Dark-matter “spikes” in Milky Way X-ray binaries

Based on 2510.11635 – Phys. Rev. D 113, 043043 (2026)
In collaboration with **B.J. Kavanagh**

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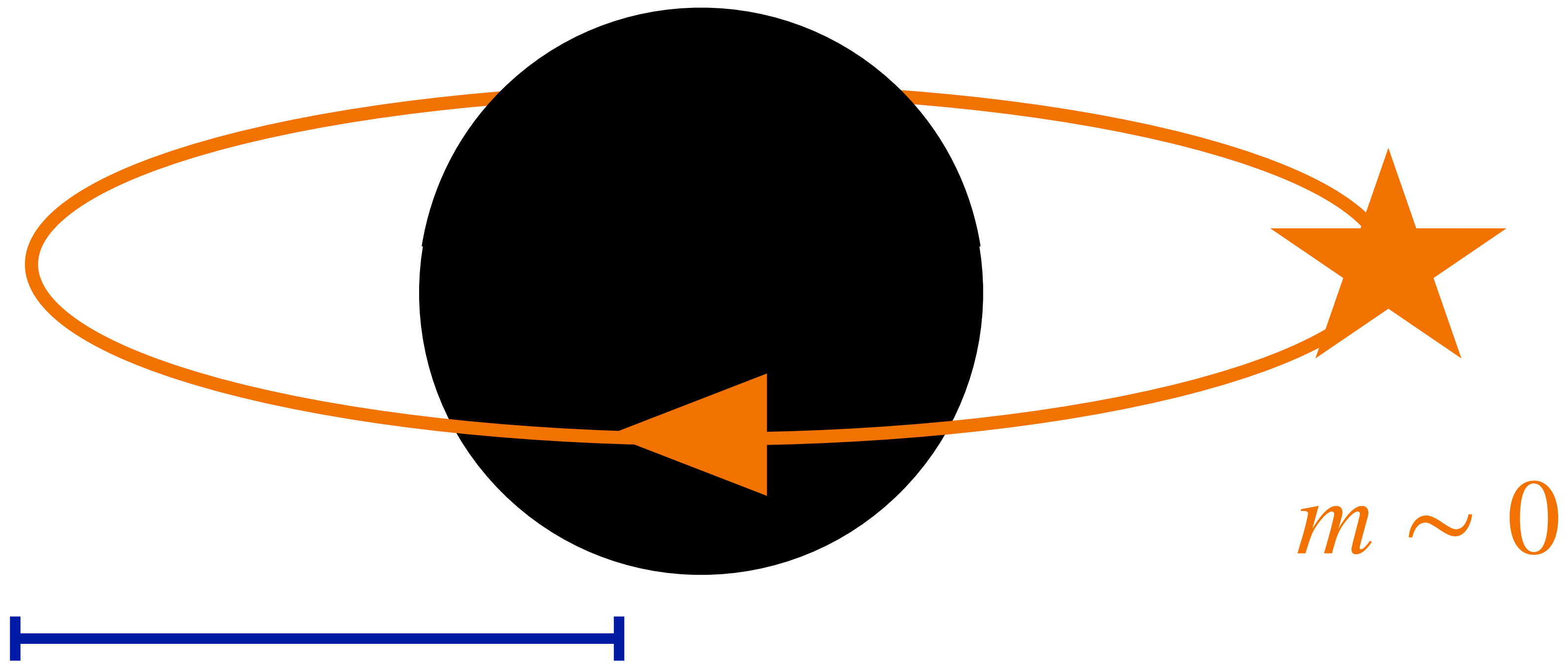
CSIC
Consejo Superior de Investigaciones Científicas

Low-mass Black-Hole X-Ray binaries

$M \sim 5 - 10\, M_\odot$



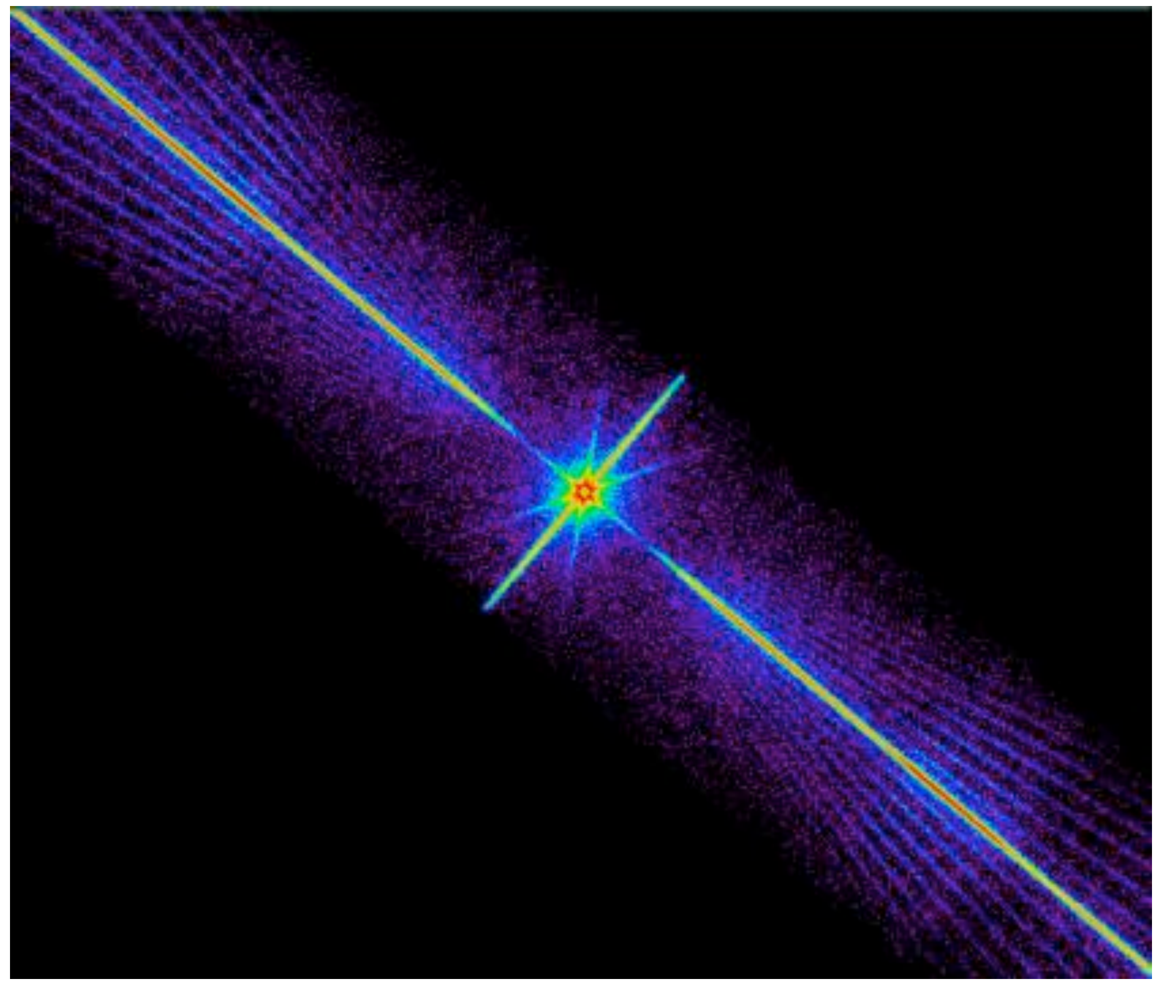
$m \sim 0.1 - 0.9\, M_\odot$

$r \sim 10^{-2}$ AU

~20 observed

~1 kpc from Sun

Period $P \sim$ few hours



XTE J1118+480 [Chandra]

