Direct detection of gravitational waves with Advanced Virgo

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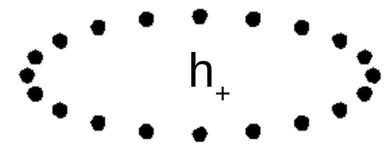
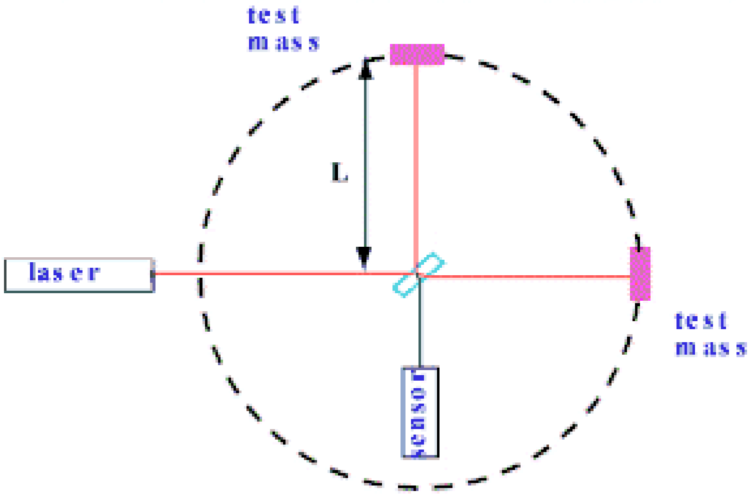
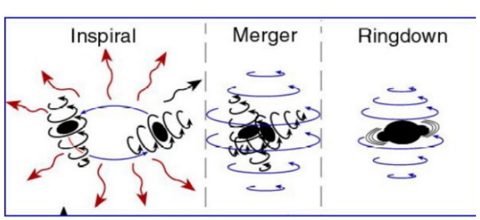
1-slide primer on Virgo

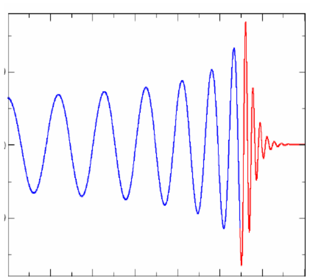
- Gravitational waves GW
  - Propagating space-time distorsion predicted by General Relativity
  - Goal: measure GW directly (*in situ)*
- Kilometric Michelson interferometer
  - Measure relative difference in optical path length to 10^{-21}, or 10^{-18} m over km
  - Sensitive band of a few 100 Hz
- 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



