# Torwards be-messenger Galactic Archeology with Gravitational Waves

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# credits to my (ex) students

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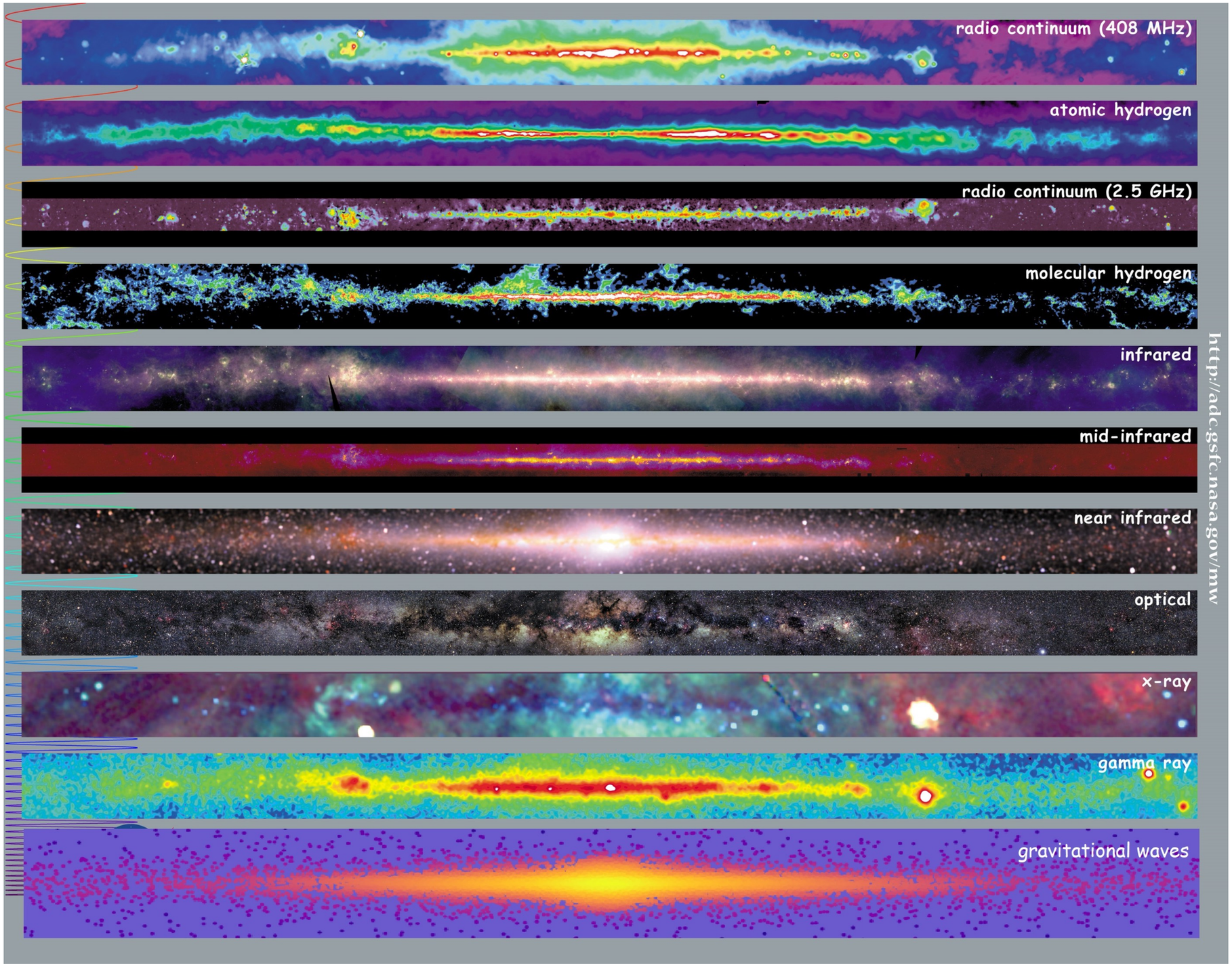
MPA fellow

