A FUTURE CHALLENGE FOR DETECTION OF DOUBLE WHITE DWARF BINARIES

Valeriya Korol

Collaborators: E.M. Rossi, P. Groot, G. Nelemans, S. Toonen and A. Brown

Sterrewacht Leiden

GRavitational-wave Astronomy Meeting, PARis 31st August 2016

OUTLINE

1. HOW MANY WD-WD BINARIES WILL eLISA DETECT?

2. HOW MANY WD-WD BINARIES WILL GAIA & LSST DETECT?

3. HOW MANY SIMULTANEOUS GW & EM WD-WD DETECTIONS SHOULD WE EXPECT?

WHY WD-WD ARE IMPORTANT?

- WDs represent the most common fate in the Galaxy:
  ~ 10^{10} WDs in total (Napiwotzki et al. 2009) and
  ~ 10^{8} in WD-WD binaries (Nelemans et al. 2001)

- 1/2 of WD-WD have P < 8 hours, so that GW emission will bring them into contact within a Hubble time (Nelemans et al. 2004)

- The most numerous low-frequency (10^{-4} - 1 Hz) GW sources in the Galaxy & guaranteed detections for the eLISA mission (Amaro-Seoane et al. 2013)

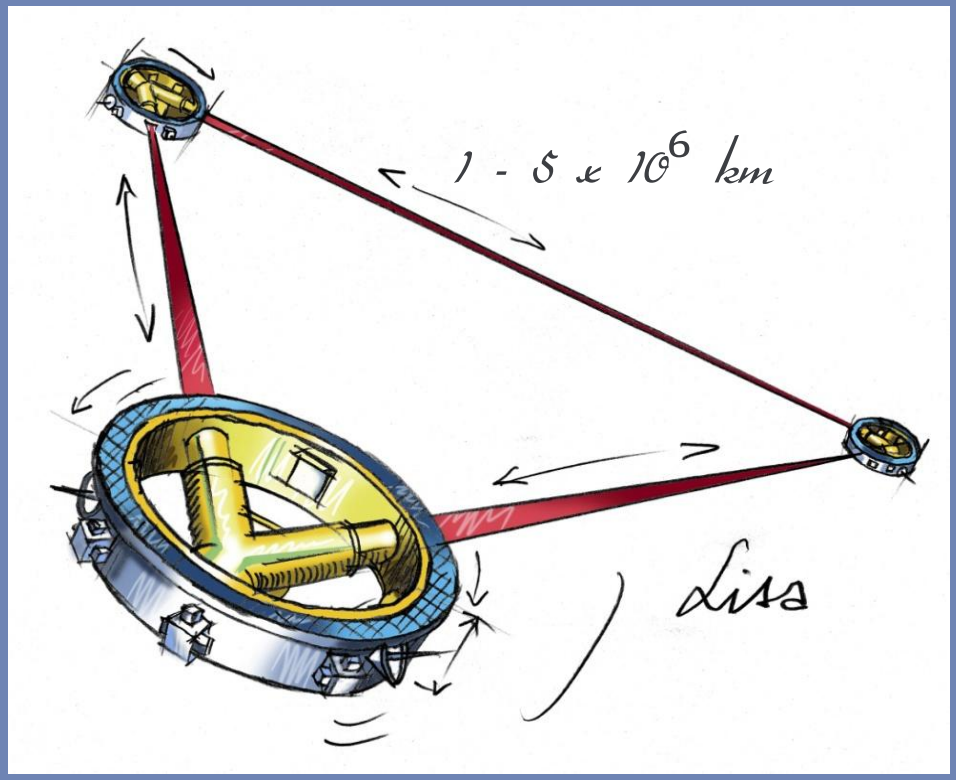
FORMATION AND EVOLUTION

- Binary needs at least 2 mass transfer phases to form a WD-WD system
- At least one mass transfer needs to be a common envelope to form a compact binary
- The following evolution of a WD-WD binary is driven by GW radiation
- Last stages are determined by tidal interaction and mass transfer
- At the end binary will merge or survive as mass-transferring binary

FORMATION AND EVOLUTION

- Binary needs at least 2 mass transfer phases to form a WD-WD system
- At least one mass transfer needs to be a common envelope to form a compact binary
- The following evolution of a WD-WD binary is driven by GW radiation
- Last stages are determined by tidal interaction and mass transfer
- At the end binary will merge or survive as mass-transferring binary

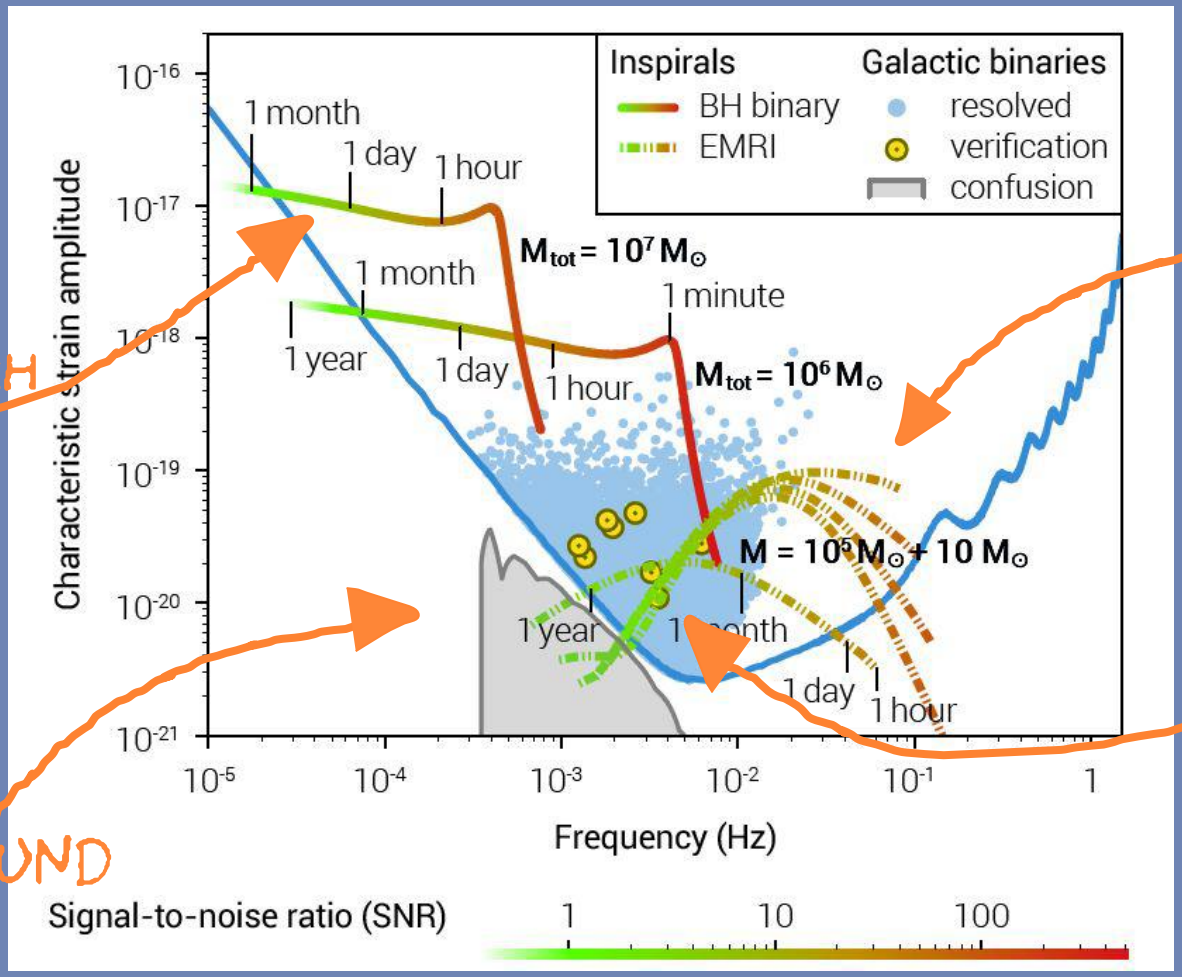
LASER INTERFEROMETER SPACE ANTENNA



©ESA-C. Vijoux

- In principle LISA is a Michelson interferometer, but floating in space!
- It consists of 3 spacecrafts in an equilateral triangle
- Connected by laser links in triangular (LISA-like) or V-shaped (eLISA-like) configuration
- Spacecraft separation of a few 10^6 km sets the range of GW frequencies:
  0.1 mHz – few Hz

LOW-FREQUENCY GW SOURCES



MASSIVE BH BINARIES

EXTREME MASS-RATIO INSPIRALS

FOREGROUND

GALACTIC BINARIES

(Amaro-Seoane et al. 2013)

HOW MANY WD-WDS CAN eLISA DETECT?

