LISA Data Analysis

Bernard F Schutz

Albert Einstein Institute – Max Planck Institute for Gravitational Physics, Golm, Germany

http://www.aei.mpg.de

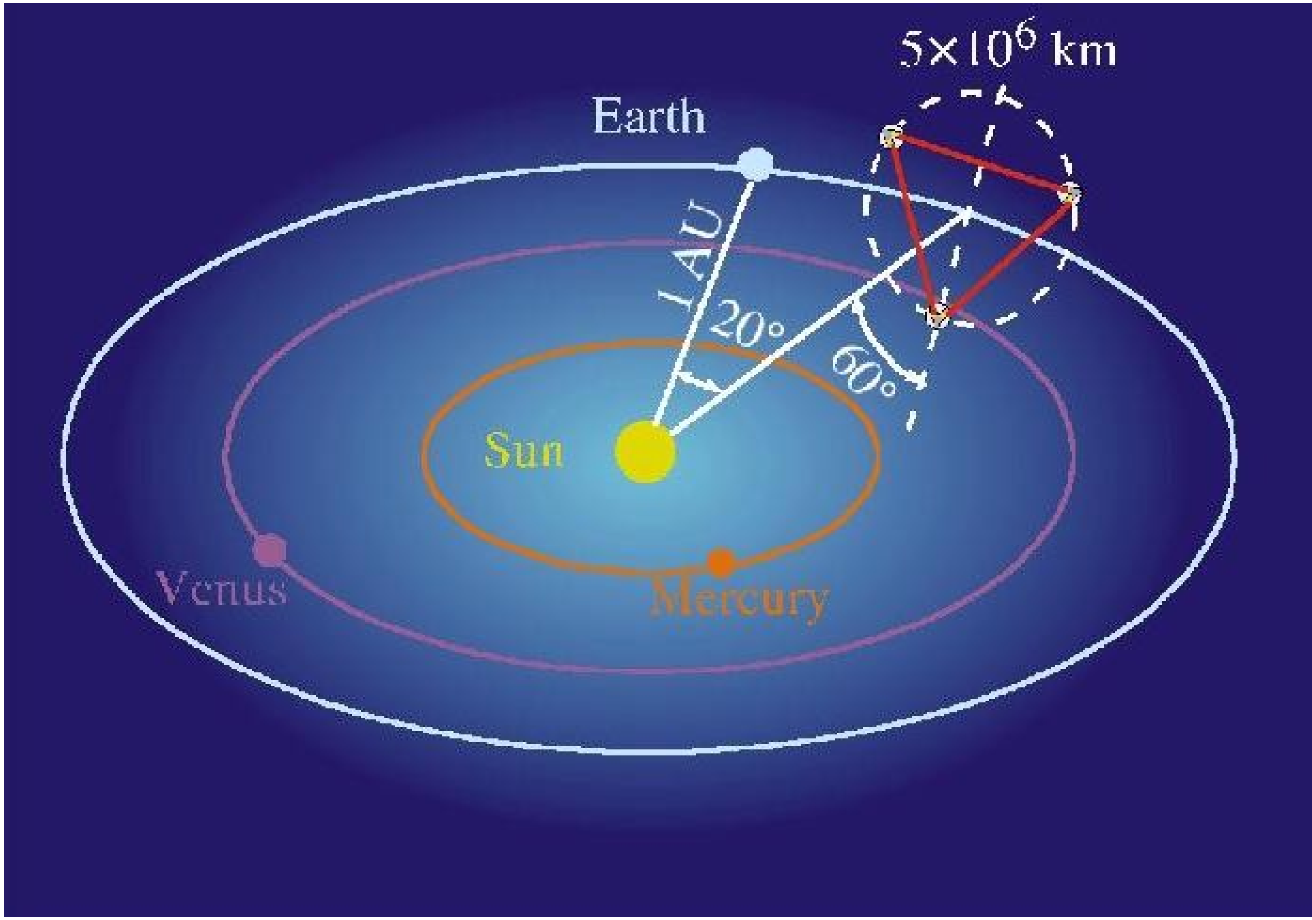
Bernard.schutz@aei.mpg.de

Outline

- Overview of LISA mission
- Time-delay interferomtery (TDI)
- GW detection against confusion
- Development of data analysis systems

