Gravitational Waves

(and the inherent chances for innovation)

17.02.2022

Symposium „Die Wissenschaft des Deutschen Zentrum für Astrophysik"

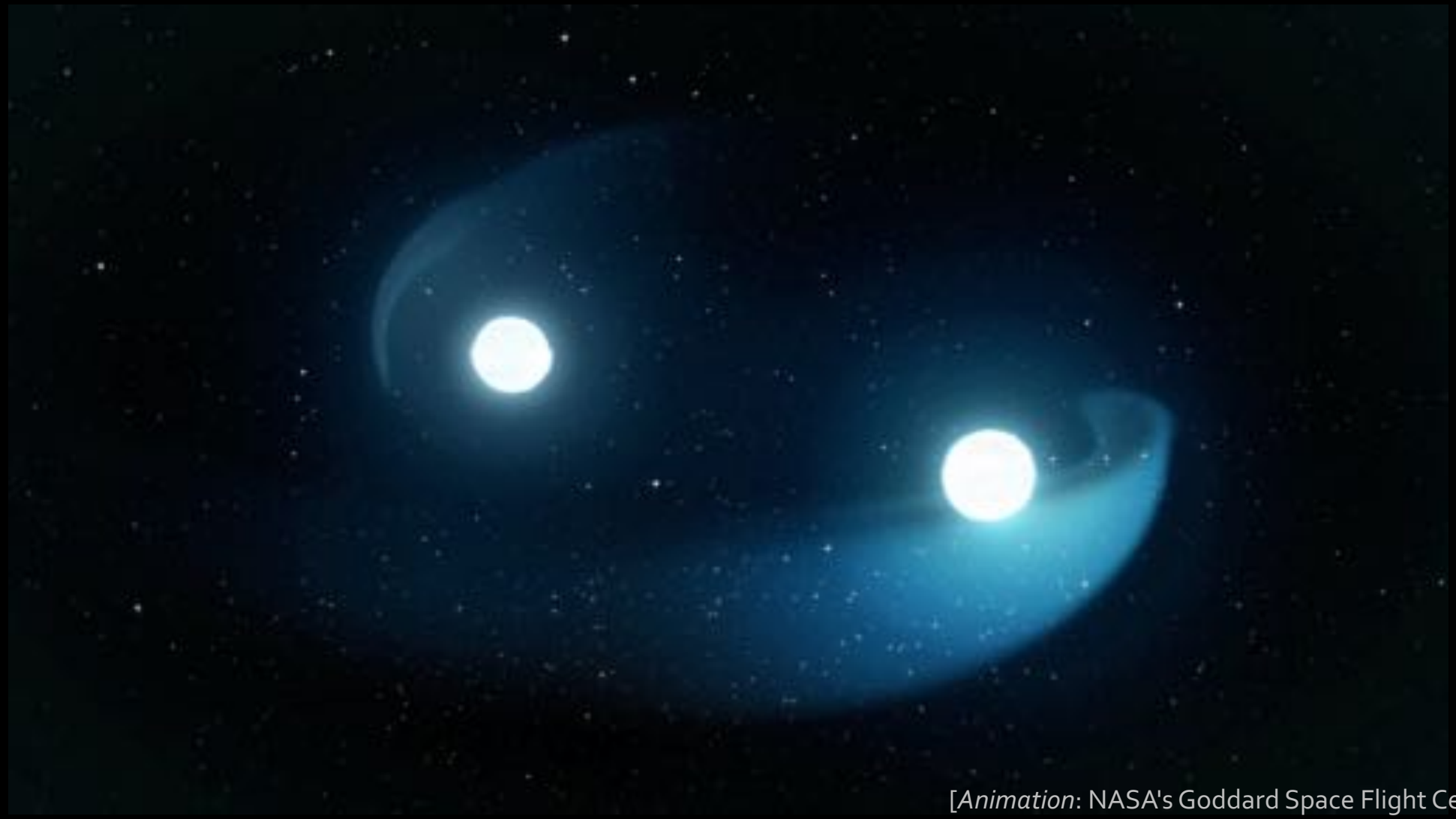
Michèle Heurs

Two black holes become one

