Advanced Virgo: technical and other noises

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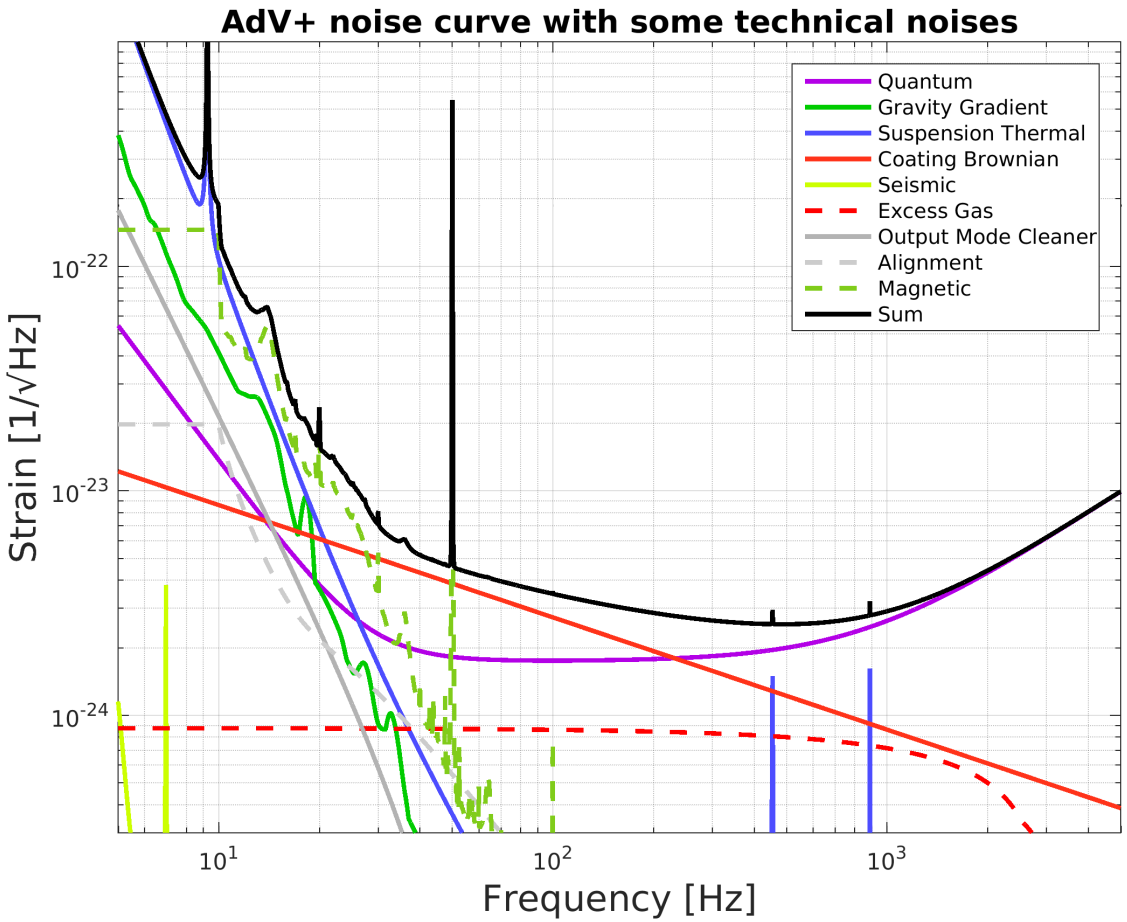
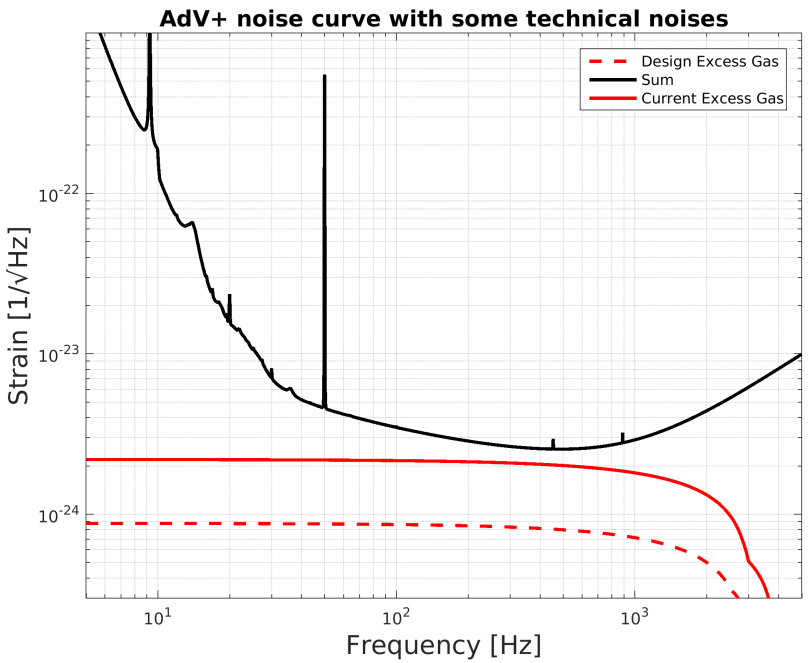
LAPP/IN2P3

