LISA Status

M Hewitson

LISA Cosmology Workshop

Mainz

Oct 16th, 2017

Contents

- Project entities
- Overview
  - status, selected, phase 0, phase A, etc
- Phase 0 Studies
- Ground Segment
- Data Analysis Organisation
- Phase A and beyond
- Thoughts on Consortium Organisation

Who's who?

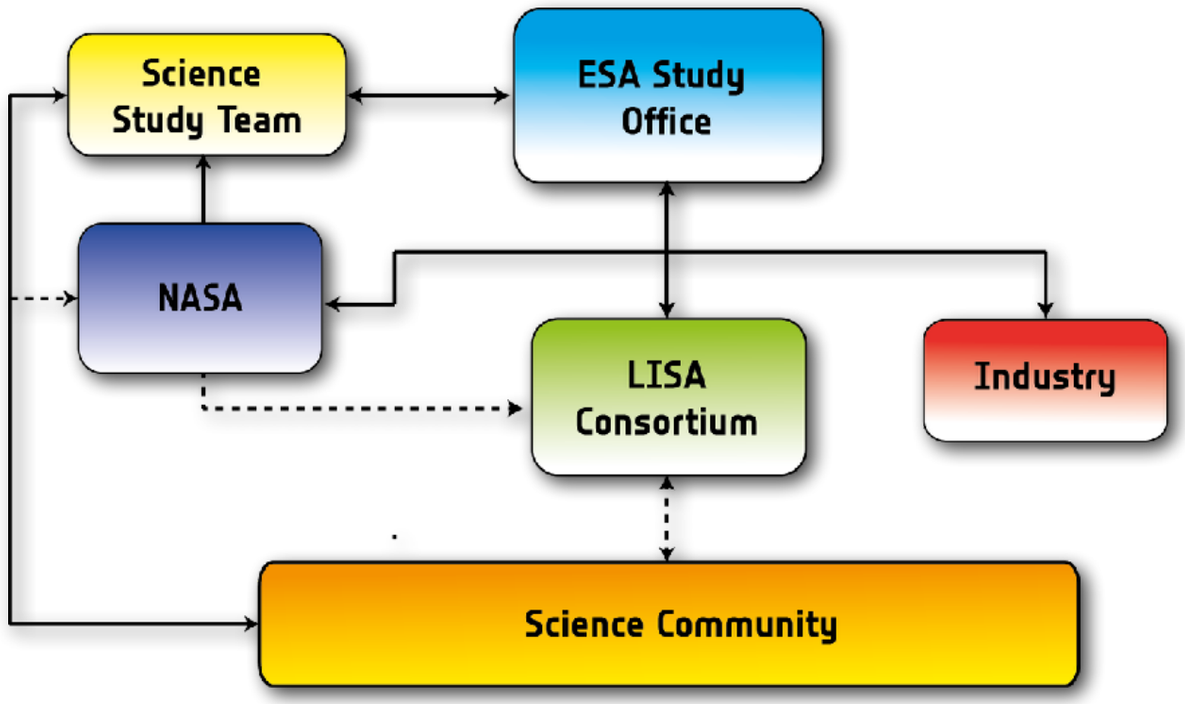
- The LISA project is ramping up now
- We have many different entities
  - LISA Study at ESA
  - LISA Science Study Team
  - NASA LISA Study Team
  - Consortium
    - Board and Executive Board
    - Payload Coordination Team
    - Ground Segment Coordination Team
    - Science Coordination Team
    - Working Groups

LISA Study at ESA

- This is the formal body within ESA responsible for the mission during the study phase
  - started March 2017
  - runs up to adoption
- Team:
  - Study Manager (Martin Gehler)
  - Payload Study Manager (Astrid Heske)
  - a number of others…
- Becomes the LISA Project at adoption

LISA Science Study Team

- The Science Study Team (SST) is the formal interface between ESA and the science community
  - SST members are appointed by ESA, and international partners
- The roles of the SST include:
  - Writing and maintaining the Science Requirements Document (SciRD)
  - Acting as the focus for the interest of the scientific community in LISA
  - Advising on scientific aspects during the development of the LISA payload and spacecraft
  - If any science requirement cannot be met, it is the role of the SST to advise ESA on the appropriate course of action
  - Defining the data access rights for LISA data following established ESA guidelines
    - NB: data access rights will be published in the Science Management Plan and agreed by SPC
  - Preparing for, and overseeing, the analysis of the LISA data
  - Promoting LISA in the scientific and public domains



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SST members

Science Study Team

Name	Institute	email
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Rita Sambruna	NASA-HQ	rita.m.sambruna@nasa.gov

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NASA LISA Study Team

- Team of US scientists
- Chaired by Kelly Holley-Bockelman
- Primary task is to coordinate input to the next Decadal survey
- Reach out to the US science community
- Observers from
  - ESA: Paul McNamara, Martin Gehler
  - ESA SST: Martin Hewitson

Consortium

- Structure is evolving from the proposal
- Payload coordination team was appointed to focus on work of Phase 0 and Phase A on the payload side
- Ground Segment Coordination team is partly formed
  - interactions with ESA have already started
    - define interfaces and responsibilities of ESA SOC and Consortium DPC
- Science Coordination Team is being discussed

Project Phases

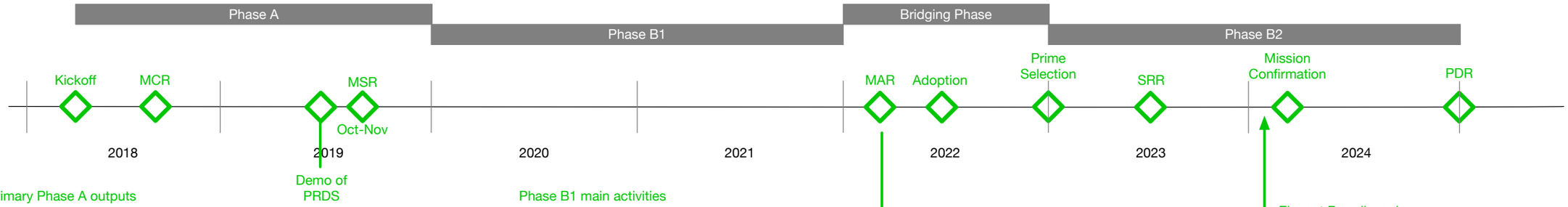
- Phase 0
  - initial mission definition
  - initial payload definition
- Phase A
  - parallel industrial studies of mission
  - study of consortium provided items
- Phase B1
  - mission definition consolidation
  - development of breadboard payload units
- Phase B2
  - further definition
  - breadboard level demonstration of critical interfaces (TBD)

One possible schedule

This schedule is based on notes and discussions collected over various meetings. It represents a possible schedule following the PLATO development model, with early adoption to allow for payload development, where the heavy industrial activity comes at some later point.

This is a working schedule for the consortium to plan against, but is not in any way an official (or even unofficial) schedule from ESA.

M Hewitson 2017-08-02



Primary Phase A outputs

Industry

- Constellation acquisition including phase lock (+CAS?)
- MOSA
- Telescope
- SE to Unit Level → SE Management Plan
- Input to BB test def
- AIVT strategy to unit level
- DFACS + Science Modes
- Performance Model (Instrument or TDI?)
- FDIR concept

Consortium

- Unit level concept design + BB design
  - engineering, functional, performance, interfaces
- Input to FDIR concept
- Input to science operations plan
- Science Exploitation Plan
  - including ground segment, commissioning and calibration
- Performance model
- BB development and test plan
- Input to >MOSA AIVT plan
- 2nd version of Consortium Management Plan
- System Engineering of payload (+ SE MP)
- Technology Roadmap
- BB-level AIVT Planning (includes definition of scope of BB)

Phase A Documents

Consortium level docs

- EID-B
- SE Management Plan
- Consortium Management Plan
- Technology Plan
- Instrument RS
- Performance Budget

- Per Unit
-
- DDD
- RS
- ICD
- AIVT Plan
- BB-DDD + AIVT Plan (units)
- BB AIVT Plan

Phase B1 main activities

Industry

- system requirements
- structure design

Consortium

- BB Unit Integration
- Payload + unit requirements
- Technology development

Critical Items Demonstrated at BB Level

Unit Level Tests:

- OB (including BL)
- Telescope
- PMS
- Interferometer Performance (Model)
- Laser + Stabilisation
- AIVT Facility

Elegant Breadboard

Interfaces to Demonstrate:

- OB → Telescope (optical, mechanical, not phase)
  - PAAM/OoP Verification
  - Optical Truss
- OB → PMS → Laser (electrical, optical functional) – should be unit level?
- OB → Telescope → GRS (Mechanical)
- CAS → Telescope
- …

BB Items Needed:

- OB (BL GSE)
- Telescope
- PAAM
- CAS
- PDS + FEE
- Mech GRS Model
- MOSA Structure
- PMS
- LA
- …

Phase 0

- First part of 2017 for system CDF
  - high-level study of main mission elements
  - included some payload activity
- Second part of 2017 for payload CDF
  - Main outputs
    - Payload Definition Document
    - Performance Analysis
    - Consortium Management Plan

