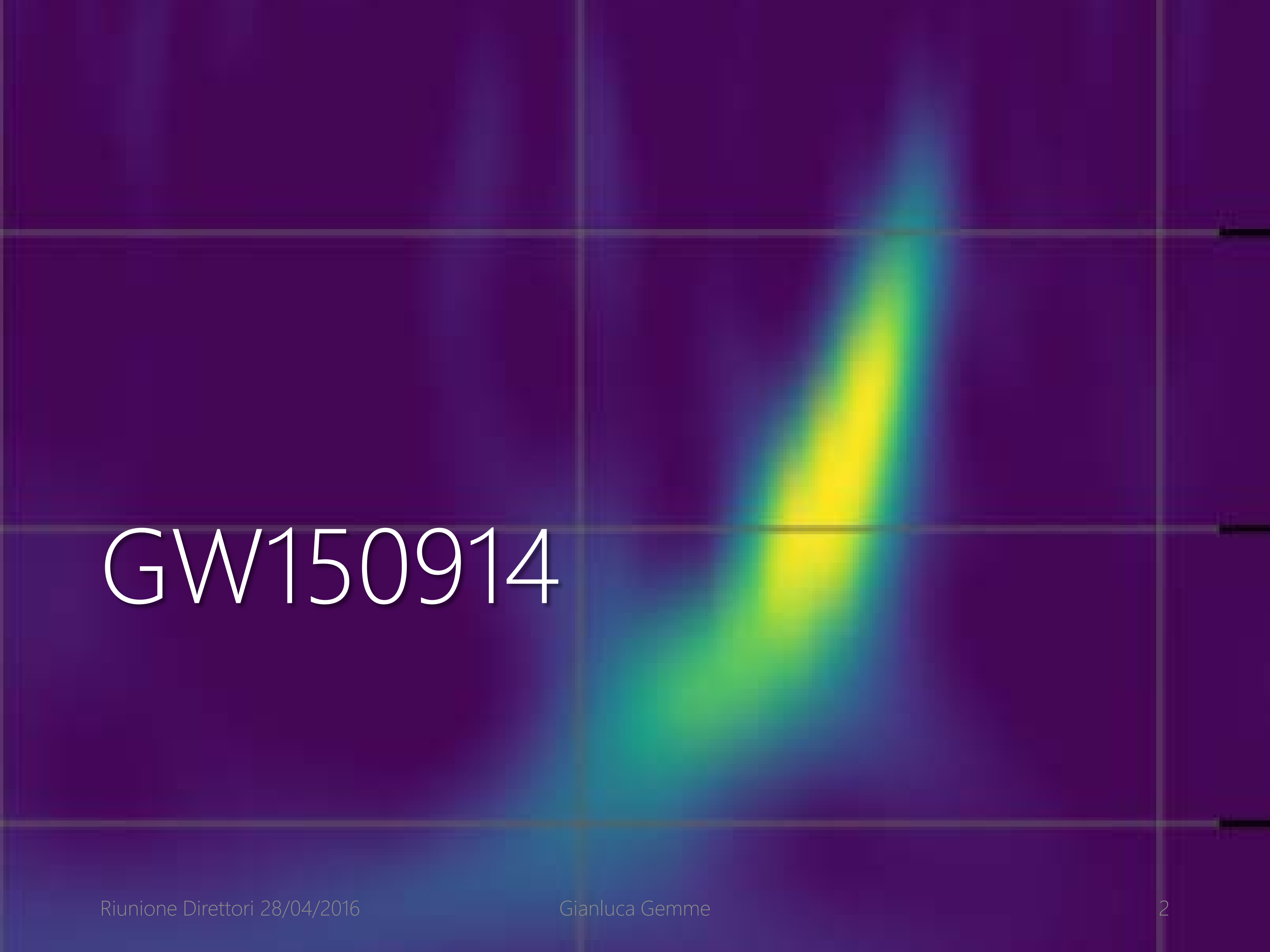
THE FUTURE OF VIRGO

BEYOND ADVANCED DETECTORS

Gianluca Gemme
INFN Genova

for the Virgo Collaboration

GW150914

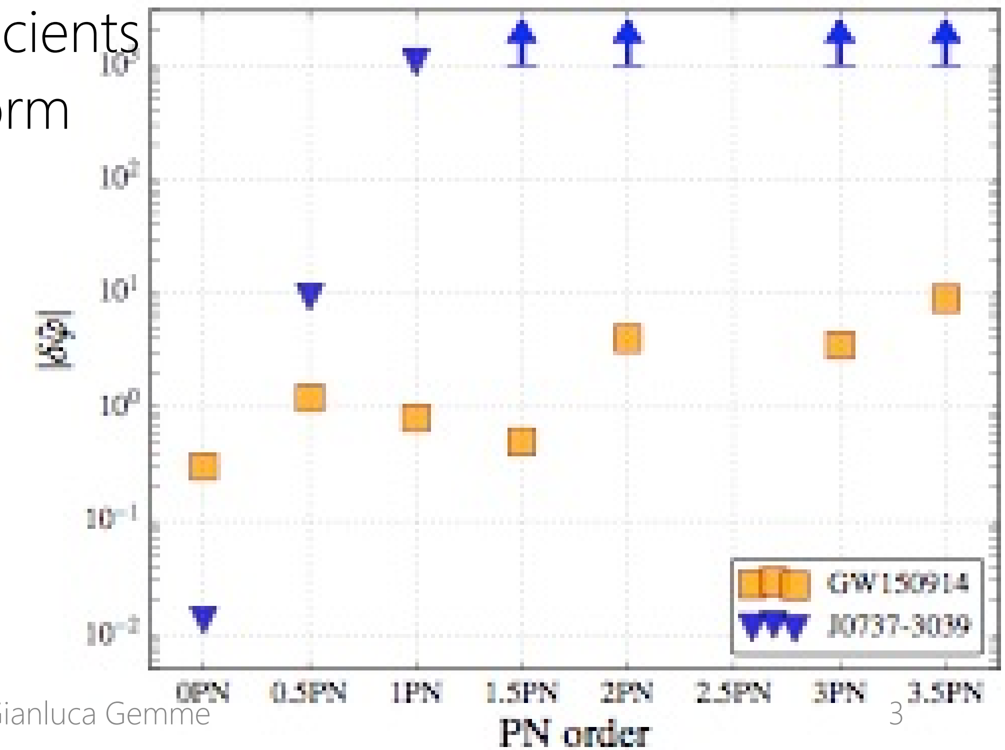


DEVIATION OF PN COEFFICIENTS FROM GR

- ✓Post Newtonian formalism
- ✓Phase of the inspiral waveform -> power series in $f^{1/3}$
- ✓Nominal value predicted by GR
- ✓Allow variation of the coefficients

  -> Is the resulting waveform consistent with data ?

