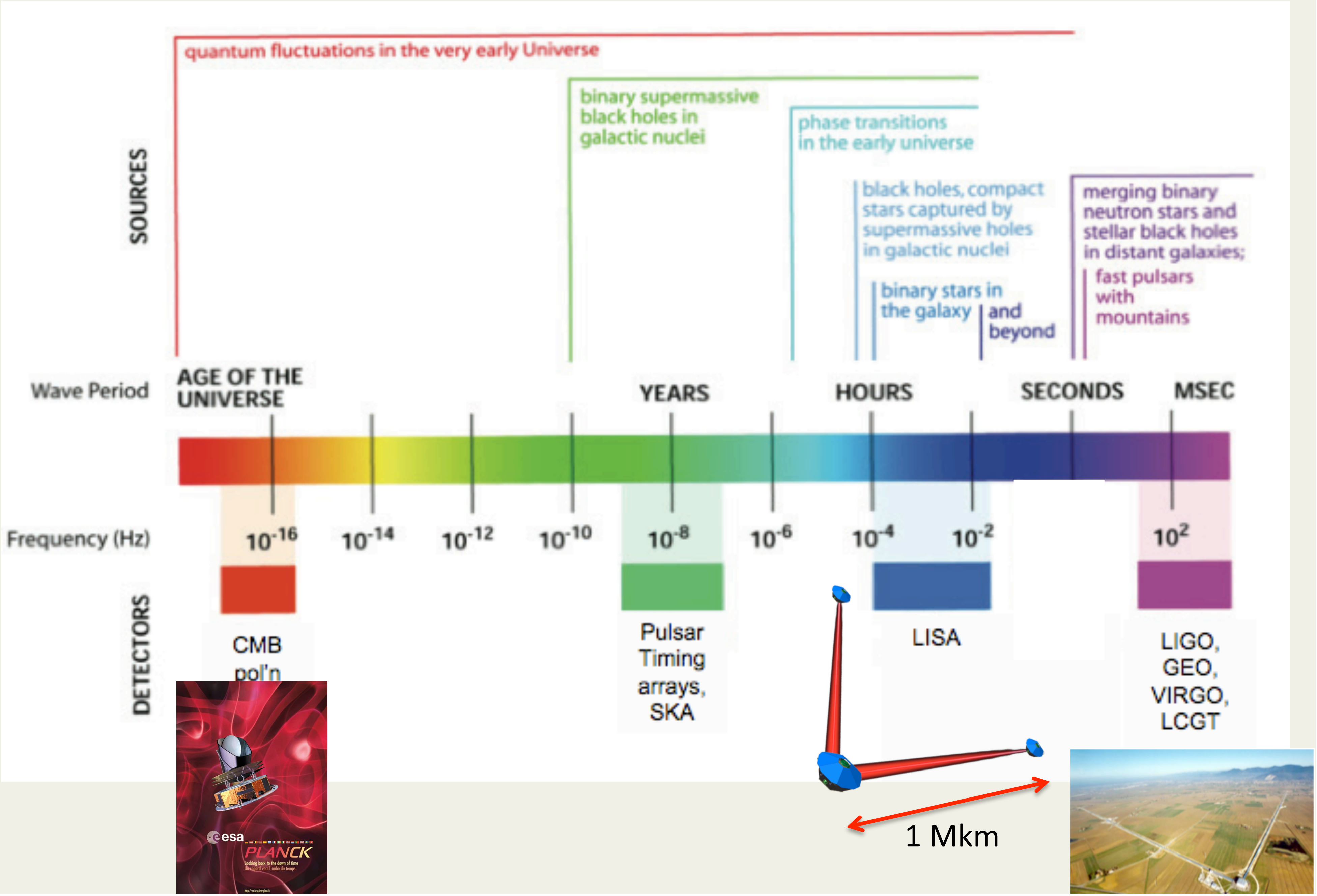
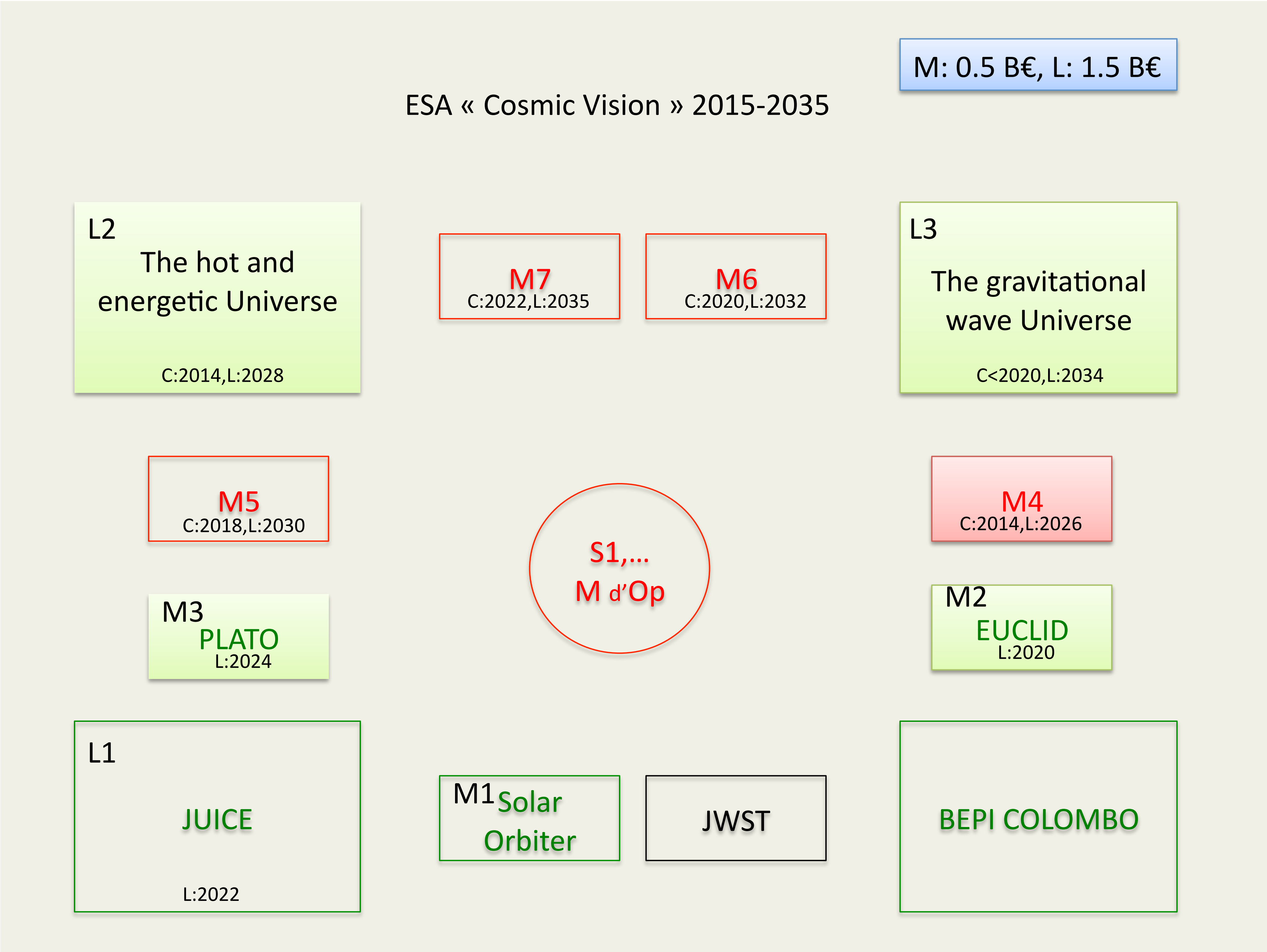
# Data access challenges for the eLISA gravitational space mission

Pierre Binétruy,

APPIC meeting
APC, 9 May 2014

# The frequency spectrum  of gravitational waves




ESA « Cosmic Vision » 2015-2035
M: 0.5 B€, L: 1.5 B€
L2
The hot and energetic Universe
C:2014,L:2028
M7
C:2022,L:2035
M6
C:2020,L:2032
L3
The gravitational wave Universe
C<2020,L:2034
M5
C:2018,L:2030
S1,…
M d'Op
M4
C:2014,L:2026
M3
PLATO
L:2024
M2
EUCLID
L:2020
L1
JUICE
L:2022
M1 Solar Orbiter
JWST
BEPI COLOMBO

# White paper : supported by more than 1200 scientists

# THE GRAVITATIONAL UNIVERSE

A science theme addressed by the *eLISA* mission observing the entire Universe

*The last century has seen enormous progress in our understanding of the Universe. We know the life cycles of stars, the structure of galaxies, the remnants of the big bang, and have a general understanding of how the Universe evolved. We have come remarkably far using electromagnetic radiation as our tool for observing the Universe. However, gravity is the engine behind many of the processes in the Universe, and much of its action is dark. Opening a gravitational window on the Universe will let us go further than any alternative. Gravity has its own messenger: Gravitational waves, ripples in the fabric of spacetime. They travel essentially undisturbed and let us peer deep into the formation of the first seed black holes, exploring redshifts as large as z – 20, prior to the epoch of cosmic re-ionisation. Exquisite and unprecedented measurements of black hole masses and spins will make it possible to trace the history of black holes across all stages of galaxy evolution, and at the same time constrain any deviation from the Kerr metric of General Relativity. eLISA will be the first ever mission to study the entire Universe with gravitational waves. eLISA is an all-sky monitor and will offer a wide view of a dynamic cosmos using gravitational waves as new and unique messengers to unveil The Gravitational Universe. It provides the closest ever view of the early processes at TeV energies, has guaranteed sources in the form of verification binaries in the Milky Way, and can probe the entire Universe, from its smallest scales around singularities and black holes, all the way to cosmological dimensions.*

