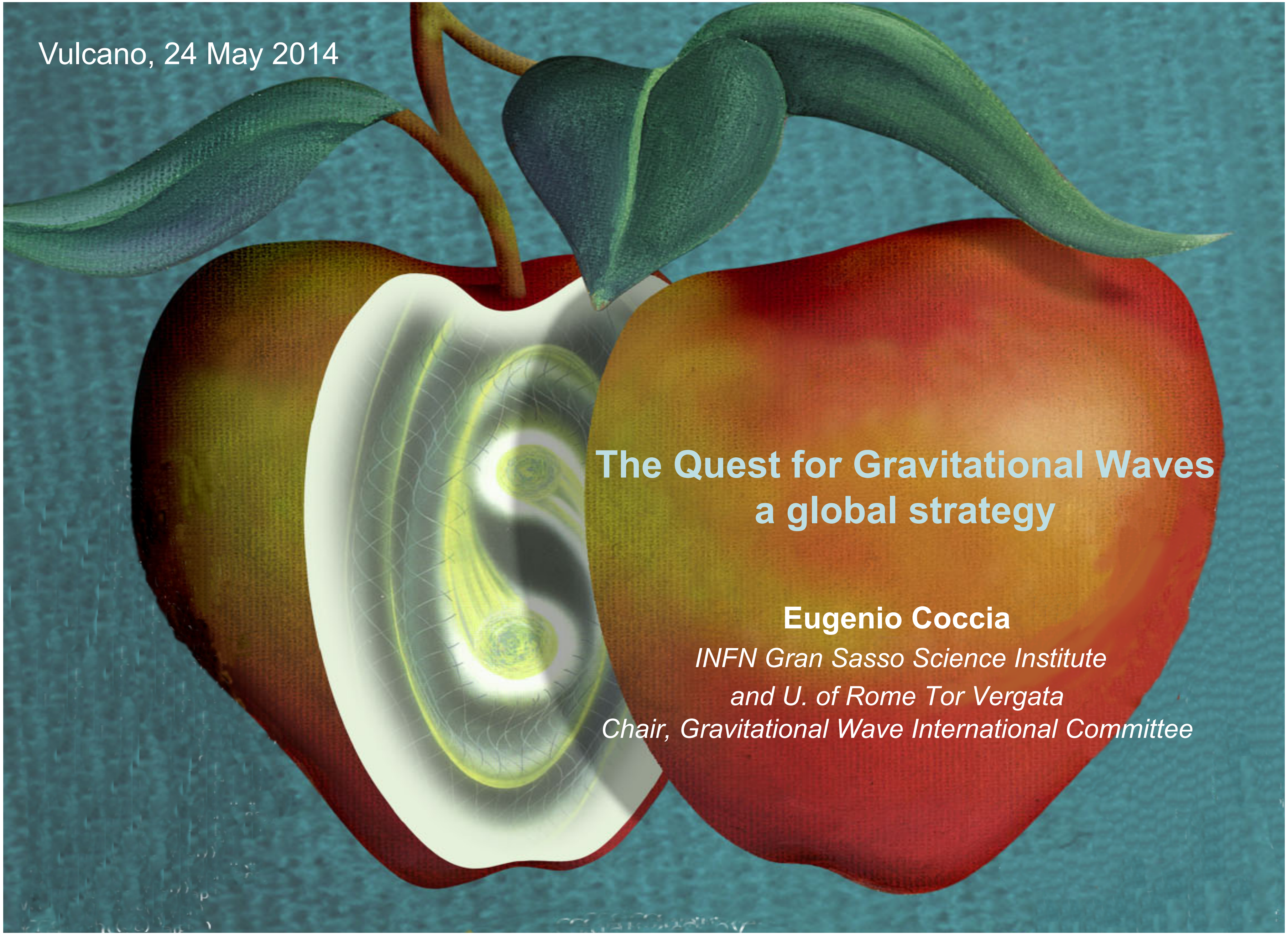
Vulcano, 24 May 2014



The Quest for Gravitational Waves
a global strategy

Eugenio Coccia

INFN Gran Sasso Science Institute

and U. of Rome Tor Vergata

Chair, Gravitational Wave International Committee

THE QUEST FOR GW: OBJECTIVES

FIRST DETECTION

test Einstein prediction

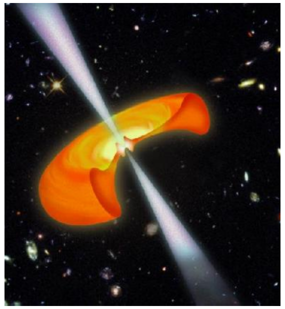
$$\mathbf{G} = \frac{8\pi G}{c^4}\mathbf{T}$$

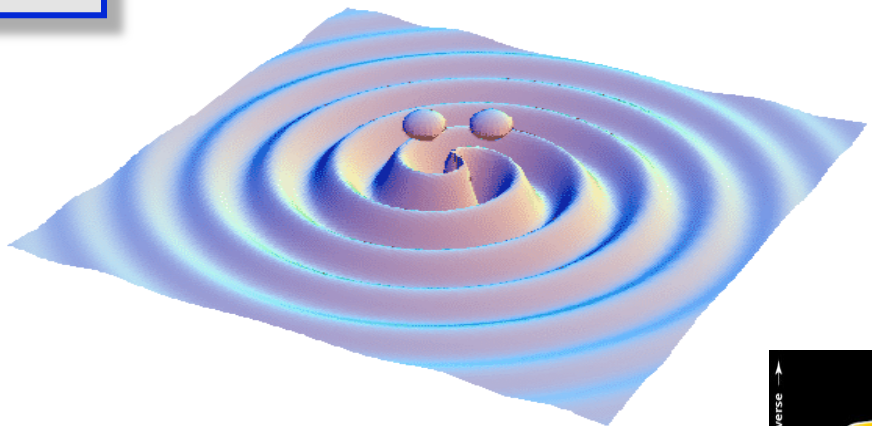
ASTRONOMY & ASTROPHYSICS

look beyond the visible

understand BH, NS and supernovae

understand GRB

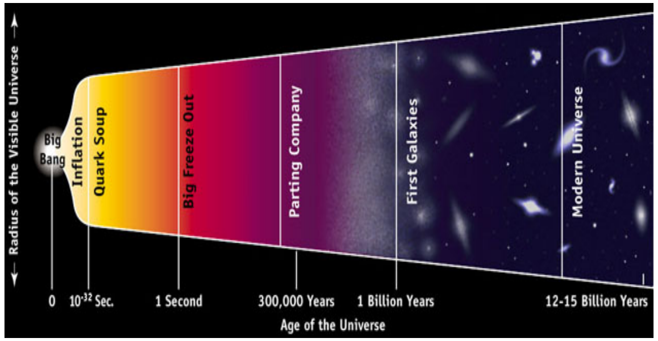




COSMOLOGY

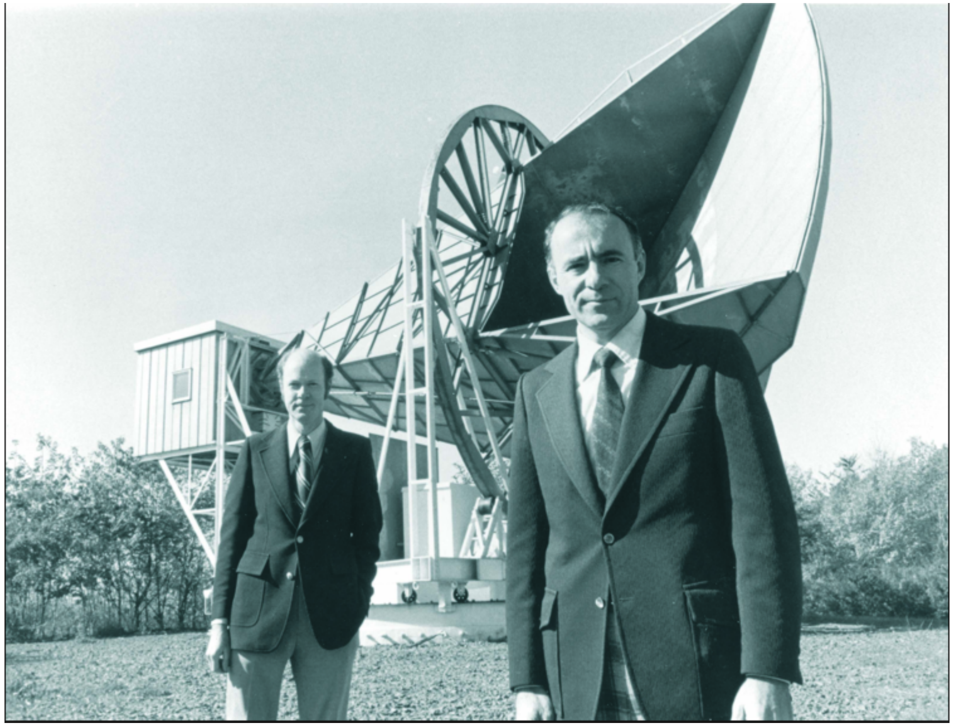
the Planck time:

look as back in time as theorist can conceive



During the sixties Amaldi tried to push the Italian physicists in the direction of new researches in the birth phase:

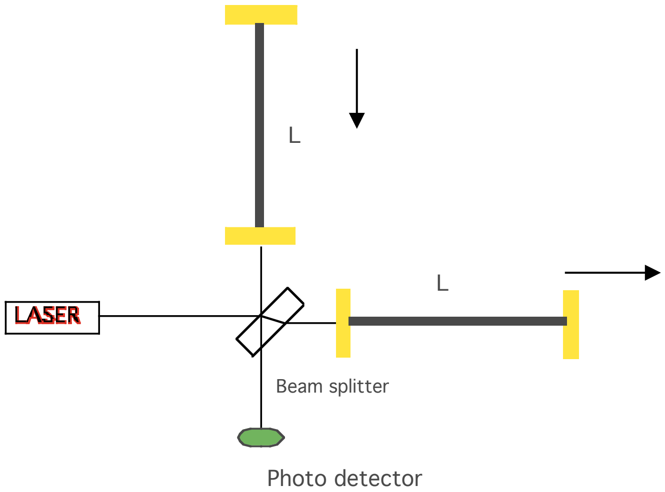
Infrared Background radiation and Gravitational Waves (after Penzias & Wilson and Weber’s experiments).

