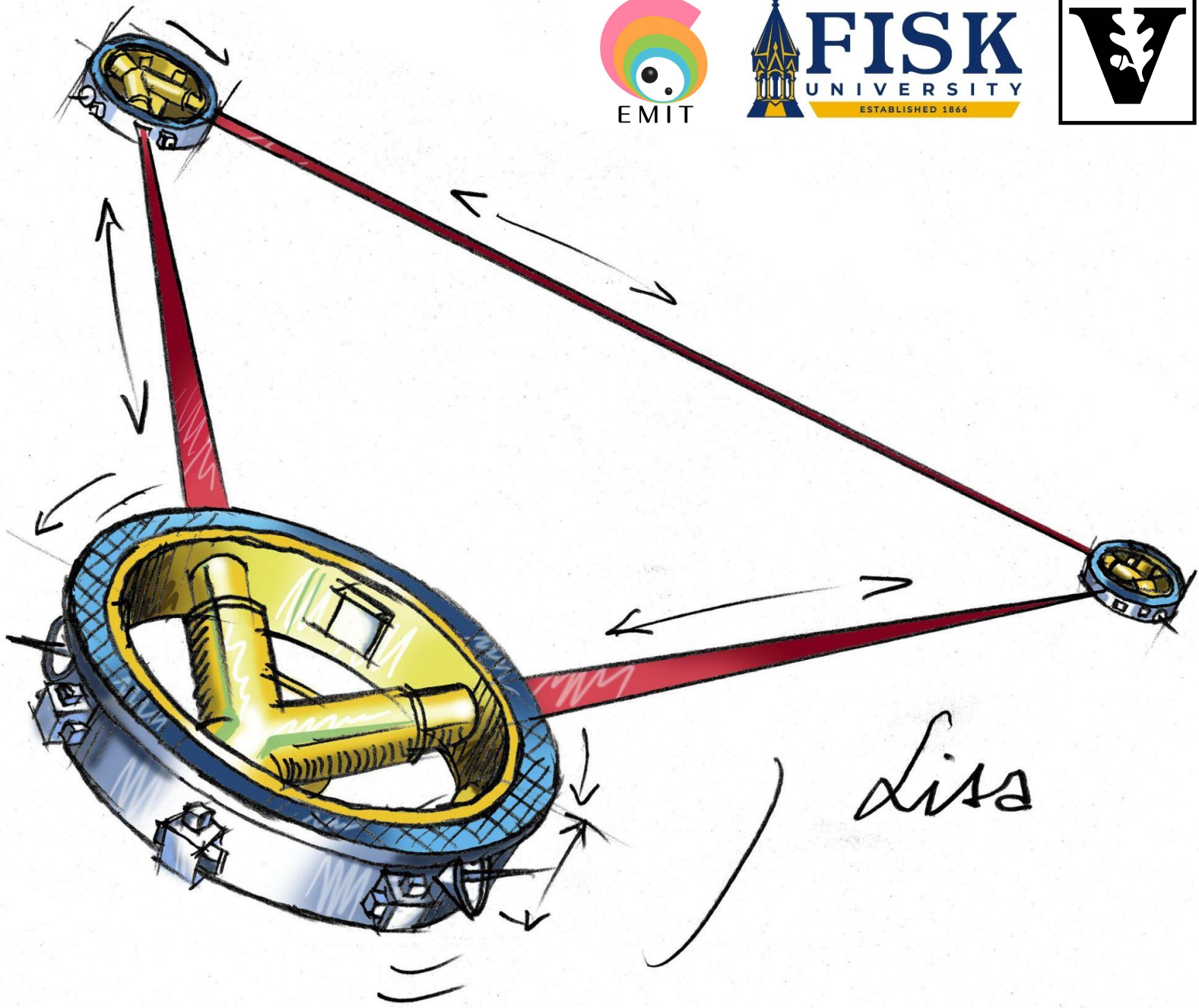
the **L**aser **I**nterferometer **S**pace **A**ntenna

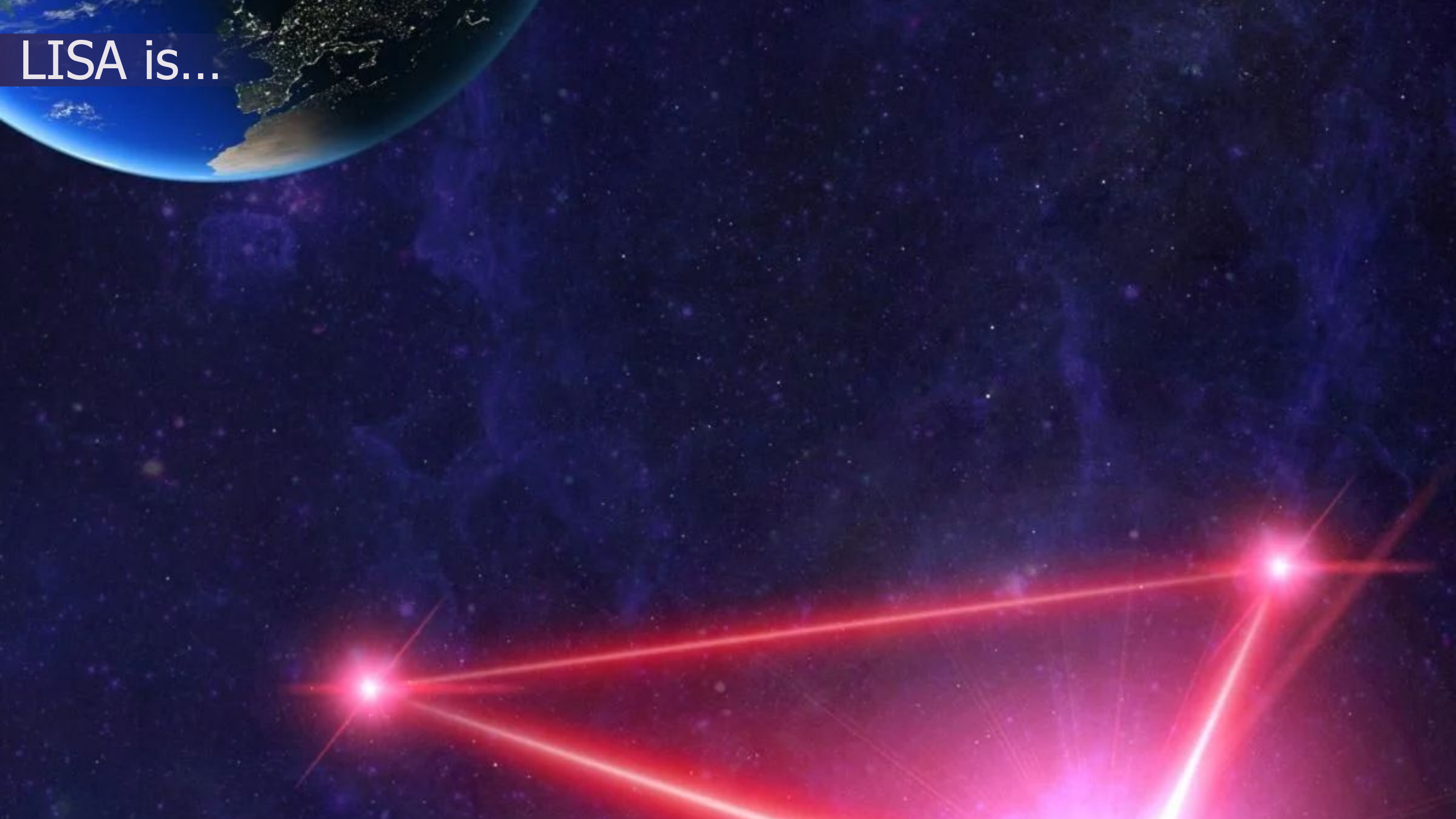


Alexander W. Criswell
EMIT Postdoctoral Fellow
Vanderbilt & Fisk Universities
alexander.criswell@vanderbilt.edu

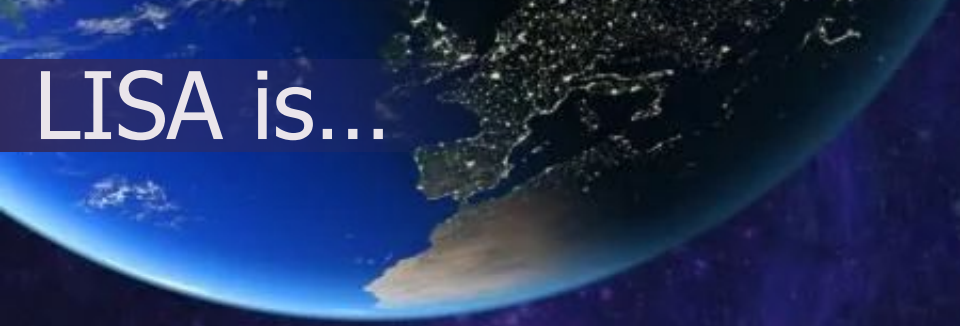
outline

- LISA - what is it
  - highlights
  - a brief history
- reminder of principles of GW detection
  - compare to LIGO, PTAs, length -> frequencies
  - 2.5 million km lasers -> mHz GWs
- what's going on in the mHz?
  - frequencies <-> spatial scales of sources
  - the usual LISA zoo
- The Rogue's Gallery
  - give overview and then break down source categories by type
  - discuss signal morphologies
  - discuss what we can learn scientifically
- (brief) Global Fit primer

LISA is...



LISA is...



a joint ESA-NASA mission

LISA is...

3 satellites
in a ~equilateral triangle
with **6** laser links
spanning **2.5 million km**

a joint ESA-NASA mission

LISA is...

The largest observatory **ever built**

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LISA is...

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a **mHz** gravitational wave detector

LISA is...

The largest observatory **ever built**

3 satellites
in a ~equilateral triangle
with **6** laser links
spanning **2.5 million km**

