Virgo: Plans for the next future

Virgo+

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On behalf of the Virgo collaboration

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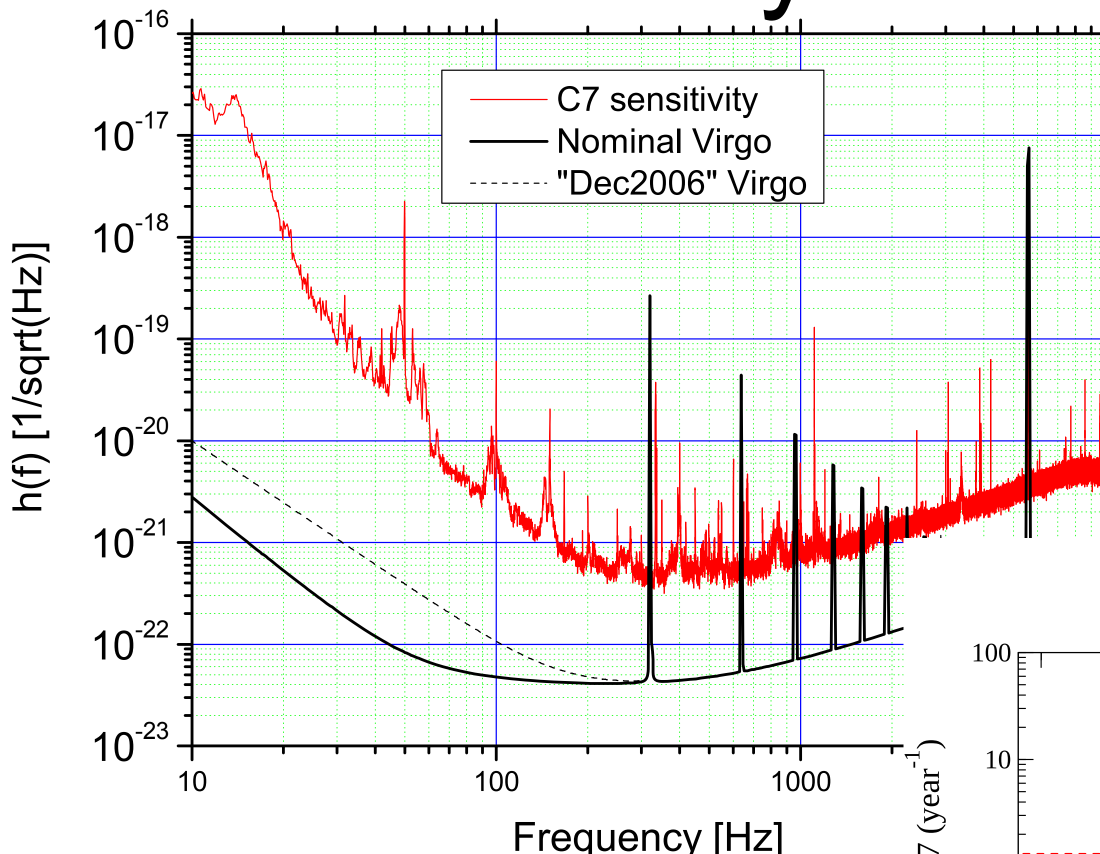
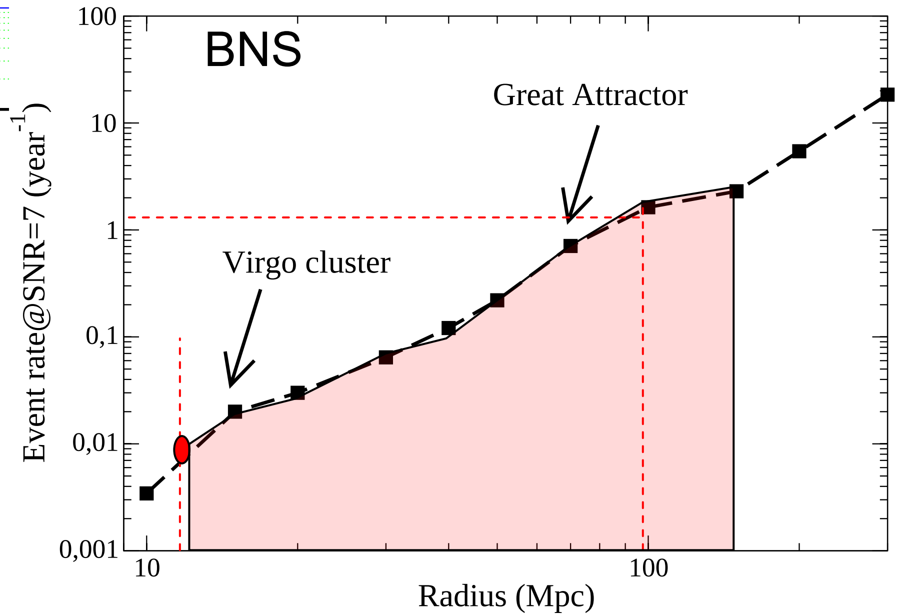
Sensitivity & Detection



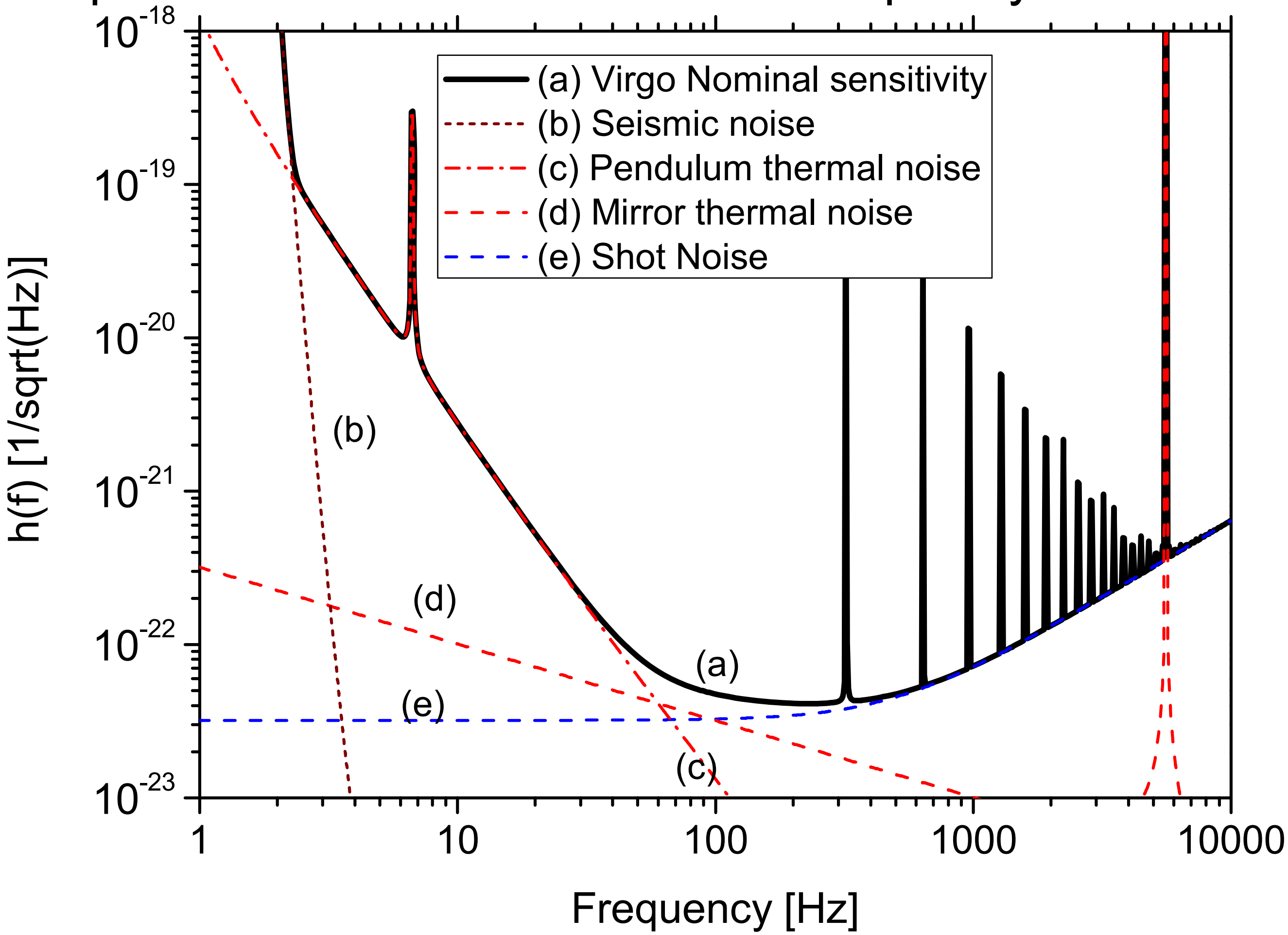
Detection performances:

Source	Virgo (SNR=8)
NS-NS 1.4-1.4Ms	31.0 Mpc (12.4)
BH-BH 10-10Ms	145 Mpc (58)
Burst $h_{rss} \approx 10^{-20}$	12.9kpc



Sensitivity improvement

- The nominal Virgo sensitivity is dominated by
  - the shot noise, at high frequency
  - the pendulum thermal noise at low frequency



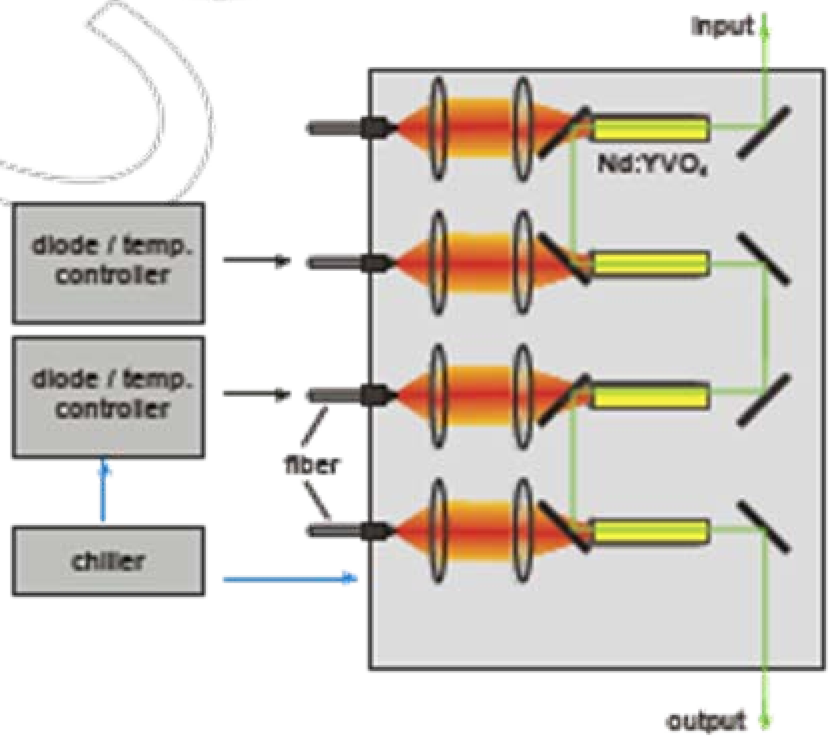
High Power Lasers Light

- Reduction of the shot noise passes through the increase of the power of the light circulating in the Fabry-Perot Cavities
  - In a shot-noise limited detector the sensitivity decreases as $\sqrt{\frac{1}{P_{laser}}}$
  - Currently the laser is a 20W, supplied by the Laser Zentrum Hannover, based on a Nd:YVO4 rod, end pumped by fibre-coupled diode lasers
  - High power laser is necessary to inject many Watts in the cavities
    - Current technology, developed by the GEO-Hannover group+LZH, permits to have hundred Watts CW lasers
    - Many technical problems on the injection and central optics limit the possible increase of power, with a reduced impact on the shut-down period
      - 50 W seems a good compromise between the noise improvement and the technical difficulties

Nd:YVO4 for 50W Amplifier

- 50W laser amplifier under development between LZH and Virgo:

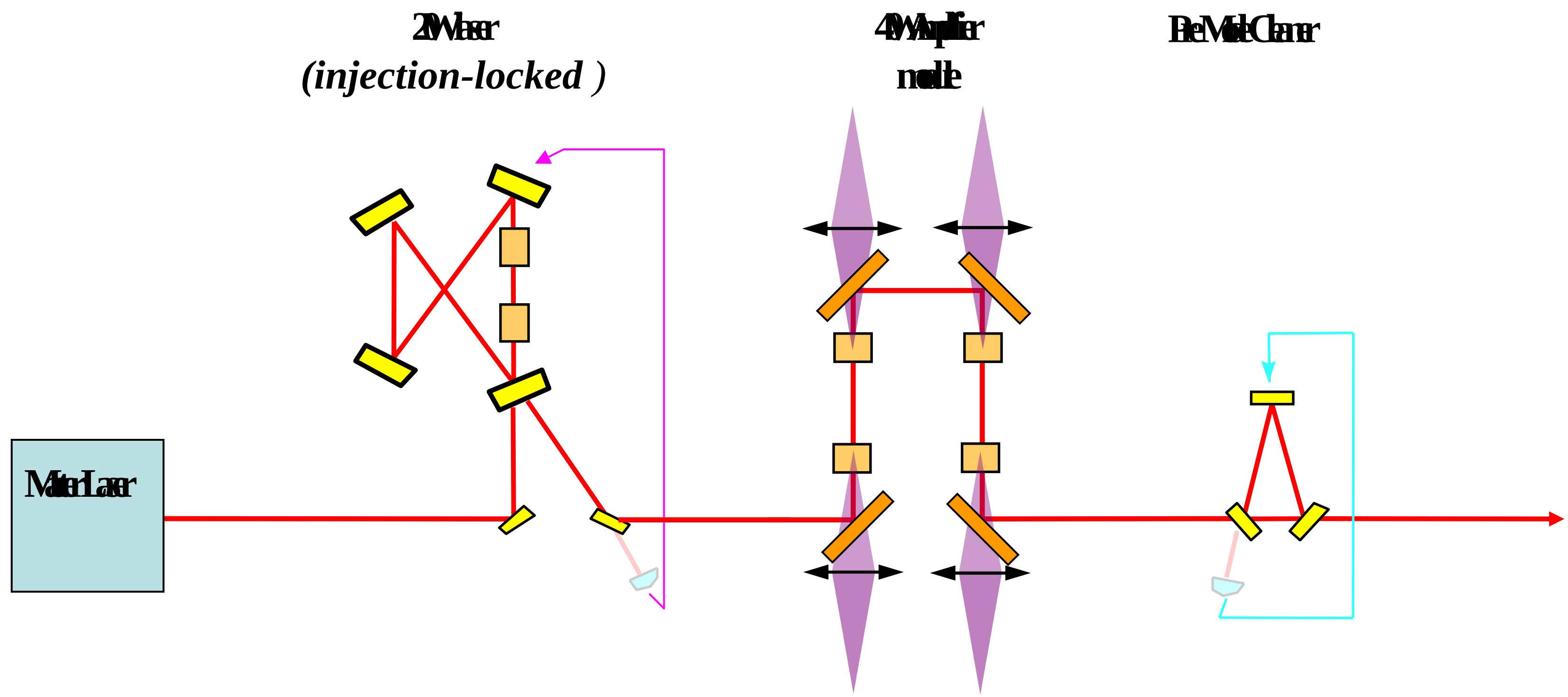
Four-stage end-pumped Nd:YVO4
Each stage pumped by 45 W laser diode
Each diode indiv temp controlled
Each 2diodes connected in series to 1 current driver
Diodes current controlled