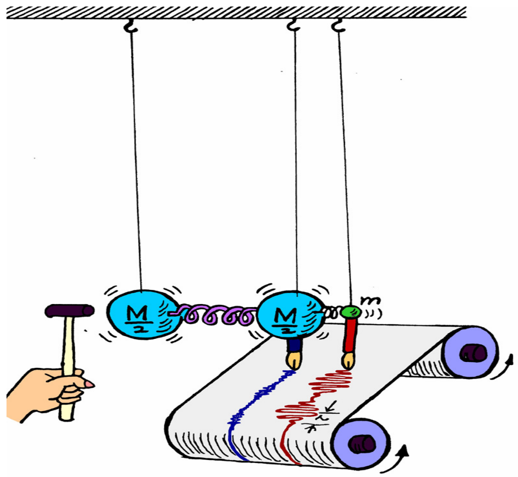


Joseph Weber 1919-2000

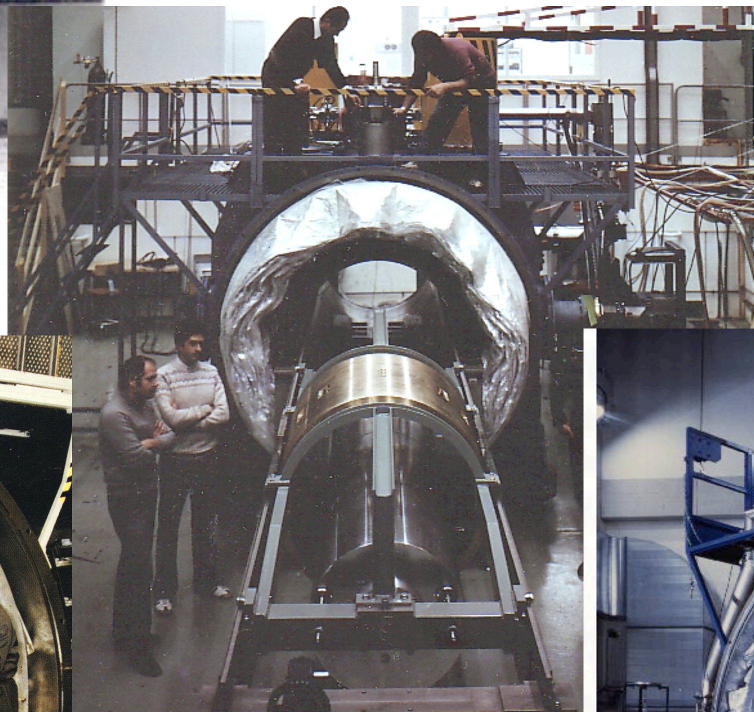
$$h = \frac{\Delta L}{L}$$

$$\ddot{x}(t) + \tau^{-1}\dot{x}(t) + \omega_0^2 x(t) = \frac{1}{2}\ddot{h}(t)$$



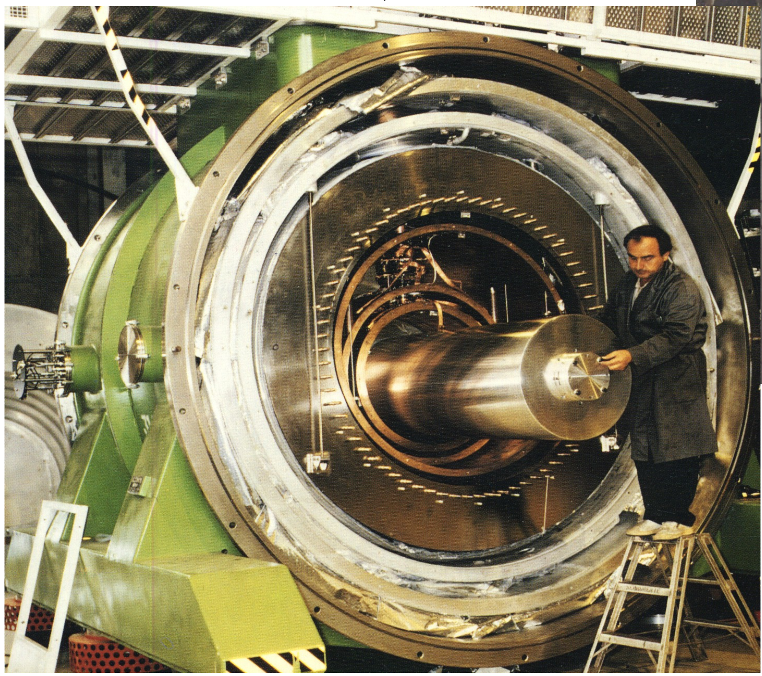


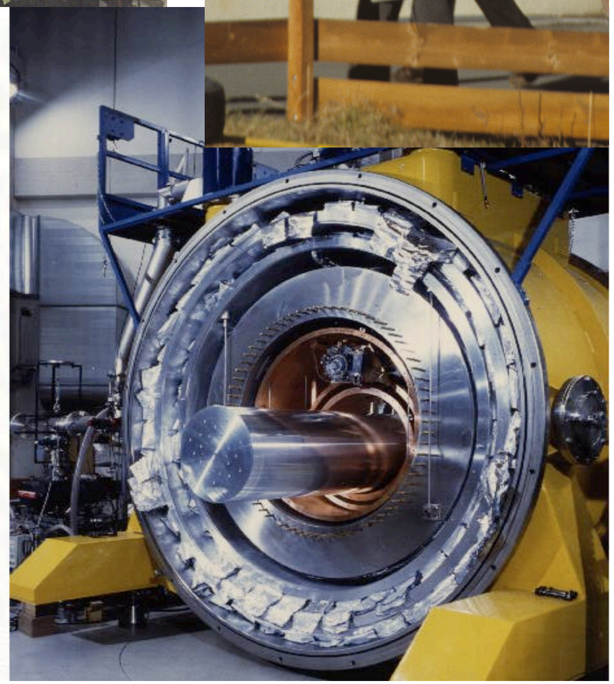
Guido Pizzella was Amaldi’s assistant and wanted to change its activity from space research (he worked with Van Allen in USA) to a more fundamental field. His decision was: Gravitational Waves (Francesco Melchiorri later choose the infrared background).



Explorer, CERN

Nautilus, LNF

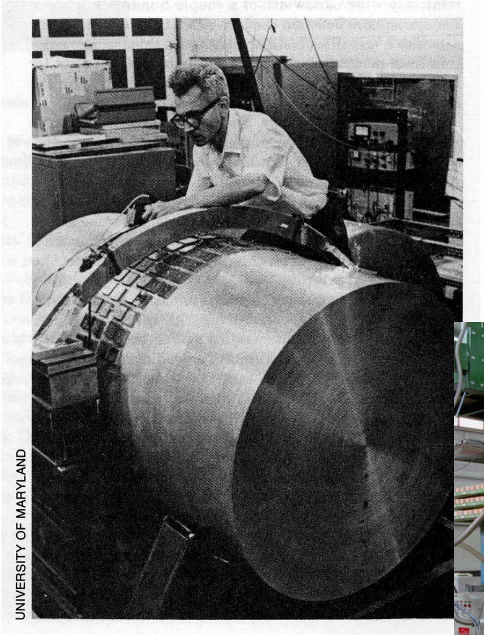




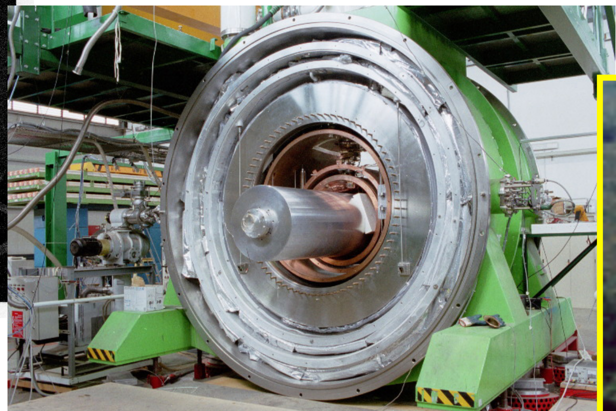
Auriga, LNL

Some perspective: 50 years of attempts at detection:

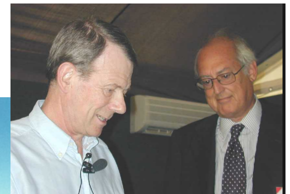
Since the pioneering work of Joseph Weber in the ‘60, the search for Gravitational Waves has never stopped, with an increasing effort of manpower and ingenuity:



60’: Joe Weber pioneering work



90’: Cryogenic Bars



1997: GWIC was formed

2000’ - : Large Interferometers

GWIC
Gravitational Wave International Committee

https://gwic.ligo.org/

Home
News
GWIC Roadmap
Thesis Prizes
Statements
Conferences
GWIC meetings
Reports to IUPAP
Simulation Programs
GWIC By-laws
Members
Related Links

The Gravitational Wave International Committee:

GWIC, the Gravitational Wave International Committee, was formed in 1997 to facilitate international collaboration and cooperation in the construction, operation and use of the major gravitational wave detection facilities world-wide. It is associated with the International Union of Pure and Applied Physics as its Working Group WG.11. Through this association, GWIC is connected with the International Society on General Relativity and Gravitation (IUPAP's Affiliated Commission AC.2), its Commission C19 (Astrophysics), and another Working Group, the AstroParticle Physics International Committee (APPIC).

GWIC's Goals:

- Promote international cooperation in all phases of construction and scientific exploitation of gravitational-wave detectors;
- Coordinate and support long-range planning for new instrument proposals, or proposals for instrument upgrades;
- Promote the development of gravitational-wave detection as an astronomical tool, exploiting especially the potential for multi-messenger astrophysics;
- Organize regular, world-inclusive meetings and workshops for the study of problems related to the development and exploitation of new or enhanced gravitational-wave detectors, and foster research and development of new technology;
- Represent the gravitational-wave detection community internationally, acting as its advocate;
- Provide a forum for project leaders to regularly meet, discuss, and jointly plan the operations and direction of their detectors and experimental gravitational-wave physics generally.

More about GWIC:

GWIC - Ten Years on (PDF) reprinted from Matters of Gravity (Fall 2007), the newsletter of the Topical Group on Gravitation of the American Physical Society.

News

- GWIC is now an IUPAP Working group (WG11)
- Progresses towards LIGO-India
- GWIC thesis Prize named after Stefano Braccini

Member Projects and Representatives

Chair

- Eugenio Coccia, University of Rome "Tor Vergata" (GWIC, 2000--, Chair 2011--)

ACIGA

- Peter Veitch, University of Adelaide, 2013--

AURIGA

- Massimo Cerdonio, University of Padua and INFN, 1997--

Einstein Telescope

- Michele Punturo, INFN-Perugia, 2009--

European Pulsar Timing Array (EPTA)

- Michael Kramer, Jodrell Bank Centre for Astrophysics (University of Manchester), 2009--

GEO 600

- Karsten Danzmann, Albert-Einstein-Institut fur Gravitationsphysik and University of Hannover, 1!
- Sheila Rowan, University of Glasgow, 2009--

IndIGO

- Bala Iyer, Raman Research Institute, 2011--

KAGRA (formerly LCGT)

- Yoshio Saito, KEK, 2013--
- Takaaki Kajita, Institute for Cosmic Ray Research, University of Tokyo, 2011--

LIGO, including the LSC

- Dave Reitze, California Institute of Technology and University of Florida, 2007--
- Gabriela Gonzalez, Louisiana State University, 2011--

LISA Community

- Neil Cornish, Montana State University, 2012--
- Bernard Schutz, Albert-Einstein-Institut fur Gravitationphysik, 2001--
- Robin Stebbins, Goddard Space Flight Center, 2001--
- Stefano Vitale, University of Trento, 2001--

NANOGrav

- Frederick Jenet, University of Texas, Brownsville, 2013--

NAUTILUS

- Eugenio Coccia, University of Rome "Tor Vergata", 2000--

Parkes Pulsar Timing Array (PPTA)

- George Hobbs, Australia Telescope National Facility (ATNF), 2013--

Spherical Acoustic Detectors

- Odylio D. Aguiar, Instituto Nacional de Pesquisas Espaciais, Brazil, 2011--

Virgo

- Francesco Fidecaro, University of Pisa, 2007--
- Jean-Yves Vinet, Observatoire de la Côte d'Azur, 2011--

Theory Community

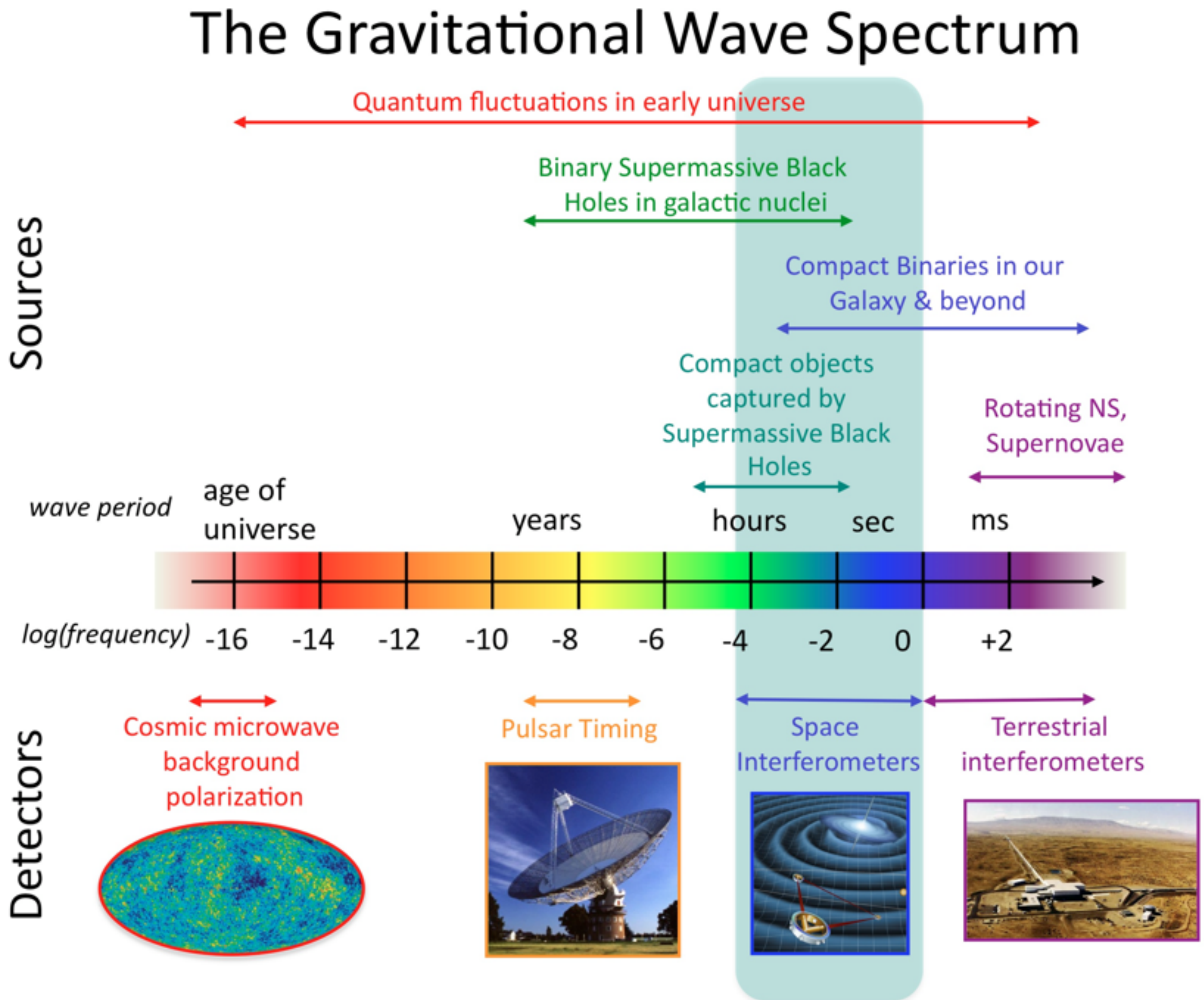
- Clifford Will, University of Florida, 2000--