**Prof. Dr. Karsten Danzmann**
Albert Einstein Institute Hannover

MPI for Gravitational Physics and
Leibniz Universität Hannover
Callinstr. 38
30167 Hannover
Germany

karsten.danzmann@aei.mpg.de

Tel.: +49 511 762 2229
Fax: +49 511 762 2784

Detailed information at
http://elisascience.org/whitepaper

## AUTHORS

Pau Amaro Seoane, Sofiane Aoudia, Gerard Auger, Stanislav Babak, Enrico Barausse, Massimo Bassan, Volker Beckmann, Pierre Binétruy, Johanna Bogenstahl, Camille Bonvin, Daniele Bortoluzzi, Julien Brossard, Iouri Bykov, Chiara Caprini, Antonella Cavalleri, Monica Colpi, Giuseppe Congedo, Karsten Danzmann, Luciano Di Fiore, Marc Diaz Aguilo, Ingo Diepholz, Rita Dolesi, Massimo Dotti, Carlos F. Sopuerta, Luigi Ferraioli, Valerio Ferroni, Noemi Finetti, Ewan Fitzsimons, Jonathan Gair, Domenico Giardini, Ferran Gibert, Catia Grimani, Paul Groot, Hubert Halloin, Gerhard Heinzel, Martin Hewitson, Allan Hornstrup, David Hoyland, Mauro Hueller, Philippe Jetzer, Nikolaos Karnesis, Christian Killow, Andrzej Krolak, Ivan Lloro, Davor Mance, Thomas Marsh, Ignacio Mateos, Lucio Mayer, Joseph Moerschell, Gijs Nelemans, Miquel Nofrarias, Frank Ohme, Michael Perreur-Lloyd, Antoine Petiteau, Eric Plagnol, Edward Porter, Pierre Prat, Jens Reiche, David Robertson, Elena Maria Rossi, Stephan Rosswog, Ashley Ruiter, B.S. Sathyaprakash, Bernard Schutz, Alberto Sesana, Benjamin Sheard, Ruggero Stanga, Tim Sumner, Takamitsu Tanaka, Michael Tröbs, Hai-Bo Tu, Daniele Vetrugno, Stefano Vitale, Marta Volonteri, Gudrun Wanner, Henry Ward, Peter Wass, William Joseph Weber, Peter Zweifel

*Affiliations can be found in a detailed list of authors at http://elisascience.org/authors*

## CONTRIBUTORS

Heather Audley, John Baker, Simon Barke, Matthew Benacquista, Peter L. Bender, Emanuele Berti, Nils Christopher Brause, Sasha Buchman, Jordan Camp, Massimo Cerdonio, Giacomo Ciani, John Conklin, Neil Cornish, Glenn de Vine, Dan DeBra, Marc Dewi Freitag, Germán Fernández Barranco, Filippo Galeazzi, Antonio Garcia, Oliver Gerberding, Lluis Gesa, Felipe Guzman Cervantes, Zoltan Haiman, Craig Hogan, Daniel Holz, C.D. Hoyle, Scott Hughes, Vicky Kalogera, Mukremin Kilic, William Klipstein, Evgenia Kochkina, Natalia Korsakova, Shane Larson, Maike Lieser, Tyson Littenberg, Jeffrey Livas, Piero Madau, Peiman Maghami, Christoph Mahrdt, David McClelland, Kirk McKenzie, Sean McWilliams, Stephen Merkowitz, Cole Miller, Shawn Mitryk, Soumya Mohanty, Anneke Monsky, Guido Mueller, Vitali Müller, Daniele Nicolodi, Samaya Nissanke, Kenji Numata, Markus Otto, E. Sterl Phinney, Scott Pollack, Alix Preston, Thomas Prince, Douglas Richstone, Louis Rubbo, Josep Sanjuan, Stephan Schlamminger, Daniel Schütze, Daniel Shaddock, Sweta Shah, Aaron Spector, Robert Spero, Robin Stebbins, Gunnar Stede, Frank Steier, Ke-Xun Sun, Andrew Sutton, David Tanner, Ira Thorpe, Massimo Tinto, Michele Vallisneri, Vinzenz Wand, Yan Wang, Brent Ware, Yinan Yu, Nicolas Yunes

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## SUPPORTERS

Among the, roughly, 1000 scientific supporters of the Gravitational Universe science theme, are

**Gerardus 't Hooft** *Utrecht University (Netherlands)*, **Barry Barish** *Caltech (United States)*, **Claude Cohen-Tannoudji** *College de France (France)*, **Neil Gehrels** *NASA Goddard Space Flight Center (United States)*, **Gabriela Gonzalez** *LIGO Scientific Collaboration Spokesperson, LSU (United States)*, **Douglas Gough** *Institute of Astronomy, University of Cambridge (United Kingdom)*, **Stephen Hawking** *University of Cambridge, DAMTP (United Kingdom)*, **Steven Kahn** *Stanford University/SLAC National Accelerator Laboratory (United States)*, **Mark Kasevich** *Stanford University, Physics Dept. (United States)*, **Michael Kramer** *Max-Planck-Institut fuer Radioastronomie (Germany)*, **Abraham Loeb** *Harvard University (United States)*, **Piero Madau** *University of California, Santa Cruz (United States)*, **Luciano Maiani** *Università di Roma La Sapienza (Italy)*, **John Mather** *NASA Goddard Space Flight Center (United States)*, **David Merritt** *Rochester Institute of Technology (United States)*, **Viatcheslav Mukhanov** *LMU München (Germany)*, **Giorgio Parisi** *Universita di Roma la Sapienza (Italy)*, **Stuart Shapiro** *University of Illinois at Urbana-Champaign (United States)*, **George Smoot** *Universite Paris Diderot (France)*, **Saul Teukolsky** *Cornell University (United States)*, **Kip Thorne** *California Institute of Technology (United States)*, **Gabriele Veneziano** *Collège de (France)* (France), **Jean-Yves Vinet** *Virgo Collaboration Spokesperson, OCA Nice (France)*, **Rainer Weiss** *MIT (United States)*, **Clifford Will** *University of Florida (United States)*, **Edward Witten** *Institute for Advanced Study, Princeton (United States)*, **Arnold Wolfendale** *Durham University (United Kingdom)*, and **Shing-Tung Yau** *Harvard University (United States)*.

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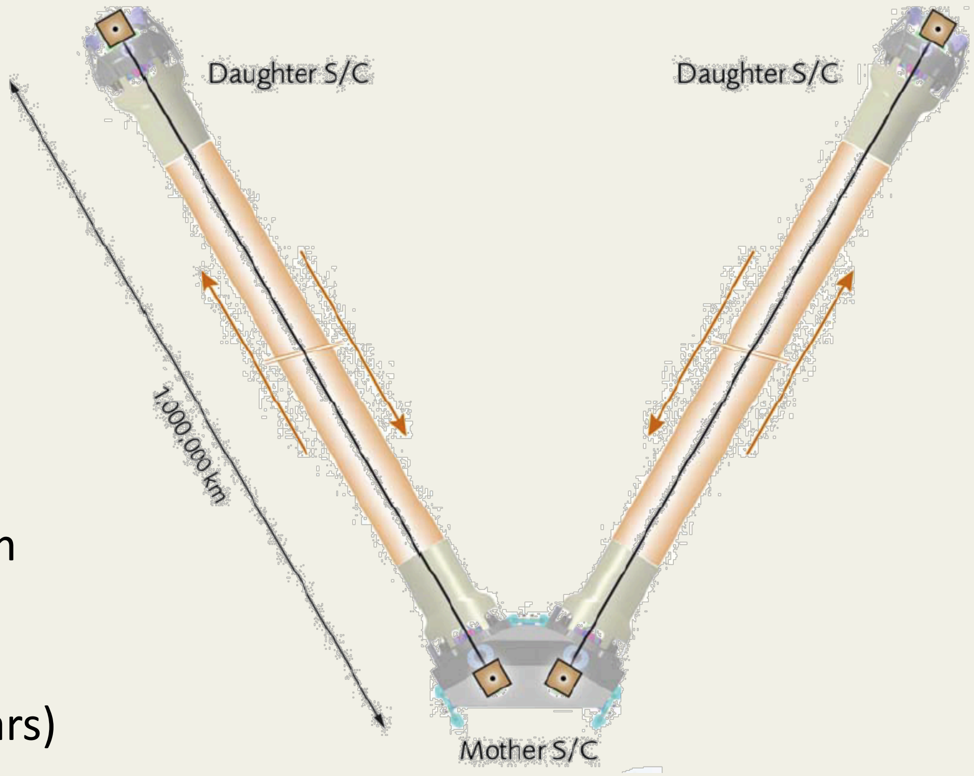
Some principles to redefine the mission LISA ➔ NGO:

- Keep the same principle of measurement and the same payload concept
- Innovate the least possible with respect to LISAPathfinder
- Optimize the orbit and the launcher: remove masse
- Simplify the payload

Solutions

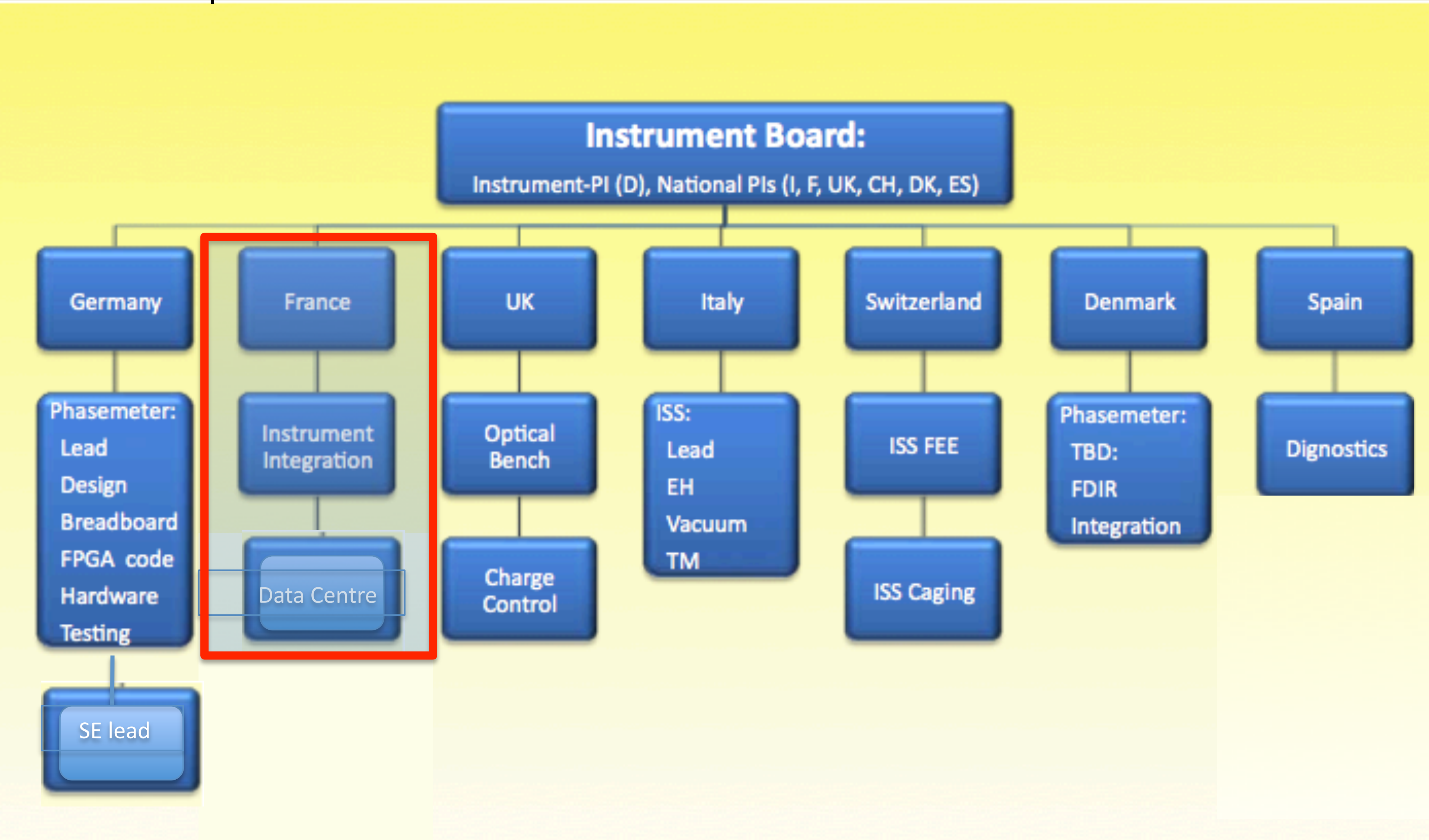



- Remove one of the triangle arms:
  mother-daughter configuration
- Reduce the arm length from 5 Mkm to 1 Mkm
- New orbit closer to Earth (drift away)
- Inertial sensor identical to LISAPathfinder
- Nominal mission length: 2 years (ext. to 5 years)

