Advanced Virgo

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For the Virgo Collaboration
and
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(Project Leader)

The Virgo Collaboration : 18 European teams

EGO Council (CNRS, INFN, NIKHEF)

RMKI,
Academy of sciences
Budapest
HUNGARY

NIKHEF, Amsterdam
Radboud University , Nijmegen
The NETHERLANDS

EGO Site Cascina

Institute of Mathematics
Polish Academy of Sciences
Varsaw
POLAND

ITALY:

INFN + Universities of
Firenze-Urbino
Genova
Napoli
Perugia
Roma La Sapienza
Roma Tor Vergata
Pisa
Padova-Trento

FRANCE :
Laboratoire de l'Accélérateur Linéaire (U. Paris-Sud+CNRS)
Laboratoire d'Annecy de Physique des Particules (CNRS)
Astroparticules et Cosmologie (U. Paris 7+CNRS)
Laboratoire des Matériaux Avancés (Lyon-CNRS)
Laboratoire Kastler-Brossel (ENS – U. Paris 6 - CNRS)
ARTEMIS, Observatoire de la Côte d'Azur (CNRS, Nice)

Virgo Collaboration : the cloud

The Virgo Antenna at Cascina : EGO site

GW sources : working groups

1) Compact Binary Coalescences
   - Neutron Stars
   - Black Holes (stellar class)

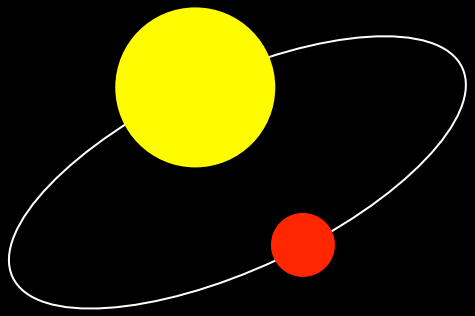
2) Bursts
   - Supernovae
   - Cosmic strings cusps
   - GRBs

3) Continuous waves
   - targeted searches
   - all sky searches
   - modulated sources (binary pulsars)

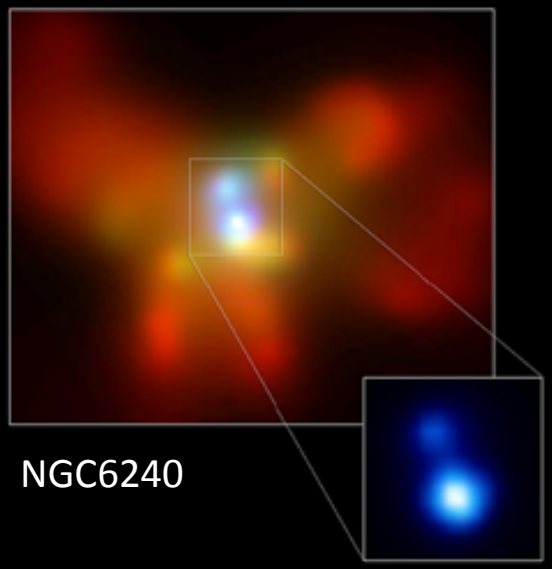
4) Stochastic waves
   - Astrophysical foreground
   - Cosmological background

Example of Source of Gravitational Waves : Compact Coalescing Binaries NS-NS, BH-NS, BH-BH

