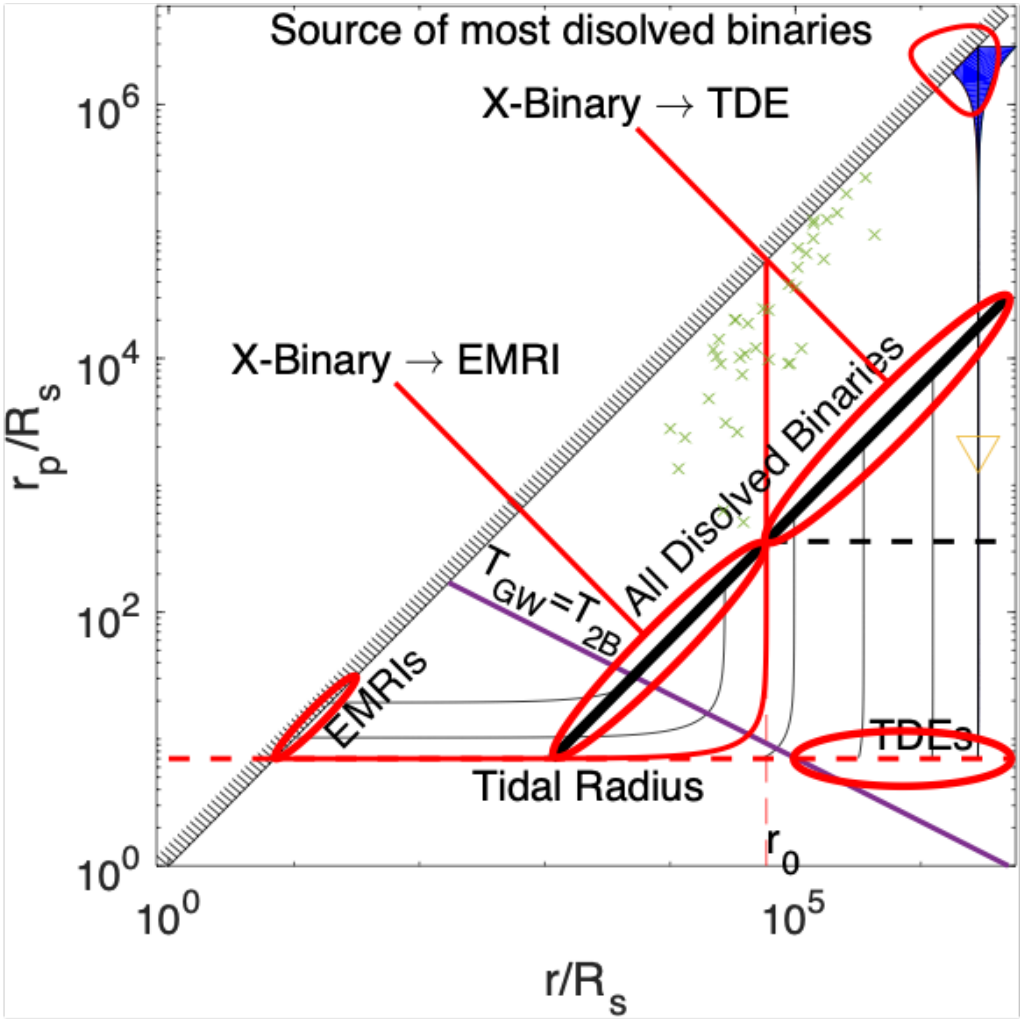
Nuclear Star Clusters as LISA sources



Hebrew University:

Re'em Sari
Giacomo Fragione
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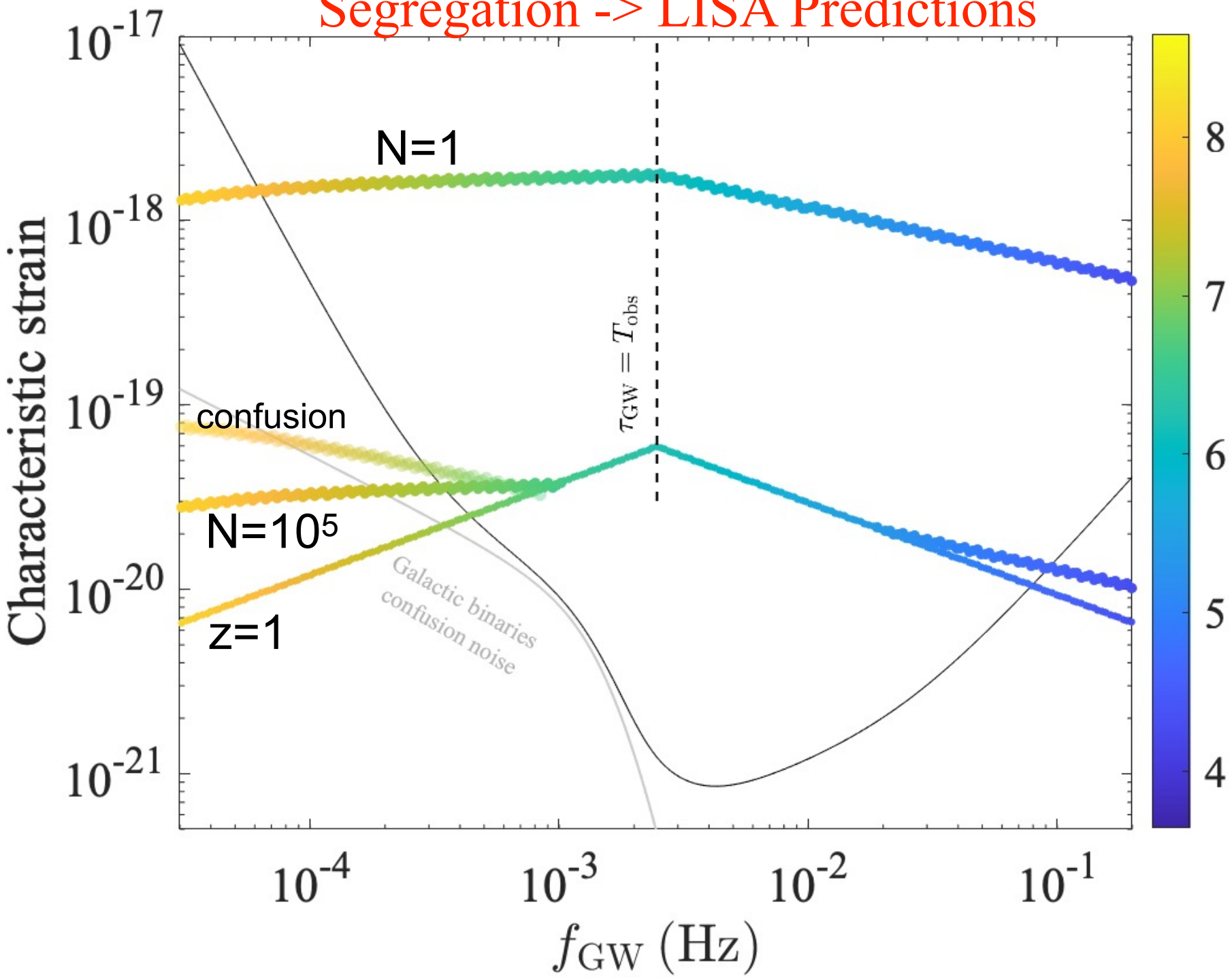
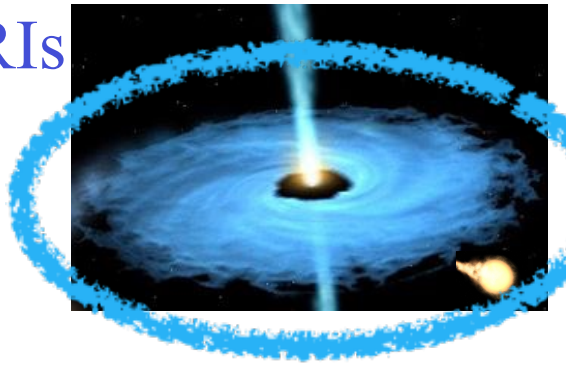
Itail Linial
Tamar Faran
Barak Rom