SIMULATED POPULATION OF CLOSE DWDS

↓

ORBIT AVERAGE GW STRAIN AMPLITUDE

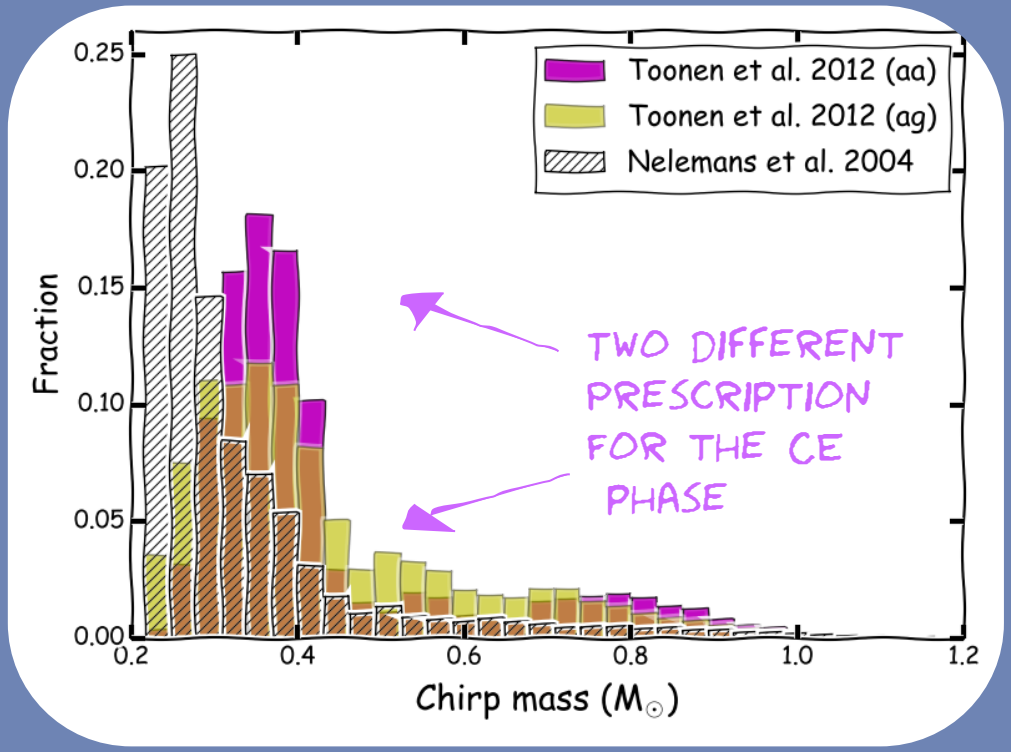
↓

ANALYTICAL FITS FOR INSTRUMENT SENSITNITY

↓

S/R > 5

NEW POPULATION SYNTHESIS MODEL



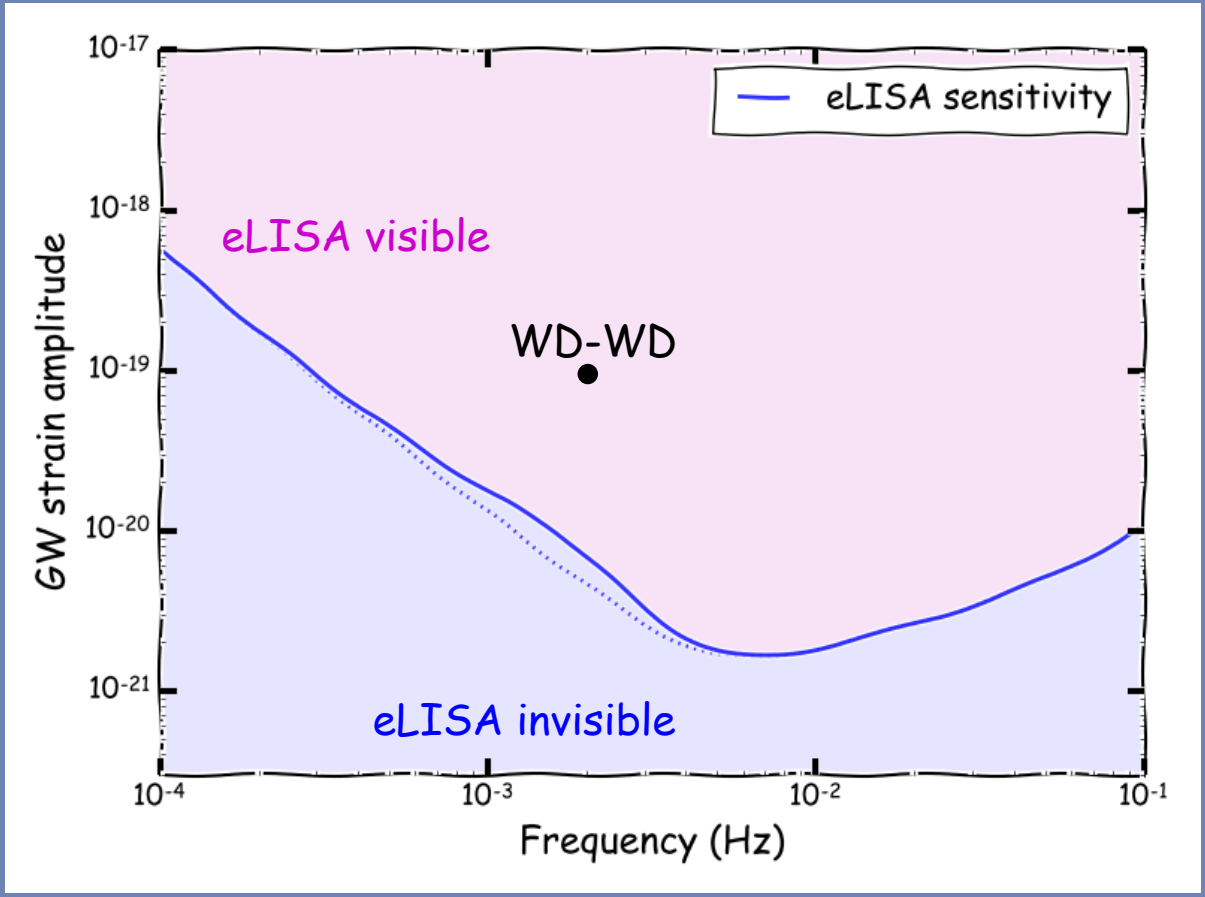
THE RESULT IS THE DIFFERENT CHIRP MASS DISTRIBUTION

Changes were made to binary population synthesis models since earlier estimates for WD-WD binaries detections:

- NEW STELLAR TRACKS
- WIND MASS LOSS PRESCRIPTION
- TREATMENT OF THE MASS TRANSFER STABILITY
- UPDATED ACCRETION PRESCRIPTIONS