Orlin Koop
PhD Groningen

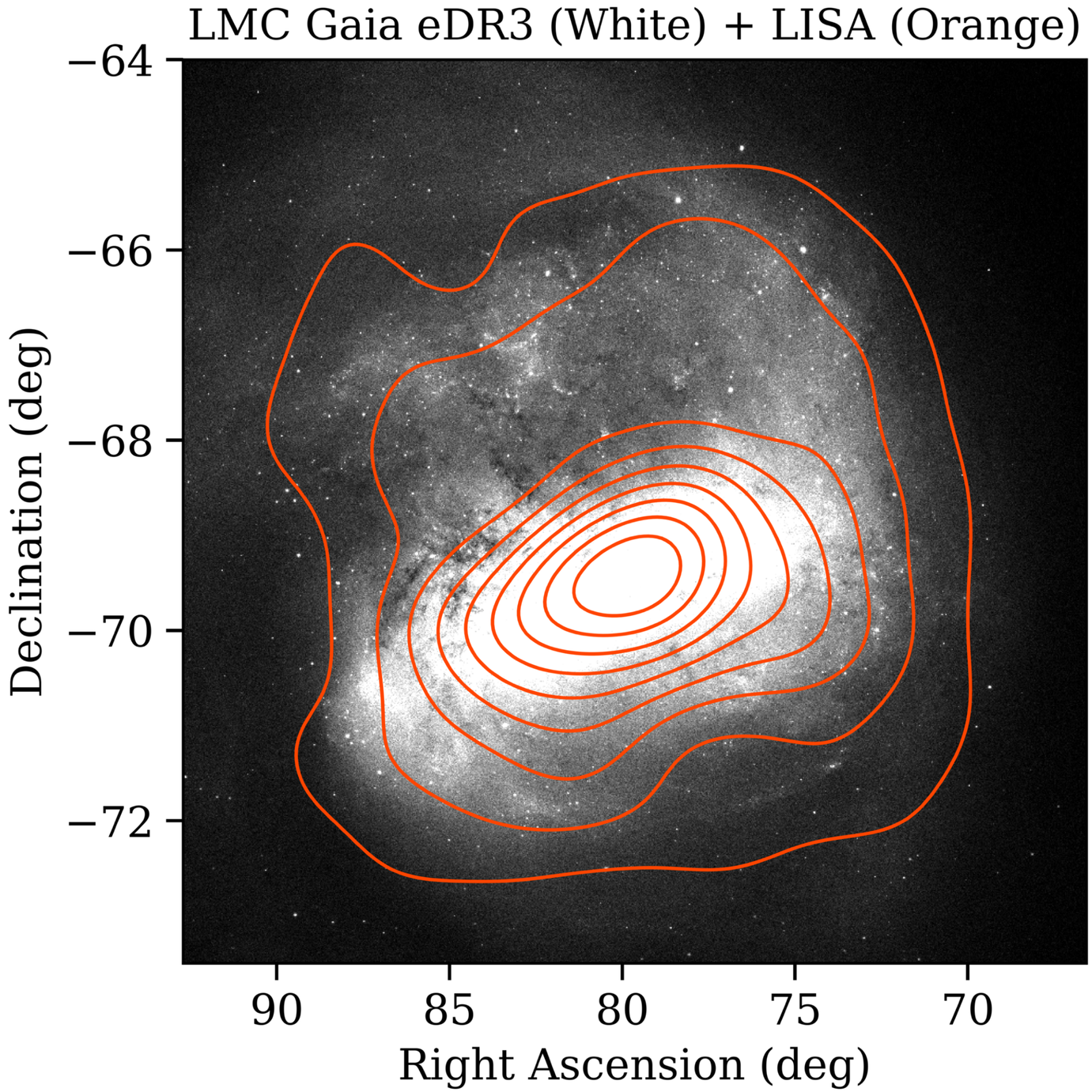
Martijn Wilhelm,
PhD Leiden

Michael Keim
PhD Yale

# What can gravitational waves uniquely bring to this field?



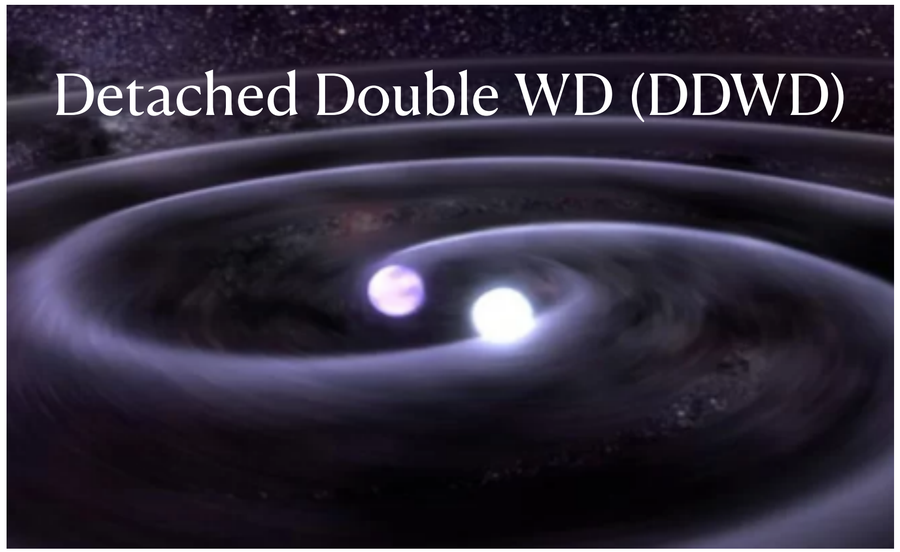

Korol, Rossi & Barausse 2019




Rossi et al. in prep.