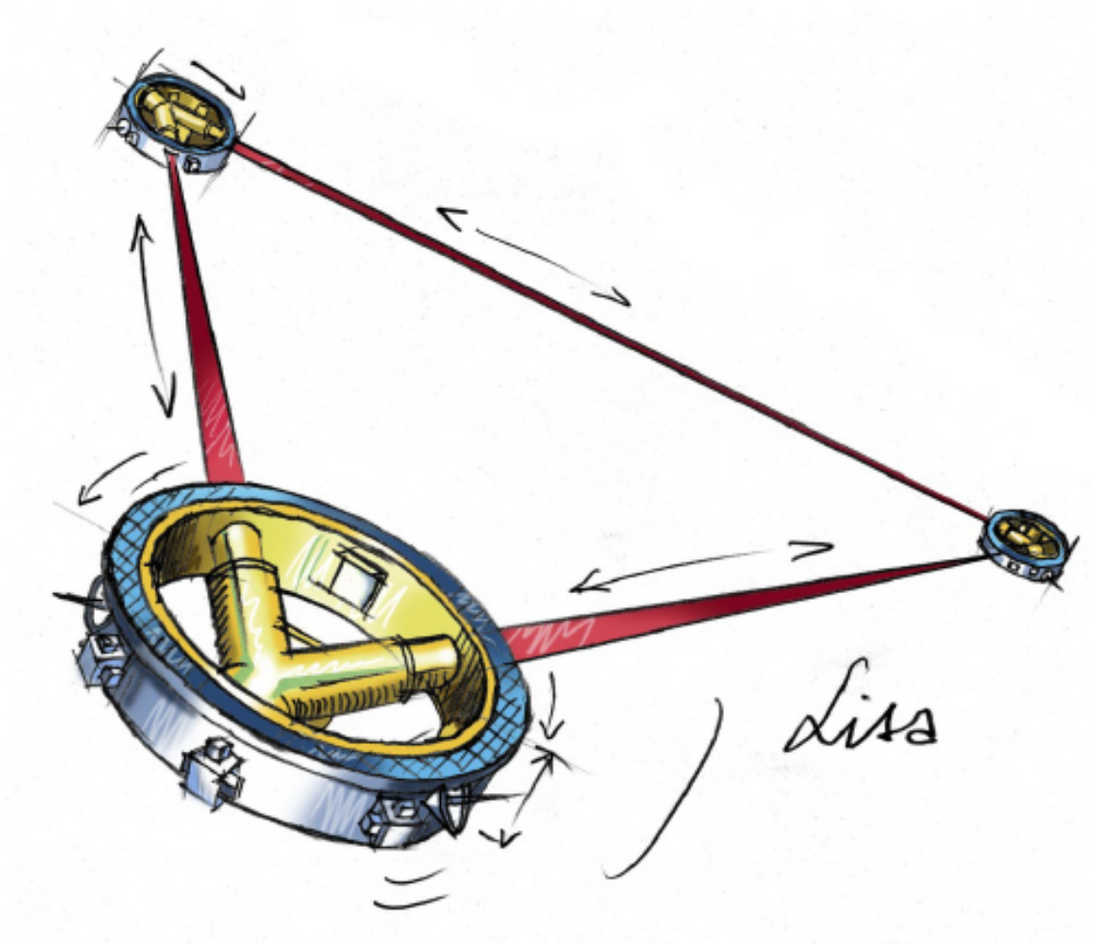
LISA
Study Introduction

Systems

Session 1
ESTEC, 08-03-2017

Prepared by the CDF* Team

(*) ESTEC Concurrent Design Facility



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LISA in ESA's Concurrent Design Facility

- Large study team at ESA
  - ~40 engineers
- Support from Consortium

Position	Team Member	Code	e-mail
Study Manager	Martin Gehler	SCI-FMA	Martin.Gehler@esa.int
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LISA in ESA's Concurrent Design Facility

STUDY SCHEDULE

SESSION	DAY	DATE	TIME
Kick Off	Wednesday	08/03/2017	13:30-17:30 CET
#2	Friday	10/03/2017	9:30-13:30 CET
#3	Wednesday	15/03/2017	9:30-13:30 CET
#4	Friday	17/03/2017	9:30-13:30 CET
#5	Wednesday	22/03/2017	13:30-17:30 CET
#6	Friday	24/03/2017	13:30-17:30 CET
#7	Wednesday	29/03/2017	9:30-13:30 CET
#8	Friday	31/03/2017	9:30-13:30 CET
#9	Wednesday	05/04/2017	13:30-17:30 CET
#10	Friday	07/04/2017	9:30-13:30 CET
#11	Wednesday	12/04/2017	9:30-13:30 CET
#12	Wednesday	03/05/2017	9:30-13:30 CET
Internal Final Presentation	Friday	05/05/2017	9:30-16:30 CET

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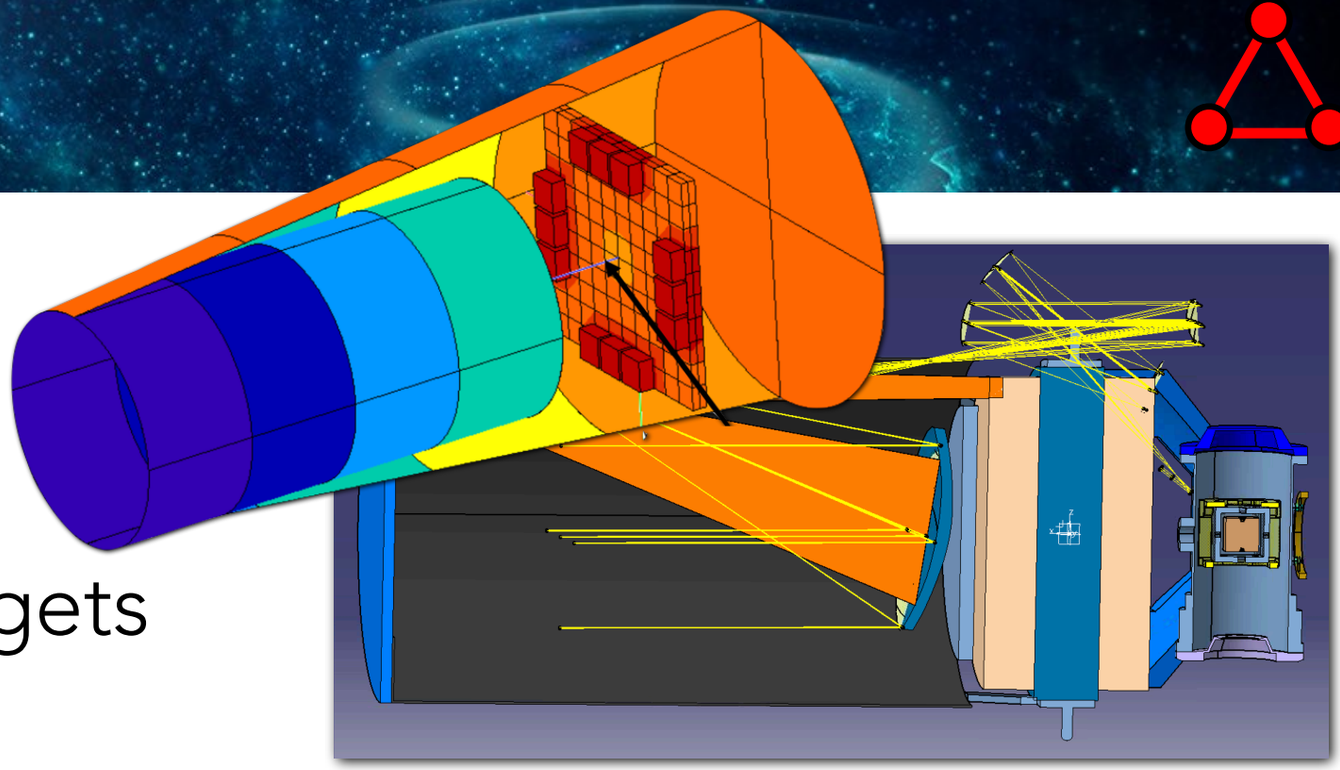
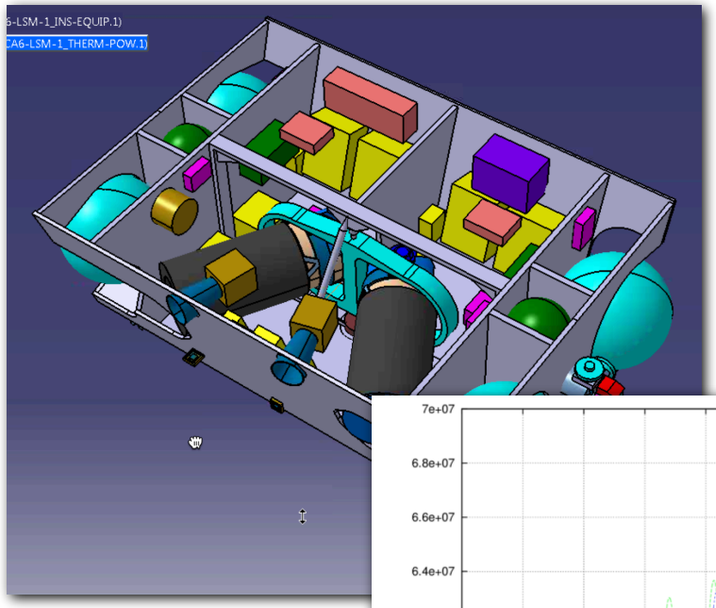
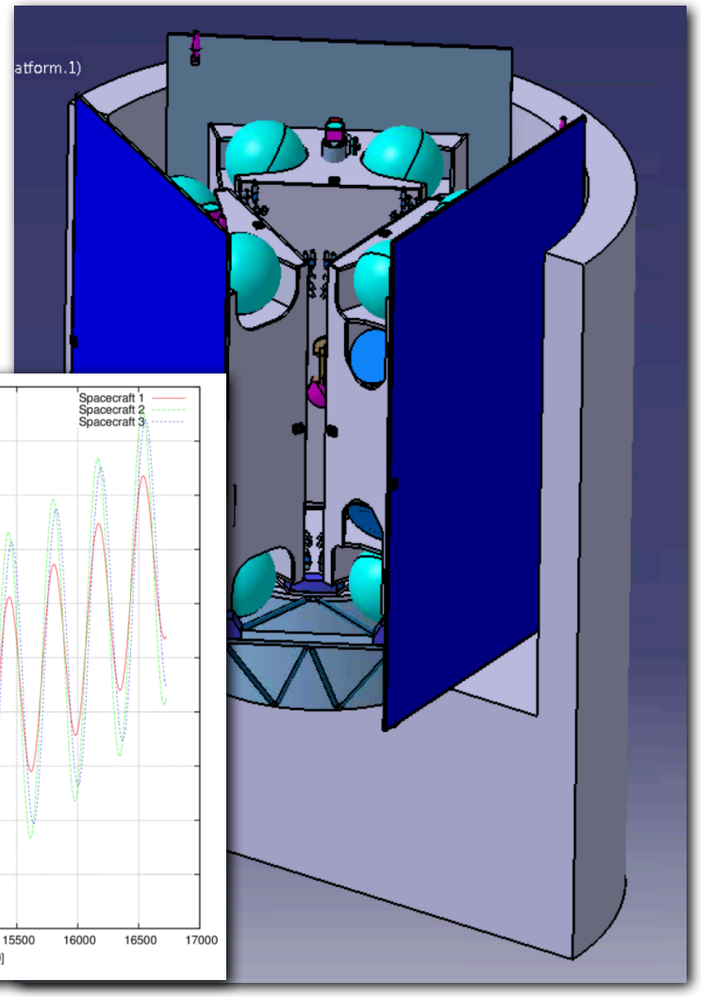
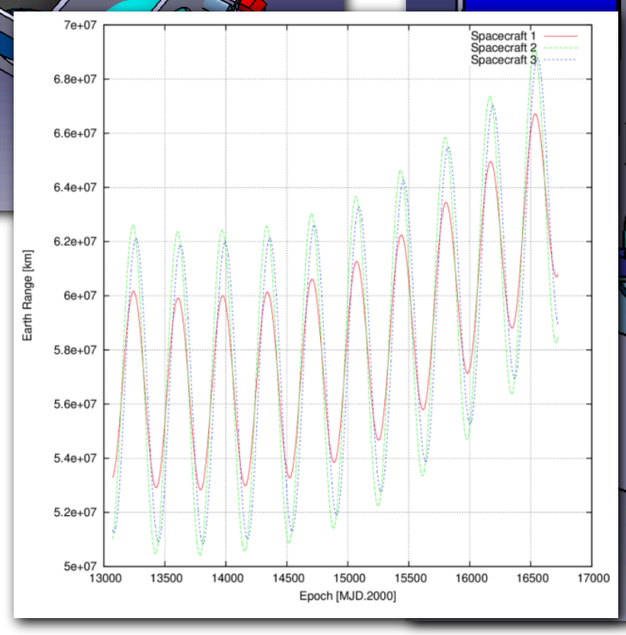
In the CDF…