a **decades-long** effort

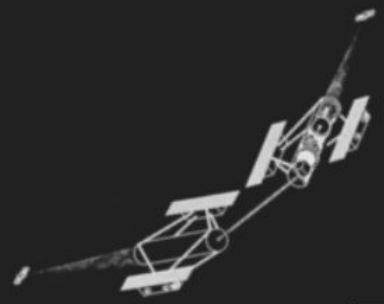
a joint ESA-NASA mission

a **mHz** gravitational wave detector

HISTORY

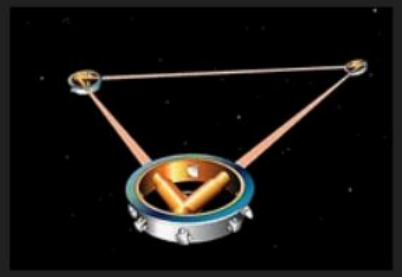
FIRST IDEAS TO MEASURE GW IN SPACE

1974



ESA M3 Proposal

1993



NASA / ESA Studies and Phase A Project

2001-2011

LISA Selected by ESA

2017

LISA

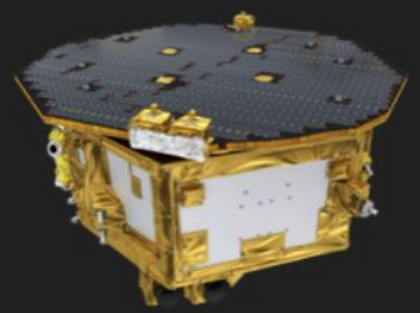
1989

ANTENNA FOR LASER GRAVITATIONAL WAVE OBSERVATIONS IN SPACE

PETE BENDER

2015

LAUNCH OF LISA PATHFINDER



2024

LISA ADOPTION

Figure credit – Nora Lützgendorf

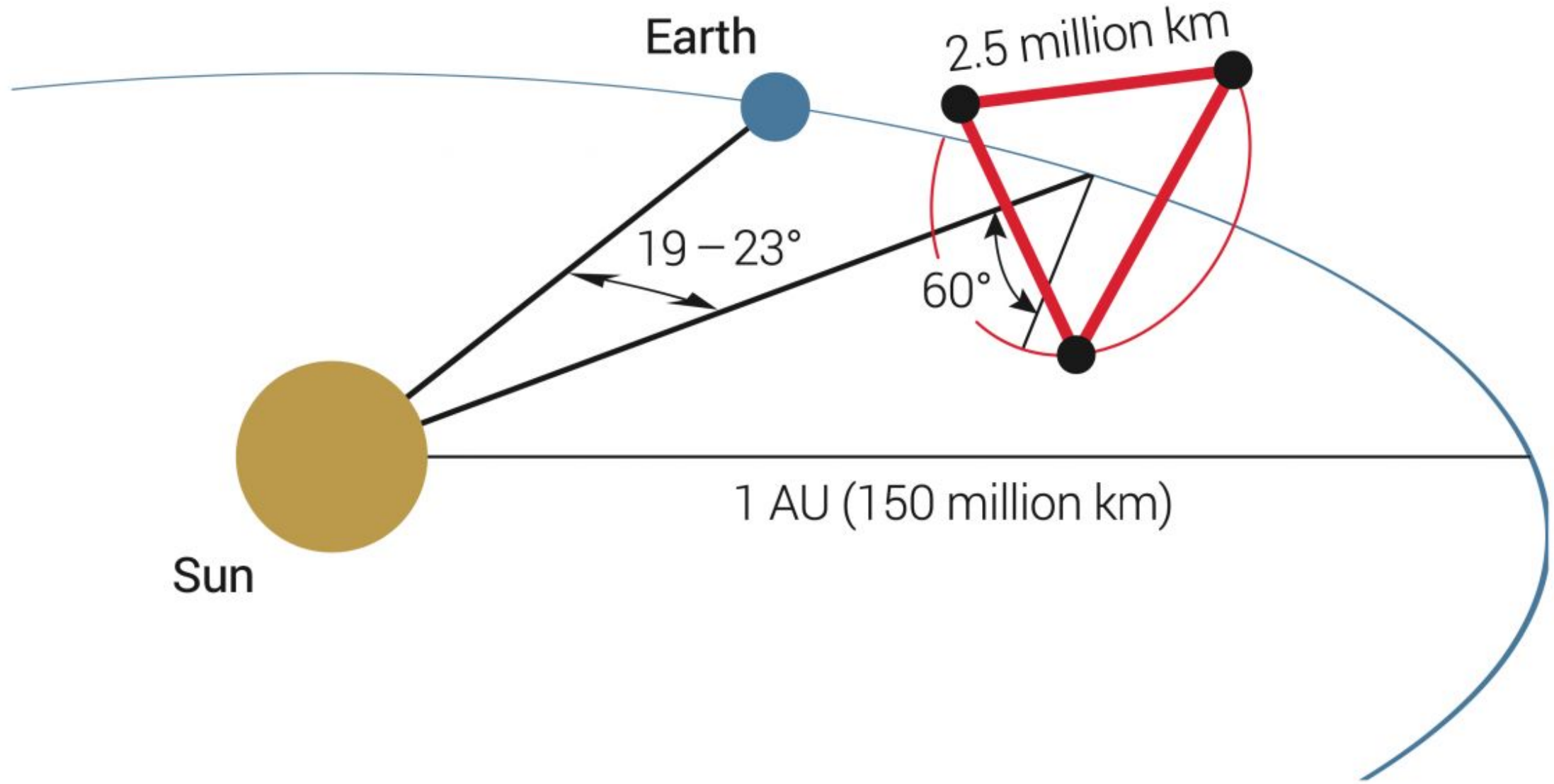


Figure credit – ESA

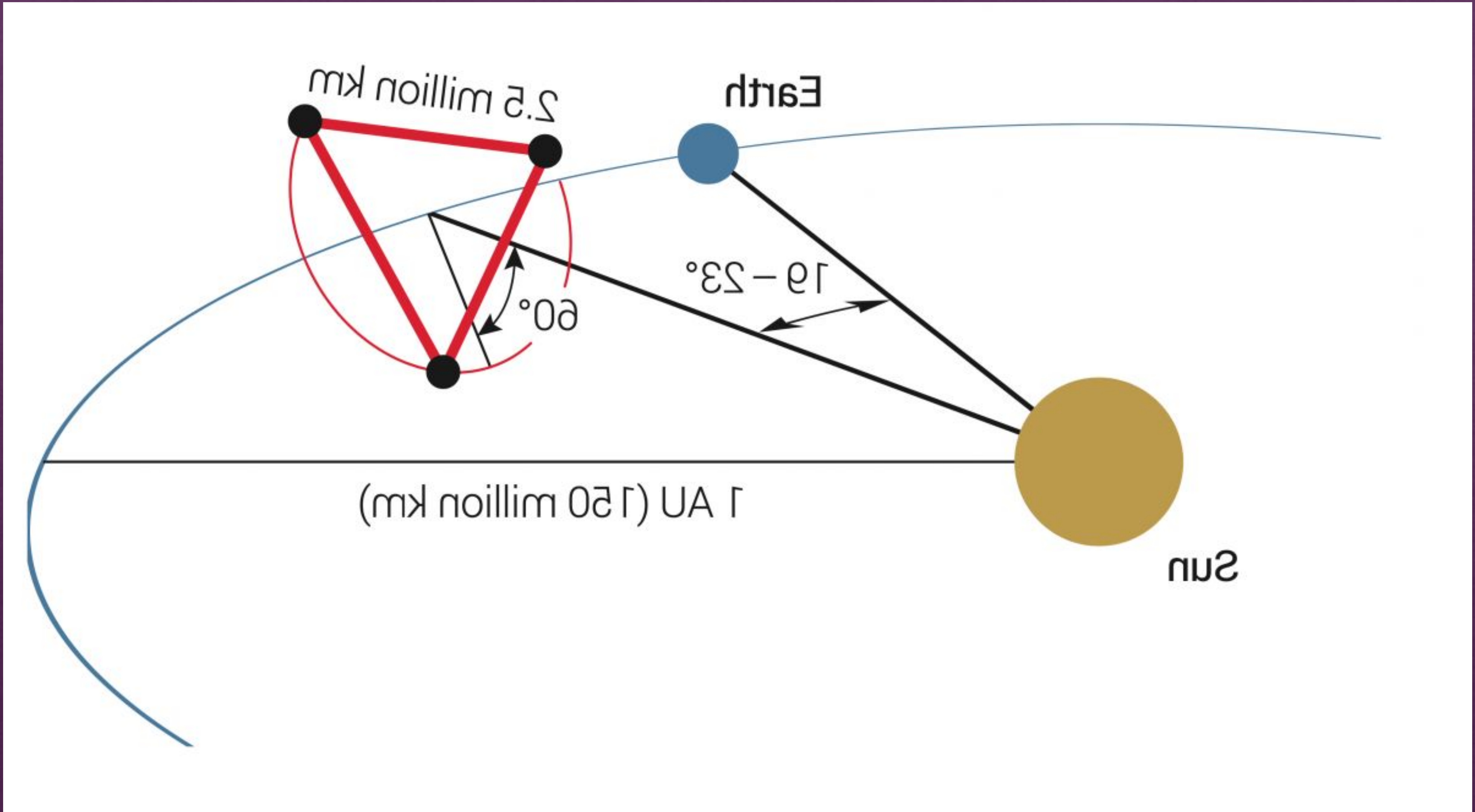


Figure credit – ESA

2.5 million km is **big**.

Why do we need an observatory of this scale?

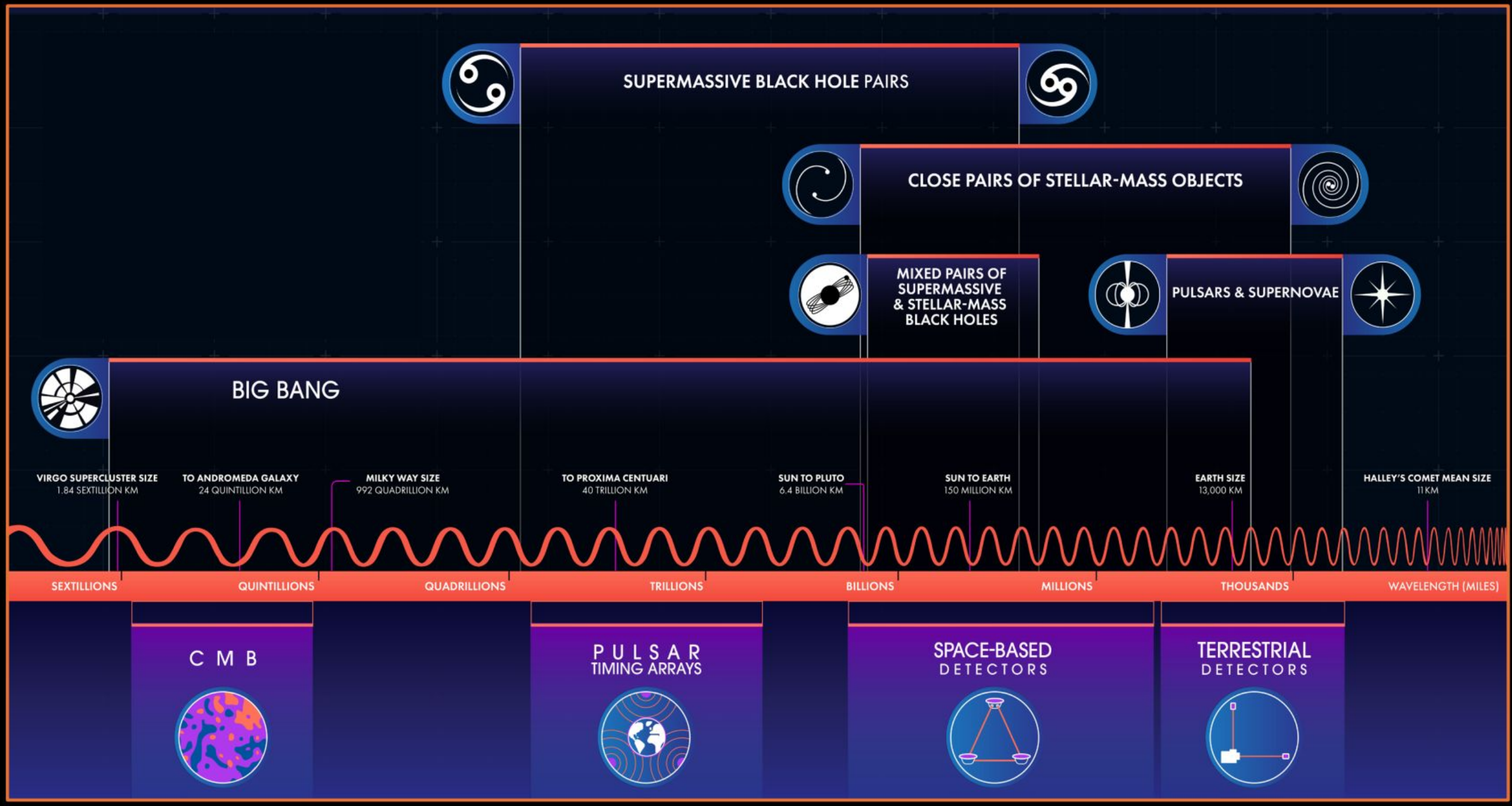


Figure credit – Joey Shapiro Key

THE SPECTRUM OF GRAVITATIONAL WAVES

esa

Observatories & experiments

Ground-based experiment

Space-based observatory

Pulsar timing array

Cosmic microwave background polarisation

Timescales

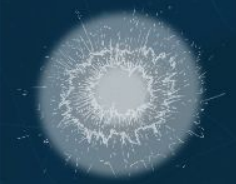
milliseconds — seconds — hours — years — billions of years

Frequency (Hz)

100 — 1 — 10^{-2} — 10^{-4} — 10^{-6} — 10^{-8} — 10^{-16}

Cosmic fluctuations in the early Universe

Cosmic sources



Supernova

Pulsar

Compact object falling onto a supermassive black hole

Merging supermassive black holes

Merging neutron stars in other galaxies

Merging stellar-mass black holes in other galaxies

Merging white dwarfs in our Galaxy

#lisa

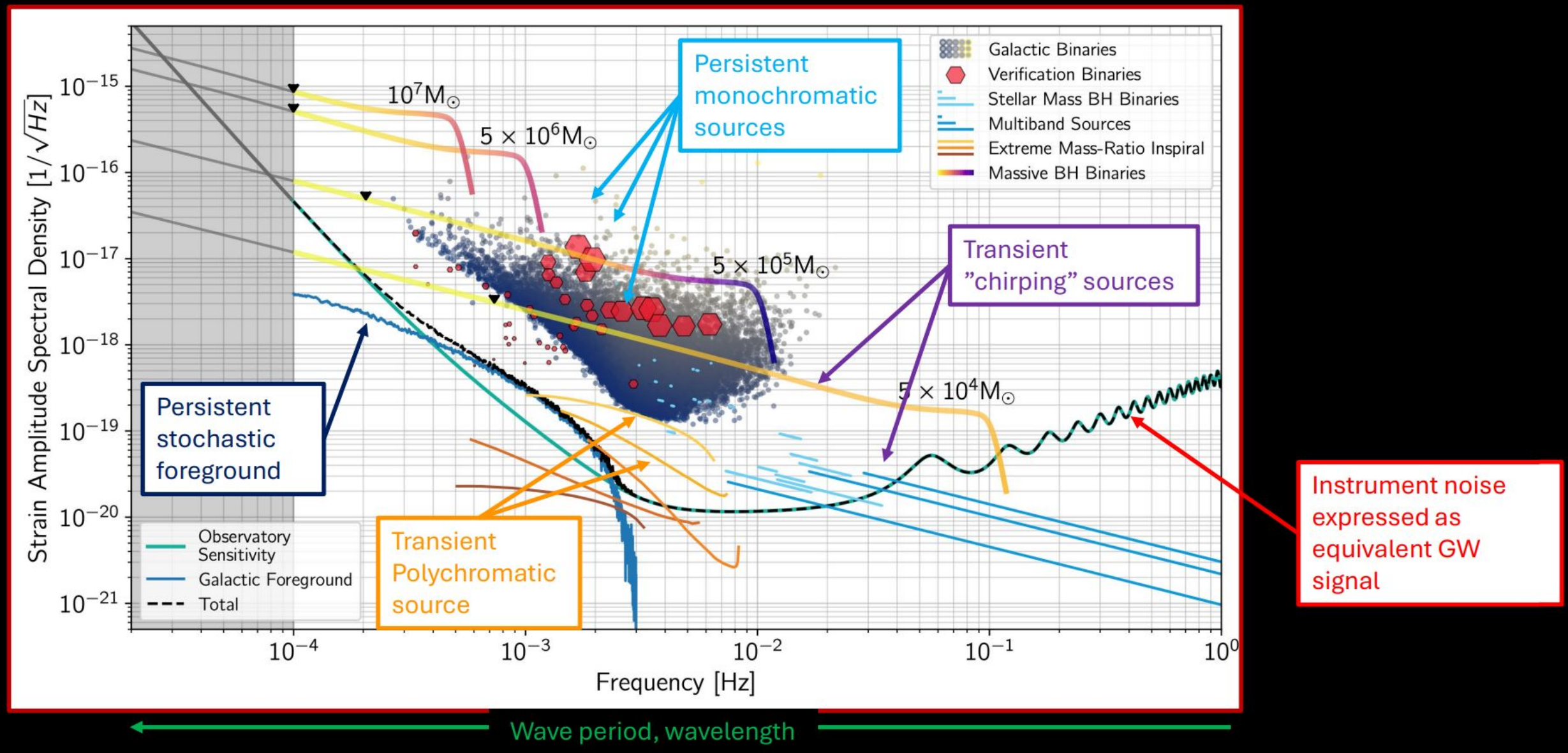


Figure credit – LISA Red Book (Colpi+24)

