Gravitational Waves Working Group

Phase II Aspera Roadmap

Sheila Rowan (in place of Harald Lueck)
for the European Gravitational-Wave Community

ApPEC/ASPERA, Paris, July 19th 2007

Detection of Gravitational waves – sources and science

WHY? - obtain information about astrophysical events obtainable in no other way

- Fundamental Physics
  - test Einstein's quadrupole formula in the strong field regime using binary inspirals
  - test Einstein's theory from network measurements of polarisation
  - confirm the speed of gravitational waves with coincident EM/GW observations
- Astrophysics:
  - provide links to γ-ray bursts by detecting NS-NS, NS-BH binaries
  - take a census of BHs by detecting 100's of BBH from cosmological distances
  - detect radiation from LMXB's
  - Measure NS normal modes; probe glitches in pulsars
- Cosmology and Fundamental Physics
  - Inform studies of dark energy
    - obtain accurate luminosity-distance Vs. red-shift relationship from inspirals at $z \sim 1$ from GW/EM observations
  - Detect possible GW background at $\Omega \sim 10^{-9}$
- New Sources and Science:
  - Intermediate Mass Binary Black Holes?
  - Burst of radiation from cosmic strings?
  - Backgrounds predicted by Brane-world scenarios?

B. Sathyaprakash, 2006

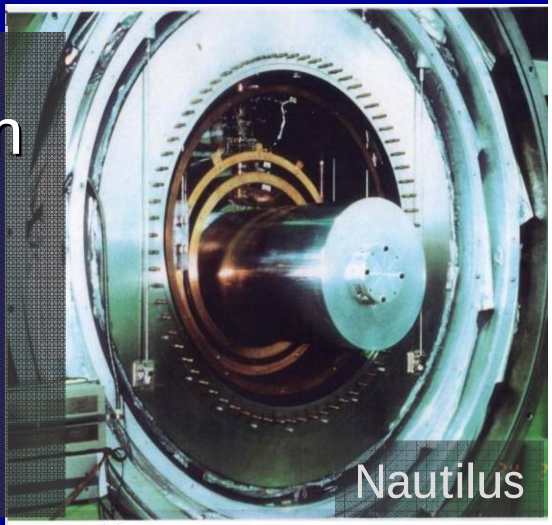
History

Auriga

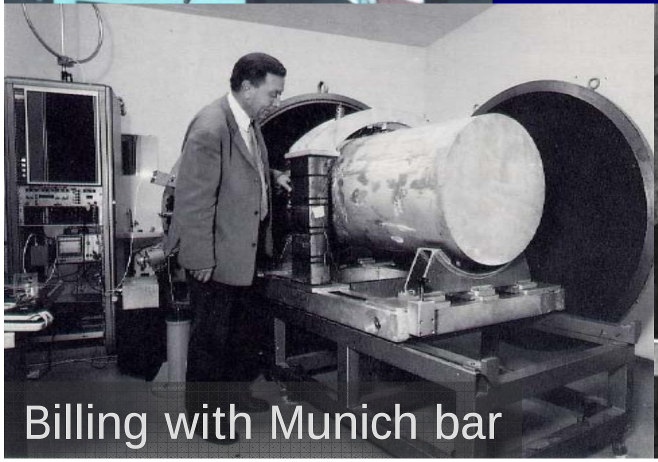
30m Garching prototype

- From the 70's on Europe has been a leading force in GW detection efforts
- Bars: Munich,Glasgow, Frascati, Legnaro, CERN
- Interferometers: Munich, Glasgow

Explorer



Nautilus



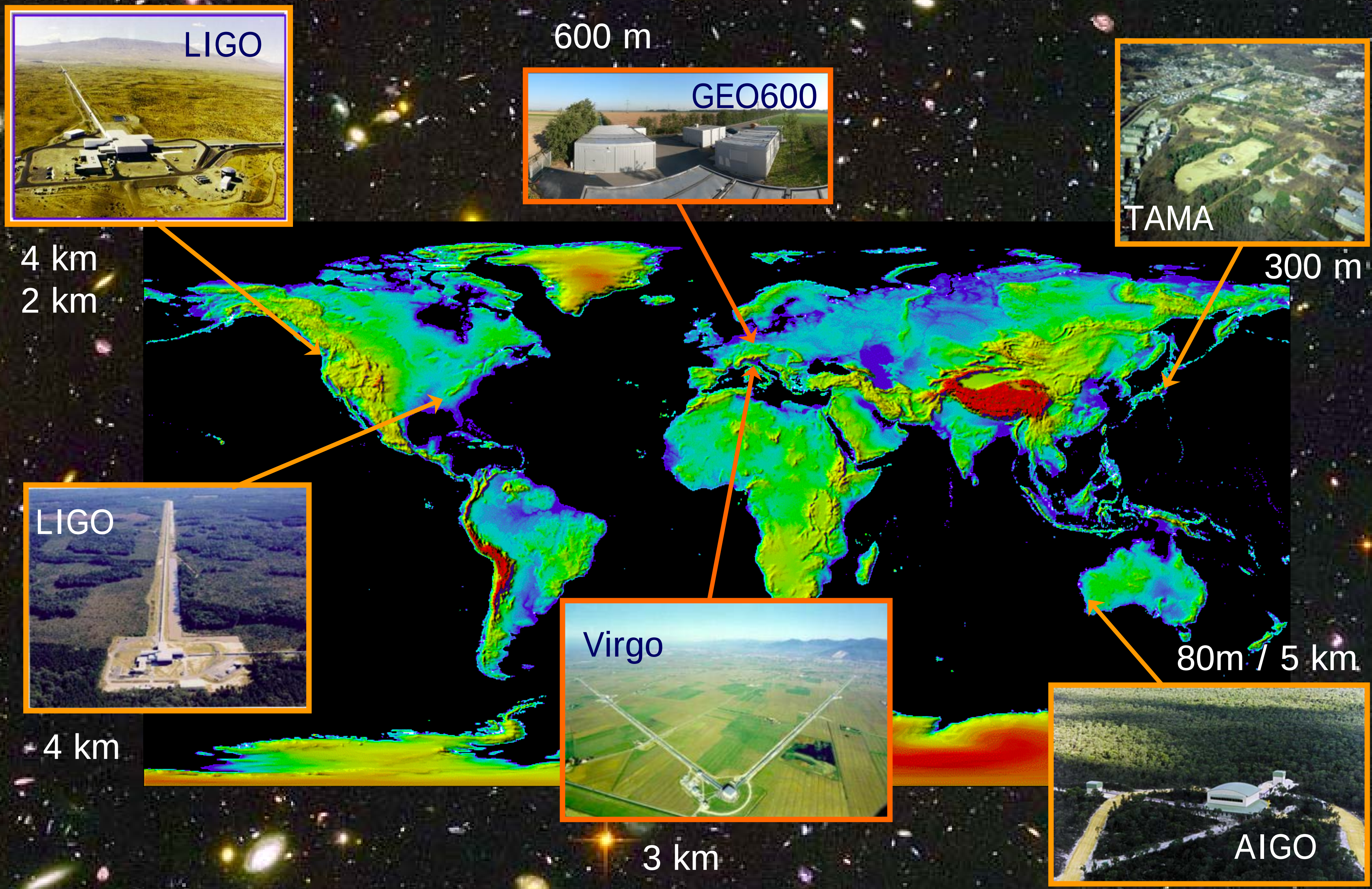
Billing with Munich bar

Glasgow bar

3m Munich interferometer

European GW expertise

Current Interferometers



Source: A. Lazzarini, modified

Science data runs to date

- Since Autumn 2001 GEO and LIGO have completed 4 science runs
  - Some runs done in coincidence with TAMA and bars (Allegro)
  - LIGO now at design sensitivity