$$h = \frac{\Delta L}{L} = 10^{-21}$$

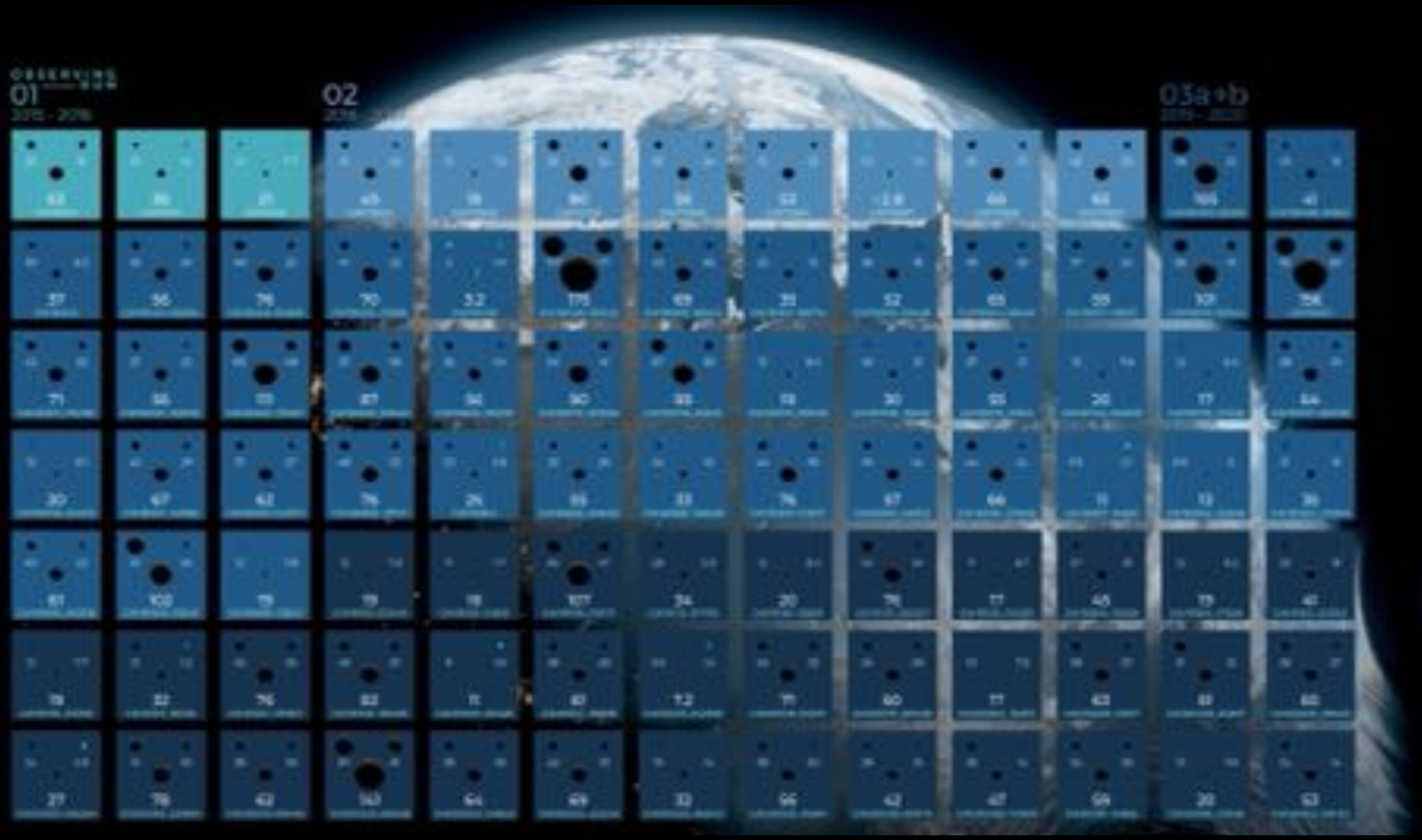
[*Animation*: Simulating eXtreme Spacetimes (SXS) Project]

Two neutron stars merge



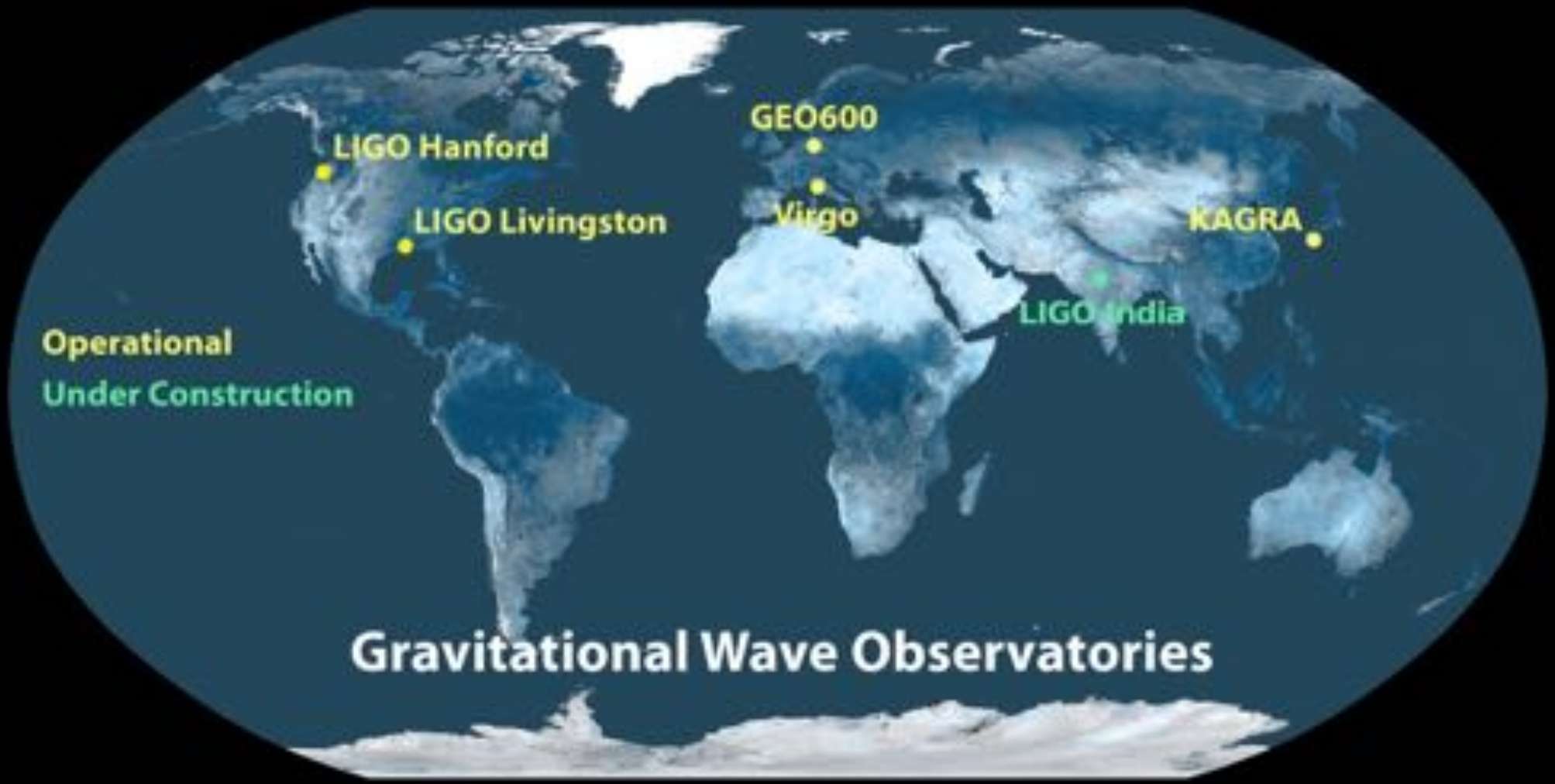
[*Animation*: NASA's Goddard Space Flight Center/CI Lab]

