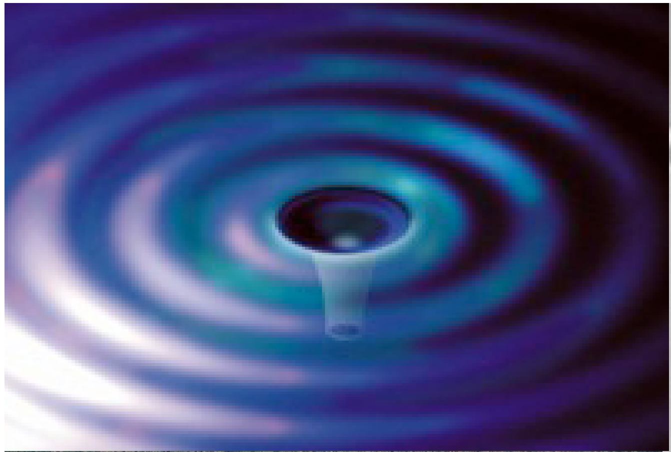

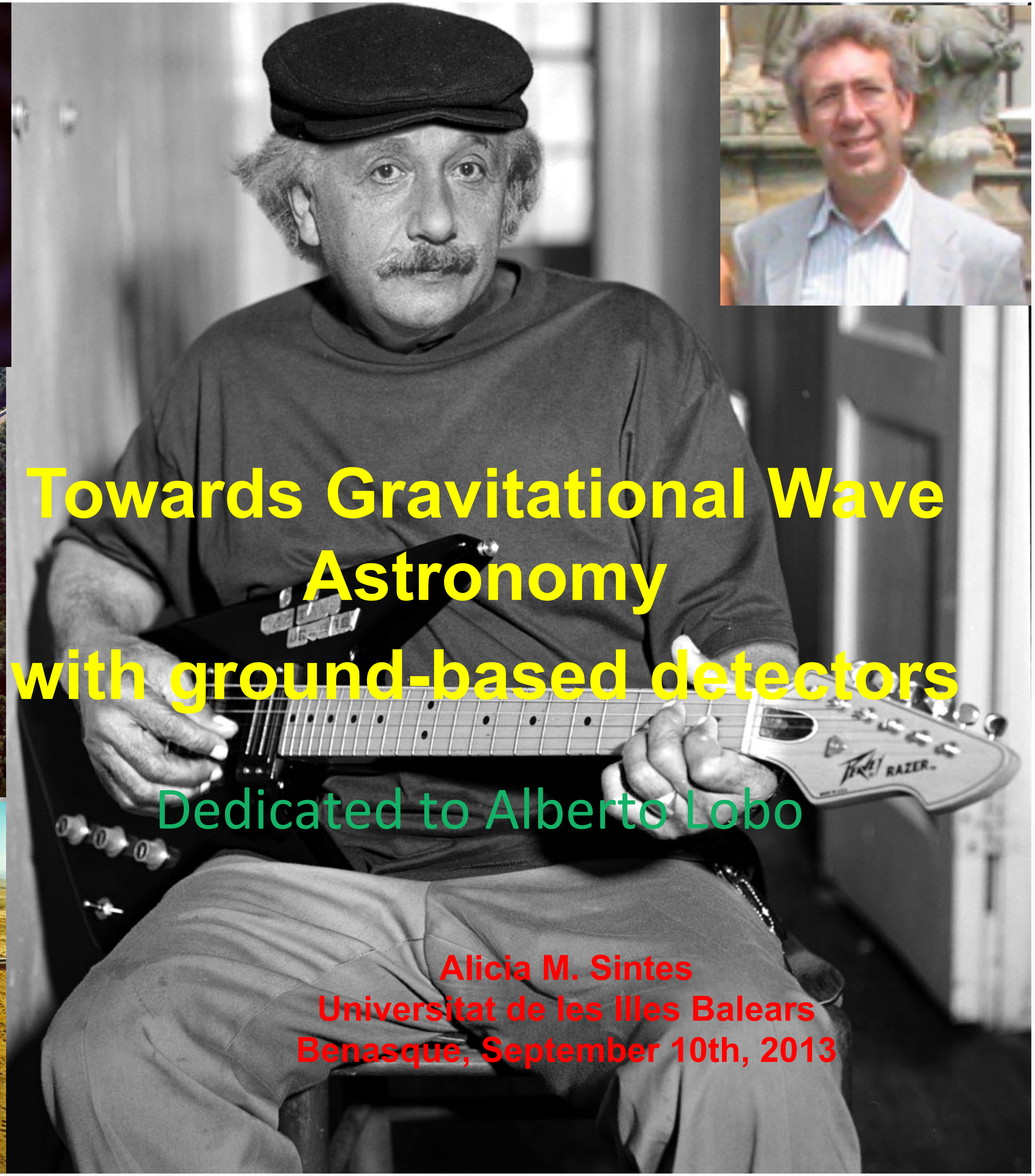

Towards Gravitational Wave Astronomy with ground-based detectors

Dedicated to Alberto Lobo

Alicia M. Sintes
Universitat de les Illes Balears
Benasque, September 10th, 2013

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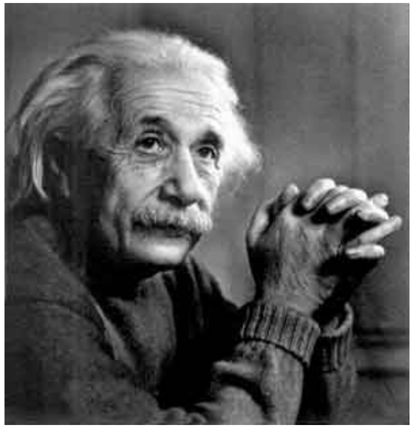
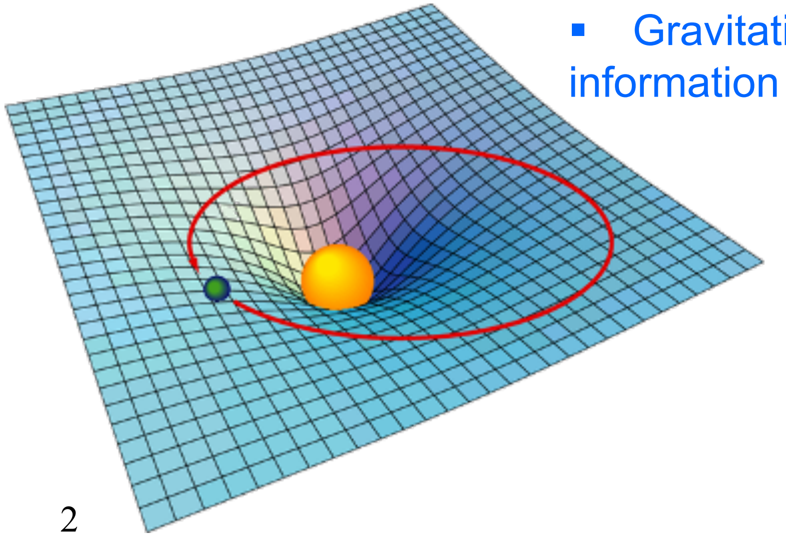
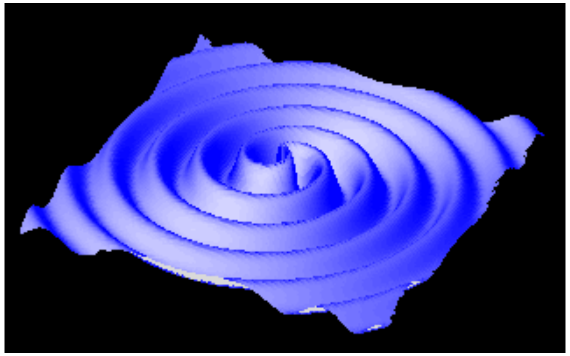
Gravitational Waves



- According to Einstein's theory of general relativity, gravity is not a force but is related to the curvature of spacetime.
- Gravitational waves are ripples in the fabric of space-time: perturbations of the space-time metric produced by rapid changes in shape and orientation of massive objects, more precisely, produced by a time-changing mass quadrupole.
- They are produced by the acceleration of large amounts of matter and violent phenomena such as collisions of black holes, supernova explosions, in particular, had to arise in the most violent event occurred in the Universe: the first moments of the Big Bang
- Gravitational waves travel at the speed of light, carrying information about its origins.





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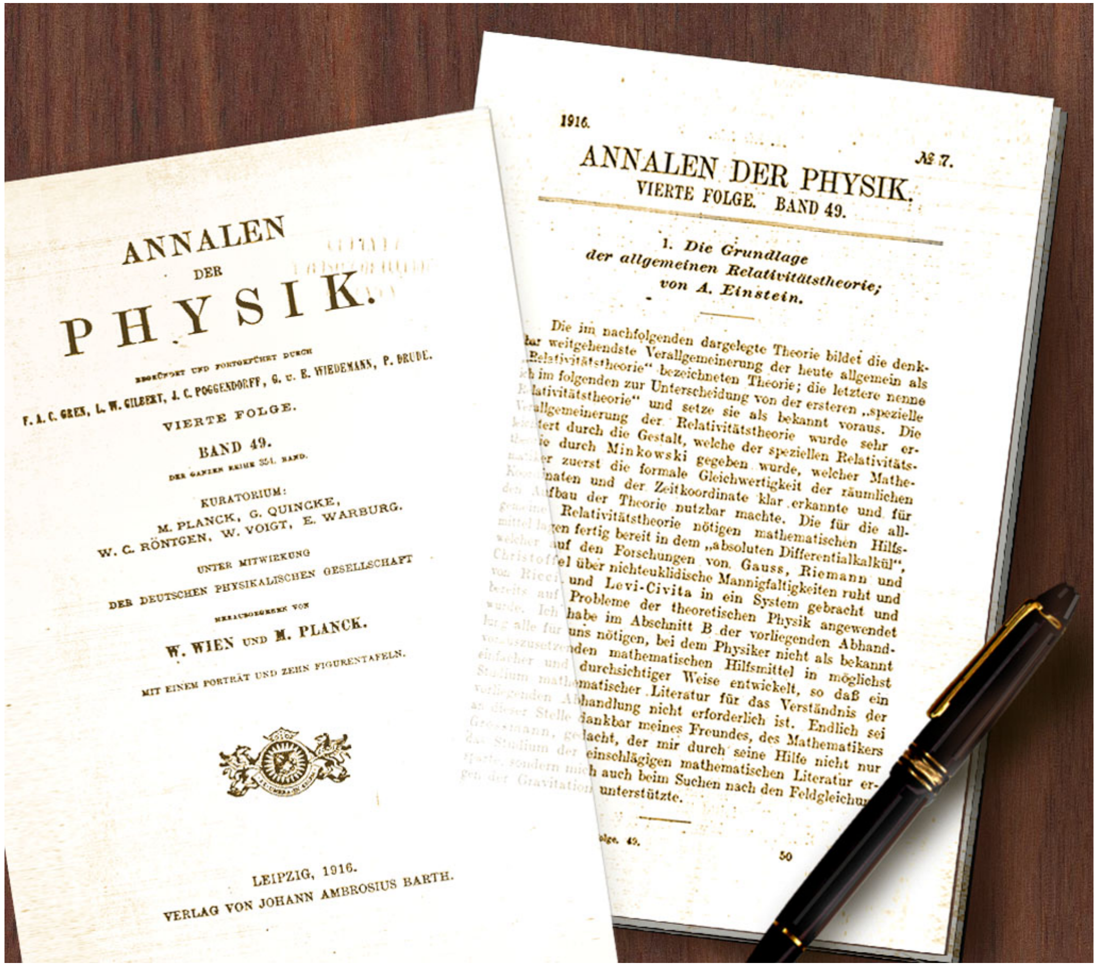
General Relativity: "a theorist's Paradise, but an experimentalist's Hell"

C. Misner, K. S. Thorne and J.A Wheeler, ***Gravitation*** p. 1131 (1973)



- Nothing exemplifies this statement like gravitational waves
- Convincing observational evidence for their existence not available until ~70 years after initial prediction (Binary Pulsar)
- After many years, direct detection still eludes us
- We hope to make a direct detection by the 100th anniversary of the theory.

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Forty Sixth Scottish Universities Summer School in Physics, Aberdeen, July 1995

Lobo, J. A.,
Sources of gravitational waves,

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6th MultiDark Consolider Workshop & RENATA meeting, Abril 2012

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A big loss

José Alberto Lobo Gutiérrez
Instituto de Ciencias del Espacio

He has been a pioneer of the field of Gravitational Wave Astronomy in Spain, devoting his life to resonant ground-based detectors and to space-based ones.

His contributions range from theoretical studies to the development of instrumentation, including data analysis methods.

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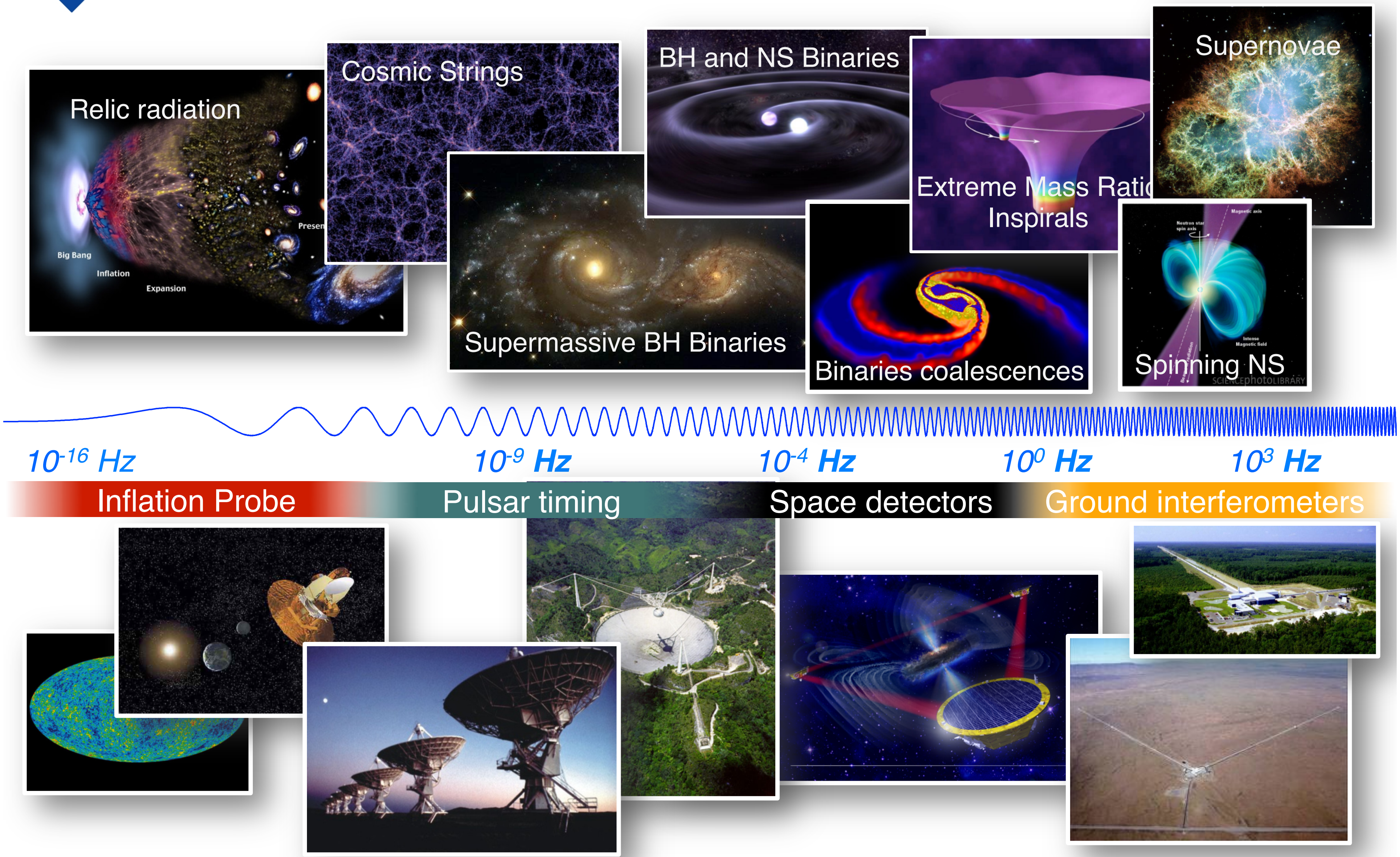
The GW Spectrum



GWs that could be plausibly detected range from 10^{-9} Hz up to 10^{11} Hz.

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Gravitational Wave Astronomy. A new field

Gravitational wave detectors will study sources characterised by extreme physical conditions: strong non-linear gravity and relativistic motions, very high densities, temperatures and magnetic fields.

Some of the key scientific questions to which answers will be sought:

fundamental physics:

- What are the properties of gravitational waves?
- Is General Relativity still valid under strong-gravity conditions?
- Are nature's black holes the black holes of General Relativity?
- How does matter behave under extremes of density and pressure?

cosmology:

- What is the history of the accelerating expansion of the Universe?
- Were there phase transitions in the early Universe?

astrophysics:

- How abundant are stellar-mass black holes?
- What is the mechanism that generates gamma-ray bursts?
- What are the conditions in the dense central cores of galactic nuclei dominated by massive black holes?
- Where and when do massive black holes form, and what role do they play in the formation of galaxies?
- What happens when a massive star collapses?
- How do compact binary stars form and evolve, and what has been their effect on star formation rates?