IUPAP Affiliate Commission AC2 (International Commission on General Relativity and Gravitation)

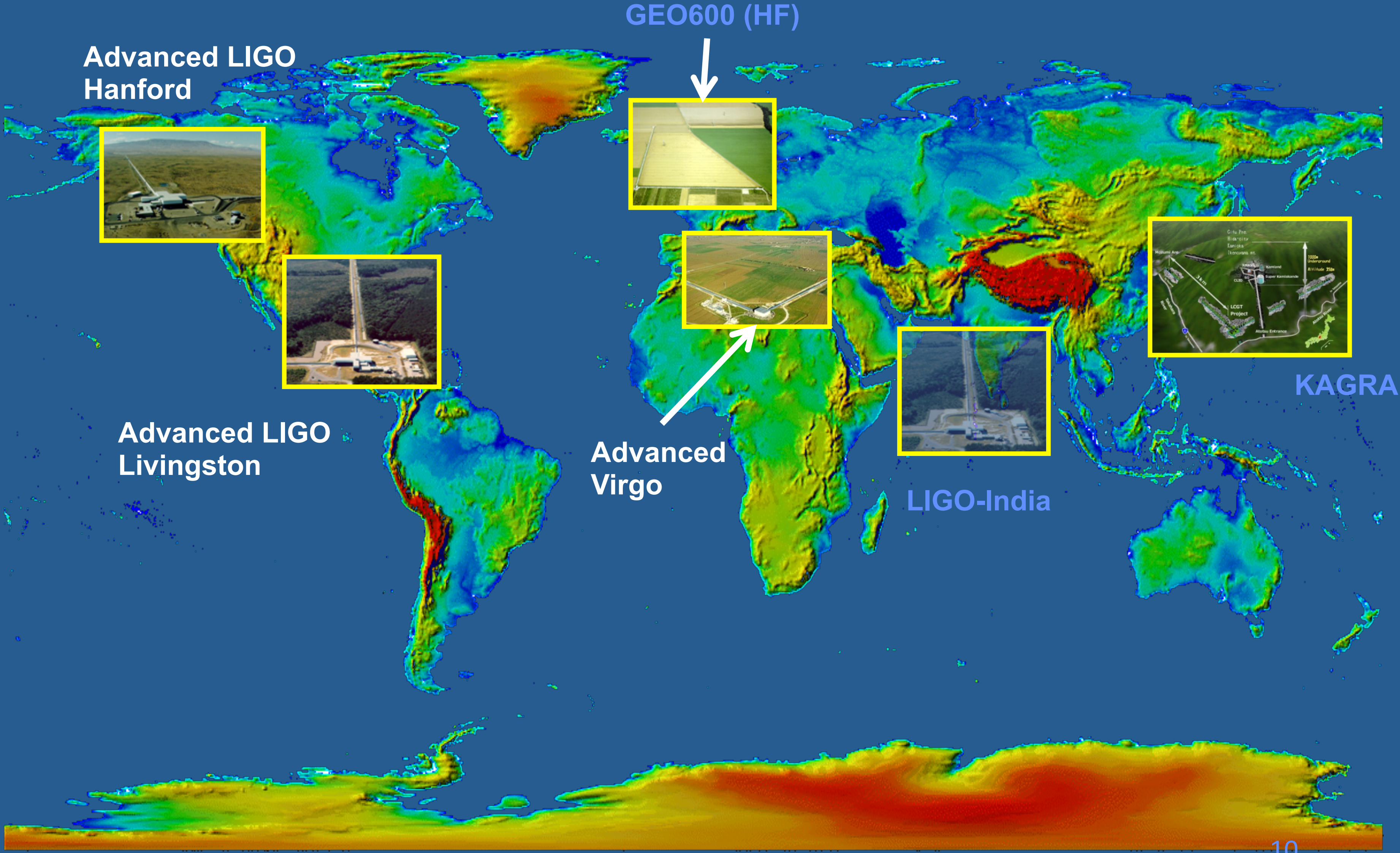
- Beverly Berger, 2013--

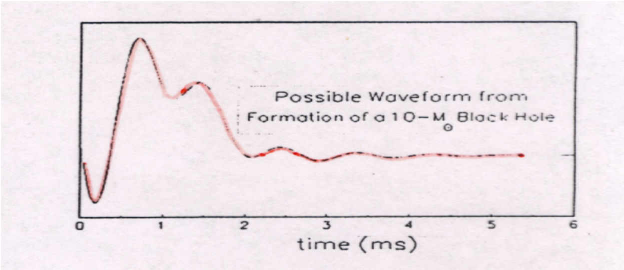
Executive Secretary

- Stan Whitcomb, California Institute of Technology, 2007--


The Gravitational Wave Spectrum
Sources
Quantum fluctuations in early universe
Binary Supermassive Black Holes in galactic nuclei
Compact Binaries in our Galaxy & beyond
Compact objects captured by Supermassive Black Holes
Rotating NS, Supernovae
wave period
age of universe
years
hours
sec
ms
log(frequency)
-16
-14
-12
-10
-8
-6
-4
-2
0
+2
Detectors
Cosmic microwave background polarization
Pulsar Timing
Space Interferometers
Terrestrial interferometers

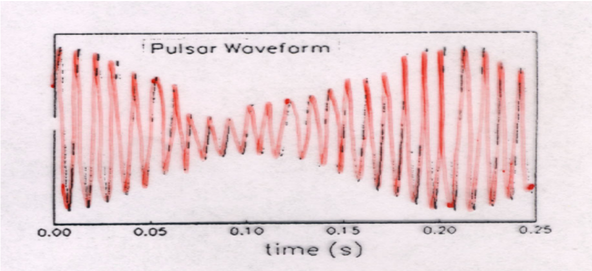
The Advanced GW Detector Network





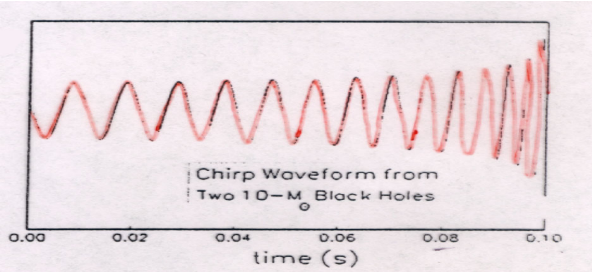
SUPERNOVAE.
If the collapse core is non-symmetrical, the event can give off considerable radiation in a millisecond timescale.

Information
Inner detailed dynamics of supernova
See NS and BH being formed
Nuclear physics at high density



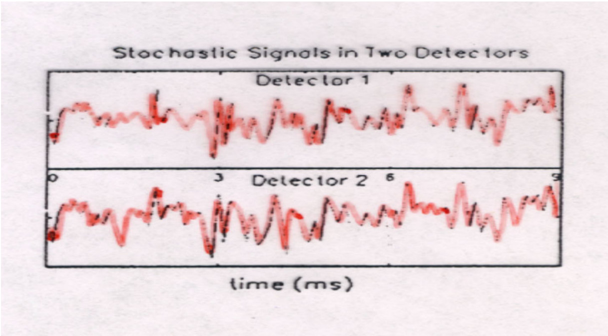
SPINNING NEUTRON STARS.
Pulsars are rapidly spinning neutron stars. If they have an irregular shape, they give off a signal at constant frequency (prec./Dpl.)

Information
Neutron star locations near the Earth
Neutron star Physics
Pulsar evolution



COALESCING BINARIES.
Two compact objects (NS or BH) spiraling together from a binary orbit give a chirp signal, whose shape identifies the masses and the distance

Information
Masses of the objects
BH identification
Distance to the system
Hubble constant
Test of strong-field general relativity



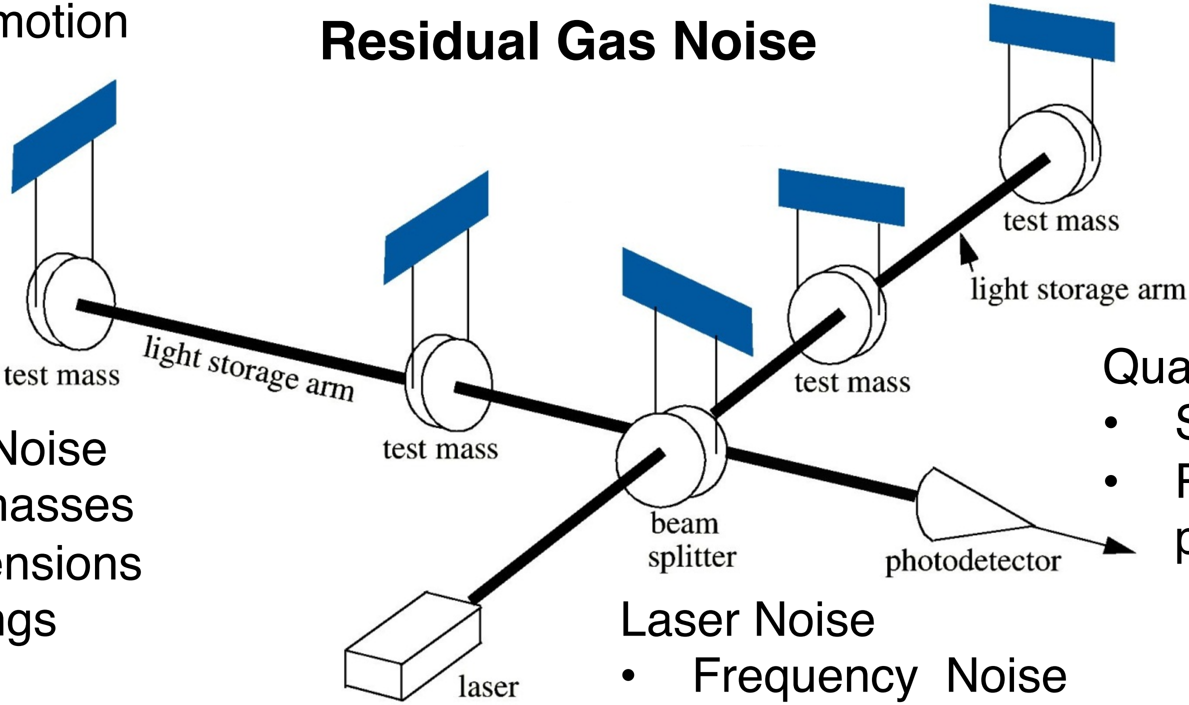
STOCHASTIC BACKGROUND.
Random background, relic of the early universe and depending on unknown particle physics. It will look like noise in any one detector, but two detectors will be correlated.

