Détection directe des ondes gravitationnelles avec Advanced Virgo

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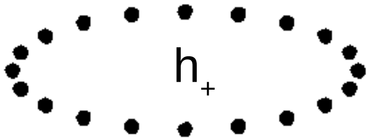
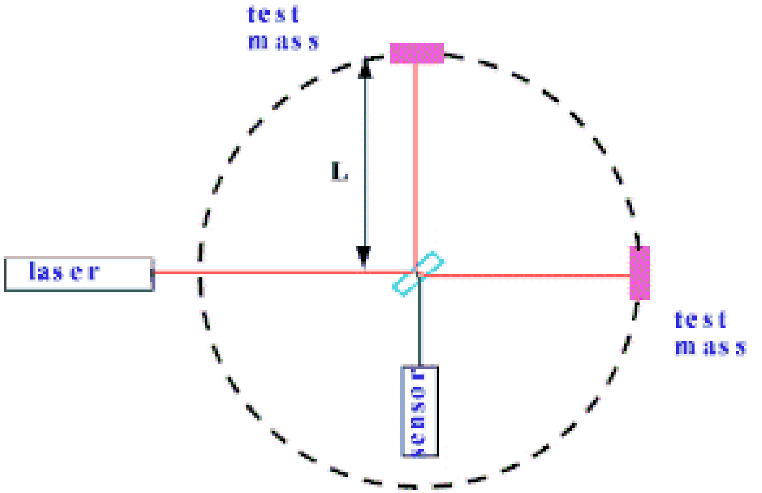
1-slide primer on Virgo

- Direct detection of GW
  - Measure space-time distorsion *in situ*
- Kilometric Michelson interferometer
  - Goal: measure relative difference in optical path length to 10^{-21}, or 10^{-18} m over km
  - Sensitive about few 100 Hz
- Target distant astrophysical sources
  - Typically: binaries of stellar mass compact objects (neutron star or black hole)

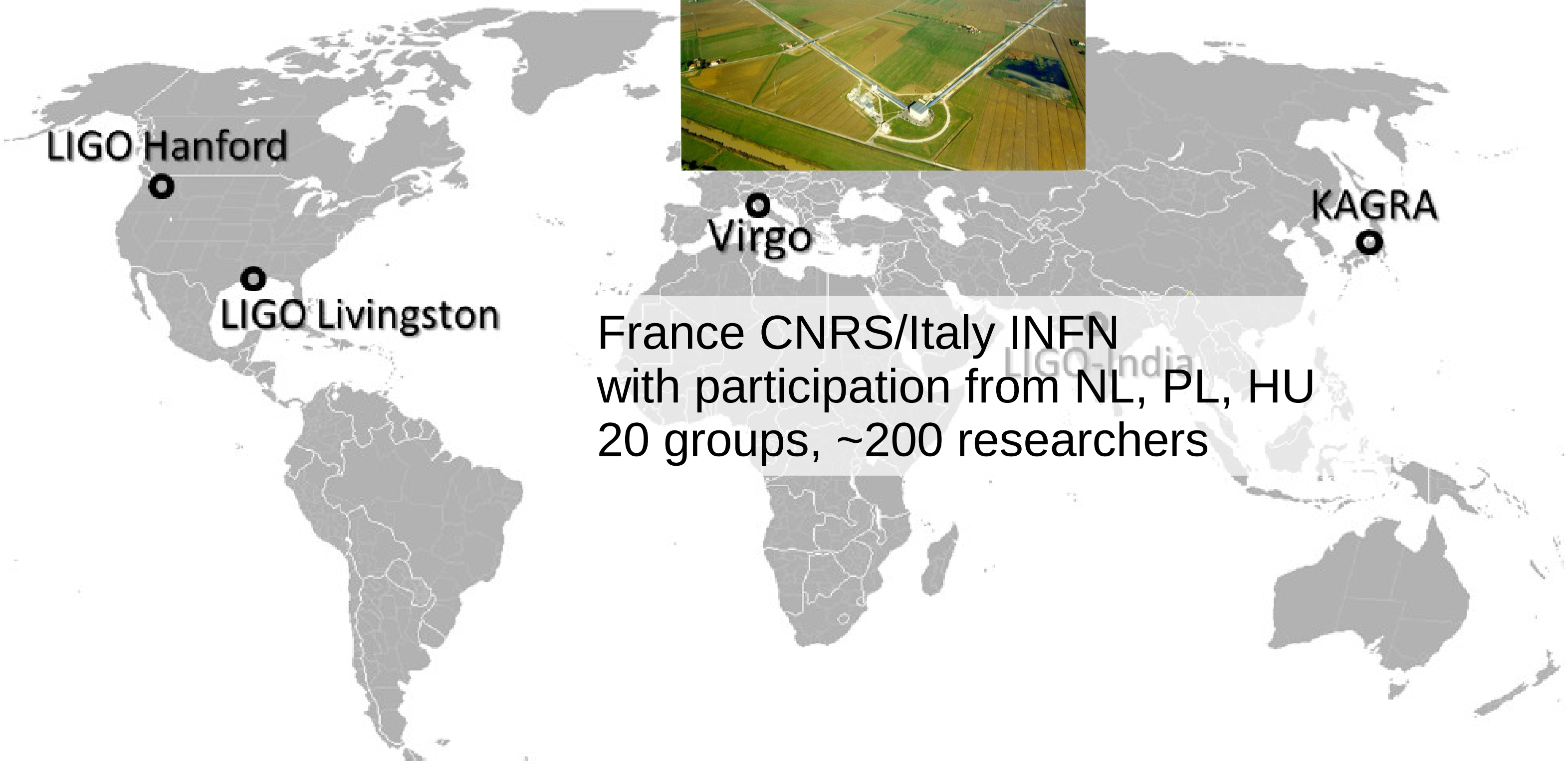
  $h \sim 10^{-21}$ for NS binaries at 15 Mpc



