

**Listening to the Cosmos
Can blind people do it better ?**

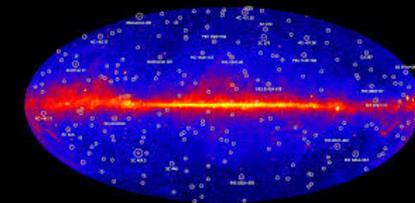
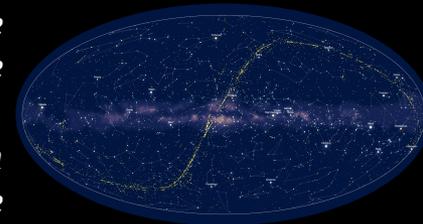
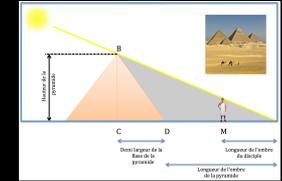
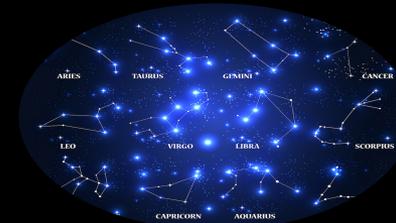
**S+T+ARTS Talks in GENOVA
28 October 2020**



**S.Katsanevas
EGO Director**

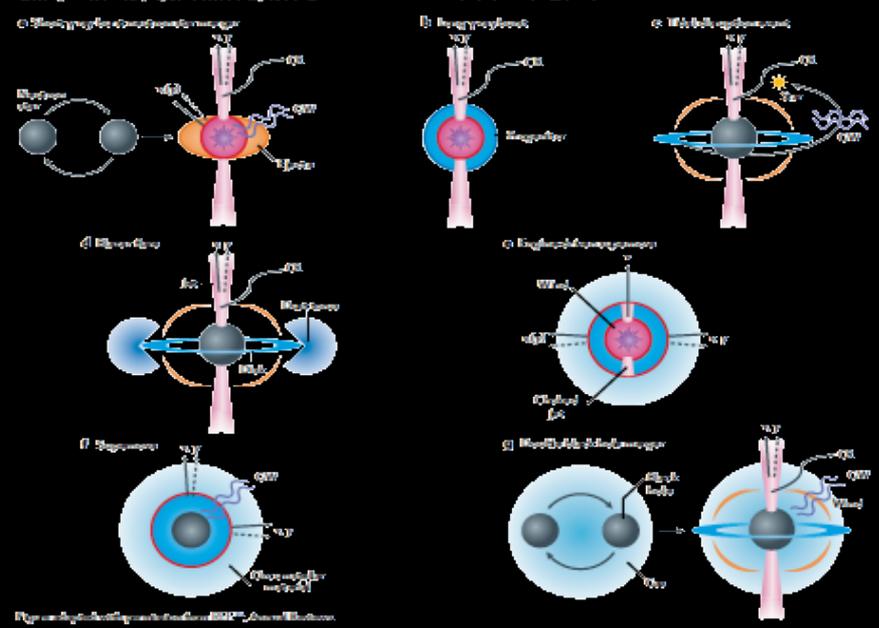
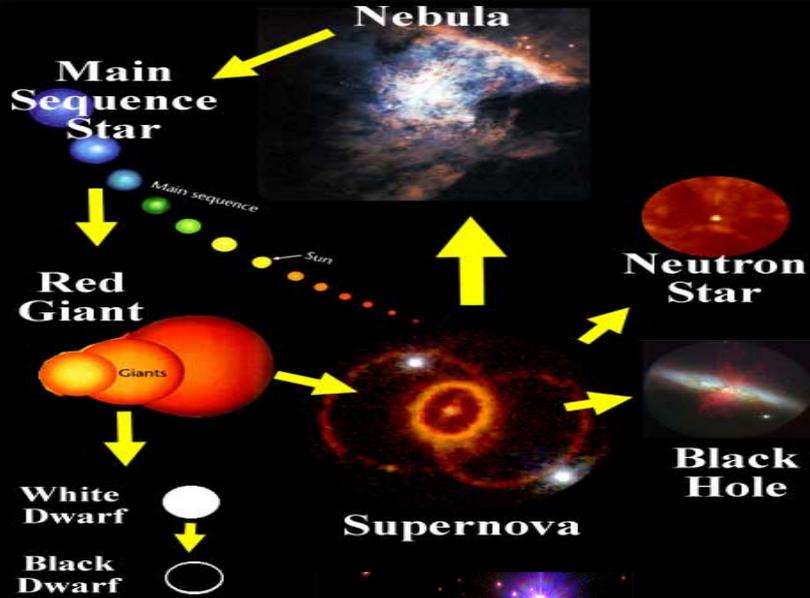
A short history of our embedding in the cosmos

1. From a continuum between the mythical, the social and the natural the real, humanity in the first years projects the familiar to the skies through the zodiac and promoted a « rhythmic embedding » of human and social life to the revolutions of the sky through astrology.
2. Thales put the first stones of a geometrisation of the sky (The pyramid story) and Pythagoras the arithmetisation and “sonification” through the celestial harmonies and the resonance of our soul to the harmonic scale. Continued by Plato (Myth of Er), Aristotle’s “natural place”.
3. Both 1 and 2 persist and even develop during medieval times and early Renaissance on the correspondence between the Macrocosm and the Microcosm (see e.g. Cassirer).
4. In the 1600’s Galileo and later Newton and Descartes put the fundamental principles of geometrisation and mechanisation of the world picture. A world of dynamic trajectories. The cosmos is a sublime picture of luminous points. that frightens Pascal.
Start of Astronomy.
5. Towards the end of the 19th Century, the spectral analysis of light and the extension to electromagnetism (Maxwell) and later the discovery of spectrometers, starts the physical study of the constitution of stars, the doppler “acoustic” effect can measure their speed w.r.t the earth. **Start of Astrophysics**
6. In early 20th century the two major theories (GR and QM) extending the Newtonian image of space-time as a fixed framework present either space-time as a deformable medium (GR) or eventually a product of entanglement (QM)
7. In the 30’s, the association of the 2 infinities (GR+QM) brings the understanding of star formation and death, introduces new cosmic objects (neutron stars, black holes...)
8. After the 50’s, the new instruments (radio telescopes, gravitational wave detectors, neutrino and large cosmic ray detectors associated to optical telescopes reveal a « dark and violent » landscape conditioning the formation and structure of the cosmos. **Era of Astroparticle.** Can we attempt a new cognitive, affective and conceptual synthesis ?

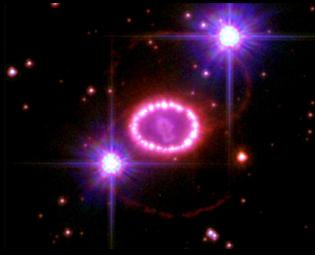


What are the violent phenomena?

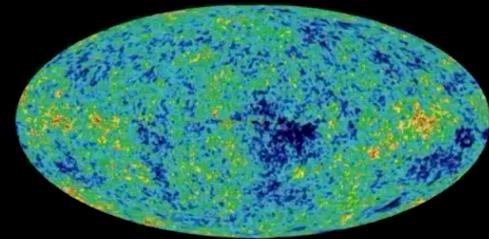
The end of stars, black holes accreting at the centre of galaxies...



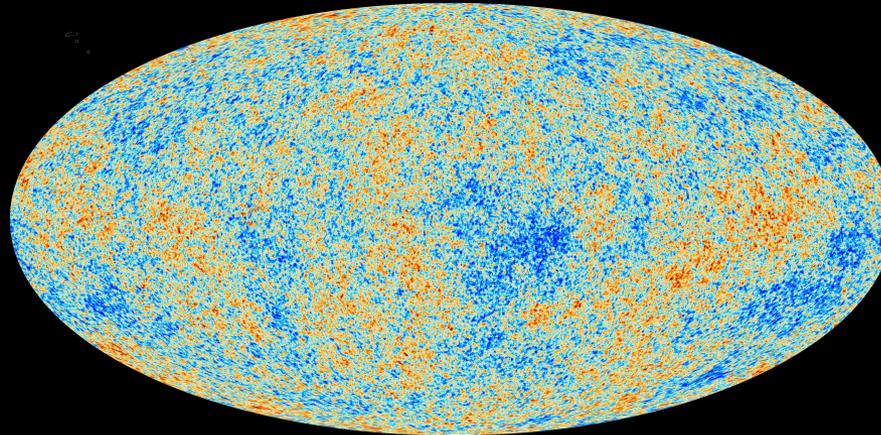
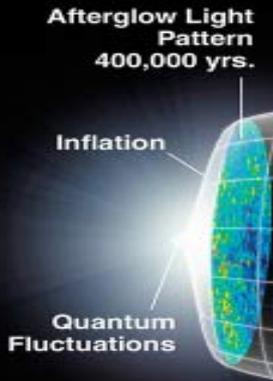
1987A



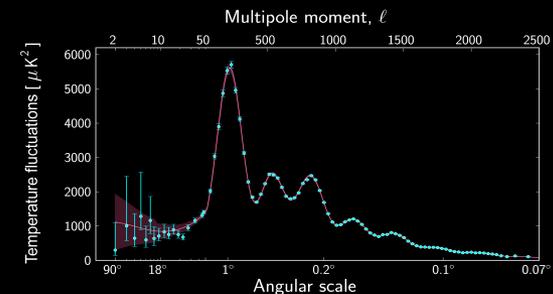
The Big Bang at the origin of structure



A revival. The primordial “sound” of the cosmological microwave background

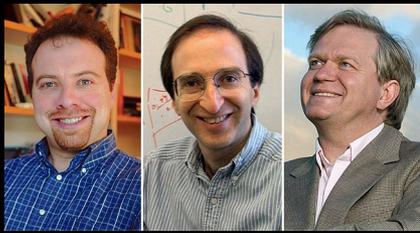


$$v = \frac{v_{son}}{\sqrt{3}}$$

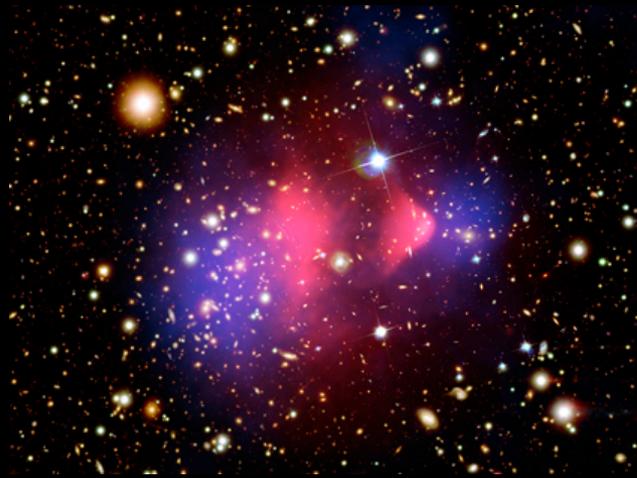
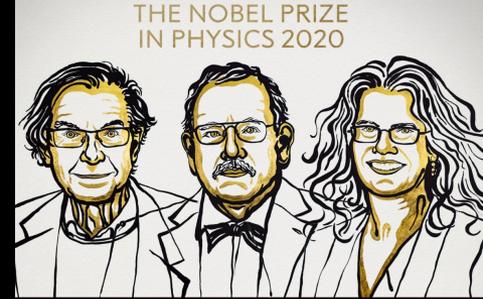


