Finding Black Holes with Lasers

Andreas Freise

LIGO-G1300827

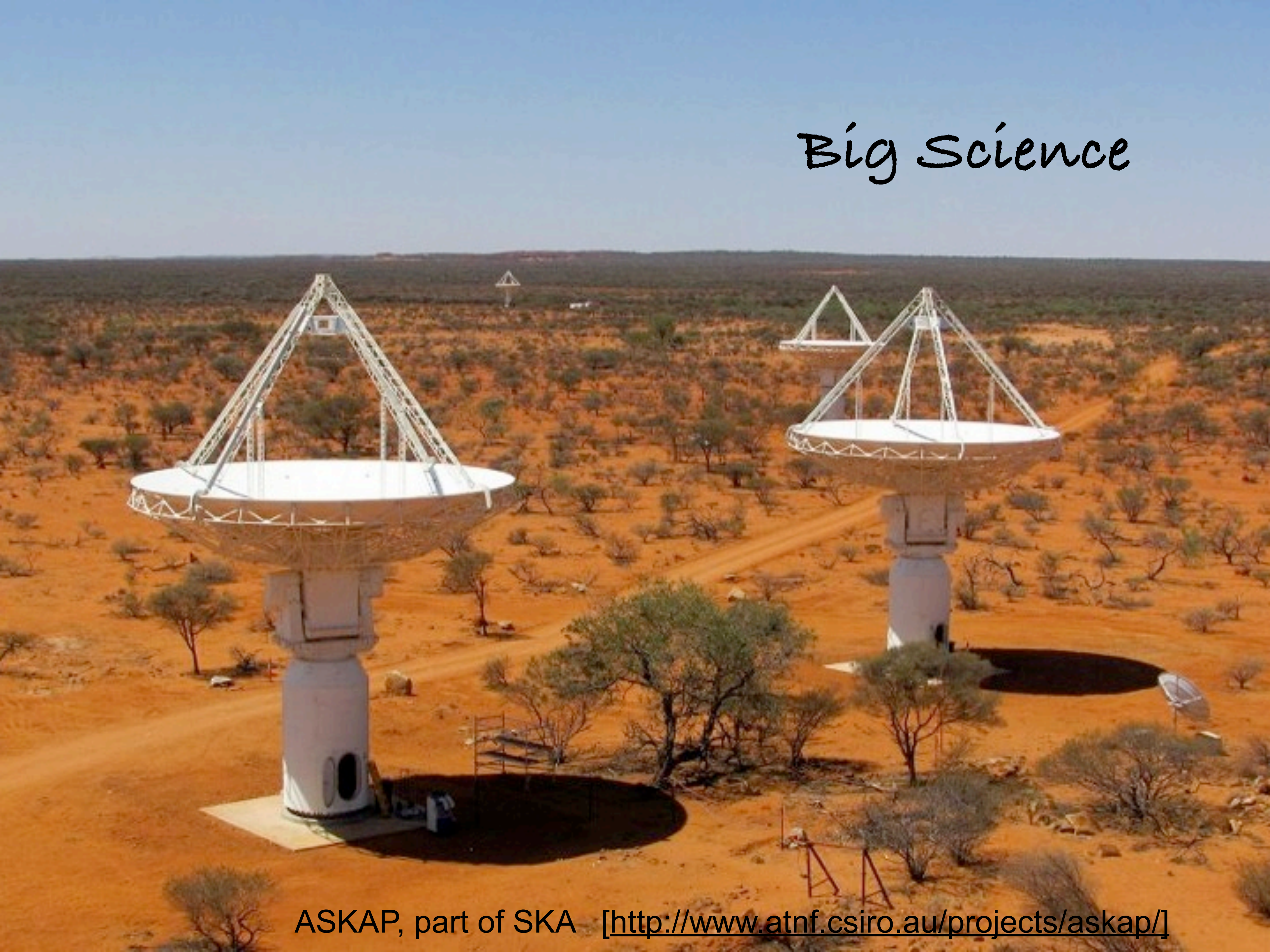
Royal Institute of Great Brtitain 18.02.2013

[Image shows guide laser at Allgäu Public Observatory in Ottobeuren, Germany. Credit: Martin Kornmesser]

UNIVERSITY OF BIRMINGHAM

Astronomy

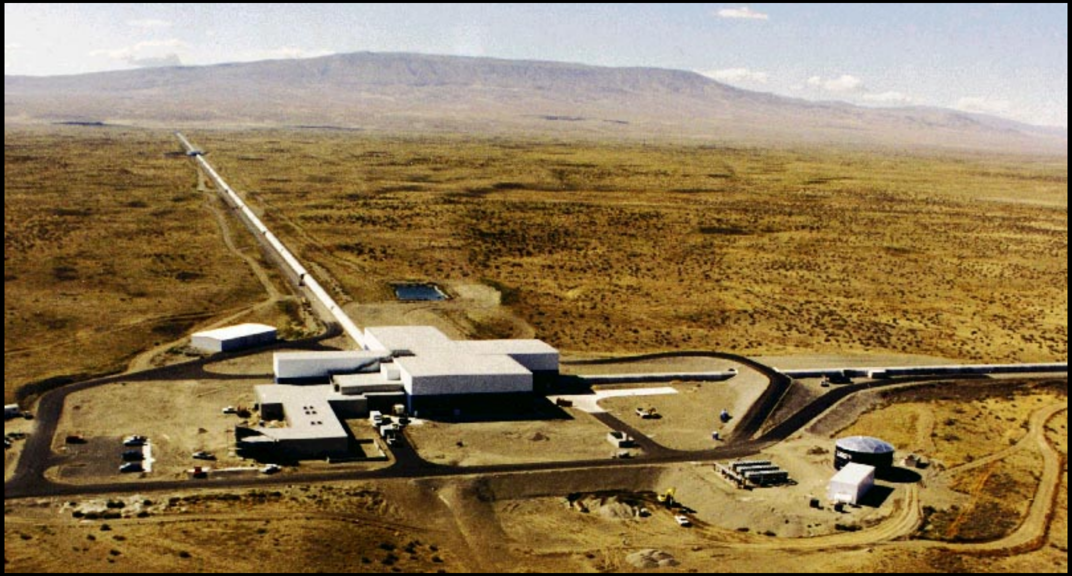
Big Science



ASKAP, part of SKA [http://www.atnf.csiro.au/projects/askap/]

LIGO

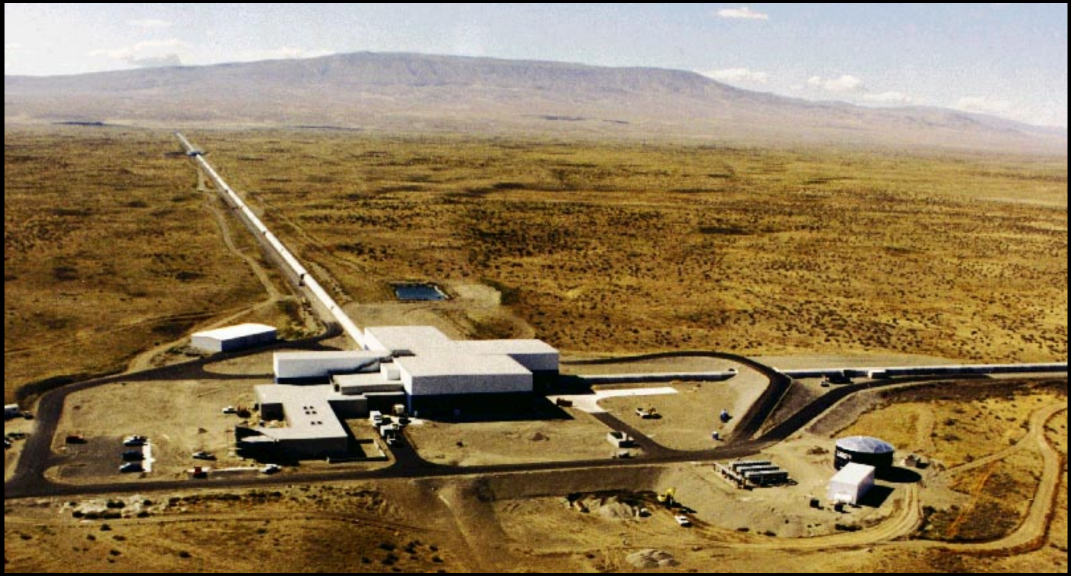
Laser Interferometer Gravitational wave Observatory



Gravitational waves!

LIGO

Laser Interferometer Gravitational wave Observatory



Gravitational waves!

LIGO

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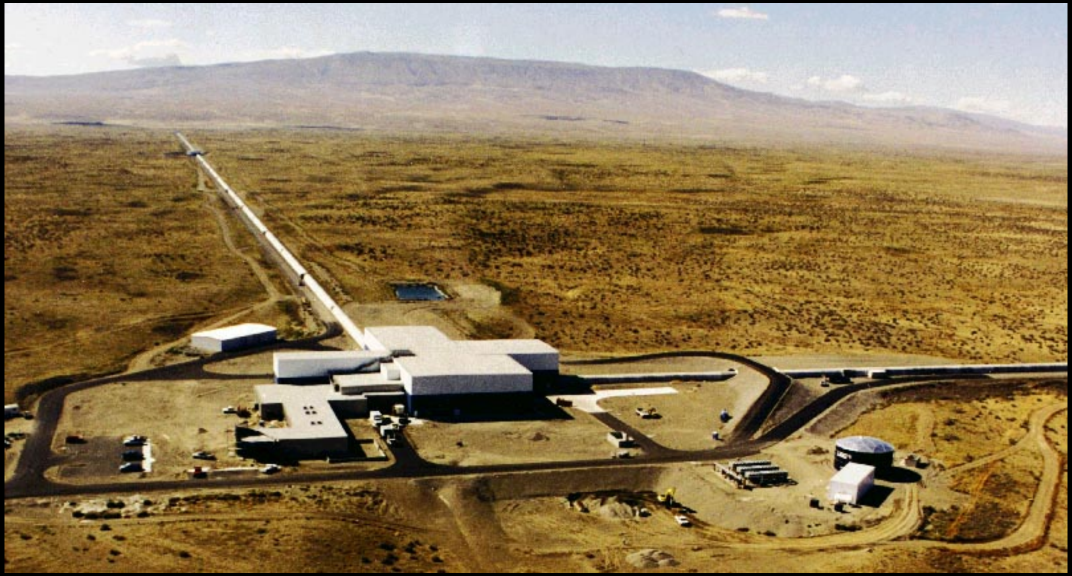


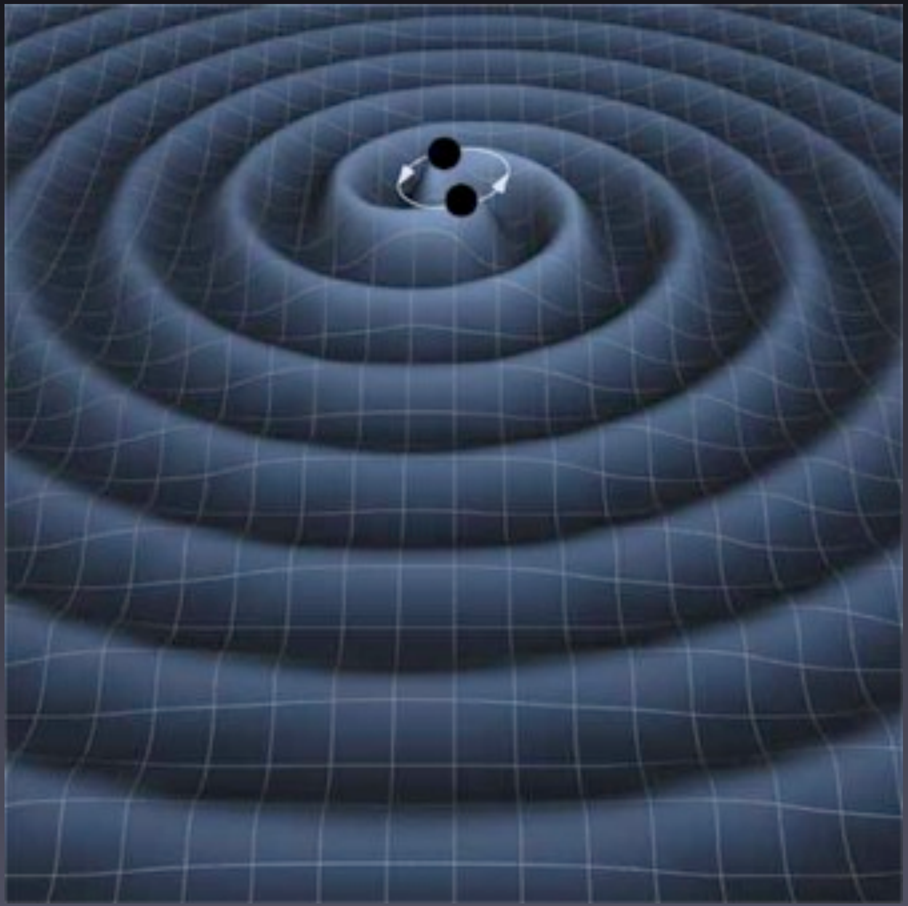
an exemplary (personal) story...

Gravitational what?

