LISA in 2014 and beyond!

22 years after the first LISA proposal in 1992

Karsten Danzmann

Albert Einstein Institute Hannover

10th International LISA Symposium

18 – 23 May 2014, Gainesville, FL, USA

The Gravitational Universe

Selected as ESA L3 Science Theme!

We finally have an approved slot in the ESA program!

We even have a launch date! 2034!

LISA Pathfinder

- Launch date has now been stable at July 2015!

LISA and LISA PATHFINDER

at the

5th International LISA Symposium

11-16 July 2004, ESTEC, Noordwijk, NL

Karsten Danzmann

Max Planck Institute for Gravitational Physics (Albert Einstein Institute) and University Hannover

on behalf of the LISA Science Team

LISA in 2004: Getting Real!

- **LISA Mission Formulation Phase beginning Fall 2004**
- **ESA Contractor selected**
- **Joint NASA/ESA Management Structure in place**
- **Joint NASA/ESA Integrated Technical Teams (ITTs) in place**
  - Interferometry Measurement System (IMS)
  - Disturbance Reduction system (DRS)
  - Constellation
- **LISA Pathfinder (LPF) Technology Mission approved by ESA SPC in November 2003**
- **LPF Mission Industrial Contract in place**
- **NASA DRS and ESA LTP P/Ls on track for launch 2008**

ESA Portal - Critical decisions on Cosmic Vision - Microsoft Internet Explorer

File Modifica Visualizza Preferiti Strumenti ?

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Indirizzo http://www.esa.int/export/esaCP/SEMFVUWLDMD_index_0.html

esa News

European Space Agency

Critical decisions on Cosmic Vision

7 November 2003

ESA PR 75-2003. At its 105th meeting, on 5/6 November, ESA's Science Programme Committee (SPC) made important decisions concerning the Cosmic Vision programme. Due to the current financial exigencies and an outlook with no budget increase or other relief, the SPC was forced to cancel the Eddington mission and rescope the BepiColombo mission.

Eddington had two aims, both remarkable and very pertinent to front-line astronomical interests. The first was to look for Earth-like planets outside our solar system - one of the key goals in the search to understand how life came to be, how it is that we live where we do in the universe and whether there are other potential life-supporting environments 'out there'. At the same time it was going to follow the path that the ESA-NASA mission SOHO had taken with the Sun of using astroseismology to look 'inside' stars. In the longer term, the loss of this one mission will not stop ESA and the scientific community pursuing the grand quests to which it would have contributed.

The loss of the BepiColombo lander is also hard to take scientifically. ESA, in conjunction with the Japanese space agency, JAXA, will still put two orbiters around Mercury but the 'ground truth' provided by the lander is a big loss. However, to land on a planet so near the Sun is no small matter and was a bridge too far in present circumstances, and this chance for Europe to be first has probably been lost.

The origins of the problems were recognised at the ESA Council meeting held in June. Several sudden demands on finance occurred in the spring, the most obvious and public being the unforeseen Ariane 5 grounding in January, delaying the launches of Rosetta and Smart-1. A temporary loan of EUR 100 million was granted, but must be paid back out of present resources by the end of 2006.

Related links
- ESA Science
- Eddington overview
- Bepicolombo overview
- LISA overview

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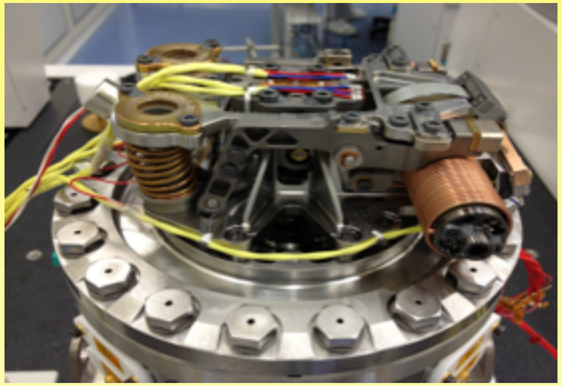
ESA's SPC was therefore caught in a vice. Immediate mission starts had to be severely limited and the overall envelope of the programme

A long and painful discussion during the SPC meeting resulted in the conclusion that only one new mission can be started at this time, namely LISA Pathfinder, the technical precursor to the world's first gravitational wave astronomical observatory, LISA. The LISA mission itself (to be carried out in cooperation with the United States) is scheduled for launch in 2012.

has to adapt constantly to the available funding as well as respond to the expectations of the scientific community, and to technological developments. Within these boundaries, the decisions made by the SPC try to maximise the outcome of Cosmic Vision across disciplines, keeping it challenging and at the same time affordable. Nonetheless, there are many European scientists with ambitions that exceed the programme's ability to respond.

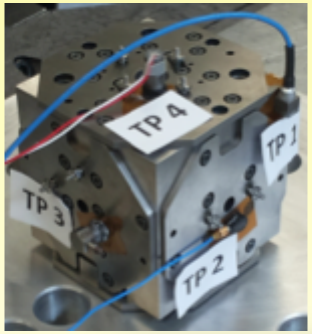
There were Problems to be solved

- But not on the new and challenging items....



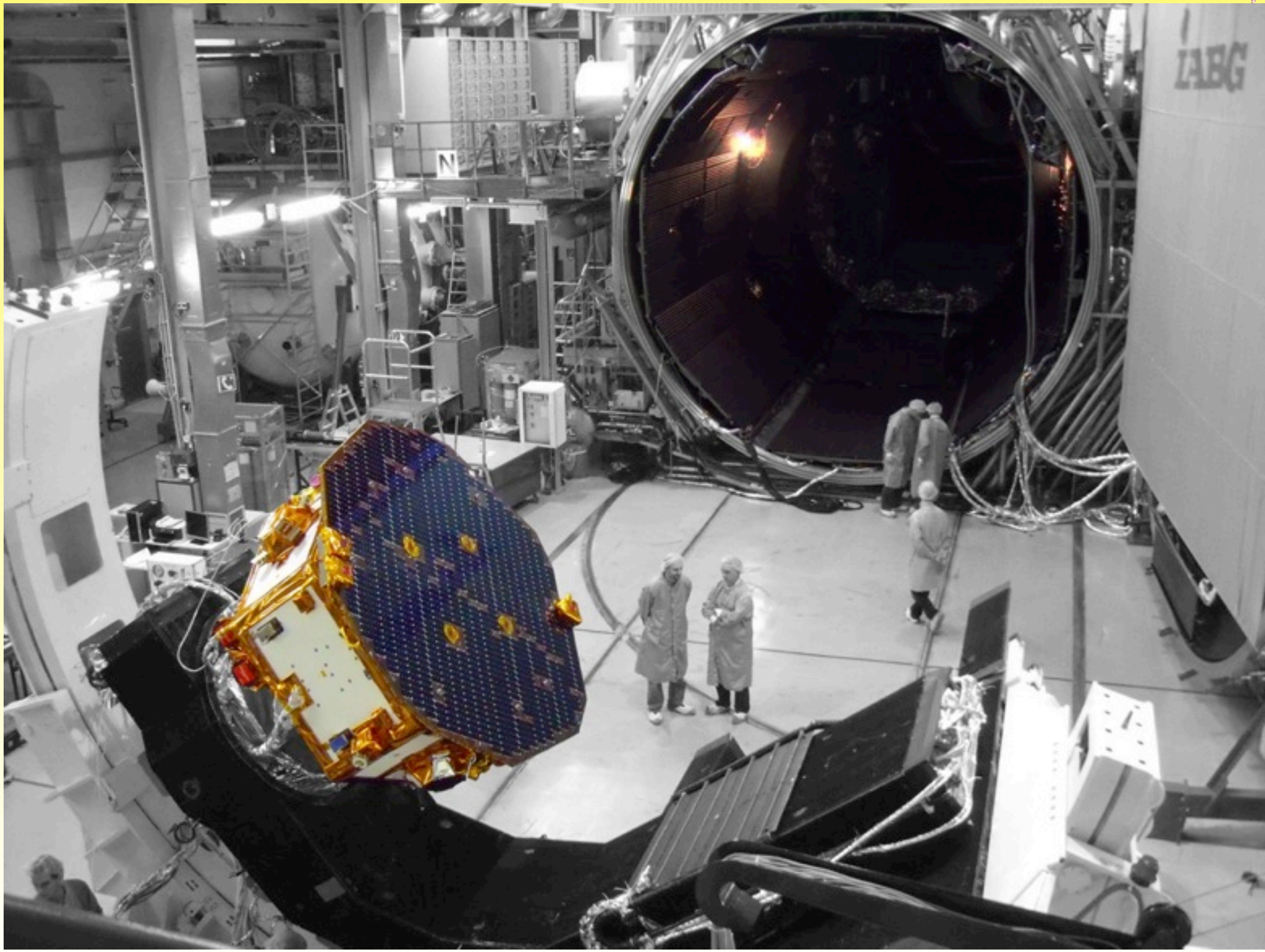
- The motor was wrong on the caging
  – Flight models of new design delivered in April 2013

- The brazing was wrong on the electrode housing
  – New assembly technique passed Qualification review on August 28, 2013 FMs delivered in November 2013



- We needed new µ-Newton thrusters
  – Cold gas thrusters and electronics can be used identical to Gaia, to be delivered in fall of 2014

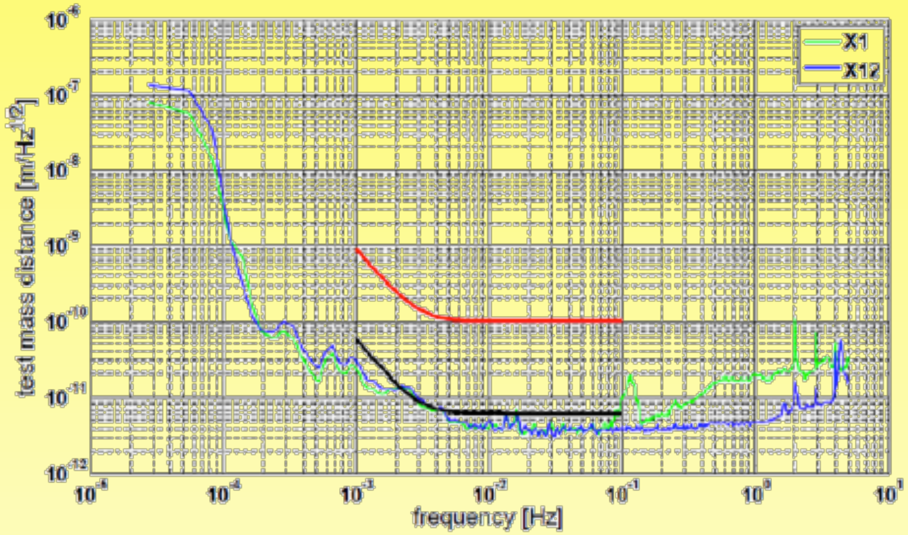
Optical Metrology Ground Testing



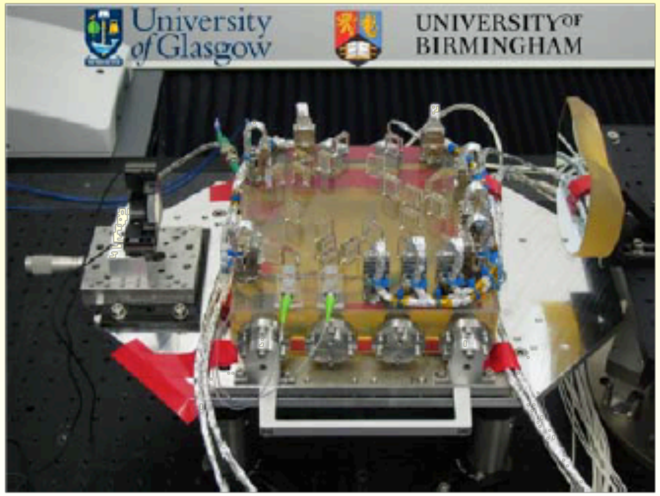
Superb Optical Performance on Ground

Optical metrology performance at hot/cold confirmed.

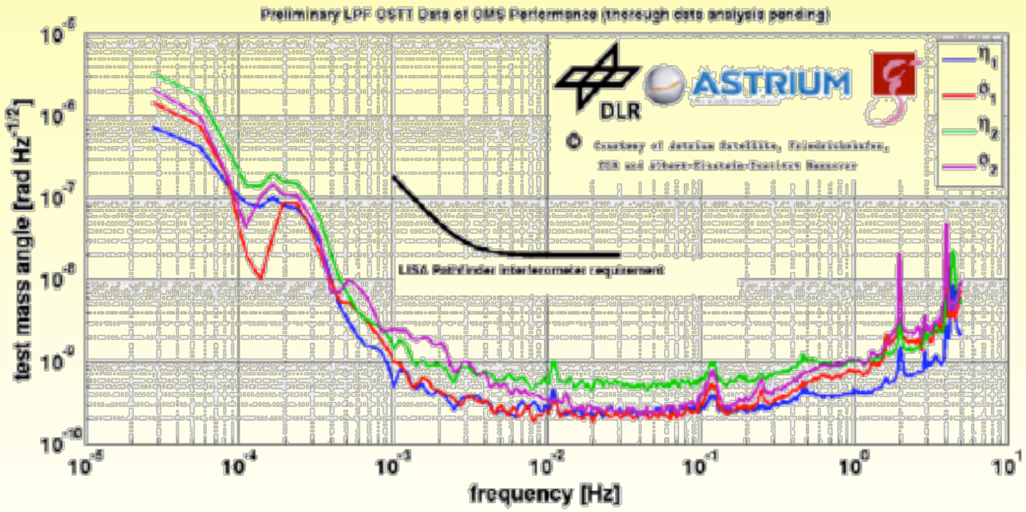
- Test mirror translation noise <6 pm/sqrtHz
- Test mirror rotational noise <1 nrad/sqrtHz



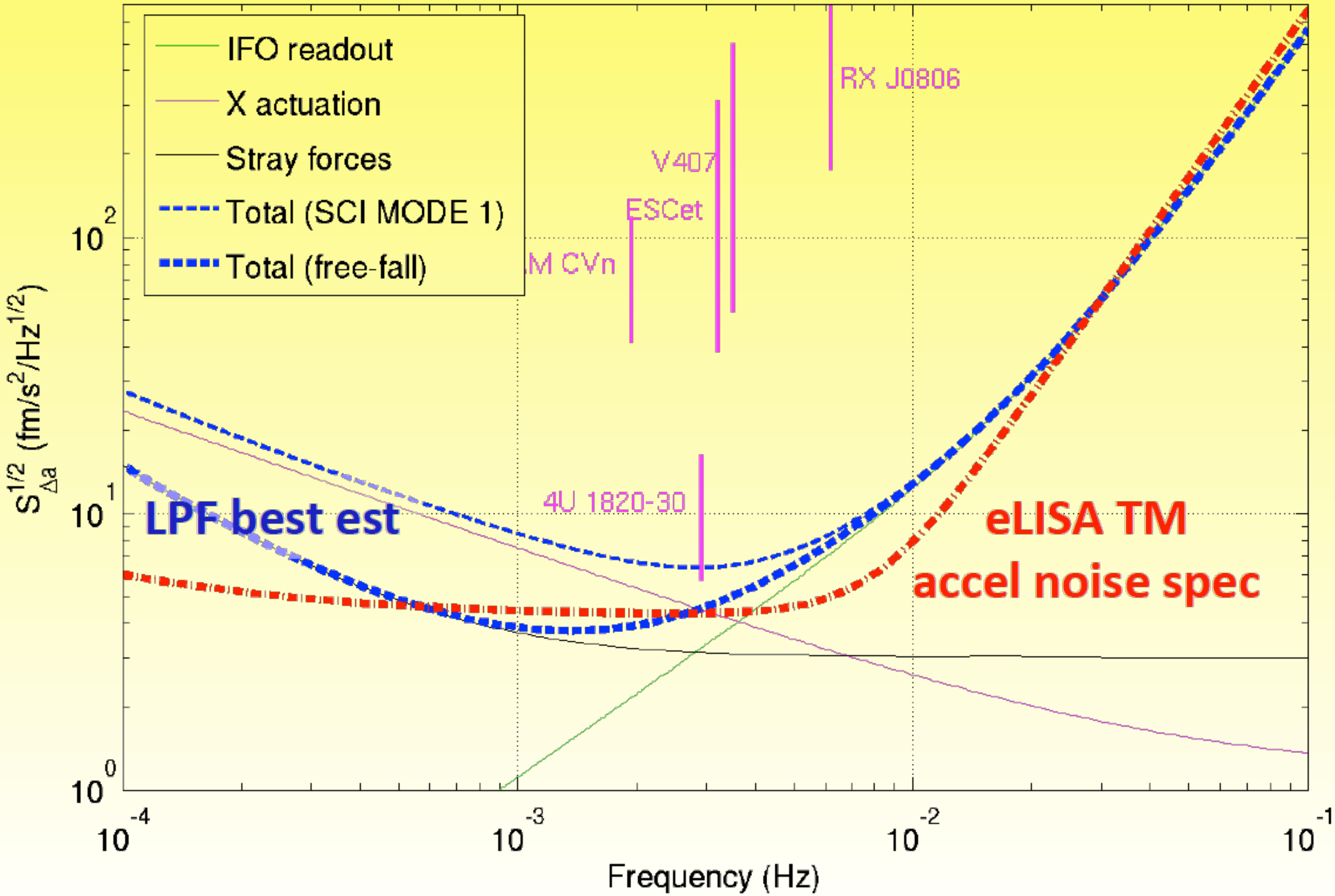
In-orbit performance expected to be better than in test chamber.



