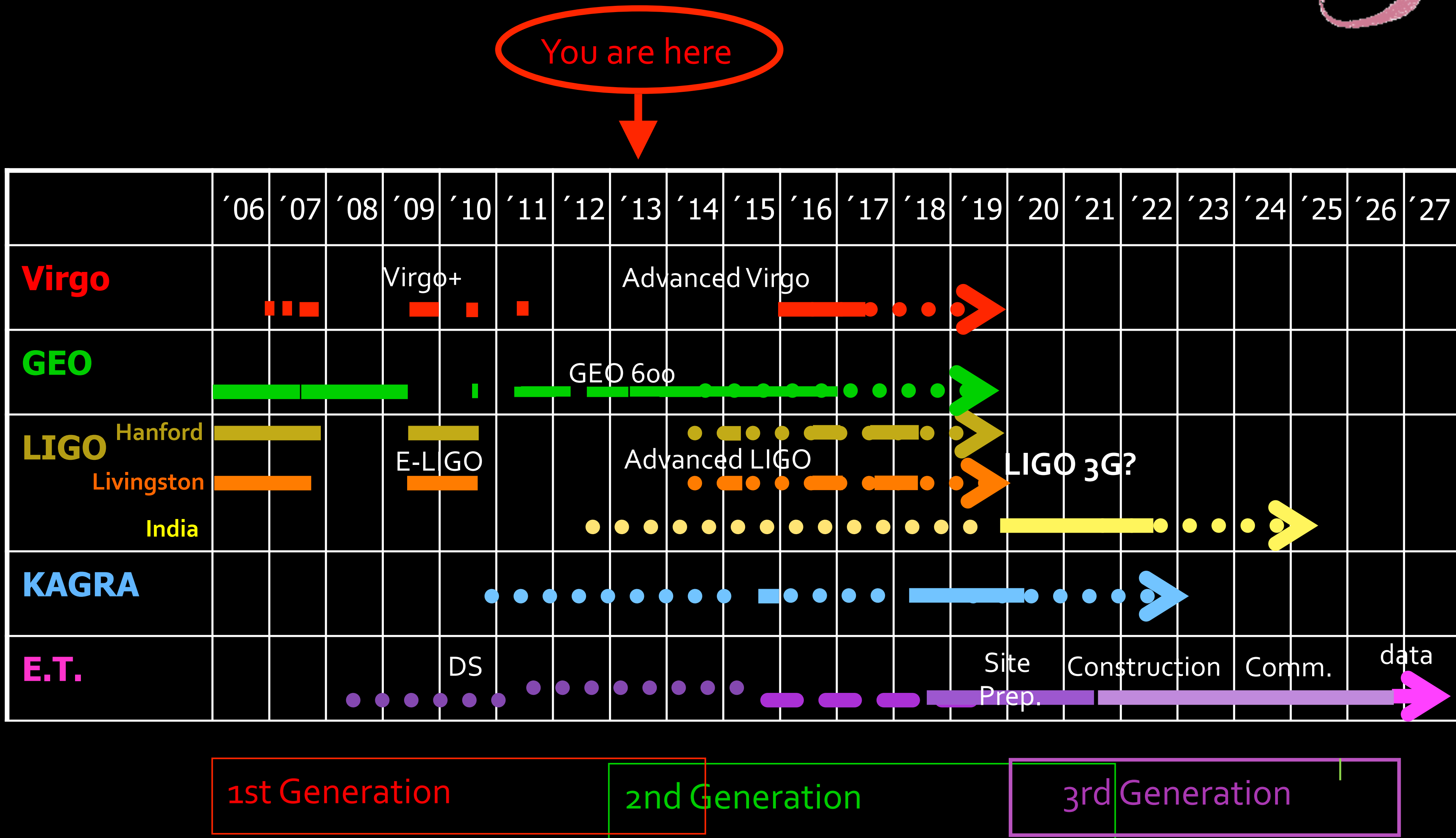
EINSTEIN TELESCOPE
STATUS/PROGRESS/OUTLOOK

