Virgo_nEXT
R&D

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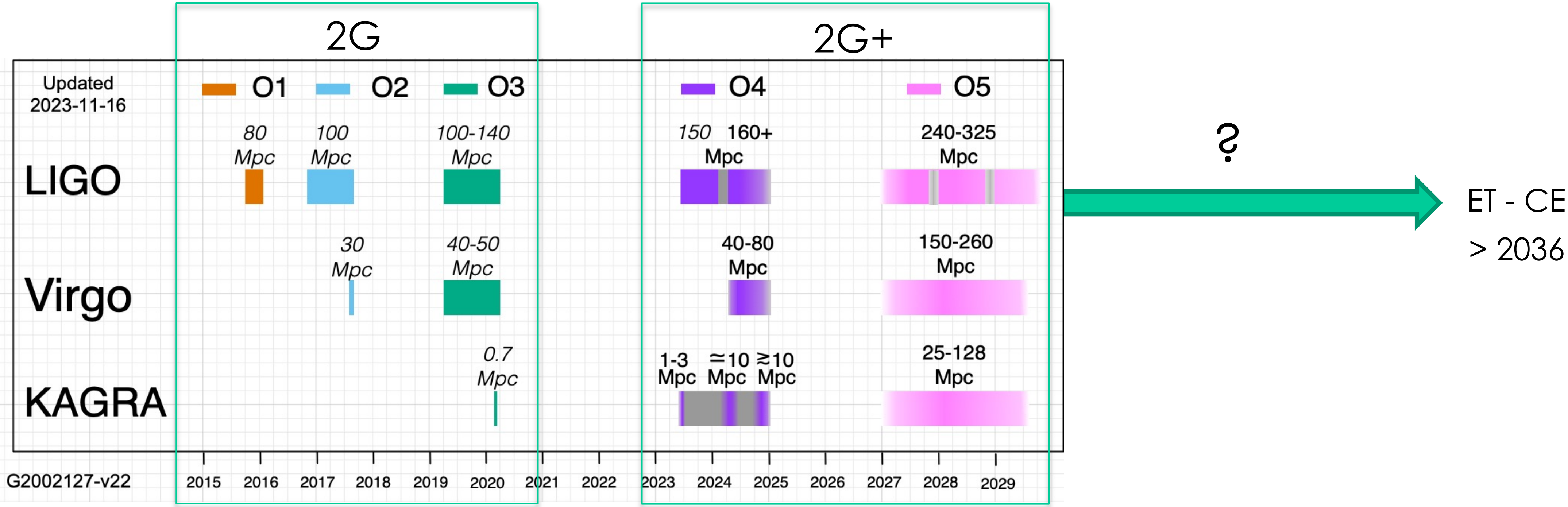
(based on recent presentations by the Virgo_nEXT coordinator Viviana Fafone at the STAC in november 2024 and at Virgo week in february 2024)