13th Mar

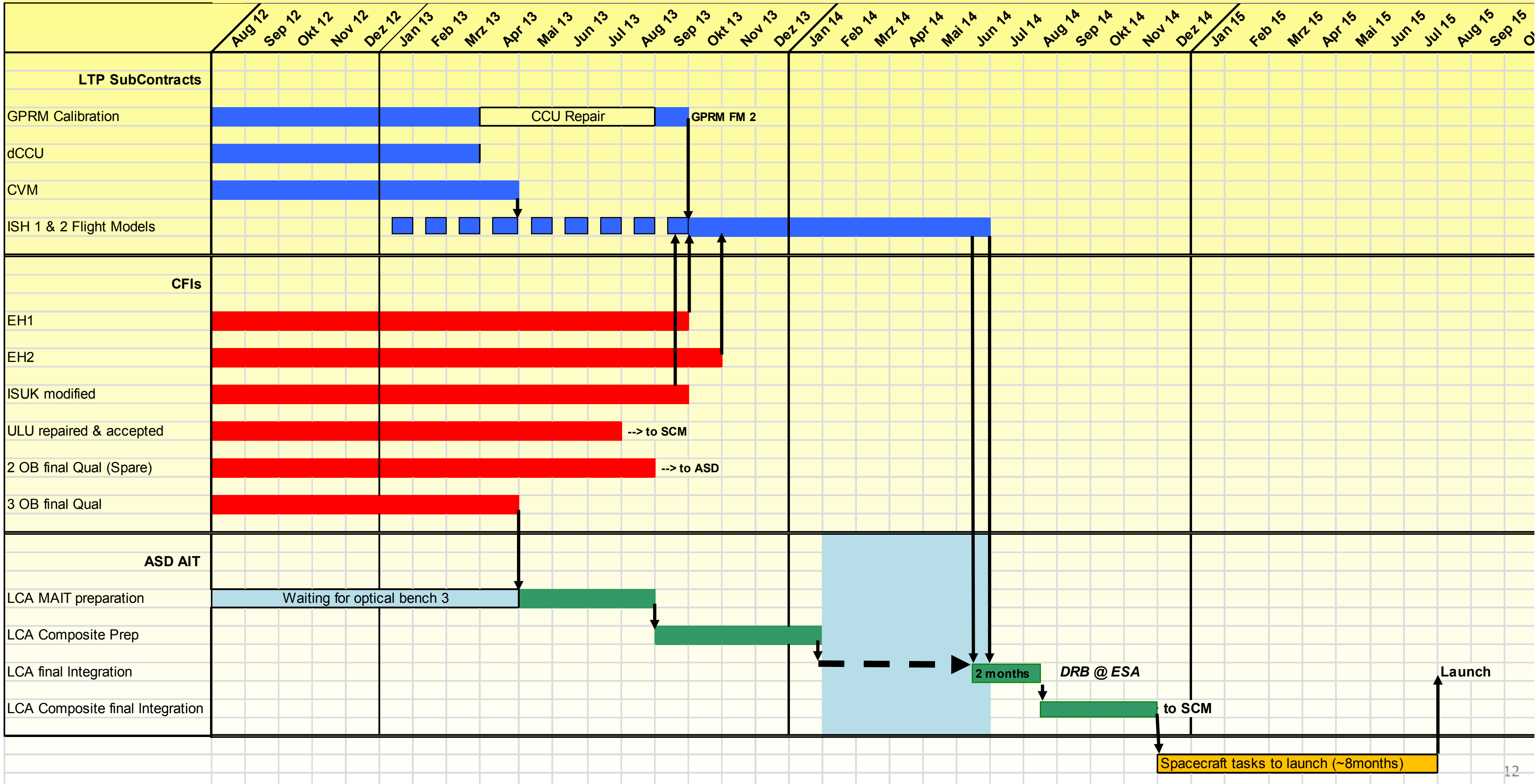


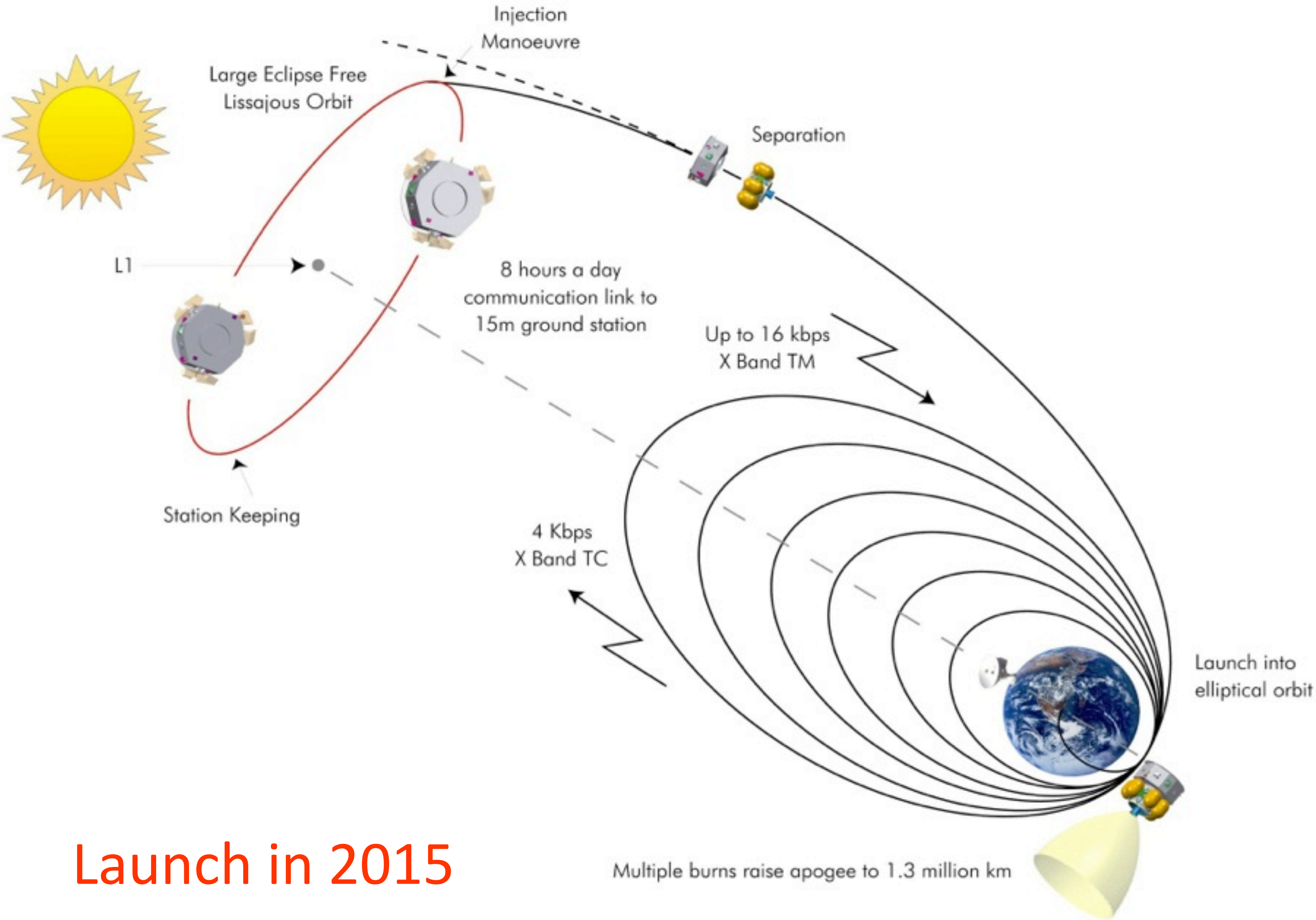
Expected Mission Performance



All Payload Hardware delivered and tested !

- All remaing integration steps successfully practiced
- Launch July 2015 now stable !





Launch in 2015

Lagrange Point L1

n Favoriten Medien
fm?fobjectid=34911

Director's Desk

- SPC
- SSAC
- AWG
- SSWG
- FPAG

DIRECTOR'S DESK

10-Jul-2004 20:27:57 UT

Cosmic Vision 2015-2025
What are the themes for space science?

02 Apr 2004

A call to the European Science Community

Deadline 1 June 2004
Submission Period is Closed

Introduction

This announcement is to invite the community to participate in a *Call for Themes for Cosmic Vision 2015-2025* to assist in developing the future plans of the Cosmic Vision programme of the ESA Directorate of Science. The European Space Agency's Science Programme Committee (SPC), the body that oversees the Agency's mandatory science activities has indicated that it is time to look further into the future. In November 2003, the SPC agreed a plan for space science, Cosmic Vision, for the years 2004-2014. Now the community is asked to help in developing the Cosmic Vision plan for the ESA Science Programme for the decade 2015-2025.

Print this Email this

SEE ALSO

- Purpose and Conclusions of the Cross-disciplinary Perspective Groups (XPG)

DOCUMENTATION

- Original letter: Cosmic Vision 2015-2025
- Original letter: Purpose and Conclusions of the Cross-disciplinary Perspective Groups (XPG)

Cosmic Vision Presentation
Paris, Feb. 2011

LISA

Unveiling a Hidden Universe

Bernard Schutz

for the

LISA International Science Team

bernard.schutz@aei.mpg.de

(Animation: AEI/Milde Science Comm)

But then in March 2011...

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Published online 22 March 2011 | *Nature* **471**, 421 (2011) | doi:10.1038/471421a

News

Europe makes do without NASA

US budget crisis forces European Space Agency to abandon plans for joint mission.

The European Space Agency (ESA) is pushing ahead without NASA support for its next big science mission, as the ongoing US budget crunch and competing priorities impose serious constraints on the US space agency (see *Nature* **471,** 278; 2011). ESA last week told leaders of three large, or 'L-class', missions that are competing for funding to revise their proposals by leaving out the substantial US contribution that had previously been assumed.

"The decision was made very reluctantly," says David Southwood, director of science and robotic exploration at ESA. "NASA could not meet our timetable to launch."

Stories by keywords
- European Space Agency
- L-Class missions
- LISA
- IXO
- EJSM-Laplace

This article elsewhere
Blogs linking to this article

22 April 2011
- China hopes research centre can quell food-safety fears
22 April 2011

Related stories
- US Mars mission takes pole position
08 March 2011
- ESA on countdown to flagship mission selection

LISA Redefinition Study for L1

- Redesign for ESA-only mission

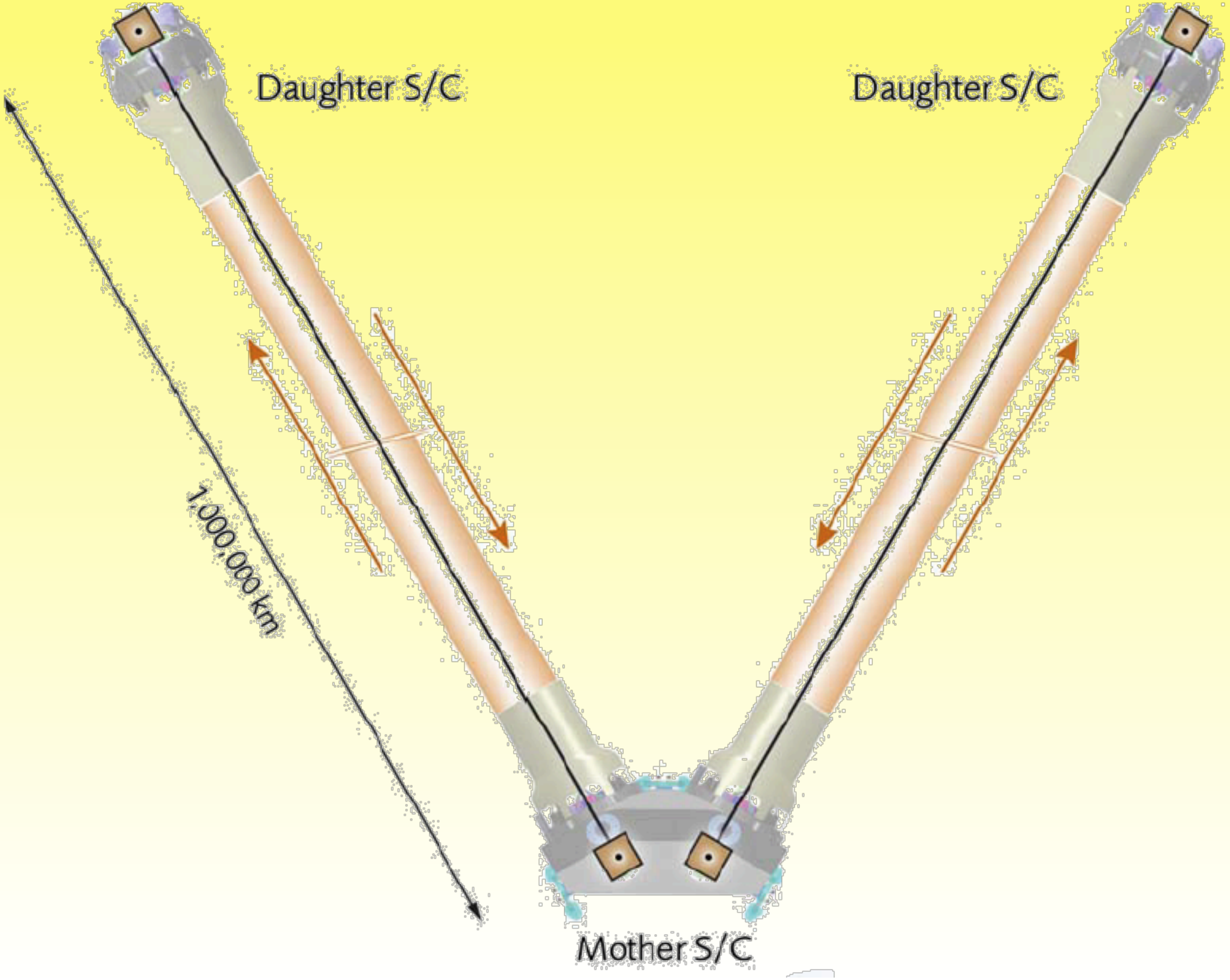
- Cost-cap for ESA cost at 850 M€ plus member state contributions around 200 M€

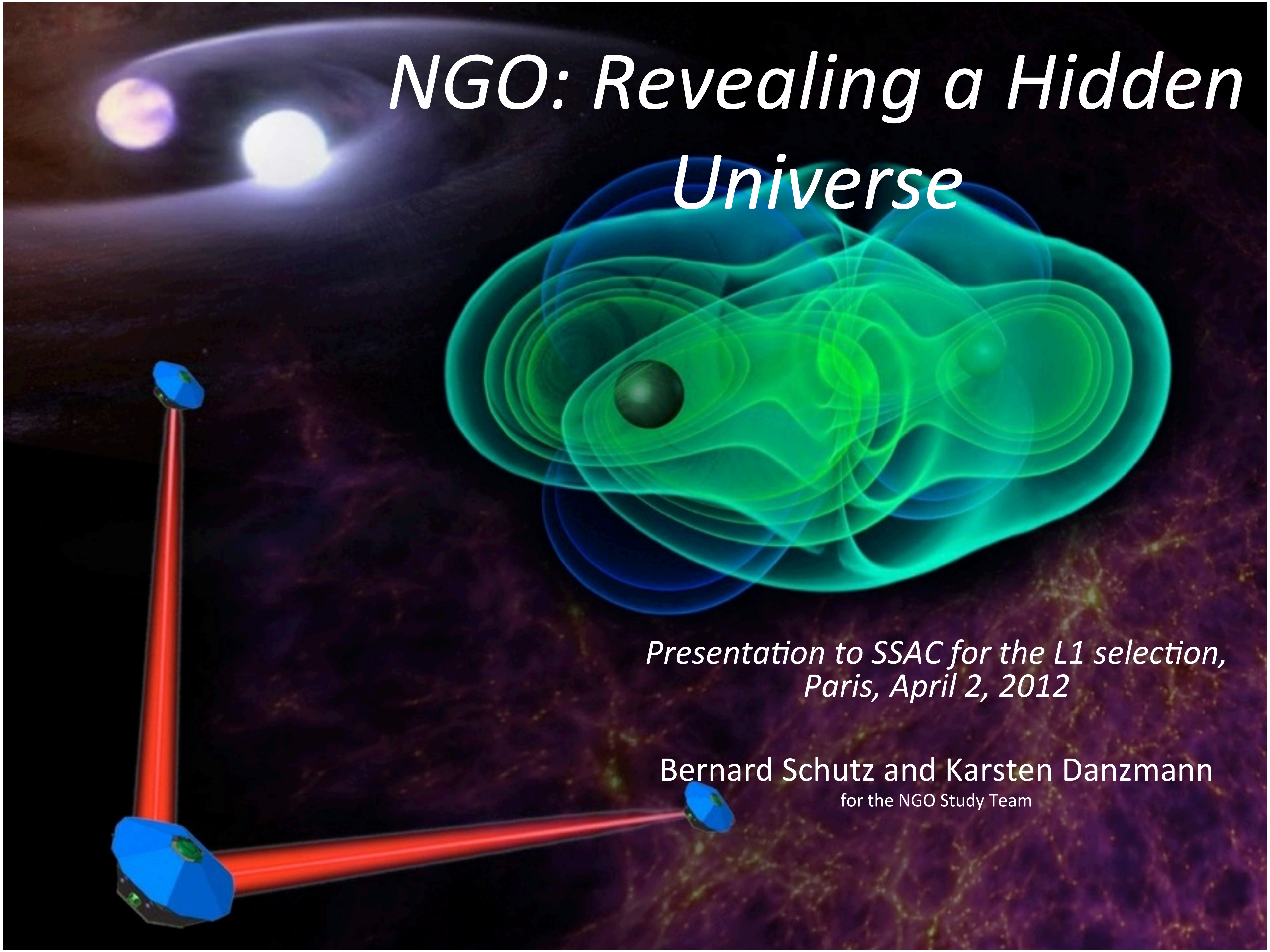
  - ➢ Build on LISA Pathfinder hardware
  - ➢ Shorter arms, smaller telescopes, simpler orbits, less mass
  - ➢ Can use cheaper launcher

→Mission Concept called NGO (eLISA)

→eLISA: evolving LISA
→NGO: specific incarnation of eLISA for ESA L1 selection!

NGO Layout




NGO: Revealing a Hidden Universe
Presentation to SSAC for the L1 selection, Paris, April 2, 2012
Bernard Schutz and Karsten Danzmann
for the NGO Study Team

May 2012: ESA L1 SPC Decision

JUICE to Jupiter's Icy Moons

esa space science

European Space Agency

ESA Home

17-May-2012

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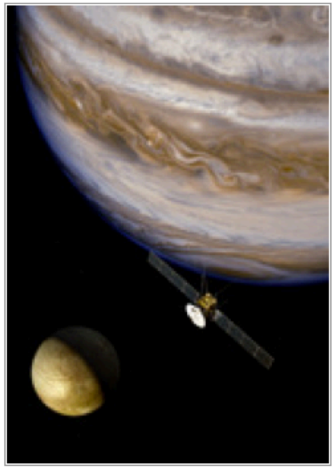
Science missions...

News



Artist's impression of JUICE

JUICE is Europe's next large science mission

2 May 2012
PR 13 2012 - Jupiter's icy moons are the focus of Europe's next large science mission, ESA announced today.

The Jupiter Icy moons Explorer – JUICE – was selected over two other candidates: NGO, the New Gravitational wave Observatory, to hunt for gravitational waves, and ATHENA, the Advanced Telescope for High-Energy Astrophysics.

JUICE is the first Large-class mission chosen as part of ESA's Cosmic Vision 2015-2025 programme.

It will be launched in 2022 from Europe's spaceport in Kourou, French Guiana, on an Ariane 5, arriving at Jupiter in 2030 to spend at least three years making detailed observations.

