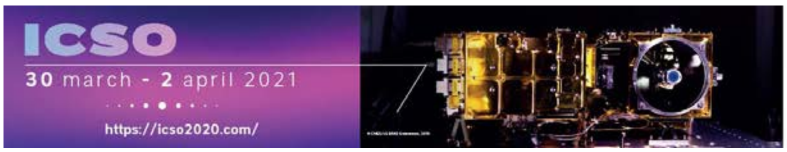
International Conference on Space Optics—ICSO 2020

Virtual Conference

30 March–2 April 2021

Edited by Bruno Cugny, Zoran Sodnik, and Nikos Karafolas



ICSO 2020
INTERNATIONAL CONFERENCE
ON SPACE OPTICS
VIRTUAL

LISA: Observing Universe with Gravitational Waves from space

esa icso proceedings cnes

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LISA CONSORTIUM
LISA: Observing Universe
with Gravitational Waves
from space
Antoine Petiteau
(APC – Université Paris-Diderot / CNRS-IN2P3)
ICSO 2020 - Remote
2nd April 2021
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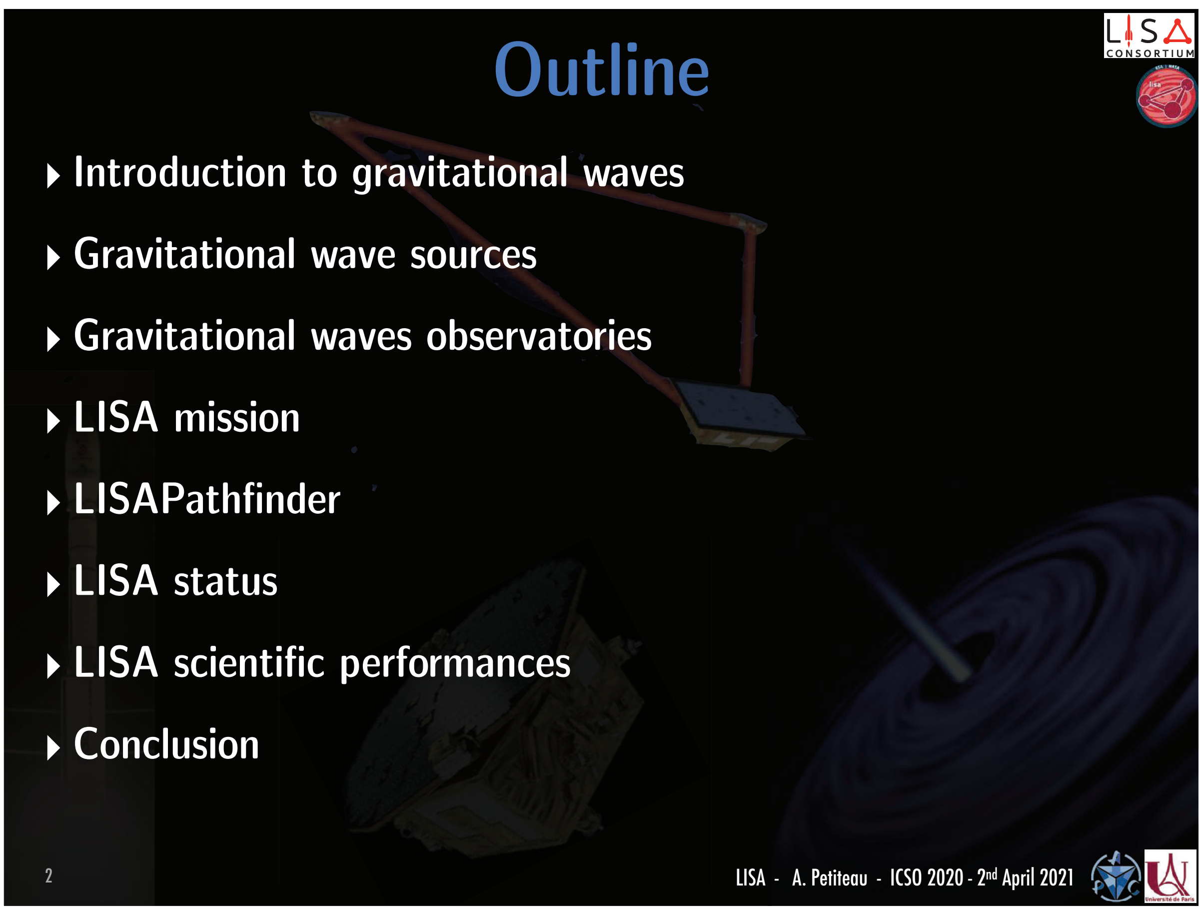
LISA CONSORTIUM
Outline
Introduction to gravitational waves
Gravitational wave sources
Gravitational waves observatories
LISA mission
LISAPathfinder
LISA status
LISA scientific performances
Conclusion
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Some history …

- Albert Einstein (1905/1916) : there is no gravity force…
  - Mass deforms geometry of space-time.
  - Bodies are moving in a curve space.
  - Gravitational information propagates at the speed of light.
  - Dissipation of energy through deformation of space-time => gravitational waves

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

geometrical deformation

distribution of energy

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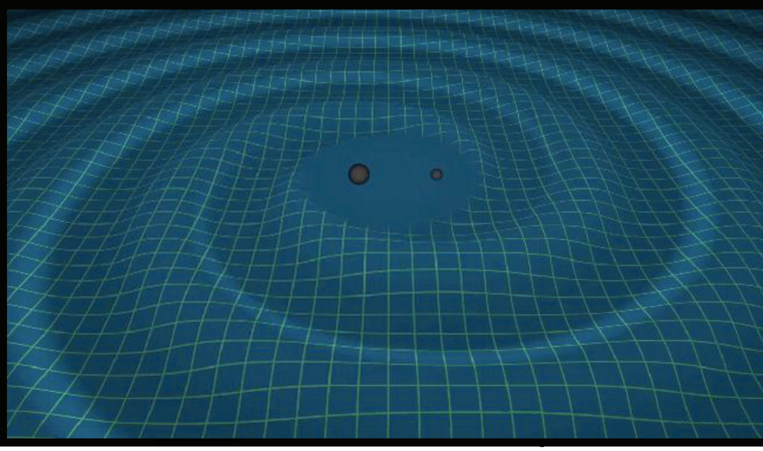
Emission of GWs

- A gravitational wave is created during the non-spherical acceleration of one or several massive objects (variation of quadrupolar moment) :
  - emission: asymetric collapse, bodies in orbits or coalescing, ...
  - no emission: isolated, spherical body possibly in rotation



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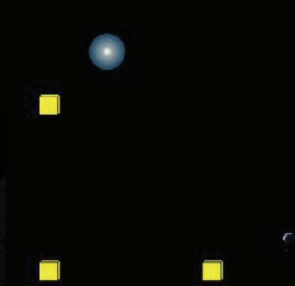
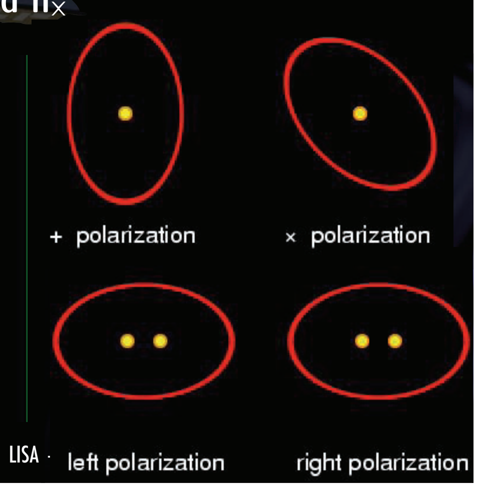
Effects of GWs

- Modification of distance between 2 objects:
  - Elastic deformation proportional to the distance between the 2 obj.,
  - Transverse deformation: perpendicular to the direction of propagation (different from ripples on water !),
  - Two components of polarisation : h_+ and $h_\times$

$$\frac{\delta L}{L} = \frac{h}{2}$$

deformation wave amplitude





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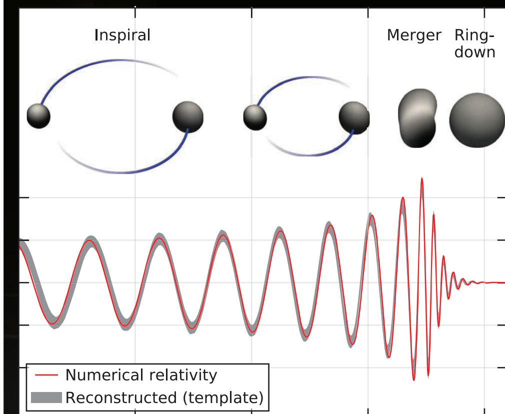
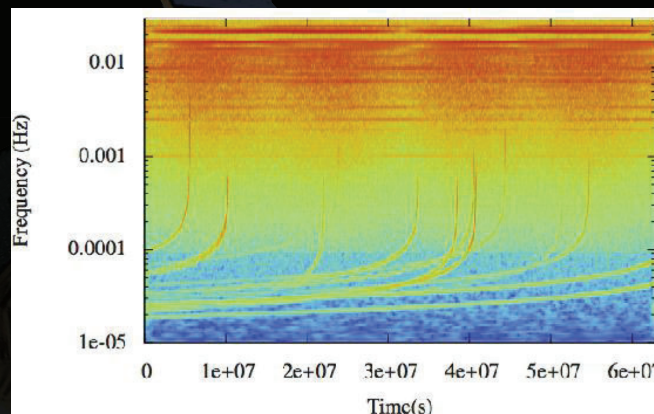
Waveform for equal mass binaries

- Computing waveform for Gravitational Wave:
  - inspiral phase: analytic (Post-Newtonian)
  - merger: numerical relativity
  - ringdown (oscillation of the resulting BH): semi-analytic





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Example: black hole binaries

- Black hole binaries are very "simple" systems described by only 17 parameters:
  - Intrinsic parameters:
    - masses (m_1 et m_2)
    - frequency and phase
    - spins (amplitude and direction)
    - eccentricity (value et position of periastron)
  - Extrinsic parameters: position source with respect to observer
    - sky position (2 angles)
    - orientation (2 angles)
    - time reference (time at coalescence)

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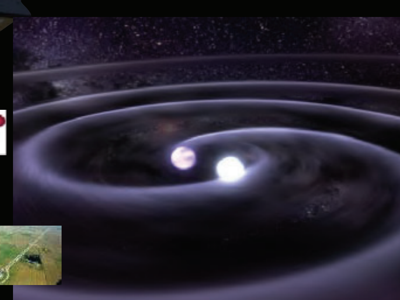
Compact solar mass binaries

- Large number of stars are in binary system.
- Evolution in white dwarf (WD) and neutron stars (NS).

  => existence of WD-WD, NS-WD and NS-NS binaries
- Estimation for the Galaxy: 60 millions.
- Gravitational waves:
  - most part in the slow inspiral regime (quasi-monochromatic): GW at mHz
  - few are coalescing: GW event of few seconds at f > 10 Hz (LIGO/Virgo)



- Several known system emitting around the mHz

  => guaranteed sources

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Black Hole Binaries

- Binaries with 2 black holes of masses between few M_{Sun} and 100 M_{Sun} , so called "Stellar mass BH Binaries"
- Inspiral: emission in the mHz band
- Merger: powerful emission around few tens Hz => many sources already observed

- Fast evolution: few years from tens mHz to tens Hz => multi-observatories observations

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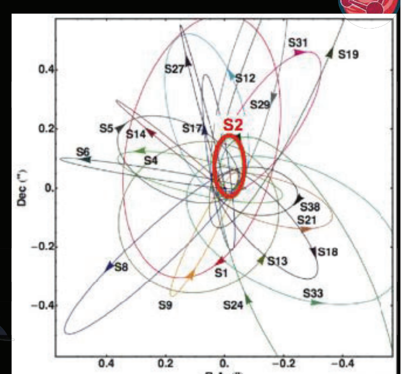
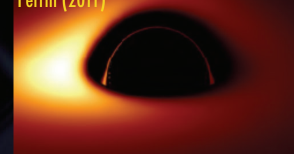
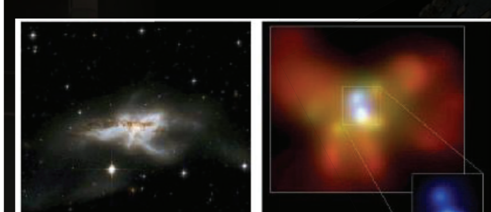
Supermassive Black Holes

- Observations:
  - Sgr A* : 4.5×10^6 M_{Sun} at the center of the Milky Way (VLT - Gravity)
  - M87: 6.5×10^9 M_{Sun} (picture EHT)
- Supermassive Black Hole are indirectly observed in the centre of a large number of galaxies (Active Galactic Nuclei).
- Observations of galaxy mergers => => SuperMassive BH Binaries (SMBHB) should exist.

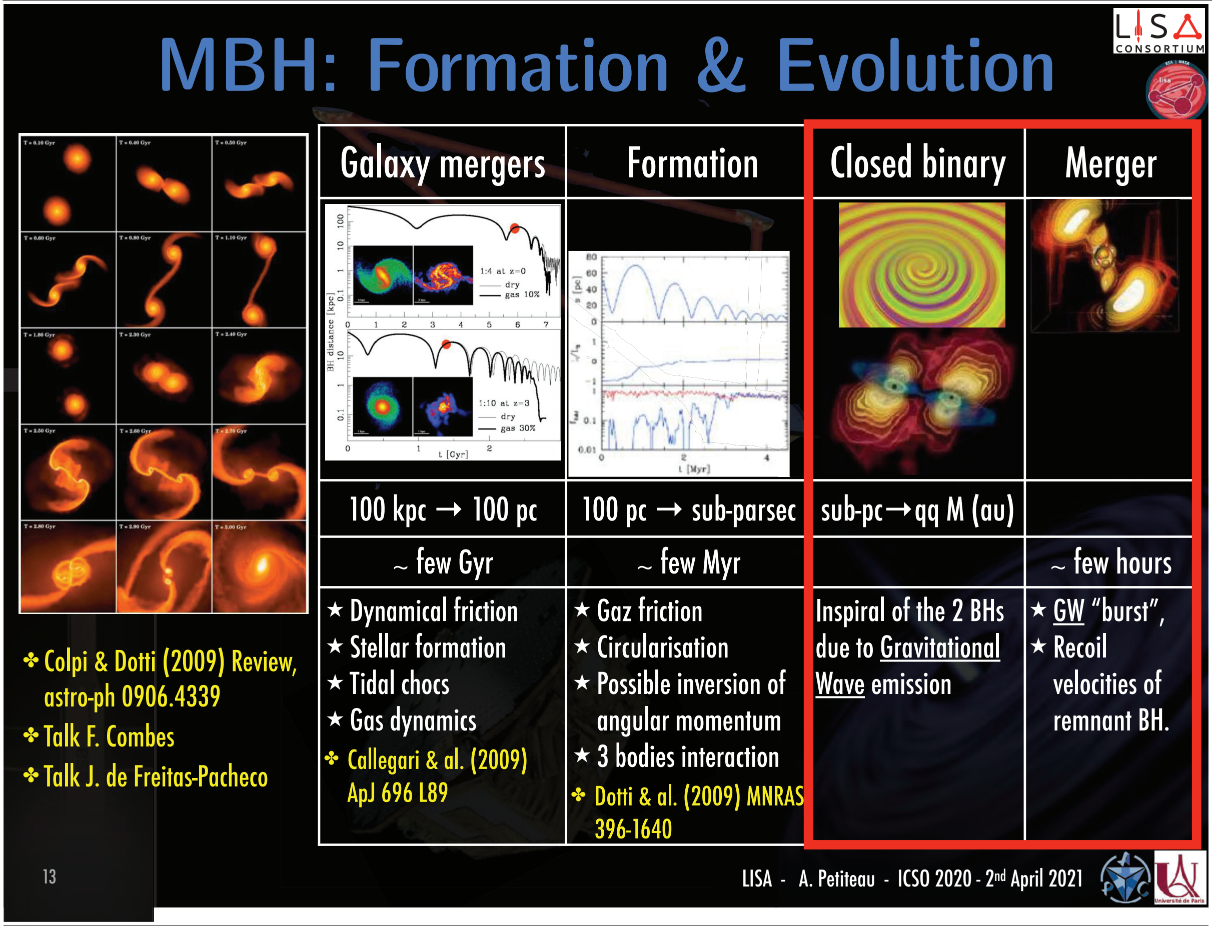



© Vincent, Paumard, Gourgoulhon, Perrin (2011)


© EHT (2019)


NGC 6240 (Komossa et al. ApJ 582 L15)


Antennae galaxies


MBH: Formation & Evolution
Galaxy mergers
Formation
Closed binary
Merger
100 kpc → 100 pc
100 pc → sub-parsec
sub-pc→qq M (au)
~ few Gyr
~ few Myr
~ few hours
★ Dynamical friction
★ Stellar formation
★ Tidal chocs
★ Gas dynamics
❖ Callegari & al. (2009) ApJ 696 L89
★ Gaz friction
★ Circularisation
★ Possible inversion of angular momentum
★ 3 bodies interaction
❖ Dotti & al. (2009) MNRAS 396-1640
Inspiral of the 2 BHs due to Gravitational Wave emission
★ GW "burst",
★ Recoil velocities of remnant BH.
❖ Colpi & Dotti (2009) Review, astro-ph 0906.4339
❖ Talk F. Combes
❖ Talk J. de Freitas-Pacheco
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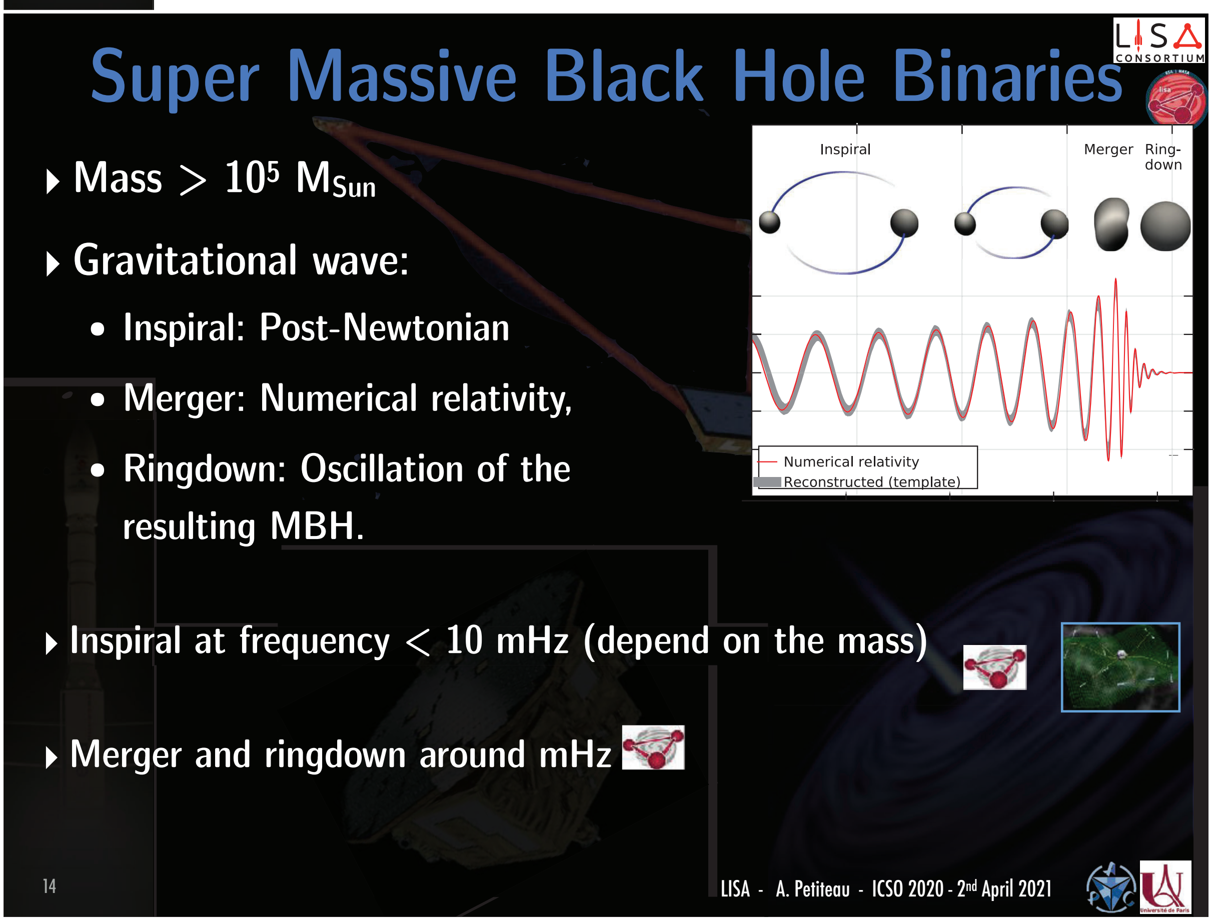
Super Massive Black Hole Binaries
Mass > 10⁵ MSun
Gravitational wave:
• Inspiral: Post-Newtonian
• Merger: Numerical relativity,
• Ringdown: Oscillation of the resulting MBH.
Inspiral at frequency < 10 mHz (depend on the mass)
Merger and ringdown around mHz
Inspiral
Merger
Ring-down
Numerical relativity
Reconstructed (template)
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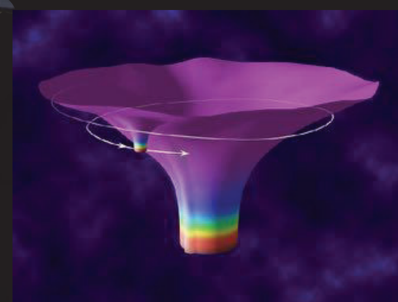
EMRIs

- Capture of a "small" object by massive black hole ($10 - 10^6$ M_{Sun}): Extreme Mass Ratio Inspiral
  - Mass ratio > 200
  - GW gives information on the geometry around the black hole.
  - Test General Relativity in stong field
  - Frequency : 0.1 mHz to 0.1 Hz
  - Large number of source could be observed by space-based interferometer



