LISA Science Requirements

LIGO-G020084-00-Z

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This Talk

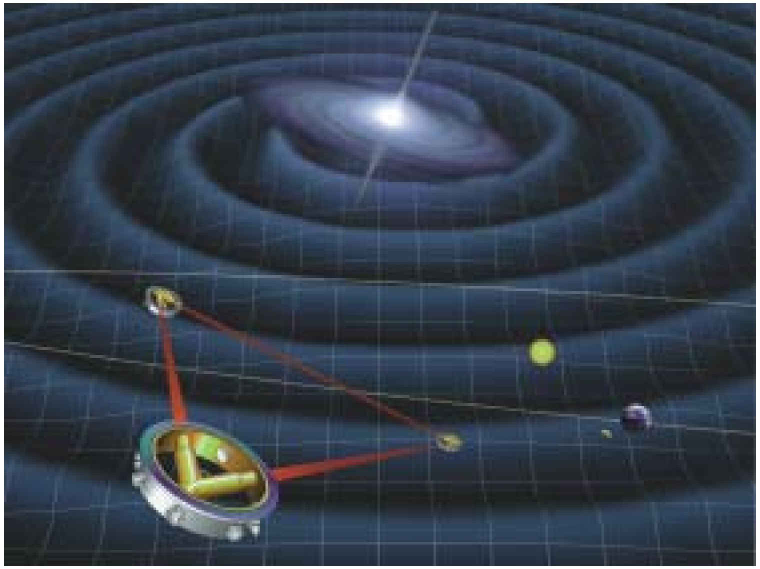
LISA Science Requirements

- Why discuss these?
- Answer: on the critical path for LISA design process
- Astrophysics and GW communities can make important contributions to science requirements issues

Points of contact between source analysts and LISA

- Structure of the LISA International Science Team (LIST)
- Note: the LIST is not an LSC !
- Working Groups and Task Groups
  - Scott Hughes will elaborate on some of the issues

Laser Interferometer Space Antenna Mission: Quick View



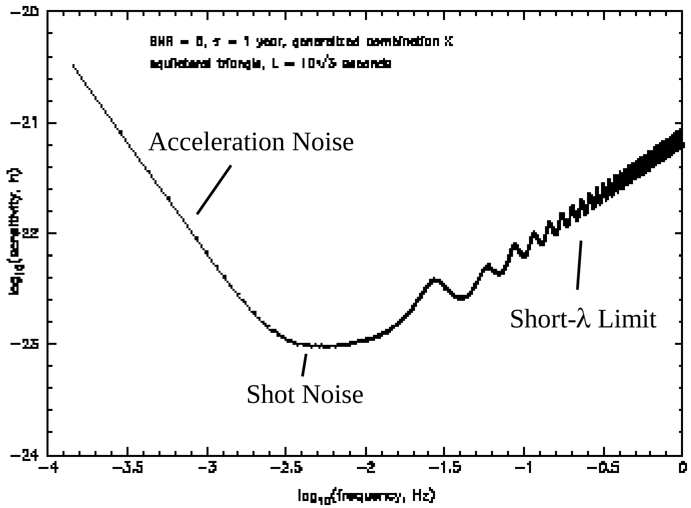
What

- 3 spacecraft constellation separated by 5 x10^6 km.
- Drag-free flight
- Gravitational waves detected as a modulation of the distance between spacecraft by picometer interferometry
- Earth-trailing solar orbit
- 5 year mission life

Why?