Binary Neutron stars

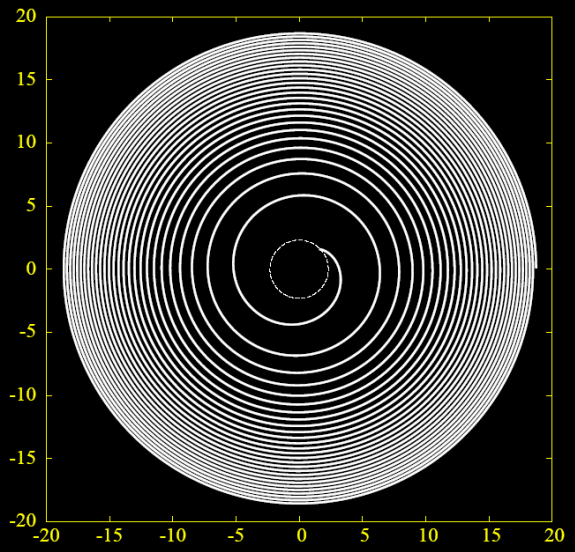


Binary
Black Holes

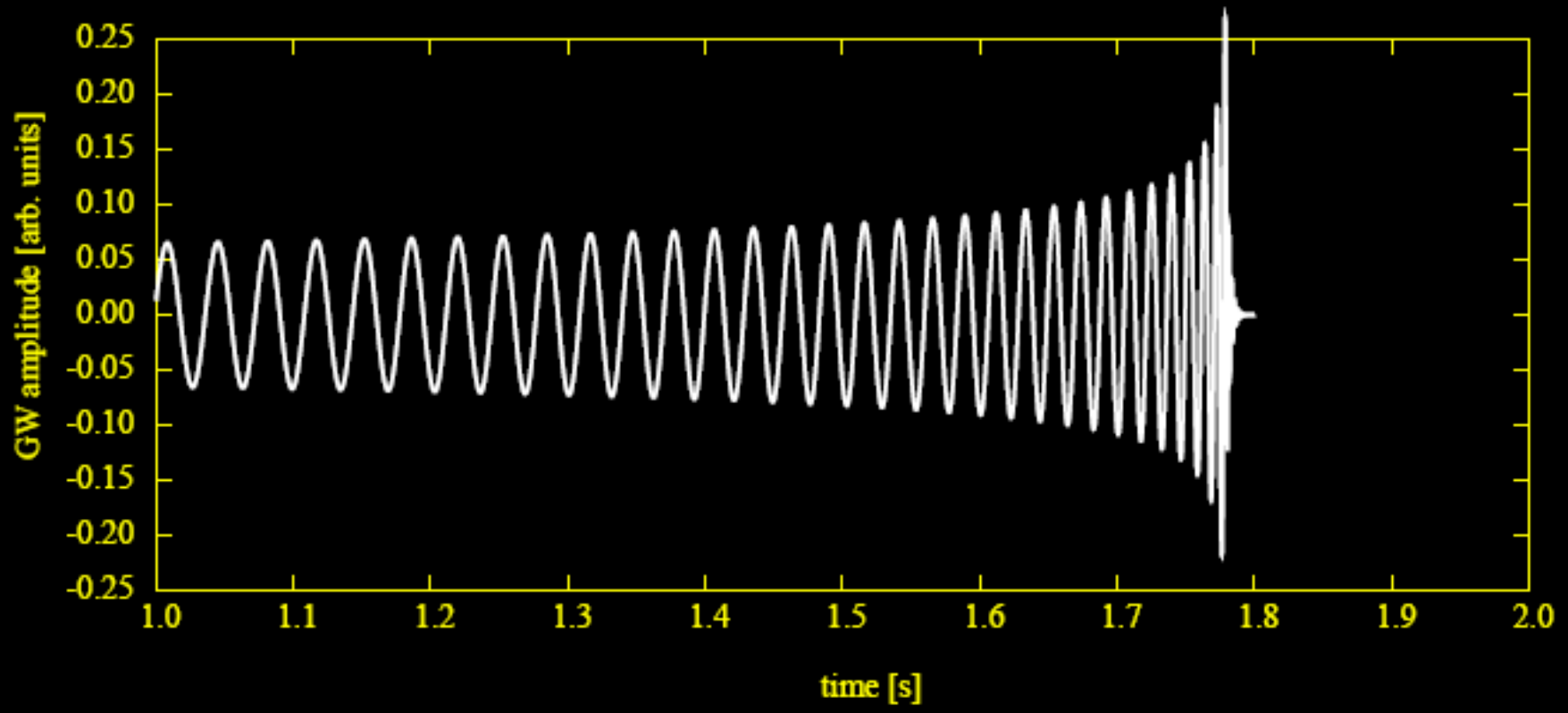


Radiation → Energy loss
→Orbit shrinking →
Acceleration

End inspiral…



Signal received from the end inspiral
Of a 10 SM-10 SM binary black hole (EOB theory)



Science goals

-First direct detection of a GW, one century after General Relativity (1916 → 2016)

-Tests of GR in the strong field regime

-Astrophysics of binary systems (spin-orbit, spin-spin couplings)

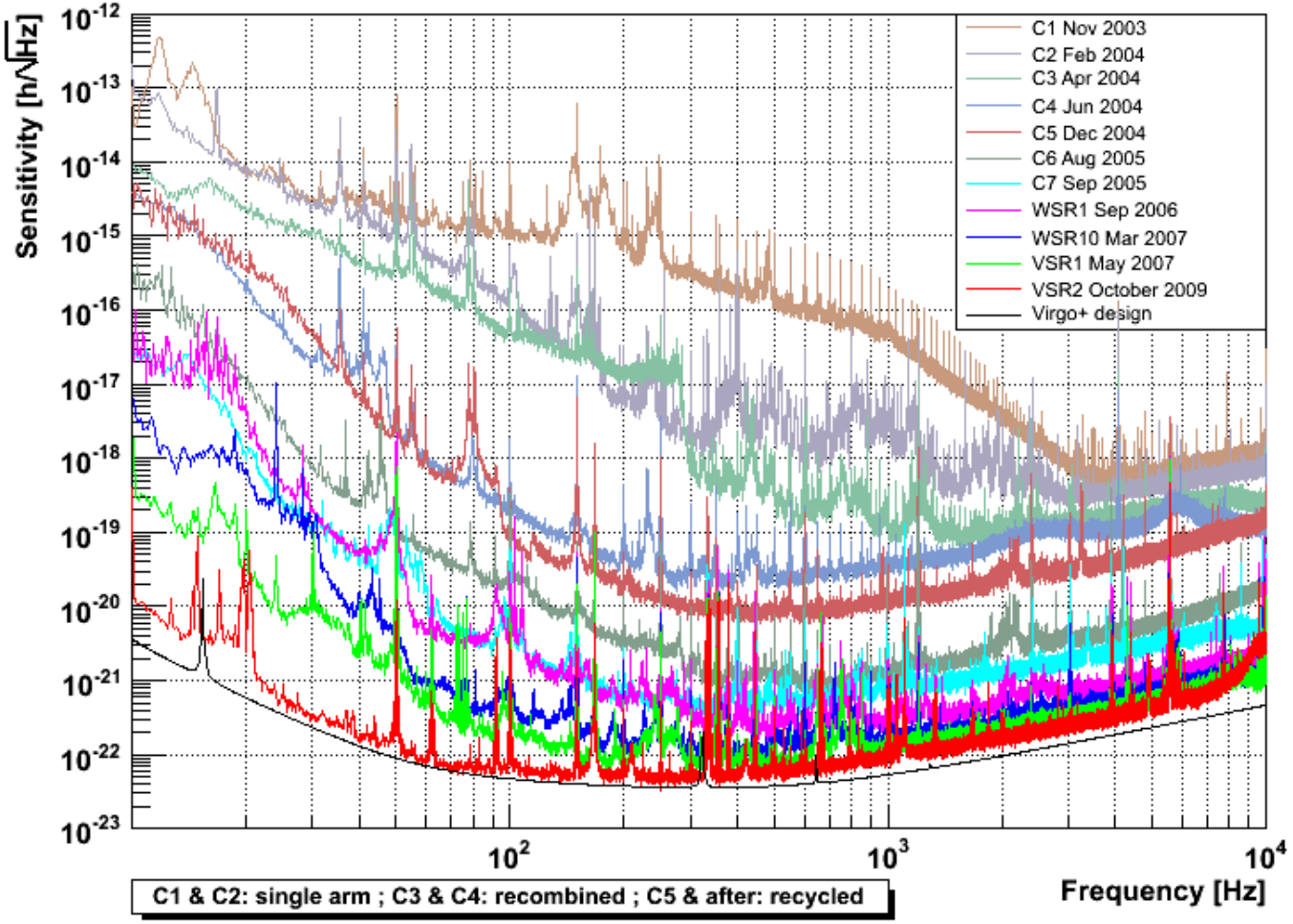
-Equations of state of neutron stars (glitches in CW from pulsars, tidal effects during merging of BNS)