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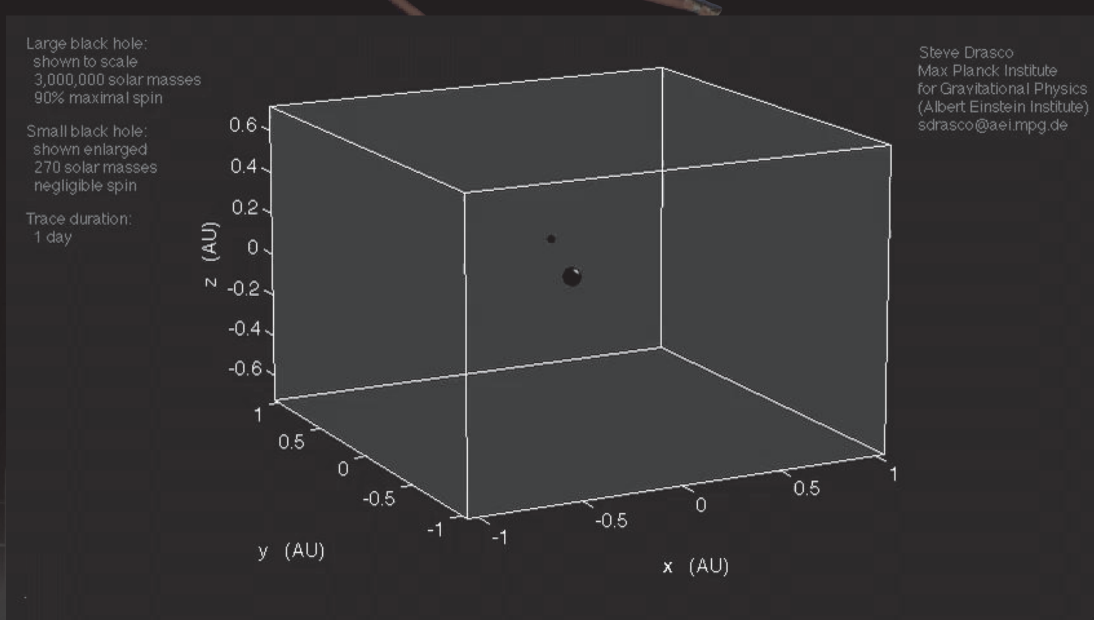
EMRIs

- Small Black Hole orbiting around a SuperMassive Black Hole



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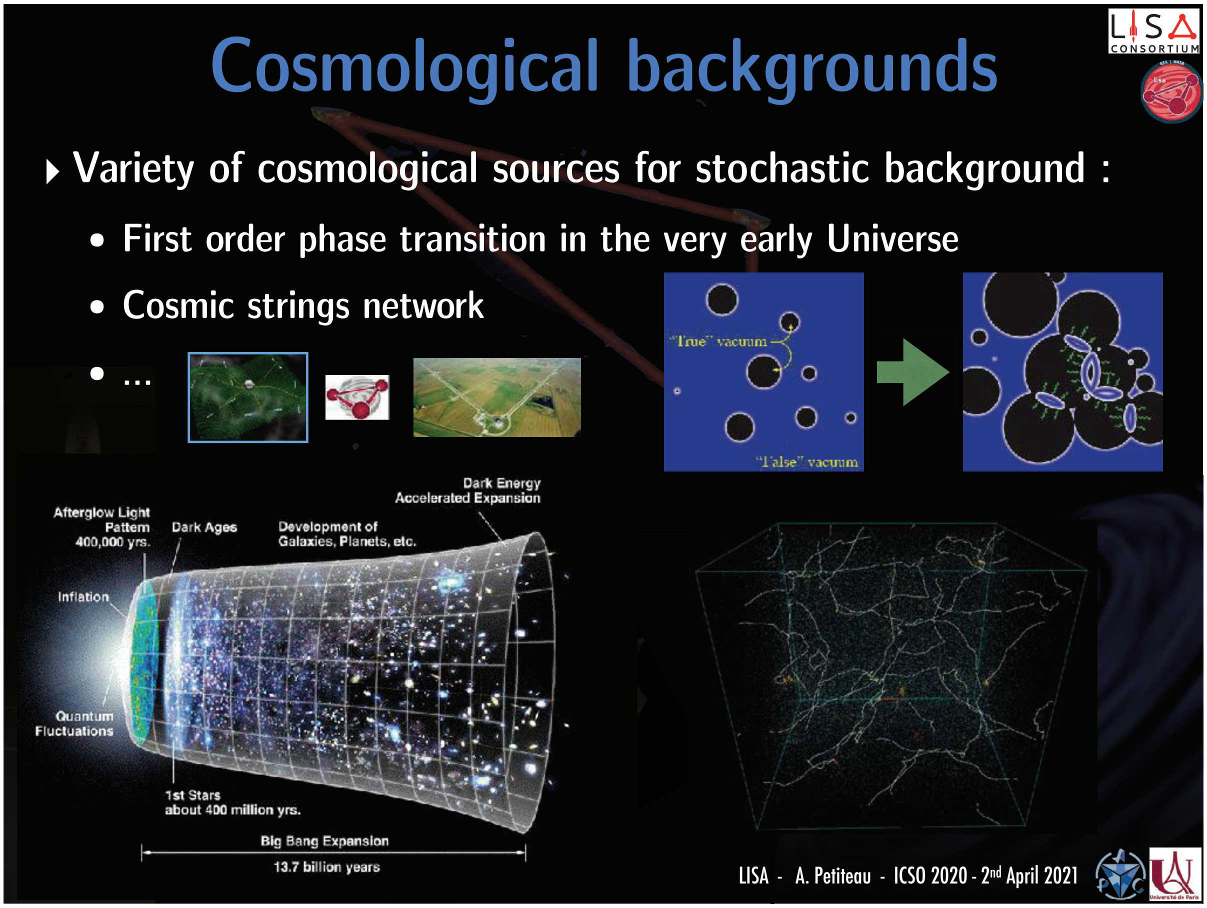
Cosmological backgrounds
Variety of cosmological sources for stochastic background :
First order phase transition in the very early Universe
Cosmic strings network
…
"True" vacuum
"False" vacuum
Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years
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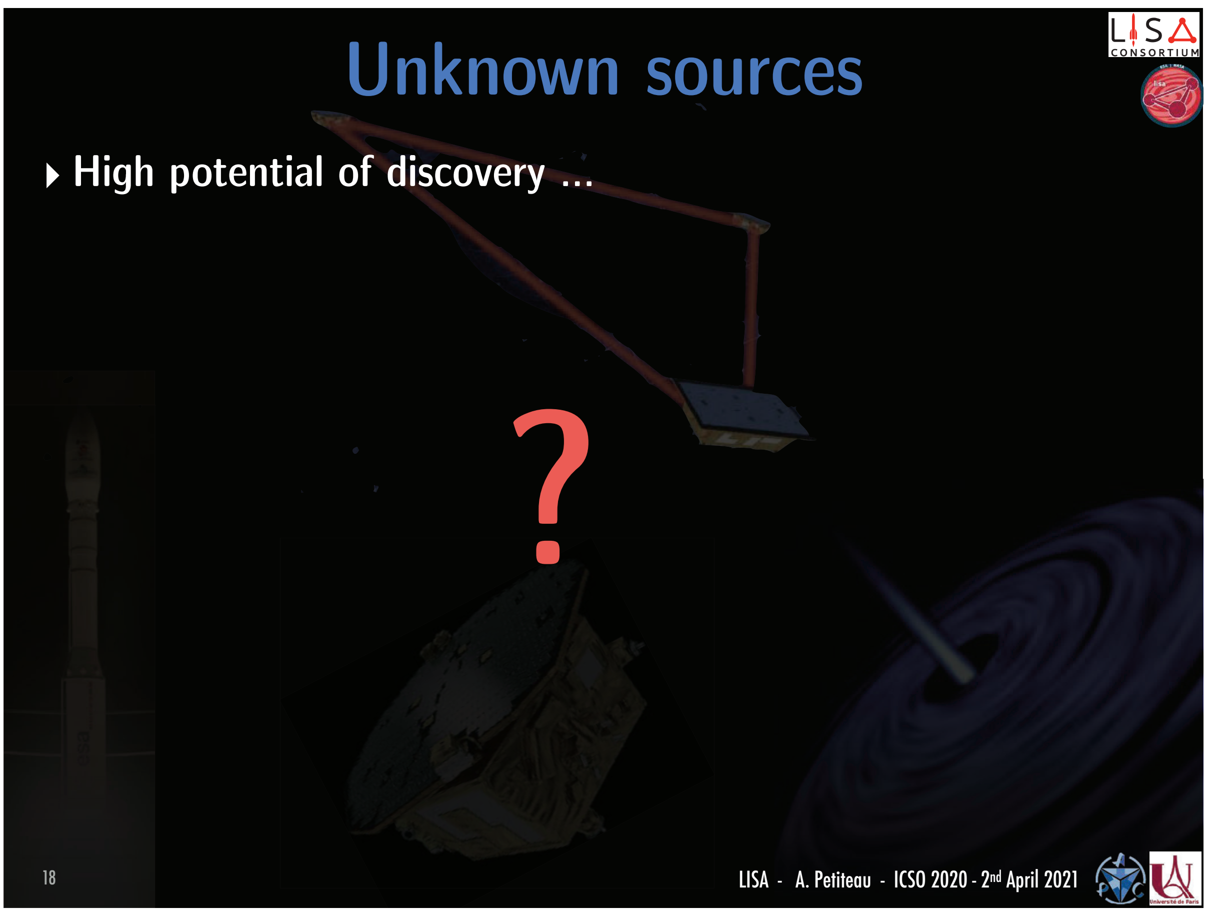
Unknown sources
High potential of discovery …
?
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What can we learn ?

- The nature of gravity (testing the basis of general relativity)
- Fundamental nature of black hole: existence of horizon, ...
- Black holes as a source of energy,
- Nonlinear structure formation: seed, hierarchical assembly, accretion,
- Understanding the end of the life of massive stars,
- Dynamic of galactic nuclei,
- The very early Universe: Higgs TeV physics, topological defects, ...
- Constraining cosmological models,
- ...

=> New observational window on the Universe (with all the unexpected !): looking at dark side of the Universe !

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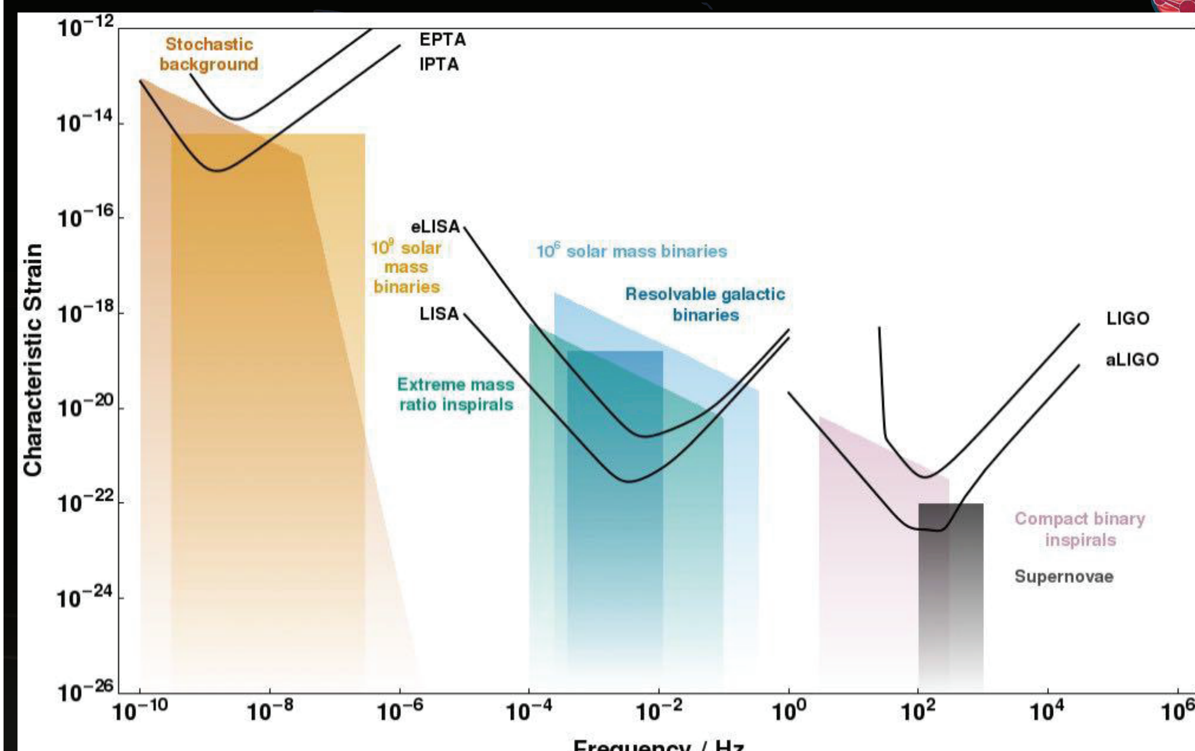
GW sources over frequency band



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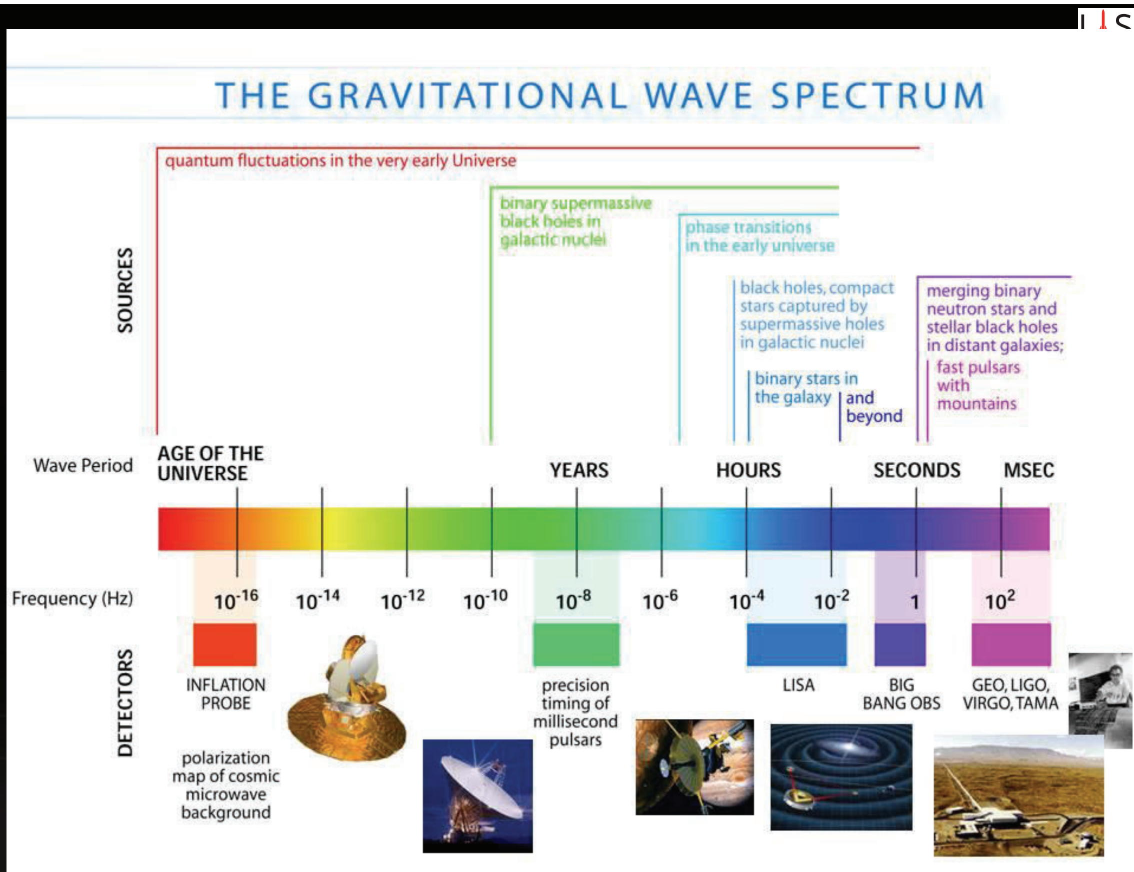

