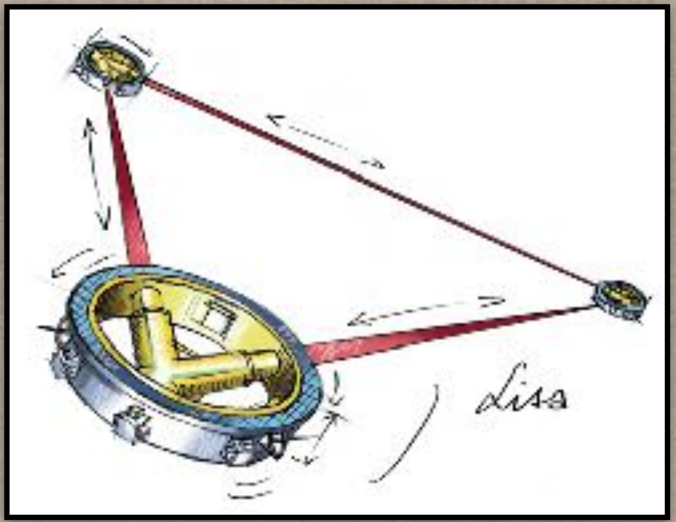


LASER INTERFEROMETER SPACE ANTENNA SCIENCE

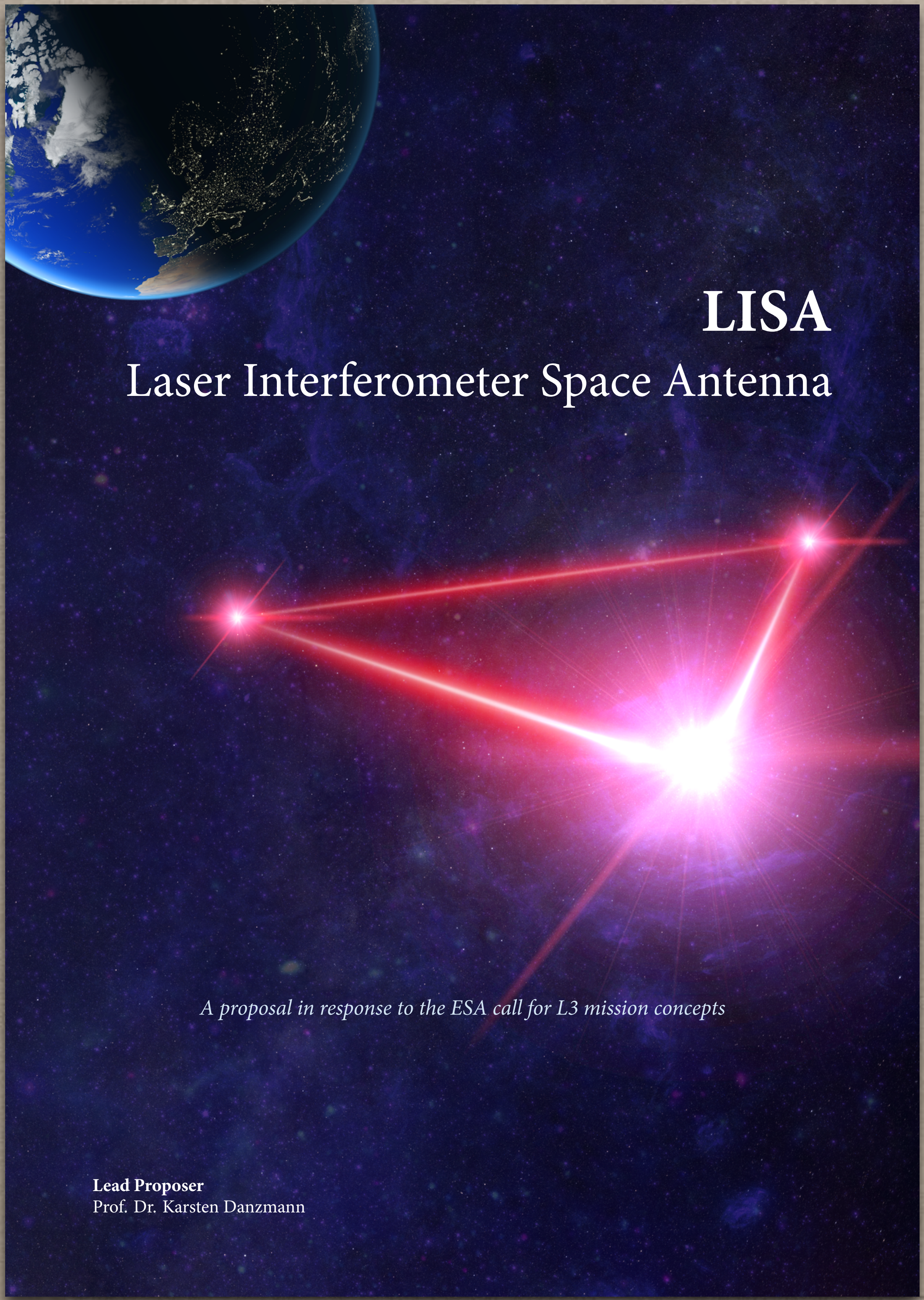
ELENA MARIA ROSSI
LEIDEN OBSERVATORY
THE NETHERLANDS

MULTIMESSANGERS WINTER WORKSHOP @PRAGUE 4-7 DECEMBER '19

LISA SCIENCE GROUP

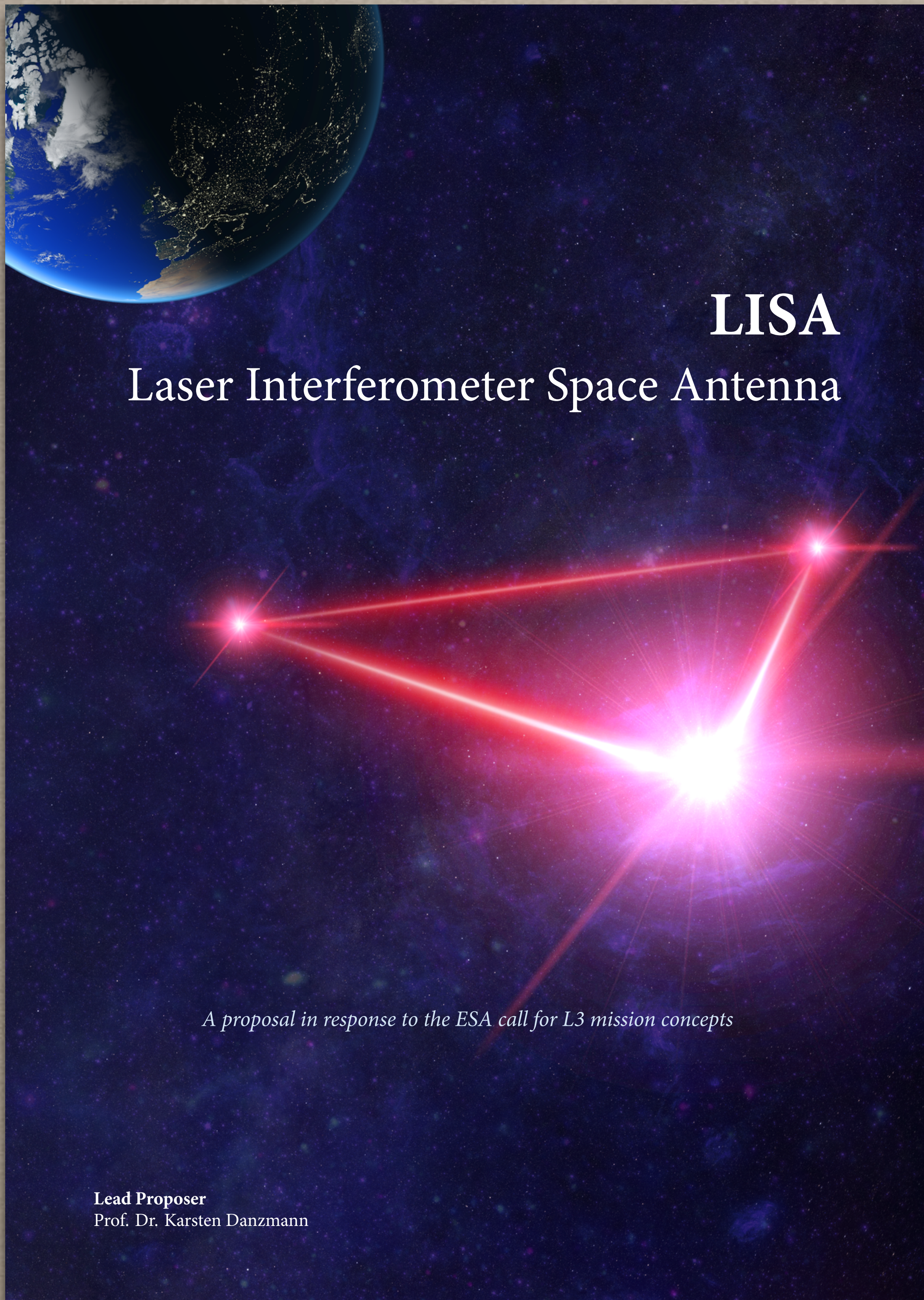
Team leader : Jon Gair

Deputy team leader : Elena Maria Rossi, Michele Vallisneri



https://arxiv.org/abs/1702.00786

- **2013 Gravitational Universe** selected by ESA as L3 science theme within the Cosmic Vision 2015-2025
- **2017 LISA proposal selected** as ESA's L3 mission
- **2034** nominal **launch**



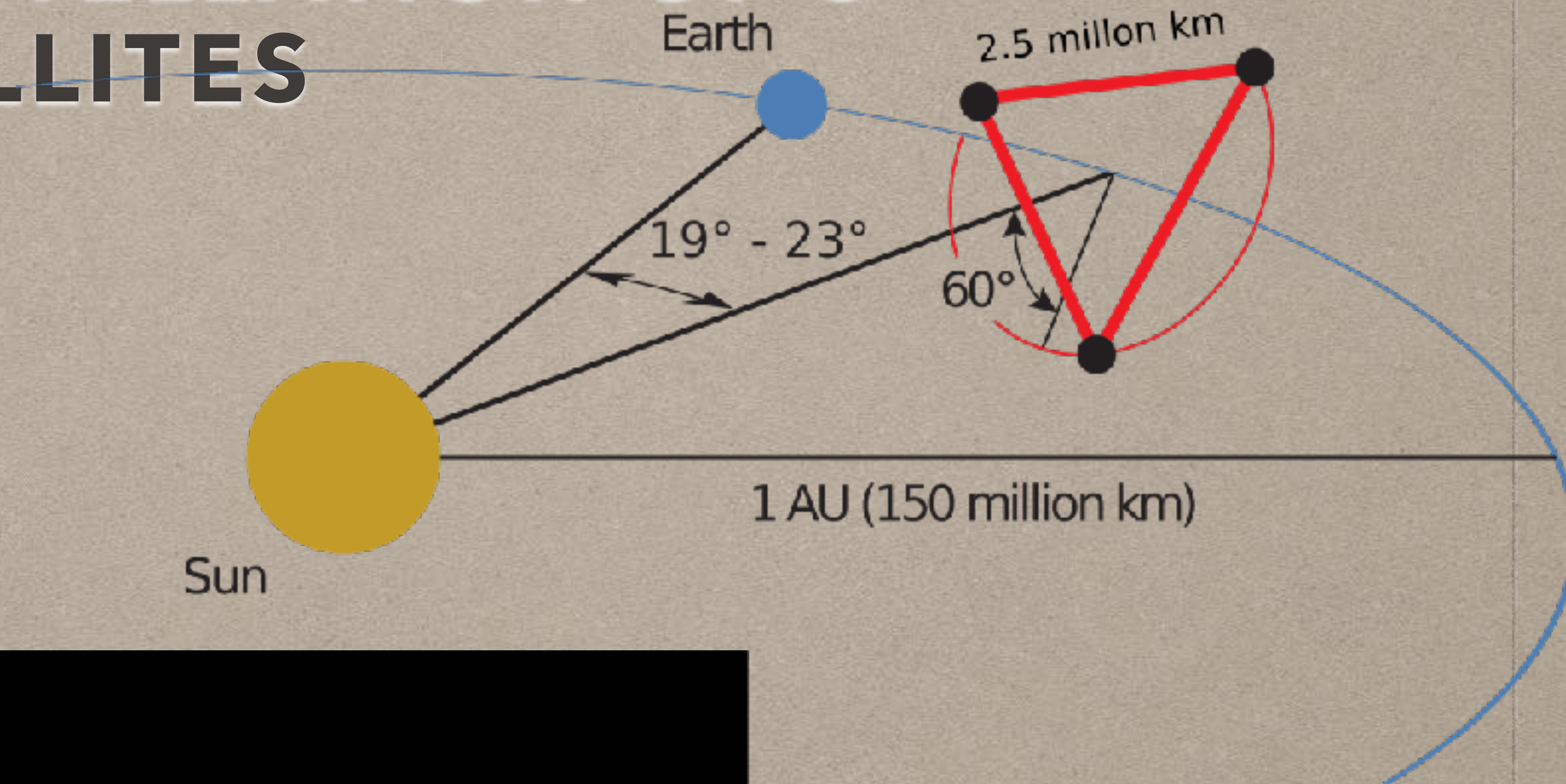
- **2013 Gravitational Universe** selected by ESA as L3 science theme within the Cosmic Vision 2015-2025
- **2017 LISA proposal selected** as ESA's L3 mission
- ~~**2034**~~ nominal **launch**

News! ESA ministers commit to biggest budget ever for next decay:

Günther Hasinger , ESA Science Director "**LISA in 2032**"