- ✓No evidence for violations of GR



arXiv:1602.03841

UPPER BOUND ON THE GRAVITON MASS

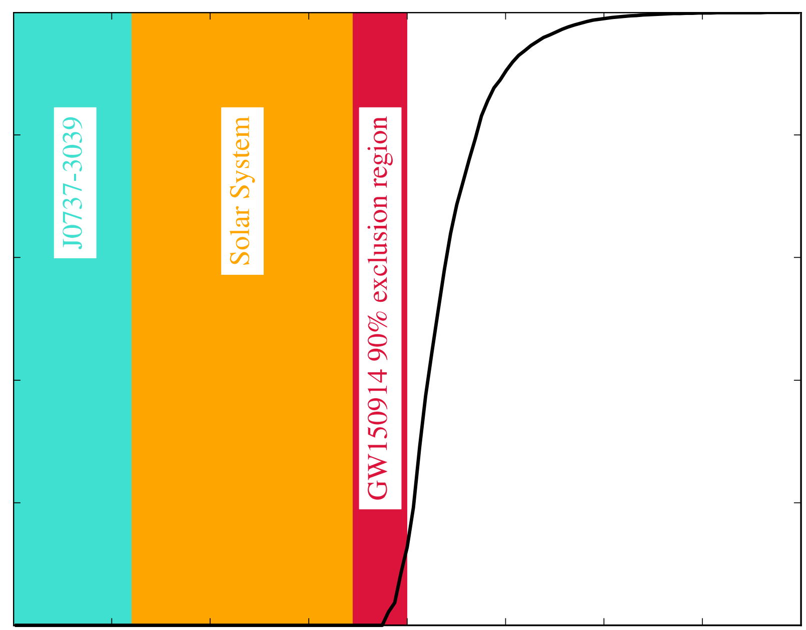
✓If $c_{GW} < c$

⇔ gravitational waves have a modified dispersion relation

✓Findings : at 90 % confidence, $\lambda_g > 10^{13}$ km

or equivalently

$$m_g < 1.2 \times 10^{-22} \text{ eV}/c^2$$



arXiv:1602.03841

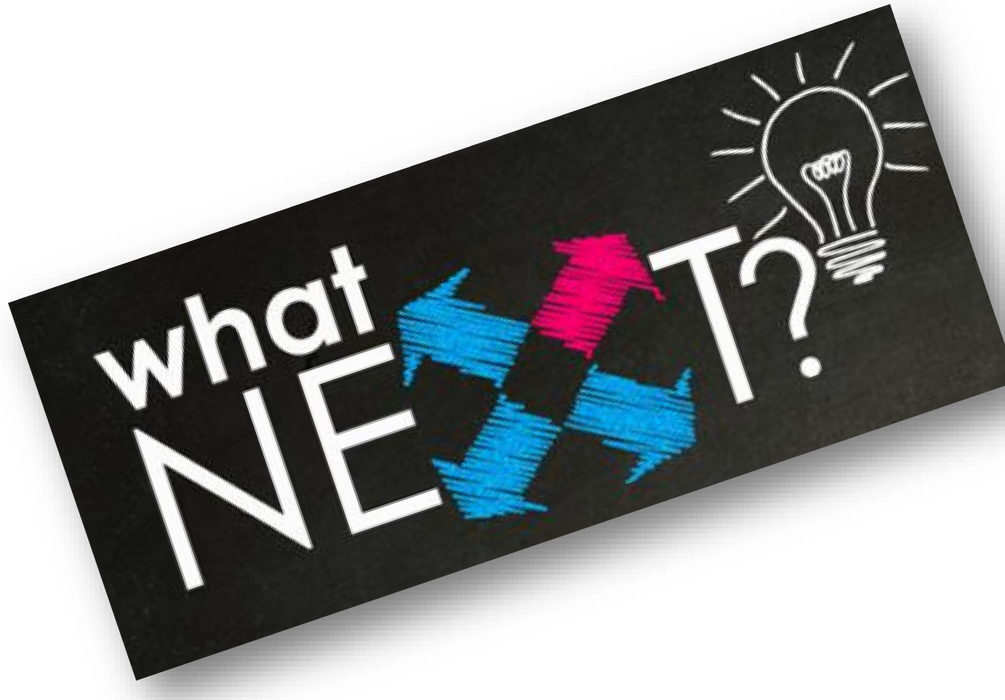
WHAT ADVANCED DETECTORS WILL ACHIEVE?

- ✓Detections!
  - BBH, BNS, possibly stellar collapse
- ✓Measure the rates
- ✓A step forward in sensitivity is needed for having precise characterization of the sources and for complementing EM observations
- ✓(Astro)physical modelling would require a large sample of events: different spins, mass ratios
- ✓NS structure characterization (if ellipticities not too low $\geq 10^{-8}$): might need to go beyond 2G

WHAT FUNDAMENTAL SCIENCE FOR 2G+/3G DETECTORS?

- ✓ Extremes of physics
  - structure and dynamics of neutron stars (EoS)
  - physics of extreme gravity
- ✓ Black holes through cosmic history
  - formation, evolution and growth of black holes and their properties
- ✓ Explosive phenomena
  - gamma ray bursts, gravitational collapse and supernovae, flaring and bursting neutron stars

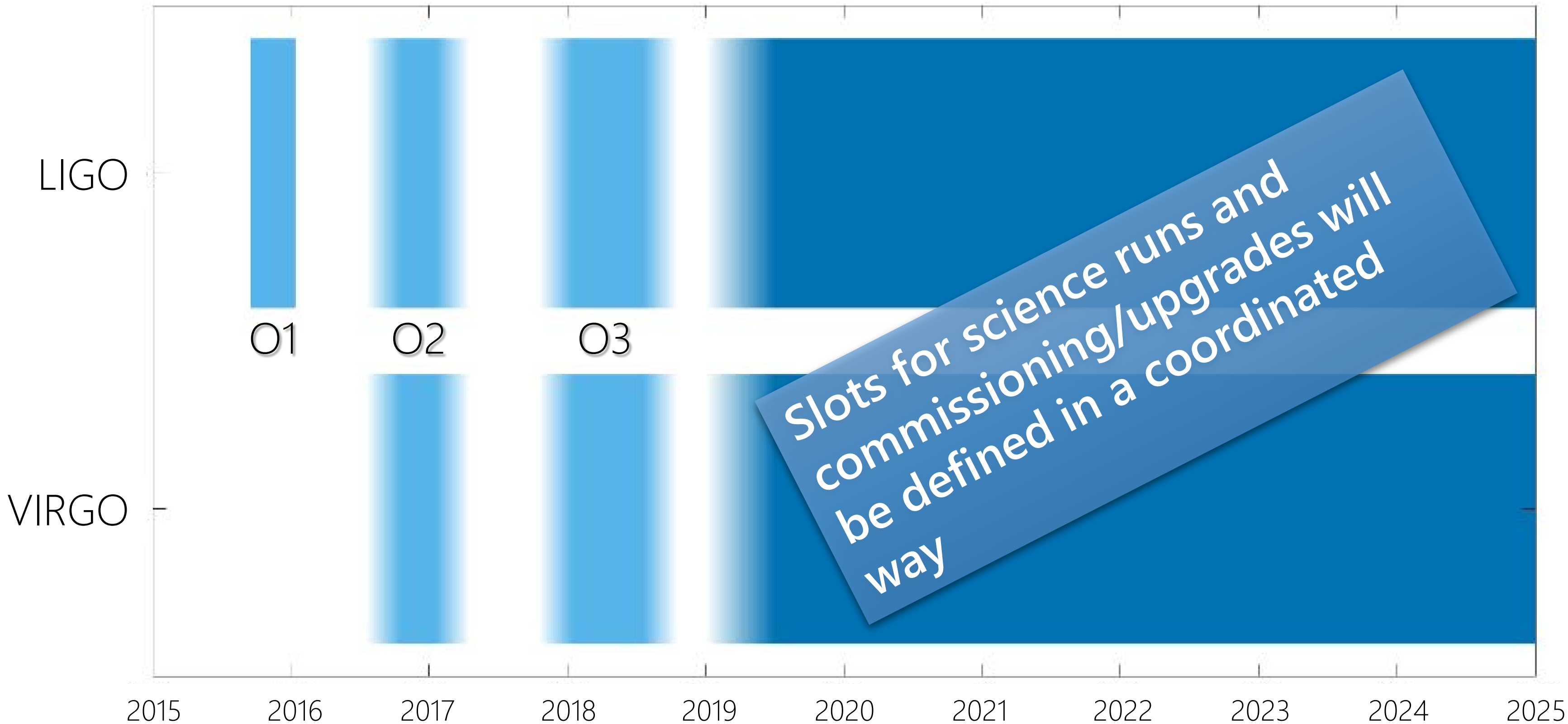
✓ **All these will require many events at high SNR**



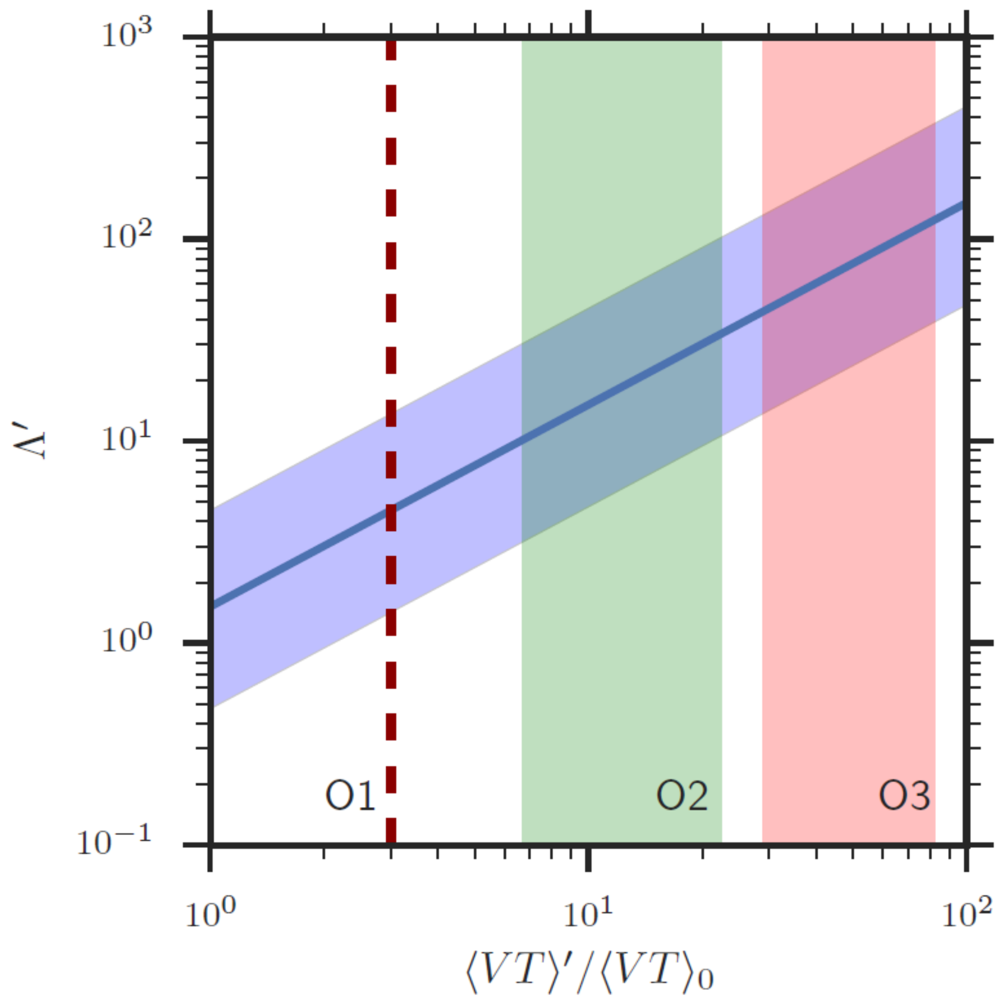
ADVANCED VIRGO

WHAT NEXT?

