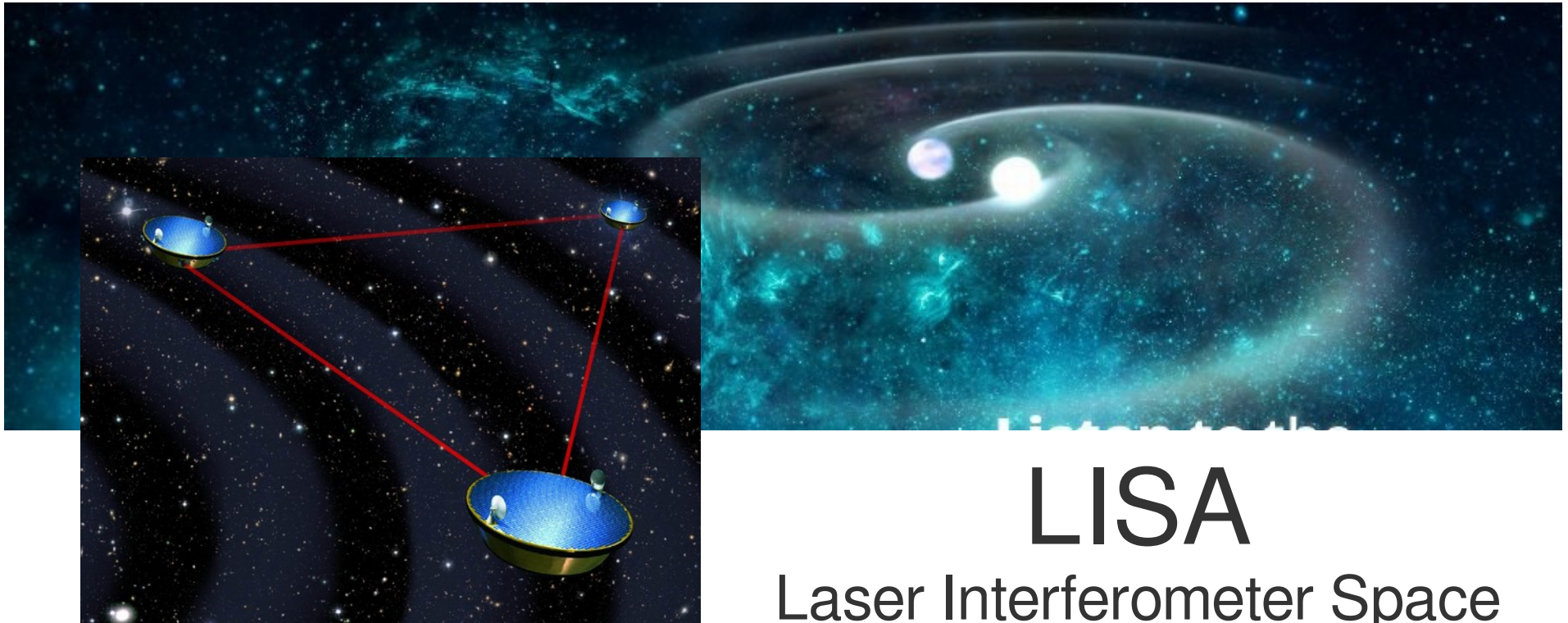




LISA

Laser Interferometer Space
Antenna

Gijs Nelemans (for the LISA-NL consortium)

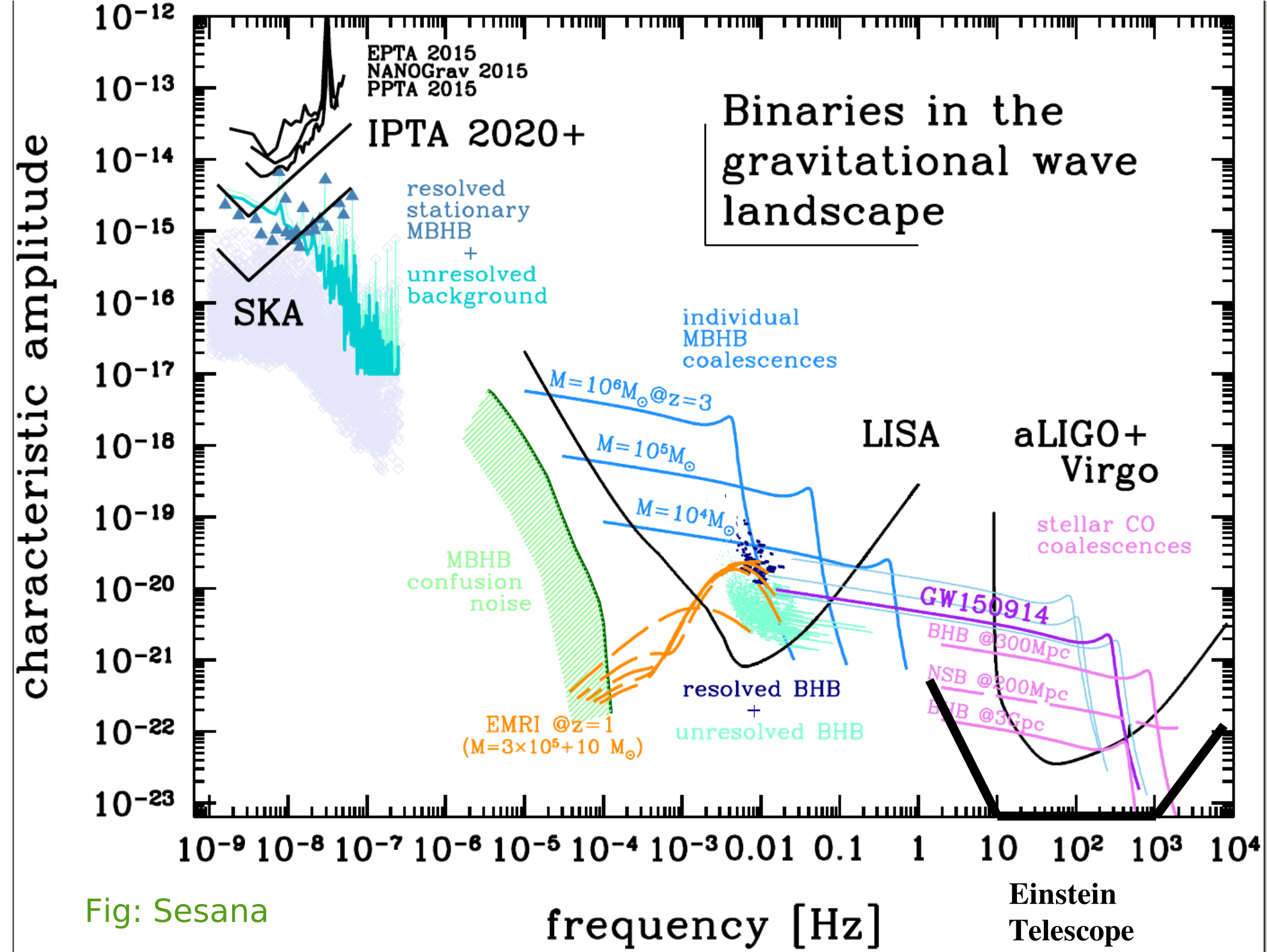
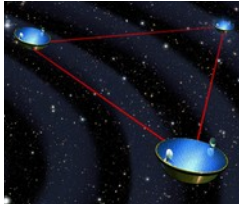