News from Gravitational Wave Detection

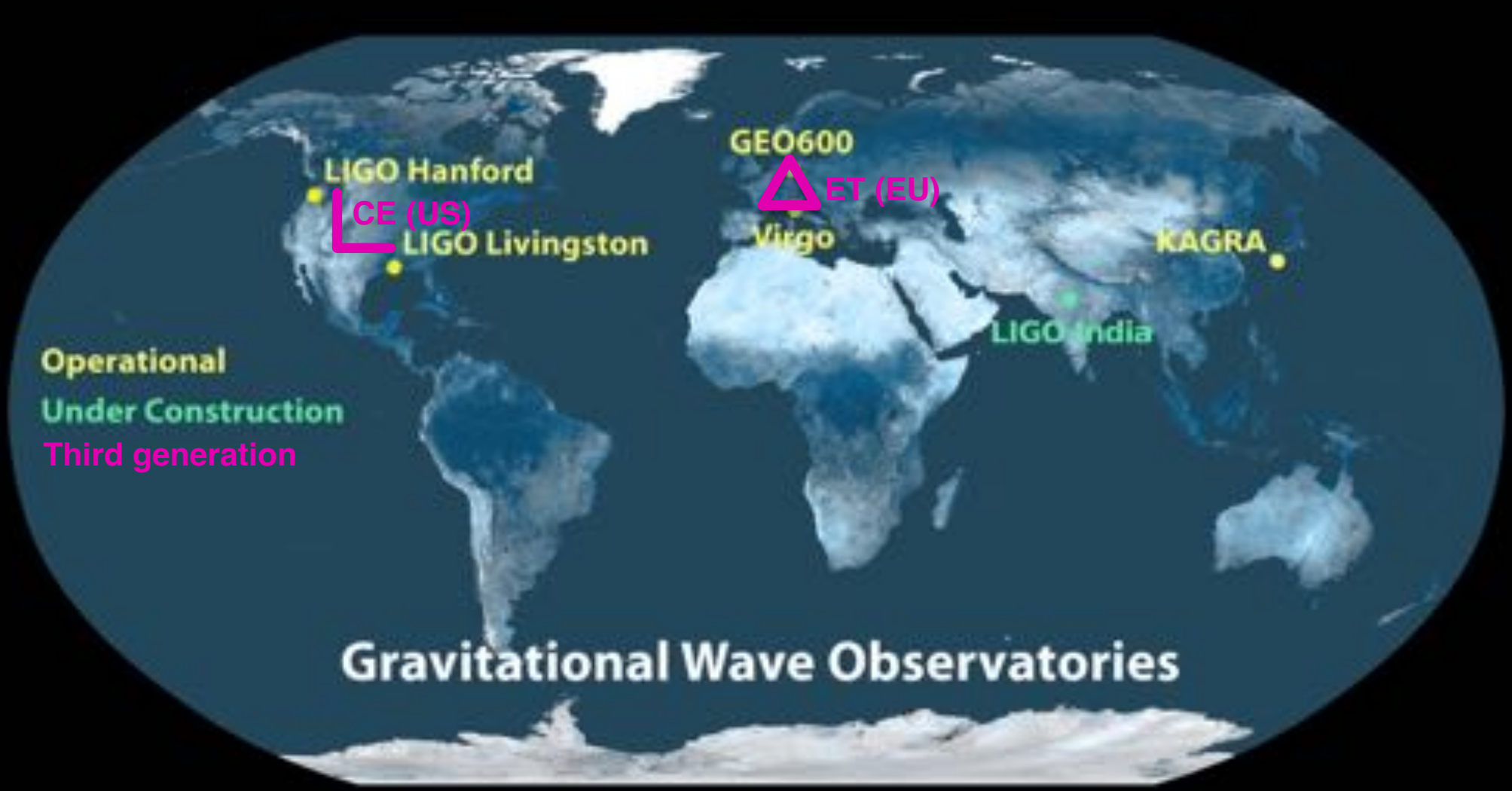


[*Image*: OzGrav, with content from GWTC-3]

