A Space-based Gravitational-Wave Observatory at NASA

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Outline

- A brief history of LISA at NASA
- NASA's strategic plan
- Recent studies
- Current activities
- Activities for the rest of the decade

BRIEF HISTORY OF LISA AT NASA

Gravitational Wave Observatory at NASA

- Brief history of the LISA concept
  - 1984: LAGOS concept by Faller, Bender, Hall, Hils and Vincent
  - Mid 1980's – 1992: NASA only studies
  - 1993-2000: Joint studies, mostly led by ESA
  - 1997: 3 spacecraft version emerged in JPL Team X study
  - 2001-2015: LISA Pathfinder and ST7 DRS
  - 2004-2011: NASA/ESA Phase A
  - 2013: ESA selects "Gravitational Universe for L3"
- The LISA concept has always gotten high rankings in NRC reviews:
  - AANM (2000) decadal: highest priority medium new start
  - Quarks to Cosmos: proceed to develop
  - Beyond Einstein Program: highest priority science
  - NWNH (2010) decadal: second priority large mission after WFIRST

NASA'S STRATEGIC PLAN

Programmatic Status (1/2)

- NRC decadals form the basis of NASA's science roadmap.
- LISA had high recommendations in both the 2000 and 2010 decadals, as well as in intervening reviews.
  - LISA got ranked second in 'large' space projects after WFIRST. Recommended for a new start contingent on Pathfinder success.
- Shortly after the 2010 decadal was released, NASA's Astrophysics Division was confronted by increases in JWST cost estimates and decreases in budget projections.
- The Astrophysics Division released the Astrophysics Implementation Plan in December 2012, updated in December 2014.
- Documents at http://science.nasa.gov/astrophysics/documents/

Programmatic Status (2/2)

- Dr. Paul Hertz, Director of Astrophysics, issued a white paper 4 Jan. '15 with a plan for the 2020 decadal review (pp 2-3)
  - NASA is planning to partner with ESA on L3
  - NASA will participate in preparations leading to L3
  - NASA will study its level of participation in L3
  - NASA will develop technology and participate in LISA Pathfinder to prepare for L3
- The mid-decade review has started and will finish in May 2016.

RECENT NASA STUDIES

2012 Mission Concept Study Findings

NASA conducted a study in 2011-2012 looking for a mission concept ≲$1B. Design trade-offs were explored for their impact on science, risk and cost. The findings can be summarized as follows:

- No concepts were found near or below $1B.
- No technology was found that dramatically reduces cost of a concept based on laser interferometry .
- The LISA architecture can be scaled down somewhat, and still do compelling science. [See poster/talk by Livas.]
- Science performance decreases far more rapidly than cost. At some point, risk increases to an unacceptable level for missions of this scale.

Final report and (many) other documents at http://pcos.gsfc.nasa.gov/studies/gravitational-wave-mission.php

Mission Concept Comparison

Parameter	NGO	SGO Mid	LISA
Measurement arm length	1 x 10^6 km	1 x 10^6 km	5 x 10^6 km
Number & type of spacecraft	1 corner (2 optical assemblies, 2 end (single optical assembly	3 corner (2 optical assemblies)	3 corner (2 optical assemblies)
Number of measurement arms, one-way links	2 arms, 4 links	3 arms, 6 links	3 arms, 6 links
Constellation	Vee	Triangle	Triangle
Gravitational-wave polarization measurement	Single instantaneous polarization, second polarization by orbital evolution	Two simultaneous polarizations continuously	Two simultaneous polarizations continuously
Orbit	Heliocentric, earth-trailing, drifting-away 9°- 21°	Heliocentric, earth-trailing, drifting-away 9°- 21°	22° heliocentric, earth-trailing
Trajectory	Launch to Geosynchronous Transfer Orbit, transfer to escape, 14 months	Direct injection to escape, 18 months	Direct injection to escape, 14 months
Duration of science observations	2 years	2 years	5 years
Launch vehicle	Two Soyuz-Fregat	Single Medium EELV (e.g., Falcon 9 Block 3)	Single Medium EELV (e.g., Atlas V 551)
Optical bench	Low-CTE material, hydroxy-catalysis construction	Low-CTE material, hydroxy-catalysis construction	Low-CTE material, hydroxy-catalysis construction
Laser	2 W, 1064 nm, frequency and power stabilized	1 W, 1064 nm, frequency and power stabilized	2 W, 1064 nm, frequency and power stabilized
Telescope	20 cm diameter, off-axis	25 cm diameter, on-axis	40 cm diameter, on-axis
Gravitational Reference Sensor	46 mm cube Au:Pt, electrostatically controlled, optical readout	46 mm cube Au:Pt, electrostatically controlled, optical readout	46 mm cube Au:Pt, electrostatically controlled, optical readout

