Title: The role of dark matter in supermassive black hole mergers

Speakers:

Collection: Dark Matter, First Light

Date: February 28, 2024 - 1:45 PM

URL: https://pirsa.org/24020058

Abstract: Increasing evidence for a stochastic gravitational background is being collected at pulsar timing arrays. The most plausible origin of the signal is the cumulative strain from the mergers of supermassive black holes at the center of galaxies across the history of the universe. I will discuss how the impact of dark matter dynamical friction on the black hole binary evolution can address some of the questions that this discovery raises. This includes the solution of the "final parsec problem" by which mergers would otherwise stall before gravitational wave emission can drive the coalesce. I will argue that the observational data favor the existence of dark matter self interactions with a cross-section and velocity dependence consistent with the ones capable of solving the small-scale structure problems of collisionless cold dark matter.

The role of dark matter in supermassive black hole mergers

Gonzalo Alonso-Álvarez

Based on [2401.14450] with Caitlyn Dewar & Jim Cline

Physics
UNIVERSITY OF TORONTO

Supermassive black holes

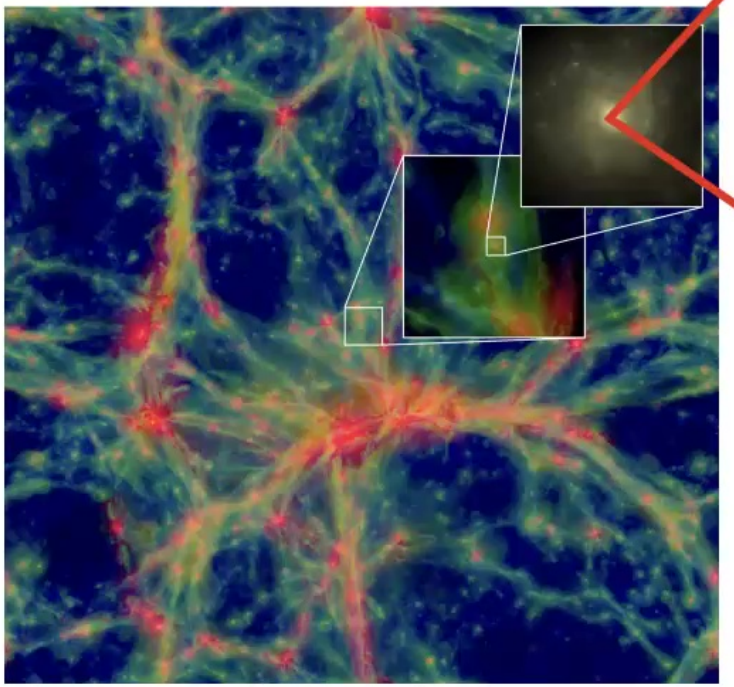


Image credit: EAGLE simulations

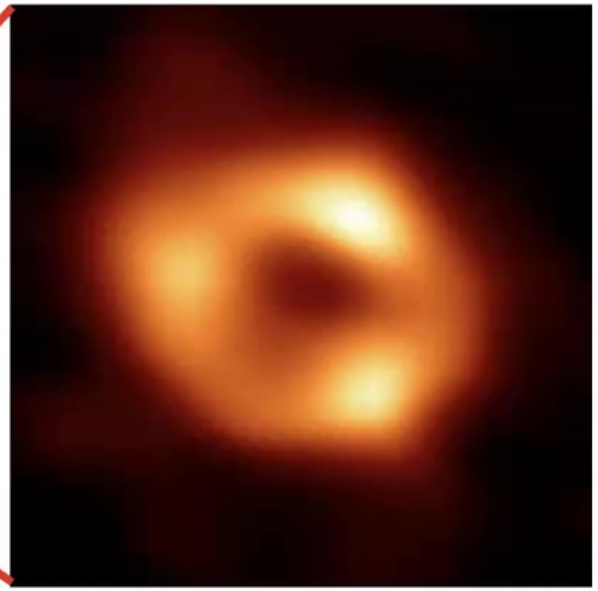
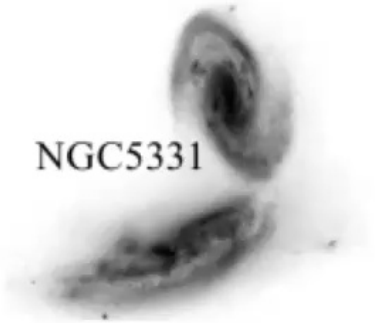


Image credit: EHT

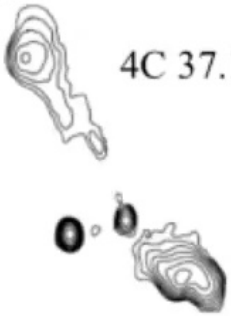
Supermassive black holes mergers

Galaxy Merger



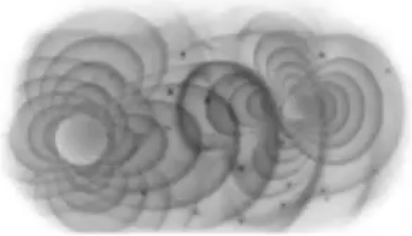
Dynamical friction drives massive objects to central positions

Binary Formation



Stellar and gas interactions may dominate binary inspiral?

Continuous GWs

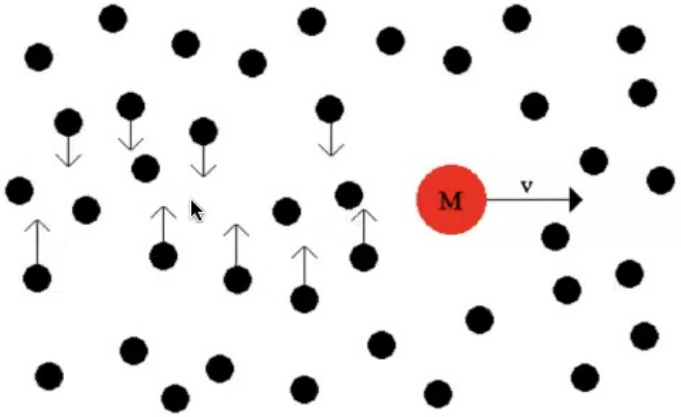


Gravitational radiation provides efficient inspiral. Circumbinary disk may track shrinking orbit.

Adapted from NANOGrav (designed by Sarah Spolaor)

