STATUS OF LIGO AND VIRGO SEARCHES FOR NEUTRON STAR BINARIES & SUPERNOVAE

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FOR THE LIGO SCIENTIFIC AND VIRGO COLLABORATIONS

OUTLINE

- Initial detector results
- Status of advanced detectors
- Searches and parameter extraction
- Multi-messenger searches

GRAVITATIONAL WAVE NETWORK

LIGO Hanford, USA

LIGO Livingston, USA

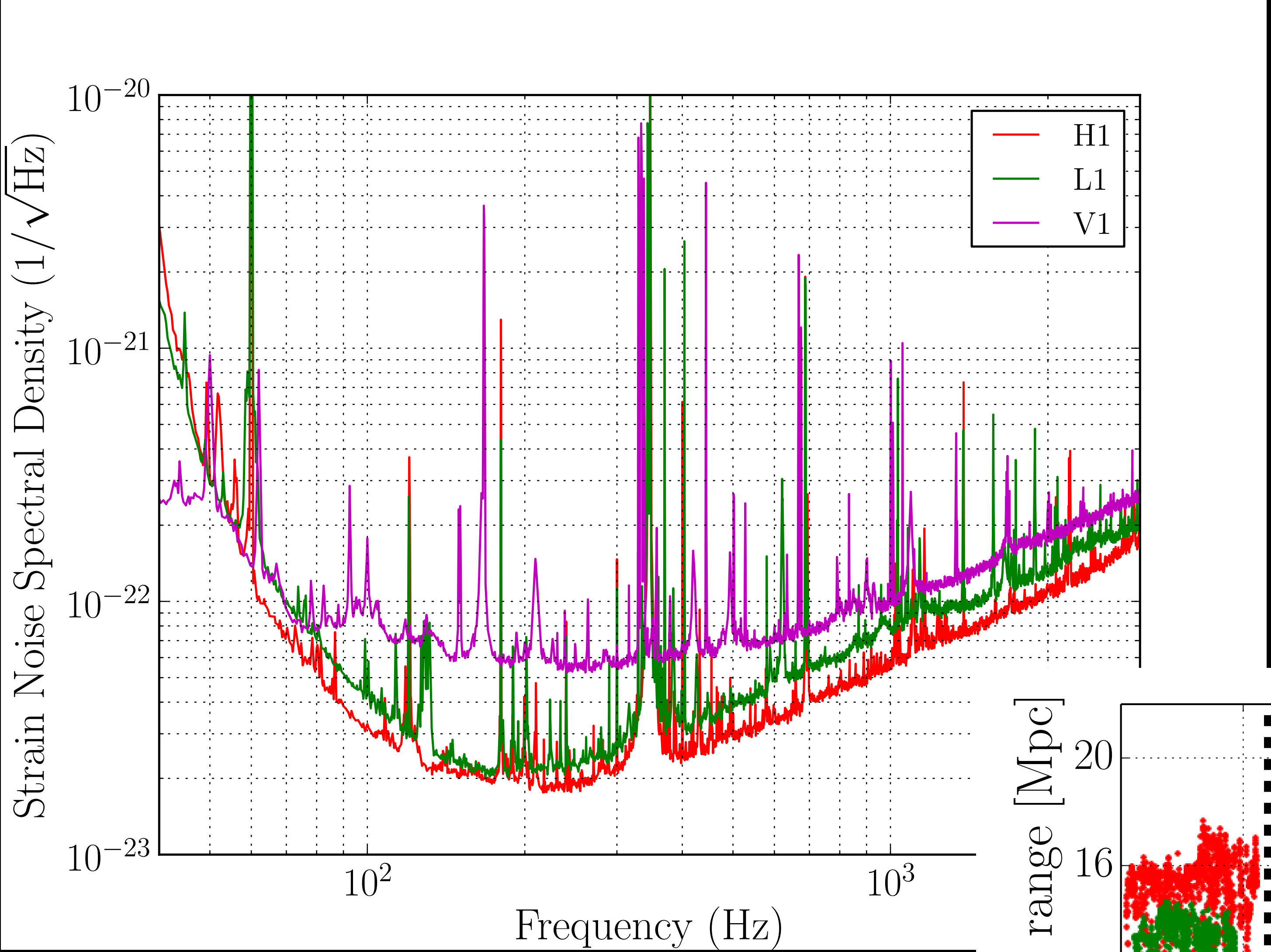