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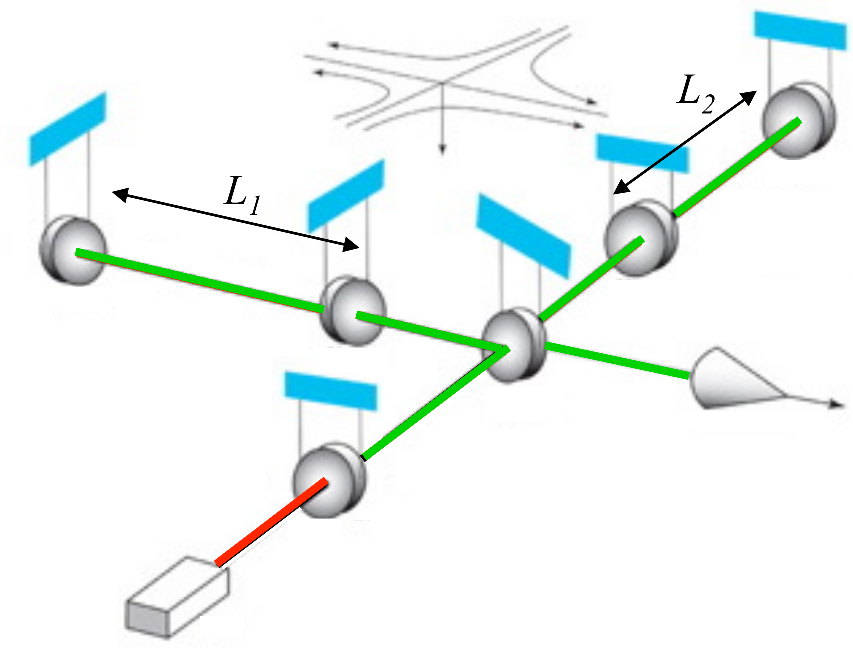
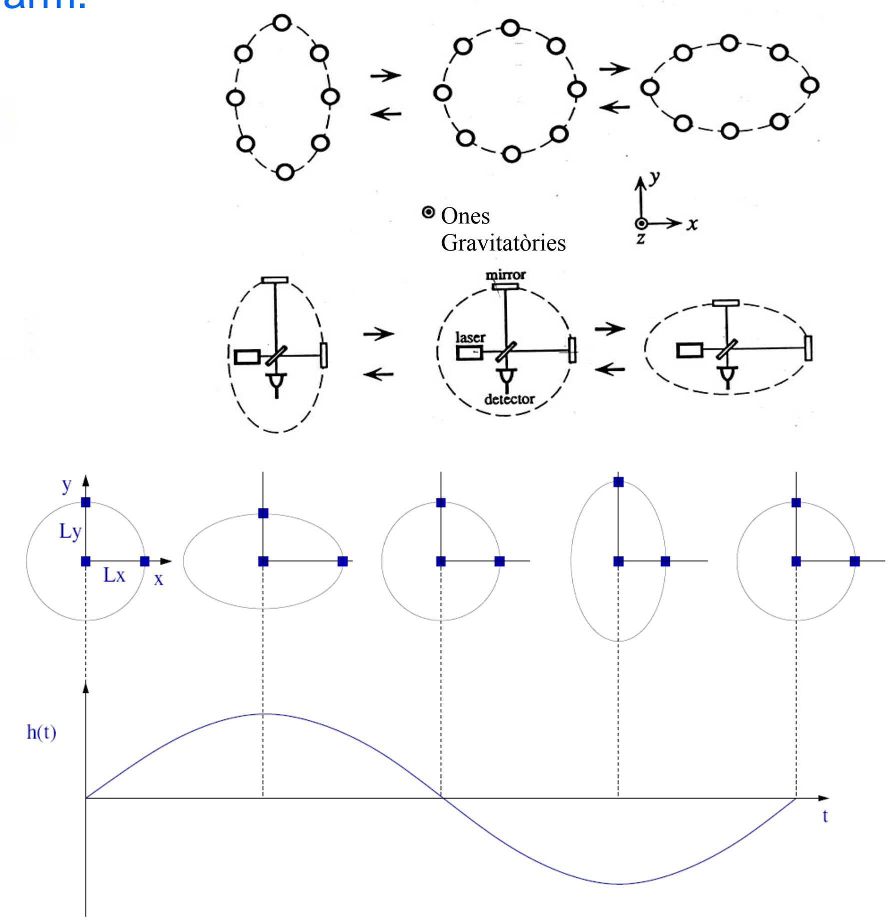
GW interferometer Layout

- Detecting a gravitational wave requires the construction of an L-shaped antenna approximately aligned with the polarization of the wave so that it is capable of detecting the squeezing of space along one arm of the antenna and the simultaneous stretching of space along the other arm.





- Laser light, which has a very accurately known wavelength, is the ruler that is used to measure the incredibly tiny squeezing and stretching that occurs.

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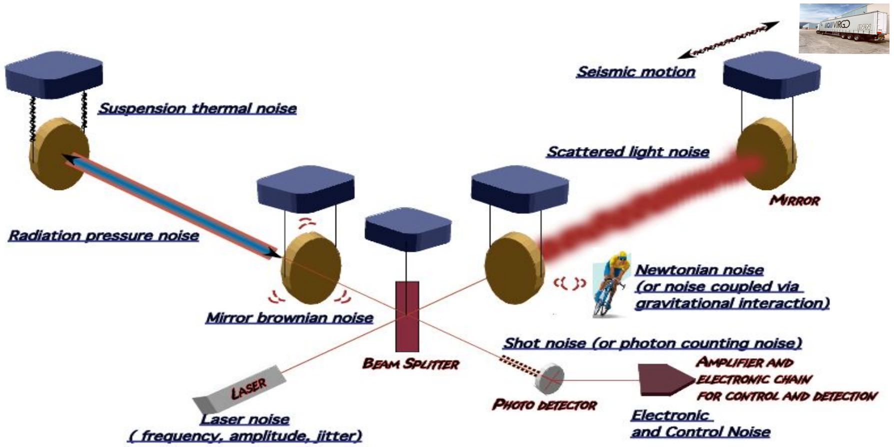
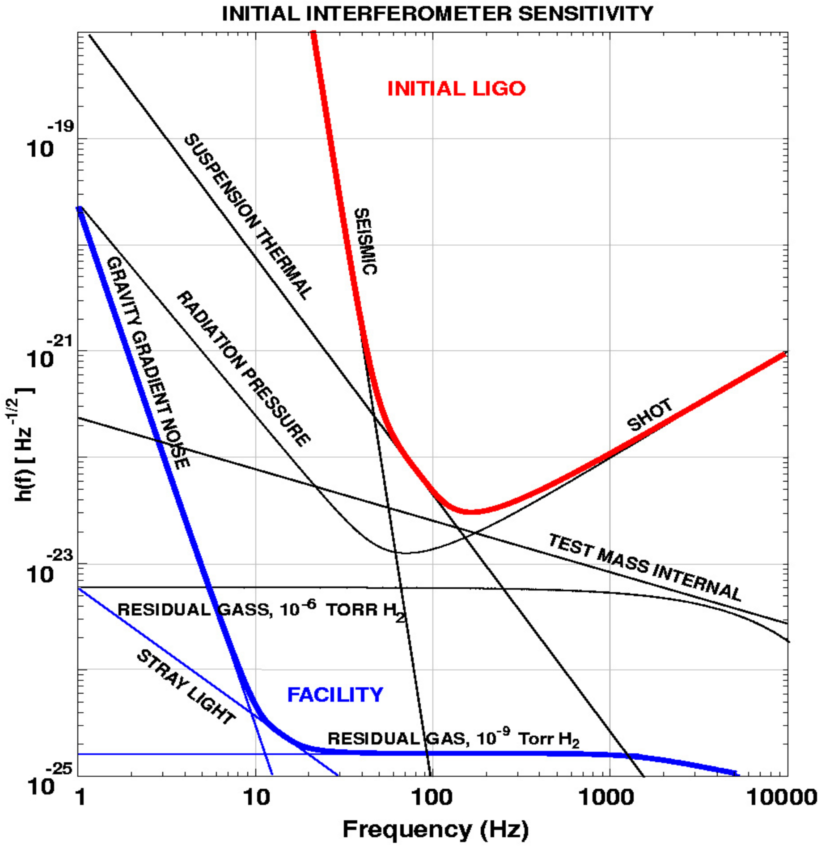
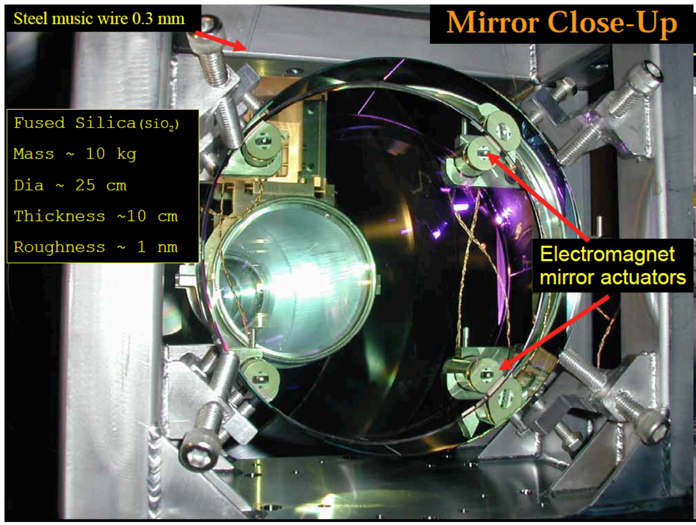
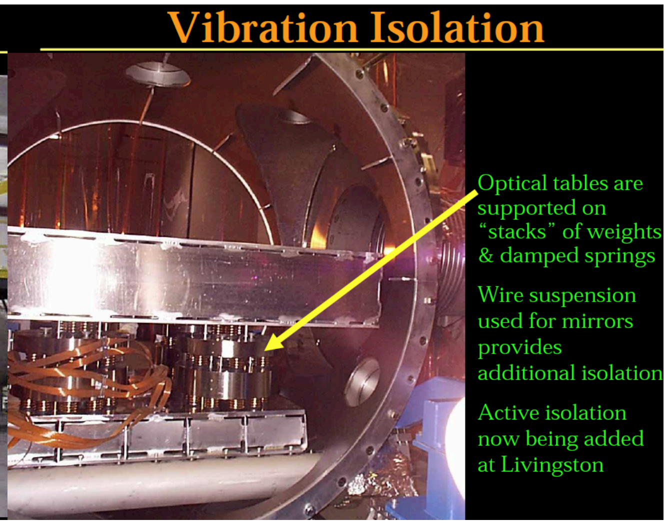
Fundamental Noise Sources





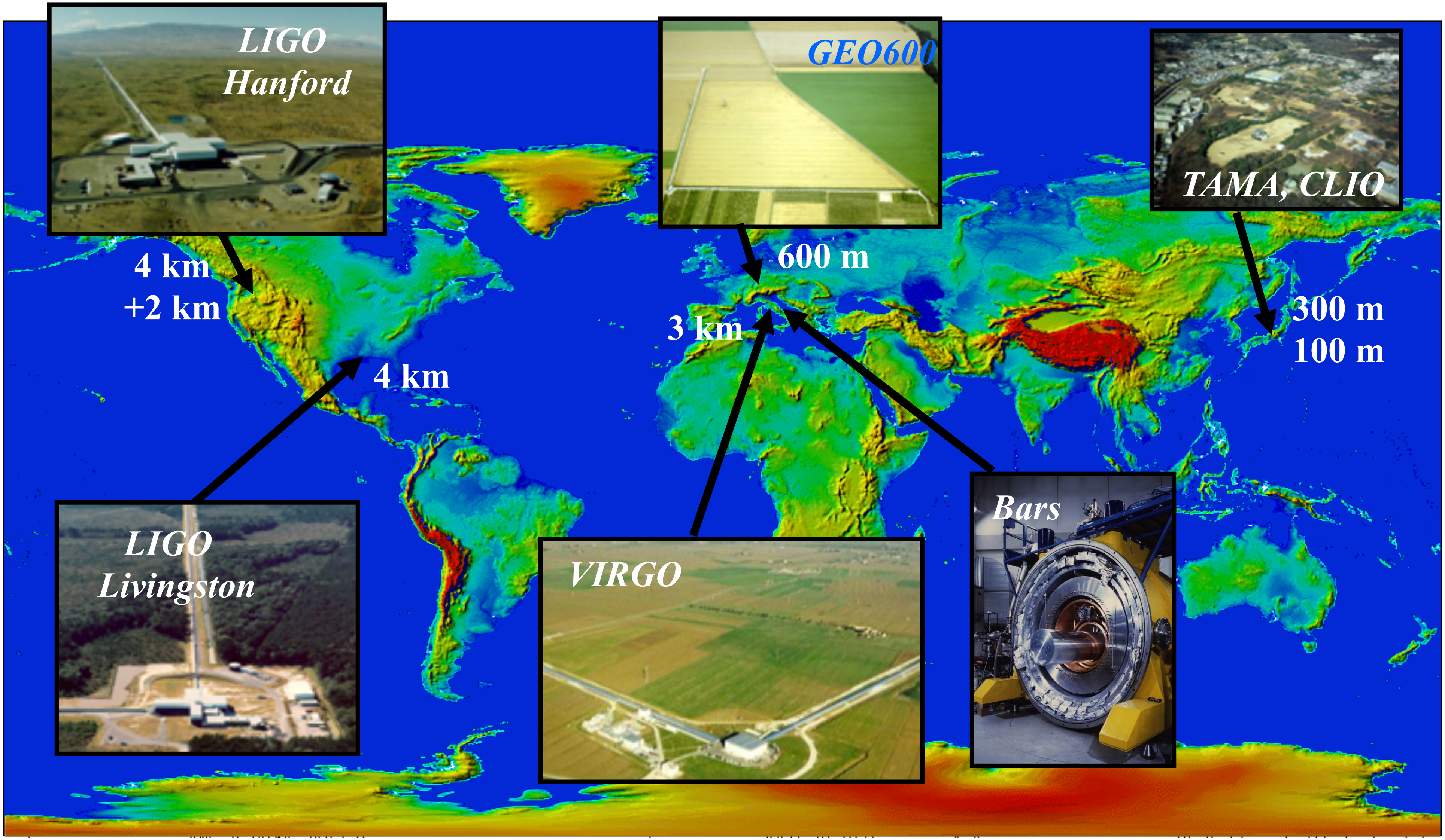
- Strain sensitivity $<3\times10^{-23}$ $1/Hz^{1/2}$ at 200 Hz
- Displacement Noise
  - » Seismic motion, Thermal Noise, Radiation Pressure
- Sensing Noise
  - » Photon Shot Noise, Residual Gas
- Big challenge: reduce all other (non-fundamental, or technical) noise sources to insignificance





UIB Universitat de les Illes Balears

The Global GW Detector Network in the Recent Past



Timeline of GW searches to 2011

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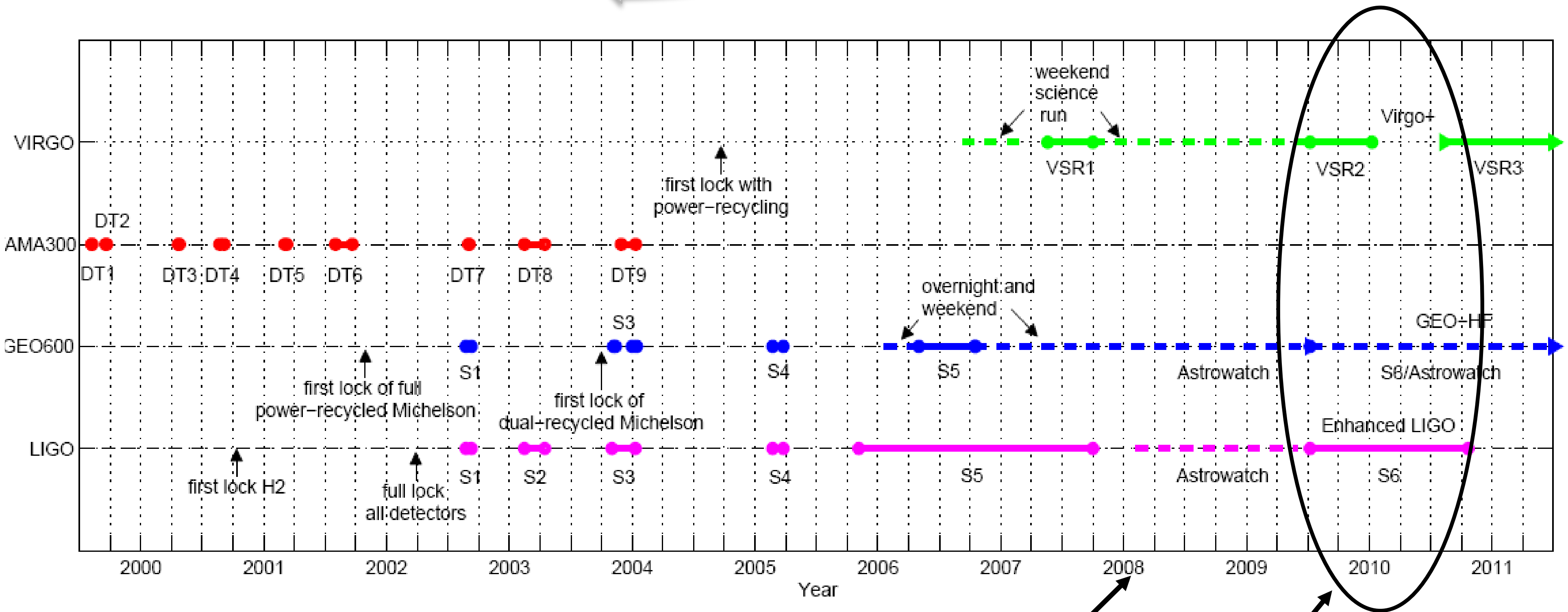
1989 — LIGO Proposal submitted to NSF

1995 — Construction started

1999 — Inauguration



Advanced LIGO construction funded

Data analysis ongoing

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Initial LIGO, Virgo, GEO

LIGO, Virgo and GEO share all data to form a global detector network.

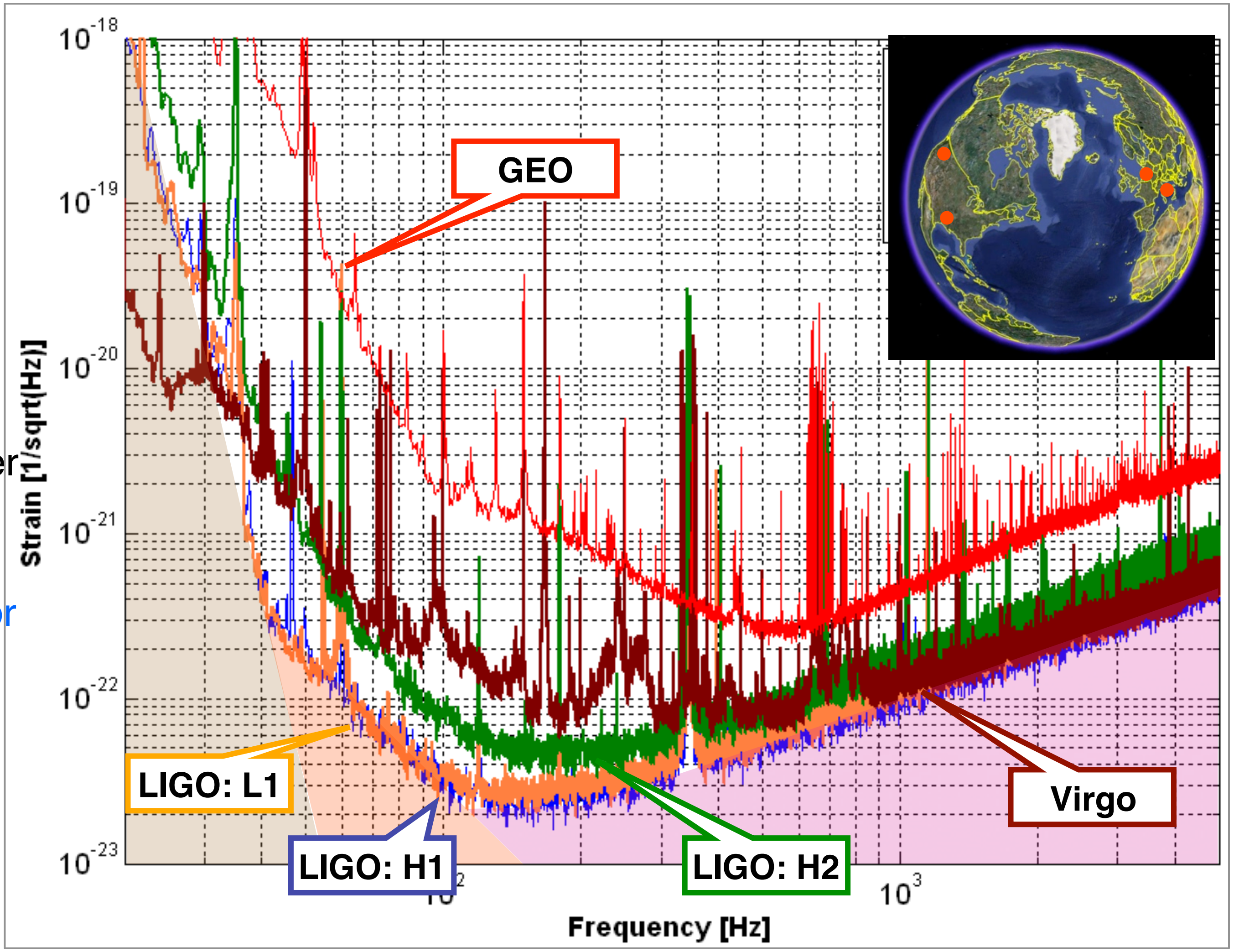
LIGO-GEO-Virgo network took data at/near design sensitivity 2005-11.

