Gavitational Wave Space Missions

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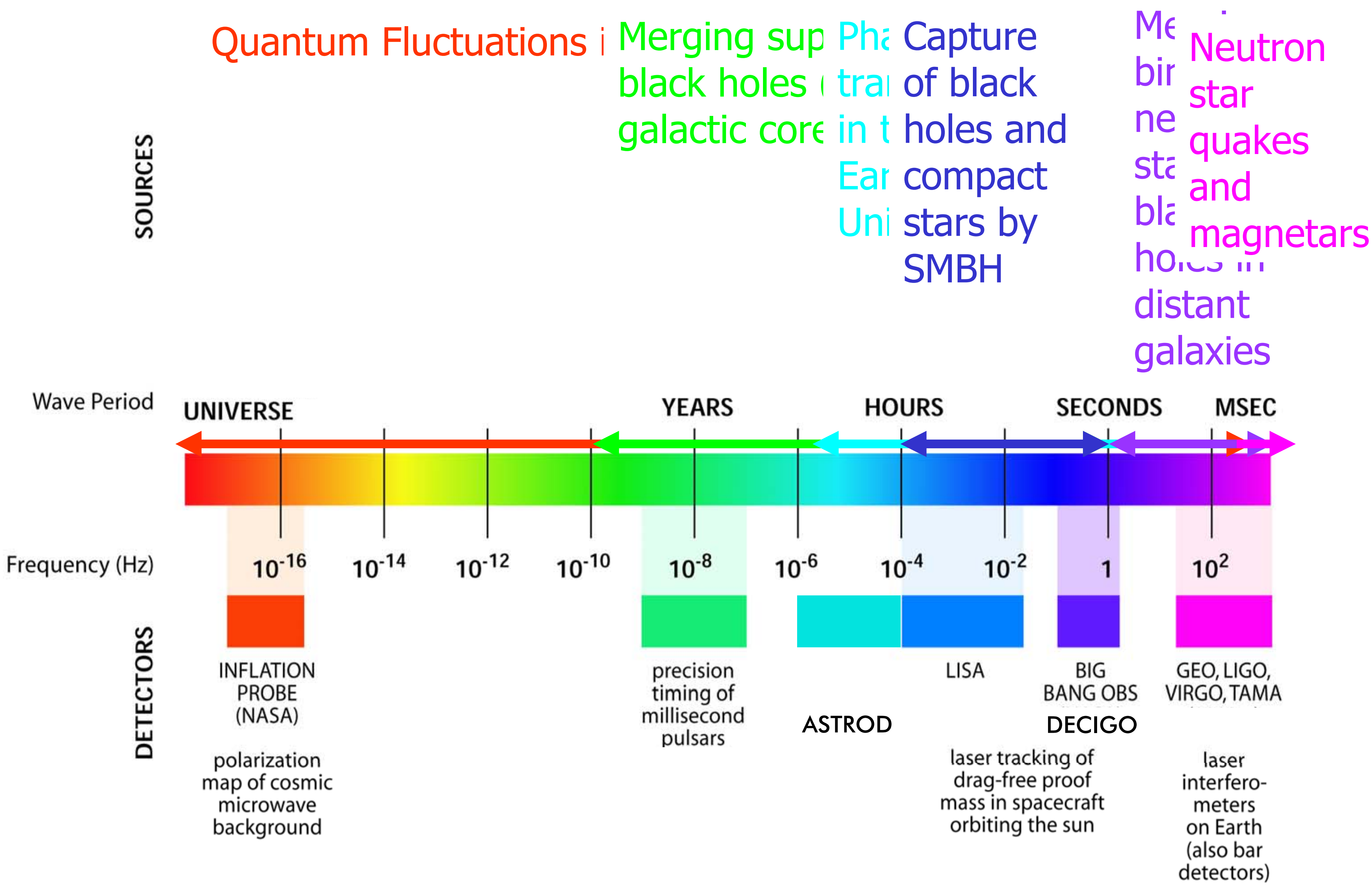
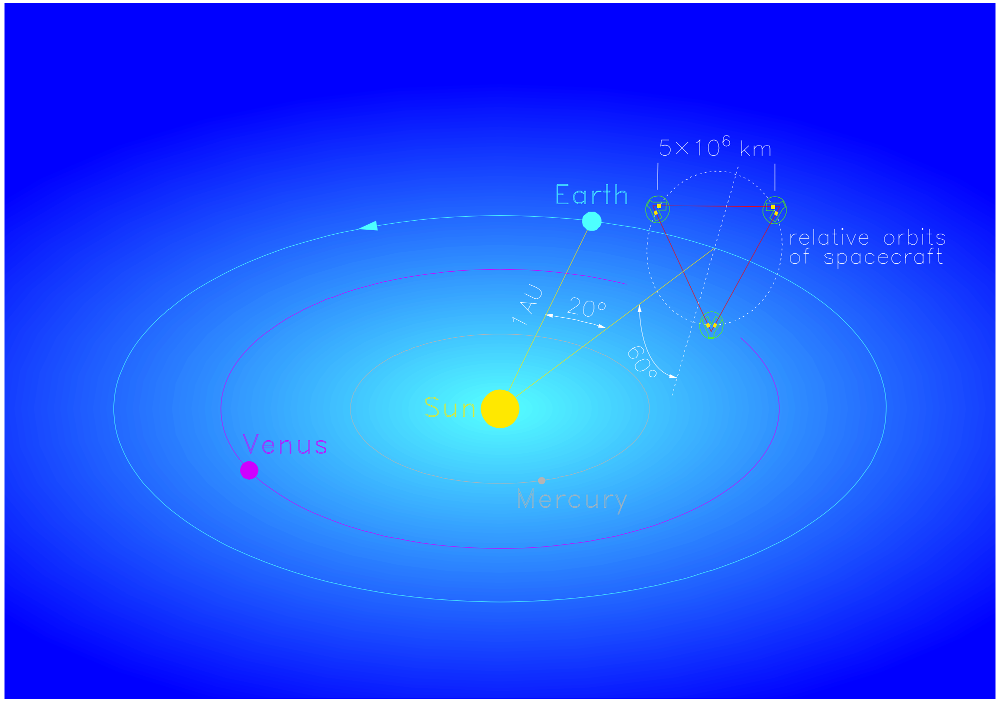
Gravitational Wave Spectrum