The worldwide detector network (current status)

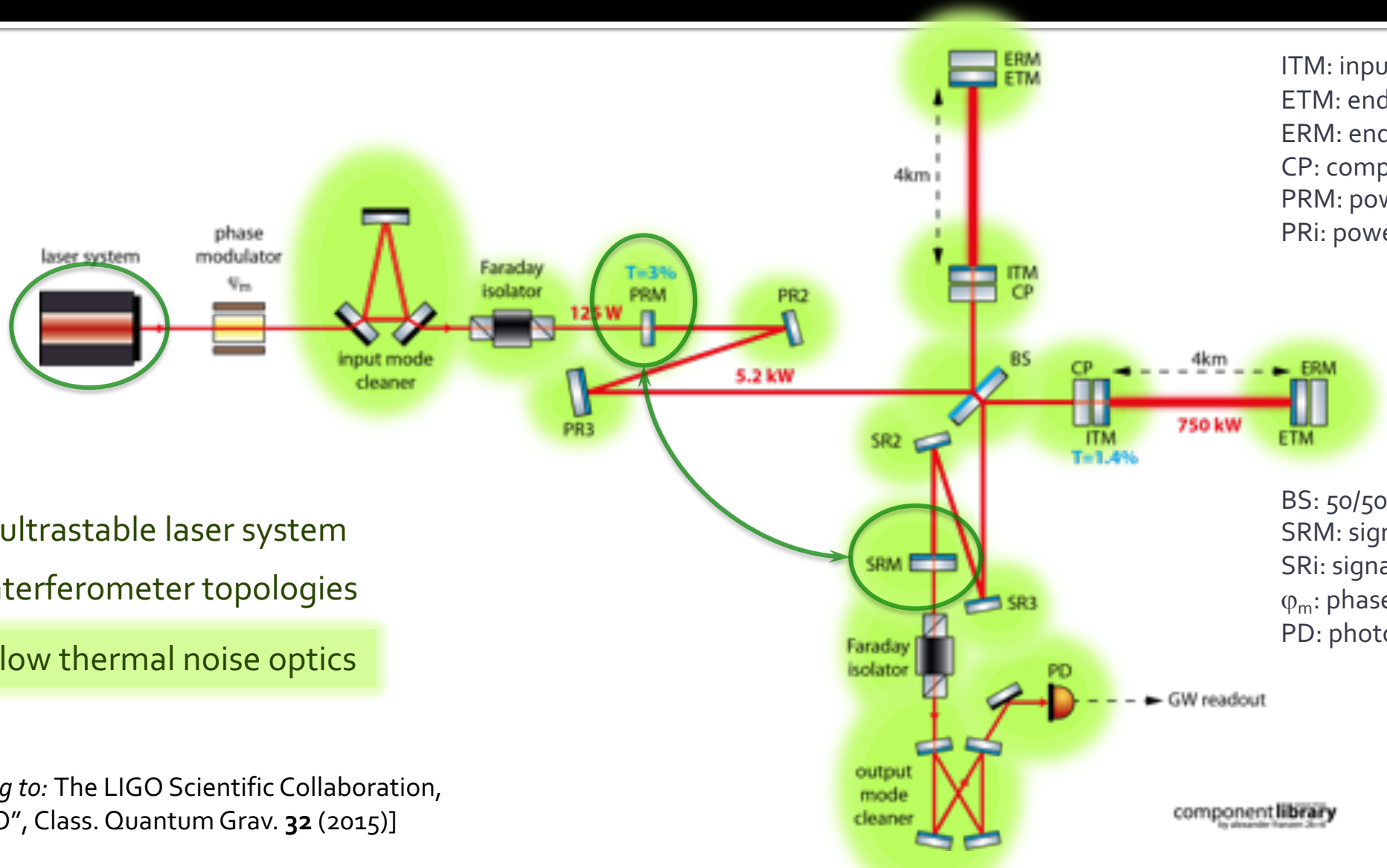


The worldwide detector network (future)



LISA

Advanced technology for aLIGO (examples)



ITM: input test mass
ETM: end test mass
ERM: end reaction mass
CP: compensation plate
PRM: power recycling mirror
PRi: power recycling mirror I

BS: 50/50 beam splitter
SRM: signal recycling mirror
SRi: signal recycling mirror i
φ_m: phase modulator
PD: photodetector

High power ultrastable laser system

Advanced interferometer topologies

Suspended low thermal noise optics

[Image according to: The LIGO Scientific Collaboration, "Advanced LIGO", Class. Quantum Grav. **32** (2015)]

