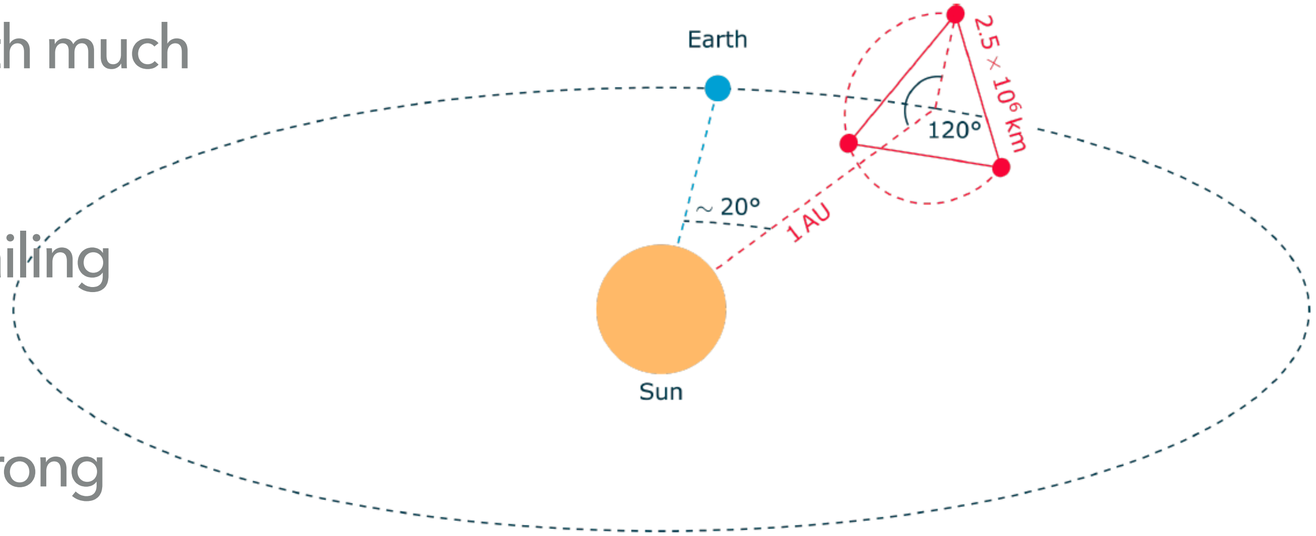
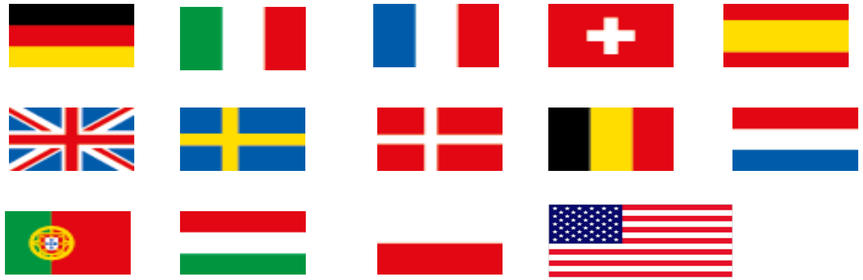

LASER INTERFEROMETER SPACE ANTENNA
LISA DATA PROCESSING

The LISA mission

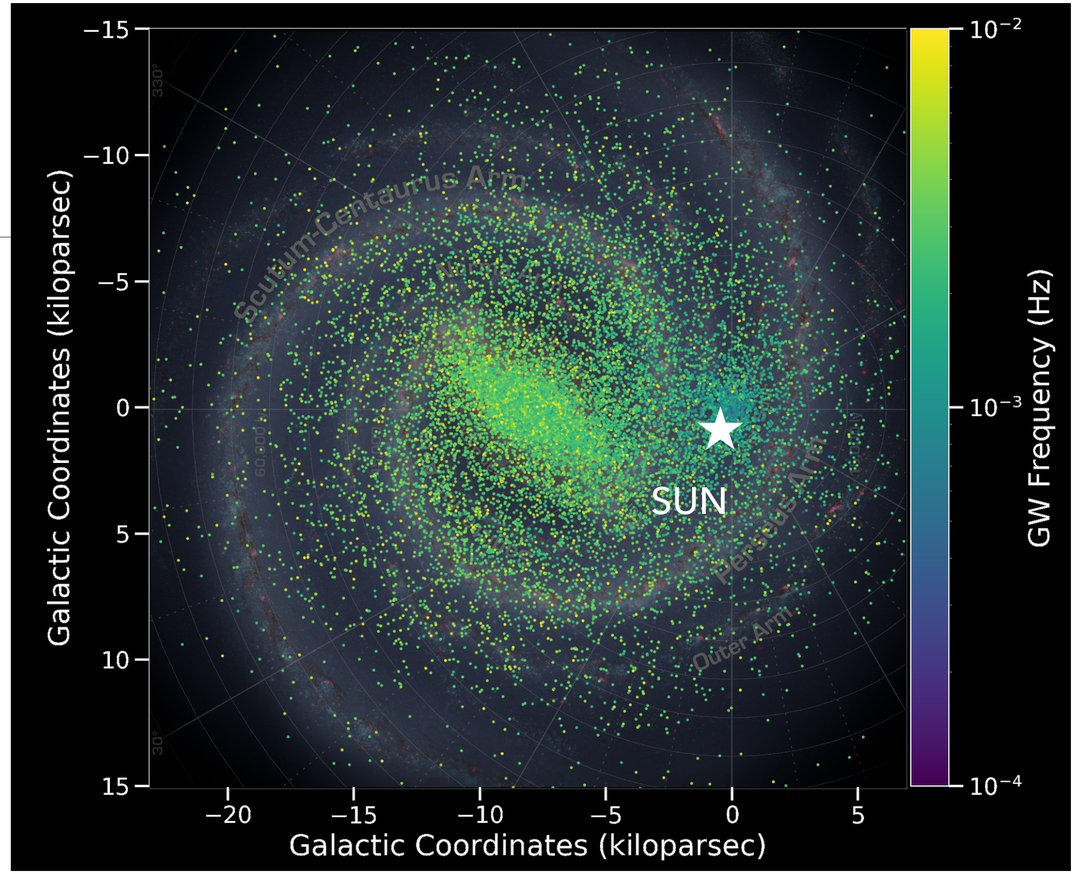
- Mission to detect Gravitational Waves with much lower frequency than LIGO/Virgo
- Three satellites in triangular formation, trailing Earth
- ESA lead, member state contributions, strong link with NASA
- Budget: ~2.6B€ (ESA: 1.5B€, NASA: ~600M€, Member states: ~500M€)
- Sensitive in mHz regime
- Launch in mid-2030s