- Overall mission analysis
  - orbits, launch, transfer, etc
- Power, mass, volume budgets
- Overall architecture
- Data handling
- Payload definition
- DFACS
- Programmatics
- Structures
- Ground stations and operations









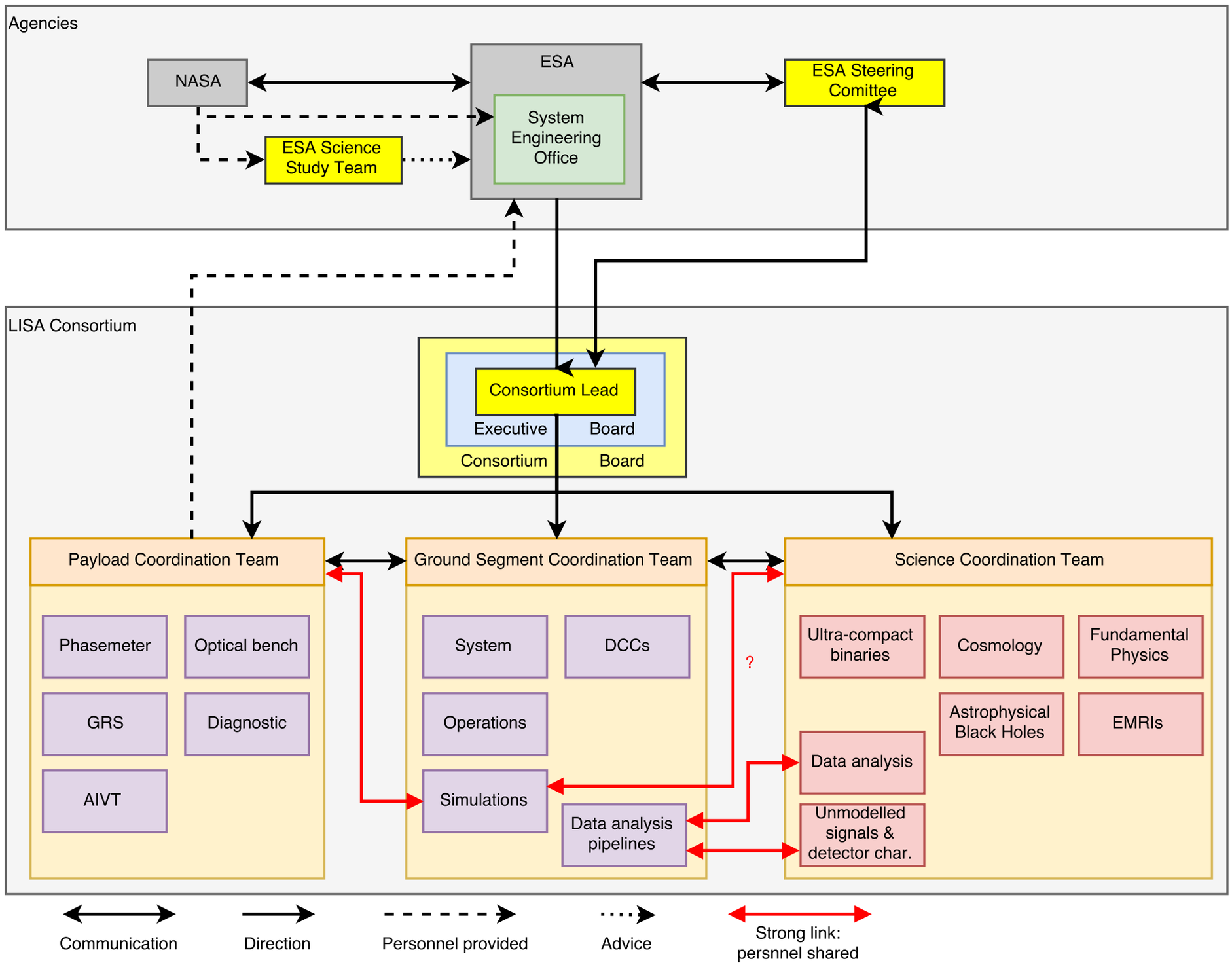
After the mission CDF…

- Need for a more in-depth look at the payload and interfaces
- ESA decided to have a Phase 0 study of the payload
- Further CDF sessions
- Parallel work by the consortium

Payload Phase 0 - CDF

- 8 CDF sessions
  - General project presentation, trade-off presentation, identification of Phase 0/A work to be done. Performance model. Consortium status.
  - **Architecture trade-off**, constellation acquisition, inter-satellite link (optical comm.), GRS functionality/ performance. **telescope and pointing**, identification of critical S/C interfaces. First definition AIV flow/Model philo. GNC expert to participate
    - included a significant discussion on functional breakdown
    - Followed by a 3 day architecture workshop
  - Assessment follow-on work from session 2, conclusions.
  - Laser, optical comm., modulation, **frequency stability**, phasemeter, payload processing unit, **data handling**.
  - Architecture and design status, critical issues, consortium status. Performance model results. Mid-term consolidation meeting and **PM #1**
  - LCA session, OB, telescope mounting **structure**, temperature and CAS constraints. Preliminary CAD model
  - **Redundancy** schemes, EMC and magnetic fields, gravitational requirements, and interfacing. Includes risk assessment
  - Conclusion, wrap-up and further work, instrument baseline design, critical issues, risk register, consortium status Final presentation, final CAD model and **PM #2**

Consortium Organisation - PCT



Payload Phase 0 - PCT

- Payload Coordination Team approved by board
- Charged to coordinate activities associated with Consortium payload items

Coordination Team Lead (**Martin Hewitson**, Deputy: Bill Weber)
Metrology System (Gerhard Heinzel, Bill Weber, Ewan Fitzsimons, Guido Müller)
Instrument System Engineer (Hubert Halloin)

Phasemeter (**Gerhard Heinze**l, Bill Klipstein)
Optical bench (**Ewan Fitzsimons**, David Robertson)
GRS (**Bill Weber**, Rita Dolesi, Luigi Ferraioli, Peter Wass, John Conklin)
Diagnostics (possibly including ‘payload’ computer) (**Miquel Nofrarias**)
AIVT (**Hubert Halloin**, Nicoletta Dinu-Jaeger, Jeff Livas)

Agency Liaisons (Oliver Jennrich, Paul McNamara, Ira Thorpe)
Laser (Invited Experts: ESA Rep, Tony Yu)
Telescope (Invited Experts: ESA Rep, Jeff Livas)

PCT Activities

- Main charge:
  - payload item scientific oversight
  - interface definition
  - interaction with payload & system primes
  - integration with system engineering teams, including ESA's system engineering office
  - oversight of technology development
- In Phase 0
  - major input to SciRD, MRD, and PDD
  - development of performance model
  - development of top-level Functional Architecture Diagram
  - development of Assembly, Integration, Verification and Testing (AIV/T) flow

Setting the scene

- The activities of the PCT are assuming the operational scenario that developed during proposal writing and CDF
- Main goal is to arrive at a baseline mission architecture and payload design before Phase A