KAGRA, Japan

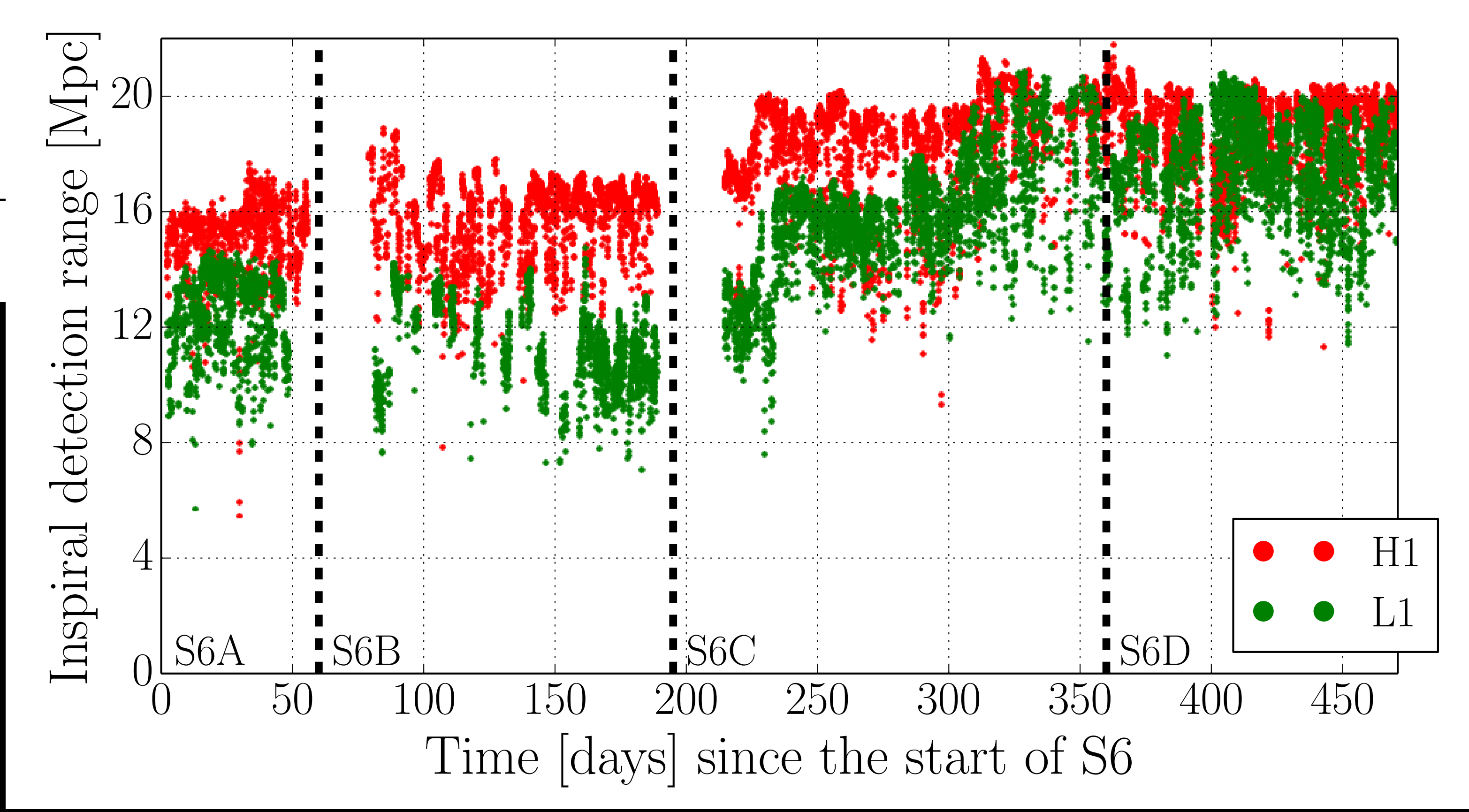
LIGO India

GEO 600, Germany

Virgo, Italy

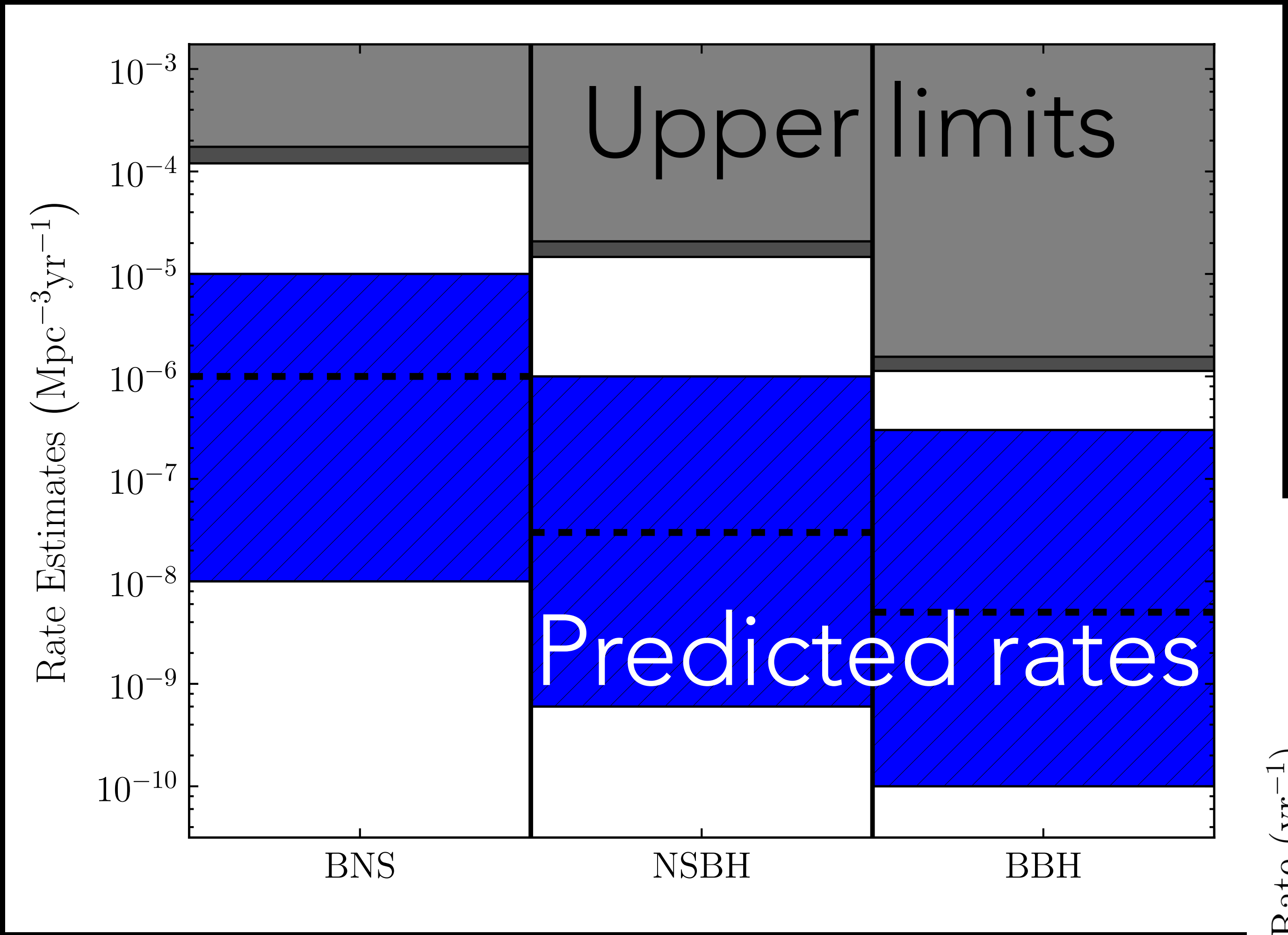
INITIAL DETECTOR SENSITIVITIES

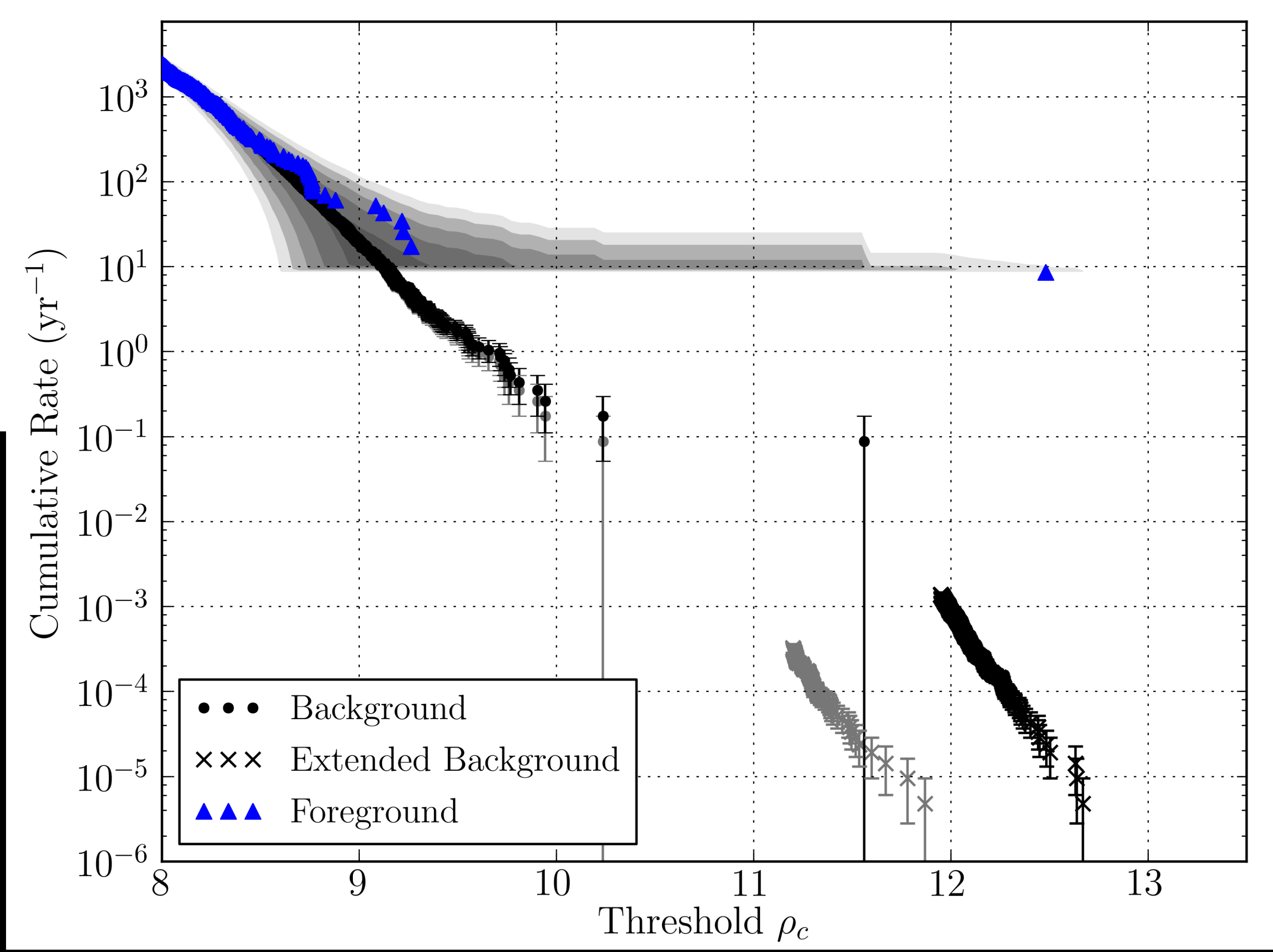




From Abadie et al, PRD (2012)
Aasi et al, CQG (2015)

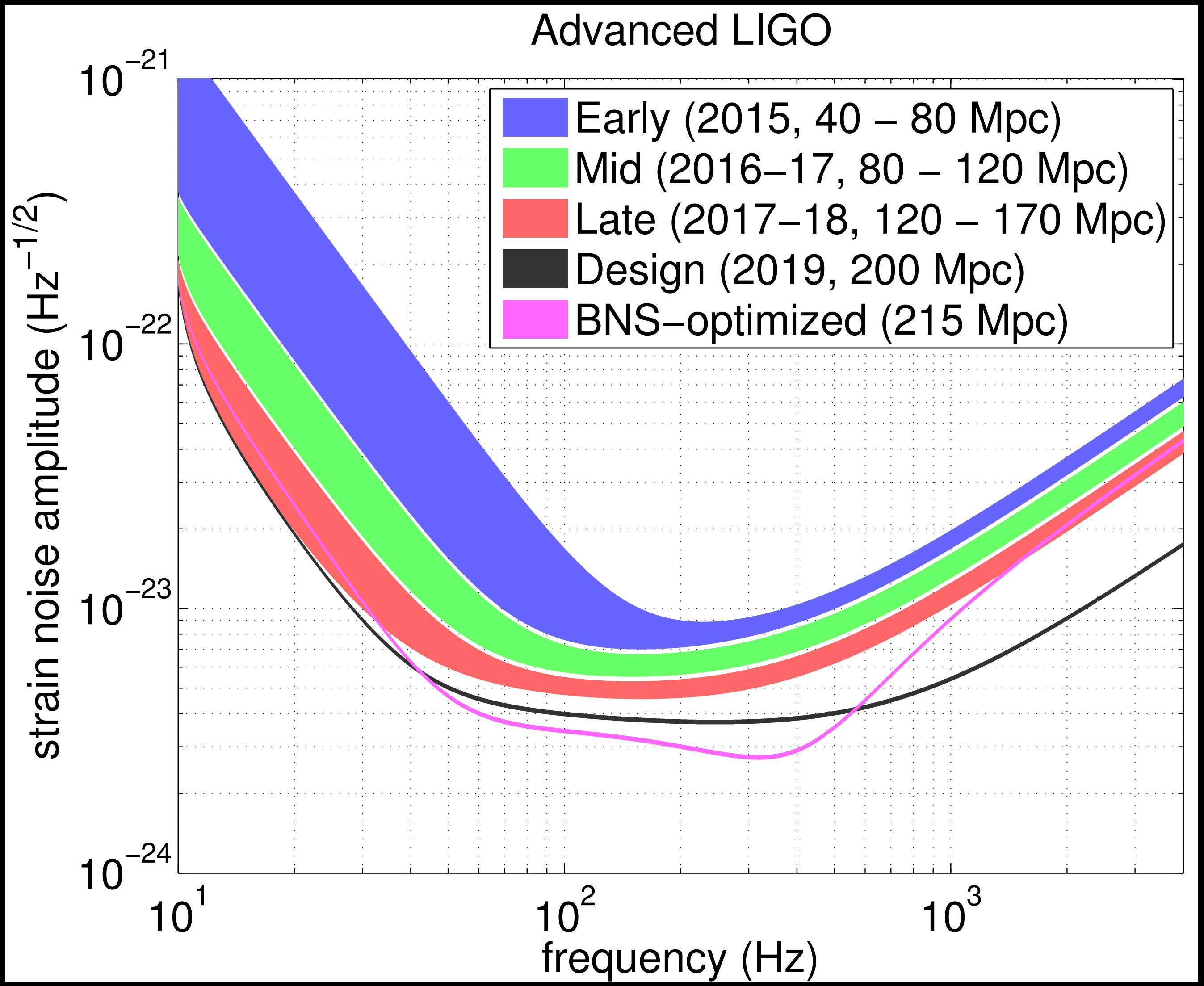
BINARY MERGER RESULTS

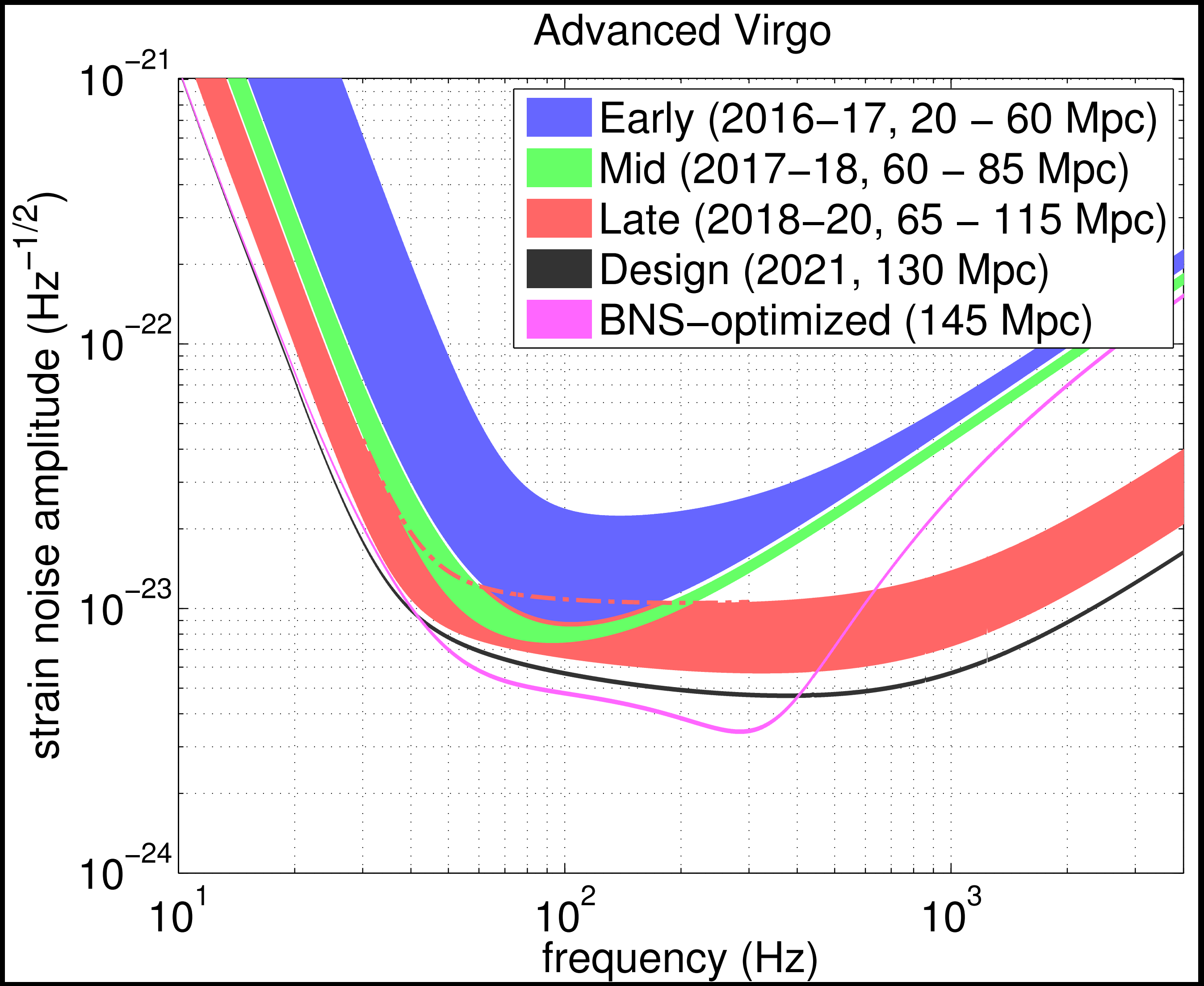




From Abadie et al, PRD (2012)