https://arxiv.org/abs/1702.00786

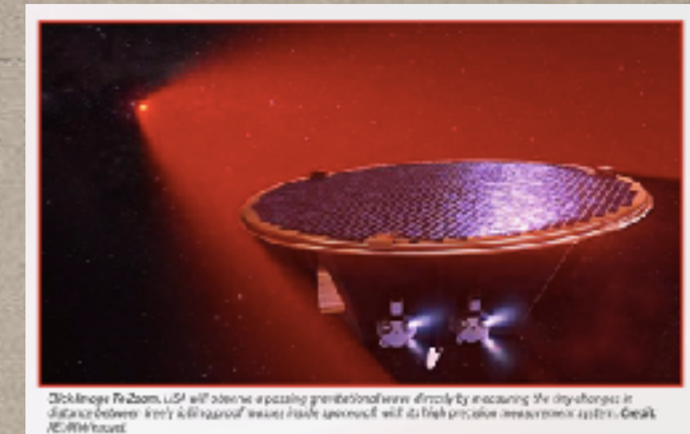
CONSTELLATION OF 3 SATELLITES

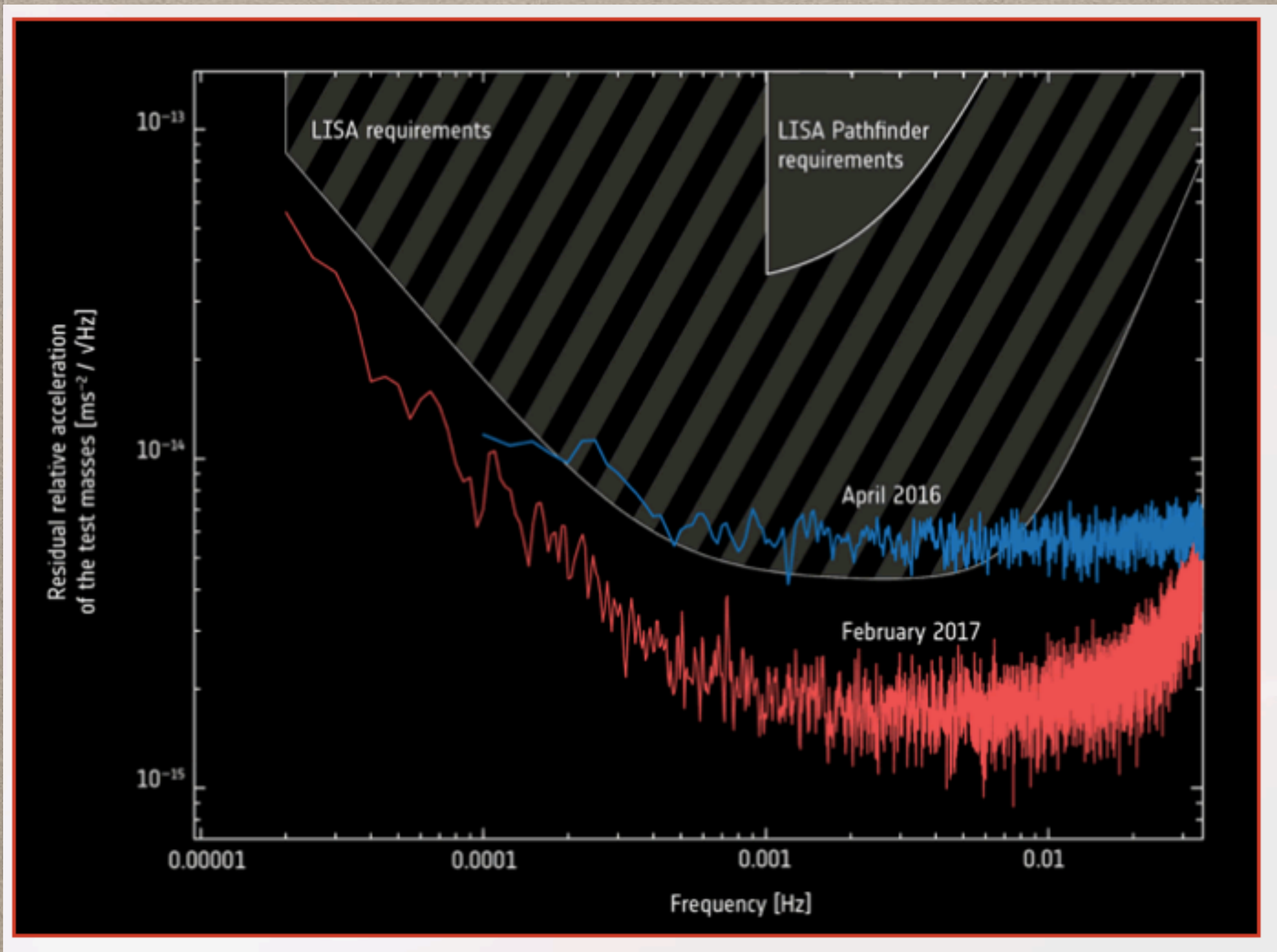


MEASUREMENT PRINCIPLE

- Probe the change in proper time between pairs of **free-falling** test masses caused by GWs
- Proper time is inferred by the time of flight of photons exchanged between the satellites
- We have **multiple links** from which we can form Michelson-like signals

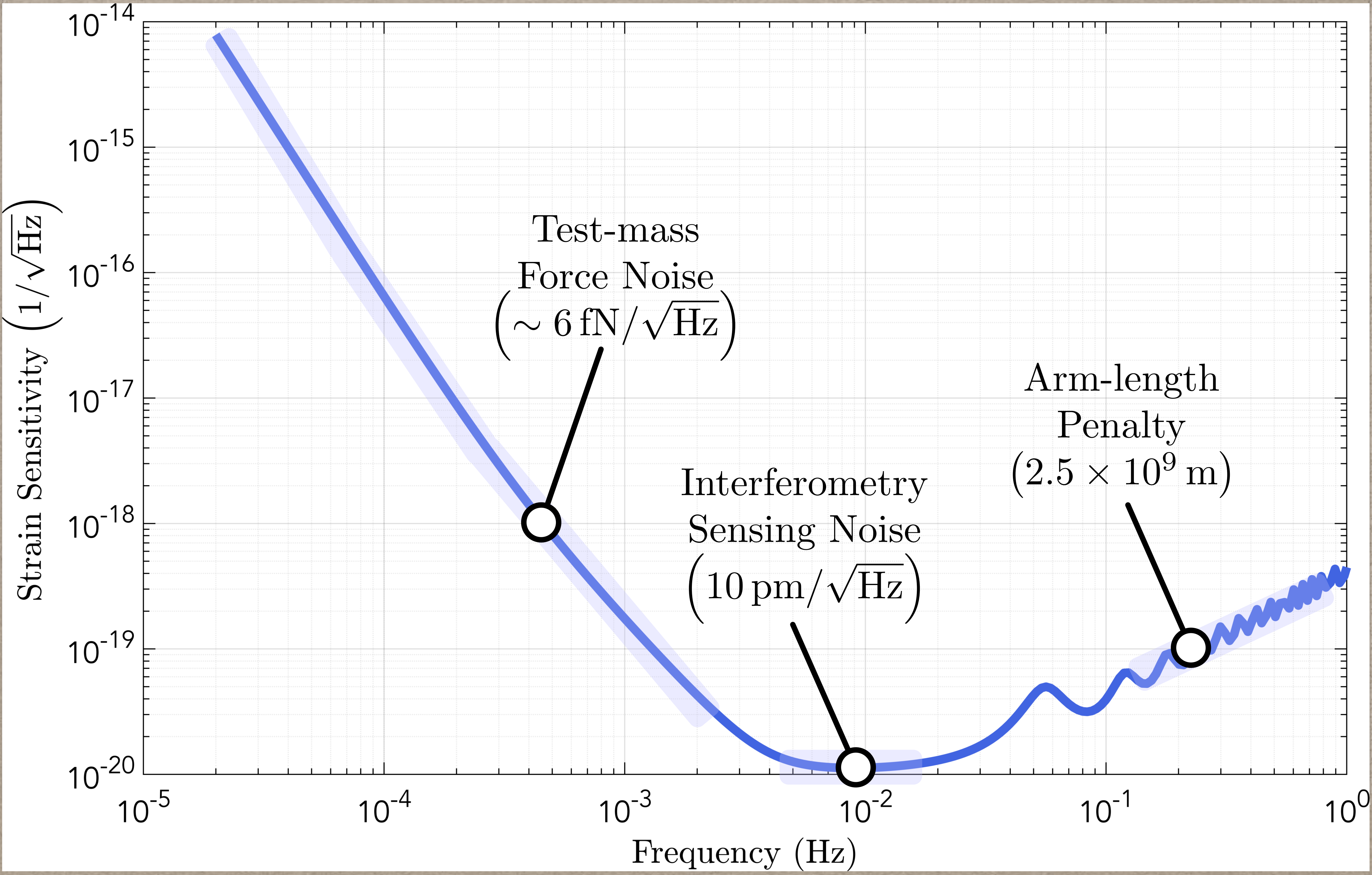
LISA PATHFINDER





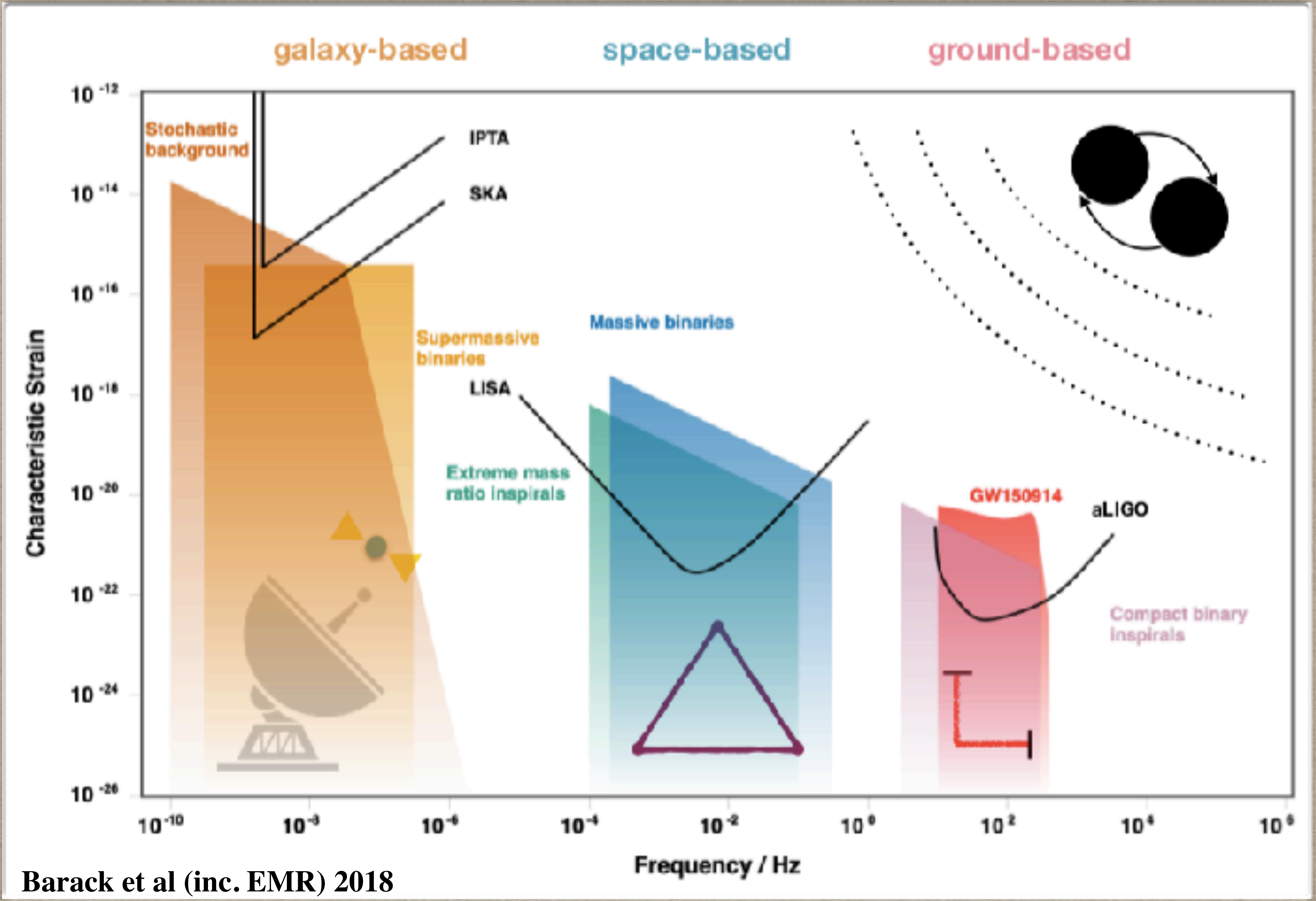
CREDIT:NASA

LISA LIMITING NOISE



LISA IS AN *OBSERVATORY*

exploring the 2 mHz ~ 15 minute time domain
for Astrophysics, Cosmology
and Fundamental physics



Barack et al (inc. EMR) 2018

Elena Maria Rossi

SUPERMASSIVE BLACK HOLES (THE LOUDEST)

Hierarchical growth of structure in the Universe, leads us to imply the existence of SMBH mergers

(Lacy & Cole 1993)

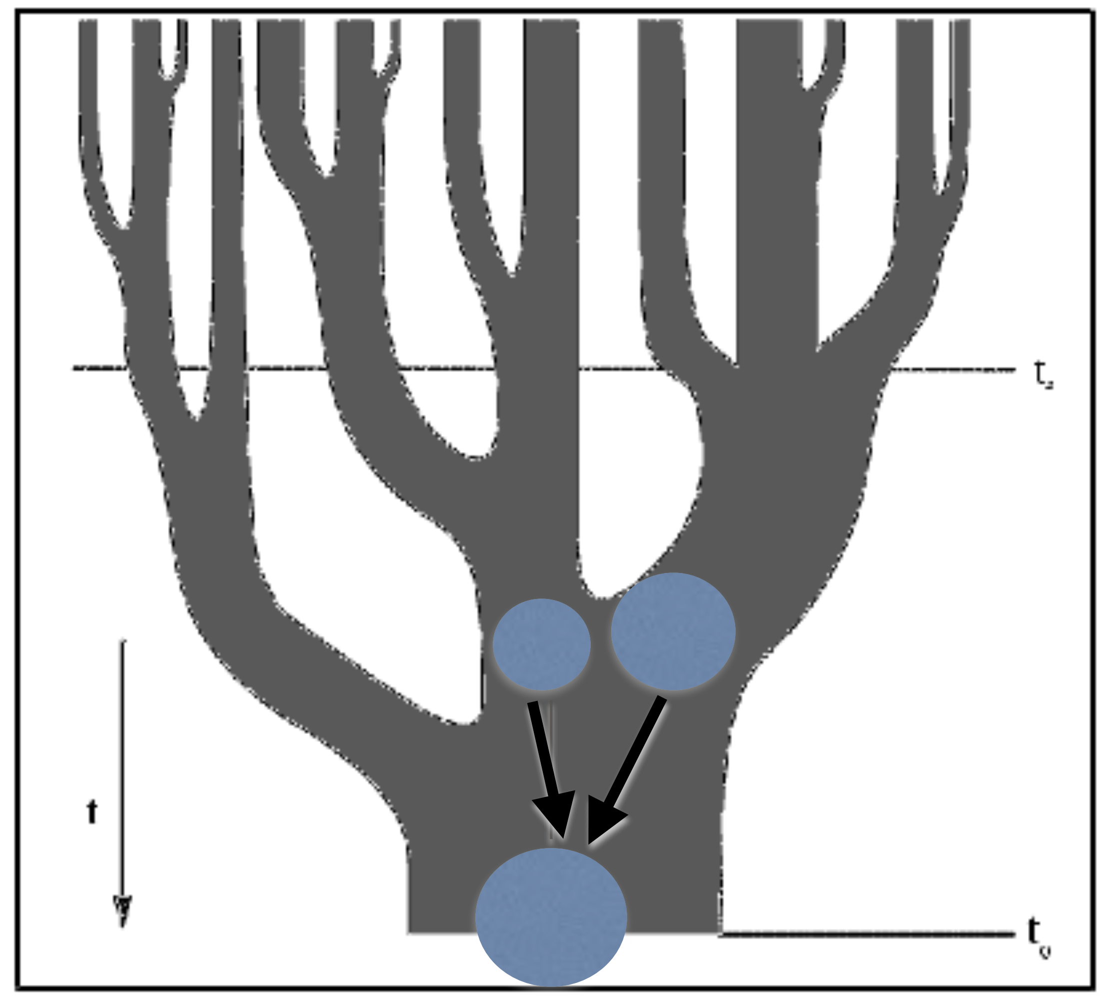
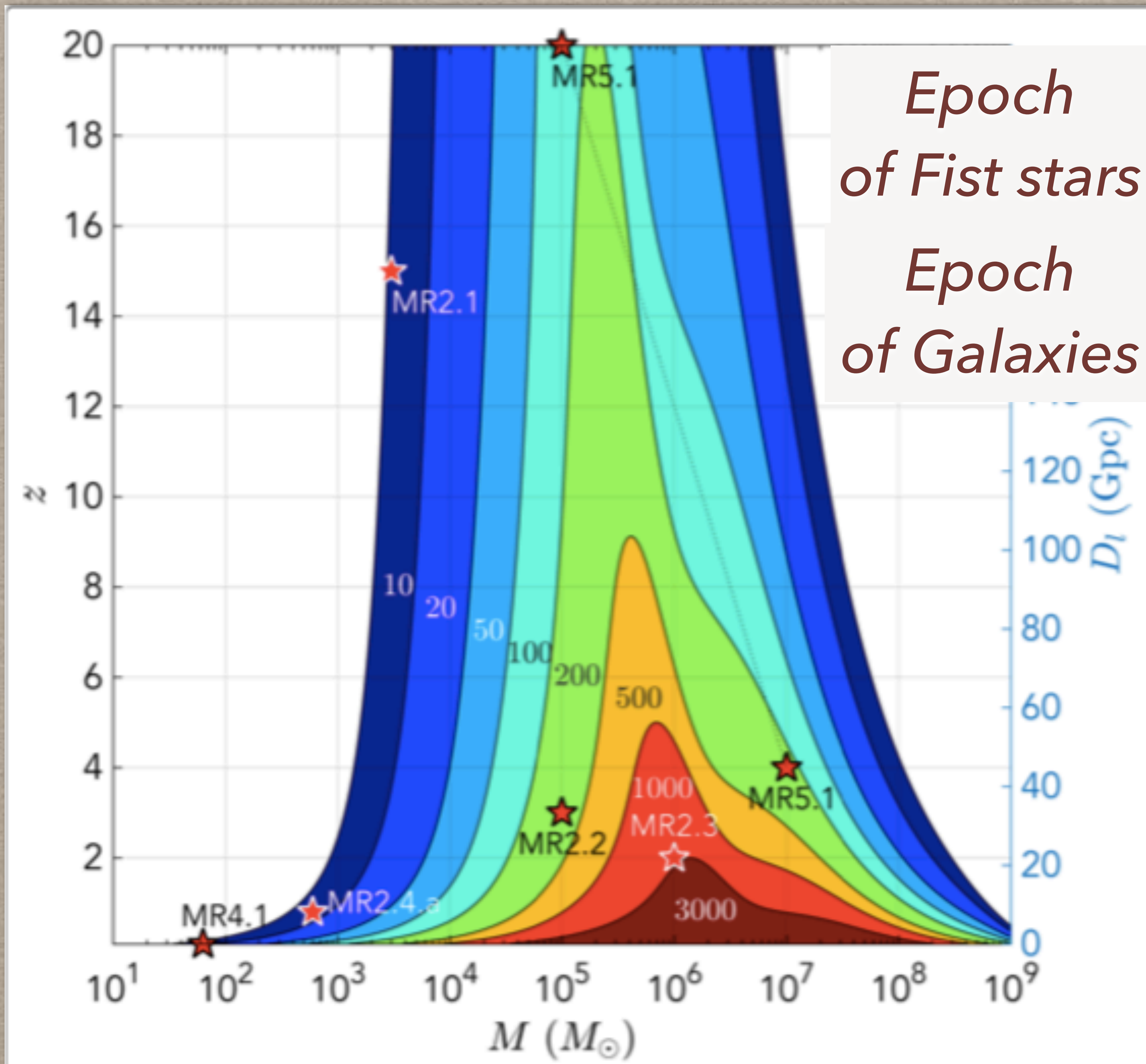