See Toonen et al. (2012) for details

GW SIGNAL FROM A WD-WD BINARY



For the majority of galactic WD-WDs

$t_{GW} \gg t_{obs}$

MONOCROMATIC SOURCE

with

SIGNAL AT THE DETECTOR

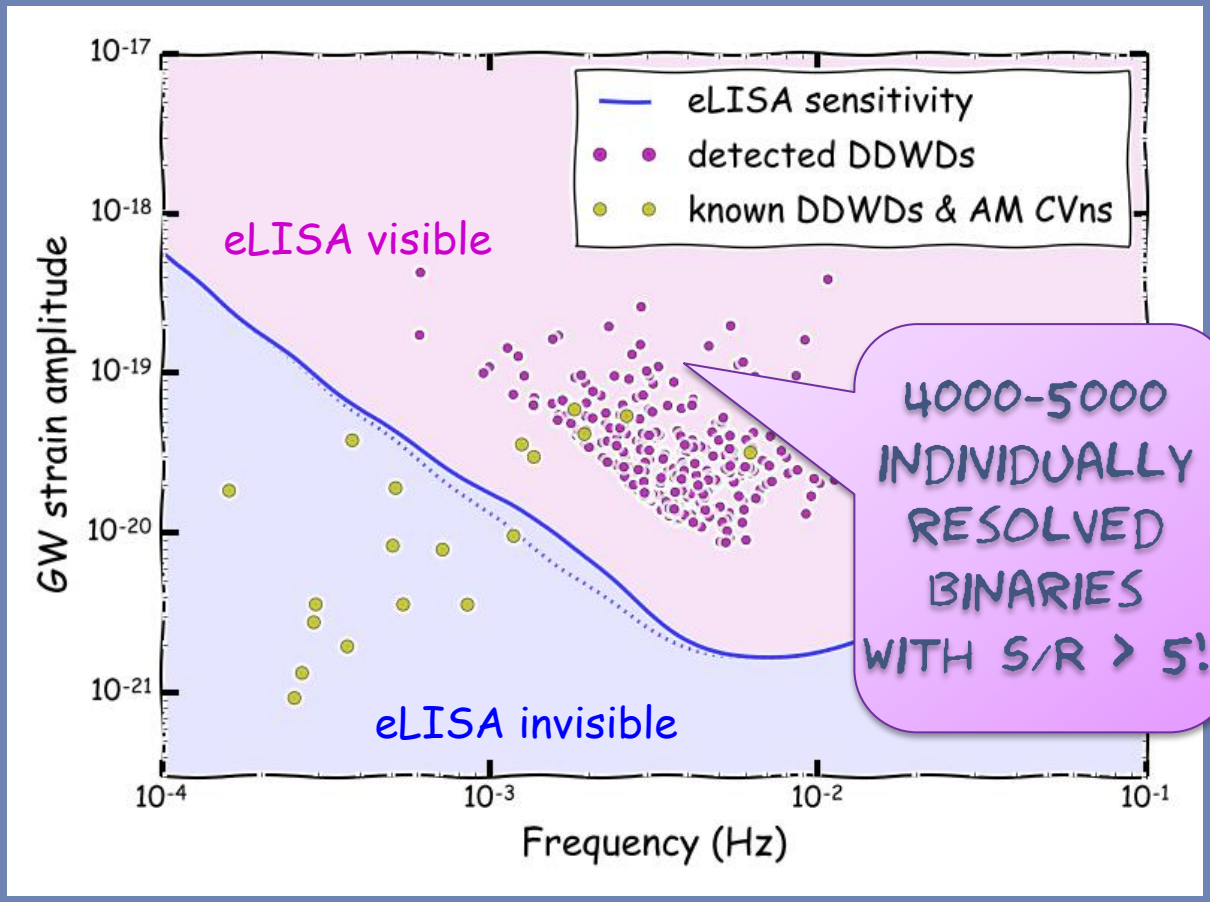
$$s(t) = F_+ h_+(t) + F_\times h_\times(t),$$

modulation of the signal due to the eLISA orbital motion

$$s(t) = \mathcal{A}(t)\cos\left[2\pi f t + \phi_{\rm P}(t) + \phi_{\rm D}(t) + \phi_0\right]$$

$$\mathcal{A}(t) = \left[h_+^2 F_+^2(t) + h_\times^2 F_\times^2(t)\right]^{1/2}$$

GW SIGNAL FROM A WD-WD BINARY



For the majority of galactic WD-WDs

$t_{GW} \gg t_{obs}$

MONOCROMATIC SOURCE

with

SIGNAL AT THE DETECTOR

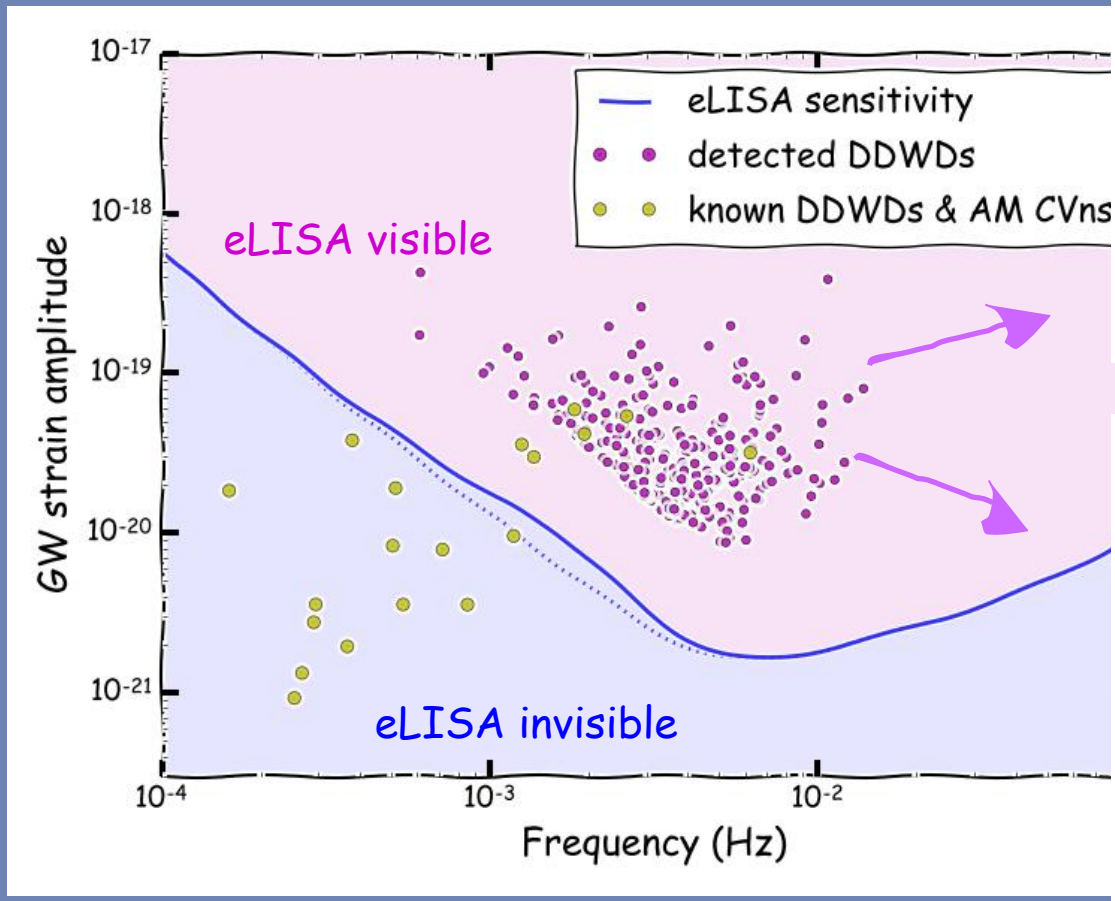
$$s(t) = F_+ h_+(t) + F_\times h_\times(t),$$

