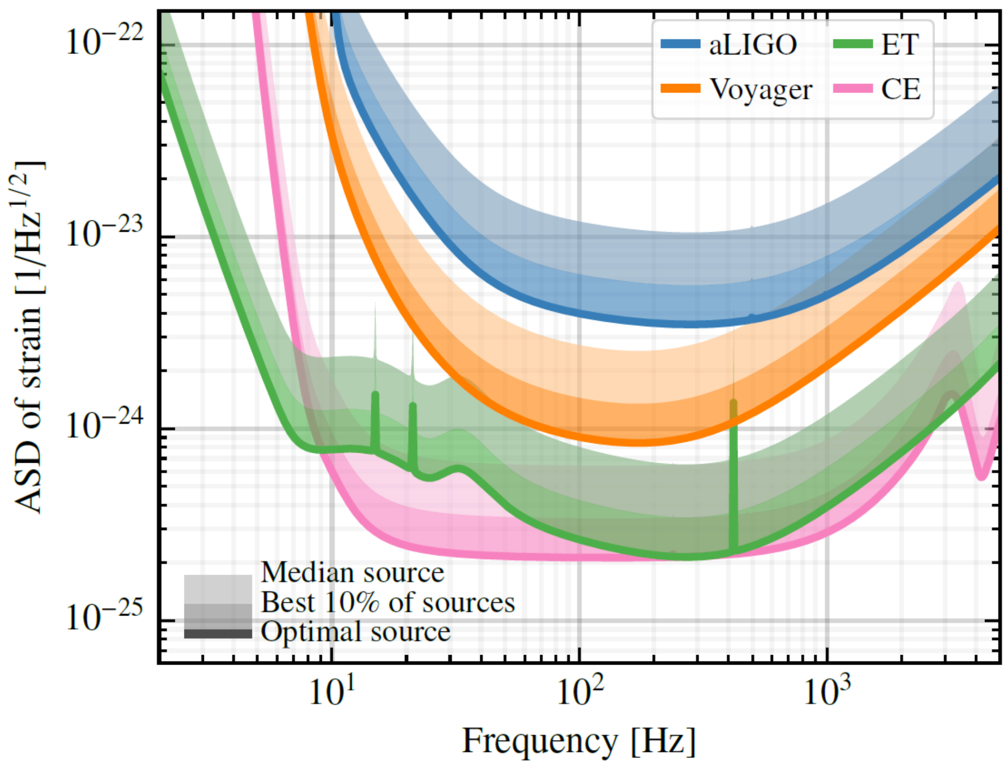
Summary Discussion: Experimental Edition