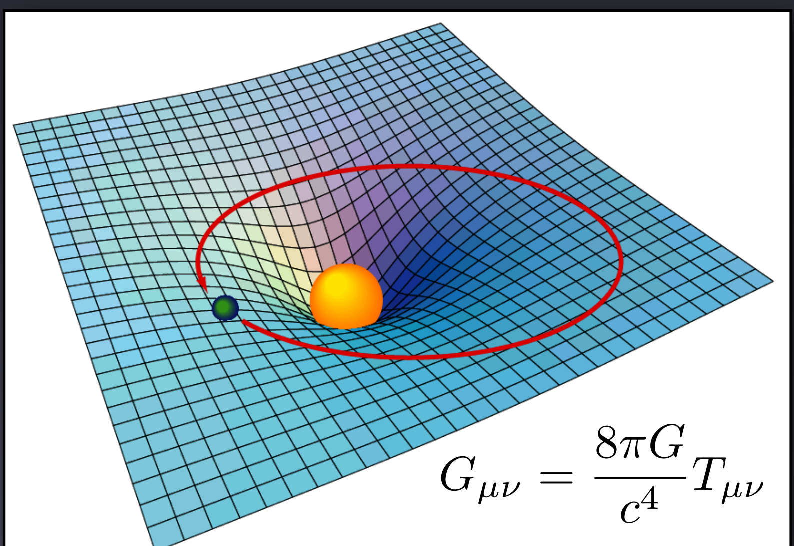
96% of the Universe

Gravitational Waves

- A fundamental prediction of general relativity
- Ripples of space-time that propagate at the speed of light
- Produced by large, compact and relativistic concentration of mass or energy
- Stretch and squeeze space



Einstein's theory of relativity



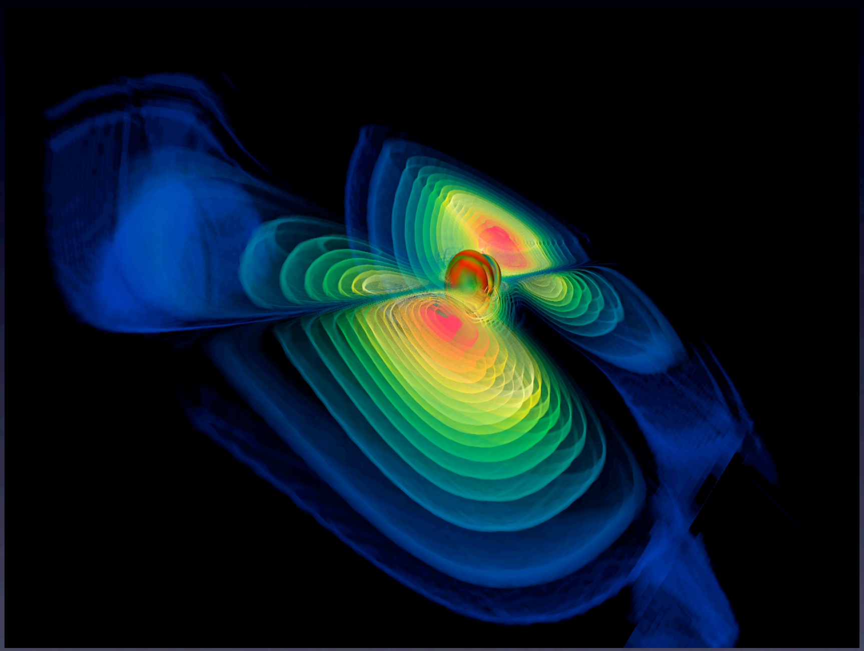
A. Freise

Generation of GWs

The Claw, Dreamworld Australia

L ~ 0. 000 000 000 000 000 000 000 000 000 000 000 000 000 000 1 W

Binary black hole merger



L ~ 10, 000, 000, 000, 000, 000, 000, 000, 000, 000, 000, 000, 000, 000, 000, 000, 000 W

Sources of Gravitational Waves

binary systems

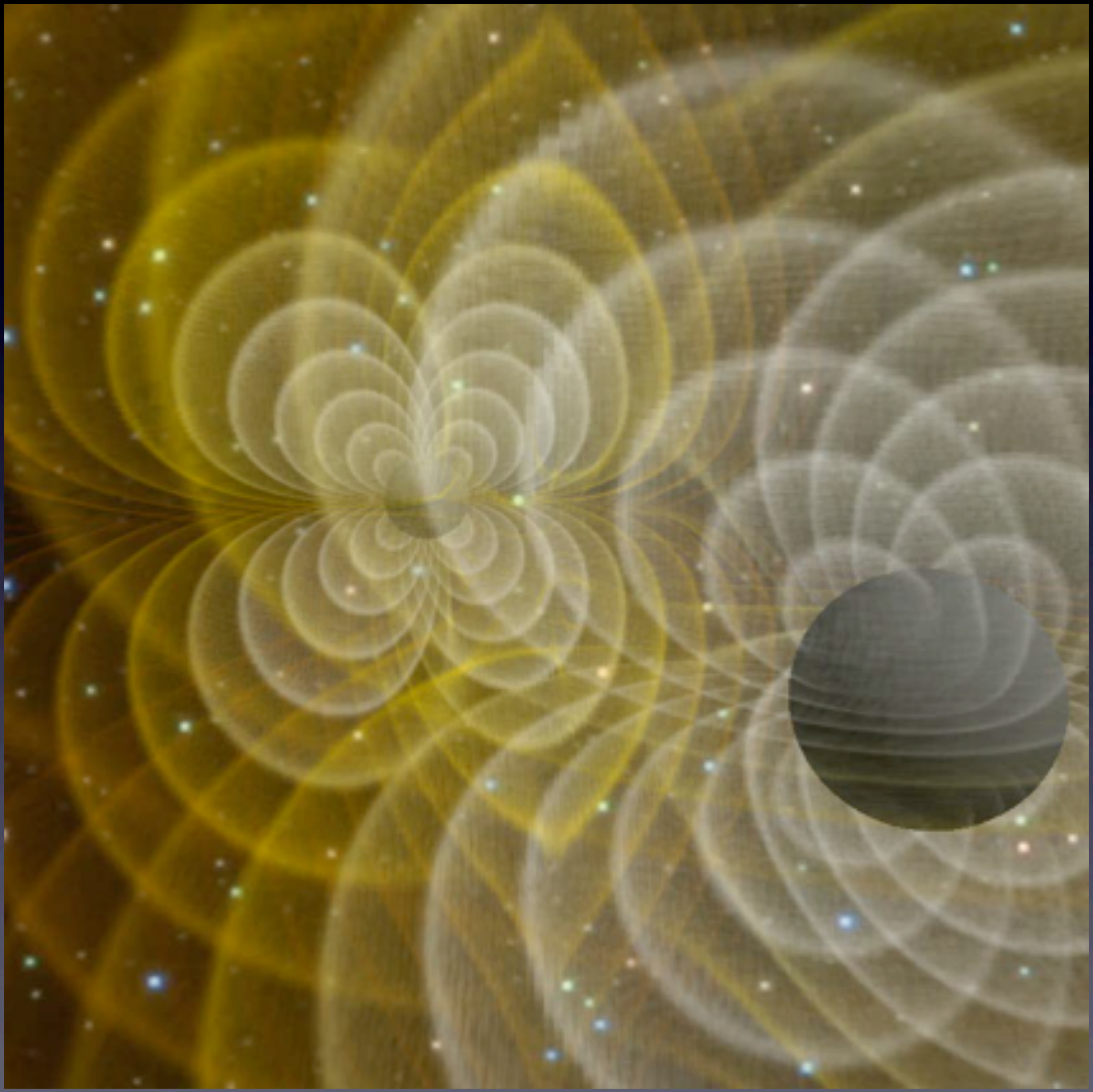
- Any mass distribution that is accelerated in a non-spherically symmetric way (waving hands, running trains, planets in orbit,...)
- Large masses necessary to get any measurable signal

supernovae

pulsars

accreting stars

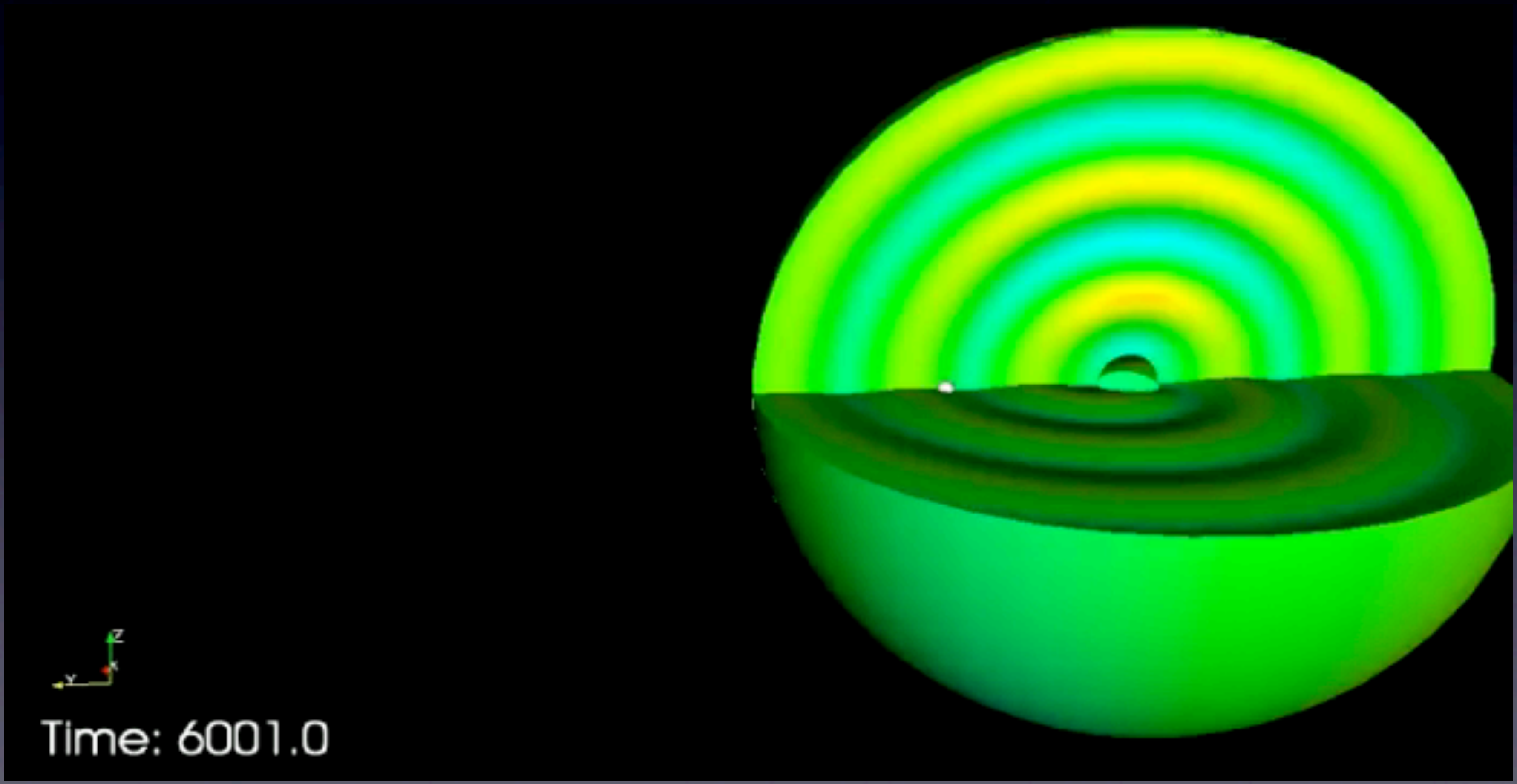
Gravitational waves from merging black holes



Baker, NASA GSFC

Gravitational waves from merging black holes

Bobbing like a Cork ...



[Credit: http://www.black-holes.org/]

And the big question:

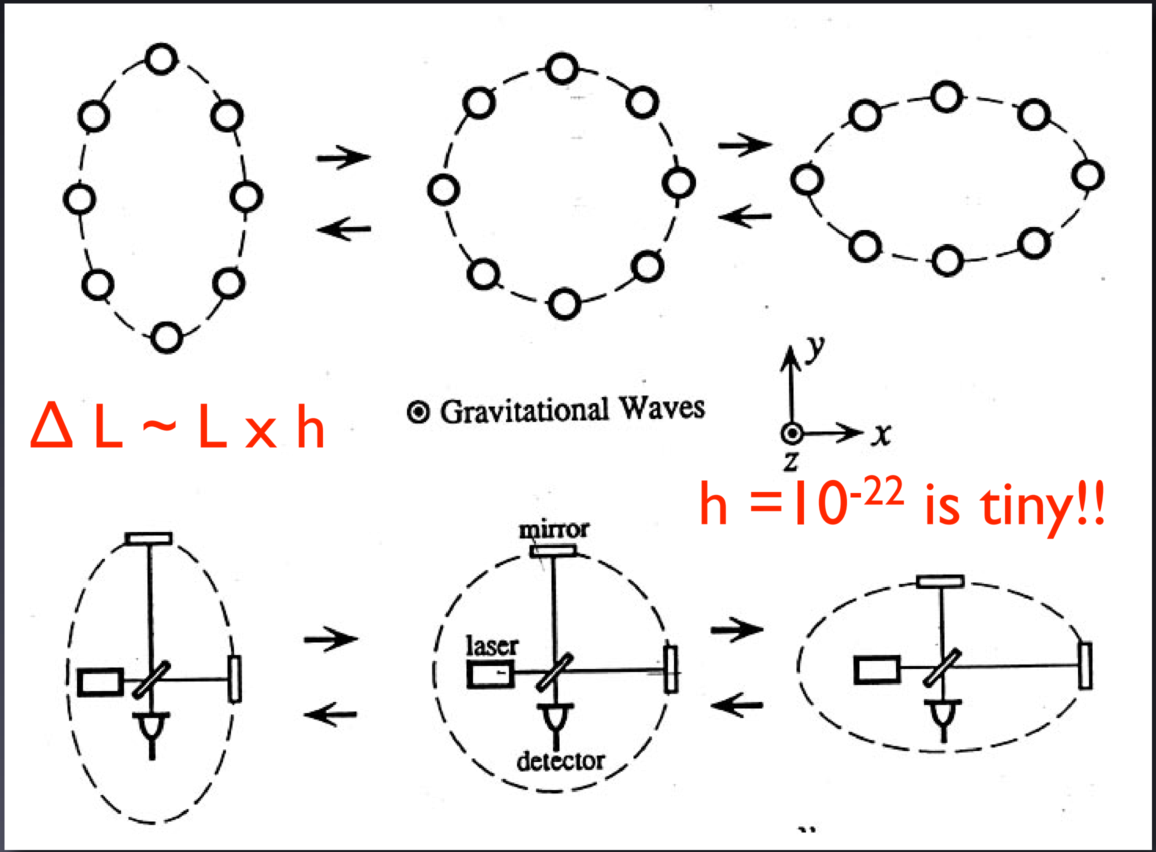
[Credit: http://www.skyandtelescope.com/]

Gravitational Wave

Detection!

Observing Gravitational Waves:

Laser Interferometers



$\Delta L \sim L \times h$

$h = 10^{-22}$ is tiny!!

