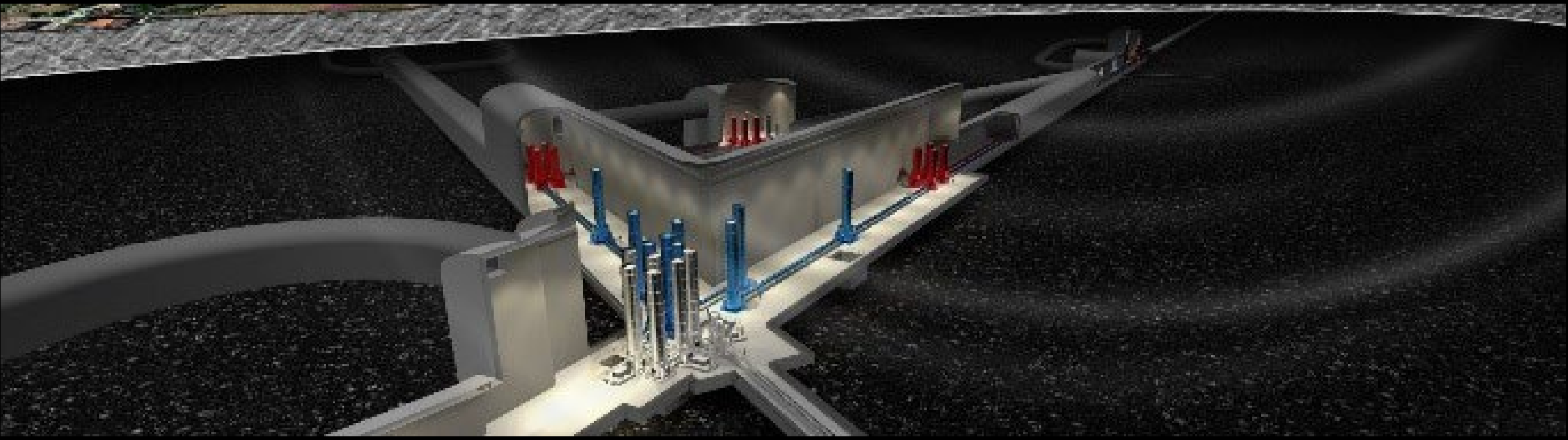
# Einstein Telescope

## The Future of Gravitational-wave Observations

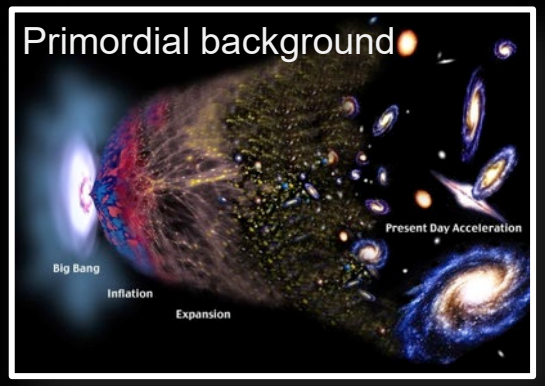


Jan Harms

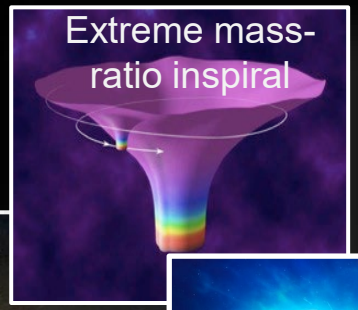
Gran Sasso Science Institute

INFN - LNGS

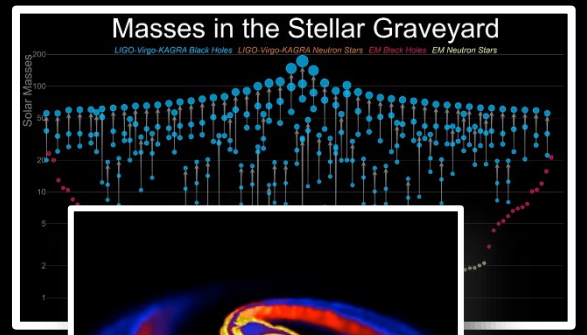
# The Landscape of Gravitational-wave Detection

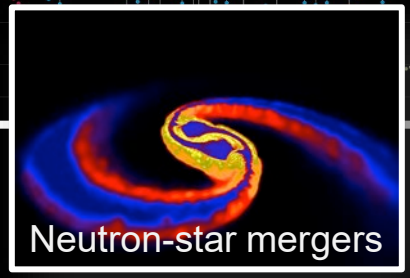


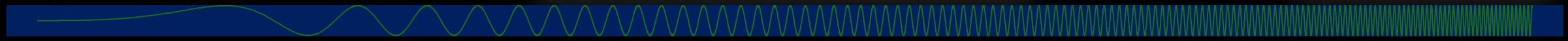






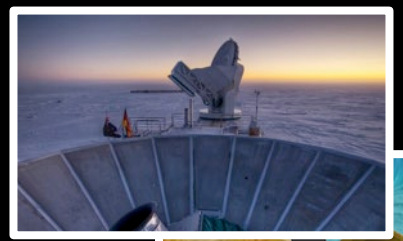


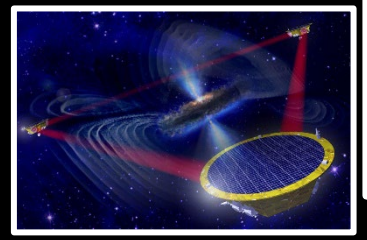
$10^{-16}$ Hz $10^{-9}$ Hz $10^{-4}$ Hz $10^{0}$ Hz $10^{3}$ Hz