Harald Lück
AEI Hannover, Germany

GWADW, Takayama, 30/5/2014

GW Timelines



Einstein Telescope

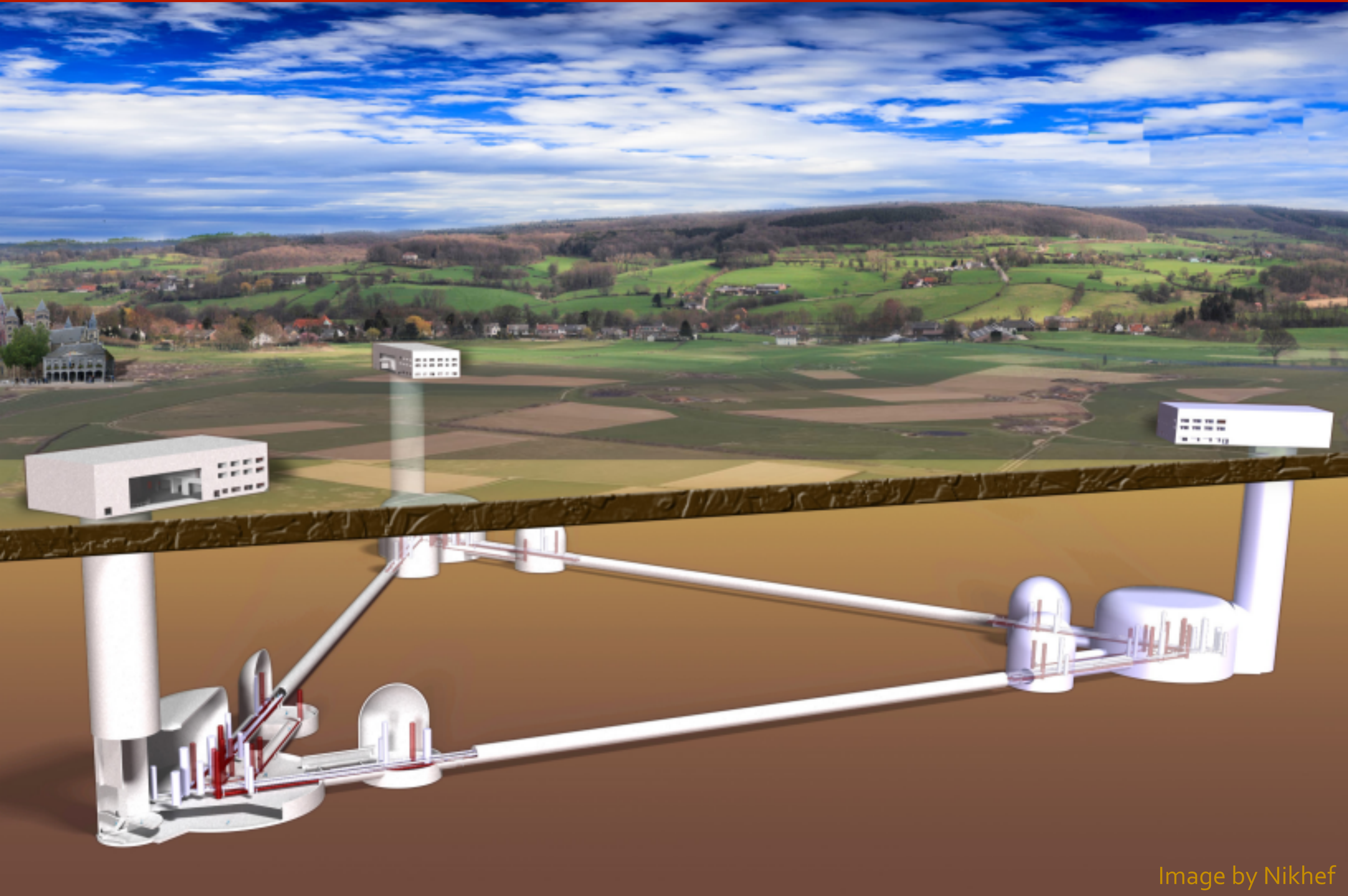
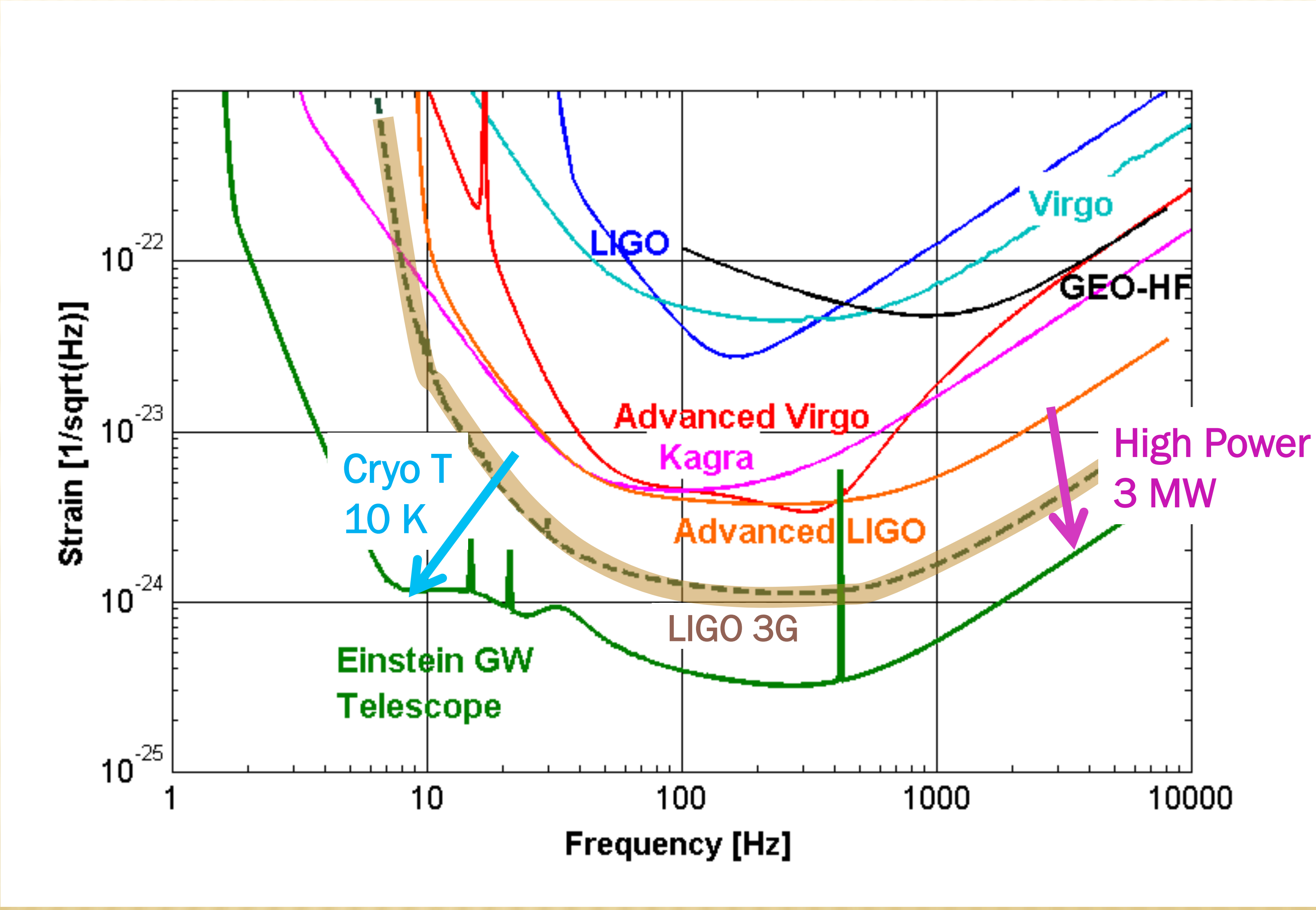