Interferometry in 1887

Sensitivity:
0.01 of a fringe

Michelson interferometer (ca. 1887)

Interferometry in 1972

ELECTROMAGNETICALLY COUPLED BROADBAND GRAVITATIONAL ANTENNA

MIT

QUARTERLY PROGRESS REPORT

APRIL 15, 1972

No. 105

Sensitivity:
0.000 000 01
of a fringe

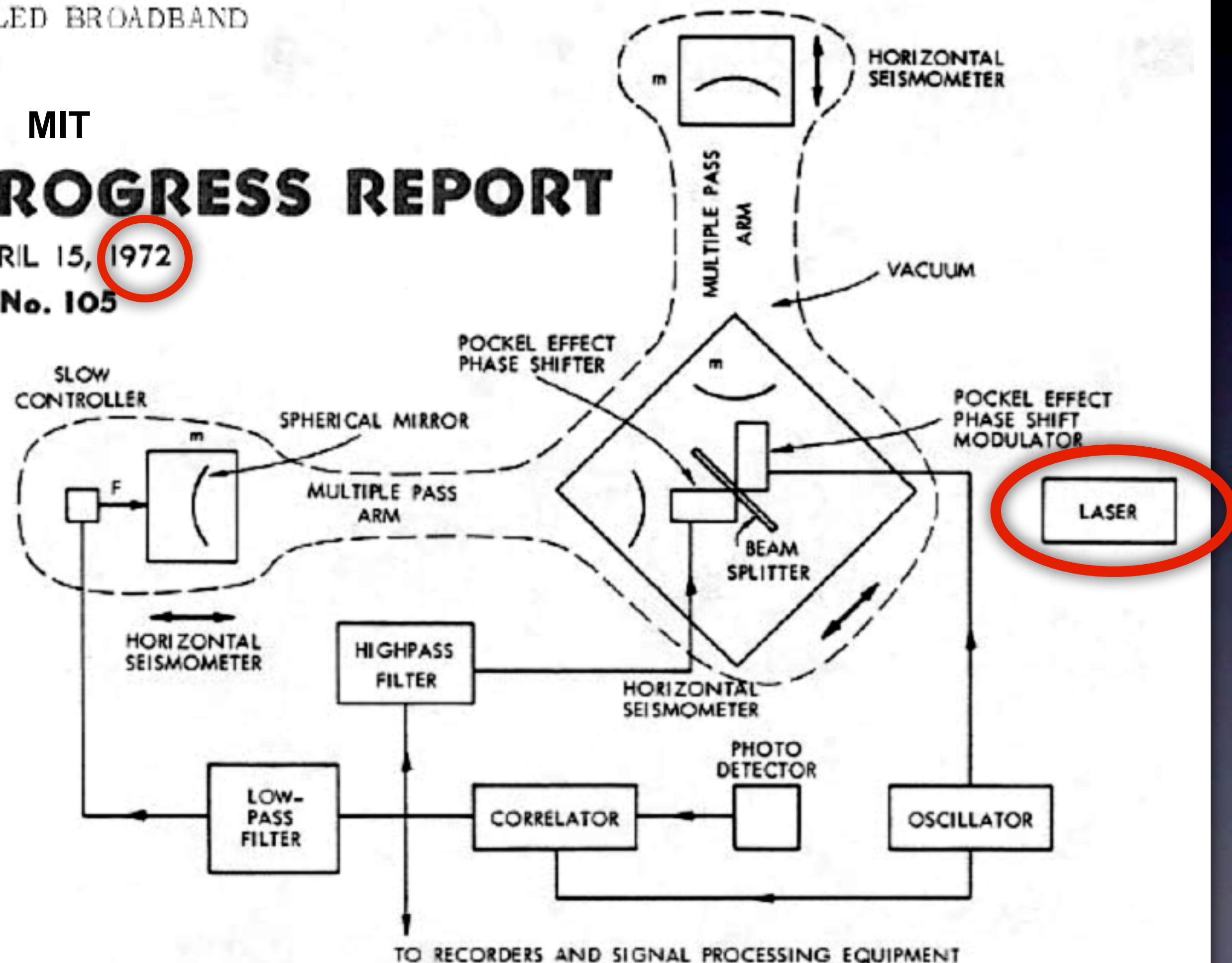
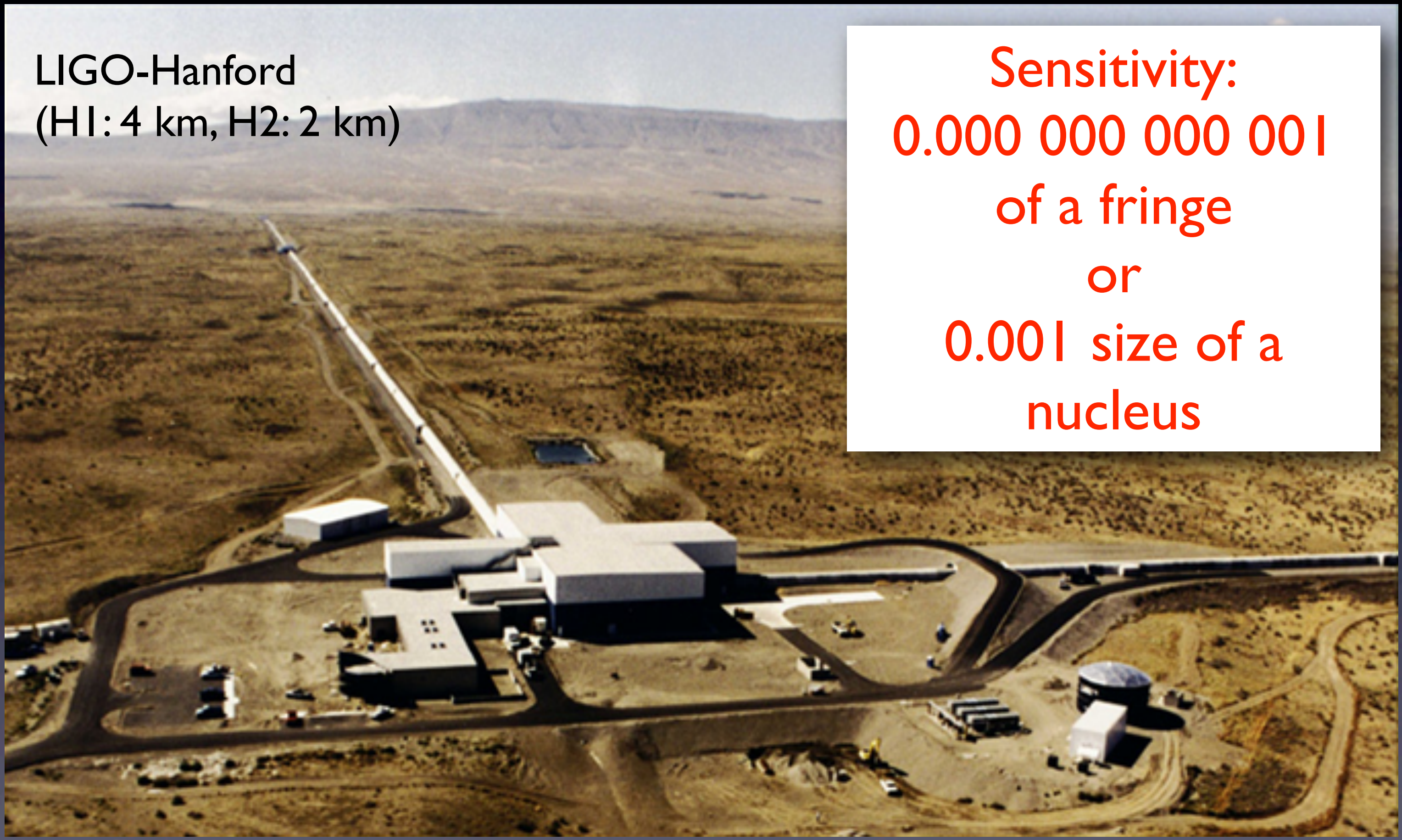
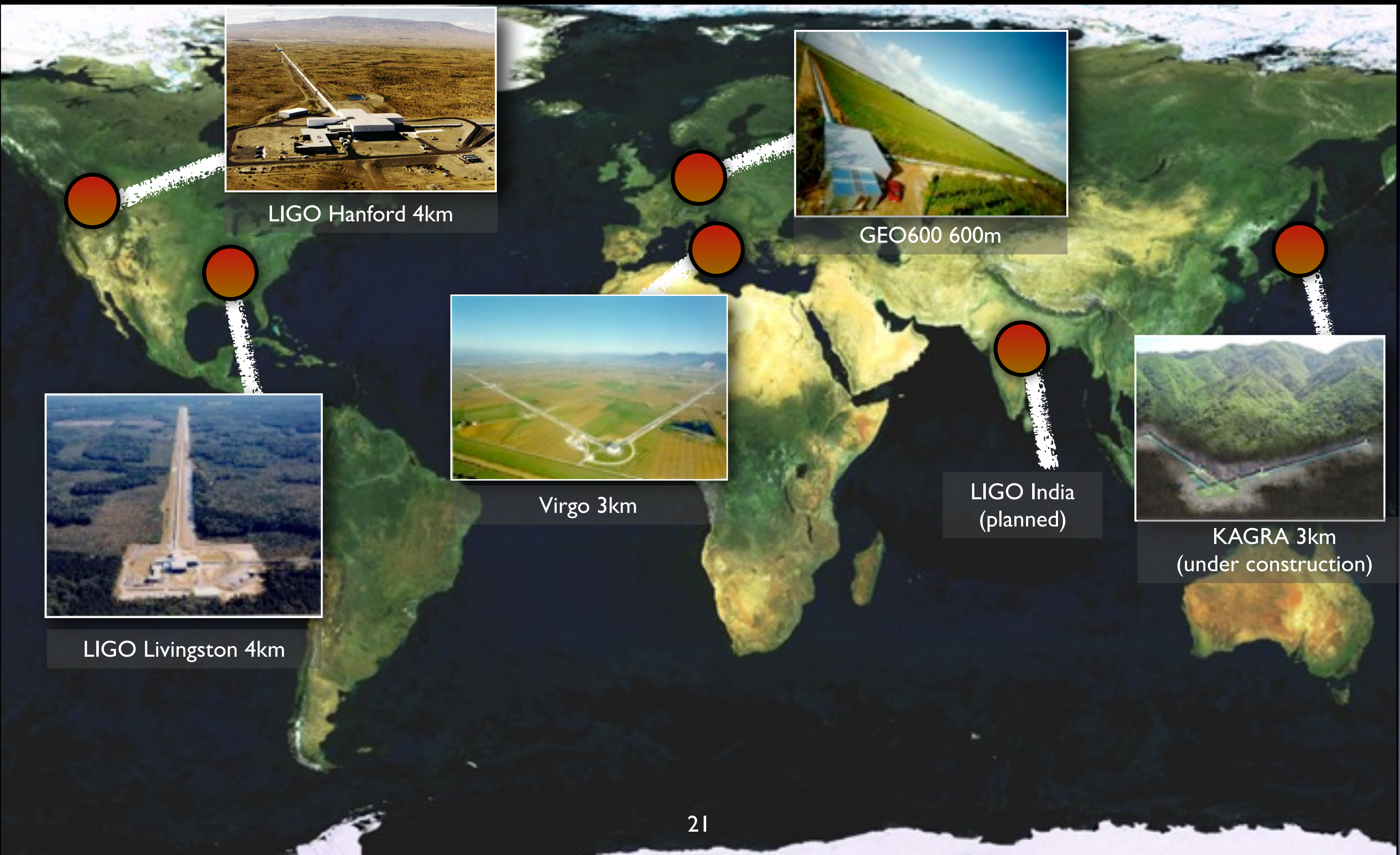


Fig. V-20. Proposed antenna.

GW interferometry today

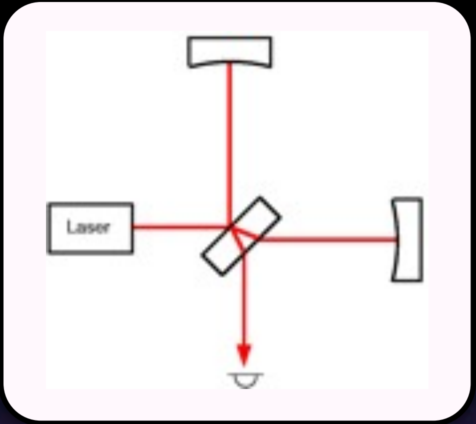


World-wide Network



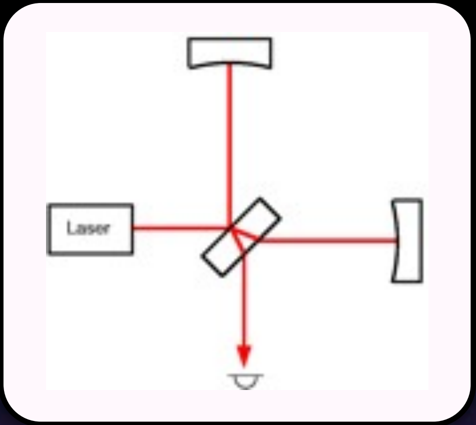
The Emergence of a New Science

The First Generation



- GEO, TAMA, Virgo, LIGO
- Proposed in the 1980ies
- Development of new technologies
- Detectors build in the 1990ies
- Development of even newer technologies
- Operation and data taking 2002-2010