Microwave background



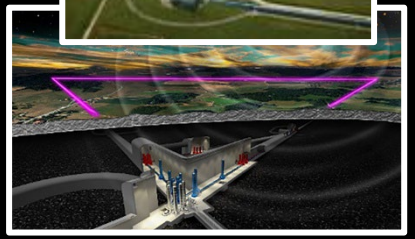
Pulsar timing

Space detectors



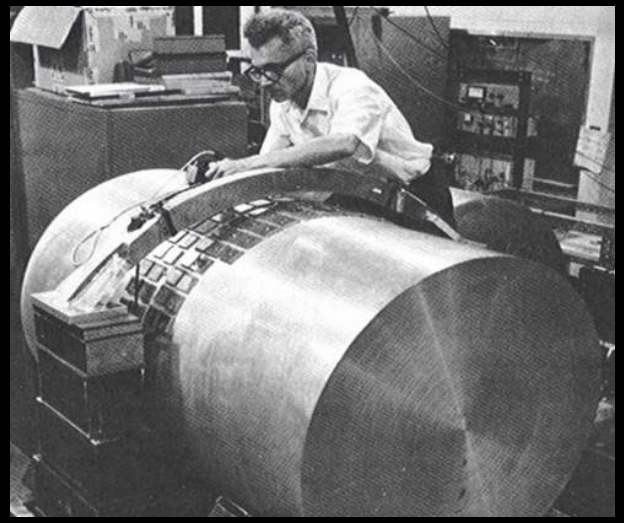
Missing link

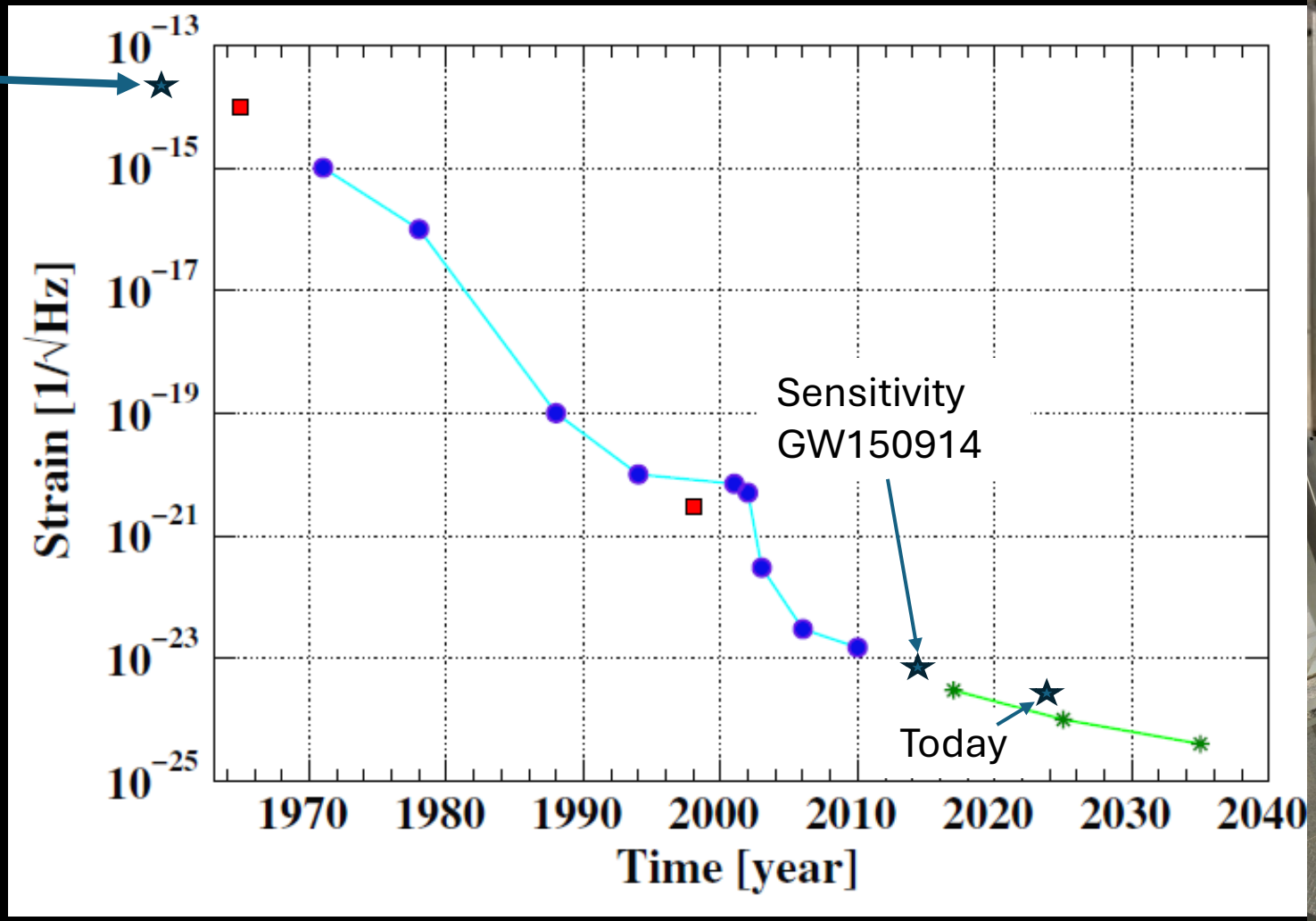
Terrestrial

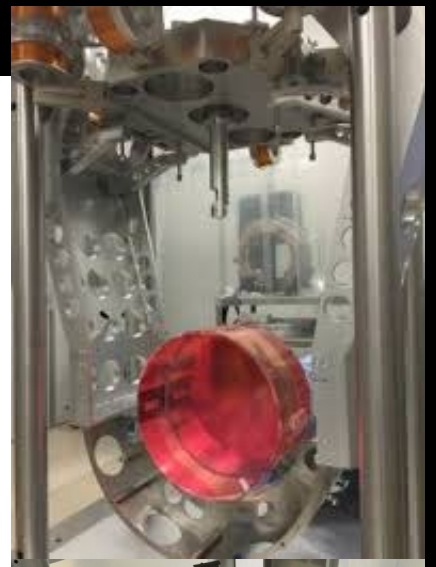


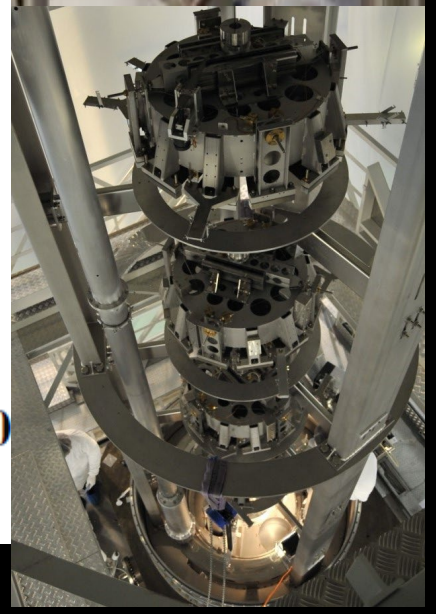
# History of GW Detector Sensitivity

World's first GW measurement in 1961: Oscillations of Earth



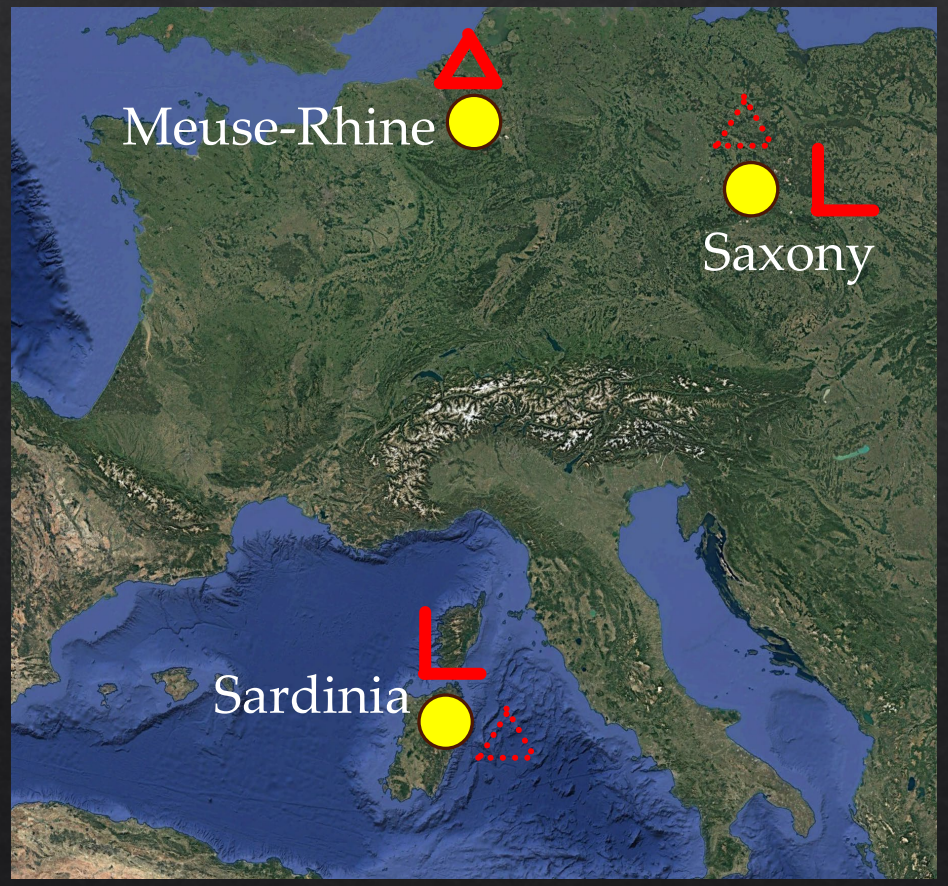




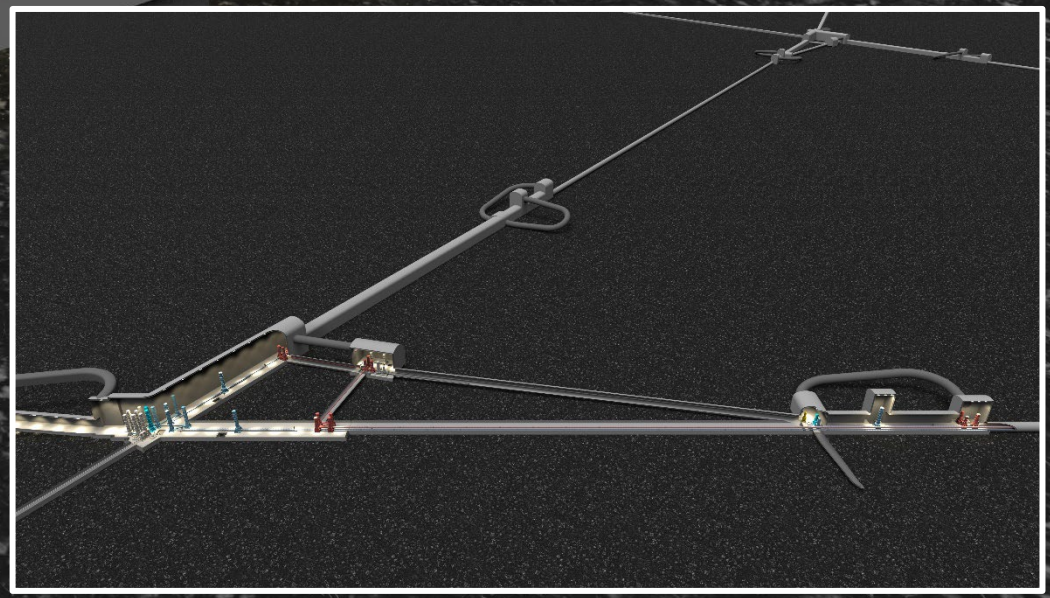
# Einstein Telescope: The Flagship Project

## Three candidate sites

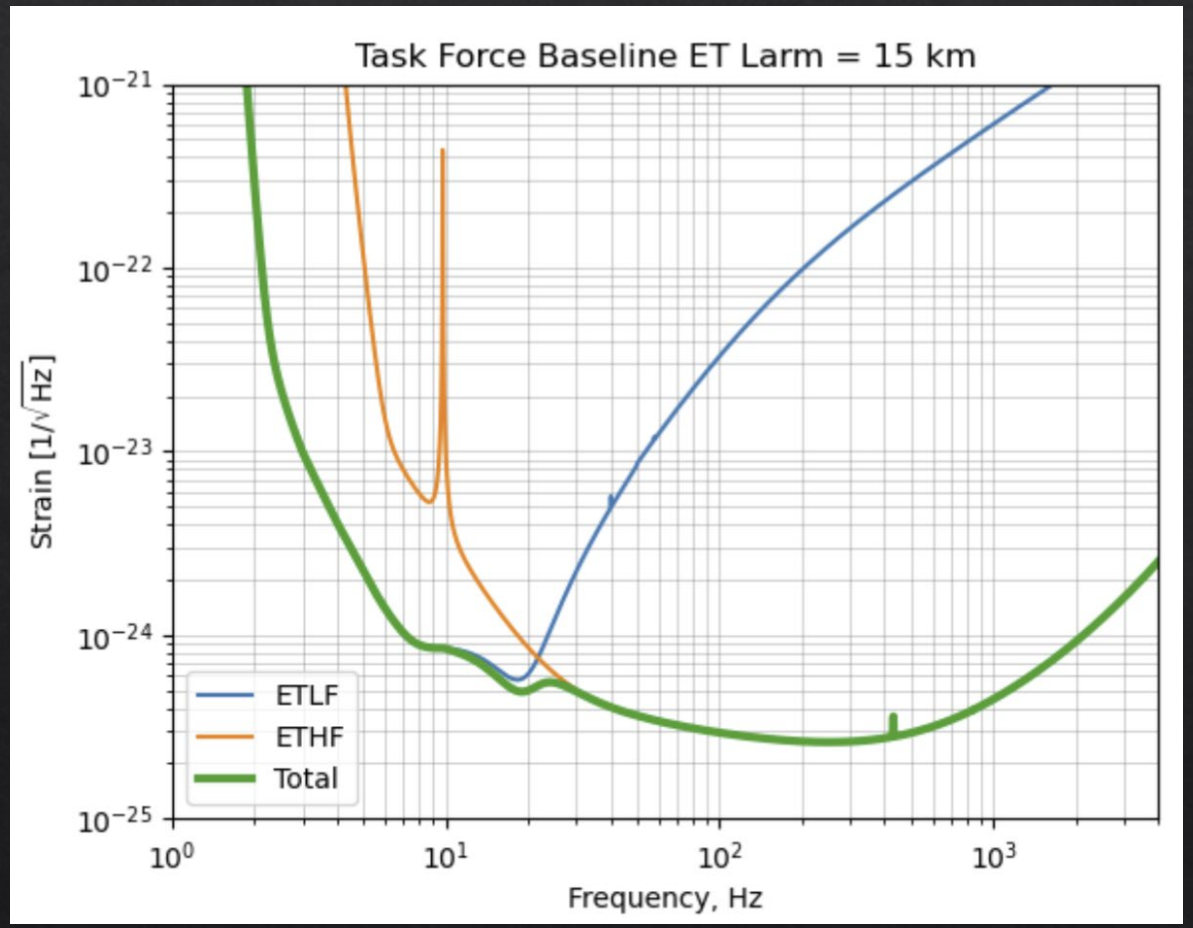



- Infrastructure to be built at a depth of about 250m
- Conceived with a relatively high technological risk to push the frontiers of technological possibilities
- More than 2000 collaboration members (600 people on instrument science, 800 people on observation science)

