Advanced Virgo and the worldwide search for Gravitational Waves

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Advanced Virgo Project Leader

Credit: LSC and Virgo for some of the materials
in this presentation (curves and photos)

GW PHYSICS IN A NUTSHELL

RIPPLES IN THE COSMIC SEA

- Linearized Einstein eqs. (far from big masses) admit wave solutions (perturbations to the background geometry)

$$\mathbf{G} = \frac{8\pi G}{c^4}\mathbf{T}$$

$$\mathbf{g} = \eta + \mathbf{h} \ \text{ with} \left|h_{\mu\nu}\right| << 1 \ \Rightarrow \left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)h_{\mu\nu} = 0$$

- **GW**: transverse space-time distortions propagating at the speed of light, 2 independent polarizations

$$\mathbf{h}(z,t) = e^{i(\omega t - kz)}\begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & h_+ & h_\times & 0 \\ 0 & h_\times & -h_+ & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

COUPLING CONSTANTS

strong	*e.m.*	*weak*	*gravity*
0.1	1/137	10^{-5}	10^{-39}

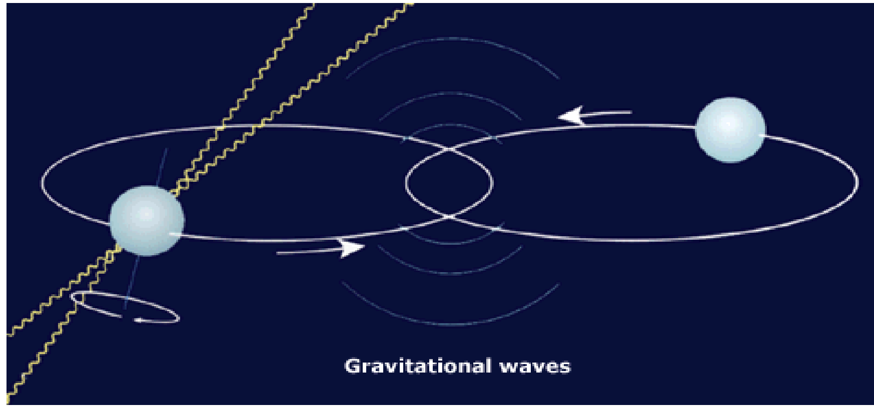
GW emission: very energetic events but almost no interaction

- In SN collapse ν withstand O(10^{3}) interactions before leaving the star, GW leave the core undisturbed
- Decoupling after Big Bang
  - GW ~ 10^{-43} s (T ~ 10^{19} GeV)
  - ν ~ 1 s (T ~ 1 MeV)
  - γ ~ 10^{12} s (T ~ 0.2 eV)

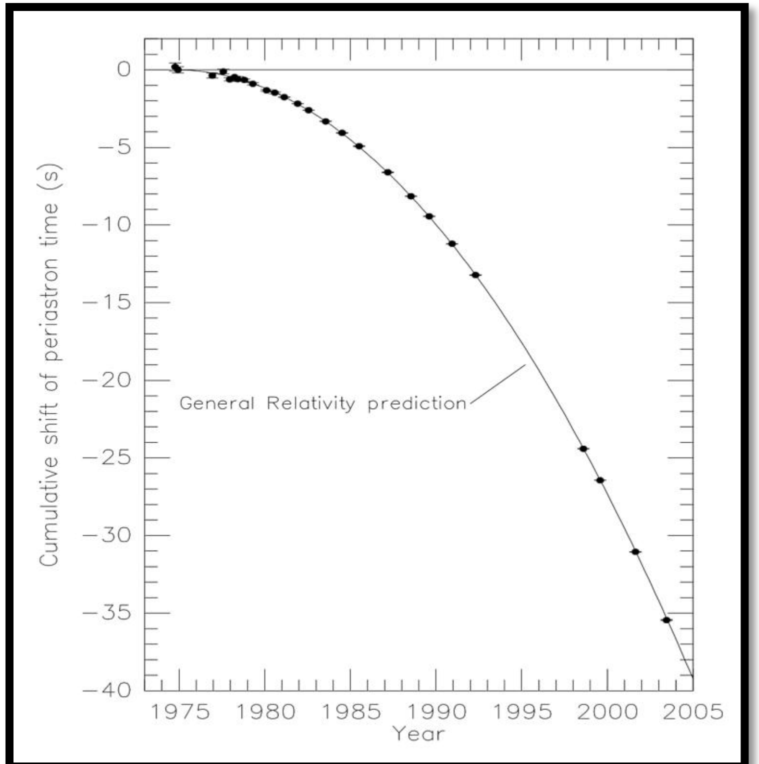
Ideal information carrier,
Universe transparent to GW all the way back to the Big Bang!!

GW DO EXIST

- PSR1913+16: pulsar bound to a “dark companion”, 7 kpc from Earth
- Relativistic clock: $v_{max}/c \sim 10^{-3}$
- GR predicts such a system to loose energy via GW emission: orbital period decrease
- Radiative prediction of general relativity verified at 0.2% level [astro-ph/0407149]



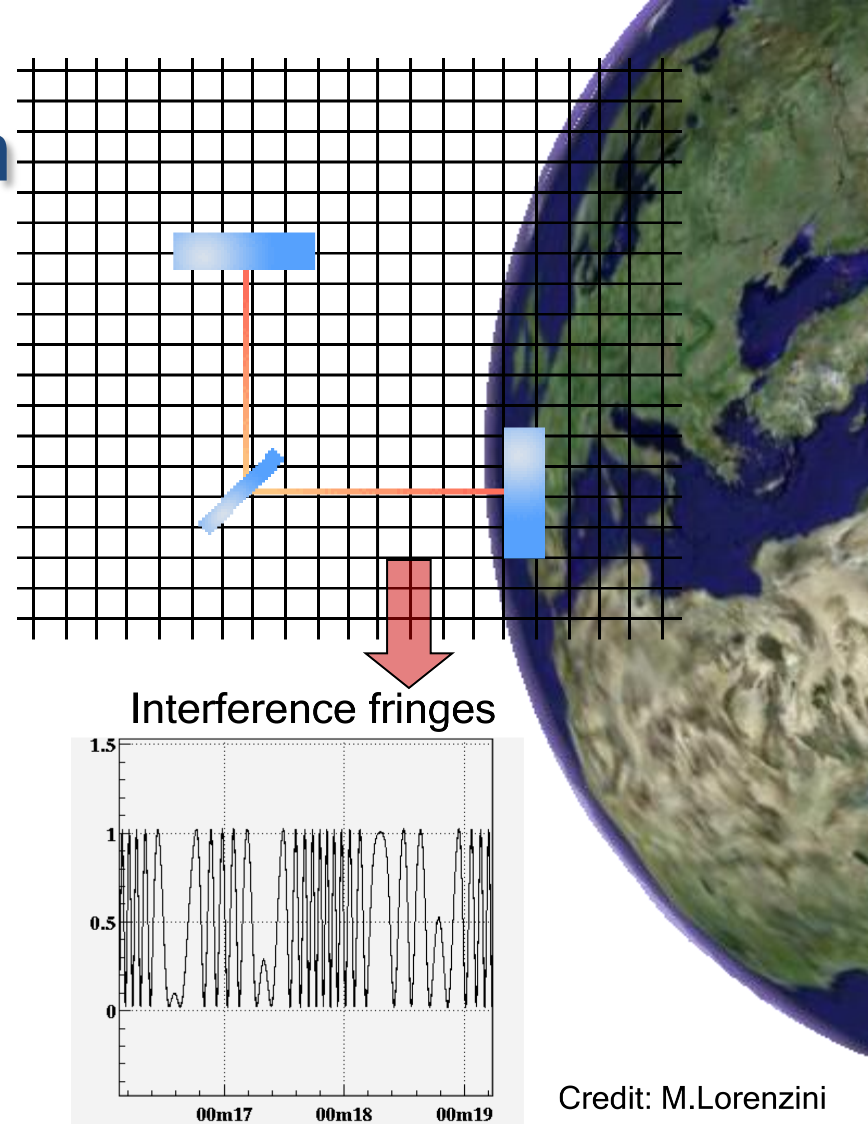
P (d)	**0322997448930(4)**
dω/dt (deg/yr)	**4.226595(5)**
M_p	**1.4414 ± 0.0002 $M_\odot$**
M_c	**1.3867 ± 0.0002 $M_\odot$**



Principle of Detection

GW induce space-time deformation

Measure space-time strain using light



Credit: M.Lorenzini

$$\Delta L \approx \frac{1}{2} hL$$

Target h ~ 10^{-21}
(NS/NS @Virgo Cluster)

Feasible L ~ 10^{3} m

Need to measure: ΔL ~ 10^{-18} m

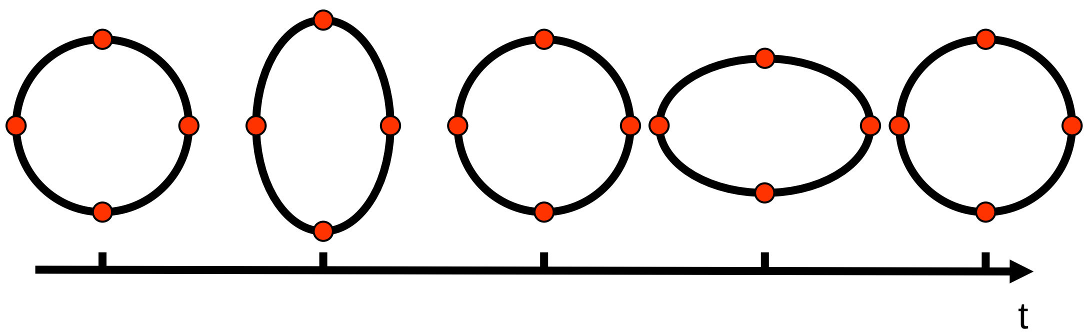
Big challenge for experimentalists!

BASIC ‘WH’ QUESTIONS

WHAT

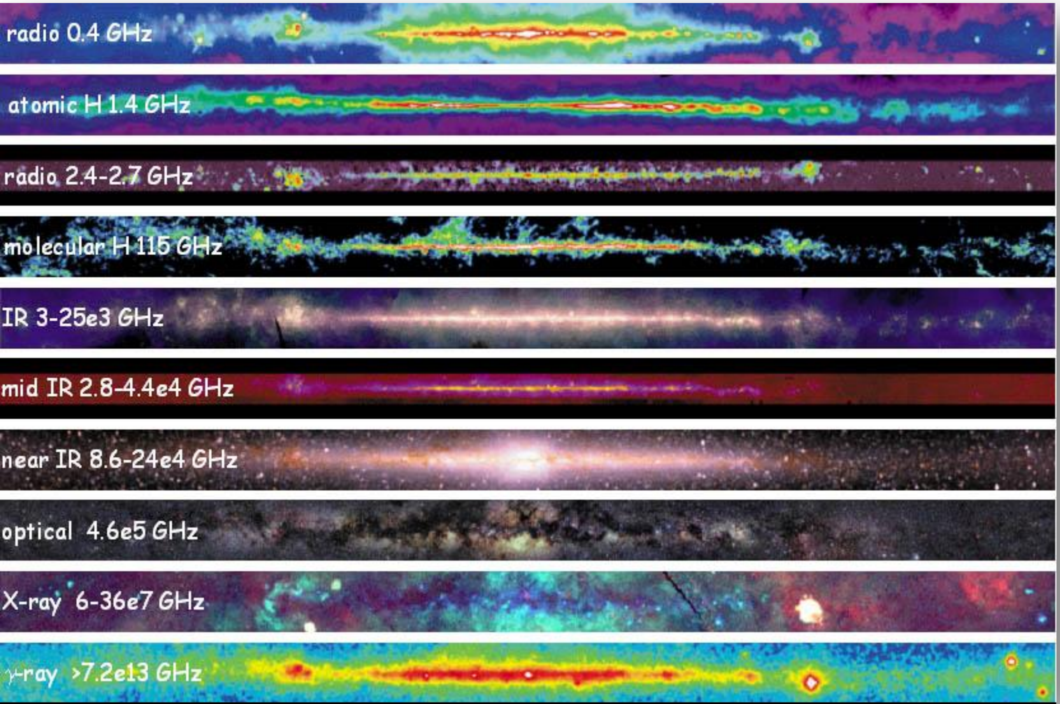
$$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right) h_{\mu\nu} = 0$$

DIRECT DETECTION OF GRAVITATIONAL WAVES

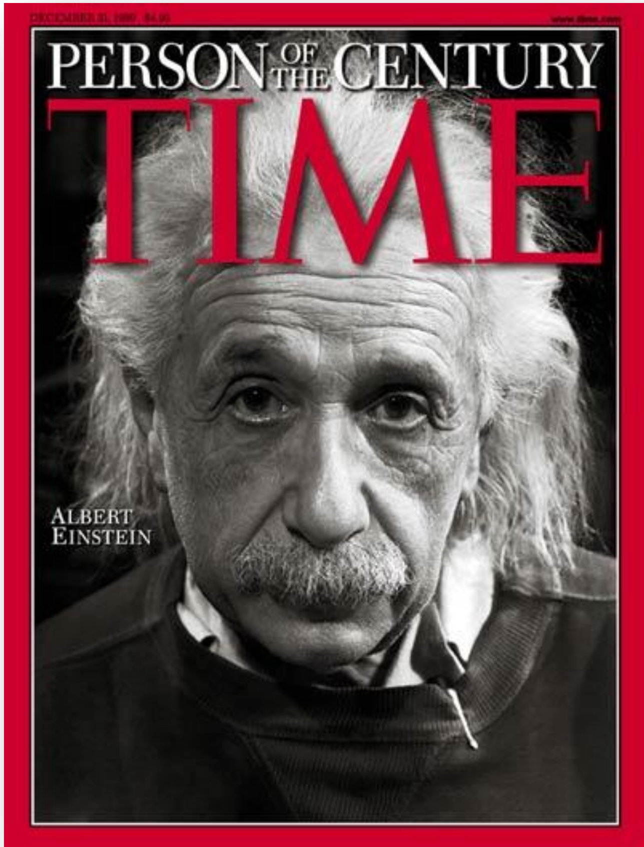


WHY

SHORT-TERM GOAL: CONFIRM THE 1916 EINSTEIN'S PREDICTION



GW ??