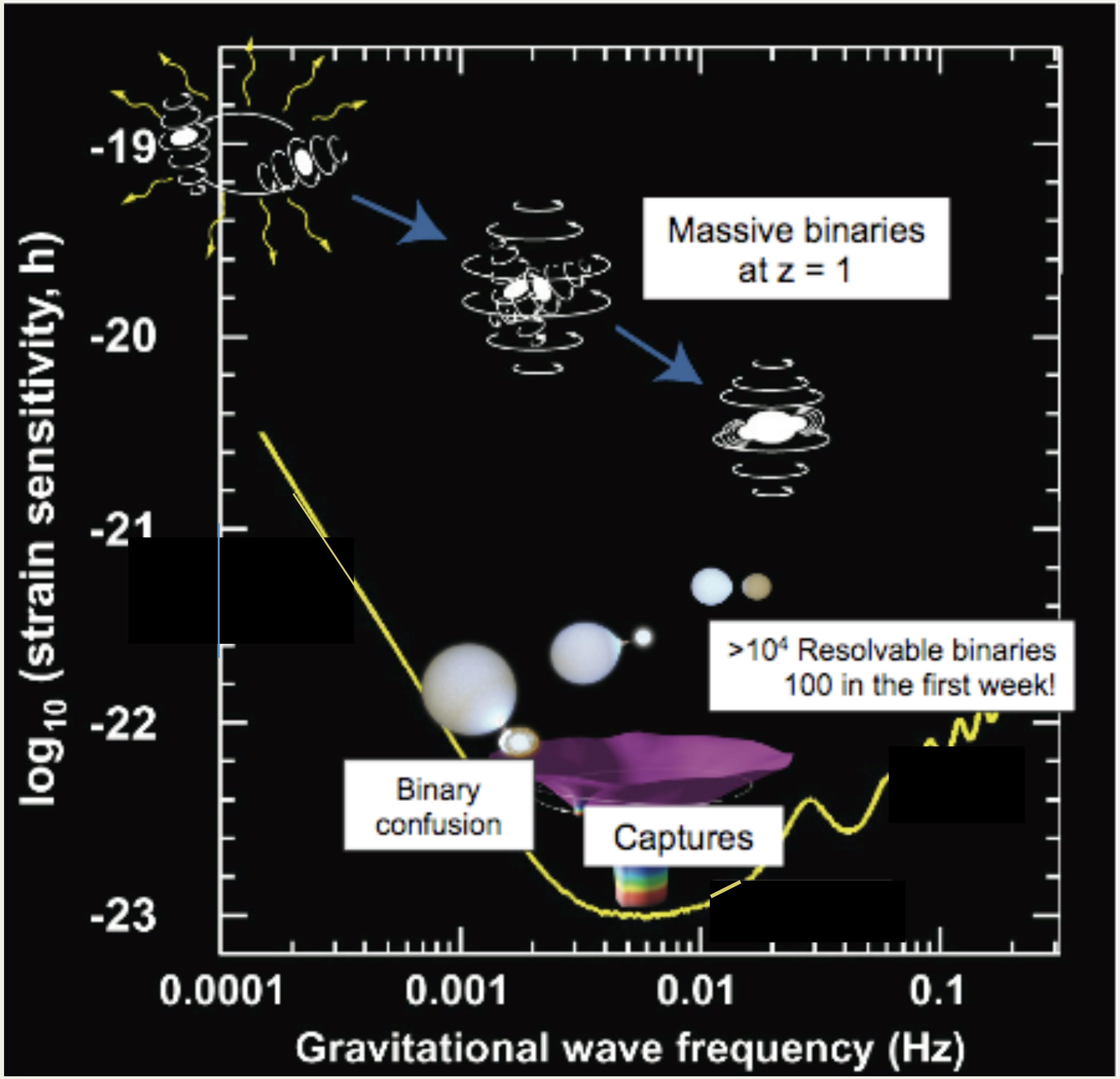
# Roadmap for eLISA

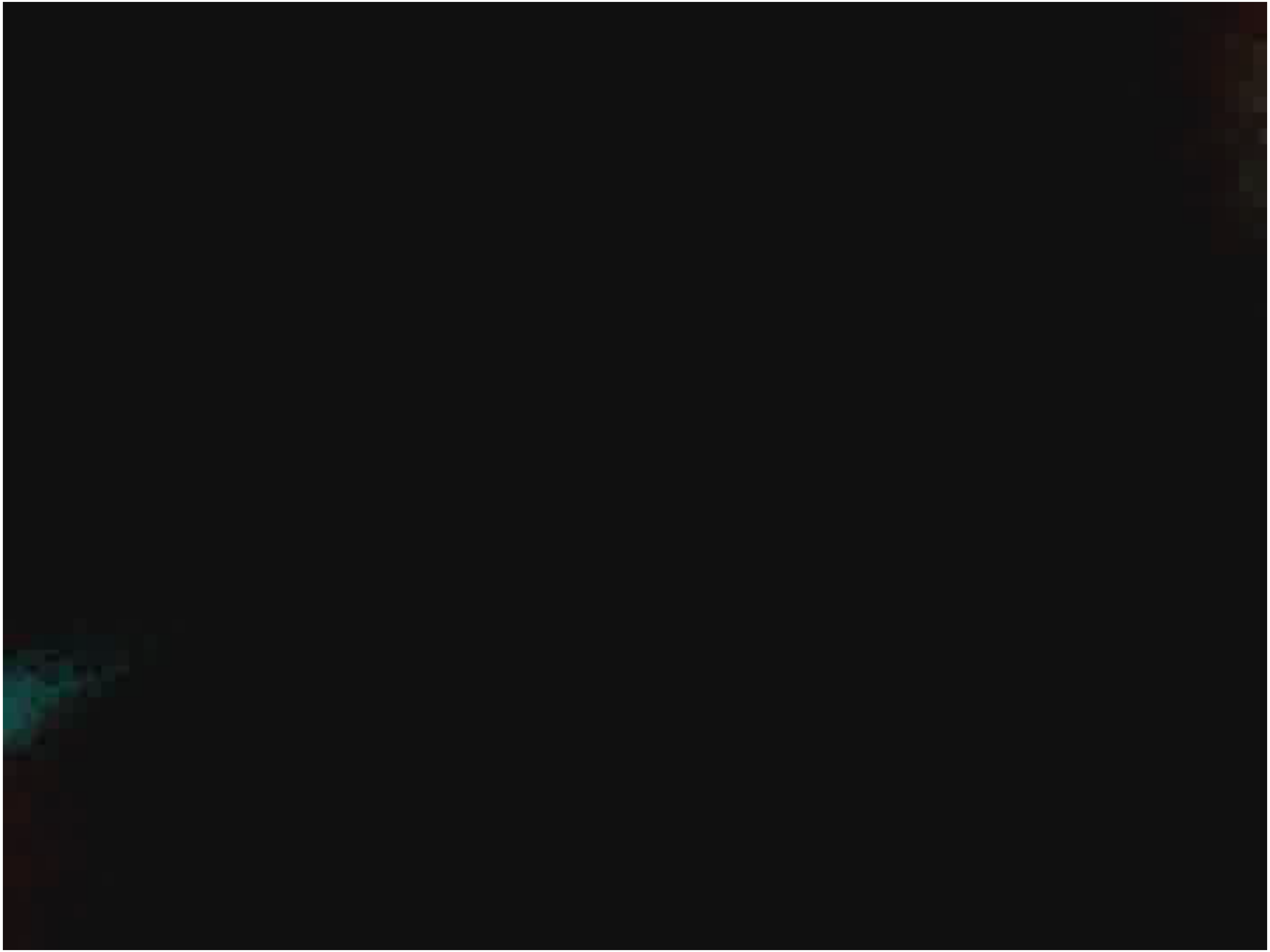
- eLISA Science Theme selected as L3 in 2013
- Technology Roadmap work 2013 – 2015
- Possibly continued Mission Concept Study 2014 – 2015
- Successful LISA Pathfinder flight in 2015
  - Assessment of technology status
  - Possibly additional work, e.g. breadboarding of Payload+ (1 to 4) years
- Selection of Mission Concept in 2015 + (1 to 4)
- Possibly Start EQM of complete Payload 2015 + (2 to 5)
- Start of Industrial Definition Study 2015 + (2 to 5)
- Start of Industrial Implementation 2015 + (6 to 9)
- Launch in 2015 + (15 to 18)