# ET Underground Infrastructure (in the triangular version)

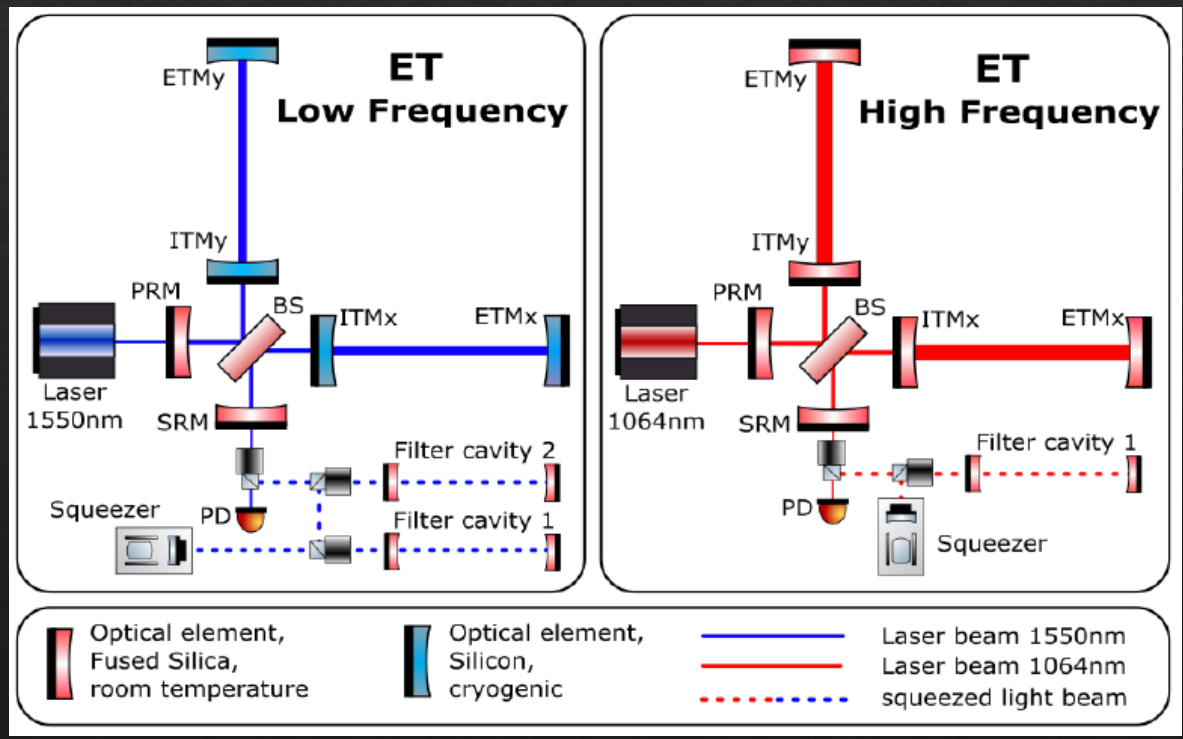


# Einstein Telescope as Xylophone




Optimized for cold temperature operation

Optimized for high laser power



# Mitigation of Noise as Technology Driver

## Environmental noise

- Seismic
- Atmospheric
- Electromagnetic

## Mitigation

- Isolation (vacuum system, suspensions)
- Noise cancellation
- Control

## Intrinsic noise

- Thermal
- Sensing and control

## Mitigation

- Lower temperature
- Increase material quality
- Improve sensors
- Optimize control

## Quantum noise

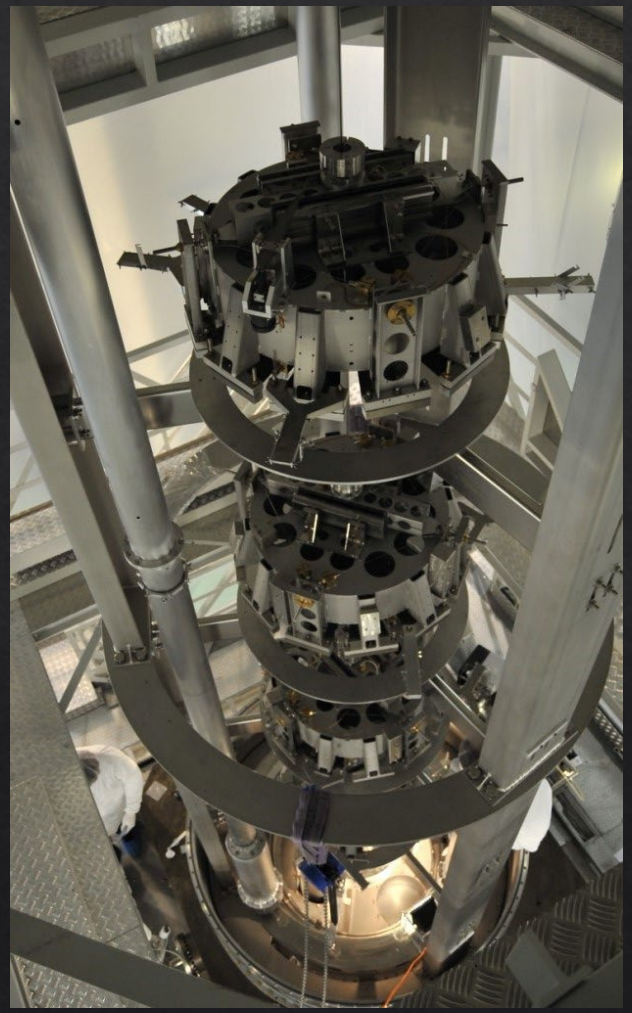
- Vacuum fluctuations
- Back action

## Mitigation

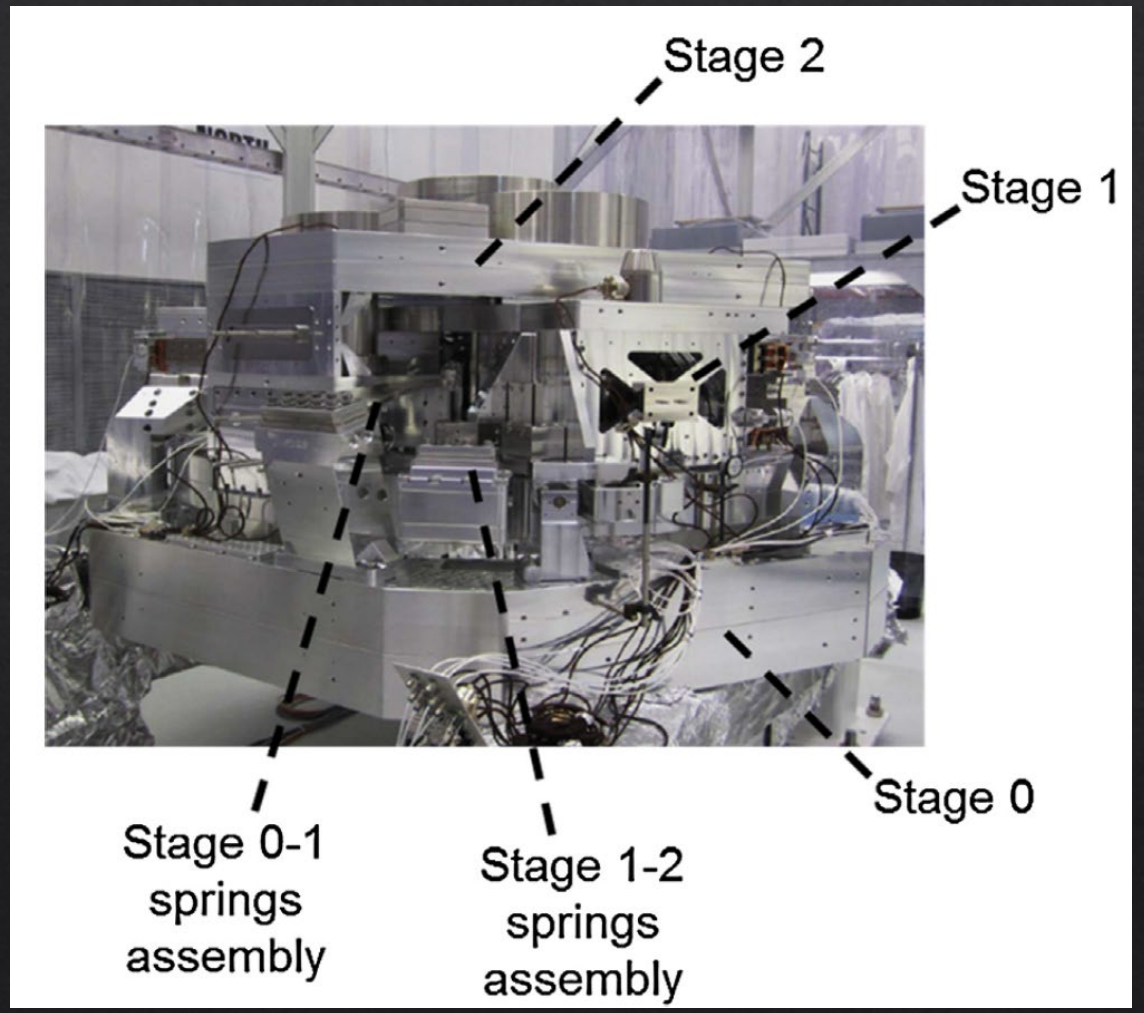
- Quantum-non-demolition
- Reduce decoherence
- Manipulate quantum state