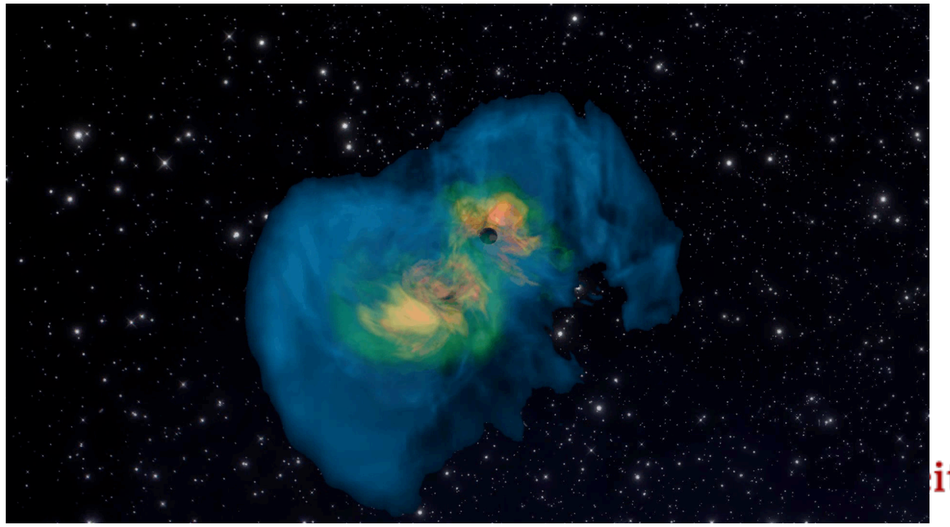




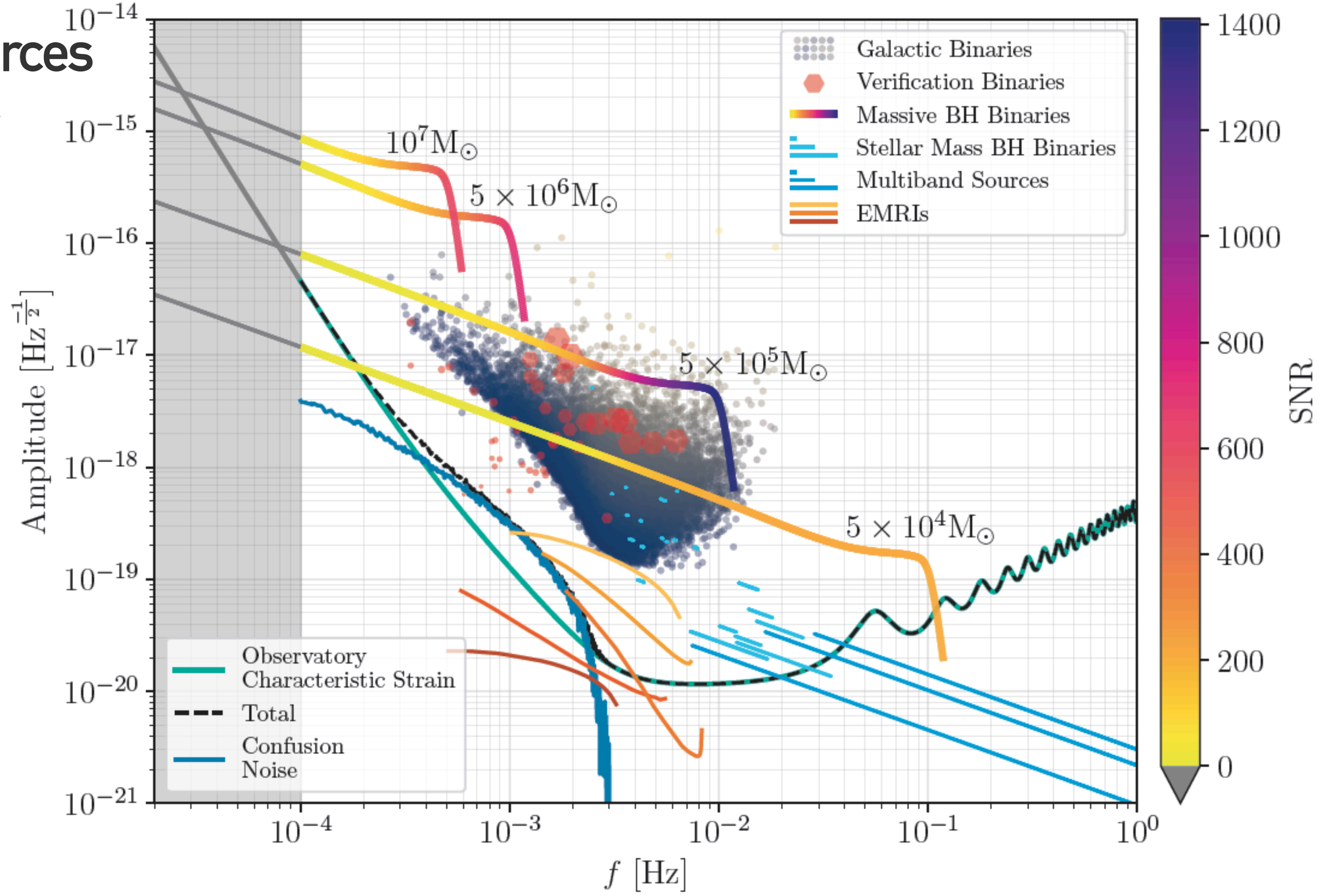
LISA science

- Massive black holes (10^5 – 10^7 M_o)
  - Their origin and growth
  - Merger physics, Electromagnetic counterparts
- Binary evolution & Milky Way structure
  - White dwarfs, neutron stars and black holes
  - Statistics and 3D positions
- Fundamental physics and testing GR
  - Black Hole physics
  - Gravitational wave properties
- Cosmology & Early Universe
  - Measure expansion
  - Signals from inflation, phase transitions, primordial black holes





