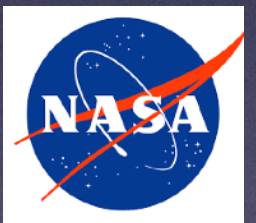


A landscape of possible higher-resolution mHz gravitational-wave missions

John Baker

Laboratoire des 2 Infinis — Toulouse. (Université de Toulouse/CNRS/IN2P3)

plus Bernard J. Kelly, Tonia M. Venters, Eleonora Castelli, Cecilia Chirenti, Zachary Nasipak, Scott Noble, Jacob Slutsky, Ira Thorpe, ++

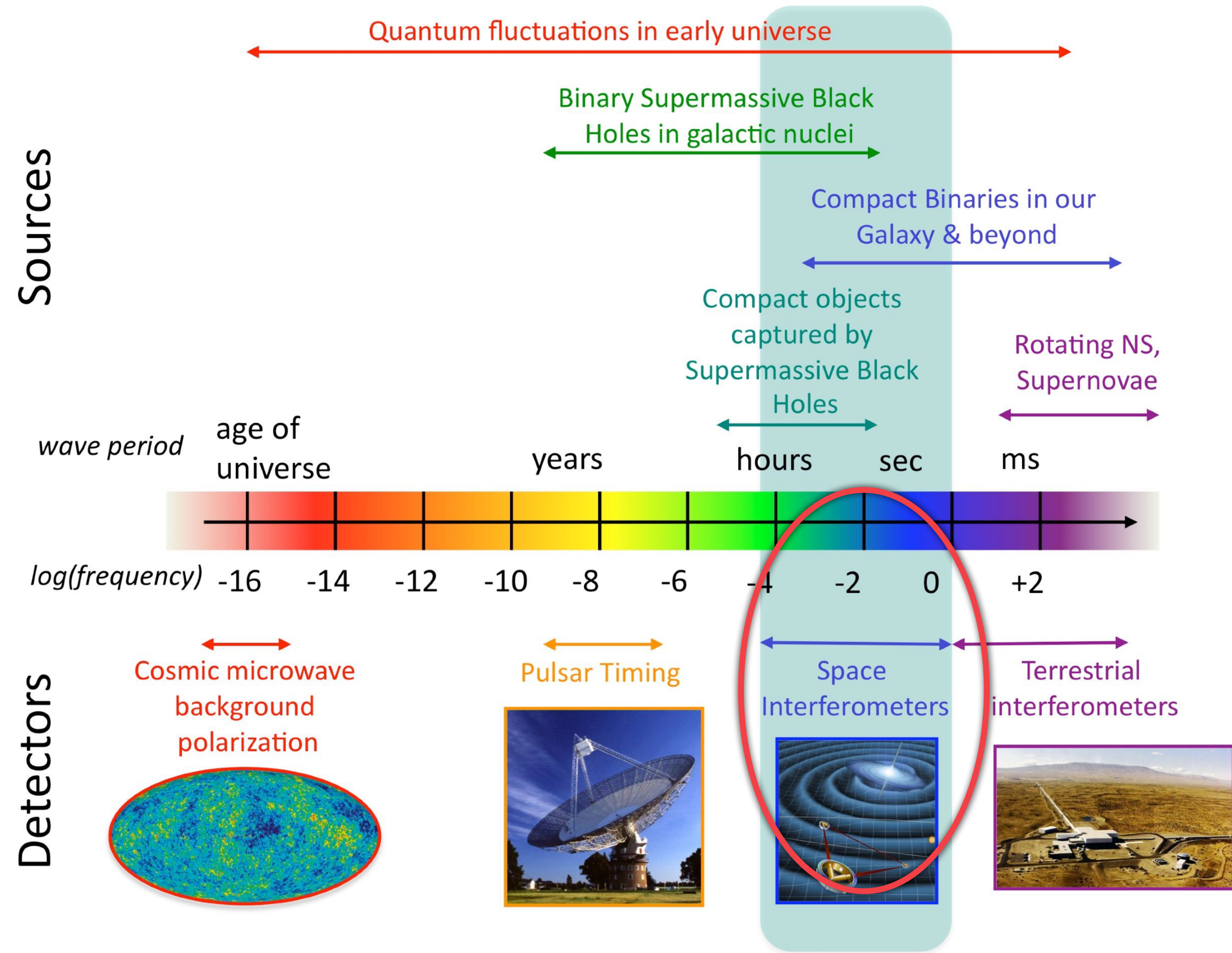


Dixième Assemblée Générale du GdR Ondes Gravitationnelles 5-6 Oct 2026

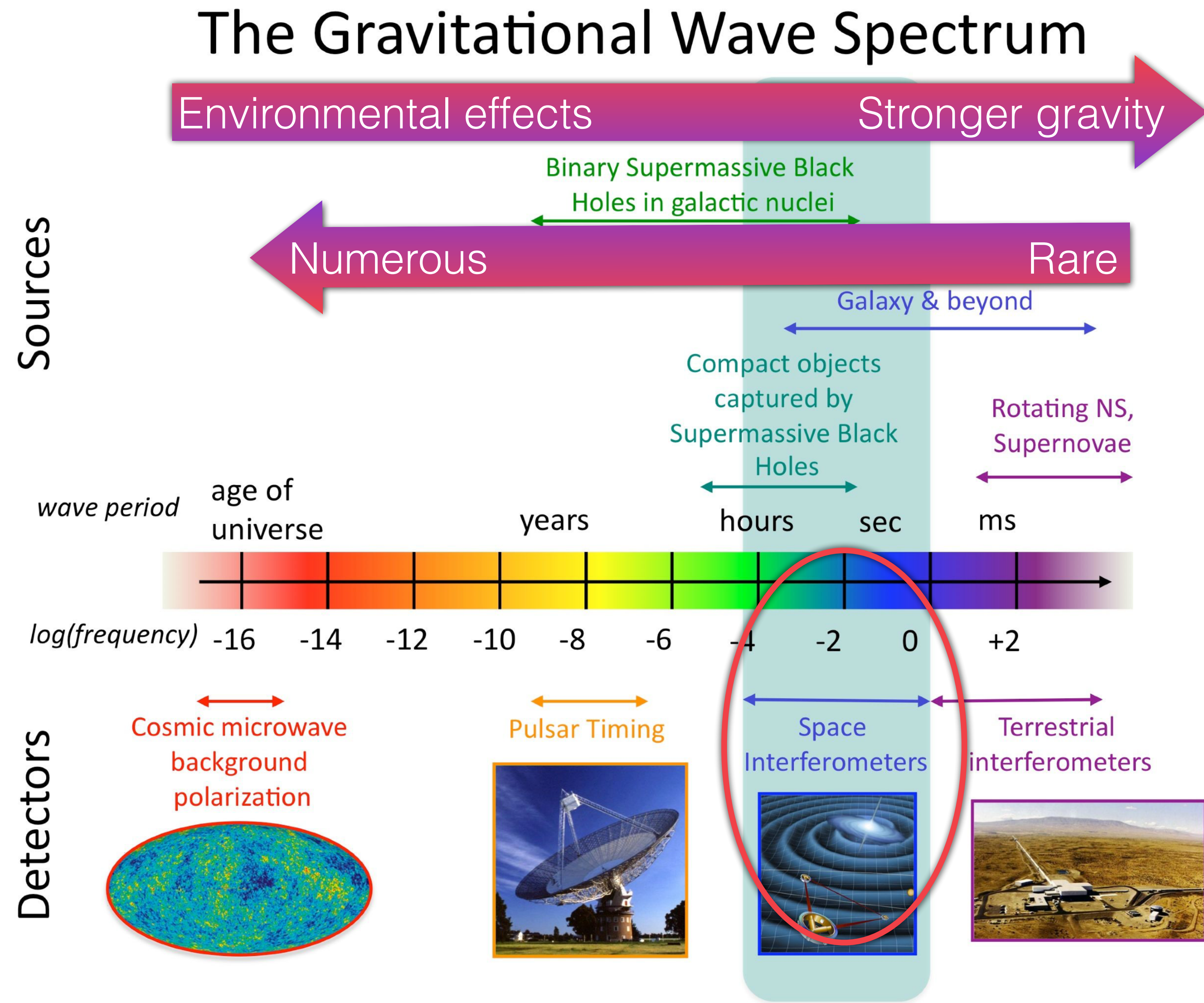


GWs in mHz!

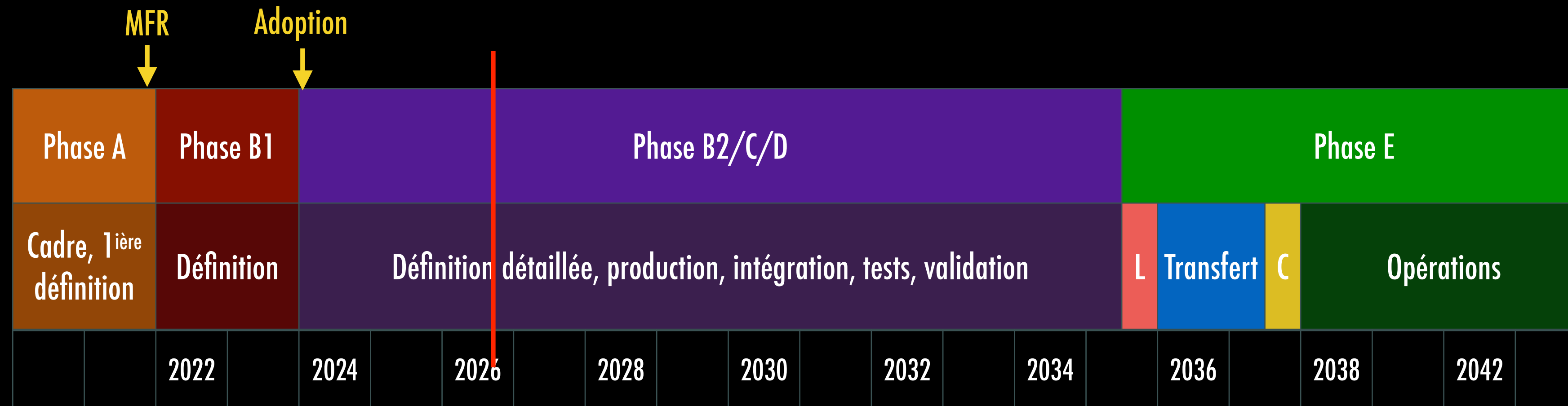
The Gravitational Wave Spectrum



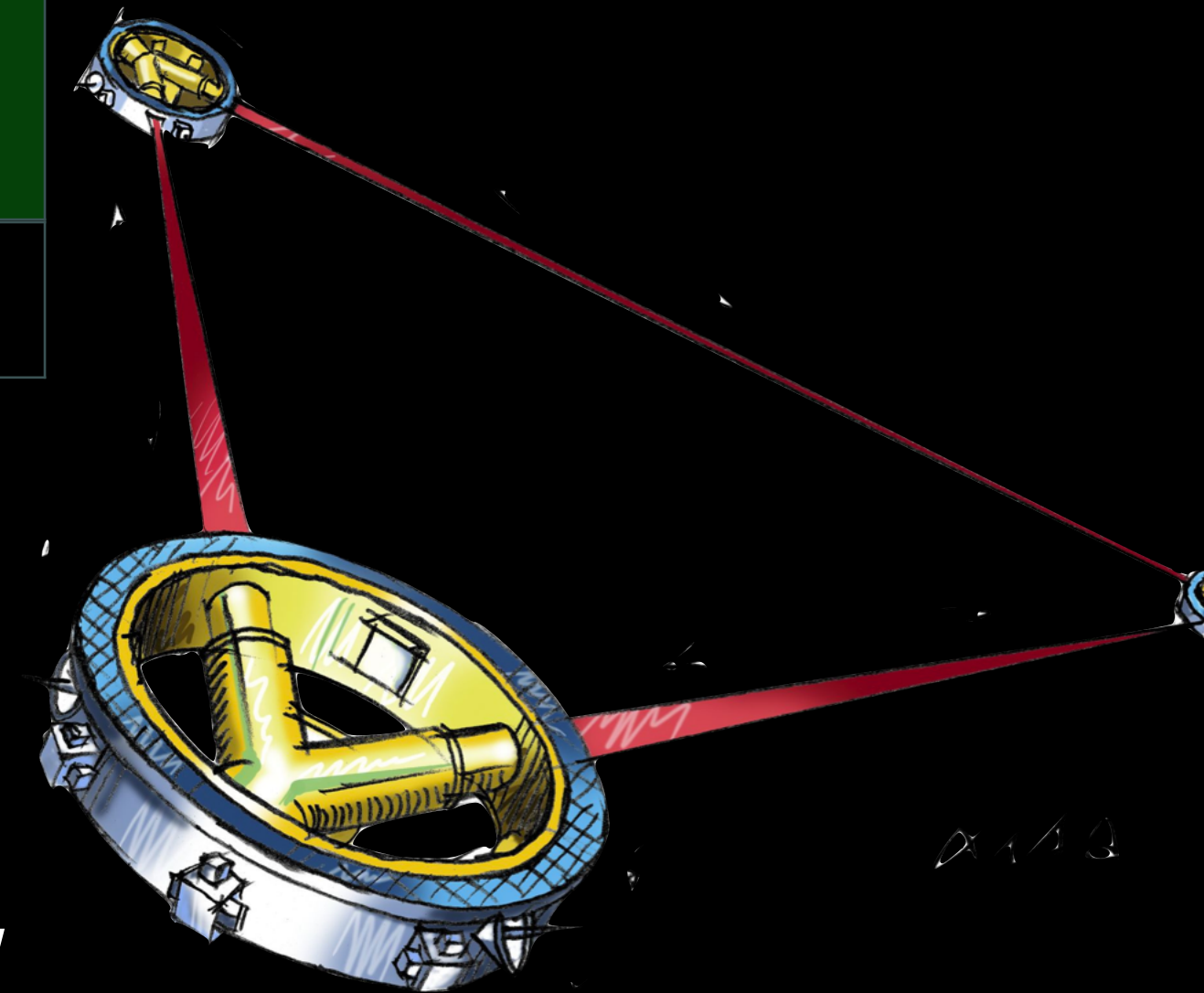
GWs in mHz!



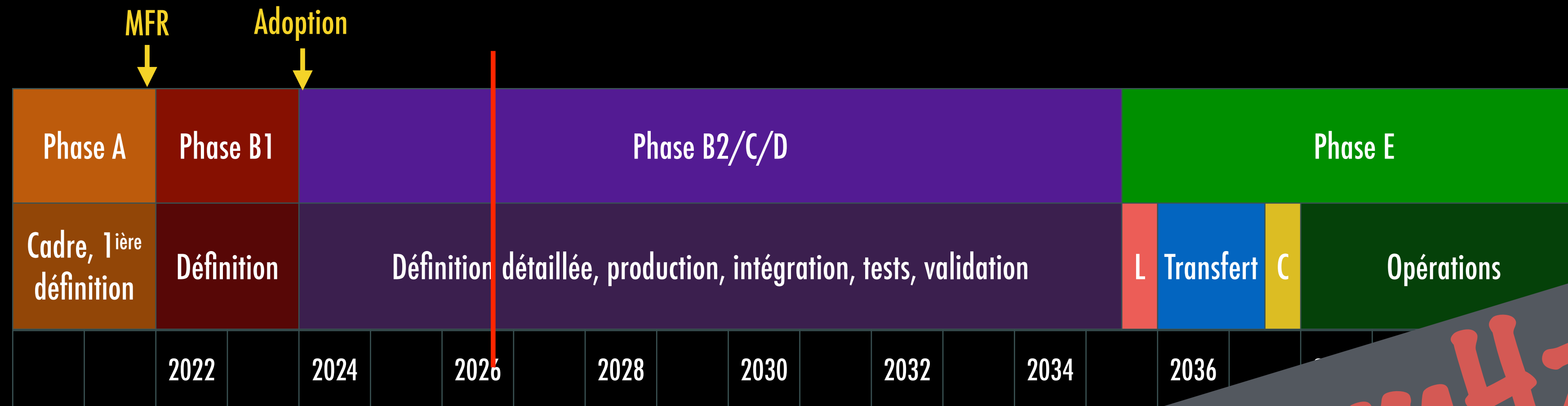
The roadmap to LISA



- ▶ 1993: First proposal to ESA and NASA
- ▶ 2016: LISA Pathfinder (ESA+NASA) successfully demonstrates LISA-like test-mass technology
- ▶ 2017: LISA mission approved by ESA after LISA Pathfinder and the first detection of GWs.
- ▶ 2018: GRACE Follow-On (NASA+Germany): successfully demonstrates LISA-like interferometry
- ▶ 2024: success of the Mission Adoption Review and adoption by ESA: design validated and we have the resources to build the instrument
- ▶ Long building phase of optical assemblies (6 flight models) + spacecrafts + data processing sys
- ▶ Launch 2035
- ▶ 1.5 years of orbital transfer
- ▶ 4.5 years of nominal mission + 6.5 years of possible extension

