ET EINSTEIN TELESCOPE

Einstein Telescope: Status and perspectives of a 3G GW observatory in Europe

Michele Punturo

INFN Perugia and EGO

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

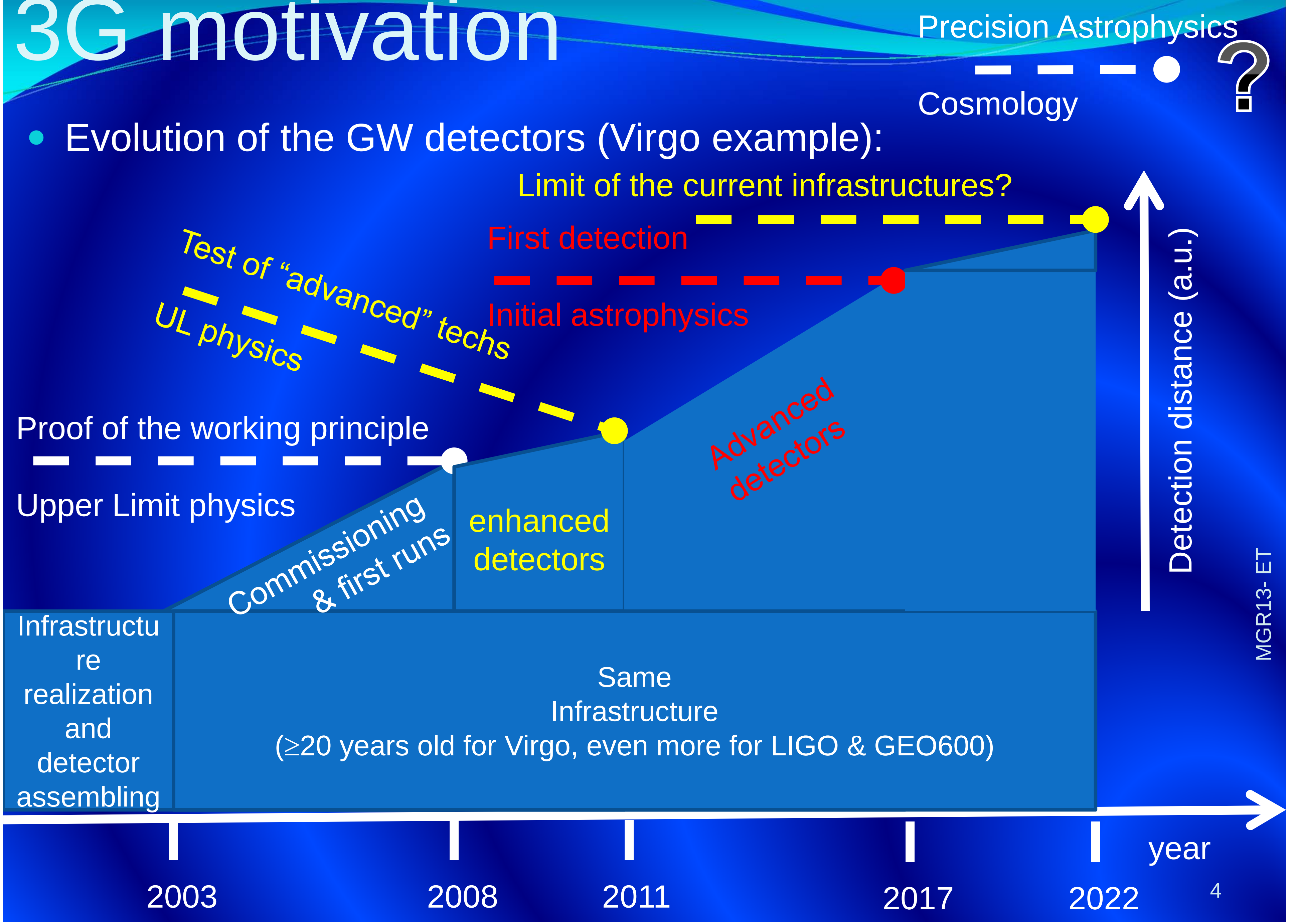
What is ET?

- The aim of the ET project is the realization of a 3G GW observatory in Europe
- The ET project is officially born in 2008, thanks to the support received from the European Commission for the conceptual design study of a GW future research infrastructure
  - ET conception occurred in 2005, at the ESF Exploratory Workshop in Perugia
- Fundamental milestone has been the delivering of the ET conceptual design study document in 2011

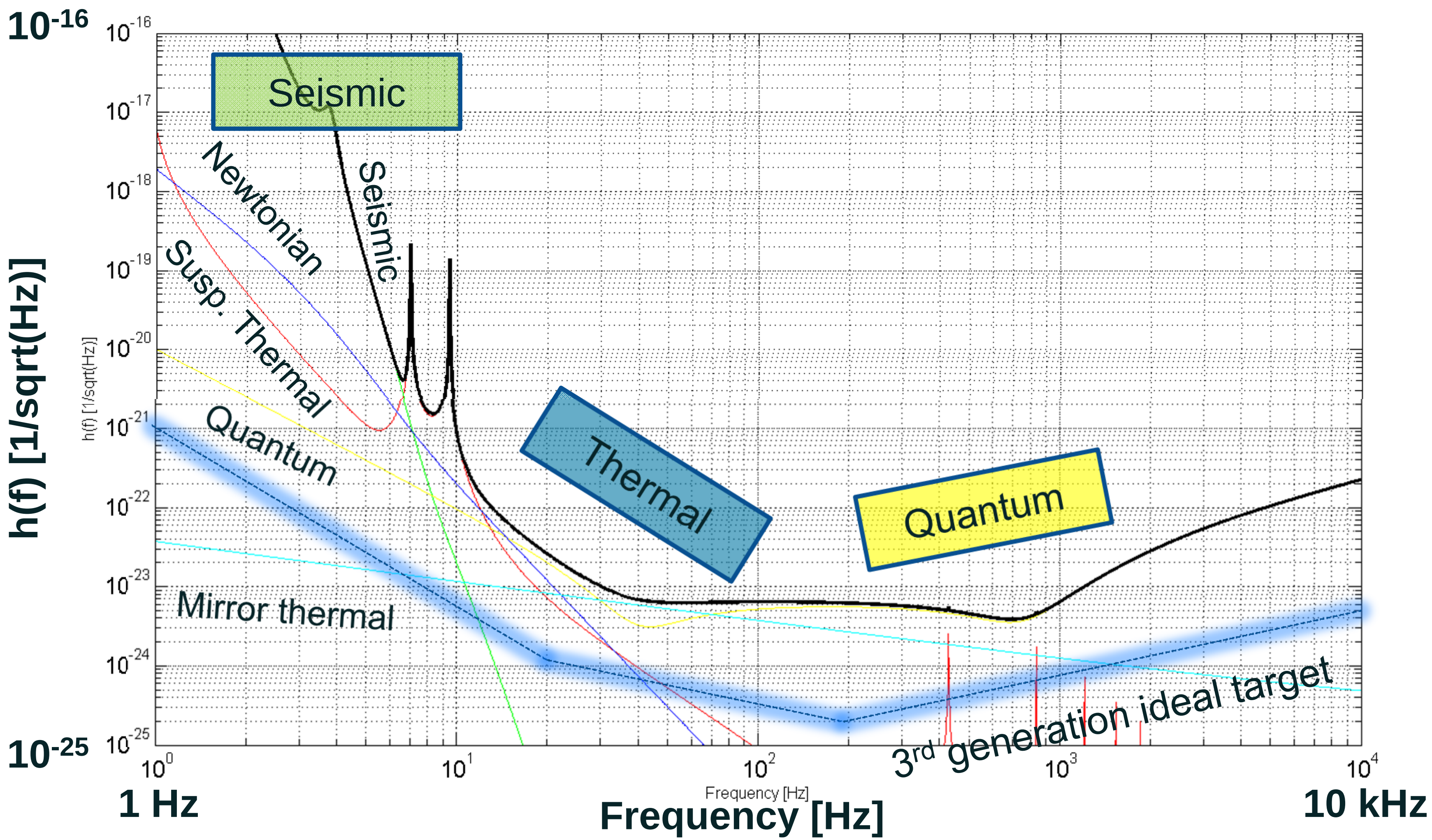
ET design key points

3G motivation

- Evolution of the GW detectors (Virgo example):