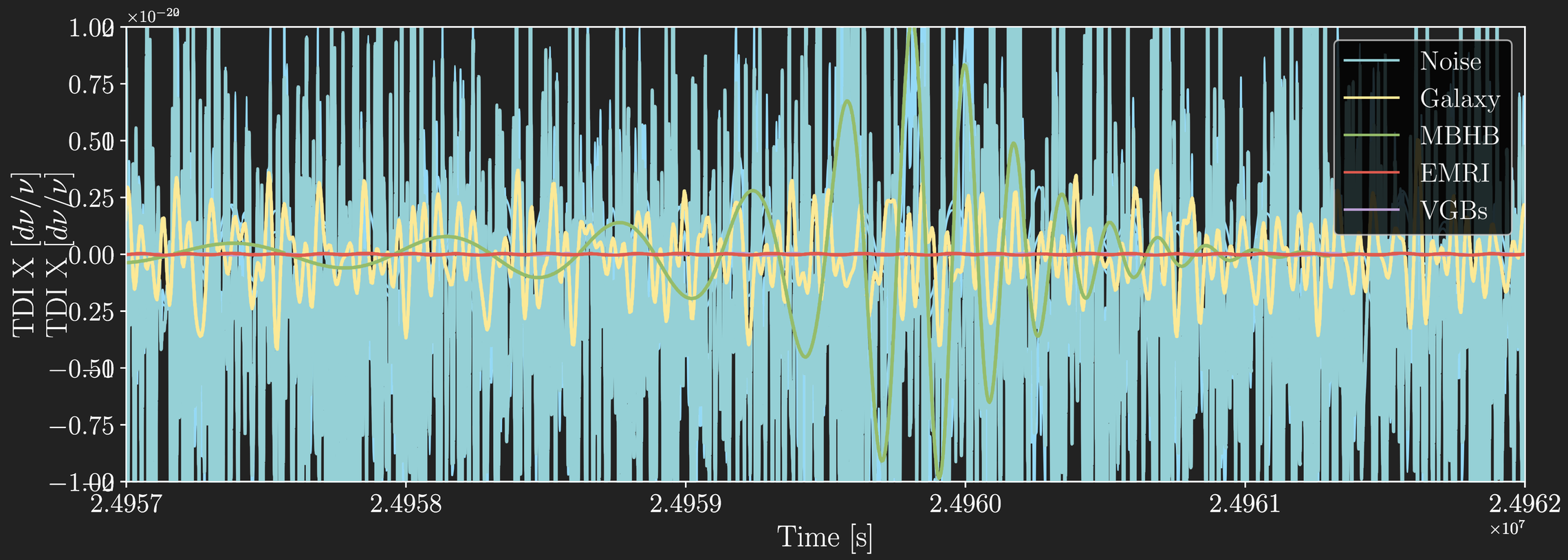
Sources


Galactic Binaries
Verification Binaries
Massive BH Binaries
Stellar Mass BH Binaries
Multiband Sources
EMRIs
$10^7 M_\odot$
$5 \times 10^6 M_\odot$
$5 \times 10^5 M_\odot$
$5 \times 10^4 M_\odot$
Observatory Characteristic Strain
Total
Confusion Noise
Amplitude $[\mathrm{Hz}^{\frac{-1}{2}}]$
f [Hz]
SNR
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
1400
1200
1000
800
600
400
200
0

LISA

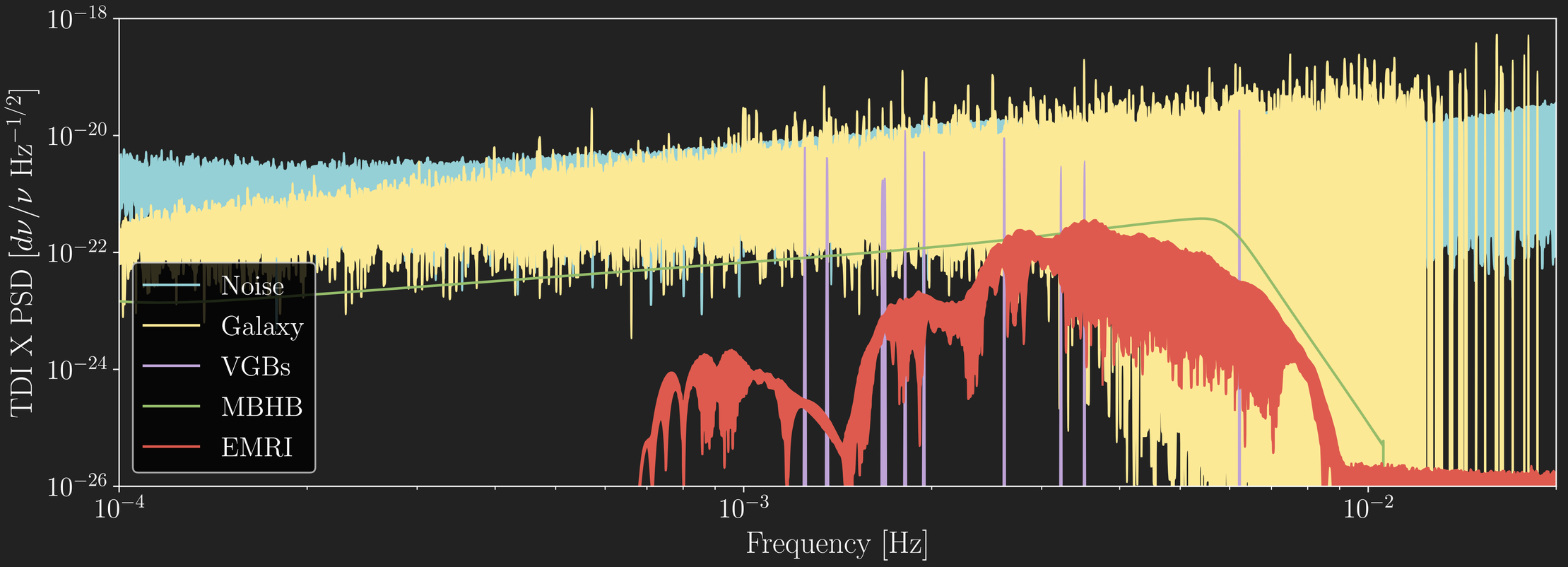
CHALLENGES

LISA DATA: MANY SIGNALS



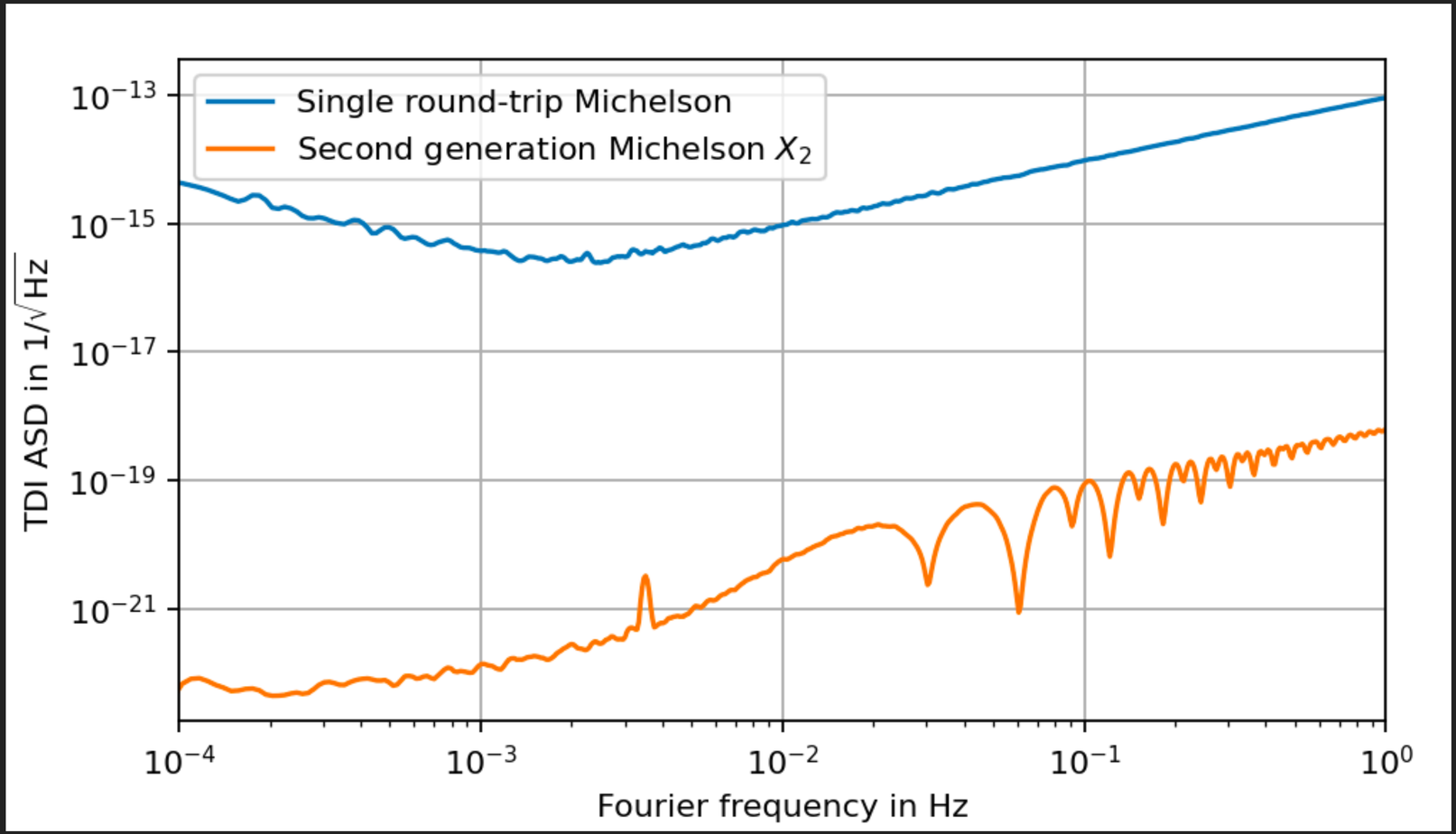
Verification GBs + EMRI + MBHB + Galaxy + Noise