ADVANCED DETECTOR PROSPECTS

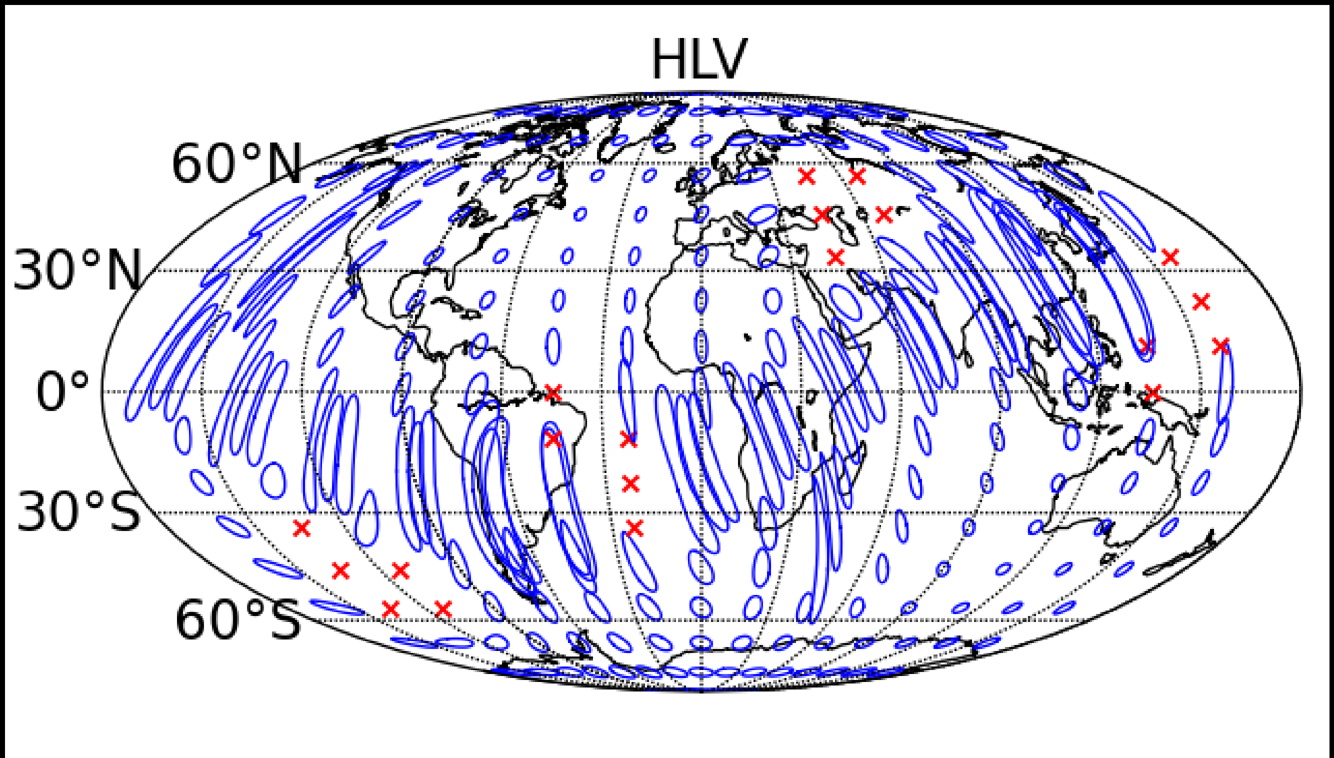


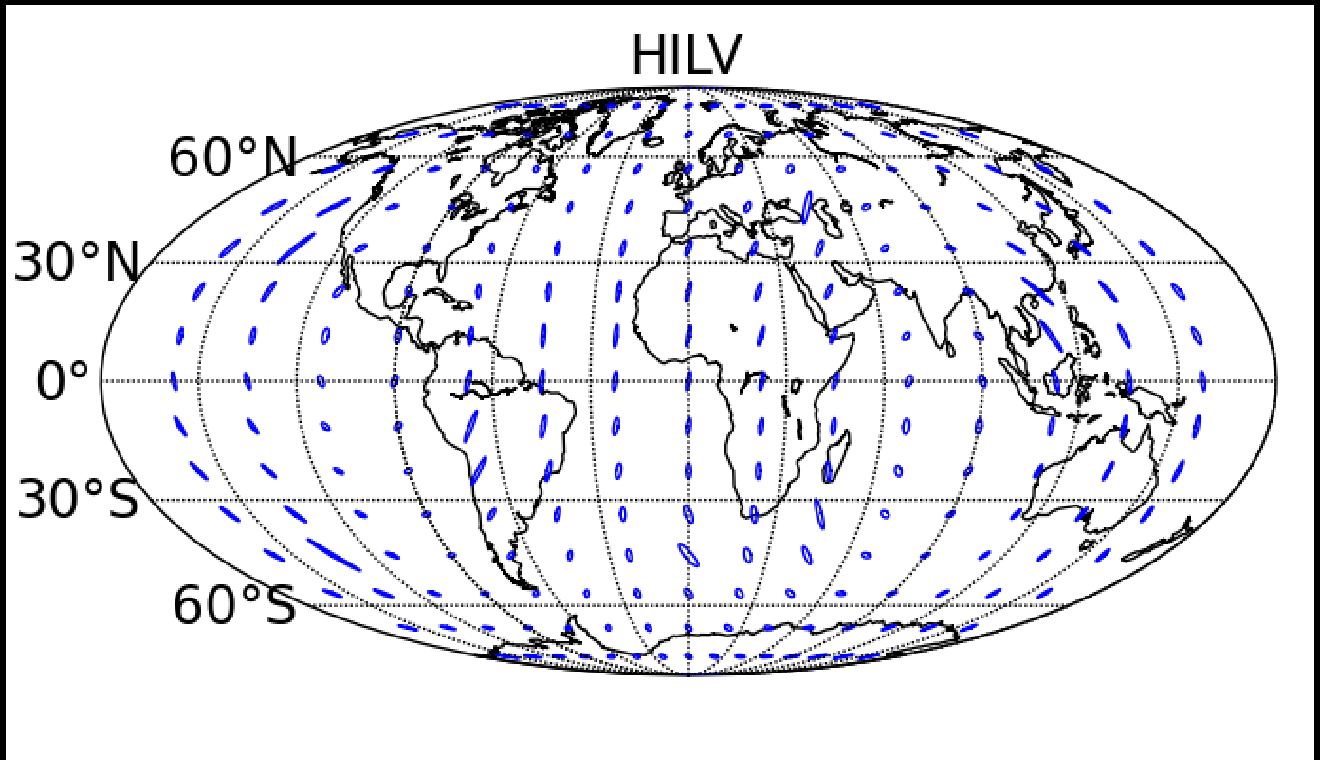


From Aasi et al, 2013

RATES & LOCALIZATION

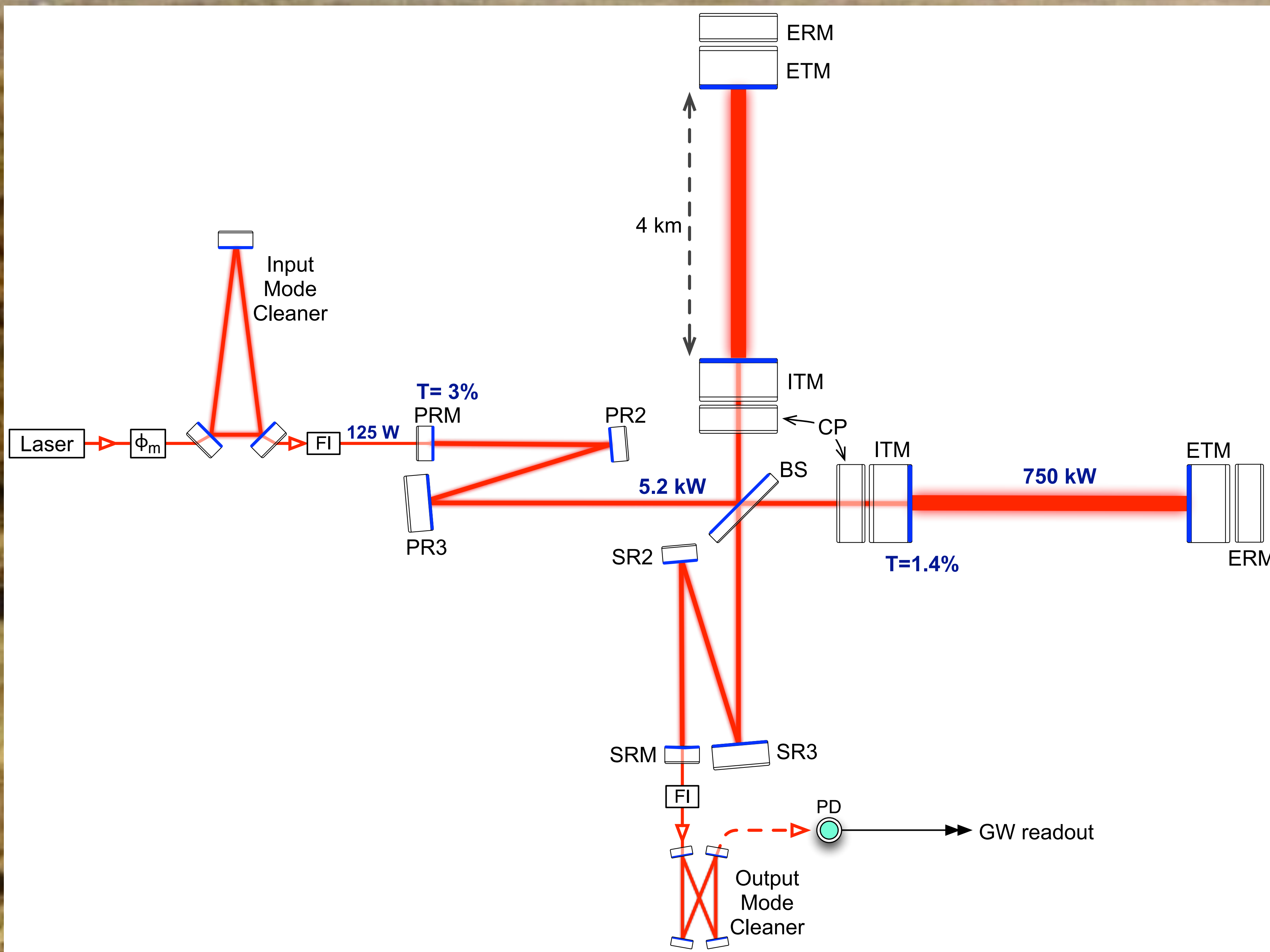
Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc)		BNS Range (Mpc)		Number of BNS Detections	% BNS Localized within	
		LIGO	Virgo	LIGO	Virgo		5 deg^2	20 deg^2
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	105	40 – 70	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

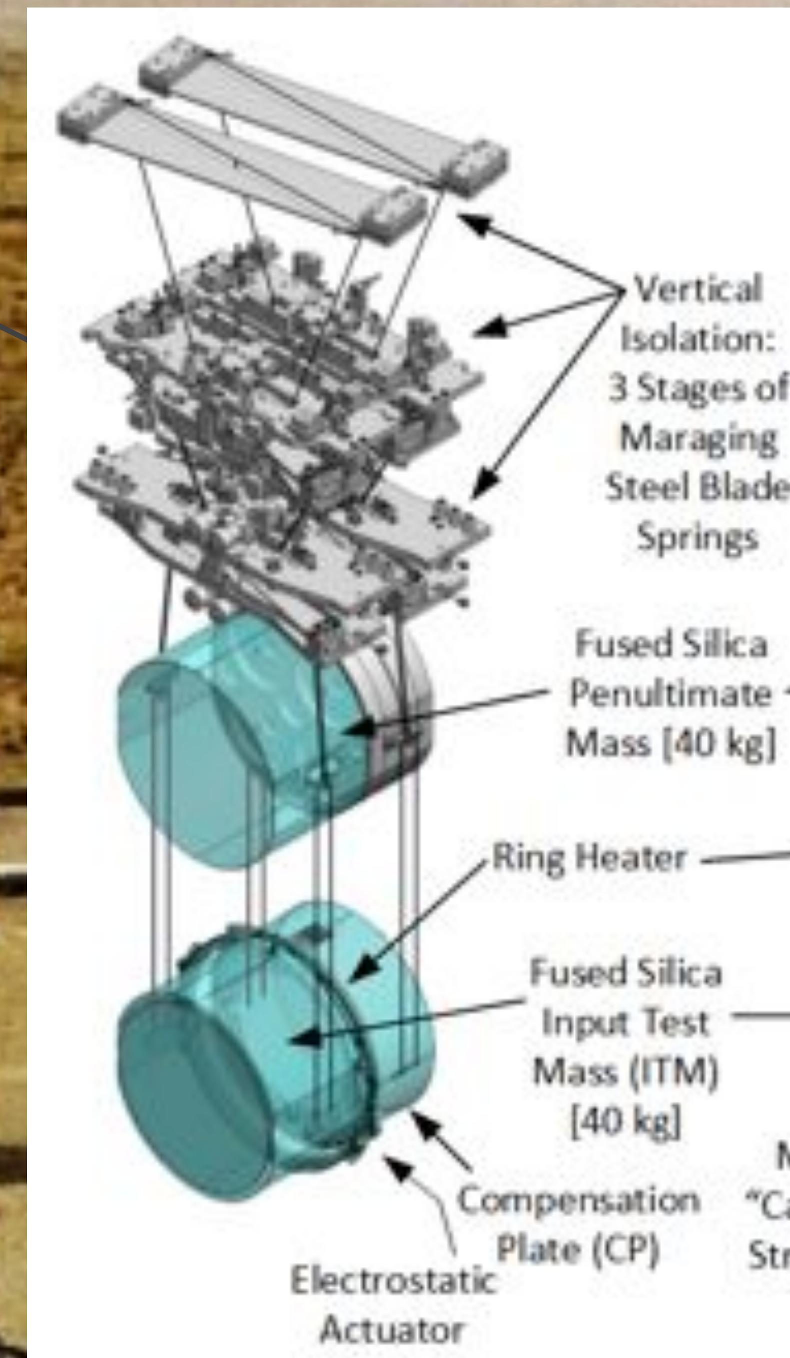




From Aasi et al, 2013

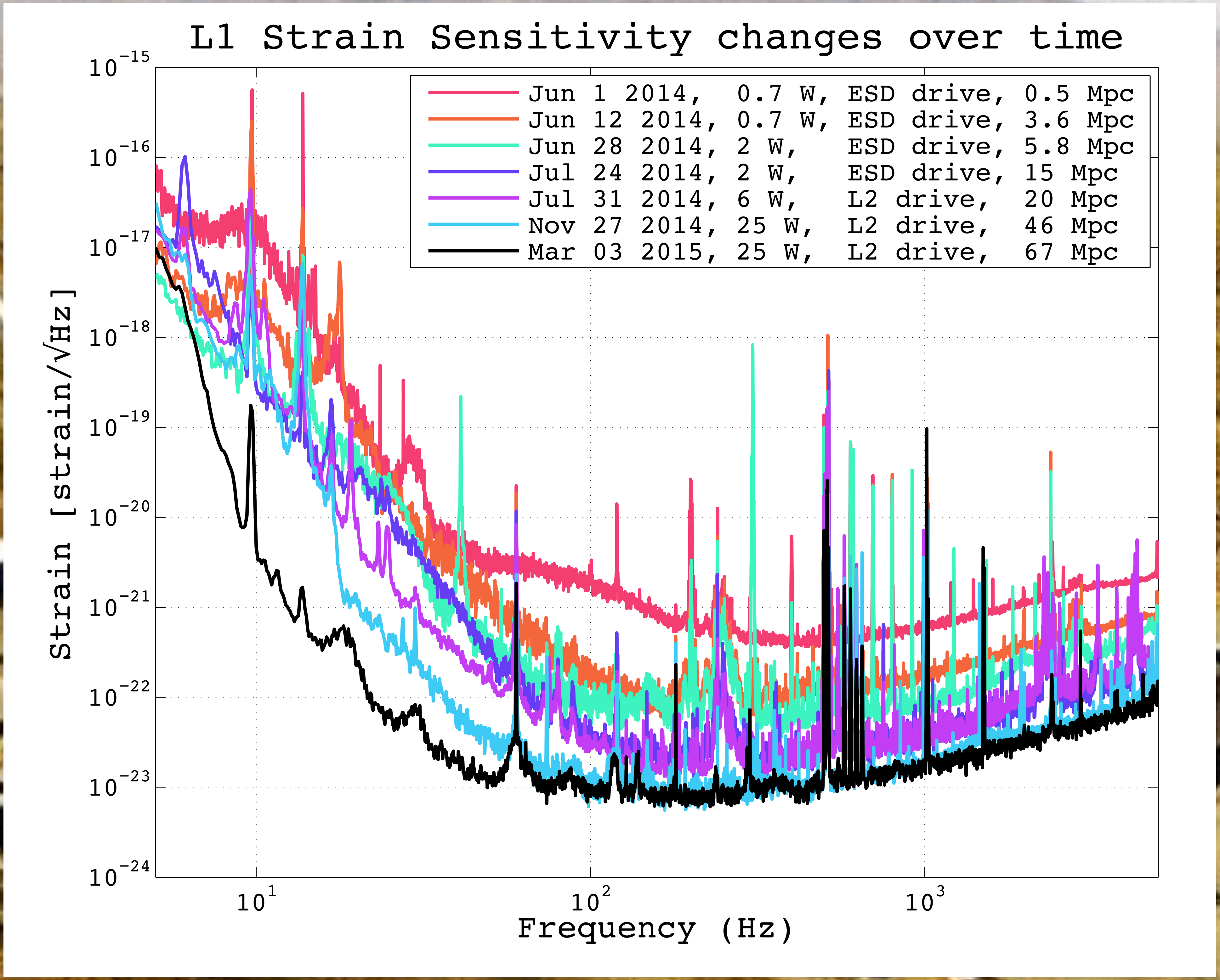
ADVANCED LIGO DETECTOR





From Aasi et al, CQG (2015)

