Advanced VIRGO EXPERIMENT

Advanced VIRGO Interferometer:

a second generation detector for Gravitational Waves observation

F. Frasconi for the VIRGO Collaboration

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The VIRGO Collaboration

INFN – Italy

Sez. Firenze/Un. Urbino

Sez. Genova

Sez. Napoli/Un. Federico II & Salerno

Sez. Perugia/Un. Perugia & Camerino

Sez. Pisa/Un. Pisa

Sez. Roma/Un. Sapienza

Sez. Roma2/Un. Tor Vergata

Sez. Padova/Un. Trento

EGO Group completes the Collaboration: about 200 authors

CNRS – France

APC - Paris

ESPCI - Paris

LMA – Lyon

LAL – Orsay

LAPP - Annecy

OCA – Nice

NIKHEF – Amsterdam (NL)

RADBOUND Un. Nijmegen

POLGRAW – Warsaw (Pol)

RMKI – Budapest (Hun)

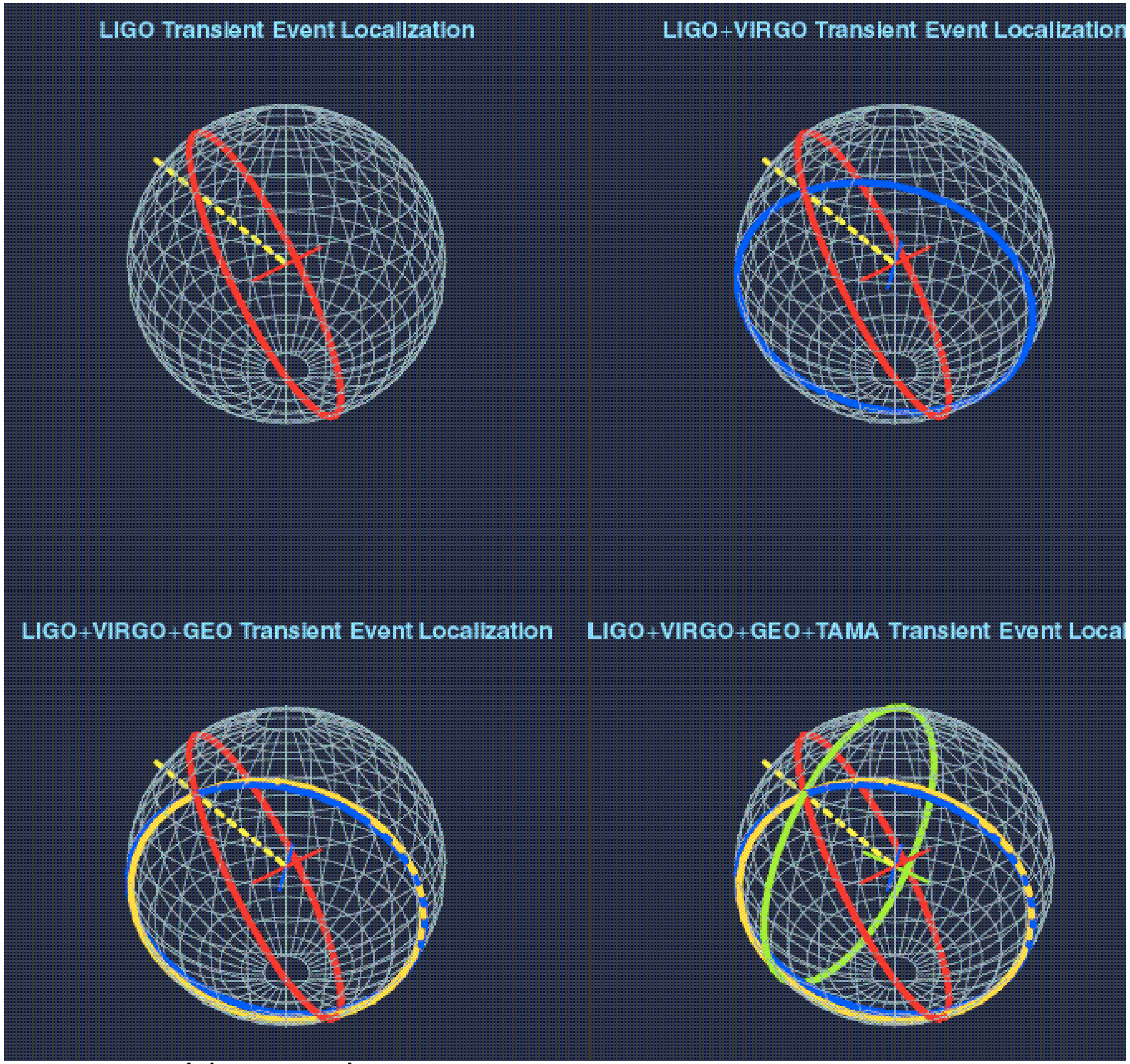
The Interferometer at EGO site

Gravitational Waves

- According to the Einstein's theory of General Relativity (1915), **Gravitational Waves (GW)** are perturbations of the "space-time" metric traveling in the Universe at the speed of light;
- They are expected to be emitted by astrophysical processes in which accelerated coherent motions of large masses take place (supernova explosions, pulsars, etc.);
- The aim of ground based interferometric detectors (ITF) is the direct observation of GW together with the possibility to localize their source in the sky (detectors network).

Importance of a detectors Network

- False alarm rejection requires coincidence
- Triangulation allows to pinpoint the source
- The Network allows to deconvolve detector response and signal wave form -> measurement of the signal parameters
- Longer observation time better sky coverage

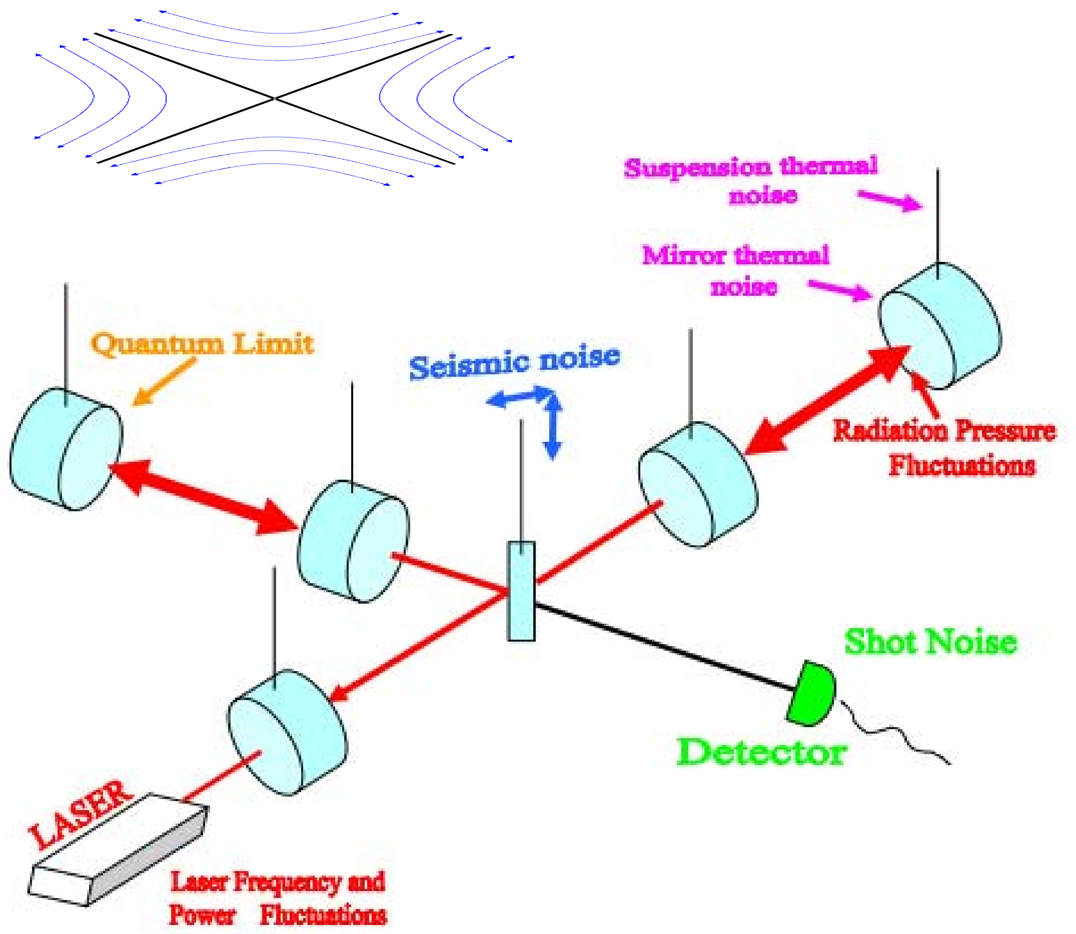


Network: ITFs of the 1st Generation

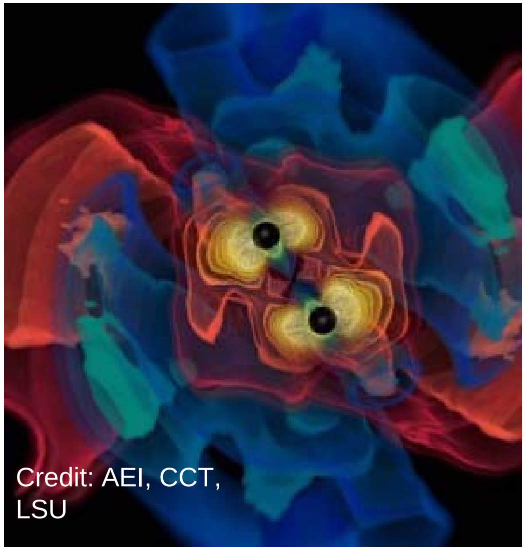
The broad band GW interferometers

- The detector is sensitive to **h** the Gravitational Wave strain amplitude (a GW impinging on the plane of a suspended interferometer stretches one arm compressing the other one alternatively)
- The detector sensitivity is expressed in terms of the amplitude spectral density of the detector noise referred to its input

