Advanced Virgo and LIGO: today and tomorrow

Michał Wąs
for the LIGO and Virgo collaborations

Basics of interferometric gravitational wave detections

Need two ingredients: two test masses and a ruler

Basics of interferometric gravitational wave detections

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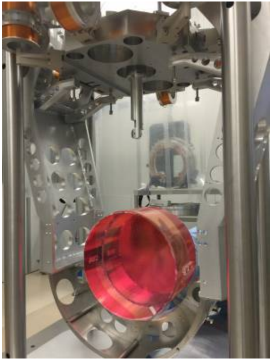
Test mass

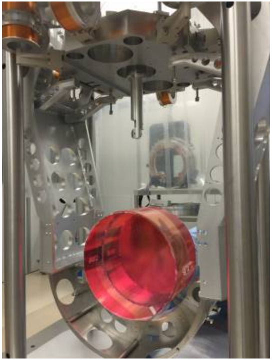


"Free falling" objects that sense the gravitational wave

Basics of interferometric gravitational wave detections

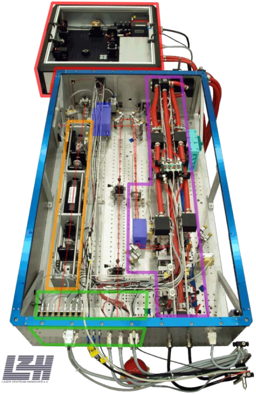
Need two ingredients: two test masses and a ruler

Test mass



"Free falling" objects that sense the gravitational wave

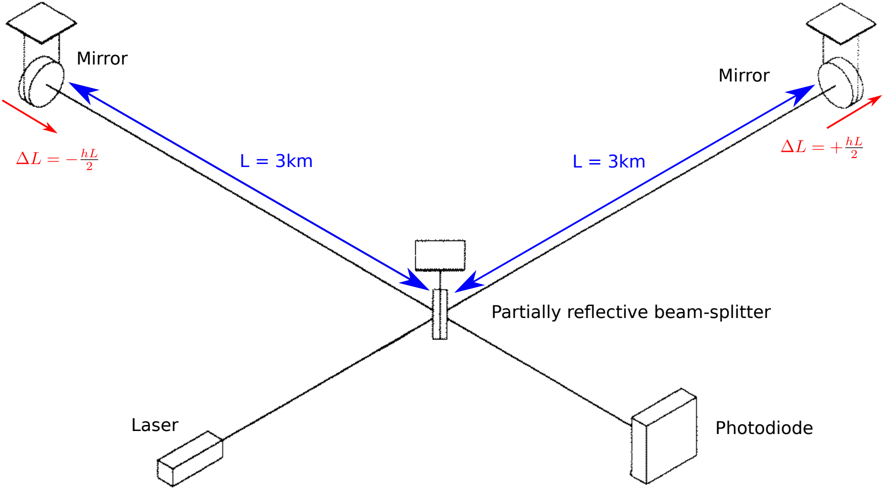
Ruler



⇒ laser light
→ the wavelength is the ruler tick mark

Basics of interferometric gravitational wave detections

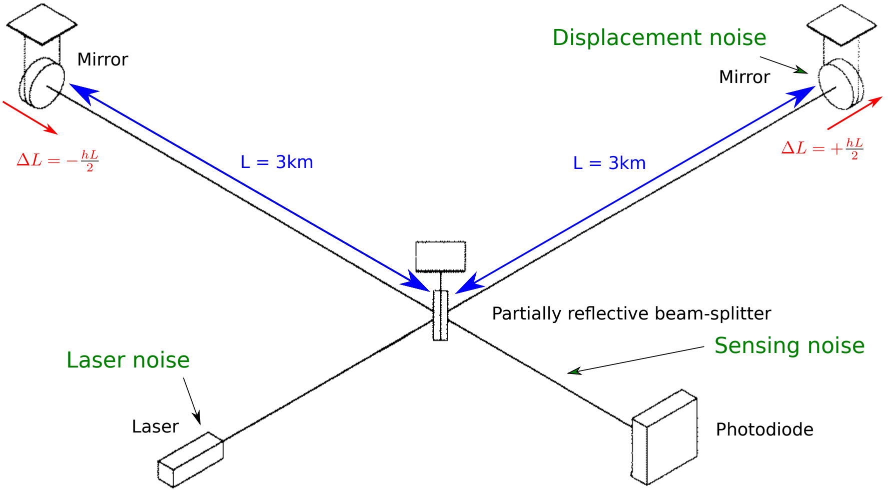
Need two ingredients: two test masses and a ruler



