LIST Science Requirements Working Group

107 Lauritsen, Caltech

Meeting Agenda/Draft SRD

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9 Dec 2005

[3rd edition 7:30pm 9 Dec 2005]

[4th edition 1:00pm 14 Dec 2005]

Science Requirements WG Agenda

1. Review of draft Science Requirements document
   A. Structure OK?
   B. Corrections needed?
   C. Additions needed?
   D. Work needed.
   E. Prioritisation of science and sensitivities.
2. 2Gm armlength instead of 5Gm? Quite bad for SMBH.
3. 0.03mHz goal?
4. 1Hz a goal, not requirement?
5. How many working links needed? [mostly less than 6]

Historical documents at http://www.srl.caltech.edu/lisa/srd_working/
and http://www.tapir.caltech.edu/listwg1/
and http://www.its.caltech.edu/~esp/lisa/listwg1.html

WG1 Participants 9 Dec 2005

US

1. Centrella
2. Cornish
3. Richstone
4. Hughes
5. Phinney (co-chair)
6. Prince
7. Schumaker
8. Hogan
9. Cutler
10. Stebbins
11. Thorne
12. Bender
13. Hellings
14. Rubbo
15. Tinto
16. Armstrong
17. Larsson
18. Jenet
19. Klimenko
20. Anderson
21. Vallisneri
22. Drasco
23. Benacquista

Europe

1. Schutz
2. Lobo
3. Vitale
4. Vinet
5. Binetruy
6. Sumner

LIST 7/8/05 draft deliverables

1. Science requirements document
2. Science management plan
3. Science data flow architecture document
   A. picture of data flow, phases of data processing and methods, science commands, sciencekeeping, calibration.
4. Science data management plan
   A. people, facilities for processing, archiving, distrib of data from level 0 (receipt on ground) to science output, science data analysis.
5. AMIGOS (analysis methods development plan)
   A. analysis technology development needs, work areas, priorities, timelines. Coordinated with ESA.

Flow of Science requirements
(old SRD has 3->6, but not 1,2; addressed here).

1. Science Objectives (e.g. Beyond Einstein: test GR)
2. Research Focus Areas (BE: measure mass, spin and at least one higher multipole moment of a black hole via EMRI)
3. Observational requirements (Measure e=0 EMRI of 10Msun into 10^6 Msun at 1Gpc)
4. Analysis methods (data reduction, backgrounds...) Not in other examples except as SIM “companion document”.
5. Data requirements (on gaps, nonstationarity, vetos). What do we need to say about non-stationarity? Non-gaussianity?
6. Measurement requirements (instrument sensitivity, reliability, latency, housekeeping, bit rates...)

Structure of Science Requirement documents (e.g. GLAST, SIM, JWST)

1. Narative introduction to the science and mission instruments and observing modes.
   A. Term definitions (baseline requirements, minimums, goals).
   B. Relevant documents to the development of the mission concept and its requirements (e.g. decadal surveys, roadmaps, science requirement analyses).
2. Science Objectives, broken down by research area.
   A. After each narrative objective, give key instrument requirements it implies.
3. Tabular summary of instrument requirements
   A. Covers sensitivity, frequency, dead time, mission lifetime, telemetry etc.
4. Mission success criteria
5. #pages ~ 30(mission cost/ $\$10^9$)

Structure of Science Requirement documents (e.g. GLAST, SIM, JWST), cont'd

6. SIM also has (separate document) “Science User Scenarios”:
   A. An explanatory supplement to the SRD
   B. Describes instrument/mission operations from a science perspective.
   C. Explains in detail the assumptions behind the requirements.
   D. Something analogous seems a good idea for LISA
7. The existing examples do not actually prioritise (potentially a problem for JWST), but there is consensus that LISA SRD should
   A. prioritize science
   B. within each science objective, put an approximate metric on the resulting requirements for sensitivity, number of arms, telemetry, gaps, etc.

LISA-related Science Objectives from NASA Strategic Roadmap 8 (June 2005))

Would be wise to retain this heritage (from Beyond Einstein Jan 2003, Decadal Survey 2000)

1. Detect gravitational waves in the frequency range 10^{-4}Hz to 1Hz.
   A. Directly detect, from known astrophysical sources, the gravitational waves predicted by general relativity.
   B. Discover new sources of low frequency gravitational waves, and search for a cosmic background.
2. Observe how black holes manipulate space, time and matter.
   A. Determine if the dense objects at the centers of galaxies, that we call "*black holes*" are truly the black holes predicted by Einstein's general relativity.
   B. Determine the precise masses *and spins* of a large sample of nearby galactic black holes.
   C. Observe the merging and growth of the first black holes to form in the Universe.

LISA-related Science Objectives cont'd

(from NASA Strategic Roadmap 8 (June 2005))

3. Determine the cosmic evolution of dark energy.
   A. (through precise cosmic distance measurements of at least two cosmologically distant sources for which redshifts can also be obtained).

LISA SRD -introduction 1

Definitions:
Baseline requirement -specification of a system parameter or capability with which system design must comply, and be verified (e.g. by analysis, test, demonstration)

Minimum requirement -minimum performance floor acceptable. Descopes, if necessary must meet these levels (i.e. these can turn into baselines of a descoped mission). If not met, would trigger a Project review.