ADVANCED LIGO SENSITIVITY

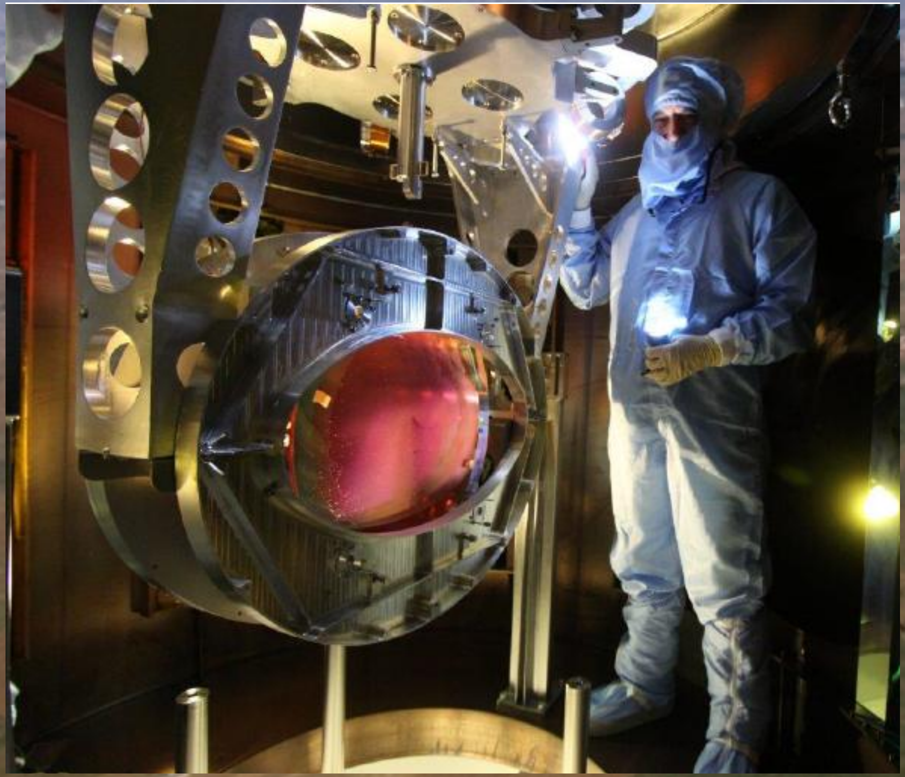


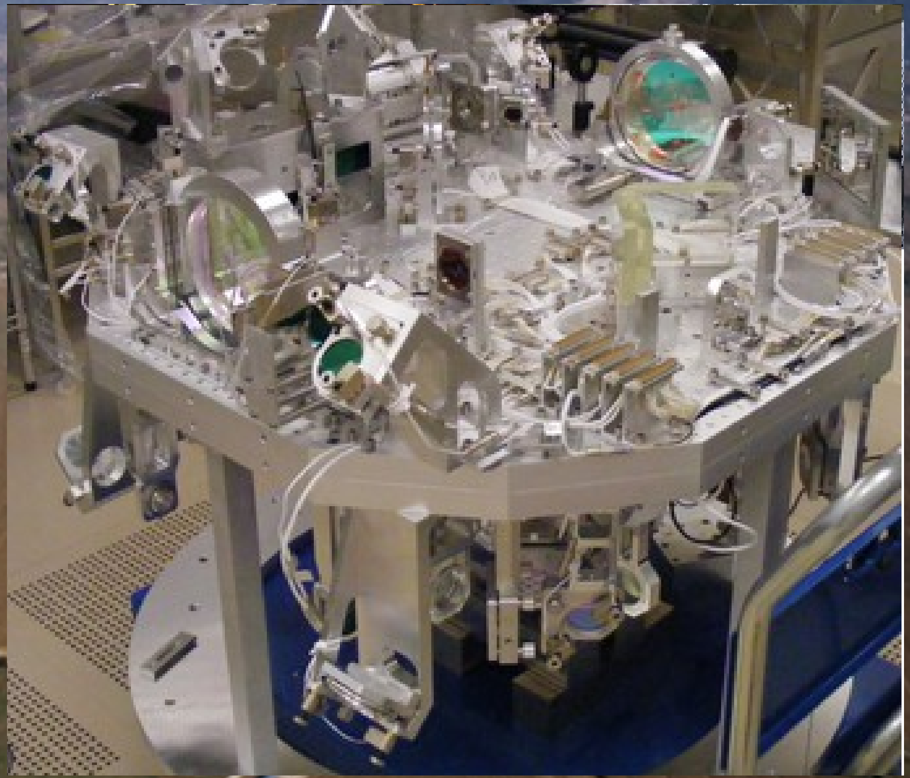
https://dcc.ligo.org/LIGO-G1401390

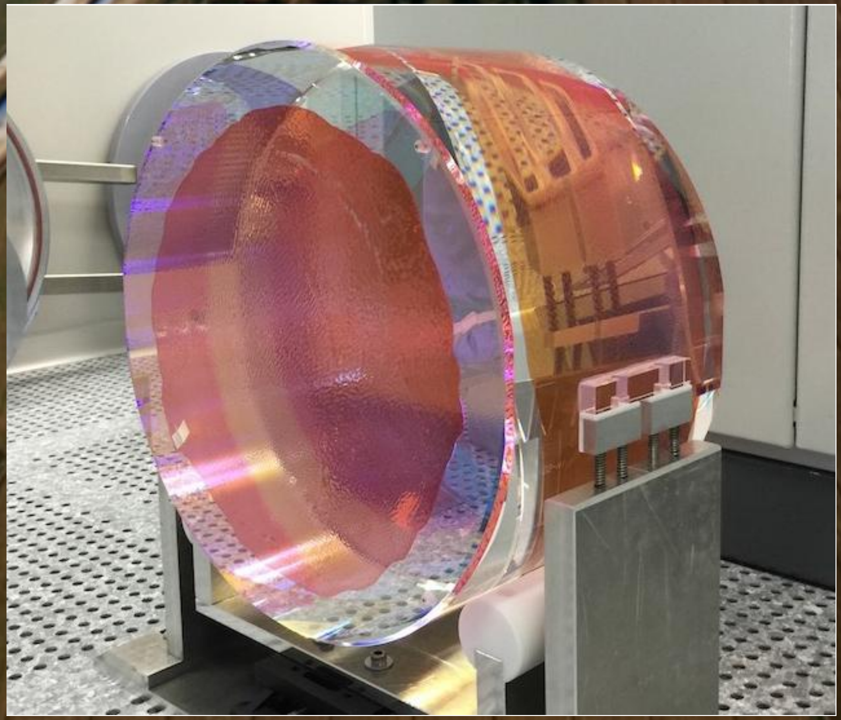
FIRST OBSERVING RUN

- Scheduled to start mid-September, with two LIGO detectors
- Currently undertaking final engineering and calibration runs

