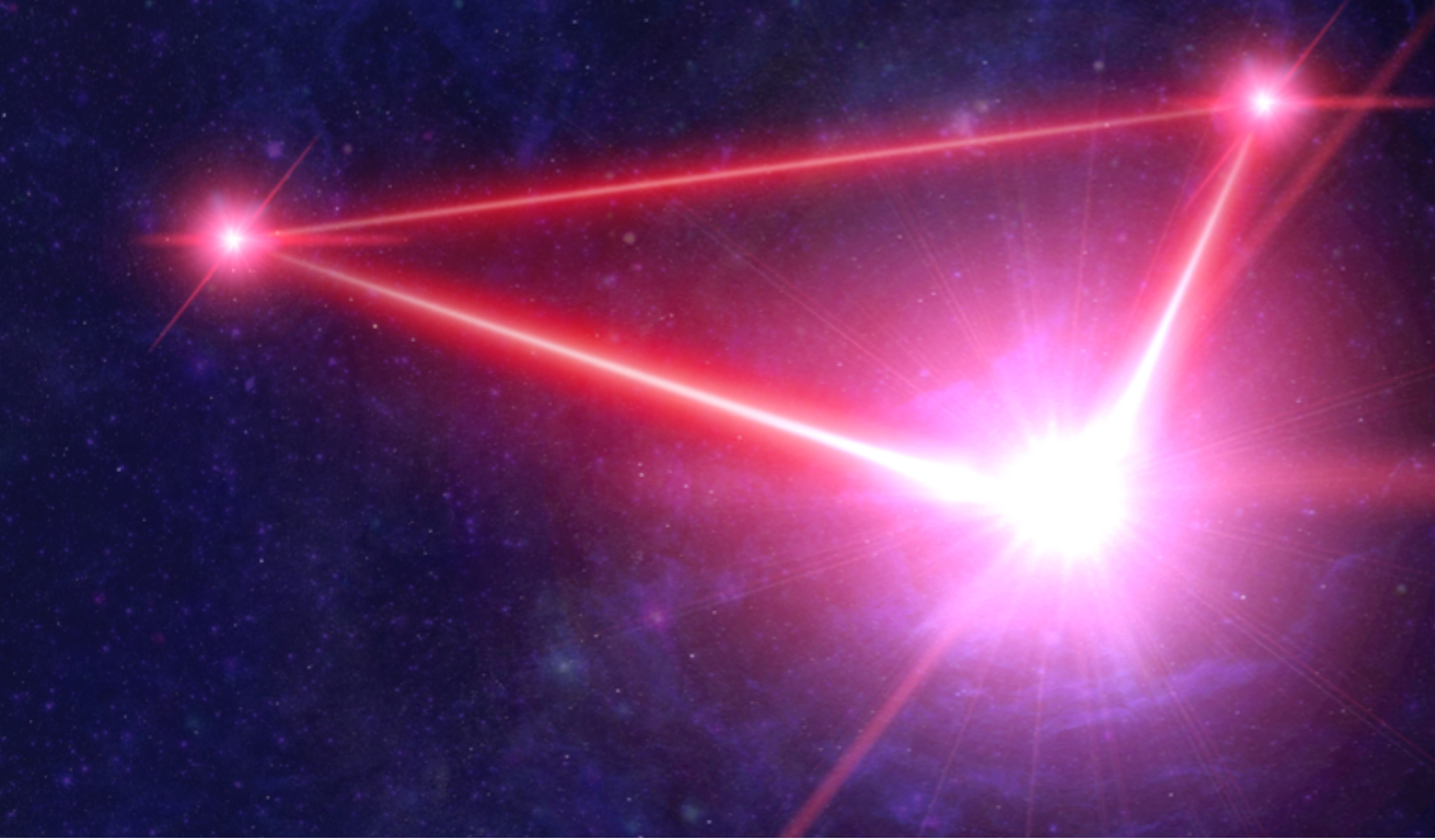


LISA 2017: A New Beginning

Ira Thorpe, NASA/GSFC
For the International LISA Science Community
33rd Institut D'Astrophysique De Paris Colloquium
"The Era of Gravitational Wave Astronomy"
26 June, 2017

LISA selected!

ESA's Science Programme Committee,
June 20th, 2017


cosmic vision

esa

ESA | SCIENCE & TECHNOLOGY | COSMIC VISION

Missions
- Show All Missions

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

Cosmic Vision themes
- The Hot and Energetic Universe
- Planets and Life
- The Solar System
- Fundamental Laws
- The Universe

S-class mission
- CHEOPS [S1]
- SMILE [S2]

M-class missions
- Euclid [M2]
- PLATO [M3]
- Solar Orbiter [M1]

L-class missions

GRAVITATIONAL WAVE MISSION SELECTED, PLANET-HUNTING MISSION MOVES FORWARD

20 June 2017

The LISA trio of satellites to detect gravitational waves from space has been selected as the third large-class mission in ESA's Science programme, while the PLATO exoplanet hunter moves into development.

These important milestones were decided upon during a meeting of ESA's Science Programme Committee today, and ensure the continuation of ESA's Cosmic Vision plan through the next two decades.

The 'gravitational universe' was identified in 2013 as the theme for the third large-class mission, L3, searching for ripples in the fabric of spacetime created by celestial objects with very strong gravity, such as pairs of merging black holes.

Merging black holes. *Credit: ESA/C. Carreau*

Predicted a century ago by Albert Einstein's general theory of relativity, gravitational waves remained elusive until the first direct detection by the ground-based Laser Interferometer Gravitational-Wave Observatory in September 2015. That signal was triggered by the merging of two black holes some 1.3 billion light-years away. Since then, two more events have been detected.

Furthermore, ESA's LISA Pathfinder mission has also now demonstrated key technologies needed to detect gravitational waves from space. This includes free-falling test masses linked by laser and isolated from all external and internal forces except gravity, a requirement to measure any possible distortion caused by a passing gravitational wave.

Search here

23-Jun-2017 13:06 UT

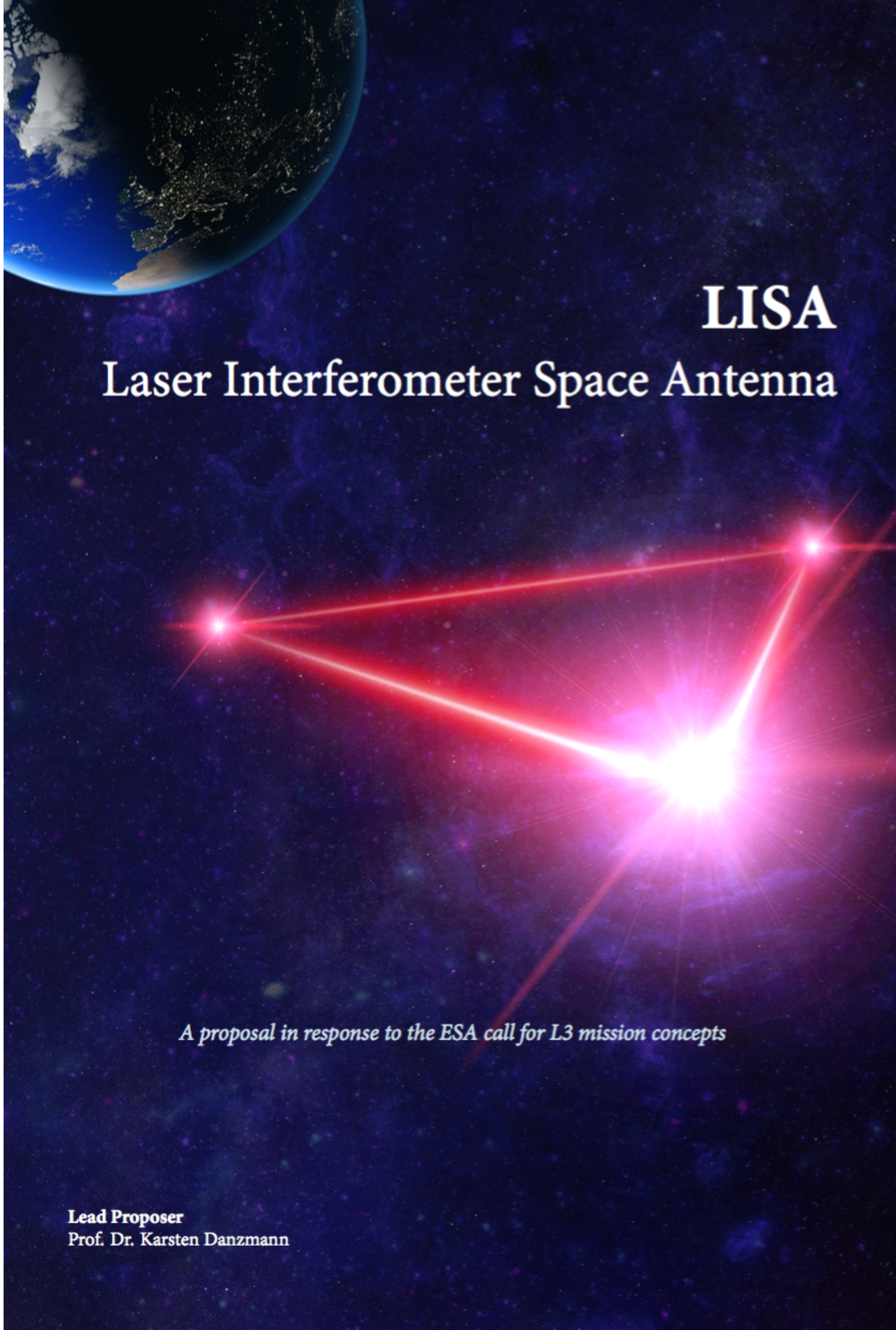
Shortcut URL
http://sci.esa.int/jump.cfm?oid=59243

Images And Videos
- Merging black holes
- Searching for exoplanetary systems

See Also
- ESA's new vision to study the invisible Universe
- LISA Pathfinder to conclude trailblazing mission

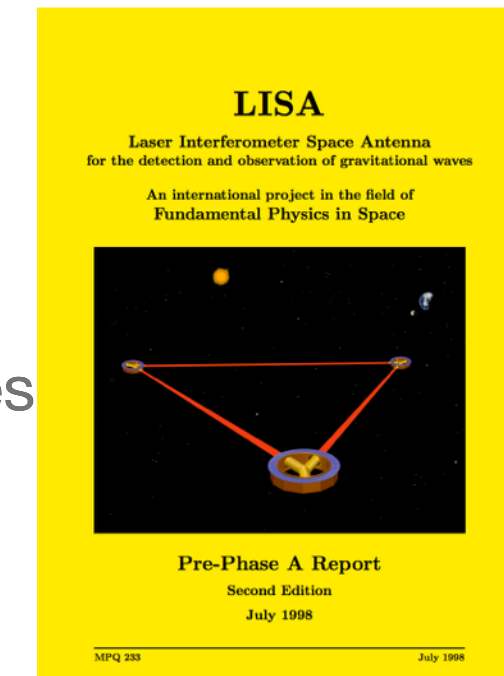
LISA 2017 Proposal

- Prepared in response to ESA's call for mission concepts to fulfill Gravitational Universe science theme
- Proposers
  - Lead: Karsten Danzmann
  - Core team of 82 scientists (Europe & US)
  - Consortium of ~300 scientists
  - Supporters ~1300 individuals



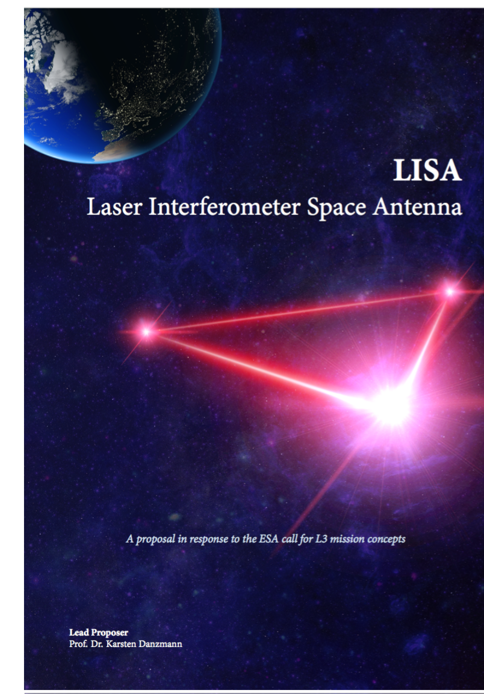
1998

- 3 spacecraft, 3 arms
- 5 million km arms
- Drag free test masses
- 40cm telescopes
- 1W laser



2017

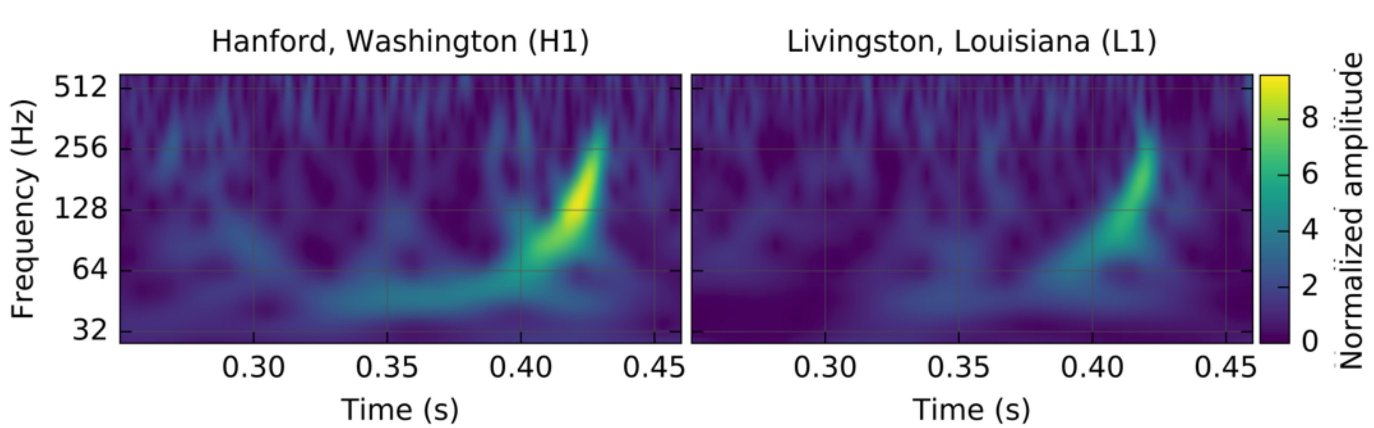
- 3 spacecraft, 3 arms
- 2.5 million km arms
- Drag free test masses
- 30cm telescopes
- 2W laser



LIGO Changes Everything

- Eliminates nagging doubts of some
- Generates enthusiasm for GWs in scientific community and general public
- Covered in hundreds of newspapers world-wide

  (see http://www.newseum.org/todaysfrontpages/?tfp_display=archive-date&tfp_archive_id=021216)



LIGO/Caltech/MIT

2,00 € Première édition. N° 10801

VENDREDI 12 FÉVRIER 2016

Libération

DERNIERS VERTS POUR LA ROUTE

Trois écolos qui entrent, Ayrault au Quai d'Orsay: ce qui pourrait être le dernier gouvernement du quinquennat se veut stratégique en vue de 2017. Suffisant?

PAGES 2-5

EINSTEIN AVAIT RAISON: L'UNIVERS VIBRE

Les ondes gravitationnelles, théorisées par le physicien il y a cent ans, ont enfin pu être observées: des plis infimes de l'espace-temps qui n'en sont pas moins une découverte majeure. PAGES 16-17

La crise financière bientôt de retour?