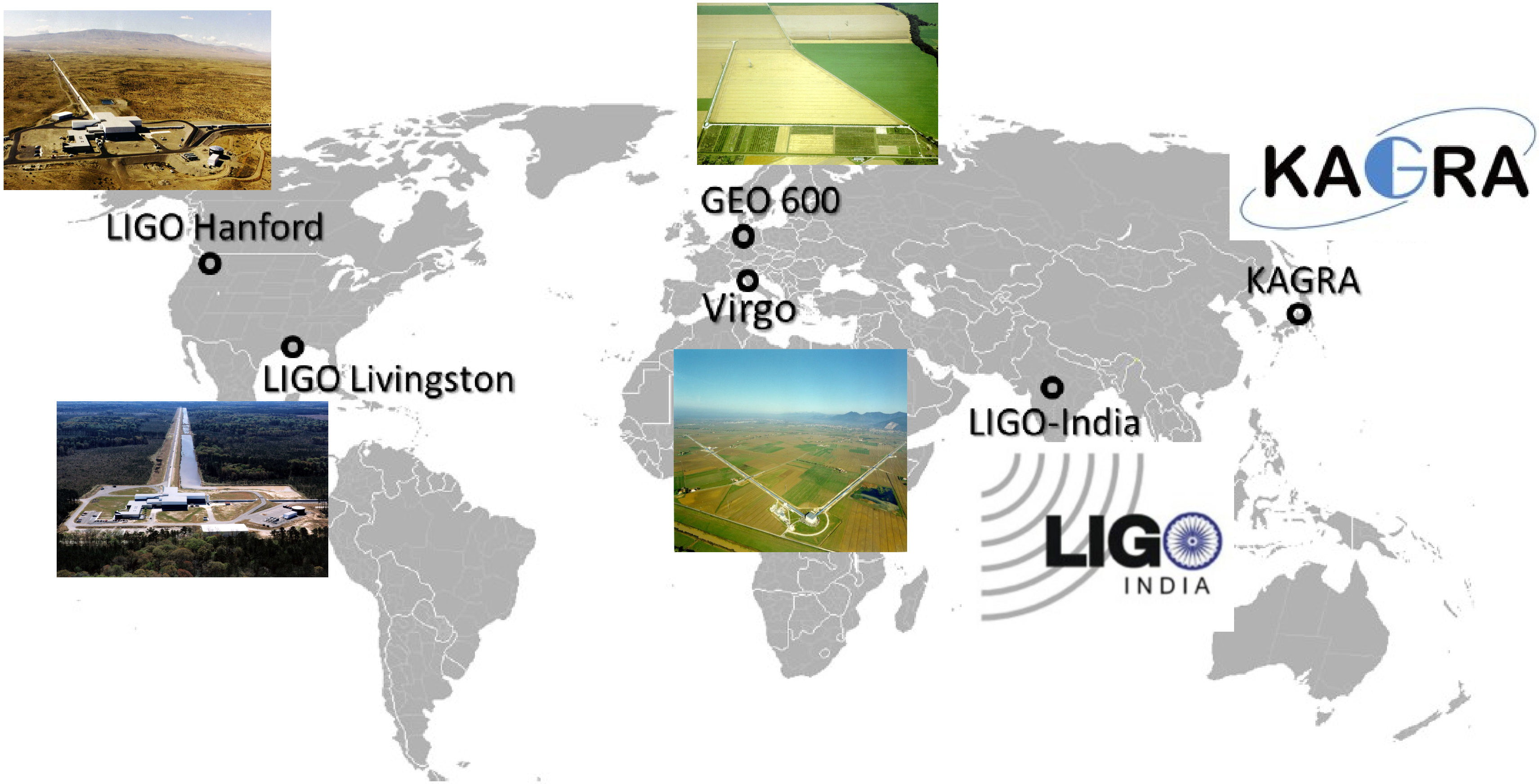






$$h(t) = \frac{\delta L(t)}{L} \propto \delta\Phi(t)$$

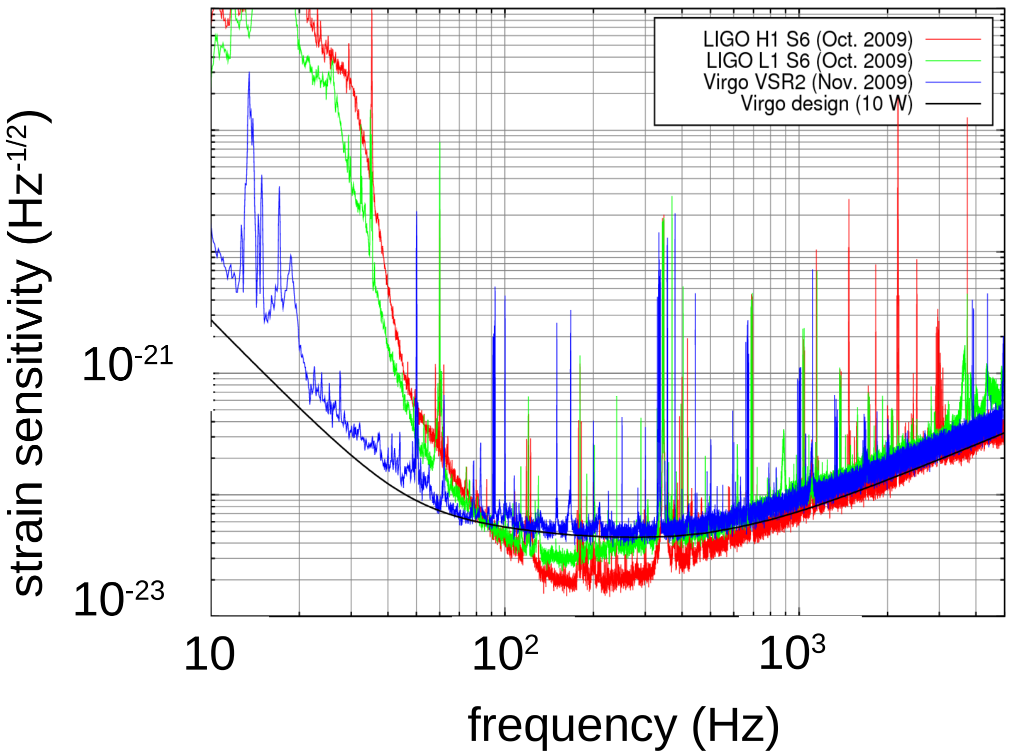
GW detectors in the world

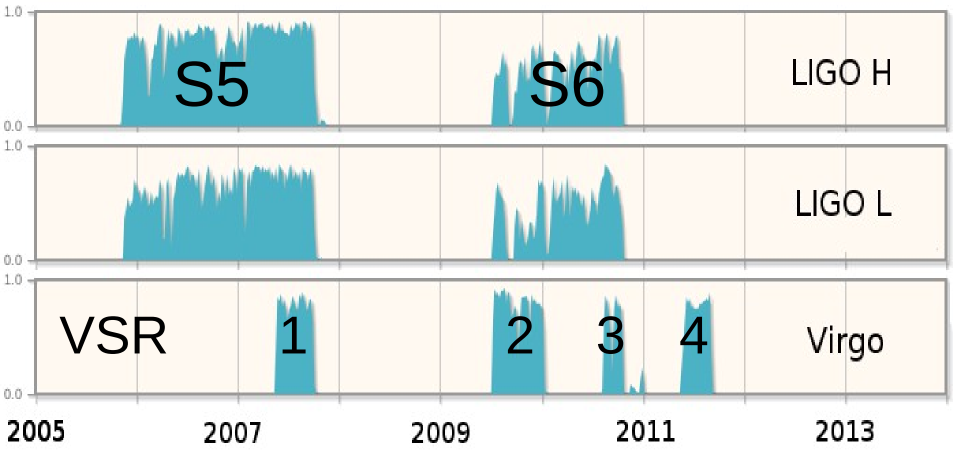


Since 2007, partnership and data exchange agreement
About 1000 people involved

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

40 papers published and more to come