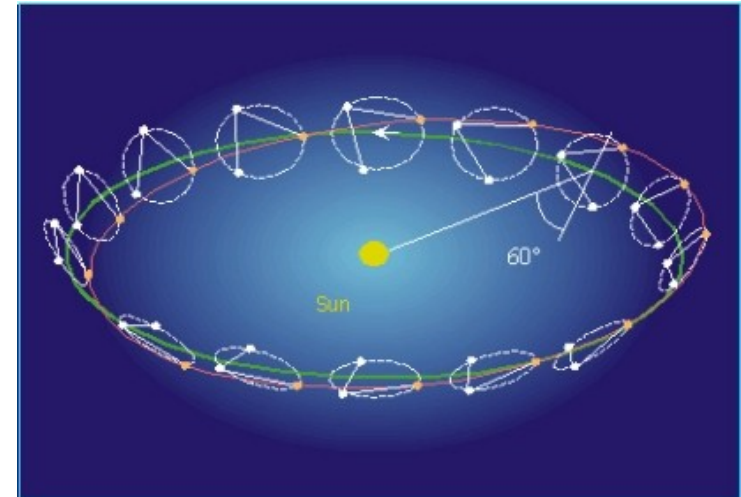
Fig: Sesana

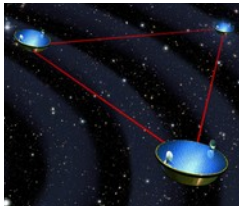


LISA



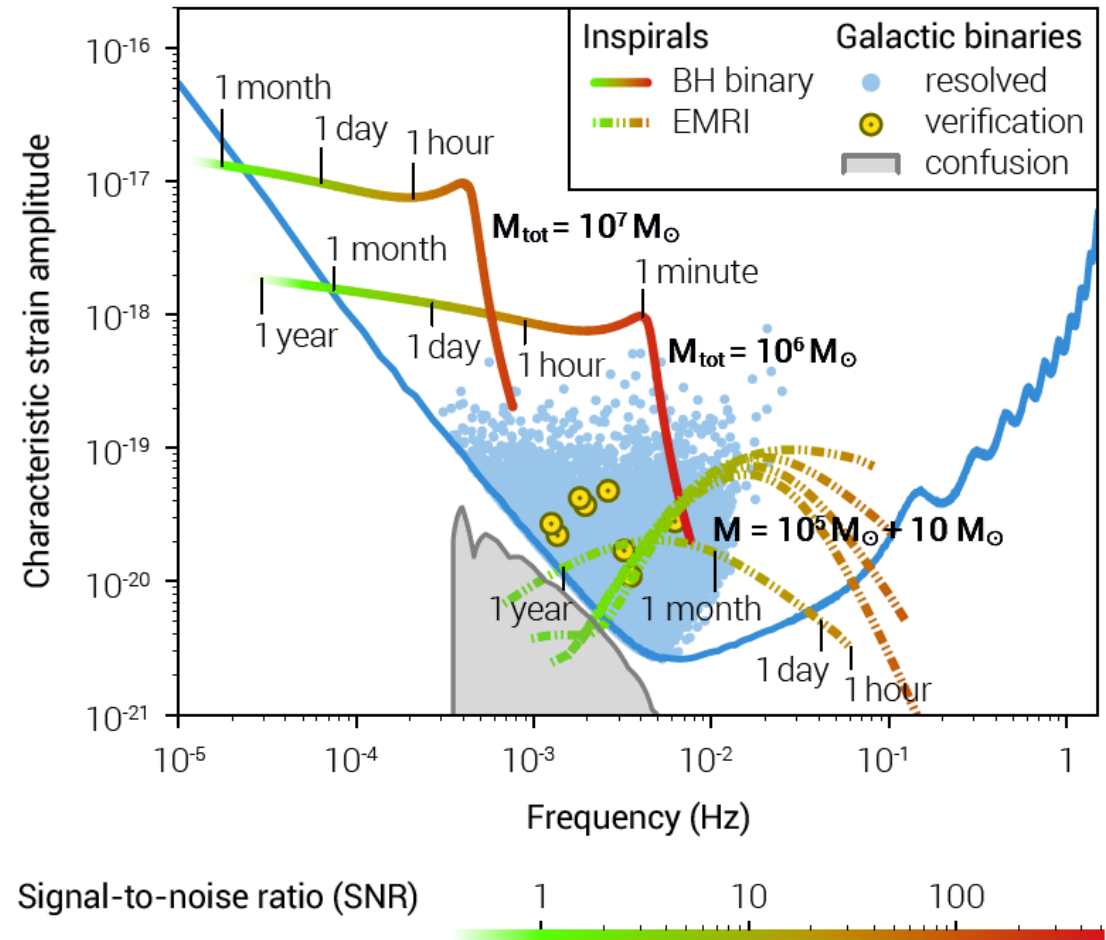
- ▶ Selected European Space Agency (ESA) mission to detect *Gravitational Waves* in space
- ▶ Three satellites in triangular formation, trailing Earth
- ▶ Scientific collaboration and payload via LISA consortium
- ▶ Strong link with US (NASA contribution significant)
- ▶ ESA LISA Pathfinder, successful technology demonstrator

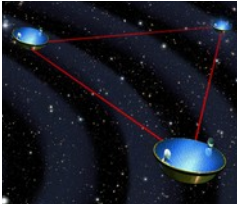




Space GW: sources

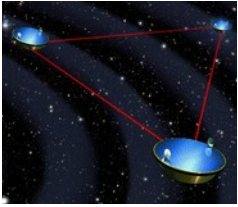
- ▶ Super Massive black hole binaries ($10^5 - 10^7 M_{\odot}$)
- ▶ Compact binaries (in the Galaxy)
- ▶ Extreme Mass-ratio Inspirals
- ▶ Early Universe: GW background, cosmic strings,
- ▶ The unknown