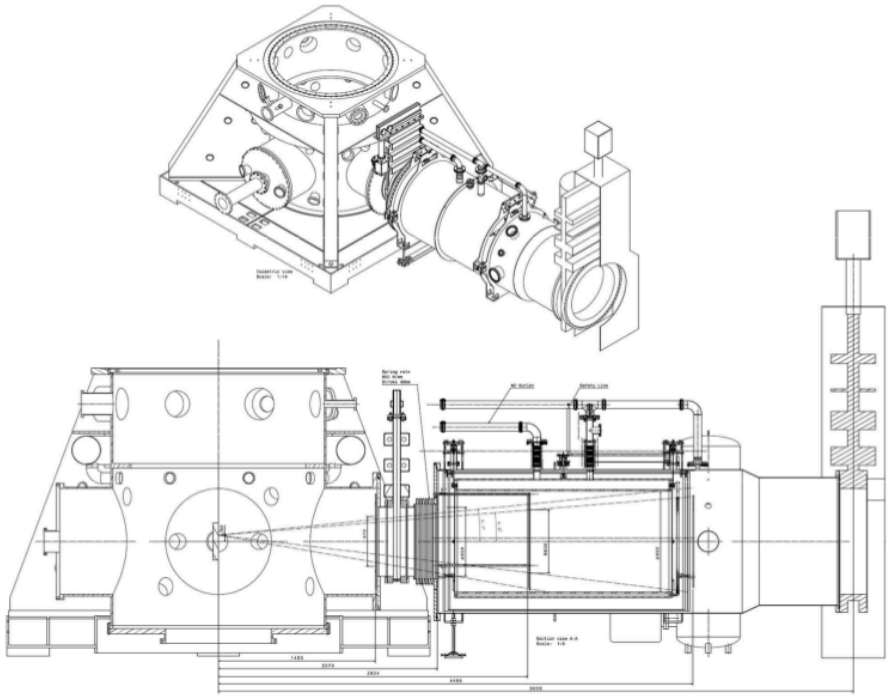
Summary



- Thermal and Quantum noise are major limitation
- But many other technical limitations exist

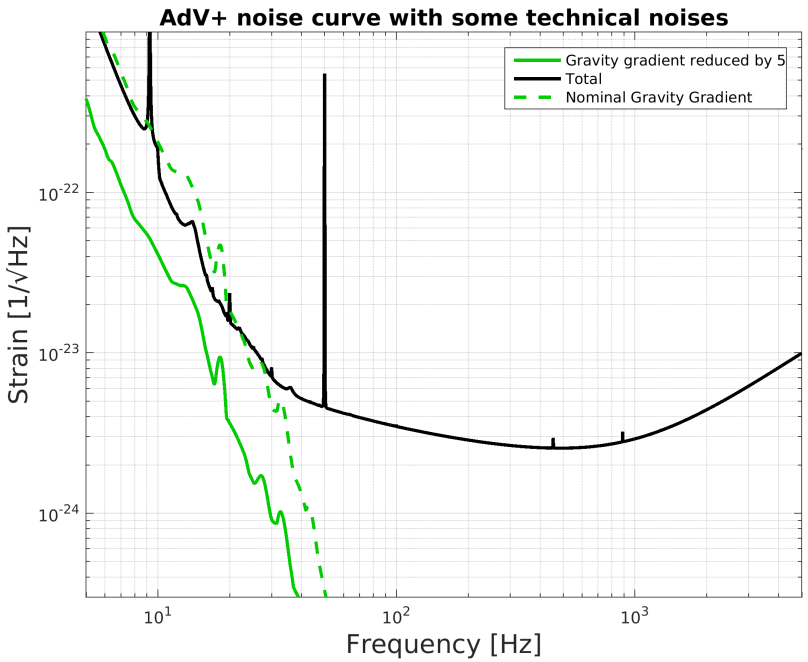
Infrastructure – vacuum is not perfect

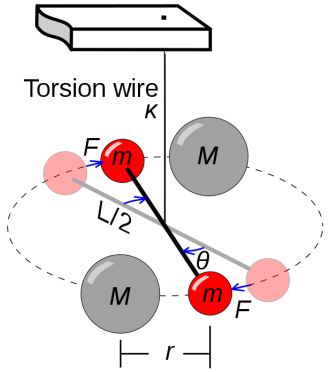


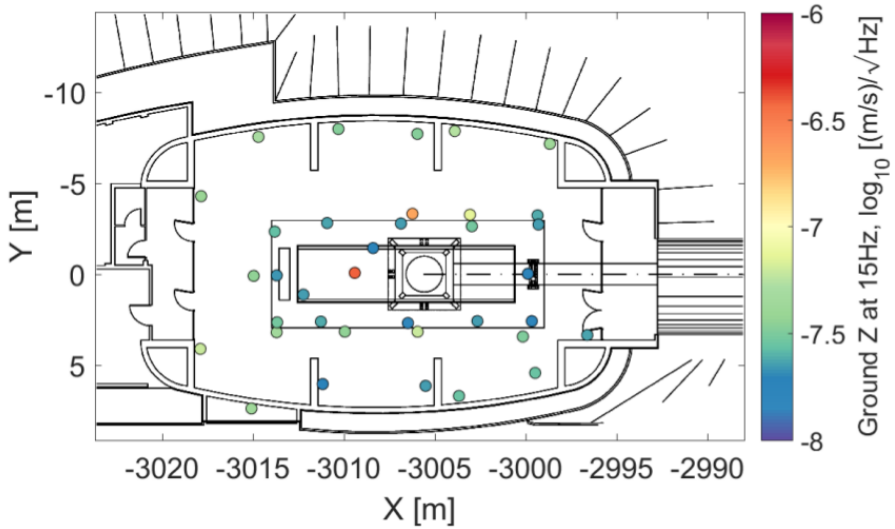


- Residual gas pressure in the arm – laser beam interacts with molecules
- Current 9×10^{-9} mbar, design 2.5×10^{-9} mbar, noise $\propto \sqrt{P}$
- 2 meter long cryogenic traps are protecting the arms from out-gasing from mirrors, suspensions, etc.
- Tube baking at 150℃ for 1 month needed to reach design

