ET: Einstein Telescope

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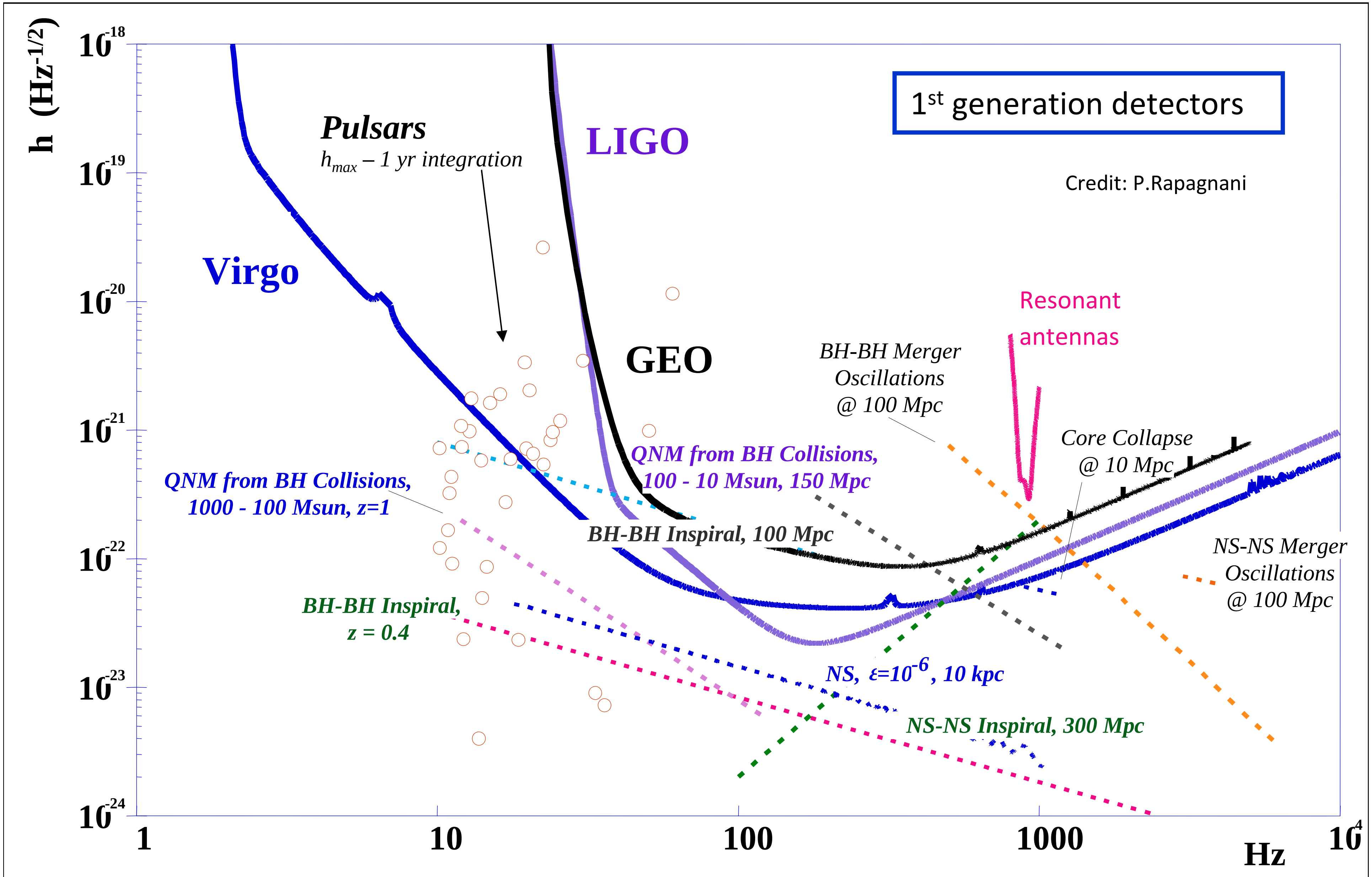
On behalf of the ET design study team

Evolution of the current GW detectors

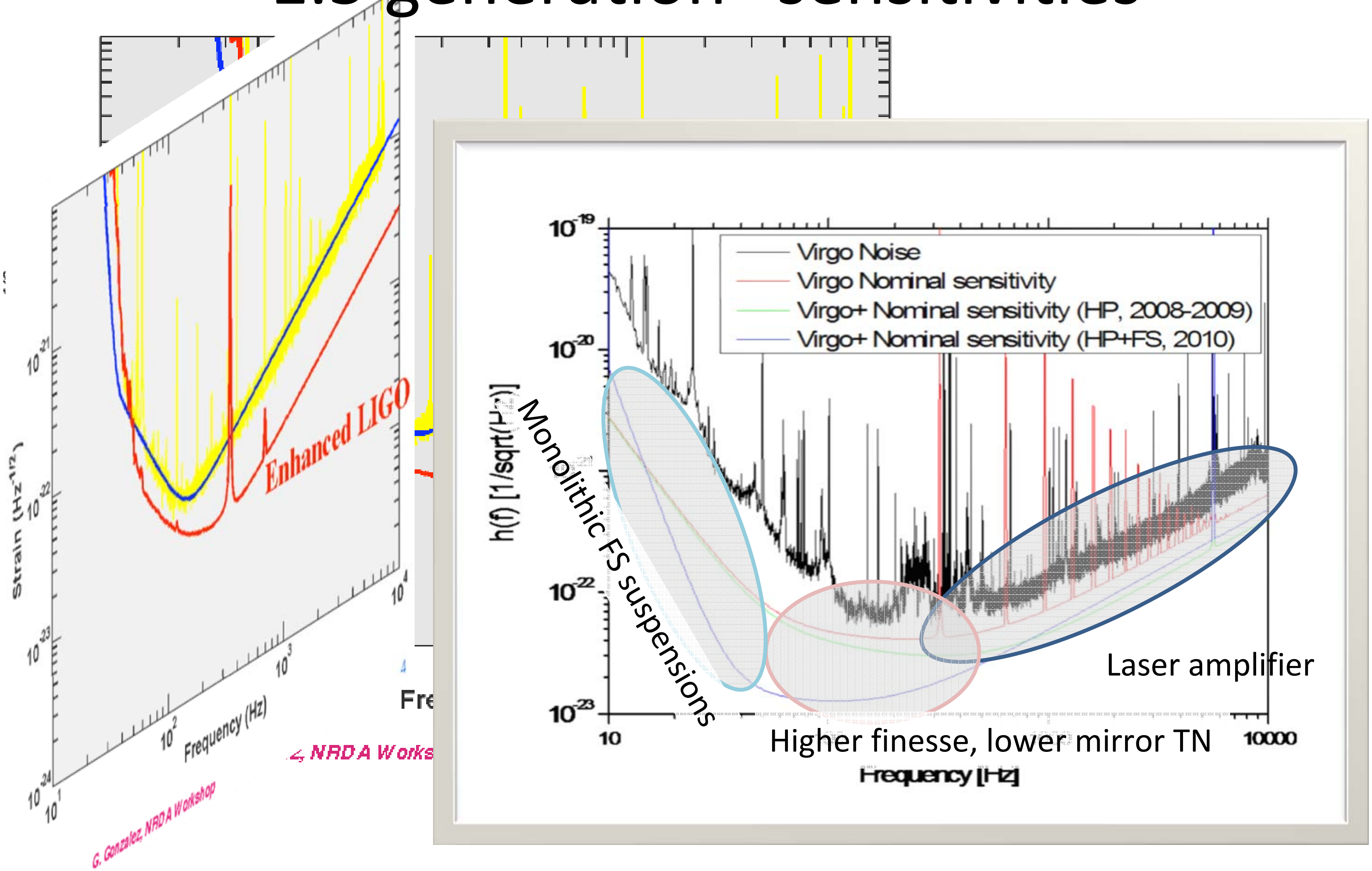
- Current Gravitational Wave interferometric detectors have a well defined evolution line in the next 5-7 years
  - LIGO just completed its S5 scientific run
  - Virgo completed in October 07 its first long scientific run in parallel with LIGO
    - Both the detectors are in upgrade/commissioning mode to implement their 1.5 generation upgrade step (Virgo+, enhanced LIGO)
  - GEO is covering ("astrowatch" mode) the down time of LIGO and Virgo in collaboration with the resonant bar detectors

- … see G.Losurdo Talk

1st generation GW detectors sensitivities



“1.5 generation” sensitivities



Advanced detectors

- Enhanced detectors are a step toward the realization of the 2nd generation detectors ("advanced")
  - Also GEO will participate to the network of enhanced detectors with an upgraded version, "specialized" in the high frequency regime thanks (mainly) to the signal recycling technology
    - GEO HF
  - They are based on "small" changes of the current detectors with available technologies that anticipate the next step
- Advanced detectors will be online in the >2013 timeslot
  - They will be based on known technologies currently under preliminary engineering phase
    - High power laser (~200W) and compliant optics
    - Lower thermal noise mirrors (substrates and coatings)
    - Lower thermal noise suspensions (FS monolithic suspensions)
    - Better seismic isolation
      - Active filtering in LIGO
      - Focused improvements of the Virgo Super-Attenuator
    - Signal recycling

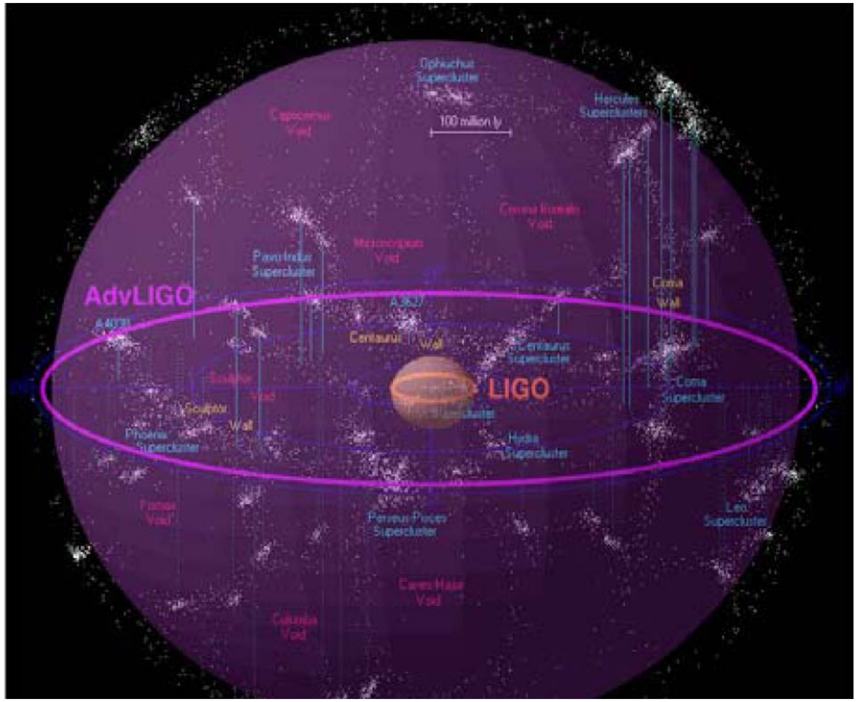
Detection progresses

Credit:

Richard Powell,

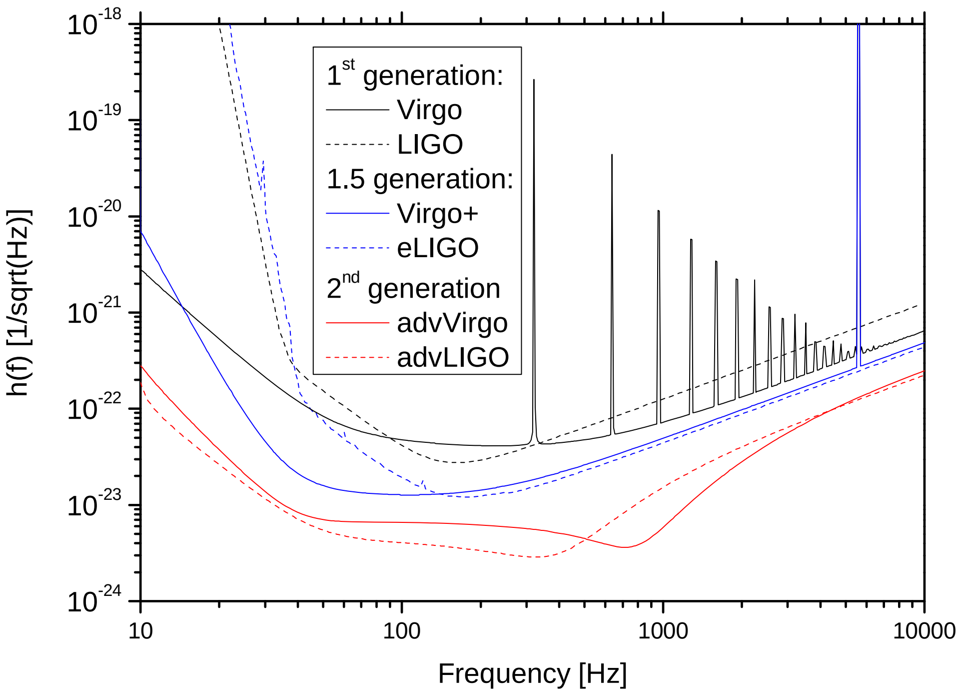
Beverly Berger.

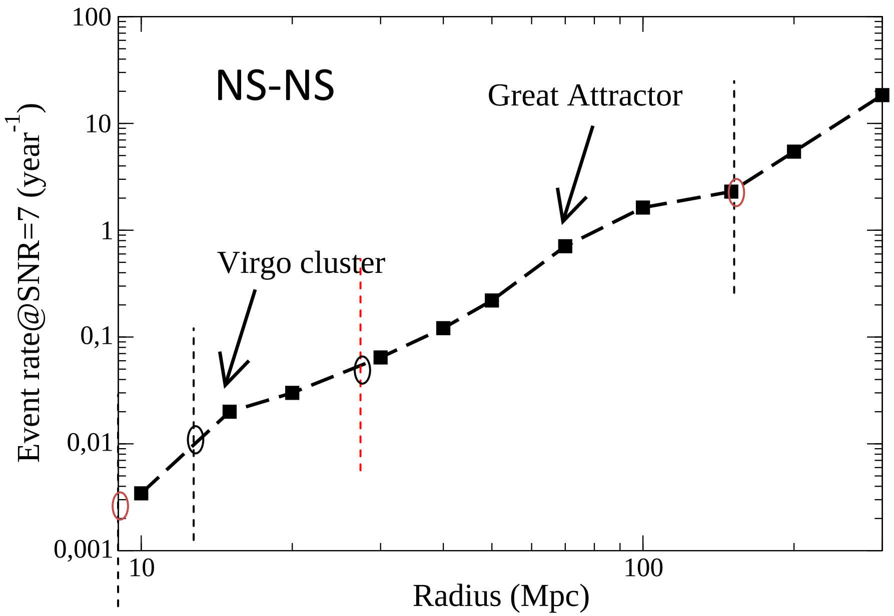
From LIGO presentation G050121



NS-NS ($1.4M_S$):

$13 \Rightarrow 15/50 \Rightarrow 120/170$ Mpc





3rd generation detectors

- Second generation detectors:
  - Will permit the detection of Gravitational Waves (GW)
  - Will open the era of the GW astronomy
  - Will be the "core business" of the next decade in experimental GW research
- But can we look beyond?
  - Precision GW astronomy needs high SNR to determine the parameters of the astrophysical process
  - Interesting phenomena involves massive bodies that requires low frequency sensitivity in GW detectors
  - We need to think to 3rd generation GW detectors

Objectives of a 3 rd generation GW detectors

From detection and initial GW astronomy to precision GW astronomy

- **Fundamental Physics**: Test general relativity in the strongly non-linear regime
  - Initial and advanced detectors won't have the sensitivity required to test strong field GR (too low SNR)
    - Most tests are currently quoted in the context of LISA, but in a different frequency range
  - We need to have good enough SNR for rare BBH mergers which will enable strong-field test of GR
- **Black hole physics:**
  - What is the end state of a gravitational collapse?
- **Astrophysics:** Take a census of binary neutron stars in the high red-shift Universe
  - Adv VIRGO/LIGO might confirm BNS mergers, possibly provide links to γ-ray bursts
  - 3^{rd} generation GW detectors could do much more: see different classes of sources (NS-NS, NS-BH) and contribute to resolve the enigma in the variety of γ-ray bursts

How to arrive to an European 3rd generation GW Observatory?

- Long preparatory path, already started:
  - ILIAS played a determinant role:
    - ILIAS-GW-WP3 realized the correct environment where to discuss, at European level, the evolution of the current detectors and where to merge the efforts addressed to the proposition of a 3rd generation GW observatory
      - It supported the meetings, the workshops and the preliminary studies
      - All the ET proposal writing meetings have been supported by WP3
      - WP3 has been also the core of the new WG6 (GW) in the ASPERA road-mapping activity
    - ILIAS-JRA3 (STREGA) partially supported R&D activities in thermal noise issues for 3rd generation GW detectors
  - European Science Foundation supported an exploratory workshop (Perugia, Sept 2005) that has been a milestone in the definition of the strategy for the proposal of a new Observatory
  - FP7 Design Study has been the perfect environment where to synthesize our ideas in a proposal and compete with other excellent proposals

ET

SEVENTH FRAMEWORK PROGRAMME

- ET: Einstein Telescope
  - An European 3rd Generation Gravitational Wave Observatory
- Conceptual design study proposed at the May 2007 FP7 call
  - Capacities
    - Research Infrastructures
      - Collaborative projects

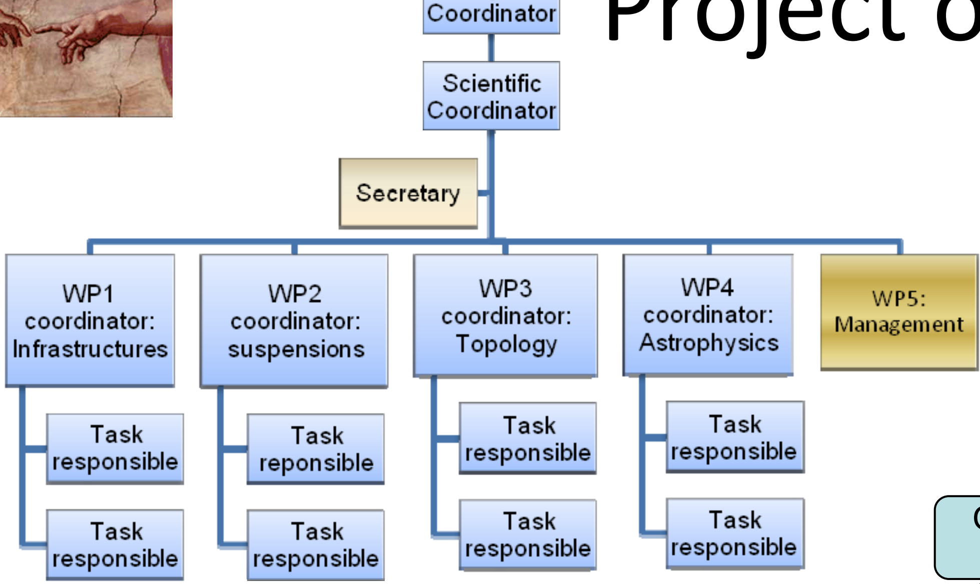
ET: Participants

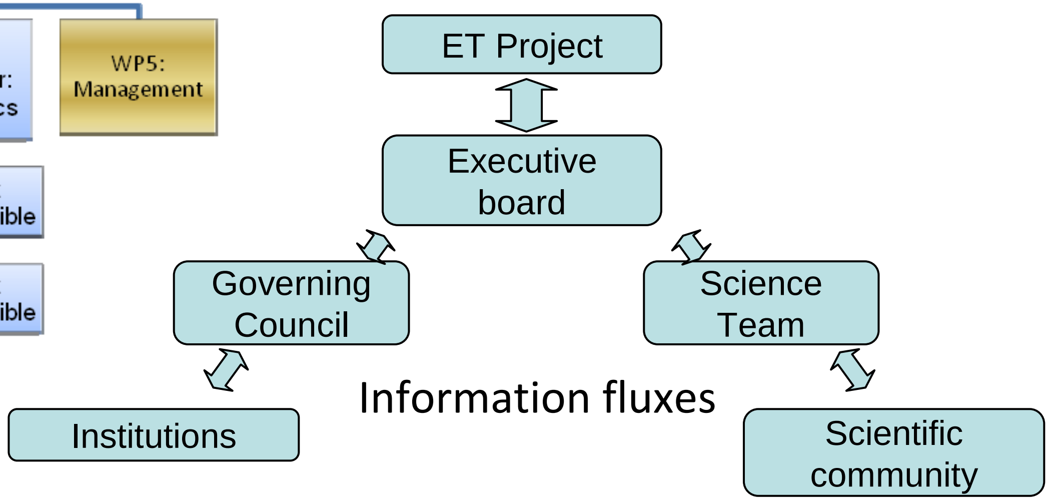
Participant no.	Participant organization name	Country
1	European Gravitational Observatory	Italy-France
2	Istituto Nazionale di Fisica Nucleare	Italy
3	Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V., acting through Max-Planck-Institut für Gravitationsphysik	Germany
4	Centre National de la Recherche Scientifique	France
5	University of Birmingham	United Kingdom
6	University of Glasgow	United Kingdom
7	NIKHEF	The Netherlands
8	Cardiff University	United Kingdom