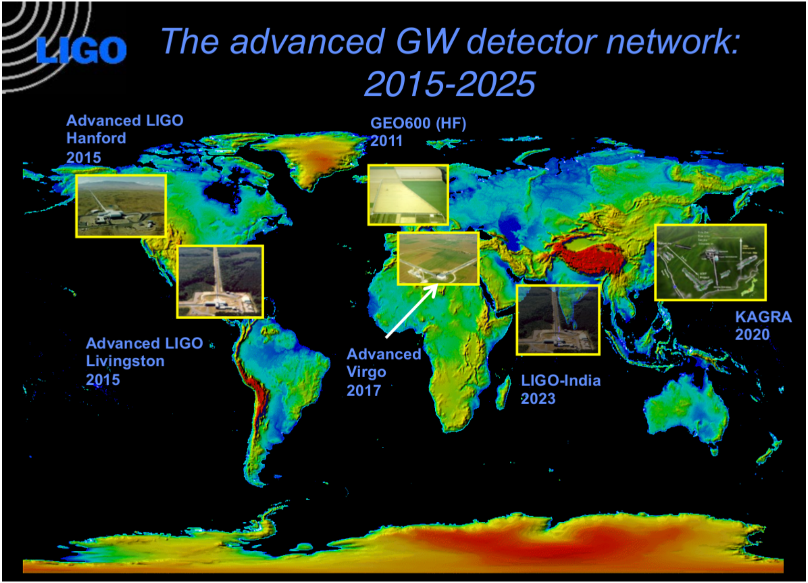
Longer arms $\longrightarrow$ larger effect

Basics of interferometric gravitational wave detections

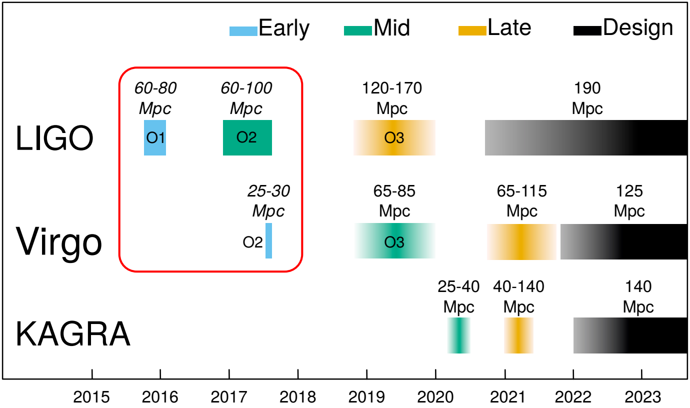
Noise can spoil measurements in many different ways



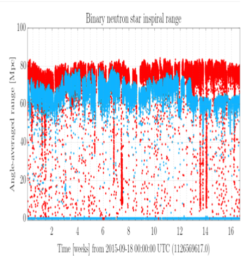
Noises don't increase with arm length

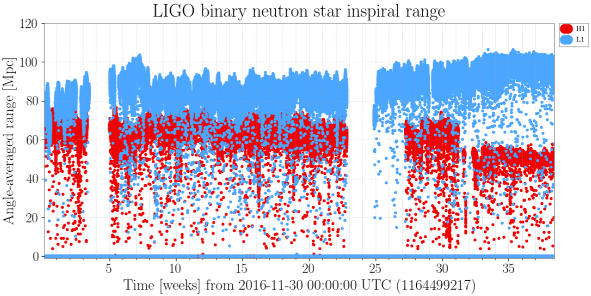

LIGO
The advanced GW detector network:
2015-2025
Advanced LIGO
Hanford
2015
GEO600 (HF)
2011
Advanced LIGO
Livingston
2015
Advanced
Virgo
2017
LIGO-India
2023
KAGRA
2020

