Prospects for multi-messenger studies of the Milky Way with LISA

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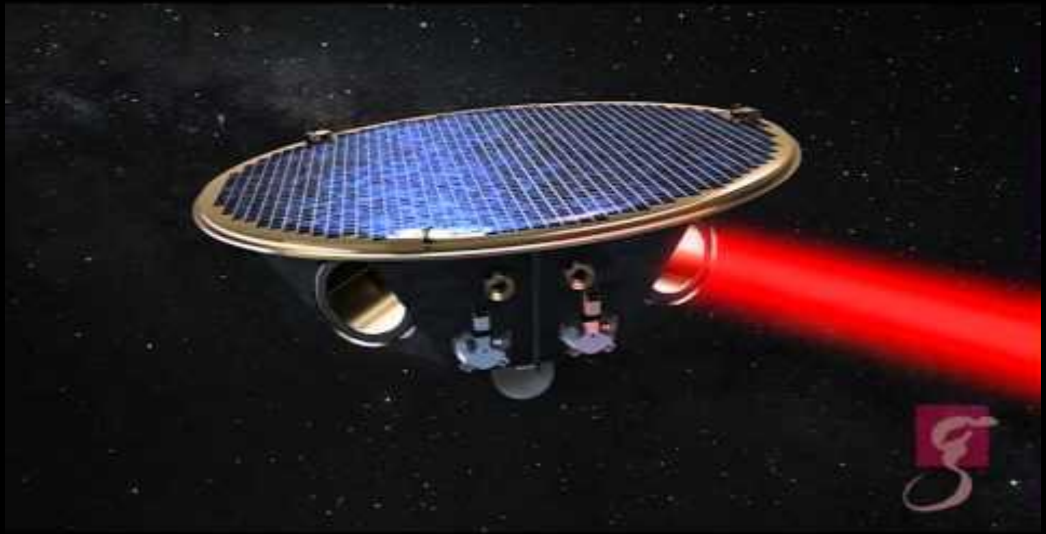
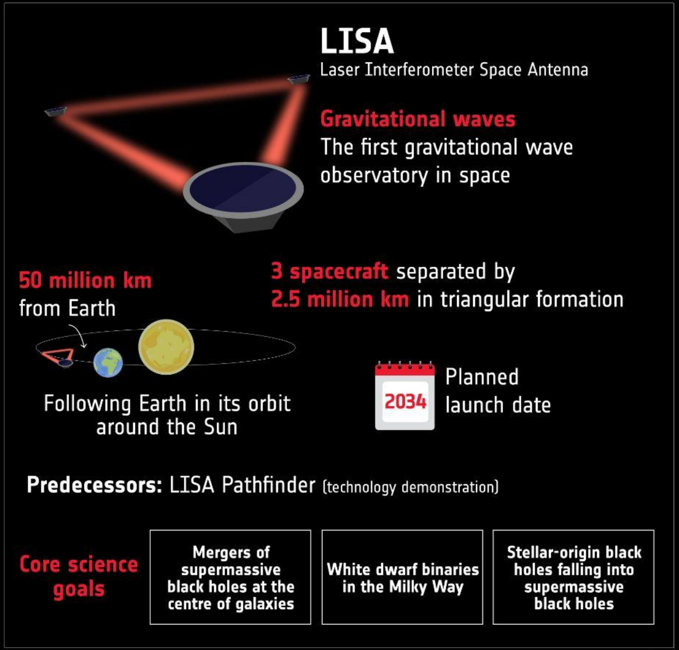
Synergies@Prague winter workshop

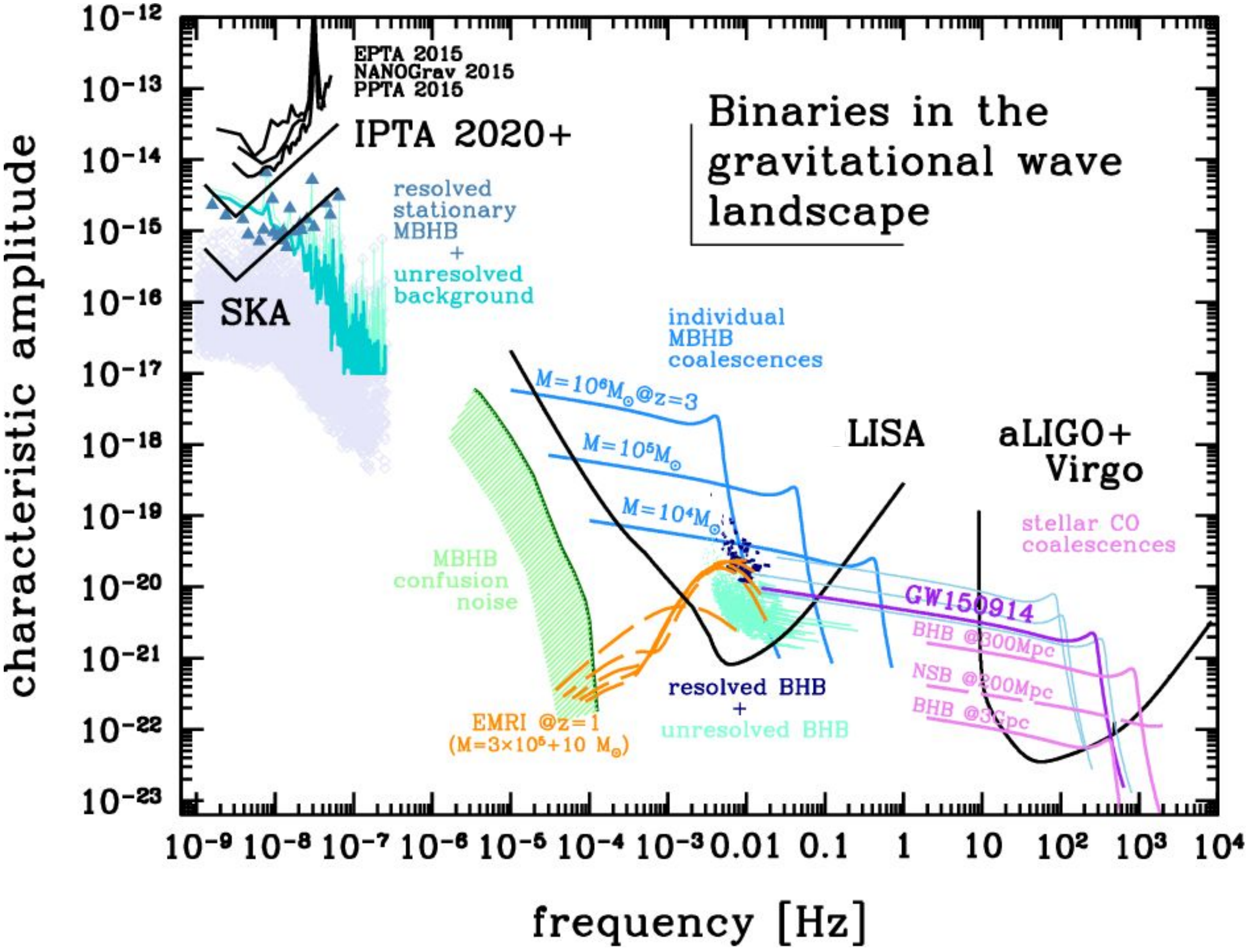
LISA CONSORTIUM

Laser Interferometer Space Antenna, in short LISA



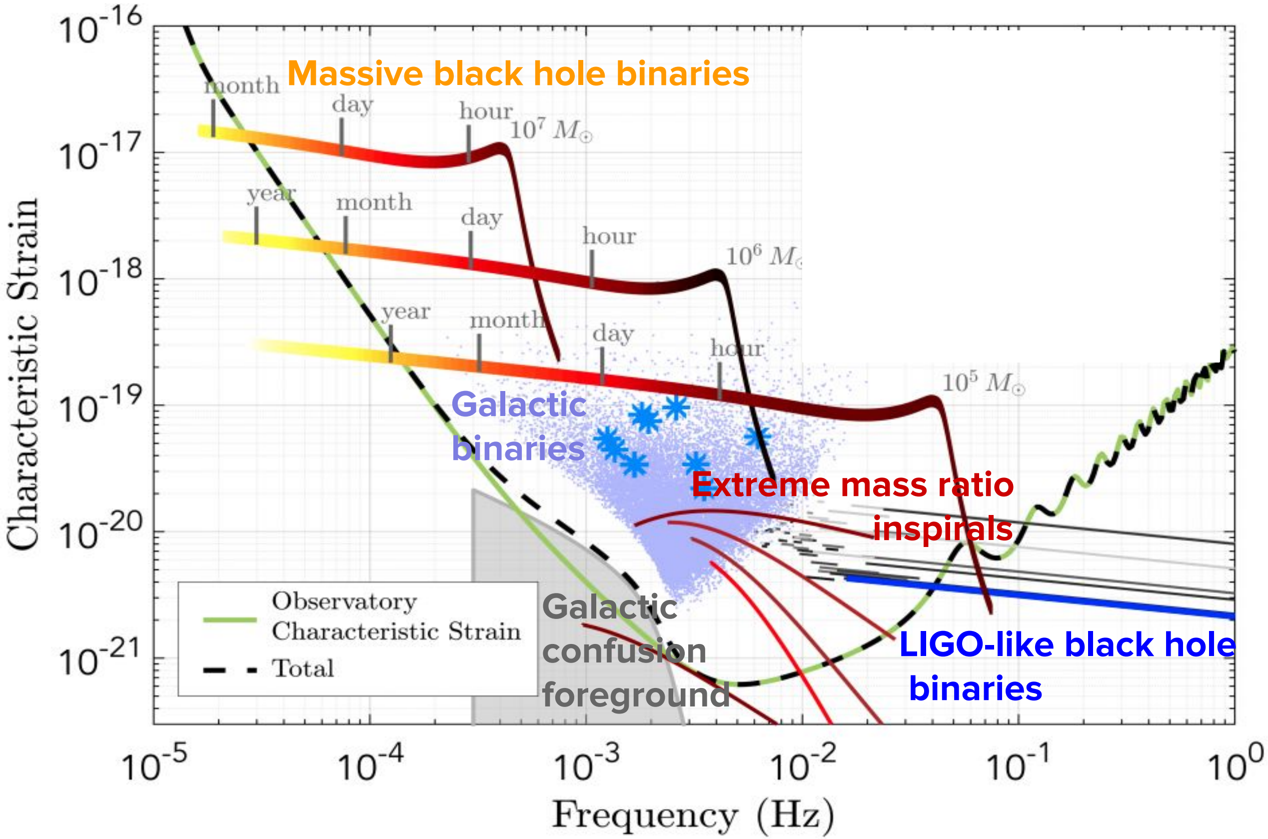


LISA mission proposal arXiv:1702.00786
LISA mission webpage sci.esa.int/lisa
LISA Consortium website elisascience.org



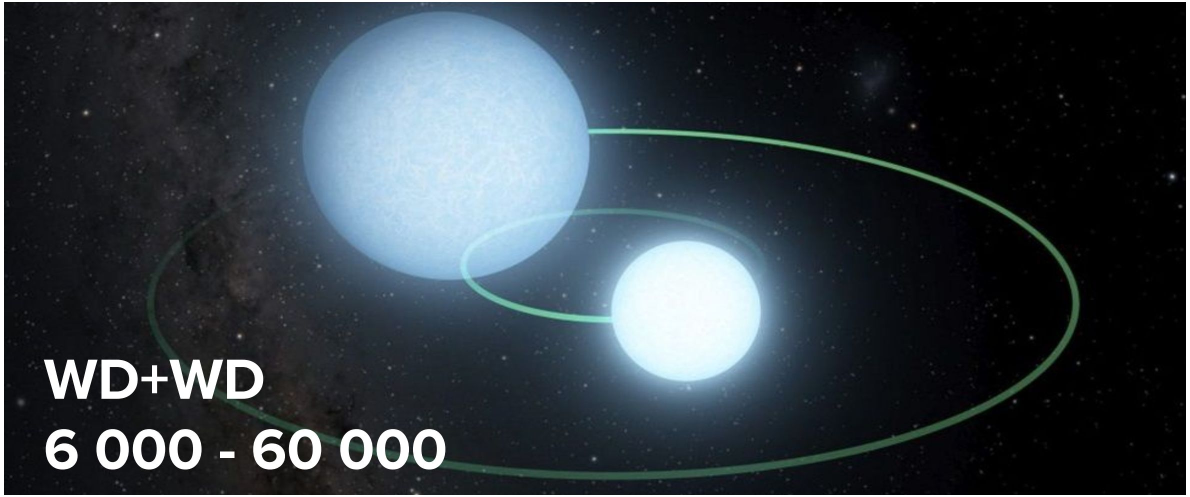
Colpi and Sesana (2016)

