The Virgo large optics

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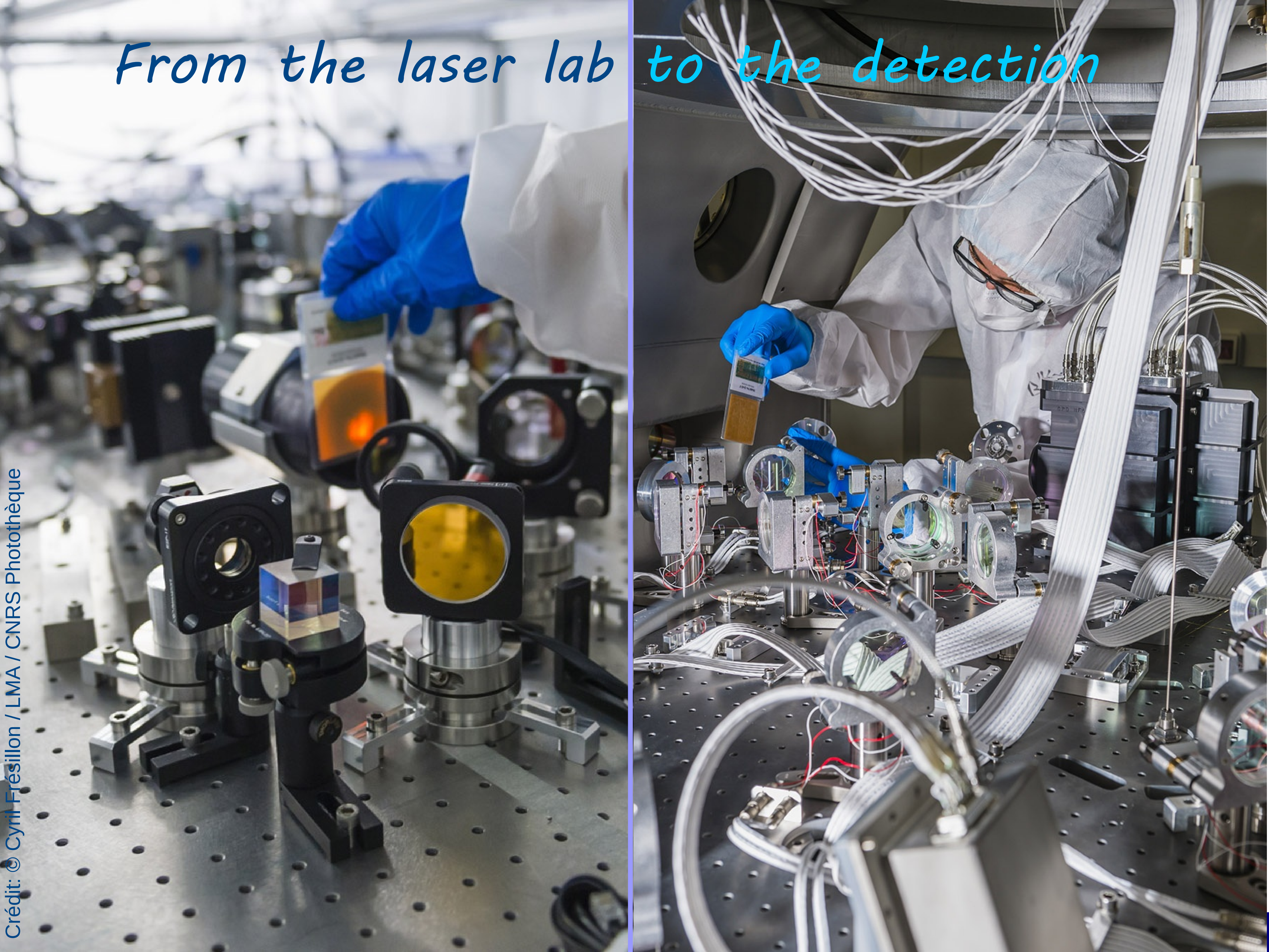
Swedish Academy Physics Class visit – June *2022*


From the laser lab to the detection
Crédit: © Cyril Frésillon / LMA / CNRS Photothèque

