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Astroparticle Physics for Europe

WG6
Gravitational Waves

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On behalf of the WG6

GW European Scientific Community

- **Experimental** research in the Gravitational Waves field involves a large community of European scientists

GW experimental research

- The European scientists participate actively to the network of GW detectors in the world
- Resonant bar detectors
  - Nautilus (LNF-INFN)
  - Explorer (CERN)
  - Auriga (LNL-INFN)

GW experimental research

- The European scientists participate actively to the network of GW detectors in the world
- Giant Interferometers:

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LIGO Scientific Community

- The LSC carries out the scientific program of LIGO.
- Approximately 540 members from 35 institutions plus the LIGO Laboratory.
- International participation from Australia, Germany, India, Italy, Japan, Russia, Spain and the U.K.
- All members of GEO are members of the LSC. GEO data and LIGO data are analyzed as one data set.

The Virgo Collaboration

- CNRS - LAPP - Annecy
- INFN - Firenze/Urbino
- INFN - Genova
- CNRS - LMA/ESPCI – Lyon/Paris
- INFN – Napoli
- NIKHEF - Amsterdam
- CNRS - OCA - Nice
- CNRS - LAL – Orsay
- INFN – Padova/Trento
- INFN - Perugia
- INFN - Pisa
- INFN – Roma La Sapienza
- INFN – Roma Tor Vergata

+ EGO (European Gravitational Observatory, CNRS-INFN consortium)

~175 physicists/engineers

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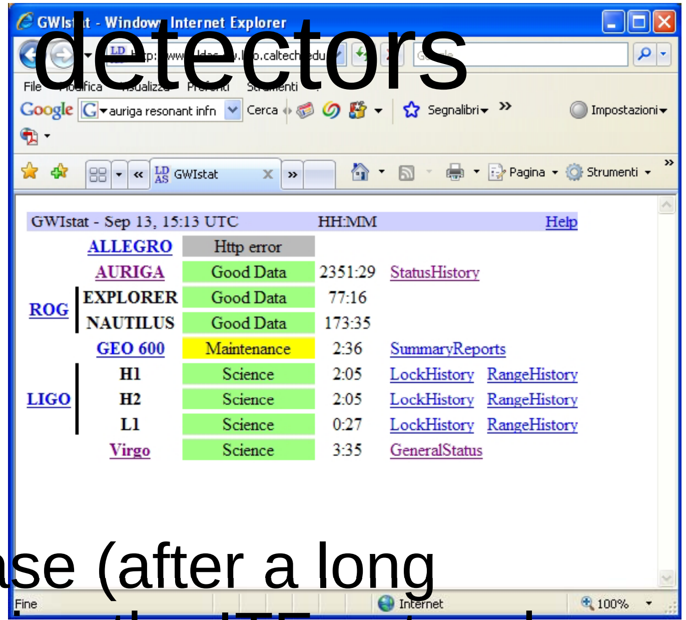
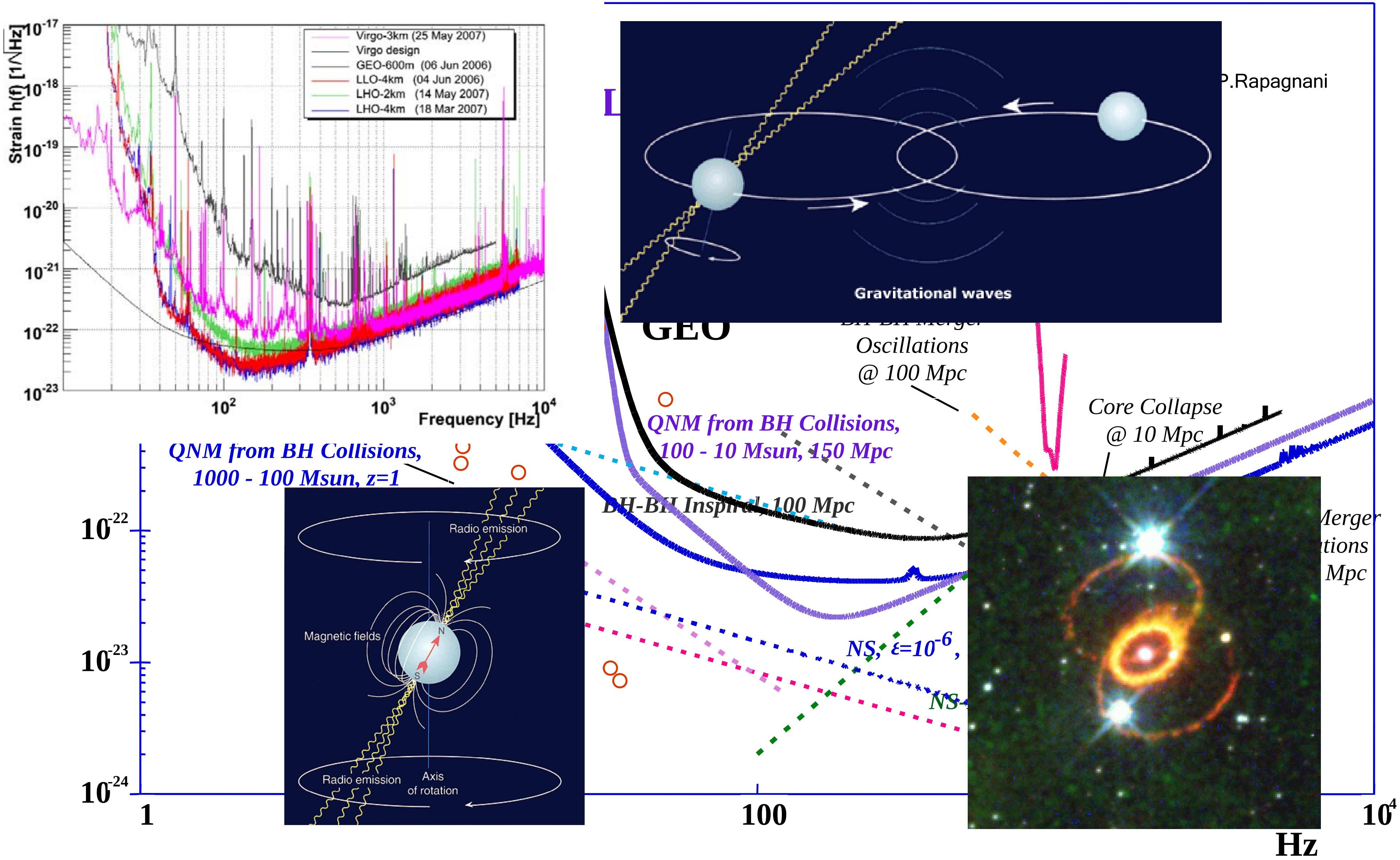
Current Status of the detectors



GWIstat - Sep 13, 15:13 UTC			HH:MM	Help	
	ALLEGRO	Http error			
	AURIGA	Good Data	2351:29	StatusHistory	
ROG	EXPLORER	Good Data	77:16		
	NAUTILUS	Good Data	173:35		
	GEO 600	Maintenance	2:36	SummaryReports	
	H1	Science	2:05	LockHistory	RangeHistory
LIGO	H2	Science	2:05	LockHistory	RangeHistory
	L1	Science	0:27	LockHistory	RangeHistory
	Virgo	Science	3:35	GeneralStatus	

- Virgo and the two LIGO detectors are in Science run (VSR1-S5) collecting and exchanging data continuously
  - The run will end the 1st of October
- GEO is in advanced commissioning phase (after a long science run in parallel with LIGO) and joins the ITF network during the nights and the week-ends
  - It will operate in astro-watch mode when the large detectors will conclude the science run
- The bar detectors are currently running with an impressive stability but a uncompetitive sensitivity
  - They will stay online until the enhanced version of the current detectors will be back on science mode (2009)