Space GW: revolutionary science

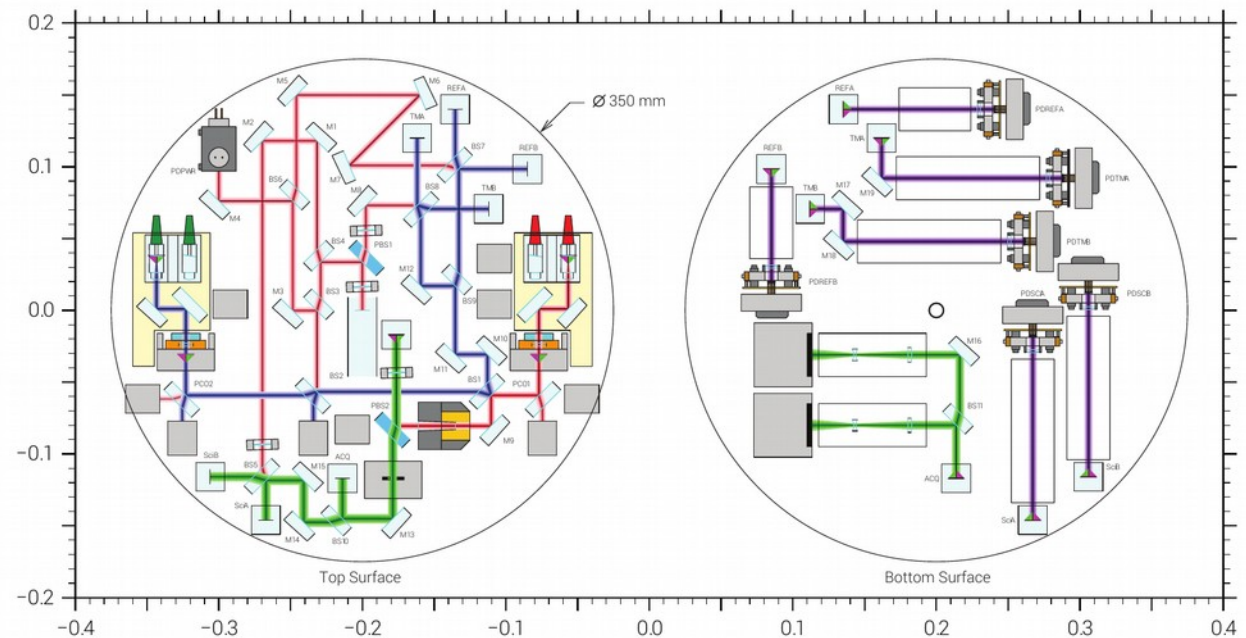
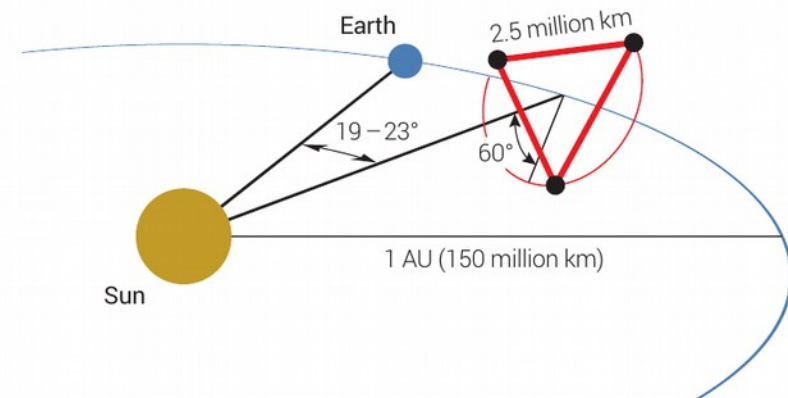
- ▶ Massive black holes ($10^5 - 10^7 M_{\odot}$)
 - ▶ Measurement of mass at $z=1$ to $\pm 0.1\%$, spin a/M to ± 0.01
 - ▶ Mass function, central cluster of black hole in ordinary galaxies to $z=0.5$
- ▶ Structure formation at high redshift
 - ▶ Observations of objects before re-ionisation: BH mergers at $z \gg 10$
 - ▶ Testing models of how massive BHs formed and evolved from seeds
- ▶ Fundamental physics and testing GR
 - ▶ Ultra-strong GR: high precision tests; prove horizon exists; test no-hair theorem, cosmic censorship; search for scalar fields etc
 - ▶ Fundamental physics: look for cosmic GW backgrounds, test the order of the electroweak phase transition, search for cosmic strings
- ▶ Compact WD binaries in the Galaxy
 - ▶ Discover ~ 10000 new white-dwarf binaries in the Galaxy
 - ▶ Precise masses & distances for dozens + *all* short periods NS-NS, BH-BH
- ▶ The unknown

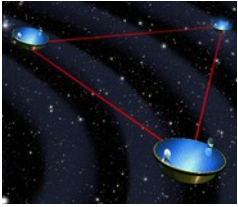


Mission concept

► LISA

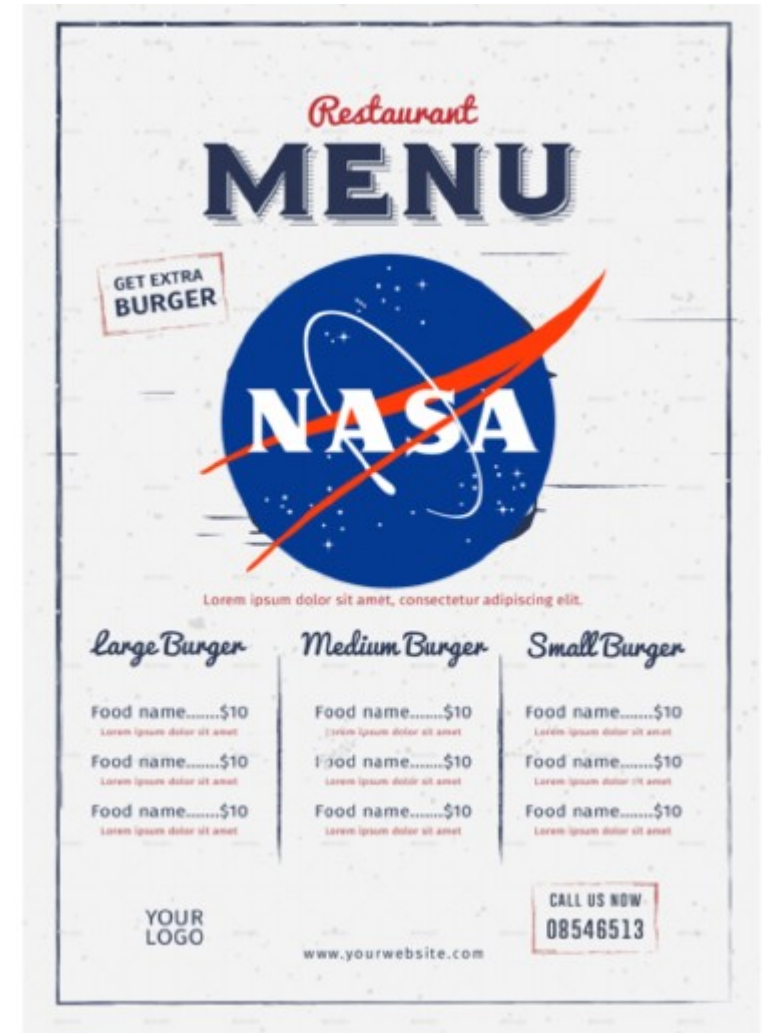
- 2.5 million km arms
- Pay load supplied by member states
- Time delay interferometry
- Use Pathfinder heritage
- Launch 2034 earliest