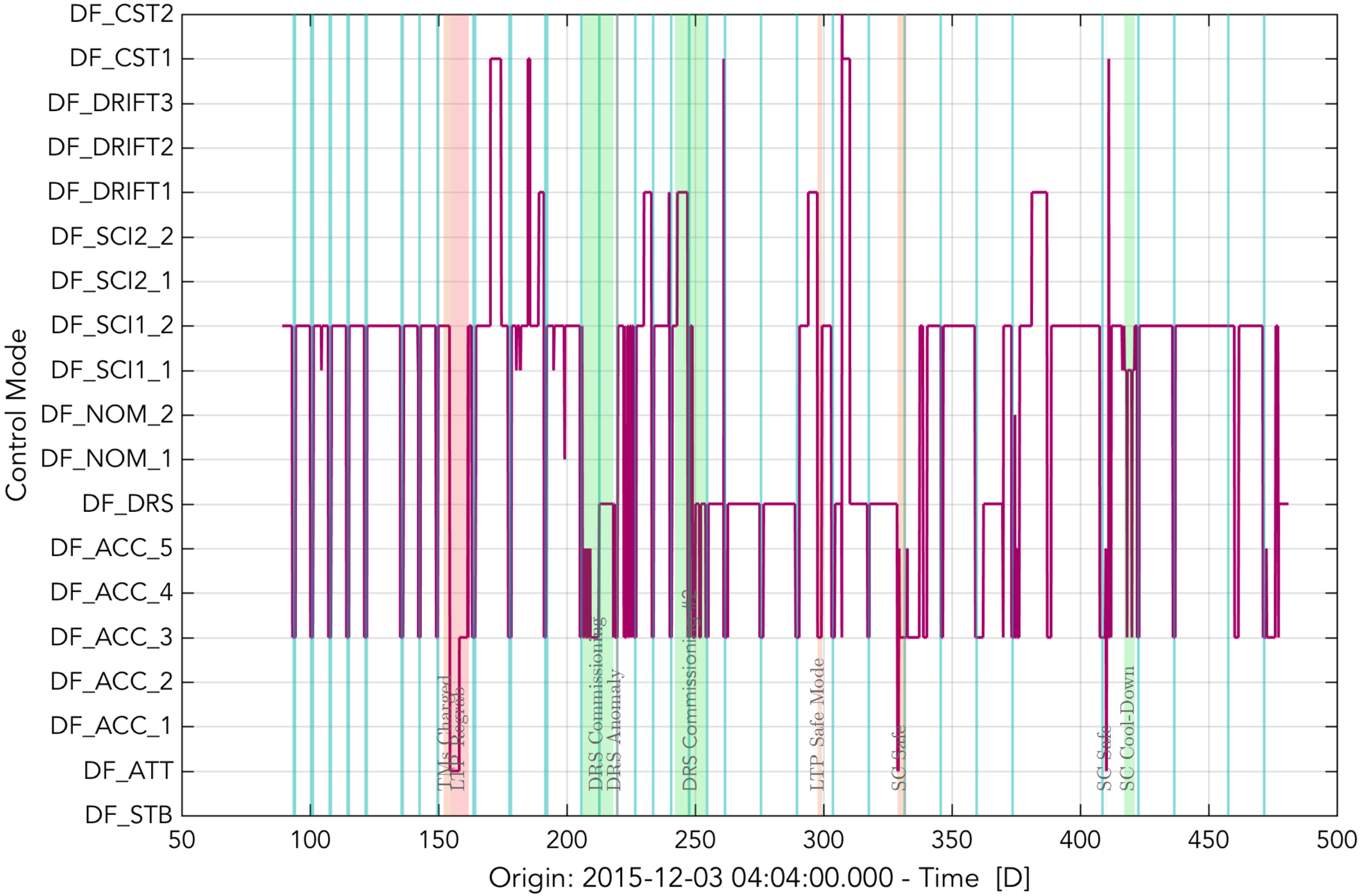
Science Operations for LISA

- Main concepts
  - continuous science coverage
  - maintenance and planned interruptions
  - data rates
  - protected periods
  - alerts

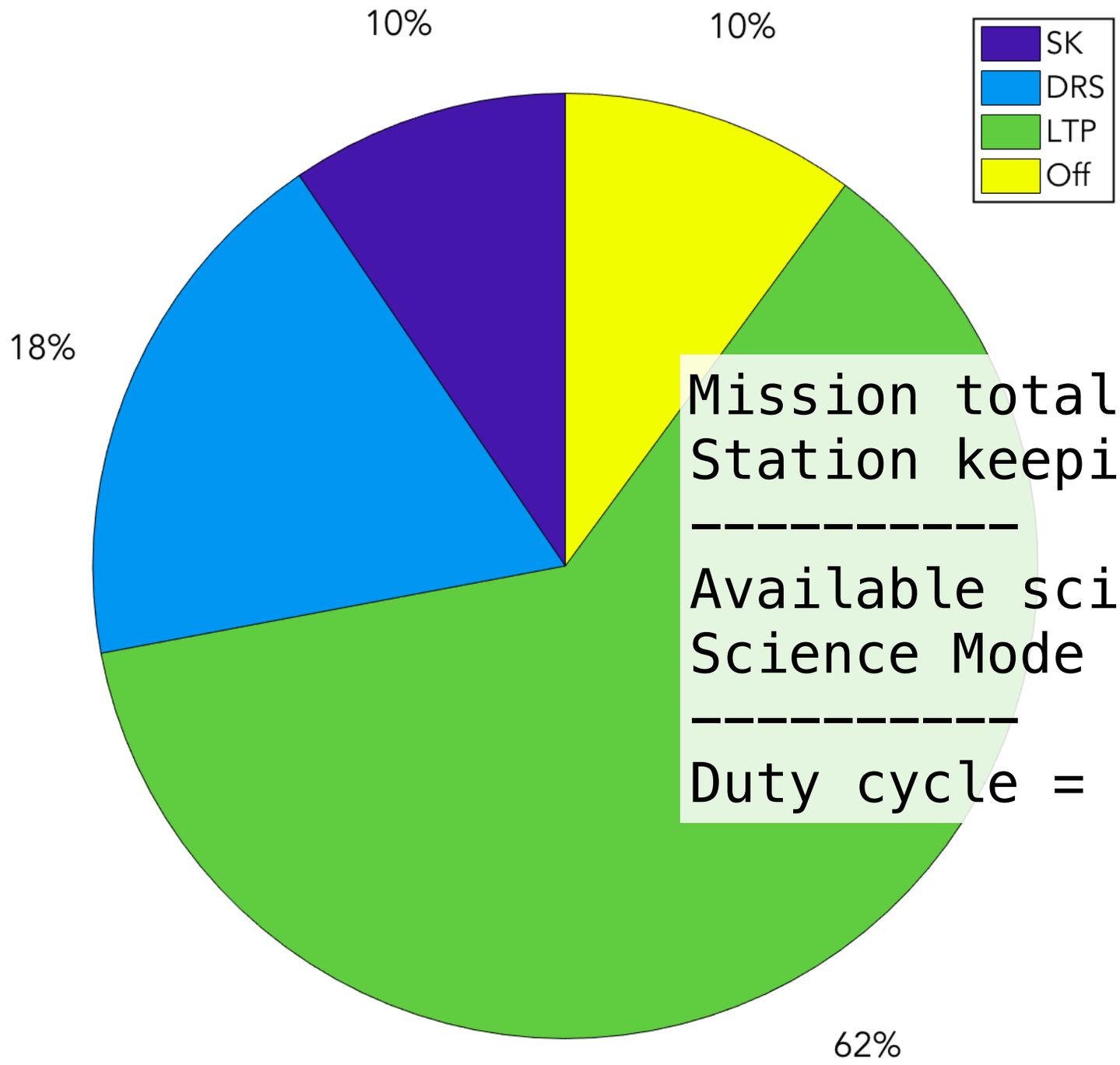
Continuous coverage

- Most LISA sources will be observed for timescales longer than time between interruptions
- Hardware design will aim to minimise downtime
- ‘Downtime’ means less than 4 active links
  - link == test mass - S/C - S/C - test mass
- Observatory operations concept (including FDIR) should aim for
  - graceful degradation of science due to anomalies
  - rapid recovery from anomalies
- S/C reliability is key

Reliability observed during LPF



Some stats




```
Mission total = 392.0 D
Station keeping = 37.3 D
-----------
Available science time = 354.7 D
Science Mode (including DRS) = 315.1 D
-----------
Duty cycle = 88.8 %
```

⇒~70% for 3 S/C

Maintenance

- A number of routine activities will be needed during science operations
- These could result in
  - loss of science data (gaps)
  - reduction in quality of science data (higher noise)
- Examples:
  - antenna repointing (degredation?)
  - frequency swap (short gap)
  - discharging (degredation, presence of signals)
  - …