# Seismic Isolation

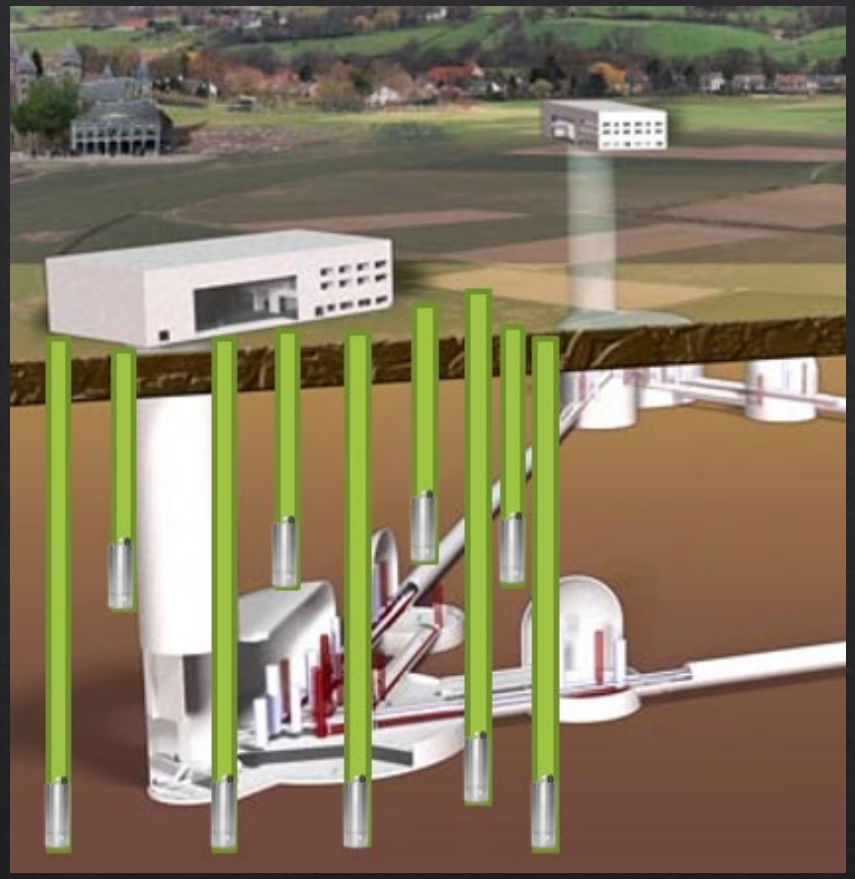
## Virgo Superattenuator



## LIGO Active Stages

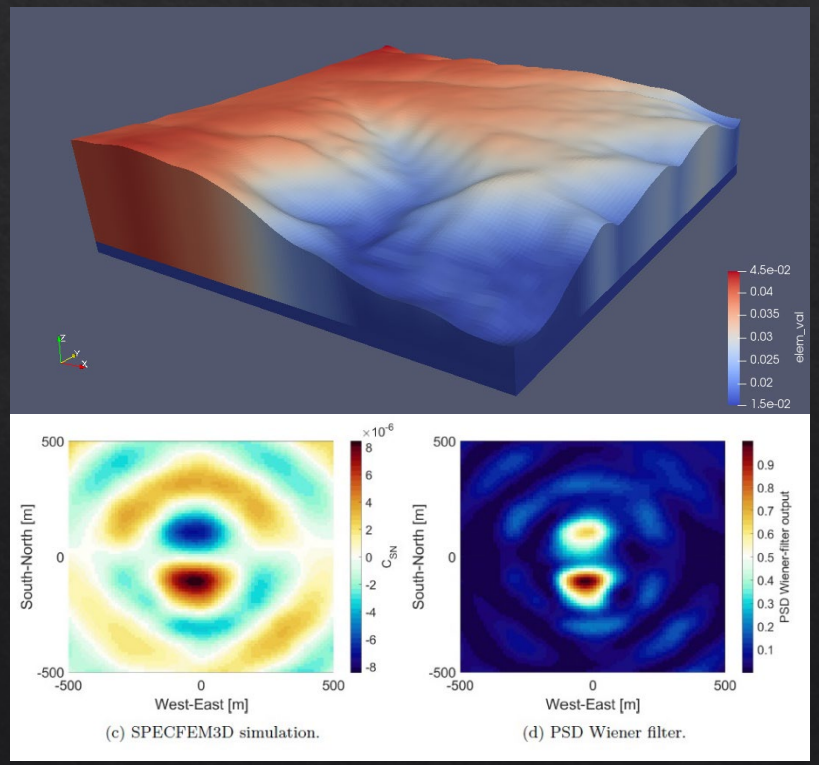


# Mitigation of Gravitational Noise from Earth



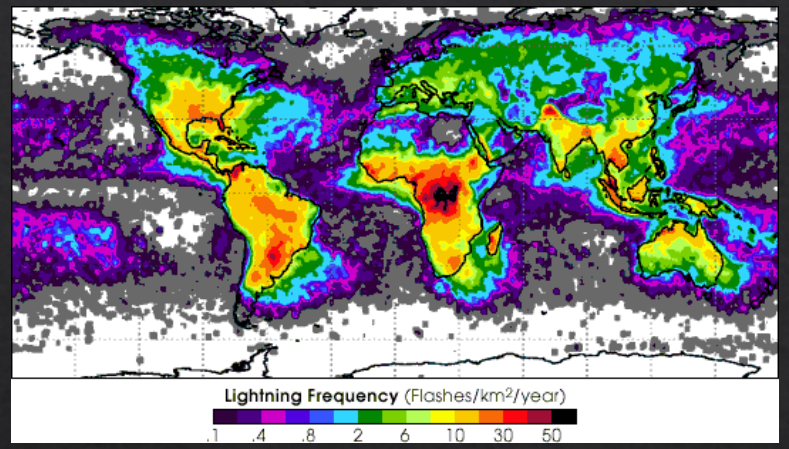
- Hundreds of borehole seismometers
- High cost, complexity, risk…

Numerical simulations of seismic fields and machine-learning based designs




(c) SPECFEM3D simulation. (d) PSD Wiener filter.

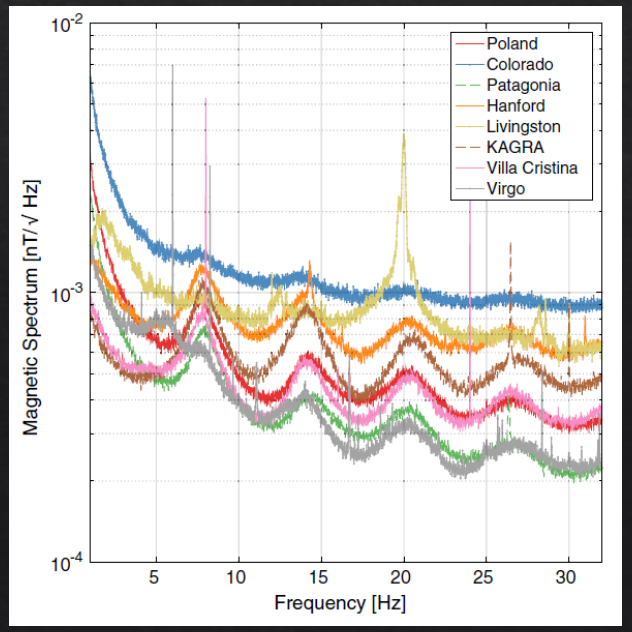
# Magnetic Fluctuations



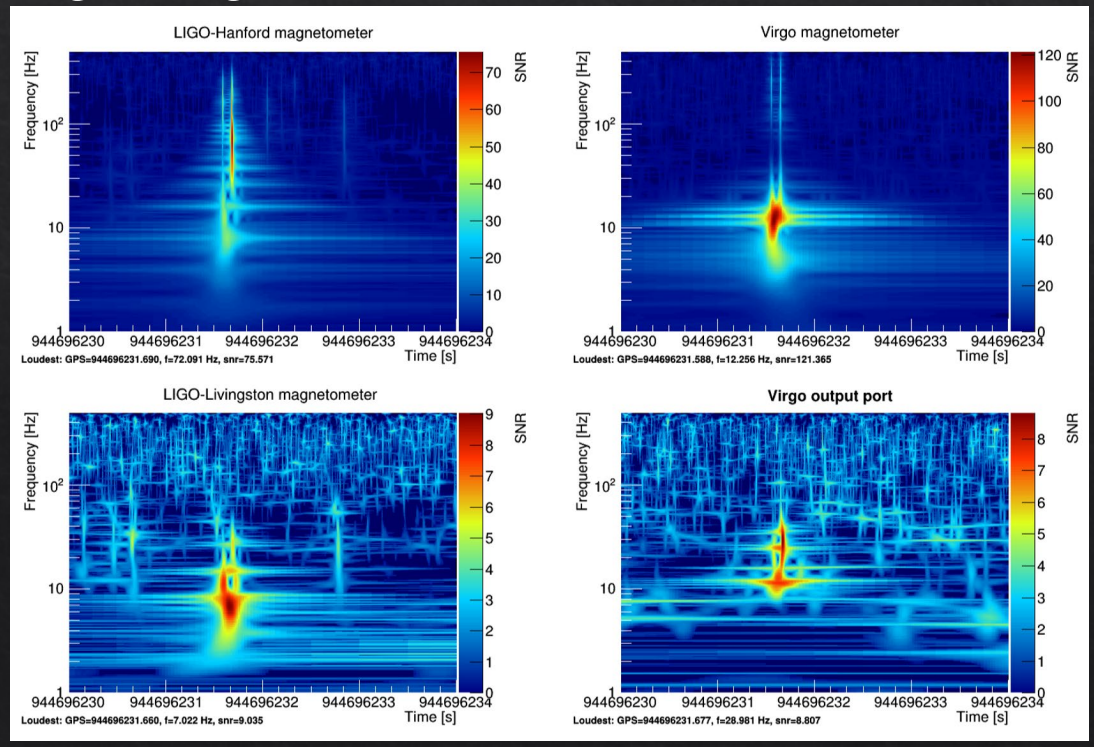

Magnetic disturbances can appear coherently in a global detector network.