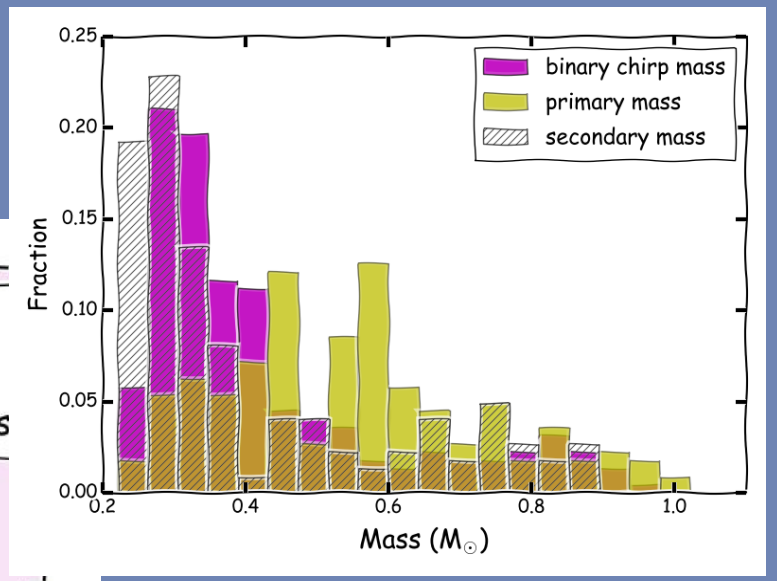
modulation of the signal due to the eLISA orbital motion

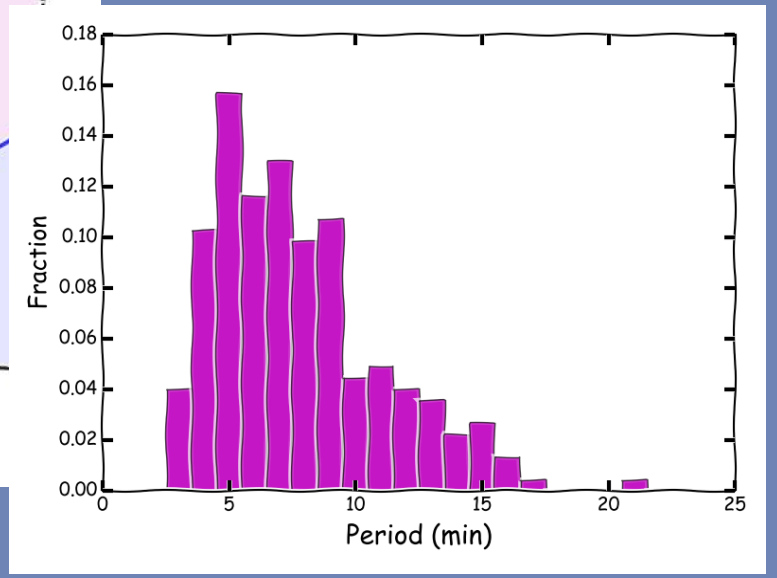
$$s(t) = \mathcal{A}(t)\cos\left[2\pi f t + \phi_{\rm P}(t) + \phi_{\rm D}(t) + \phi_0\right]$$

$$\mathcal{A}(t) = \left[h_+^2 F_+^2(t) + h_\times^2 F_\times^2(t)\right]^{1/2}$$

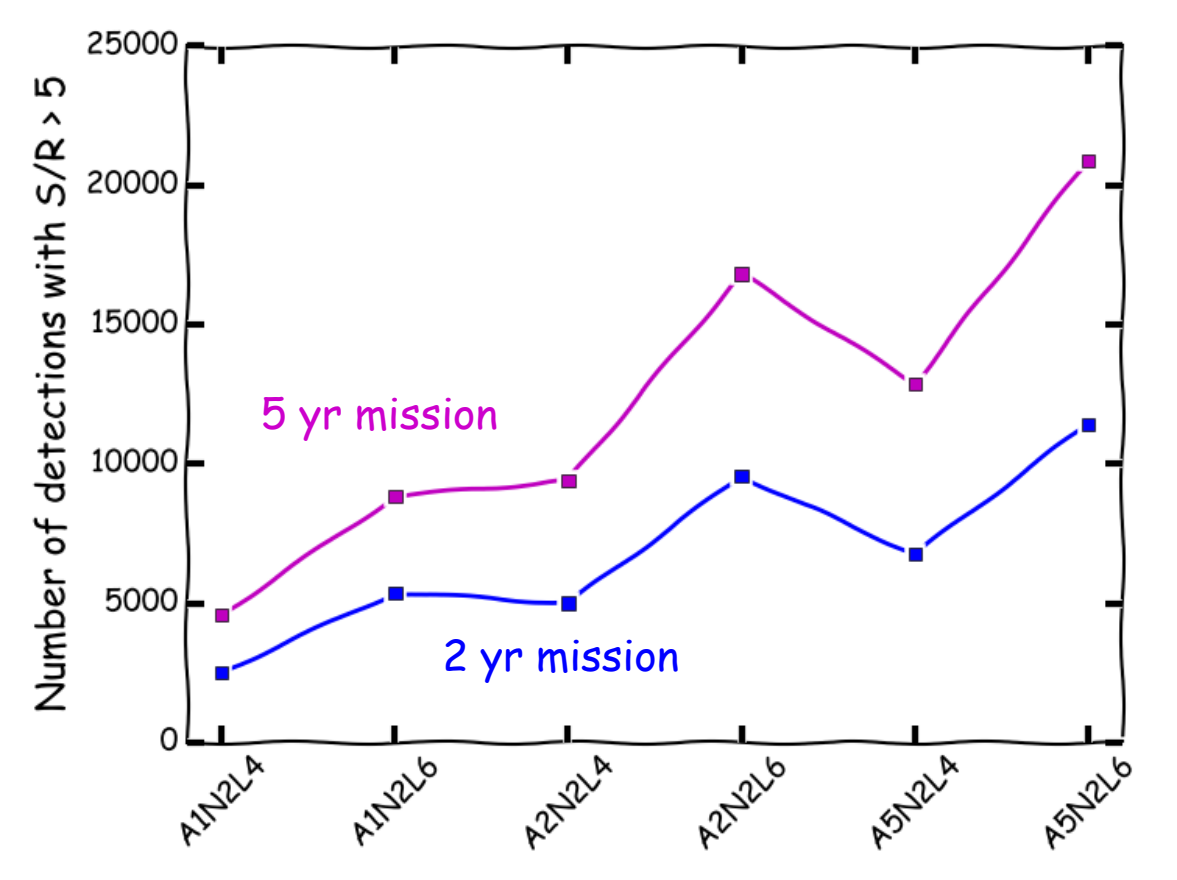
PROPERTIES OF eLISA DETECTIONS







IMPACT OF DESIGN ON THE NUMBER OF DETECTIONS



A1, A2 & A5 = 1, 2 & 5 Mkm arm length

N2 = LISA Pathfinder acceleration noise

L4 & L6 = 4 & 6 links design

HOW MANY EM COUNTERPARTS CAN WE DETECT?

RECIPE FOR GAIA & LSST

SIMULATED POPULATION OF CLOSE DWDS

↓

SIMULATED LIGHT CURVES

↓

SAMPLING

↓

DETECTION TEST

HOW MANY EM COUNTERPARTS CAN WE DETECT?