Q1: Enabling Technologies

ESFRI

ET EINSTEIN TELESCOPE

Challenging engineering

New technology in cryo-cooling

New technology in optics

New laser technology

High precision mechanics and low noise controls

High quality opto-electronics and new controls

- The multi-interferometer approach asks for two parallel technology developments:

- **ET-LF:**
  - Underground
  - Cryogenics
  - Silicon (Sapphire) test masses
  - Large test masses
  - New coatings
  - New laser wavelength
  - Seismic suspensions
  - Frequency dependent squeezing

- **ET-HF:**
  - High power laser
  - Large test masses
  - New coatings
  - Thermal compensation
  - Frequency dependent squeezing

Evolved laser technology

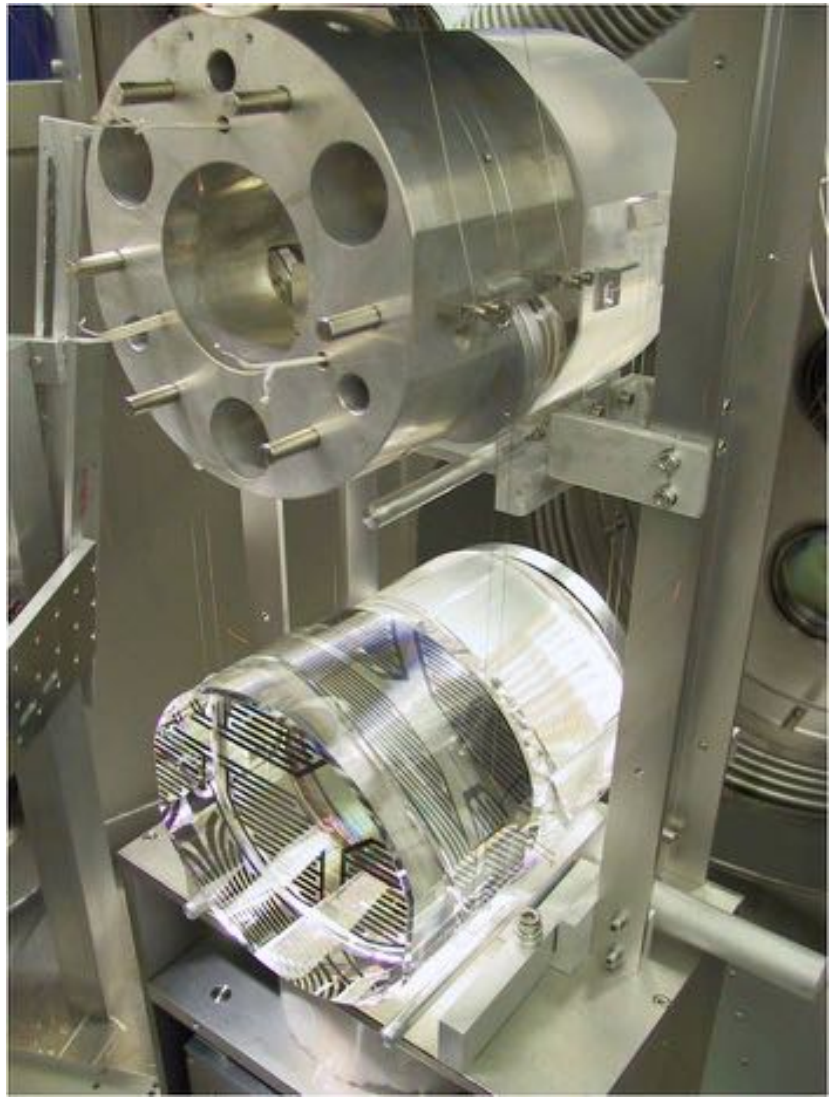
Evolved technology in optics

Highly innovative adaptive optics

High quality opto-electronics and new controls

[*Source*: ESFRI Defense Presentation (2021)]