Dynamical friction

SMBH creates stellar/gas overdensity behind it



Gravitational pull of the wake slows down SMBH

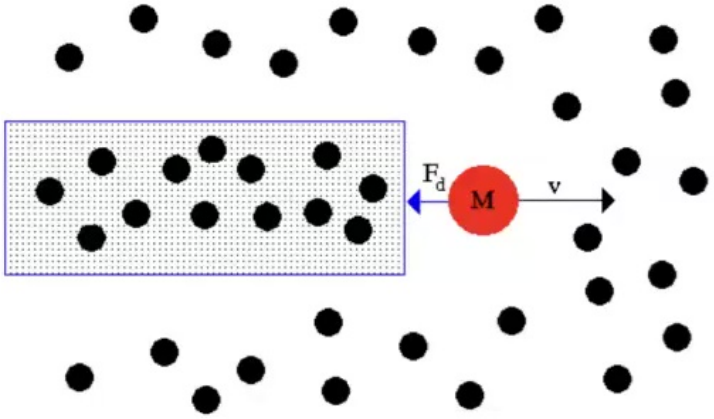
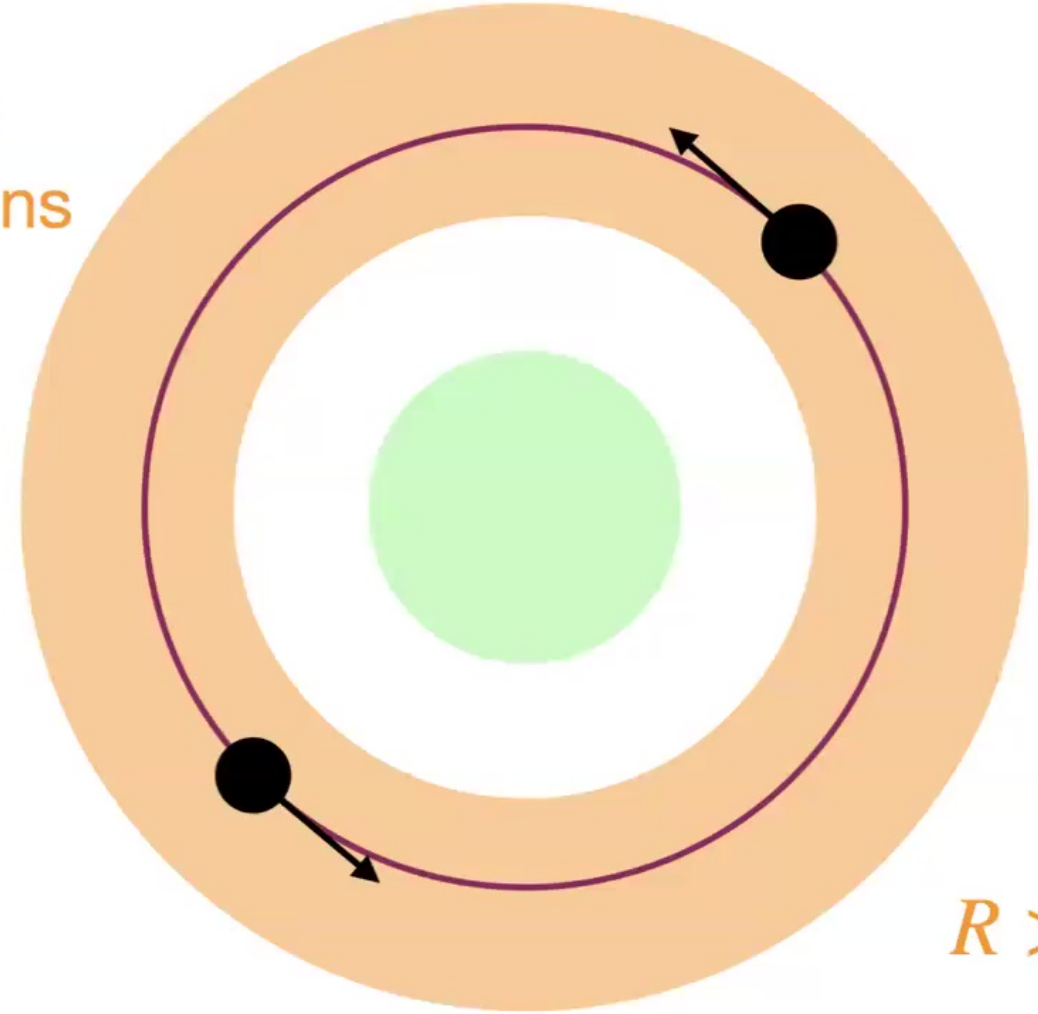


Image credit: J. Schombert (adapted)