LISA DATA: MANY SIGNALS



Verification GBs + EMRI + MBHB + Galaxy + Noise

SIGNALS BURIED IN LASER NOISE



TIME DELAY INTERFEROMETRY

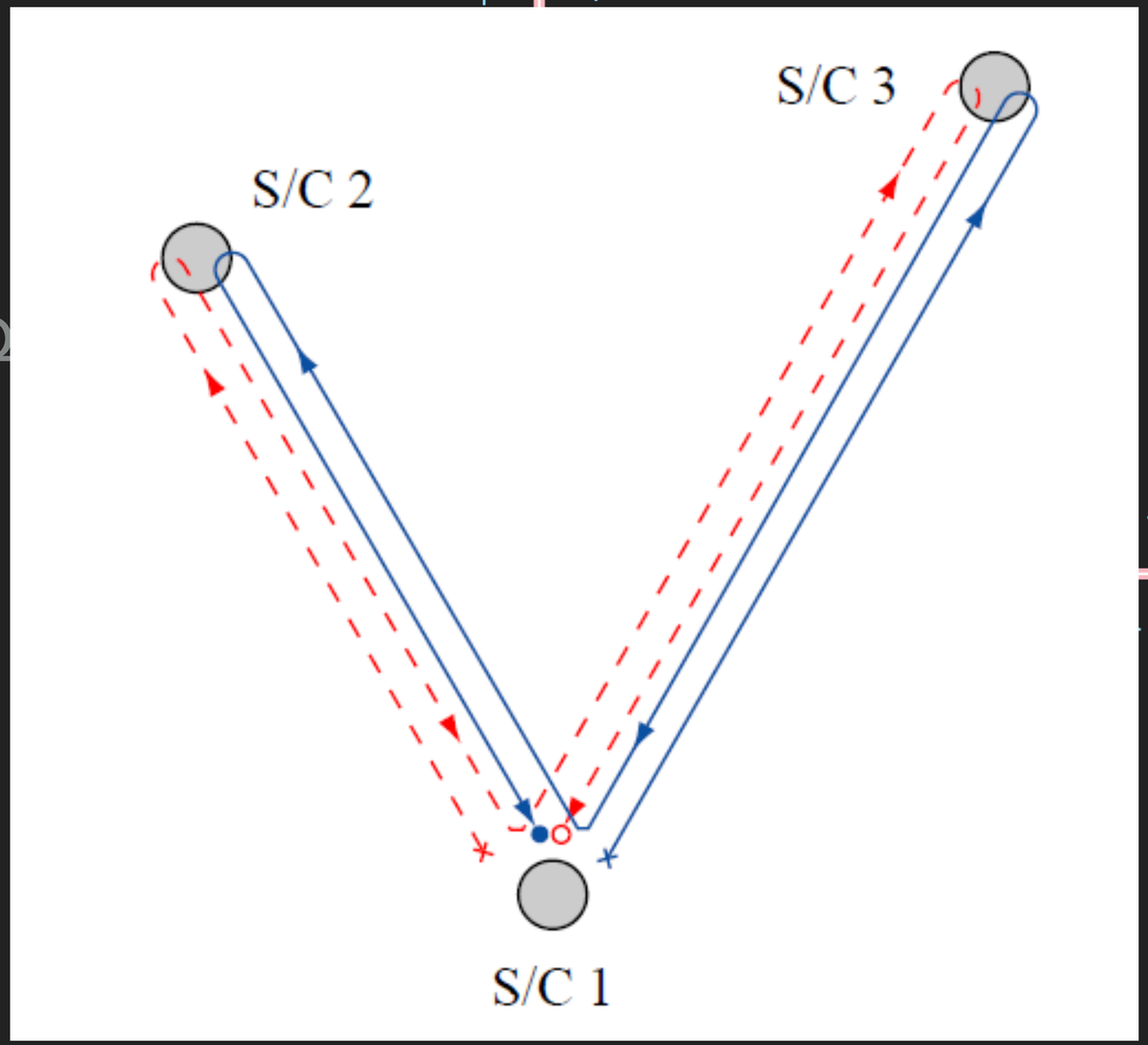
Why?

- Laser Noise: 10^{-13}
- Gravitational Waves: 10^{-20}

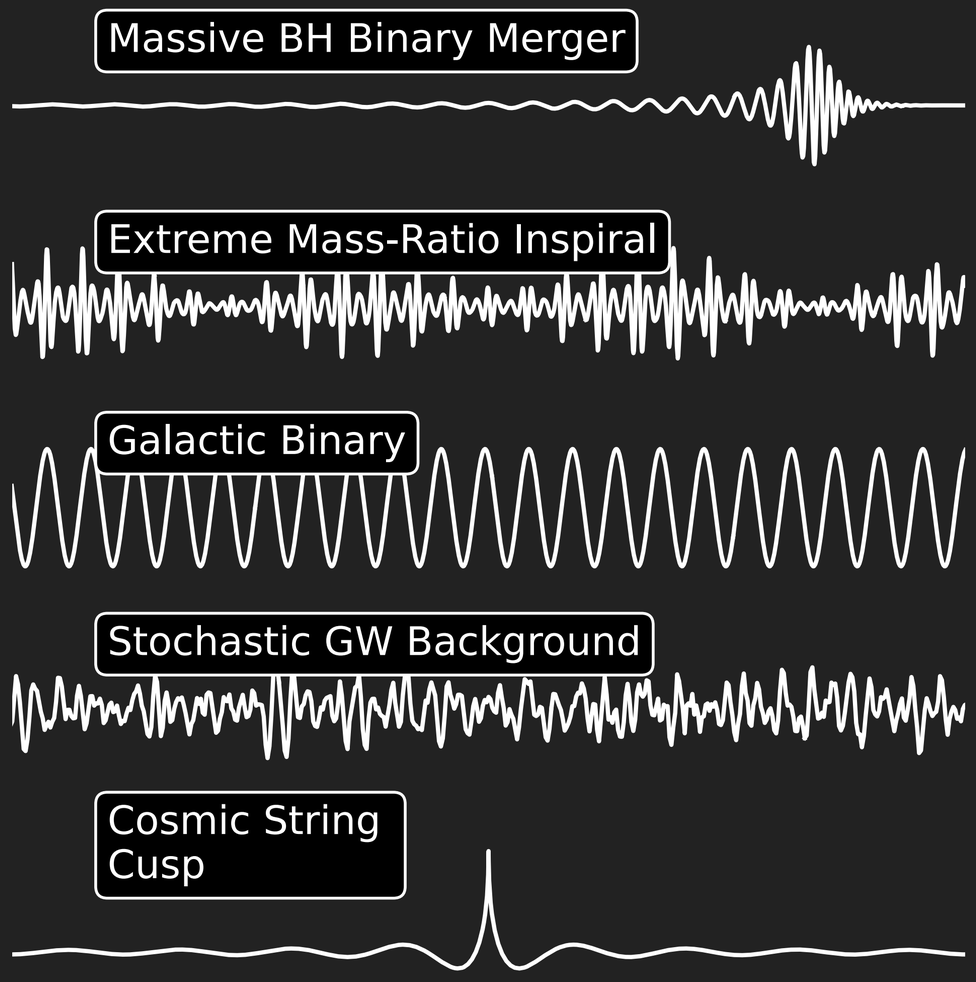
Solution:

