Prospects and challenges for gravitational wave astronomy and astrophysics

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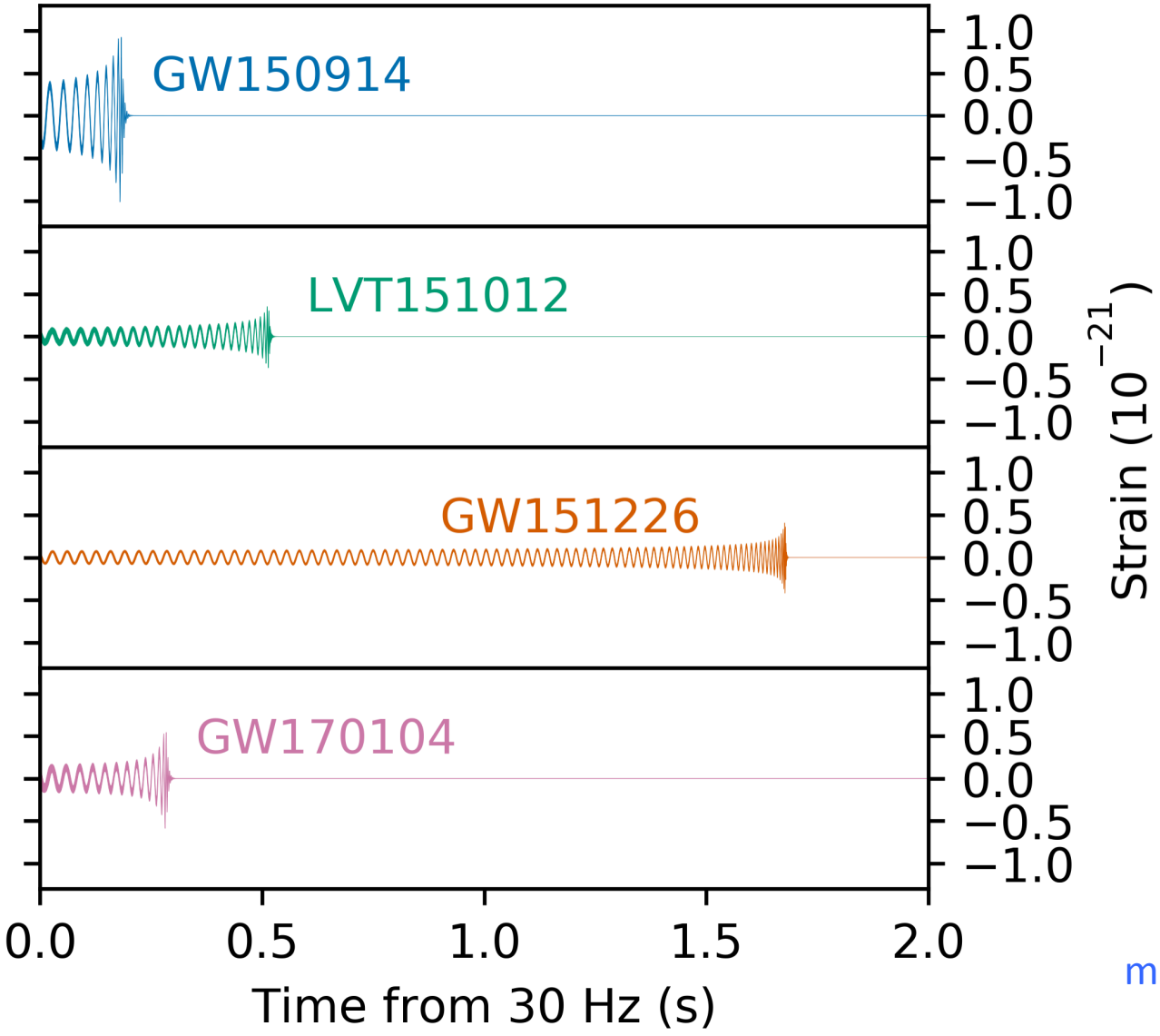
Second BHI Conference on Black Holes

May 9, 2018

Outline

- Prospects for the Science
- Challenges for the technology
- Strategic planning – challenges and opportunities