Three measured period decay rates $\dot{P}$

$\rightarrow$ ***all three anomalously large***

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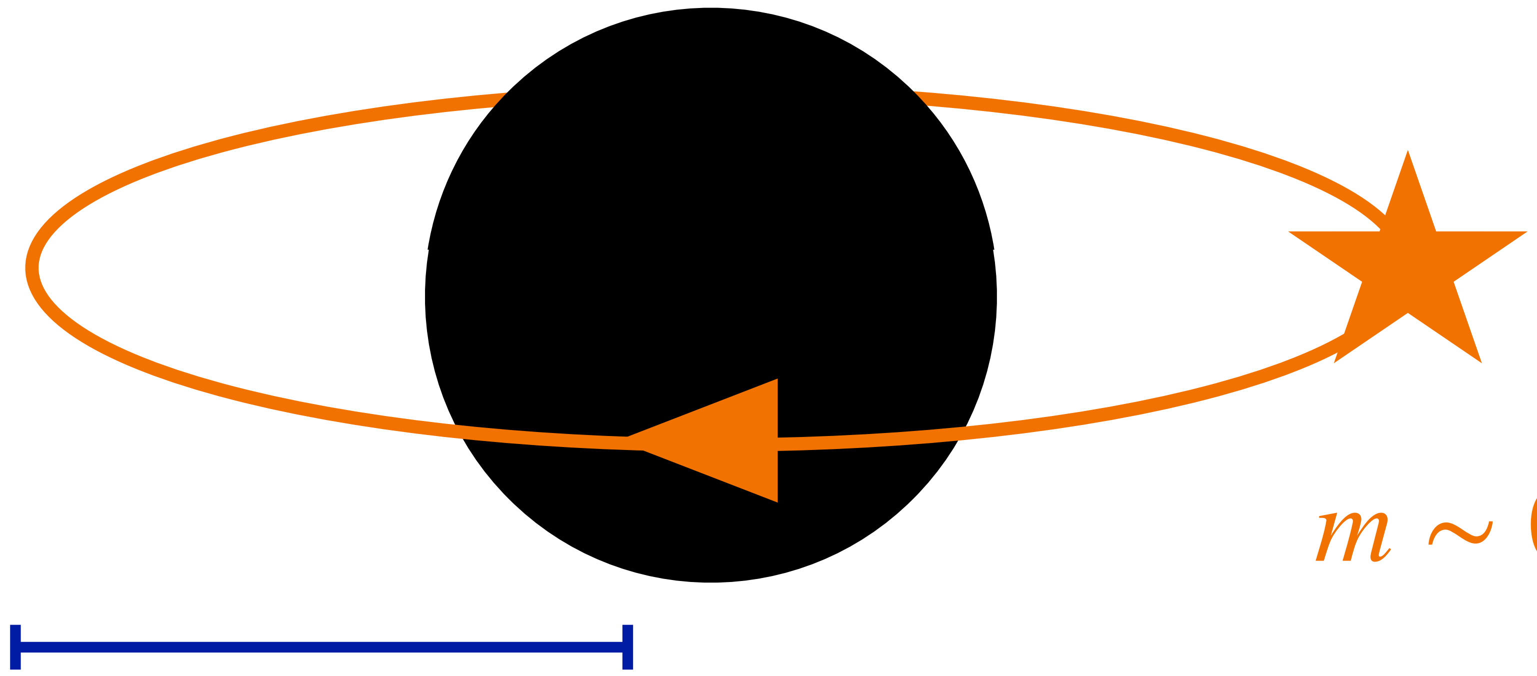

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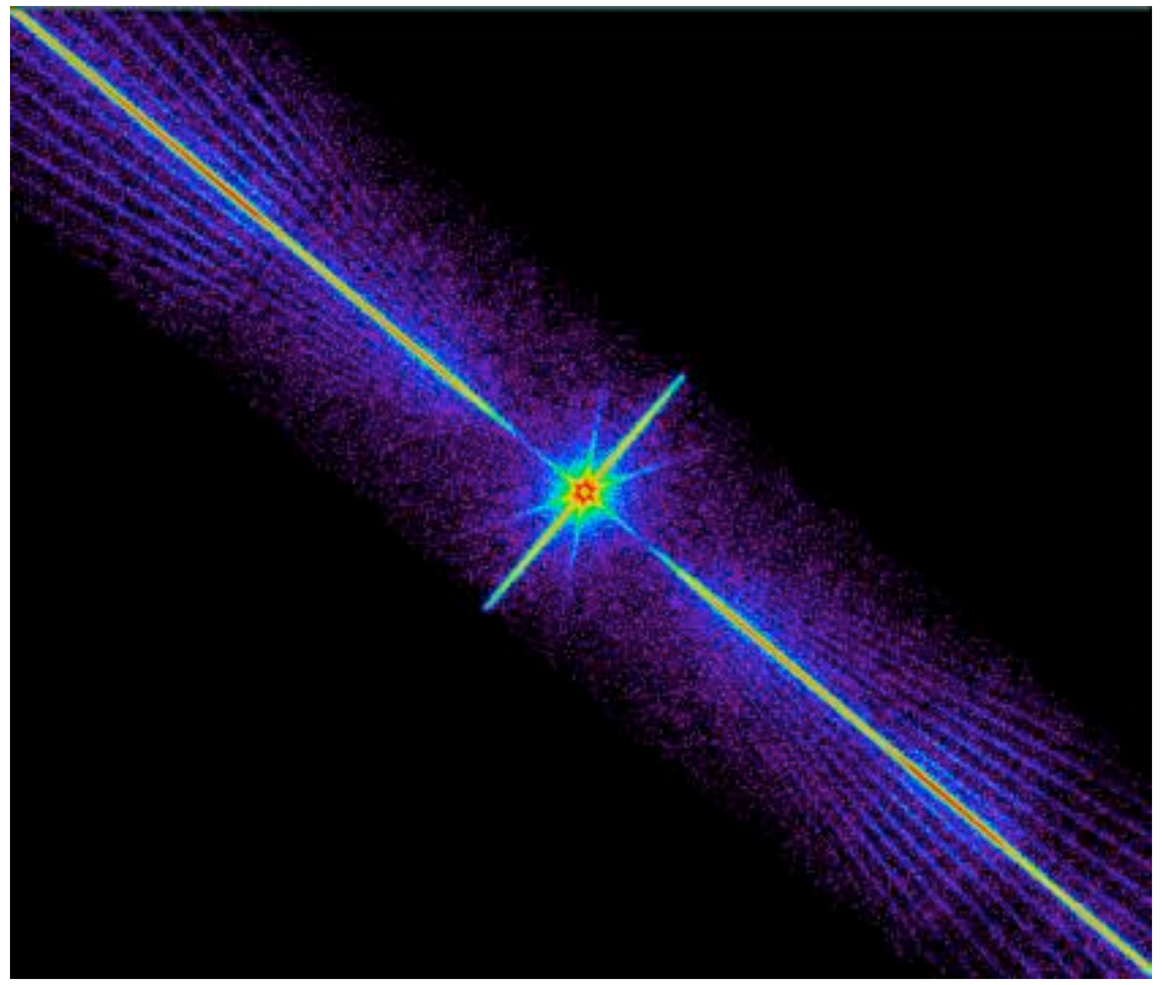