- Possibility to replace the current master laser with a fiber laser

(LZH prop)

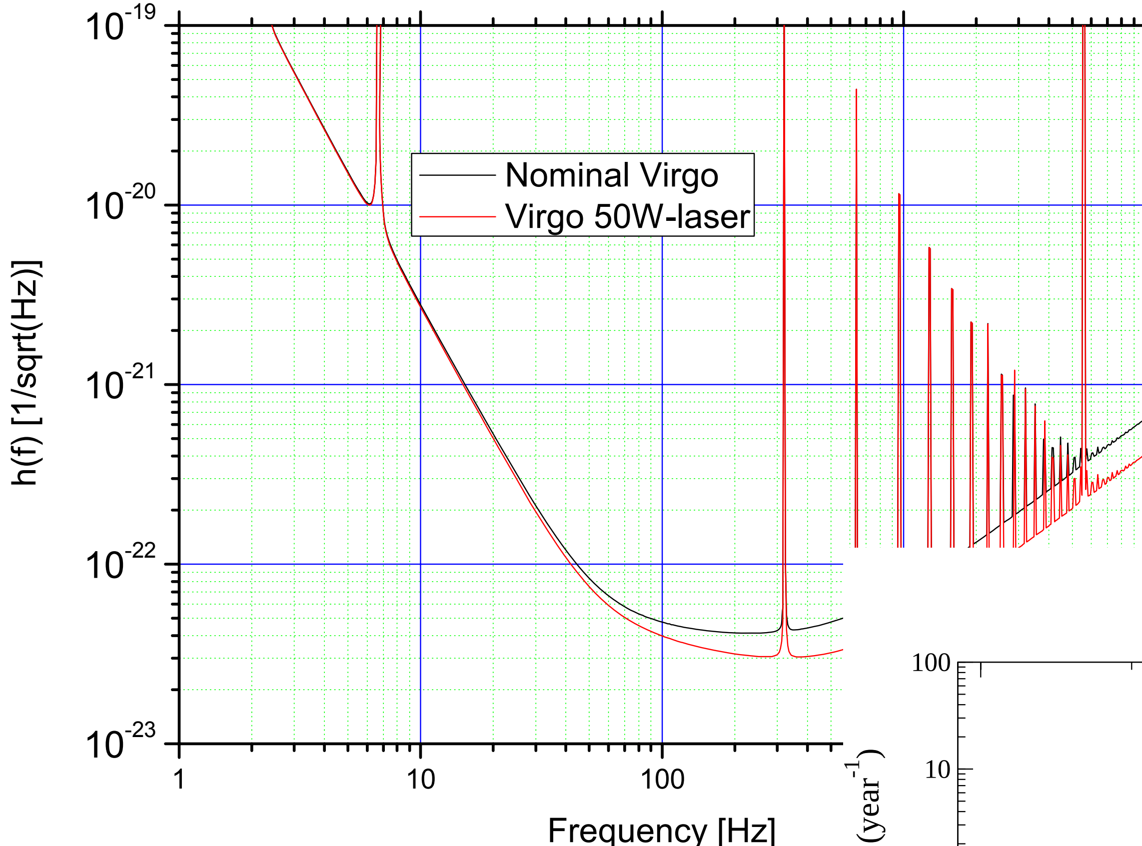
Possible laser system



Nd-YvO4 crystal

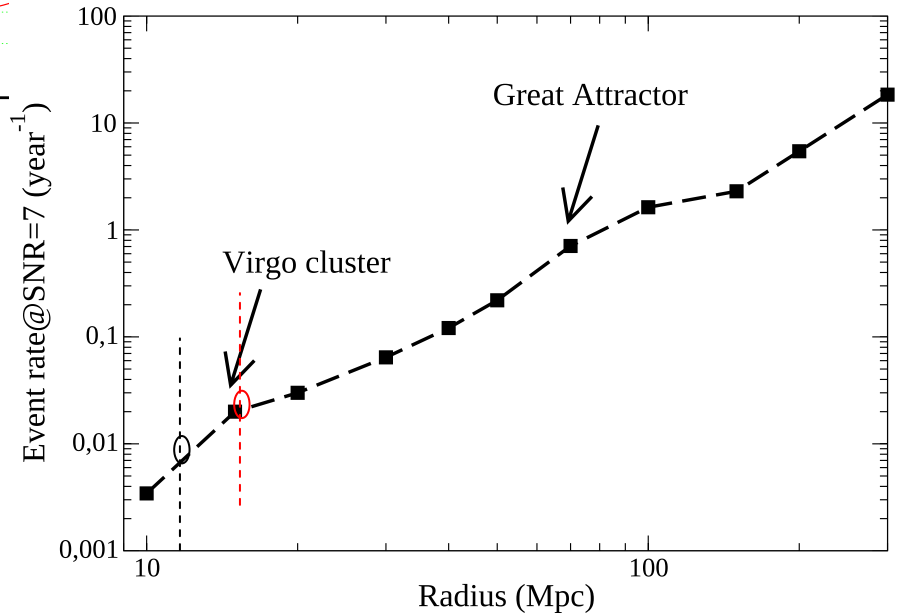
Crystal pumping module

50/2 W laser effect



Source	Virgo 50 W (dist. Mpc)
NSNS	37.4 (15.0)
BHBH	172 (68.8)