Image by Nikhef

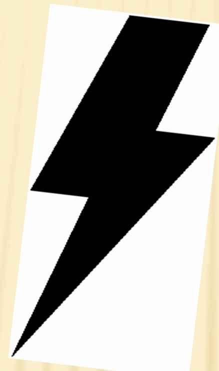
1ST, 2ND 2+, AND 3RD GENERATION



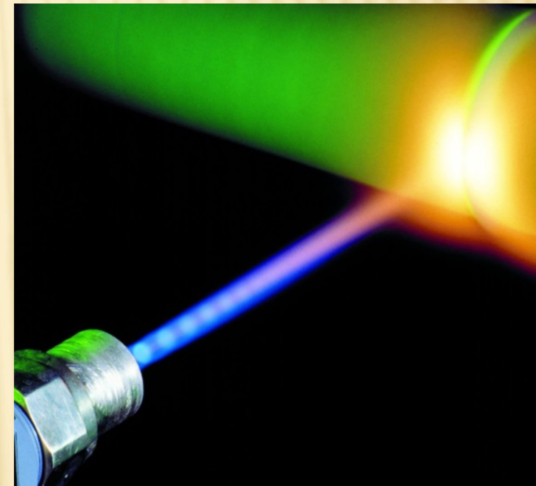
CONFLICT OF INTERESTS

Need Cryogenics for
lowThermal Noise: 10K

www.miami.com



High Power for low
Shot Noise: 3MW



jgindo.wordpress.com

http://s658.photobucket.com

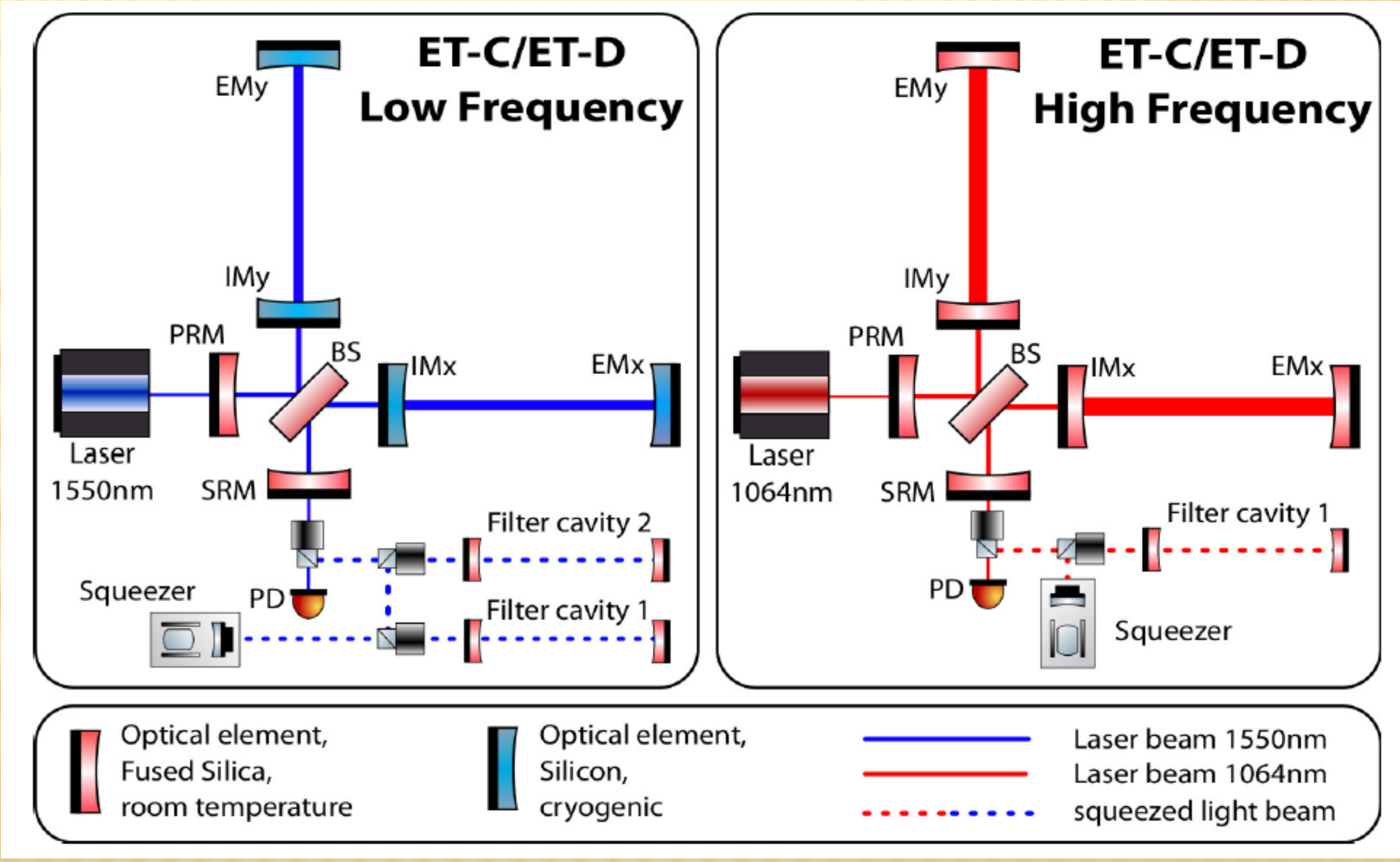
ET XYLOPHONE STRATEGY

Split detector into two interferometers optimised for

Low Frequencies and High Frequencies

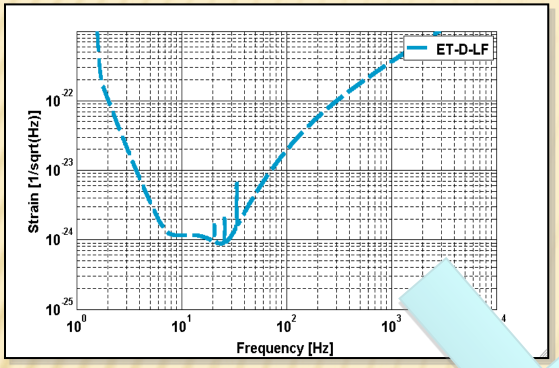
10K, 18kW, 1550nm

300K, 3MW, 1064nm



ET-D XYLOPHONE SENSITIVITY

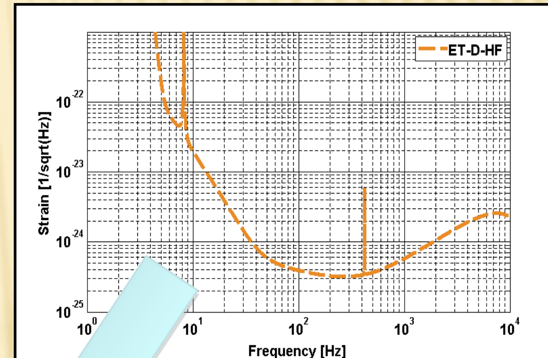
Slide: Christian Gräf, 2013, modified

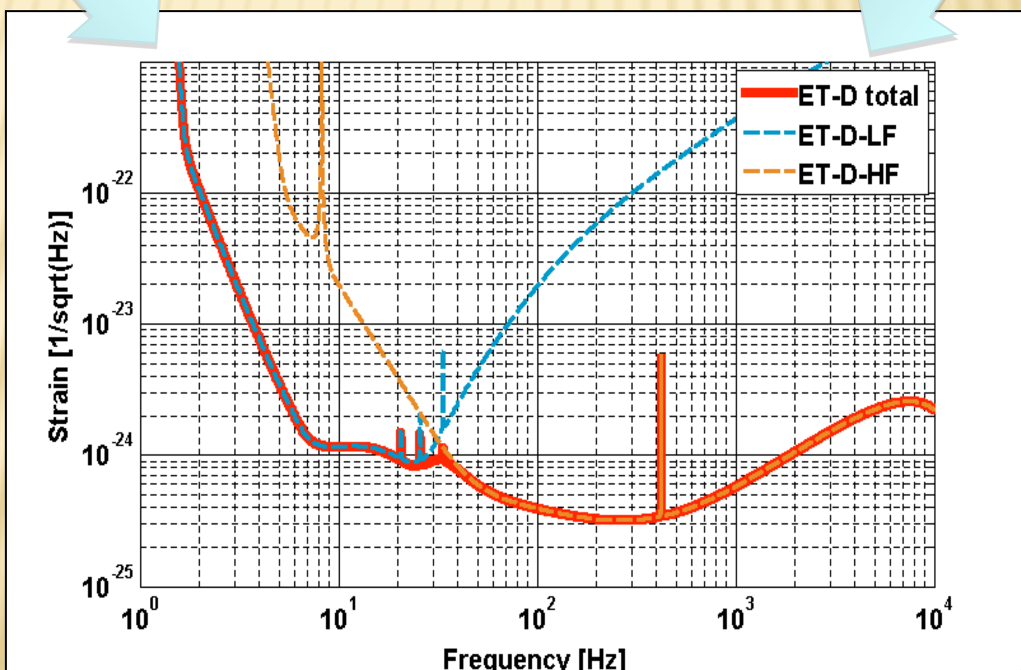


Combining the two interferometers

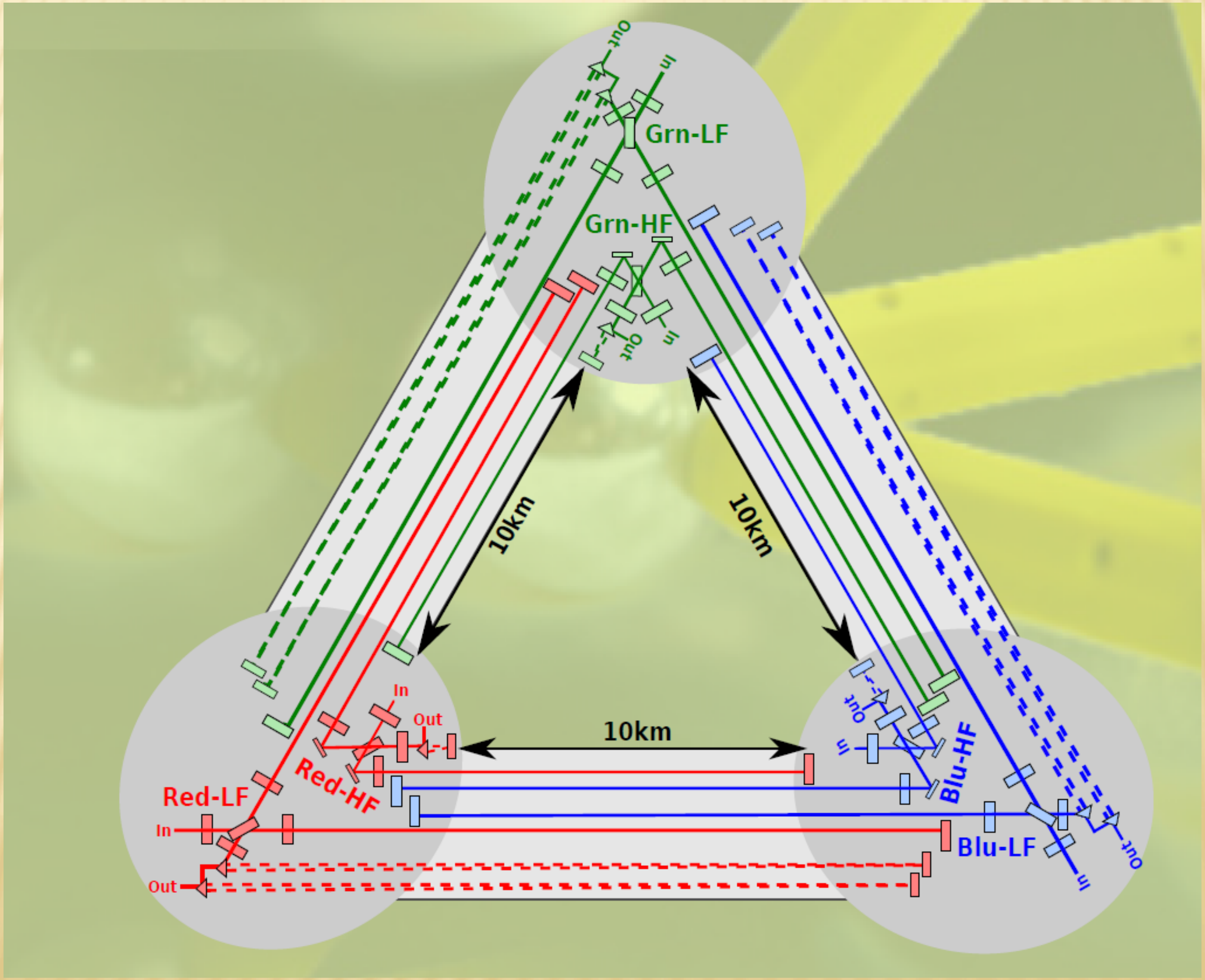
ET-D-LF

ET-D-HF





TRIANGULAR CONFIGURATION
SIX INTERFEROMETERS IN TOTAL



ET EINSTEIN TELESCOPE

EINSTEIN TELESCOPE

WHAT NEW TECHNOLOGIES DOES IT NEED?

- ET is based mostly on „advanced“ technology
  - Longer arms („1.5“x10km) & underground
  - Higher power than advanced detectors (3 MW)
  - Cryogenic optics for low thermal noise
  - Split into two (Xylophone) to make Cryo and MW compatible
  - Larger, heavier optics; HOM (LG33) beams;
  - Laser Wavelength (Silicon:1550nm; fused Silica: 1064nm)
  - Frequency dependent 10 dB squeezing
  - No new coatings in baseline concept, but will be used as state of the art allows

ONGOING PROJECTS (HTTP://WWW.ET-GW.EU/)

- **ELiTES** (FP7-PEOPLE-IRSES)
  3/2012 – 2/2016
  - common ET / KAGRA aspects
- **ET R&D**, (ASPERA 3rd common call)
  5/2013 – 4/2016
  - addresses long term R&D needs
- **GraWIToN** (FP7-PEOPLE-2013-ITN, Marie Curie Actions)
  2/2014 – 1/2017 13 PhDs
  - Optics, Simulation, High power lasers, Data Analysis