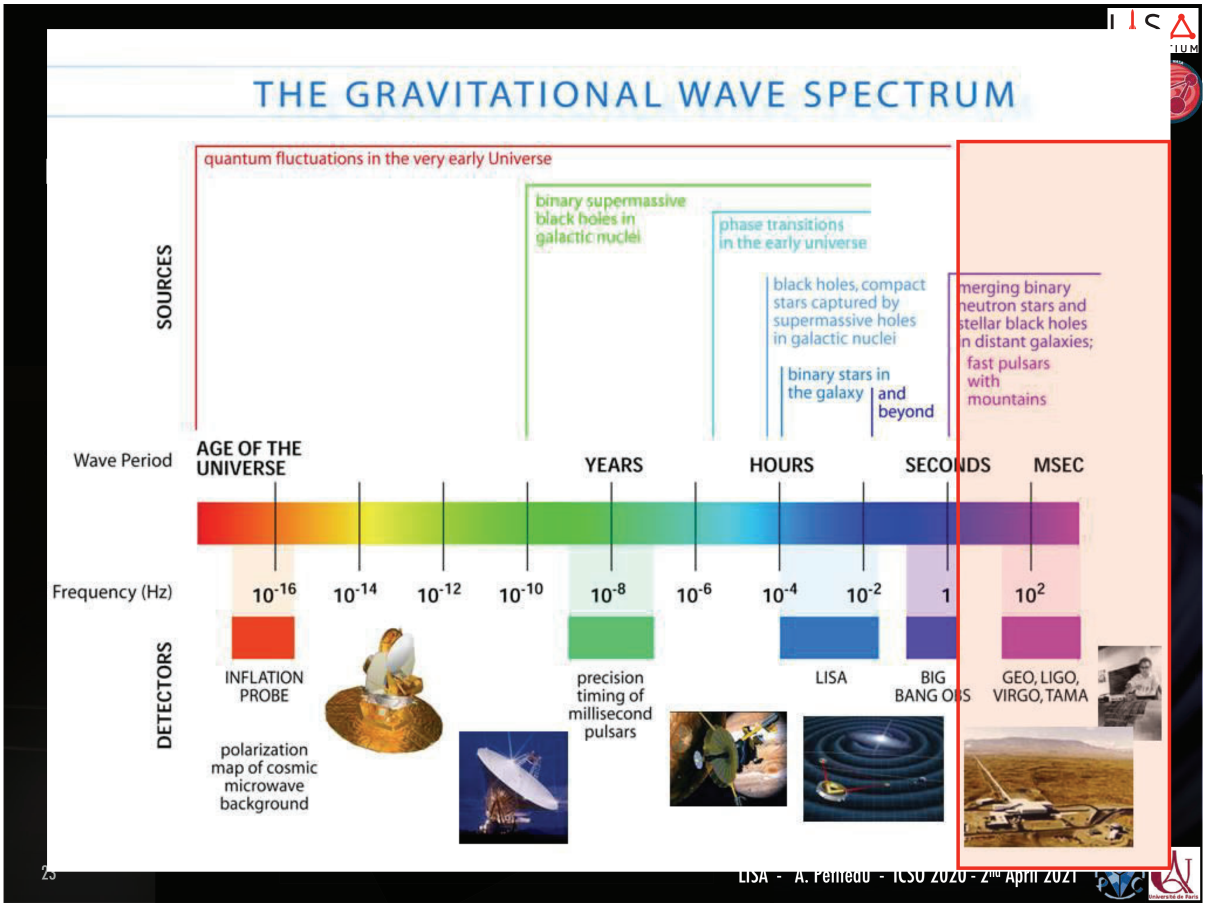
THE GRAVITATIONAL WAVE SPECTRUM
SOURCES
quantum fluctuations in the very early Universe
binary supermassive black holes in galactic nuclei
phase transitions in the early universe
black holes, compact stars captured by supermassive holes in galactic nuclei
binary stars in the galaxy
and beyond
merging binary neutron stars and stellar black holes in distant galaxies;
fast pulsars with mountains
Wave Period
AGE OF THE UNIVERSE
YEARS
HOURS
SECONDS
MSEC
Frequency (Hz)
DETECTORS
INFLATION PROBE
polarization map of cosmic microwave background
precision timing of millisecond pulsars
LISA
BIG BANG OBS
GEO, LIGO, VIRGO, TAMA
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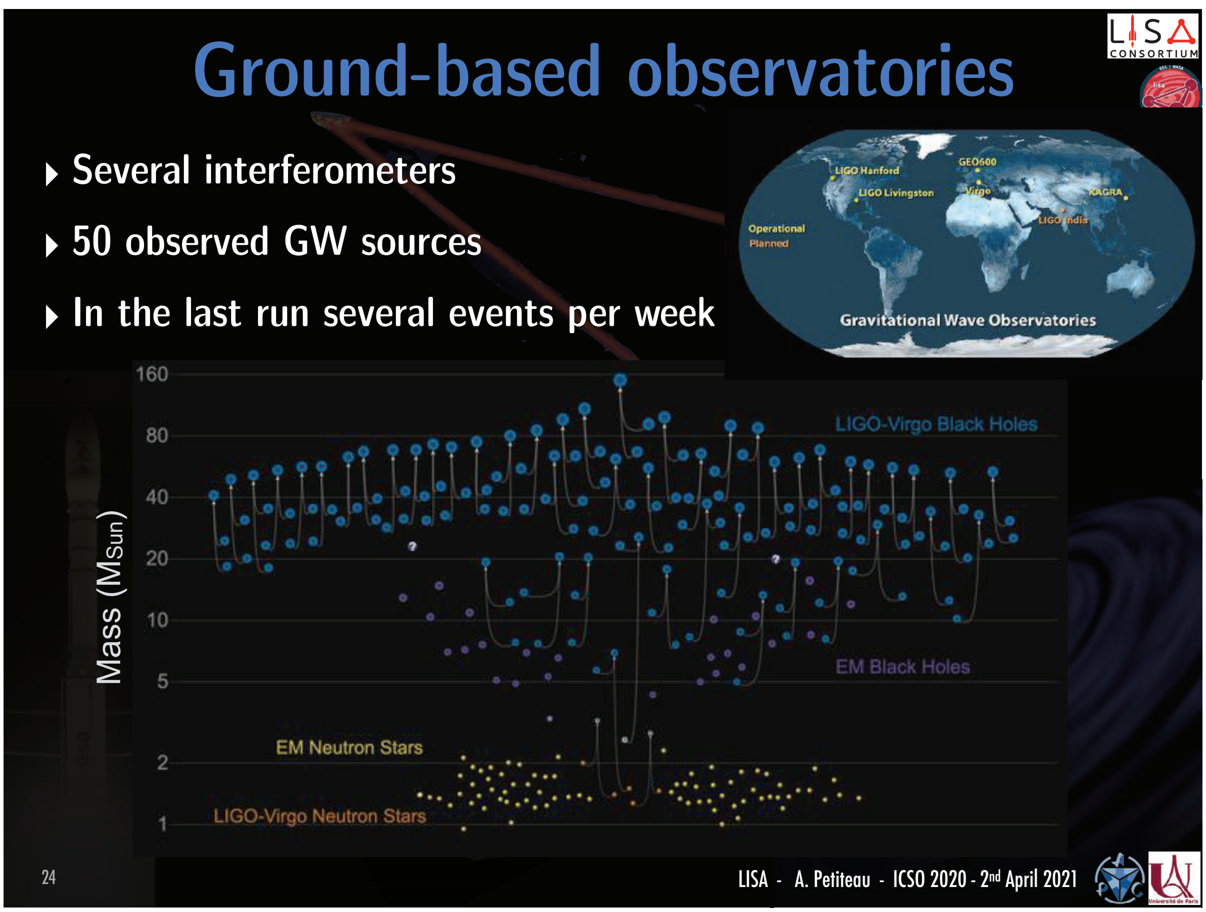
Ground-based observatories
Several interferometers
50 observed GW sources
In the last run several events per week
LIGO Hanford
LIGO Livingston
GEO600
Virgo
KAGRA
LIGO India
Operational
Planned
Gravitational Wave Observatories
Mass (MSun)
LIGO-Virgo Black Holes
EM Black Holes
EM Neutron Stars
LIGO-Virgo Neutron Stars
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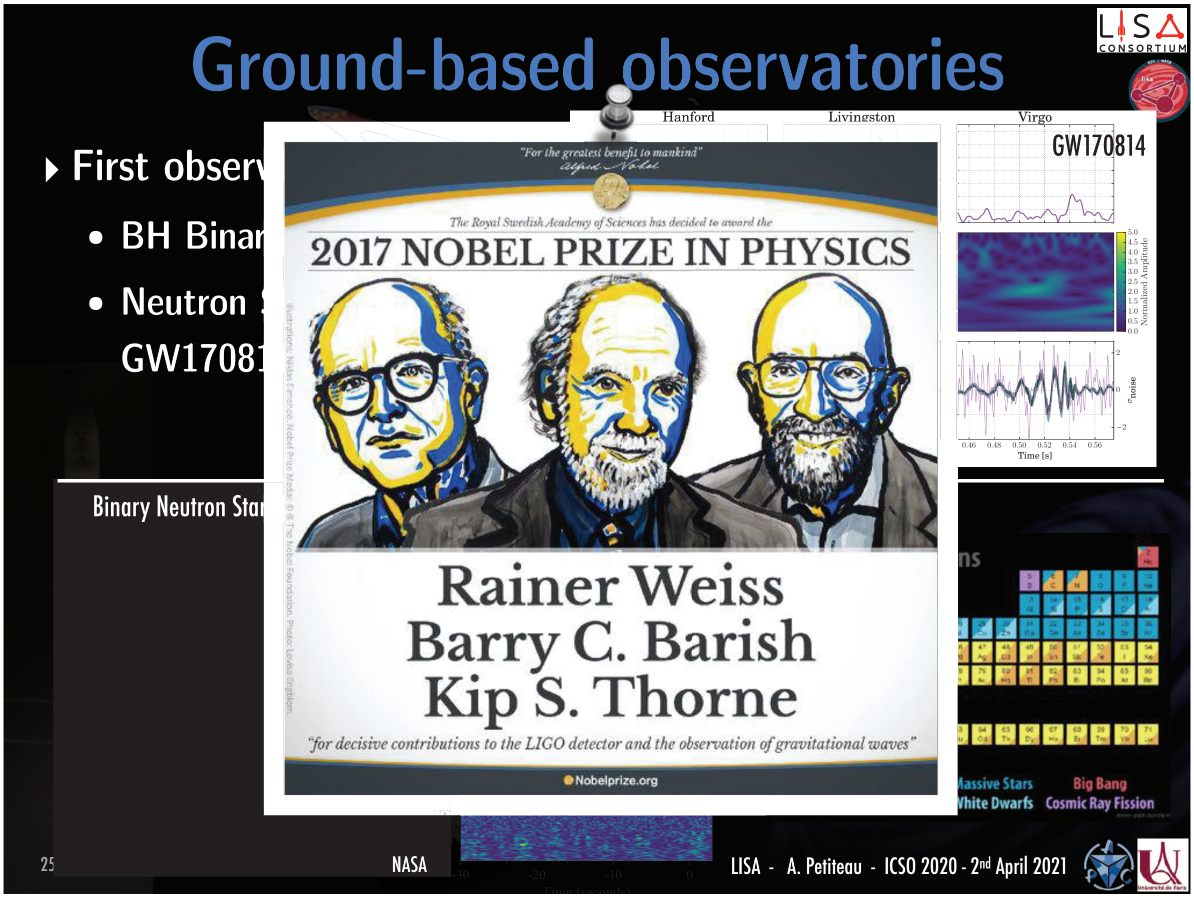
Ground-based observatories
First observ
BH Binar
Neutron S
GW17081
Binary Neutron Star
Hanford
Livingston
Virgo
GW170814
"For the greatest benefit to mankind"
The Royal Swedish Academy of Sciences has decided to award the
2017 NOBEL PRIZE IN PHYSICS
Rainer Weiss
Barry C. Barish
Kip S. Thorne
"for decisive contributions to the LIGO detector and the observation of gravitational waves"
Nobelprize.org
Massive Stars
Big Bang
White Dwarfs
Cosmic Ray Fission
Time [s]
25
NASA
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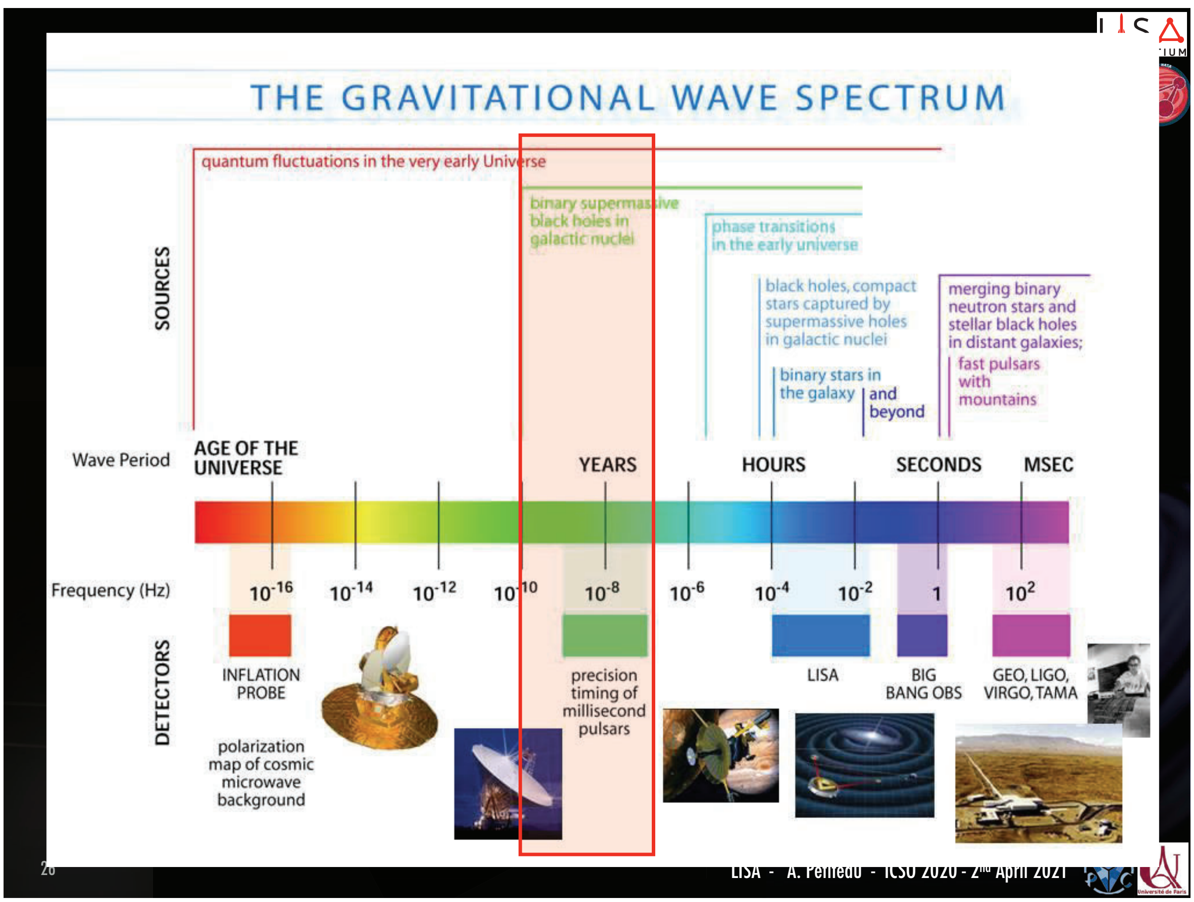
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10^-8
10^-6
10^-4
10^-2
1
10^2
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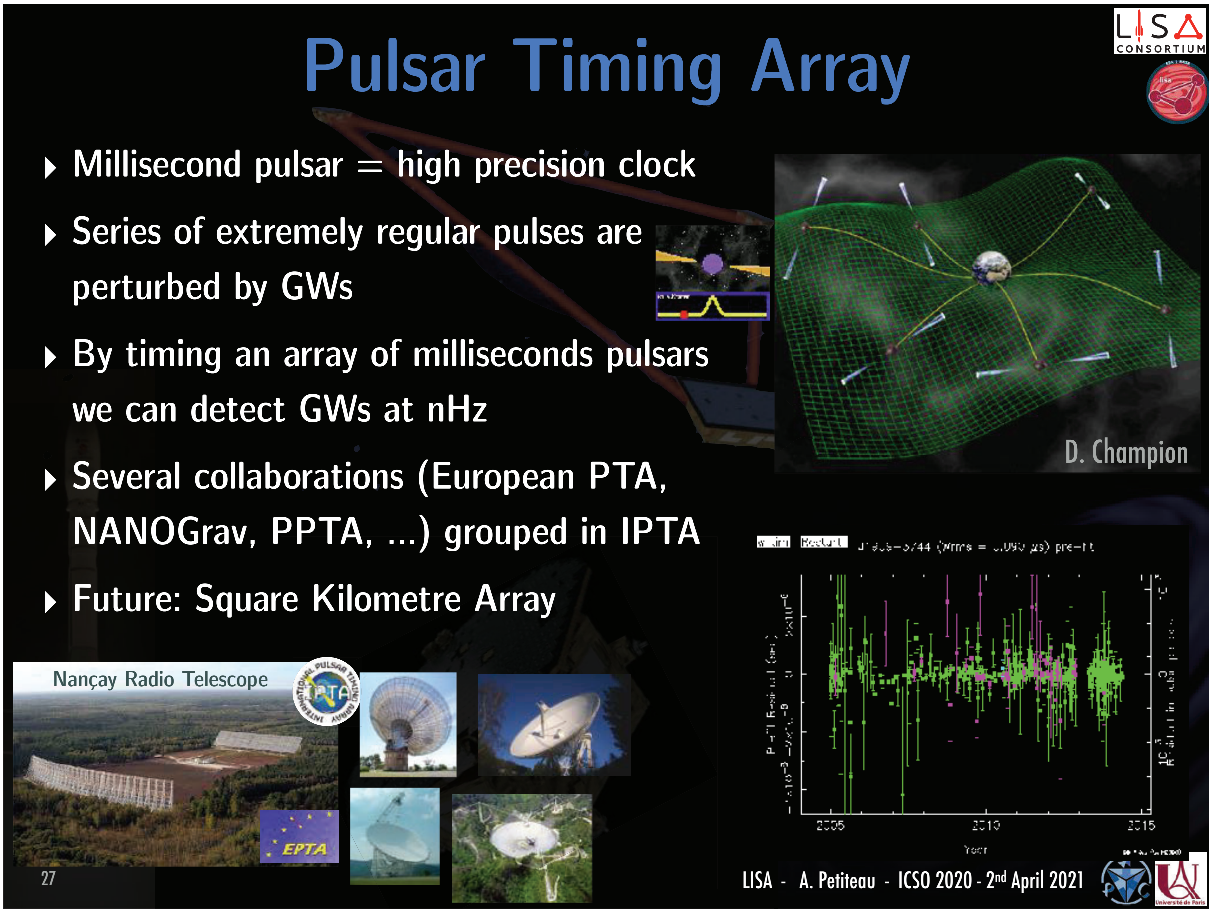
Pulsar Timing Array
Millisecond pulsar = high precision clock
Series of extremely regular pulses are perturbed by GWs
By timing an array of milliseconds pulsars we can detect GWs at nHz
Several collaborations (European PTA, NANOGrav, PPTA, ...) grouped in IPTA
Future: Square Kilometre Array
D. Champion
Nançay Radio Telescope
EPTA
2005
2010
2015
Year
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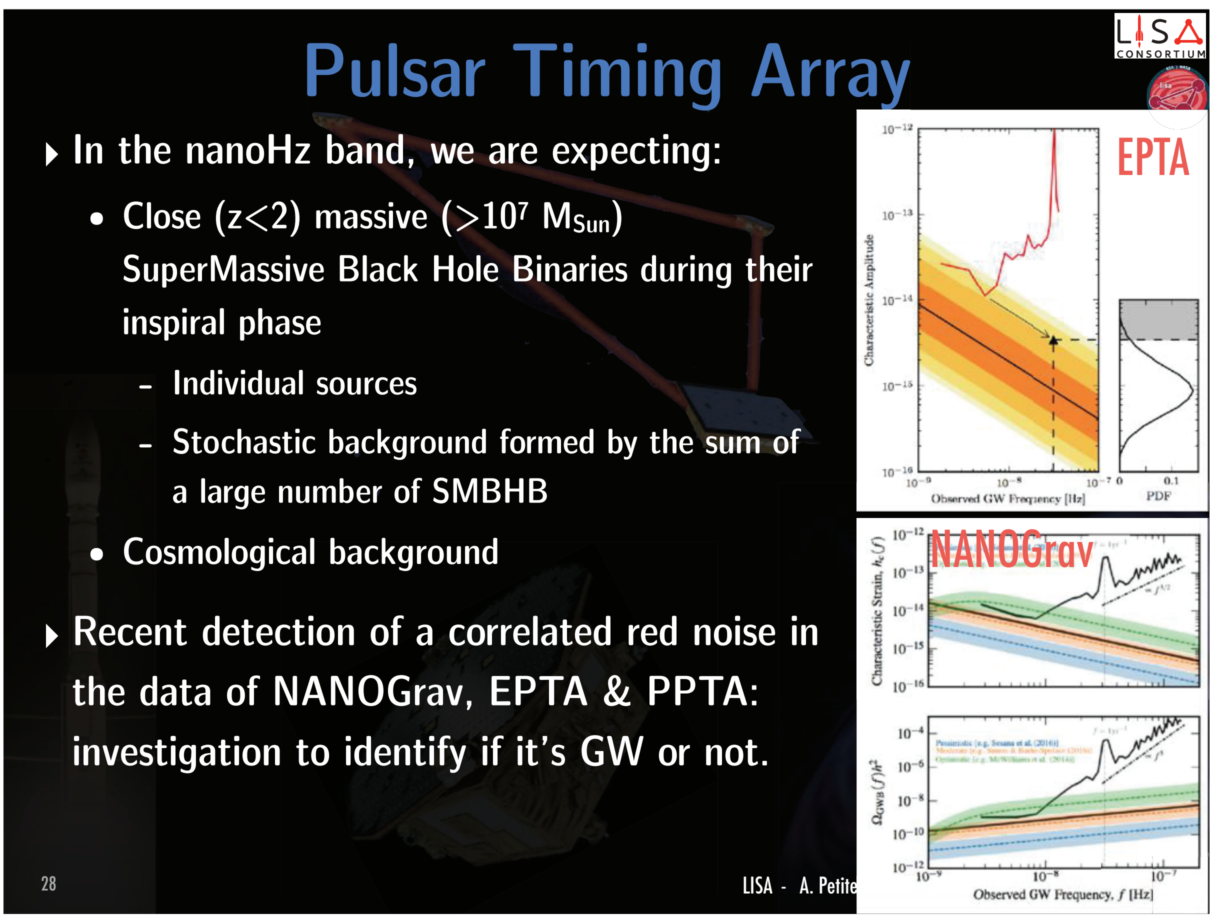
Pulsar Timing Array
In the nanoHz band, we are expecting:
Close (z<2) massive (>10⁷ MSun) SuperMassive Black Hole Binaries during their inspiral phase
Individual sources
Stochastic background formed by the sum of a large number of SMBHB
Cosmological background
Recent detection of a correlated red noise in the data of NANOGrav, EPTA & PPTA: investigation to identify if it's GW or not.
EPTA
Characteristic Amplitude
Observed GW Frequency [Hz]
PDF
NANOGrav
Characteristic Strain, $h_c(f)$
$\Omega_{GWB}(f)h^2$
Observed GW Frequency, f [Hz]
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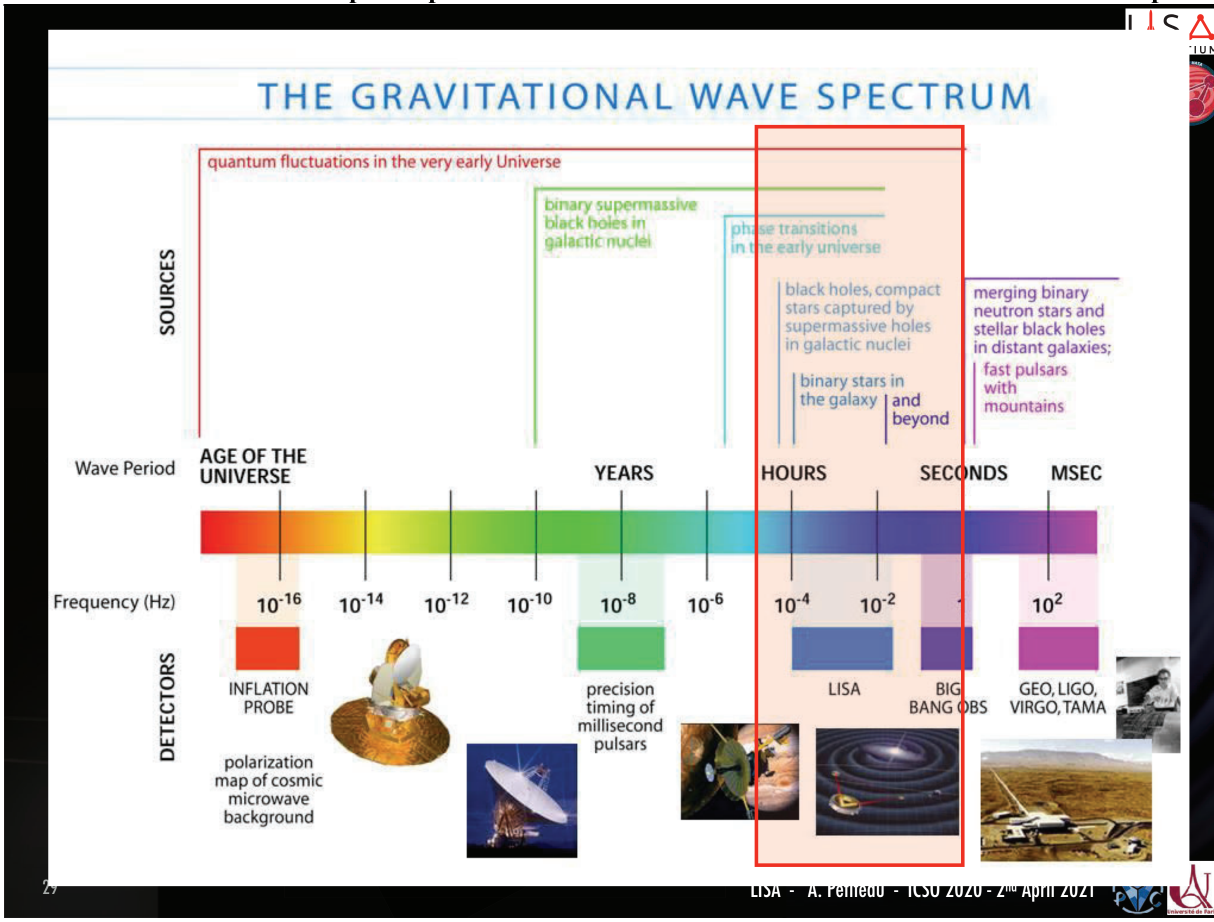
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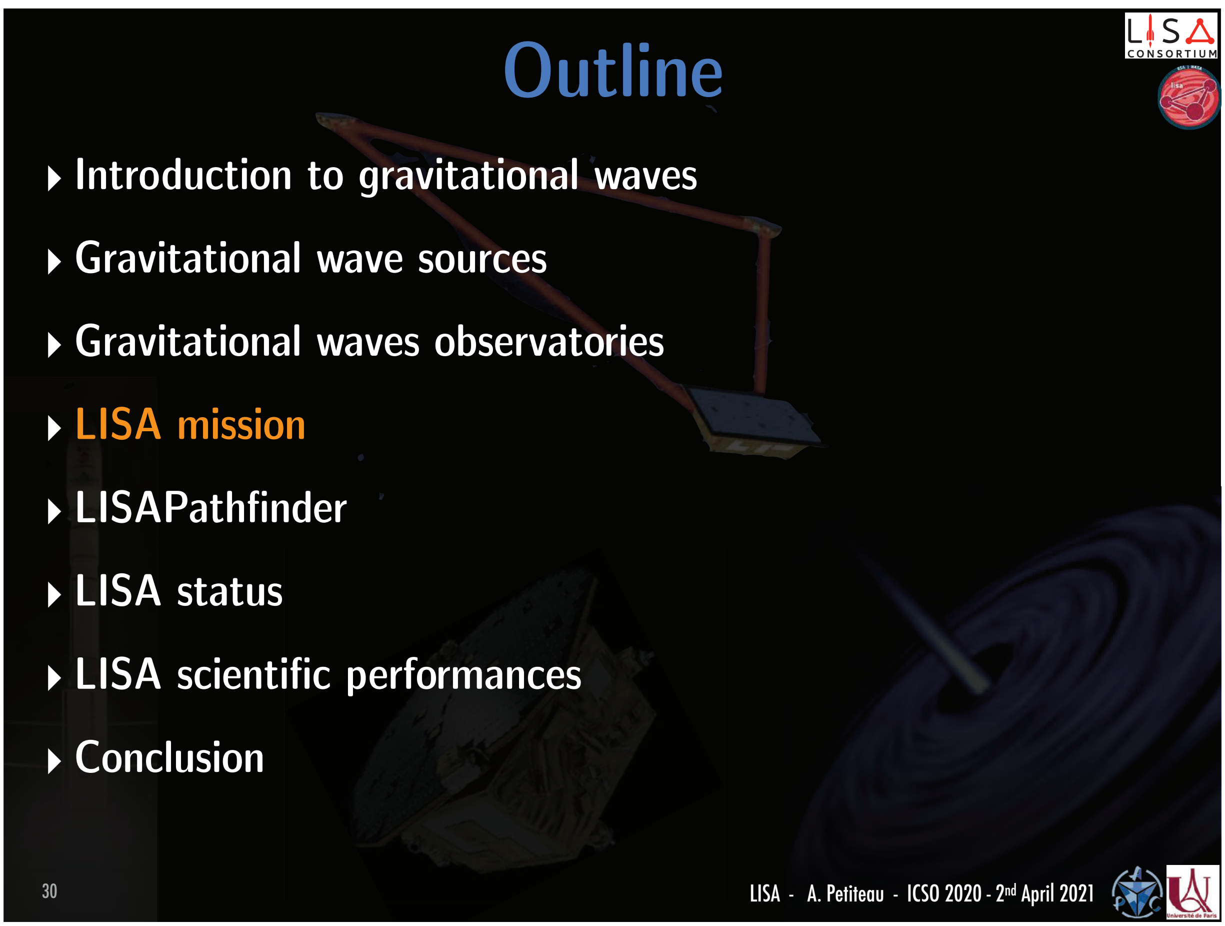
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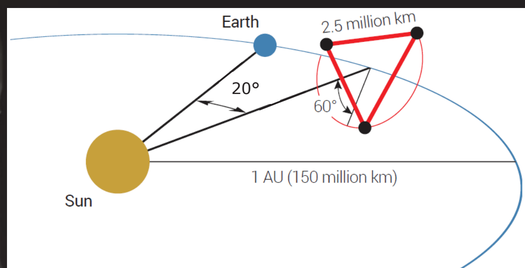
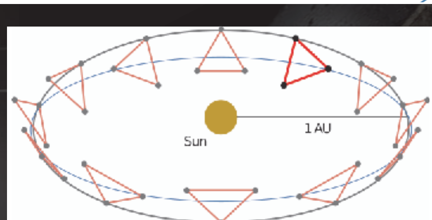
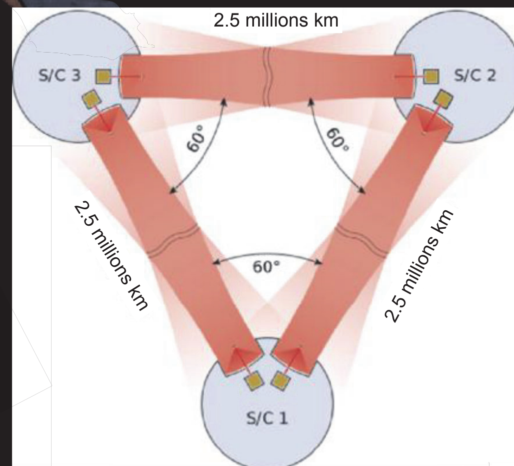
LISA mission