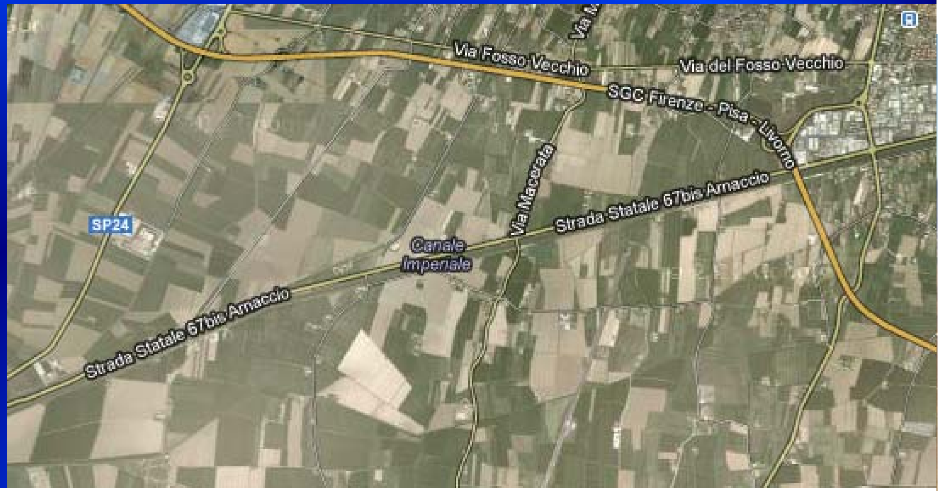


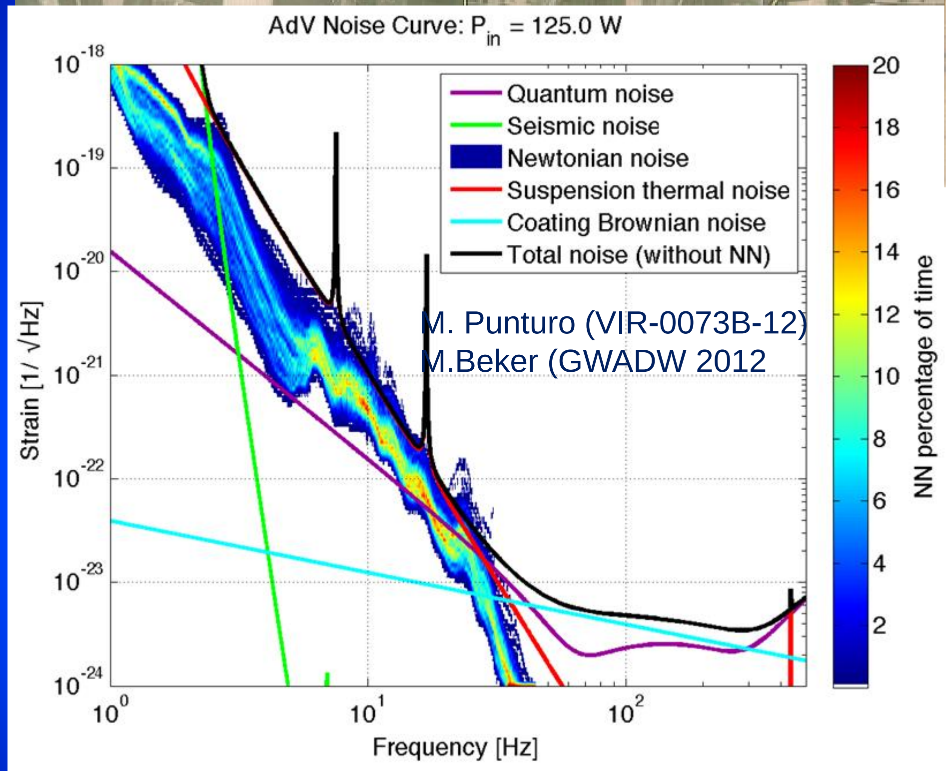
How to gain a factor of 10?



Limits of the current infrastructures

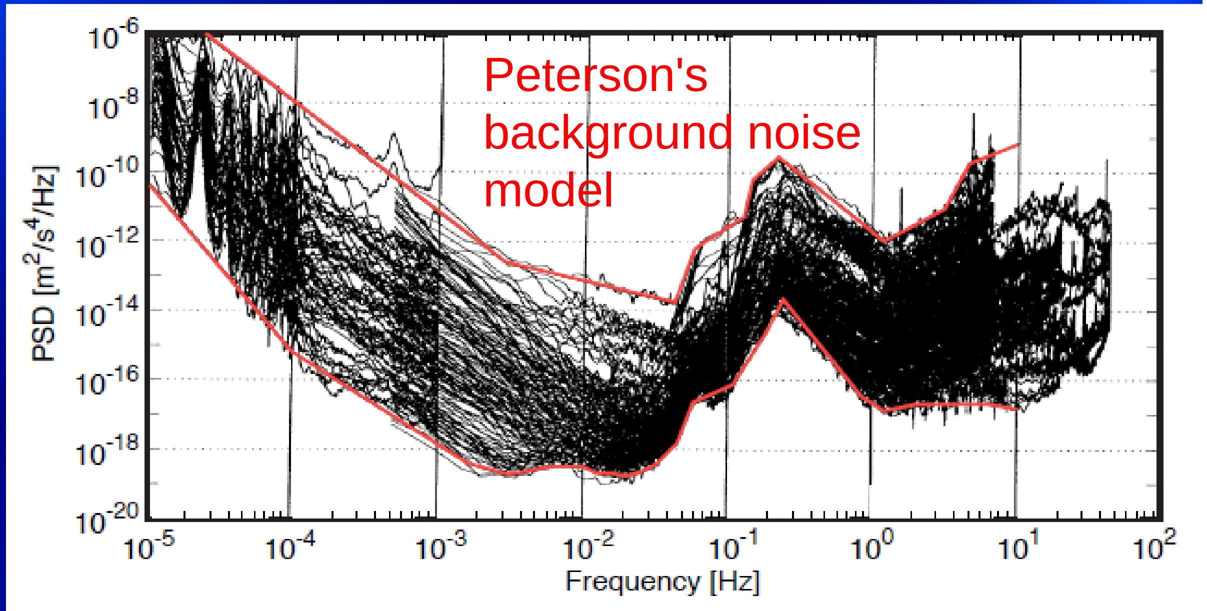
- Debated point
  - How far are the limits?
- Length is obviously a limit
- Environmental conditions are a limit (through wind, seismic noise, Newtonian noise, …)
- Infrastructure original design could be a limit
  - AdV relevant infrastructure works to mitigate stray light effects
  - MSRC vs NDRC dilemma in AdV





Underground

- Reduction of the environmental/seismic/Newtonian noise sources:
  - Good location
  - Underground site



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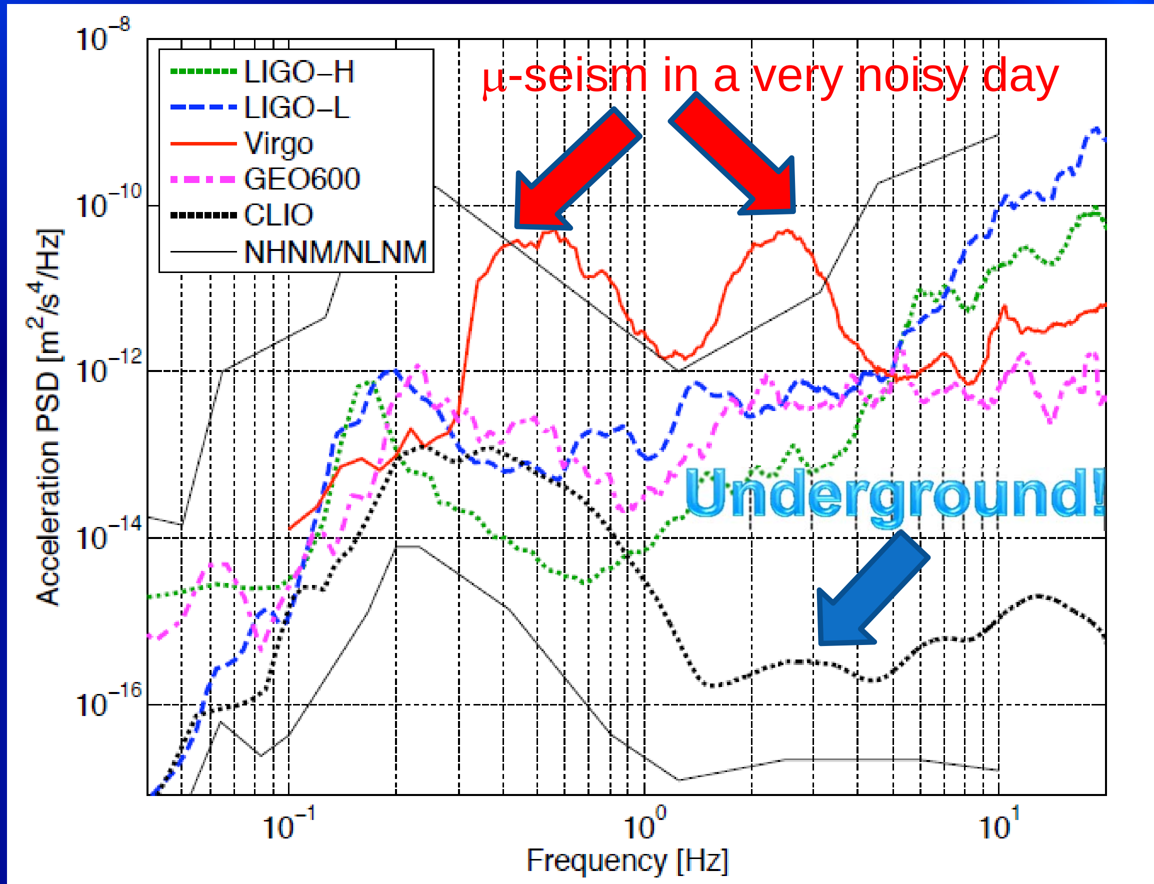

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D. Rabeling (Talk)