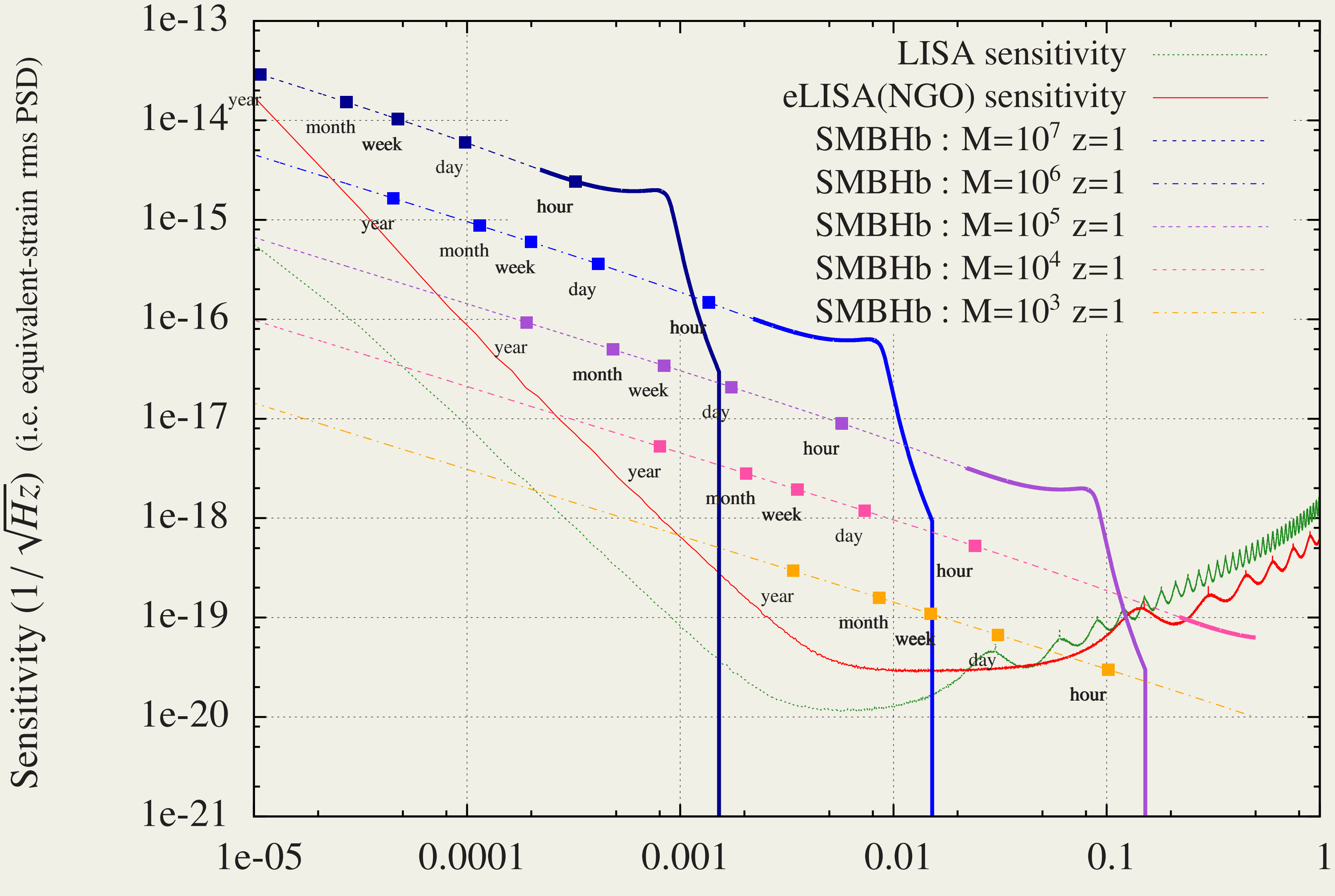
The European consortium for eLISA



The science of eLISA

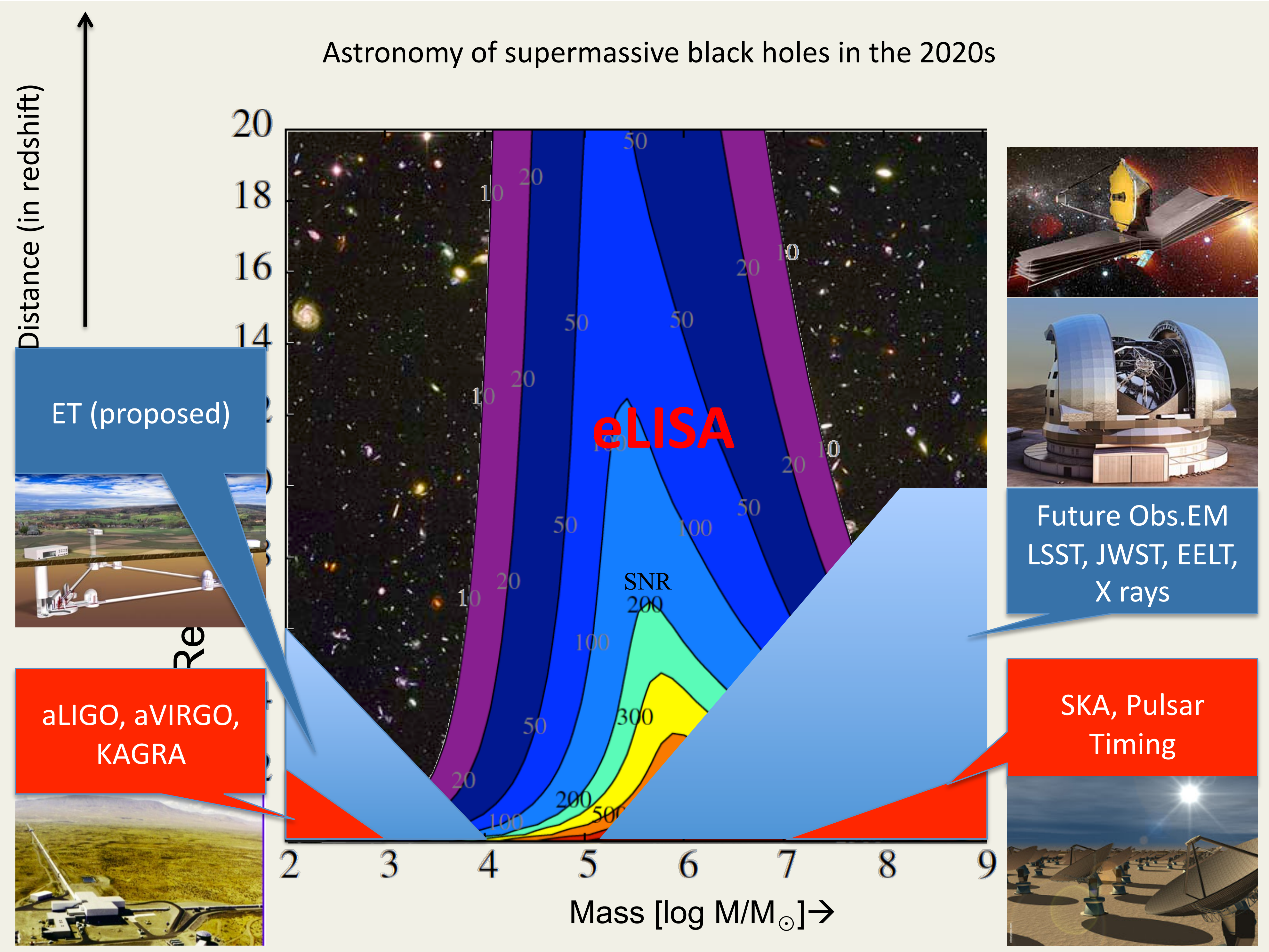






LISA sensitivity
eLISA(NGO) sensitivity
SMBHb : M=10^7 z=1
SMBHb : M=10^6 z=1
SMBHb : M=10^5 z=1
SMBHb : M=10^4 z=1
SMBHb : M=10^3 z=1
Sensitivity (1 / √Hz) (i.e. equivalent-strain rms PSD)
Frequency (Hz)
1e-13
1e-14
1e-15
1e-16
1e-17
1e-18
1e-19
1e-20
1e-21
1e-05
0.0001
0.001
0.01
0.1
1
year
month
week
day
hour


A. Petiteau



Astronomy of supermassive black holes in the 2020s
Distance (in redshift)
eLISA
SNR
ET (proposed)
aLIGO, aVIRGO, KAGRA
Future Obs.EM LSST, JWST, EELT, X rays
SKA, Pulsar Timing
Mass [log M/M$_\odot$]→

Test of gravity in strong regime

Plunge Merger Ringdown

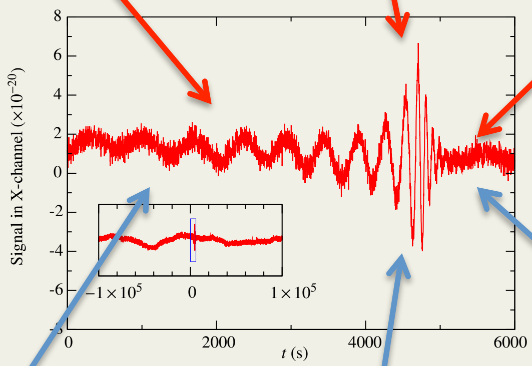



Figure 2.23.: *Gravitational wave signal for the final few orbits, plunge, merger and ringdown of a coalescing binary. The total mass of system* $M(1+z) = 2\times10^6\,M_\odot$, *mass ratio* $m_1/m_2 = 2$, *spin magnitudes* $a_1 = 0.6$ $a_2 = 0.55$, *misalignment between spins and orbital angular momentum few degrees, the distance to the source* $z = 5$. *The inset shows the signal on a larger data span.*