Monolithic mirror suspensions



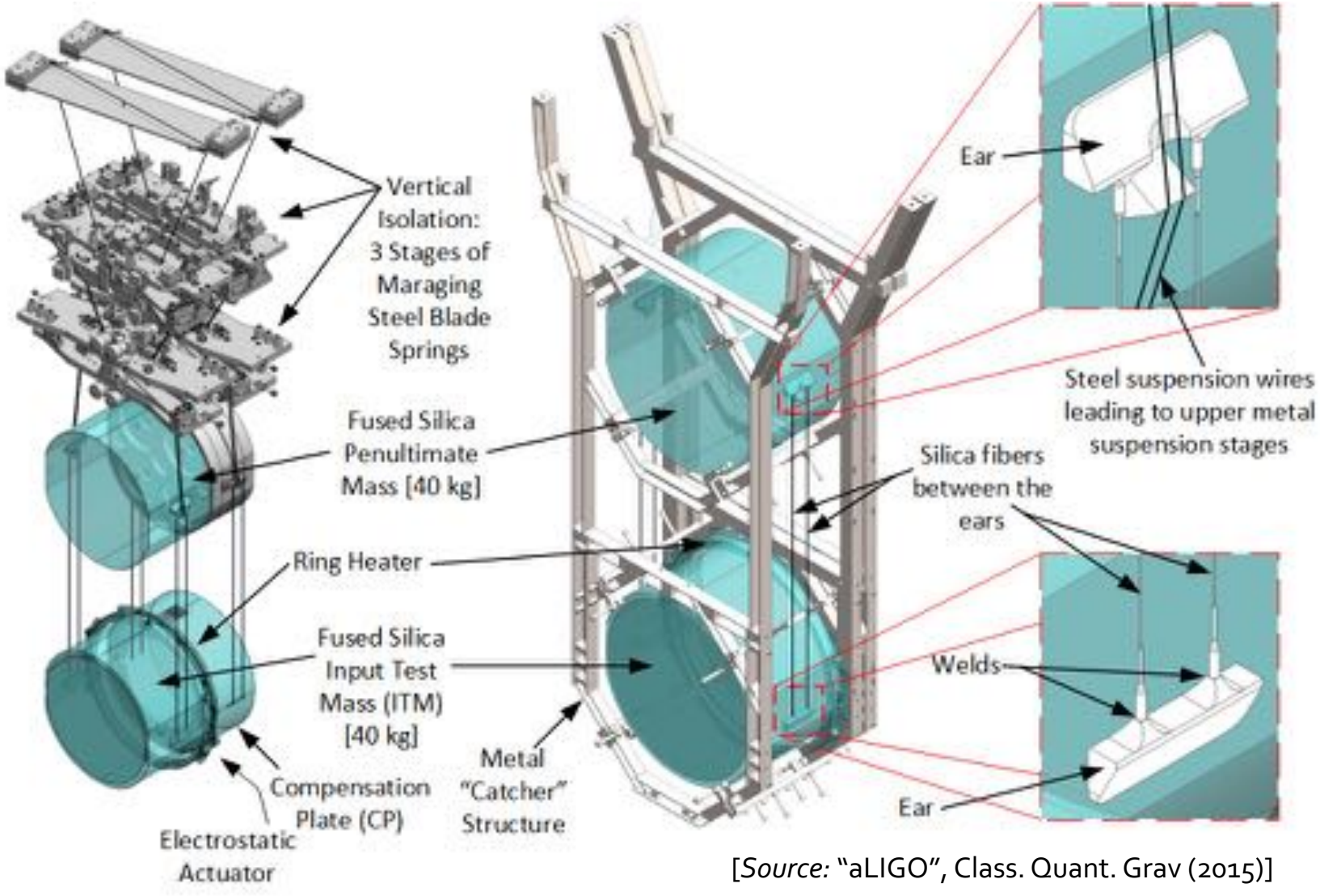
←
GEO600 triple suspension
fused silica mirror
180 mm diameter
m = 10 kg
suspended by FS fibres
reaction chain for electro-static actuation

[*image*: H. Lück]

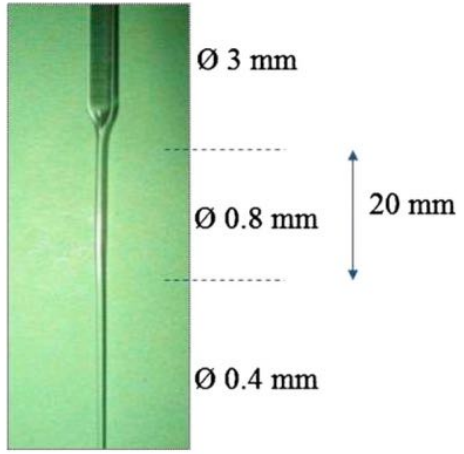
→
aLIGO quadruple suspension
fused silica mirror:
340 mm diameter
200 mm thickness
m = 40 kg
suspended by FS fibres:
400 um diameter
600 mm length

[*image*: M. van Veggel, RSTA 2018]

Monolithic mirror suspensions



[*Source:* "aLIGO", Class. Quant. Grav (2015)]



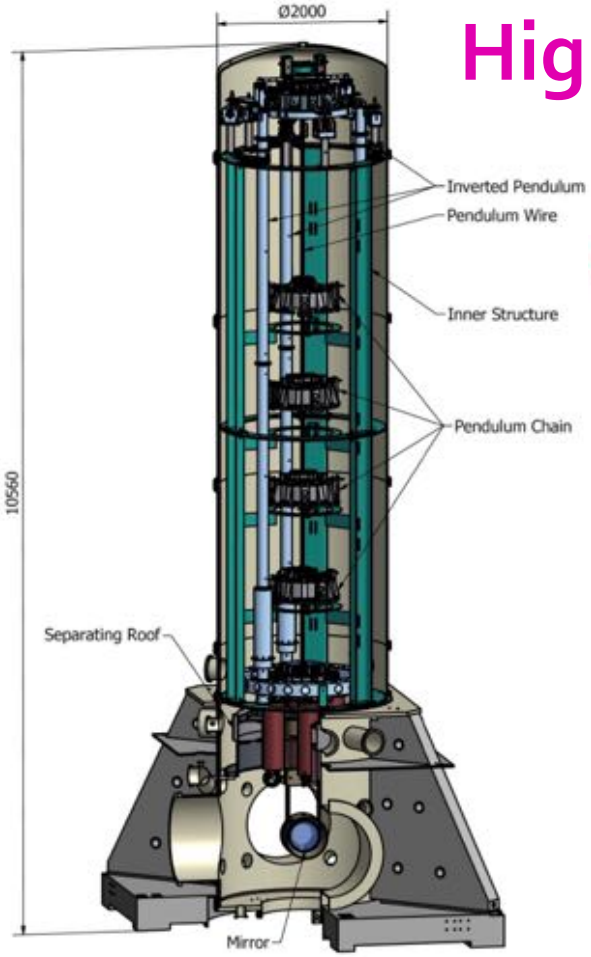
[*Source:* S. M. Aston "Update on quadruple suspension design for Advanced LIGO", Class. Quantum Grav. 29 (2012)]