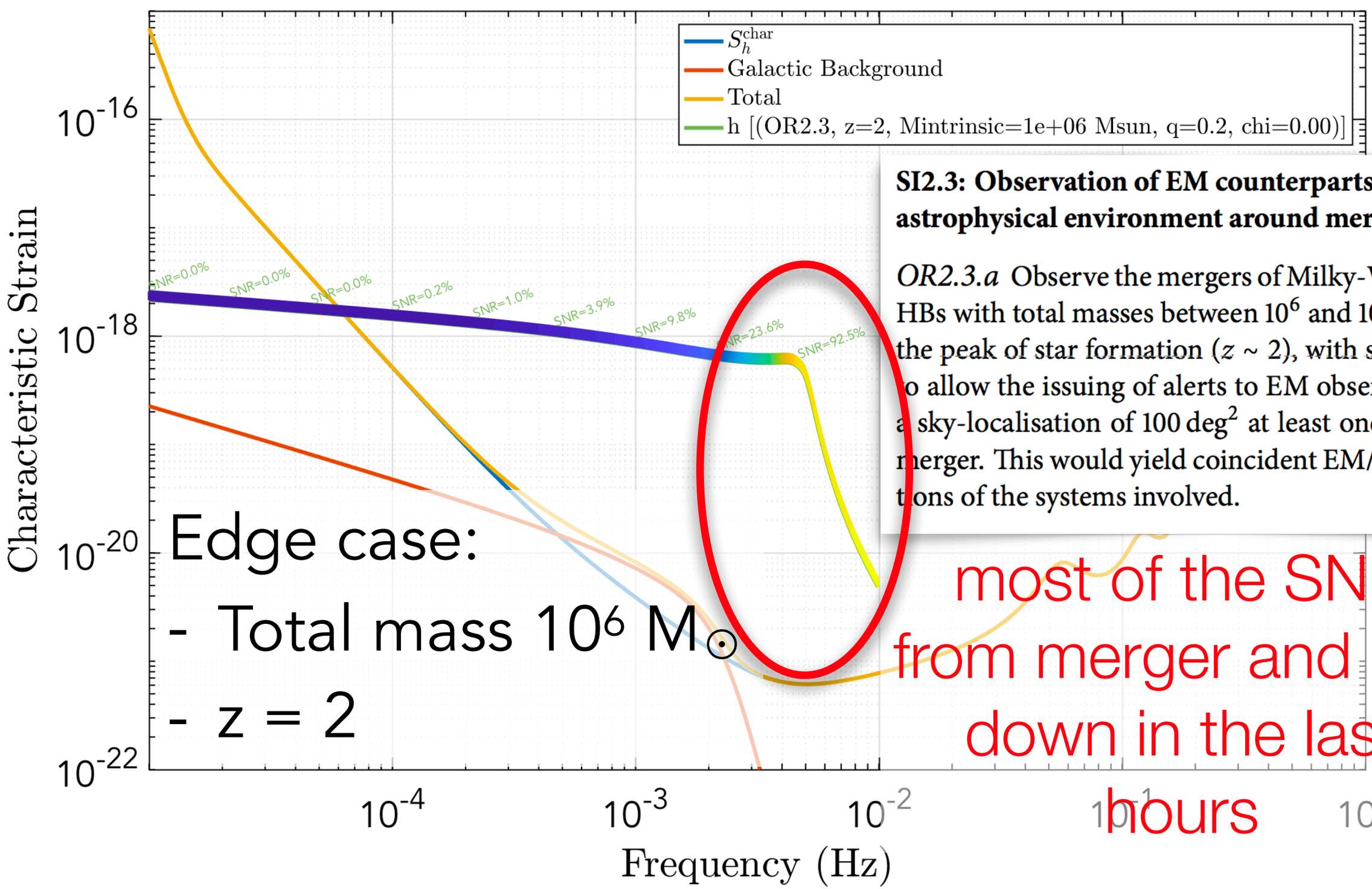
Data rates

- Science data flow:
  - raw phases and auxiliary data acquired on-board at a high rate (e.g. 30Hz)
  - resampled (properly!) on-board to be downlinked at a lower rate (e.g. 3Hz)
- Channel grouping
  - High priority science (needed for TDI)
  - Auxiliary Science (for characterisation and monitoring)
  - Housekeeping and environmental monitoring
- Current guesstimate is 157 channels
- Aiming for 3Hz downlink
  - further studies of TDI needed to set this
- Current link budget from CDF
  - ~40 kbit/s

Protected periods

- We will have the ability to detect the inspiral of some SMBHBs and predict when the merger will take place
  - Accuracy of minutes days prior to merger
- For the predicted merger time we should:
  - cancel any planned maintenance
    - both MOC and SOC
  - implies scheduling of maintenance with margin

Protected periods: example



SI2.3: Observation of EM counterparts to unveil the astrophysical environment around merging binaries

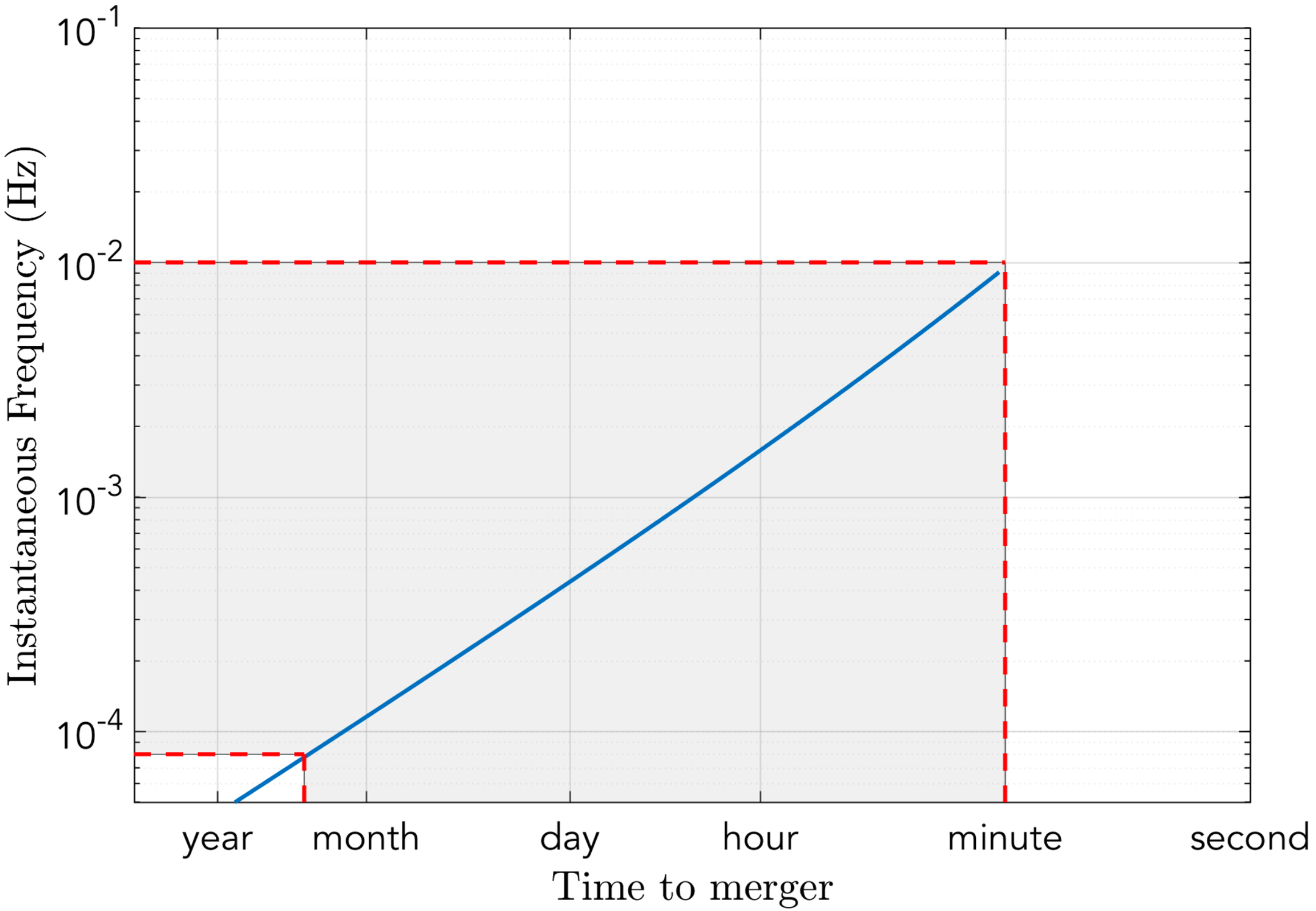
OR2.3.a Observe the mergers of Milky-Way type MBHBs with total masses between 10^6 and 10^7 $M_\odot$ around the peak of star formation ($z \sim 2$), with sufficient SNR to allow the issuing of alerts to EM observatories with a sky-localisation of 100 deg^2 at least one day prior to merger. This would yield coincident EM/GW observations of the systems involved.

Edge case:

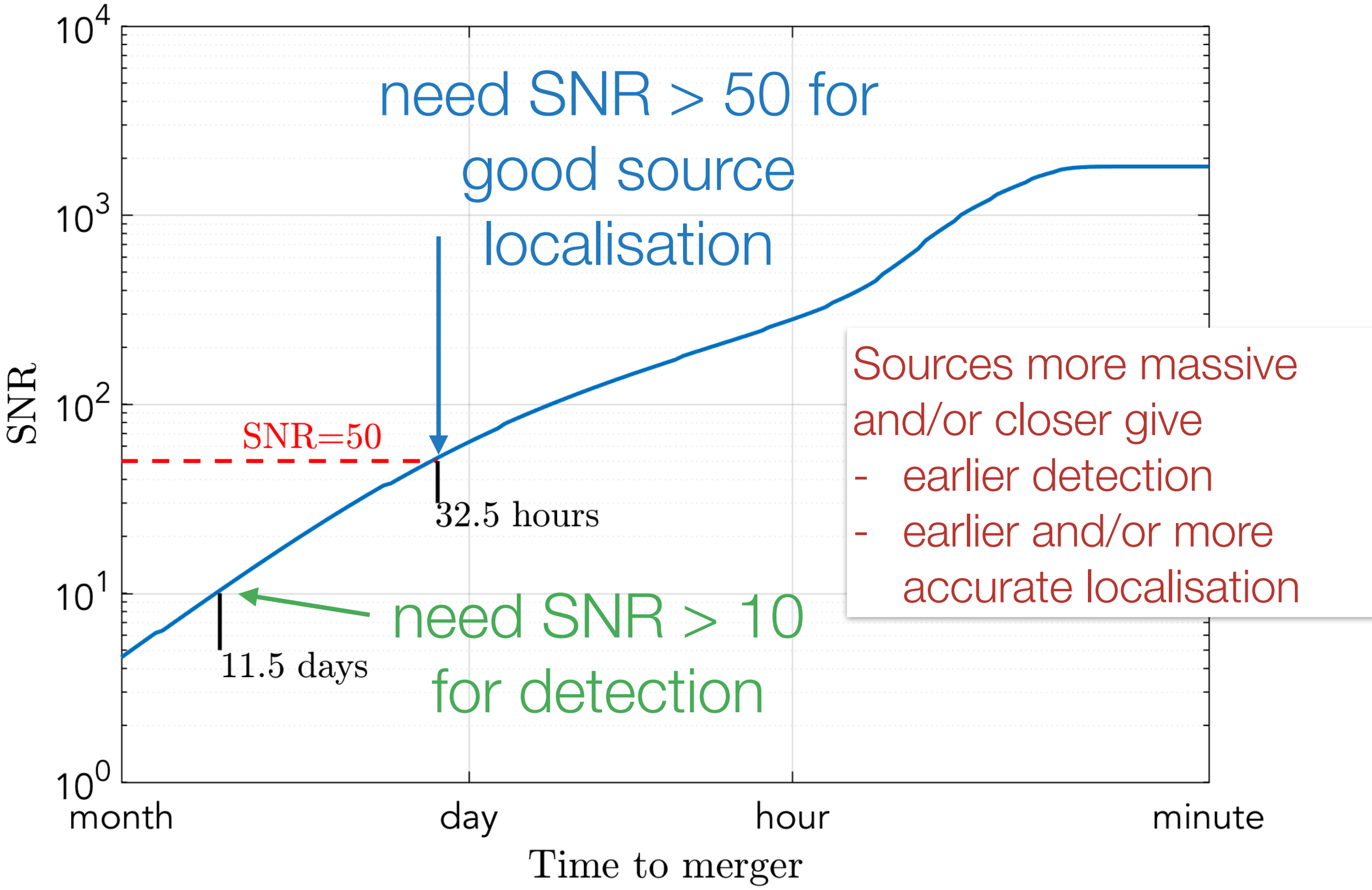
- Total mass 10^6 $M_\odot$
- z = 2

most of the SNR from merger and ring down in the last hours

Time-scales


10^{-1}
10^{-2}
10^{-3}
10^{-4}
Instantaneous Frequency (Hz)
year
month
day
hour
minute
second
Time to merger