- NS-NS signal detection benefits of the improved sensitivity at high frequency



Mirror Losses New Model

- The Virgo nominal sensitivity is realized adopting a constant in frequency model for the mirror Brownian noise
- S.D.Penn et al. shown that this corresponds to an over-estimation of that noise and they proposed a model for Suprasil 312:

$$\phi\left(f,\frac{S}{V}\right)=C_1\left(\frac{V}{S}\right)^{-1}+C_2\left(\frac{f}{1Hz}\right)^{C_3}+C_4\phi_{th-elastic}\approx 7.12\times10^{-9}\frac{S}{V}+4.63\times10^{-12}f^{\,0.813}$$

- But the current Virgo Input Mirrors are made in Suprasil 311-SV very similar to Suprasil-312
  - Reducing the other noises we should have an "advanced" performance level

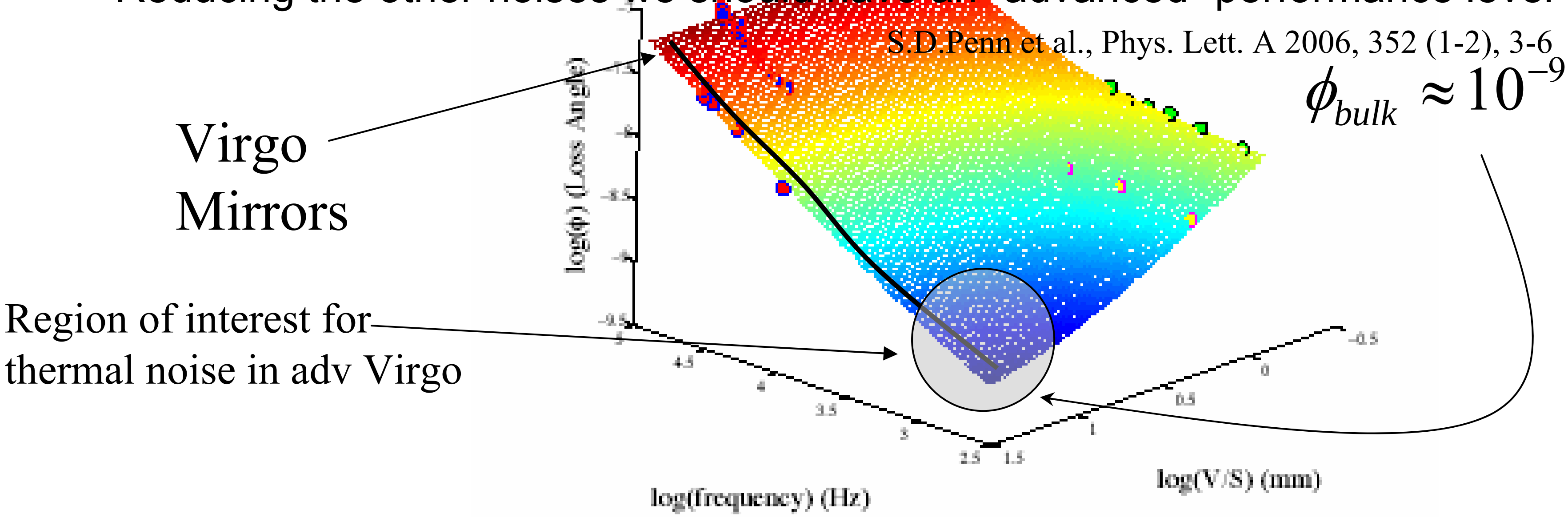


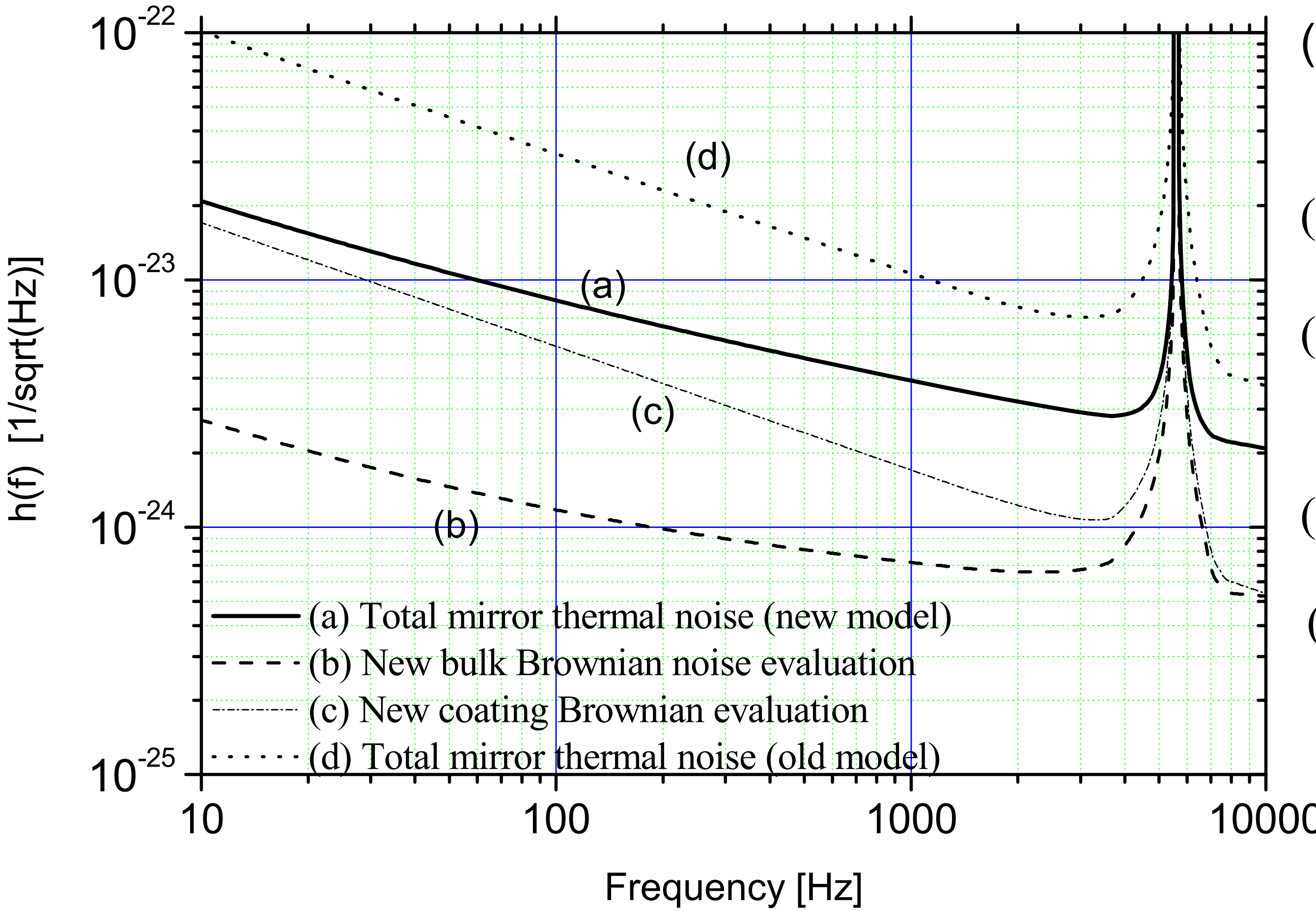
FIG. 2: Suprasil 312 mechanical loss data with best fit surface.