  H(f) $[(Hz)^{-1/2}]$

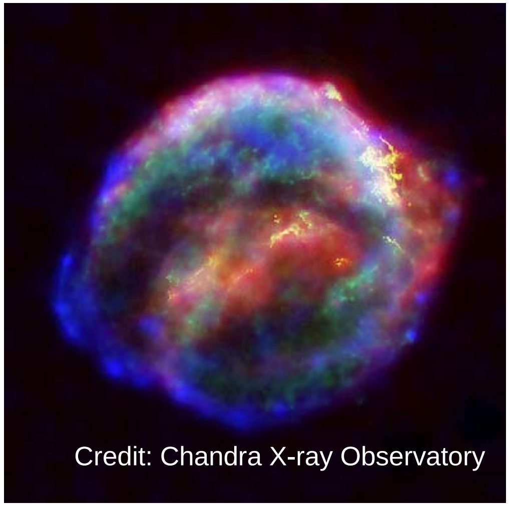


Sources of GW



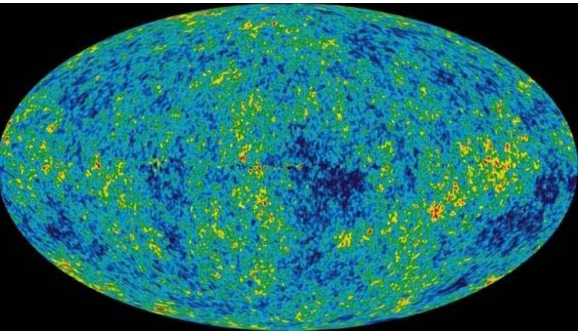
Coalescing Binary Systems

- Neutron stars, low mass black holes, and NS/BS systems



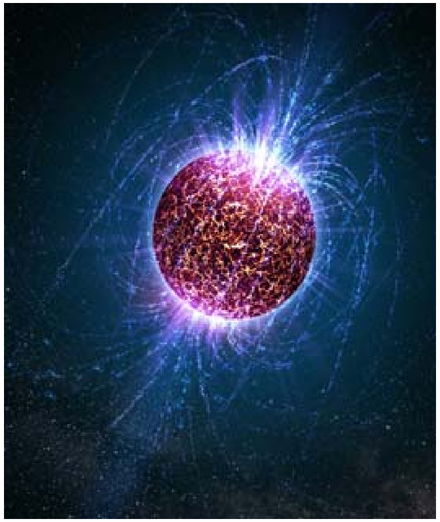
'Bursts'

- galactic asymmetric core collapse supernovae
- cosmic strings
- ???



Cosmic GW background

- Stochastic, incoherent background
- unlikely to detect, but can bound in the 10-10000 Hz range



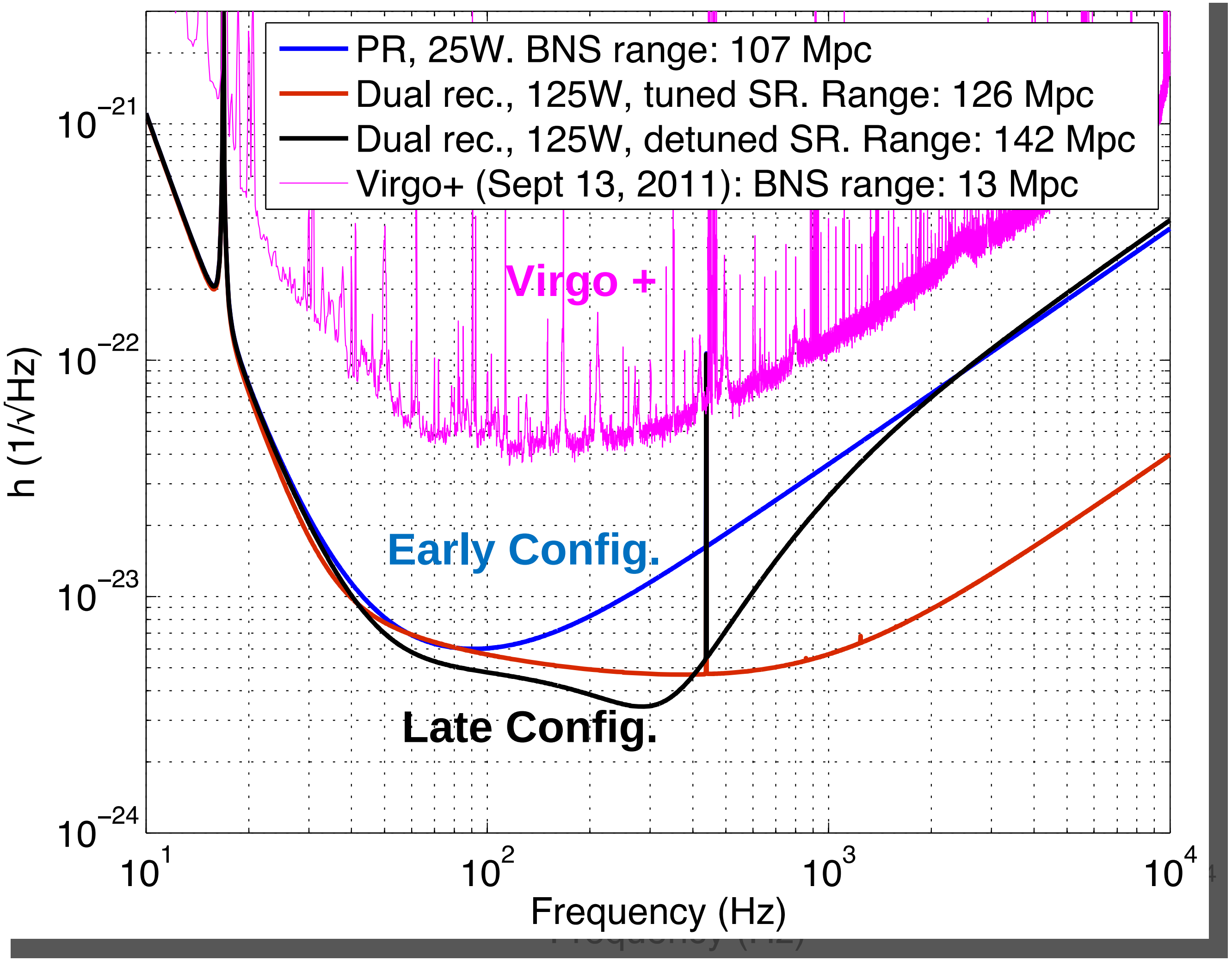
Continuous Sources

- Spinning neutron stars
- probe crustal deformations, 'quarki-ness'

Advanced VIRGO Interferometer

- Advanced VIRGO: upgrade of the VIRGO Interferometer
- Michelson Interferometer with two Fabry-Perot cavities along the arms 3 km long each one

Evolution of ITF sensitivity

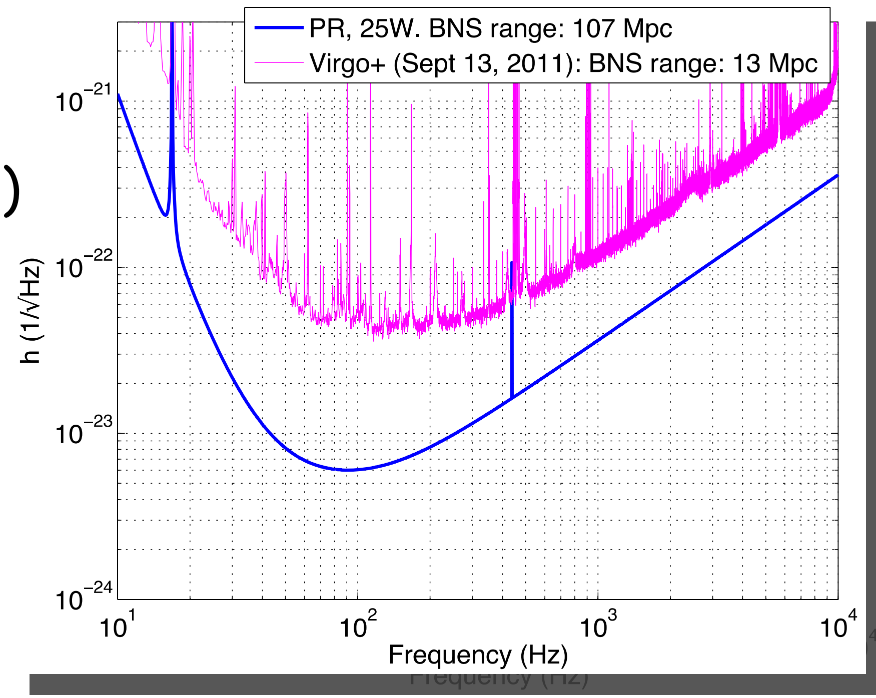


Toward AdV operation

• Start in 2015 putting in operation the ITF with a simplified configuration, similar to VIRGO+ : likely to reduce the commissioning time