Transient sources (BNS, BBH and bursts; in connection with astrophysical triggers, e.g., GRB or neutrinos)

Continuous sources (pulsars)

Stochastic background

Toward 2nd generation detectors

- Advanced Virgo
  - x 10 more sensitive → x 1000 more sources

    Larger frequency bandwidth
  - Same infrastructure – new instrumentation

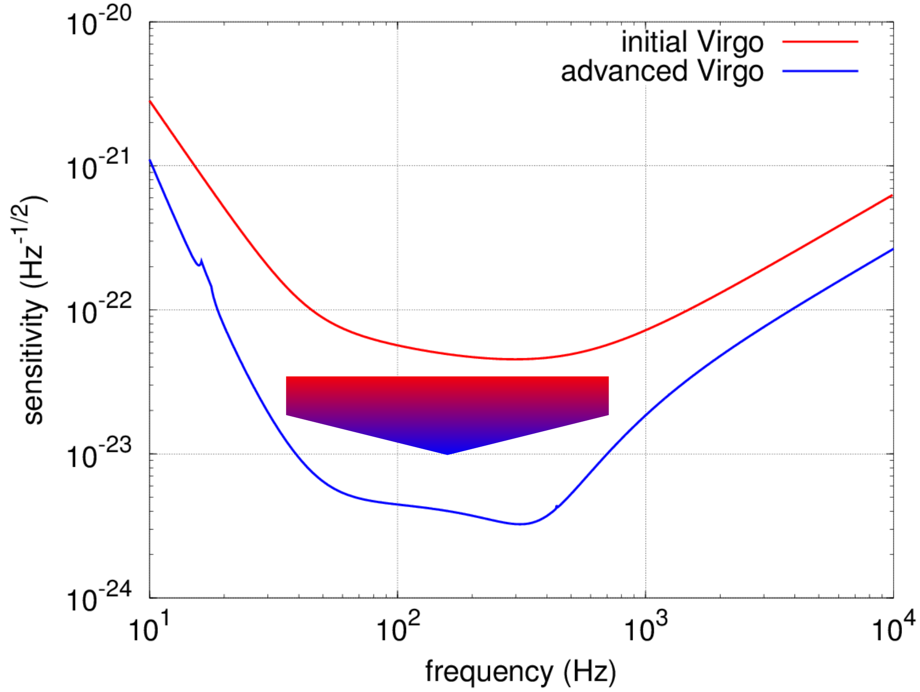
    x 10 more laser power (200 W)