Pierre Chanial

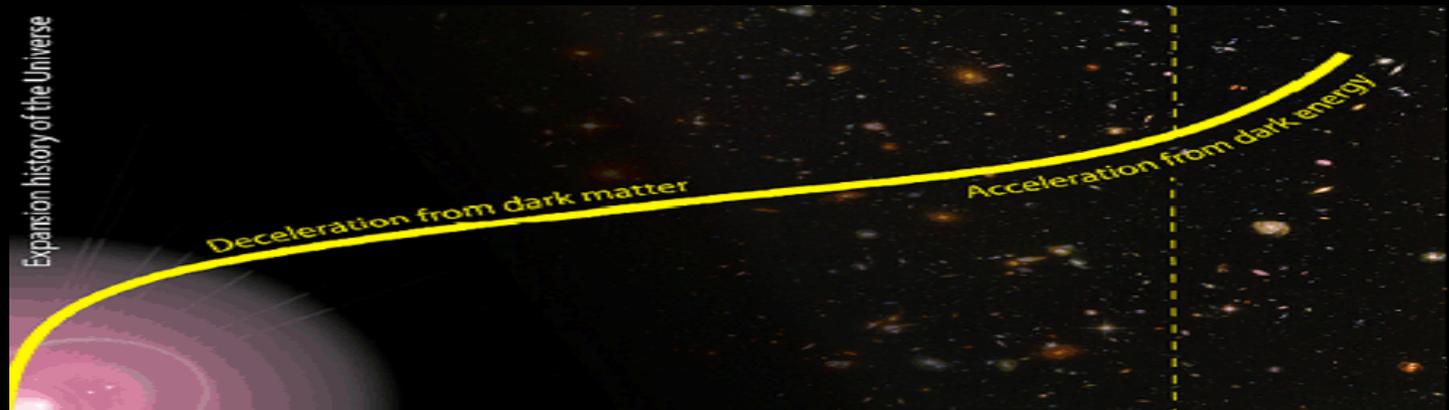
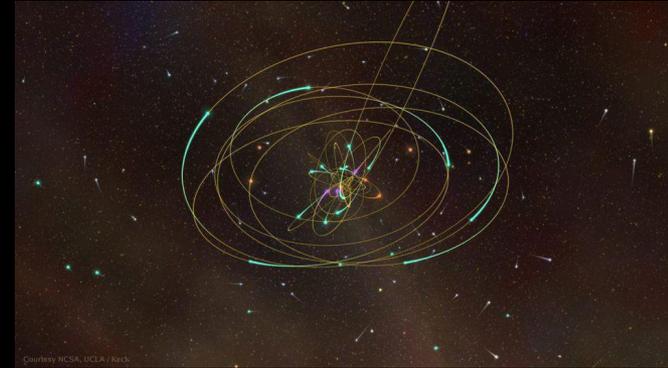
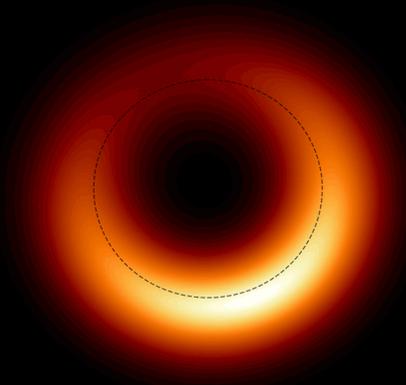
- A violent change at the origin of the visible Universe (inflation?) creates waves as if we were hitting a bell or a string (also gravitational waves). Knowing that the waves in the plasma have almost the speed of sound one knows the distance they should have travelled after 400.000 y.
- Furthermore the harmonic analysis of the fluctuations informs us on the constitution of the Universe at this epoque. As in current life the harmonic analysis of a sound informs us on the geometry and constitution the object hit.
- Isaac Bashevits Singer to Penzias and Wilson. It is you that have heard the Big Bang ? illustration vs new tool



What are the dark phenomena? Black holes, Dark Matter and Energy for the scaffolding of the Universe



2009



Big Bang

10 Billion years ago

5 Billion Years ago

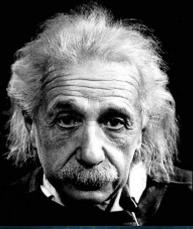
Today

New ways to sense the Universe: Multi-messenger Astrophysics



Factor (Hz)	Multiple	Value	Item	
1,E-18	1 attohertz	~2.29 aHz	Hubble frequency (once in 13.8 billion years)	
1,E-03	1 millihertz	1.40 mHz	Acoustic- Millisecond pulsars, PSR J1748-2446ad	GW-sky
1,E-01	1 decihertz	1,89 dHz	Frequency of the lowest note sang by a singer	GW-sky
1	1 hertz	1-2 Hz	Acoustic- Frequency of a heart beat, common tempos in music	GW-sky/moon/earth
		12 Hz	Acoustic - the lowest possible frequency that a human can hear	GW-earth
		440 Hz	Acoustic - concert pitch (La) for tuning musical instruments	GW-earth
1,E+03	1 kilohertz	14 kHz	Acoustic - the typical upper limit of adult human hearing	GW-earth
1,E+06	1 Megahertz	530 kHz to 1.710 MHz	Electromagnetic - AM radio broadcasts	Radio Telescopes
		88 MHz to 108 MHz	Electromagnetic - FM radio broadcasts	Radio Telescopes
1,E+09	1 Gigahertz	1.42 GHz	Electromagnetic - hydrogen line or 21 cm line /5G	Radio Telescopes
		160.2 GHz	Electromagnetic - peak of cosmic microwave background radiation /5G	CMB Telescopes
1,E+12	1 Terahertz	21 THz to 33 THz	Electromagnetic - infrared light	Telescopes
		428 THz to 750 THz	Electromagnetic - visible light, from red to violet	Telescopes
1,E+15	1 Petahertz	2.47 PHz	Electromagnetic - Lyman-alpha line	Telescopes
1,E+18	1 ExaHertz			
	30PHz/30Exahz	0,1-100 keV	Electromagnetic - X-rays	Satellites
	300 EHz +		Electromagnetic - Gamma rays	Satellites
1,E+27			Cosmic rays: TeV Gamma rays and neutrinos	Astroparticle Detectors
1,E+35			Cosmic Rays Ultrahigh Energy protons 10 ²⁰ eV	Astroparticle Detectors
1,E+43			Planck scale frequency	

If we constructed a piano to play the Celestial Harmony, we would need a 61 m piano (1cm/note/tenth of a decade)

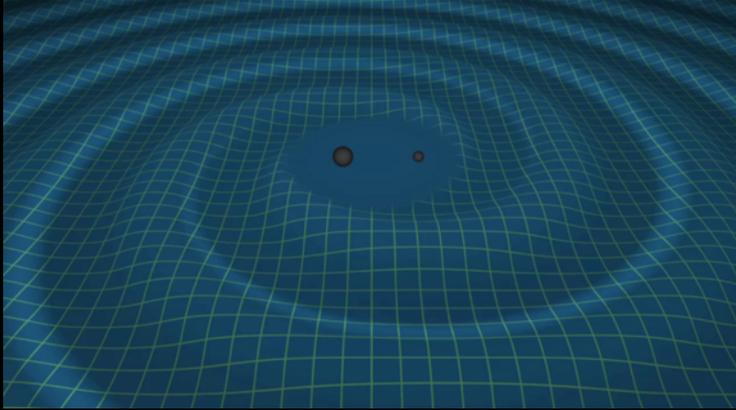


Einstein's Theory of Gravity 1915

For Einstein Space-Time is a deformable medium

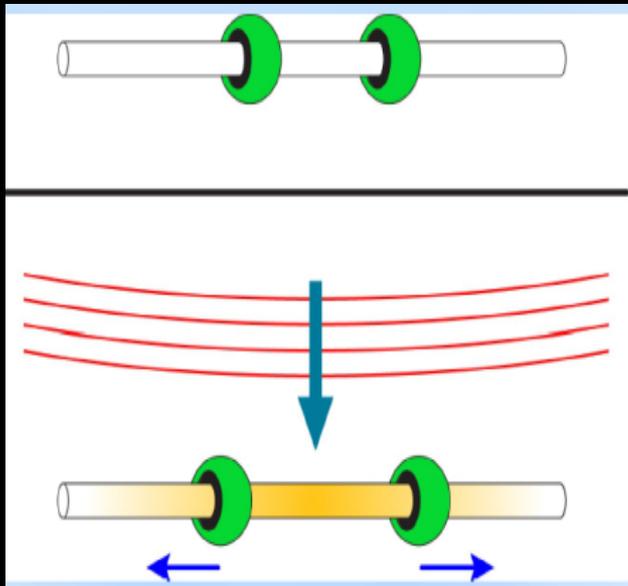
Mass and Energy deform space-time around them and inversely they follow the deformed paths inside it

Waves can be produced by violent phenomena



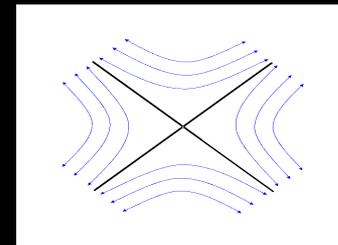
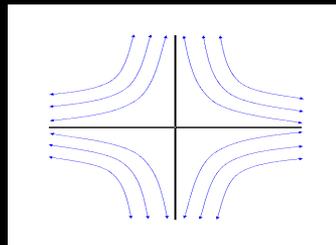
Spacetime Mass-Energy

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$



h_+

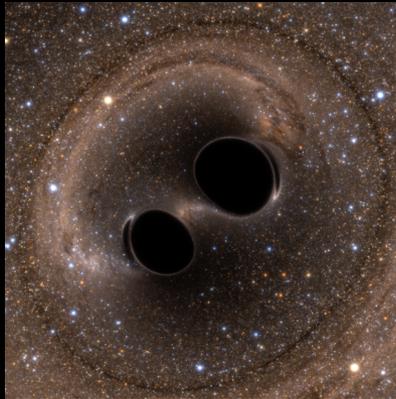
h_x



$\sim 10^{-43}$

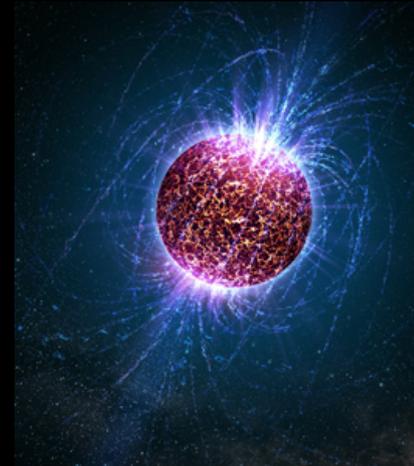
The Astrophysical Gravitational-Wave Source Catalog