Gravity – direct interaction between ground mass and mirrors

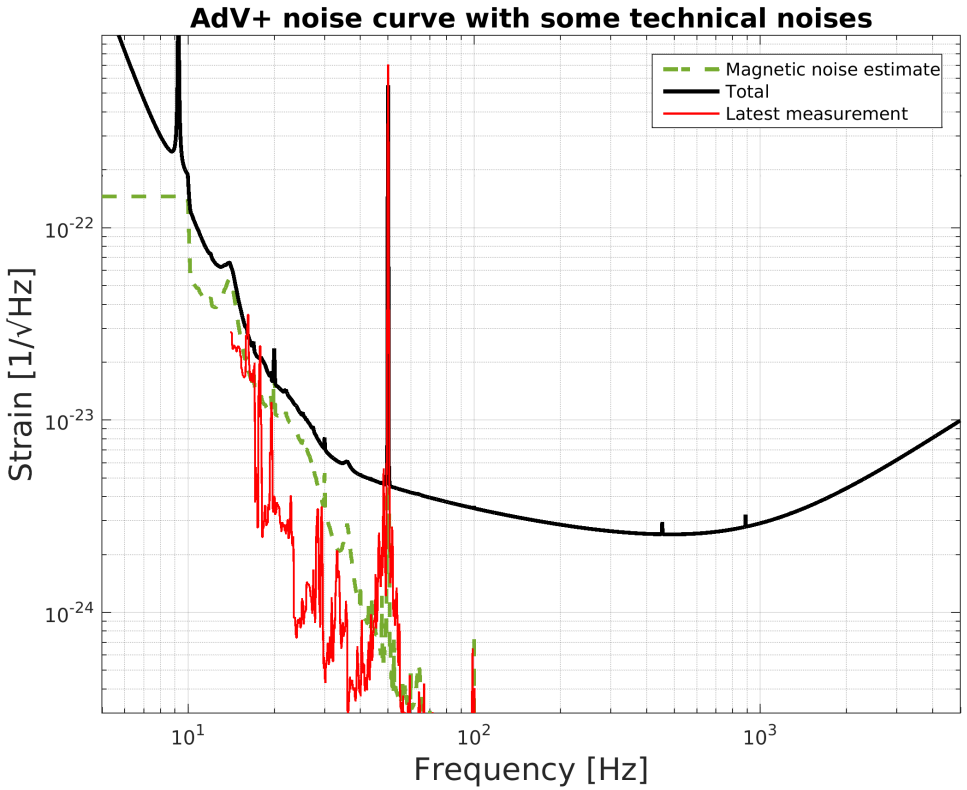


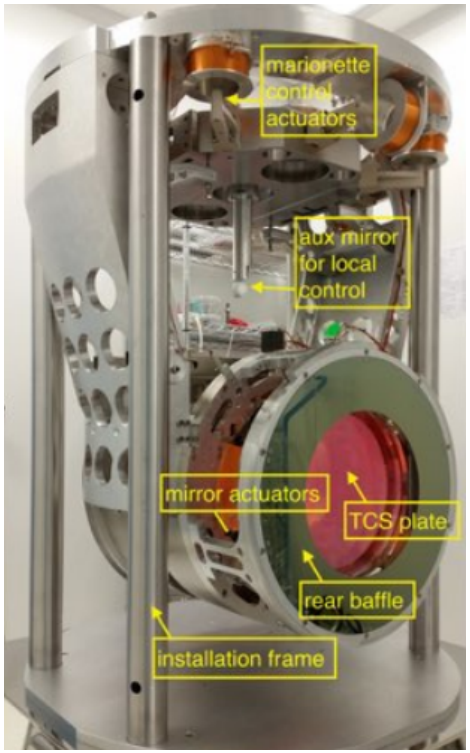




- Subtraction of gravity gradient interaction not demonstrated
- Active research on measuring ground motion with arrays of seismic sensors and modeling interaction
- Advanced Virgo+ assumes a factor 5 subtraction will be achieved
- Infra-sound (air motion) could also be an issue