The First Generation



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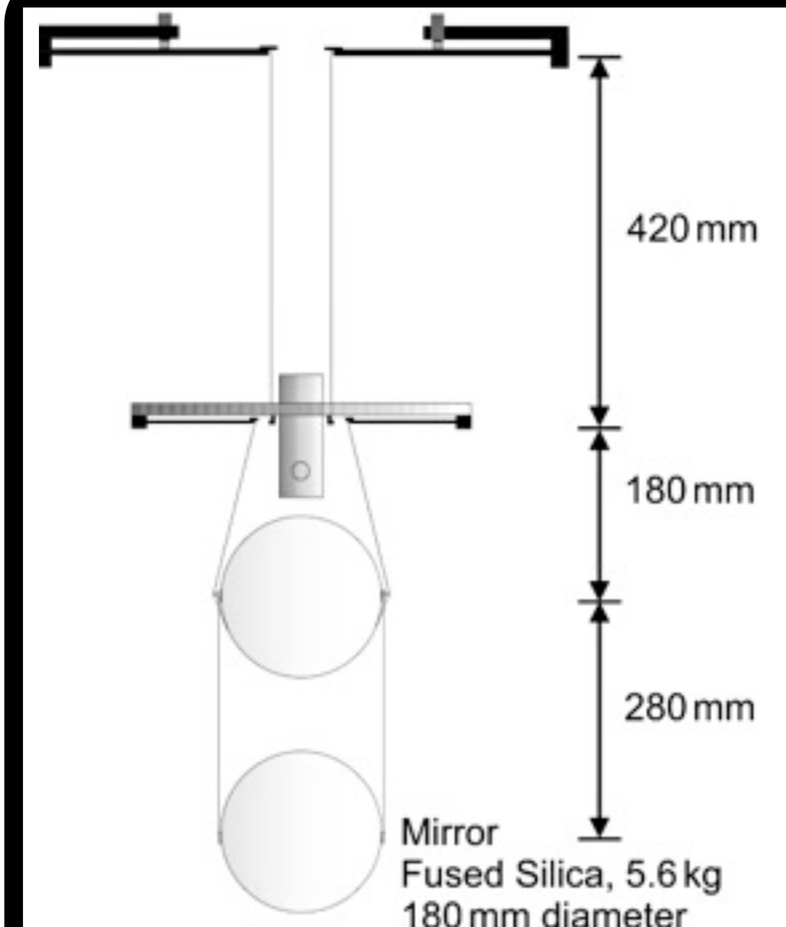
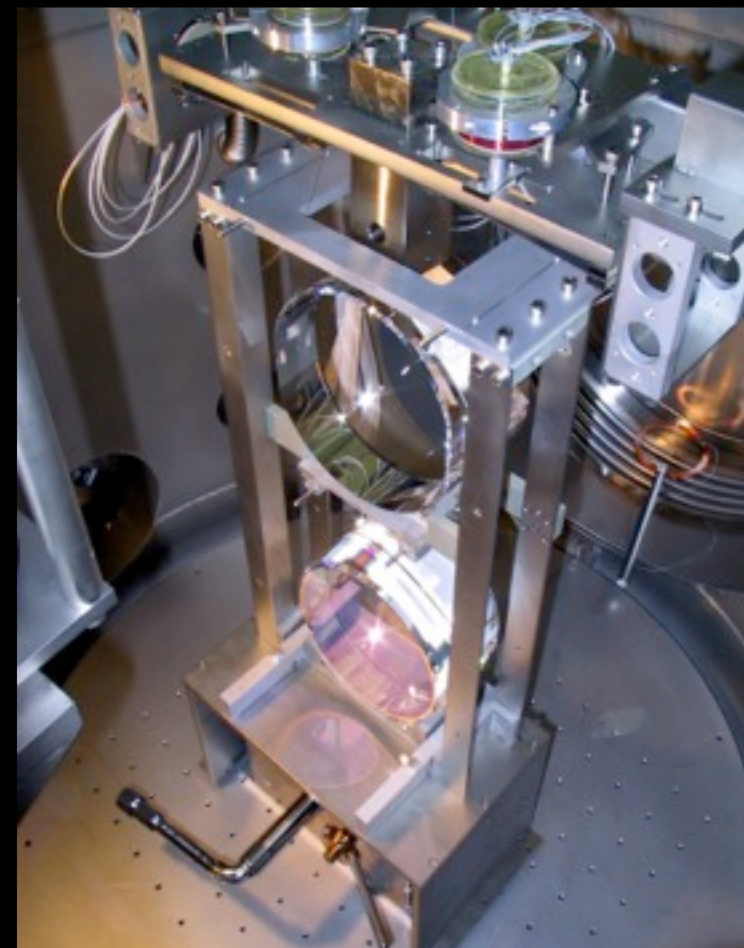
GEO 600 (British/German)

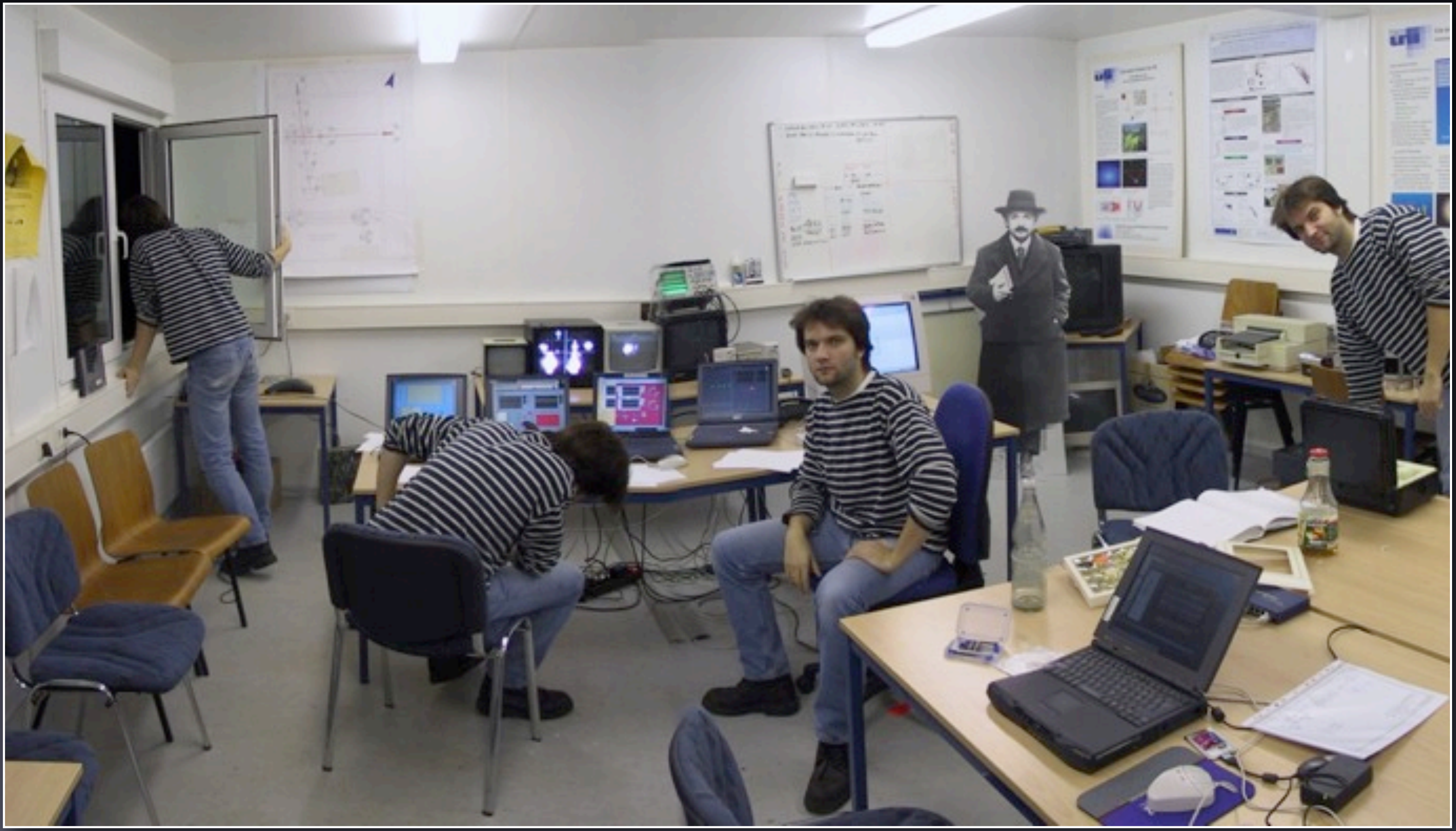
[Credit: Albert-Einstein Institute / GEO 600]

A GEO600 Mirror Suspension





GEO 600 control room (2001)



[Credit: https://wwwcascina.virgo.infn.it/]

Virgo Main Optics

High quality

fused-silica mirrors

- 35 cm diameter, 10 cm thick
- Substrate losses 1 ppm
- Coating losses <5 ppm
- Surface deformation $\lambda/100$ (rms on 150mm)

[Credit: https://wwwcascina.virgo.infn.it/]

Virgo Control Room (2003)

2012

www.ligo.org/magazine

2012

www.ligo.org/magazine

2012

www.ligo.org/magazine

Result?

- No gravitational wave yet!
- We learned a lot!
- Global gravitational wave community

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- No gravitational wave yet!

- We learned a lot!
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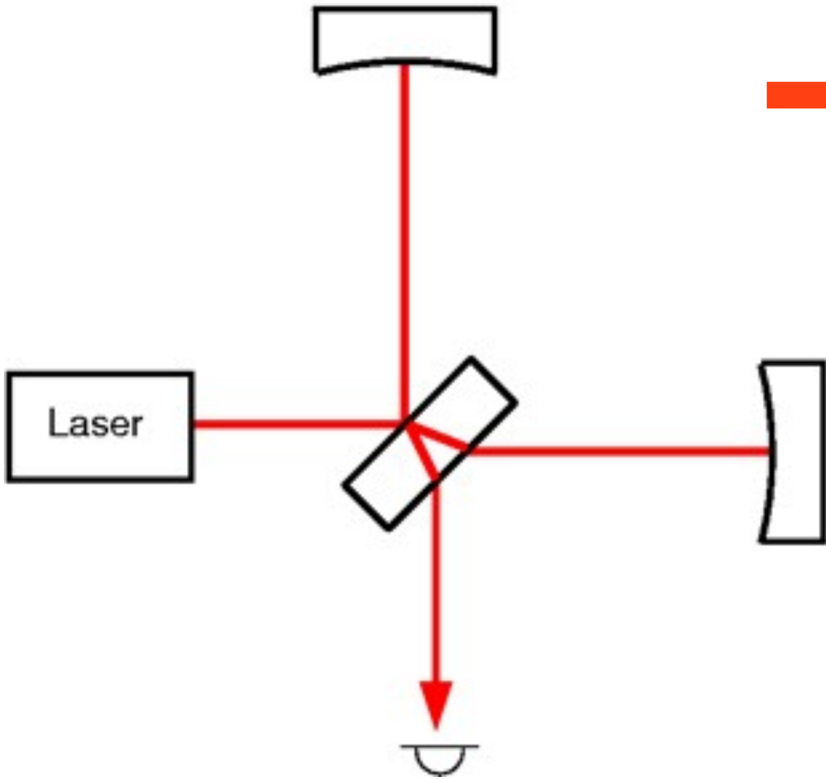
Advanced LIGO

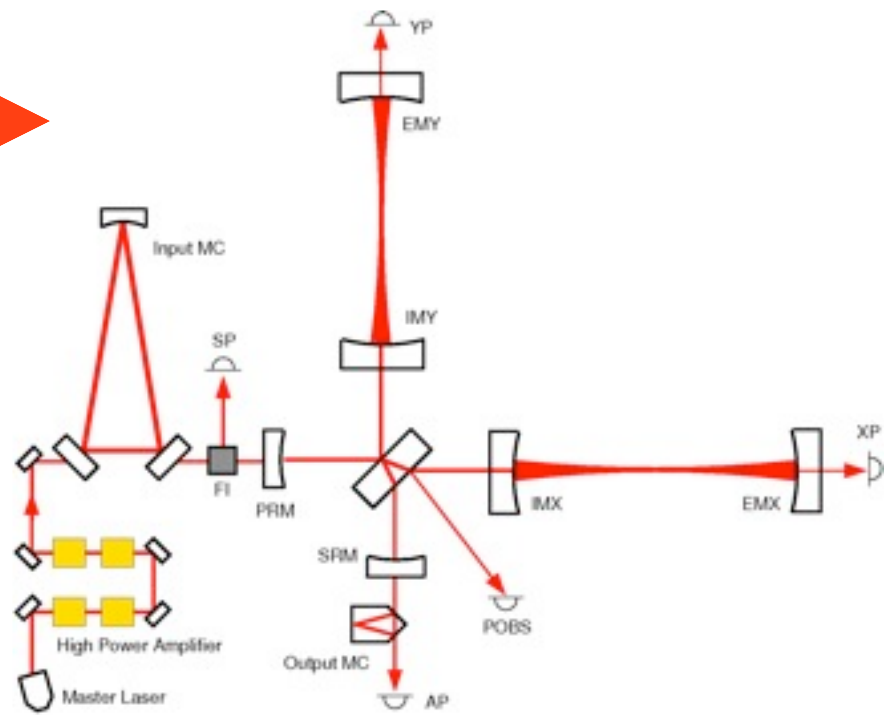
LIGO Scientific Collaboration

- Australian Consortium for Interferometric Gravitational Astronomy
- The Univ. of Adelaide
- Andrews University
- The Australian National Univ.
- The University of Birmingham
- California Inst. of Technology
- Cardiff University
- Carleton College
- Charles Sturt Univ.
- Columbia University
- Embry Riddle Aeronautical Univ.
- Eötvös Loránd University
- University of Florida
- German/British Collaboration for the Detection of Gravitational Waves
- University of Glasgow
- Goddard Space Flight Center
- Leibniz Universität Hannover
- Hobart & William Smith Colleges
- Inst. of Applied Physics of the Russian Academy of Sciences
- Polish Academy of Sciences
- India Inter-University Centre for Astronomy and Astrophysics
- Louisiana State University
- Louisiana Tech University
- Loyola University New Orleans
- University of Maryland
- Max Planck Institute for Gravitational Physics
- University of Michigan
- University of Minnesota
- The University of Mississippi
- Massachusetts Inst. of Technology
- Monash University
- Montana State University
- Moscow State University
- National Astronomical Observatory of Japan
- Northwestern University
- University of Oregon
- Pennsylvania State University
- Rochester Inst. of Technology
- Rutherford Appleton Lab
- University of Rochester
- San Jose State University
- Univ. of Sannio at Benevento, and Univ. of Salerno
- University of Sheffield
- University of Southampton
- Southeastern Louisiana Univ.
- Southern Univ. and A&M College
- Stanford University
- University of Strathclyde
- Syracuse University
- Univ. of Texas at Austin
- Univ. of Texas at Brownsville
- Trinity University
- Universitat de les Illes Balears
- Univ. of Massachusetts Amherst
- University of Western Australia
- Univ. of Wisconsin-Milwaukee
- Washington State University
- University of Washington