- 'Upper Limits' have been set for a range of signals

- **>19 major papers published or in press since 2004**

S5: started on 4th Nov. 2005 at Hanford (LLO a few weeks later)

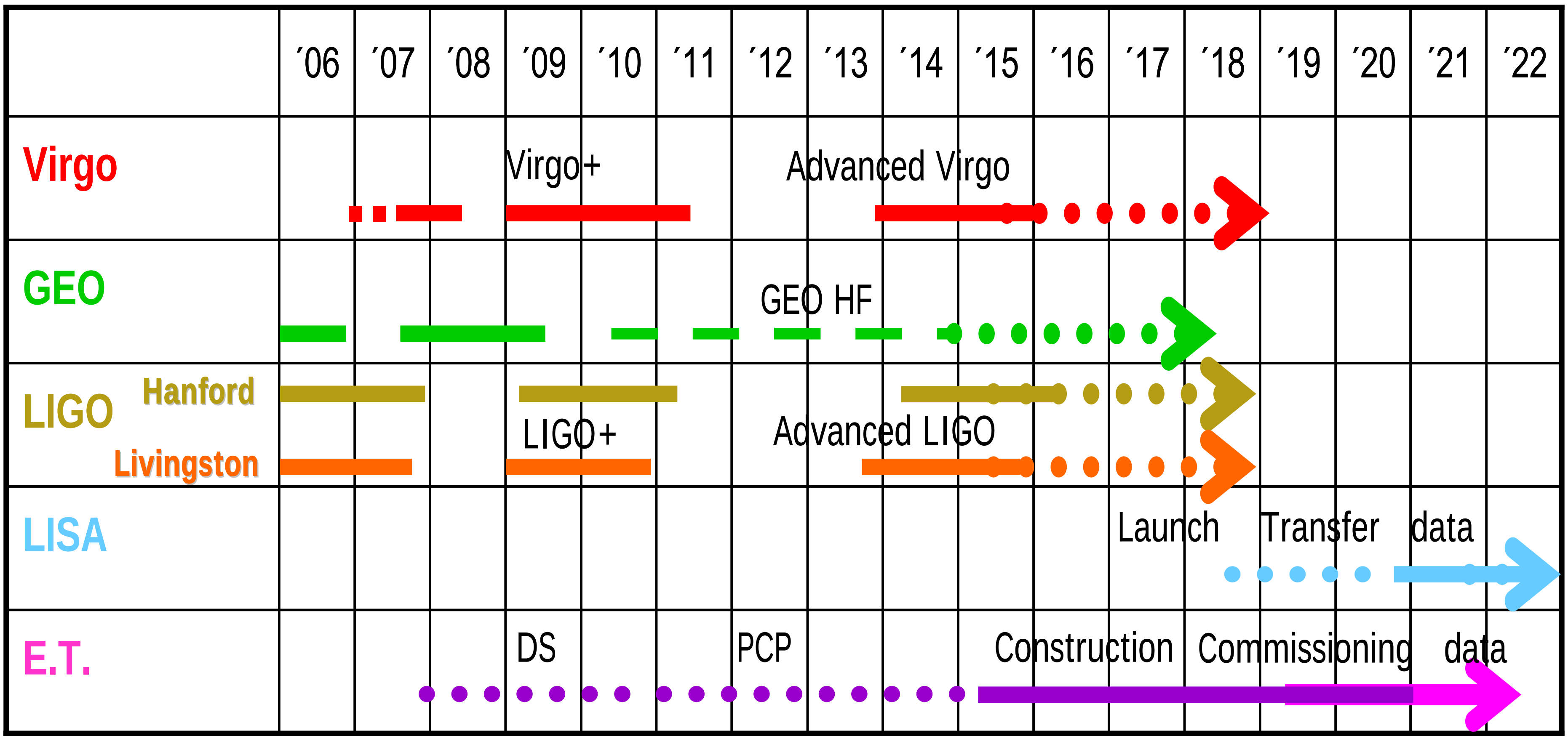
GEO joined initially for overnight data taking in Jan 06, then 24/7 till Oct 06 then interleaved with commissioning