The final parsec problem

Stellar interactions

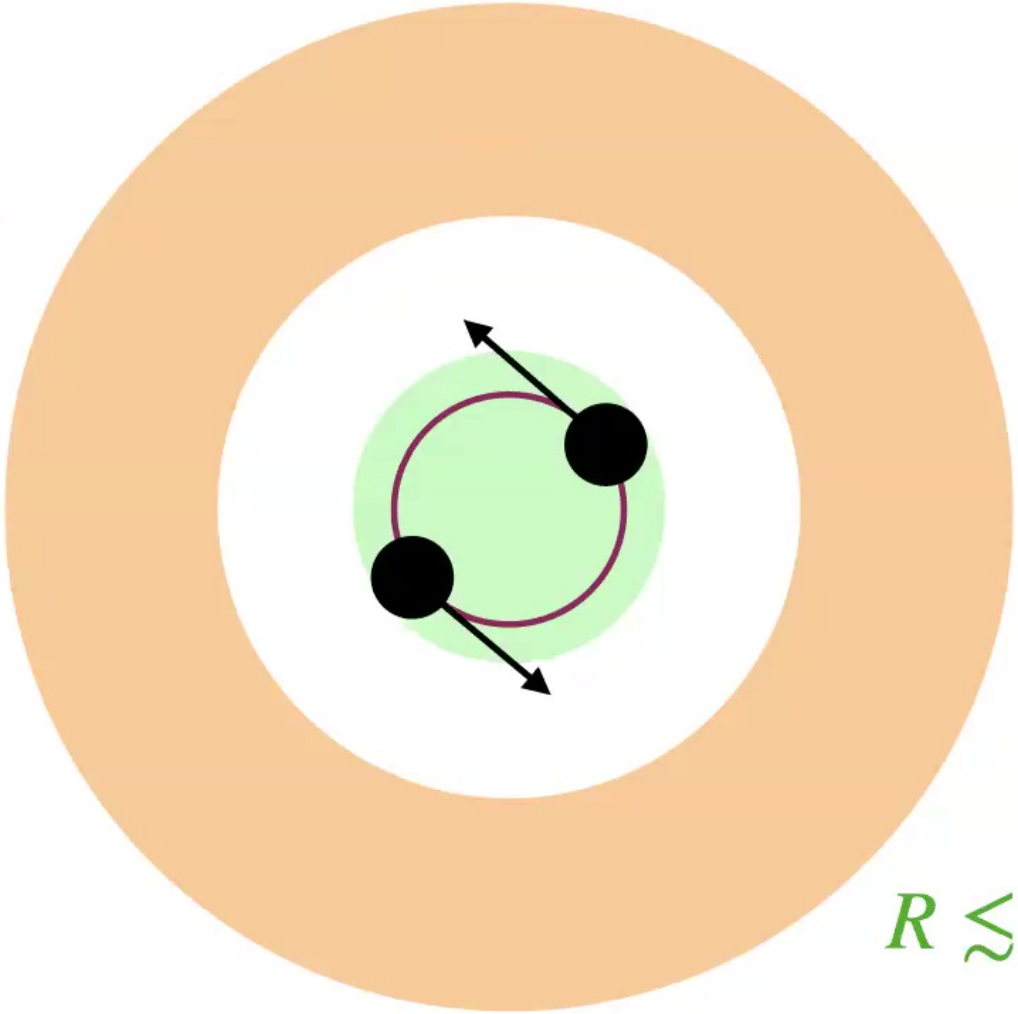


$R >$ few pc

Gonzalo Alonso-Álvarez

The final parsec problem

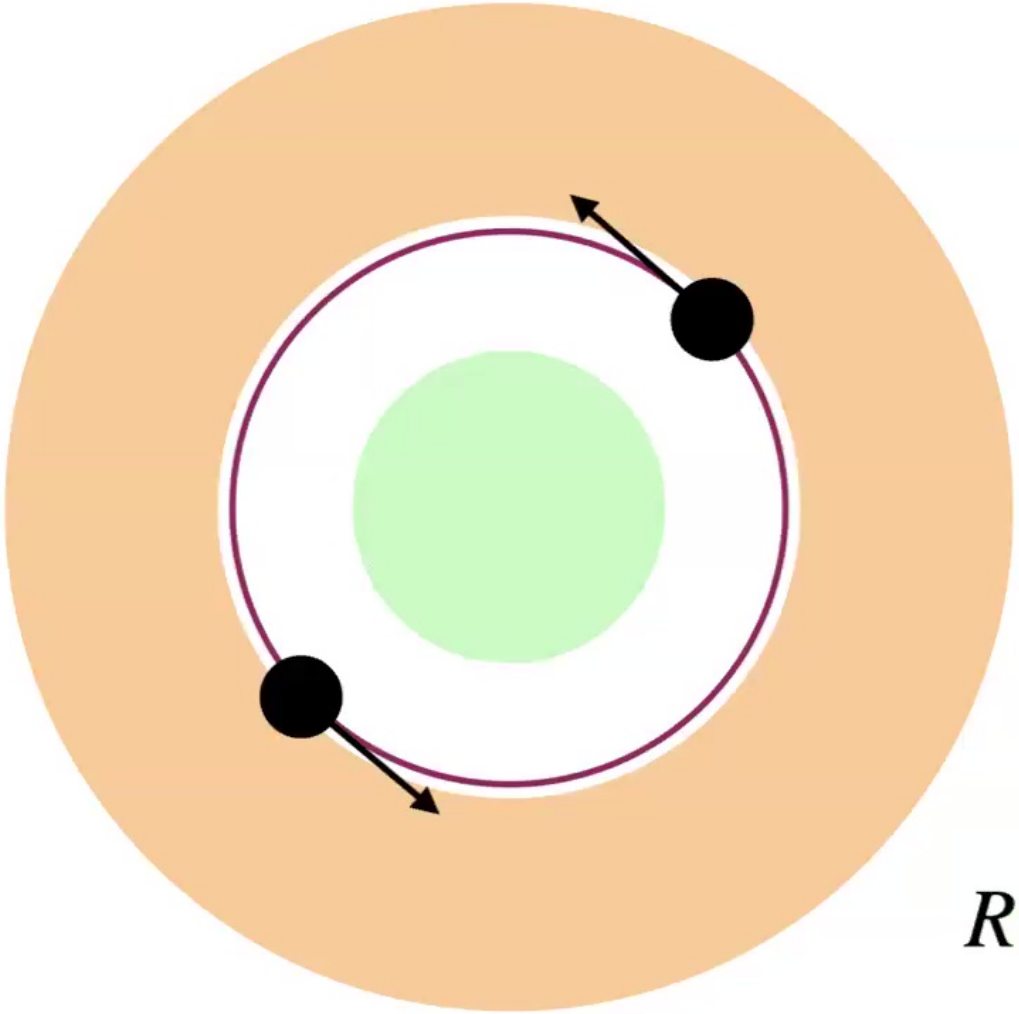
GW emission



$R \lesssim 0.1\,\mathrm{pc}$

The final parsec problem

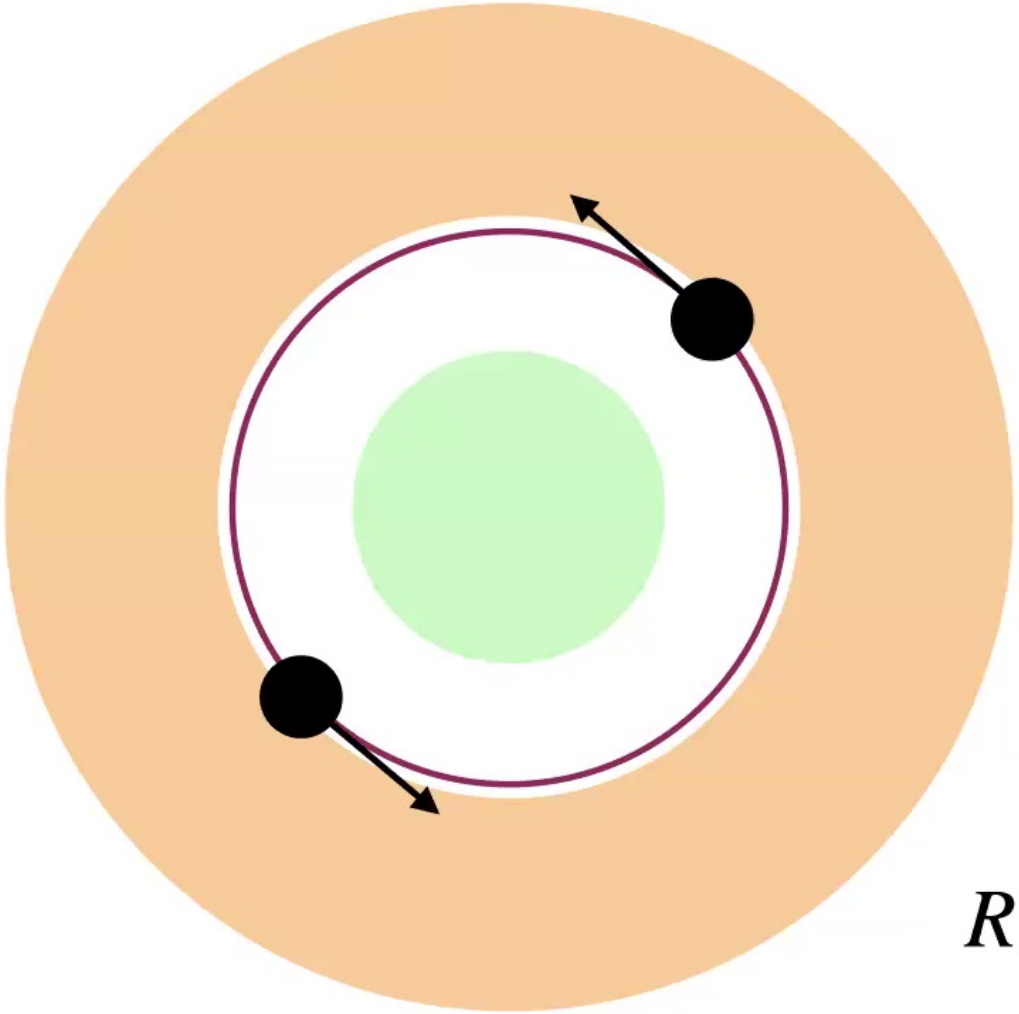
?



$R \sim \mathrm{pc}$

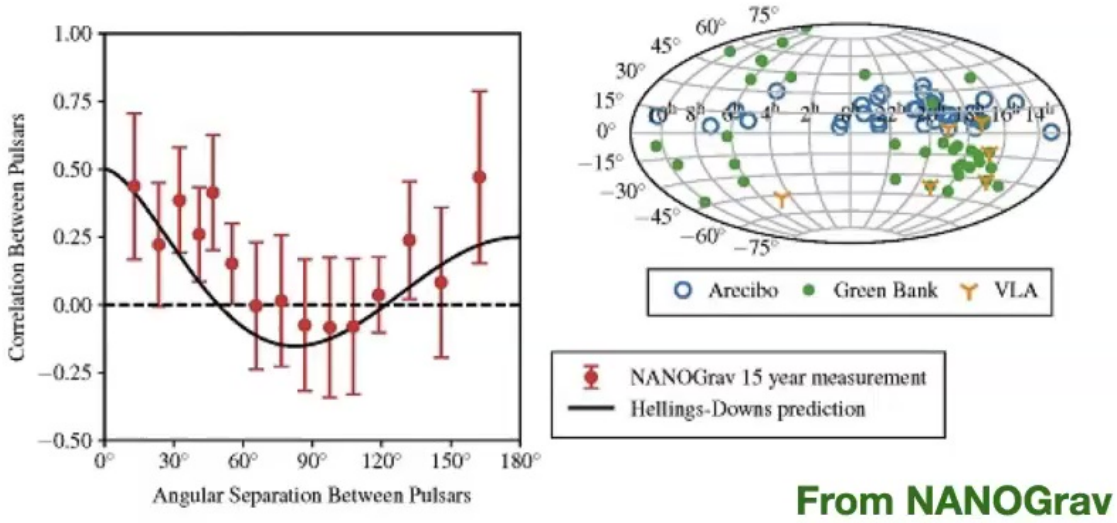
The final parsec problem?

?