-Formation of black holes

-Stochastic background : Cosmology

Initial Virgo : 7 years of development, commissioning and technology improvements

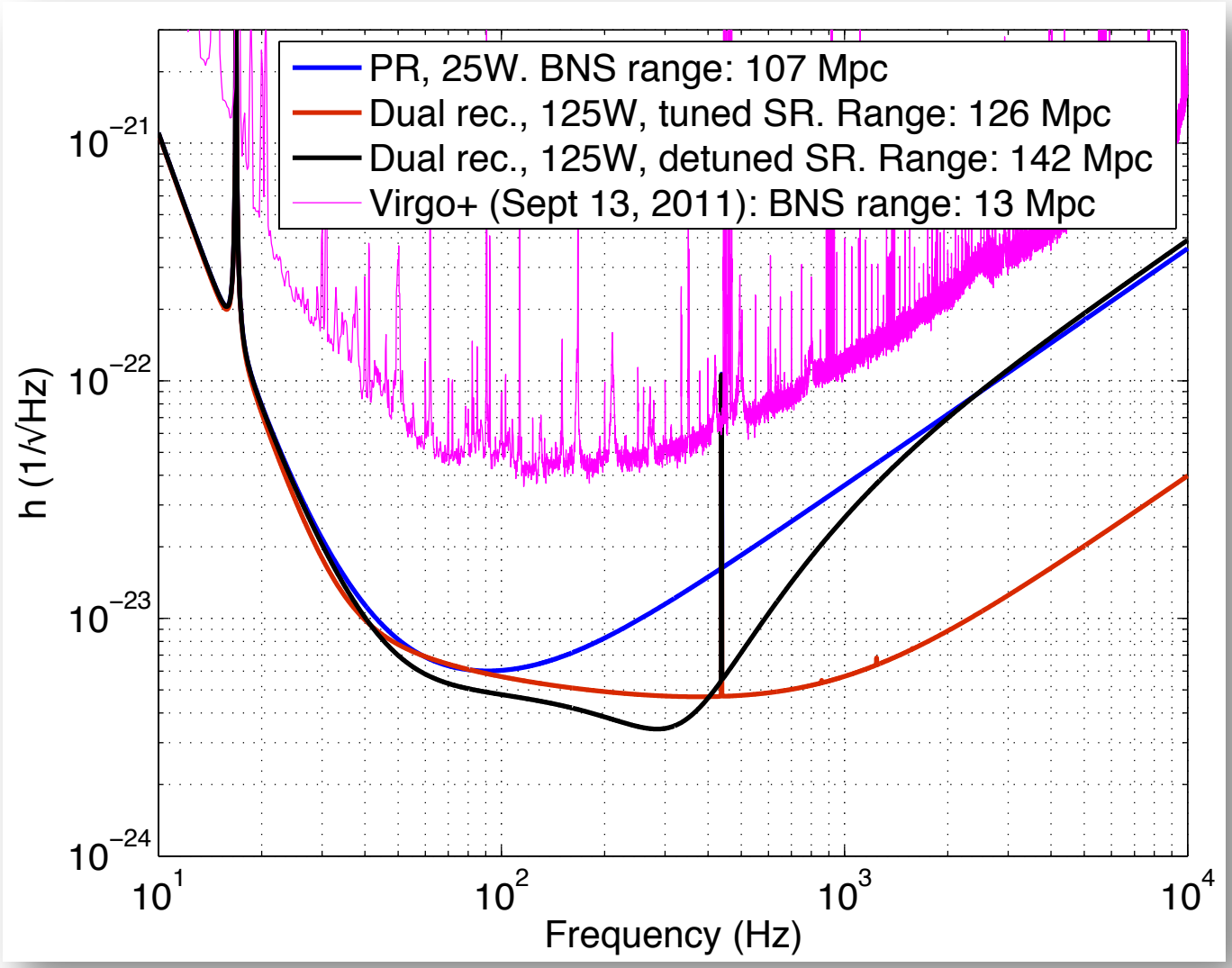
$h \sim [\ (10^{-44}\ Hz^{-1}) \times (1\ kHz)\ ]^{1/2} \sim 3 \times 10^{-21}$