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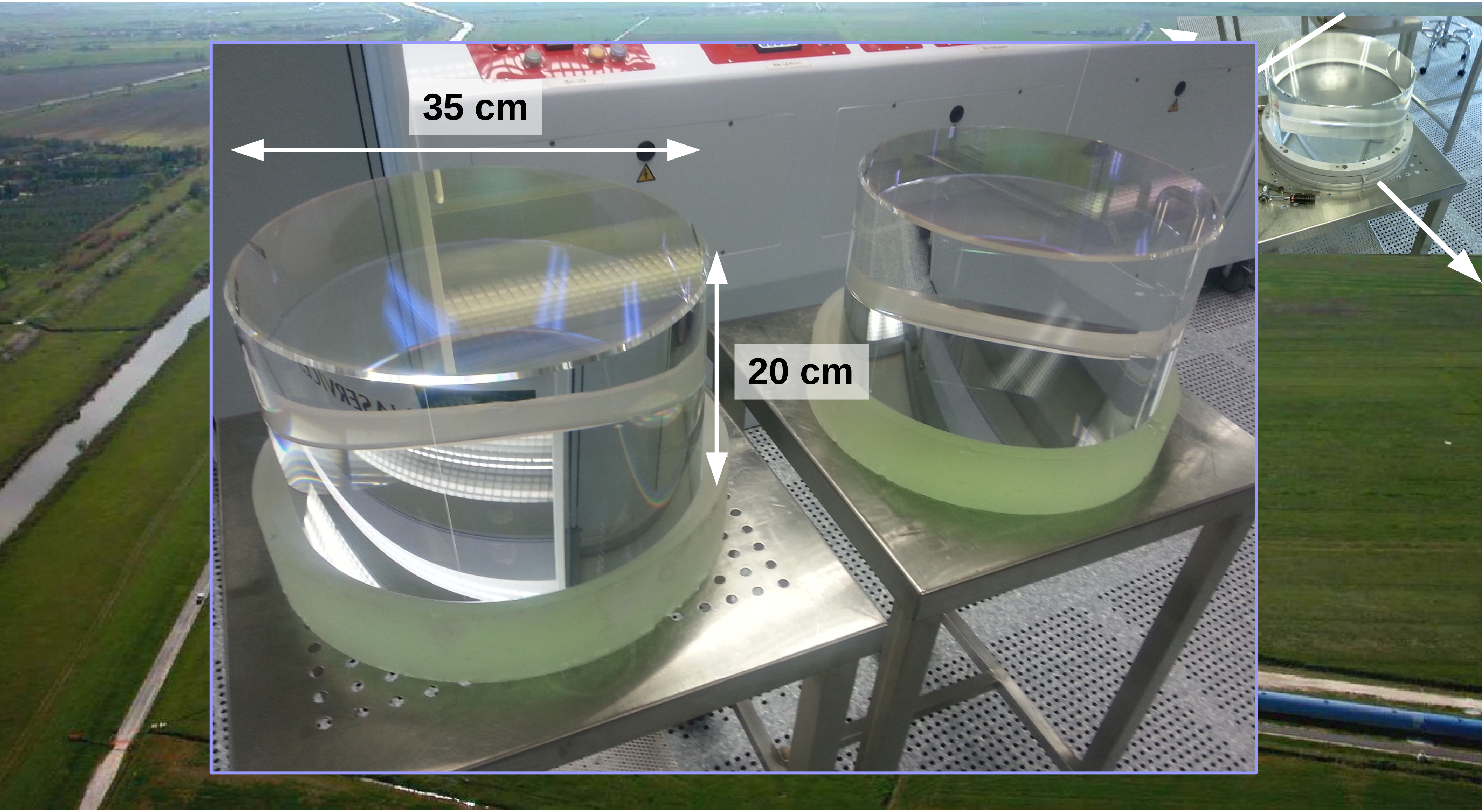
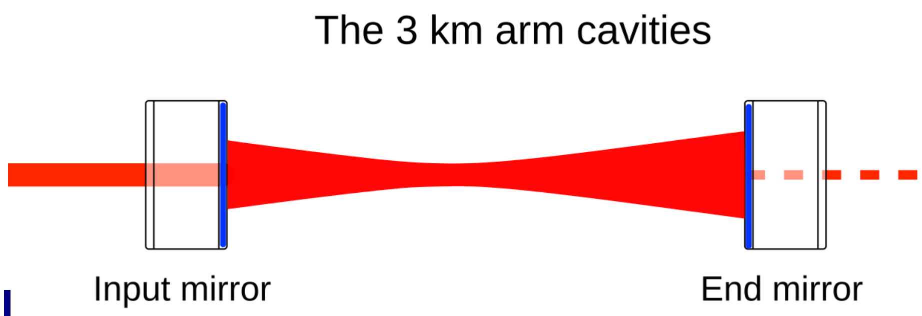