Information
Confirmation of Big Bang, and inflation
Unique probe to the Planck epoch
Existence of cosmic strings

Limits to Sensitivity

Vibrational Noise
- Ground motion
- Acoustic

Residual Gas Noise

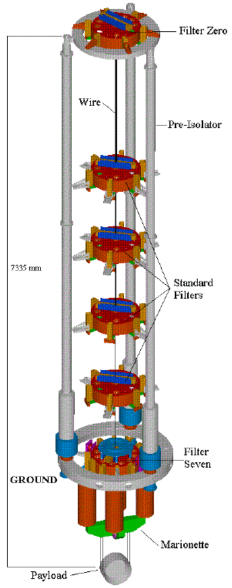


Thermal Noise
- Test masses
- Suspensions
- Coatings

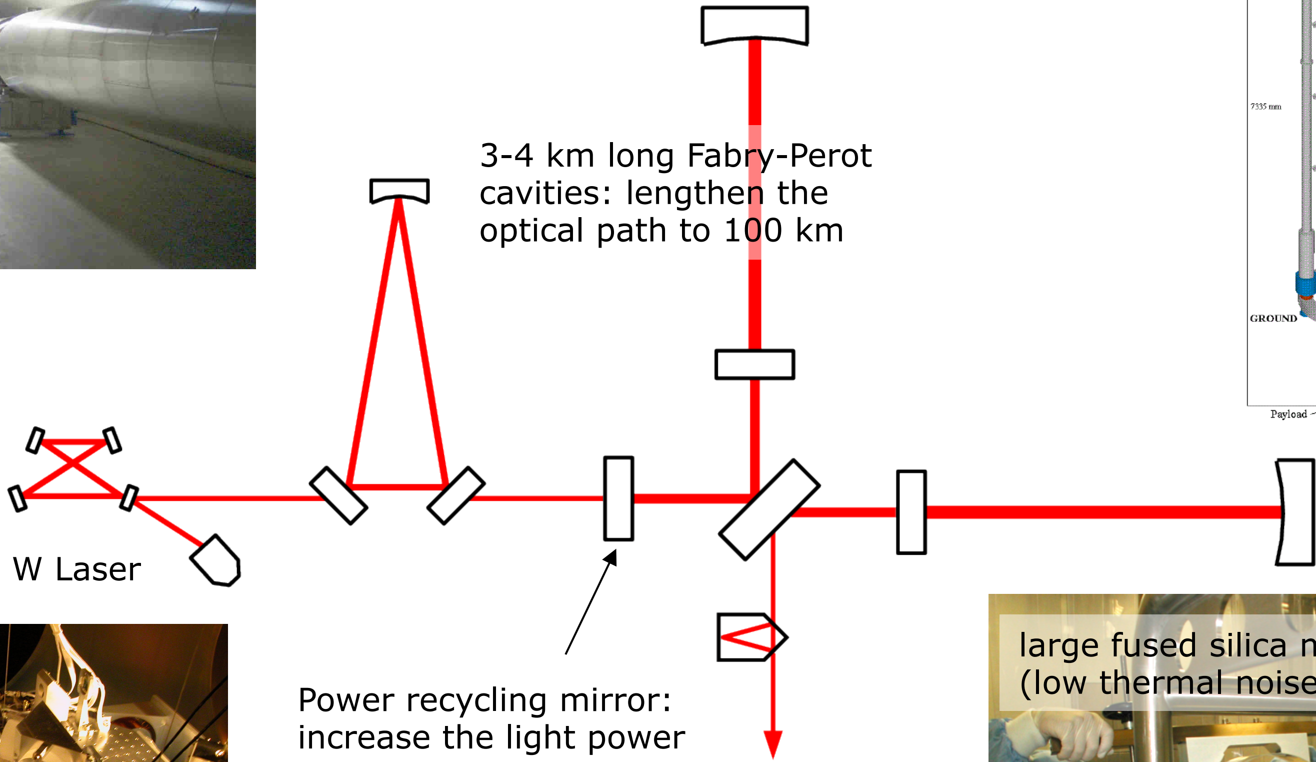
Quantum Noise
- Shot Noise
- Radiation pressure Noise

Laser Noise
- Frequency Noise
- Intensity Noise

A real detector scheme



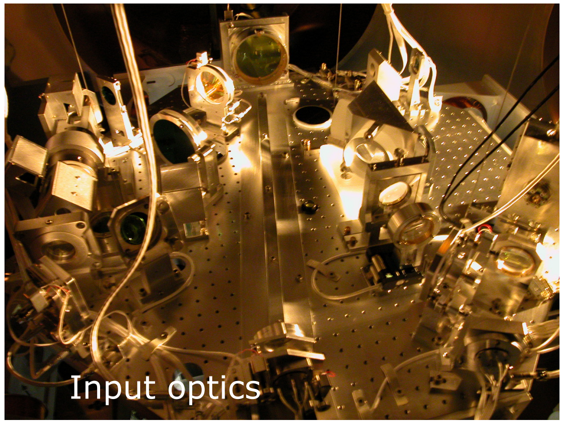
Isolation from ground vibrations

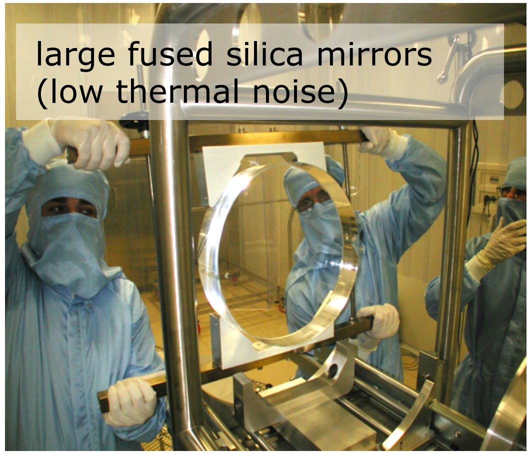


3-4 km long Fabry-Perot cavities: lengthen the optical path to 100 km

10-20 W Laser

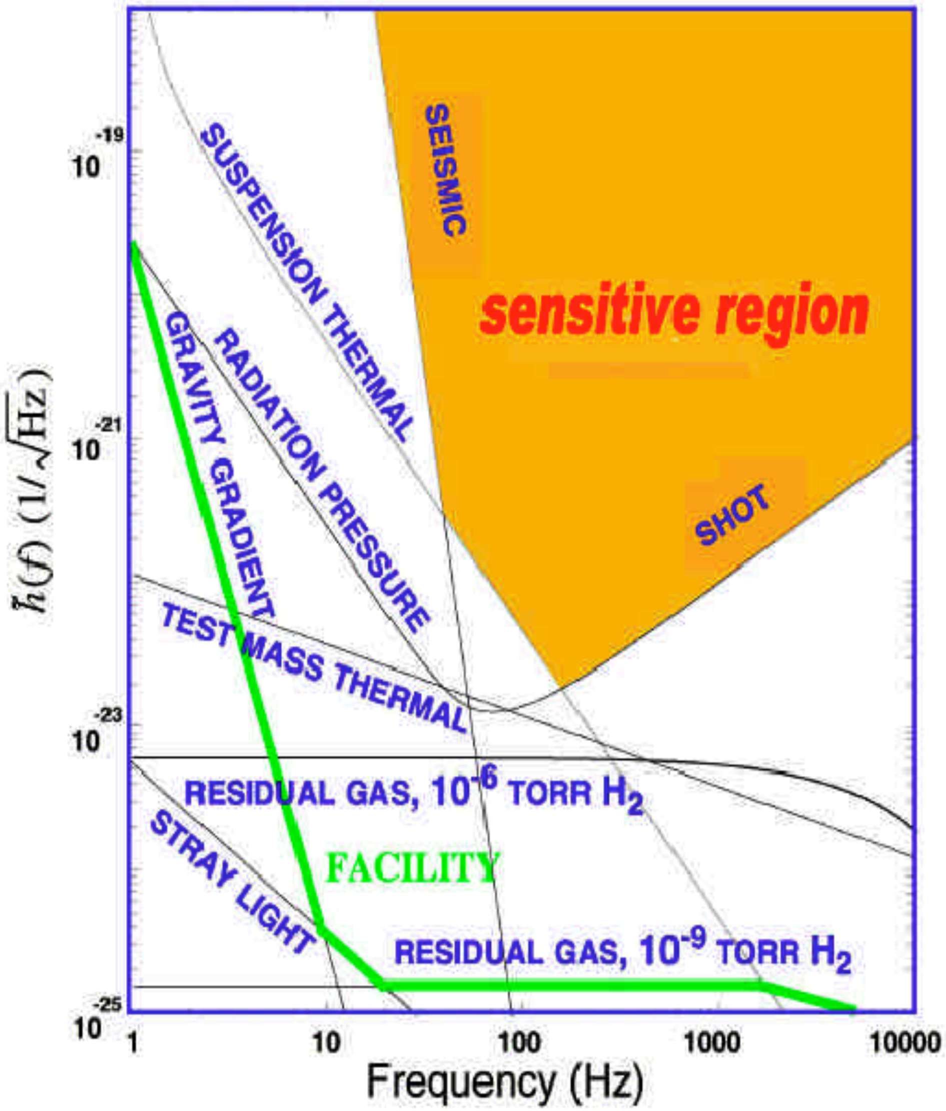
Power recycling mirror: increase the light power to 1 kW