XTE J1118+480 [Chandra]

Three measured period decay rates $\dot{P}$

→ ***all three anomalously large***

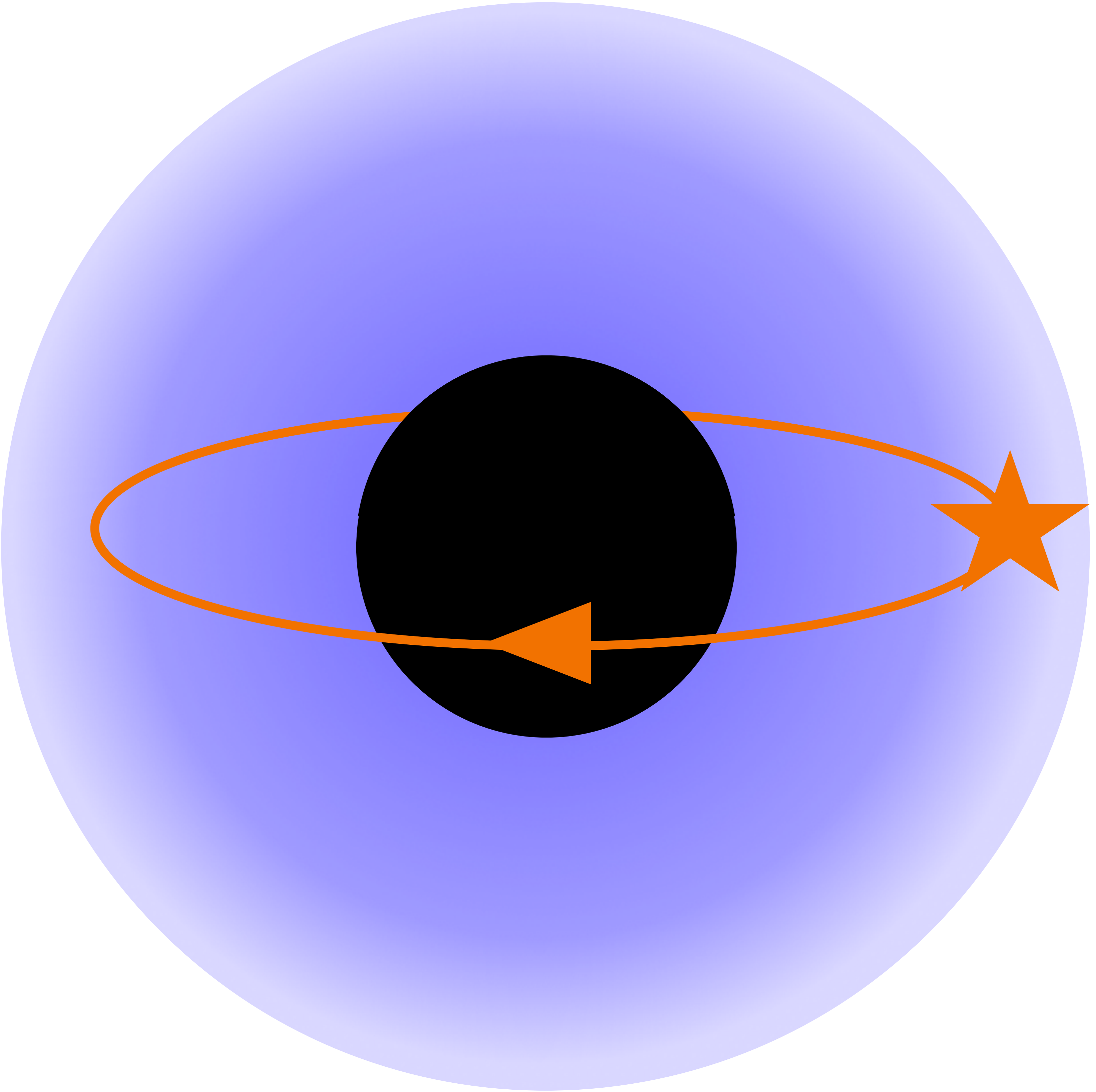
System A) } $\sim 10\times$ expected
System B) }

System C) $\sim 100\times$ expected

Gonzalez Hernandez et al. 2011,2013,2016
A) XTEJ1118+400 B) A0620-00 C) NM1991

Gondolo & Silk 1999

*Dark Matter "**spikes**"*



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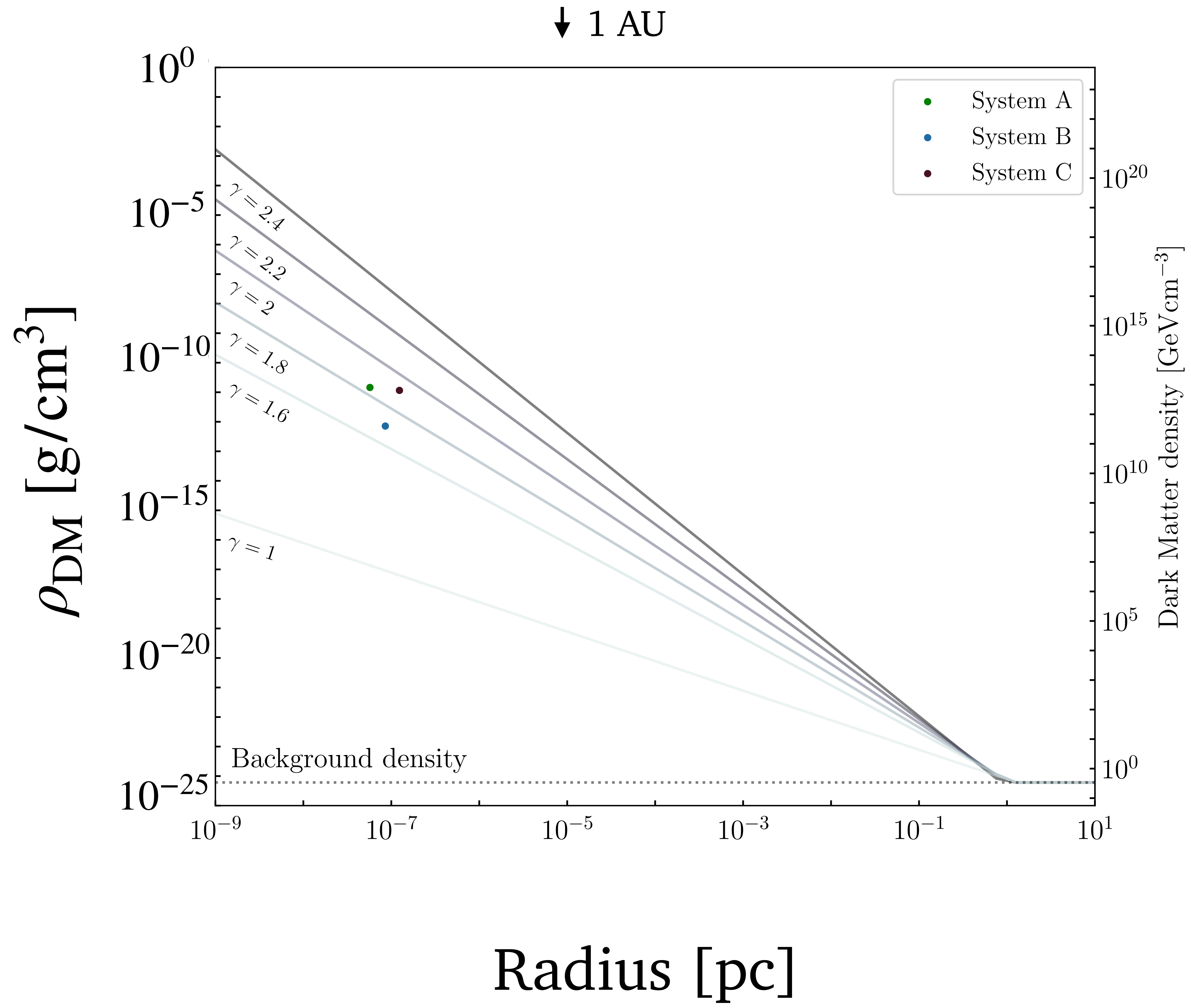

..are dark matter spikes responsible for the anomalies ?