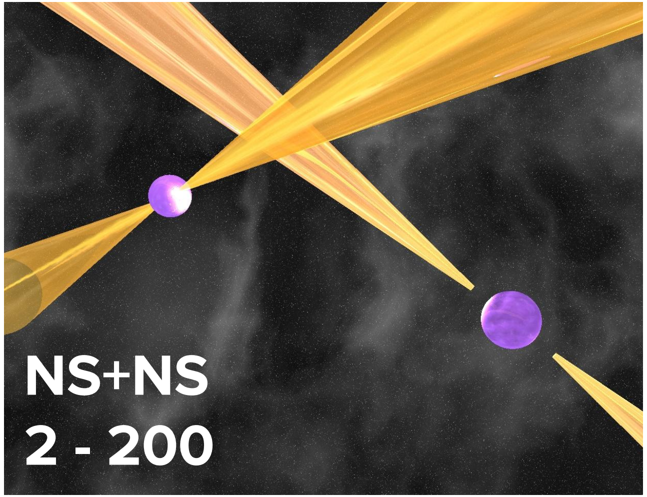
LISA sources

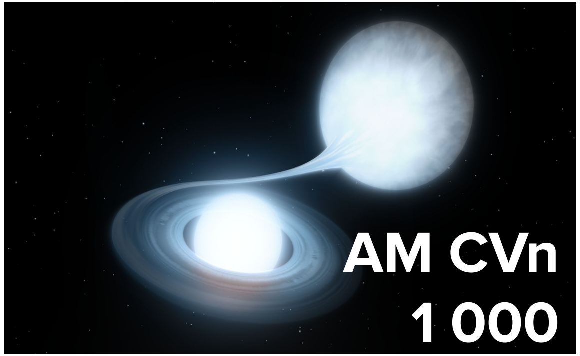


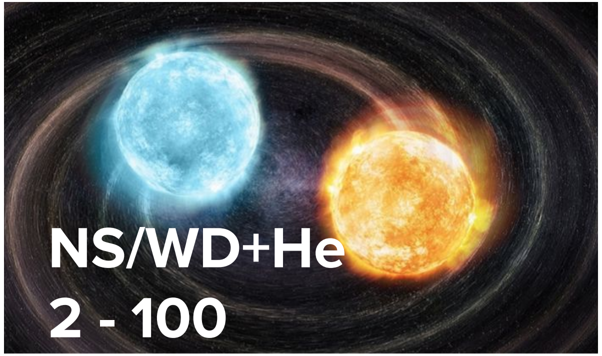
LISA mission proposal arXiv:1702.00786

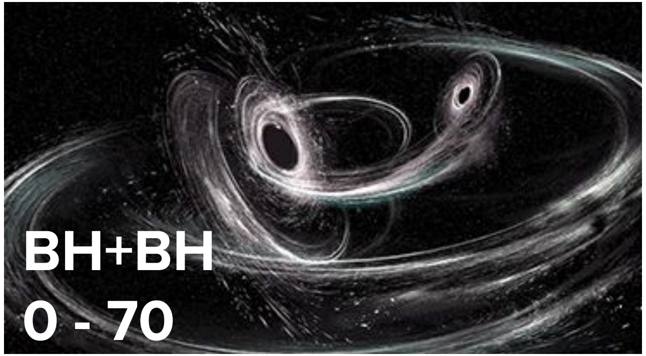
Zoo of Galactic GW sources

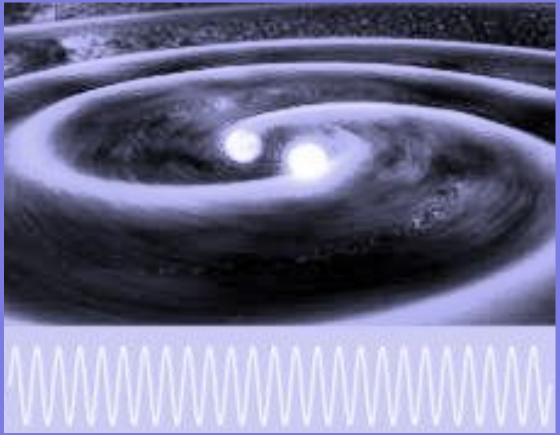






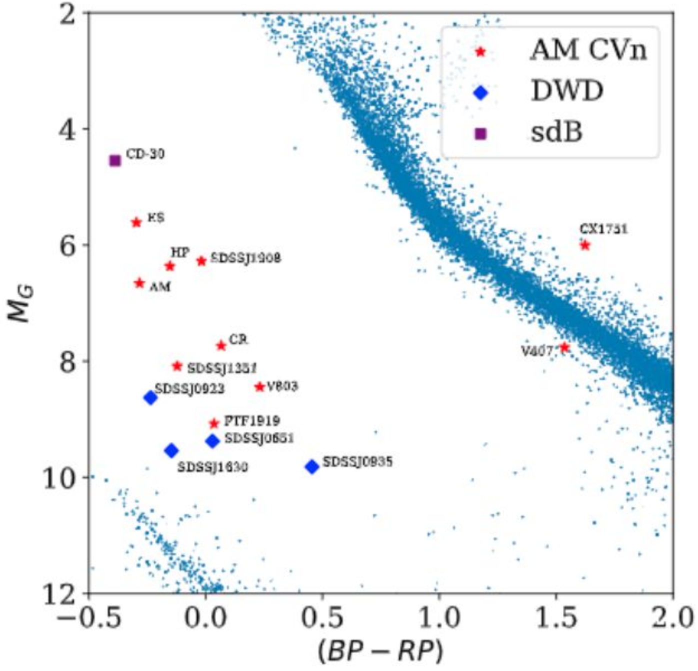




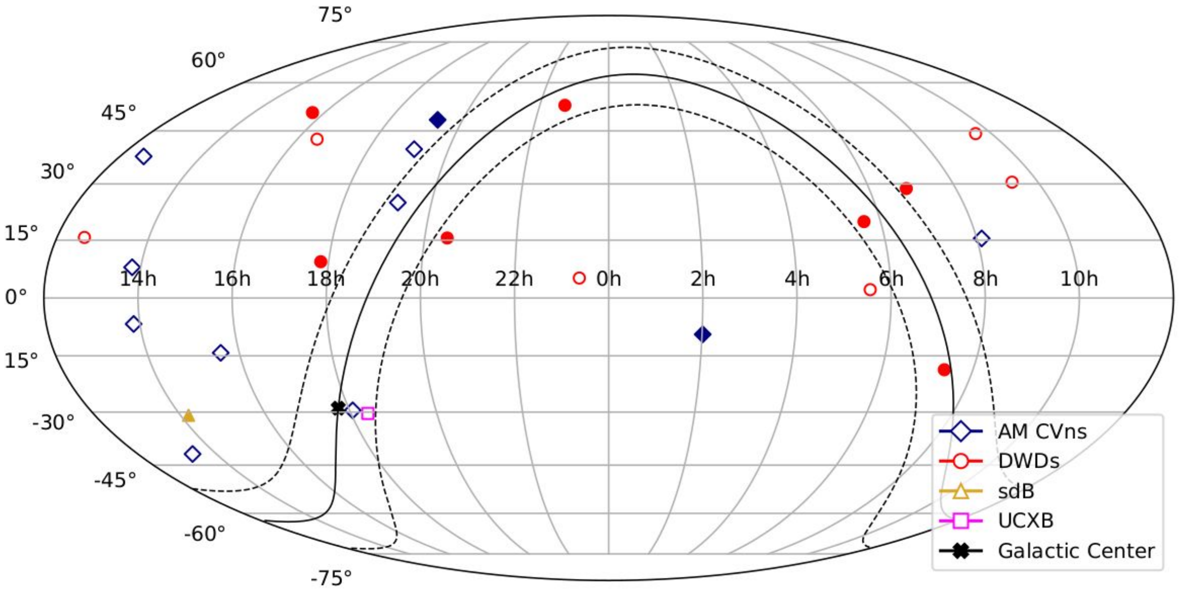


Let's focus on double white dwarfs (DWDs)

About 20 of known DWDs are detectable



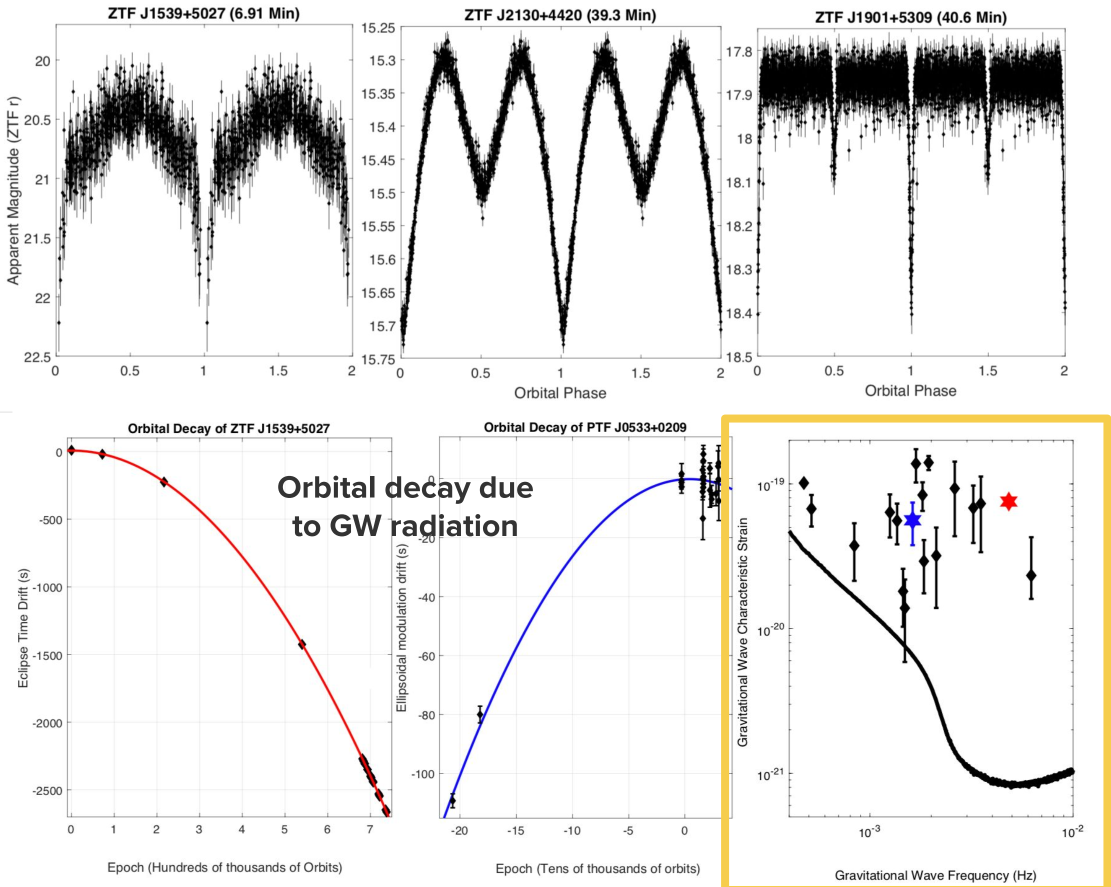
Kupfer, Korol et al. (2021), in prep.