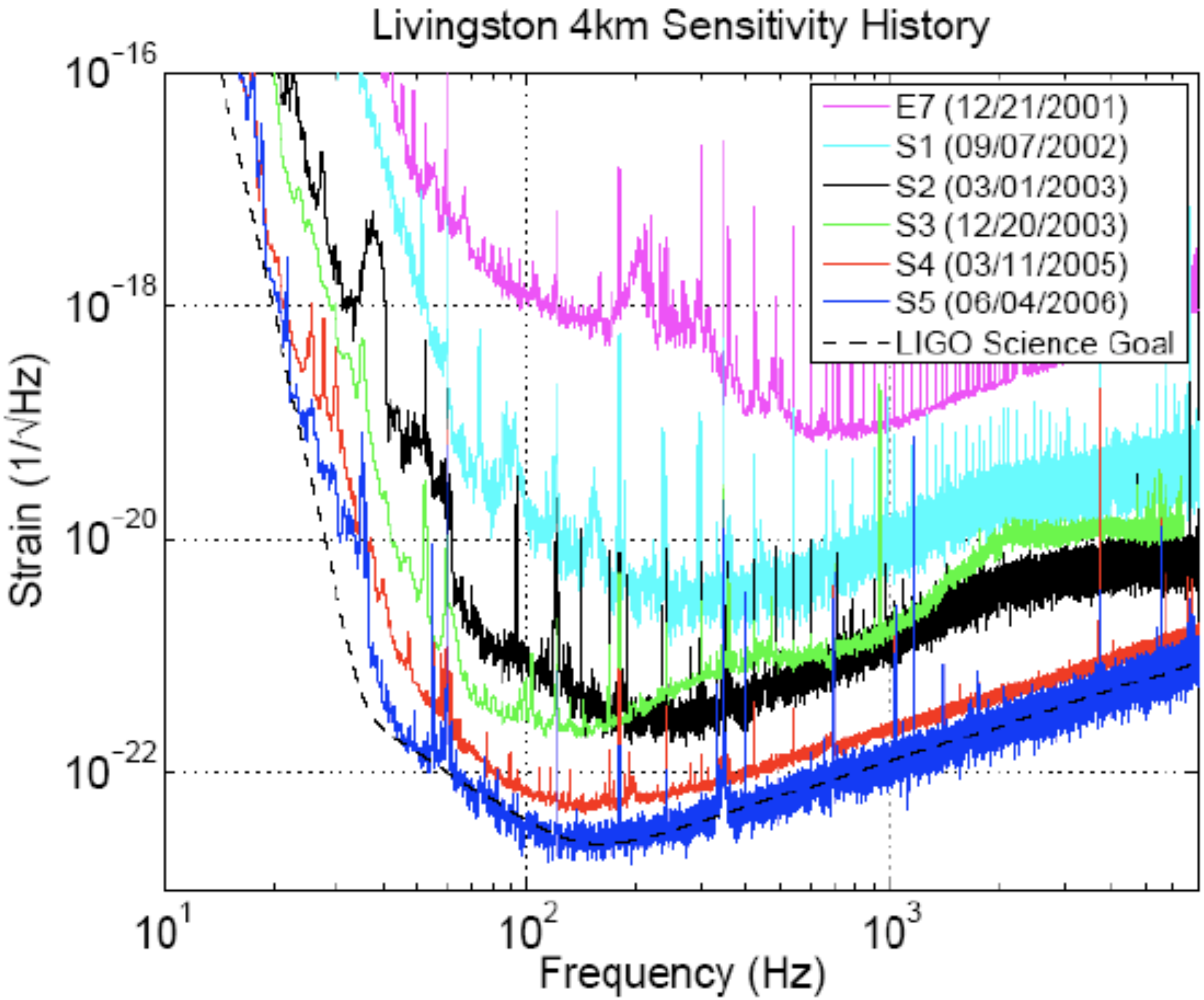




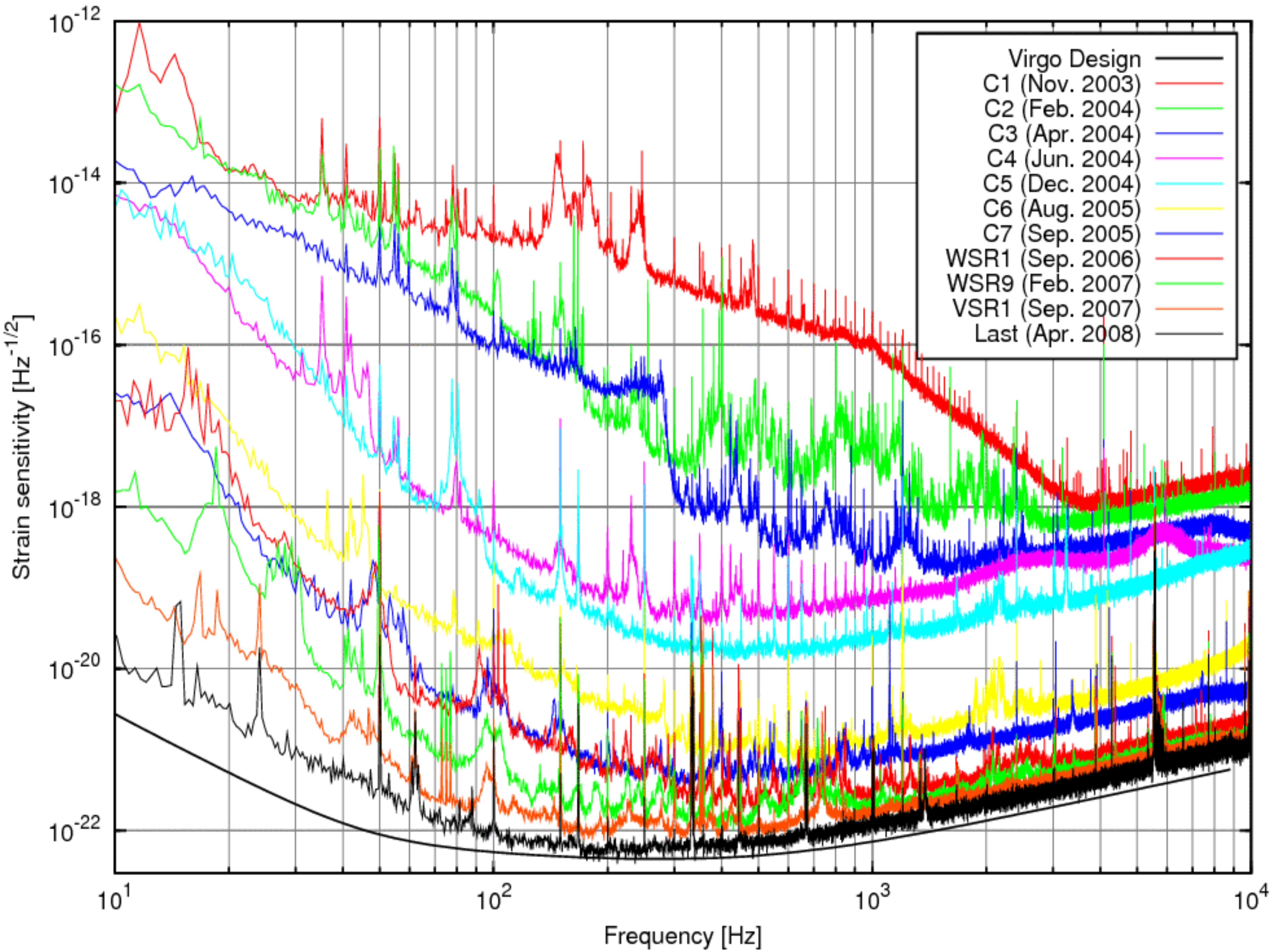
- Interferometry is limited by three fundamental noise sources
  - <u>seismic noise</u> at the lowest frequencies
  - <u>thermal noise</u> at intermediate frequencies
  - <u>shot noise</u> at high frequencies

- Many other noise sources lurk underneath and must be controlled as the instrument is improved





Livingston 4km Sensitivity History
E7 (12/21/2001)
S1 (09/07/2002)
S2 (03/01/2003)
S3 (12/20/2003)
S4 (03/11/2005)
S5 (06/04/2006)
LIGO Science Goal
Strain (1/√Hz)
Frequency (Hz)



Virgo Design
C1 (Nov. 2003)
C2 (Feb. 2004)
C3 (Apr. 2004)
C4 (Jun. 2004)
C5 (Dec. 2004)
C6 (Aug. 2005)
C7 (Sep. 2005)
WSR1 (Sep. 2006)
WSR9 (Feb. 2007)
VSR1 (Sep. 2007)
Last (Apr. 2008)
Strain sensitivity [Hz^-1/2]
Frequency [Hz]
10^-12
10^-14
10^-16
10^-18
10^-20
10^-22
10^1
10^2
10^3
10^4

Results from Initial Detectors: Some highlights from LIGO and Virgo

Several ~year long science data runs by LIGO and Virgo

Since 2007 all data analyzed jointly

- Limits on GW emission from known ms pulsars
  - Crab pulsar emitting less than 2% of available spin-down energy in gravitational waves
- Limits on compact binary (NS-NS, NS-BH, BH-BH) coalescence rates in our local neighborhood (~20 Mpc)
- Limits on stochastic background in 100 Hz range
  - Limit beats the limit derived from Big Bang nucleosynthesis

LIGO-VIRGO recent papers

All sky search for periodic gravitational waves in the full LIGO S5 science data.
Published in Phys.Rev. D85 022001, 2012.

Directional limits on persistent gravitational waves using LIGO S5 science data.
Phys. Rev. Lett. 107:271102, 2011.

Beating the spin-down limit on gravitational wave emission from the Vela pulsar.
Astrophys. J. 737, 93, 2011

Search for Gravitational Wave Bursts from Six Magnetars.
Astrophys. J. 734, L35, 2011.

Search for gravitational waves from binary black hole inspiral, merger and ringdown.
Phys. Rev. D83:122005, 2011.

Search for GW inspiral signals associated with Gamma-Ray bursts during LIGO's fifth and Virgo's first science run.
Astrophys. J. 715:1453-1461, 2010.

Searches for gravitational waves from known pulsars with S5 LIGO data.
Astrophys. J. 713:671-685, 2010.

Search for GW bursts associated with Gamma-Ray bursts using data from LIGO Science Run 5 and Virgo Science Run 1.
The LIGO and the Virgo Collaborations
Astrophys. J. 715:1438-1452, 2010.

All-sky search for gravitational-wave bursts in the first joint LIGO-GEO-Virgo run.
Phys. Rev. D81, 102001, 2010

Search for Gravitational Waves from Compact Binary Coalescence in LIGO and Virgo Data from S5 and VSR1.
Phys. Rev. D82, 102001, 2010

An upper limit on the stochastic GW background of cosmological origin
Nature 460, 08278, 2009

Constraints on cosmic (super)strings from the LIGO-Virgo gravitational-wave detectors
e-Print: **arXiv:1310.2384 [gr-qc] |**

First Searches for Optical Counterparts to Gravitational-wave Candidate Events
e-Print: **arXiv:1310.2314**

A directed search for continuous Gravitational Waves from the Galactic Center
e-Print: **arXiv:1309.6221 [gr-qc] |**

A search for long-lived gravitational-wave transients coincident with long gamma-ray bursts
e-Print: **arXiv:1309.6160 [astro-ph.HE]**

Gravitational waves from known pulsars: results from the initial detector era
e-Print: **arXiv:1309.4027 [astro-ph.HE]**

Prospects for Localization of GW Transients by the Advanced LIGO and Advanced Virgo Observatories
e-Print: **arXiv:1304.0670 [gr-qc]**

Parameter estimation for compact binary coalescence signals with the first generation GW detector network
LIGO and Virgo Collaborations (J. Aasi (Caltech) *et al.*). Apr 5, 2013. 23 pp.
Phys.Rev. D88 (2013) 062001

Search for GW from Binary Black Hole Inspiral, Merger and Ringdown in LIGO-Virgo Data from 2009-2010
Phys.Rev. D87 (2013) 022002

Einstein@Home all-sky search for periodic gravitational waves in LIGO S5 data
Phys.Rev. D87 (2013) 4, 042001

MoU LSC-Virgo **Purpose of agreement:**

The purpose of this Memorandum of Understanding (MOU) is to establish and define a collaborative relationship between VIRGO on the one hand and the Laser Interferometer Gravitational Wave Observatory (LIGO) on the other hand in the use of the VIRGO, LIGO and GEO detectors based on laser interferometry to measure the distortions of the space between free masses induced by passing gravitational waves.

We enter into this agreement in order to lay the groundwork for decades of world-wide collaboration. We intend to carry out the search for gravitational waves in a spirit of teamwork, not competition. Furthermore, we remain open to participation of new partners, whenever additional data can add to the scientific value of the search for gravitational waves. All partners in the collaborative search should have a fair share in the scientific governance of the collaborative work.

Among the scientific benefits we hope to achieve from the collaborative search are: better confidence in detection of signals, better duty cycle and sky coverage for searches, and better source position localization and waveform reconstruction. In addition, we believe that the intensified sharing of ideas will also offer additional benefits.

3. This agreement governs cooperative scientific work between VIRGO and LIGO. The terms governing work on data analysis are exclusive; that is, the parties agree that all of the data analysis work that they do will be carried out under the framework of this agreement. The terms governing other forms of collaborative work are not exclusive; they may, in addition, make agreements with other parties that are not governed by this agreement, as long as such agreements do not involve sharing of data.

4. The agreement described herein represents a scientific collaboration between independent projects, not a merger. Each project will maintain its own separate governance. Decisions on issues that bear on collaborative work will be made in discussion among the leadership of the projects, each representing their Collaborations' position as determined according to their own governing structures.

5. Goals for joint data analysis will be proposed by LSC/Virgo collaboration Joint Data Analysis Groups, will be discussed jointly by both Collaborations and will be approved by each Collaboration according to their own governing structures. The specific mechanisms for the coordination of the data analysis activities are described in an Attachment to this MOU.

Harry Collins, a British sociologist of science at the School of Social Sciences, Cardiff University, has written for over 30 years on the sociology of gravitational wave physics.

- *Gravity's Shadow: the search for gravitational waves*, University of Chicago Press, 2004.

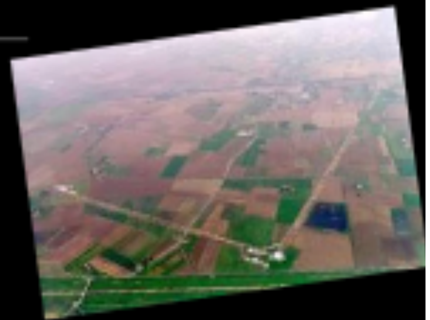
- *Gravity's Ghost: Scientific Discovery in the Twenty-first Century,* University of Chicago Press, 2010. ISBN 978-0-226-11356-2

Basic Glossary: Multimessenger Approaches

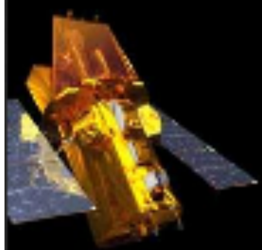
"Multi-messenger astrophysics": connecting different kinds of observations of the same astrophysical event or system

"Looc-Up" strategy:

GW Data —— Flow of trigger information ——> **Telescopes, Satellites or other external entities**



"ExtTrig" strategy:



Telescopes, Satellites or other external entities —— Flow of trigger information ——> **GW** Search

Open Questions for Multimessenger Observations

- What is the speed of gravitational waves?
  (subluminal or superluminal?)

- Can gravitational wave detectors provide an early warning to electromagnetic observers?
  (to allow the detection of early light curves)

- What is the precise origin of SGR flares?
  (what is the mechanism for GW and EM emission and how are they correlated?)

- What happens in a core collapse supernova before the light and neutrinos escape?

- Are there electromagnetically hidden populations of GRBs?

- What GRB progenitor models can we confirm or reject?

- Is it possible to construct a competitive Hubble diagram based on gravitational wave standard sirens?