Goals -performance parameters that would significantly enhance scientific return. These do not drive mission design, and are not required to be verified. Project just attempts a mission design that does not preclude achieving the goals, and tracks them, so that if resources allow the better performance can be achieved.

LISA SRD -introduction 2

Conventions:

Sensitivity: the LISA sensitivity requirements are stated in terms of $\mathrm{sqrt}(S_h(f))$, defined as the single-sided, sky-averaged, polarization-averaged rms spectral density of gravitational wave strain measured in the “Michelson” X observable of TDI (i.e. using two arms of the LISA constellation), with units $\mathrm{Hz}^{-1/2}$ (Note that sometimes it is convenient to plot the dimensionless $\mathrm{sqrt}(fS_h(f))$, when illustrating the SNR of sources). At low frequencies (<1mHz), where acceleration noise dominates and the gravitational wave transfer function is independent of frequency, this is (with acceleration noise on one proof mass $a=3\ 10^{-15}\ \mathrm{m\ s^{-2}Hz^{-1/2}}$ in the pre-phase A baseline design with arm length L=5 Gm, at gravitational wave frequency f):

$$\sqrt{S_h}=\frac{4}{L}\frac{a}{(2\pi f)^2}\sqrt{\frac{5}{3}}=7.8\times10^{-20}\left(\frac{1\,\mathrm{mHz}}{f}\right)^2\mathrm{Hz}^{-1/2}$$

With this convention, for example, the sky-averaged SNR of sweeping sources at distance D with characteristic amplitude $h_c=(\pi D)^{-1}\,\mathrm{sqrt}(2dE/df)$ is given by:

$$\mathrm{SNR}^2=\int\frac{h_c^2(f)}{f\,S_h(f)}\,d(\ln f)$$

LISA SRD -introduction 3

Conventions 2:

SNR: all SNRs quoted are for isolated sources (but including the conventional gaussian approximation to galactic white dwarf noise), optimal signal processing, gaussian noise, and duty cycle 1 (though 0.9 wouldn't make much difference for most sources provided it was well divided over the time the source was contributing SNR in the LISA band).

The actual instrument performance needed to assure those SNRs may be higher due to source confusion/subtraction issues, non gaussian noise components, inadequate computer power to perform optimal processing (e.g. for EMRI -though this case has been taken into account in the estimates), etc.

LISA SRD -introduction 4

The Laser Interferometer Space Antenna (LISA) mission is designed to discover and observe gravitational waves from a wide variety of astronomical sources, at wave frequencies between approximately 10^{-4}Hz and 1Hz.

Einstein's general theory of relativity predicts the existence of these waves, and there is strong indirect evidence that they exist (the decay of several binary pulsar orbits at precisely the rate predicted by relativity due to the loss of orbital energy to gravitational waves).
Yet they have not yet been detected directly. LISA's objectives are to discover these waves, and to study the following sources (in increasing order of difficulty and/or decreasing certainty; also a decreasing priority order except possibly #4?):

1. (Min) Known galactic binary stars
2. (Min) Unknown galactic binary stars
3. (Min) Merging Supermassive black holes
4. Merging Seed black holes
5. Stellar mass objects captured by supermassive black holes in galactic nuclei
6. Gravitational wave backgrounds (from stars, and the early universe)
7. Gravitational wave bursts (from stars, cosmic strings...)

LISA SRD -Obj 1

LISA's first objective is to discover gravitational waves and verify that they are in accord with the predictions of relativity, by detecting the waves of precisely predictable frequency and sky position, and approximately predictable amplitude (given uncertainty in the masses and distance of the stars) from known white dwarf binaries (e.g. RX J0806.3+1527, ES Cet, V407 Vul).

Standard LISA 1yr/1mo: (NB SNRs uncertain by at least 2 due to unknown inclination, poorly known M2, distances)
RXJ0806 SNR=235/38, dl=0.3/1.1deg, db=0.06/1.2deg, chirp to 4%/no chirp
ES Cet SNR=198/40 dl=0.07/2deg, db=0.11/3deg, i, phi to <1/5 deg no chirp
V407 Vul SNR=77/20, dl=0.13/11deg, db=0.8/13deg, i, phi to 1/10 deg, no chirp

With 10x worse LISA, SNR reduced by 10, positions uncertain by 1-2 degrees, inclinations by 10 degrees.
With only 1 Michelson, position uncertainty in 1 mo (performance verification) is >90 deg! With 2 Michelson it is ~1 deg! Position uncertainty varies a lot (x5) with LISA position rel to source during that month.

LISA SRD -Obj 1 cont

Obj 1: Discover low frequency gravitational waves and verify that they are in accord with the weak field source predictions of relativity,

Obj 1A: by detecting the waves of precisely predictable frequency and sky position, and approximately predictable amplitude (given uncertainty in the masses and distance of the stars) from known white dwarf binaries (e.g. RX J0806.3+1527, ES Cet, V407 Vul).

Obj 1B: Improve limit on graviton mass below present 6E-22 eV, by comparing phase of gw and optical emission of these binaries (cf astro-ph/0311054)

Obj 1C: limits on emission at other than quadrupole (2x orbit) frequencies useful as GR tests? Other polarizations?