- Laser Interferometer Space Antenna
- 3 spacecrafts on heliocentric orbits and distant from 2.5 millions kilometers
- Goal: detect relative distance changes of 10^{-21}: few picometers







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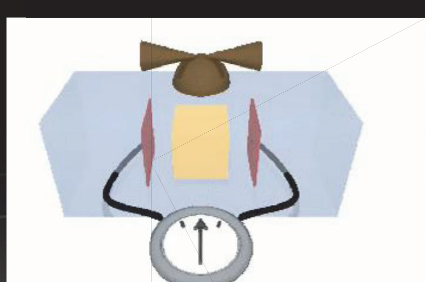
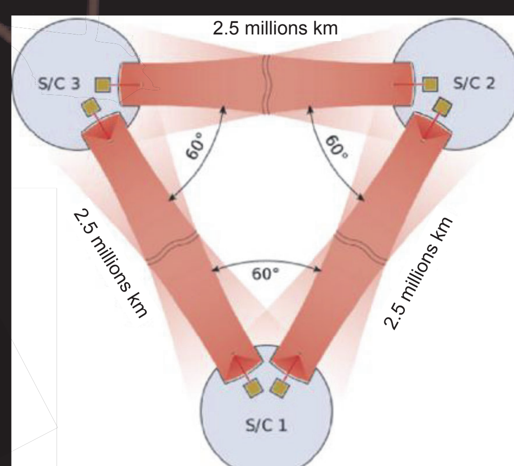
LISA mission

- Spacecraft (SC) should only be sensible to gravity:
  - the spacecraft protects test-masses (TMs) from external forces and always adjusts itself on it using micro-thrusters
  - Readout:
    - interferometric (sensitive axis)
    - capacitive sensing





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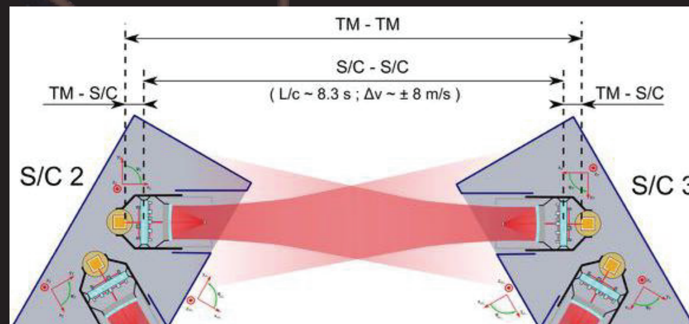
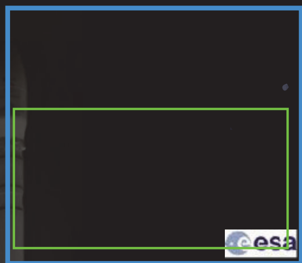
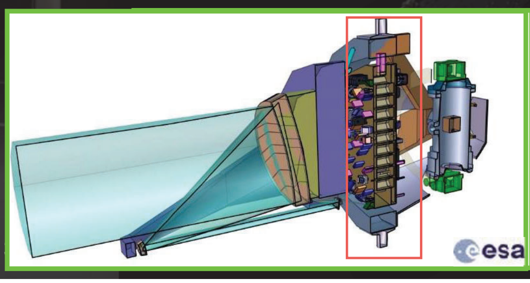
LISA mission

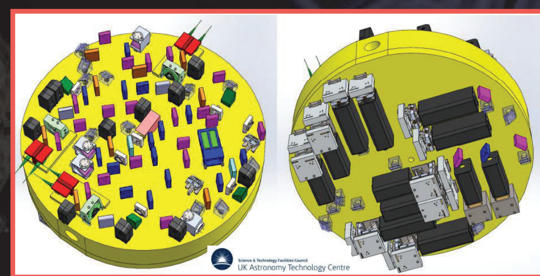
- Several steps for an extremely precise measurements

(TM2→SC2) + (SC2→SC3) + (SC3→TM3)



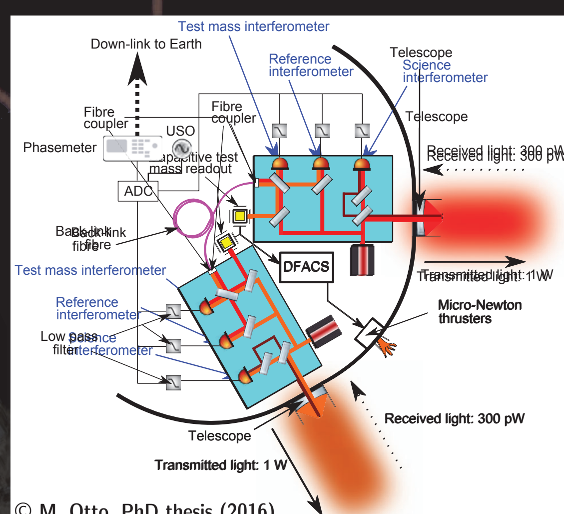






LISA mission

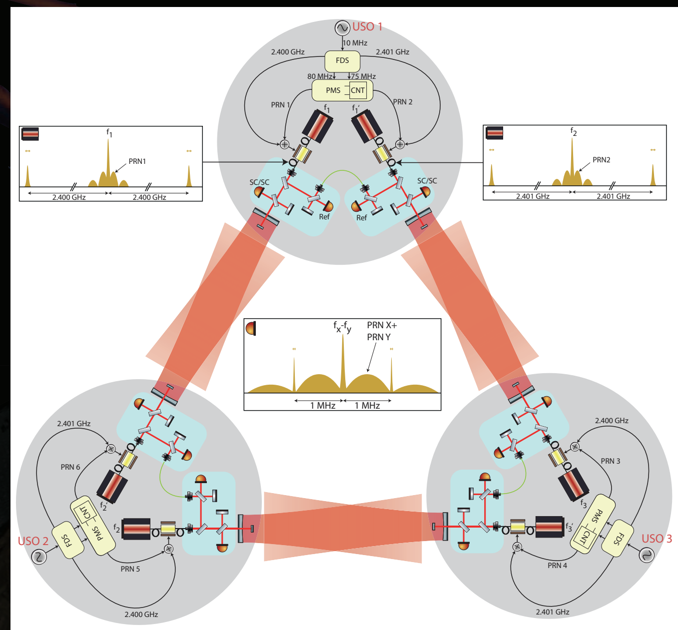
- Exchange of laser beams to form several interferometers
- Phasemeter measurements on each of the 6 Optical Benches:
  - Distant OB vs local OB
  - Test-mass vs OB
  - Reference using adjacent OB
  - Transmission using sidebands
  - Distance between spacecrafts



- Noises sources:
  - Laser noise : 10^{-13} (vs 10^{-21})
  - Clock noise (3 clocks)
  - Acceleration noise (see LPF)
  - Read-out noises
  - Optical path noises

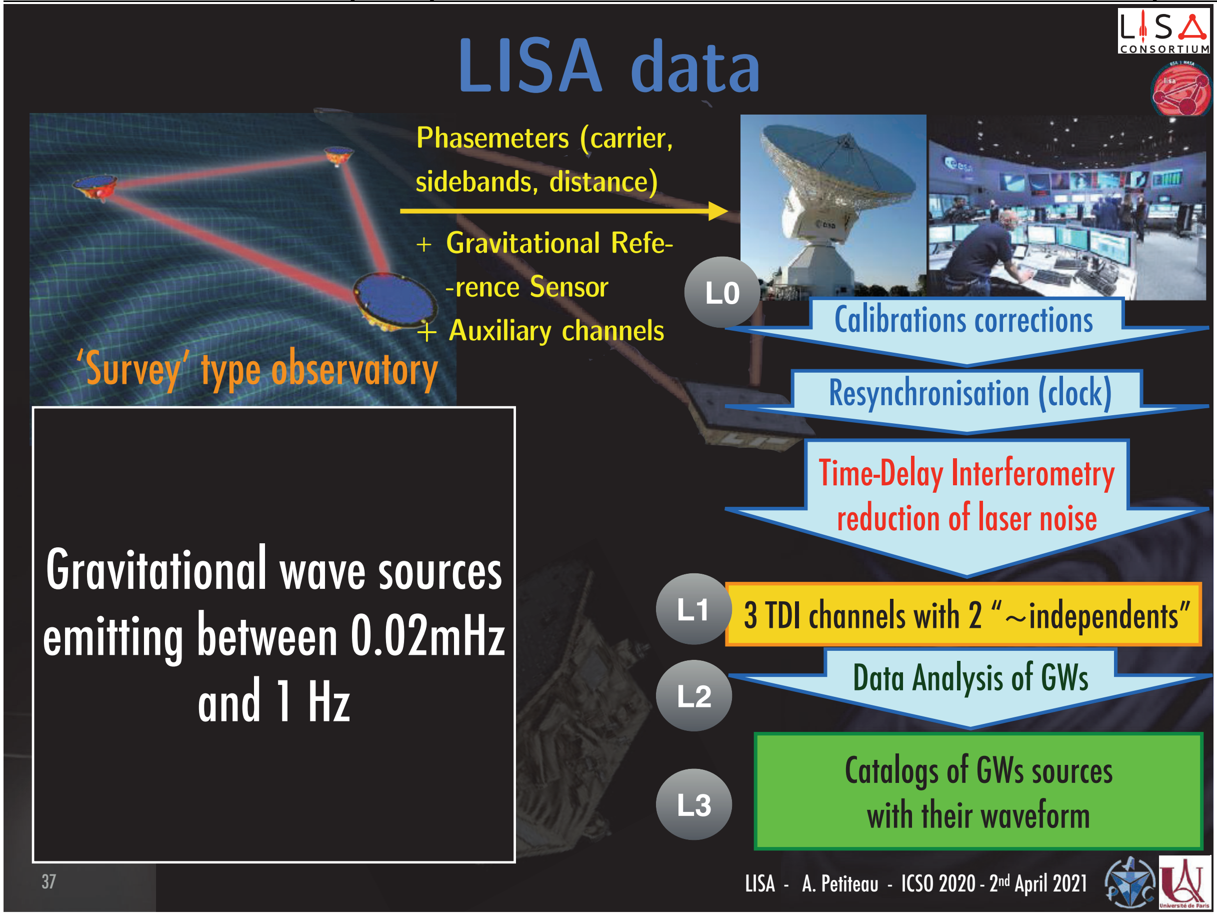
LISA mission

- Measurements via exchange of beams:
  - Heterodyne interferometry with carrier for inter-spacecraft measurement => GWs
  - Sideband for transferring amplified clock jitter => correction of additional clock jitter
  - Pseudo-Random Noise => ranging (measure arm length)



LISA technology requirements

- Free flying test mass subject to very low parasitic forces:
  - Drag free control of spacecraft (non-contacting) with low noise microthruster
  - Large gaps, heavy masses with caging mechanism
  - High stability electrical actuation on cross degrees of freedom
  - Non contacting discharging of test-masses
  - High thermo-mechanical stability of spacecraft
  - Gravitational field cancellation
- Precision interferometric, local ranging of test-mass and spacecraft:
  - pm resolution ranging, sub-mrad alignments
  - High stability monolithic optical assemblies
- Precision million km spacecraft to spacecraft precision ranging:
  - High accuracy laser frequency stabilization + noise suppression with TDI
  - "Tilt to length" coupling (control of alignement + ground correction)
  - Low level of stray-light
  - High stability telescopes
  - High accuracy phase-meter and frequency distribution
  - Constellation acquisition
  - Precision attitude control of spacecraft


LISA data
Phasemeters (carrier, sidebands, distance)
+ Gravitational Refe- -rence Sensor
+ Auxiliary channels
'Survey' type observatory
L0
Calibrations corrections
Resynchronisation (clock)
Time-Delay Interferometry reduction of laser noise
L1
3 TDI channels with 2 "~independents"
L2
Data Analysis of GWs
L3
Catalogs of GWs sources with their waveform
Gravitational wave sources emitting between 0.02mHz and 1 Hz
37
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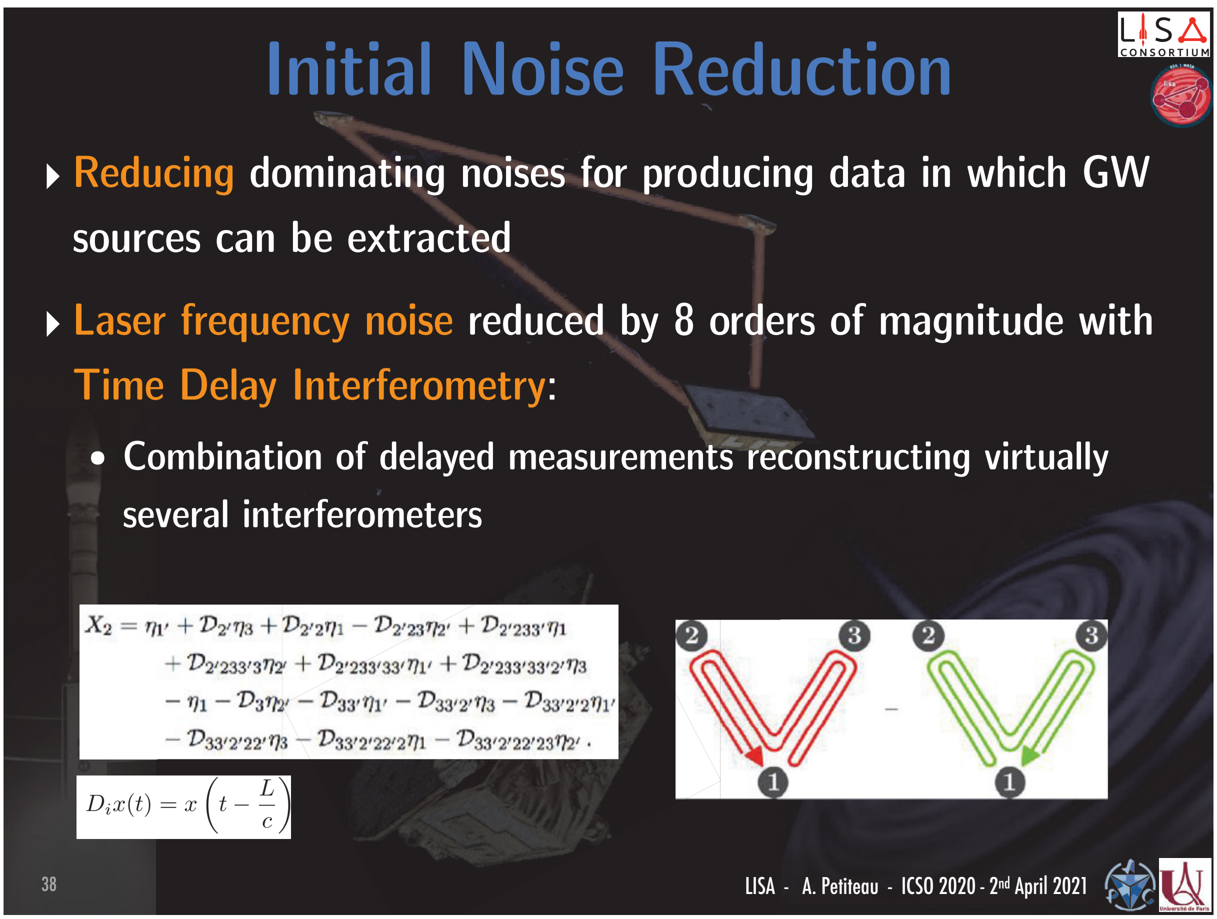
Initial Noise Reduction
Reducing dominating noises for producing data in which GW sources can be extracted
Laser frequency noise reduced by 8 orders of magnitude with Time Delay Interferometry:
• Combination of delayed measurements reconstructing virtually several interferometers
$X_2 = \eta_{1'} + \mathcal{D}_{2'}\eta_3 + \mathcal{D}_{2'2}\eta_1 - \mathcal{D}_{2'23}\eta_{2'} + \mathcal{D}_{2'233'}\eta_1 + \mathcal{D}_{2'233'3}\eta_{2'} + \mathcal{D}_{2'233'33'}\eta_{1'} + \mathcal{D}_{2'233'33'2'}\eta_3 - \eta_1 - \mathcal{D}_3\eta_{2'} - \mathcal{D}_{33'}\eta_{1'} - \mathcal{D}_{33'2'}\eta_3 - \mathcal{D}_{33'2'2}\eta_{1'} - \mathcal{D}_{33'2'22'}\eta_3 - \mathcal{D}_{33'2'22'2}\eta_1 - \mathcal{D}_{33'2'22'23}\eta_{2'}\,.$
$D_i x(t) = x\left(t - \frac{L}{c}\right)$
2 3 2 3
1 1
38
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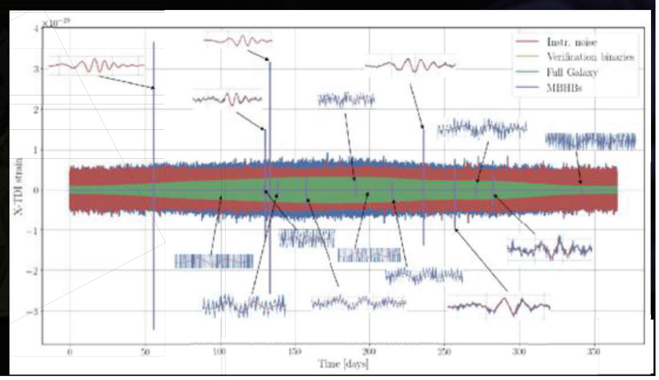
GW data analysis

- Large number of overlapping sources
  => challenging for data analysis
- Exploration of multiple technics
- First data of this kind + fluctuations of computational charge
  (fluctuations of event rates, new calibrations, ...)
  => flexible Distributed Data Processing Center
- Prototyping already started:
  LISA Data Challenge,
  detailed simulations
  (instrument & GW sources)