Croissance atone, banques surexposées, pétrole bradé… Tous les éléments sont réunis pour un nouveau krach. DÉCRYPTAGE, PAGES 18-19 Lire aussi l'interview de l'économiste Patrick Artus: «Les marchés financiers sont gavés de liquidités». IDÉES, PAGES 24-25

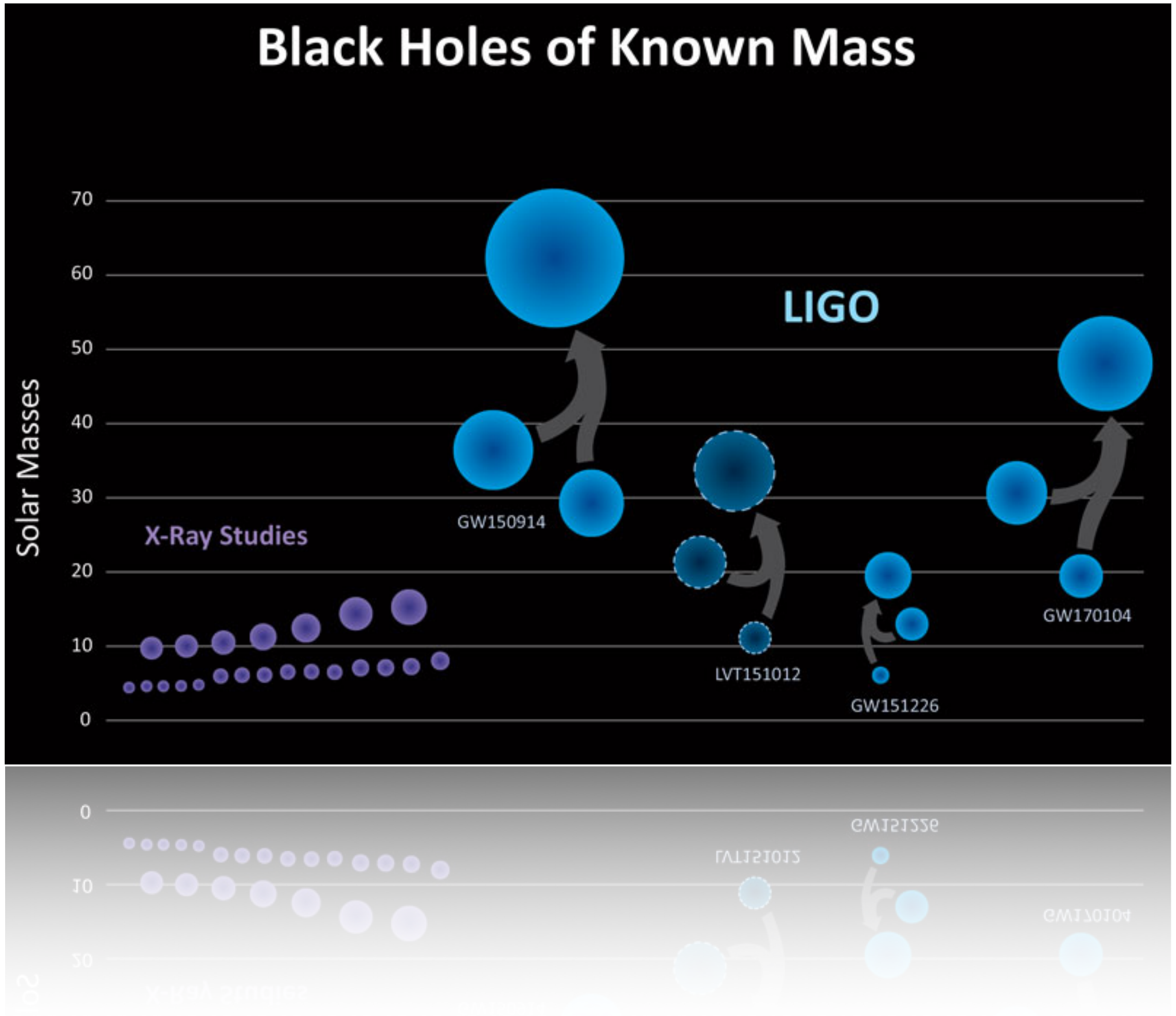
Basket: Kobe Bryant, le crépuscule d'une star

Dernier All Star Game, ce week-end, pour la légende des Lakers: point d'orgue d'une ultime saison en forme de jubilé. PAGES 20-21

Discovery potential validated

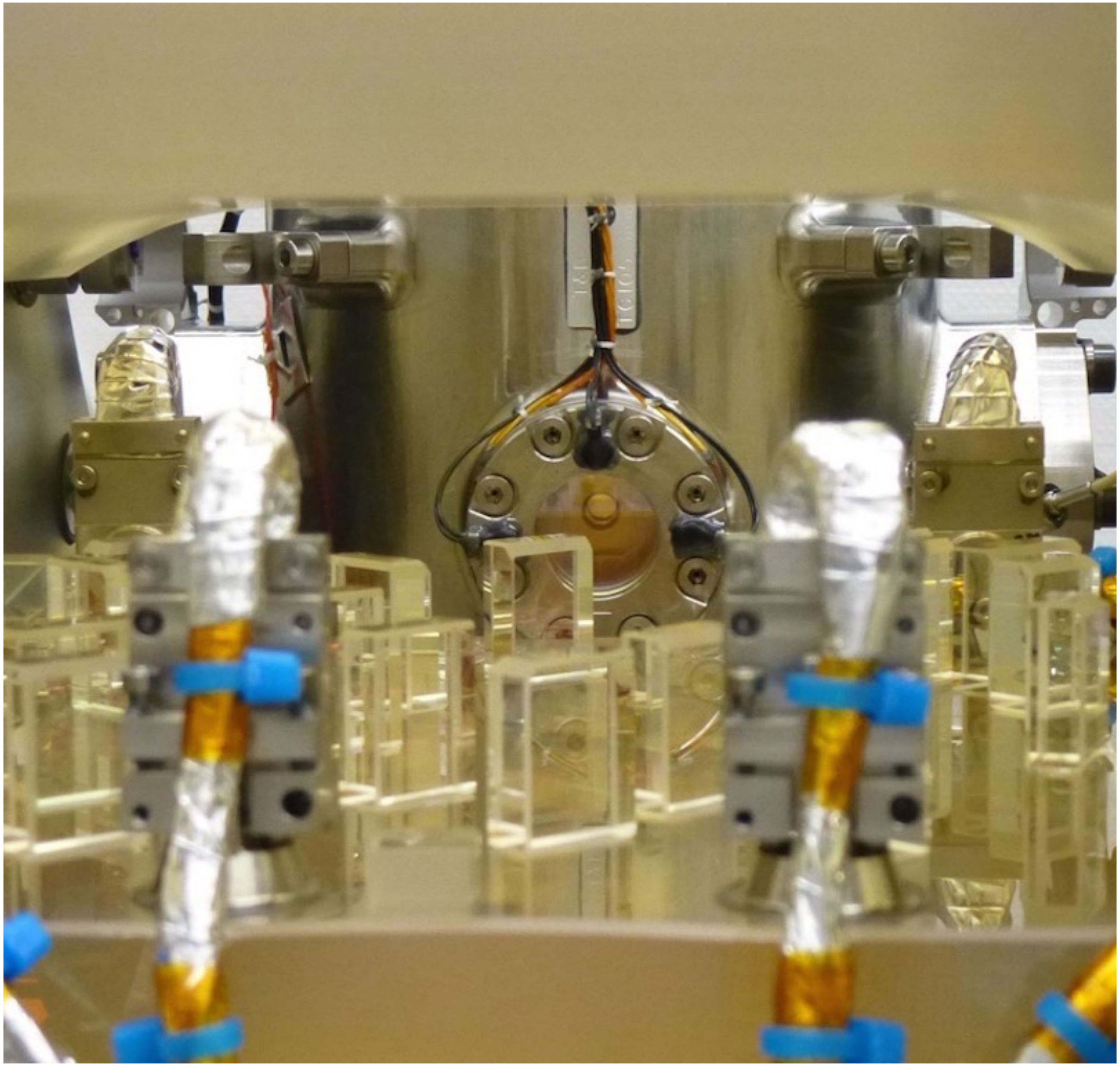
- Very first detection yields a new scientific question - *where do the high-mass progenitor BHs come from?*
- Opening additional GW wavebands (LISA, PTAs, CMBpol) will lead to additional discoveries.

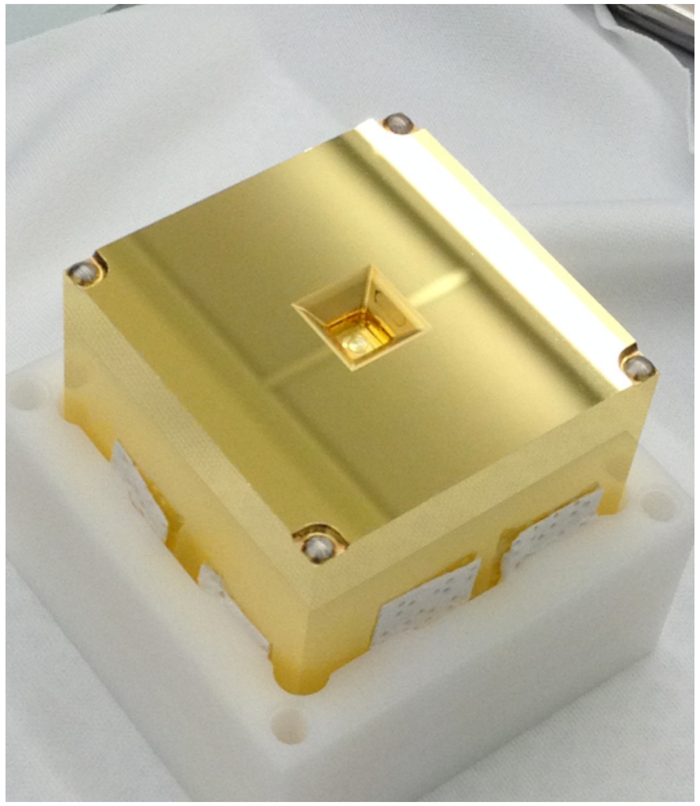
LIGO/Caltech/Sonoma State (Aurore Simonnet)



LISA Pathfinder *also* changed everything

- It *is* possible to transfer precision metrology technologies from the research lab to aerospace
- New technologies on LPF
    - high-mass, large-gap drag-free test masses
    - 18 DoF kinematic control system
    - non-contact UV charge control
    - ~~pico~~ *femto*-meter interferometry
        - precision micronewton thrusters (cold gas & colloidal)
        - magnetic and thermal diagnostic system
- A ‘collaboration pathfinder’ as well





LPF Instruments

U. Glasgow, U. Birmingham, U. Trento, CGS, Airbus Defense & Space, ESA, Busek, JPL, NASA

Integration of science payload, spacecraft, and propulsion module ESA, iABG, Airbus Defense & Space

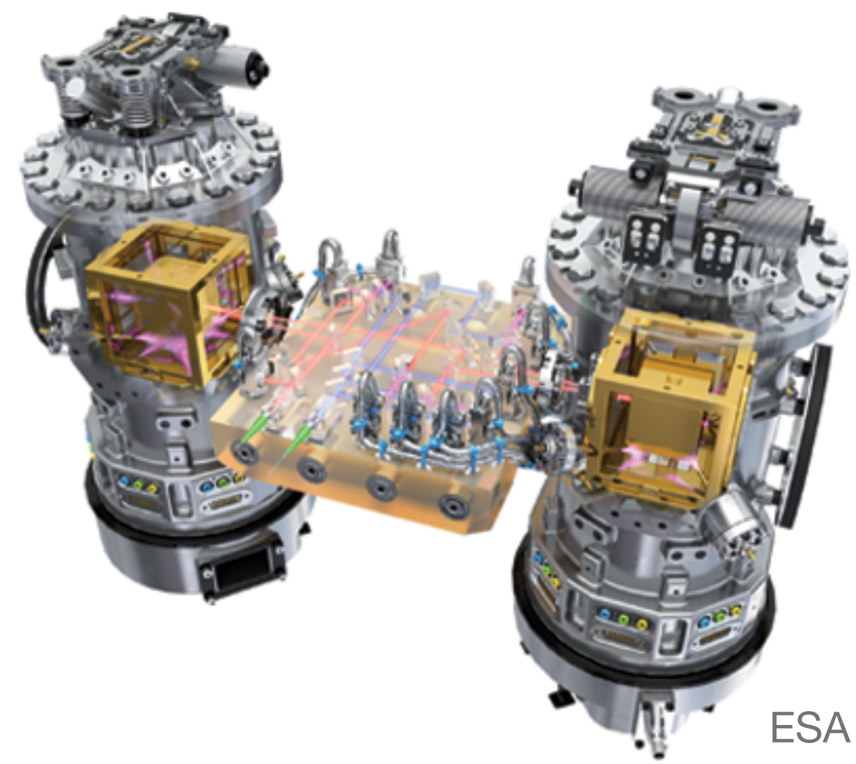
Launch integration ESA, CNES, Airbus Defense & Space

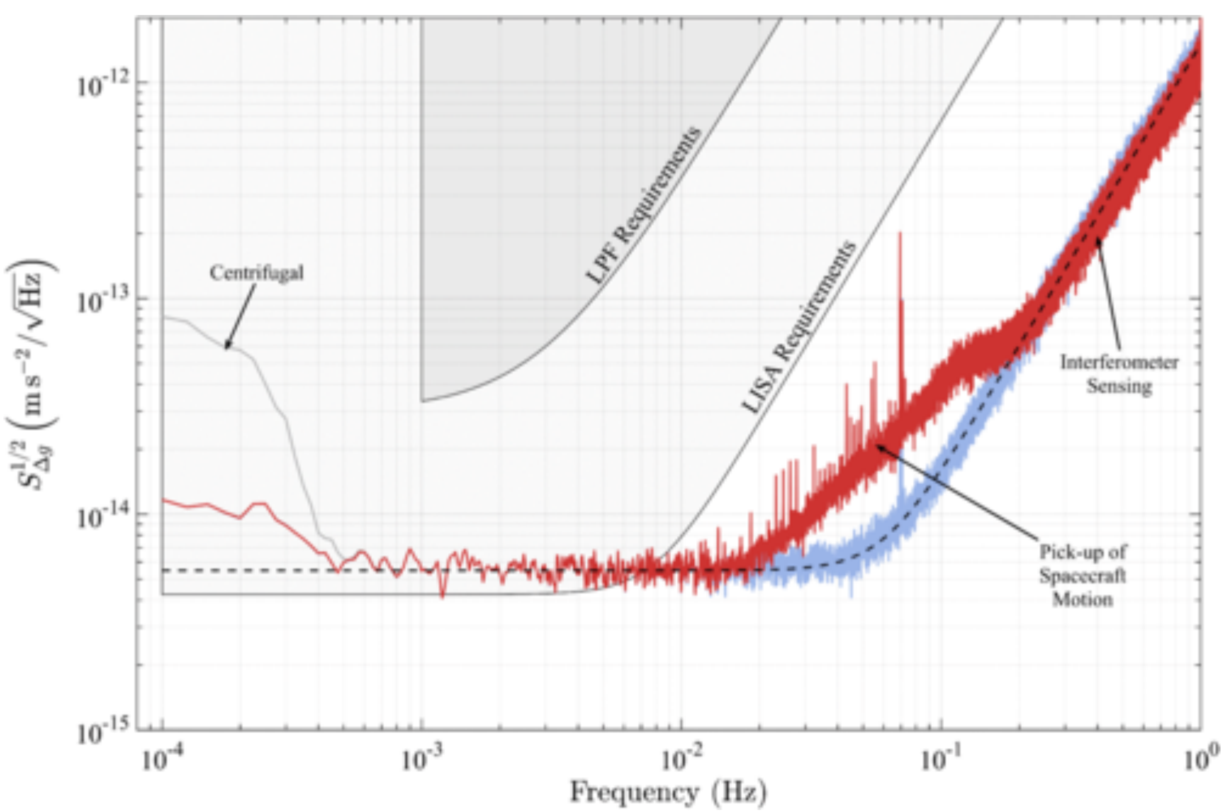
2015-12-03 01:04:00

Kourou, French Guiana

First results: success!