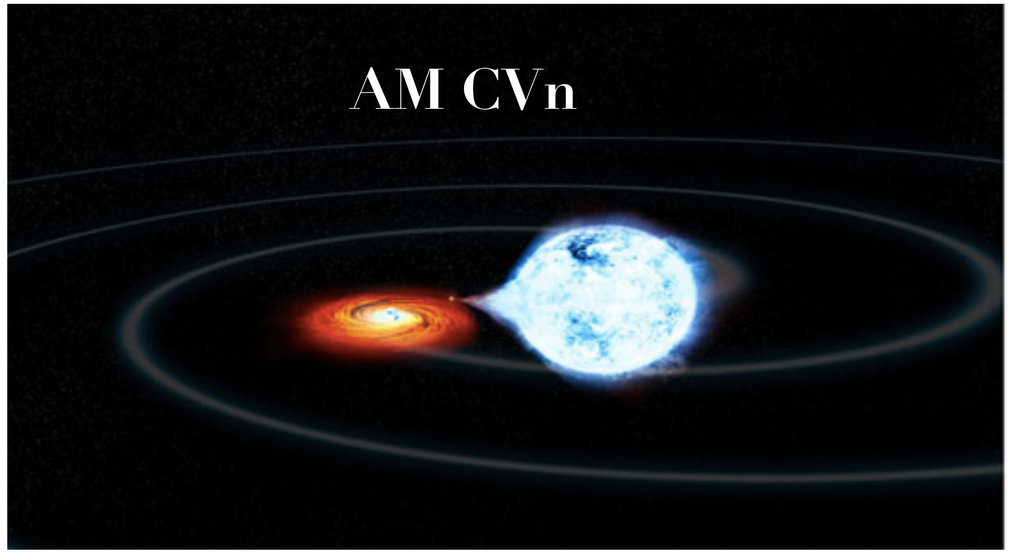
# GW Sources: White Dwarf (WD) Binaries

**now~$10^8$ in Milky Way**

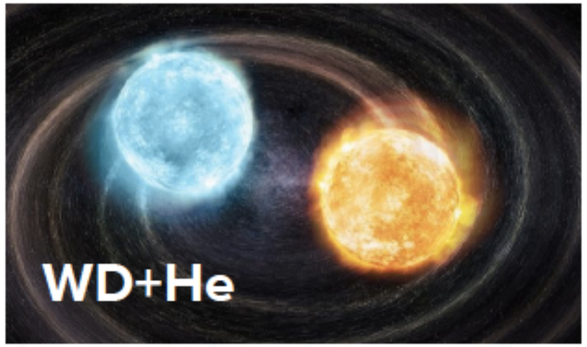



Credit: NASA/Tod Strohmay

**now ~$10^5$ in Milky Way**




Credit: NASA/CXC/M. Weiss

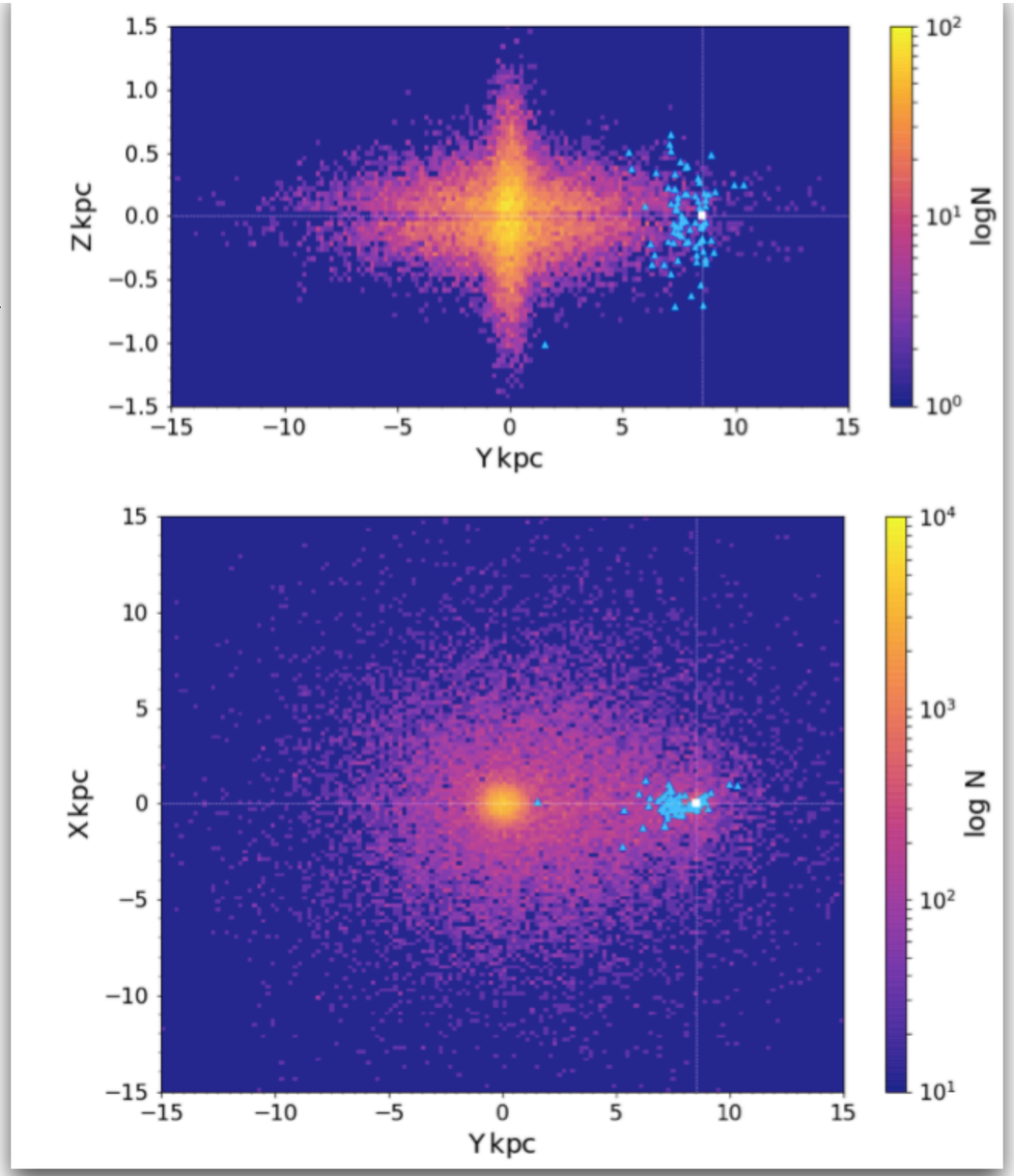



Korol, EMR et al. 2017, Breivik +17; Kremer+2017, Lamberts +2019

Nelemans + 2001, 2004, Nissanke +2012, Shah et al. 2012; Ruiter et al. 2010, Toonen + 2012

# Getting information from the other side of the Galactic Centre

Korol, EMR & Barausse 2019




**PINK**: 10-40 thousands w LISA

**BLUE**: ~200 w Gaia+LSST

Korol, EMR + 17

Stellar evolution code: SeBa (S. Portogeis-Zwart +96) in S. Toonen's implementation and validation (Toonen + 2012, 2017)

# The strengths of a bi-messenger approach

## Gravitational Waves

- no absorption
- single distance measurement method
- tracing low mass stars everywhere in a galaxy and Local Group

## Optical electromagnetic Waves

- absorption