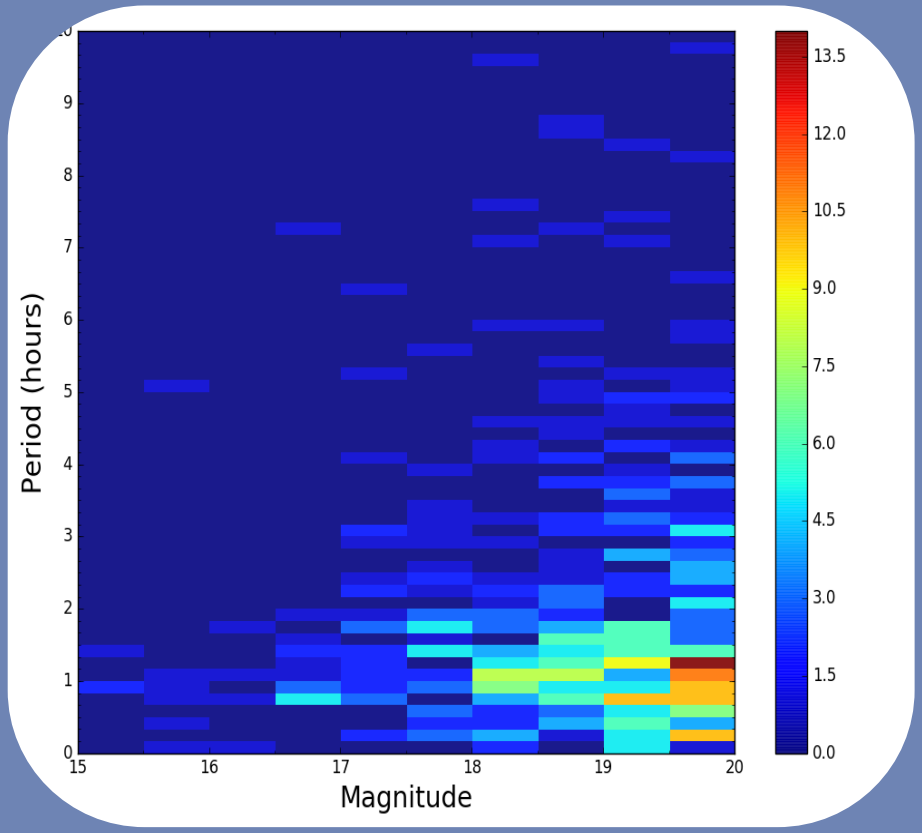
	GAIA	LSST
SKY COVERAGE OF SURVEY	WHOLE SKY	HALF OF THE SKY
DEPTH PER OBSERVATION	$G \approx 20$	$r \approx 24$
NUMBER OF OBSERVATIONS	70 IN 5 YEARS	1000 IN 10 YEARS
CADENCE OF OBSERVATIONS	TRUE POINTING	1 IN 3 DAYS

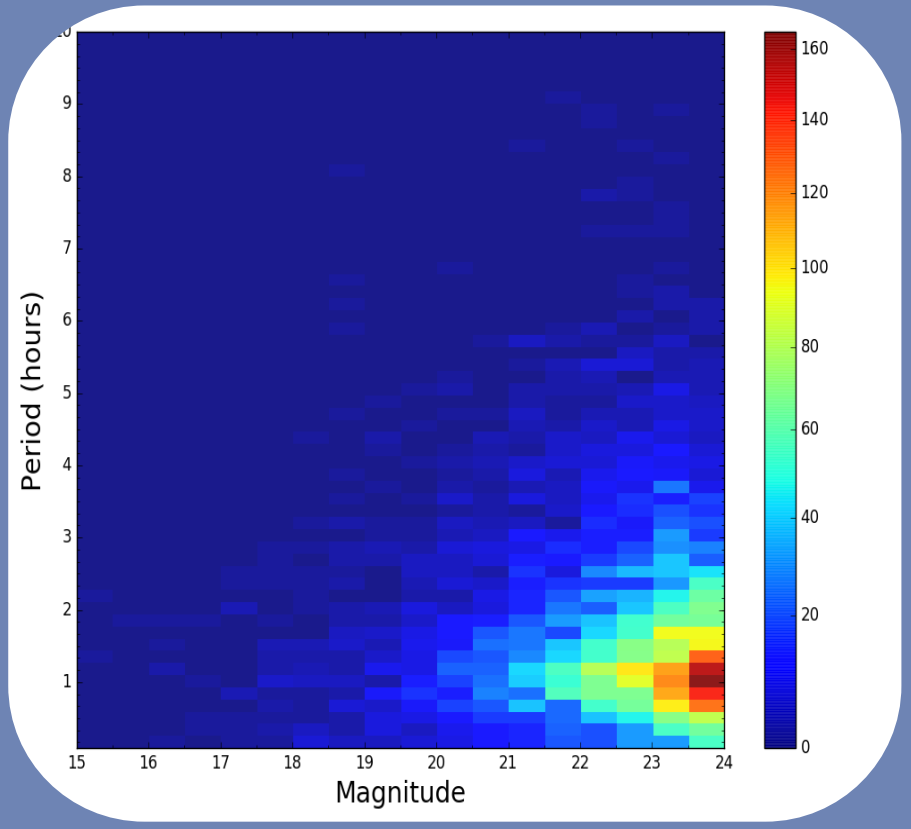
HOW MANY EM COUNTERPARTS CAN WE DETECT?

	GAIA	LSST
SKY COVERAGE OF SURVEY	WHOLE SKY	HALF OF THE SKY
DEPTH PER OBSERVATION	$G \approx 20$	$r \approx 24$
NUMBER OF OBSERVATIONS	70 IN 5 YEARS	1000 IN 10 YEARS
CADENCE OF OBSERVATIONS	TRUE POINTING	1 IN 3 DAYS
DETECTED WD-WD ECLIPSERS	400	7×10^3

HOW WELL WE CAN RECONSTRUCT GALACTIC POPULATION?