Mirror technology for next generation GWDs

- "*One-stop-shop*" *for mirrors* (substrates, polishing and coating)
  - *(crystalline) silicon mirror substrates*
  - *crystalline coatings*
  - *nanostructured mirrors*
  - *at cryogenic temperatures*
- Possible collaborations with
  - IKZ (Leibniz Institut für Kristallzüchtung, Berlin)
  - IOF (Fraunhofer Forschungsinstitut für Optik & Feinmechanik, Jena)
- Connection to Silicon Saxony

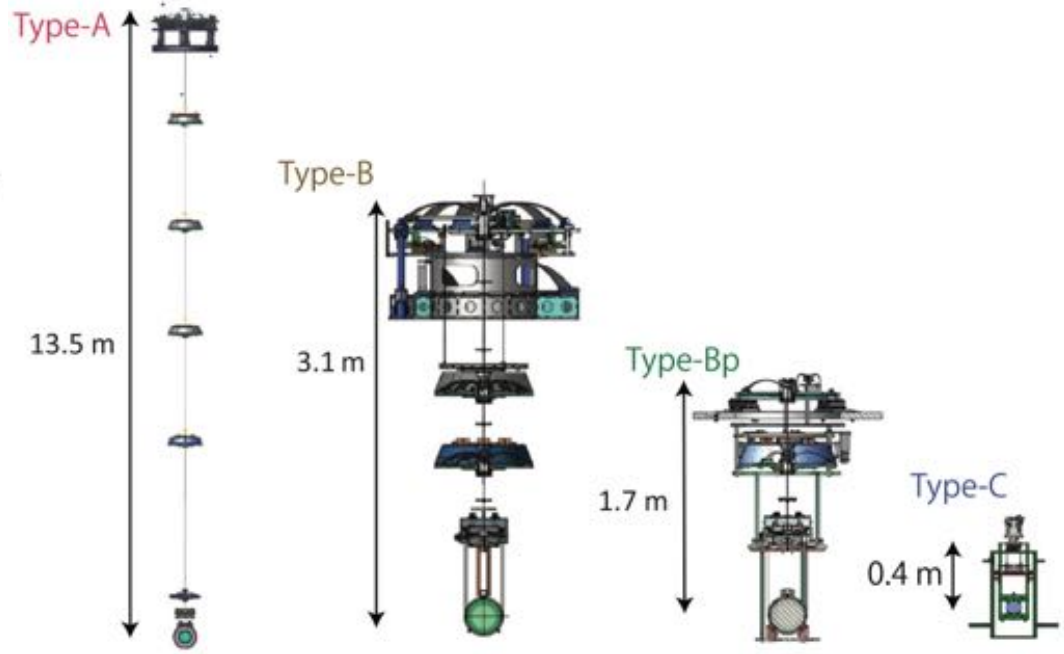
Suspended test masses, quo vadis?

Higher?



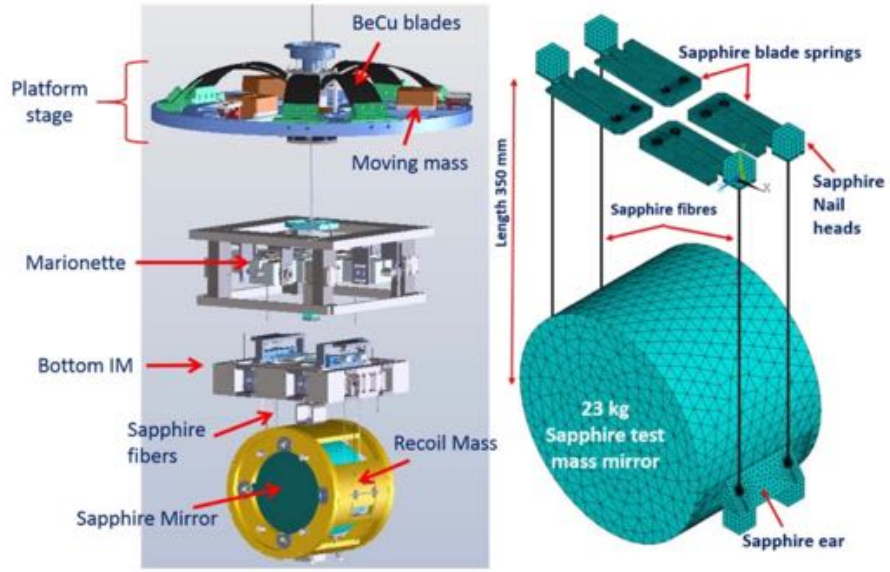
[*Source:* T. Accadia et al. "Virgo: a laser interferometer to detect gravitational waves ", JINST 7 P03012 (2012)]

...or nested?