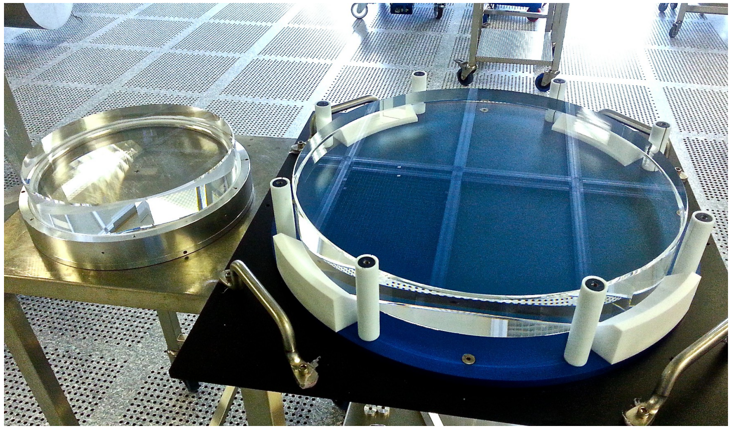
    Increase finesse – x 65 more light power stored in the cavities

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

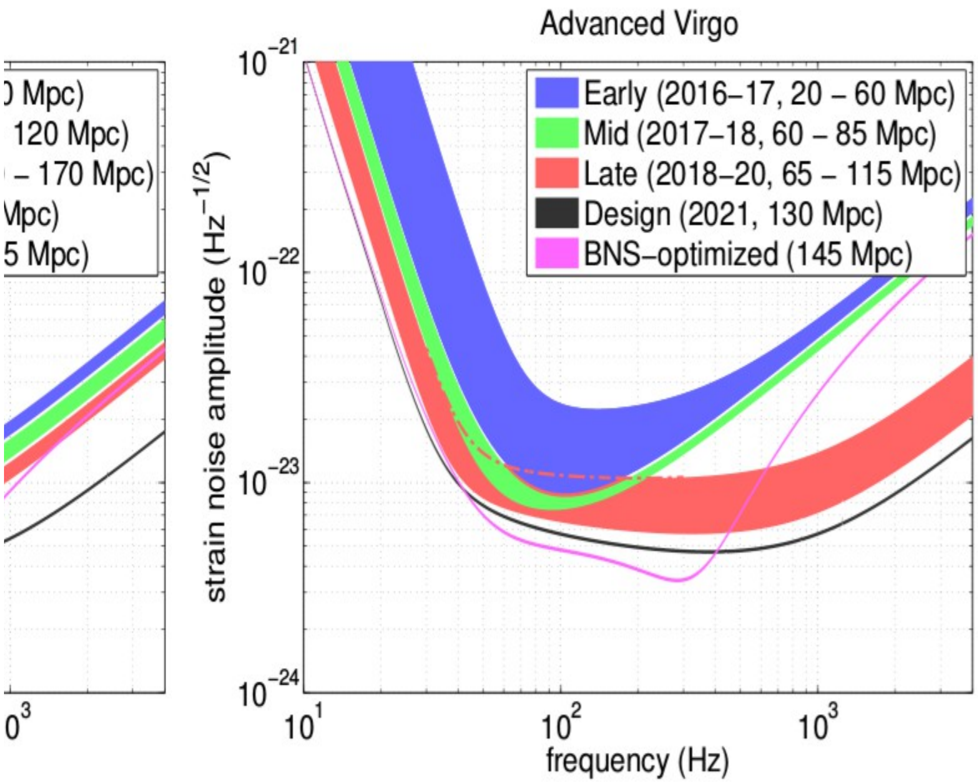
    GW signal recycling
  - Being installed