The arm cavities



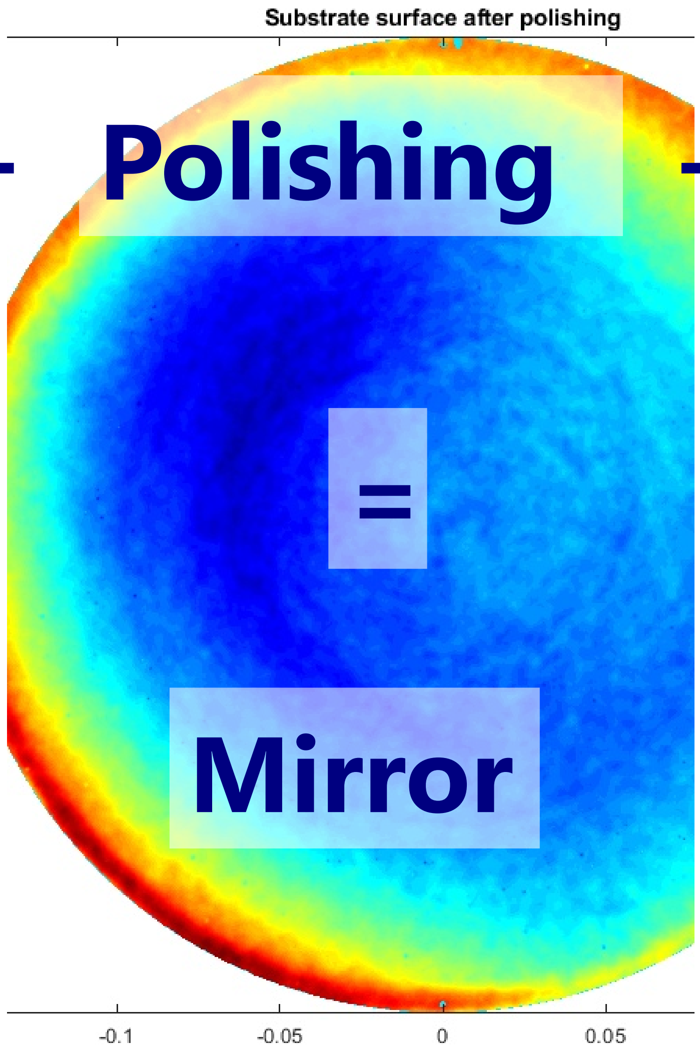
- 3 km long Fabry-Perot cavities
- where the gravitational wave signal is encoded to the phase of the light
- loosing light = loosing signal

Very strong requirement on the amount of light lost per round trip: < 0.008 %

Required outstanding mirrors of unprecedented quality

The 3 ingredients of a mirror:

Substrate + **Polishing** + **Coating**



= Mirror

All 3 ingredients need to be exceptional!

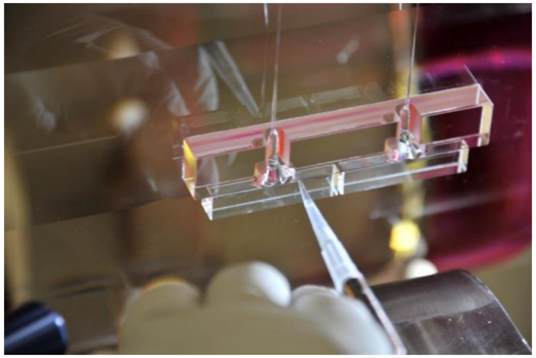
Dedicated partnerships with labs / companies for the procurement