$$h(t) = \frac{\delta L(t)}{L} \propto \delta\Phi(t)$$

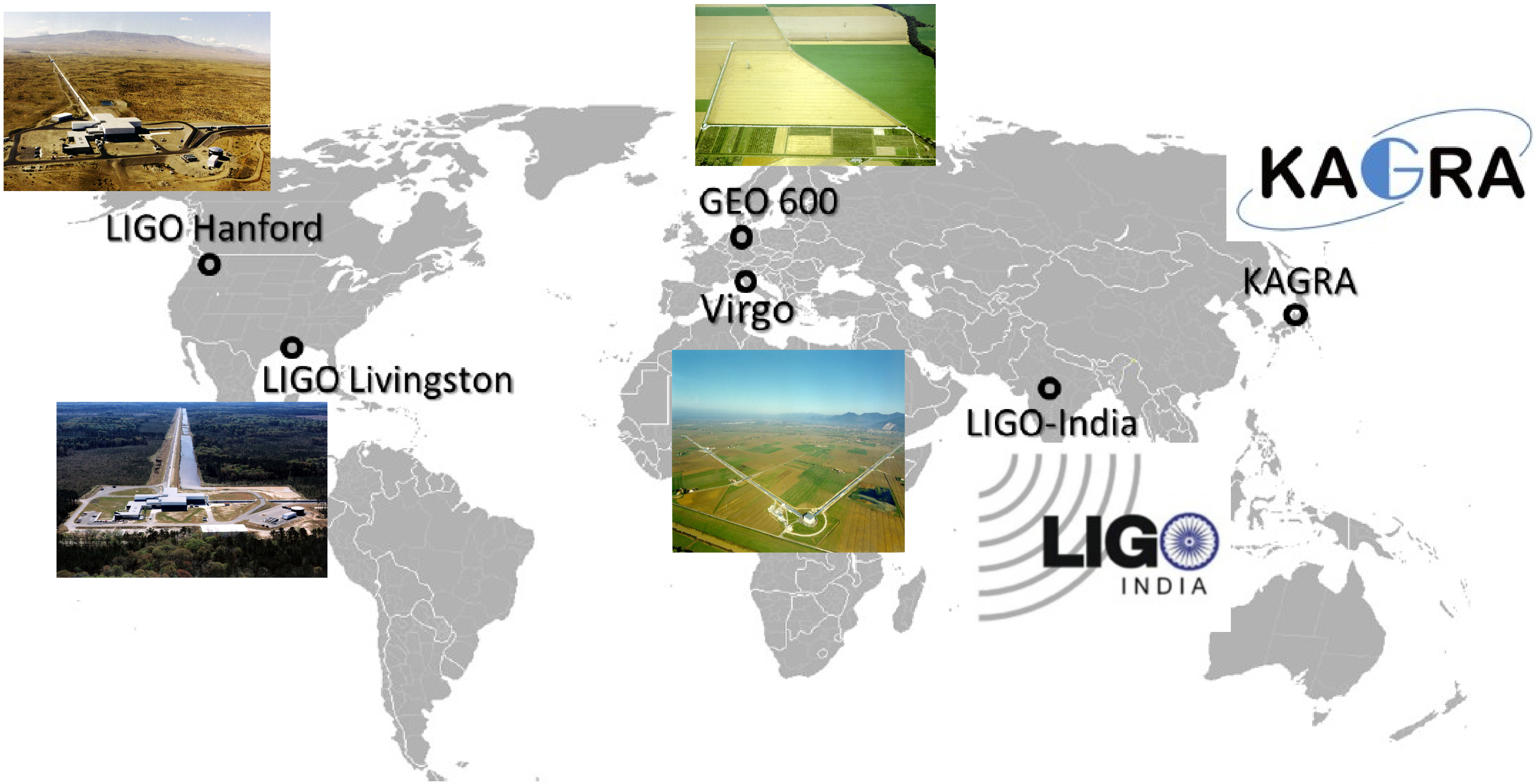


GW detectors in the world



France CNRS/Italy INFN
with participation from NL, PL, HU
20 groups, ~200 researchers