tens of millions of gravitational wave signals

tens of millions of
gravitational wave signals

in the observatory

tens of millions of
gravitational wave signals

in the observatory

all the time

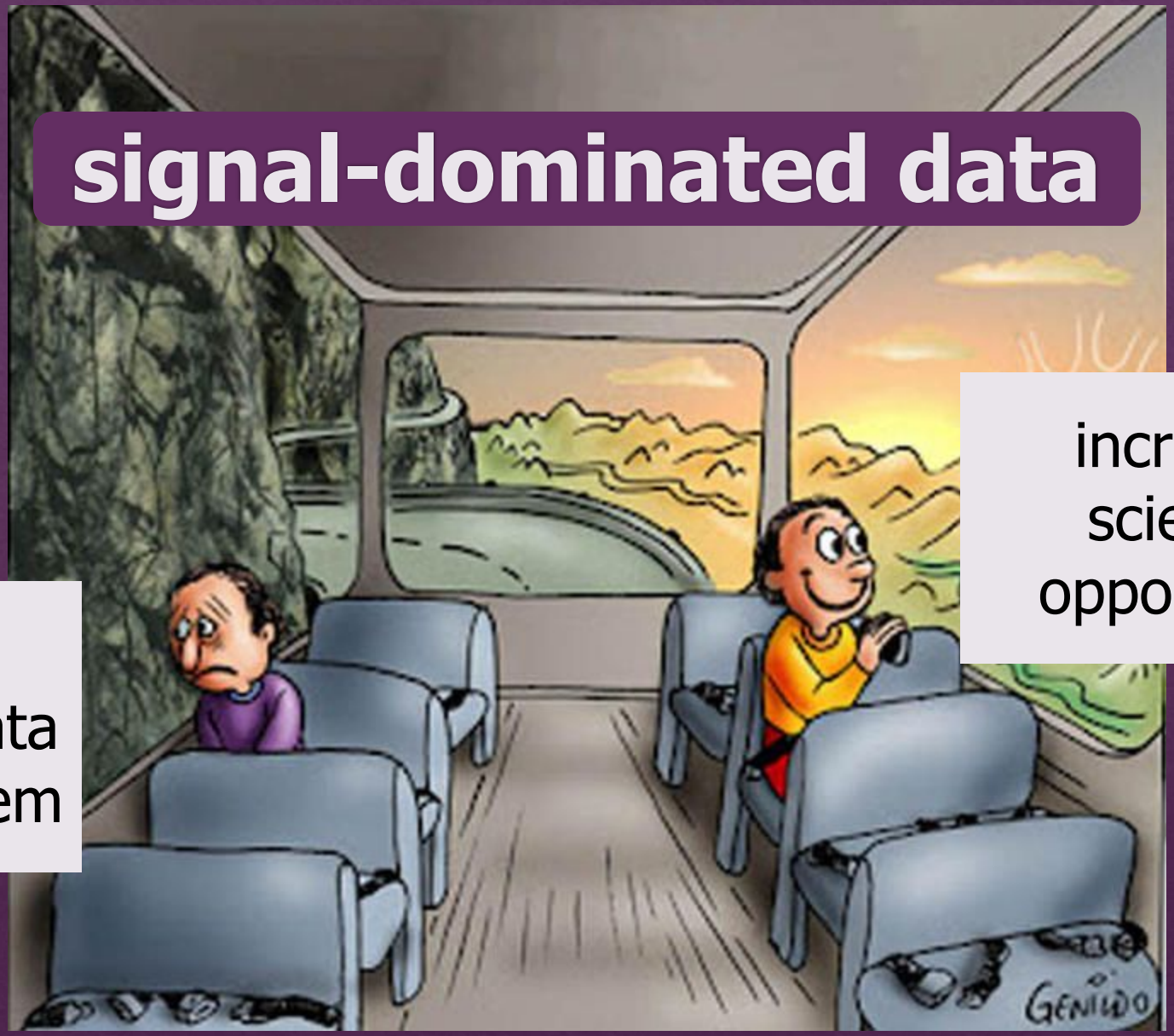
tens of millions of
gravitational wave signals

in the observatory

all the time

all at once.

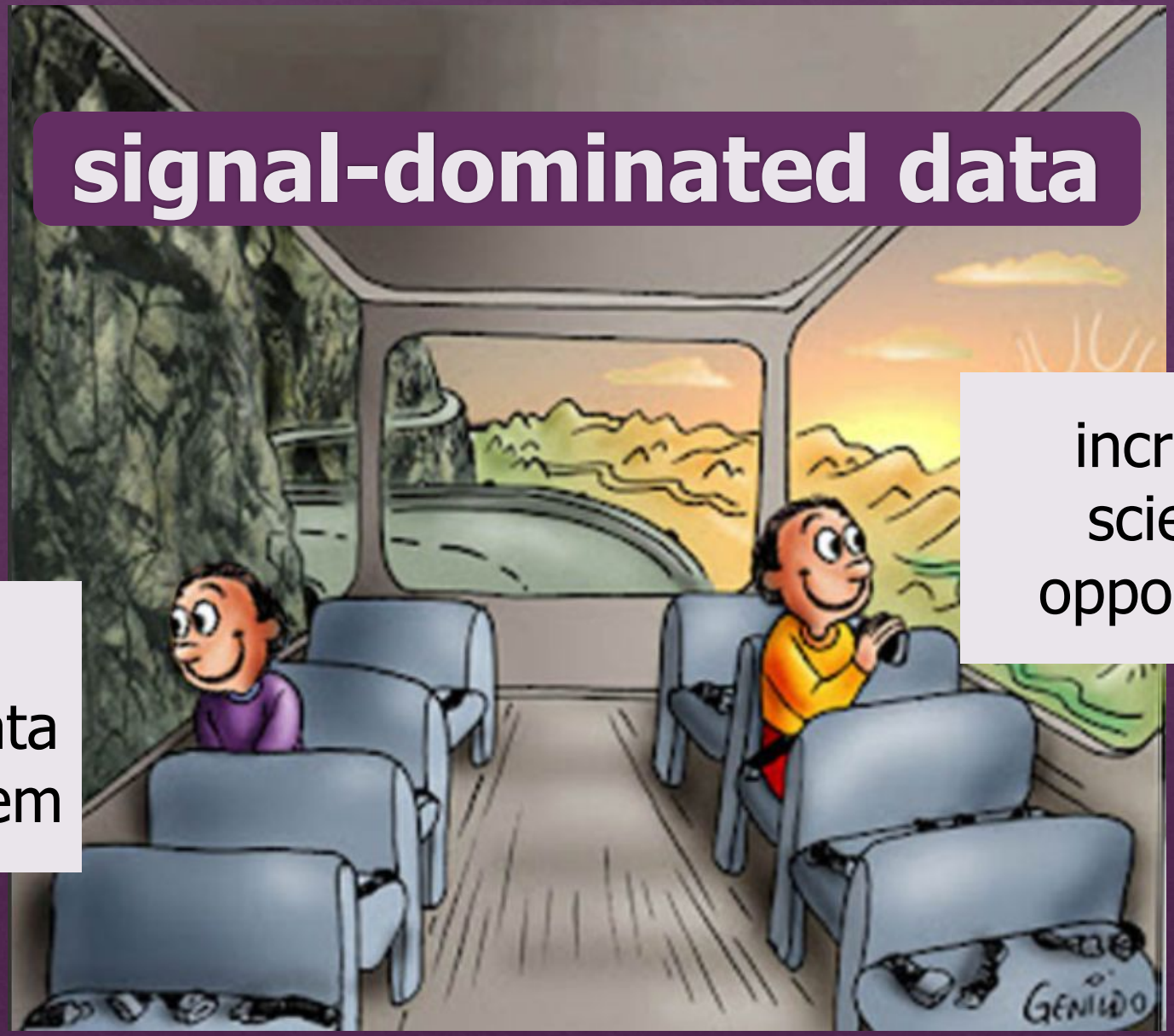
signal-dominated data



incredibly challenging data analysis problem

incredible scientific opportunity!

signal-dominated data



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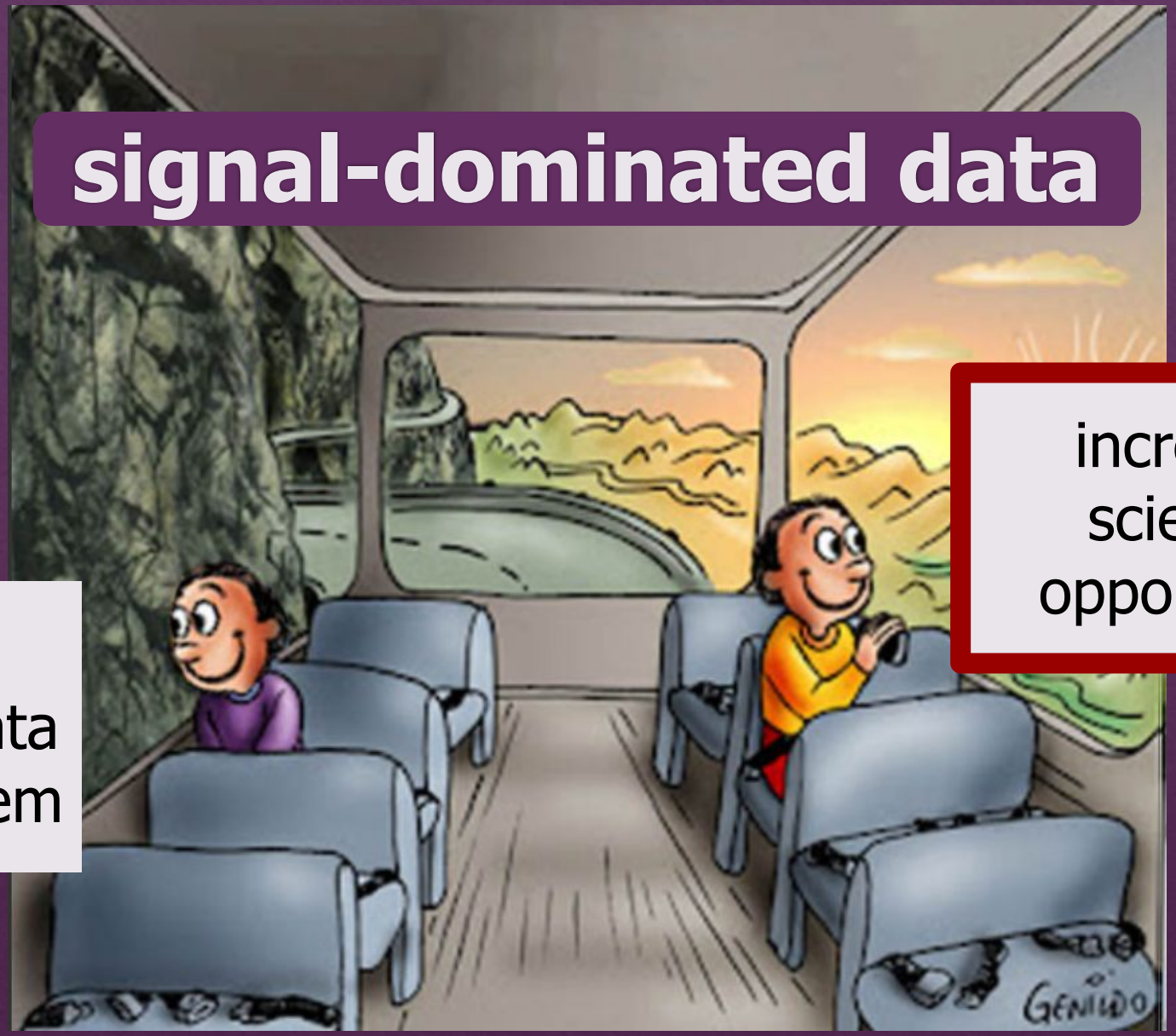
signal-dominated data



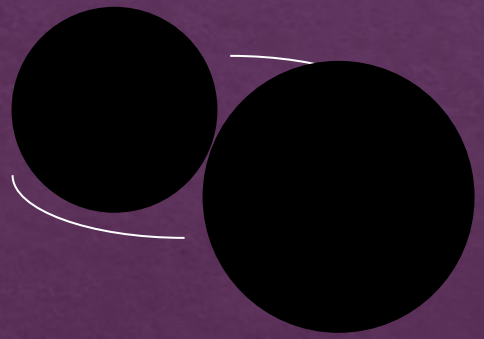
incredibly challenging data analysis problem

incredible scientific opportunity!