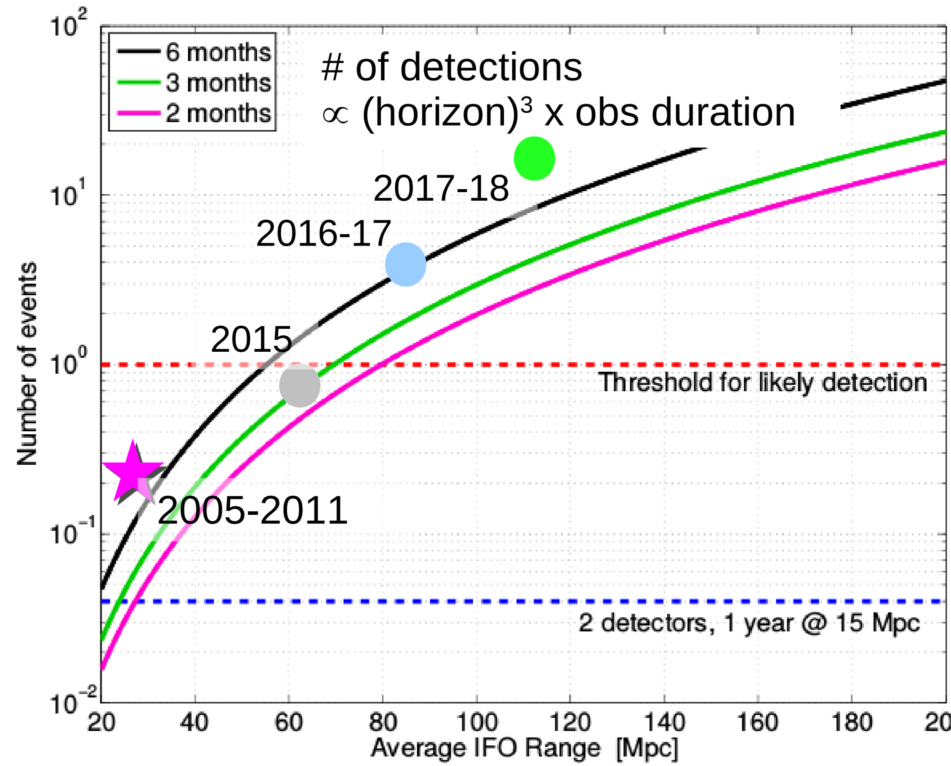
    Current plan : 1st science data in 2016





Science with 2nd generation 2015-2022+





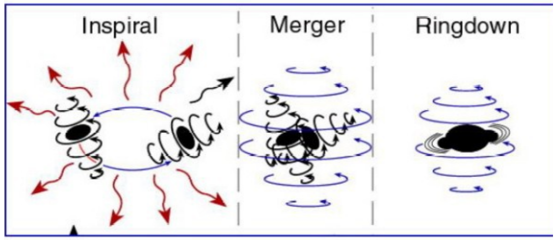
Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_\odot c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within 5 deg^2	20 deg^2
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	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

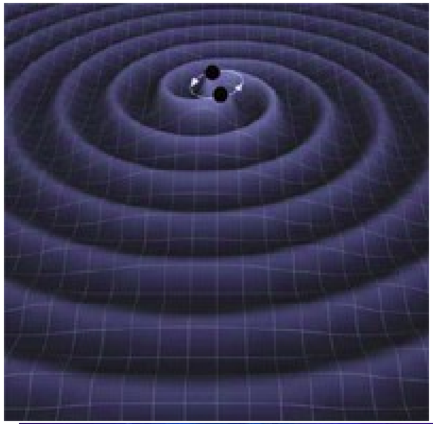
ArXiv:1304.0670

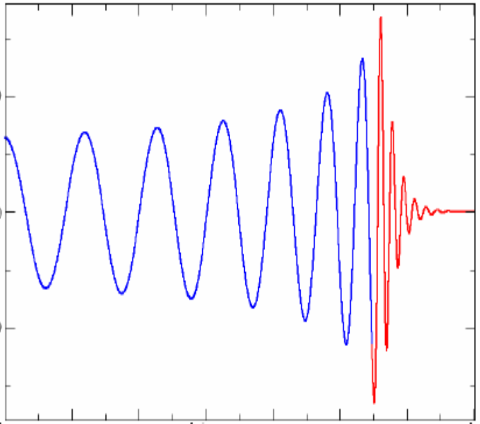
Gravitational wave transients

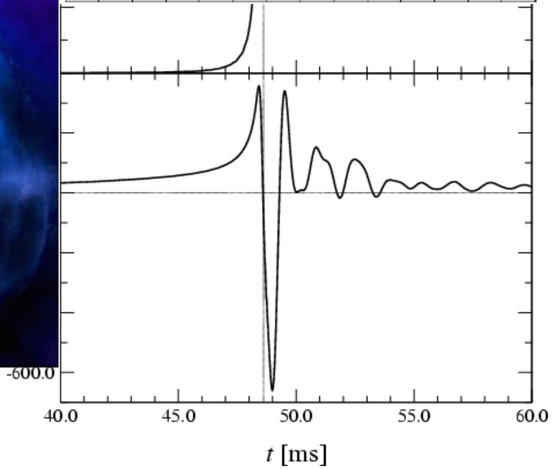
- Binary mergers
  - post-Newtonian model + numerical relativity
  - “Chirp”-like GW signals
- Supernova core collapses
  - No comprehensive view of the collapse
  - Numerical simulations
  - “Burst”-like GW signal
- … and others