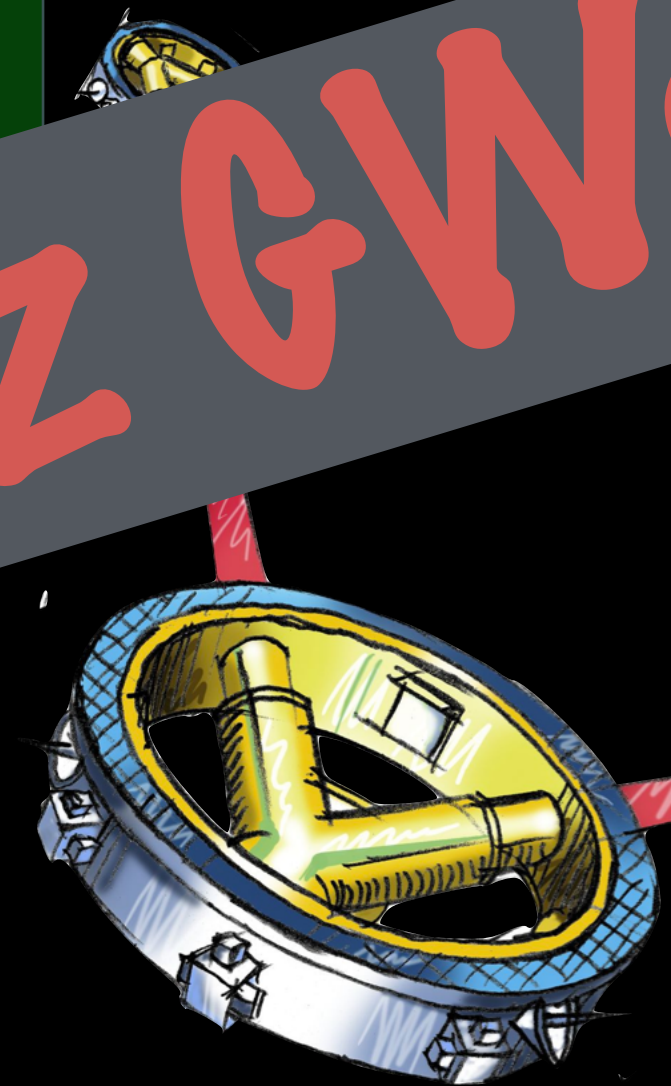


The roadmap to LISA



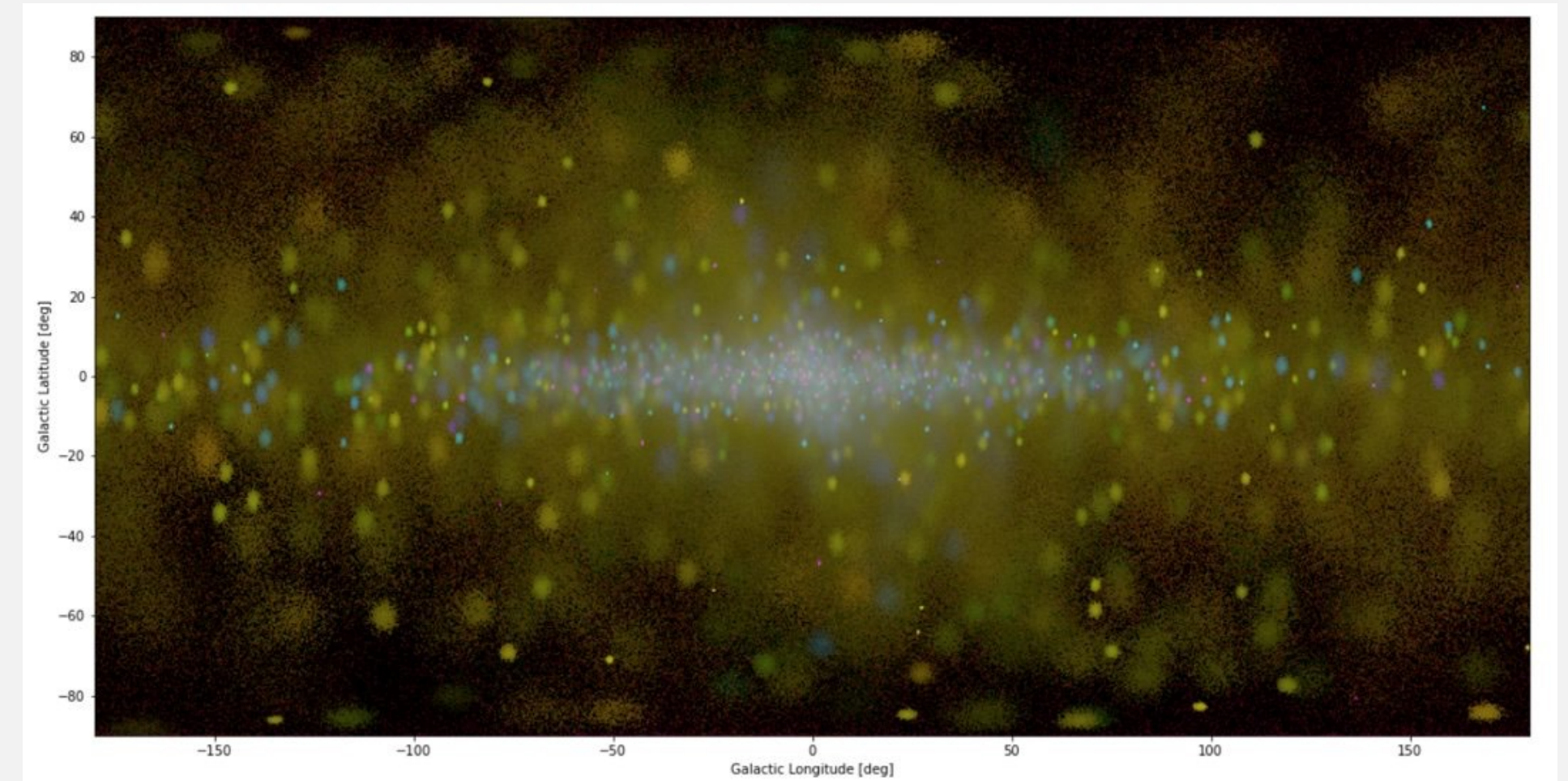
- ▶ 1993: First proposal to ESA and NASA
- ▶ 2016: LISA Pathfinder (ESA+NASA) successfully demonstrates LISA-like technology
- ▶ 2017: LISA mission approved by ESA and NASA for the first detection of GWs.
- ▶ 2018: GRACE-FO successfully demonstrates LISA-like interferometry
- ▶ 2020: Mission Review and adoption by ESA: design validated and we will build the instrument
- ▶ Launch 2035
- ▶ 1.5 years of orbital transfer
- ▶ 4.5 years of nominal mission + 6.5 years of possible extension

What comes next for mHz GWs?

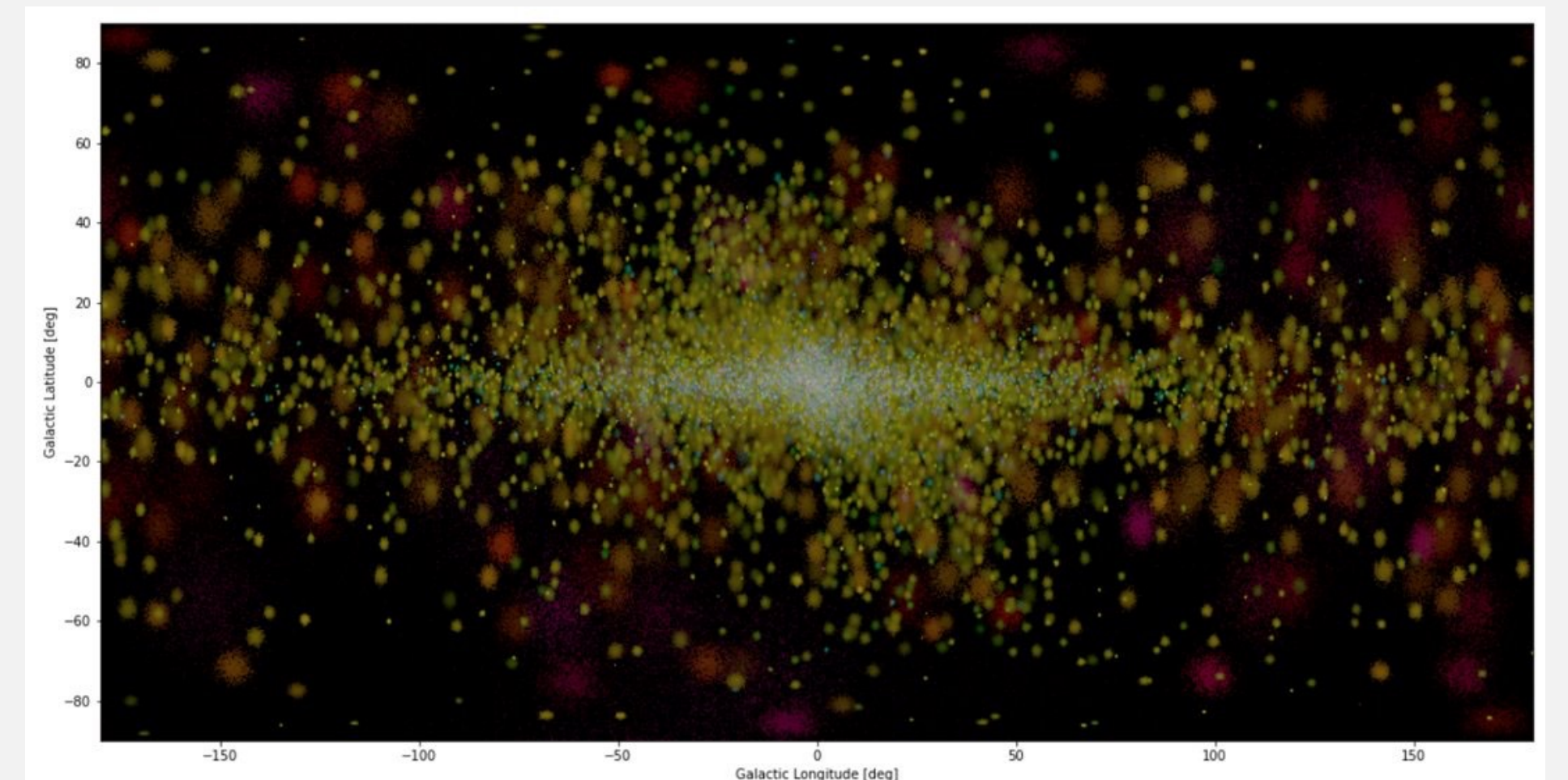


A NATURAL FUTURE MHZ GW DIRECTION: **BETTER RESOLUTION!**

- Science key:
 - Accurate localization provides a permanent connection with other astronomy info!
 - E.g. 'A binary merged' —> '*That* binary merged!'



Milky Way with LISA (simulated)



Milky Way with 10x LISA resolution (simulated)

What is better resolution?

- **Angular resolution:**

- Ability to distinguish nearby points in a image

- Ideally diffraction limited: Rayleigh criterion:

$$\delta\alpha \approx 1.22 \frac{\lambda}{D_{size}}$$

- Image is formed by power distribution

- >GW sensitivity $\sim 1/R_{dist}^2$

- eg. stochastic GWB inhomogeneity, MW galaxy binary confusion

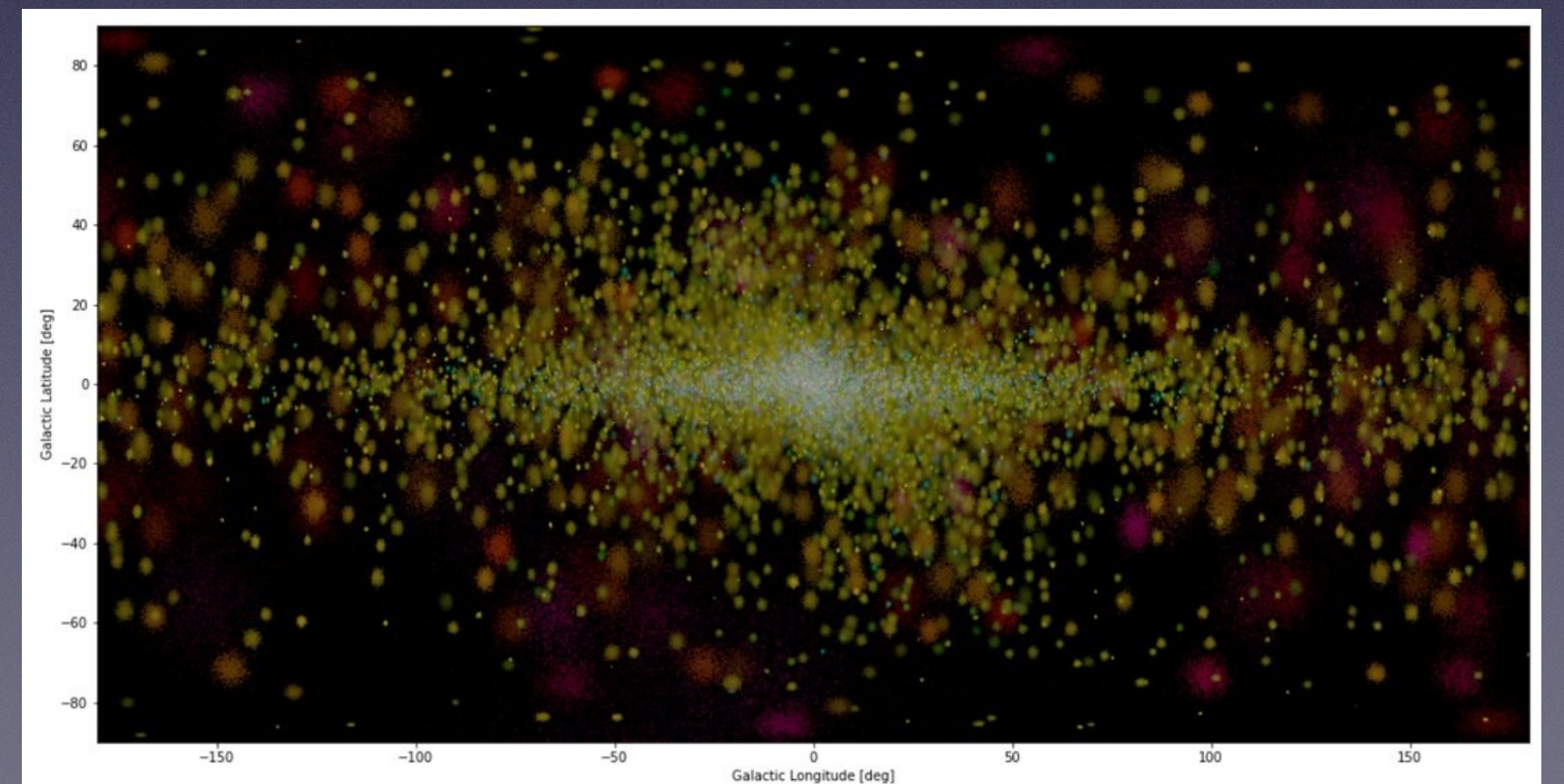
- **Astrometric localization:**

- applicable to a point source

$$\delta\alpha \approx \frac{C_1}{\rho_{SNR}} \frac{\lambda}{D_{size}} = \frac{C_1}{\rho_{SNR}} \frac{c}{\omega_{GW} D_{size}}$$

- e.g. Bayesian inference sky localization

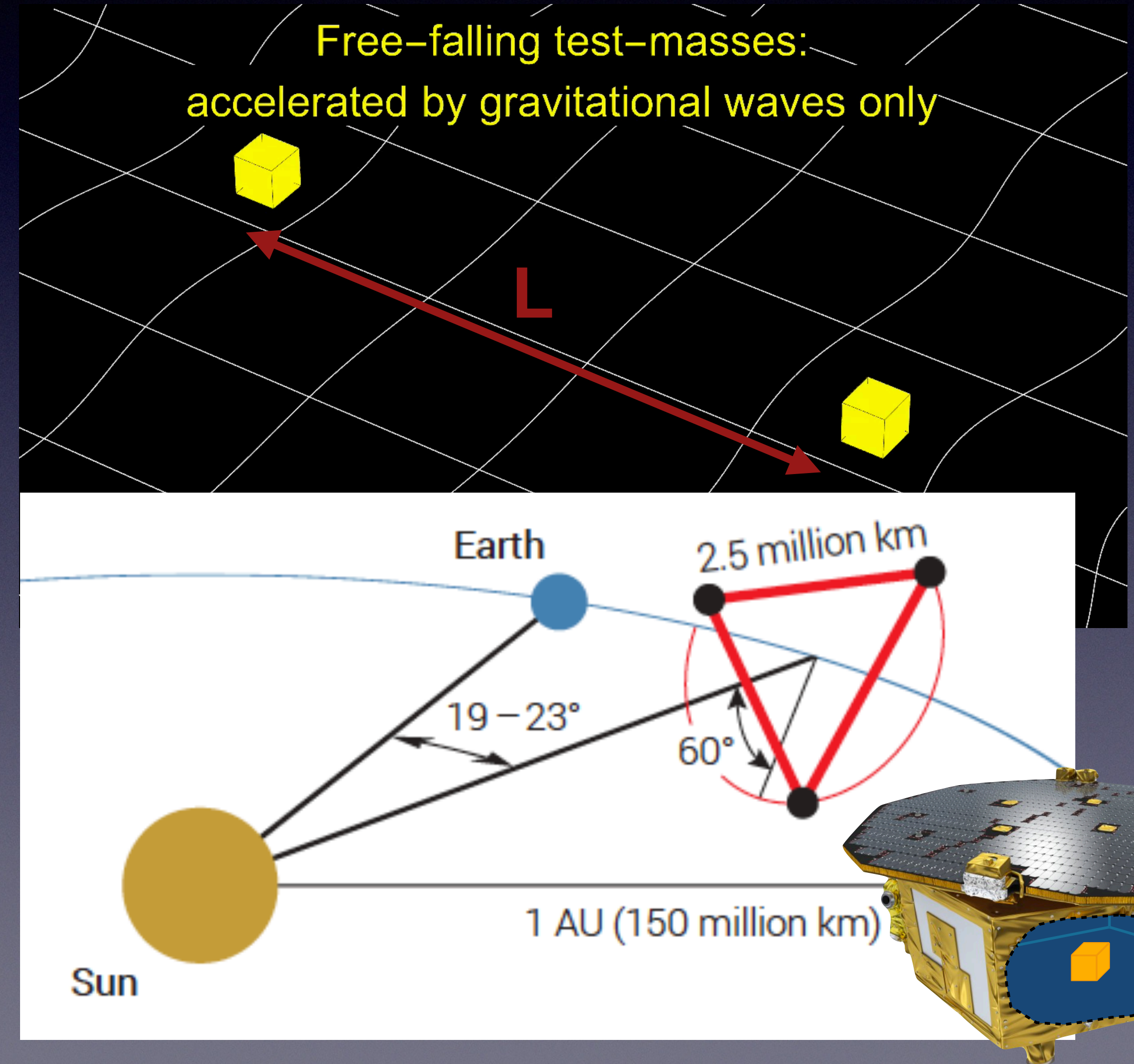
- can also synthesize image from localized point sources —>