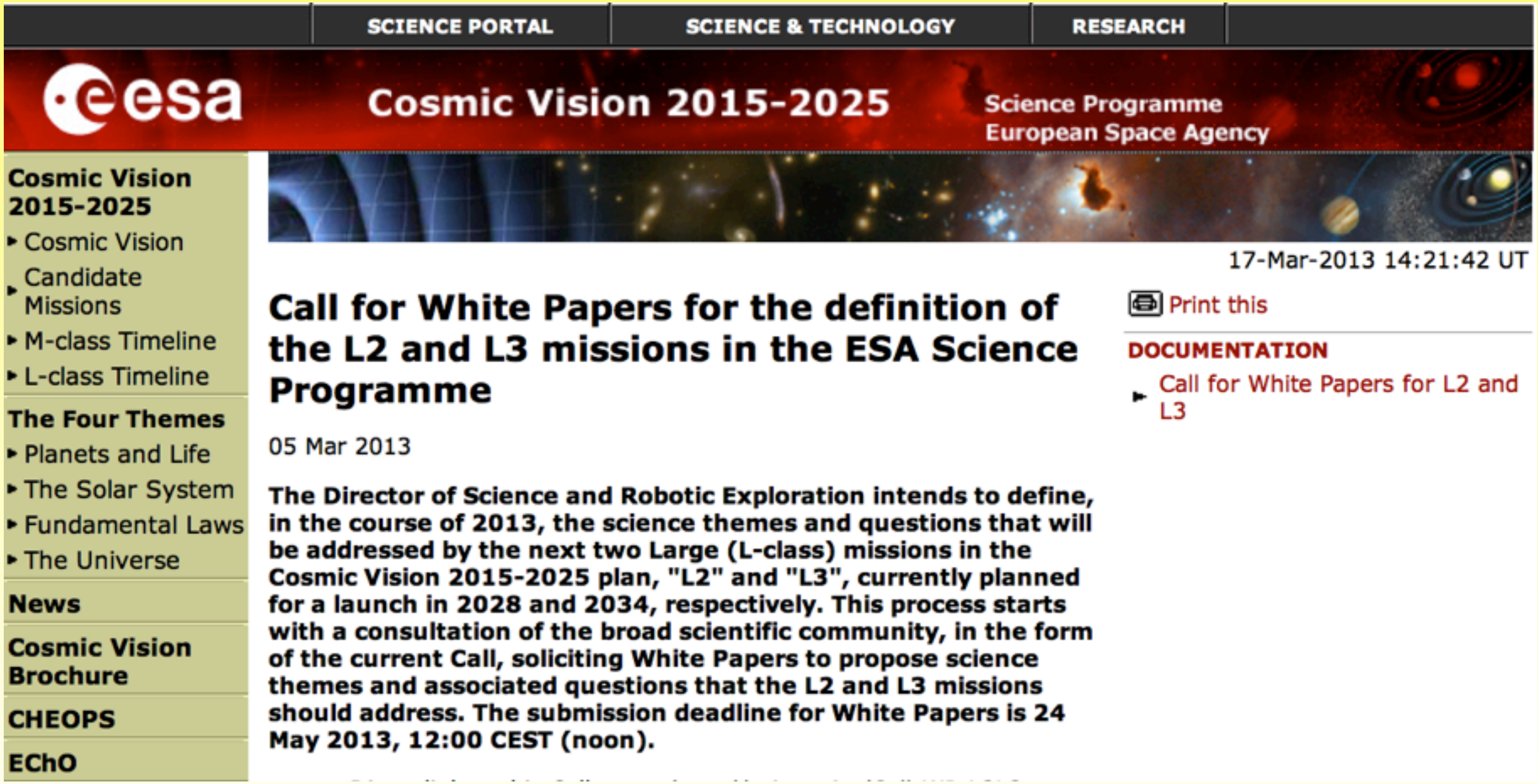
More about ESA's Cosmic Vision...
- Defining the Cosmic Vision
- Missions beyond imagination

Related articles
- ESA's Cosmic Vision workshop 2004
- Plans for the future
- How a mission is chosen

Related links
- More on Cosmic Vision 2015-2025

Cosmic Vision 2015-2025: ESApod
- Cosmic Vision

March 2013: New ESA Call for Large Missions



SCIENCE PORTAL | SCIENCE & TECHNOLOGY | RESEARCH

esa — Cosmic Vision 2015-2025 — Science Programme European Space Agency

Cosmic Vision 2015-2025
- Cosmic Vision
- Candidate Missions
- M-class Timeline
- L-class Timeline

The Four Themes
- Planets and Life
- The Solar System
- Fundamental Laws
- The Universe

News

Cosmic Vision Brochure

CHEOPS

EChO

17-Mar-2013 14:21:42 UT

Call for White Papers for the definition of the L2 and L3 missions in the ESA Science Programme

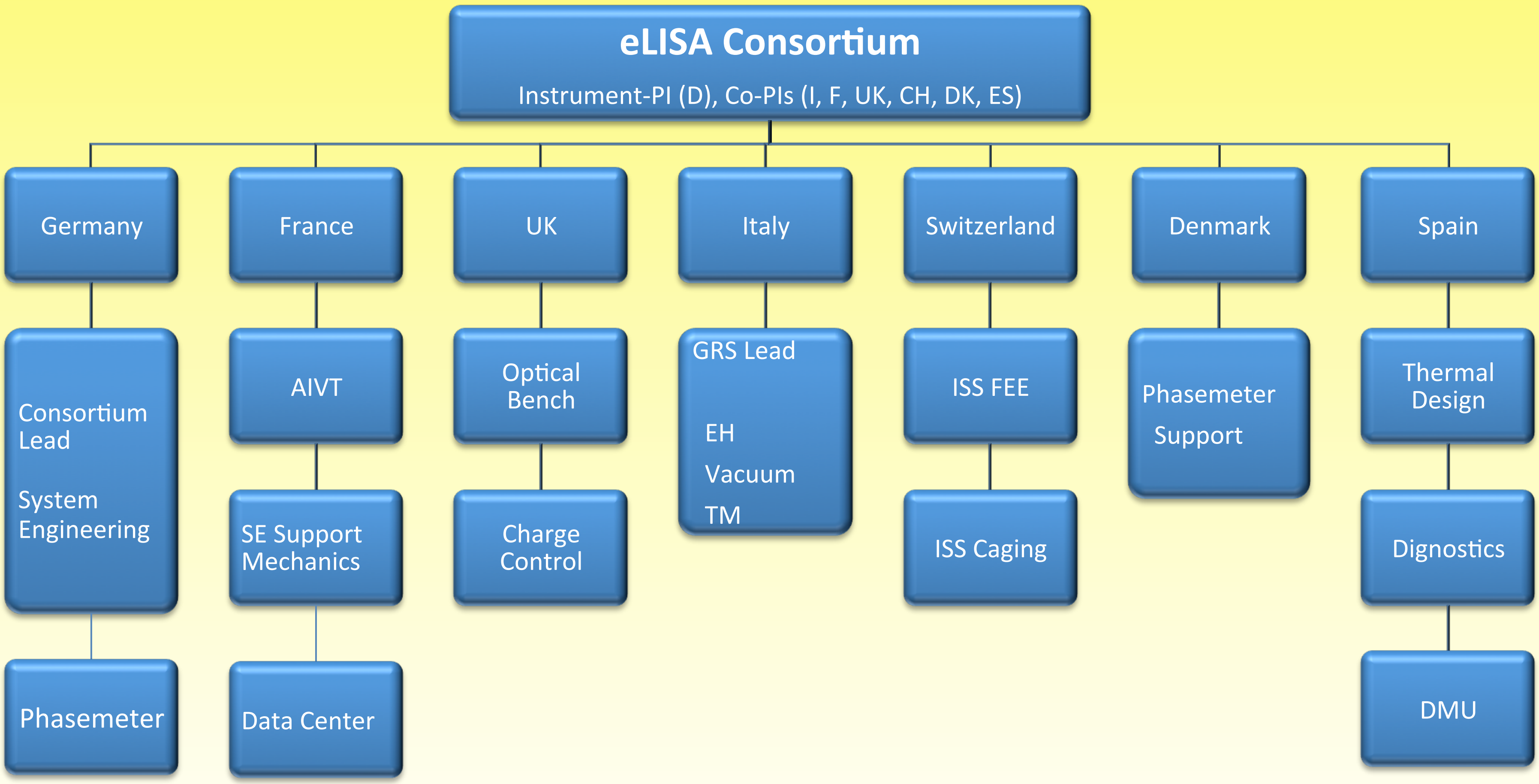
05 Mar 2013

The Director of Science and Robotic Exploration intends to define, in the course of 2013, the science themes and questions that will be addressed by the next two Large (L-class) missions in the Cosmic Vision 2015-2025 plan, "L2" and "L3", currently planned for a launch in 2028 and 2034, respectively. This process starts with a consultation of the broad scientific community, in the form of the current Call, soliciting White Papers to propose science themes and associated questions that the L2 and L3 missions should address. The submission deadline for White Papers is 24 May 2013, 12:00 CEST (noon).

Print this

DOCUMENTATION
- Call for White Papers for L2 and L3

NGO Consortium (NC) maintained as eLISA Consortium



THE GRAVITATIONAL UNIVERSE

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

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)*.