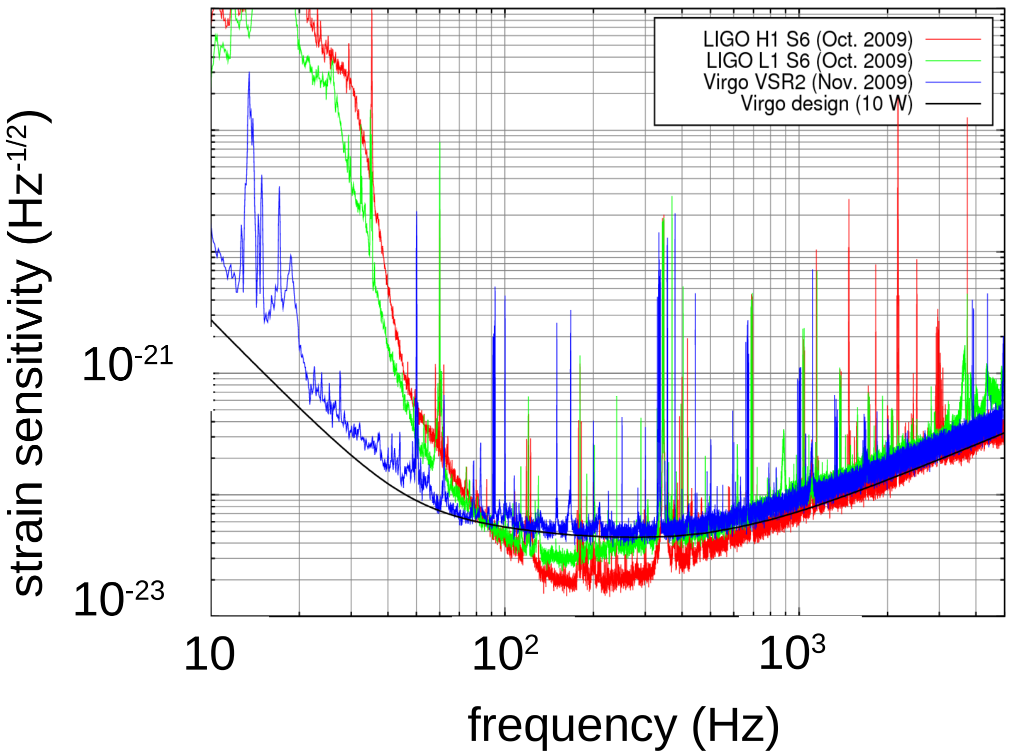
GW detectors in the world

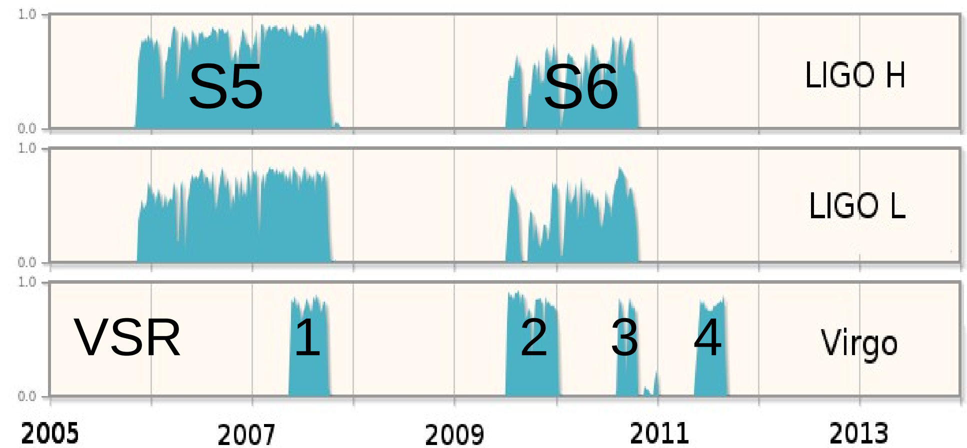


Since 2007, partnership and data exchange agreement

Science from 1st generation 2005-11

Reached design sensitivity!