Figure 6. A schematic representation of a "merger tree" depicting the growth of a halo as the result of a series of mergers. Time increases from top to bottom in this figure and the widths of the branches of the tree represent the masses of the individual parent halos. Slicing through the tree horizontally gives the distribution of masses in the parent halos at a given time. The present time t_0 and the formation time t_f are marked by horizontal lines, where the formation time is defined as the time at which a parent halo containing in excess of half of the mass of the final halo was first created.

SUPERMASSIVE BLACK HOLES



LISA is ideal for studying of structure formation beyond the re-ionisation epoch

Elena Maria Rossi

HOW DO SUPERMASSIVE BLACK HOLE FORM ?

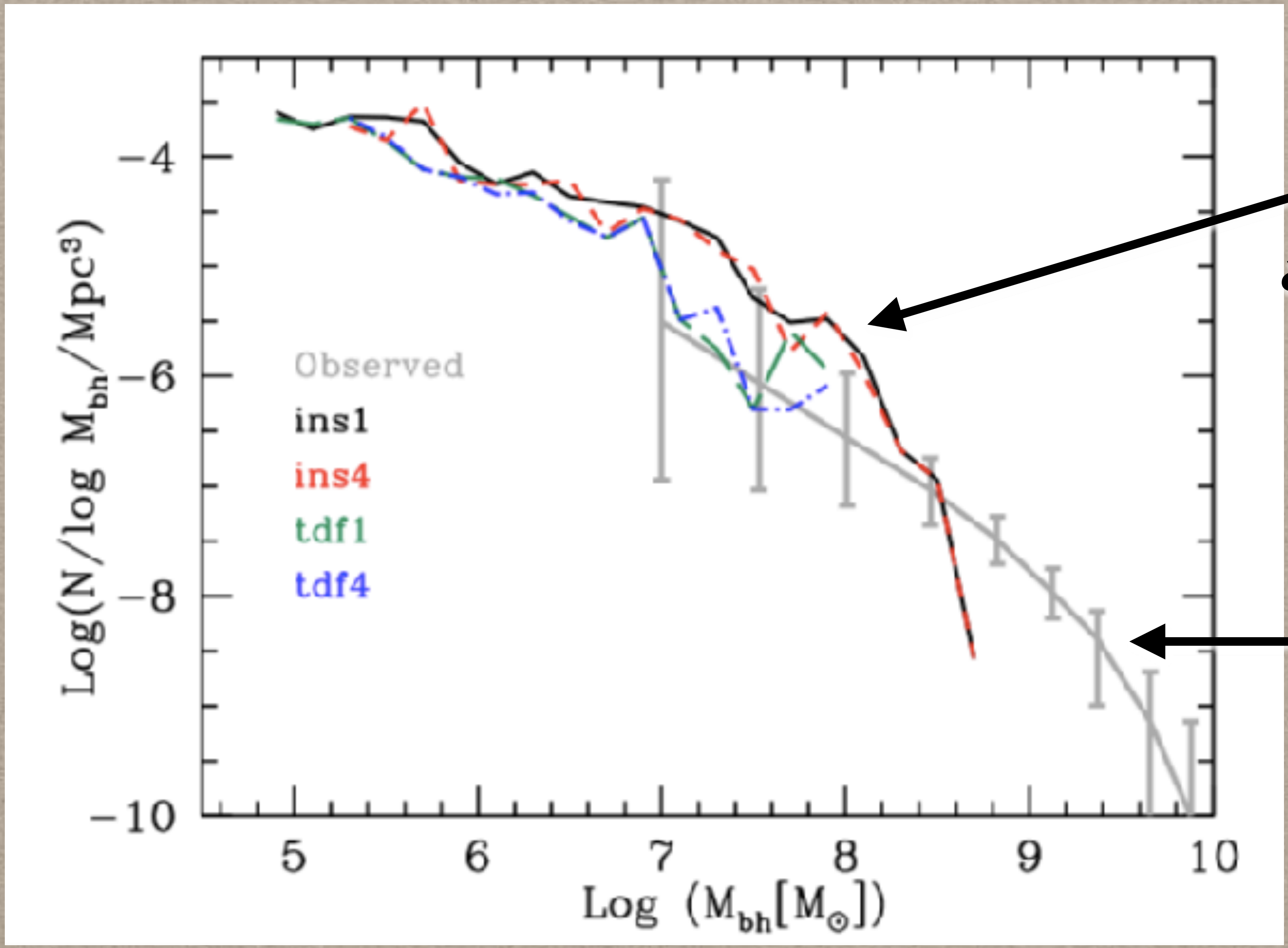
LISA detections to discriminate between formation scenarios:

Dayal, EMR + 2019
DeGraf & Sijacki 2019
Latif et al. 2019
Bonetti et al. 2019
Ricarte & Natarajan 2018
Hartwig, Agarwal & Regan, 2018
Colpi 2018
….

predictions very by an order of magnitude between papers…

Sesana, Volonteri & Haardt 2007

HOW DO SUPERMASSIVE BLACK HOLE FORM ?



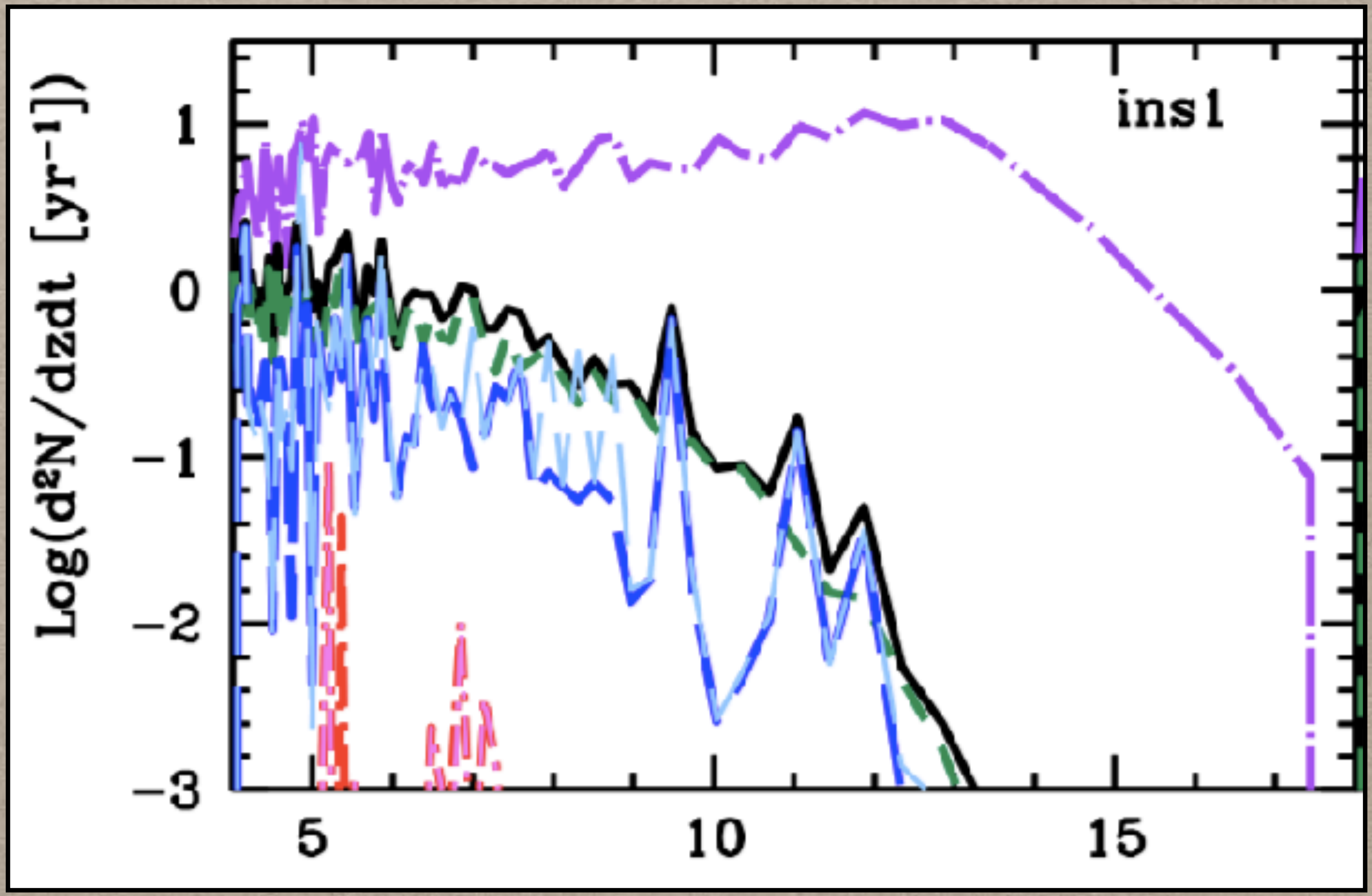
PoP3 seeds can describe the average population