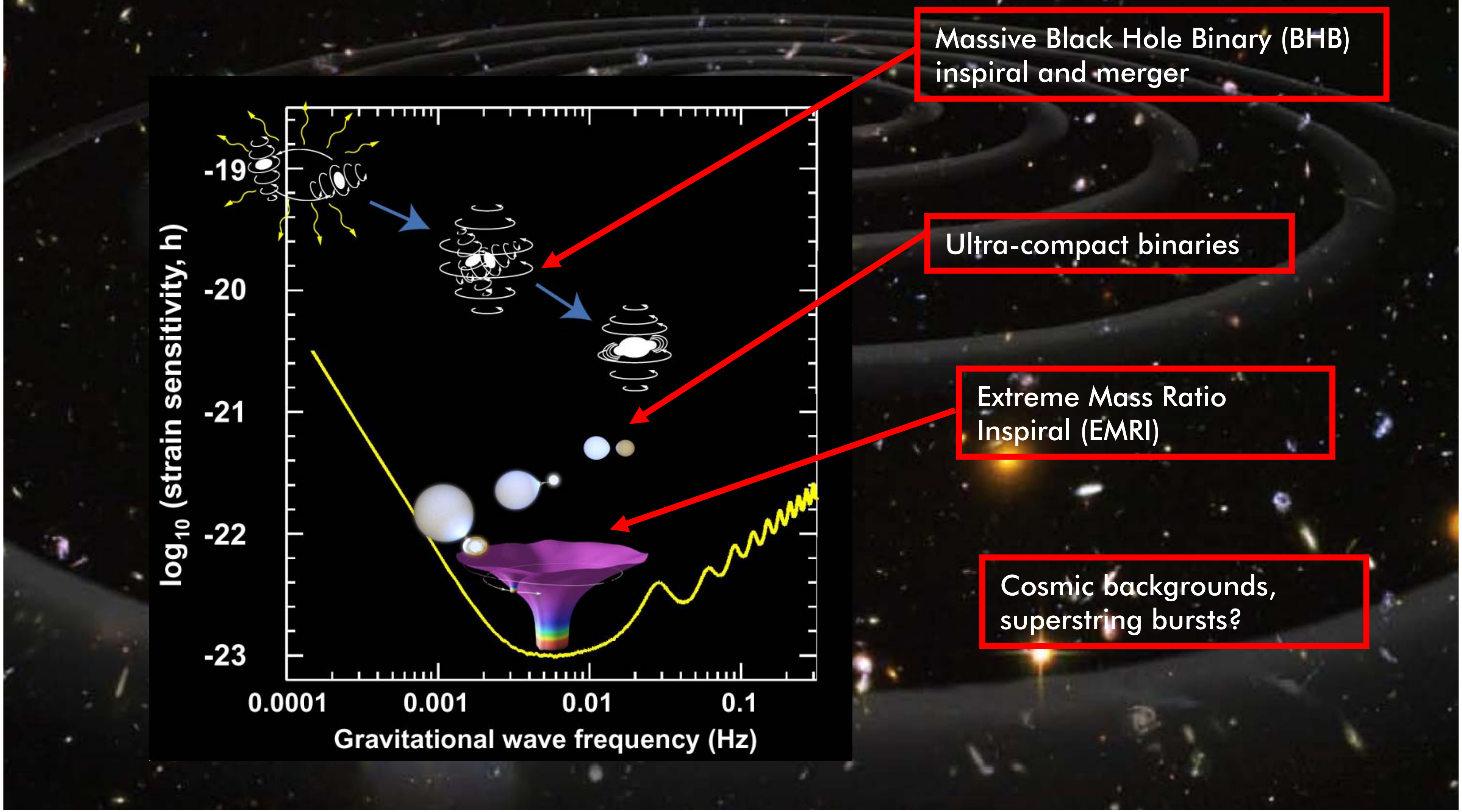


A Collaborative NASA/ESA Mission

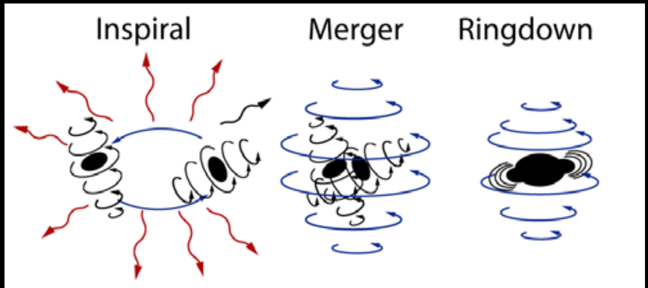
- *Cluster of 3 S/C in heliocentric orbit*
- *Laser interferometer measures distance changes between free flying test masses inside the S/C*
- *Equilateral triangle with 5 million km arms*
- *Trailing the Earth by 20 ° (50 million km)*
- *Inclined against ecliptic by 60 °*

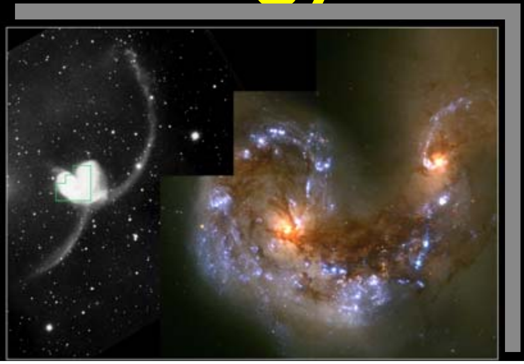


LISA: A Universe Full of Strong GW Sources



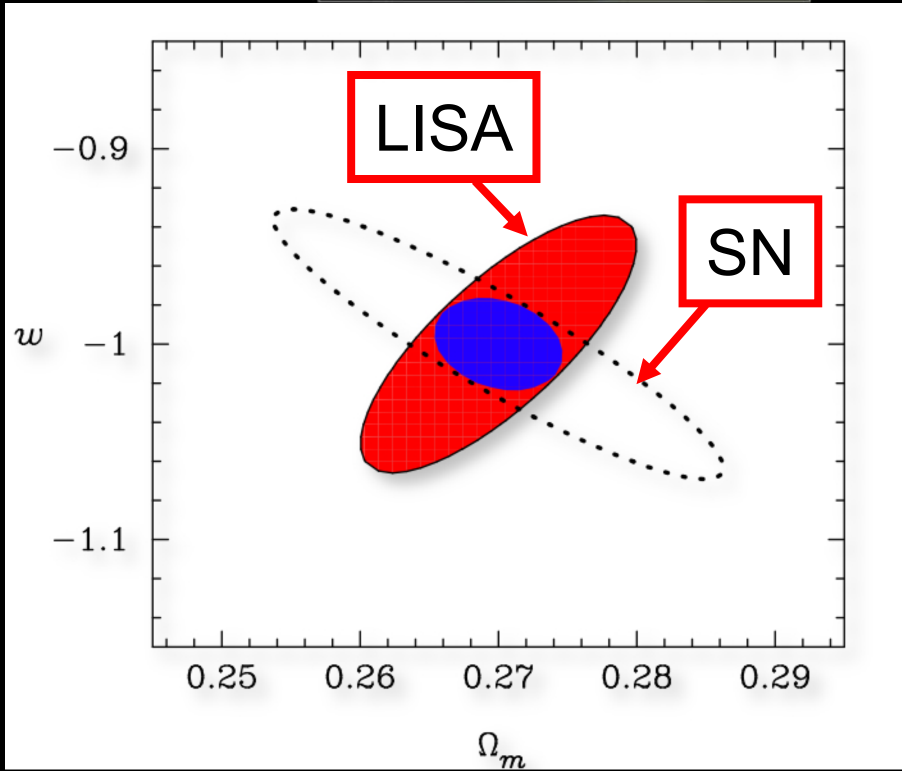
Absolute Distances from SMBH Mergers: Hubble Constant and Dark Energy