Introduction to Virgo_nEXT



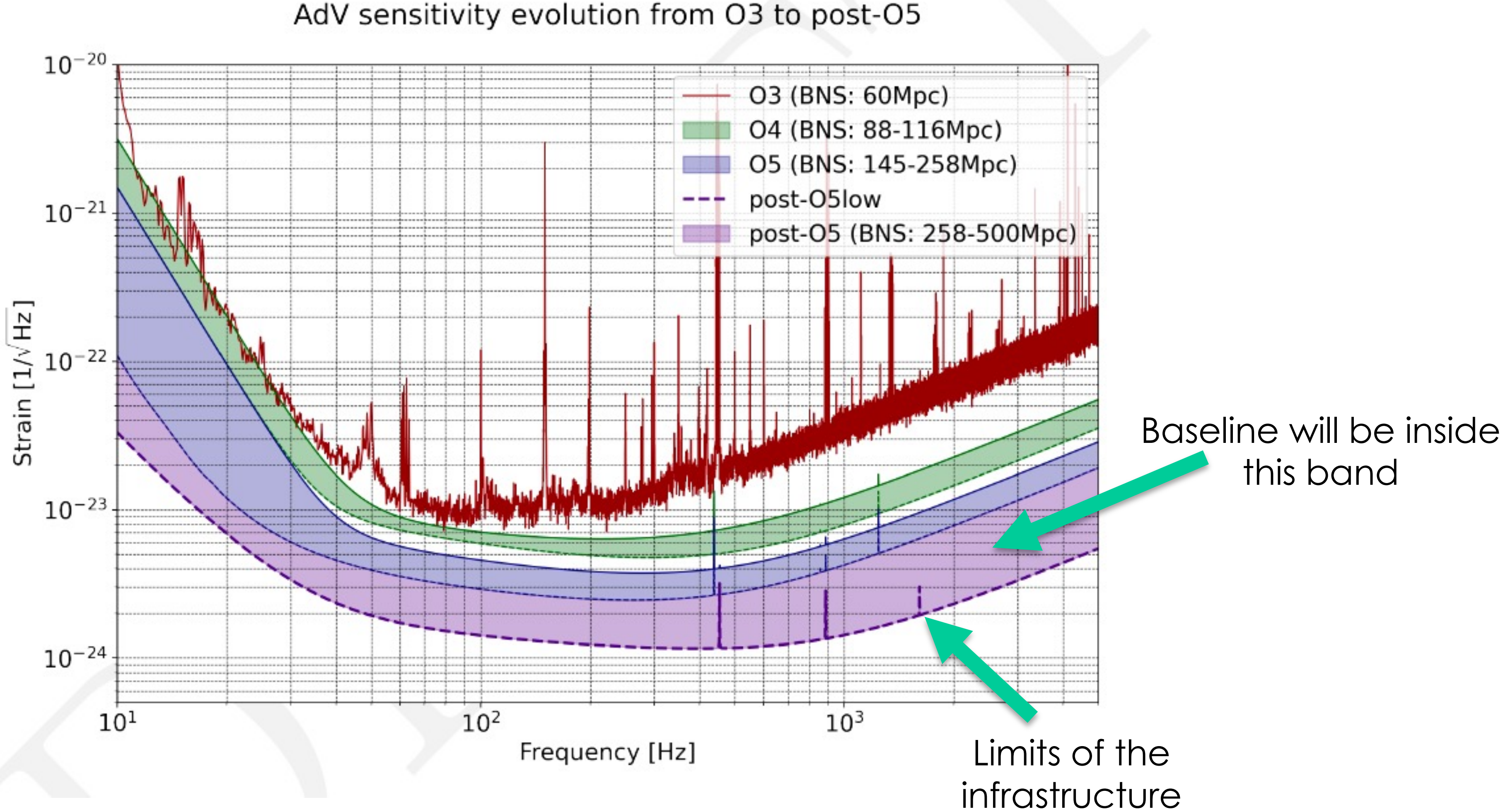
Advanced Virgo
and Advanced LIGO

Advanced Virgo+
and Advanced LIGO +

Introduction to Virgo_nEXT

- Define a plan for the “dark ages” between Virgo and ET
- Maintain Virgo competitiveness, secure Virgo role in the global GW detector network
- Maximize investment/scientific output achievable in the EGO/Virgo infrastructure
- Pave the way to the 3rd generation (test technologies and risk reduction)
- Maintain community of high-level experimentalists for 3rd generation. Train a new generation of experts, those who will run ET

Virgo_nEXT


AdV sensitivity evolution from O3 to post-O5
O3 (BNS: 60Mpc)
O4 (BNS: 88-116Mpc)
O5 (BNS: 145-258Mpc)
post-O5low
post-O5 (BNS: 258-500Mpc)
Strain [1/√Hz]
Frequency [Hz]
Baseline will be inside this band
Limits of the infrastructure