ET: Status of the project

- The proposal passed the first selection and now we are in an advanced negotiation phase
- We agreed a budget reduction to 3M€ for 38Months of activity
  - Main costs: man power and travels
- Description of Work document accepted by the European Officer
  - We are submitting the signed documents to prepare the Grant Agreement
  - Consortium Agreement under final definition

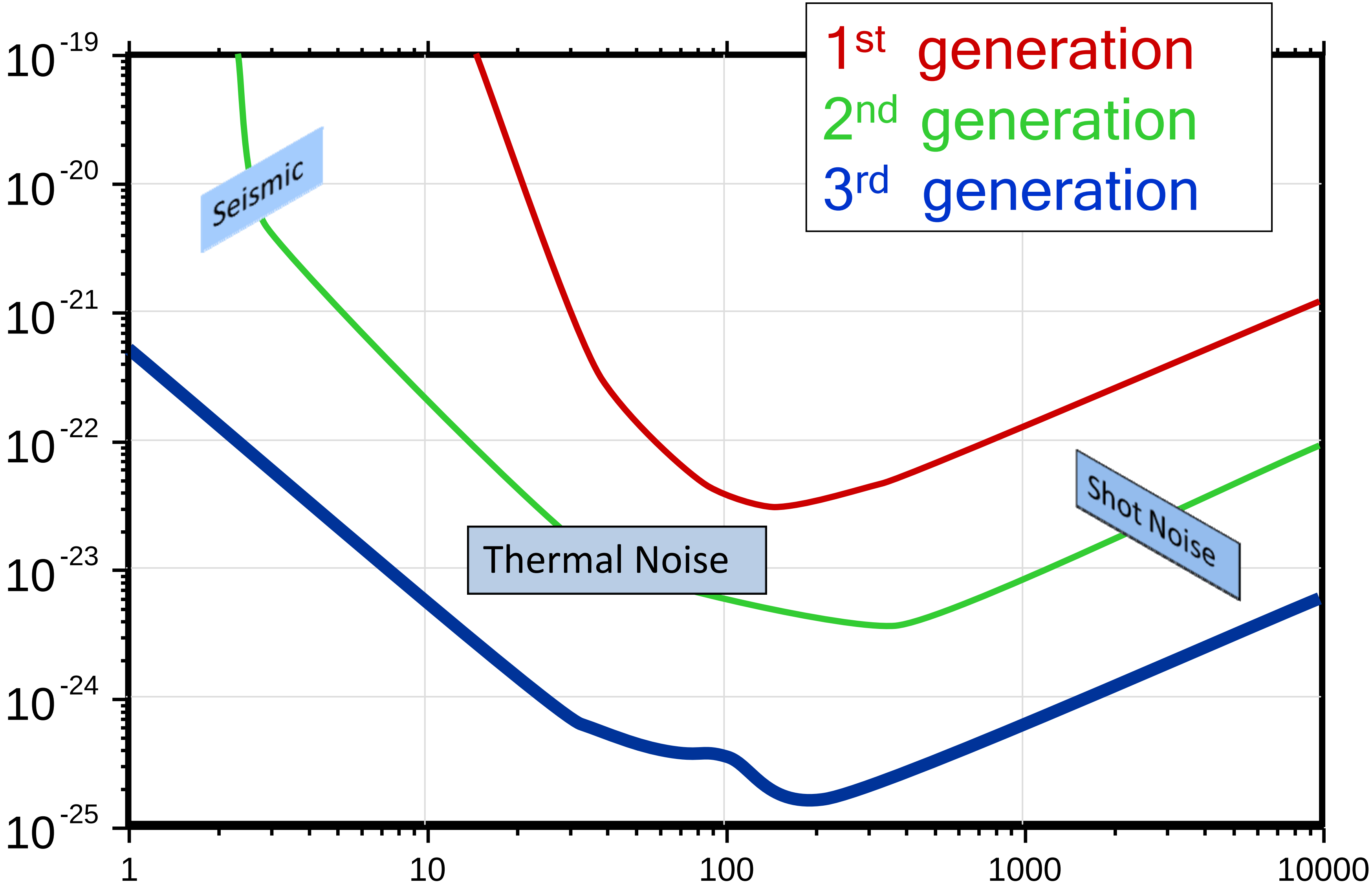
Project organization





- Project organization driven by the "Physics":
  - 4 working groups are devoted to the major technical and scientific issues
  - Let see the main technical aspects:

3 main noise sources



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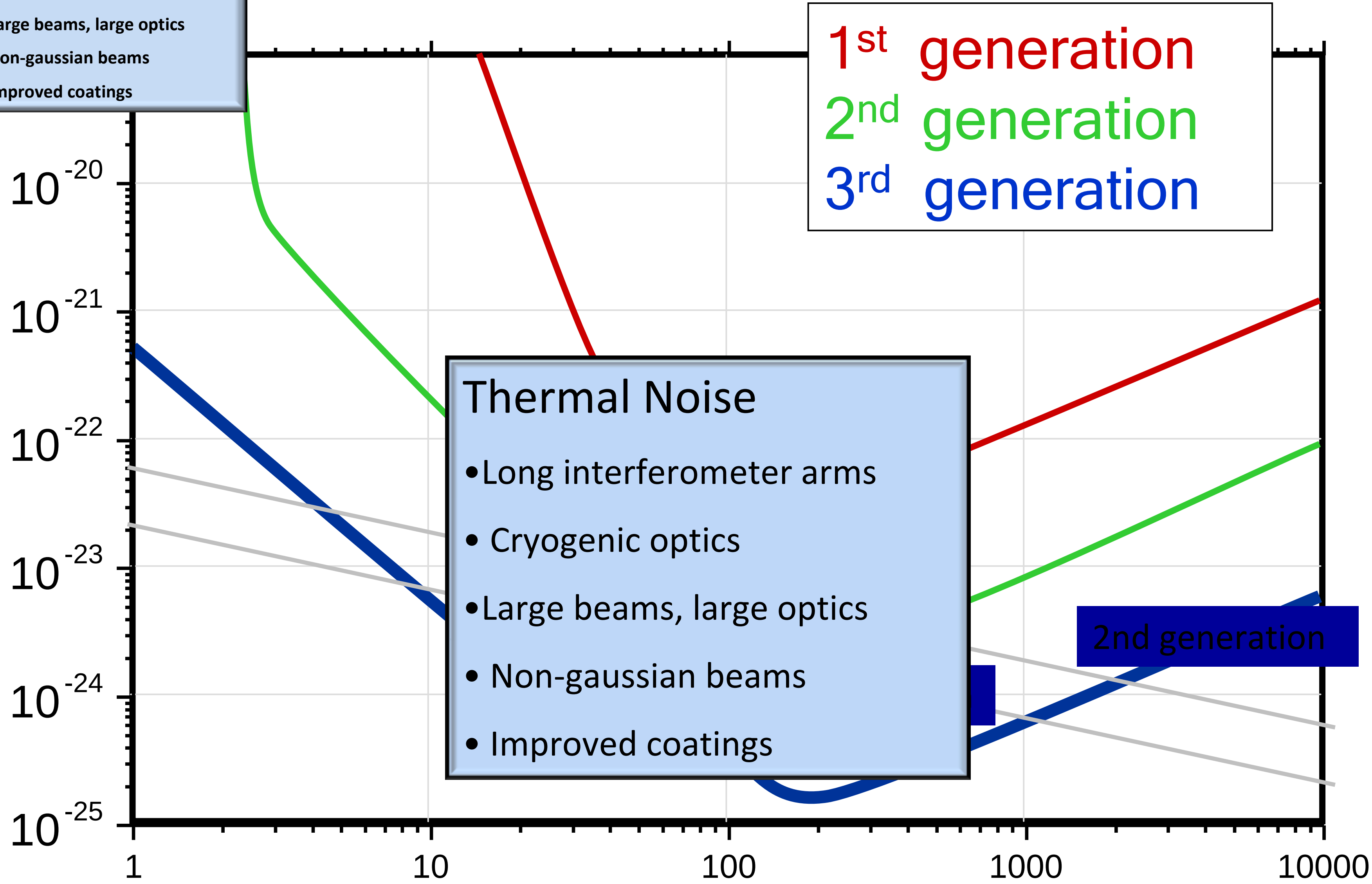

Thermal Noise

- Long interferometer arms
- Cryogenic optics
- Large beams, large optics
- Non-gaussian beams
- Improved coatings

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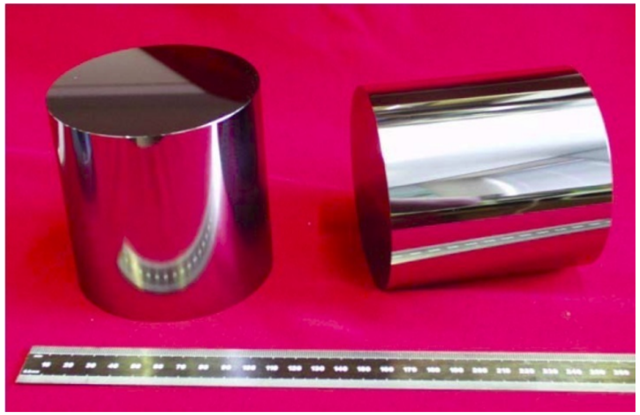
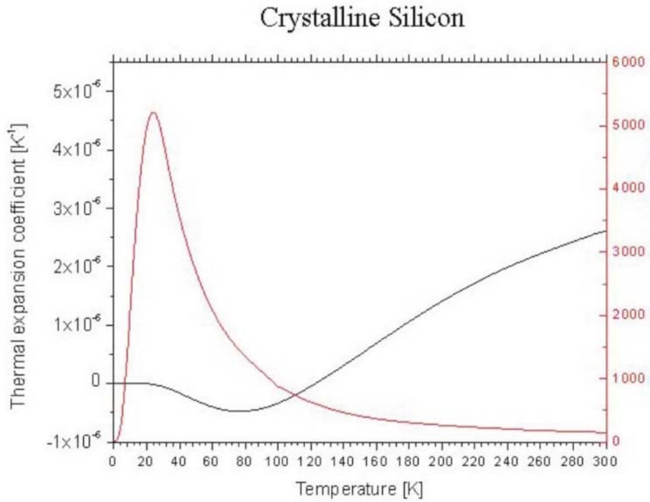
Cryogenic Optics