NGO Layout as Strawman for eLISA

Heliocentric orbit trailing earth by 20°

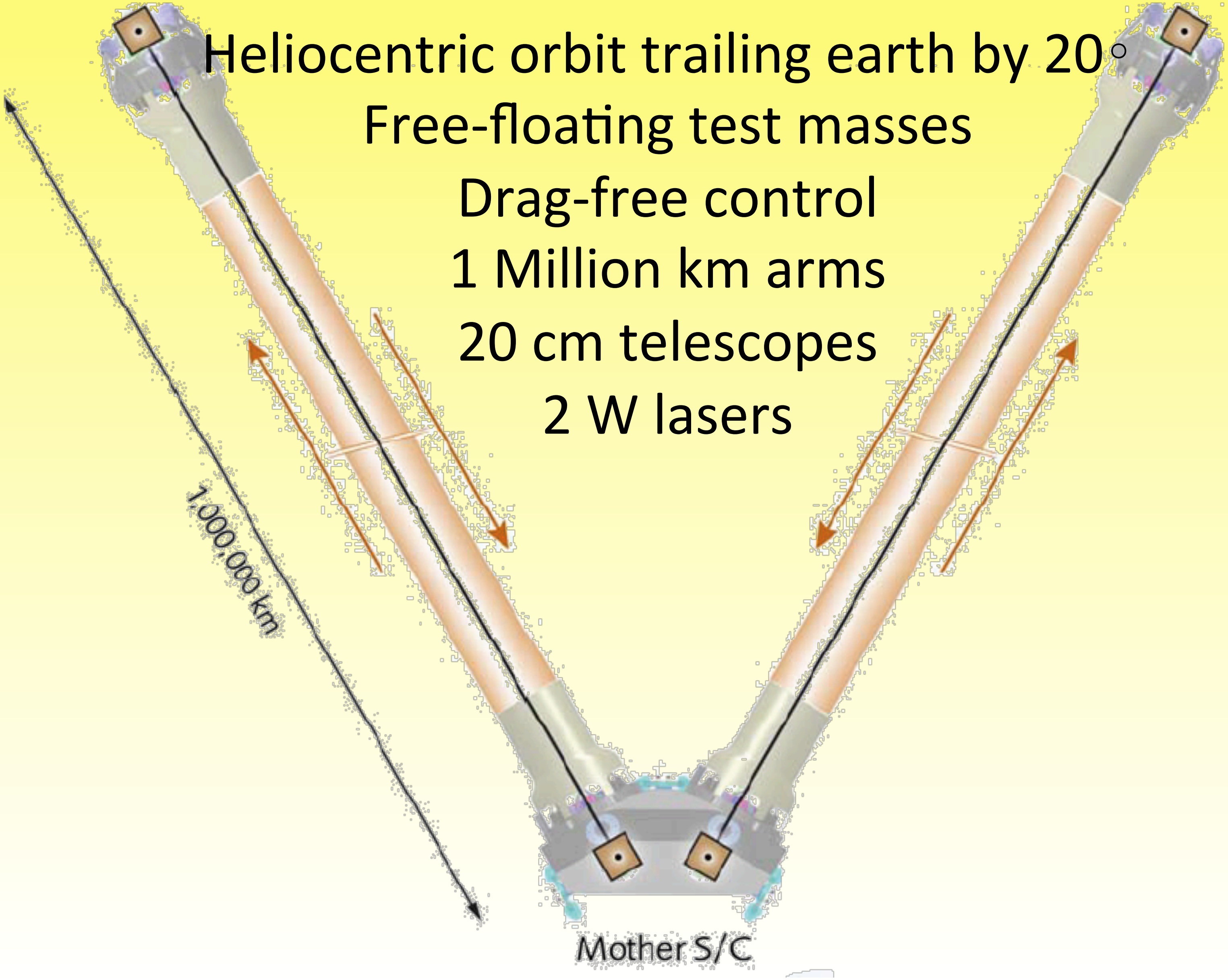
Free-floating test masses

Drag-free control

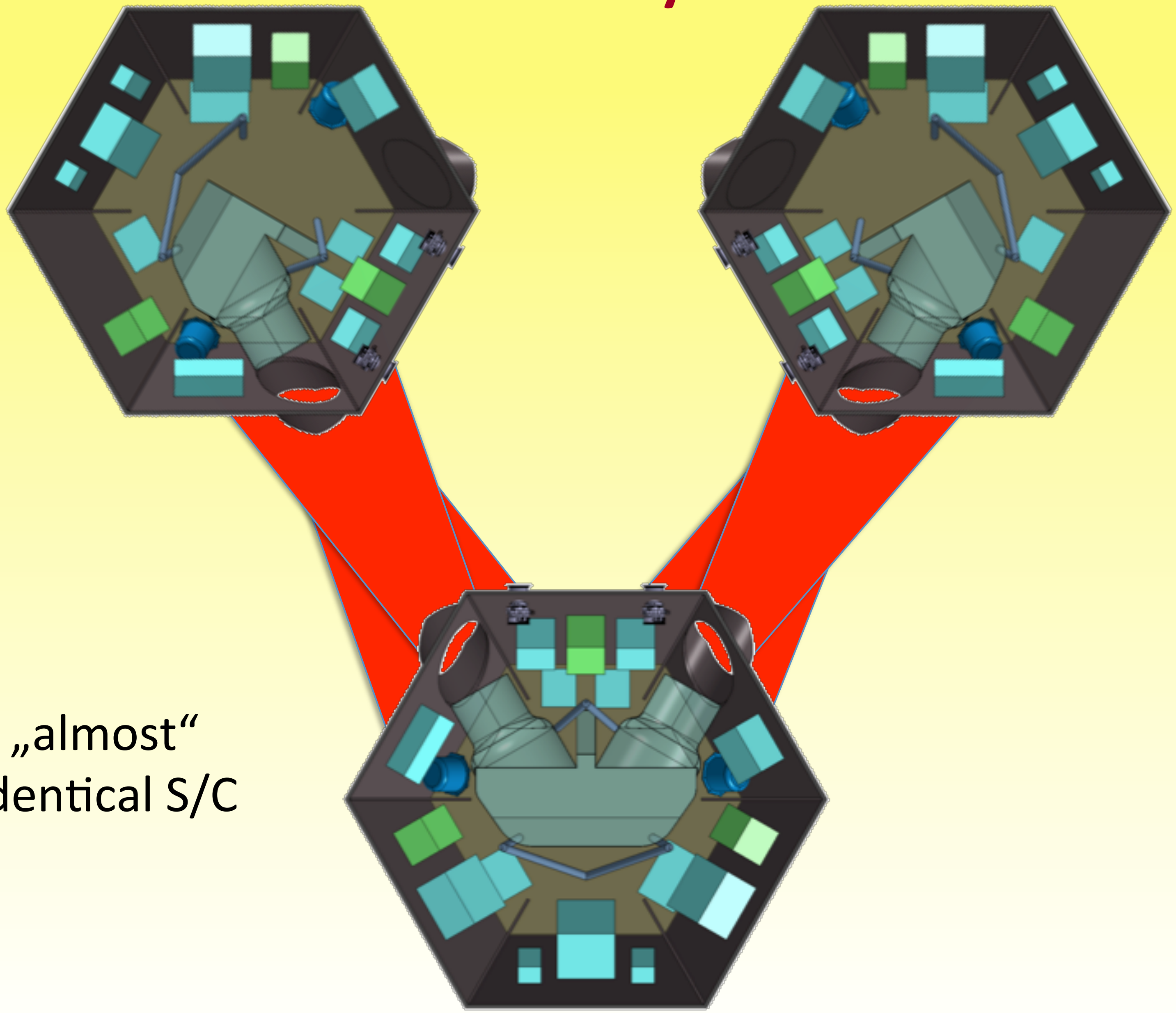
1 Million km arms

20 cm telescopes

2 W lasers

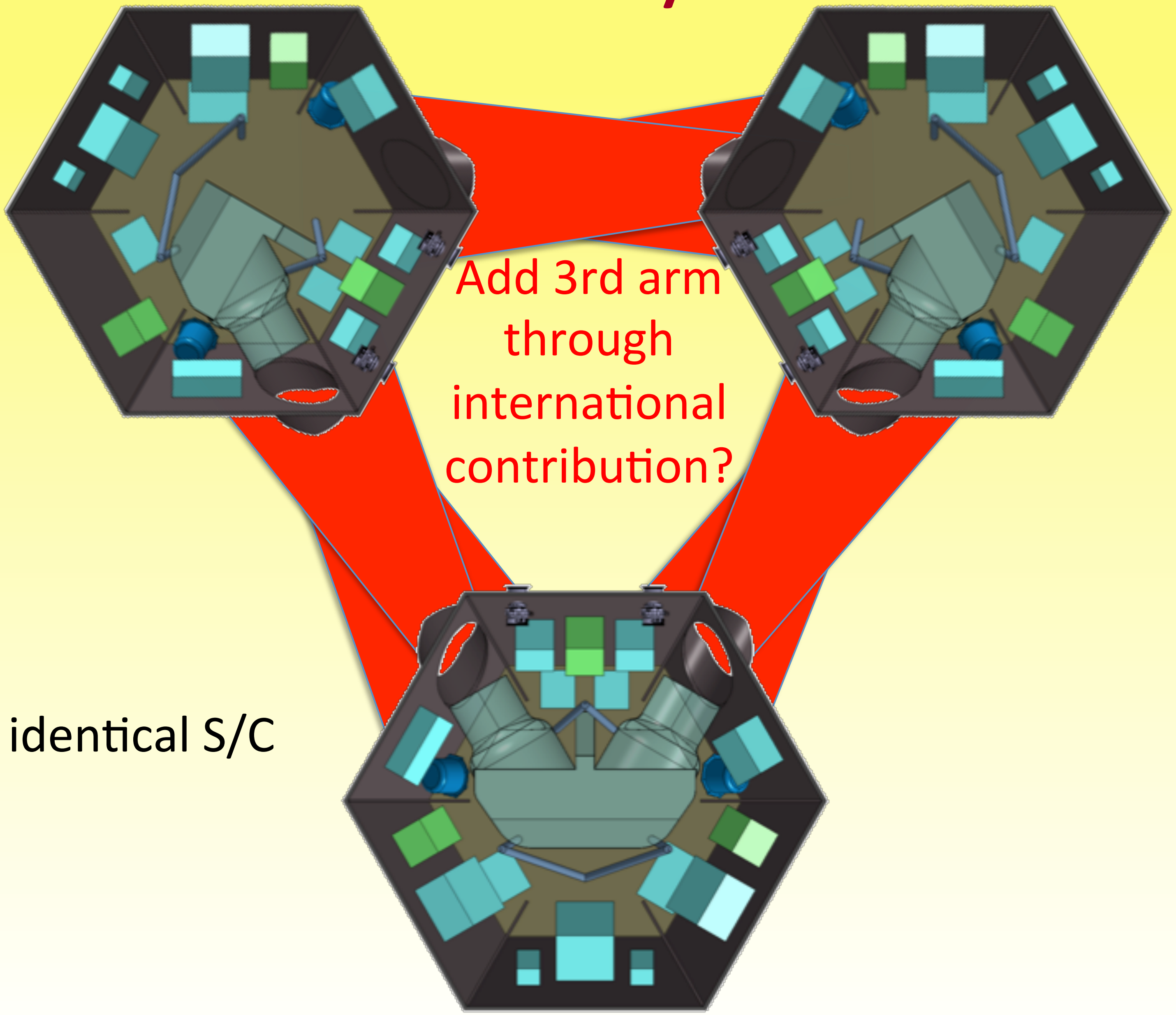


eLISA Lay-Out



3 „almost“
identical S/C

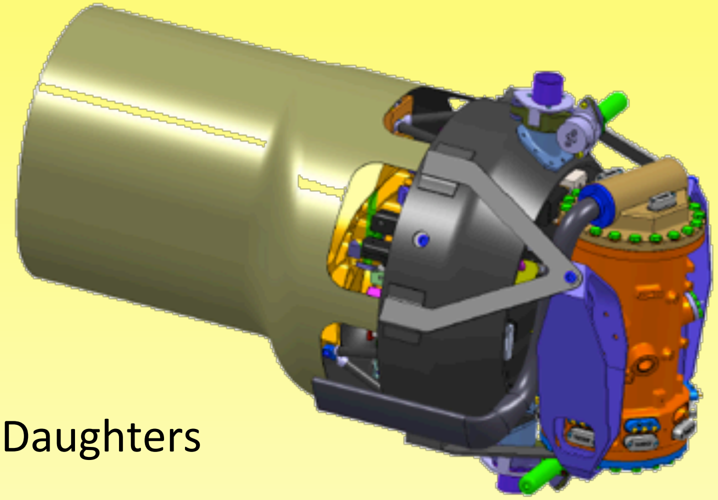
eLISA Lay-Out

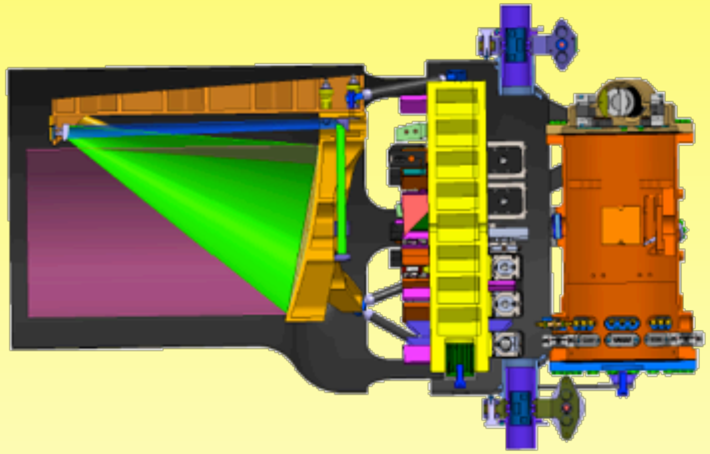


3 identical S/C

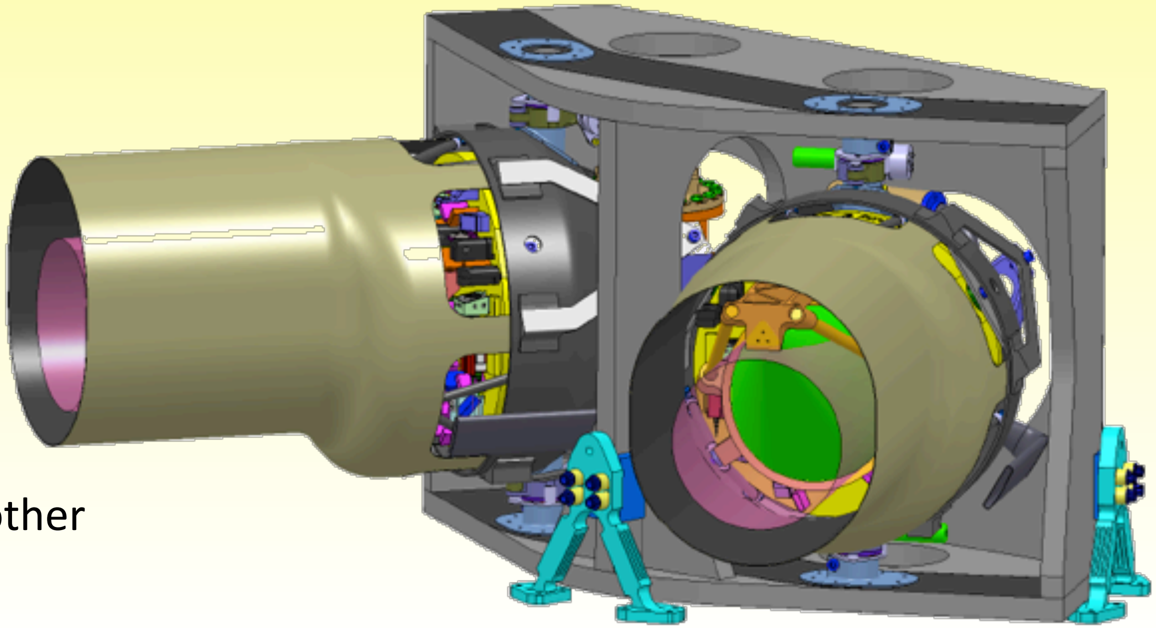
Optical Assembly

adapted from Classic LISA





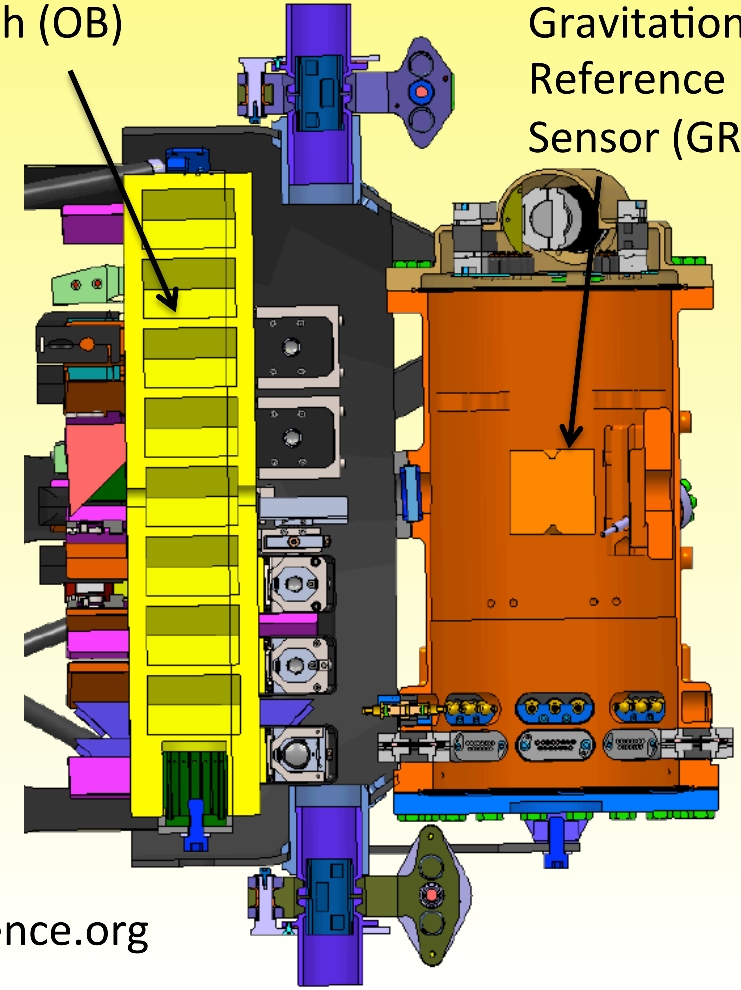
Daughters

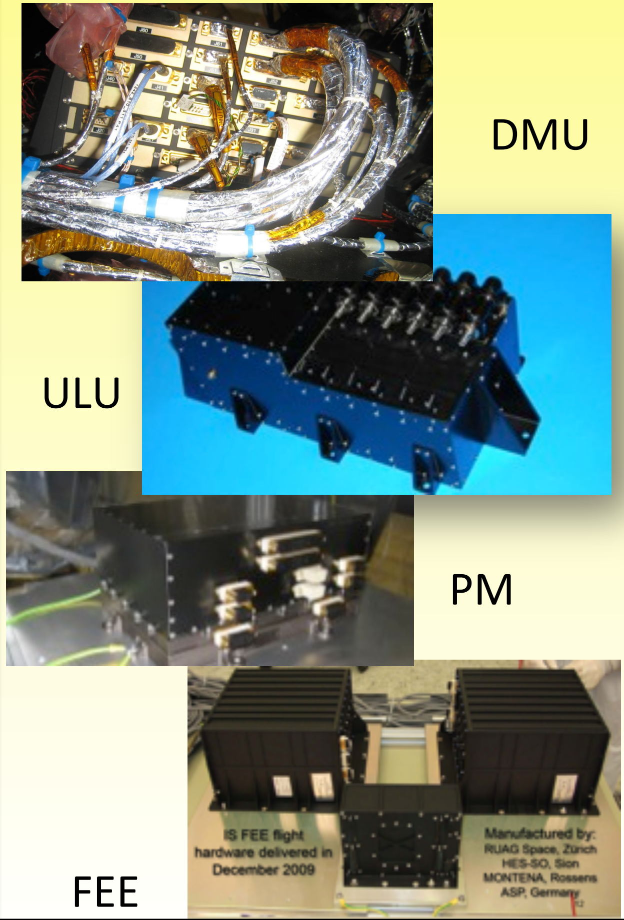


Mother

The Science Instrument

- Provided by eLISA Consortium (D, F, I, UK, ES, CH, DK, NL)
- Also providing LISA Pathfinder Instrument



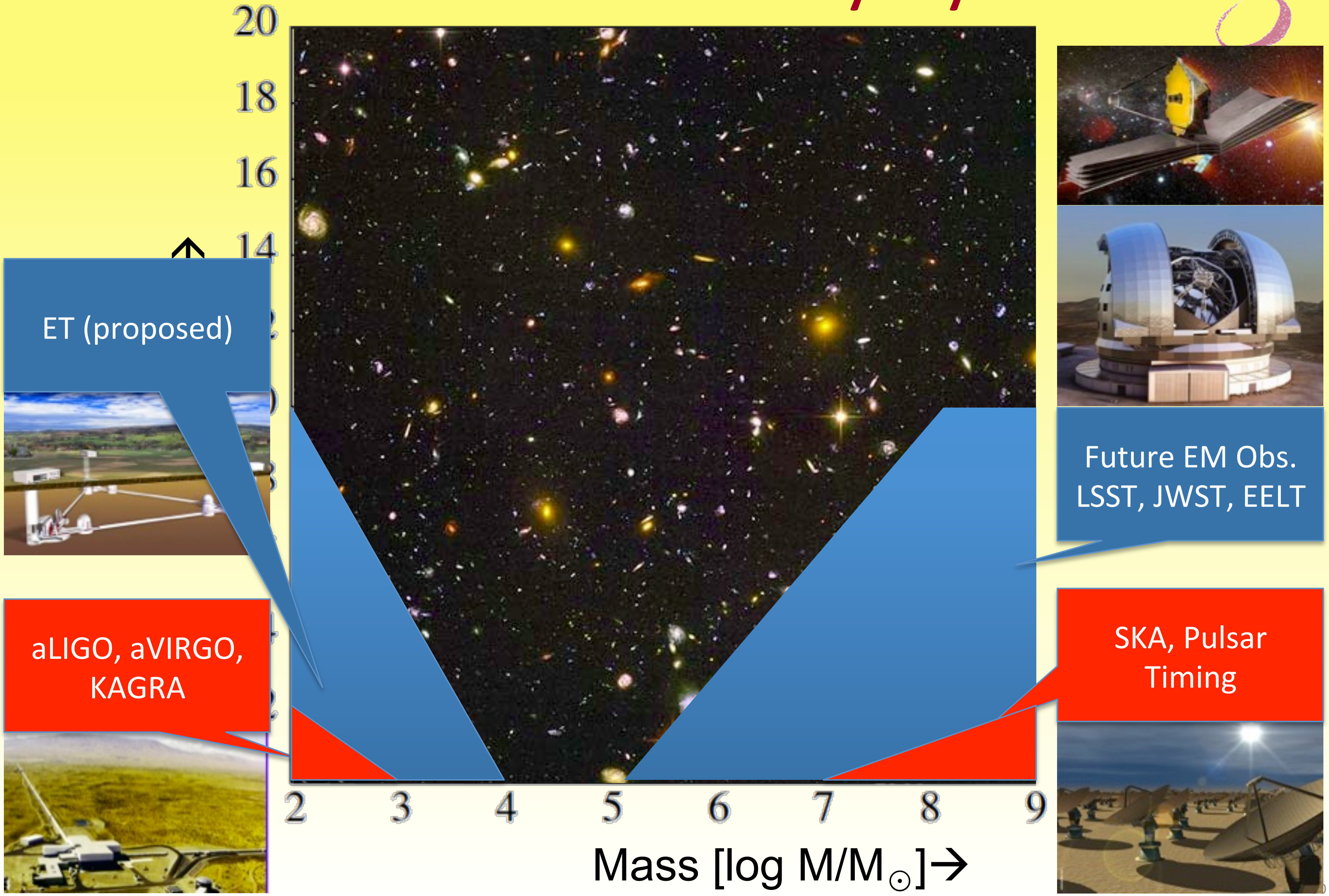


www.elisascience.org

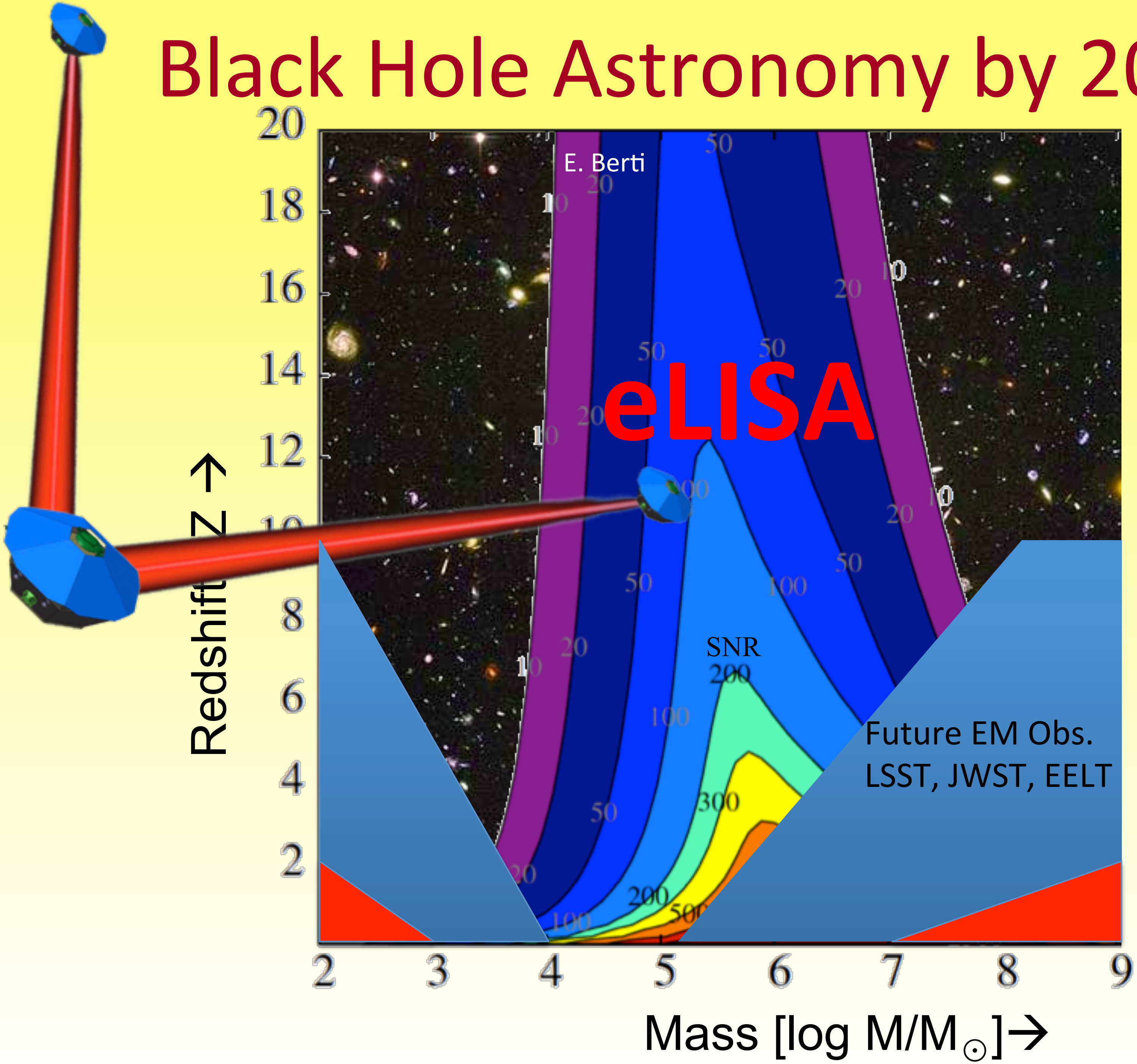
Strawman Mission Scenario

- Go with L1 NGO as baseline
  - Cost envelope in 2013 e.c. is (1000 M€ from ESA plus 400 M€ from MSs) = 1400 M€
  - NGO L1 cost assessed by ESA was 1268 M€
    - Affordable as ESA only!
  - Plus 250 M€ international contrib. = 1650 M€ total
    - 250 M€ = 330 M$ → M-Class or Probe @ NASA!
- Going to 3 arms possible with no design change
- Use international contributions for cost risk mitigation or performance enhancement !