Stan Whitcomb

The goal

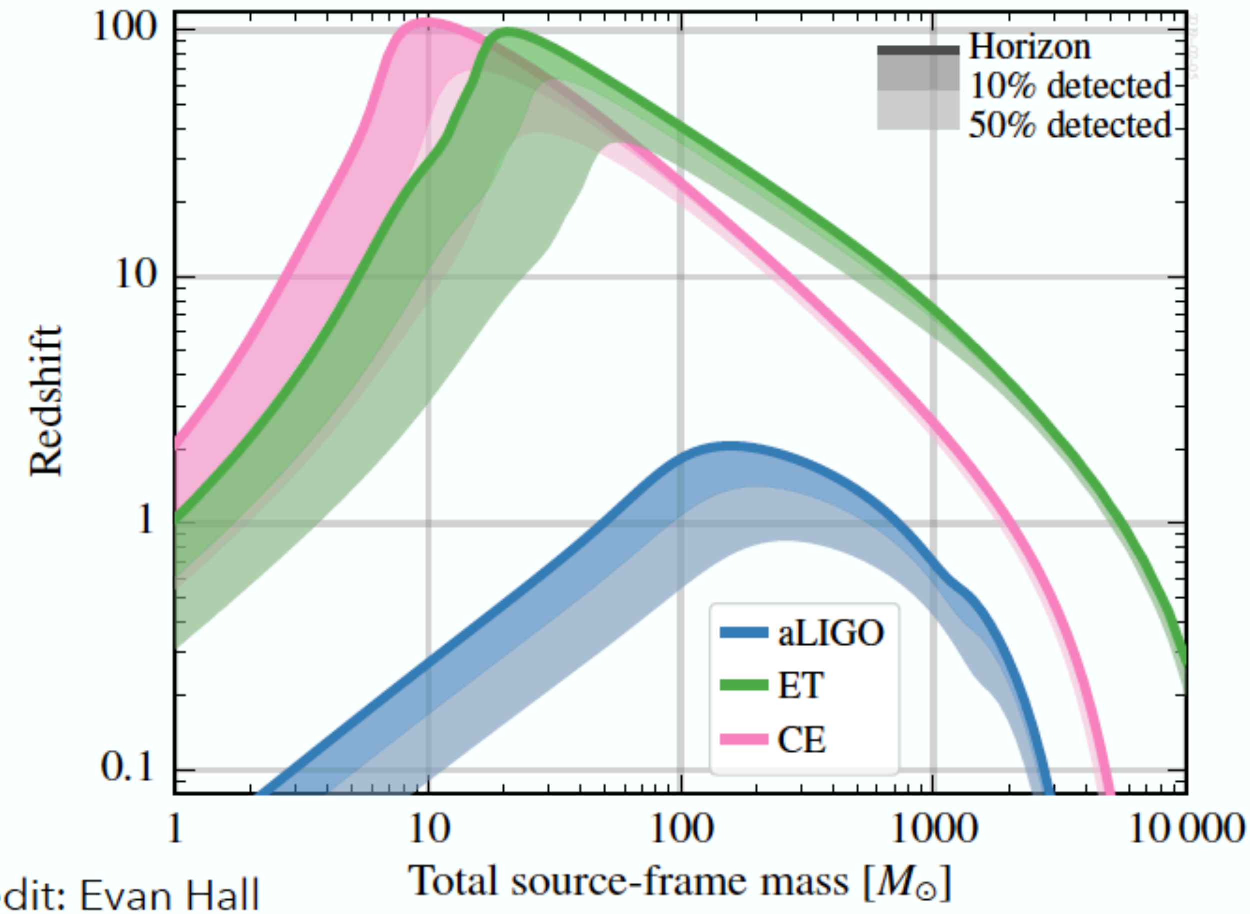
David McClelland



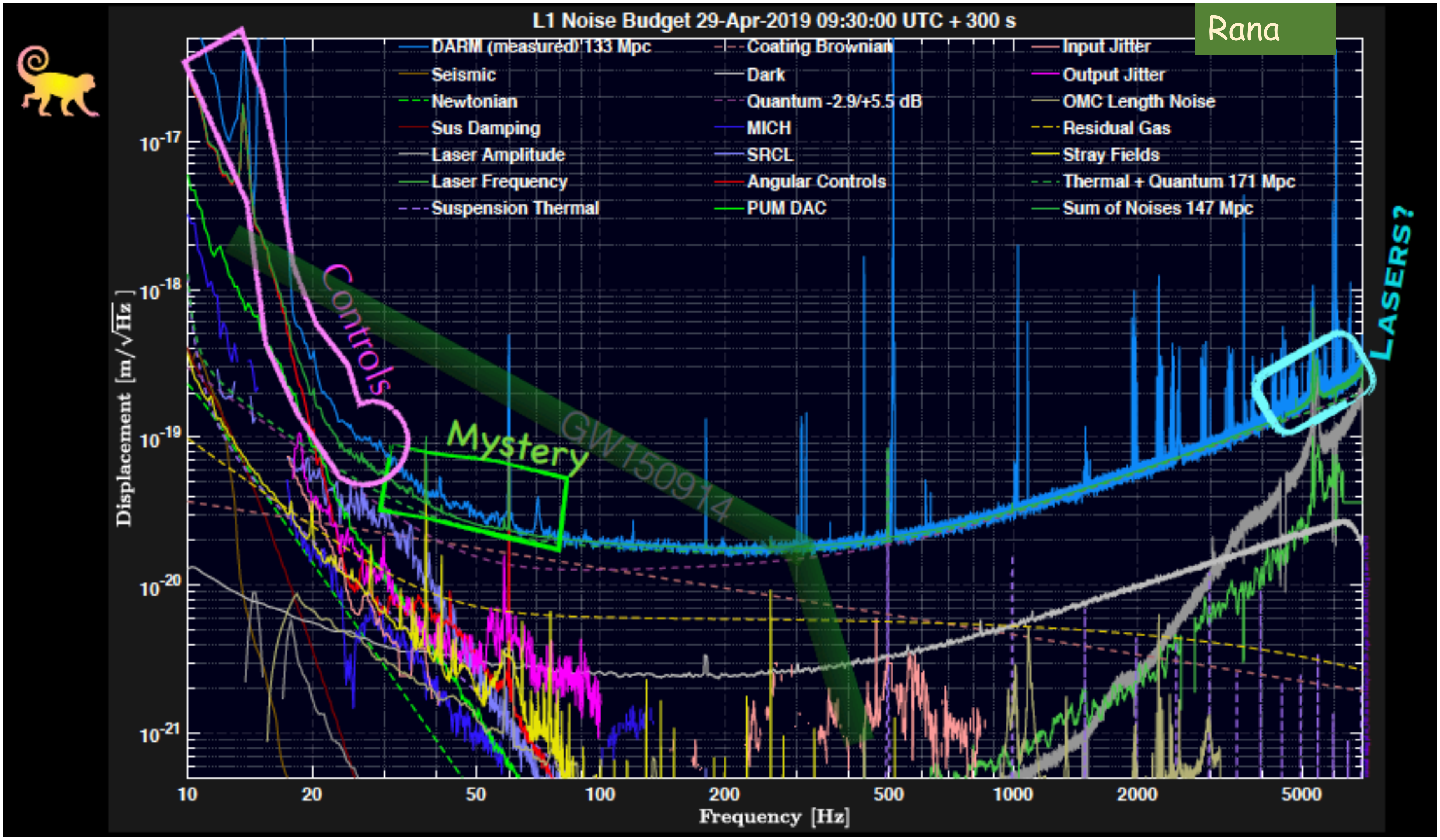
Sathya

FUTURE OF GW ASTRONOMY

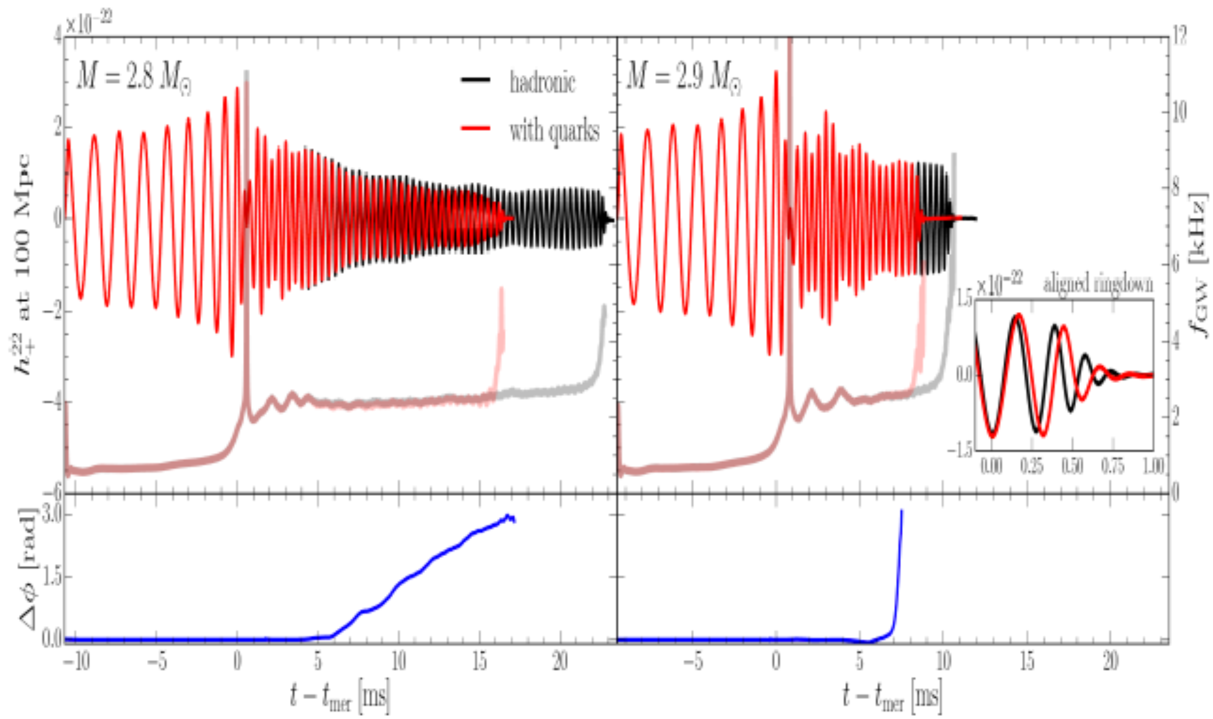
EINSTEIN TELESCOPE AND COSMIC EXPLORER



Credit: Evan Hall


Rana
L1 Noise Budget 29-Apr-2019 09:30:00 UTC + 300 s
DARM (measured) 133 Mpc
Seismic
Newtonian
Sus Damping
Laser Amplitude
Laser Frequency
Suspension Thermal
Coating Brownian
Dark
Quantum -2.9/+5.5 dB
MICH
SRCL
Angular Controls
PUM DAC
Input Jitter
Output Jitter
OMC Length Noise
Residual Gas
Stray Fields
Thermal + Quantum 171 Mpc
Sum of Noises 147 Mpc
Controls
Mystery
GW150914
LASERS?
Displacement [m/√Hz]
Frequency [Hz]
10
20
50
100
200
500
1000
2000
5000
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}

Imprint of quarks in GW



E. R. Most et al., arxiv:1807.03684

Varun Bhalerao

GW170817-like scaling

Name	Type	Distance (Mpc)	90% area (sq deg)	Optical	IR (Ks)	X-ray (10 keV-1000 keV)
S190425z	99% BNS	156 ± 41	7461	20	21	5e-8
S190426c	49% BNS	377 ± 100	1131	22	23	9e-9
S190510g	42% BNS	227 ± 92	1166	21	22	2e-8
S190718y	2% BNS, 98% Terrestrial	227 ± 165	7246	21	22	2e-8
S190814bv	100% NSBH	267 ± 52	23	21	22	2e-8
Fake event	100% BNS	500	–	22	23	5e-9
GW170817	100% BNS	41	31	17	18	7e-7

Scaling from Kasliwal et al. (2017) and Abott et al 2017 (Fermi + Integral +LVC)

Typical optical surveys reach ~21 mag (ZTF, PanSTARRs), ~23 DECam
IR ~ 17.5 (Gattini), X-ray / Gamma ray ~ few e-7