What is Virgo_nEXT

Parameter	O4 high	O4 low	O5 high	O5 low	post-O5low
Power injected	25 W	40 W	60 W	80 W	277 W
Arm power	120 kW	190 kW	290 kW	390 kW	1.5 MW
PR gain	34	34	35	35	39
Finesse	446	446	446	446	446
Signal recycling	Yes	Yes	Yes	Yes	Yes
Squeezing type	FIS	FDS	FDS	FDS	FDS
Squeezing detected level	3 dB	4.5 dB	4.5 dB	6 dB	10.5
Payload type	AdV	AdV	AdV	AdV	Triple pendulum
ITM mass	42 kg	42kg	42 kg	42 kg	105 kg
ETM mass	42 kg	42kg	105 kg	105 kg	105 kg
ITM beam radius	49 mm	49 mm	49 mm	49 mm	49 mm
ETM beam radius	58 mm	58 mm	91 mm	91 mm	91 mm
Coating losses ETM	2.37e-4	2.37e-4	2.37e-4	0.79e-4	6.2e-6
Coating losses ITM	1.63e-4	1.63e-4	1.63e-4	0.54e-4	6.2e-6
Newtonian noise reduction	None	1/3	1/3	1/5	1/5
Technical noise	“Late high”	“Late low”	“Late low”	None	None
BNS range	90 Mpc	115 Mpc	145 Mpc	260 Mpc	500 Mpc

Where we are

- Concept Study integrated by two documents on the relevance of stable recycling cavities for VnEXT operability (VIR-0047A-23) and on the coating plans (VIR-0132A-23) ✓
- Preliminary VnEXT R&D plan (VIR-0678B-23) ✓
  - Initial discussion at July '23 EGO Council
- Next step: Baseline Design Report (target: December '24 EGO Council) – TBC

The Preliminary VnEXT R&D plan

- The document includes a technical description, a preliminary timeline and budget evaluation for those R&D activities requiring equipment procurement.
- The proposed R&Ds refer to activities characterized by a level of maturity with a potential impact at the VnEXT time horizon, and compatible with each other, within an integrated detector design.
- Their relevance for the development of VnEXT emerges from clear limitations of the present instruments.
- Many technologies on which VnEXT is based will be relevant for ET
- In order to finalize the developments for VnEXT implementation, specific funds or strategic investments are needed.

Preliminary VnEXT R&D plan

Contents

Ongoing activities

- The internal review of the Preliminary VnEXT R&D plan has started
- The review team has been (almost) set up following the VSC mandate:
  - No member of the collaboration with roles of responsibility in the project organization (e.g. system or sub-system manager) or strongly involved in commissioning will be involved in the review
- Reviewers have been asked to report on:
  - Clarity of the stated objectives
  - Overall coherence and completeness of the proposed R&D
  - Consistency and motivation of the financial requests and of the proposed timeline
  - Potential overlaps with topics already included in other projects (AdV+ or ET)
  - The added value of the VnEXT R&D outcomes

Ongoing activities

- Reviewer team:
  - FDS: C. Amra + 1 being defined
  - HPL: E. Tournefier, F. Bondu
  - TCS: M. Tacca, S. Melo
  - IOO: F. Cleva, A. Van de Walle
  - PIM: A. Perreca, G. Ciani
  - COAT, MIR: M. Punturo, J. Steinlechner, L. Conti
  - PAY: L. Trozzo, F. Frasconi
  - SAS: E. Tapia, E. Calloni
  - SLC: A. Allocca, P. Picard
  - DEC: B. Swinkels, A. Gennai