- Record data for each arm individually
- Delay and combine in post-processing

➡ Laser noise cancels out

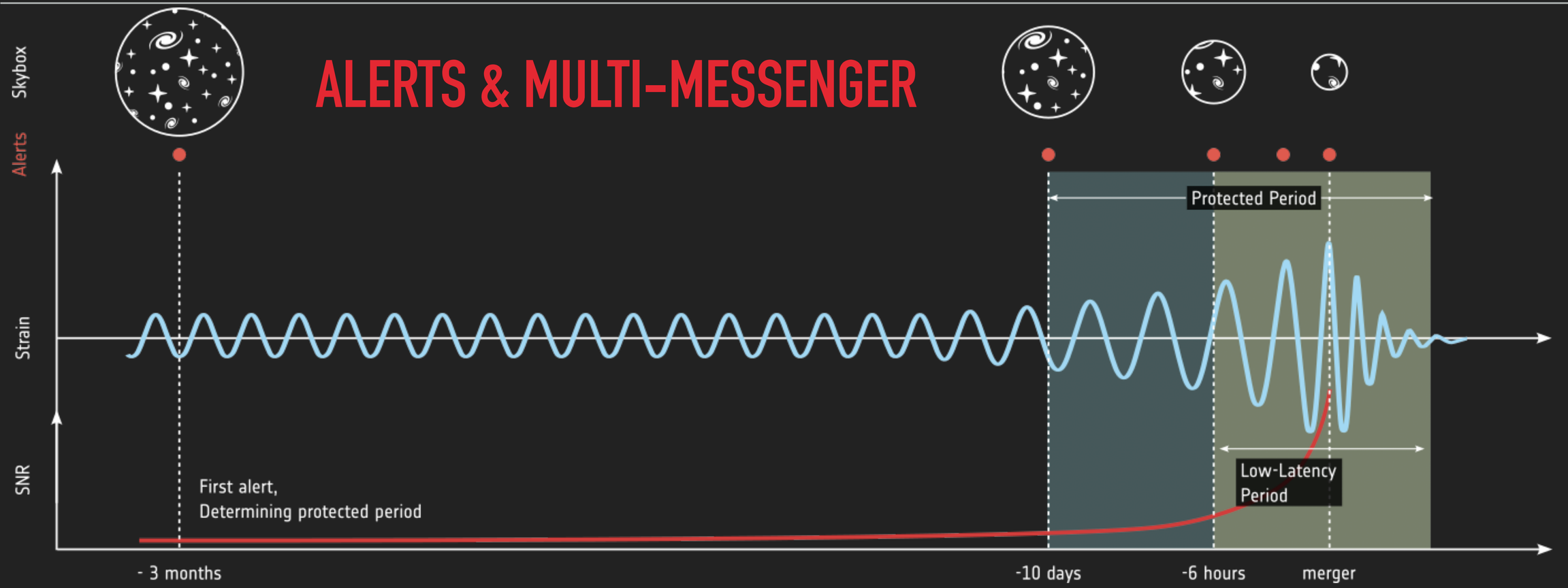


WAVEFORMS CRUCIAL



- Needed for Global Fit
- Status: good understanding, some serious development needed (EMRIs, IMRIs)
- Coordinated effort (Distributed Data Processing Center - DDPC, Consortium) to complete waveform models
- Different aspects
  - Accuracy for strong sources
  - Speed for discovery and low-latency searches