Jo van den Brand

Table of O1 and O2 triggers with source proper

See https://dcc.ligo.org/LIGO-G1801864

Virgo data contributed to Parameter Estimation of 5 events

Event	$m_1/M_\odot$	$m_2/M_\odot$	$\mathcal{M}/M_\odot$	$\chi_{\rm eff}$	$M_{\rm f}/M_\odot$	$a_{\rm f}$	$E_{\rm rad}/(M_\odot c^2)$	$\ell_{\rm peak}/({\rm erg\,s^{-1}})$	$D_{\rm L}/{\rm Mpc}$	z	$\Delta\Omega/{\rm deg}^2$
GW150914	$35.6^{+4.8}_{-3.0}$	$30.6^{+3.0}_{-4.4}$	$28.6^{+1.6}_{-1.5}$	$-0.01^{+0.12}_{-0.13}$	$63.1^{+3.3}_{-3.0}$	$0.69^{+0.05}_{-0.04}$	$3.1^{+0.4}_{-0.4}$	$3.6^{+0.4}_{-0.4} \times 10^{56}$	430^{+150}_{-170}	$0.09^{+0.03}_{-0.03}$	194
GW151012	$23.2^{+14.0}_{-5.4}$	$13.6^{+4.1}_{-4.8}$	$15.2^{+2.0}_{-1.2}$	$0.04^{+0.28}_{-0.19}$	$35.7^{+9.9}_{-3.7}$	$0.67^{+0.13}_{-0.11}$	$1.5^{+0.5}_{-0.5}$	$3.2^{+0.8}_{-1.7} \times 10^{56}$	1060^{+540}_{-480}	$0.21^{+0.09}_{-0.09}$	1491
GW151226	$13.7^{+8.8}_{-3.2}$	$7.7^{+2.2}_{-2.6}$	$8.9^{+0.3}_{-0.3}$	$0.18^{+0.20}_{-0.12}$	$20.5^{+6.4}_{-1.5}$	$0.74^{+0.07}_{-0.05}$	$1.0^{+0.1}_{-0.2}$	$3.4^{+0.7}_{-1.7} \times 10^{56}$	440^{+180}_{-190}	$0.09^{+0.04}_{-0.04}$	1075
GW170104	$31.0^{+7.2}_{-5.6}$	$20.1^{+4.9}_{-4.5}$	$21.5^{+2.1}_{-1.7}$	$-0.04^{+0.17}_{-0.20}$	$49.4^{+5.2}_{-3.9}$	$0.66^{+0.09}_{-0.11}$	$2.2^{+0.5}_{-0.5}$	$3.2^{+0.7}_{-1.0} \times 10^{56}$	960^{+430}_{-410}	$0.19^{+0.07}_{-0.08}$	912
GW170608	$11.2^{+5.4}_{-1.9}$	$7.5^{+1.5}_{-2.1}$	$7.9^{+0.2}_{-0.2}$	$0.04^{+0.19}_{-0.06}$	$17.9^{+3.4}_{-0.7}$	$0.69^{+0.04}_{-0.04}$	$0.8^{+0.1}_{-0.1}$	$3.4^{+0.5}_{-1.3} \times 10^{56}$	320^{+120}_{-110}	$0.07^{+0.02}_{-0.02}$	524
GW170729	$50.7^{+16.3}_{-10.2}$	$34.4^{+8.9}_{-10.2}$	$35.8^{+6.3}_{-4.9}$	$0.37^{+0.21}_{-0.26}$	$80.3^{+14.5}_{-10.3}$	$0.81^{+0.07}_{-0.13}$	$4.9^{+1.6}_{-1.7}$	$4.2^{+0.8}_{-1.5} \times 10^{56}$	2760^{+1290}_{-1350}	$0.48^{+0.18}_{-0.21}$	1069
GW170809	$35.2^{+8.3}_{-5.9}$	$23.8^{+5.2}_{-5.1}$	$25.0^{+2.1}_{-1.6}$	$0.07^{+0.17}_{-0.16}$	$56.4^{+5.2}_{-3.7}$	$0.70^{+0.08}_{-0.09}$	$2.7^{+0.6}_{-0.6}$	$3.5^{+0.6}_{-0.9} \times 10^{56}$	990^{+320}_{-380}	$0.20^{+0.05}_{-0.07}$	310
GW170814	$30.7^{+5.5}_{-2.9}$	$25.6^{+2.8}_{-4.0}$	$24.3^{+1.4}_{-1.1}$	$0.07^{+0.12}_{-0.11}$	$53.6^{+3.2}_{-2.5}$	$0.73^{+0.07}_{-0.05}$	$2.8^{+0.4}_{-0.3}$	$3.7^{+0.5}_{-0.5} \times 10^{56}$	560^{+140}_{-210}	$0.12^{+0.03}_{-0.04}$	99
GW170817	$1.46^{+0.12}_{-0.10}$	$1.27^{+0.09}_{-0.09}$	$1.186^{+0.001}_{-0.001}$	$0.00^{+0.02}_{-0.01}$	≤ 2.8	≤ 0.89	≥ 0.04	$\geq 0.1 \times 10^{56}$	40^{+10}_{-10}	$0.01^{+0.00}_{-0.00}$	22
GW170818	$35.5^{+7.5}_{-4.7}$	$26.9^{+4.4}_{-5.2}$	$26.7^{+2.1}_{-1.7}$	$-0.09^{+0.18}_{-0.21}$	$59.8^{+4.8}_{-3.7}$	$0.67^{+0.07}_{-0.08}$	$2.7^{+0.5}_{-0.5}$	$3.4^{+0.5}_{-0.7} \times 10^{56}$	1020^{+430}_{-370}	$0.20^{+0.07}_{-0.07}$	35
GW170823	$39.5^{+10.1}_{-6.6}$	$29.4^{+6.5}_{-7.1}$	$29.3^{+4.2}_{-3.1}$	$0.08^{+0.19}_{-0.22}$	$65.6^{+9.3}_{-6.5}$	$0.71^{+0.08}_{-0.09}$	$3.3^{+0.9}_{-0.8}$	$3.6^{+0.6}_{-0.9} \times 10^{56}$	1860^{+840}_{-840}	$0.34^{+0.13}_{-0.14}$	1780