need massive seeds for these

Dayal, EMR + 2019; observation from Willott +2010

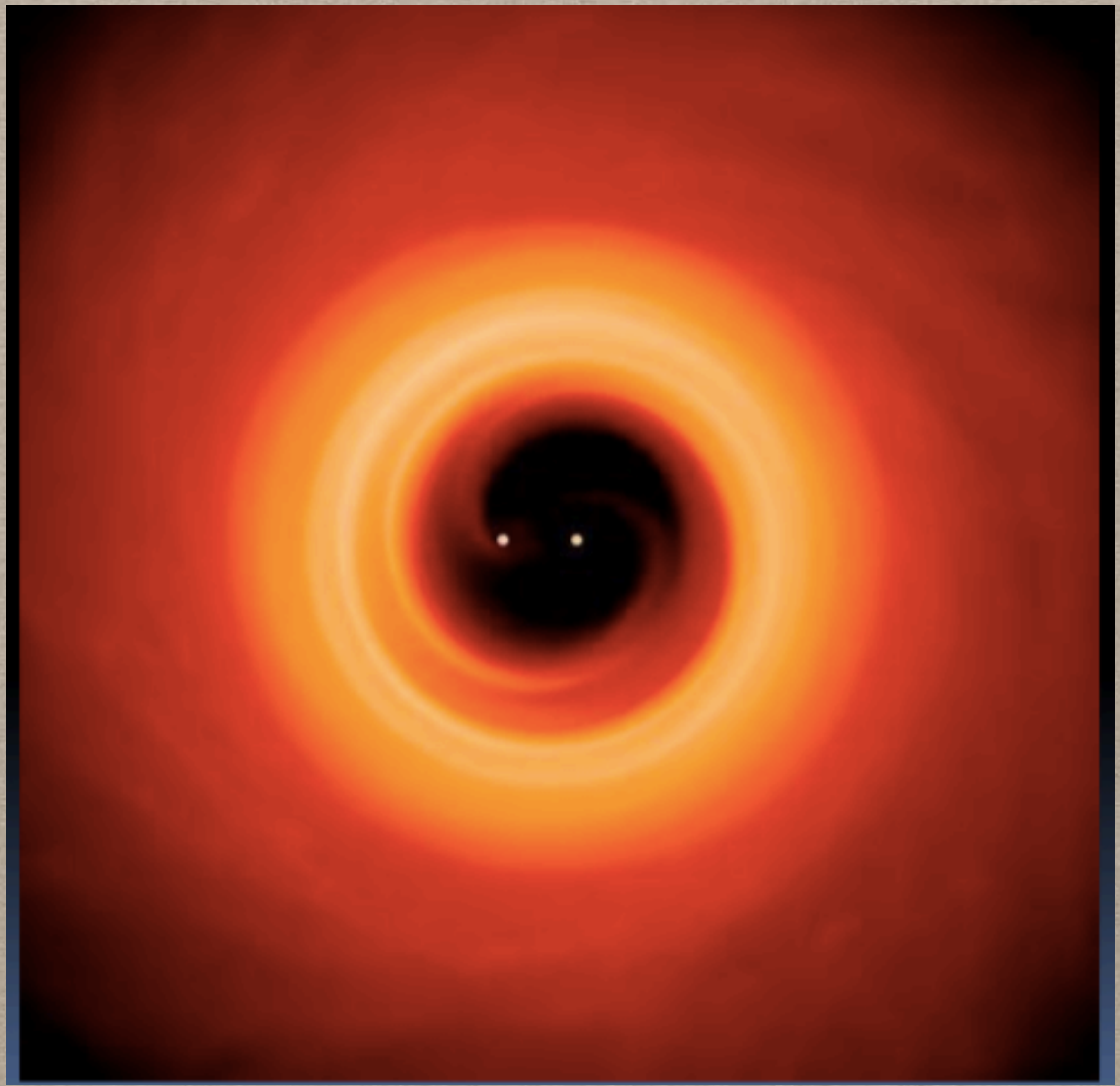
A FEW DETECTED PER YEAR…

Dayal, EMR + 2019



Most of the information is in the background…

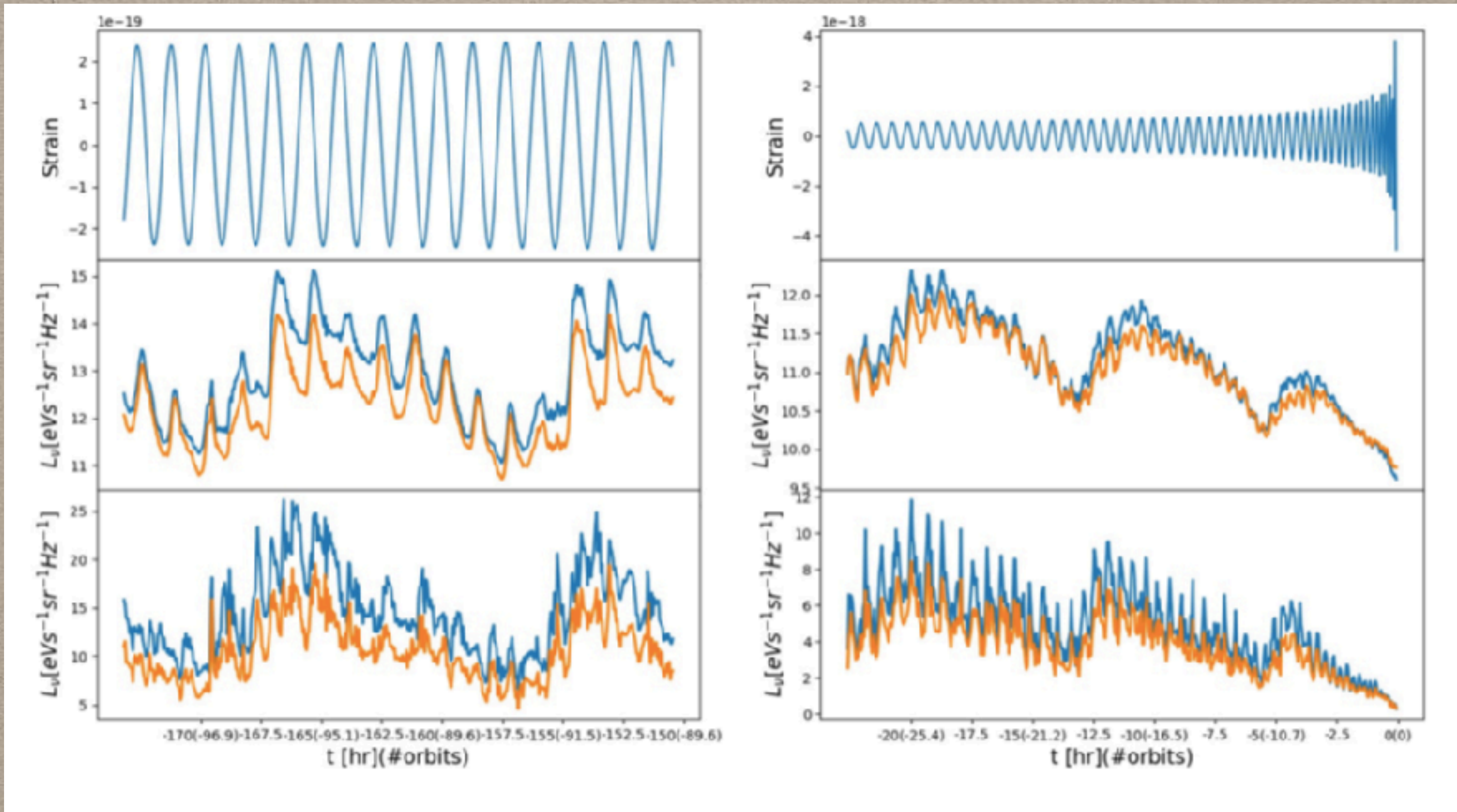
ELECTROMAGNETIC COUNTERPARTS TO MERGER



credit J. Cuadra

PRECURSORS TO MERGER

~1 week to merger **~last 2 hr to merger**



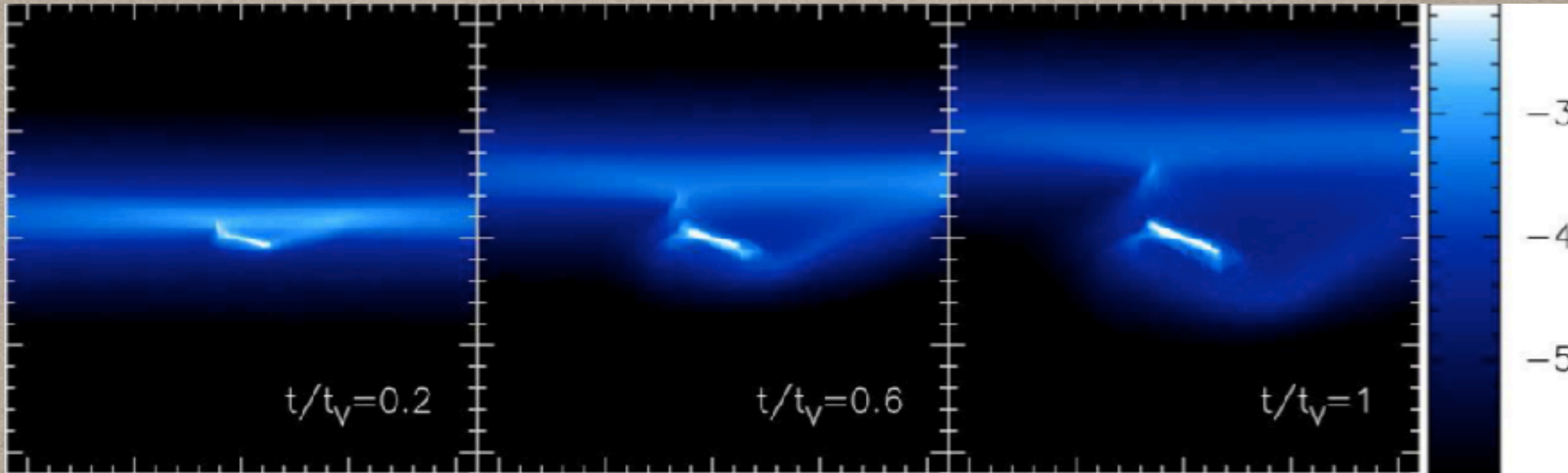
Gravitational signal

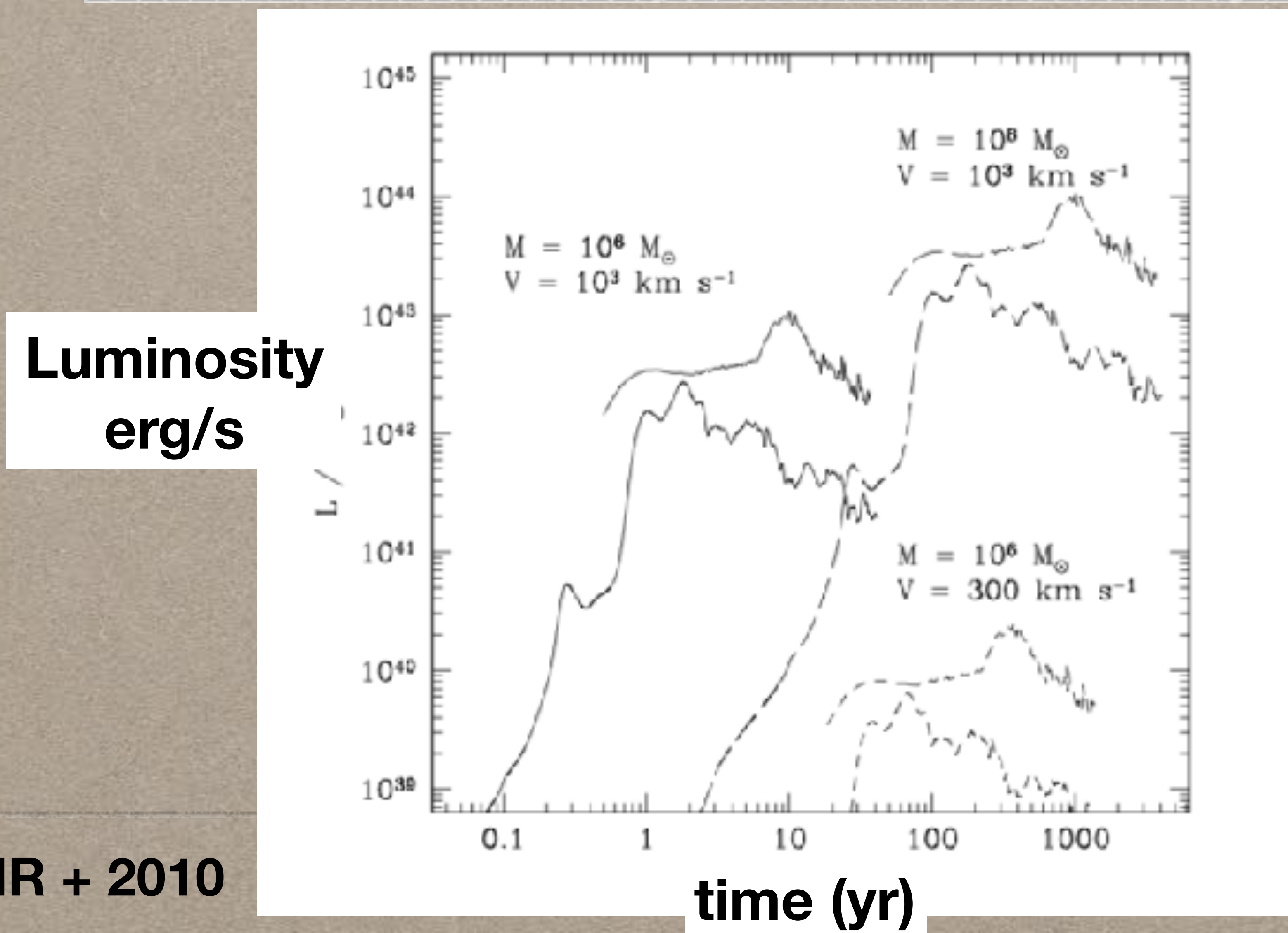
2 KeV

10 KeV

Tang et al. 2018

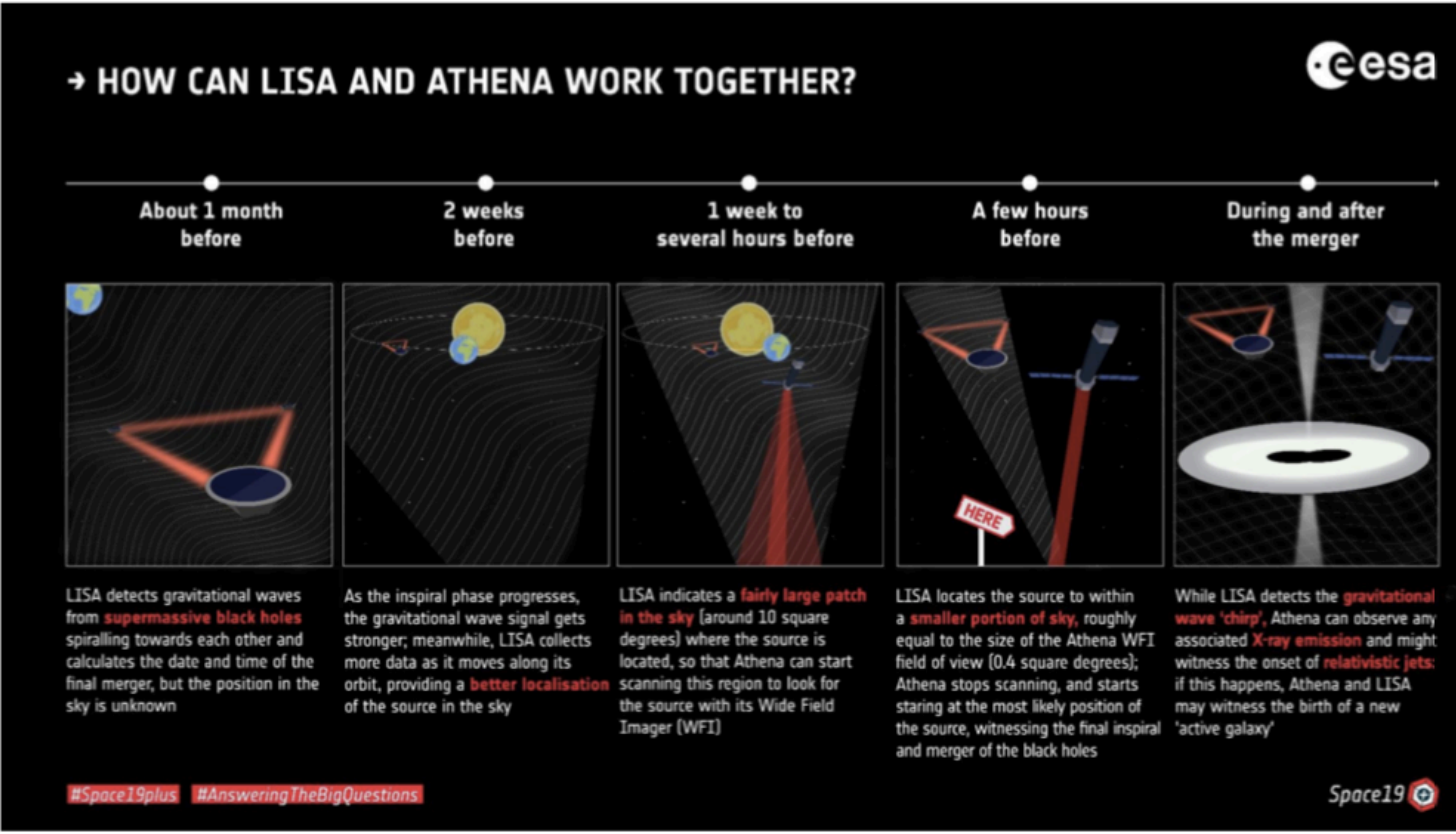
"AFTERGLOWS"





- Months timescale rise
- Bolometric luminosity at fraction of Eddington

EMR + 2010



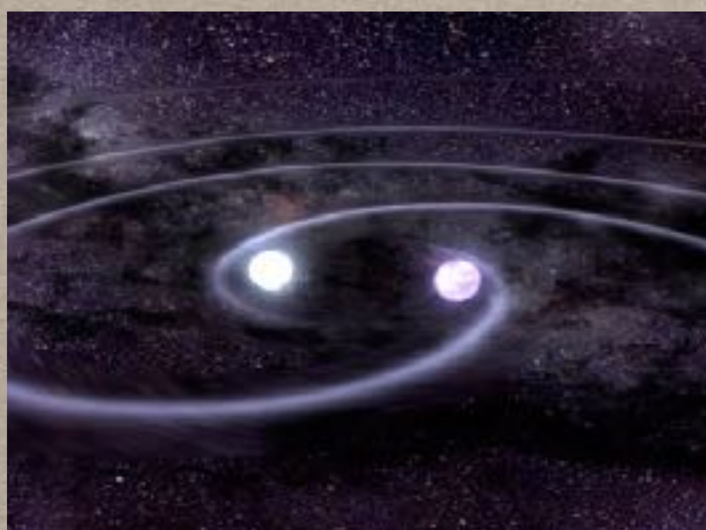
Courtesy of Paul McNamara

ULTRA COMPACT STELLAR MASS BINARIES (THE MOST NUMEROUS)