One order of magnitude missing…

Advanced Virgo

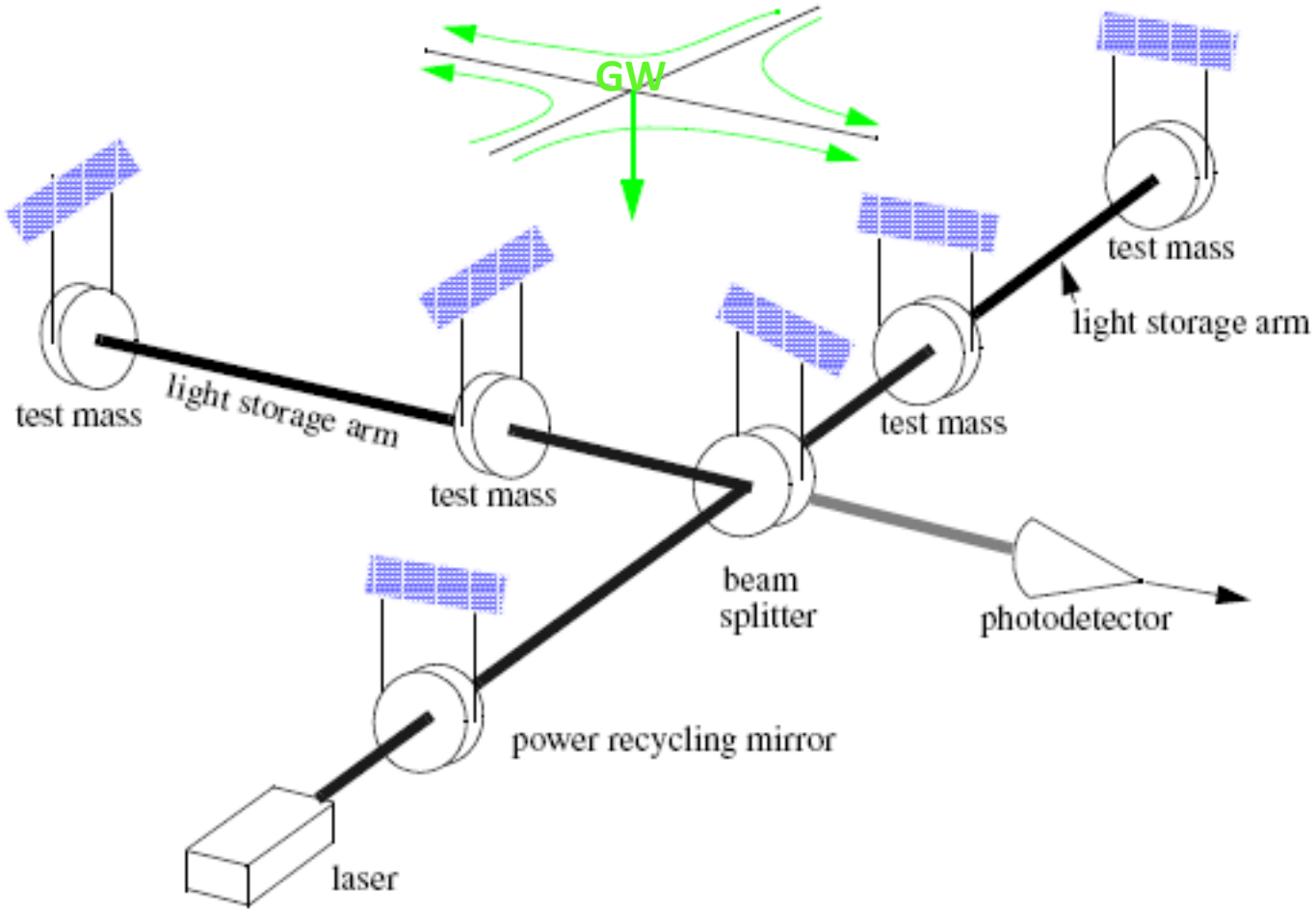
Planned sensitivity evolution



1 order of magnitude in h

3 orders of mag. in probed volume of space

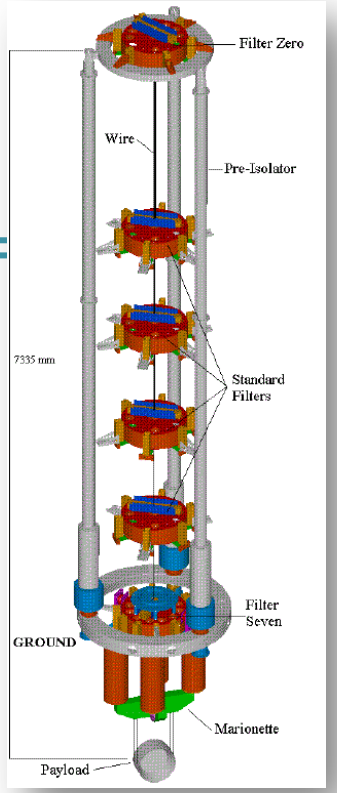
A generic GW interferometer

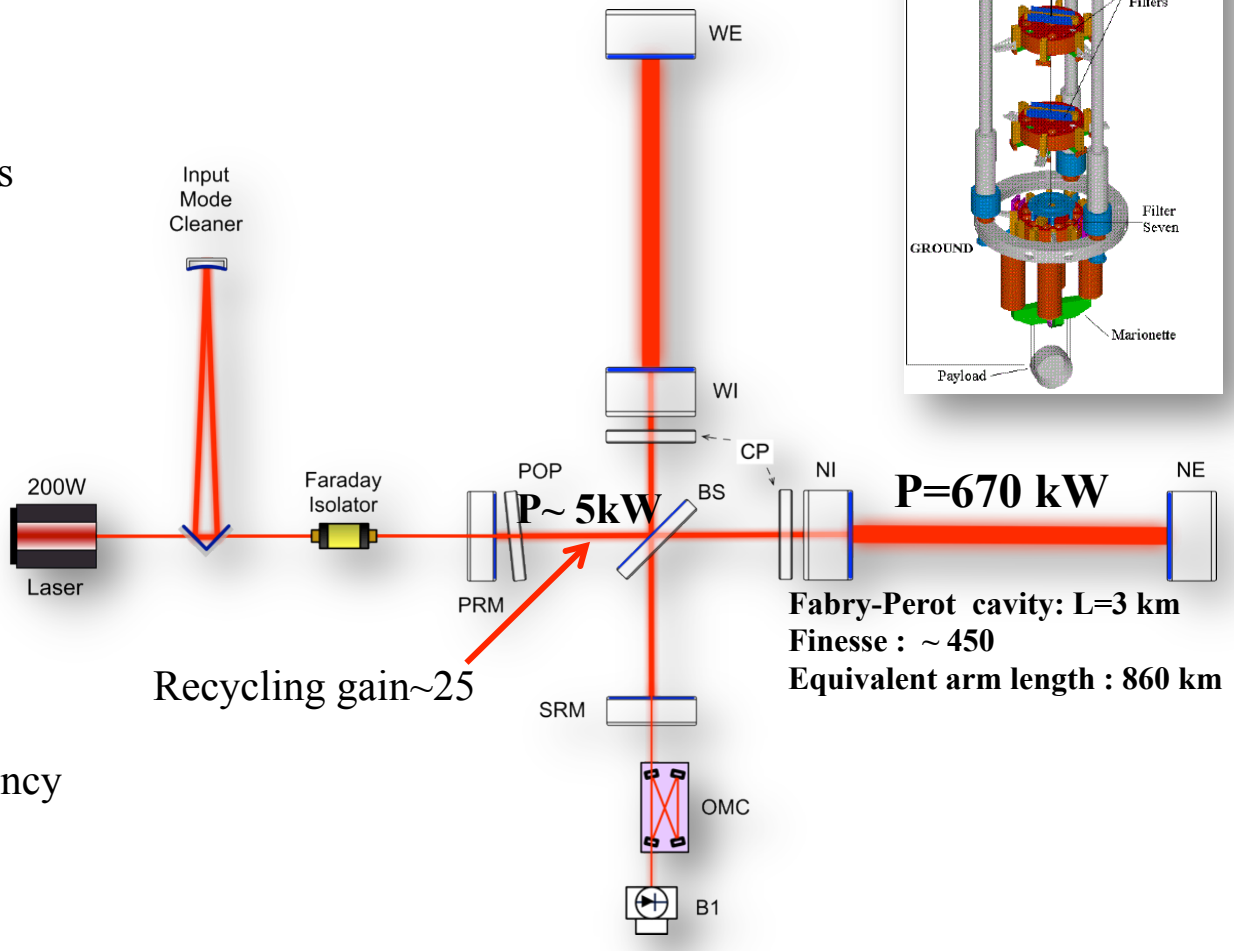


DETECTOR DESIGN

- 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





SHOT NOISE MITIGATION