Segregation -> LISA Predictions

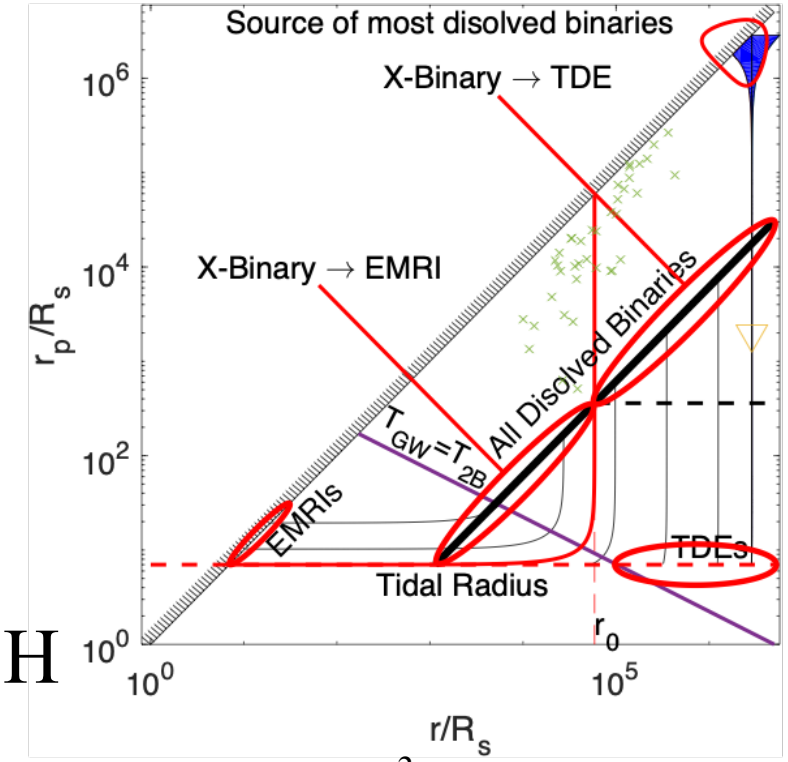


Other Phenomena

- Mass transfer to the supermassive black hole.
  - MS extreme mass ratio inspiral - MS-EMRIs
  - emission of gravitational waves



- Tidal Disruption Events.
  - Explosion of stars



- Breakup of binaries produces:
  - Hyper Velocity Stars
  - S- stars ?

- Plunges of compact objects into BH
- QPEs

Dimensionless #s in The Milky Way

- Stars compared to black hole:

$$\frac{M}{m} \sim 4 \times 10^6 \qquad \propto M$$

Other galaxies with m-sigma relation

- Radius of influence compared to Schwarzschild:

$$\frac{R_h}{R_s} \sim 4 \times 10^6 \qquad \propto M^{-1/2}$$

- Tidal radius compared to Schwarzschild:

$$\frac{R_t}{R_s} \sim 10 \qquad \propto M^{-2/3}$$

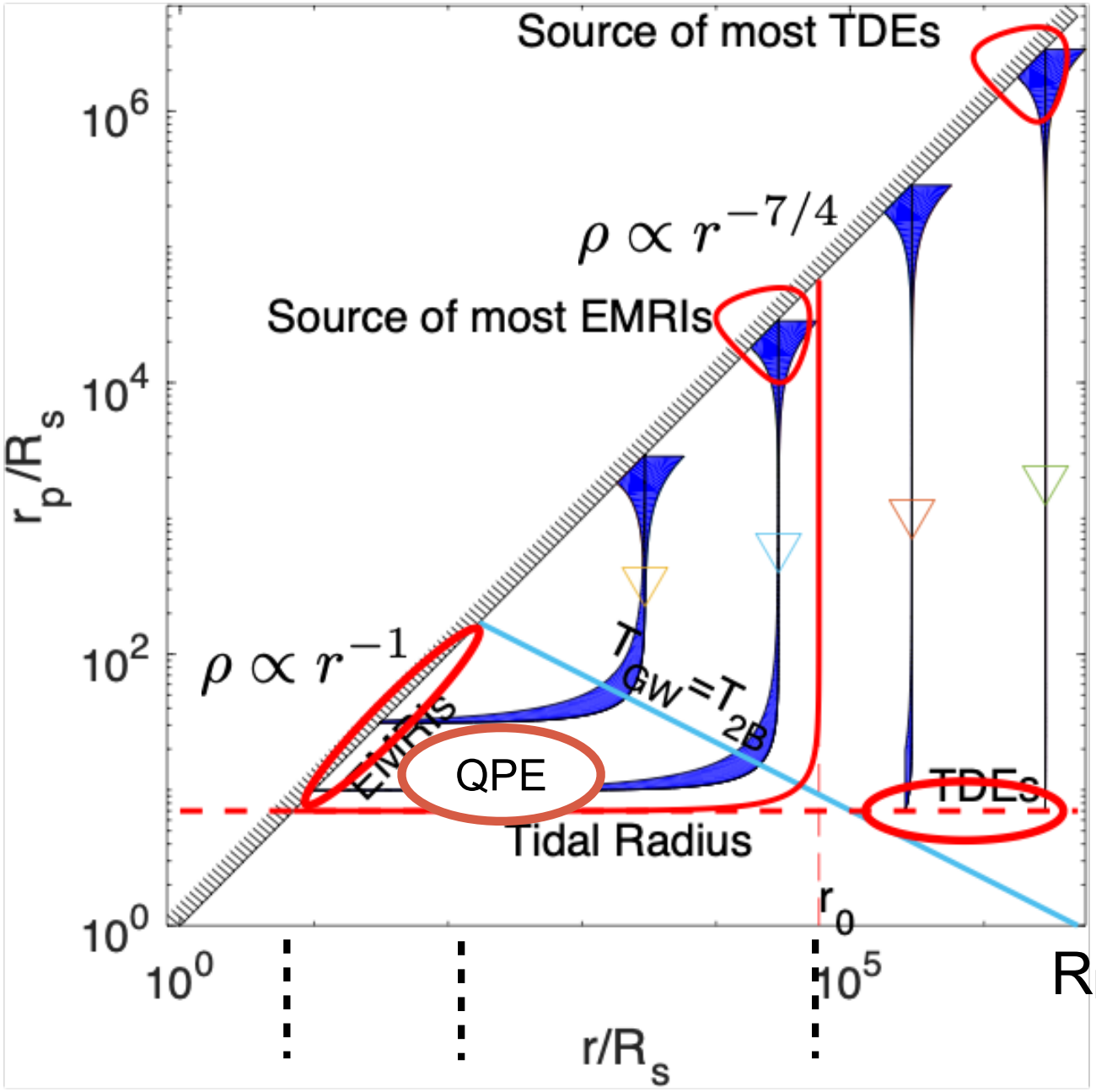
Gravitational Waves & Eccentric Orbits

$$T_{GW} = \frac{R_s}{c}\frac{M}{m}\left(\frac{r_p}{R_s}\right)^4\left(\frac{r}{r_p}\right)^{1/2}$$

$$T_{2B} = \frac{R_s}{c}\left(\frac{M}{m}\right)^2 N(r)^{-1}\left(\frac{r}{R_s}\right)^{3/2}\frac{r_p}{r}$$

$$T_{GW} = T_{2B} \quad \rightarrow \quad r_p = R_s\left(\frac{r}{R_h}\right)^{-1/2}$$

Scatterings & Gravitational Waves



1AU 15AU 6000AU=0.03pc

$$r_0 = R_h \left(\frac{R_s}{R_t}\right)^2$$

$$\frac{\mathcal{R}_{\rm EMRIS}}{\mathcal{R}_{\rm TDEs}} = \left(\frac{R_s}{R_T}\right)^2$$

~1%

Galaxy mass
Stellar mass
Compact objects

2 Body Relaxation & The Cusp

- The typical time for significant scattering.

$$T_{rel} = \left[\frac{N(r)}{r^3} \left(\frac{Gm}{v^2} \right)^2 v \right]^{-1} = P(r) \left(\frac{M}{m} \right)^2 N(r)^{-1}$$

- Constant partical flux:

Peebles

$$\frac{N(r)}{T_{rel}} = const. \rightarrow N \propto P(r)^{1/2} \propto r^{3/4} \qquad \rho \propto r^{-9/4}$$

- Constant energy flux:

Bahcall Wolf

$$\frac{E(r)N(r)}{T_{rel}} = const. \rightarrow N \propto r^{1/2} P(r)^{1/2} \propto r^{5/4} \quad \rho \propto r^{-7/4}$$

Segregation

- Naive flux = #stars * n sigma v
- Only “zero flux” solutions: flux << naive flux
- Balanced solutions (zero flux):
  - Mass dependent sinking (Dynamical Friction)
  - Scattering
- Generalised Bacall Wolf solutions

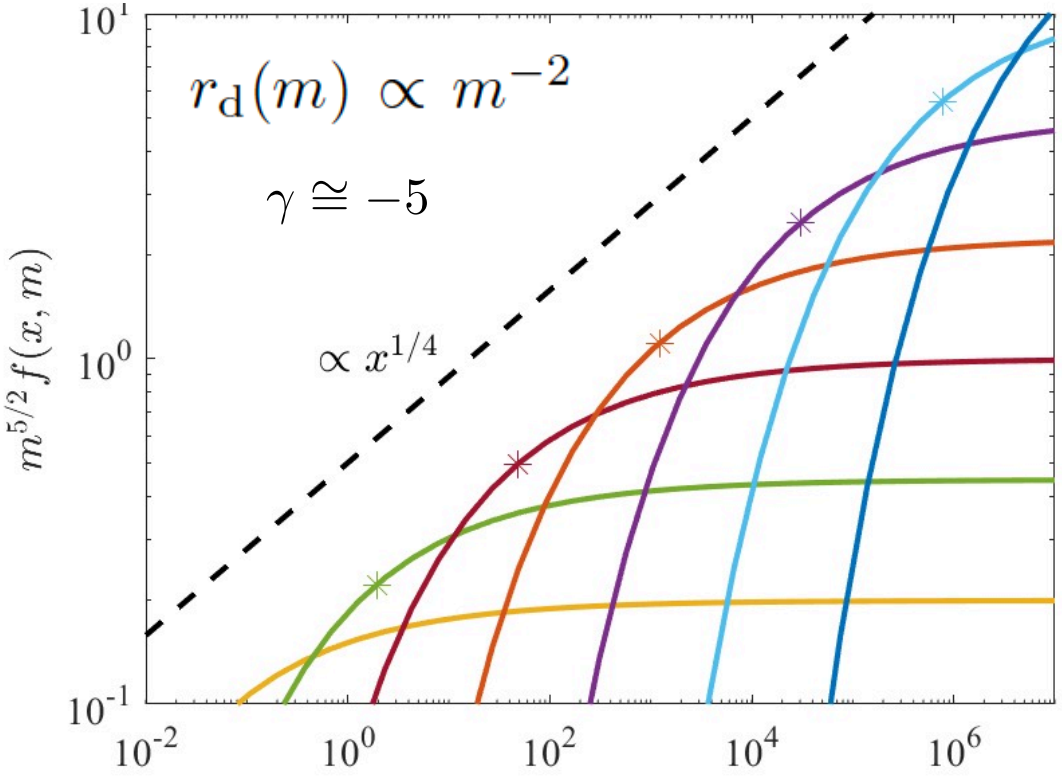
Segregation

$$0= Q(x,m) = \int_{m_{\min}}^{m_{\max}} m'\, dm' \int_{x_{\min}}^{x_{\max}} dx' \, \{\max(x,x')\}^{-3/2} \times \{m f(x,m) \partial_{x'} f(x',m') - m' f(x',m') \partial_x f(x,m)\} \,, \quad (1)$$