- Test masses and suspensions thermal noise reduces at low temperature: $\langle X^2 \rangle \sim T$
- Thermoelastic noise of the mirror substrates and coatings decrease: $\langle X^2 \rangle \sim \alpha T^2$
  - Thermal expansion rate α decreases at low temperature;
- Mechanical Q of some materials increases at low temperature
- Thermal lensing:
  - Thermal conductivity increases and consequently reduces thermal gradients on the coating;
  - Refraction index variation with temperature is very small at low temperature;

    (Sapphire @ 20K $\beta = 9 \times 10^{-8}$, Fused Silica @ 300K $\beta \sim 10^{-6}$)

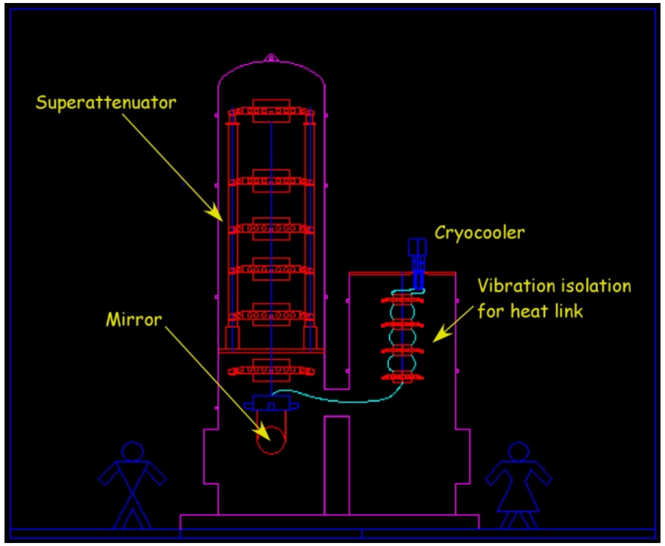
ILIAS “supported” or related activities





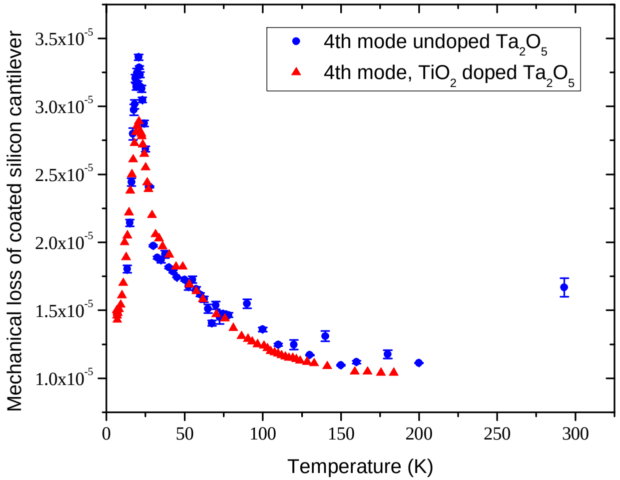
Silicon substrates

R&D activities in many European Labs: Glasgow, INFN Florence & Perugia, Jena University, …



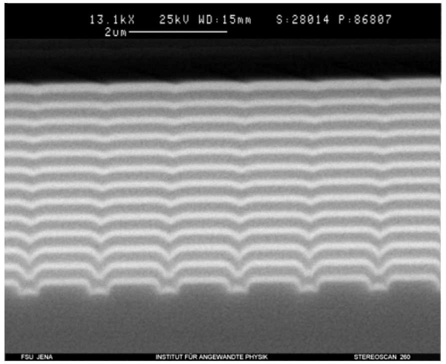
Cryogenic Super attenuator

R&D activities in INFN Rome & Pisa



Coatings studies

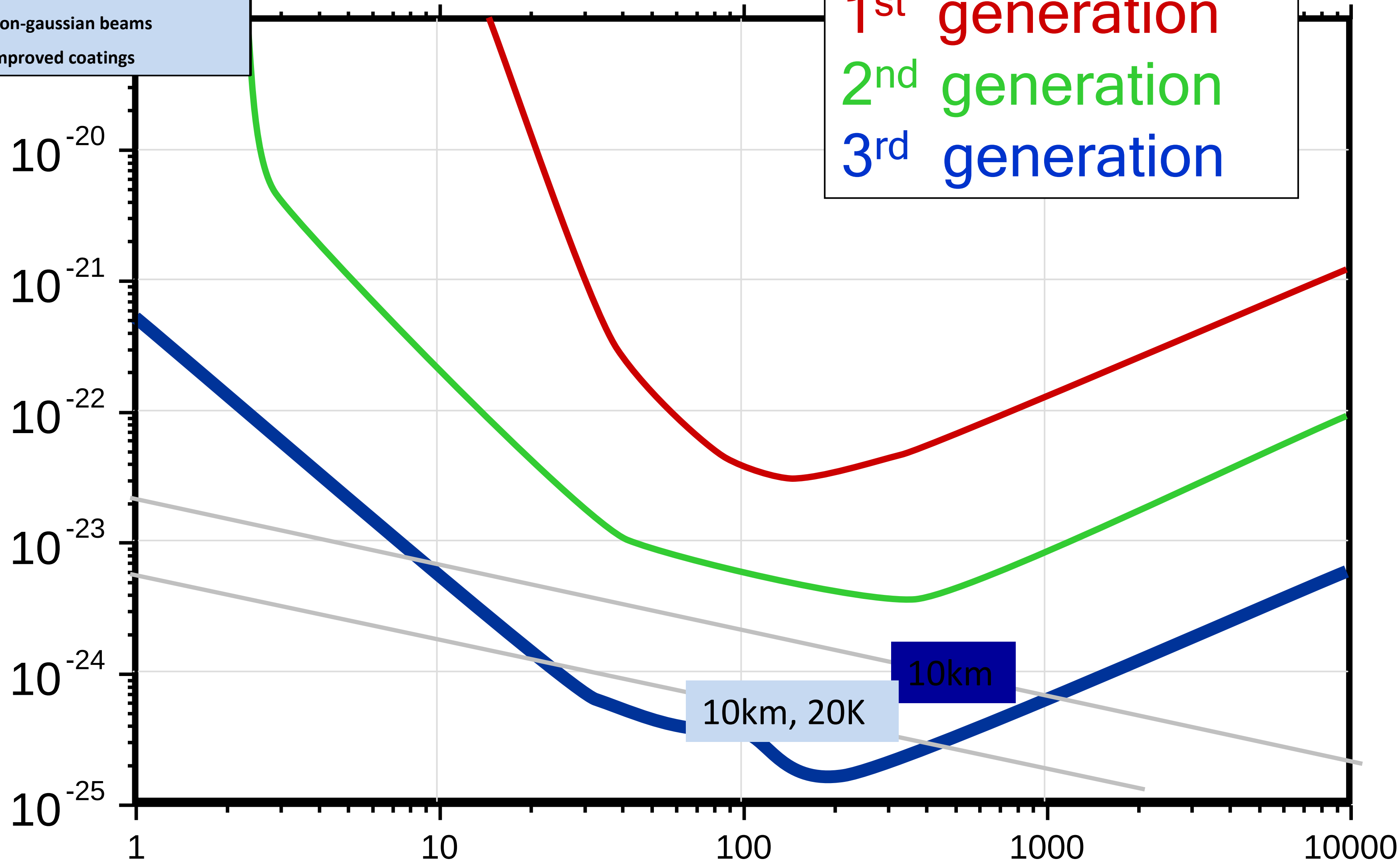
R&D activities in many European Labs: Glasgow, INFN Perugia, LMA-Lyon, MPG Hannover, …



3 main noise sources

Thermal Noise

- Long interferometer arms
- Cryogenic optics
- Large beams, large optics
- Non-gaussian beams
- Improved coatings