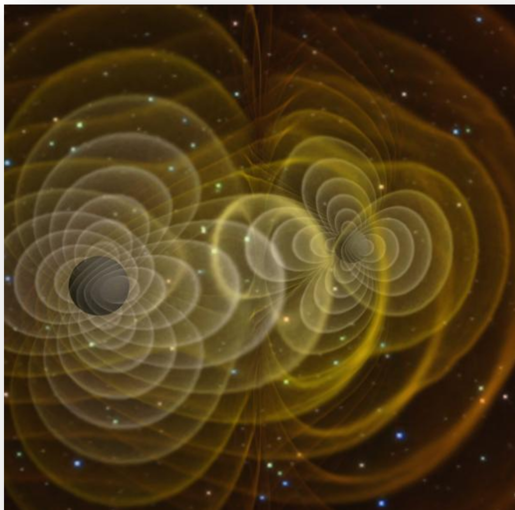
MID-TERM GOAL: GW ASTRONOMY

OPEN A NEW WINDOW

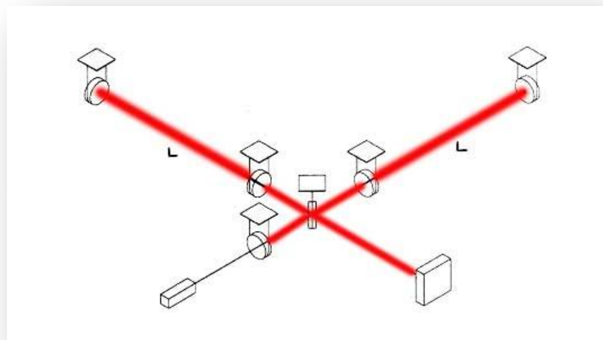
ON THE UNIVERSE

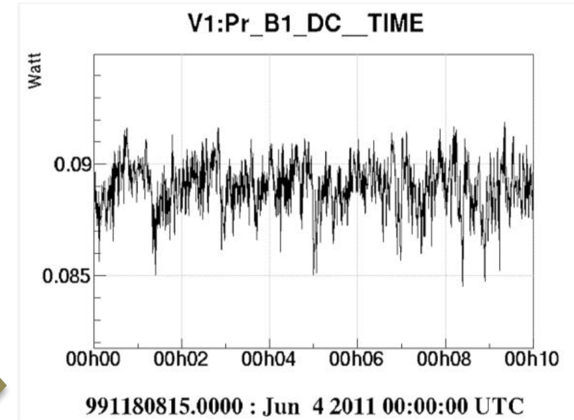
HOW

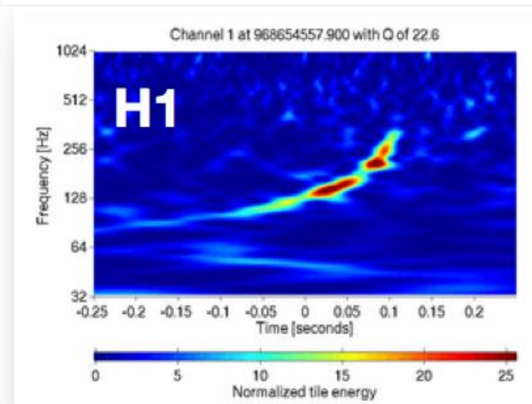
LARGE INTERFEROMETRIC DETECTORS



Henze, NASA







SPACE-TIME STRAIN TO PHOTO-CURRENT TRANSDUCERS:

REQUIRED SENSITIVITY: 10^{-19}-10^{-20} m

PHYSICS AT THE MILLIFERMI SCALE!

WHERE


LIGO - WA
GEO600 - D
KAGRA – J
(2018)
LIGO - LA
Virgo - I
indigo
LIGO
LIGO – India
(> 2020)

WHO

The LIGO Scientific Collaboration

The Virgo Collaboration

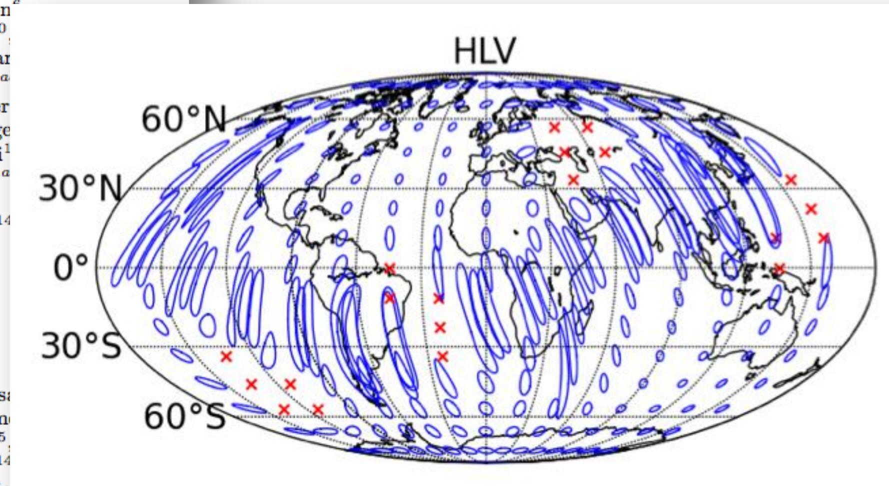
APC Paris
ARTEMIS Nice
EGO Cascina
INFN Firenze-Urbino
INFN Genova
INFN Napoli
INFN Perugia
INFN Pisa
INFN Roma La Sapienza
INFN Roma Tor Vergata
INFN Trento-Padova
LAL Orsay – ESPCI Paris
LAPP Annecy
LKB Paris
LMA Lyon
NIKHEF Amsterdam
POLGRAW(Poland)
RADBOUD Uni. Nijmegen
RMKI Budapest

WHEN

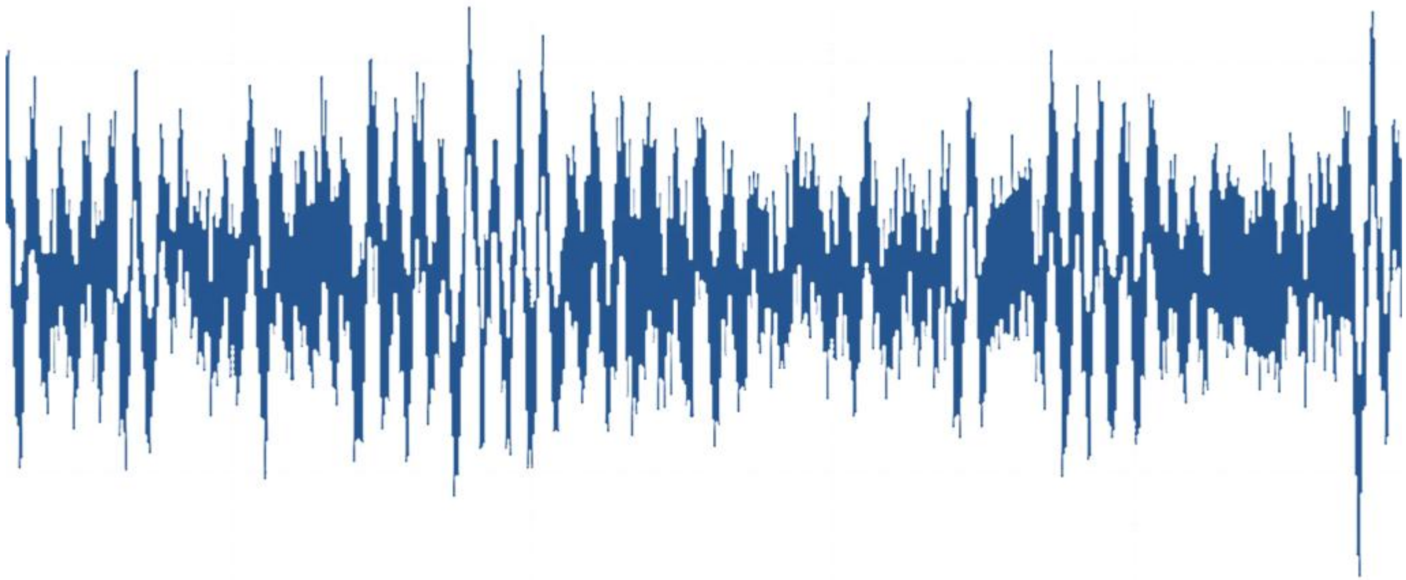
Prospects for Localization of Gravitational Wave Transients by the Advanced LIGO and Advanced Virgo Observatories

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
P. Astone[17a], D. Atkinson[18], P. Aufmuth[10,9], C. Aulbert[9,10], L. Austin[1], B. E. Aylott[19], S. Babak[20],
P. Baker[21], G. Ballardin[22], S. Ballmer[23], Y. Bao[15], J. C. Barayoga[1], D. Barker[18], F. Barone[5ac], B. Bar
L. Barsotti[24], M. Barsuglia[25], M. A. Barton[18], I. Bartos[26], R. Bassiri[3,27], M. Bastarrika[3], A. Basti[14a
J. Batch[18], J. Bauchrowitz[9,10], Th. S. Bauer[11a], M. Bebronne[4], B. Behnke[20], M. Bejger[28c], M.G. Beker
A. S. Bell[3], C. Bell[3], G. Bergmann[9,10], J. M. Berliner[18], A. Bertolini[9,10], J. Betzwieser[6], N. Beveridge
P. T. Beyersdorf[29], T. Bhadbade[27], I. A. Bilenko[30], G. Billingsley[1], J. Birch[6], S. Biscans[24], M. Bitossi
M. A. Bizouard[31a], E. Black[1], J. K. Blackburn[1], L. Blackburn[32], D. Blair[33], B. Bland[18], M. Blom[11a
O. Bock[9,10], T. P. Bodiya[24], C. Bogan[9,10], C. Bond[19], F. Bondu[34b], L. Bonelli[14ab], R. Bonnand[35],
R. Bork[1], M. Born[9,10], V. Boschi[14a], S. Bose[36], L. Bosi[37a], B. Bouhou[25], J. Bowers[2], C. Bradaschia[14
P. R. Brady[13], V. B. Braginsky[30], M. Branchesi[38ab], J. E. Brau[39], J. Breyer[9,10], T. Briant[40],
D. O. Bridges[6], A. Brillet[34a], M. Brinkmann[9,10], V. Brisson[31a], M. Britzger[9,10], A. F. Brooks[1],
D. A. Brown[23], D. D. Brown[19], F. Brueckner[19], K. Buckland[1], T. Bulik[28b], H. J. Bulten[11ab],
A. Buonanno[41], J. Burguet–Castell[42], D. Buskulic[4], C. Buy[25], R. L. Byer[27], L. Cadonati[43],
G. Cagnoli[35,44], E. Calloni[5ab], J. B. Camp[32], P. Campsie[3], K. Cannon[45], B. Canuel[22], J. Cao[46],
C. D. Capano[41], F. Carbognani[22], L. Carbone[19], S. Caride[47], A. D. Castiglia[48], S. Caudill[13],
M. Cavaglià[16], F. Cavalier[31a], R. Cavalieri[22], G. Cella[14a], C. Cepeda[1], E. Cesarini[49a], T. Chalermsongs
S. Chao[101], P. Charlton[50], E. Chassande-Mottin[25], X. Chen[33], Y. Chen[51], A. Chincarini[52], A. Chiumm
H. S. Cho[53], J. Chow[54], N. Christensen[55], Q. Chu[33], S. S. Y. Chua[54], C. T. Y. Chung[56], G. Ciani[15],
F. Clara[18], D. E. Clark[27], J. A. Clark[43], F. Cleva[34a], E. Coccia[49ab], P.-F. Cohadon[40], C. N. Colacino[14
A. Colla[17ab], M. Colombini[17b], M. Constancio Jr.[12], A. Conte[17ab], D. Cook[18], T. R. Corbitt[2], M. Cordie
N. Cornish[21], A. Corsi[103], C. A. Costa[2,12], M. Coughlin[57], J.-P. Coulon[34a], S. Countryman[26],
P. Co
T. D. C
S. L. Da
M. Davier[31
W. Del P
S. Dhurandha
F. Do
J. C. Drigge
S. S. Eikenb
M. Fact
D. Fazi[63],
L. Fio

DATA TAKING WILL START IN 2015
DETECTION?



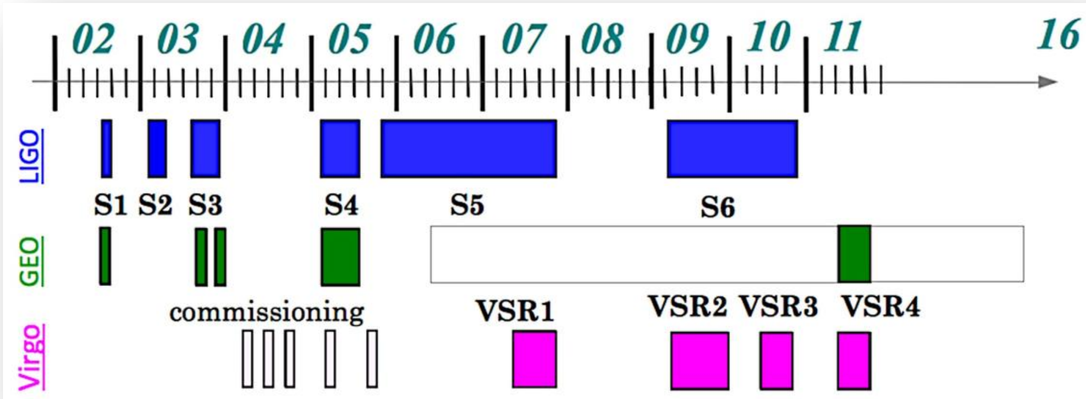
Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_\odot c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections	% BNS Localized within 5 deg^2	20 deg^2
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	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



DETECTORS

1st GENERATION DETECTORS

- The interferometers of the 1t generation (LIGO, Virgo, GEO600) have run in the 1st decade of 2000's



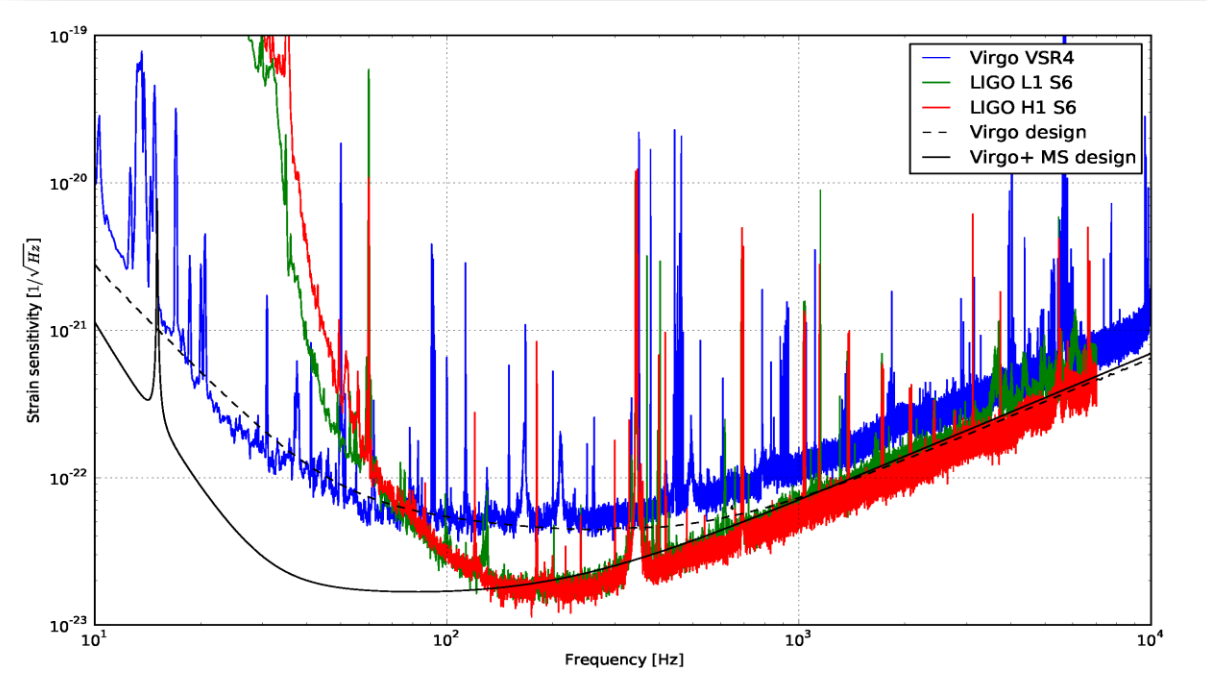
- The sensitivity finally achieved was enough to detect a coalescing BNS in ~100 galaxies…
  - …but such events happen ~1/10000 yr per galaxy…
- No detection done but a rich legacy has been left. A richness being invested in a new generation of detectors that promises to detect GW and open a new window on the universe