Spectral sensitivity limited by the shot noise :

Possible improvements

$$S_h^{1/2}(f) = \frac{\lambda}{8\mathcal{F}L}\frac{1}{g}\sqrt{1+\left(\frac{4\mathcal{F}Lf}{c}\right)^2}\sqrt{\frac{P_L}{h_P\nu}}$$

Laser power

Cavities finesse

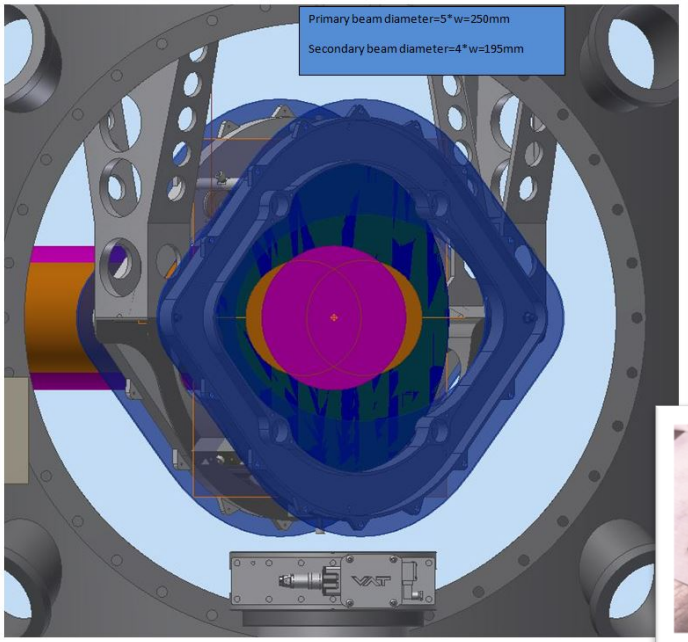
Arm length

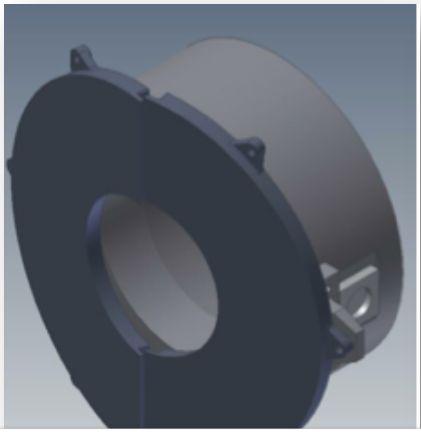
Recycling gain

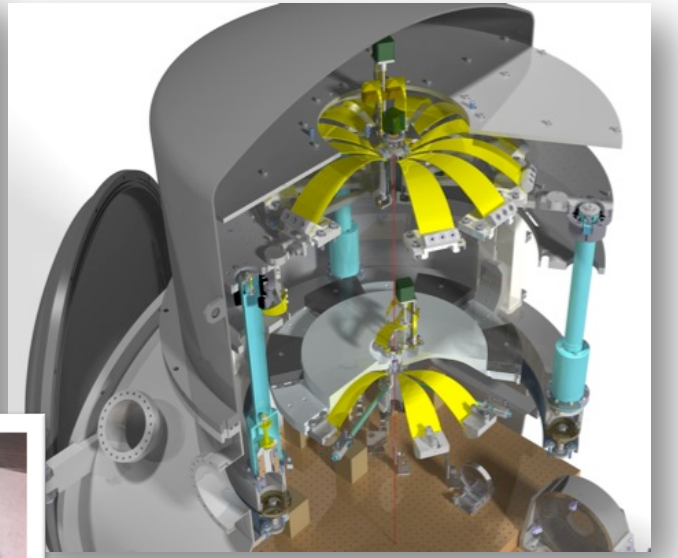
For more details : https://wwwcascina.virgo.infn.it/vpb/