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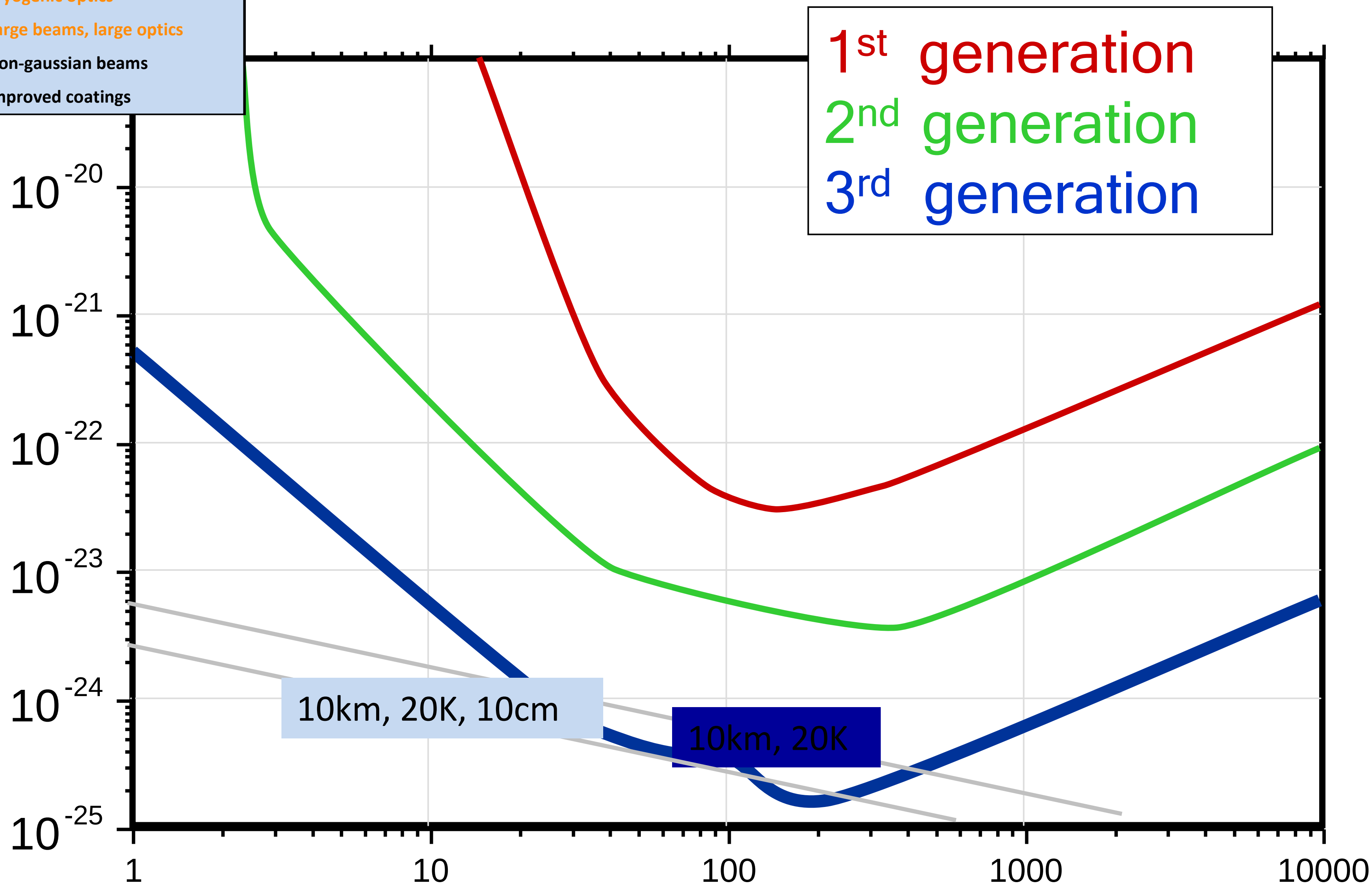
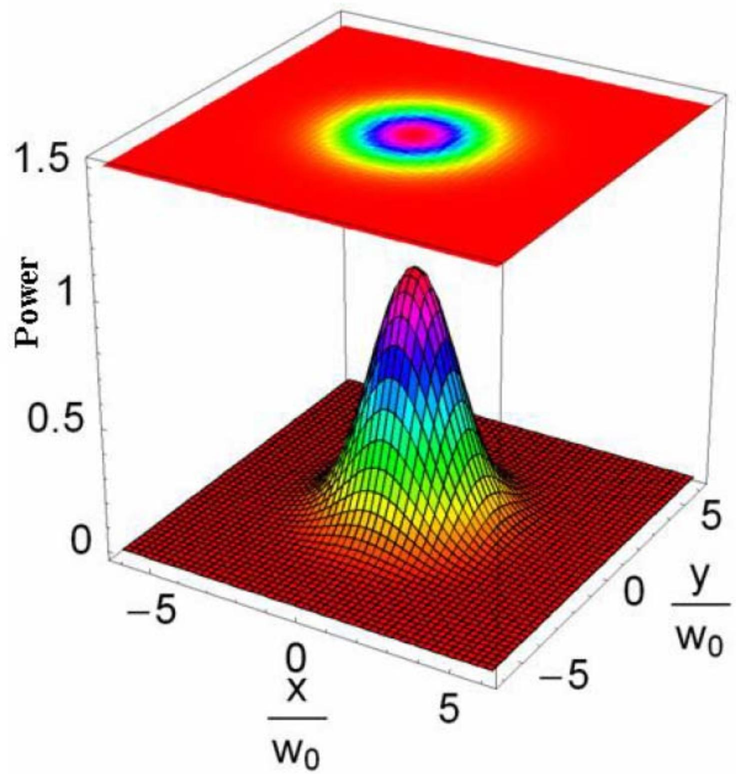
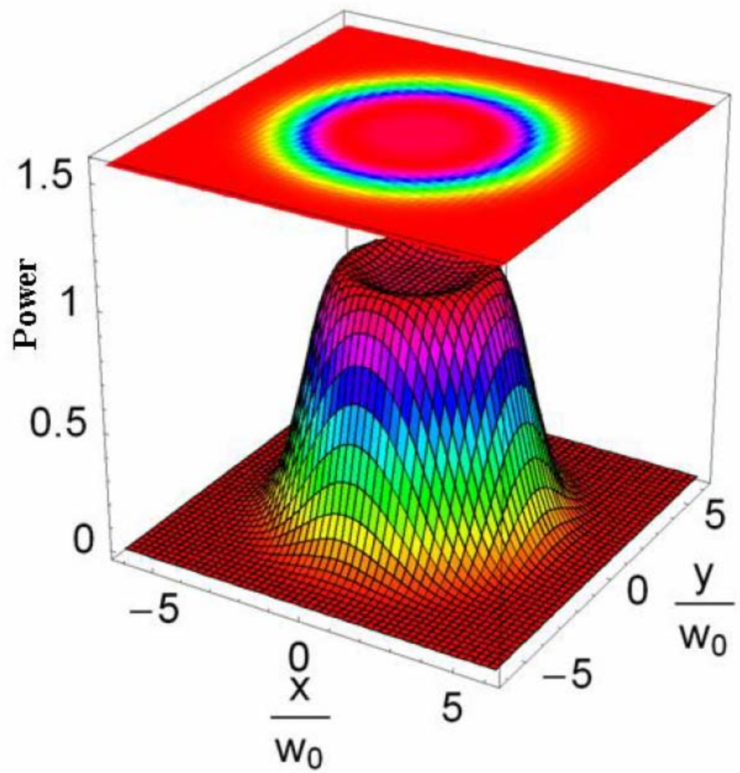


Non Gaussian Beams

- Thermal noise in a GW interferometric detector could be further reduced by using “flatter” beams:





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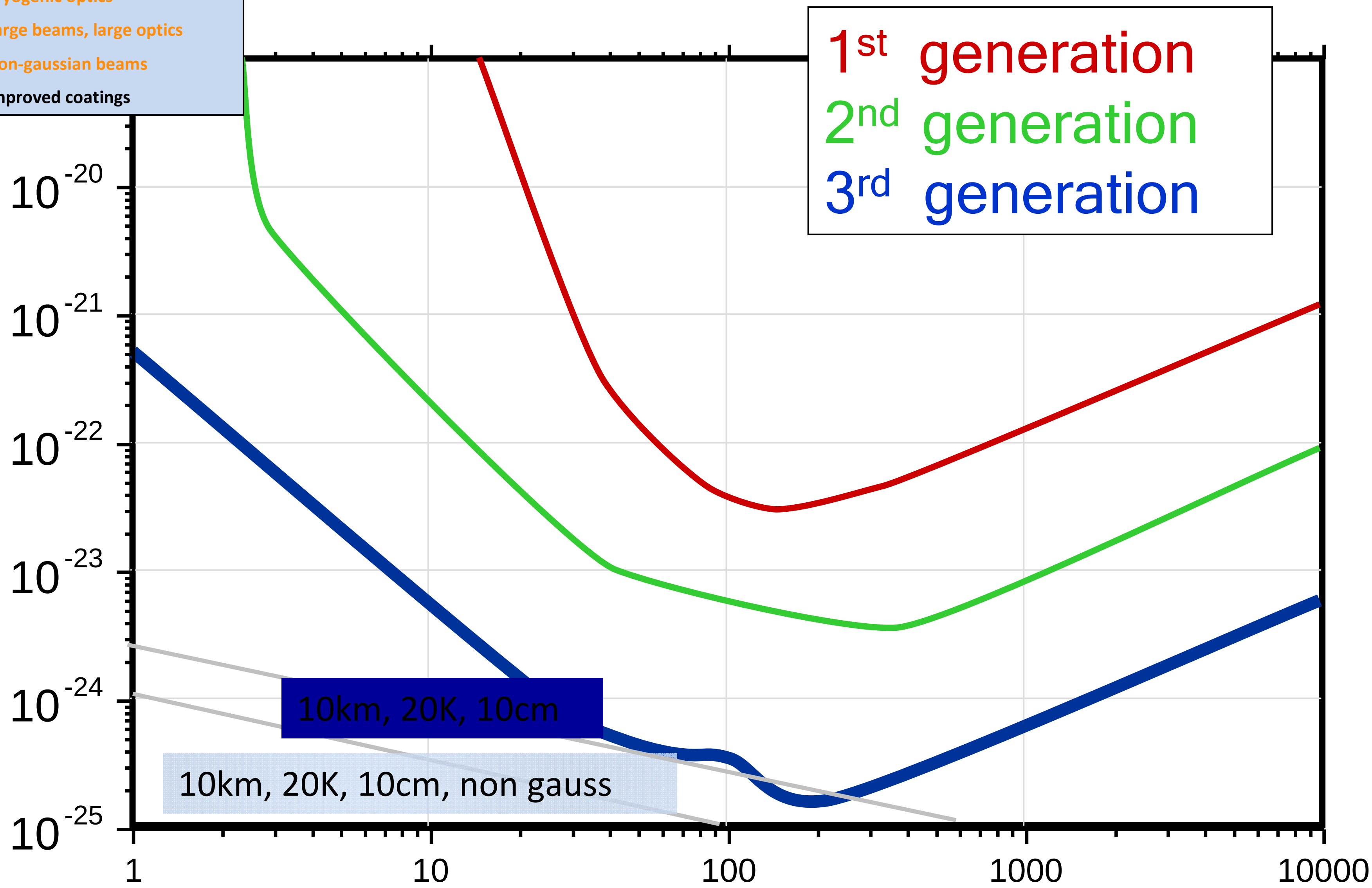


