Hidden Friend's Wake: Dark Matter and a Binary at the Galactic Center*

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Abstract

Recent dynamical evidence suggests that Sgr A*, the massive object at the center of the Milky Way, may be a binary of two black holes rather than a single black hole. The existence of such a binary has dynamical consequences for the distribution of dark matter at the galactic center (GC), with dramatic implications for dark matter (DM) annihilation signals. We show that the existence of a binary companion would significantly relax constraints on the dark matter annihilation cross section from the galactic center and would substantially weaken the case for dark matter annihilation as the origin of the claimed galactic center excess.

The Hidden Friend's Wake

Our Milky Way

. Central black hole, **Sagittarius A*** (Sgr A*)

. Particulate **Dark Matter** agglomerates towards center

. Dark matter density spikes → annihilation signatures

. Spike sensitive to perturbations (e.g., binary companion)

. **Sgr A* not alone**

Galaxy Formation

. Galaxies **coalesce** during collisions

. Galaxy centers contain **seedling black holes**

. **Sgr A* merging with companion black hole** (constrained by observation)

. New scientific instruments & data (EHT, orbital stability constraints, etc.)

What *if* a companion black hole to Sgr A* exists in our Milky Way?

→ Dark matter distribution

→ Dark matter self-annihilation luminosity

How does a companion black hole affect the density spike in our own galaxy?

Analytic Solution

Single Black Hole Case

Gondolo, P., Silk, J. (1999). Dark Matter Annihilation at the Galactic Center.

$$\rho(r) = \rho_0 \left(\frac{r}{r_0}\right)^{-\gamma}, \quad 0 < \gamma < 2 \quad \xrightarrow{\text{adiabatic}} \quad \rho'(r) \approx \rho_R \left(\frac{R_{sp}}{r}\right)^{\gamma_{sp}}, \quad 2.25 \le \gamma_{sp} \le 2.5$$

. Modified power law $\rho'(r)$ with evolved parameters

. New slope parameter γ_{sp} is **strictly steeper** than γ

. Dark matter **self-annihilation** depletes inner halo

. Maximal density set by annihilation: $\rho_{core} = \dfrac{m}{\sigma v \cdot t_{bh}}$

→ m mass of dark matter

→ σv cross-section · velocity

→ t_{BH} age of black hole (Sgr A* $\sim 10^{10}$ yrs)

Single Black Hole Case

Gondolo, P., Silk, J. (1999). Dark Matter Annihilation at the Galactic Center.

. Final dark matter density profile: $\rho_{sp}(r) = \dfrac{\rho'(r)\rho_{core}}{\rho'(r) + \rho_{core}}$

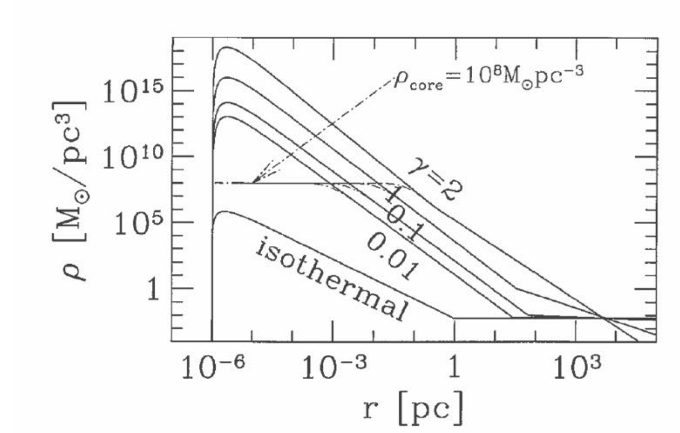


FIG. 1. Examples of spike density profiles.

GC Companion Effects

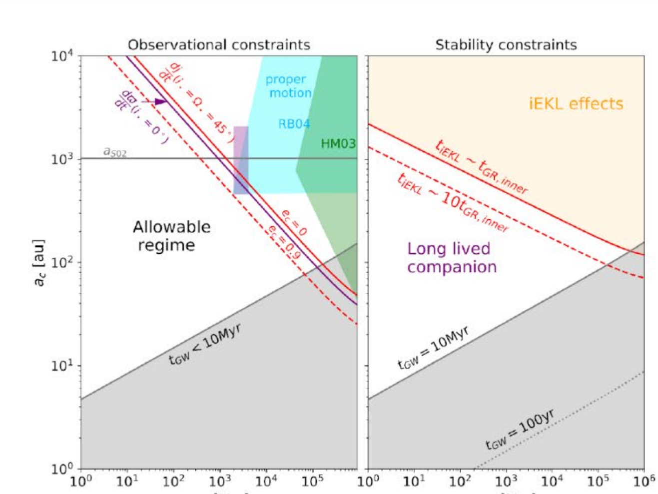
Sgr A* Hidden Friend

Justification for inquiry:

. **Galaxy formation** hierarchy

. Further **orbital configuration** constraints

Naoz, S., et al. (2019). A Hidden Friend for the Galactic Center Black Hole, Sgr A*.