Ambient magnetic fields – magnets are glued to mirrors

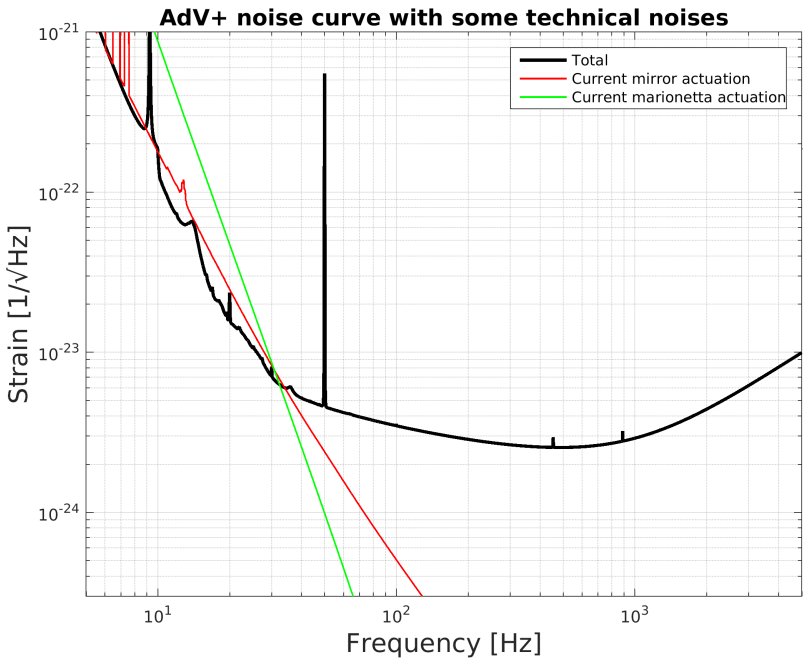


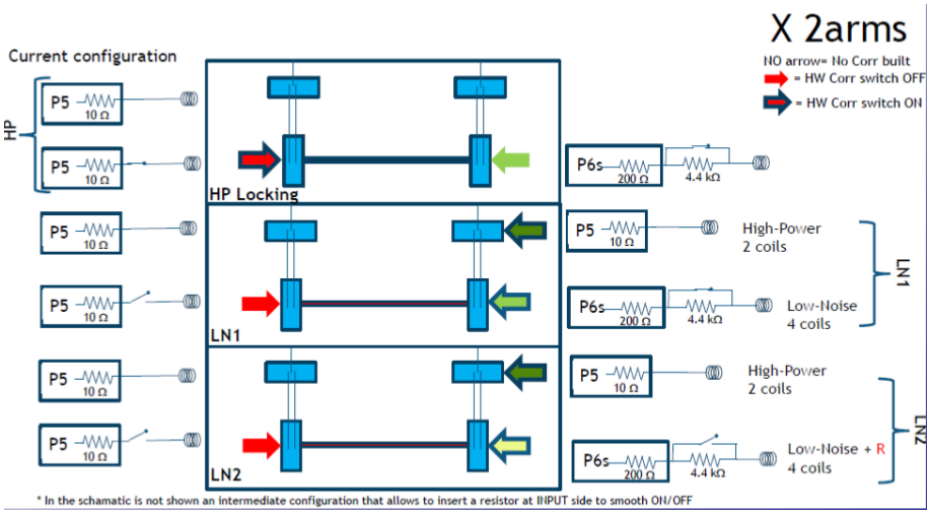


- Magnets on mirrors couple with ambient magnetic field
- Strong magnets needed to move $\sim 100\,\mathrm{kg}$ mirrors by several um to put interferometer on resonance
- Ambient magnetic field needs to move mirrors by less than 10^{-20} m at 10 Hz $\Rightarrow$ 14 orders of magnitude of dynamic

$\Rightarrow$ Stronger coils to push on magnets? Electrostatic actuators used at LIGO but couple with electric fields from ionizing vacuum pumps

Actuators electronic noise

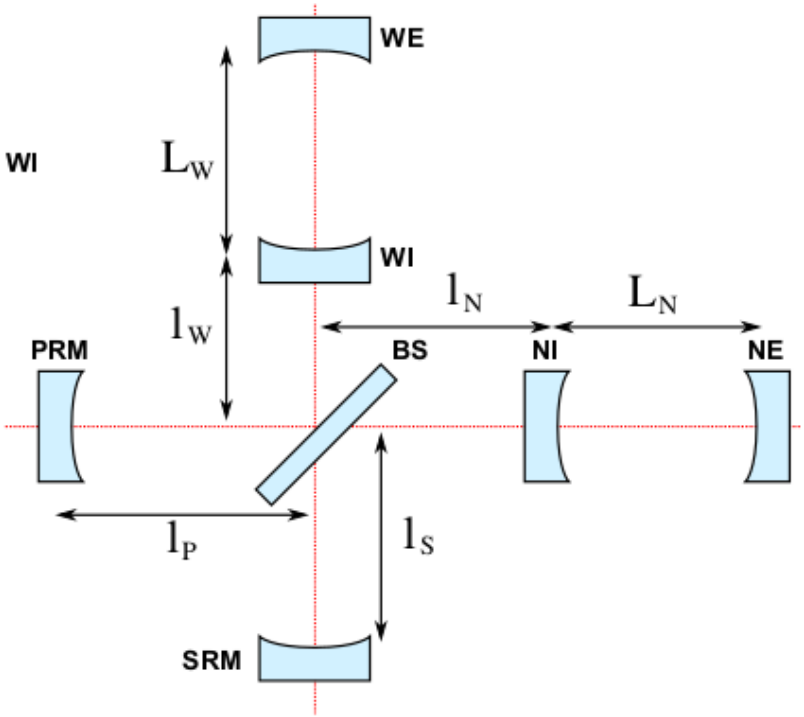


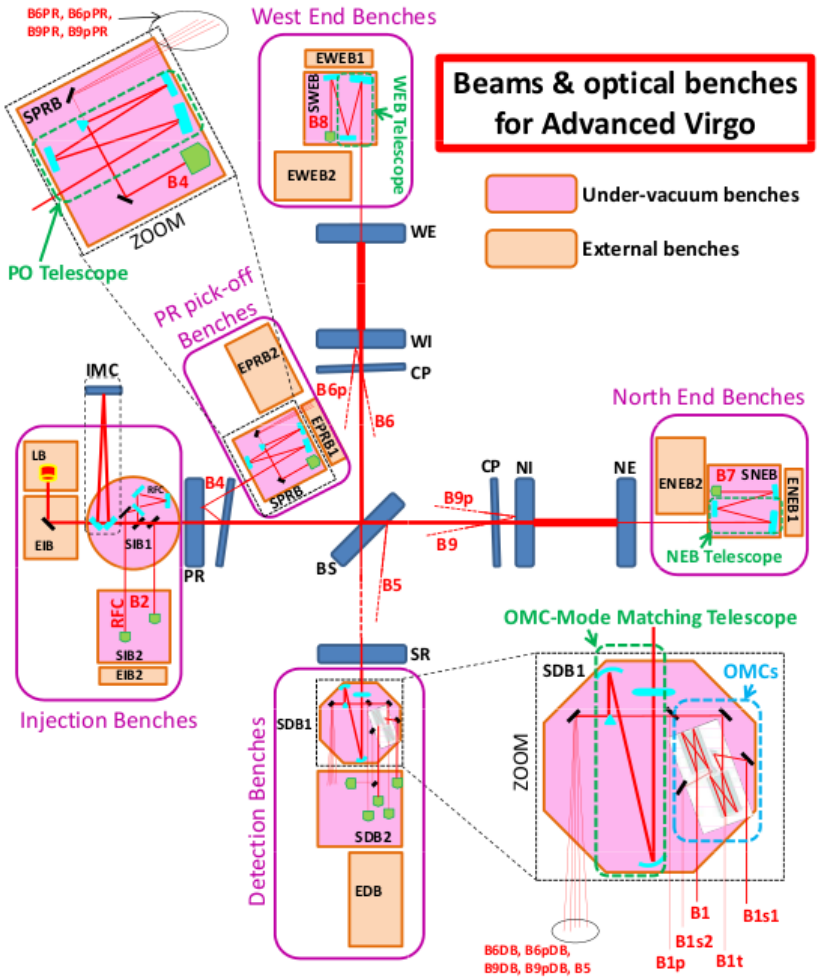


- Electronic noise on current generation that drives coils pushing on mirror and marionetta
- Several stages used during interferometer lock acquisition
- Hierarchal control to put large dynamic low frequency actuation on marionetta
- Additional resistors that lowers dynamic range and noise