Results of O1 and O2 run announced June 1, 2017



m1=36, m2= 29, Δm=3

if at 1 au

h ~10^{-6}

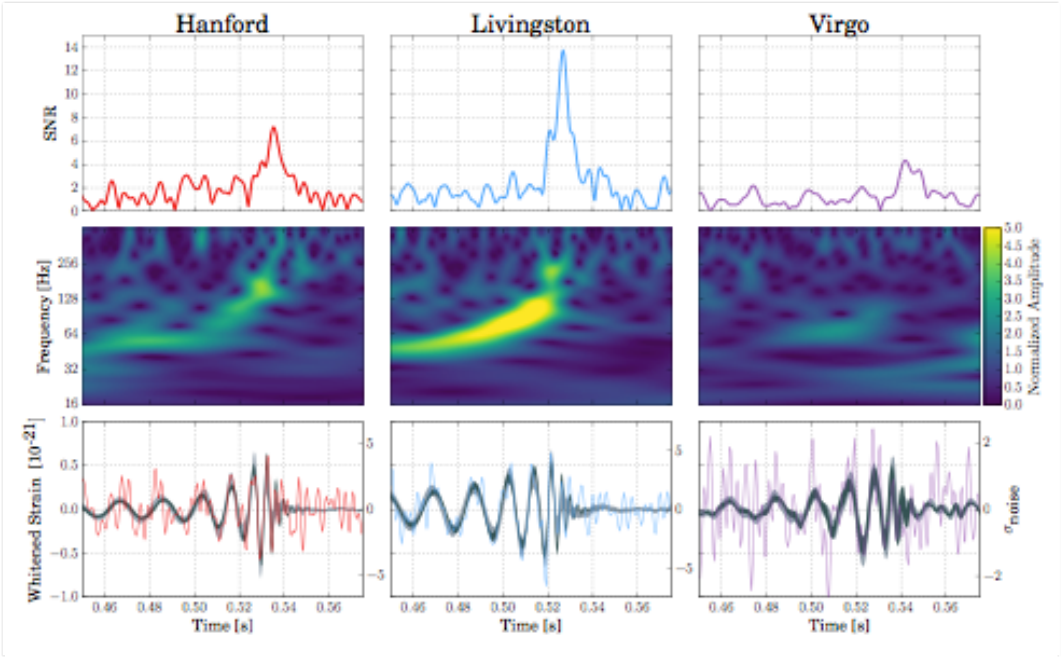
I_g~ 10^{25} w/m^2

m1=23, m2= 13, Δm=1.5

m1=14.2, m2= 7.5, Δm=1

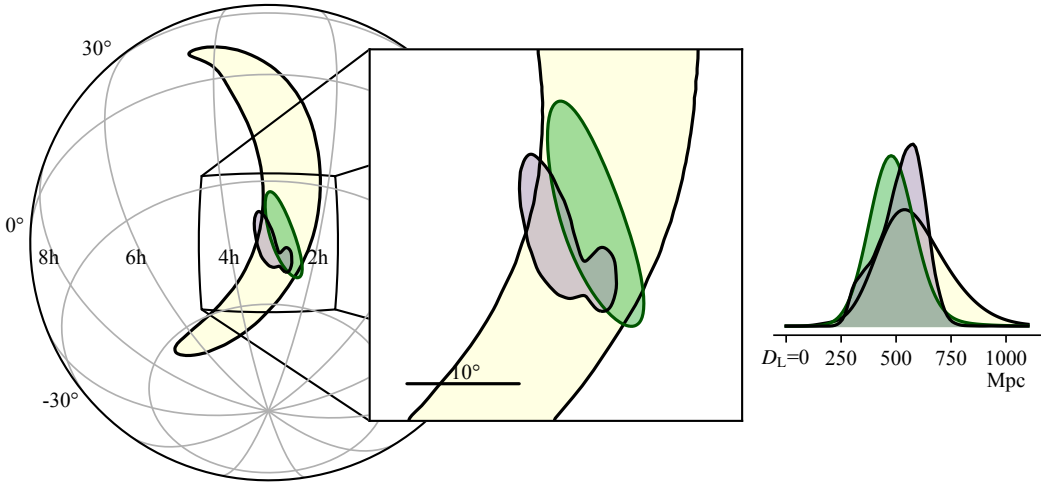
m1=31, m2= 19, Δm=2

masses in source frame



Triple coincidence
GW 170814

M_1 = 30
M_2 = 25
ΔM = 2.7



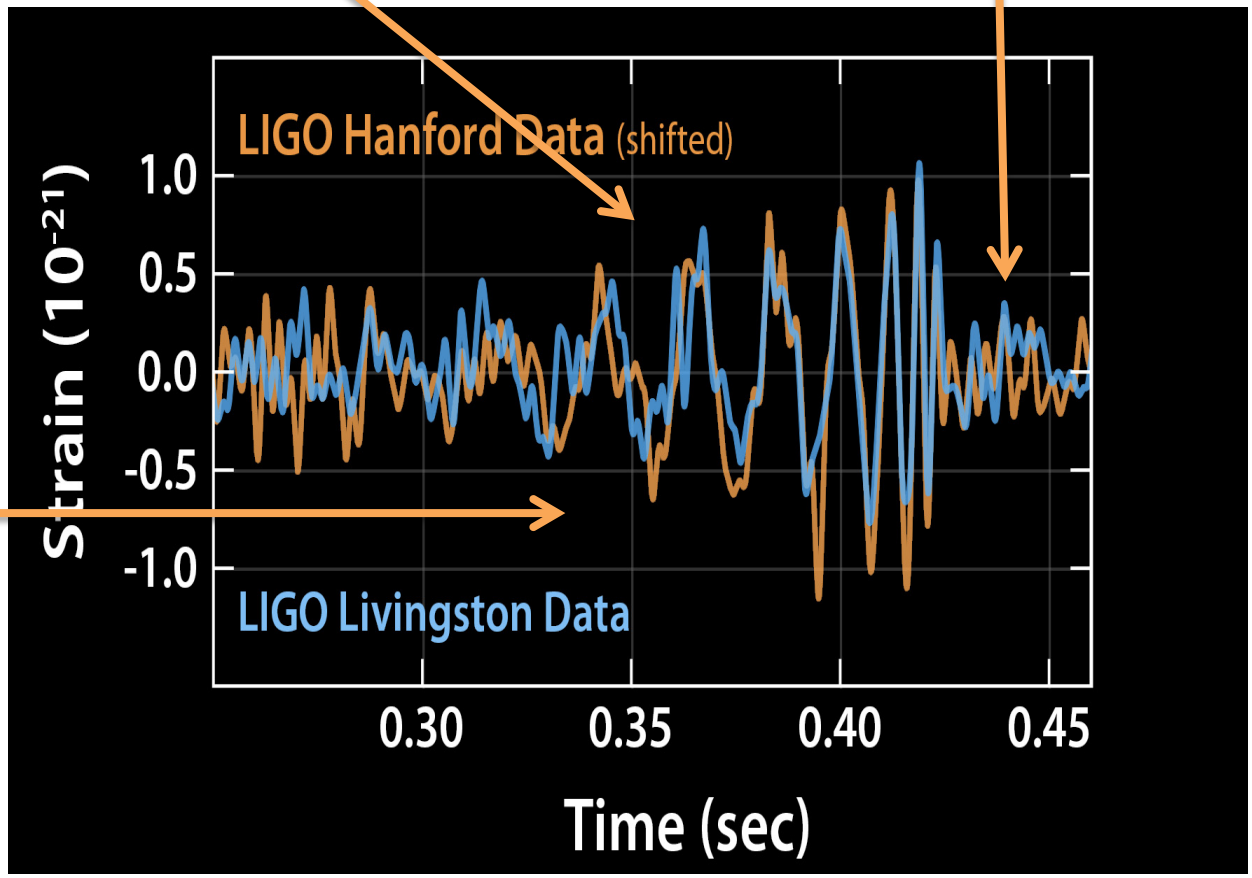
Localization on sky and distance

New measurements for General Relativity

modulation of post Newtonian
waveform by spin − orbit coupling
Hawking area theorem

ringdown of metric normal
modes at event horizon

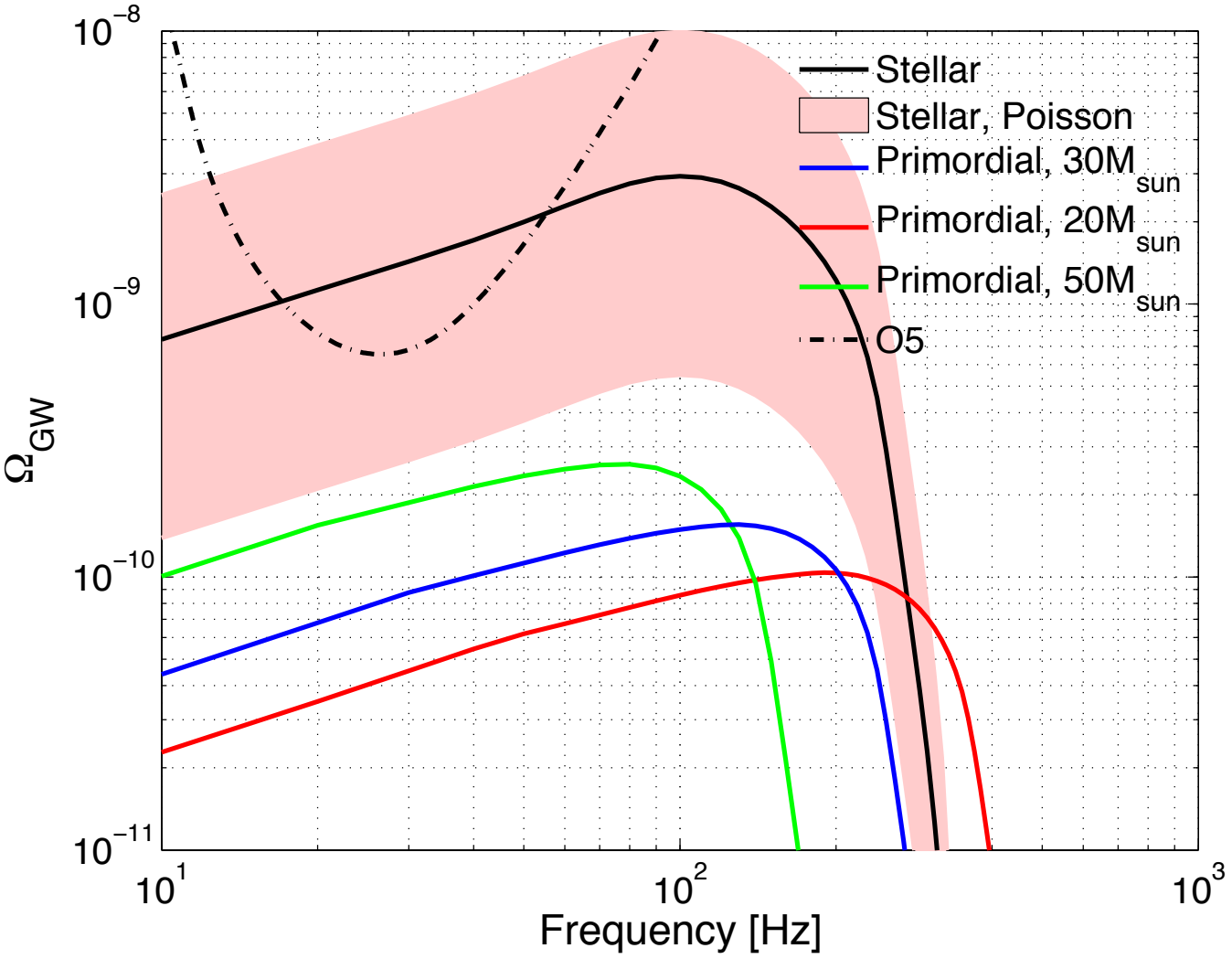
low frequency
non-linear memory



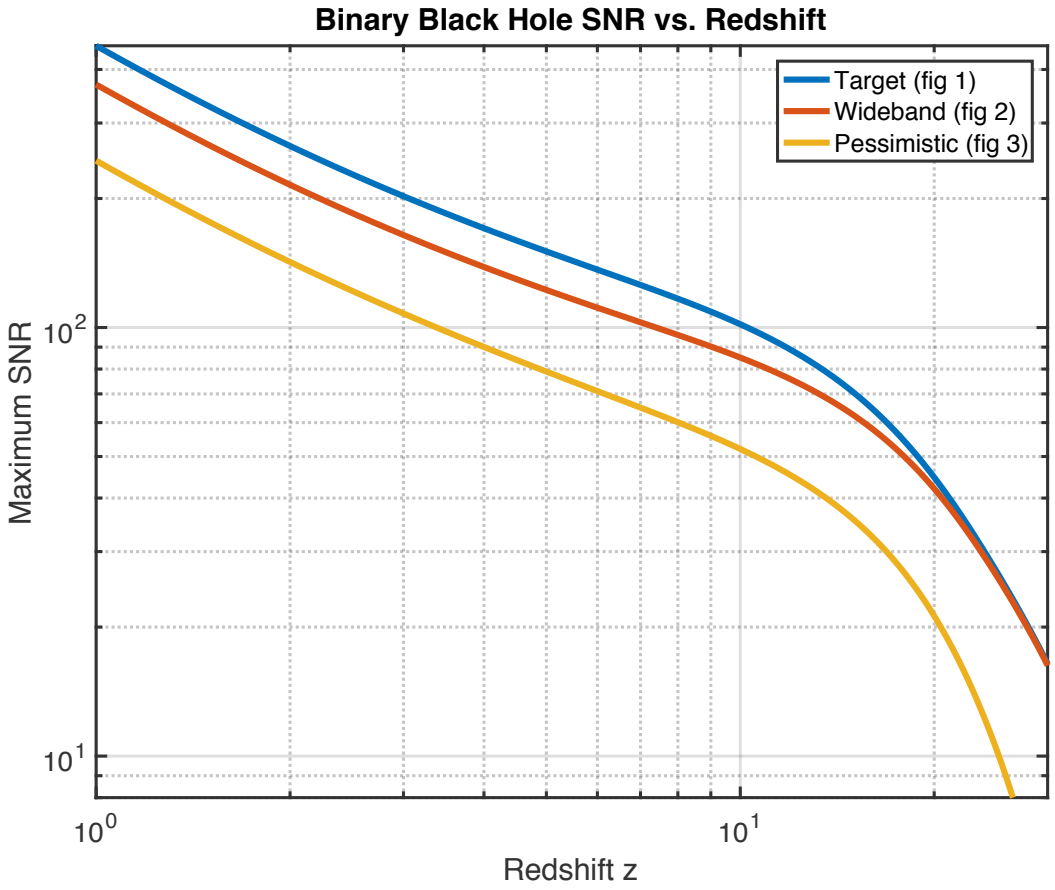
BH Astronomy

- Formation and rates
  - Common stellar envelope − correlated spins
    - first stars
    - continuous at all epochs
  - Dynamical − globular clusters, random spins
  - Primordial
  - EM counterparts − improved position, lower latency
- Statistics and distribution
  - mass distribution of binary BH
  - distribution in distance (z)
- Cosmology

stochastic background of PBHs



(Mandic et al. 2017)