OBSERVATORIES

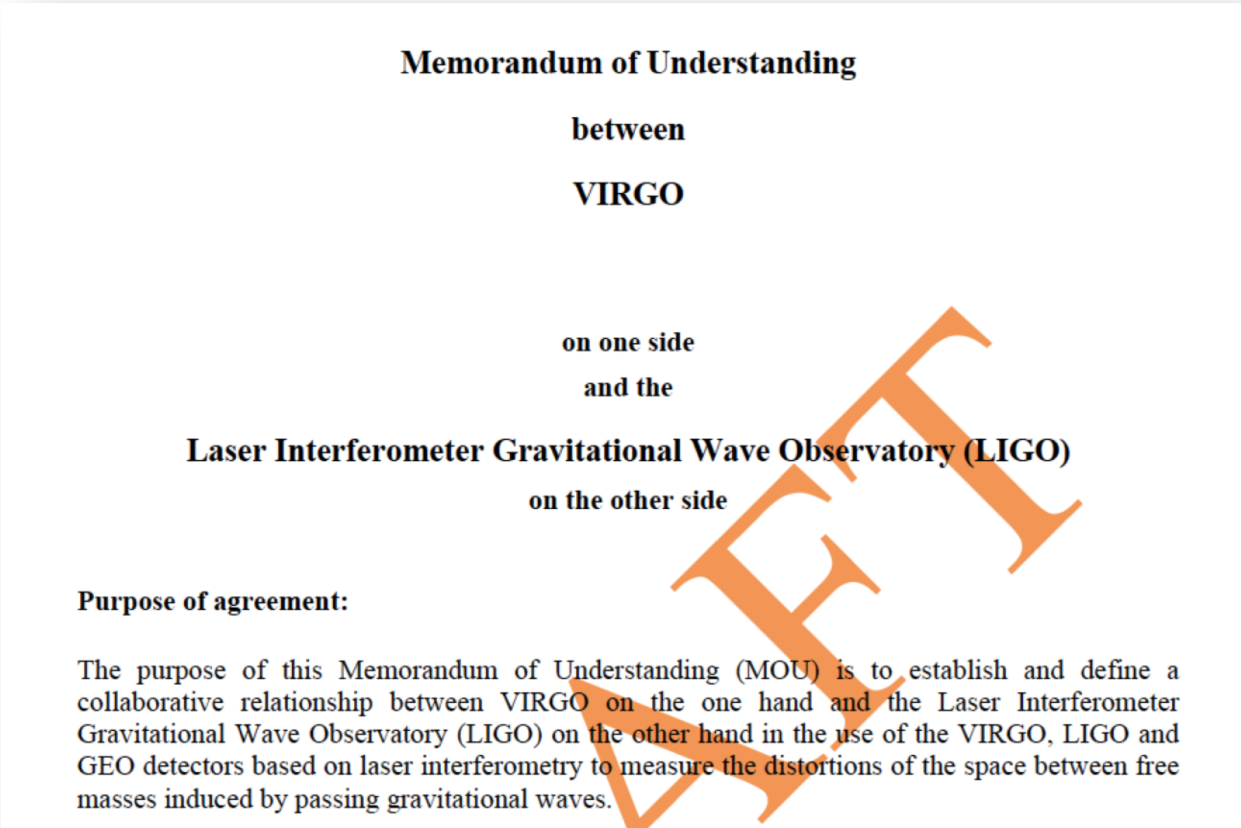
- The infrastructure of km-scale interferometers were established
- The same ones will be used for the next generation of LIGO, Virgo and GEO
- New ones will be needed for two new detectors in Japan (KAGRA) and India (LIGO-India)

NOISE AND SENSITIVITY

- The noise has been mostly understood
- The 1st generation design sensitivities have been approached closely (and somewhere exceeded upon detector upgrades)
- Excellent duty cycle (~80%): reliable instruments!



NETWORK



Memorandum of Understanding

between

VIRGO

on one side

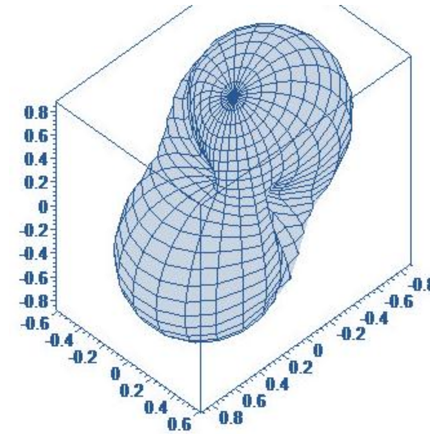
and the

Laser Interferometer Gravitational Wave Observatory (LIGO)

on the other side

Purpose of agreement:

The purpose of this Memorandum of Understanding (MOU) is to establish and define a collaborative relationship between VIRGO on the one hand and the Laser Interferometer Gravitational Wave Observatory (LIGO) on the other hand in the use of the VIRGO, LIGO and GEO detectors based on laser interferometry to measure the distortions of the space between free masses induced by passing gravitational waves.



GW “TELESCOPES” CANNOT BE POINTED

SOURCE LOCALIZATION REQUIRES NETWORKING

LIGO, Virgo, GEO exchanging data since 2007.
MoU being renewed.

OBSERVATIONAL RESULTS

O(100) PAPERS ON ASTROPHYSICS/COSMOLOGY/ ASTROPARTICLE PHYSICS

THE ASTROPHYSICAL JOURNAL, 715:1438–1452, 2010 June 1 doi:10.1088/0004-637X/715/2/1438

SEARCH FOR GRAVITATIONAL-WAVE BURSTS ASSOCIATED WITH GAMMA-RAY BURSTS USING DATA FROM LIGO SCIENCE RUN 5 AND VIRGO SCIENCE RUN 1

PHYSICAL REVIEW D **82,** 102001 (2010)

Search for gravitational waves from compact binary coalescence in LIGO and Virgo data from S5 and VSR1

PHYSICAL REVIEW D **87,** 022002 (2013)

Search for gravitational waves from binary black hole inspiral, merger, and ringdown in LIGO-Virgo data from 2009–2010

PHYSICAL REVIEW D **81,** 102001 (2010)

All-sky search for gravitational-wave bursts in the first joint LIGO-GEO-Virgo run

THE ASTROPHYSICAL JOURNAL, 715:1453–1461, 2010 June 1 doi:10.1088/0004-637X/715/2/1453

SEARCH FOR GRAVITATIONAL-WAVE INSPIRAL SIGNALS ASSOCIATED WITH SHORT GAMMA-RAY BURSTS DURING LIGO'S FIFTH AND VIRGO'S FIRST SCIENCE RUN

A first search for coincident gravitational waves and high energy neutrinos using LIGO, Virgo and ANTARES data from 2007

The ANTARES collaboration, the LIGO scientific collaboration and the Virgo collaboration

THE ASTROPHYSICAL JOURNAL, 737:93 (16pp), 2011 August 20

BEATING THE SPIN-DOWN LIMIT ON GRAVITATIONAL WAVE EMISSION FROM THE VELA PULSAR

nature Vol 460|20 August 2009|doi:10.1038/nature08278

LETTERS

An upper limit on the stochastic gravitational-wave background of cosmological origin

The LIGO Scientific Collaboration* & The Virgo Collaboration*

The Astrophysical Journal, 713:671–685, 2010 April 10 doi:10.1088/0004-637X/713/1/671

SEARCHES FOR GRAVITATIONAL WAVES FROM KNOWN PULSARS WITH SCIENCE RUN 5 LIGO DATA

B. P. Abbott[1], R. Abbott[1], F. Acernese[2ac], R. Adhikari[1], P. Ajith[3], B. Allen[3,4], G. Allen[5], M. Alshourbagy[6ab], R. S. Amin[7], S. B. Anderson[1], W. G. Anderson[4], F. Antonucci[8a], S. Aoudia[9a], M. A. Arain[10], M. Araya[1], H. Armandula[1], P. Armor[4], K. G. Arun[11], Y. Aso[1], S. Aston[12], P. Astone[8a], P. Aufmuth[13], C. Aulbert[3], S. Babak[14], P. Baker[15],

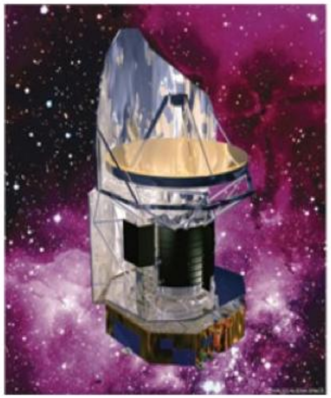
Table 1
(Continued)

Pulsar	Start–End (MJD)	ν (Hz)	$\dot{\nu}$ (Hz s^{-1})	Distance (kpc)	Spin-down Limit	Joint $h_0^{95\%}$	Ellipticity	$h_0^{95\%}/h_0^{sd}$
J2033+17[bj]	53702–54522	168.10	-3.1×10^{-16}	1.4	7.93×10^{-28}	7.49×10^{-26}	8.65×10^{-7}	94
J2051−0827[bj]	53410–54520	221.80	-6.1×10^{-16}[a]	1.3	1.04×10^{-27}	7.57×10^{-26}	4.65×10^{-7}	73
J2124−3358[jp]	53410–54510	202.79	-5.1×10^{-16}[a]	0.2	5.13×10^{-27}	4.85×10^{-26}	6.96×10^{-8}	9.4
J2129−5721[bp]	53687–54388	268.36	-2.0×10^{-15}[a]	2.5	8.71×10^{-28}	6.12×10^{-26}	5.13×10^{-7}	70
J2145−0750[bjp]	53409–54510	62.30	-1.0×10^{-16}[a]	0.5	2.05×10^{-27}	3.83×10^{-26}	1.17×10^{-6}	19

THE UPPER LIMIT SET ON THE PULSAR EMISSION ALLOWS TO LIMIT THE ELLIPTICITY TO O(10^{-8}):
WE ARE MEASURING THE STAR RADIUS ASYMMETRY WITH AN ACCURACY OF ~0.7 mm

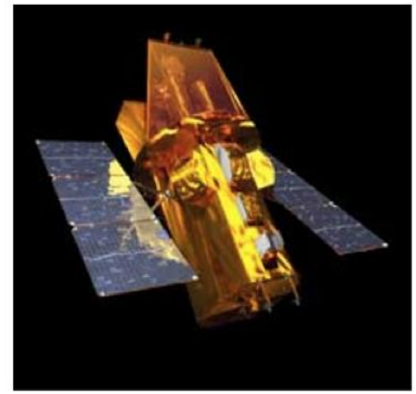
MULTI-MESSENGER


radio


infrared

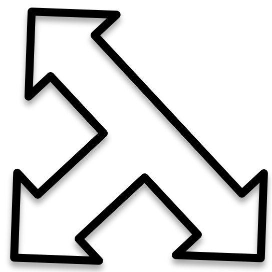

visible

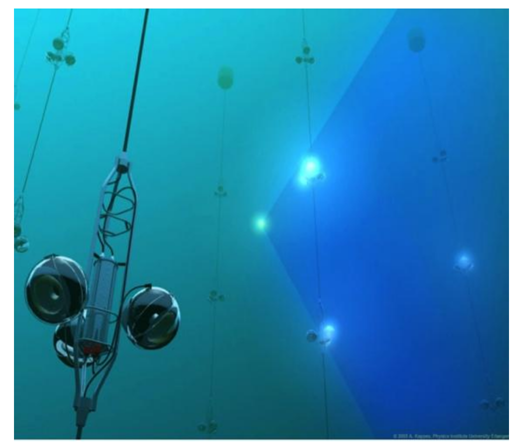

X-rays


gamma-rays (keV)


gamma-rays (MeV)

OBSERVE THE SAME EVENT WITH DIFFERENT INSTRUMENTS: DEEPER AND RICHER UNDERSTANDING OF ITS PHYSICAL NATURE



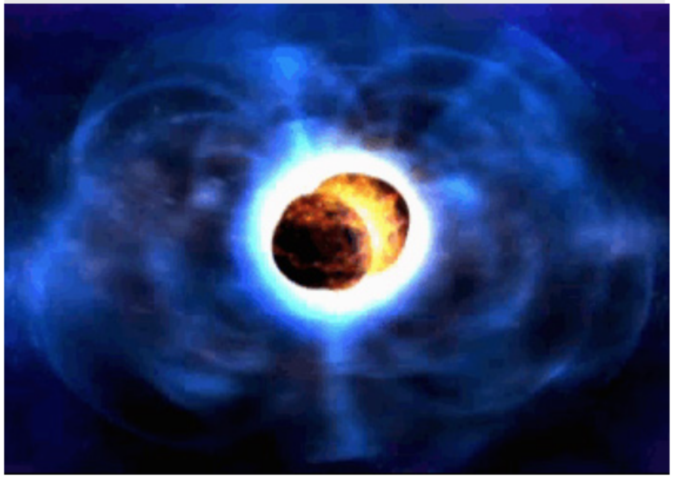


IDENTIFICATION AND FOLLOW UP OF ELECTROMAGNETIC COUNTERPARTS OF GRAVITATIONAL WAVE CANDIDATE EVENTS

The LIGO Scientific Collaboration (LSC) and the Virgo Collaboration currently plan to start taking data in 2015, and we expect the sensitivity of the network to improve over time. Gravitational-wave transient candidates will be identified promptly upon acquisition of the data; we aim for distributing information with an initial latency of a few tens of minutes initially, possibly improving later. The LSC and the Virgo Collaboration (LVC) wish to enable multi-messenger observations of astrophysical events by GW detectors along with a wide range of telescopes and instruments of mainstream astronomy.

In 2012, the LVC approved a statement (LSC, Virgo) that broadly outlines LVC policy on releasing GW triggers (partially-validated event candidates). Initially, triggers will be shared promptly only with astronomy partners who have signed an Memorandum of Understanding (MoU) with LVC involving an agreement on deliverables, publication policies, confidentiality, and reporting. After four GW events have been published, further event candidates with high confidence will be shared immediately with the entire astronomy community (and the public), while lower-significance candidates will continue to be shared promptly only with partners who have signed a MoU.

Through June to October 2013, we organized rounds of consultations with groups of astronomers that have expressed interest in the GW-EM follow-up program. Thanks to these consultations, we could define the framework and guiding rules for this program that are collected into a standard MoU template.



Devour thy Neighbor: An artist's illustration of two neutron stars close to merger look misshaped, becoming more oblong the closer they get to one another. A black hole is then formed and gamma rays shoot out as a GRB. (Credit: NASA/Swift)

OPEN CALL FOR PARTICIPATION TO GW-EM FOLLOW-UP PROGRAM, DUE FEB 16 2014.

On Dec 16 2013, we issued a call for proposals to sign standard MoU with the LVC. This call is open to all professional astronomers with demonstrated experience, and require that a partner bring some useful observing resource(s), not just astronomy expertise, to participate. GW triggers will be sent to groups that are in position to make observations in the course of next science runs circa 2015-2017 (arXiv:1304.0670, LIGO-P1200087, VIR-0288A-12). Our intent is to accept and sign MoUs with all qualified applicants. We expect to issue this call yearly in spring.