ADVANCED DETECTORS TIMELINE



HOW MANY BBH MERGER IN FUTURE DATA?



arXiv:1602.03842

EXPECTATIONS FOR FUTURE RUNS

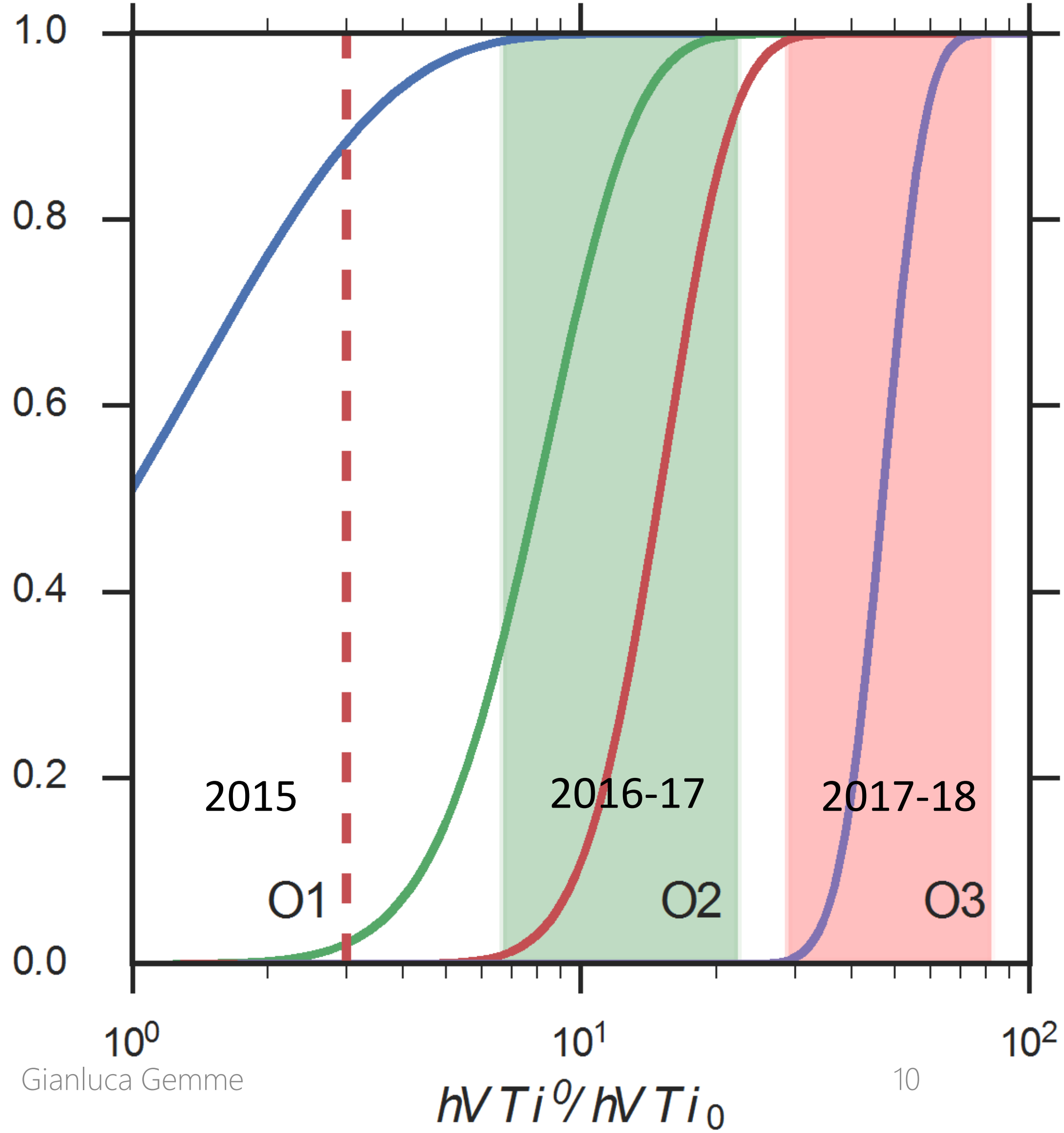
Probability of observing

- ✓N > 0 (blue)
- ✓N > 5 (green)
- ✓N > 10 (red)
- ✓N > 35 (purple)

highly significant events,

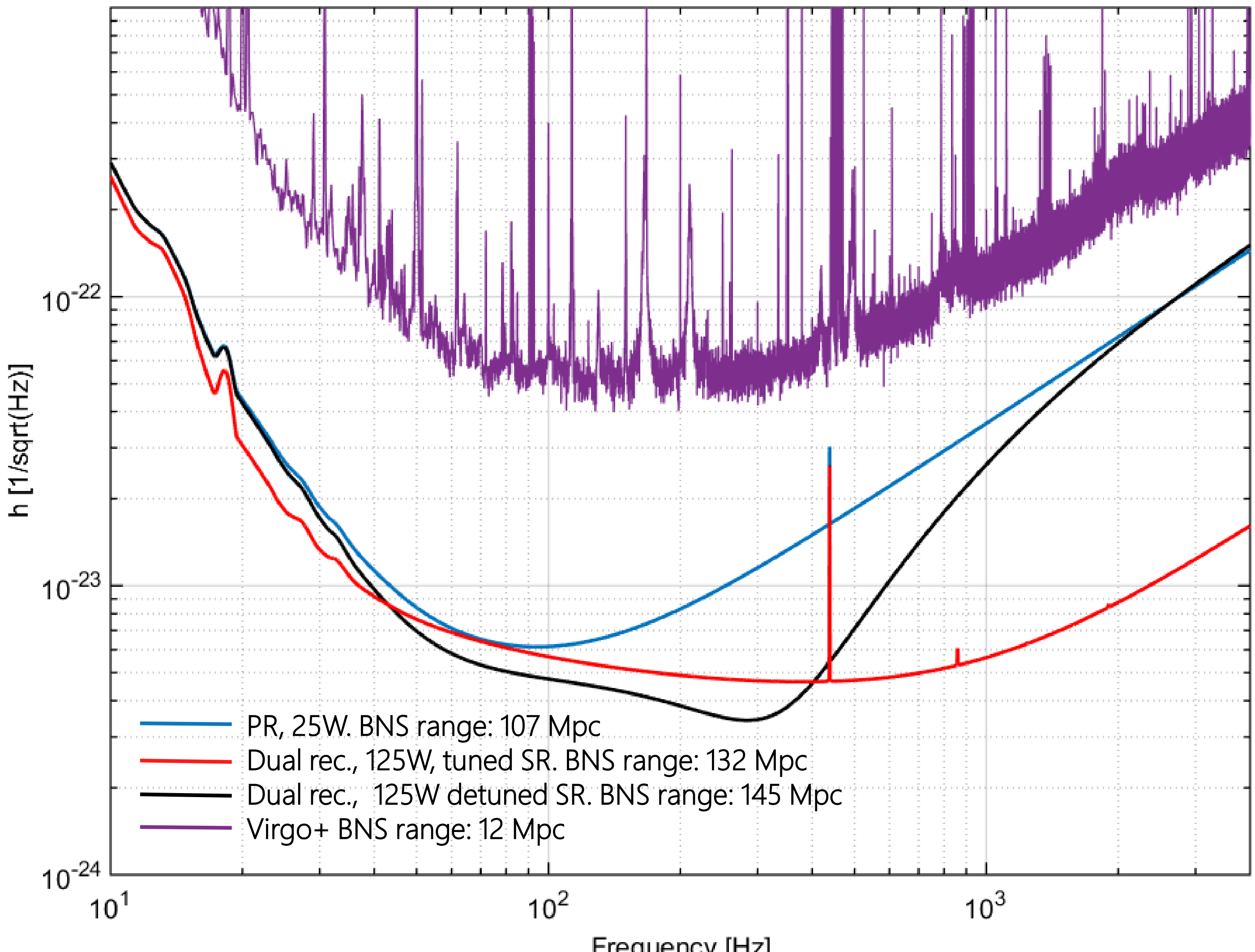
(FARs <1/century)