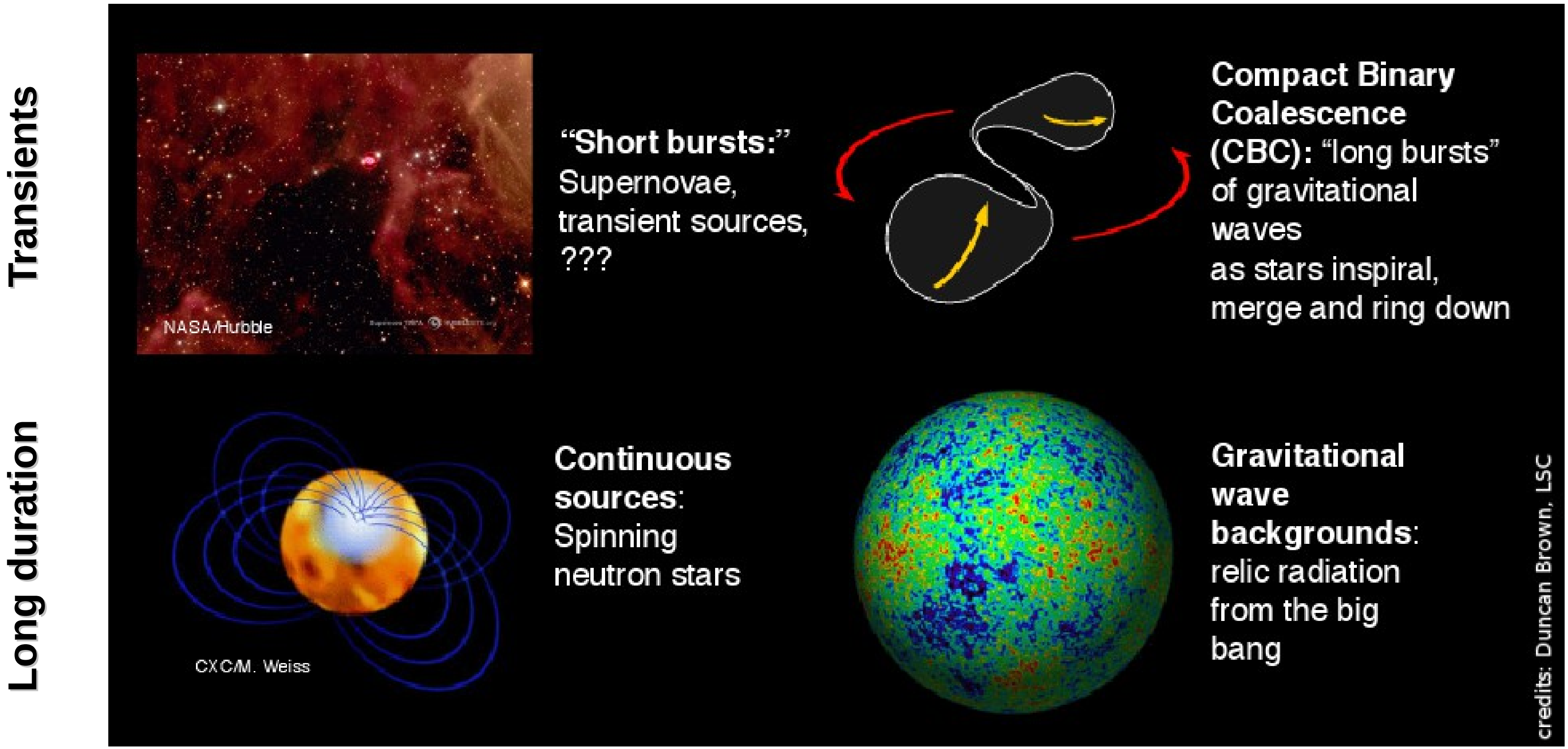
3 joint LIGO – Virgo science runs

~2 yrs total

“horizon” = detection range of coalescing binaries of neutron stars (BNS)

