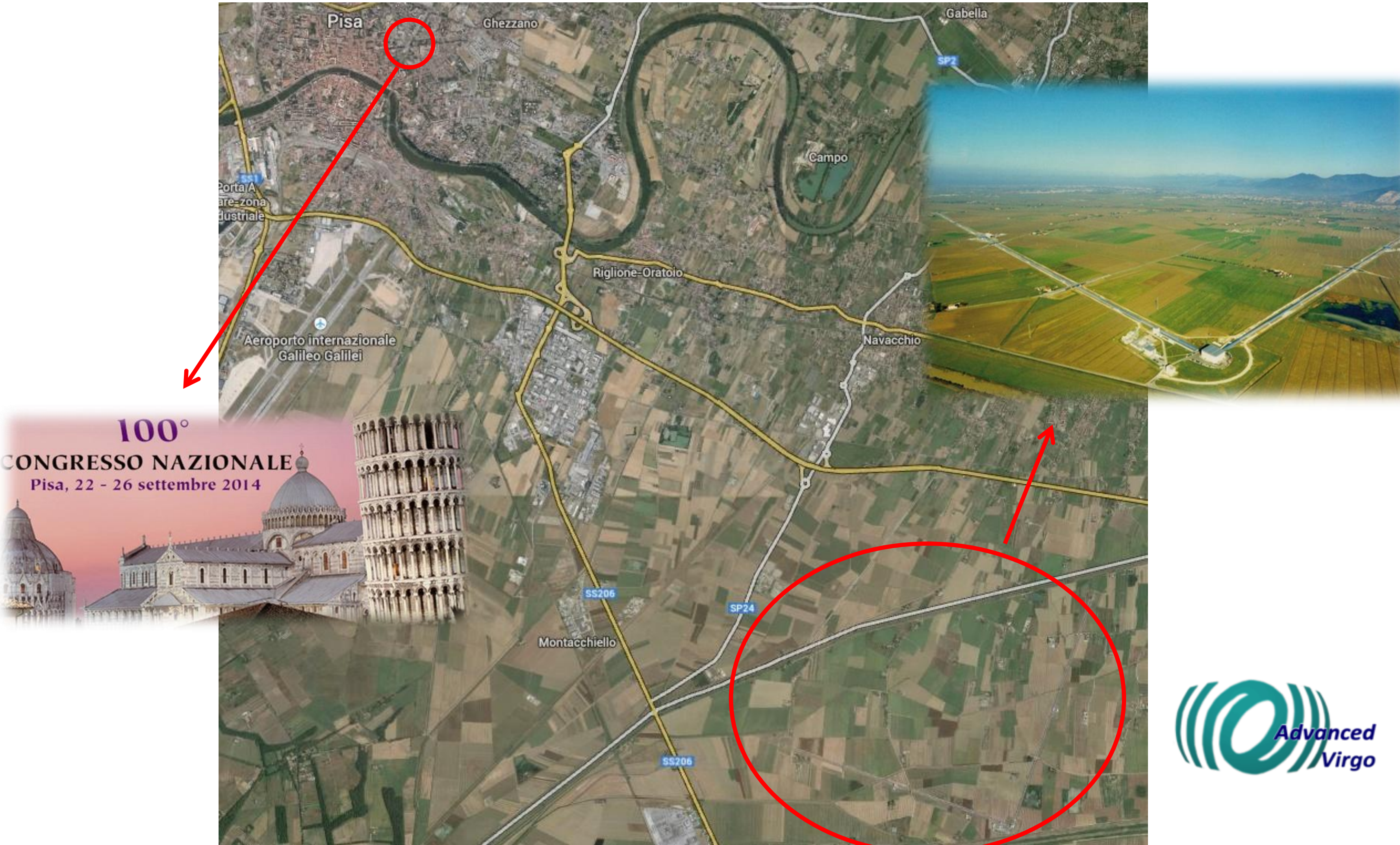
Advanced Virgo: Status and Perspectives

A.Chiummo
on behalf of the VIRGO collaboration

Advanced Virgo



Advanced Virgo

EGO - VIRGO

Advanced Virgo

EGO - VIRGO

Advanced Virgo

In a nutshell:

- Advanced Virgo (AdV): upgrade of the Virgo interferometric detector of gravitational waves
- Participated by scientists from Italy and France (former founders of Virgo), The Netherlands, Poland and Hungary
- Funding approved in Dec 2009
- Construction in progress. End of installation: fall 2015
- First science data in 2016

5 European countries
19 labs, ~200 authors

APC Paris
ARTEMIS Nice
EGO Cascina
INFN Firenze-Urbino
INFN Genova
INFN Napoli
INFN Perugia
INFN Pisa
INFN Roma La Sapienza
INFN Roma Tor Vergata
INFN Trento-Padova
LAL Orsay – ESPCI Paris
LAPP Annecy
LKB Paris
LMA Lyon
NIKHEF Amsterdam
POLGRAW(Poland)
RADBOUD Uni. Nijmegen
RMKI Budapest

What's going on (and why)?

EGO - VIRGO

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What's going on (and why)?

What's going on (and why)?
To answer the question, let's come back to some one hundred years ago…

Gravitational Waves

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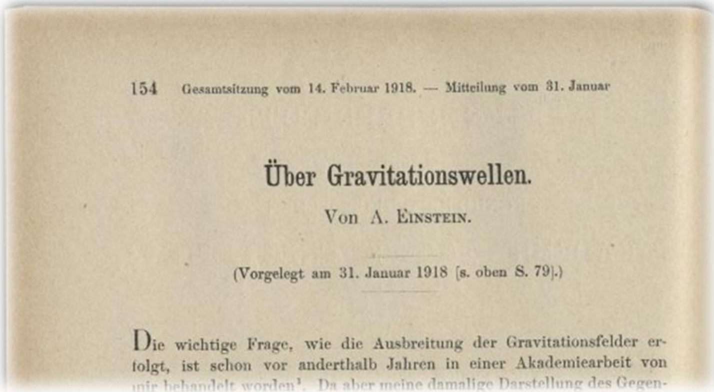


154 Gesamtsitzung vom 14. Februar 1918. — Mitteilung vom 31. Januar

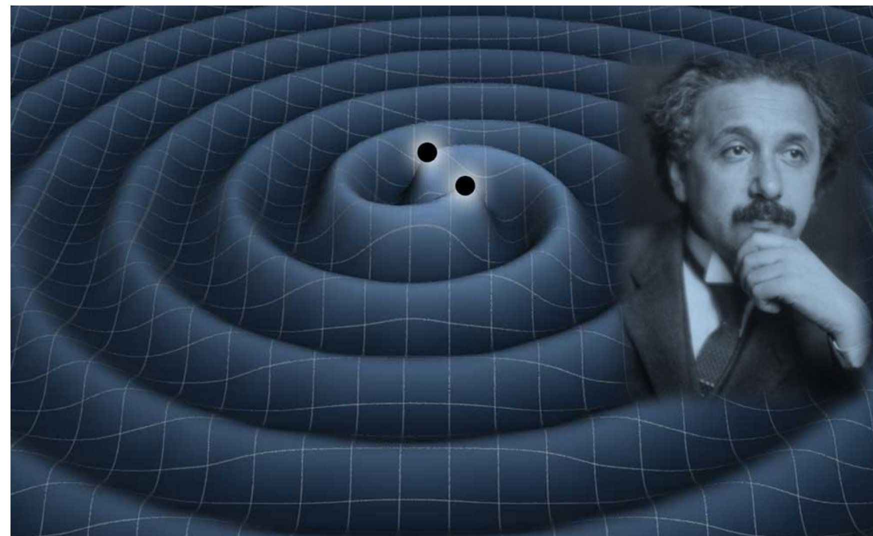
Über Gravitationswellen.

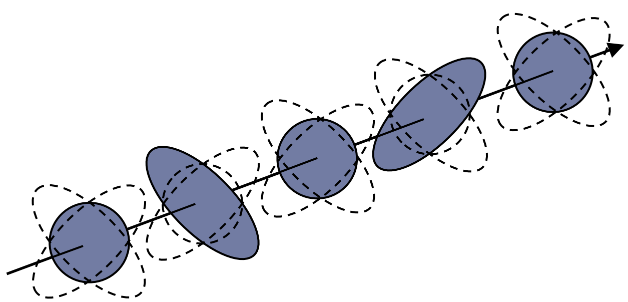
Von A. Einstein.

(Vorgelegt am 31. Januar 1918 [s. oben S. 79].)

Die wichtige Frage, wie die Ausbreitung der Gravitationsfelder erfolgt, ist schon vor anderthalb Jahren in einer Akademiearbeit von mir behandelt worden[1]. Da aber meine damalige Darstellung des Gegen-

... when Einstein firstly predicted the gravitational waves





Tiny interaction with matter:
- Extremely difficult to detect
- Ideal messengers from remote space-time regions

❑ **What are GWs?**
- a consequence of General Relativity
- ripples in space-time due to cosmic cataclisms
- quadrupolar distortions of distances between freely falling masses

Gravitational Waves

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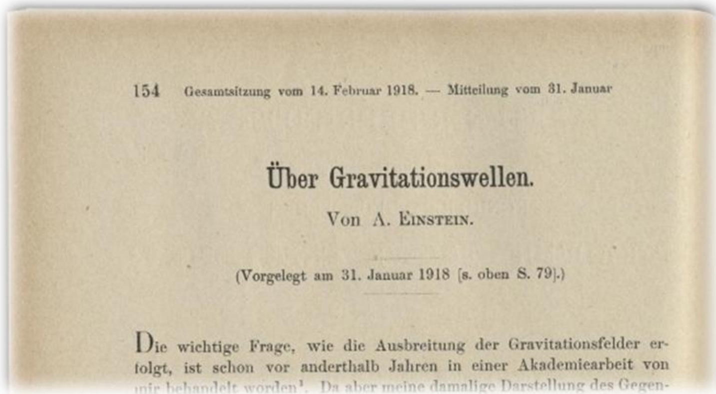