as a function of surveyed time-volume



arXiv:1602.03842

ADV SENSITIVITY EVOLUTION

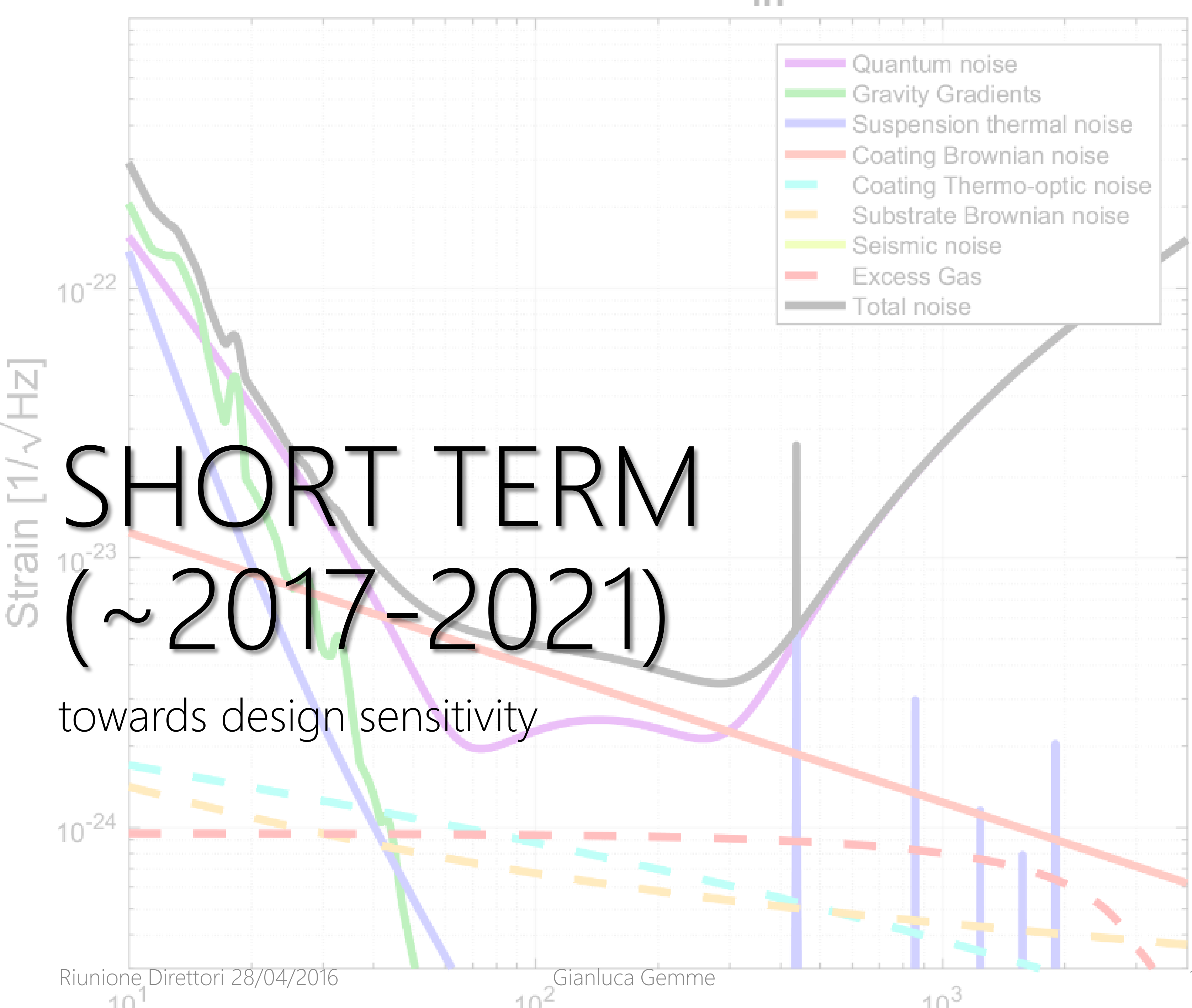


ADVANCED VIRGO: WHAT NEXT?

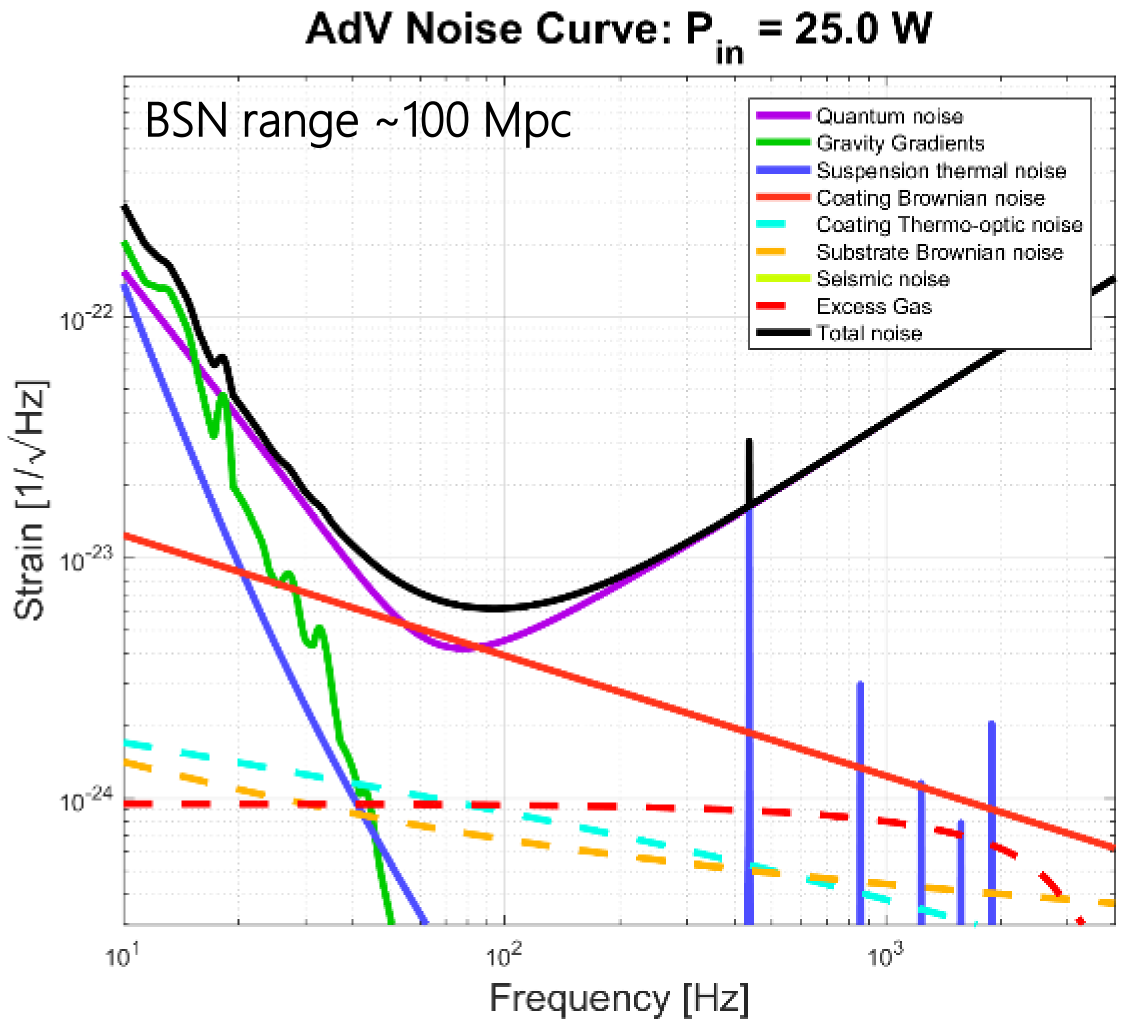
- ✓ In the upcoming (~10) years our target is to maximize the scientific outcome of the detector
  - Need do maximize data taking
  - Need to minimize downtime
- ✓ SHORT TERM (~2017-2021): **towards design sensitivity**
  - high power laser, signal recycling, frequency independent squeezing
  - R&D for gravity noise cancellation
- ✓ MEDIUM TERM (~2021-2025): **the best we can do in the current infrastructure**
  - frequency dependent squeezing, gravity noise cancellation
  - better coatings, larger beams, heavier masses
- ✓ LONG TERM (>2025) **a new infrastructure**
  - increased length (~10km), underground, cryogenics, laser wavelength, new materials, topology, xylophone, …

SHORT TERM (~2017-2021)