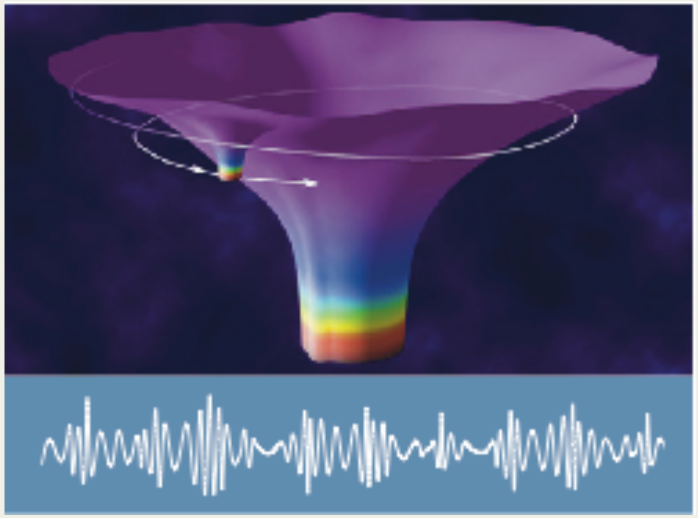
RG: approximation postNewtonienne

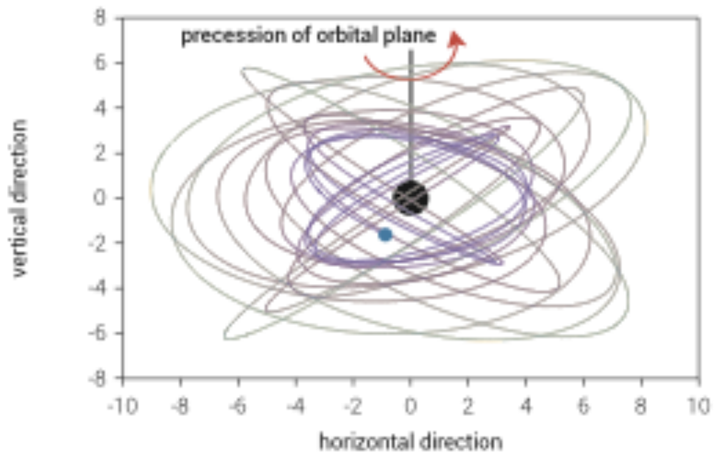
Théorie de perturbation

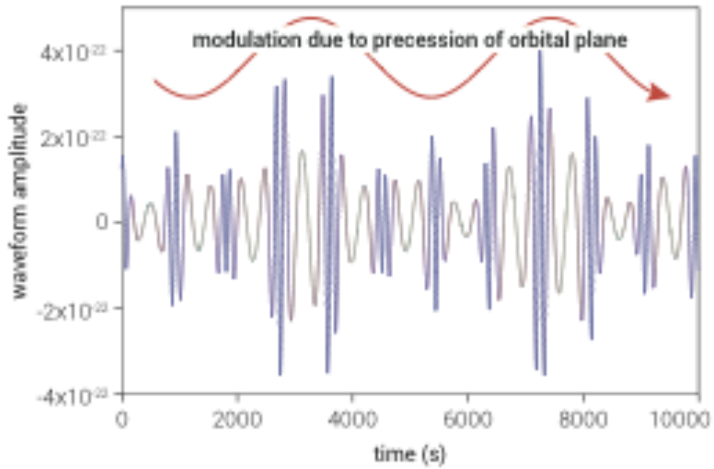
RG: relativité numerique

$L_{GW} = 10^{23}\ L_\odot$

## EMRI (Extreme Mass Ratio Inspiral)



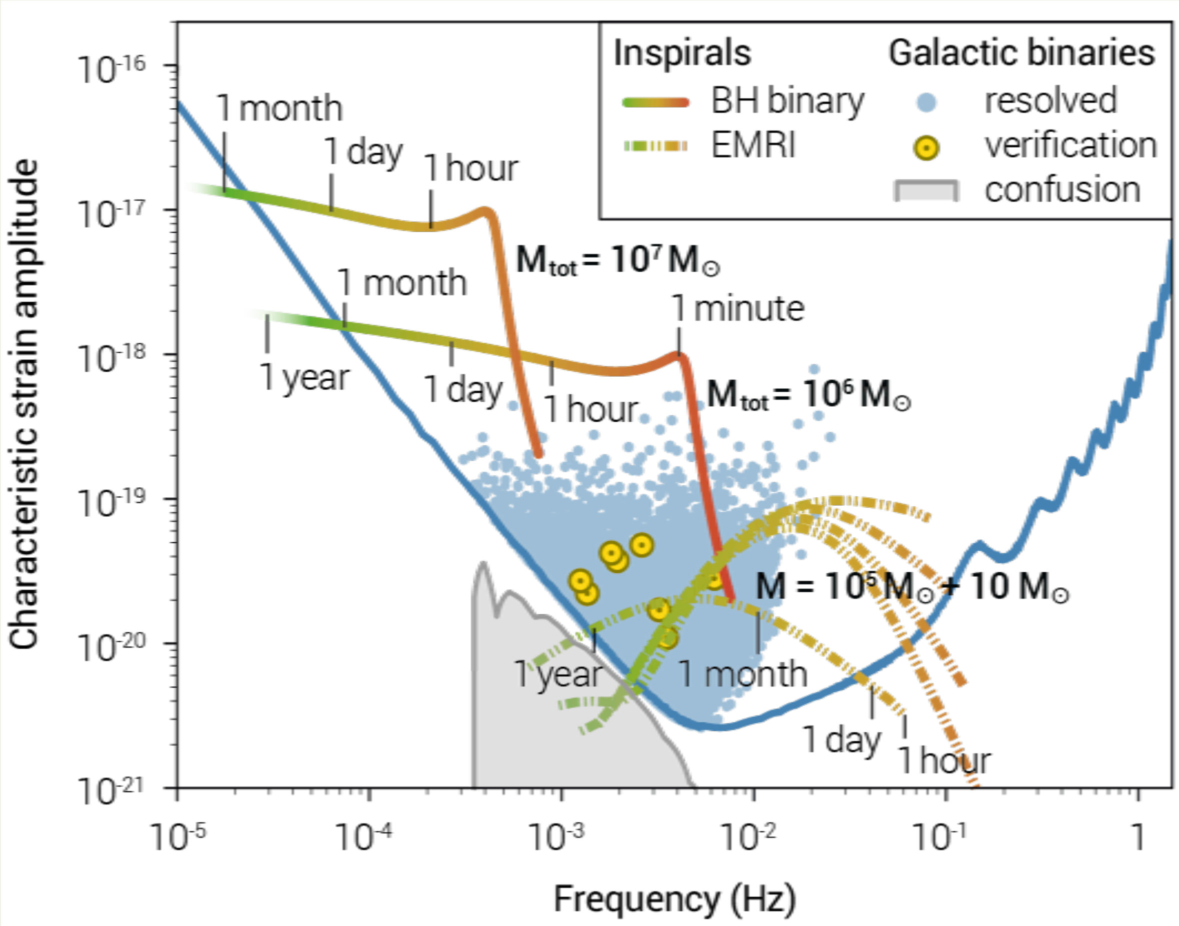



Gravitational waves produced by massive objects (stars or black holes of mass10 to 100 $M_{\odot}$) falling into the horizon of a supermassive black hole.

Allows to identify in a unique way the geometry of space-time close to a black hole (the object cycles some $10^5$ times before plunging into the horizon)

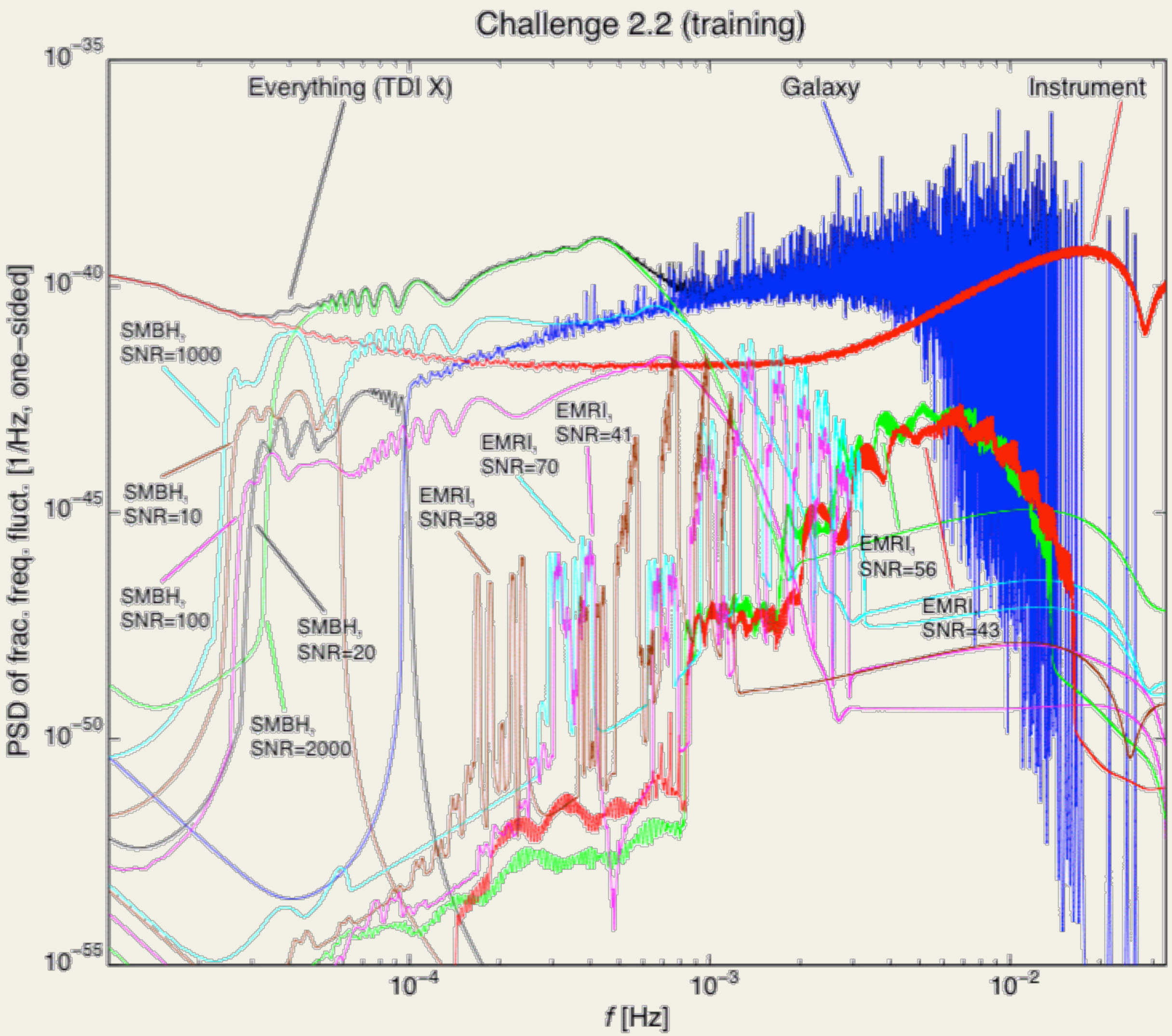
Data analysis




Challenge: signals from the whole Universe all with a latge S/N ratio.
How to separate them?

(≠ ground interferometers)

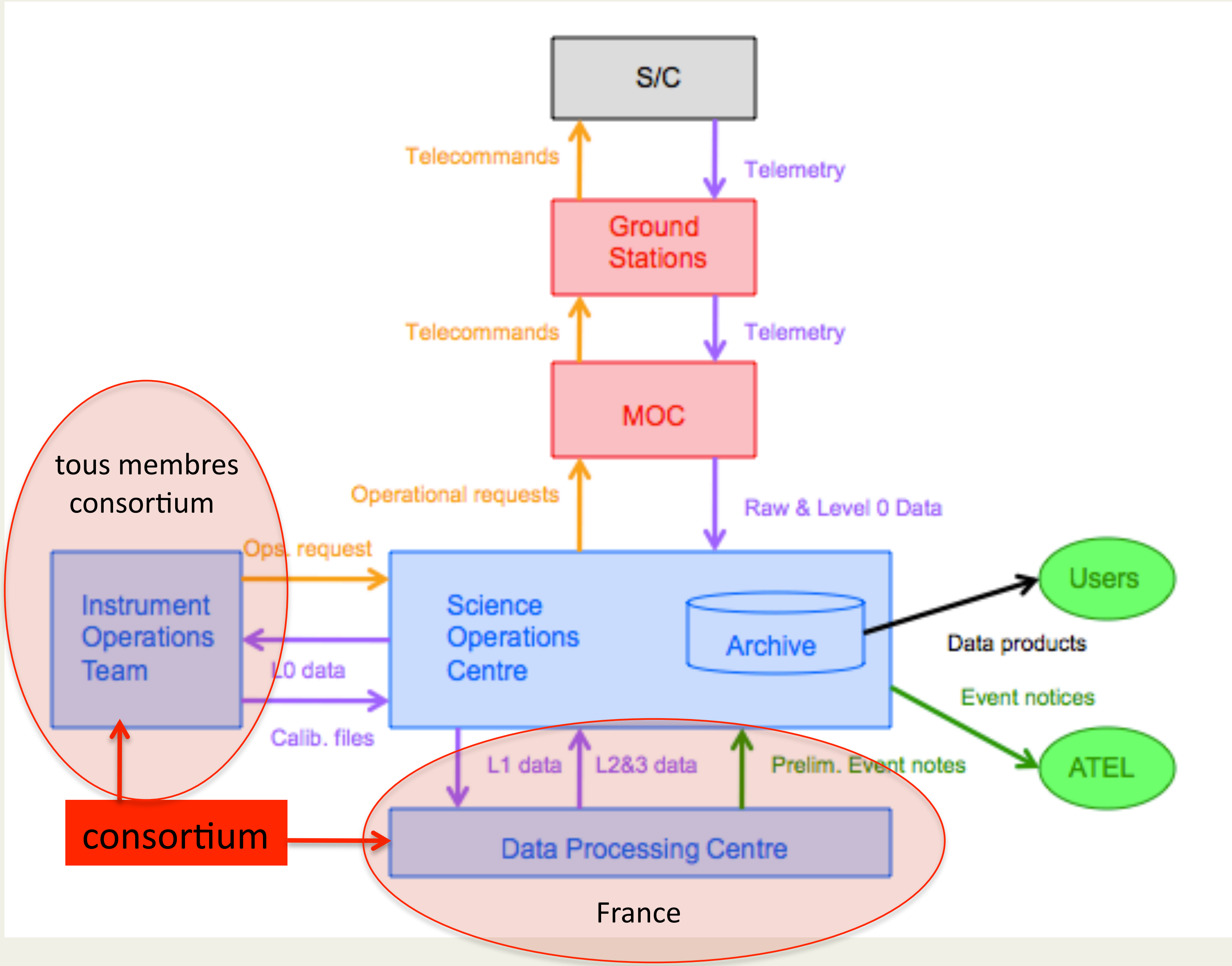
important progress of the analysis methods these last years
thanks to the Mock LISA Data Challenge




- 4 supermassive black holes
- 5 EMRI
- 26.1 million galactic binaries
- instrumental noise

Data processing

Data policy: all data publicly released



Centre François Arago (APC): external data center for the LISAPathfinder mission (2015-2016)
foreseen data processing center for eLISA

François Arago Centre (FACe)

LISAPathfinder exercise at FACe

Capgemini
CONSULTING.TECHNOLOGY.OUTSOURCING

cnes

# eLISA Phase 0

People matter, results count.