$R \sim \mathrm{pc}$

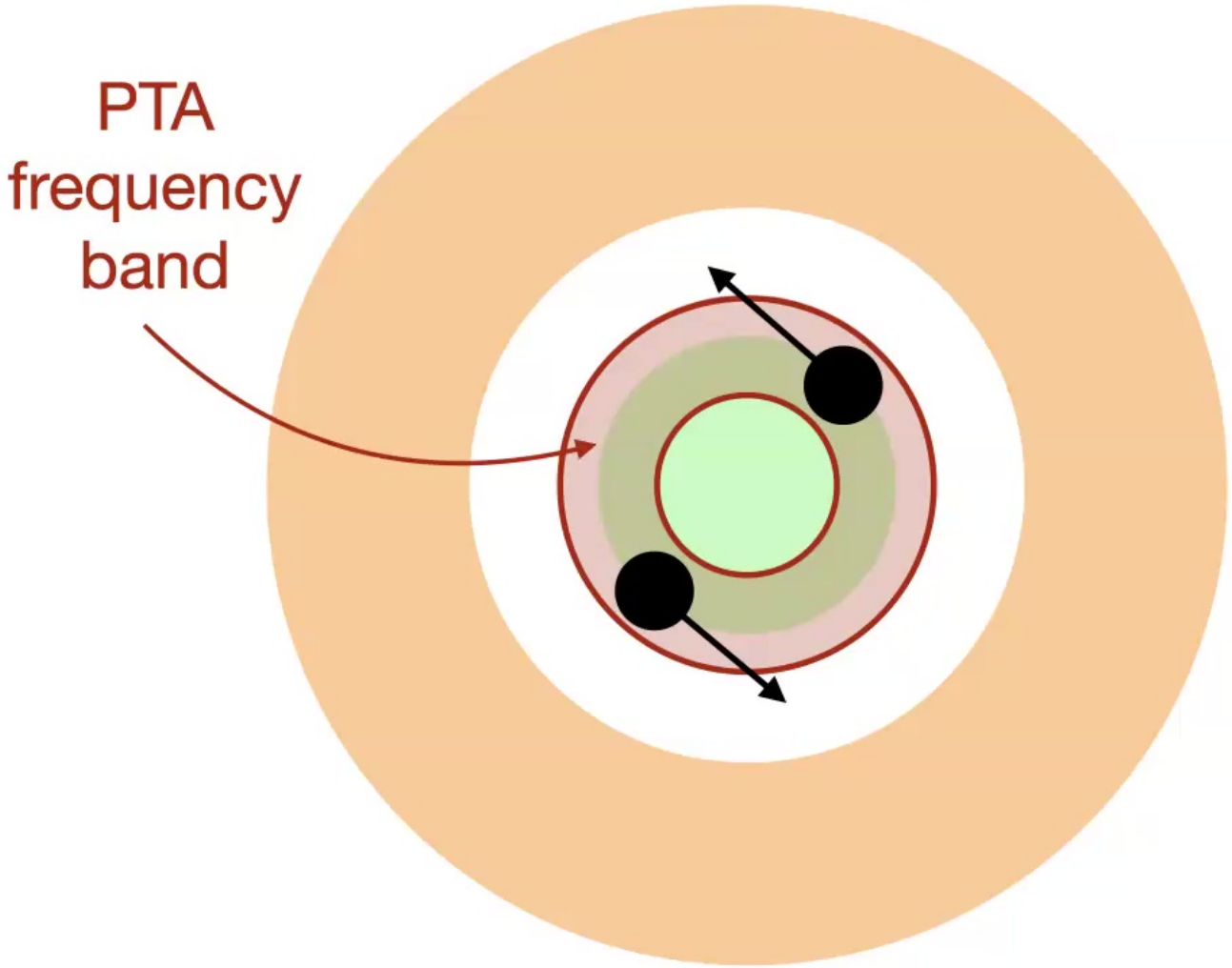
GW signal at Pulsar Timing Arrays



From NANOGrav

Plausible source:
Supermassive black hole mergers

The final parsec problem!



Gonzalo Alonso-Álvarez

Dark matter spikes around SMBH

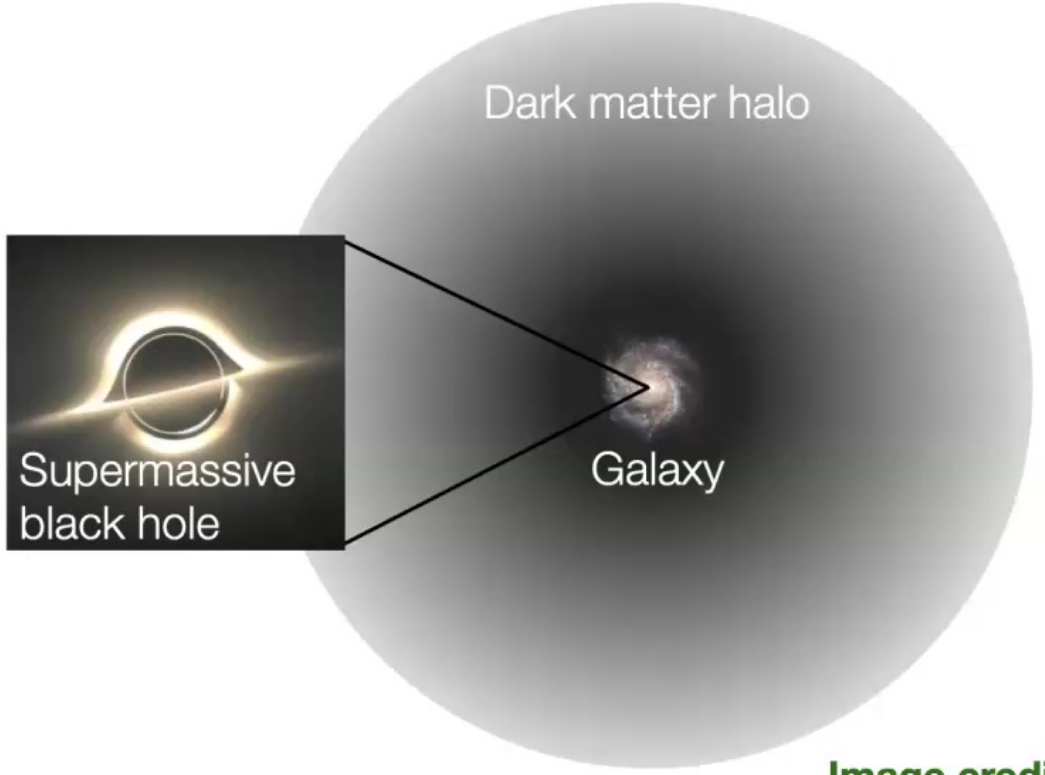
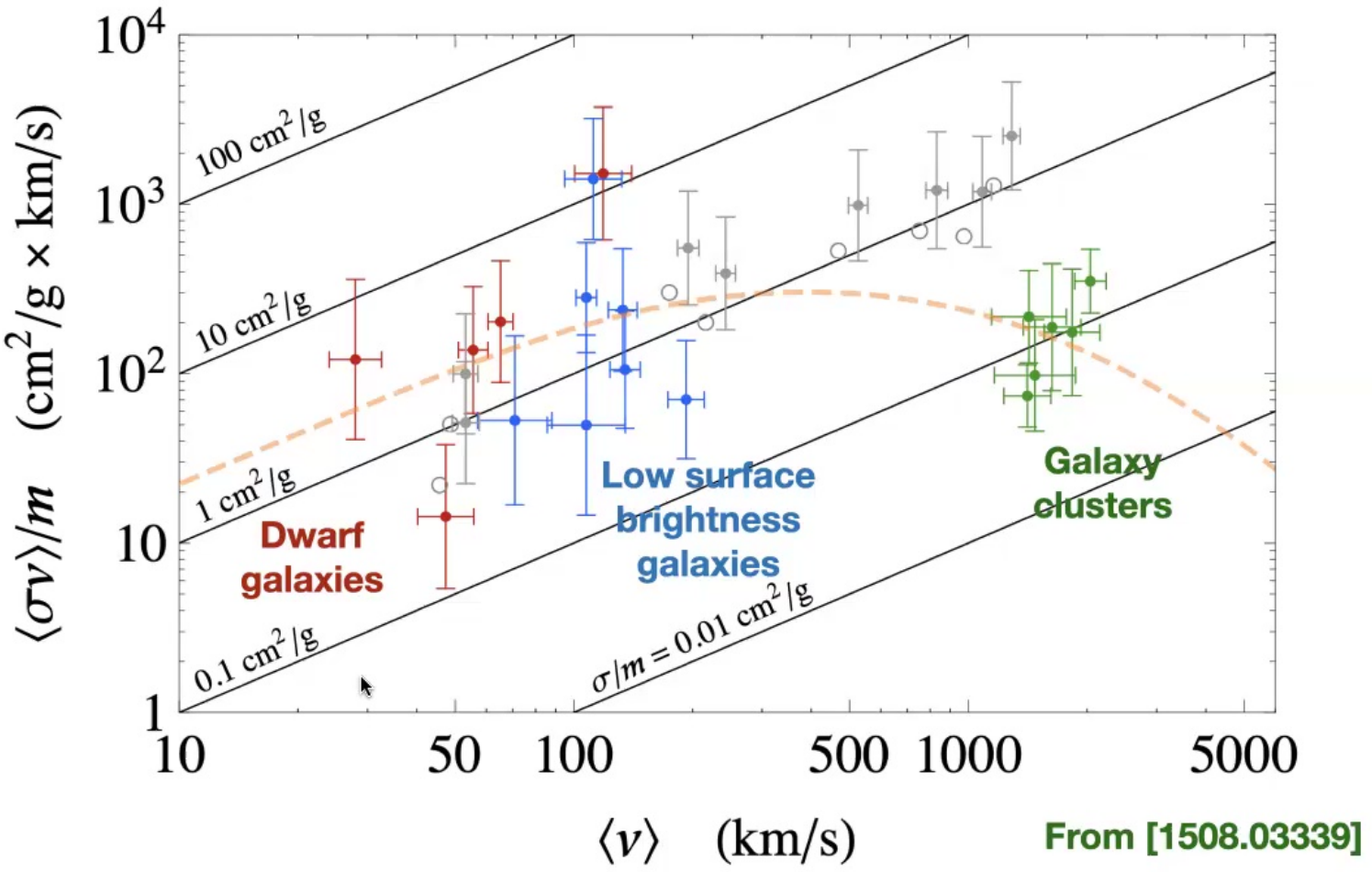