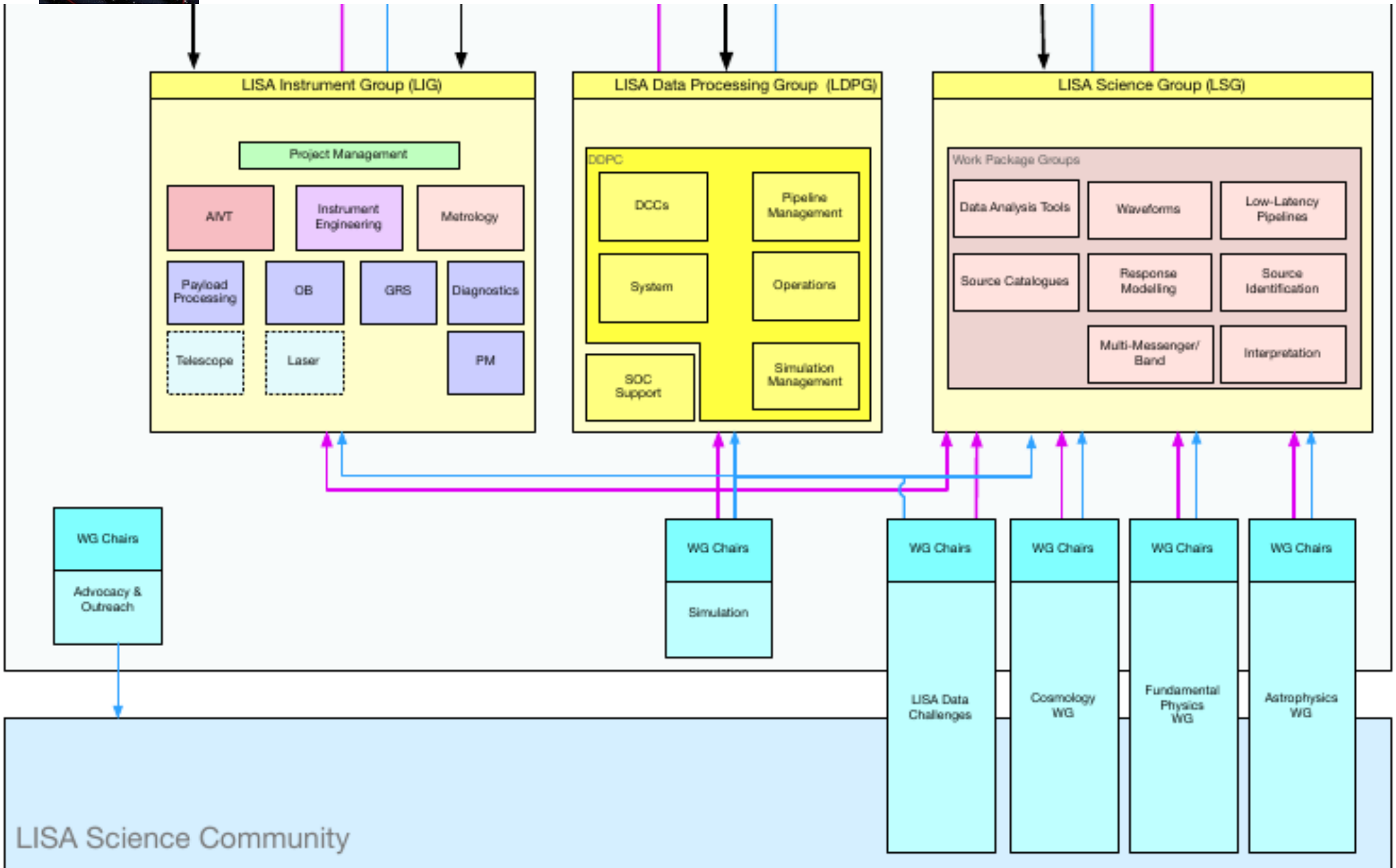


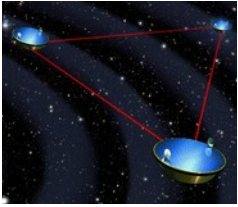


Status

- ▶ Selected for ESA L3 launch (2034)
- ▶ Budget:
 - ▶ ESA: 1B
 - ▶ NASA: few 100M
 - ▶ Member states: few 100M
- ▶ Currently in phase-A (design study)
- ▶ Both system (mission) and instrument
- ▶ Mission Formulation Review this year
- ▶ Decisions and work NOW!
- ▶ Adoption around 2024
- ▶ Launch 2034 earliest