39

Outline

- Introduction to gravitational waves
- Gravitational wave sources
- Gravitational waves observatories
- LISA mission
- LISAPathfinder
- LISA status
- LISA scientific performances
- Conclusion

40

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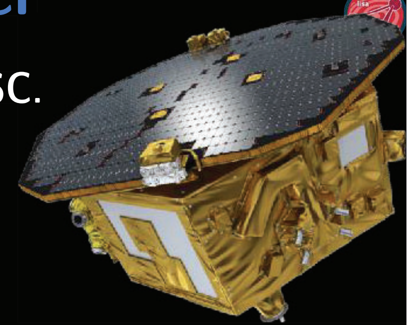
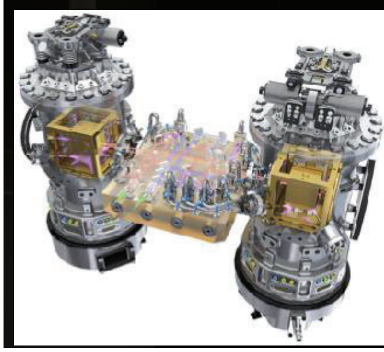
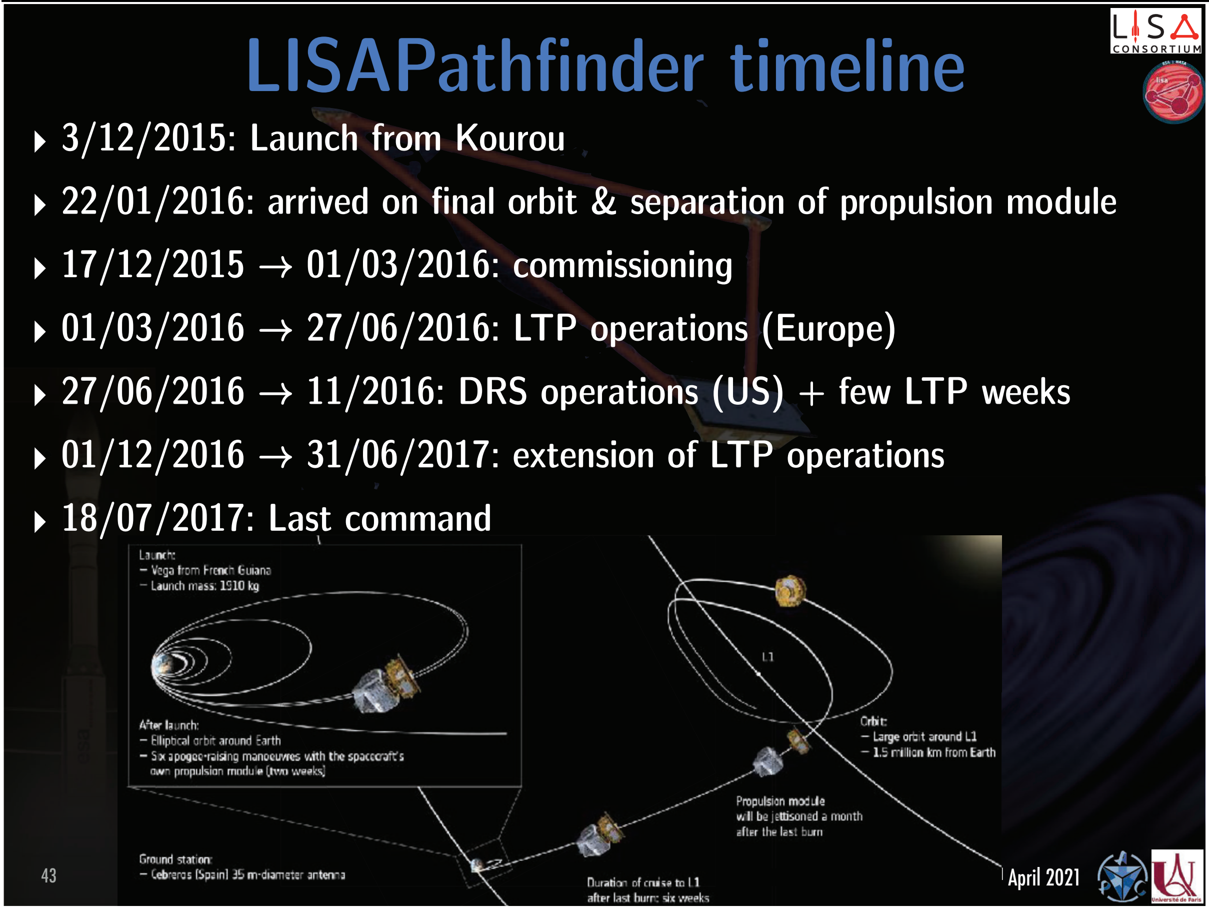
LISAPathfinder

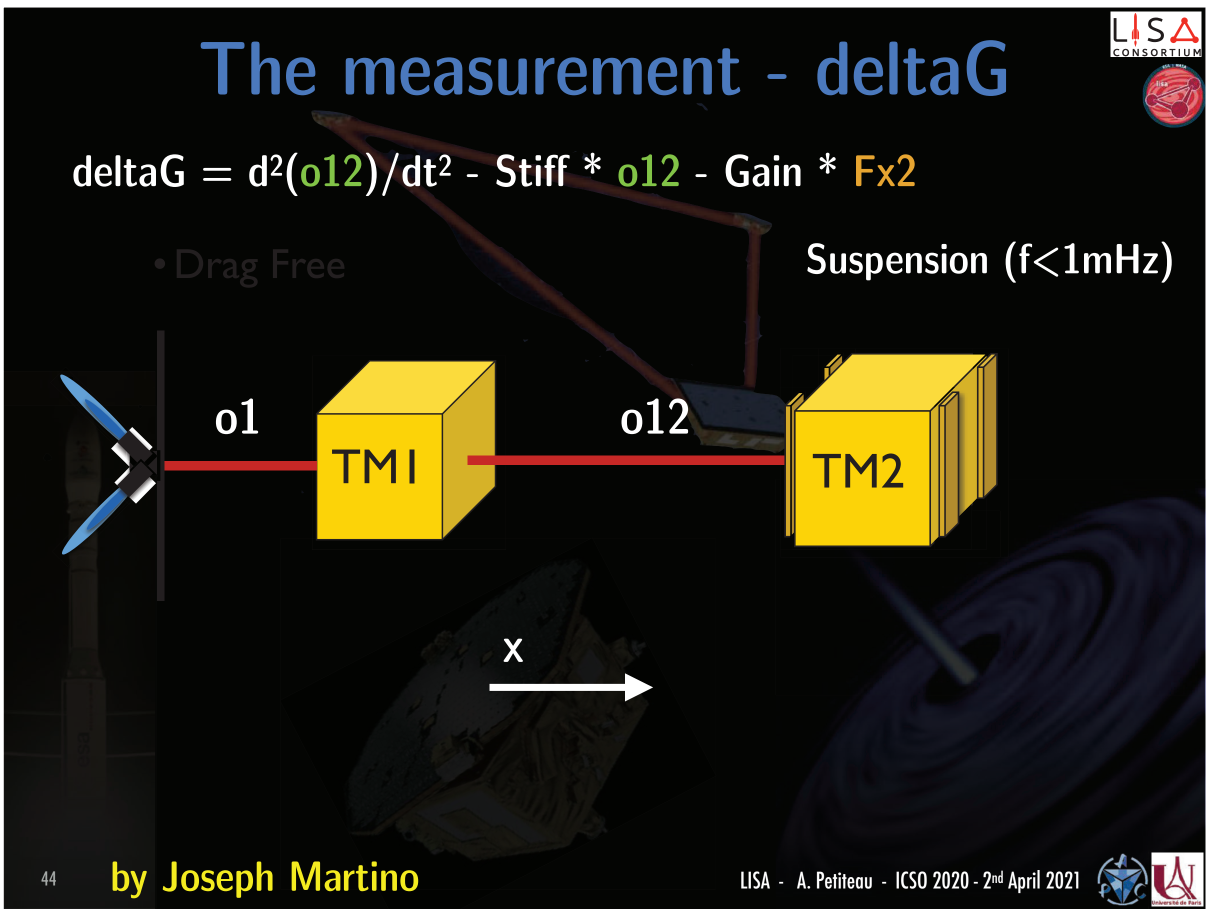


- Basic idea: Reduce one LISA arm in one SC.
- LISAPathfinder is testing:
  - Inertial sensor,
  - Drag-free and attitude control system
  - Interferometric measurement between 2 free-falling test-masses,
  - Micro-thrusters



LISAPathfinder timeline


LISAPathfinder timeline
3/12/2015: Launch from Kourou
22/01/2016: arrived on final orbit & separation of propulsion module
17/12/2015 → 01/03/2016: commissioning
01/03/2016 → 27/06/2016: LTP operations (Europe)
27/06/2016 → 11/2016: DRS operations (US) + few LTP weeks
01/12/2016 → 31/06/2017: extension of LTP operations
18/07/2017: Last command
Launch:
– Vega from French Guiana
– Launch mass: 1910 kg
After launch:
– Elliptical orbit around Earth
– Six apogee-raising manoeuvres with the spacecraft's own propulsion module (two weeks)
Ground station:
– Cebreros (Spain) 35 m-diameter antenna
L1
Orbit:
– Large orbit around L1
– 1.5 million km from Earth
Propulsion module will be jettisoned a month after the last burn
Duration of cruise to L1 after last burn: six weeks
43
April 2021


The measurement - deltaG
deltaG = d²(o12)/dt² - Stiff * o12 - Gain * Fx2
• Drag Free
Suspension (f<1mHz)
o1
TM1
o12
TM2
x
44
by Joseph Martino
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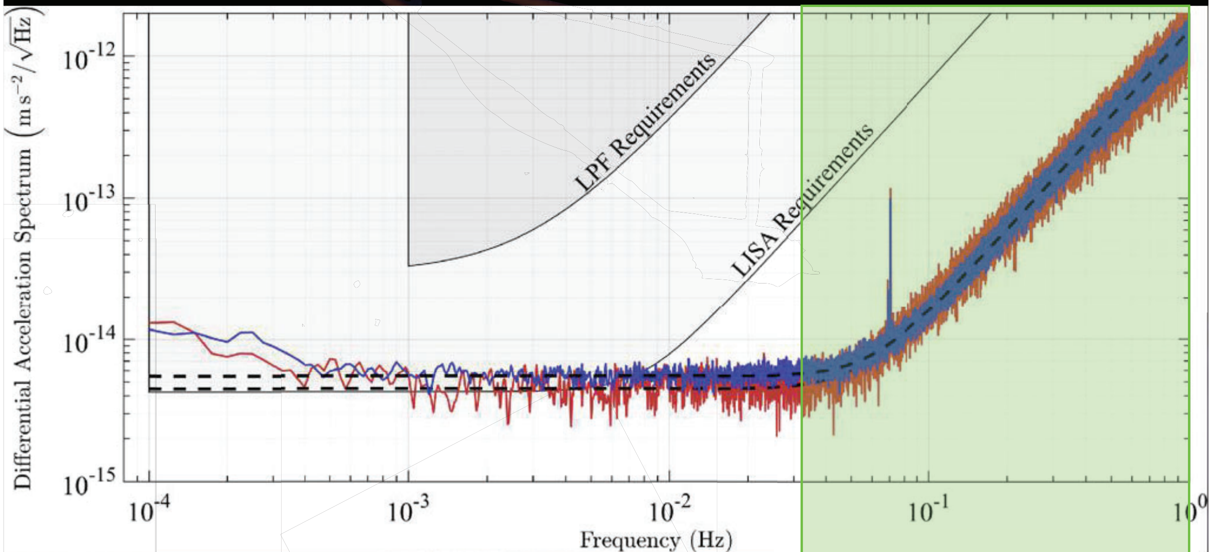
First results

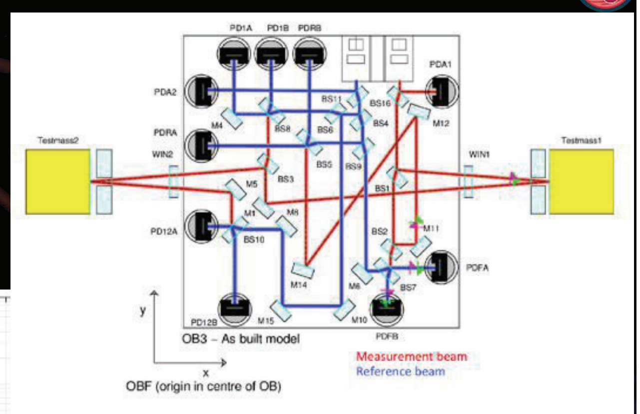
M. Armano et al. PRL 116, 231101 (2016)

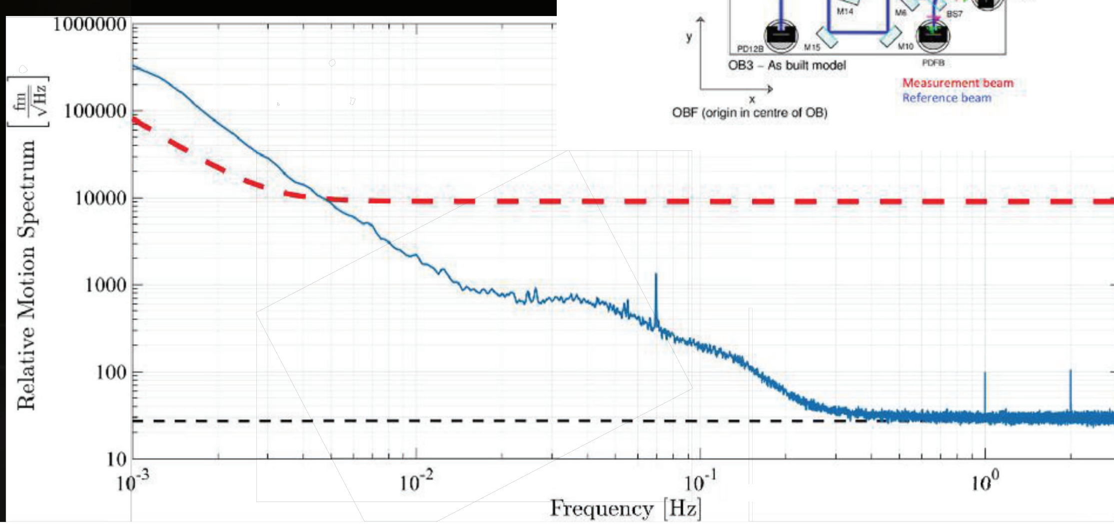


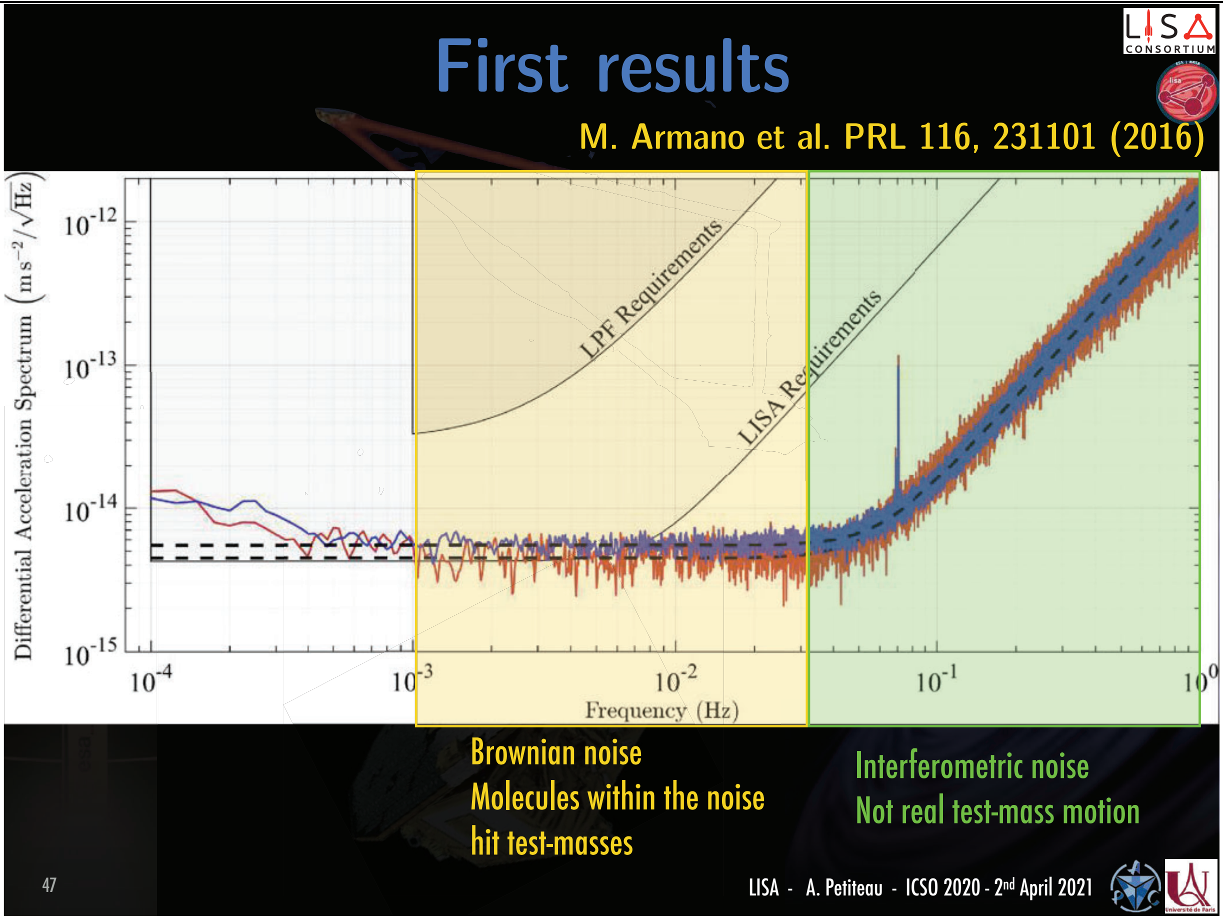
Interferometric noise
Not real test-mass motion

High frequency limit

- Optical measurement system:
  - Interferometric precision: 30 fm.Hz$^{-1/2}$
  - Orientation of test-masses