towards design sensitivity

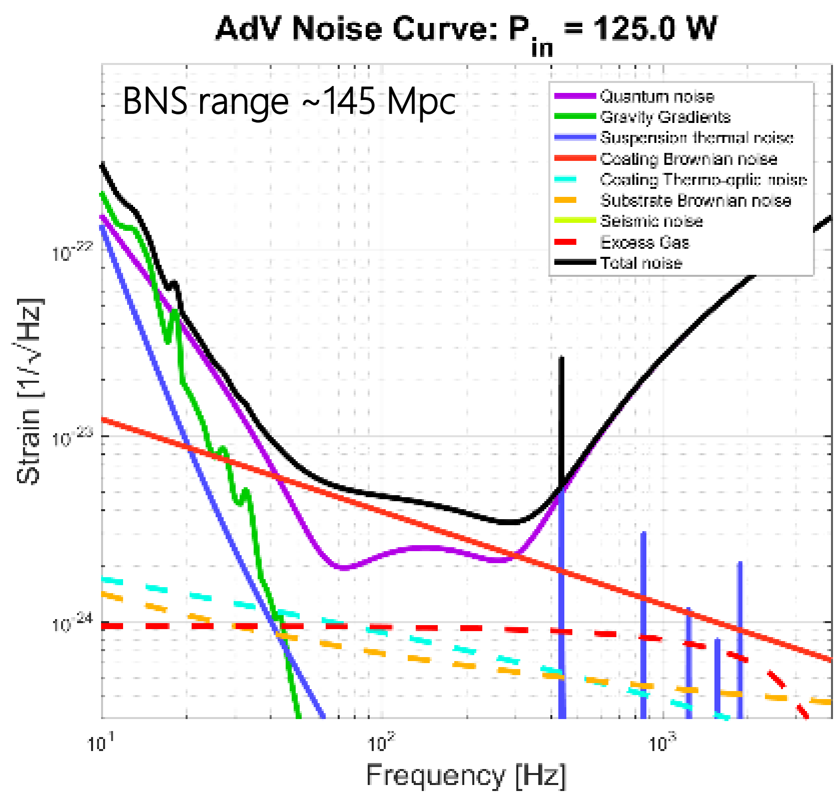


INITIAL ADV SENSITIVITY



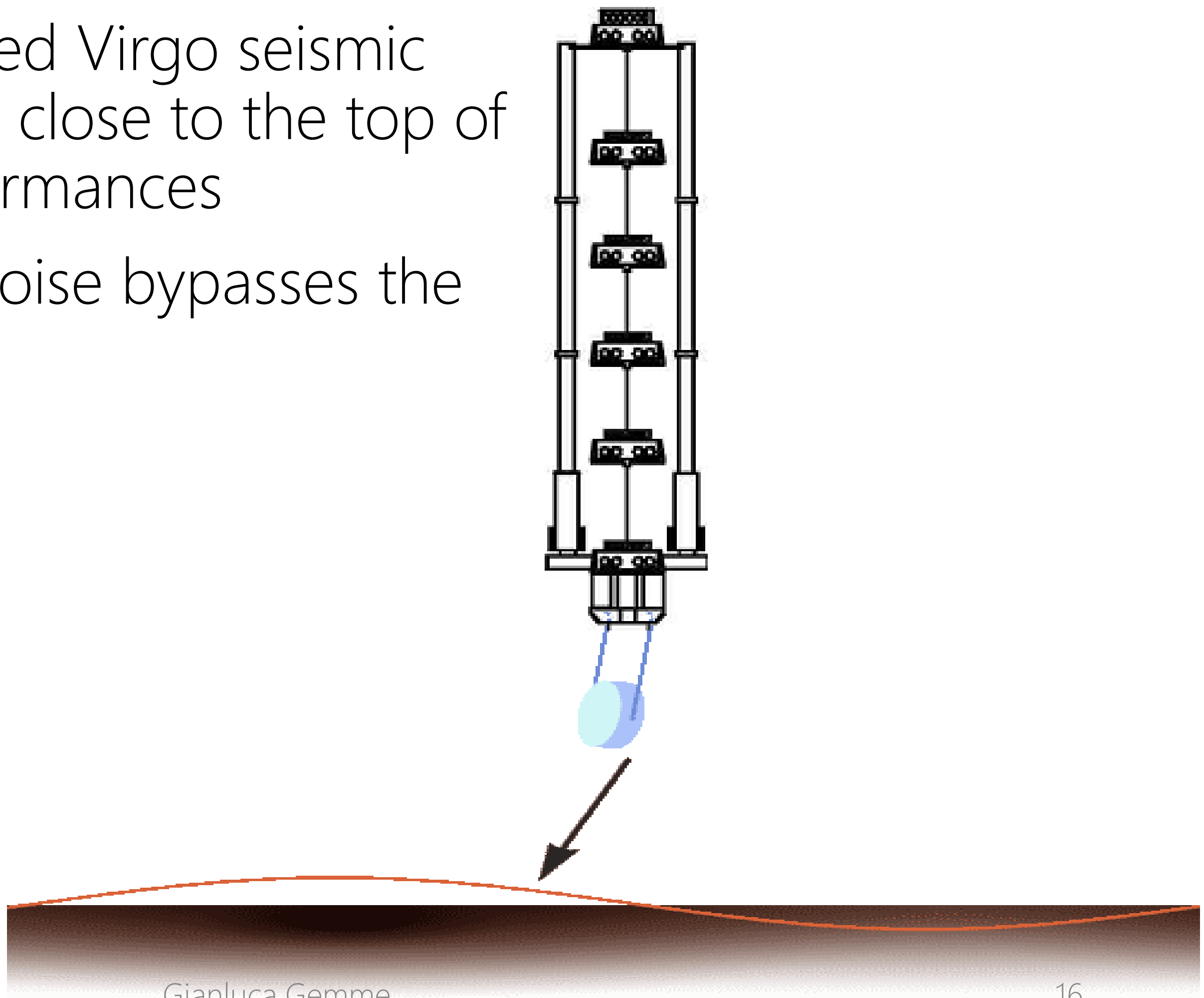
REACHING ADV DESIGN SENSITIVITY

- ✓ AdV baseline design
  - Signal recycling
  - High power laser
  - Tiltmeters (robustness at low freq)
- ✓ Frequency independent squeezing between O2–O3 (~2017-2018)
  - High frequency sensitivity improvement
  - Intermediate step towards frequency dependent squeezing
  - Risk mitigation
  - Total investment **~1M€**



NEWTONIAN NOISE

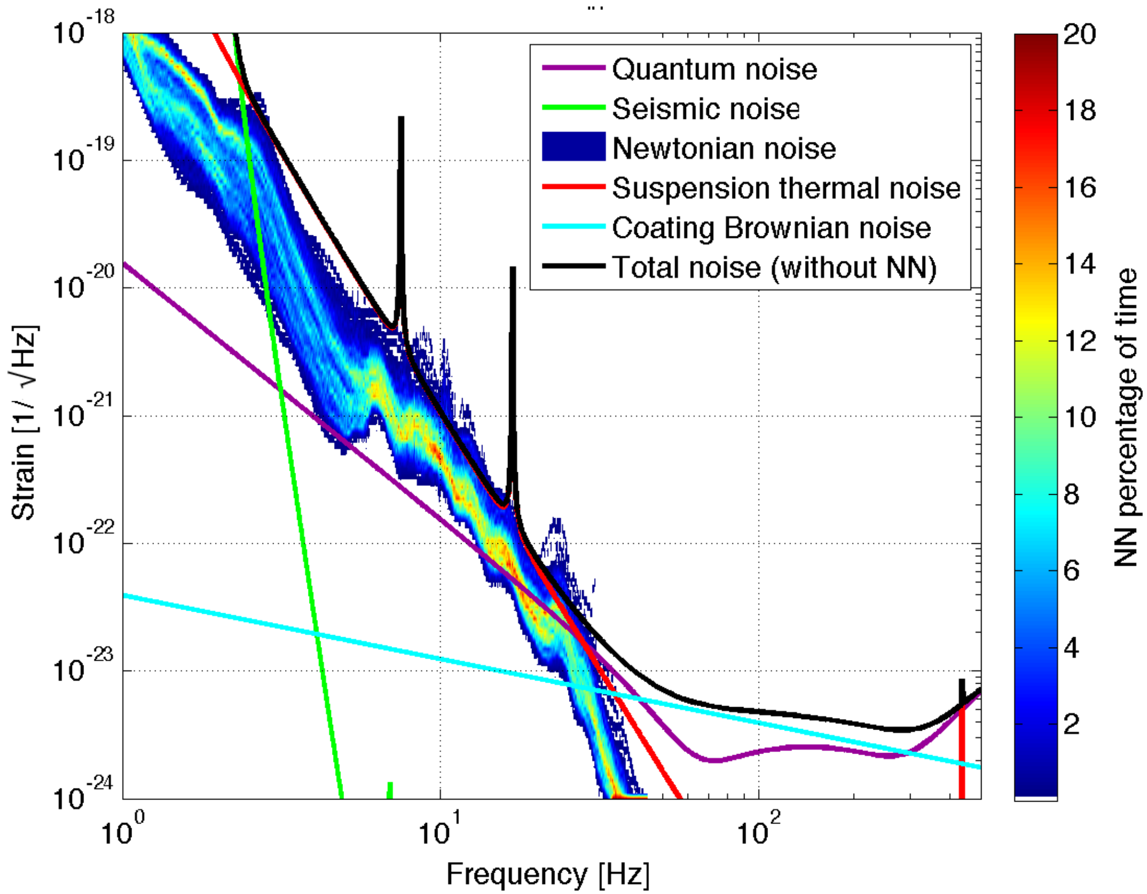
- ✓Virgo and advanced Virgo seismic filtering is already close to the top of the possible performances
- ✓Gravity gradient noise bypasses the seismic filtering