Detection and localisation

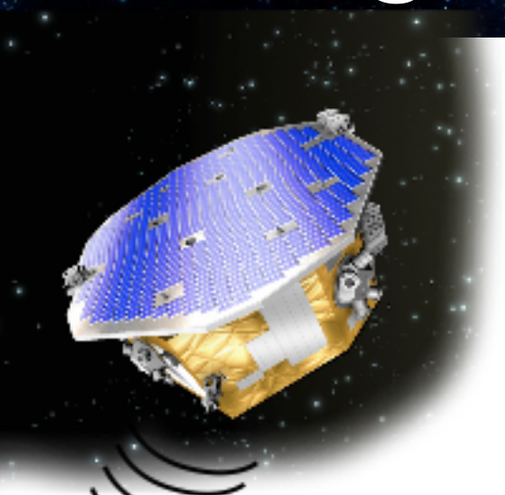


Sources more massive and/or closer give
- earlier detection
- earlier and/or more accurate localisation

Alerts

- For some mergers we want the ability to trigger alerts to EM observatories to allow for prompt coincident observations
- Needs low-latency data processing through full chain
- From our edge case example:
  - we know enough to trigger the alert 32 hours prior to merger

Raising an alert



MOC

Depacketising

SOC

Preprocessing

TDI

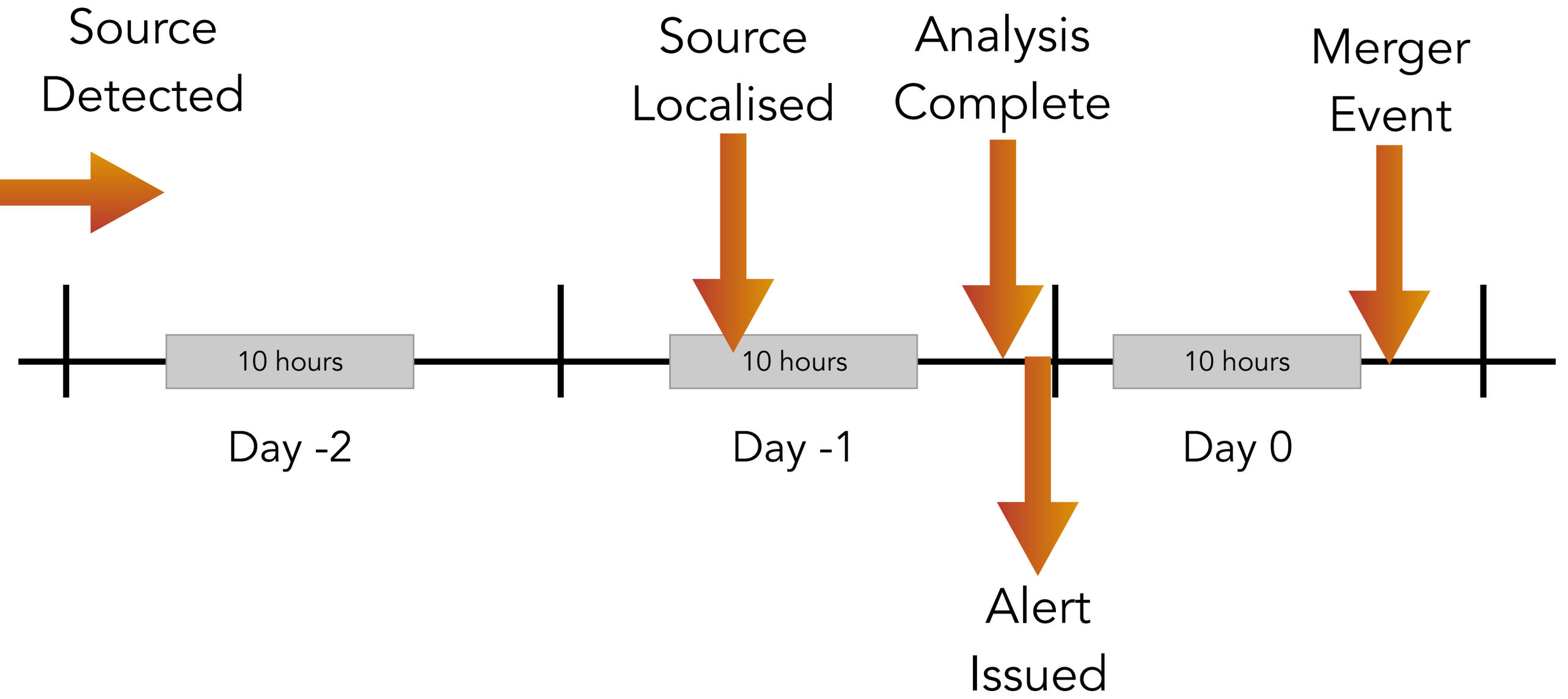
Issue Alert

DPC

low-latency analysis

Generate Alert

Timing (worst case?)

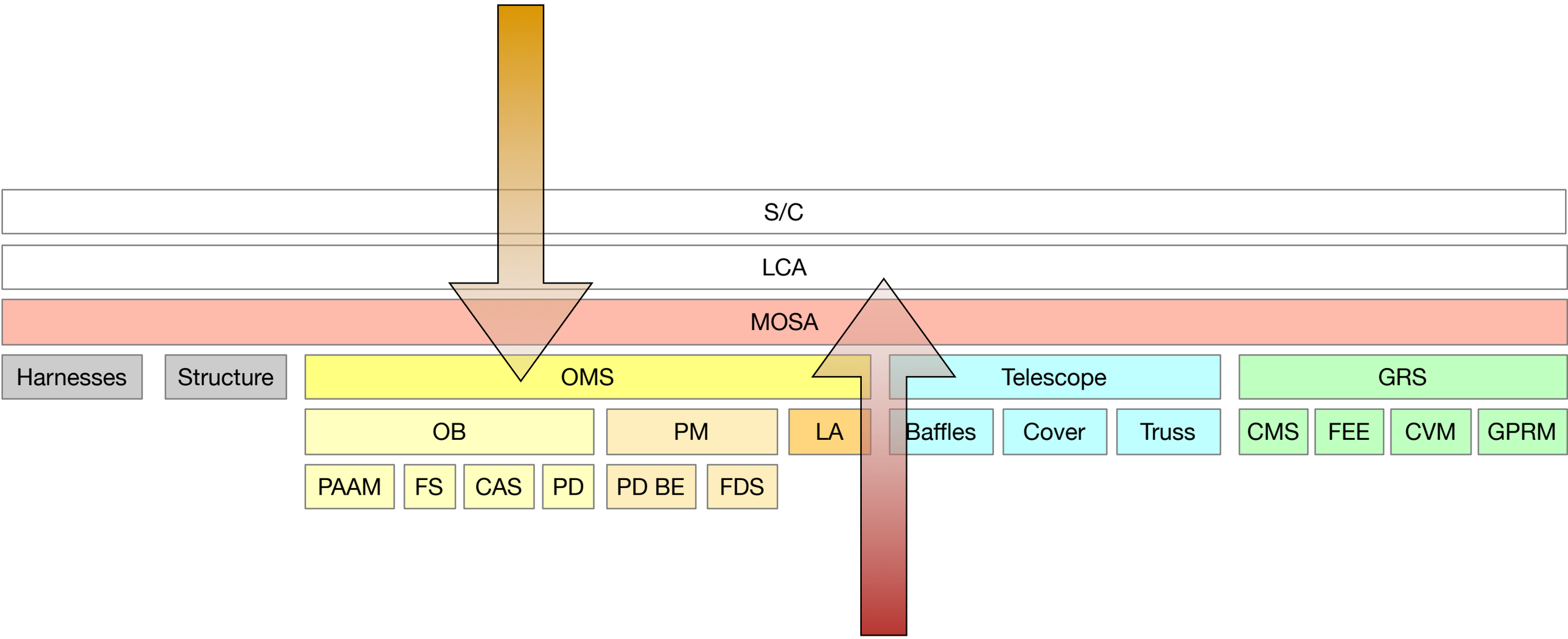


Who's responsible for what? A working assumption…

- Consortium is responsible to deliver the 'LISA Instrument'
  - all sub-units (PM, OB, GRS, Diagnostics, etc)
- Laser Assembly, Telescope and MOSA structure comes from ESA
  - via NASA and Prime
- Consortium performs integration with Telescope and structure
  - France/CNES performing AIVT
  - with strong involvement of ESA, NASA and Prime