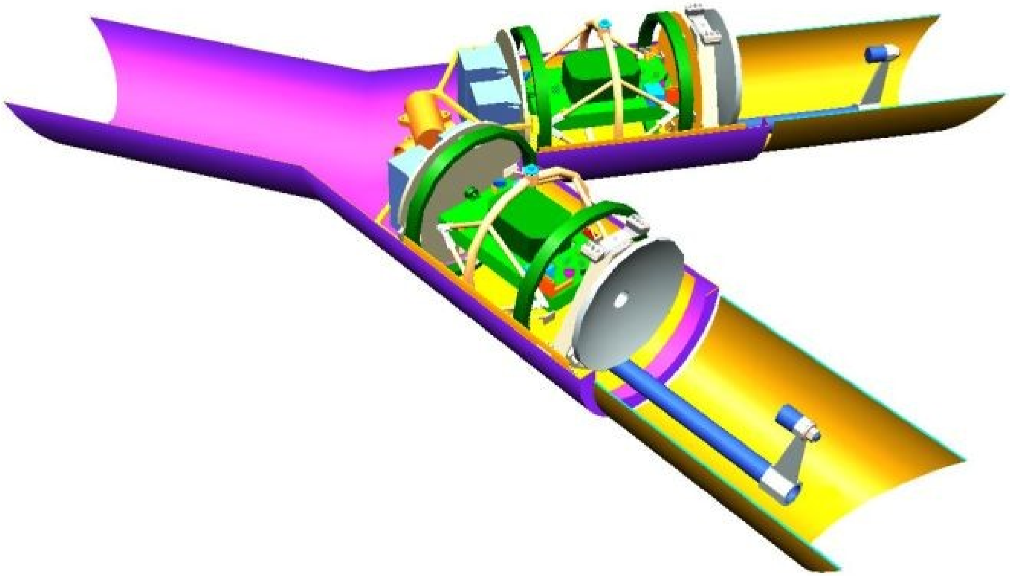
Overview of LISA mission

- LISA launch (2015 or later)
- One year to stations
- Some months commissioning
- Observations for nominal lifetime 3-5 years.
- Hope reliability allows mission extension to ~10 years: few consumables.



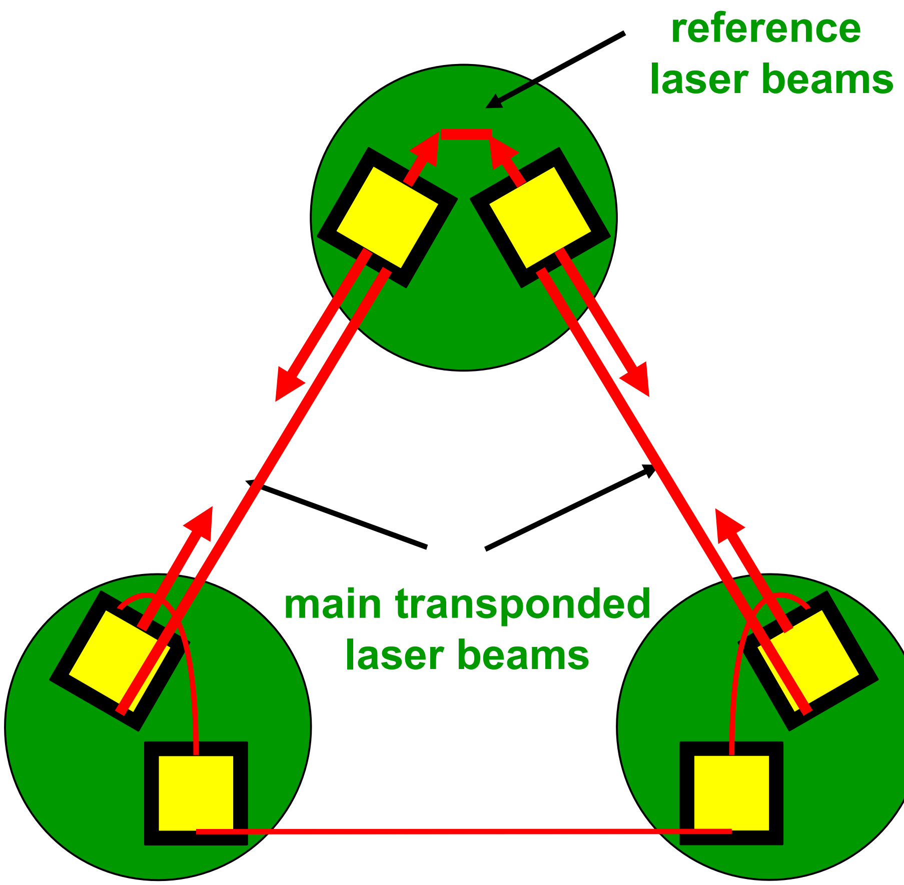
Drag-free and optical transponding

- LISA's interferometry uses free-flying proof masses.
- S/C is a shield
- Arms are too long for interferometry by reflection: beams transponded back to source by phase-locked lasers