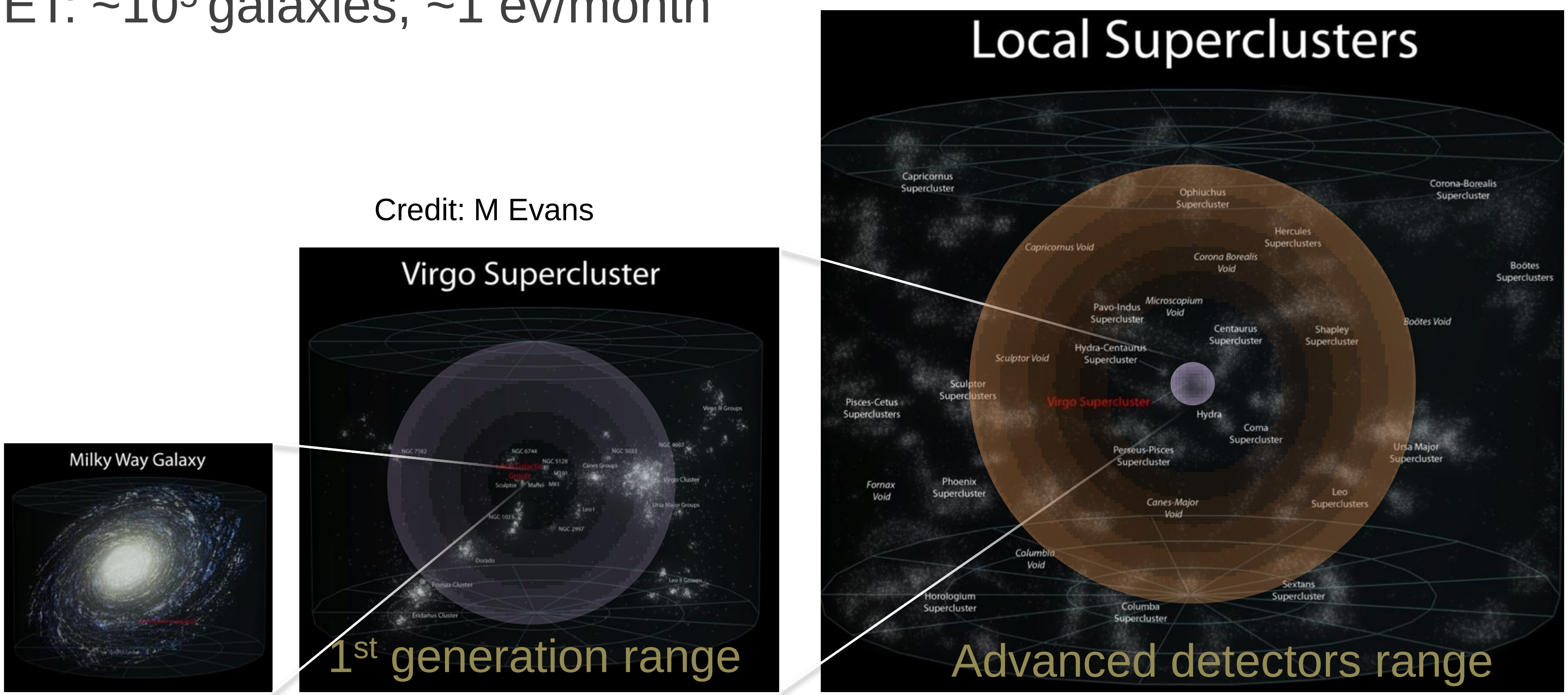
If you are interested in signing this agreement with LSC and Virgo, please read this document that provides important details of the GW-EM follow-up program, fill the application form in LIGO-F1300021, and email it to emf@ligo.org. **Also**, please fill the information fields below (including the filename of the file you emailed to us) and submit it before Feb 16, 2014.

JOINT GW-EM OBSERVATIONS

- Consider the GW signal in its astrophysical context
- Give a precise (arcsecond) localization, identify host galaxy
- Get a multi-messenger picture of the most energetic events
- Get an insight into the physics of the progenitors (mass, spin, distance) and their environment (temperature, density, redshift)
- Start the GW astronomy to answer many open questions:
  - Connection between GRB and mergers of compact objects
  - birth and evolution of black holes
  - Equation of state of nuclear matter (neutron stars)
  - Cosmology (long term)
  - …

ADVANCED DETECTORS

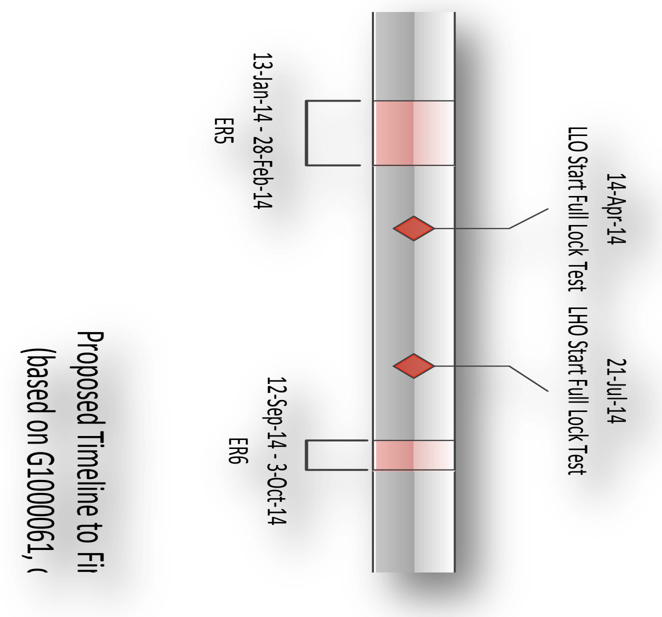
- Starting the GW astronomy requires increasing dramatically the number of observable galaxies
- We have the technology to expand substantially the observable universe. A “second generation” network is being realized
- TARGET: ~10^5 galaxies, ~1 ev/month



Credit: M Evans

ADVANCED LIGO

- Concept: ~1999
- Project start: April 2008
- Funding: $205 M$ from NSF, in-kind contribution from Germany/UK
- Installation close to completion, commissioning started
- Third interferometer to be shipped to India



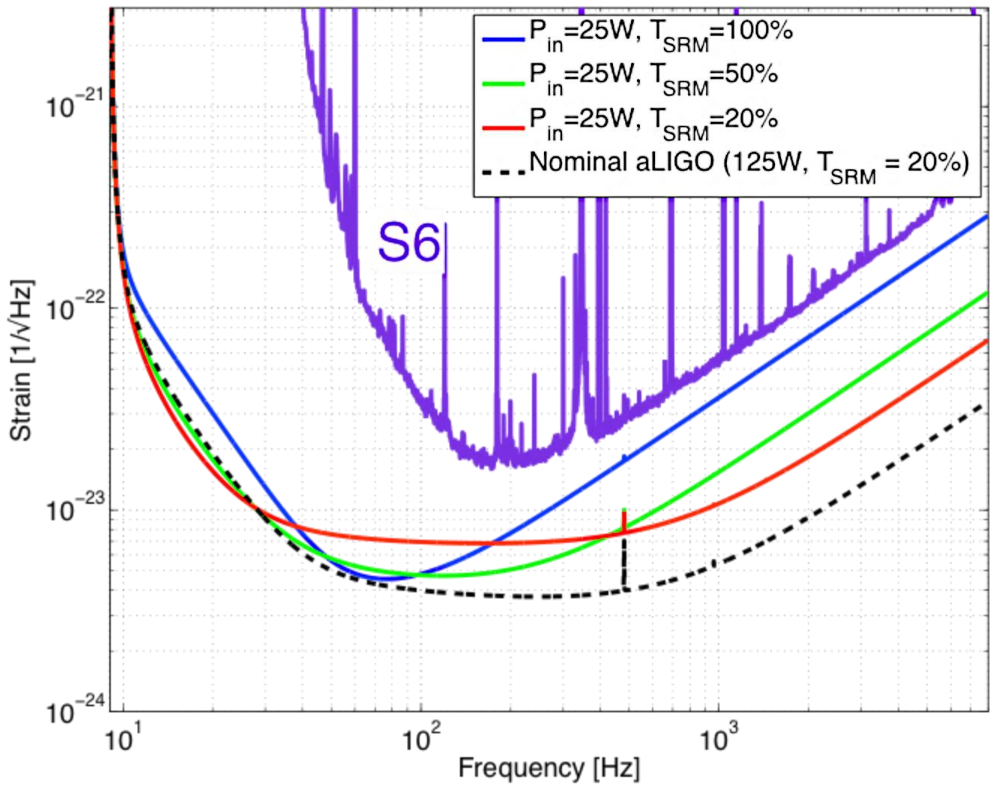
ADVANCED VIRGO

- 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

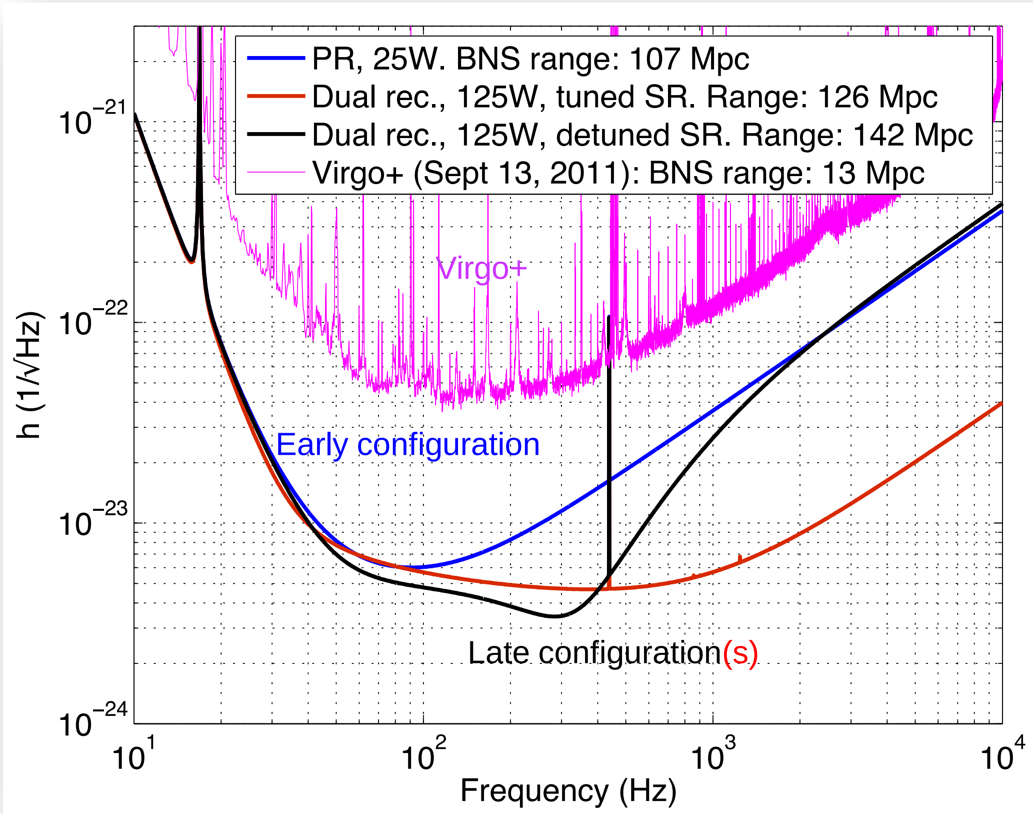
5 European countries
19 labs, ~200 authors

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

SENSITIVITIES



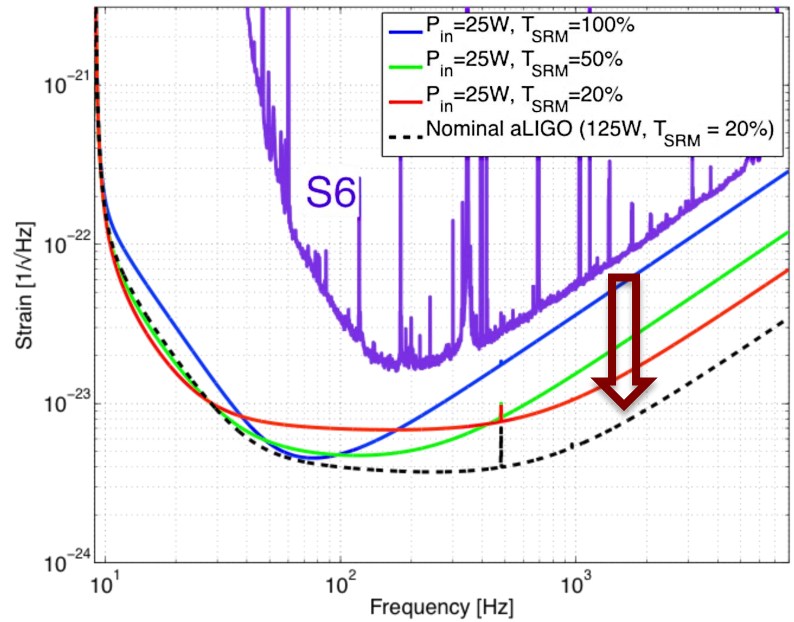
LIGO



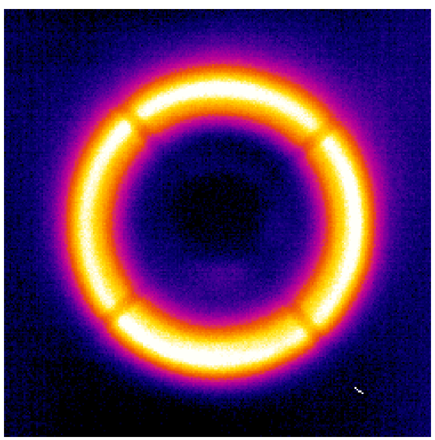
Virgo

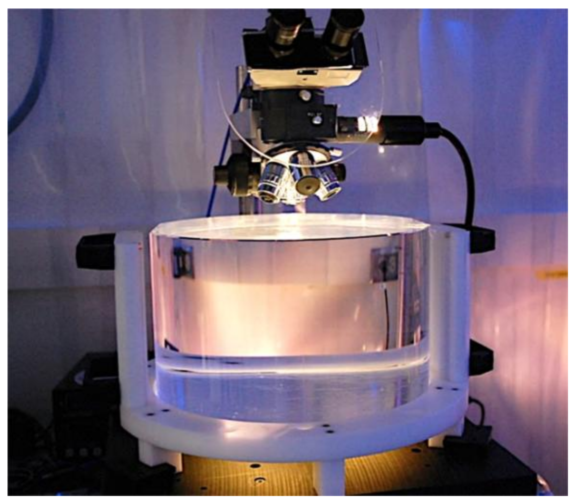
TECHNOLOGIES

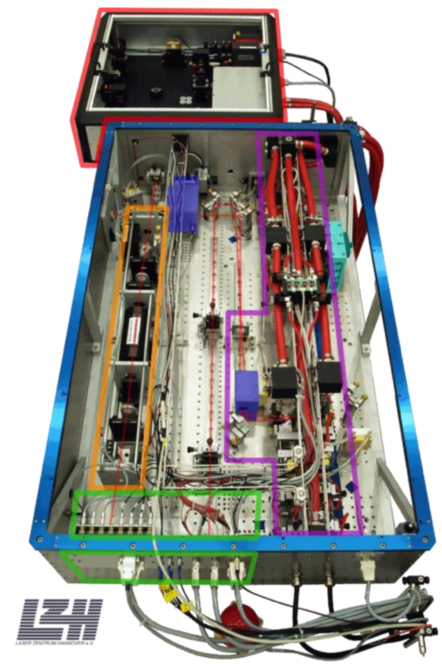
HIGH FREQUENCY RANGE



- 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)
  - Smart systems to correct for thermal aberrations