LISA Sources

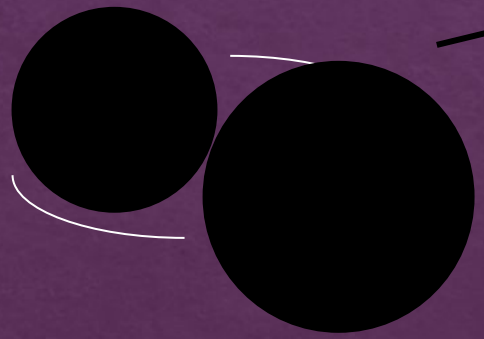
LISA Sources

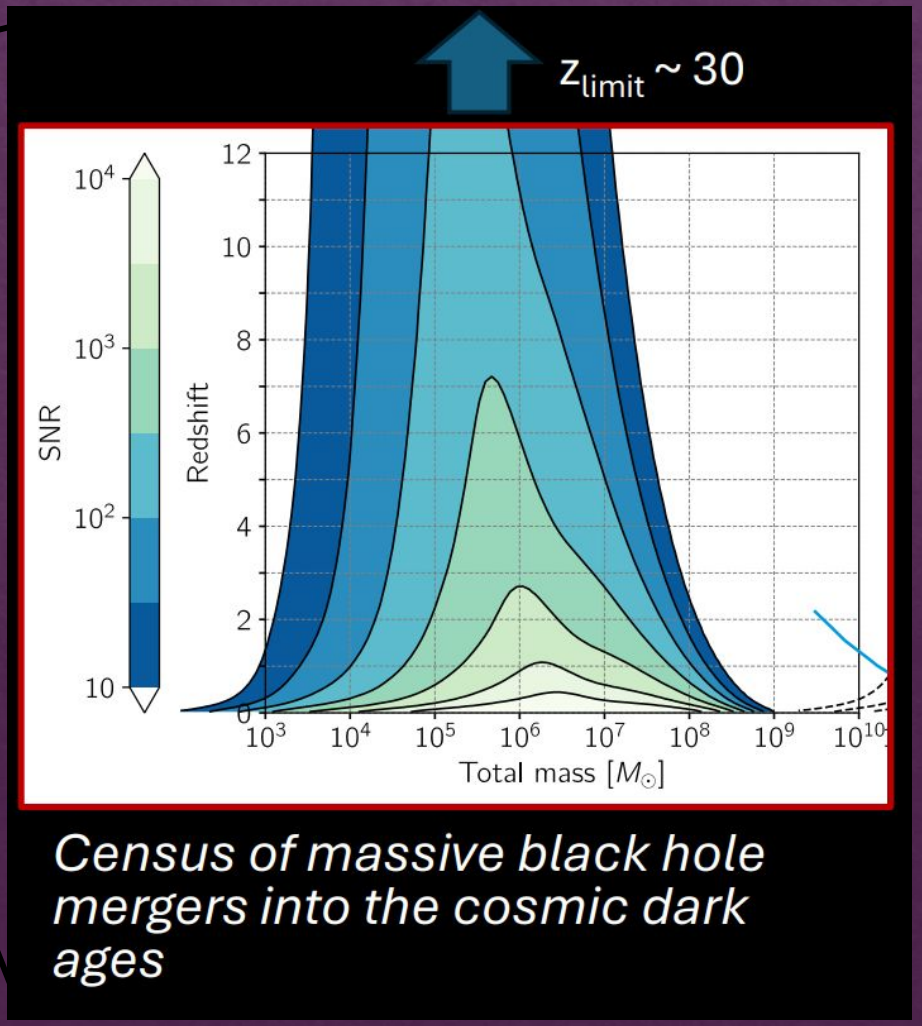
Massive Binary Black Hole Mergers



LISA Sources

Massive Binary Black Hole Mergers

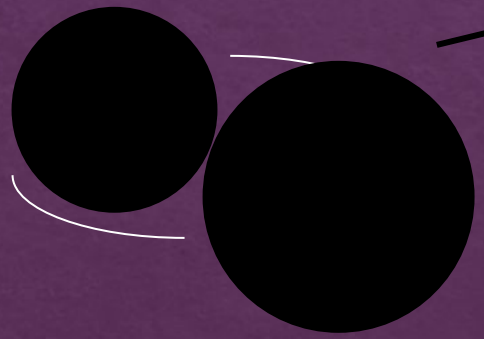


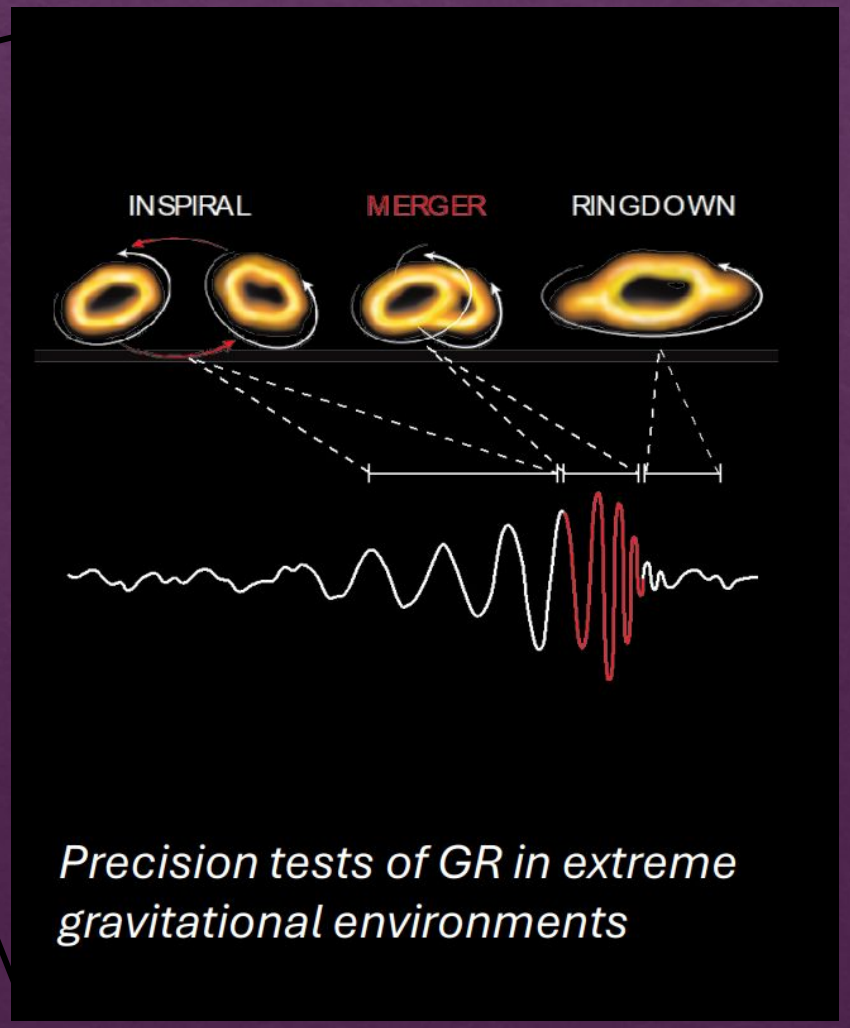


Census of massive black hole mergers into the cosmic dark ages

LISA Sources

Massive Binary Black Hole Mergers





LISA Sources

Massive Binary Black Hole Mergers

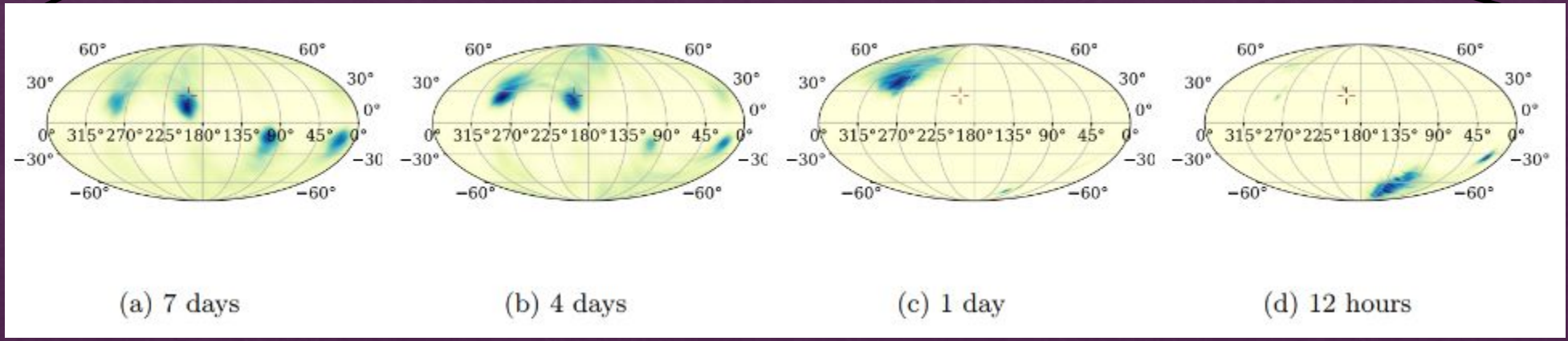
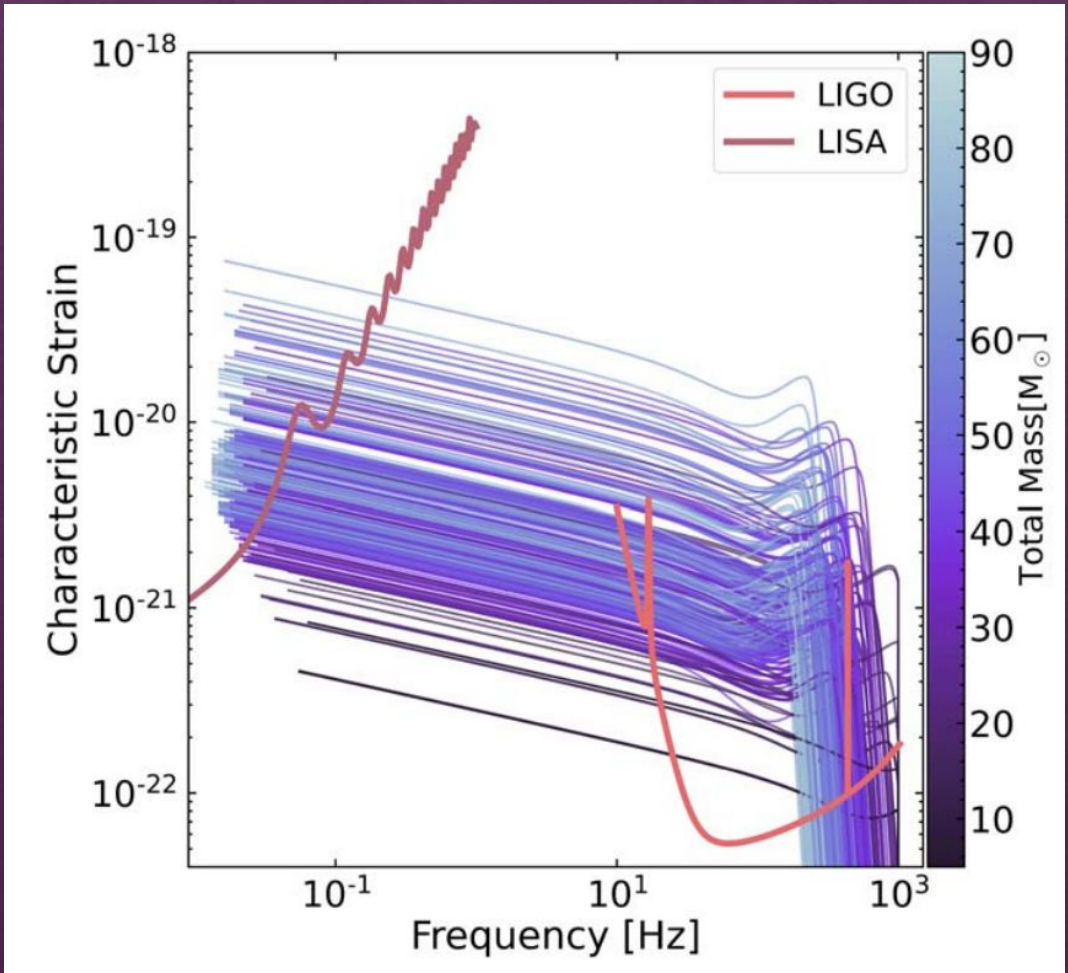


Figure credit – Davies+24

LISA Sources



Stellar-origin compact binaries far from merger

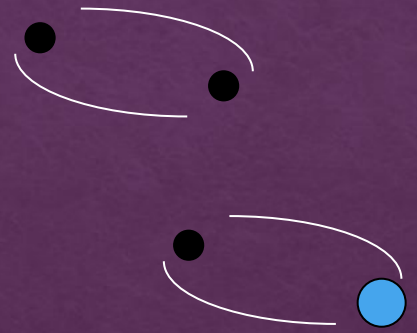
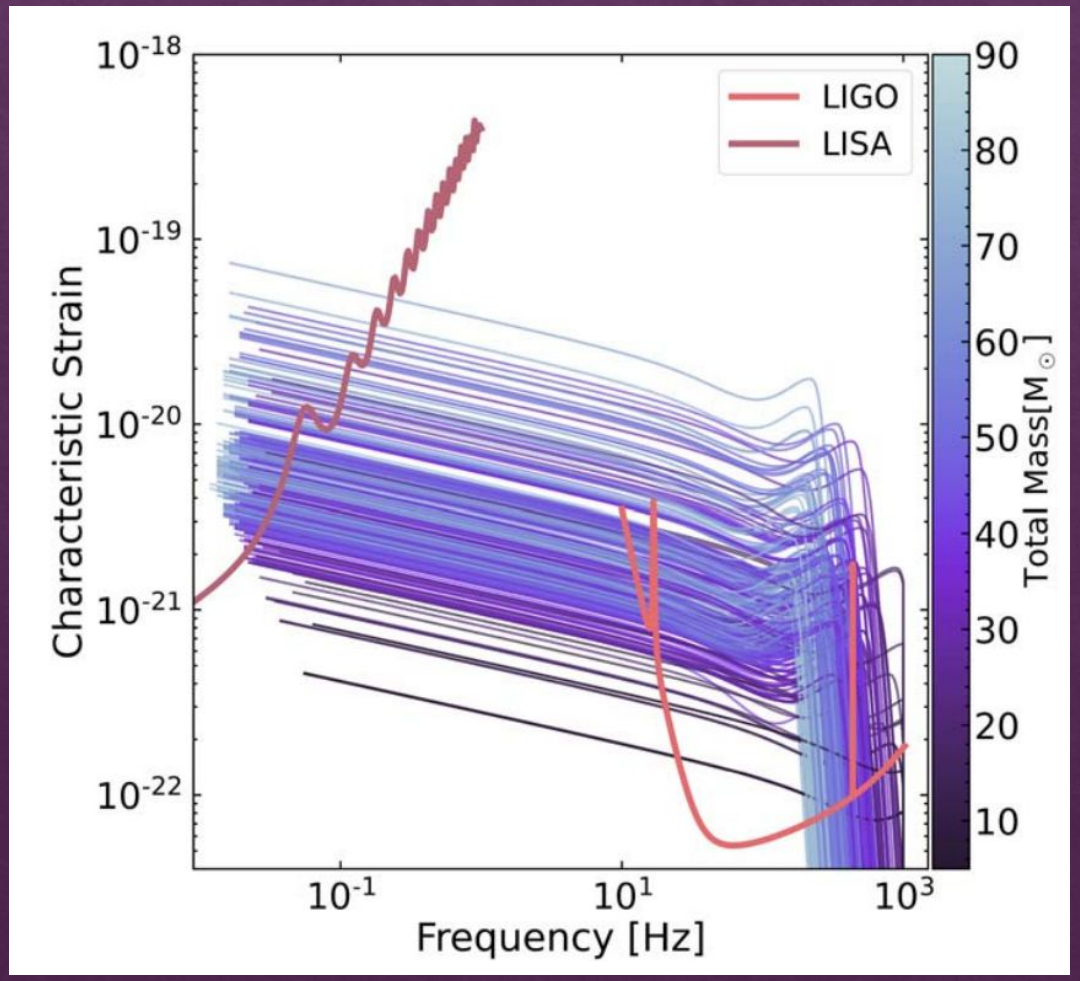
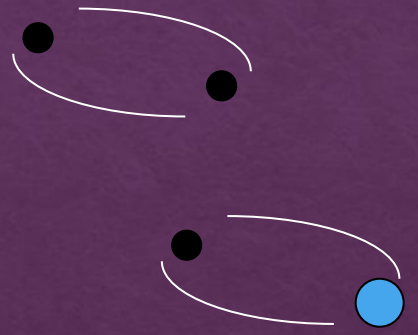