Observational requirements:

S1.1 Shall have SNR>10 for at least 3 verification binaries at 3-7mHz. This is also a minimum requirement, and a mission success criterion, though if we want minimum mission to be 10x less sensitive than LISA, might need to relax the SNR or consider only 1 or 2 verification binaries. Also 3mHz crowded -trouble at low SNR?

S1.3 Shall have ability to determine sky position and orbital inclination to ~1 deg. With standard LISA, get these to 1 deg (2 Michelson) or 2 deg (1 Michelson) within 3 months. Strictly sets min mission lifetime of only 3 months? Does not require all 6 arm links.

S1.2 ~~Requirement to also detect possible verification binaries at 1mHz.~~ Drop?

S1.4 To get performance verification in 1 month: requires 2 Michelson, nearly full LISA. Minimum mission cannot do this.

LISA SRD -Obj 2

LISA's second objective is to discover thousands of additional white dwarf binaries (both detached and accreting) in the Milky Way and its surrounding globular clusters and satellite galaxies. This will provide unique insights into the evolution of binary stars, and the mysteries of tides in fluid stars. Correlation of this list of periods and positions with electromagnetic surveys will reveal eclipses (from large synoptic survey telescopes), X-ray emission, and distances and/or orbits (from GAIA and SIM) will provide heretofore unobtainable information on the masses, mass-transfer rates, and tidal coupling of these stars.

LISA SRD -Obj 2

Obj 2. Determine the birth rate and evolutionary history of white dwarf binaries in the Milky Way,
Obj 2A by discovering hundreds to thousands of new white dwarf binaries (both detached and accreting AM CVn) in the Milky Way at 1-10mHz
Goal: and its surrounding globular clusters and satellite galaxies.
Obj 2B. Measure frequency derivative for a significant sample (>10) of detached binaries to determine importance and character of tidal interaction, synchronisation of white dwarfs, test importance of GW loss.
Obj 2C. Measure the binary positions to ~1 deg^2 to enable synoptic survey telescope optical IDs, or X-ray followup, and perhaps subsequent GAIA parallaxes, SIM orbits, etc. Will provide previously unobtainable information on tidal heating, masses, mass transfer mechanisms and rates... [astro-ph/0310889, astro-ph/0312193, astro-ph/0509632]

LISA SRD -Obj 2 cont'd

Observational requirement:
S2.1 SNR>40 (giving 1 degree positions) for at least 400 resolvable (f>3mHz) binaries including 50 AMCVn [cf astro-ph/0312193] (from Obj 2A, 2C). This represents more than an order of magnitude growth over optical samples, plus gives the unique GW measurement of mass/distance for all.
NB 1 Michelson is OK for this, though requires slightly longer sensitivity or lifetime to reach the SNR.
S2.3 To measure GW chirp to 10% for detached systems, f>3mHz, SNR~40 requires mission lifetime > 2 years (from Obj 2B). NB 1 Michelson OK for this.
S2.2 Move to backgrounds

LISA SRD -Obj 3

LISA's third objective is to discover gravitational waves from merging pairs of supermassive black holes in the nuclei of recently-merged galaxies. These are the most violent events in the universe, where a strongly curved spacetime is changing rapidly in both space and time. LISA will measure the waveforms with much higher precision than ground-based detectors are likely to measure (for much smaller black holes), enabling a variety of unique studies of the predictions of general relativity. LISA will also provide advance notice of the position and time of the mergers, enabling electromagnetic telescopes to search for effects of the merger on matter surrounding the black holes.

LISA SRD -Obj 3

Obj 3. Observe and find out if relativity correctly describes the violent dynamical space-time of merging supermassive black holes by

Obj 3A: More precisely than advanced LIGO, measure gravitational waves from merging pairs of massive black holes in the nuclei of recently-merged galaxies, from the early (weak field, PN) through the strong dynamical and ring-down phases. This enables precision measurement of initial and final angular momenta, and masses for comparison with simulations, even if precise waveform extraction still problematic in numerical relativity.

Obj 3B: Provide at least 1 week notice of the position (to ~ degree) and time (to < hour) of the mergers, enabling electromagnetic telescopes to search for effects of the merger on matter surrounding the black holes.

Obj 3C: Measure luminosity distance to several mergers to <10%(and with EM redshift) as indep probe of cosmography/dark energy/H0. [rer]

NB: for 1e6/3e5 at z=1, pure acceleration noise

5Gm arm gives SNR(1y-6mo)=13, SNR(1y-2week)=107 [73 if 1 Mich]

2Gm arm gives SNR(1y-6mo)=5.5, SNR(1y-2week)=47 [32 if 1 Mich]

At 1y-6mo before merger, f=0.044-0.057mHz, and r/M=87-73. At 2 weeks before, f=0.14mHz, r/M=39.

This is a strong driver for a 0.03mHz goal, and for 5Gm arms. With 2Gm arms or wall below 0.1mHz, we lose ability (for Schwarzschild or pure phase ev; see Scott) to give useful (>3 deg) advance notice to EM telescopes (but retain retrospective ability).