ALERTS & MULTI-MESSENGER

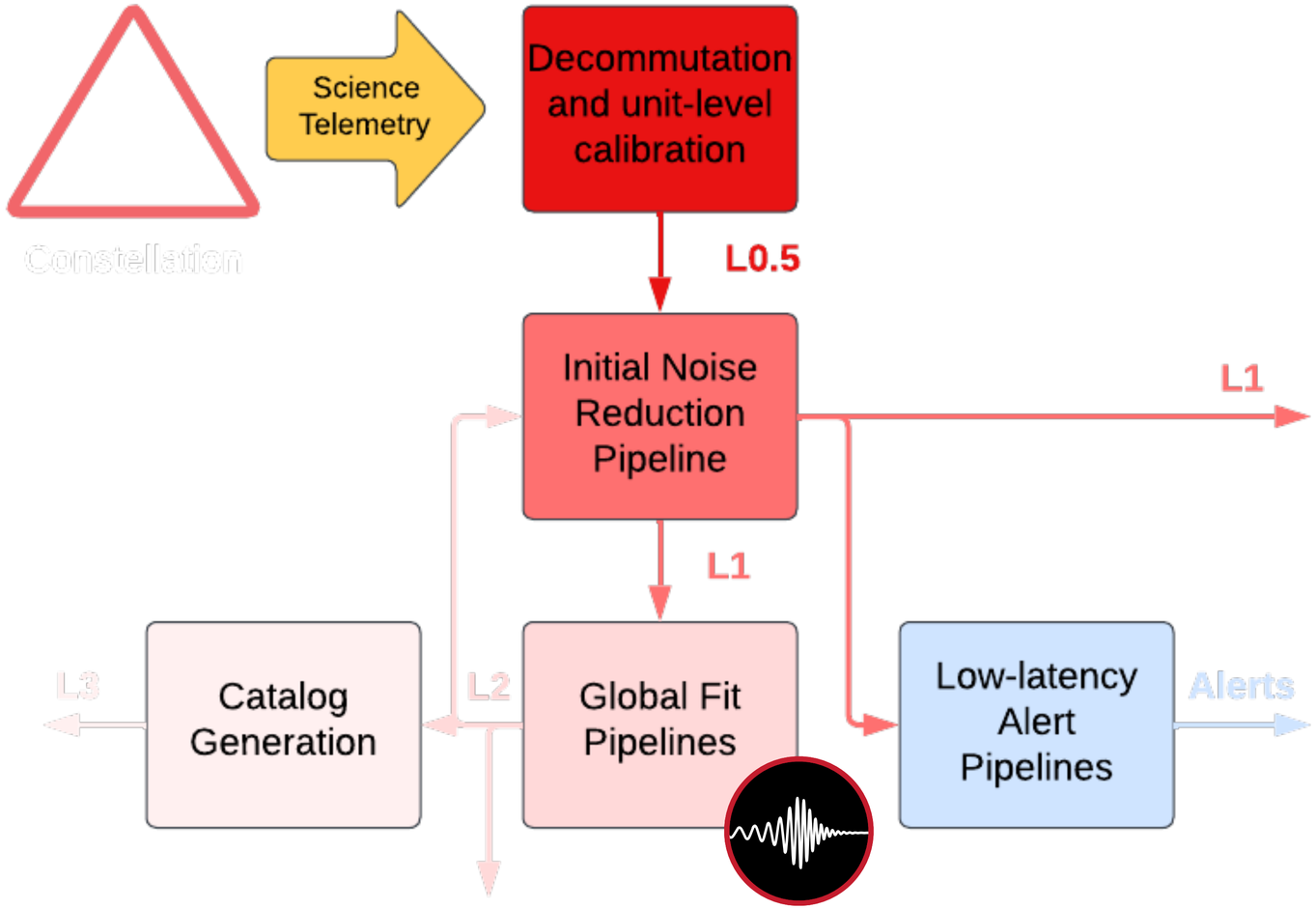


- Several low-latency alert pipelines
  - Alerts for new sources
  - Updates on known transients
- Realtime in 8/24 h of data exchange
- Protected periods
- Multi-messenger will be done “online” with alerts but also “offline” for long lived sources (Galactic binaries, Stellar BH)

LISA

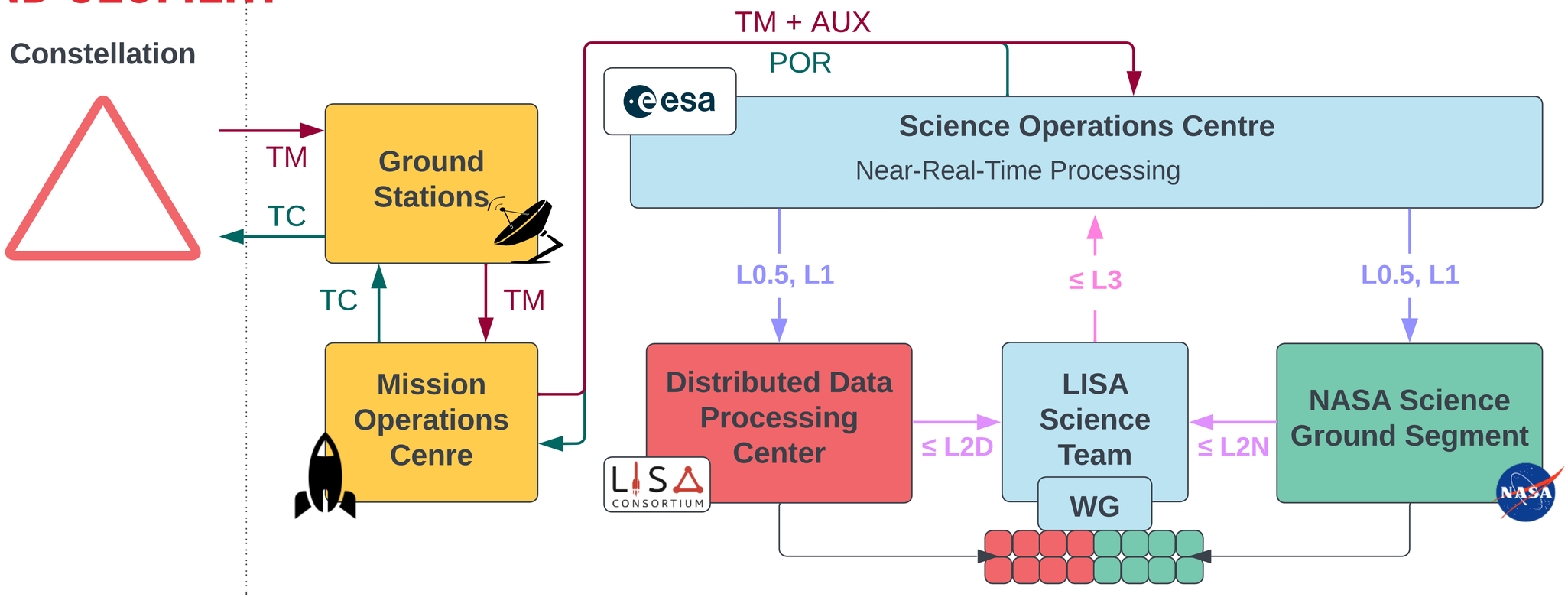
DATA PROCESSING

DISENTANGLING ALL SOURCES



- Main inputs: interferometric measurements + 3 armlengths
- Noise reduction: suppress laser noises and clock noises (Time Delay Interferometry)
- Global fits: iterative/simultaneous fitting for extracting a large number of overlapping sources
- Stochastic signals and residuals
- Detected sources combined to form catalogs

