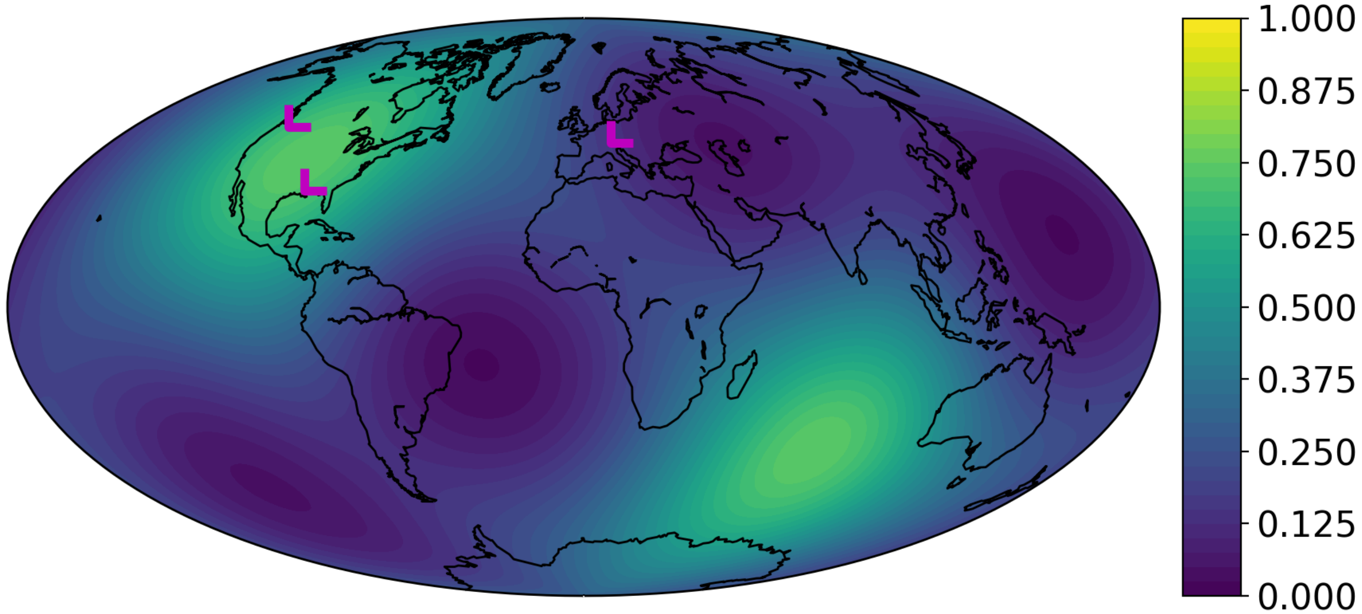
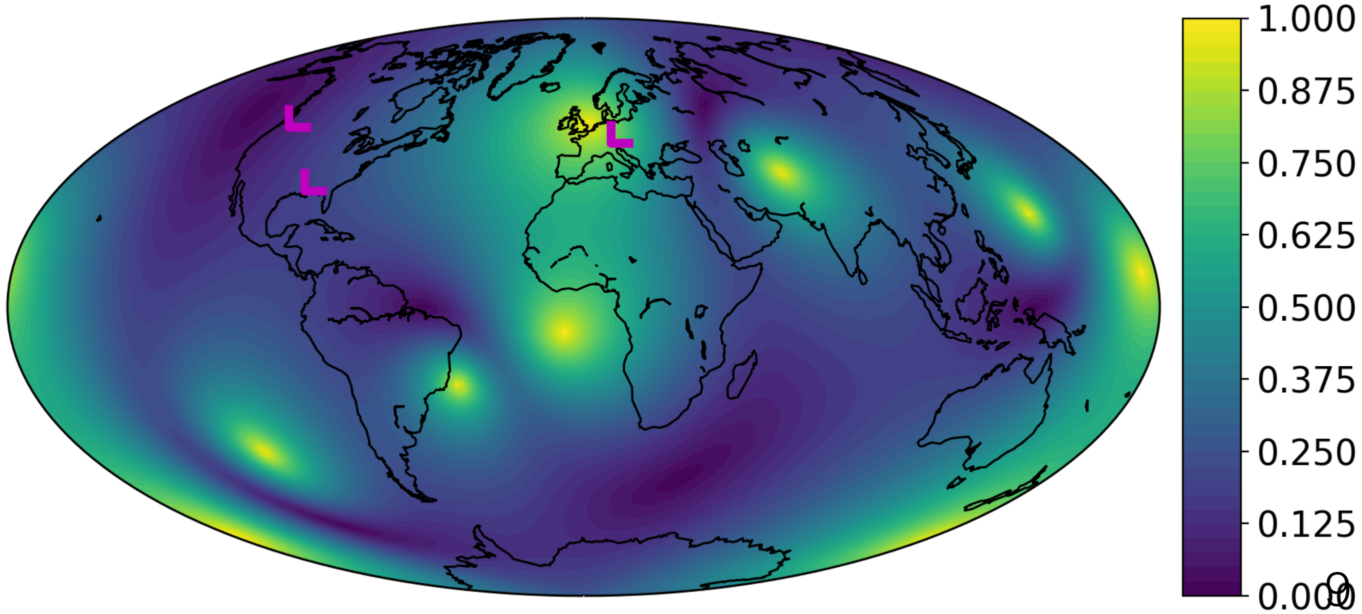
Volume weighted sensitivity