First results
M. Armano et al. PRL 116, 231101 (2016)
LPF Requirements
LISA Requirements
Differential Acceleration Spectrum (m s^{-2}/$\sqrt{Hz}$)
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Frequency (Hz)
Brownian noise
Molecules within the noise hit test-masses
Interferometric noise
Not real test-mass motion
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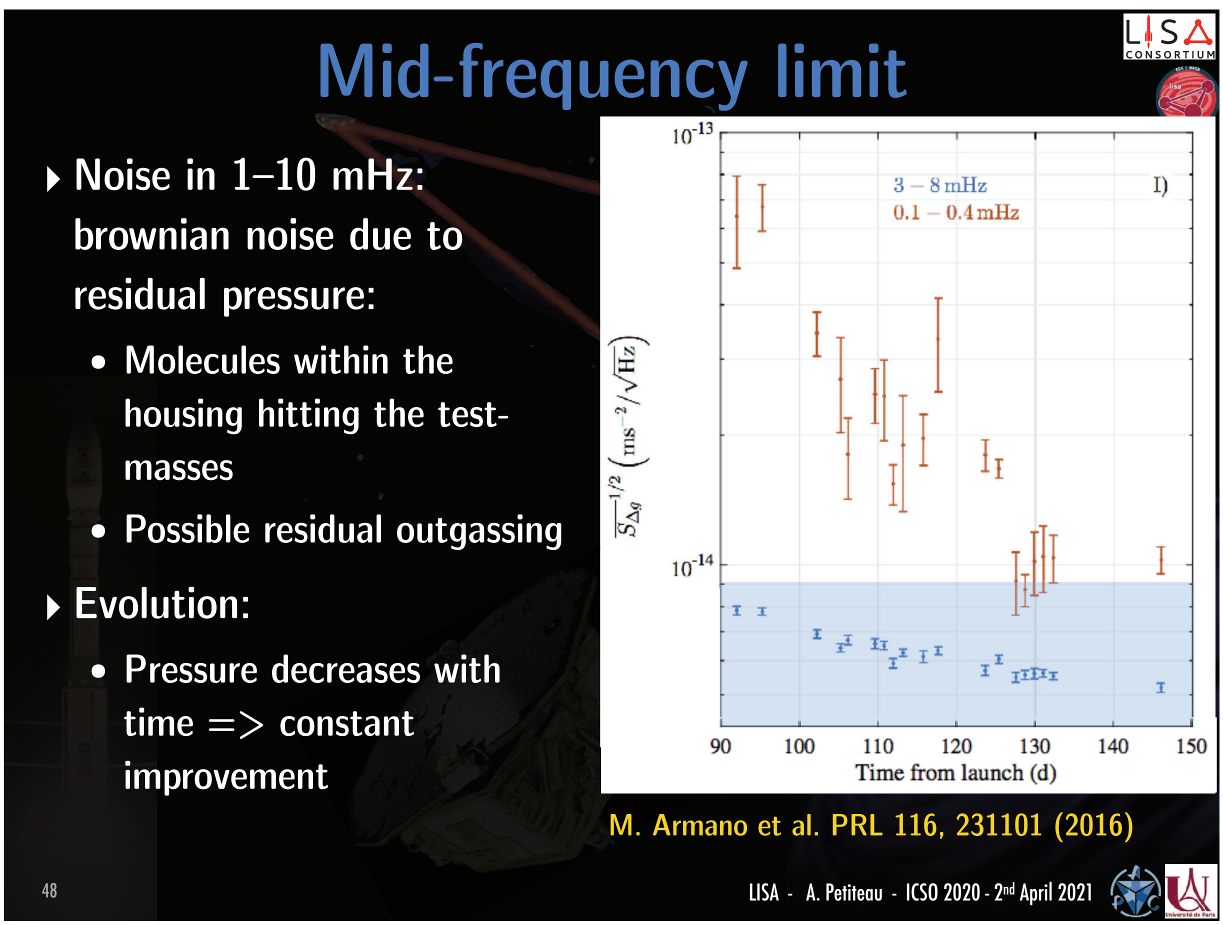
Mid-frequency limit
Noise in 1–10 mHz: brownian noise due to residual pressure:
Molecules within the housing hitting the test-masses
Possible residual outgassing
Evolution:
Pressure decreases with time => constant improvement
10^{-13}
10^{-14}
3 – 8 mHz
0.1 – 0.4 mHz
I)
$\overline{S_{\Delta g}}^{1/2}$ (ms^{-2}/$\sqrt{Hz}$)
90
100
110
120
130
140
150
Time from launch (d)
M. Armano et al. PRL 116, 231101 (2016)
48
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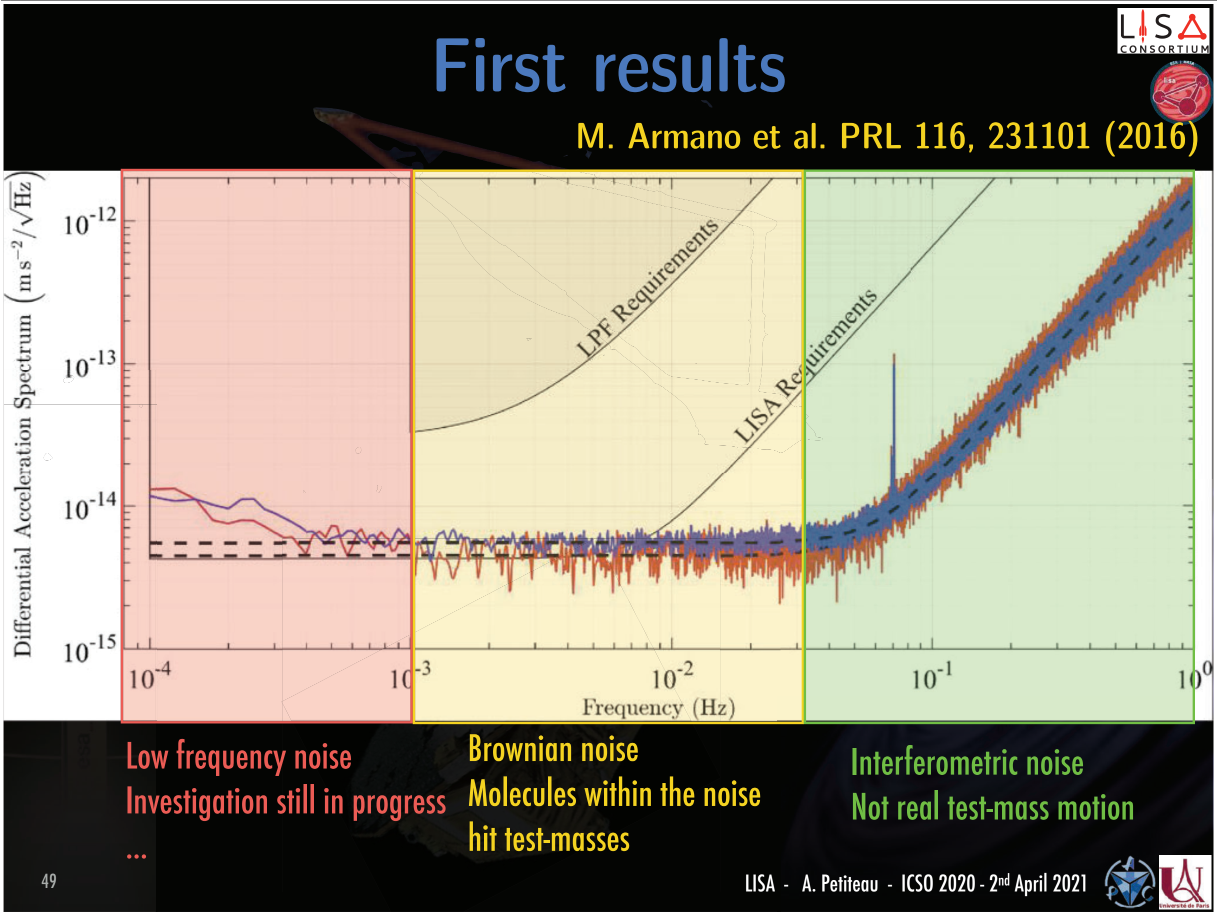
First results
M. Armano et al. PRL 116, 231101 (2016)
Differential Acceleration Spectrum $(m\,s^{-2}/\sqrt{Hz})$
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
Frequency (Hz)
LPF Requirements
LISA Requirements
Low frequency noise
Investigation still in progress
...
Brownian noise
Molecules within the noise
hit test-masses
Interferometric noise
Not real test-mass motion
49
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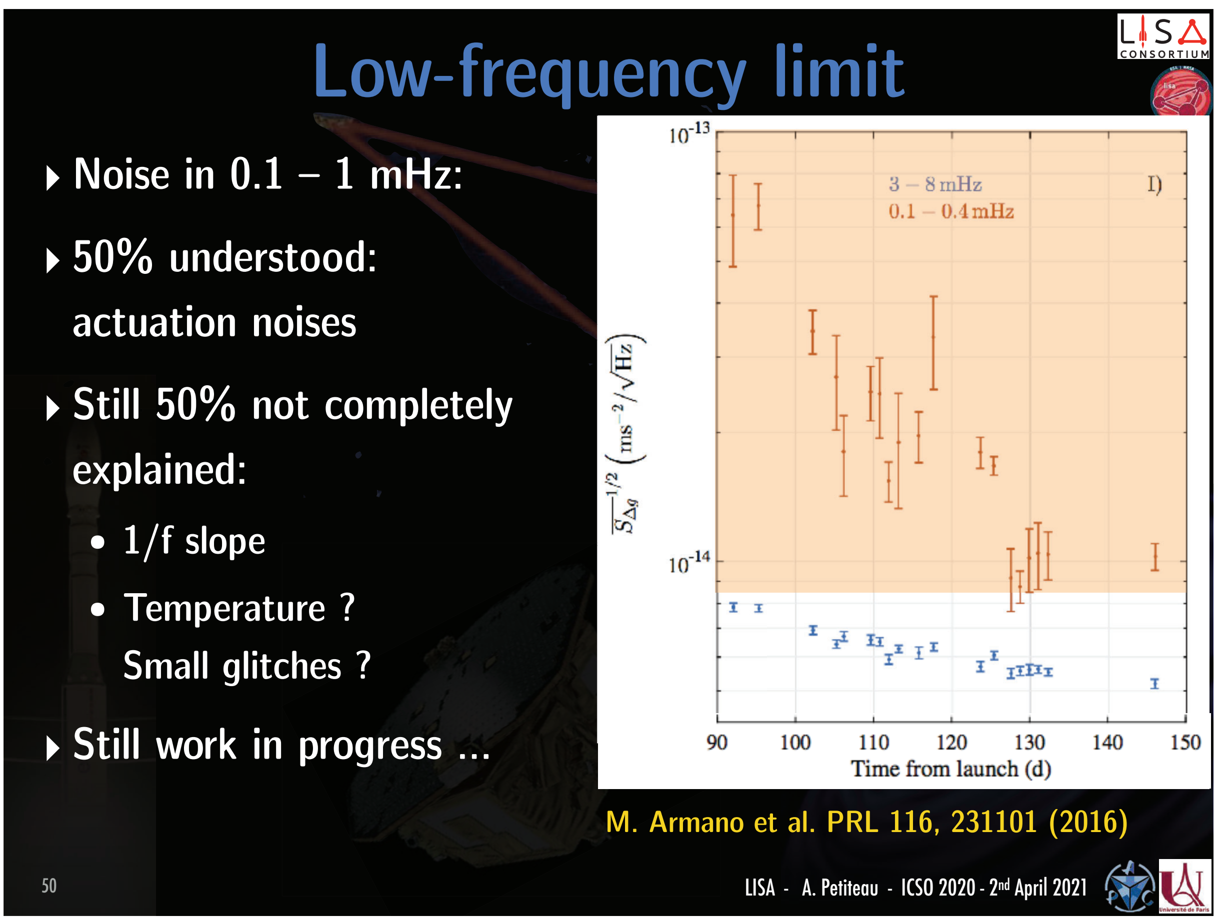
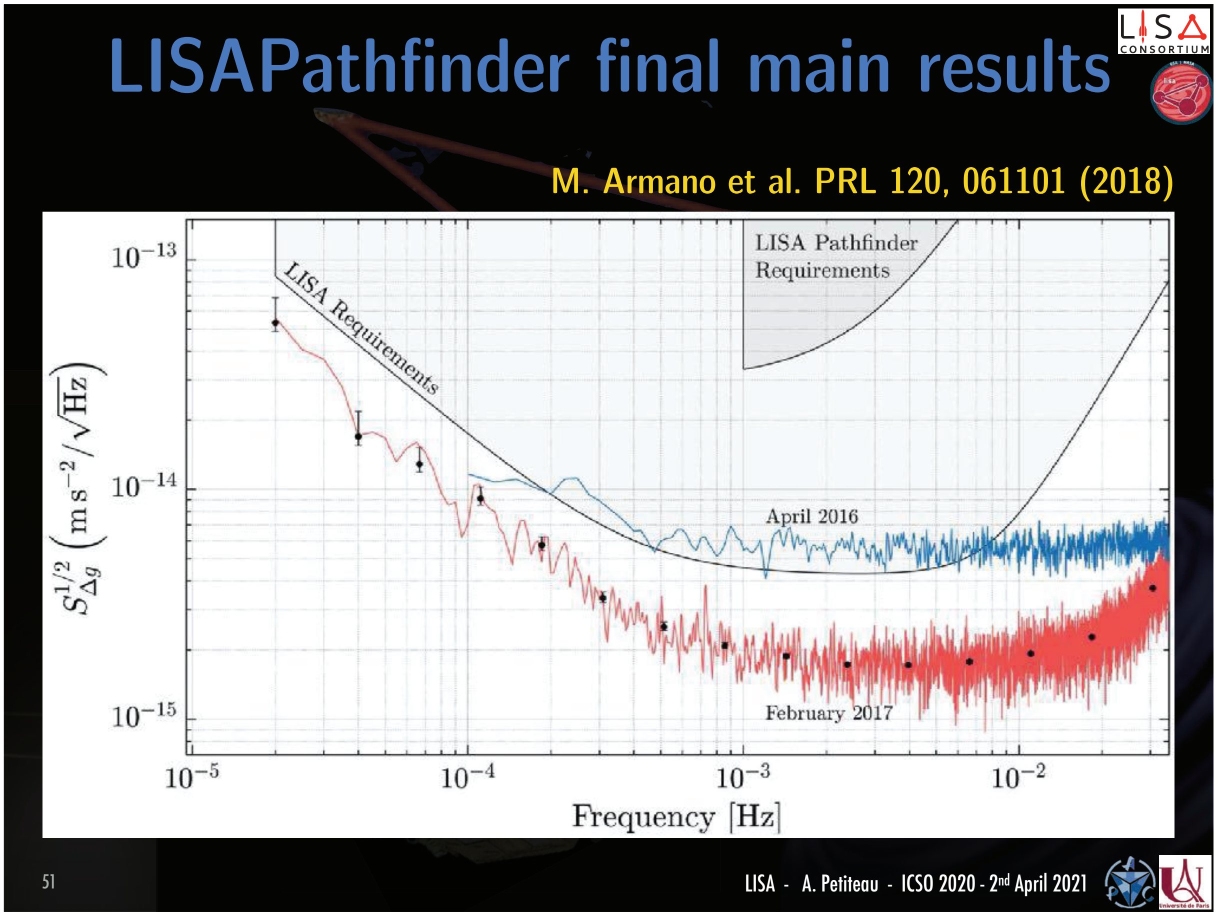

Low-frequency limit
Noise in 0.1 – 1 mHz:
50% understood:
actuation noises
Still 50% not completely
explained:
1/f slope
Temperature ?
Small glitches ?
Still work in progress ...
10^{-13}
10^{-14}
3 – 8 mHz
0.1 – 0.4 mHz
I)
$\overline{S_{\Delta g}}^{1/2}$ $(m s^{-2}/\sqrt{Hz})$
90
100
110
120
130
140
150
Time from launch (d)
M. Armano et al. PRL 116, 231101 (2016)
50
LISA - A. Petiteau - ICSO 2020 - 2nd April 2021


LISAPathfinder final main results
M. Armano et al. PRL 120, 061101 (2018)
LISA Pathfinder Requirements
LISA Requirements
April 2016
February 2017
$S_{\Delta g}^{1/2}\ (\mathrm{m\,s^{-2}}/\sqrt{\mathrm{Hz}})$
10^{-13}
10^{-14}
10^{-15}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
Frequency [Hz]
51
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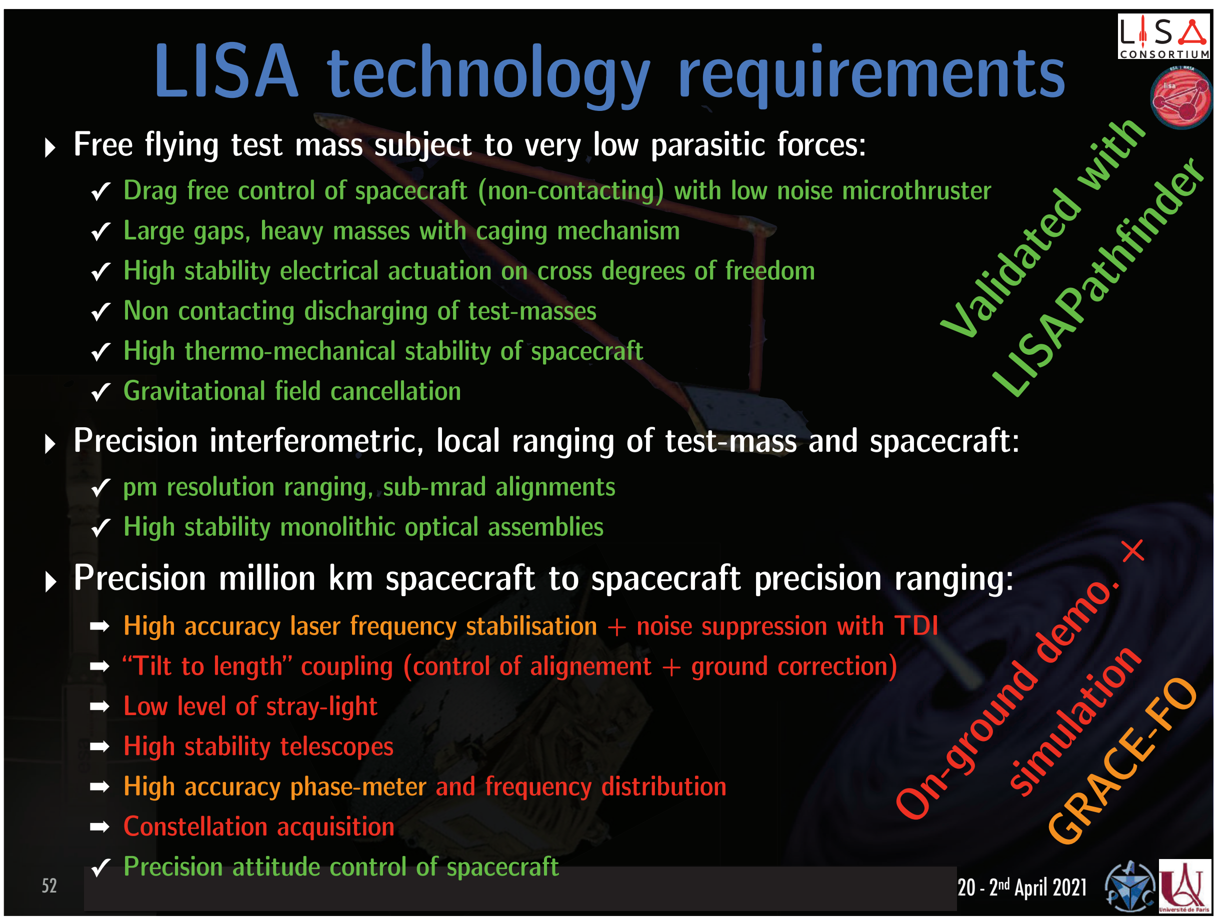
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➡ Low level of stray-light
➡ High stability telescopes
➡ High accuracy phase-meter and frequency distribution
➡ Constellation acquisition
✓ Precision attitude control of spacecraft
On-ground demo. ×
simulation
GRACE-FO
52
20 - 2nd April 2021

Outline

- Introduction to gravitational waves
- Gravitational wave sources
- Gravitational waves observatories
- LISA mission
- LISAPathfinder
- LISA status
- LISA scientific performances
- Conclusion

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History of LISA

- 1978: first study based on a rigid structure (NASA)
- 1980s: studies with 3 free-falling spacecrafts (US)
- 1993: proposal ESA/NASA: 4 spacecrafts
- 1996-2000: pre-phase A report
- 2000-2010: LISA and LISAPathfinder: ESA/NASA mission
- 2011: NASA stops => ESA continue: reduce mission
- 2012: selection of JUICE L1 ESA
- 2013: selection of ESA L3 : « The gravitational Universe »
- 2015-2016: success of LISAPathfinder + detection GWs