- LPF requirements met "out of the box"
- Noise model validated
  - no major surprises
  - some interesting effects
- Results published in PRL in June 2016, just 3 months into science ops!


ESA

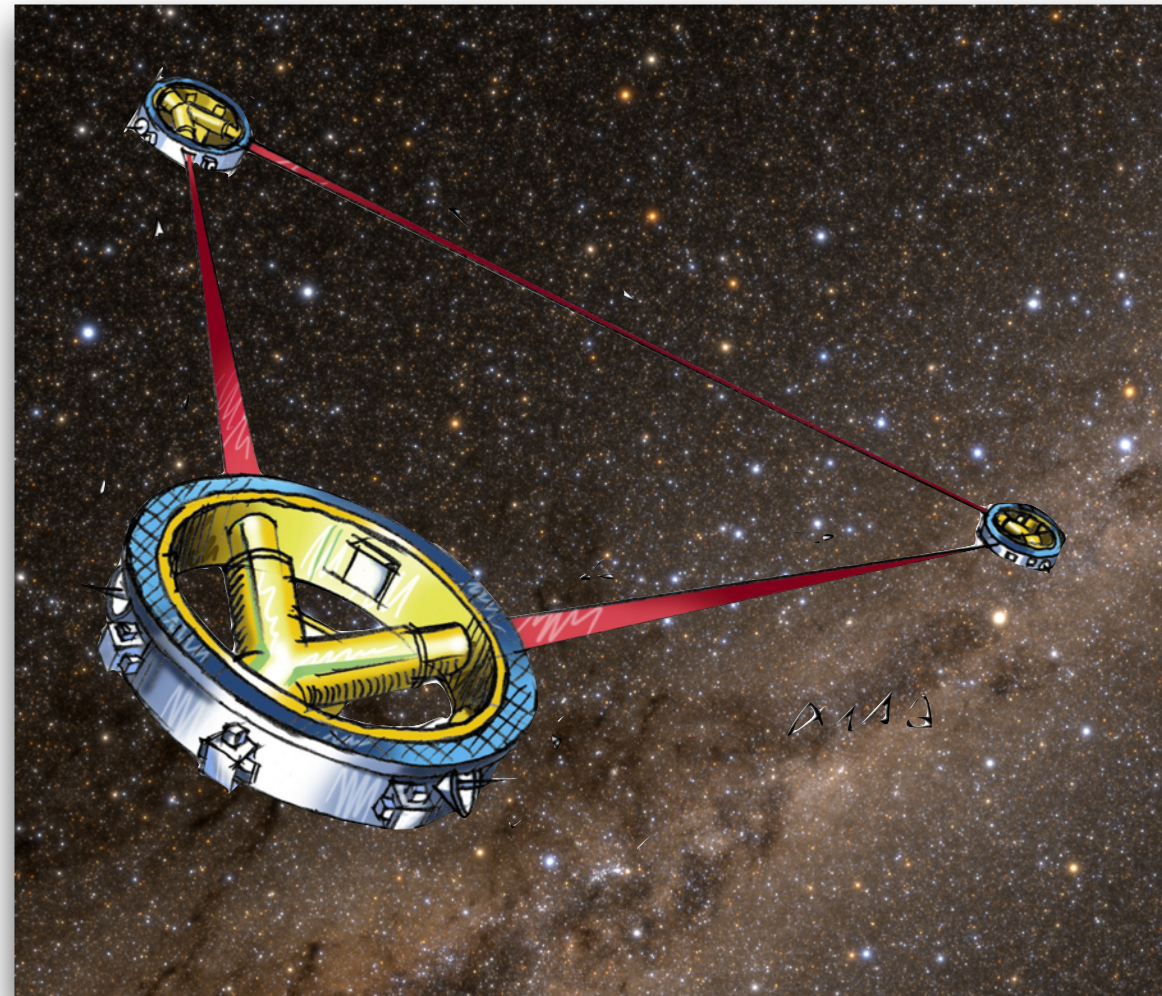


LPF continues its mission

- Performance improves with time (pressure) and tuning of the instrument
- Suite of dedicated experiments to validate noise model and characterize individual components
- End in sight
  - Science operations ends this week
  - Mission ops end 18 July

NASA/STScI

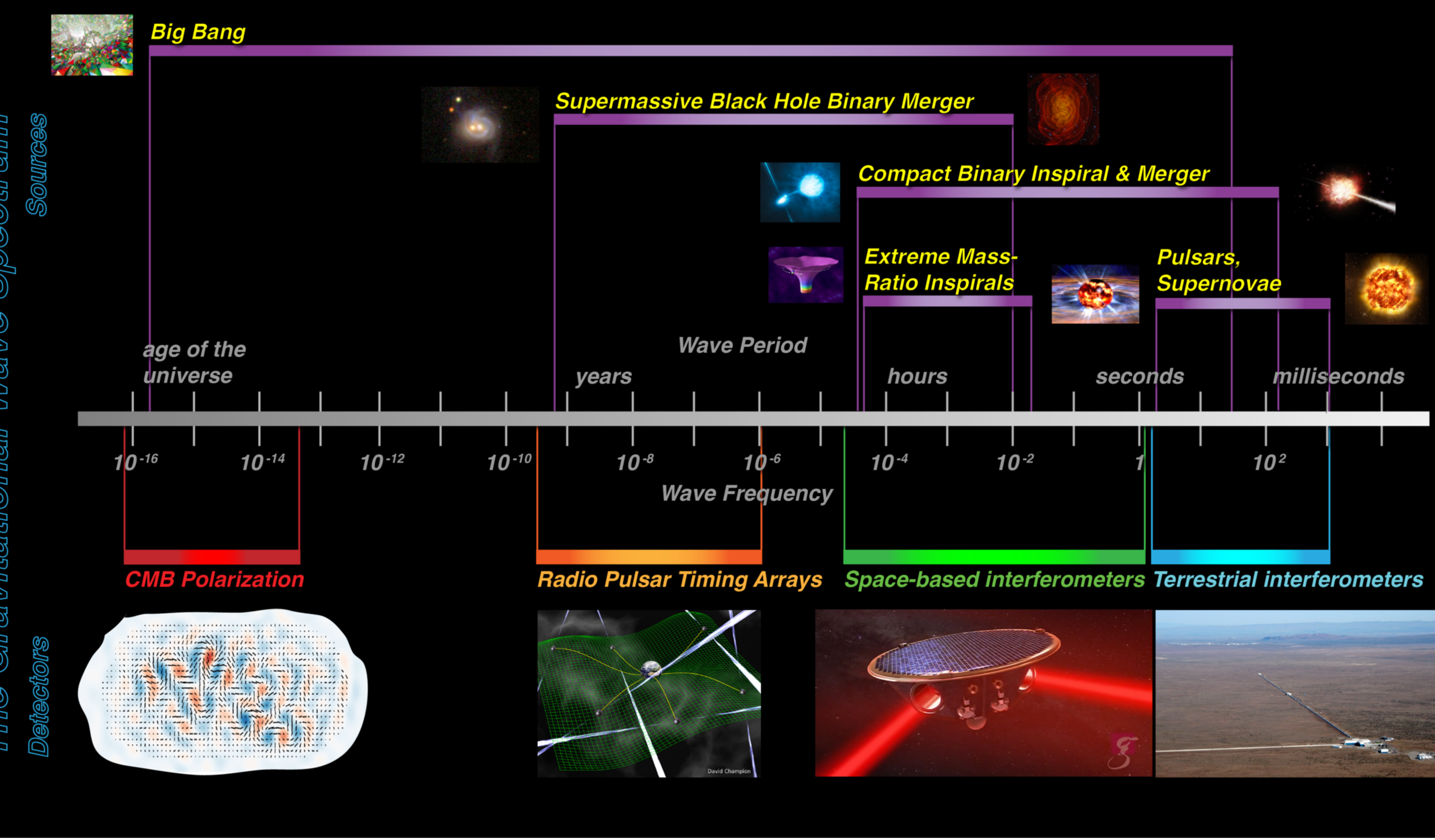
- Avoid terrestrial disturbances
- Access new spectral bands



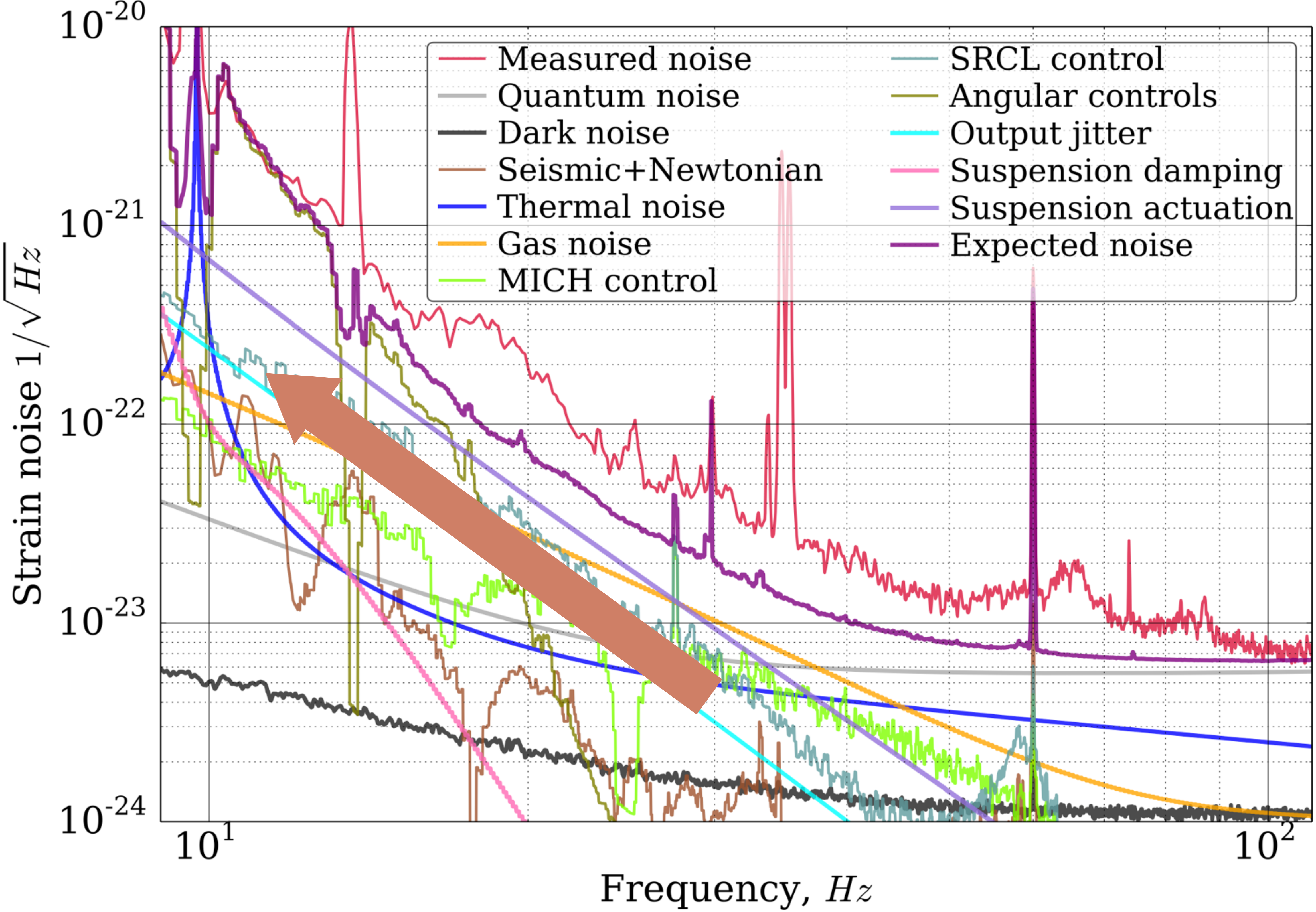
- Avoid terrestrial disturbances
- Access new spectral bands

Why go to space?

Same reasons as for EM telescopes



The Gravitational Wave Spectrum



Advanced LIGO Noises

THE GRAVITATIONAL UNIVERSE

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

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MPI for Gravitational Physics and
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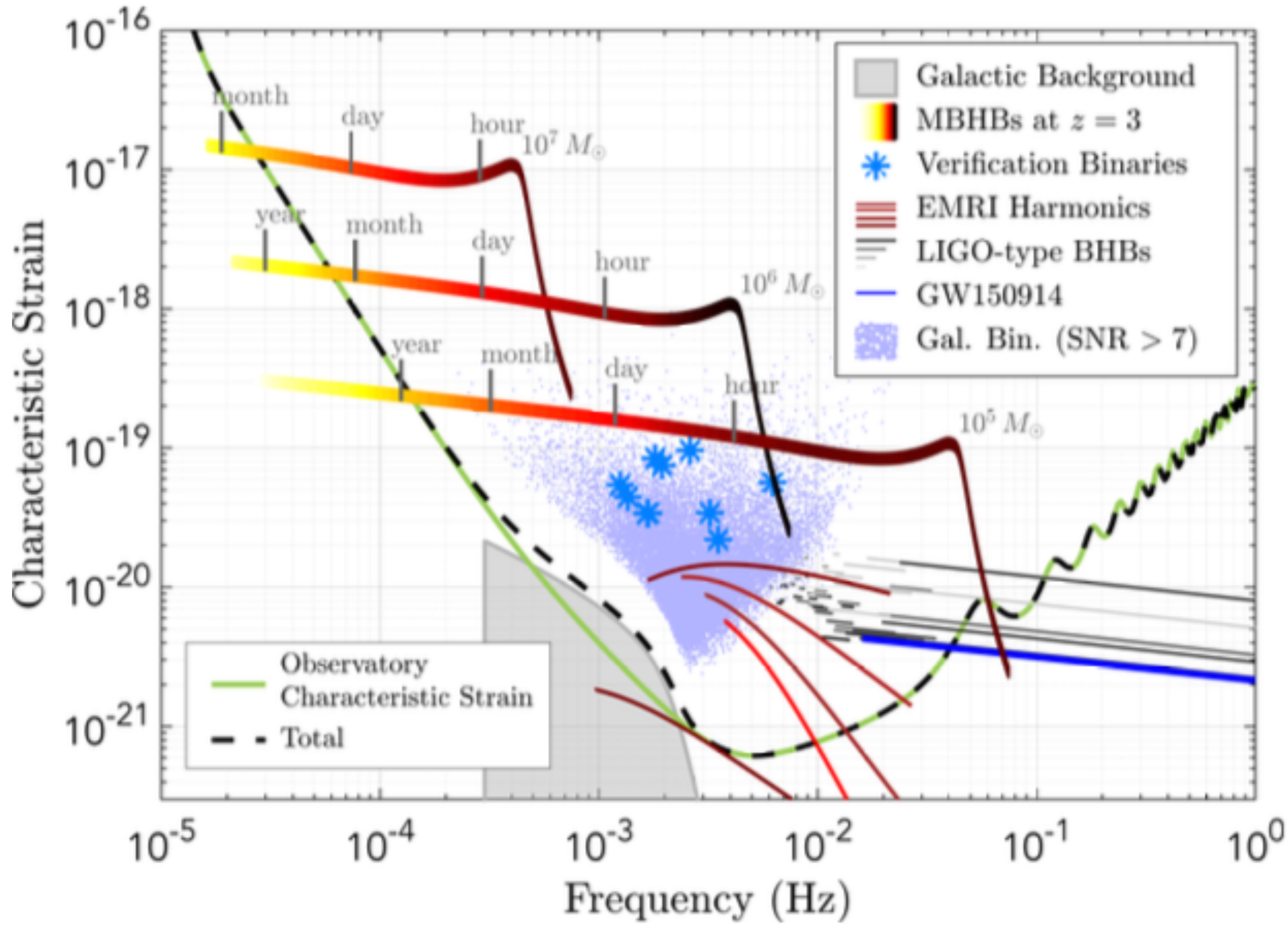
The last century has seen enormous progress in our understanding of the Universe. We know the life cycles of stars, the structure of galaxies, the remnants of the big bang, and have a general understanding of how the Universe evolved. We have come remarkably far using electromagnetic radiation as our 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 $z \sim 20$, 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