Courtesy of Thomas Kupfer

See also: Kupfer, Korol et al. (2018), arXiv:1805.00482

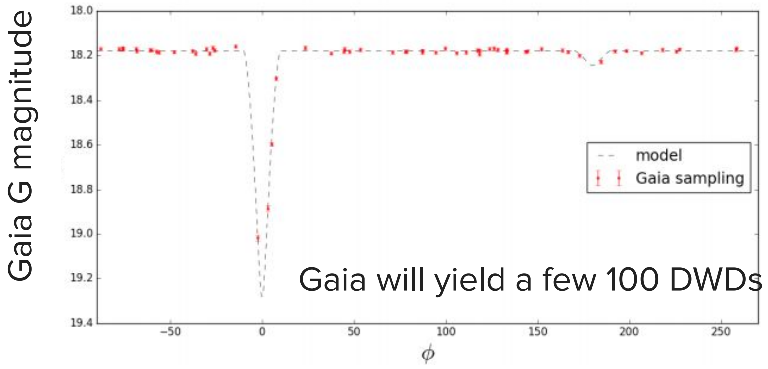
DWDs are guaranteed LISA sources



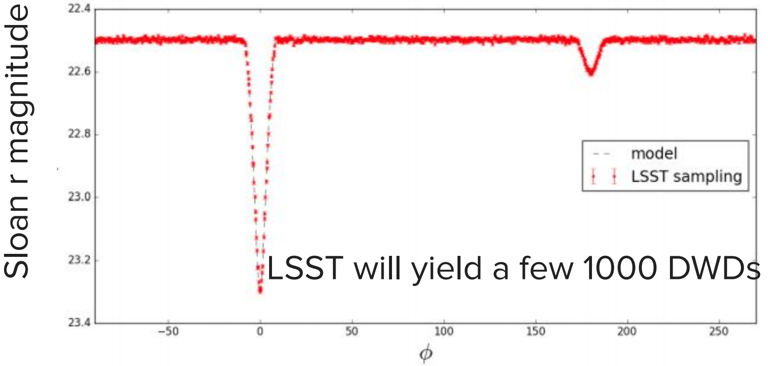
Orbital decay due to GW radiation

Burdge et al. 2019, 2020;
Kupfer et. al. 2020;
Coughlin et al. 2020;
Kupfer, Korol et al 2018

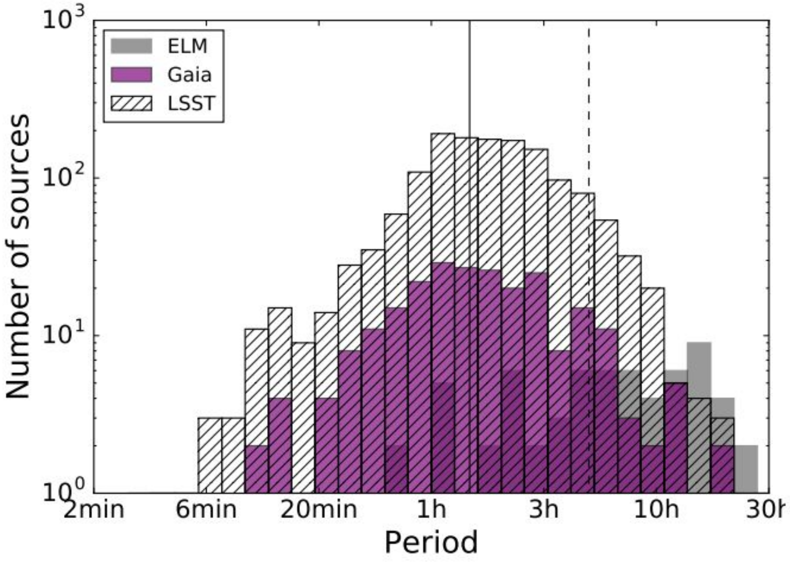
Prospects for detecting DWDs before LISA



Gaia will yield a few 100 DWDs



LSST will yield a few 1000 DWDs



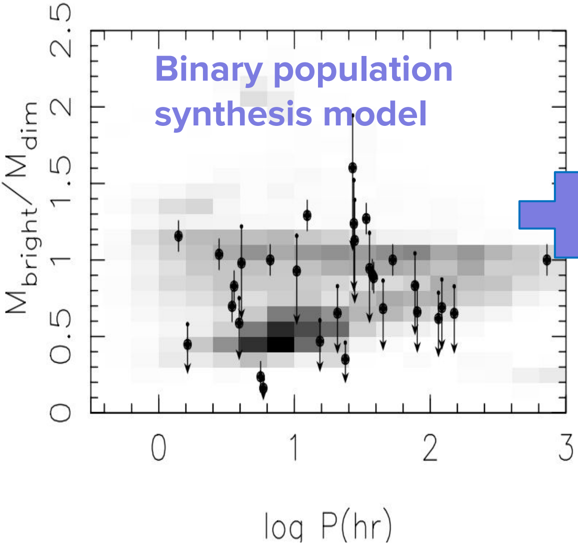
Korol et al. (2017), arXiv:1703.02555

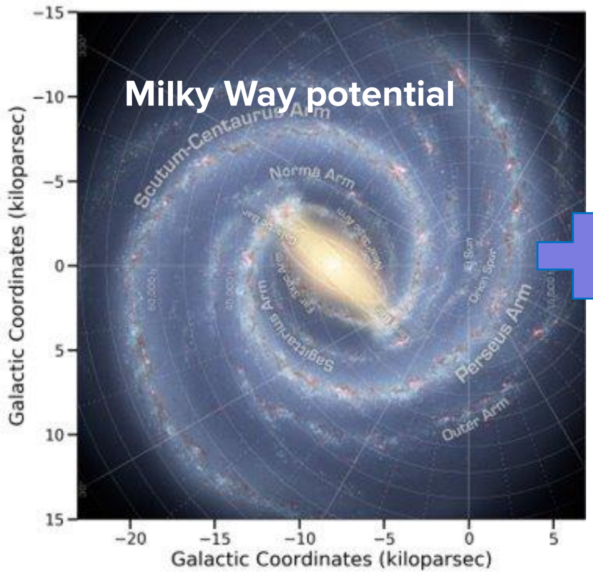
Note: that searches for DWDs in the long-baseline surveys have to account for orbital period change due to GW radiation (e.g. Burdge et al. 2019)

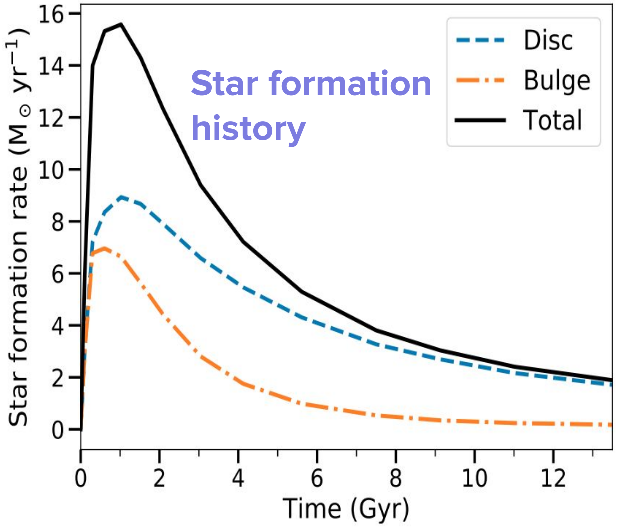
How many DWDs will LISA detect?

Synthetic population for LISA

Toonen et al. 2012







Boissier & Pranzos 1999

Synthetic LISA data

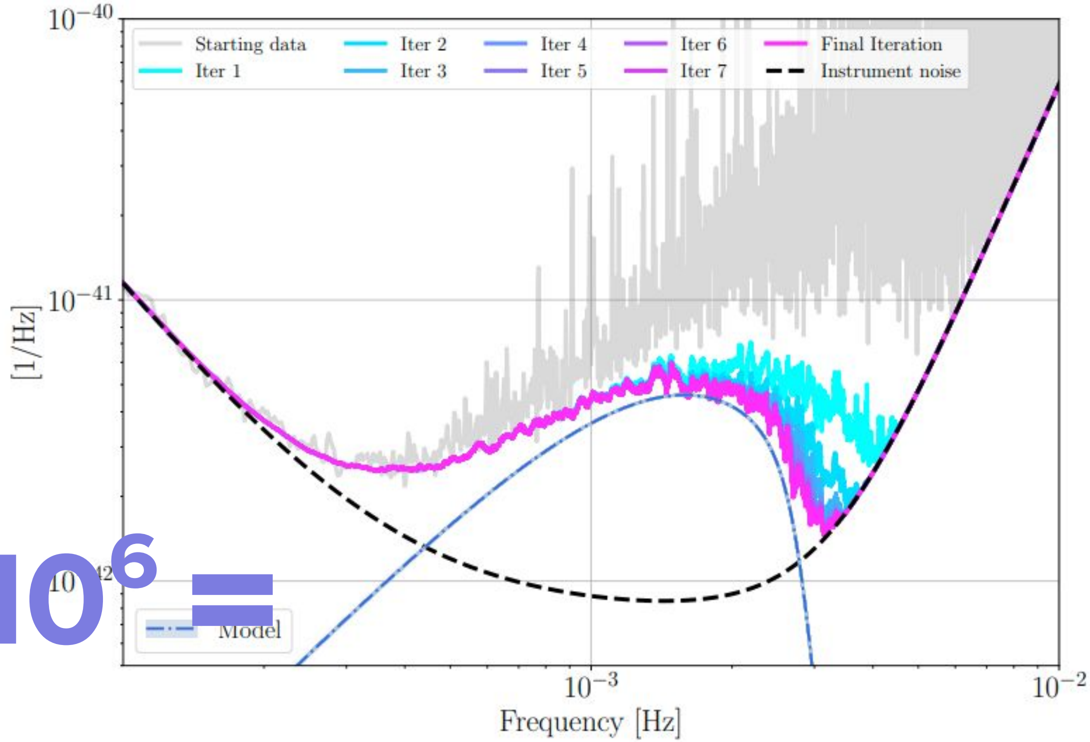
Gravitational radiation from the DWDs, to a good approximation, can be treated as a quasi-monochromatic signal with linear drifts in frequency

$$f_{\mathrm{GW}}(t) = f_0 + \dot{f}_0(t - t_0)$$

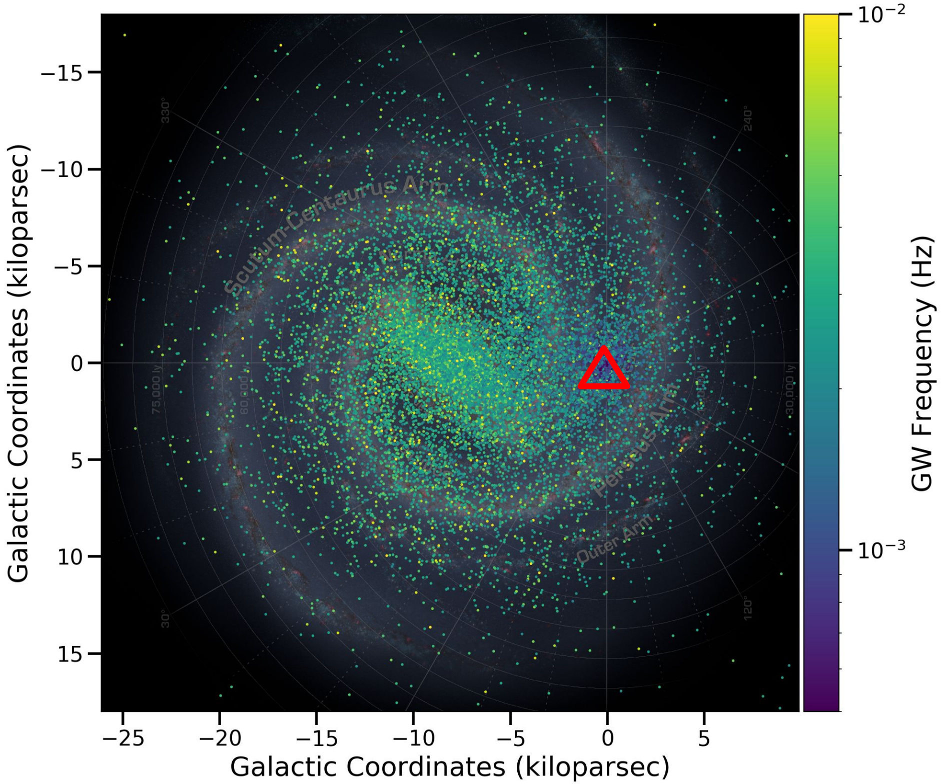
Each of the signals can be described by 8 parameters