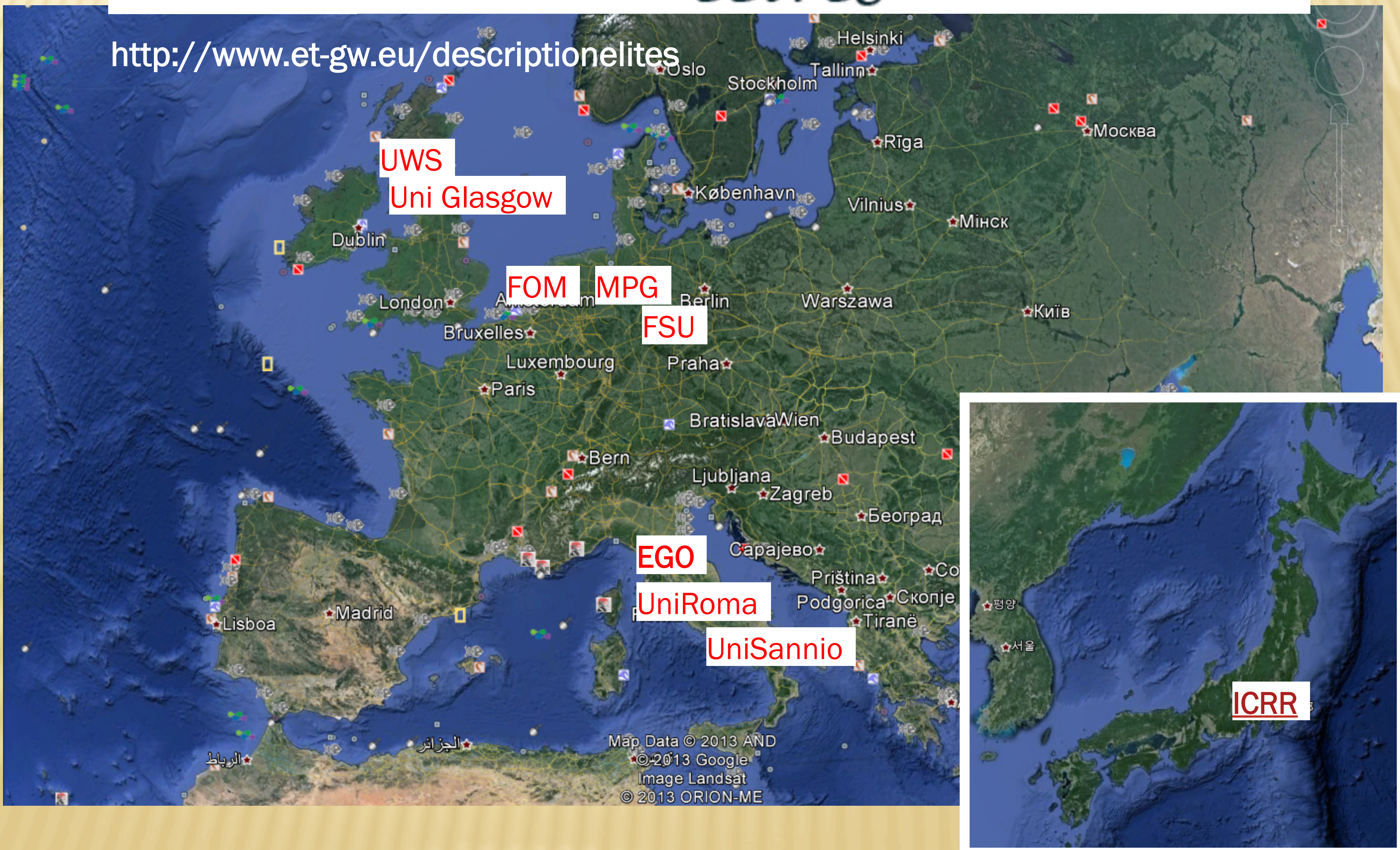
MARIE CURIE ACTIONS

KAGRA

SEVENTH FRAMEWORK PROGRAMME

ET EINSTEIN TELESCOPE

ELiTES



MARIE CURIE ACTIONS

KAGRA

SEVENTH FRAMEWORK PROGRAMME

ELiTES

ET EINSTEIN TELESCOPE

3/2012 – 2/2016

- **WP1**, "*Cryogenics and suspensions*",
  - Measure of the performance of designed cryogenic suspension system in a practical interferometer from the point of seismic and vibration isolation
  - Design and test of auxiliary attenuation system for thermal link
- **WP2**, "*Mirror thermal noise and cryogenics*
  - Investigation of the mechanical loss in both silicon and sapphire bulk materials;
  - Performance of suitable optical coatings on sapphire substrates for the development of the mirrors for LCGT and to share the complimentary expertise contained within the LCGT and ET groups (e.g. Japanese expertise in studying low temperature properties of sapphire, European expertise in studying low temperature coatings)
  - Assessment of the properties and suitability of silicate bonding for bonding sapphire, and comparison with the properties of bonded silicon, to develop techniques for constructing sapphire suspensions for use in LCGT and as a possible alternate suspension material for use in ET
  - Characterisation of the thermal and mechanical properties of suspension elements (fibres, bond areas, etc.)
- **WP3**, "*Large-scale cryogenic infrastructure for LCGT and ET*“
  - Specifying noise sources arising from cooling system quantatively and qualitatively
  - Optimum design of raditation shield
  - Prevention of possbile contamination of clean surface of mirrors

ET R&D

5/2013 – 4/2016

- 3rd ASPERA common call
- essential R&D tasks in preparation for a more technical design phase

ET R&D PROJECT

http://www.et-gw.eu/etrddescription

ET R&D PROJECT

Four Working Projects

- **WP1**, "*ET's scientific potential*"
  - Mock ET data and science challenges of increasing complexity
  - Explore how well astrophysical models of GW sources could be tested with ET
  - Investigate possible strong field tests of GR with ET
  - Probe ET's potential for understanding the geometry and dynamics of the Universe
- **WP2**, "*Long term seismic and GGN studies of selected sites*"
  - Studies at candidate sites
  - Sensor and network development
  - Modeling of seismic and GGN noise
- **WP3**, "*Optical properties of silicon at cryogenic temperatures*"
  - Stress induced birefringence of silicon-based optic
  - Homogeneity of optical properties within larger samples
  - Investigation of Whispering Gallery Mode Oscillators made of silicon to probe absorption and scattering
- **WP4**, "*ET Control systems*"
  - Mitigation scheme for radiation pressure effects for the ET-HF interferometer.
  - Control scheme for the injection of frequency dependent squeezed light.
  - Low-frequency control scheme for the ET-LF interferometer.
  - Mitigation scheme for correlated noise in co-located interferometers.
  - Contamination of potential null stream signals by technical noises.

WP1: *ET'S SCIENTIFIC POTENTIAL*

- Sathyaprakash (Cardiff University, UK)
  - Carry out a series of mock ET data and science challenges of increasing complexity
  - Explore how well astrophysical models of GW sources could be tested with ET
  - Investigate possible strong field tests of GR with ET
  - Probe ET's potential for understanding the geometry and dynamics of the Universe

WP2: *LONG TERM SEISMIC AND GGN STUDIES OF SELECTED SITES*

- Jo v.d. Brand (Nikhef, NL)
  - Studies at candidate sites
  - Sensor and network development
  - Modeling of seismic and GGN noise

WP3: *OPTICAL PROPERTIES OF SILICON AT CRYOGENIC TEMPERATURES*

- Ronny Nawrodt (FSU Jena, DE)
  - Stress induced birefringence of silicon-based optic
  - Homogeneity of optical properties within larger samples
  - Homogeneity of optical properties within larger samples
  - Investigation of Whispering Gallery Mode Oscillators made of silicon to probe absorption and scattering