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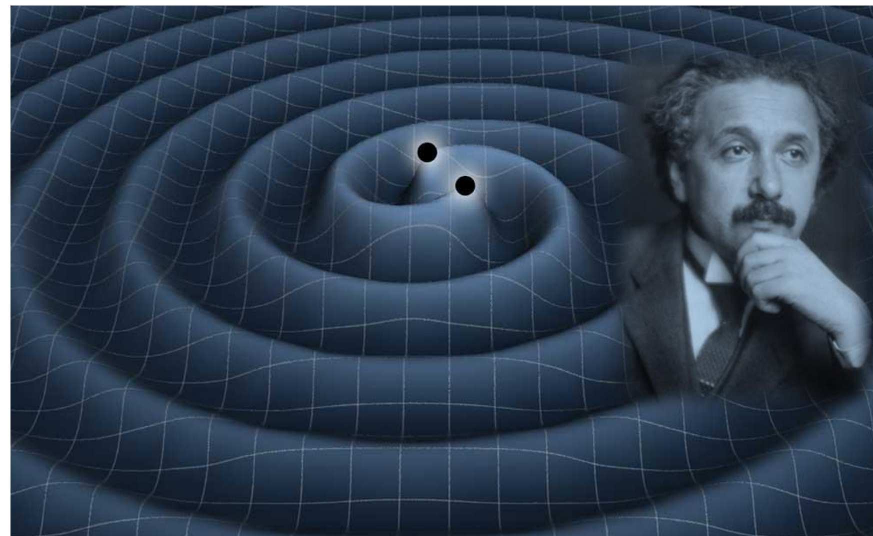

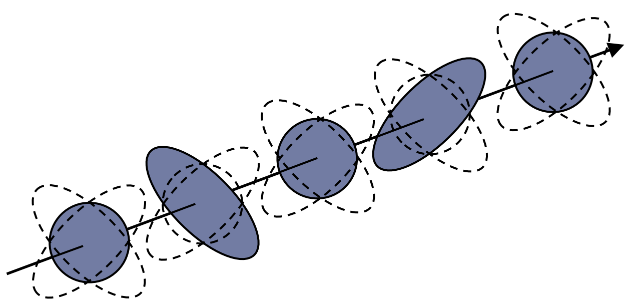

Tiny interaction with matter:

- Extremely difficult to detect
- Ideal messengers from remote space-time regions

Does this radiation exist?

❑ **What are GWs?**

- a consequence of General Relativity
- ripples in space-time due to cosmic cataclisms
- quadrupolar distortions of distances between freely falling masses

Gravitational Waves

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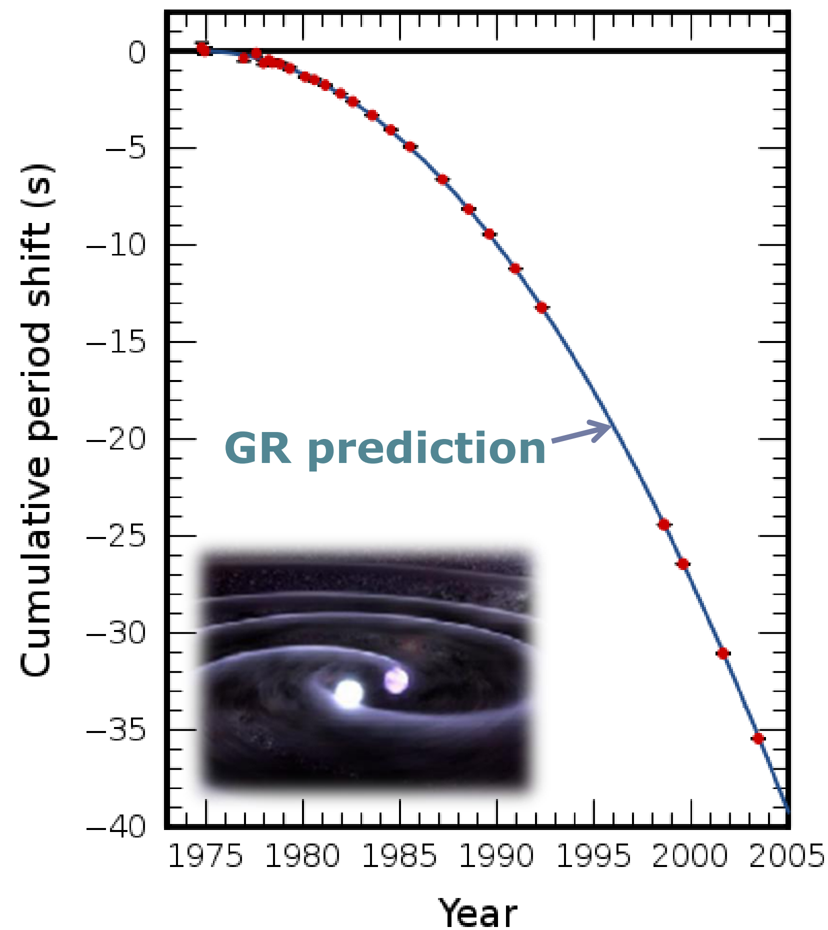
Indeed…

The Nobel Prize in Physics 1993
Russell A. Hulse, Joseph H. Taylor Jr.

Ok, but how to *directly* detect it?

Binary Pulsar 1913+16



J. M. Weisberg, J. H. Taylor,
http://arxiv.org/abs/astro-ph/0407149

GW Detectors

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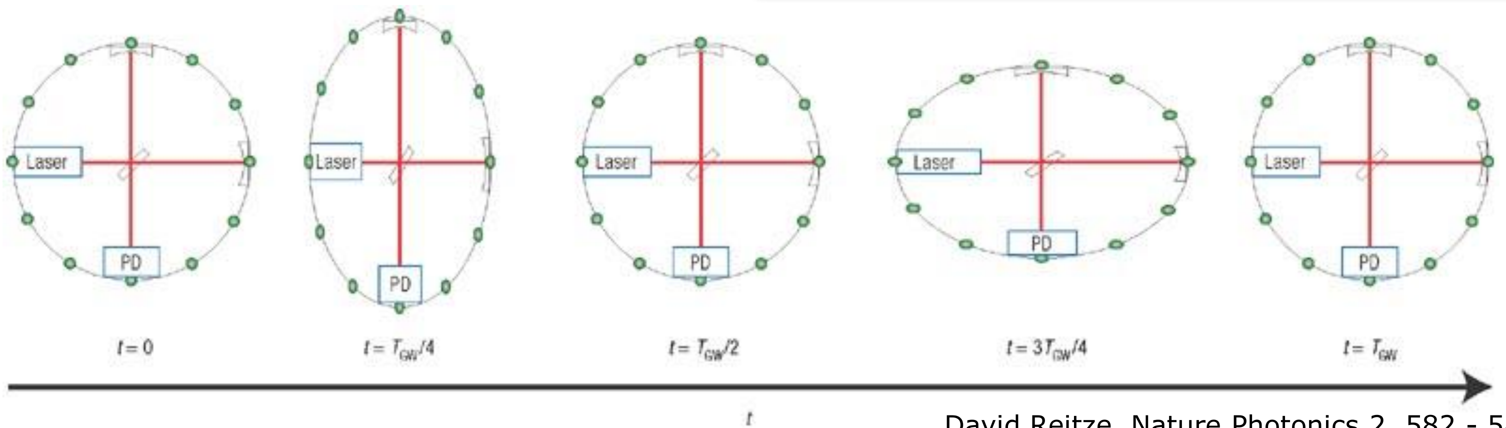
Ok, but how to *directly* detect it?



David Reitze Nature Photonics 2, 582 - 585 (2008)

- Michelson interferometer is a natural candidate
- GW amplitude given by dimensionless strain h:

$$h = \Delta L / L \approx 10^{-22} m / m$$

- ***Long arms***
- ***Low noise***

GW Detectors

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- ***Long arms***
- ***Low noise***

- **Long arms: 3km (“easy”)**
- **“only” the largest vacuum environment in Europe**

GW Detectors - Noise

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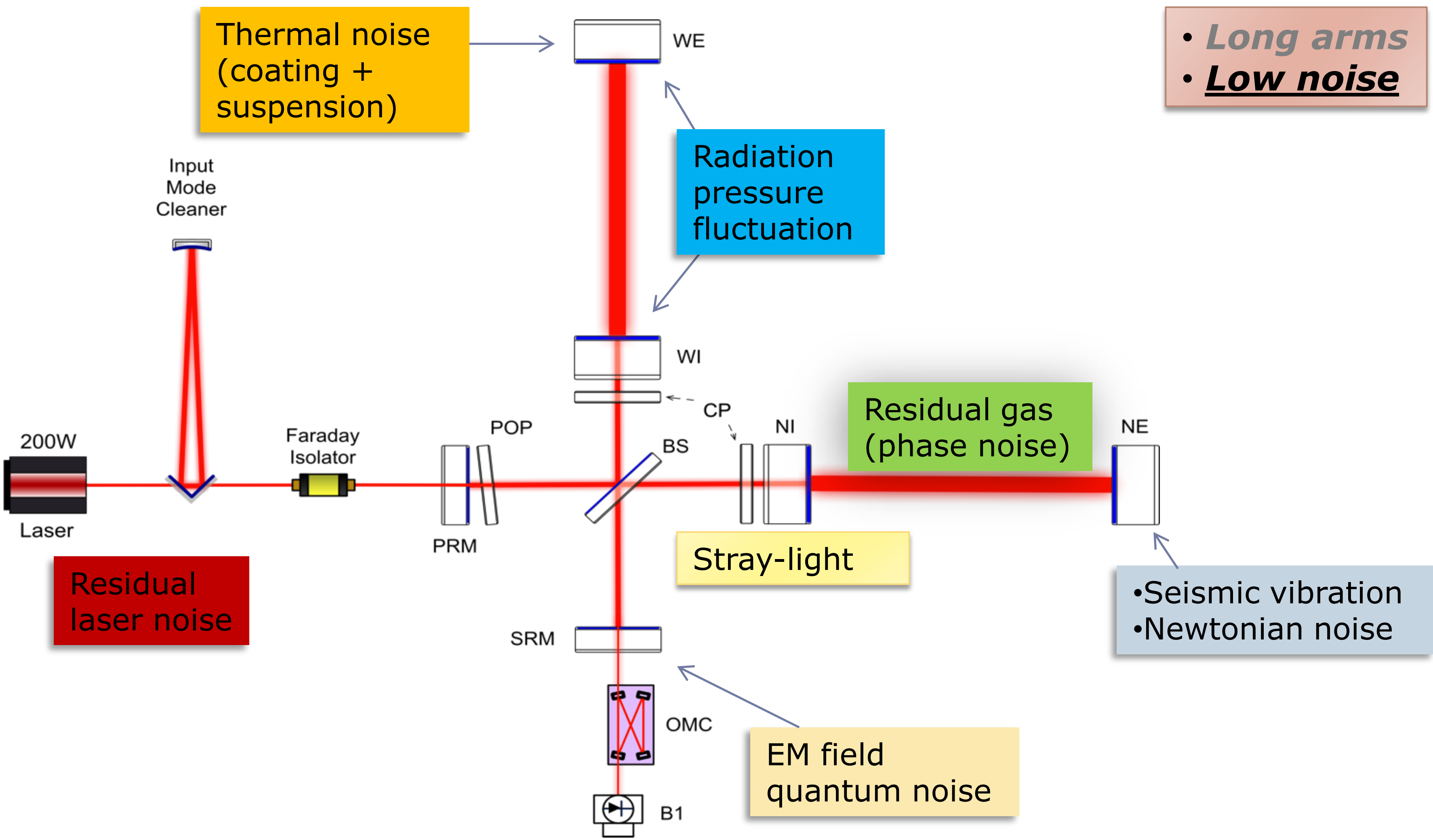
- ***Long arms***
- ***Low noise***