The LIGO Scientific Collaboration includes over 50 Universities and 800 researchers.

LIGO's maximum range for binary coalescences:

- neutron star – neutron star: 40 Mpc
- neutron star – black hole: 90 Mpc
- Virgo: about half that

Expected detection rates < 1 yr^{-1}.



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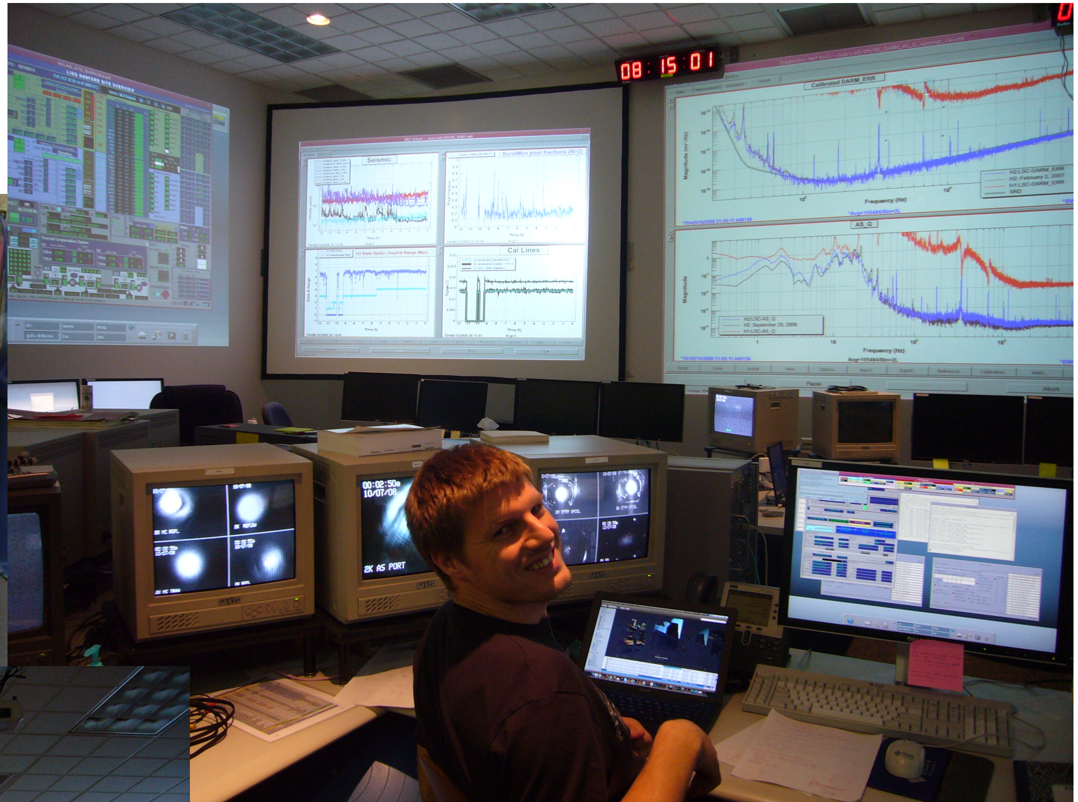

SCIENCE PAPERS BEING PUBLISHED

THE ASTROPHYSICAL JOURNAL, 715:1438–1452, 2010 June 1 doi:10.1088/0004-637X/715/2/1438

SEARCH FOR GRAVITATIONAL-WAVE BURSTS ASSOCIATED WITH GAMMA-RAY BURSTS USING DATA FROM LIGO SCIENCE RUN 5 AND VIRGO SCIENCE RUN 1

PHYSICAL REVIEW D 82, 102001 (2010)

Search for gravitational waves from compact binary coalescence in LIGO and Virgo data from S5 and VSR1

PHYSICAL REVIEW D 81, 102001 (2010)

All-sky search for gravitational-wave bursts in the first joint LIGO-GEO-Virgo run

THE ASTROPHYSICAL JOURNAL, 715:1453–1461, 2010 June 1 doi:10.1088/0004-637X/715/2/1453

SEARCH FOR GRAVITATIONAL-WAVE INSPIRAL SIGNALS ASSOCIATED WITH SHORT GAMMA-RAY BURSTS DURING LIGO'S FIFTH AND VIRGO'S FIRST SCIENCE RUN

nature

LETTERS

Beating the spin-down limit on gravitational wave emission from the Vela pulsar

arXiv:1104.2712v2 [astro-ph.HE] 15 Apr 2011

An upper limit on the stochastic gravitational-wave background of cosmological origin

The LIGO Scientific Collaboration* & The Virgo Collaboration*

13

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A Turning Point

- The era of the 1st generation ground-based interferometric detectors is ending… leaving a remarkably rich heritage
  - established the infrastructures
    - The same ones will be used for the next generation of LIGO, Virgo and GEO
    - New ones will be needed for KAGRA and LIGO-India
  - basically reached the design sensitivities (and somewhere exceeded upon detector upgrades)
  - realized robust and reliable instruments
  - developed the paradigm for data analysis
  - established a network
  - started the multi-messenger approach
  - did real astrophysics
  - tested some technologies for 2nd generation (and beyond)
  - a large (O(1000)) community grew around these projects and is now solidly established
- Such richness is being invested in a new generation of detectors that finally promises to detect gravitational waves and open a new window on the universe

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The Global Network c. 2020

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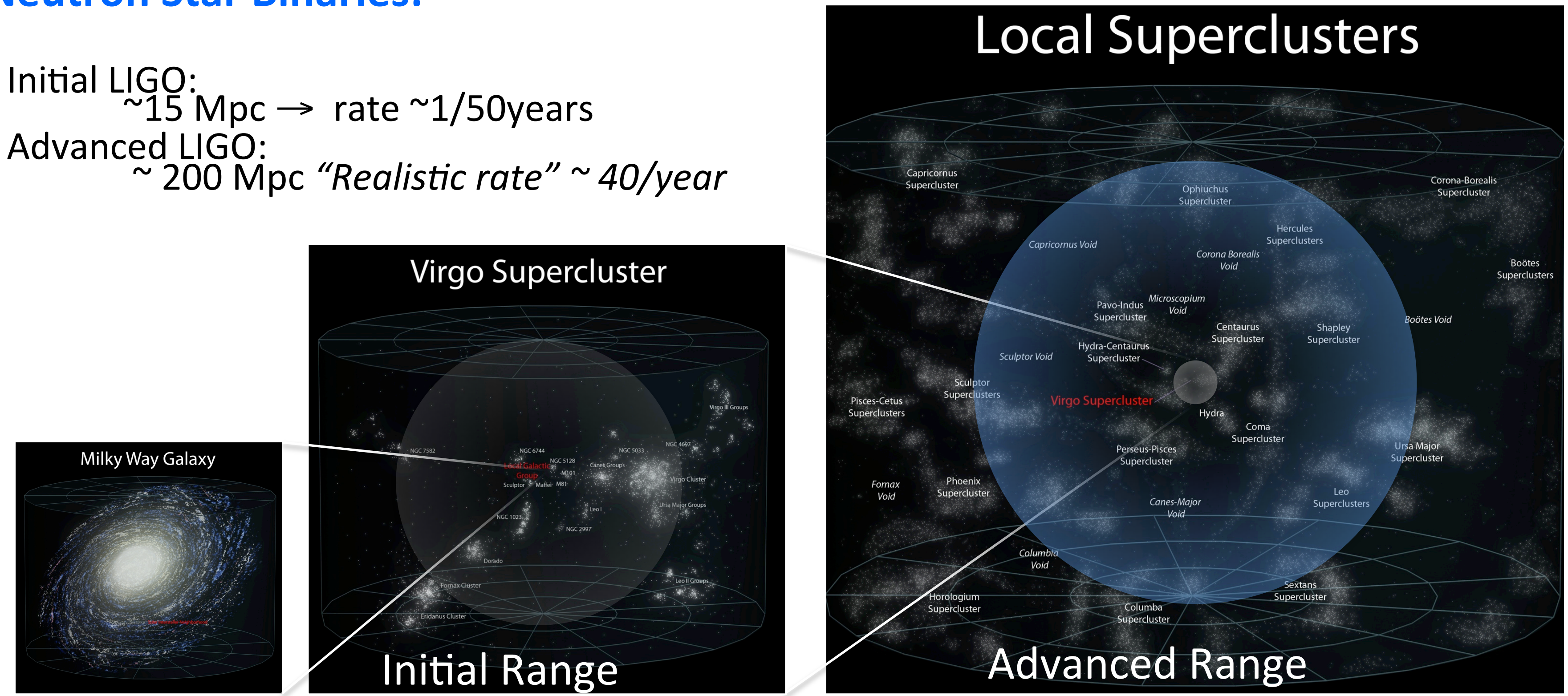
Advanced Sensitivity: 10x More Range

- Advanced detectors will reach about 100,000 galaxies
- Events happen once every 10,000 years per galaxy…
- Roughly 1 per month!

(considering only NS-NS mergers)

Neutron Star Binaries:

Initial LIGO:
~15 Mpc → rate ~1/50years
Advanced LIGO:
~ 200 Mpc *"Realistic rate" ~ 40/year*



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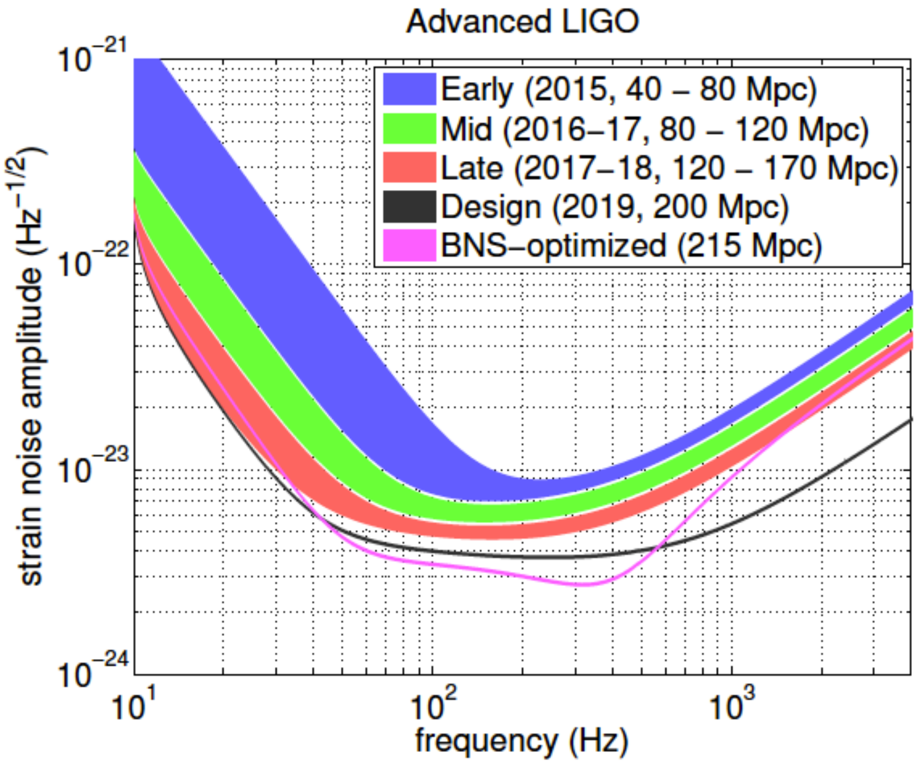
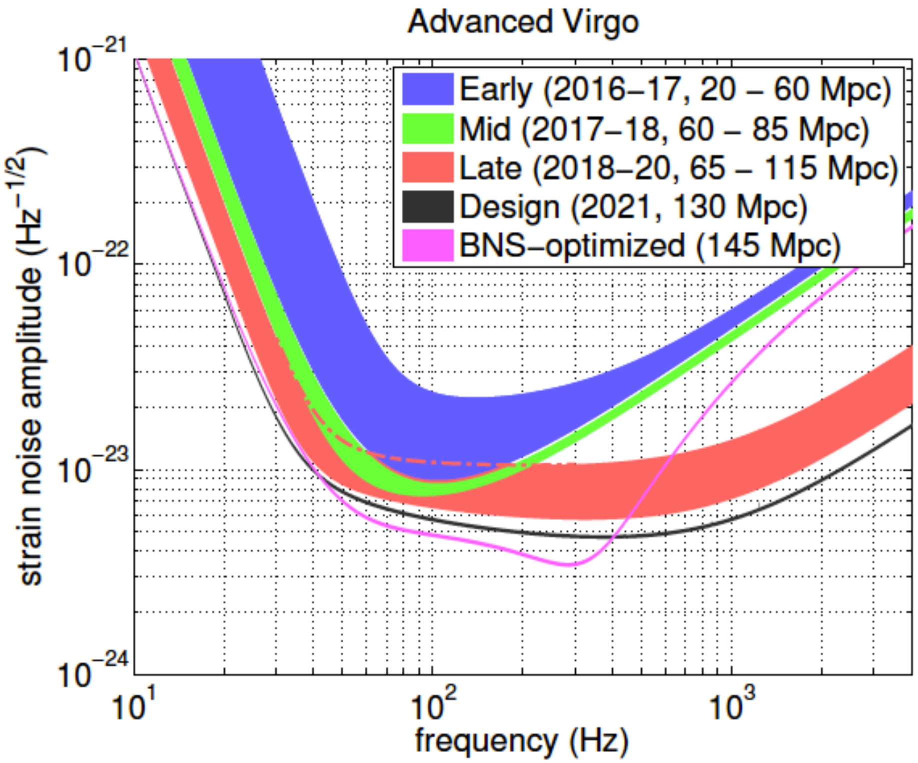
Rough Timeline





KAGRA: scheduled to begin observation in 2017

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

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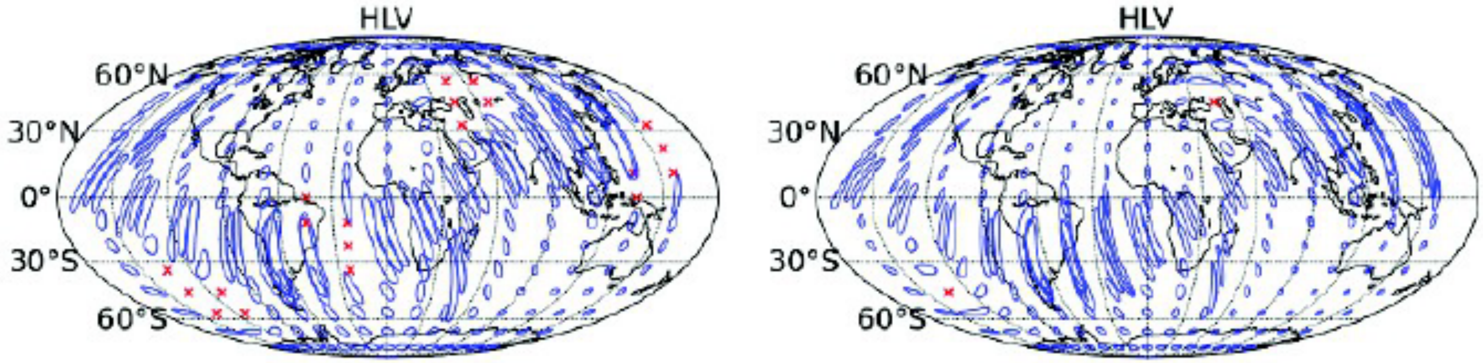
Advanced LIGO/Virgo sky localization

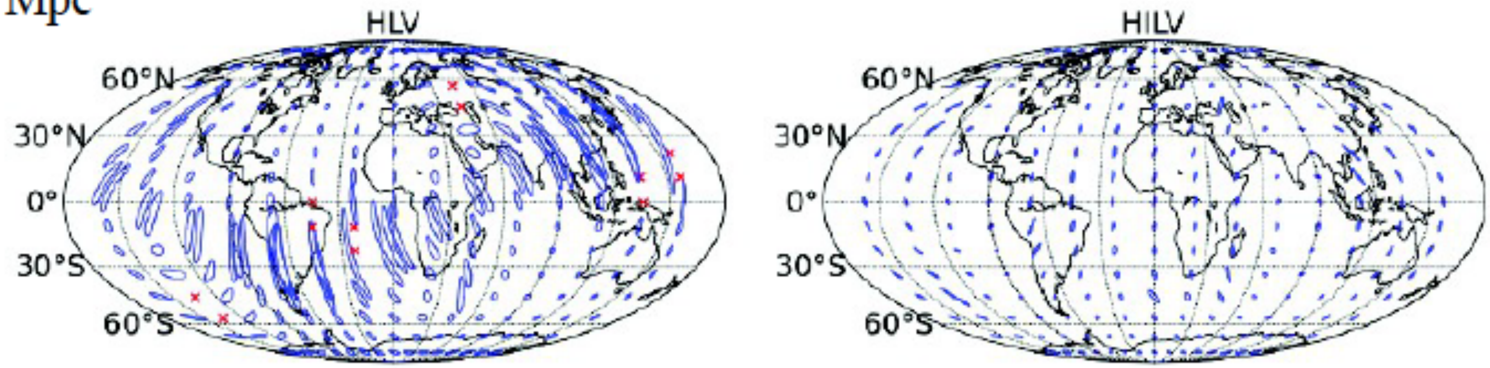
BNS source @ 80 Mpc

2016-2017 runs

2018-2019 runs



BNS source @ 160 Mpc



2019+ runs

HLV + LIGO India 2022+

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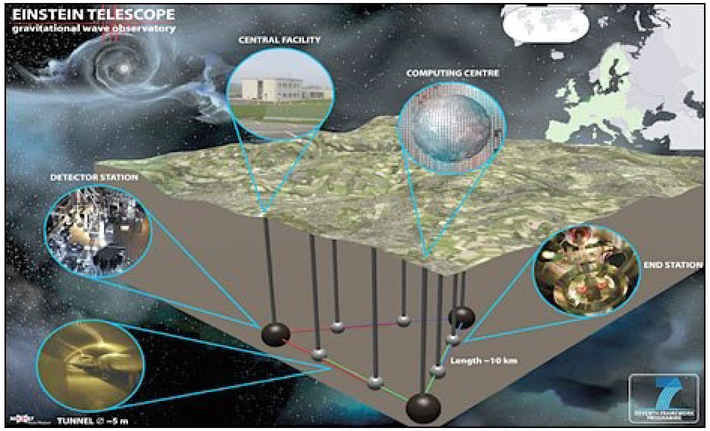
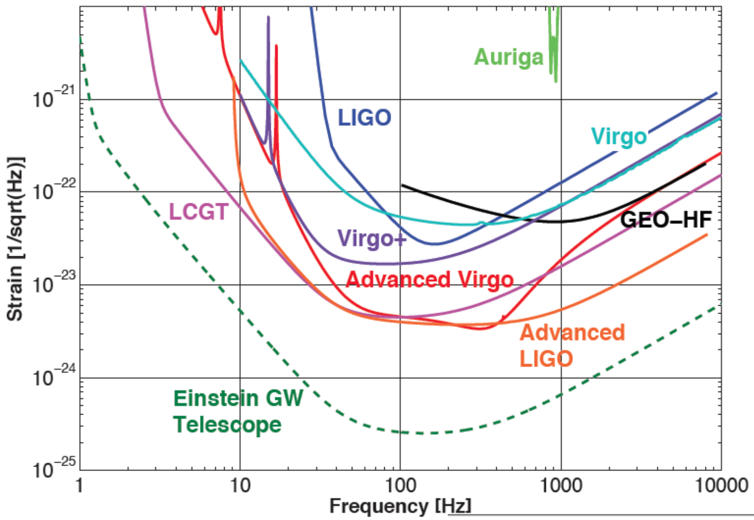
Einstein Telescope: Conceptual design



Expected ET Sensitivity



- Einstein Telescope is a future third generation gravitational wave detector (beyond Advanced LIGO, Advanced Virgo, KAGRA)
- Conceptual design study funded by EU, recently concluded
  - Available at: http://www.et-gw.eu/etdsdocument
- Multiple interferometers, 10 km arm length, arranged in triangular configuration
- Underground
- Assuming technologies one should be able to achieve in 10-15 years
- ET is one of ASPERA's "Magnificent Seven" astroparticle physics large projects.