Next steps

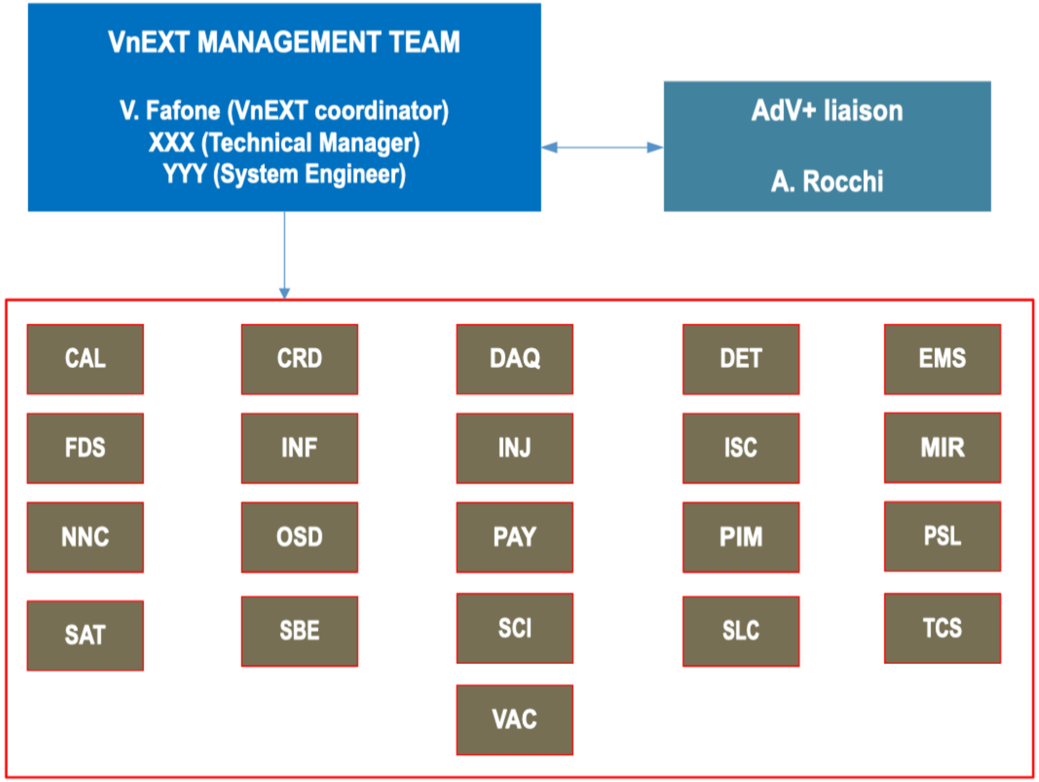
- Viviana's proposal to organize the work
  - Define the structure of the BD: it will be organized in chapters each corresponding to a work package
  - Define WP coordinators
  - Define the structure of the Management Team: a few crucial roles are needed:
    - Technical manager: definition of the deliverables and the wbs for the preparatory phase and BD
    - System engineer: management of the review process (preparatory phase and BD chapters) – infrastructure and organization of the reviews
  - Given the strong coordination needed with the AdV+ upgrades, an AdV+ liason will be beneficial

Next steps

- Viviana's proposal to organize the work

  - Final delivery: one document presenting an integrated plan (preparatory phase and construction)
  - The definition of the preparatory phase will be directly connected with the work already done/ongoing on the proposed R&D

Preliminary OBS(*)



(*) Organization Breakdown Structure

Preliminary WP structure

- Preliminary WP structure (in alphabetic order for the time being):
  - CAL: calibration
  - CRD: coating
  - DAQ: data acquisition
  - DET: detection
  - EMS: env. mon. & sens.
  - FDS: freq. dep. sqz.
  - INF: infrastructure
  - INJ: injection
  - ISC: ITF sens & control
  - MIR: mirrors
  - NNC: Newtonian noise canc.
  - OSD: Optical system design
  - PAY: payload
  - PIM: param. instab. mitig
  - PSL: power stabilized laser
  - SAT: superattenuator
  - SBE: suspended benches
  - SCI: science case
  - SLC: stray light control
  - TCS: Thermal compensation system
  - VAC: vacuum

Conclusions

- Virgo_nEXT plans affected by the actual work on stable cavities
- Global plan has been asked by the Council and STAC – it also will affect the Virgo_nEXT plans
- However, R&D is still needed for Virgo_nEXT
- In France we should have your own vision and coordinate ourself with Virgo_nEXT organization

Frequency-dependent squeezing

Quantum noise reduction

Increasing the robustness and efficiency to reach 10 dB injected:

- Squeezing Source Optimization
  - geometry, non-linear medium, escape efficiency
- Losses and Phase noise reduction
  - low-loss devices and optics, mode-matching sensing, and actuation
- System controls improvement
  - filter cavity lock precision, angular controls and auto-alignment, temperature and humidity stabilization

High power laser

Quantum noise reduction

- Fiber amplifier is the technology chosen as O4/O5 high power laser source
- It is also the technology which does not require breakthroughs to provide the input power for post O5 scenarios (order of 300W)
- Anyway, unexpected issues prevented the use for O4:
  - Reliability issues
  - Excess phase noise
- R&D is needed to improve the available industrial design:
  - some solutions in terms of reliability have been already demonstrated at LZH and could be ported to the Virgo HPL source, fulfilling requirements
  - Prototype with some 350W of output power has already been demonstrated and needs to be consolidated
  - The origin of the high-frequency phase noise needs to be understood and a mitigation strategy to be proposed and experimentally demonstrated.