Image credit: M. Powell

DM density enhanced by gravity of SMBH

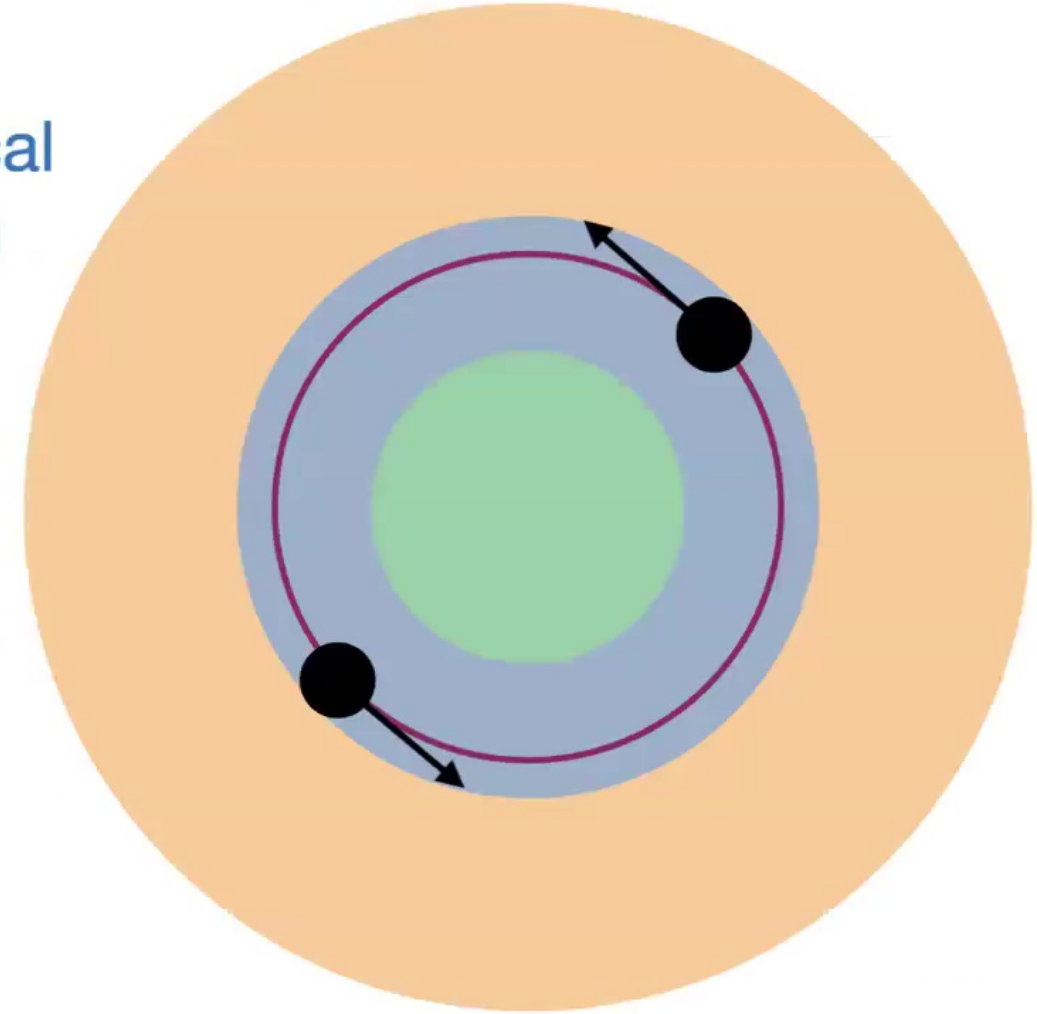
Self-interacting dark matter



From [1508.03339]

Can DM bridge the final parsec gap?