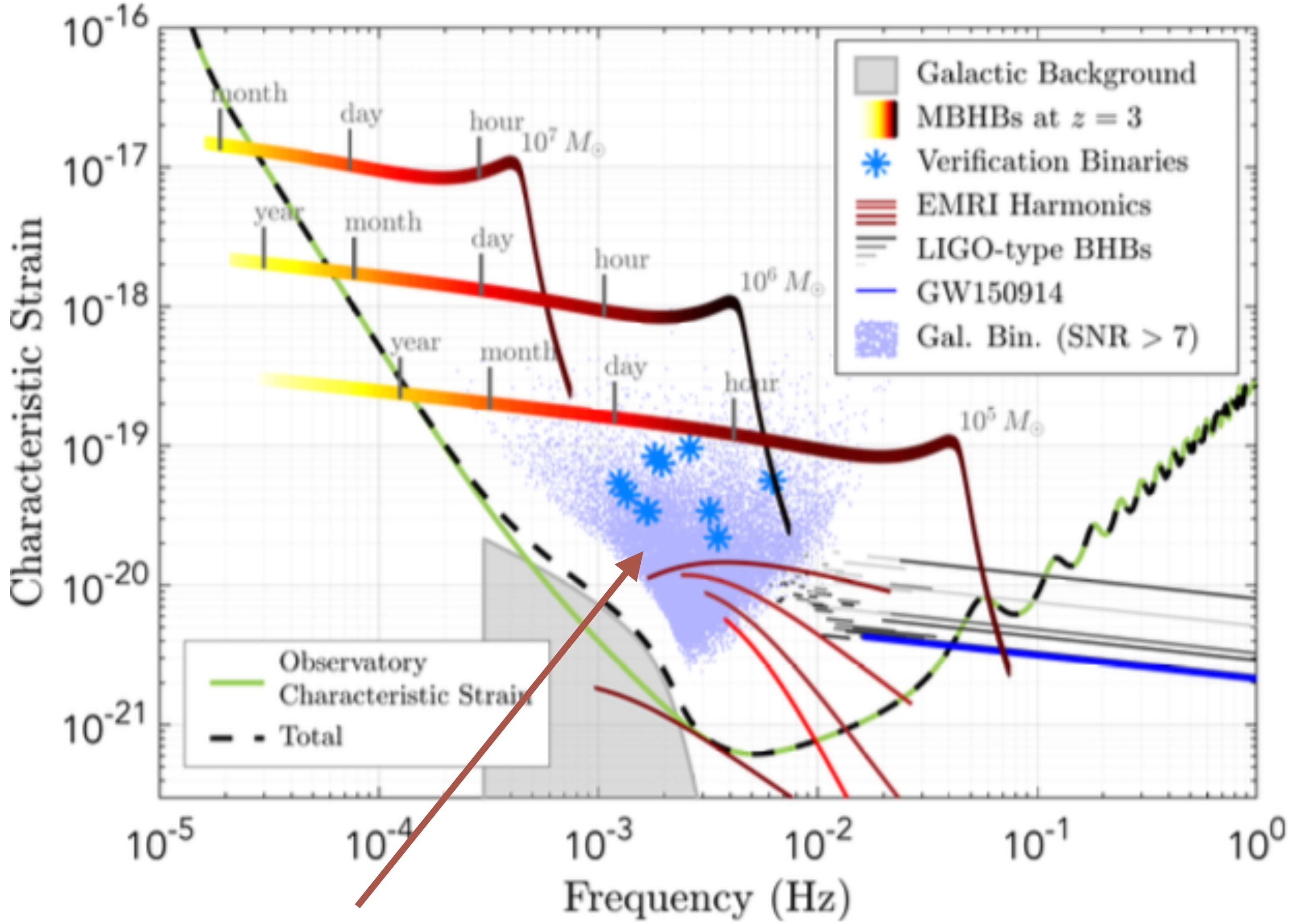
The LISA Science Case

Selected in 2013 as Science Theme for 3rd Large Mission opportunity in ESA's Cosmic Visions Programme



LISA Sources and Noise

See talks by N. Cornish Tuesday @ 9 and A. Sesana Thursday @ 14:15



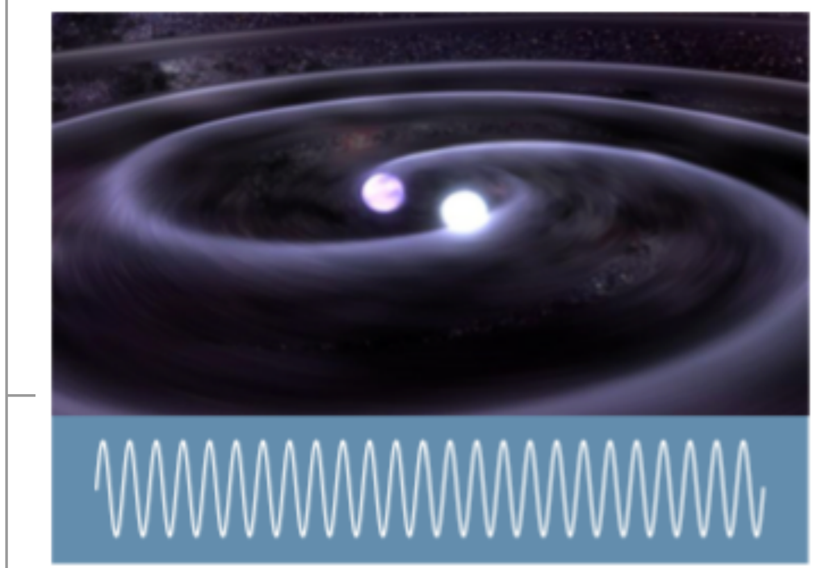


Figure 8: Illustration of a compact binary star system and a representative waveform of the expected gravitational waves. Two stars orbiting each other in a death grip are destined to merge all the while flooding space with gravitational waves. *Credit: GSFC/D.Berry.*

Galactic Binaries

Galactic Binary Science

- Demographics of compact binary systems in the Milky Way
  - ratio of WD, NS, and BH components
- Astrophysics of some WD systems
  - mass transfer rates
- Structure of Milky Way in WD binaries
- Multimessenger astronomy
  - GR tests
  - resolve astrophysical degeneracies

Kilic, et al. (2014) MNRAS Letters, 444, L1

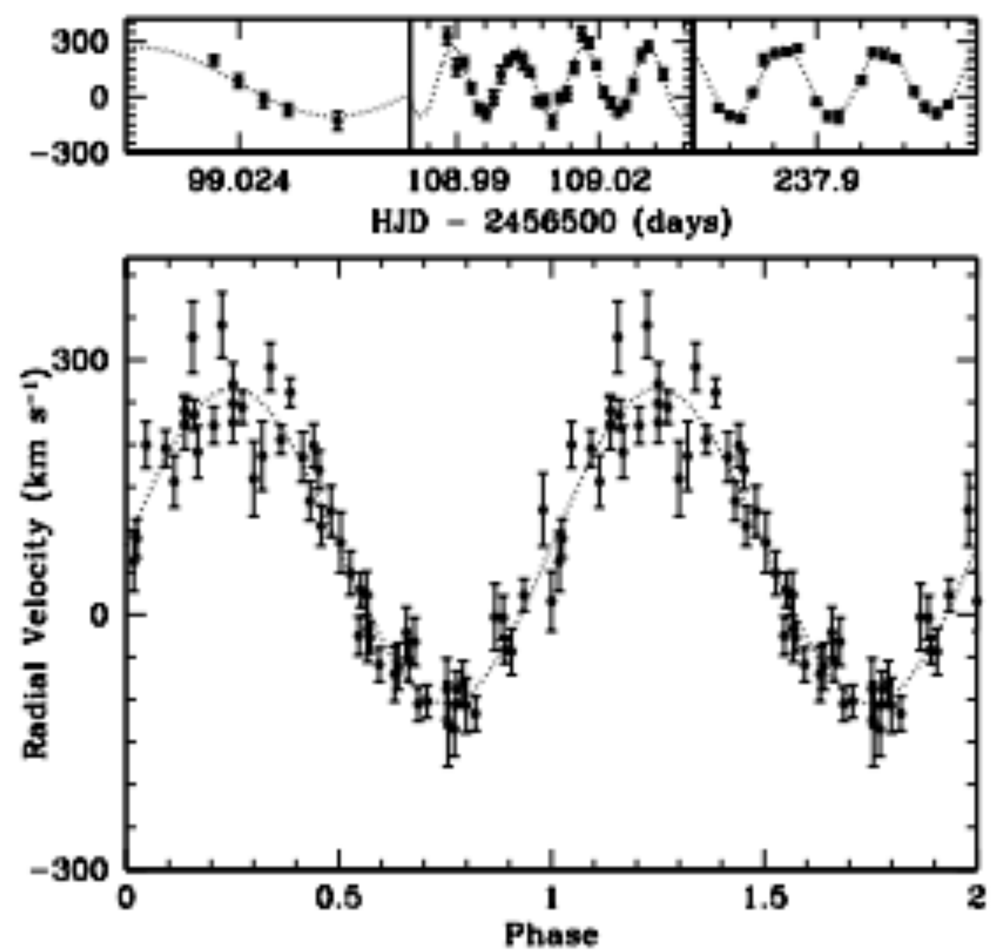
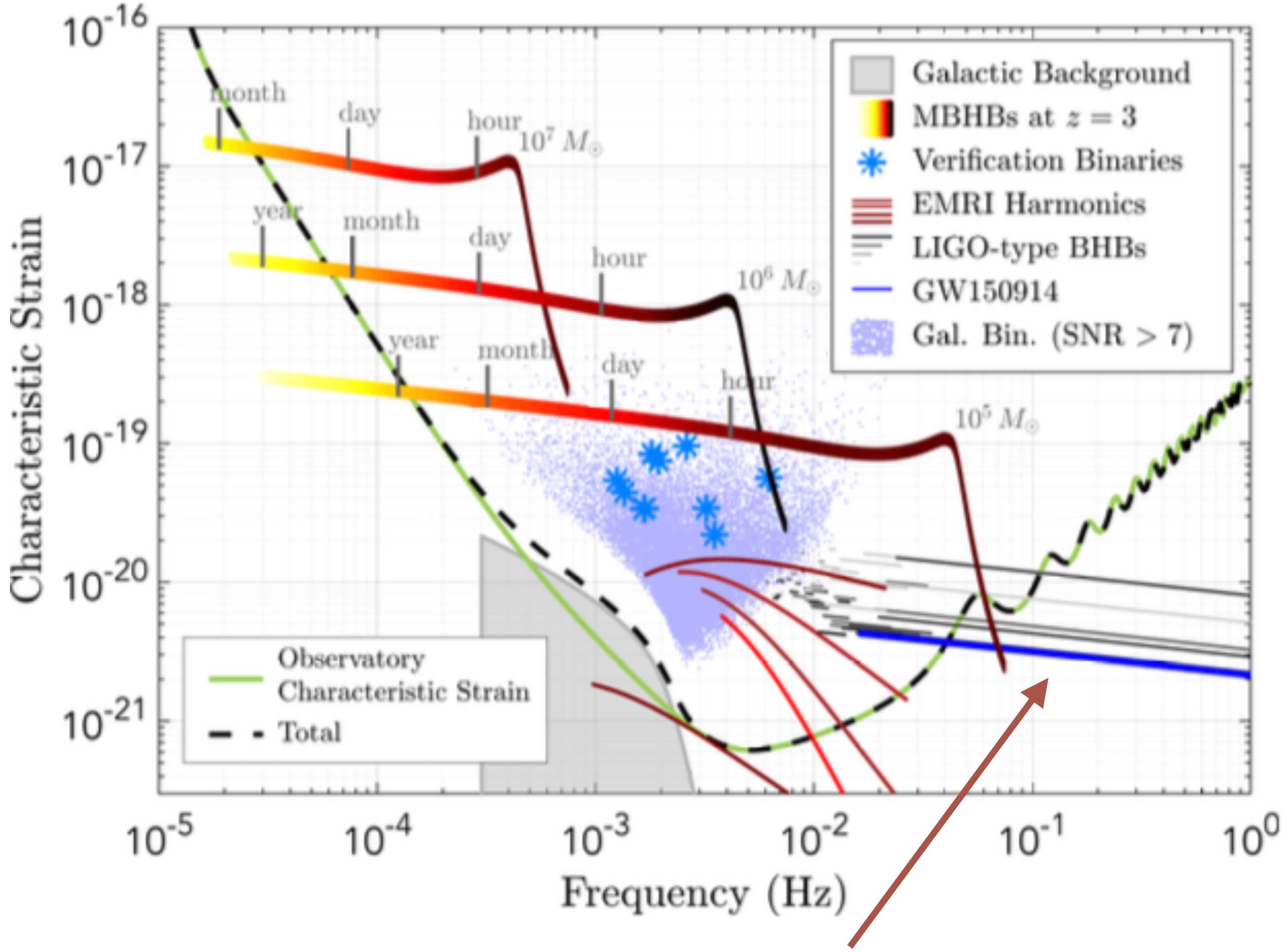
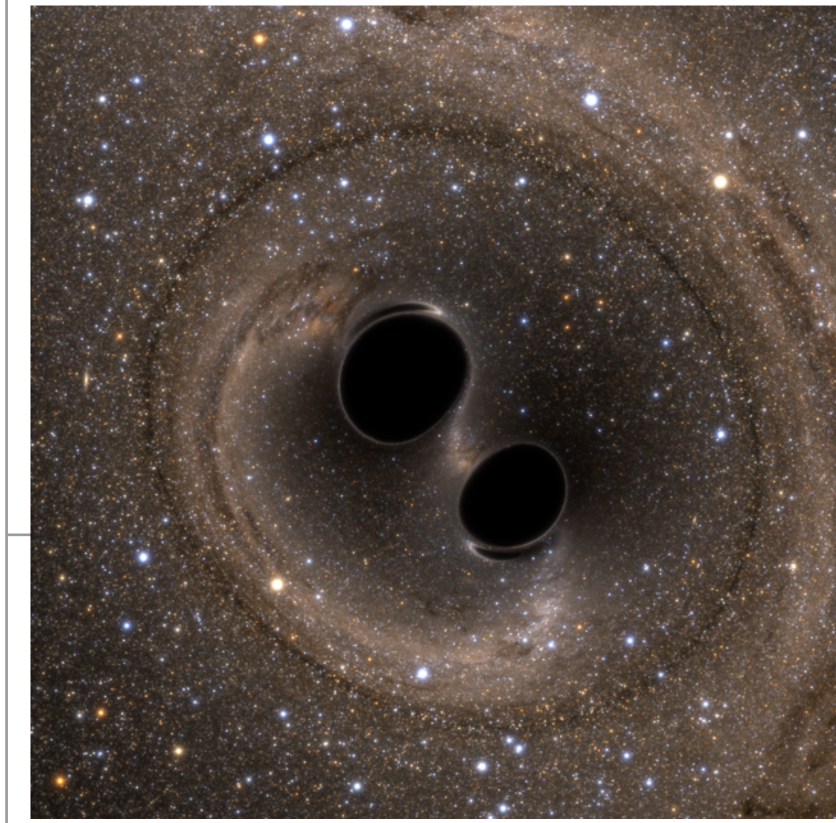


Figure 3. The radial velocities of the Balmer lines in WD 0931+444. The bottom panel shows all of these data points phased with the best-fit period. The dotted line represents the best-fit model for a circular orbit with a period of 0.01375 d.