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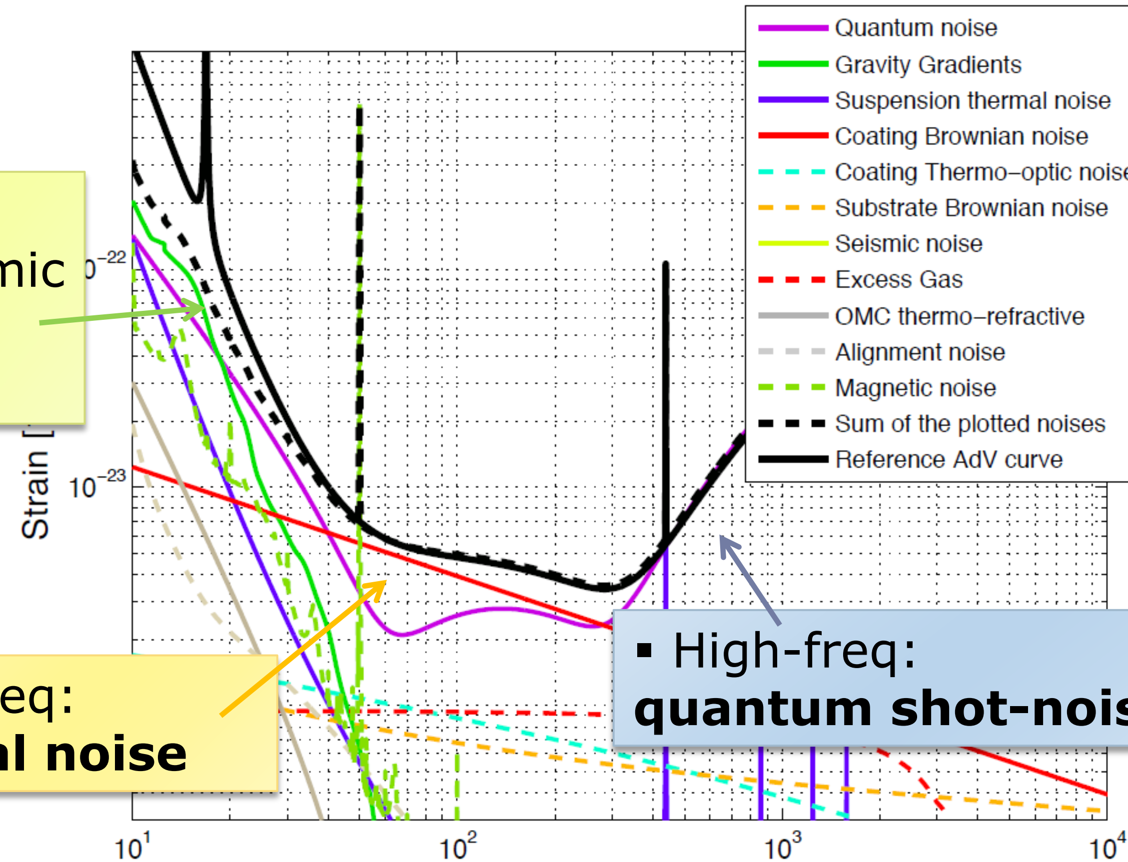
GW Detectors - Noise

- *Long arms*
- ***Low noise***

Limiting noises:



- Low-freq: **newtonian noise**, seismic noise, residual technical noises
- Mid-freq: **thermal noise**
- High-freq: **quantum shot-noise**

GW Detectors - Noise

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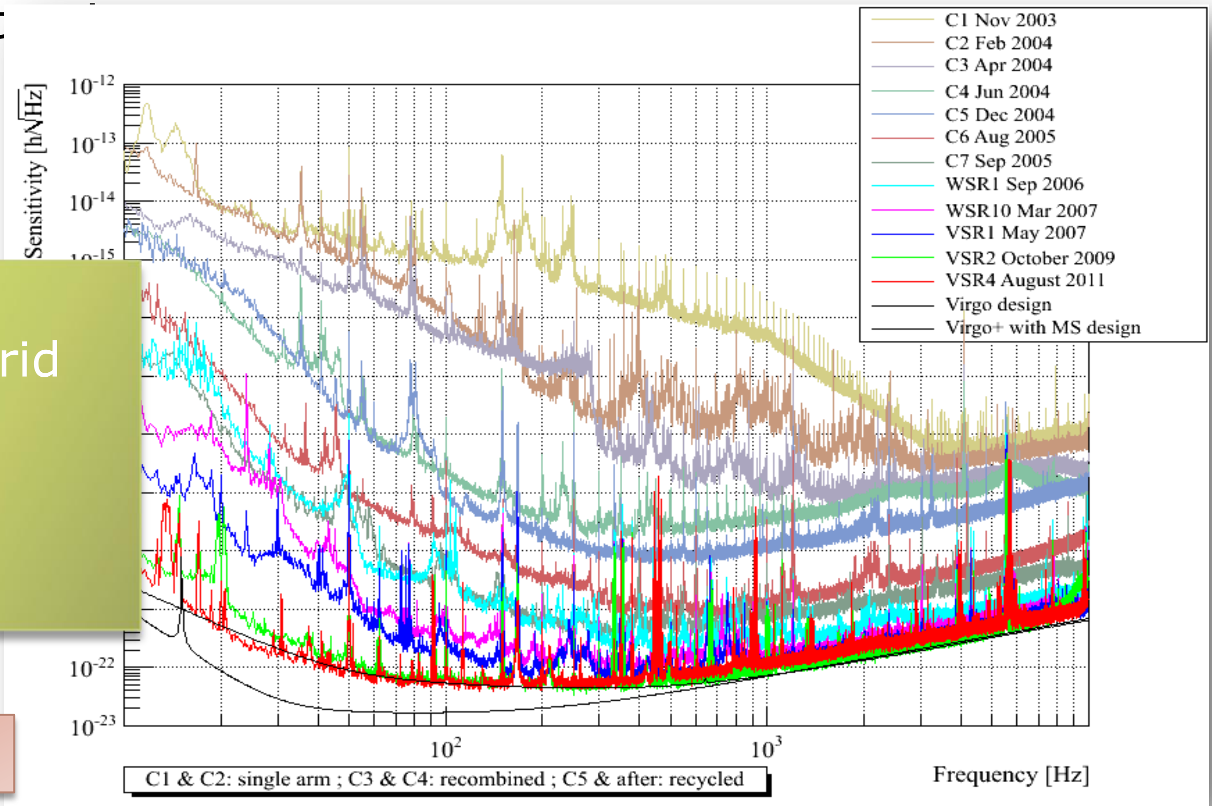
<u>Limiting noises:</u>

- Low-freq: seismic noise
- Mid-freq: thermal noise
- High-freq: laser shot



It took 10 years of commissioning to get rid of excess "technical noises" with Virgo:

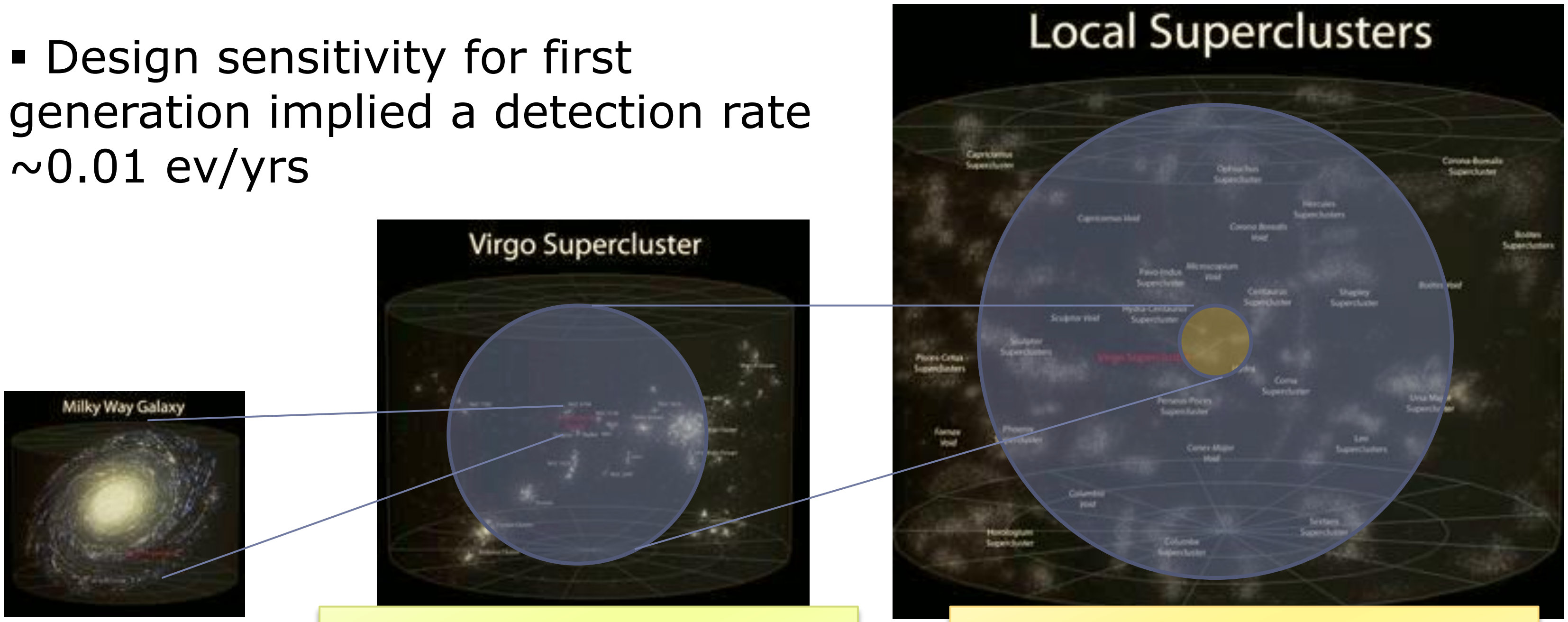
We learned a lot

But no detection yet!