Science Comparison

	NGO	SGO Mid	LISA
MBH Totals	40-47	41-52	108-220
Detected z > 10	1-3	1-4	3-57
Both mass errors < 1%	13-30	18-42	67-171
One spin error < 1%	3-10	11-27	49-130
Both spin errors < 1%	<1	<1	1-17
Distance error < 3%	3-5	12-22	81-108
Sky location < 1 deg^2	1-3	14-21	71-112
Sky location < 0.1 deg^2	<1	4-8	22-51
EMRIs	12	35	800
Resolved CWDBs	3,889	7,000	40,000
Interacting	50	100	1,300
Detached	5,000	8,000	40,000
Sky location < 1 deg^2	1,053	2,000	13,000
Sky location < 1 deg^2, distance error < 10%	533	800	8,000
Stochastic Background	0	0.2	1

Special acknowledgement to Ryan Lang (Univ. of Florida) and Neil Cornish (Montana State Univ.)

Technology Development Roadmap

- Started in 2012, completed November 2013.
- Purpose: Make a plan to develop technology for a future GW mission
- The eLISA and SGO Mid concepts require the same technology.
- The roadmap is a U.S.-centric plan to develop technologies for a LISA-like mission in the 2030's.
- This roadmap *predates* the selection of L3.
- Links to final document and annual program technology reports at http://pcos.gsfc.nasa.gov/technology/

Other recent NASA activities

- GW Science Interest Group/Physics of the Cosmos Program Analysis Group (POCs: John Conklin and Neil Cornish)
- Participation in ESA's Gravitational Observatory Advisory Team (GOAT) since October 2014
  - 3 NASA members and 1 NASA observer

CURRENT ACTIVITIES IN THE U.S.

Technology Development

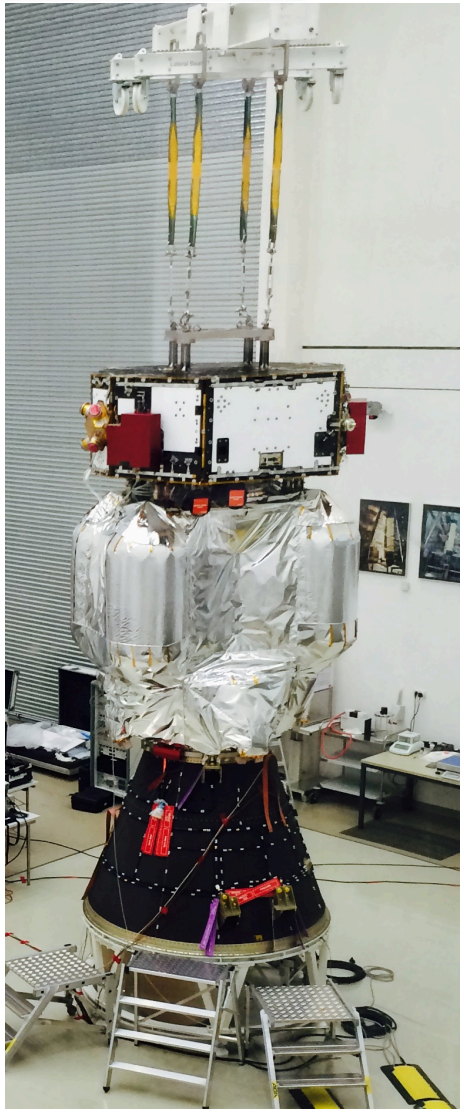
For details, see Guido Mueller talk Tuesday at 14:50.