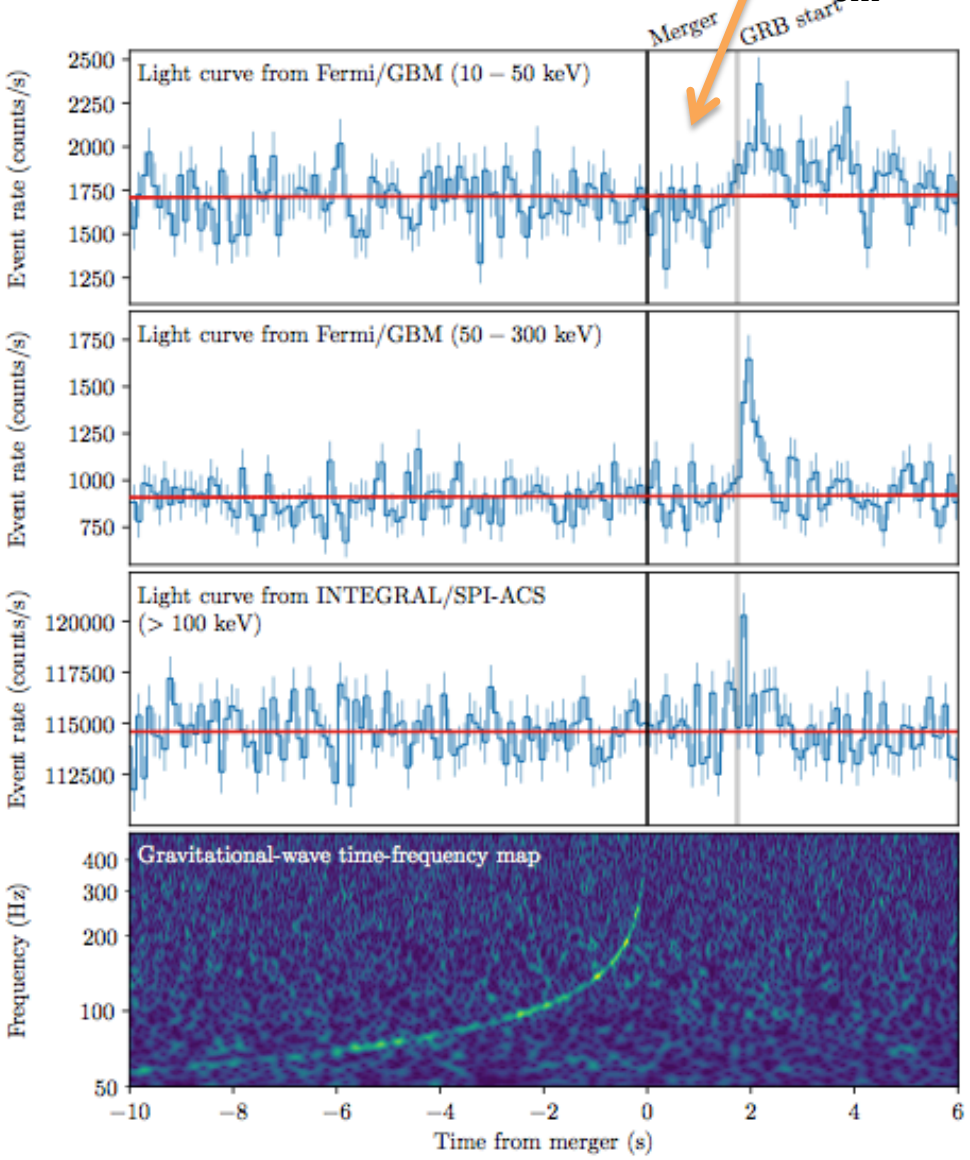


Evans, Vitale

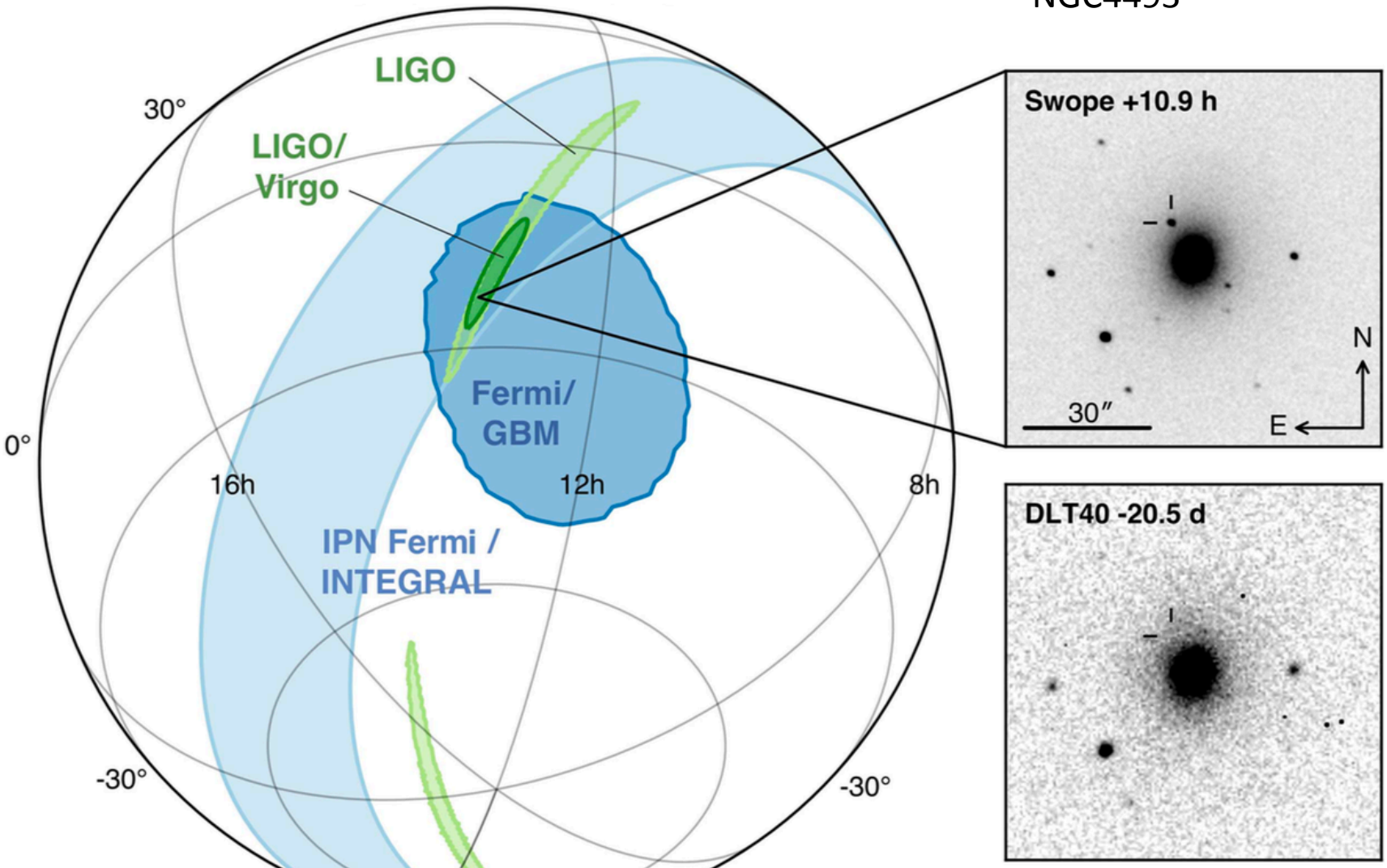
Binary Neutron Star Coalescence

$$\frac{c_{gw}}{c_{em}} = 1 \pm 10^{-15}$$

Short high energy gamma ray bursts are associated with NS collisions



NGC4493

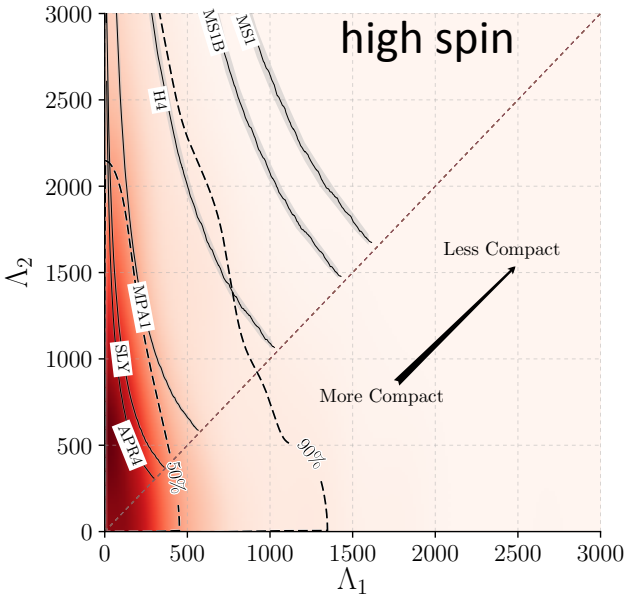

LIGO
LIGO/
Virgo
Fermi/
GBM
IPN Fermi /
INTEGRAL
30°
0°
-30°
16h
12h
8h
-30°
Swope +10.9 h
N
E
30″
DLT40 -20.5 d