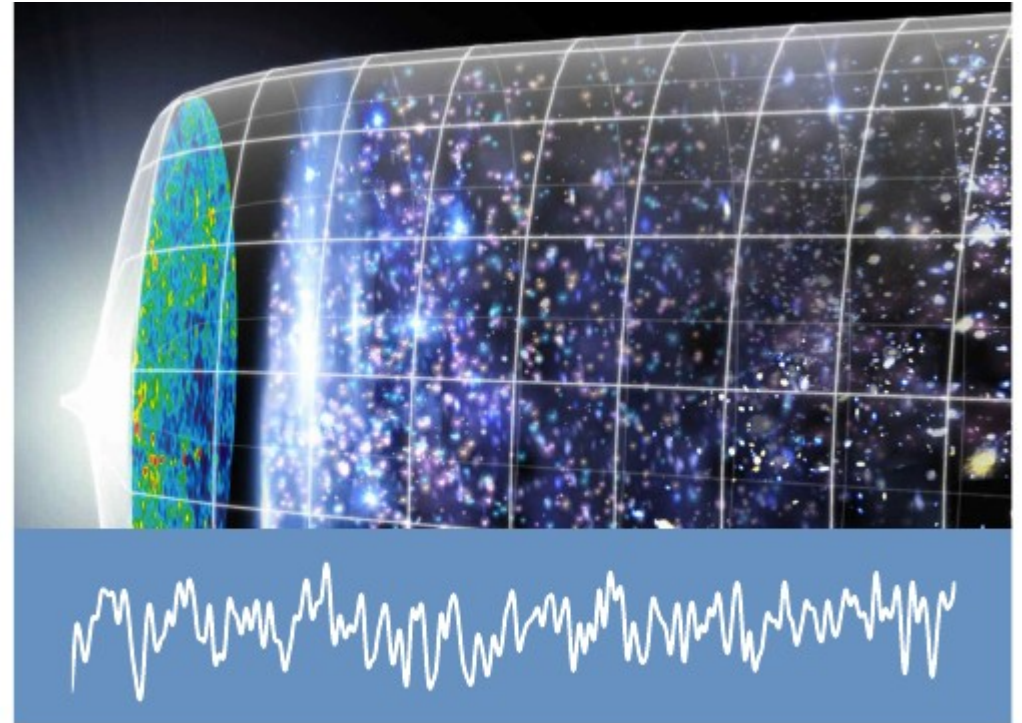


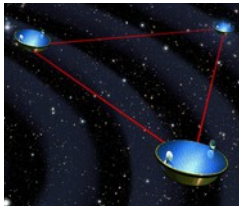


Dutch contributions

► Science

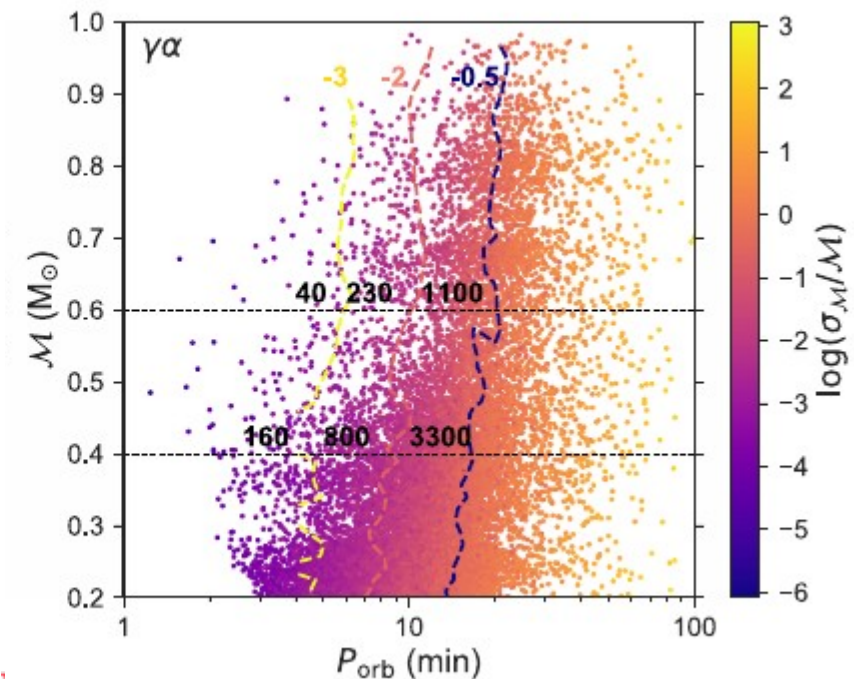
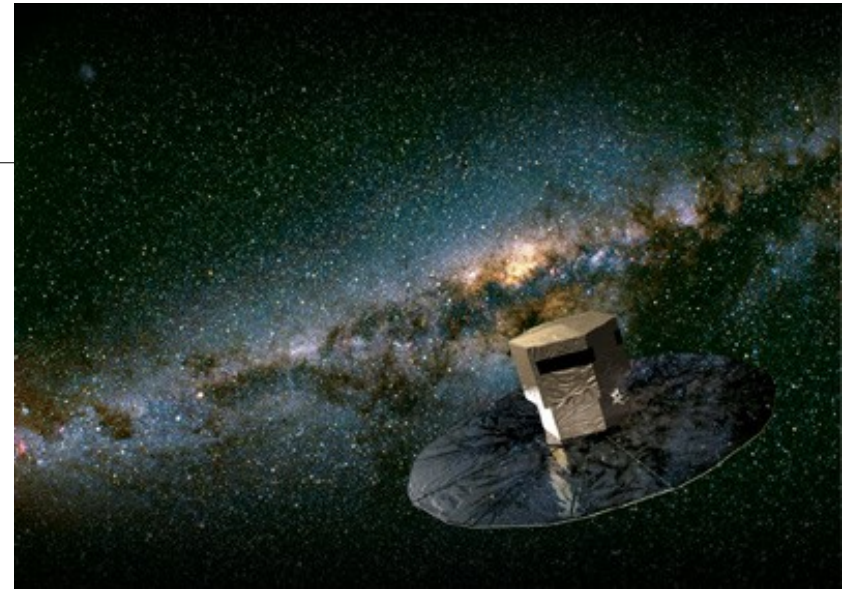
- Compact binaries
(RU, UL, SRON, UvA)
- Fundamental physics
(Nikhef, UvA, UU, UM, RU)
- Early Universe
(Nikhef, RUG, UU, UL)
- Structure formation
(UL, RUG)

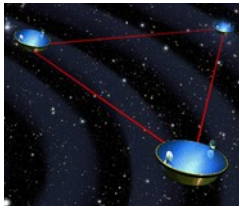




Compact binaries

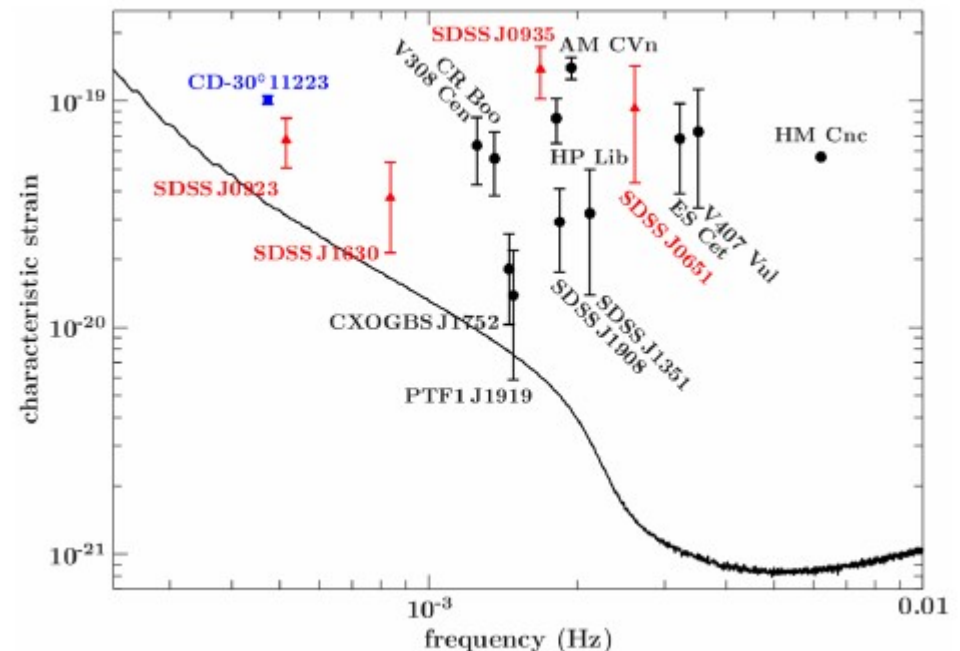
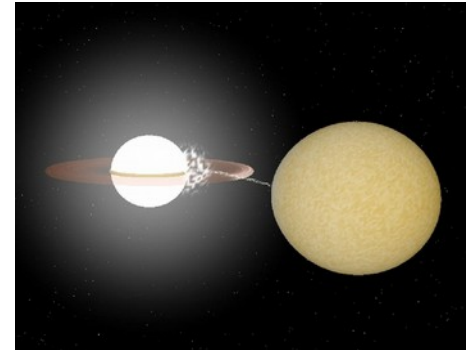
- ▶ Many detectable also with Gaia and LSST (Korol et al 2017)
- ▶ Ultimate test for existence of massive WD merger (Rebassa-Mansergas et al. 2019)
- ▶ Importance of triples (Robson et al. 2018 PRD 98 064012, Antonini et al. 2017 ApJ 841, 77 BBH mergeres from triples)