$$\{\mathcal{A}, f_0, \dot{f}_0, \lambda, \beta, \iota, \psi, \phi_0\}$$

X 10^6 =



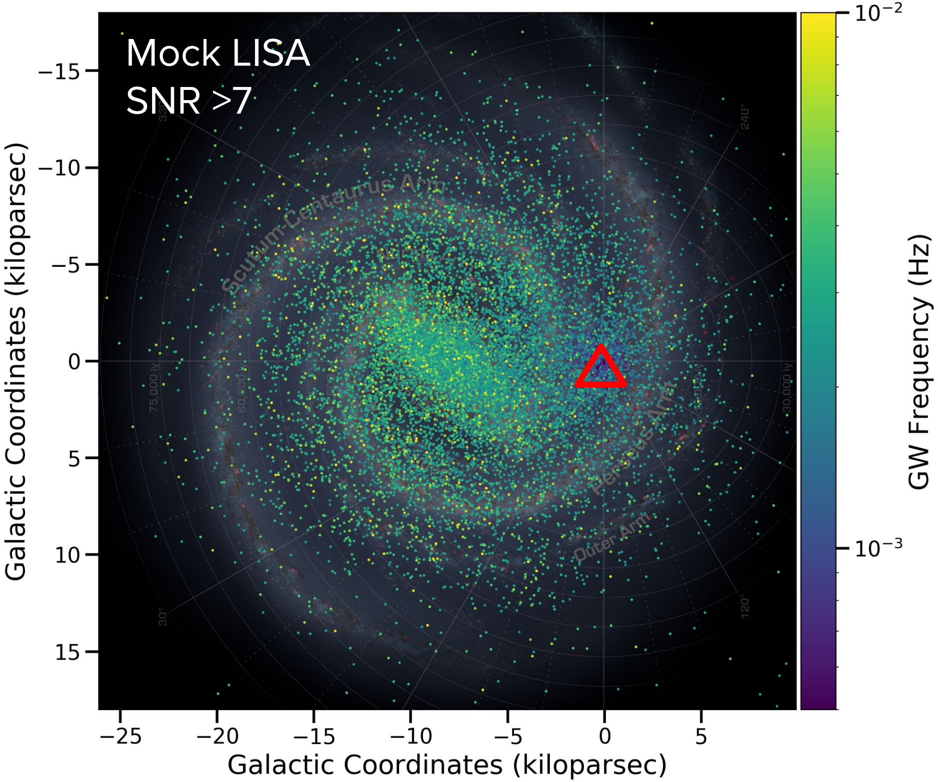
Karnesis et al. (2021)

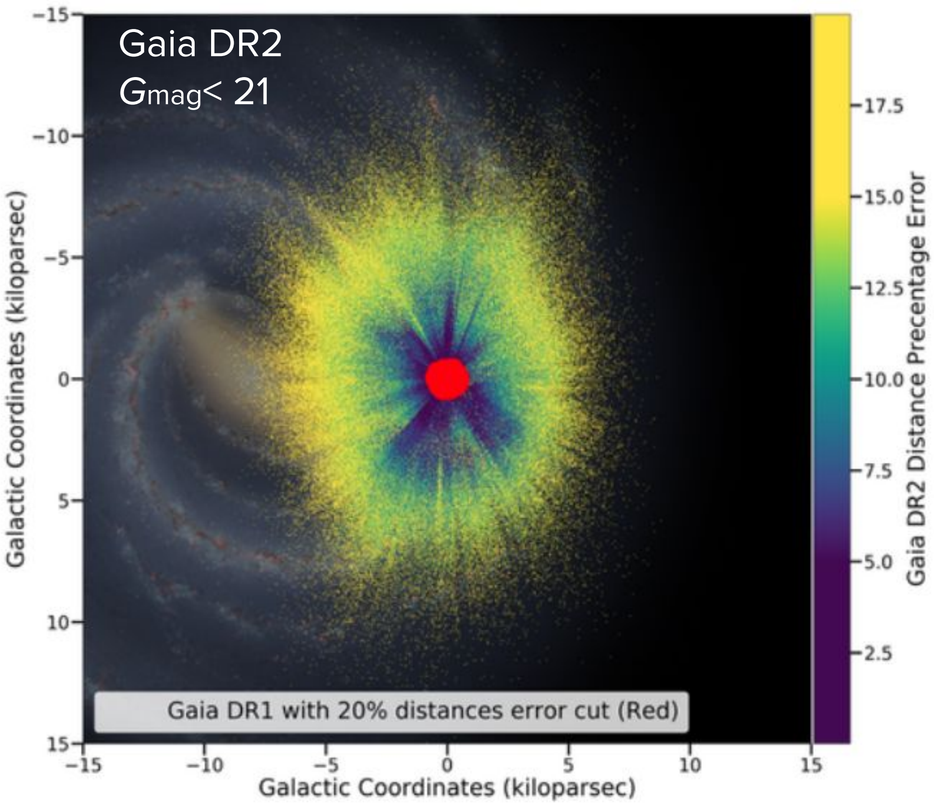


Wilhelm, Korol et al. 2020

The result !

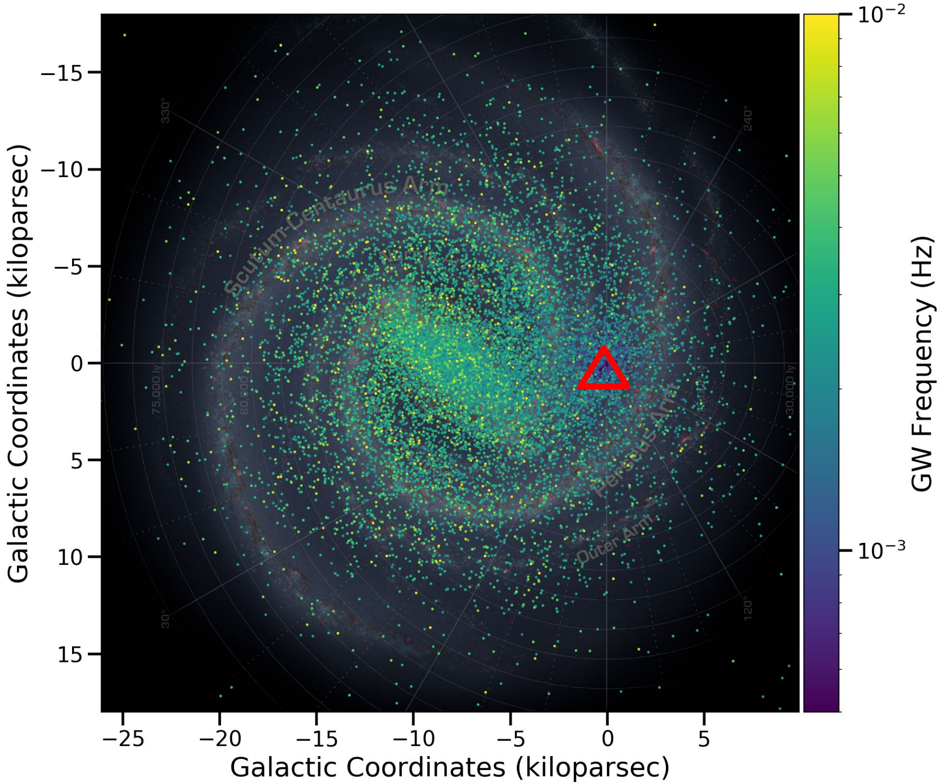
LISA vs EM Galactic surveys





Wilhelm, Korol et al. 2020

https://pypi.org/project/mw-plot/



Wilhelm, Korol et al. 2020

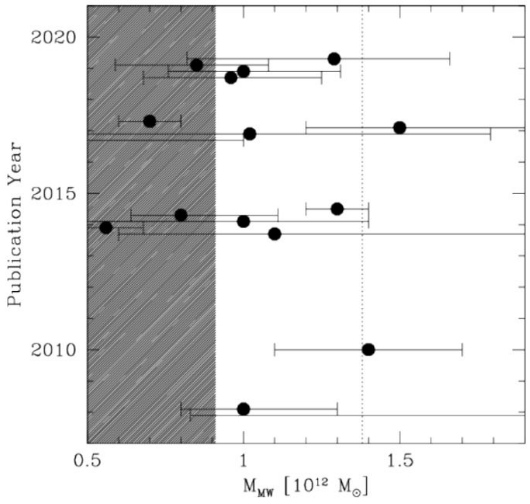
DWDs detected by LISA can be exploited as Galactic tracers

- **Trace stellar density**
- **Numerous and widespread:** 10 – 60 thousand are detectable
- **Detectability in the Galaxy:** everywhere
- **Measurement of the distance:** directly from the LISA signal for a few - several thousands
- **Contamination:** none

What we will learn from GW+EM data?

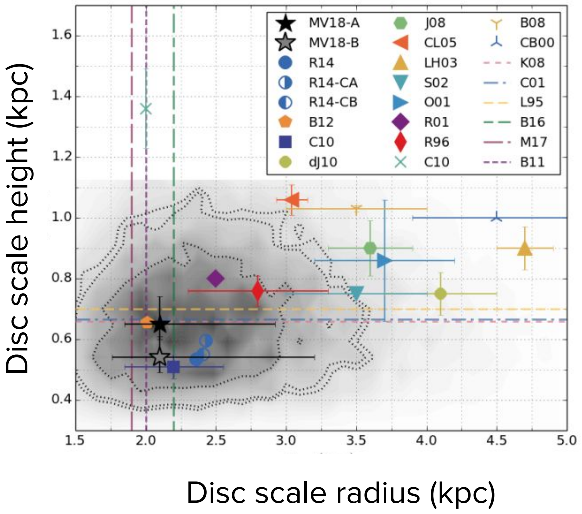
The Milky Way is a unique laboratory to test galaxy formation theories and ΛCDM: current constraints are still poor

Milky Way's total mass



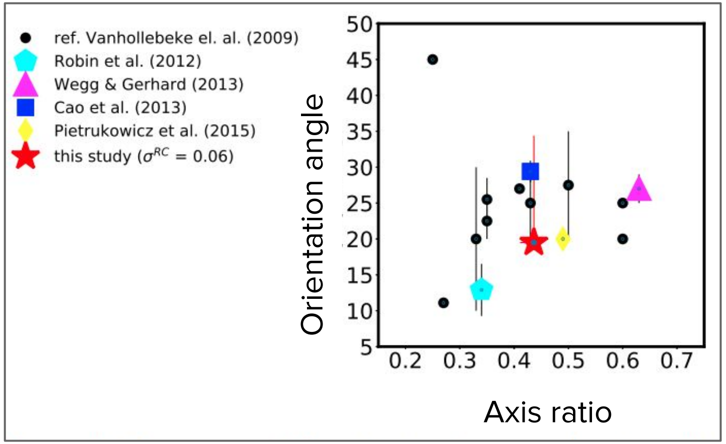
Zaritsky et al. 2019

Disc scale parameters



Mateu & Vivas 2018

Bar's geometry



Simion et al. 2017

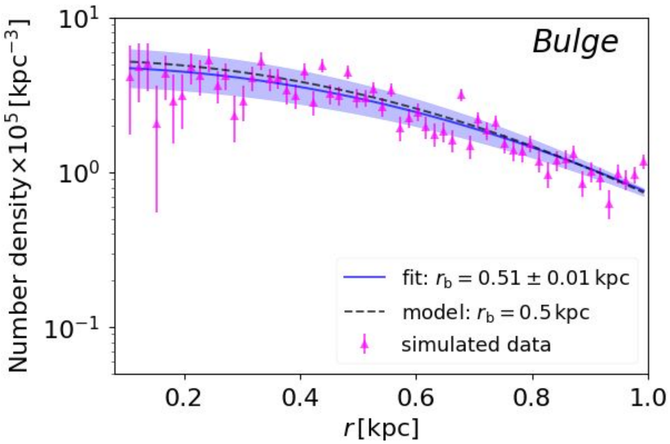
The shape of the Milky Way's components

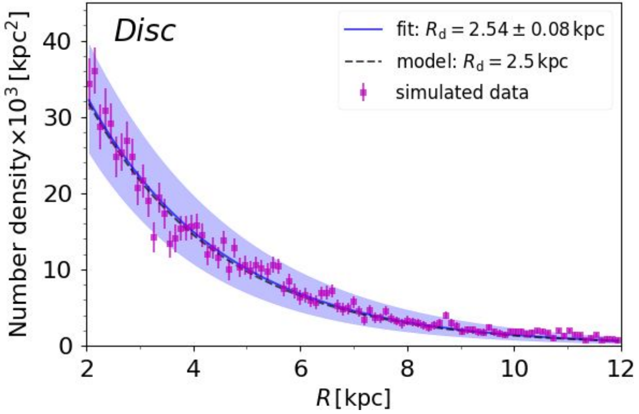
The spatial distribution of DWDs with measured distances (several thousand) constrains:

- Bulge scale radius to 2%
- Disc scale radius to 3%
- Disc scale height to 16%

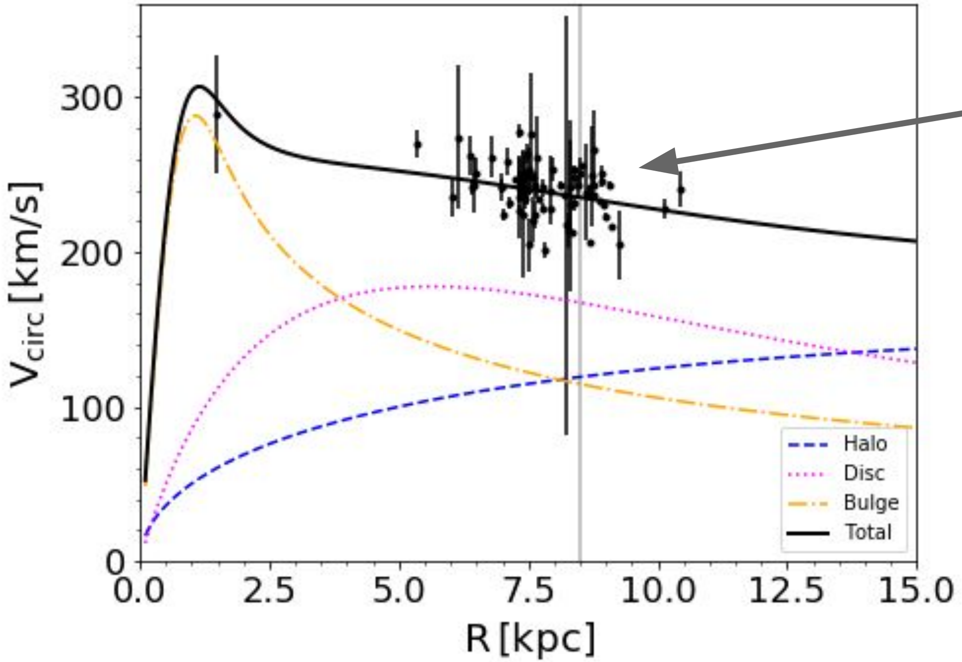
Korol, Rossi & Barausse 2019

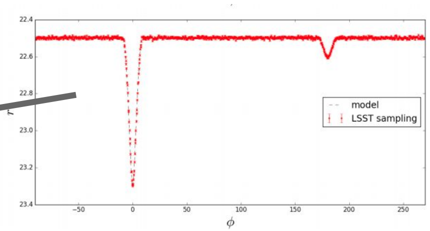
See also Adams et al. 2012; and Benaquista & Holley-Bockelmann 2006, Breivik et al. 2020 for constraints on the disc scale height from galactic foreground





Combining GW and EM data into rotation curve





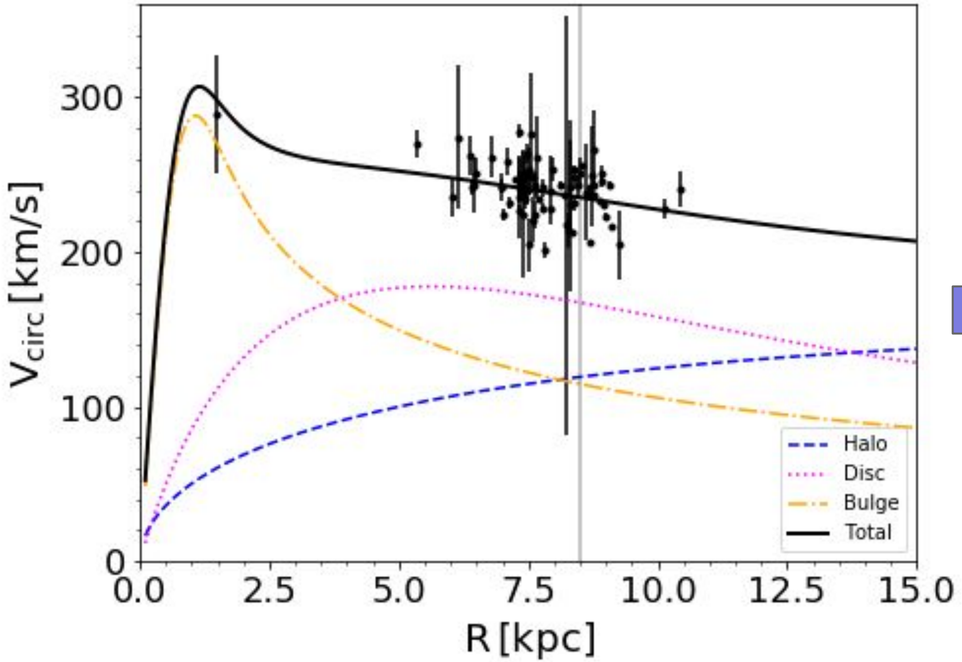
EM proper motions

GWs distances +EM parallaxes

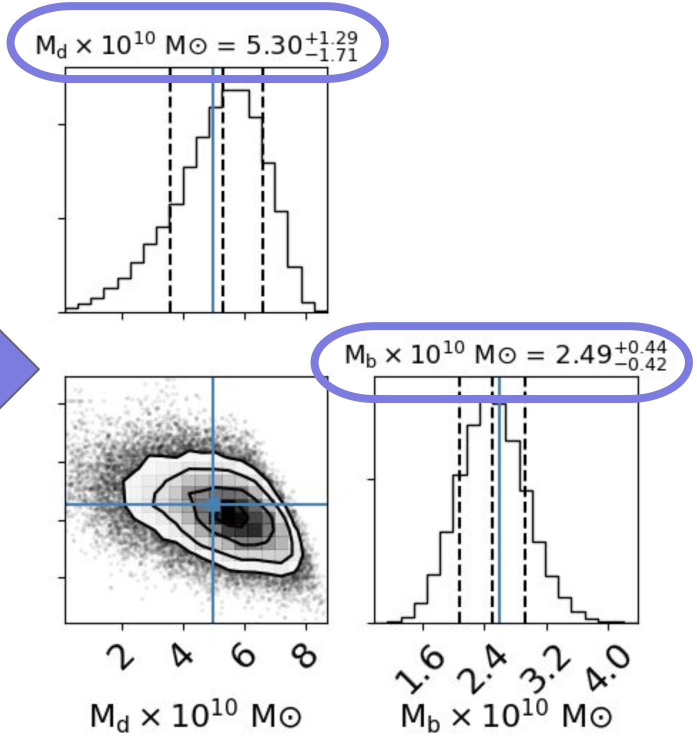
Korol, Rossi & Barausse 2019

Combining GW and EM data into rotation curve

EM proper motions



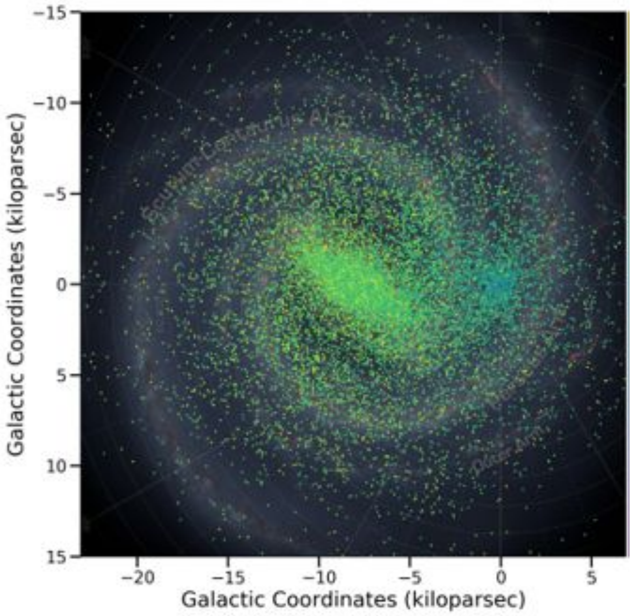
GWs distances +EM parallaxes



Korol, Rossi & Barausse 2019

Structural parameters of the central bar

Fourier transformation of the DWDs spatial distribution can reveals shape of the bar.



(Wilhelm, Korol et al. 2020)

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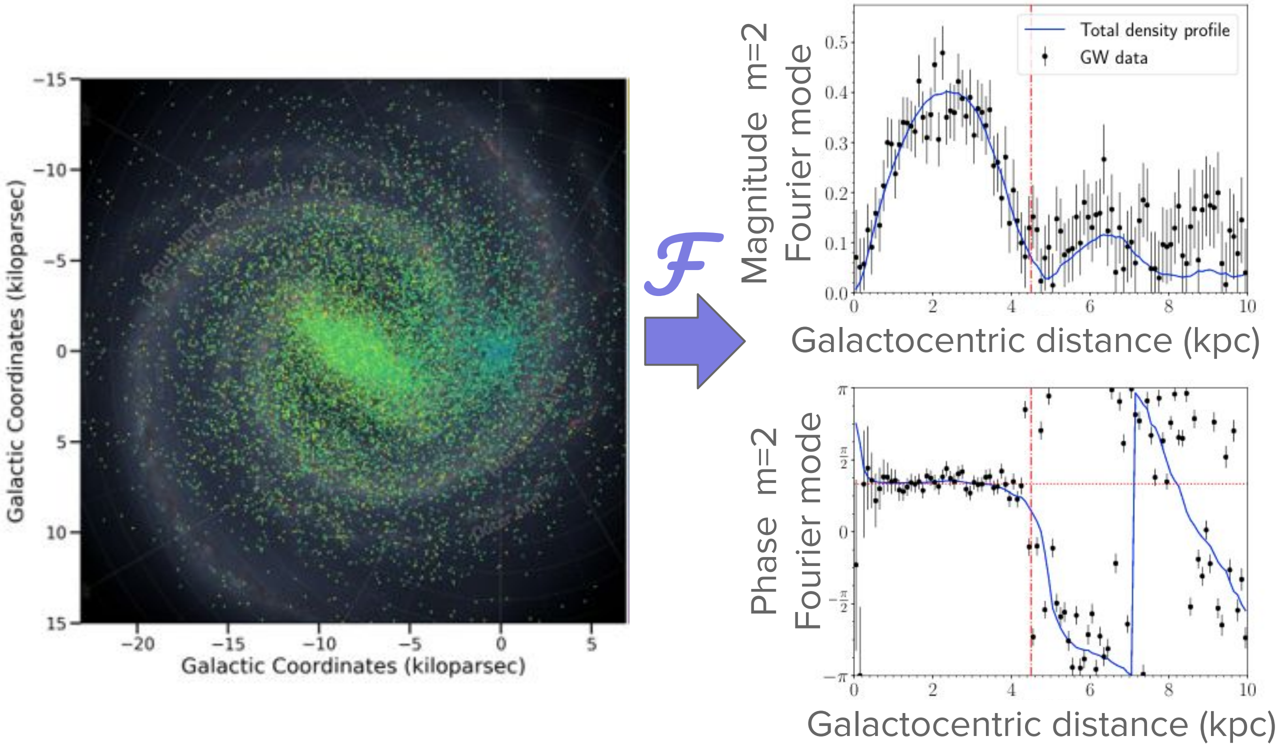