Advanced detectors time-line

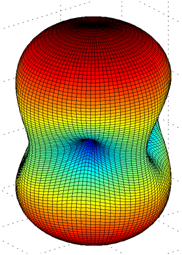


O2 vs O1 in LIGO

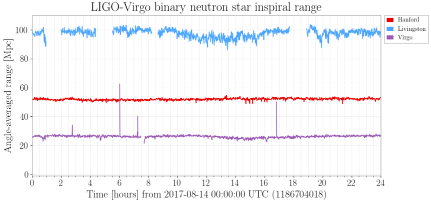


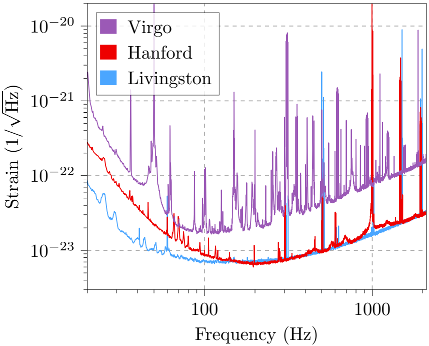


- Binary neutron star range:
  - Average horizon distance
  - Horizon $\simeq 2.26 \times$ range
- Similar sensitivity
- Longer duration
  - O1: 16 weeks, $\sim$50 days of coincident operations
  - O2: 37 weeks, $\sim$120 days of coincident operations



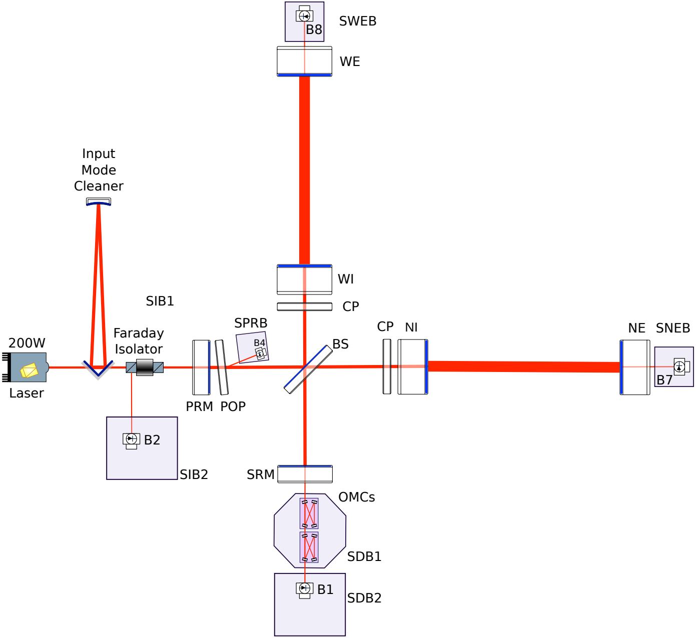
advanced Virgo joined O2 for last month



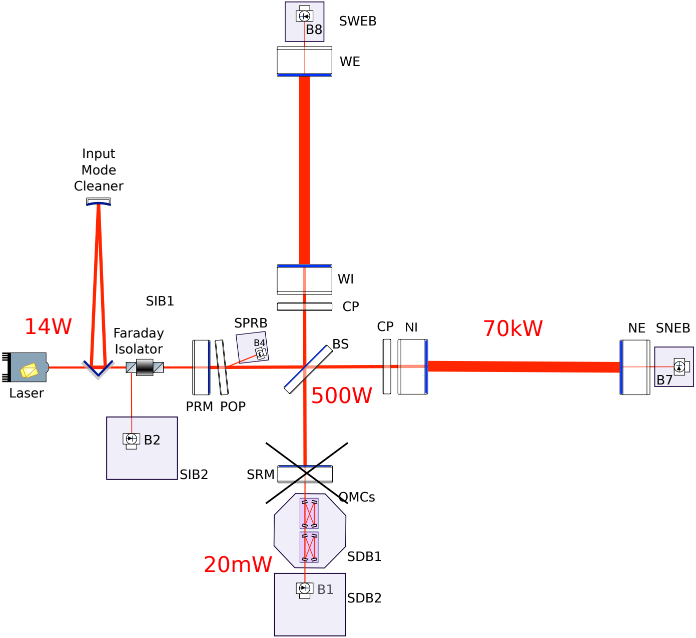


- Only 3.5 weeks
- Sensitivity 2-3 times lower than LIGO
- Very good stability, 82% duty cycle: 20 days of data
- Lots of science