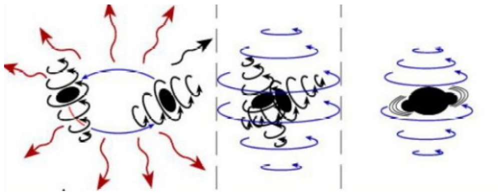
LIGO ~ 40 Mpc and Virgo ~ 20 Mpc

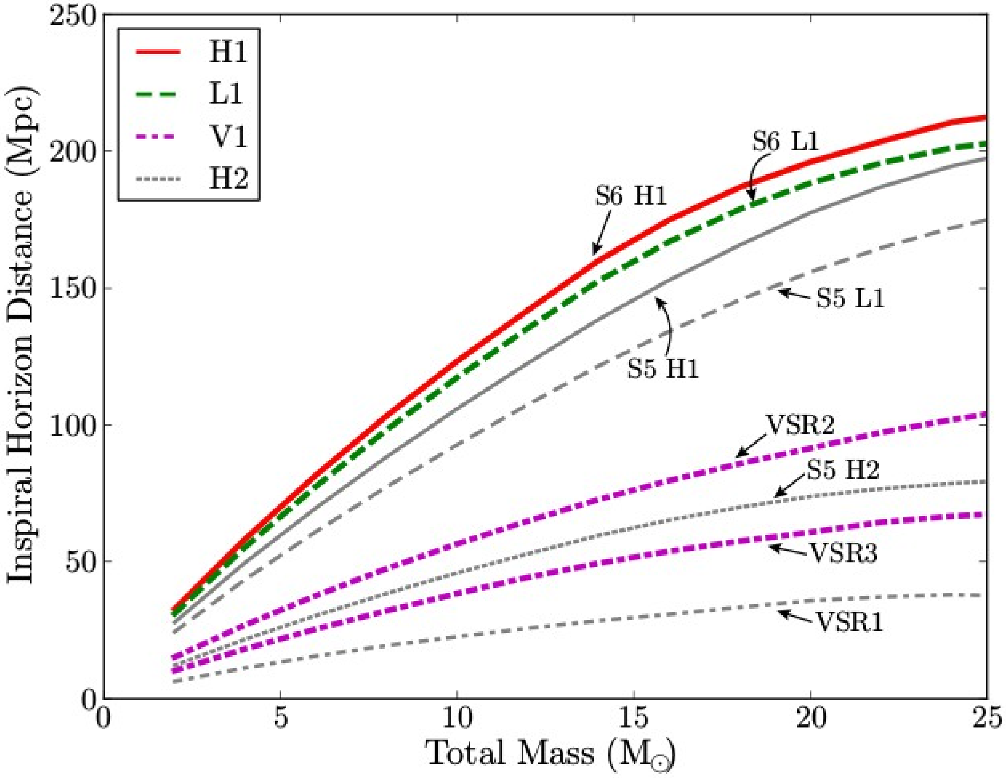
Sources of gravitational waves

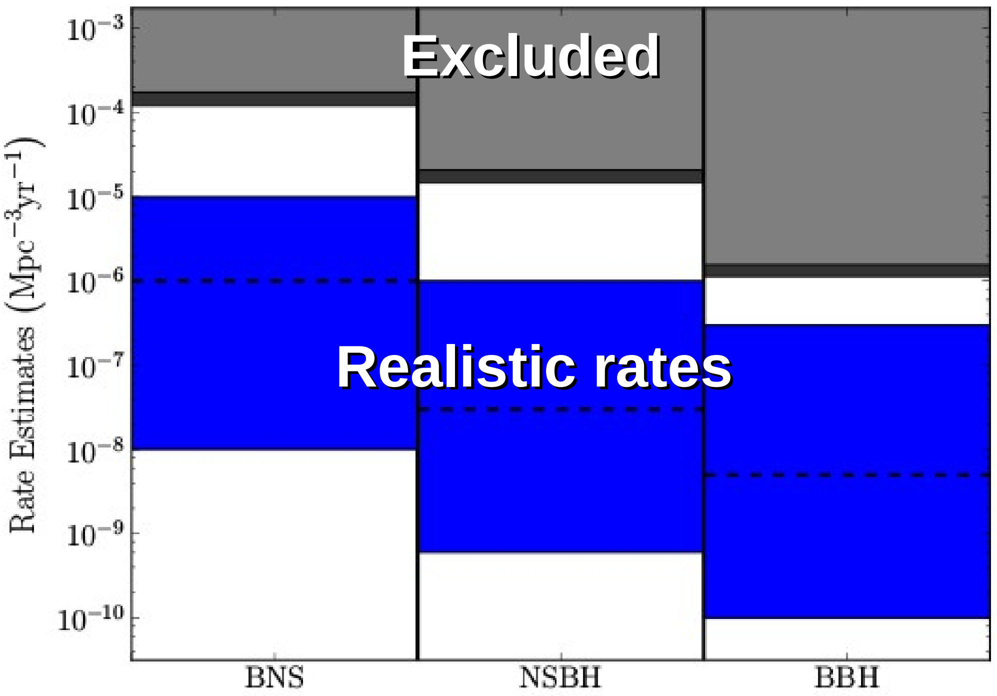


Science from 1st generation 2005-11

Coalescing binaries







Phys. Rev. D 85, 082002 (2012)

Science from 1st generation 2005-11

~40 papers and more to come...

Transient searches...

- Upper limits on GW transients [Phys. Rev. D 85, 122007 (2012)]
- GW constraints for magnetars [ApJ 734 L35 (2011)]
- GW constraints for Vela pulsar glitch [Phys. Rev. D 83 042001 (2011)]
- Coincidences with High Energy Neutrinos [JCAP 06 008 (2013)]
- Cosmic strings [Accepted by Phys. Rev. Lett., arXiv:1310.2384]
- Long duration transients (>10 s) [Phys. Rev. D 88 122004 (2013)]

Continuous waves (pulsars)

- Beat spin down limits for Crab and Vela pulsars [ApJ 713 671 (2010), ApJ 737 93 (2011)]

Stochastic background

- Beat Big Bang Nucleosynthesis limit at 100 Hz [Nature 460 990 (2009)]