Figure credit – Krystal Ruiz-Rocha +25

LISA Sources



Stellar-origin compact binaries far from merger



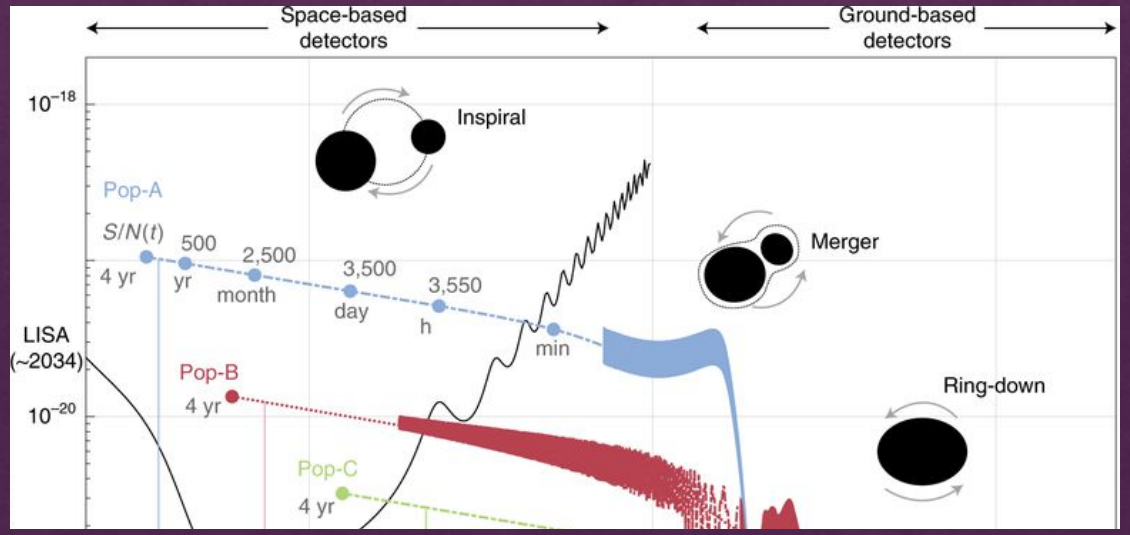
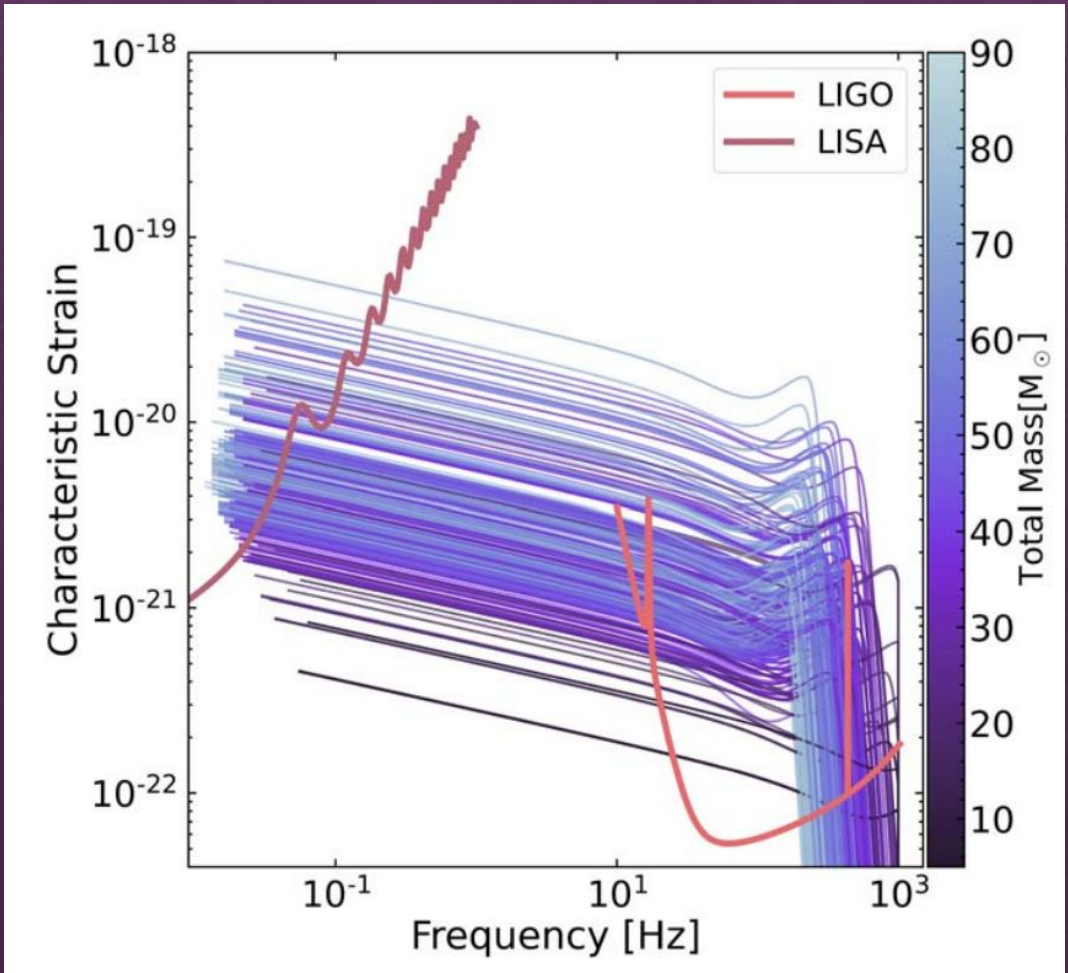
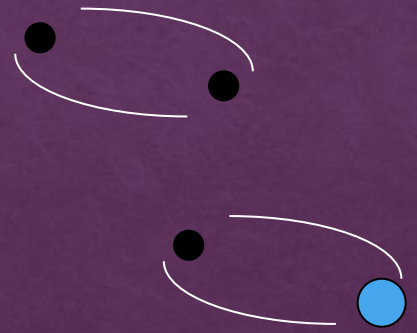


Figure credit – Krystal Ruiz-Rocha +25, Jani+20

LISA Sources



Stellar-origin compact binaries far from merger



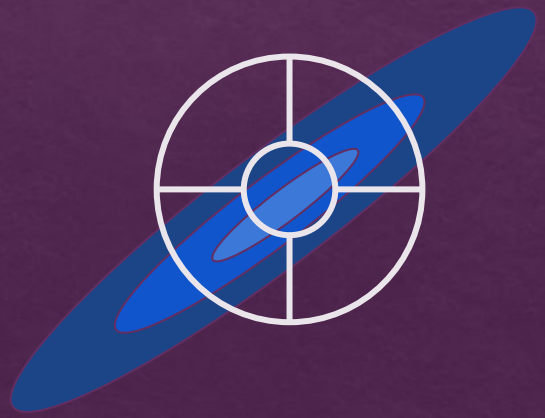


Figure credit – Krystal Ruiz-Rocha +25

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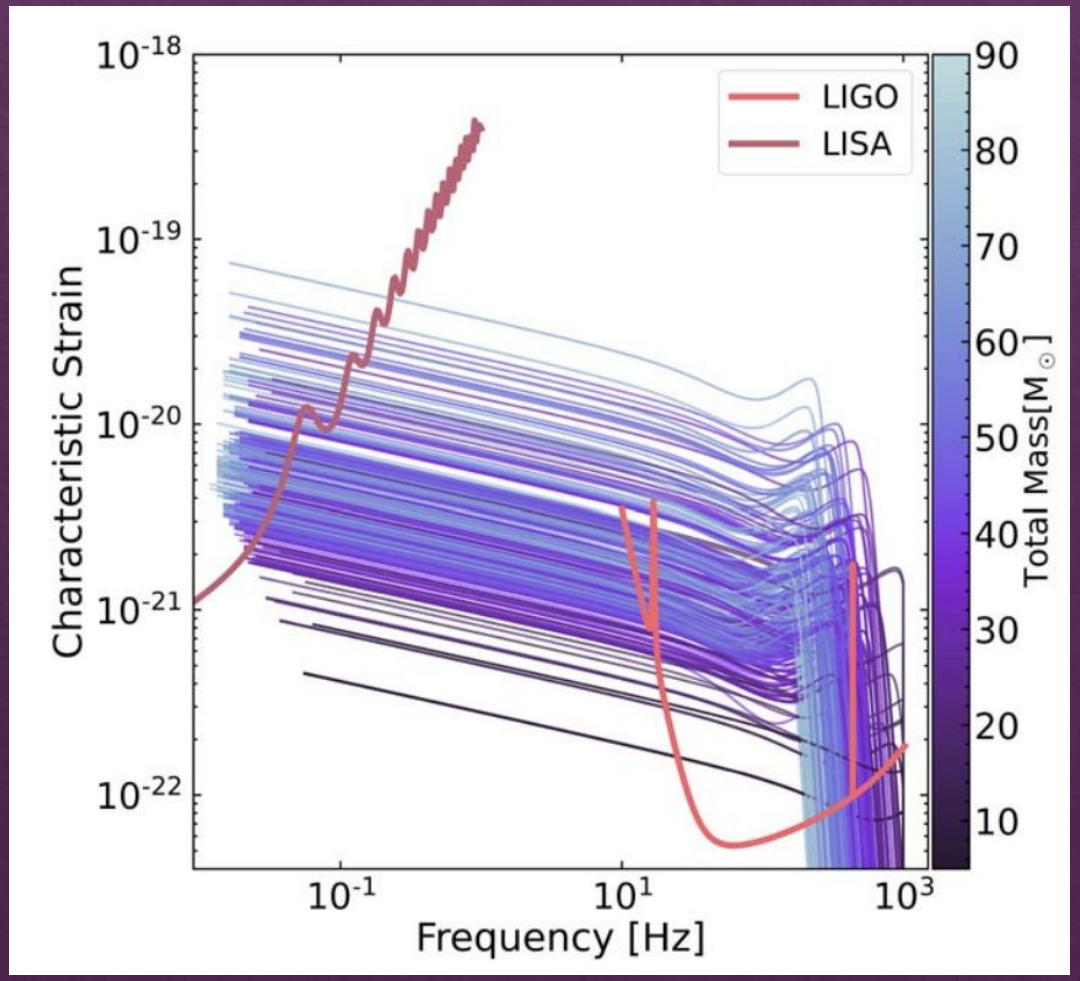

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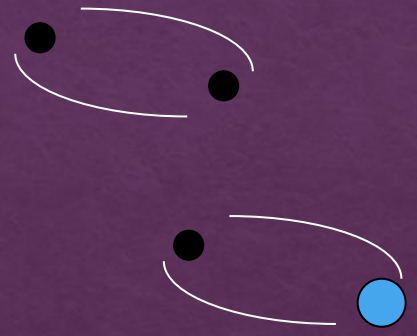


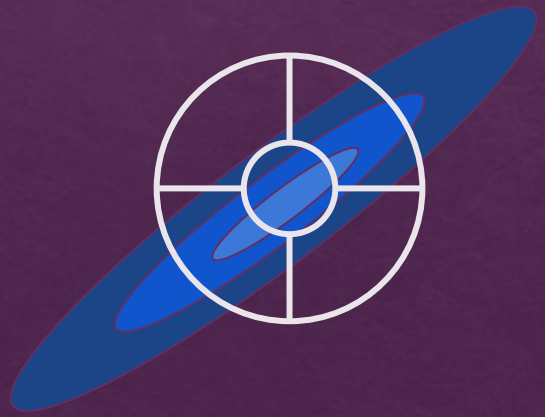
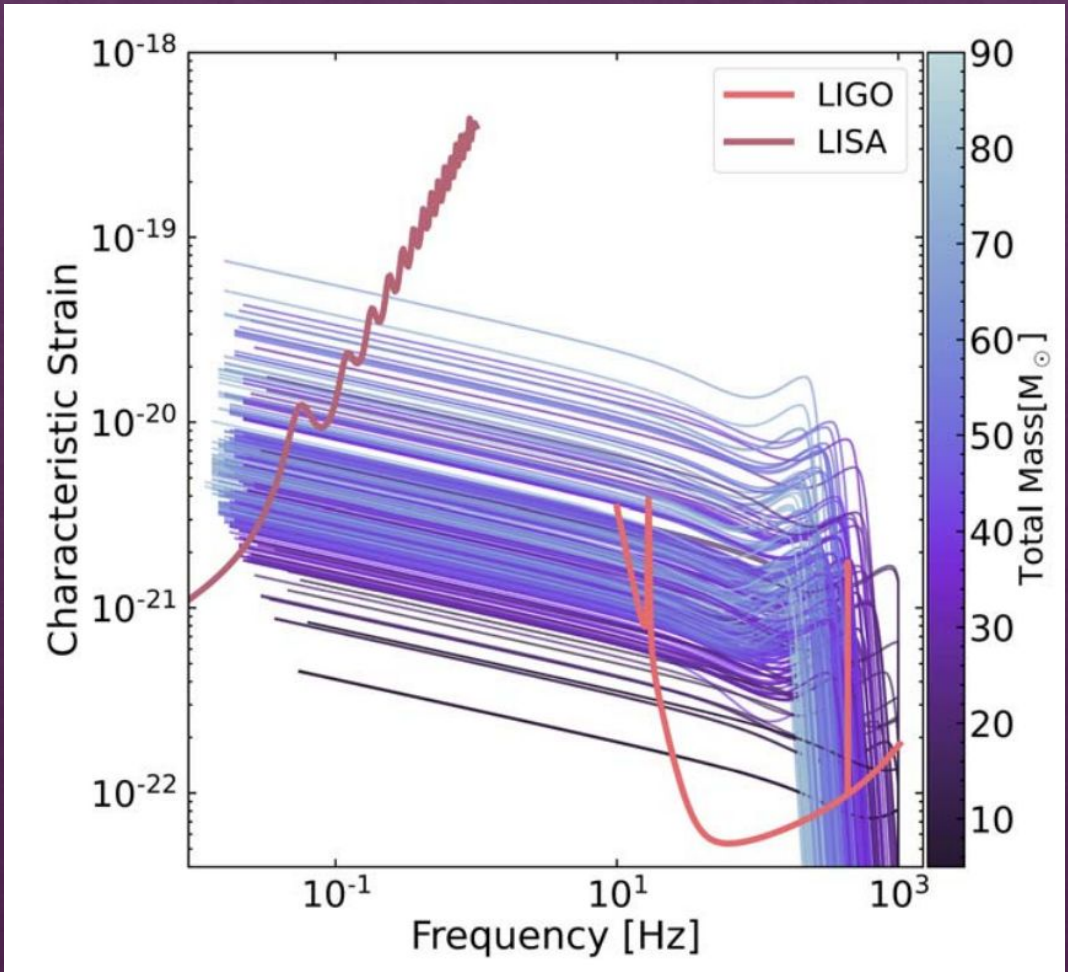


Figure credit – Krystal Ruiz-Rocha +25

LISA Sources



Stellar-origin compact binaries far from merger

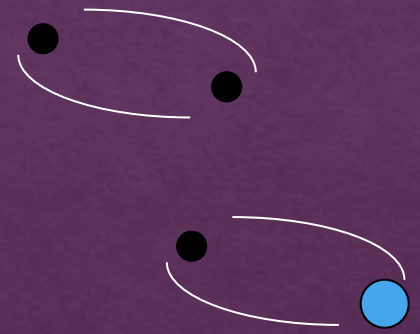
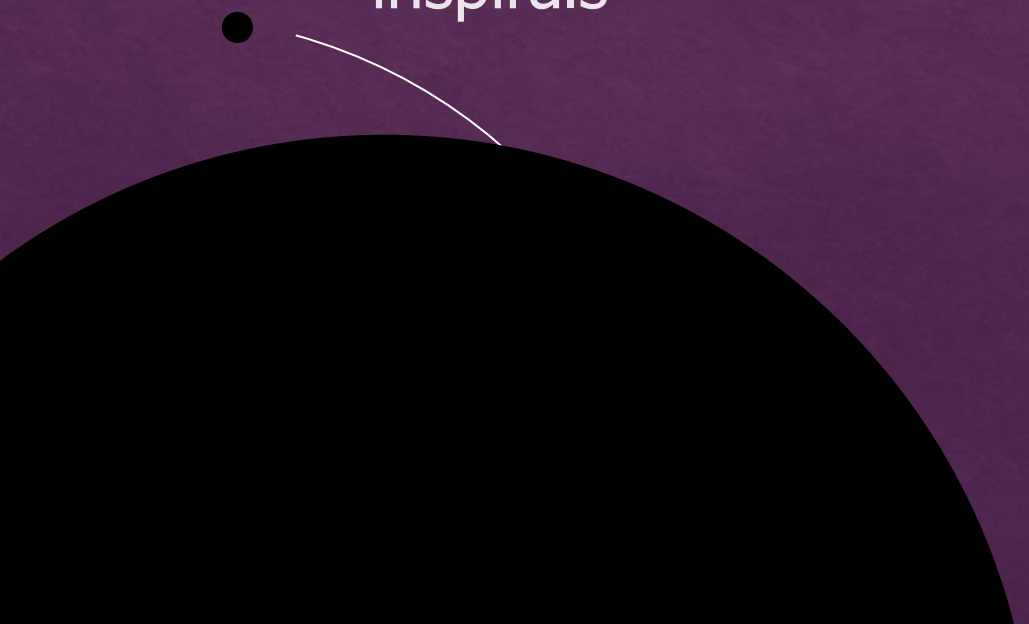