Call for mission at ESA

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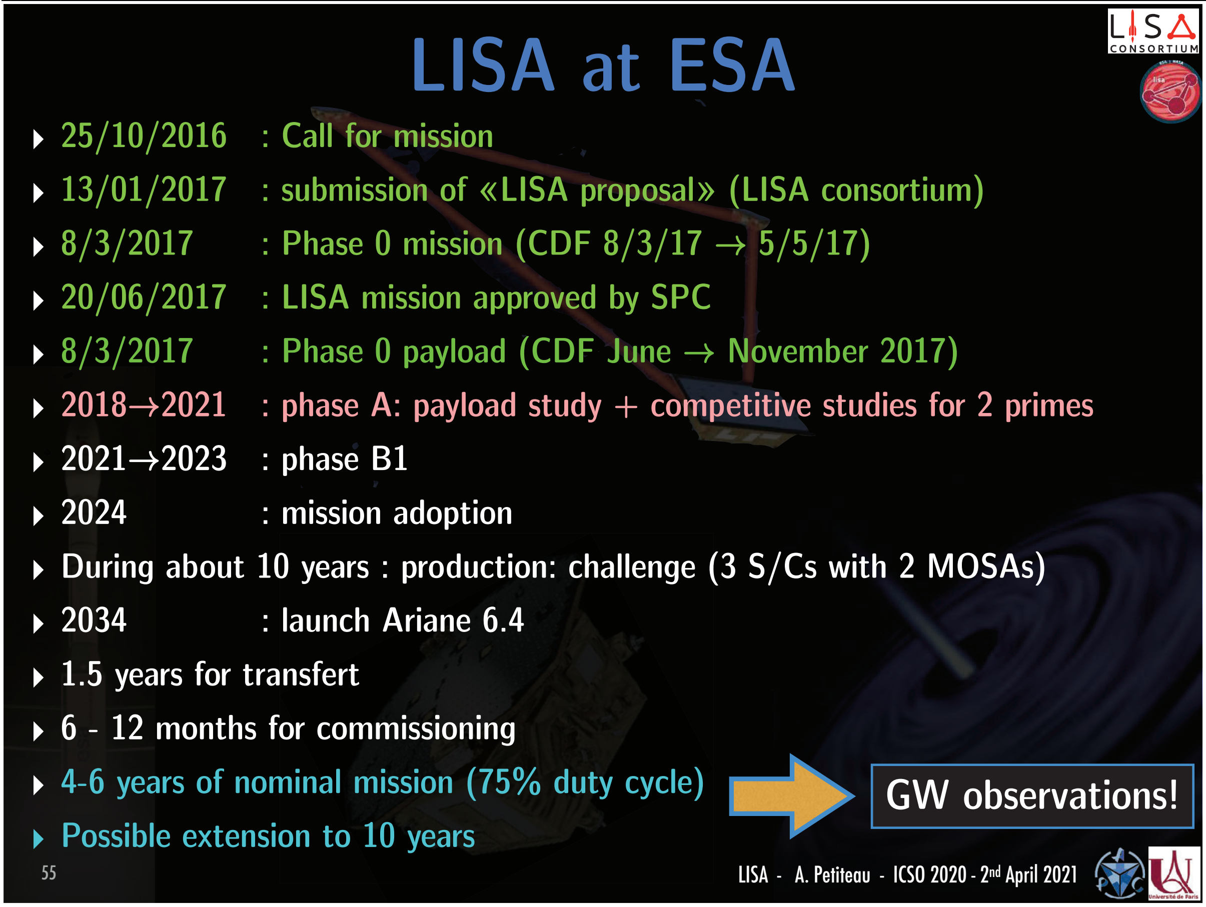
LISA CONSORTIUM
LISA at ESA
25/10/2016 : Call for mission
13/01/2017 : submission of «LISA proposal» (LISA consortium)
8/3/2017 : Phase 0 mission (CDF 8/3/17 → 5/5/17)
20/06/2017 : LISA mission approved by SPC
8/3/2017 : Phase 0 payload (CDF June → November 2017)
2018→2021 : phase A: payload study + competitive studies for 2 primes
2021→2023 : phase B1
2024 : mission adoption
During about 10 years : production: challenge (3 S/Cs with 2 MOSAs)
2034 : launch Ariane 6.4
1.5 years for transfert
6 - 12 months for commissioning
4-6 years of nominal mission (75% duty cycle)
Possible extension to 10 years
GW observations!
55
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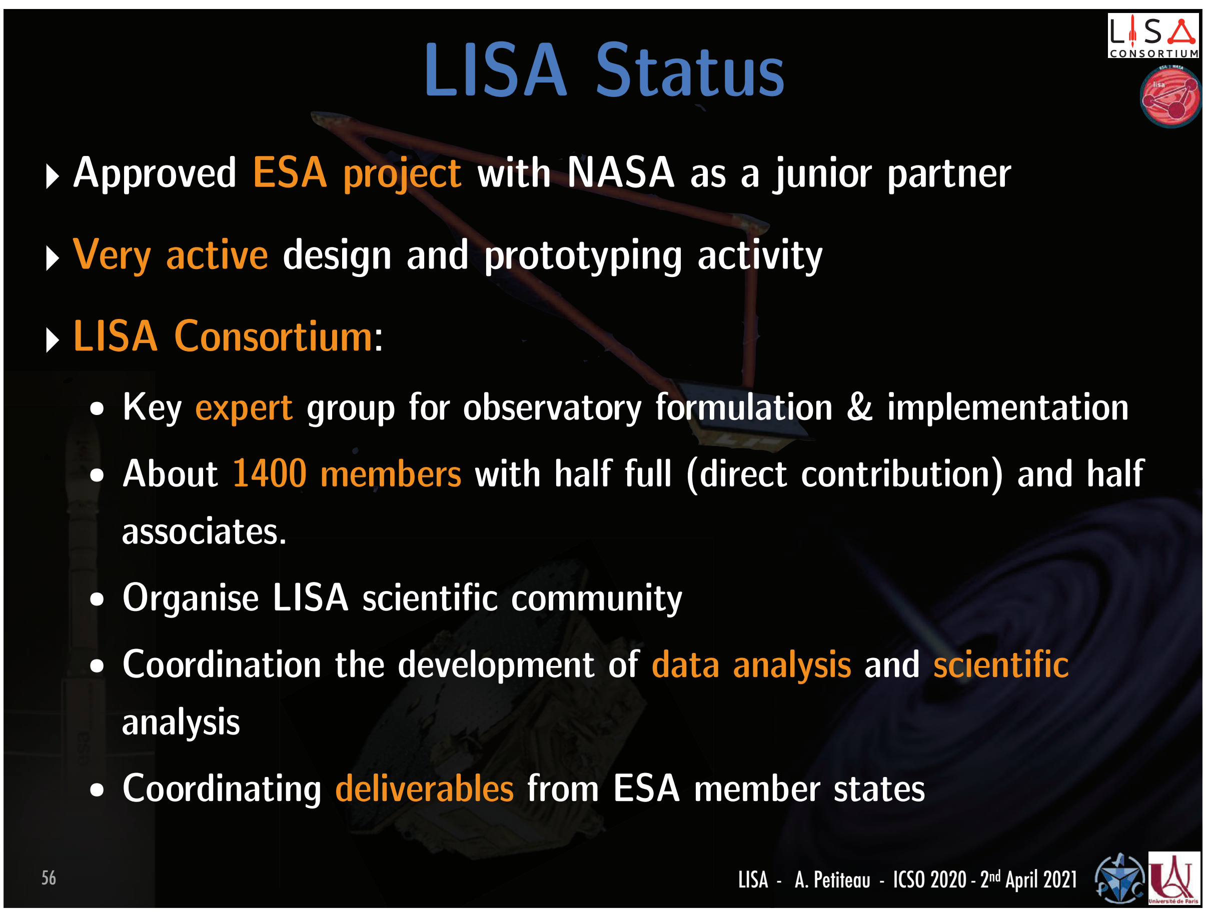
LISA CONSORTIUM
LISA Status
Approved ESA project with NASA as a junior partner
Very active design and prototyping activity
LISA Consortium:
Key expert group for observatory formulation & implementation
About 1400 members with half full (direct contribution) and half associates.
Organise LISA scientific community
Coordination the development of data analysis and scientific analysis
Coordinating deliverables from ESA member states
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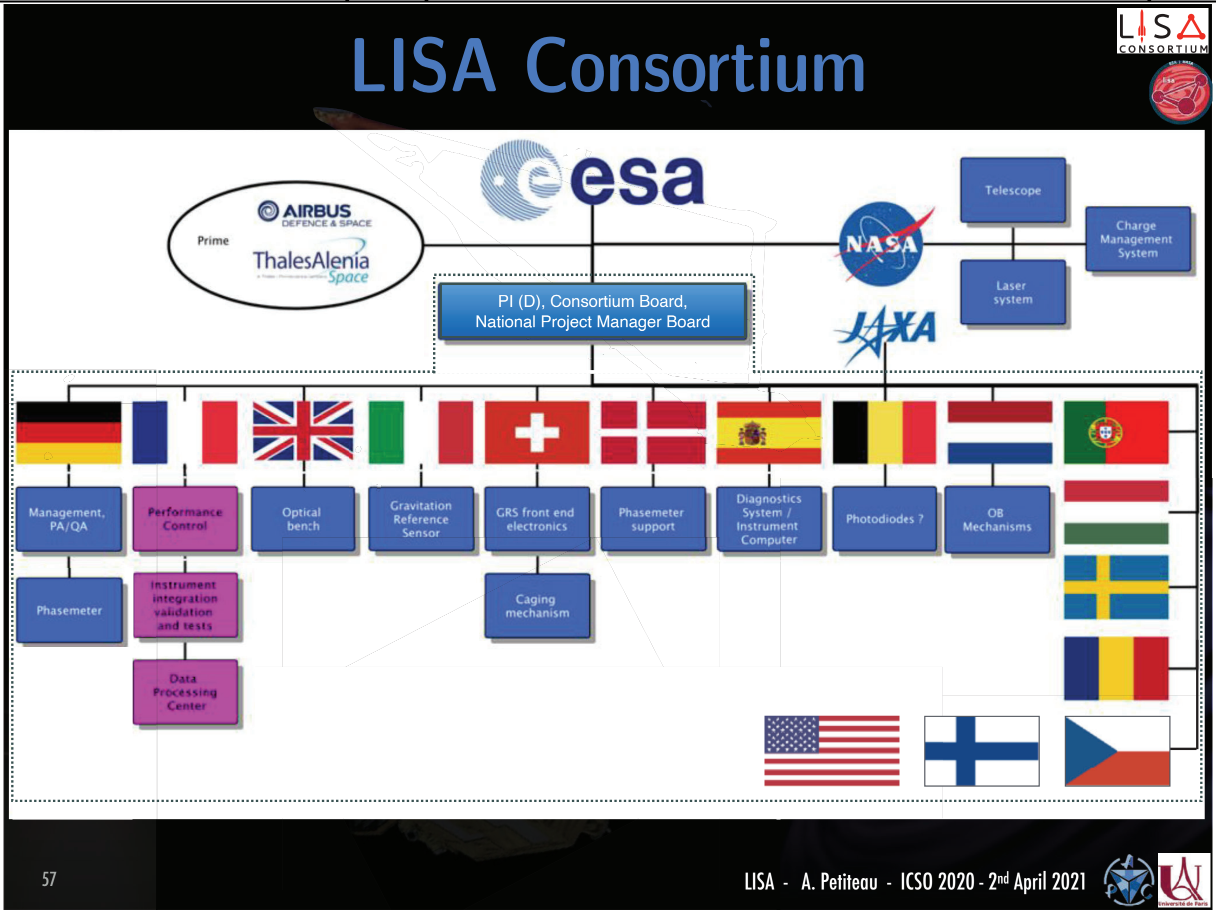
LISA Consortium
esa
Prime
AIRBUS DEFENCE & SPACE
ThalesAlenia Space
PI (D), Consortium Board,
National Project Manager Board
NASA
JAXA
Telescope
Laser system
Charge Management System
Management, PA/QA
Performance Control
Optical bench
Gravitation Reference Sensor
GRS front end electronics
Phasemeter support
Diagnostics System / Instrument Computer
Photodiodes ?
OB Mechanisms
Phasemeter
Instrument integration validation and tests
Caging mechanism
Data Processing Center
57
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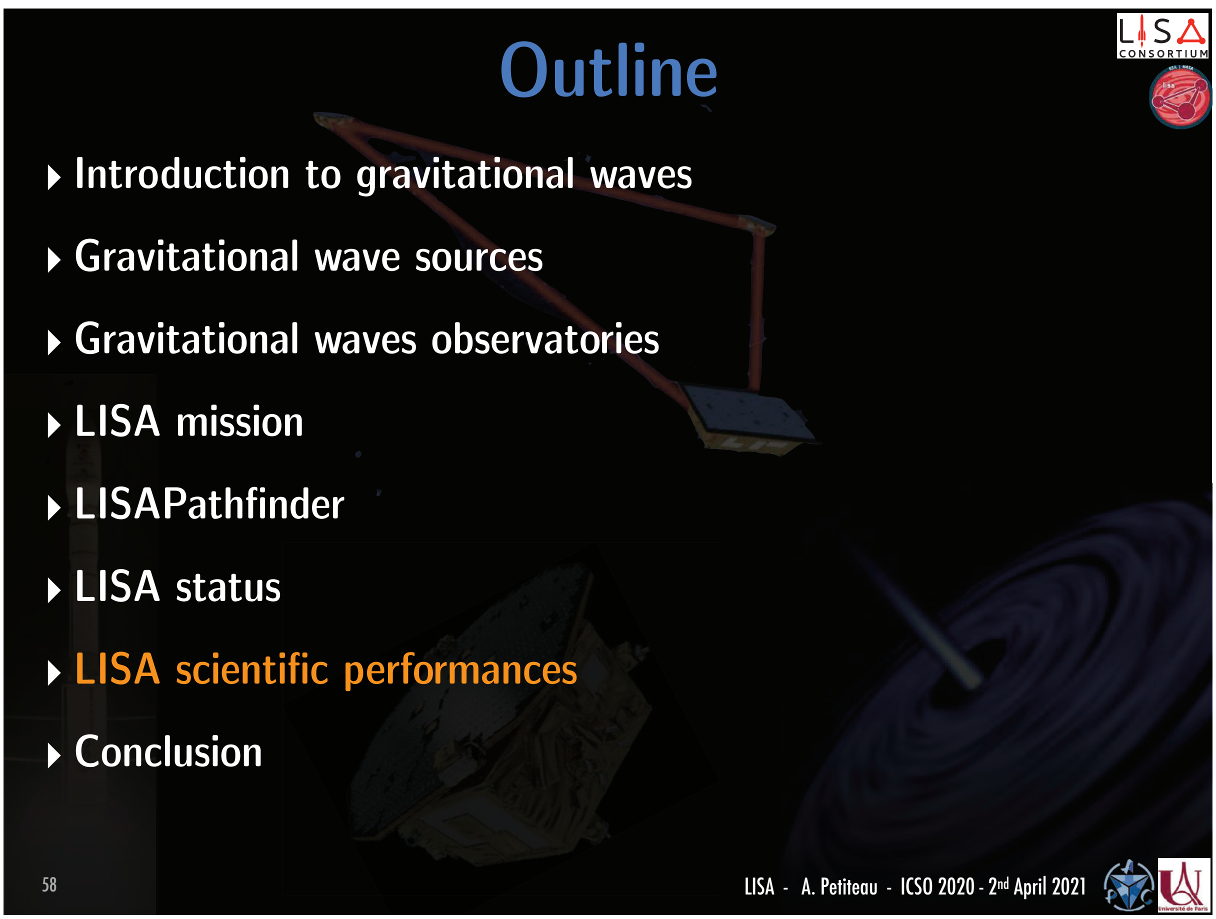
Outline
Introduction to gravitational waves
Gravitational wave sources
Gravitational waves observatories
LISA mission
LISAPathfinder
LISA status
LISA scientific performances
Conclusion
58
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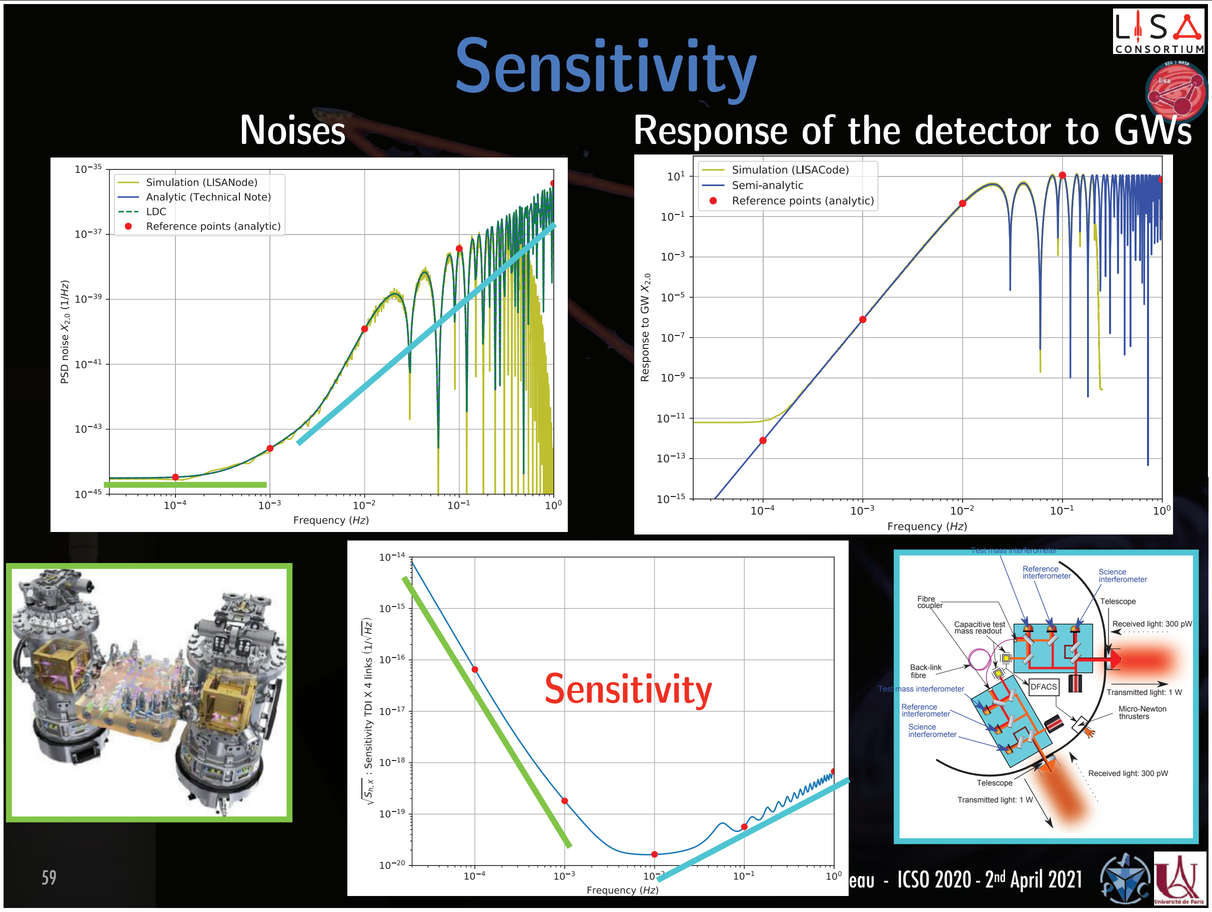
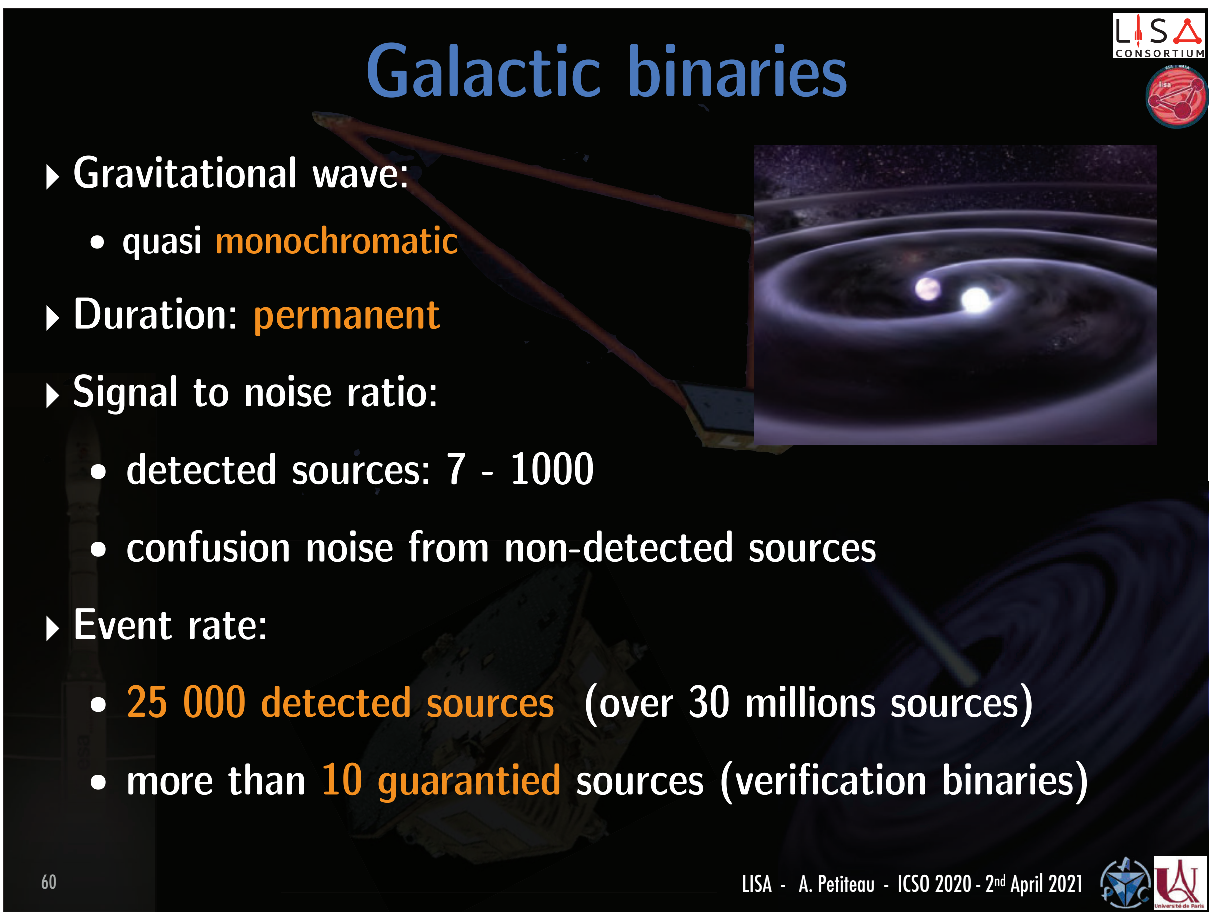

Sensitivity
Noises
Response of the detector to GWs
Simulation (LISANode)
Analytic (Technical Note)
LDC
Reference points (analytic)
PSD noise $X_{2.0}$ (1/Hz)
Frequency (Hz)
Simulation (LISACode)
Semi-analytic
Reference points (analytic)
Response to GW $X_{2.0}$
Frequency (Hz)
Sensitivity
$\sqrt{S_{h,X}}$: Sensitivity TDI X 4 links ($1/\sqrt{Hz}$)
Frequency (Hz)
Reference interferometer
Science interferometer
Fibre coupler
Telescope
Capacitive test mass readout
Received light: 300 pW
Back-link fibre
Test mass interferometer
DFACS
Transmitted light: 1 W
Micro-Newton thrusters
Received light: 300 pW
Telescope
Transmitted light: 1 W
59
eau - ICSO 2020 - 2nd April 2021


Galactic binaries
Gravitational wave:
quasi monochromatic
Duration: permanent
Signal to noise ratio:
detected sources: 7 - 1000
confusion noise from non-detected sources
Event rate:
25 000 detected sources (over 30 millions sources)
more than 10 guarantied sources (verification binaries)
60
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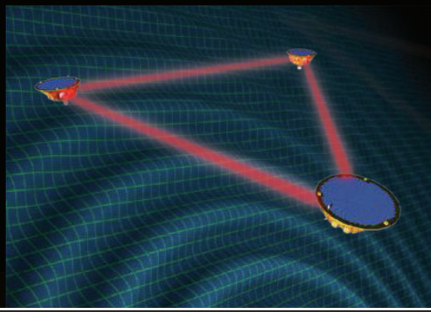
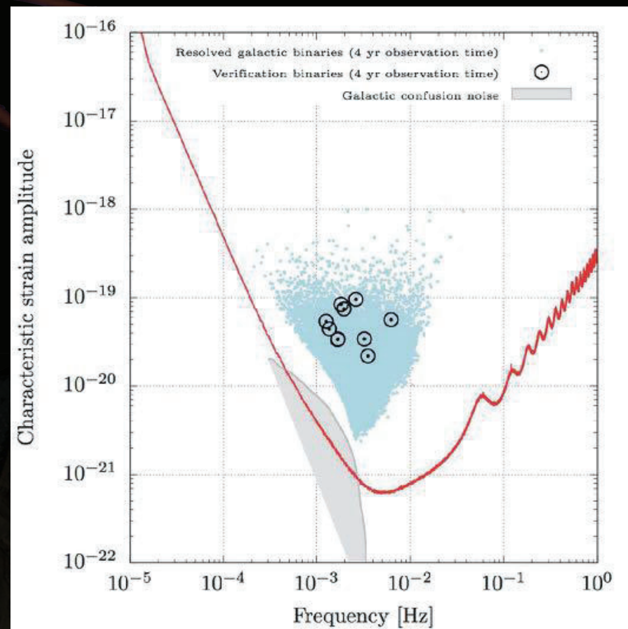
Galactic binaries



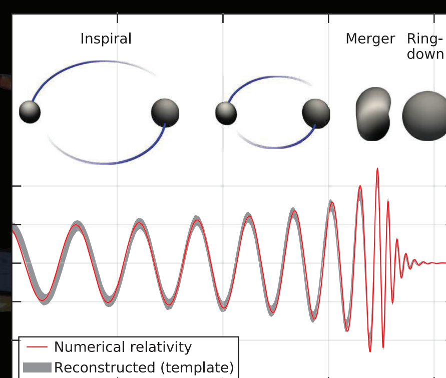
GW sources

- 6 x10^7 galactic binaries



Super Massive Black Hole Binaries

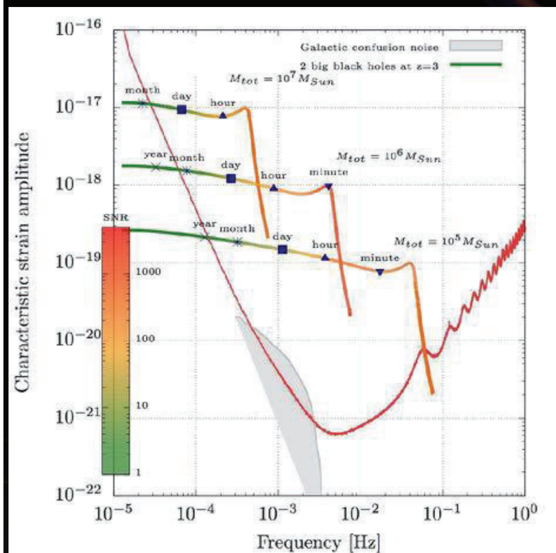
- Gravitational wave:
  - Inspiral: Post-Newtonian,
  - Merger: Numerical relativity,
  - Ringdown: Oscillation of the resulting MBH.