Globally coherent disturbances and noise

Schumann resonances




Lightning transient can be coincident



# Machine Learning for Detector Control

## Improving cosmological reach of a gravitational wave observatory using Deep Loop Shaping

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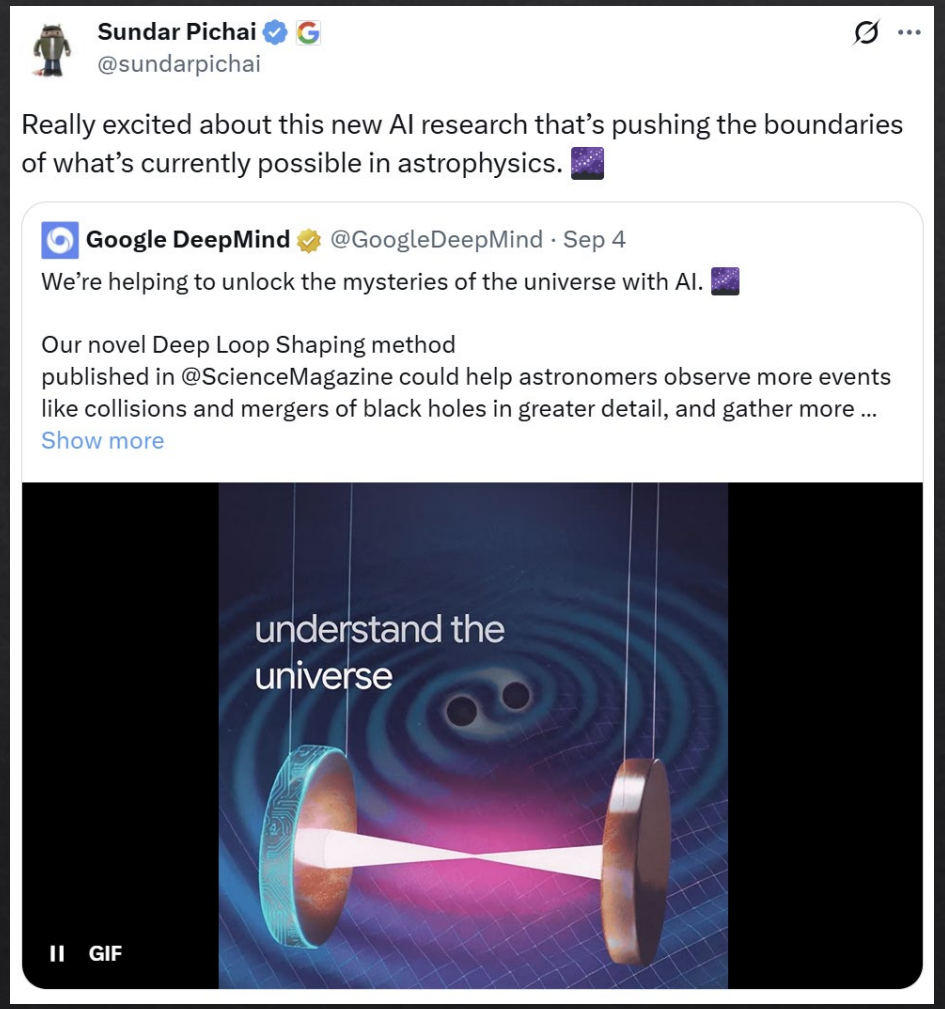
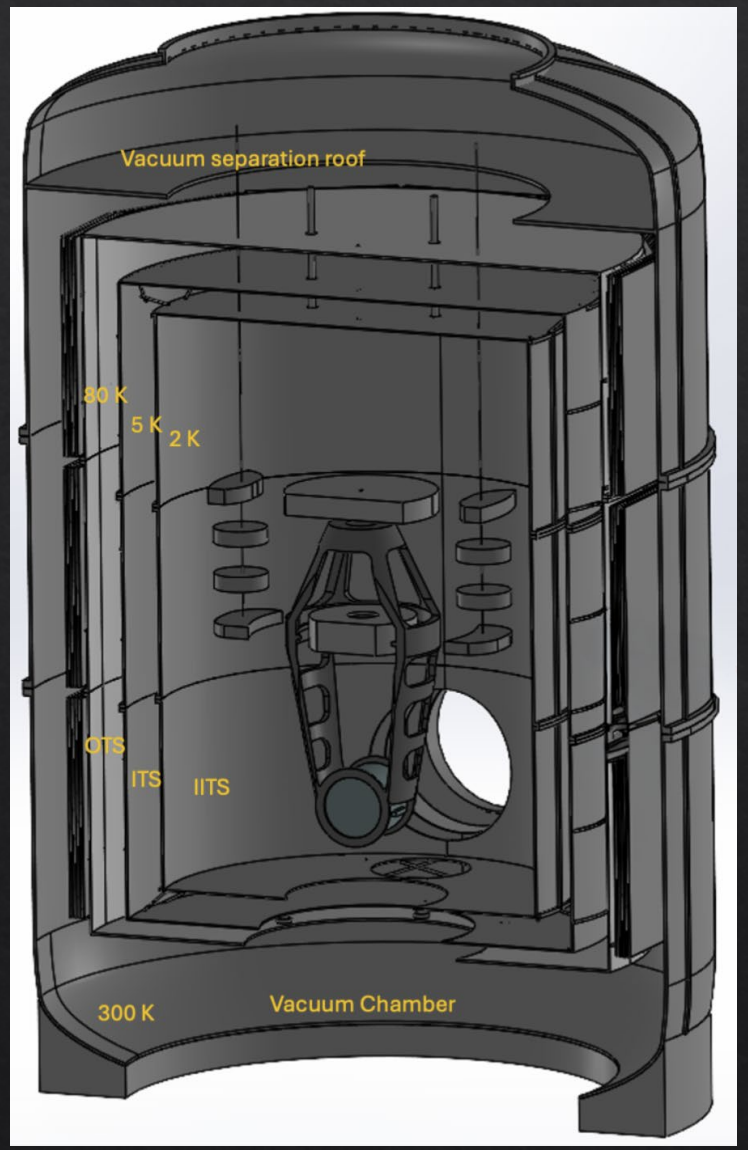
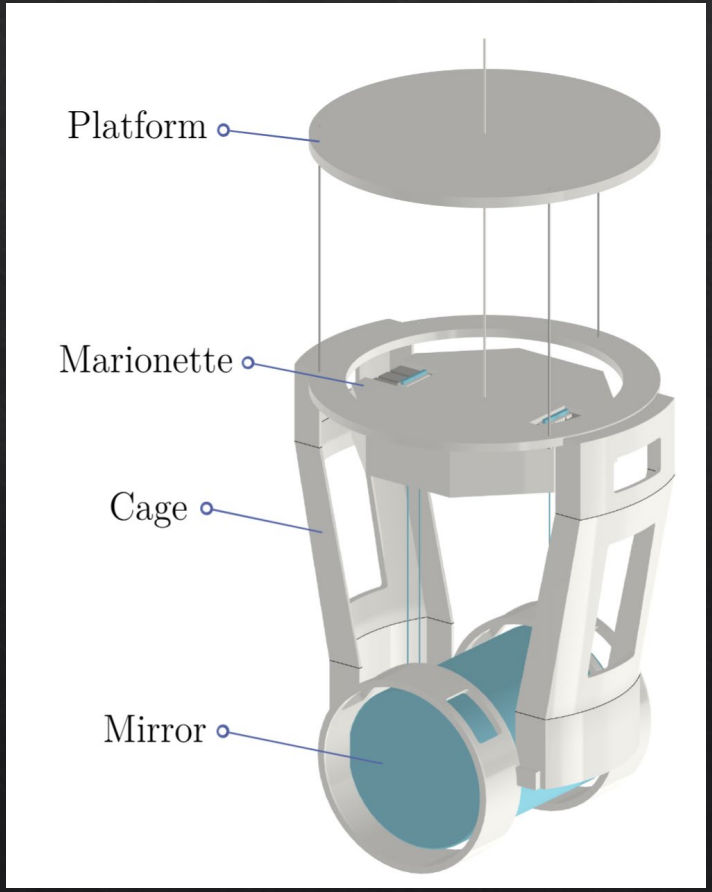



https://www.science.org/doi/10.1126/science.adw1291

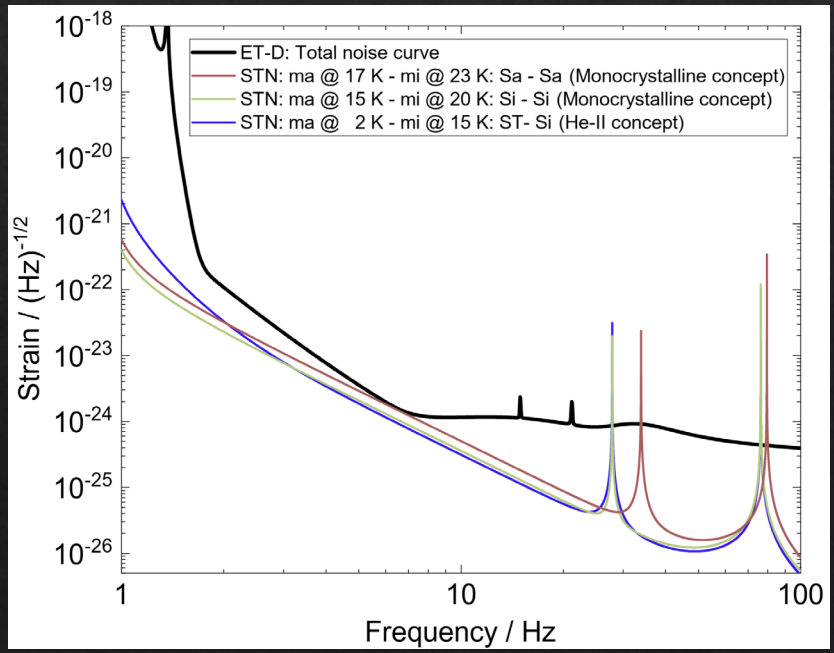
# Cryogenics and the ET-LF Payload



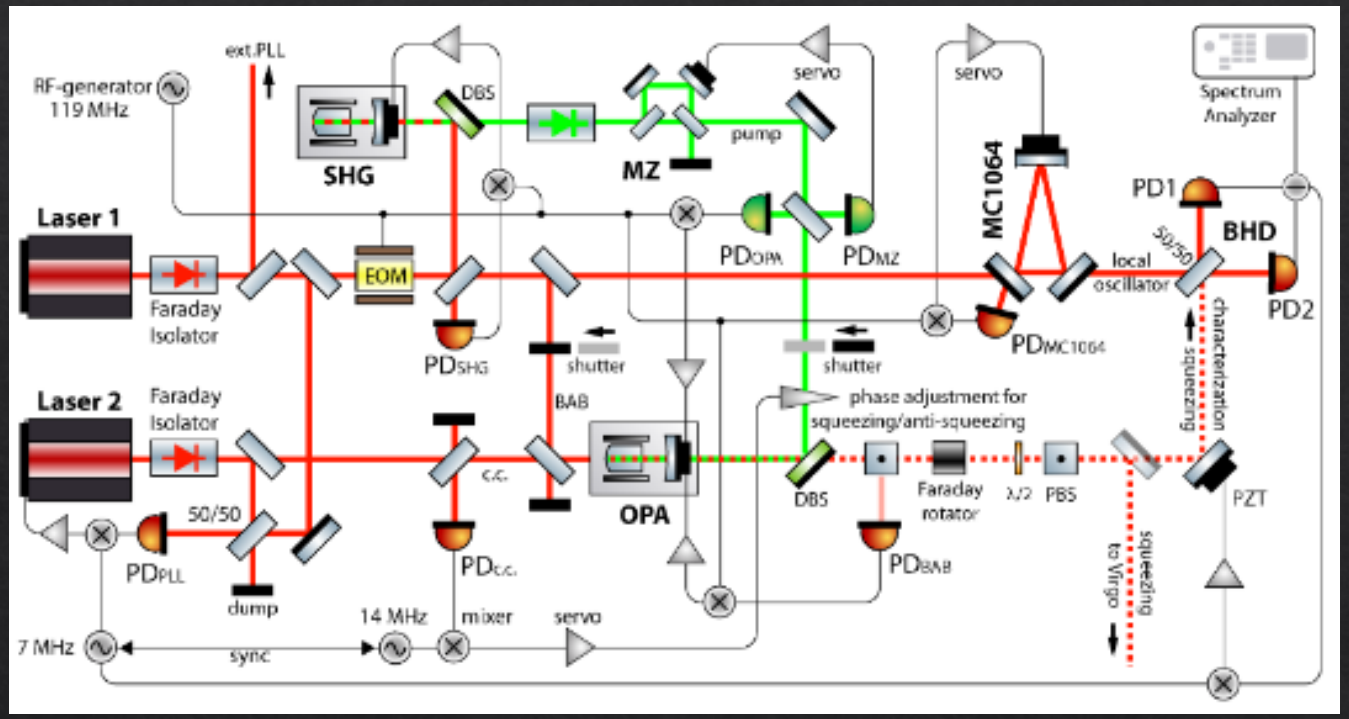

Cooling to 10-20K is the most delicate problem to solve for ET.