LISA SRD -Obj 3

Observational requirement:

S3.1 Sufficient lifetime to make possible the observation of a substantial number of supermassive black hole mergers (>10) with different combinations of masses.

S3.2 Sufficient sensitivity at frequencies above 1 mHz to study lower mass black holes (10^5Msun) at moderate redshift (z=3-6).

S3.3 Sufficient sensitivity at 0.1mHz. Is Sagnac mode needed to calibrate low freq noise, so one knows what threshold to set? 5links maybe ok. 4 probably not.

[Goal: and preferably 0.03mHz]

to permit studies of the known galactic black holes (~3 10^6 Msun) merging with 3 10^5 Msun black holes at z=1-3. Distance should be determined to <10% (Obj 3C), chirp mass, reduced mass and spins to <1% (Obj 3A), and position to a few degrees (Obj 3B).

S3.4 Capability to provide continuous data availability during a 6 day period prior to and including final merger, specified 2 weeks before the event. No scheduled system down time during this 6 day period. T[include histogram of volume improvements vs time]o enable specification 2 weeks before the event, data latency (period between data taking and completion of data reduction) should not be longer than 4 days (it might be cceptable if this is not routine, but can be scheduled with 1 week notice; however note that latencies > 2 days mean that all seed black hole mergers (e.g. 10^5Msun at z=10) would be detected only after the fact.).

LISA SRD -Obj 4

LISA's fourth objective is to study the history of the growth of black holes in galactic nuclei by searching for gravitational waves from merging pairs of seed black holes (10^2 - 10^5 solar masses) in merging galaxies at redshifts up to 30, and to quantify the merger rate and properties of the merging holes as a function of redshift.

LISA SRD -Obj 4

Obj 4: Study the origin, merger and growth history of black holes in galactic nuclei by
Obj 4A: searching for gravitational waves from merging pairs of seed black holes (10^2 - 10^5 solar masses) in merging galaxies at redshifts up to 30.
[plausible mass ratios and rates in astro-ph/0401543, 0409255]. Use the detections to
Obj 4B: quantify the merger rate and properties of the merging holes as a function of redshift (and perhaps host galaxy properties, if host galaxies are identified by electromagnetic signatures of the merger). Objective 3 will contribute to this as well, defining the more recent history.

S4.1: 4A requires adequate sensitivity at 0.1-10mHz, and adequate mission lifetime to produce a sample of >10 events.
S4.2: 4B requires adequate precision to determine the parameters, as well as determine luminosity distance well enough to be a distance indicator, or identification of electromagnetic counterparts (cf. astro-ph/0410343) either at the time of merger or with delay.

LISA SRD -Obj 5

LISA's fifth objective is to detect gravitational waves from stellar-mass compact objects (black holes, neutron stars, white dwarfs) captured by, and spiralling into the massive black holes in galactic nuclei (“extreme mass-ratio inspirals” or EMRI). Such detections should enable unique tests of the (commonly accepted, but unproven) hypothesis that the dense central objects in galactic nuclei are actually the Kerr black holes of general relativity.

Depending on the merger rates, there may be enough of one or more sources in objectives 3-5 (supermassive black hole mergers, seed black hole mergers, and EMRI) to provide a substantial sample of measured black hole masses and spins, from which one could learn much about the accretion and merger histories and environments of the black holes.

LISA SRD -Obj 5

Obj 5: Perform a precise test of the null hypothesis that the dense central objects in galactic nuclei are actually the Kerr black holes of general relativity, by

Obj 5A: detecting gravitational waves from stellar-mass compact objects (black holes, neutron stars, white dwarfs) captured by, and spiralling into the massive black holes in galactic nuclei (“extreme mass-ratio inspirals” or EMRI). Use the detections to measure mass quadrupole and higher moments, and to measure tidal coupling to the BH to compare with the predictions for BH in GR, and to

Obj 5B: determine precise masses and spins for a substantial sample of quiescent galactic black holes, to constrain the accretion and merger physics (perhaps by comparing with estimates for actively accreting black holes e.g. from X-ray iron lines).

Obj 5C: Constrain the stellar dynamical properties of the central star clusters around supermassive black holes (Obj 3 and Obj 4 will also contribute to this, through information on the rate at which the “final parsec problem” gets solved), by making use of the observed rates, masses of EMRIs, and correlations with central black hole mass.

Obj 5D: Use precision GW distances and EM counterparts to determine H_0 to <3%.

LISA SRD -Obj 5

S5.1: Capability to detect gravitational waves emitted during the last year of inspiral for a 10Msun black hole orbiting a 3 10^5-3 10^6 Msun black hole at 1Gpc with optimal SNR>40.

S5.2 Ability to determine the evolution of the signal polarization due to precession of the orbital plane. (2 Michelsons gives substantial improvement over 1 in precision, particularly for sky position and distance -cf Obj 5D and host identification).

S5.3 Adequate observation time for EMRI's to sweep over a range of r/M to map space-time, and to provide a good sample of events.

LISA SRD -Obj 6

LISA's sixth objective is to search for gravitational wave backgrounds, principally

- The (anisotropic) background from galactic binary white dwarfs (expected level within a factor of two of 4E-19/root Hz at 1mHz, and 5E-18/root Hz at 0.1mHz, scaling as $f^{-7/6}$)

- The isotropic background from extragalactic binary white dwarfs (expected level within a factor of three of 5E-20/root Hz at 1mHz, scaling as $f^{-7/6}$).