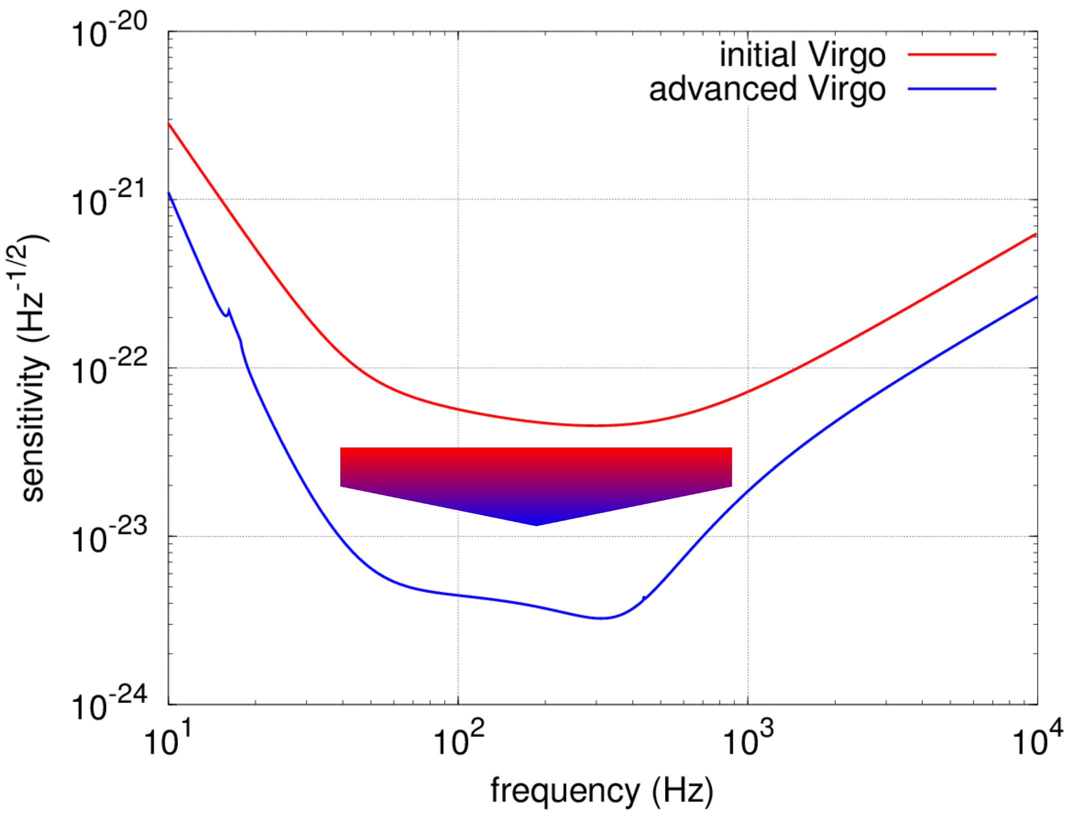
Toward 2nd generation detectors

- Advanced Virgo

  x 10 more sensitive
  → x 1000 more sources

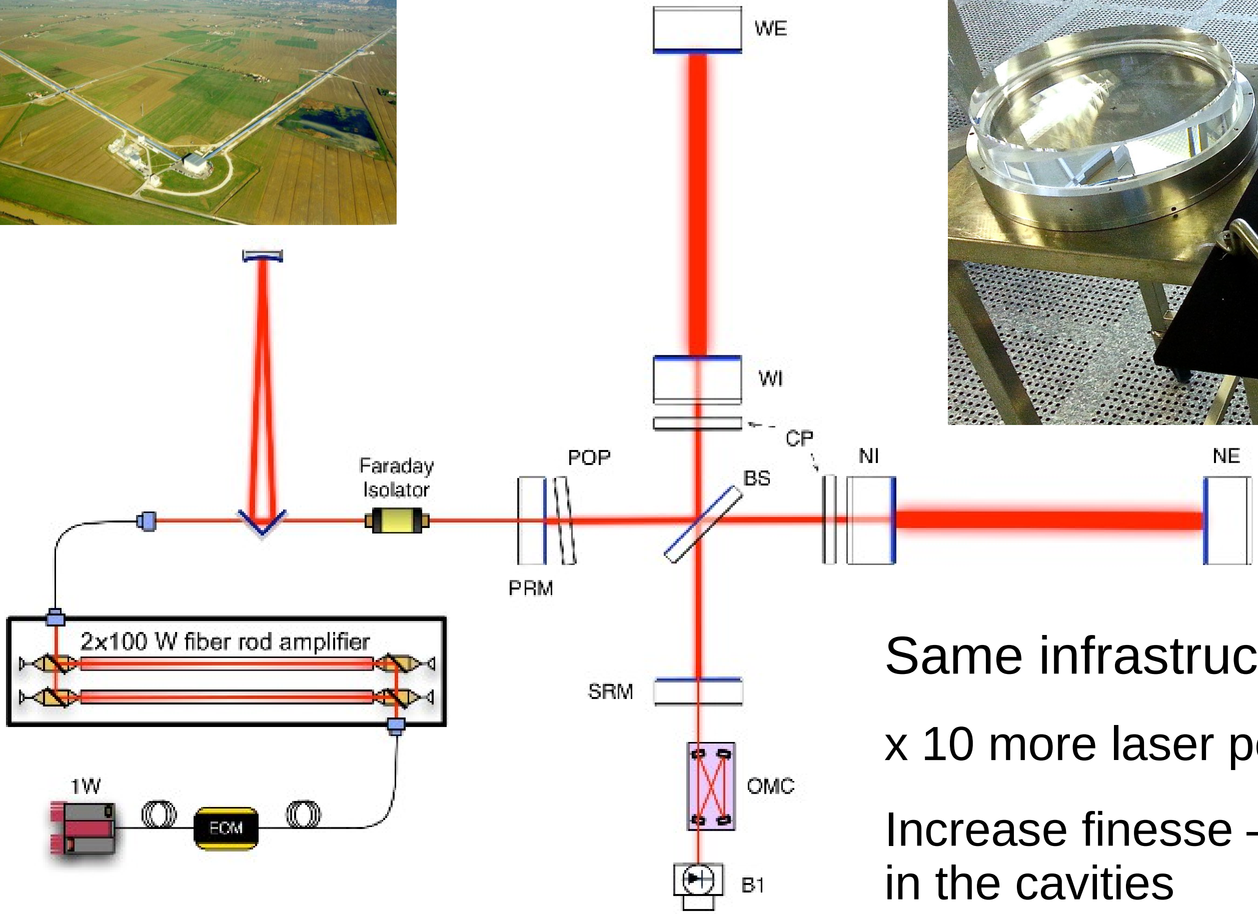
  Being installed

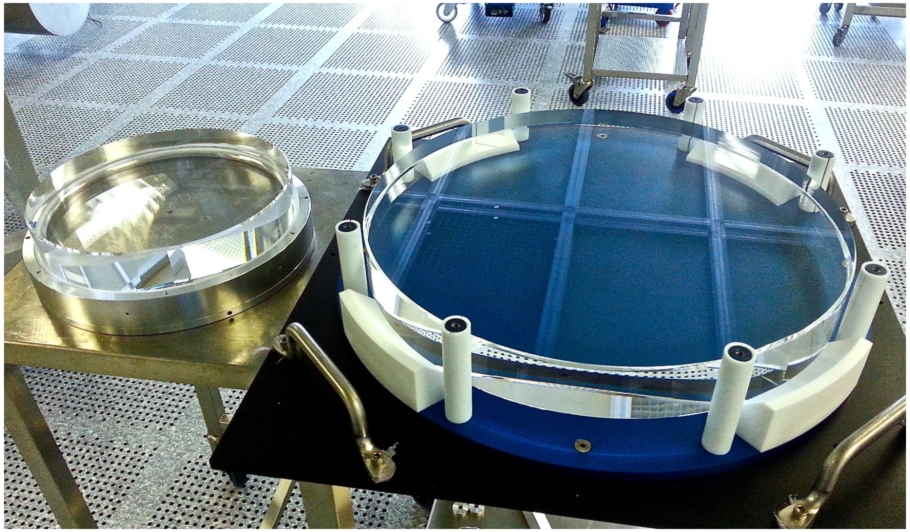
  First science data in 2016