- stellar crowding
- parallax, spectroscopic distance, variable stars, etc...
- low and high mass stars
- Detecting motion (dynamics)

# What has been explored so far...

## Milky Way

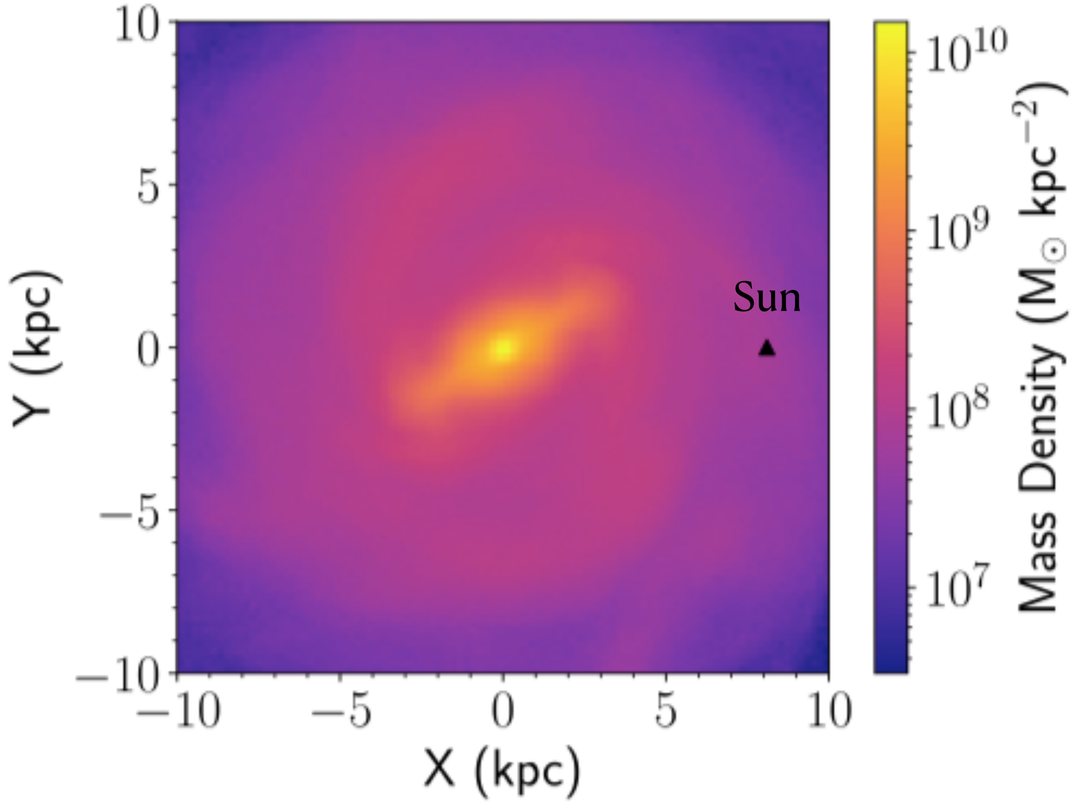
- Tracing the global stellar mass distribution with GWs only ( Benacquista & Holley-Bockelmann '06; Adams & Cornish '12, '14; Georgousi et al. 2022; Breivik+20) and in combination of EM dynamical tracers (Korol, EMR, et al. 2019)
- Directly imaging and characterising the Milky Way's bar (Wilhelm, Korol, EMR & D'Onghia 2021)

## Milky Way's satellites

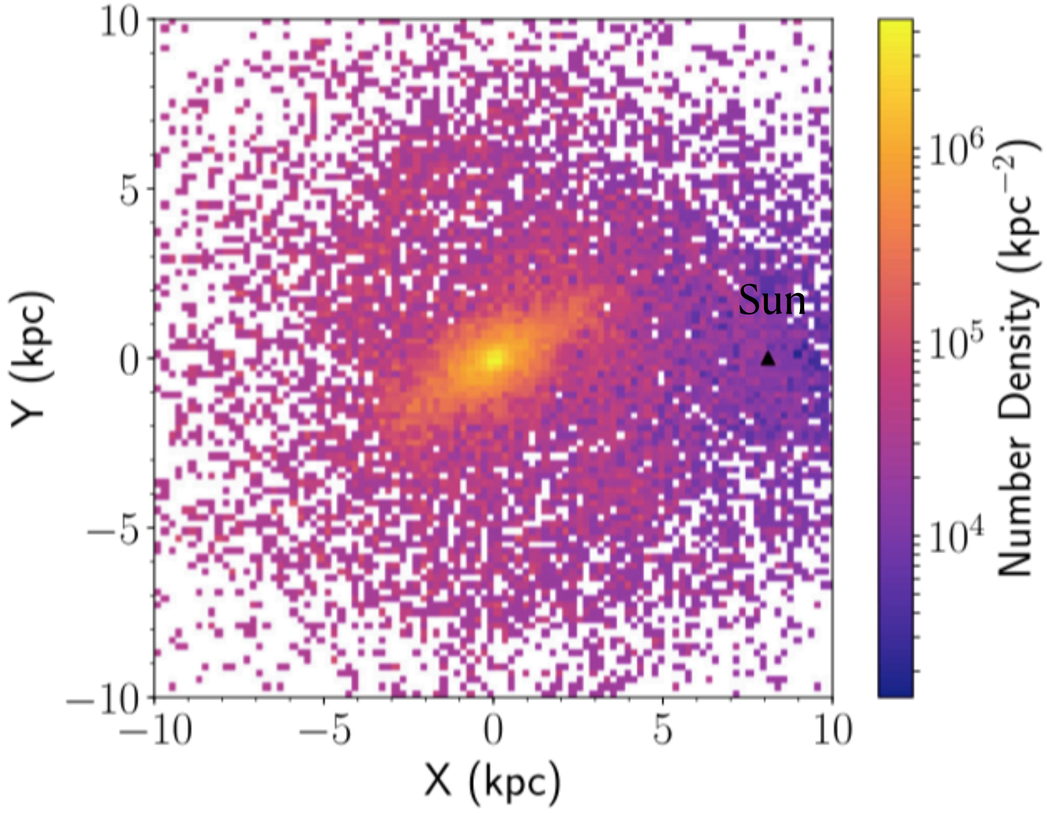
- Statistically characterise the populations of DWDs in the Local Group (Koop, Korol, EMR 2018, Korol et al.2021, Lamberts + 2021 )
- Infer the mass of Satellites (Korol et al. (incl. Belokurov, EMR; Korol, Belokurov, et al. 2021)
- Discovering new satellites (Roebber, Elinore et al.2020)
- Infer the star formation history (Keim, Korol &EMR 2022)