Relative sensitivity to 2nd polarization

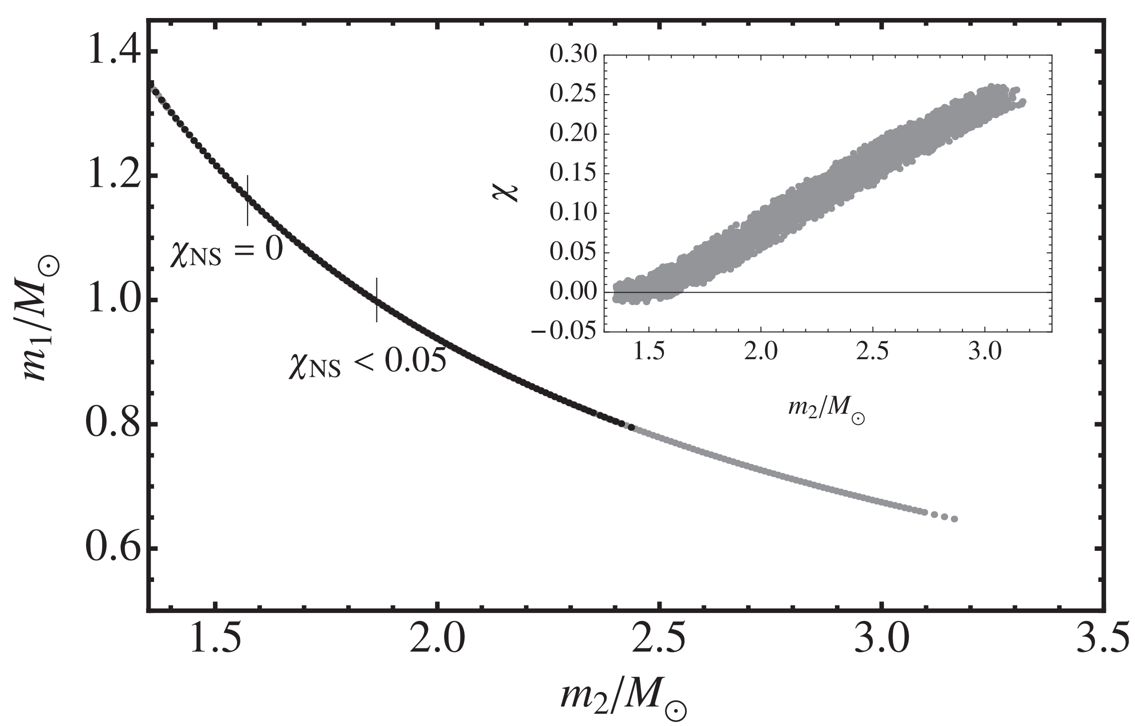


GW only observations

- Will measure chirp mass well, not component masses

(Hannam+, 2013)

HANNAM ET AL.