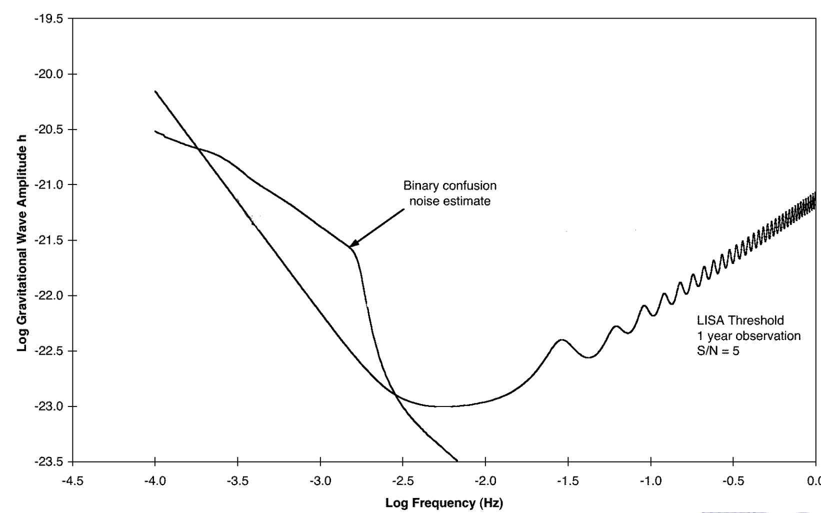
- Gravitational radiation from compact binary star systems in our galaxy
- Massive and super-massive black hole mergers
- Gravitational capture of compact stellar objects into massive black holes
- Signatures of gravitational radiation from the early universe

LISA Sensitivity



From about 0.2-3 mHz LISA will be limited by galactic GW background rather than instrumental background =>
add WD binary confusion noise estimate
(e.g. Bender and Hils)

Unequal-arm "Michelson" combination of signals which cancels laser phase and opticalbench noise: "X combination" (Armstrong, Estabrook, & Tinto)