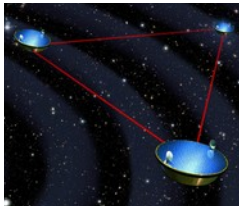




Compact binaries

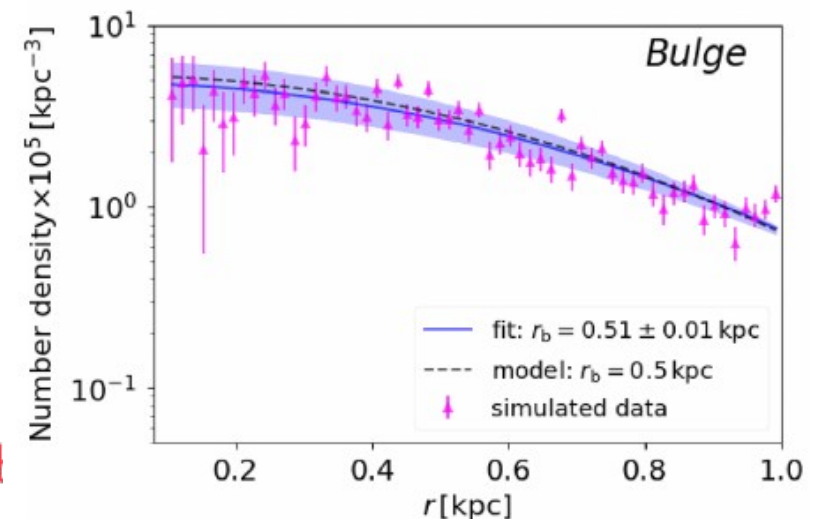
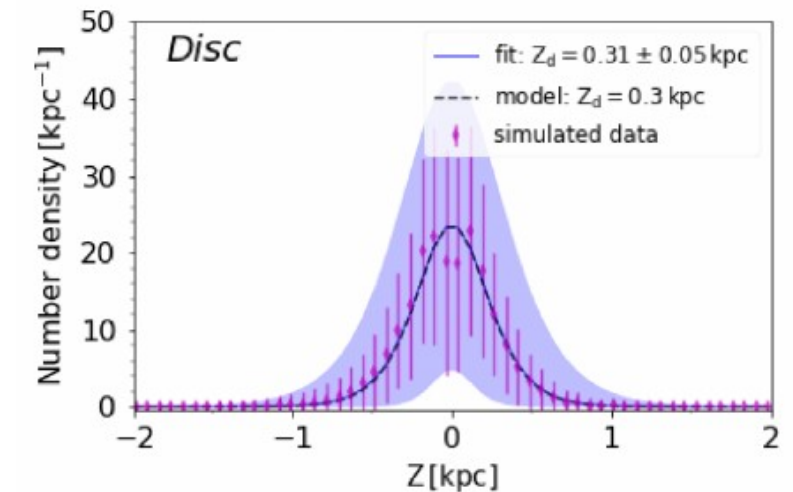
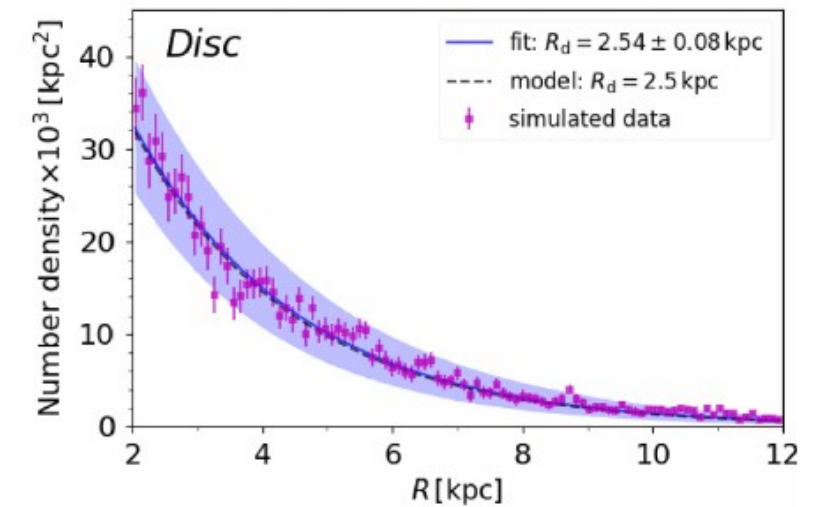
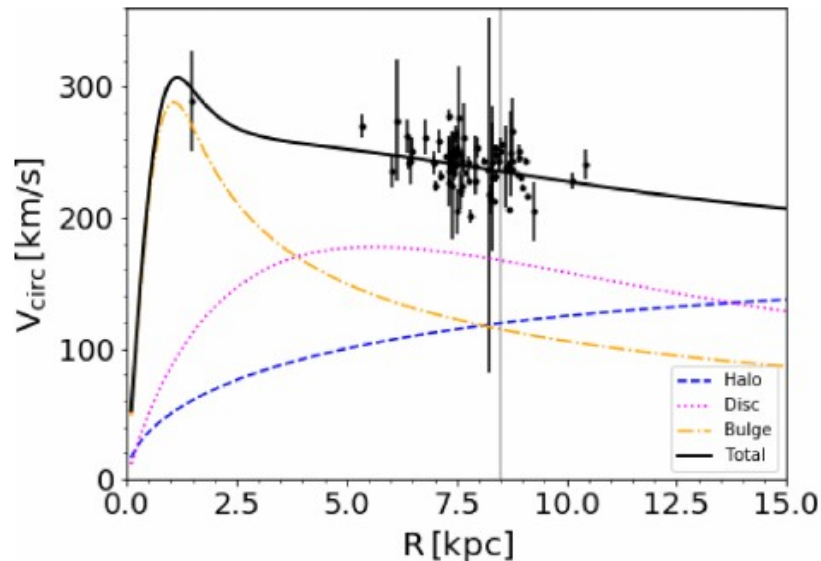
- Verification sources with Gaia distances (Kupfer et al. 2018, MN, 480, 302)
- Also Ramsay et al 2018 (A&A, 620,141)



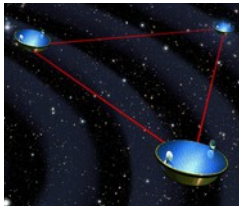


The Milky Way

- Measure structure Milky Way (Korol et al. 2019)
- Several double WD detectable in M31 (Korol et al. 2018)
- Signals from MW satellites (Korol et al. 2021, MN, 502, 55, Roebber et al. 2020, ApJ, 894, 15)