Replacement of the Virgo mirrors

- Virgo mirror are in a “mixed” configuration
  - Input mirrors in Suprasil SV-311 (low losses)
  - End mirrors in Herasil (High losses, no frequency dependence (*Numata et al.*))
- Replacing all the mirrors we could
  - Use low dissipation material for all the mirrors
  - Adopt better performance coatings
  - Install monolithic fused silica suspension

Mirror thermal noise evaluation

- R&D activities in LIGO with the support of the LMA-Virgo group demonstrated that it is possible to decrease the mechanical dissipation of the coatings introducing TiO_2 dopants in the Ta_2O_5/SiO_2 layers



(d) Evaluated with

$\phi_{Ta2O5}=4\times10^{-4}$,

$\phi_{Subs}\approx10^{-6}\text{-}10^{-7}$

(b) Evaluated with

ϕ_{Subs} Penn's Model

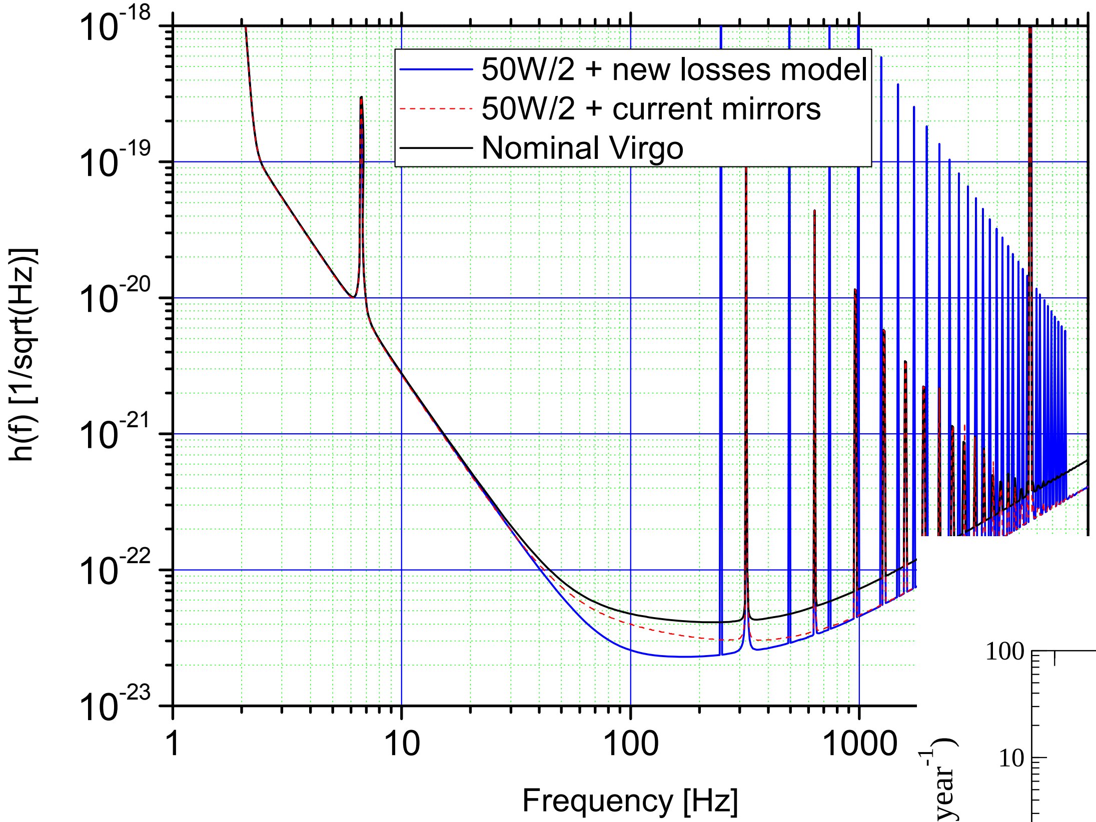
(c) Evaluated with

$\phi_{Ta2O5}=1.6\times10^{-4}$

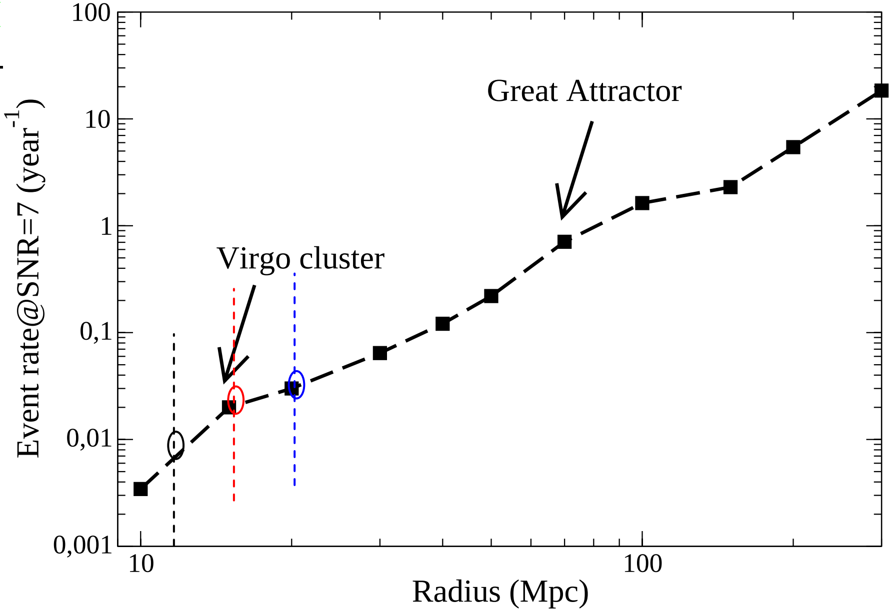
(a) Incoherent sum:

$$(a)=\sqrt{(b)^2+(c)^2+\ldots}$$

New mirrors and 50W laser amplifier



- NS-NS signal detection benefits of the improved sensitivity at intermediate frequency



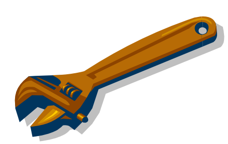
Complete the upgrade

- In effect, the previous improvement is "incomplete" and maybe "fictitious":
  - To substitute four mirrors we need to invest a lot of money, a large effort and a long shutdown period
    - Large cost of the substrates
    - Large cost of the coatings
    - At least one month of preparatory work for each mirror before to shut-down the ITF and 3 weeks to install each payload
    - Presence of a large excess loss due to the friction of the suspension wires on the mirror lateral faces.
  - Steel wire suspension is not the selected technology for the 2nd generation ("advanced") detectors
    - Could we anticipate the upgrade of the suspension?
    - Virgo have already a second generation seismic filtering system!