Detached double white dwarfs

AM CVn stars

Hot subdwarfs



Predicted:	**10^8**	**10^5**	**10^8**
Observed with EM	**~10**	**10^2**	**10^3**

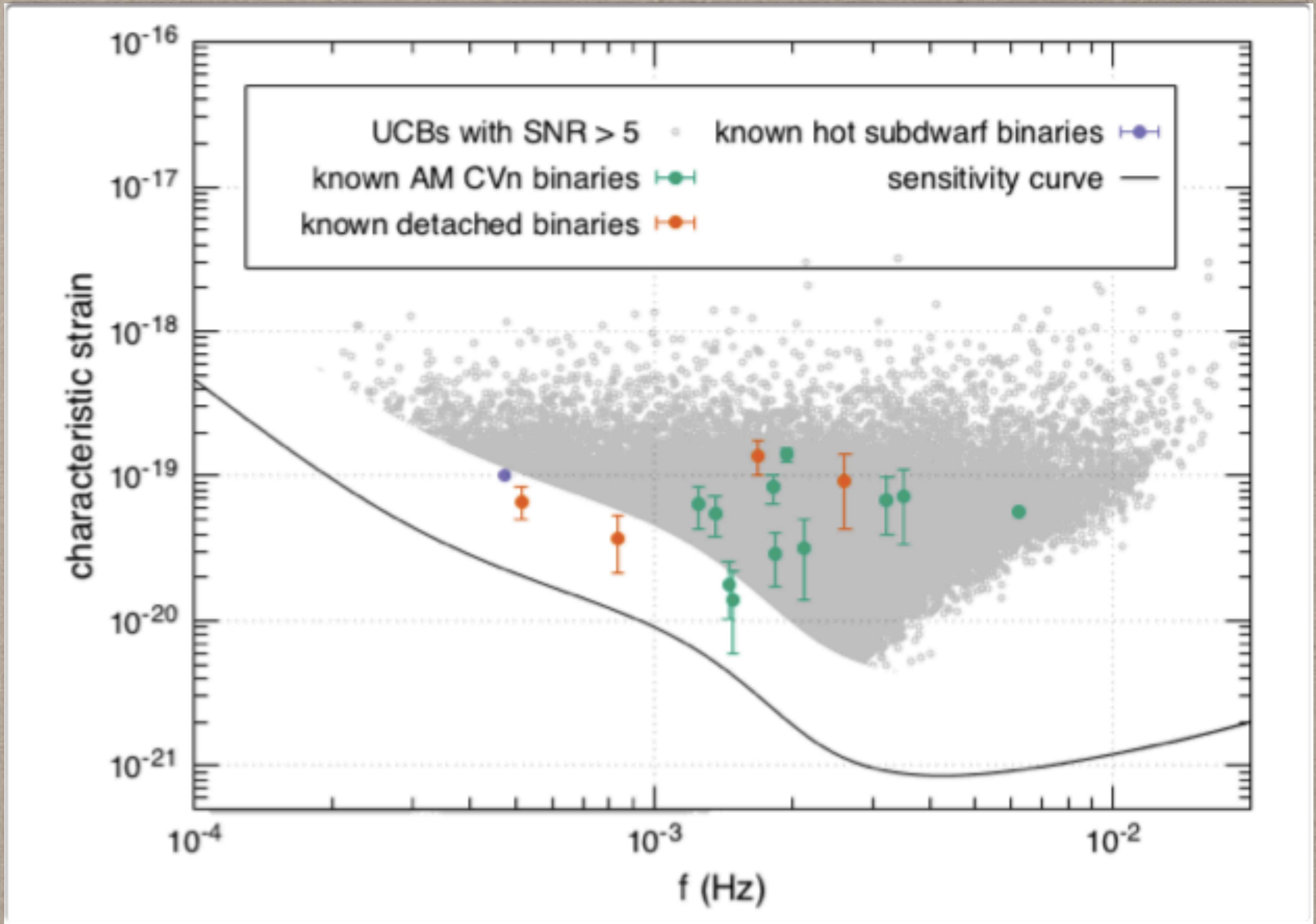
see e.g. Astro2020 Science White Paper
Littenberg et al. 2019

Elena Maria Rossi

CURRENT SAMPLE

- ~10 SNR > 20
- 3 SNR > 100

Kupfer, Korol..EMR 2018



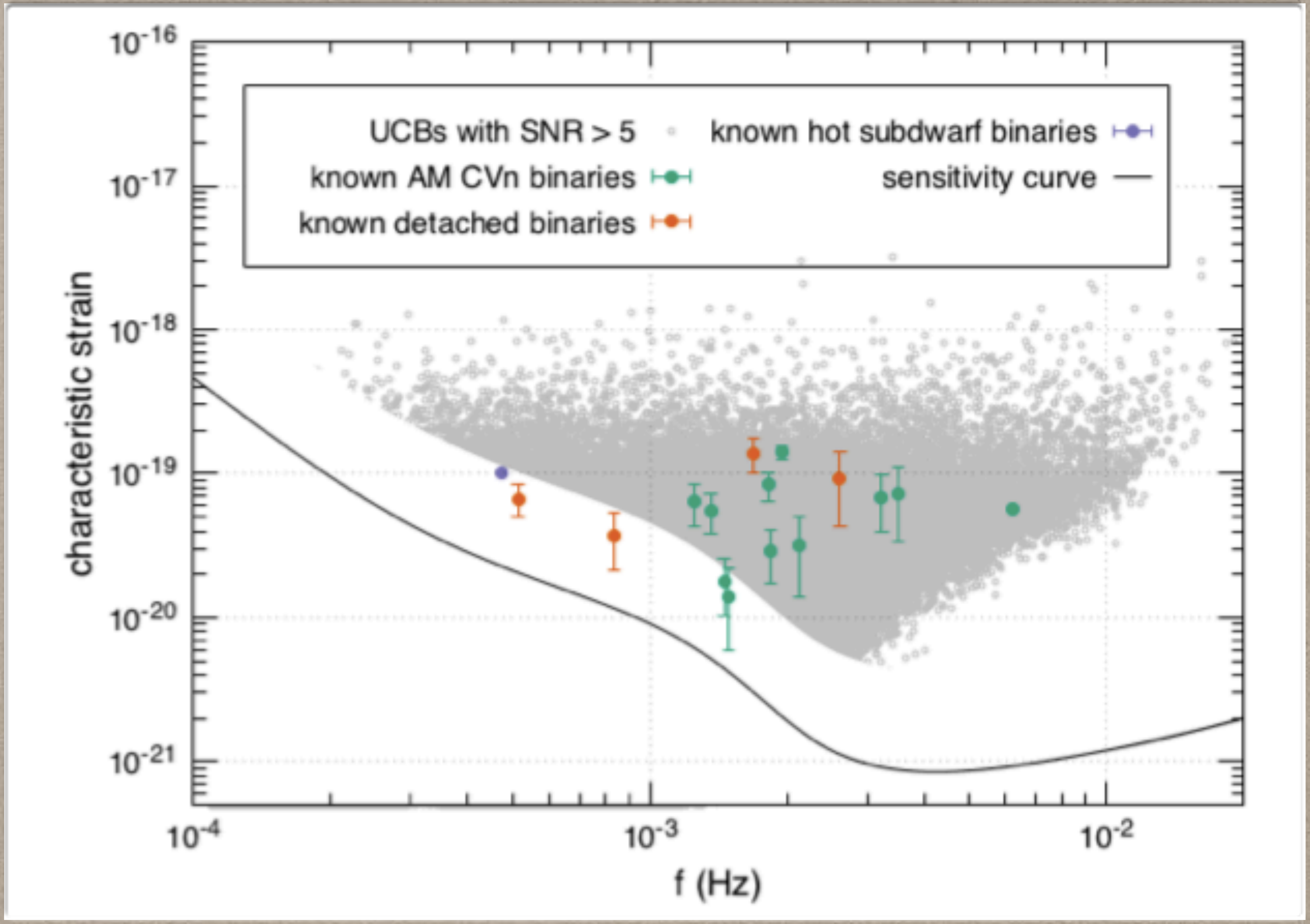
Littenberg + 2019

THE FUTURE SAMPLE !

- 25 000 resolved binaries w LISA
- 8 000 precise distance < 0.3
- 5 000 w precise localisation (~arcmin^2)
- *a few 100 in Gaia and/or LSST*

Korol, EMR et al. 2018
Breivik + 2018

Gijs + 01, 04



Littenberg + 2019

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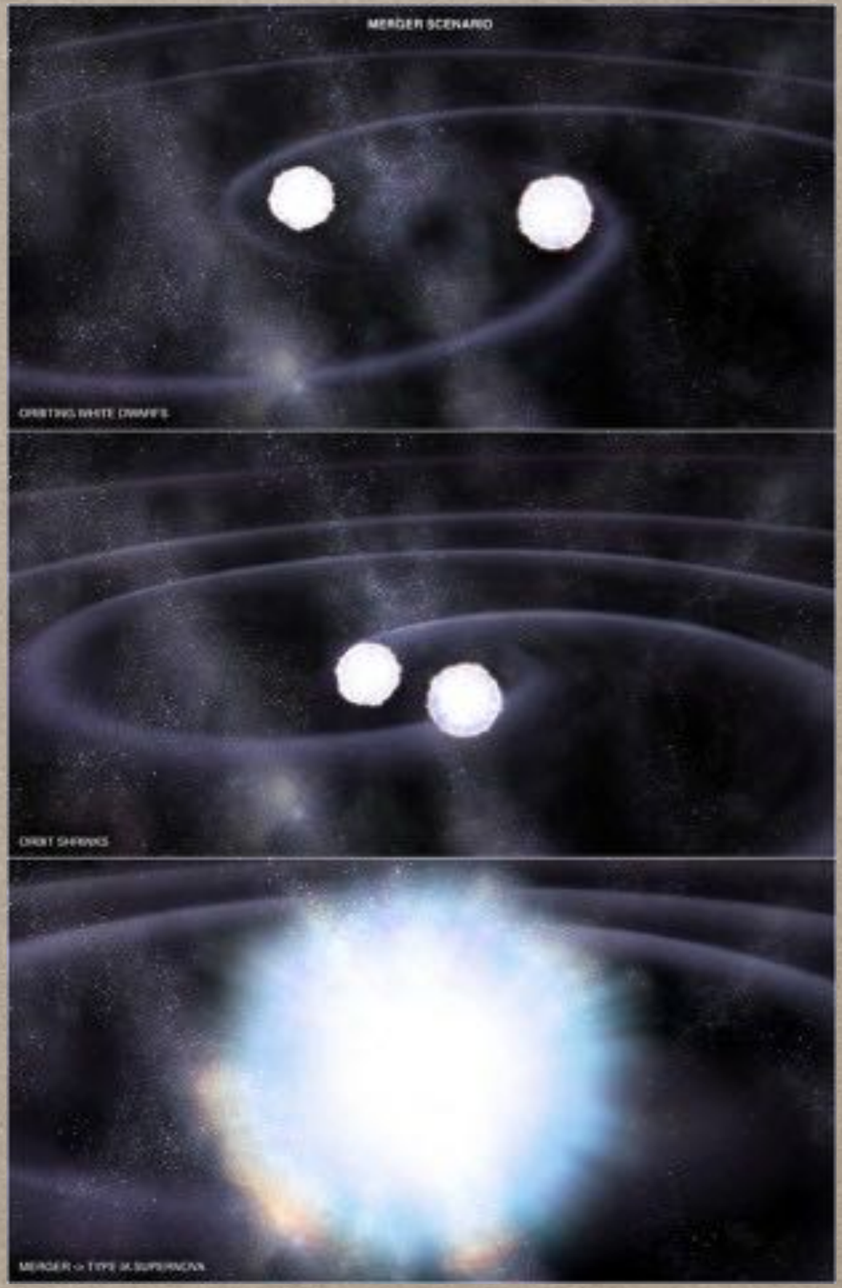
QUEST FOR SUPERNOVA 1A PROGENITORS

WD-WD binary "merger"