Drag-Free GW Sensing

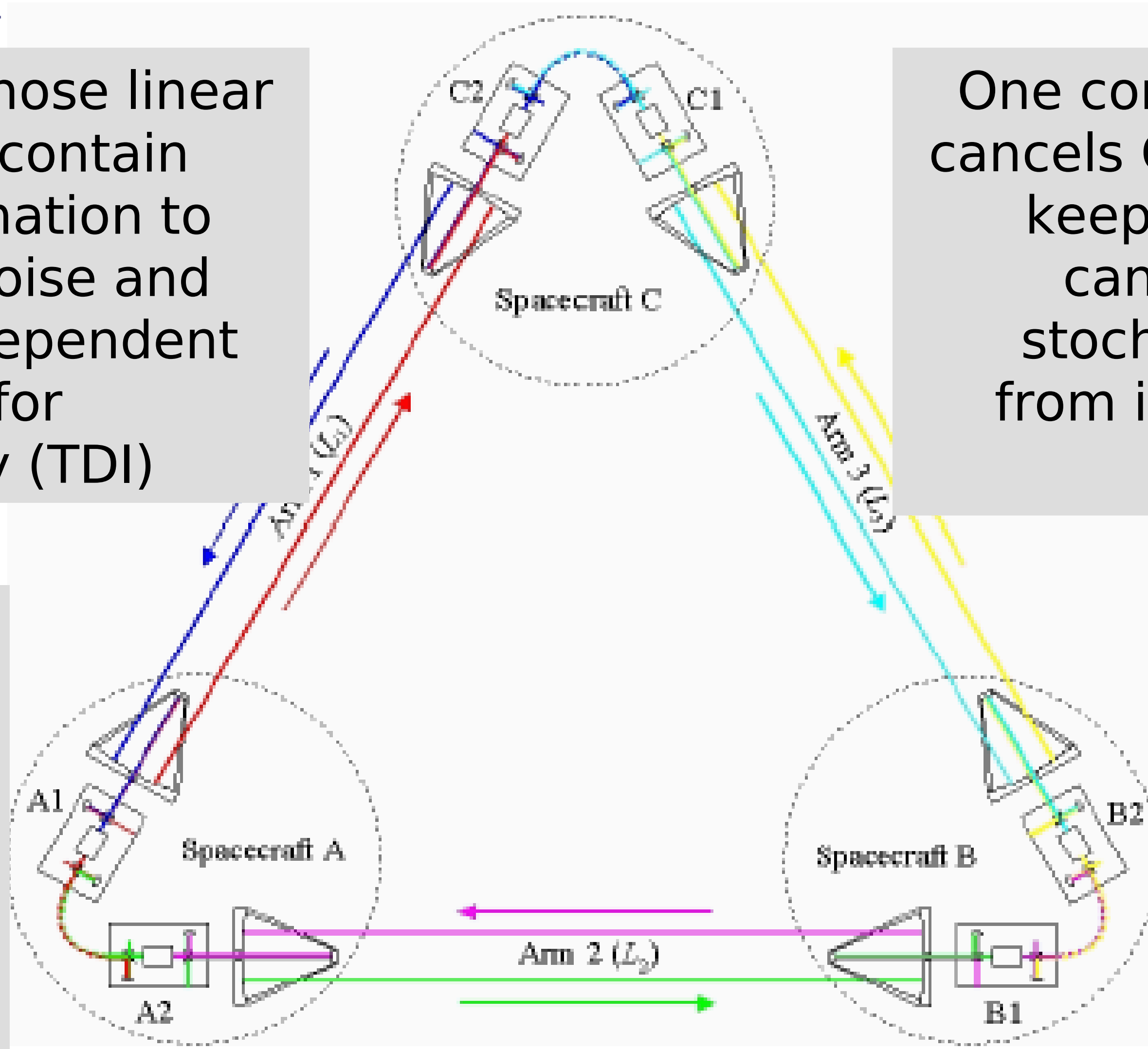
- Each S/C carries 2 test masses, 2 lasers, 2 telescopes.
- Local lasers phase-locked
- Lasers on distant S/C locked to incoming light
- Forms laser transponder, effectively an *active mirror*
- Laser beams reflected off *free-flying* test masses, insensitive to spacecraft motion.
- Effectively 3 Michelsons
- Long arms ⇒ displacements in picometer range, *much* easier than ground-based interferometry