GW Detectors -Horizons

But no detection yet...

- Design sensitivity for first generation implied a detection rate ~0.01 ev/yrs



1st gen GW detectors

Advanced GW detectors

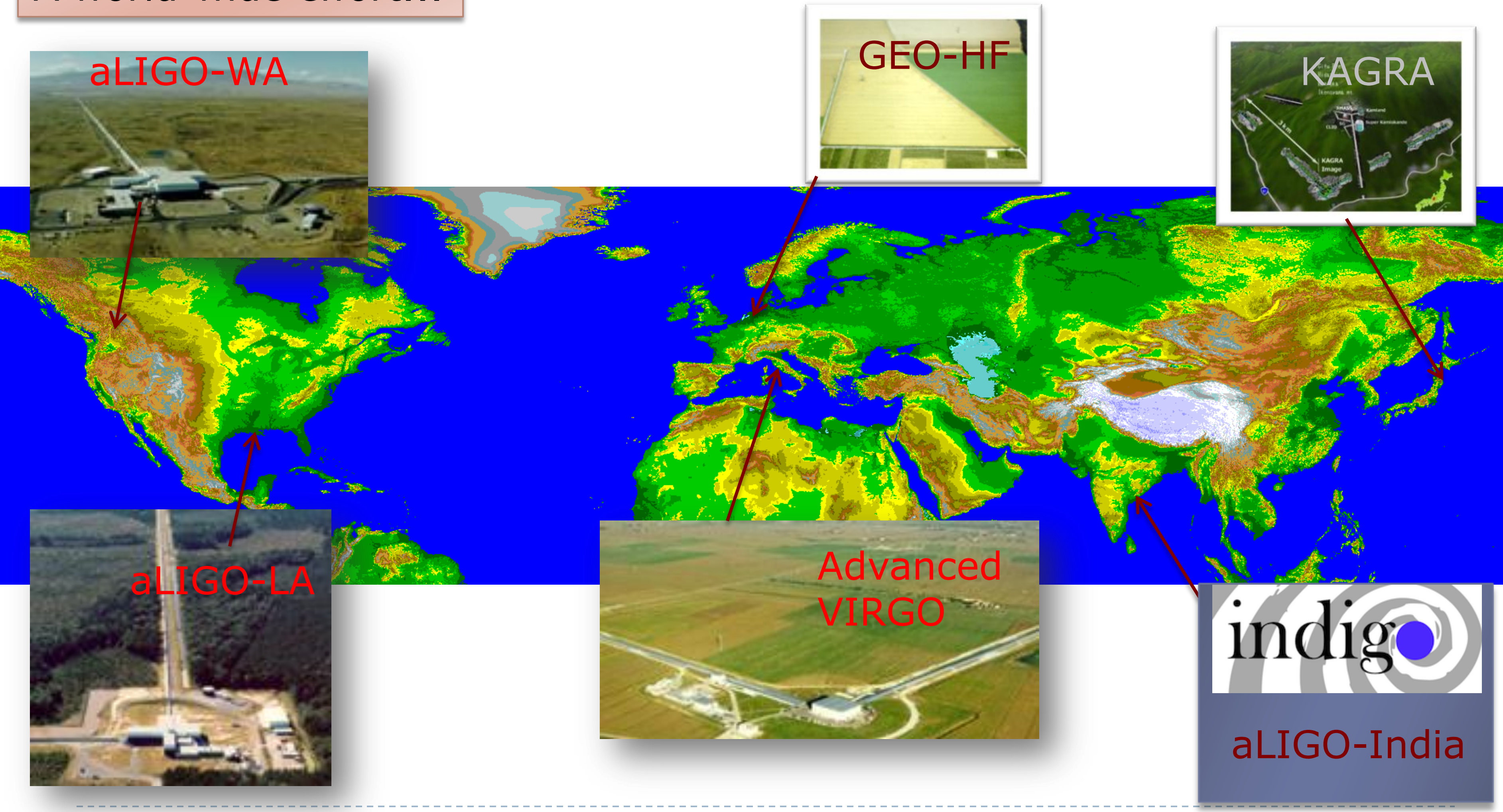
- Improved sensitivity is needed for GW astronomy
- Explore a volume 1000x bigger → strain noise (h) 10x lower

We need to modify the hardware...

GW Detectors – The network

EGO - VIRGO

A world-wide effort...



GW Detectors – Advanced Virgo

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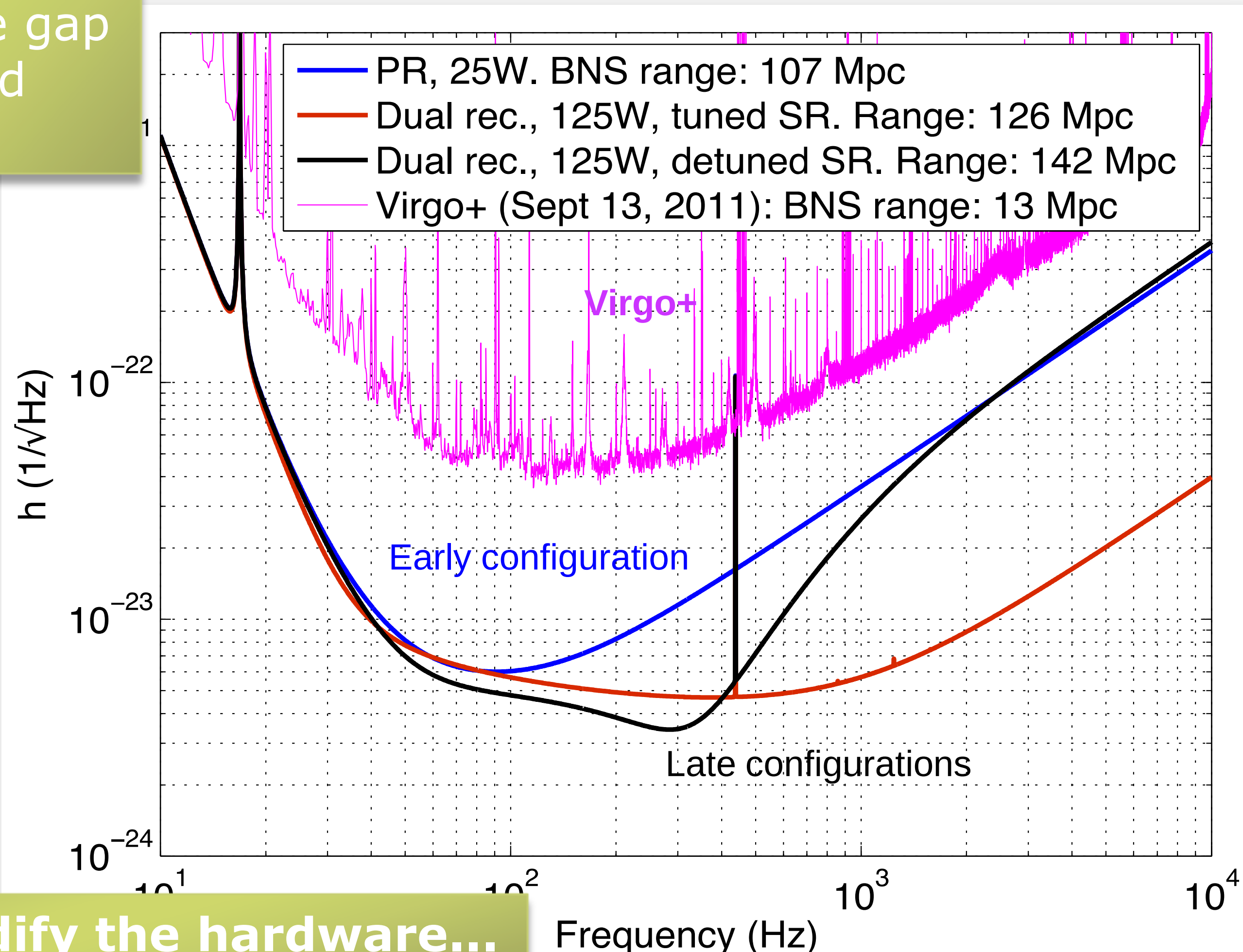
How do we fill the gap between Virgo and Advanced Virgo?