Virgo joined May 18th 2007

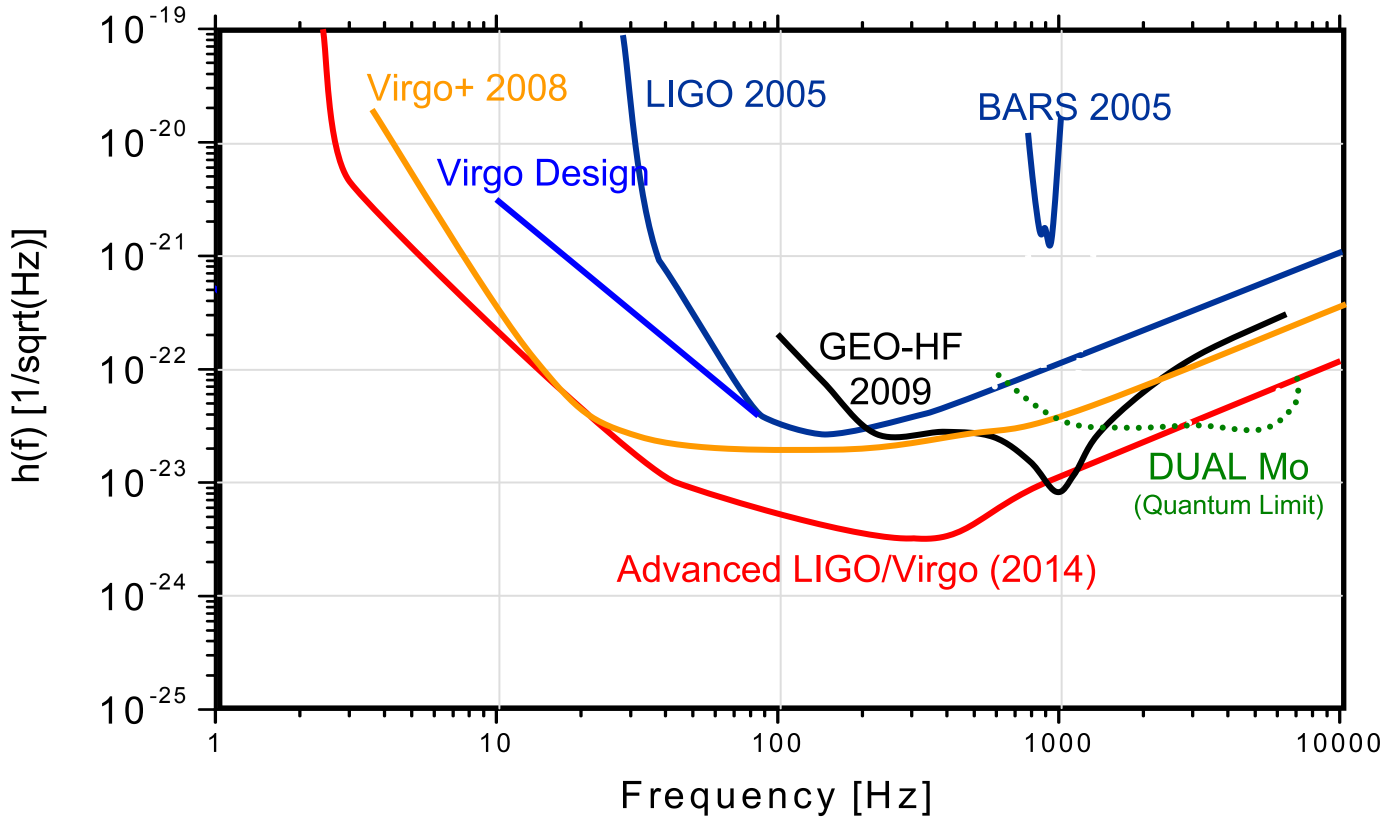
Planned detector evolution

- There is some possibility of detection with the initial instruments
  - For example, binary black hole rates could be as high as 1 event per 4 years
- However detection with the initial instruments is not guaranteed
- Thus plans for improving the sensitivity are in place
  - GEO-HF
  - ‘Enhanced’ then ‘Advanced’ LIGO
  - ‘Virgo +’ then ‘Advanced’ Virgo
  - 3rd generation instrument – Einstein Telescope (E.T.)
- These upgrades will be interleaved with periods of data taking
- Sensitivity improvements are broadly aimed at reducing
  - Photoelectron shot noise
  - Thermal noise
  - Seismic noise

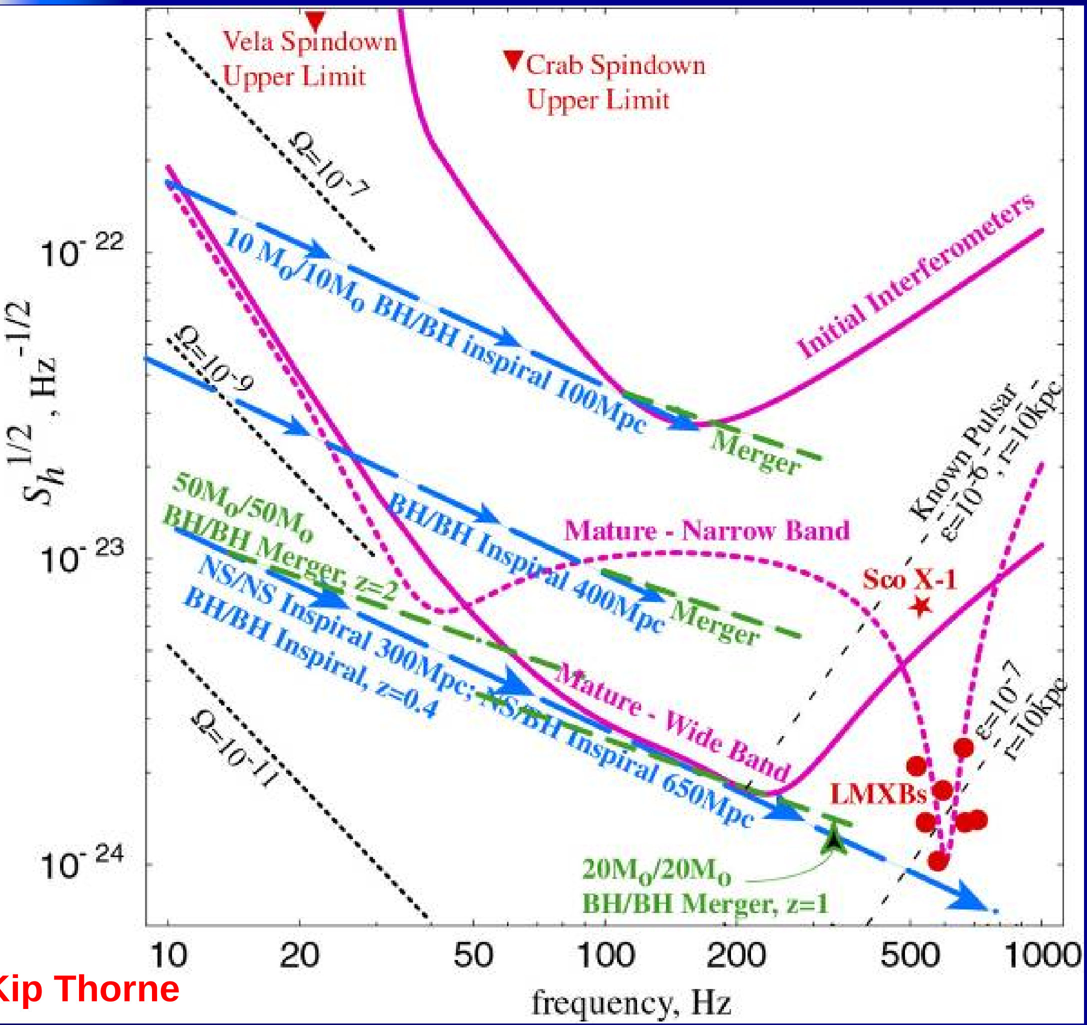
Future detectors and data taking plans



Advanced Projects



Science Potential of Advanced Instruments



Kip Thorne

Binary neutron stars:

From ~20 Mpc to ~350 Mpc

Known pulsars:

From ε = 3×10^{-6} to 2×10^{-8}

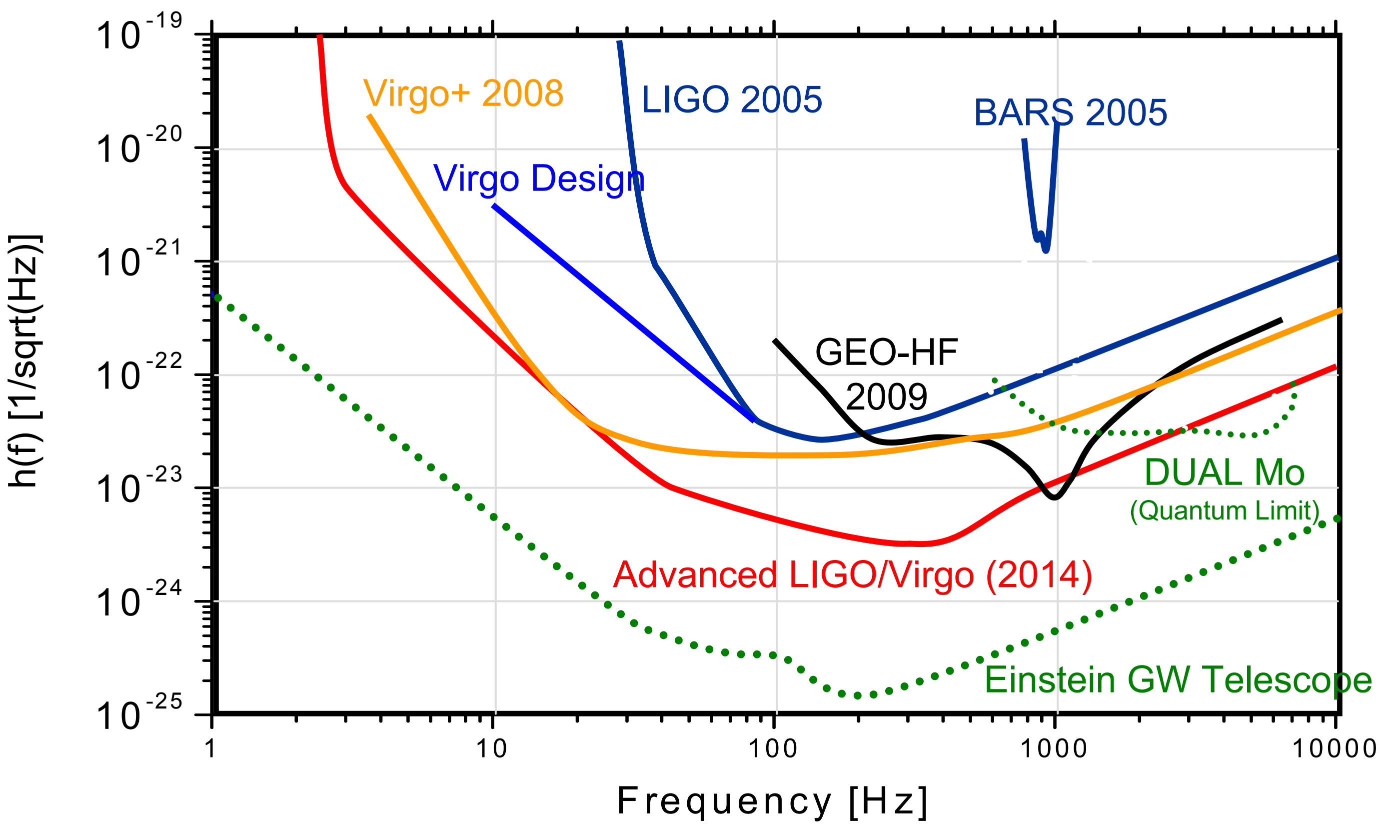
Binary black holes:

From ~100Mpc to z=2

Stochastic background:

From Ω_{GW} ~3×10^{-6} to ~3×10^{-9}

E.T.



Virgo+ 2008
LIGO 2005
BARS 2005
Virgo Design
GEO-HF 2009
DUAL Mo
(Quantum Limit)
Advanced LIGO/Virgo (2014)
Einstein GW Telescope
h(f) [1/sqrt(Hz)]
Frequency [Hz]
10^-19
10^-20
10^-21
10^-22
10^-23
10^-24
10^-25
1
10
100
1000
10000

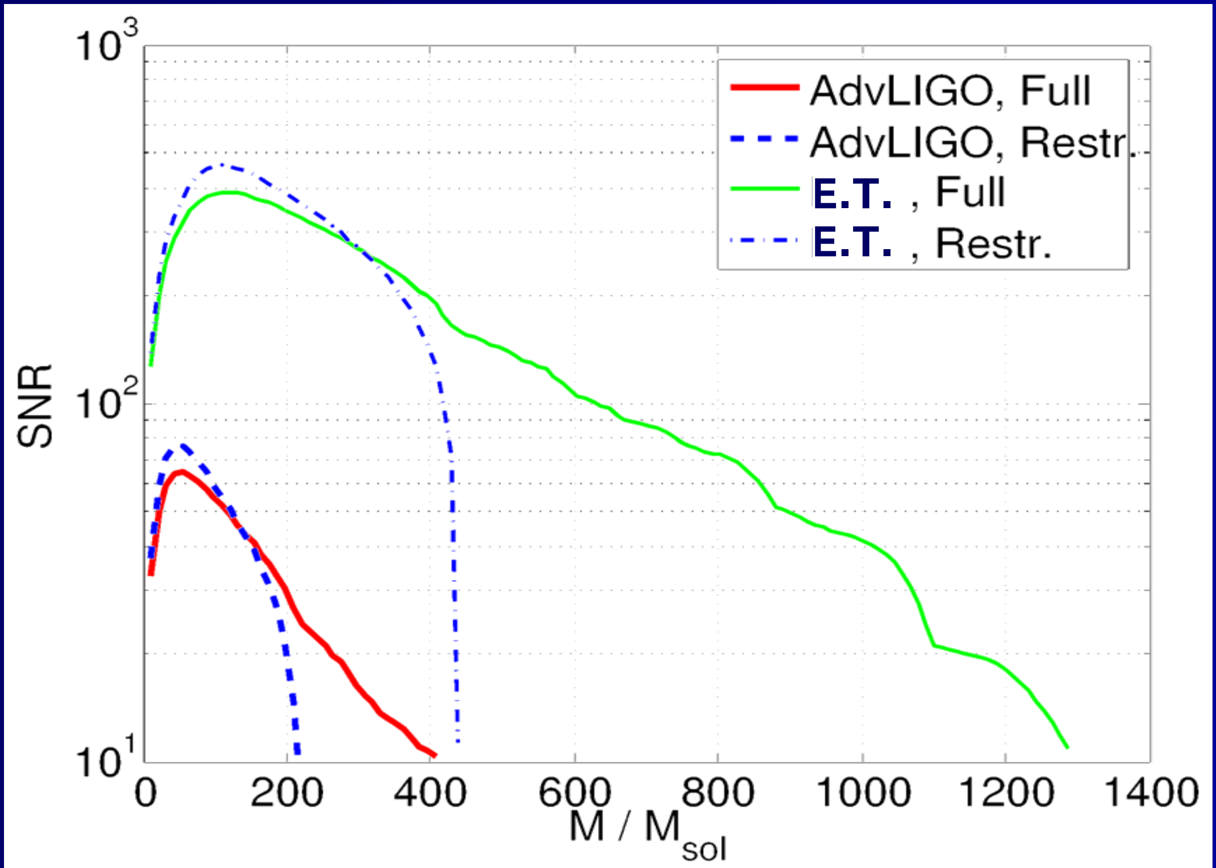
Sources and Science from E.T.
Exploiting the possibilities of GW astronomy

- **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
  - E.T. will have good enough SNR for rare BBH mergers which will enable strong-field test of GR
- **Cosmology**: Resolve 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 from E.T.
Exploiting the possibilities of GW astronomy

- **Astrophysics:** Take a census of binary neutron stars in the high red-shift Univ.
  - Adv VIRGO/LIGO will provide info on BNS mergers, possibly provide links to γ-ray bursts
  - E.T. should be able 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
  - Higher harmonics that are unimportant in Initial or Advanced detectors highly relevant in E.T.
  - Can see IMBH in higher harmonics

Effect of higher harmonics on SNR in E.T.