Source	BNS	NS-BH	BBH
Rate ($\mathrm{Mpc}^{-1}\,\mathrm{Myr}^{-1}$)	0.1–6	0.01–0.3	2×10^{-3}–0.04
Event Rate (yr^{-1}) in aLIGO	0.4–400	0.2–300	2–4000
Event Rate (yr^{-1}) in ET	$\mathcal{O}(10^3$–$10^7)$	$\mathcal{O}(10^3$–$10^7)$	$\mathcal{O}(10^4$–$10^8)$

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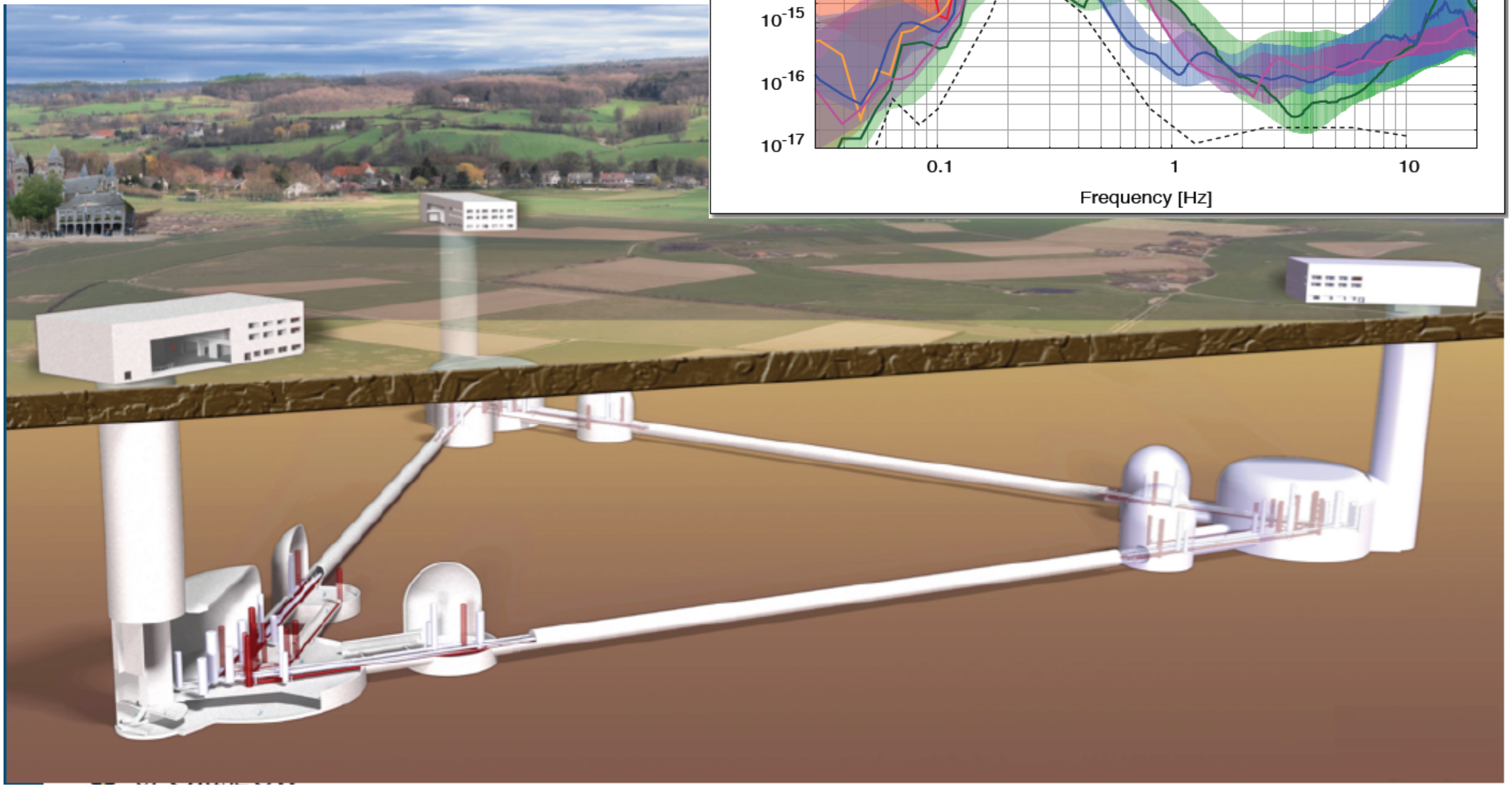
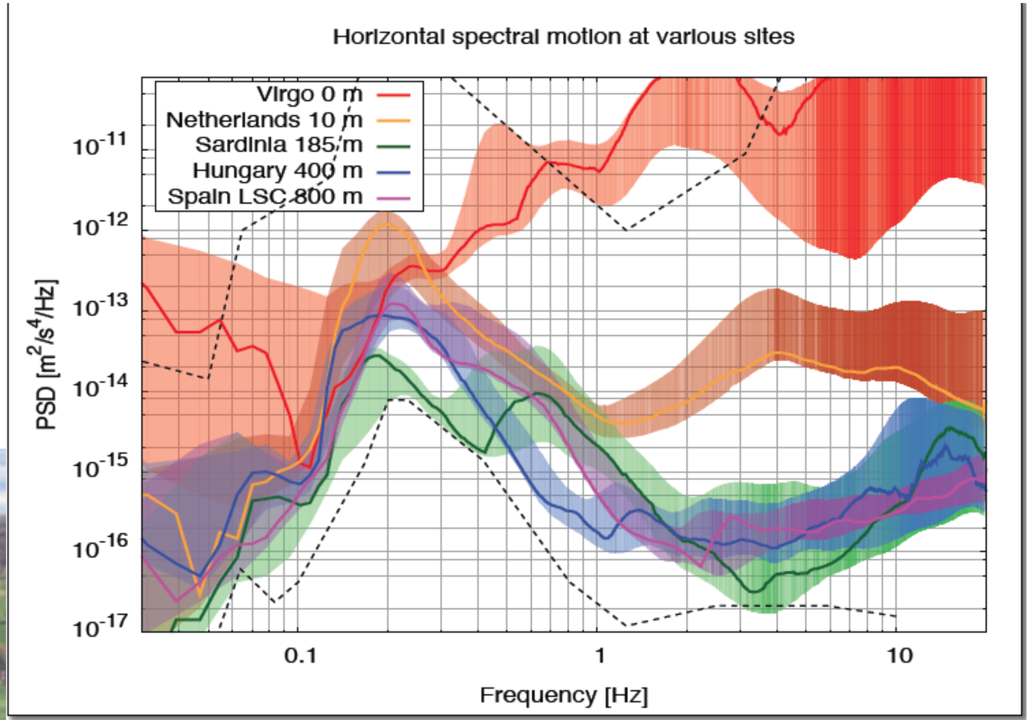
Artist's view of ET





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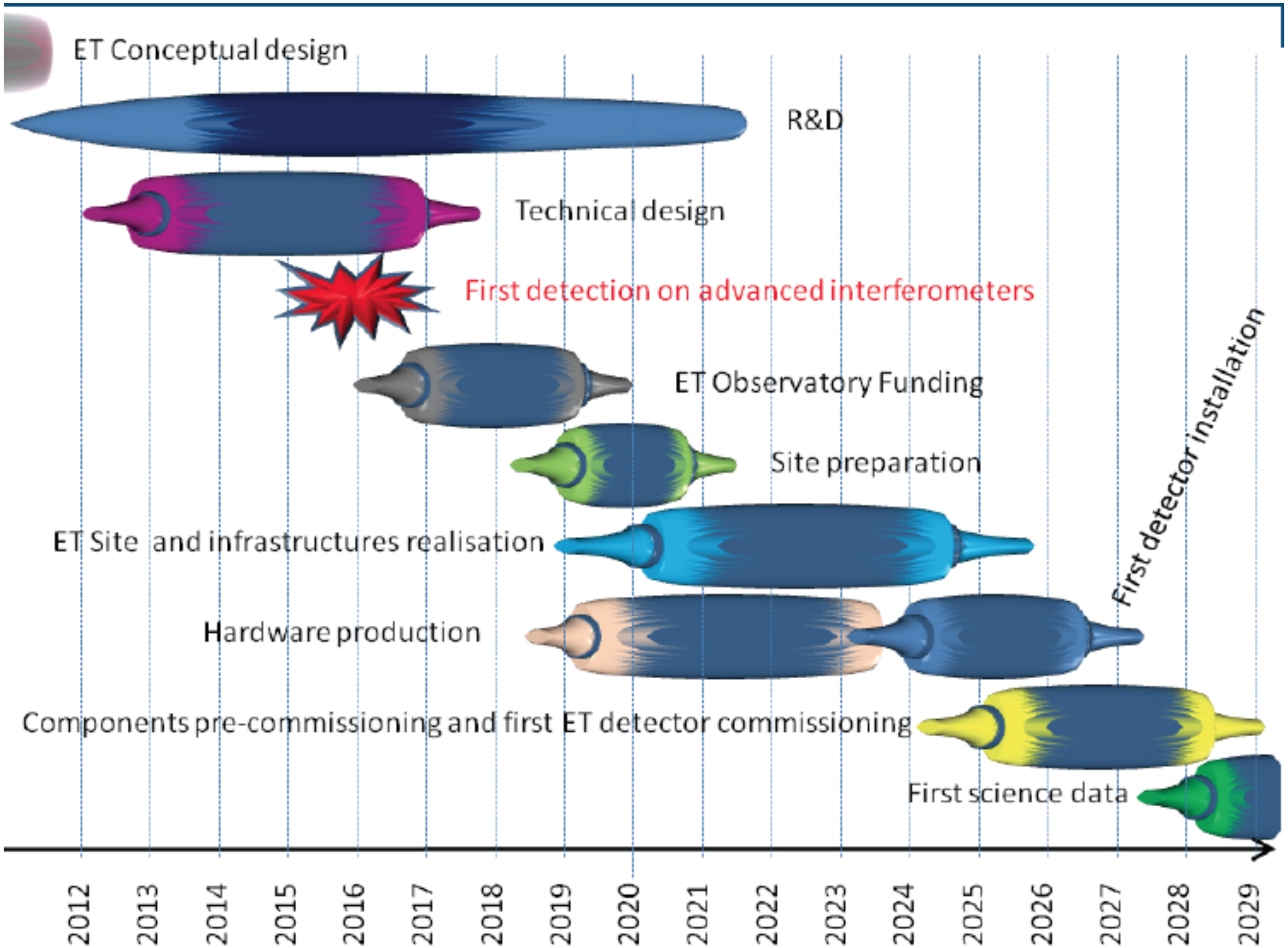
ET timeline



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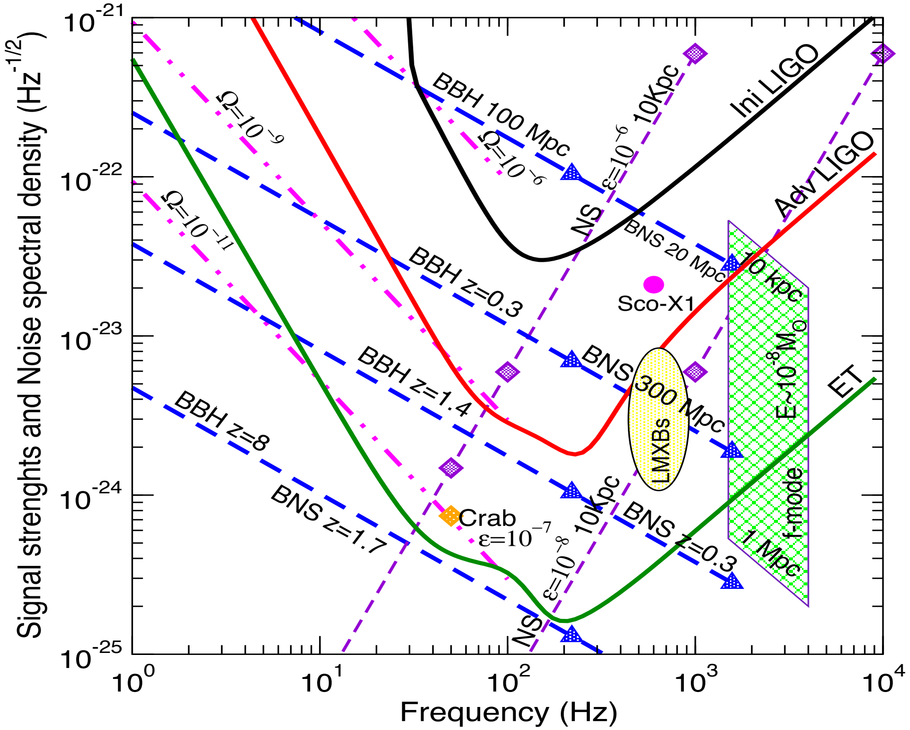
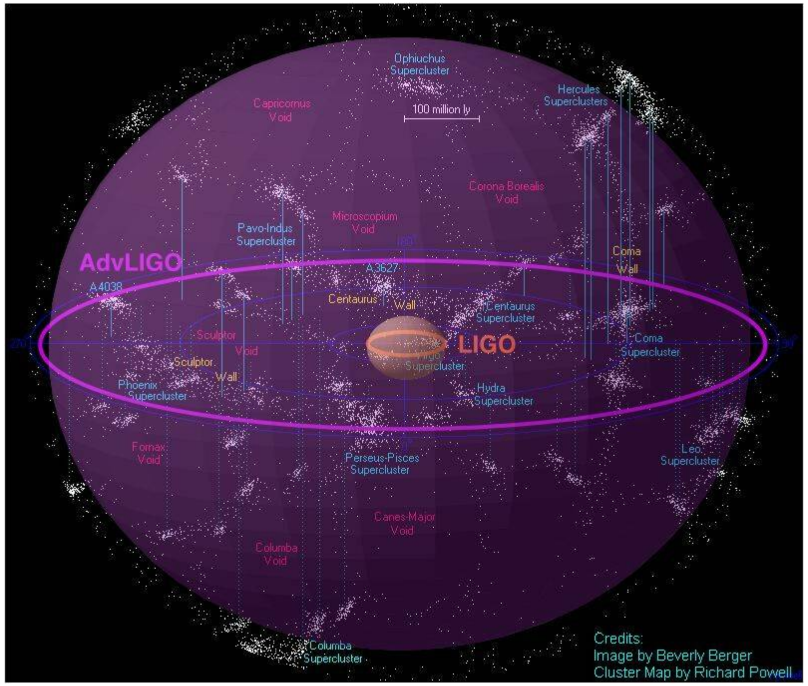
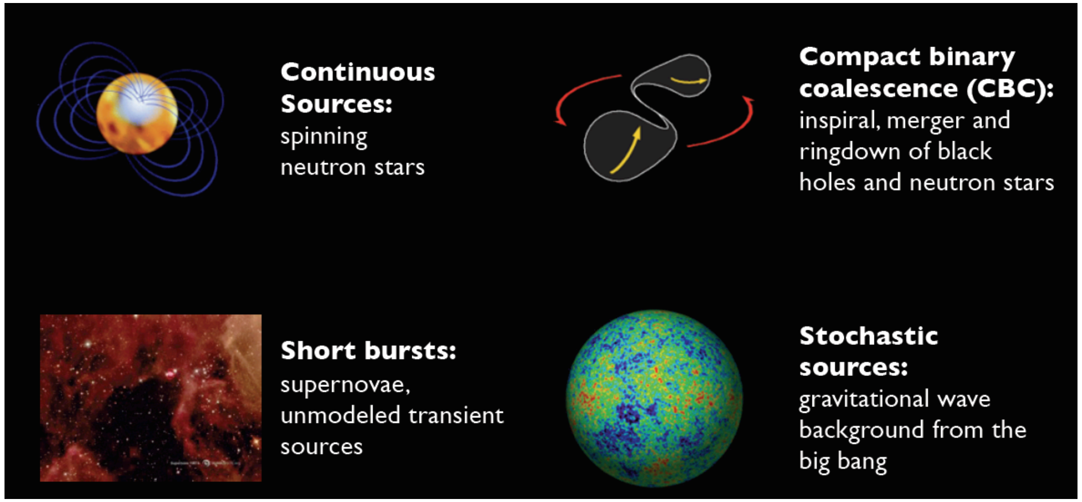
Sources for Ground Based Detectors

From Schutz & Sathyaprakash, Living Reviews in Relativity







Advanced LIGO reach (example):
h sensitivity will improve by 10, with improved bandwidth

NS-NS x10 better amplitude sensitivity

- ⇒ x1000 rate=(reach)^3
- ⇒ 1 day of Advanced LIGO
  - » 1 year of Initial LIGO !