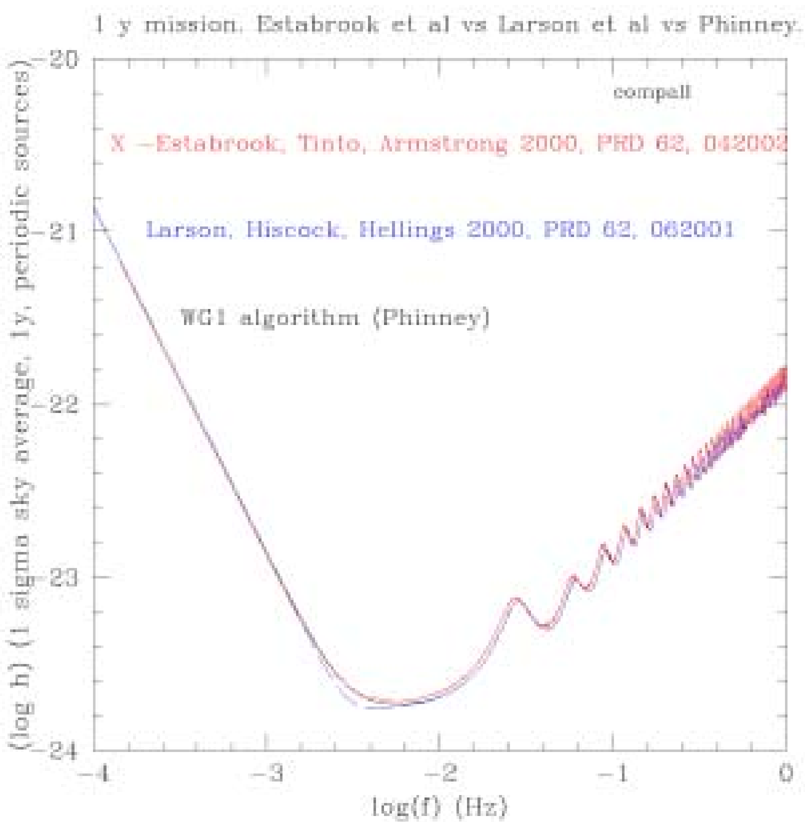


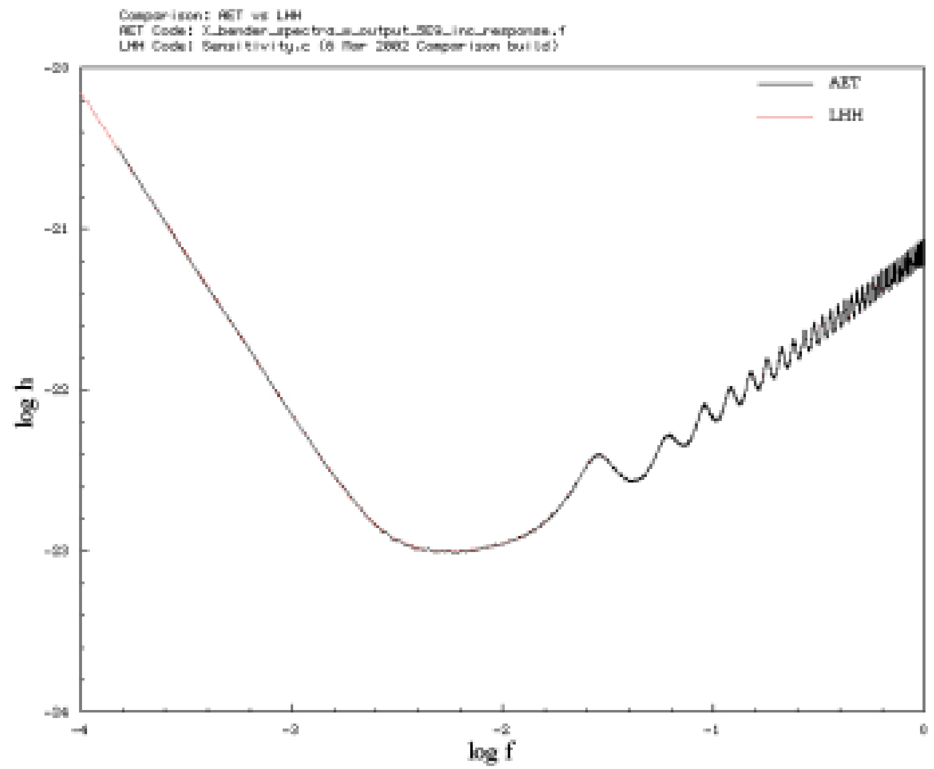
LISA Science Requirements

LISA International Science Team (LIST) has the responsibility for setting the science requirements for LISA

- Assigned to “Sources Working Group” (WG1)
  - Phinney and Schutz, co-chairs
- “Task Group” formed to help formulate science requirements
  - Phinney, Schutz, Armstrong, Brady, Brobeck, Creighton, Cutler, Estabrook, Farmer, Hartl, Hellings, Huges, Kennefick. Larson, Lindblom, O’Shaughnessy, Prince, Tinto, Thorne
- Draft produced (Dec 2001)
  - See http://www.srl.caltech.edu/lisa or http://www.tapir.caltech.edu/listwg1
- Comments on draft are welcome! Please read the draft and comment!

Comparison of Sensitivity Estimates





[Shane Larson]

SPACEBORNE GRAVITATIONAL WAVE OBSERVATORY

SENSITIVITY CURVE GENERATOR

Enter Your Observatory Parameters

The default values for the Observatory Parameter fields will generate a standard LISA sensitivity curve (all-sky + polarization average, SNR = 1) for the root spectral density of gravitational wave strain vs. gravitational wave frequency.

1.0		Sensitivity curve SNR -- LISA = 1.0
5.0E9	meters	Armlength -- LISA = 5.0E9 meters
0.3	meters	Telescope Diameter -- LISA = 0.3 meters
1064.0	nanometers	Laser wavelength -- LISA = 1064 nanometers
1.0		Laser Power [Watts] -- LISA = 1.0 Watt
0.3		Optical train efficiency -- LISA = 0.3
3.0E-15		Root spectral density acceleration noise [m/(s^2 root Hz)] -- LISA = 3.0E-15
4.0E-11		Root spectral density position noise budget (1-way) [m/(root Hz)] -- LISA = 4.0E-11
Laser Shot Noise		sets value of sensitivity floor -- LISA = Laser Shot Noise