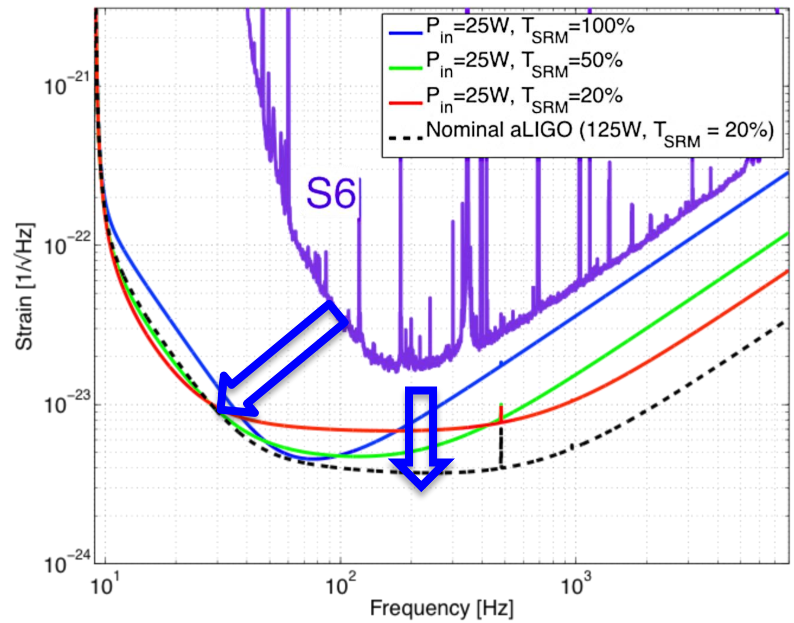


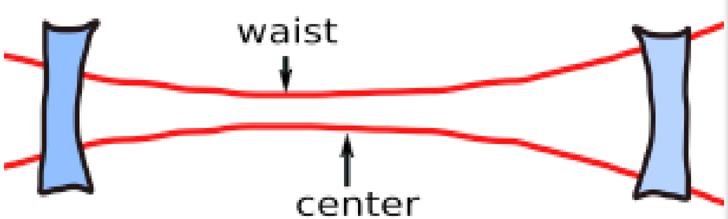


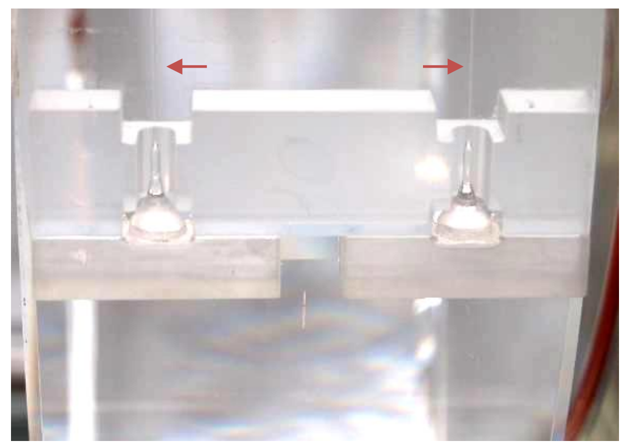
TECHNOLOGIES

MID FREQUENCY RANGE

- Dominated by thermal noise of
  - Mirror coatings
  - Suspensions
- Reduced by:
  - Improved optical configuration: larger beam spot
  - Test masses suspended by fused silica fibers (low mechanical losses)
  - Mirror coatings engineered for low losses

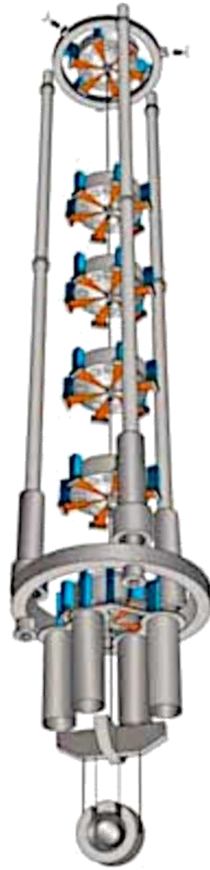




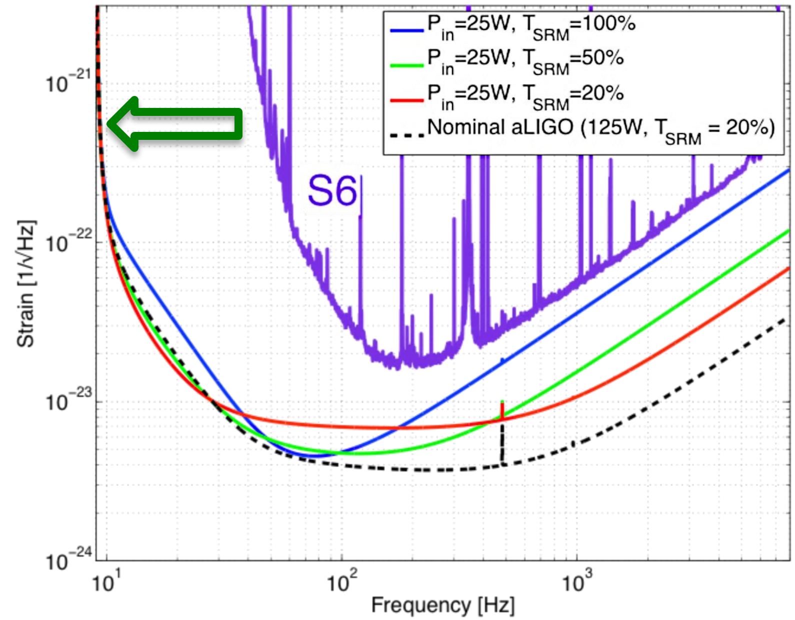


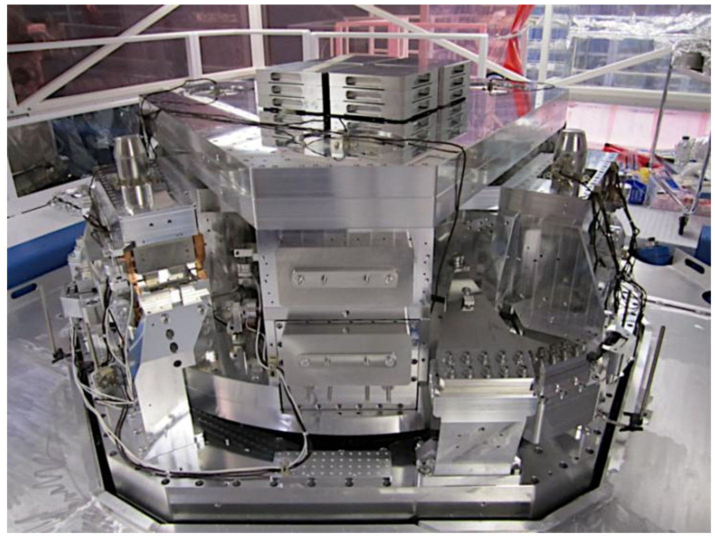
TECHNOLOGIES

- Dominated by seismic noise
- Managed by suspending the mirrors from extreme vibration isolators
  - Virgo Superattenuator (from 1st generation)
  - LIGO active system
- Technical noises of different nature are the real challenge in this range
- Ultimate limit for ground based detectors: gravity gradient noise



LOW FREQUENCY RANGE

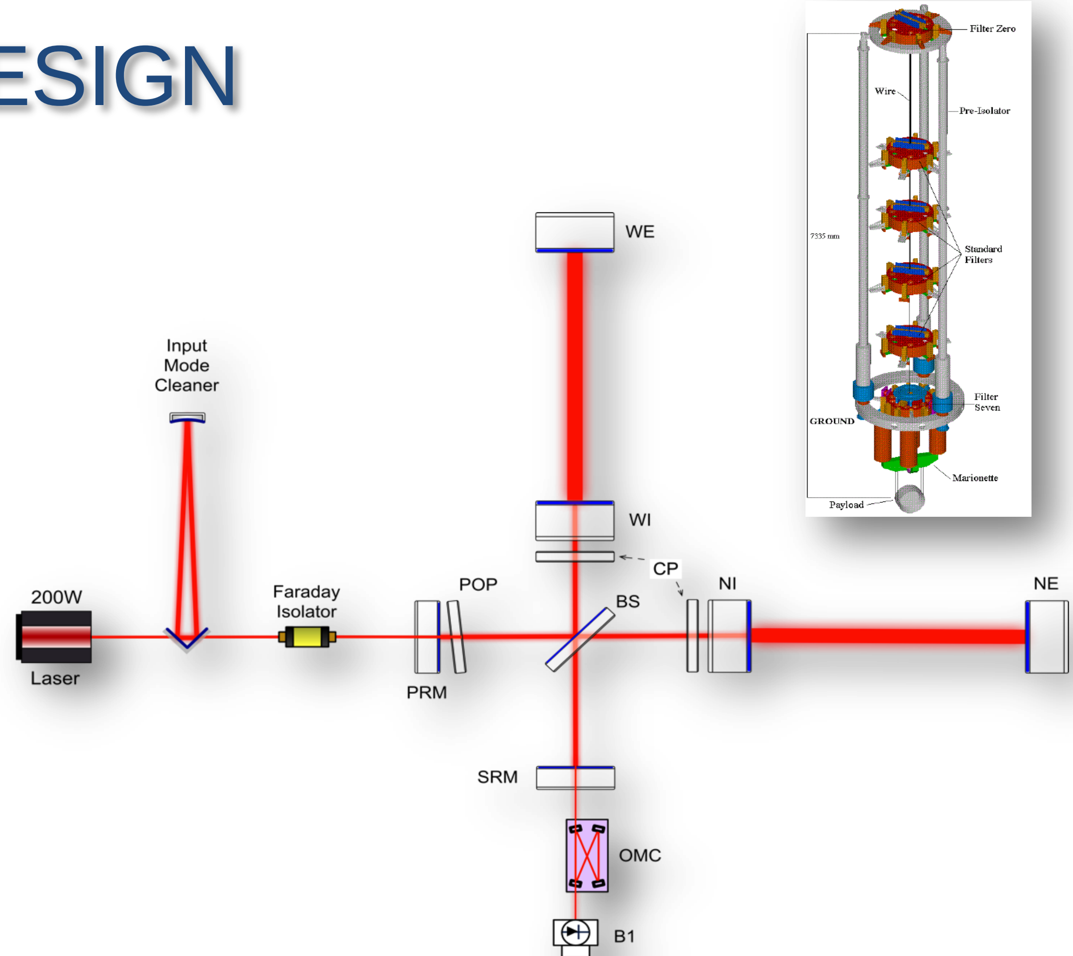




ADVANCED VIRGO

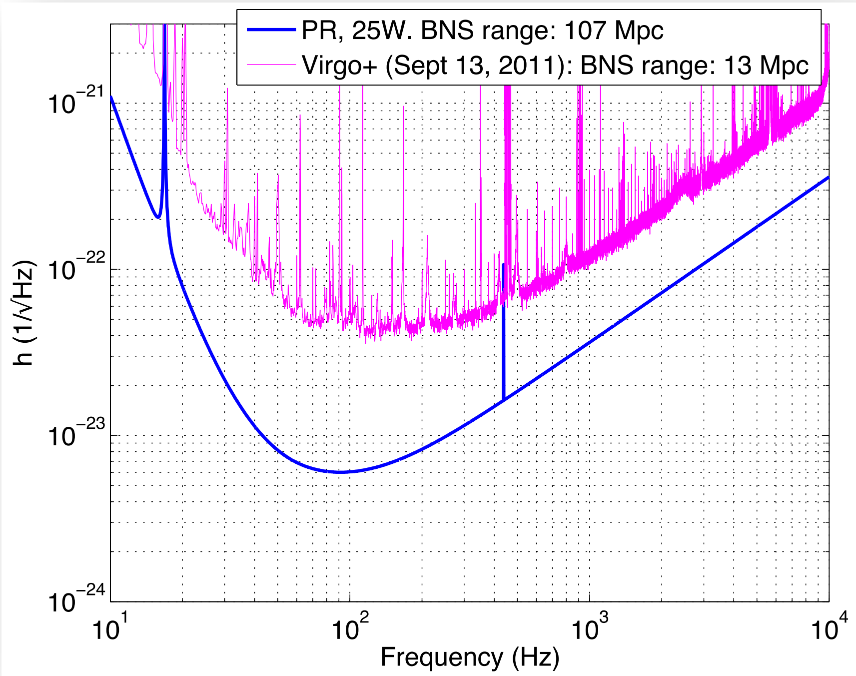
DETECTOR DESIGN

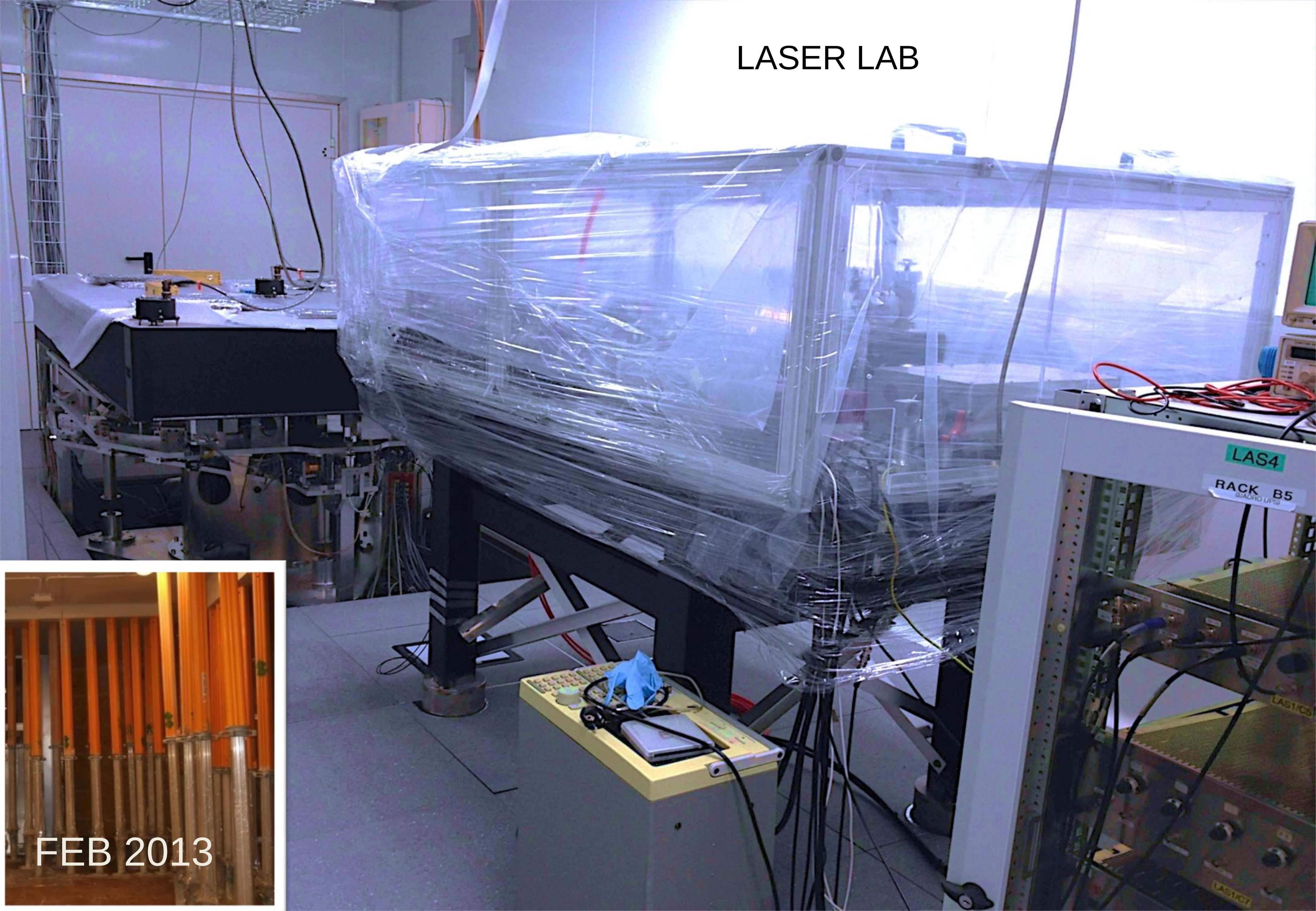
- MAIN CHANGES wrt Virgo
  - larger beam
  - heavier mirrors
  - higher quality optics
  - thermal control of aberrations
  - *200W fiber laser*
  - *signal recycling*
- Vibration isolation by Virgo superattenuators
  - performance demonstrated
  - large experience gained with commissioning at low frequency