- Possible isotropic cosmological backgrounds, as predicted in various models of the early universe, for example from phase transitions and dimensionality changes.

LISA SRD -Obj 6

Obj 6: Search for gravitational wave backgrounds, in particular
Obj 6A: determine the spatial distribution of binary white dwarfs in the Galaxy, by measuring the angular structure of the Galactic background (combined with the positions of individually identified sources: Obj 2) between 0.1 and 1 mHz.
Obj 6B: Constrain common envelope evolution and the Galactic star formation history by measuring the spectrum of the galactic white dwarf background between 0.1 mHz (injection) and 1 mHz.
Obj 6C: Constrain the cosmological star formation history of binary white dwarfs by seeking to detect the isotropic background from extragalactic binary white dwarfs between 1mHz and 10mHz.
Obj 6D: Constrain models of the very early universe by seeking isotropic (but possibly spectrally featured) cosmological backgrounds over the entire LISA frequency band.

LISA SRD -Obj 6

S6.1: Detect annual modulations [gr-qc/0403014, gr-qc/0403259, gr-qc/0504112] in the galactic white dwarf background.
S6.2: Detect or establish upper limits on the isotropic gravitational wave background, over the frequency range 0.1mHz-0.1Hz.
[for best limits, this requires capability to synthesize symmetric Sagnac mode to distinguish gravitational wave background from instrumental background (6 links required). This and Objective 7 are the only objectives for which this appears to make a large quantitative improvement. For all other objectives one or two links could be lost without major degradation. But are there other options to calibrate instrument noise?]

LISA SRD -Obj 7

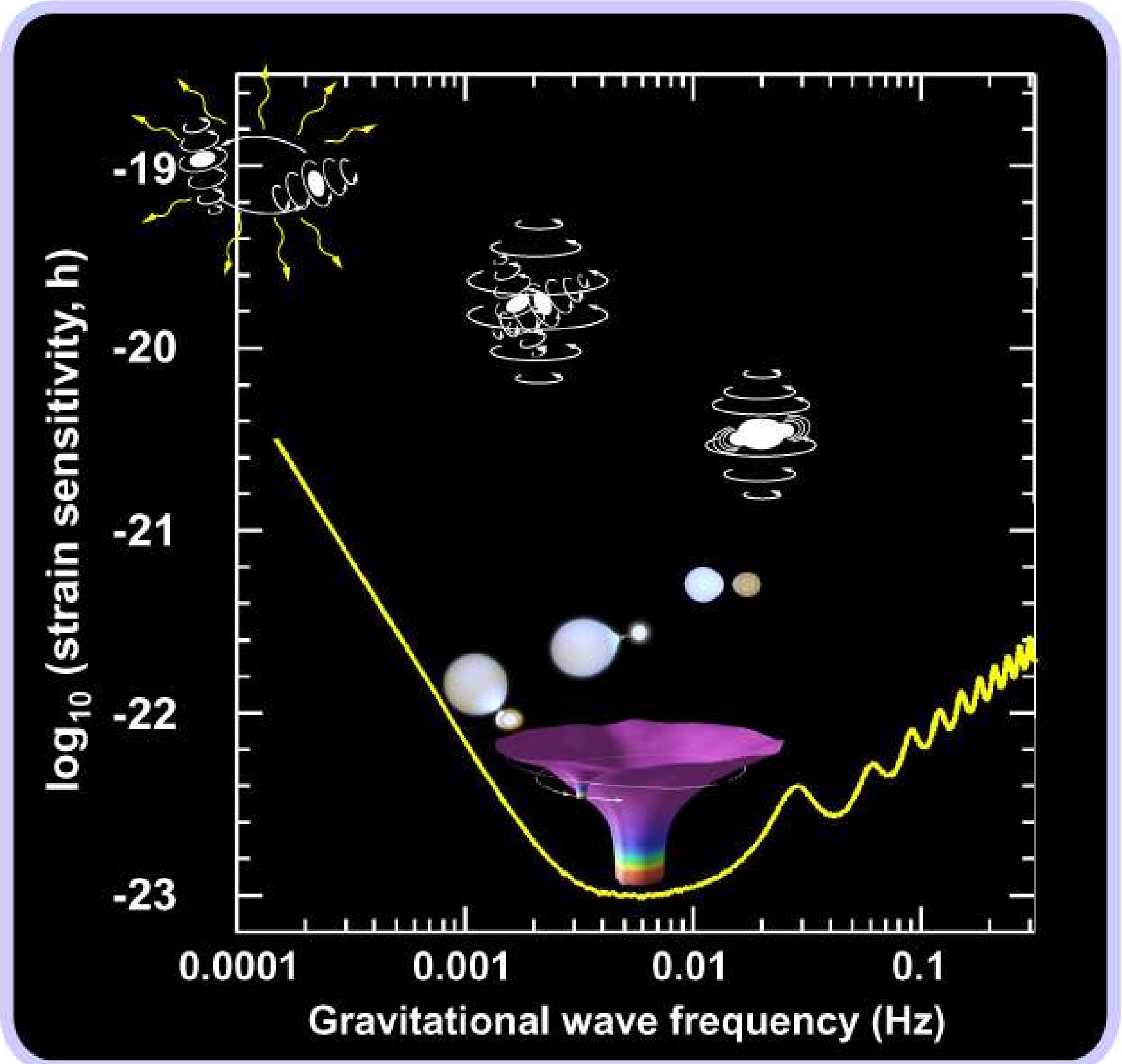
LISA's seventh objective is to search for gravitational wave bursts, principally

- From gauge theory cosmic strings and cosmic F- and D-superstrings.
(Current limits $G\mu<10^{-7}$; LISA could reach $10^{-7}>G\mu>10^{-11}$).