***Massive** system are required but **none** has been so for unambiguously identified in optical*

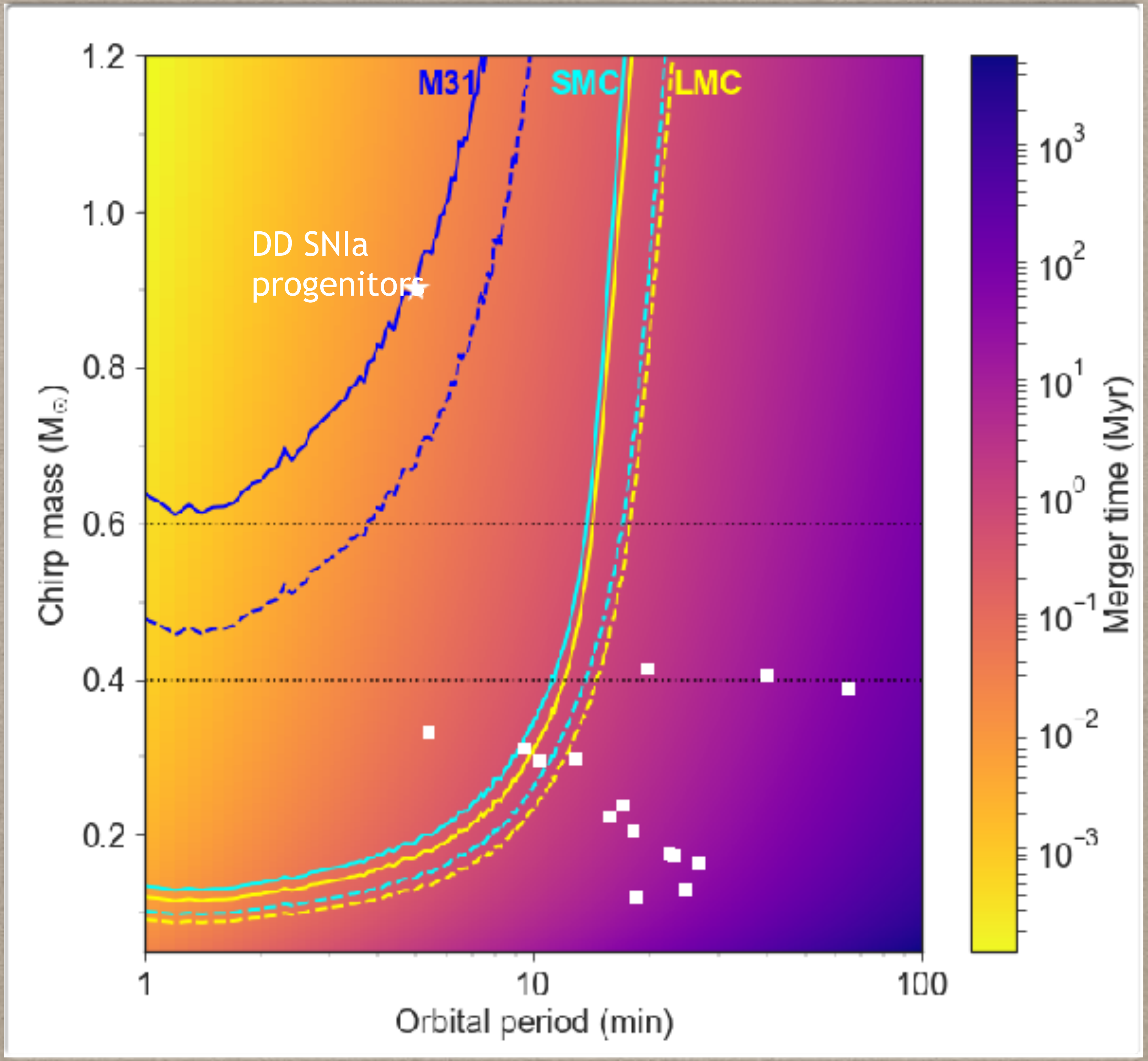
Rebassa-Mansergas + 2018



Credit: NASA/CXC/SAO

Elena Maria Rossi

LISA a unique tool to access SNIa progenitors



Rebassa-Mansergas + 2018, Korol, Koop & EMR 2018

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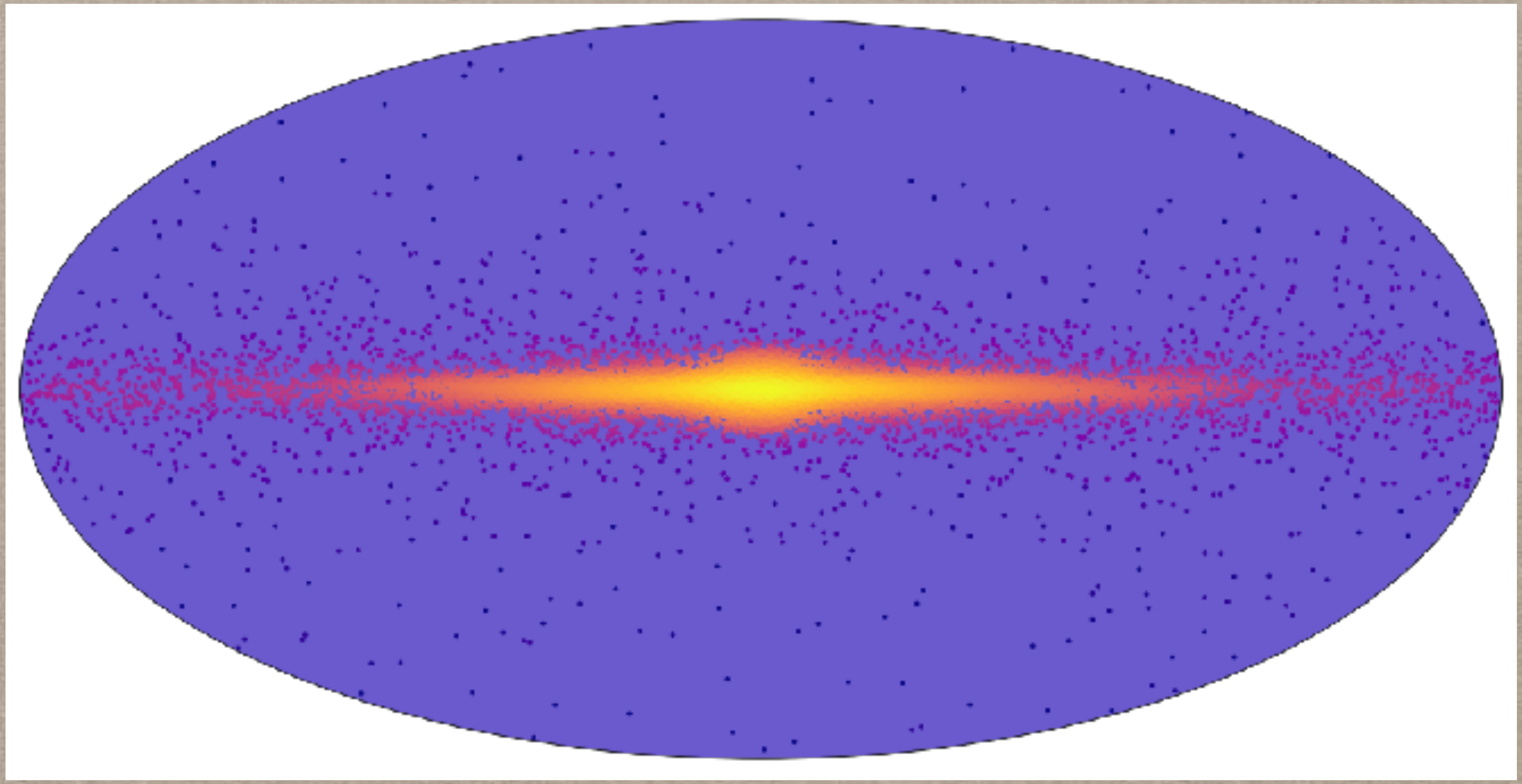
NEAR FIELD COSMOLOGY WITH GRAVITATIONAL WAVES

LISA's view of the Milky Way

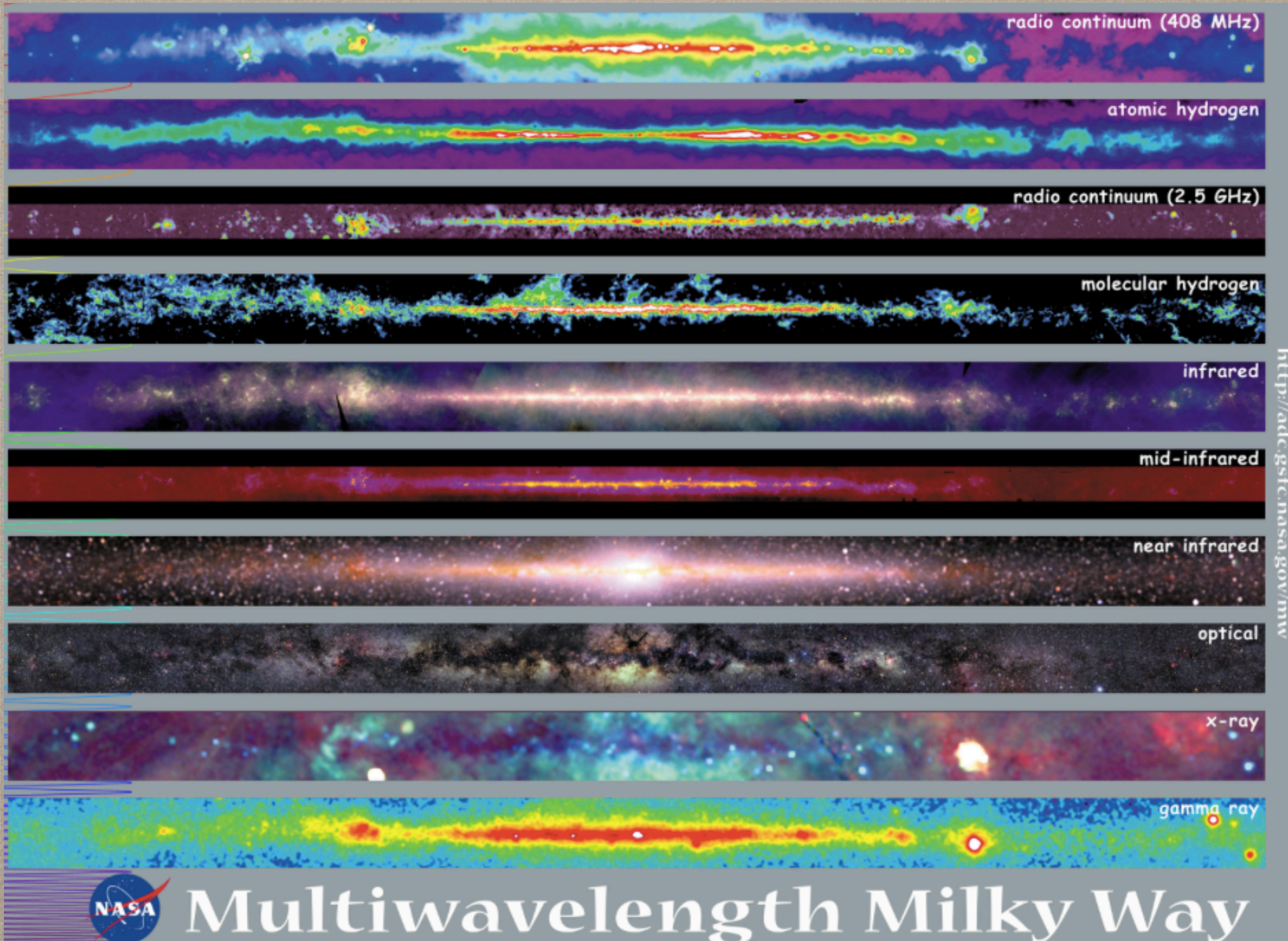


Korol, EMR, Barausse 2018

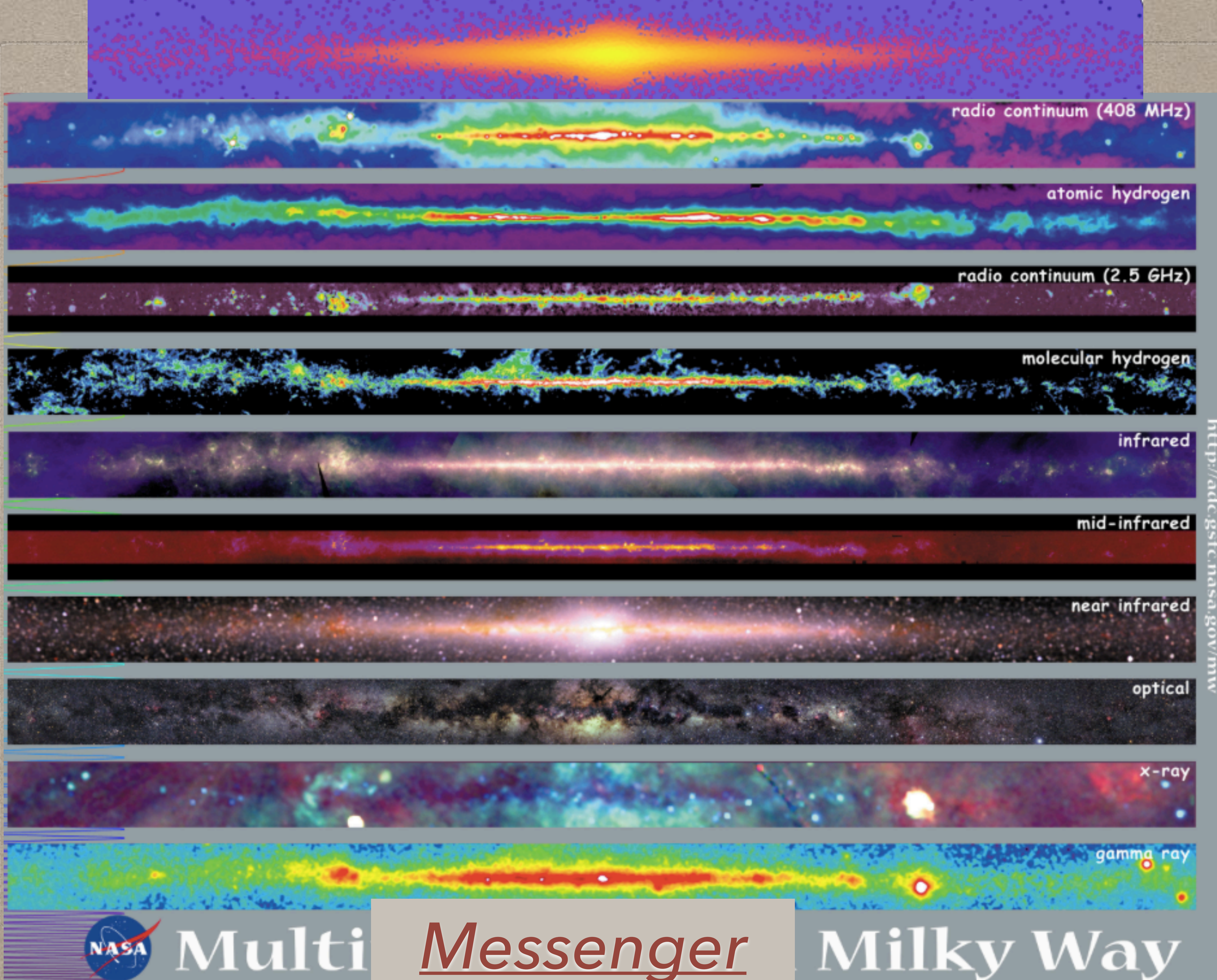
Lamberts + 2019

Benacquista & Holley-Bockelmann 2006
Adams, Cornish & Littenberg 2012 , Lambert + 2019

Elena Maria Rossi



radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw
NASA
Multiwavelength Milky Way


radio continuum (408 MHz)
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radio continuum (2.5 GHz)
molecular hydrogen
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mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw
NASA
Multi
Milky Way

Messenger

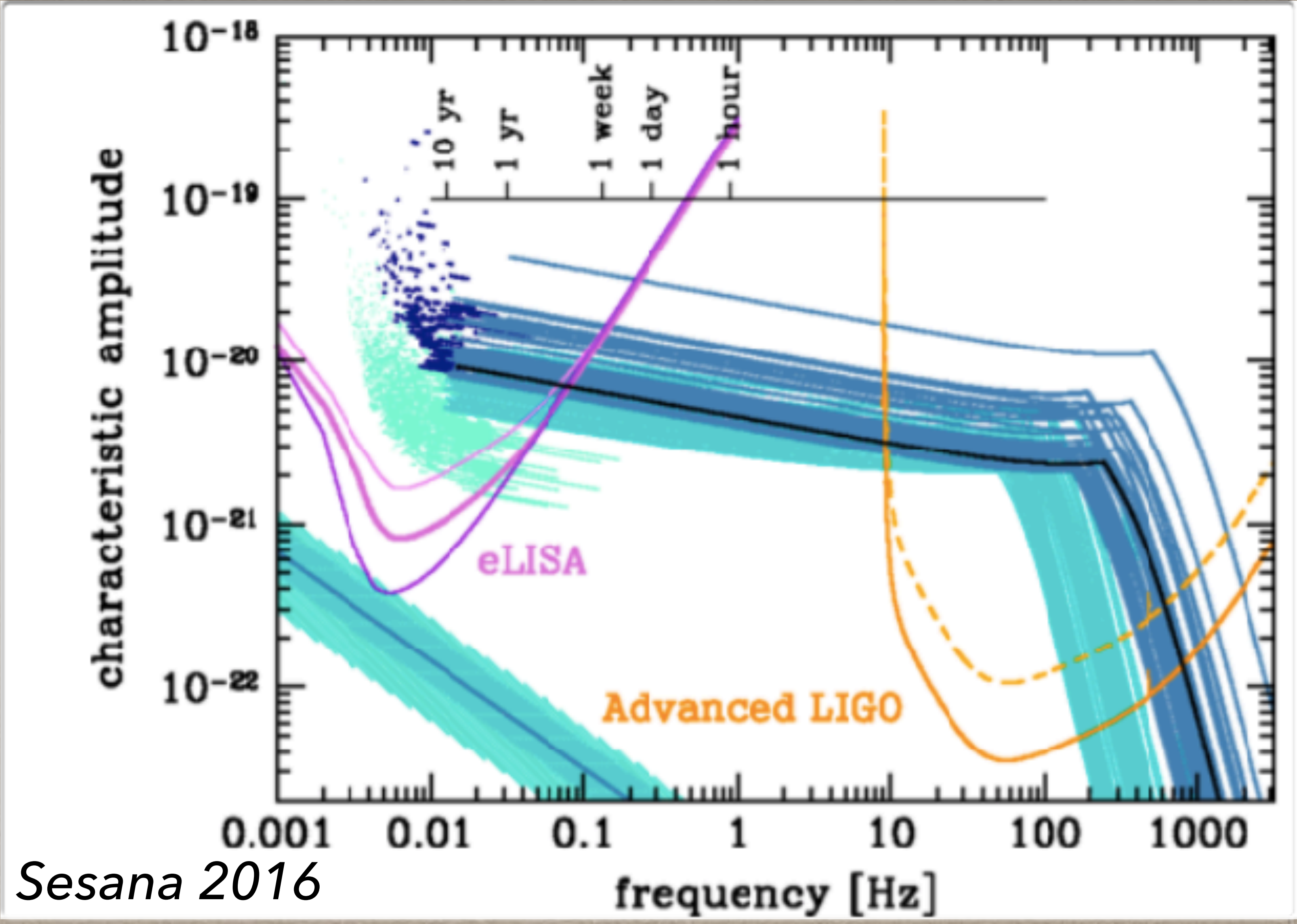
MASSIVE STELLAR MASS BLACK HOLES (A LA LIGO/VIRGO)

- ~100 BHs localised weeks in advance

with < 10s & < 1 deg^2 before merger

- Measuring binary properties (e.g. mass <1%)

- Searching counter-part when in LISA



Sesana 2016

Multi-band astrophysics!