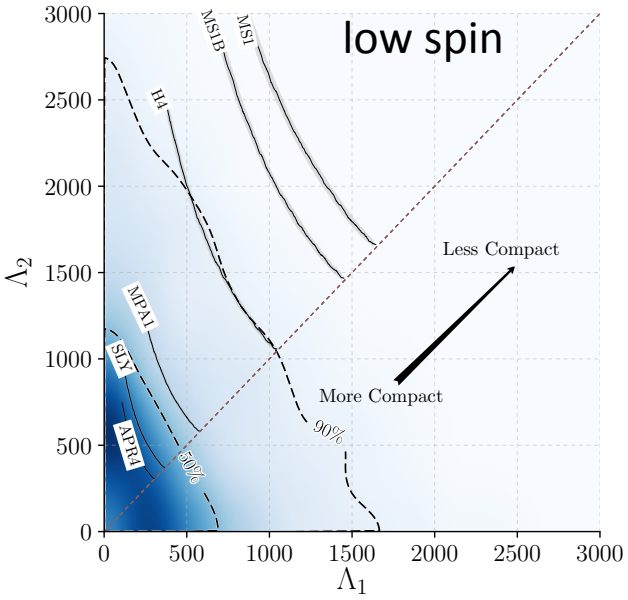
Binary NS Physics and Astronomy

- Nuclear physics
  - Equation of state
    - Tidal distortion and orbital phase
    - Spectroscopy of normal modes post collision
  - Structure of NS
    - CW detection of rotation from non-sphericity
    - Non spheroidal modes before collision
    - glitches and change of wave amplitude
  - Formation of heavy elements
    - R-process in kilonova
- General Relativity
  - CW polarization and speed
- Astronomy
  - Formation processes
  - Spin orientations, magnitudes

Cosmology: Standard object at known distance − possibly with independent measure of z. Systematic errors different than standard EM techniques

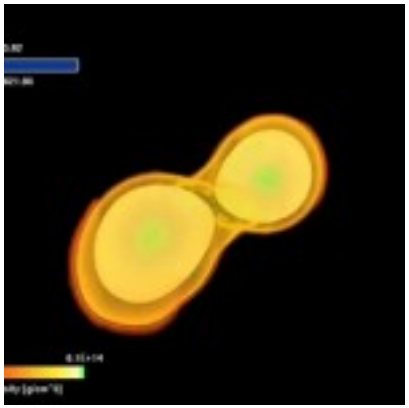
Neutron Star Tidal Distortion

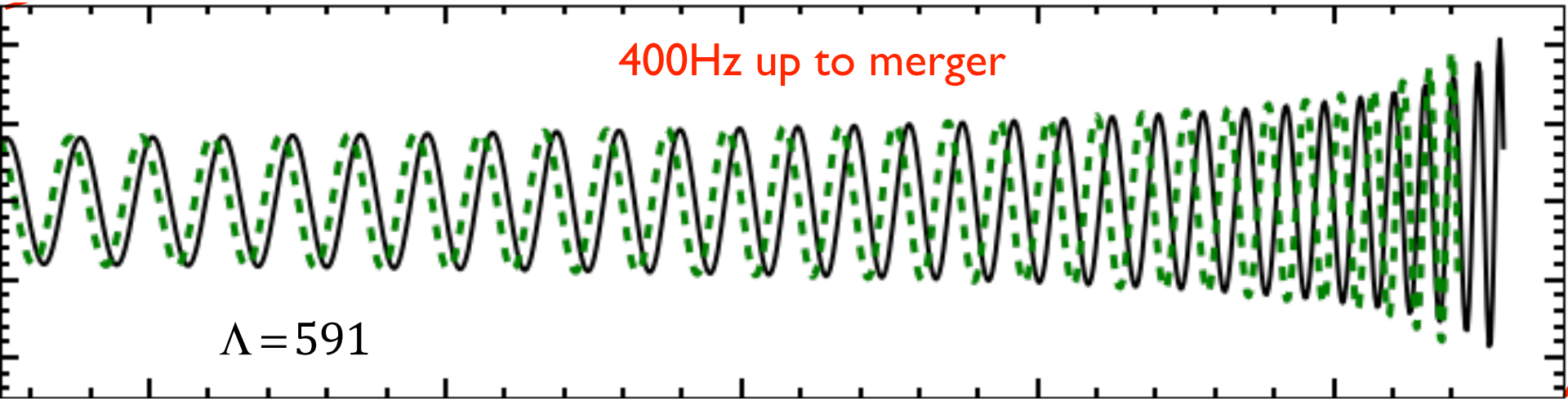




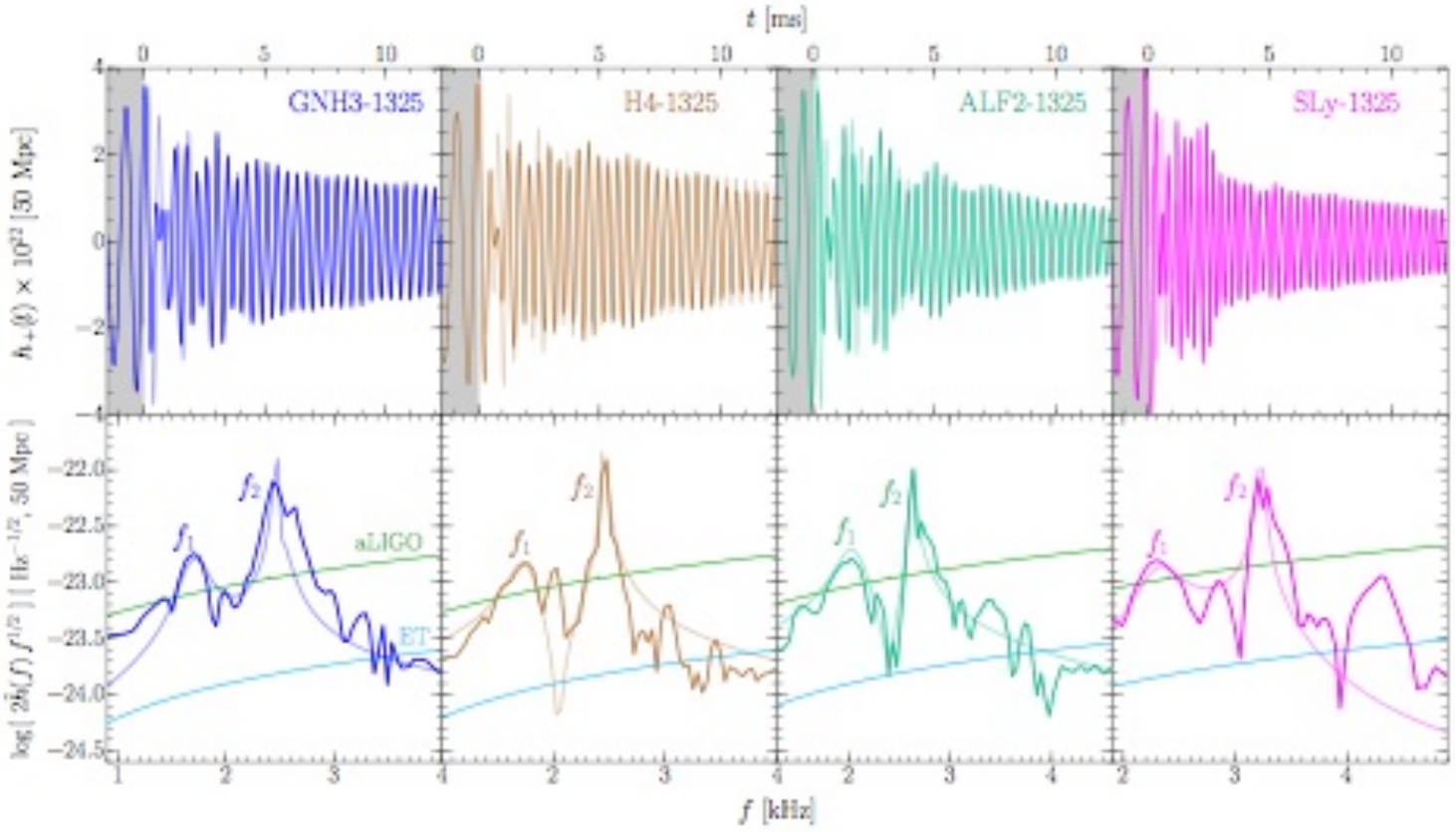
$$Q_{ij} = \lambda \frac{d^2V(r)}{dx_i dx_j}$$