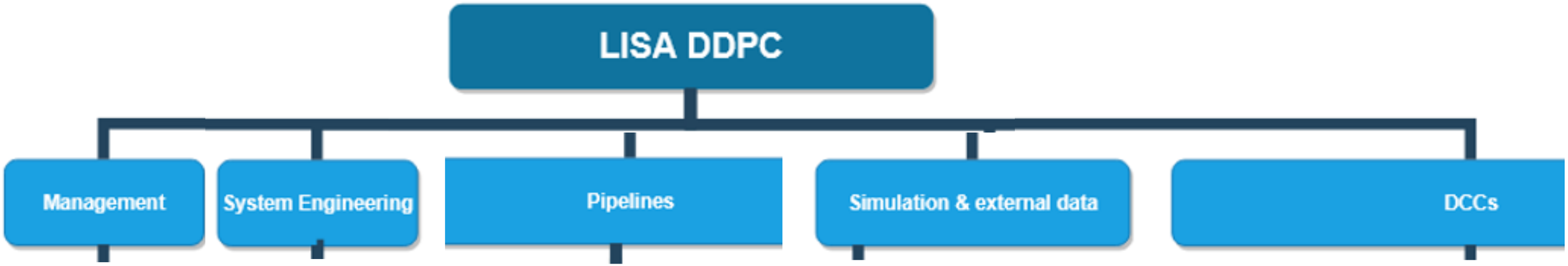
GROUND SEGMENT



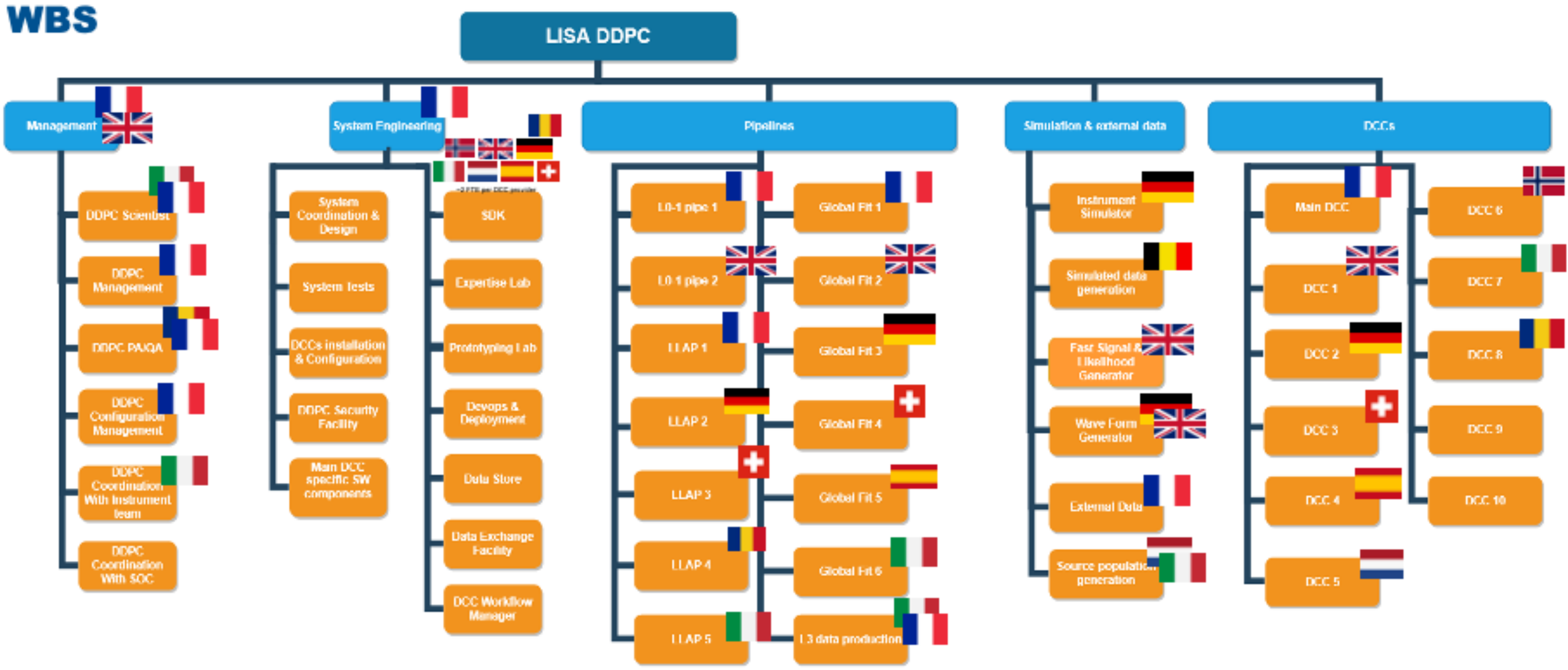
- Distributed Data Processing Center (DDPC), Europe
- NASA data processing
- Several versions of L1, L2 data on different time scale

DDPC

- Responsibilities DDPC shared between ESA member states
- France in the lead
- NL will contribute
- Global structure

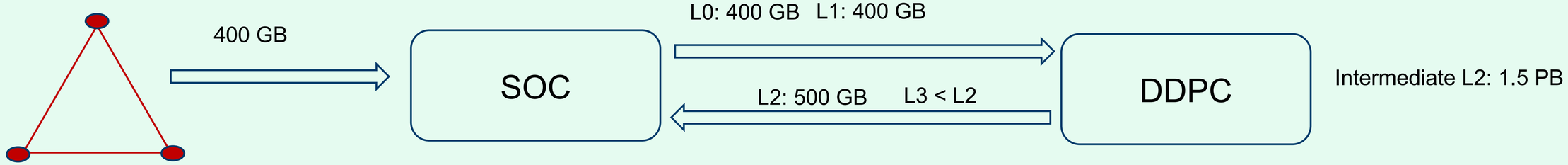


DDPC

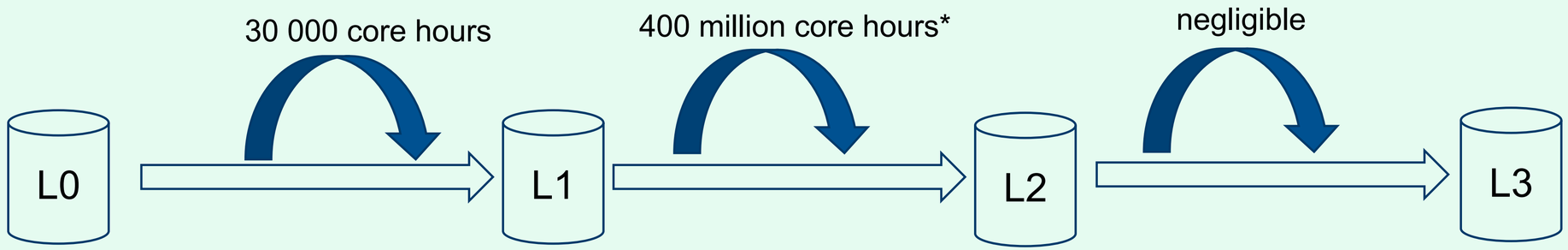

WBS
LISA DDPC
Management
DDPC Scientist
DDPC Management
DDPC PA/QA
DDPC Configuration Management
DDPC Coordination With Instrument team
DDPC Coordination With SOC
System Engineering
System Coordination & Design
System tests
DCCs installation & Configuration
DDPC Security Facility
Main DCC specific SW components
SDK
Expertise Lab
Prototyping Lab
Devops & Deployment
Data Store
Data Exchange Facility
DCC Workflow Manager
Pipelines
L0-1 pipe 1
L0-1 pipe 2
LLAP 1
LLAP 2
LLAP 3
LLAP 4
LLAP 5
Global Fit 1
Global Fit 2
Global Fit 3
Global Fit 4
Global Fit 5
Global Fit 6
L3 data production
Simulation & external data
Instrument Simulator
Simulated data generation
Fast Signal & Likelihood Generator
Wave Form Generator
External Data
Source population generation
DCCs
Main DCC
DCC 1
DCC 2
DCC 3
DCC 4
DCC 5
DCC 6
DCC 7
DCC 8
DCC 9
DCC 10