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







HIGH QUALITY OPTICS

- Mirrors may limit the sensitivity in a wide frequency range…

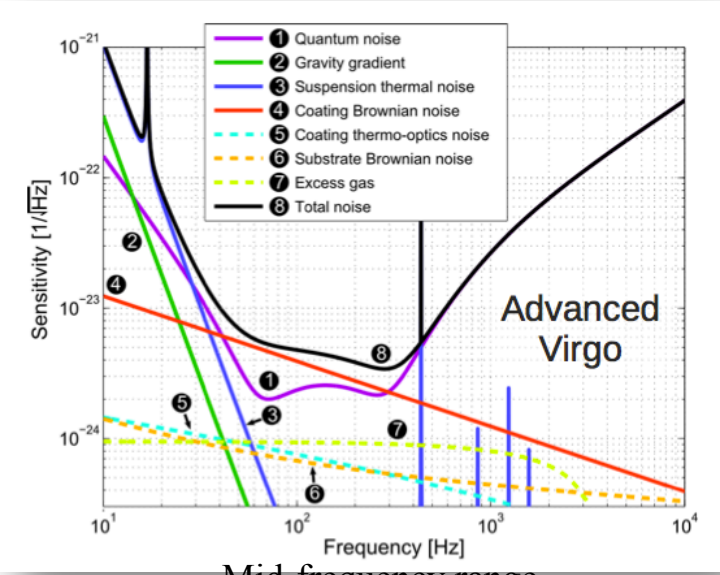
RADIATION PRESSURE and SUSPENSION THERMAL noises depend on mirror mass

Scattered light from flatness/roughness

Thermal noise from mirrors

$$S_x^{1/2}(f) = \frac{4k_B T}{2\pi f}\Phi\frac{1-\sigma^2}{\sqrt{\pi}Yw}$$

(BHV, 1998)



Mid-frequency range dominated by coating THERMAL NOISE

Mirror geometry/flatness may change the optical gain and, thus, the SHOT NOISE

Aberrations depend on coating absorption (thermal lensing) and substrate inomogeneity

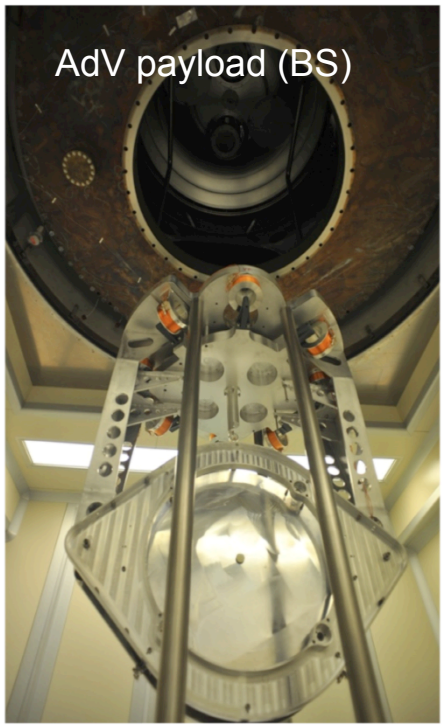
- REQUIREMENTS: large mass/diameter, good flatness/roughness, low absorption, good homogeneity, good coating uniformity, high Q

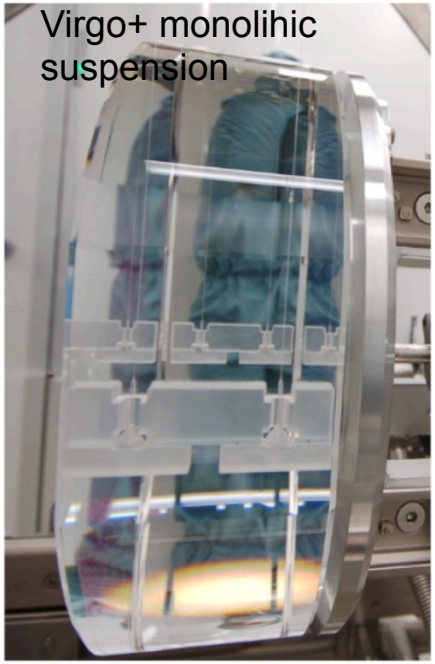
HIGH QUALITY OPTICS

- Large test masses: 35cm diameter, 20cm thick, 42 kg
- New fused silica grade (Suprasil 3002):
  - **Better bulk absorption** (0.2 ppm/cm measured at LMA): better for thermal lensing
  - refractive index homogeneity <0.3 ppm on 200 mm CA
  - High quality factor > 10^7
- Polishing much improved: 0.2 nm rms on 160 mm diameter achieved
  - ion beam figuring
  - better metrology
- Coatings much improved, New metrology