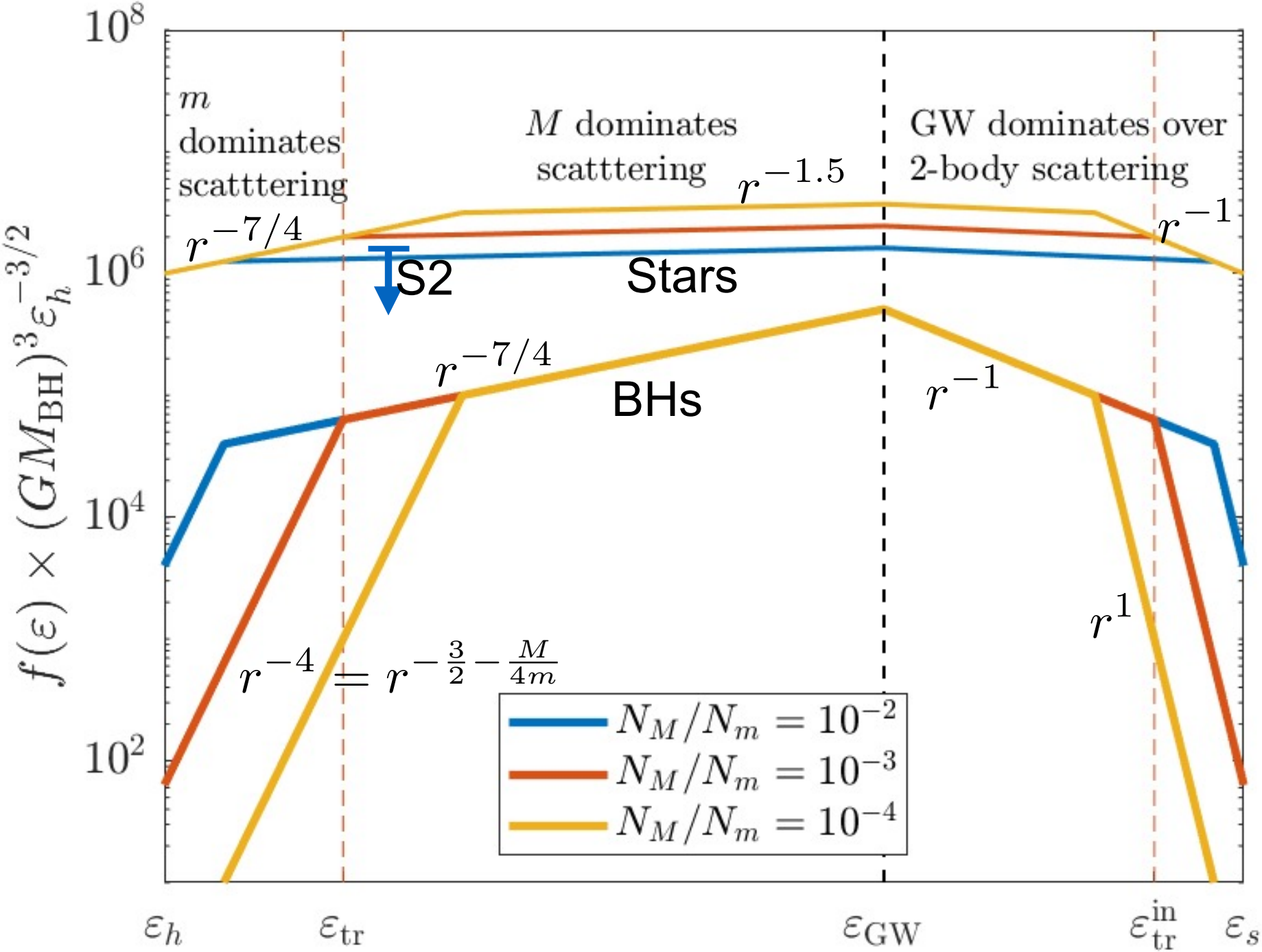
$$f(x,m) \propto m^{-(\gamma+15)/5} \cdot \exp\left(-mAx^{5/(4\gamma+10)}\right).$$

New Self Similar Solution
With mass spectrum.

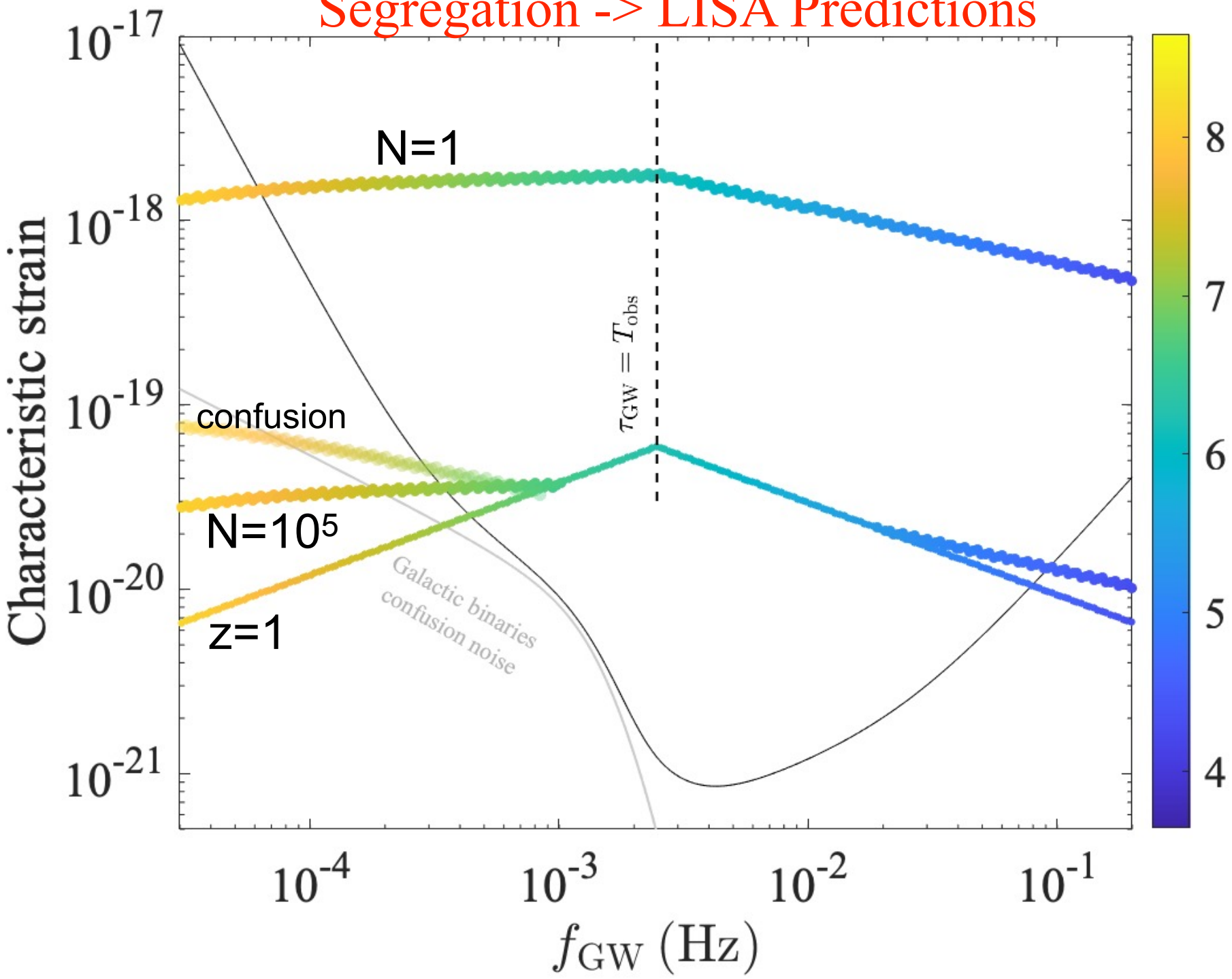
Meaning:
for a given mass:
- Strong segregation at low E
- Flat distribution at high E
- cross section m^(3/2).