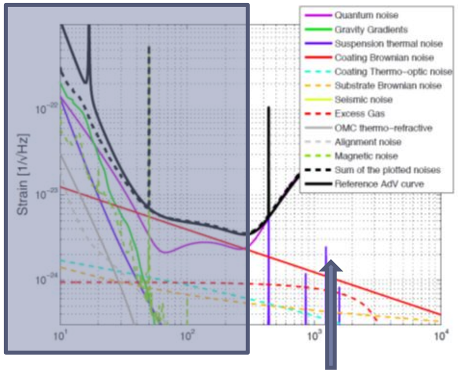


We need to modify the hardware…

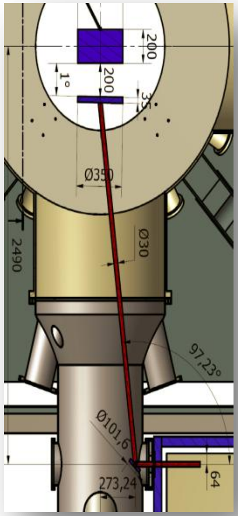
GW Detectors – Advanced Virgo

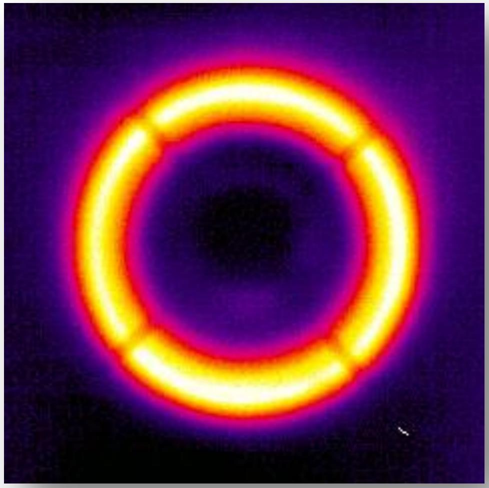
EGO - VIRGO

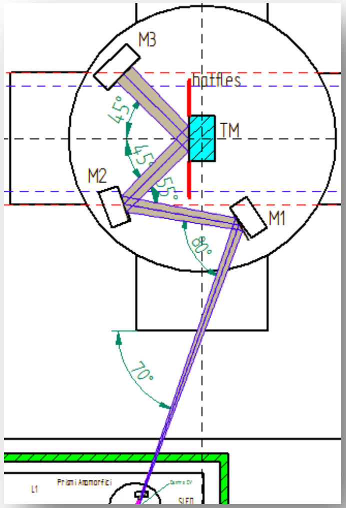
- High frequency range:
  - Dominated by laser shot noise.
    Improved by increasing the power:
    >100W input, ~1 MW in the cavities

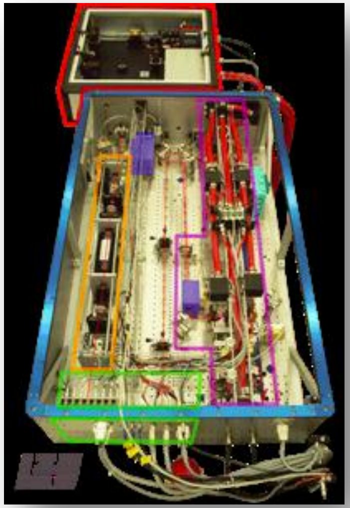


- Requires:
  - New laser amplifiers (solid state, fiber)
  - Heavy, low absorption optics (substrates, coatings)
  - Sophisticated systems to correct for thermal aberrations





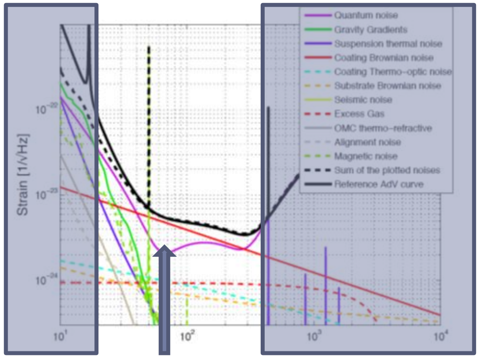




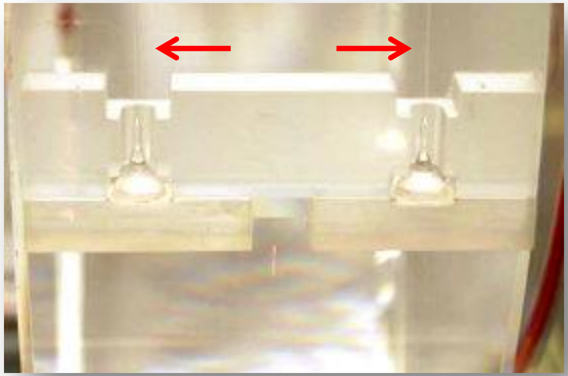
GW Detectors – Advanced Virgo

EGO - VIRGO

- Mid frequency range:
  - Dominated by thermal noise of mirror coatings and suspensions



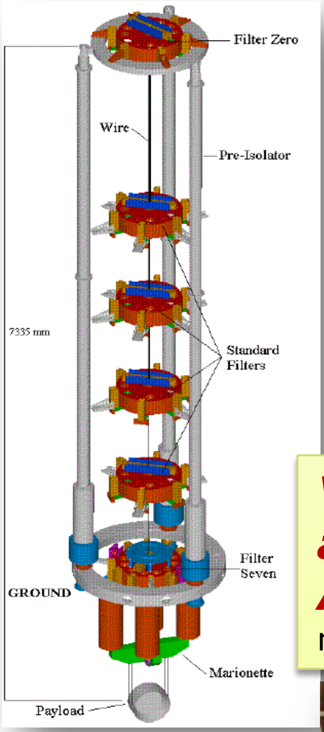
- Reduced by:
  - ***Larger beam spot*** (sample larger mirror surface)
  - Test masses suspended by fused silica fibers (low mechanical losses)
  - Mirror coatings engineered for low losses

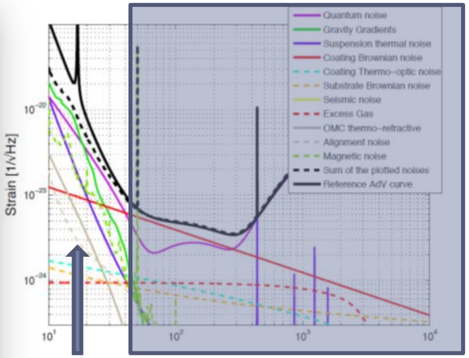


GW Detectors – Advanced Virgo

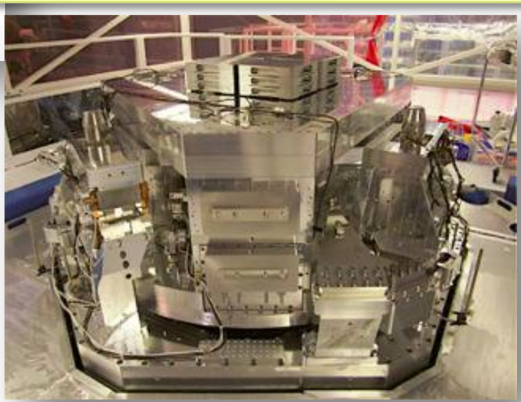
EGO - VIRGO

- Low frequency range:
  - Dominated by seismic noise
  - Managed by suspending the mirrors from extreme vibration isolators
  - Technical noises of different nature are the real challenge in this range
  - Ultimate limit for ground-based detectors:
    gravity gradient noise





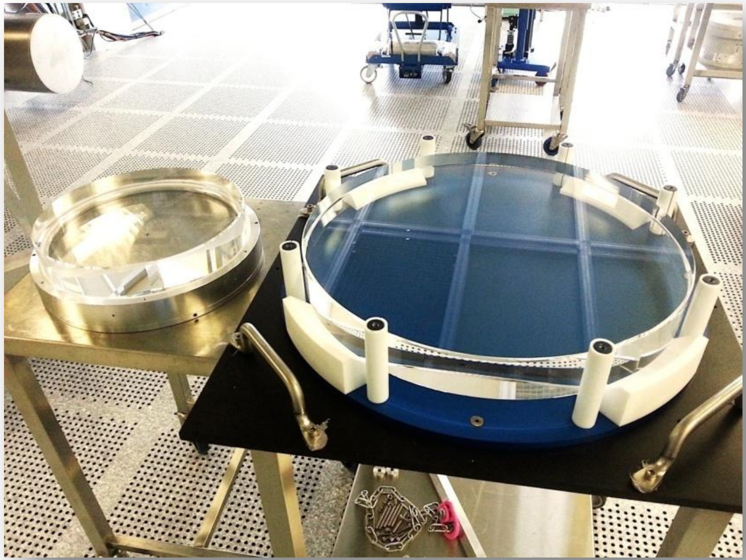
Virgo suspensions already compliant with AdV sensitivity (upgrade needed for new payloads)

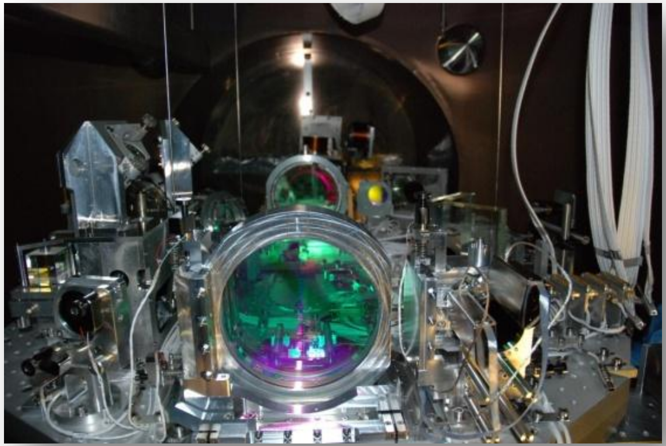


GW Detectors – Advanced Virgo

EGO - VIRGO

- Impact of larger beam:
  - required new vacuum links
  - re-design of input benches, telescopes
  - large BS (55cm)

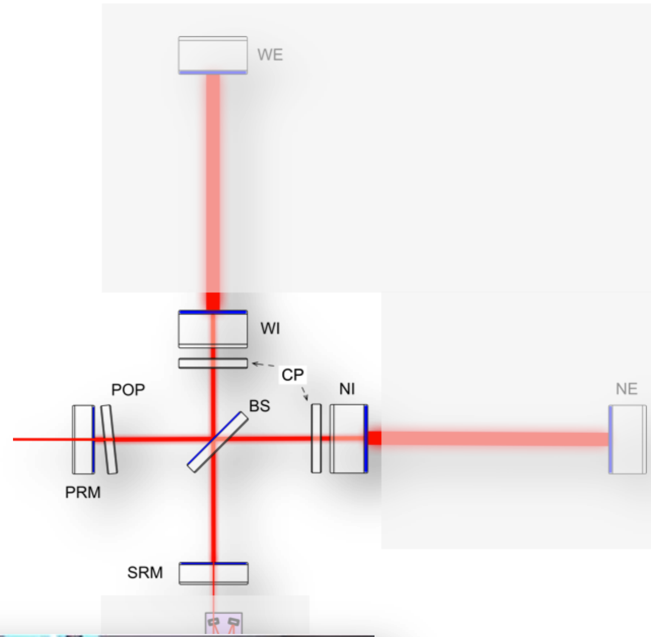




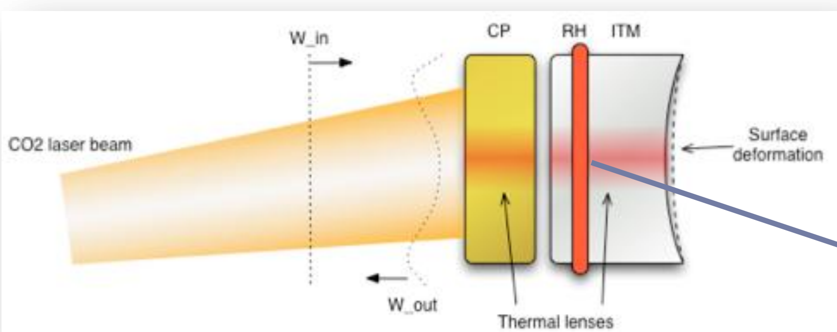
GW Detectors – Advanced Virgo

EGO - VIRGO

- Impact of larger beam:
  - Fit larger beam in the same topology as for Virgo → higher degeneracy in recycling cavities!
  - Control sidebands high order modes are nearly resonant and very sensitive to thermal effects, substrate defects