Figure credit – Krystal Ruiz-Rocha +25

LISA Sources

Extreme mass-ratio inspirals



LISA Sources

Extreme mass-ratio inspirals

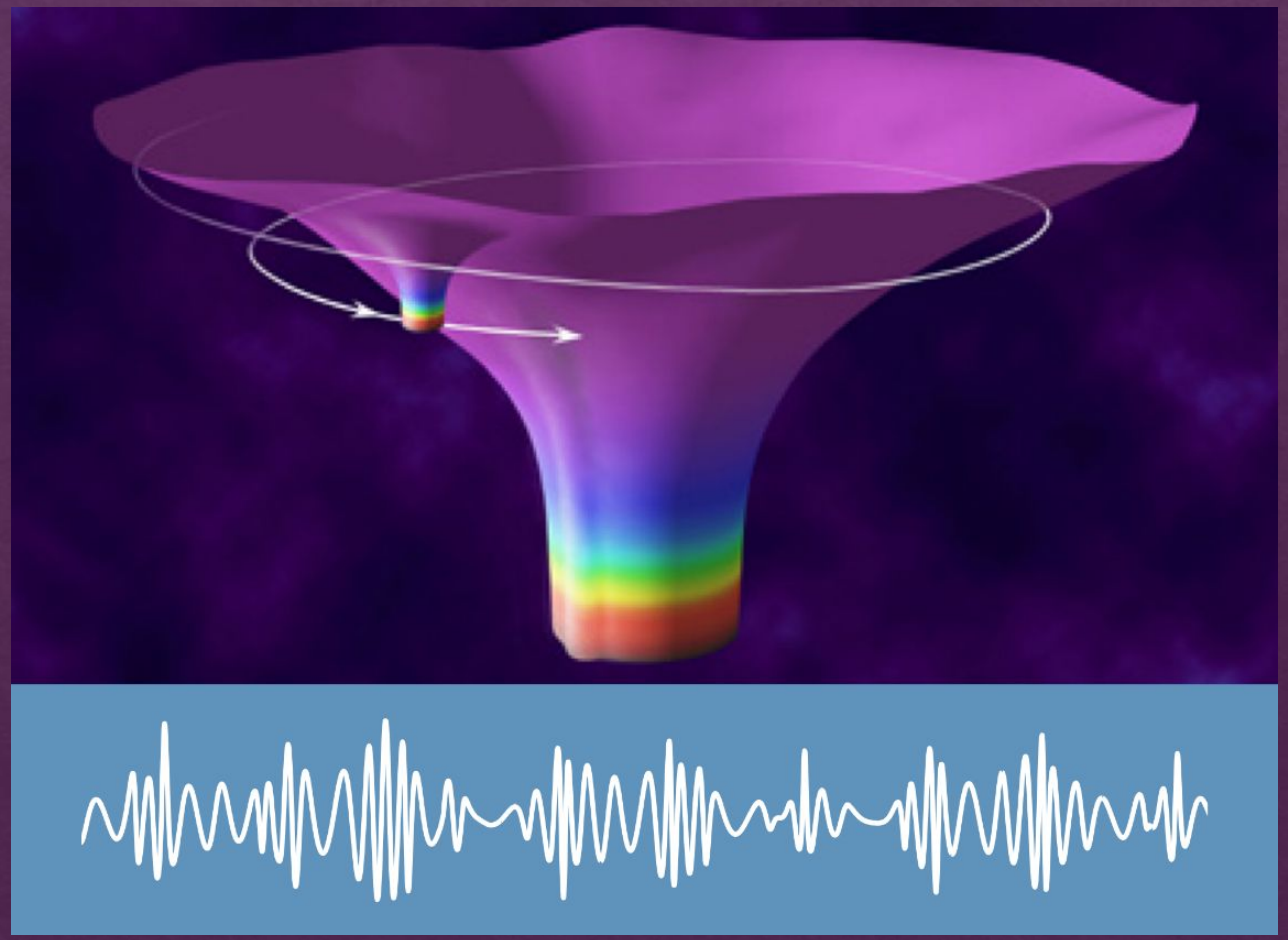
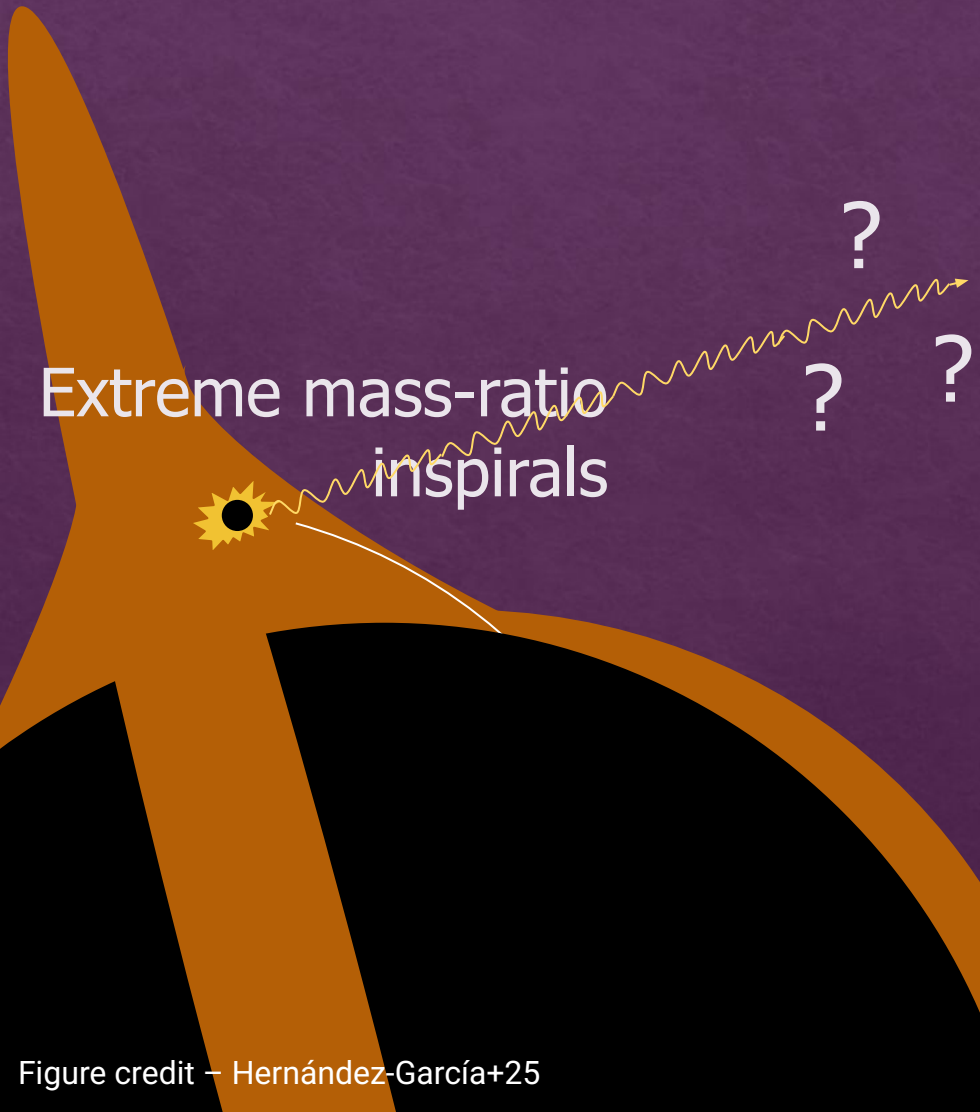


Figure credit – Amaro-Seoane+13

LISA Sources



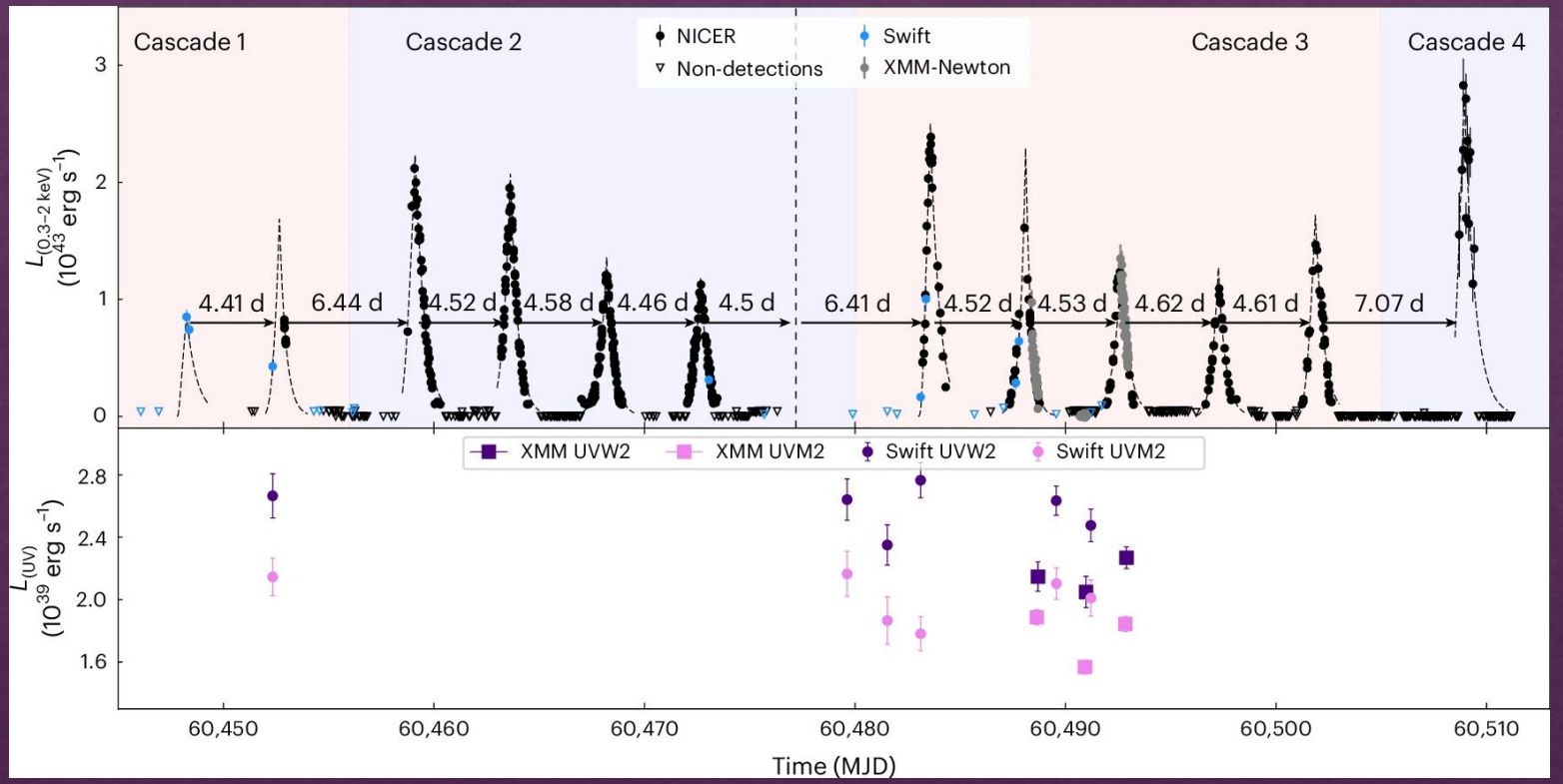


Figure credit – Hernández-García+25

LISA Sources

Galactic Binaries

LISA Sources

every mHz close compact binary in the Milky Way

Galactic Binaries

LISA Sources

every mHz close compact binary in the Milky Way

→ ~10,000 individually-resolvable systems

Galactic Binaries

LISA Sources

every mHz close compact binary in the Milky Way

→ ~10,000 individually-resolvable systems

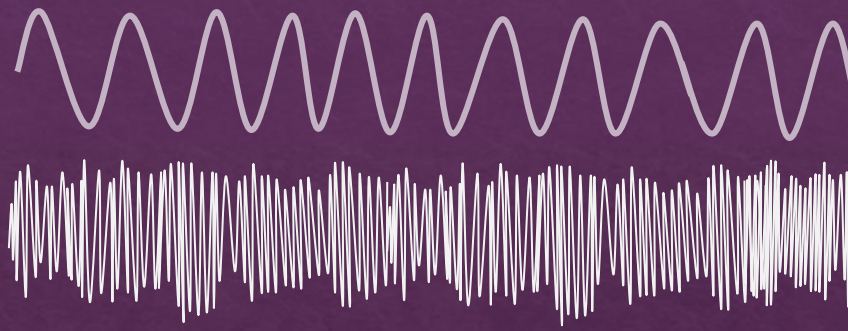
Phenomenal opportunity for non-time-domain and archival multimessenger astronomy!