Soft Gamma Repeater - GW results

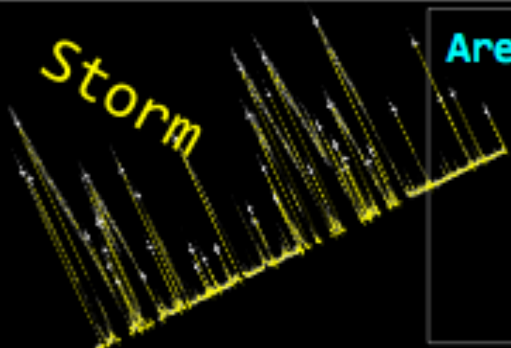
PRD, 80, 042001, 2009
CQG, 24, 659, 2007

Long-lived quasiperiodic GWs after giant flare ?

December 2004 giant flare of SGR 1806-20
Searched for GW signals associated with X-ray QPOs
GW energy limits are comparable to total EM energy emission -> *Abbott et al., PRD 76, 062003 (2007)*

Are there GW bursts at times of SGR flares ?

2004 giant flare plus 188 other flares from SGR 1806-20 and SGR 1900+14 during first calendar year of LIGO S5 run (First search for neutron star *f*-modes ringing down (~1.5-3 kHz, 100ms), also for arbitrary lower-frequency transients…) For certain assumed waveforms, GW energy limits are as low as 3×10^{45}erg, comparable to EM energy emitted in giant flares
-> *Abbott et al., PRL 101, 211102 (2008)*

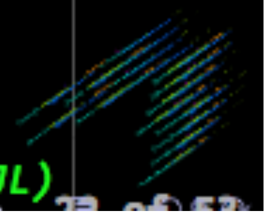


Are repeated GW bursts associated with multiple flares ?

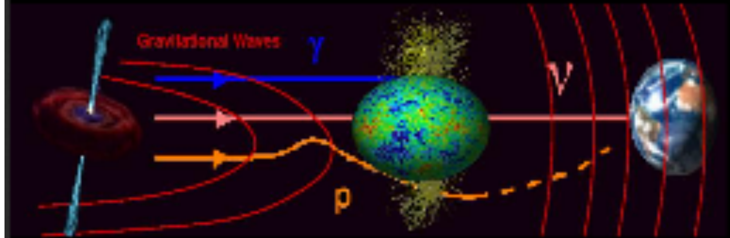
"Storm" of flares from SGR 1900+14 on 29 March 2006
"Stack" GW signal power around each EM flare. Gives per-burst energy limits an order of magnitude lower than the individual flare analysis for the storm events
-> *Abbott et al., ApJ 701, L68 (2009)*

Can we see gravitational waves from newly discovered close-by SGRs ?

SGR 0501+4516 and SGR 0418+5729 are 5-10x closer than SGR 1806-20 and SGR 1900+14… our GW energy scales as distance²… stay tuned!
-> *Abadie et al., LIGO-P0900192_TBS(ApJL)*



Some GW+HEN source candidates



Long GRBs: In the prompt and afterglow phases, high-energy neutrinos (10^5-10^{10} GeV) are expected to be produced by accelerated protons in relativistic shocks (e.g., *Waxman & Bahcall 1997; Vietri 1998; Waxman 2000*).

Short GRBs: HENs can also be emitted during binary mergers (*Nakar 2007; Bloom et al. 2007; Lee & Ramirez-Ruiz 2007*).

Low-Luminosity GRBs: Associated with particularly energetic population of core-collapse supernovae (*Murase et al. 2006; Gupta & Zhang 2007; Wang et al. 2007*). Local event rate can be significantly larger than that of conventional long GRBs (*Liang et al. 2007; Soderberg et al. 2006*).

"Choked" GRBs: Plausibly from baryon-rich jets. Optically thick, can be hidden from conventional astronomy, neutrinos and GWs might be able to reveal their properties (*Ando & Beacom (2005), Razzaque et al. 2004; Horiuchi & Ando 2008*).

	SN	"Failed" GRB	GRB
Energy	10^{51} erg	10^{51} erg	10^{51} erg
Rate/gal	$\sim 10^{-2}$ yr^{-1}	10^{-5}–10^{-2} yr^{-1}	$\sim 10^{-5}$ yr^{-1}
Γ	~1	~3–100	~ 100–10^3

Barion rich
Nonrelativistic
Frequent

Baryon poor
Relativistic jets
Rare

Similar kinetic energy

taken from Ando (2009)

missing link between SN and GRB?

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

LSC LIGO Scientific Collaboration VIRGO

IDENTIFICATION AND FOLLOW UP OF ELECTROMAGNETIC COUNTERPARTS OF GRAVITATIONAL WAVE CANDIDATE EVENTS

The LIGO Scientific Collaboration (LSC) and the Virgo Collaboration currently plan to start taking data in 2015, and we expect the sensitivity of the network to improve over time. Gravitational-wave transient candidates will be identified promptly upon acquisition of the data; we aim for distributing information with an initial latency of a few tens of minutes initially, possibly improving later. The LSC and the Virgo Collaboration (LVC) wish to enable multi-messenger observations of astrophysical events by GW detectors along with a wide range of telescopes and instruments of mainstream astronomy.

In 2012, the LVC approved a statement (LSC, Virgo) that broadly outlines LVC policy on releasing GW triggers (partially-validated event candidates). Initially, triggers will be shared promptly only with astronomy partners who have signed an Memorandum of Understanding (MoU) with LVC involving an agreement on deliverables, publication policies, confidentiality, and reporting. After four GW events have been published, further event candidates with high confidence will be shared immediately with the entire astronomy community (and the public), while lower-significance candidates will continue to be shared promptly only with partners who have signed a MoU.

From June to October 2013, we organized rounds of consultations with groups of astronomers that have expressed interest in the GW-EM follow-up program. Thanks to these consultations, we could define the framework and guiding rules for this program that are collected into a standard MoU template.

LSC AND VIRGO POLICY ON RELEASING GRAVITATIONAL WAVE TRIGGERS TO THE PUBLIC IN THE ADVANCED DETECTORS ERA

The LSC and Virgo recognize the great potential benefits of multi-messenger observations, including rapid electromagnetic follow-up observations of GW triggers. Both Collaborations (the LSC and Virgo) will partner with astronomers to carry out an inclusive observing campaign for potentially interesting GW triggers, with MoUs to ensure coordination and confidentiality of the information. They are open to all requests from interested astronomers or astronomy projects which want to become partners through signing an MoU. They encourage colleagues to help set up and organize this effort in an efficient way to guarantee the best science can be done with gravitational wave triggers.

After the published discovery of gravitational waves with data from LSC and/or Virgo detectors, both the LSC and Virgo will begin releasing especially significant triggers promptly to the entire scientific community to enable a wider range of follow-up observations. This will take effect after the Collaborations have published papers (or a paper) about 4 GW events, at which time a detection rate can be reasonably estimated. The releases will be done as promptly as possible, within an hour of the detected transient if feasible. Initially, the released triggers will be those which have an estimated false alarm rate smaller than 1 per 100 years.


LSC
VIRGO
Comprehensive Multimessenger Studies
LIGO Livinston
LCGT
GEO
ET
LIGO Hanford
Virgo
Swift
Antares
Fermi
LVD
QUEST
TAROT
Super-K
IceCube
Arecibo
Green Bank
LOFAR

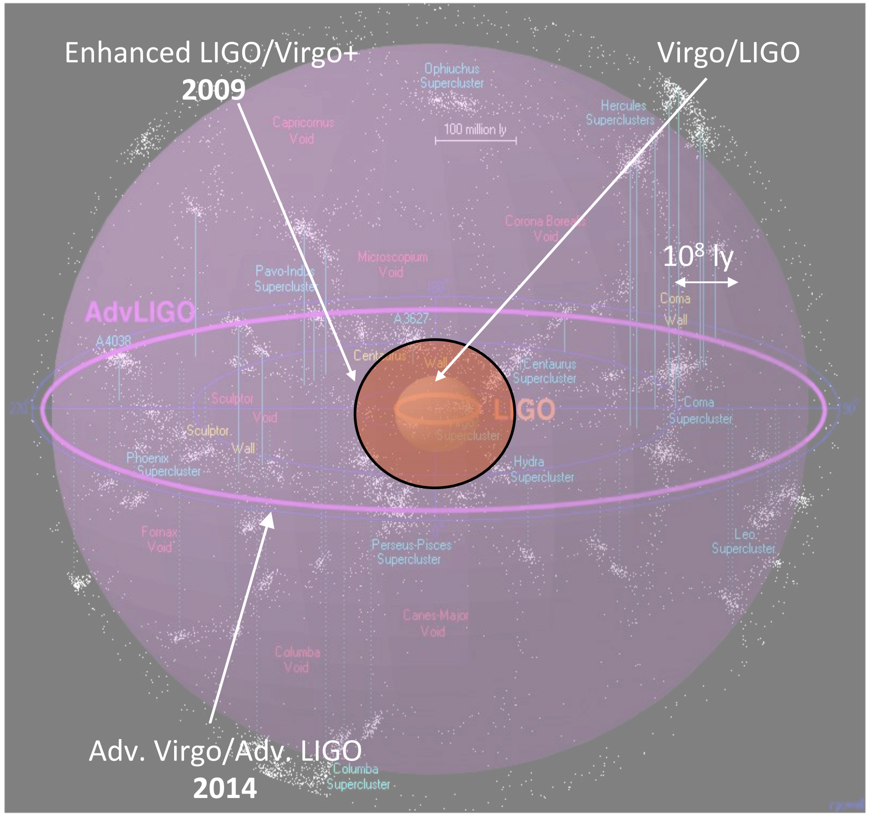
2nd GENERATION:
DISCOVERY AND ASTRONOMY

2^{nd} generation detectors:
Advanced Virgo, Advanced LIGO

GOAL:
sensitivity 10x better →
look 10x further →
Detection rate 1000x larger

NS-NS detectable as far as 300 Mpc
BH-BH detectable at cosmological distances

10s to 100s of events/year expected!