⇒ Scheme will need to be further expanded

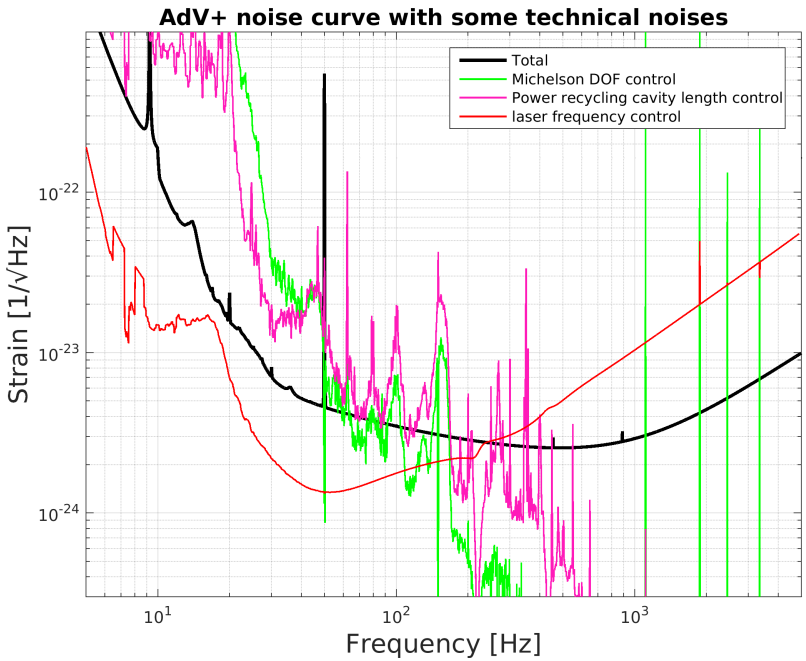
Other degrees of freedom

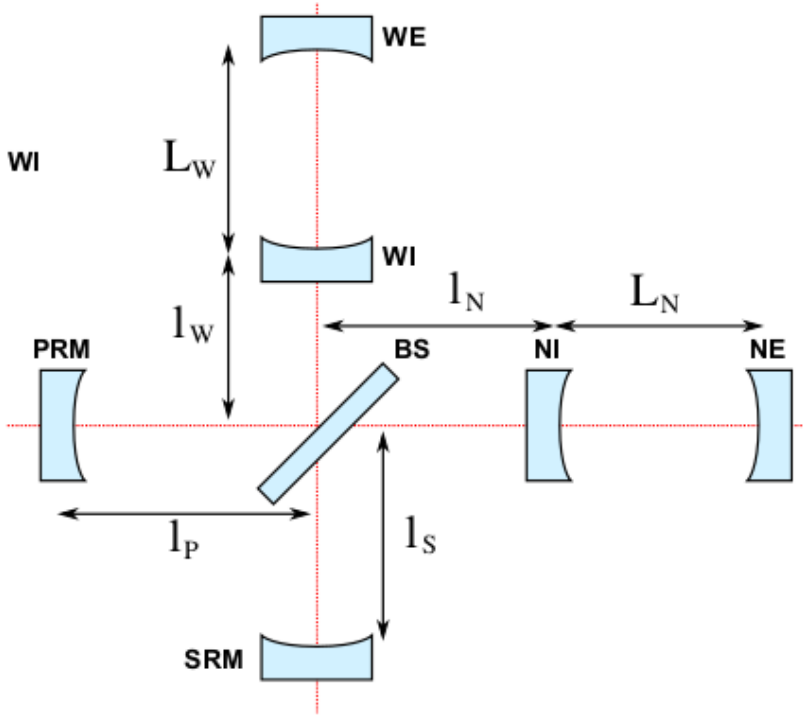




- Several radio-frequency side-bands to create error signals for all degrees of freedom
- Detected on pick-off beams using photo-diodes and quadrant photo-diodes