LISA Measurement

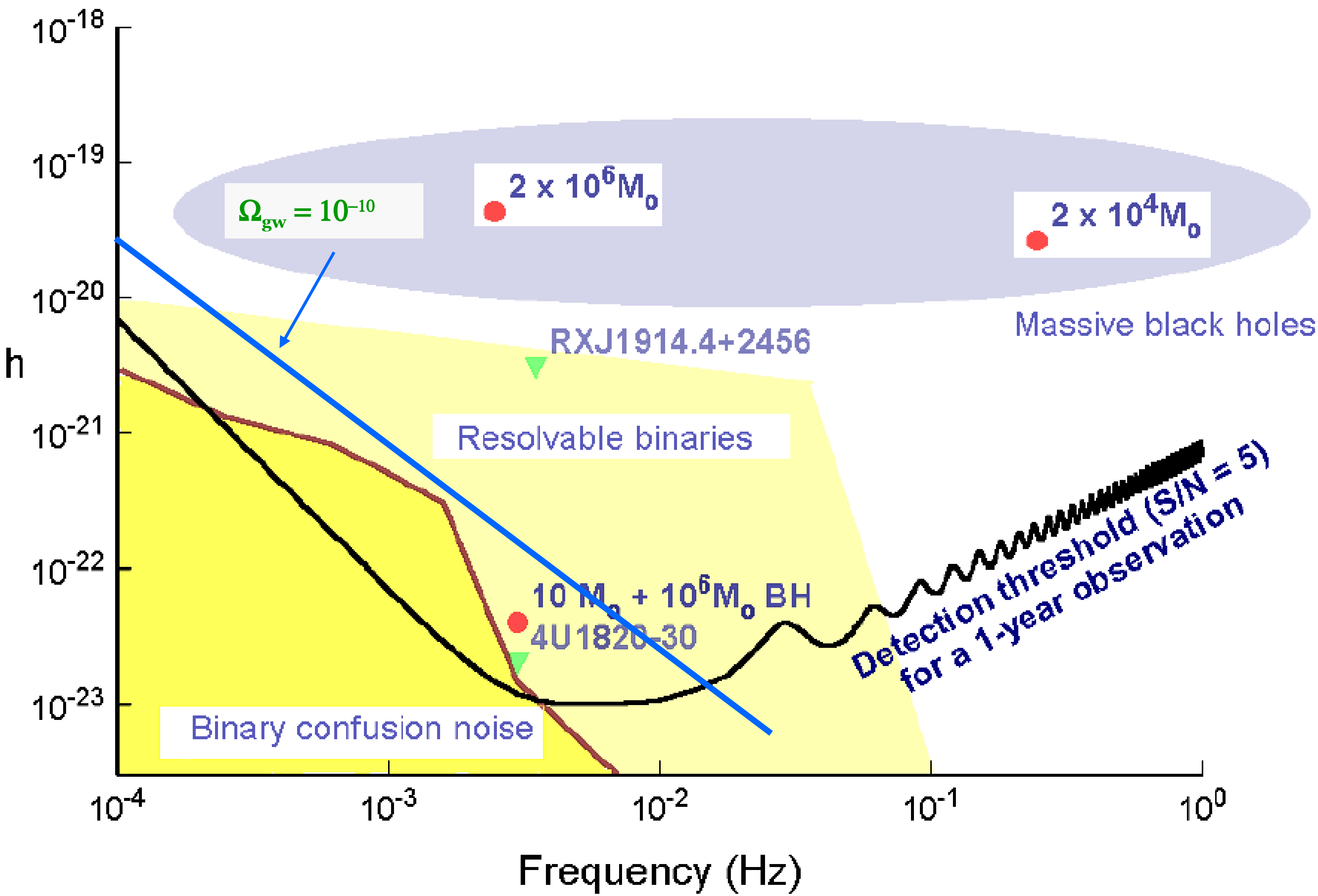
12 signals, whose linear combinations contain enough information to cancel laser noise and produce 3 independent data streams for interferometry (TDI)

One combination cancels GW signal, keeps noise ⇒ can separate stochastic GWs from instrument noise.