ADVANCED VIRGO STATUS



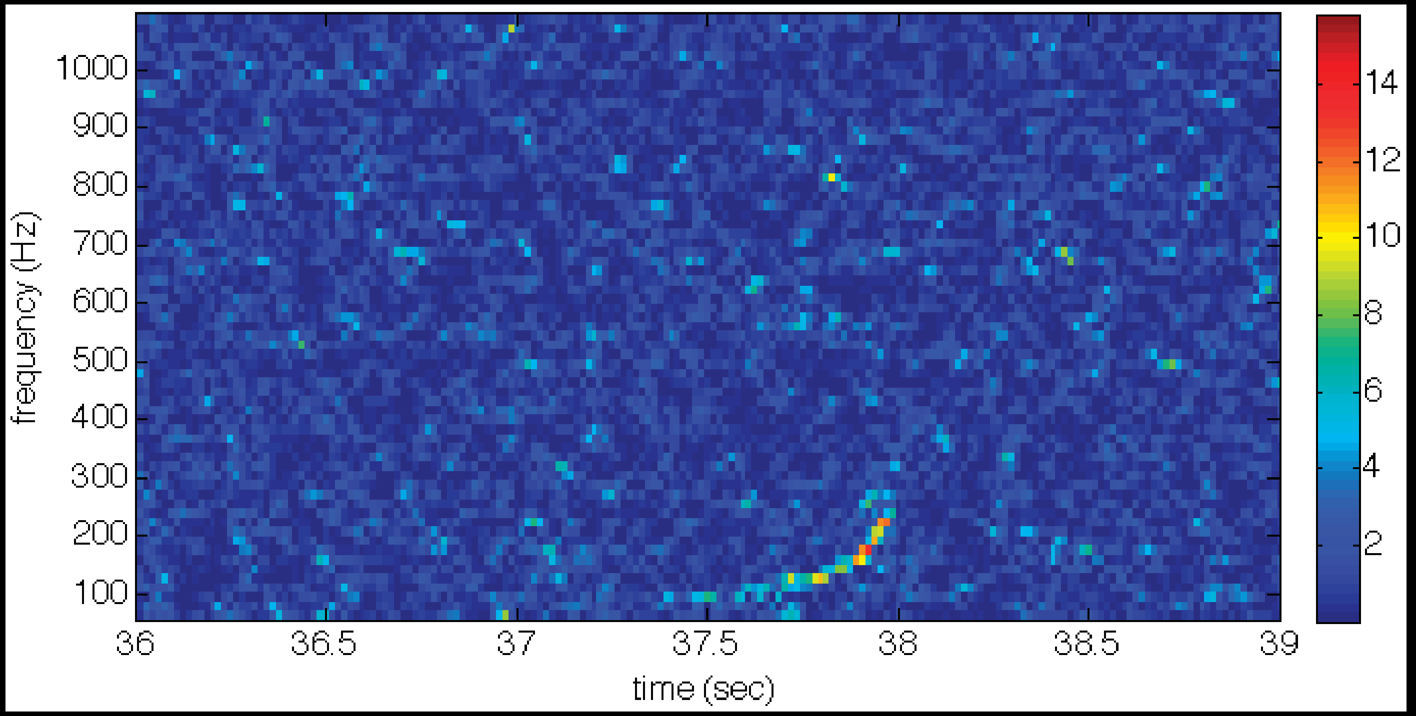


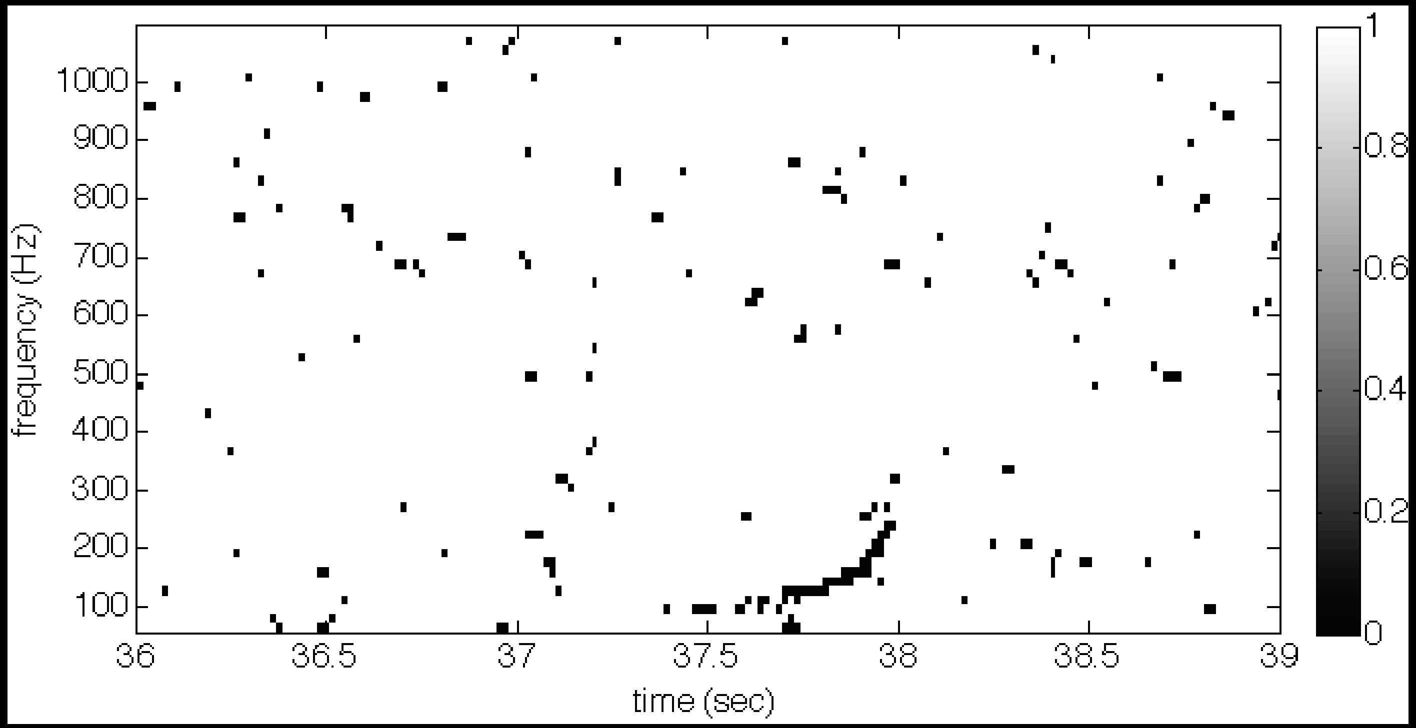


- Advanced Virgo is being installed
- Main goal is to join observing run in 2016

SEARCHING FOR SHORT DURATION GRAVITATIONAL WAVE BURSTS

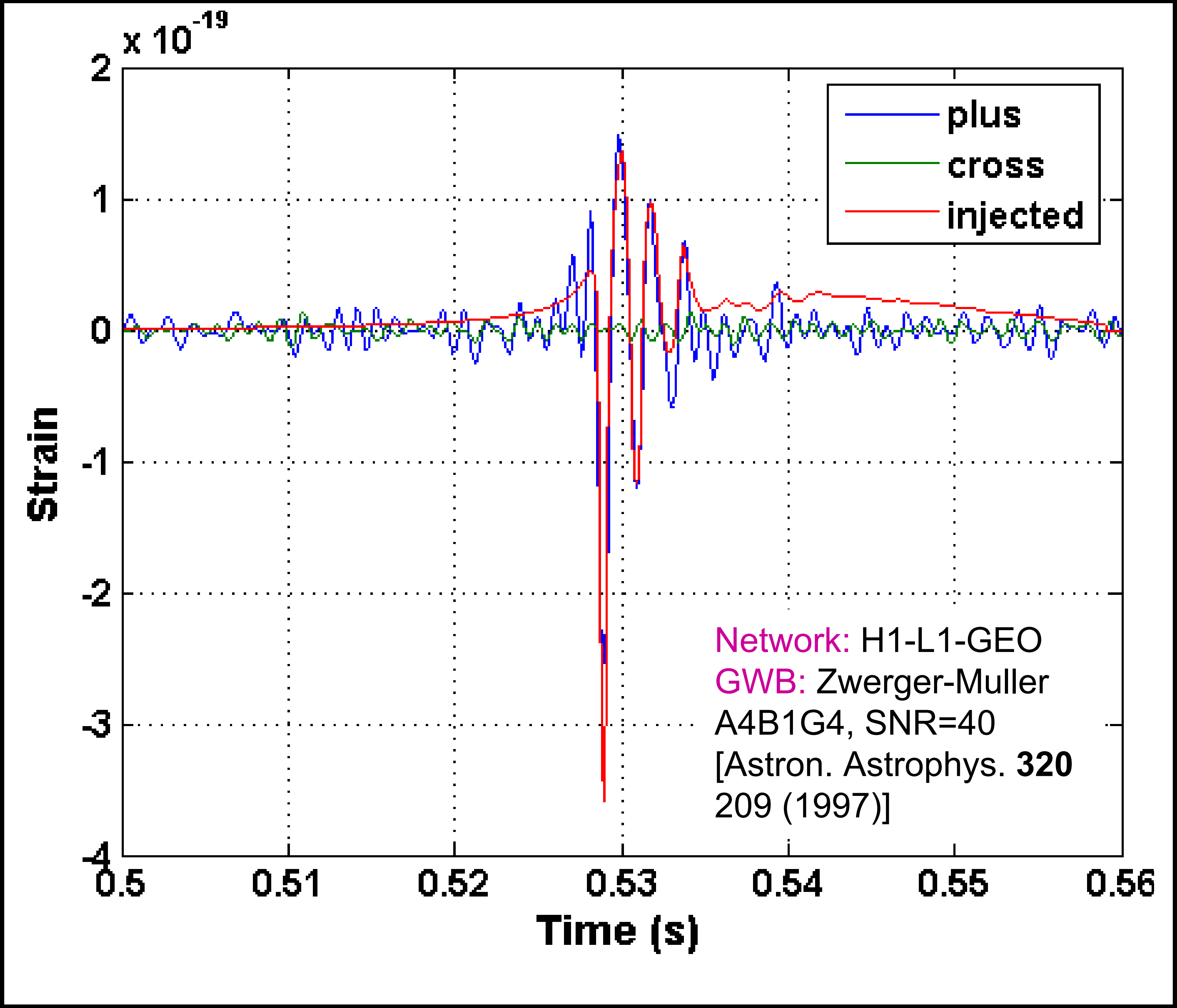
- Minimal assumptions about gravitational waveform
- Search for coherent signal in multiple detectors





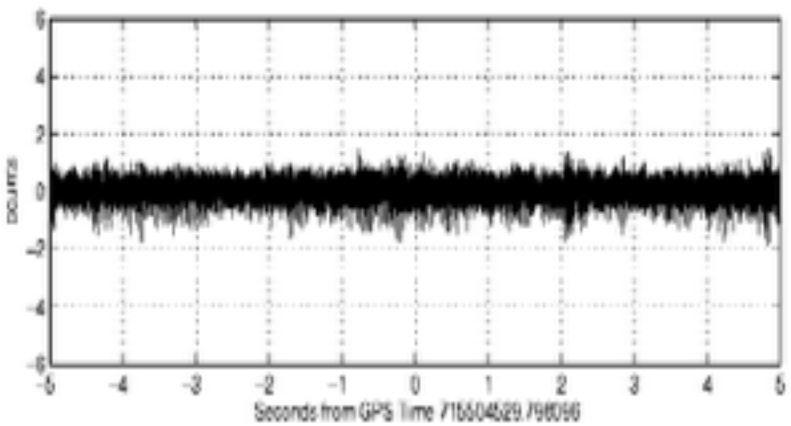
GRAVITATIONAL WAVE EXTRACTION

The main features of the waveform can be extracted from the data.



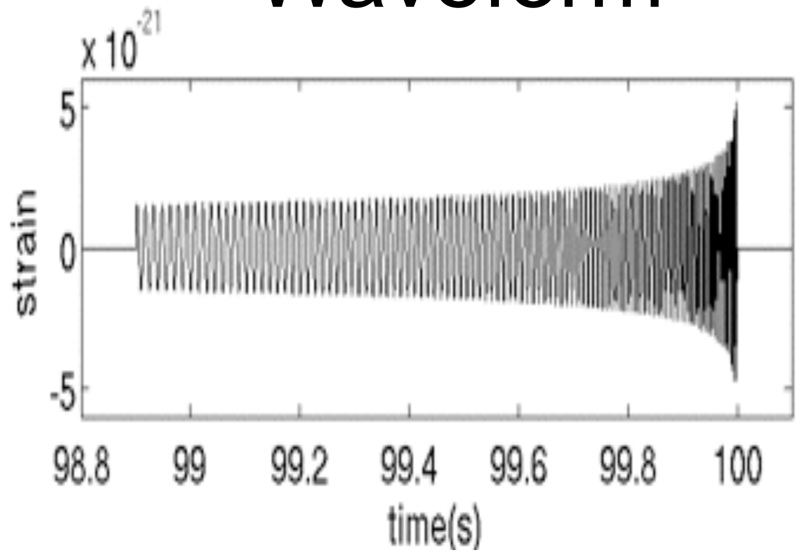
SEARCHING FOR BINARY MERGERS

Data



x

Waveform



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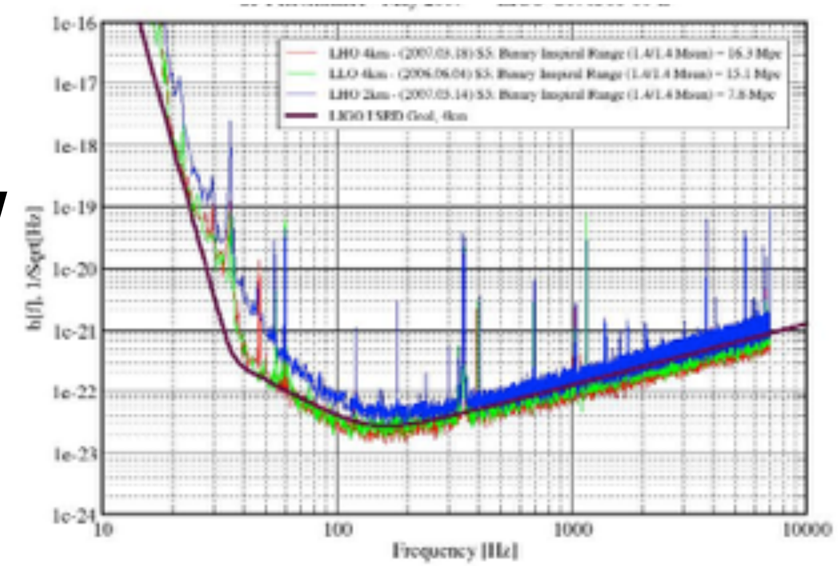
Sensitivity



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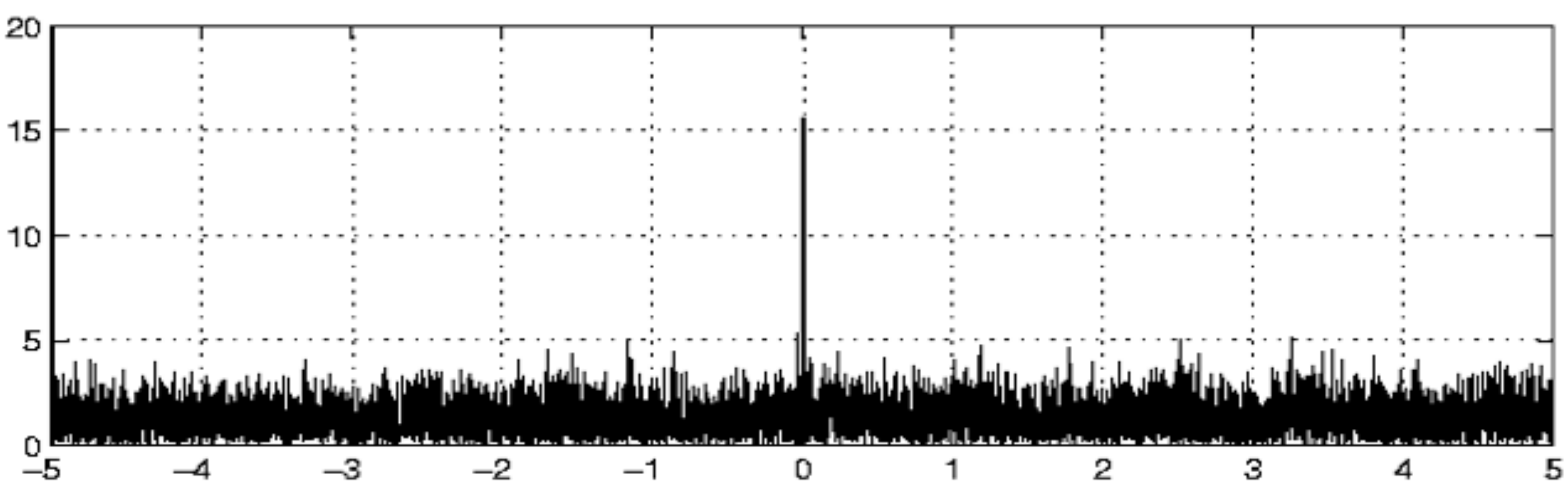
SNR