- Will increasingly move towards population based statements on masses, spins, equation of state

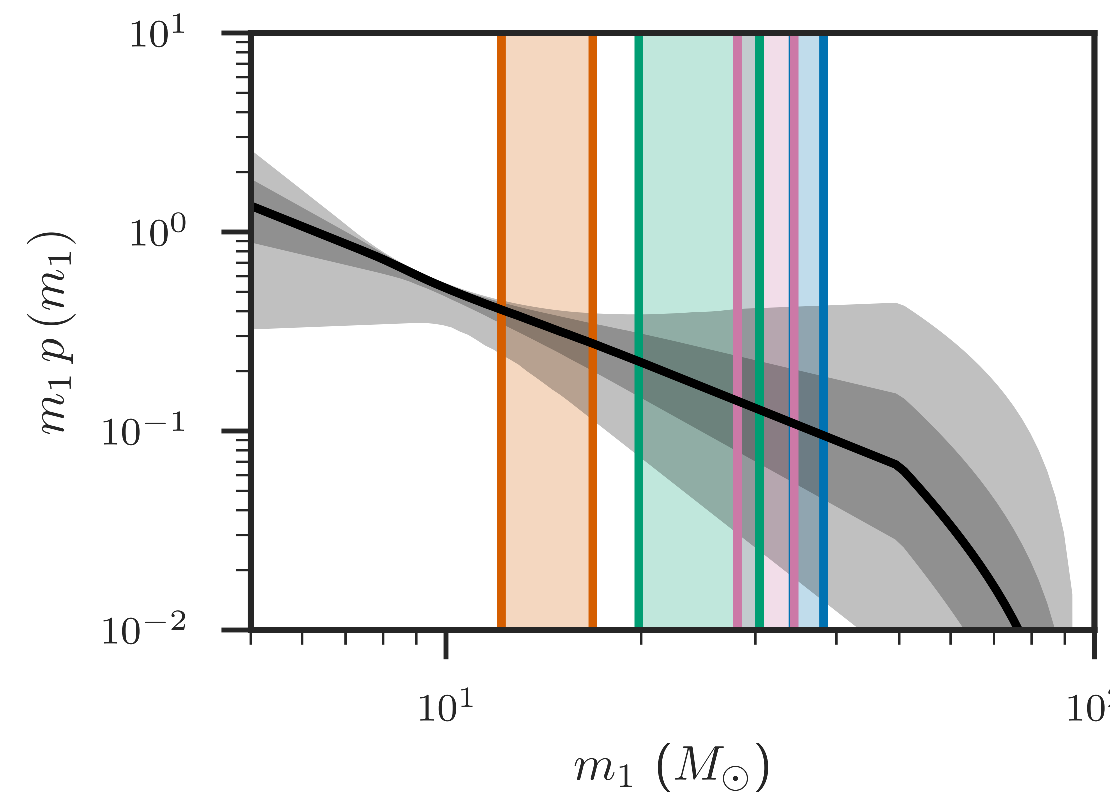
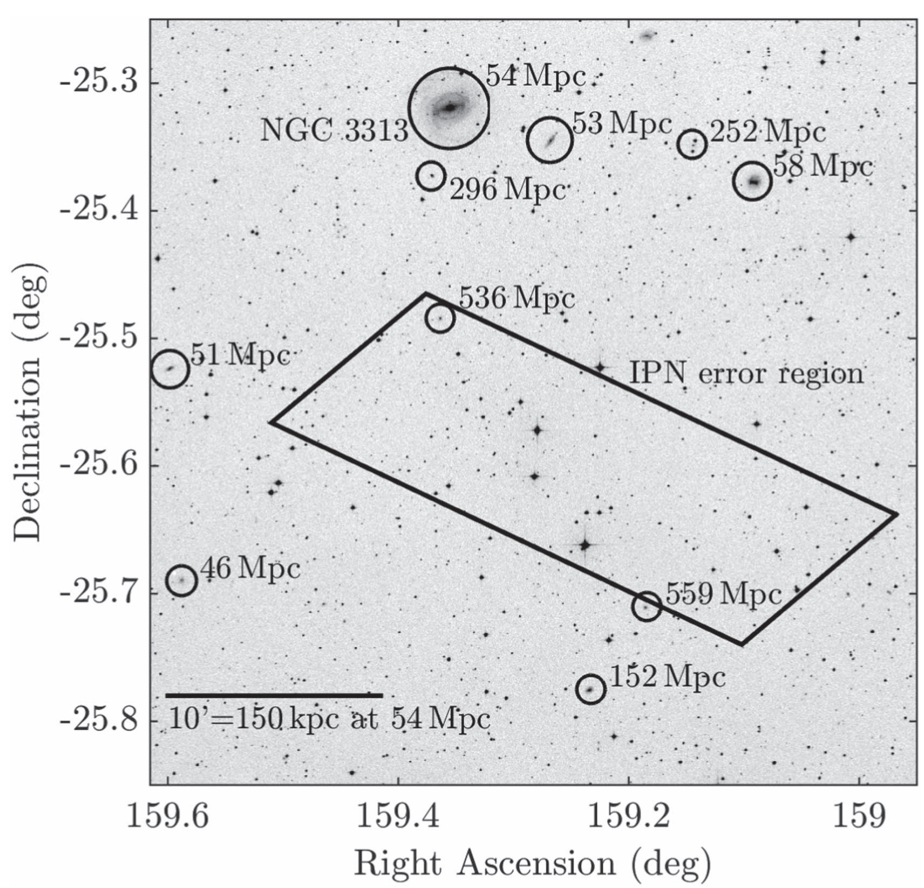