Units and engineering concept for Phase A

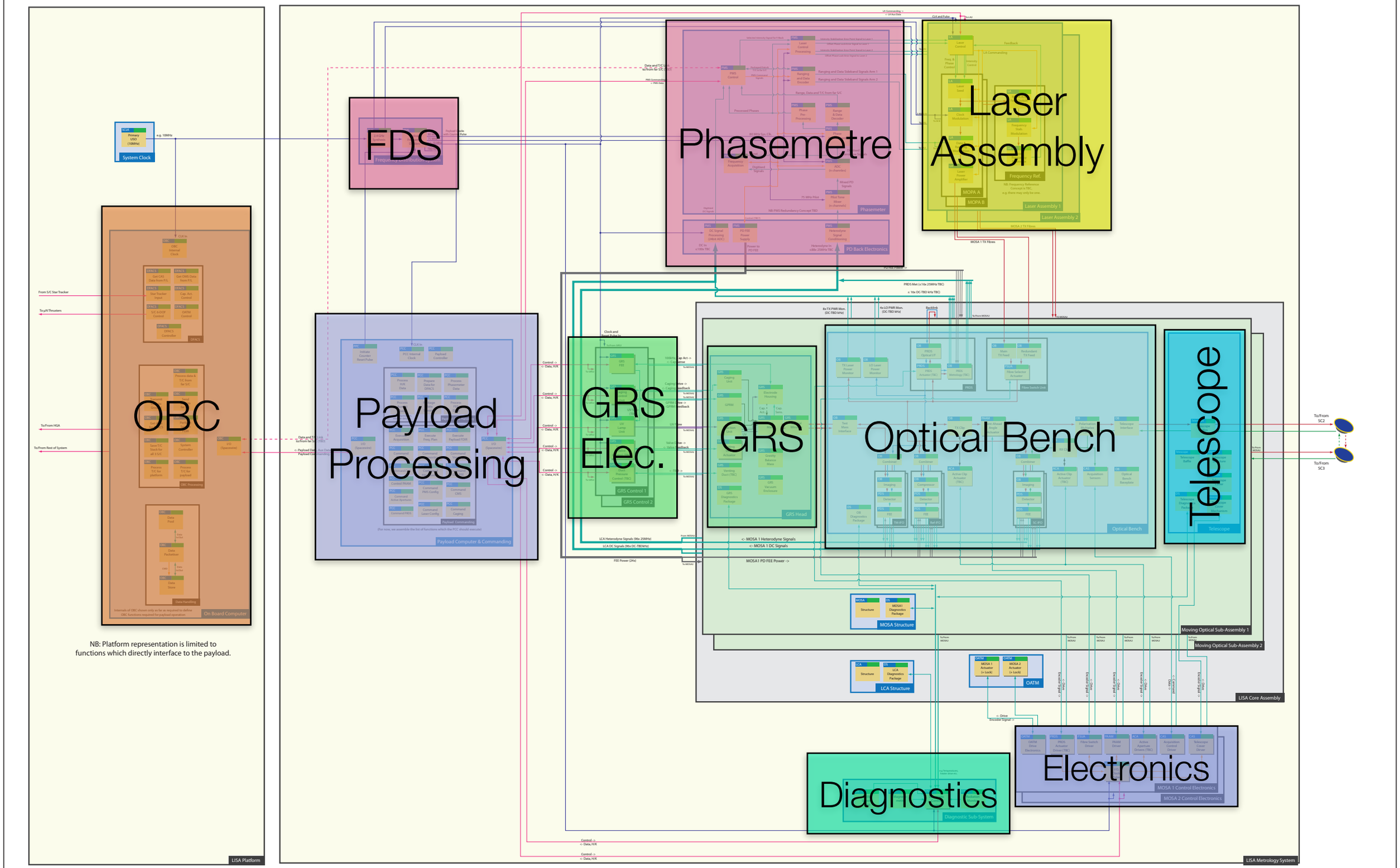
Primes engineer ‘into’ payload



Consortium engineers ‘upto’ LCA

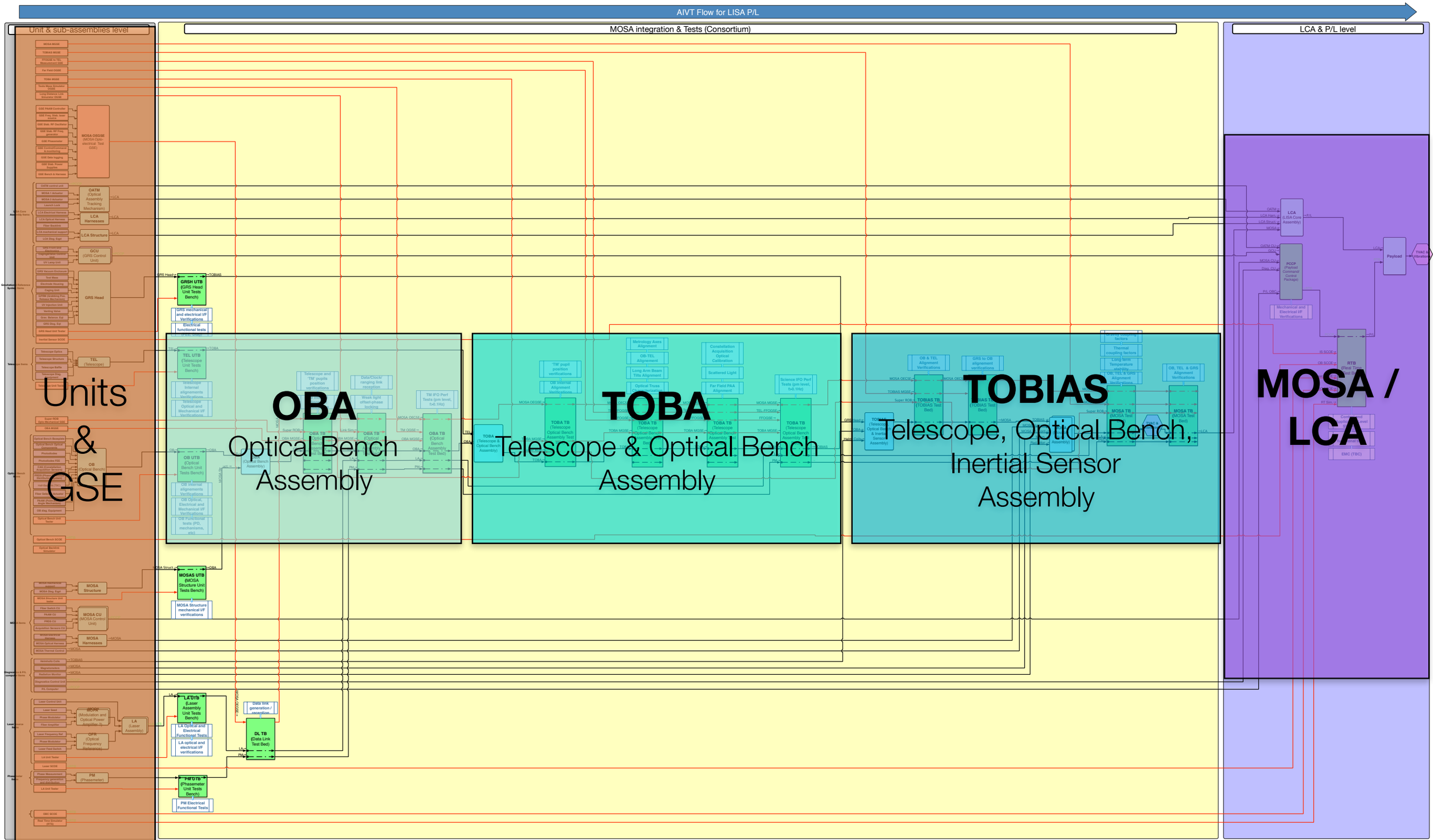
needs to be critically reviewed in Phase A

Functional Breakdown



NB: Platform representation is limited to functions which directly interface to the payload.

AIVT flow


AIVT Flow for LISA P/L
Unit & sub-assemblies level
MOSA integration & Tests (Consortium)
LCA & P/L level
Units & GSE
OBA
Optical Bench Assembly
TOBA
Telescope & Optical Bench Assembly
TOBIAS
Telescope, Optical Bench, Inertial Sensor Assembly
MOSA / LCA

Towards a baseline architecture

- Many trades have been investigated and discussed
- Most have been closed (for now) to allow us to establish a baseline architecture
- These trades will be reviewed in Phase A by the industrial teams
- Some trades remain open

Many trades reviewed

Breathing angle compensation scheme	Closed. Baseline is Telescope pointing.	Selection of in-field pointing (IFP) or telescope pointing (TP) as the main payload breathing angle compensation scheme.
IFPM Metrology	Closed. Baseline is Telescope pointing.	If we have IFP, do we need dedicated out-of-loop laser metrology if the IFPM
PRDS Implementation	Open. Pending PRDS study.	If we have TP, what method is to be used to achieve pm-level reciprocity of the backlink (so-called PRDS)?
Optical Truss	Closed. Baseline is no optical truss, assumption being we can build the telescope to required spec.	Do we need to implement an Optical Truss to monitor telescope stability.
Acquisition Sensor Architecture	Closed. Current baseline is to have the CAS on the bench.	Is the Acquisition sensor (CAS) mounted on the OB, and if so does it present a heat-issue. If it's not, how is the pick-off for the Acquisition sensor achieved.
PAAM Metrology	Closed. Current baseline is to step the PAAM and therefore we don't need metrology (no continuous PAAM motion)	Do we need dedicated out-of-loop laser-metrology of the PAAM?
Read-out channels required	Open. Impact from PRDS choice.	How many read-out channels are really required (photodiode elements and PMS channels)
QPD Diameter	Open.	What diameter of photodiodes do we use? (This is arguably an internal OB trade, but it is related to the supplier of the diodes and FEE.)
Tilt-to-Length Compensation Scheme	Open. Active pupil versus post-processing.	How do we compensate for tilt-to-length (TTL) coupling?
MOSA Mounting and Alignment Strategy	Closed. Adopted concept of a single MOSA structure to mount OB, Telescope and GRS.	How do we mount, align and test the Telescope-OB-GRS combination?
GRS Vacuum Protocol	Open.	How do we implement venting in the GRS?
TM release Sequence	Open pending results of LPF tests.	Do we modify the release to improve robustness?
UV Light source	Open.	UV Light source, modification to the illumination scheme
Discharge Scheme	Open.	Continuous or intermittent discharge
Frequency Distribution	Closed. Baseline arrived at; to be documented on FB diagram.	What is the scheme for frequency distribution?
Laser stabilisation architecture	Open. In particular the study of unequal arm-length IFO for stabilisation needs to be revised. Does the stabilisation need to be on the OB? If not, it's internal to	The laser frequency must be stabilised - ultimately this must be achieved through TDI, but in order for TDI to work the initial laser frequency stability must be between around 30 and 300 Hz/√Hz - depending on whether arm locking is used.