WP4: *ET CONTROL SYSTEMS*

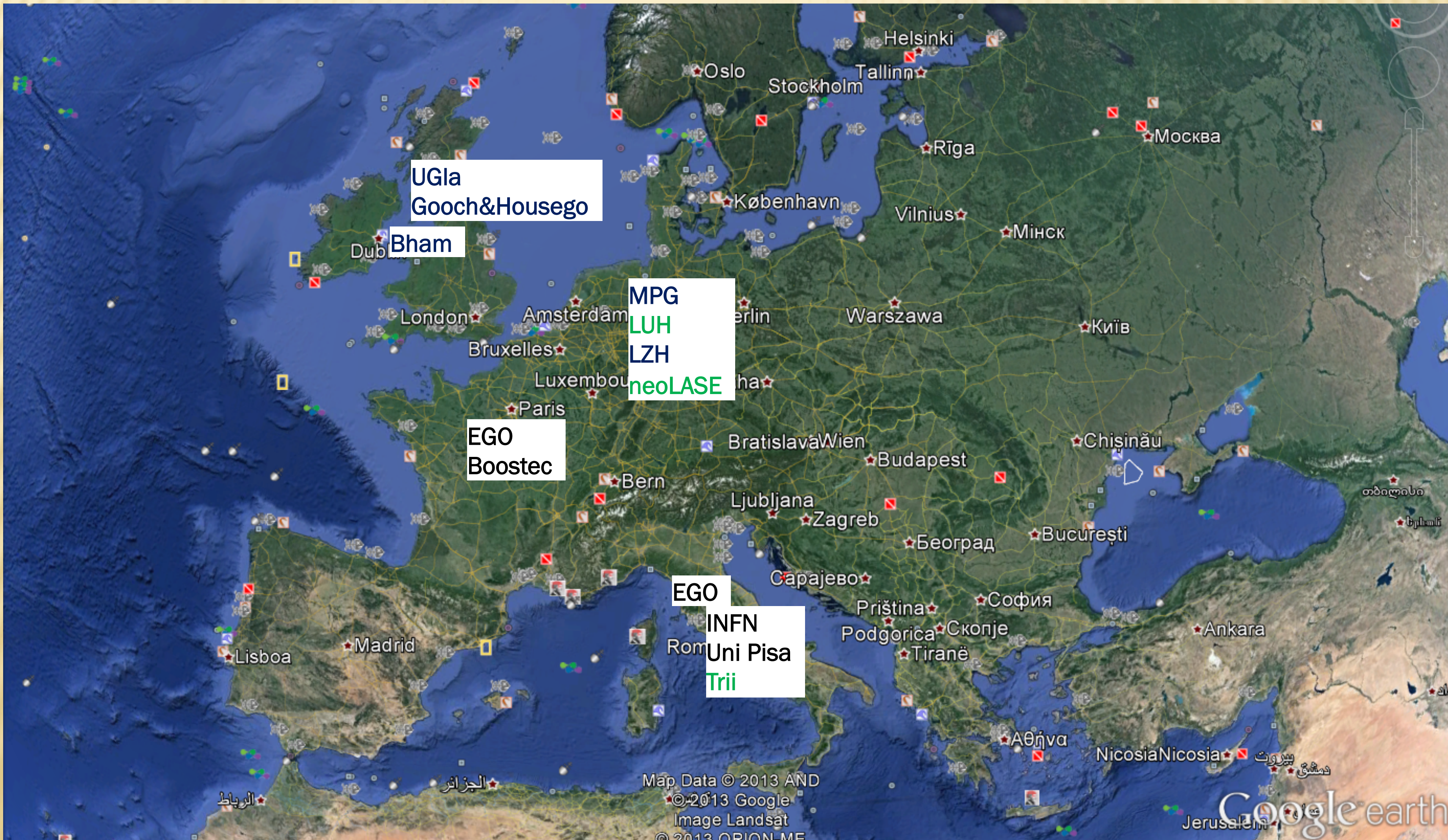
- Andreas Freise (Birmingham University, UK)
  - Mitigation scheme for radiation pressure effects for the ET-HF interferometer.
  - Control scheme for the injection of frequency dependent squeezed light.
  - Low-frequency control scheme for the ET-LF interferometer.
  - Mitigation scheme for correlated noise in co-located interferometers.
  - Contamination of potential null stream signals by technical noises.

GraWIToN

2/2014 – 1/2017

Optics, Simulation, High power lasers, Data Analysis

http://www.grawiton-gw.eu/index.php/jobopportunities for 13 ESRs



CURRENTLY…

- Prepare for the Horizon 2020 call:
  EGWII
  INFRAIA-1-2014/2015:
  Integrating and opening existing national and regional research infrastructures of European interest
- **Deadline:** 02/09/2014 at 17.00.00 Brussels time

THE CALL:

- **Integrating gravitational wave research.** This activity aims at integrating the communities of researchers studying gravitational waves and their astrophysical sources: both laser and atom interferometers with their extreme technological requirements; observations of graviational-wave sources through electromagnetic waves and high-energy particles; numerical/theoretical studies of such sources. It should address also the computing and data handling needs of these communities.

EGWII

- Involves almost all institutions involved in GW in Europe
- Start: Spring 2015; Duration 4 years
- Will consist of
  - Networking activities
  - Transnational access to the research Infrastructures
  - Joint research activites
  - Outreach & management

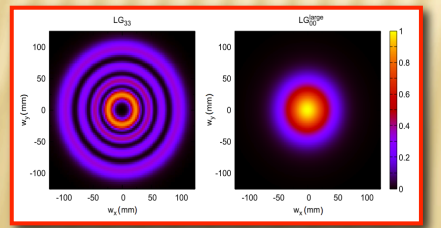
NEXT ET GENERAL MEETING

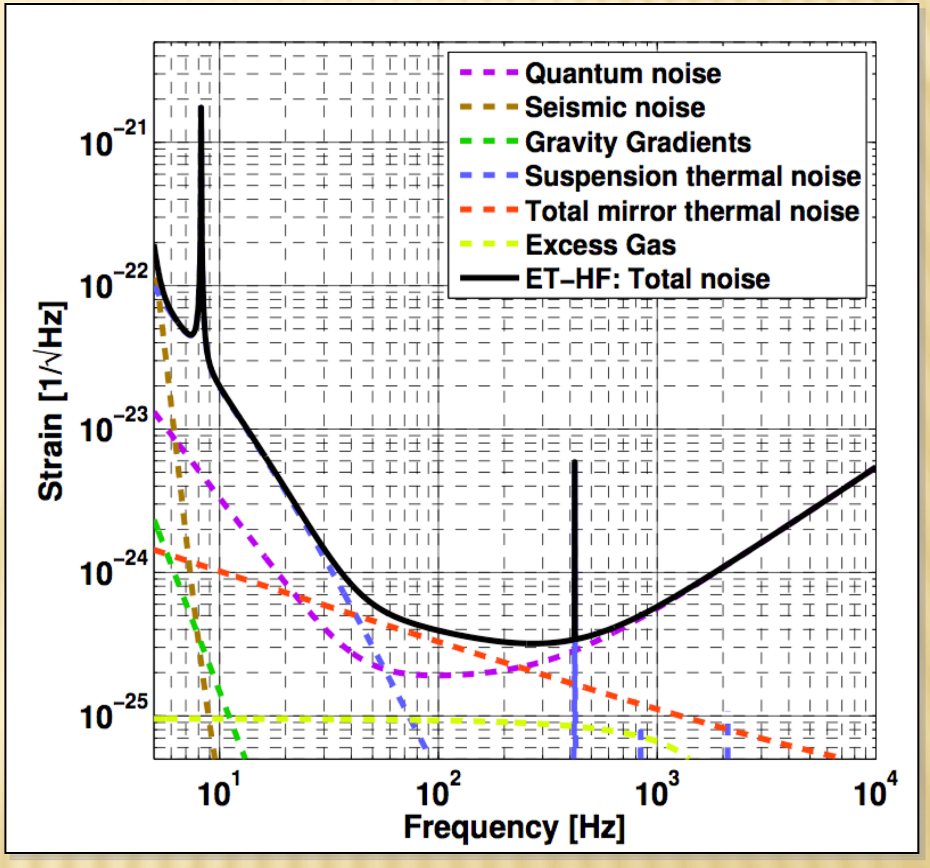
- $19^{th}/20^{th}$ of November 2014
- LMA
  →Lyon