Make Curve | Reset to LISA

(Shane Larson)

LISA Science Requirements

Six categories of **sources investigated**

1) Known Verification Binaries
2) Galactic binaries
3) Merging supermassive black holes
4) Intermediate Mass/Seed supermassive black holes
5) Gravitational captiures from nuclear star clusters
6) Extragalactic backgrounds and bursts

Draft LISA Science Requirements

Requirement	10^{-4}Hz	10^{-3}Hz	5×10^{-3}Hz	10^{-2}Hz	Arm	T_{miss}
(1) Verification binaries		4x 5x (5y)	3x (1.5y)		long	1.5y
(2) Galactic binaries		4x 5x (5y)	3x (2y)		short	2y
(3) Cosmic backgrounds	Sagnac channel, < 3 glitch/d					
(4) Gravitational capt		4x	1x	1x	short	3y
(5) Merging supermassive	5x	10x	10x		long	3y
(6) High z BHs		4x	1.5x	1.5x	short	3y

Max expected source freqs: 0.03Hz (2,4,6). ⇒ Min data sampling rate 0.2Hz?

Goal	10^{-4}Hz	10^{-3}Hz	5×10^{-3}Hz	10^{-2}Hz	Arm	T_{miss}
(1) Verification binaries						
(2) Galactic binaries	1x	3x	2x	2x		5y
(3) Cosmic backgrounds	< 1 glitch/d					
(4) Gravitational capt			1/4x	1/4x	short	5y
(5) Merging supermassive	1x*				long	> 5y
(6) High z BHs					short	

* (5) White acceleration noise at least down to 3×10^{-5}Hz. (2,3,4,6) sources could exist at > 0.03Hz. ⇒ data sampling rate 1Hz? (1,2,5) have *Sagnac mode* as goal.

(Units: Pre-Phase A Sensitivity)

(LISA Science Requirements – March 7, 2002)

Draft LISA Science Requirements: Comments

Gravitational capture of compact objects by supermassive BHs

- Most challenging requirement and goal
- Also one of the highest-priority LISA science objectives

Merging supermassive BHs

- Typically high-signal to noise, but sets goal and requirement at 10^{-4} Hz (in order to get accurate distance and other parameters for 10^6 M_{sol} BHs)

High-Z intermediate mass seed BHs

- 10^3-10^5 M_{sol} BHs at z = 7 - 30
- Somewhat speculative, but highly interesting for probing protogalaxies

Cosmic backgrounds/bursts

- Standard slow-roll inflation not detectable
- Explore as much phase space as possible, but no firm requirement

Compact Object Inspiral into a Supermassive BH

Important Science Objective for LISA

Potential to "map" spacetime of MBH as compact object spirals in (e.g. 10^6 orbits available for mapping)

- Distinguish between Kerr and alternate metrics ("no hair")
- For Kerr, all multipoles parametrized by mass M_{BH} and spin a_{BH}