- From the relativistic collapse of very massive objects.

Obj 7: Detect or establish upper limits on the rate of gravitational wave bursts. Limits better than 1 per day are constraining of popular models (1 per year very constraining). Correlate with ground-based burst detections (string prediction).

S7.1 Detect or establish upper limits of less than 1 per year on the background of cosmic gravitational wave bursts. Non gaussian instrumental bursts which cannot be unambiguously identified and removed via comparison of simultaneous TDI data streams should have an event rate of less than 1 per day.

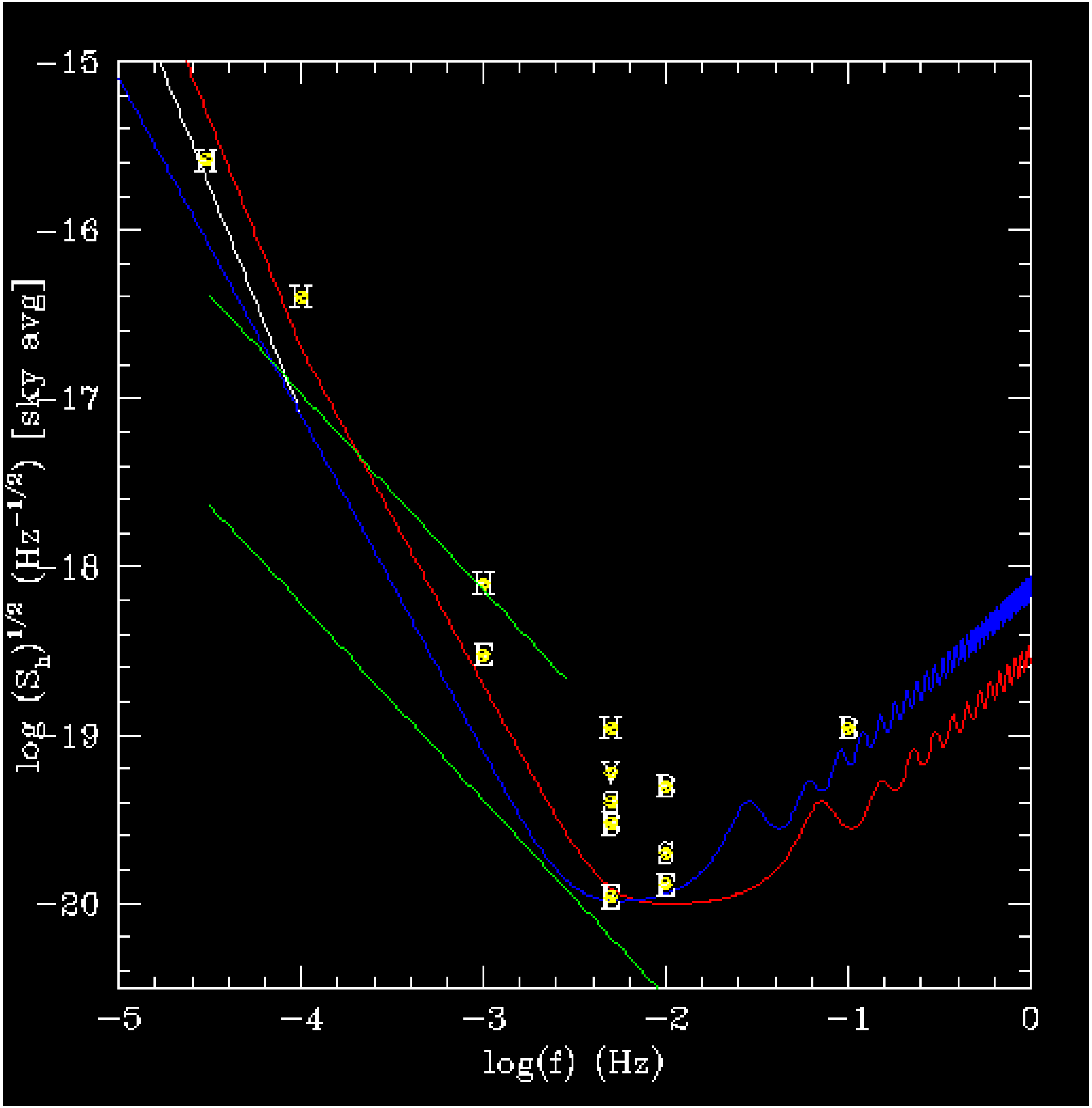


LISA's gravitational wave strain sensitivity at S/N (Signal/Noise) =5 for one year integration of periodic sources randomly distributed over the sky. Sources plotted include a merging pair black holes (10^6 and $3x10^5$ times the sun's mass, at redshift 1; total S/N=2500), binary white dwarfs 3000 light years away (left to right: S/N=6, 80 and 170), and a solar mass compact object spiralling into a million solar mass black hole, at redshift 0.2 (S/N=30).