Credit M.Lorenzini

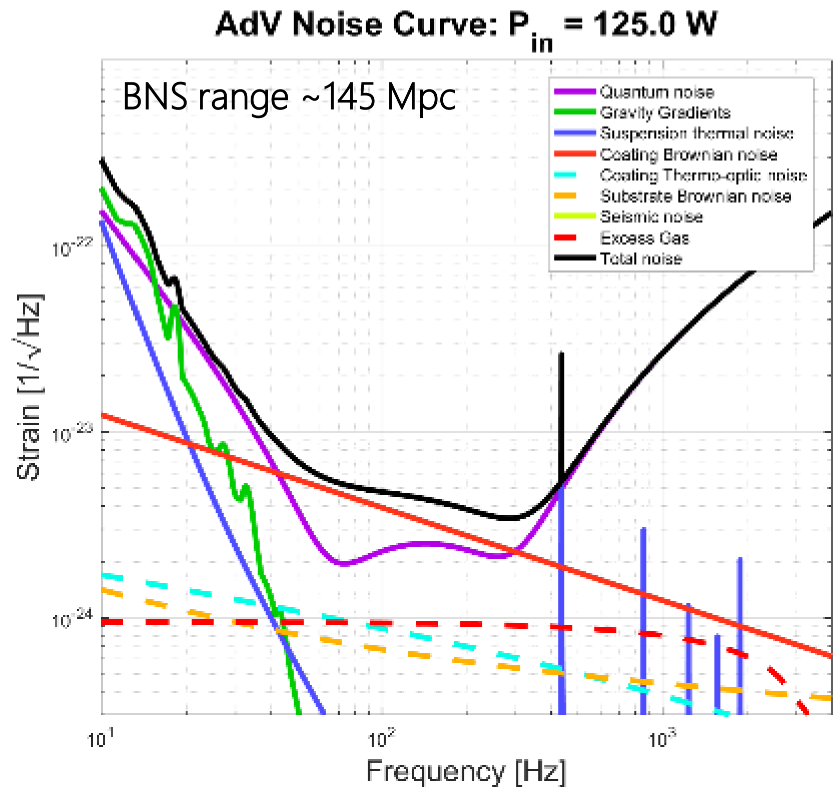
NEWTONIAN NOISE IN ADV

- NN noise could limit the AdV sensitivity during high seismic activity days



REACHING ADV DESIGN SENSITIVITY

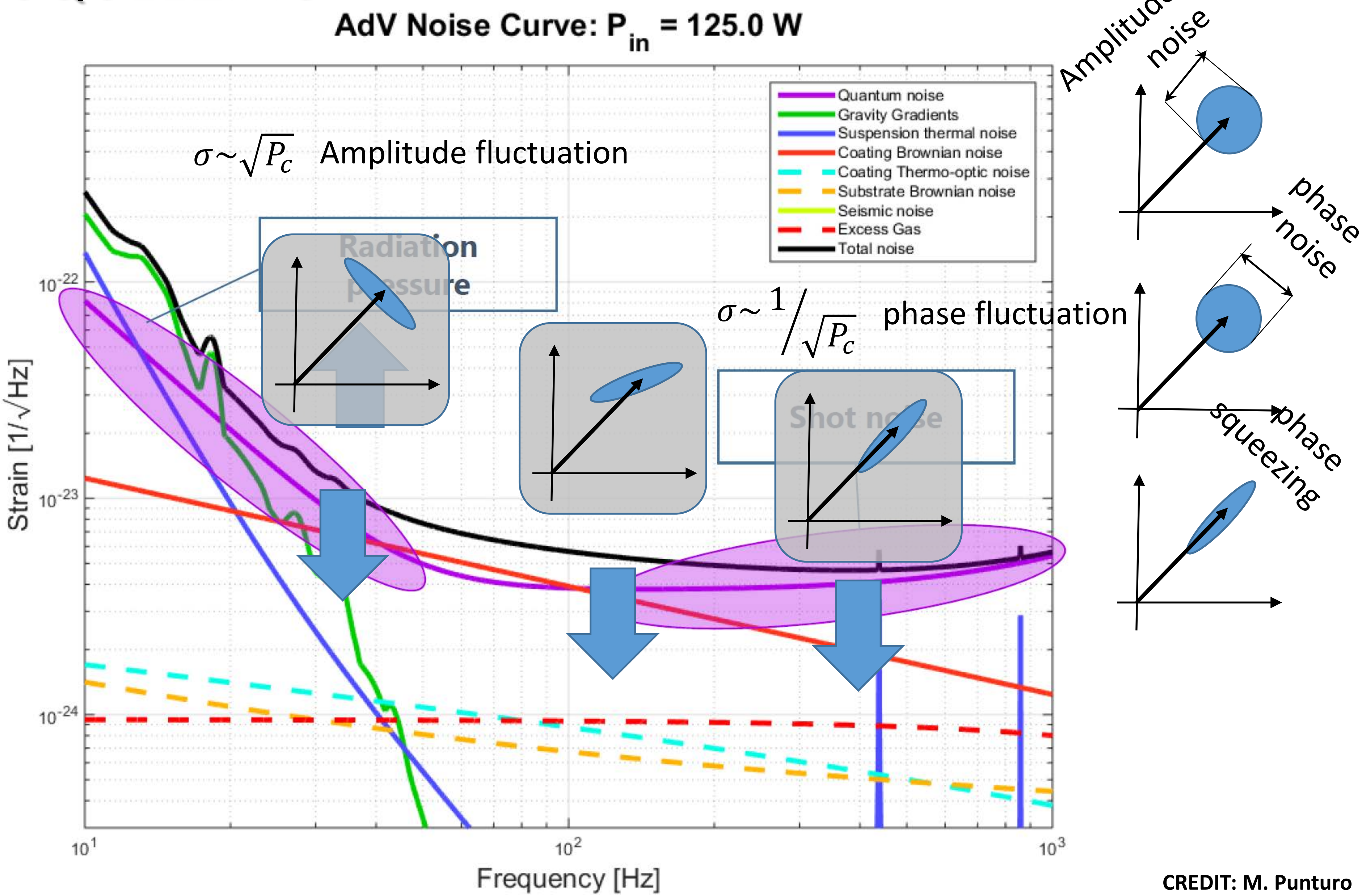
- ✓AdV baseline design
  - Signal recycling
  - High power laser
  - Tiltmeters (robustness at low freq)
- ✓Frequency independent squeezing between O2–O3 (~2017-2018)
  - High frequency sensitivity improvement
  - Intermediate step towards frequency dependent squeezing
  - Risk mitigation
  - Total investment ~1M€
- ✓R&D on NN
  - Site characterization
  - Coherent noise detection
  - Cost ~150k€



MEDIUM TERM (~2021-2025)

beyond design sensitivity…
…the best we can do in the current infrastructure

FREQUENCY DEPENDENT SQUEEZING



CREDIT: M. Punturo

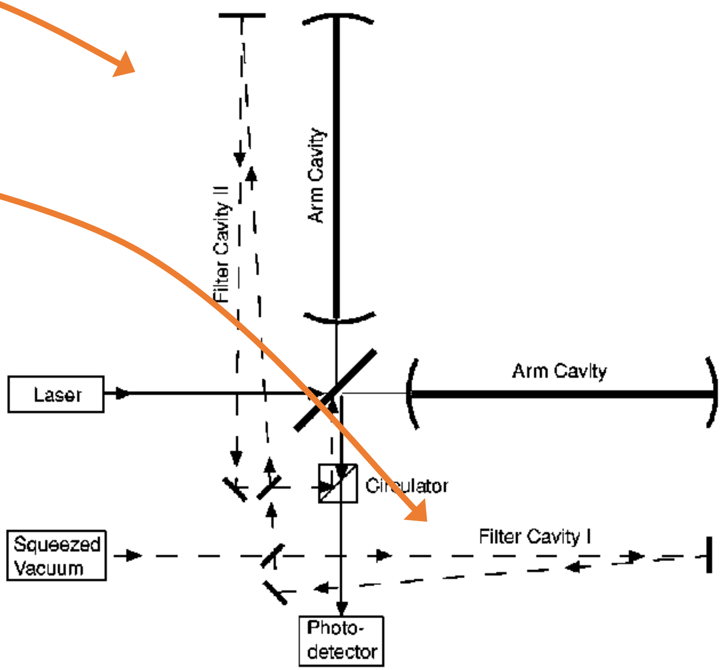
REALIZING A FREQUENCY-DEPENDENT SQUEEZE ANGLE

filter cavities

✓ Filter cavities

✓ Difficulties

– Low losses
– Highly detuned
– Multiple cavities



- Conventional interferometers →
  - Kimble, Levin, Matsko, Thorne, and Vyatchanin, Phys. Rev. D **65**, 022002 (2001).
- Signal tuned interferometers →
  - Harms, Chen, Chelkowski, Franzen, Vahlbruch, Danzmann, and Schnabel, gr-qc/0303066 (2003).