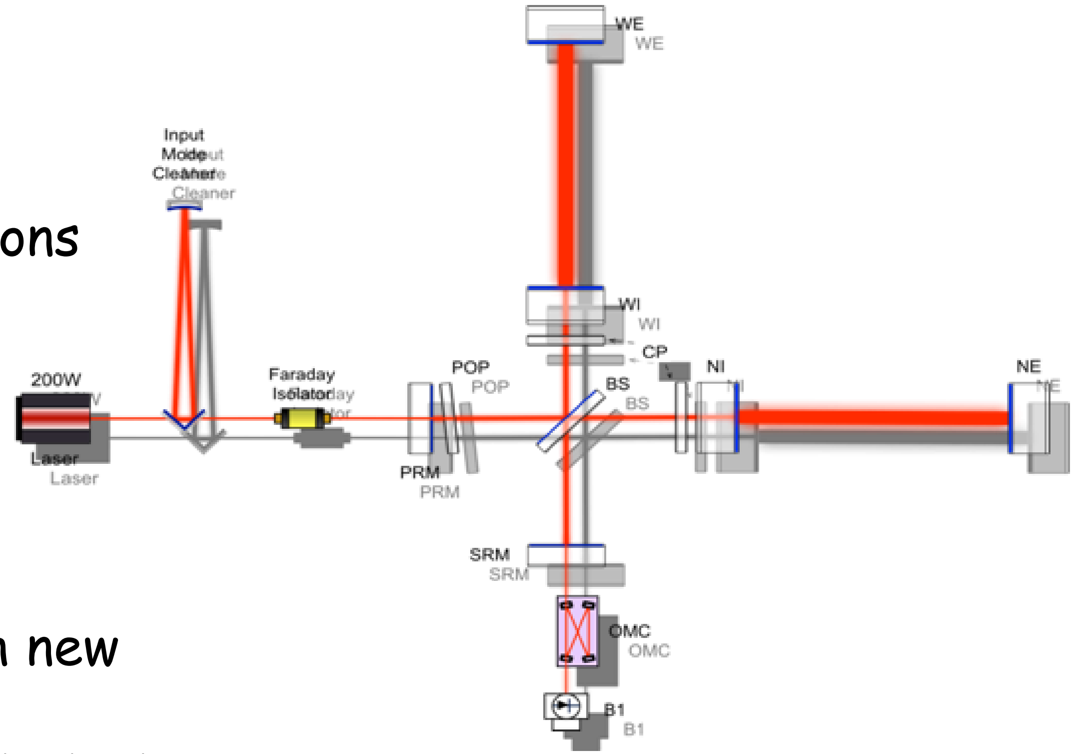
- without Signal recycling
- VIRGO+ laser up to 60 W
- low power (reduced risks with thermal effects and high power laser)

• Target BNS inspiral range: > 100 Mpc



Detector Design

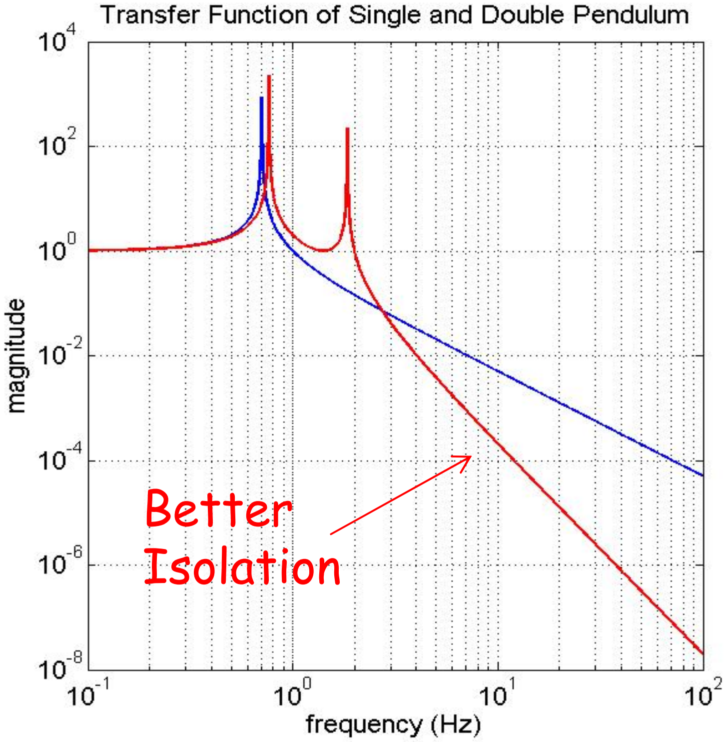
- Main changes with respect to VIRGO:
  - larger beam
  - heavier mirrors
  - higher quality optics
  - thermal control of aberrations
  - 200W fiber laser
  - Signal Recycling



- Vibration isolation by VIRGO Superattenuators:
  - performance compliant with new requirements
  - wide experience with commissioning at low frequency

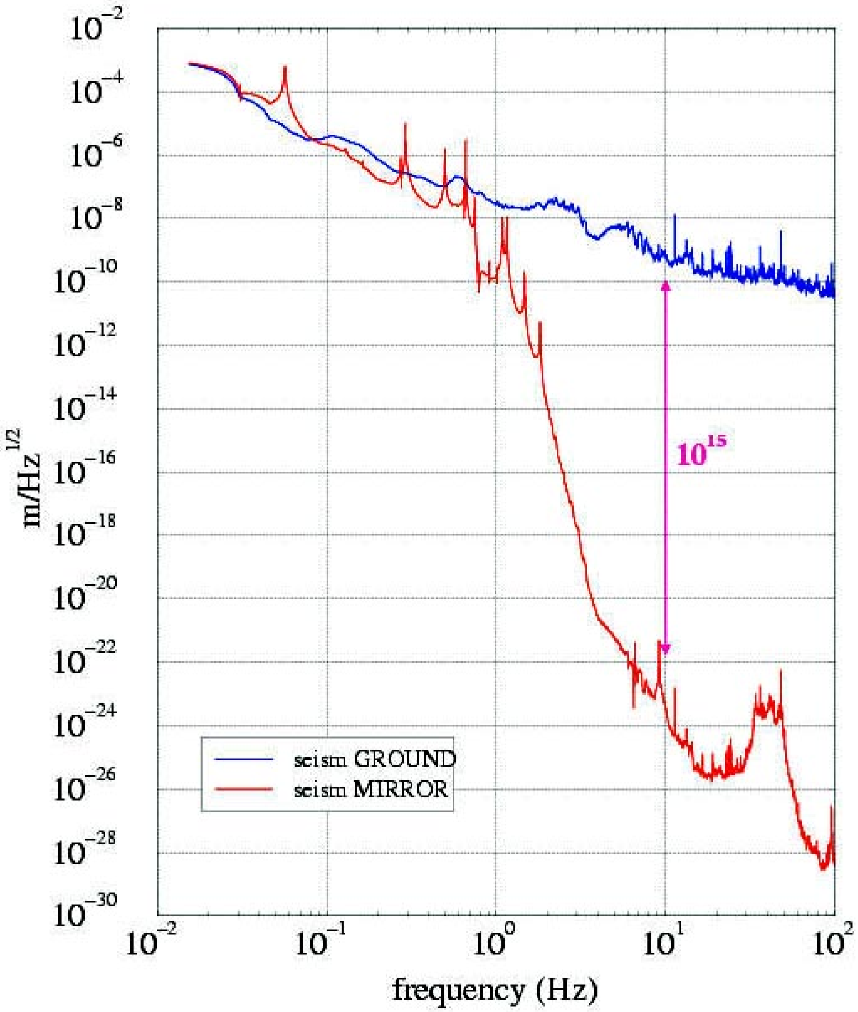
Seismic Noise

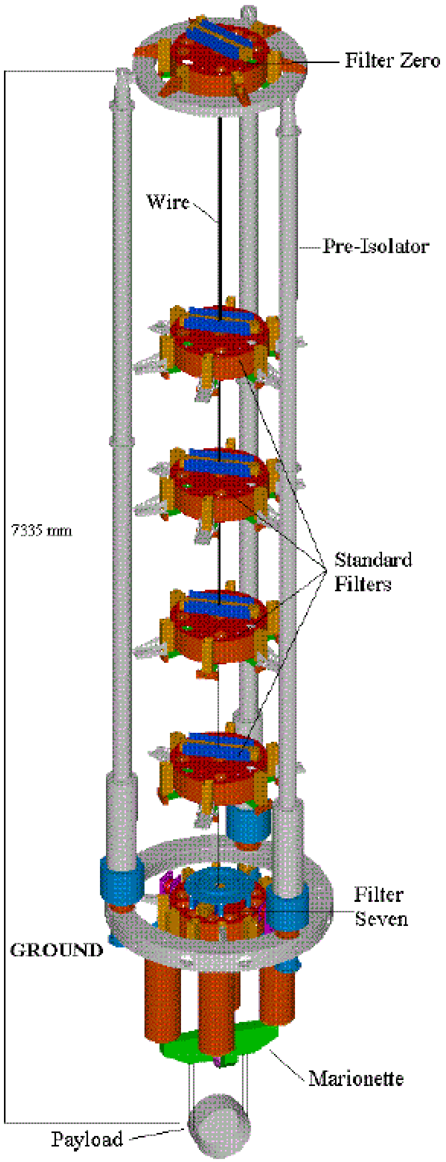
- Seismic noise limits sensitivity of ground based detectors at low frequencies - "seismic wall"
- Typical seismic noise at EGO site at 10 Hz is ~ few x 10^{-10} m/√Hz
  - many orders of magnitude above target noise level
- Solution - multiple stages of isolation system
- Isolation required in vertical direction as well as horizontal due to cross-coupling