Basic mHz GW Mission Concept

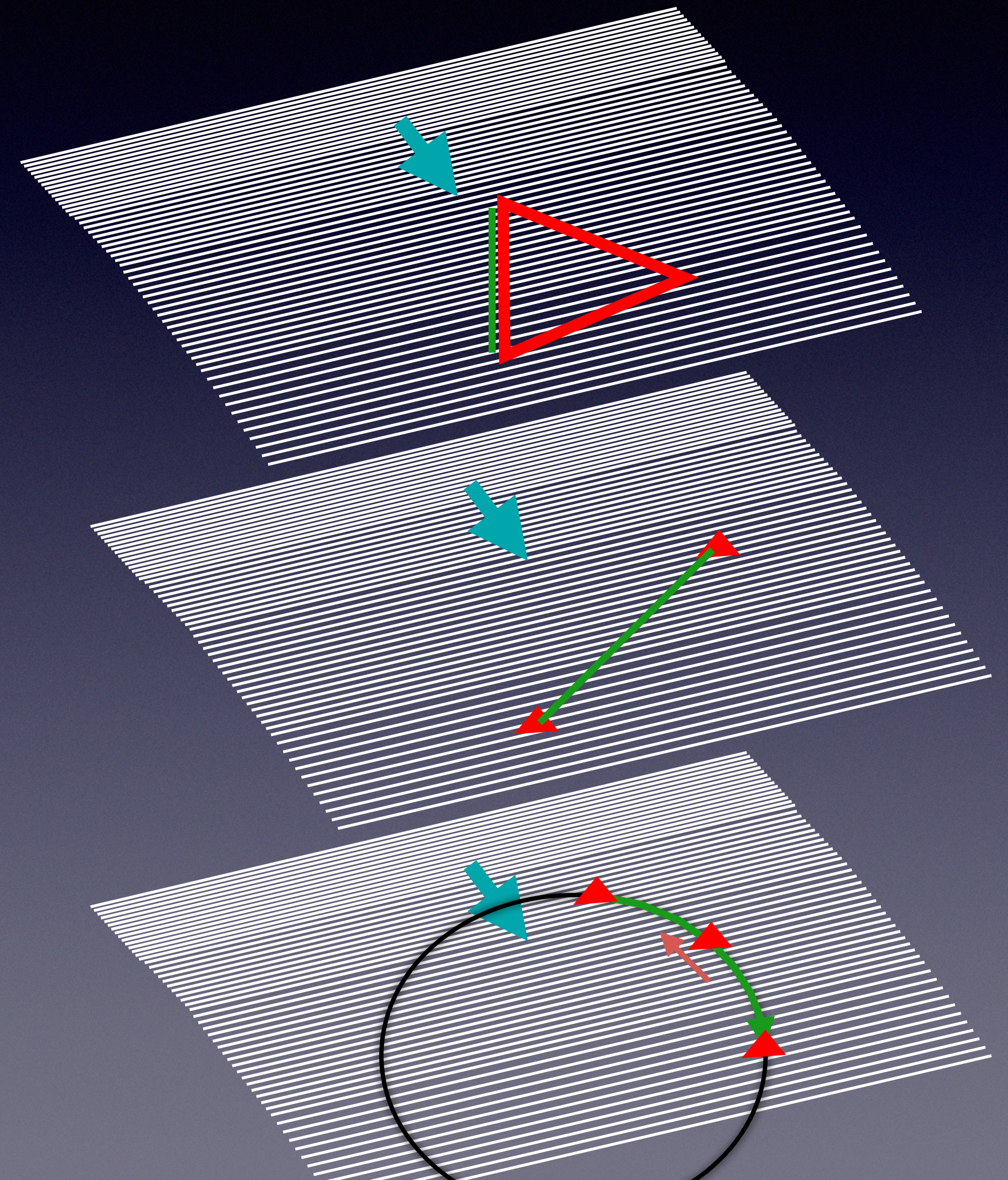
- **Basic requirement:**
Precisely measure the relative motion of free-falling masses
- **Extremely precise measurement:**
using laser interferometry: $\Delta L/L \lesssim 10^{-20}$
- **Extremely freely falling masses:**
tiny non-gravitational force accelerations
- **LISA solution:**
 - $L \sim 2.5$ million km
 - $\Delta L \sim 10^{-11}$ m
 - $a \sim 3 \times 10^{-15}$ m/s²

Must be in space!



Ways to locate sources

- **Relevant for short chirps:**
 - **1** Triangulation within the **constellation**
—> effective size is **arm-length**
 - **2** Between **multiple constellations**
(like L-V-K, not relevant for LISA alone)
—> effective size is **separation** distance
- **Relevant for long-duration signals:**
 - **3** Across LISA's **orbit** through the year
—> effective size is up to ~ **A.U.**



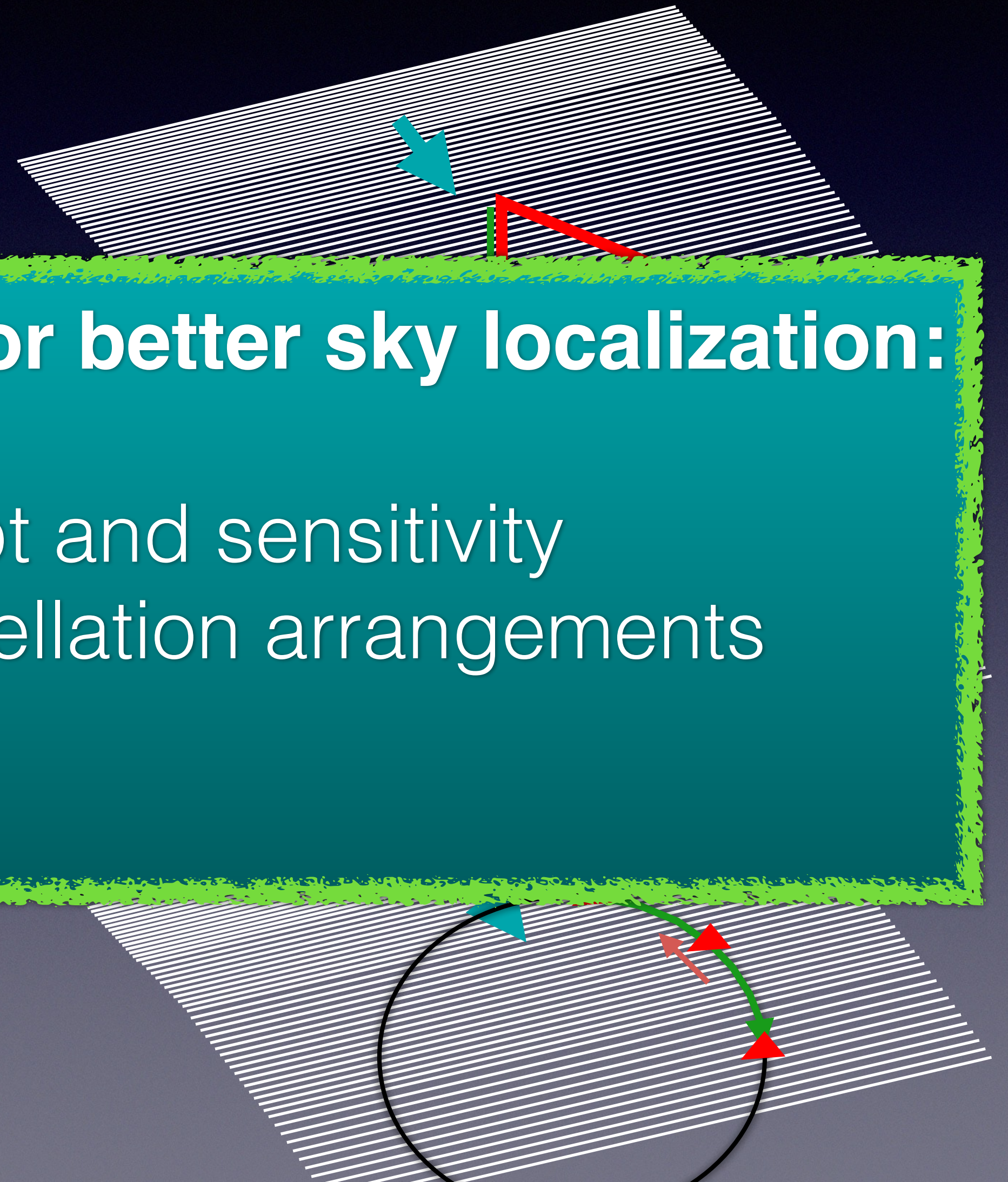
Ways to locate sources

- Relevant for short chirps:

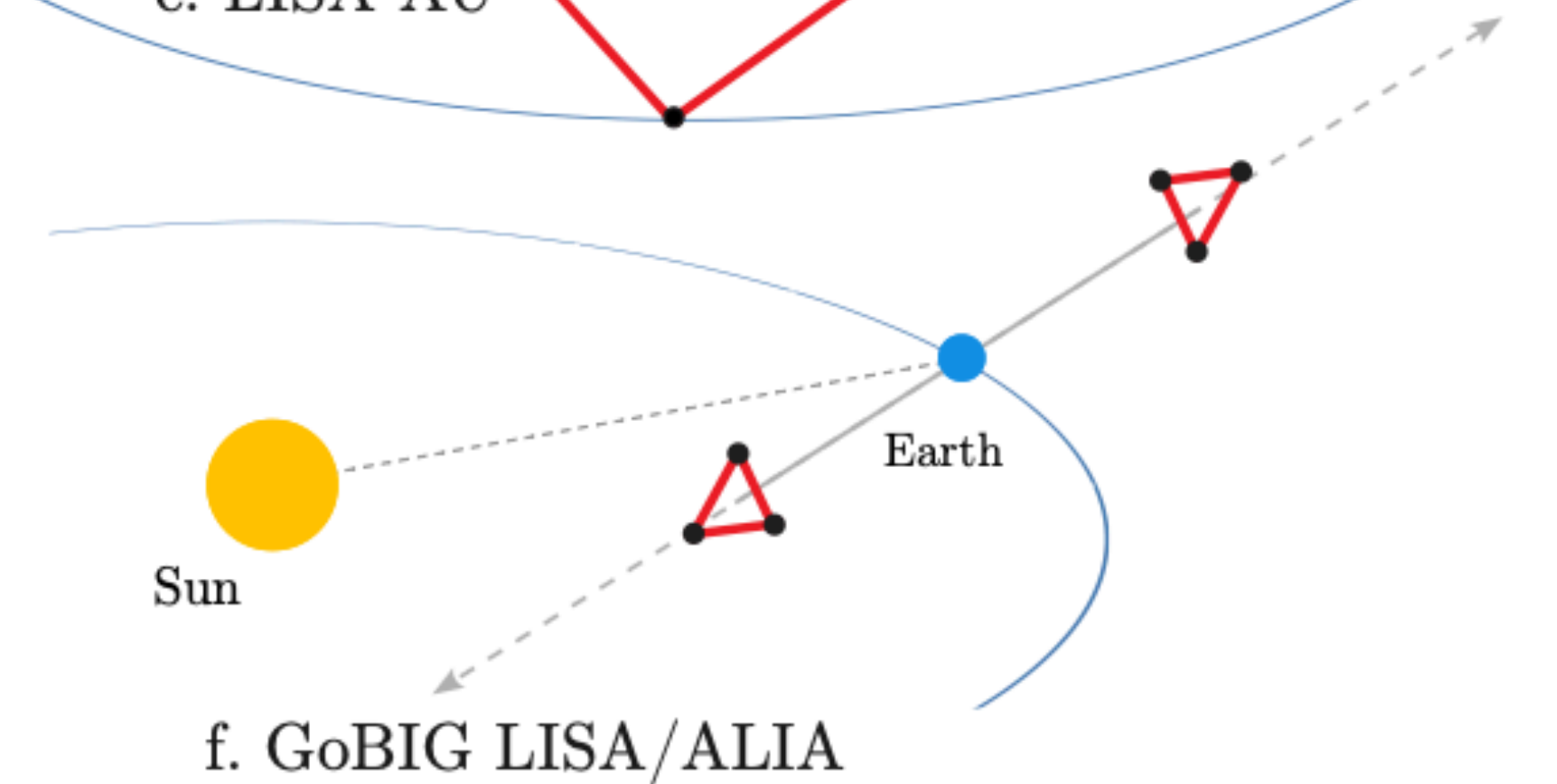
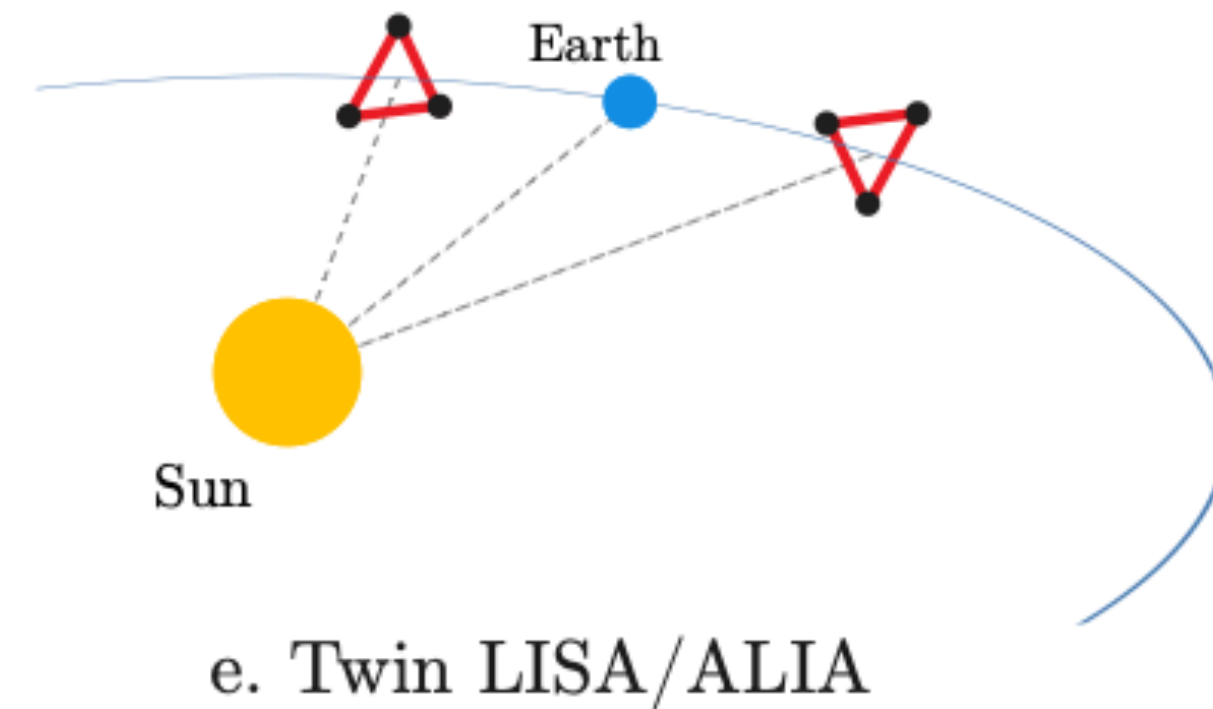
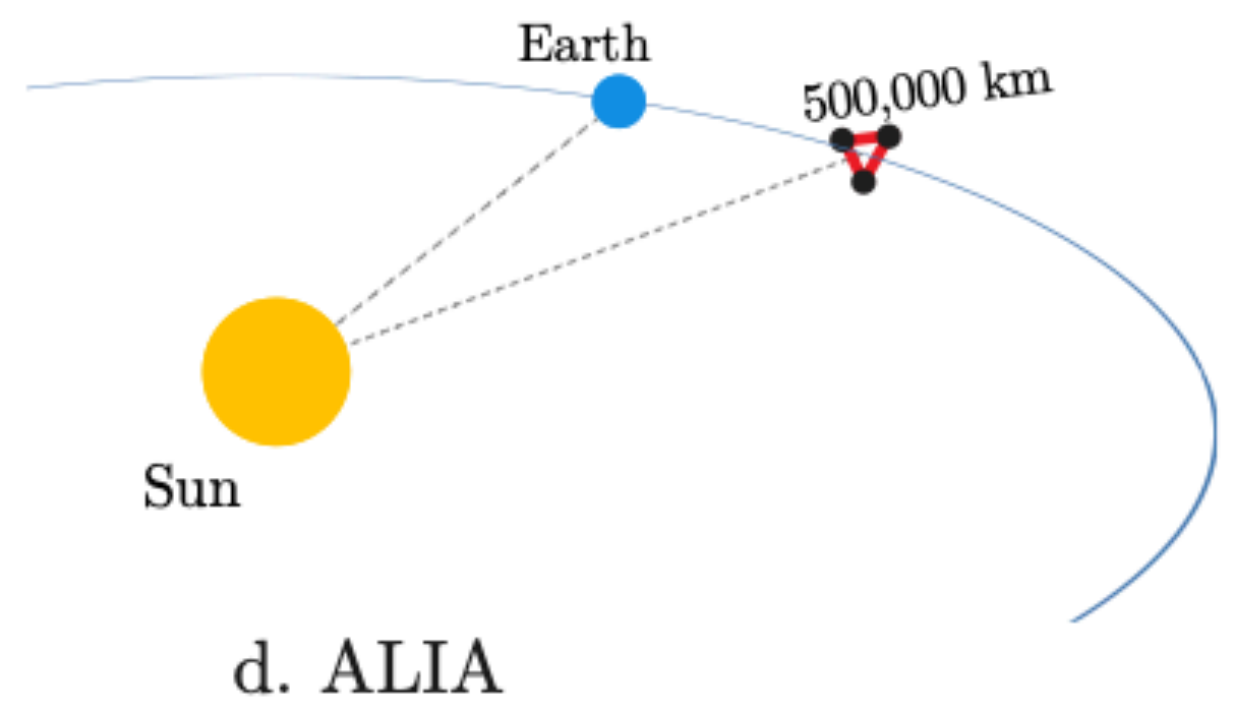
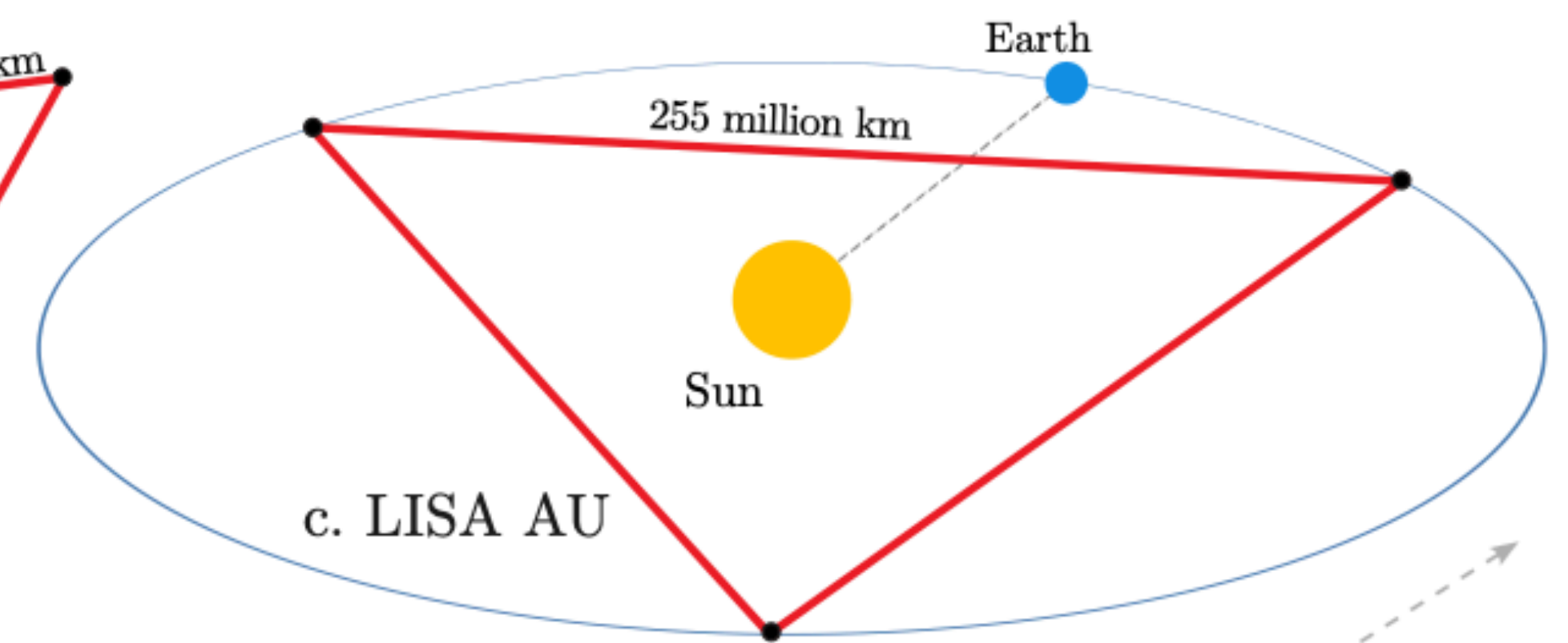
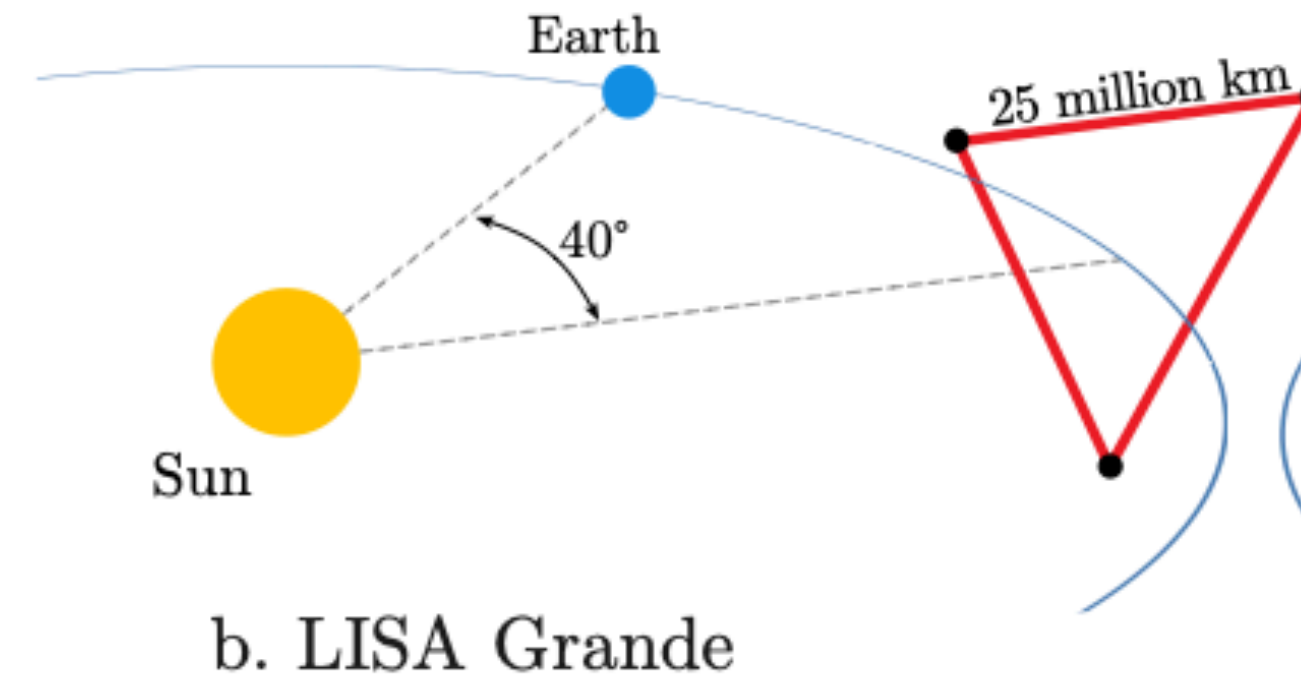
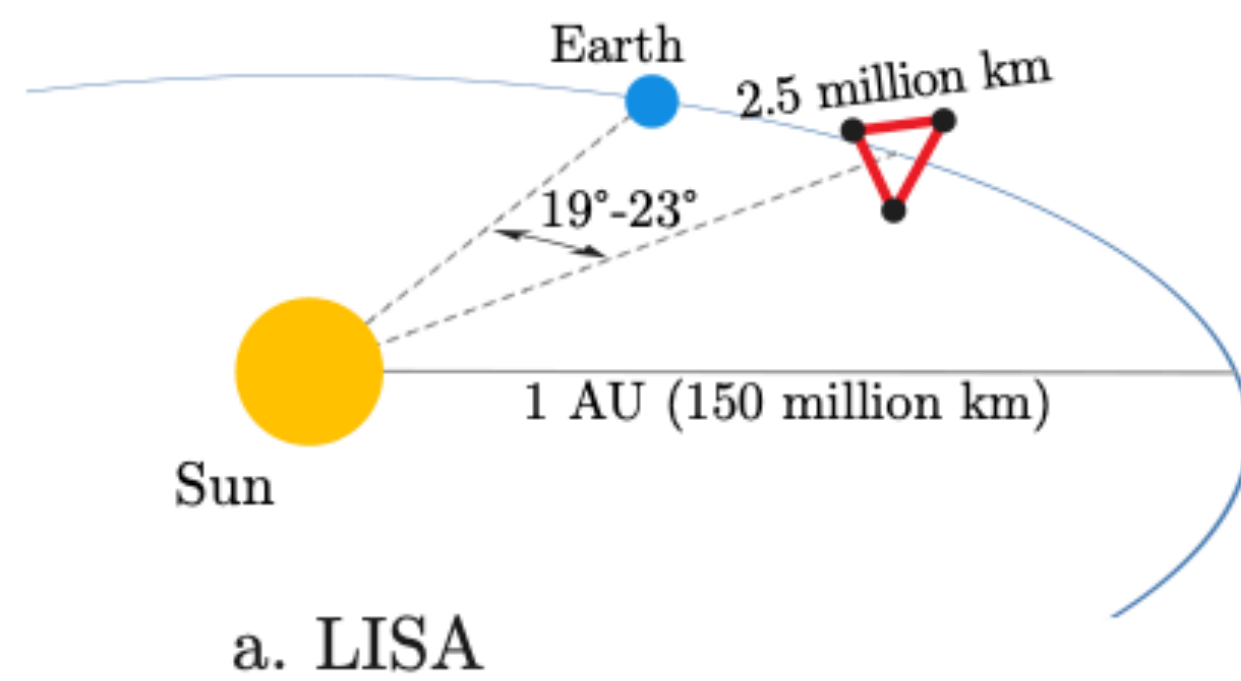
Study how to make a **bigger** “LISA” for better sky localization:

1. Freeze basic LISA technology concept and sensitivity
2. Consider directions of LISA-like constellation arrangements
3. Estimate localization capabilities
4. Consider applications

• Across LISA's orbit through the year
—> effective size is up to ~ **A.U.**



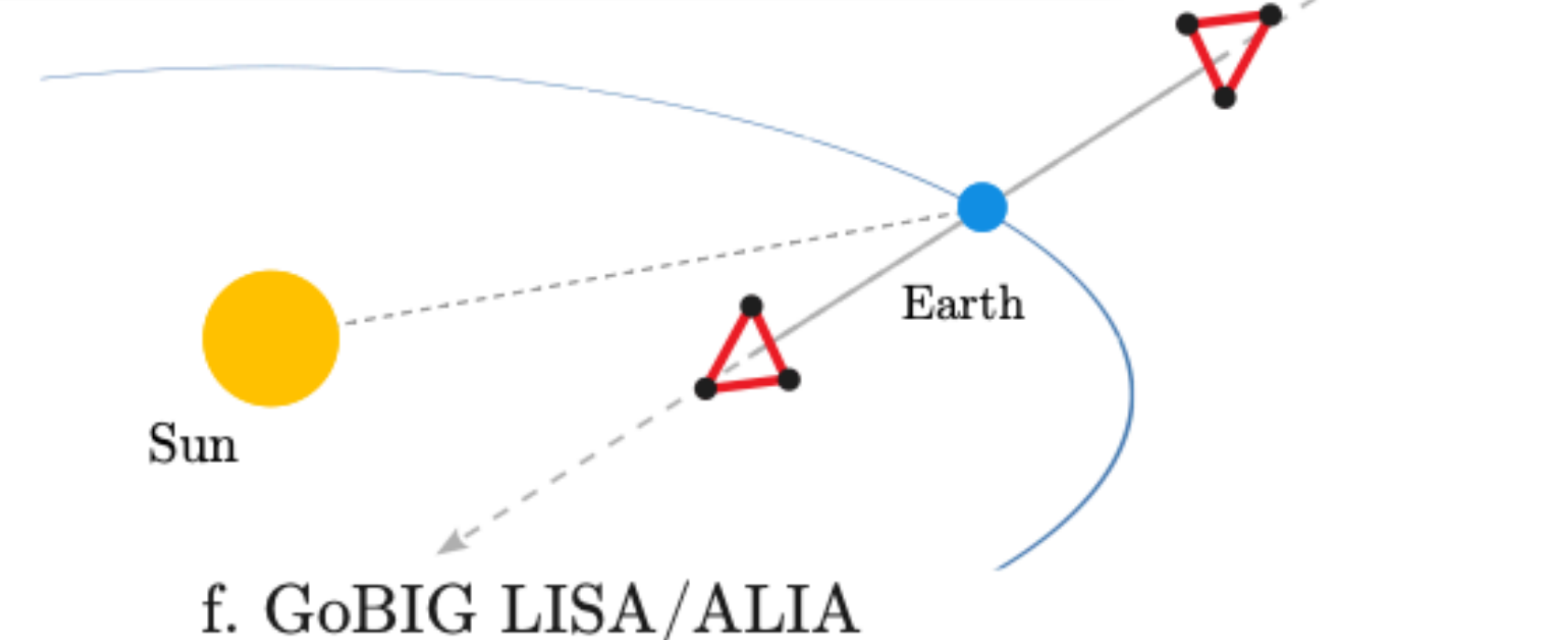
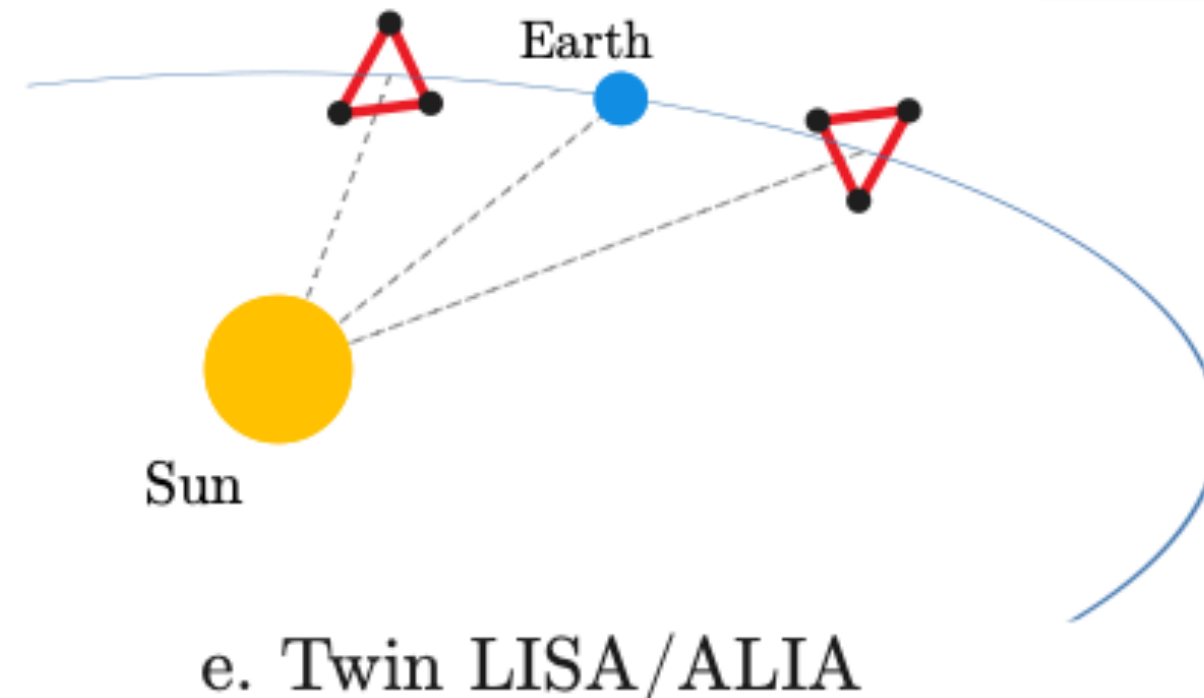
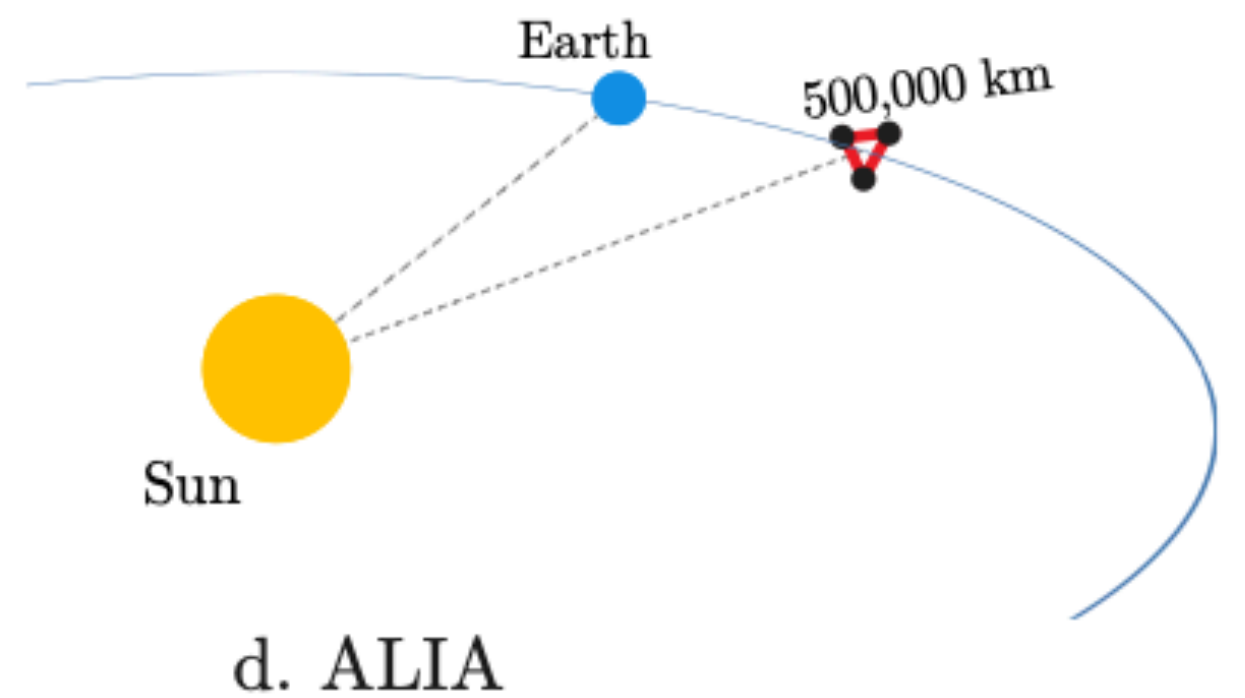
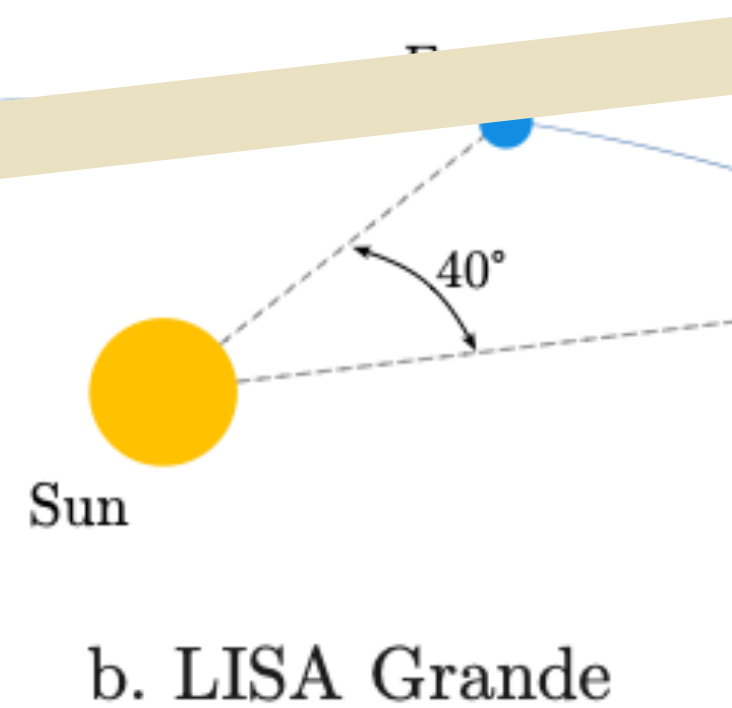
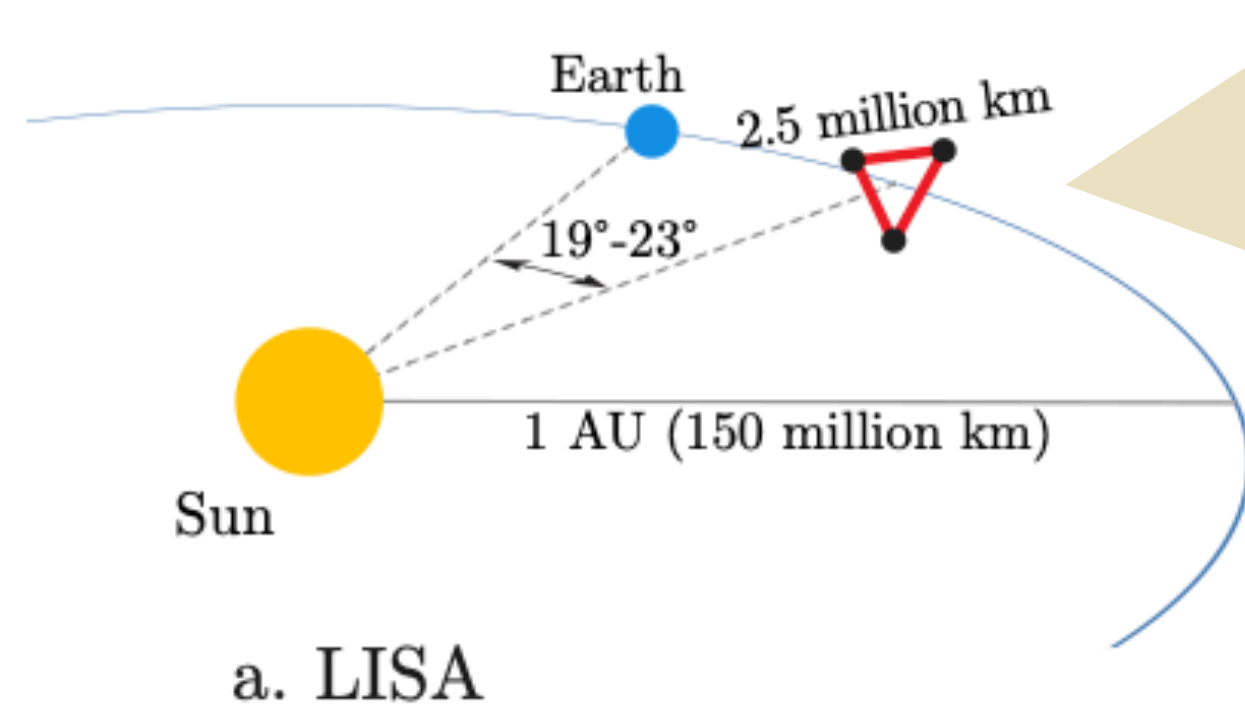
Mission design directions for improving sky localization