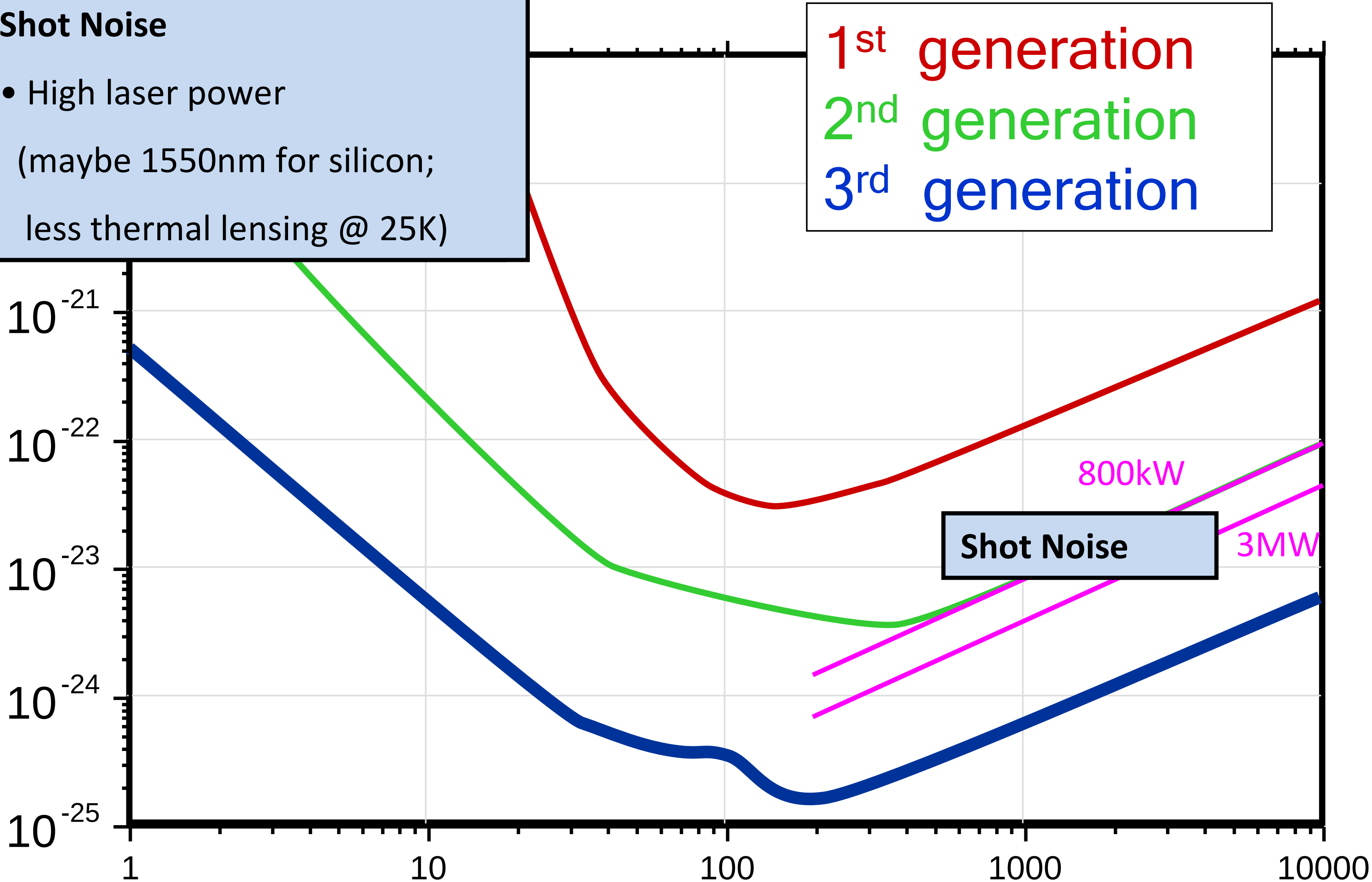
3 main noise sources

Shot Noise

- High laser power

  (maybe 1550nm for silicon;

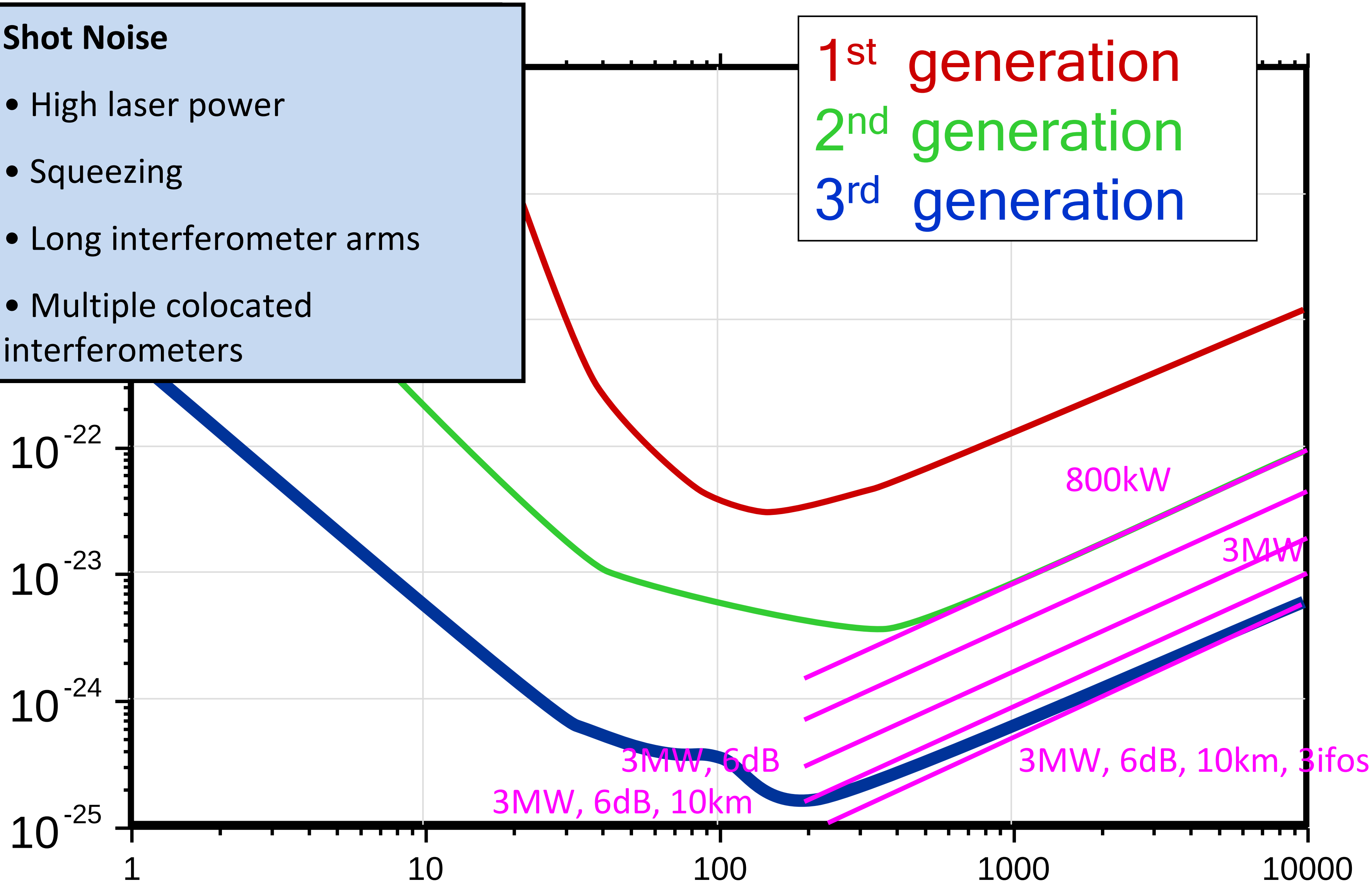
  less thermal lensing @ 25K)



3 main noise sources

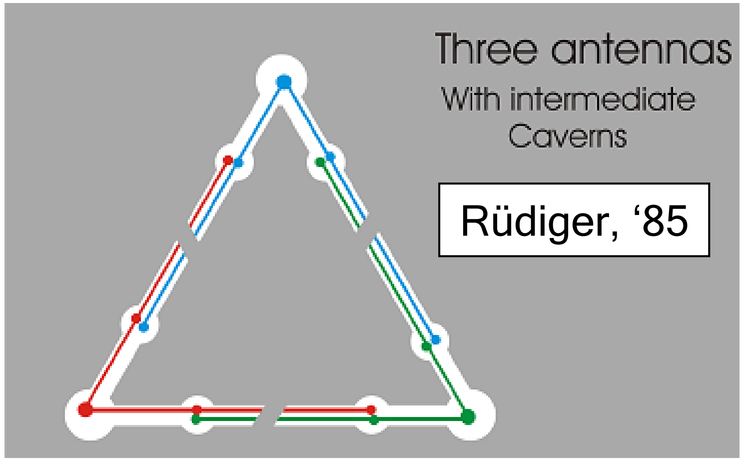
Shot Noise

- High laser power
- Squeezing
- Long interferometer arms
- Multiple colocated interferometers

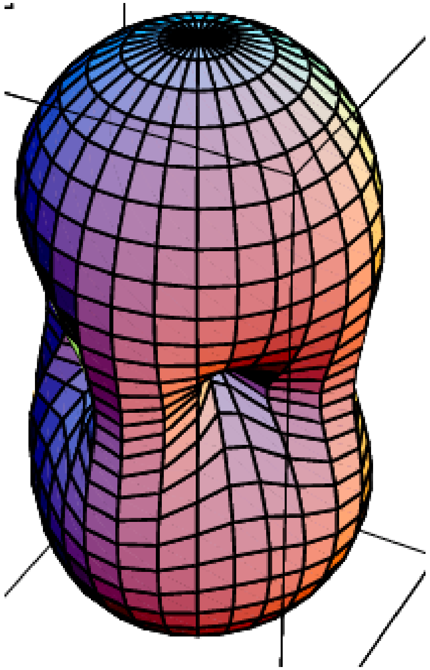


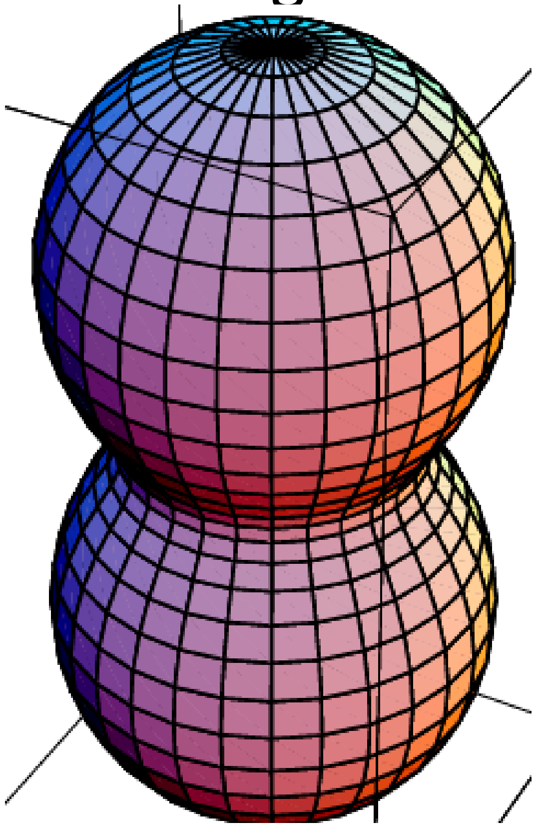
Co-located interferometers

- "Old" idea still under debate
  - Possible implementation: 3 detectors in a triangle configuration



Antenna Patterns:



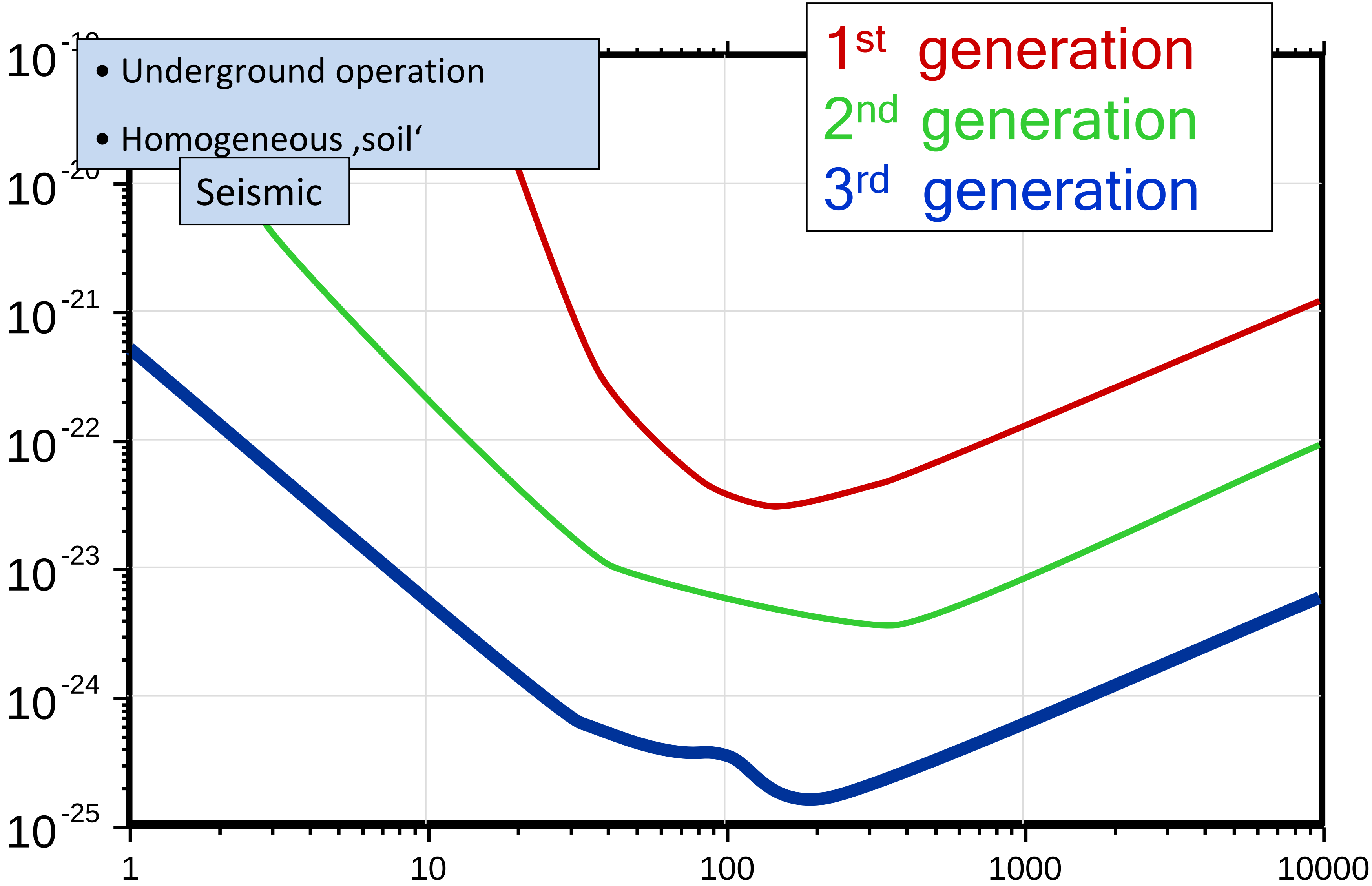


Credit: Cella, Vicerè

Angular response of a standard ITF

Angular response of the triangle configuration

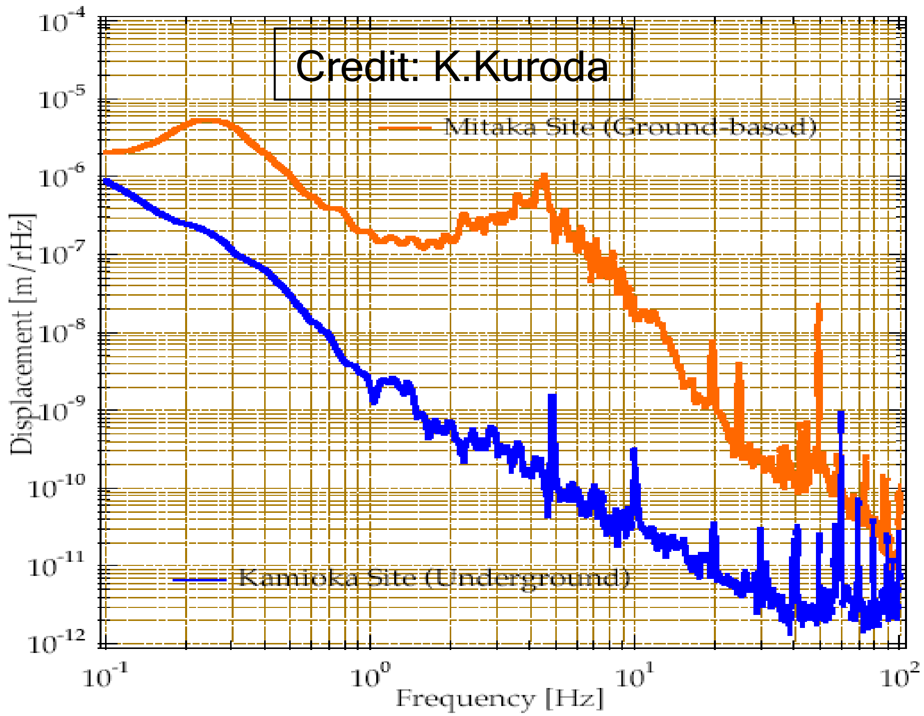
3 main noise sources



Underground operations

- **LISM:** 20 m Fabry-Perot interferometer, R&D for LCGT, moved from Mitaka (ground based) to Kamioka (underground)
  - Seismic noise strongly reduced

10^2 overall gain
10^3 at 4 Hz



Seismic Isolation Shortcut

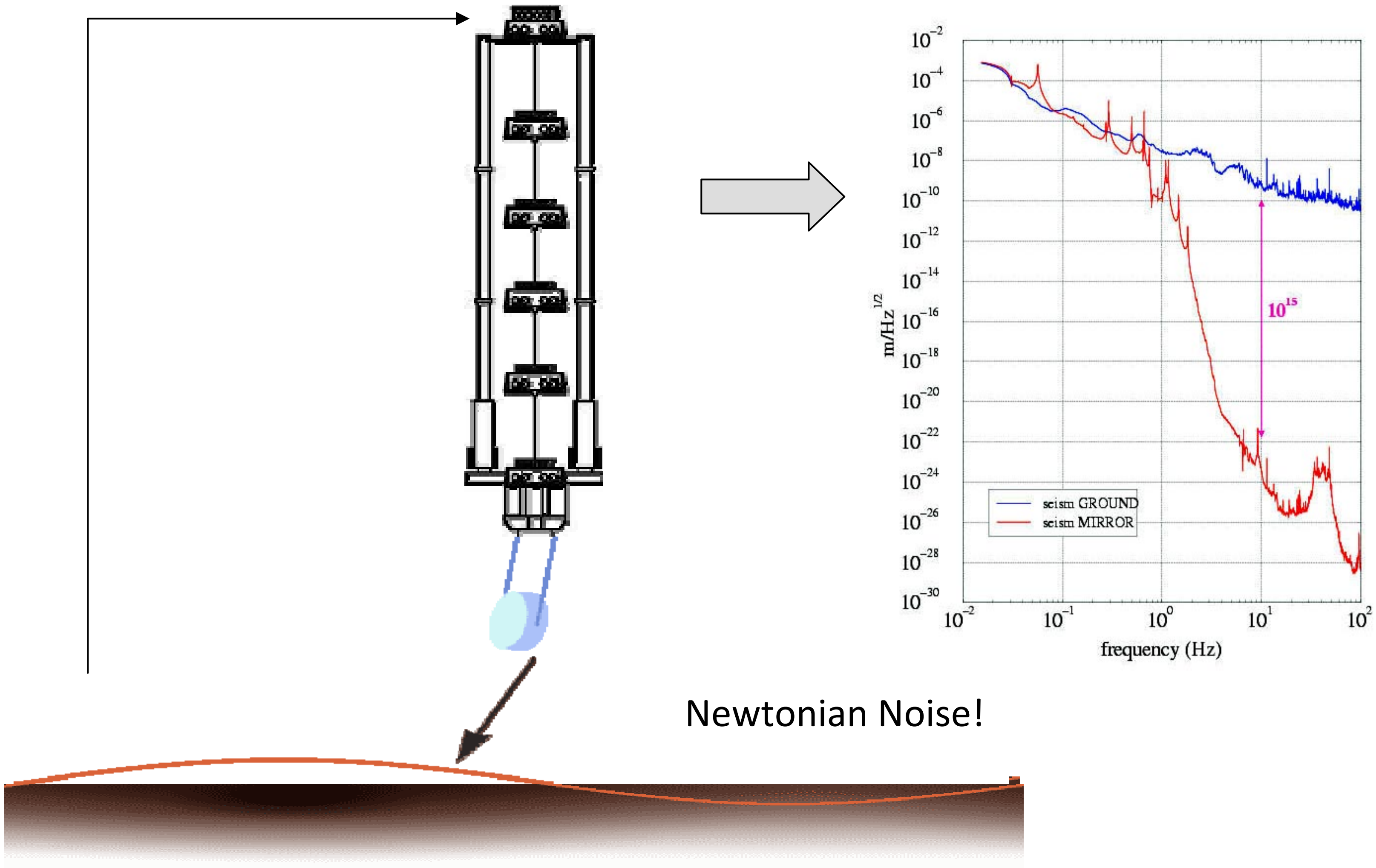
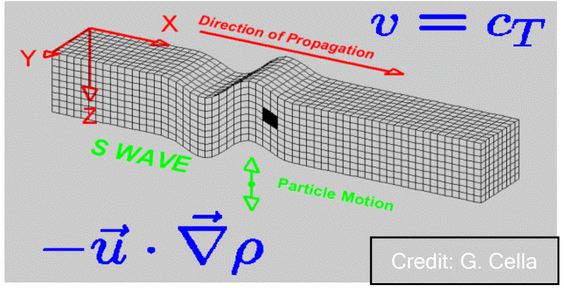