tidal distortion



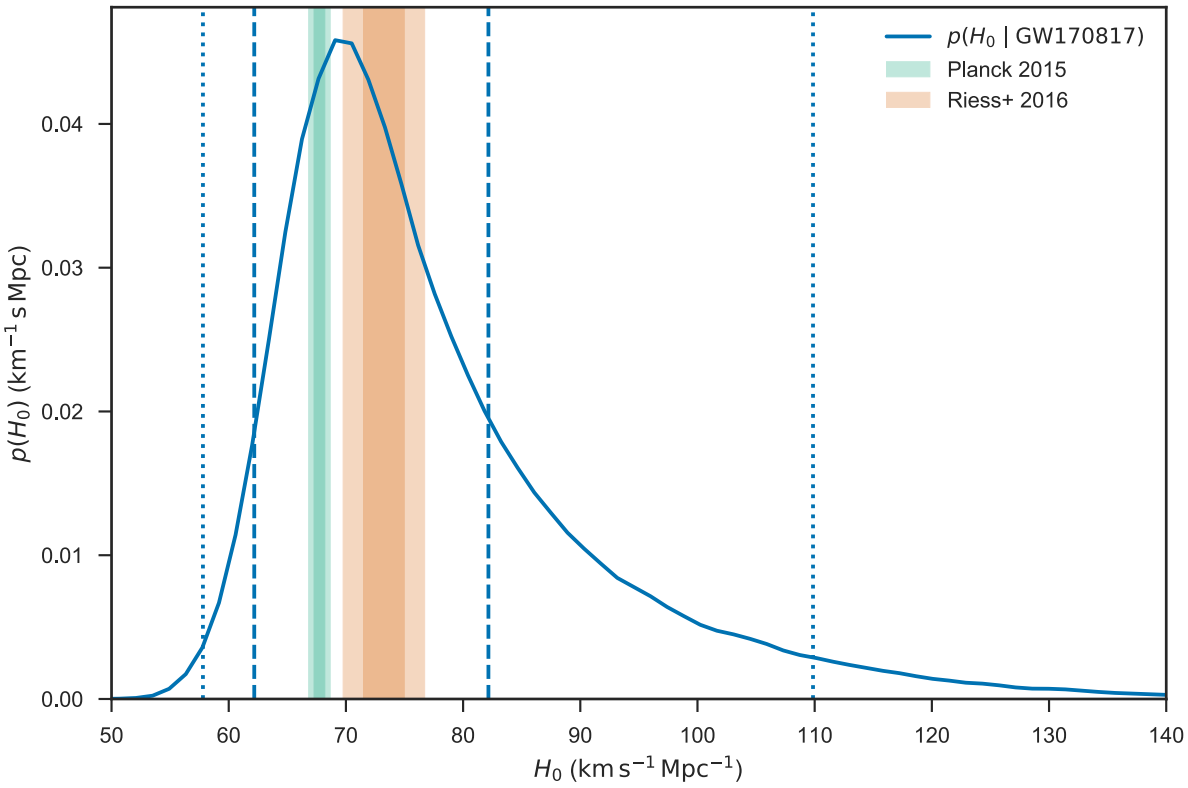


Binary neutron star spectroscopy



S.Bose,K.Chakravarti, L.Rezzolla, B.S. Sathyaprakash, K. Takami

Hubble constant measurement: Galaxy z and distance from GW amplitude



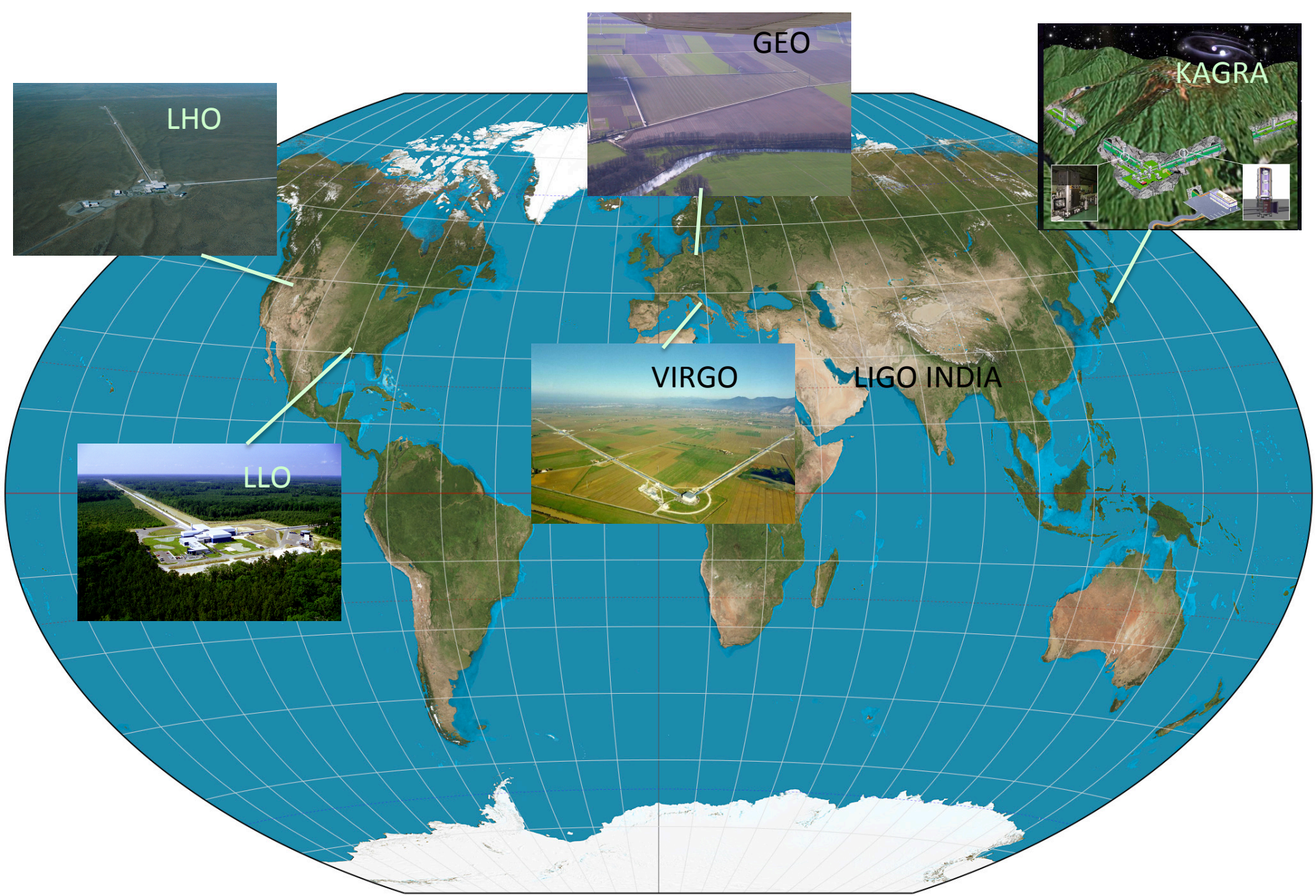
The scientific and technical challenges

- Given the radical difference between GW sources (accelerating mass) and EM (accelerating charge) and the penetrating ability of GW there must be sources unique to the GW sky not known to EM astronomy. What is an effective way to search for them?
- The critical importance of detector sensitivity: the need to improve the limiting h_{min} – the minimum detectable gravitational strain.

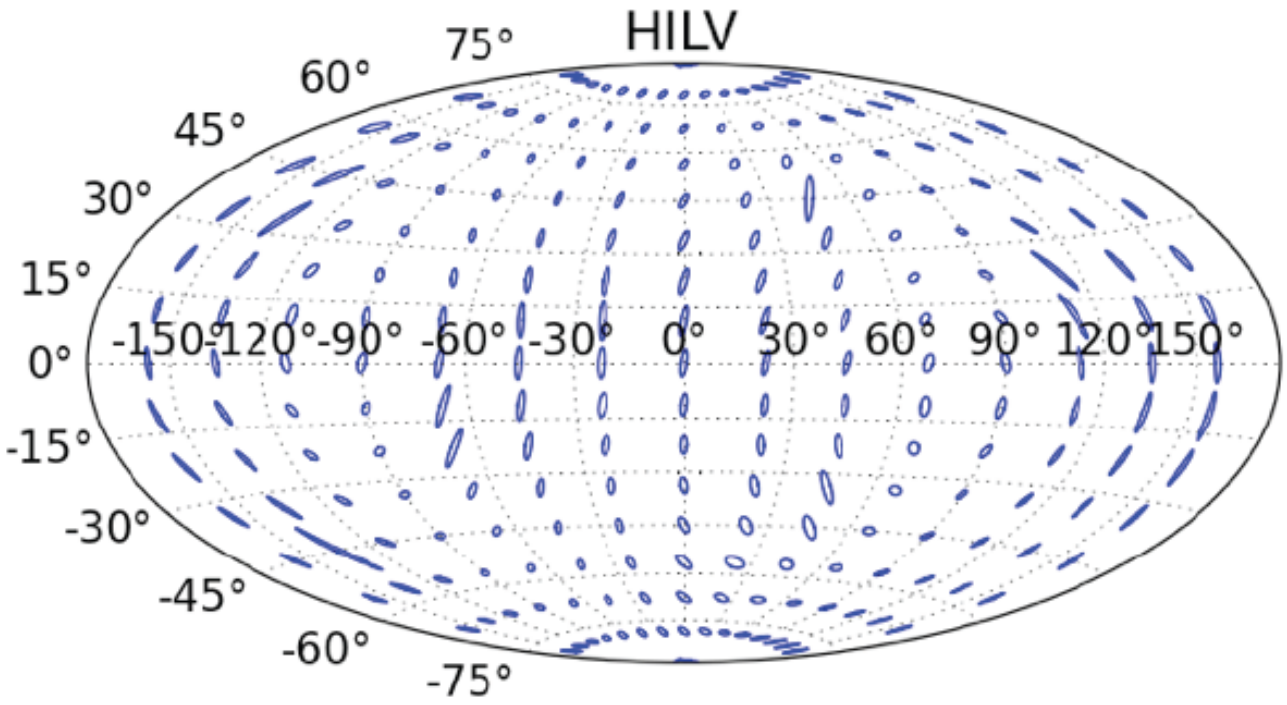
$$\text{Transient detection events} \propto T_{obs} \text{ but } \propto \frac{1}{h_{min}^3}$$

$$\text{SNR periodic sources} \propto \sqrt{T_{obs}} \text{ but } \propto \frac{1}{h_{min}}$$

$$\text{SNR stochastic background} \propto \sqrt{\sqrt{T_{obs}}} \text{ but } \propto \frac{1}{h_{min}}$$