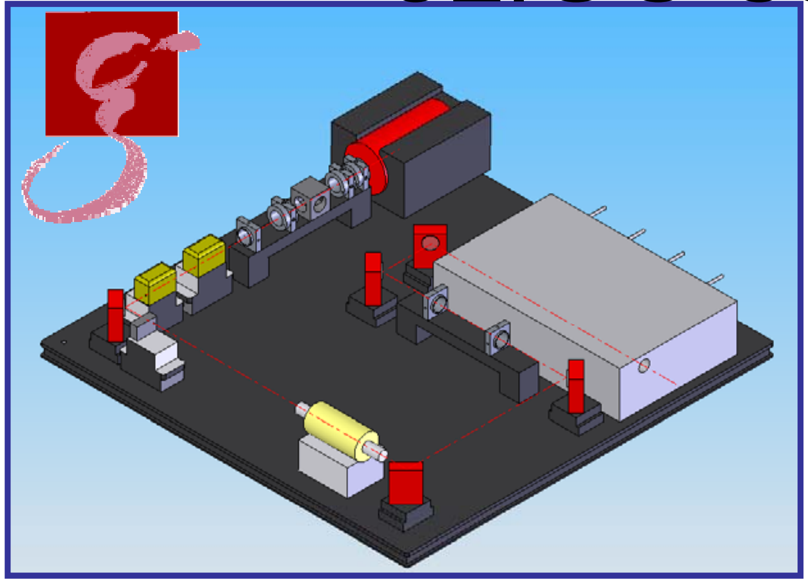
Current sensitivities



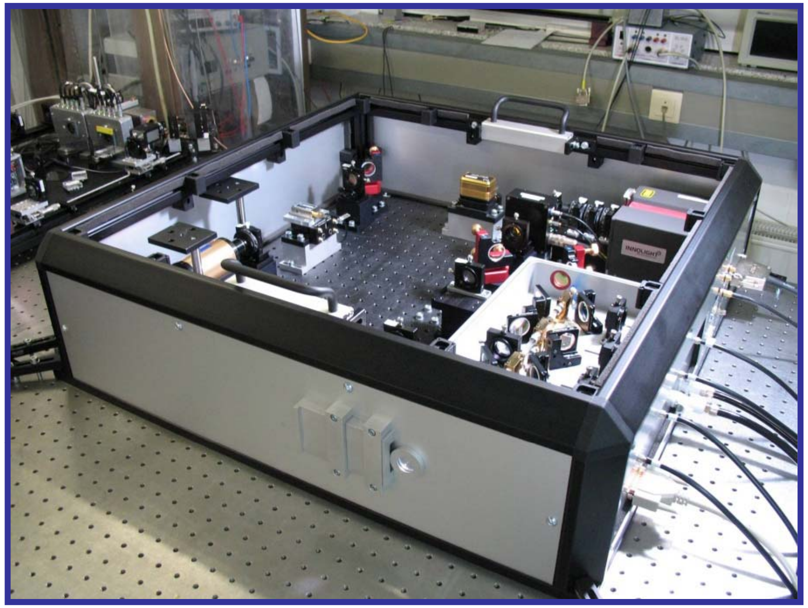
Next Future

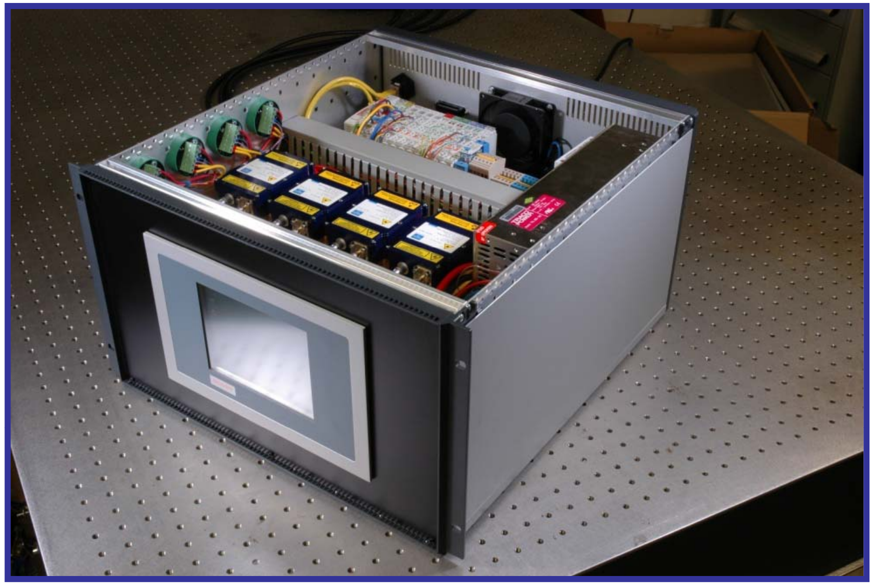
- The large detectors will undergo to an enhancing phase in the 2007-2009 period
  - Virgo (→Virgo+) and LIGO (→ enhanced LIGO) will upgrade some of the components to profit completely of the current potentialities
    - Higher power lasers
    - Better control electronics
    - Better optics and mechanics
    - …
  - AEI scientist fundamental contribution for the development of the new laser amplifier of LIGO

eLIGO 35W front-end



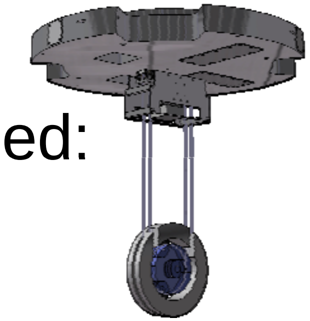
- 2W NPRO and 35W Vanadat amplifier form combined system
- AOM, EOM and Faraday isolators included
- NPRO and amplifier controlled via touchpad or via PC interface (Beckhoff / EPICS)
- system will be used as Enhanced LIGO laser

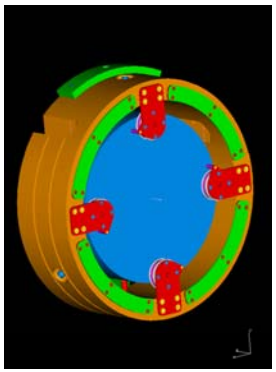


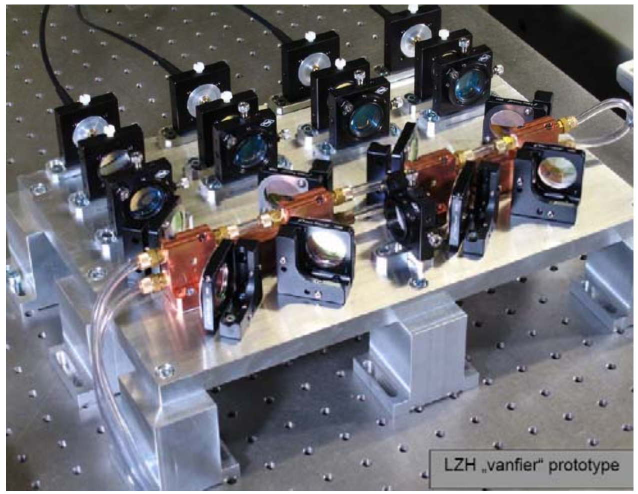


Virgo+ Project

- After the VSR1 conclusion Virgo re-enters in commissioning mode to with the aim to reduce the excess noise (control, thermal issues, scattered light,...) that are spoiling the current sensitivity
- Then (Spring 2008) few apparatuses will be upgraded:
  - New laser amplifier (50W)
  - New suspension & payload
  - Thermal compensation
  - New control electronics
  - Better Optics







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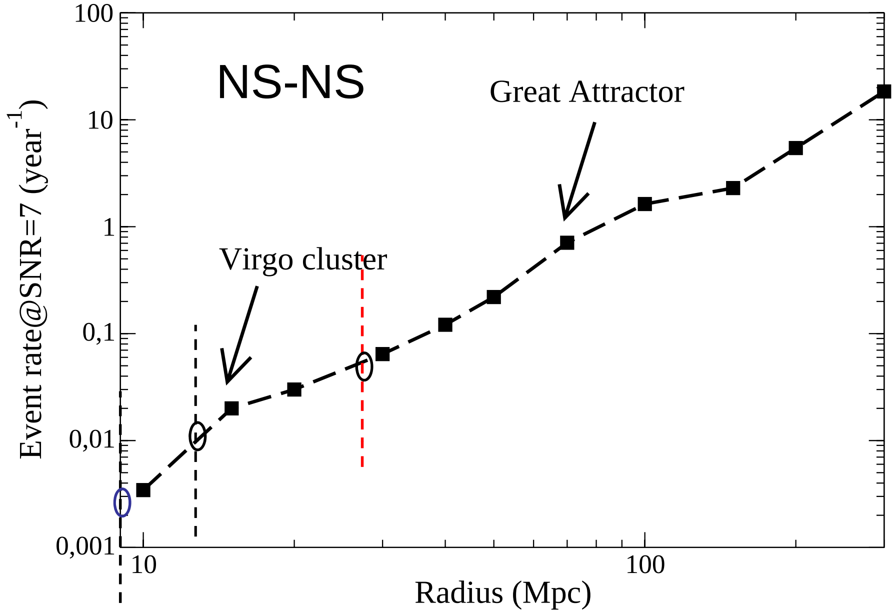
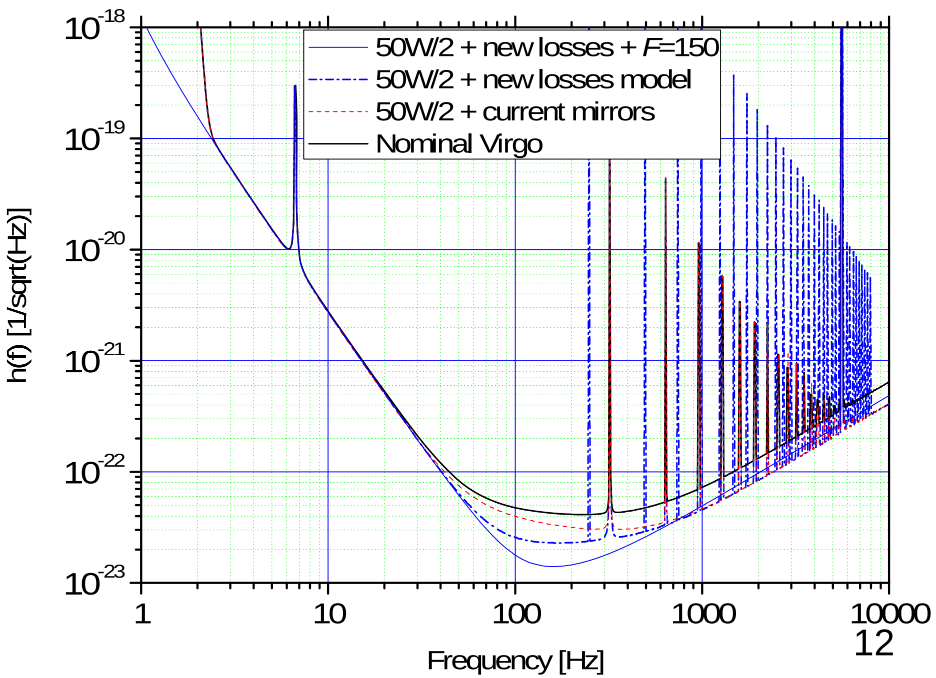
Expected Virgo+ performances