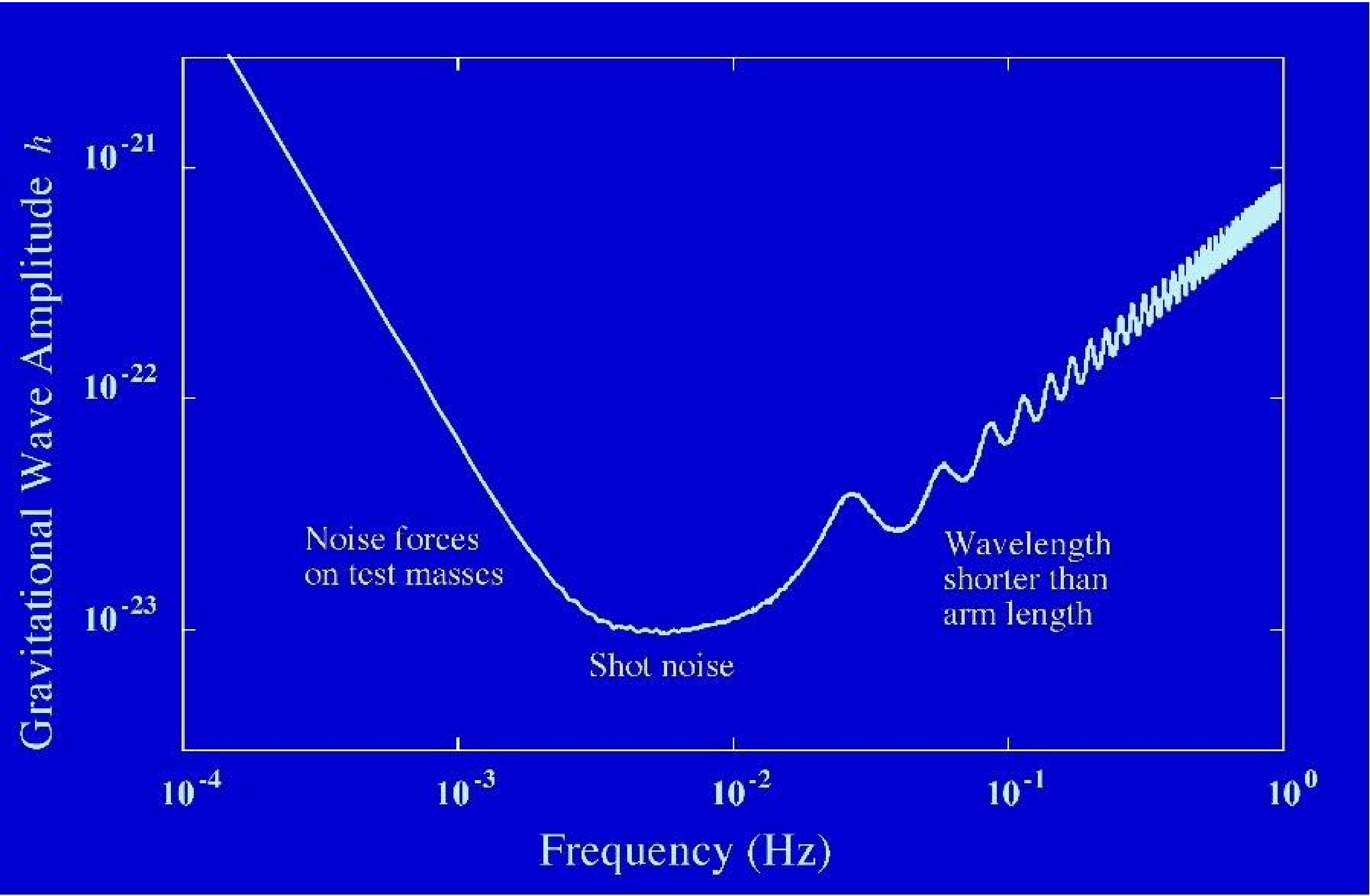


Armlength slowly changes, >1000 km in 1 yr ⇒ LISA is self-calibrating!