ET-D HIGH FREQUENCY DETECTOR

Slide: Christian Gräf, ET Symp., 2013, modified

- **Quantum noise:** 3MW, tuned Signal-Recyling, 10dB Squeezing, 200kg fused silica mirrors.
- **Suspension Thermal and Seismic:** Superattenuator (standard Virgo)
- **Gravity gradient:** No Subtraction needed
- **Thermal noise:** 290K, 12cm beam radius, fused Silica, LG33 (reduction factor of 1.6 compared to TEM00).

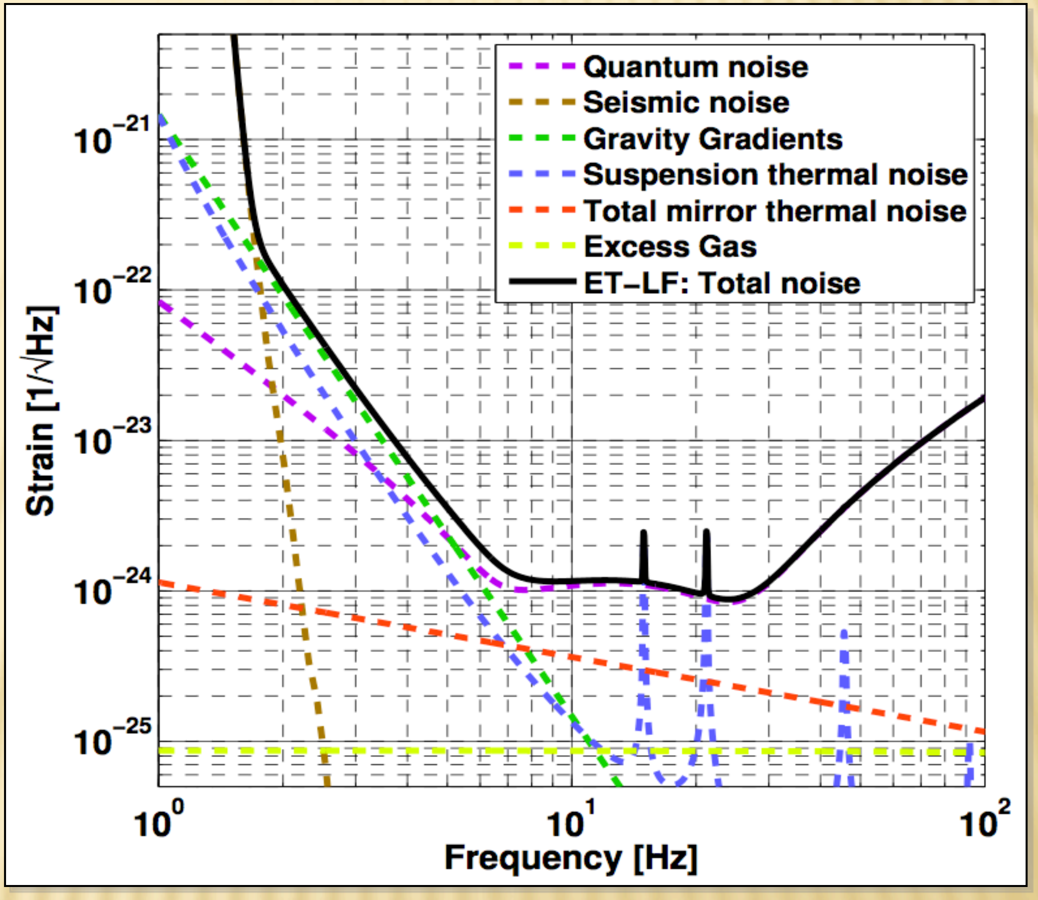




Coating Brownian reduction factors (compared to 2G):
3.3 (arm length), 2 (beam size) and 1.6 (LG33) = **10.5**
Shot Noise reduction factors (compared to 2G):
1.6 (arm length), 1.9 (power), 3.2 (squeezing (10dB)) = **9.7**

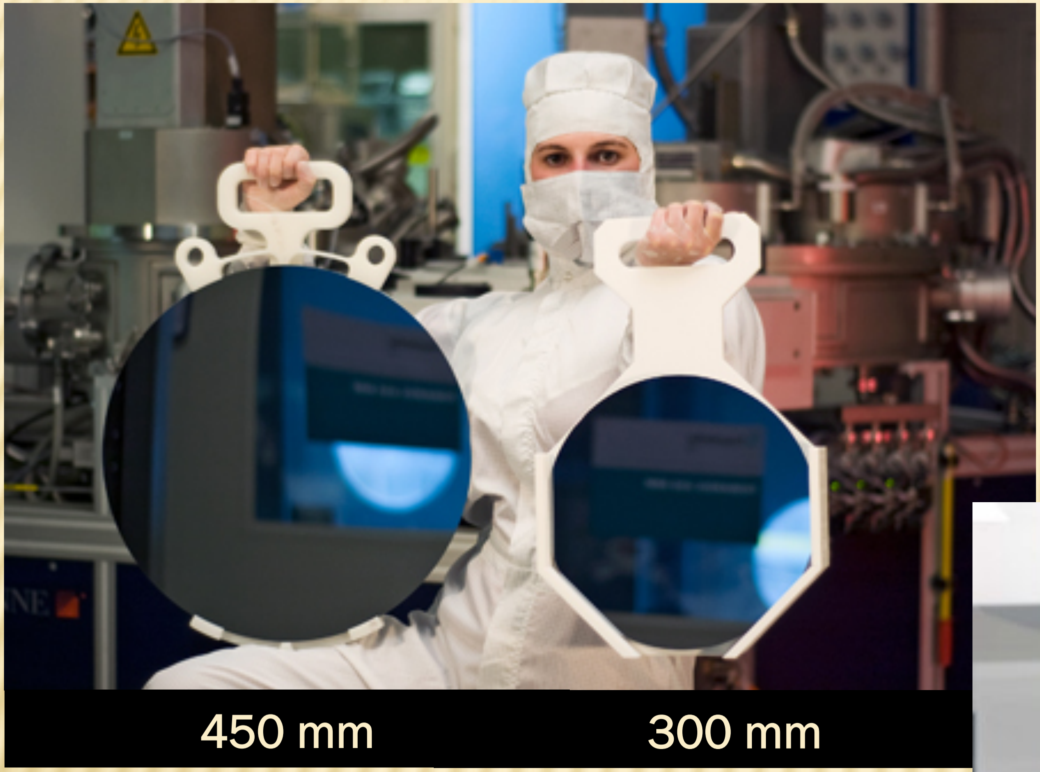
ET-D LOW FREQUENCY DETECTOR

- **Quantum noise:** 18kW, detuned Signal-Recyling, 10 dB frequency dependent Squeezing, 211kg mirrors.
- **Seismic:** extended Superattenuator, 17m tall
- **Gravity gradient:** no subtraction assumed in noise curve
- **Mirror thermal :** 10K, Silicon, 12cm beam radius, TEM00.
- **Suspension Thermal:** penultimate mass@2K, 3mm diameter silicon fibres, 2m long; limiting noise contribution from 1Hz-10Hz