Enable low-frequency observations of gravitational waves.



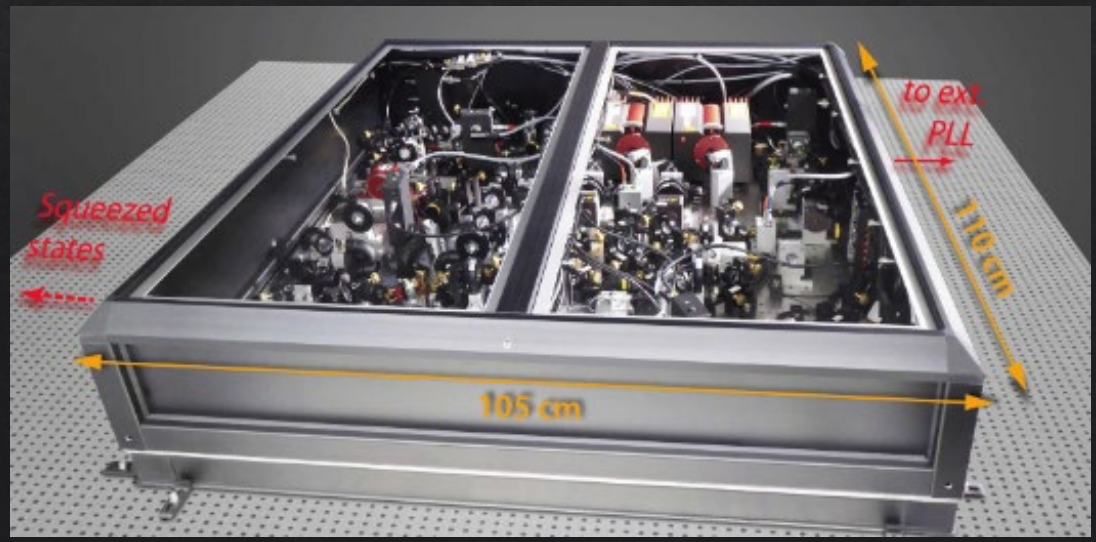
# Quantum Technologies




We need to make quantum fluctuations lower than the noise of the vacuum

We need to build an optical system that is close to perfection

Virgo squeezed-light source



# Large R&D and Integration Facilities

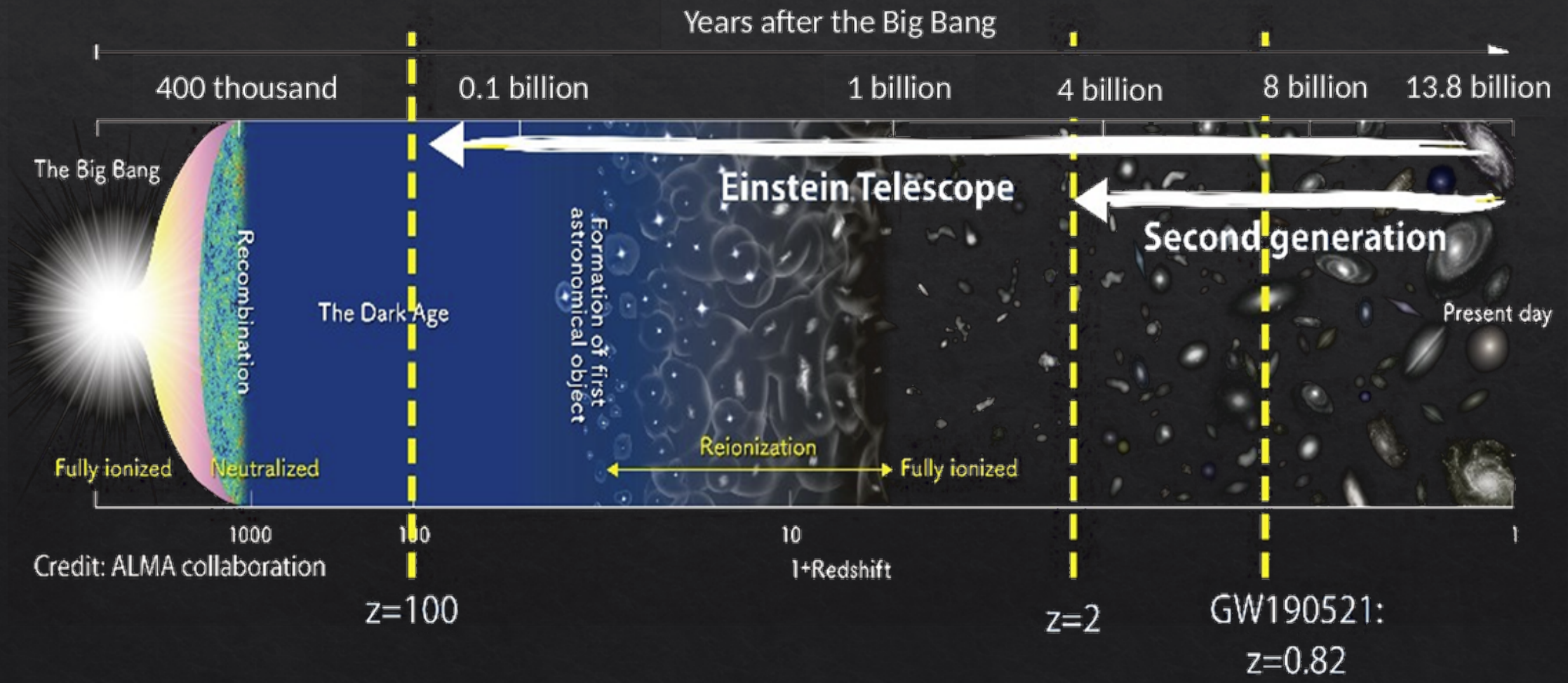
## Amaldi Research Center

## CAOS



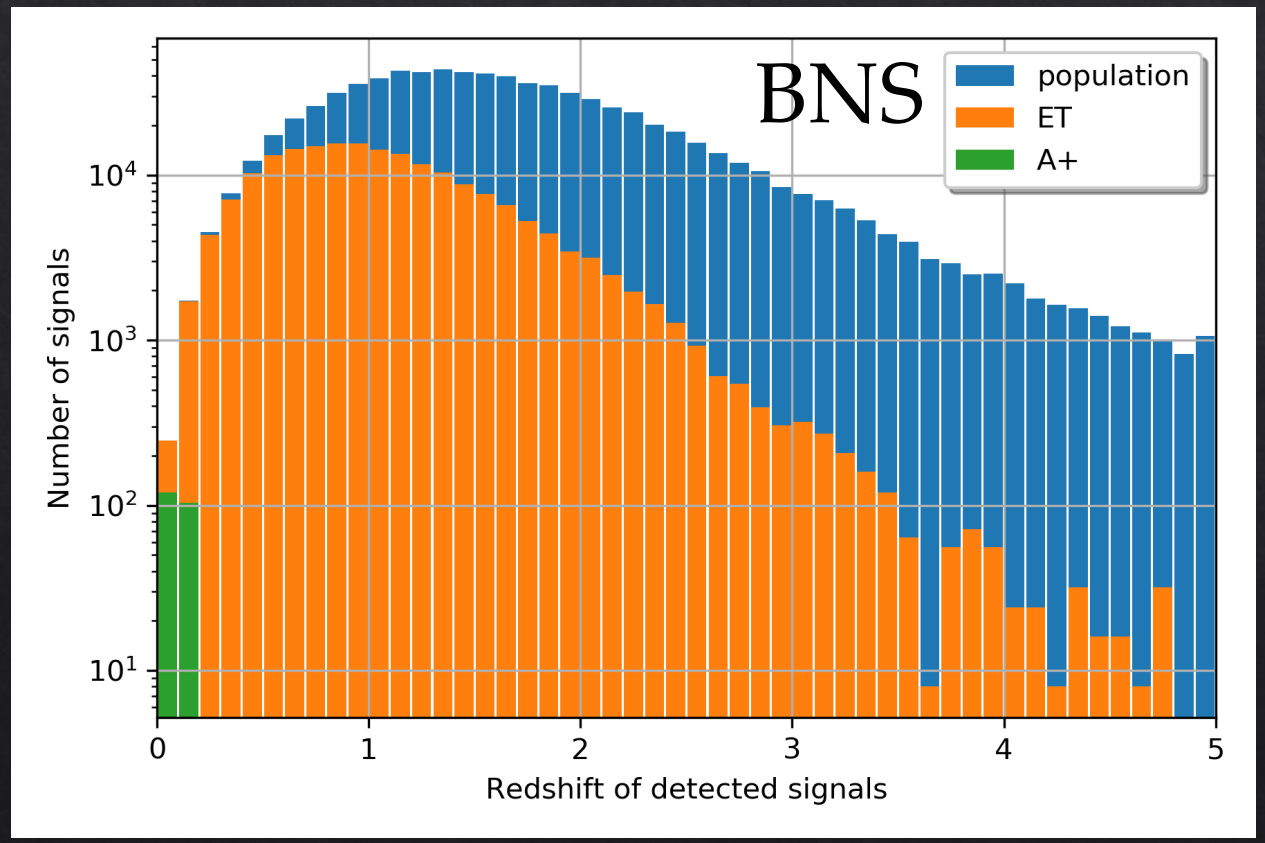
## ETpathfinder

# Detection Horizon

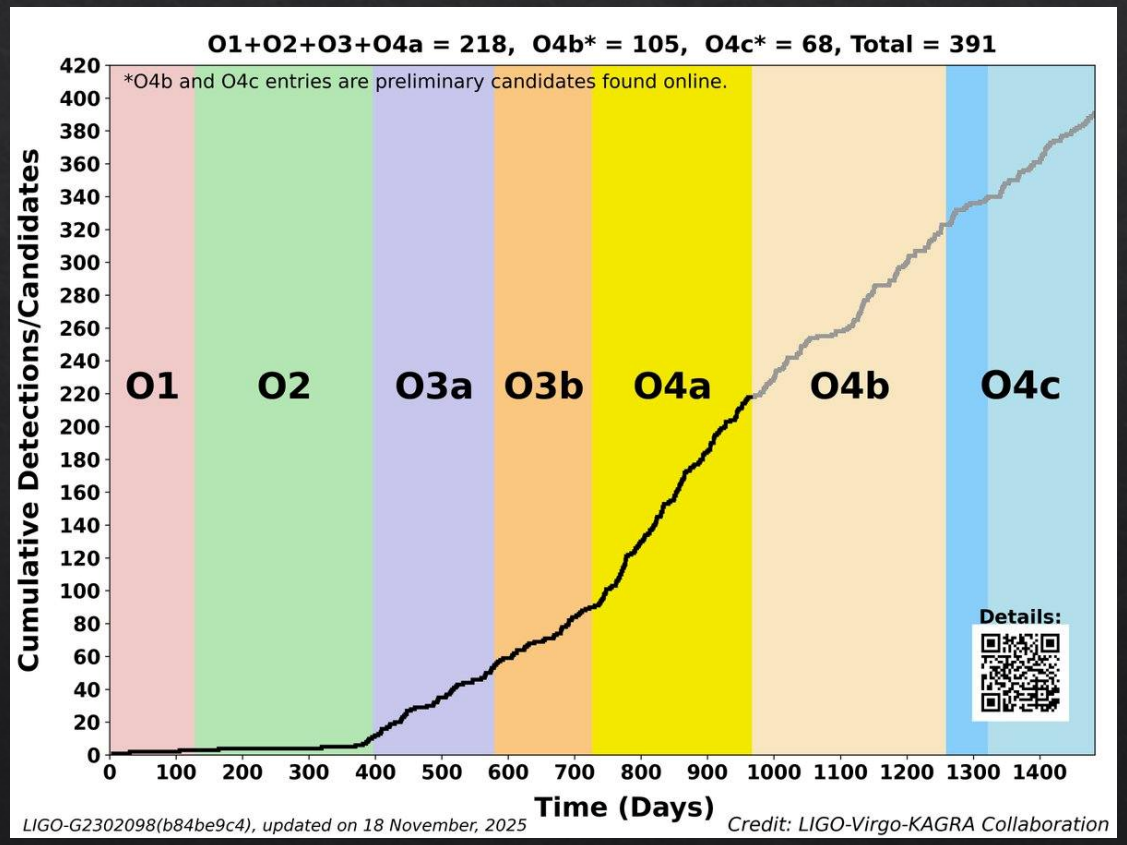