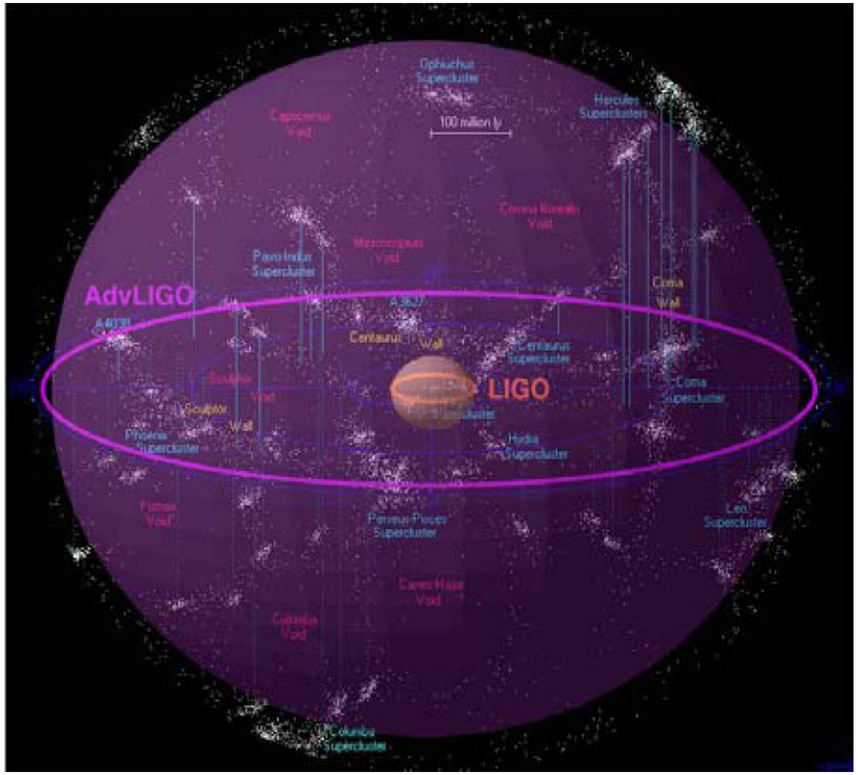
- The Virgo+ upgrades are still under definition and hence the design sensitivity is still unfrozen
  - Roughly, an improvement of a factor ~2-3 in detection distance (respect to the nominal curve) is expected for the NS-NS coalescence signal
- The enhanced or "+" phase is considered, in any case, a necessary intermediate step toward the advanced detectors realization





The advanced Detectors

- Although the detection is possible with the enhanced detectors, even in the most optimistic scenario the statistics is too low also for preliminary GW astronomy:
  - advanced detectors needed
- **Advanced LIGO** approved:
  - x10 sensitivity, year >2013
  - looking 10 times further means access a universe volume ~1000 times larger
- **Advanced Virgo** conceptual design will be completed in Fall 2007
  - Technical design will be completed in 2009
  - Critical review expected in 2009



Credit: *Richard Powell, Beverly Berger.*
From LIGO presentation G050121

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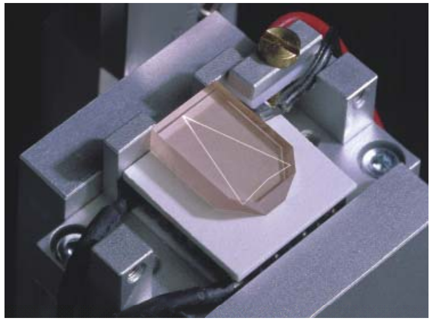
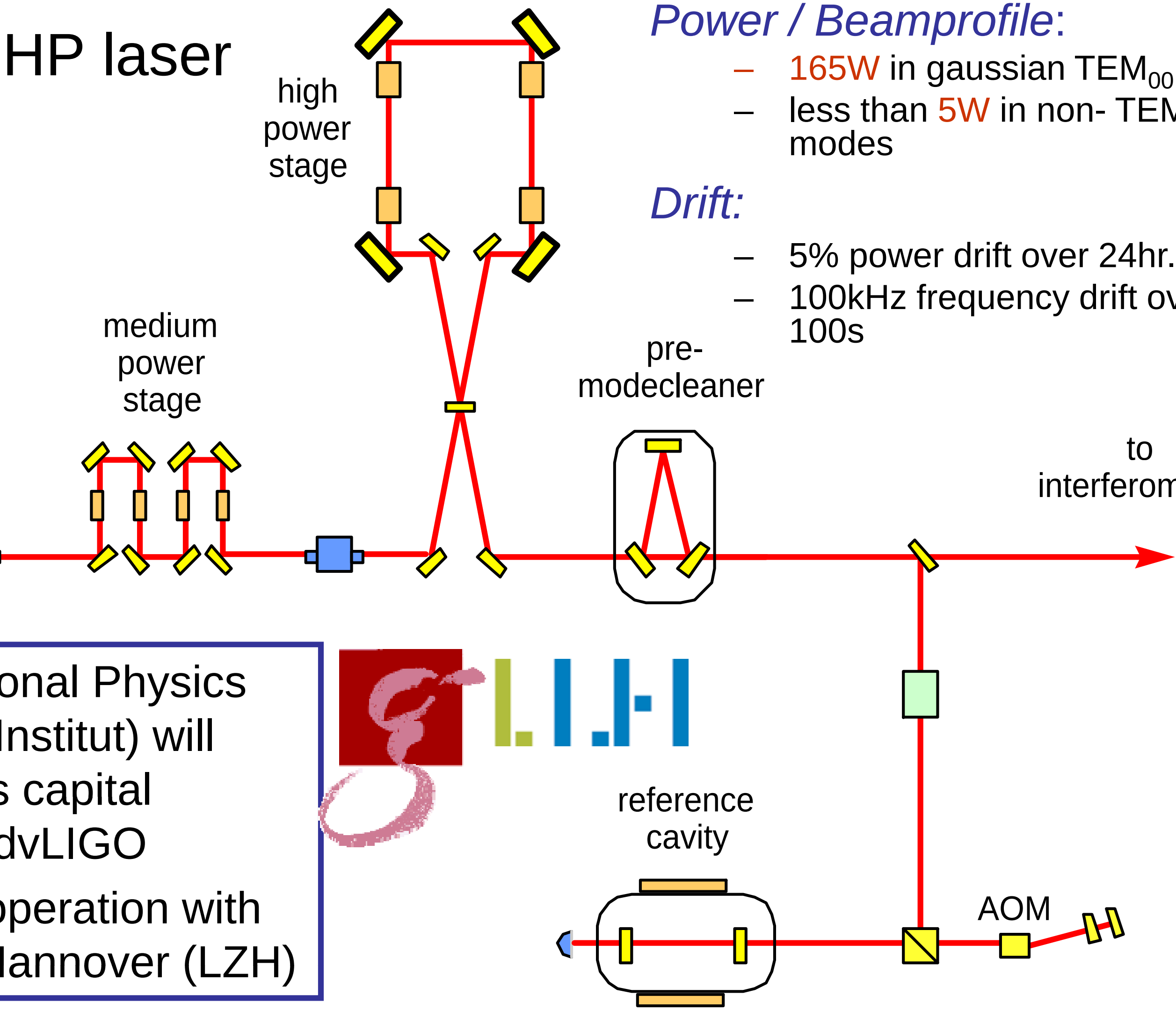
European contribution to advLIGO

- Prestabilized HP laser





Power / Beamprofile:

- 165W in gaussian TEM_{00} mode
- less than 5W in non- TEM_{00} modes

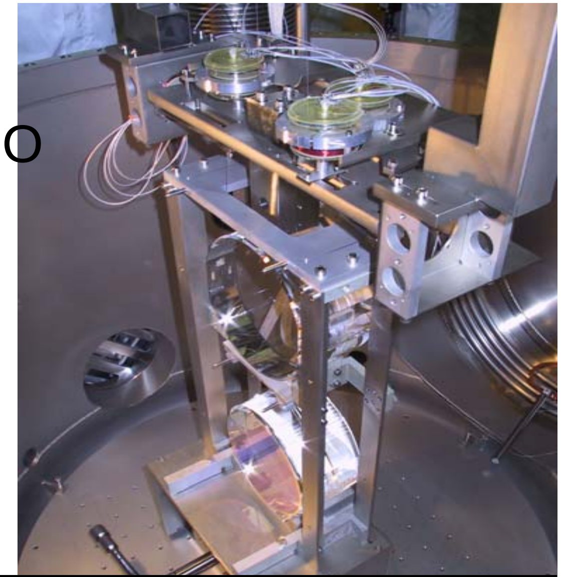
Drift:

- 5% power drift over 24hr.
- 100kHz frequency drift over 100s

- MPI for Gravitational Physics (Albert-Einstein-Institut) will provide lasers as capital contribution to AdvLIGO
- laser build in cooperation with Laser Zentrum Hannover (LZH)

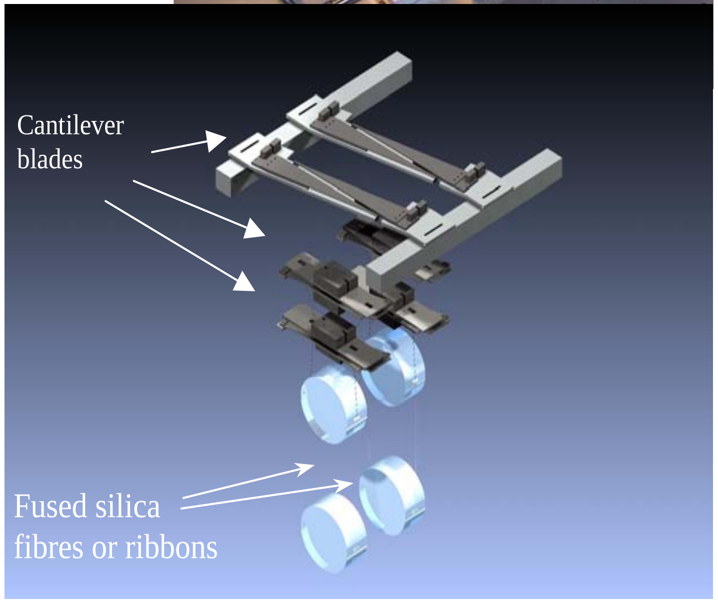
Credits: B.Willke

European contribution to advLIGO

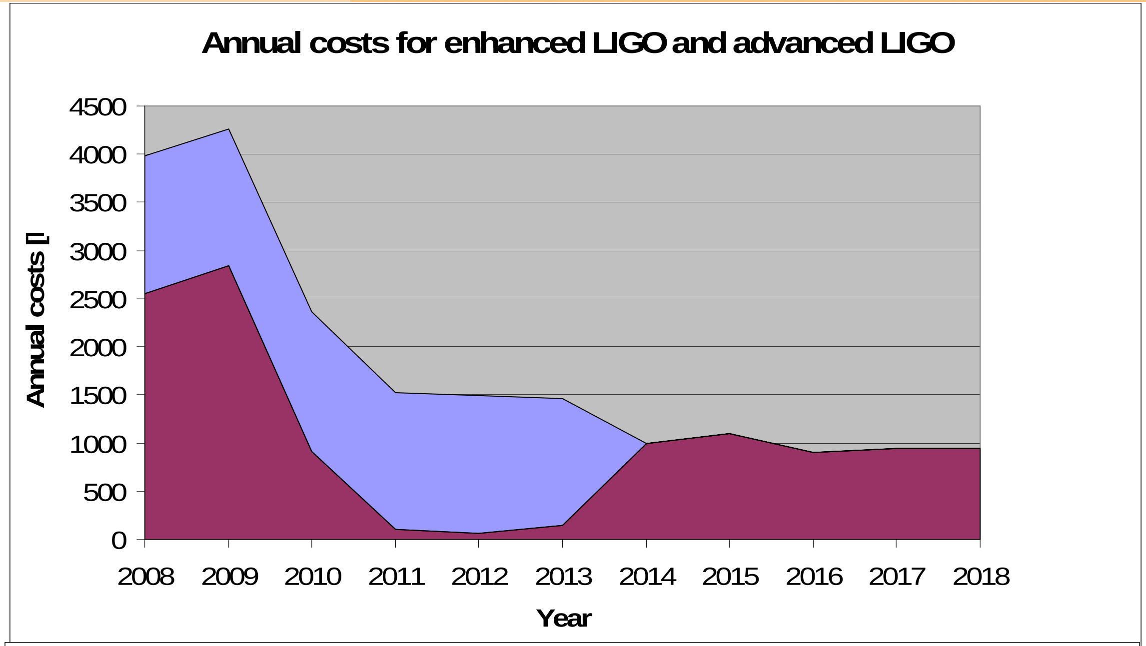


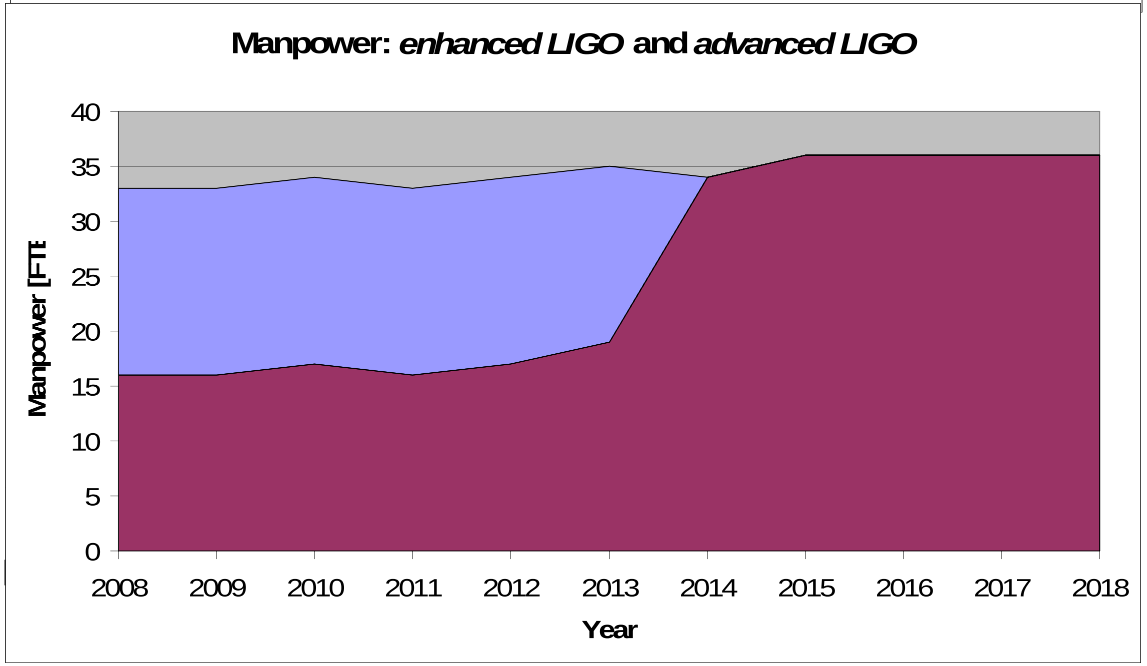
- Low dissipation suspensions
  - Based on the pioneering and currently unique GEO technology developed at the Glasgow University
    - Fused silica fibres "silicate-bonded" to mirrors
  - Evolution of the GEO technology
    - Possibly based on fused silica ribbons
    - Reduction of the thermal noise at low frequency
- Capital contribution from the UK
  - ~£8 million
- Participating universities
  - Glasgow, RAL, Birmingham, Strathclyde

UNIVERSITY OF BIRMINGHAM
UNIVERSITY OF STRATHCLYDE
UNIVERSITY of GLASGOW
IGR



European contribution to the cost & Man Power of eLIGO & advLIGO projects





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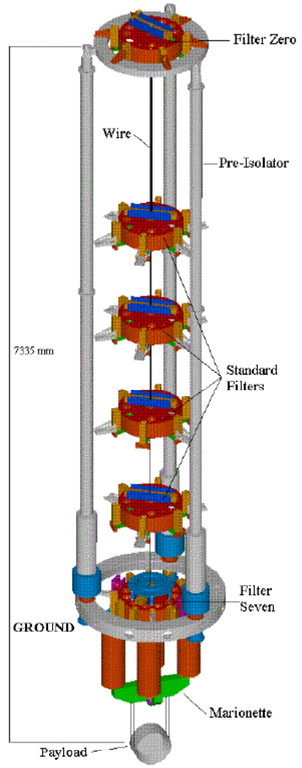
Advanced Virgo