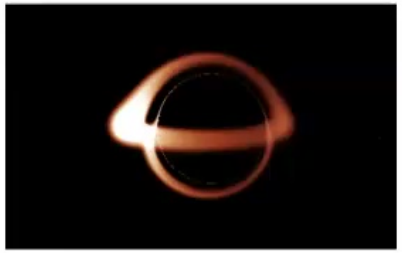
DM dynamical friction



Black hole mass to dark matter profile

NFW parameters

DM halo mass

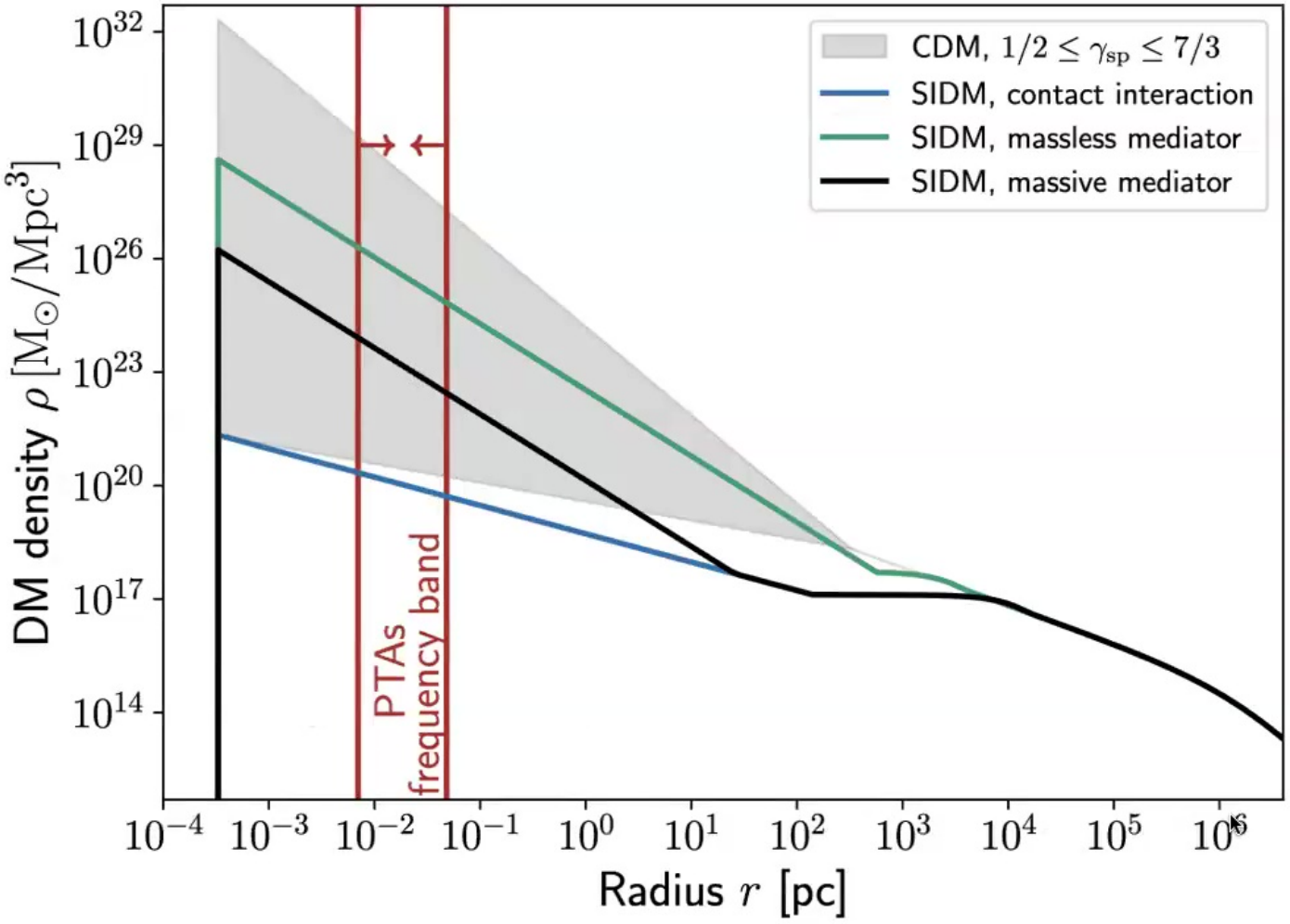


Black hole mass

Stellar bulge mass

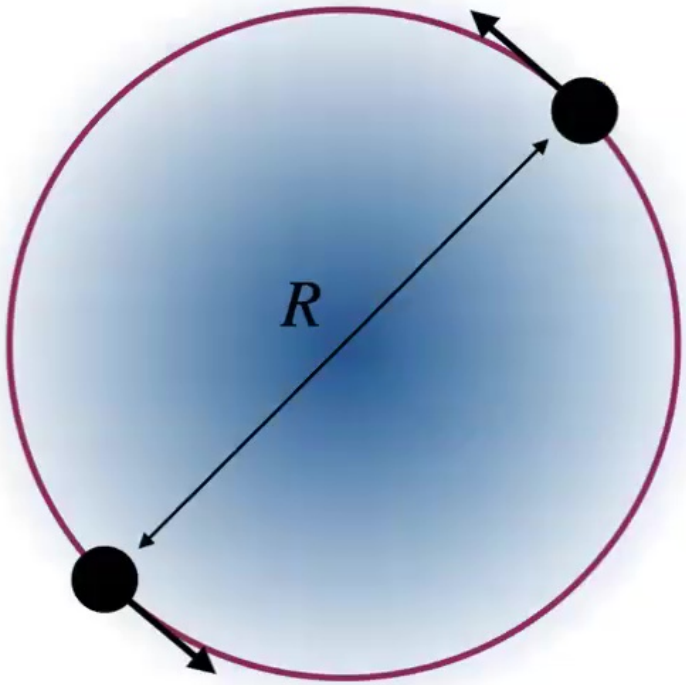
Stellar mass

Dark matter spike profile



Black hole merger dynamics

Circular orbit



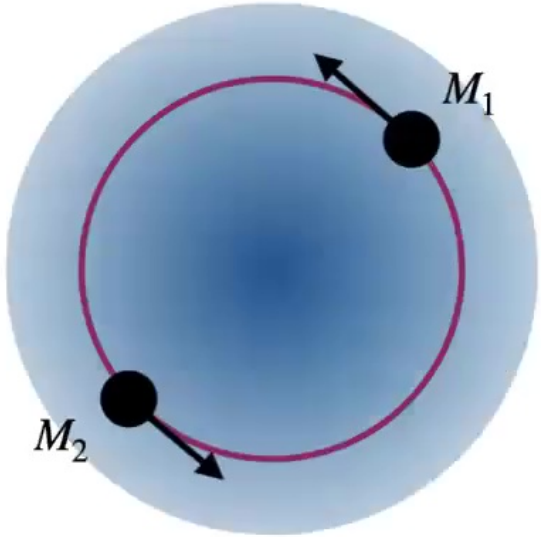
Hardening timescale

$$t_{\rm h} = \left(\frac{d \log R}{dt} \right)^{-1} \lesssim 0.5\,{\rm Gyr}$$

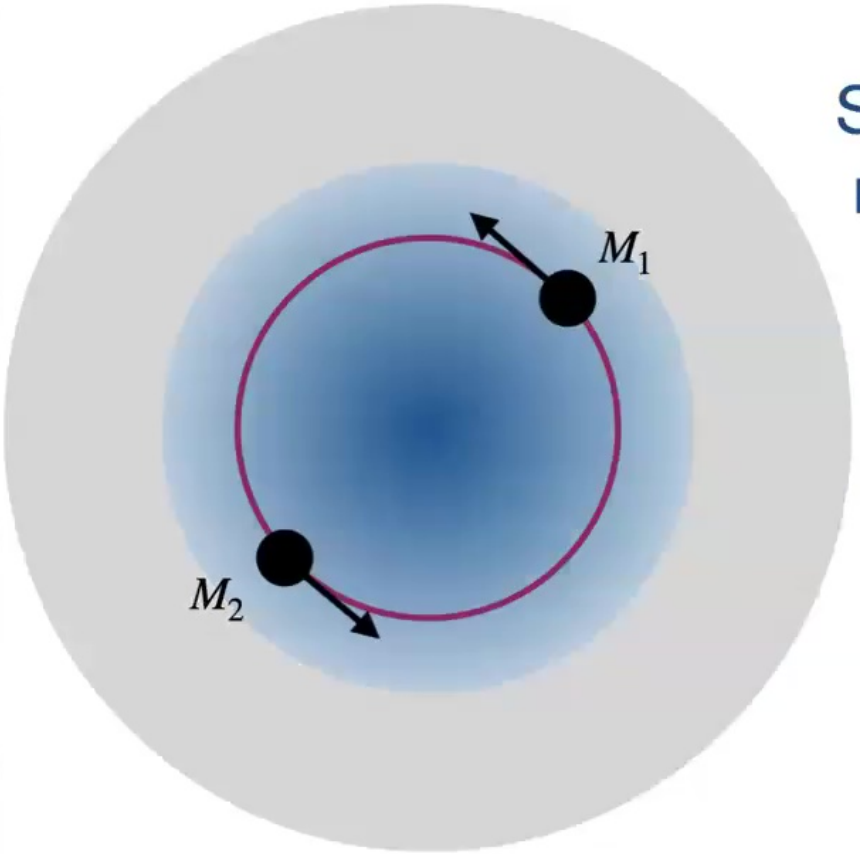
Backreaction on dark matter spike

CDM: $\Delta E_{\rm orbit} \gg U_{\rm spike}$

Spike evaporates and only replenished gravitationally



Backreaction on dark matter spike



CDM: $\Delta E_{\rm orbit} \gg U_{\rm spike}$

Spike evaporates and only replenished gravitationally

SIDM:

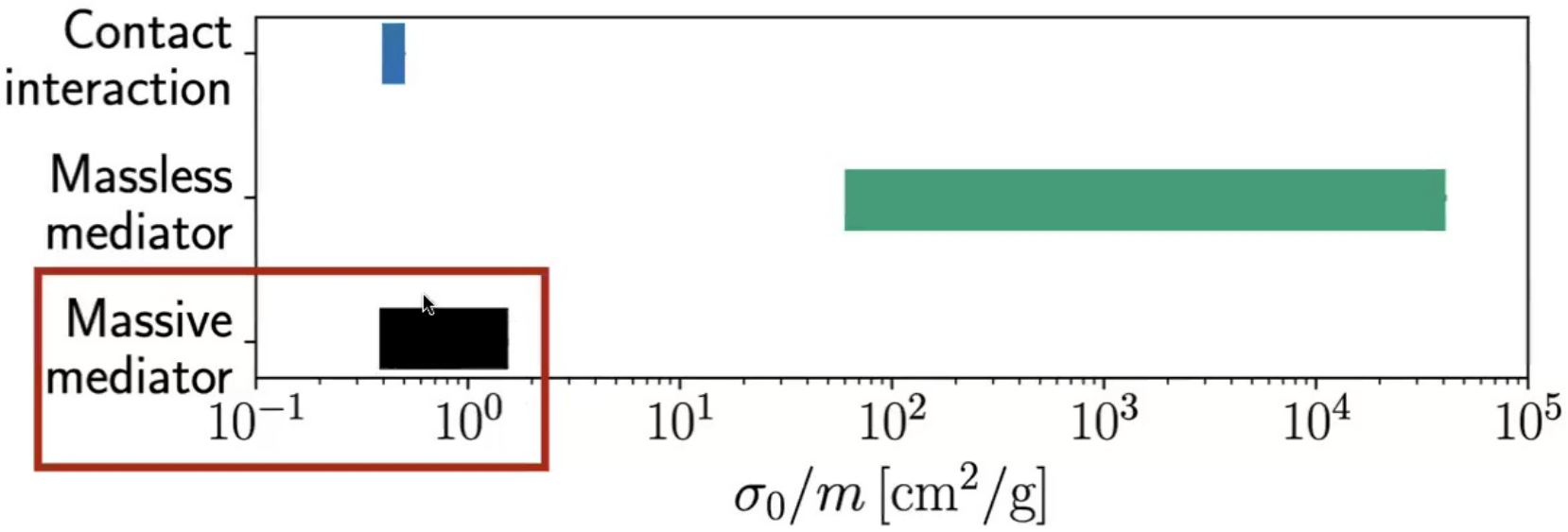
Whole core is in equilibrium with spike

$$U_{\rm core} \gg U_{\rm spike}$$

The core acts as a particle & energy reservoir

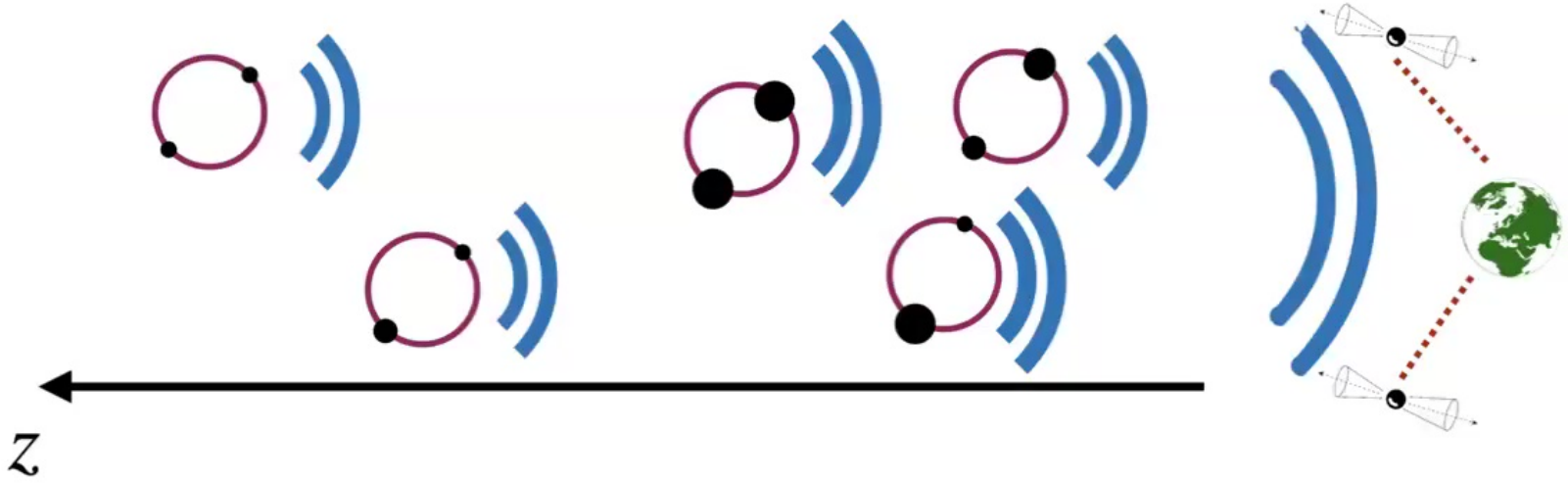
Dark matter self-interaction cross section