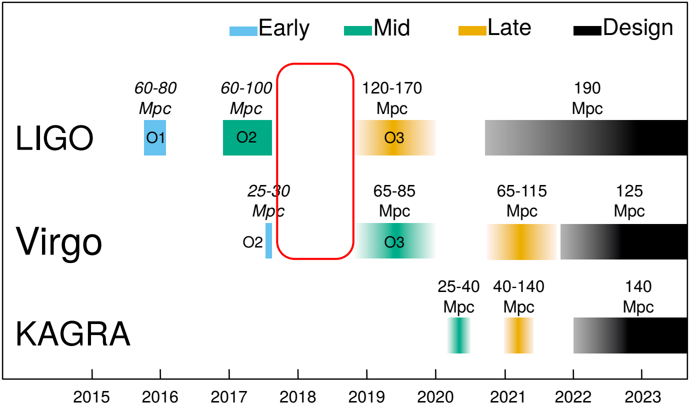
Advanced Virgo design



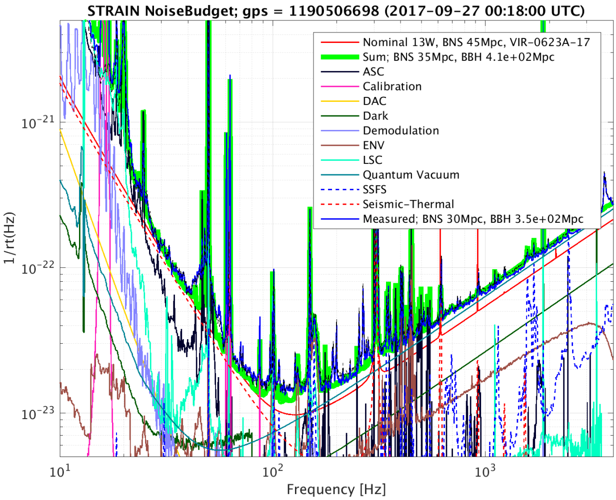
Advanced Virgo during O2



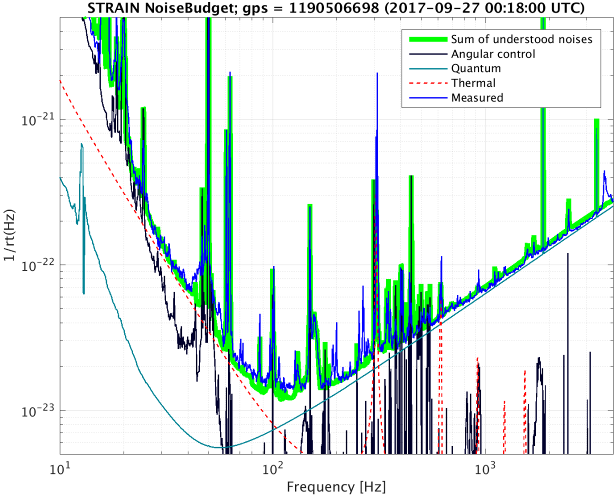
Advanced detectors time-line



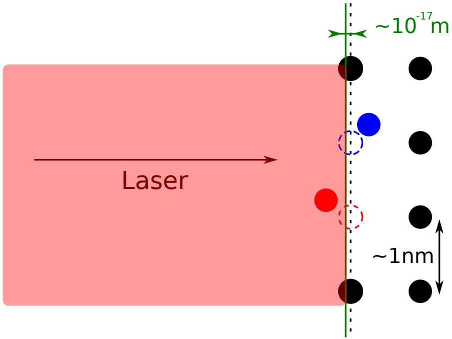
Advanced Virgo full noise budget



Advanced Virgo main limitations

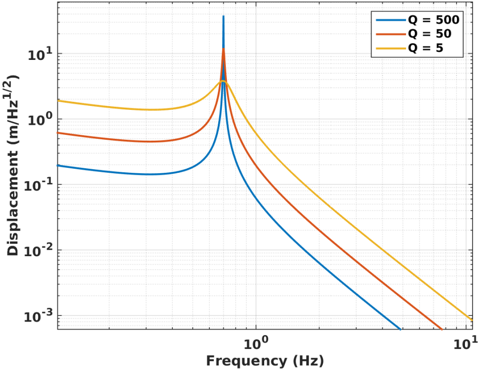


Thermal fluctuation: mirror surface moves by itself



- Atoms fluctuate by $\sim 10^{-9}$ m
- Laser probes over 10 cm $\times$ 10 cm $\Rightarrow$ $N \sim 10^{16}$ atoms
- Statistics saves us: $10^{-9}\,\mathrm{m}/\sqrt{N} \sim 10^{-17}$ m