Chan & Lee 2212.05664

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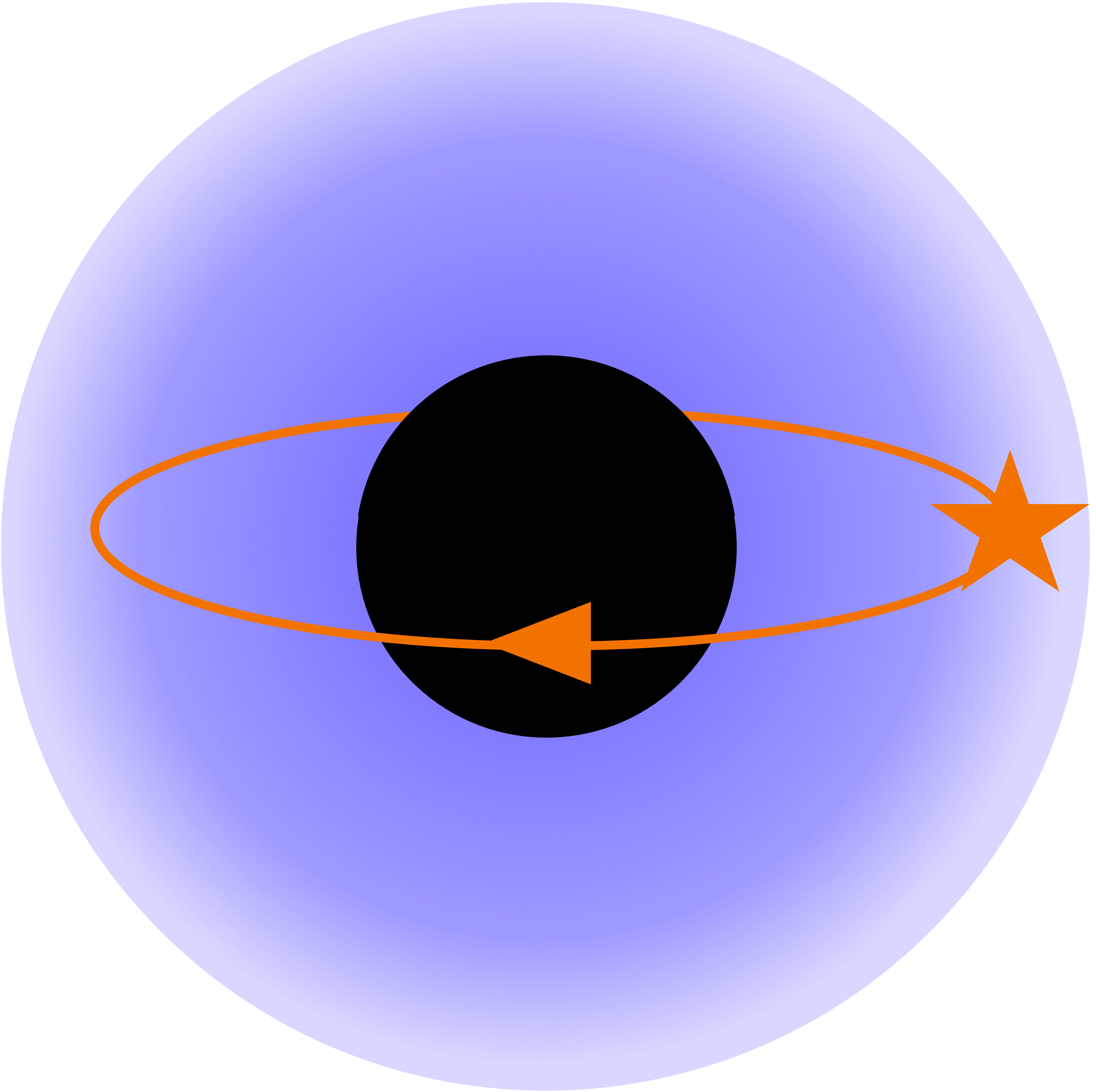

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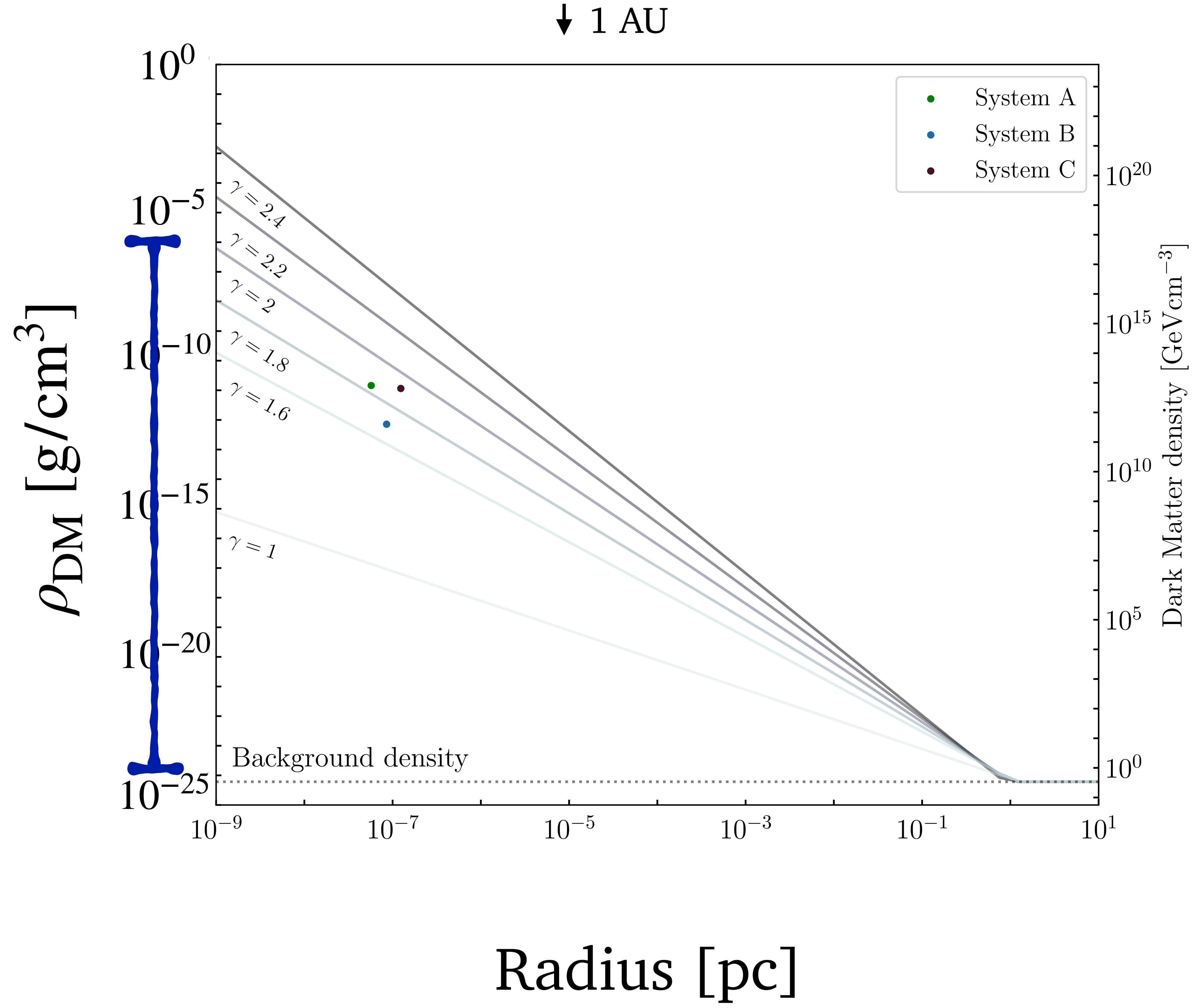