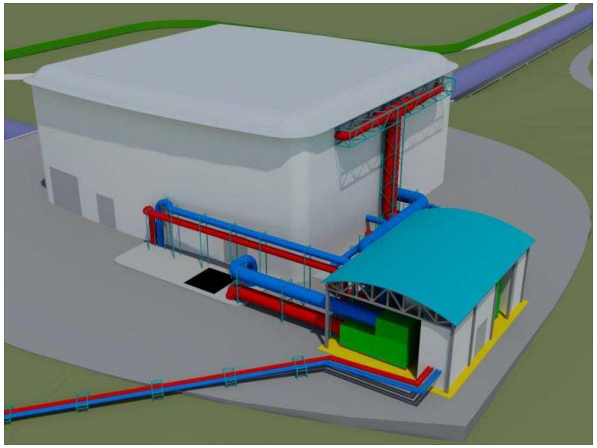
CREDIT: N. Mavalvala

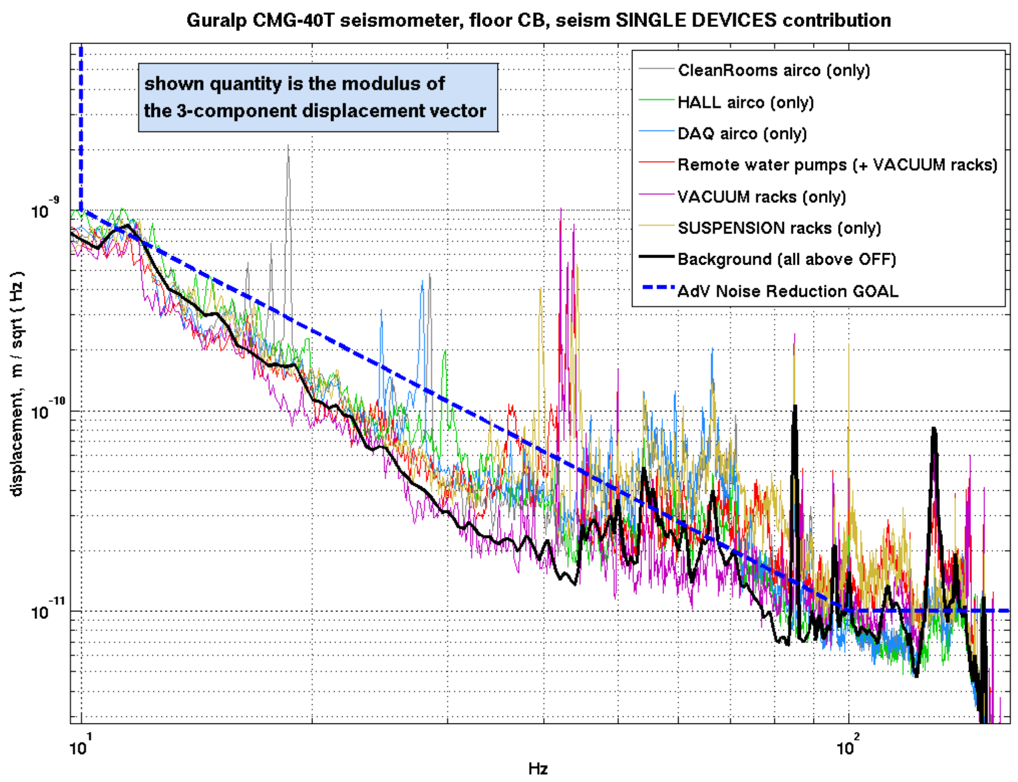
ADV+

- ✓ Quantum noise
  - Frequency dependent squeezing (possibly after O3 ~2018-2019)
  - Total investment **~2.5M€**
- ✓ Newtonian noise
  - NN cancellation **~350k€**
- ✓ Thermal noise
  - Installation of 'better' mirrors (lower loss, lower scatter; lower coating thermal noise)
  - Increasing mirror mass (x2)
  - Larger beams
  - R&D **~1M€**
- ✓ Goal: 50% improvement in BNS horizon
- ✓ ...clearly can keep us busy till 2025

IMPROVING THE ROBUSTNESS
ANTHROPOGENIC NOISE REDUCTION

- ✓ Moving machinery out of the experimental buildings (mainly HVAC equipment, pumps,…)
- ✓ Improvement of air distribution duct paths
- ✓ Already proposed in AdV – excluded for financial reasons
- ✓ Cost estimate: **~500k€**

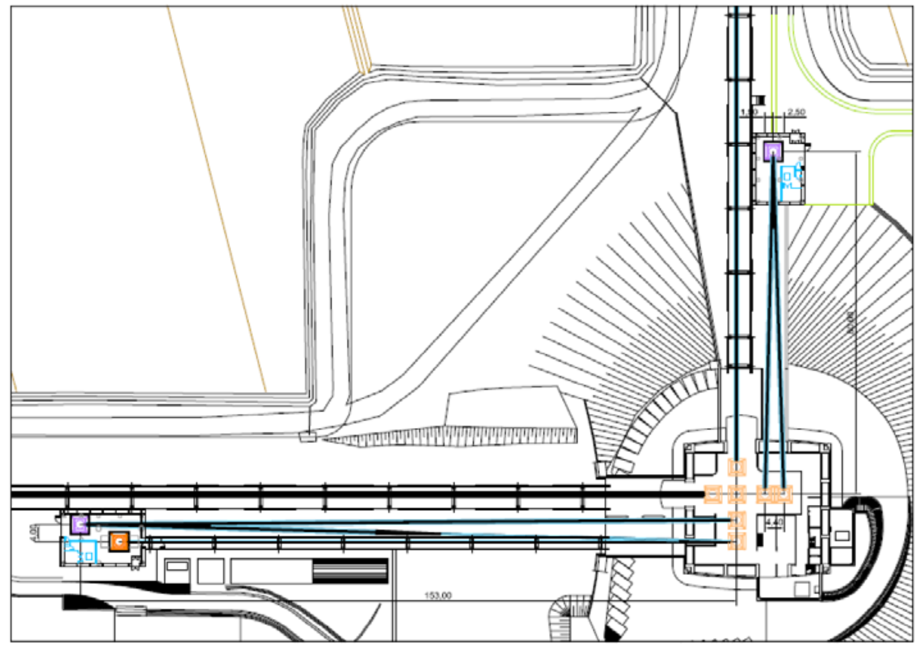




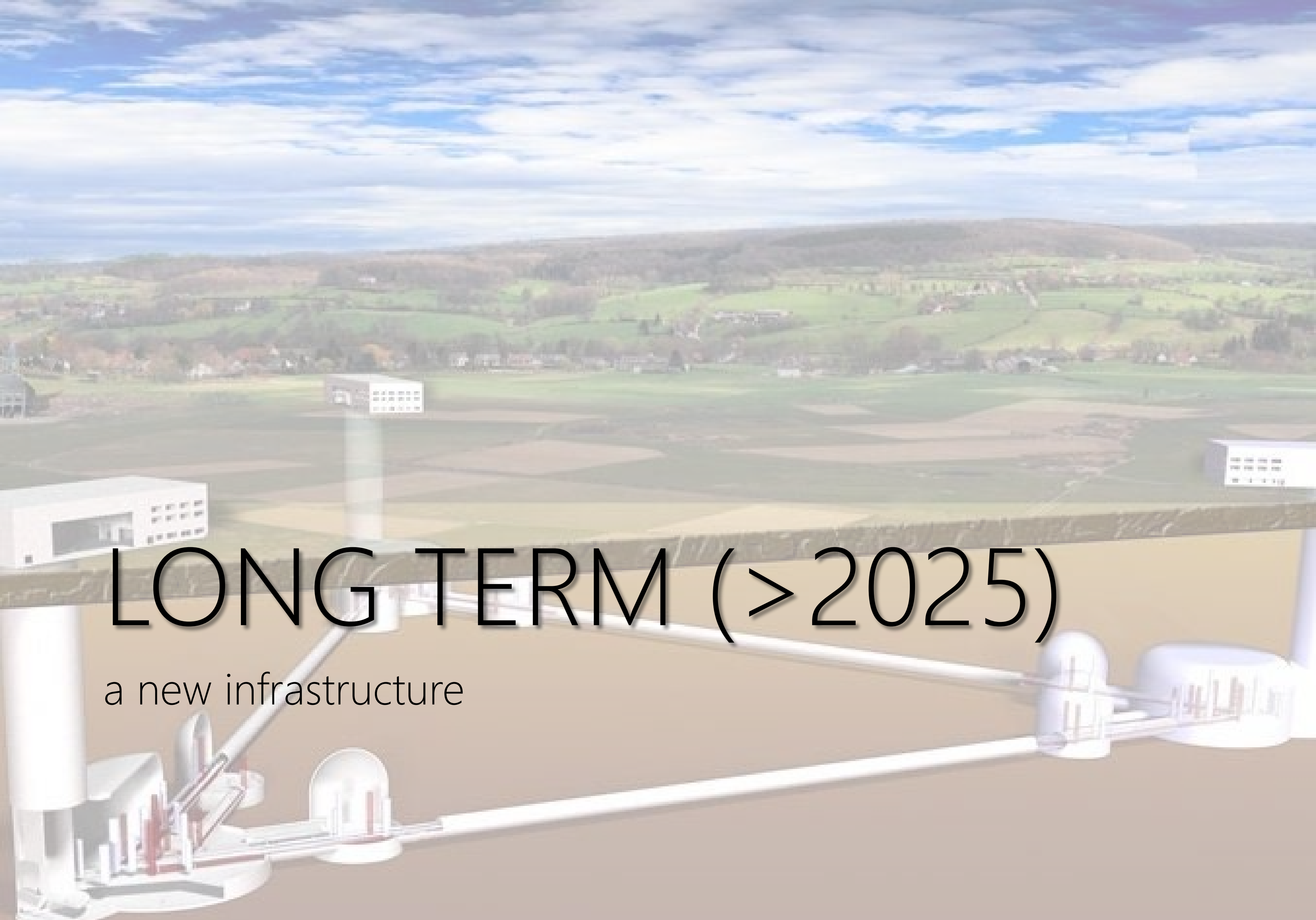
IMPROVING THE ROBUSTNESS

COPING WITH THERMALLY INDUCED ABERRATIONS

- ✓ AdV uses marginally stable recycling cavities
- ✓ Potential problem @high laser power and if larger beams are used (thermally induced aberrations)
- ✓ Upgrade of the thermal compensation system
- ✓ Long stable cavities proposed in AdV in 2010 and excluded for financial reasons
- ✓ Not negligible impact on science