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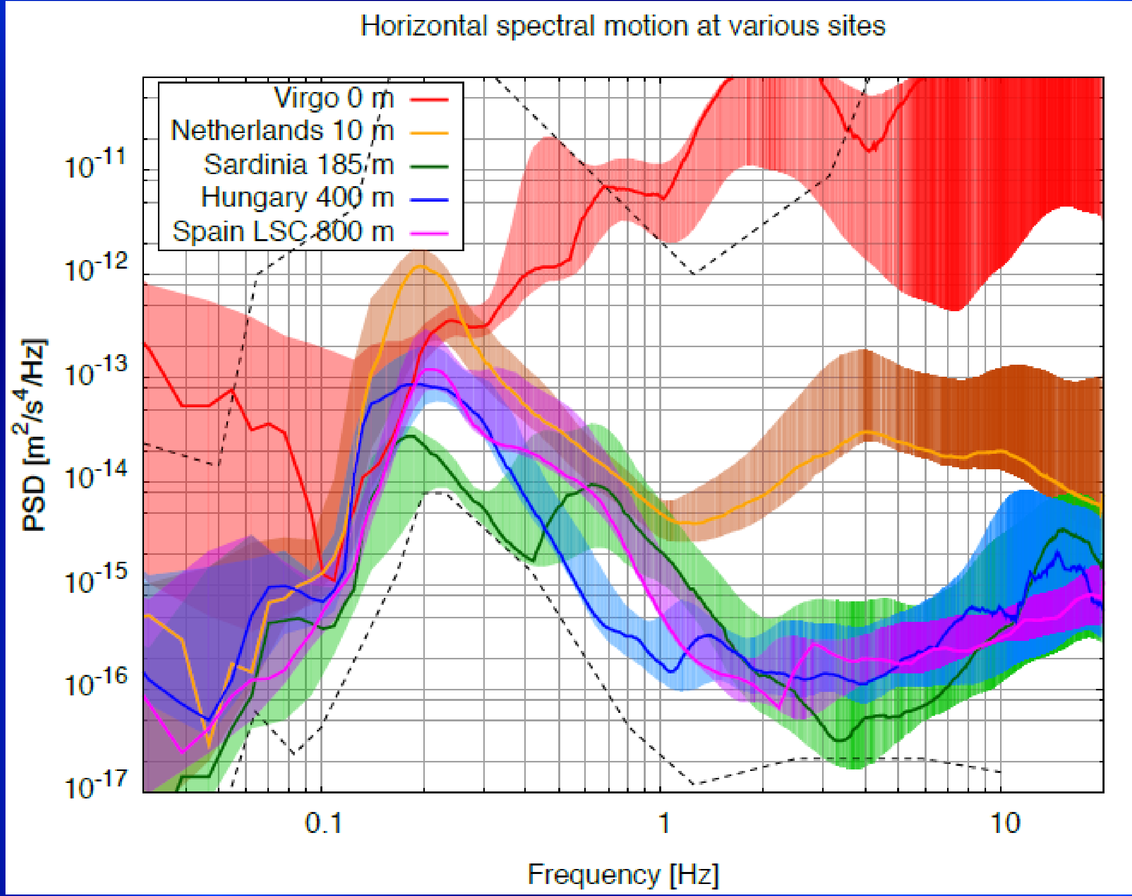
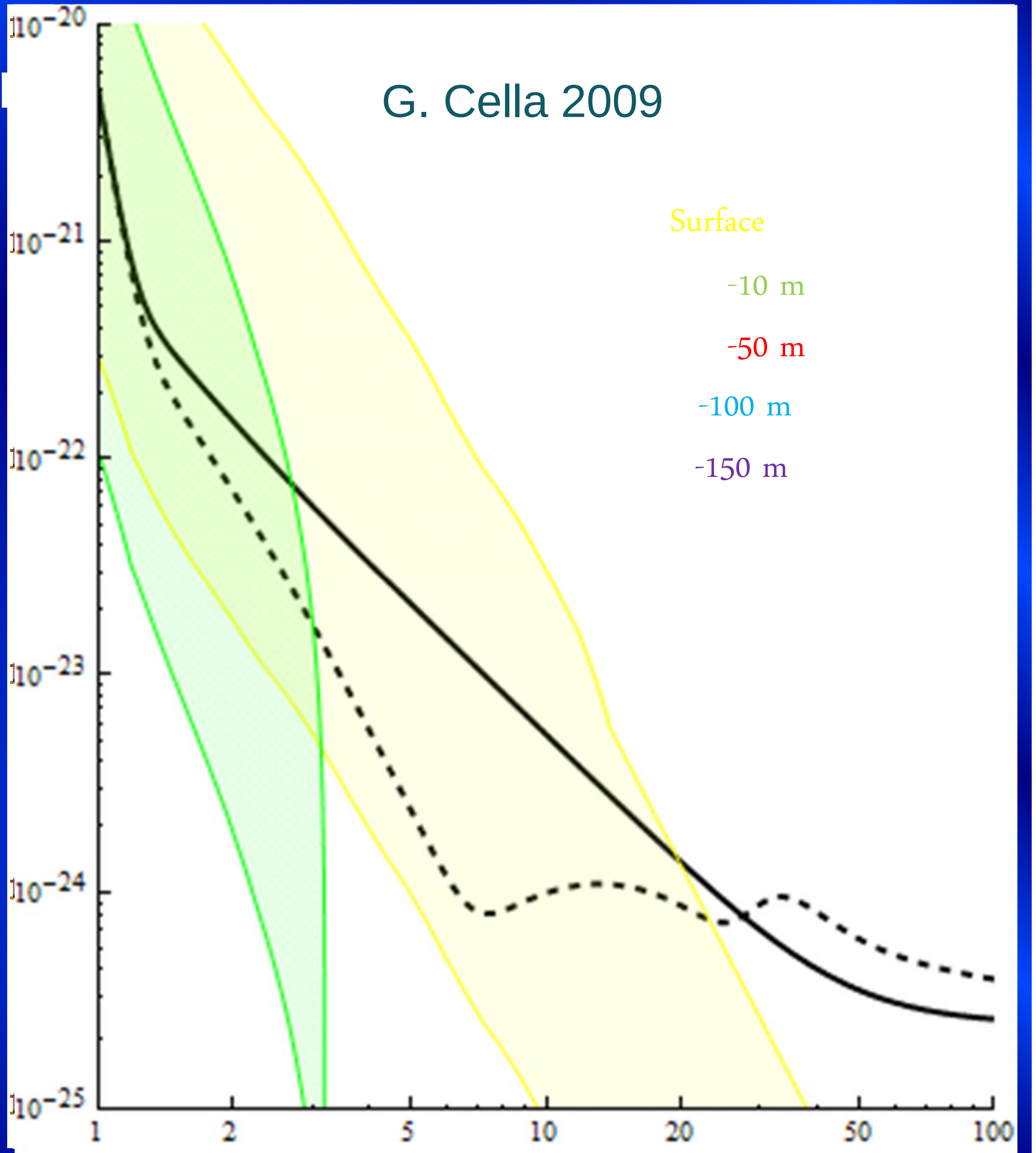


Underground

- Reduction of the enviro[n]
  noise sources:
  - Good location
  - Underground site
  - -200 m seems a possible compromise between performances and costs



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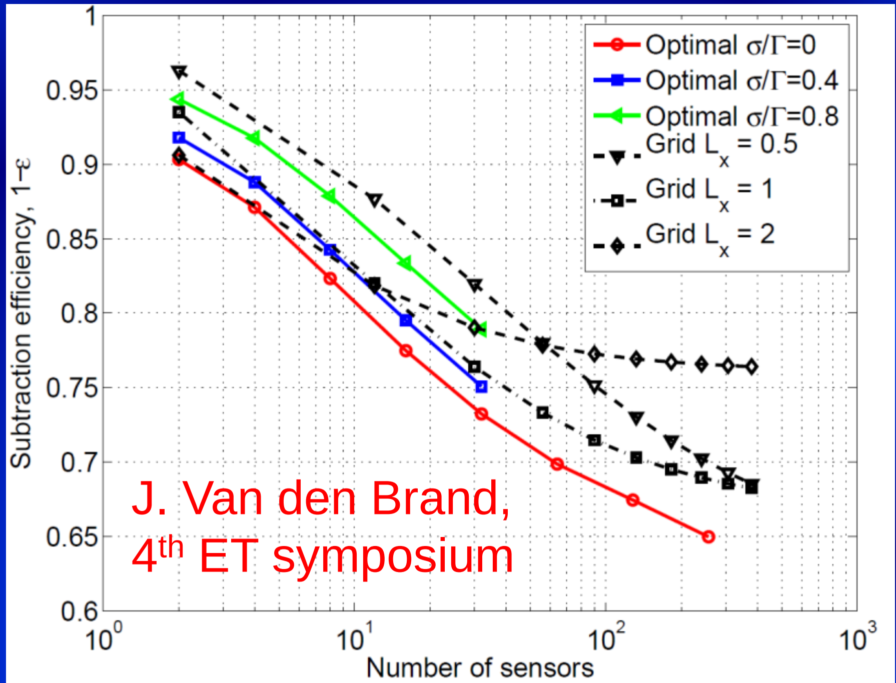
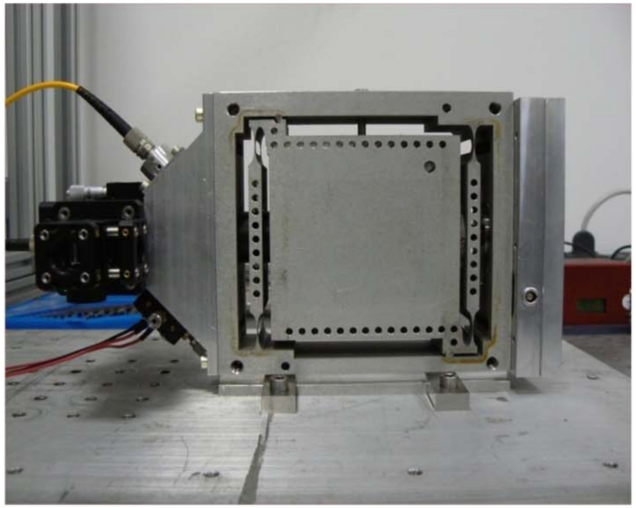


  - NN subtraction progresses could modify this scenario (see next talk, by M.Beker and J.Harms)

University of Salerno (UNISA) – INFN Napoli

F. Acernese, G. Giordano, R. Romano, F. Barone (UNISA e INFN Napoli)
R. De Rosa (UNINA e INFN Napoli)

Research activity:



- Development of inertial sensors with low readout noise (10^{-13} m/Hz$^{1/2}$ @ 1Hz), large measurement band (10^{-6} Hz – 10Hz) and low thermal noise (Q=15000 @ 1Hz under vacuum) applied to:
  - Seismic noise measurements
  - Inertial damping of suspended bench and/or attenuation system
- Data analysis and development of underground laboratories composed by seismic and environmental monitoring stations for site seismic characterizations (Sos Enattos mine, Sardinia).