Segregation - Two Mass Groups



Segregation -> LISA Predictions



Segregation Linial & Sari 2022

Strong segregation (AH)

zero flux solutions.
no constant flux (AH)

In our galaxy

~0.1 Mass transferring stars

Mass excess within S2 orbit

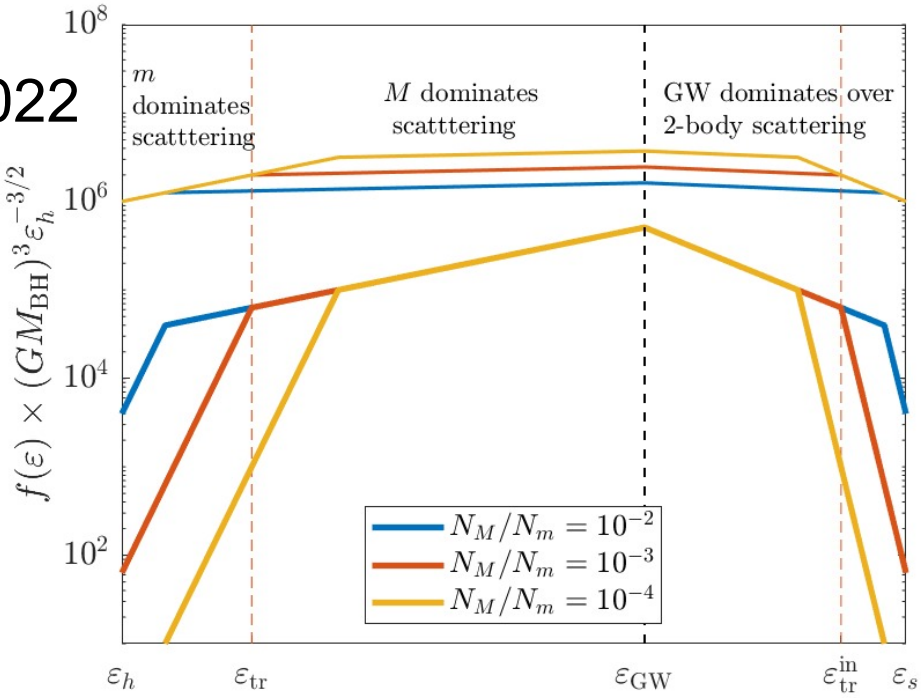
1500 Ms in BH independent of #BH
3000 Ms in MS stars
Slight tension with GRAVITY observations.
Should be detected soon.

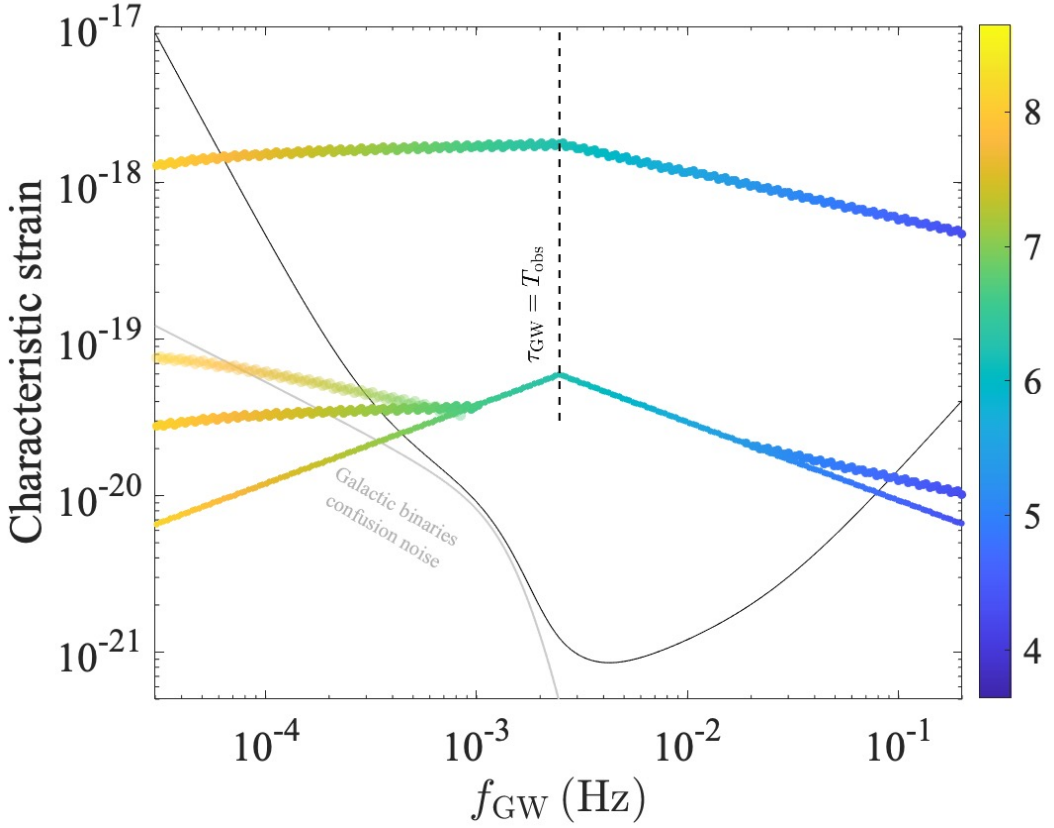
LISA will detect 10^3 sources SNR>8.

Mostly black holes
Independent of #BH in galactic centers.