[*Source:* T. Aki et al., "Vibration isolation system with a compact damping system for power recycling mirrors of KAGRA", Class. Quantum Grav. **36** (2019) 095015]

...and cryogenic?



[*Source:* R. Kumar et al., "Status of the cryogenic payload system for the KAGRA detector", Journal of Physics: Conference Series **716** (2016)]

Suspension technology for next generation GWDs

- *Seismic isolation concepts* (superattenuators vs. nested geometries,…)
- *Sophisticated controls* (modern control, machine learning,…)

In an underground laboratory:

- *Newtonian Noise investigations*
- *Subtraction of body waves* (requires seismic 3D sensor arrays)
- *Atmospheric NN* (cavern geometry, pressure changes in tunnels,…)

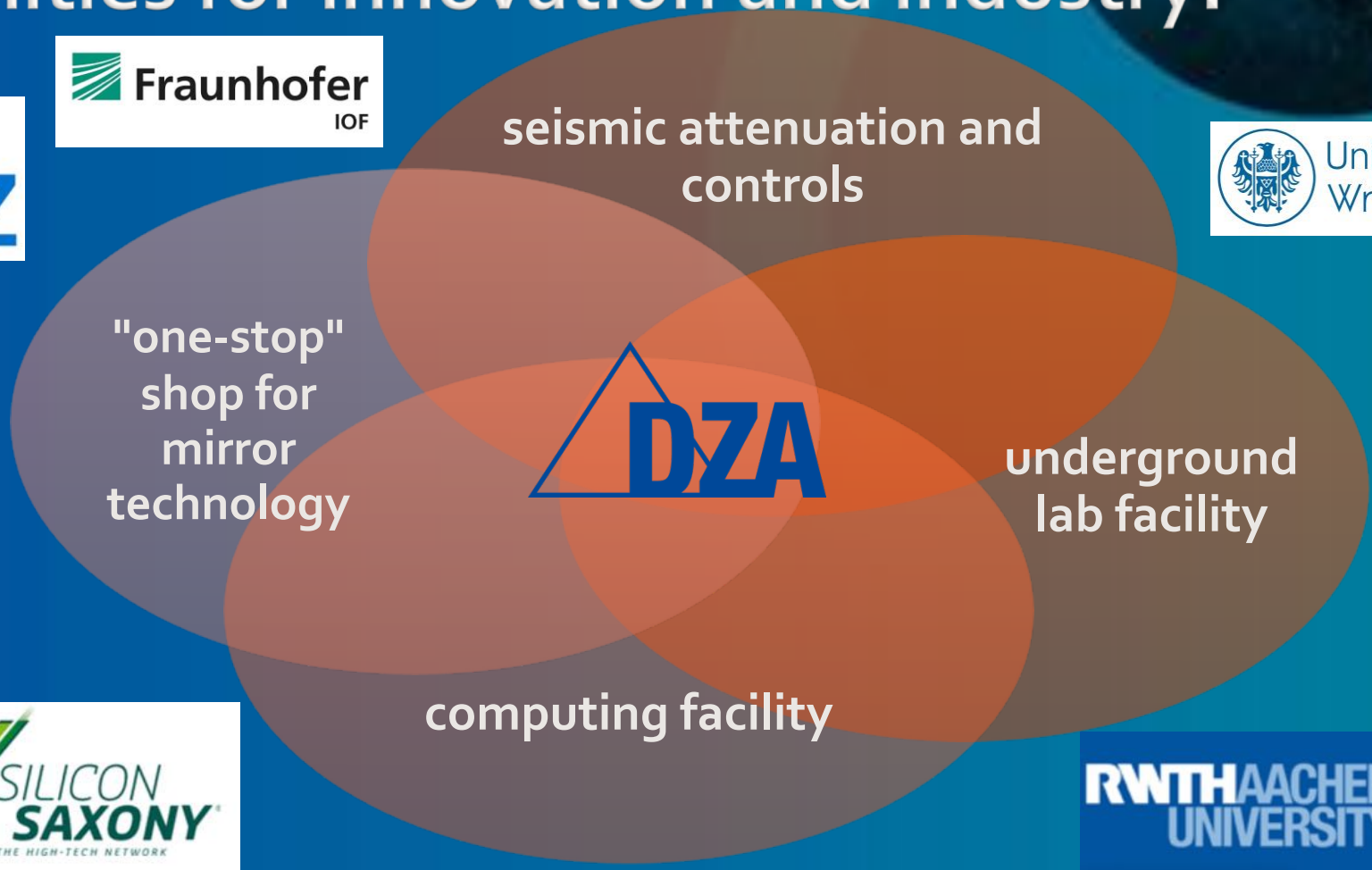
Underground lab facility for next generation GWDs

- Lab of approx. (30 x 30 x 30) m^3 size
  at 200 m depth in Lusatia granite
- kilometer-scale *3D seismometer sensor array*

⇒ *Metrological validation* of advanced full-scale seismic isolation concepts

Photos: Tunnel / cavern in Sos Enattos (Sardinia) during ET site workshop (Oct. 2021)

Modern instrumentation for future astrophysics – opportunities for innovation and industry!



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