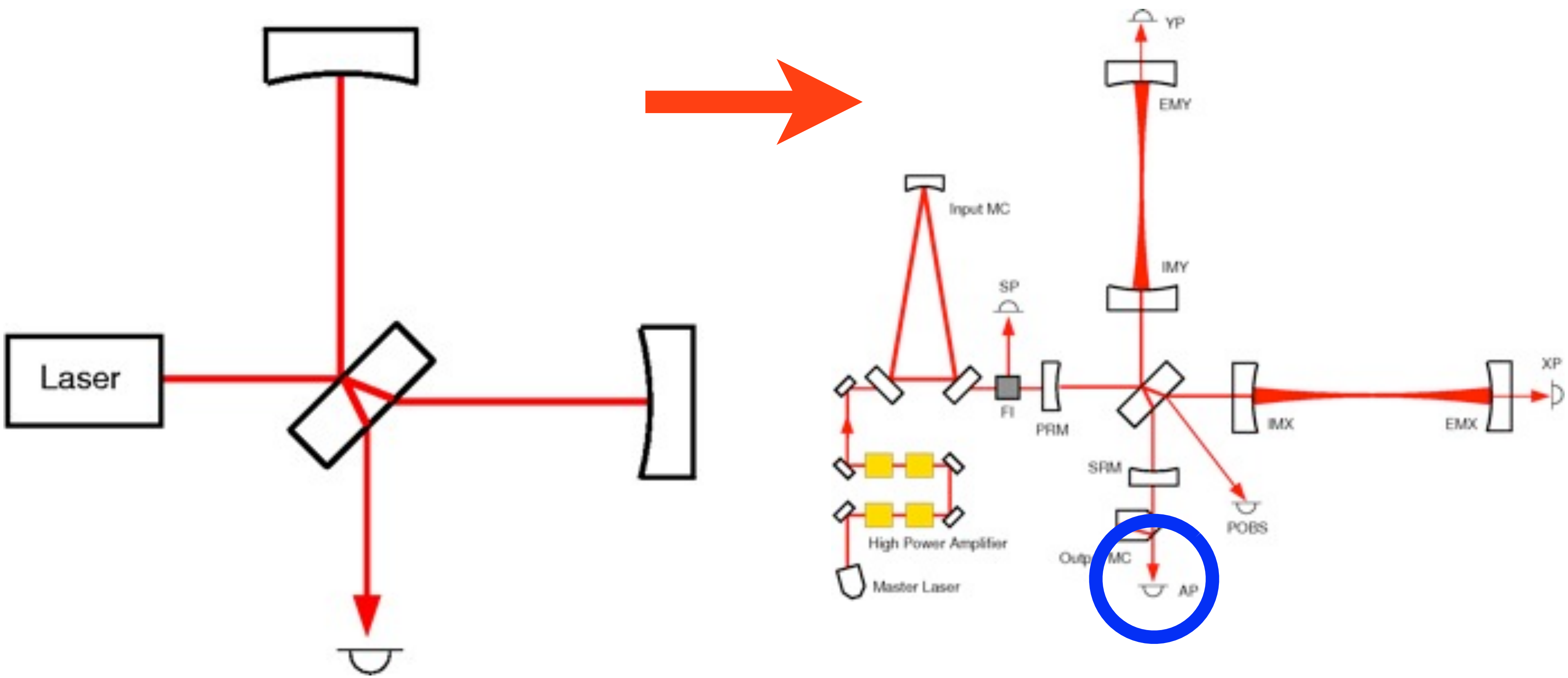
[Credit: LIGO Laboratory]

Advanced Interferometry

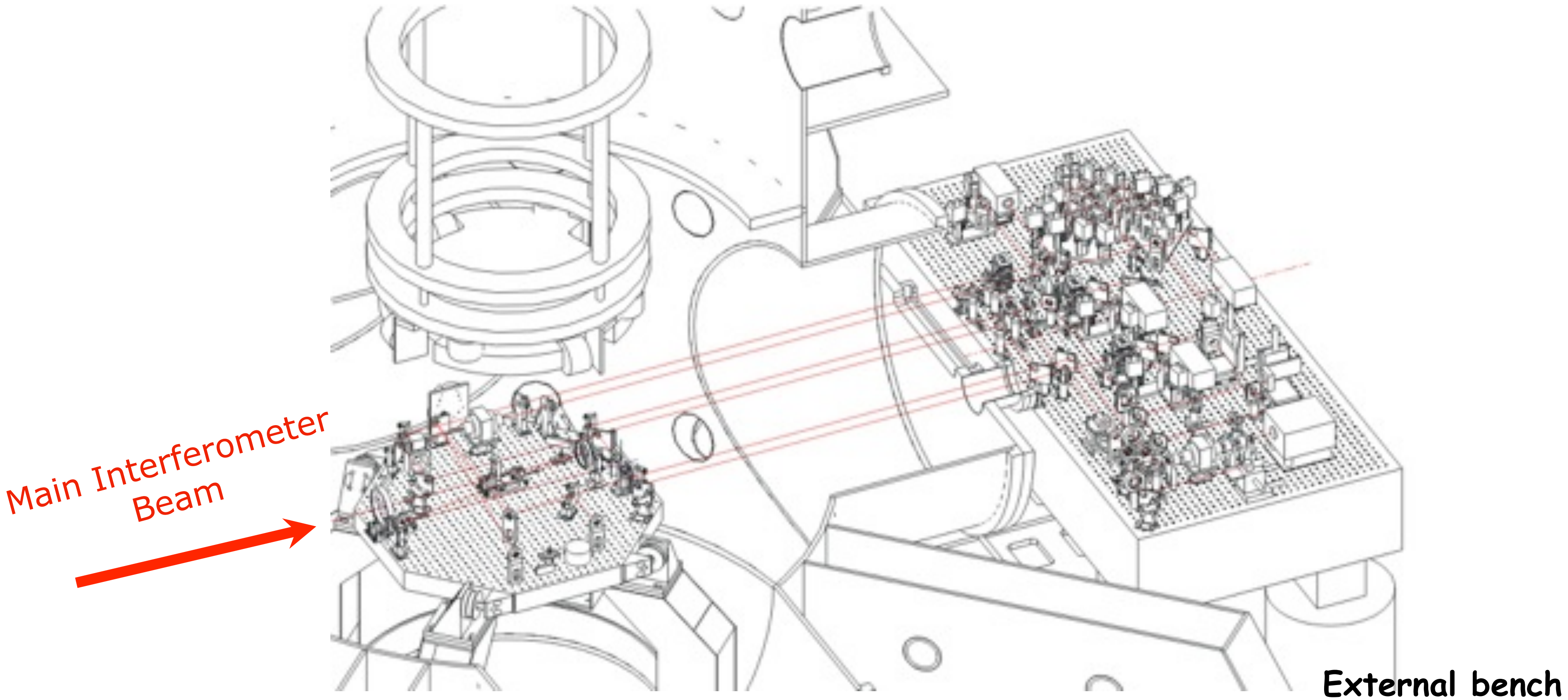




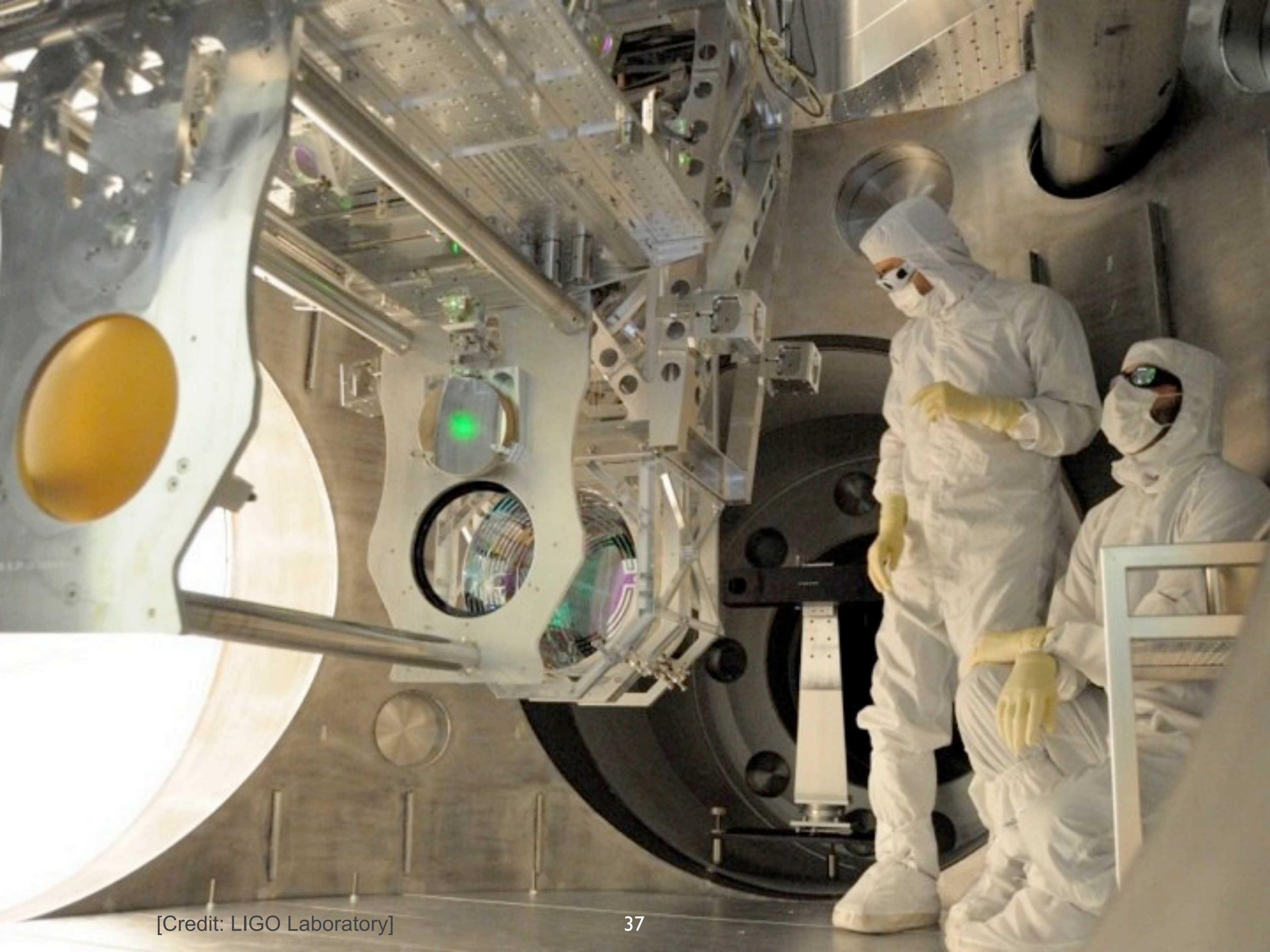
Advanced Interferometry



Michelson used his eye to measure the light, this is how one photo detection port looks today:



[Credit: https://wwwcascina.virgo.infn.it/]



[Credit: LIGO Laboratory]

David Willetts, Minister of State for Universities and Science

[Credit: John James]

Advanced LIGO is expected to achieve first detection!

Advanced LIGO is expected to achieve first detection!

What shall <u>we</u> do then?

Preparing for Advanced LIGO

Commissioning and Simulation Workshop, LIGO Livingston 28.01. - 01.02.2013

The `Arm' Cavity

[Images:Virgo, and LIGO Laboratory]

The `Arm' Cavity

[Images:Virgo, and LIGO Laboratory]

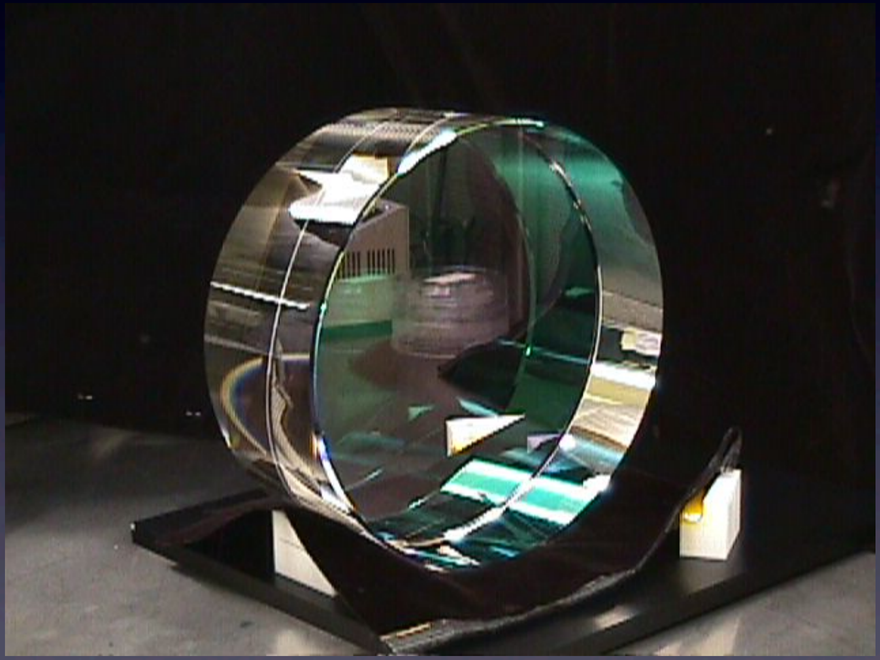
The `Arm' Cavity

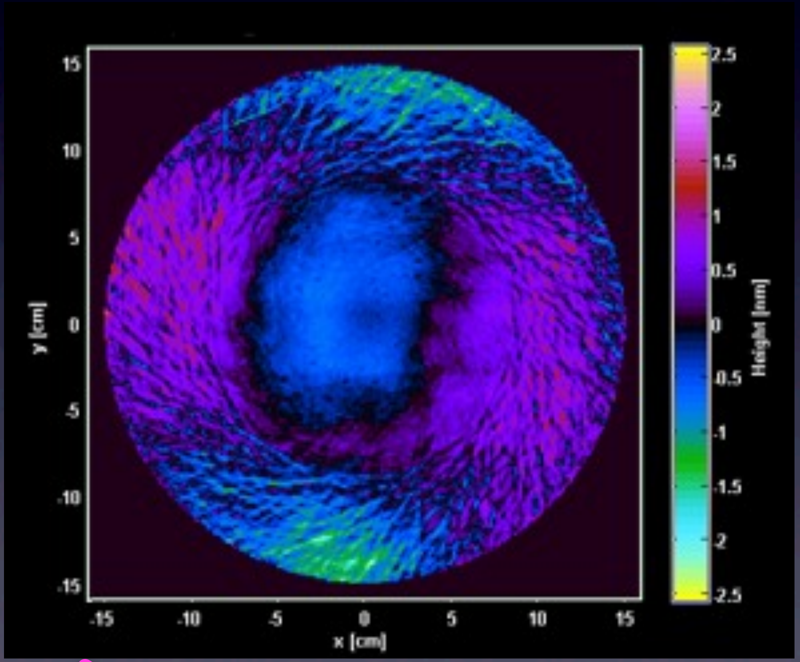
[Images: Virgo, and LIGO Laboratory]