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The Gravitational Wave Signal Tableau

Short duration ↔ Long duration

Waveform known ↕ Waveform unknown

Cosmic string cusp / kink

NS / BH ringdown

Low-mass inspiral

Asymmetric spinning NS

High-mass inspiral

Binary tracked by low-frequency detector

Binary merger

Rotation-driven instability

Cosmological stochastic background

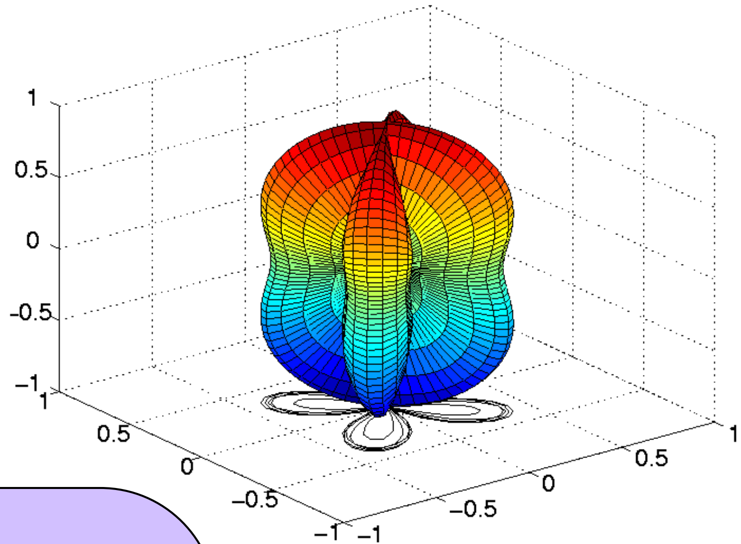
Stellar core collapse

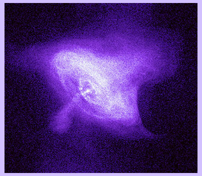
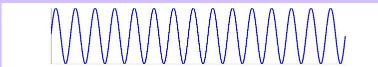
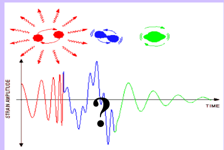
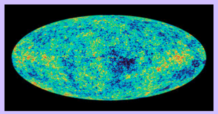
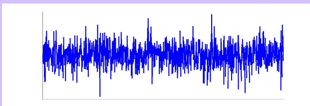
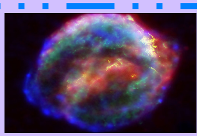
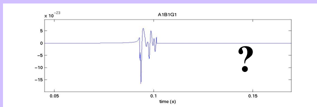
Many overlapping signals

??? ??? ???

Why GW data analysis is challenging?

- All sky sensitivity
  - Quadrupolar antenna pattern
  - multiple detectors to determine direction to source
- Wide frequency band sensitivity
- Large data rates
  - Hundreds of instrumental and environmental channels
  - up to 10 MB per second from each detector
- Low event rates
- Large number of parameters and templates to search over



	Long duration	Short duration
Matched filter	 Crab pulsar (NASA, Chandra Observatory) 	 
Template-less methods	 NASA, WMAP 	 NASA, HEASARC 

Sources and methods

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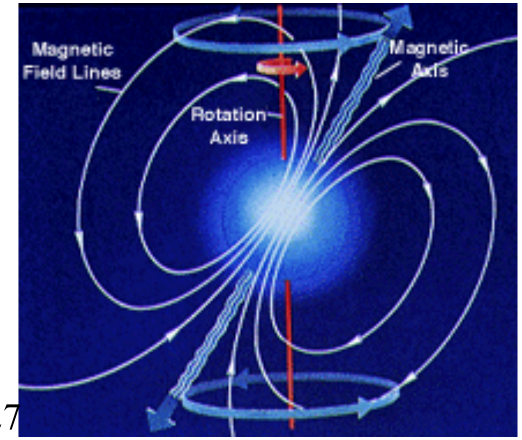
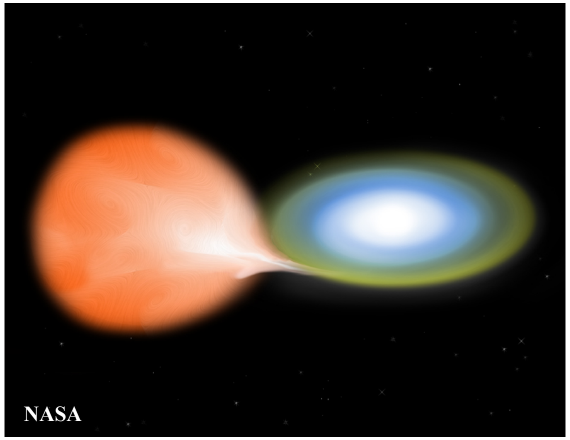
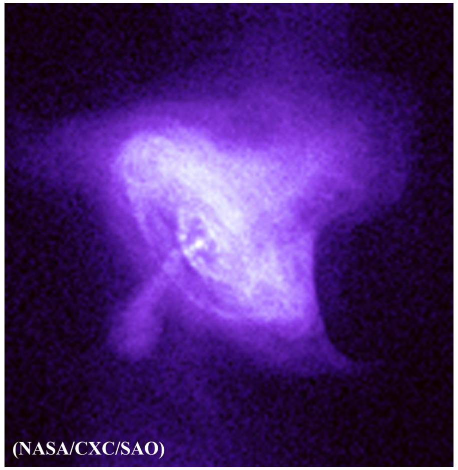
Exploring the galactic neutron star population with gravitational waves

- Our galaxy might contain ~10^9 NS, of which ~10^5 are expected to be active pulsars. Up to now ~2000 pulsars have been identified

- Different searches:
  - non-accreting known pulsars for which timing data is available;
  - non-accreting known stars without timing data;
  - unknown isolated stars;
  - accreting stars in known binary or stars in unknown binary systems.
- And for each of these we have to face a different data analysis challenge.
  - Most of the searches are computationally limited.
  - Directly constrained by astronomical observations.







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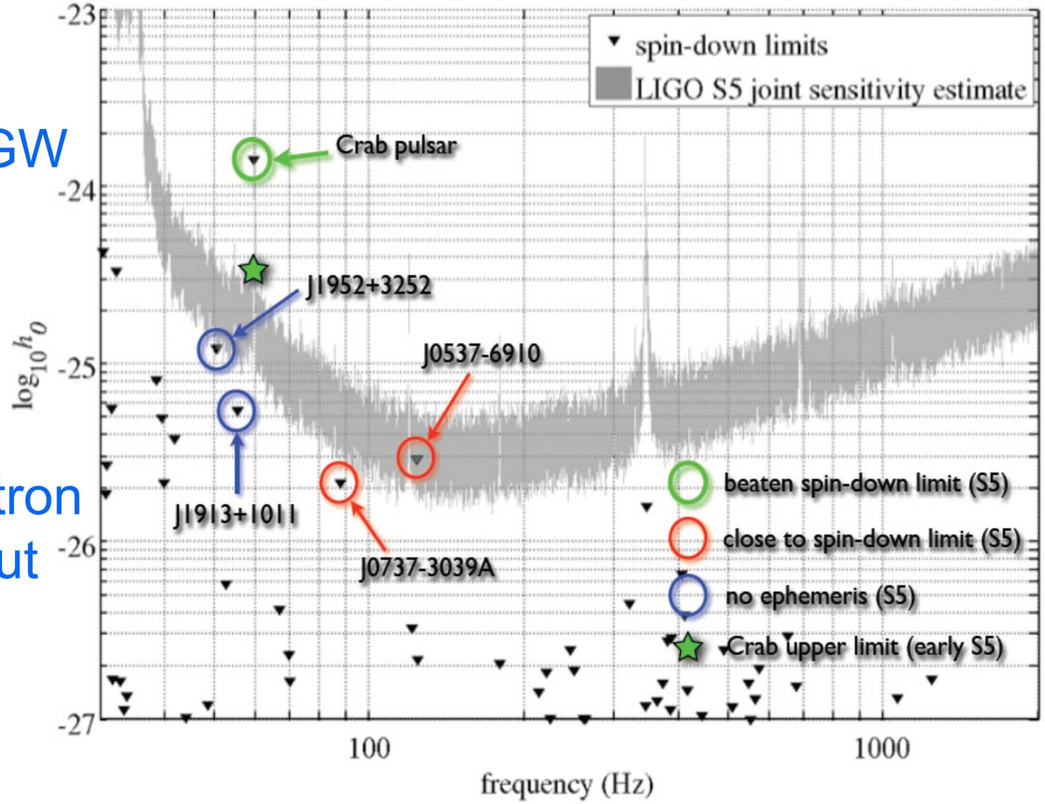
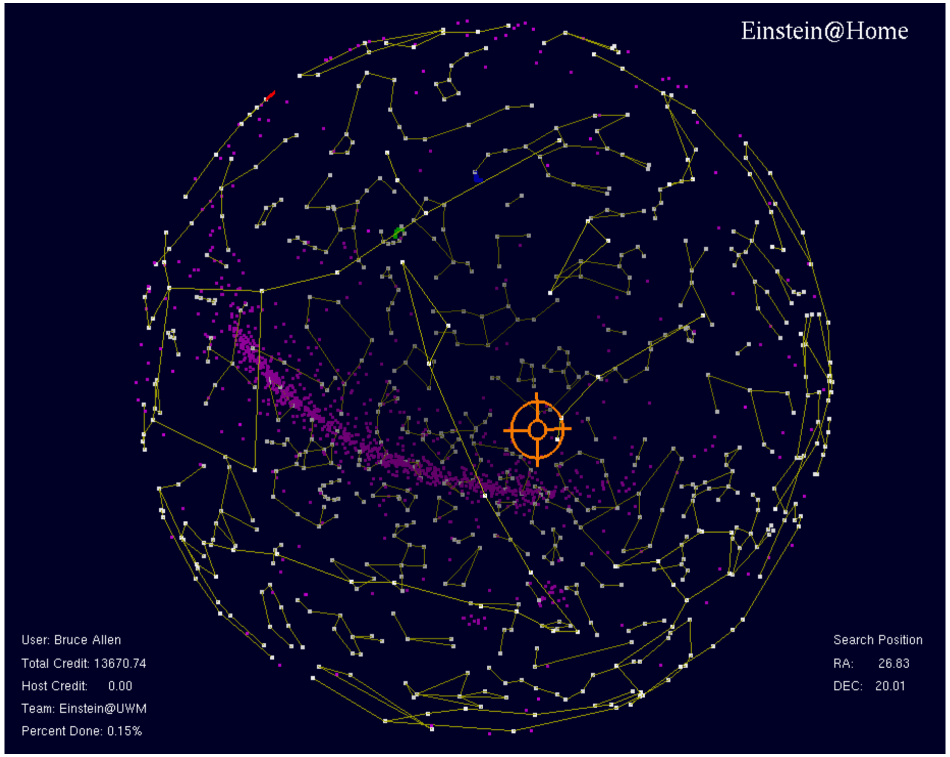
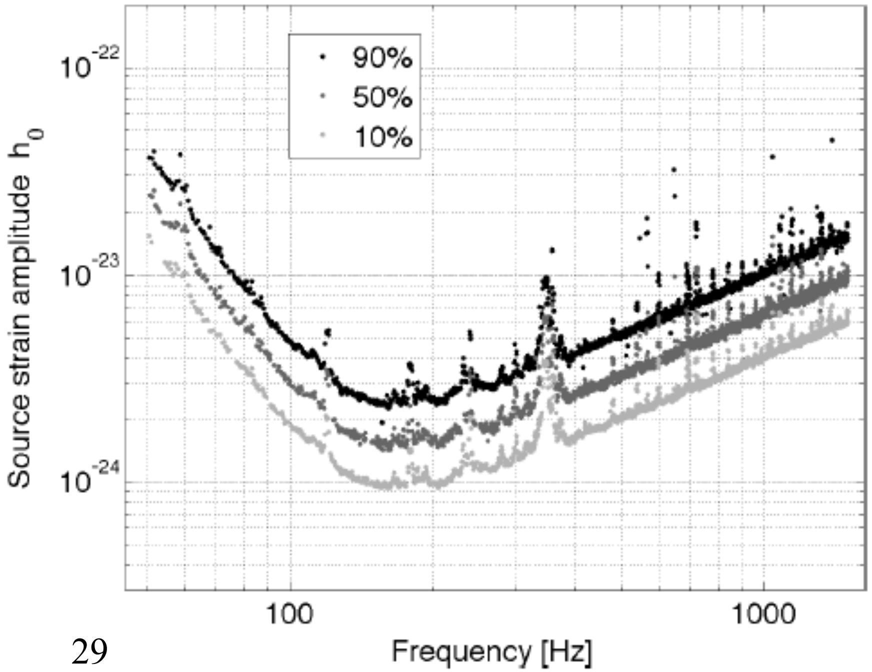
GW observations of neutron stars

- To date, LIGO and Virgo have not plausibly detected GW emissions from neutron stars (but analysis of existing data is ongoing).
- For 3 young neutron stars (Crab, Vela, Cassiopeia A), GW observations have placed more stringent limits than EM observations.
- Several broad-area searches have placed upper limits on GW fluxes from unknown neutron stars.
- Advanced detectors could plausibly detect Galactic neutron stars in the next five years (but no guarantees).







Einstein@home

http://www.einsteinathome.org/

- Einstein@Home, a volunteer distributed computing project, where host home or office computers automatically download "workunits" from the servers,carry out analyses when idle, and return results.
- Distributed using BOINC & run as a screensaver
- Shortly after January 1st 2013, Einstein@Home passed the 1 Petaflop computing-power barrier.
- Since 2009, E@H looks for signals in Arecibo (Parkes) data, using 30% of the search time. Found several new pulsars

Cosmology Highlight

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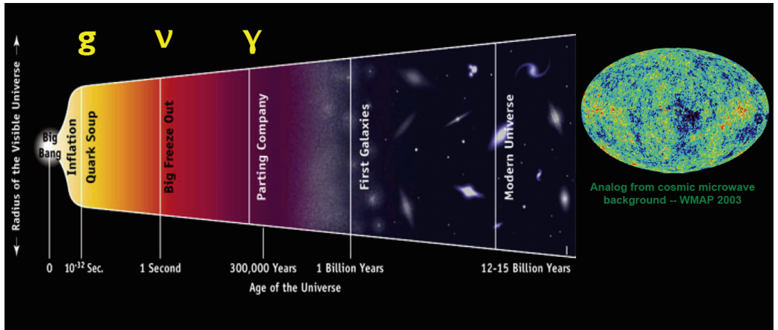
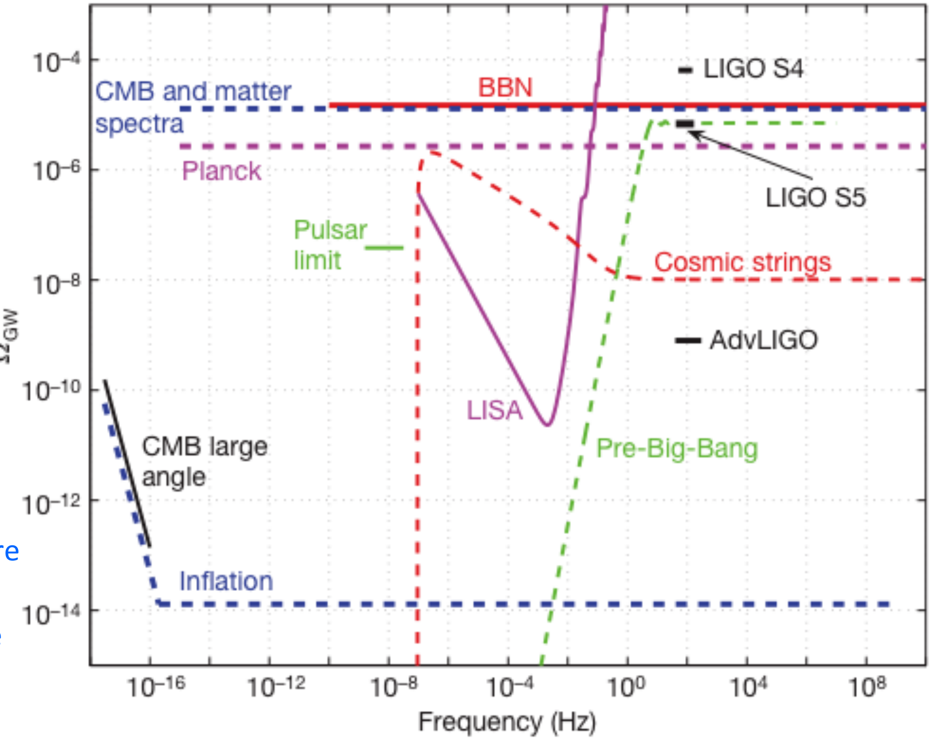
- A stochastic background of gravitational waves is expected to arise from a superposition of a large number of unresolved gravitational-wave sources of astrophysical and cosmological origin. Direct measurements of the amplitude of this background are of fundamental importance for understanding the evolution of the Universe when it was younger than one minute.



$$\int_0^\infty d\ln f\,\Omega_{GW}(f) = \frac{\rho_{GW}}{\rho_{critical}}$$

Comparison of different stochastic GW background measurements and models. *Abbott et al Nature **460 (2009)**.*



- LIGO S5 result constrains the energy density of the stochastic GW background of the Universe to be < 6.9×10^{-6} around 100 Hz, assuming a flat spectrum of GWs.
- The data rule out models of early Universe evolution with relatively large equation-of-state parameter, as well as cosmic (super)string models with relatively small string tension that are favoured in some string theory models.
- This search for the stochastic GW background improves on the indirect limits from Big Bang nucleosynthesis and cosmic microwave background at 100 Hz.