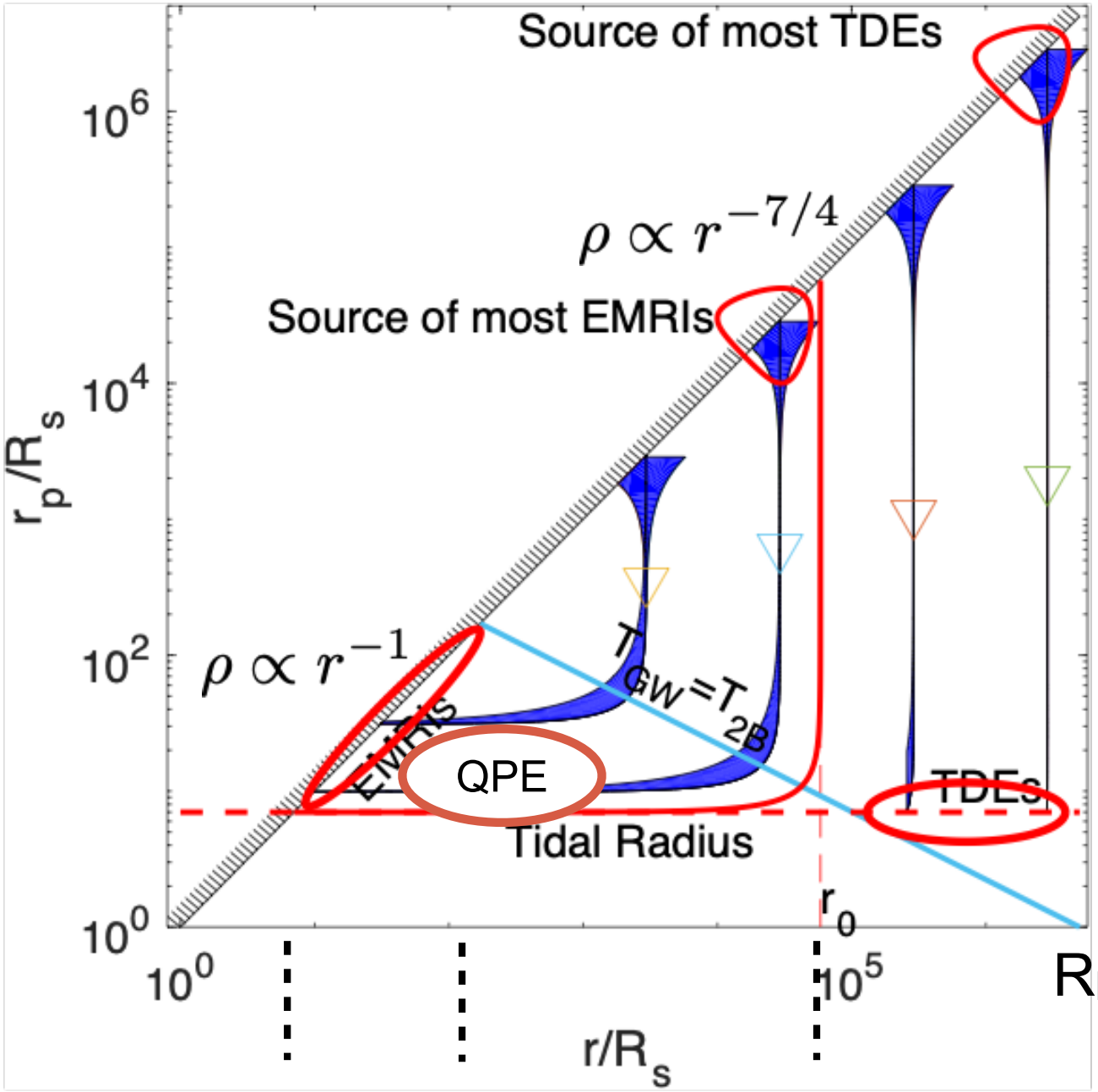
Dominates noise for LISA.