FIG. 8. The posterior probability distribution for the primary component mass m_1 of binary black holes inferred from the hierarchical analysis. The black line gives the posterior median as a function of mass, and the dark and light grey bands give the 50% and 90% credible intervals. The colored vertical bands give the 50% credible interval from the posterior on m_1 from the analyses of (left to right) GW151226, LVT151012, GW170104, and GW150914. The marginal mass distribution is a power law for $m_1 \le 50\,M_\odot$, and turns over for $m_1 \ge 50\,M_\odot$ due to the constraint on the two-dimensional population distribution that $m_1 + m_2 \le 100\,M_\odot$.

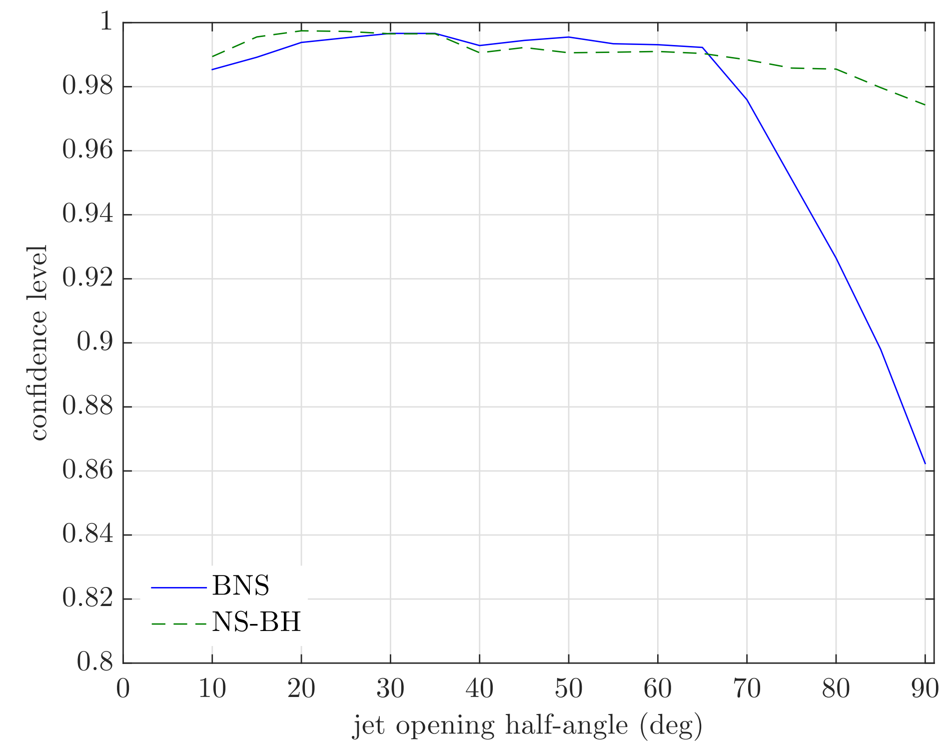
GW170104 supplemental material

GRB only observations

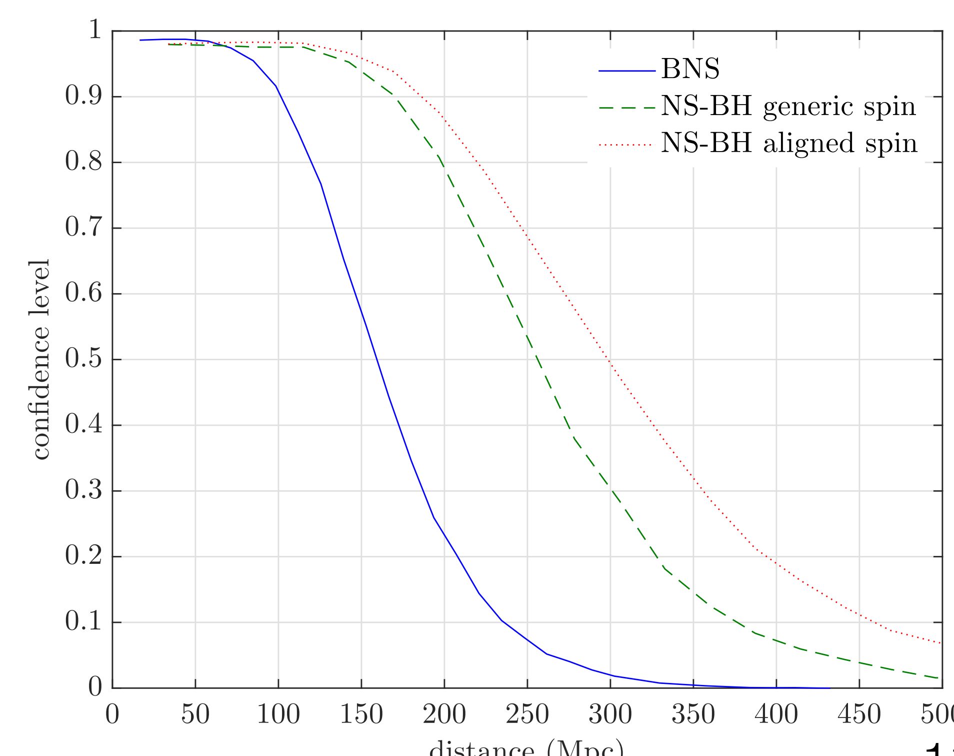
- Dedicated search [−5, +1) s from time of short GRBs
- With no detection, place exclusion
- Example: GRB150906B



Exclusion confidence at 54 Mpc



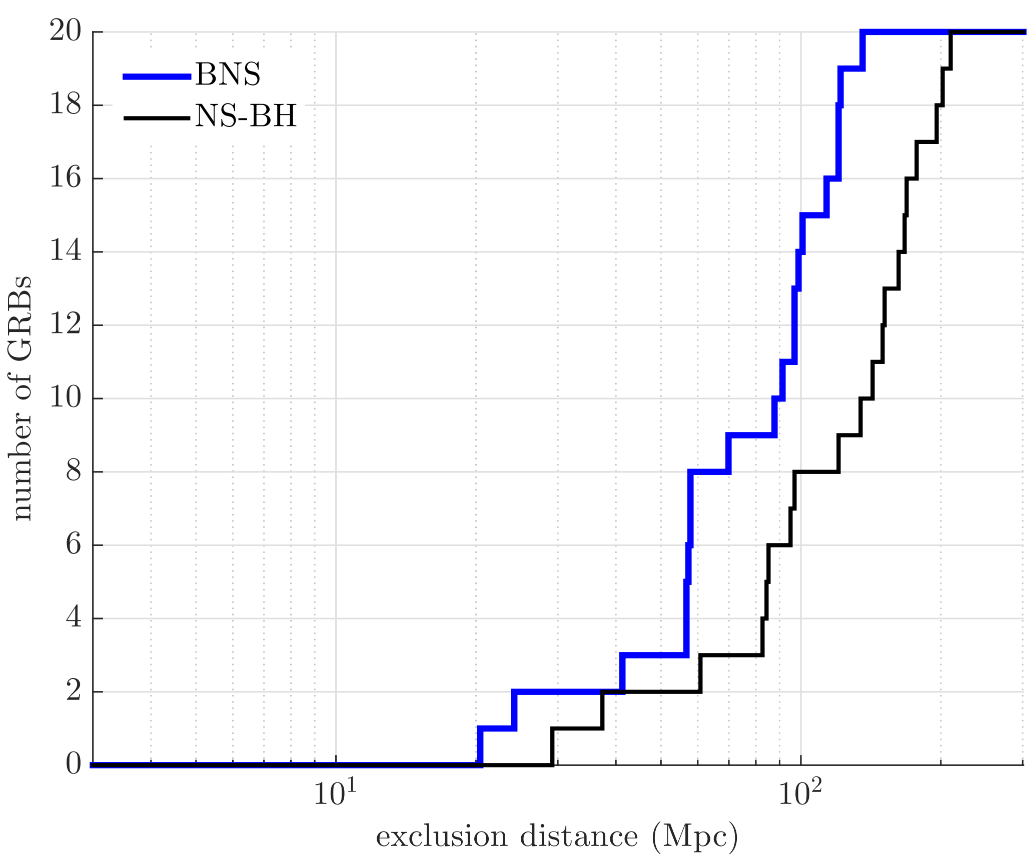
90% exclusion distance (max 30° opening)