What inside the new R.I.?

- Thermal noise and quantum noise are the main limit above few Hz.
- Key ingredients to reduces these noises:
  - Cryogenics
  - High Power & Frequency dependent squeezing, possibly new topologies

Cryogenic design

- Current working hypothesis:
  - Silicon optics (sapphire as backup?)
    - Good thermal noise performances
    - Optical absorption issues
      - News in this workshop

A. Khalaidovksi (poster)
G. Hoffman (talk)
M. Granata (Talk)
R. Nawrodt (Talk)
J. Komma (Talk)

Cryogenic design

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  - Silicon suspension
    - Good idea, but huge engineering difficulties
    - interesting evolution, for Sapphire monolithic suspensions, tested within KAGRA thanks also to the ELiTES project

E. Majorana (talk)
G. Hammond(Poster)

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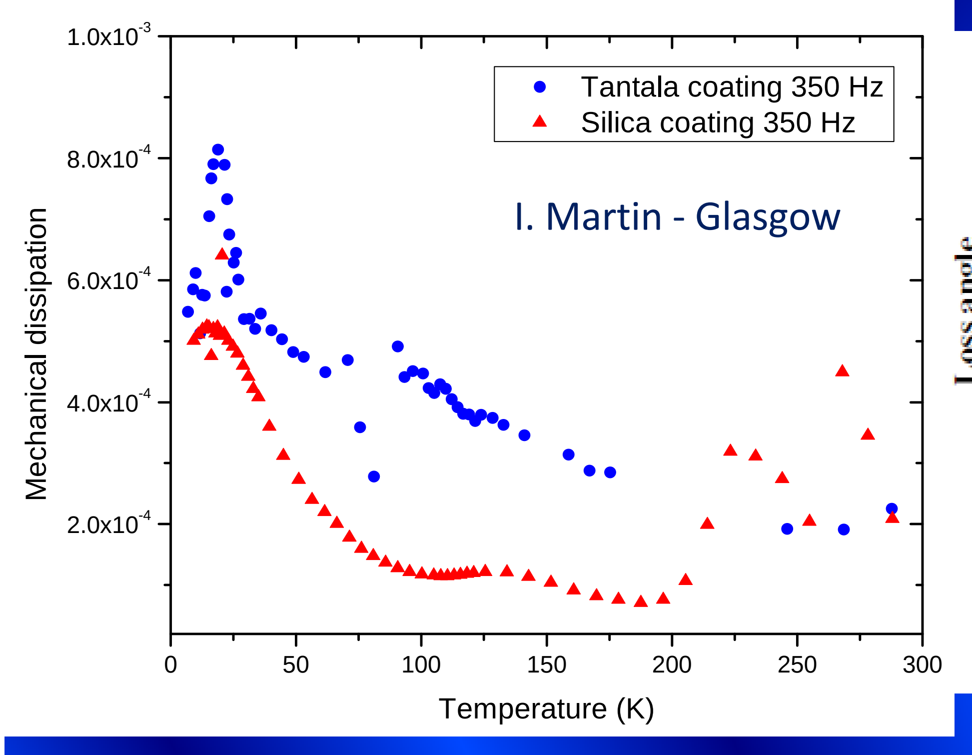
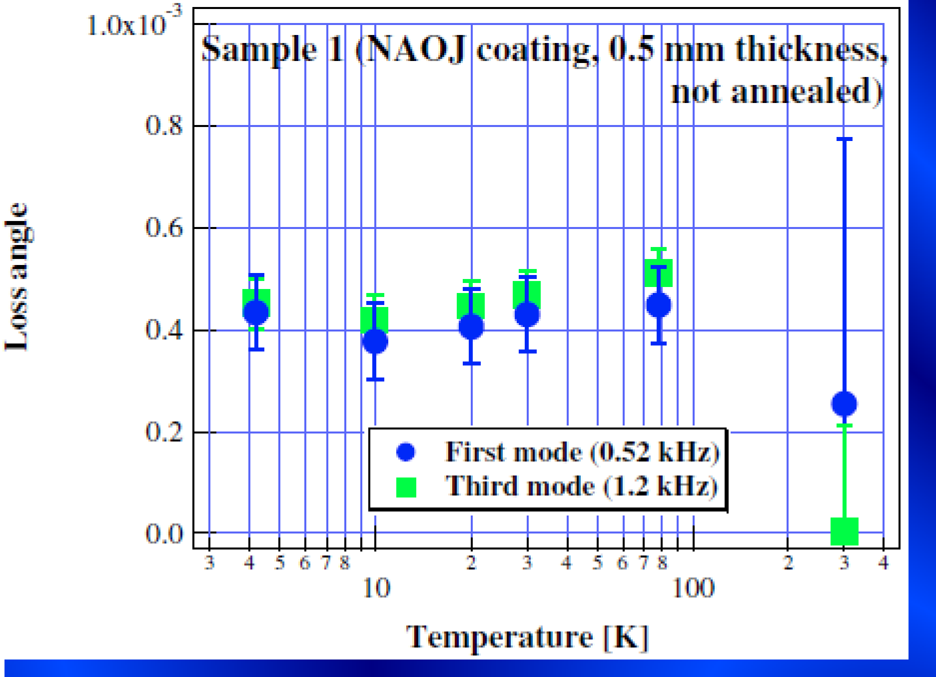
  - Coating puzzle
    - How coatings behave at low temperature?

Conflicting results?





K. Yamamoto et al, Physical Review D 74, 022002 (2006)

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  - Coating puzzle
    - How coatings behave at low temperature?
    - Dopants (Ti, Hafnia), New materials (Si), crystalline coatings (AlGaAs, AlGaP), waveguide coatings

Entire "Mitigating Thermal Noise I" session

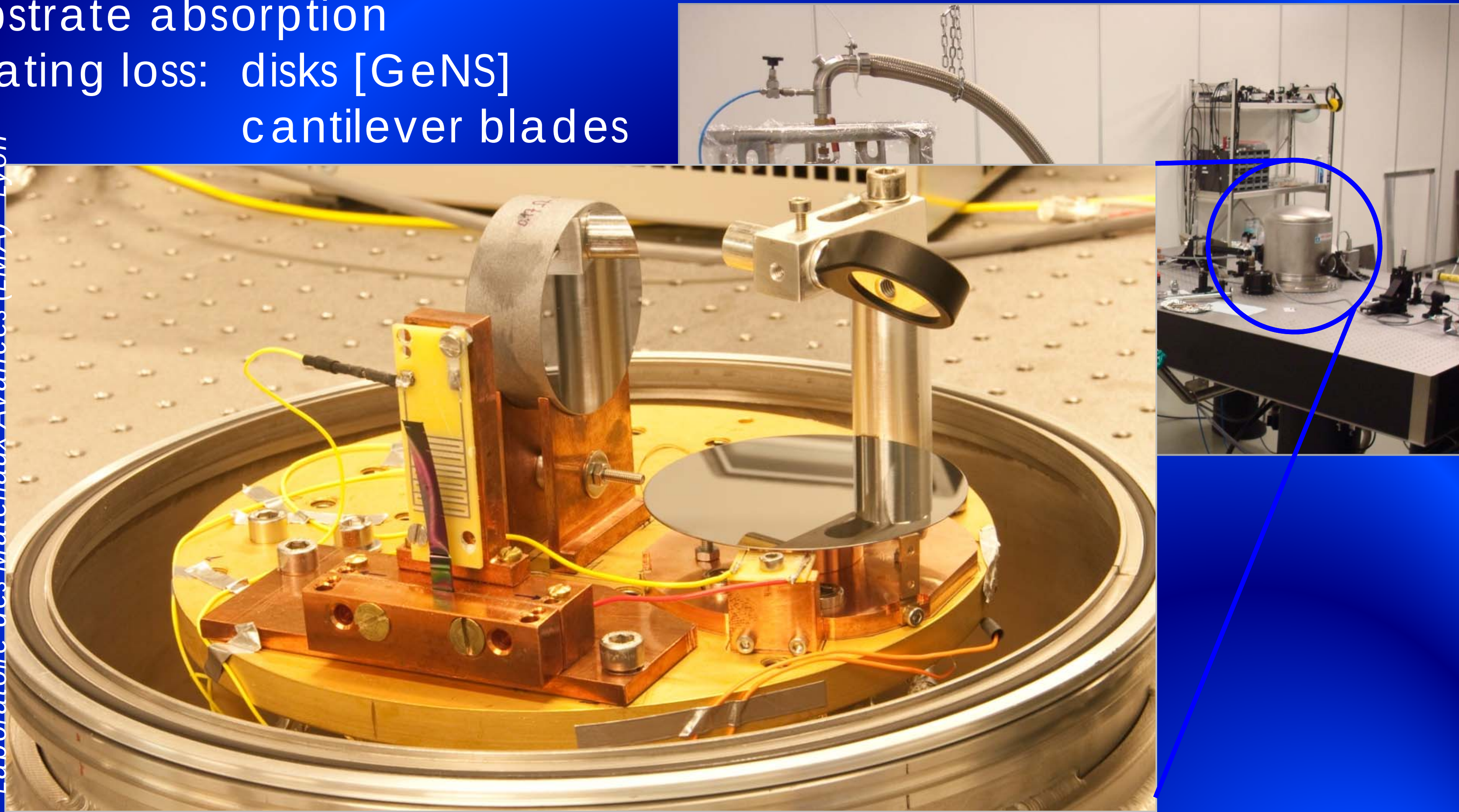
Experimental setup @ LMA

3 experiments:
- substrate absorption
- coating loss: disks [GeNS]
  cantilever blades