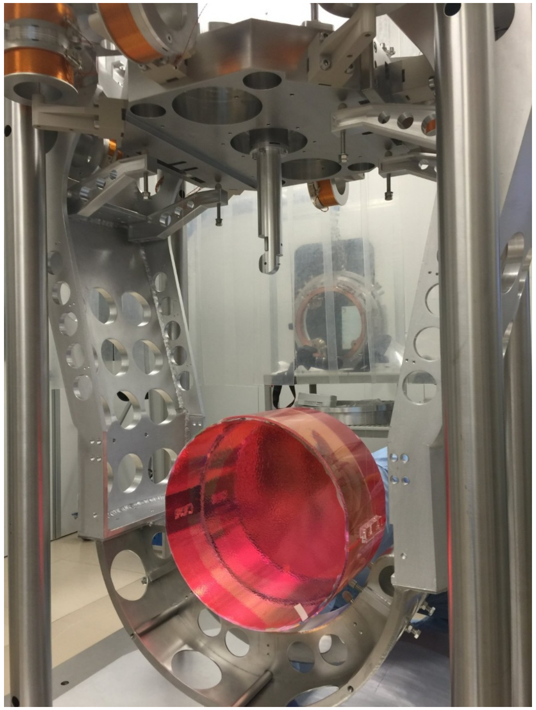
The fused silica substrates and polishing

THE test mass substrate for the room temperature first and second generations of gravitational wave detectors.

A well justified choice:

- extremely good optical properties
- available in large size
- low thermal noise and possibility of monolithic suspension
- after polishing, surface RMS < 0.2 nm ($P\text{-}V = \lambda/300$)





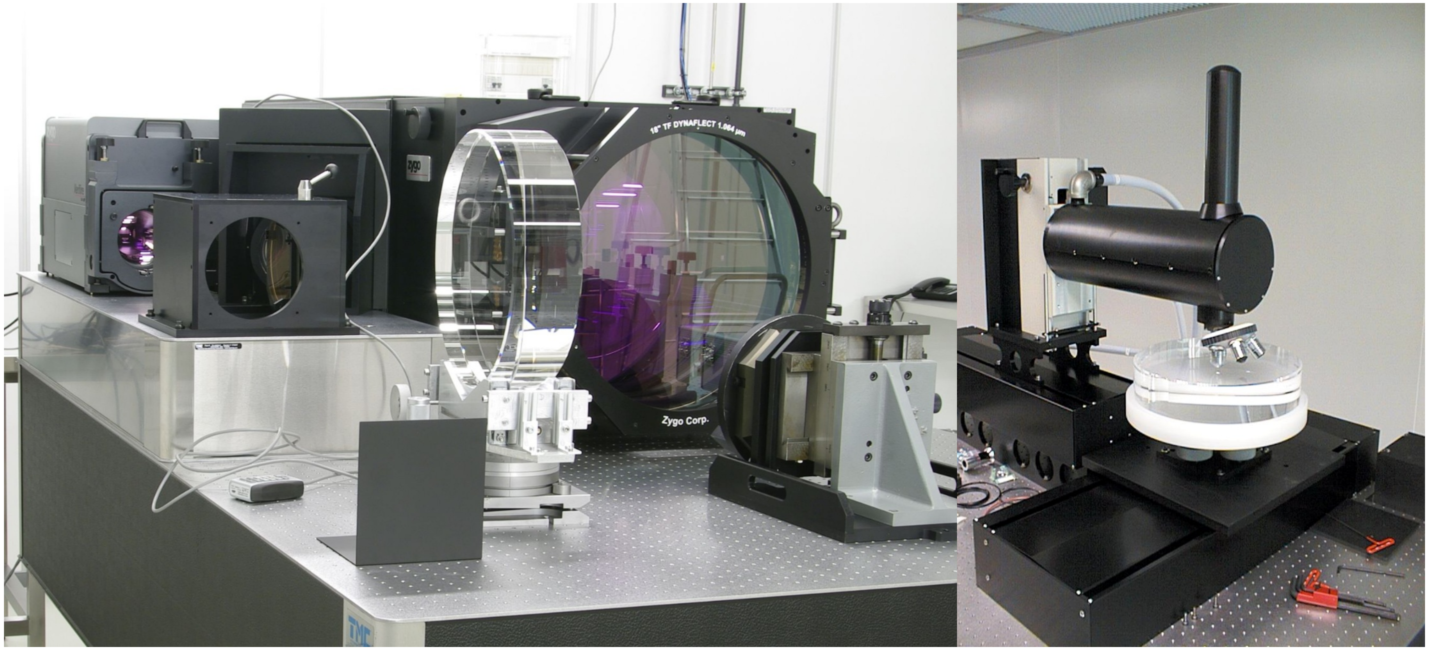
For the coating, the Ion Beam Sputtering (IBS) custom machine in the LMA clean room, the largest in the world


where all the coatings for the test masses of the GW detectors have been made (Virgo – LIGO - Kagra)