- Project developed by the (growing) Virgo community
- Support by external groups (Birmingham University, Glasgow University, MPG) through the European FP6 network ILIAS-GW and the EGO R&D programs
  - High Power laser
    - LZH-GEO technology
    - Fiber Laser technology (Nice, CNRS)
  - Fused Silica suspension
    - INFN Perugia & Glasgow technologies
  - Low dissipation coatings
    - LMA-CNRS technology
  - Minor (but not negligible) modifications to the Virgo suspension
    - INFN Pisa technology



AdvDetectors Sensitivity

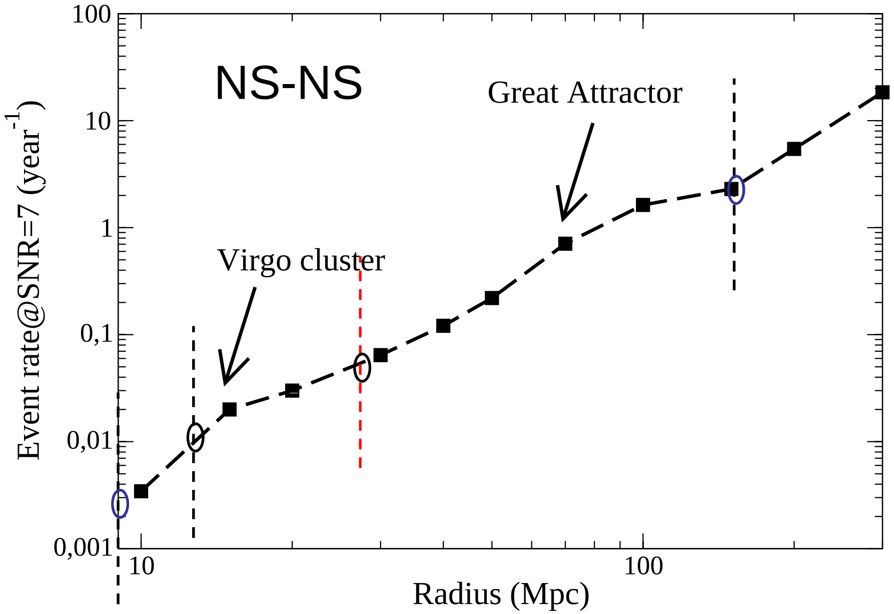
- The definition of the expected sensitivity of the advanced detectors needs still some evaluation
  - Technical design to be completed
  - But some figure could be already draft

advVirgo (TBC)

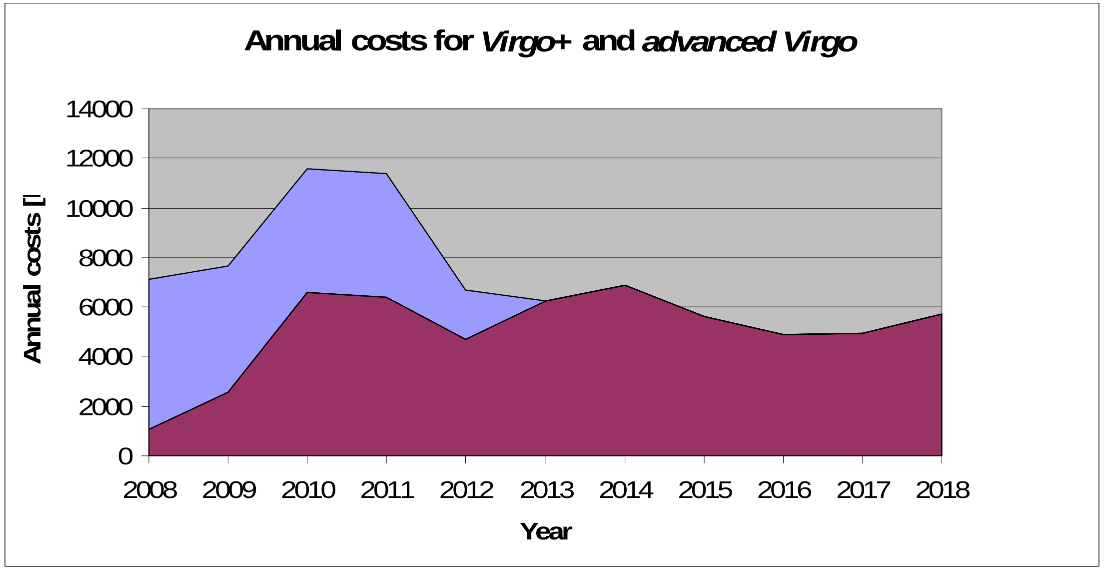
- BNS range: 121 Mpc
- BBH range: 856 Mpc
- 1 kHz sens.: 6 10^{-24}

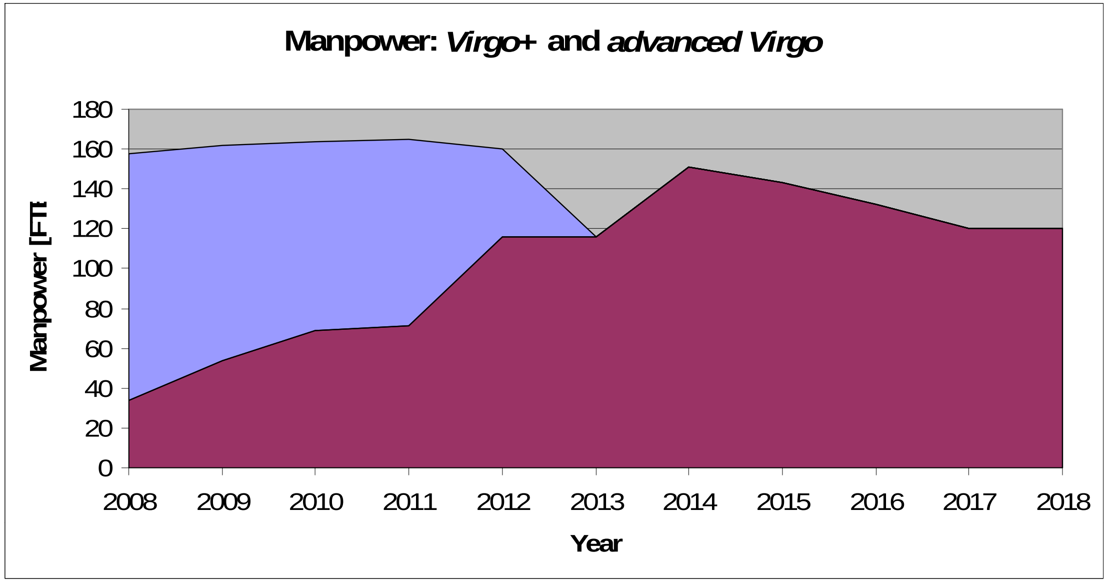
advLIGO

- BNS range: 172 Mpc
- BBH range: 972 Mpc
- 1 kHz sens.: 1.5 10^{-23}



Virgo+ and adv Virgo expected costs and man power effort



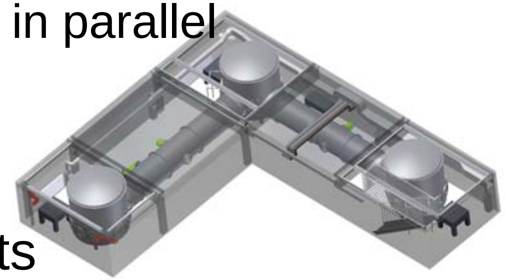


GEO600 → GEO-HF

- The limited length of the GEO detector prevent to match the LIGO and Virgo detectors sensitivity in all the frequency range
- But GEO, thanks to the signal recycling technology, has the possibility to select a limited frequency range where its sensitivity could match the large (current and enhanced) detectors
  - **GEO HF project**
    - **Timeframe 2008 – 2013:**
      - Sequential upgrade of GEO600 detector:
      - Improve sensitivity to provide scientific data to the network;
      - Match Virgo/LIGO sensitivity in upper frequency range
      - Bridge Virgo/LIGO downtimes as much as possible
      - Interleaved upgrades/commissioning and data taking

GEO600 → GEO-HF

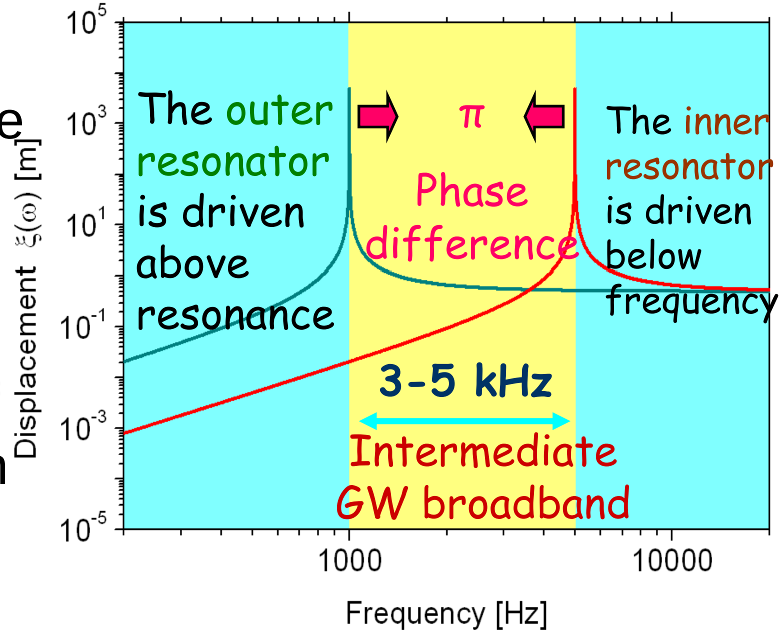
- **Timeframe 2014 – 2018:**
  - GEO-HF detector mainly testbed for future technologies
  - Possible science data taking in parallel with the adv detectors in “particular” configurations
  - Prototype / Laboratory research for future technologies in parallel