The LIGO-India Advantage

Tarun Souradeep

First GW detection by Advanced LIGO-US observatories

Current:
Two US detectors sky-localization (620 square degree 2500 full moons)

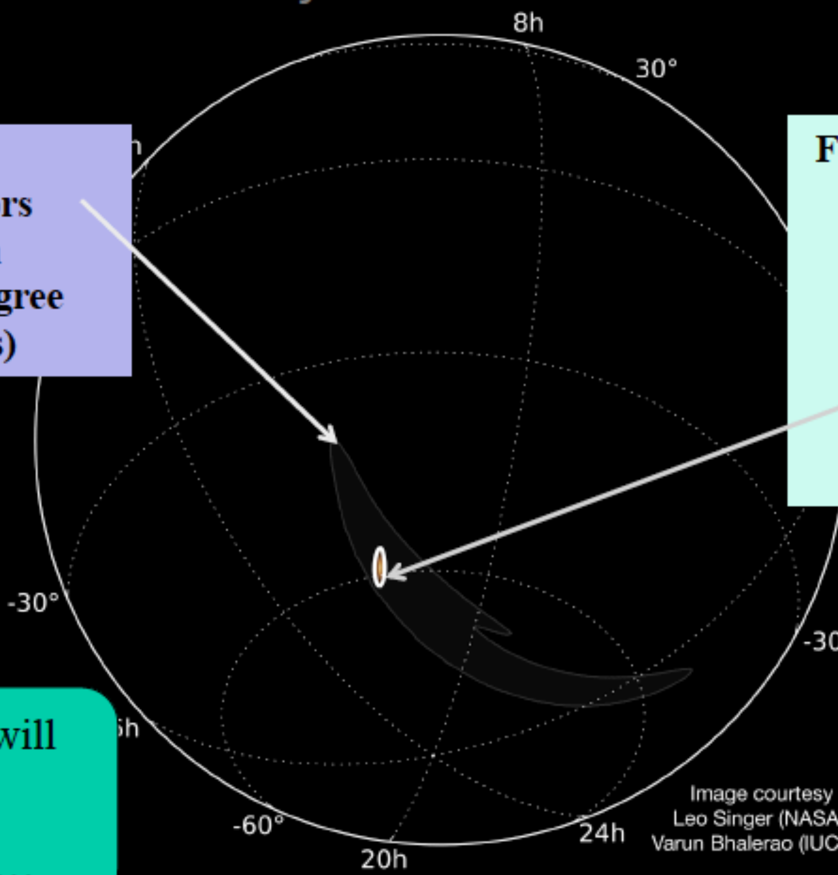
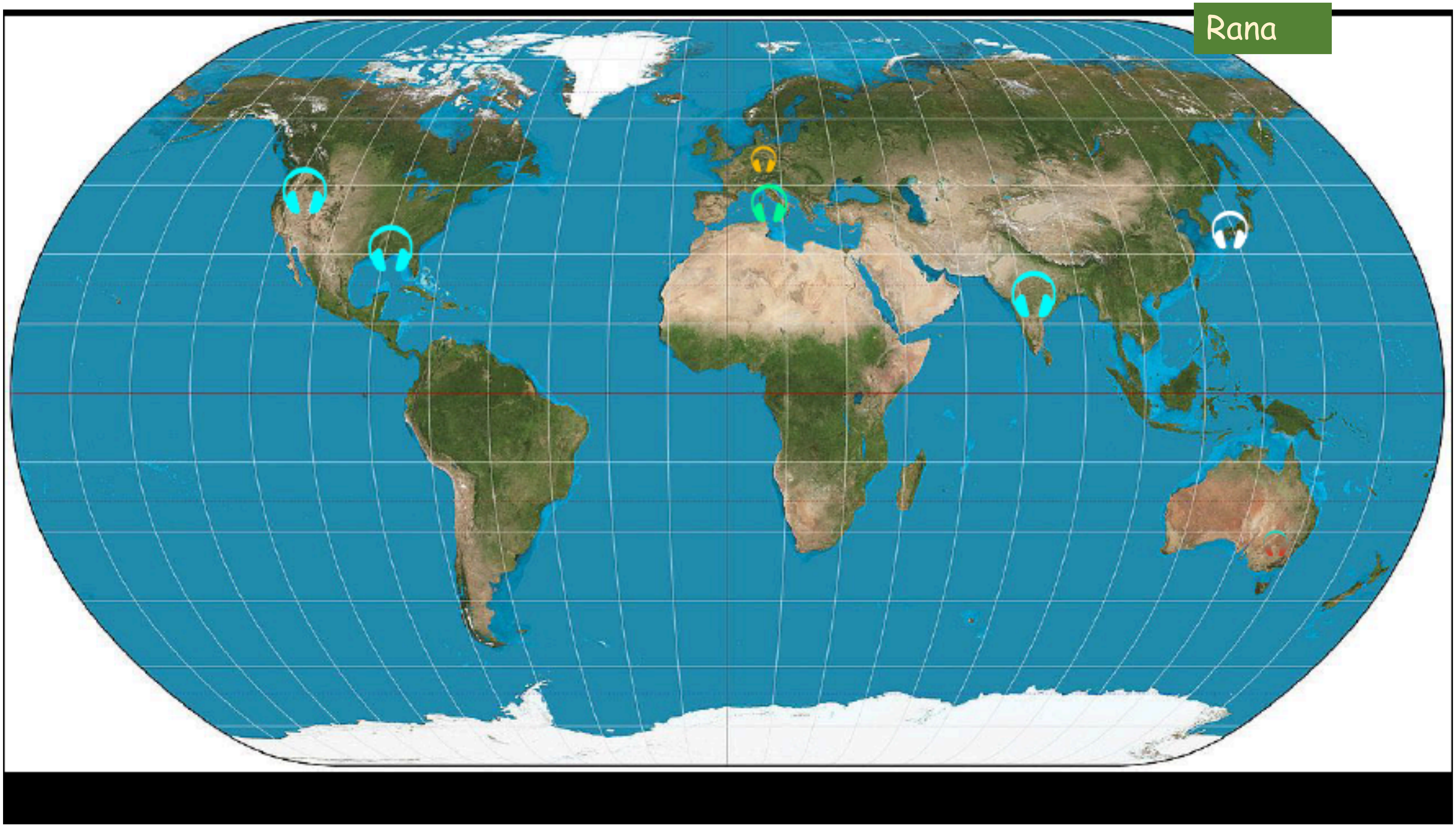