(Wilhelm, Korol et al. 2020)

Structural parameters of the central bar

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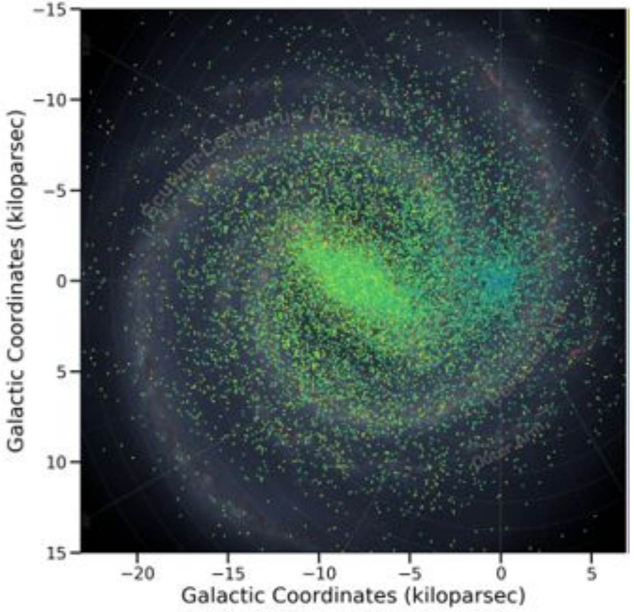
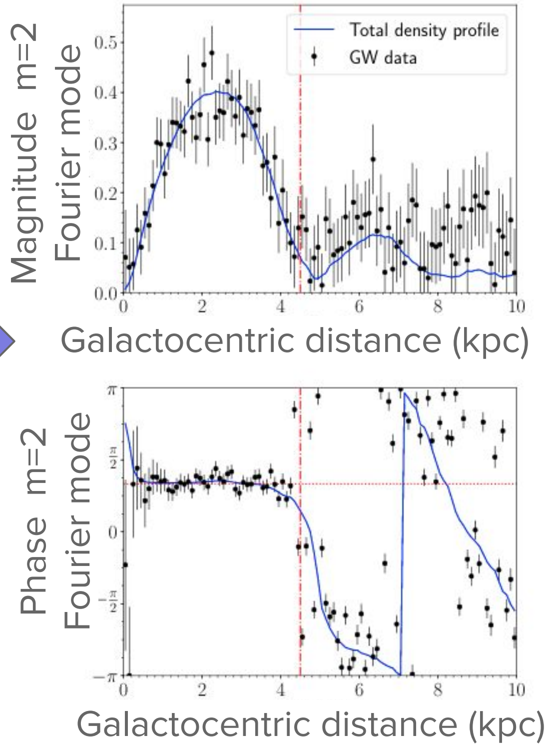


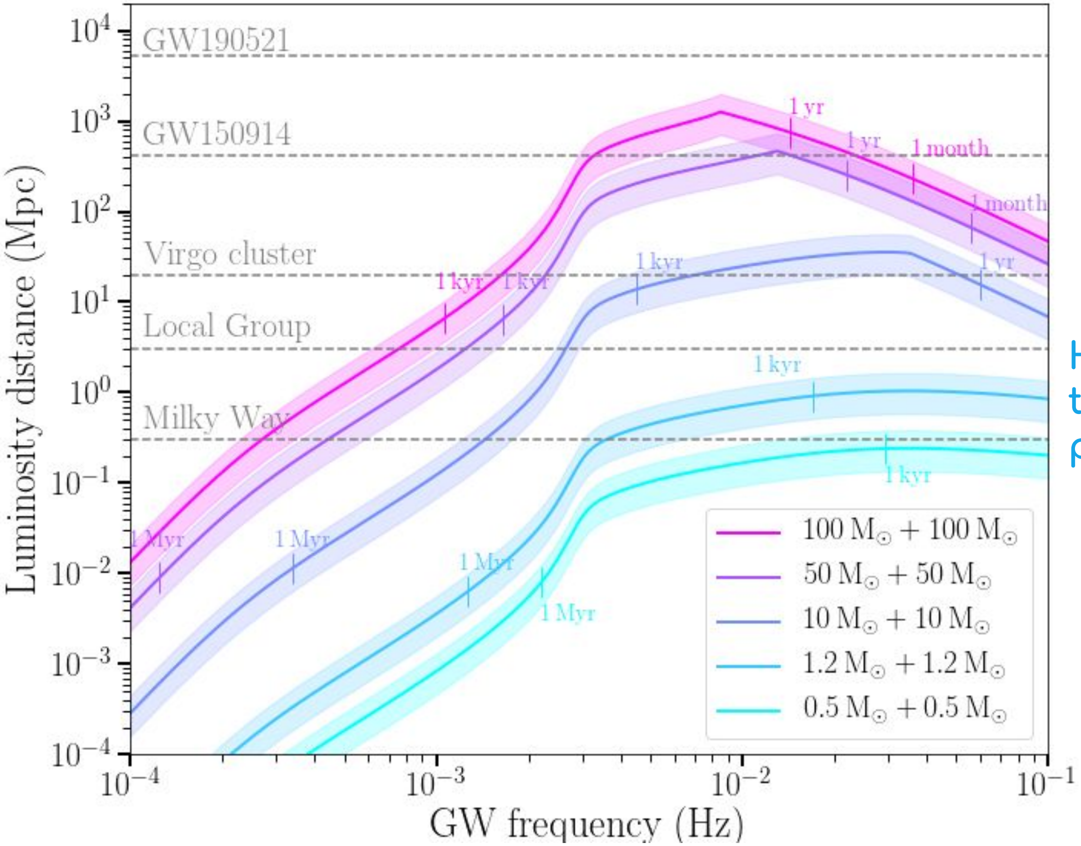


Specifically, It will constrain:

- axis ratio to 10%
- length to 1%
- orientation angle to 1°

(Wilhelm, Korol et al. 2020)

Observable horizons

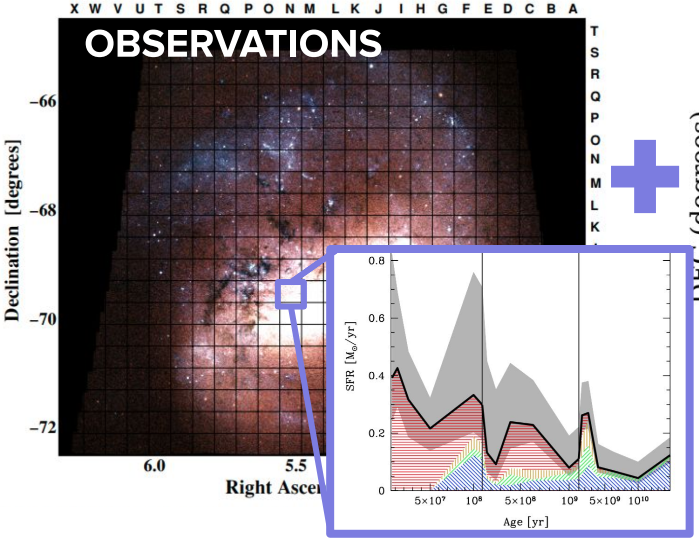


Horizon for type Ia SN progenitors

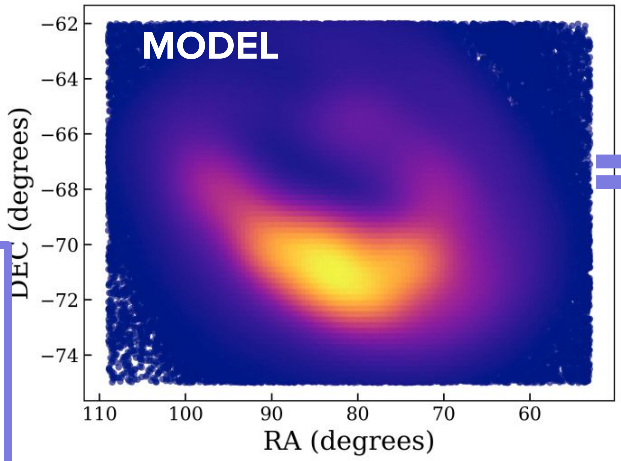
LISA Astrophysics white paper, soon on Living Reviews of Relativity

DWDs in the Large Magellanic Cloud

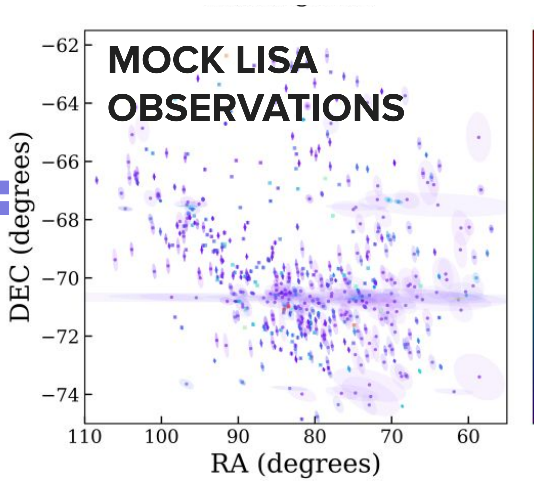
Detailed model combining a spatially resolved star formation history and a state-of-the-art numerical simulation of the LMC predicts a few hundred resolved DWDs!



Harris & Zaritsky 2009



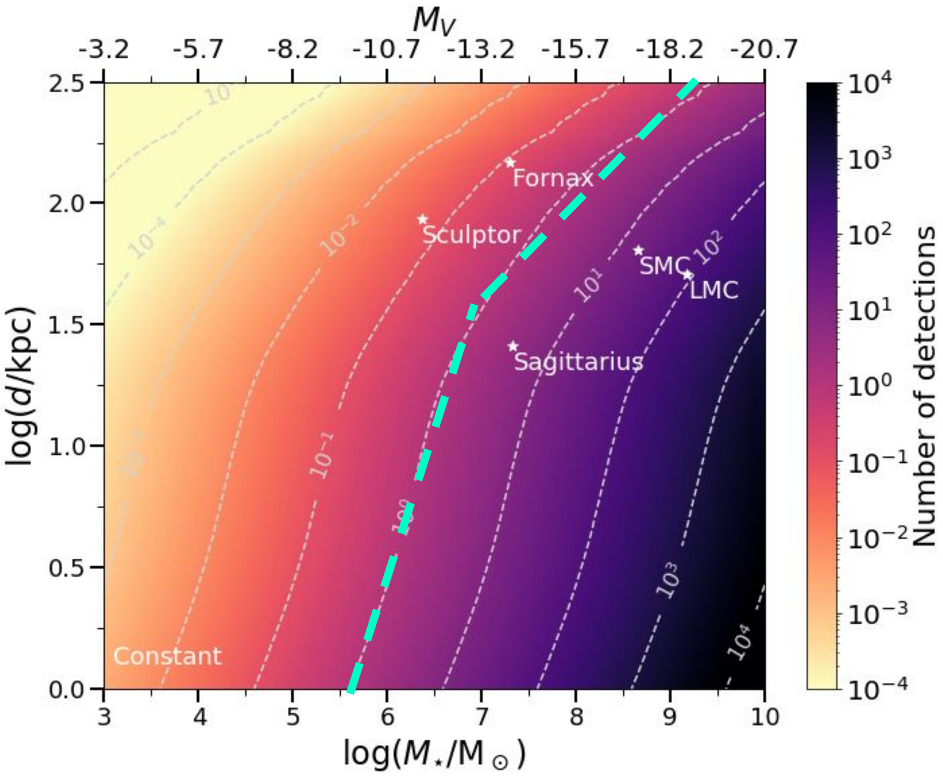
Lucchini et al. 2019



Keim, Korol et al. in prep.