- Prototype interferometer (10m, start: now)
  - Provide platform for ultra-sensitive QND experiments
  - (radiation pressure effects with squeezed light, QND readout, suspension point interferometer, etc.)
  - Test 3rd generation techniques
  - Set up and test digital control system to be implemented in GEO600

Bars→Dual

- Current resonant detectors should be kept online until the enhanced ITF will be back on science mode (2009)
- Current technology has been overwhelmed by the interferometers
- R&D supported by INFN for the study of a new concept of GW detector based on the resonant mode(s) of a solid body
  - **DUAL**



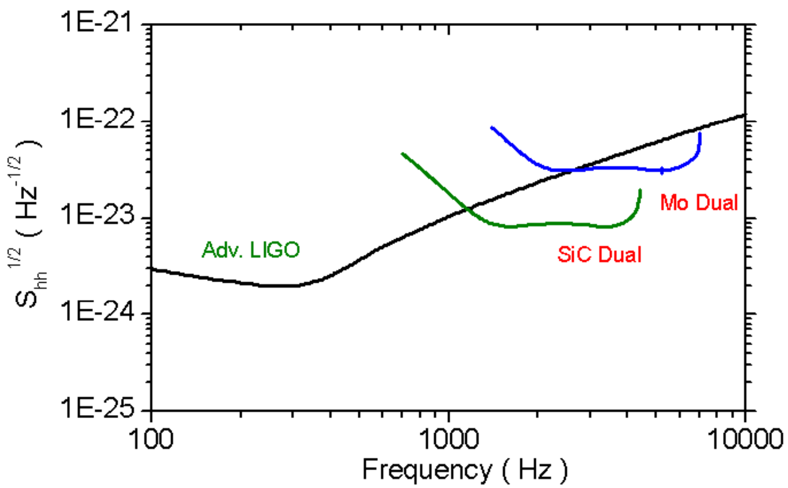
- The DUAL concept works also between the modes of the same body

PRL 87 (2001) 031101, PRD 68 (2003) 102004,

PRD 74 (2006) 022003

Bars→Dual

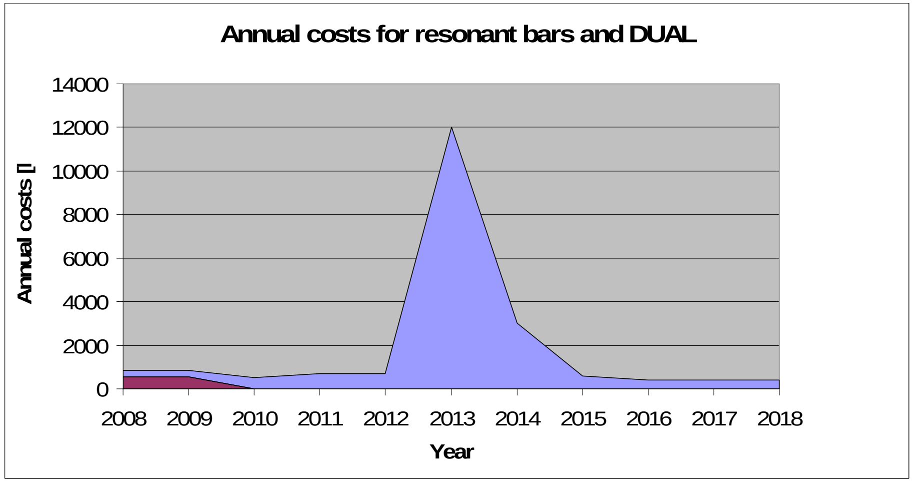
- Spectral sensitivity <u>at the SQL</u>

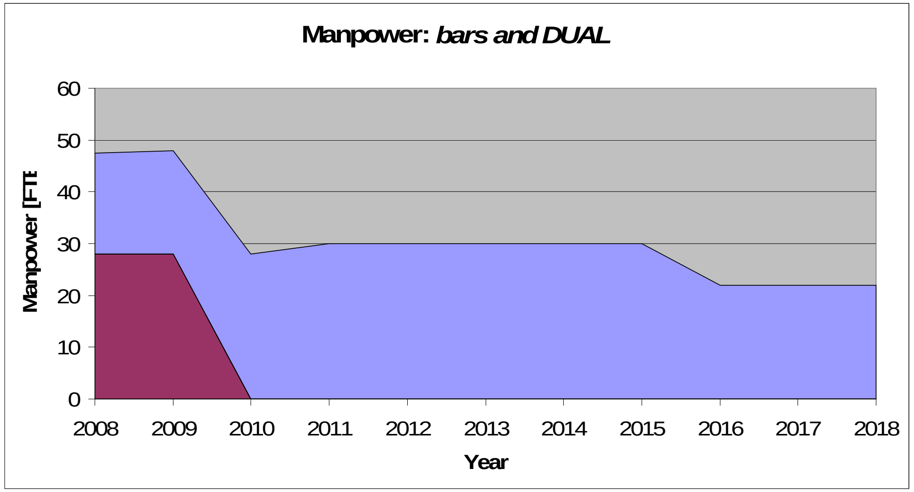


Mo Dual 16.4 ton height 2.3m 0.94m

SiC Dual 62.2 ton height 3.0m 2.9m

$Q/T = 2 \times 10^8 K^{-1}$



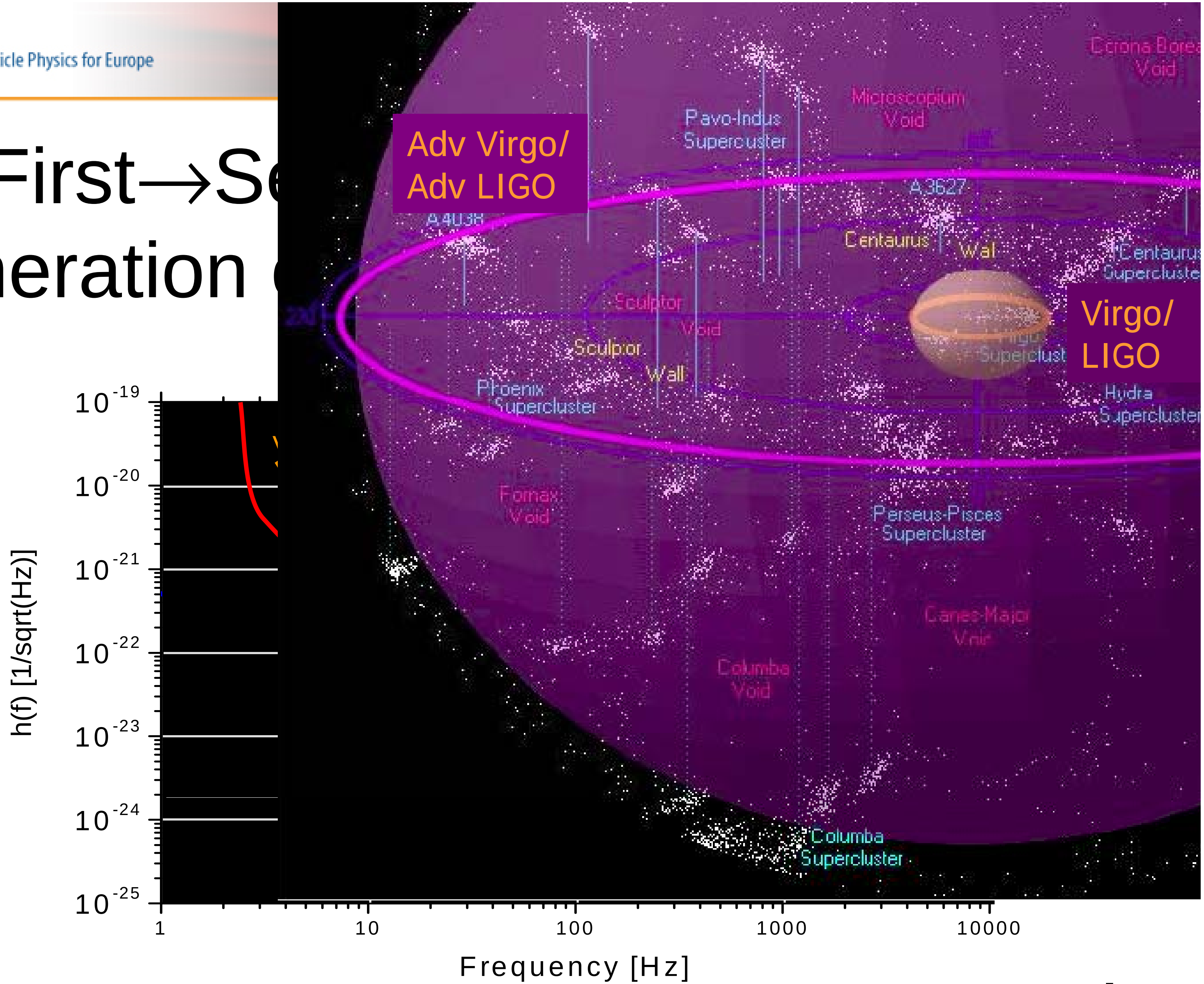


Beyond Advanced Detectors

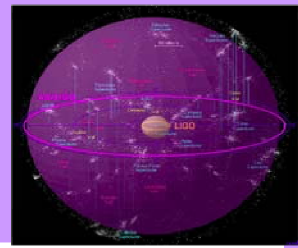
- Advanced detectors will “surely” permit to detect gravitational waves
- But to perform a precision GW astronomy we will should go beyond:

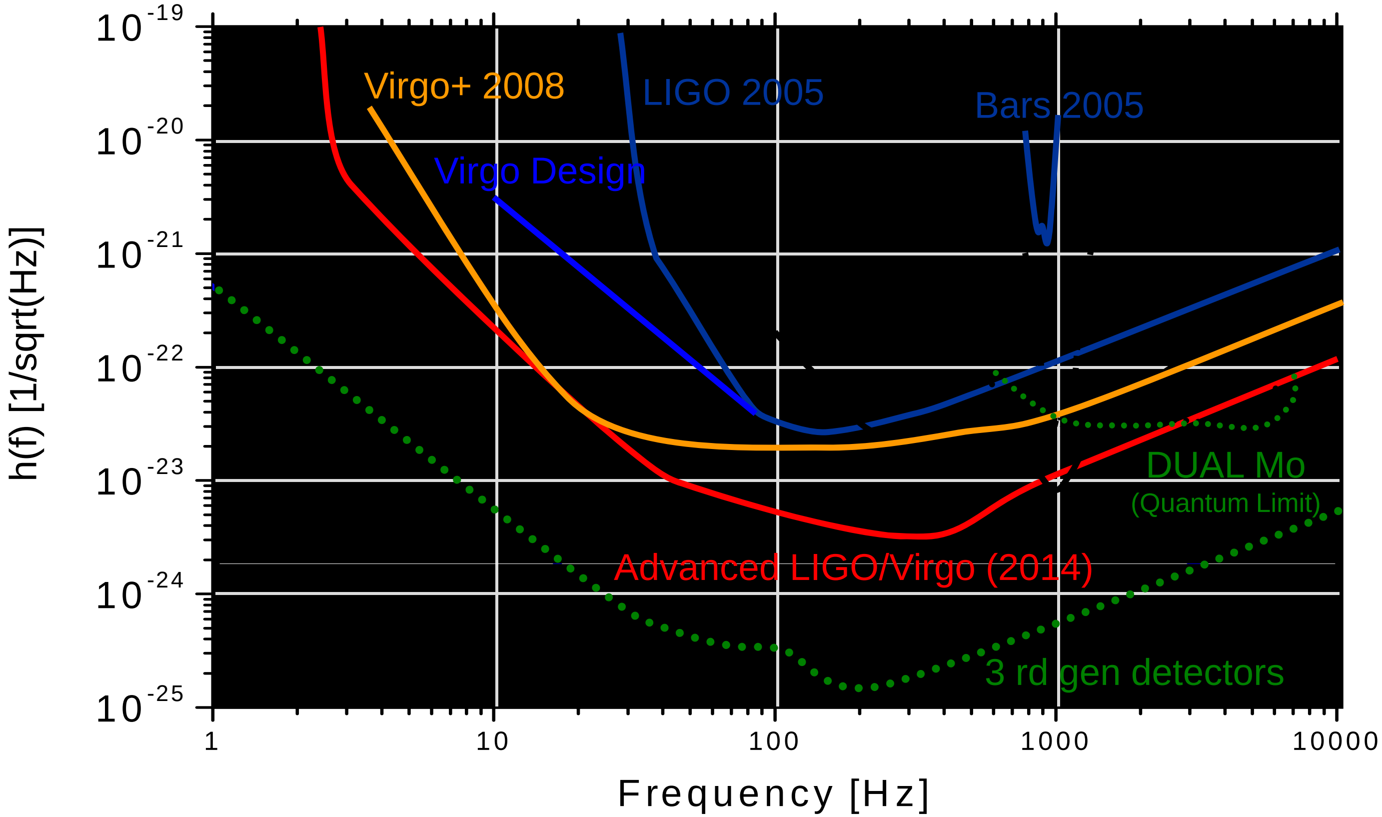
–3rd generation of GW detectors

First→Se
generation



3 rd Generation GW detectors





Objectives of a 3 rd generation GW detectors

From detection and initial GW astronomy to precision GW astronomy

- **Fundamental Physics**: Test general relativity in the strongly non-linear regime
  - Initial and advanced detectors won't have the sensitivity required to test strong field GR (too low SNR)
  - Most tests are currently quoted in the context of LISA, but in a different frequency range
  - We need to have good enough SNR for rare BBH mergers which will enable strong-field test of GR
- **Black hole physics:**
  - What is the end state of a gravitational collapse?
- **Cosmology**: study the problem of dark energy
  - Obtain accurate luminosity vs. distance relationship from inspirals at a red-shift $z \sim 1$ from GW/EM observations

Sources and Science

- **Astrophysics:** Take a census of binary neutron stars in the high red-shift Universe
  - Adv VIRGO/LIGO might confirm BNS mergers, possibly provide links to γ-ray bursts
  - We want to do much more: see different classes of sources (NS-NS, NS-BH), determine their orientation and resolve the enigma in the variety of γ-ray bursts
- **New Sources and Science:** Detect intermediate mass binary black holes at cosmological distances

How to arrive to an European Observatory?

- Long preparatory path :
  - WG3 of the ILIAS-GW FP6 initiative operated in the last years to realize the basis of a common European enterprise
    - All the GEO & Virgo collaborators are participating to this common effort
  - STREGA (JRA3-ILIAS) is exploring the technologies for the thermal noise reduction in 3^{rd} generation GW detectors
  - Exploratory workshop (Sept. 2005) on 3^{rd} generation GW detectors supported by the European Science Foundation (ESF)
    - Milestone in the definition of the future strategy in GW research
  - … and, finally, FP7:

ET

SEVENTH FRAMEWORK PROGRAMME

- ET: Einstein Telescope
  - An European 3rd Generation Gravitational Wave Observatory
- Conceptual design study proposed at the last FP7 call (2/5/2007)
  - Capacities
    - Research Infrastructures
      - Collaborative projects

ET

- Participants

Project Coordinator →

Participant no.	Participant organization name	Country
1	European Gravitational Observatory	Italy-France
2	Istituto Nazionale di Fisica Nucleare	Italy
3	Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V., acting through Max-Planck-Institut für Gravitationsphysik	Germany
4	Centre National de la Recherche Scientifique	France
5	University of Birmingham	United Kingdom
6	University of Glasgow	United Kingdom
7	National Institute for Nuclear Physics and High Energy Physics	The Netherlands
8	Cardiff University	United Kingdom

Proposed Design Study

- Conceptual Design Study
  - Proposal writing coordinators
    - M.Punturo, H.Lueck (Chairpersons of the WG6 ASPERA WG)
  - Available documentation:
    - http://www.ego-gw.it/ILIAS-GW/FP7-DS/fp7-DS.htm
- Working Packages:
  - Site and infrastructure
  - Thermal noise of mirrors and suspensions / cryogenics
  - Optical configuration
  - Astrophysics issues
  - Management

ET: Baseline Concept

- Underground location
  - Reduce seismic noise
  - Reduce gravity gradient noise
  - Low frequency suspensions
- Cryogenic
- Overall beam tube length ~ 30km
- Possibly different geometry

Status of the Project

- We positively passed the EC referees examination
  - **Maximum** score in the scientific content of the project
    - Proposal submitted: 51
    - Survived the selection process: 12+2
      - "Physics" DS: 3
  - Negotiation meeting 6 September 2007 in Brussels
    - Negotiators:
      - F.Menzinger, M.Punturo, H.Lueck
    - Good starting point
      - Minor remarks by the referee
      - Budget limit (3M€) imposed by EC close to our requests (3.6M€)
        - » Budget (almost) fully devoted to man power
      - Proposed duration: 38 months
  - Breaking News:
    - Description of Work (DoW) document positively passed the analysis of the EC officer
    - We are negotiating the budget