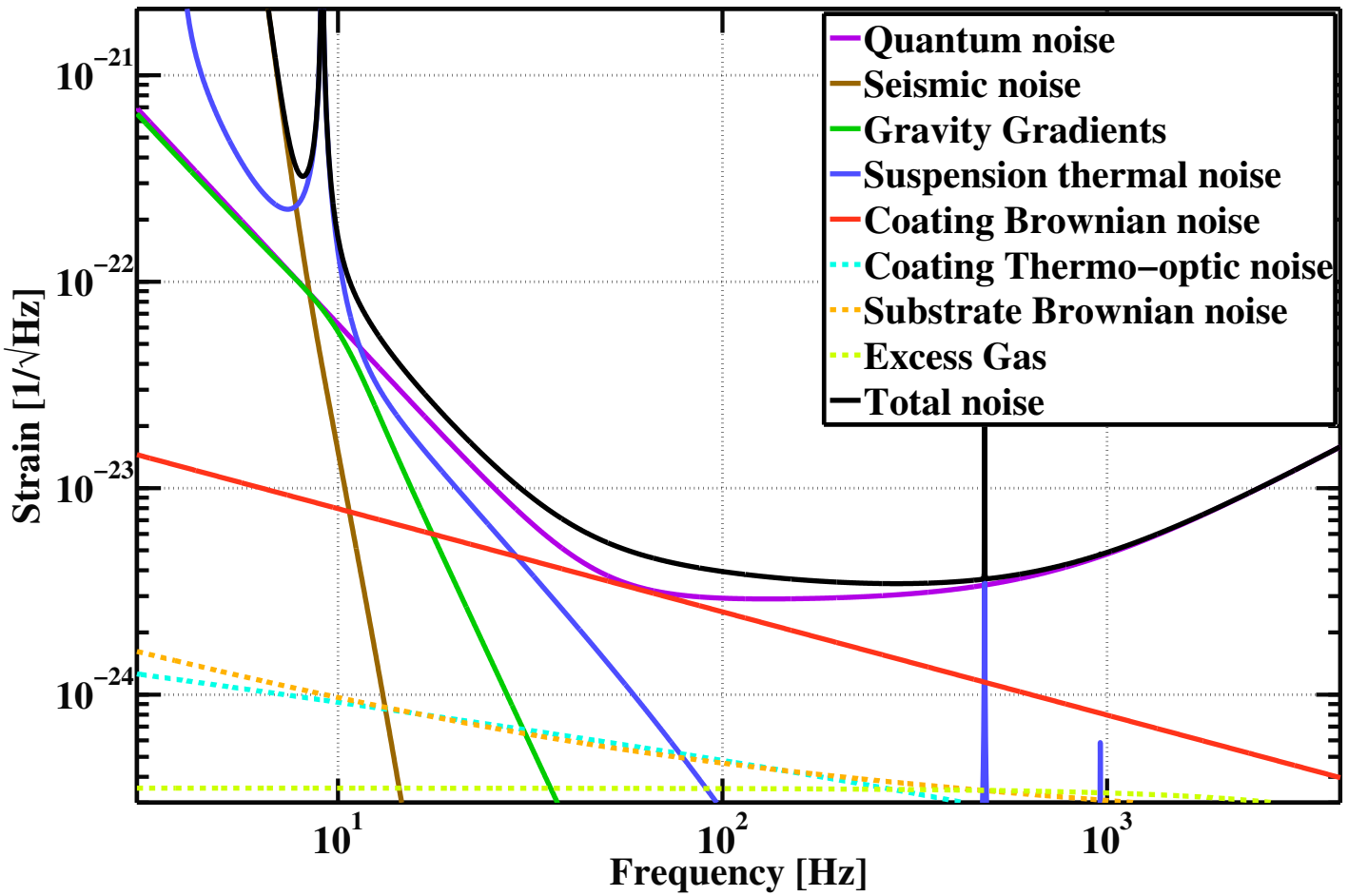

LHO
GEO
KAGRA
VIRGO
LIGO INDIA
LLO

Localization with more detectors



Fairhurst 2011

Design noise budget Advanced LIGO



advanced LIGO to A+

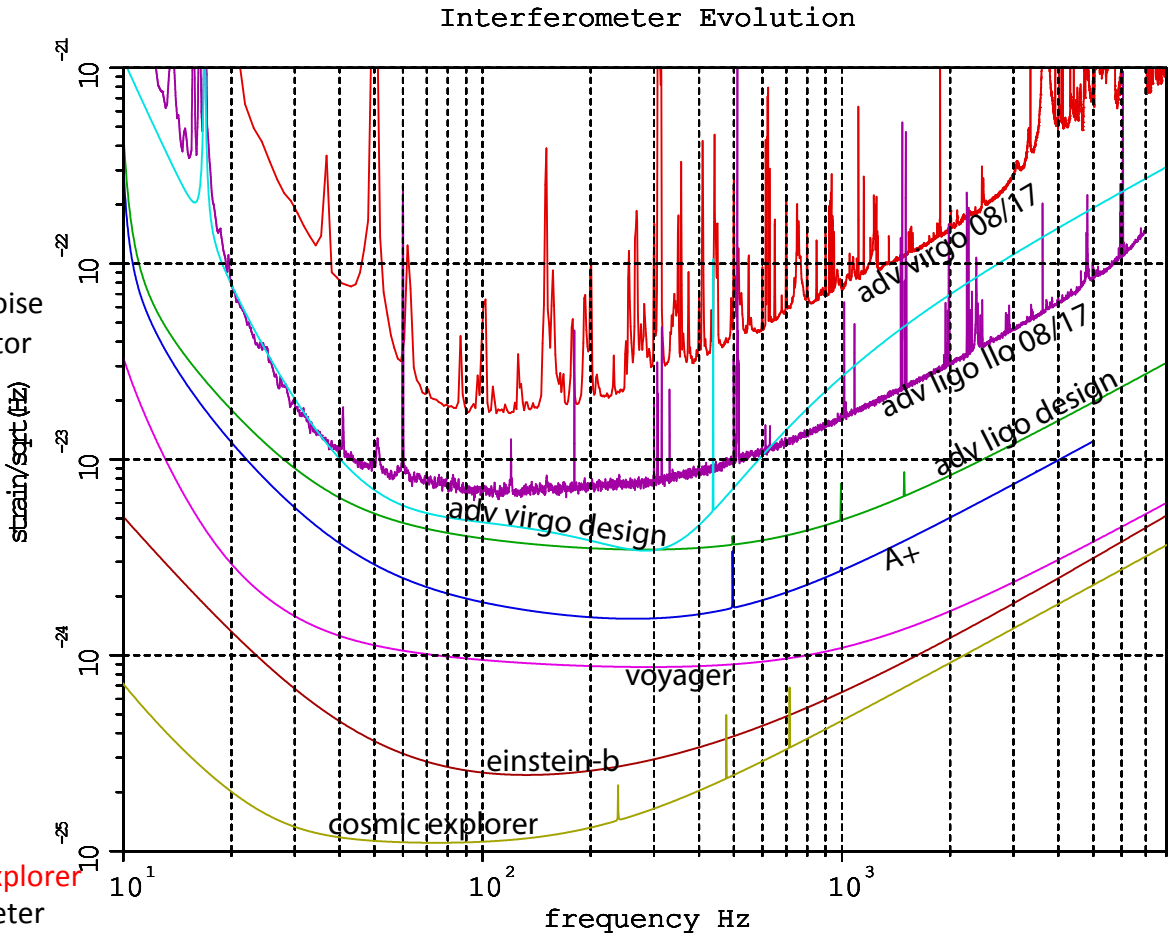
higher power
frequency dependent SQL
reduced coating thermal noise
Balanced homodyne detector

Einstein

10km equilateral triangle
buried several km
cryogenics
high and low freq ifo

A+ or Voyager to Cosmic Explorer

40km surface L interferometer



today to adv ligo design

higher power
phase noise SQL
improved vac
reduced charge noise
reduced scattering