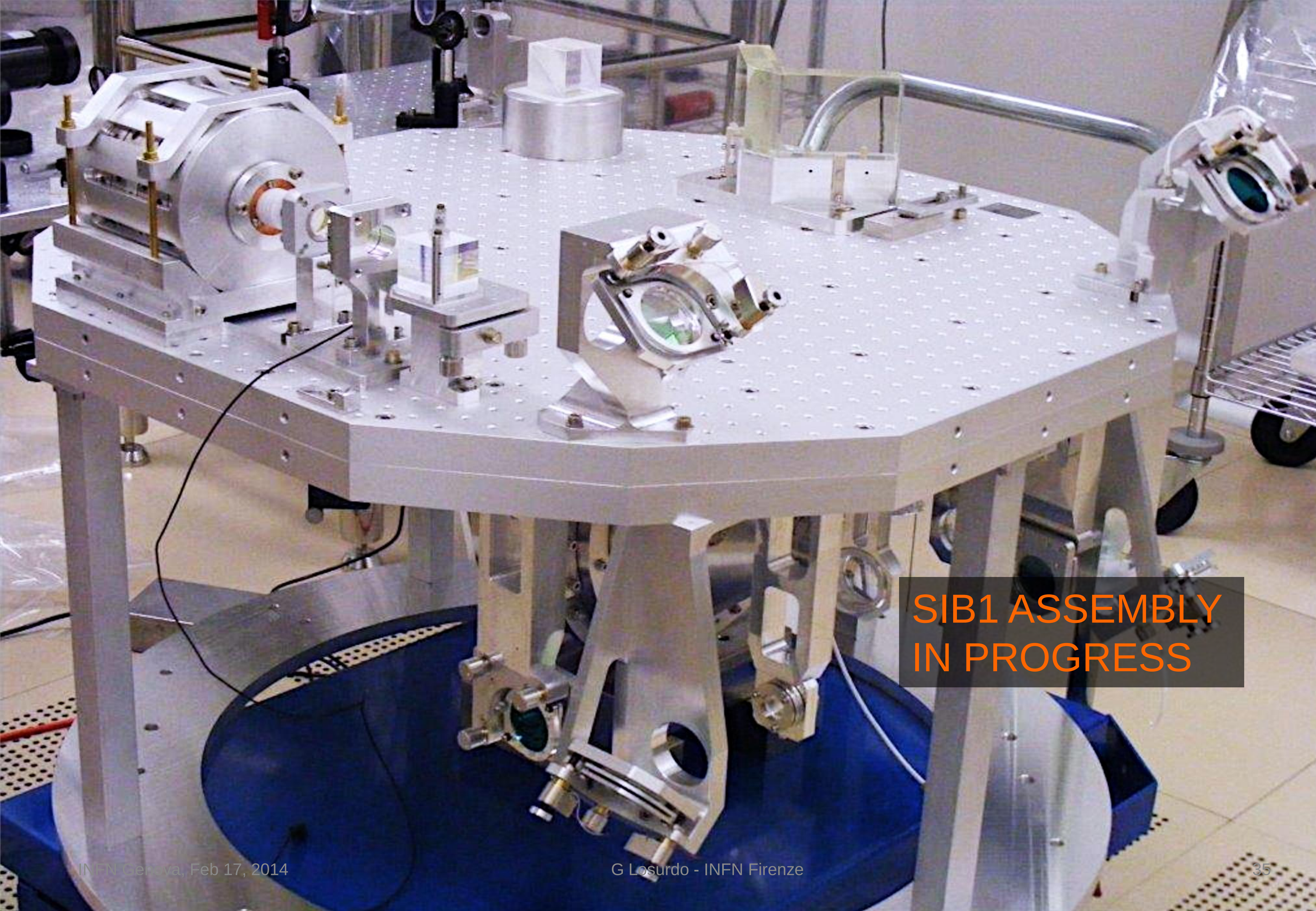


2015 CHALLENGE

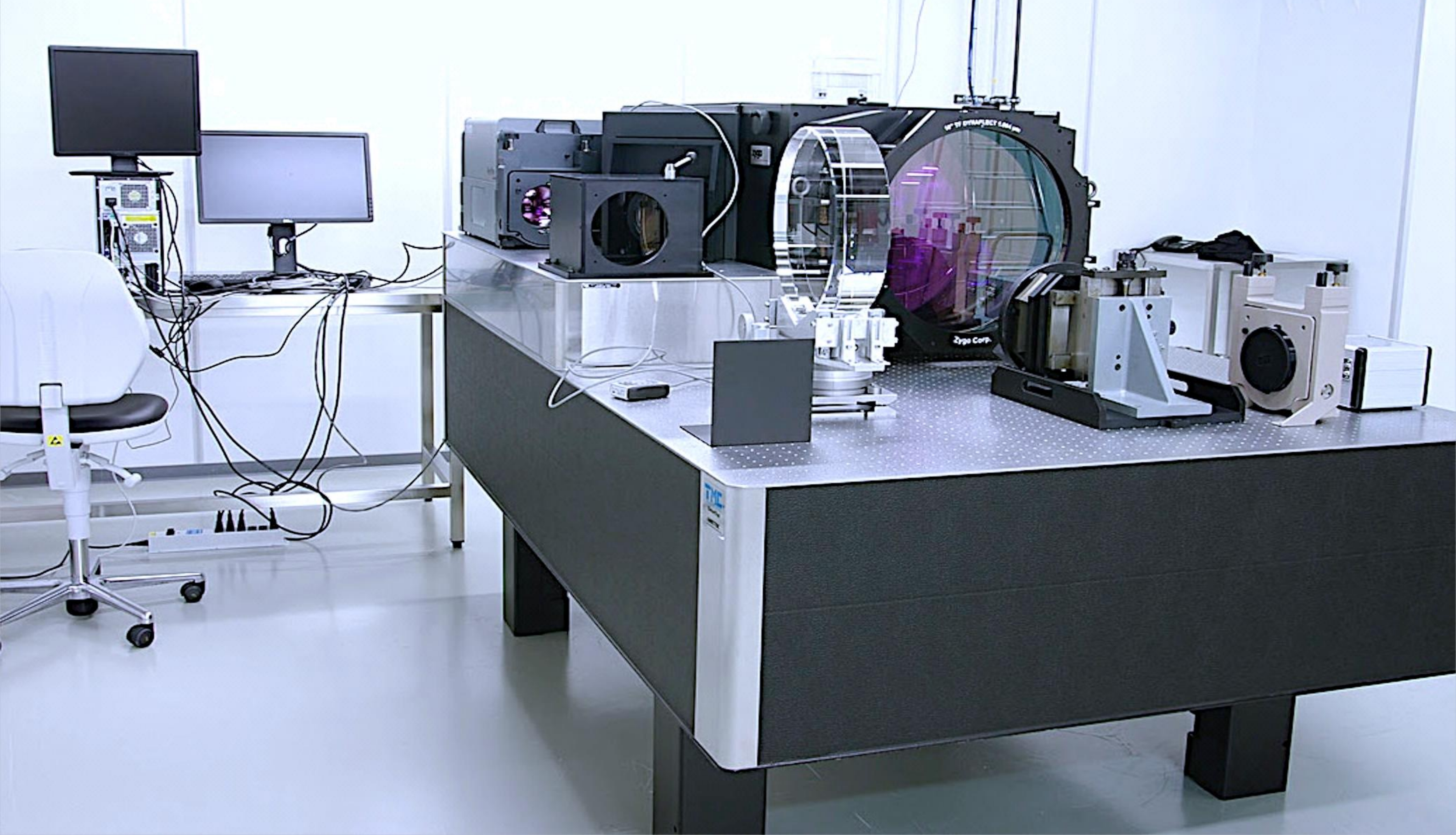
- Start in 2015 with a simplified configuration, similar to Virgo+: likely to reduce commissioning time
  - No signal recycling (reduce locking complexity)
  - Virgo+ laser (up to 60W)
  - Low power (reduce risks with thermal effects and high power laser)
- Target BNS inspiral range: >100 Mpc
- Configuration upgrade schedule to be discussed with the partners




LASER LAB
LAS4
RACK B5
FEB 2013

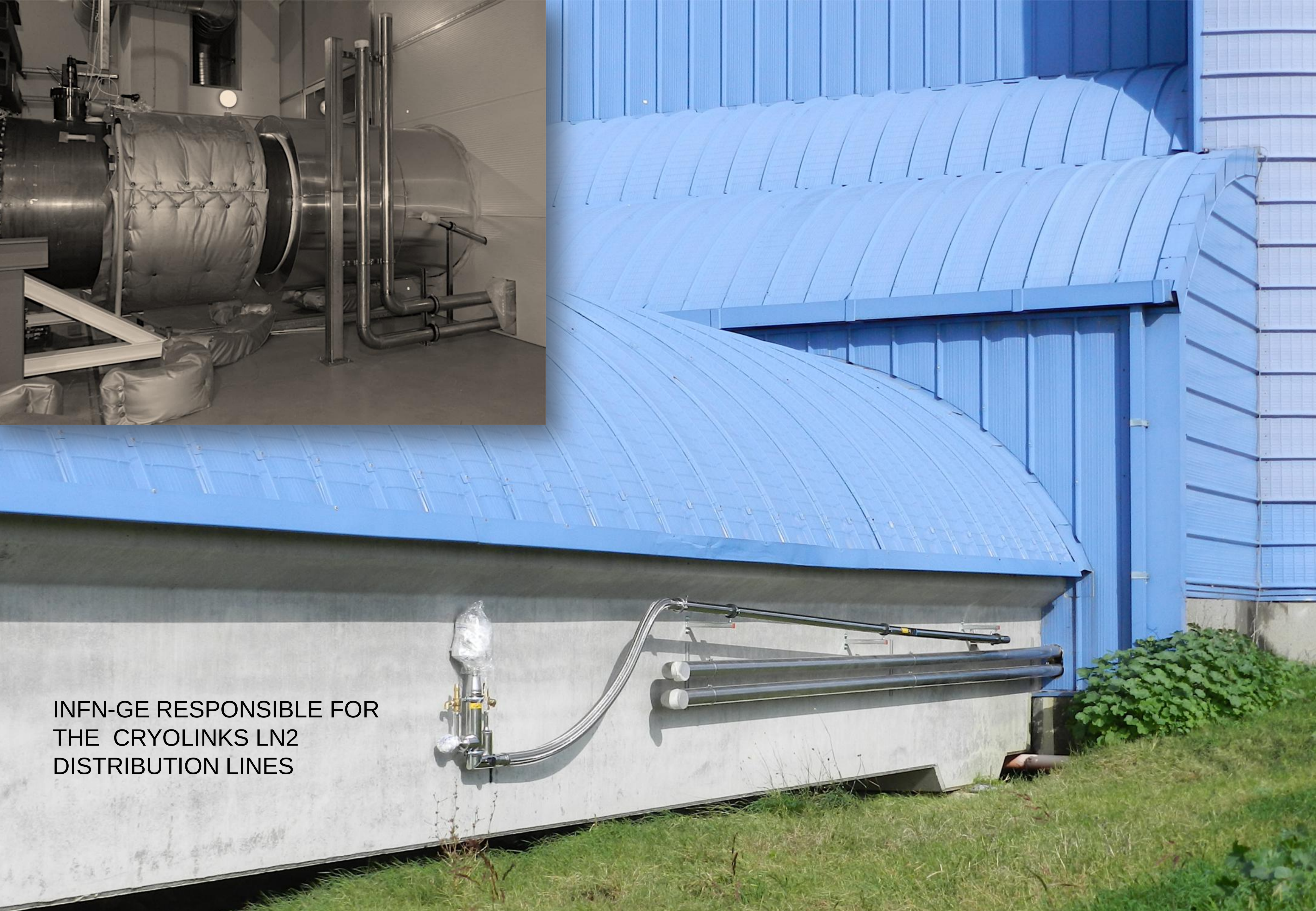

SIB1 ASSEMBLY
IN PROGRESS

THE NEW METROLOGY INTERFEROMETER @ LMA:
measure optics surfaces with 0.1 nm accuracy