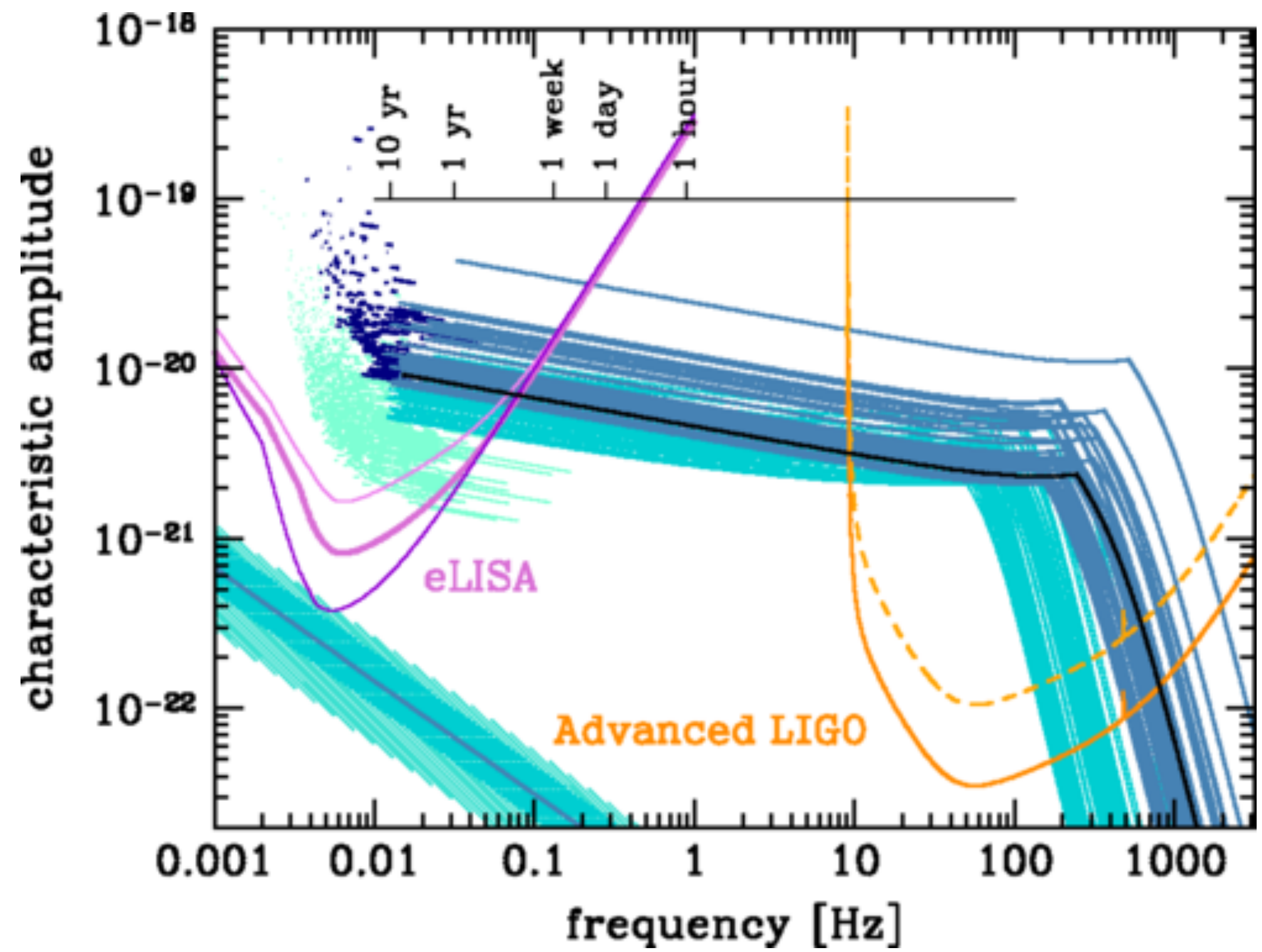


The SXS Project

BH binaries and multiband GW astronomy

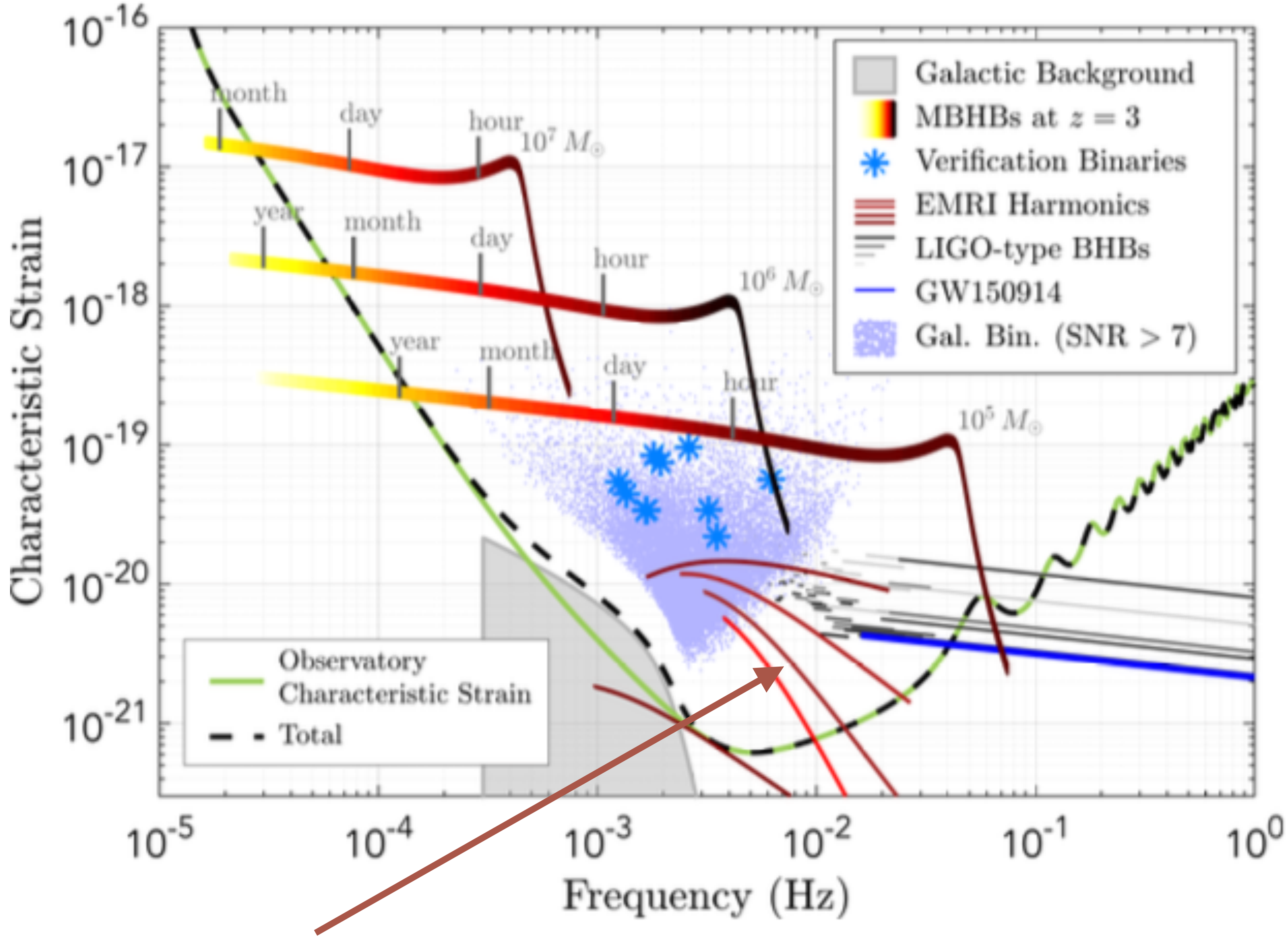
Multiband GW astronomy

- LIGO has detected a population of heavy BH binaries that was un- (under?) represented in earlier models
- Sources not only detectable by LISA but *individual systems could be measured by LISA and ground based observatories*
- Multiband GW astronomy
  - GR tests
  - Early-warning for EM counterparts



A. Sesana, Phys. Rev. Lett. 116, 231102

See talks by K. Inayoshi, Thursday @ 16:15 and N. Tamanini Friday @ 15:15



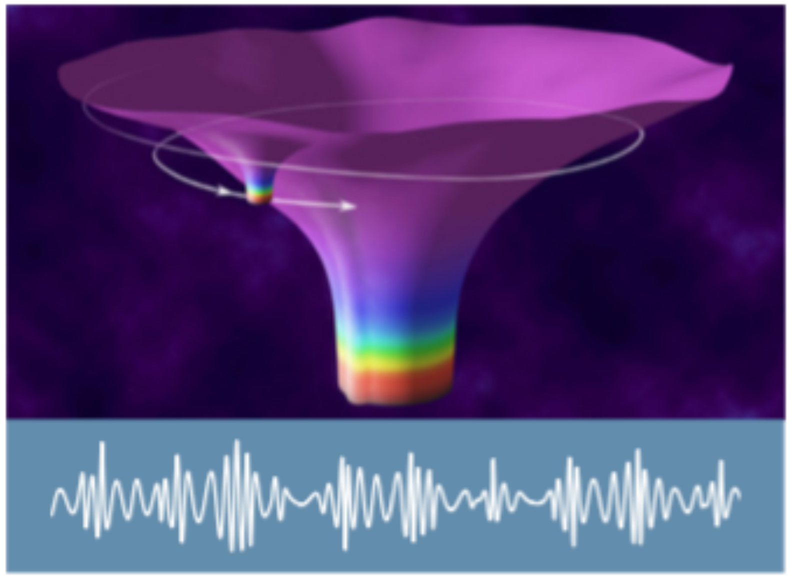


Figure 4: An artist's impression of the spacetime of an extreme-mass-ratio inspiral and a representative waveform of the expected gravitational waves. A smaller black hole orbits around a supermassive black hole. Credit: NASA.

Extreme mass ratio inspirals

EMRI science

- Precision test of GR - BH as test particle
- Astrophysics of compact objects in nuclear clusters
- **Challenge: modeling GR (or non-GR) waveforms over the 10^4 - 10^5 cycles measurable by LISA.**

See talks by C. Kavanagh Tuesday @ 17:45,
M. Oltean Tuesday @ 18:10,
M . van de Meent Wednesday @ 15:15,
and W. Han Wednesday @ 17:35

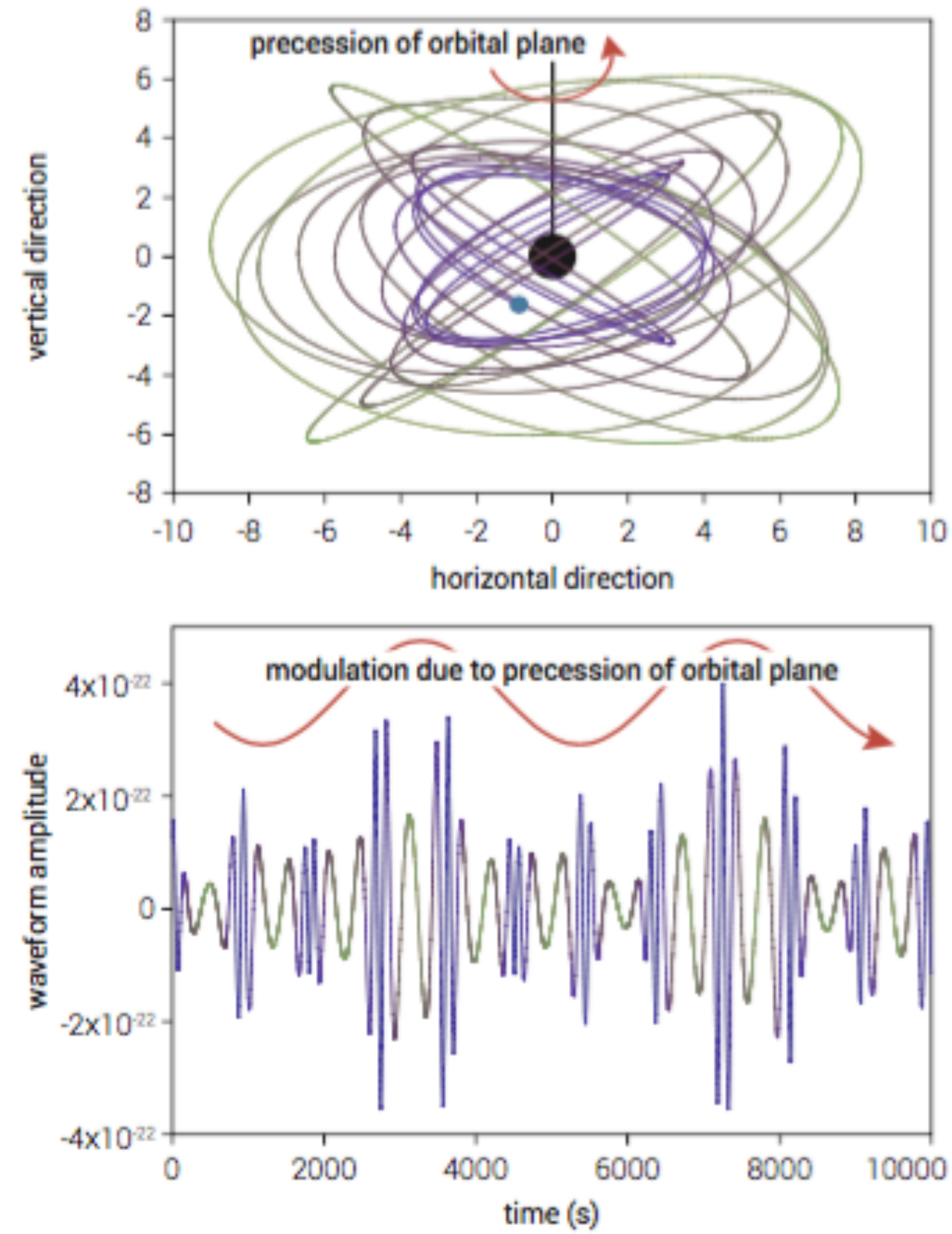
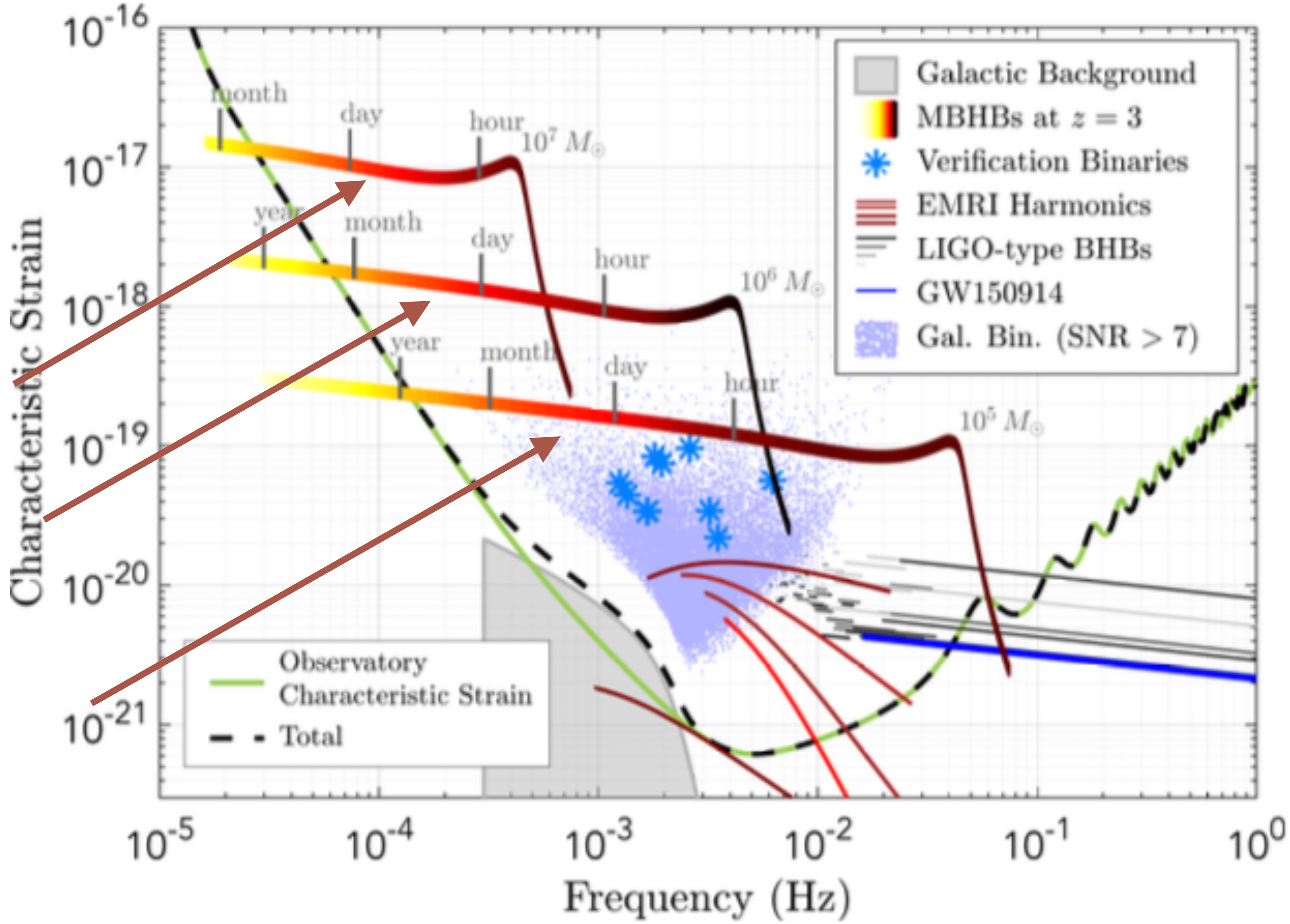