Mission design directions for improving sky localization

LISA

- Our reference point and base concept
- Other concepts here are understood as directions away from LISA that may improve localization



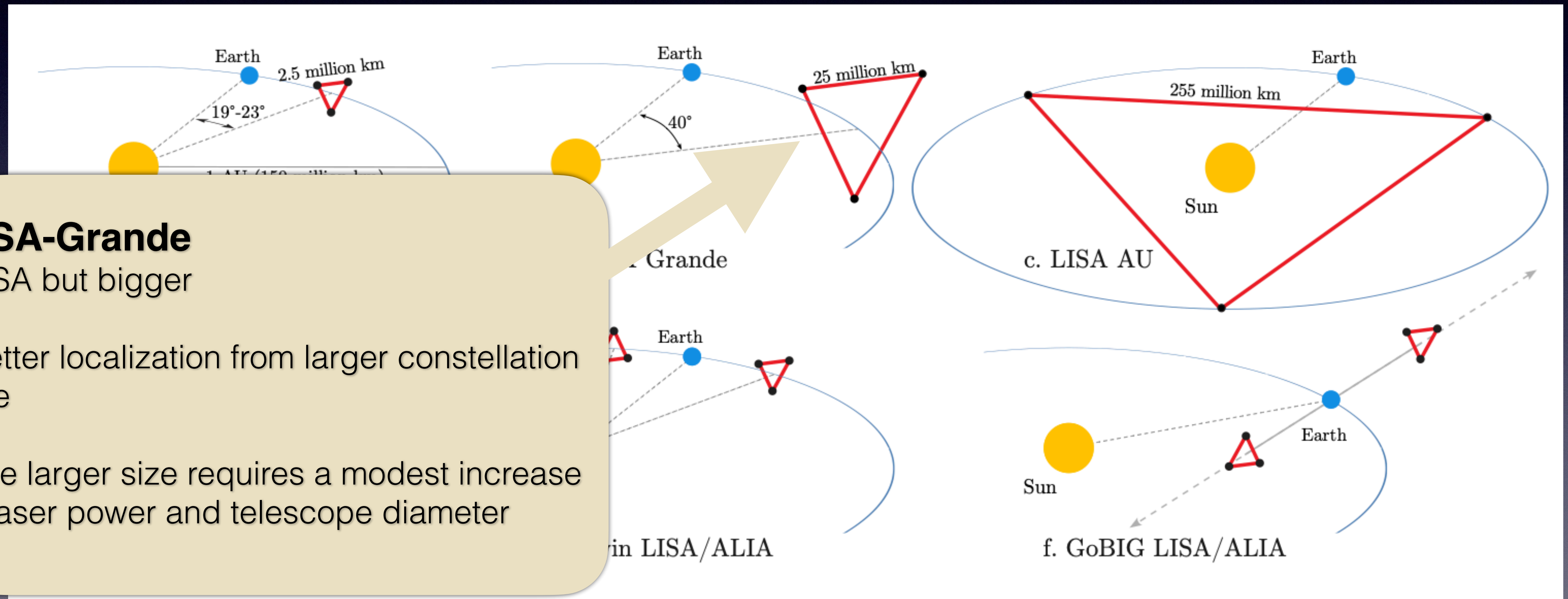
Mission design directions for improving sky localization

LISA-Grande

-LISA but bigger

-Better localization from larger constellation size

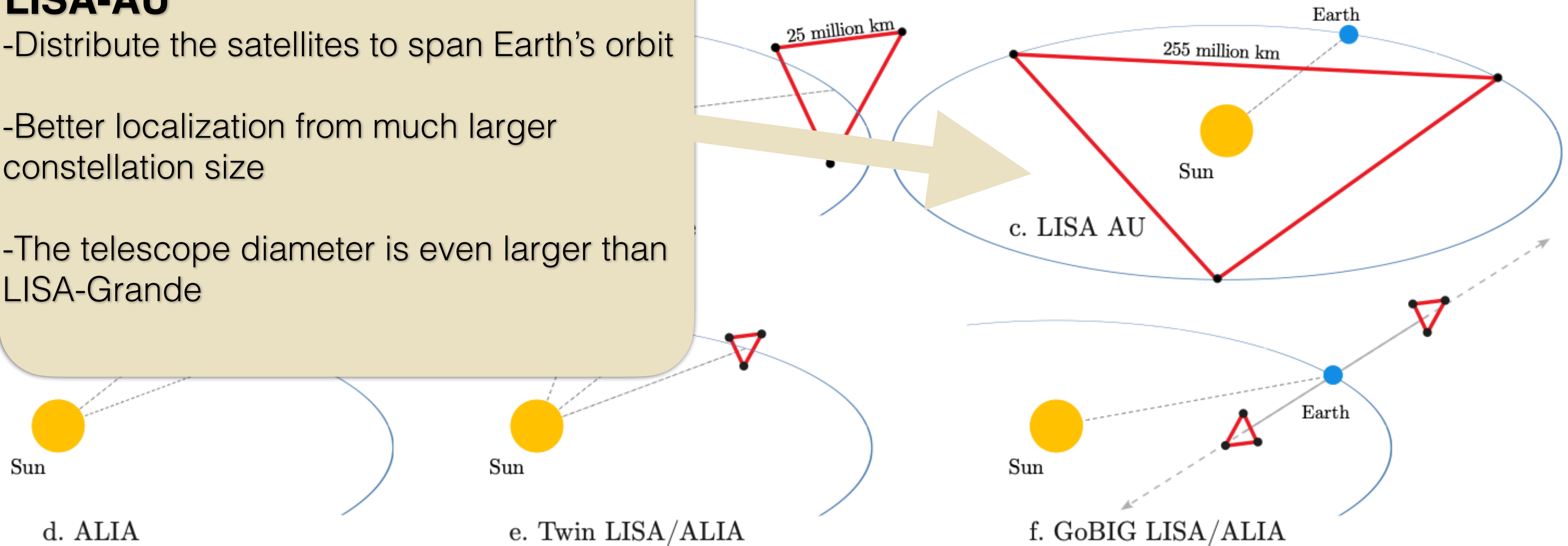
-The larger size requires a modest increase in laser power and telescope diameter