Dominated by BHs.
Exceeds galactic binaries.
@ 3×10^{-4} Hz



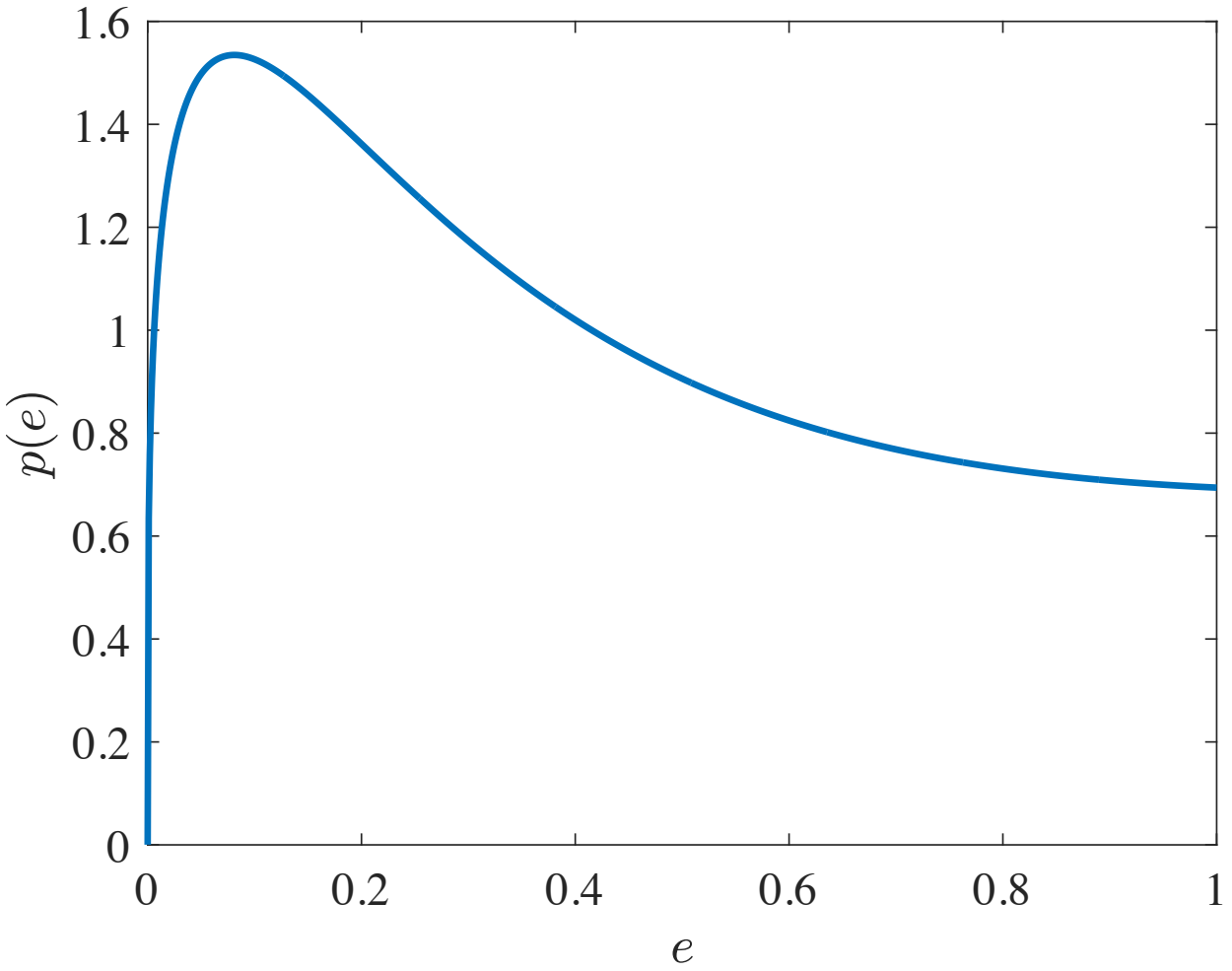


Scatterings & Gravitational Waves

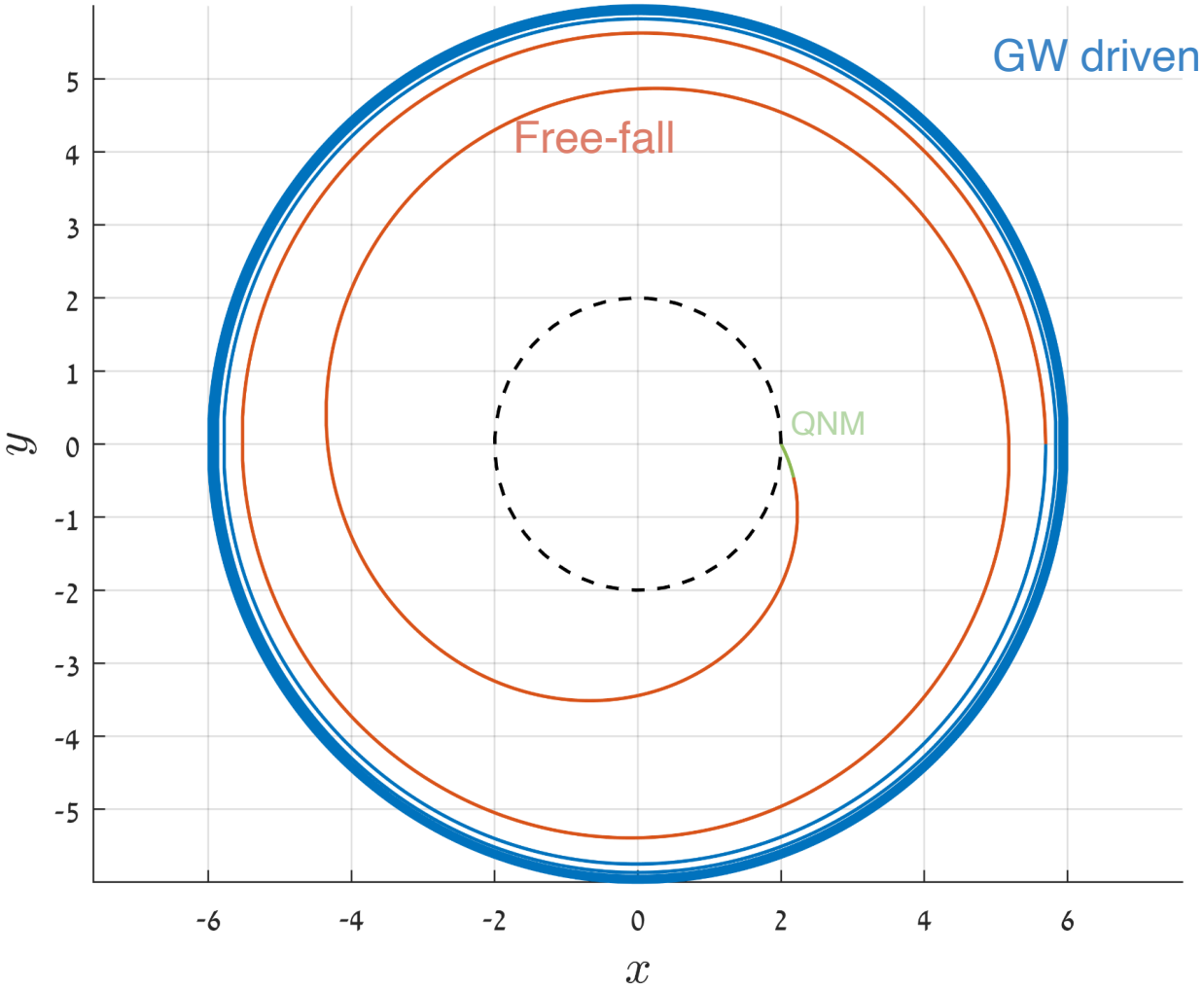


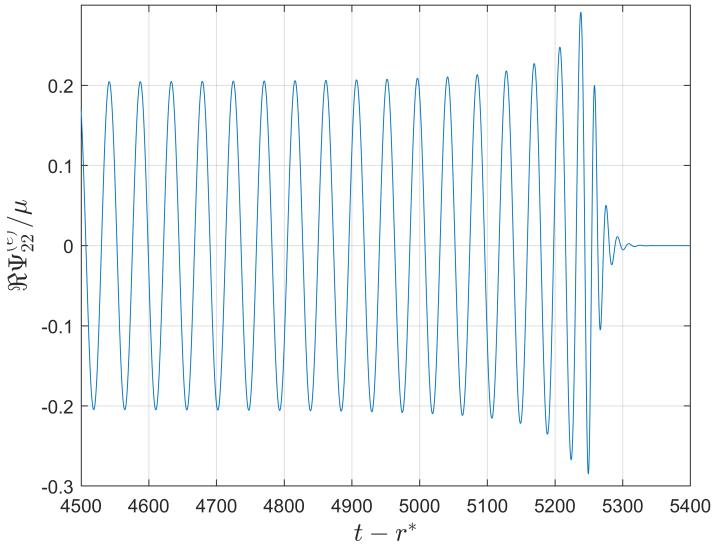
1AU 15AU 6000AU=0.03pc

Eccentricity Distribution



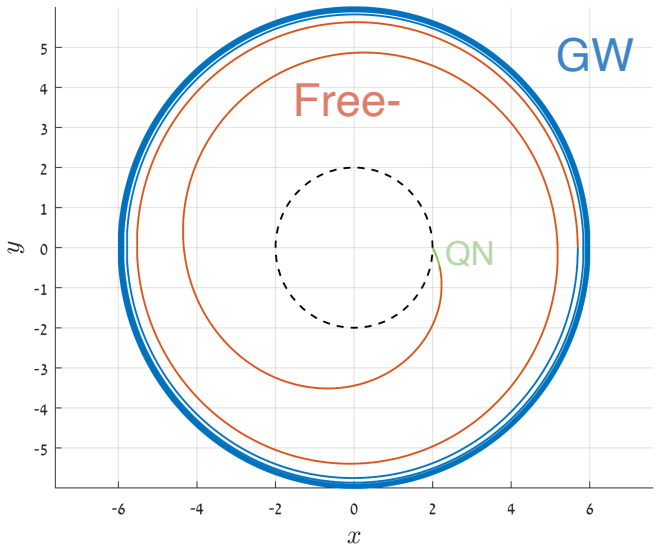
Geodesic Universal Infall (GUI) Trajectory