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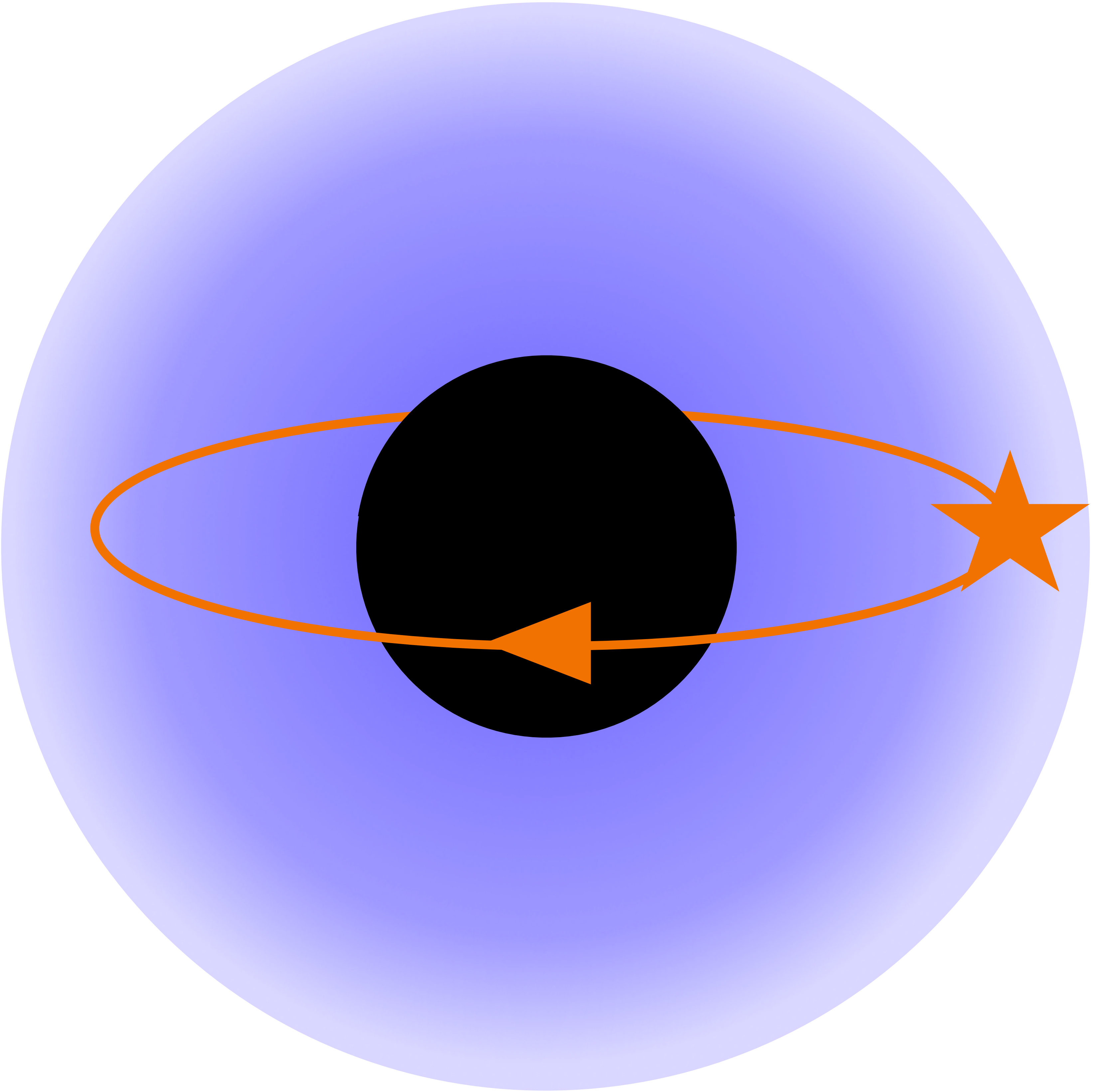
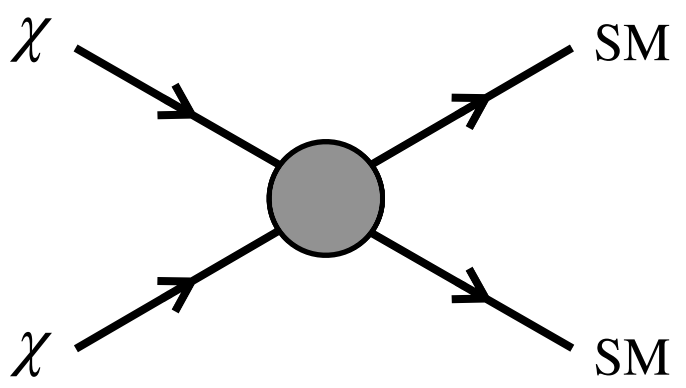