Mission design directions for improving sky localization

LISA-AU

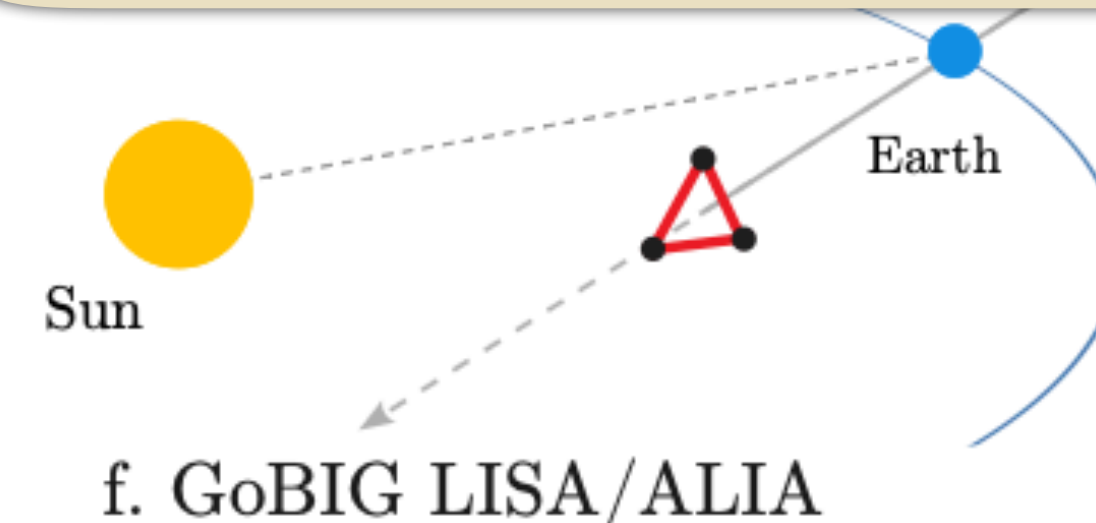
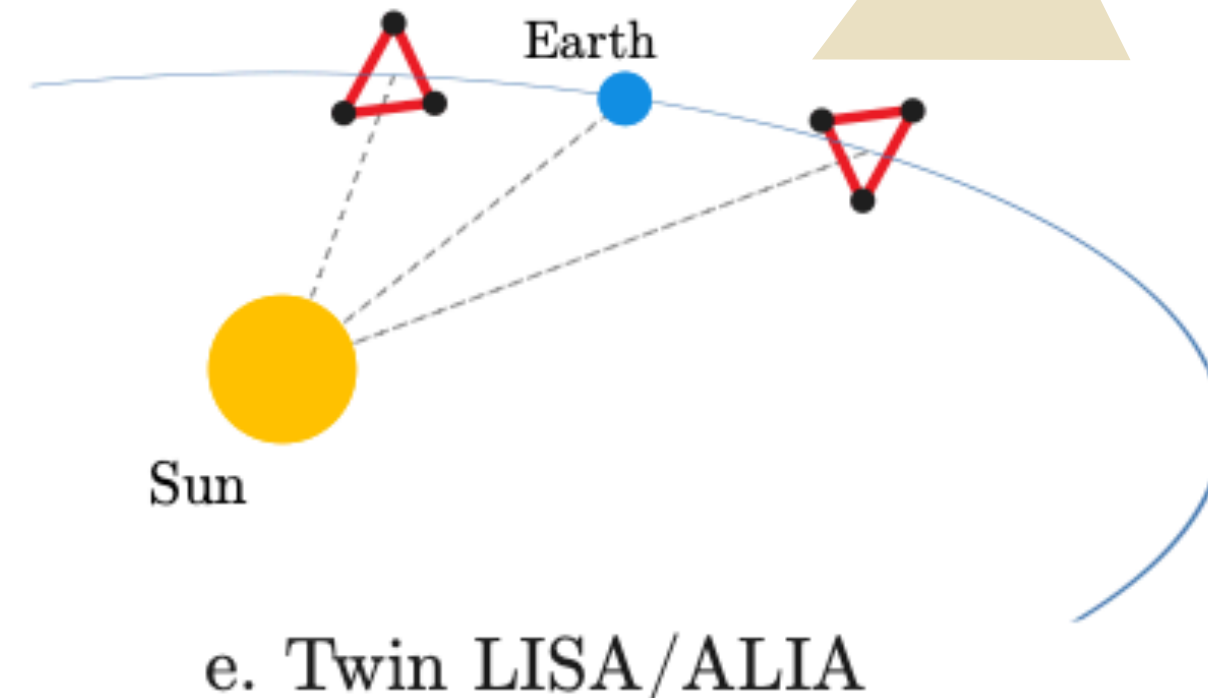
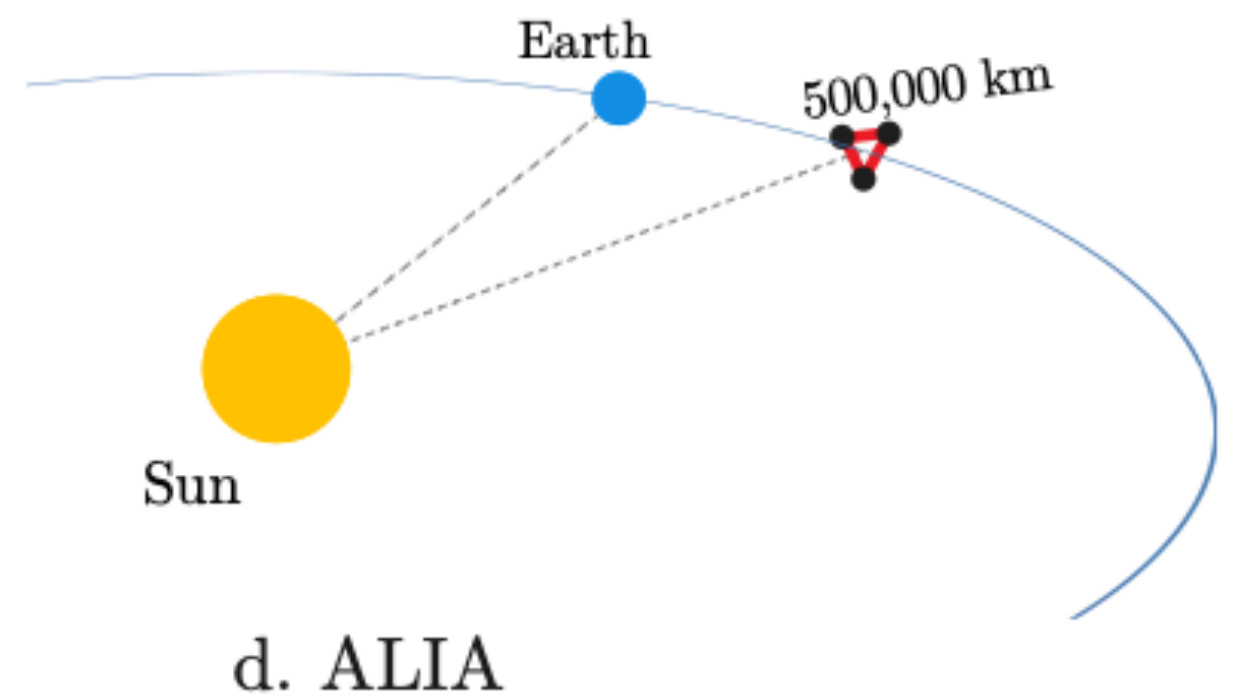
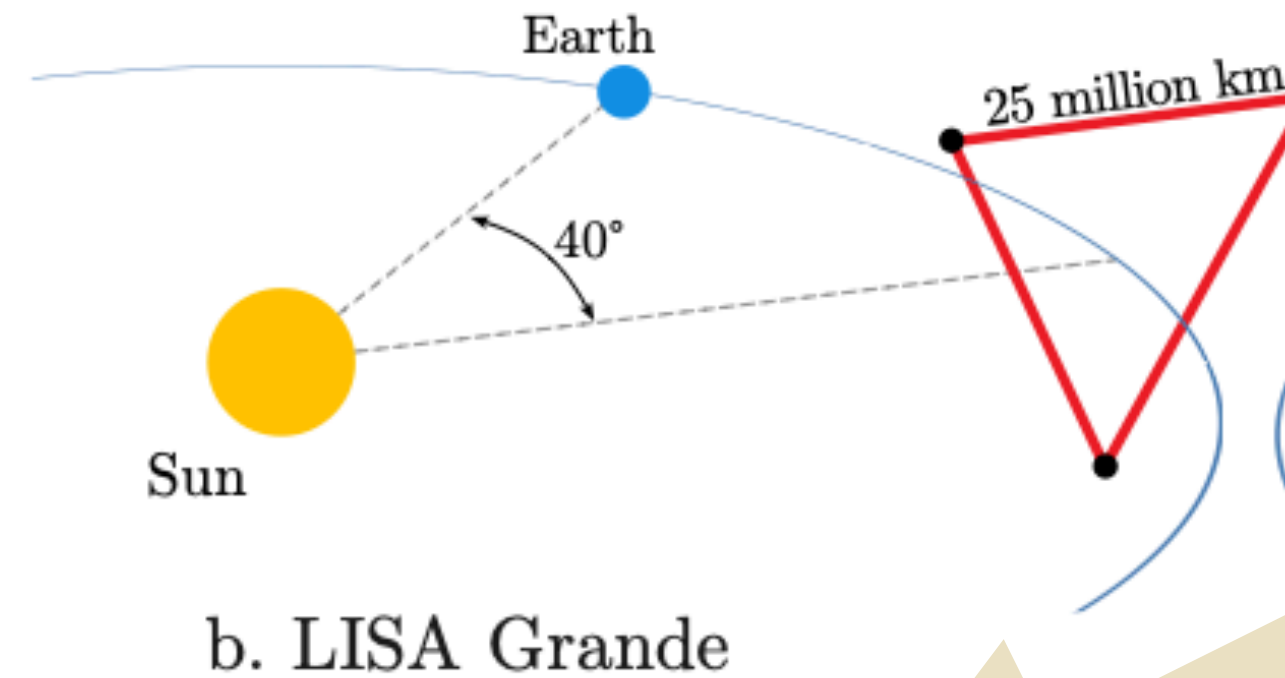
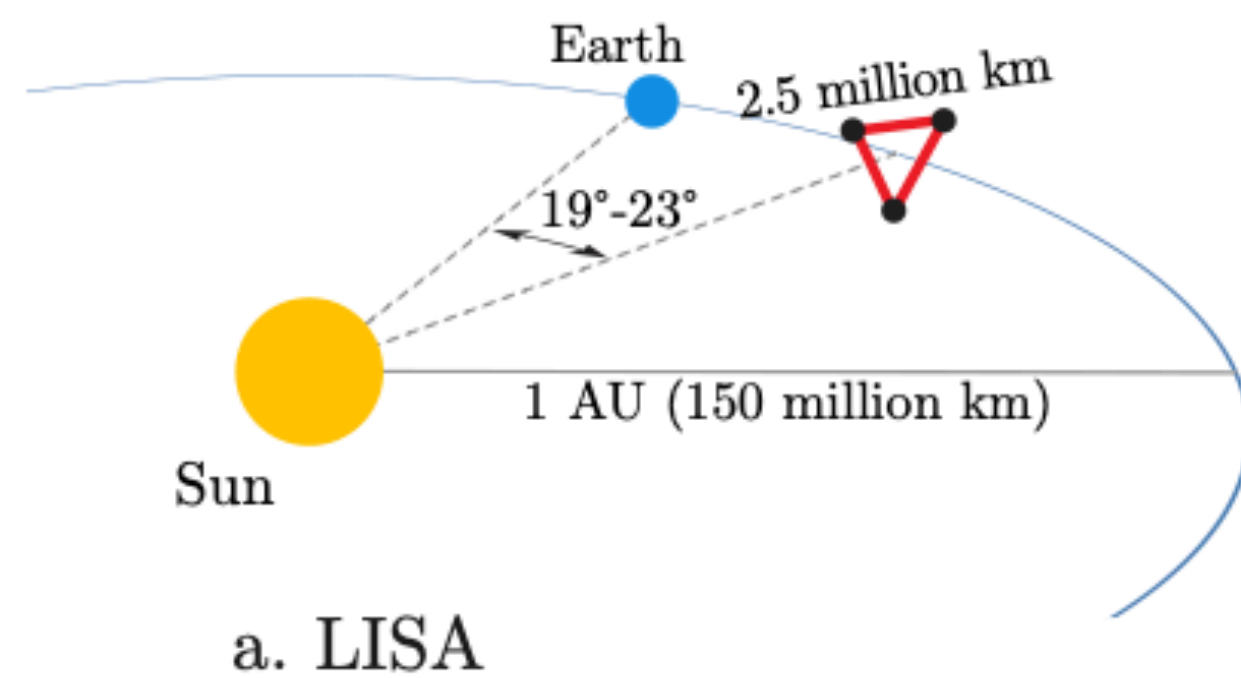
- Distribute the satellites to span Earth's orbit
- Better localization from much larger constellation size
- The telescope diameter is even larger than LISA-Grande



Mission design directions for improving sky localization

Twin-LISA

- Make two LISA's on different sizes of Earth
- Better localization from triangulation between the constellations
- No other changes



Mission design directions for improving sky localization

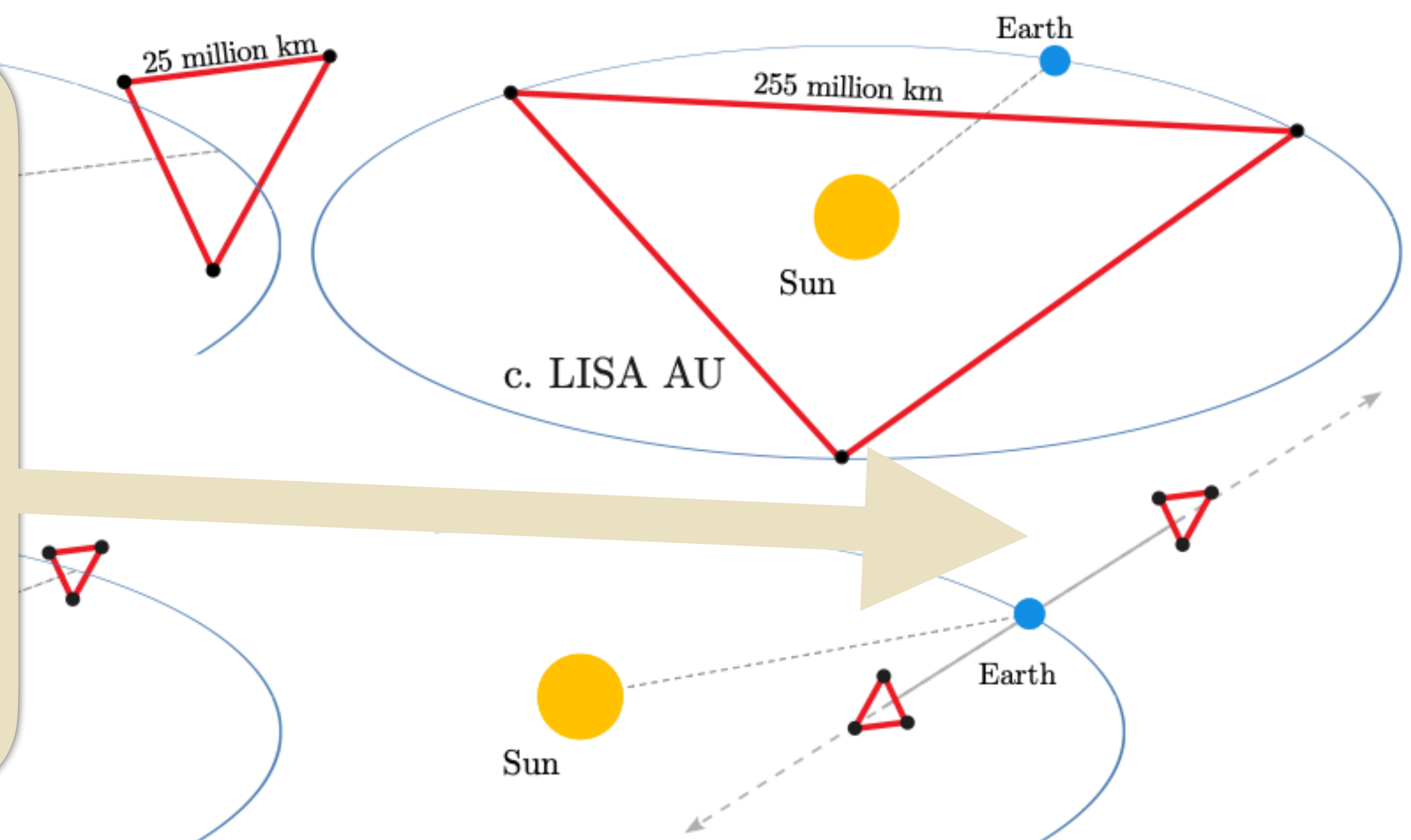
GoBIG-LISA

- Send LISA-like triangles away from the Sun on escape trajectory
- Better localization from extreme triangulation
- Also requires a second constellation
- Communication and power questions
- Constellation size would slowly evolve