Figure 5: EMRI orbit and signal. In the top panel we see the geometrical shape of the ornate relativistic EMRI orbit. The lower panel shows the corresponding gravitational wave amplitude as a function of time.



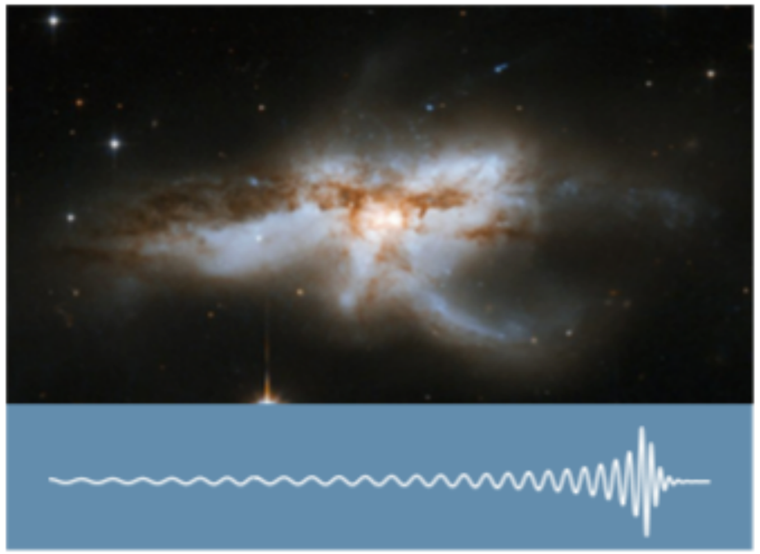


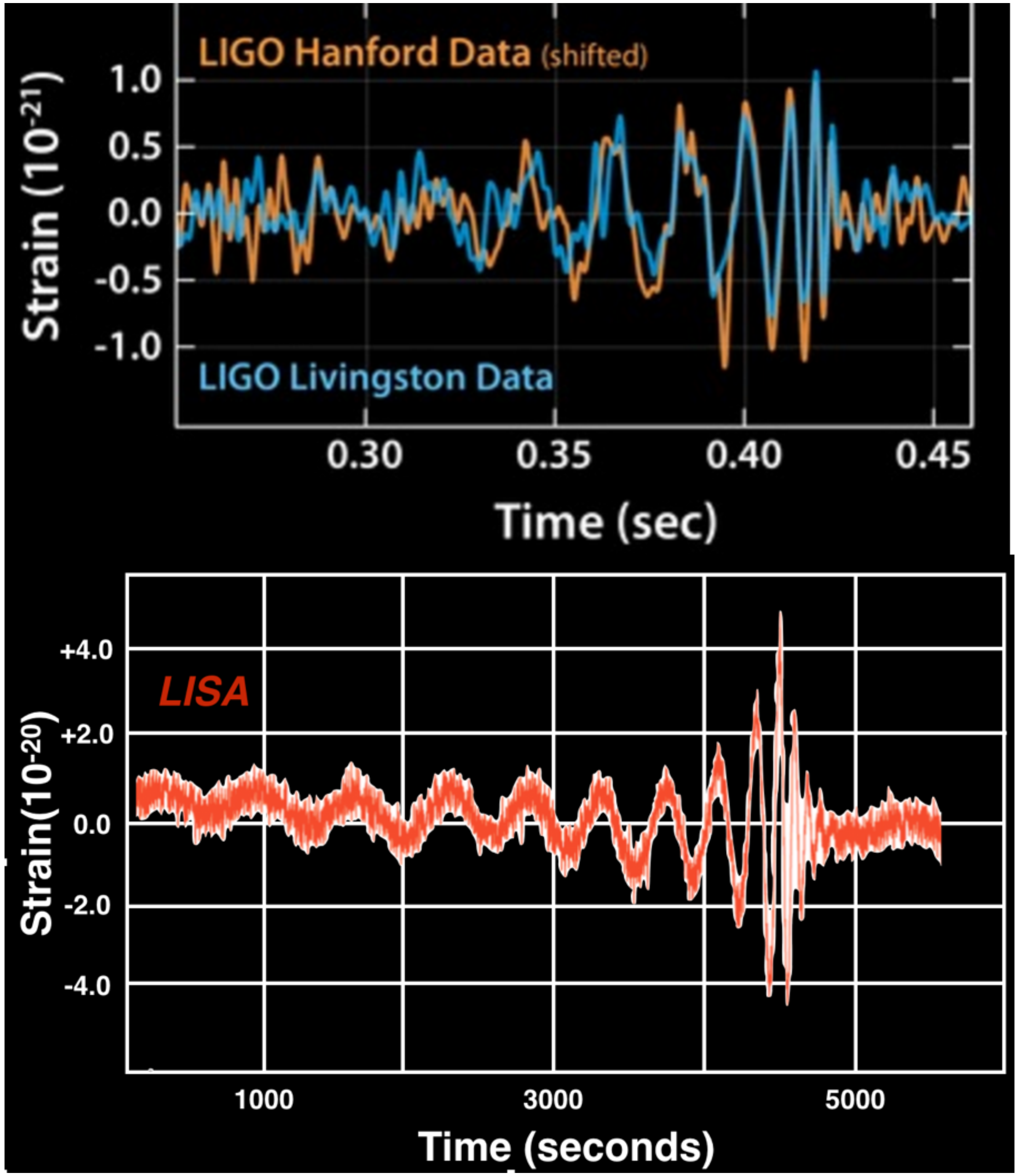
Figure 1: Merging galaxy NGC 6240 and a representative waveform of the expected gravitational waves from the coalesence of two super-massive black holes. Observations with NASA's Chandra X-ray observatory have disclosed two giant black holes inside NGC 6240. They will drift toward one another and eventually merge into a larger black hole. *Credit: NASA, ESA, the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration, and A. Evans (University of Virginia, Charlottesville/NRAO/Stony Brook University).*

Massive Black Hole Binaries

Massive Black Hole Binary Science

- Measure masses, distances, spins, for 10s-100s of events
- Understand BH merger rate, mass function, etc.
- Use BH mergers as a tracer for galaxy assembly

See talks by S. Marsat Tuesday @ 15:40 and M. Volonteri Thursday @ 15:15



10^5 M⊙ x 10^5 M⊙ at z = 20 (220 Gpc)

Backgrounds & Discovery Space

- “Unknowns, both known and unknown”
- Astrophysical
    - Intermediate mass black holes
- Physics
    - Inflationary GWs
    - Cosmic string cusps
    - vacuum transitions

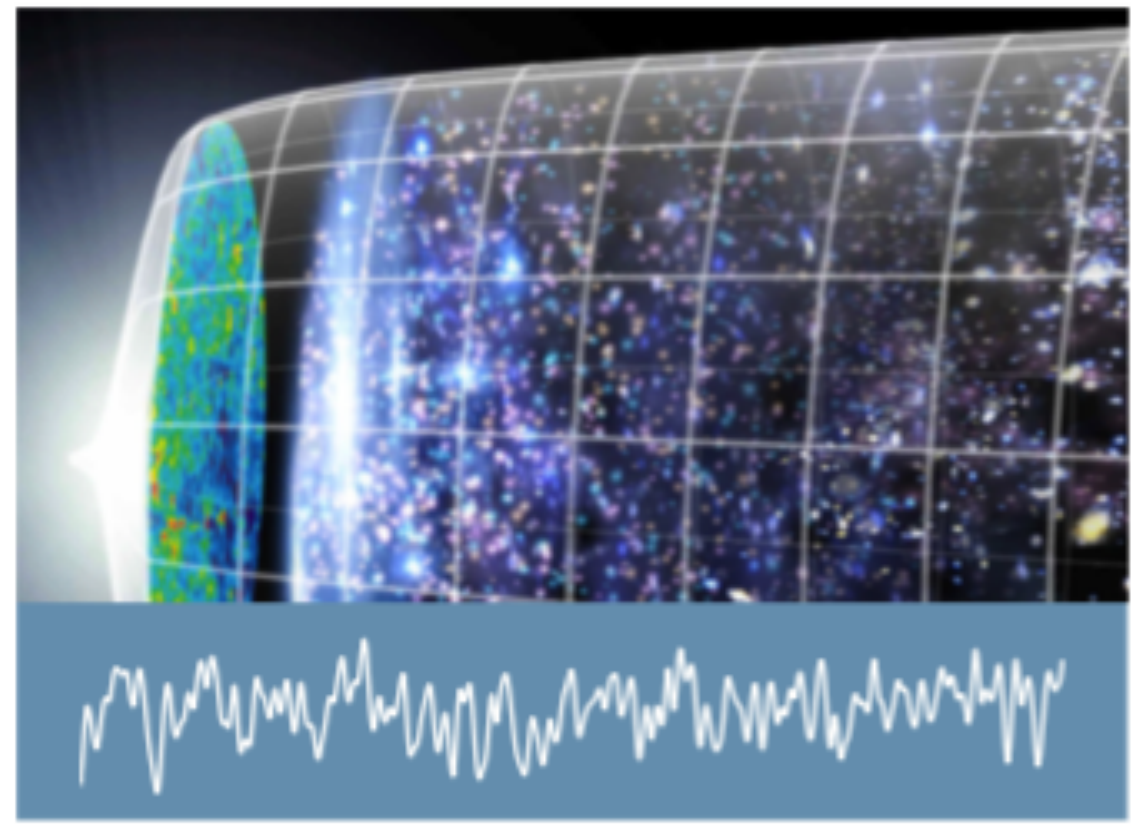
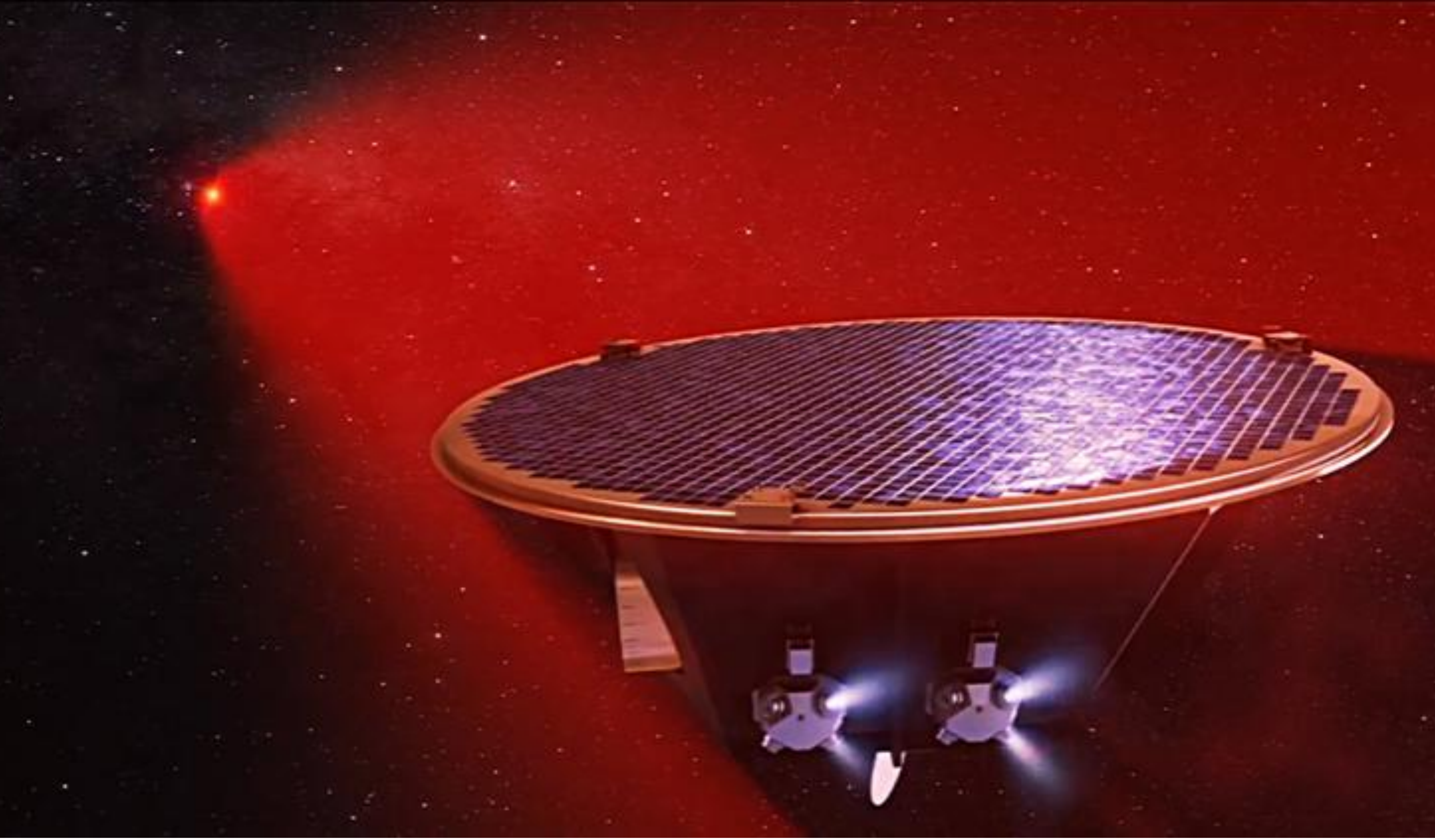


Figure 7: Evolution timeline (big bang and the early Universe) and a typical random waveform of the expected gravitational waves. Gravitational waves are the only way to see beyond the cosmic microwave background. Credit: NASA / WMAP science team.