# Mapping the Central bar & Spiral Arms

stellar mass density



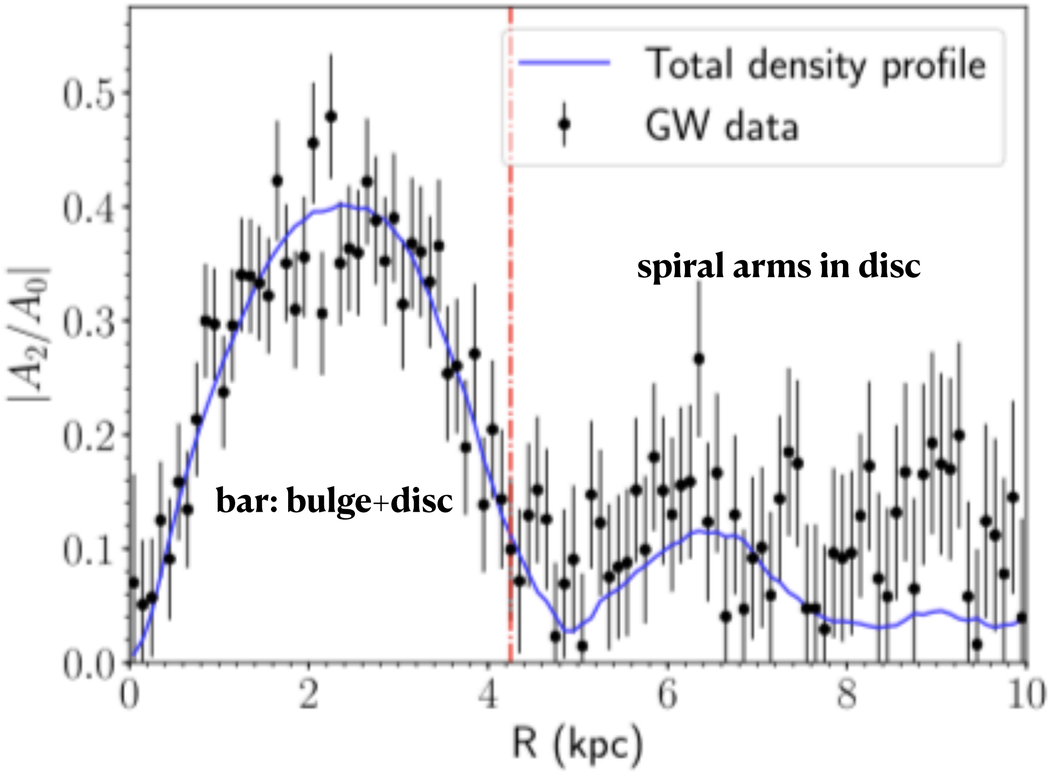

DWD number density

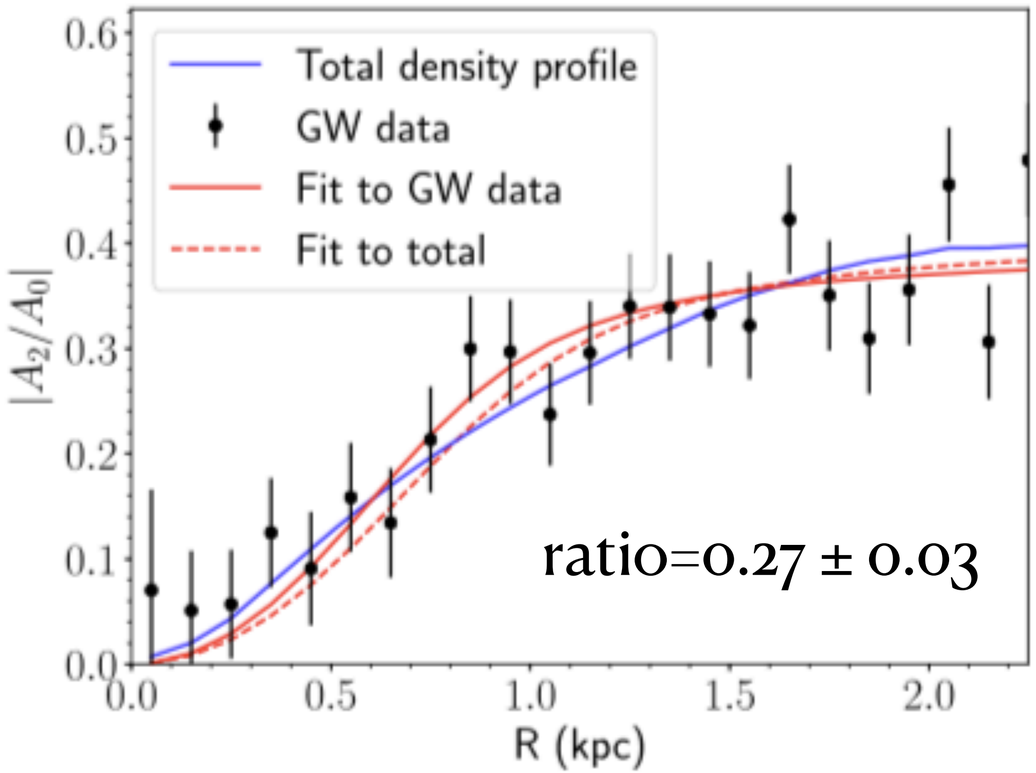



Simulated N-body Galaxy by E. D'Onghia

Wilhelm, Korol, EMR & D'Onghia 2021

# Fourier analysis: Amplitude of m=2

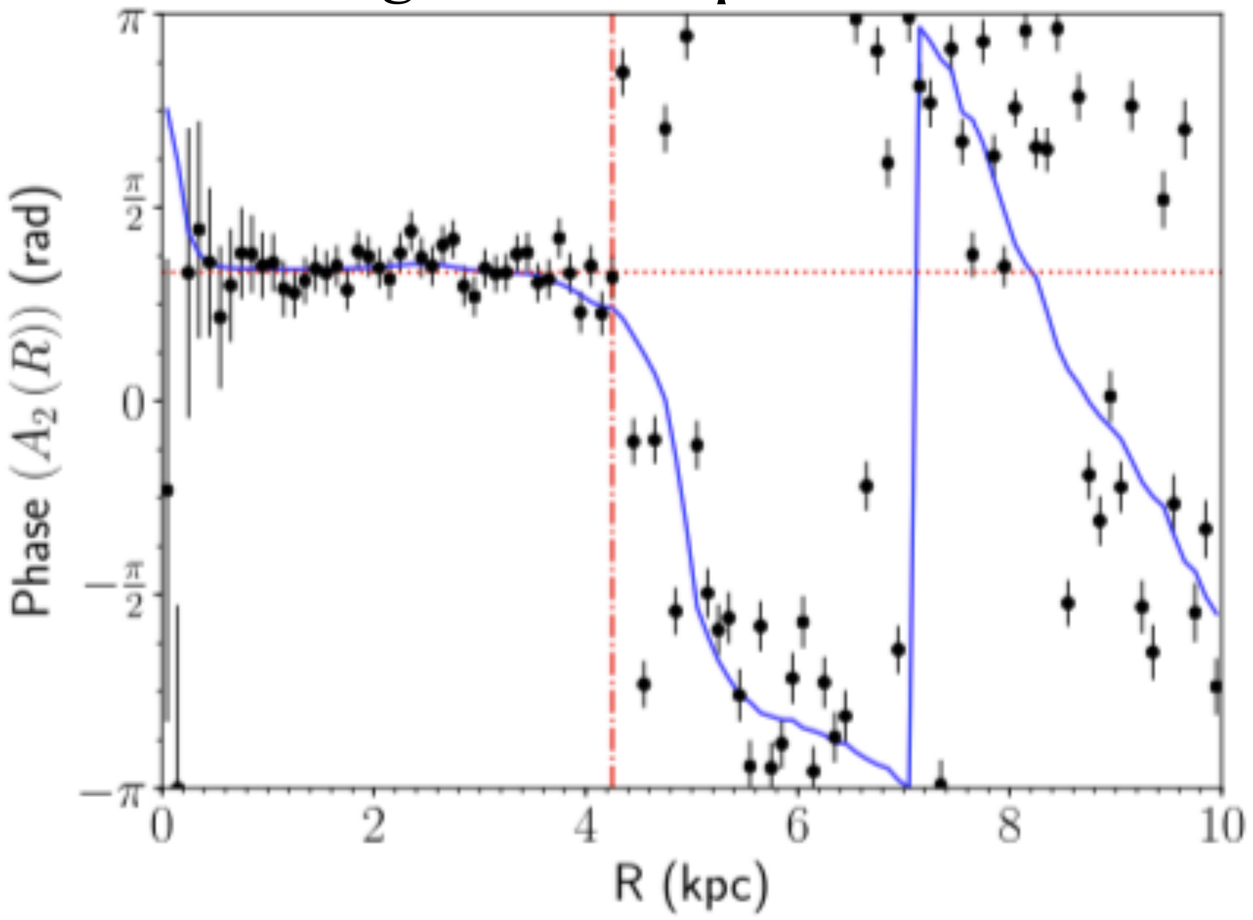



**Bar's Axis ratio** derived from total stellar distribution and from WD consistent within one sigma

# Fourier analysis: Phase of m=2

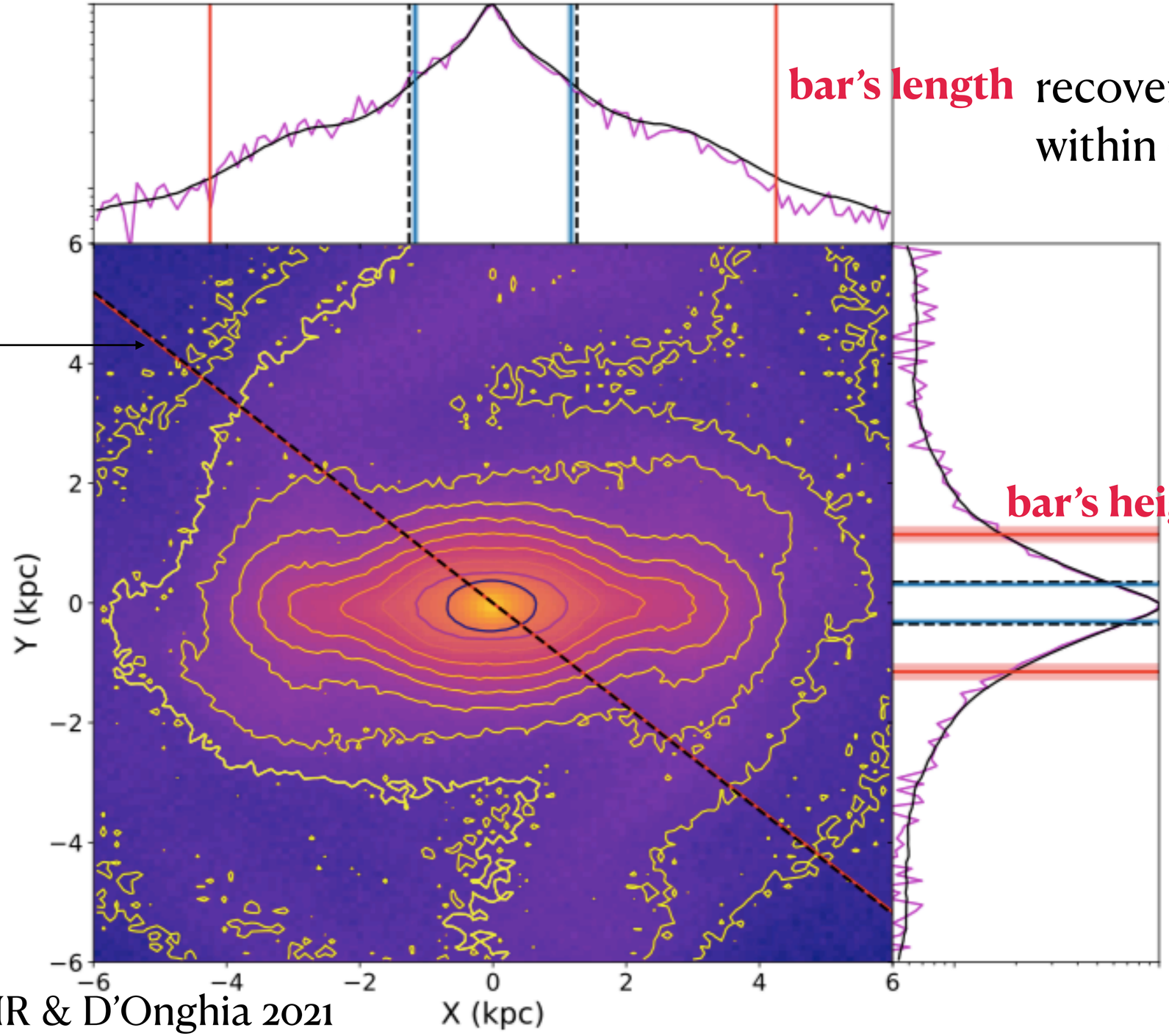