The purpose of the study:

Following theAPC study of a DPC for the L1 proposal, it was decided to request CNES to perform a "Phase 0" study to consolidate the evaluation of human resources and of the cost of the infrastructure.

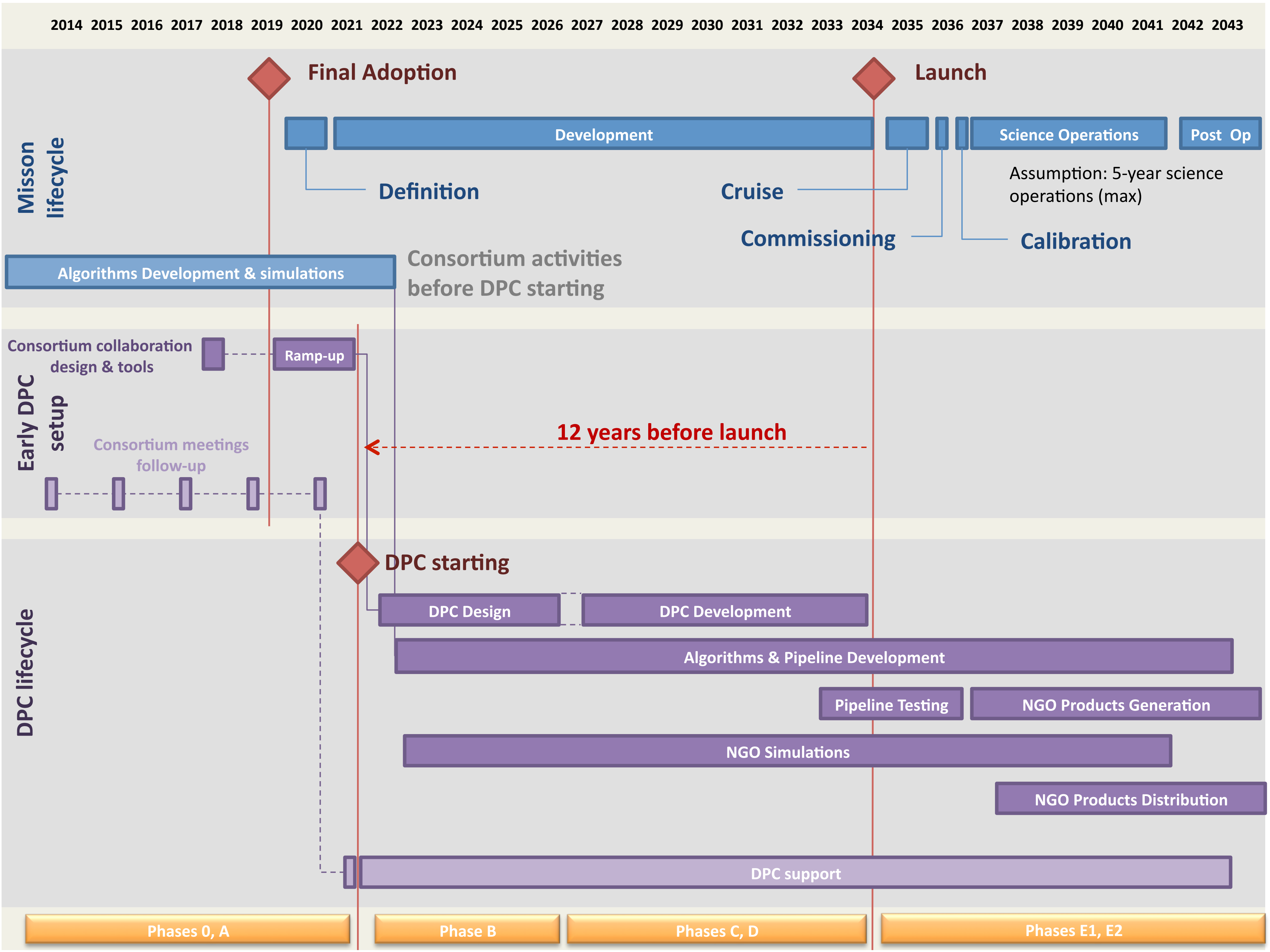
The aim was to evaluate costs relative to the French contribution and the fraction of this that the CNES would cover.

As the eLISA DPC was the first one to address the problem of data analysis of a GW mission in space, the phase 0 was also the occasion to see what sort of innovative solutions could be envisioned.

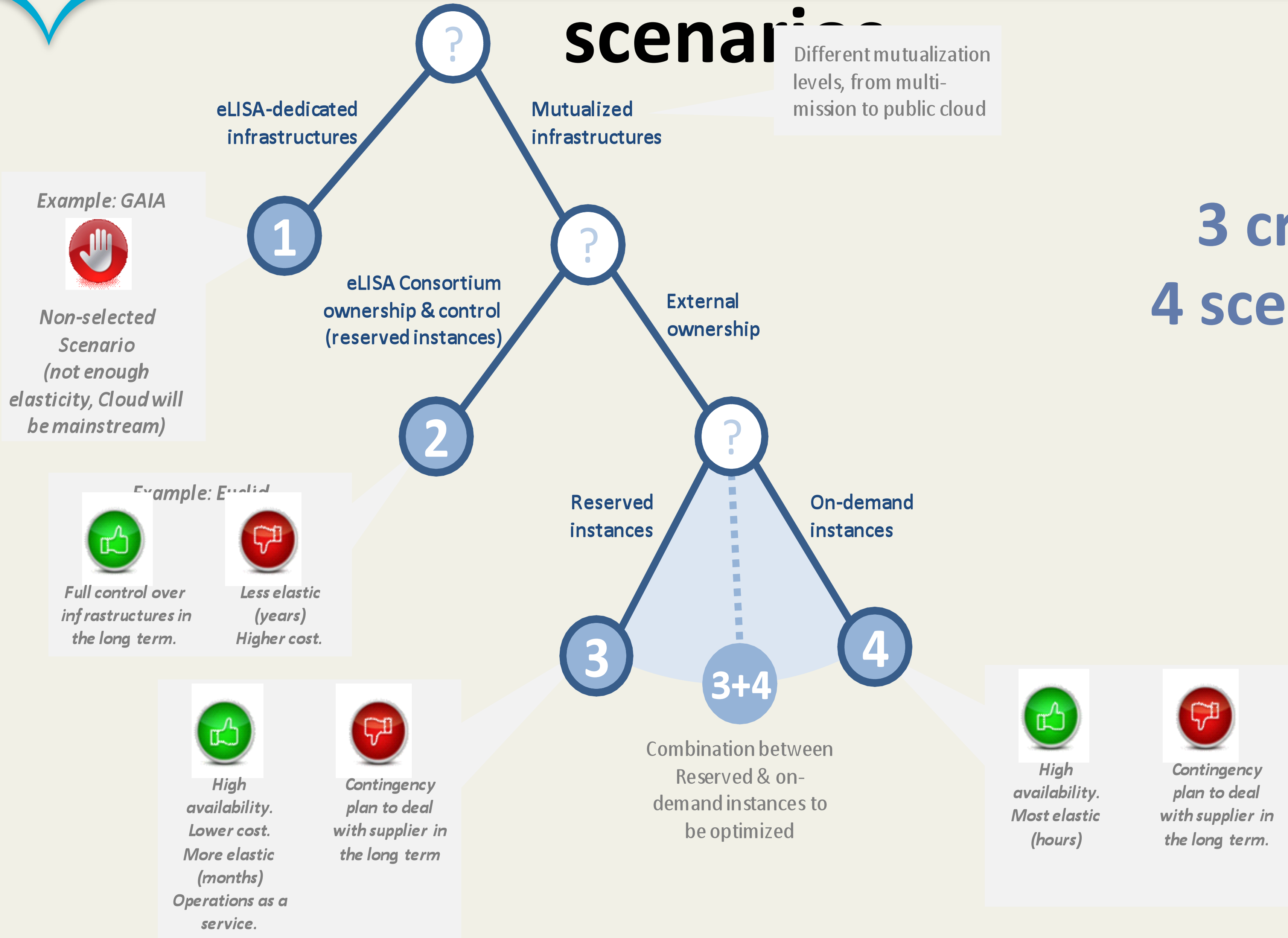
# The Main Outcomes of the Study

The study has identified a number of items:

- The eLISA DPC will be the first one of its kind and certain risks/issues can be identified:
  - The uncertainty in the number of sources which will be detected,
  - The CPU power necessary for specific events, e.g coalescences of MBHB,
  - The relation between the SOC/IOTs and the DPC, particularly in relation to data quality.
  - The assumed launch date (2034) and the development of the DPC up to the launch.
- The evaluation was based on a 2034 launch and 5 year mission + 2 years Post-Op.
- After evaluation, the amount of storage was not considered to be a driver,
- The need for "software assistance" to the pipeline consortium programmers was identified.
- The MLDCs were considered as a valuable tool to define the requirements of the DPC, particularly up to mission selection.
- A development platform (software, input/output conventions, databases, version control,…) should be defined/adopted by the consortium and tested during the upcoming MeLDCs
- The study suggests that the period up to mission selection should be used to define an "Early DPC Setup". It recommends that CNES assists the consortium in this period.