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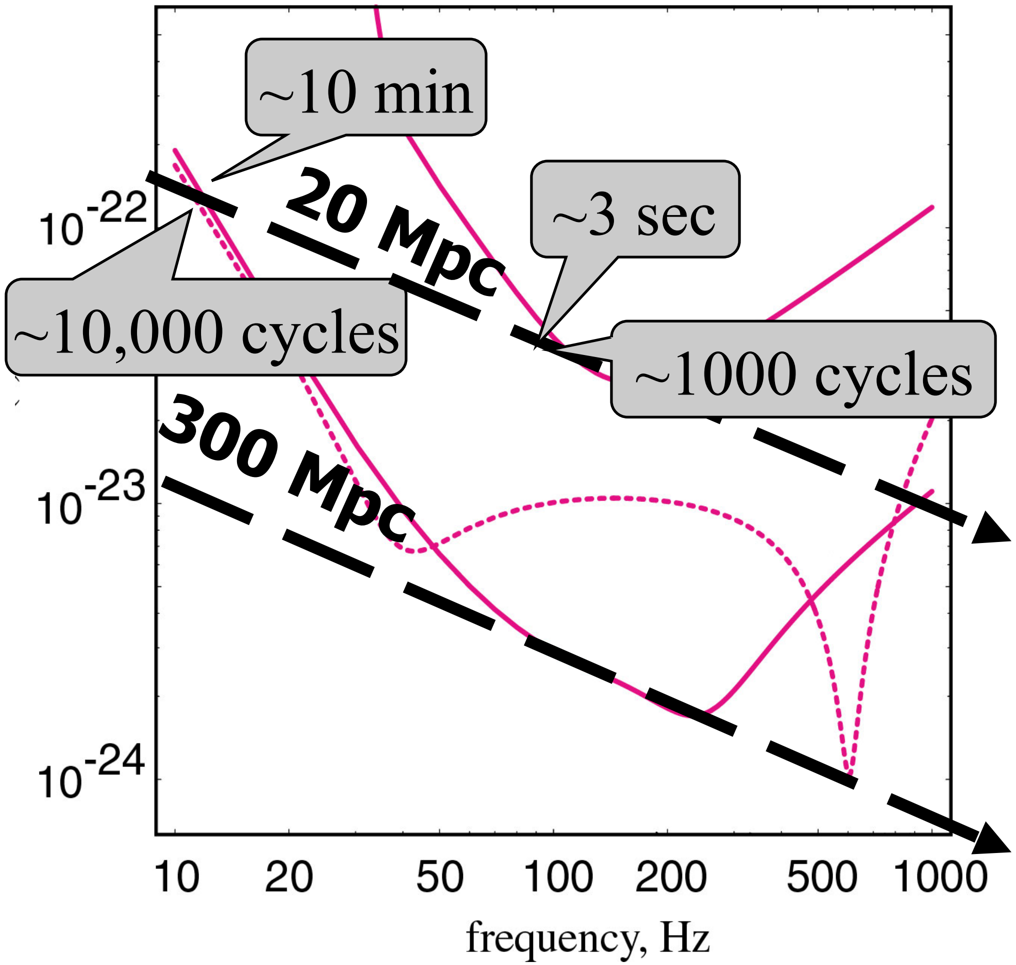
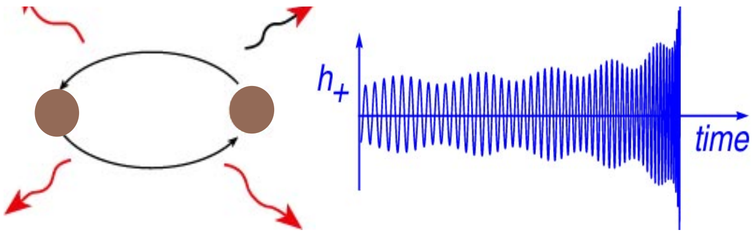
Neutron Star Binary Inspiral

NS-NS coalescence 'inspiral'

- Initial interferometers
  - Range: 20 Mpc
- Advanced interferometers
  - Range: 300Mpc



Signal shape very well known

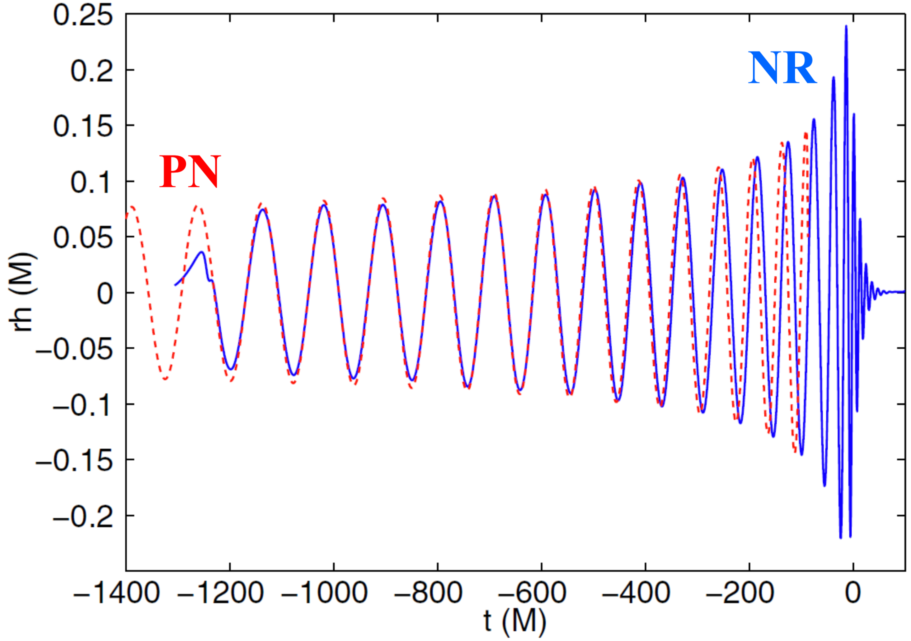


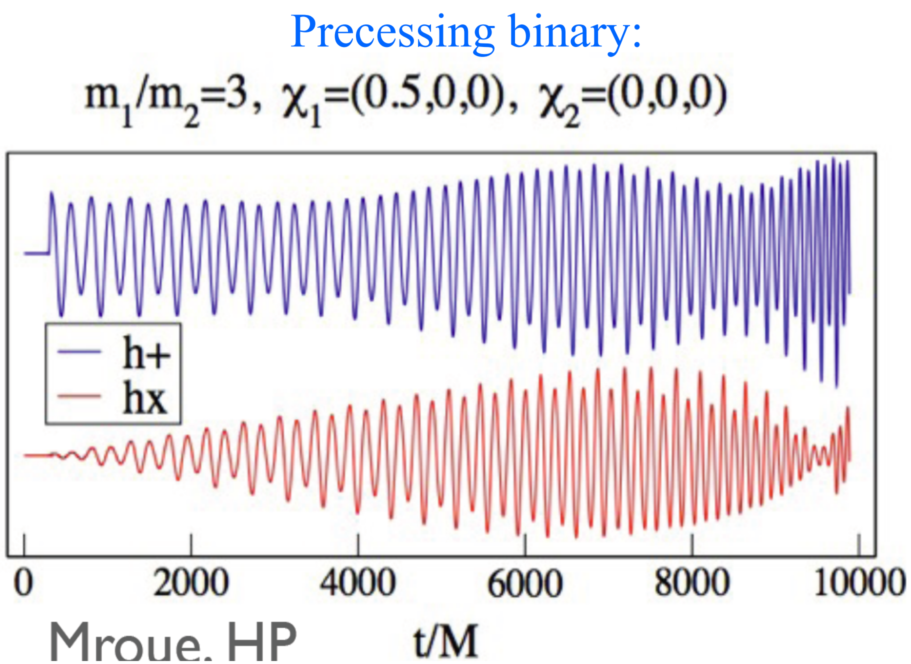
Into the Merger

Merger dynamics are driven by strong-field gravity

- Post-Newtonian expansion loses accuracy
- Neutron star tidal deformation can affect final part of inspiral
- Black hole spins can cause orbital plane to precess and strongly influence final "plunge"

Numerical relativity to the rescue !





Compact binary inspiral, merger, ringdown

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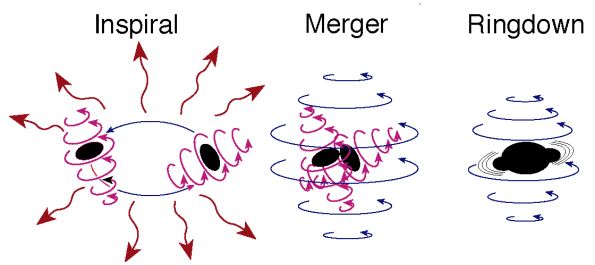
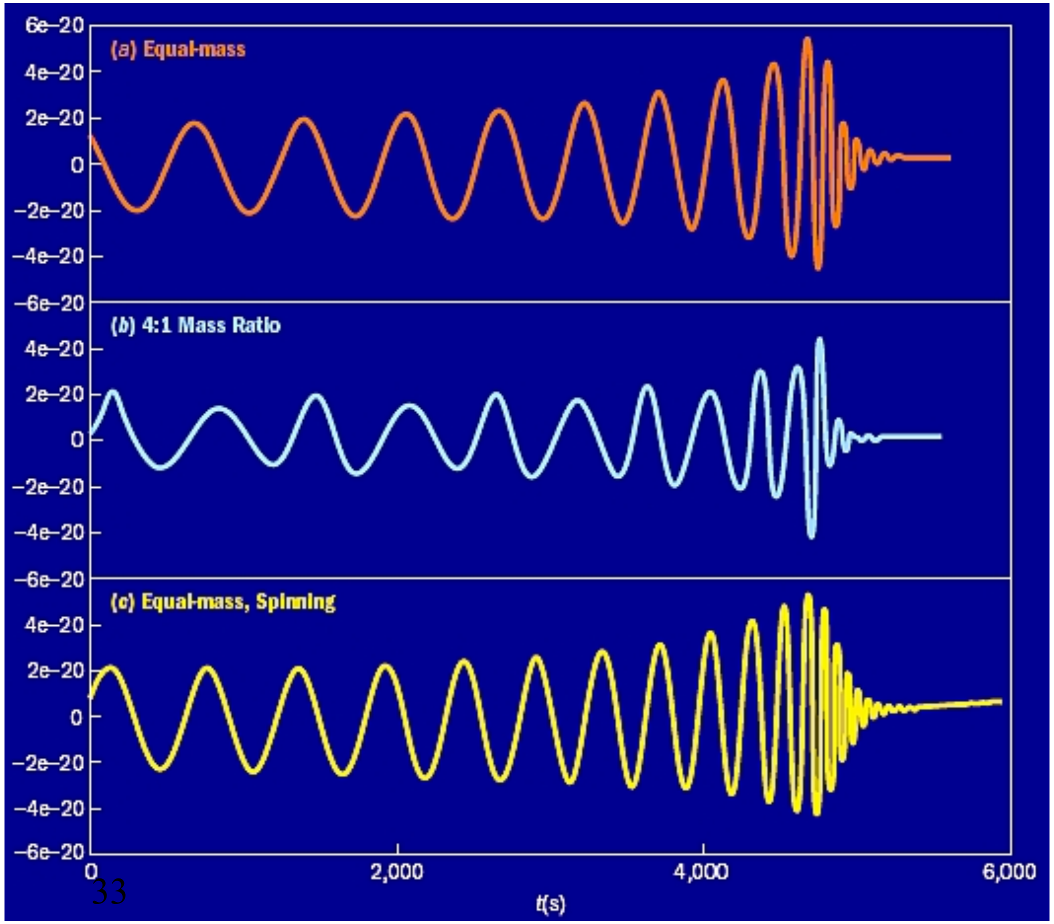
- Until not so long ago, data analysis methods for coalescing binaries had to rely on post-Newtonian approximations, which break down before merger, and perturbative ringdown signals.





By matching post-Newtonian and full-GR numerical relativity results, it is now feasible to construct "complete" waveforms describing the inspiral, merger and ringdown of compact binaries.

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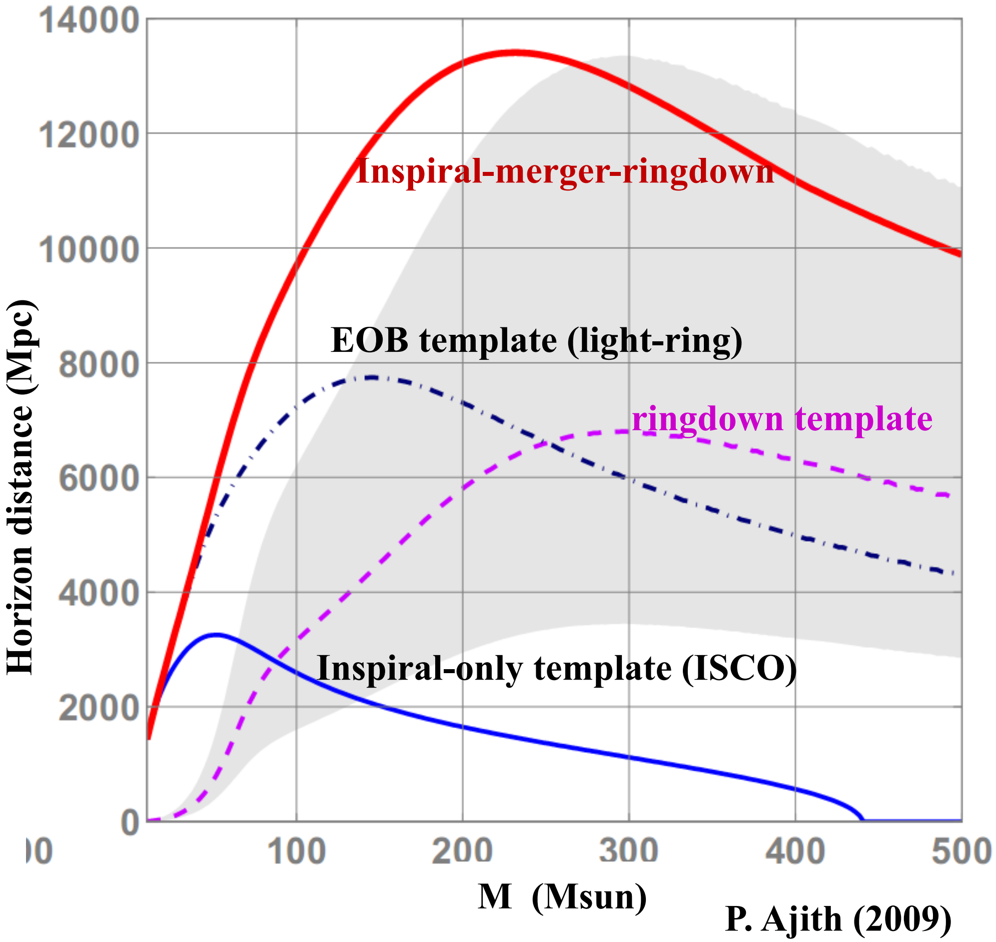
Horizon distance & template banks for compact binary mergers



Horizon distance: Distance in Mpc at which one Advanced LIGO detector can see an optimally-located, optimally oriented binary merger with an SNR=8, as a function of total mass.

Averaging over sky location and orientation degrades this by ~2.26.

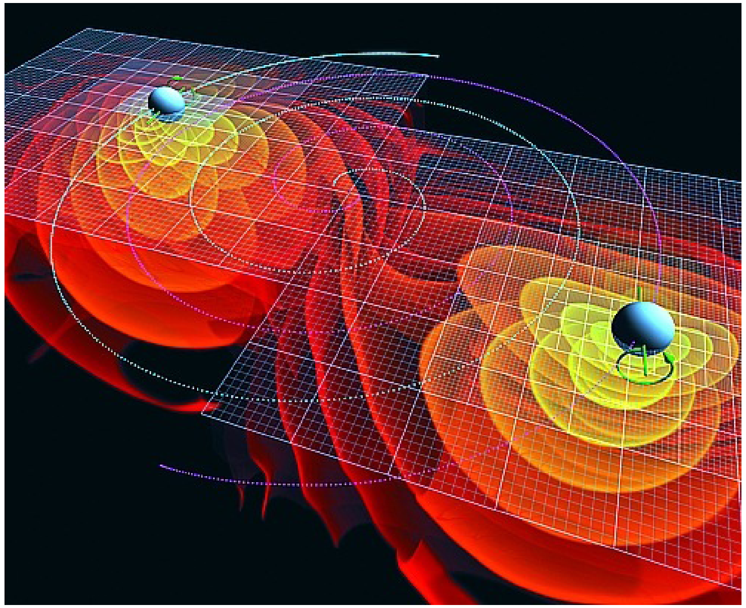
Important to use the right templates, including IMR, and spin effects!

Results show that numerical simulations in full GR will have significant implications on detection rates and the accuracy of parameter estimation.

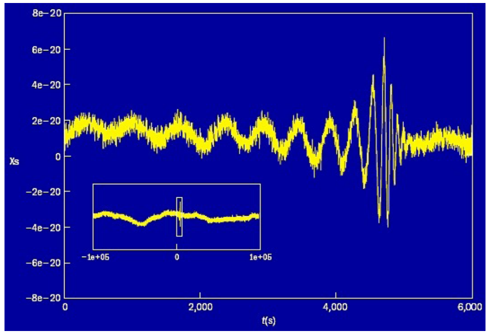
To take full advantage of the increasing sensitivity of GW detectors:

- need increasingly accurate source models and templates
- need significant further advances in source modeling techniques.

Accurate modeling of black hole binaries



- Group members played a crucial role in developing numerical models of the coalescensce of relativistic binaries in GR,
  - leading to a wealth of astrophysical relevant information, (recoil velocities after merger, final spins, final mass)
  - as well as modeling their GW emission to construct waveforms



- We use several million CPU hours per year through allocations at BSC and CESGA in Spain, LRZ Munich, the Vienna Scientific Cluster, DEISA Extreme Computing Initiative, the TeraGrid (USA),…
- Husa is the PI of a collaboration involving 20 scientists from UIB, Cardiff, Jena, Vienna, CalTech, and AEI.
- In the last call for computing time by PRACE, the European Consortium of Supercomputer centers, the group has been granted 37 million cpu hours in SUPERMUC, the 2nd most powerful supercomputer in Europe at present and 16.7 million hours in the previous call.

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Interface NR - DA - AR

Generate “complete” BBH waveforms,

e.g., hybrid waveforms, constructed by matching PN and NR

Propose analytical template families which are very close to the “complete” BBH waveforms.
Explicitly parametrized in terms of the physical parameters of the system

Parameter estimation using the “complete” BBH waveforms

Inject numerical and/or hybrid waveforms into LIGO/VIRGO data.