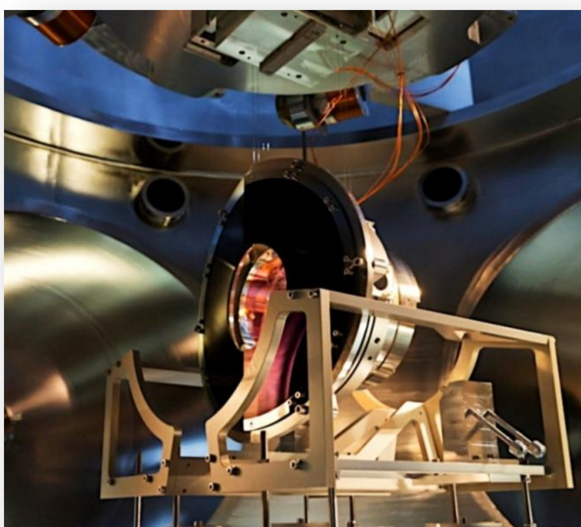
- Requires proper management of aberrations
  - Optics quality
  - Active aberrations control

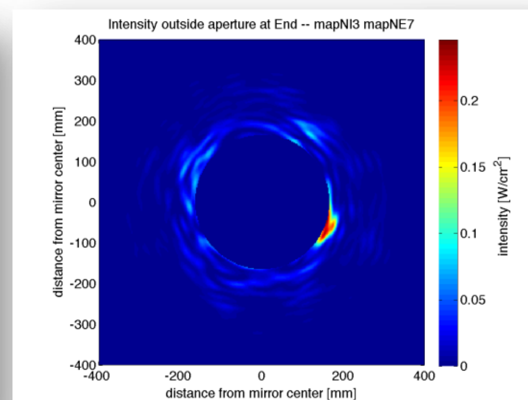


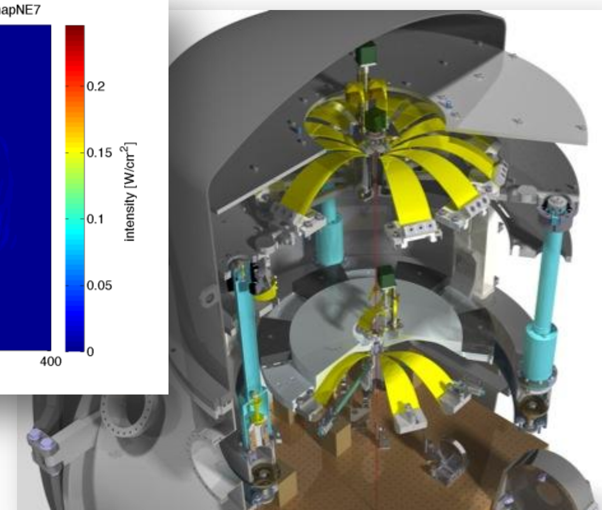
GW Detectors – Advanced Virgo

EGO - VIRGO

- Stray-light mitigation:
  - Learned form 1st generation: scattered light is one of the major risks towards the final sensitivity goal
  - Large investment to mitigate it:
    - Better optics quality
    - Baffles to shield mirrors, pipes, vacuum chambers exposed to scattered light
    - Photodiodes suspended in vacuum to isolate them from acoustic/seismic noise
    - If required, control the position of the benches wrt the interferometer
    - Significant simulation effort







From Virgo to ***Advanced Virgo***

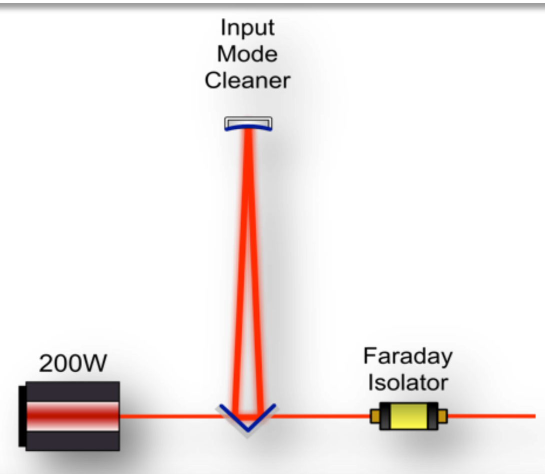
EGO - VIRGO

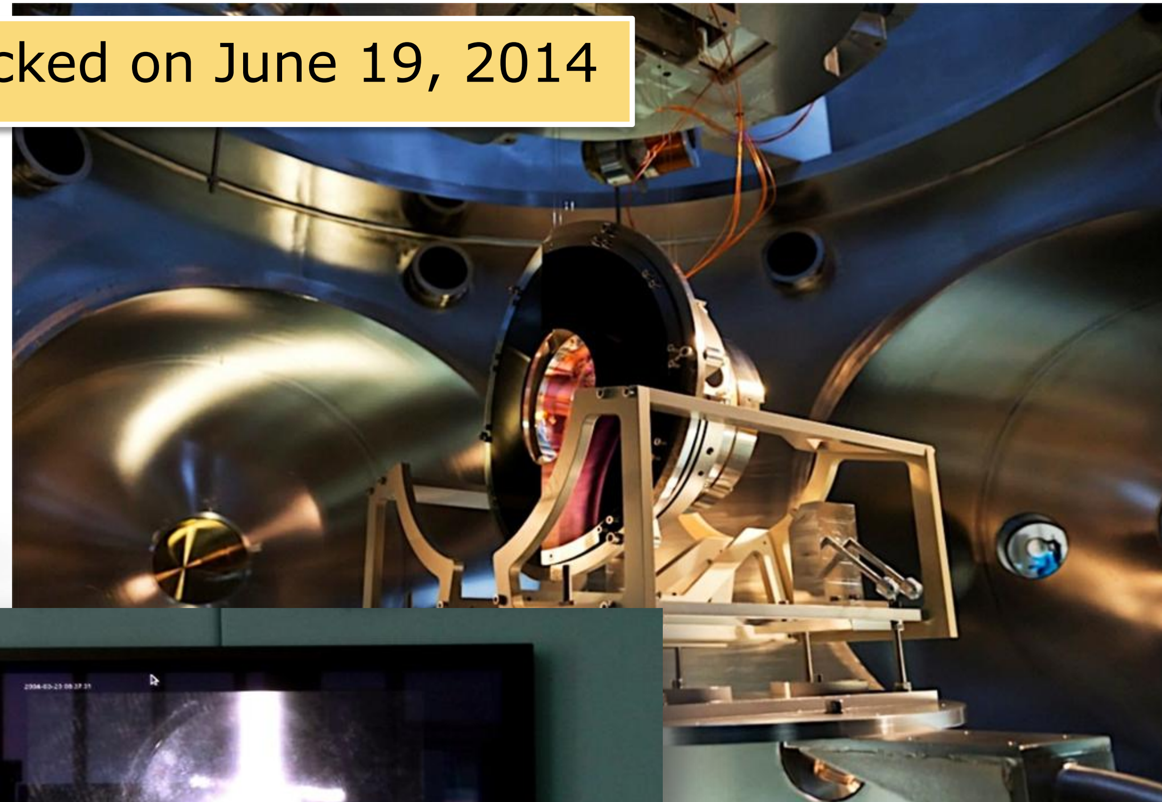
Where are we now?

AdV - Current Status

EGO - VIRGO

Input mode cleaner locked on June 19, 2014

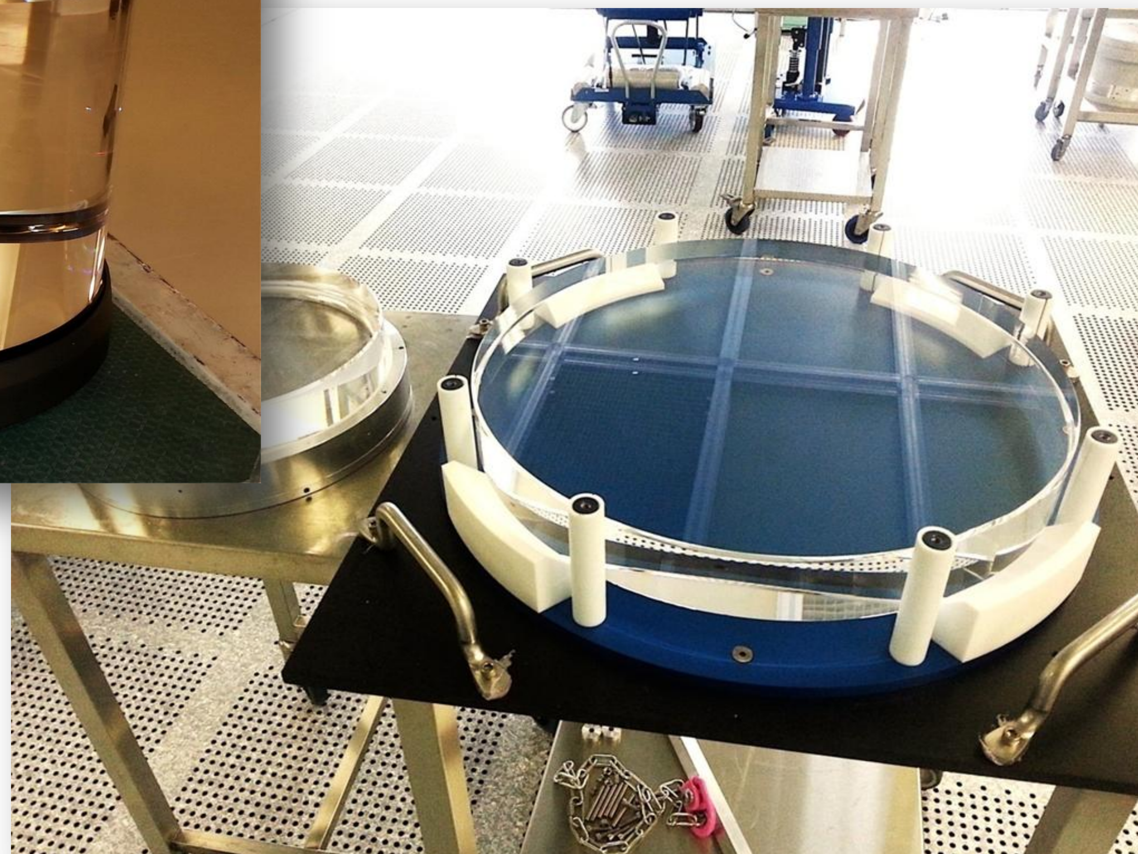




First top level milestone achieved on schedule.