e.g. star quakes, cosmic strings

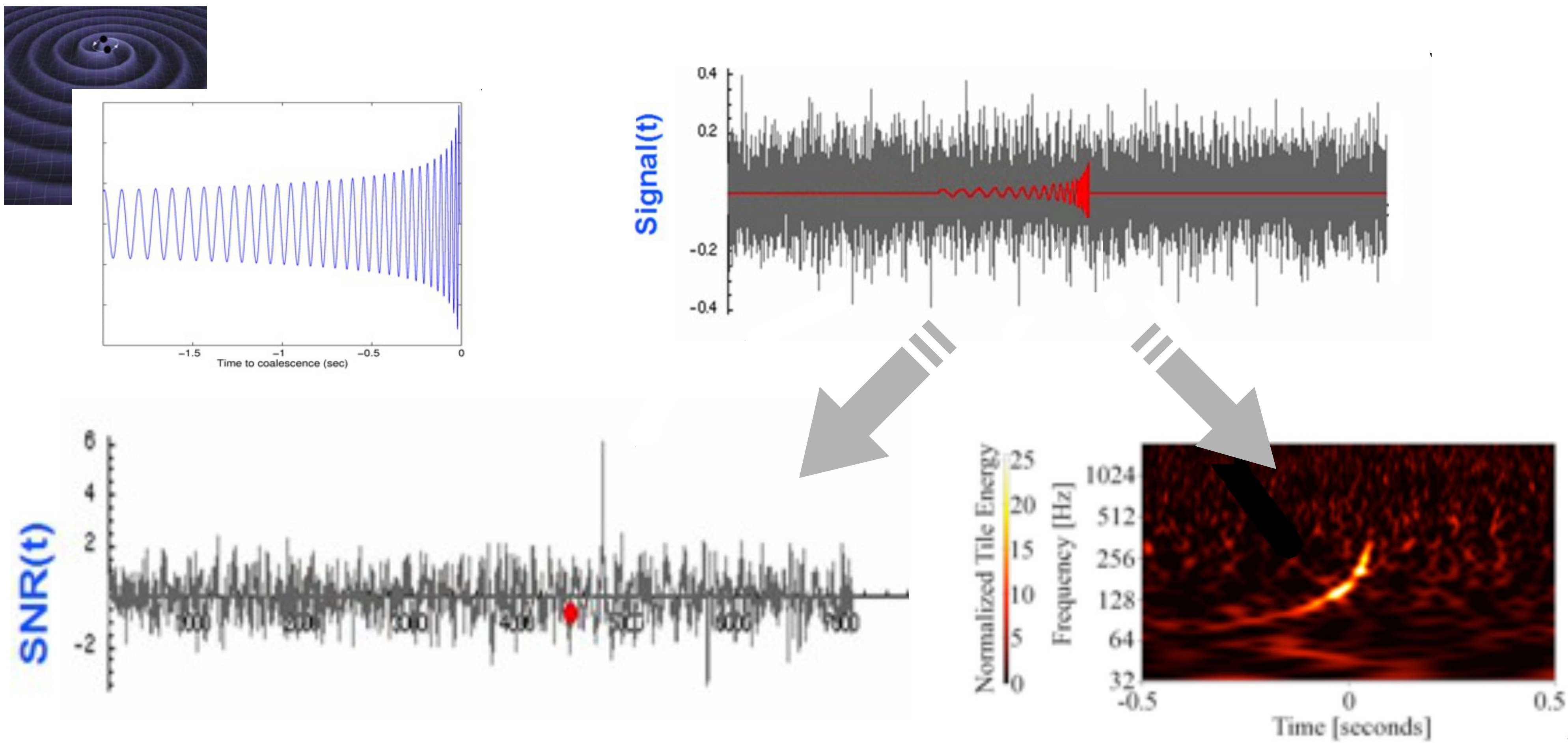








How our data get analyzed?