Sources at a distance of 100 Mpc

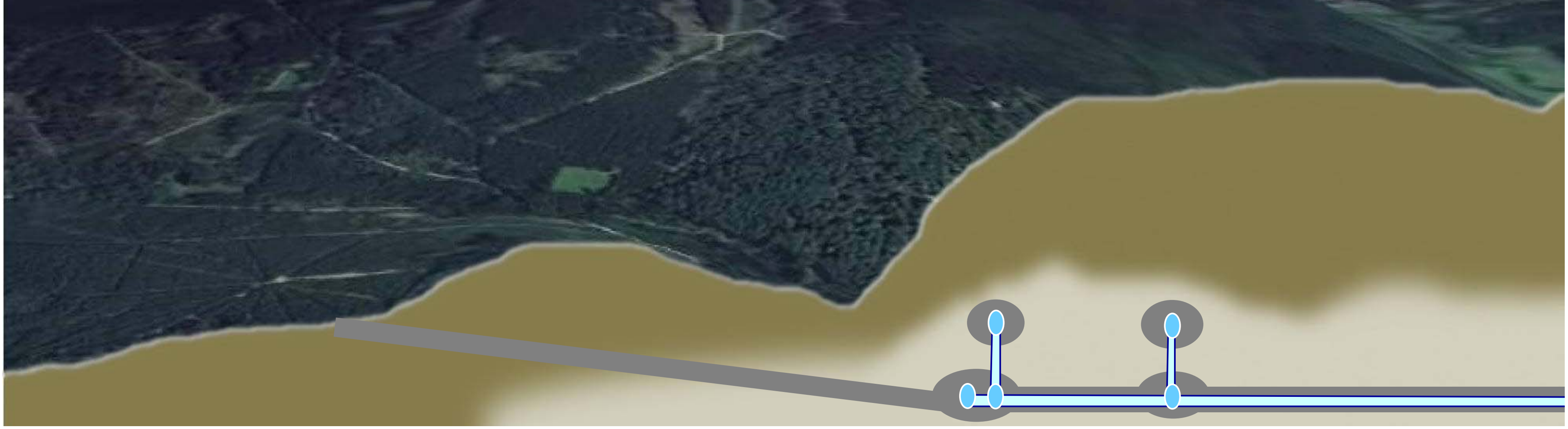
Need for new infrastructure

- Existing facilities subject to high, unshieldable environmental noise levels (seismic, gravity gradient noise)

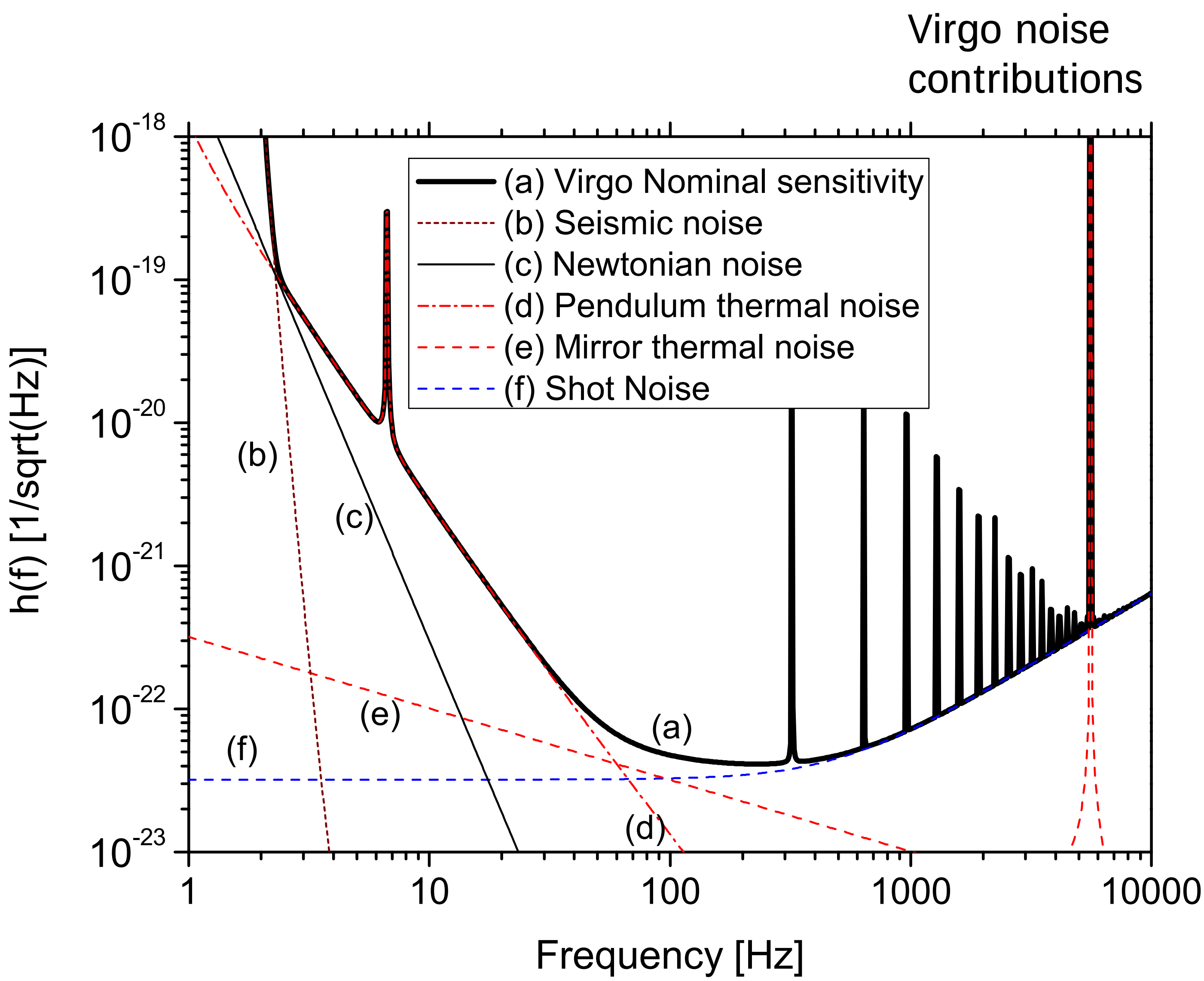
- Data taking with advanced detectors incompatible with installation of third generation techniques in same envelope (requires long comissioning times)