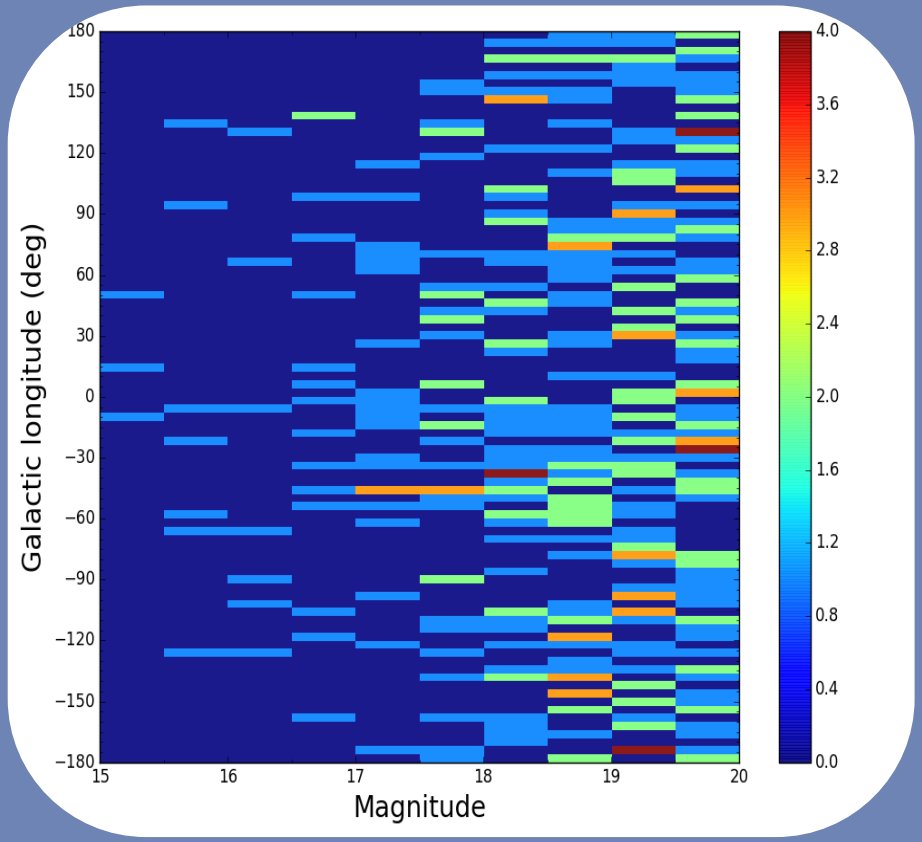
GAIA VS LSST

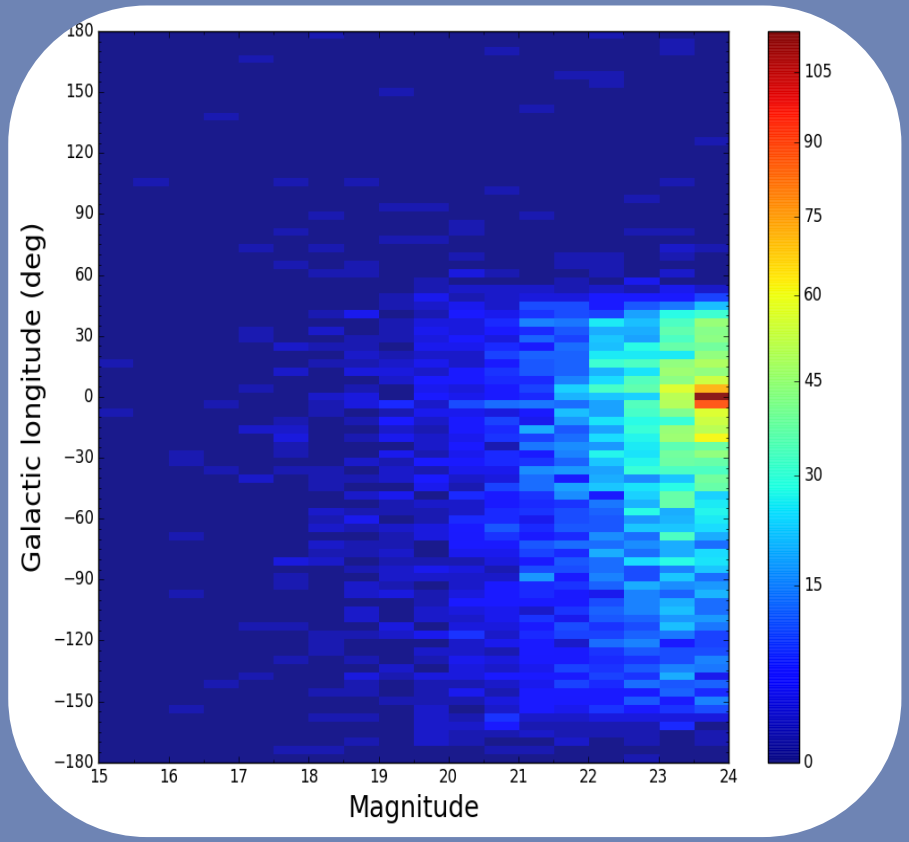




HOW WELL WE CAN RECONSTRUCT GALACTIC POPULATION?