continuous-flow cryostat - liquid He, T < 10 K

M. Granata, C. Michel, N. Morgado, L. Pinard, G. Cagnoli, V. Dolique, R. Flaminio, D. Forest

Laboratoire des Matériaux Avancés (LMA) - Lyon

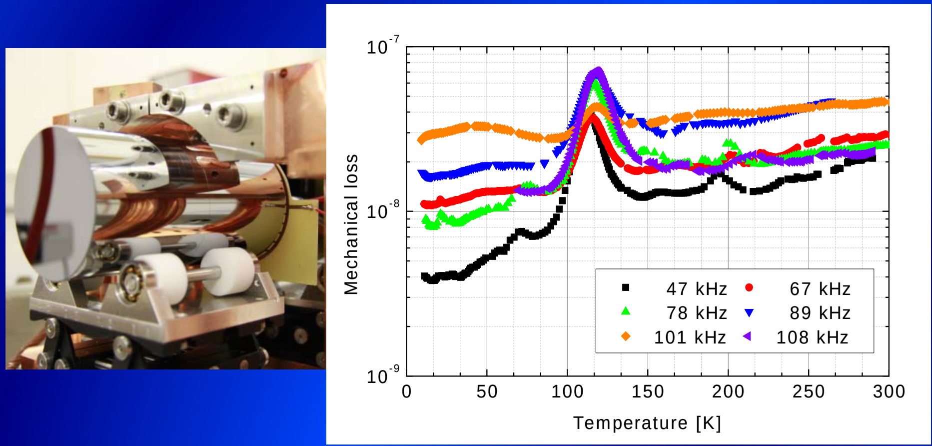


previous results: J. Degallaix & al., ET-0024A-12 / M. Granata & al., ET-0019A-12

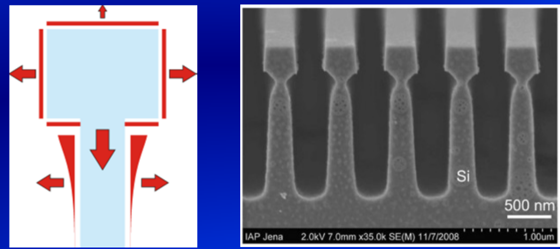
latest results: M. Granata & al., talk @ GWADW13

ET related research at FSU Jena

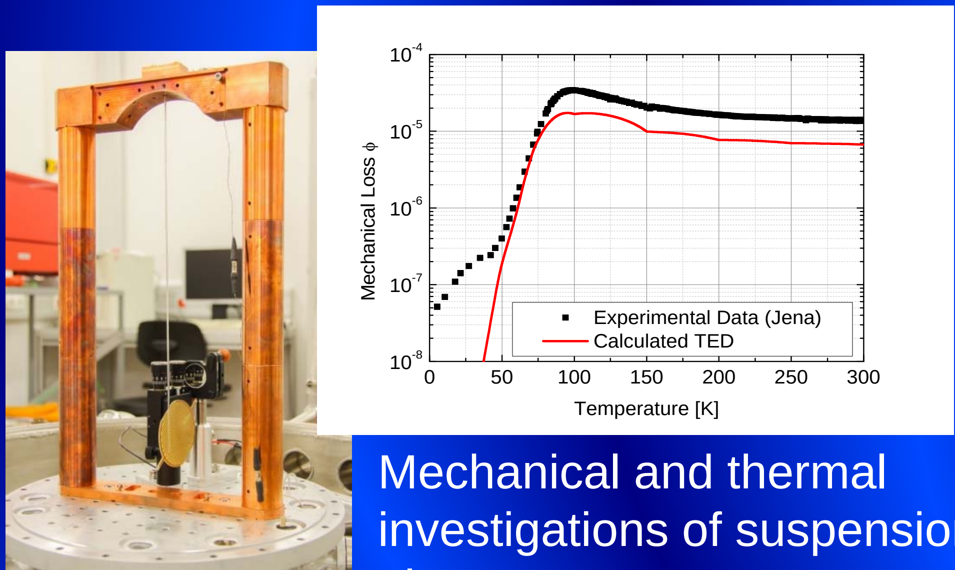
R. Nawrodt, C. Schwarz, D. Heinert, S. Kroker *, J. Komma, G. Hofmann
Institute for Solid State Physics
* Institute of Applied Physics



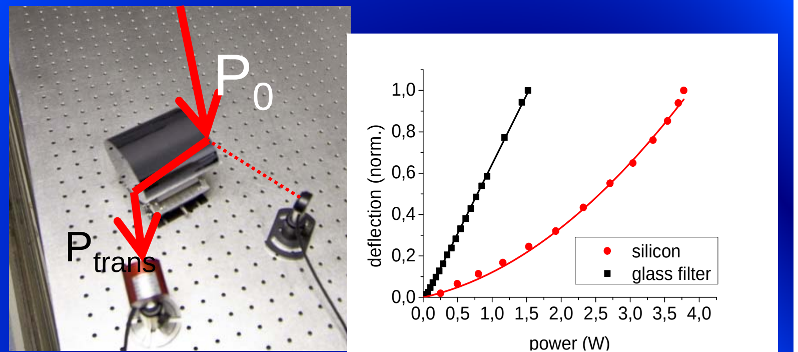
Investigation of the mechanical loss of bulk materials at cryogenic temperatures



Modelling of TN in complex opto-mechanical systems



Mechanical and thermal investigations of suspension elements

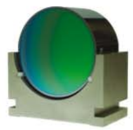


Investigation of optical properties of silicon at room temperature and cryogenics

AEI Hannover - Silicon Absorption Measurements

Approach:

- Photo-thermal self-phase modulation technique and impedance mismatch measurements
- Prototype test mass (100mm diameter, 65mm length) and coatings measured



Observations:

- Non-linear intensity dependence of optical absorption, confirming results by Degallaix *et al*.
- Absorption in Si/SiO2 coatings: 1000 ppm/coating
- **Absorption in test mass: 250 ppm/cm ↔ 3000 ppm round-trip loss (13 cm RT length)**
- Paper submitted to CQG, available as *arXiv:1304.4126 or P1300044-v2* on LIGO DCC

Possible explanation for unexpectedly high absorption values:

- Surface layer of amorphous silicon

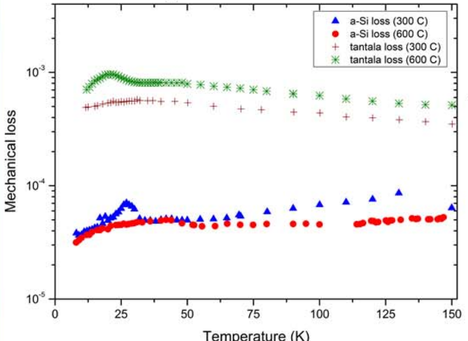
→ Literature absorption values: ca. 100/cm – 2000/cm

→ Further analysis of absorption and surfaces in preparation

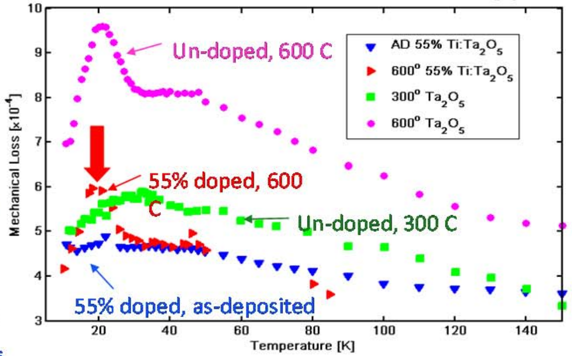
→ **PLEASE COME AND SEE THE POSTER BY ALEXANDER KHALAIDOVSKI**

Cryogenic coating studies

- Effect of heat-treatment and doping on the cryogenic loss of tantala coatings
- Alternative coating materials e.g. amorphous silicon, silica-doped hafnia, single-crystalline coatings (GaP/AlGaP stacks in conjunction with Stanford)
- Relationship between structure and loss in coating materials
- Cryogenic loss in multilayer coatings (in conjunction with LMA and ICRR, Tokyo)



Comparison of Ta_2O_5 and a-Si coatings with various heat-treatments (optical loss of a-Si requires further study)



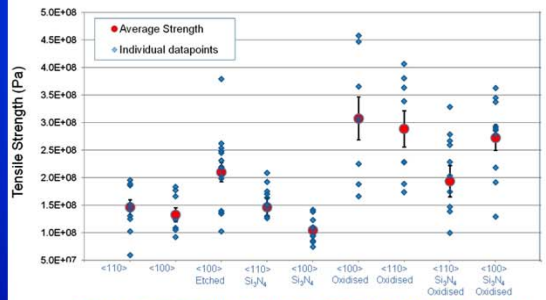
Effect of high TiO_2 doping concentration on cryogenic loss in Ta_2O_5 coatings

Silicon suspension and mirror development

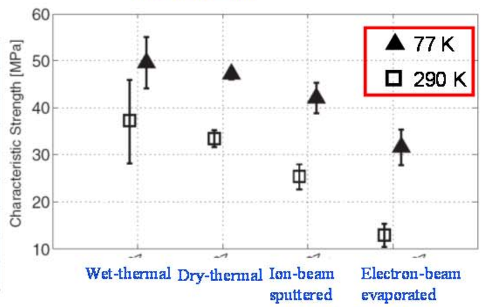
- ...ension development
  - strength tests of thin silicon samples, modelling heat extraction, dilution factor, suspension thermal noise
- Silicon surface loss studies (with Jena)
- Hydroxide catalysis bonding of silicon
  - Strength, thermal conductivity, mechanical loss
  - Observed increase in Si-Si bond strength at 77 K, with a minimum oxide layer of 50nm required for reliable bonds.
- Bulk Si loss studies (with Jena)

Bonded Si cylinders for mechanical loss measurements

Silicon strength sample



Breaking strength of silicon samples (0.5mm thick) showing increase in strength for oxidised samples