Advantages of a **double** over **single** pendulum, same overall length

Mirror Suspensions





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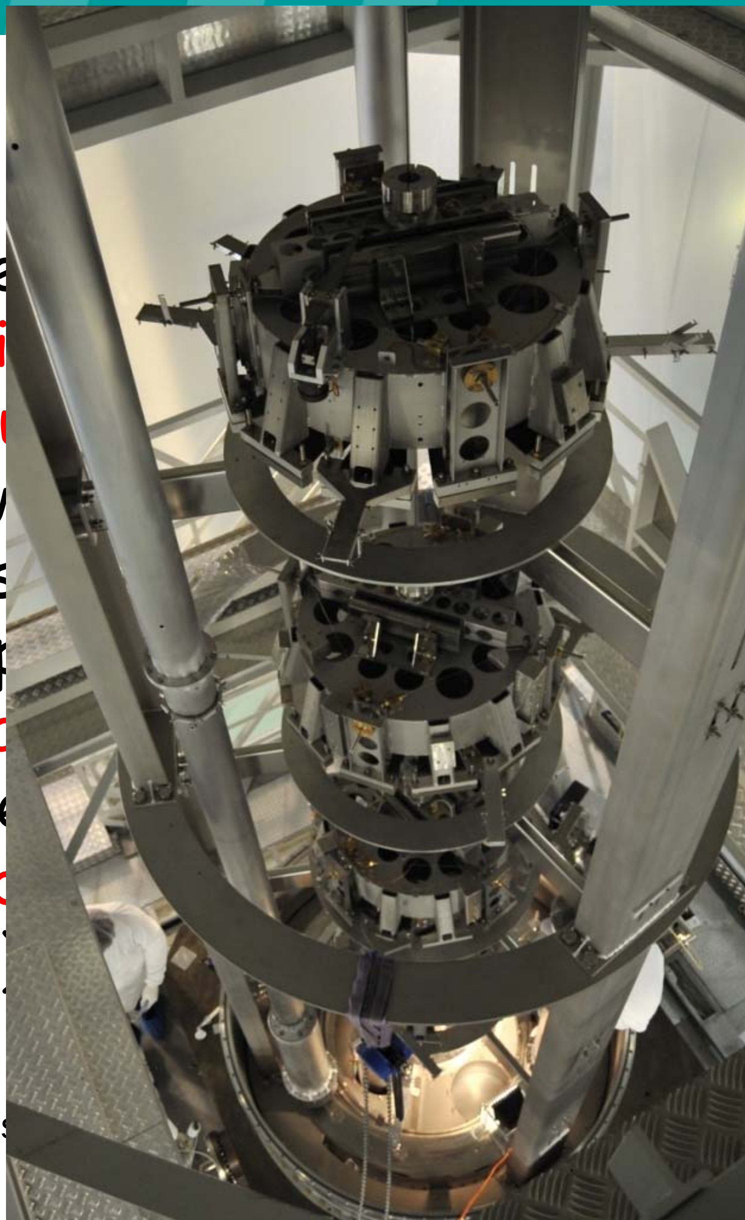
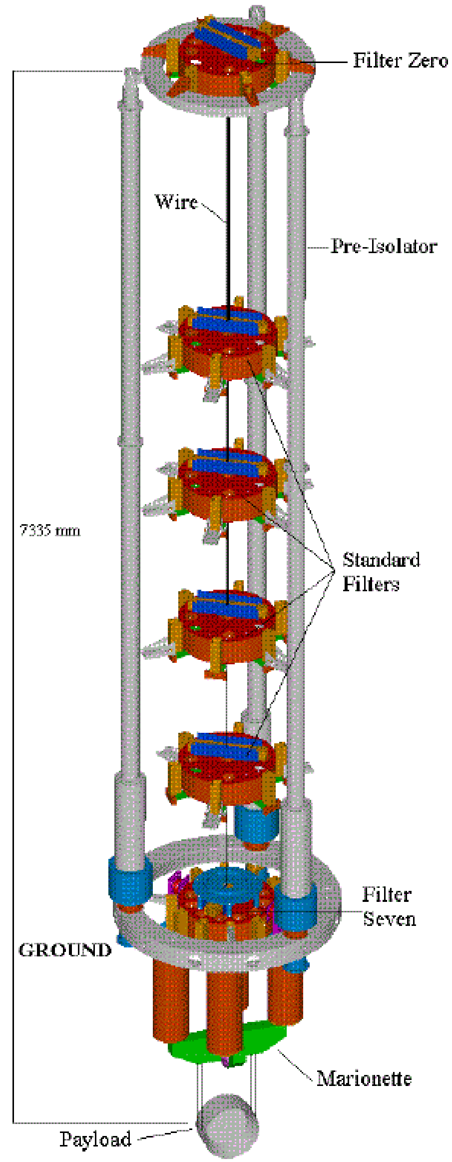
The SA chain

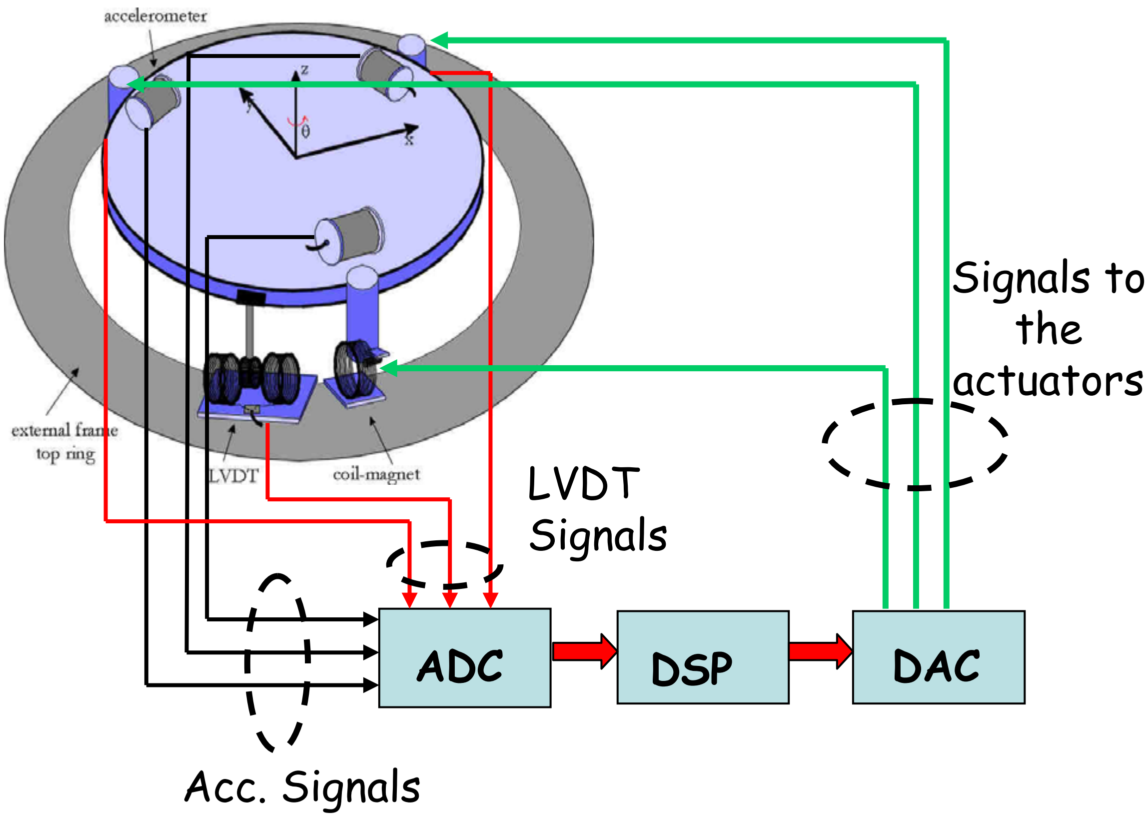


• The ... is a pre-i... frequ... ed to allow ... l of the s... .