Baseline Concept

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



Typical noise sources



Working Packages

(1) Site and infrastructure

(2) Thermal noise of mirrors and suspensions / cryogenics

(3) Optical configuration

(4) Astrophysics issues

(5) Management

WP1: Site requirements and identification

- Identify strategies to reach a further reduction of the seismic noise effects beyond the second generation detectors expectations.
- Seismic requirements and methods to reach sensitivity goals @ low frequencies
- Gravity gradient noise evaluation
- Site selection and evaluation

WP2: Thermal Noise Requirements

Identify strategies to minimize thermal noise of test-masses

- Material Losses @ low temperatures
  Identify materials for:
  - Mirror bulk
  - Mirror coating
  - Mirror suspension wires
- Seismic Attenuation Requirements
  - Suspension seismic attenuation requirements (input from WP1, site selection)
  - Identification of control strategy and optimal mode frequencies
- Preliminary conceptual Design of the overall Cryogenic Suspension
  - Upper suspension stage
    - Active vs. Passive
    - Conceptual design of damping, alignment and optical losses requirements
    - Cryogenic compatibility
  - Last Stage
    - Test mass requirements (geometry and size (input from WG3), mechanical and optical losses req., test mass definition, suspension wire material and size, actuation of the last stage)
- Finalizing Conceptual Design of Cryogenic Suspension

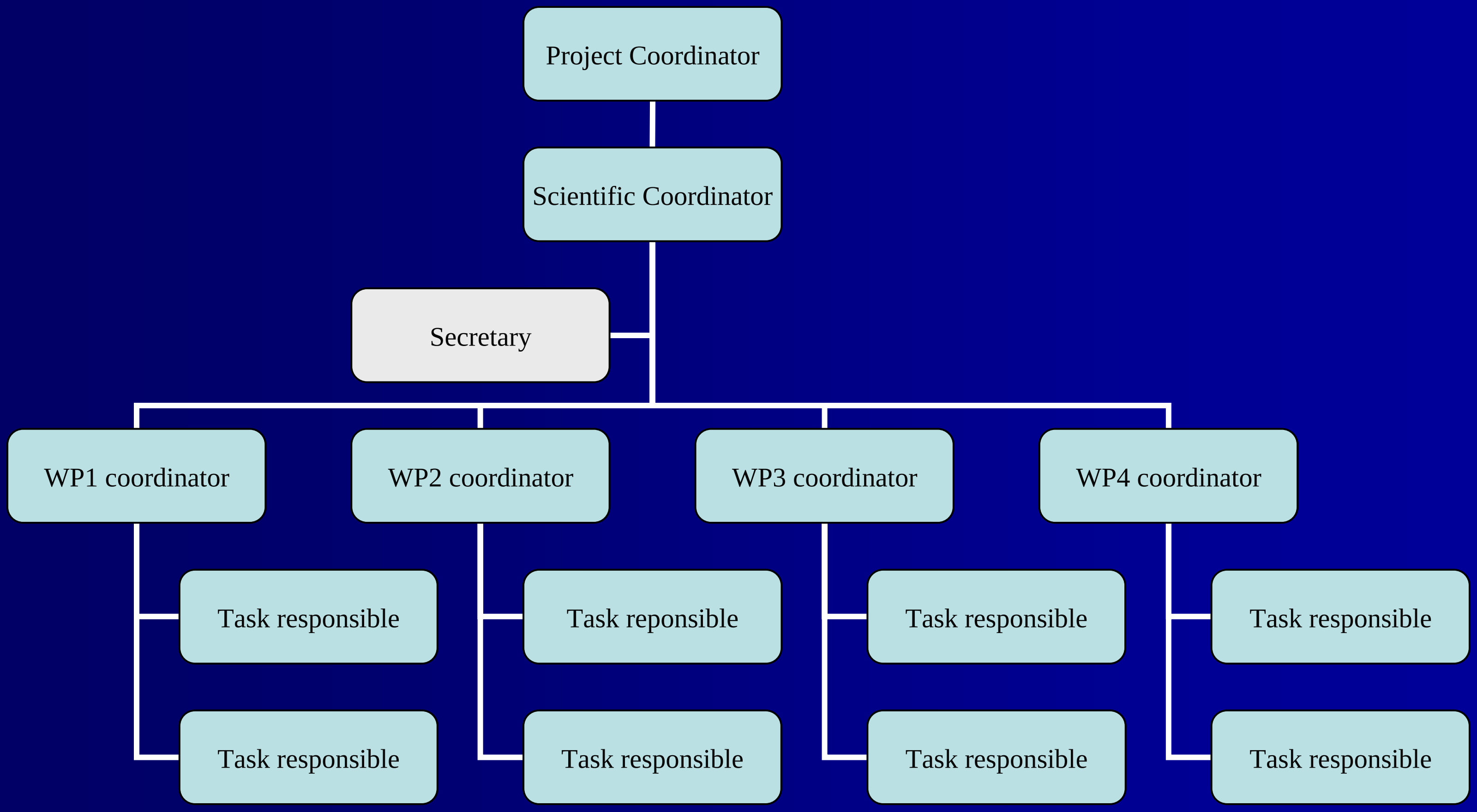
WP3:
Topology Identification

- **Evaluation of available and developing technologies** for the suppression of quantum noise.
  Quantify the feasibility and cost of:
  - recycling techniques,
  - using laser sources with larger wavelength
  - use of squeezed light sources
  - constructing interferometers as speed or momentum meters
  - displacement-noise-free interferometry
  - all-reflective interferometry.
- Modelling of **Interferometer Topologies** (= arrangement of optical components)
  Determine quantum noise limited sensitivity of different technologies for similar bounding conditions
- Modelling of **Interferometer Geometries** (= interferometer shape/s)
  Quantify signal extraction and noise reduction capabilities of multiple interferometers in dependence of their relative geometry (co-located, co-linear, etc.)
- **Effects of high Laser Power**
  - Opto-mechanical coupling
  - thermal lensing
  - Parametric instabilities
  - feasibility of all-reflective techniques
- **Cross-Compatibilities**
- **Trade-off analysis**
  - pre-selection of geometry and topology
  - trade-off analysis taking into account WP1 & WP2 results
- Modelling of **Interferometer Configurations** (= parameters, e.g. cavity Finesse)
  - Initial design of optical-readout and control configuration for given topology
  - Quantify technical noise propagation to detector output
  - Iterate optical design