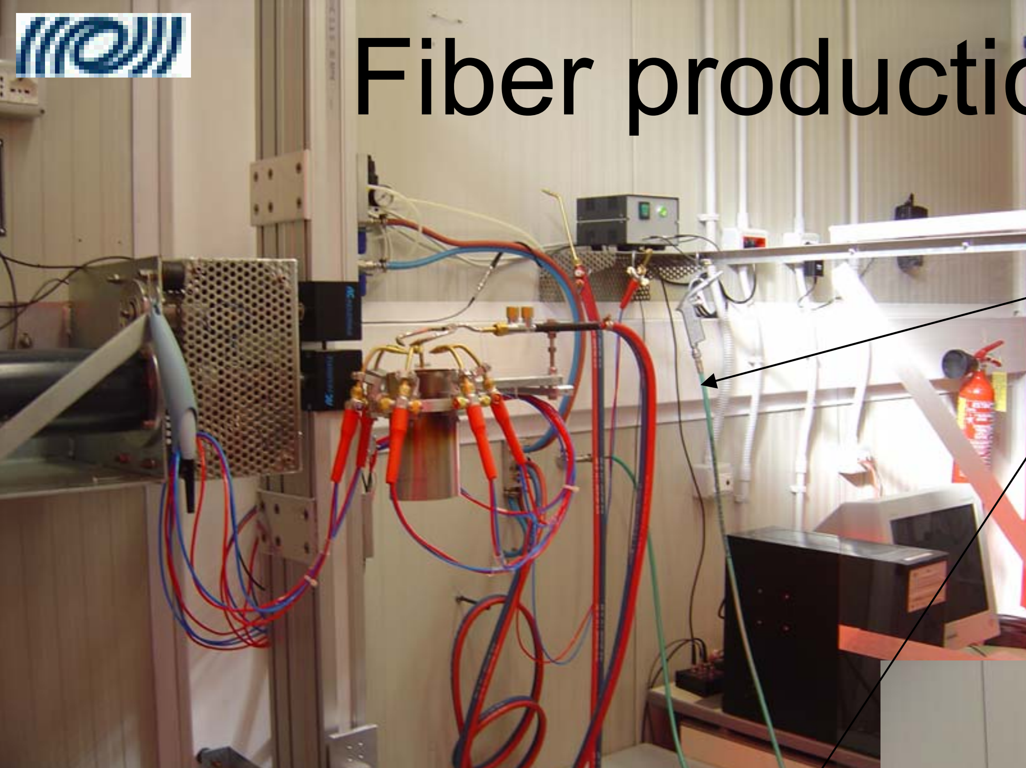
Monolithic fused silica suspension

- Thanks to the well known low mechanical dissipation of the fused silica, a similar monolithic suspension promises an excellent performance in terms of thermal noise
- Multi-year R&D activity performed in Virgo
- Collaboration with the GEO-Glasgow group
- Large engineering effort now in Virgo to realize a FS monolithic last stage
  - Two fiber production machines available in Cascina
    - H_2-O_2 flames “standard” machine completely automated ✓
    - New CO_2 laser machine ✓
  - Well defined planning available
    - Realization of a test payload having
      - Stainless steel marionette
      - Dielectric reference mass
      - Monolithic fused silica suspension fibers attached to the mirror through silicate bonding
      - Dummy mirror ✓
      - Full Virgo local control system
        - » Magnet-Coil actuation system
        - » Digital (ADC-DSP-DAC) control system
        - » Optical lever monitoring