Galactic Binaries

LISA Sources

every mHz close compact binary in the Milky Way

- ~10,000 individually-resolvable systems
- ~tens of **millions** of unresolved systems



Galactic Binaries

LISA Sources

every mHz close compact binary in the Milky Way

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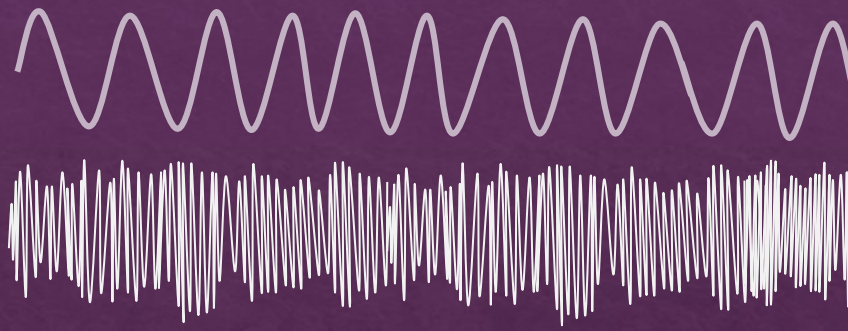
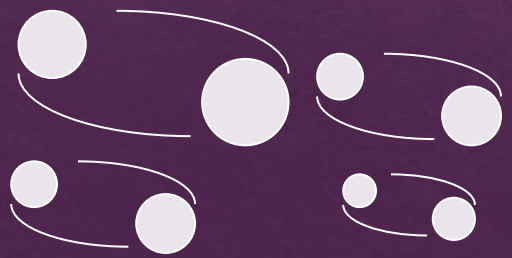
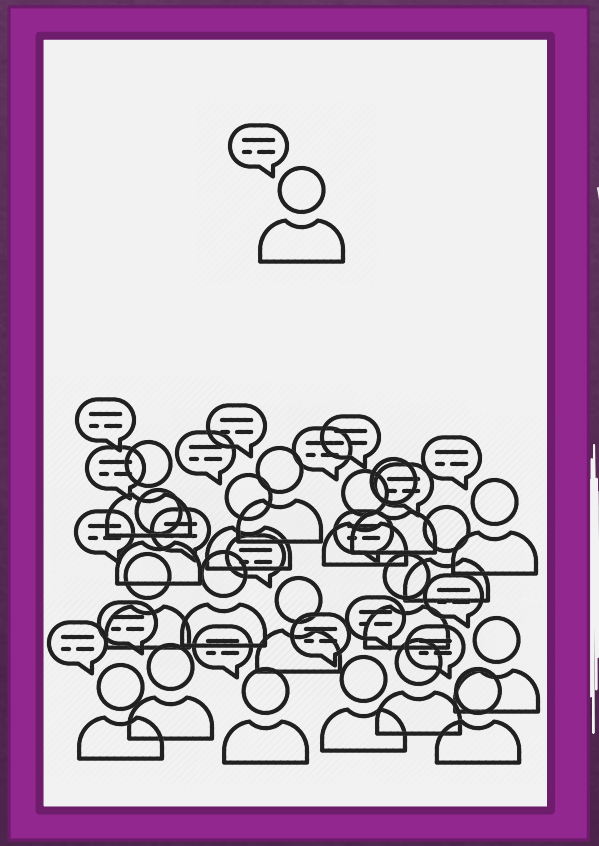


A fantastic scientific opportunity!
…and a source of noise
for other science goals



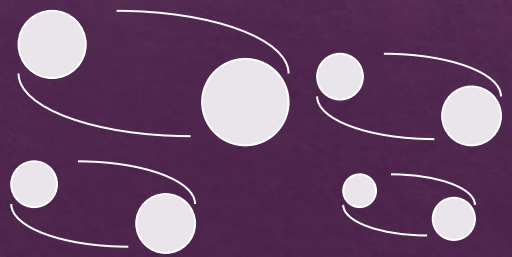
Galactic Binaries

LISA Sources



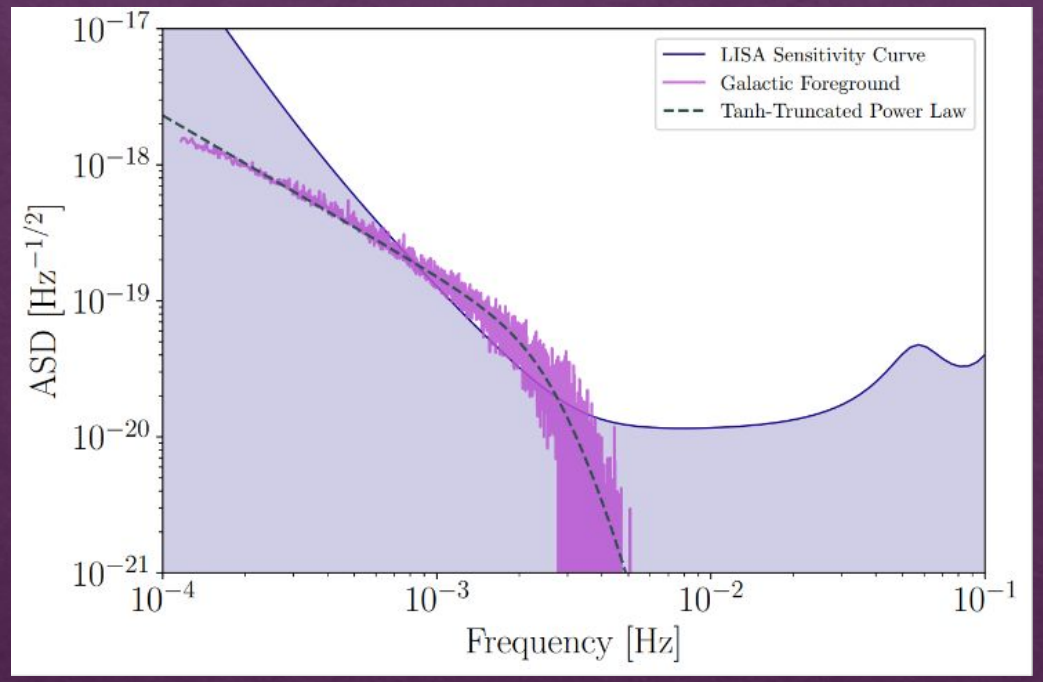
resolved = **deterministic**

unresolved = **stochastic**



Galactic Binaries

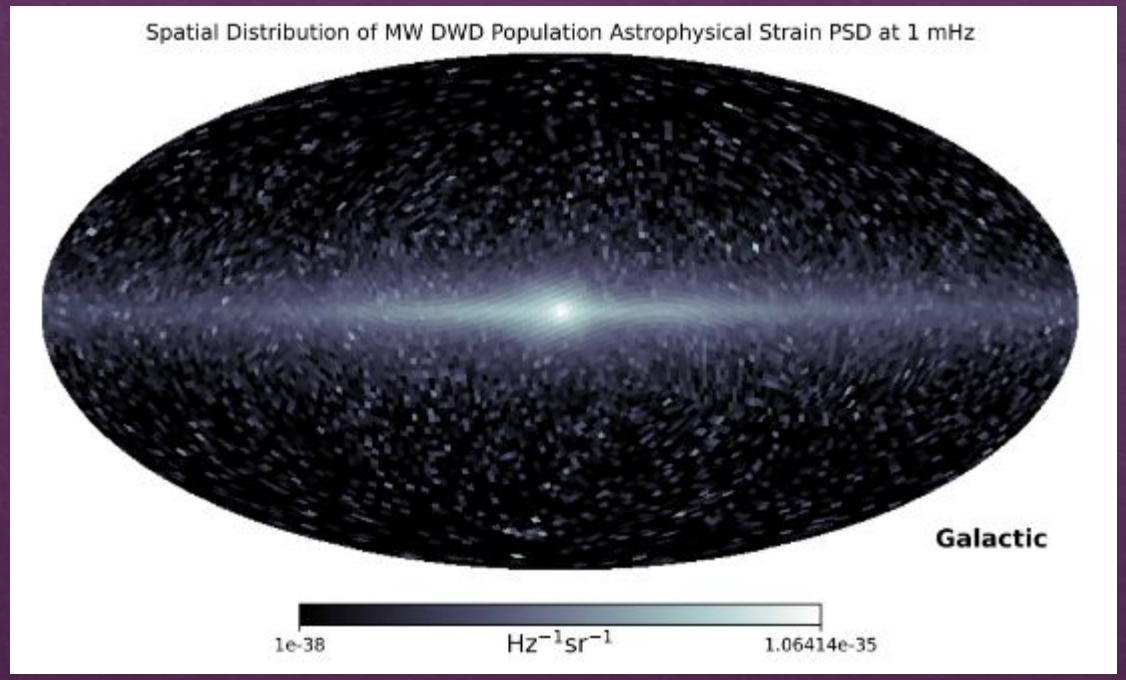
LISA Sources



Fourier transform of the stochastic signal gives its amplitude spectral density (frequency spectrum)

Galactic Binaries

LISA Sources



Anisotropy matters!

The Galactic foreground traces the shape of the Galaxy on the sky – this is measurable by LISA!

Galactic Binaries

LISA Sources

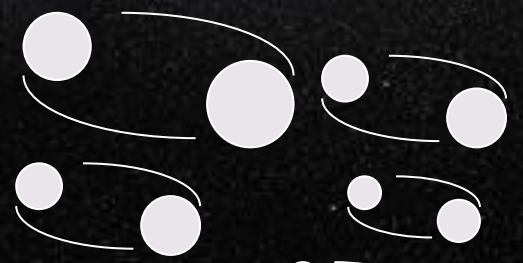
every mHz close compact binary in the Milky Way

Galactic Binaries

LISA Sources

this will allow us to learn about…

the morphology and history of the Milky Way (and its dwarf galaxy satellites!)



Galactic Binaries

LISA Sources

this will allow us to learn about…

binary stellar evolution

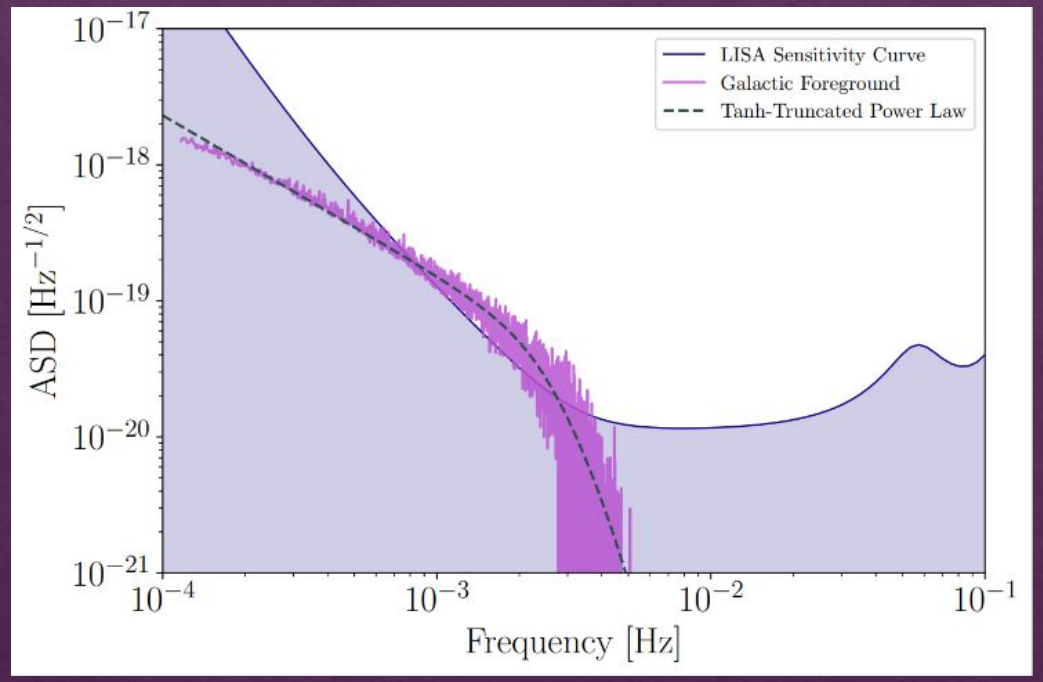
Galactic Binaries

Figure credit – NASA/ESA/CSA/STScI/JPL/Caltech (JWST)