Also measure astrophysical parameters

- Masses, spins, distances, properties of nuclear star clusters

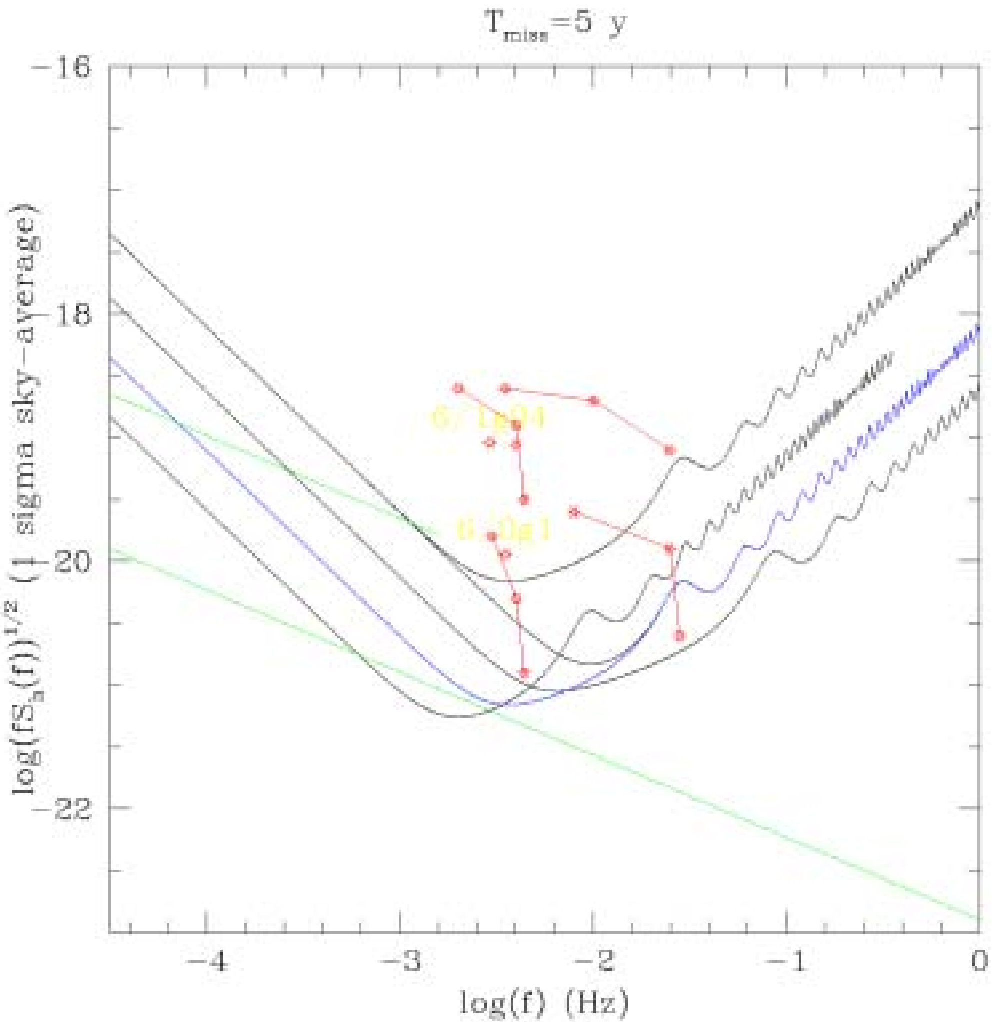
Rates are difficult to estimate

- Loss cones, stellar density, IMF, triaxiality, merger history, black hole mass function, etc.
- See e.g. Hils & Bender (95), Sigurdson & Rees (97), Sigurdson (97), Freitag (01)

LISA may be able to see to $\geq$ 1 Gpc

- However, orbits may be sufficiently complex that coherent detection of signal is difficult
- Olbers' confusion could contribute non-negligible background
- May lower observable event rate

Gravitational Capture of Compact Objects by Supermassive Black Holes



Left pair: Schwarzschild. Right pair: a/M=0.998. Upper pair: $10M_\odot/10^6M_\odot$, $z = 0.1$ (0.4 Gpc) —strongest in 1 year with Freitag normal rate. Lower pair: $1M_\odot/10^6M_\odot$, $z = 0.25$ (1 Gpc) —strongest in 1 year with Bender & Hils rate.

Circular equatorial prograde orbits, m=2 harmonic, points at 1y, 1 mo, 1 day. See Finn & Thorne (2000) PRD 62, 124021.