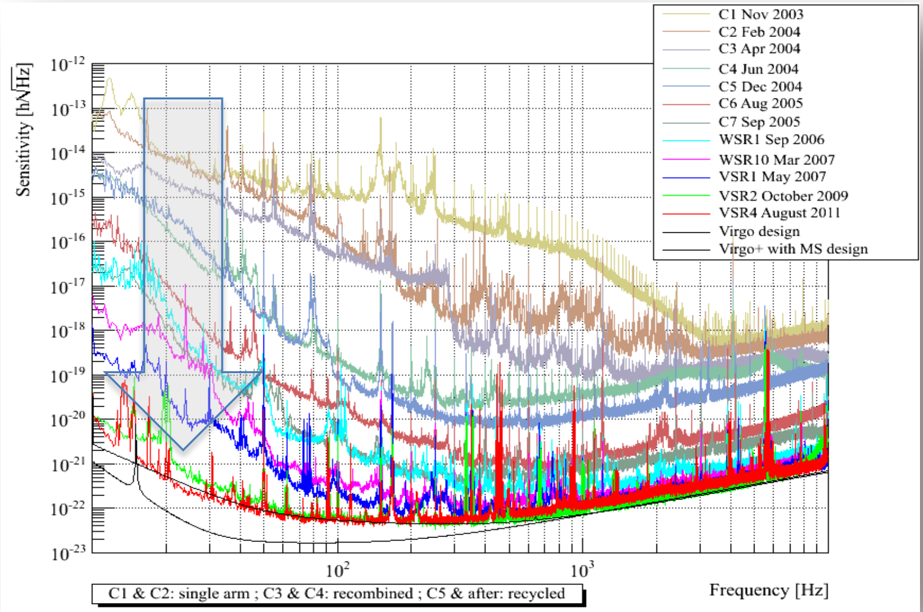
VACUUM

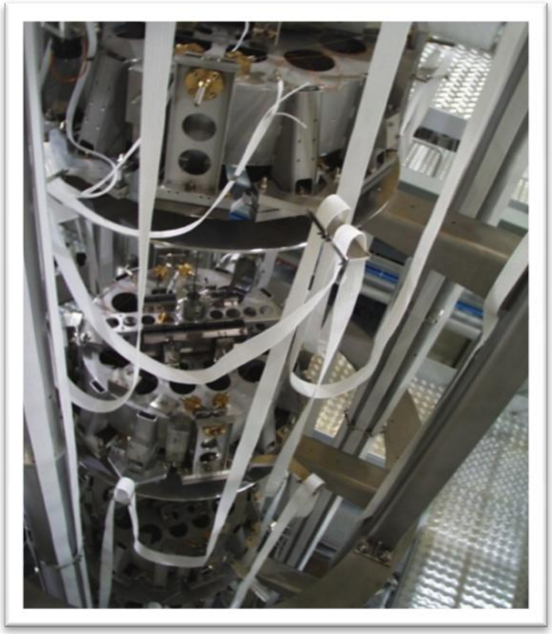
CRYOLINKS CONSTRUCTION COMPLETE

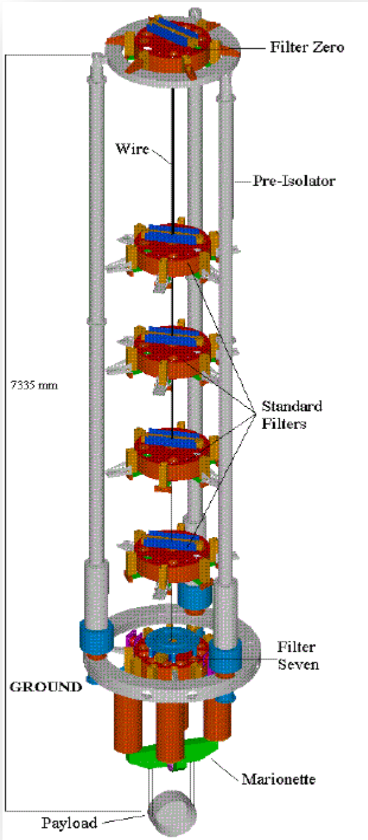

INFN-GE RESPONSIBLE FOR
THE CRYOLINKS LN2
DISTRIBUTION LINES

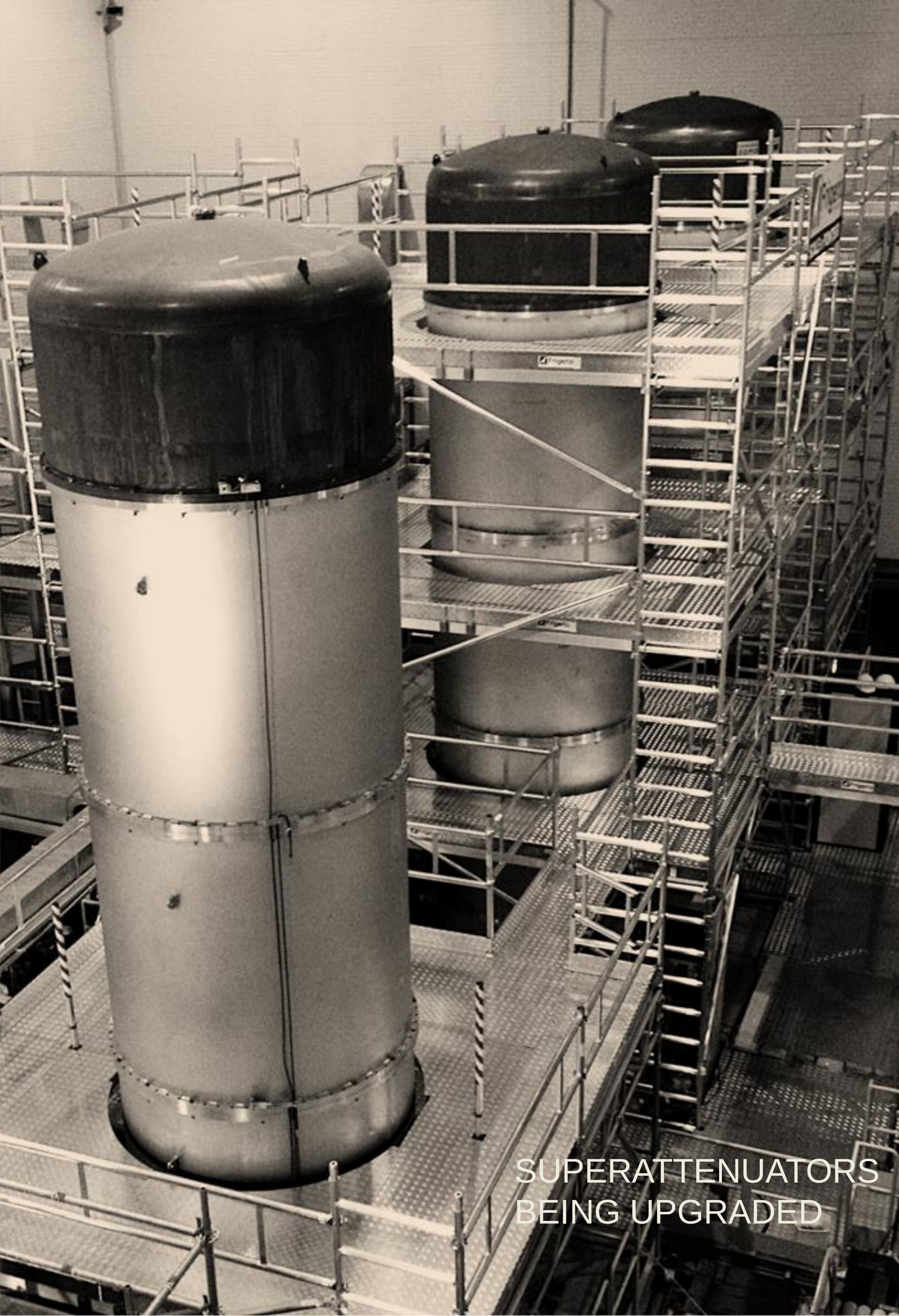
VIBRATION ISOLATION

- Advanced Virgo will use the same *superattenuators* as Virgo
  - but top platform to be controlled in 6 d.o.f.
- Main advantages:
  - Performance demonstrated
  - Large experience gained with LF commissioning/operation

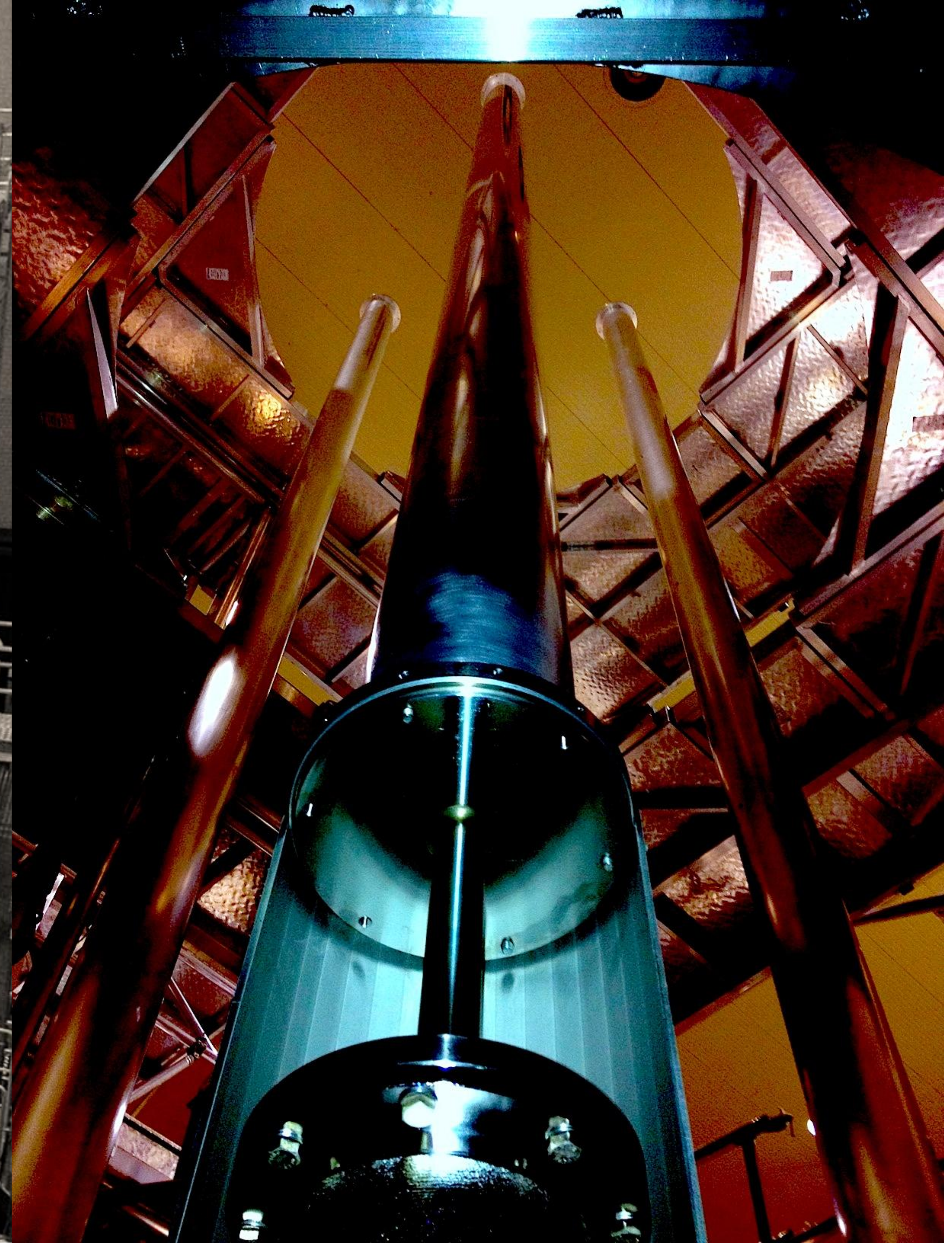








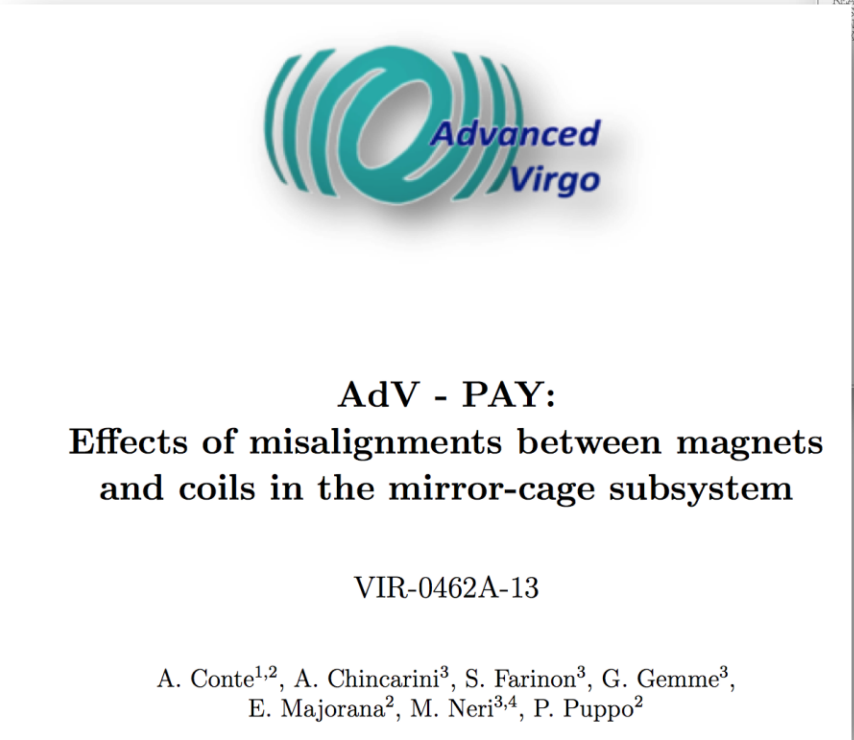
SUPERATTENUATORS
BEING UPGRADED



PAYLOADS

PAYLOADS

- Genova brought the expertise to studystray magnetic fields and unwanted couplings with the mirror (dangerous noise to be tackled in advance!)

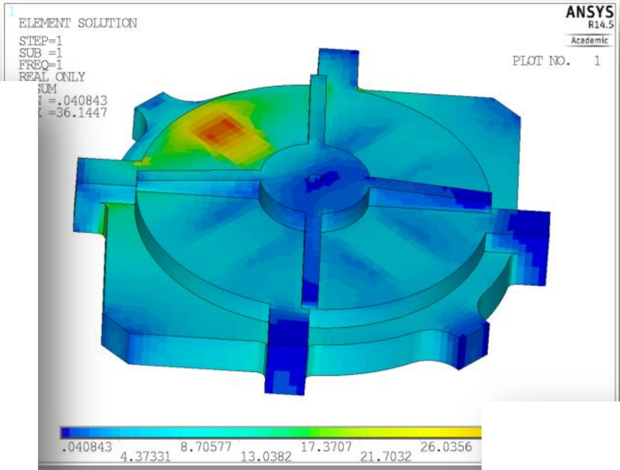


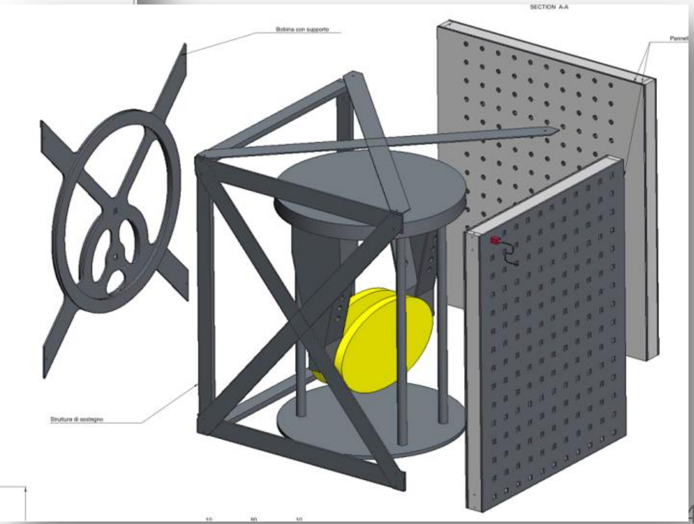
Advanced Virgo

AdV - PAY:
Effects of misalignments between magnets and coils in the mirror-cage subsystem

VIR-0462A-13

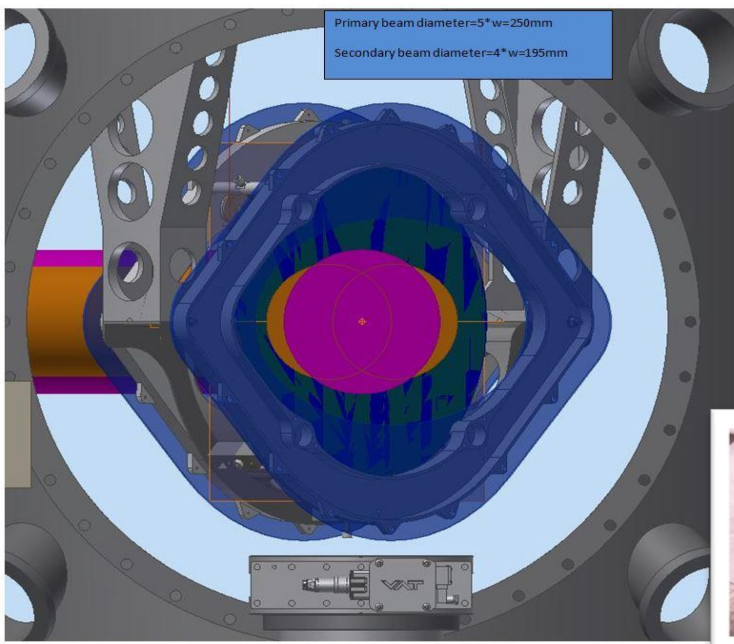
A. Conte[1,2], A. Chincarini[3], S. Farinon[3], G. Gemme[3], E. Majorana[2], M. Neri[3,4], P. Puppo[2]