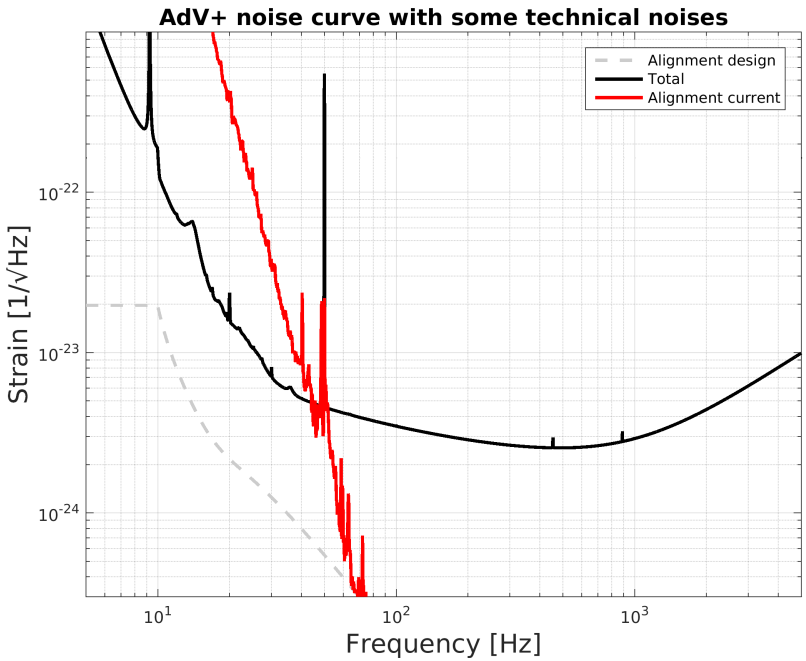
Longitudinal control

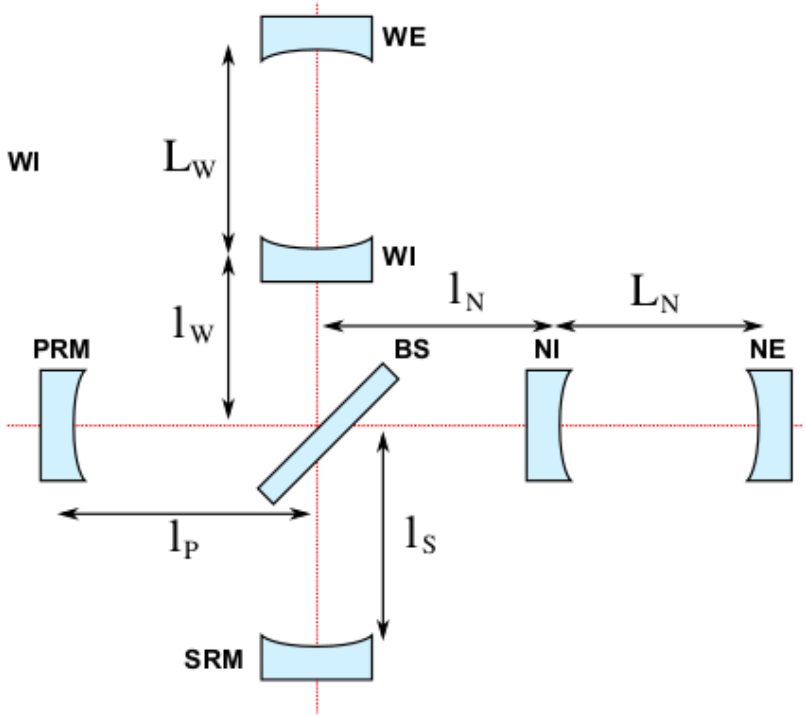




- Bad alignment and actuation diagonalization, optical defects increases couplings
- Months of commissioning and optimization will be needed
- Frequency noise coupling will be changed with the installation of signal recycling in 2020
- Marginally stable optical cavities currently forces use of more noisy error signals $\Rightarrow$ thermal compensation system to correct defects & aberrations
  - $MICH = l_N - l_W$
  - $PRCL = l_P + (l_W + l_N)/2$
  - $Frequency = (L_N + L_W)/2$

Alignment control

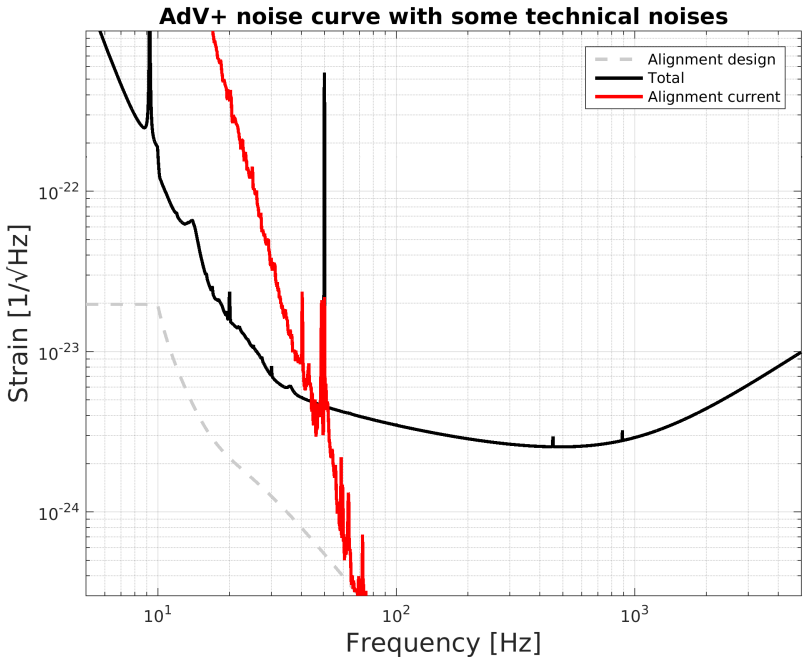


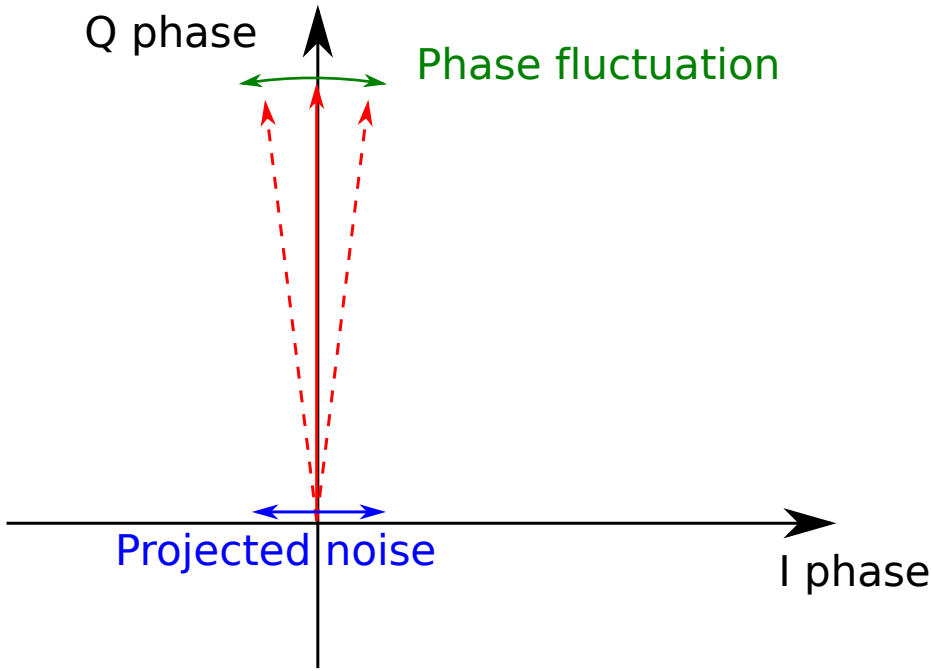


- Complex problem with 28 degrees of freedom
- Degrees of freedom are coupled optically, and actuation on the mirrors is also coupled
- Control signals derived from quadrant photo-diode demodulated at radio frequencies (wavefront sensing)
- Design assumes quadrant are limited by photon shot noise
- In reality large offsets and demodulation phase noise are dominating

$\Rightarrow$ Improvement in global alignment understanding & optical aberration reduction