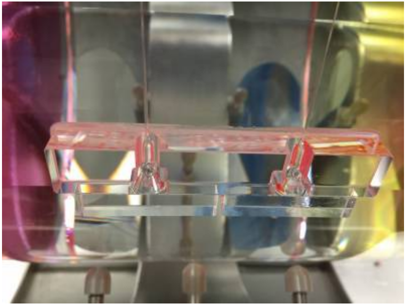
Thermal fluctuation: mirror surface moves by itself



- Low loss material $\longrightarrow$ high Q
- Concentrate thermal fluctuations at a single frequency
- Reduce fluctuations elsewhere by $1/\sqrt{Q}$

$$Q \sim 10^6 \Rightarrow \frac{10^{-17}\,\mathrm{m}}{\sqrt{Q}} \simeq 10^{-20}\,\mathrm{m}$$

Thermal fluctuation: mirror surface moves by itself



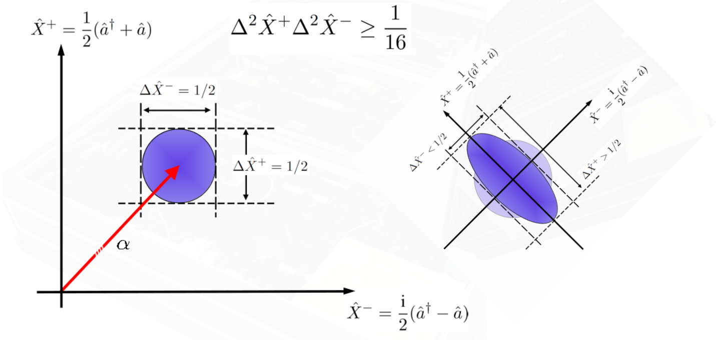
- Fused silica (suprasil) 40 kg mirrors
- Polished with roughness of 0.05 nm on 1 mm scale
- Curvature deviation of 1 nm over 10 cm
- Avoid glass-steel friction $\Rightarrow$ suspend mirrors on 0.4 mm glass fiber
- Improves Q from $\sim 10^6$ to $\sim 10^8$ $\longrightarrow$ factor 10 in thermal noise

- In 2016 glass fibers systematically broken by dust
  temporarily suspended mirrors on steel wires

Quantum shot noise

- Quantum fluctuations in number of detected photon in time τ

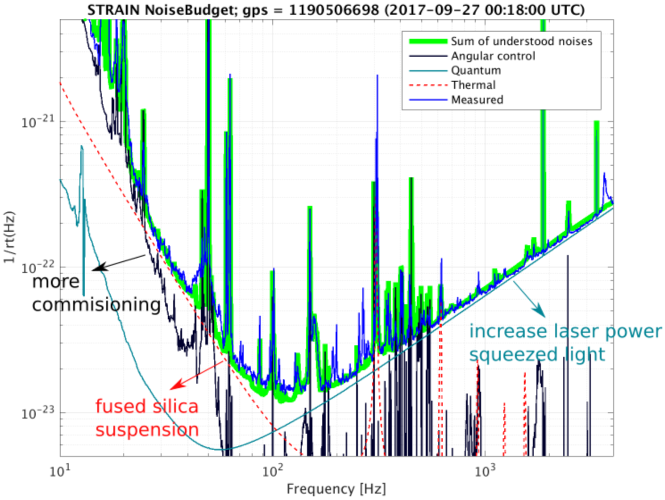
$$\frac{\Delta P}{P} = \sqrt{\frac{hc}{\tau \lambda P}}$$



Ways to reduce quantum shot noise:

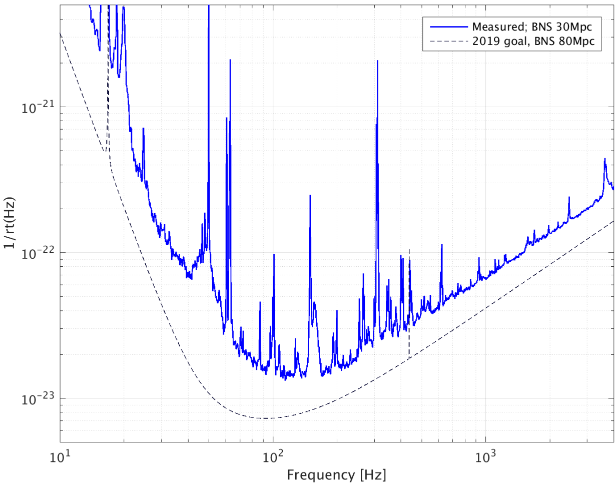
- higher power P, noise $\propto 1/\sqrt{P}$
- squeeze the light quantum state