Matched filtering

Excess power

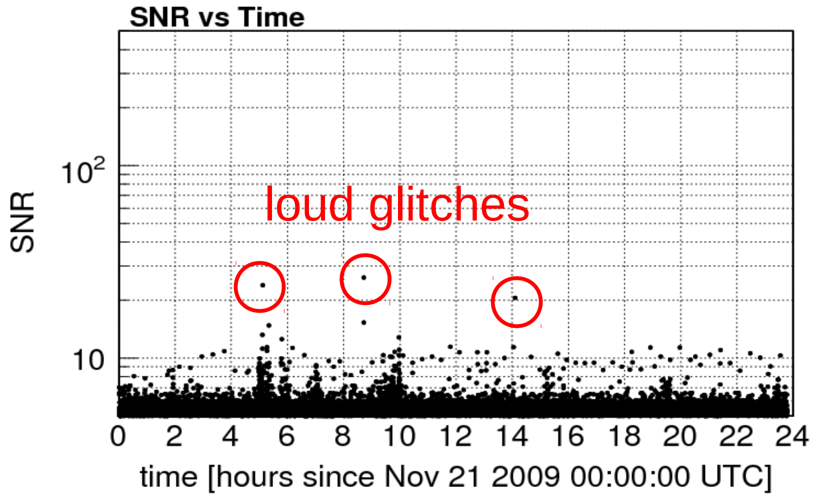
Stringent algorithmic constraints

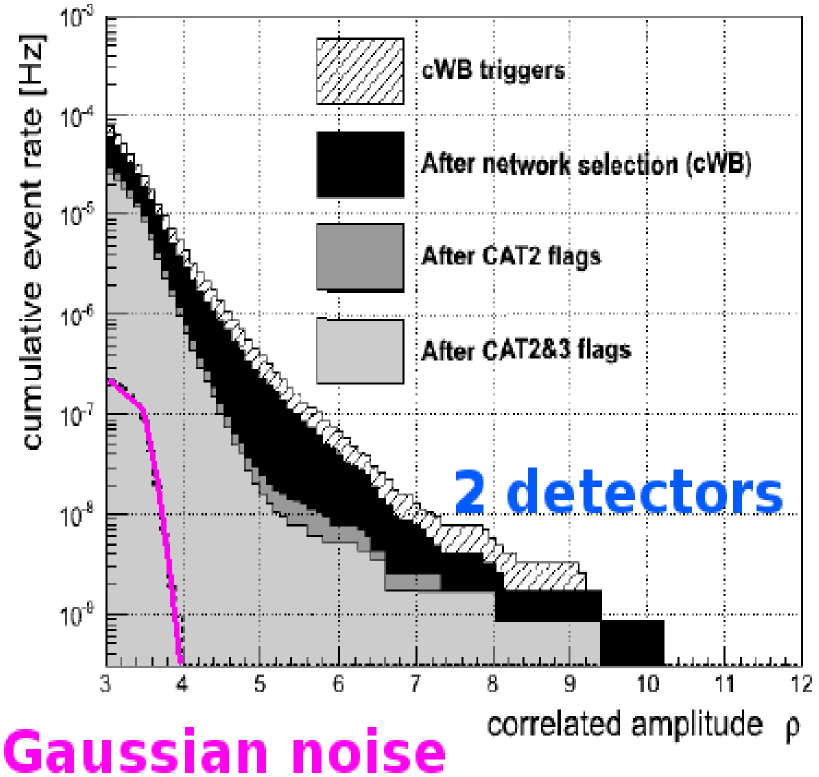
Background estimated from the data itself – Monte-Carlo simulations

5σ detection limit → analysis pipelines should run ~10^6 faster than real time

Dealing with real data

- Data is non-Gaussian
  - ✓ Background has heavy tail
  - ✓ Glitches limit sensitivity of transient searches
- Data quality is a key issue
  - ✓ How to use the (~1000) auxiliary channels that monitor the detector environment?
  - ✓ Optimal learning procedures are being designed





Collaboration with China

- Only **1 LIGO group** in China (Tsinghua University)
- Eric Lebigot currently doing a long-term visit

- **Joint work** with APC: GW **burst detection**
  - Fast approximate GW template matching
  - GPU acceleration
- Other Tsinghua contributions
  - Data quality: Detection of interferometer glitches with **machine learning**
  - **Virtual machine** for the GW data analysis (desktop & clusters)