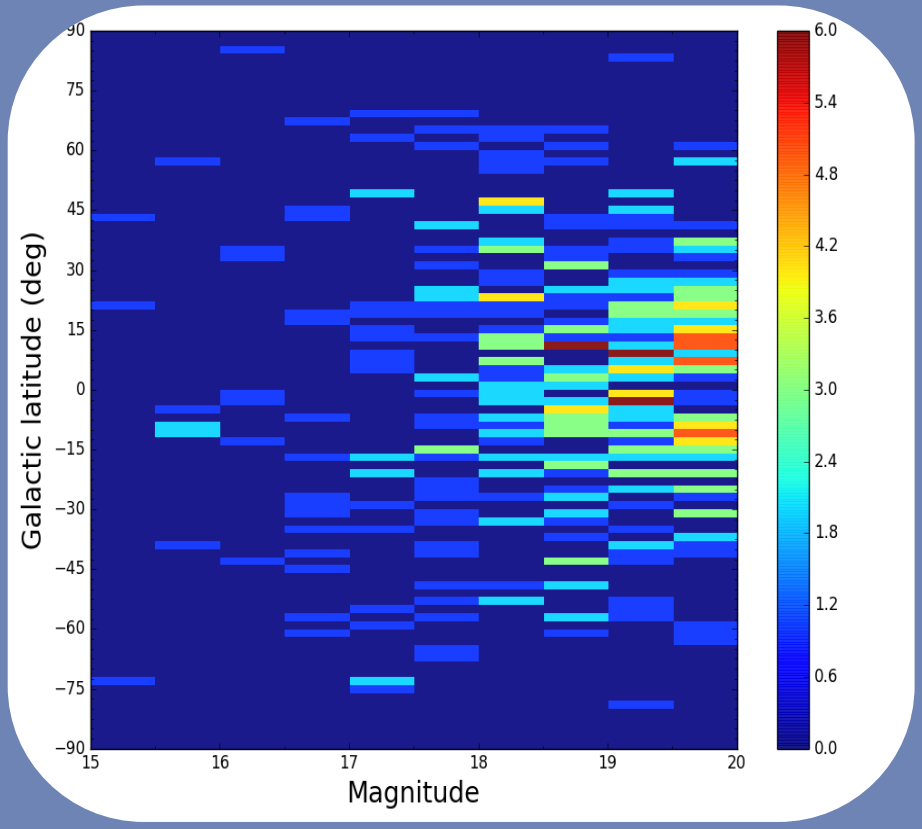
GAIA VS LSST

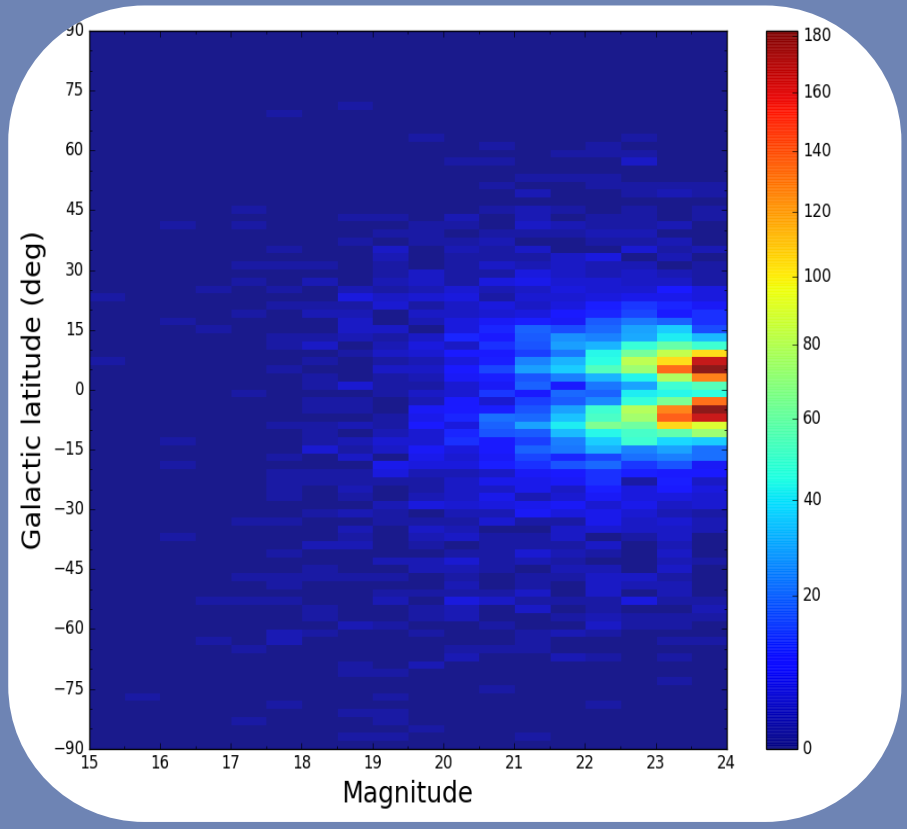




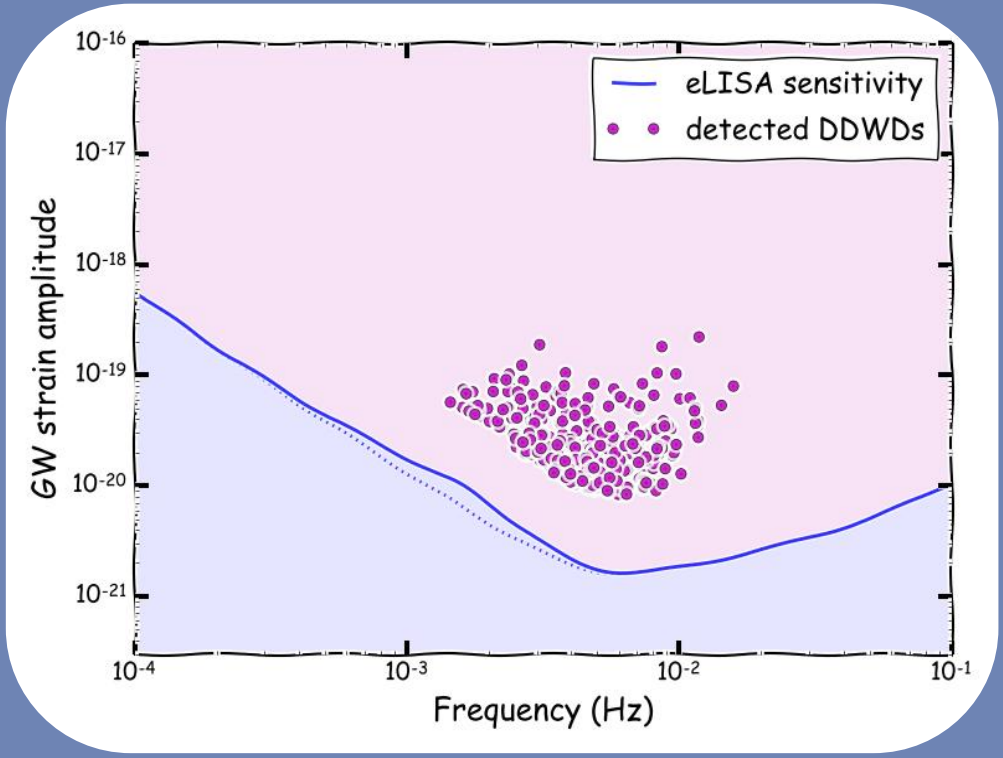
HOW WELL WE CAN RECONSTRUCT GALACTIC POPULATION?

GAIA VS LSST



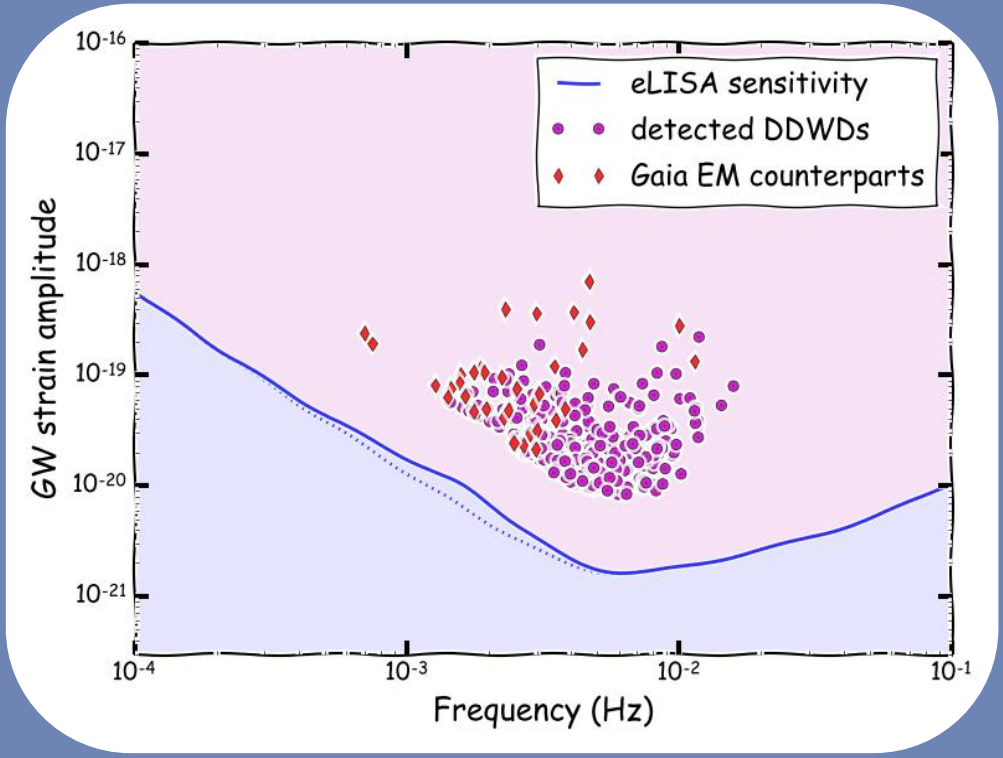


HOW MANY SIMULTANEOUS GW & EM WD-WD DETECTIONS?



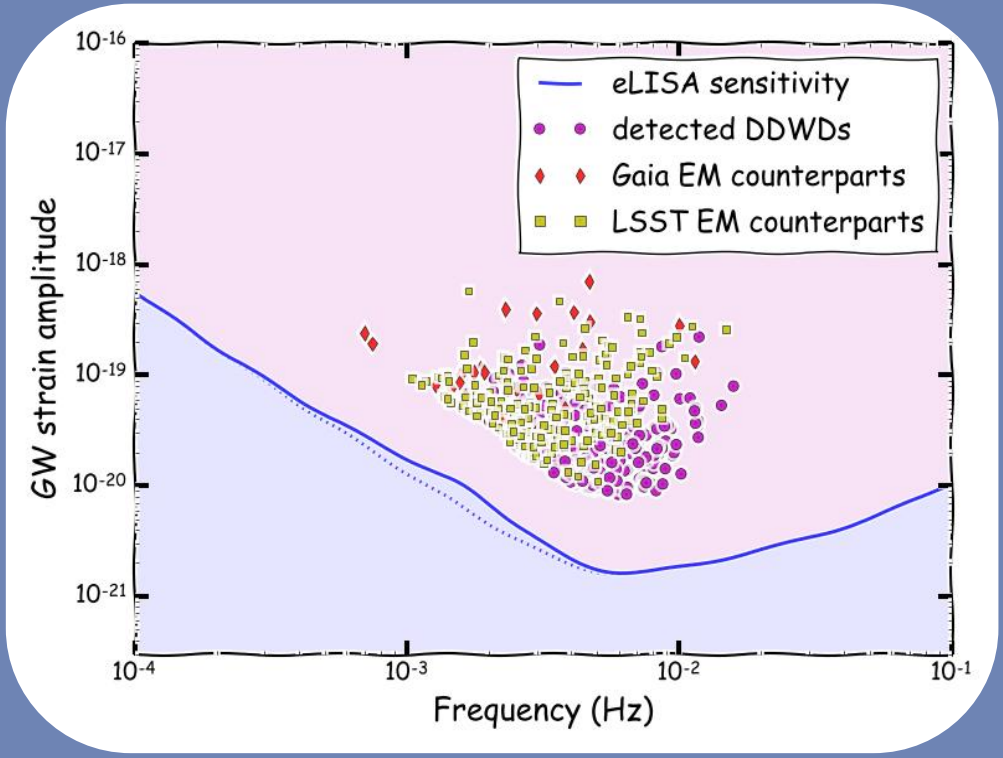
- 10^3 - 10^4 individually resolved sources
- up to 10^2 EM counterparts detected with Gaia
- up to 10^3 EM counterparts detected with LSST
- these detections will significantly extend the sample of VERIFICATION BINARIES!

HOW MANY SIMULTANEOUS GW & EM WD-WD DETECTIONS?



- 10^3 - 10^4 individually resolved sources
- up to 10^2 EM counterparts detected with Gaia
- up to 10^3 EM counterparts detected with LSST
- these detections will significantly extend the sample of VERIFICATION BINARIES!