bar: bulge+disc  spiral arms in disc




value of phase

Length of the bar and viewing angle

where phase = constant




**bar's length** recovered within 0.2 kpc

**viewing angle** recovered within 1 degree

**bar's height**

ratio=0.27 ± 0.03

Wilhelm, Korol, EMR & D'Onghia 2021

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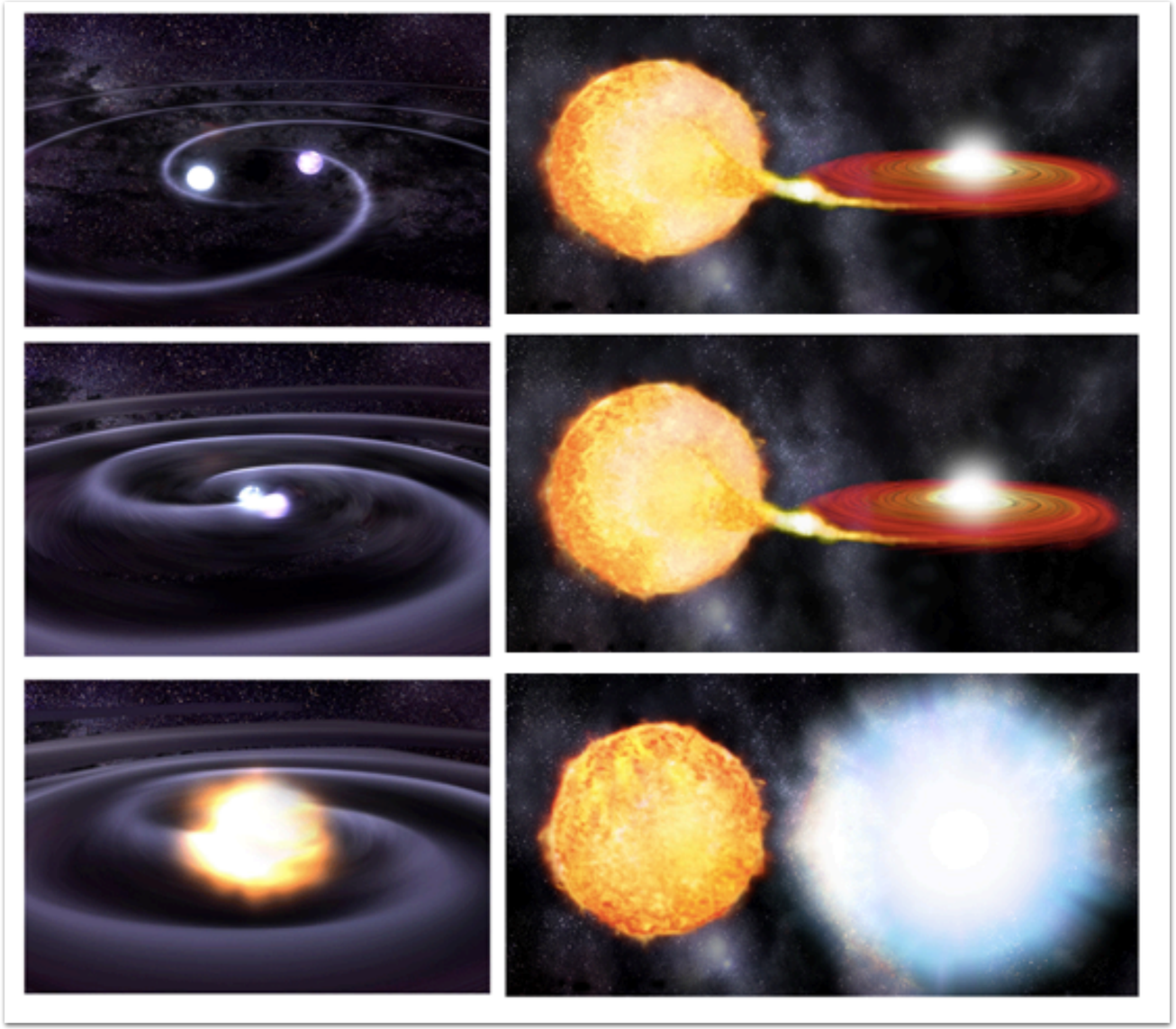
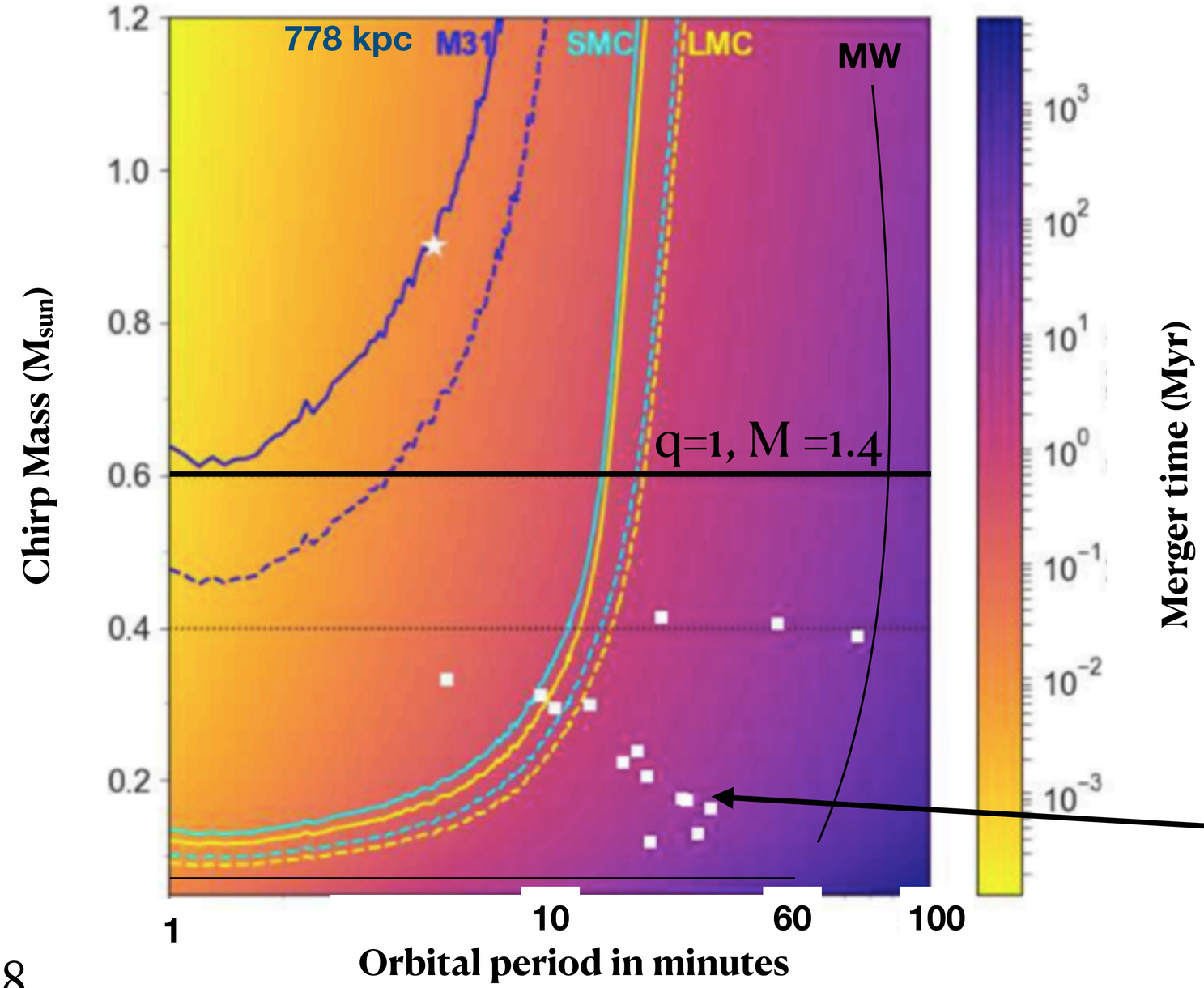
# Supernova Ia Progenitors (unsolved problem!)