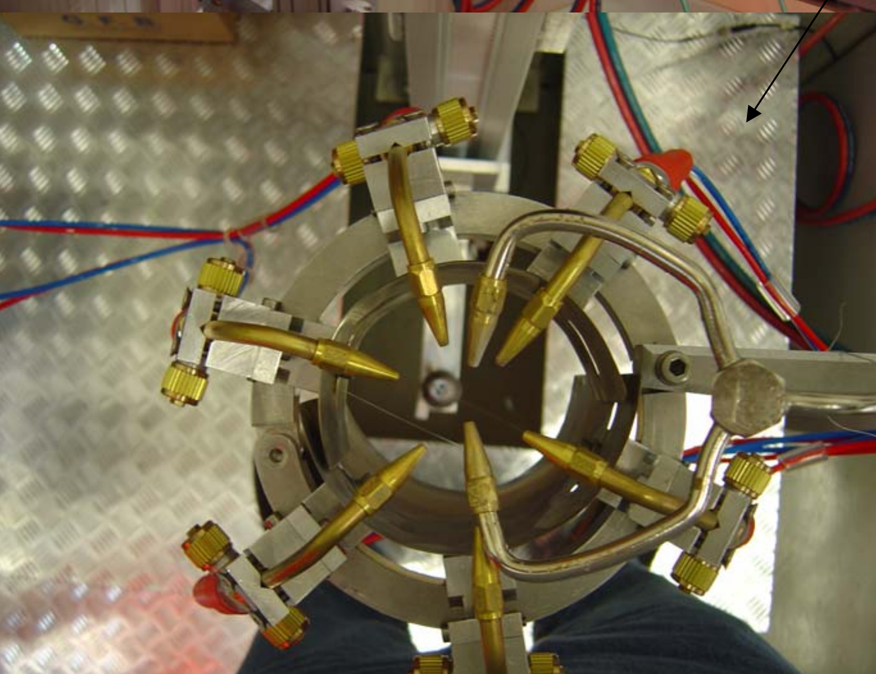
Status



Fiber production Facilities

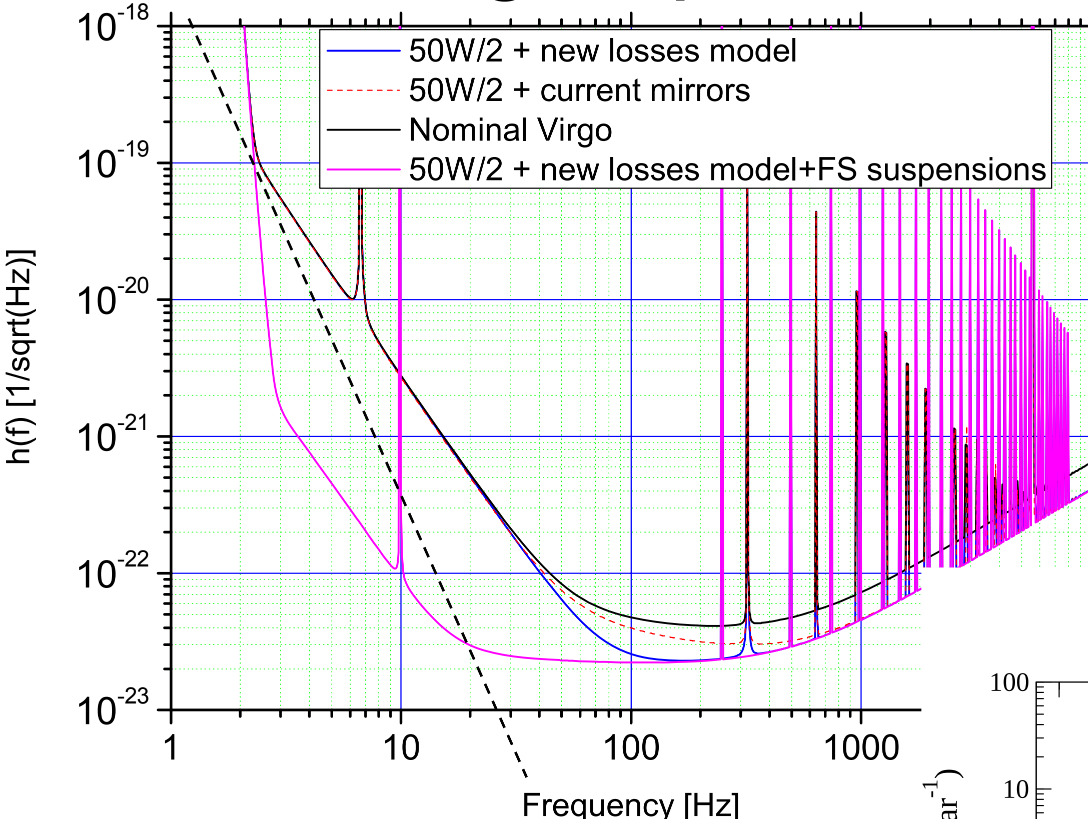


H2-O2 gasses Machine



CO2 laser Machine

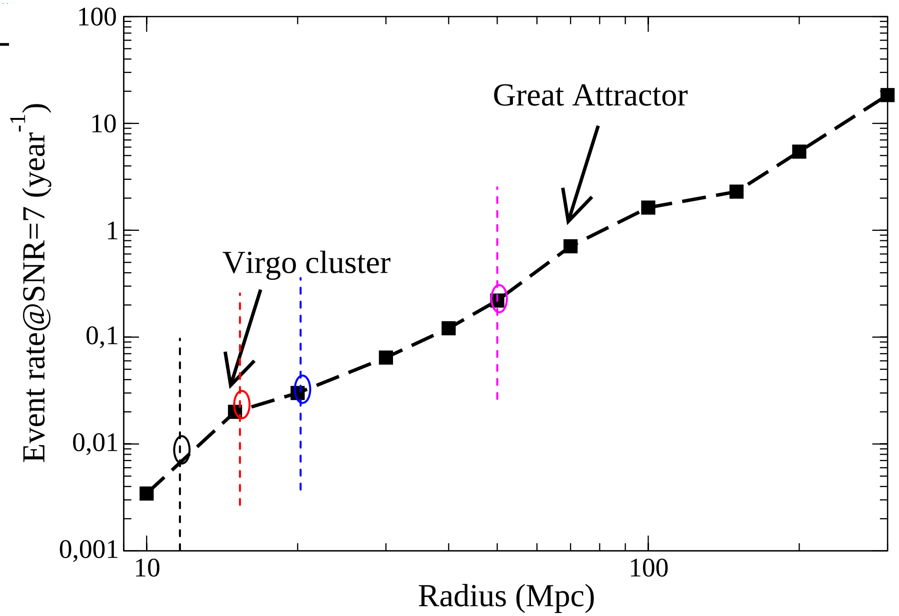
Virgo+ performances 1/2



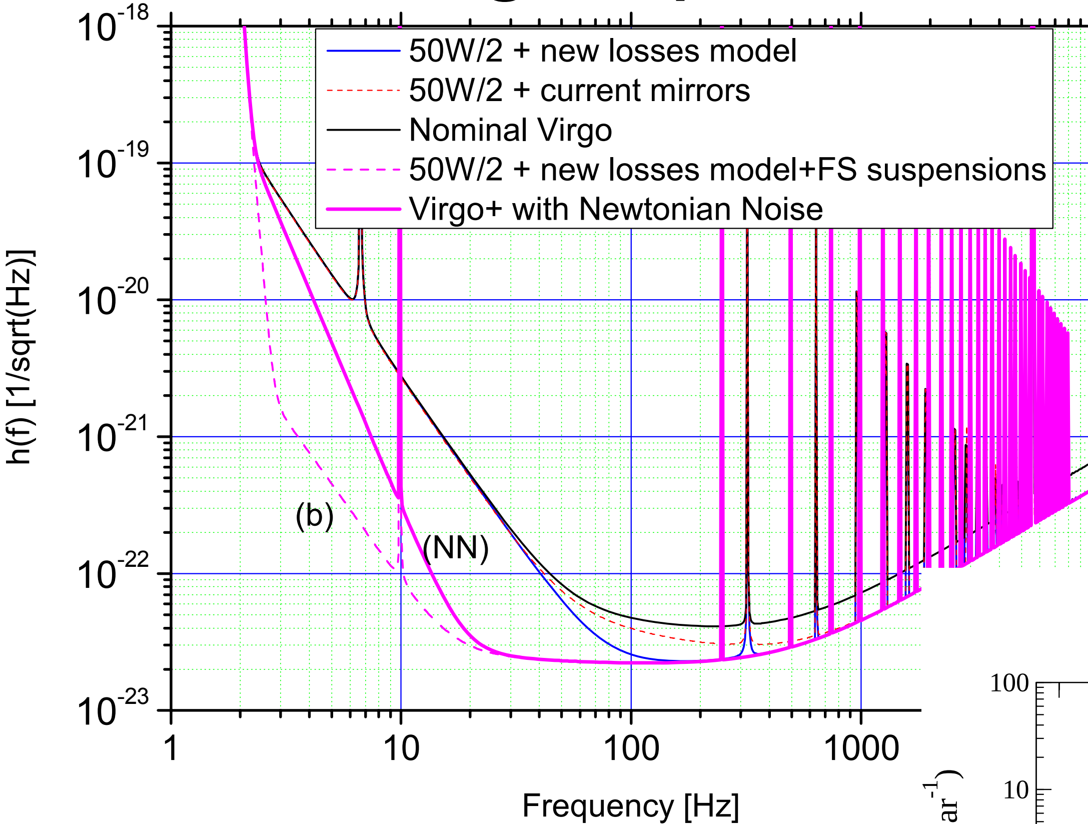
- Too optimistic view:
  - The Gravity gradient noise “obscure” the low frequency part
  - Cella-Cuoco model:

$$h_{NN}(f) \approx \frac{3 \cdot 10^{-11}}{f^2} x_{seism}(f)$$

- NS-NS signal detection benefits of the improved sensitivity at intermediate frequency