AdV - Current Status

Most of the large optics polished



The surface figure of the polished test masses is better than specifications

AdV - Current Status

EGO - VIRGO

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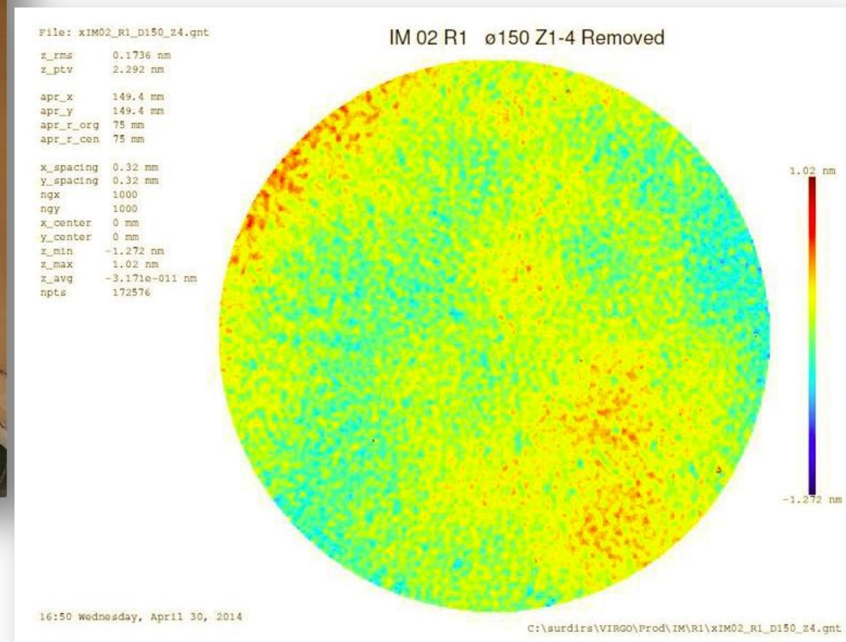


The surface figure of the polished test masses is better than specifications

IM02: Flatness: 0.17 nm rms on 150mm Ø (spec.: 0.5 nm rms)
RoC: 1425 m (spec.: 1420 [-5,+15] m)

AdV - Current Status

EGO - VIRGO

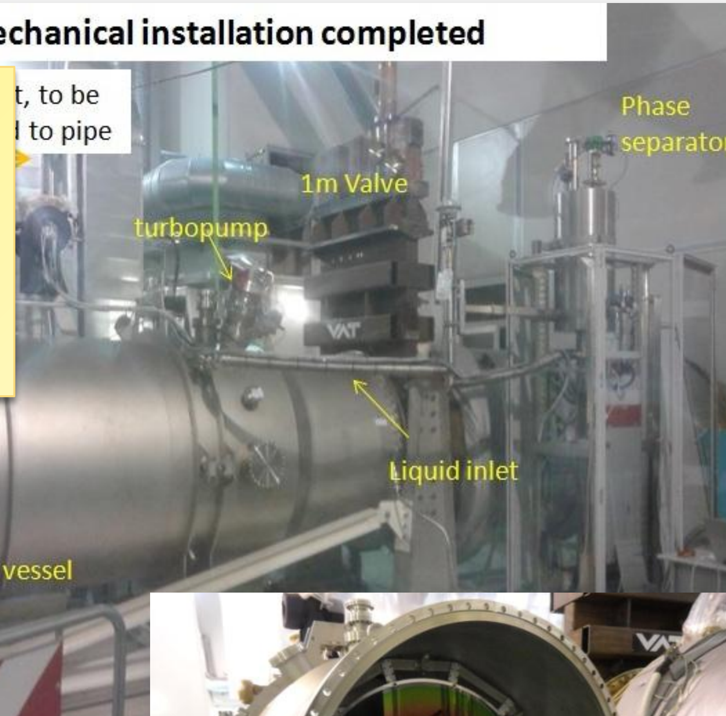
Ongoing:
- Superattenuators being upgraded to hold the new payloads

BS payload ready to be installed

AdV - Current Status

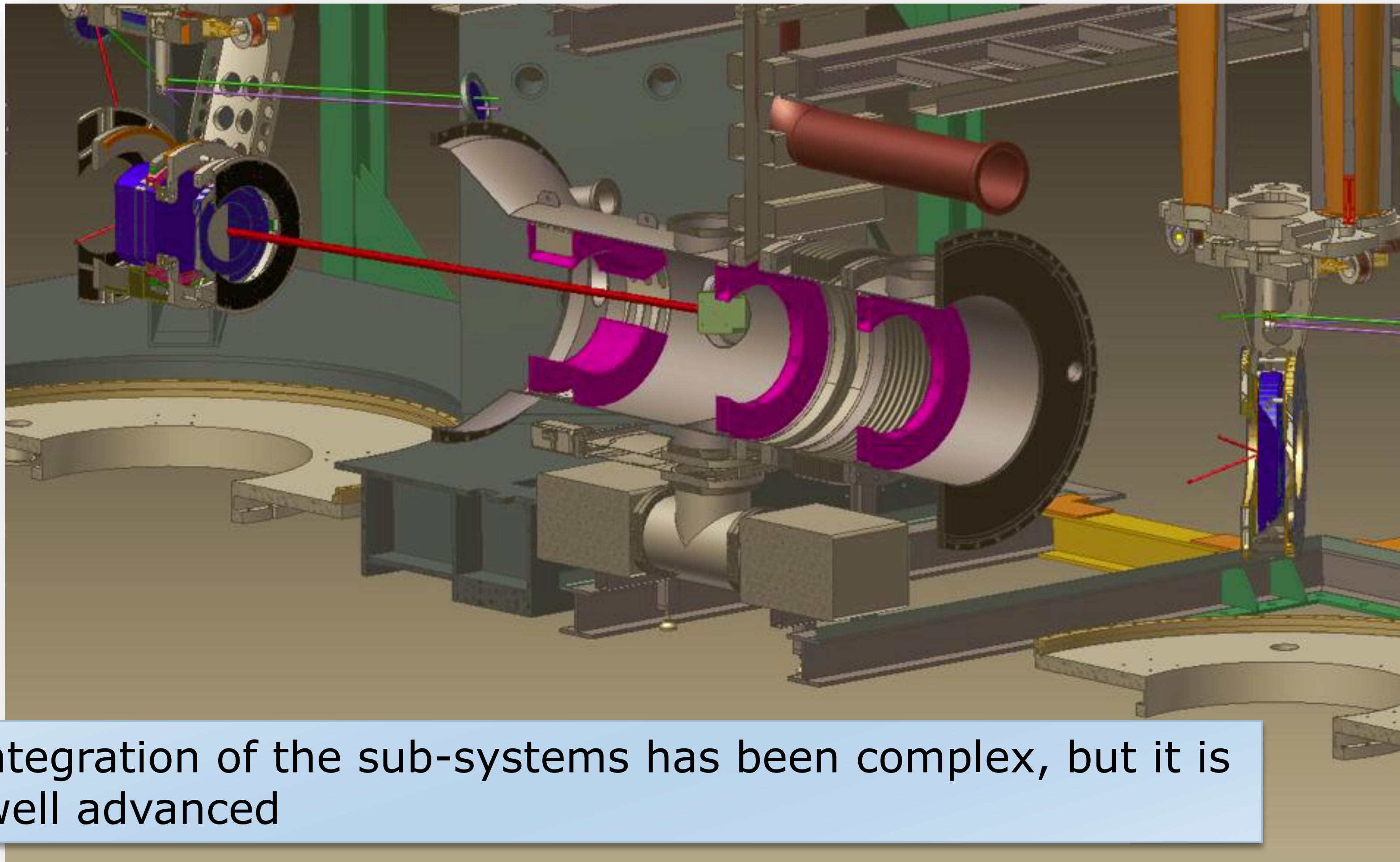
EGO - VIRGO

Ongoing:
- Vacuum links upgrade
- Installation of baffles for stray-light control
- Installation of new, larger cryogenic traps
- Installation of vacuum towers for suspended benches



AdV - Current Status

EGO - VIRGO



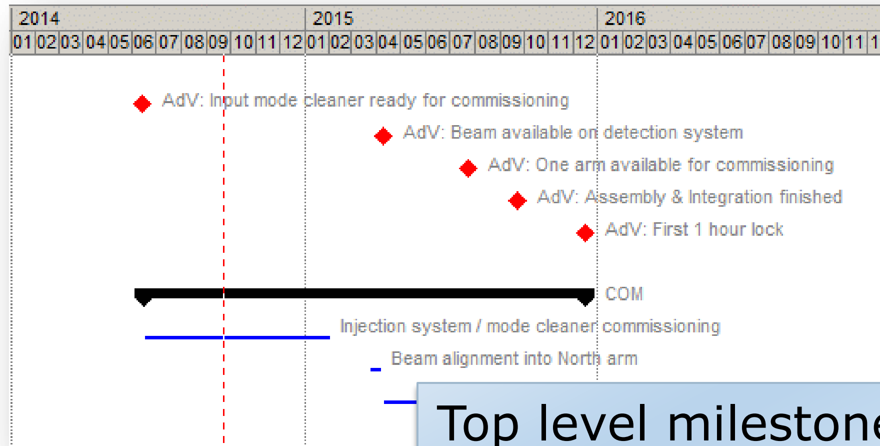
The integration of the sub-systems has been complex, but it is now well advanced