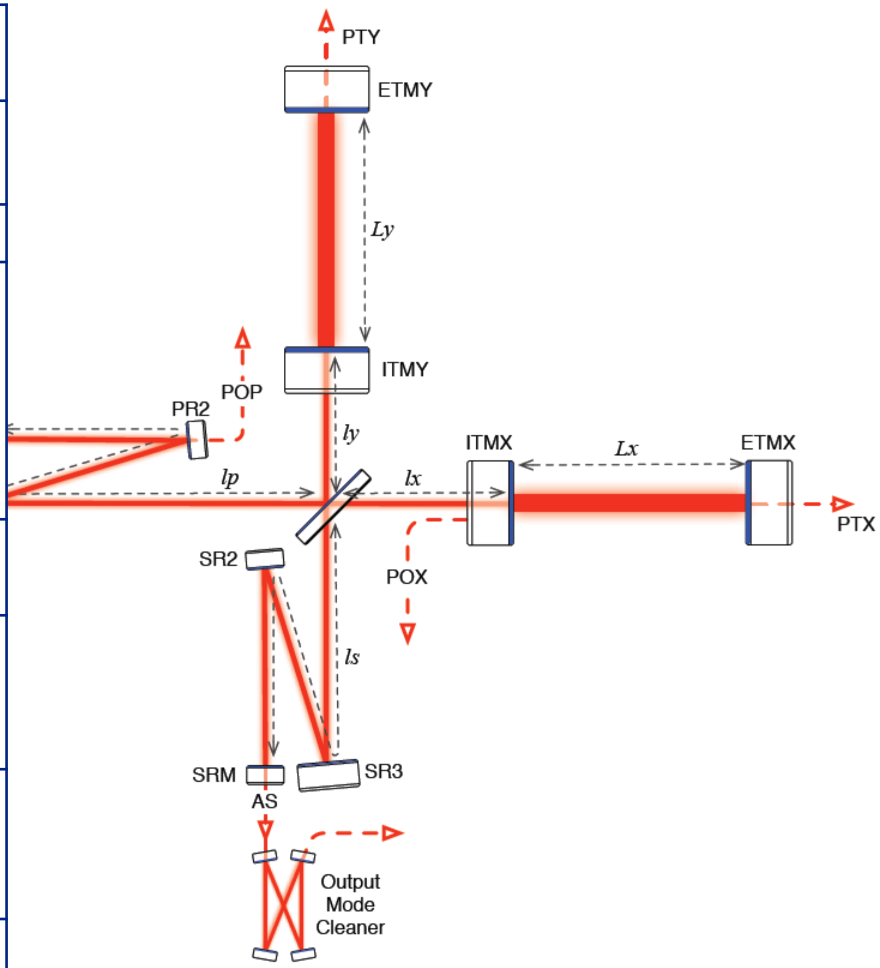


Credit: R.Powell, B.Berger

Advanced LIGO/Virgo overview

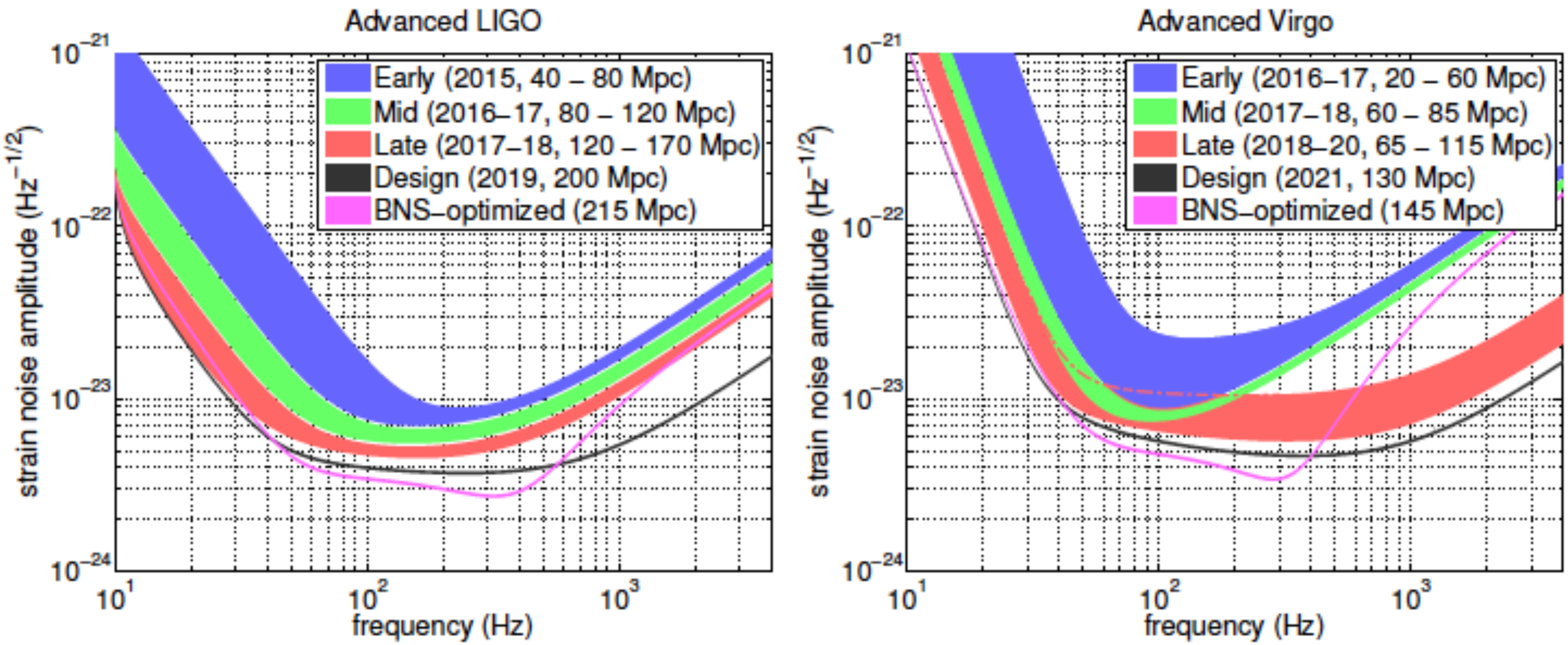
What is Advanced?

Parameter	Initial LIGO/Virgo	Advanced LIGO/ Virgo
Input Laser Power	10 W (10 kW arm)	180 W (>700 kW arm)
Mirror Mass	10 kg/20kg	40 kg
Interferometer Topology	Power-recycled Fabry-Perot arm cavity Michelson	Dual-recycled Fabry-Perot arm cavity Michelson (LIGO stable recycling cavities)
GW Readout Method	RF heterodyne	DC homodyne
Optimal Strain Sensitivity	3 x 10-23 / rHz 6 x 10-23 / rHz	Tunable, better than 5 x 10-24 / rHz in broadband
Seismic Isolation Performance	flow ~ 50 Hz flow ~ 10 Hz	flow ~ 12 Hz flow ~ 10 Hz
Mirror Suspensions	Single Pendulum/ Hepta Pendulum	Quadruple Pendulum/ Hepta Pendulum

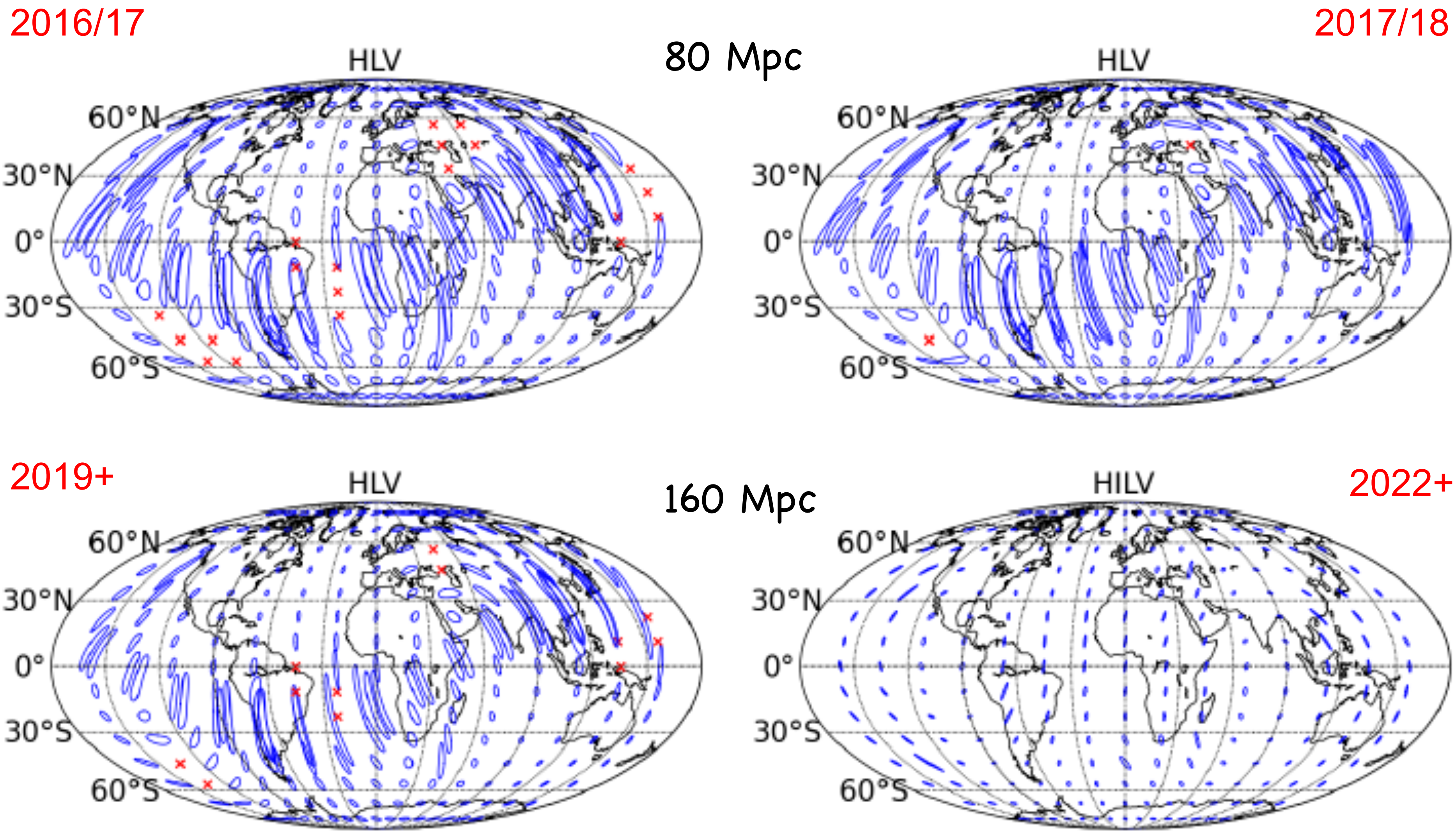


4

Plausible scenario
for the operation of the LIGO-Virgo network over the next decade

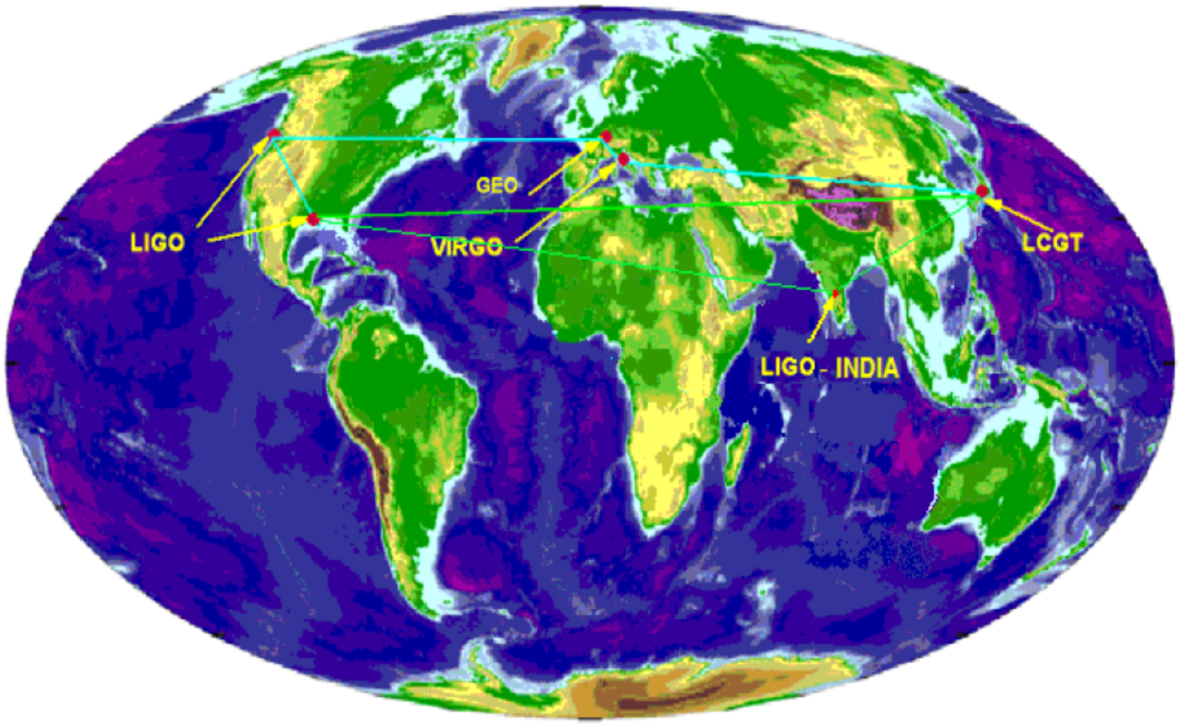


Epoch	Estimated Run Duration	$E_{\rm GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within 5 $\deg^2$	20 $\deg^2$
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20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



Localization expected for a BNS system

The ellipses show 90% confidence localization areas, and the red crosses show regions of the sky where the signal would not be condently detected.