Effect of different types of oxide on Si-Si bond strength – ion-beam sputtered oxide gives almost as strong bonds as thermal oxide

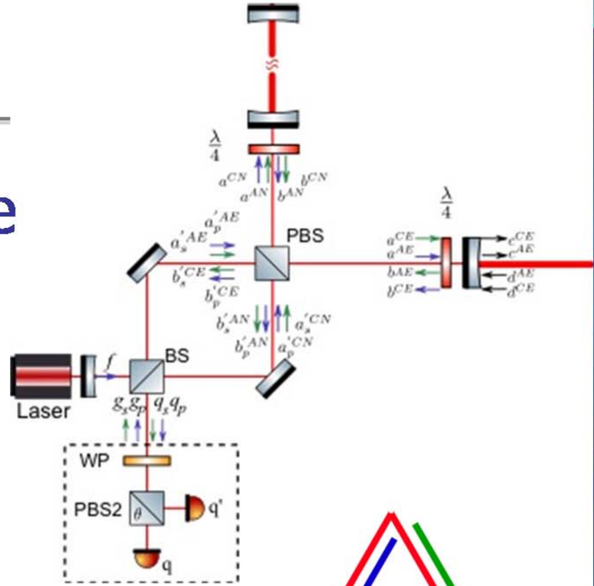
Quantum Noise reduction

- Classical solutions
  - Heavy mirrors
  - High power laser
- Xylophone design
  - Cross-compatibility High Power/ Cryogenics
- Squeezing
  - Impact on the R.I. of the filter cavities
- New topologies

H. Grote (Talk)
“Light sources and Interferometer Topologies” session

R+D for the Einstein Telescope

UNIVERSITY OF BIRMINGHAM

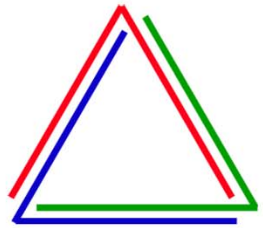


ET quantum noise and alternative topologies

•Investigate the Sagnac interferometer as an alternative for ET-LF

•Developed a DC readout scheme for the Sagnac topology

[M. Wang et. al. Phys. Rev. D (2013) http://arxiv.org/abs/1303.5236]



ET control and noise cancellation

•Development of sensing and control scheme and noise model for ET

•Investigation of noise correlations and possible noise cancellation strategies for co-located interferometers

•Coordinator of working group 4 of the ASPERA ET R+D project

Numerical modelling for future GW detectors

•Development of optical models for high power interferometers that combine beam shape distortion effects with radiation pressure and quantum noise

•Development of Finesse, used in the GW community since 2000 [http://arxiv.org/abs/gr-qc/0309012], available as open source since 2012: www.gwoptics.org/finesse

•Coordinator of simulation sub-program in ERC Training Network GraWIToN

EGO EUROPEAN GRAVITATIONAL OBSERVATORY

Many challenges in Advanced detectors can be tackled with Adaptive optics

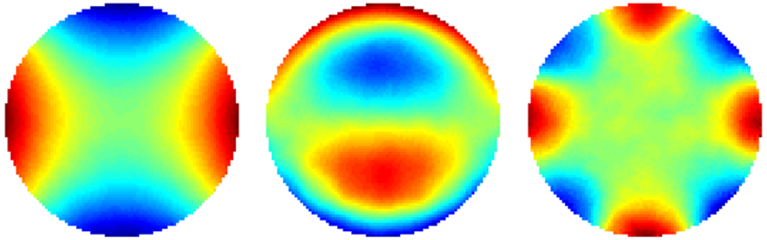
Optimize mode matching in optical resonators

Thermally Deformable mirror (**TDM**)

A deformable mirror designed to meet the special requirements in GW detectors:

- Low noise actuation
- Minimize scattered light
- Use high power lasers
- Vacuum compatible

Aberrations generated experimentally by TDM



2nd generation
Input matching > 99%

3rd generation
Minimize losses on squeezed light path

Ref: M. Kasprzack, et al. , Appl. Opt. 52, (2013)

Generation of unwanted high order modes (HOM) in arm cavities by imperfect mirrors

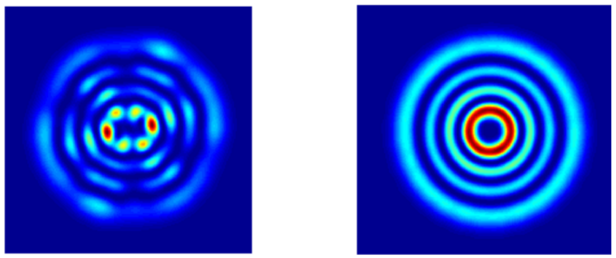
Central Heating Residual Aberration Correction (**CHRAC**)

Heat pattern projected onto cavity mirrors modifies surface figure by thermo-elastic effect.
→ Suppress scattering into selected HOM's

2nd generation
Reduce HOM content in arm cavity
→ Decrease round trip losses

3rd generation
LG33 mode sensitive to mirror imperfections
→ Suppress generation of other order 9 modes

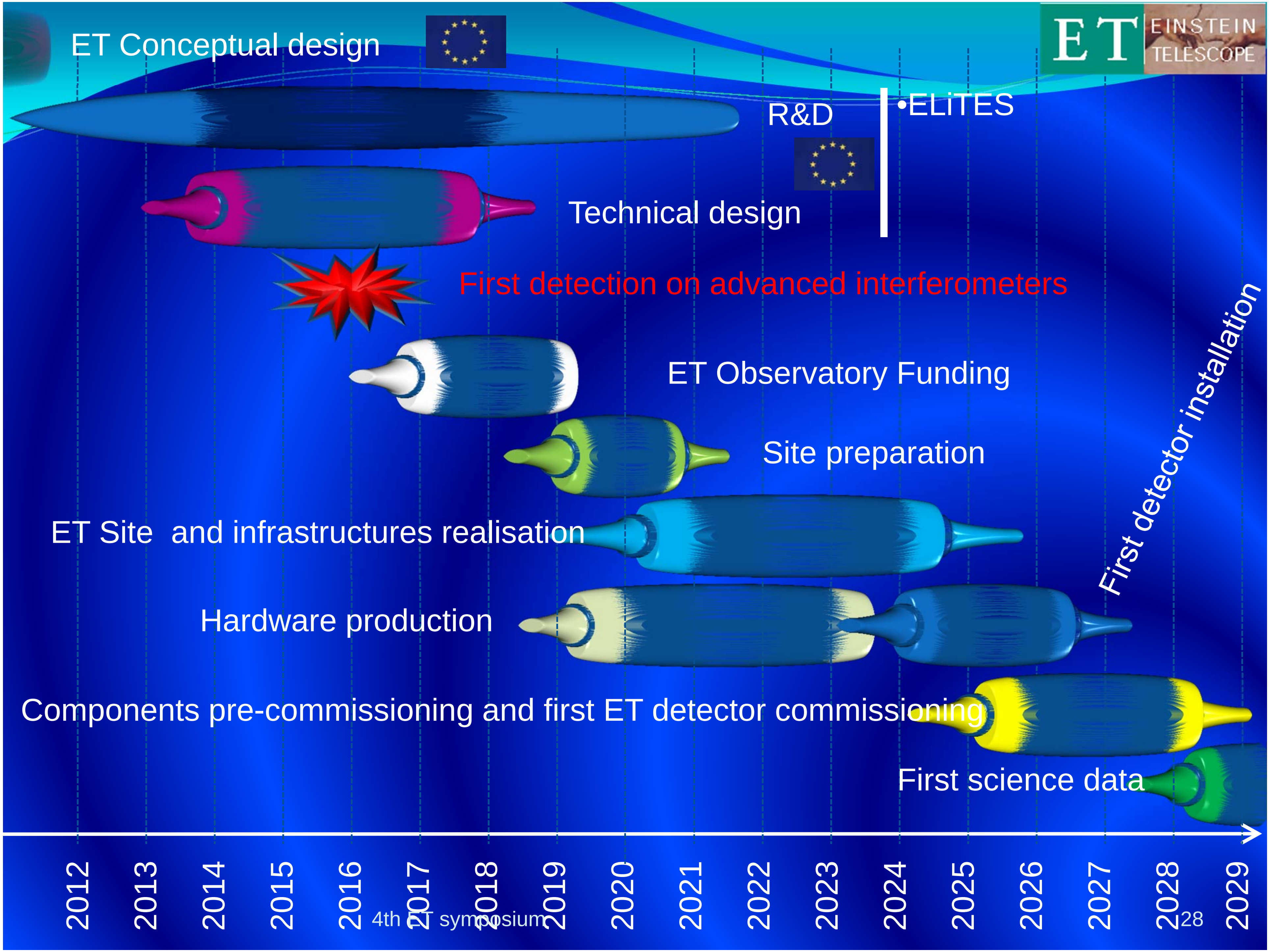
Simulated cavity mode before & after correction



Ref: R. A. Day, Phys. Rev. D 87, 082003, (2013)

ET strategy

- Two conflicting elements are dominating the ET scenario:
  - Need of a long term support, to develop technologies (R&D), to build-up the team (networking)
  - Direct support from the national research institutions will be null or low profile until advanced detectors will be operative and the detection achieved
- We had to develop a strategy compliant with these constrains
  - ET has been configured as a long term project based on EU “federal” support
    - Past:
      - Kick-off meeting supported by the European Science Foundation (Exploratory workshop in 2005)
      - Design study supported by the European Commission (FP7)
    - Present & Future:



ET Conceptual design
EINSTEIN TELESCOPE
R&D
•ELiTES
Technical design
First detection on advanced interferometers
ET Observatory Funding
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ET Site and infrastructures realisation
Hardware production
First detector installation
Components pre-commissioning and first ET detector commissioning
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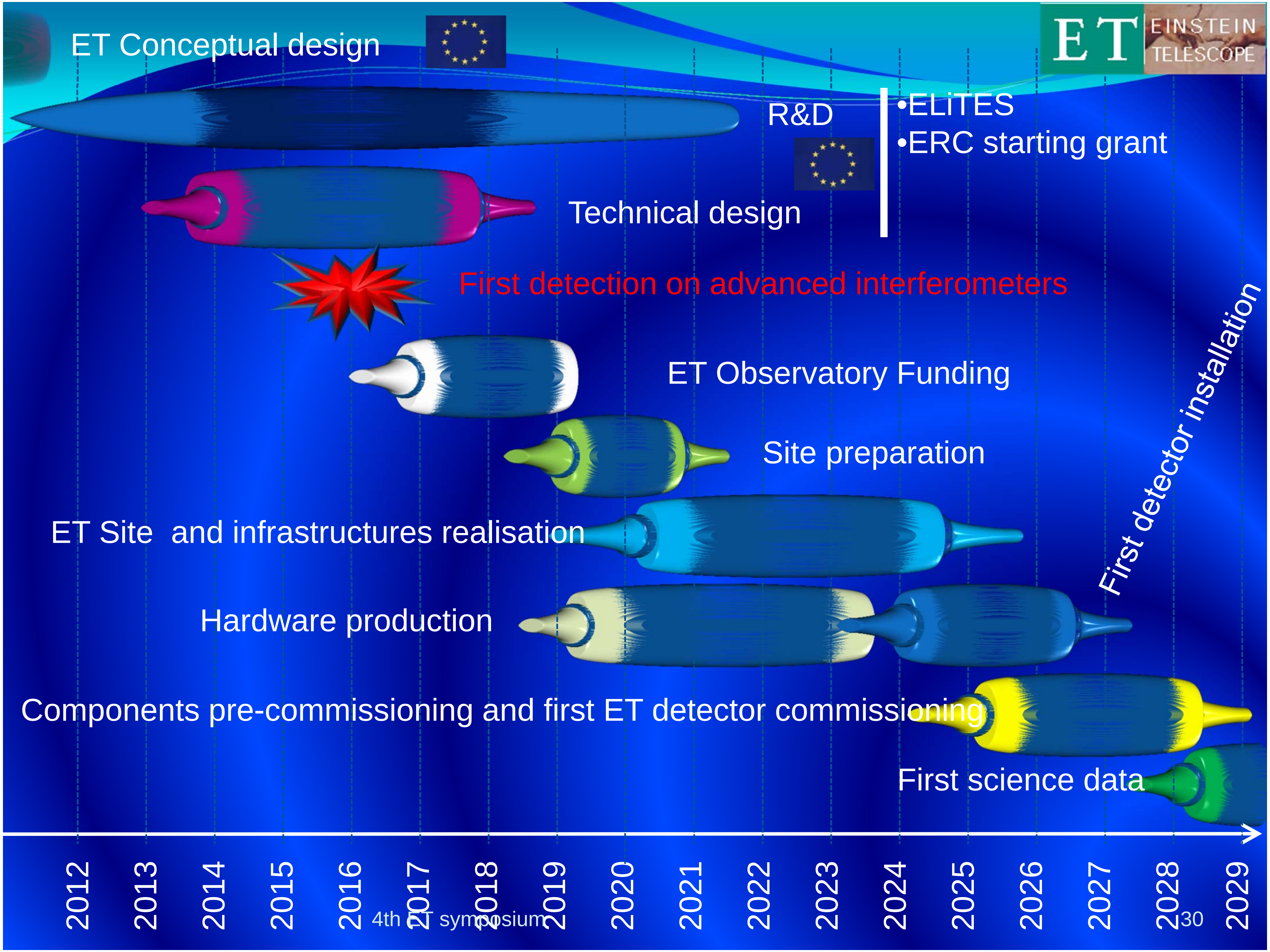
ELiTES: Synergies with KAGRA

- KAGRA is pioneering the development of an underground infrastructure and of the cryogenic interferometer for GW detection
- For ET is mandatory to have a synergy with KAGRA
- A 4 years European-Japanese joint project “ELiTES” supported by European Commission under FP7-IRSES is started in 2013
  - Exchange of scientists focused mainly on cryogenic issues common to ET and KAGRA



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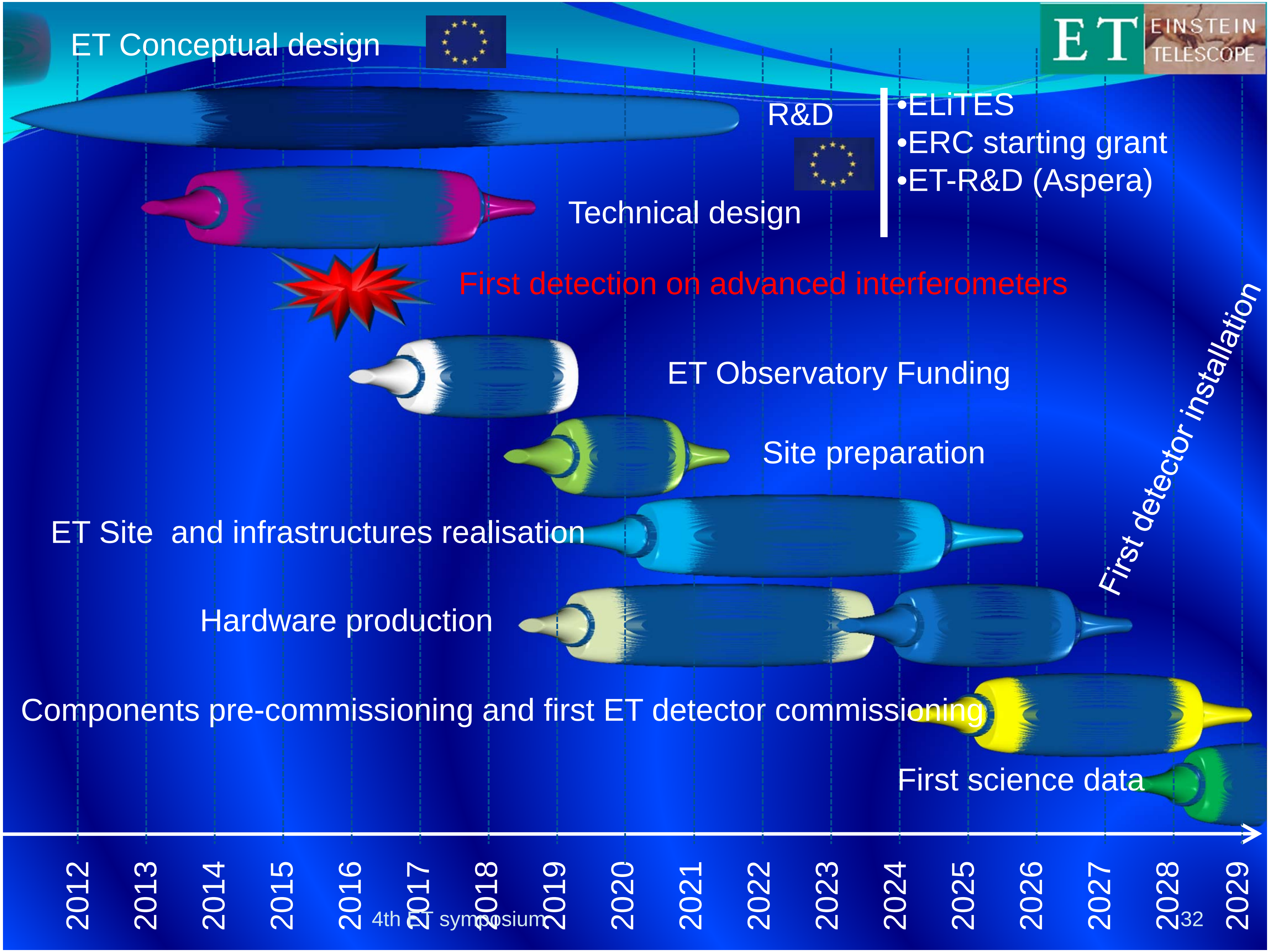
Interferometry beyond the Standard Quantum Limit using a Sagnac Speedmeter