$\sim \rho_{\rm DM}^2$



Gondolo & Silk 1999
Bertone et al. 2005

De Almeida et al
2603.16559

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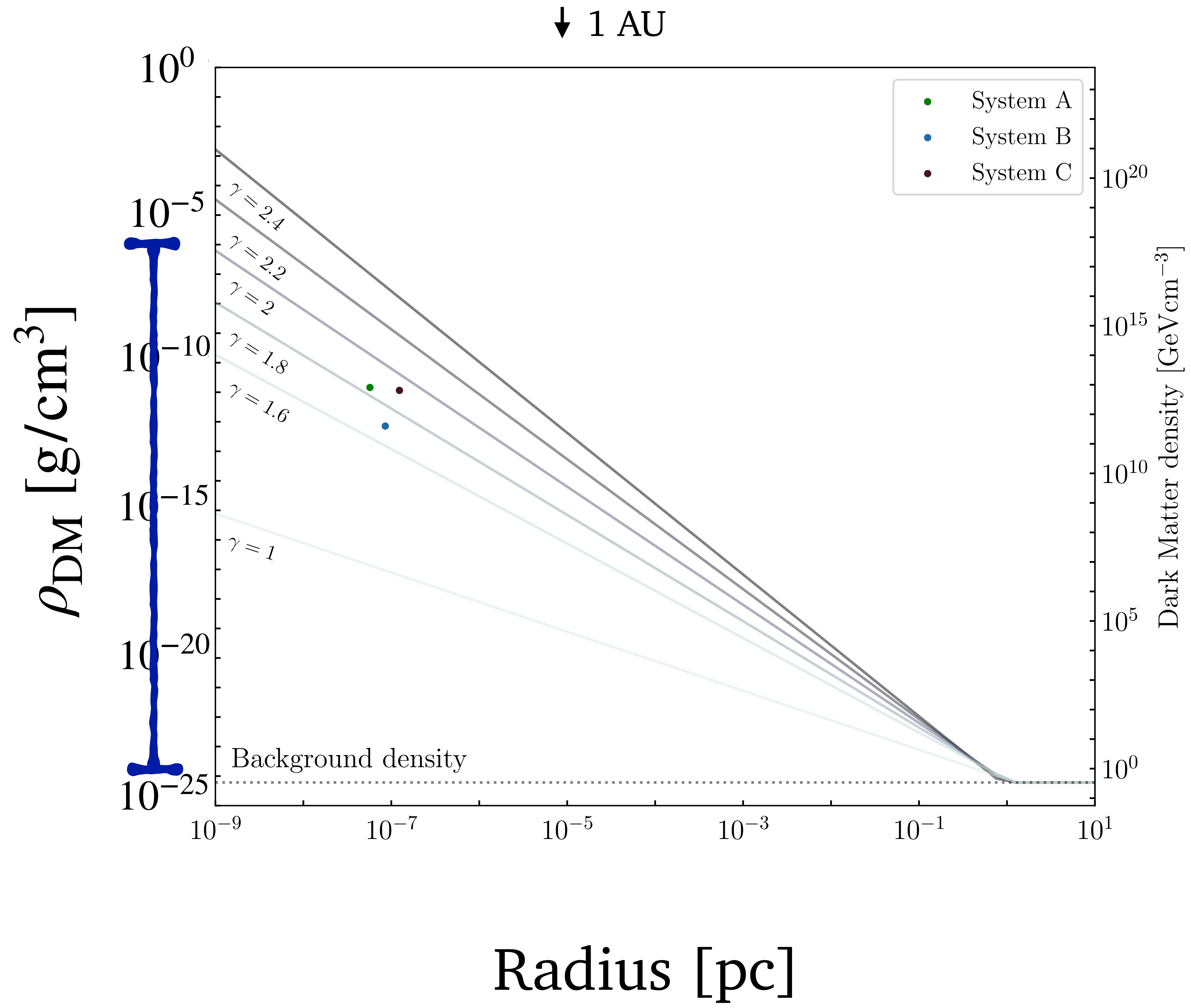

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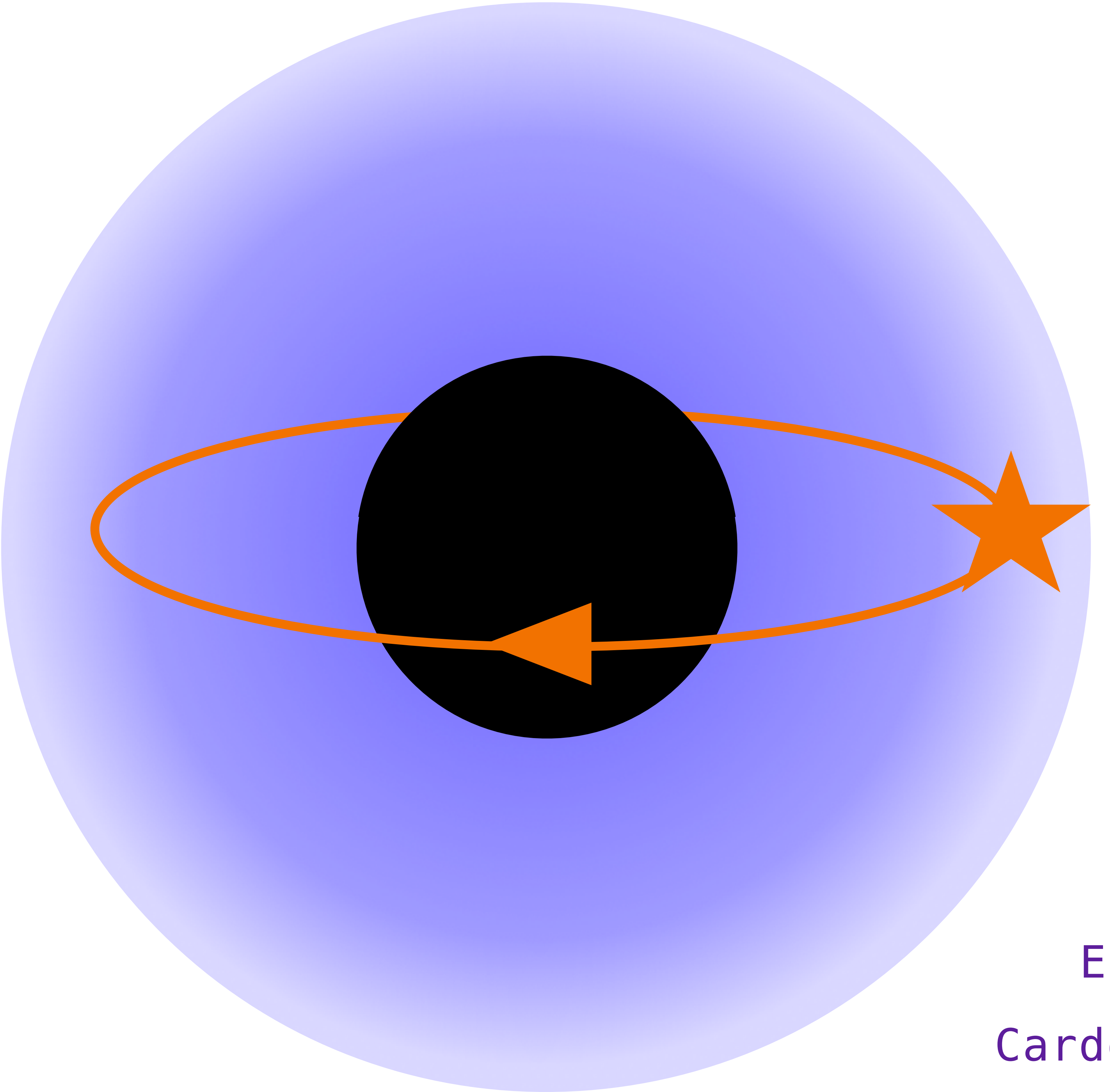

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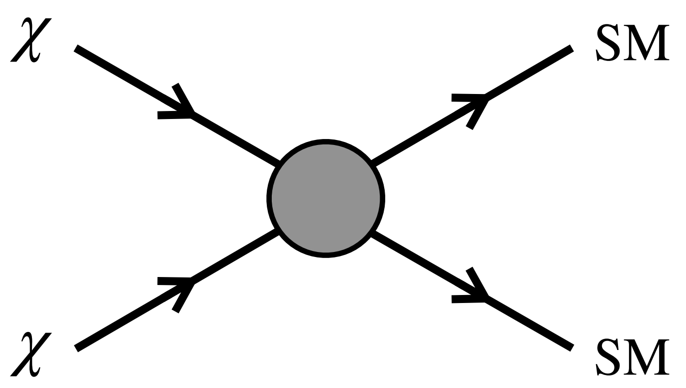