High-SNR GW Observing

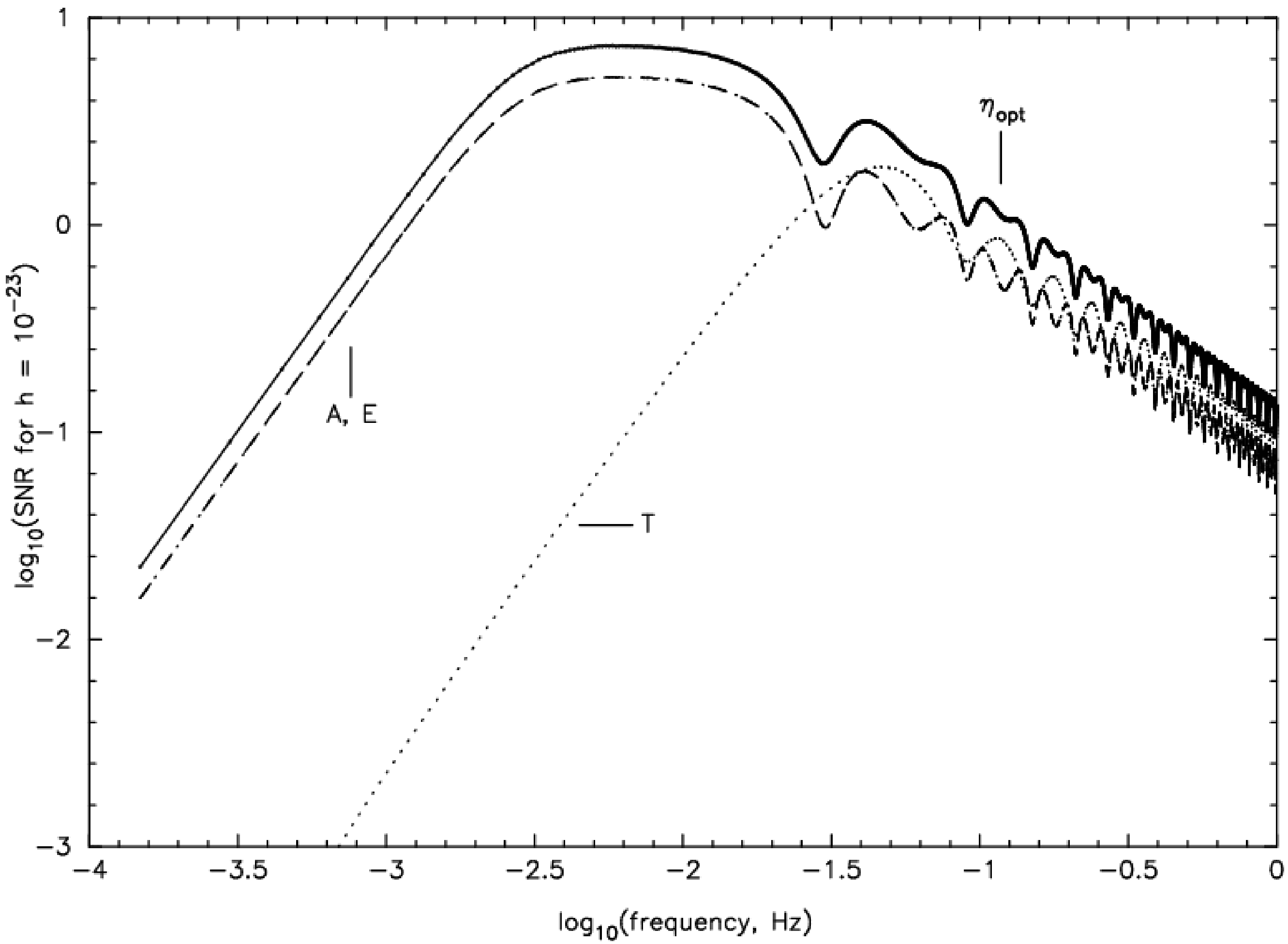


Sensitivity limits



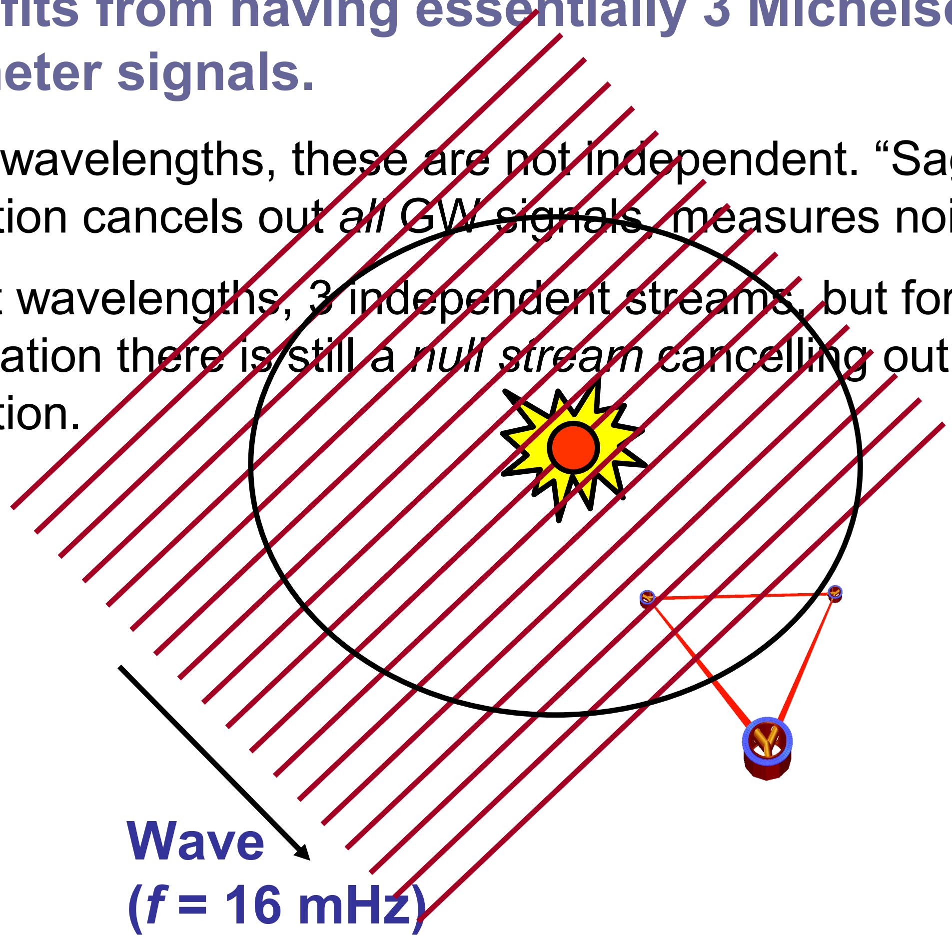
TDI variables

- **Massimo Tinto and Sanjeev V. Dhurandhar, "Time-Delay Interferometry", *Living Rev. Relativity* 8, (2005), 4. http://www.livingreviews.org/lrr-2005-4**