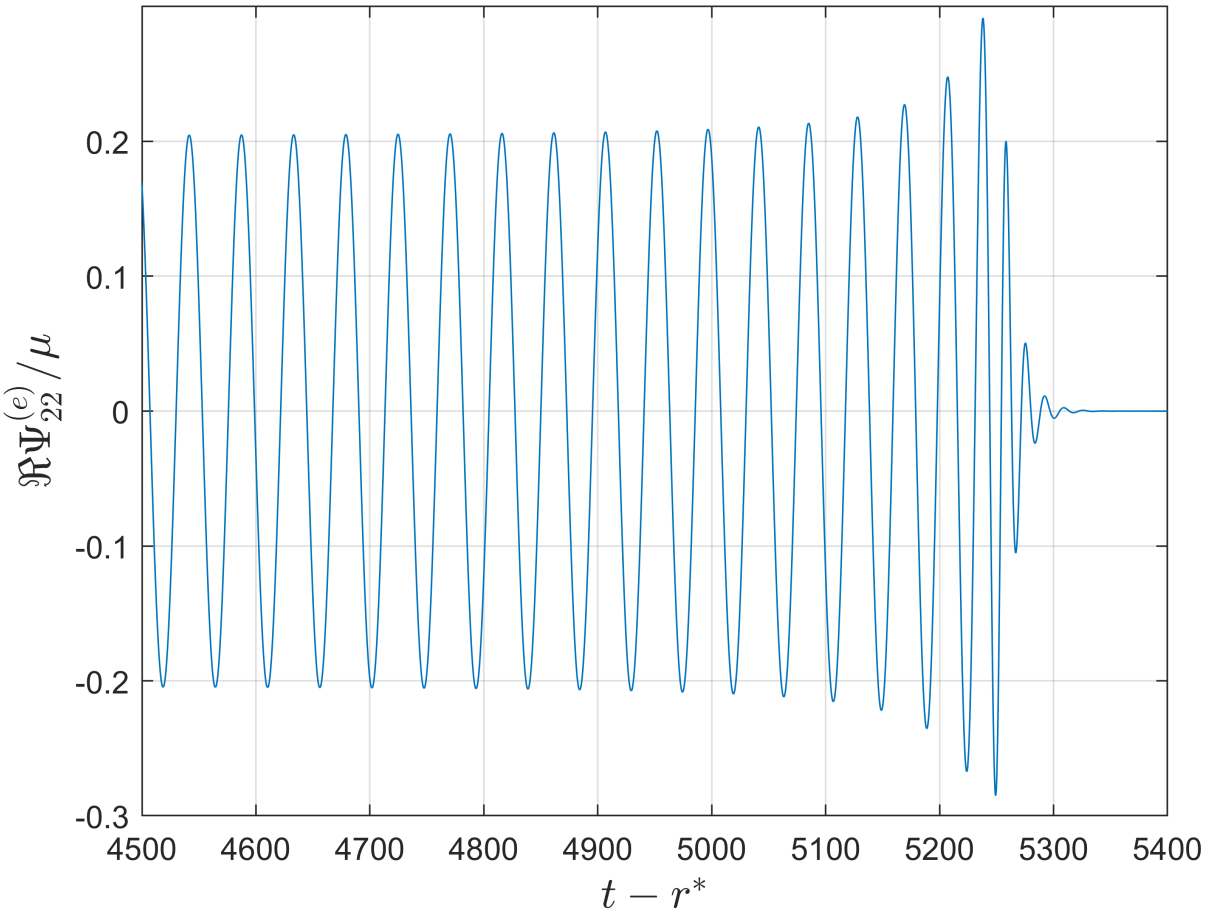




(Rom & Sari, 22)

Geodesic Universal Infall (GUI) Trajectory





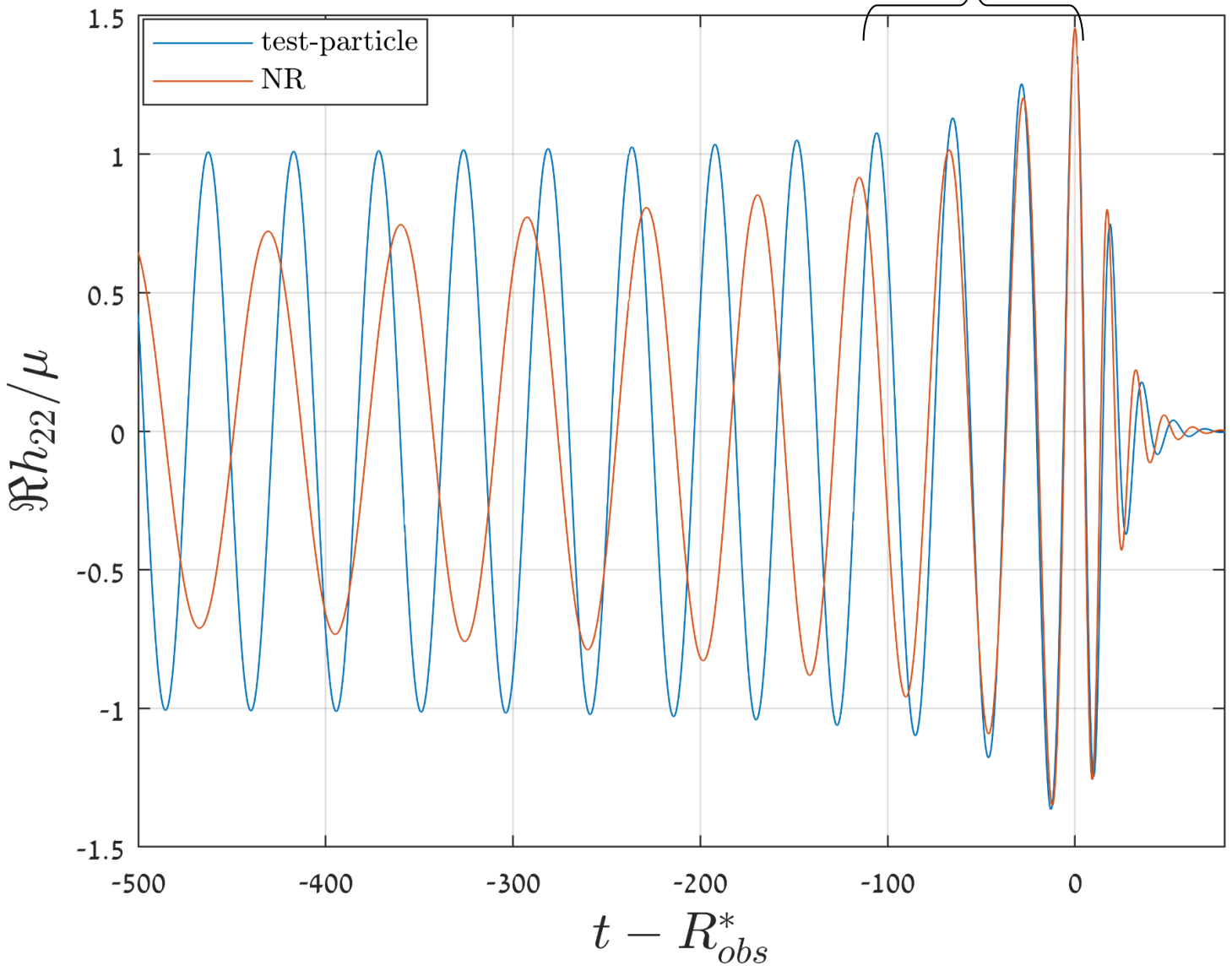
(Rom & Sari, 22)

Test Particle Waveform vs. NR

$v/c = 0.0467\,\nu^2$

$N \propto \nu^{-3/10}$

$\nu = m/M = 0.1$



Segregation -> LISA Predictions