→ Short → long



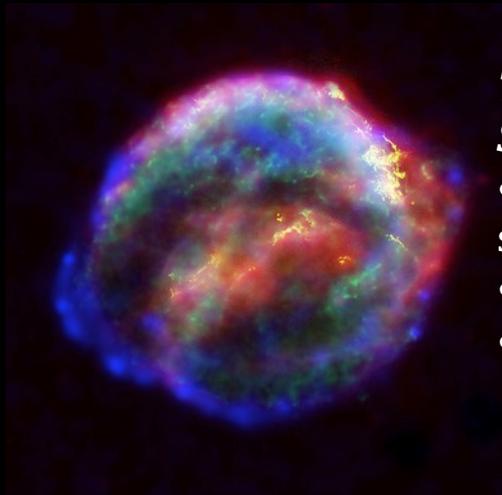
Coalescing Binary Systems CBC

- ✓ Black hole – black hole
- ✓ Neutron star – neutron star
- BH-NS
- Analytical waveform



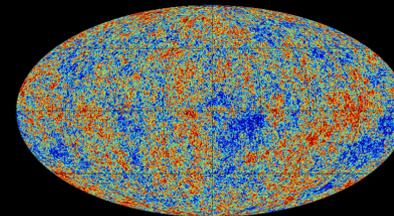
Continuous Sources

- Spinning neutron stars
- Monotone waveform



Transient 'Burst' Sources

- core collapse supernovae
- cosmic strings
- unmodeled waveform



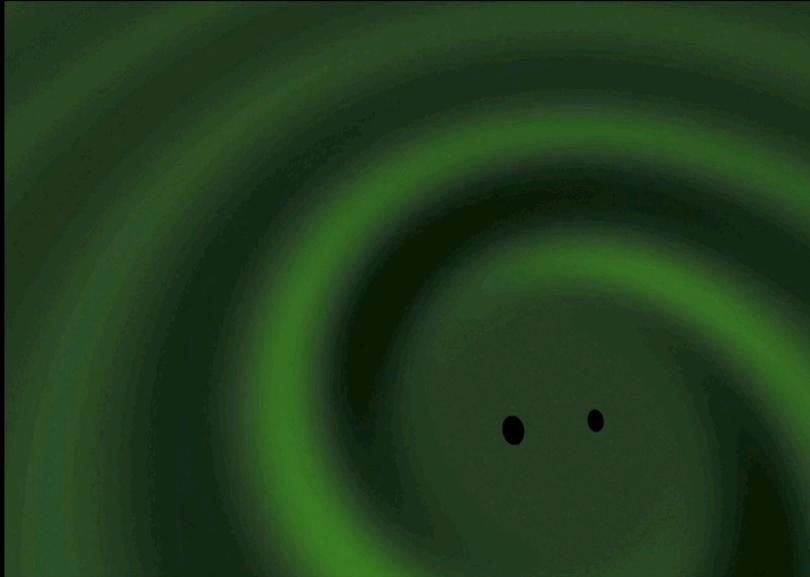
Cosmic GW Background

- Residue of the Big Bang,
- Stochastic, incoherent background

Known → unknown form

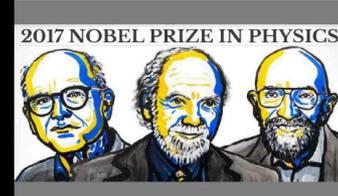
Transient Burst and Continuous sources the next goal!

The first GW event: 14 September 2015



"For the greatest benefit to mankind"
— Alfred Nobel
Nobel Prizes 2017

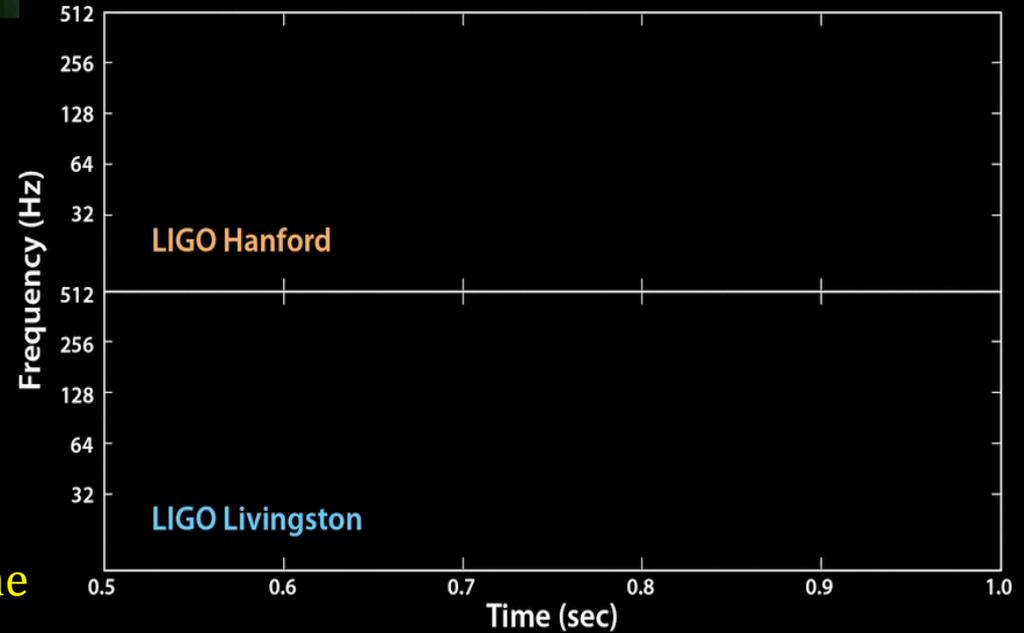
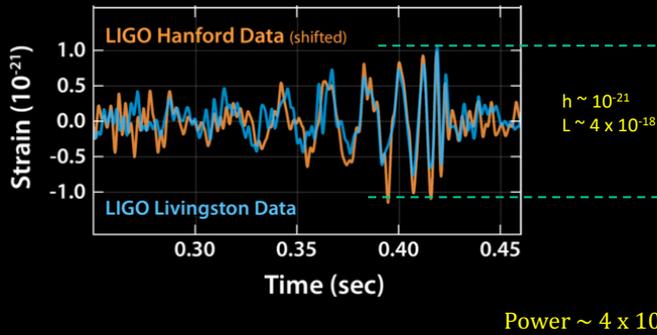
2017 October 3



Rainer Weiss Barry C. Barish Kip S. Thorne



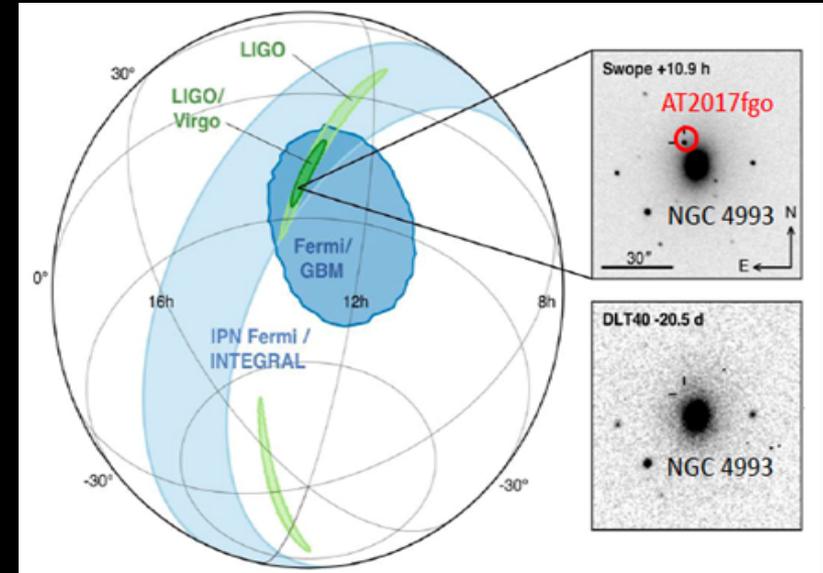
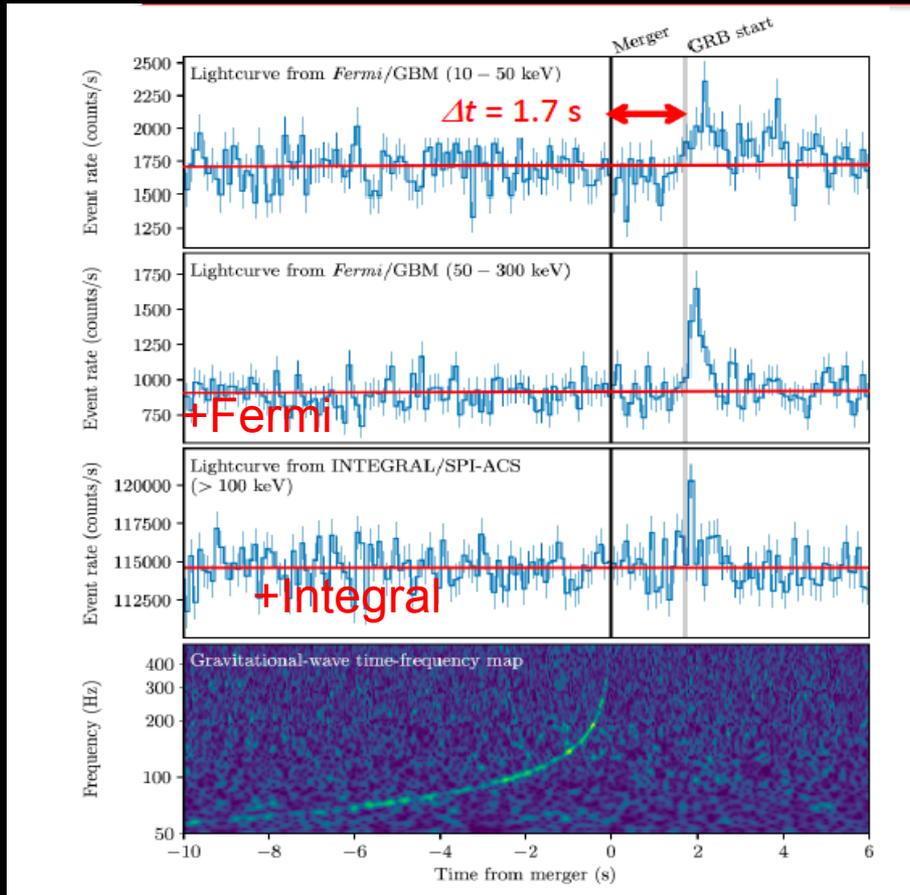
"for decisive contributions to the LIGO detector and the observation of gravitational waves".



The frequencies of the deformation in the "acoustic bandwidth" (20Hz -20 KHz) Pascal do not be frightened anymore...