Strain sensitivity ($S_h(f)$ in $Hz^{-1/2}$) and other measurement requirements derived from science requirements.

	0.03mHz	0.1mHz	1mHz	5mHz	10mHz	100mHz	1Hz	Arm links	Miss life
Verification (O1)				6.00E-20				4	0.5y
Binaries (O2)				3.00E-20	5.00E-20	1.10E-19		4	2y
SMBH (O3)	2.60E-16	4.00E-17	8.00E-19	1.10E-19				4	5y
Seed BH (O4)				4.00E-20	2.00E-20			4	3y
EMRI (O5)			3.00E-19	1.10E-20	1.30E-20			4	3y
Bkgrnd (O6)							discovery	6	2y
Bursts (O7)							discovery	4 or 5	1y

O1: SNR>10 in 6mos for V407 Vul to get 1 deg position with 1 Michelson.
O2: 5, 10mHz from Fig 8 of astro-ph/0312193;100mHz: SNR>5 for highest freq (1/30y) 0.6+0.3 binary at 8kpc. 2 yr life needed to get chirp.
O3: .0.03, 0.1mHz from 3E6+3E5 at z=3 spin, chirp, D_L reqs. 1mHz from 3e5+1e5 at z=4 spin, chirp, D_L, 5mHz to see merger/ringdown. Lifetime needed to assure >1 detection. Optimistic rates (e.g. astro-ph/0409255, 0401543) might relax lifetime.
O4: 1E4+3E3 at z=10 to get D_L and hence z to 20%. Lifetime to assure sample of >10.
O5: frequency band to cover inspiral of 10/3E6Msun. 10mHz also needed for 10/3e5Msun detection. Sens req to guarantee event rate (cf LIST emri report)



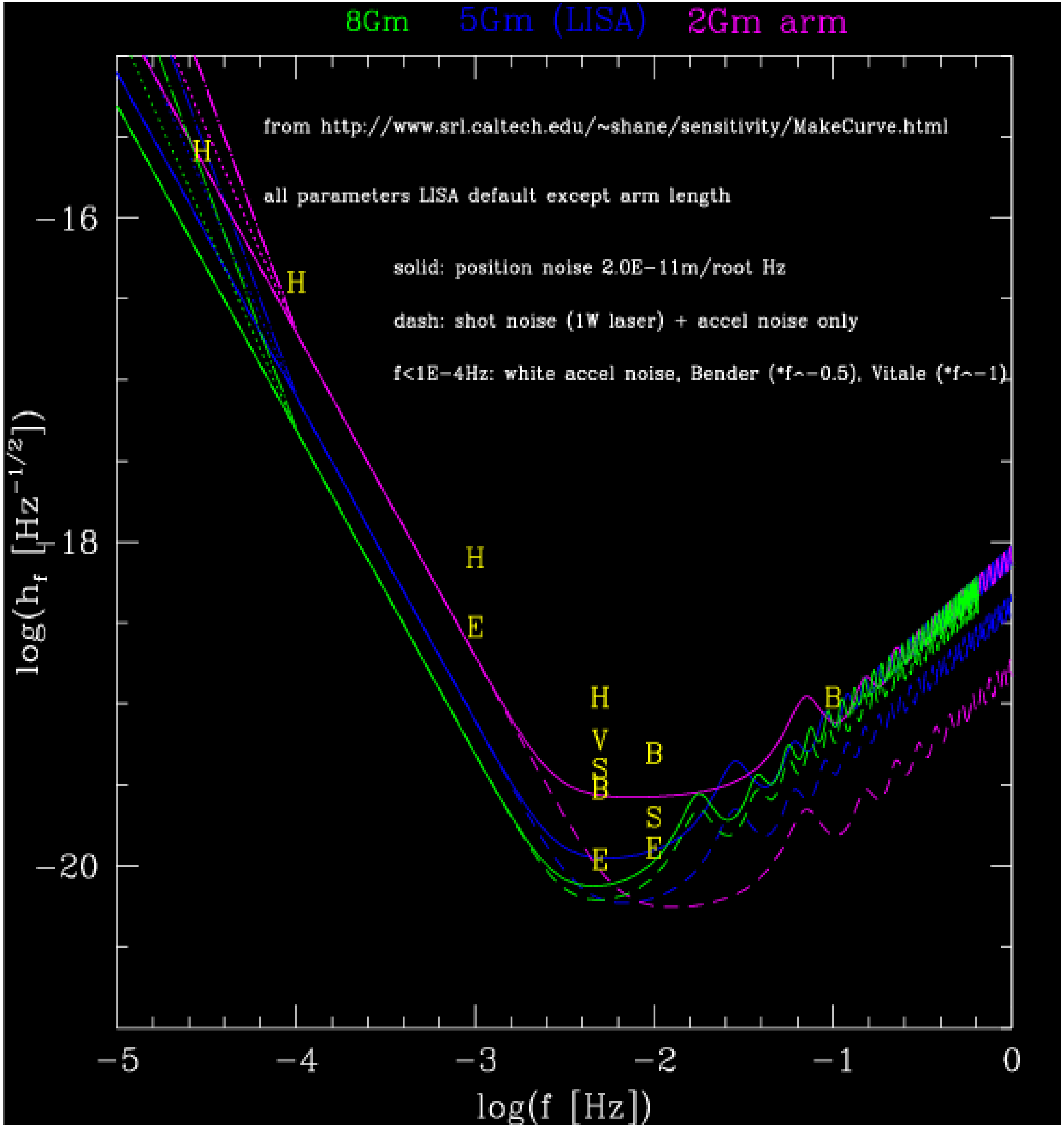
Blue: Pre-PhA, 5Gm arm LISA, white accel noise (Larson sens calc)
White: as blue, but Benders root{S_h} scale as f^{-0.7}.
Red: as white, but 2Gm arms (ASSUMING all other position noises scale w/ shot. May be hard to achieve: see next plot).