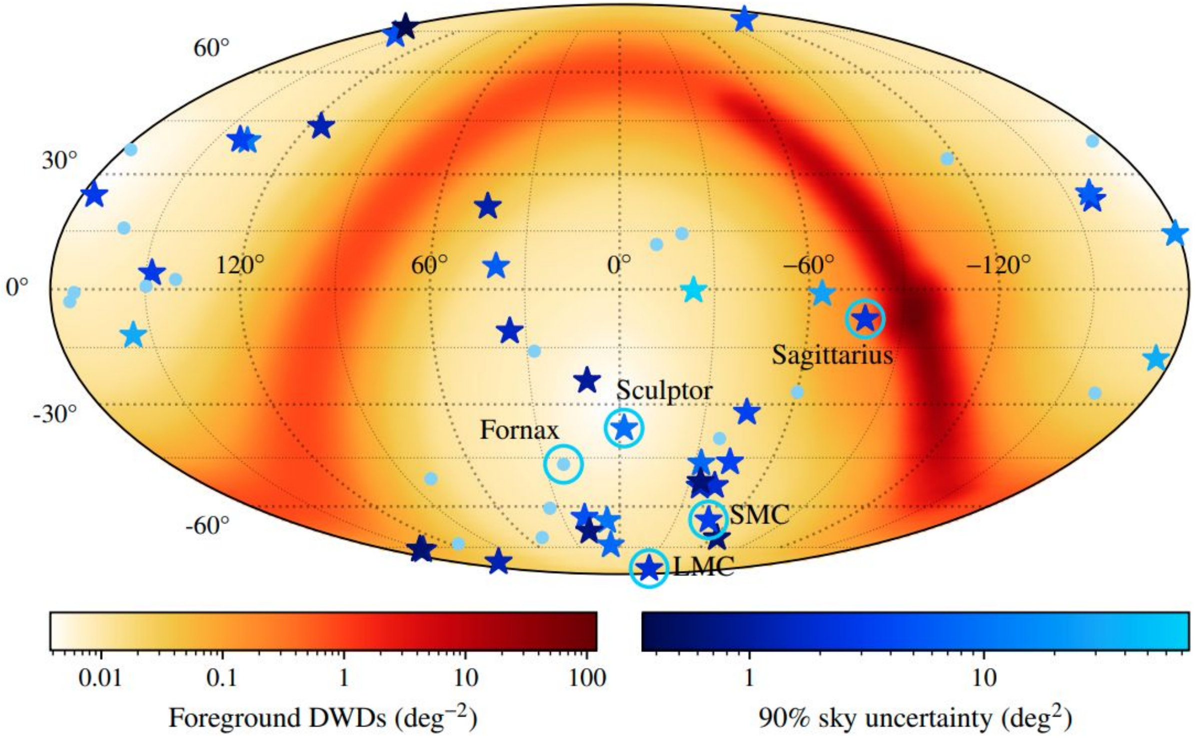
Discovering Milky Way satellites in gravitational waves

- Satellites with stellar mass > 10^6 M☉ host detectable LISA sources
- LISA detections can inform us about the total stellar mass and star formation history of the satellites
- Discovery of satellites invisible to electromagnetic observatories



Korol et al. 2020; Roebber et al. (incl.Korol) 2020
See also Lamberts et al. 2019

Discovering Milky Way satellites in gravitational waves

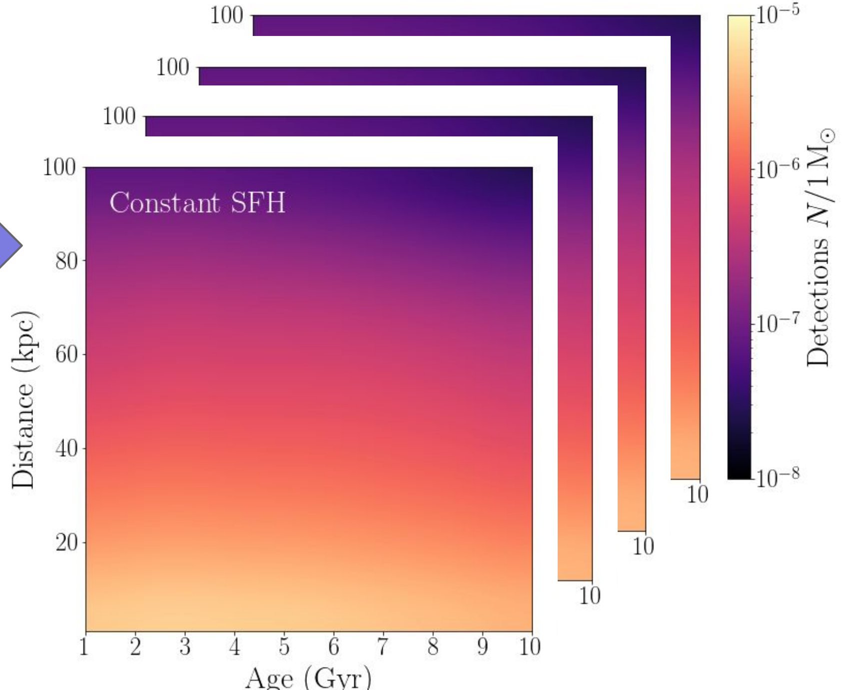


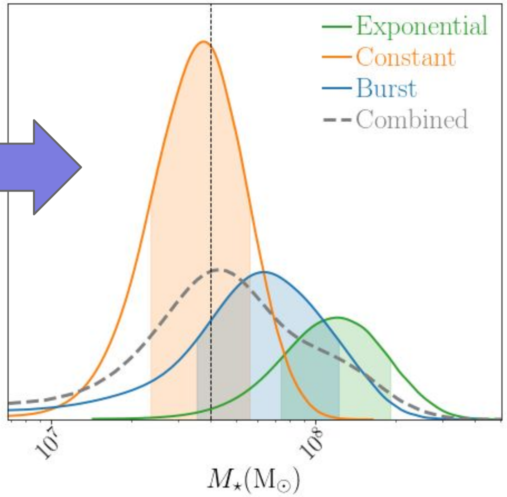
Roebber et al. (incl.Korol) 2020

Weighing Milky Way satellites

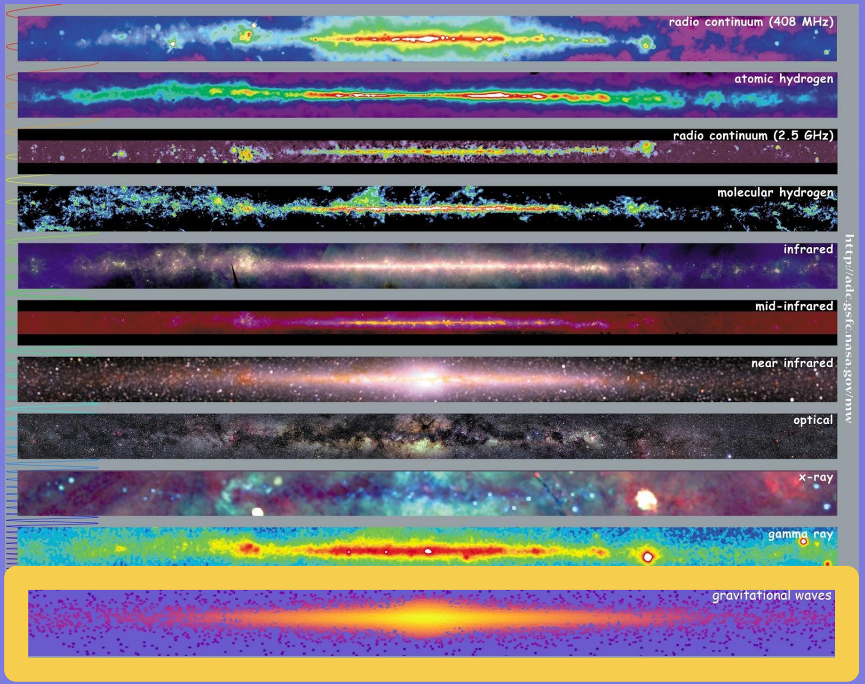
By exploiting our models we can recover the satellite's total stellar mass: to within a factor two if SFH is known and to an order of magnitude when marginalising over different SFH models. If no detections are identified with the satellite we can still place an upper limit on its stellar mass.

Number $N \pm \sqrt{N}$
Distance $D \pm \Delta D$





Korol et al. 2021



LISA is an all-sky Galactic GW survey that will deliver a number of guaranteed results

Conclusions

1. LISA is an all-sky survey that does not suffer from contamination and dust extinction, and can map the entire Milky Way and its neighbourhood.

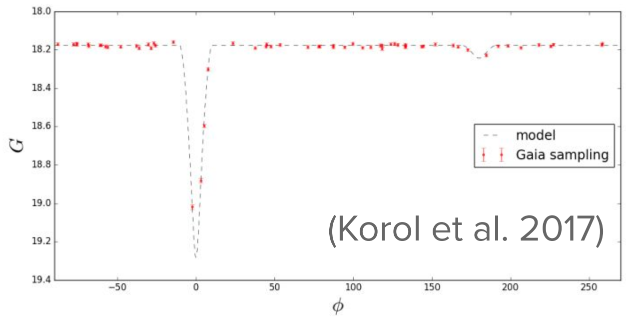
2. The density distribution of LISA detections can be used to constrain scale parameters of the Milky Way’s bulge, bar and disc.

3. LISA can detect known Milky Way satellites and potentially discover new ones through populations invisible to electromagnetic observatories.

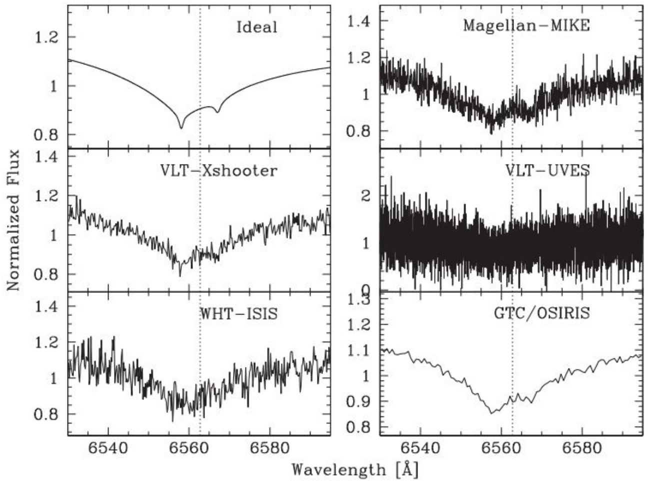
4. We can weigh Milky Way satellites using LISA detections.

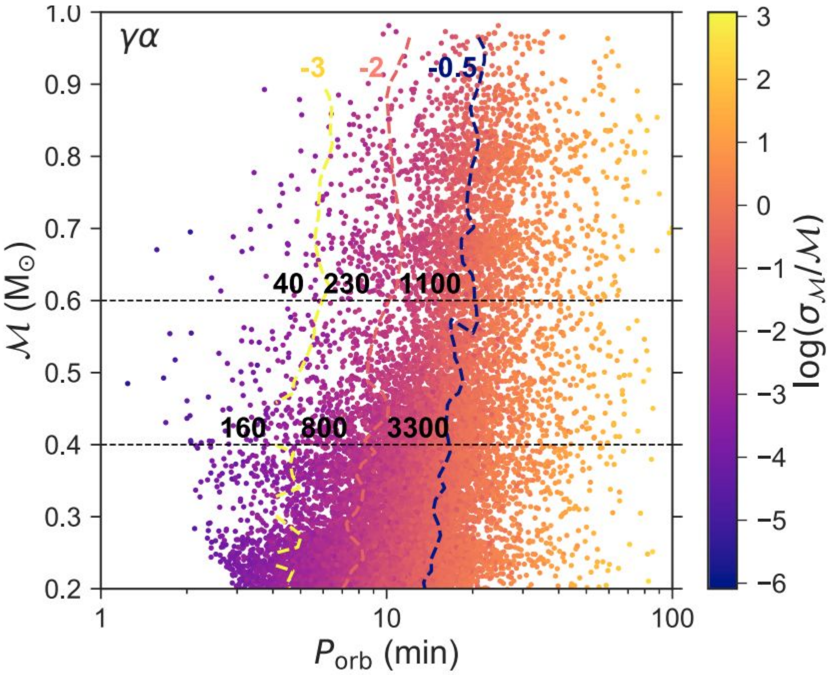
Backup slides

Why we don't see double degenerate SN Ia progenitors?