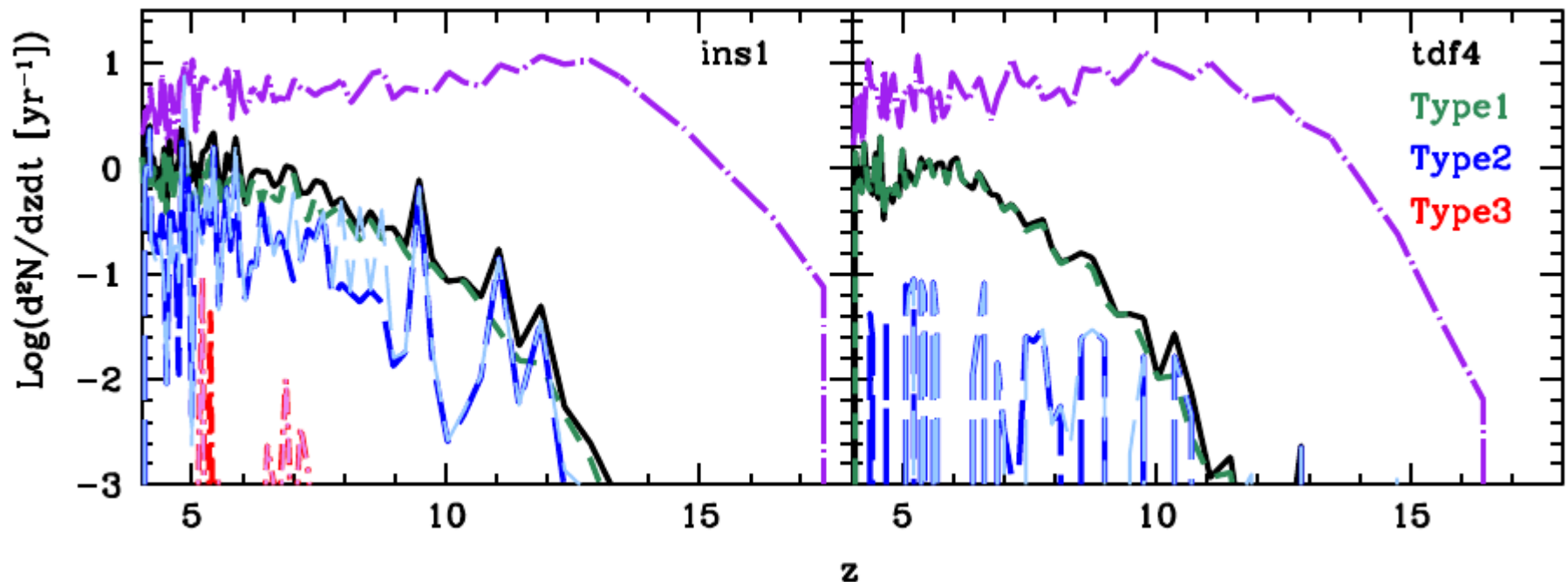


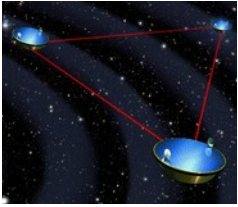
Radl



Structure formation/seeds

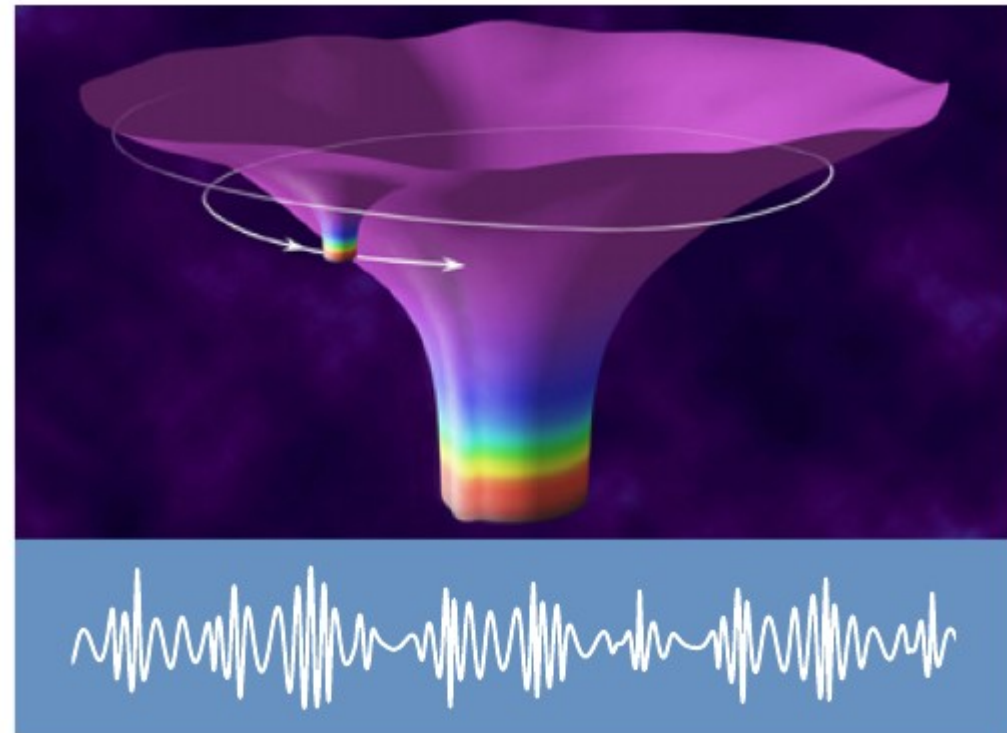
- Dayal et al. 2019 (MN, 486, 2336)
- Rossi (JphCS, 840, 2027), Toscani et al. 2019, IJMPD, 2844015)
- Also Duncan et al. 2019, ApJ, 876, 110; Salcido et al. 2016 (MN 463, 870)
- Tidal disruptions (Pfister et al. 2021, 2103:05883; Toscani et al. 2020, MN, 498, 507)

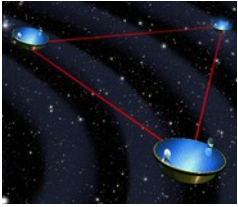




Fundamental physics

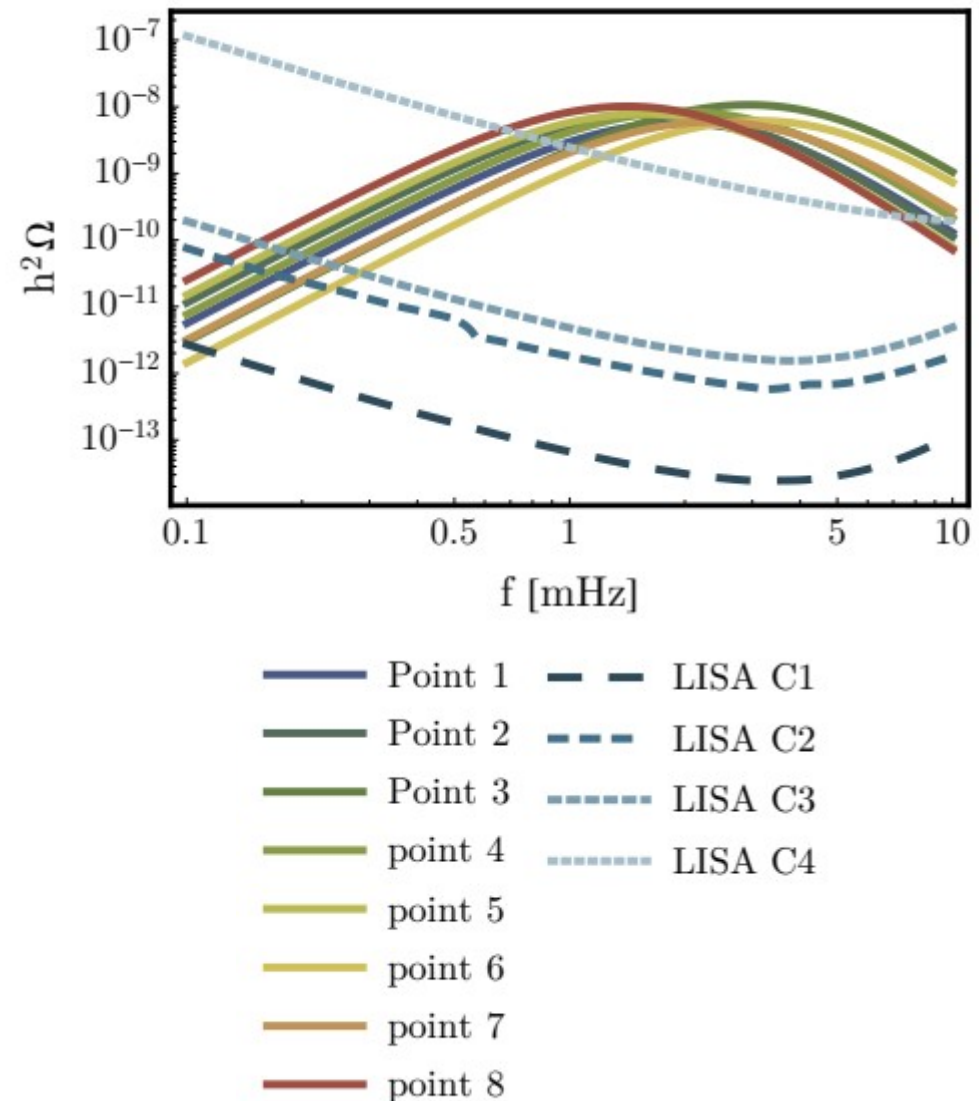
- ▶ Memory effect, (Nichols 2018 PRD 98f4032)
- ▶ Tidal resonances in EMRIs, (Bonga et al. 2019, PRL, 123, 1103)
- ▶ Test GR (e.g. Kasta et al. 2018, PRD, 98, 124033)
- ▶ Dark matter (Edwards et al, 2020, PRL, 124, 161101)