Virgo+ performances 2/2



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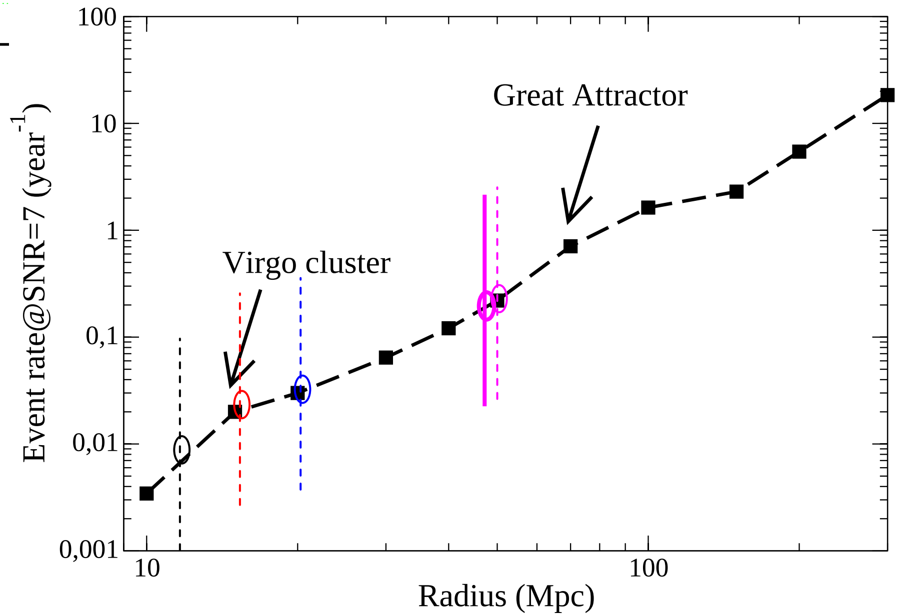
$$h_{NN}(f) \approx \frac{3 \cdot 10^{-11}}{f^2} x_{seism}(f)$$

- The low frequency limit due to the Newtonian noise weakly affects the NSNS detection performances

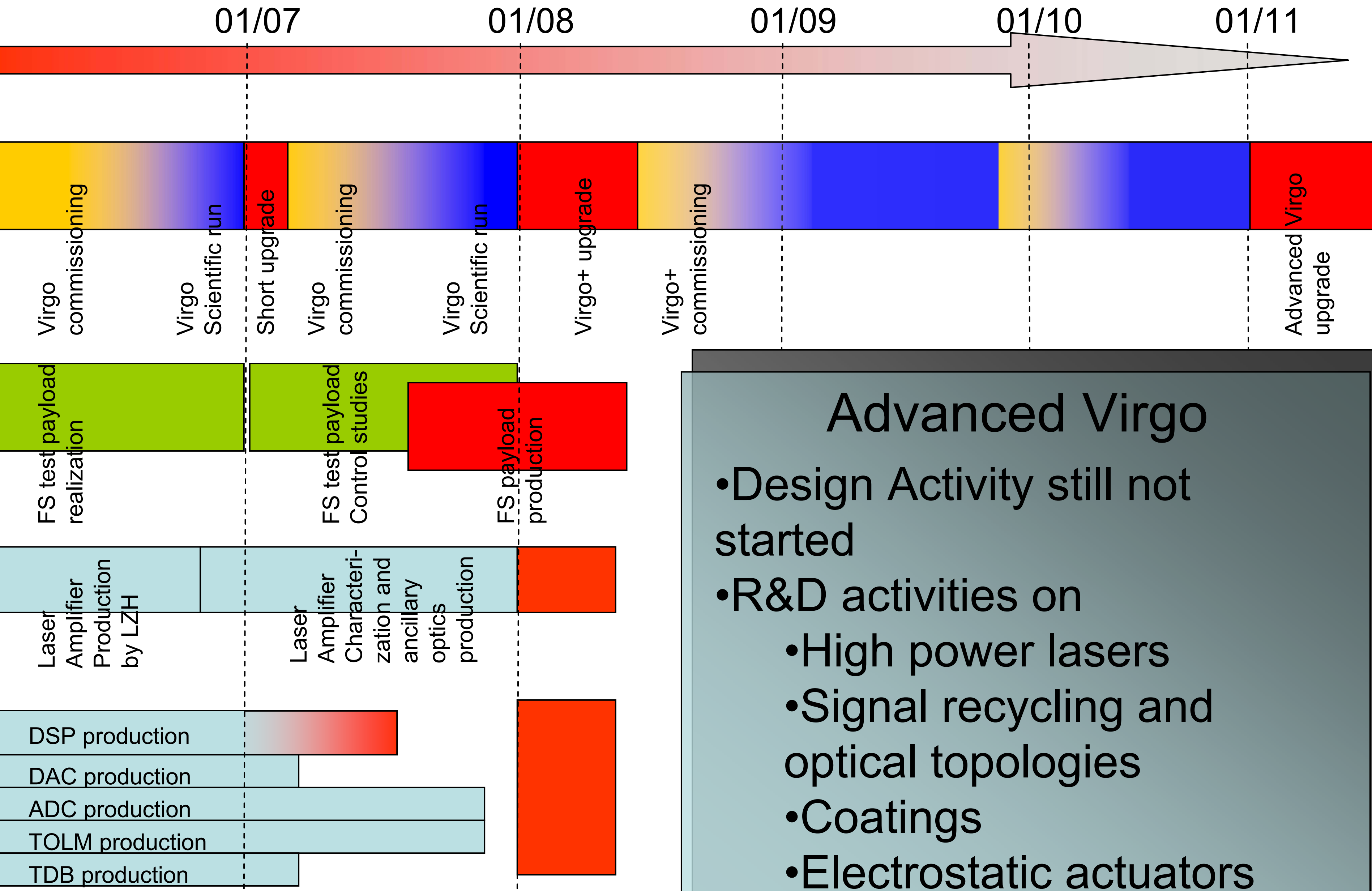
	Virgo+ (NN) Mpc	Curve (b) Mpc
NSNS	114 (45.6)	121 (48.2)
BHBH	584 (234)	664 (265)



What is necessary?

- Physicists are fascinated by fundamental noises and frustrated by technical ones
  - Control noises are currently limiting the low frequency sensitivity of all the GW ITFs in the World
  - In particular, the required low frequency performances of Virgo and furthermore of Virgo+ are a challenging stress test of:
    - Actuation electronics
      - New coil drivers with lower noise under realization
      - New DACs with a larger dynamic range under study
    - DAQ electronics
      - New ADC with higher sampling frequency and number of bits under study
    - “Filtering” electronics
      - New generation DSP boards with high computational power under realization (to fulfill the increasing request of CPU power)
  - High power laser requires
    - Upgrade of some components in our input and detection optics
    - Thermal compensation devices
      - Absorption in the input mirror is suppressed by the good quality of our mirror substrates
        - » Nevertheless a thermal compensation system is under study (LIGO+GEO experience)

Planning



Advanced Virgo

- Design Activity still not started
- R&D activities on
  - High power lasers
  - Signal recycling and optical topologies
  - Coatings
  - Electrostatic actuators

Conclusions

- In the next months Virgo will approach his final sensitivity
- A series of well defined upgrades will permit to increase the detector performances with a relatively small impact on the operational time:
  - Virgo+ is currently an engineering effort rather than a R&D activity
- A huge R&D activity is, instead, necessary to arrive to the Advanced Virgo design