Improvements planned for 2018



- High power laser 35 W $\longrightarrow$ 100 W
- Squeezing
- Mirror suspended on fused silica fiber

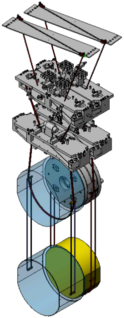
Improvements planned for 2018

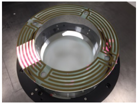


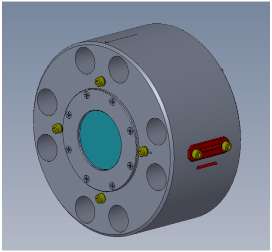
- High power laser 35 W $\longrightarrow$ 100 W
- Squeezing
- Mirror suspended on fused silica fiber

Improvement at LIGO

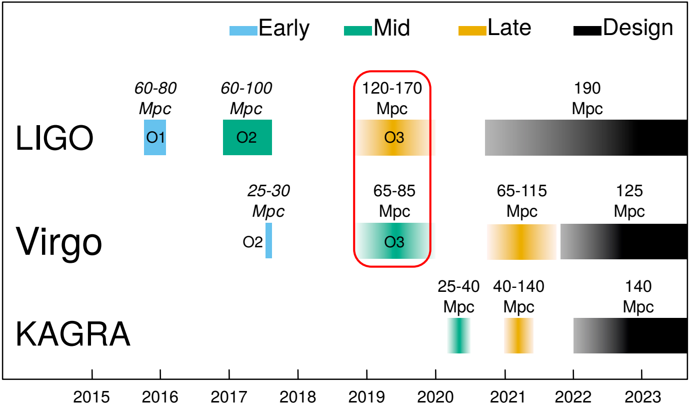
- Replace mirror with point defect at Hanford
- Change high power laser (200 W $\longrightarrow$ 70 W)
  $\longrightarrow$ less jitter due to water cooling
- Replace end mirrors and reaction mass
  - Better quality of coatings
  - Annular reaction mass
    $\longrightarrow$ remove squeezed film gas damping
- Monolithic signal recycling mirror





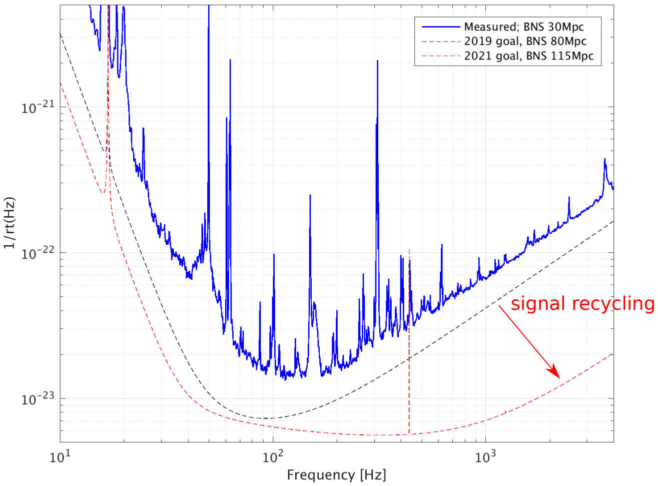


Advanced detectors time-line



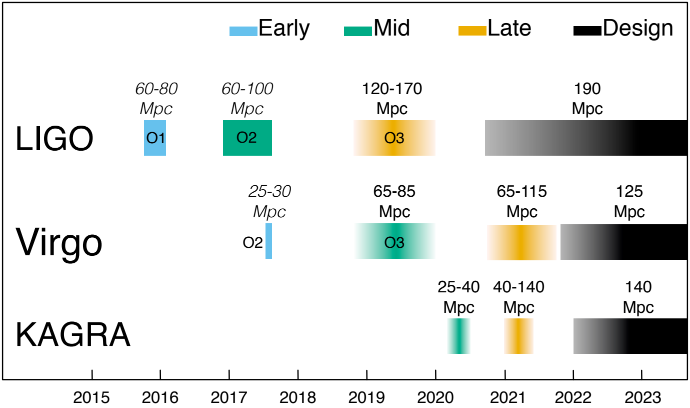
- O3 starts end of 2018 for $\sim$ 1 year

Following step after 2019 data taking



- Install signal recycling mirror
- ...

Summary



- LIGO and Virgo finished a very successful observing run in August 2017
- Many upgrades on-going till end of 2018
- A year long observation in 2019
- More improvements will follow