# Detection Numbers

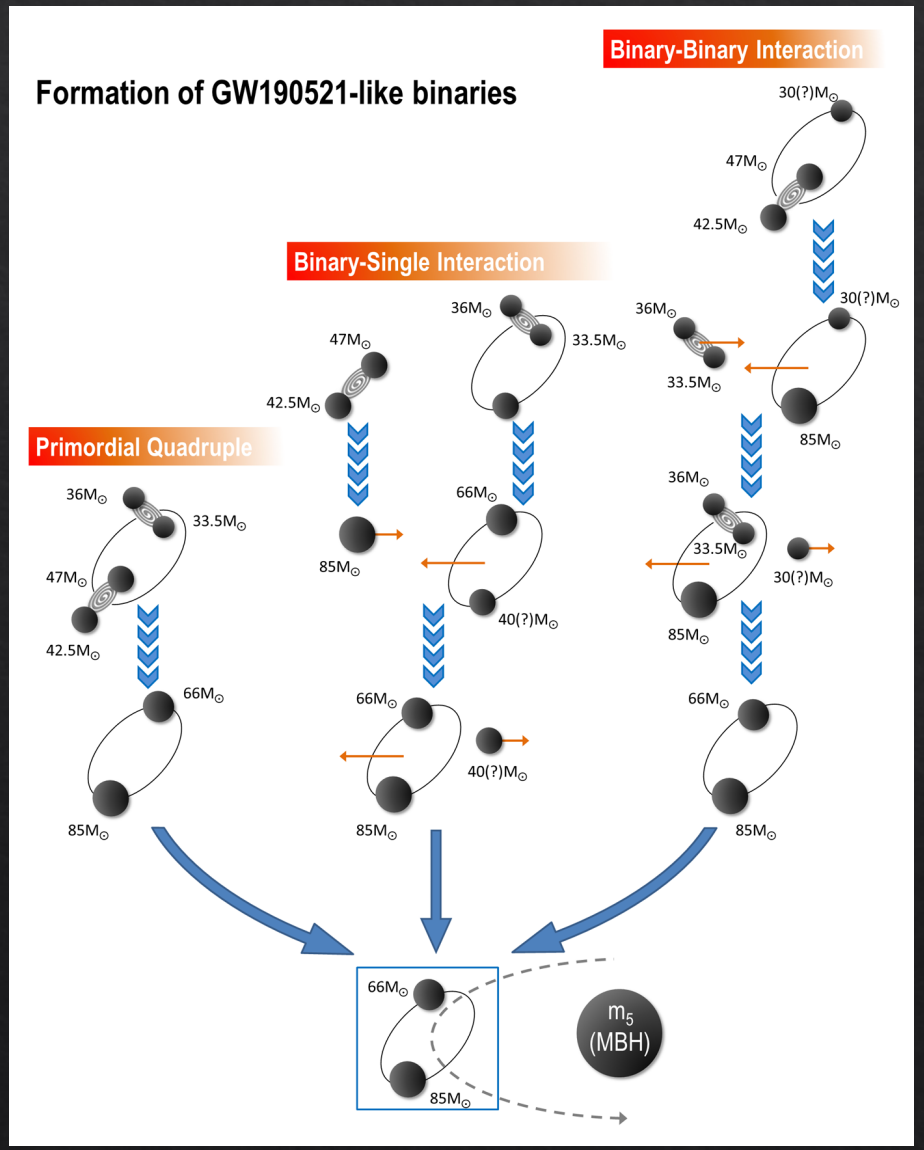
ET is expected see of order 100000 binary neutron stars (and 100000 BBH per year)



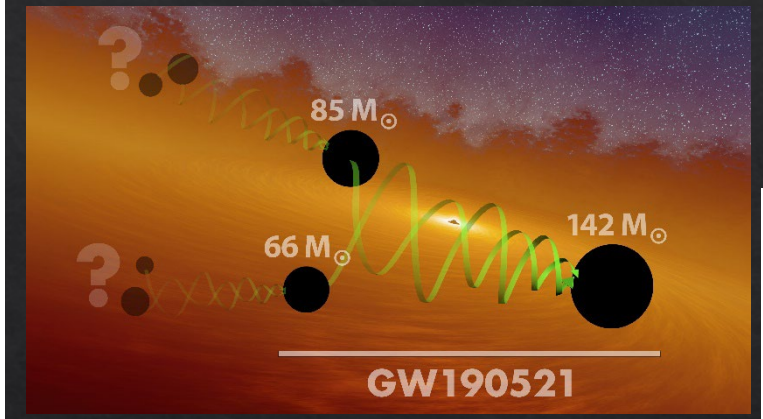

Virgo/LIGO: hundreds of detections after 4 years of observation



# Dynamical BH Interactions

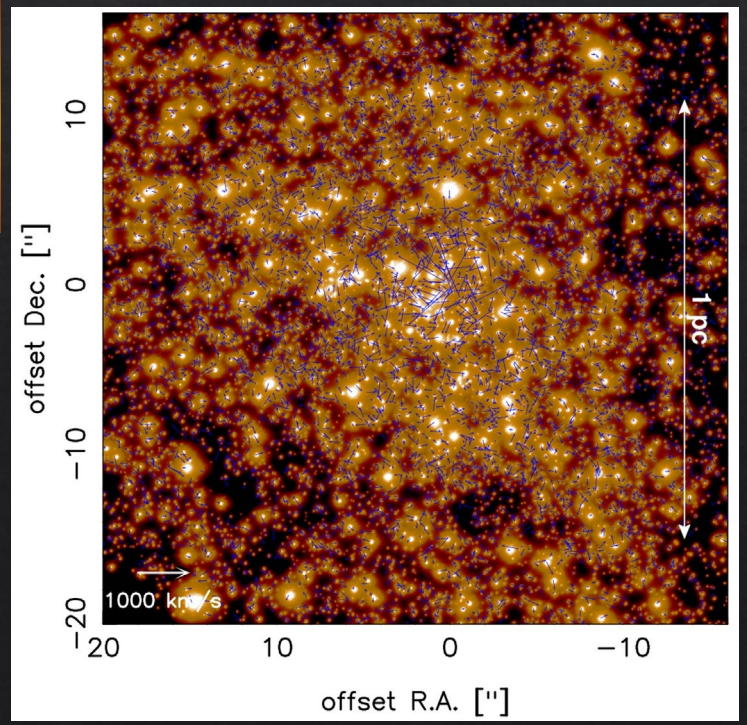



Lui/Lai, 2021




The cores of star clusters are expected tp have a high density of BHs facilitating dynamical BH interactions.