H_0 and Dark Energy parameters potentially measured to <1%

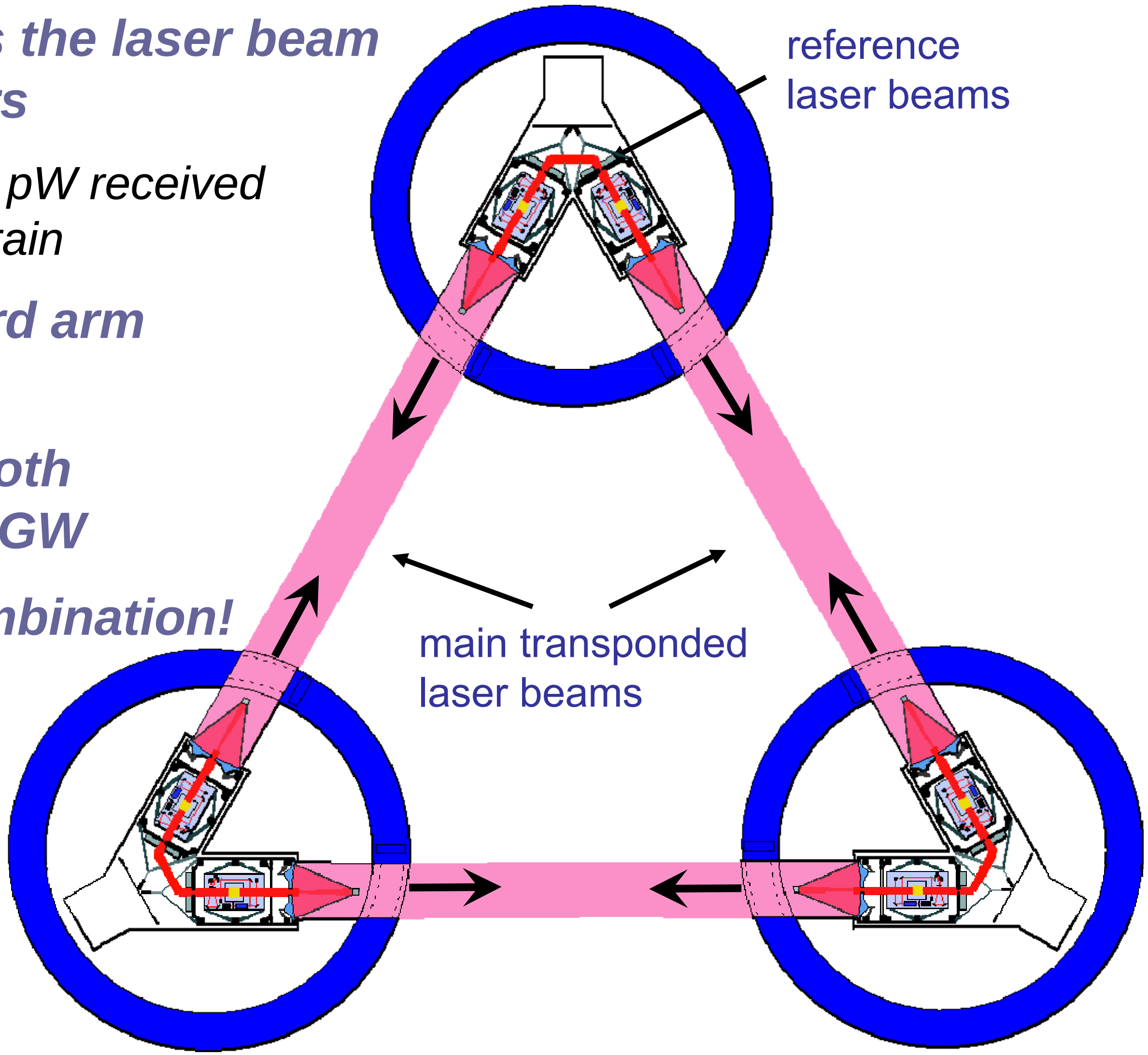
- 100's of events expected to z~3
- ~10's to z~20
- Cosmological distance requires redshift via identification of host
- Noise from weak lensing
- Comparable precision to CMB, WL, BAO, CL, SN techniques
- ***Absolute*** **&** ***independent*** **measurement**



100 BHB, 3000 SNIa (Dalal et al 0601275), includes lensing noise

LISA layout

- *Laser transponder with 6 links, all transmitted to ground*
- *Diffraction widens the laser beam to many kilometers*
  - *1 W sent, still 100 pW received by 40 cm Cassegrain*
- *Michelson with 3rd arm and Sagnac mode*
- *Can distinguish both polarizations of a GW*
- *Can form Null combination!*