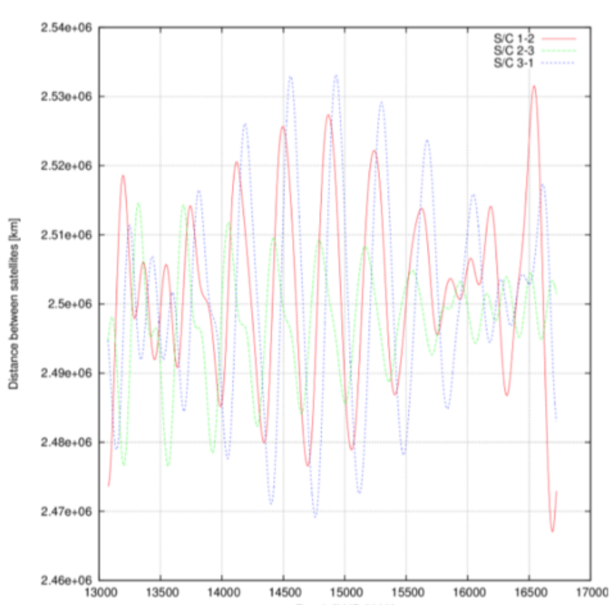


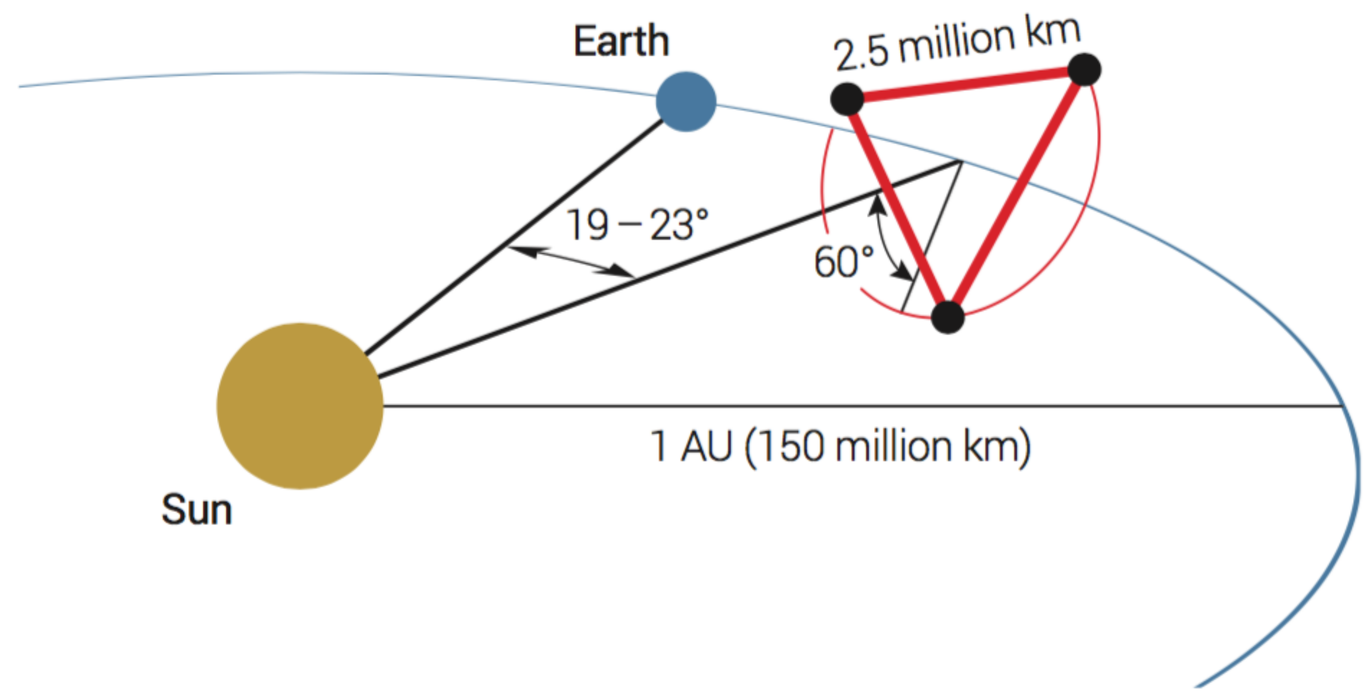
Mission Concept

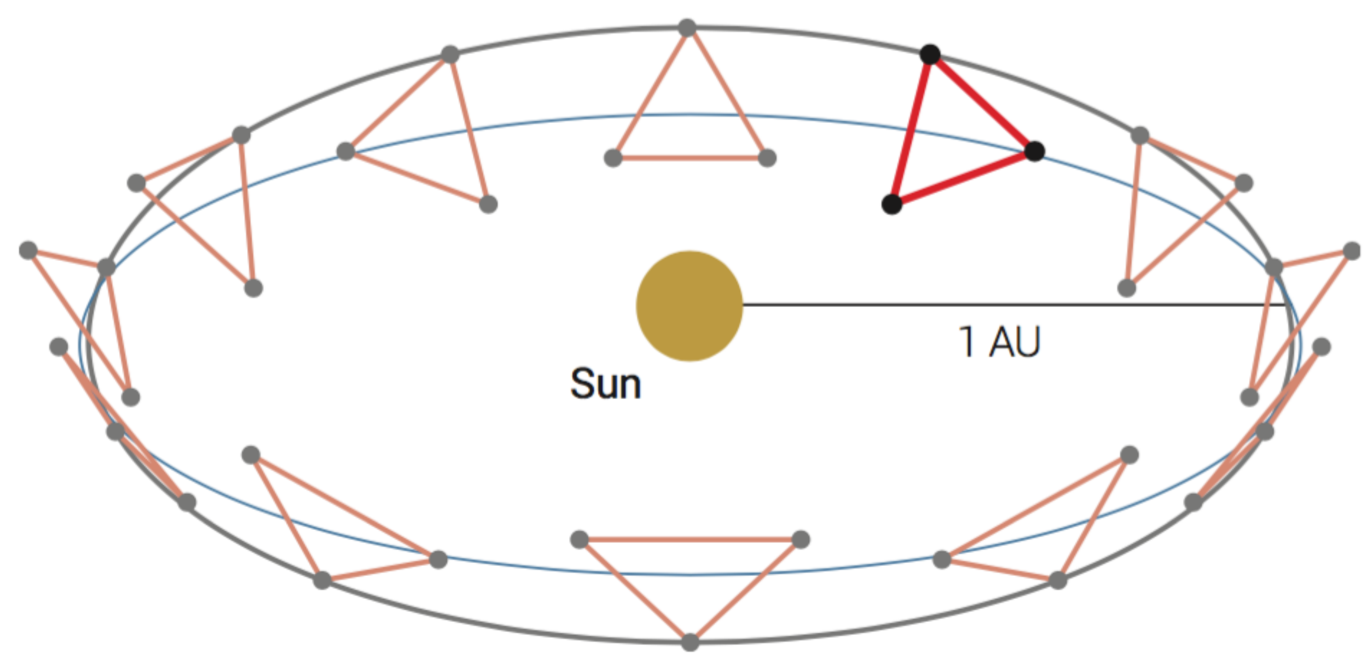
From LISA 2017 Proposal

Mission Design

- Passively-maintained constellation
- Trade between cruise cost, comms cost, and constellation stability
- Stable for 5-15 years

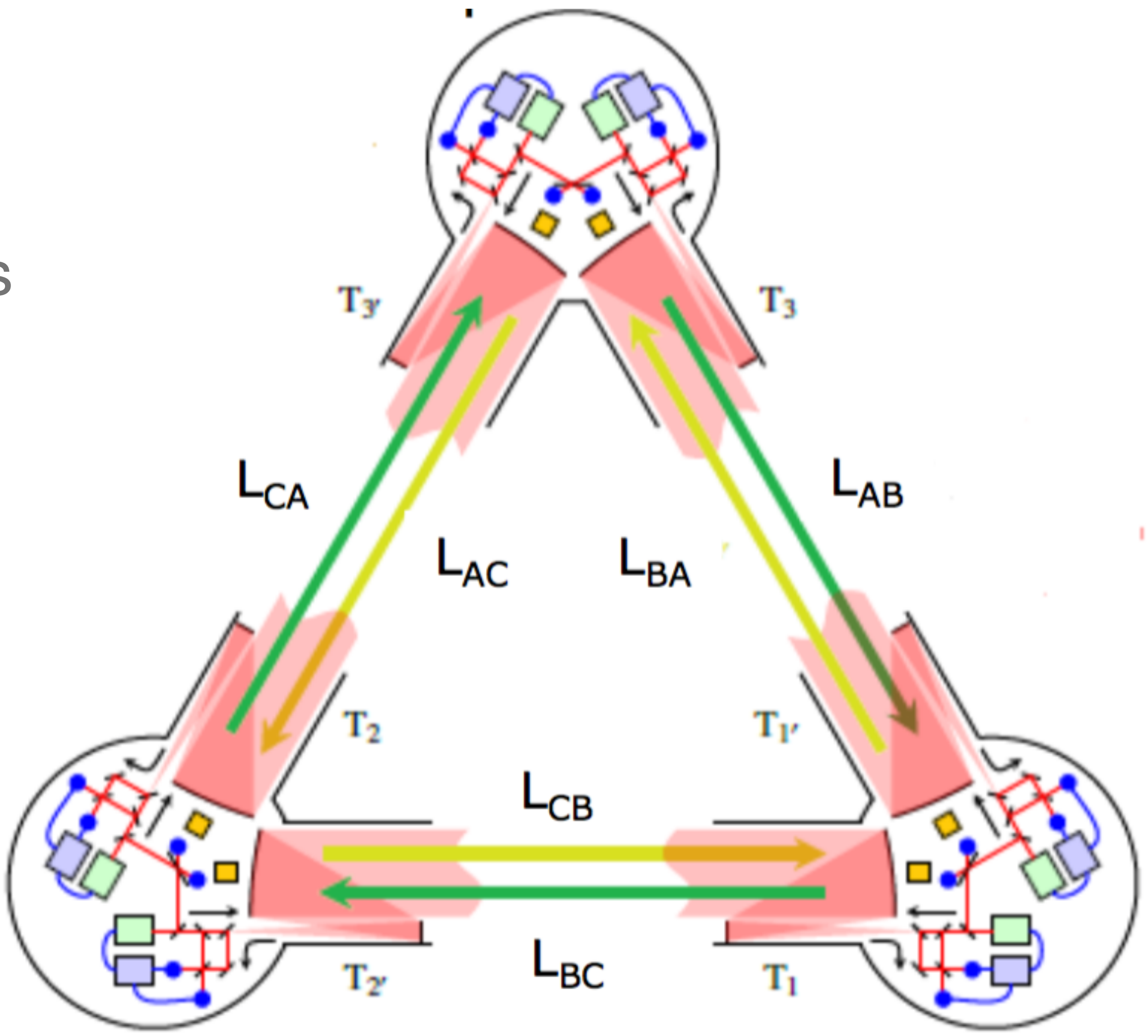






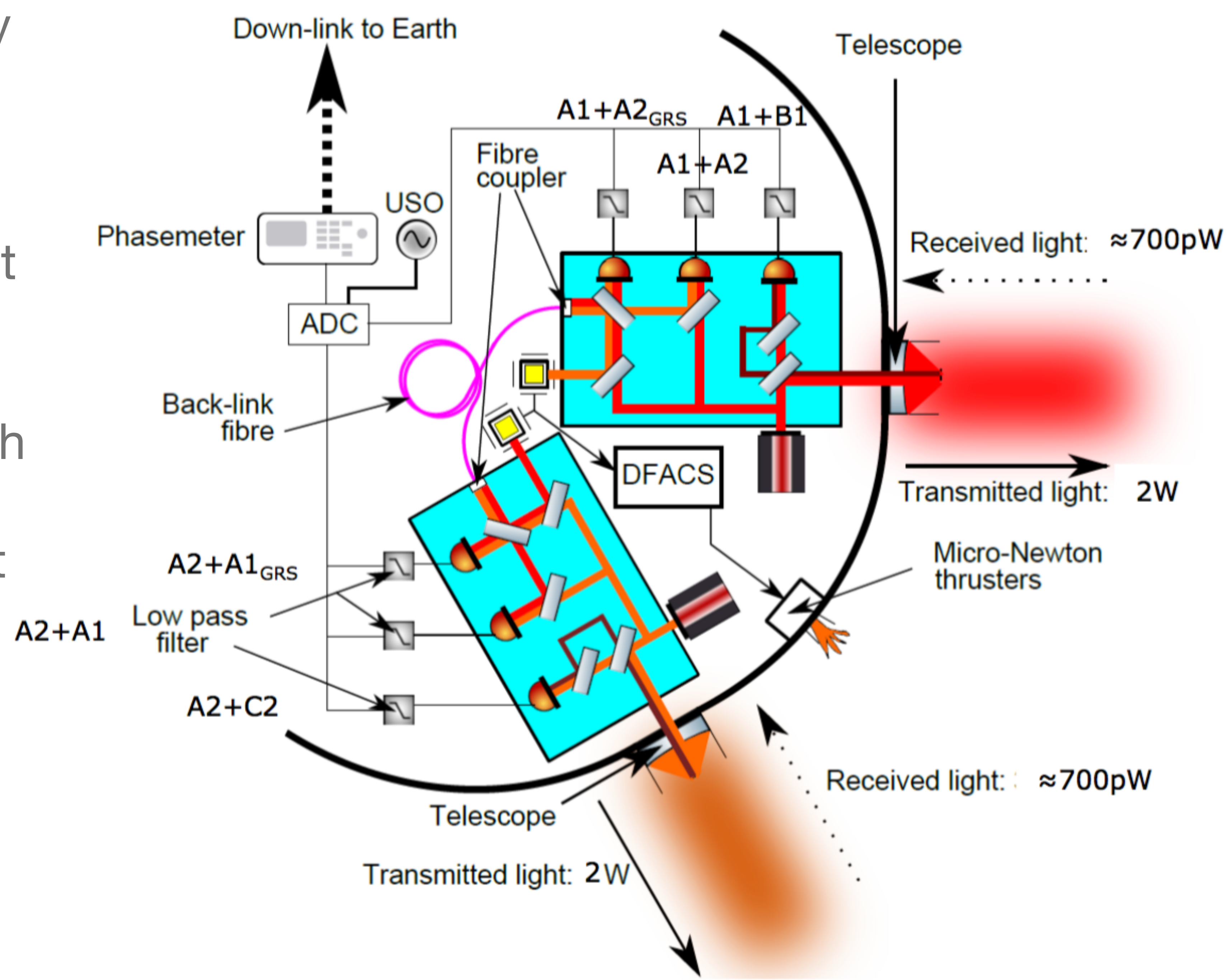
Measurement Concept

- measurement over six one-way ‘links’
- link signal
    - **laser noise** + gw signal + test mass noise + readout noise
- Combine signals on ground (TDI)
    - ~~laser noise~~ + gw signal + test mass noise + readout noise