LISA Sources

Stochastic Backgrounds

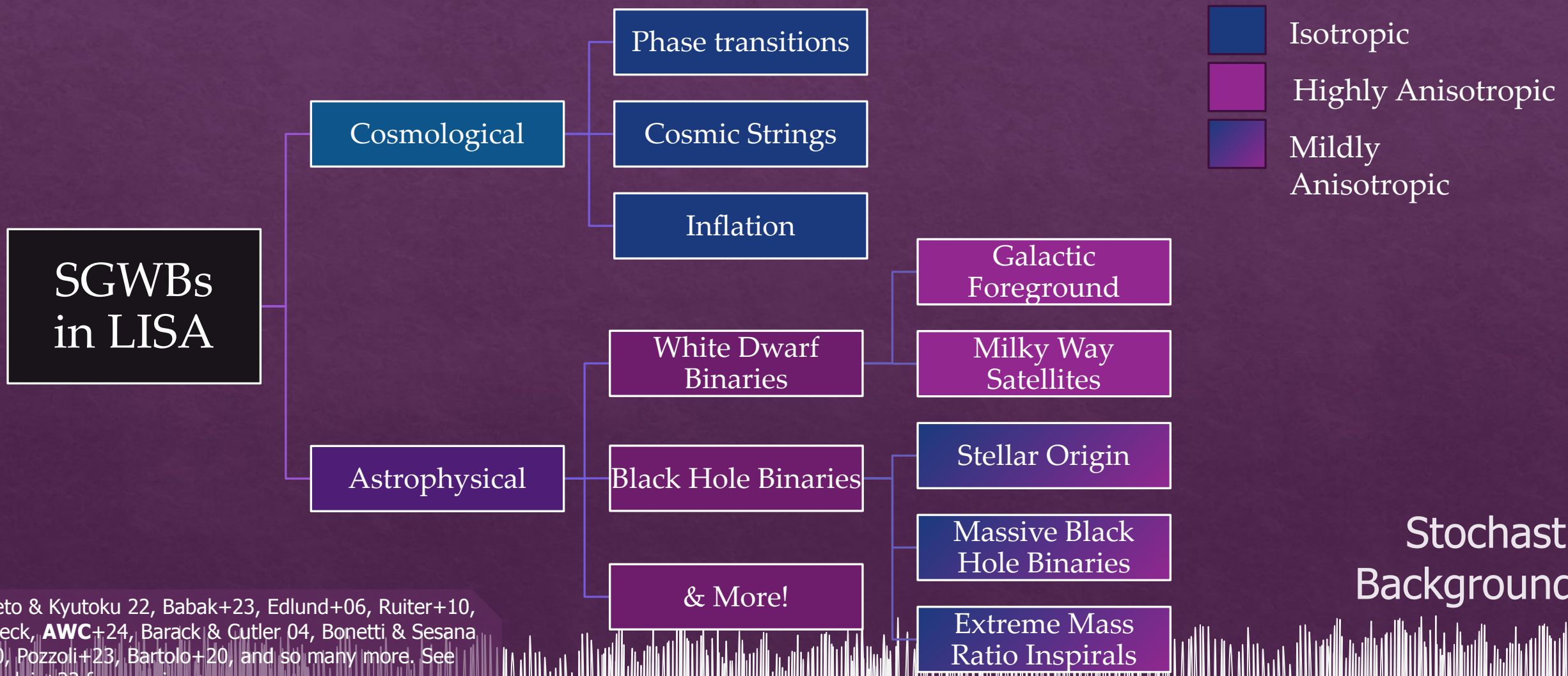
LISA Sources



Beyond the
Galactic Foreground

Stochastic
Backgrounds

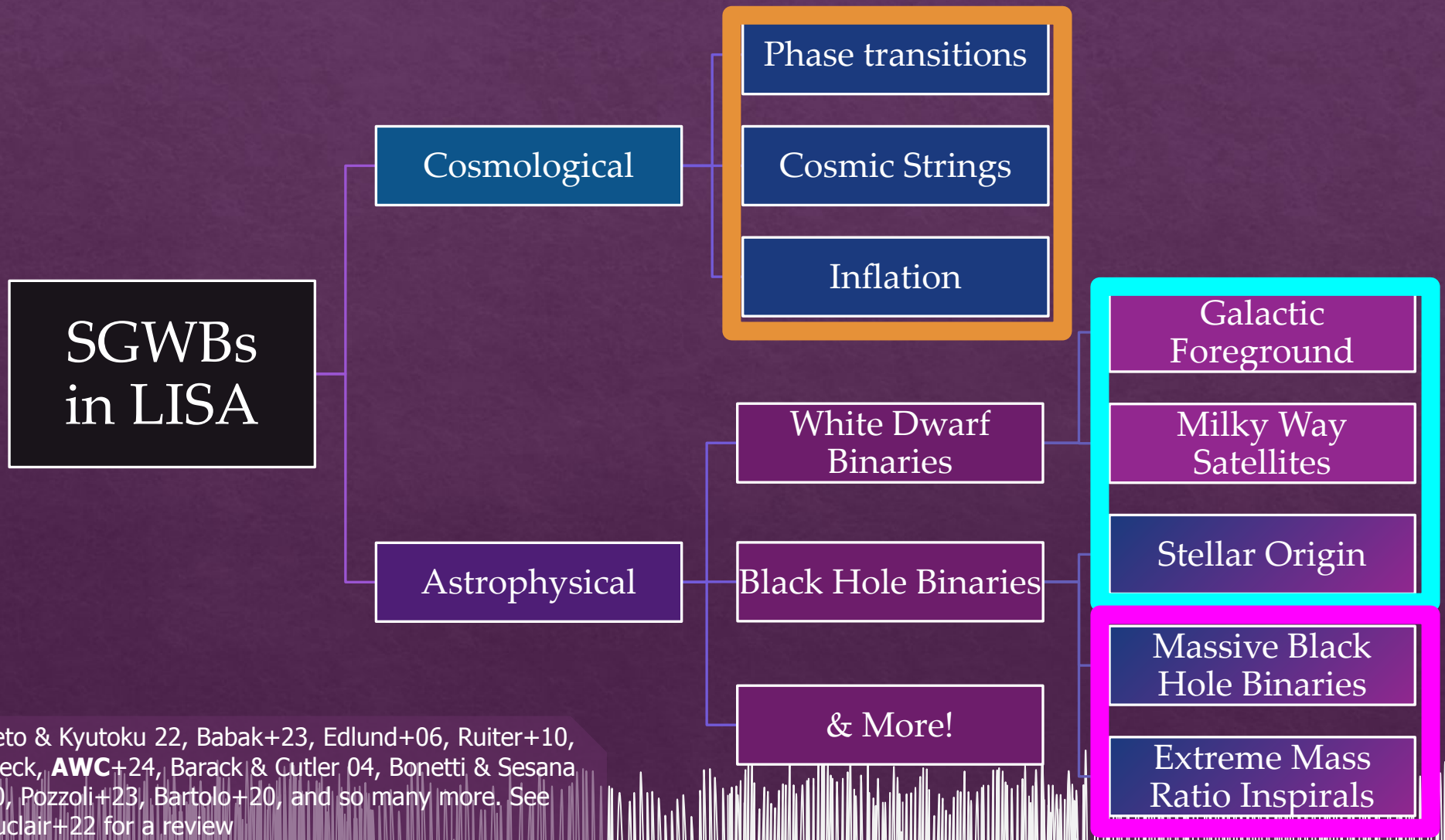
LISA Sources



Stochastic Backgrounds

Seto & Kyutoku 22, Babak+23, Edlund+06, Ruiter+10, Rieck, **AWC**+24, Barack & Cutler 04, Bonetti & Sesana 20, Pozzoli+23, Bartolo+20, and so many more. See Auclair+22 for a review

LISA Sources



Likely or Guaranteed

Big If True

Lots or none at all!

Isotropic

Highly Anisotropic

Mildly Anisotropic

Stochastic Backgrounds

Seto & Kyutoku 22, Babak+23, Edlund+06, Ruiter+10, Rieck, **AWC**+24, Barack & Cutler 04, Bonetti & Sesana 20, Pozzoli+23, Bartolo+20, and so many more. See Auclair+22 for a review

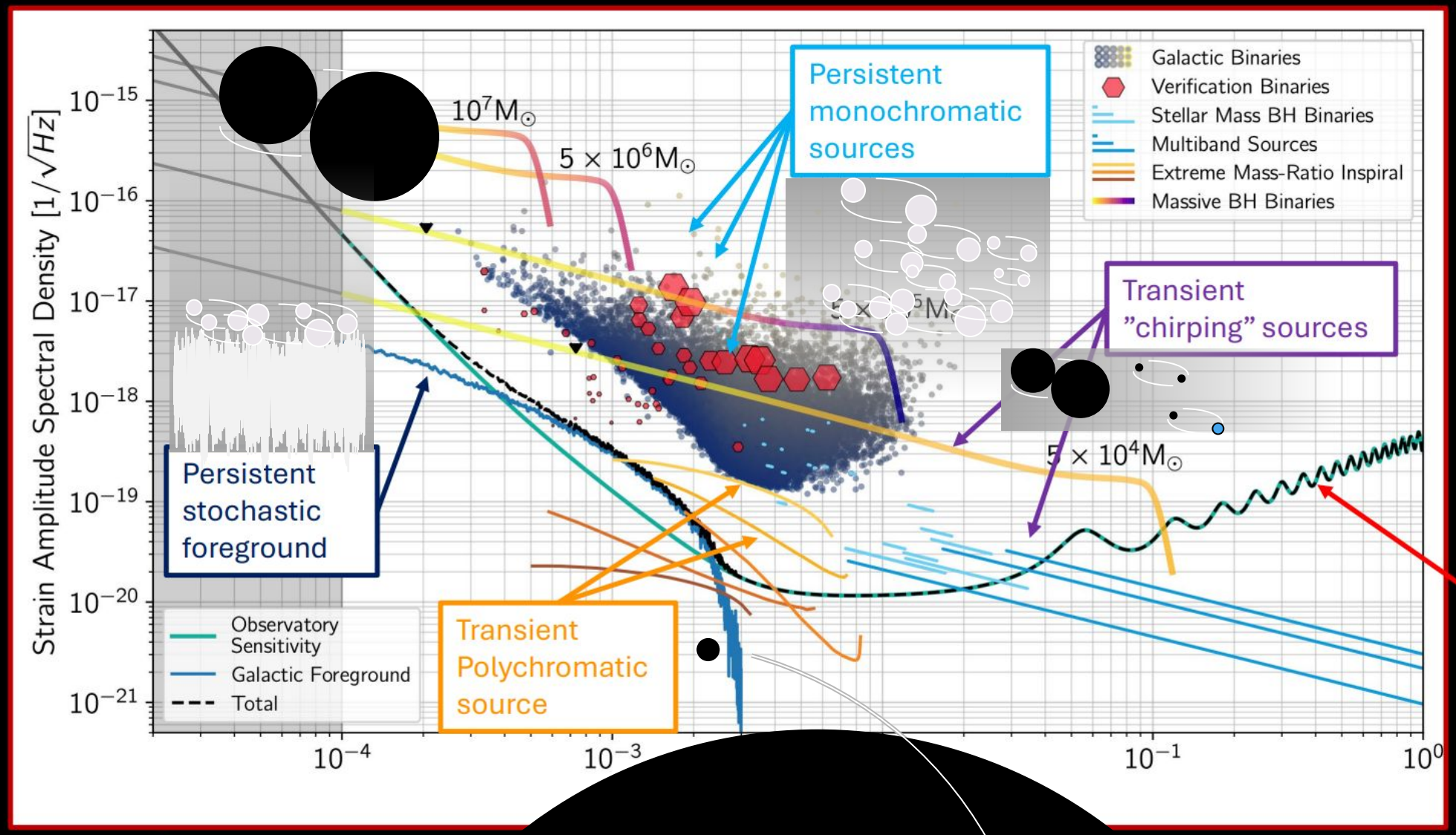
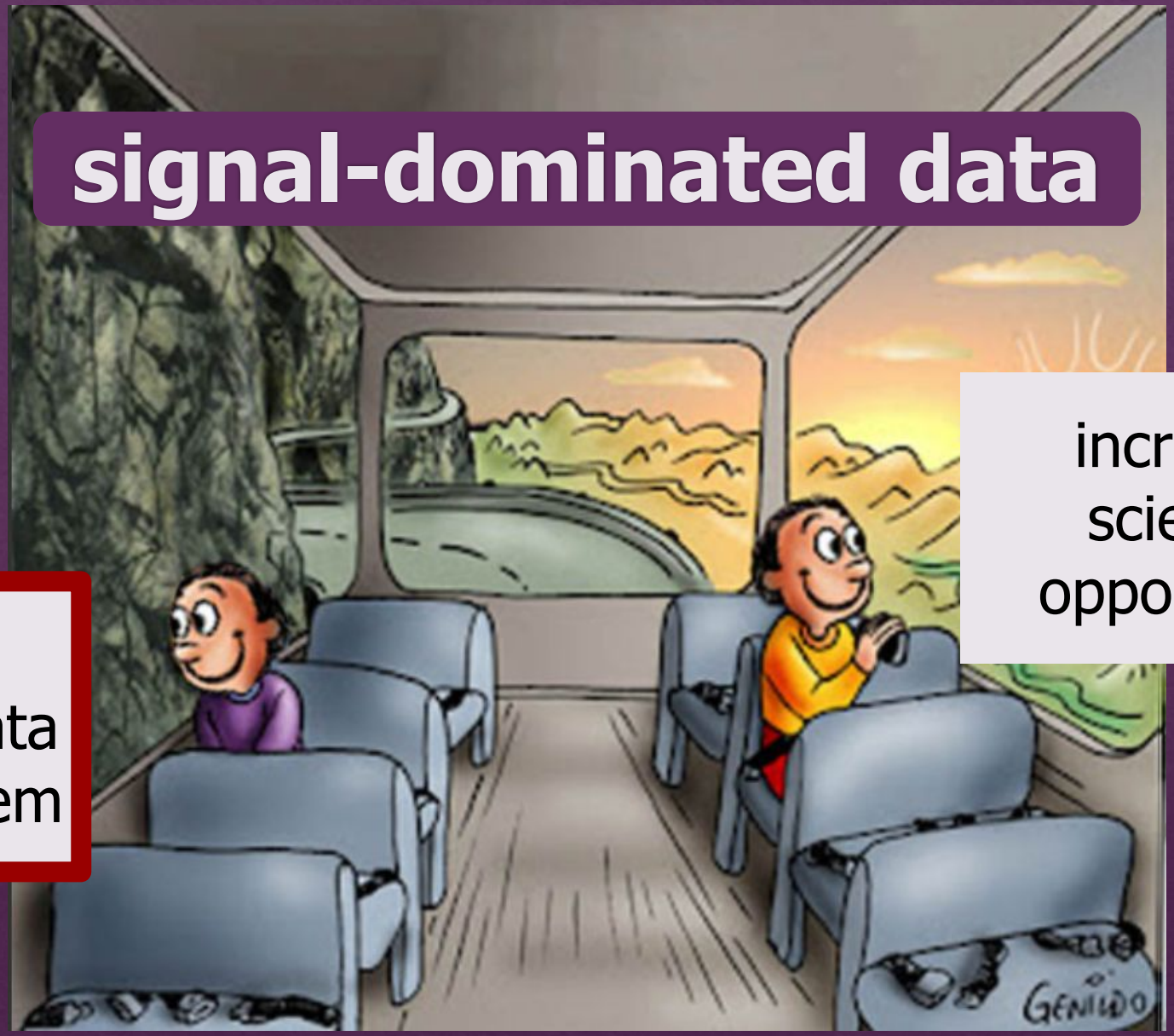


Figure credit – LISA Red Book (Colpi+24)

signal-dominated data



incredibly challenging data analysis problem

incredible scientific opportunity!

the LISA Global Fit

the LISA Global Fit

or

the LISA Global Fit

or

how do you model
everything,
everywhere,
all at once?

the LISA Global Fit

or

how do you model
everything,
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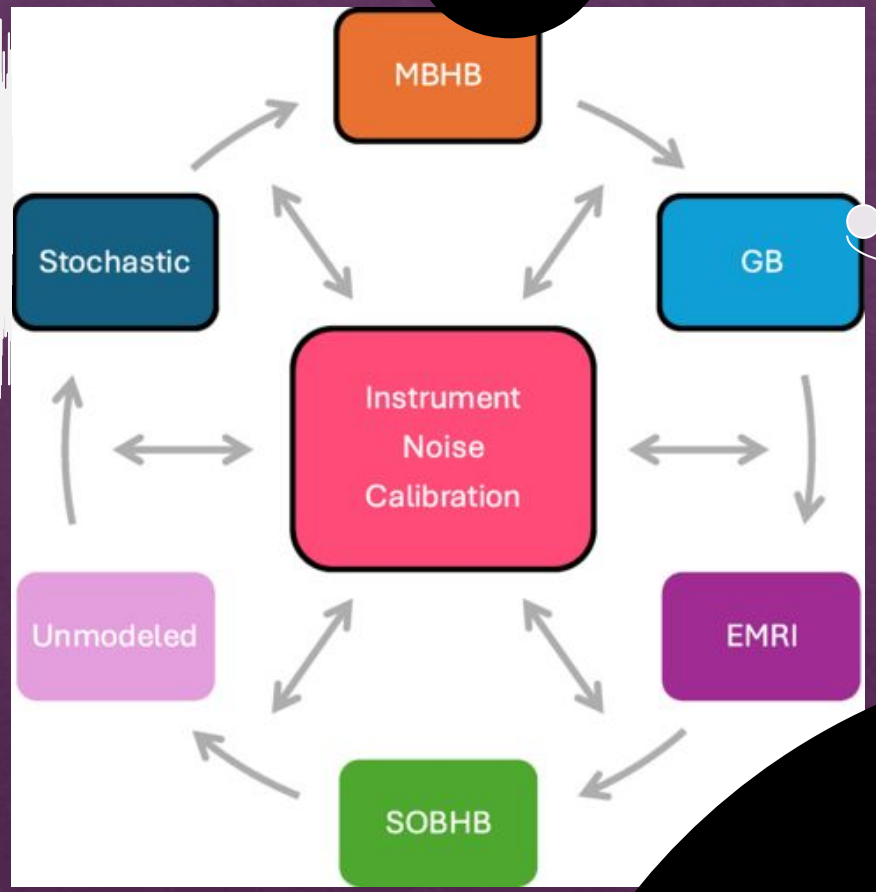
all at once?

? ? ?



Questions?