Test of search pipelines

The Numerical INJection Analysis (NINJA) Project

- Collaboration between simulators and searchers
  - Simulate a population of binary black hole signals from contributed waveforms
  - Testing GW search sensitivity to BH waveforms
  - Both detection and parameter estimation
  - Make use of real detector data
  - www.ninja-project.org

The NR-AR Project

- Collaboration between numerical and analytical relativity
  - Produce accurate NR waveforms covering large fraction of parameter space, including BBH with generic spins
  - Develop and calibrate analytical families of templates: Phenom, EOB, PN- Phenom…

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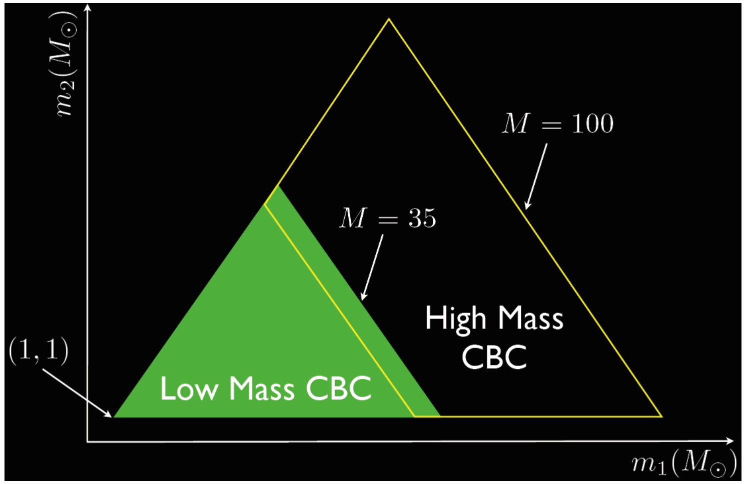
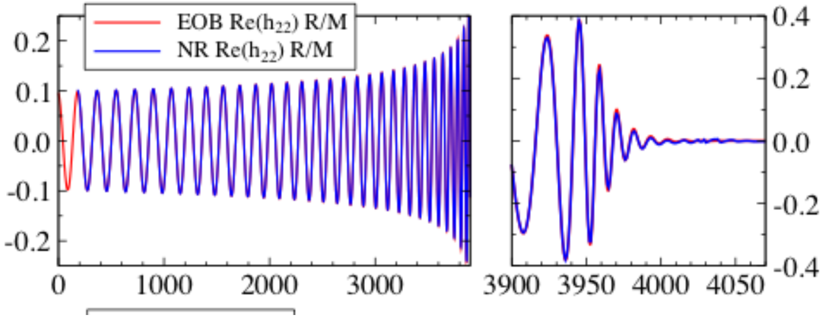
CBC searches



We have several analytic families of waveform covering inspiral, merger, ringdown

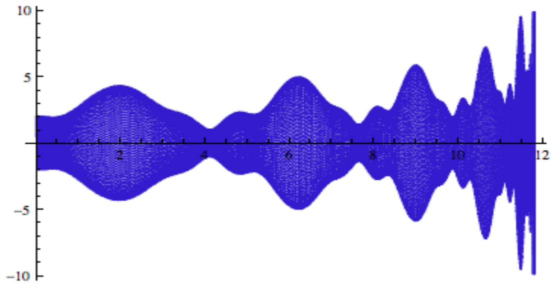


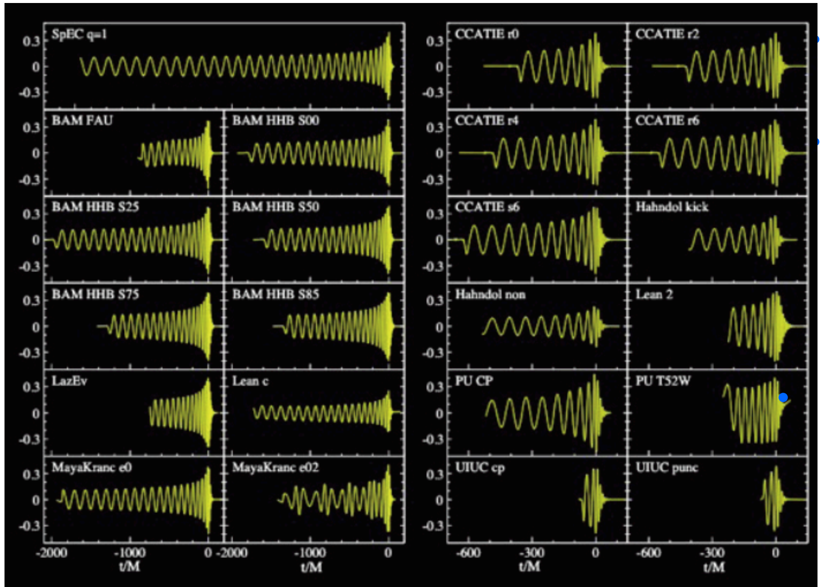
- Low mass search
  - Using non-spining and spining waveforms

Spin adds 6 extra dimensions to the parameter space, and precession of the orbital plane

First efforts focused on non-precessing waveforms

- Spins aligned with orbital angular momentum
- Analytic models of these waveforms are available





Aylott et. al. 2009 Class. Quantum Grav. 26 165008

High mass search

- Major progress in numerical and analytical relativity has allowed us to use "complete" inspiral merger ringdown templates and extend search reach
- Search underway using these templates

Binary Inspiral Searches

Latest published results from LIGO+Virgo

[Abadie et al., PRD 85, 082002 (2012)]

Search using matched filtering

No inspiral signals detected

90% confidence limits on coalescence rates:

For binary neutron stars:

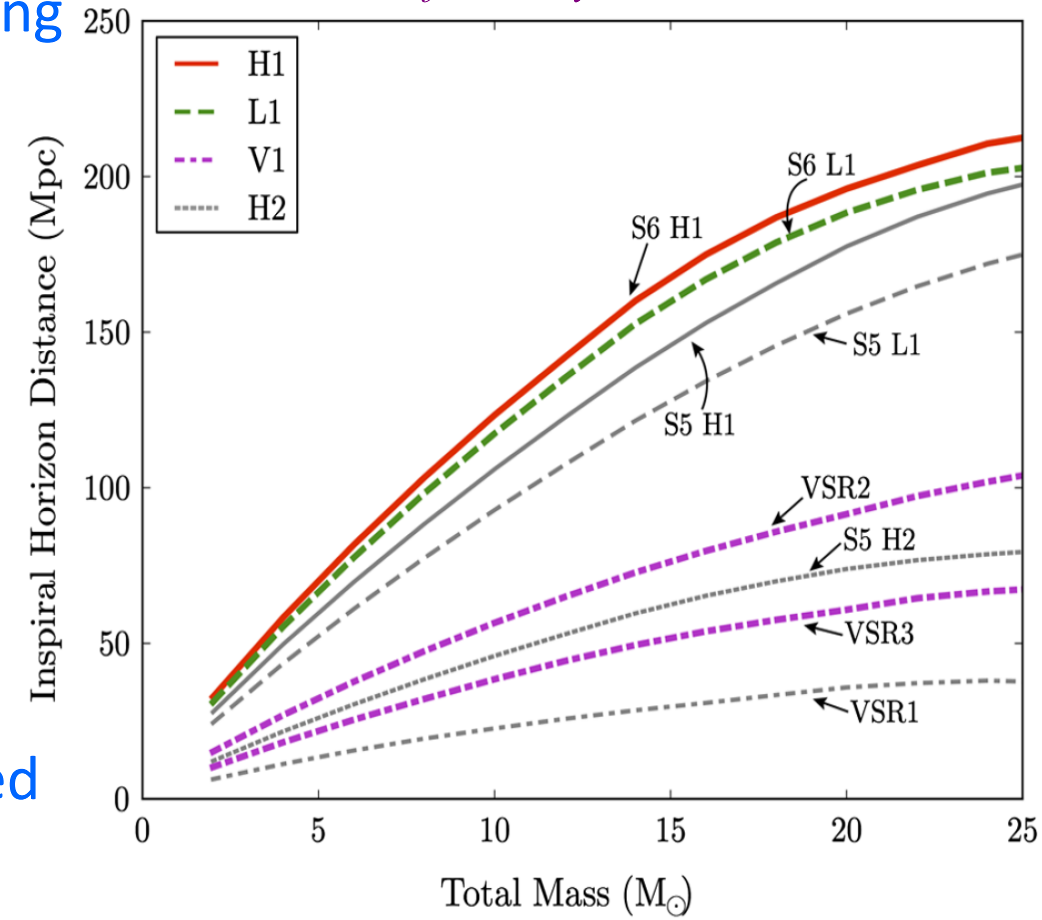
$< 1.3 \times 10^{-4}$

per Mpc^3 per year

For binary black holes with $5+5\ M_{\odot}$: $< 6.4 \times 10^{-6}$

Not yet confronting expected range of merger rates

How far away could we hear?



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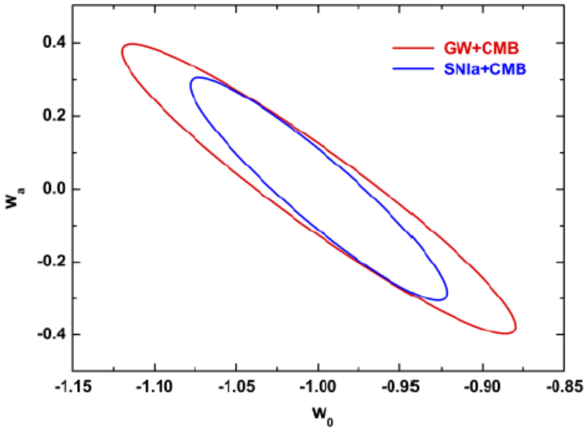
Cosmology with binary inspirals



- We could exploit distance-redshift relationship to probe dynamics and contents of the Universe.
- Binary neutron stars and black holes are standard sirens (Schutz '86):
  - Distance can be inferred from the gravitational wave signal itself, if (some) information about sky position, orientation
  - No need for a cosmic distance ladder!
  - Systematics will be known
- Need to extract redshift:
  - Use electromagnetic counterparts, e.g. Gamma ray bursts[Nissanke et al., arXiv:0904.1017]
  - Assuming a mass distribution [Taylor, Gair, Mandel, arXiv: 1108.5161]
  - Use galaxy clustering [Del Pozzo, arXiv:1108.1317]
  - If EOS of neutron stars are known, get redshift from the GW waveform through effect of tidal deformations on orbital motion [Messenger & Read, arXiv:1107.5725]

$w = p_{DE}/\rho_{DE}$ EOS of dark energy could be time dependent: $w(a) \simeq w_0 + w_a (1 - a) + ...$

With ET: comparable accuracies to conventional measurements, but completely independent systematics (*no cosmic distance ladder!*) [Sathyaprakash, Schutz, VDB, arXiv: 0904.4151], [Zhao, VDB, Baskaran, Li, arXiv:1009.0206]

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Target Signals for GW Burst Searches

Catastrophic events involving solar-mass compact objects can produce transient "bursts" of gravitational radiation in the LIGO frequency band. Precise nature of gravitational-wave burst (GWB) signals typically unknown or poorly modeled.

Modeled burst search

Targets:

- Black hole ringdown
- Neutron star ringdown
- Cosmic string cusp
- Parabolic encounter

Use matched filtering

Issues generally similar to binary inspiral searches

Generic burst search

Targets:

- Binary black hole merger
- Core collapse supernova
- Signals deviating from model expectations
- Other unexpected or unmodeled sources

Use robust detection methods that do not rely on having a model of the signal

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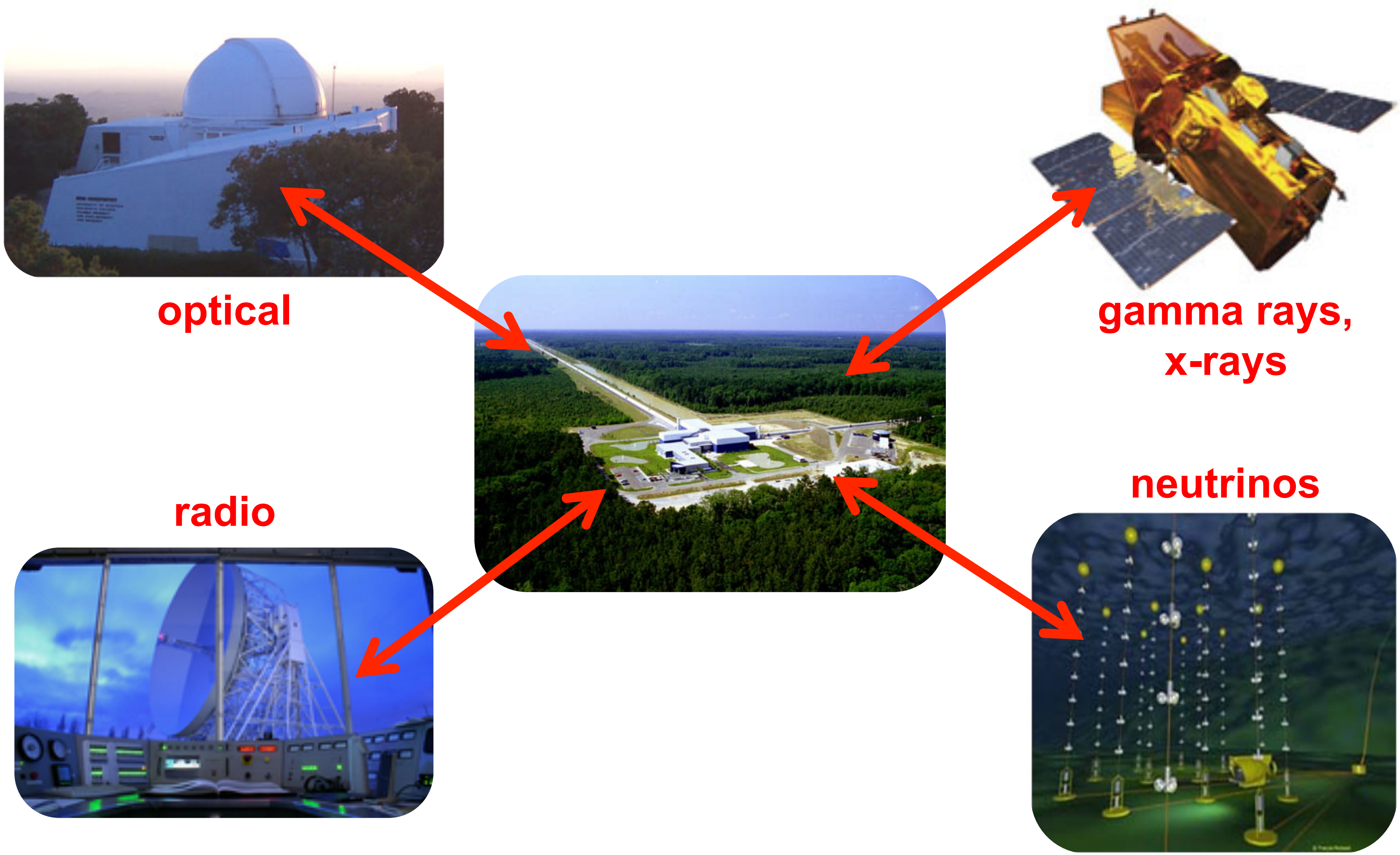
LIGO-Virgo is fully engaged in multi-messenger astrophysics



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The flow of information

- EM triggers ⇒ GW detector analysis
  - From, eg, space-based X-ray and gamma ray telescopes
  - Knowing precise time and sky location of event reduces noise contamination in GW detector network; searches can go deeper
- GW detections ⇒ Pointing EM telescopes
  - To catch prompt emission, must point quickly
  - requires development of low-latency GW detection and sky localization pipelines, protocols to pass info, telescope scanning strategies and coordination

- GW detections + all-sky telescopes
  - Eg, neutrino detectors, optical transient surveys, wide-field radio transient surveys
  - Can be done offline, using data “in the can” – “data mining”
- Prototypes for all of these paths have been developed; they need to be flawless and ready in 2015!

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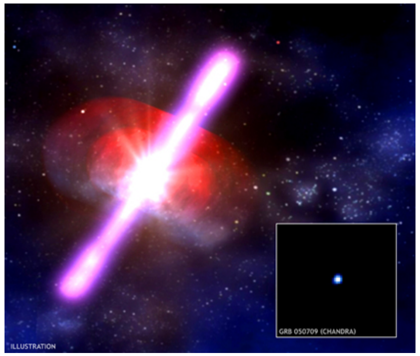
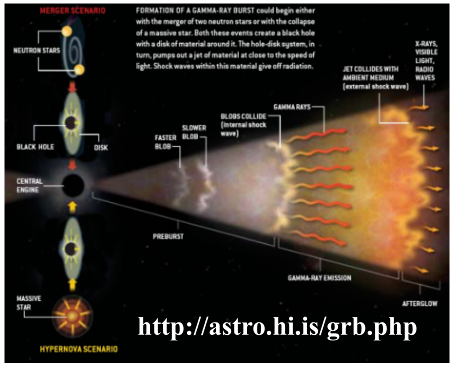
Astrophysics with joint GW – EM observations

- External triggers: Short-hard GRBs:
  - Confirm (or rule out) merger progenitor
  - Study progenitor systems, including orientation and beaming
  - Relate GW and EM energy release
  - Relate merger parameters to hosts (metallicity, SFR, …)





- Follow-ups: detect optical afterglow, host galaxy, redshift…
  - Low latency pipeline, sky localization
- CBC mergers as cosmological standard sirens.
  - Independent, self-calibrating measurement of Hubble constant
  - a(z), dark energy EoS

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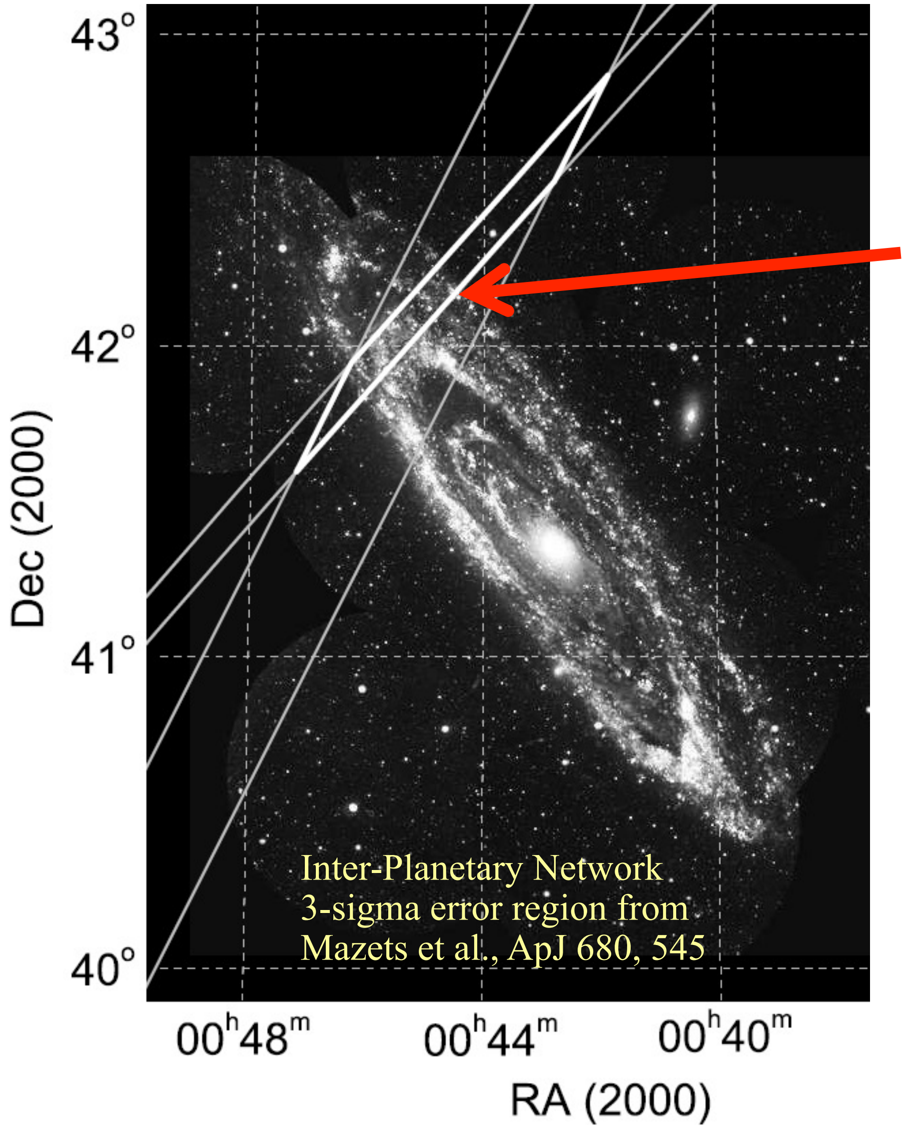
Example: GRB 070201