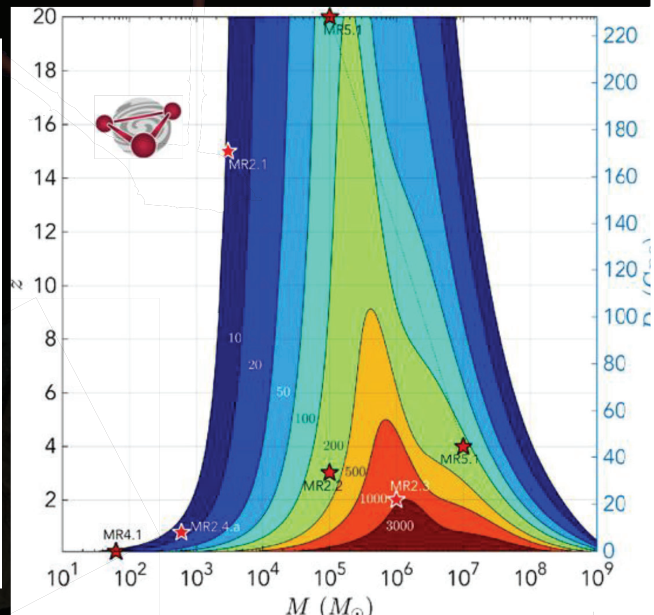


- Duration: between few hours and several months
- Signal to noise ratio: until few thousands
- Event rate: 10-100/year

Super Massive Black Hole Binaries

- LISA: SMBHB from 10^4 à 10^7 solar masses in "all" Univers





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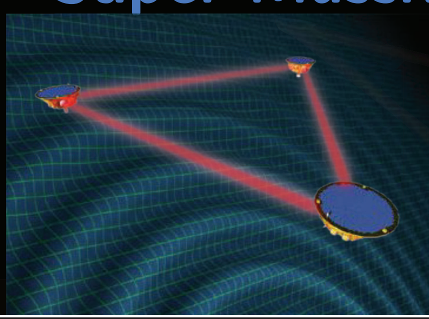
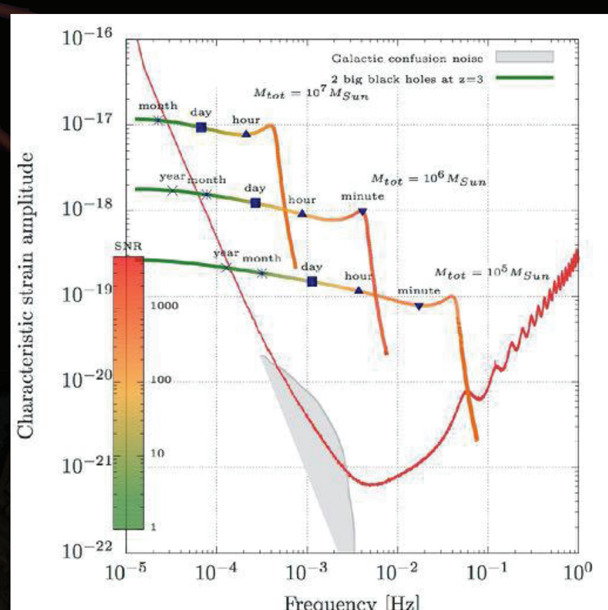
Super Massive Black Hole Binaries



GW sources

- 6 x10^7 galactic binaries
- 10-100/year SMBHBs



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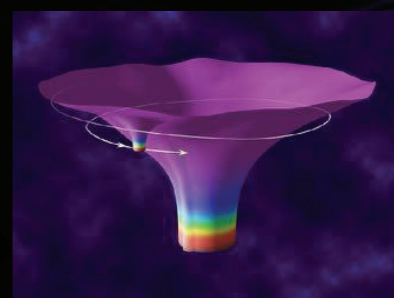
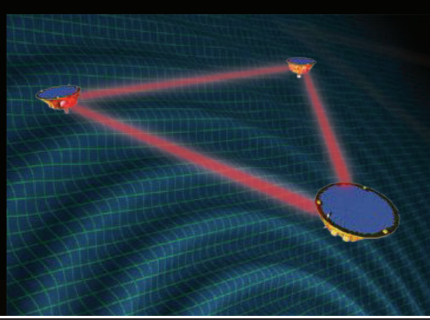
EMRIs

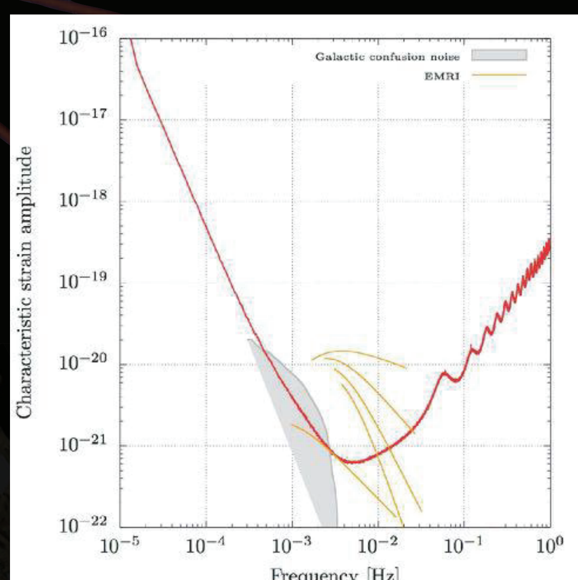
- Gravitational wave:
  - very complex waveform
  - No precise simulation at the moment
- Duration: about 1 year
- Signal to Noise Ratio: from tens to few hundreds
- Event rate:
  from few events per
  year to few
  hundreds

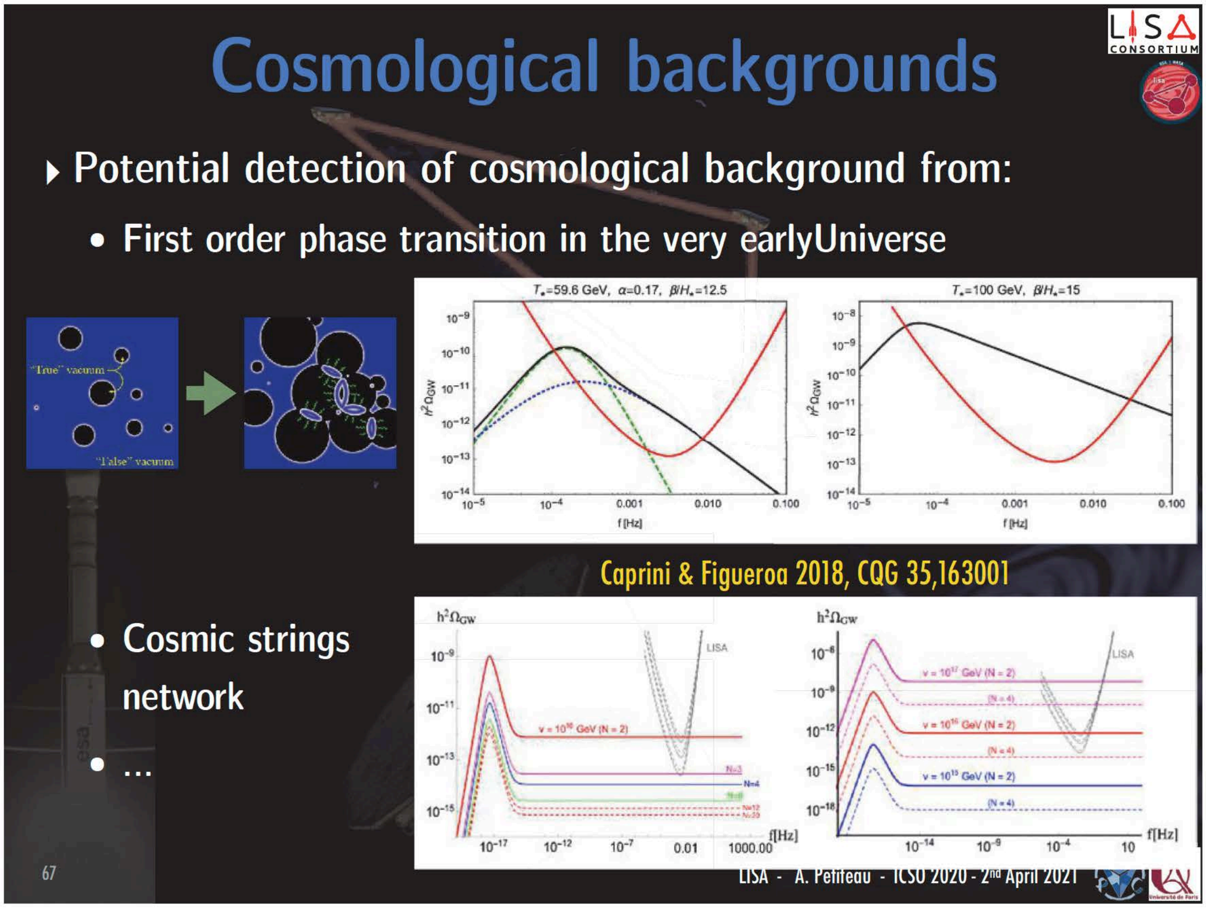


EMRIs



GW sources
- 6 x10^7 galactic binariess
- 10-100/year SMBHBs
- 10-1000/years EMRIs




Cosmological backgrounds
Potential detection of cosmological background from:
• First order phase transition in the very earlyUniverse
"True" vacuum
"False" vacuum
Caprini & Figueroa 2018, CQG 35,163001
• Cosmic strings network
• ...
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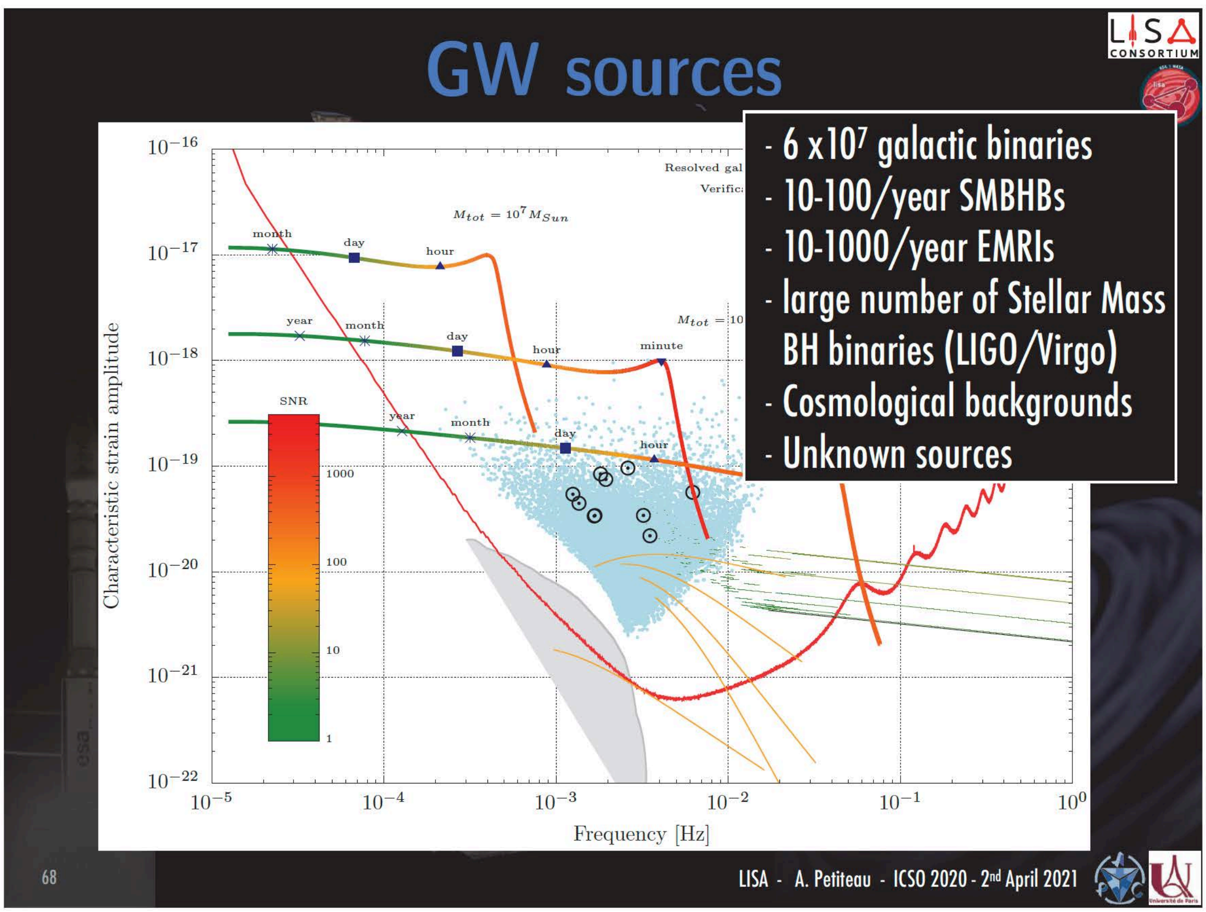
GW sources
- 6 x10^7 galactic binaries
- 10-100/year SMBHBs
- 10-1000/year EMRIs
- large number of Stellar Mass BH binaries (LIGO/Virgo)
- Cosmological backgrounds
- Unknown sources
Characteristic strain amplitude
Frequency [Hz]
SNR
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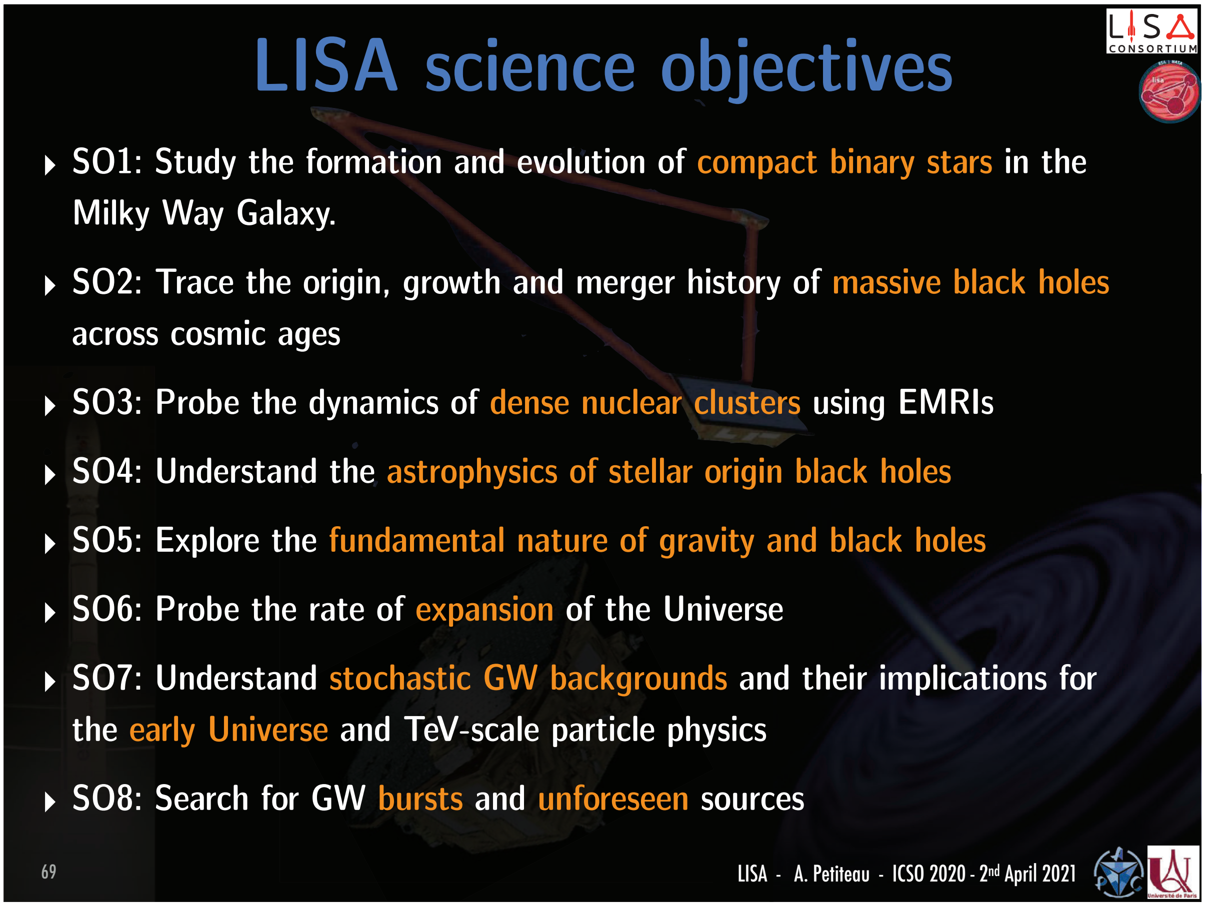
LISA science objectives
SO1: Study the formation and evolution of compact binary stars in the Milky Way Galaxy.
SO2: Trace the origin, growth and merger history of massive black holes across cosmic ages
SO3: Probe the dynamics of dense nuclear clusters using EMRIs
SO4: Understand the astrophysics of stellar origin black holes
SO5: Explore the fundamental nature of gravity and black holes
SO6: Probe the rate of expansion of the Universe
SO7: Understand stochastic GW backgrounds and their implications for the early Universe and TeV-scale particle physics
SO8: Search for GW bursts and unforeseen sources
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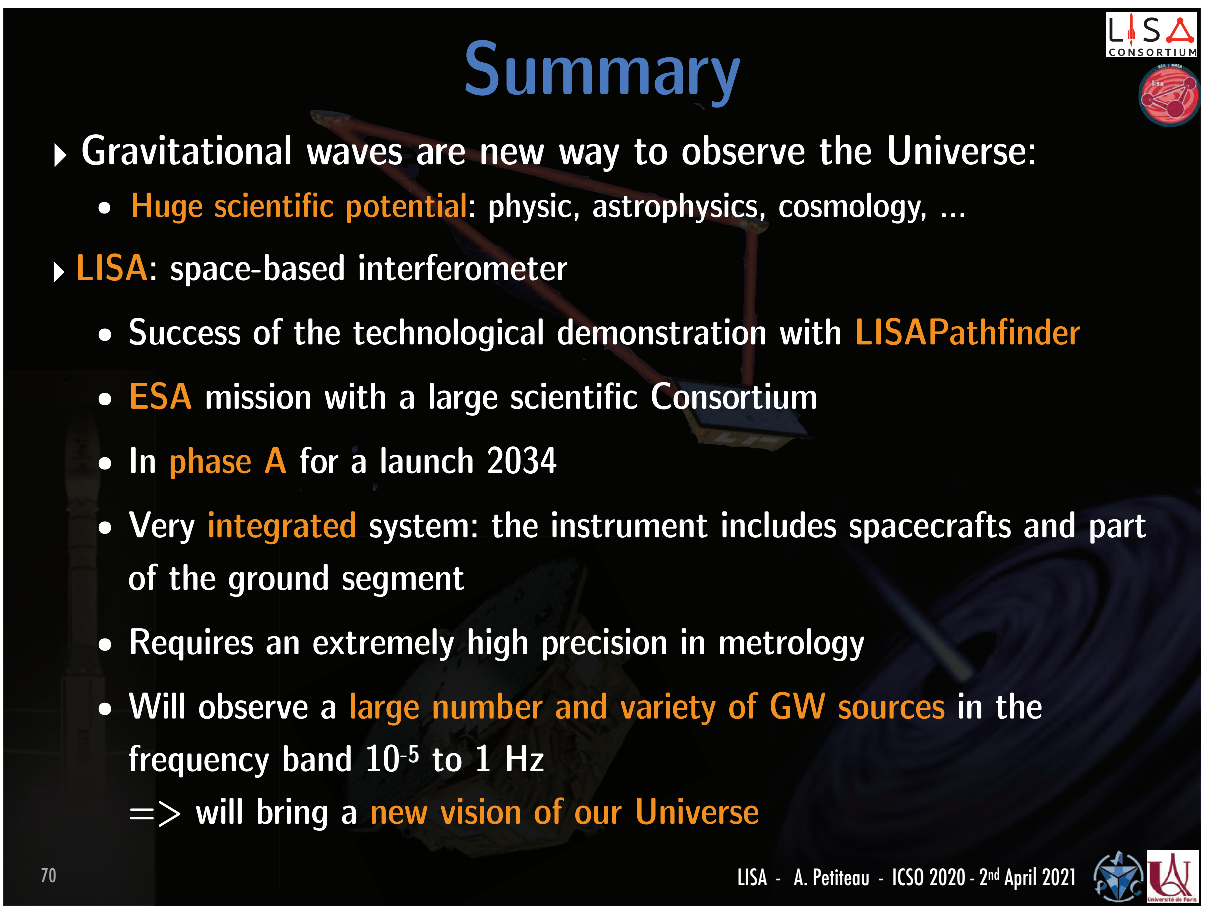
Summary
Gravitational waves are new way to observe the Universe:
Huge scientific potential: physic, astrophysics, cosmology, …
LISA: space-based interferometer
Success of the technological demonstration with LISAPathfinder
ESA mission with a large scientific Consortium
In phase A for a launch 2034
Very integrated system: the instrument includes spacecrafts and part of the ground segment
Requires an extremely high precision in metrology
Will observe a large number and variety of GW sources in the frequency band 10-5 to 1 Hz
=> will bring a new vision of our Universe
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Thank you