Example closed trades

- Breathing angle compensation scheme
  - baseline is telescope pointing
    - confirmation pending fibre reliability tests
    - reasonable expectation that backlink fibre with full balanced detection can be made to work
      - already shown in lab
- Optical Truss
  - baseline is not to include it, but to allow for it in design
    - aim to build telescope with the required level of stability
      - tests by Florida and GSFC show this should be possible
- PAAM Metrology
  - adopt step-and-stare scheme
  - PAAM is fixed most of the time ⇒ no metrology needed

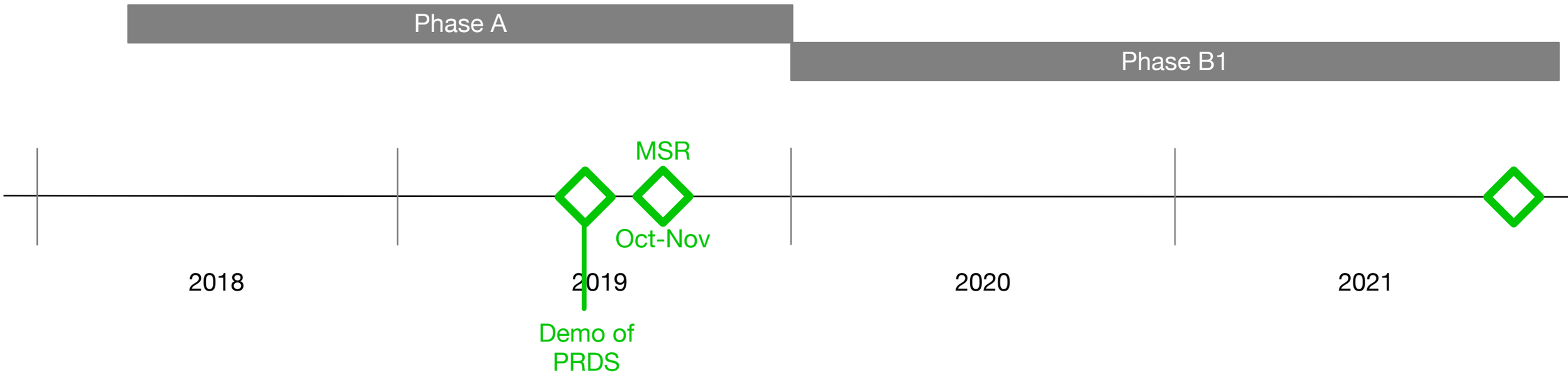
Example open trades

- Number of readout channels required
  - open pending Phase Reference Distribution Scheme (backlink) architecture
- TM release sequence
  - open pending results of LPF tests
- Computer and command architecture
  - open pending studies in Phase A
- Discharge scheme
  - open pending further study. Will likely implement both capability to allow continuous and intermittent

Phase 0 activities

June 9th	Payload CDF Kickoff
June 15-16	Payload CDF Session #1
July 5th	Payload CDF Session #2
July 5th	PCT Kick-off telecon
July 6th	PCT Face-to-face #1
July 31st	PCT Telecon
Aug 22-24	LISA Architecture workshop
Aug 29th	PCT Telecon
Sept 7th	PCT Face-to-face #2
Sept 8th	Payload CDF Session #3
Sept 19th	Payload CDF Session #4
Sept 20th	PCT Face-to-face #3
Sept 27th	PCT Face-to-face #4
Sept 28th	Payload CDF PM#1
Oct 19th	Payload CDF Session #6
Oct 20th	PCT Face-to-face #5
Nov 1st	PCT Face-to-face #6
Nov 2nd	Payload CDF Session #7
Nov 20th	Payload CDF PM#2
Nov 23rd	PCT Face-to-face #7

Phase A



- Two parallel industrial studies
  - both will design down to individual payload items (TBD)
- Consortium Phase A study
  - design up to MOSA/LCA level

Consortium/PCT Activities in Phase A

- BB Definition
  - BB development and test plan
  - Unit level concept design + BB design
    - engineering, functional, performance, interfaces
  - BB-level AIVT Planning
    - includes definition of scope of BB
- Input to FDIR concept
- Input to science operations plan
- Payload AIVT Plan
  - Input to >MOSA/LCA AIVT plan
- Science Exploitation Plan
  - including ground segment, commissioning and calibration
- Performance model
- 2nd version of Consortium Management Plan
- System Engineering of payload (+ SE MP)
- Technology Roadmap

Consortium level docs

- EID-B
- SE Management Plan
- Consortium Management Plan
- Technology Plan
- Instrument RS
- Performance Budget

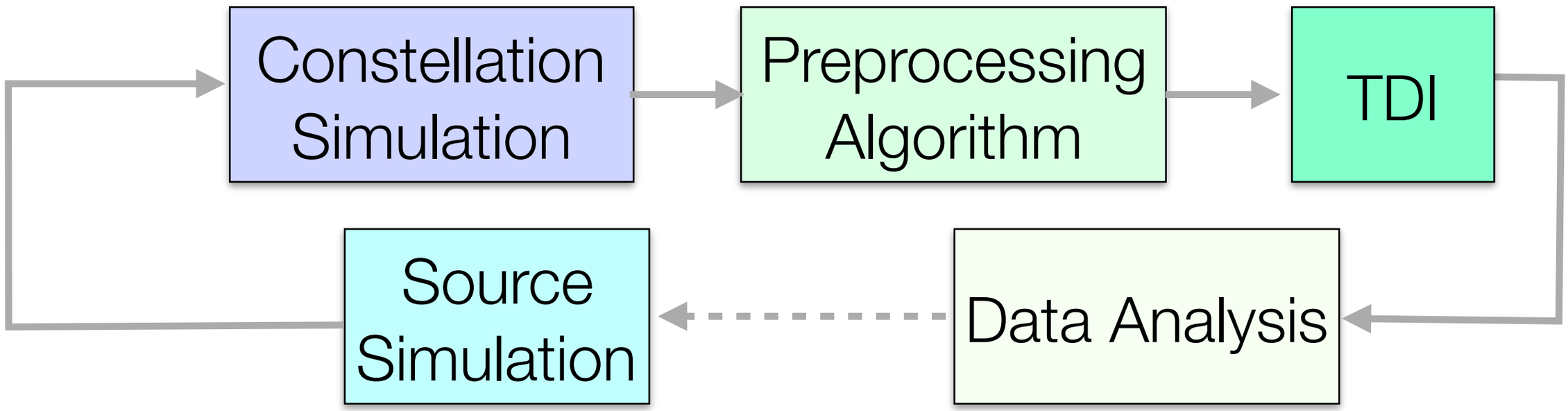
- Per Unit
-
- DDD
- RS
- ICD
- AIVT Plan
- BB-DDD + AIVT Plan (units)
- BB AIVT Plan

Simulation Working Group

- There is a lot of interaction with the simulation working group
  - studies of TDI
  - end-to-end simulation
  - preprocessing
  - science performance
  - impact of operations etc
- Sim WG and PCT will work closely on a number of projects

Simulation Working group in Phase A

- By the end of phase A we should:
  - have a reasonably detailed simulation of PM outputs
  - have a prototype preprocessing algorithm
  - have a prototype TDI algorithm
- Use this to demonstrate:
  - clock-noise removal
  - interpolation of data streams to a common grid and fiducial time
  - suppression of frequency noise and S/C jitter



Sim WG - status

WG Goals

- Build a modular and detailed simulator for LISA
- Support Consortium decisions during Phase A
- Support LISA data analysis development

WG Activity

- New simulator infrastructure available.
  LISA Node.
  - Design document will be ready for the LISA Consortium Meeting
- WG is active and working
  Meetings: Sept 4th-6th Zurich.
  WG chairs have been appointed and tasks assigned
  Telecons: almost weekly schedule
- WG is supporting LDC activities
  LISA Code is currently used.
  The switch to LISA Node will be done after test campaign

A test campaign for LISA Node will start soon

Status of data analysis and science coordination

- Development of analysis methodologies restarted
  - LISA Data Challenges
  - Definition of analysis and science deliverables
    - A recent meeting in Edinburgh to start this
- Consortium needs to
  - define more clearly what it ‘promises’ to deliver in terms of
    - science products
    - analyses/scientific interpretation
  - plan the activities to ensure this will be delivered
  - establish funding for this work
    - which means we need a well defined scope to allow for costing

Goals of Edinburgh meeting

- to extract from our proposal the core science deliverables of the consortium
- to turn that into a set of work packages
  - eventually assign responsibility to those work packages
    - get the work done
    - give people a vehicle for funding requests

Meeting structure

- First two days reviewing the SOs and SIs
  - Answered for each:
    - the science products the consortium will deliver to the community
    - each analysis the consortium intends to carry out during science ops (pipelines)
    - the tools/elements needed to allow the assembly of the pipeline(s)
    - the external inputs the consortium needs
- Third day:
  - derived a set of work packages from those answers above
  - assigned a rough prioritisation
    - urgent, end of phase A, adoption (TRL6), development of science operations
  - organised a document to present to the consortium

Output

- 63 work packages defined
  - grouped into 8 groups
    - waveform modelling
    - data analysis tools
    - instrument response modelling
    - low-latency pipelines
    - individual and global source identification codes
    - source catalogues
    - multi-messenger, multi-band
    - interpretation, key-science projects
- Notes and work package list is in the DMS
- Jon Gair will lead the writing of a document
  - short writeup of each work package
  - each work package has been assigned a book captain
- Schedule:
  - document to be released to consortium 2 weeks prior to Consortium meeting
  - present document at consortium meeting for discussion

Summary

- LISA mission is proceeding at a high pace!
- Baseline of the mission is coming together
- Phase 0 is nearing the end
- Beginning to plan Phase A activities
- Definition of consortium is on-going and should be settled soon