How Are the Last Parsecs Passed by Merging Supermassive Black Holes?

Chitta Ranjan Das

Bogoliubov Laboratory of Theoretical Physics (BLTP), The Joint Institute for Nuclear Research (JINR)

Monday 18 November 2024 at 11:00 A.M.

Journal: Phys. Rev. Lett. 133, 021401 (2024)

Dark-matter

Final parsec problem

- Over cosmic history, galaxies have been combining to form ever-larger formations. The supermassive black holes that reside in the centers of galaxies must eventually combine with one another to create an even more enormous black hole.
- How can supermassive black holes approach each other to the point when they spiral and coalesce? The converging holes' progress halts in calculations when they approach the so-called last parsec, which is roughly one parsec, or 3.26 light-years. They ought to almost circle one another forever.
- In-spiral times were believed to be as high as the universe's age. We were worried that there would not be any black holes merging.

Final parsec problem

- There is proof that they do combine. A background hum of gravitational waves in the universe ripples in the fabric of space-time was discovered last year through investigations of the faint movements of pulsing stars using a pulsar timing array. These gravitational waves most likely originate from supermassive black holes that are in near proximity to merging and circle snugly within a parsec of one another. This was our first proof that the final-parsec problem is indeed solved by black hole binaries.

Final parsec problem's solution

- The two black holes may become closer if dark matter takes away their angular momentum.
  - Self-interacting dark matter is a more complicated concept. The supermassive black holes might be dropped within a parsec of one another if these particles drag on them sufficiently.

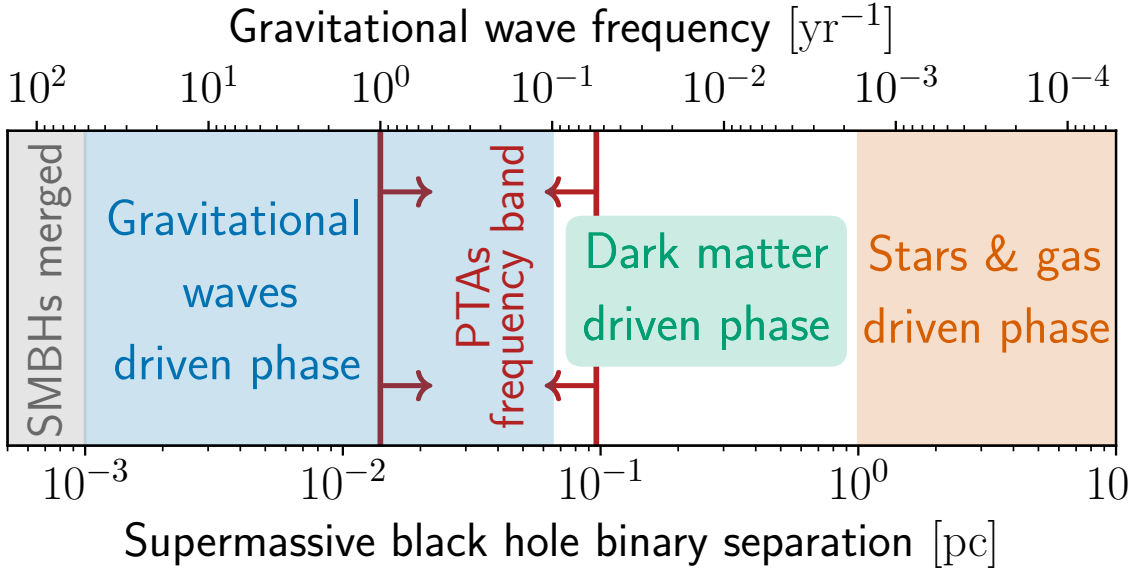
    Self-Interacting Dark Matter Solves the Final Parsec Problem of Supermassive Black Hole Mergers,
    Gonzalo Alonso-Álvarez, James M. Cline, and Caitlyn Dewar,
    Phys. Rev. Lett., **133**, *021401 (2024)*
  - Another dark matter contender that is frequently referred to as fuzzy dark matter might also work.

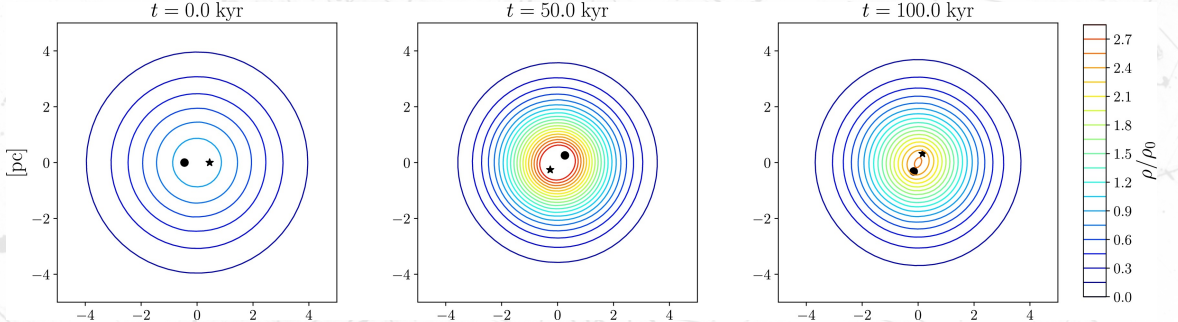
    

    Final parsec problem of black hole mergers and ultralight dark matter,
    Hyeonmo Koo, Dongsu Bak, Inkyu Park, Sungwook E. Hong and Jae-Weon Lee,
    Physics Letters B, **856**, *138908 (2024)*

Self-interacting and Ultralight or Fuzzy dark matter

- On the other hand, self-interacting dark matter is made up of light particles with at least one force between them. Particles of self-interacting dark matter would not be as readily dispersed and would instead tug at the black holes' heels, slowing them down because they scatter off one another. It has some kind of viscosity and remains there, creating friction. The final-parsec problem might then be resolved if such friction leads to a merger within 100 million years.
- Fuzzy dark matter, also known as ultralight, would be made up of particles with very small masses that would combine to create enormous waves. Additionally, these particles would be concentrated in the galactic center and encounter friction with the black holes, which would enable the fuzzy dark matter to effectively remove their orbital energy and angular momentum. Instead of dispersing, this dark matter would vibrate due to the black holes.


Gravitational wave frequency $[\mathrm{yr}^{-1}]$
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
SMBHs merged
Gravitational waves driven phase
PTAs frequency band
Dark matter driven phase
Stars & gas driven phase
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Supermassive black hole binary separation $[\mathrm{pc}]$


$t = 0.0$ kyr
$t = 50.0$ kyr
$t = 100.0$ kyr
[pc]
ρ/ρ_0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0

Dynamical friction

- The two supermassive black holes in a merging galaxy gradually approach one another because of gravitational interactions with stars, gas, and dark matter.
- Dynamical friction turns out to be ineffective at distances ranging from a fraction of a parsec to a few parsecs, depending on the masses of the black holes. The two black holes in the heart of the forming galaxies consume matter and then hurl it away, creating a hole. The sharp decline in star and gas density leaves the black holes in relatively empty space. Then, without anything to slow them down, they ought to presumably circle one another indefinitely.
- Unless anything is removing this energy, they are kept from falling by the orbit's conservation of angular momentum.