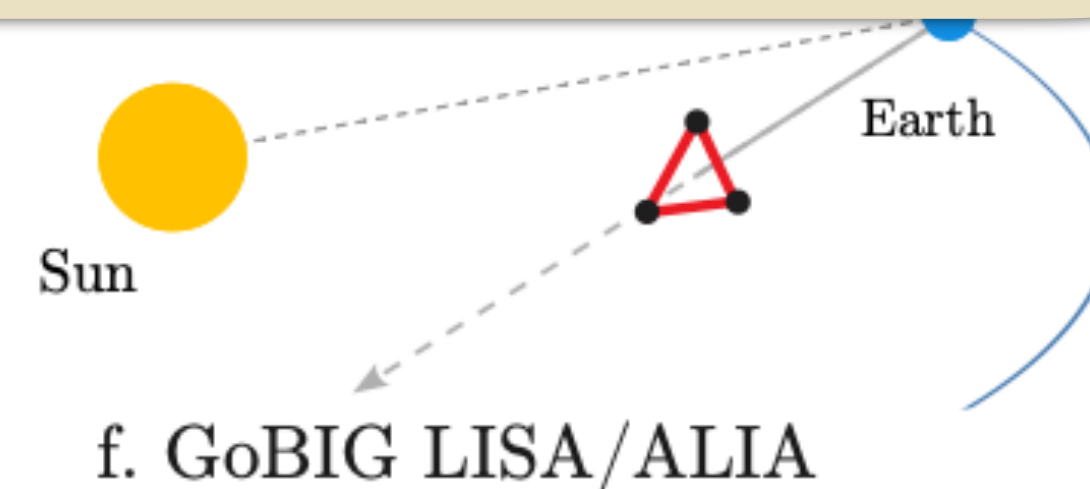
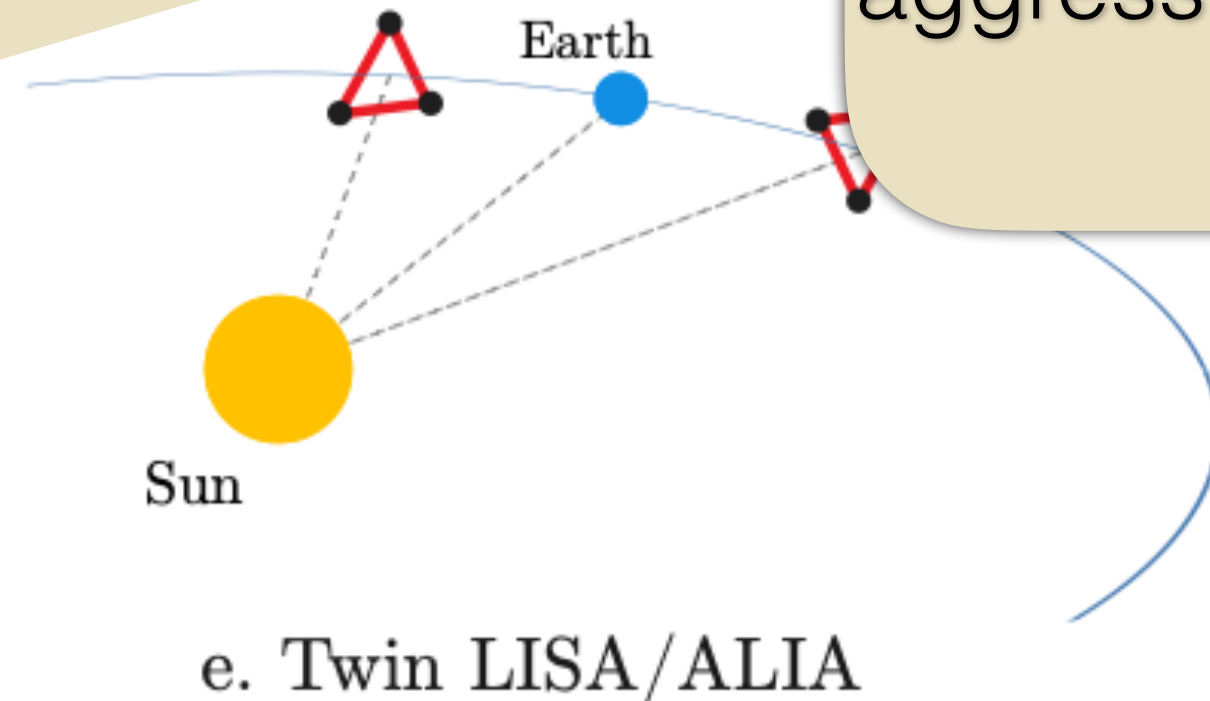
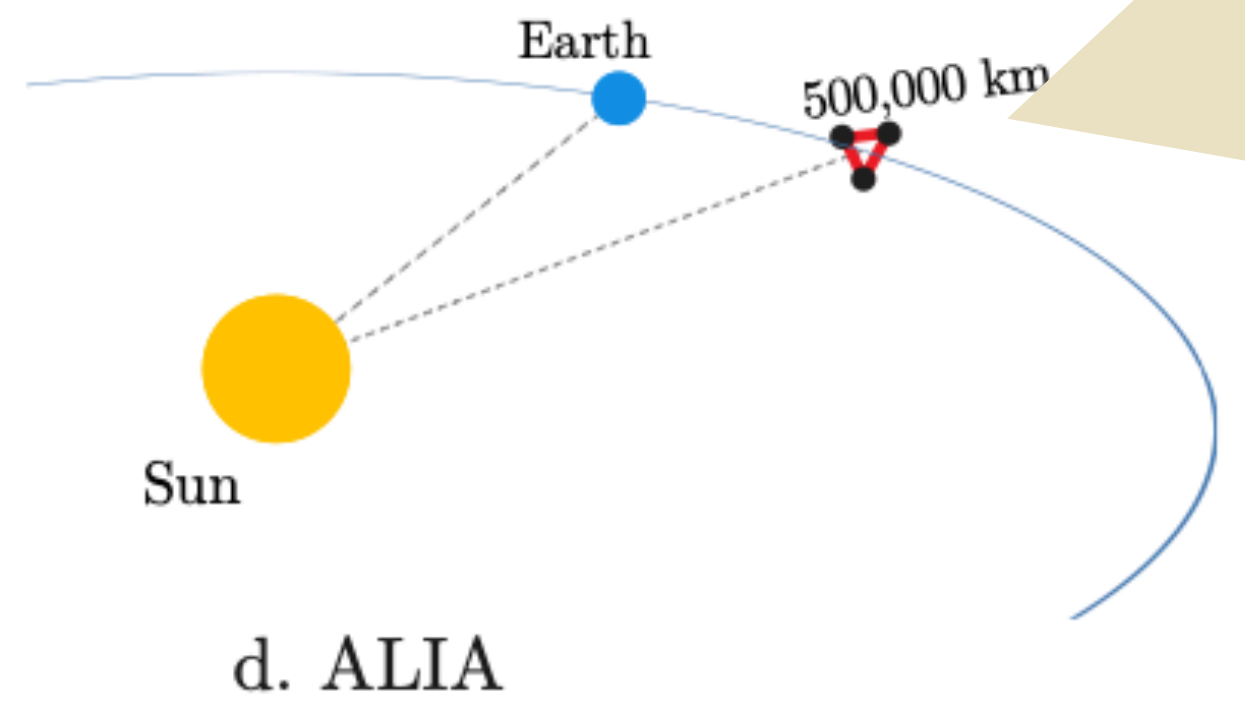
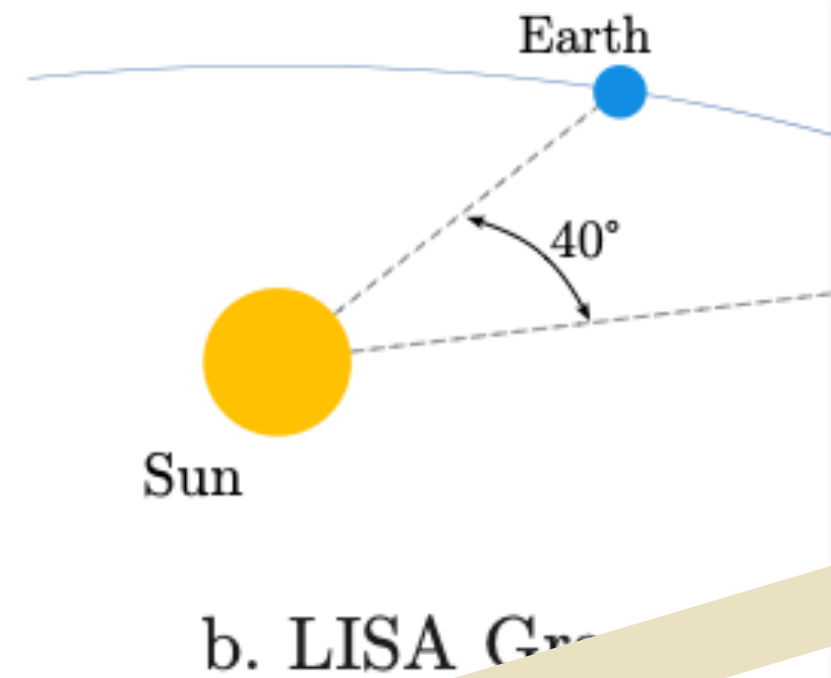
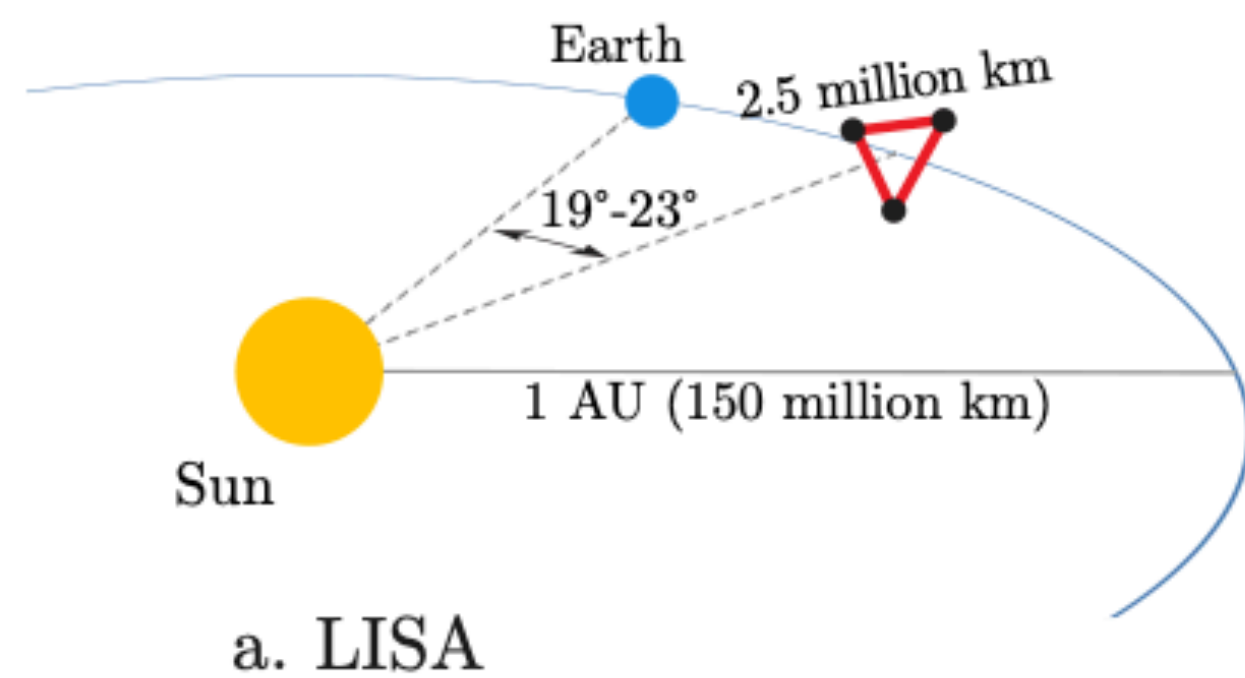
d. ALIA

e. Twin LISA/ALIA

f. GoBIG LISA/ALIA



Mission design directions for improving sky localization



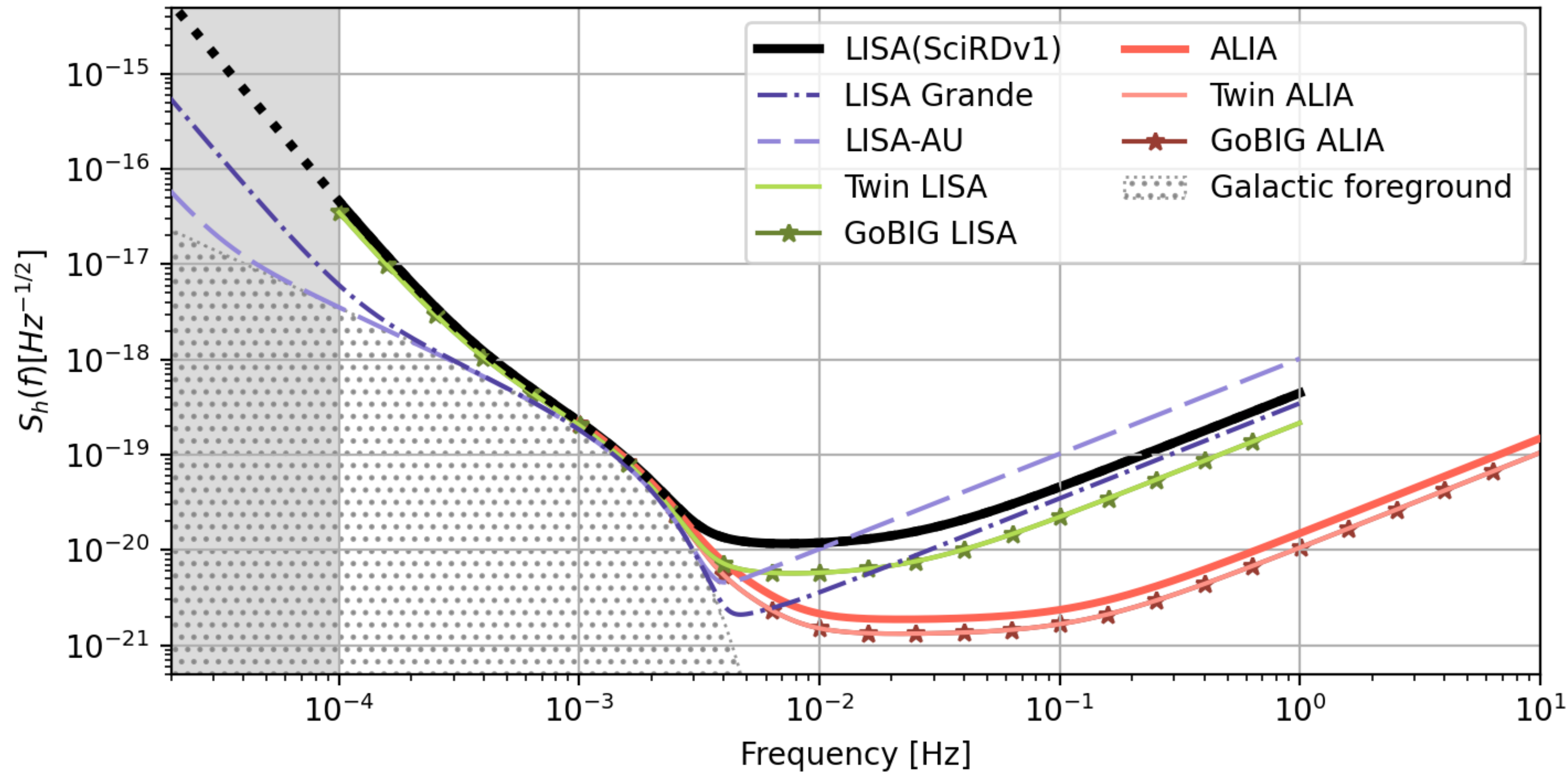
ALIA

- An alternative reference concept more sensitive at higher frequency.
- Localization study for higher freq sources
- Smaller constellation and a bit more aggressive version of LISA-like technology

Instrument adaptation summary

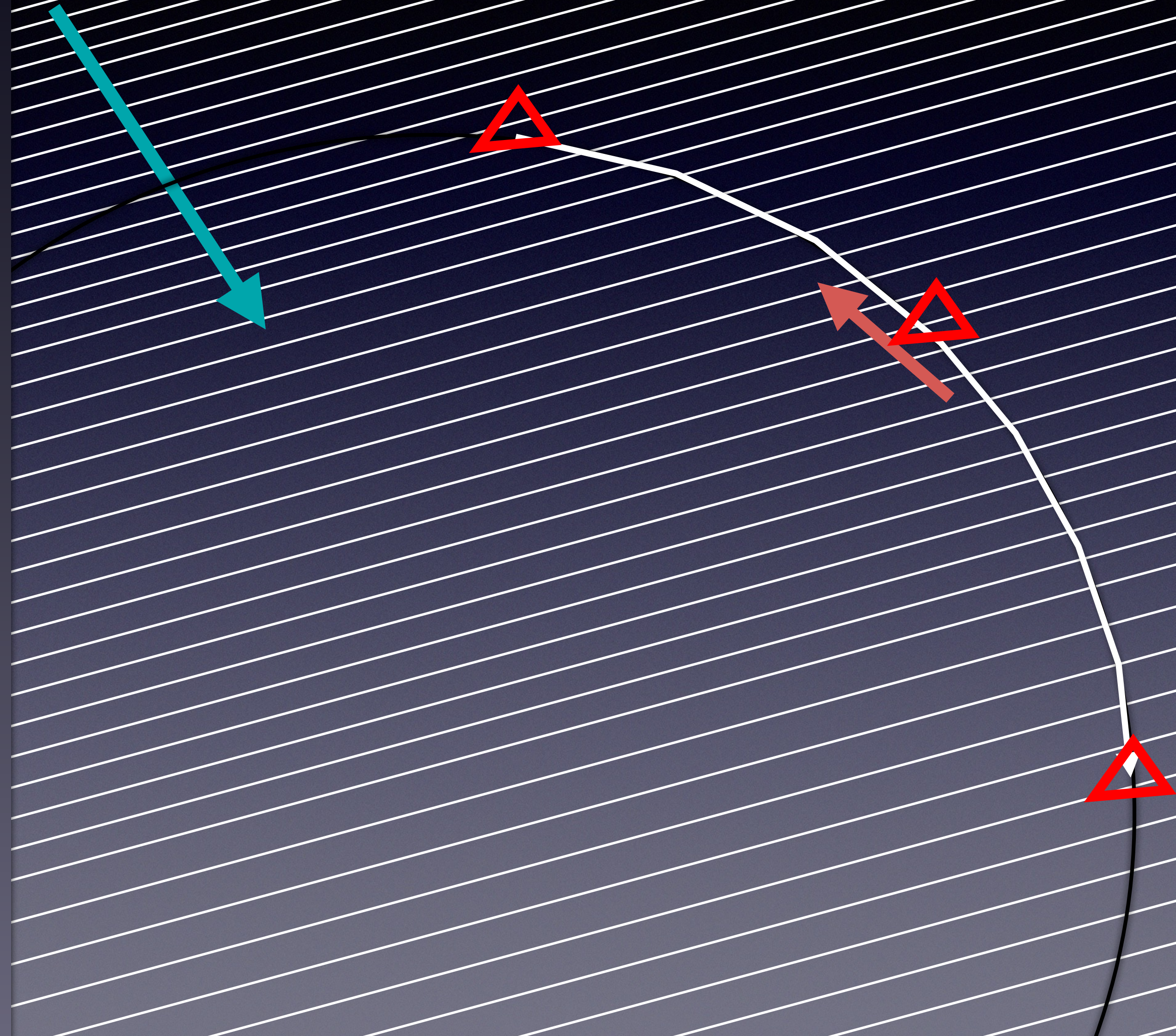
Name	Purpose	Laser Power P [W]	Telescope Diameter D [m]	Constellation Armlength L [M km]	Residual Acceleration [fm s ⁻²]	Orbital Separation Δ [AU]
LISA	Baseline	2.0	0.3	2.5	3	NA
LISA Grande	Low Frequency/Larger Arms	4.0	0.5	25	3	NA
LISA-AU	Extreme arm-length	4.0	1.0	255	3	NA
Twin LISA	Triangulation	2.0	0.3	2.5	3	1
GoBIG LISA	Extreme Triangulation	2.0	0.3	2.5	3	30
ALIA	High Frequency/Smaller Arms	10	1.0	0.5	0.6	NA
Twin ALIA	High Frequency Triangulation	10	1.0	0.5	0.6	1
GoBIG ALIA	High Frequency Extreme Triangulation	10	1.0	0.5	0.6	30