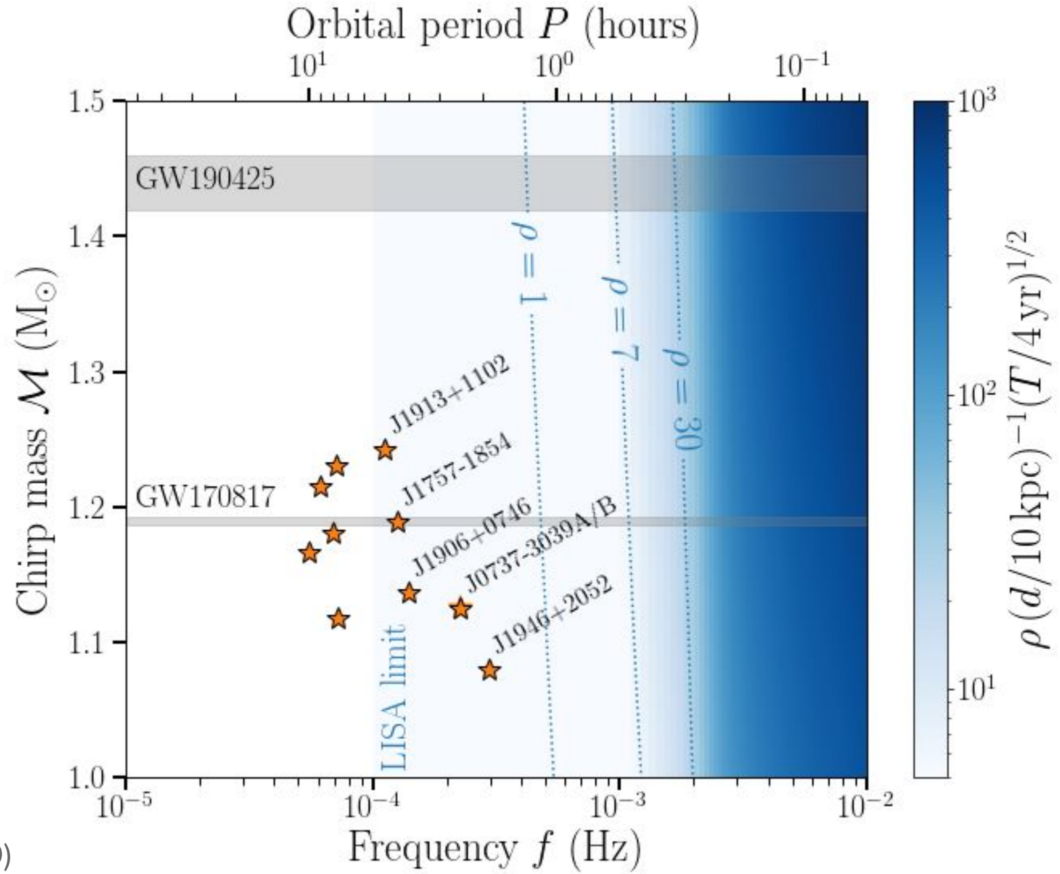
(Korol et al. 2017)





(Rebassa-Mansergas, Toonen, Korol et al. 2018)

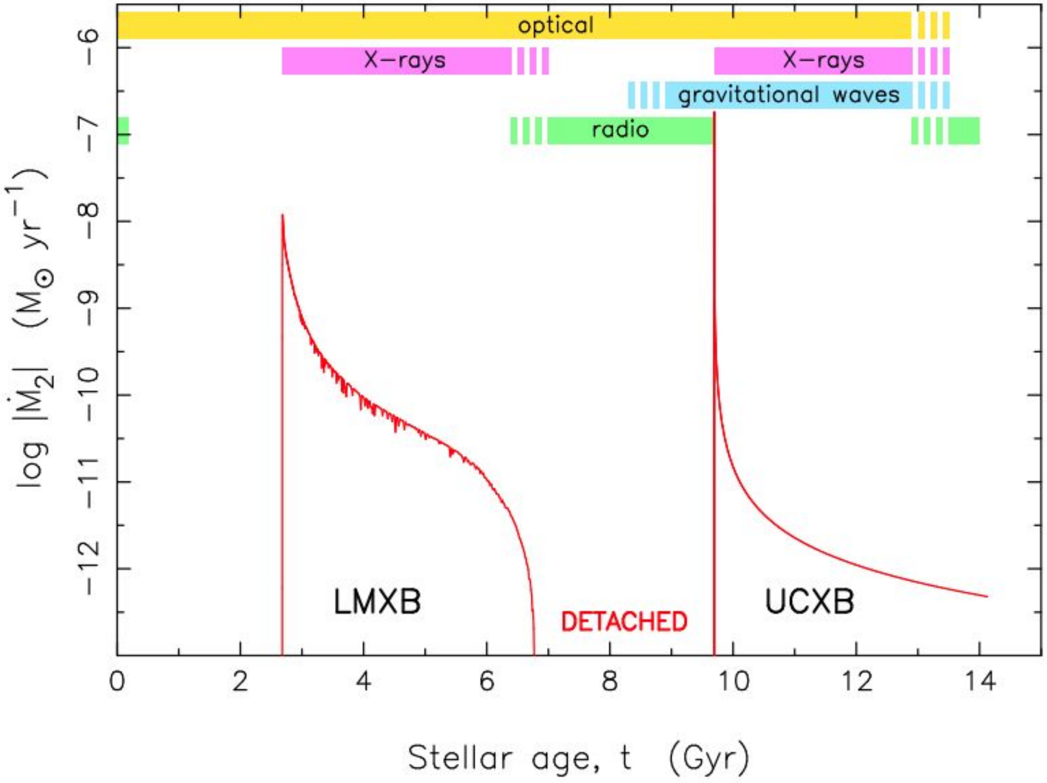
Currently known DNS binaries



Korol & Safarzadeh (2020)

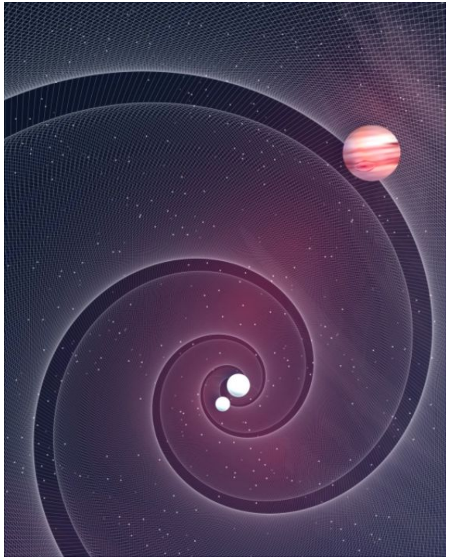
Science investigations highlights

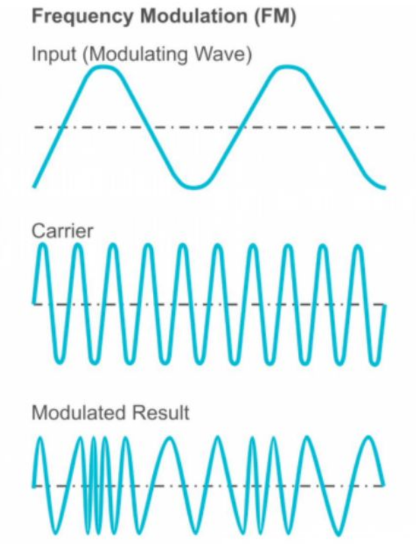
Multi-messenger synergies

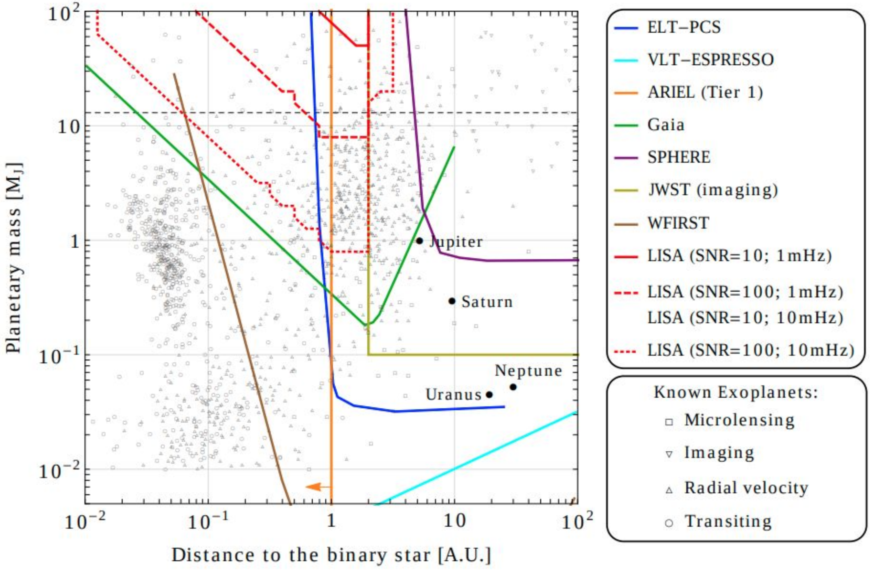


Tauris (2018)

Detecting a new population of exoplanets orbiting DWDs



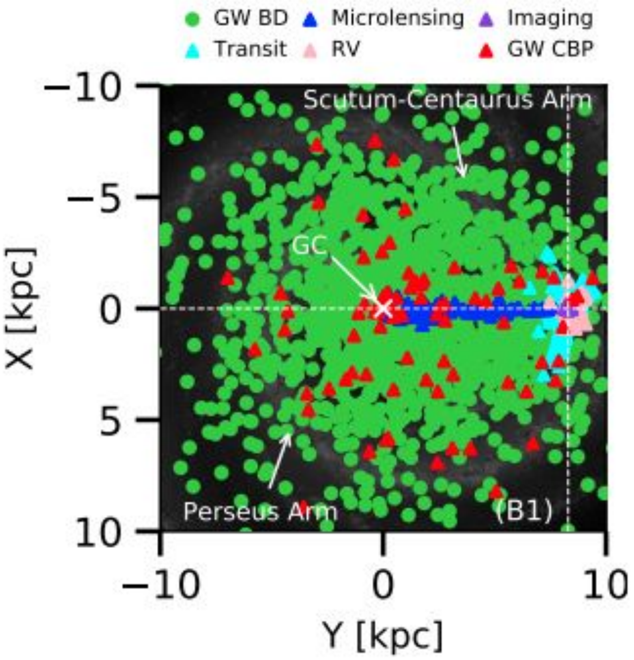




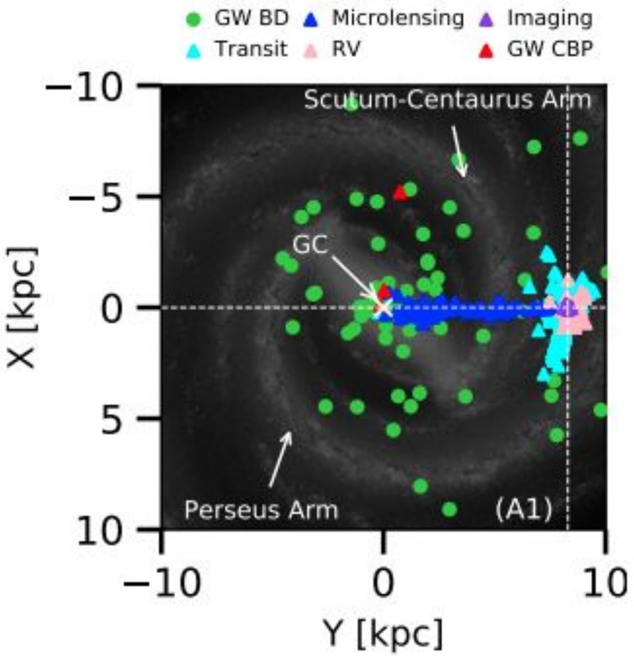
Tamanini & Danielski 2018
See also Danielski, Korol et al. 2019

Detecting a new population of exoplanets orbiting DWDs

Optimistic scenario



Pessimistic scenario



Danielski, Korol et al. 2019