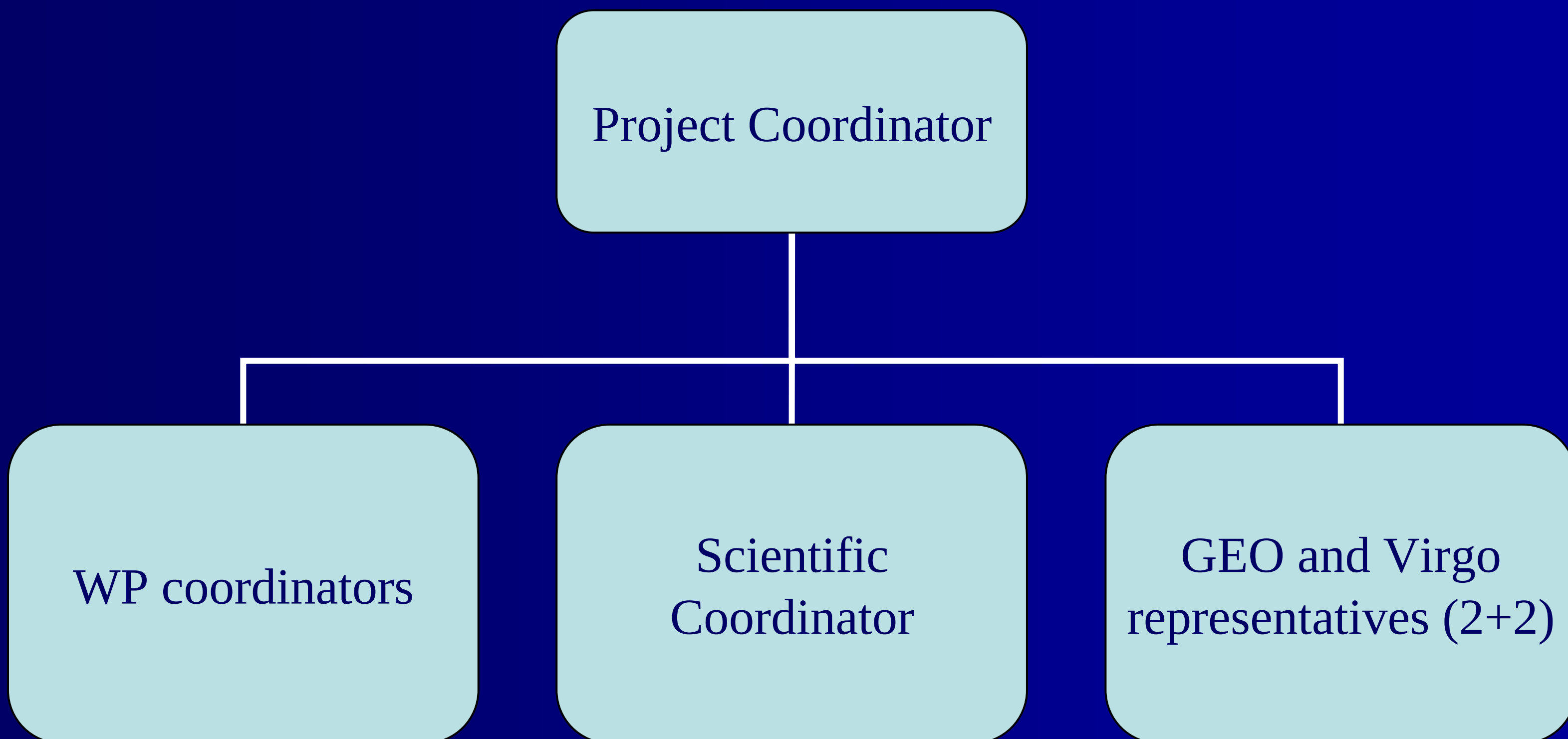
WP4: Astrophysics Issues

- **White paper** Assuming a 1 Hz – 10 kHz frequency range of operation produce a straw man document discussing a minimum and an optimistic science requirement for E.T. Study tunings to low frequency (1-10 Hz), medium frequency (10-100 Hz), high frequency (0.1-1 kHz) and very high frequency (1-10 kHz) sources.
- **Science potential** Consider in detail the potential of such an interferometer to study different classes of sources.
- **Cosmology** number counts, relationship to star formation rate history, observation of intermediate mass black hole binaries, origin and evolution of super-massive black holes at galactic nuclei, primordial stochastic backgrounds of gravitational waves.
- **Multi-window observation** Explore how to go beyond conventional GW astronomy goal. For example, the scientific benefit of multi-messenger astronomy deploying high energy astrophysics combined with E.T. observations to study accretion disk environments, x-ray binaries, magnetars, glitching radio pulsars, transient x-ray and radio sources, etc.
- **Strong field tests of GR**
- **Input from numerical relativity** Explore how numerical relativity simulations would be helpful in E.T. observations of binary black holes and how observations can be used to guide the simulations.
- **Computing requirements** Estimate the computational resources required for data analysis.