NRC Beyond Einstein Review

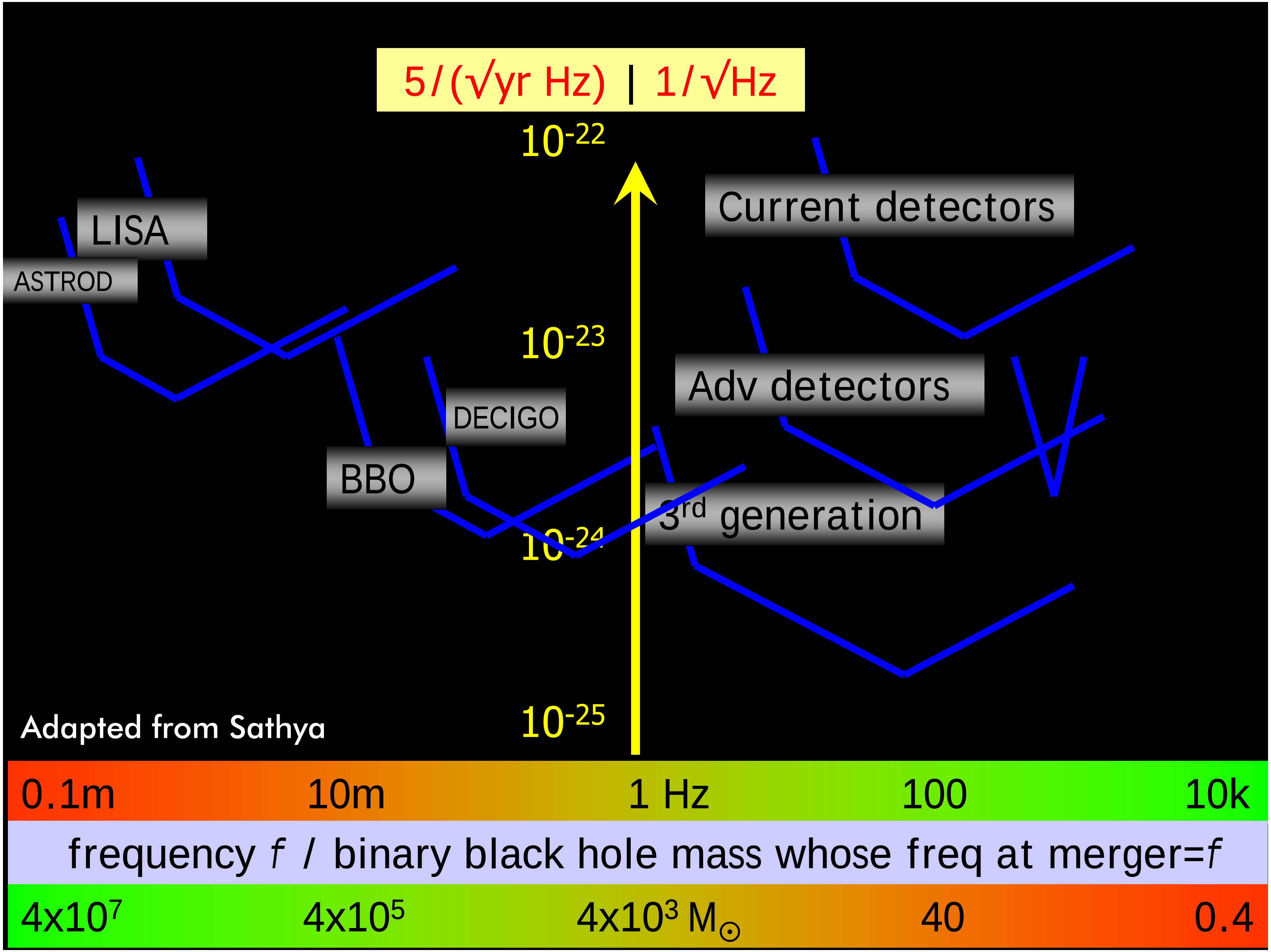
November 6-8, 2006
Washington

BEPAC Recommendations for LISA

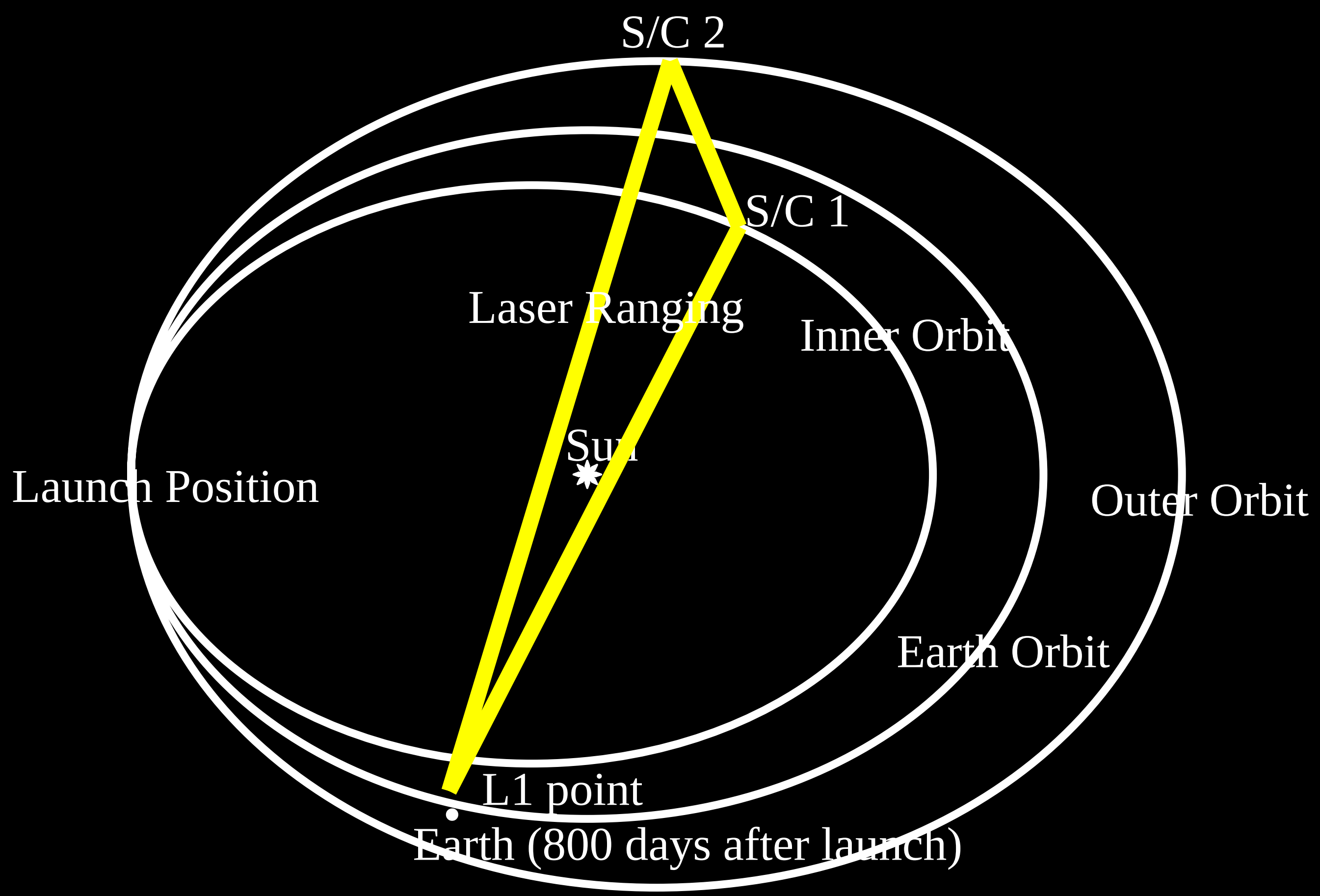
- "On purely scientific grounds LISA is the mission that is most promising and least scientifically risky. Even with pessimistic assumptions about event rates, it should provide unambiguous and clean tests of the theory of general relativity in the strong field dynamical regime and be able to make detailed maps of space time near black holes. ***Thus, the committee gave LISA its highest scientific ranking***."
- " LISA is an extraordinarily original and technically bold mission concept. LISA will open up an entirely new way of observing the universe, with immense potential to enlarge our understanding of physics and astronomy in unforeseen ways. ***LISA, in the committee's view, should be the flagship mission*** of a long-term program addressing Beyond Einstein goals."
- "***NASA should invest additional Beyond Einstein funds in LISA*** technology development and risk reduction, to help ensure that the Agency is in a position to proceed in partnership with ESA to a new start after the LISA Pathfinder results are understood."
- "LISA was recommended second in implementation because of money and programmatics. But even assuming an unnecessarily pessimistic financial contribution from ESA, and being second in Beyond Einstein, the assumed ***launch date of LISA as ESA Cosmic Vision Mission L1 in 2018 is still feasible and the committee strongly recommends that***."