Elena Maria Rossi

FUNDAMENTAL PHYSICS

Probing dark matter , Mass of Graviton and Test of General Relativity

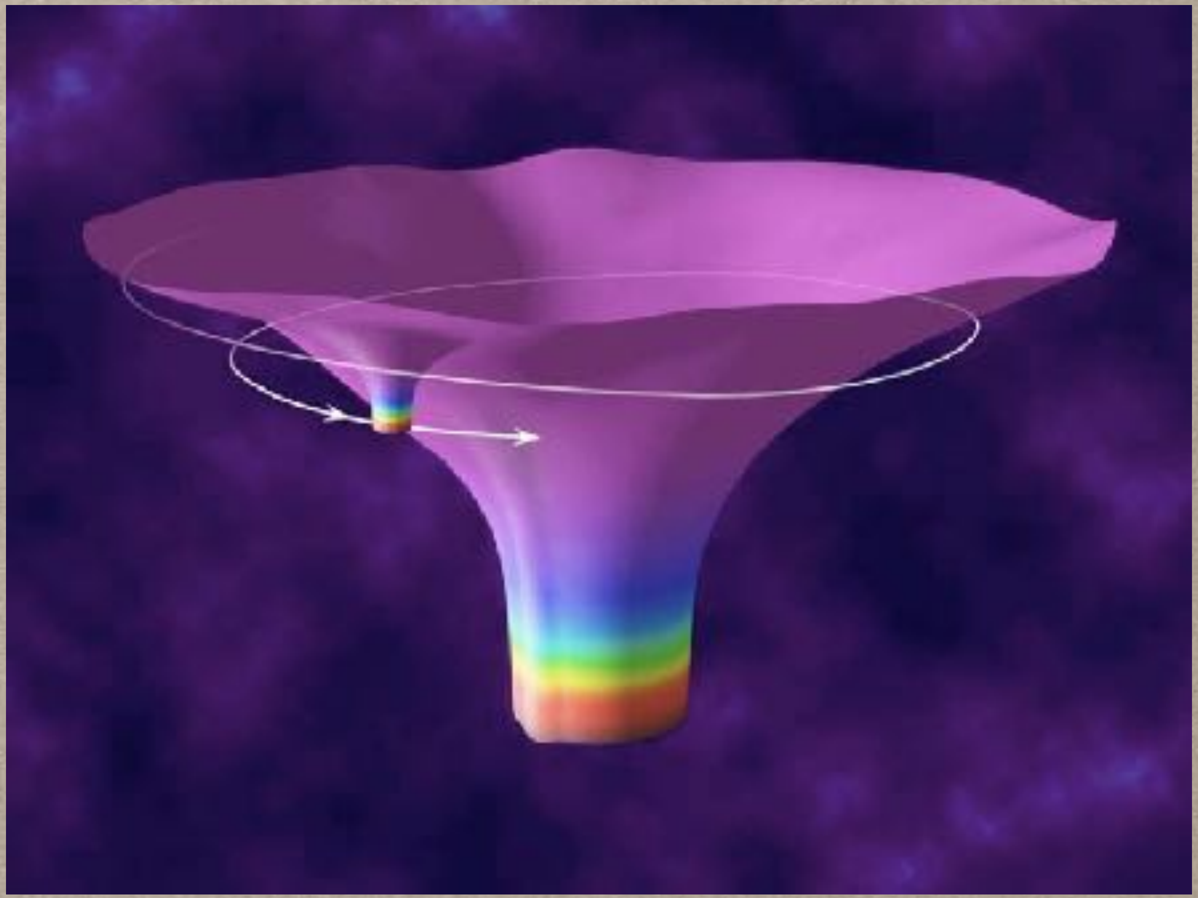
see e.g. Astro2020 Science White Paper (Berti +2019)
Gair et al. Living Review , and Barack + 2018

TESTS OF GENERAL RELATIVITY

SMBH-SMBH binary

Image credit: The SXS Project

Extreme Mass Ratio Inspiral



TESTS OF GENERAL RELATIVITY

SMBH-SMBH binary

Image credit: The SXS Project

testing deviation from GR in

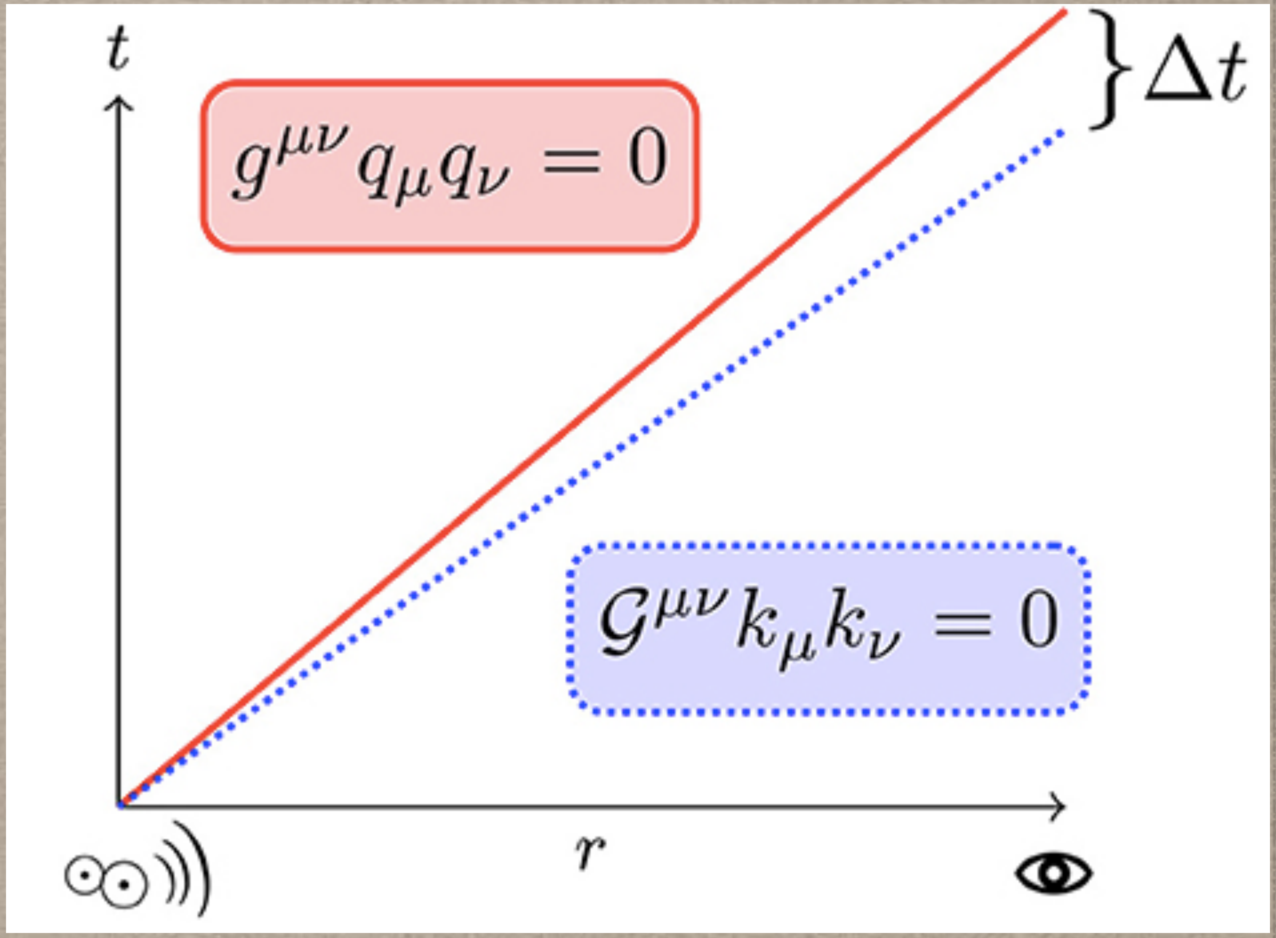
- *GW propagation*
- *BH dynamics*

TESTS OF GENERAL RELATIVITY

SMBH-SMBH binary

Cartoon by Pilar Ruiz-Lapuente

Image credit: The SXS Project



testing deviation from GR in

- ***GW propagation***
- *BH dynamics*

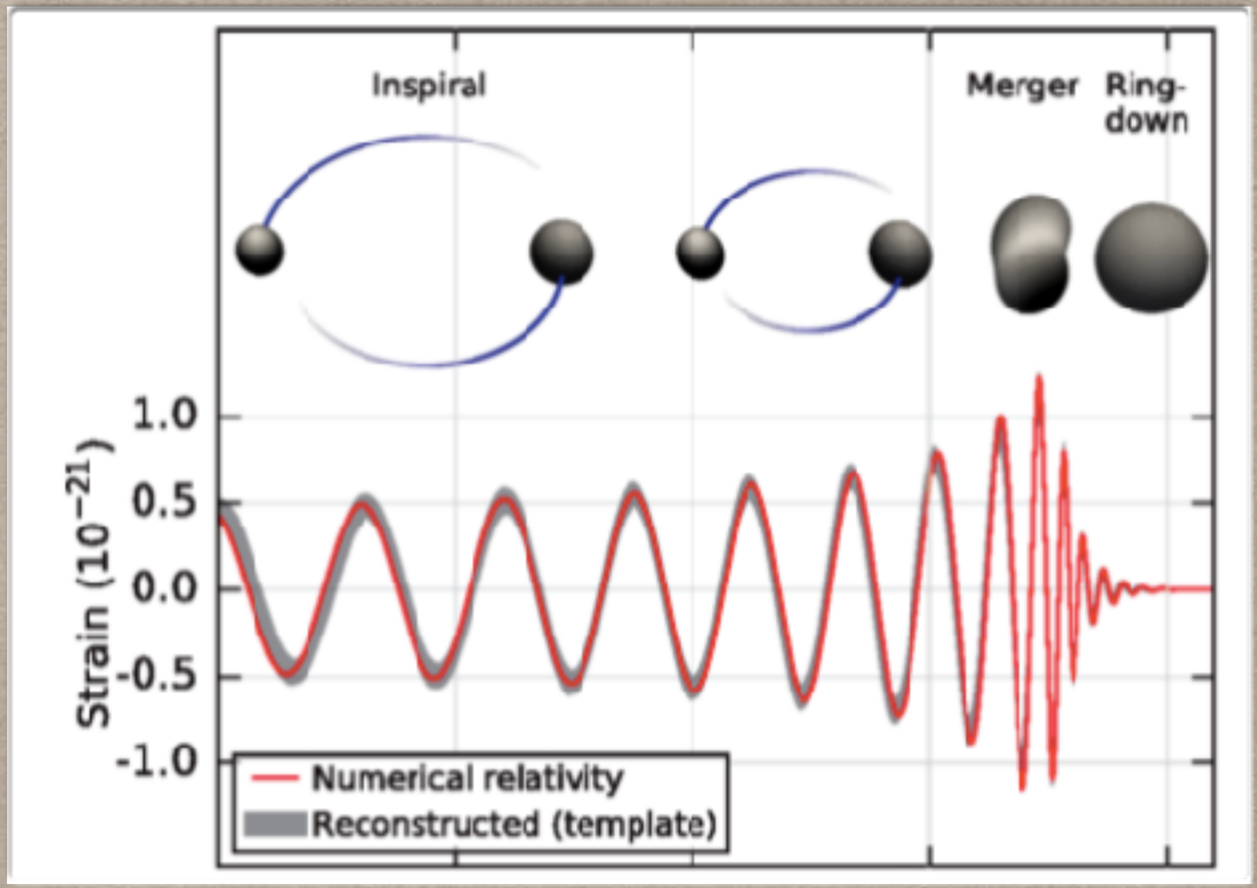
In modified gravity theory there is a time delay between photons and GW

TESTS OF GENERAL RELATIVITY

SMBH-SMBH binary

credit: LIGO/VIRGO collaboration

Image credit: The SXS Project



testing deviation from GR in

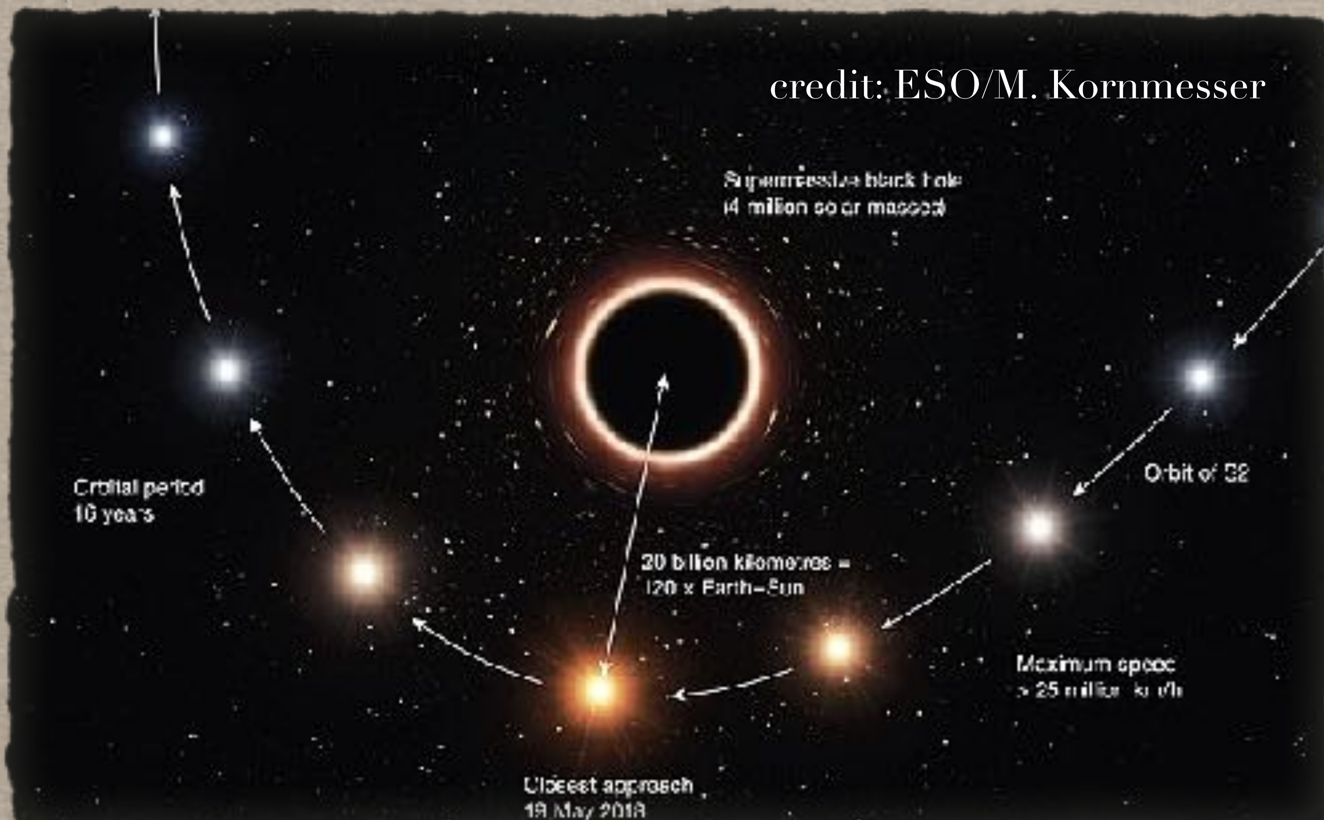
- *GW propagation*
- ***BH dynamics***

Testing no-hair theorem with BH spectroscopy in a dynamic, non-stationary spacetime (Ring-down phase)

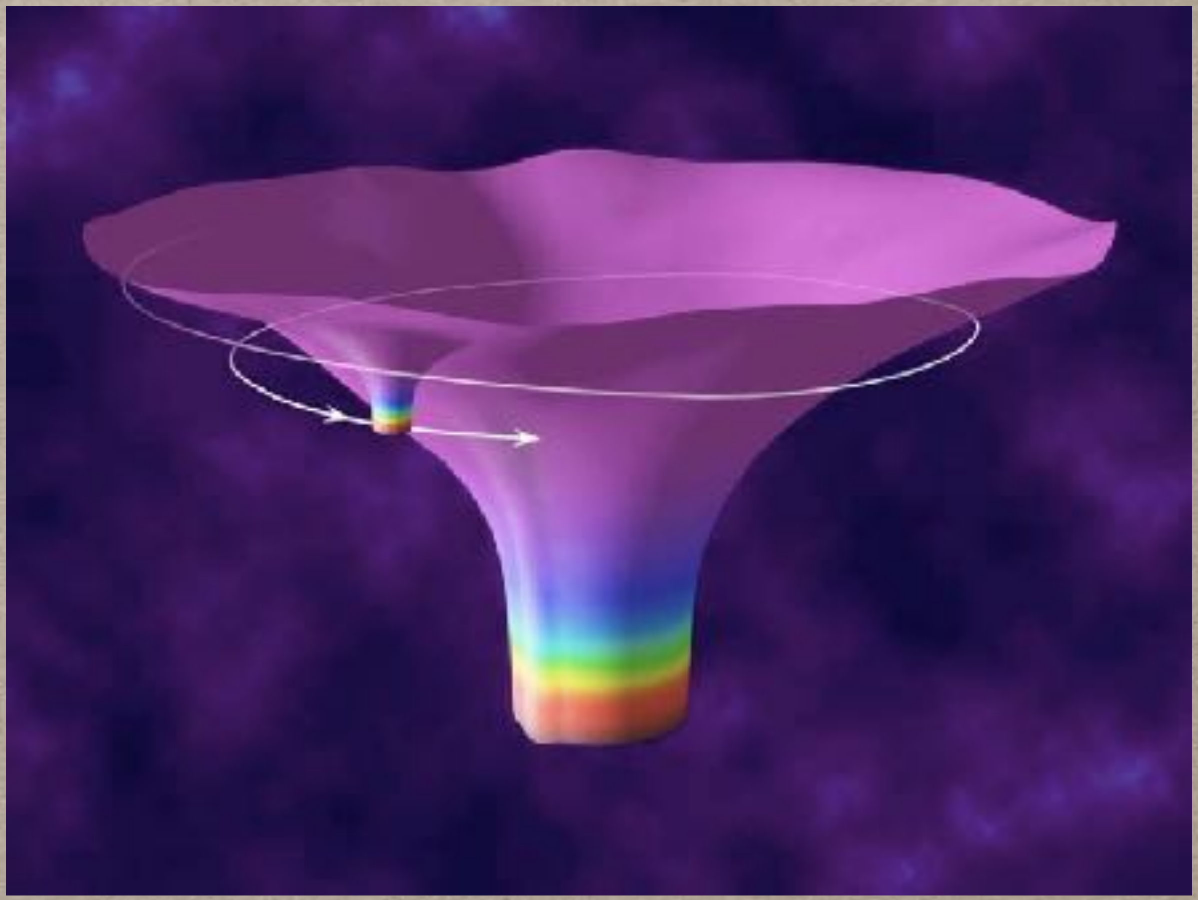
Elena Maria Rossi

TESTS OF BH SPACETIME

Stars orbiting SrA* ~120 AU



Extreme Mass Ratio Inspiral



*With 10^4-10^5 GW cycles in the LISA band, measurements of deviation from Kerr metric at **0.01-1% level** with a few to a thousands EMRIs, with SNR up to a few 100*

Elena Maria Rossi

COSMOLOGY

see e.g. Astro2020 Science White Paper Caldwell + 2019

Extremely rich science..