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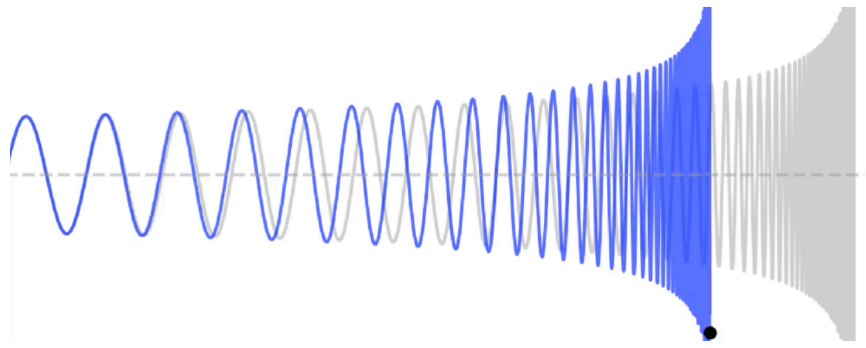
GW signal

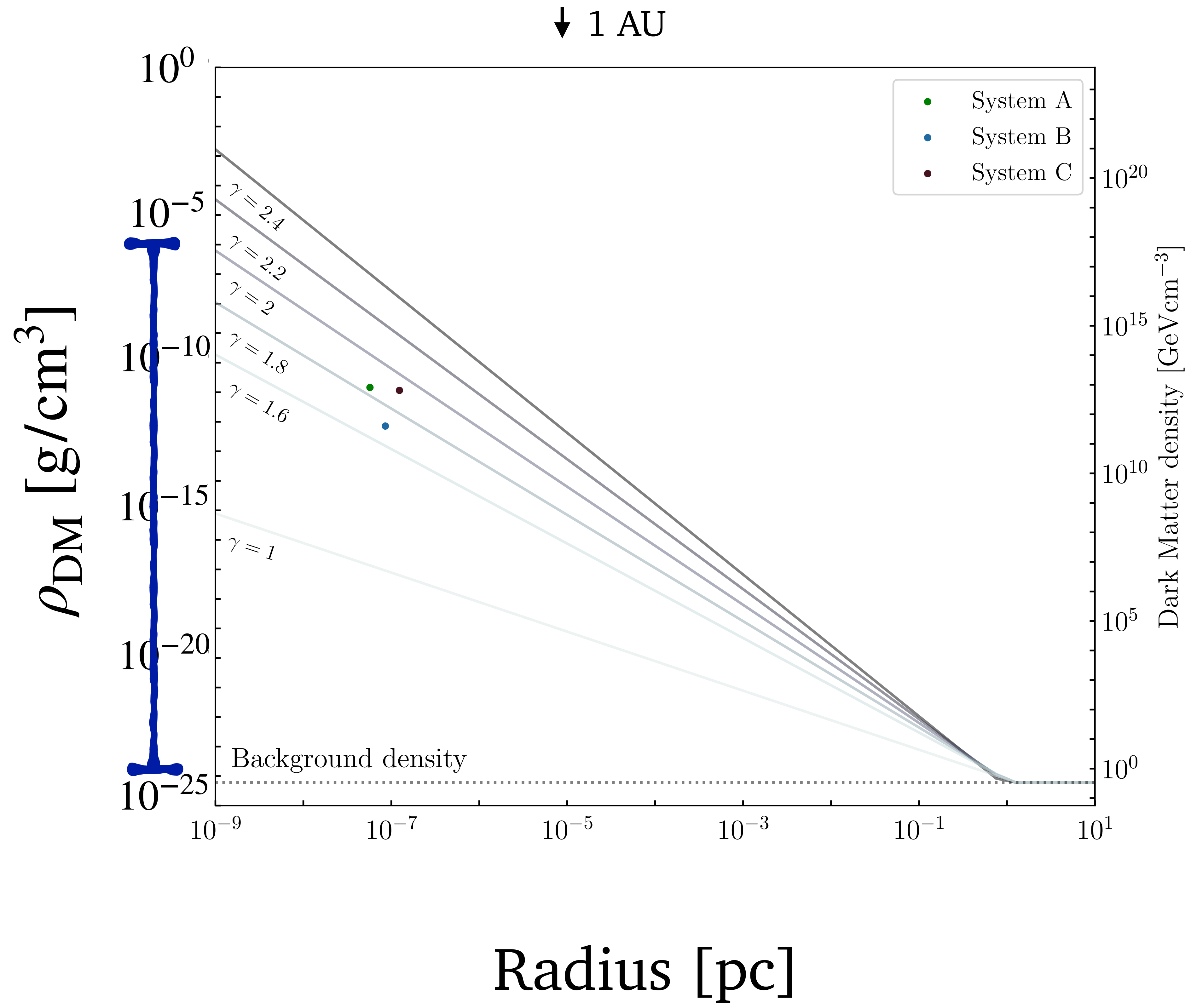


Eda et al. 1301.5971

Cardoso & Maselli 1909.05870

…

$\rho_{\mathrm{DM}}(r) \propto r^{-\gamma}$



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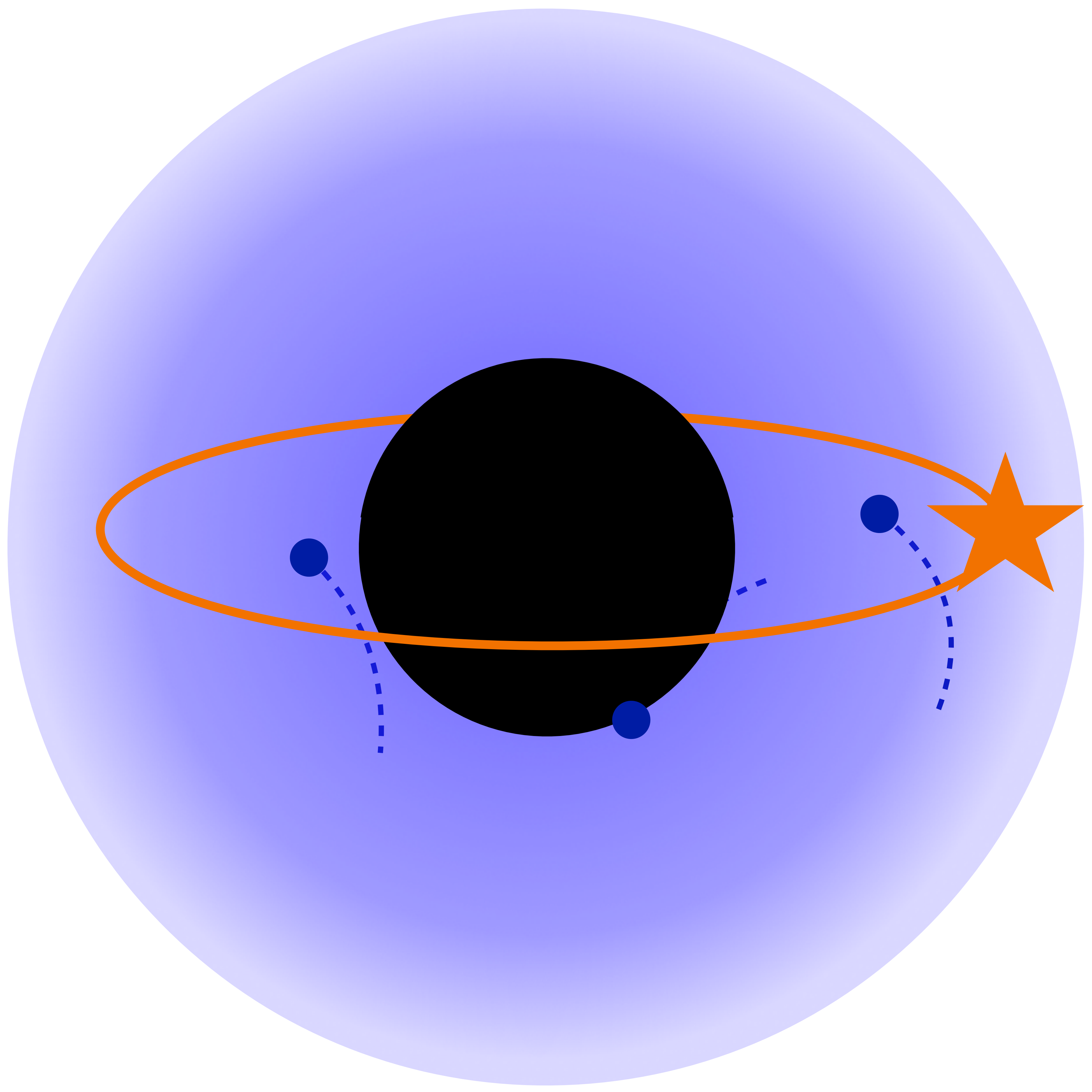
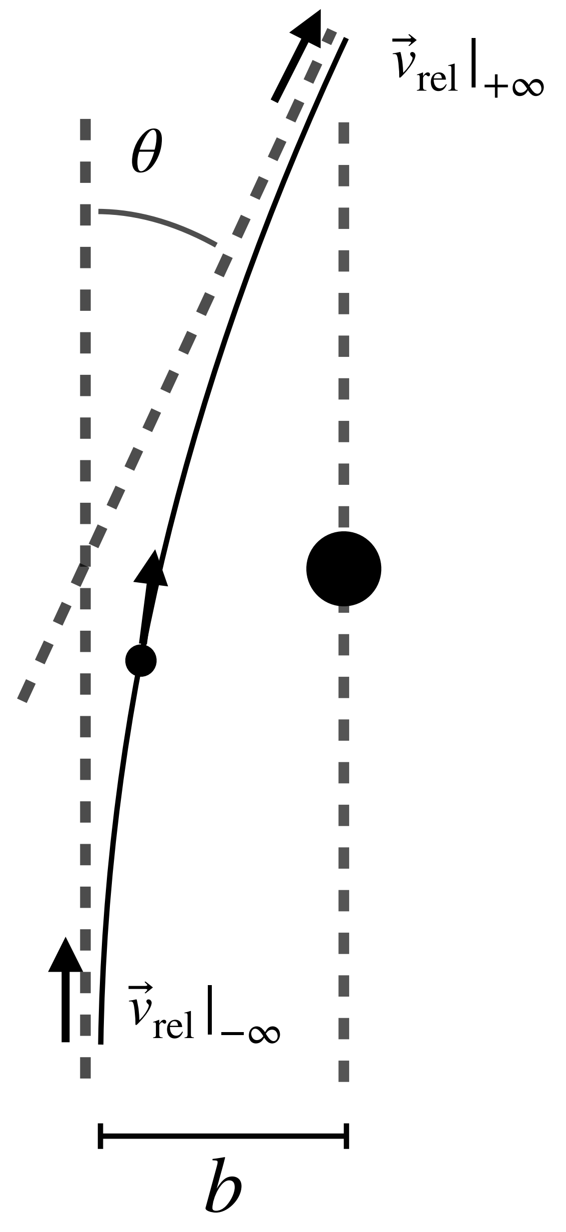