Larger observation bandwidth

Detector highlights: Advanced Virgo





Same infrastructure – new instrumentation

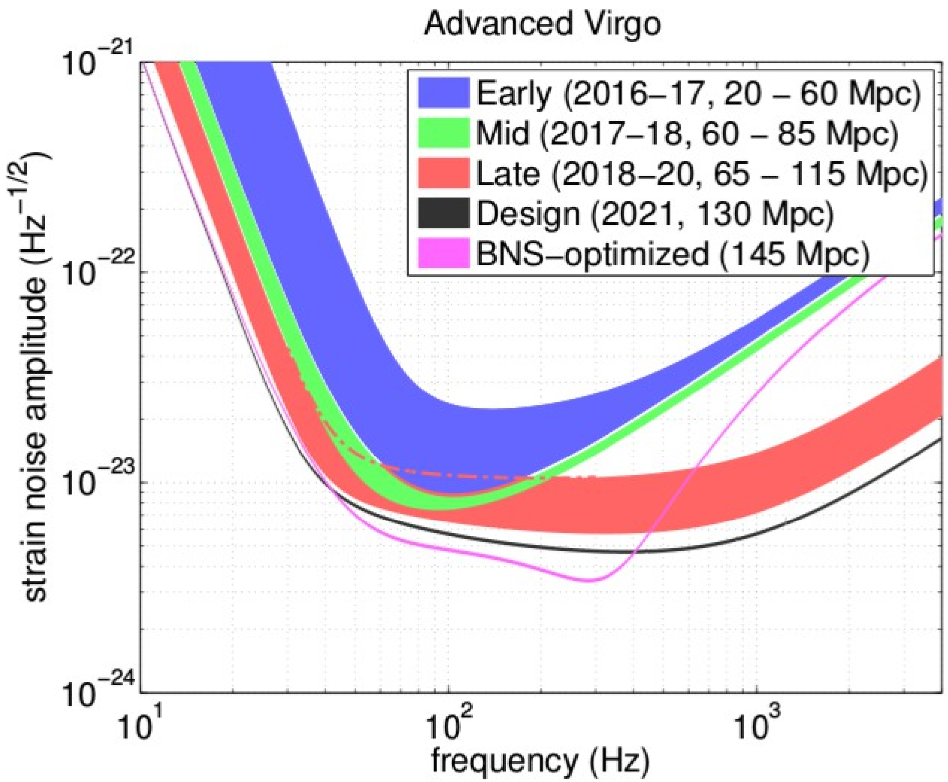
x 10 more laser power (200 W)

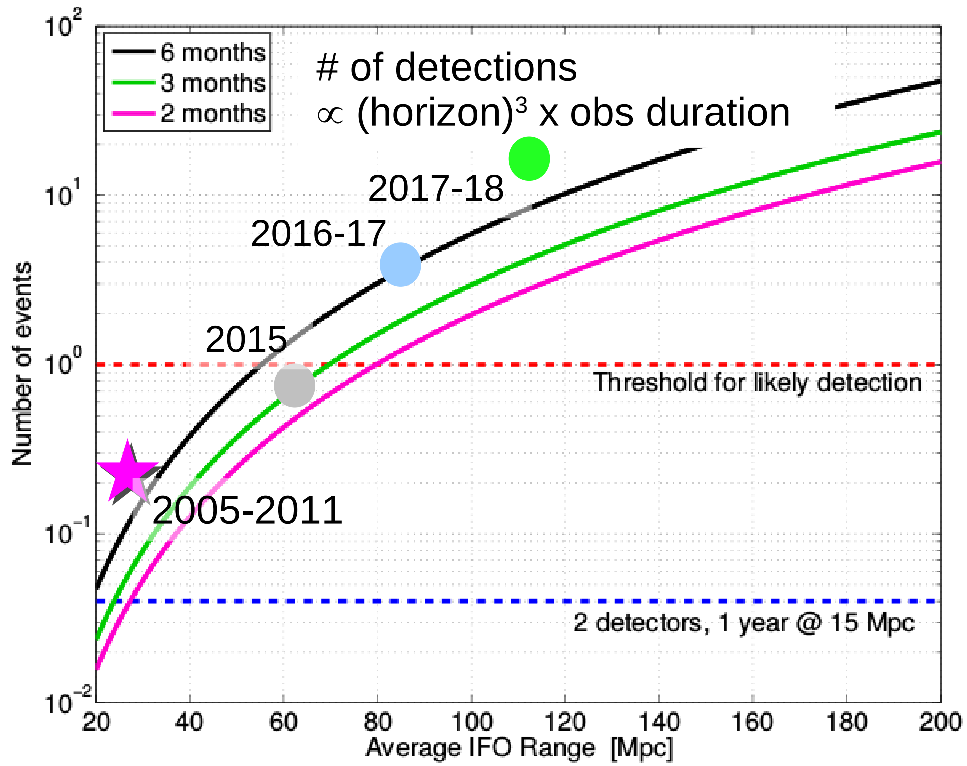
Increase finesse – x 65 more light power stored in the cavities