COSMOLOGY

see e.g. Astro2020 Science White Paper Caldwell + 2019

- *Measurements of the cosmological parameters using LISA standard sirens (Tamanini + 2017)*
- *Testing modified gravity at cosmological distances with LISA standard sirens (Belgacem +2019)*
- *Testing cosmic strings*
- *Testing particle physics models' predictions for first-order phase transitions*
- *Testing Inflationary models*
- *Cosmological stochastic background (e.g. Caprini +2019)*

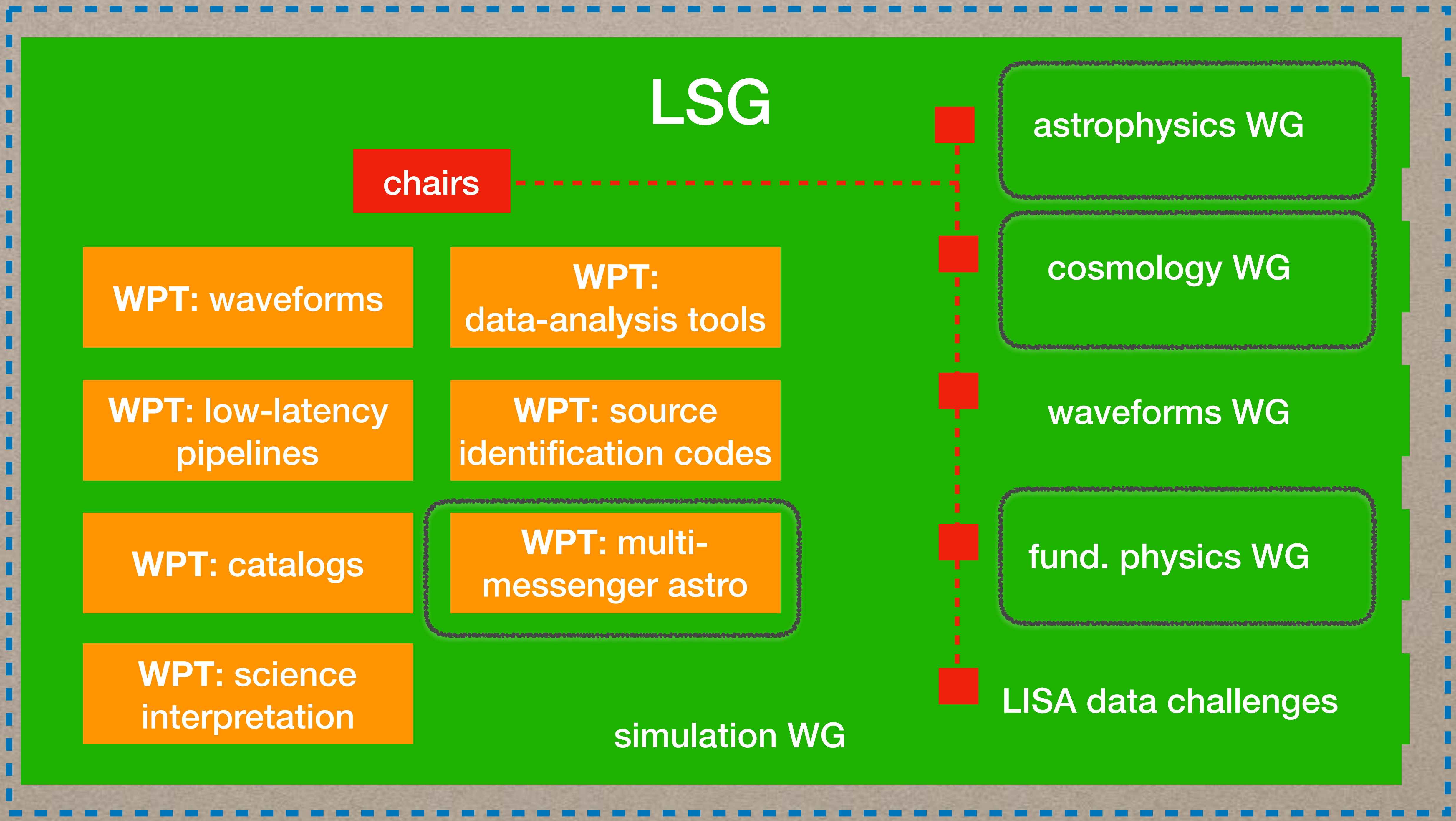
MULTIMESSANGER SCIENCE OPPORTUNITIES WITH LISA

Primary Thematic Science Area: Multi-Messenger Astronomy and Astrophysics
Secondary Areas: Cosmology and Fundamental Physics, Galaxy Evolution,
Formation and Evolution of Compact Objects

Multimessenger science opportunities with mHz gravitational waves

John Baker,[1,2] Zoltán Haiman,[3] Elena Maria Rossi,[4]
Edo Berger,[5] Niel Brandt,[6] Elmé Breedt,[7] Katelyn Breivik,[8] Maria Charisi,[9] Andrea Derdzinski,[3] Daniel J. D'Orazio,[5] Saavik Ford,[10, 11] Jenny E. Greene,[12] J. Colin Hill,[13, 14] Kelly Holley-Bockelmann,[15] Joey Shapiro Key,[16] Bence Kocsis,[17] Thomas Kupfer,[18] Shane Larson,[19] Piero Madau,[20] Thomas Marsh,[21] Barry McKernan,[10, 11] Sean T. McWilliams,[22] Priyamvada Natarajan,[23] Samaya Nissanke,[24] Scott Noble,[25, 1] E. Sterl Phinney,[9] Gavin Ramsay,[26] Jeremy Schnittman,[1] Alberto Sesana,[27, 28] David Shoemaker,[29] Nicholas Stone,[3] Silvia Toonen,[30, 27] Benny Trakhtenbrot,[31] Alexey Vikhlinin,[5] and Marta Volonteri[32]

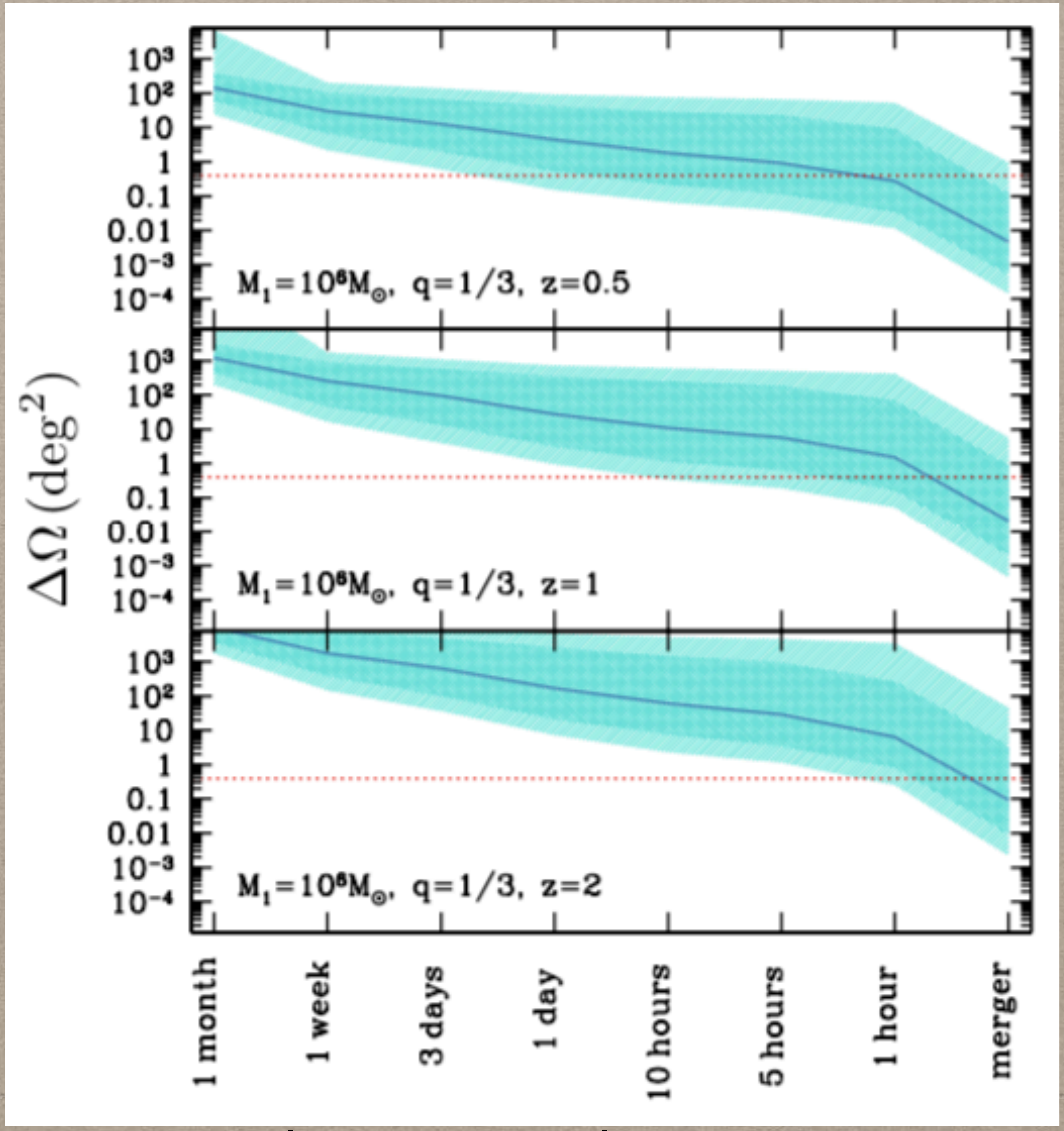
LISA SCIENCE GROUP



CHAIRS: JON GAIR, MICHELE VALLISNERI & ELENA MARIA ROSSI

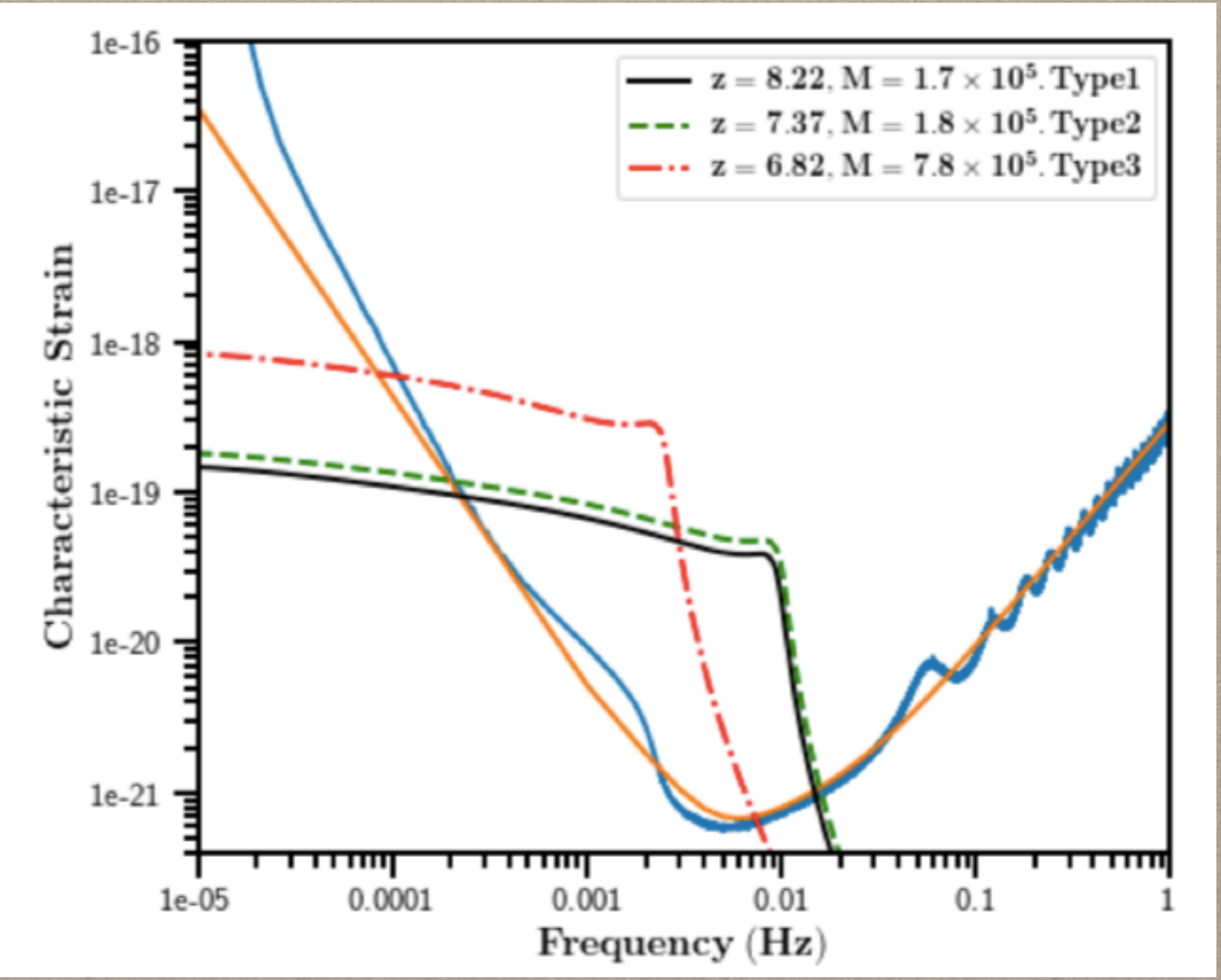
BACK UP SLIDES

PRE-MERGER LOCALISATION



Athena-LISA synergy working group document

DIFFERENT SEEDING MODELS



Dayal , EMR + 2018