Height above curve is S/N per octave (except for 1 day point, where explicit sqrt(delf/f) is used)

Gravitational Captures: Key Issues

Rates

- Depend on large number of factors: e.g. mass, spin of central supermassive BH; characteristics of nuclear star cluster; merger history of galaxy

Phase space of orbits/counting of templates

- Number of trials required for detection

Signal processing algorithms

- Whether "optimal processing" is feasible

Self-background of gravitational captures

- Olbers' contribution

(These will be discussed in more detail in separate session)

Need contributions by community in both astrophysics and relativity

TaP's "Wish List"

Progress on key issues for gravitational capture estimates

- Rates!
- Orbits!
- Backgrounds!

Definitive resolution of "last parsec" issue for merging supermassive BHs

Research on "LISA Astrophysics"

- Galaxy mergers and supermassive BH binaries
- Nuclear star clusters
- WD binary population
- Understanding tides on WDs
- High-z galaxy formation and mergers
- Origin of seed black holes

New sources of low-frequency GW

LISA International Science Team

- **European Members**

  Karsten Danzmann, U. Hannover/ MPI Quantenoptik, Co-Chair, ESA Project/Mission Scientist

  Alain Brillet, Observatoire de la Côte d'Azur

  Massimo Cerdonio, U. Padova

  Michael Cruise, U. Birmingham

  Curt Cutler, AEI Potsdam

  Guenther Hasinger, MPE Garching

  Jim Hough, U. Glasgow

  Bernard Schutz, AEI Potsdam

  Pierre Touboul, ONERA

  Stefano Vitale, U. Trento

US Members

Tom Prince, Caltech/JPL, Co-Chair, NASA Mission Scientist

Tuck Stebbins, GSFC, NASA Project Scientist

Peter Bender, U. Colorado

Sasha Buchman, Stanford

Bill Folkner, JPL

Craig Hogan, U. of Washington

Sterl Phinney, Caltech

Doug Richstone, U. Michigan

David Shoemaker, MIT

Chris Stubbs, U. Washington

Kip Thorne, Caltech

LISA International Science Team (LIST)

Elements of Charter

- Members:
  - Approximately 20: nominally half from US, half from Europe
- Reporting:
  - Reports to LISA Program Scientist at NASA HQ and Head of the Fundamental Physics Office at ESTEC.
  - Advises the NASA and ESA project management offices
- Structure:
  - US and European Co-chairs; US Mission Scientist is US co-chair
  - Meets approximately twice per year
  - LIST will organize working groups to carry out its responsibilities

LIST (continued)