Short, hard gamma-ray burst

Leading model for short GRBs: merger involving a neutron star

Consistent with being in M31

Both LIGO Hanford detectors were operating

Searched for inspiral & burst signals

No plausible GW signal found → very unlikely to be a merger in M31

Abbott et al., ApJ 681, 1419 (2008)

Consistent with SGR giant flare in M31

Similar analysis done for GRB 051103

Abadie et al., ApJ 755, 2 (2012)

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Systematic GRB–GW Searches

Most recently, analyzed 154 GRBs reported via GCN during 2009-10 while 2 or 3 LIGO/Virgo detectors were taking good data

GW burst search

Done for 150 GRBs

Coherent burst search allowing for arbitrary GW waveform

Assumed circular polarization since rotational systems are efficient GW emitters and the rays are believed to be beamed

Compact binary coalescence search

Done for 26 short or “short-like” GRBs

Coherent matched filtering search for inspiral waveforms from a binary with at least one neutron star

Abadie et al., ApJ 760, 12 (2012)

Earlier science runs: *Abbott et al., PRD 77, 062004 ; ApJ 715, 1438 ; ApJ 715, 1453*

Space and Time Windows

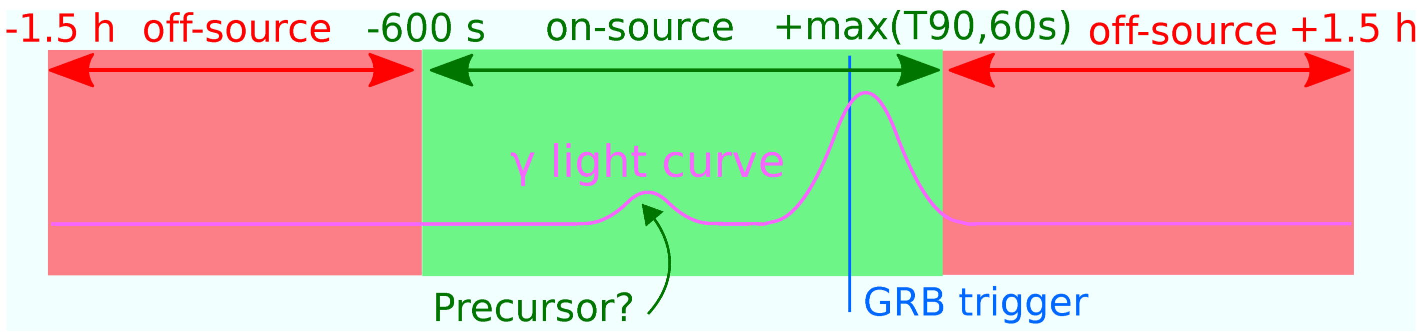
Searched over sky region reported for the GRB

GRBs reported by *Swift* and other satellites are generally well localized

GRBs detected by Fermi GBM have large error regions

Time window allowed for relative time offset from GRB trigger

Burst:

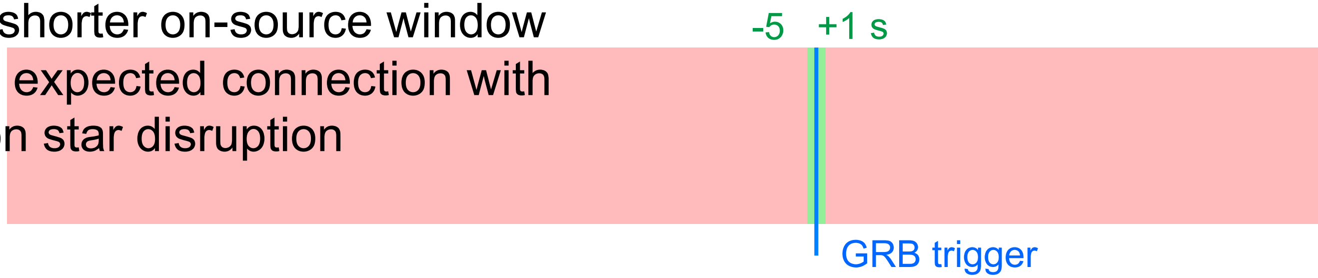


Generous "on-source" window allows for seen or unseen precursor

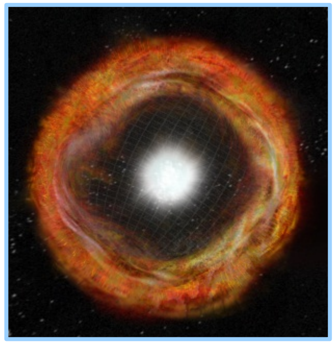
e.g. GRB 060124 precursor was 570 s early *[Romano et al. 2006]*

CBC:

Much shorter on-source window due to expected connection with neutron star disruption



Goal: Probe Supernova Dynamics



Bill Saxton, NRAO/AUI/NSF

Core-Collapse Supernovae (type Ib/c and type II) occur frequently and liberate up to

~10^{53} erg

~1% as EM radiation

- Optical
- Radio
- X-ray
- Gamma ray

~99% as neutrinos

- Low-energy
- High-energy??

??? as gravitational waves

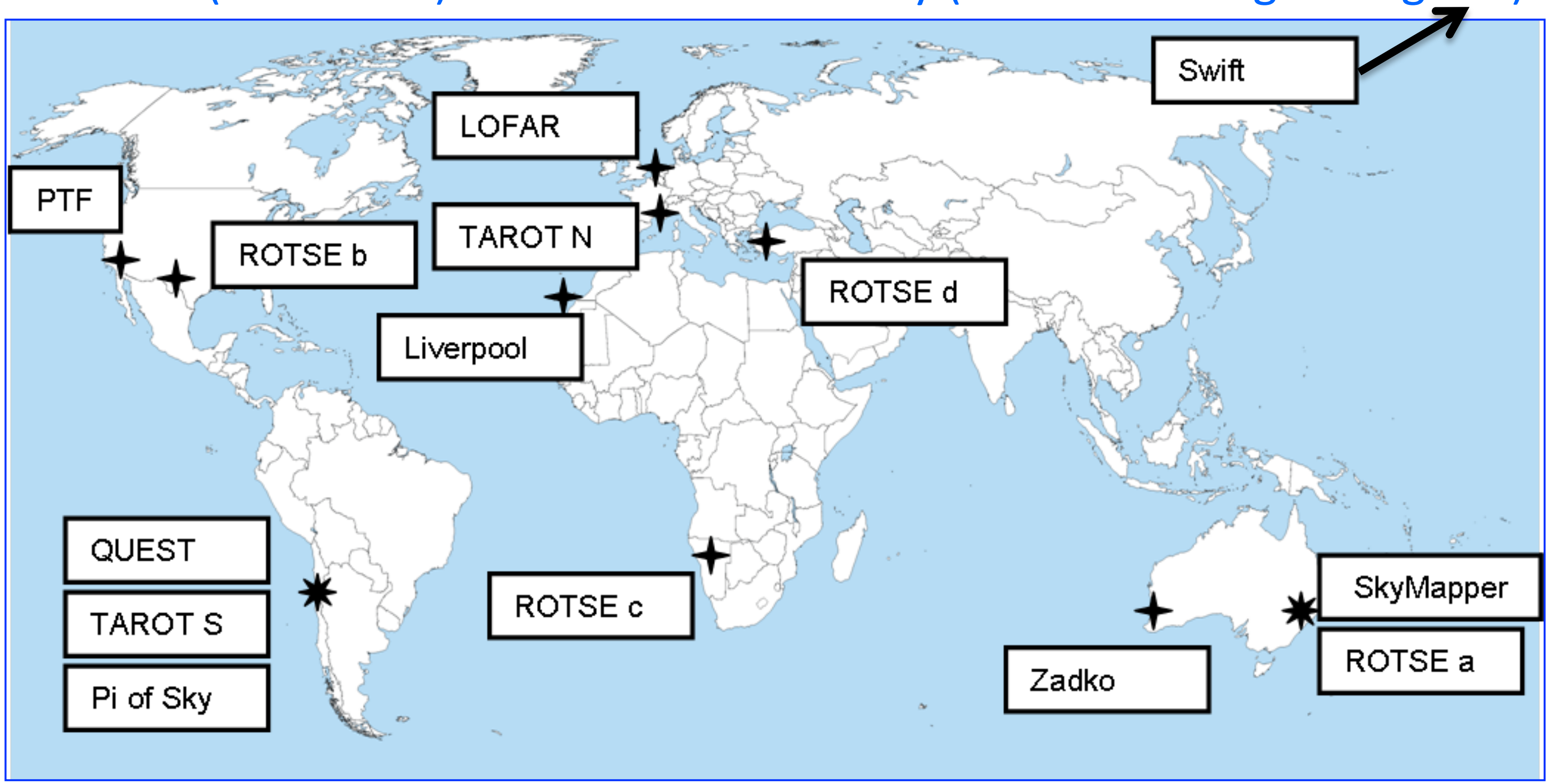
- Depends on mass flows in and around the core

→ Detecting (or not detecting) a GW signal may tell us what is driving supernova explosions

Telescope Network

GW detections ⇒ Pointing EM telescopes

- LIGO and Virgo partnered with rapid-pointing telescopes for observation run in summer and fall of 2010.
- Total of 14 triggers sent out (FAR < ¼ d), 8 followed up.
- Image analysis with participation by LIGO and Virgo scientists.
- Also Swift (one event) and LOFAR radio array (commissioning during run).



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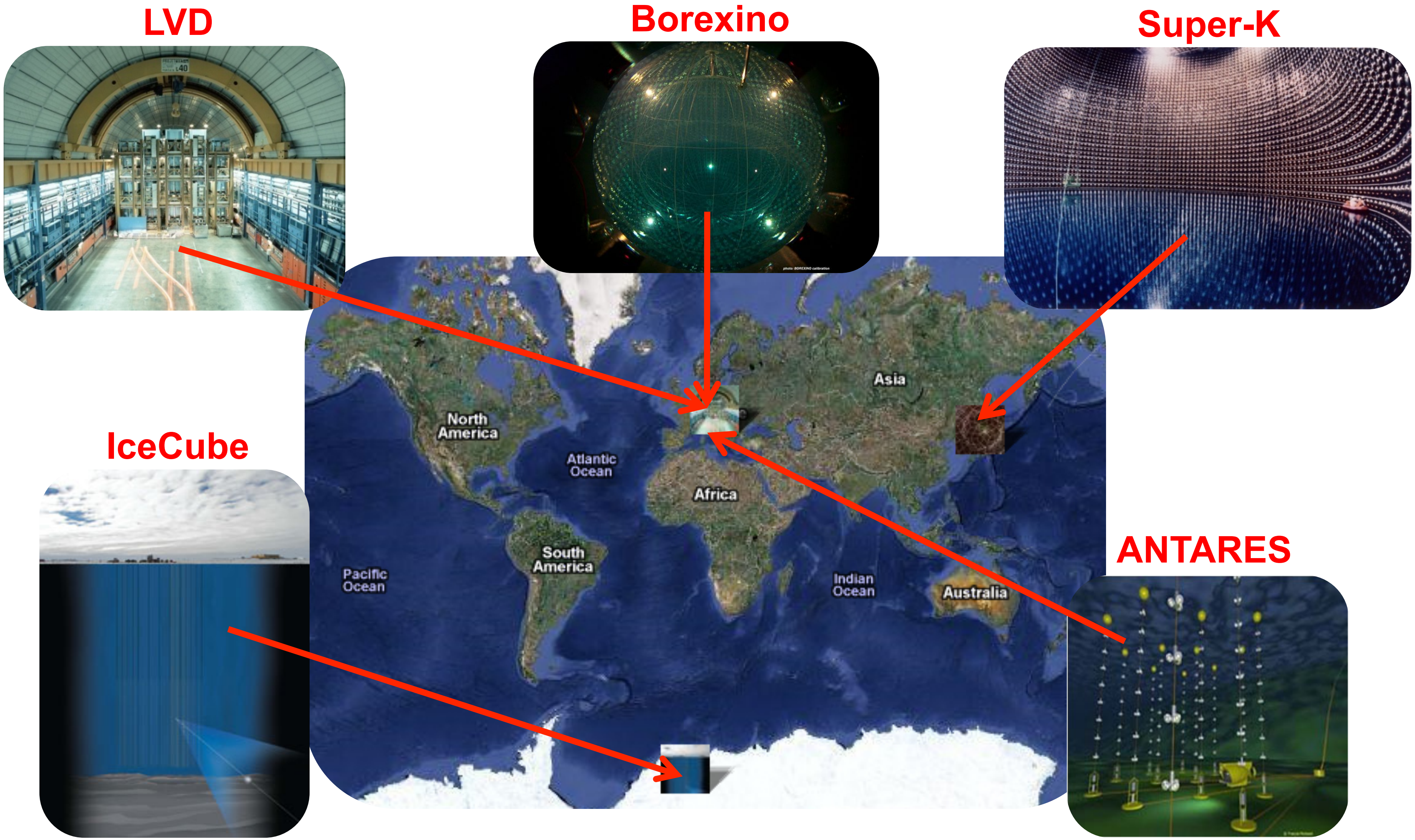
Gravitational waves and neutrinos

(nascent collaborations)



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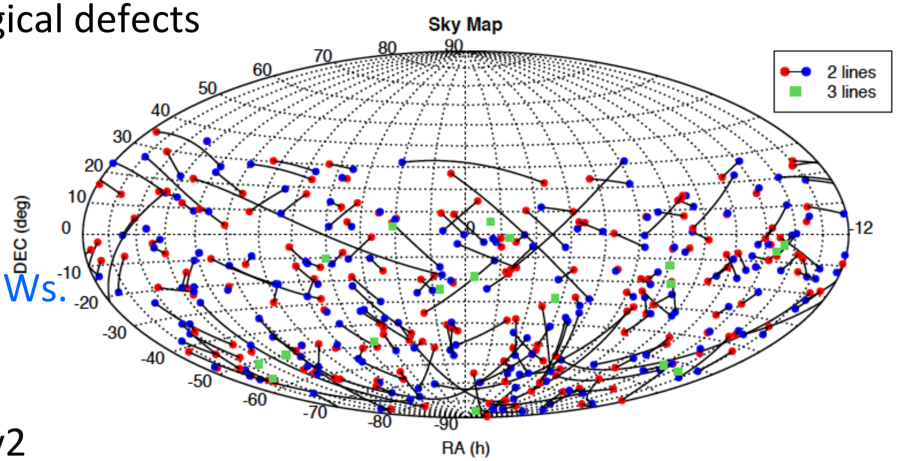
A First Search for coincident GWs and HENs using LIGO, Virgo and ANTARES data from 2007

Several known astrophysical sources are expected to produce both GWs and HENs:

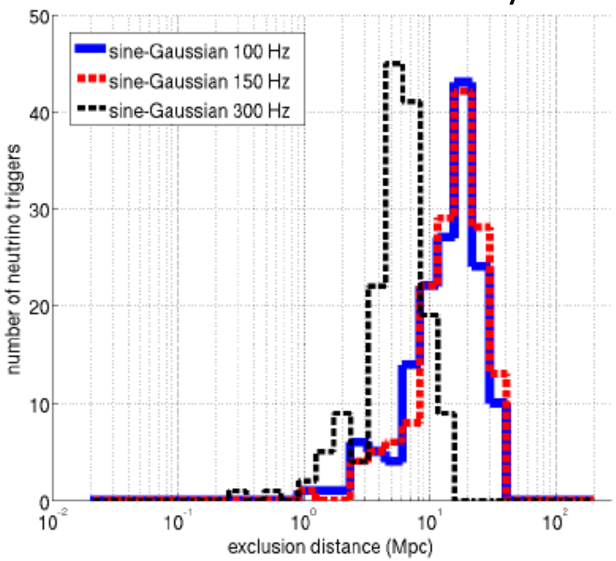
- Plausible galactic sources of joint emission are Soft Gamma Repeaters (SGRs)
- One of the most interesting extragalactic sources are gamma-ray bursts (GRBs)
- Other sources include: cosmic strings and topological defects

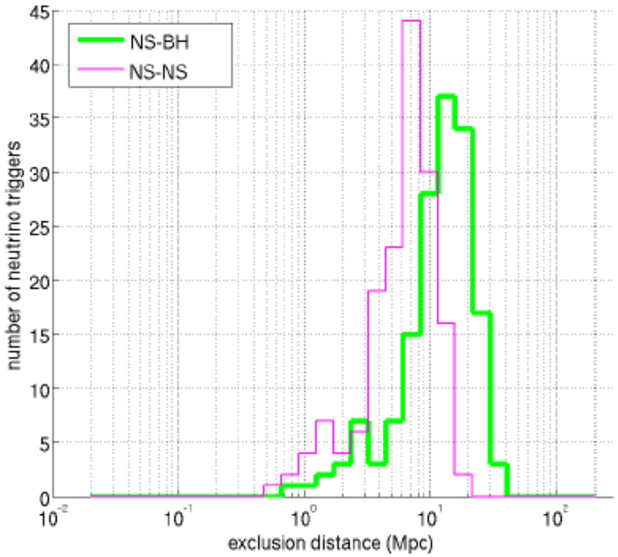
ANTARES (operating with 5 active lines) selected 216 potential neutrino events. LIGO-Virgo exploited the knowledge of the time and possible directions of the neutrino event to improve the search sensitivity for GWs.

No coincidences were found.



17 May 2012 arXiv:1205.3018v2





That means that if any any of the neutrino candidates came from the astrophysical sources considered, they must have been too far away for the gravitational waves to be detectable.

Summary

- It is an exciting time to be searching for gravitational waves
    - No detections so far…
    - …but the data allow us to start probing regions of the parameter space that are astrophysically and cosmologically relevant
- LIGO and Virgo are fully engaged in multi-messenger astrophysics.
- Advanced detector era is just around the corner.
- Detections before end of decade are virtually guaranteed
- Future observatories will be able to realize precision gravitational wave astronomy.

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Follow us: http://grg.uib.es/

http://www.facebook.com/uibgrg , @UIBGRG

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Outreach: Social Networks

We have Facebook & Twitter accounts and we have found out they are a very good tool to connect with:

- science journalists
- science bloggers
- students
- research groups
- scientific associations
- people in general

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Outreach: Science Fairs & Activities

- We attended a Science Fair
- We organized exhibits, talks and video games stand for the Science Week
- Other activities:
  - public & high school talks
  - Translating & producing new outreach resources
  - writing news and texts for the press
  - radio interviews
  - ...

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REDongra

REDONGRA is part of the FPA (National Program for Particle Physics) and it has financial support from the Ministry of Economy and Competitiveness.

REDONGRA is a Spanish Network of Research Groups working on gravitational waves.

Objectives :

- Coordinate the different Spanish research groups that currently work on gravitational waves.
- Provide a forum for interaction for groups from different scientific fields involved: High Energy Physics, Astrophysics, General Relativity and Advanced Instrumentation Engineering.
- Provide a platform for dissemination of research results, both within and outside the scientific community.