PAYLOADS

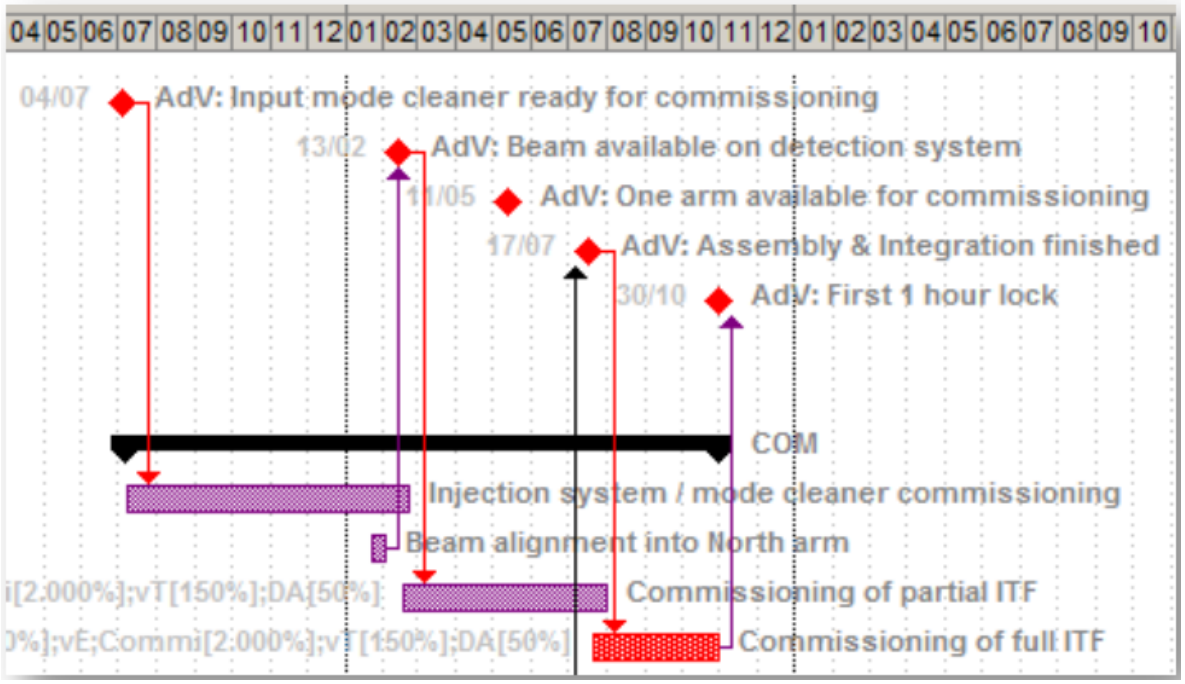
- Use of larger mirrors plus need of baffles and compensation plates requires upgrading the payloads
- Test masses suspended with silica fibers (as in Virgo+)
- The silica-steel interface at the level of the upper stage will be improved



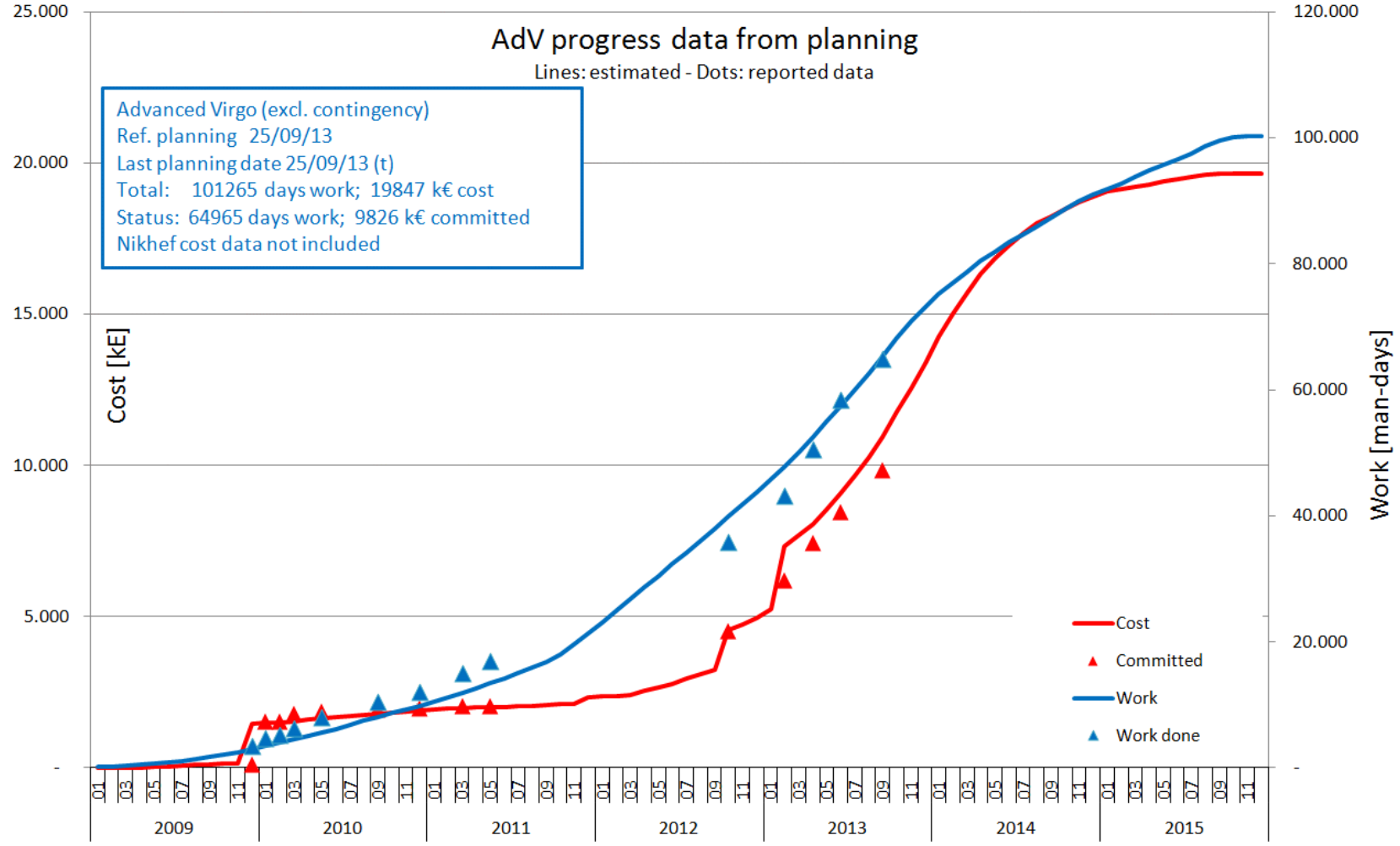


STATUS AND PLANS

- ~50% of budget committed so far
- Infrastructure works complete in Oct '13: equipment installation starts
- Early commissioning to start next year (input mode cleaner)
- End of installation/integration: fall 2015