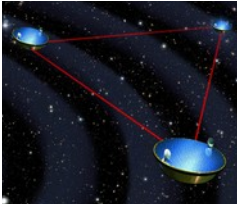




Early Universe/cosmology

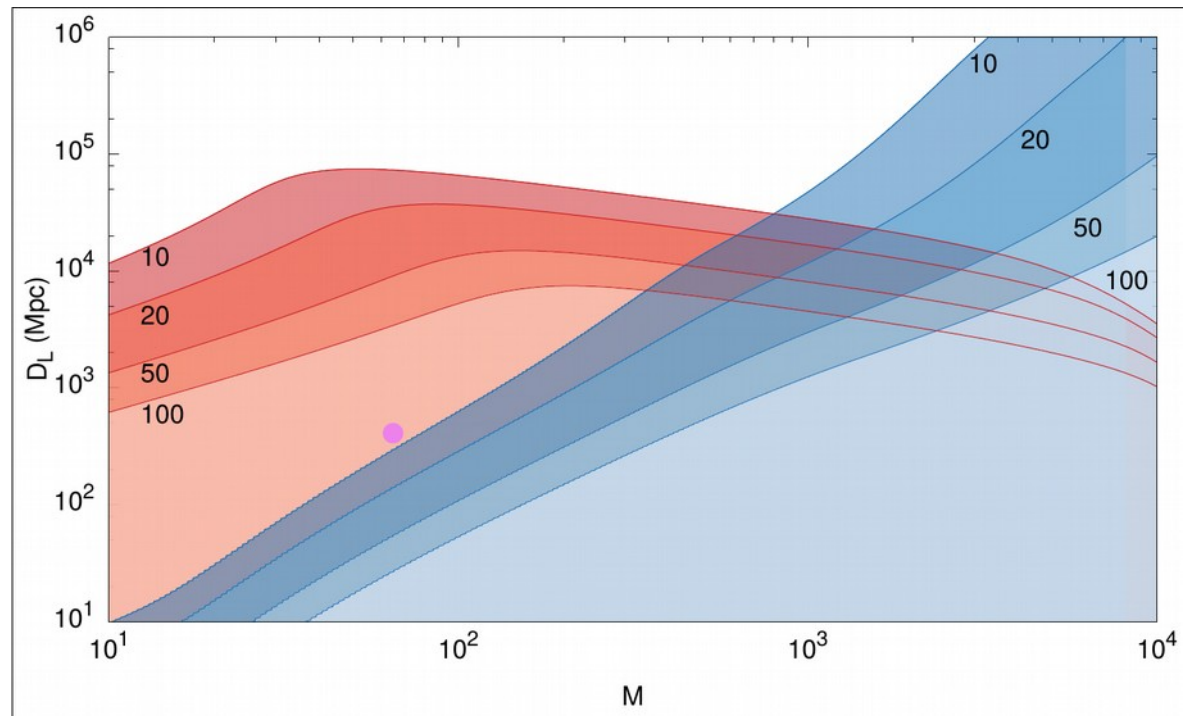
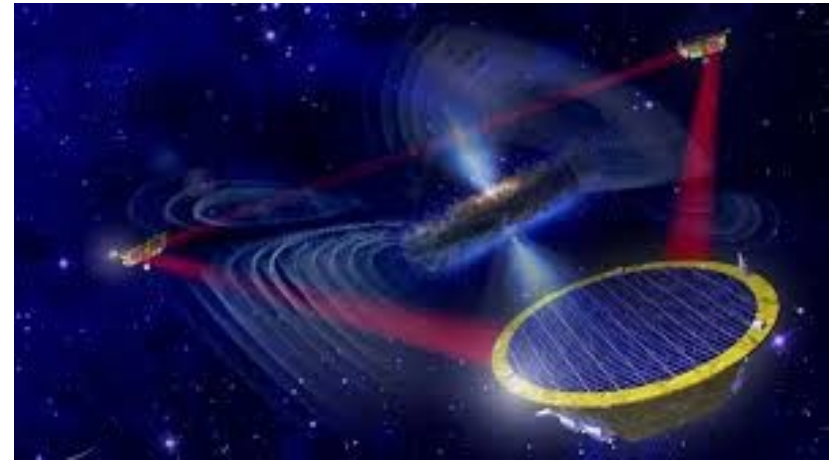
- Phase transition
(Prokopec et al.
2019, JCAP, 02, 009)
- Precision cosmology
(Mukherjee et al.
2021, PRD, 103,
043520)

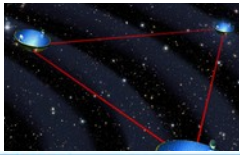




Conclusions

- ▶ LISA is a great mission for Astronomers and Physicists
- ▶ NL (=you!) well positioned to be part of the LISA consortium (ask me or Elena Rossi)
- ▶ Currently phase A
- ▶ Launch far away, decisions and work now!
- ▶ Complementarity LISA and ET





EM follow-up



- ▶ **BlackGEM**
 - ▶ Array newly designed telescopes (PI Groot)
 - ▶ Installation in Chile ongoing
 - ▶ Dedicated to follow-up GW sources to detect in optical
- ▶ **Other facilities**
 - ▶ Coordination via ENGRAVE (Jonker, Levan, Groot)
 - ▶ Large programmes on La Palma, ESO (Chile), Hubble Space Telescope etc.



Radboud Universiteit



Radboud Universiteit Nijmegen