The first GW from a BNS: 17 August 2017

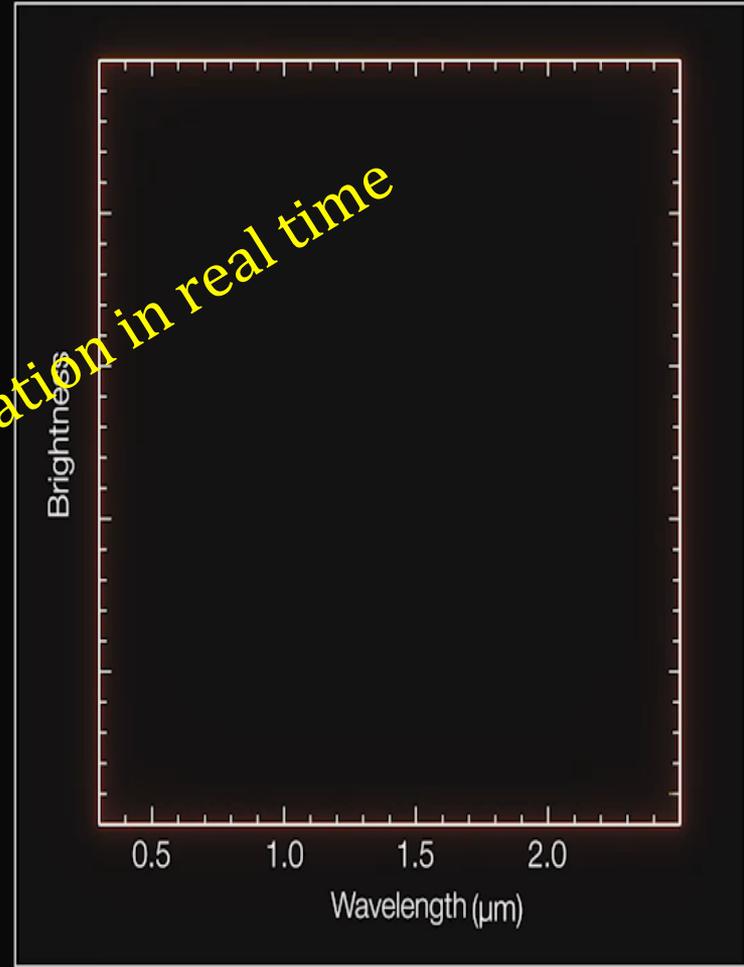
GW170817 a BNS @ 40Mpc: observed by about 70 observatories around the world



Start of multi messenger astronomy!

GW170817-GRB170817A-AT2017fgo

Observed by about 70 observatories around the world



The first "global" observation in real time

Time: -1225 days

GW170817-GRB170817A-AT2017fgo

Some of the things we have learned

GW170817 : Constraining the Neutron Star Equation of State



Gravitational waveforms contain information about NS tidal deformations

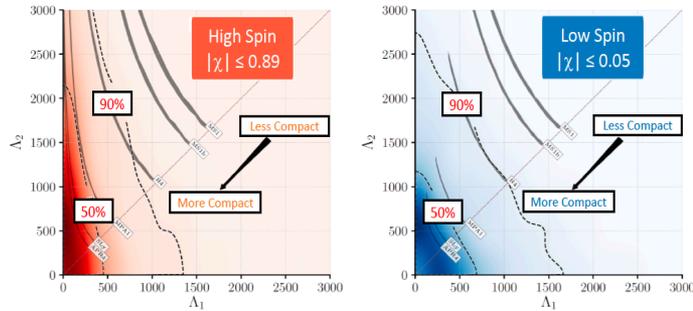
- allows to constrain NS equations of state (EOS)
- become significant above $f_{GW} \approx 600$ Hz

$$\Lambda = \frac{2}{3} k_2 \left(\frac{R}{M} \right)^5$$

k_2 = second Love number
R/M stellar radius/mass

Tidal deformability parameter \rightarrow

Probability density for the tidal deformability parameters



GW170817 data consistent with more compact NS

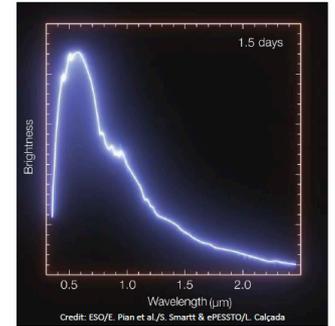
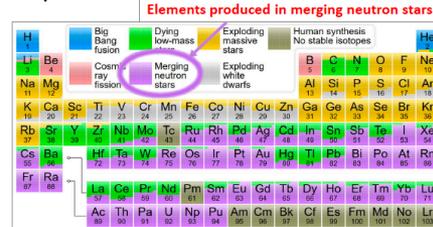
Binary Neutron Star Mergers Produce Kilonovae



- Electromagnetic follow-up of GW170817 provides strong evidence for kilonova model
 - kilonova-isotropic thermal emission produced by radioactive decay of rapid neutron capture ('r-process') elements synthesized in the merger ejecta

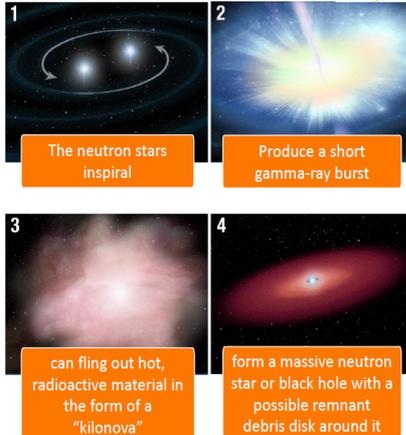
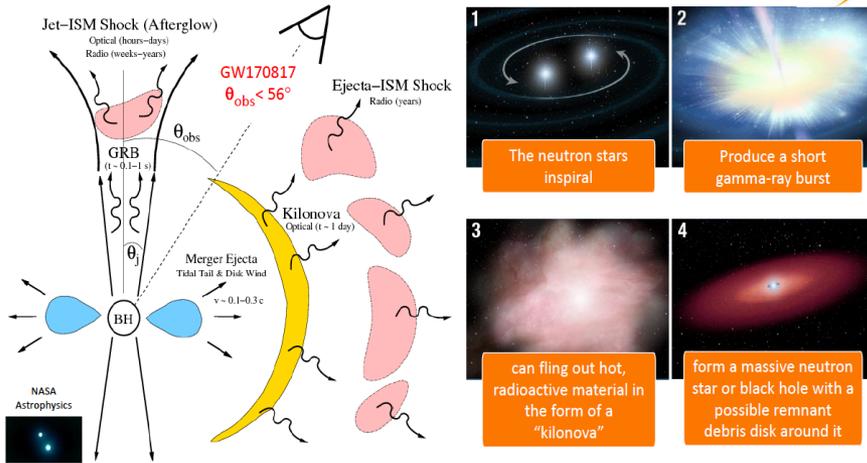
- Spectra taken over 2 weeks period across all electromagnetic bands consistent with kilonova models
 - "Blue" early emission dominated by Fe-group and light r-process formation; later "red" emission dominated by heavy element (lanthanide) formation

- Recent radio data prefers 'cocoon' model to classical short-hard GRB production!



Animation is based on a series of spectra of the kilonova observed by the X-shooter instrument on ESO's Very Large Telescope in Chile.

GRB170817A, AT2017fgo : Electromagnetic Counterparts of BNS Mergers

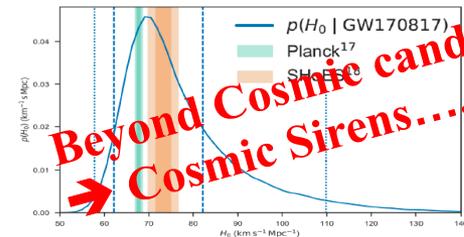


GW170817 : The Hubble Constant



- Gravitational waves are 'standard sirens', providing absolute measure of luminosity distance d_L
- ... without the need for a cosmic distance ladder!
- Association with host galaxy NGC 4993 & luminosity distance directly measured from the GW signal, the Hubble constant is inferred to be

$$H_0 = 70_{-8}^{+12} \text{ kms}^{-1} \text{ Mpc}^{-1}$$

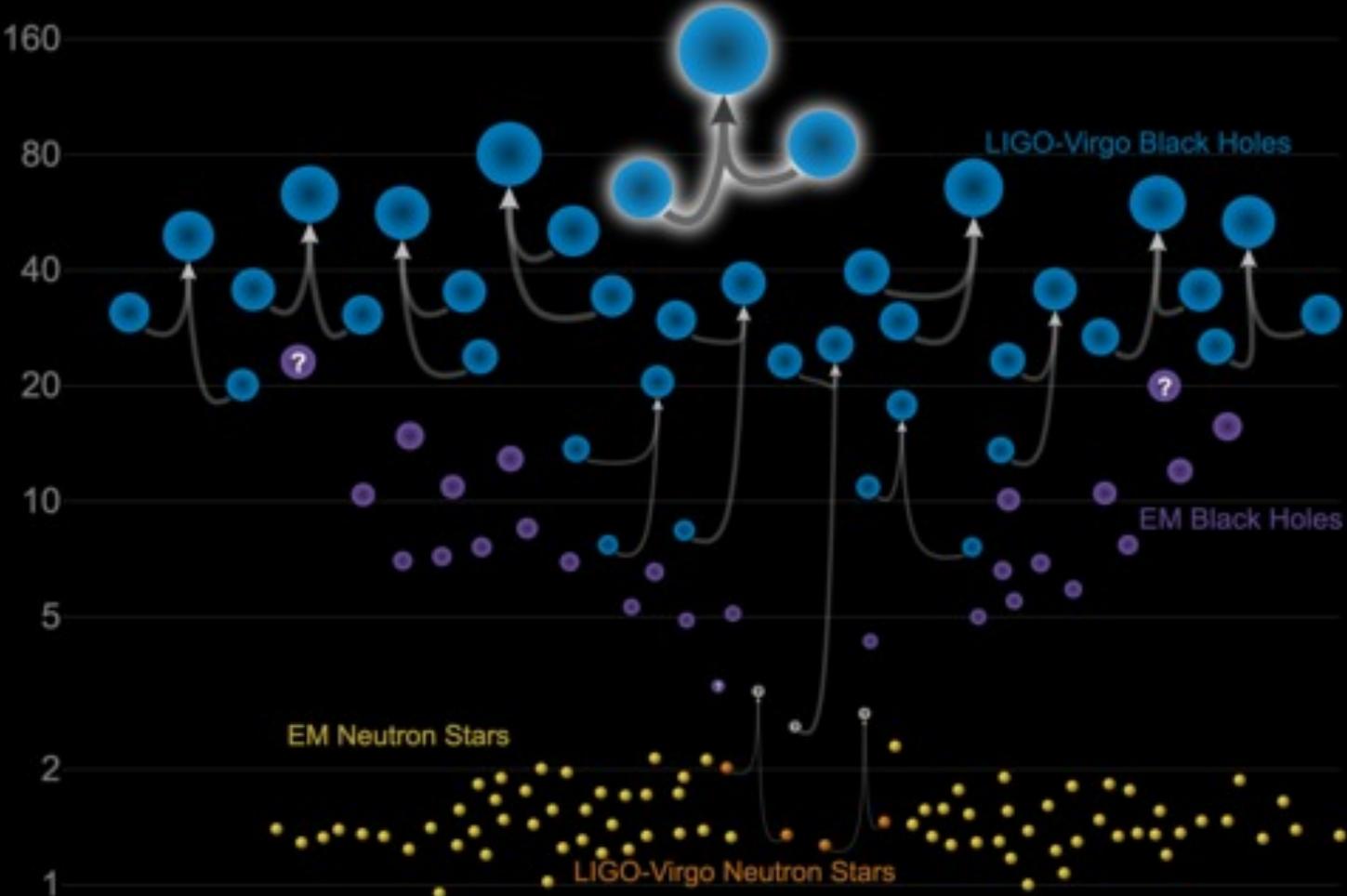


Nature 551, 85–88 (2017)