# Looking up and out of the Galaxy

*left* of lines are observed parameter space




LISA-Gaia binaries DR2

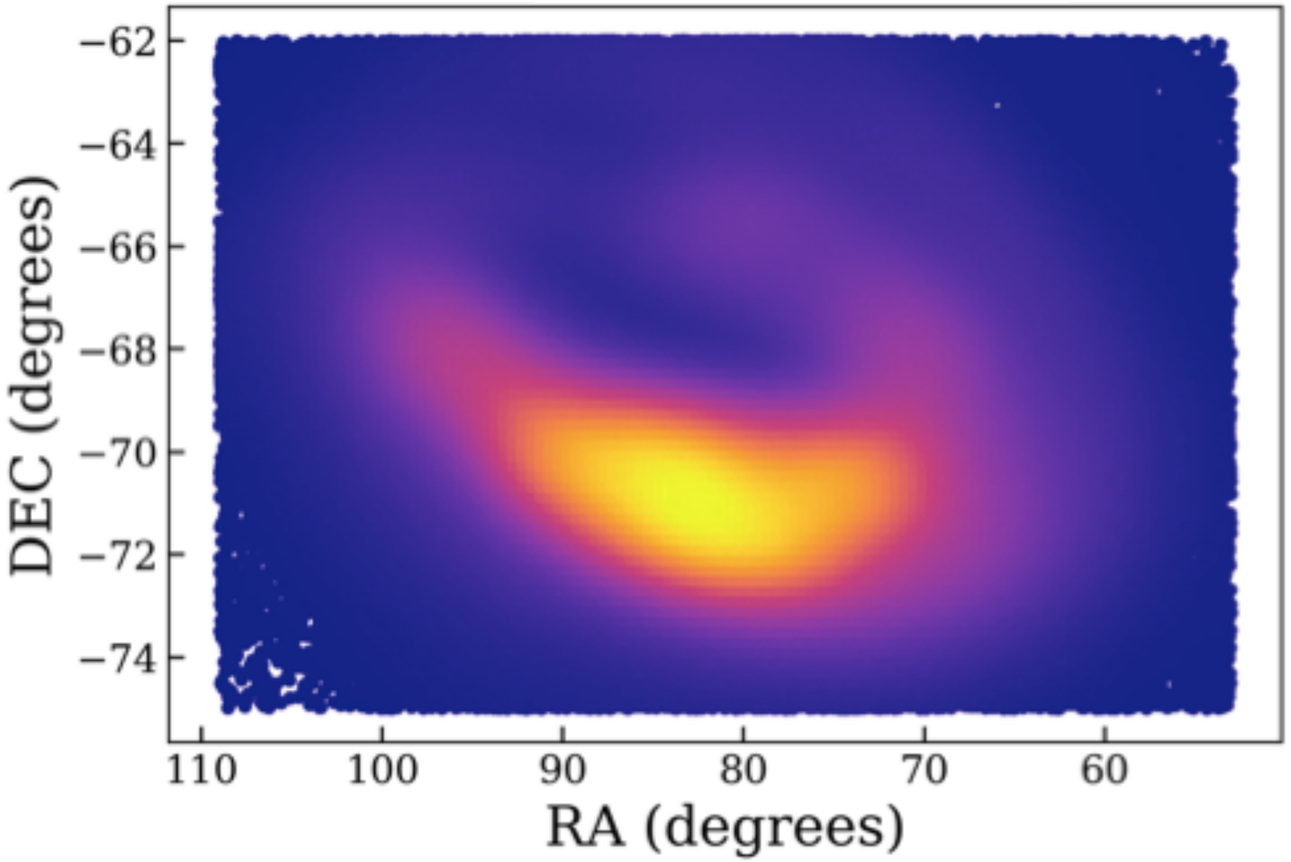
Kupfer, Korol, … EMR 2018

Koop, Korol & EMR 18

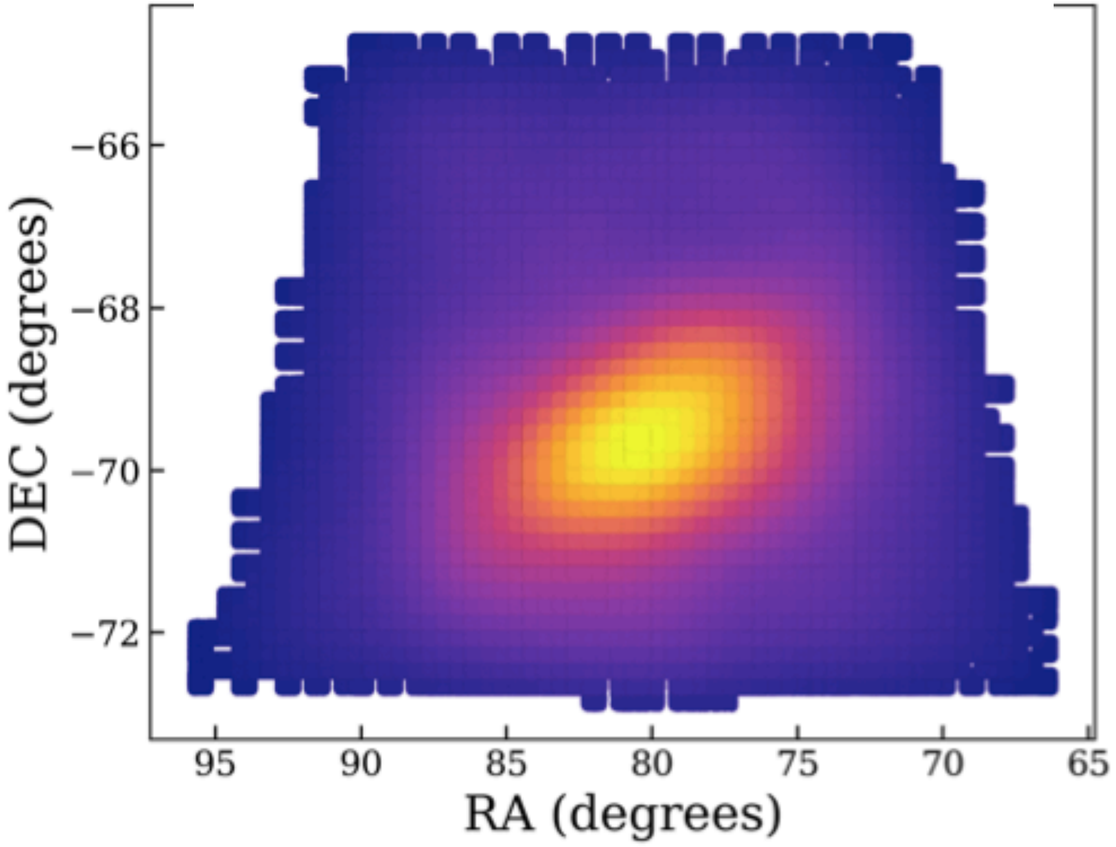
# The Large Magellanic Cloud

# LMC will be a resolved galaxy in LISA sky

LMC simulation




LMC model from observations




Underlying numerical simulation by Lucchini et al. 2020

Keim, Korol & EMR 2022.