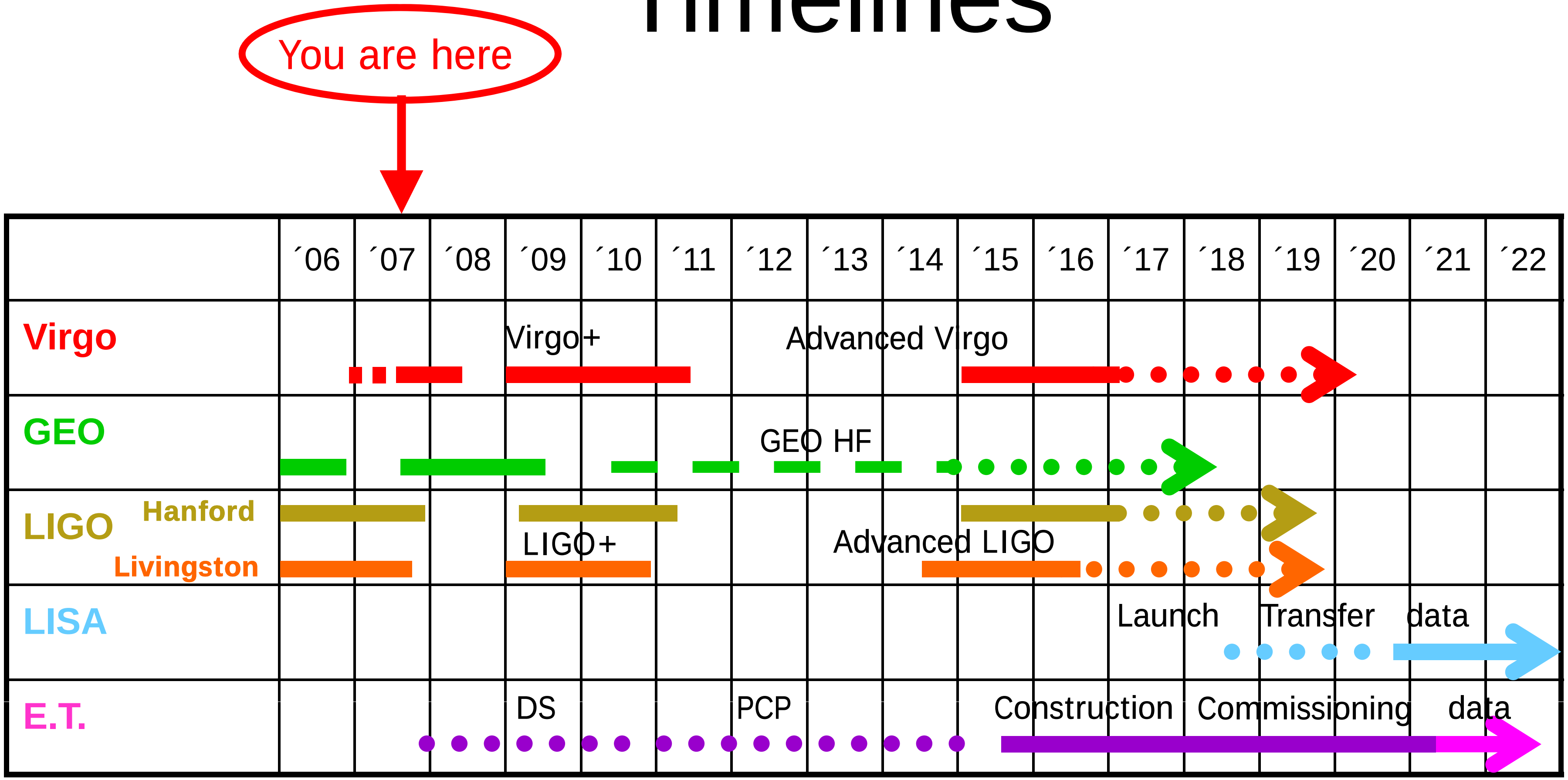
ET Negotiation
Next Steps

- Conclusion on the Negotiation: 28th of September
  - First signatures
- Approval of the Project:
  - October-November 07
- Contract signature between EGO and EC within 45 days after the project approval
- Consortium agreement to be ready at the same time
- Starting date:
  - Nominally the first day of the month after the project approval
  - Realistically, not before Feb-March 2008

ET: Science team

- EC referees appreciated the idea (in the proposal) to realize an open community behind the DS
  - Participation open to all scientists of the GW community willing to contribute to this project through their expertise and networking ability.
  - The Science Team is to keep continuous contact between the scientists working in the project with the larger GW scientific community and to allocate resources (man power and know-how) available outside the project for all the activities in the project that need external support
- First step in the realization of this community:
  - 4th ILIAS-GW general meeting + ENTApP
    - Tuebingen, Germany – 8-10 October 2007
    - http://www.tat.physik.uni-tuebingen.de/ILIASGW4

Timelines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Virgo+
Advanced Virgo
GEO
GEO HF
LIGO
Hanford
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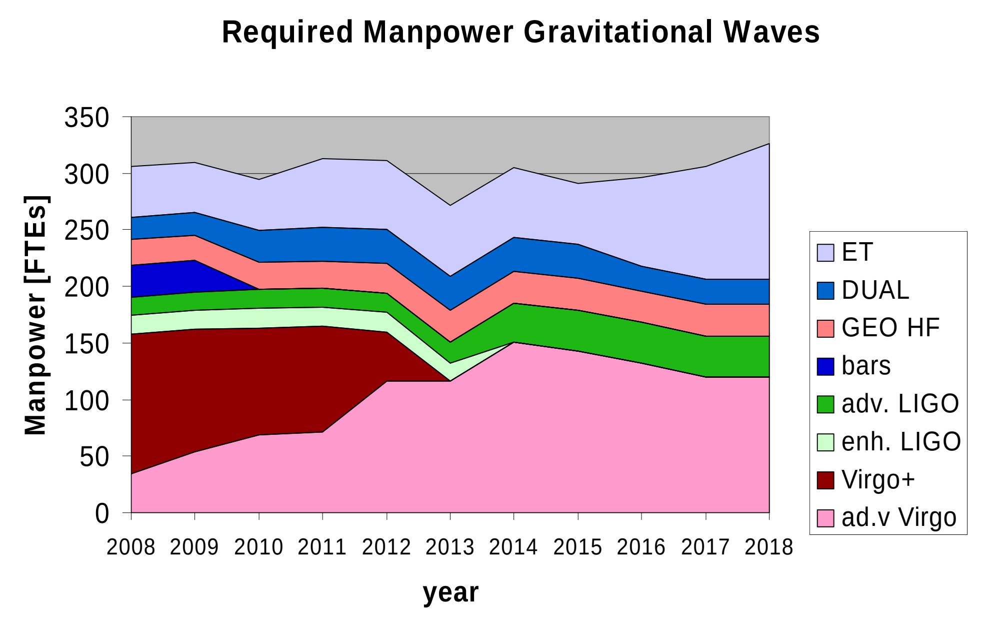
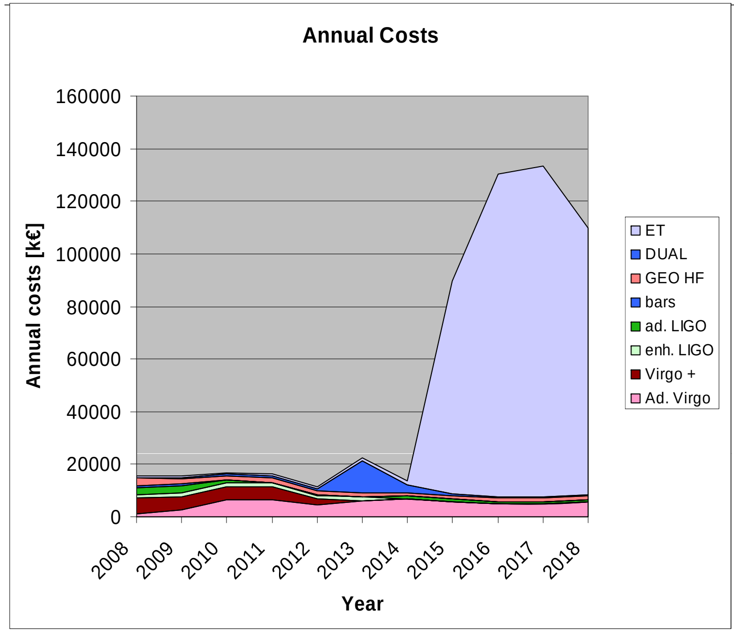
Overall effort



- •Permanent and postdocs
- •Construction and analysis
- •No distinction between engineers and physicists
- •Only the agents belonging to ASPERA or affiliated to it.
- •running experiments' operation personnel included
- • PHDs excluded! This causes a non negligible error in estimating the financial impact.



- *Investment (R&D+ Construction + Commissioning +Operation costs)*
- *No labour included, unless it is externalised labour (eg hire people to excavate a large cavity, prepare a large series of detectors etc)*
- *•Mostly money demanded from the agencies affiliated to ASPERA or EU*
- *LISA not included*
- *E.T. construction largely external costs*