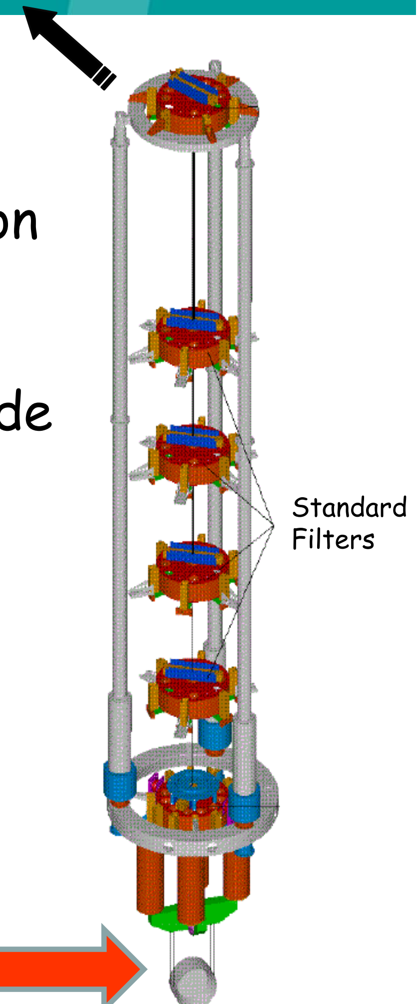
• It p... hierc... suspe... rain and c... ~200 mHz)



Main features of SA



Passive attenuation chain
+
Active Mode Damping



Residual swing at Payload level
LONGITUDINAL: about 100 nm pp
ANGLES: fractions of μrad pp

Activities on SA for AdV

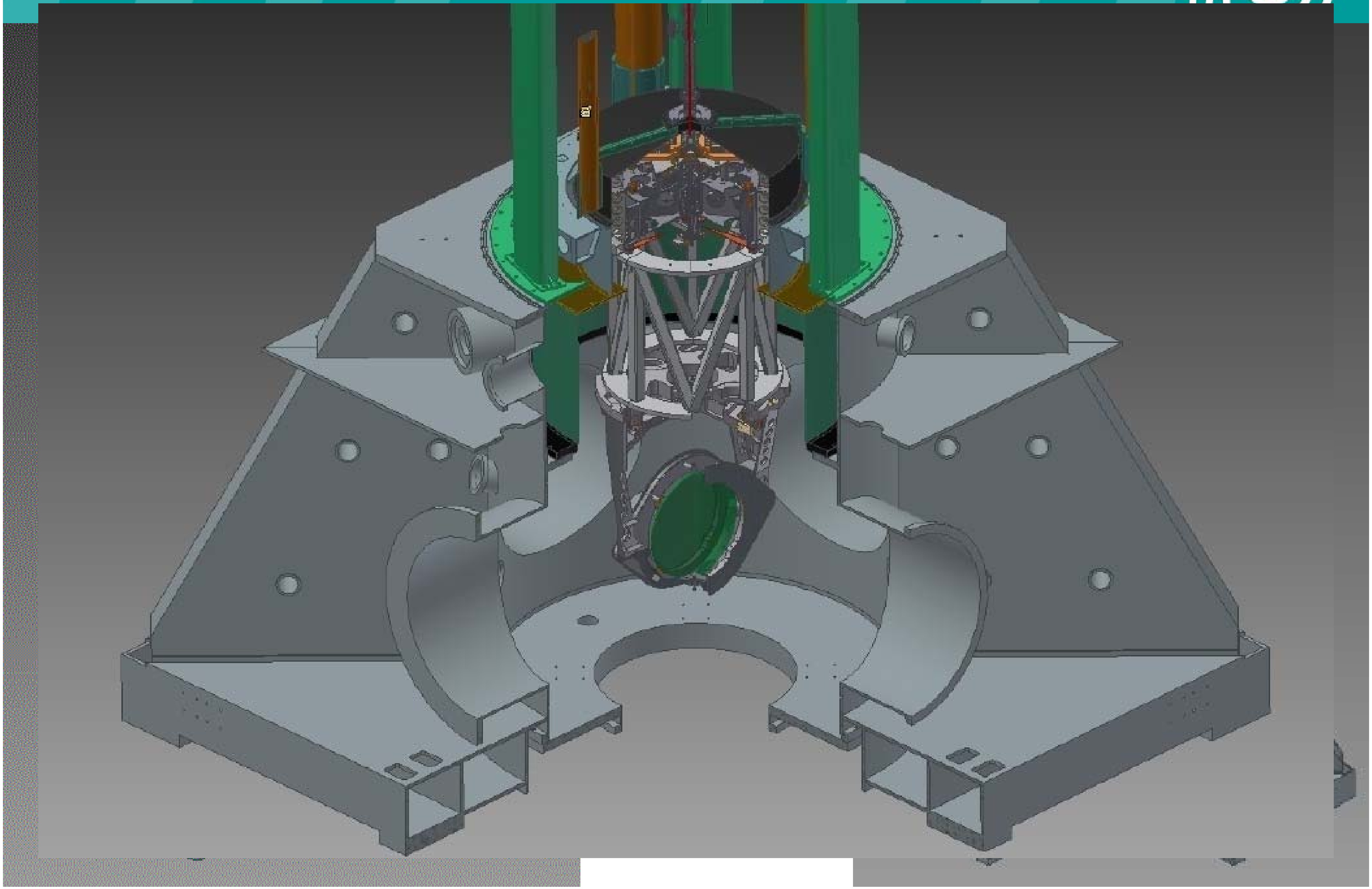
- Different spatial distribution of the mechanical filters along the suspension chain (optimization of seismic noise filtering in accordance with a new geometry of the Intermediate Vacuum Chamber)

- Re-tuning of mechanical filters in accordance with the load to be supported (heavier mirrors + new TCS + baffles)

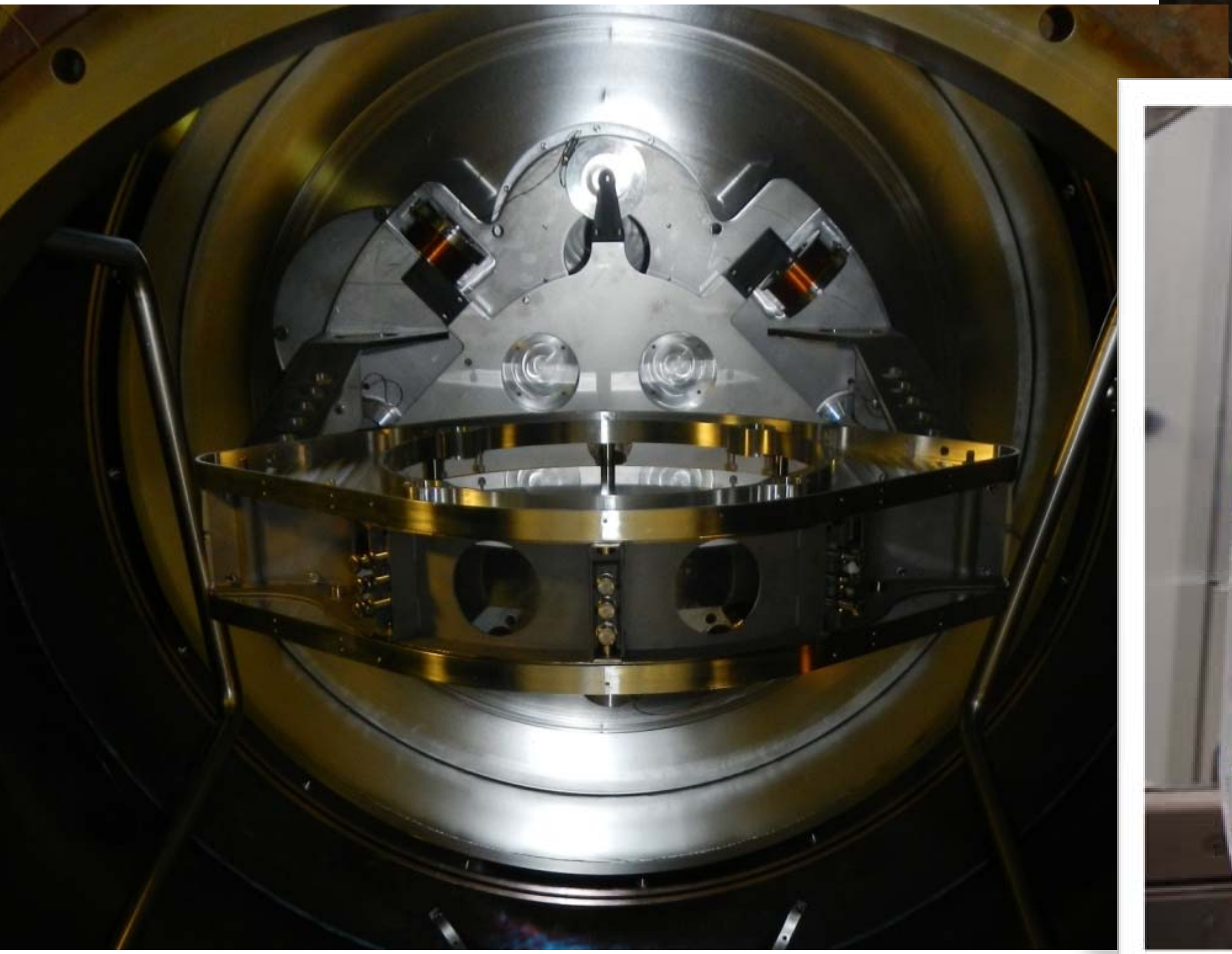
- Re-design and construction of the last mechanical filter (Filter7) in accordance with the new Payloads geometry (presence of large baffle for diffused light mitigation)