LISA Status

- ***ESA-NASA collaboration agreement since August 2004***
  - *Joint Management Structure working well!*
  - *Mission Formulation Study began in January 2005*
- ***Technology precursor LISA Pathfinder in Phase C/D***
  - *Launch in 2010*
- ***LISA technically well on track for launch in 2015!***
  - *Launch date is determined by budget*
- ***ESA SPC Meeting 22 Feb 2007: LISA L1 launch in 2018!***
- ***NASA Beyond Einstein Review: Report released September 6, 2007***
  - *LISA is Flagship mission! Schedule compatible with ESA!*


5/(√yr Hz) | 1/√Hz
10-22
10-23
10-24
10-25
LISA
ASTROD
DECIGO
BBO
Current detectors
Adv detectors
3rd generation
Adapted from Sathya
0.1m
10m
1 Hz
100
10k
frequency f / binary black hole mass whose freq at merger=f
4x10^7
4x10^5
4x10^3 M⊙
40
0.4

ASTROD Mission Concept



from W T Ni

ASTROD scientific objectives

- Test Relativistic gravity with 3-5 orders of magnitude improvement in sensitivity. That includes the measurement of relativistic parameters β, γ, measurement of dG/dt, and the anomalous constant acceleration towards the Sun (Pioneer anomaly).
- Improvement by 3-4 orders of magnitude in the measurements of solar, planetary and asteroids parameters. That also includes a measurement of solar angular momentum via Lense-Thirring effect and the detection of solar g-modes by their changing gravity field.
- Detection of low frequency gravitational waves (5 μHz-5 mHz) from massive black hole and galactic binary stars. Background gravitational waves will also be explored.

from W T Ni

ASTROD technological requirements

- Weak-light phase locking to 100 fW.
- Heterodyne interferometry and data analysis for unequal-arm interferometry.
- Coronagraph design and development: sunlight in the photodetectors should be less than 1 % of the laser light.
- High precision space clock and/or absolute stabilized laser to 10^{-17}.
- Drag-free system. Accelerometer noise requirement: $(0.3\text{-}1)\times10^{-15}[1+10\times(f/3\text{mHz})^2]$ $\text{ms}^{-2}\text{Hz}^{-1/2}$ at $0.1 \text{ mHz} < f < 100 \text{ mHz}$.
- Laser metrology to monitor position and distortion of spacecraft components for gravitational modeling.

from W T Ni

Technological requirements: ASTROD (I) drag-free

ASTROD I acceleration noise of free fall test masses

$$\frac{S_{f_x}^{1/2}}{m} \approx 3\times10^{-14}\left[\left(\frac{0.3mHz}{f}\right)+30\left(\frac{f}{3mHz}\right)^2\right] ms^{-2}Hz^{-1/2}$$

$$10^{-4}\,Hz \le f \le 0.1\,Hz$$

LISA acceleration noise of free fall test masses

$$\frac{S_{f_x}^{1/2}}{m} \le 3\times10^{-15}\left[1+\left(\frac{f}{3mHz}\right)^2\right] ms^{-2}Hz^{-1/2}$$

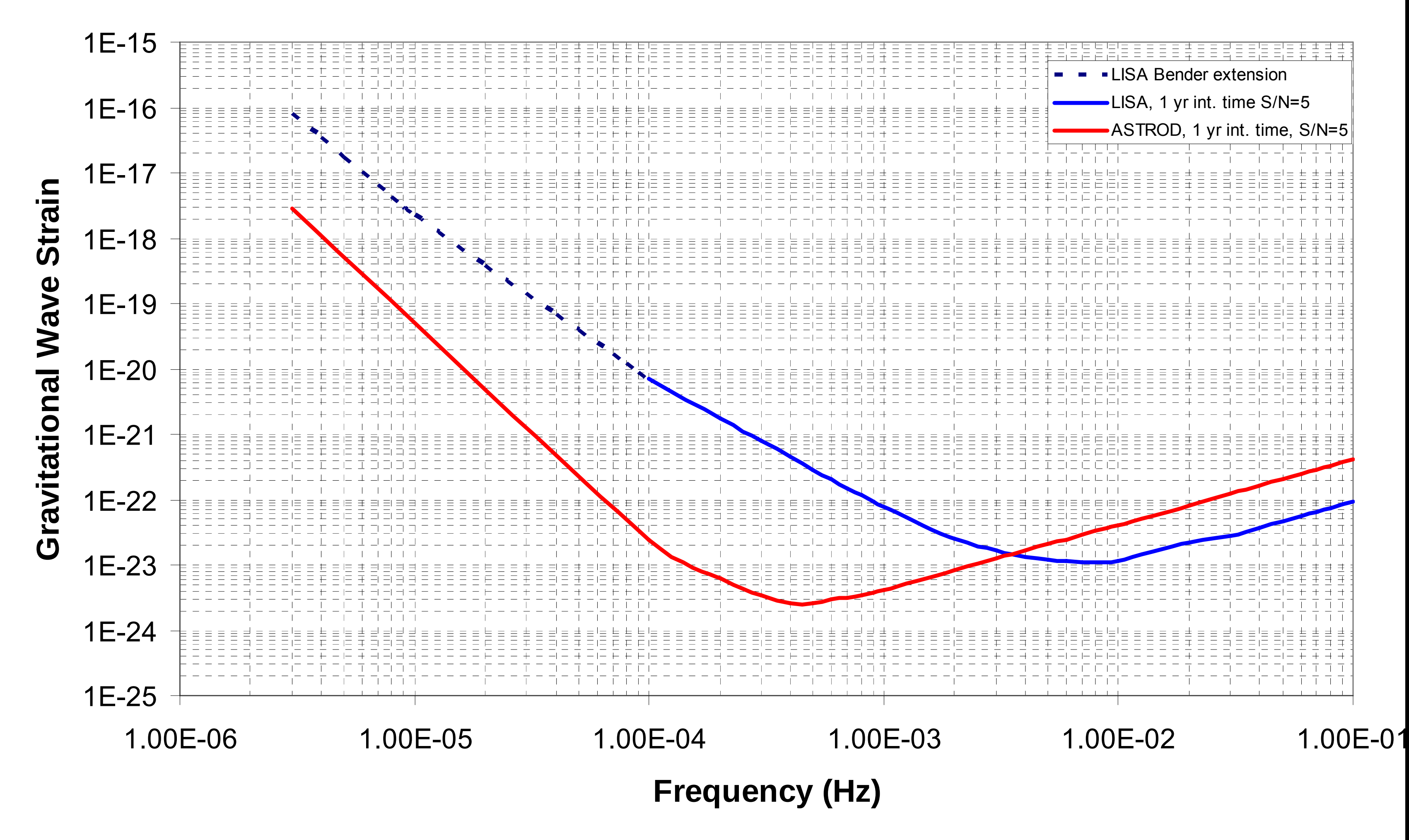
$$10^{-4}\,Hz \le f \le 0.1\,Hz$$

ASTROD aims to improve LISA acceleration noise at **0.1 mHz** by a factor 3-10, i.e., approx. **$0.3\text{-}1\times10^{-15}$ ms^{-2} Hz$^{-1/2}$.**