$$\rho > 10^5 M_\odot pc^{-3}$$

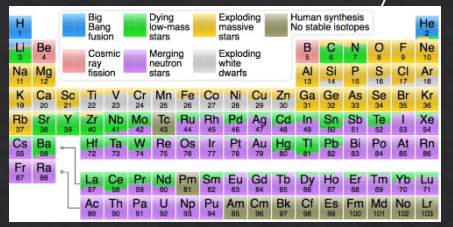


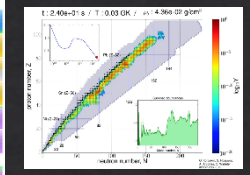
# Astrophysics: Merging Neutron Stars

Relativistic astrophysics

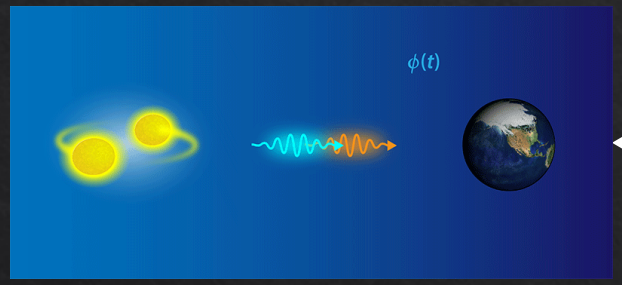
Radioactively powered transients

Nucleosynthesis



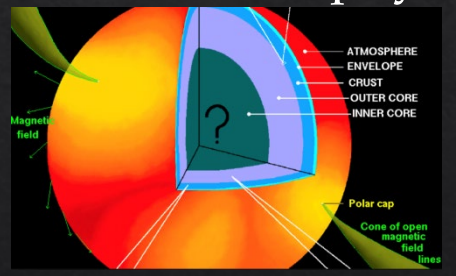



Testing general relativity

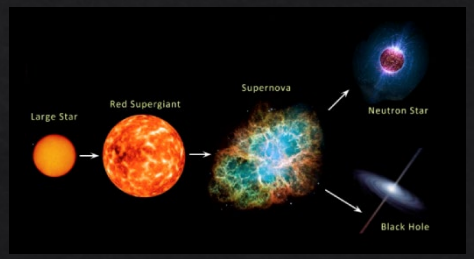




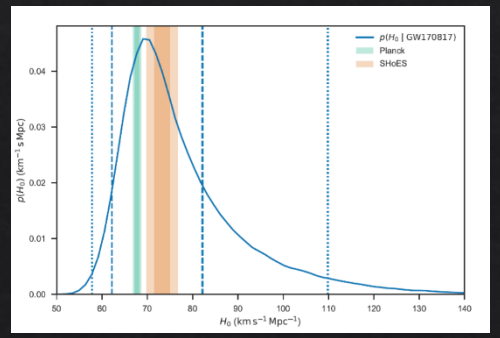
Nuclear matter physics




Compact-object formation and evolution

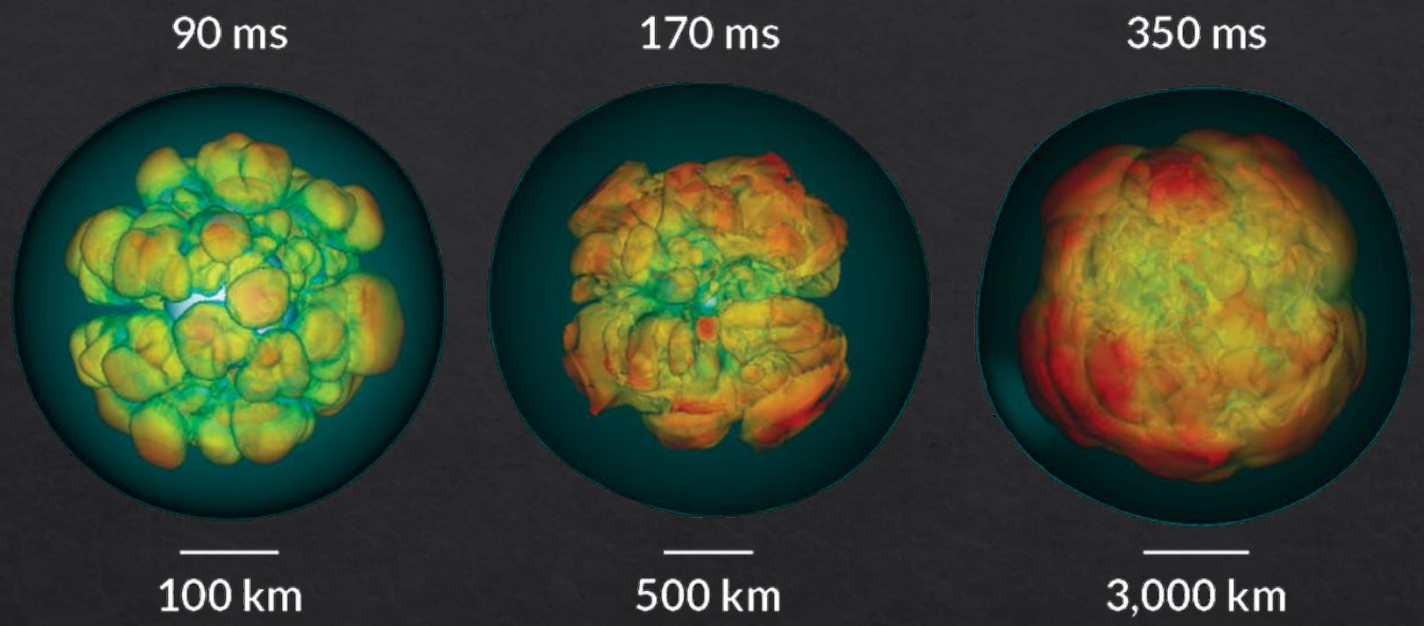



Cosmology

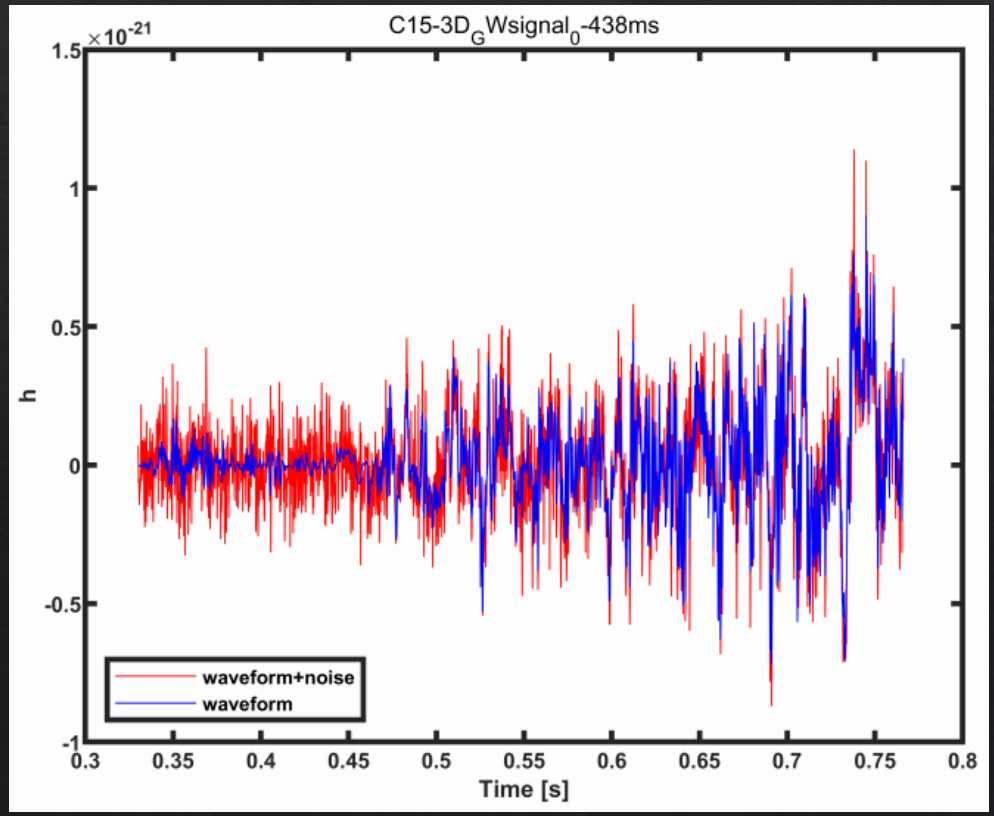



Credit: M Branchesi

# Core-Collapse Supernovae

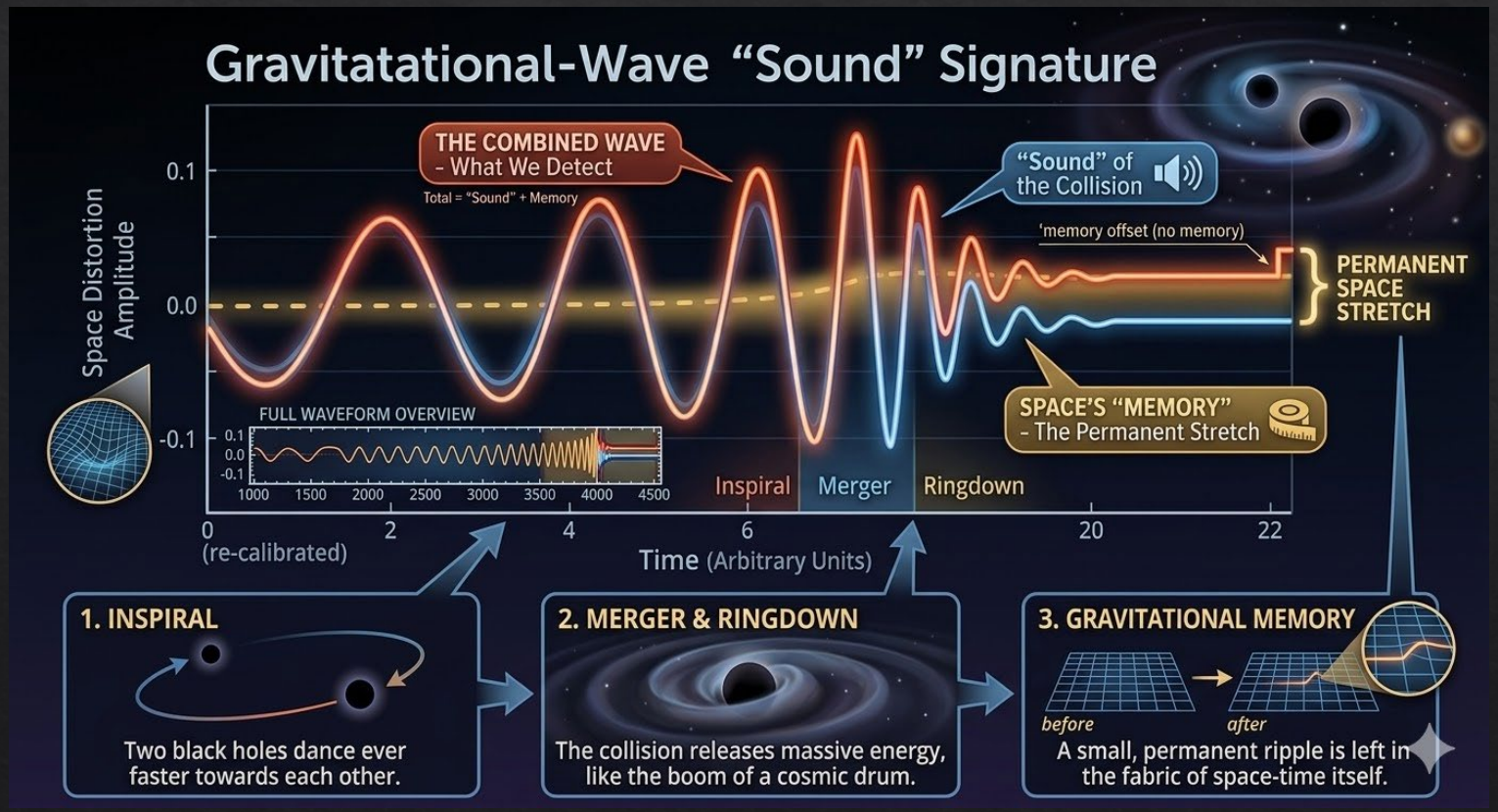



Modeling of supernova signals is an complex problem and computationally very demanding



# Fundamental Physics

Black holes: the ultimate engine of discovery [cit Cardoso, 2020]




Do black holes have a quantized area? Search for gravitational-wave echoes!