- Telescope Subsystem – Jeff Livas (GSFC), Shannon Sankar (GSFC) and Guido Müller (UF)
- Phase Measurement System – Bill Klipstein+ (JPL)
- Laser Subsystem – Jordan Camp and Kenji Numata (GSFC)
- Micronewton Thrusters – John Ziemer+ (JPL)
- Arm-locking Demonstration – Kirk McKenzie+ (JPL)
- Torsion Pendulum – John Conklin+ (UF)
- Multi-axis Heterodyne Interferometry – Ira Thorpe (GSFC)
- UV LEDs – John Conklin+ (UF)
- Optical Bench – Guido Müller+ (UF)

LISA researchers at JPL are leading the Laser Ranging Interferometer on the GRACE Follow-On mission.

LISA Pathfinder

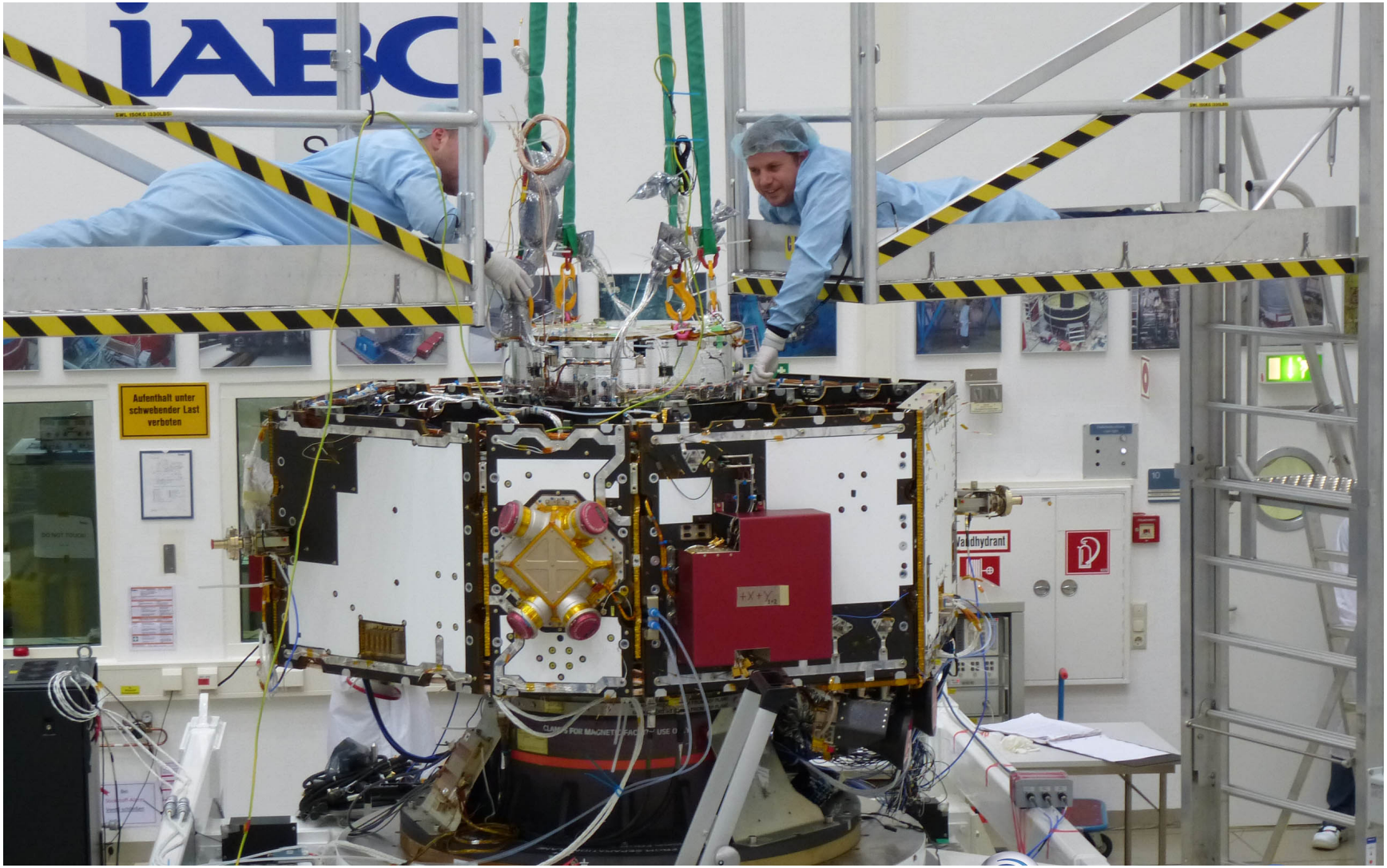
- Mission to demonstrate technology for a LISA-like gravitational wave observatory
- European payload has 2 Gravitational Reference Sensors, interferometer and “drag-free” control system.
- NASA participation in European payload operations and data analysis
- Launch scheduled for 27 November 2015.