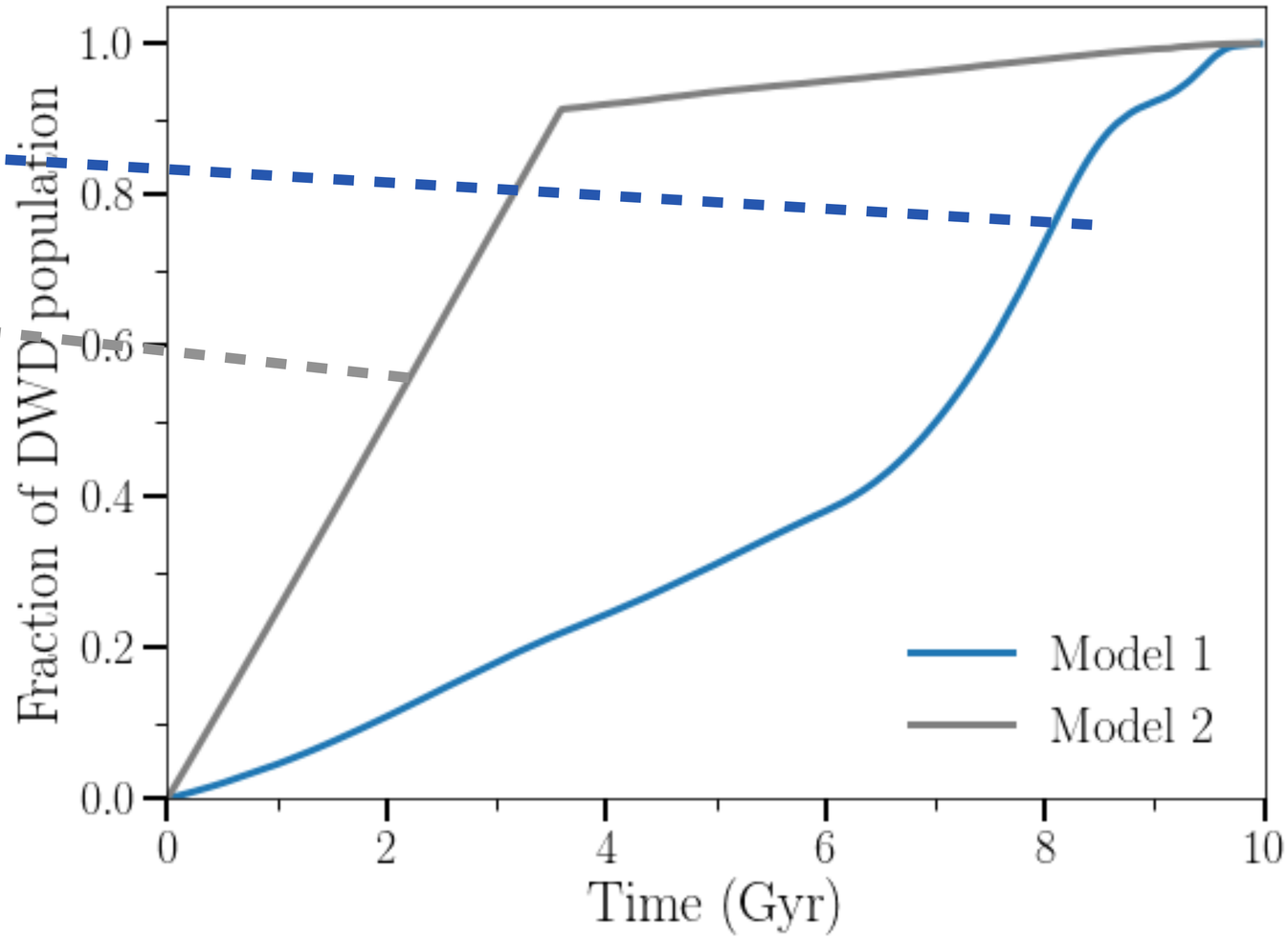
# Can we infer SFH from GW observations?

## 2 models for LMC Star Formation History

Keim, Korol & EMR 2022

From observations (Harris+Zaritsky 09)

star formation in the Lucchini et al. simulation.



# Can we infer SFH from GW observations?

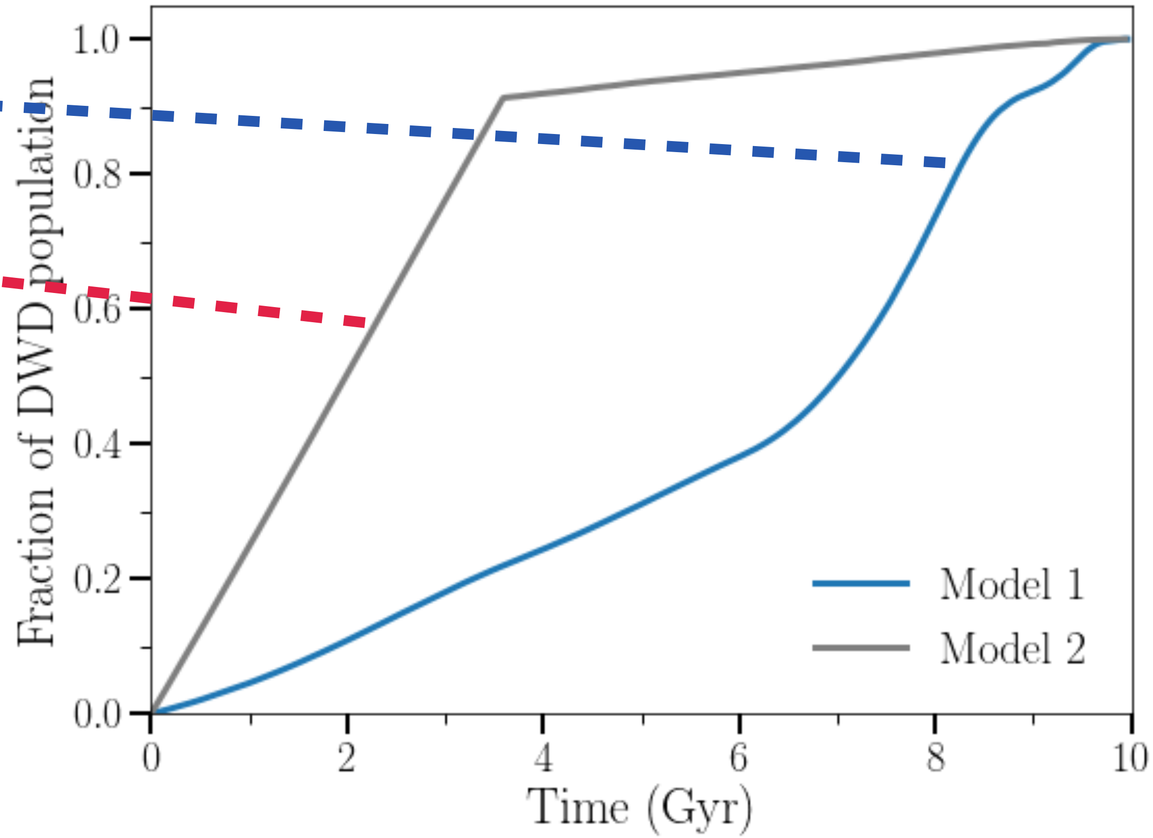
## 2 models for LMC Star Formation History

Keim, Korol & EMR 2022

613 total; 125 super Chandrasekar

293 total, 46 super Chandrasekar

Difference of a factor of
2 in total detections and
~2.7 in massive DWDs



# Can we infer SFH from GW observations?

## 2 models for LMC Star Formation History

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Period and Mass distributions are statistically different at least for these SFHs