Can LISA see common-envelope events?

Mathieu Renzo, T. Callister, K. Chatziioannou, L. van Son, C. M. F. Mingarelli, M. Cantiello, K. E. S. Ford, B. McKernan, and G. Ashton

arXiv:2102.00078
LISA can see Galactic double white dwarfs formed via common envelope

\[ \text{PTA} \quad \Rightarrow \quad \text{LIGO/Virgo} \]

Robson et al. 2019
Common Envelope Evolution

Is *not* GW-driven!
But GW passively trace the dynamics
Common envelope evolution in one slide

a. Mass transfer becomes dynamically unstable
Common envelope evolution in one slide

Example from Ivanova et al. 13b

a. Mass transfer becomes dynamically unstable

b. Loss of corotation between the cores and the envelope
Common envelope evolution in one slide

Example from Ivanova et al. 13b

arXiv:2102.00078
Common envelope evolution in one slide

Plunge-in might be detectable

Loud but short and rare

Example from Ivanova et al. 13b

arXiv:2102.00078
Common envelope evolution in one slide

Example from Ivanova et al. 13b

- Mass transfer becomes dynamically unstable
- Loss of corotation between the cores and the envelope
- Dynamical plunge-in
- Self-regulated, thermal-timescale inspiral
Common envelope evolution in one slide

Example from Ivanova et al. 13b

a. Mass transfer becomes dynamically unstable
b. Loss of corotation between the cores and the envelope
c. Dynamical plunge-in
d. Self-regulated, thermal-timescale inspiral

Common envelope ejection and formation of a short period binary

Stellar merger
Common envelope evolution in one slide

Example from Ivanova et al. 13b
How many sources do we expect?

\[ N_{CE} = R_{CE,init} \times \Delta t_{CE} \]
How many sources do we expect? $N_{CE} = R_{CE,\text{init}} \times \Delta t_{CE}$

$R_{CE,\text{init}} = 0.18^{+0.02}_{-0.09} \ (0.06^{+0.03}_{-0.02})$

c.f. LRN rate $\sim 0.3 \, \text{yr}^{-1}$

Kochaneck et al. 14, see also Howitt et al. 20

$\min(M_{GW \text{ emitting}}) \ [M_{\odot}]$

arXiv:2102.00078
How many sources do we expect? \( N_{CE} = R_{CE,\text{init}} \times \Delta t_{CE} \)

\[
R_{CE,\text{init}} = 0.18^{+0.02}_{-0.09} \left( 0.06^{+0.03}_{-0.02} \right)
\]

c.f. LRN rate \( \sim 0.3 \text{ yr}^{-1} \)

Kochaneck et al. 14, see also Howitt et al. 20

Duration (in band) is very uncertain

\[
\Delta t_{CE} \sim 10^{-2} - 10^{5} \text{ years}
\]

(e.g., Meyer & Meyer-Hofmeister 79, Fragos et al. 19, Igoshev et al. 20, Chamandy et al. 20, Law-Smith et al. 20)

\[
0 \lesssim N_{CE} \lesssim 1000
\]
Could we detect something?
Could we see it? An answer not relying on a specific model

\[ \log_{10}(a/\left[R_\odot\right]) \]

\[ \log_{10}(\dot{f}_{GW}/[\text{Hz}]) \]

\[ \log_{10}(\dot{f}_{GW}/[\text{s}^{-2}]) \]

\[ \log_{10}(f_{GW}/[\text{Hz}]) \]

\[ \log_{10}(a/\left[R_\odot\right]) \]

\[ \text{SNR} \]

\[ M_{\text{core}} = 0.5 M_\odot, \ M_2 = 0.3 M_\odot, \]
\[ D = 3 \text{ kpc}, \ T = 5 \text{ years}, \]
\[ \text{averaged over orientation and sky location} \]
Could we see it? An answer not relying on a specific model

\[ \log_{10}(a/R_{\odot}) \]

\[ \log_{10}(f_{GW}/[\text{Hz}]) \]

\[ \log_{10}(|\dot{f}_{GW}|/[\text{s}^{-2}]) \]

GW Emission

\[ M_{\text{core}} = 0.5 M_{\odot}, \ M_2 = 0.3 M_{\odot}, \]
\[ D = 3 \text{ kpc}, \ T = 5 \text{ years}, \]
averaged over orientation and sky location
Could we see it? An answer not relying on a specific model

\[ \log_{10}\left( \frac{a}{R_\odot} \right) \]

\[ \log_{10}\left( |\dot{f}_{GW}| / [s^{-2}] \right) \]

Gas Drag (No Feedback)
GW Emission

\[ M_{\text{core}} = 0.5 M_\odot, \quad M_2 = 0.3 M_\odot, \]
\[ D = 3 \text{ kpc}, \quad T = 5 \text{ years}, \]

averaged over orientation and sky location
Could we see it? An answer not relying on a specific model

\[
\log_{10}(a/[R\odot])
\]

\[
\log_{10}(|\dot{f}_{GW}|/[s^{-2}])
\]

\[
\log_{10}(f_{GW}/[\text{Hz}])
\]

\[
\log_{10}(a/[R\odot])
\]

\[
\log_{10}(f_{GW}/[\text{Hz}])
\]

\[
\log_{10}(\dot{f}_{GW}/[\text{s}^{-2}])
\]