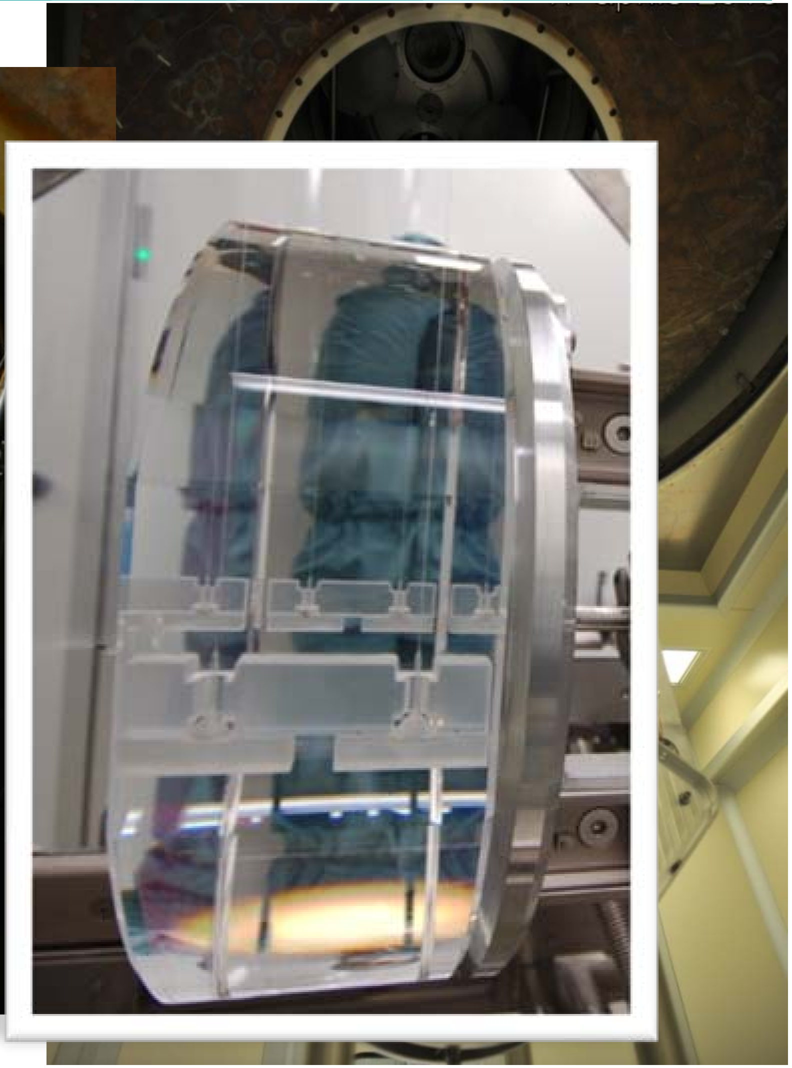
- Construction of new control electronics:
  - analog and digital parts embedded in a single board
  - about 100 channels per SA

Mirror Suspension Comparison



AdV Payloads





Stray light mitigation

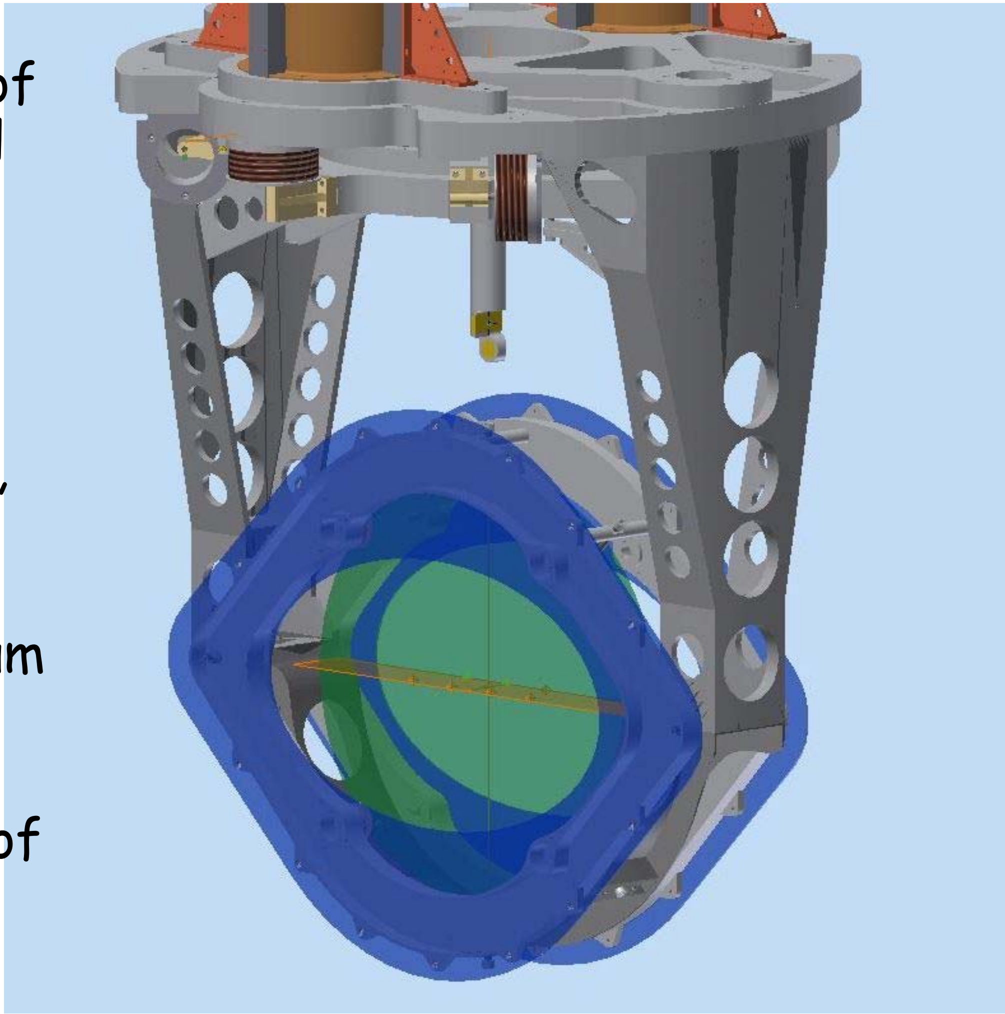
- Lesson from 1st generation detector: scattered light is one of the major risks towards the final sensitivity goal
- A big effort has been done to mitigate it:

  - better optics quality

  - baffles to shield mirrors, pipes, vacuum chamber exposed to scattered light

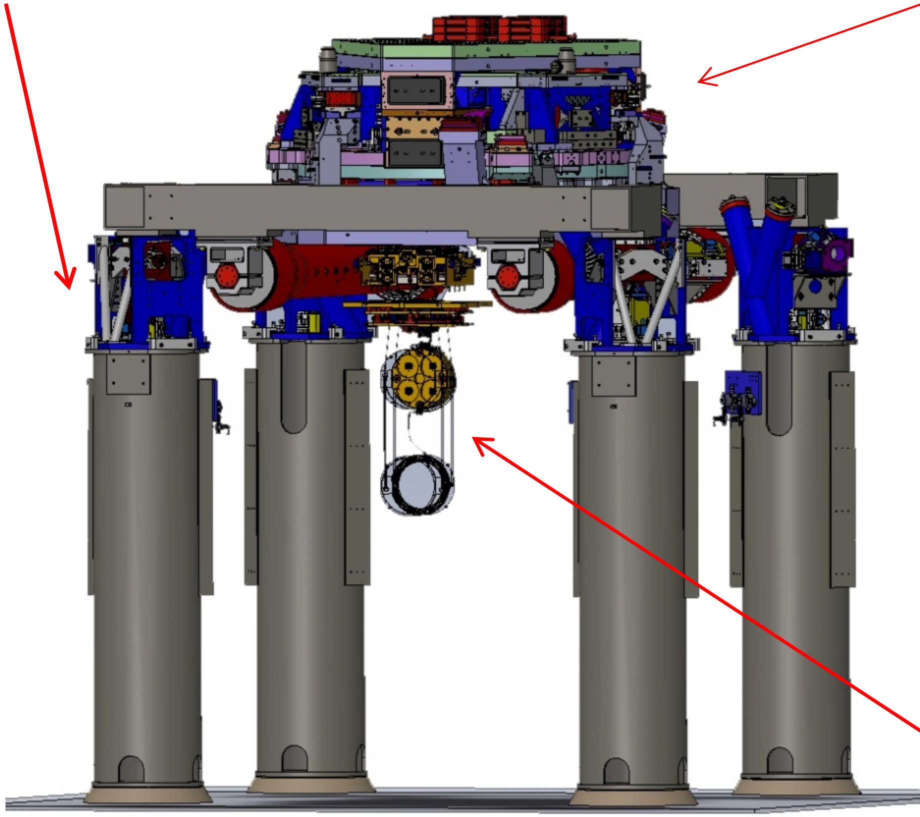
  - photodiodes suspended in vacuum to isolate them from seismic/acoustic noise

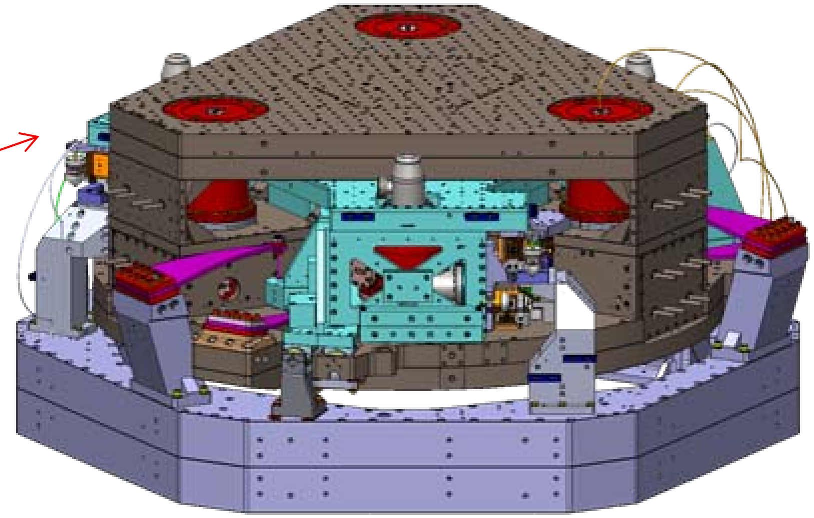
  - if needed, control the position of the benches with respect to the ITF



aLIGO Seismic Isolation

Hydraulic external pre-isolator (HEPI – one stage of isolation; low frequency positioning)