LIST Functions

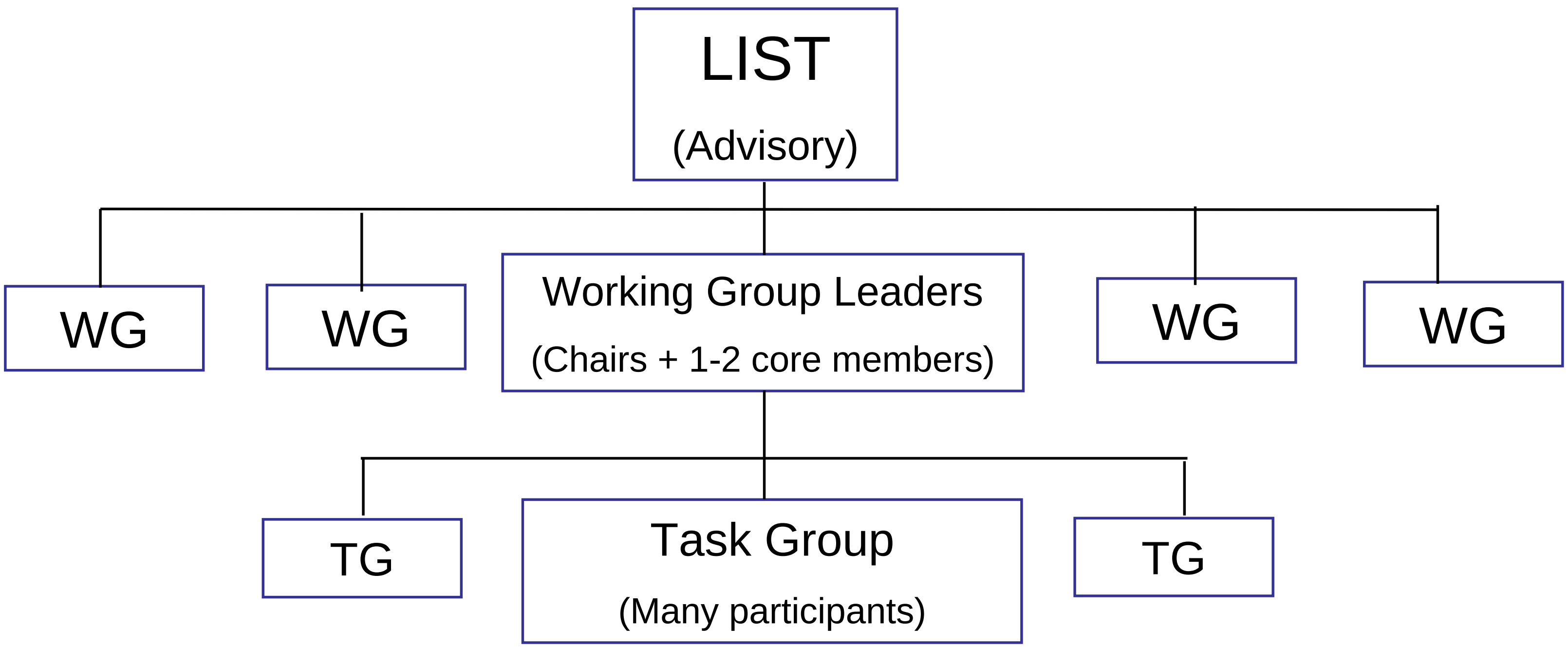
- Represent European and US science communities
- Advise NASA and ESA on :
  - scientific goals, design requirements, scientific use policy, international arrangements, satellite operations, and data analysis policies
- Undertake studies and provide recommendations through the mechanism of working groups
- Serve as an advocacy group for LISA
- Suggest processes and structures for providing opportunities for broad scientific community to become informed about mission and contribute to it
- Provide recommendations on education and outreach

LIST Structure

LIST

- Primary scientific advisory group for LISA
- About 20 members
- EU/US co-chairs (Karsten Danzmann, Tom Prince)

Structure



LIST Structure

LIST Working Group Leaders

- 5+1 groups
  - WG1: Sources and Data Analysis
    co-chairs Phinney and Schutz, core member Hughes
  - WG2: Interferometry, Lasers, and Optics
    co-chairs Hough and Spero
  - WG3: Disturbance Sensors and Drag-free Control System
    co-chairs Buchman and Sumner, core member Bender
  - WG4: Science Operations
    co-chairs Cruise and Folkner
  - WG5: Integrated Modeling, Prototyping, Integration and Testing
    co-chairs Sanford and Shoemaker, core member McGraw
  - Payload working group
    co-chairs Danzmann and Herring

LIST Task Groups

- Carry out detailed work of LIST
- Organized by working group chairs and core members
- Topical, can have finite lifetime, fluctuating membership

LIST Points of Contact

Points of contact for source modeling activity

- Conferences and Workshops are the best points of contact
  - Discussion and dissemination of new results of relevance to LISA
  - Example: LISA Symposium at Penn State in July, 2002
- Sources and Data Analysis Working Group (WG1)
  - Points of contact: Scott Hughes, Sterl Phinney, Bernard Schutz
  - Also: Task group leaders (as they arise)
  - Scott Hughes has solicited input on forming new task groups
  - Emphasis: results that impact the science requirements and design of LISA

Concluding Comments

- Contributions to LISA from the GW Source Modeling community are most welcome
- Gravitational Capture problem is currently the most urgent
- Many astrophysics issues as well as GW source modeling issues
- LIST encourages support of research by NASA and NSF
  - Includes GW source modeling
  - Also includes a broad range of astrophysics research of relevance to LISA