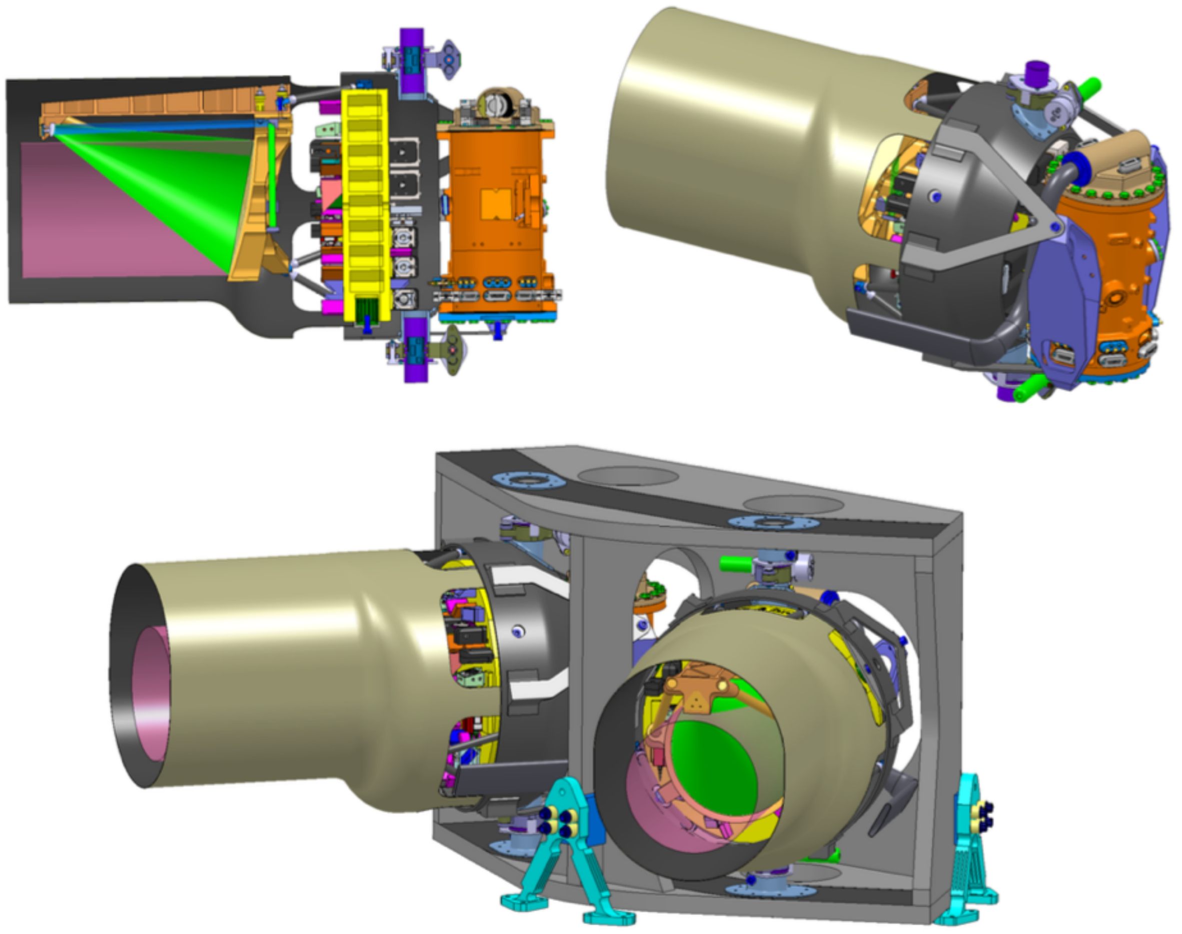
Payload Concept

- heterodyne interferometry
- three measurements
  - local bench to local test mass
  - local bench to far bench
  - local bench to adjacent bench

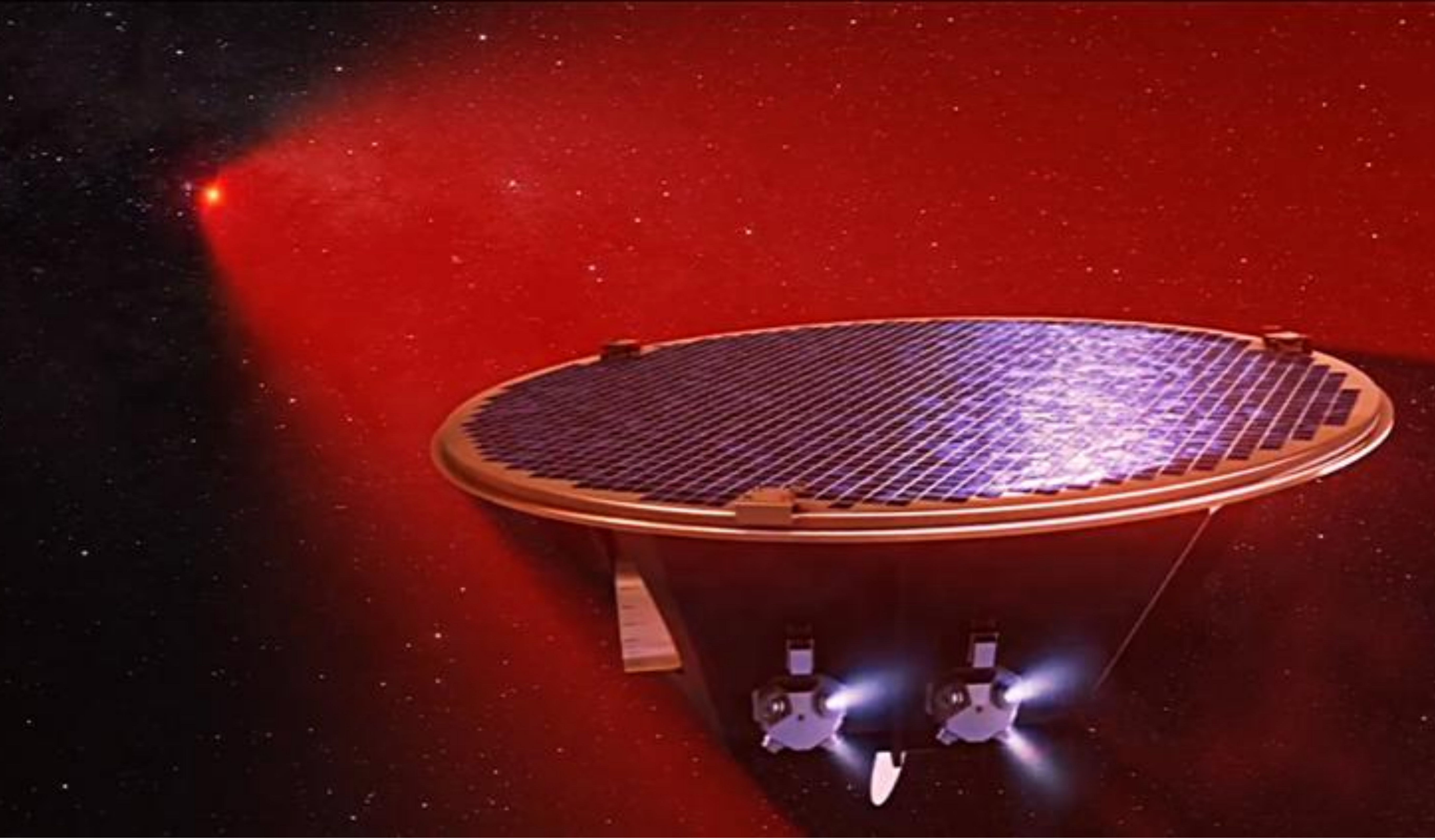


Key technologies

- stable laser
  - 2W output power
  - frequency and intensity stability in mHz band
  - modulated at GHz for clock transfer
- high-fidelity phase meter
  - linear at $1:10^{12}$
- stable optical bench
  - picometer stability
- low-disturbance test mass
  - femto-g accelerations
- Stable, low-scatter telescope
  - picometer stable
  - 10^{-10} scattering rejection



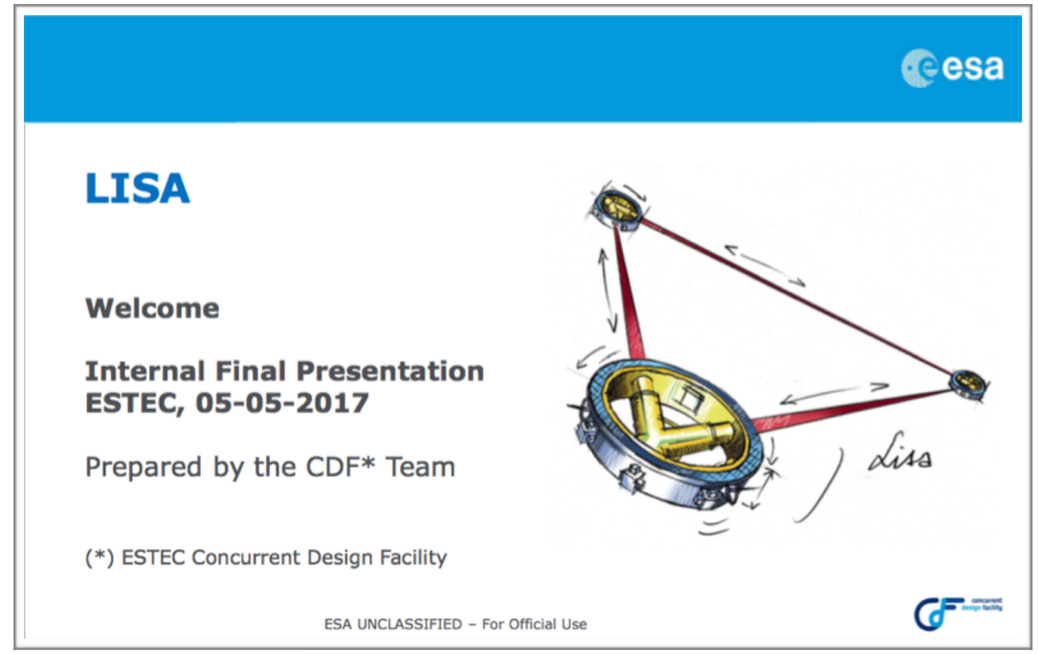
Straw man payload concept from 2011 design (courtesy Airbus D&S)



Status and Outlook

Near term

- Phase 0: prepare for industrial study
  - stand up science team
  - develop formal mission requirements
    - science requirements
    - mission requirements
    - payload description
- Aggressively pursue remaining technology development



L3 Concurrent Design Facility Study, ESA/ESTEC (O. Jennrich)

See talk by J. Conklin Monday @ 15:40

NASA Involvement

- L3 Study Team formed late 2015
  - Issued report with goals for US in 2016
- Study Office formed at GSFC in 2016
  - support technology development
  - support mission development activities
  - Actively engaged with ESA and the LISA consortium
- Ongoing ESA/NASA discussions at HQ level

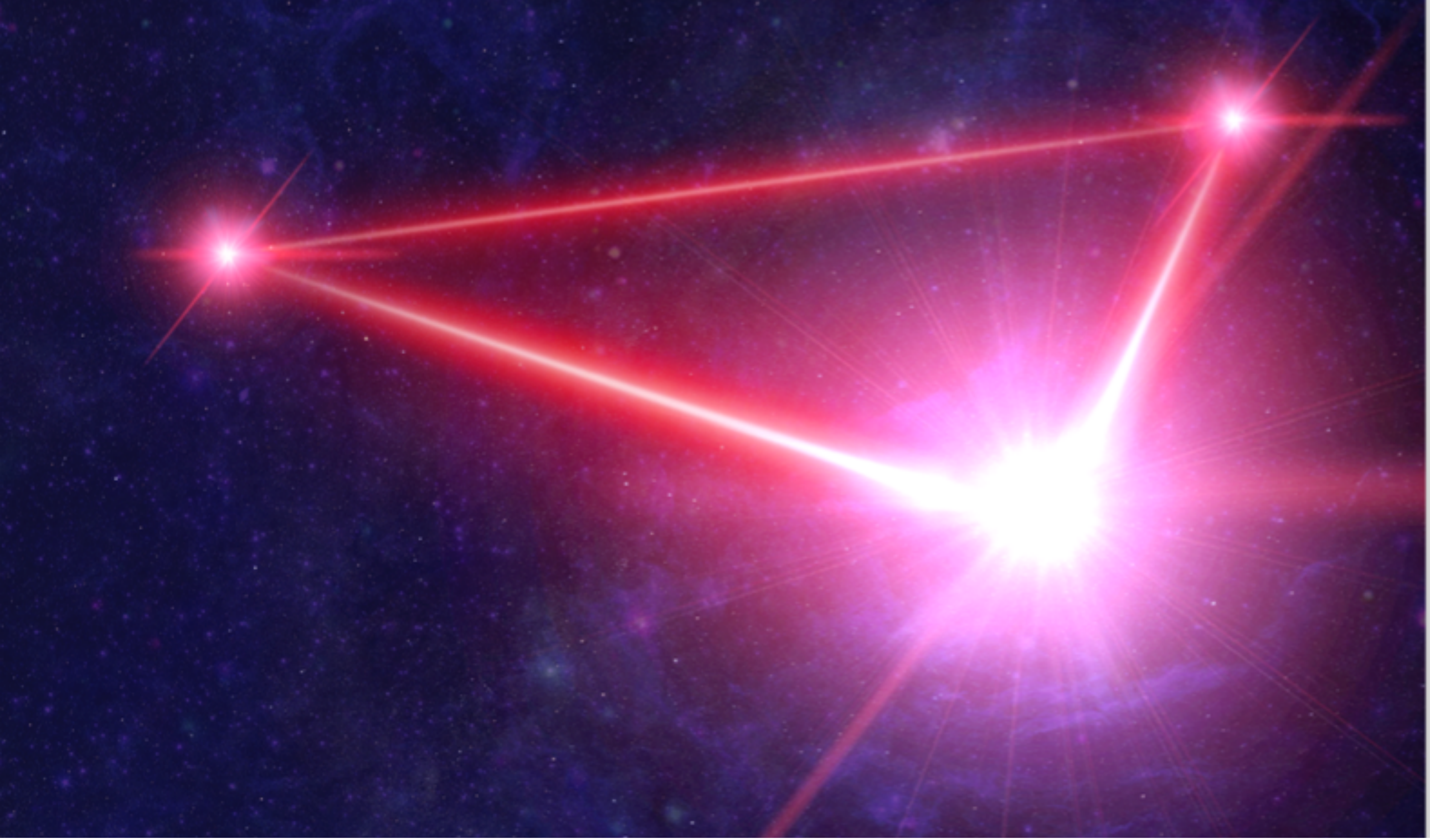
L3ST & friends, Washington, DC Feb. 2017

new, improved lisa.nasa.gov

Long term

- 2017 ~ 2023: Design phase
  - finalize design
  - Complete technology development
  - Finalize roles and responsibilities
- mid-2020s: Implementation Phase
  - Build and test flight hardware
  - Integrate spacecraft
- early-2030s: Operations Phase
  - Launch, cruise, & commissioning
  - 4-10 years of incredible science!

I. Thorpe, Conchas, New Mexico, USA



Questions?

Thank you for your attention