WP5: Management



WP5: Management
Executive board



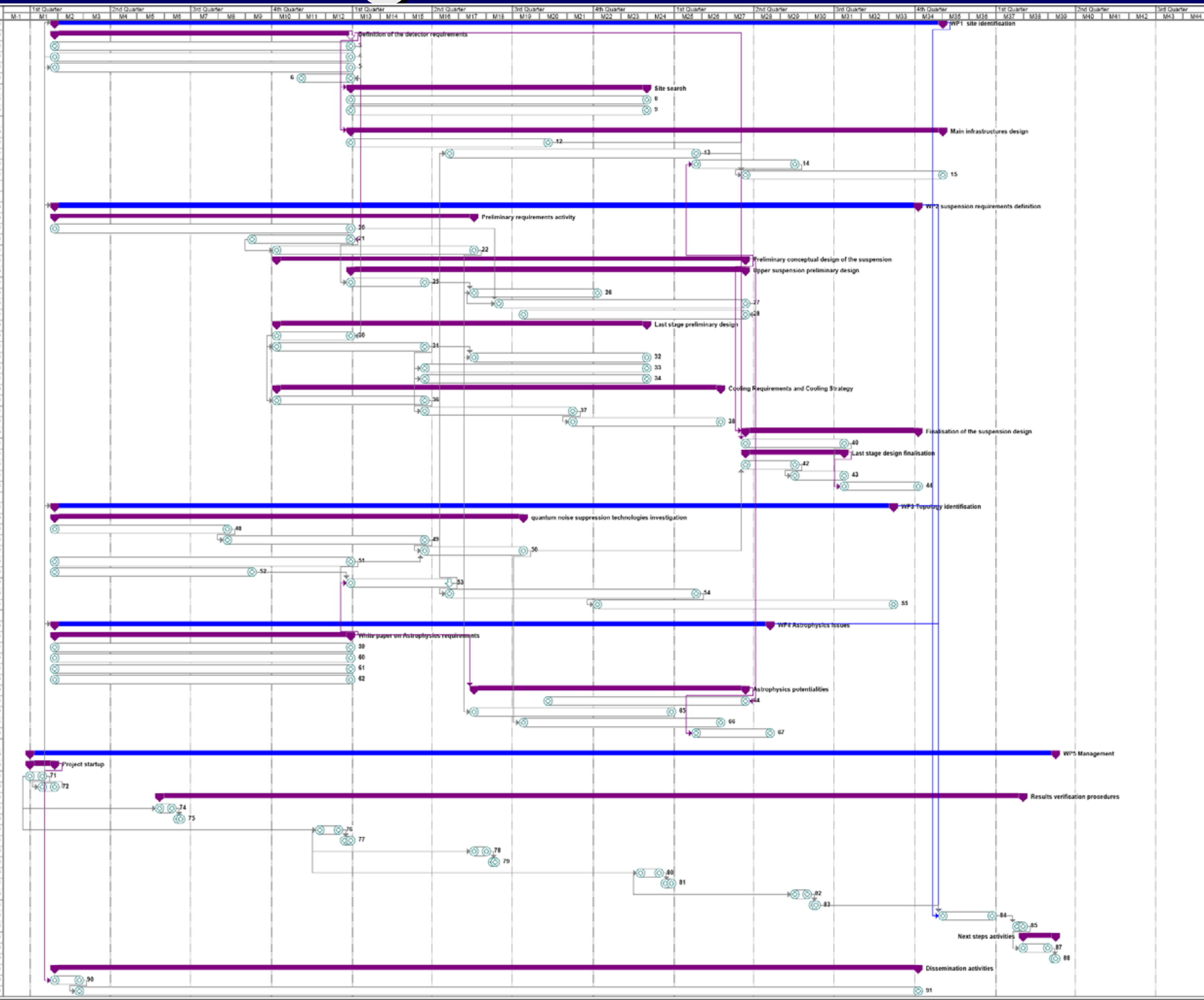
WP5: Management
Science team

- Participation open to all scientists of the GW community willing to contribute to this project through their expertise and networking ability.
- Co-chaired (first 6 months) by GEO spokesperson and by Virgo-EGO Scientific Forum coordinator

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

Timing of the DS

ID		Task Name	Duration
1		**WP1 site identification**	720 days
2		**Definition of the detector requirements**	240 days
3		Tolerances study	12 mons
4		Study of the seismic noise	12 mons
5		Newtonian noise evaluation	12 mons
6		White book about the site requirements	2 mons
7		**Site search**	240 days
8		Study of geo-science aspects	12 mons
9		Study of legal aspects	12 mons
10			
11		**Main infrastructures design**	480 days
12		Definition of the building requirements	8 mons
13		definition of the tunnel/pipes requirements	10 mons
14		definition of the cryogenic facilities requirements	4 mons
15		Design and cost evaluation of the main infrastruc	8 mons
16			
17			
18		**WP2 suspension requirements definition**	700 days
19		**Preliminary requirements activity**	340 days
20		material intrinsic requirements (cryo temperature	12 mons
21		Seismic attenuation requirements	4 mons
22		identification of the control strategy	8 mons
23		**Preliminary conceptual design of the suspension**	380 days
24		**Upper suspension preliminary design**	320 days
25		Attenuation strategy choice	3 mons
26		Control conceptual design	5 mons
27		Suspension element preliminary design	10 mons
28		Cryogenic compatibility	9 mons
29		**Last stage preliminary design**	300 days
30		Test masses requirements	3 mons
31		Suspension fibre design	6 mons
32		Control strategy definition	7 mons
33		Reaction and Control Masses Preliminary D	9 mons
34		E.M. Shielding and Contamination Control D	9 mons
35		**Cooling Requirements and Cooling Strategy**	360 days
36		Test Mass Cooling Strategy	6 mons
37		Thermal Link Definition	6 mons
38		Thermal Links Conceptual Design	6 mons
39		**Finalisation of the suspension design**	140 days
40		Upper suspension design finalisation	4 mons
41		**Last stage design finalisation**	80 days
42		Optical absorption requirements of the test r	2 mons
43		Fiber geometry	2 mons
44		Criogenic design completion	3 mons
45			
46		**WP3 Topology identification**	680 days
47		**quantum noise suppression technologies investig**	380 days
48		Analysis of the available and developping techno	7 mons
49		Cross-compatibility of the different technologies	8 mons
50		requirements definition in terms of circulating pow	4 mons
51		Detector topologies modeling	12 mons
52		Detector geometries modeling	8 mons
53		Detector geometry and topology decision process	4 mons
54		refinement of the adopted technologies list	10 mons
55		refinement of the optical layout design	12 mons
56			
57		**WP4 Astrophysics issues**	580 days
58		**White paper on Astrophysics requirements**	240 days
59		Inspirals	12 mons
60		Periodic	12 mons
61		Stochastic	12 mons
62		Multimessengers	12 mons
63		**Astrophysics potentialities**	220 days
64		low frequency signal sources	8 mons
65		medium frequency signal sources	8 mons
66		High frequency signal sources	8 mons
67		Computational power requirements	3 mons
68			
69		**WP5 Management**	832 days
70		**Project startup**	20 days
71		Executive board setup	2 wks
72		Working groups setup	2 wks
73		**Results verification procedures**	700 days
74		Intermediate reporting preparation 1	2 wks
75		short report meeting 1	3 days
76		Annual report preparation 1	3 wks
77		Annual meeting 01	1 wk
78		Intermediate report preparation 2	2 wks
79		Short report meeting 2	3 days
80		Annual report preparation 2	3 wks
81		Annual meeting 2	1 wk
82		Intermediate reporting preparation 3	2 wks
83		Short report meeting 3	3 days
84		Final report preparation	2 mons
85		Conclusive meeting	1 wk
86		**Next steps activities**	27 days
87		Proposal to the institutions preparation	1 mon
88		Conclusive executive board meeting	2 days
89		**Dissemination activities**	700 days
90		Web server setup	1 mon
91		outreaching activities	34 mons



Funding requested from EU (~75%)

	WP1		WP2		WP3		WP4		WP5		
	Qty	Costs k€	Qty	Costs K€	Qty	Costs k€	Qty	Costs k€	Qty	Costs k€	
1 year fellowship	2	100	0	0	2	100	0	0			
2 year fellowship	2	200	0	0	2	200	3	300			
3 year fellowship	0	0	2	300	0	0	0	0			
Total man-years	6		6		6		6				
subcontracting		100									
Activity cost		33		33		33		33		6	
Coordination personnel cost										300	
Secretary									1	200	
Travel costs		50		50		50		50		50	
General meetings										30	
Dissemination activites										10	
Total		483		383		383		383		596	2229
Total incl. 60% overhead											3567

Participating institutions

Participant no.	Participant organization name	Country
1	European Gravitational Observatory	Italy
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

DRAFT costings for Phase II Roadmap – Gravitational Waves working group

Summary of all of the projects' total costs over time, 2008-2018 beginning with the R&D phase

NOTE! Staff costs are NOT included in the investment costs. All costs NON inflation corrected.

	Total costs (kEuro)	FTE
Project 1: bars	1080	56
Project 2: DUAL	19300	284
Project 3: GEO HF	19050	256
Project 4: enhanced LIGO	8475	101
Project 5: adv. LIGO	17486	290
Project 6: Virgo+	23626	464
Project 7: Adv. Virgo	40436	1126
Project 8: Einstein Telescope	380000	736

Questions for the PRC

- Costings –Include personnel and Full Economic Costs?
- Inflation – to be included? At what rate?
- What precisely to present in Amsterdam?
- What happens after the Amsterdam meeting?
- Mechanism for feedback from PRC to the WGs and on what timescale?