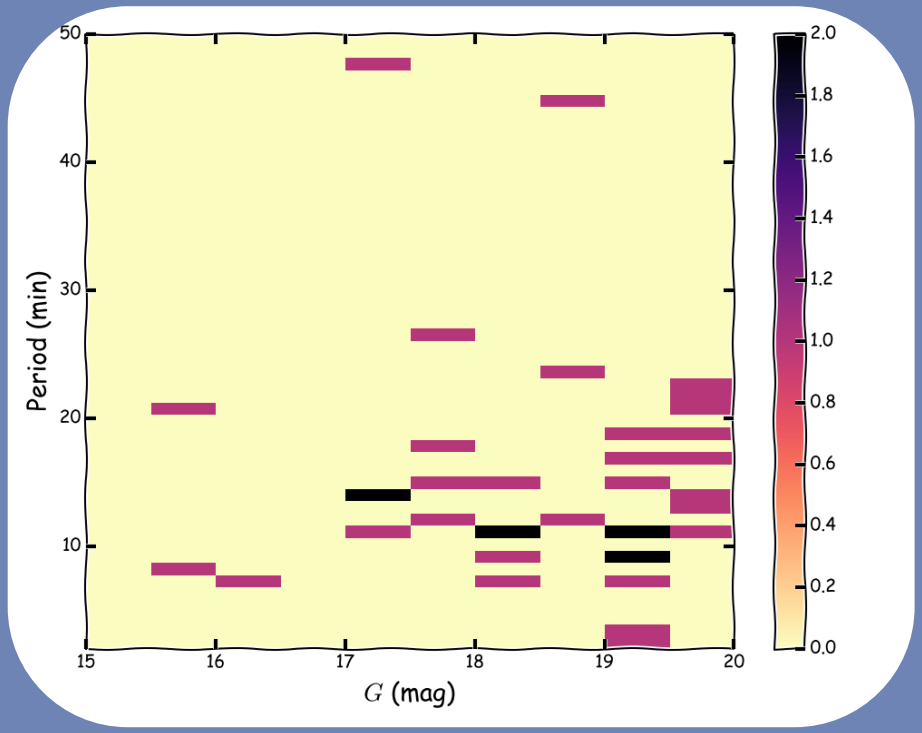
HOW MANY SIMULTANEOUS GW & EM WD-WD DETECTIONS?

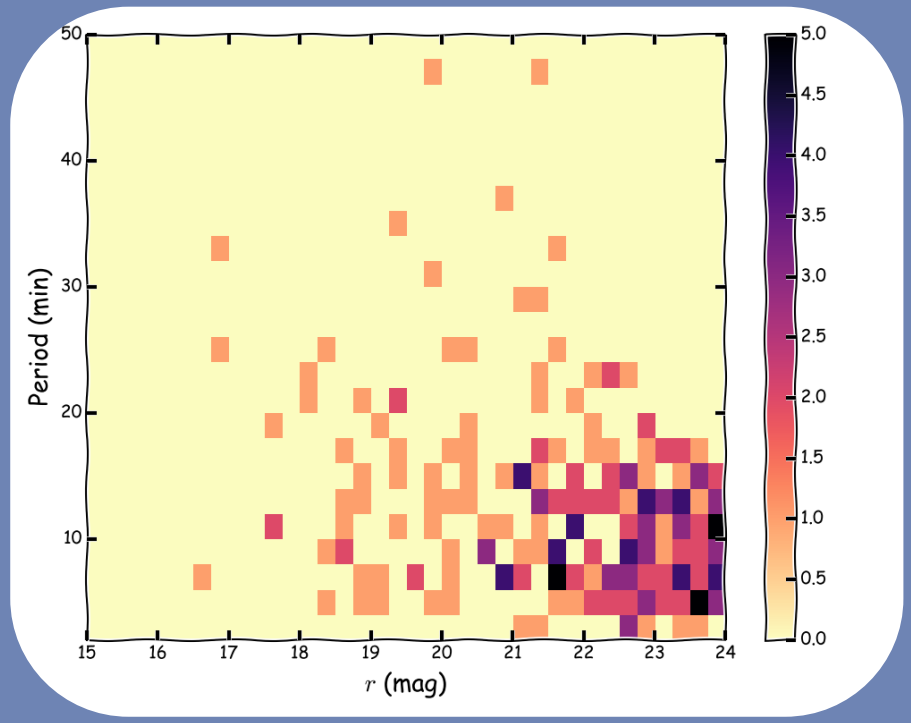


- 10^3 - 10^4 individually resolved sources
- up to 10^2 EM counterparts detected with Gaia
- up to 10^3 EM counterparts detected with LSST
- these detections will significantly extend the sample of VERIFICATION BINARIES!

HOW MANY SIMULTANEOUS GW & EM WD-WD DETECTIONS?

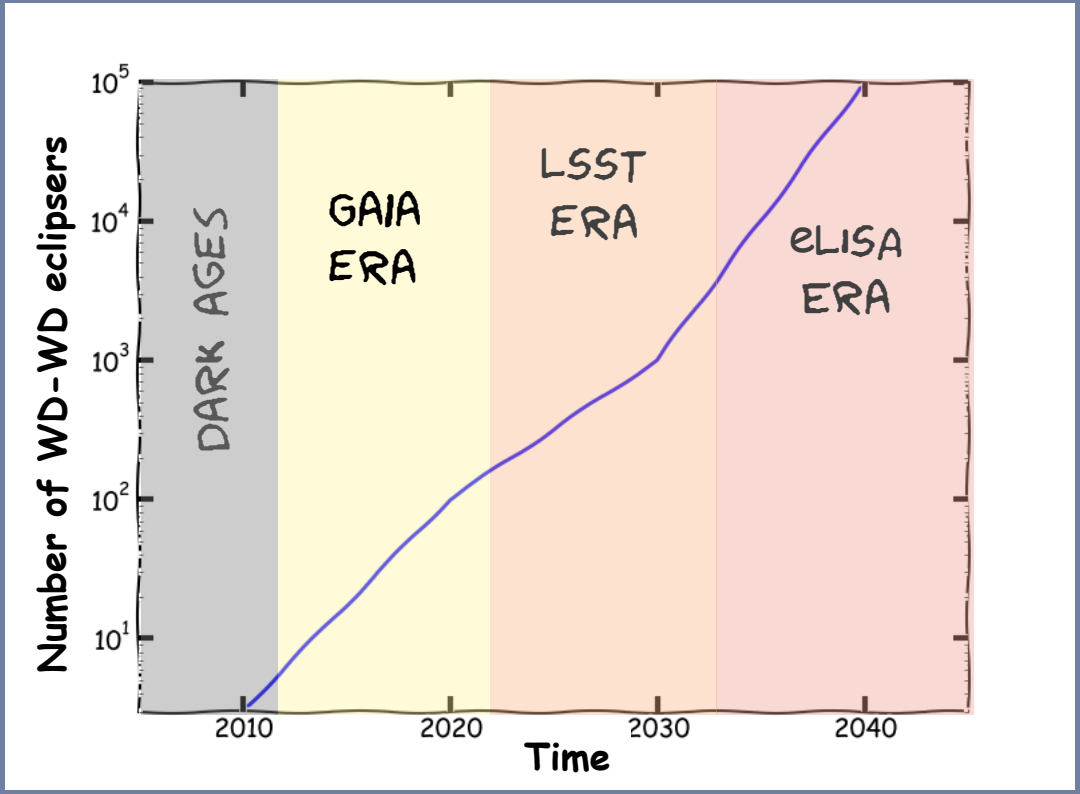
GAIA VS LSST





A BRIGHT FUTURE!

COMPARED TO THE FEW WD-WD ECLIPSERS KNOWN BY 2011 WE EXPECT:



- $> 10^2$ eclipsing WD-WDs detected with Gaia by 2020
- $> 10^3$ eclipsing WD-WDs detected with LSST by 2030
- $> 10^4$ WD-WDs detected with eLISA

THANK YOU FOR
YOUR ATTENTION