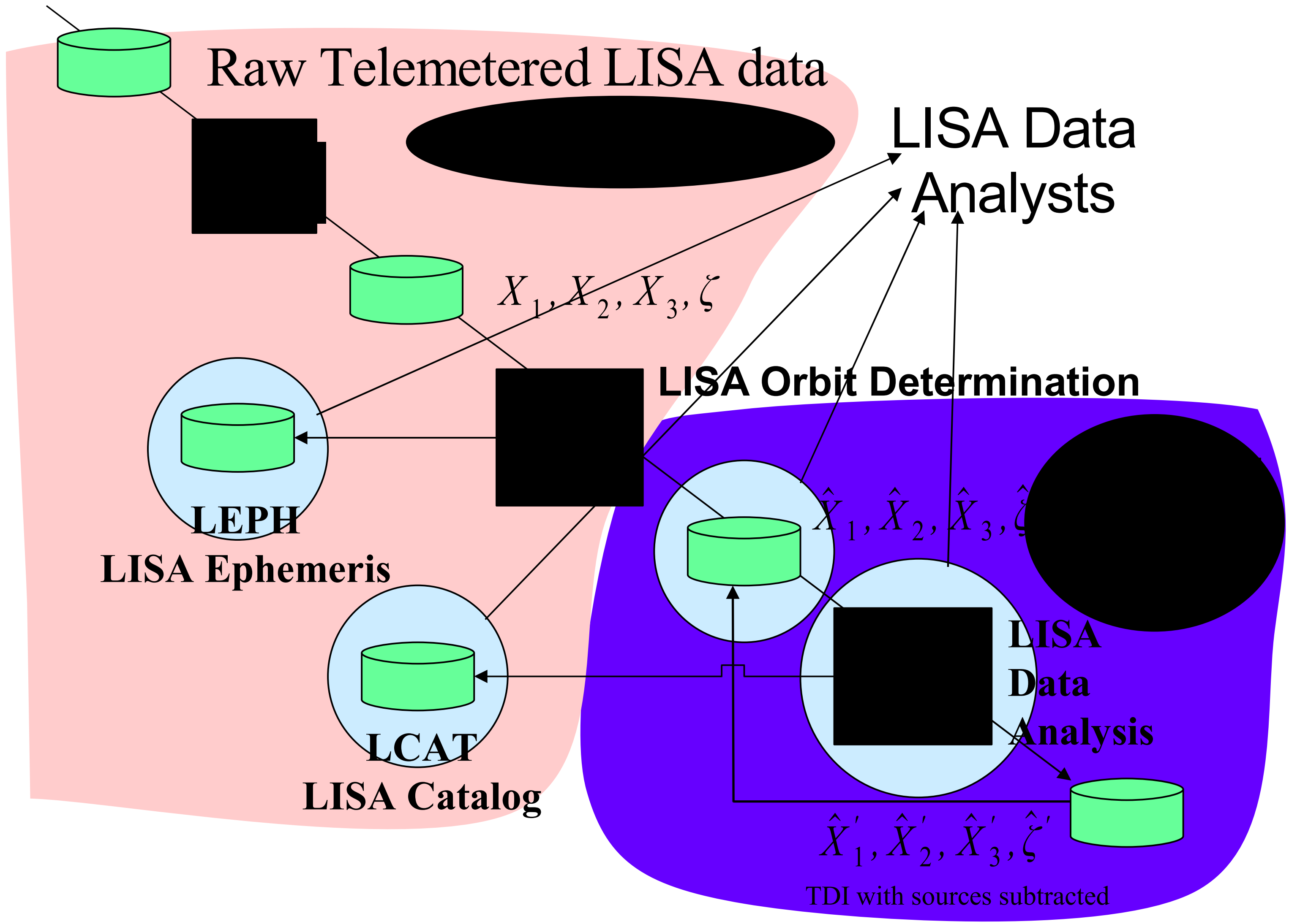


Tools for LISA data analysis

- **LISA can use amplitude and phase modulation to locate sources on the sky, separate overlapping signals.**
- **LISA benefits from having essentially 3 Michelson interferometer signals.**
  - For long wavelengths, these are not independent. “Sagnac” combination cancels out *all* GW signals, measures noise.
  - For short wavelengths, 3 independent streams, but for signals from a given location there is still a *null stream* cancelling out any signal from that location.



Possible LISA science data flow



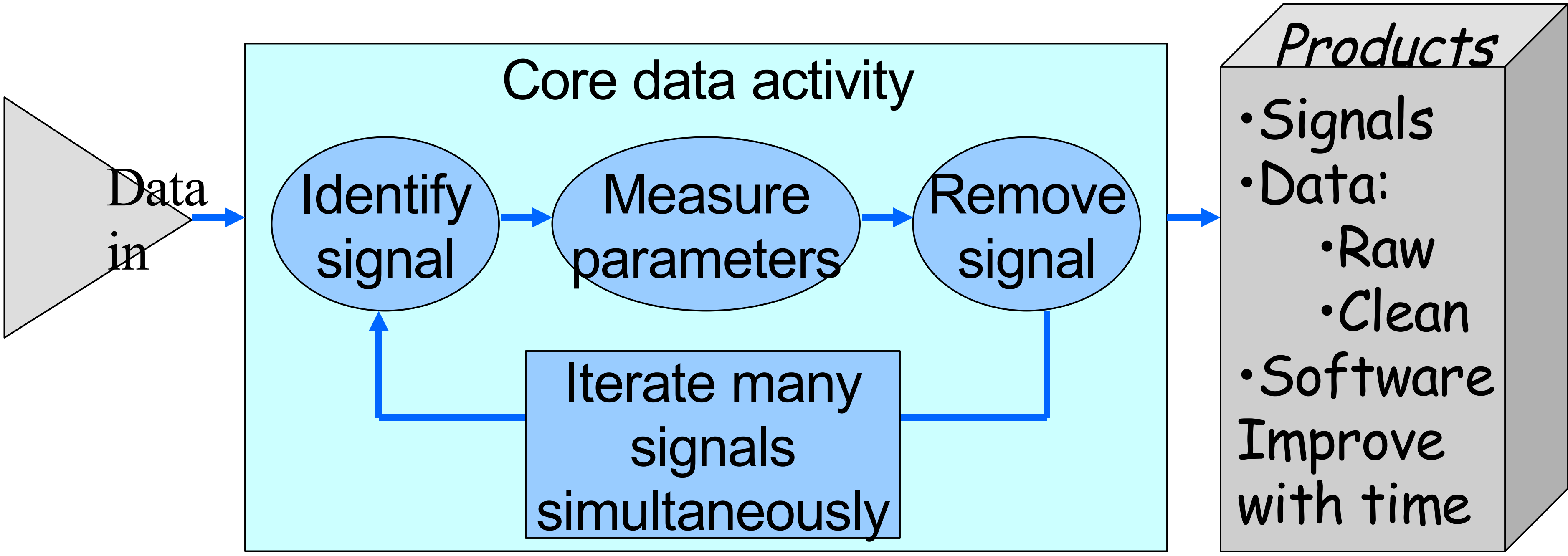
(Ron Hellings 2004)