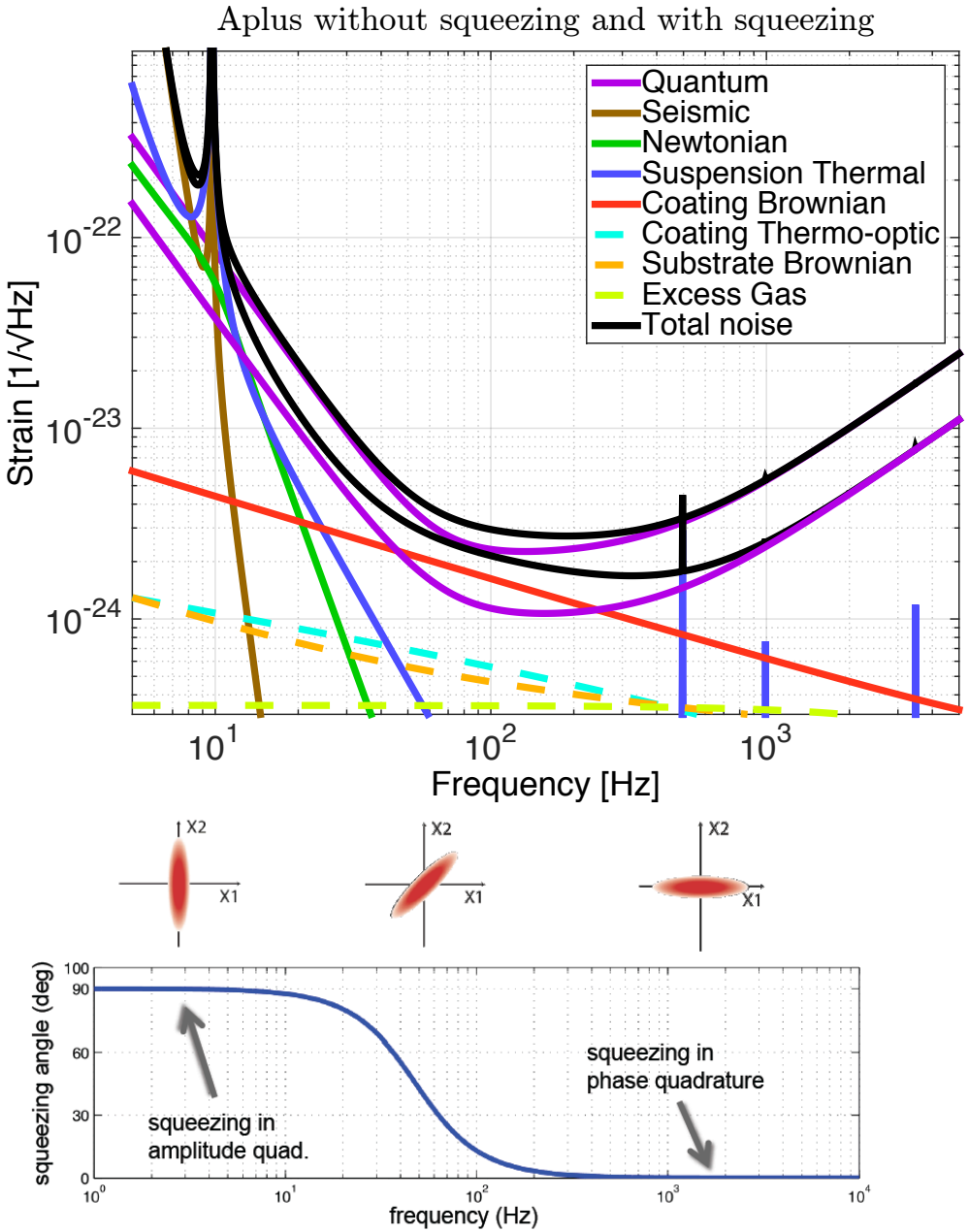
A+ to voyager

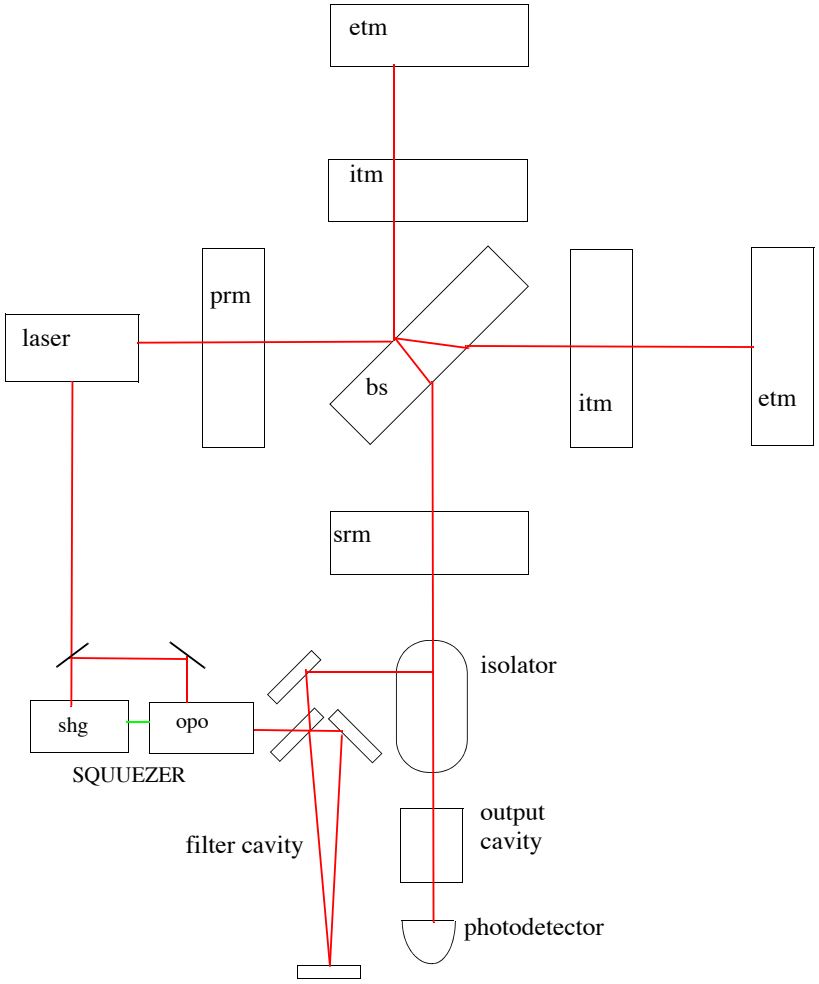
heavier silicon optics
120K and 2 micron
measure Newtonian grad
higher power
improved seismic isol
improved control system

Strategic planning

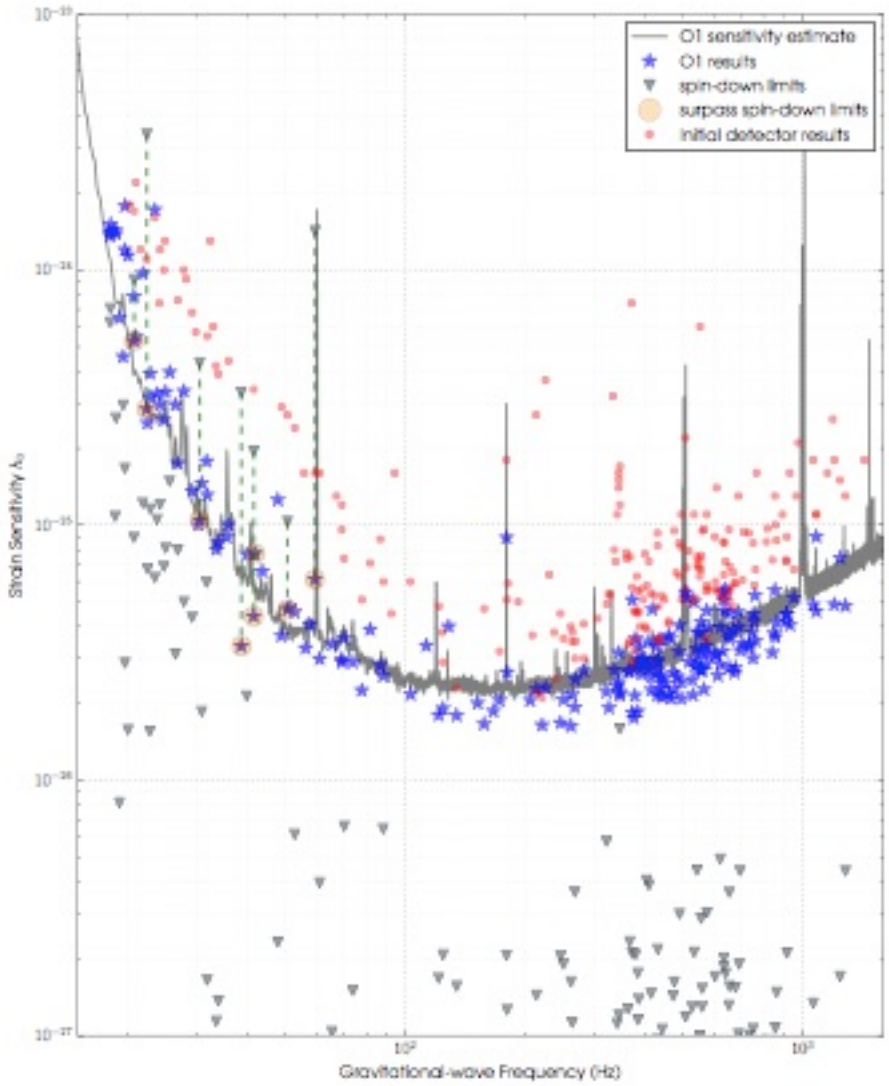
- 3rd generation detector science opportunities
  - Networks of 3rd and 2nd generation detectors
  - How to facilitate multi-messenger astronomy
- 3rd generation detector configurations
  - single ifo, multiple ifo
  - cryogenic
  - buried, surface
- 3rd generation engineering studies
  - value engineering − cost reduction
  - realistic cost estimates
- Preparing the support of the scientific community
  - NRC studies
  - Decadal reviews ?