Uncertainty almost dominated by estimation of doppler shift contribution from the peculiar motion of NGC 4993

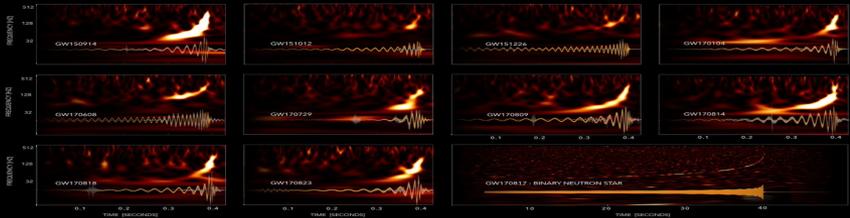
Masses in the Stellar Graveyard

in Solar Masses

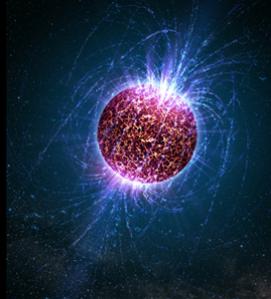


GRAVITATIONAL-WAVE TRANSIENT CATALOG-1

LIGO | Virgo | Gravity | 100%



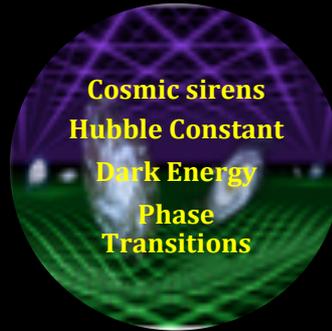
GW and Fundamental Science



Cosmology and Astrophysics

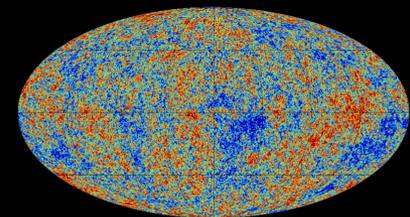
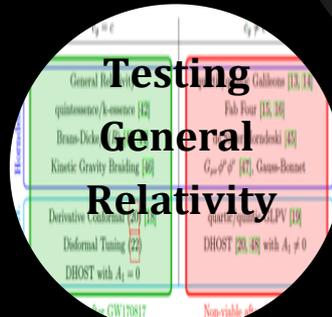
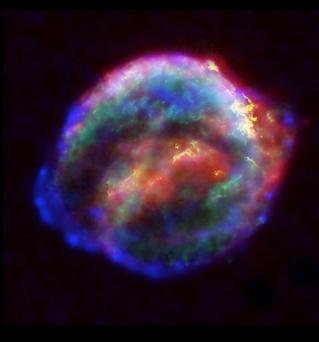
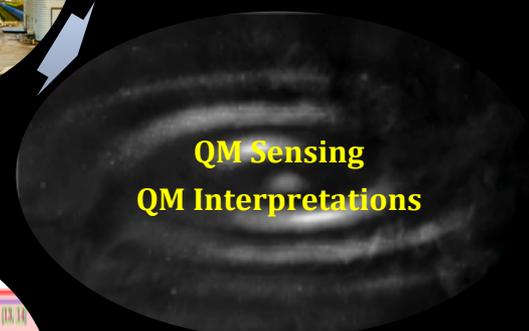
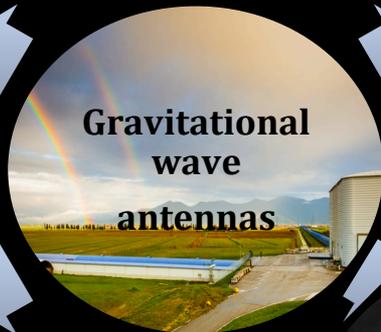
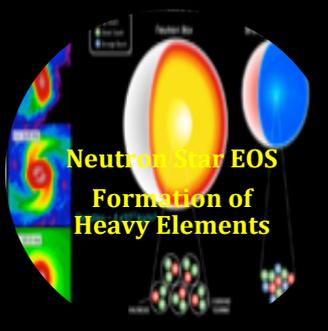
Cosmology and Particle Physics

EU program
AHEAD2020



Astrophysics and Nuclear Physics

Testing Quantum Mechanics

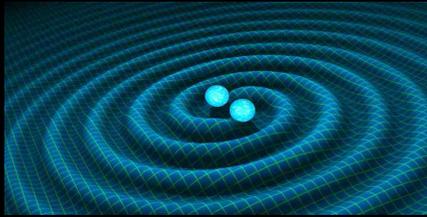


The VIRGO interferometer

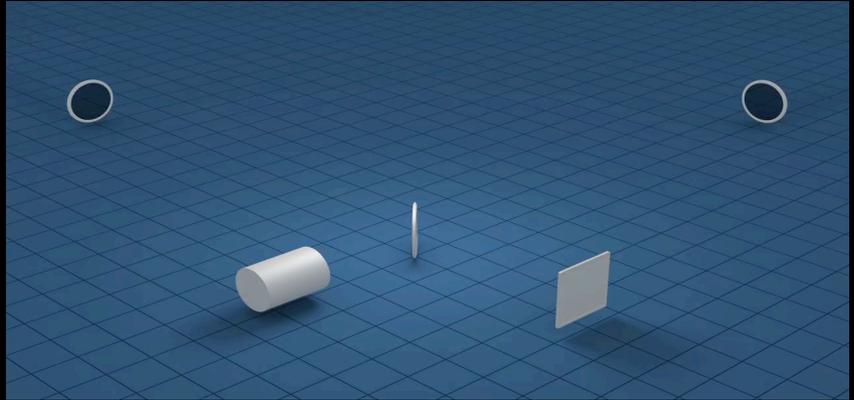
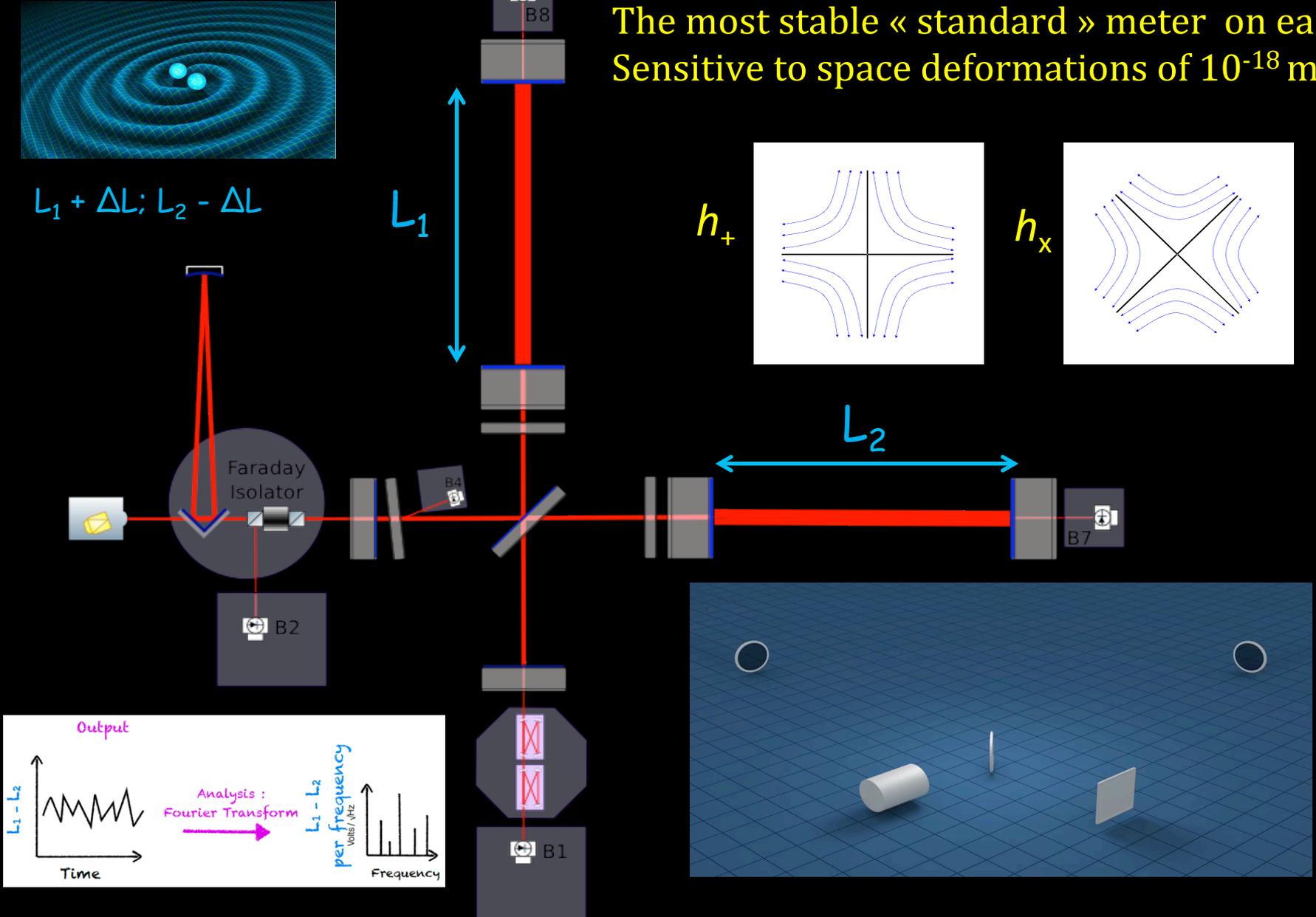


The Advanced Virgo antenna

The most stable « standard » meter on earth
 Sensitive to space deformations of 10^{-18} m