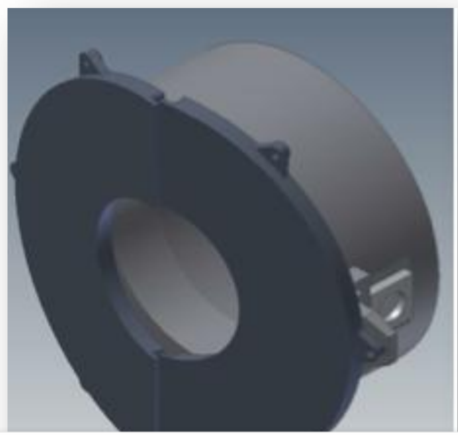


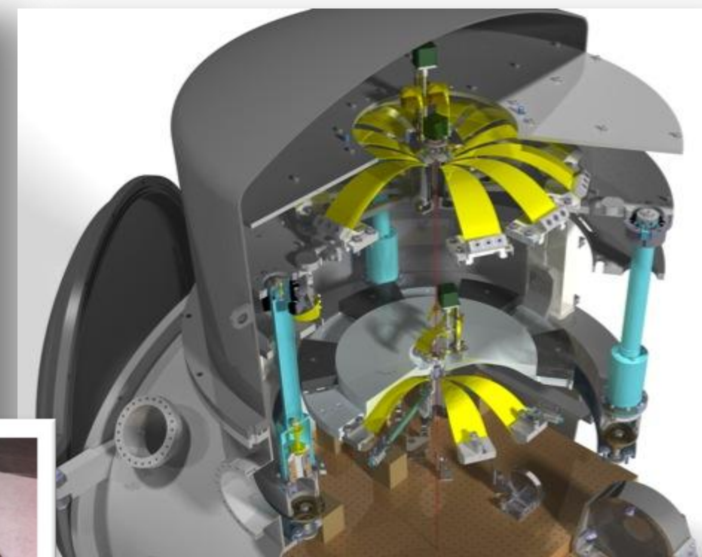


STRAY LIGHT MITIGATION

- 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

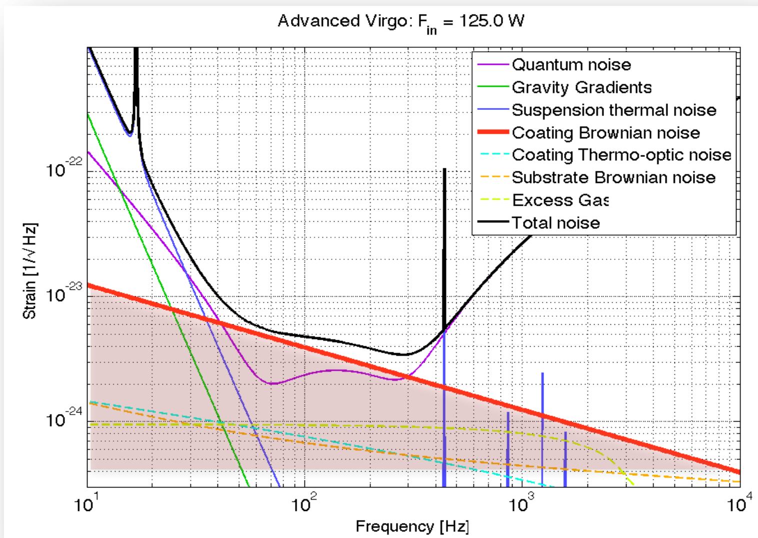




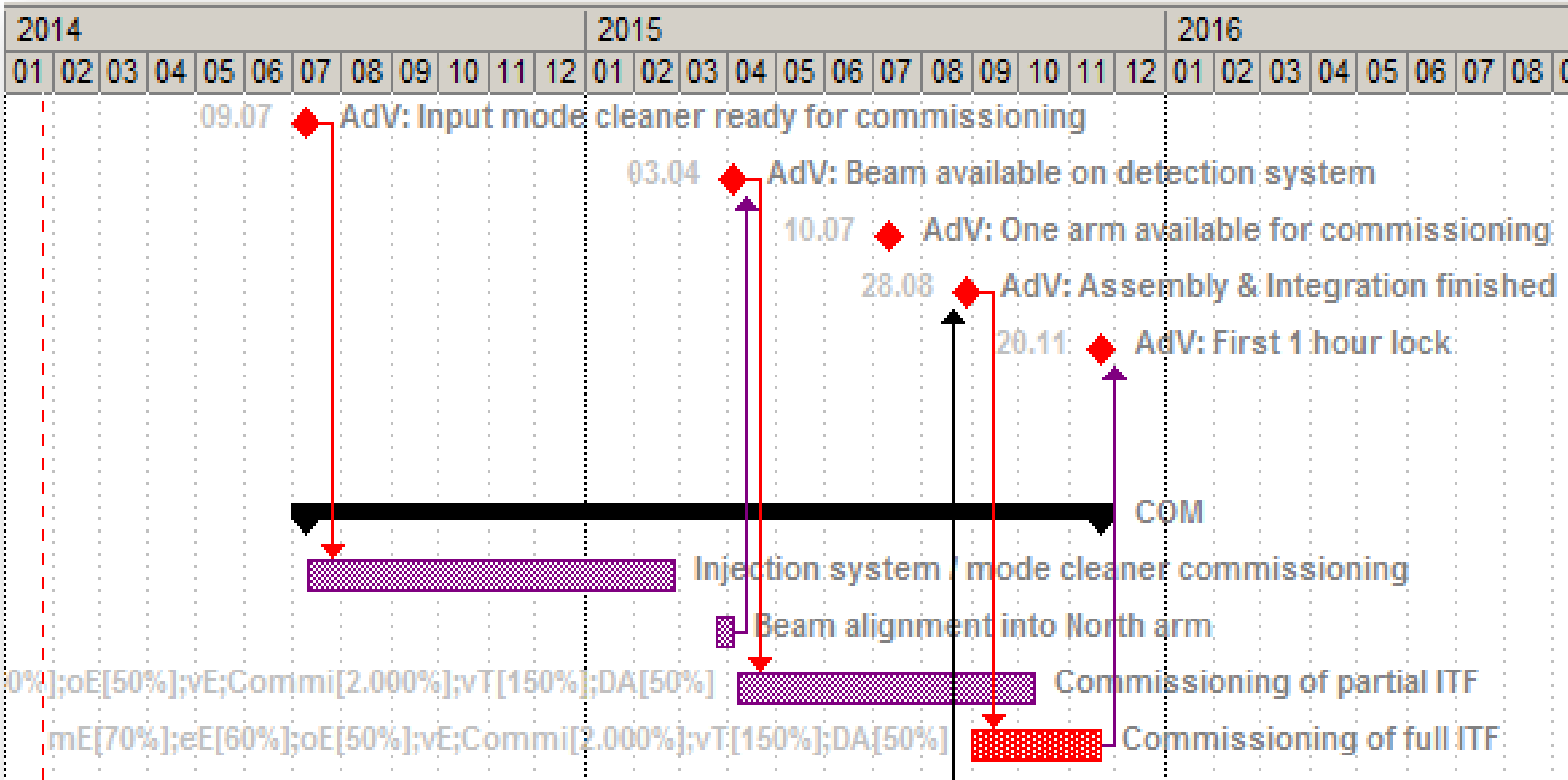


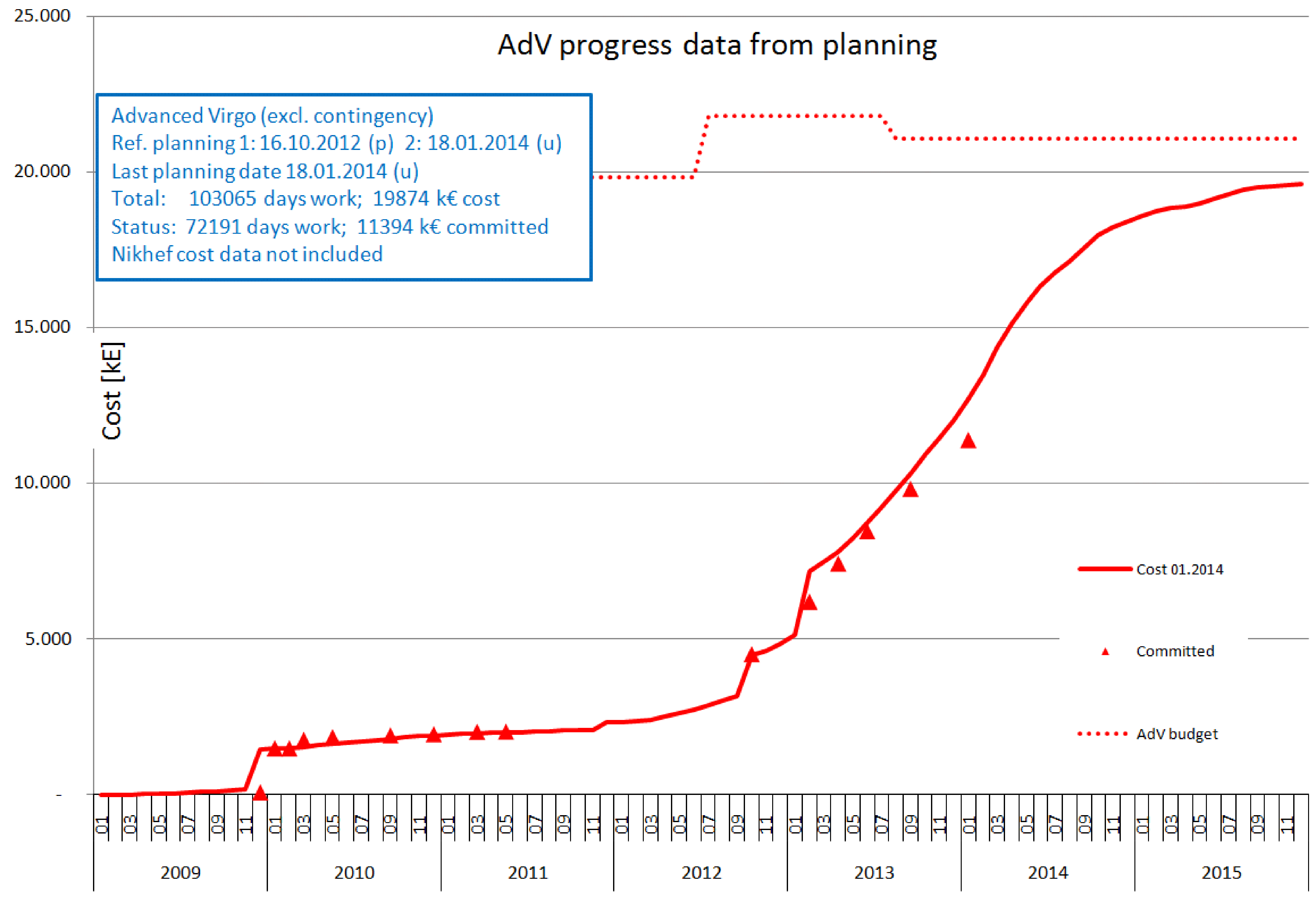
INCREASING THE BNS INSPIRAL RANGE

- Mirror coating thermal noise is the dominating noise in the mid frequency range (dissipation dominated by the high refractive index layer)
- Doping Ta_2O_5 with Ti has improved it, but losses are still $O(10^{-4})$
- Advanced Virgo to use large spot size (~5cm) on the test masses
  - impact of size of the vacuum links/valves, BS size…



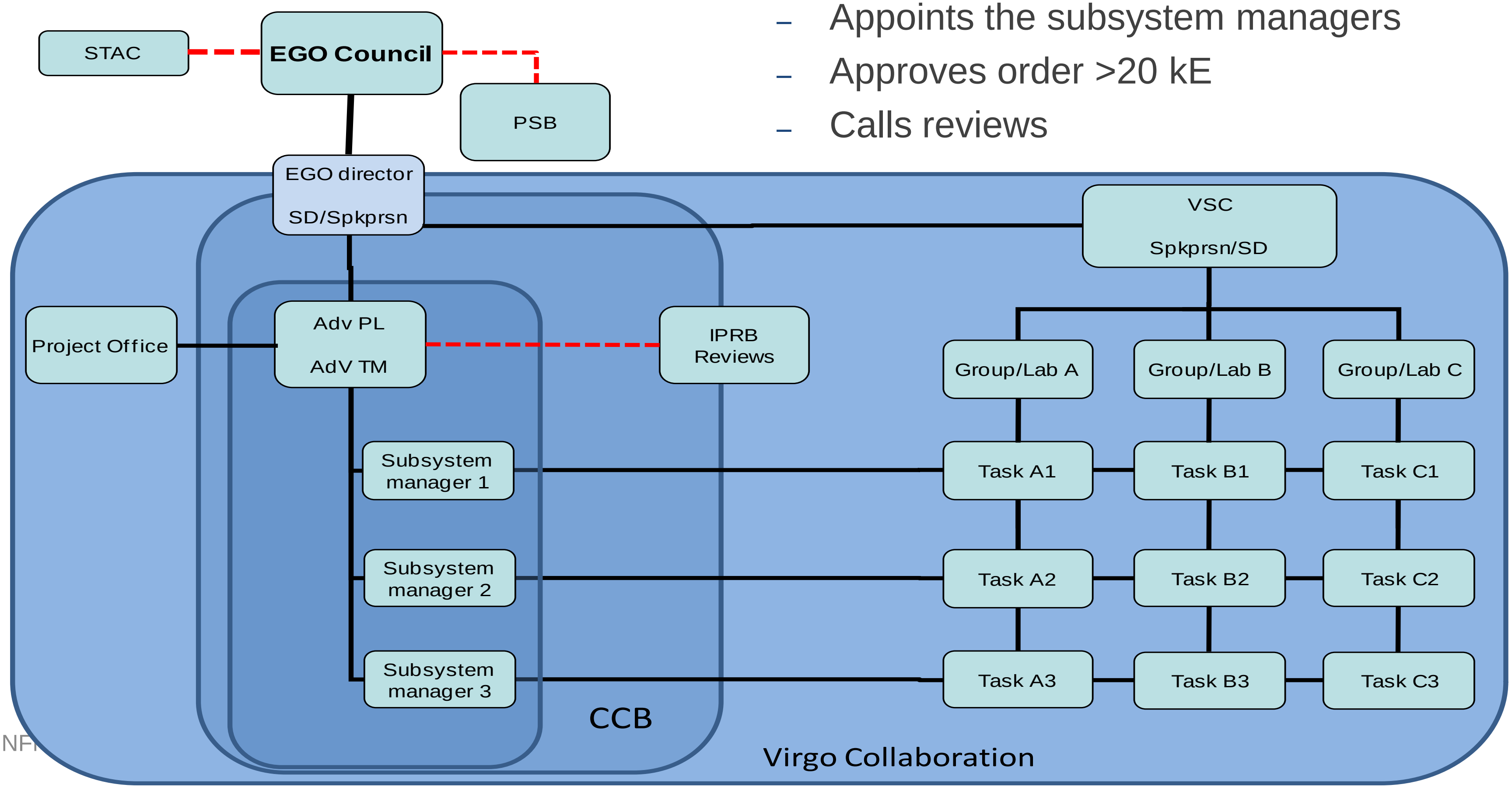
AdV CRUCIAL DATES




AdV progress data from planning
Advanced Virgo (excl. contingency)
Ref. planning 1: 16.10.2012 (p) 2: 18.01.2014 (u)
Last planning date 18.01.2014 (u)
Total: 103065 days work; 19874 k€ cost
Status: 72191 days work; 11394 k€ committed
Nikhef cost data not included
Cost [kE]
25.000
20.000
15.000
10.000
5.000
-
Cost 01.2014
Committed
AdV budget
2009
2010
2011
2012
2013
2014
2015

MANAGEMENT CHART

- Project structure over a Collaboration organization
- The project leader
  - Appoints the subsystem managers
  - Approves order >20 kE
  - Calls reviews



INFN-GE COMMITTMENTS

- Main AdV commitments:
  - LN2 distribution lines
  - Magnetic characterization of the payloads
  - Locking studies
  - R&D on coatings
- People
  - Diego Bersanetti (PhD – Interferometer sensing and control)
  - Davide Bondi (tecnico – Vacuum)
  - Andrea Chincarini (staff - Payloads - EM follow-up image analysis)
  - Stefania Farinon (staff - Payloads)
  - Gianluca Gemme (staff, group leader – vacuum, payloads, …)
  - Martina Neri (PhD - Payloads)
  - Luca Rei (Ass.Ric. PRIN - EM follow-up image analysis - computing(?))
  - C Boragno, F Buatier, M Canepa, M Giovannini, L Mattera: CSN5 R&D AdCoate

CONCLUDING REMARKS

- **Interferometer technology demonstrated**
- **LIGO/Virgo upgrades to 2nd generation funded, construction in progress. More detectors to come.**
- **Preparing for multi-messenger observation**
- **First long run in 2016: stay tuned!**

2016: CENTENNIAL OF GENERAL RELATIVITY
We look forward to celebrating it with a discovery