ASTROD bandwidth 5 μHz≤*f*≤5mHz

from W T Ni

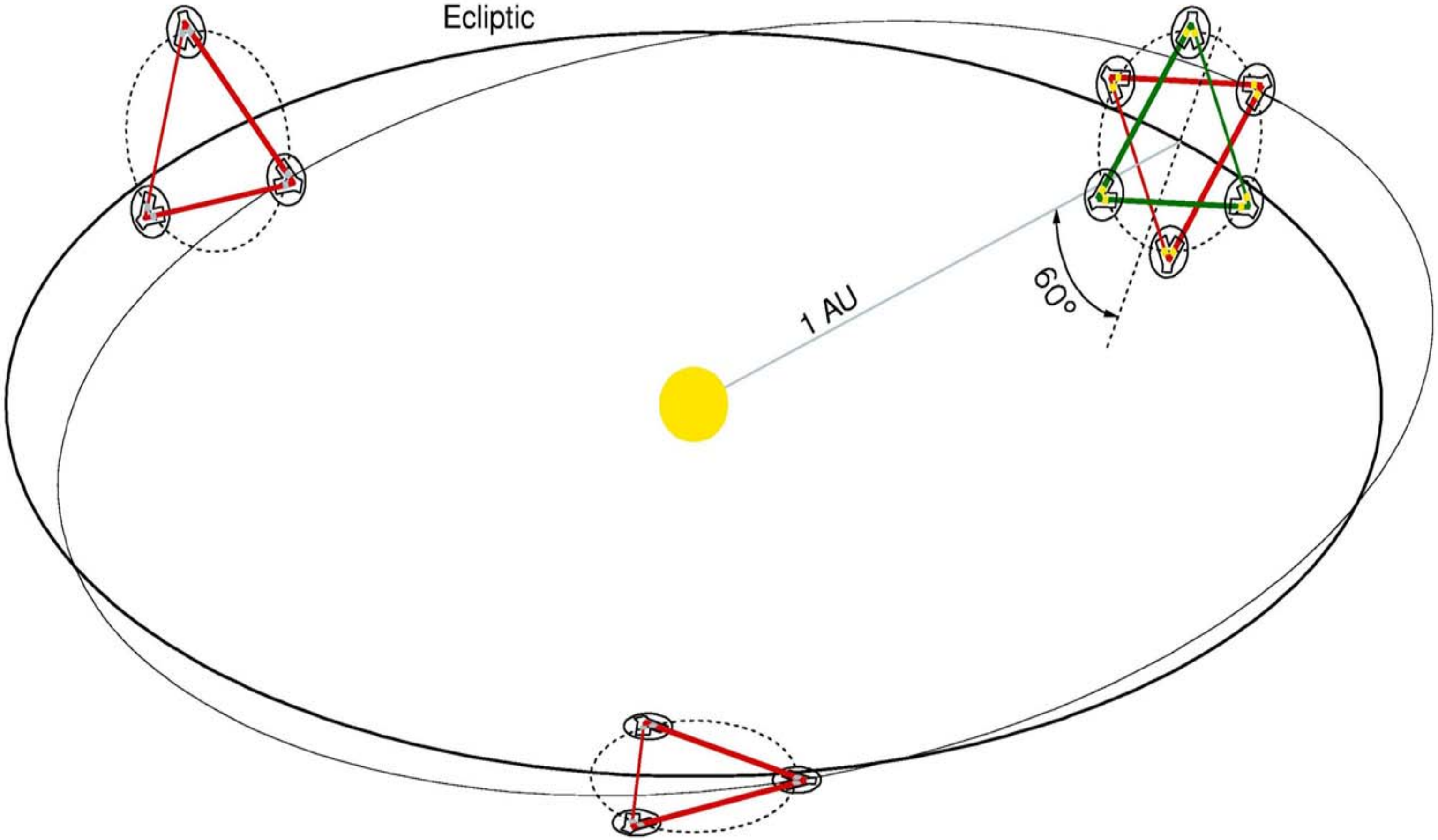
LISA and ASTROD GW strain sensitivity (S/N≈5, int. time 1yr)



from W T Ni

Very Large Baseline Interferometry

- VLBI with Gravitational Waves to improve resolution
- Resolve and remove every compact binary in the Universe!

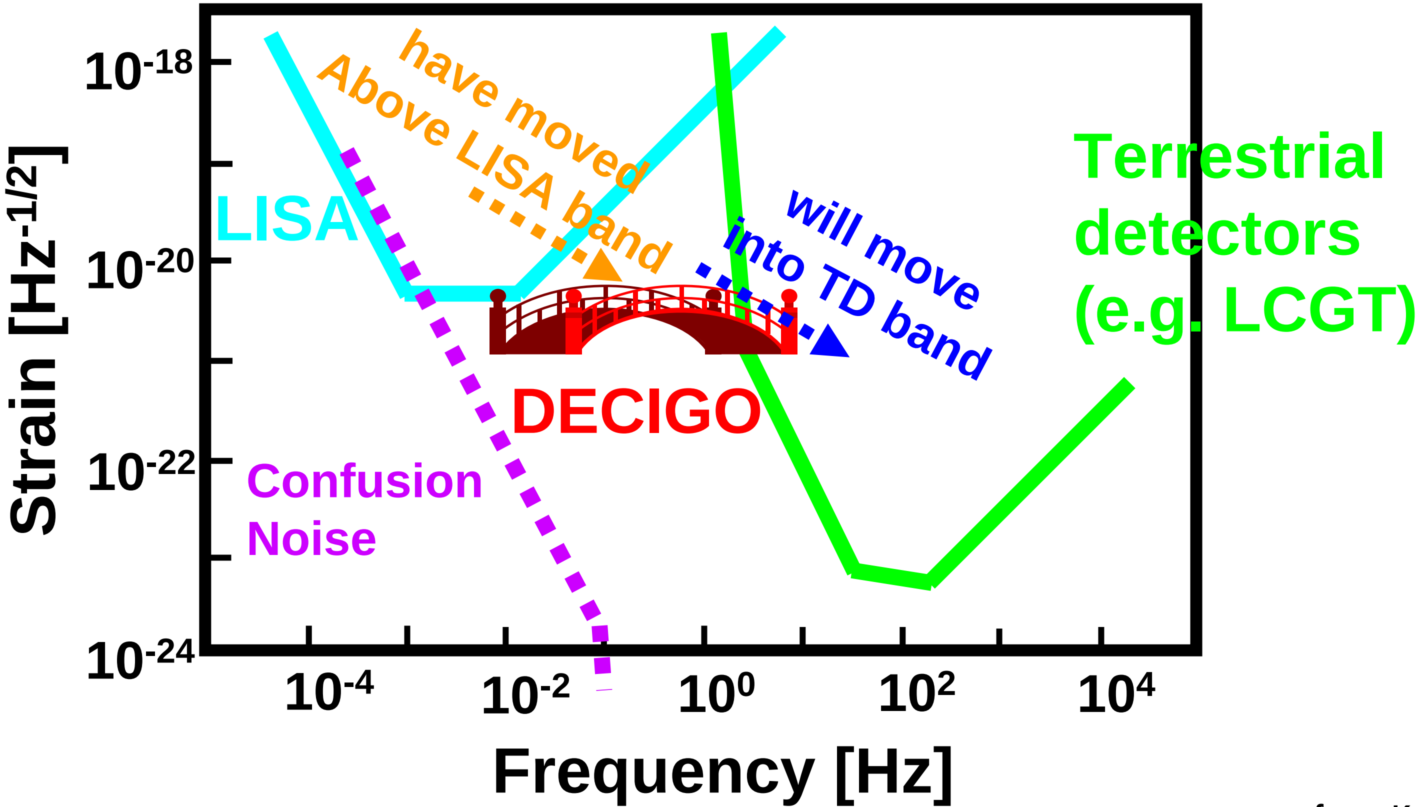


What is DECIGO?