As mirror TN is no longer limiting, one could relax the assumptions on the material parameters and the beam size…

LARGE SILICON SUBSTRATES



Source: http://www.iisb.fraunhofer.de/content/dam/iisb/de/images/geschaeftsfelder/halbleiterfertigungsgeraete_und_methoden/gadest_2011/

Large Silicon Substrates are available but only in CZ grown Crystals. Whether the purity reachable is sufficient is currently being tested

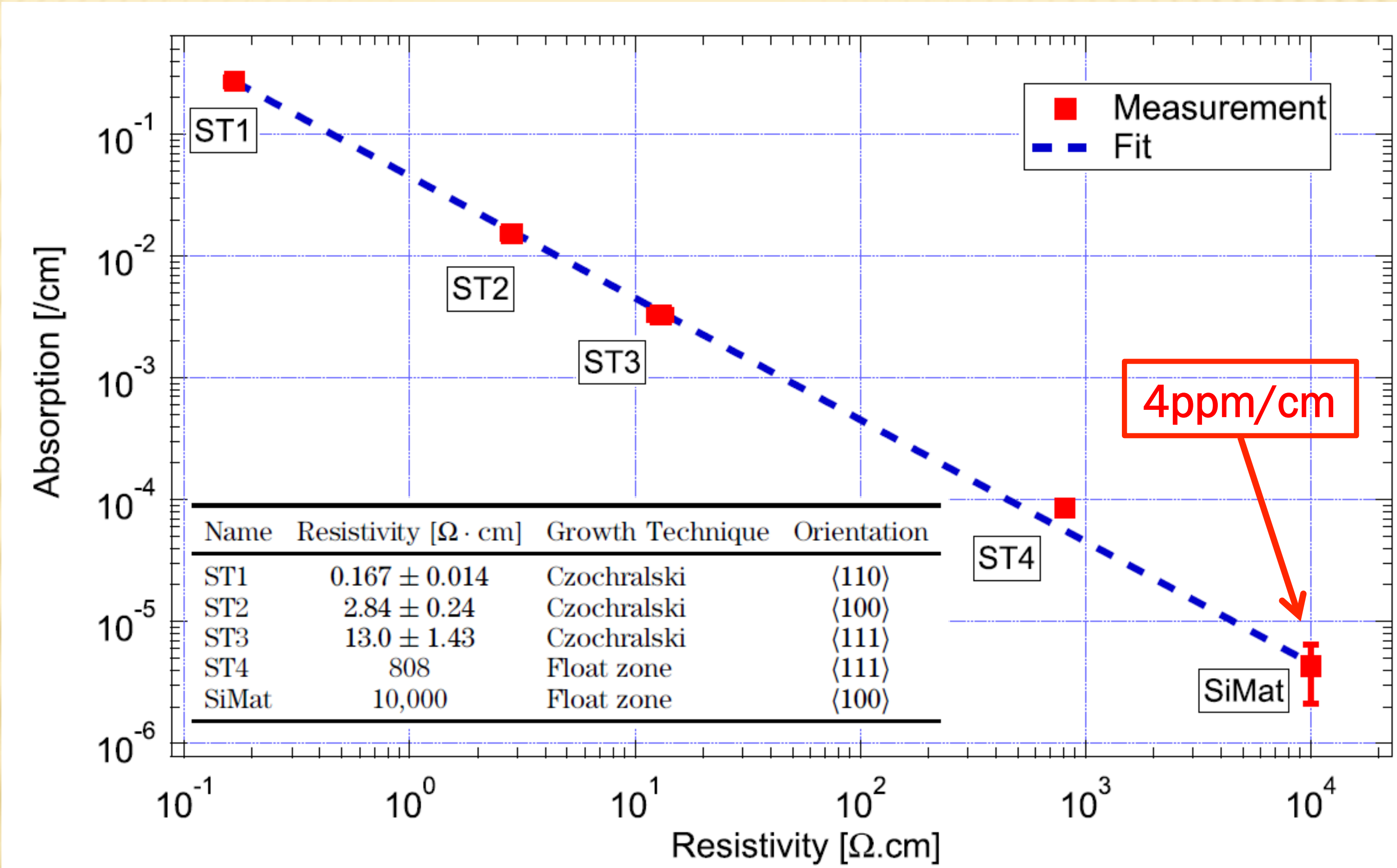
Source: http://www.quora.com/Semiconductors/How-do-silicon-boules-not-break-off-during-semiconductor-fabrication

HEAVY SILICON BOULES

Silicon Boules can be grown to a weight of 450kg

Source: www.pvatepla.com

SILICON ABSORPTION



Name	Resistivity [$\Omega \cdot$ cm]	Growth Technique	Orientation
ST1	0.167 ± 0.014	Czochralski	⟨110⟩
ST2	2.84 ± 0.24	Czochralski	⟨100⟩
ST3	13.0 ± 1.43	Czochralski	⟨111⟩
ST4	808	Float zone	⟨111⟩
SiMat	10,000	Float zone	⟨100⟩

OPTICS LETTERS / Vol. 38, No. 12 / June 15, 2013

- Requires pure (float zone) material
- Inconsistent measurements across groups
- Indications for enhanced absorption close to surfaces
- Under investigation

ET PARAMETERS

Parameter	ET-D-HF	ET-D-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	min 45 cm/ T
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase	tuned (0.0)	detuned (0.6)
SR transmittance	10 %	20 %
Quantum noise suppression	freq. dep. squeez.	freq. dep. squeez.
Filter cavities	1×10 km	2×10 km
Squeezing level	10 dB (effective)	10 dB (effective)
Beam shape	LG_{33}	TEM_{00}
Beam radius	7.25 cm	9 cm
Scatter loss per surface	37.5 ppm	37.5 ppm
Seismic isolation	SA, 8 m tall	mod SA, 17 m tall
Seismic (for $f > 1$ Hz)	$5 \cdot 10^{-10}\,\mathrm{m}/f^2$	$5 \cdot 10^{-10}\,\mathrm{m}/f^2$
Gravity gradient subtraction	none	none