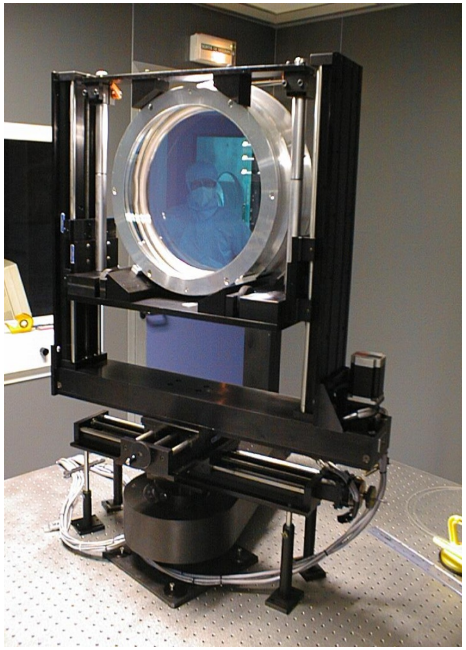
A key aspect : the metrology

For such specifications and size, custom made instruments to measure the:

- transmission / reflection (R > 99.999%)
- optical absorption (Abs < 1ppm)
- surface (flatness < 0.5 nm RMS)
- scattering (S < 10 ppm)



Surface measurement (large and small scales)

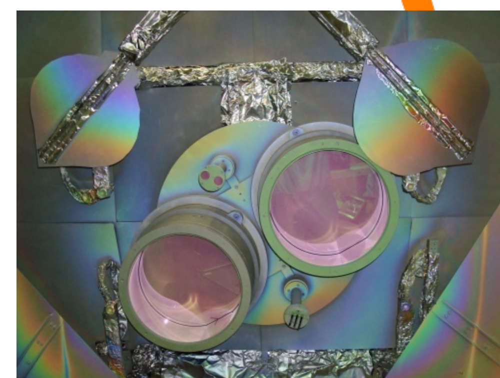


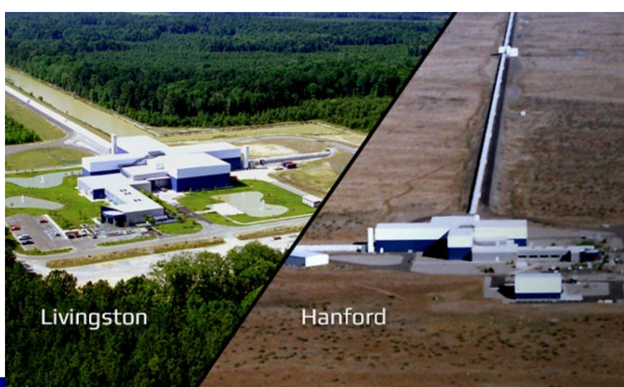
Scattering measurement

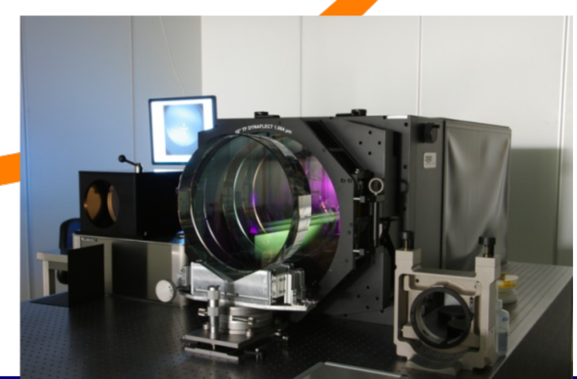
All meausrement also done in a clean room

A long story, the GW main mirrors are:

- 10 years R&D on the materials
- 4 years R&D on the uniformity
- 24 substrates of 40 kg coated
- 480 h of coating (including 15 nights)
- 0.1 mm total thickness coating
- 240 days of metrology