Image courtesy
Leo Singer (NASA),
Varun Bhalerao (IUCAA)

Forecast : LIGO-India in joint operation sky-localization 100 time smaller (5 square degrees 20 full moons) !!!

LIGO-India will make a BIG difference !!!!

B. P. ABBOTT *et al.* PHYS. REV. X 6, 041015 (2016)


Rana

Science harvesting with the global GW detector network

Jo van den Brand

At the same time making Virgo as sensitive and efficient as we can

Fundamental physics

Access to dynamic strong field regime, new tests of General Relativity
Black hole science: inspiral, merger, ringdown, quasi-normal modes, echo's
Lorentz-invariance, equivalence principle, polarization, parity violation, axions

Astrophysics and astronomy

First observation for binary neutron star merger, relation to sGRB, evidence for a kilonova
Start of gravitational wave astronomy, population studies, formation of progenitors, remnant studies

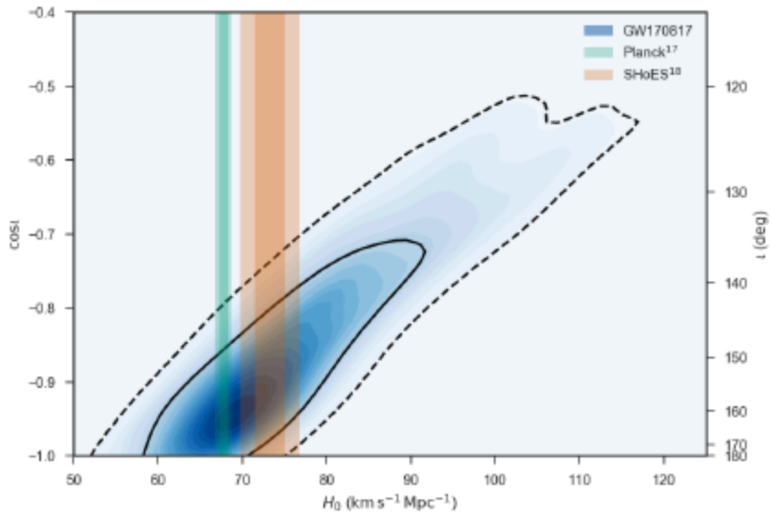
Cosmology

Binary neutron stars and black holes can be used as standard "sirens", DM and DE, primordial black holes

Nuclear physics

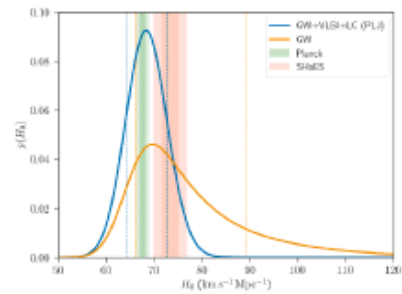
Tidal interactions between neutron stars get imprinted on gravitational waves, access to equation of state

Degeneracy with inclination



Distance-inclination degeneracy: GW amplitude from by a distant binary viewed face-on (or face-off) is similar to that of a closer binary viewed edge-on.