Approach to LISA data analysis

- **Requirement is to resolve overlapping signals. This involves not just detecting them but also measuring all parameters needed to remove them from the data stream.**
- **Main data-analysis approach will be iterative:**
  - Solve for strong sources approximately, subtract them.
  - Solve for next strongest, subtract, go back to strongest and remove their residuals better.
  - Binary orbital parameters improve with time, so their signals can be subtracted better after 2nd year. So transient events (black hole mergers) in first year also improve after 2 years.
- **Data products: source detections and parameters, cleaned-up data streams, full data streams.**
- **Highly integrated analysis system required, but no decisions yet by agencies on how or where this analysis will be done, what proprietary data rights the scientists will have, etc.**

Features of LISA data analysis

- LISA data analysis differs from ground-based because LISA is a high S/N instrument limited by source confusion as much as by instrumental noise.



Challenges of LISA data analysis

- **Confusion challenge**
  - Source identification not unique. Must use intelligent principles to identify “best” identifications. How to guarantee that iterative scheme finds the globally “best” solution? What is the right search method?
- **Network challenge**
  - LISA actually has 3 interferometer signals, optimum combinations depend on source location and polarisation. Modulation complicates this.
- **Computational challenge**
  - Parameter space for EMRIs is huge. Even with anticipated improvements in computing, a hierarchical search will be needed. Not clear how to do this against a background of weaker EMRIs.
- **Theory challenge**
  - Some signal templates not yet known well enough, including EMRIs and BH merger waveforms.
- **Organizational challenge**
  - There is no legacy analysis system: it must be designed in scientific community but be highly integrated.

Development of DA Systems

- **Considerable work in community on data analysis methods for LISA, plus experience with LIGO/GEO/VIRGO/TAMA data analysis**
- **LIST has drawn on this to define LISA mission requirements and objectives – a definition of performance expectations for the LISA hardware**
- **Workshop at AEI 22-24 March 2004 with wide participation.**
- **General agreement on a number of points:**
  - Core data analysis cannot be distributed among independent teams or guest observers; must be organized in coordinated way.
  - Core data analysis is a project responsibility: agencies should organize and fund it adequately and ensure that it is managed properly during entire lifetime of mission.
  - Data analysis activity should be divided between data analysis centers and the LISA community, coordinated by centers. Centers have other jobs, too, such as outreach, archiving, community-building
  - Software development a key issue, must start early enough.
  - Data analysis must be fully functional and tested by the beginning of the mission: many sources are transients.
  - Data products must include full data release as well as specific (and time-critical) measurements.
  - Key start-up activities should be funded by agencies soon:
    - Further research into sources and algorithms
    - DA team should be formed in time to advise Phase-B design

Problems being addressed

- Simultaneous removal of strong signals, effect on accuracy of various parameter determinations. Removal not trivial when signals come from different families.
- EMRI signals have complex structure. Relativity problem not yet solved, so we don't have full waveform predictions. Work also needed on doing searches over the parameter space.
- Black hole merger waveforms cannot be reliably predicted.
- Optimal use of TDI data streams (best antenna pattern, phase-delay pointing at higher frequencies, consistency at all frequencies). Must be studied for each kind of source.
- Real-world problems: handling gaps, estimating instrumental noise, coping with sensitivity degradation, specifying sciencekeeping data need, protected periods.
- Prepare data analysis methods for degraded missions (loss of an arm).
- Source refinements: filters for interacting WD binaries, filters for merged BH ringdown, waveforms from intermediate-mass-ratio BH systems (say, 100:1 or 500:1), "exotic" sources like cosmic strings.
- Standard data architecture tasks: quality assurance, testing, data synthesizers, estimate computing resources required, decide on data products, data pipeline, communication paths among data analysis/acquisition/operations teams.

ESA and NASA data activities

- NASA has vested responsibility with JPL (Prince/Schumaker), developing AMIGOS document, cooperating with community
- ESA has vested responsibility with ESTEC (Jennrich), has set up DAST, involving over 50 European institutes.
- LIST oversees coordination and has launched the Mock LISA Data Challenge (MLDC) to stimulate work and allow testing and comparison of algorithms.

MLDC

- **Challenge 1 – The goal of this challenge is to foster the development and validation of building blocks of and basic tools for LISA data analysis and tackle analysis of data sets containing a single signal or non-overlapping multiple signals (with one exception, see Chapter 5) embedded in Gaussian and stationary noise with no contribution from galactic and/or extragalactic foregrounds. Training data sets (where all the source parameters are public) will also be provided.**
  - Sources: galactic binaries, verification binaries and massive black hole binaries (only in-spiral portion of the whole coalescence).
  - Release date: 30 June 2006
  - Due date: 1 December 2006
  - Note: Data sets containing one EMRI will also be distributed for this first round; however, due to the difficulty of the problem results are requested by the due date of challenge 2, tentatively June 2007

Links

- MLDC home http://astrogravs.nasa.gov/docs/mldc/
- LIST home http://www.srl.caltech.edu/lisa/people_frame.html
- LIST WG1b home
  http://www.tapir.caltech.edu/dokuwiki/listwg1b:home
- LISC home http://www.lisa-science.org/
  (see Markus Pössel if you want to contribute)