Binary Black Hole System

Kavanagh, B., et al. (2020). Detecting dark matter around black holes with gravitational waves: Effects of dark-matter dynamics on the gravitational waveform

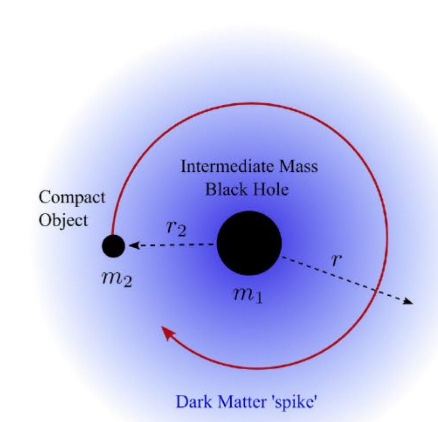
. Dark matter exerts **dynamical friction** force

. Energy conservation:

$$\frac{dE_{orb}}{dt} = -\frac{dE_{GW}}{dt} - \frac{dE_{DF}}{dt}$$

$$\frac{dE_{GW}}{dt} = \frac{32G^4M(m_1m_2)^2}{5(cr_2)^5}$$

$$\frac{dE_{DF}}{dt} = 4\pi(Gm_2)^2\rho_{DM}(r_2)\xi(v)v^{-1}\log\Lambda$$



. Orbital energy → dark matter halo → **density coring** effect

Hidden Friend's Effects

. Simplifying assumptions:

→ **static** r_2, binary separation (further research necessary)

→ **Hollowed halo** in response to energy injection

. **Scouring radius** set by dynamical friction:

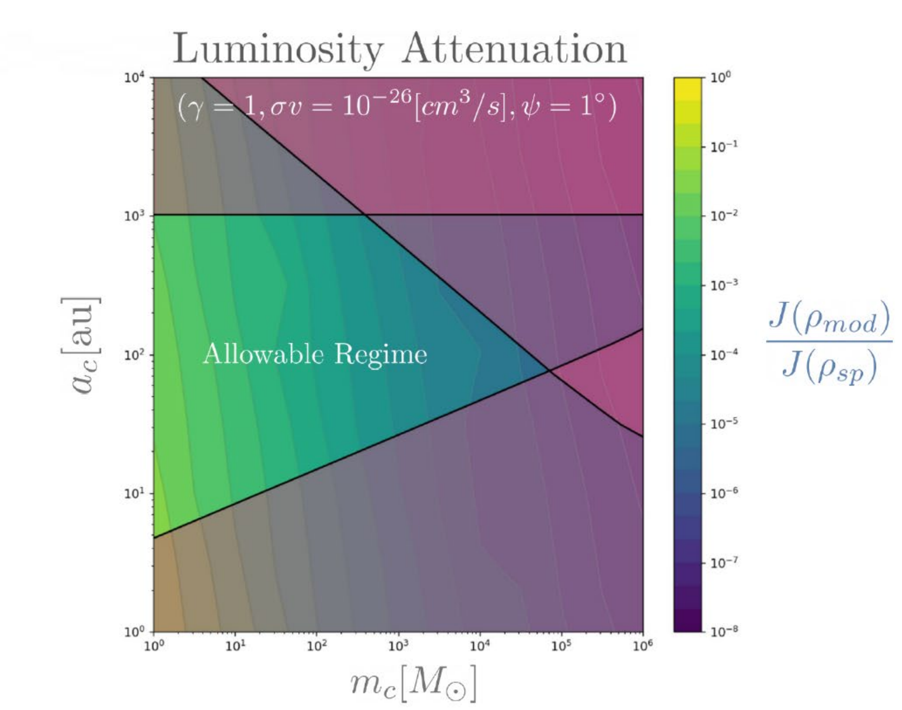
$$r_{sc} \rightarrow E_{BE}(r^*) = \Delta E(r^*)$$

. Final, **modified** dark matter density profile:

$$\rho_{mod}(r) = \begin{cases} 0 & r < r_{sc} \\ \rho_{sp}(r) & r > r_{sc} \end{cases}$$

. Annihilation luminosity, **J-factor** ratio $\sim \dfrac{J(\rho_{mod})}{J(\rho_{sp})}$

$$J(\Delta\Omega, \psi) \approx \int dl(\psi)(\rho_{DM})^2$$



Conclusion

There are many interesting prospects for the existence and detection of a companion black hole in our Milky Way, and we have explicitly estimated the impact of such an object on any DM spike that might have formed in our galaxy.

References

[1] Gondolo, P., Silk, J. (1999). Dark Matter Annihilation at the Galactic Center.

[2] Kavanagh, B., et al. (2020). Detecting dark matter around black holes with gravitational waves: Effects of dark-matter dynamics on the gravitational waveform

[3] Naoz, S., et al. (2019). A Hidden Friend for the Galactic Center Black Hole, Sgr A*.