ST7 Disturbance Reduction System

- NASA payload on LISA Pathfinder called ST7 Disturbance Reduction System
- A NASA flight project managed by the Jet Propulsion Laboratory
- Consists of micronewton thrusters and “drag-free” control system, using European inertial sensors.
- Preparing for operations, data analysis and extended mission.

ST7 Microthrusters on LPF



Gravitational Observatory Advisory Team (GOAT)

- GOAT is an ad-hoc ESA advisory committee whose charge is

  "To evaluate and recommend on possible scientific and technical approaches for a gravitational wave observatory envisaged for a planned launch date in 2034."

- Range of interest: technical feasibility, science goals, data analysis, system view, technology, partners, cost and schedule
- U.S. members (3/10) have been active in the internal studies and debates
- GOAT Intermediate Report (15 Jun. '15) at: http://www.cosmos.esa.int/web/goat/home

MidTerm Decadal Assessment

- In between decadal reviews, National Research Council reviews progress by agencies on recommendations.
- Committee has been named. Dr. Jackie Hewitt is chair. Rai Weiss, Neil Cornish, Ned Wright are members.
- Statement of task
- Schedule
  - First meeting: 8-10 Oct. '15, Washington, DC
  - Second meeting and symposium: 14-16 Dec. '15, Irvine, CA
  - Third meeting: 14-16 Jan. '16, Washington, DC
  - Final report due 1 May '16
- Details at http://sites.nationalacademies.org/SSB/CurrentProjects/SSB_161177

ACTIVITIES FOR THE REMAINDER OF THE DECADE

NASA activities 2015-2017

- Operations and data analysis on Pathfinder and ST7
- GW Science Interest Group/Physics of the Cosmos Program Analysis Group (POCs: John Conklin and Neil Cornish)
- Continued participation in ESA's GOAT
- Participation in early ESA lead-in activities: mission concept proposal/selection, Phase A start in 2017, …
- Technology development to meet the L3 schedule (ISO TRL6 by Q4 2019)
- NRC Midterm review: kick-off meeting in October, workshop in December, final meeting in January
- Pre-decadal study in 2017-2018
- Preparations for next decadal

NASA activities 2018-2020

- GW Science Interest Group/Physics of the Cosmos Program Analysis Group
- Participation in early ESA lead-in activities: payload AO, payload engineering model, …
- Technology development to meet the L3 schedule (ISO TRL6 by Q4 2019)
- Pre-decadal study in 2017-2018
- Astro2020 decadal survey, a US role in L3 needs
  - A strong endorsement for science and feasibility.
  - Recommended financial commitment

Summary

- NASA's strategic plan for a gravitational wave observatory is to participate in ESA's L3
- Since 2012, NASA has been actively working towards that goal through
  - Discussions with ESA
  - Participation in LPF and ST7
  - Participation in GOAT and eLISA Consortium meetings
  - Technology development
- To that goal, NASA has to
  - Successfully negotiate a role
  - Participating in the successful execution of LPF and ST7, baseline and extended missions
  - Develop appropriate technology
  - Receive an endorsement for L3 participation from the 2020 decadal review