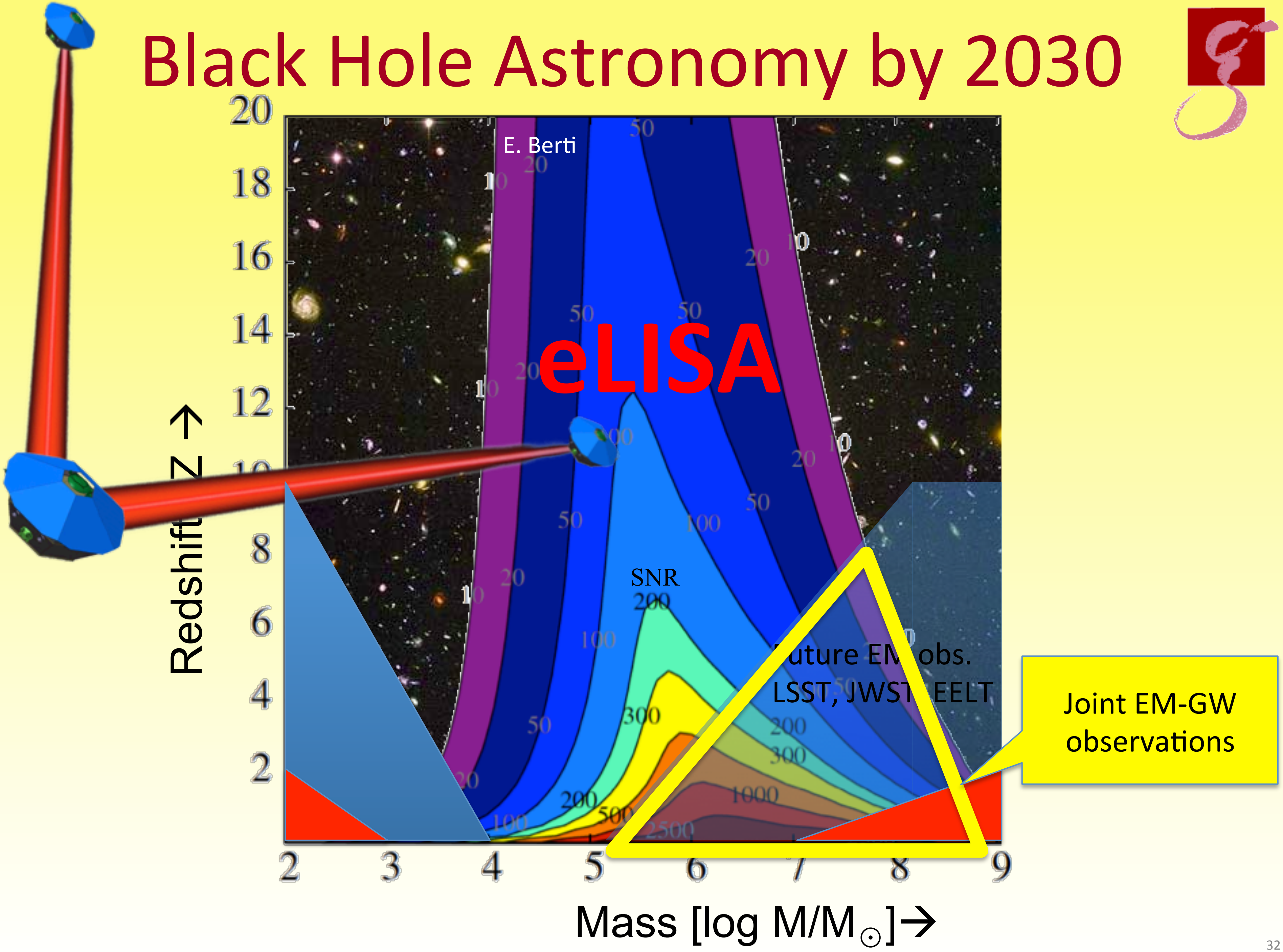
Black Hole Astronomy by 2030



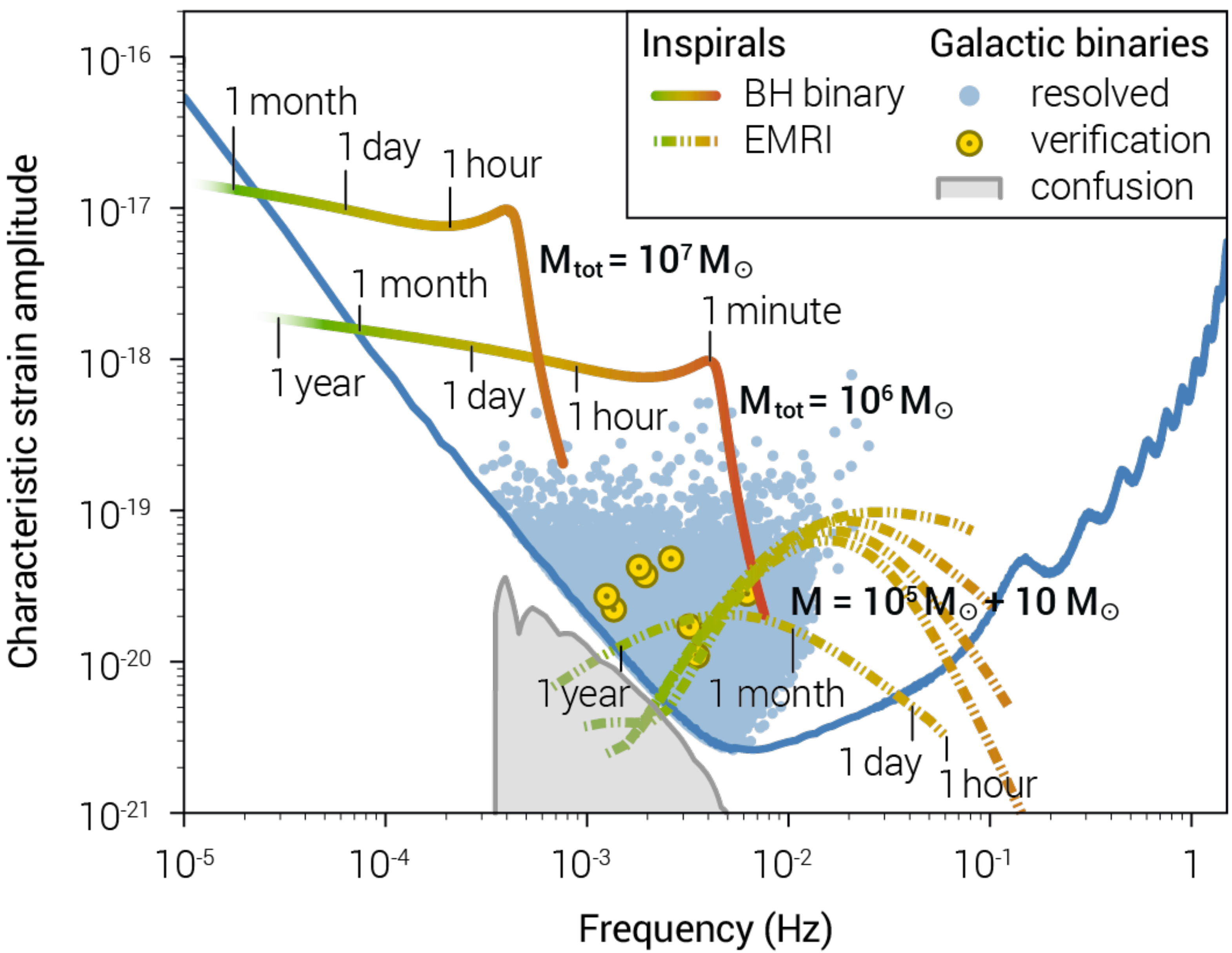
Black Hole Astronomy by 2030



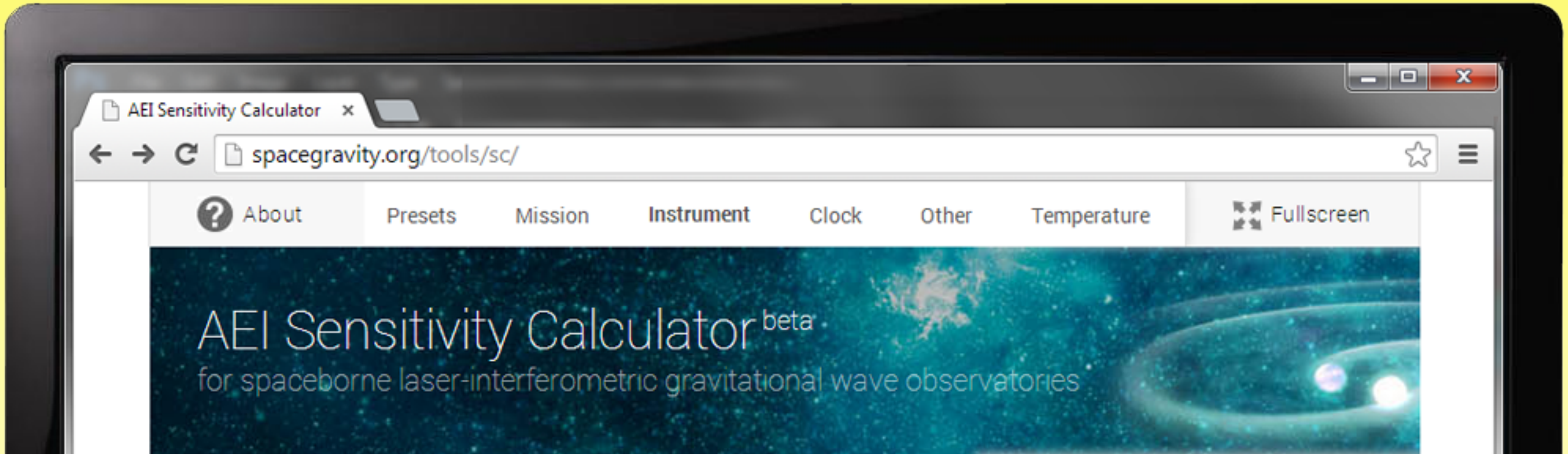
Black Hole Astronomy by 2030



Sensitivity and Black Hole Science



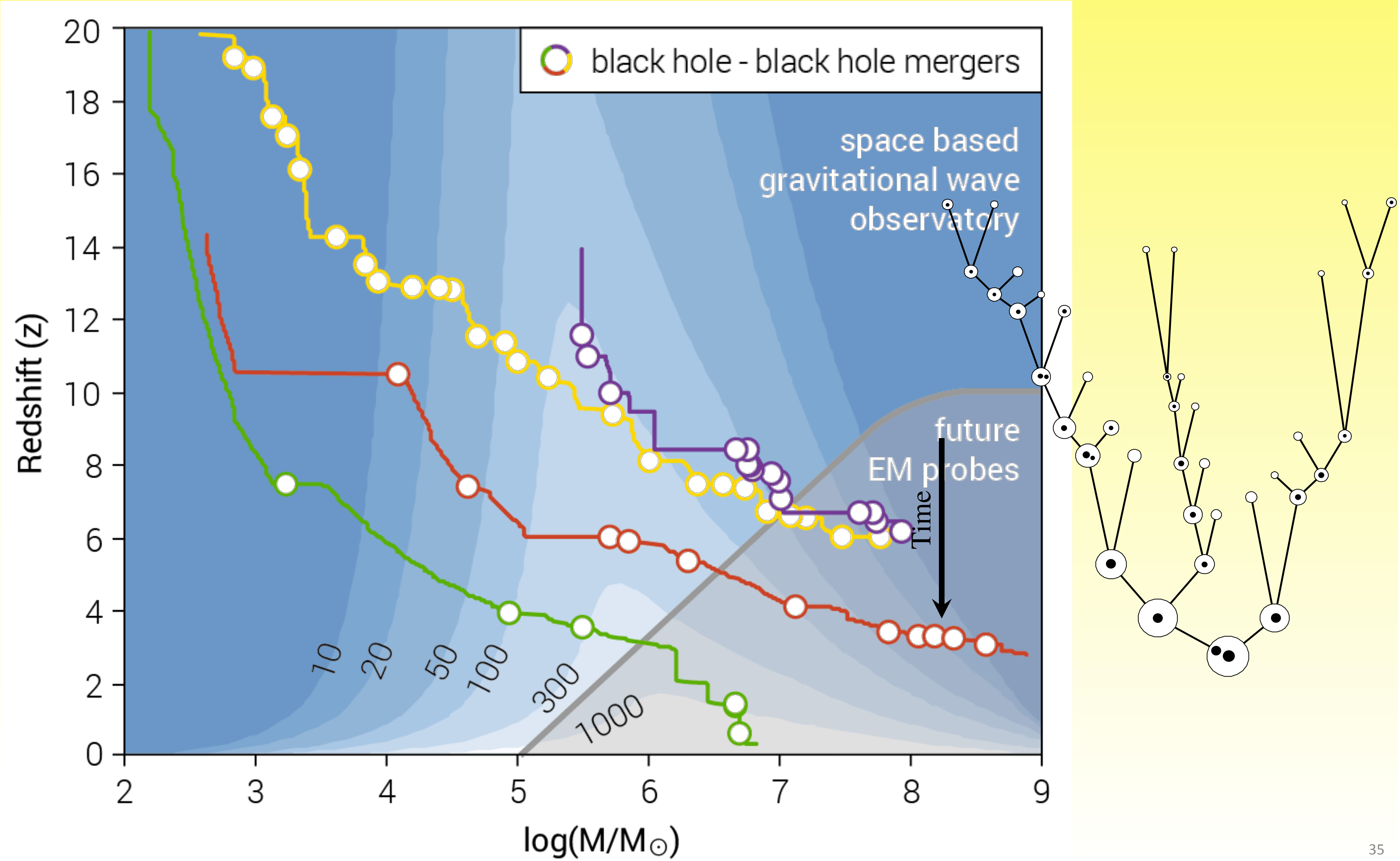
AEI Sensitivity Calculator



- Beta version („Symposium preview“)
- 4, 6 and 24 link configurations
- electronic and optical design properties
- optimal beam waist and local laser power
- influence of thermal noise on optics and electro-optics

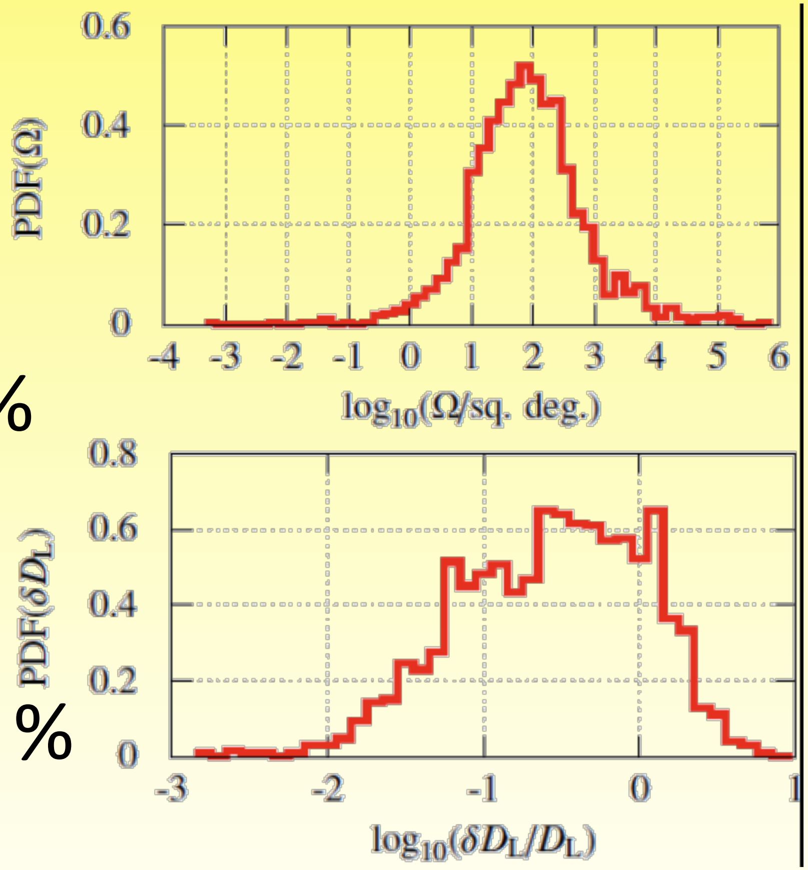
Try it outside and get the link to the online tool.

All Binary Black Holes cross eLISA band: Trace Galaxy Mergers



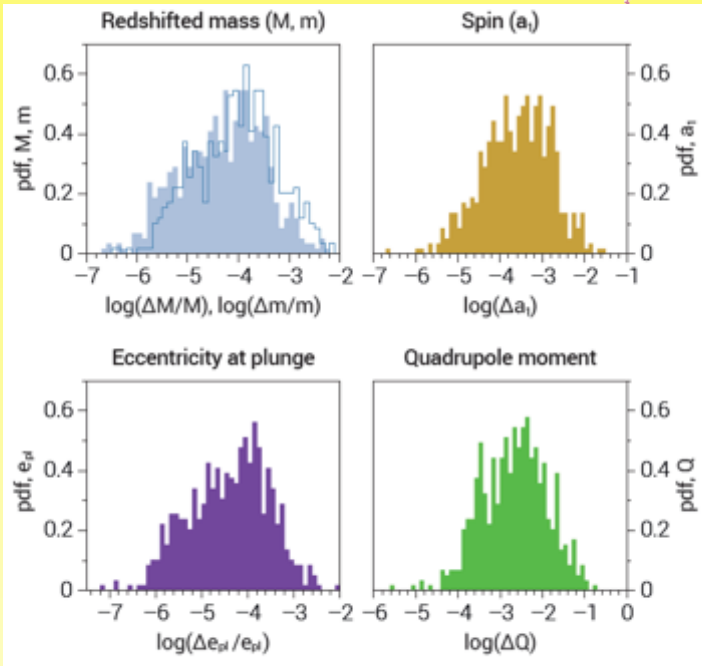
eLISA Black Hole Physics at high SNR

- BBH rest mass $10^4 – 10^7$
- Out to redshift $z >> 10$
- 10 – 100 events per year
- Redshifted mass to 0.1%-1%
- Absolute spin to 0.01-0.1
- Luminosity distance 1 – 50 %
- Sky location 1° - 10 °



Extreme Mass Ratio Inspirals

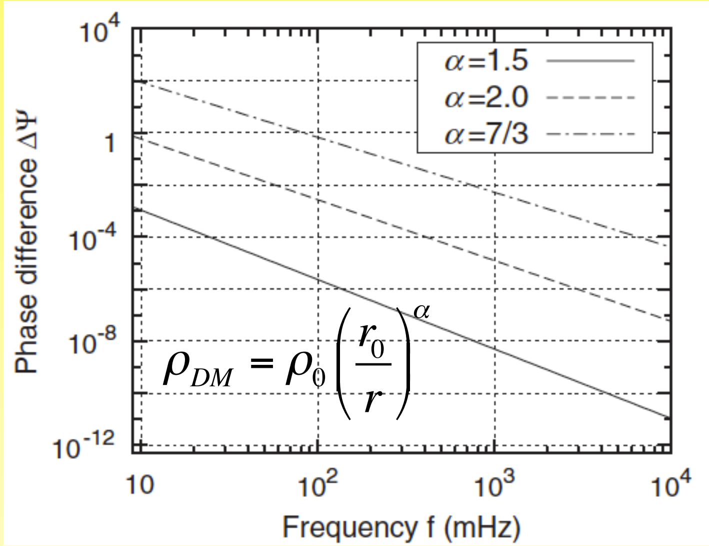
- SNR 20 up to $z \approx 0.7$ for 10^5-10^6
- Dozens of events per year
- Mass, spin to 0.1% – 0.01 %
- Quadrupole moment to < 0.001 $M_\odot^3 G^2/c^4$



- Do Black Holes have hair?
  - New objects in General Relativity
    - Boson Stars, Gravastars, non-Kerr solutions (Manko-Novikov)
  - Deviations from General Relativity
    - Chern-Simons, Scalar-Tensor, Light scalar fields (axions) and black hole bomb instabilities

eLISA as Dark Matter Probe

- Dark Matter spike around BH changes inspiral GW phase
- Sensitive even to non-interacting Dark Matter



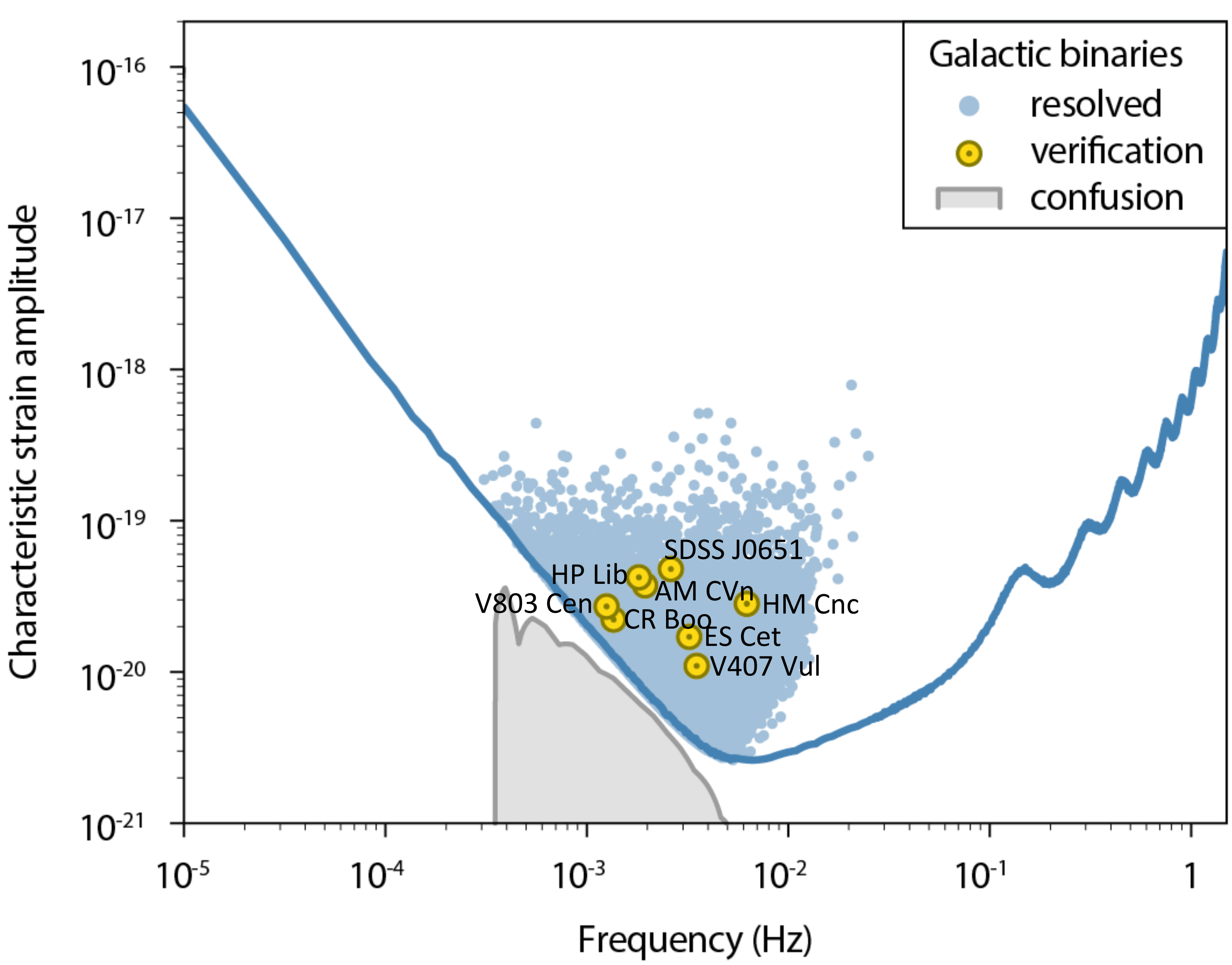
PRL **110,** 221101 (2013) PHYSICAL REVIEW LETTERS week ending 31 MAY 2013

New Probe of Dark-Matter Properties: Gravitational Waves from an Intermediate-Mass Black Hole Embedded in a Dark-Matter Minispike

Kazunari Eda,* Yousuke Itoh, and Sachiko Kuroyanagi
Research center for the early universe, School of Science, University of Tokyo, Tokyo 113-0033, Japan

Joseph Silk
Institut d' Astrophysique, UMR 7095, CNRS, Université Pierre et Marie Curie Paris VI, 98 bis Boulevard Arago, Paris 75014, France

eLISA has Verification Binaries

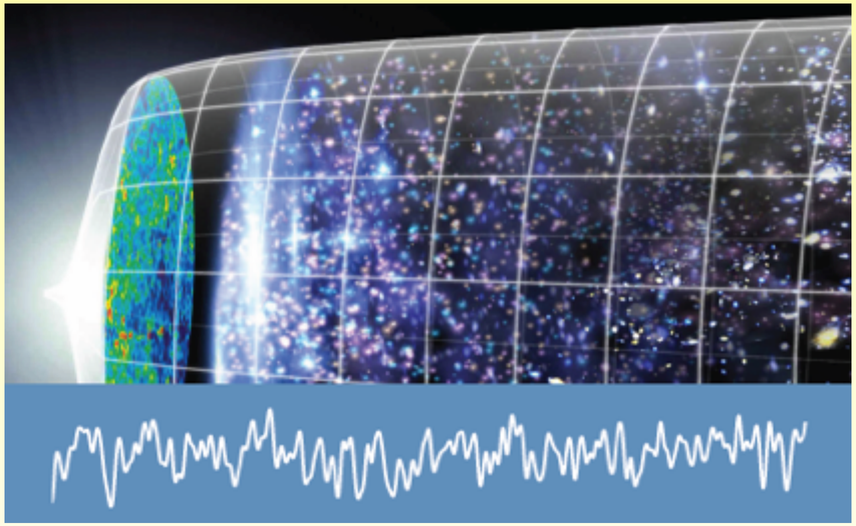


STOCHASTIC GW BACKGROUND

- Wavelength of primordial Gravitational Waves set by horizon scale at time of emission (with temperature T_*):

$$f_0 \approx 10^{-4}\,\mathrm{Hz}\sqrt{H_*(t)\times\frac{1\,\mathrm{mm}}{c}} \approx 10^{-4}\,\mathrm{Hz}\frac{kT_*}{1\,\mathrm{TeV}}$$

- eLISA band
  - 0.1-100 mHz ⟹ 1-1000 TeV (LHC)
  - 1 mm scale @ TeV
  - 3×10^{-18} - 3×10^{-10} s after the Big Bang
- eLISA sensitive to LHC physics and beyond
  - Higgs self-couplings and potential
  - Supersymmetry
  - Extra dimensions
  - Strings
  - Dark Energy density ≈ $(0.1\ \mathrm{mm})^{-4}$
    - Signature in eLISA band?