- Lower limit: large enough core
- Upper limit: fast enough merger

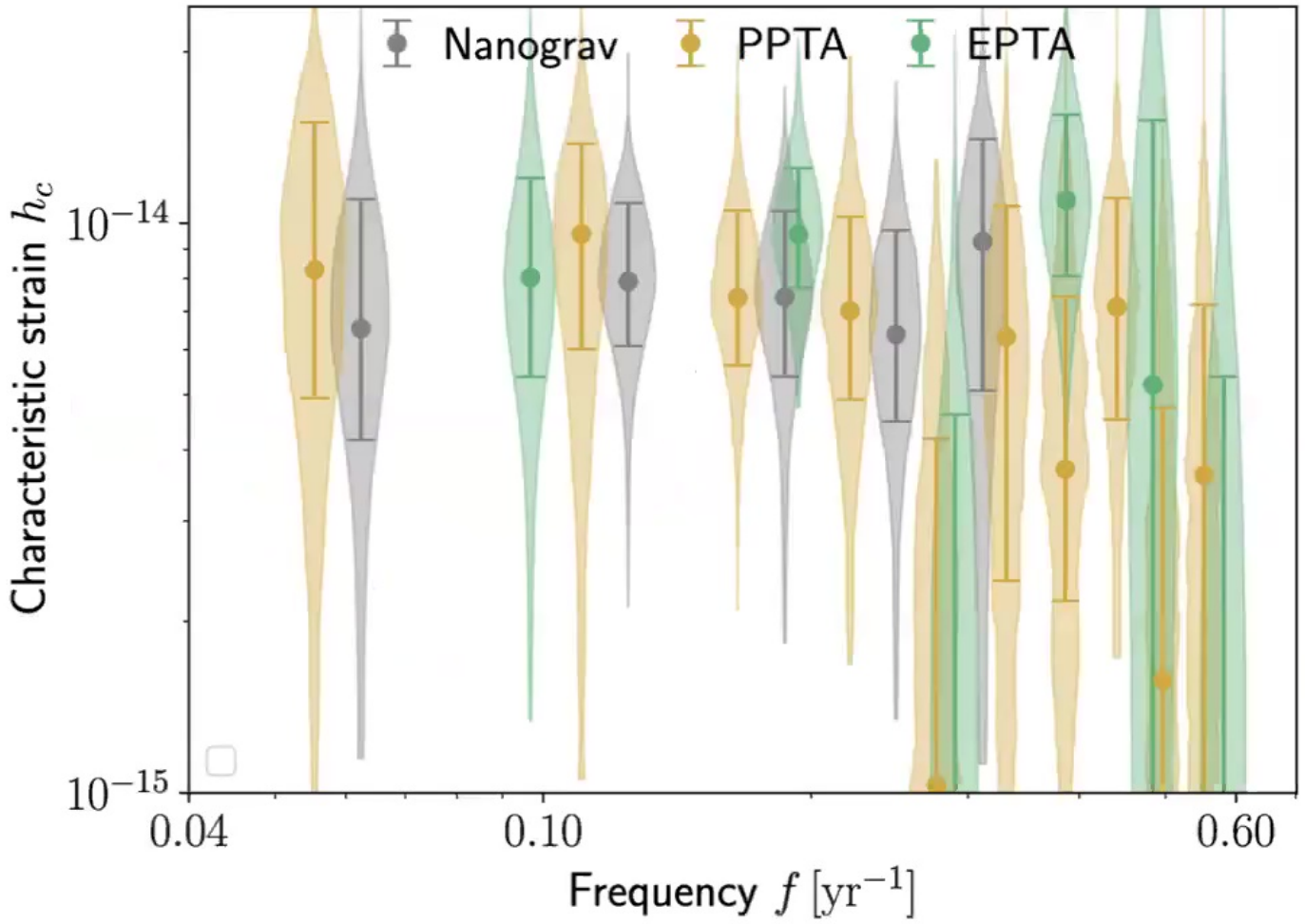


Gravitational wave spectrum

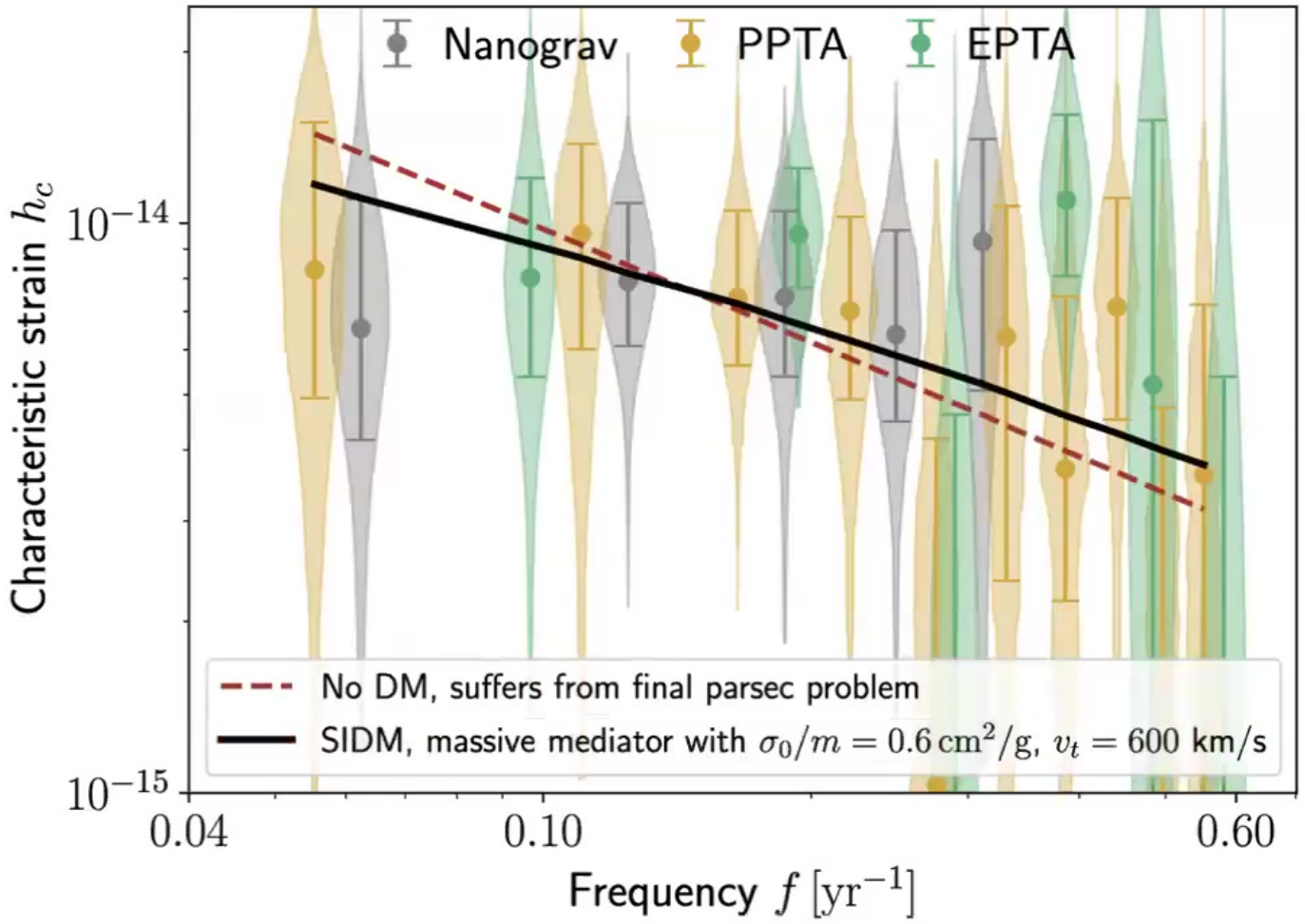
Add contributions from all SMBH mergers:



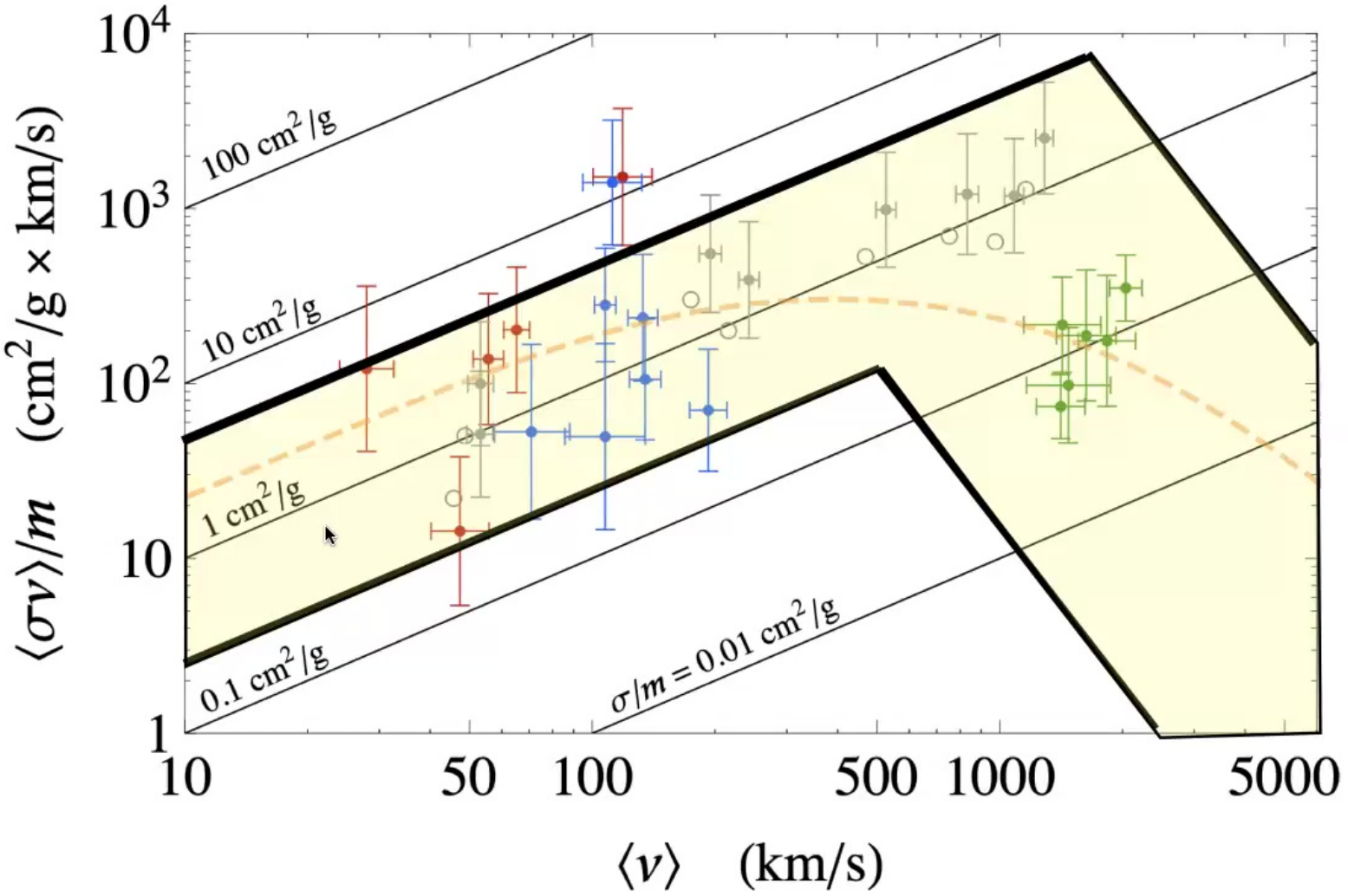
Pulsar Timing Array signal



Pulsar Timing Array signal



Comparison with small-scale structure



Conclusions

- Self-interacting dark matter solves the final parsec problem of supermassive black holes.
- Compatible with small scale structure hints.
- Correlated softening of the gravitational wave spectrum at pulsar timing arrays.