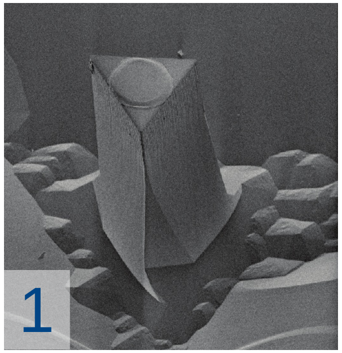


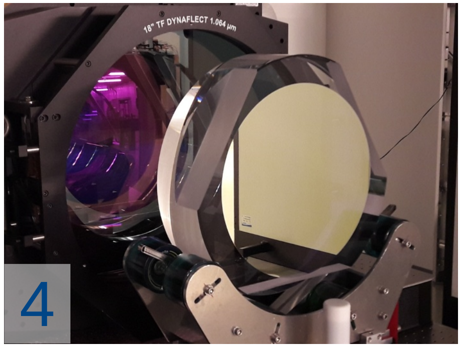


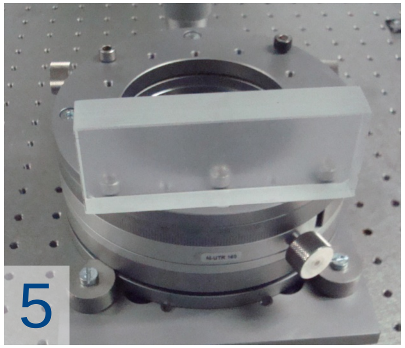
Sharing our technologies

Our extremely low loss mirrors and expertise have benefited to other experiments :

1. Opto-mechanics
2. X ray sources
3. Vacuum birefringence
4. Etalon for solar telescope
5. Synchrotron







Also regular help on designing optical cavities, dealing with polishing companies or special cleaning or metrology.

The near future: mirrors for AdV+

A large upgrade of AdV is currently planned (×3 more sensitive).

The key aspect will be larger and heavier mirrors:

- mirrors diameter: 550 mm (+60%)
- weight: 105 kg (×2.5)
- better coating materials

Intense research effort worldwide to find coating materials with lower thermal noise:

- exploring new parameters / materials
- increase coating uniformity
- lowering scattering point defects
- better anti reflective coating