AdV – Project Current Status

EGO - VIRGO

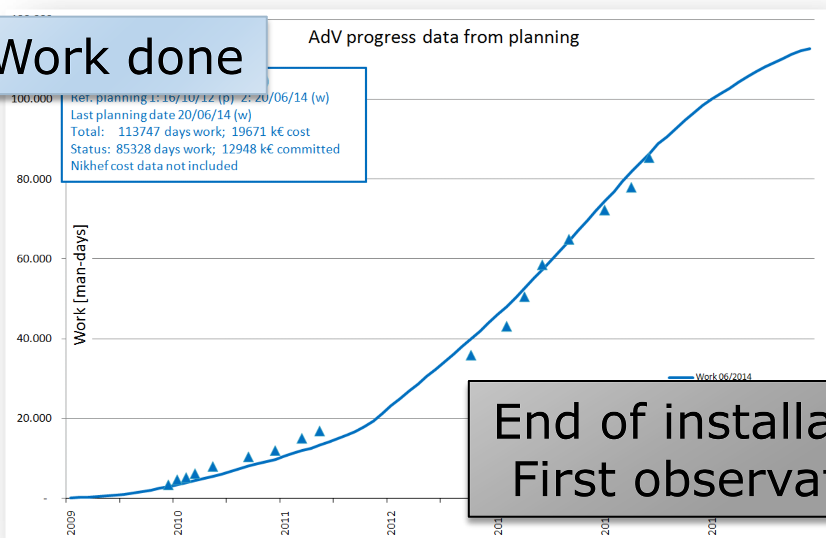
- First top-level milestone achieved on time, high commitment to meet the final goal on schedule

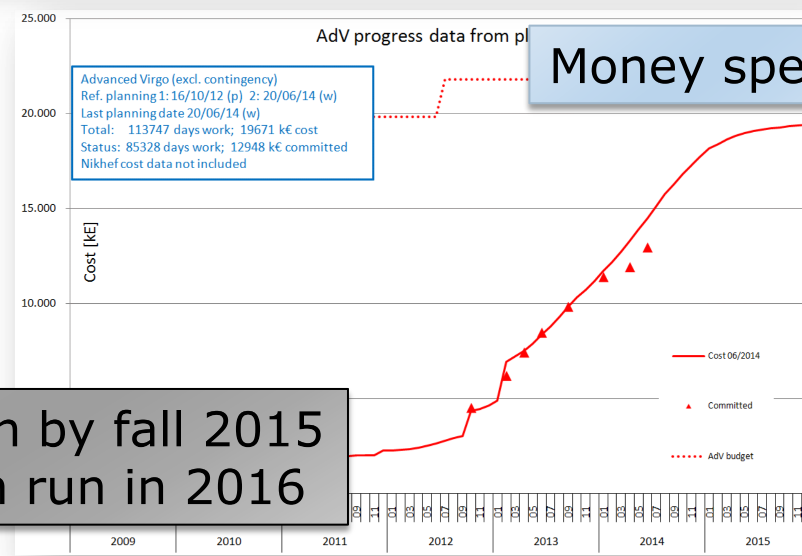
- Work done and funds committed follow roughly the expected curve



Top level milestones

Work done





Money spent

End of installation by fall 2015
First observation run in 2016

AdV - 2016 challenge

EGO - VIRGO

Prospects for Localization of Gravitational Wave Transients by the Advanced LIGO and Advanced Virgo Observatories

J. Aasi[1], J. Abadie[1], B. P. Abbott[1], R. Abbott[1], T. D. Abbott[2], M. Abernathy[3], T
F. Acernese[5ac], C. Adams[6], T. Adams[7], P. Addesso[8], R. X. Adhikari[1], C. Affeldt[9,10], I
O. D. Aguiar[12], P. Ajith[1], B. Allen[9,13,10], A. Allocca[14ac], E. Amador Ceron[13], D. A
S. B. Anderson[1], W. G. Anderson[13], K. Arai[1], M. C. Araya[1], C. Arceneaux[16], S. Ast[9,1
P. Astone[17a], D. Atkinson[18], P. Aufmuth[10,9], C. Aulbert[9,10], L. Austin[1], B. E. Aylott
P. Baker[21], G. Ballardin[22], S. Ballmer[23], Y. Bao[15], J. C. Barayoga[1], D. Barker[18], F. Bar
L. Barsotti[24], M. Barsuglia[25], M. A. Barton[18], I. Bartos[26], R. Bassiri[3,27], M. Bastarrika
J. Batch[18], J. Bauchrowitz[9,10], Th. S. Bauer[11a], M. Bebronne[4], B. Behnke[20], M. Bejger[28
A. S. Bell[3], C. Bell[3], G. Bergmann[9,10], J. M. Berliner[18], A. Bertolini[9,10], J. Betzwieser[6
P. T. Beyersdorf[29], T. Bhadbade[27], I. A. Bilenko[30], G. Billingsley[1], J. Birch[6], S. Biscans
M. A. Bizouard[31a], E. Black[1], J. K. Blackburn[1], L. Blackburn[32], D. Blair[33], B. Bland[1
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R. Bork[1], M. Born[9,10], V. Boschi[14a], S. Bose[36], L. Bosi[37a], B. Bouhou[25], J. Bowers[2], C
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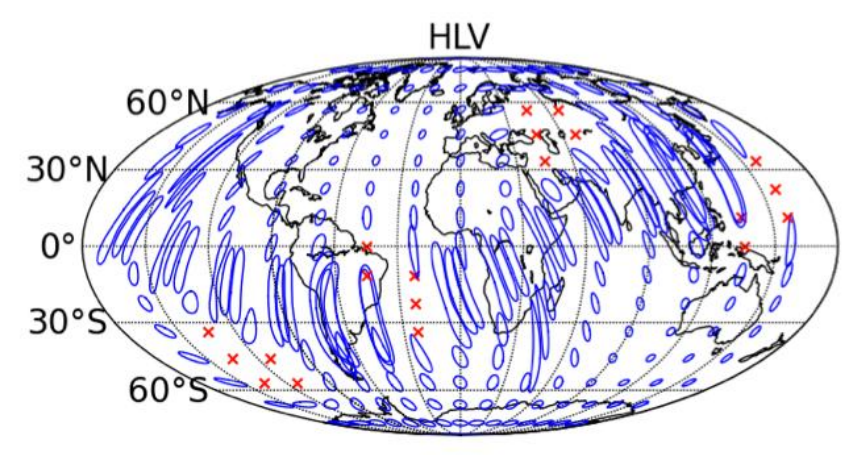

The appointment we cannot miss

Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within 5 deg^2	20 deg^2
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	105	40 – 80	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	105	80	200	130	0.4 – 400	17	48

AdV – Sensitivity evolution

EGO - VIRGO

At the dawn of GW astronomy age…

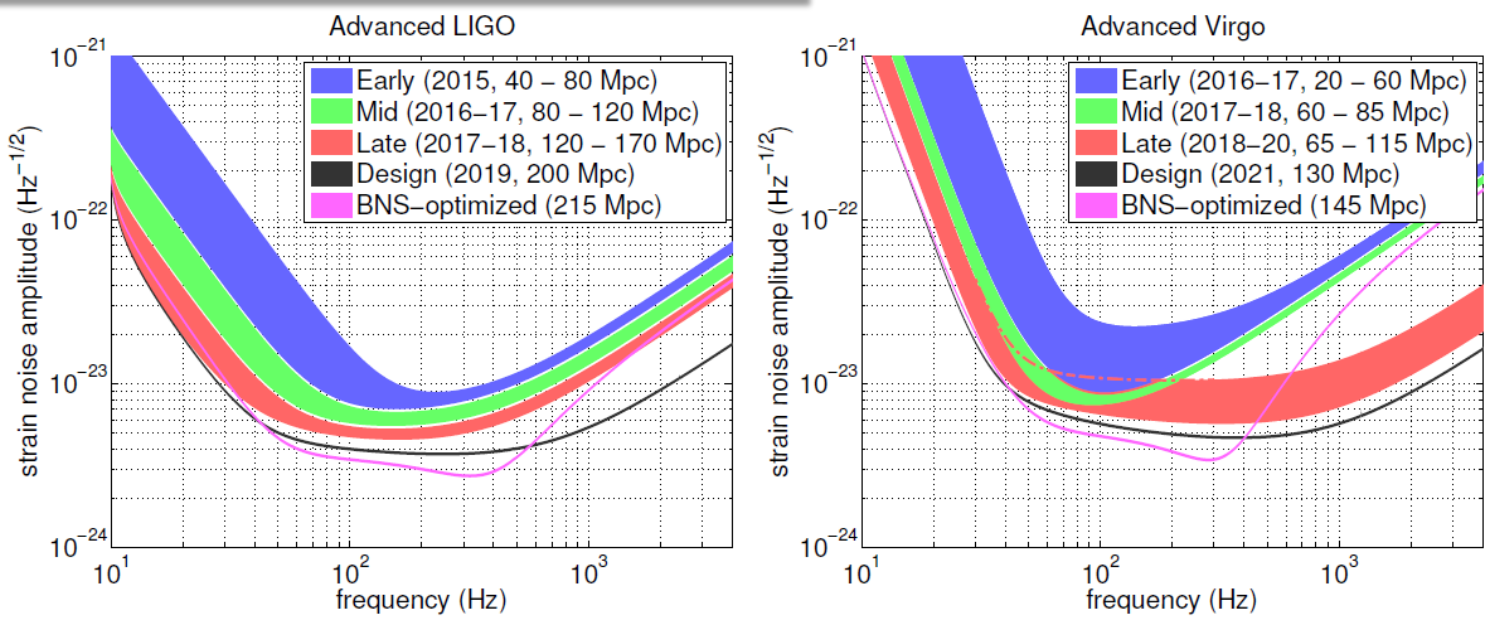

Figure 1: aLIGO (left) and AdV (right) target strain sensitivity as a function of frequency. The average distance to which binary neutron star (BNS) signals could be seen is given in Mpc. Current notions of the progression of sensitivity are given for early, middle, and late commissioning phases, as well as the final design sensitivity target and the BNS-optimized sensitivity. While both dates and sensitivity curves are subject to change, the overall progression represents our best current estimates.

~20km and 400yrs far…

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Thank you
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