The `Arm' Cavity

[Images:Virgo, and LIGO Laboratory]

The Mirror Surface



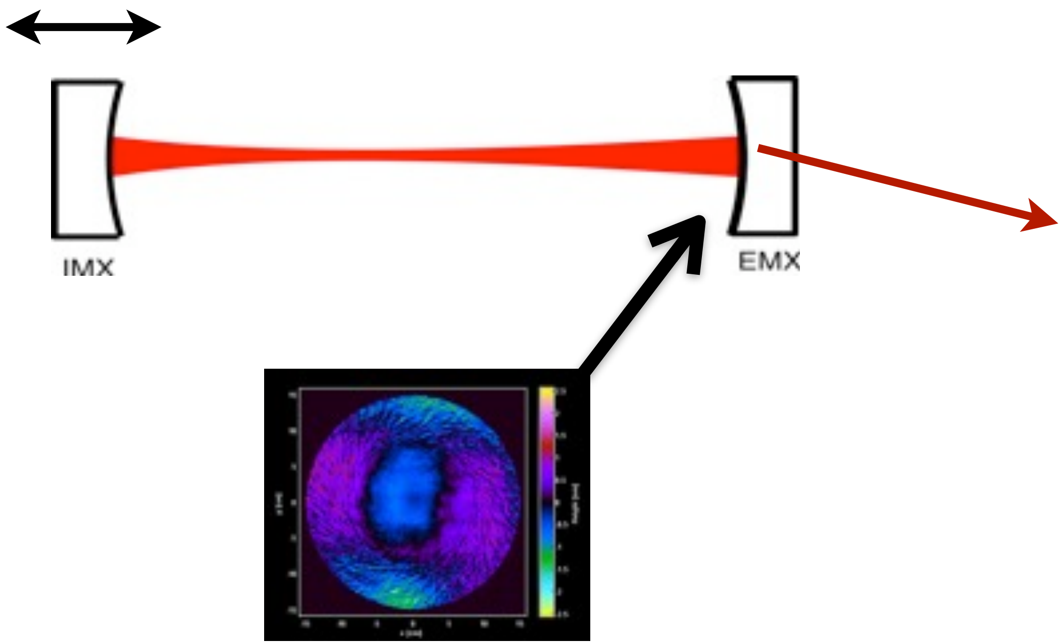


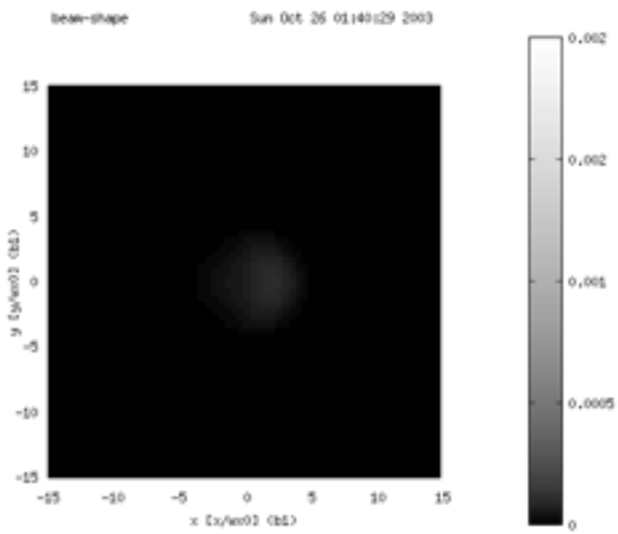
Surface measurement

[Images: Virgo, and LIGO Laboratory]

Beam shape distortions

Acceptance of mirrors from manufacturer: Computer model is used to estimate the optical distortions due to the measured mirror distortions.

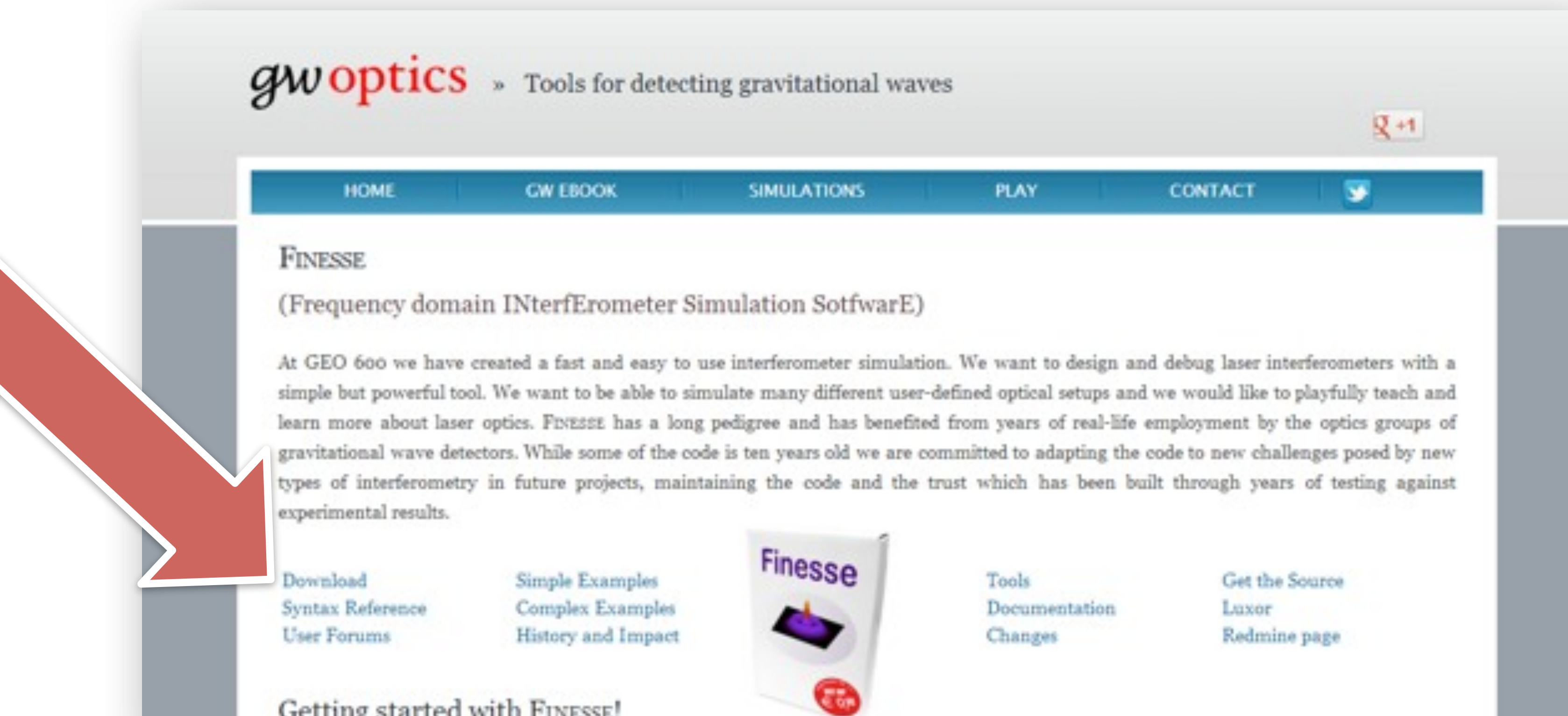




Beam shape inside arm cavity

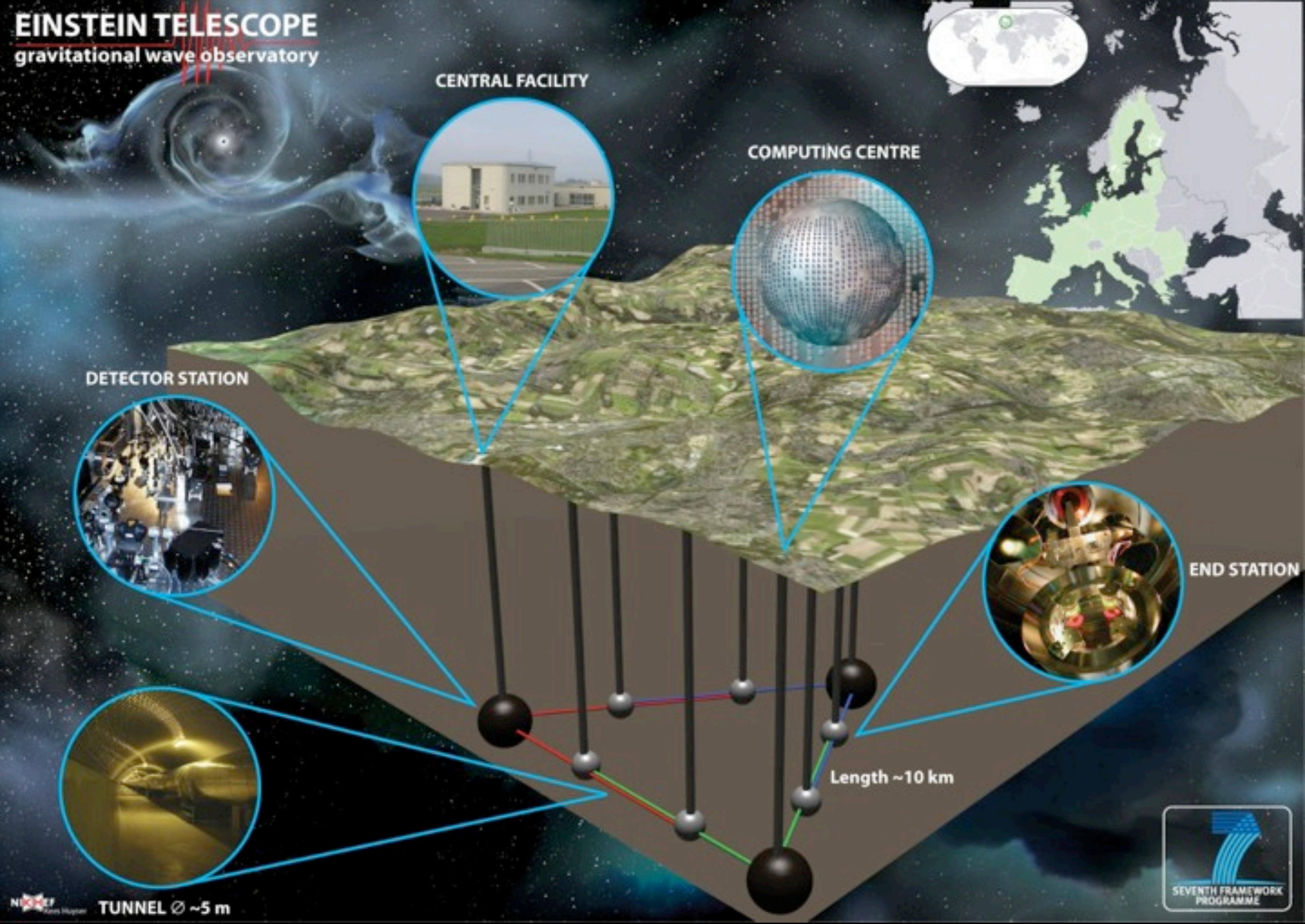
FINESSE: Open Source Simulation

- Started in 1997 and developed as my PhD side project, used extensively worldwide
- Versions available for Windows, Linux and Mac OSX, open source, download at www.gwoptics.org/finesse