- ✓ Long cavities: cost/time estimate (infrastructures, buildings, system) for 180m PR – 80m SR **~8M€/two years**
- ✓ For TCS upgrade **~500k€/three years**



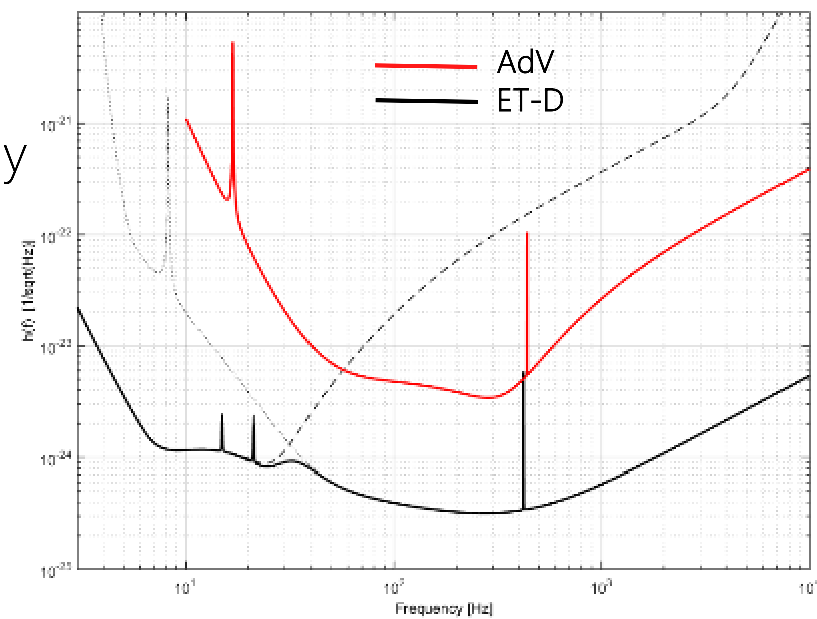
LONG TERM (>2025)

a new infrastructure

EINSTEIN TELESCOPE

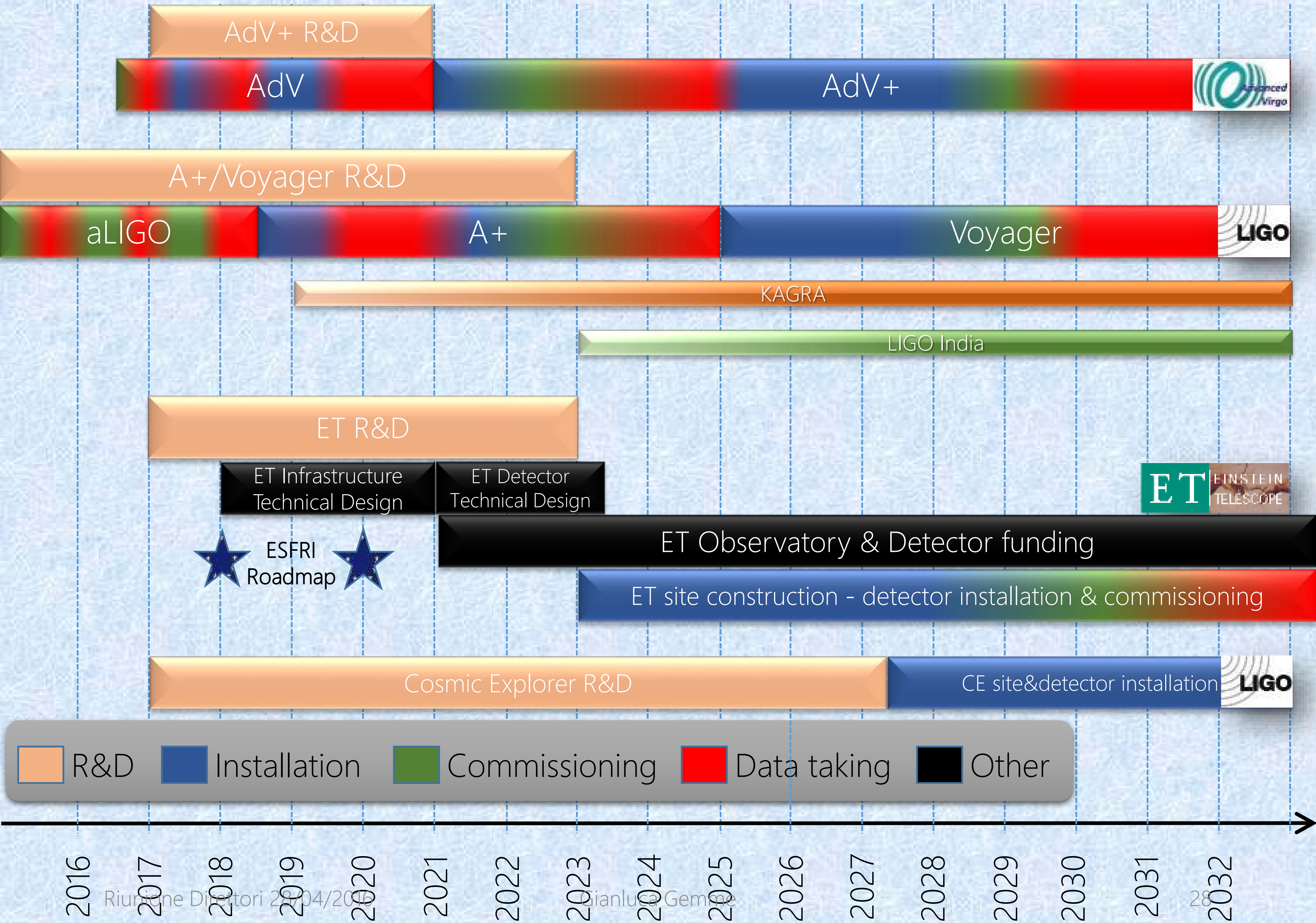
✓Design study of ET funded by the European Commission under FP7

- interest primarily focused on the Infrastructure rather than on the detector and its technologies
- The infrastructure should no limit the sensitivity of the future hosted detectors
  - Size
  - Environmental noises (seismic and NN)
- ET absorbed and developed many concepts in GW detectors:
  - Underground and cryo-compatible facility, pioneered in Japan by CLIO and KAGRA
  - Triangular geometry, concept used in LISA
  - Xylophone configuration



TIMELINE FOR THIRD GENERATION

- ✓ Need to have a compelling argument – our data, and physics/astronomy customers, grow with time to motivate a ~bn € expense
- ✓ Actions to be put in place:
  - Need to maintain the competences, renew and expand the INFN leadership
  - Need to attract partners at the National and European level (credibility, excellence)
  - ERIC@EGO is a fundamental tool
- ✓ Timing:
  - Infrastructure: technical design must start now (ESFRI roadmap)
  - Site selection 2021-2022; construction starts 2023
  - Detector: timing may be limited by R&D bearing fruit, full-scale prototype tests,… guess ~6 years from now
  - Detector: end-2022 review of concept - go-ahead mid-2023
  - Commissioning of new Observatory: end of next decade
- ✓ Adequate funding for R&D is needed soon (motivated by the science to date). Ballpark figure ~200M€, globally
  - Some actions already in place: IGRAINE, PIRE


AdV+ R&D
AdV
AdV+
A+/Voyager R&D
aLIGO
A+
Voyager
LIGO
KAGRA
LIGO India
ET R&D
ET Infrastructure Technical Design
ET Detector Technical Design
ESFRI Roadmap
ET EINSTEIN TELESCOPE
ET Observatory & Detector funding
ET site construction - detector installation & commissioning
Cosmic Explorer R&D
CE site&detector installation
LIGO
R&D
Installation
Commissioning
Data taking
Other
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032

CONCLUSIONS

- ✓ Three-phase scenario
  - **Short term (~2017-2019)** – well defined technologies. In some cases (squeezing) need to finalize design soon for the integration in the existing infrastructure
  - **Medium term (~2025)** – R&D effort already started, needs to be finalized. Further detections will tell us where to concentrate our efforts
  - Total investment ~5M€ (R&D for AdV+ partially preparatory for 3G)
  - **Long term (>2025)** - some infrastructure requirements already established. Needs a focused, coordinated effort (worldwide) to finalize some key concepts:
    - Topology
    - Underground/on surface
    - 3G Network/mixed 3G-2G
    - Working temperature/Materials
    - New technologies
  - Coordinated R&D funding must start now: IGRAINE (Europe), PIRE (USA)
    - Need to attract partners at the National and European level (ERIC)
  - Total investment ≥ 1B€ (~200M€ in R&D)
- ✓ **Vision document almost finalized with details on technical requirements, implementation timeline and cost**