From Abbott et al, arXiv:1611.07947

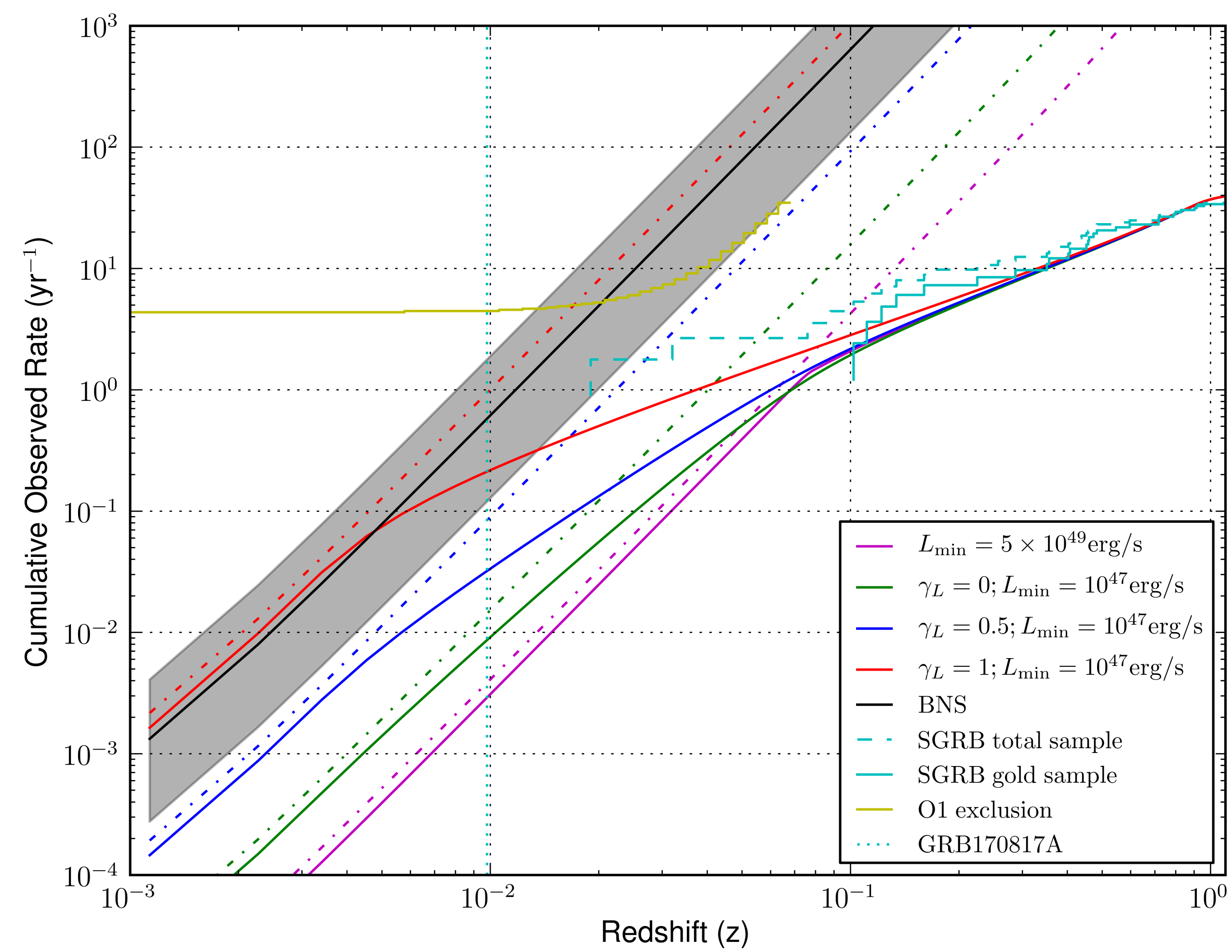
GRB only observation

- Population exclusion from O1



From Abbott et al, arXiv:1611.07947

- With future observations, begin to restrict fraction of nearby GRBs

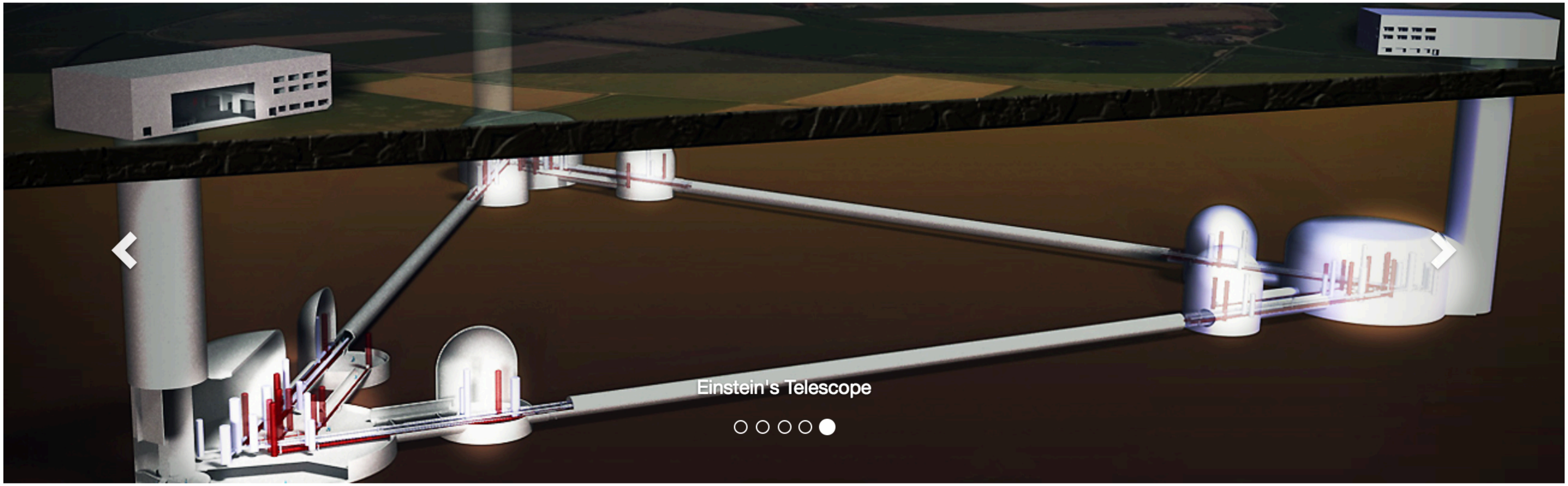


Discussion

- Expect binary neutron star merger observations in upcoming LIGO-Virgo-KAGRA observing runs
- Majority of sources expected to be weaker and at greater distance than GW170817
- Joint, GW only and EM only observations allow us to probe NS properties, GRBs and kilonovae.

GWIC 3G

Planning for a 3rd Generation Ground-based Gravitational-wave Observatory Network



Expanding the Reach of Gravitational Wave Astronomy to the Edge of the Universe

Science Case Team

Chairs: Kalogera, Sathayprakash

Register

https://gw-astronomy.org/registry/pages/public/gwic-3g-sct-wg-sign-up

- Analytical and Numerical Relativity: *Buonanno, Lehner*
- Compact Binaries: *Bailes, Kalogera, Mandel*
- Cosmology: *Mandic, Sathyaprakash*
- Detector Networks: *Evans, Fairhurst, Hild*
- Extreme Gravity: *Buonanno, Van Den Broeck*
- Multi-Messenger Observations: *Bailes, Kasliwal*
- Neutron stars: *Papa, Reddy, Rosswog*
- Seed Black Holes: *Colpi, Fairhurst*
- Supernovae: *Bizourd, Burrows*