Alignment control





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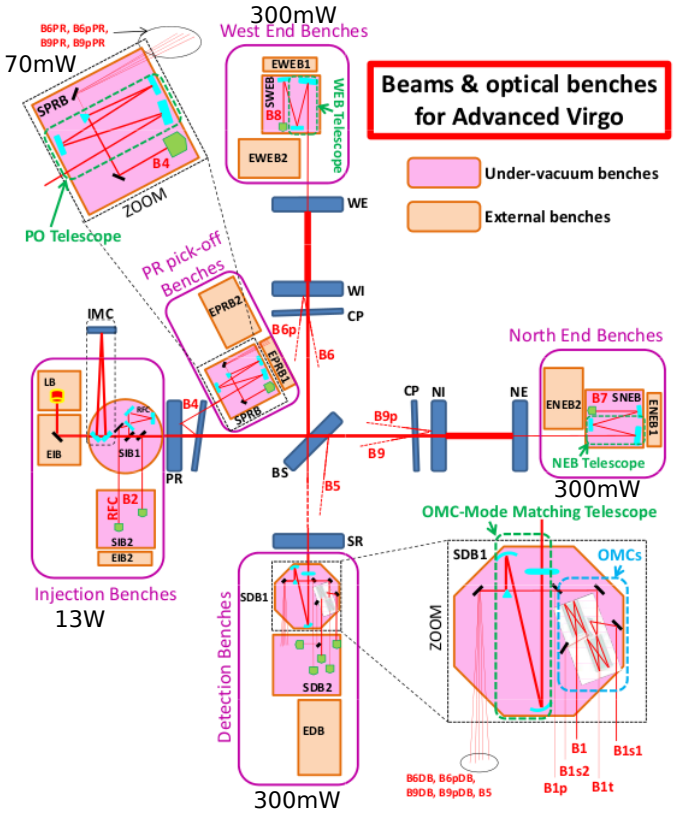
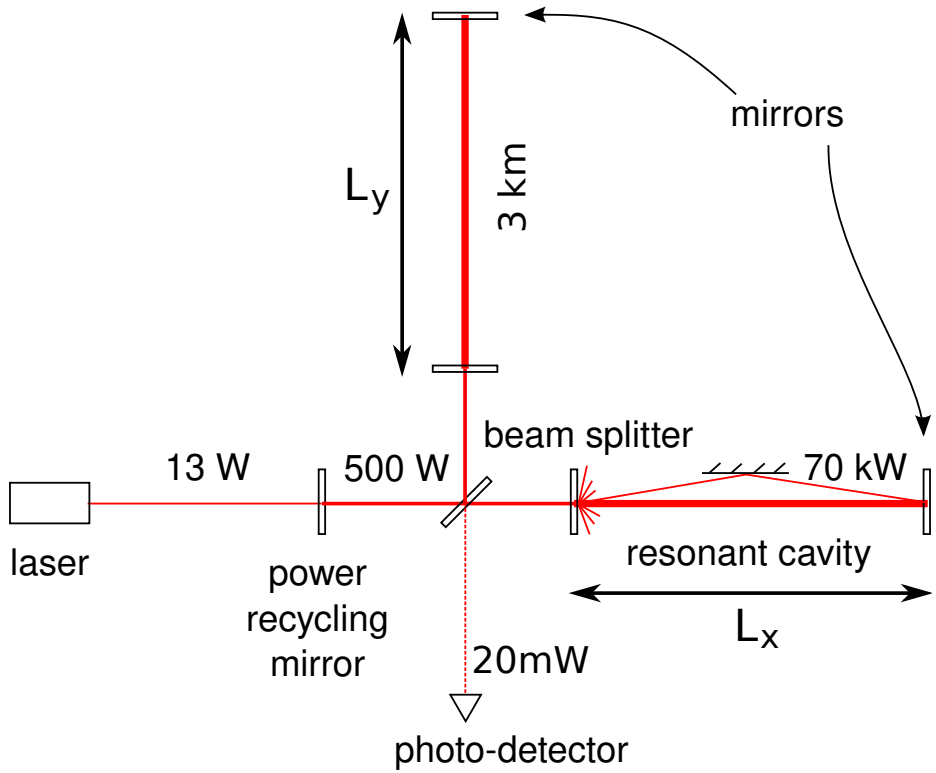
Scattered light