Larger beam size – lower thermal noise from coatings – larger mirrors

GW signal recycling

Science with 2nd generation 2015-2022+





Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_\odot c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within 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 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

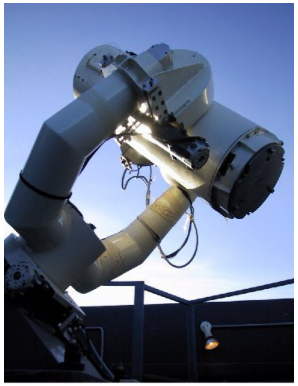
ArXiv:1304.0670

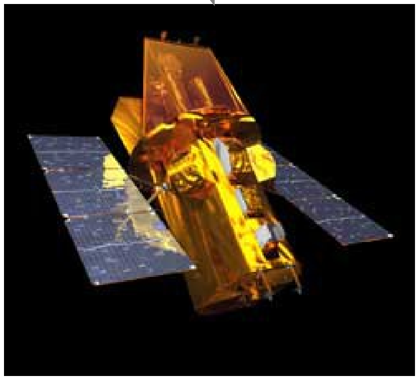



GW astronomy

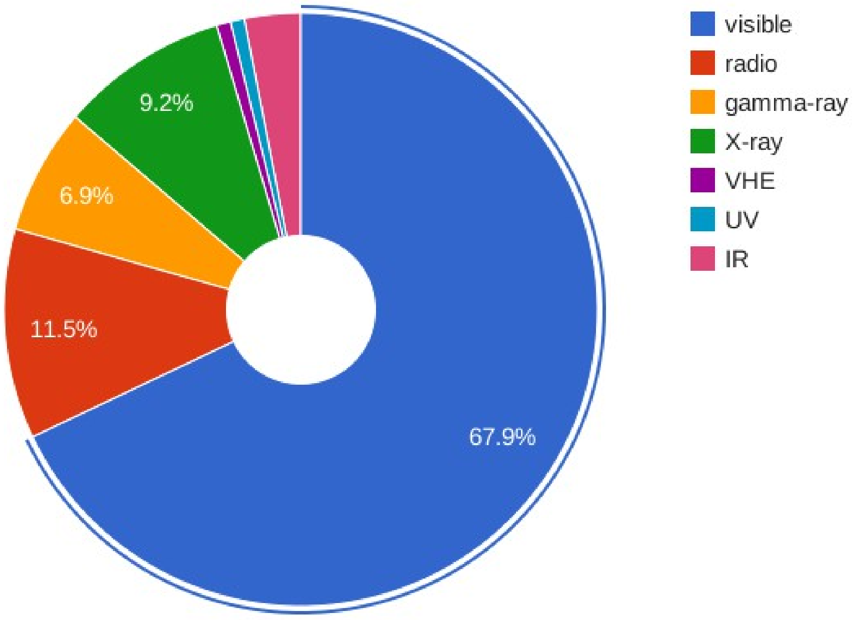
“photon-based” astronomy







GW-EM follow-up program



- Open call for collaborations (Feb 2014)
  - ✔ Great success!
  - ✔ More than 60 groups expressed interest
  - ✔ From 19 countries
  - ✔ ~150 instruments (12 space-based)
  - ✔ Full EM spectrum from radio to very high-energies

http://www.ligo.org/science/GWEMalerts.php

Potential impact on fundamental physics

For a recent review: Yunes and Siemens, livingreviews.org/lrr-2013-9

Test of gravitation in the strong field ($\chi \propto m/r$ or $\nu = v/c$ not small)

For ref., binary pulsar J0737–3039: $\chi \sim 6 \times 10^{-6}$ $\nu \sim 2 \times 10^{-3}$

Test GR against alternative theories, or detection of anomalies

Coalescing compact binaries as a test-bed

- Deviation of post-Newtonian coefficients
  Arun et al, Phys. Rev. D74, 024006 (2006), Yunes et al, Phys. Rev. D80, 122003 (2009), Li et al, Phys. Rev. D85, 082003 (2012)
- Violations of the cosmic censorship conjecture ($j/m^2 > 1$?) and the no-hair theorem (tidal Love number $\neq 0$?)
  Wade et al., Phys. Rev. D 88, 083002 (2013)
- Testing wave polarization states arising in alternative theory of gravity
  K. Chatziioannou et al, Phys. Rev. D86, 022004 (2012), K. Hayama et al, Phys. Rev. D87, 062003 (2013)

Conclusions

- **Virgo has fullfilled its mission**

  Reach target sensitivity, major science objectives published

- **With Advanced Virgo, the next decade will probably see the 1st direct detection of GW**

  Synergy with high-energy astrophysics

  Potential impact on fundamental physics

  Many challenges and a lot of excitement ahead!