Abbott *et al.* Nature **551** #7678, 85-88 (2017)

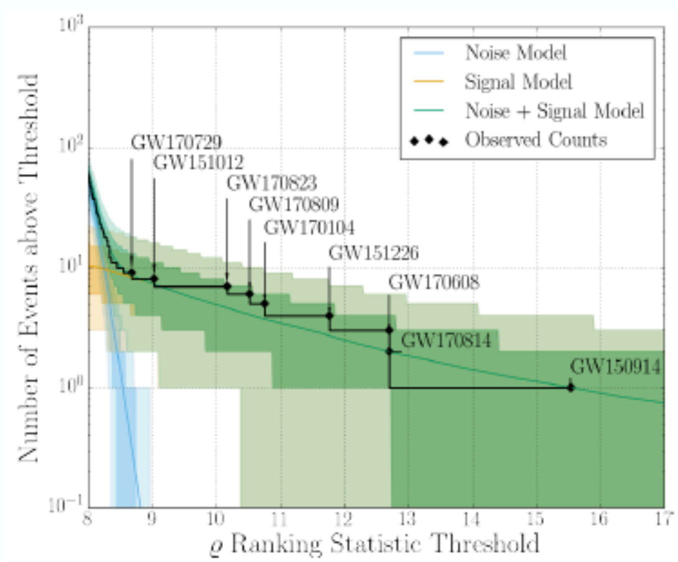


Hotokezaka *et al.* (2018): **jet** $\longrightarrow$ **inclination** $\longrightarrow$ H_0

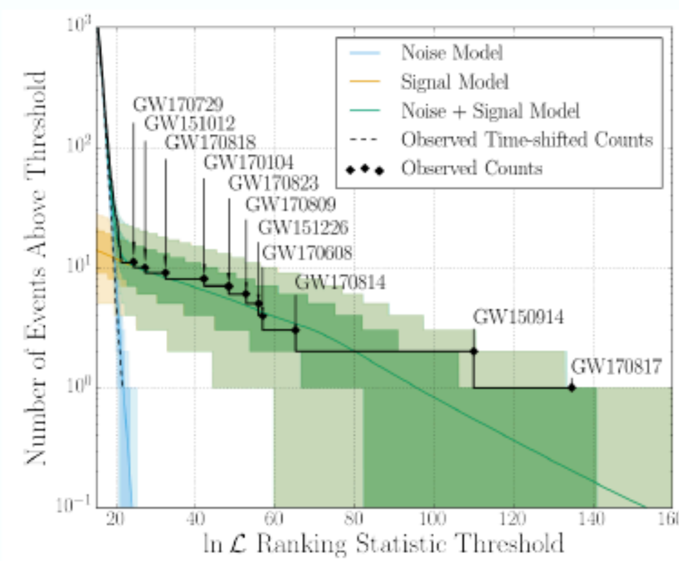
Sathya

EVENTS AND THEIR ASTROPHYSICAL SIGNIFICANCE

PyCBC



GSTLAL



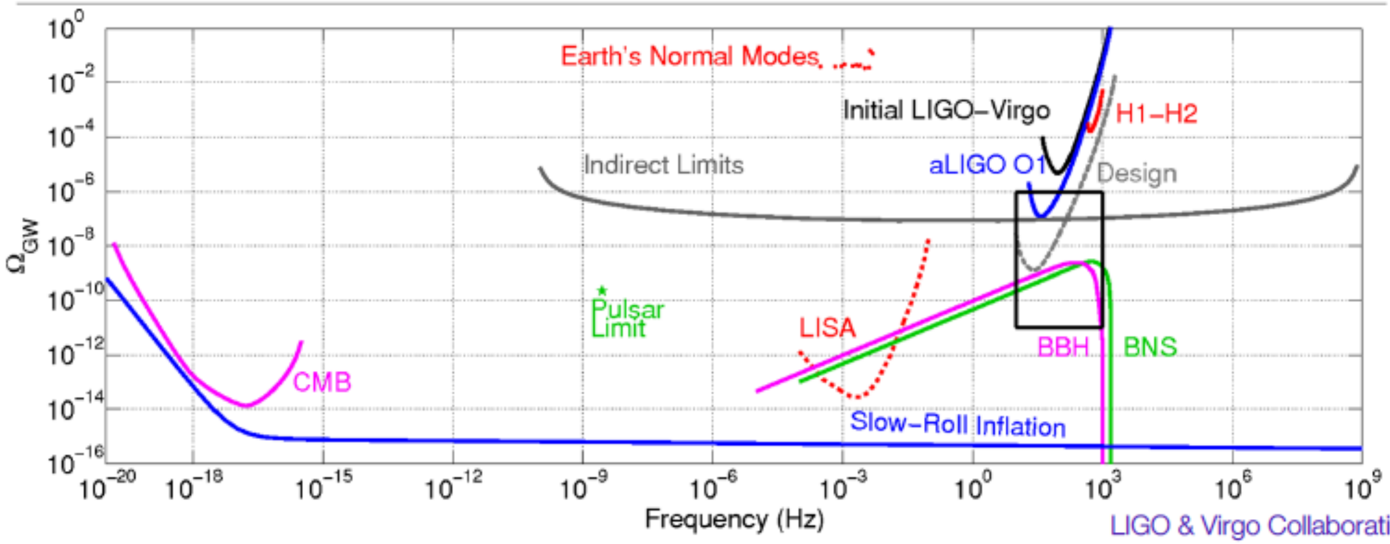
Abbott+ arXiv:1811.12907

Varun Bhalerao

What can we do?