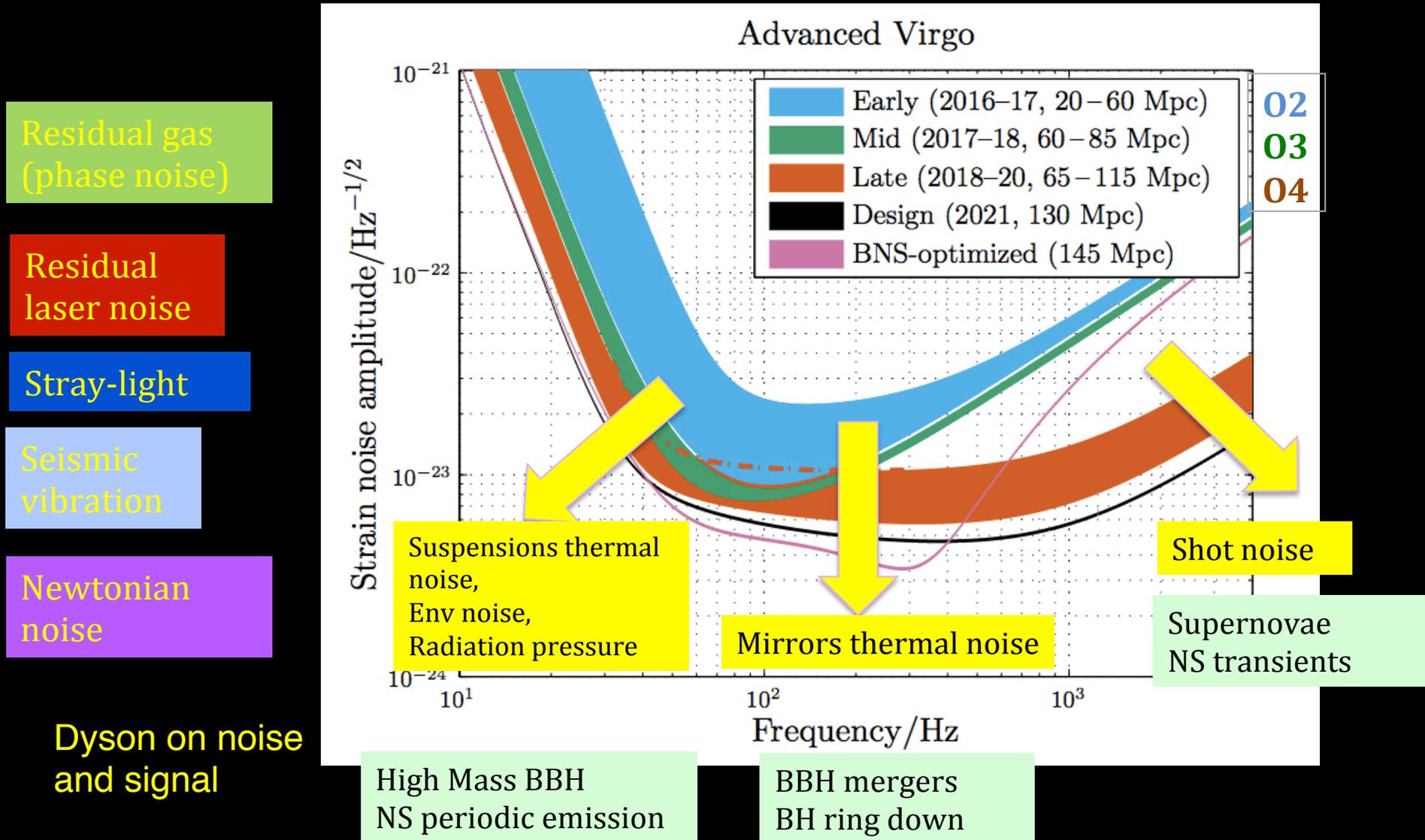


$$L_1 + \Delta L; L_2 - \Delta L$$

 L_1
 h_+
 h_x
 L_2


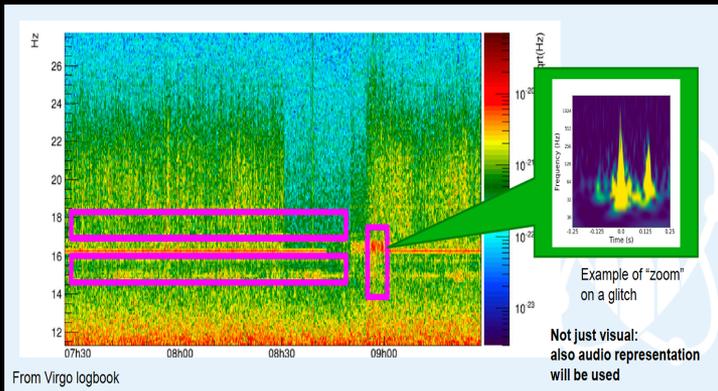
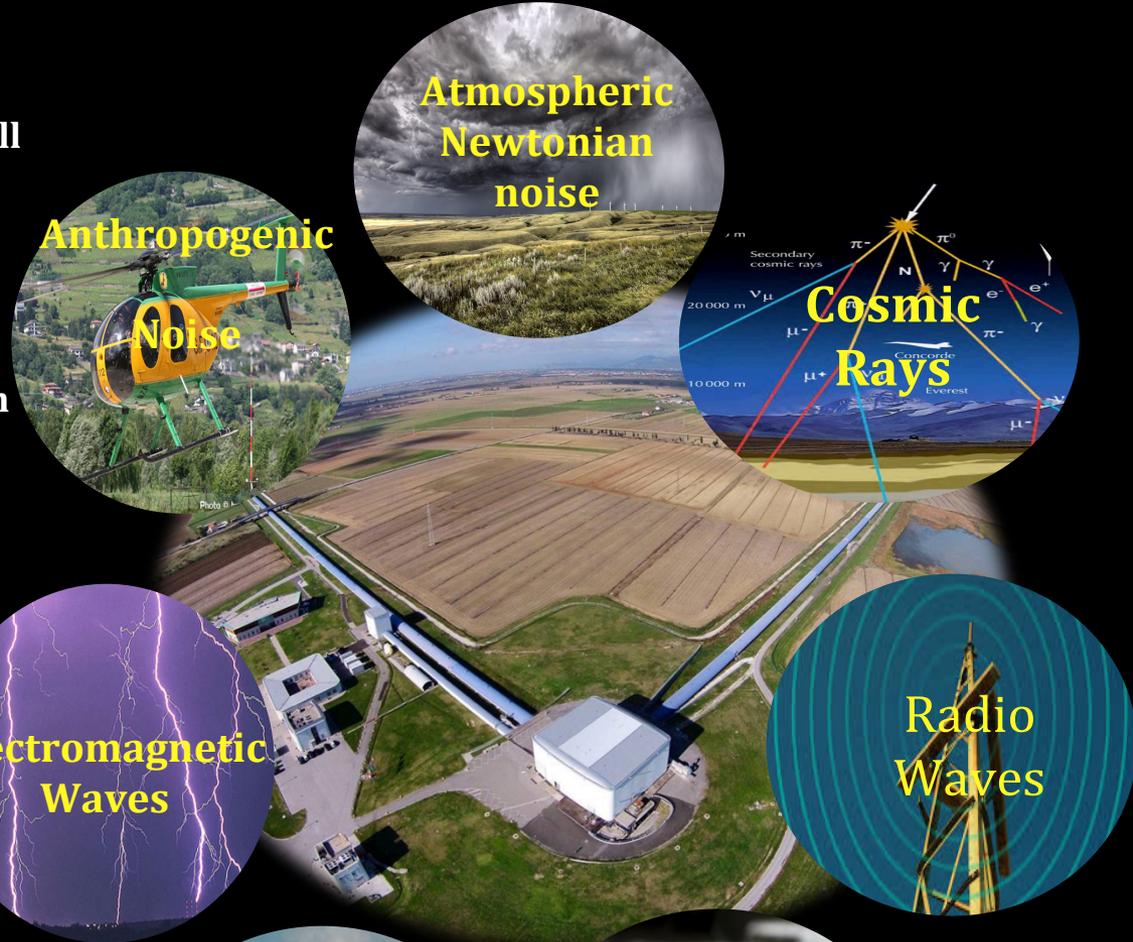
“Satanic” Noise (A. Giazotto)

Sources at different frequencies: a complex task at different technology fronts



Imbedding of Virgo/EGO in Environment

- Virgo: A laser interferometer sensitive to all influences of the environment. Monitored with 2500 “slow sensors”
- Need to understand the Geosphere before understanding the Universe
- Collaboration with Geoscientists (seismicity), Ecologists (impact of waves on coastal erosion), Atmospheric scientists (clouds and newtonian noise), Regional instances on Anthropogenic noise.
- Citizen Science task: classify and characterise signals and “noise” depending on the point of view



EGO/Virgo and Society



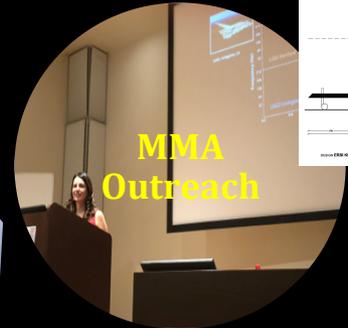
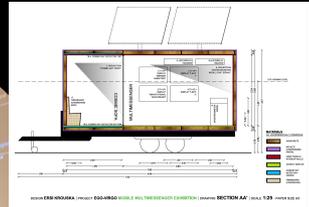
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AHEAD2020



FRONTIERS
Demonstrators



EU program
Ccoordinator
Multisensorial
studies



Visits on the site
>8000/y



Many activities funded by EU programs, Private Foundations

GOALS

Develop

- 1. Interdisciplinary scientific knowledge with the support of citizens in a two way process. Associate research on “fundamental science” with environmental concerns*
- 2. Multi-sensorial “multi-messenger” understanding of the cosmos .Go beyond the Visual*
- 3. Inclusion and diversity . Treat gender issues. Extend participation to visually impaired, confined, seniors*
- 4. Critical thinking in a world of increased digital connectivity . Effectively separate signal from background noise, formulate hypotheses, estimate proper biases, manage uncertainty, collective thinking versus herd thinking,...*
- 5. Paths traversing traditional frontiers of the modes of apprehension of reality . E.g. the cognitive and the affective: Art and Science*





A common platform ZONIVERSE

Citizen Science Platform with more than 1,000,000 volunteers

- www.zooniverse.org



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REINFORCE WP3 Demonstrator - GW Noise Hunters

ABOUT CLASSIFY TALK COLLECT RECENTS LAB

First Demonstrator for the REINFORCE WP3

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PROJECTS ABOUT GET INVOLVED TALK BUILD A PROJECT NEWS SIGN IN REGISTER

Deep Sea Hunters

ABOUT CLASSIFY TALK COLLECT

Help us at KM3NeT searching for neutrinos, by understanding specific sources of noise in our detector: bio-activity in the deep sea!

[Learn more](#)

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REINFORCE WP5

ABOUT CLASSIFY TALK COLLECT

Look for signatures of new massive long lived particles which could be a sign of New Physics.

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PROJECTS ABOUT GET INVOLVED TALK BUILD A PROJECT NEWS SIGN IN REGISTER

Diaphane trial 2 (10/6/2020, 2:03:36 PM)

ABOUT CLASSIFY TALK COLLECT

An English Version of our Diaphane Site is coming soon, stay tuned.

Muon Tomography is a non invasive method to monitor the internal structure of massive objects by using particles originating from Stars and Galaxies far far away...

[Learn more](#)

An important tool : Sonification

- Not only increasing inclusion . Also increasing the researchers discrimination power of signal over background through the use of sound. Wanda Merced Diaz and Beatriz Garcia

WMD: You seeing people tend to either linearize of stationarize events....