Gas Drag (No Feedback)
GW Emission

\[M_{\text{core}} = 0.5 \, M_{\odot}, \quad M_2 = 0.3 \, M_{\odot},\]
\[D = 3 \, \text{kpc}, \quad T = 5 \, \text{years},\]
averaged over orientation and sky location

\(M_{\text{core}} = 0.5 \, M_{\odot}, \quad M_2 = 0.3 \, M_{\odot},\)
\(D = 3 \, \text{kpc}, \quad T = 5 \, \text{years},\)
averaged over orientation and sky location
Could we see it? An answer not relying on a specific model

\[
\log_{10}(a/\left[R_\odot\right])
\]

\[
\log_{10}(|\dot{f}_{GW}|/\left[s^{-2}\right])
\]

\[
\log_{10}(f_{GW}/\left[ \text{Hz} \right])
\]

\[
\log_{10}(a/\left[R_\odot\right])
\]

\[
M_{\text{core}} = 0.5 M_\odot, \quad M_2 = 0.3 M_\odot,
\]

\[
D = 3 \text{ kpc}, \quad T = 5 \text{ years},
\]

averaged over orientation and sky location

\[
\text{SNR}
\]

\[
\text{SNR}
\]

\[
\text{SNR}
\]

arXiv:2102.00078
Could we see it? An answer not relying on a specific model

\[ \log_{10}(a/[R_\odot]) \]

\[ \log_{10}(|\dot{f}/[Hz]|) \]

\[ \log_{10}(|\dot{f}/[s^{-2}]|) \]

\[ M_{\text{core}} = 0.5 M_\odot, M_2 = 0.3 M_\odot, \]
\[ D = 3 \text{ kpc}, T = 5 \text{ years}, \]

averaged over orientation and sky location.
Would we recognize GWs from common envelope?
“Stealth bias” assuming GR in vacuum: chirp mass

\[
\log_{10}(f_{GW}/[\text{Hz}])
\]

\[
\log_{10}(\frac{\dot{f}_{GW}}{[\text{s}^{-2}]})
\]

\[
\log_{10}(\frac{\ddot{f}_{GW}}{\text{Measurable}})
\]

\[
\log_{10}(\frac{\dot{f}_{GW}}{\text{Measurable}})
\]

\[
\log_{10}(\frac{M_{c}}{[M_{\odot}]})
\]

arXiv:2102.00078
"Stealth bias" assuming GR in vacuum: chirp mass

"Braking index"

\[ n = \frac{f \ddot{f}}{\dot{f}^2} \]
\[ n_{GR} = \frac{11}{3} \]
“Stealth bias” assuming GR in vacuum: chirp mass

“Braking index”
\[ n = \frac{\ddot{f}}{f^2} \]
\[ n_{GR} = \frac{11}{3} \]

EM counterparts:
- Optical/IR transients (Blagorodnova et al. 20)
- “weird” red giant star (Clayton et al. 17)
Conclusions
Can LISA see common-envelope events? Maybe!

- ~ One CE-begin per 10 yr
- $0 \lesssim N_{\text{CE}} \lesssim 1000$
- If stalls at short separation they might be detectable

Direct window on the inside

If non-detection

- stalls at large separation
  and/or
- stalling phase is short
Backup slides
Dynamical phases are **loud but short** and thus **rare**

Requires massive donor star

Ginat *et al.* 2020
Rate of common-envelope initiation with pre-CE separation

\[ \text{Initiation rate } R_{CE,\text{init}} \left[ \text{yr}^{-1} \right] \]

\[ q_c = 0.1 \]
\[ q_c = 1 \]
\[ q_c = 2 \]

Clayes et al. 14

\[ q_c, Z = 0.002 \]

Clayes et al. 14

\[ q_c, \text{indip. dist} \]

all CE

both post MS

\[ \min(a_{\text{pre-CE}}) \left[ R_\odot \right] \]

\[ \min(M_{\text{GW emitting}}) \left[ M_\odot \right] \]
“Stealth bias” assuming GR in vacuum: chirp mass & distance

“Braking index” $n = \frac{\ddot{f}}{\dot{f}^2} \Rightarrow n_{GR} = \frac{11}{3}$
Most common envelope events cross the LISA band

\[ \text{MGW emitting} = M_{\text{core}} + M_{\text{WD}} \] [M\(_\odot\)]

\[ 10^{-2} \quad 10^{-1} \quad 10^0 \quad 10^1 \quad 10^2 \]

\[ \alpha = 1, \lambda = 0.3 \]

\[ M_{\text{WD}} = 0.3M_{\odot} \]

\[ M_{\text{WD}} = 1.4M_{\odot} \]

LISA frequency range

10 R\(_\odot\)

100 R\(_\odot\)

500 R\(_\odot\)

1500 R\(_\odot\)
LISA planned launch ≈ 2034
Other mHz GW detectors planned
e.g., TianQin