2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037 2038 2039 2040 2041 2042 2043
Final Adoption
Launch
Misson lifecycle
Development
Science Operations
Post Op
Definition
Cruise
Assumption: 5-year science operations (max)
Commissioning
Calibration
Algorithms Development & simulations
Consortium activities before DPC starting
Early DPC setup
Consortium collaboration design & tools
Ramp-up
12 years before launch
Consortium meetings follow-up
DPC lifecycle
DPC starting
DPC Design
DPC Development
Algorithms & Pipeline Development
Pipeline Testing
NGO Products Generation
NGO Simulations
NGO Products Distribution
DPC support
Phases 0, A
Phase B
Phases C, D
Phases E1, E2

# Physical Infrastructures criteria & scenarios




## 3 criteria,
## 4 scenarios

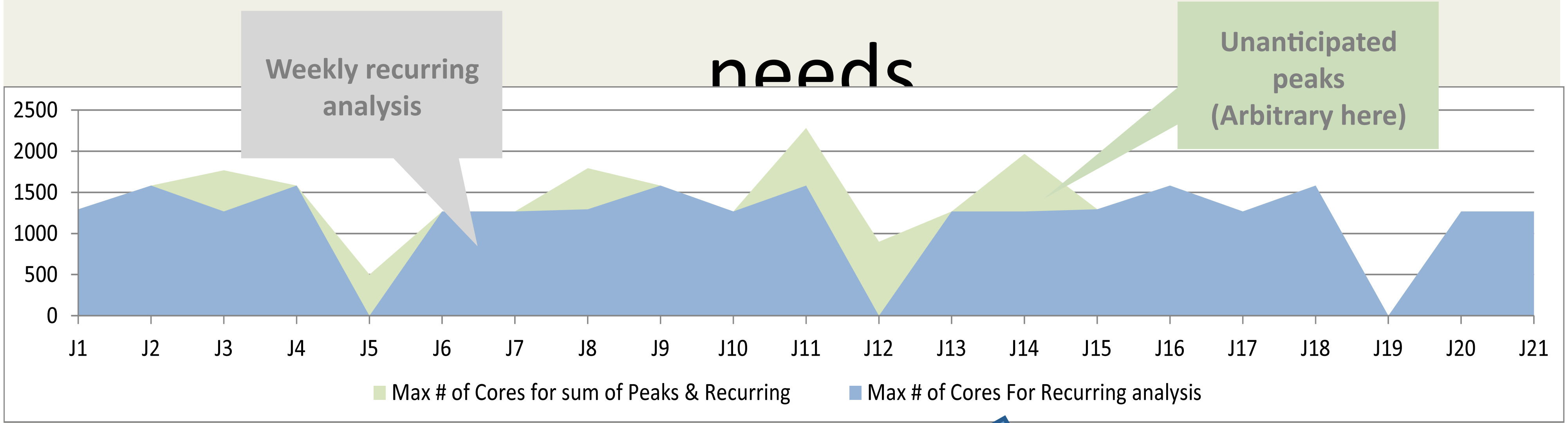
§9.1

# Physical Infrastructures scenarios: Key characteristics

Frontier may depends on scenario & technology.
Example: hadoop as-a-service could be in « OS » layer

| | Scenario 1 eLISA-dedicated infrastructures | Scenario 2 Mutualized infrastructures, eLISA consortium ownership & control | Scenario 3 Cloud infrastructures, Reserved instances | Scenario 4 Cloud infrastructures, On-demand instances |
|---|---|---|---|---|
| Pipelines & Algorithms | Designed, Owned & Operated by NGO Consortium | | | |
| NGO Reference Platform (Software) | Designed, Owned & Operated by NGO Consortium | Designed, Owned and mostly Operated by NGO Consortium. Low-level layers could be operated by key partners or third-party | | |
| Operating System (OS) | Controlled & Operated by NGO Consortium | Controlled & Operated by NGO Consortium or key partners (eg: IN2P3, helix nebula) | Controlled & Operated by third-party | |
| Hardware | | | | |

# Simulated use case of infrastructure needs

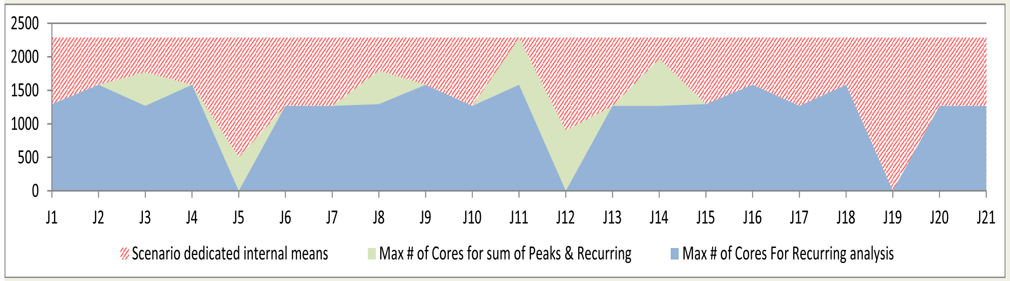


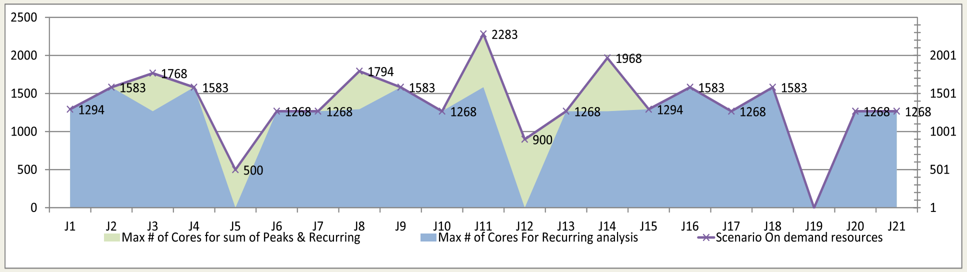

**Scenarios 1, 2 and 3**

**Dedicated or Reserved infrastructures**

**Scenario 4**

**Purely on-demand infrastructures**




- These scenarios are characterized by an initial investment equals to maximum needs to be sure to be able to cover resource needs

- This scenario maximizes resource allocation by providing on-demand hosting according to on-the-fly needs. It allows managing resource needs, without facing any initial investment: resource allocation depends upon the instantaneous needs of the resources

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# Cost and Human ressources

| | Items | Actor | 2014 to 2018 (per year) | 2018 to 2020 (per year) | 2020 to 2028 (per year) | 2028 to 2034 (per year) | 2034 to 2036 (per year) | 2036 to 2041 (per year) |
|---|---|---|---|---|---|---|---|---|
| | | | *Phase 0, A* | | *Phases B, C* | *Phases C, D* | *Phase E1, E2* | |
| Human Resources (FTE) | Governance : DPC Manager | APC | 0,25 | 0,25 | 1 | 1 | 1 | 1 |
| | Governance : DPC Scientist | APC | 0,25 | 0,25 | 1 | 1 | 1 | 1 |
| | Governance: DPC System Team leader | CNES | 0,05 | 0,25 | 1 | 1 | 1 | 1 |
| | Science Operations | APC | 1 | 0 | 0 | 1 | 2 | 2 |
| | L2 & Simulation IT Support | CNES | 0,05 | 0,5 | 1 | 2,5 | 2 | 1 |
| | Reference Platform Development & Operations (System Team) | CNES | 0.5 | 0,5 | 2,5 | 3 | 2 | 2 |
| | Total FTE (per year) | | 2.1 | 1,75 | 6,5 | 9,5 | 9 | 8 |
| | Total man.year | | 2,6 | 3,5 | 52 | 57 | 18 | 40 |

Early DPC

## Why start so early?

- allow as soon as possible the community to develop code in a coordinated way: this is very important if one has to release the data publicly.
- coordinate with the ground interferometers
- the data will address a large community (astrophysicists) which is not used to this kind of data: provide simulated data and associated software to get acquainted with such data.
- because this is a discovery mission, the development of code will not stop with the launch: conceive the centre and its development platform in way that allows flexibility and adapt to new discoveries or new theories; better start early to benefit evolution of thinking in coming years.

# Website eLISA

https://www.elisascience.org/