Active isolation platform (two stages of isolation – isolate above ~ 0.2 Hz)

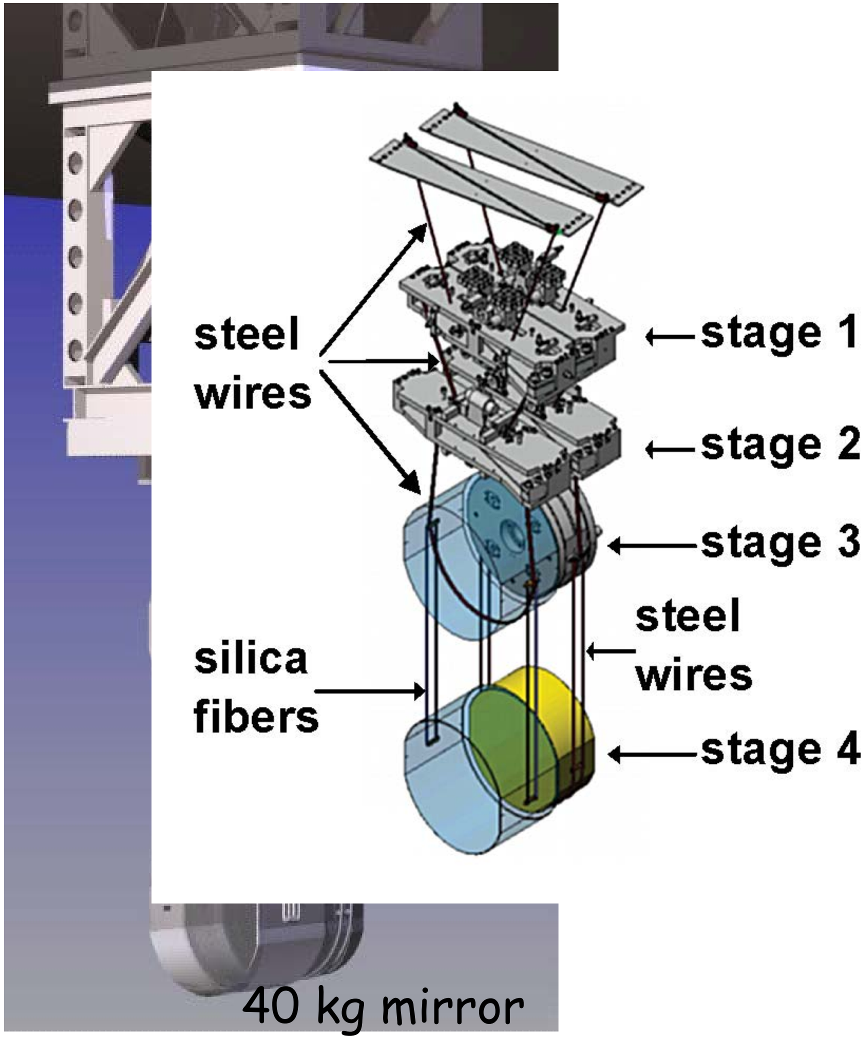
Quadruple pendulum (four stages of isolation) with monolithic silica fiber last stage

aLIGO Seismic Isolation (cont.)

- Thermal noise reduction: use monolithic fused silica suspension as final stage
- Seismic isolation: use quadruple pendulum + 3 stages of maraging steel blades for vertical isolation
- Control noise minimizing: apply damping at top mass (for 6 degrees of freedom) + use quiet reaction pendulum for global control actuation

  - coil/magnet actuation at top 3 stages

  - electrostatic drive at test mass
- Design is developed from the GEO 600 triple pendulums which have been in operation for more than 10 years

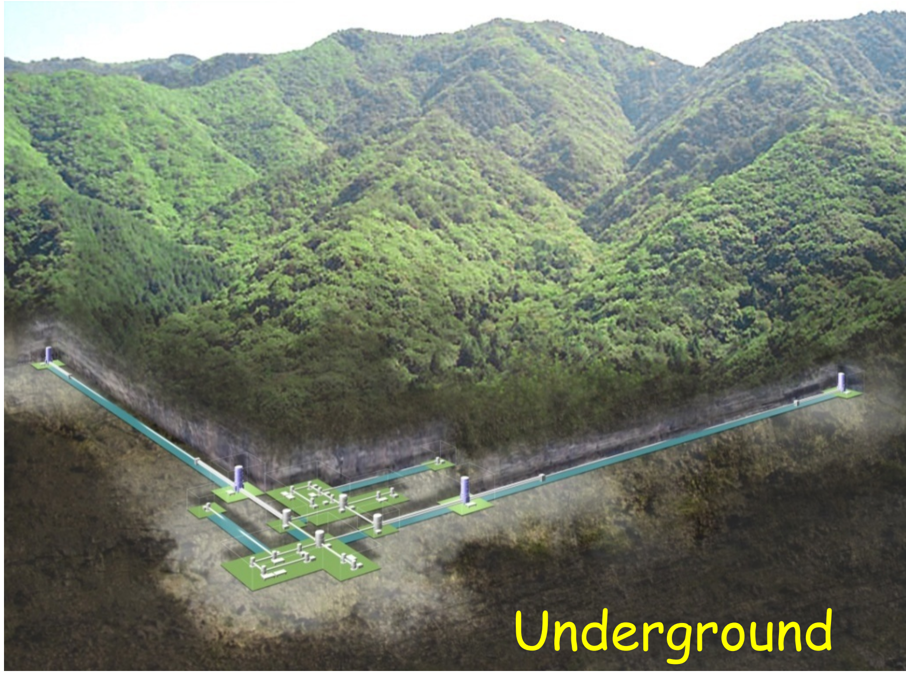


KAGRA: underground detector

• Underground ITF located in the Kamioka mine (Japan) with 3 km orthogonal arms:
- reduced seismic noise (about a factor 50 @ 10 Hz) and gravity noise
- simplified seismic isolation system

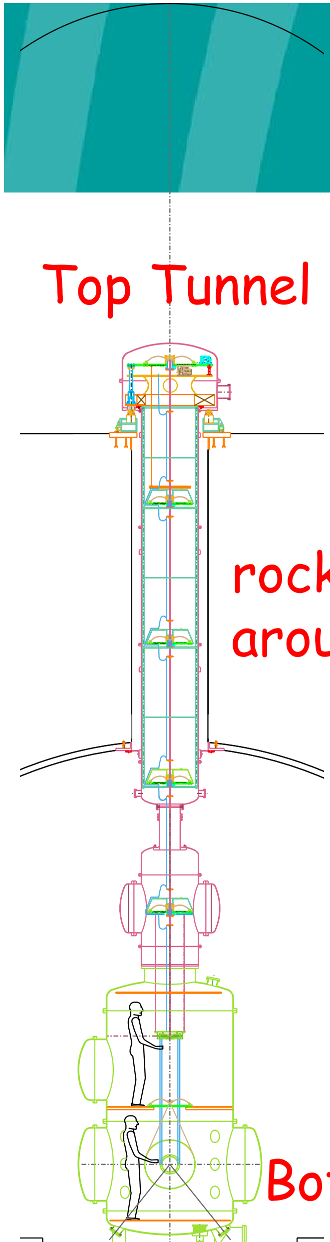
• Second phase: cryogenic cooling of test masses:
- reduced thermal noise

KAGRA



KAGRA Vibration Isolation

Top Tunnel

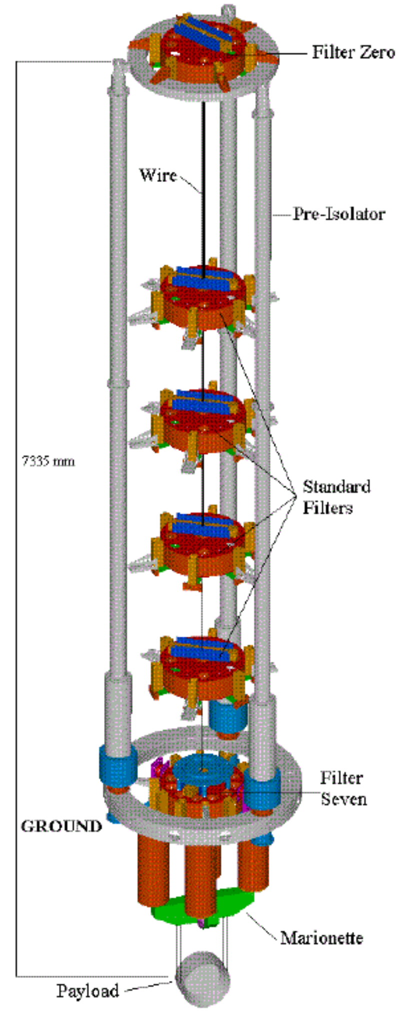


rocks all around

Bottom Tunnel

- KAGRA SAS (Seismic Attenuation System) is mounted between two tunnels:

  - a simplified and improved version of the VIRGO Superattenuator
- Good filtering performance
- New Features:
  - Geometric anti-spring (**GAS**) filters replaces Magnetic anti-spring (**MAS**) filters
  - Magnetic damping stage
  - Compact pre-isolator stage (IP)