PROGRESS


AdV progress data from planning
Lines: estimated - Dots: reported data
Advanced Virgo (excl. contingency)
Ref. planning 25/09/13
Last planning date 25/09/13 (t)
Total: 101265 days work; 19847 k€ cost
Status: 64965 days work; 9826 k€ committed
Nikhef cost data not included
Cost [kE]
Work [man-days]
25.000
20.000
15.000
10.000
5.000
-
120.000
100.000
80.000
60.000
40.000
20.000
-
Cost
Committed
Work
Work done
2009
2010
2011
2012
2013
2014
2015

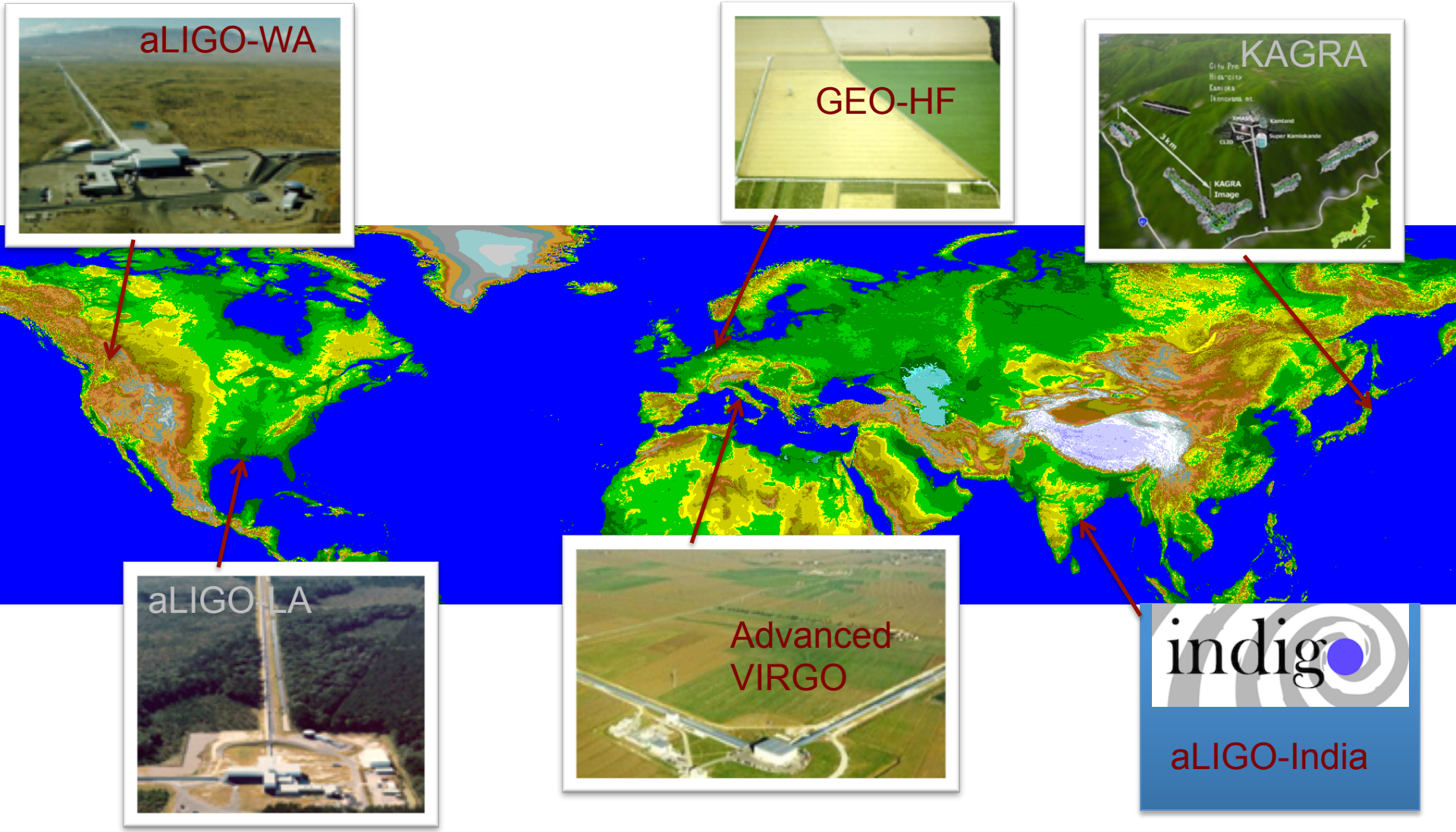
Networking

-Agreement with LIGO for common Data Analysis
-Sharing the data
-Common use of computing centers
    -CCIN2P3 (Lyon)
    -CNAF (Bologna)
    -NIKHEF (Amsterdam)
    -AEI cluster (Potsdam)
    - USA ….

-Three-dimensional data for coherent analysis
    (Livingston,Hanford,Virgo) → sky cell localization

-Virgo ~ one year late behind LIGO ☹ try to keep the rythm…

2nd GENERATION NETWORK



EM follow-up Program

Look for Counterparts to the GW events in the EM spectrum

- Studies of a policy of agreements with astronomy teams (Boston, February)

-Meeting at ESO (Garching,March) EGO-Virgo + ESO Directorate

- Call for letters of interest (July)

-Meeting in Europe (Amsterdam, August) ~ 50 attendees

-Meeting in the USA (Chicago, September) ~ 60 attendees

-Actual interest of the A&A community for a new astronomy

-Preparation of a template Memorandum

SUMMARY

- Advanced Virgo construction now well on track
- Start with simplified configuration (>100 Mpc BNS inspiral range) to speed up the commissioning → data taking transition
- Goal: first science data in 2016