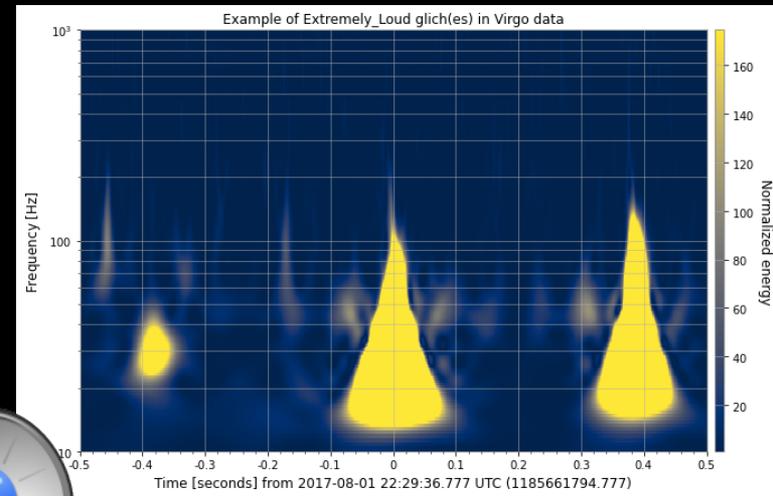
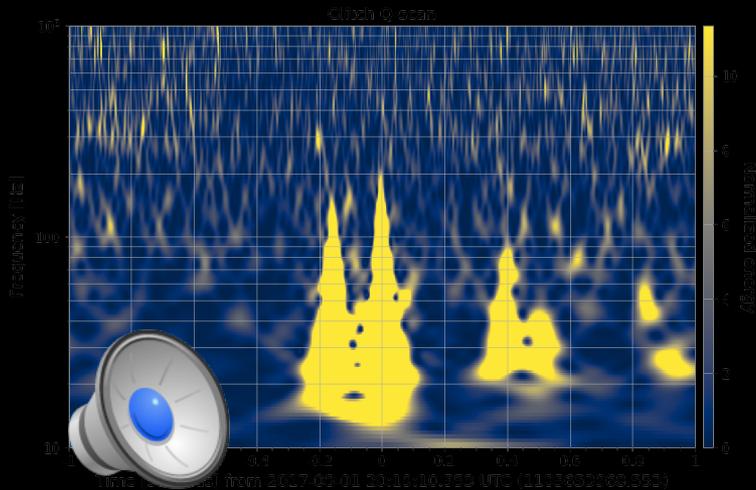


https://www.ted.com/talks/wanda_diaz_merced_how_a_blind_astronomer_found_a_way_to_hear_the_stars?language=it

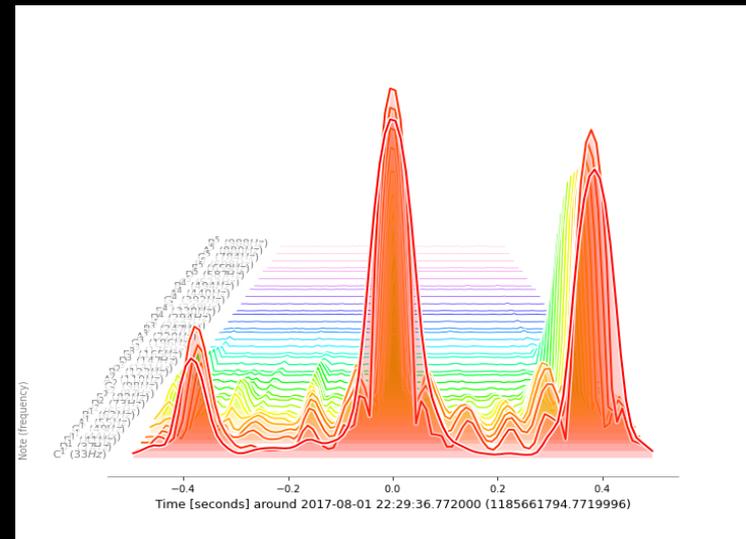
Wanda joins Ego starting January 2021

New sonification software (SonoUno) <https://pypi.org/project/sonoUno/>

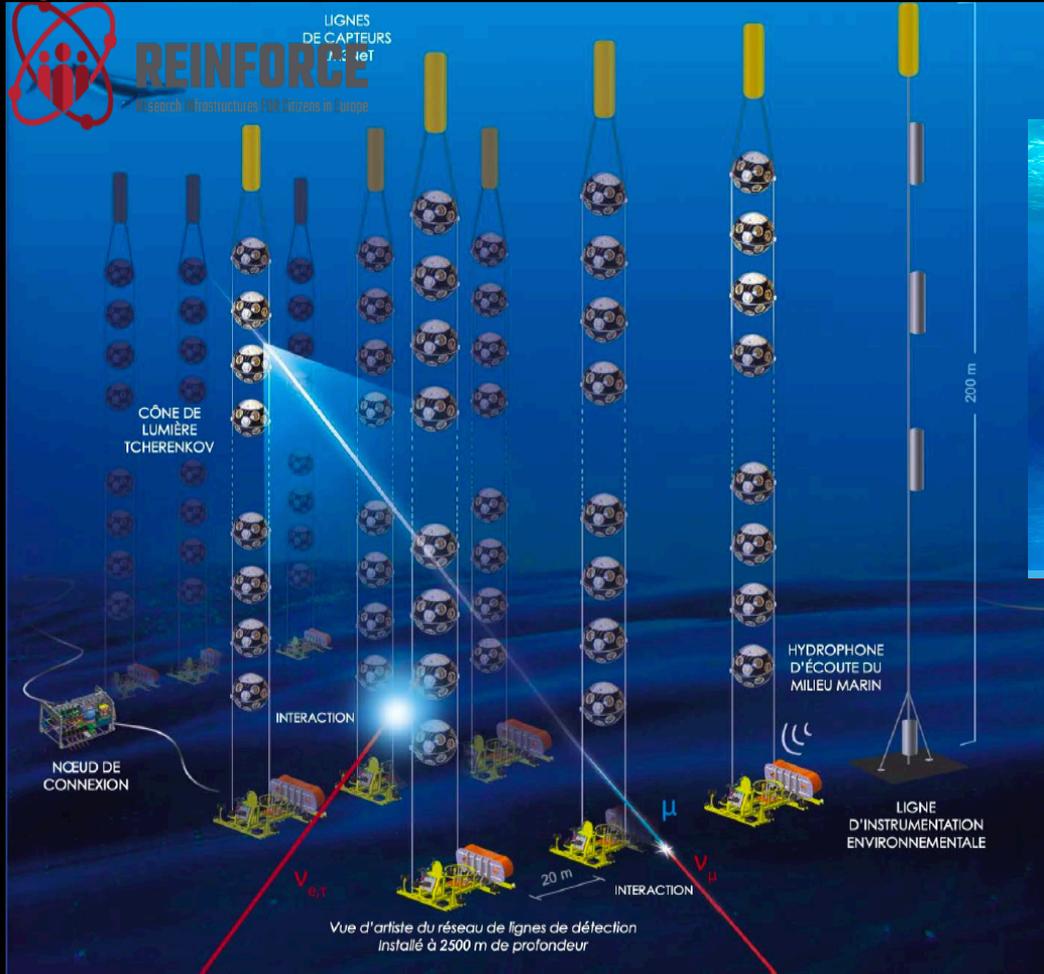
Example 1 : Characterise GW “Glitches” Environmental or events of cosmological origin ?



Within the same time-frequency map of Q-scans, we divide the frequency range into certain number of bands. In this example, the edges of these bands are chosen to be the notes of the C (Do) major scale of Occidental music (the white keys of a piano). In each band we compute the RMS energy over 0.01 seconds. In such a way, we obtain a time series, for each band, that corresponds to the "energy" of the note that identifies the interval, and to the colored curve in the plot. From this we also obtain the audio file, where each note is activated every time the band RMS exceeds a "noise threshold", and with an intensity proportional to the energy.



Example 2: Imbedding Deep sea Neutrino Observatories in the Biosphere



KM3NeT

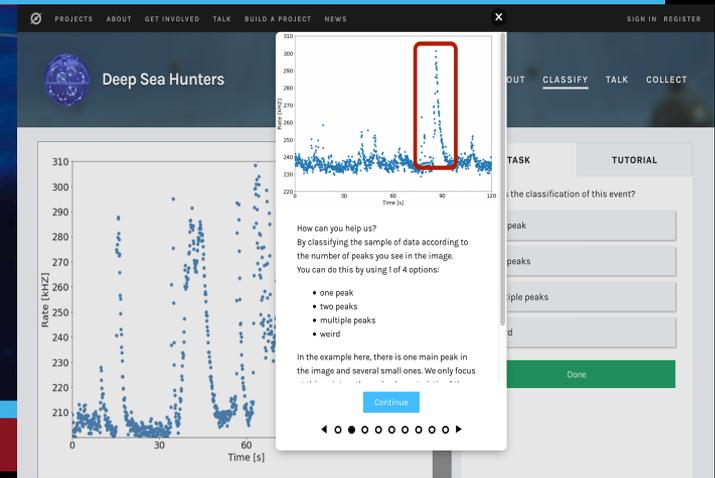
Deep Sea Hunters

Bioluminescent organisms:
Optical Signals



Ceteceans:
Acoustic Signals





Deep Sea Hunters

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OUT CLASSIFY TALK COLLECT

TASK TUTORIAL

How can you help us?
By classifying the sample of data according to the number of peaks you see in the image. You can do this by using 1 of 4 options:

- one peak
- two peaks
- multiple peaks
- weird

In the example here, there is one main peak in the image and several small ones. We only focus on the main peak.

Continue

Last but not least Critical Thinking and Art & Science

- Develop in parallel, critical sense, through discussions hangouts, sprints etc / Collaboration in progress with Sense and Sensibility in Science, Big ideas course of S.Perlmutter , Berkeley
- Co-create events with artists , e.g. exhibition The Rhythm of Space, co-founded with Foundation Carasso, and participation of key artists



A poem by AIMA people seeing a work of art on black holes :

Riflessione:

Nucleo sferico, globo, forma.

Nero. Terra notturna illuminata
dalla luna.

Abisso.

Pieno o vuoto...

...liscio!

Mistero esoterico.

Ragione. Emozione.

Inquietudine. Oppressione.

....freddo!

Pupilla di Polifemo.

<https://sites.ego-gw.eu/ilritmodellospazio/>

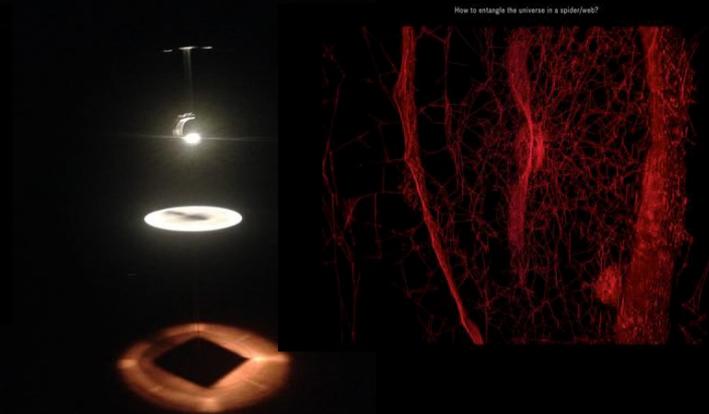
<https://www.youtube.com/playlist?list=PLjqllcYxValr0BwpbsocYSjZtZILxt64V>

An exhibition on Art and Science Rythm of Space

Museo della Grafica Pisa, 12 October 8 December 2019

T. Saraceno, L. Lijn, A. Csorgo, B.Lamarche, R. Dellaporta, G. Alda/A. Ortiz...

Scientists and artists are the world's noticers. Their job is simply to notice what other people cannot.
Franck Oppenheimer



Also with T. Saraceno "On air" in Paris and Palazzo Strozzi
In discussion for Exploratorium SF, Paris, Rome, Athens, Jerusalem

A global program A+/AdV+/KAGRA/LIGO India The next 10 years

- > x100 sources
- A global international network (MoU with KAGRA/ICRR)
- A global Multimessenger network



LIGO Scientific Collaboration:

- 1263 collaborators (including GEO)
- 20 countries
- 9 computing centres
- ~1.5 G\$ of total investment