- Best detection bet: Optical / X-ray
- Data available:
  - » Prompt high-energy
  - » Lightcurves
  - » X-ray afterglows / OIR spectra will be rare

LIGO O1 Isotropic Search Upper Limits



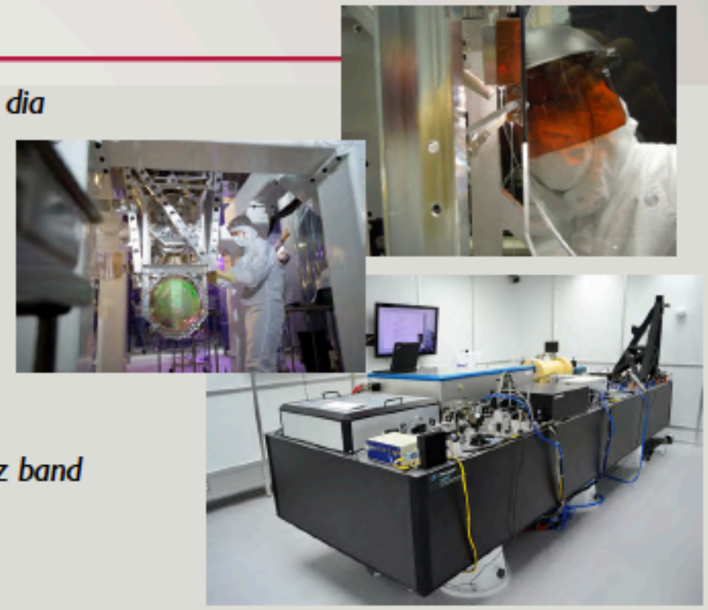
LIGO & Virgo Collaboration
PRL 118, 121101 (2017)

Spectral index α	Frequency band with 99% sensitivity	Amplitude Ω_α	95% C.L. upper limit	Previous limits [36]
0	20–85.8 Hz	$(4.4 \pm 5.9) \times 10^{-8}$	1.7×10^{-7}	5.6×10^{-6}
2/3	20–98.2 Hz	$(3.5 \pm 4.4) \times 10^{-8}$	1.3×10^{-7}	–
3	20–305 Hz	$(3.7 \pm 6.5) \times 10^{-9}$	1.7×10^{-8}	7.6×10^{-8}

Suresh Doravari

R&D FOR THIRD GENERATION DETECTORS

- Large mirrors and relevant metrology – *200 to 300 kg, 0.5-1.0 m dia*
- Silicon cryogenic suspension – *123 K for CE and 10 K for ET*
- Suspensions – *large mirrors + lower suspension modes*
- Newtonian noise – *seismometer arrays and active feedforward control*
- High power laser – *1060, 1550, 2000 nm lasers at ~ 100-200 W*
- Reducing technical noise – to enable observations in the < *10 Hz band*
- Coating Thermal Noise – *low loss at cryogenic temperatures*
- Quantum noise – *freq dependant squeezing with ~km long filter cavities*



Ref: LIGO-T1800133-v3
Instrument Science White Paper 2018

Suresh Doravari

INDIAN SCENARIO : PLAYING TO OUR TRADITIONAL STRENGTHS

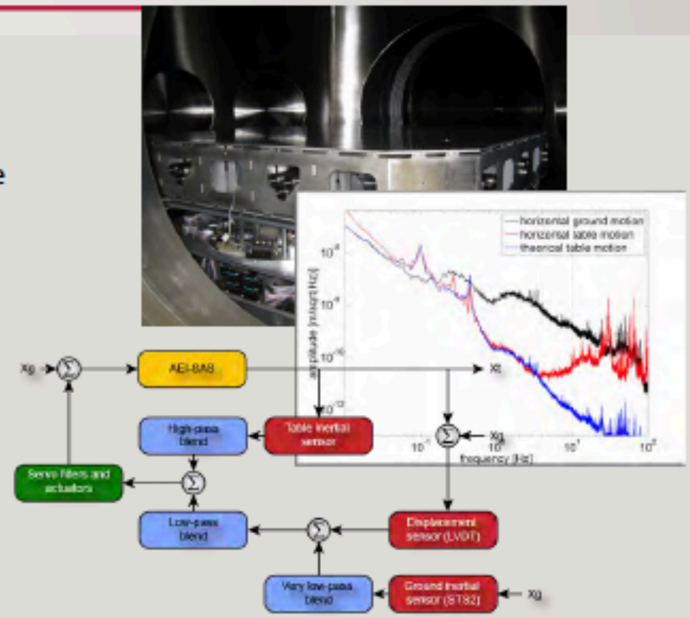
Analysis of available detector data

Interferometer modelling , System Identification , Control

a. "LIGO-In-a-Box" – a Neural Network to mimic the IFO response
b. Techniques based on Bayesian inference for sysID
c. Markov Chain Monte Carlo of Finesse and FFT methods
d. Nonlinear regression methods using Machine Learning
e. Control algorithms using ML, NN techniques

Computing thermal noise in coatings using numerical methods

FEM analysis with adaptive mesh refinement with parallel computing



Picture Credits: Thesis of Gerald Bergmann