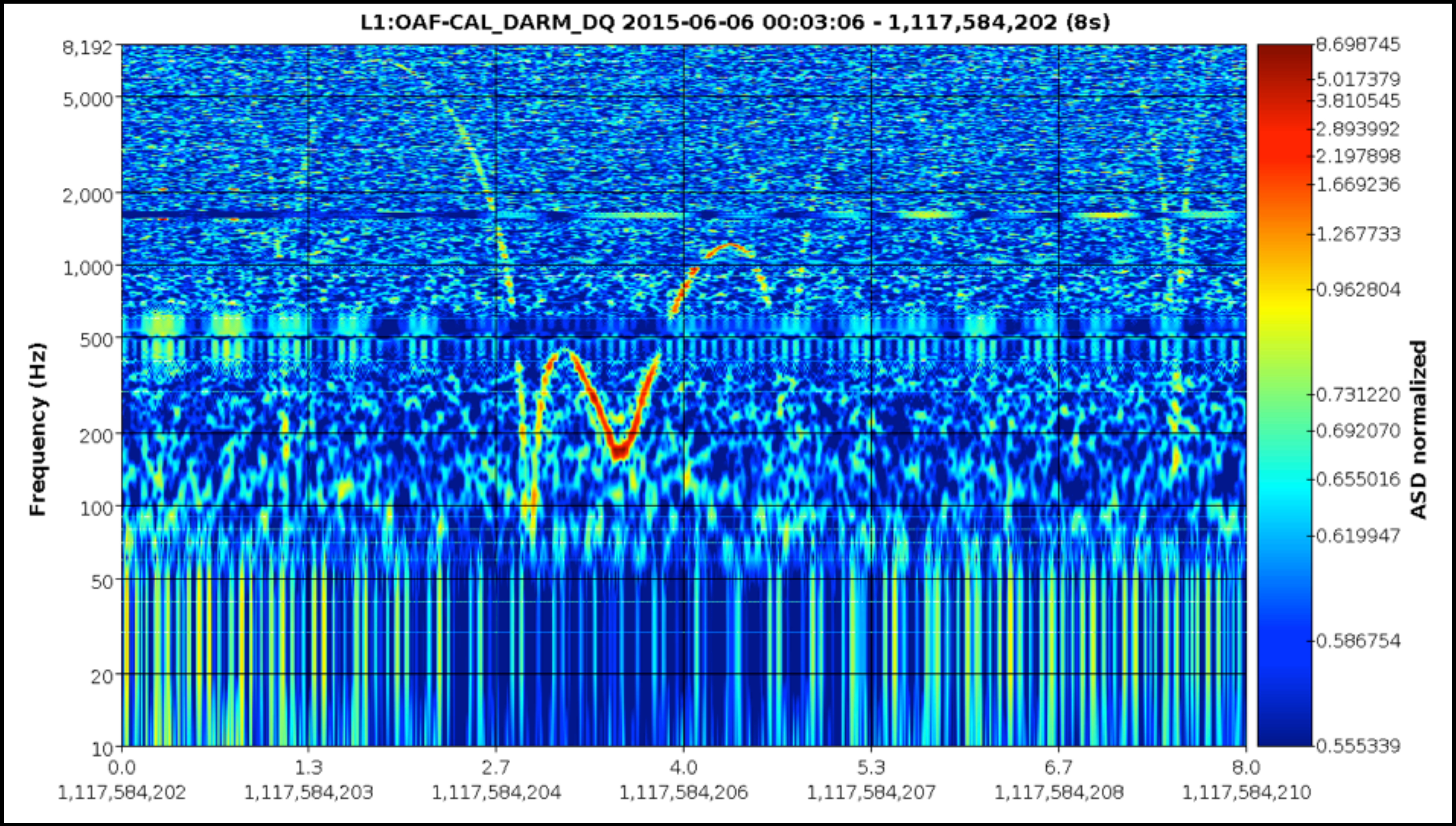
Time of merger

WAVEFORM ISSUES

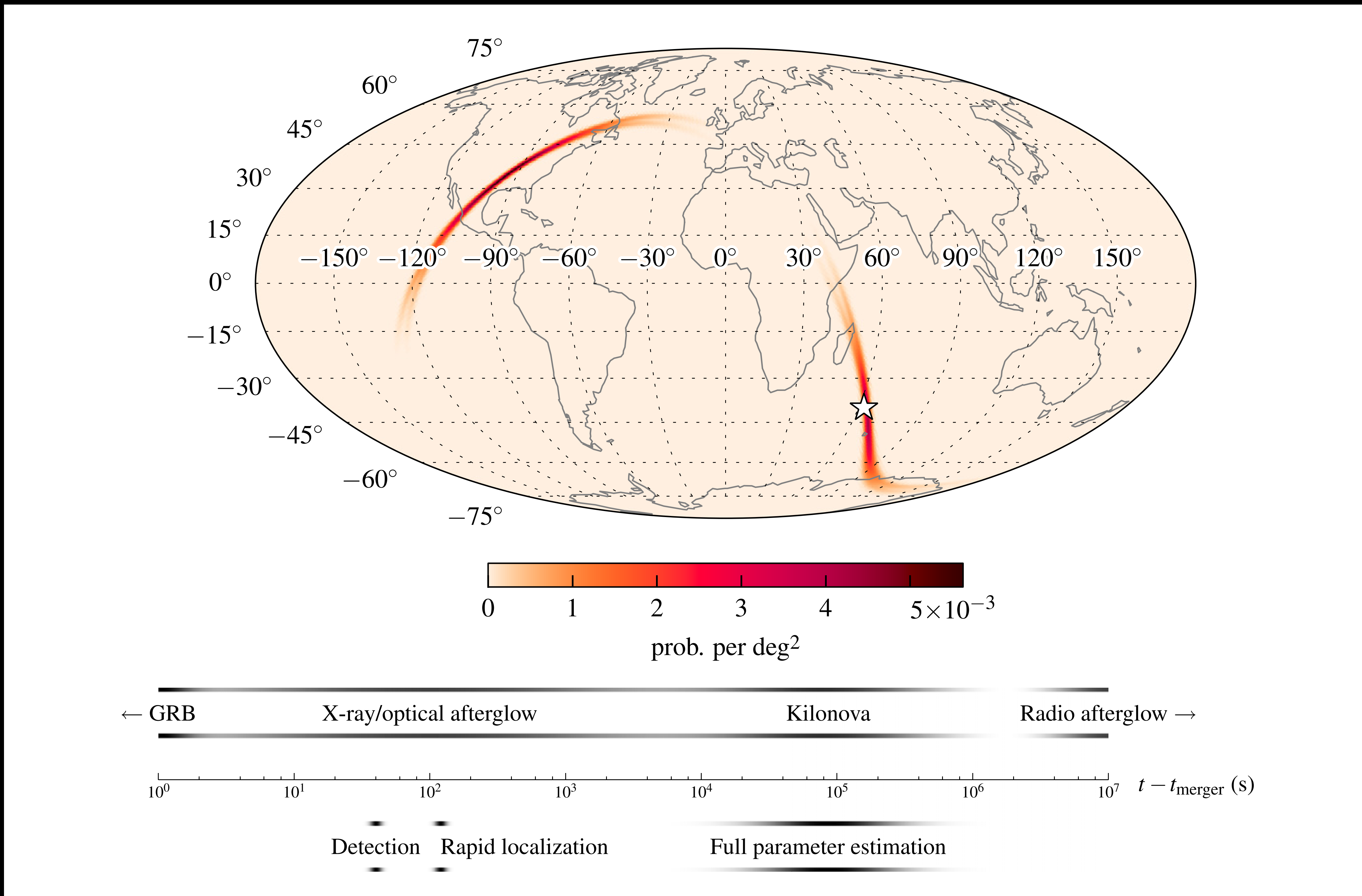
- Template waveforms last up to 10 minutes (from 15 Hz) and include thousands of gravitational wave cycles
- Require detailed waveform models from post-Newtonian theory and numerical simulations
- Waveforms depend sensitively on masses and spins of NS/BH: must search 10^5 waveform templates for first run, 10^6 at full sensitivity
- Waveforms depend upon NS equation of state: not included in current detection templates

REAL DATA

- Real data contains non-Gaussian transients
- These can mask signals in the data and increase the noise background for transient searches



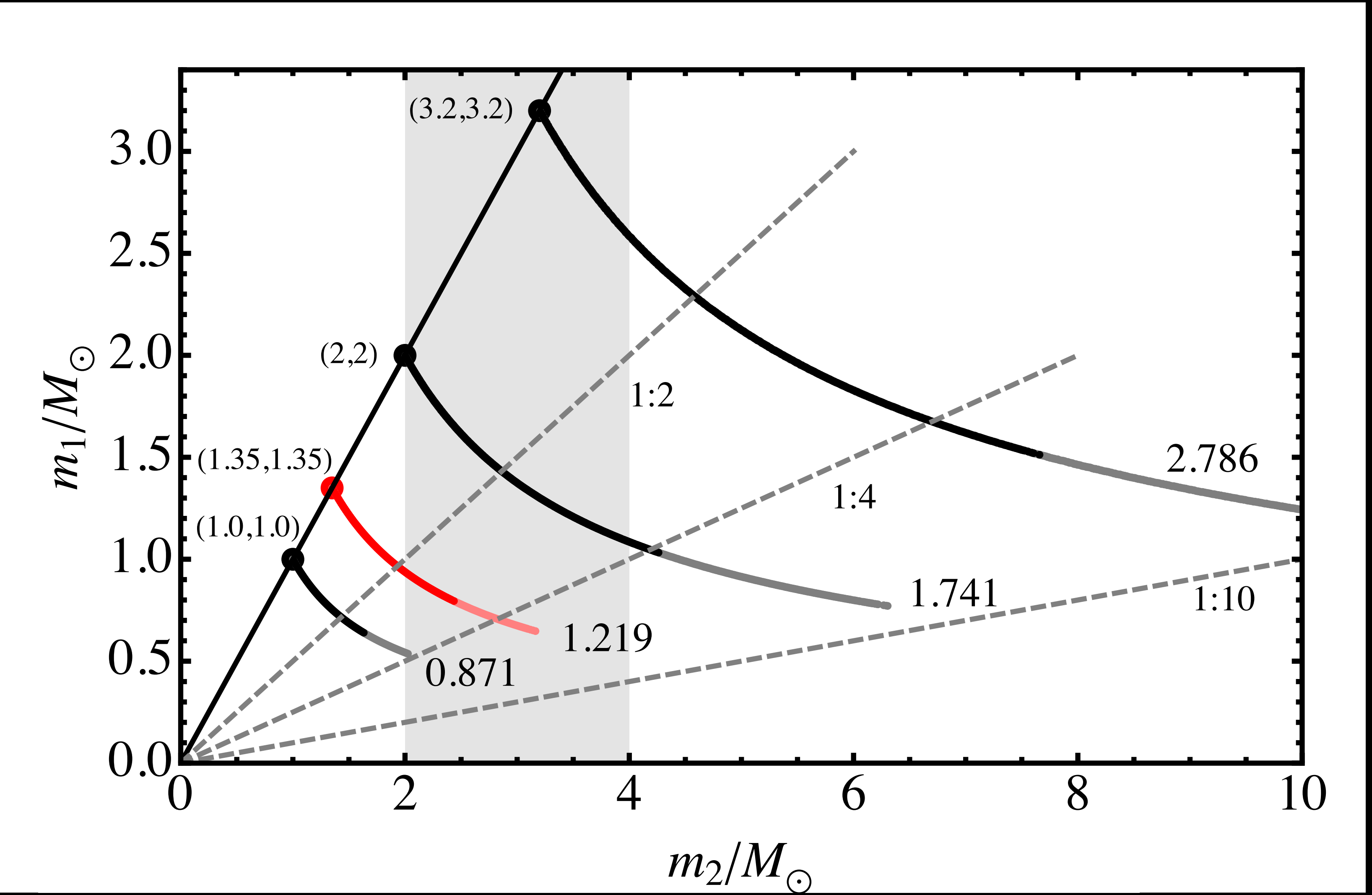
RAPID SEARCH AND LOCALIZATION



From Singer et al, ApJ (2014)

MEASURING PHYSICAL PARAMETERS

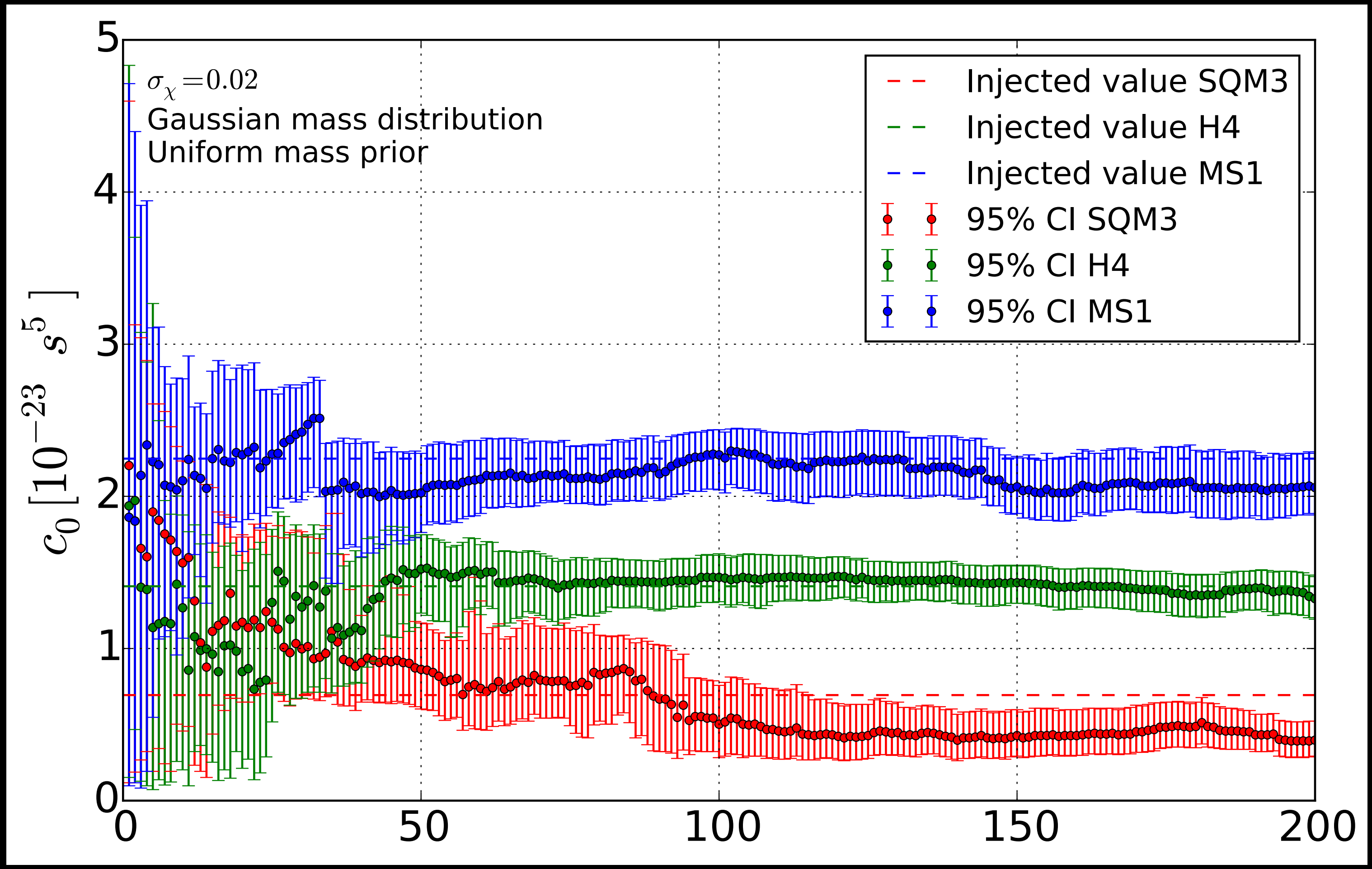
- Detailed parameter estimation analysis returns distributions for all signal parameters.
- First few detections likely to be weak: unlikely to extract parameters accurately.