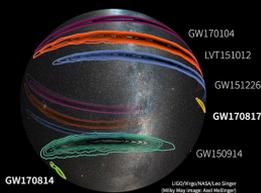
Virgo Collaboration:

- 343 collaborators
- 6 countries
- 6 computing centres
- ~0.42 G€ of total investment

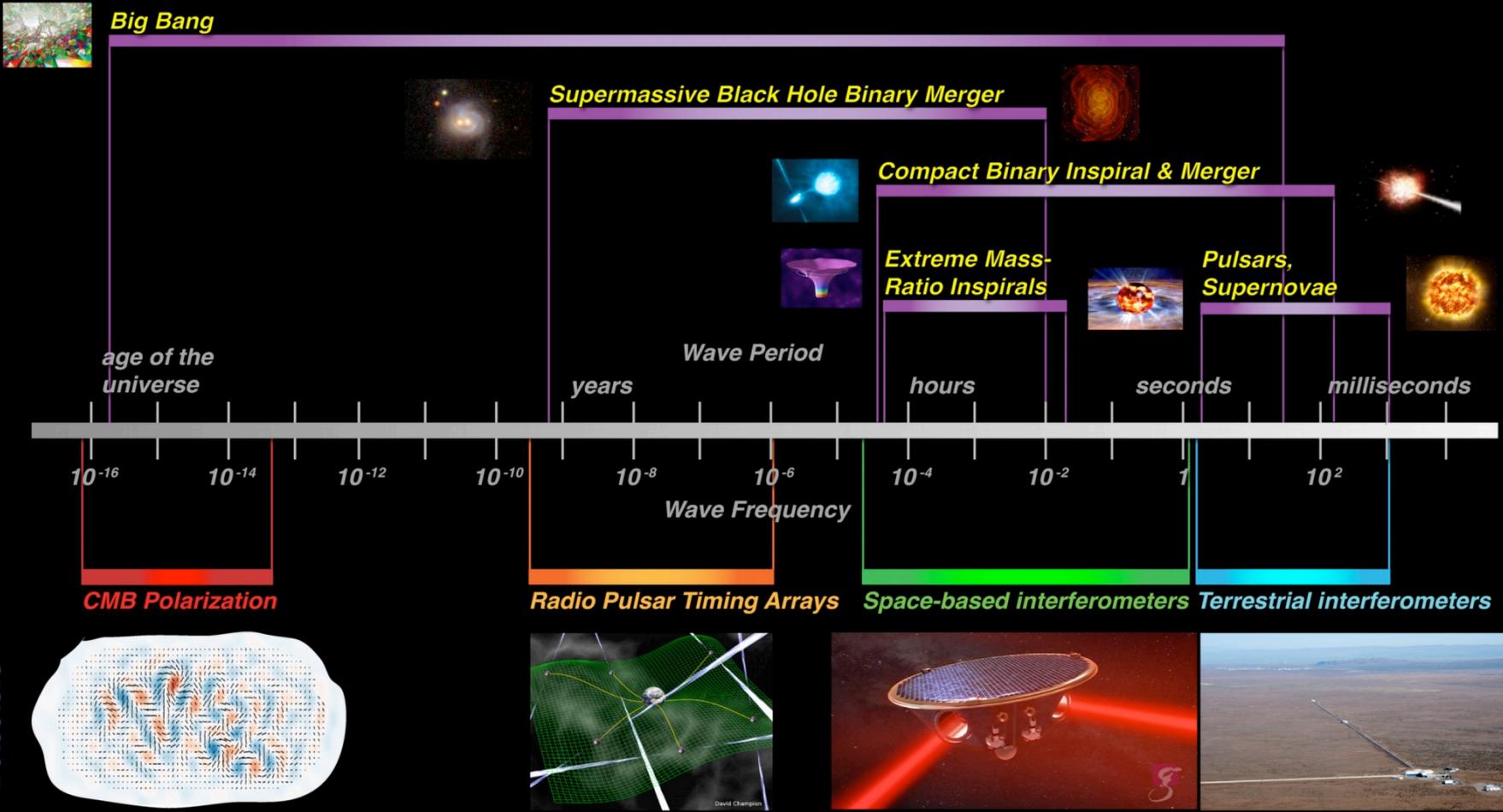
KAGRA Collaboration:

- 260 collaborators
- 12 countries
- 5 computing centres
- ~16.4 G¥ of construction costs

Ground-Space complementarity



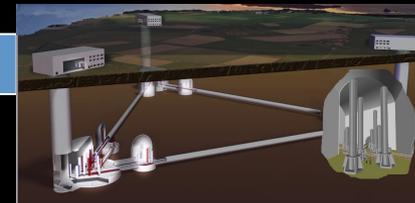
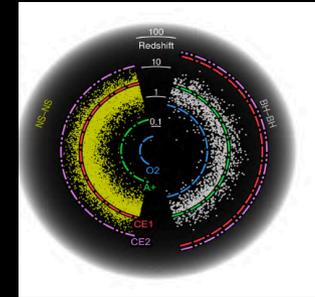
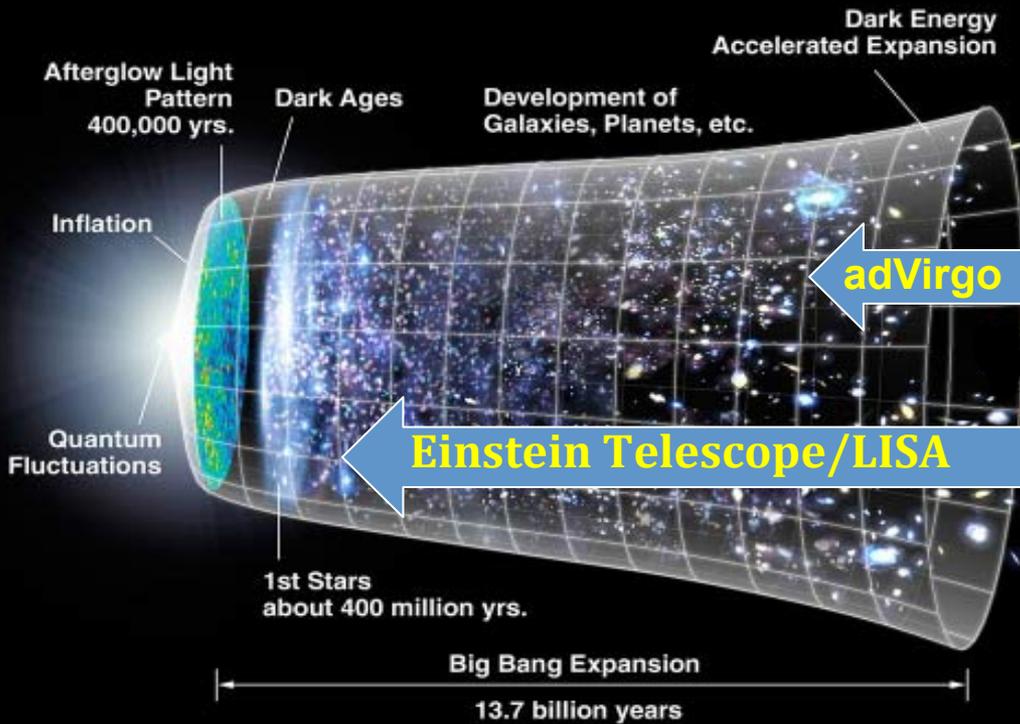
The Gravitational Wave Spectrum



LISA

The next 20 years

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034
AdV	O4 prep		O4 run x10 sources	O5 prep	O5 prep	O5 run x10 sources									
Einstein Telescope	ESFRI roadmap		ET preparation												ET run x1000 sources



Cosmos, genealogy of the concept



✓ *Cosmos appears for the first time in Homer, Book XIV of Iliad to describe the splendid order of ornaments of Hera* / She (Hera) cleansed every mark from her lovely body with rich and gentle ambrosial oil, deeply fragrant. If its scent was released in Zeus' palace, whose threshold was of bronze, it would spread through heaven and earth. With this she anointed her shapely form, then combed her hair, and with her own two hands plaited the lovely glistening ambrosial tresses that flowed from her immortal head. Then she clothed herself in an ambrosial robe that Athena had worked smooth, and skilfully embroidered, fastening it over her breasts with golden clasps, and at her waist with a hundred-tasselled belt. She fixed an earring, a gracefully gleaming triple-dropped cluster, in each pierced lobe then covered her head in a beautiful shining veil, glistening bright as the sun, and bound fine sandals on her shining feet. **When she thus, arranged around herself her cosmos, she left the room.** **Aetius:** "Pythagoras was the first to use the concept cosmos to describe the totality of things"

✓ **Andrei Linde** : Dear Stavros, Thanks a lot! I always thought that cosmology is very sexy, but now in such a poetic representation my suspicions became reality! Thank you so much, I will try to explore it further! Andrei

✓ Not only a spatial order → **Plato:** "Rhythm is the order of movement (kinesews taxis)"

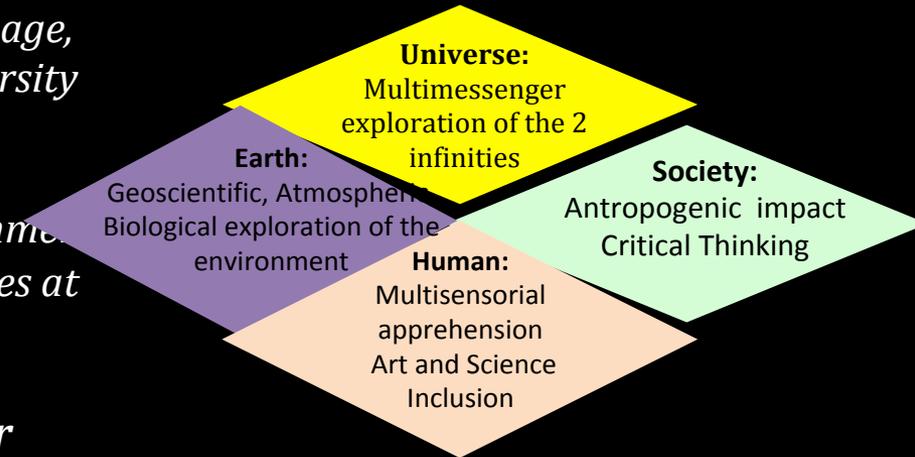
✓ **K. Papaioannou:** « Thus cosmos signifies at the same time adornment and all splendor in general; Universe or totality of beings and a political constitution based on the law; Principle of order and harmony which regulates both the relations between beings and between the elements of each being; Virtue or the Good immanent in each being and enabling it to become what it is and to maintain itself as it is,»

Conclusion

REINFORCE perceives citizen science as a participatory process, in which citizens are trained in frontier science in constant connection with researchers through their communities of practice, they provide their feedback, they voice their concerns and

- *explore the boundaries of knowledge.*
- *explore multi-modal apprehensions of reality (image, sound,...) and therefore tackle inclusion and diversity issues*
- *forge interdisciplinary connections studying the embedding of large infrastructures in the environment.*
- *support critical thinking and art/science activities at the interface of research and society*

In short invent new ways of understanding of our embedding in the Cosmos, where cosmos here denotes beyond the Universe, Earth, Society and the Human



The four Cosmos