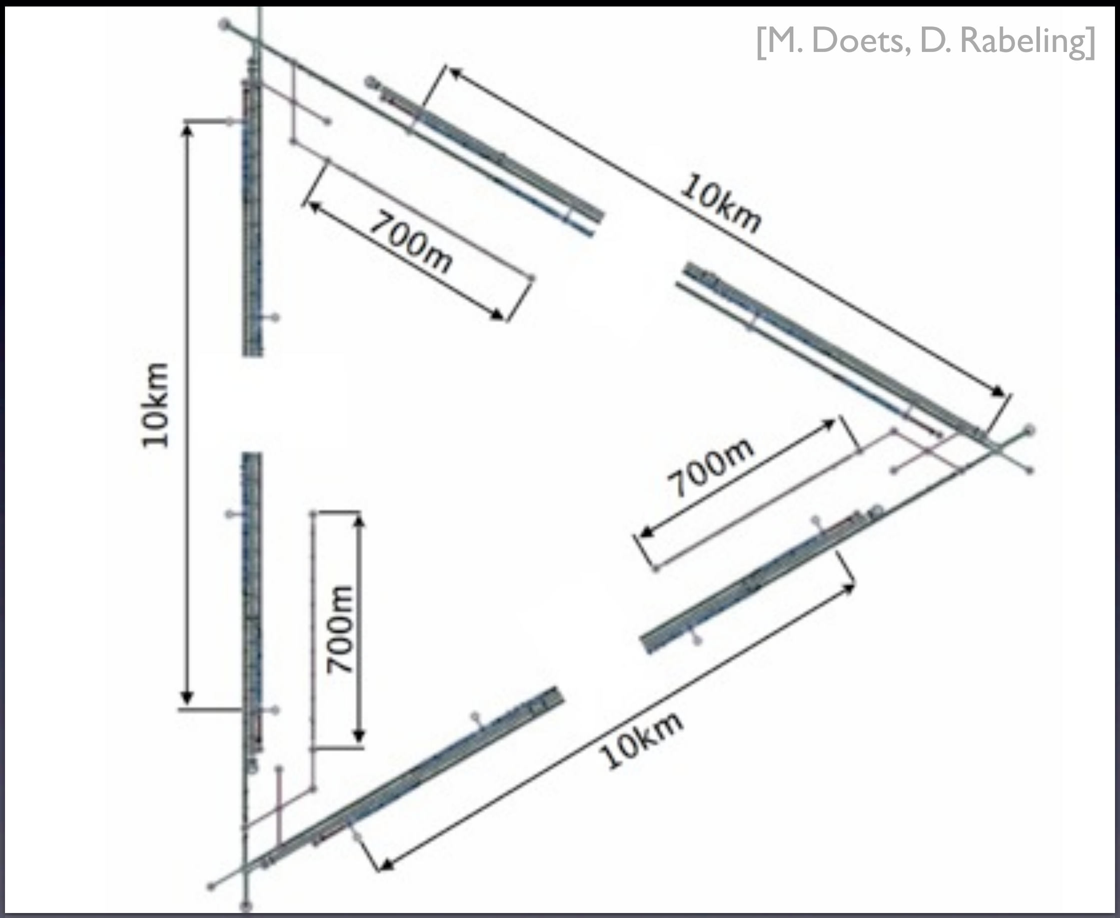


Reflection from the Advanced LIGO pre-Modecleaner cavity, image by Kate Dooley

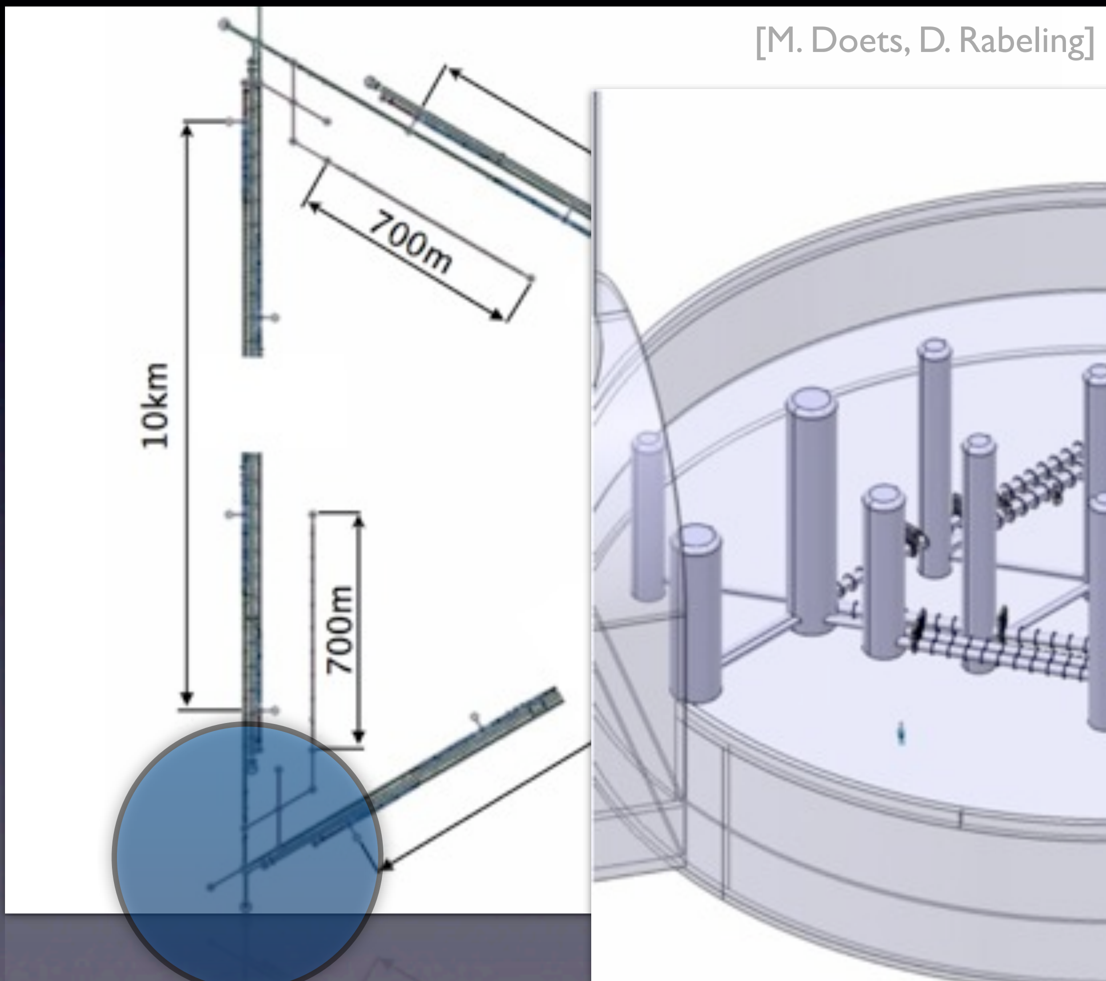
The Einstein Telescope

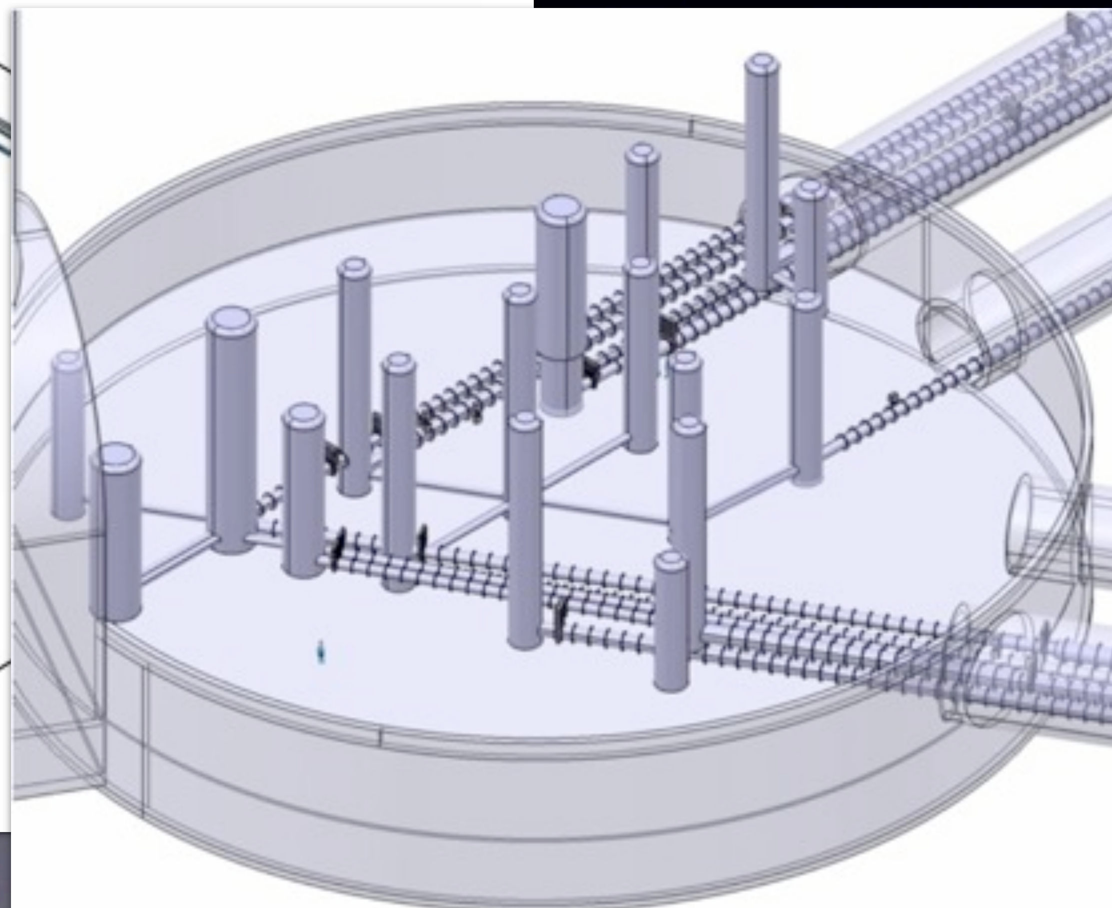

EINSTEIN TELESCOPE
gravitational wave observatory
CENTRAL FACILITY
COMPUTING CENTRE
DETECTOR STATION
END STATION
Length ~10 km
TUNNEL ∅ ~5 m
SEVENTH FRAMEWORK PROGRAMME