Stefan Hild

ET general meeting

Hannover, December 2012



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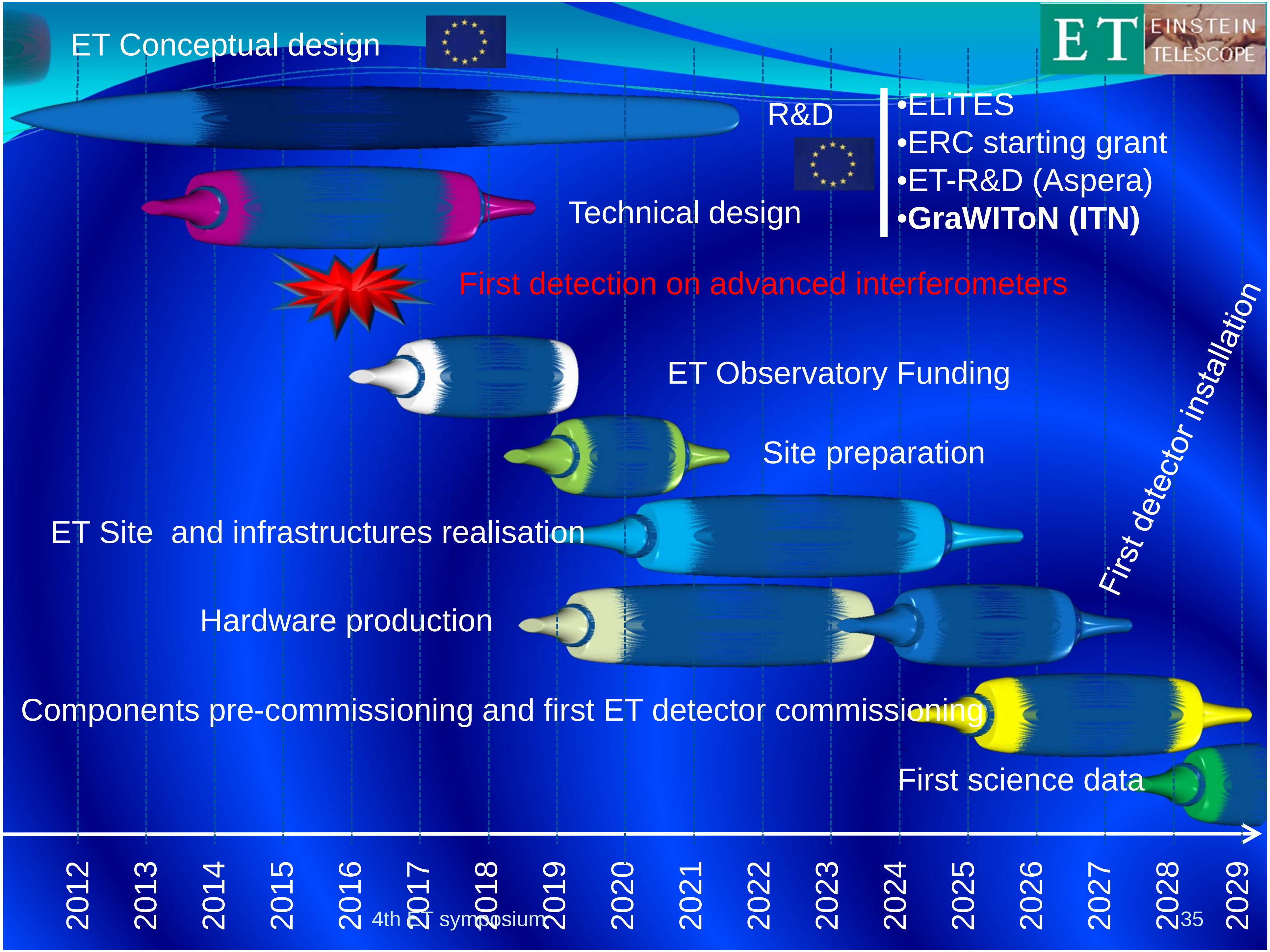
ET-R&D

- ET-R&D is a project funded by national agencies, in a quasi-European framework (ASPERA)
  - Coordinated by H.Lueck

Participants	Country	Legal Entity Name	Department /Division/ Laboratory	Scientist in charge
Full Partners	Netherlands	NIKHEF: National Institute for subatomic Physics		J. v.d. Brand
	Germany	LUH-AEI: Leibniz Universität Hannover, Albert Einstein Institut	Institut für Gravitationsphysik	H. Lück
		FSU: Friedrich-Schiller-Universität Jena	Institut für Festkörperphysik	R. Nawrodt
	Russia	**The Russian ET Consortium**	**MSU-SAI**: Moscow State University, Sternberg Astronomical Institute (lead) **MSU-PD**: Moscow State University, Physics Department **INR RAS**: Institute of Nuclear Research Russian Academy of Science	V. Rudenko (SAI, lead), V. Vyatchanin (PD), L. Bezrukov (INR RAS)
	Poland	**The Polish ET Consortium**	University of Warsaw (lead), University of Zielona Gora, University of Bialystok, Warsaw University of Technology, Polish Academy of Science (Inst. of Mathematics), Polish Academy of Science (Nicolaus Copernicus Astronomical Centre)	T. Bulik (UW, lead), D. Rosinska (UZ), P. Jaranowski (UwB), T. Starecki (WUTechnol.), A. Krolak (IMPAN), M. Bejger (CAMK)
	United Kingdom	UNIBHAM: Birmingham University	School of Physics and Astronomy	A. Freise
		UNIGLASGOW: University of Glasgow	Institute for Gravitational Research	I. Martin
		UNICARDIFF: Cardiff University	School of Physics and Astronomy	B.S. Sathyaprakash
		UWS: University of the West of Scotland		S. Reid

Activities

WP No	Work Package Title	Lead Participant	Other Participants involved
WG 1	ET's scientific potential	Cardiff	Nikhef, Polish ET Consortium, Glasgow, MSU-SAI, Nice
WG 2	Long term seismic and GGN studies of selected sites	Nikhef	Polish ET Consortium, Hungary, MSU-SAI, BNO INR RAS, La Sapienza, Salerno, INFN Napoli, INFN Pisa
WG 3	Optical properties of silicon at cryogenic temperatures	FSU	LUH-AEI, FSU, Glasgow, LMA, Russian ET Consortium, UWS
WG 4	ET Control systems	UniBham	LUH-AEI, Glasgow, MSU PD, EGO
WG 5	Management	LUH-AEI	EGO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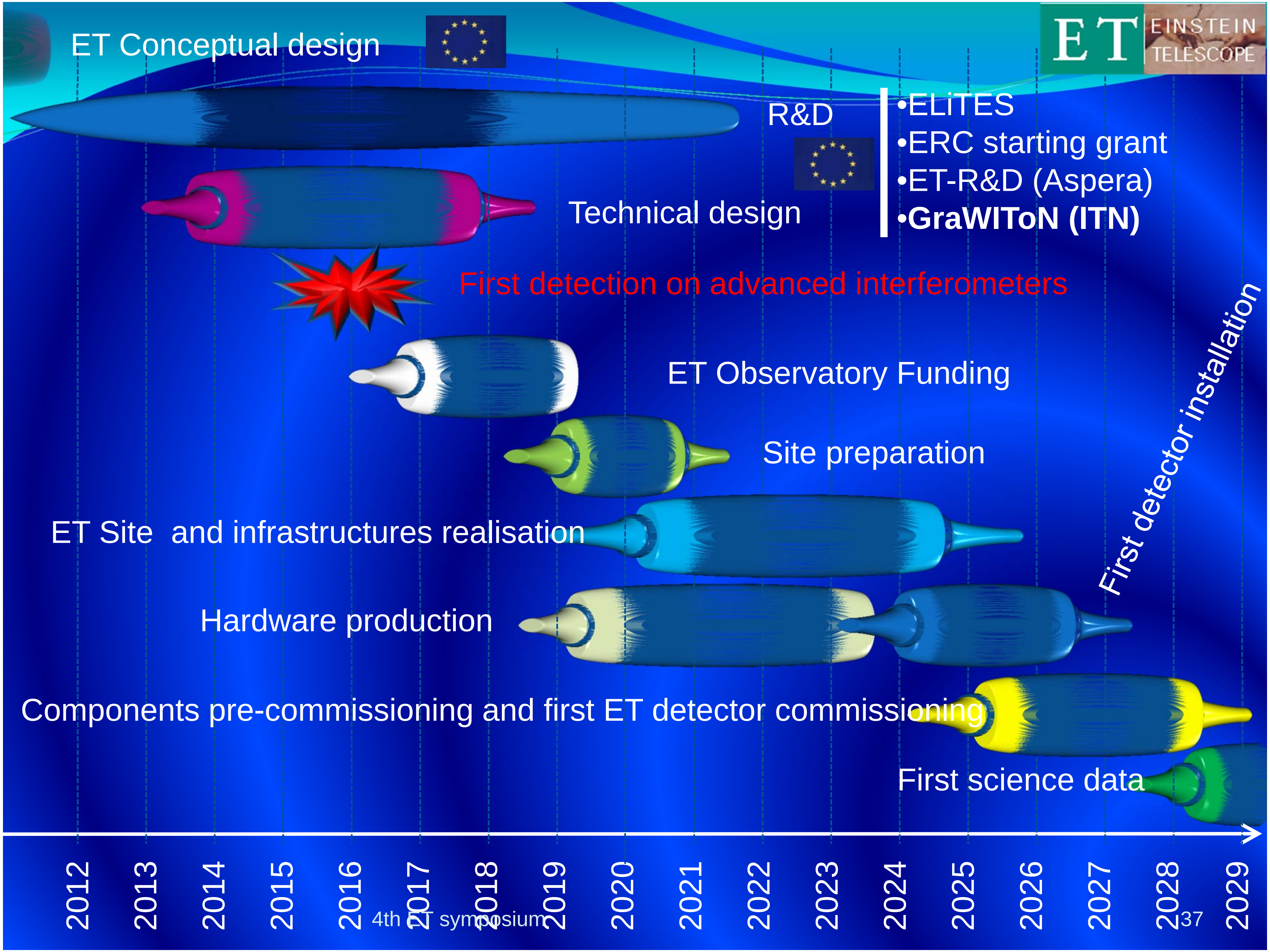
GraWIToN

- GraWIToN is an “Initial Training Network” (Marie Curie Actions) focused on GW, with special accent on ET
- It is composed by 13 members (Institution, universities, research centers and 3 private companies) in 4 EU countries
- It aims to the training of 13 PhD students on GW subjects; funds for
  - Salaries
  - Research activities
- We are concluding the negotiation in these days and the project will starts in February 2014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4th ET symposium
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EINSTEIN TELESCOPE

SEVENTH FRAMEWORK PROGRAMME

HORIZON 2020

R&D

C starting grant

R&D (Aspera)

GW Research Infrastructures
have been pre-selected as
TOPICS WITH HIGH POTENTIAL
AND WITH MERIT FOR FUTURE
HORIZON 2020 ACTIONS
FOR INTEGRATING AND
OPENING EXISTING NATIONAL
RESEARCH
INFRASTRUCTURES

rst science data

2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029

Conclusions

- ET is a long term project of a 3G GW observatory
  - Currently the activities are focused to the development of the needed technologies and to the definition of the technical design
  - It is configured as a “background” activity, based on funds $\neq$ from the “advanced detectors” and it will ramp-up after the first detection
    - Again on EU funding strategy… meeting tomorrow on R.I. integration