Some numbers

Data size per year



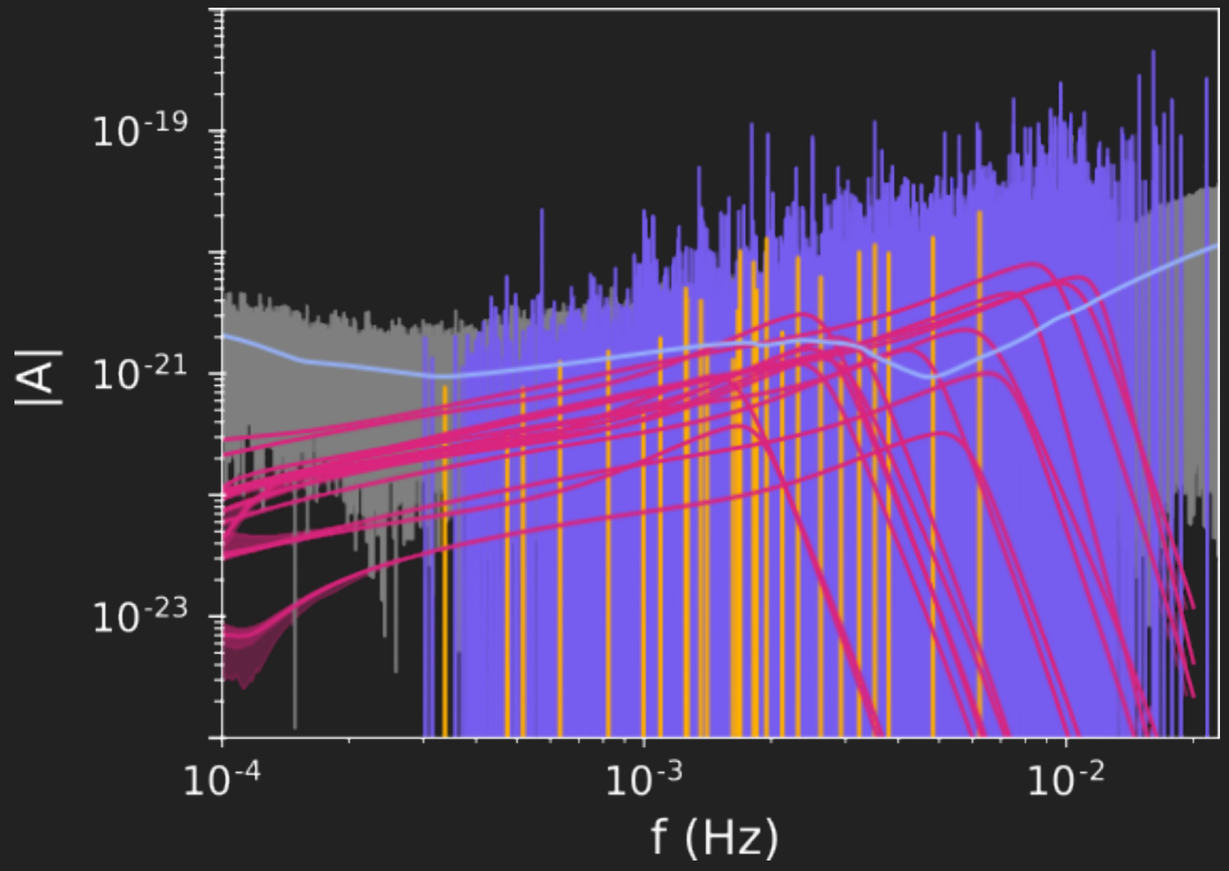
Core hours per year



* Considering 2 global fit running in parallel
/!\ Carbon footprint

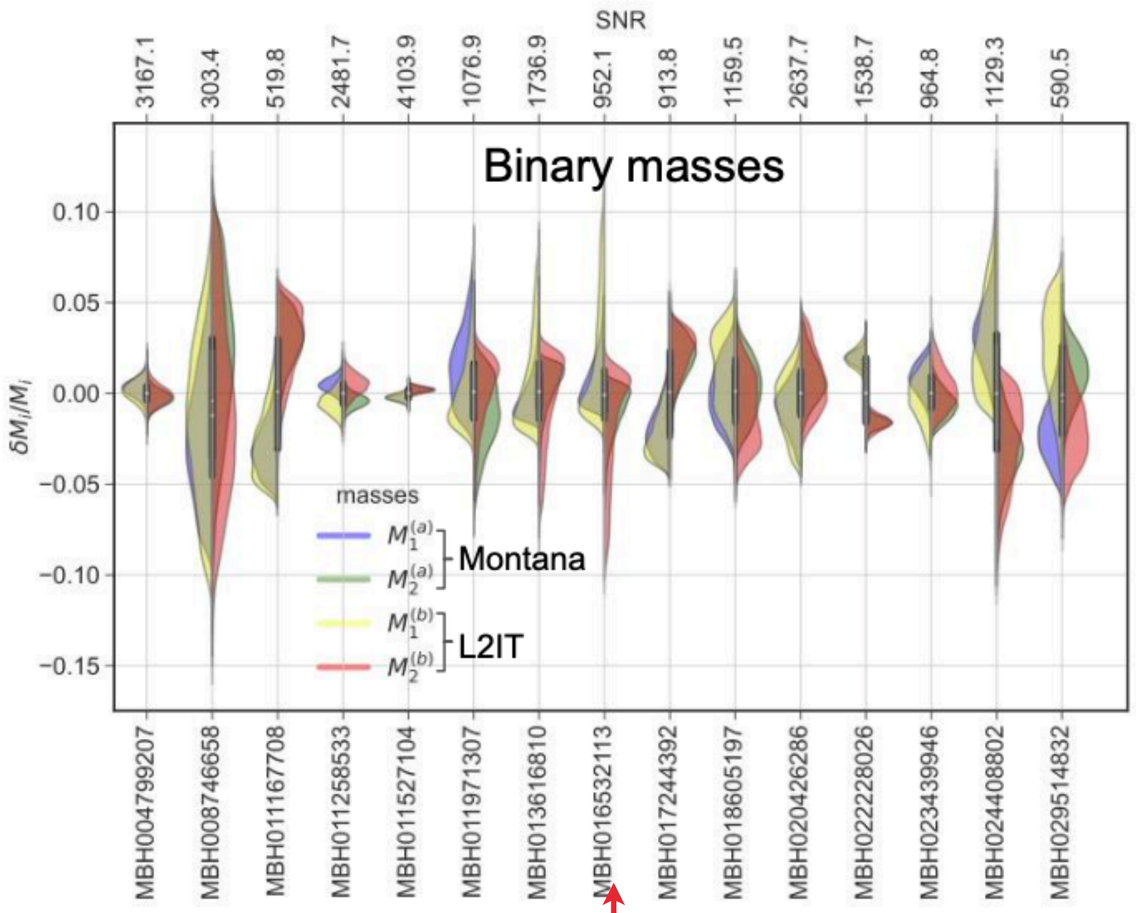
MAKING IT HAPPEN

- Distributed Data Processing Center (DDPC, Europe) & NASA Science Ground Segment
- Consolidated catalogs (L3) merged under ESA (PS/LST)
- Feasibility
  - LISA Data Challenges ongoing
  - Clear plan to final system
- Data will be made public, including tools and documentation



LISA DATA CHALLENGE

- Simulated datasets of increasing complexity to drive the development of LISA data analysis pipeline
- History:
  - 2005-2012: Mock LDC
  - (Re-)started in 2017
  - Future: via DDPC
- Example: Sangria, the last finalised challenge: 1 year, all GBs + MBHBs + noises
  - Results for Galactic Binaries:
    - Injections with SNR > 8 : 7800
    - Well recovered : 5000 to 6000
    - Partially recovered: 1000 to 2000 (up to 25%)
  - MBHBs



BIG DATA CHALLENGES

- Data processing
  - Synergy with other fields?
  - Role of community
- Data storage and management
  - ESA experience
  - Good plan, synergy/example possible
- Emerging technologies
  - ?