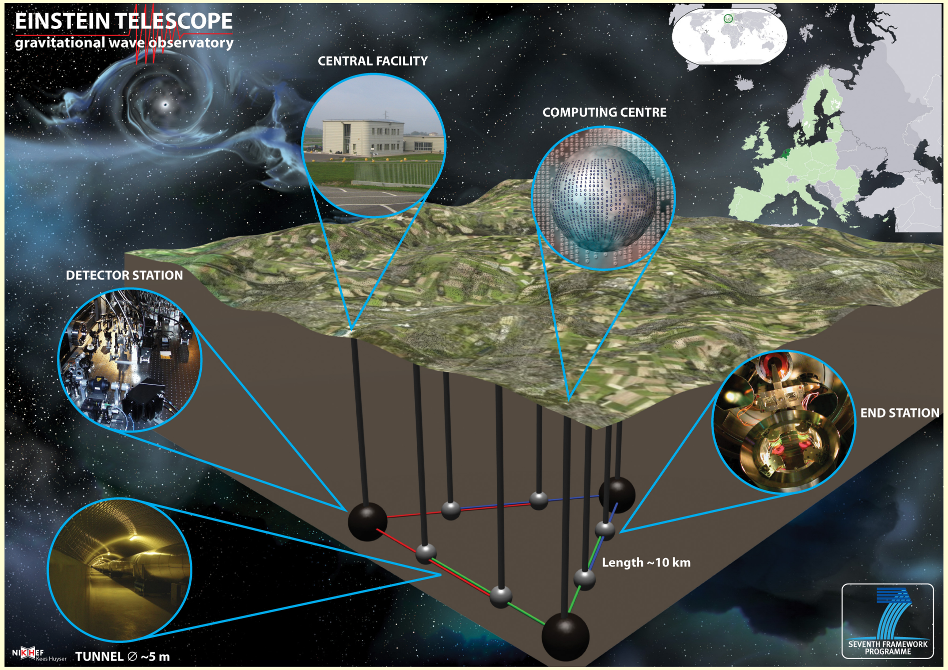
- We are on the threshold of a new era of gravitational wave astrophysics
- First generation detectors have broken new ground in optical sensitivity
  - Initial detectors have proven technique
- Second generation detectors are starting installation
  - Will expand the “Science” (astrophysics) by factor of 1000
- In the next decade, emphasis will be on the *NETWORK*

GWIC
Gravitational Wave International Committee

8 Recommendations to GWIC to guide the development of the field

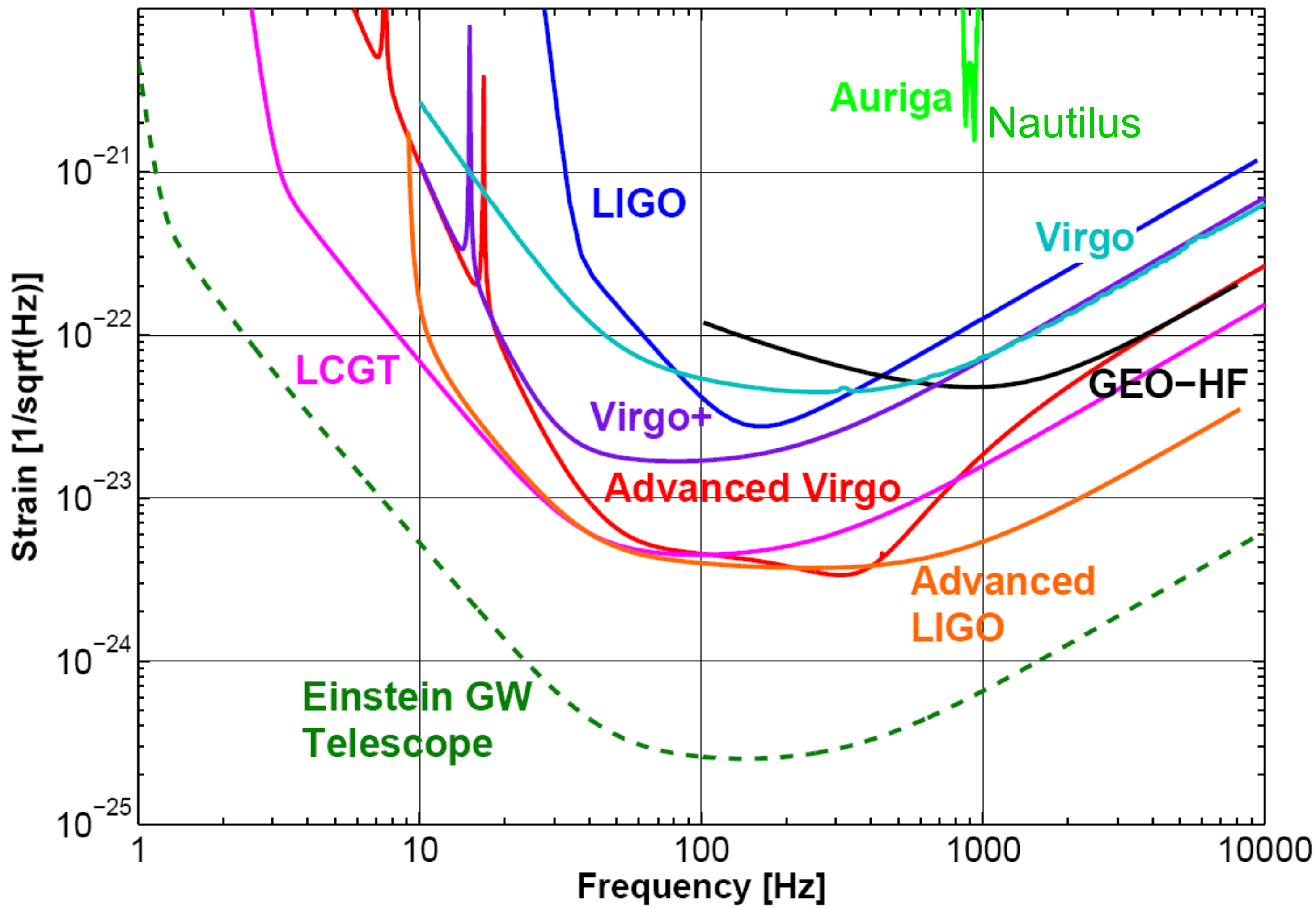
8.5 Toward a third-generation global network

"Background— The scientific focus of a third-generation global network will be gravitational wave astronomy and astrophysics as well as cutting edge aspects of basic physics. Third-generation underground facilities are aimed at having excellent sensitivity from ~1 Hz to ~10^4 Hz. As such, they will greatly expand the new frontier of gravitational wave astronomy and astrophysics.

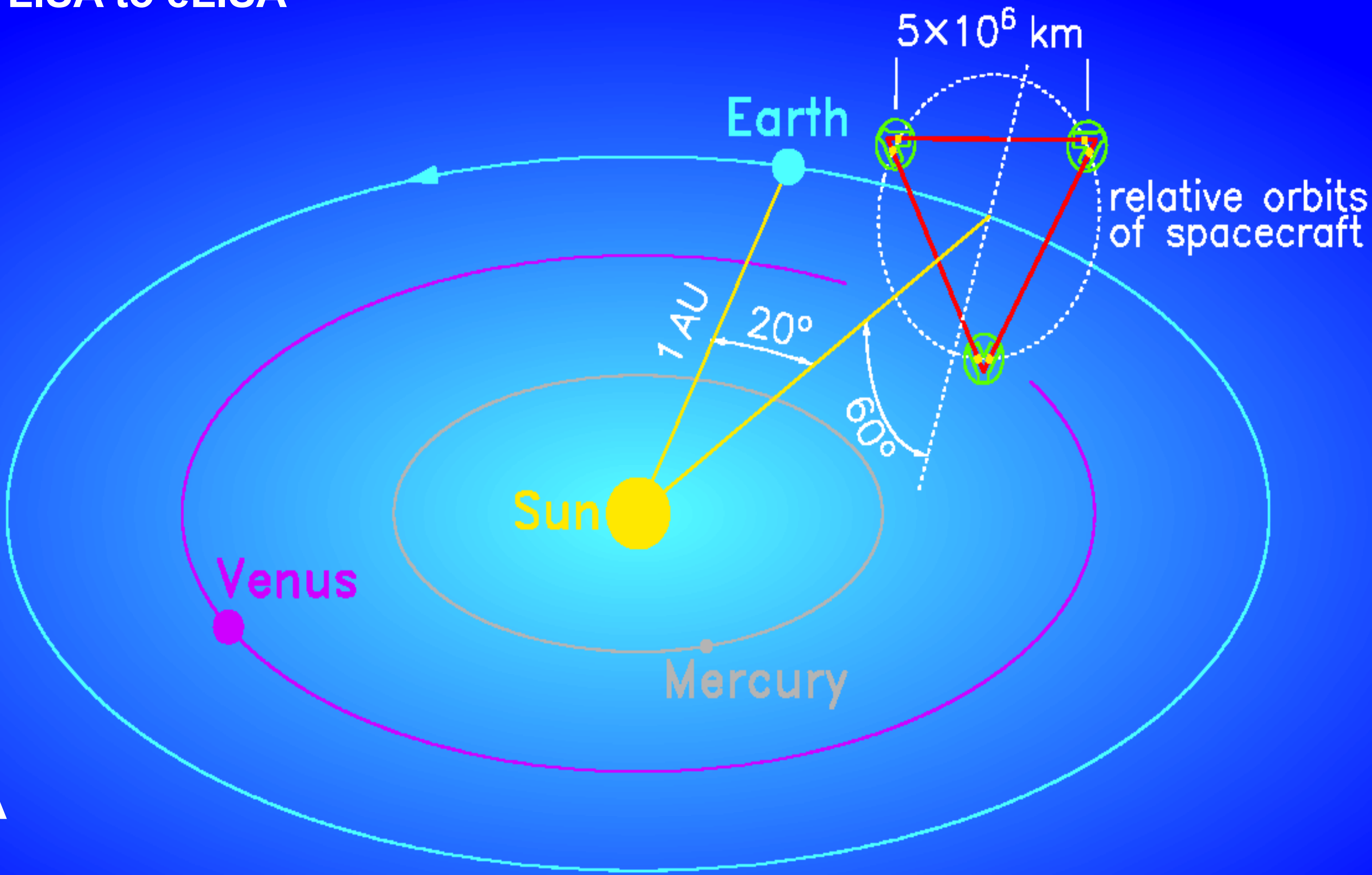


In Europe, a three year-long design study for a third-generation gravitational wave facility, the Einstein Telescope (ET), has recently begun with funding from the European Union.

Summary of sensitivities



From LISA to eLISA



eLISA

- Savings mainly in weight, launch cost.
- Two active arms, not three;
- Smaller arms (1Gm, not 5Gm);
- Re-use LISA Pathfinder hardware;

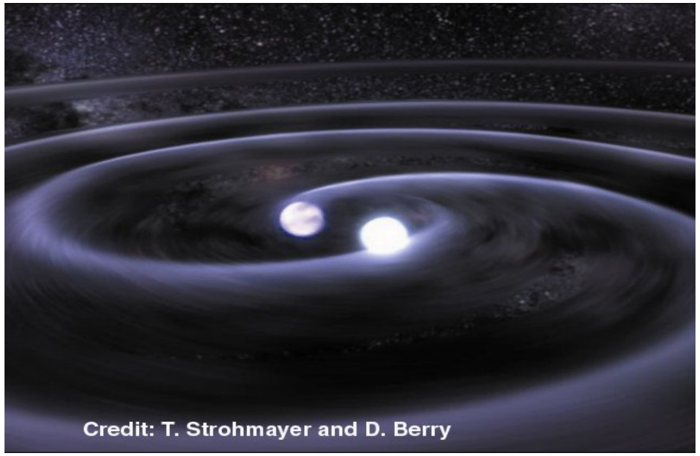
2030

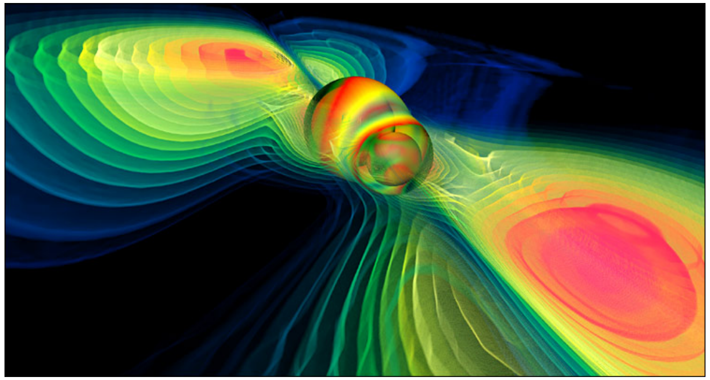
THE GLOBAL PLAN

- Advanced Detectors (LIGO, VIRGO +) will initiate gravitational wave astronomy through the detection of the most luminous sources - compact binary mergers.

- Third Generation Detectors (ET and others) will expand detection horizons and provide new tools for extending knowledge of fundamental physics, cosmology and relativistic astrophysics.

- Observation of low frequency gravitational wave with LISA/NGO will probe the role of super-massive black holes in galaxy formation and evolution





Every newly opened astronomical window has found unexpected results

Window	Opened	1st Surprise	Year
Optical	1609 Galilei	Jupiter's moons	1610
Cosmic Rays	1912	Muon	1930s
Radio	1930s	Giant Radio Galaxies CMB Pulsars	1950s 1964 1967
X - ray	1948	Sco X-1 X-ray binaries	1962 1969 Uhuru
γ - ray	1961 Explorer 11	GRBs	Late 1960s+ Vela