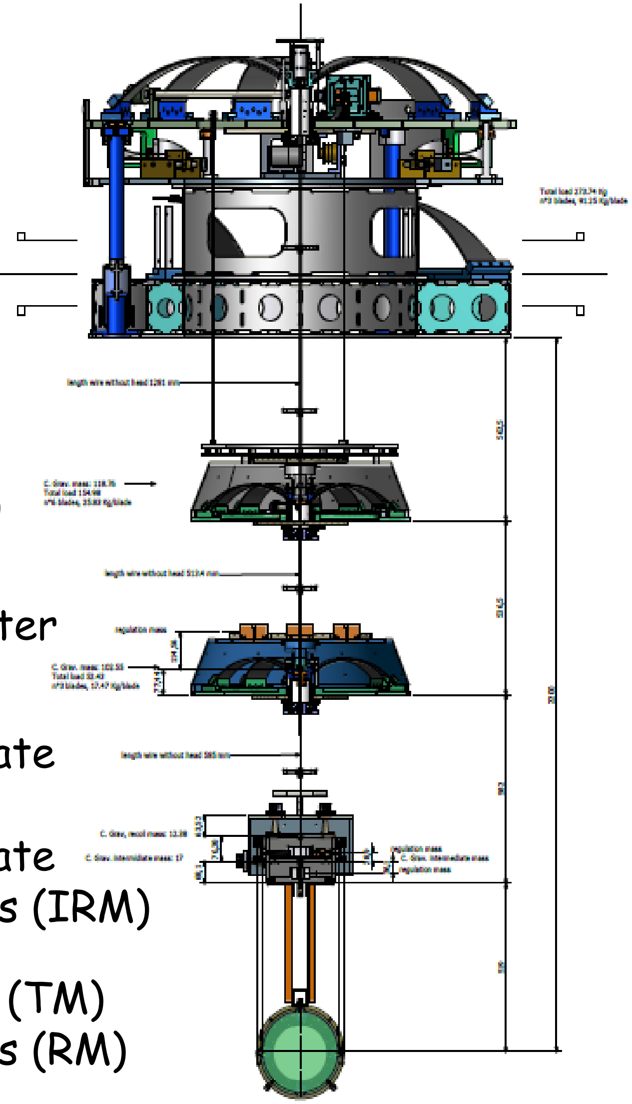
KAGRA SAS schematic view

Cryostat in the F-P cavities: to be cooled down at cryogenic temperatures in a second phase

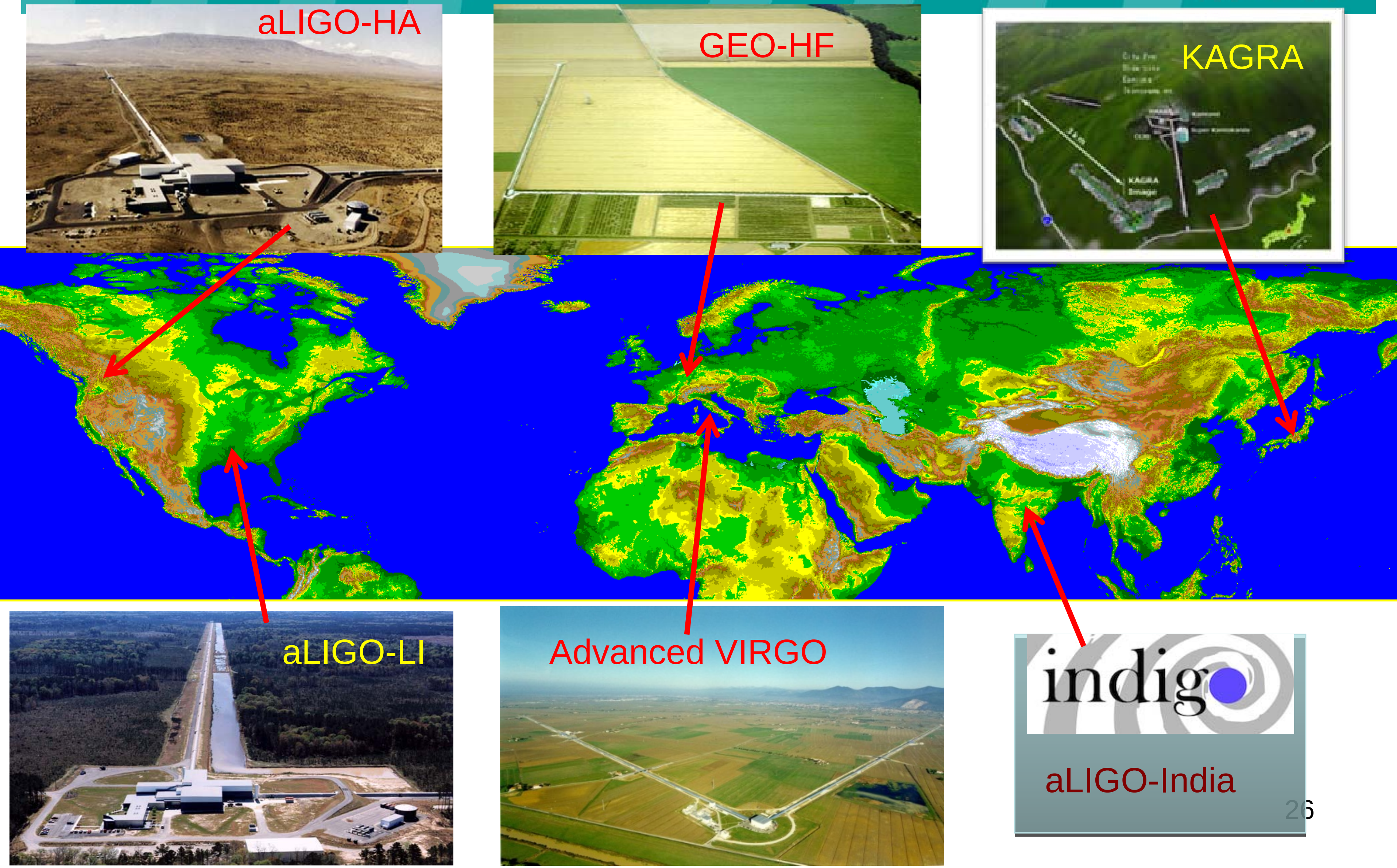
Pre-isolator
- Top Filter (Filter 0)
- Inverted Pendulum

Filter Chain
- Geometric anti-spring (GAS) chain (Filter 1-3)

Payload
- Bottom Filter (BF)
- Intermediate Mass (IM)
- Intermediate Recoil Mass (IRM)
- Test Mass (TM)
- Recoil Mass (RM)



Network: ITFs of the 2nd Generation



2nd Generation Network

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. Accadia[4],
F. Acernese[5ac], C. Adams[6], T. Adams[7], P. Addesso[8], R. X. Adhikari[1], C. Affeldt[9,10], M. Agathos[11a],
O. D. Aguiar[12], P. Ajith[1], B. Allen[9,13,10], A. Allocca[14ac], E. Amador Ceron[13], D. Amariutei[15],
S. B. Anderson[1], W. G. Anderson[13], K. Arai[1], M. C. Araya[1], C. Arceneaux[16], S. Ast[9,10], S. M. Aston[6],
P. Astone[17a], D. Atkinson[18], P. Aufmuth[10,9], C. Aulbert[9,10], L. Austin[1], B. E. Aylott
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J. Batch[18], J. Bauchrowitz[9,10], Th. S. Bauer[11a], M. Bebronne[4], B. Behnke[20], M. Bejger
A. S. Bell[3], C. Bell[3], G. Bergmann[9,10], J. M. Berliner[18], A. Bertolini[9,10], J. Betzwieser[6],
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M. A. Bizouard[31a], E. Black[1], J. K. Blackburn[1], L. Blackburn[32], D. Blair[33], B. Bland
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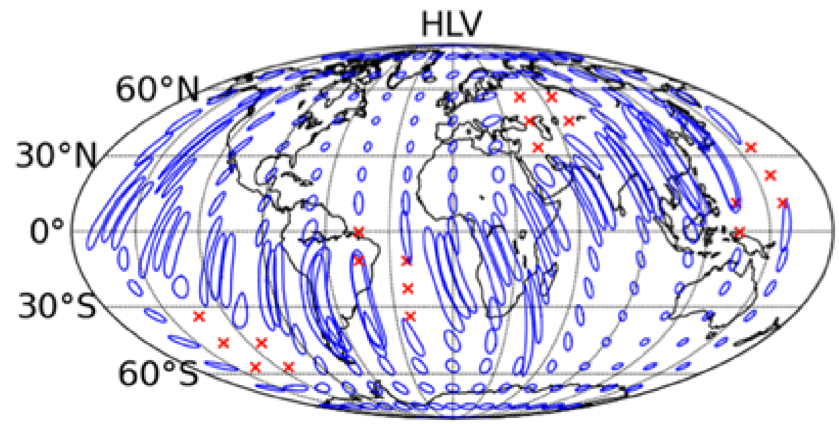
Source localization in the sky



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Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc)		BNS Range (Mpc)		Number of BNS Detections	% BNS Localized within	
		LIGO	Virgo	LIGO	Virgo		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

Conclusions

- Still waiting for the first detection …
- Fundamental experience acquired with the 1^{st} generation of ground based ITF:

  - wide experience collected in operating sophisticated detectors

  - important results obtained with collected data
- The construction of the Advanced Detectors (target sensitivity 10 times better) is in progress:

  - end of AdV installation in the fall of 2015
- They will increase of a factor 10^3 the observable volume of the Universe opening the phase of the GW astronomy