Deci-hertz Interferometer Gravitational Wave Observatory

(Kawamura, et al., CQG 23 (2006) S125-S131)

- **Bridges the gap between LISA and terrestrial detectors**
- **Low confusion noise ⇒ Extremely high sensitivity**

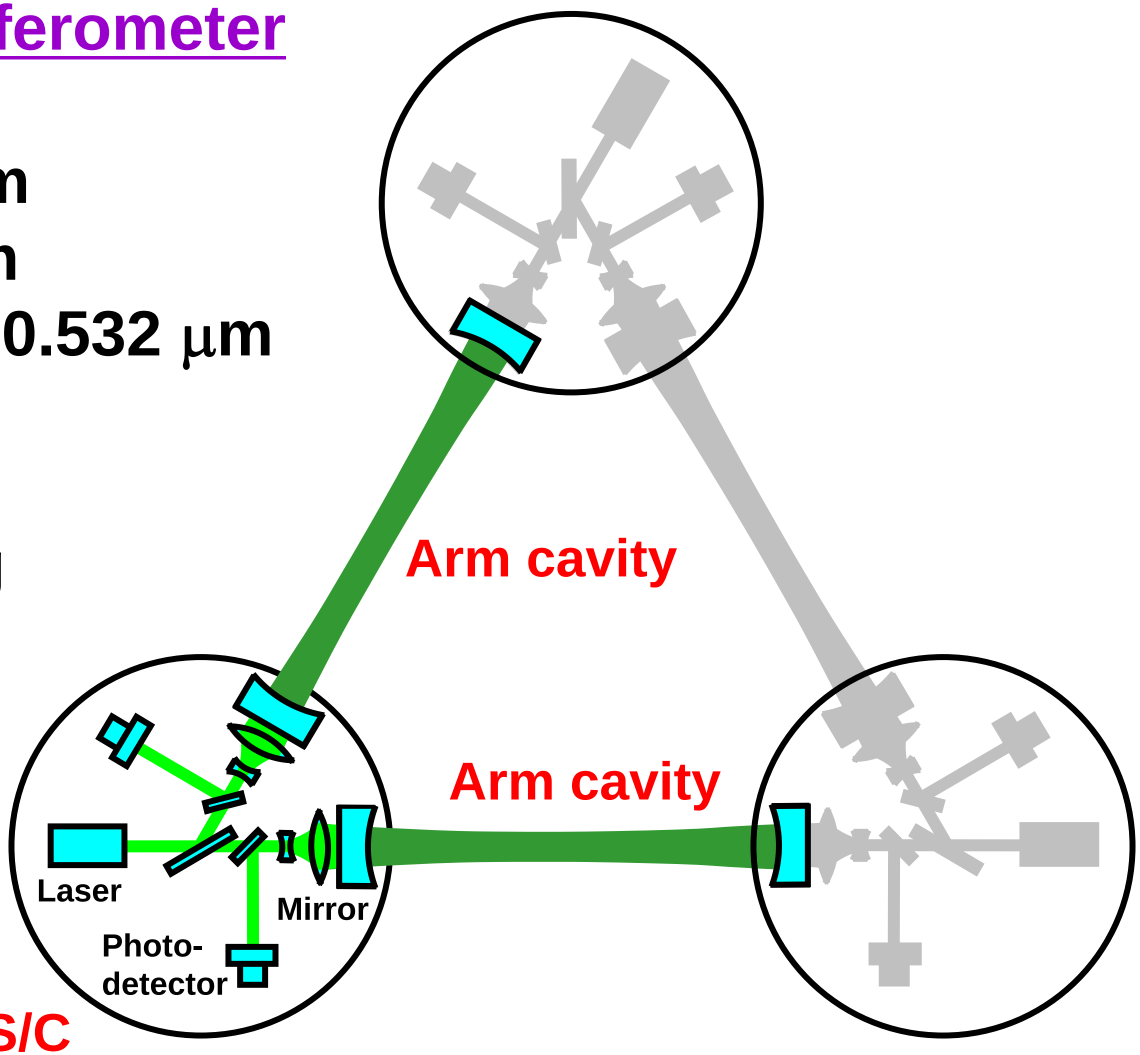


from Kawamura

Pre-conceptual design

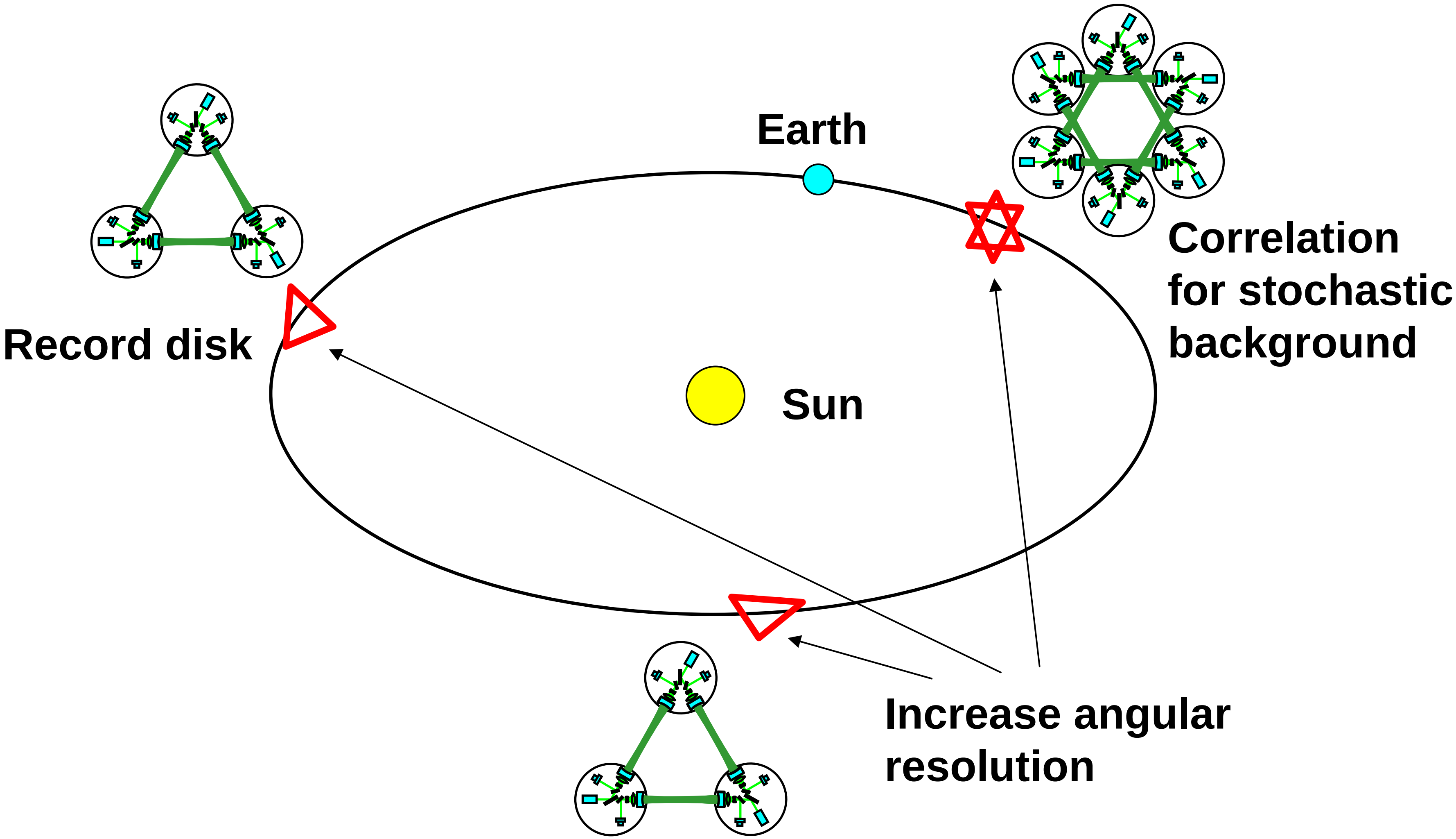
Differential FP interferometer

Arm length: 1000 km
Mirror diameter: 1 m
Laser wavelength : 0.532 μm
Finesse: 10
Laser power: 10 W
Mirror mass: 100 kg
S/C: drag free
3 interferometers



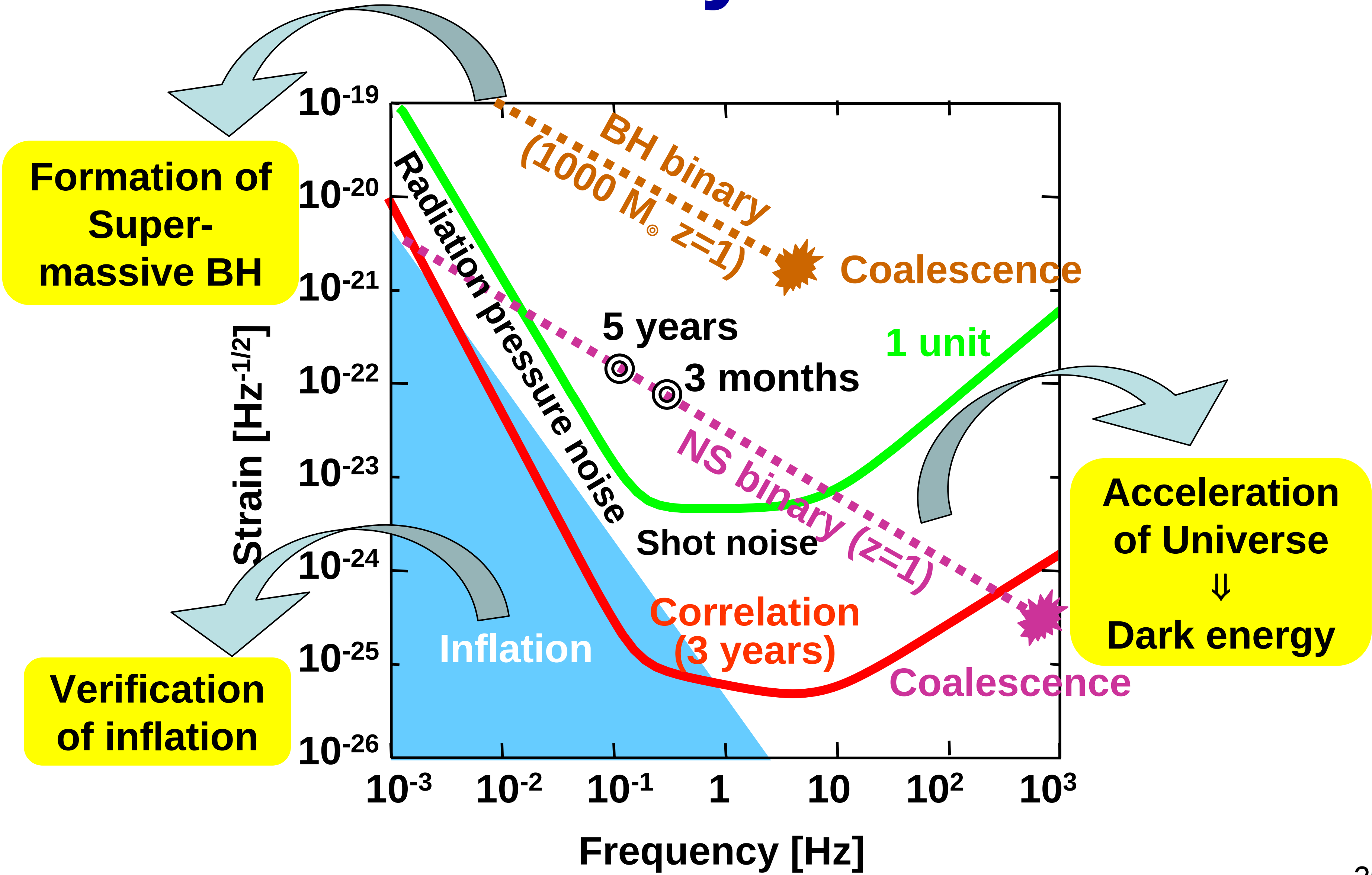
from Kawamura

Orbit and constellation (preliminary)



from Kawamura

Goal Sensitivity and Science



from Kawamura

Requirements

- Acceleration noise should be suppressed below radiation pressure noise
  - Force noise: DECIGO = LISA/50

    (Acceleration noise in terms of h: 1, Distance: 1/5000, Mass: 100)
  - Fluctuation of magnetic field, electric field, gravitational field, temperature, pressure, etc.
- Sensor noise should be suppressed below shot noise.
  - Phase noise: DECIGO = LCGT×10

    (Sensor noise in terms of h: 1, storage time: 10)
  - Frequency noise, intensity noise, beam jitter, etc.
- Thruster system should satisfy range, noise, bandwidth, and durability.

from Kawamura

Very Large Baseline Interferometry with BBO

- Big Bang Observer
- Very similar to DECIGO, but factor 10 lower frequencies (10 mHz to a few Hz)
- No Fabry-Perot Cavities
- 50 000 km arms
- $3x10^{-17}$ m/s^2/rtHz
- 300 W of 532 nm lasers
- 3.5 m mirrors

Let us not forget CMBPol!

- Formerly called Inflation probe
- Not a laser interferometer
- But looking at very low frequency GWs around 10^{-16} Hz
- And probably has best shot at GWs from slow-roll inflation