Missions
· Show All Missions

Cosmic Vision 2015-2025
· Cosmic Vision
· Candidate Missions
· M-class Timeline
· L-class Timeline

The four themes
· Planets and Life
· The Solar System
· Fundamental Laws
· The Universe

S-class mission
· CHEOPS

M-class missions
· Euclid
· Solar Orbiter

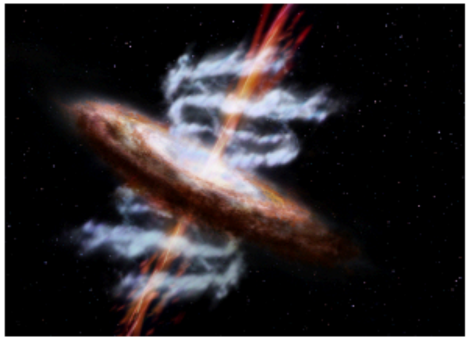
M-class candidates
· EChO
· LOFT
· MarcoPolo-R
· PLATO
· STE-QUEST

ESA'S NEW VISION TO STUDY THE INVISIBLE UNIVERSE

28 November 2013

The hot and energetic Universe and the search for elusive gravitational waves will be the focus of ESA's next two large science missions, it was announced today.

Both topics will bridge fundamental astrophysics and cosmology themes by studying in detail the processes that are crucial to the large-scale evolution of the Universe and its underlying physics.



Artist's impression of a galaxy with outflows and jets. *Credit: ESA/AOES Medialab*

The science theme "the hot and energetic Universe" was selected for L2 – the second Large-class mission in ESA's Cosmic Vision science programme – and is expected to be pursued with an advanced X-ray observatory.

This mission, with a launch date foreseen for 2028, will address two key questions. How and why does ordinary matter assemble into the galaxies and galactic clusters that we see today, and how do black holes grow and influence their surroundings?

Black holes, which lurk unseen at the centres of almost all galaxies, are regarded as one of the keys to understanding galaxy formation and evolution.

The L3 mission will study the gravitational Universe, searching for ripples in the very fabric of space–time created by celestial objects with very strong gravity, such as pairs of merging black holes.

Predicted by Einstein's theory of general relativity but yet to be detected directly, gravitational waves promise to open a completely new window on the Universe.

Planned for launch in 2034, it will require the development of a spaceborne gravitational wave observatory, or extreme precision 'gravitometer', an ambitious enterprise that will push the boundaries of current technology.

Search here

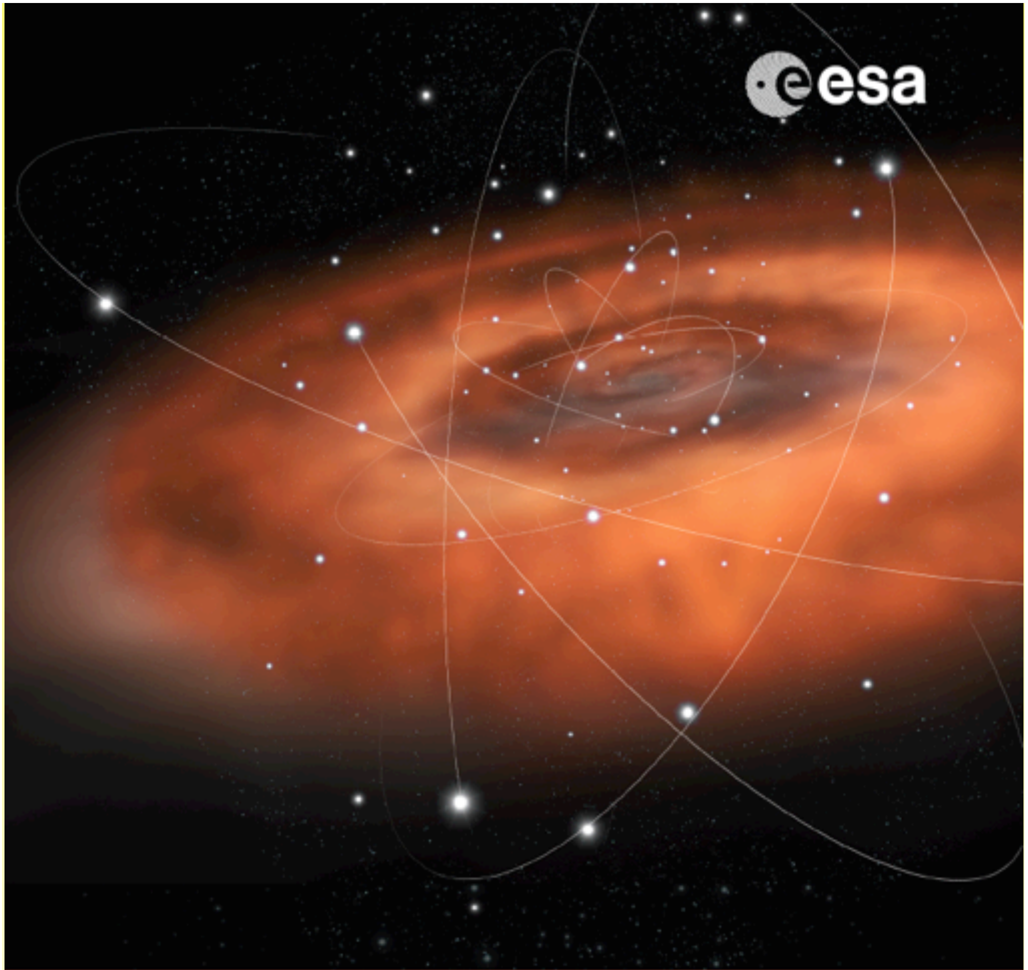
16-Dec-2013 13:34 UT

Shortcut URL
http://sci.esa.int/jump.cfm?oid=53259

Images and Videos

· Artist's impression of a galaxy with outflows and jets

Related Publications
· Report on science themes for the L2 and L3 missions



→ REPORT OF THE SENIOR SURVEY COMMITTEE ON THE SELECTION OF THE SCIENCE THEMES FOR THE L2 AND L3 LAUNCH OPPORTUNITIES IN THE COSMIC VISION PROGRAMME

October 2013

www.esa.int

European Space Agency

Prepared by the Senior Survey Committee:
Dr. Catherine Cesarsky (CEA, Chair)
Prof. Willy Benz (Bern University)
Dr. Sergio Bertolucci (CERN)
Prof. Giovanni Bignami (INAF)
Dr. Thérèse Encrenaz (Meudon Observatory)
Prof. Reinhard Genzel (MPE)
Dr. Jason Spyromilio (ESO)
Prof. John Zarnecki (Open University)

Cover image: An artist's impression of the environment at the centre of our Galaxy, the Milky Way
Credit: ESA – C. Carreau
Layout: Sapienza Consulting, United Kingdom

This report is available online at http://sci.esa.int/ssc_report

5.1.1. The L2 Science Theme: *The Hot and Energetic Universe*

Over the past five decades, compelling evidence has emerged that black holes are common in the Universe, with masses ranging from stellar remnants (~10 M_{Sun}) to supermassive systems (~10^{10} M_{Sun}). Almost every massive galaxy plausibly contains a massive black hole at its centre, estimated to hold between about 0.015 to 0.06% of the entire mass of its spheroidal stellar component. These supermassive black holes appear to have formed ~10–13 Gyr ago, at about the same time as their host galaxies. The evolution of the hosts and their embedded supermassive lack holes seems to have been closely connected, probably through energy exchange and mergers of galaxies and black holes. This co-evolution of supermassive black holes and galaxies is a remarkable and unexpected discovery, which clearly requires further exploration.

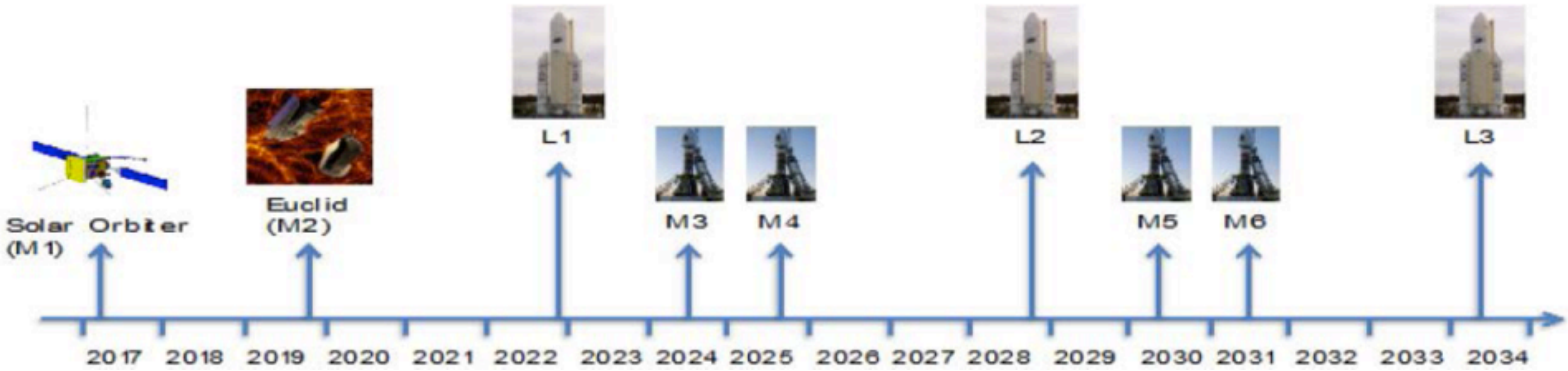
Jets and outflows driven by a black hole at the centre of a galaxy. ESA/AOES medialab

5.1.2. The L3 Science Theme: The Gravitational Universe

In our quest for understanding the Universe, gravitational waves are the most attractive of the observing windows that have not been exploited yet. The exploration of the Universe with gravitational waves is of the greatest importance to astrophysics and physics alike. A space observatory can operate at low frequencies, in the range 0.1 to 100 mHz, where sources are plentiful, and since gravitational waves do not suffer from obscuration, they give access at once to the whole Universe. Unlike electromagnetic waves, gravitational waves can probe the early stages of the Universe, before decoupling of light and matter and emission of the microwave background. The scientific results from a gravitational wave observatory promise to yield deep insights into some of the most fundamental mysteries of physics.

ESA's L2 and L3 Missions

- Call for Science Themes 2013
- Selection of Themes in Nov 2013
- LISA Pathfinder launch 2015
- Launch of L2 in 2028 - Athena
- Launch of L3 in 2034 - LISA



Details in SPC Document

ESA Unclassified – For official use

ESA/SPC(2013)29
Att.: Annex
ESA/SSAC(2013)7
Paris, 31 October 2013
(Original: English)

EUROPEAN SPACE AGENCY

SCIENCE PROGRAMME COMMITTEE

Selection of the science themes for the L2 and L3 missions

Summary:

Following the evaluation of the 32 White Papers proposing science themes for the L2 and L3 mission opportunities (currently foreseen in 2028 and 2034), which were received in response to the Call issued in March 2013, the Senior Survey Committee convened by the Director of Science and Robotic Exploration has issued its recommendations (in annex to the present document). Based on these recommendations the Director of Science and Robotic Exploration is herewith proposing to the SPC the selection of the science themes for the L2 and L3 mission opportunities.

A 3 Stage Process:

1: Science theme selection

2: Mission concept selection

3: Mission adoption

For the L3 opportunity, contingent on the selection of the proposed science theme “The gravitational Universe”, the Executive intends to immediately start assessing the status of the available technologies for the mission concepts proposed in the relative White Paper (which builds on the studies performed for the LISA mission in the past). A key milestone toward the implementation of the proposed science theme for the L3 opportunity will be the flight of the LISA Pathfinder mission in 2015.

In keeping with a similar schedule as for the L2 mission, a restricted Call for Missions will be issued later in the present decade (to be confirmed depending on the evolution of the Programme’s planning), which will lead to a similar process as for the L2 mission. The Executive intends to initiate, in coordination with Member States, key technology developments that will enable the scientific community to respond to the L3 Call for Missions with mature and technologically feasible mission concepts.

- L3 mission concept selection in 2020!
- Crucial technologies ready by 2019!

eLISA Technology Roadmap 2012-2015

Document No. LISA-AEI-RP-6001

Report

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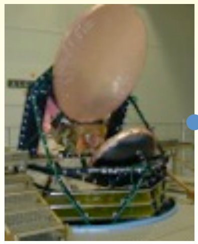
Bernard Schutz, AEI Potsdam
Tim Sumner, Imperial College London
Stefano Vitale, University of Trento
Harry Ward, University of Glasgow

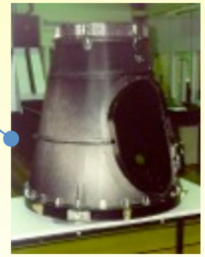
Telescope Subsystem – Heritage

- CFRP thermostable structures, supporting mainly Zerodur mirror substrates (abridged list)
  - µm/µrad absolute accuracy and stability required for all instruments below

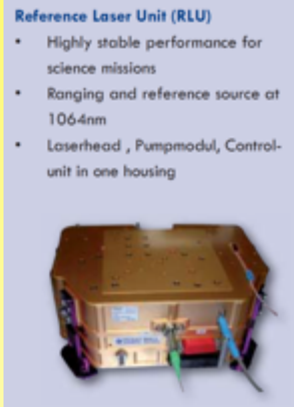




Instrument	Models	Status
Gomos on Envisat (LEO)	2 FM's + 1 QM	in orbit since 2002
Cartosat-2 (LEO)	4 FM's	in orbit since 2007
Kompsat 3 (LEO)	1 FM	in orbit since 2012
Kompsat 3A (LEO)	1 FM	launch in 2013
Seviri on MSG (GEO)	4 FM's + 1 QM	in orbit since 2002
Planck reflectors (L2)	1 FM + 1 QM	in orbit since 2009

Laser Subsystem – Heritage of TESAT Nd:YAG Lasers



Reference Laser Unit (RLU)

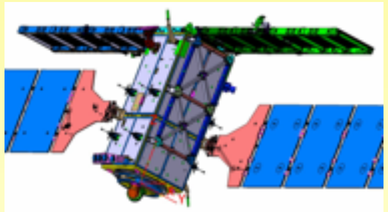
Reference Laser Head (RLH)
- with Reference Cavity

TESAT SPACECOM
PIONEERING WITH PASSION

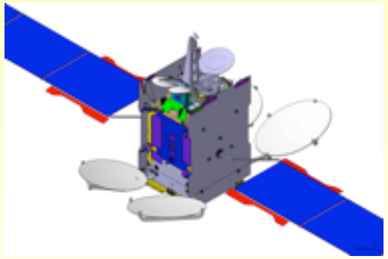
NFIRE (NASA)

Alphasat (Astrium SAS & TAS France)

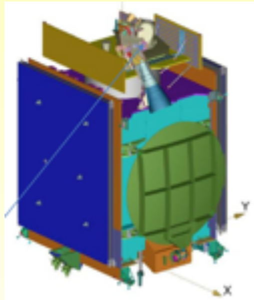
TerraSAR-X (Astrium GmbH)



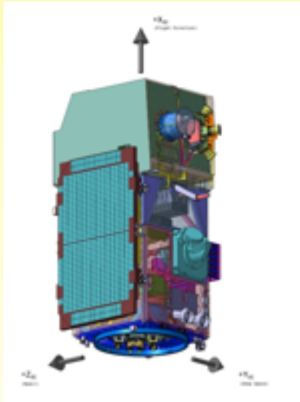
Sentinel 1 (TAS Italy)



EDRS-A (Astrium SAS)



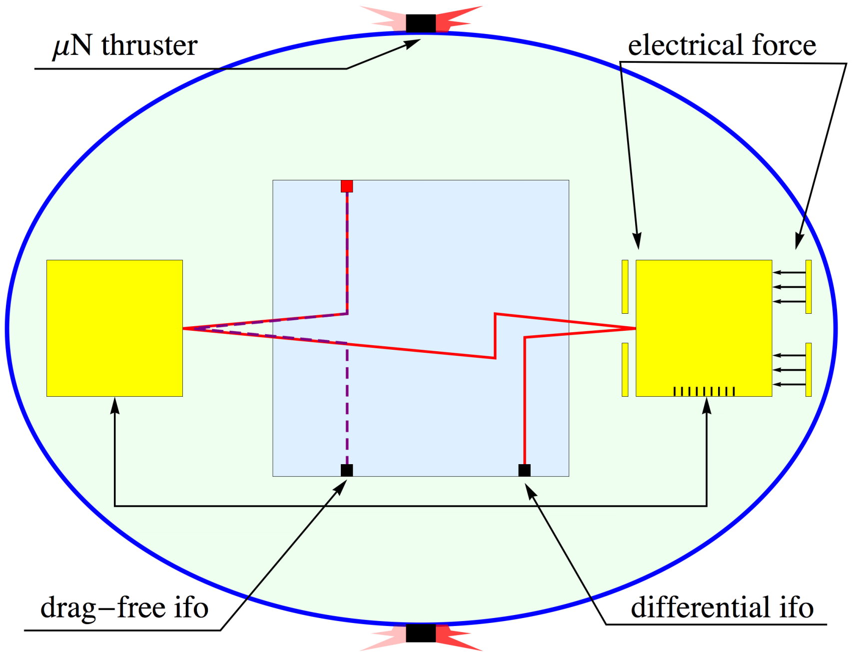
EDRS-C



Sentinel 2 (Astrium GmbH)