Thermal Compensation System

Quantum noise reduction

- Non-spherical correction systems
  - Due to the Gaussian shape of the ITF beam, a non-negligible residual of higher-order aberration will be present after the RH correction. The effect on both the optical path length and the deformation of the HR face exceeds the requirements (<0.5 nm RMS for HR and < 2 nm for optical path length).
  - Residuals can be compensated by shining an optimized heating pattern.
  - Actuators to produce such heating patterns need to be designed and produced
- Improved HWS sensing for thermal aberrations
  - To cope with stray curvature signals induced by room temperature fluctuations (the thermal defocus coming from the sensor itself).
  - To cope with the increased magnification of telescopes, spatial resolution and the obsolescence of hardware

Input/output and auxiliary optics

Quantum noise and technical noise reduction

- Development of Faraday Isolators and Electro-Optic Modulators able to withstand an optical beam of 400 W at 1064 nm.
- General upgrades of the actuators of the injection system in order to enhance their characteristics and enable their operation while maintaining the ITF lock
- Faraday isolators for the output benches
- Output mode-cleaner cavity
- Improved OMC mode matching and alignment
- Photodedectors and associated electronics
- Homodyne readout

Parametric Instabilities mitigation

Quatum noise reduction

- With the possible and aimed adoption of the optical stable cavities and the increment of power, VnEXT will start to face several PI events. An effort will be needed for the application of Acoustic Modal Dampers and also other mitigation strategies for the new configuration.
- R&D description
  - Optomechanical simulations on PI mitigation by radiation pressure of auxiliary lasers
  - Implementation of a PI-limited table-top optical cavity
  - Mitigation of PI using the steering beam technique
  - Investigations of different radiation pressure-based techniques

Coatings

Thermal noise reduction

- 2 solutions, discussed in the Coating document, have been proposed for funding:
  - Amorphous coatings
  - Crystalline coatings based on oxides
- AlGaAs crystalline coatings based on are of interest and a contribution from Virgo for their developments is under discussion
- The selection procedure for new material has been identified: 3 phases to reduce complexity and costs
  - Exploratory/Preparation phase
  - Optimization phase
  - Production phase

Mirrors - coatings

Thermal noise reduction

- Coating optimization: scattering and point-absorber reduction
  - investigate the impact of the deposition parameters
  - optimize the process regarding the point defect density
  - develop a simulation code in order to compute the mirror BRDF according to the point defect parameters
- R&D for coating optimization in GC: upgrade of the machine
  - Production of the targets of the selected materials suitable for GC
  - Upgrade for low point-scatterers density and low point-absorber density
  - Thickness improvement w/o or w/ masking
  - Monitoring of the deposition chamber

Payload

Thermal noise and technical noise reduction

- Triple pendulum
  - more stages = hierarchical distribution of correction = driving noise reduction
  - suspension thermal noise reduction
- Comparable results can be reached using 2-stage marionette with very high Q (e.g. adopting SiO_2)

Seismic Superattenuator

Technical noise reduction

- Development of compact seismic filters (PIP) for a compact Superattenuator
  - Requested by the increase in height of the payload
- Development of steering filter and marionetta
  - To achieve better payload controllability
- Development of position / distance sensors for Superattenuator control
  - To reduce RMS motion impacting technical noise at low frequency
- Development of Low Noise / High Dynamics Digital to Analog Conversion modules
  - Actuation dynamic range is already a significant source of noise

Scattered light mitigation

Technical noise reduction

- Reduction of stray light sources
  - Metrology
    Upgrades of existing benches, new benches and new facilities
  - Effect of cleanliness
  - R&D on some particular components
- Reduction of relative motions
- Reduction of circulating stray light

Digital electronics and Calibration

Technical noise reduction

- ADC/DAC channels: new design for generic channels and new specific channels: faster, lower-noise, higher dynamic, …
- Low-noise digital demodulation system, with low-noise clock distribution
- Calibration: continuous evolution