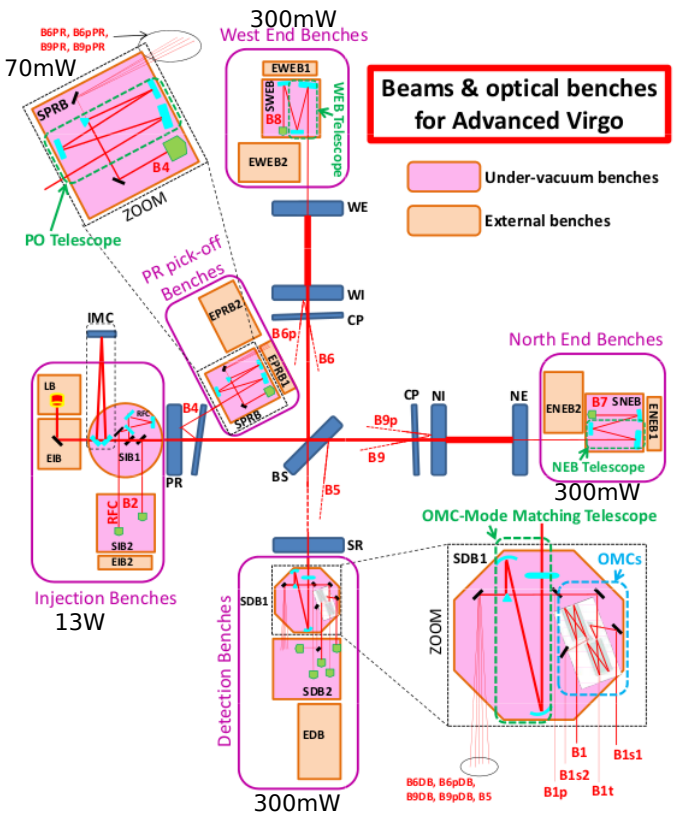


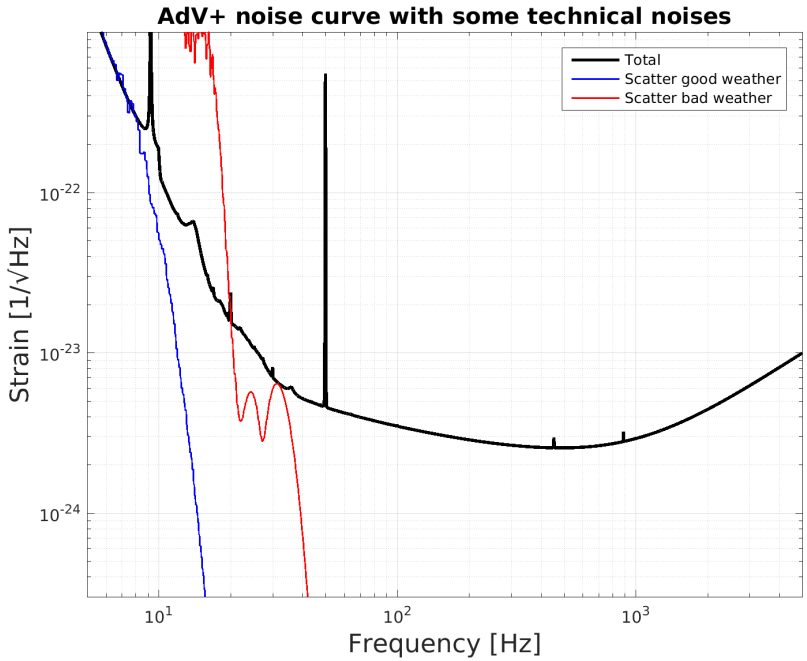
- >90% of injected light lost inside the interferometer
  - absorption in mirrors (causes thermal lensing)
  - mirror imperfection $\Rightarrow$ scattered light

  $\Rightarrow$ put absorbing materials everywhere
- Difficult, measure light phase with 10^{-12} precision

  $\Rightarrow$ $\sim$ 1 photon per second in 100 kW

Scattered light



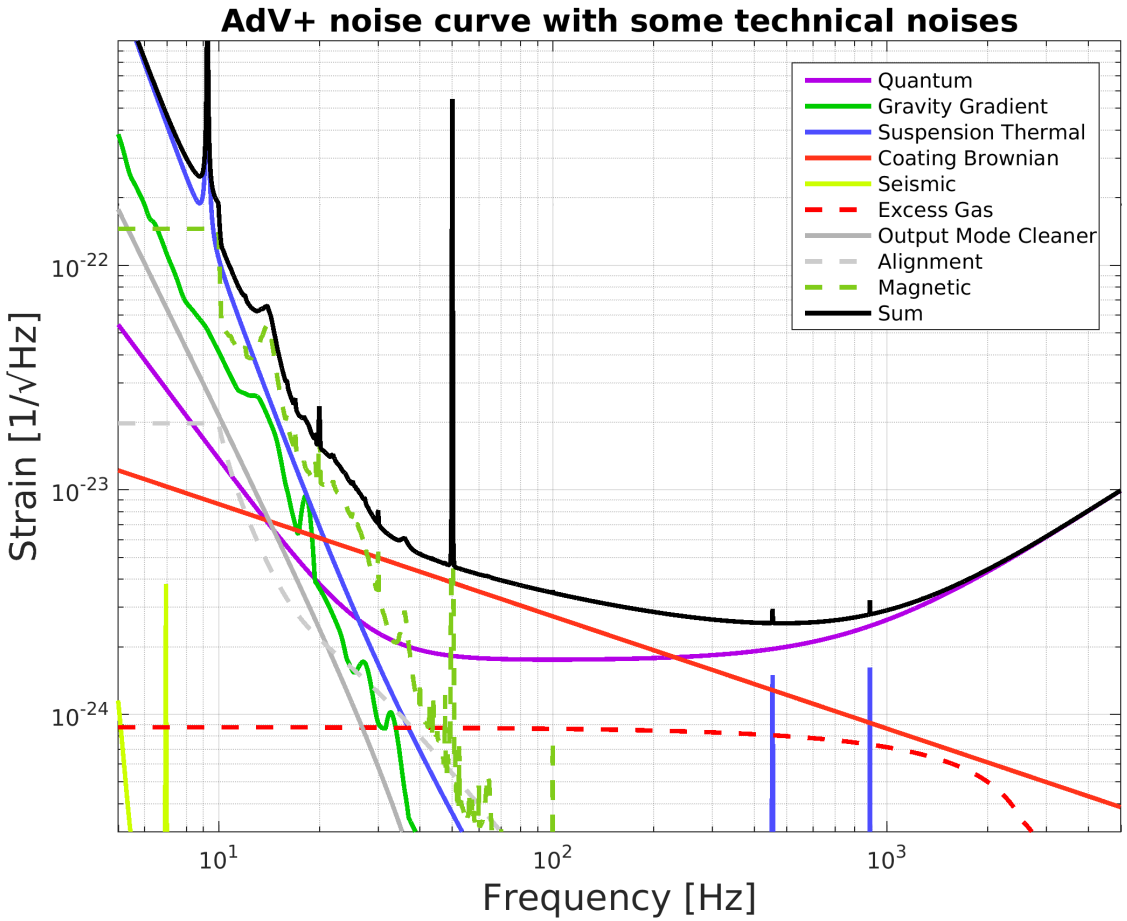


- $\sim$ 10% of light detected at various ports
- Non linear coupling of scattering surface motion $x(t)$

$$n(t) = K sin\left(\frac{4\pi}{\lambda} x(t)\right)$$

  - In bad weather ground motion at 0.3Hz leads to noise up to 50Hz
  - Improve relative position control of all objects (reduce $x(t)$)

Conclusion



- Technical noises are currently limiting Advanced Virgo
- Commissioning of Advanced Virgo still in early stages
- Tackling technical noises in Advanced Virgo+ will require further developments