Front end electronics for capacitive sensing and actuation

- LPF more demanding than eLISA :
  - actuation along the measurement axis adds acceleration noise
- eLISA actuation along cross-axes:
  - may only disturb sensitive axes because of misalignments

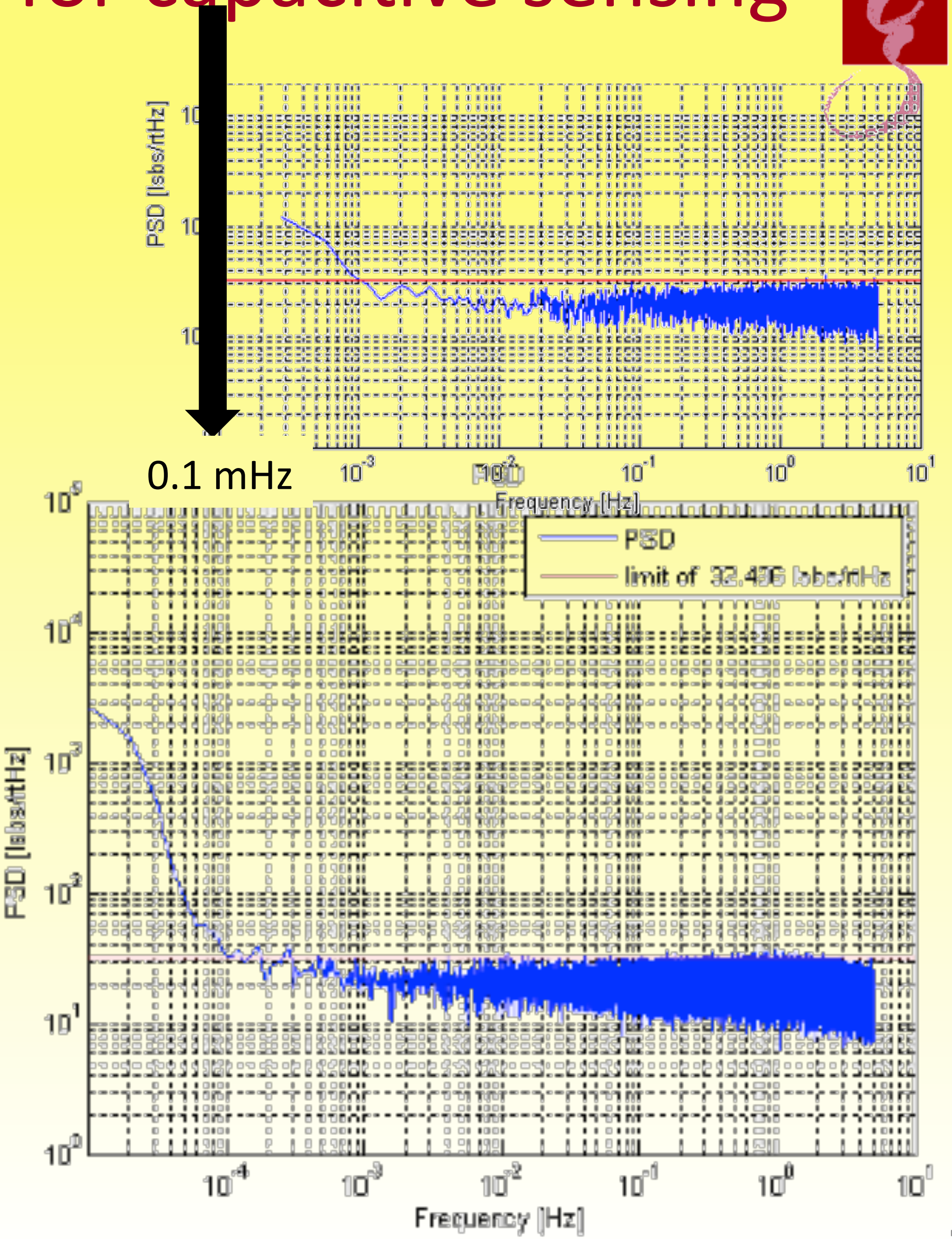


Front end electronics for capacitive sensing and actuation

- LPF must only meet requirements above 1 mHz

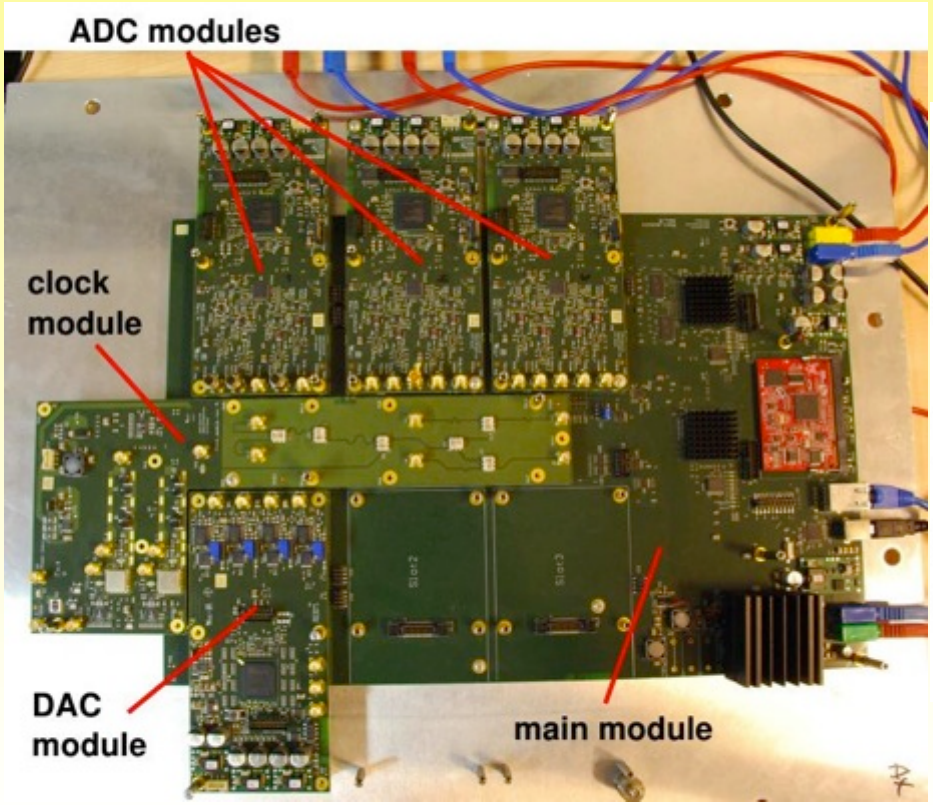
- eLISA must meet requirements at 0.1 mHz

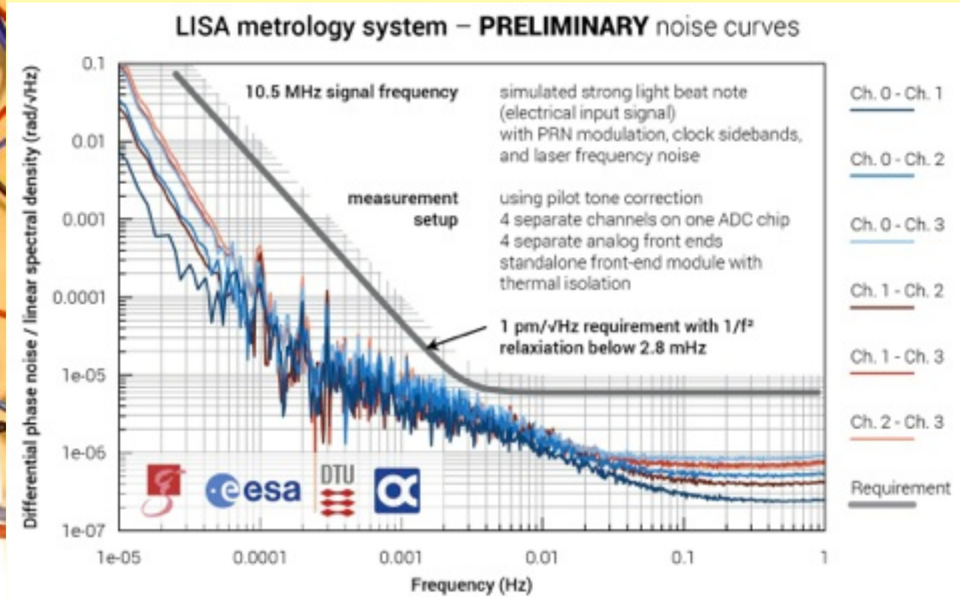
FEE upgrade under joint development ESA SSO



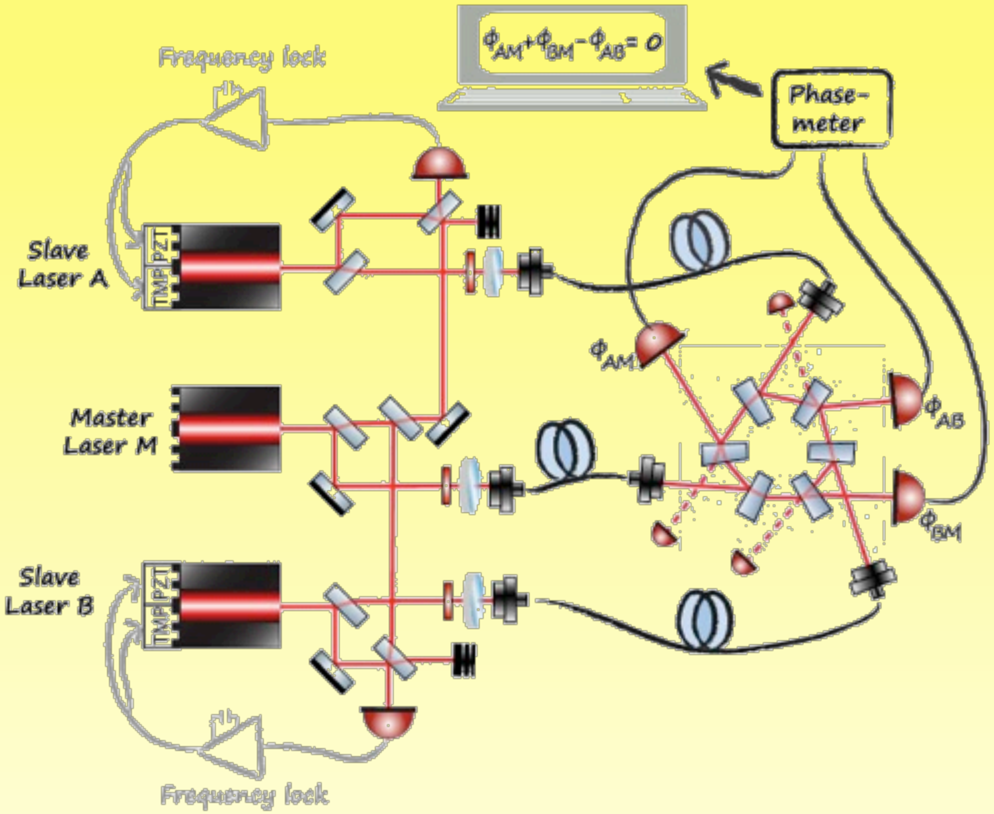
Phasemeter

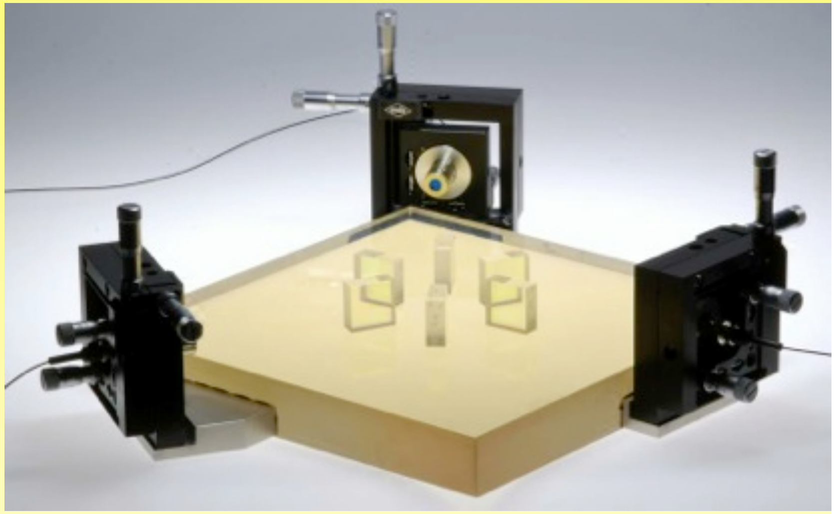
- European development (D, DK, ESA)
- LISA phasemeter with flight representative hardware, full performance and all functions
- Paper with algorithm details published





Optical Phasemeter Test



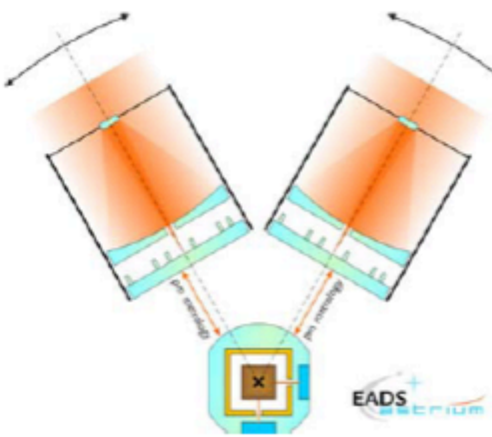
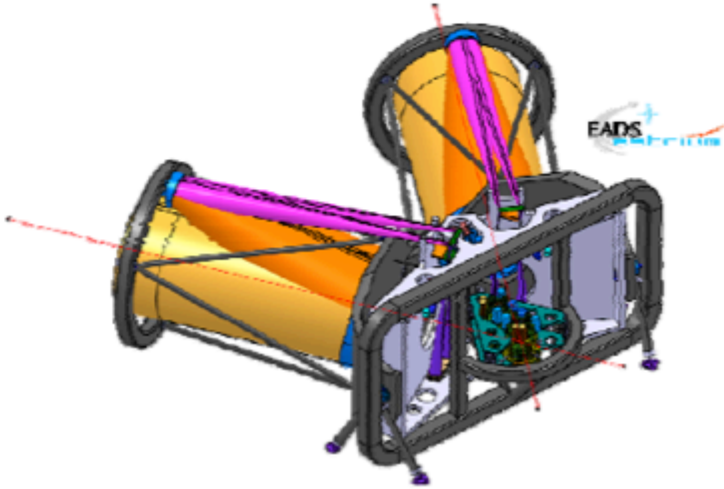
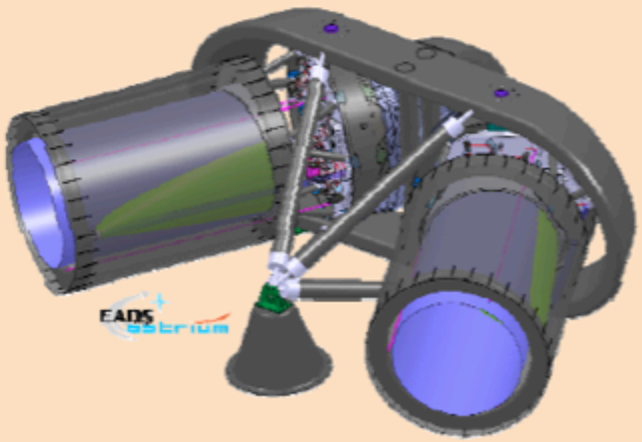
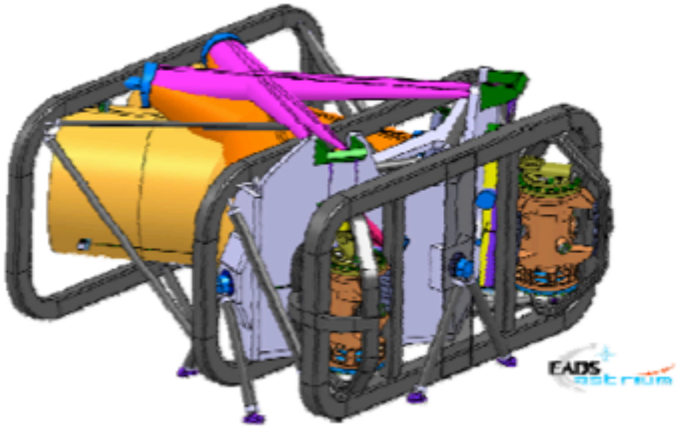


- Replace 2 identical signals in 2 channels (a-a=0):
- Create 3 signals with a+b+c=0, with arbitrary dynamics
- Has been done digitally, our setup is first optical test (full chain)
- Can also test TDI with 3 independent phasemeters
- Status: Functional, noise hunting/improvements in progress

Technology Roadmap Additions

- National agency funding
- Key items
- Revisit In-Field pointing
- Single active proof mass
- Schedule
- Complete Payload Breadboard
- System Study by semi-industrial outfit
- Have a Consortium System Engineer

New Look at In-Field Pointing?

Telescope Pointing	In-Field Pointing
	
Baseline (selected by ESA) 	

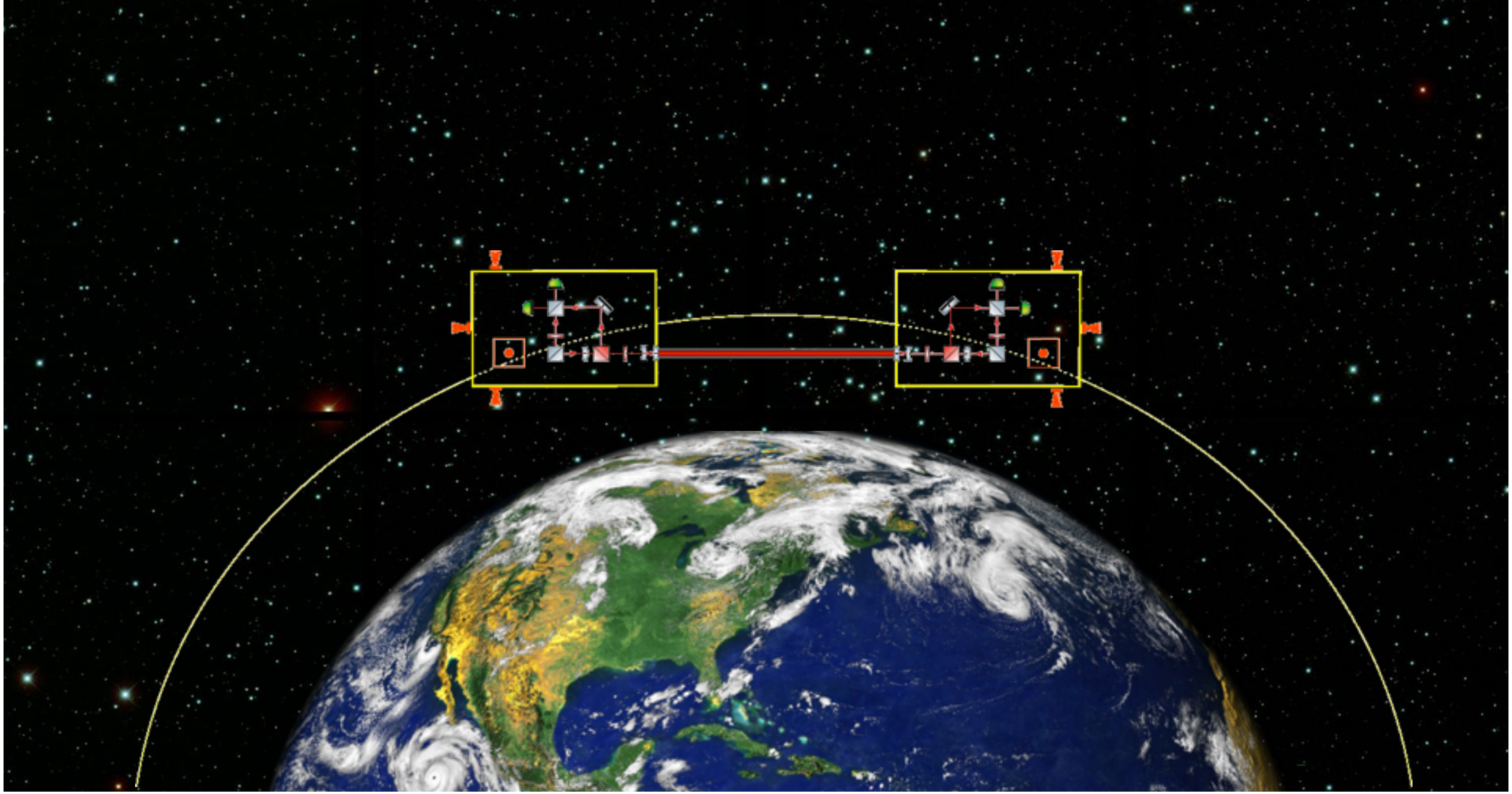
18. and 19.06.2013
AEI Hannover

eLISA Technology Roadmap Activities Germany

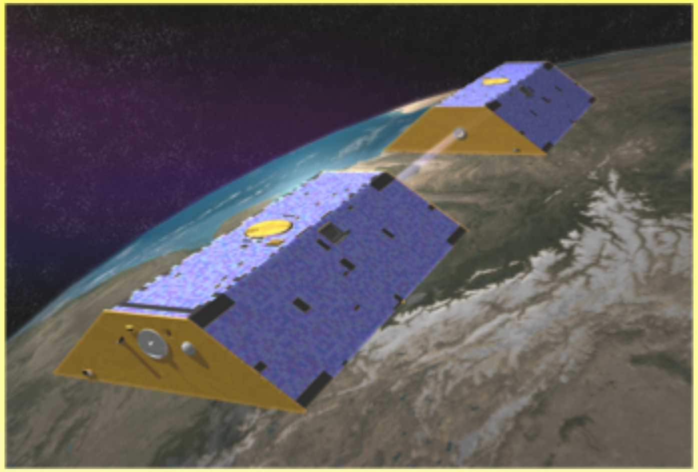
Kick Off Meeting &
Progress Meeting #1

Jens Reiche for the
AEI eLISA Team

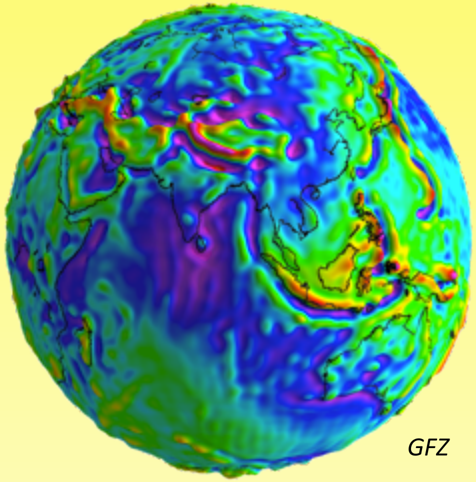
LISA Technology for Gravity Field Missions