backup slides

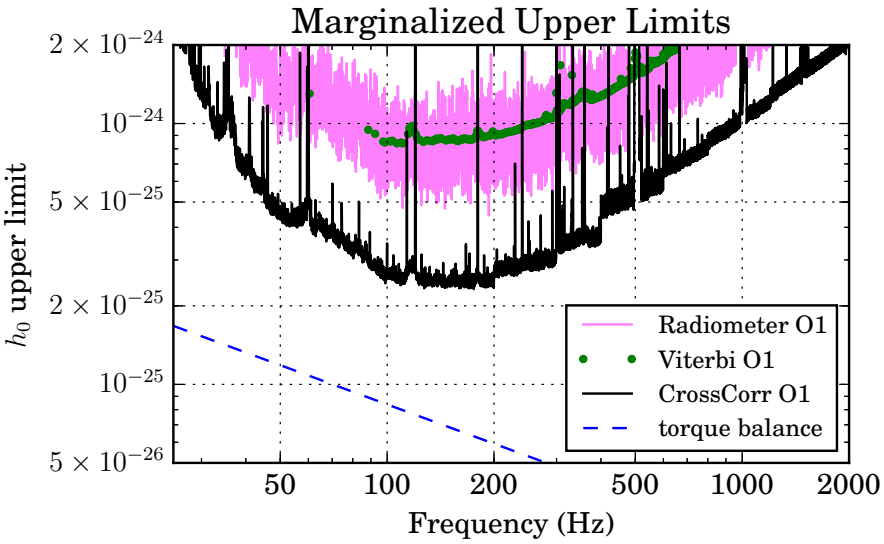




E.Oelker, T. Isogai, J.Miller, M.Tse, L.Barsotti,N.Mavalvala,M.Evans



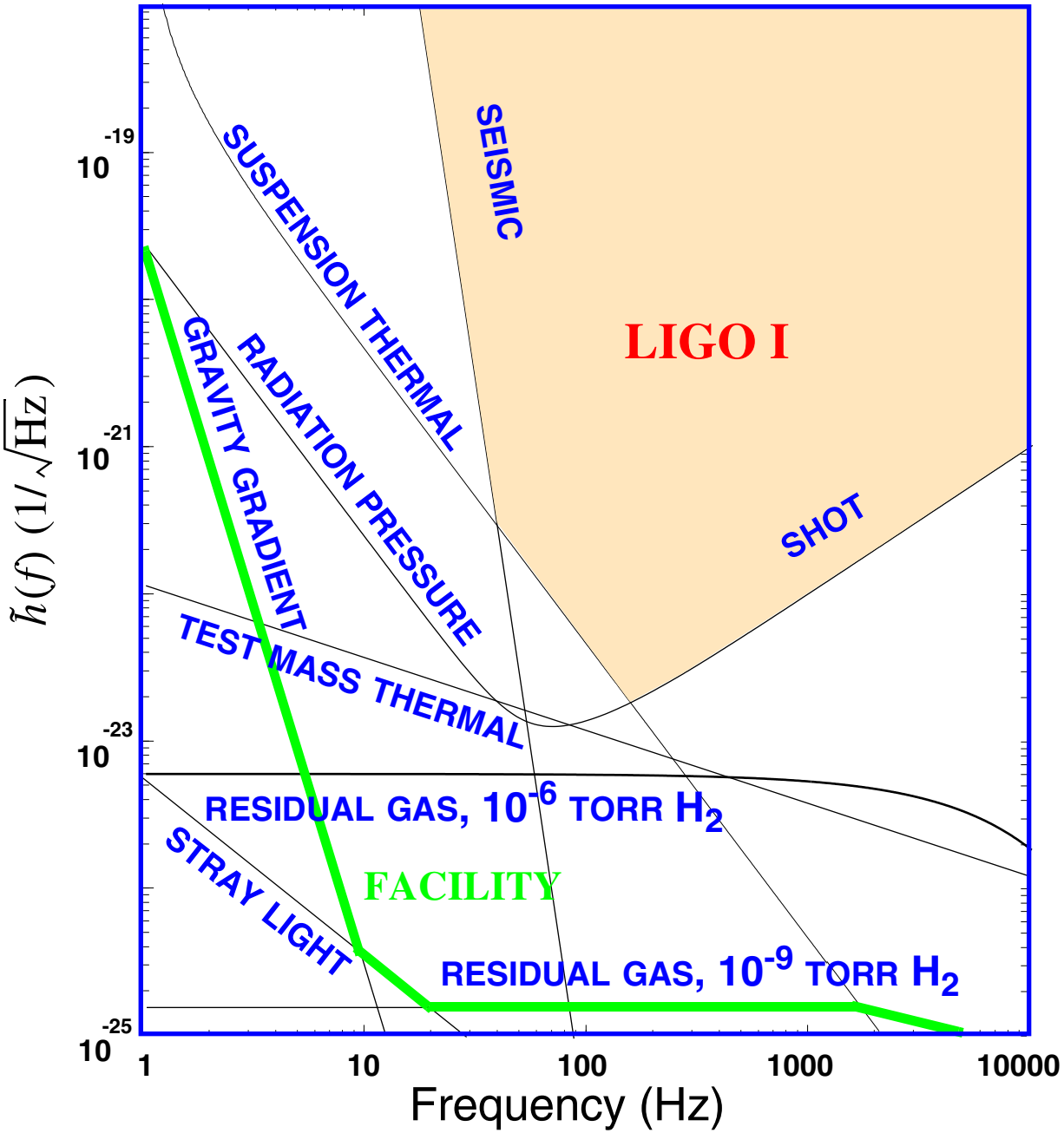
CW search periodic sources

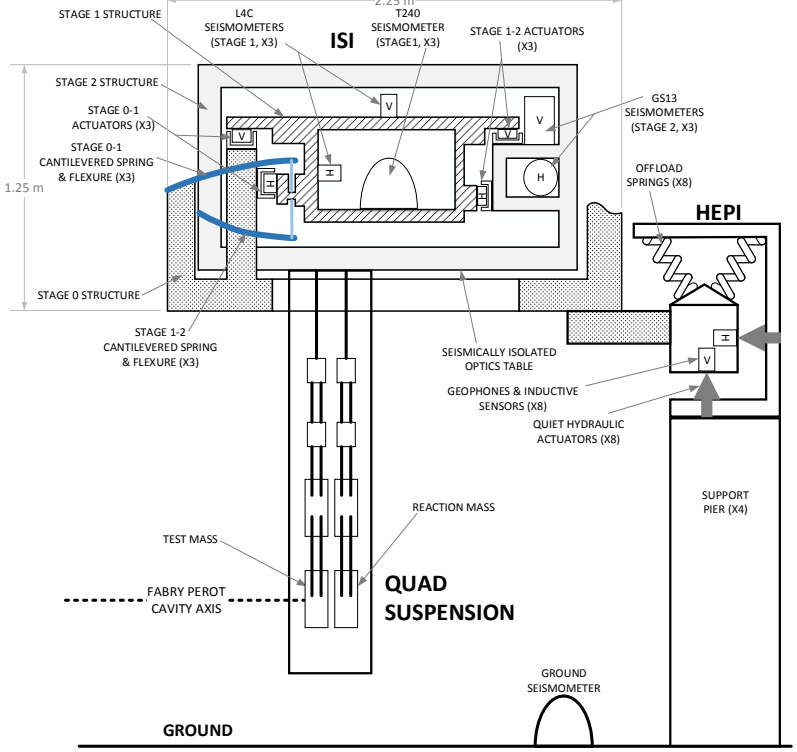


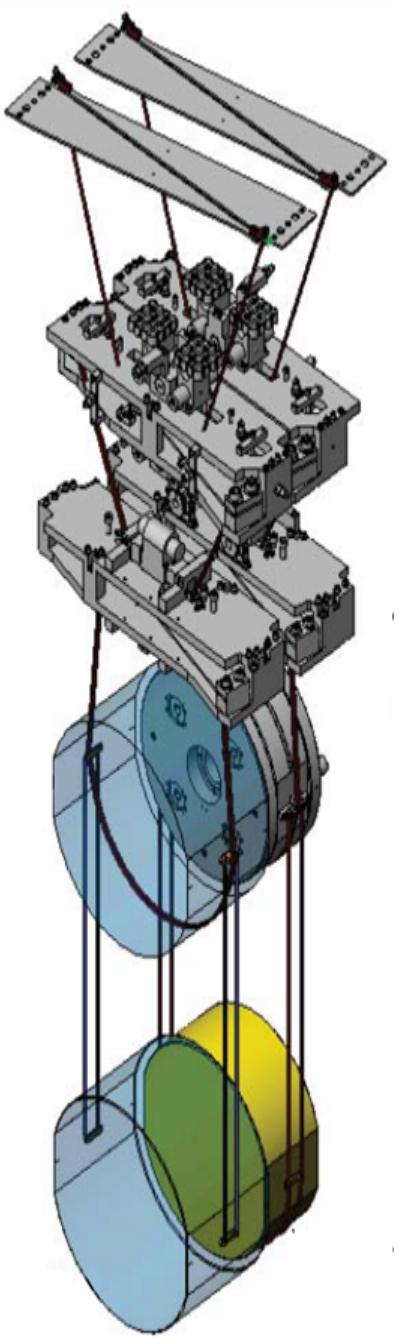
CW radiometer search
Scorpius X1

K. Riles preprint

Initial LIGO Interferometer Noise Budget







Advanced LIGO design noise budget