Large Infrastructure

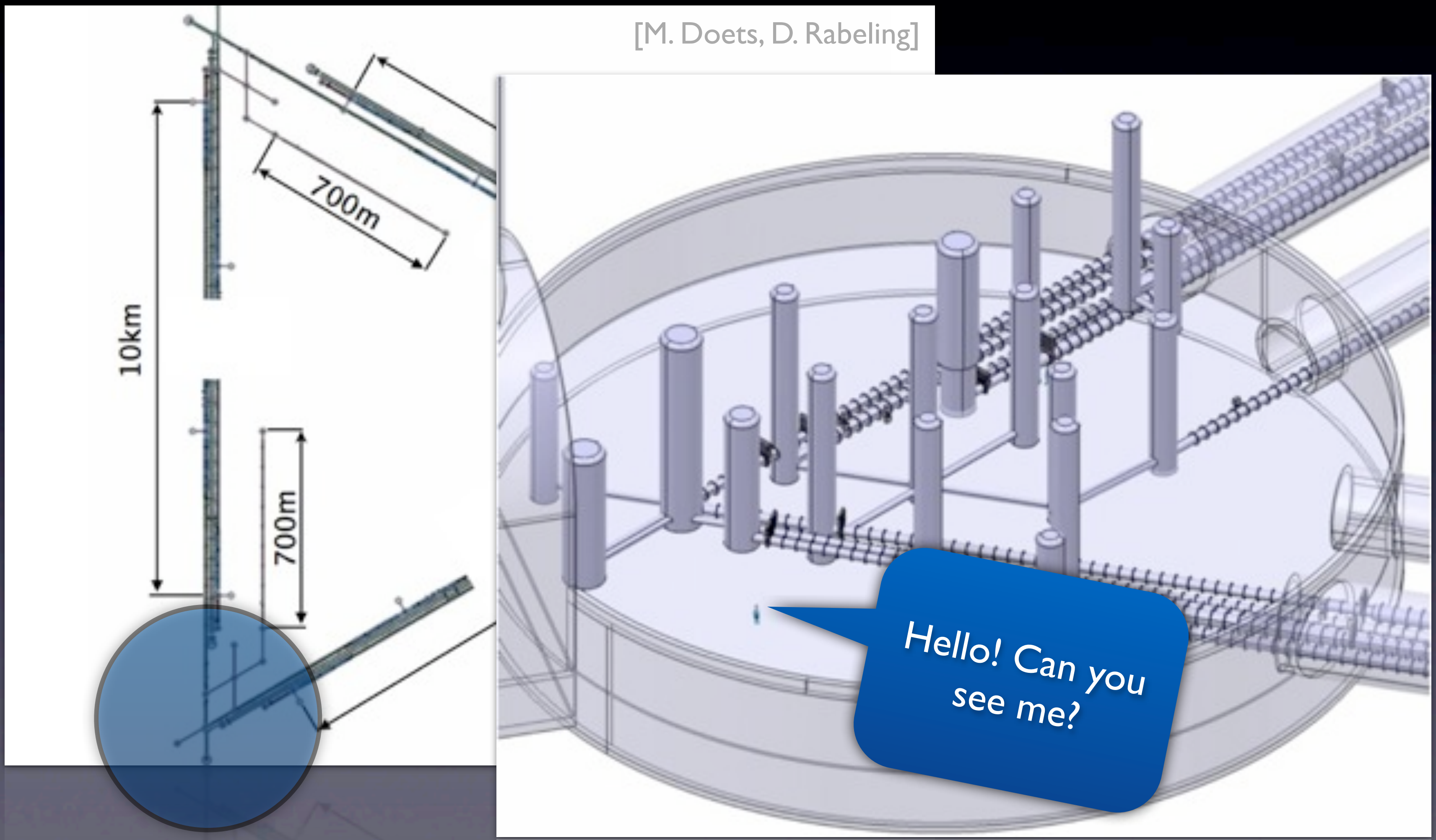


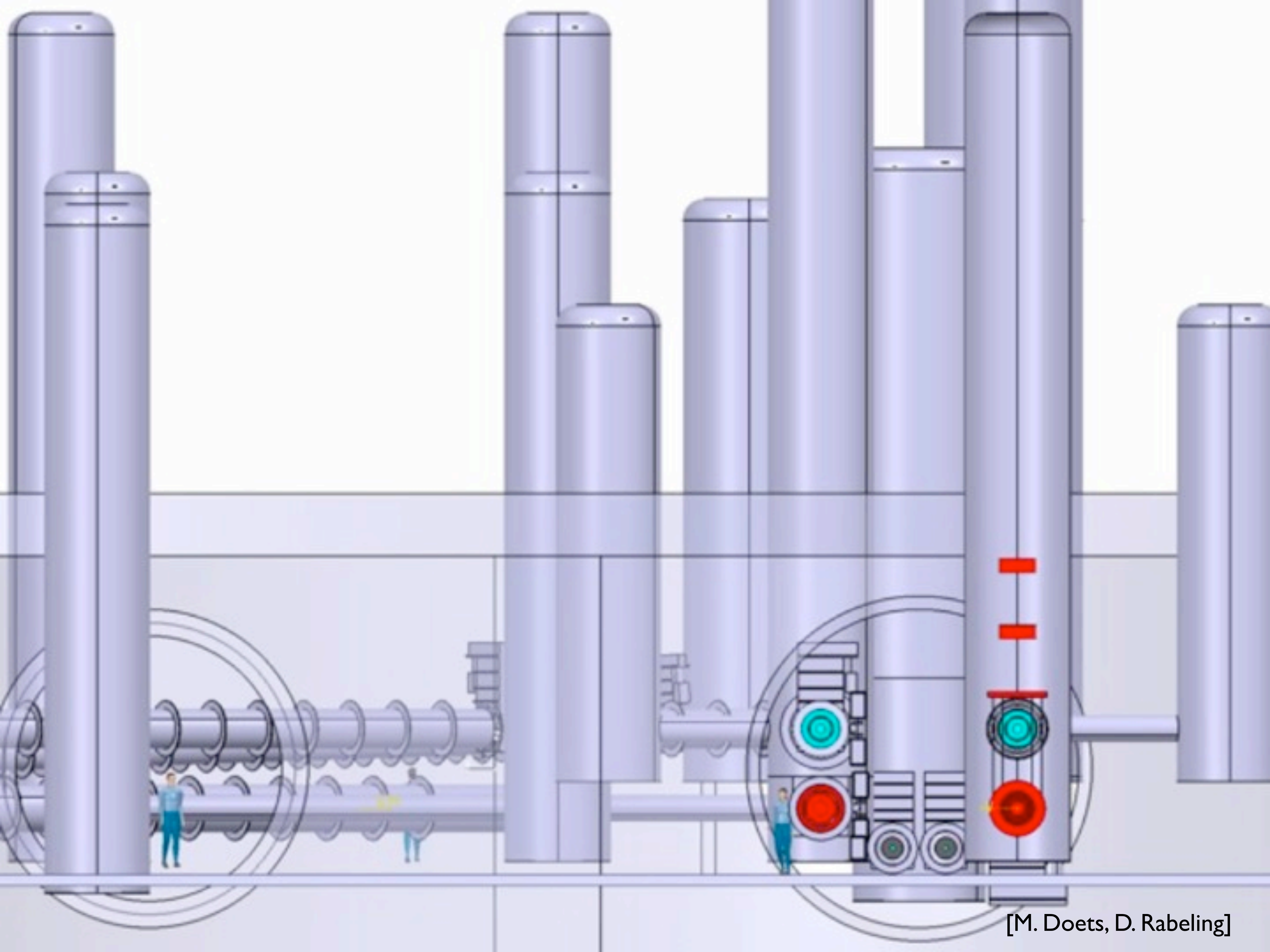
Large Infrastructure



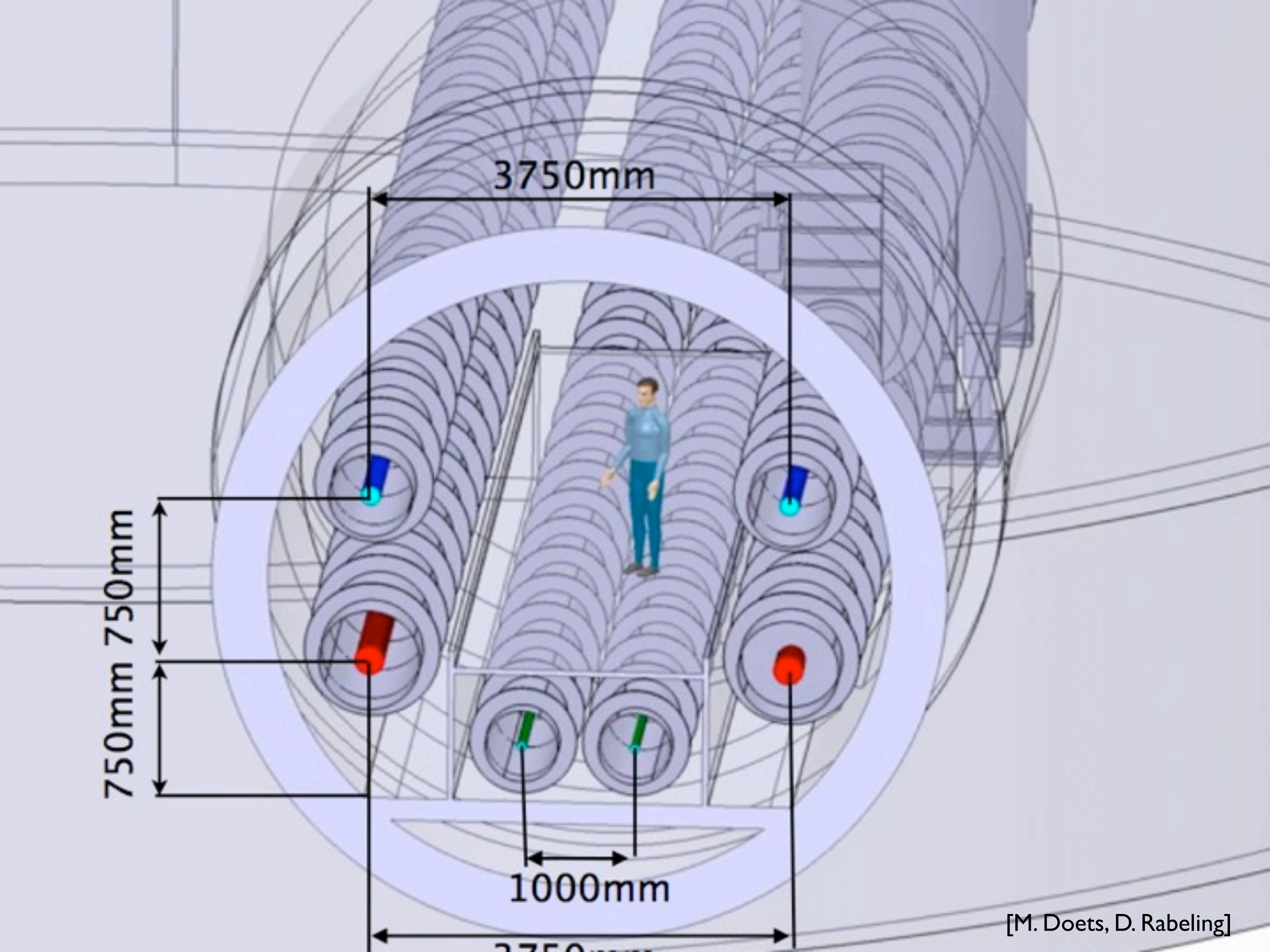


Large Infrastructure





[M. Doets, D. Rabeling]



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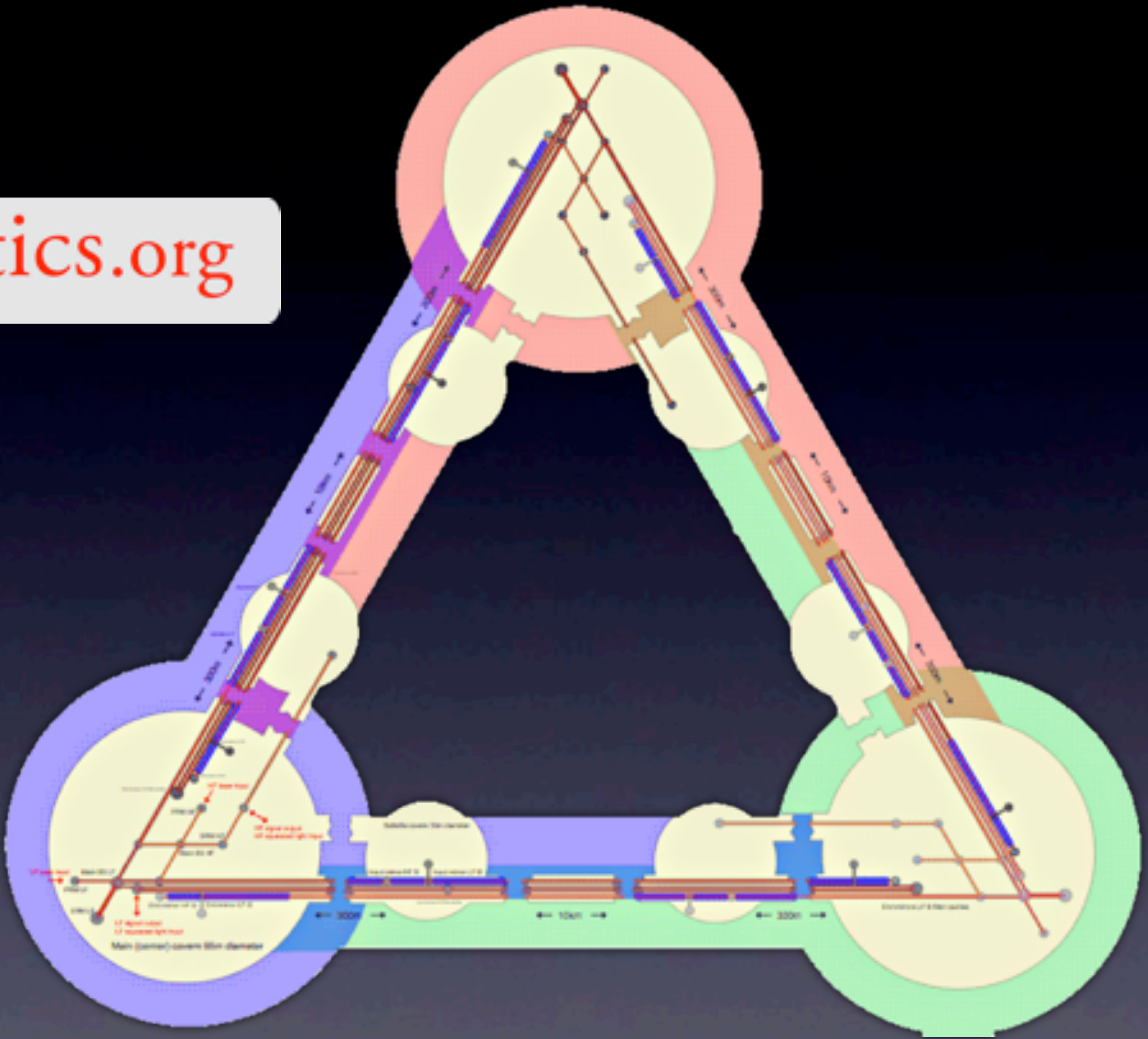
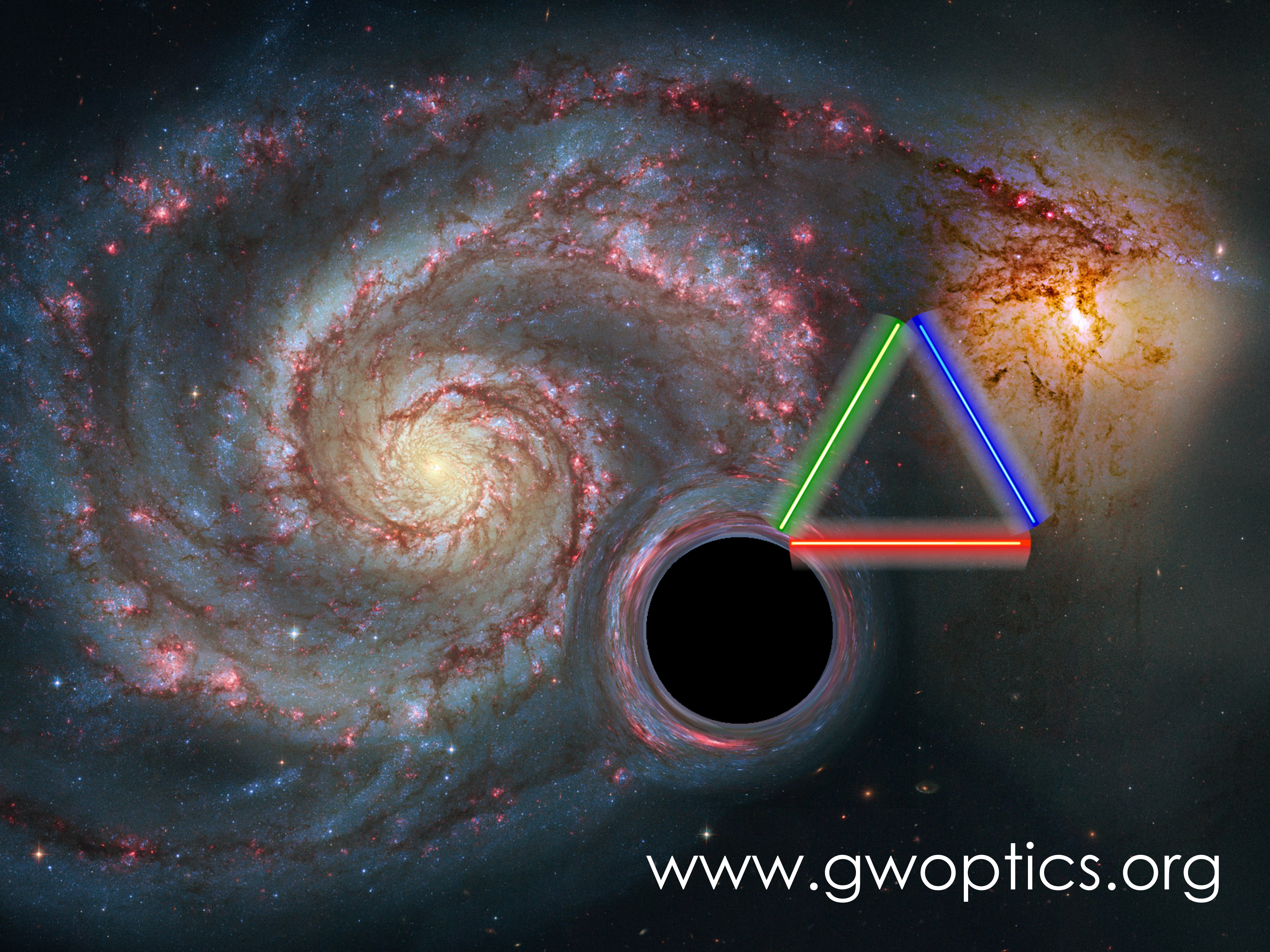


gwoptics.org

Science is a slow process

You can have a big impact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Acknowledgements

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    - GEO 600, http://www.geo600.org/
    - Virgo, http://wwwcascina.virgo.infn.it/
    - Einstein Telescope, http://www.et-gw.eu/
    - LISA, http://lisa.nasa.gov/
    - KAGRA, http://gwcenter.icrr.u-tokyo.ac.jp/
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    - Albert Einstein Institute, http://www.aei.mpg.de/
    - NIKHEF, http://www.nikhef.nl/
    - Numerical Relativity group, FSU Jena, https://www.tpi.uni-jena.de/
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    - Caltech-Cornell, http://www.black-holes.org/

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- Lainey Bird
- Sky and Telescope Magazine
- John James
- Kate Dooley (LIGO/GEO)
- Martin Doets, David Rabeling (Nikhef)