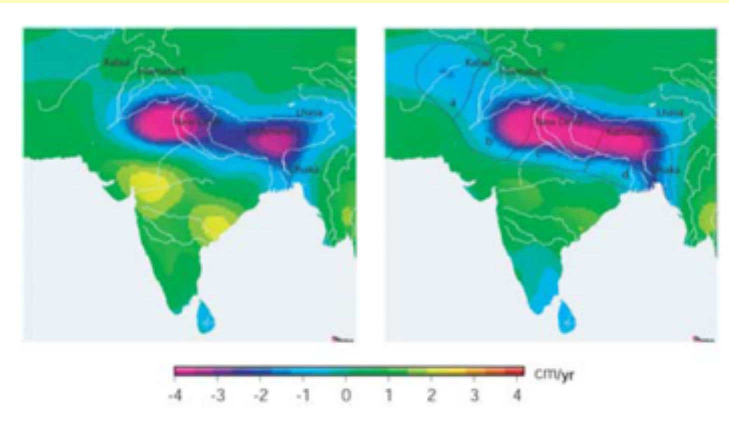
Gravity Recovery and Climate Experiment (GRACE)



GRACE Mission (UTCSR, GFZ, DLR, JPL). *Image credit: NASA*

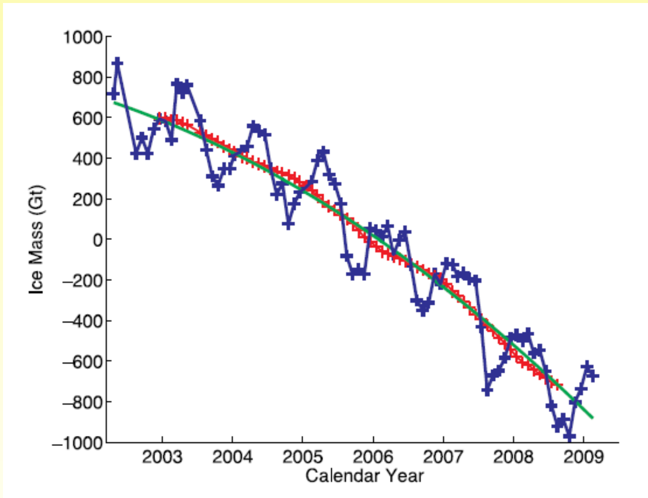


GFZ



Tiwari et al., *"Dwindling groundwater resources in northern India, from satellite gravity observations"*, Geophys. Research Lett. **36**, L18401 (2009).

Groundwater loss in India

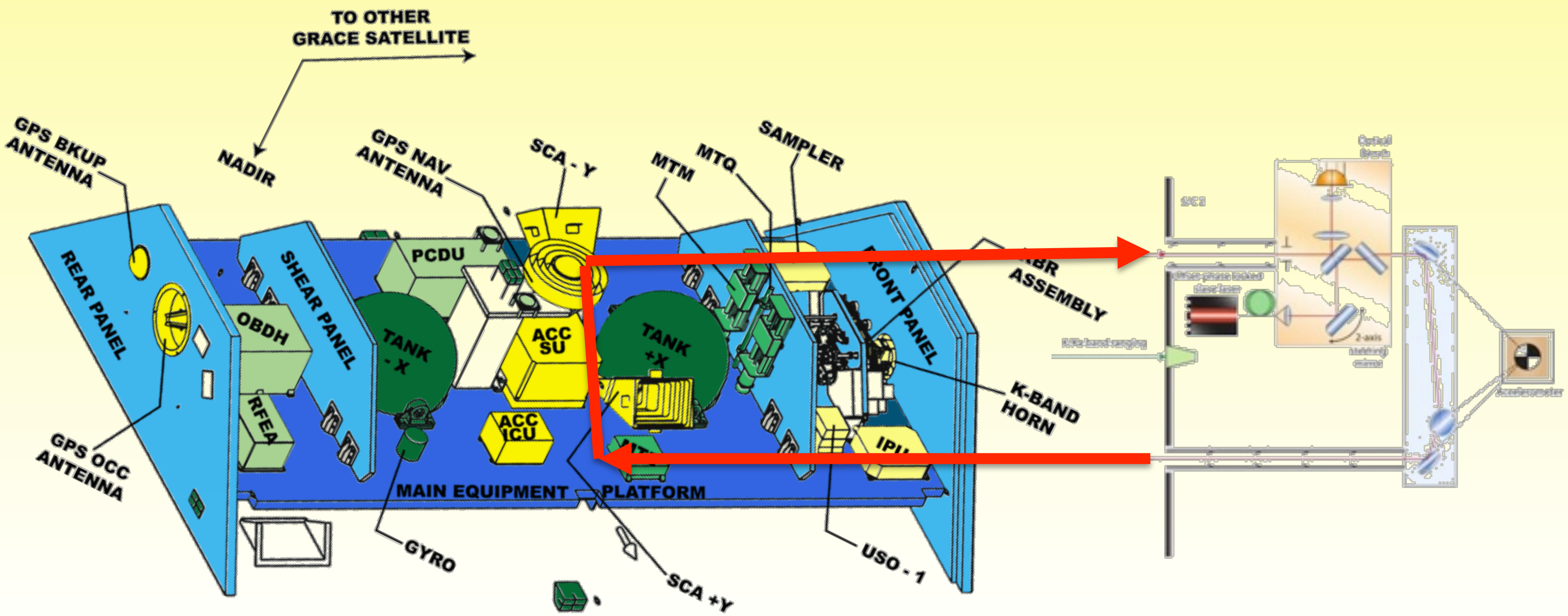


Velicogna, *"Increasing rates of ice mass loss from the Greenland and Antarctic ice sheets revealed by GRACE"* Geophys. Research Lett. **36**, L19503 (2009).

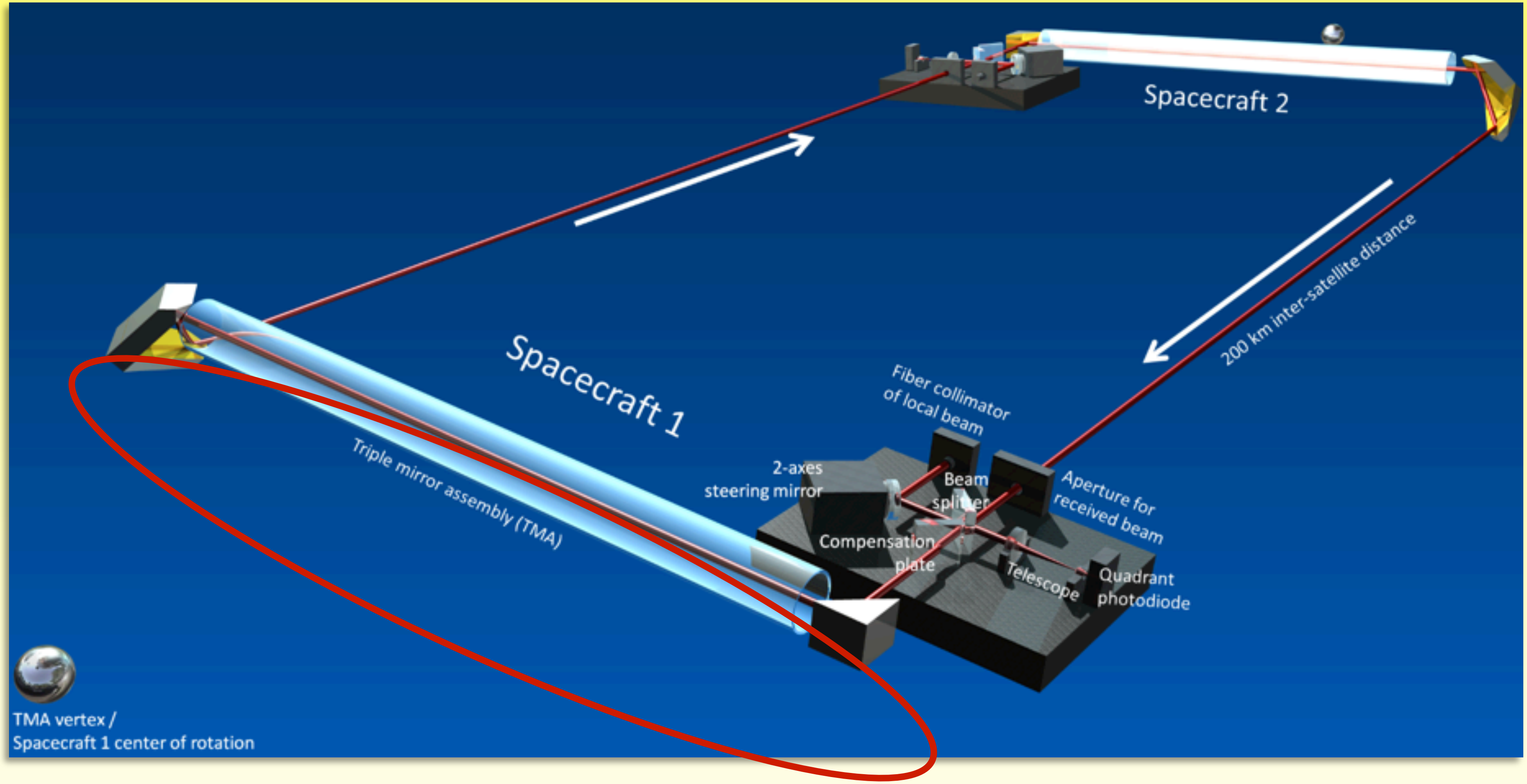
Ice mass loss in Greenland

GRACE Follow-On Mission Approved!

- USA/Germany, approved in Dec 2011, launch in 2017!
- LISA-type laser interferometry
- First-ever intersatellite laser ranging instrument (LRI)!



LRI Optics

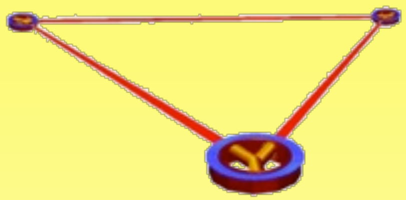


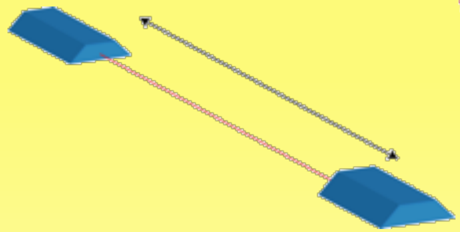
Sheard et al. :

"Intersatellite laser ranging instrument for the GRACE follow-on mission",

Journal of Geodesy, 2012 (DOI: 10.1007/s00190-012-0566-3).

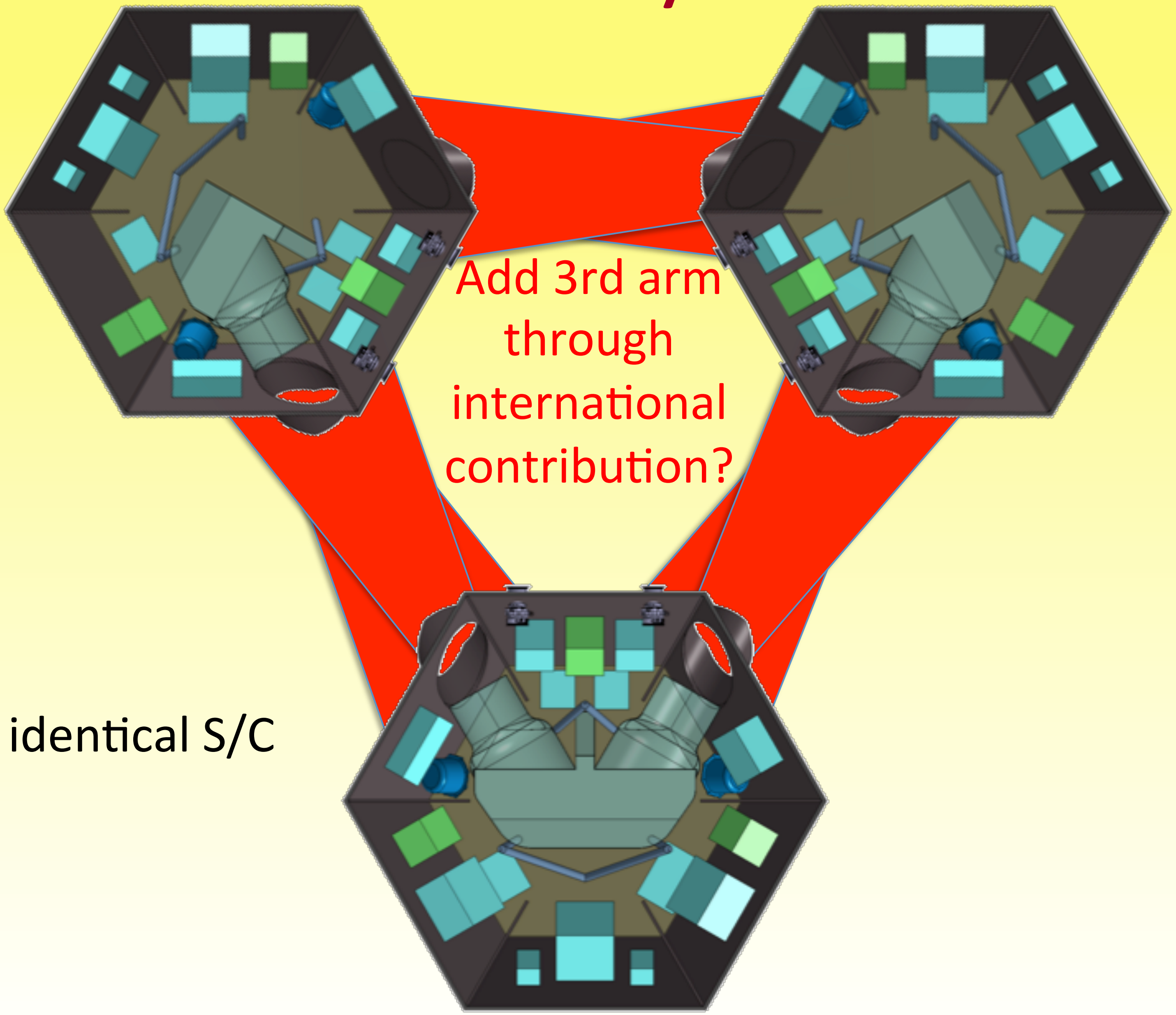
LISA and GRACE Follow-On





	LISA	LRI on GFO
Inter-satellite distance	5 million km	170...270 km
Orbit	Heliocentric (1 a.u.)	Low Earth Orbit (400...500 km)
Orbit environment	No atmospheric drag, stable thermal environment	Atmospheric drag, large thermal disturbances
Attitude and Orbit Control System	Drag-free using µN thrusters	Attitude control with magnetic torquers and cold gas thrusters
Measurement band	**100 µHz – 1 Hz**	**200 µHz –100 mHz**
Measurement noise	12 pm/√Hz (× freq. dep.)	80 nm/√Hz (× freq. dep.)
Telescope aperture diameter	38 cm	≈1 cm
Transmit beam waist radius	17 cm	≈2 mm
Transmit power	1 W	≈20 mW
Effective received power (at photodetector)	**≈100 pW**	**≈100 pW**
Maximum relative L.O.S. velocity	±15 m/s	≤ ±3 m/s (depending on orbits)

eLISA Lay-Out



3 identical S/C

International Contributions for L3

- Must not be mission critical
  - Flight equivalent must exist in Europe
- Must bring real cost savings
  - Needs clean interfaces
  - Minimize shadow engineering required in ESA and Member States
  - Low friction losses required
- Ideally we want third arm back
  - Has implications both at ESA and Member States
- We need a creative mix of contributions

International Contributions

- What is noble work and what is not?
- Easily identifiable S/C building blocks:
  - Launcher
  - Propulsion modules
  - Thrusters
  - Pieces like: Solar array, power supplies, batteries, structures, mechanisms, star trackers, TTC, antennas
- Easily identifiable Payload items:
  - Telescopes
  - Lasers, Modulators, reference cavities
  - CCDs, Diodes, Pre-Amps
  - Proof masses
  - Actuators
  - Electronics, USO

International plans for space-based detectors

- USA
  - Scenario 1: Junior partner in eLISA
  - Scenario 2: NASA-led mission (SGO)
  - Technology: Telescope, Laser system, Interferometry , Optical Bench technology, GRS, Charge management, torsion pendulum test benches
- China
  - Scenario 1: Join eLISA with a 20% contribution
  - Scenario 2: Develop a similar Chinese mission
  - Technology: Telescopes, interferometry, GRS and torsion pendulum
- Japan: Decigo-Pathfinder was strong candidate for a small mission by Jaxa, not selected

Roadmap for eLISA as ESA L3

• 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)

Summary

- LISA Pathfinder
  - Has all payload hardware tested and delivered
  - Will fly in 2015 on a robust schedule
  - Will fly hardware designed for and usable by eLISA
- All crucial technology needs to be available for L3 mission concept selection in 2020

- Some form of LISA will fly!
  - Either as ESA L3 in 2034
  - Or as truly international collaboration!
    - And maybe even earlier!

We will hear the Universe!