From Hannam et al, ApJL (2013)

NEUTRON STAR EQUATION OF STATE

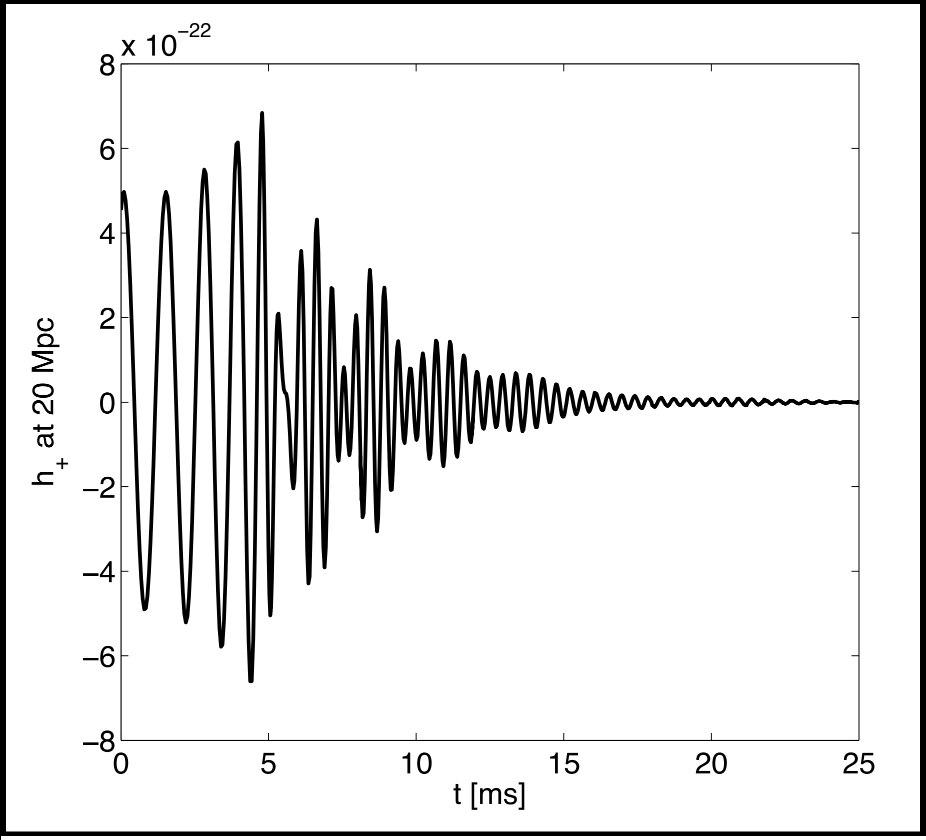
- Equation of state affects the waveform evolution
- Effect only likely to be observable for nearby events.
- Can extract equation of state from a population of tens of events.

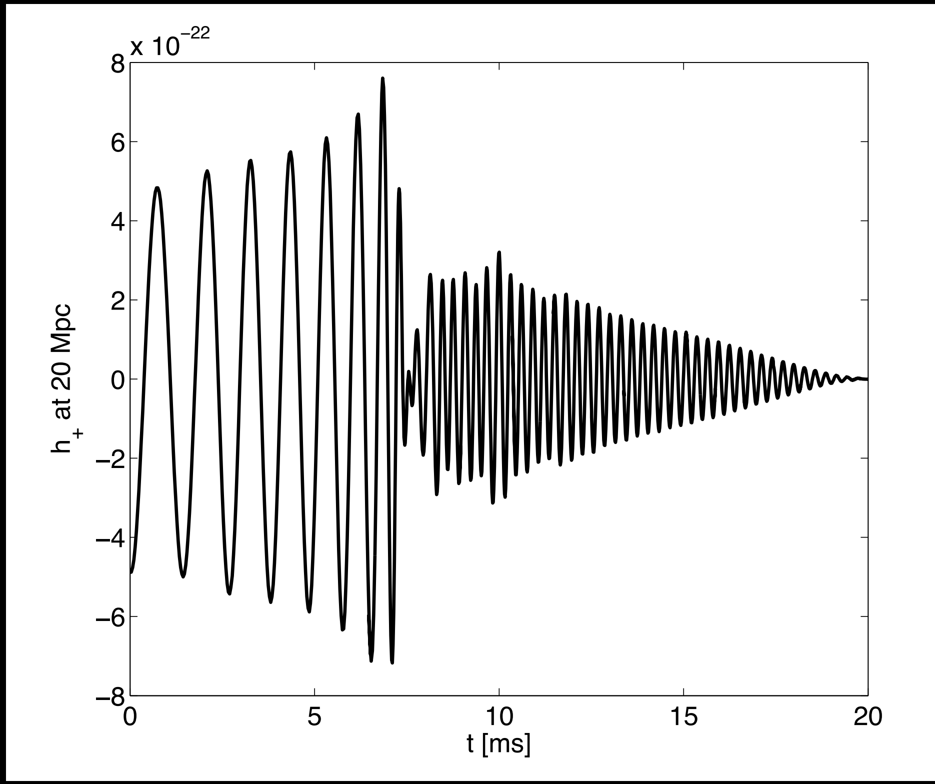


Agathos et al, PRD (2015).

POST MERGER OSCILLATIONS

- Use burst methods to search for post-merger oscillations following observed inspiral
- Only likely to be observable for nearby events

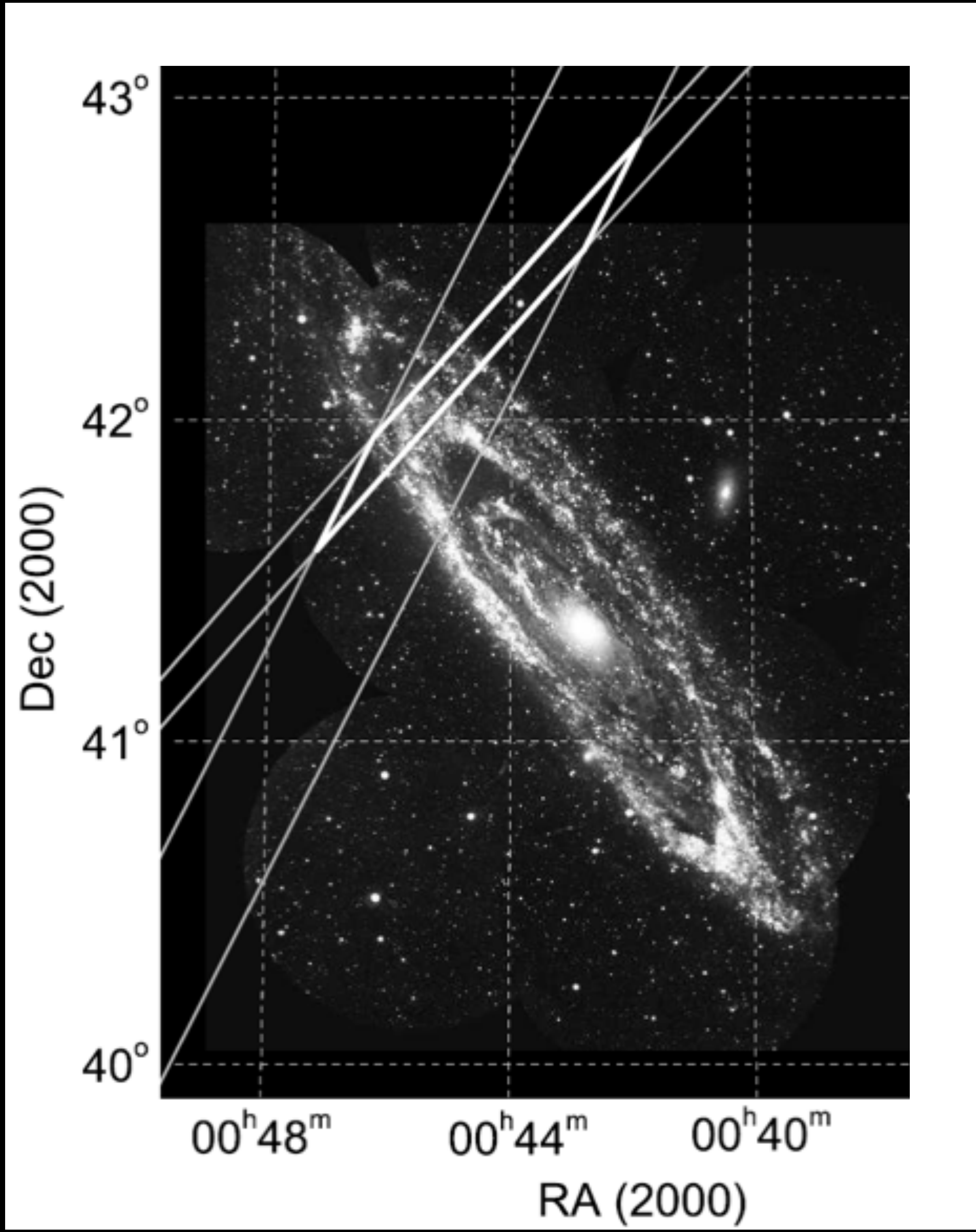




From Bauswein et al 2012

TRIGGERED SEARCHES

- Additional “triggered” searches around astrophysical interesting events: GRBs, nearby supernova
- Use time and sky location to reduce search parameter space
- Can increase sensitivity by a factor of two



GRB 070201 localisation
Mazets et al., ApJ (2008)

GRB PROSPECTS

If short bursts are from NS-NS binaries:

Epoch	Run Duration	BNS Range (Mpc)		Number of GW–GRB detections		
		LIGO	Virgo	All Sky	Fermi GBM	Swift BAT
2015	3 months	40 - 80	-	2×10^{-4} - 0.02	2×10^{-4} - 0.02	3×10^{-5} - 0.003
2016–17	6 months	80 - 120	20 - 60	0.004 - 0.2	0.003 - 0.1	3×10^{-4} - 0.03
2017–18	9 months	120-170	60 - 85	0.02 - 0.8	0.01 - 0.5	7×10^{-4} - 0.1
2019+	(per year)	200	65 - 130	0.1 - 2	0.07 - 1	0.01 - 0.2
2022+	(per year)	200	130	0.2 - 3	0.1 - 2	0.02 - 0.3

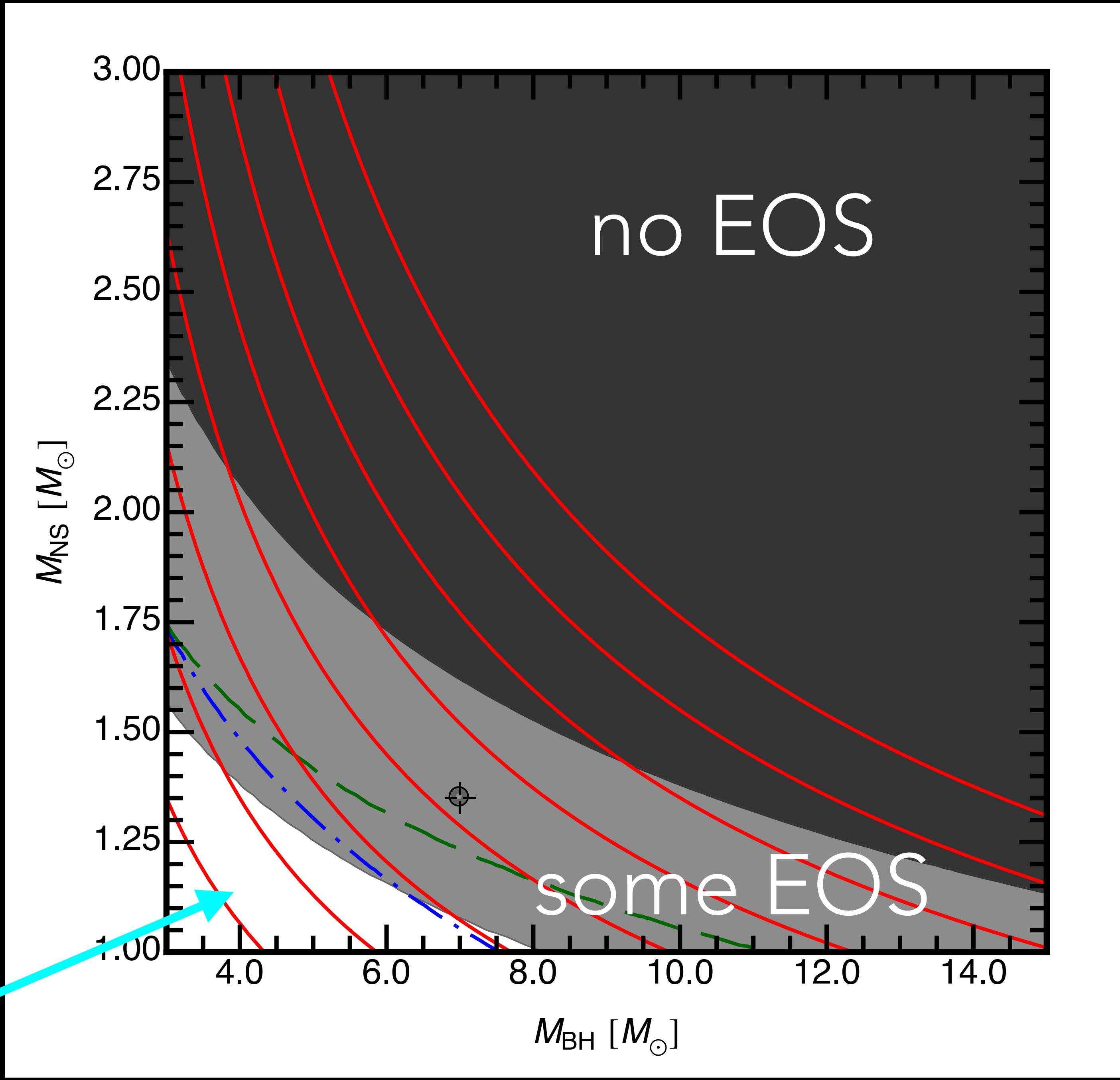
If short bursts are from NS-BH binaries:

Epoch	Run Duration	NSBH Range (Mpc)		Number of GW–GRB detections		
		LIGO	Virgo	All Sky	Fermi GBM	Swift BAT
2015	3 months	70 - 130	-	3×10^{-4} - 0.06	2×10^{-4} - 0.03	4×10^{-5} - 0.007
2016–17	6 months	130 - 200	30 - 100	0.005 - 0.5	0.003 - 0.3	7×10^{-4} - 0.07
2017–18	9 months	200 - 280	100 - 140	0.03 - 2	0.02 - 1	0.004 - 0.3
2019+	(per year)	330	110 - 220	0.2 - 6	0.1 - 2	0.02 - 0.5
2022+	(per year)	330	220	0.4 - 10	0.2 - 3	0.03 - 0.7

From Clark et al, ApJ (2015)

EQUATION OF STATE FROM JOINT GW-EM OBSERVATIONS

- GW measurement restricts masses to one line
- EM emission for given masses depends on equation of state

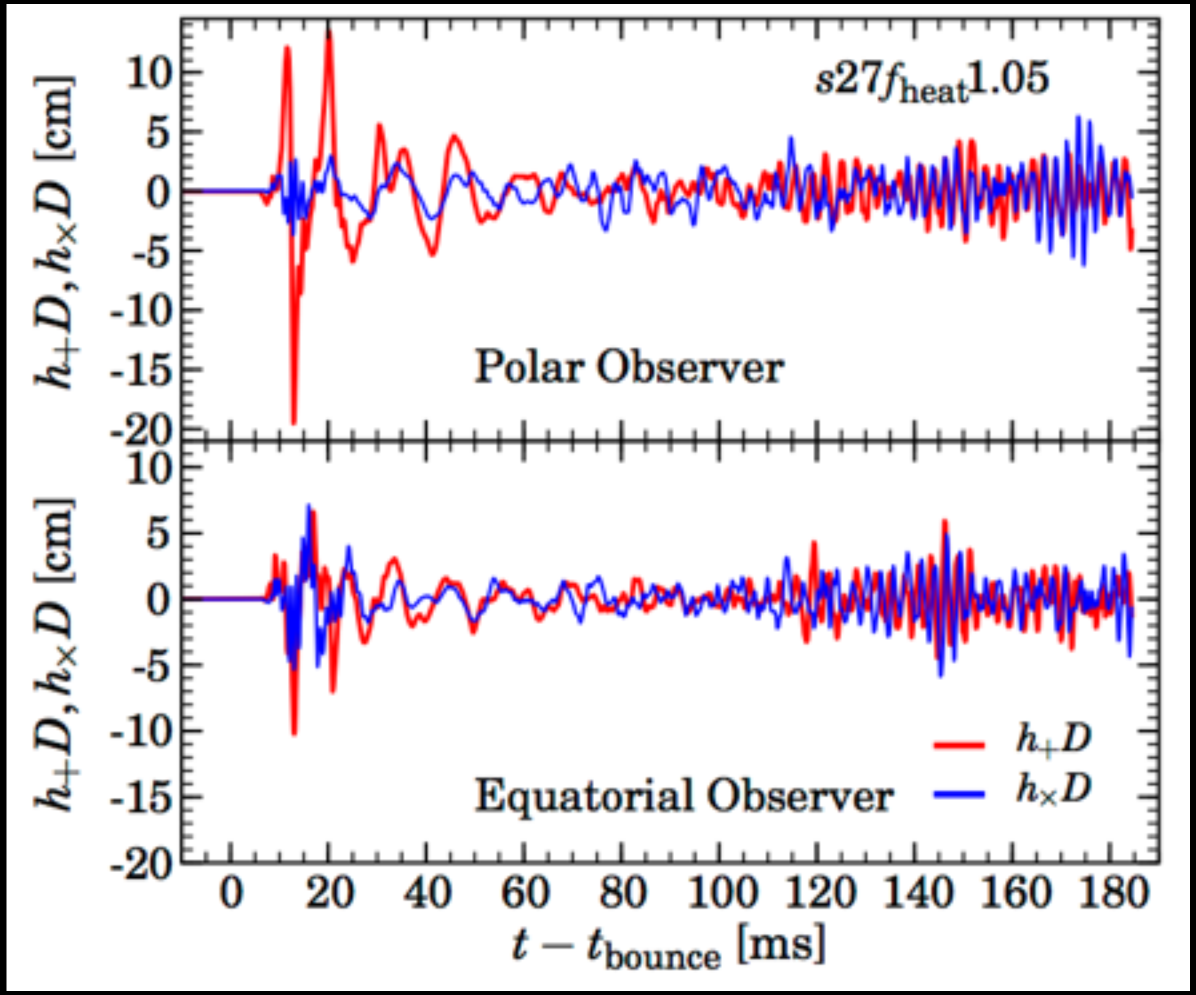


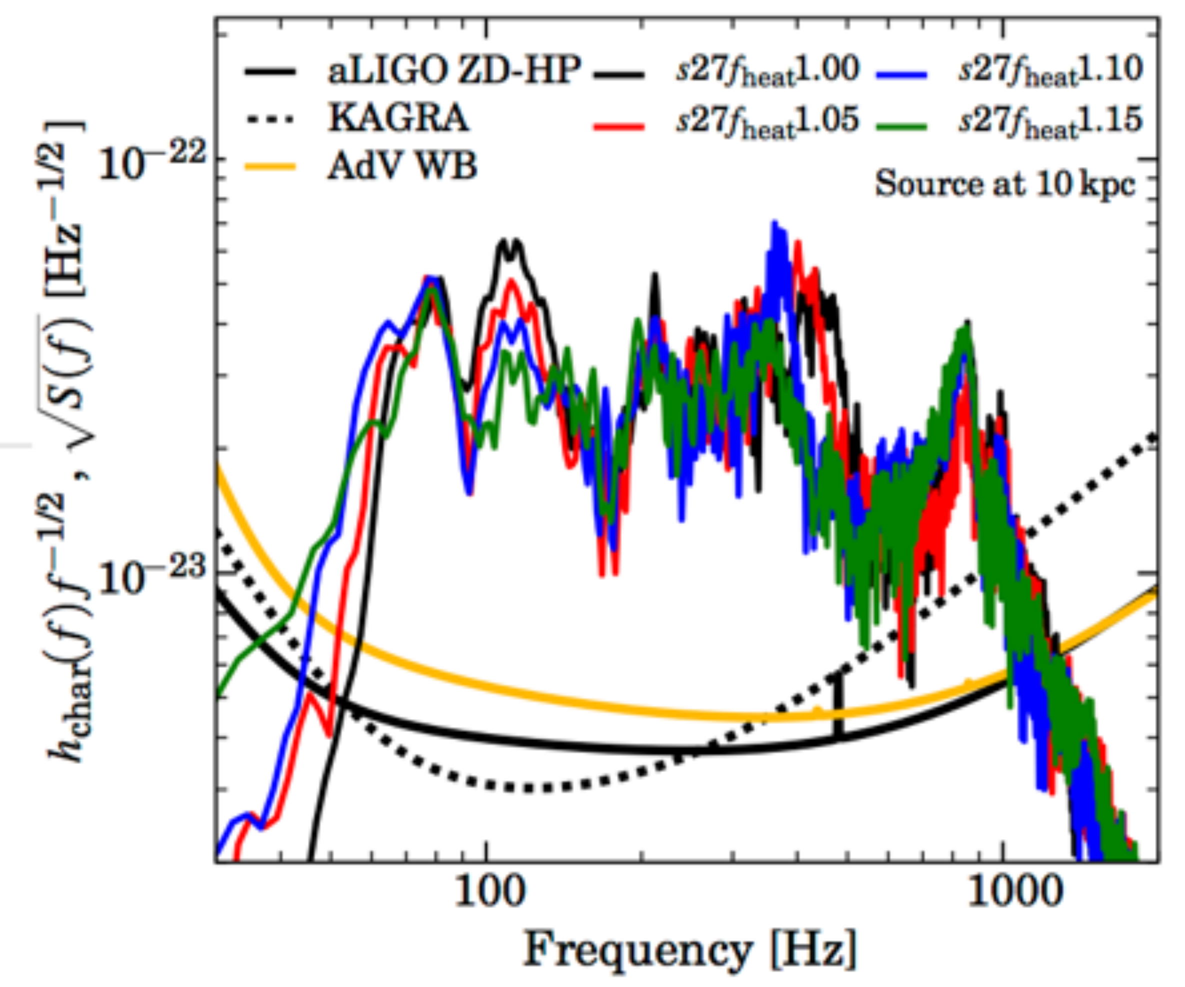
all EOS

From Pannarale and Ohme, ApJL (2015)

SUPERNOVA SEARCHES

- GW from a galactic supernova should be observable
- Maybe also for nearby galaxies

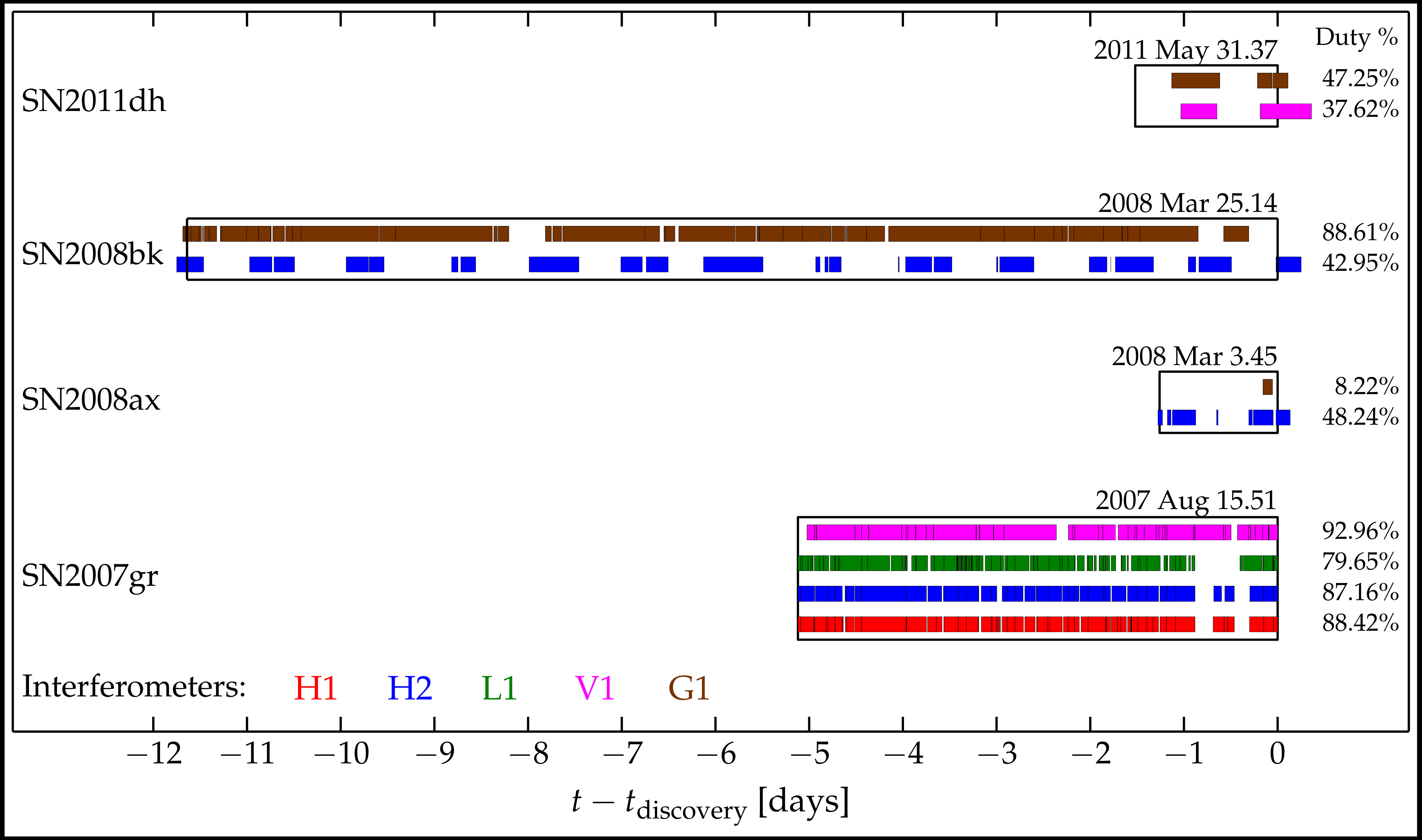




From Ott (2013)

SUPERNOVA SEARCHES

Time of supernova explosion not well known: typically will not have GW data covering the full time range



DISCUSSION

- Advanced LIGO will begin its first observing run next month
- Virgo will join later runs and sensitivity of both LIGO and Virgo will improve over time
- We will search for generic GW transients and binary mergers: detections likely in the next few years.
- Observations will allow for measurements of waveforms and parameters
- Joint searches with EM and Neutrino partners will give more complete picture of sources