Green: galactic (upper) and extragalactic (lower) binary backgrounds.

letters: SRD sensitivity requirements for

V: Verification binaries
B: Galactic binaries
H: SMBH
S: seed black holes
E: EMRI

Short arms fatal for all science?



Note:
solid curves assume position noise indep of arm length at 20pm/rtHz.
With standard shot noise contributions, this is nearly true (would be 38/2 for 2Gm, 40/2 for 5Gm, 42/2 for 8Gm if included shot noise scaling sqrt(S_x) ~ L).

Long dash curves are shot noise only.

Phinney's personal Mission Success Criteria (*not* needed in SRD)

1. Detect verification binaries.
2. At least double (detect >5-10) the known sample of <10 min orbital period binary white dwarfs.
3. Detect at least one other type of source (SMBH, seeds, EMRI, burst, extragalactic cosmic background...).

Consider a New Minimum Mission=same as Phinney success criteria?

1. Detect verification binaries.
2. At least double (detect >5-10) the known sample of <10 min orbital period binary white dwarfs.
3. Detect at least one other type of source (SMBH, seeds, EMRI, burst, extragalactic cosmic background...).

#3 allows choice depending on cost/engineering issues of sensitivity line from either

• SMBH (previous min mission), with relaxed sensitivity at 1-10mHz, but strong requirement below 0.1mHz (e.g hard if go to 2Gm arm) and long lifetime, or seed BH, or

•EMRI (no requirement <1mHz, lifetime less important, but stringent sensitivity requirements above 3mHz).

Danger: allows descope (reduced low freq sens) to remove SMBH science, a major attraction to astronomy community participation.

Science Requirements WG Agenda

1. Review of draft Science Requirements document
   A. Structure OK?
   B. Corrections needed?
   C. Additions needed?
   D. Work needed.
   E. Prioritisation of science and sensitivities.
2. 2Gm armlength instead of 5Gm? Quite bad for SMBH if no spin. [await Hughes' results w/ spin in Jan 2006]
3. 0.03mHz goal? [ditto]
4. Make 1Hz a goal, instead of requirement?
5. How many working links needed? [mostly less than 6]
6. How to formulate requirements on reliability in flight, and level of ground verification?

Science Management Plan

1. Overview of mission
2. Schedule: dates of AOs, selections, deliverables, data rights.
3. Project Science Mangement (Project roles)
4. Community Science Teams involvement
5. Science Management
   A. Overview of operations (ground station, data pipeline..)
   B. Architecture (responsibilities of MOC, science teams, data analysis centers etc)
6. Data products (`real time' event warning, annual updates of catalogs of specfied source types, cleaned data for outside analysis, etc).
   A. Data rights, delivery periods, publication policy.
7. Outreach, press releases.

Questions on the data analysis/mission requirements interface

1. What types of planned data gaps are anticipated?
2. What are limitations on science-motivated interruptions of such planned data gaps (e.g. because interesting event is predicted and shouldn't be missed)- durations, notice? Latency of regular and extraordinary requested downloads?
3. What are likely causes and natures of nonstationarity in the noise at *f* on all time scales from *1/f* to a year and longer?
4. How can instrument noise be independently determined (e.g. at >10mHz, and if link fails so Sagnac unavailable, at lower freqs)?
5. What sort of housekeeping data could be useful in identifying 3,4 above, plus flagging problems, vetoing bad data (solar flares, bad servo, thruster problems, proof mass charge...)? Is this bit-rate or storage limited?

Questions on the data analysis/mission requirements interface -2

6. What forms of non-gaussian noise are likely present? -steady periodic noise? Bursts? Modulations? Correlated effects between s/c? What will be effects of servo-control loops? Differences in noise character between high frequency (shot noise, pointing, laser ampl and photodector) and low frequency (proof mass-acceleration noises)?
7. Allowed differences between arms (e.g. how likely one arm to have 2-3x the noise of the others, possibly with very different spectrum, or a lot more gaps/vetos. How bad before this constitutes a loss of link for science?)?
8. See also Jennrich “F” task table and Schutz Appendix “LISA data analysis development task schedule”.