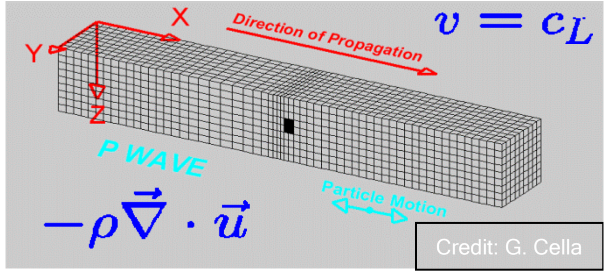
Figure: M.Lorenzini

Newtonian Noise

credit: G.Cella

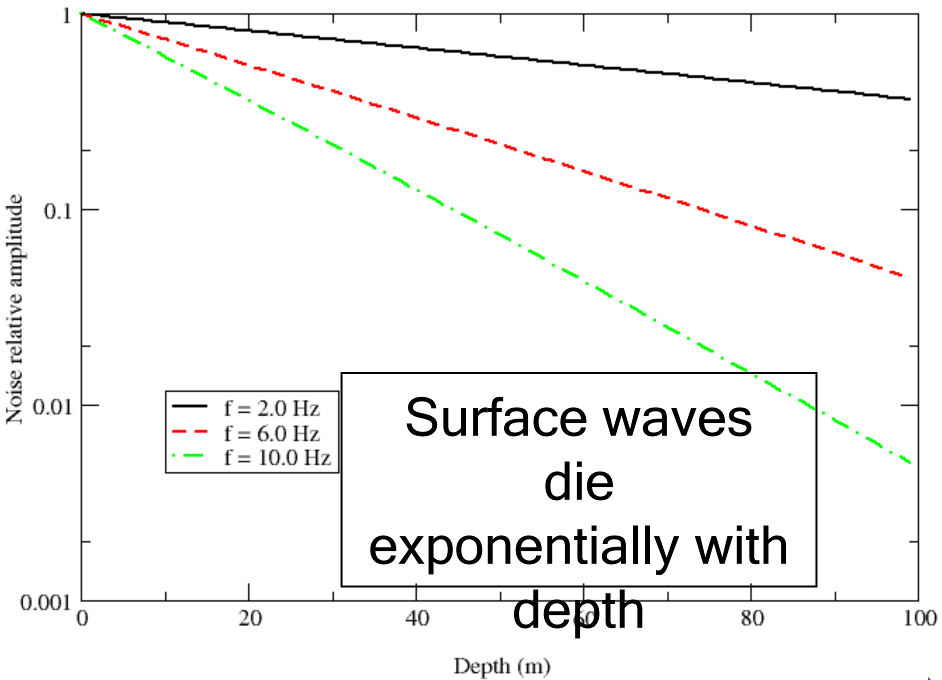


Surface waves

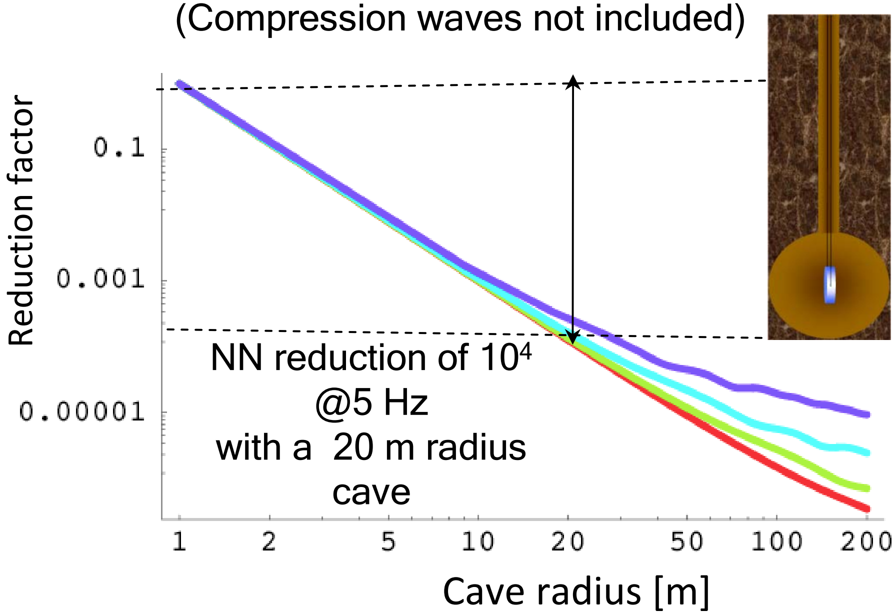


Compression waves

- Surface waves give the main contribution to newtonian noise

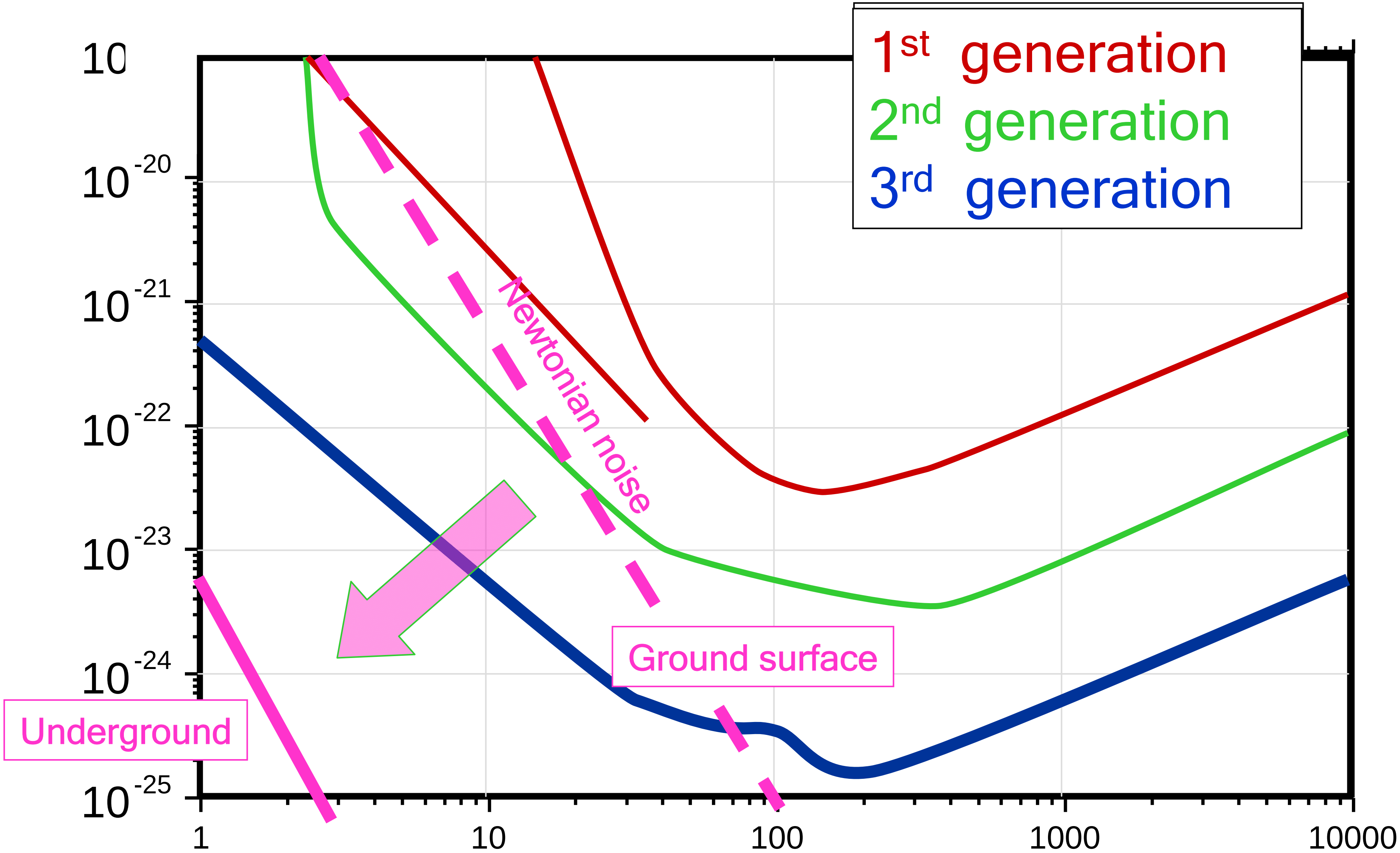


(Compression waves not included)



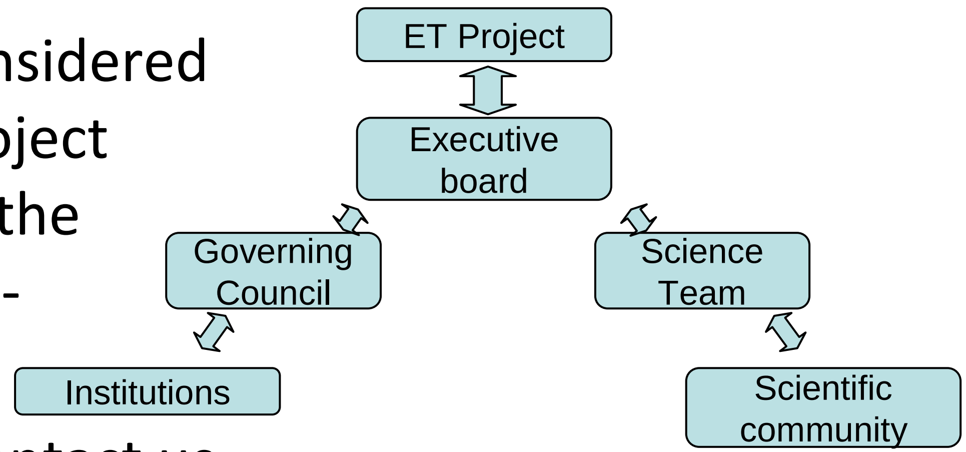
10^2 less seismic noise x 10^4 geometrical reduction → 10^6 overall reduction (far from surface)

3 main noise sources



Conclusions

- The target of the four Working Groups in the ET project is to try to transform these (and many other) ideas in a coherent conceptual design
- It is an huge job for a restricted set of persons
- ET is an emerging facility for the whole Europe and we don't want to limit the contribution to the founding team/institutions
- The proposal writers created in the project structure a special body that permits the exchange with a larger Scientific Community
- The Science Team has been considered extremely important by the project referee and already promoted the interest of European and extra-European Scientists



- If you are interested, please, contact us

Conclusions: Planning