TDI sensitivity - GW Imager Concepts

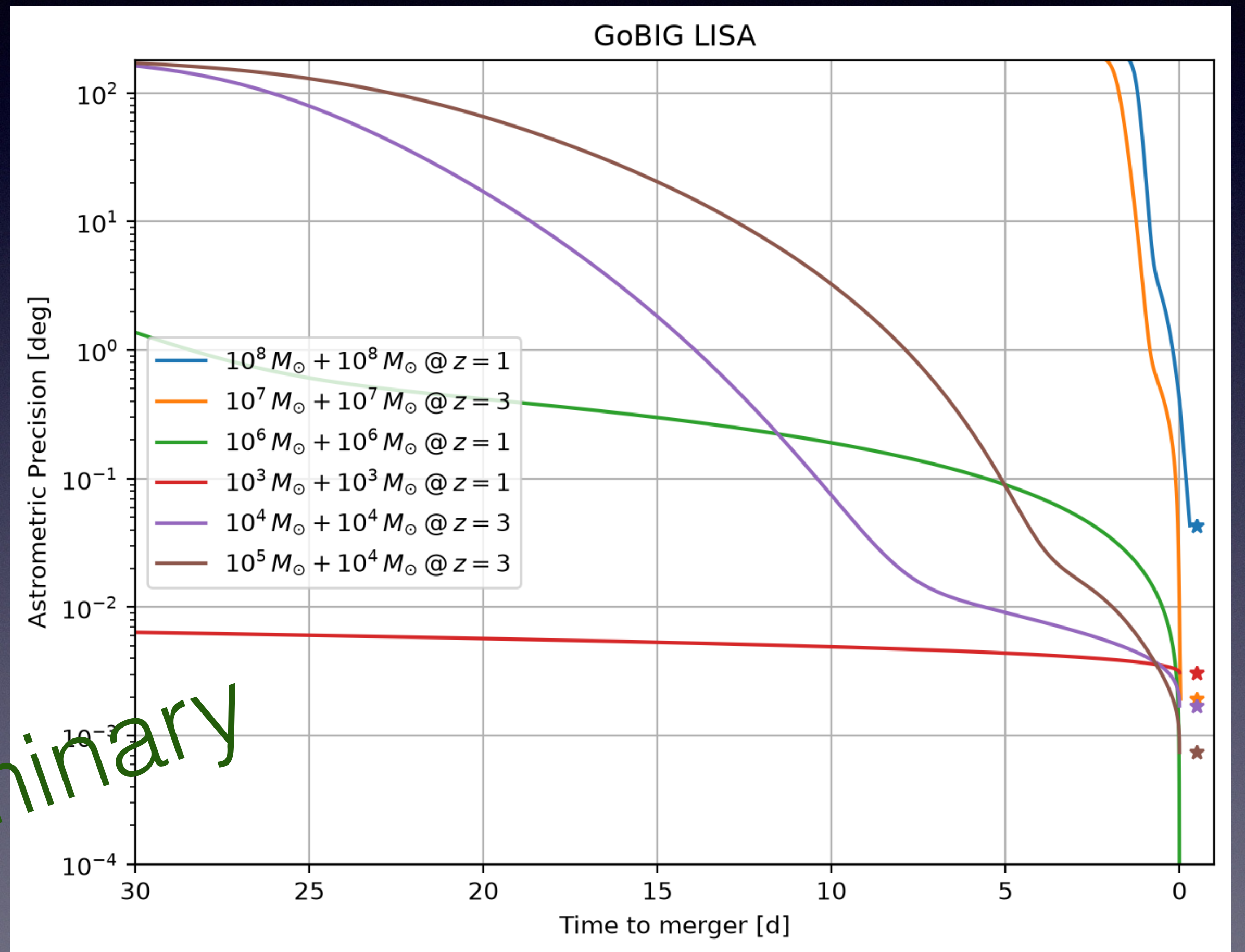
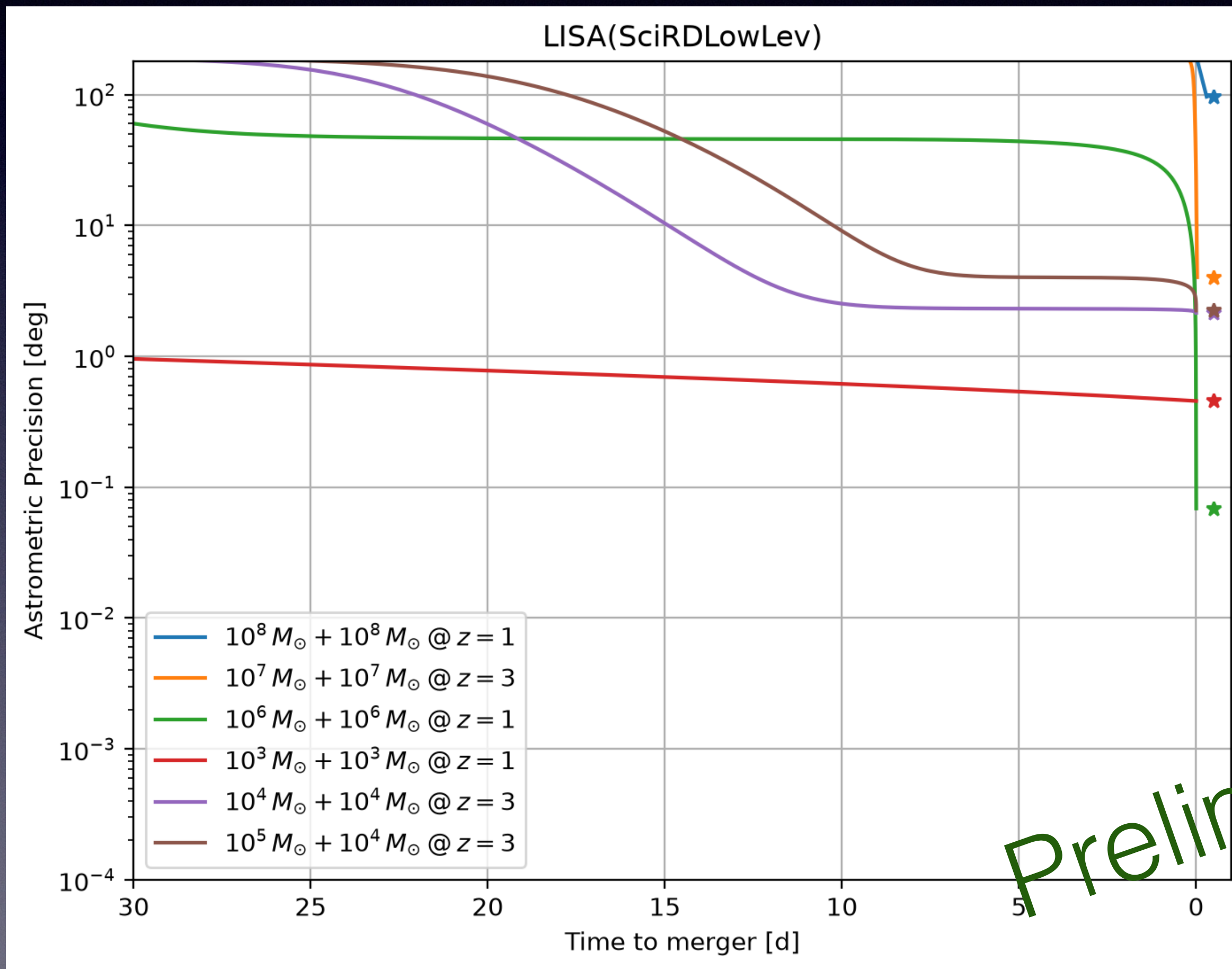


Estimating sky localization precision

- $\delta\alpha \approx \frac{C_1}{\rho_{\text{SNR}}} \frac{c}{\omega_{\text{GW}} D_{\text{size}}}$
What happens when freq and position can vary?
- Simplifying assumptions:
 - localization from wave phase only
 - waveform shape inference assumed uncorrelated (known)
 - only consider a 1-D sky-angle
 - ignores higher modes (for now)
- Fisher information analysis:
 - 3 params $\{t_0, m, \theta\}$
 - “ m ” is a temporal rescaling param
 - eliminate t_0 coupling by coord choice
 - >a computable integral
- Then separately estimate the constellation, multi-constellation and orbit contributions

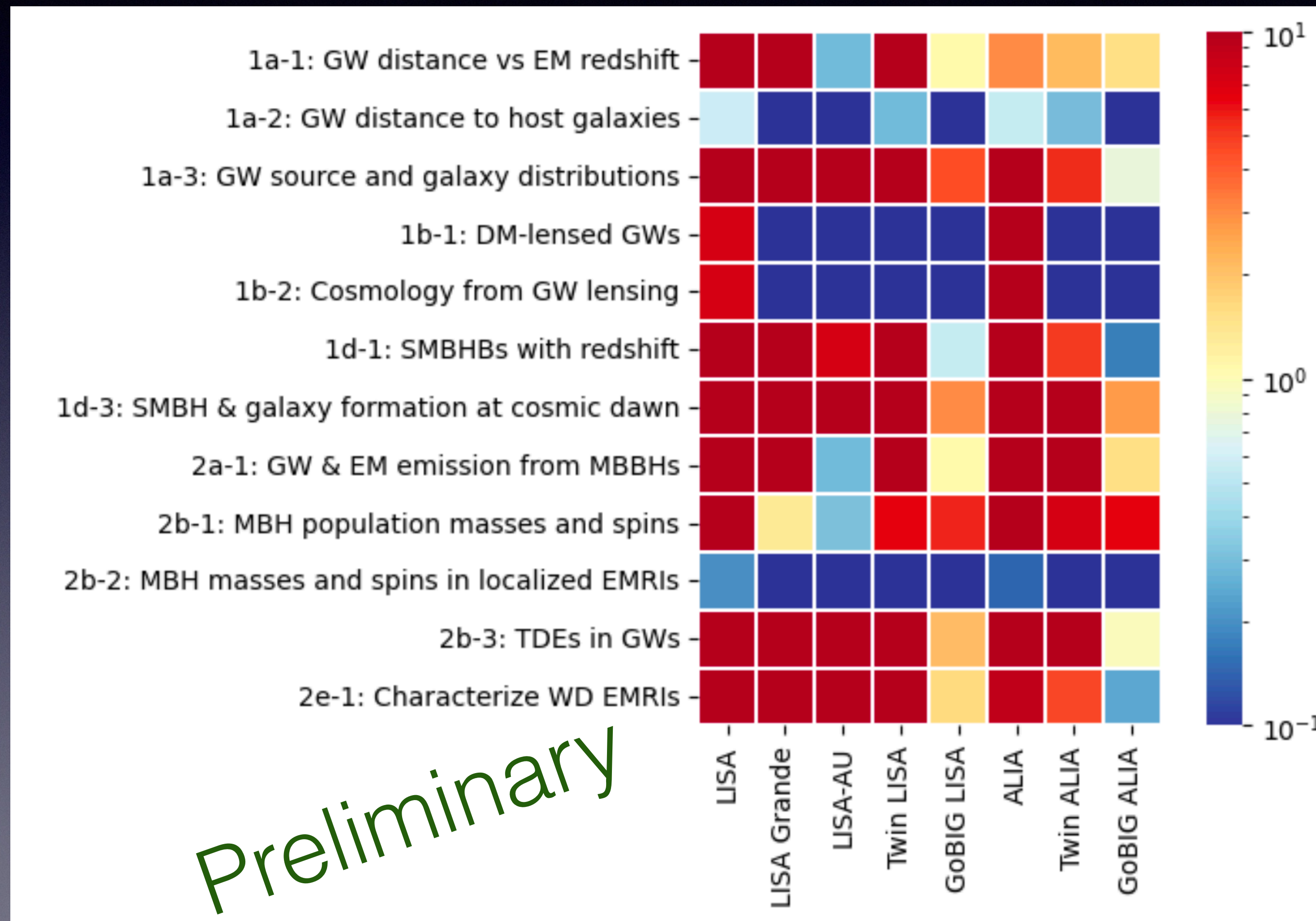


Example localization estimates



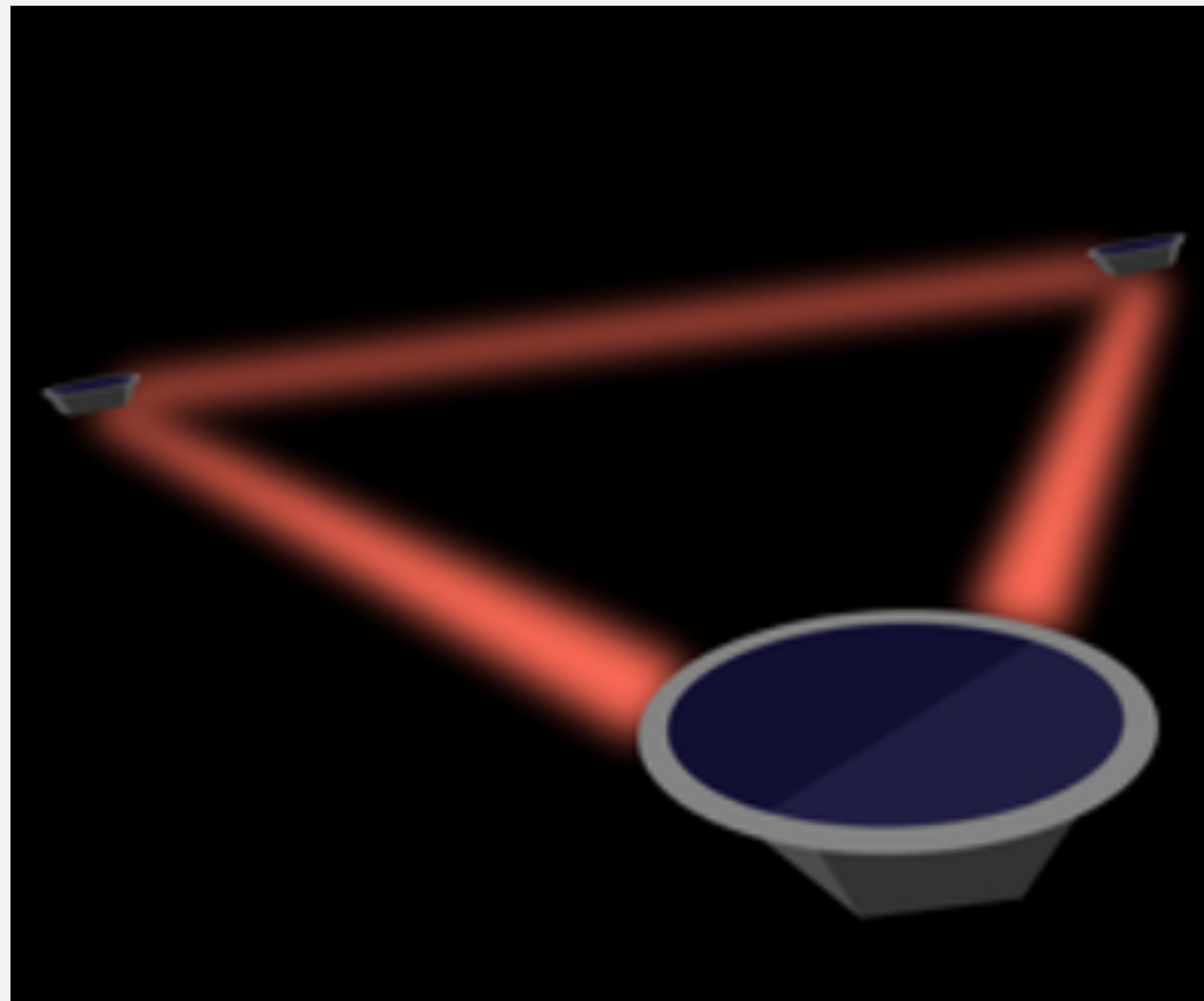
Preliminary

Then compare across a range of science objective scenarios

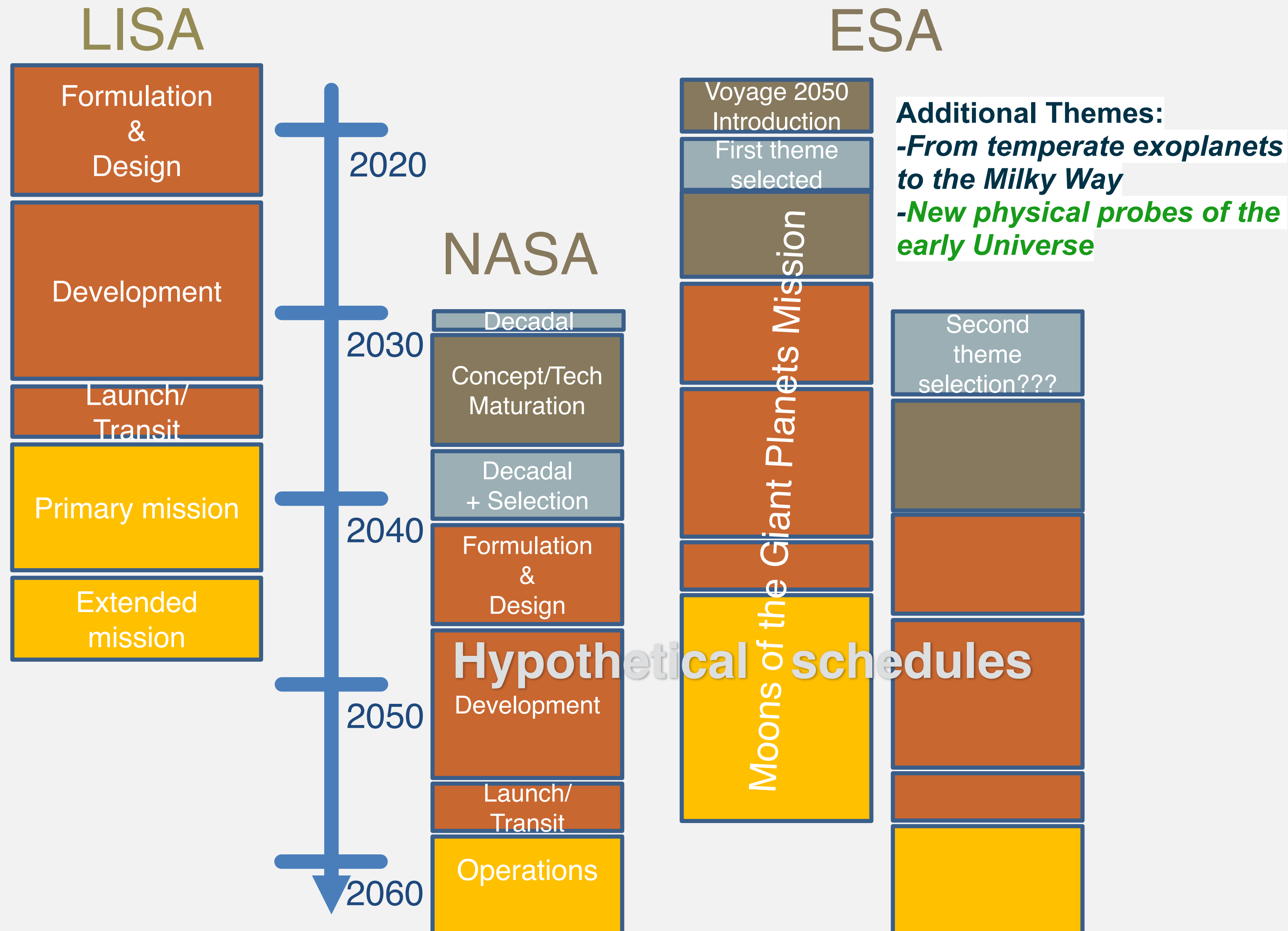


PATH TO FUTURE A GW MISSION

Current mission



LISA to launch 2035



LISA-like mHz localization summary

- **Now** is already time to be working on future mHz GW missions
- We present resources for exploring possibilities:
 - A **range of configurations** to improve localization precision with accessible LISA-like technology
 - A simplified approach gives **localization estimates**
- Further **understanding of scientific opportunity** will be critical to motivate the next mission.