Next generation detectors: the Einstein Telescope

10 km long arm, underground, partially cryogenic

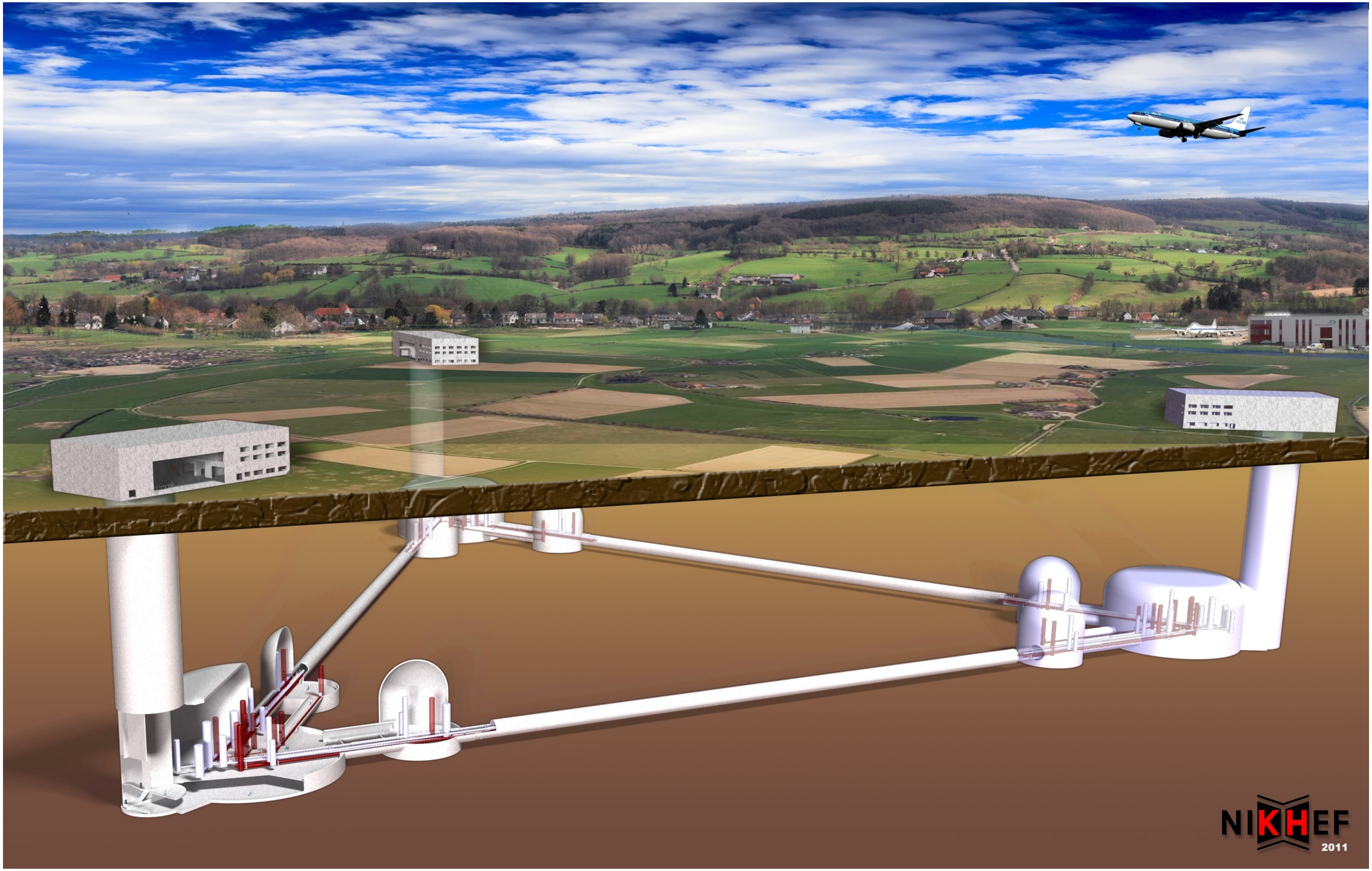


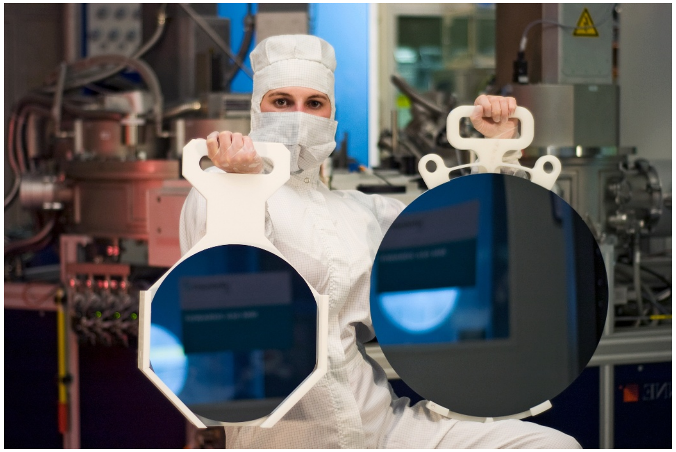
Image credit: Nikkef

Next generation mirrors

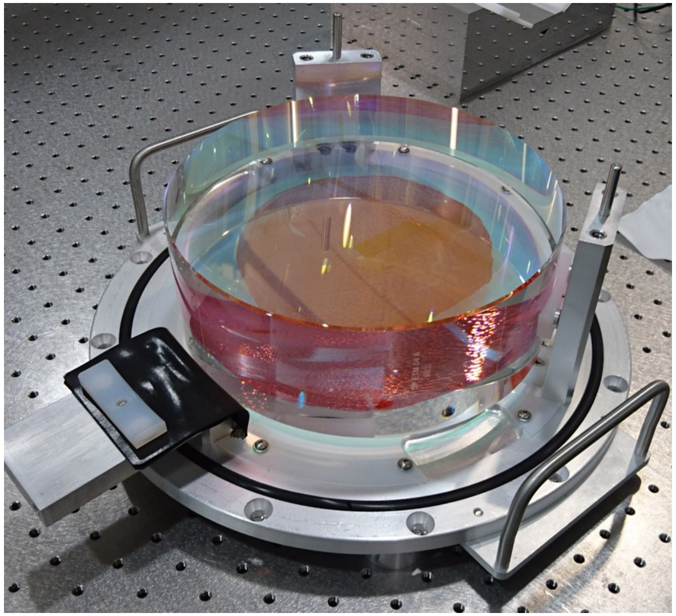
- At 300K: fused silica
  - diameter of 600 mm
  - > 100 kg

Challenges of cryogenic mirrors

- New substrates
  - in silicon
  - or sapphire
- New coating materials



Silicon wafers of diameter 300 mm and 450 mm



Sapphire substrate

https://wccftech.com/foundries-tsmc-companies-shift-300mm-wafers/ From Kagra logbook post 3613

Conclusion

- At the heart of current GW detectors, (likely) the best mirrors ever made

- only the beginning of this new astronomy, but we can already expect larger and more challenging mirrors in the future