Dynamical friction



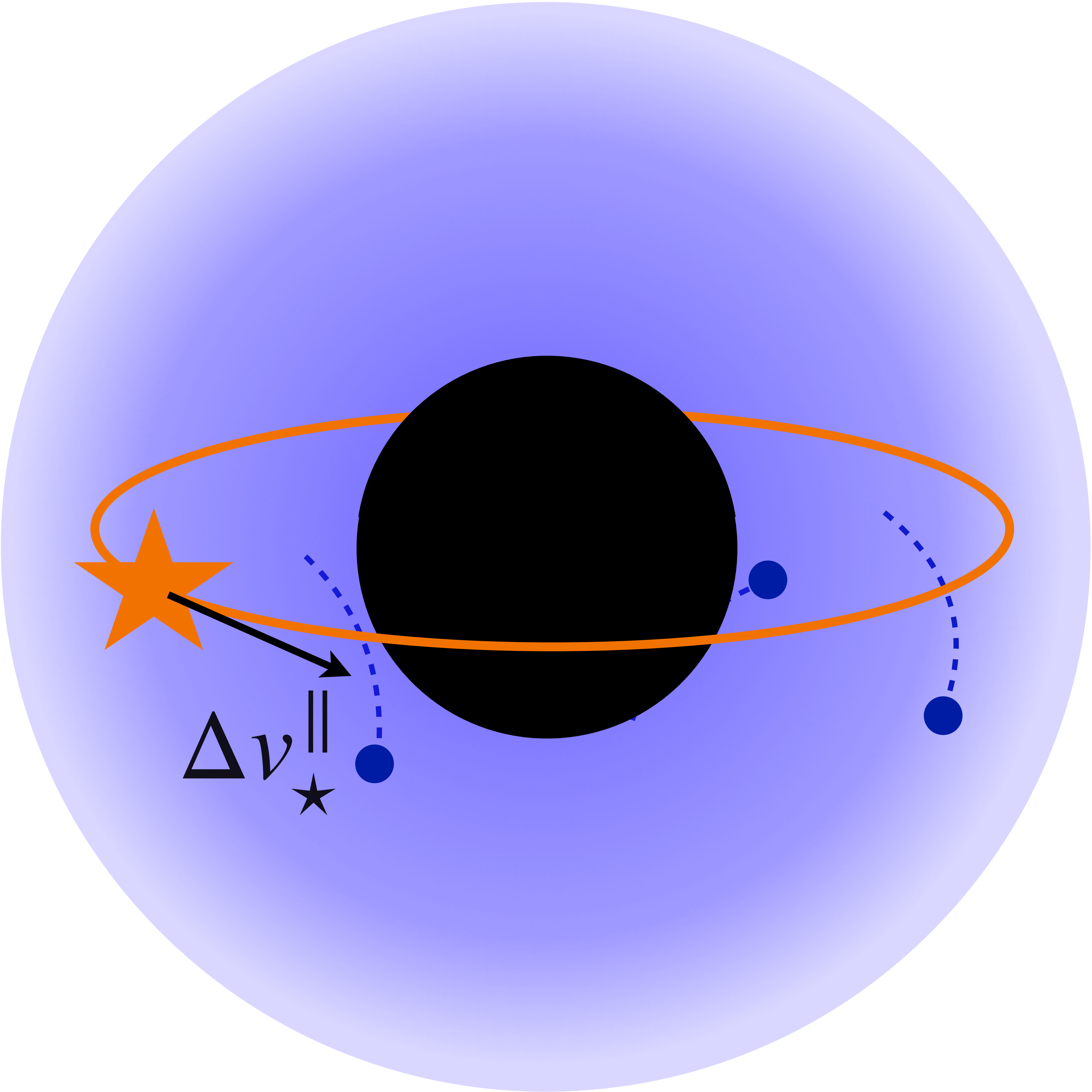
Chandrasekhar 1941

$$\mathscr{F}_{\rm DF} \simeq m_\star \frac{dN_{\rm encounters}}{dt} \Delta v_\star^{\parallel} \simeq \frac{4\pi G^2 \rho_{\rm DM} m_\star^2}{v_{\rm rel}^2}$$



***Purely gravitational** energy loss mechanism*

Dynamical friction



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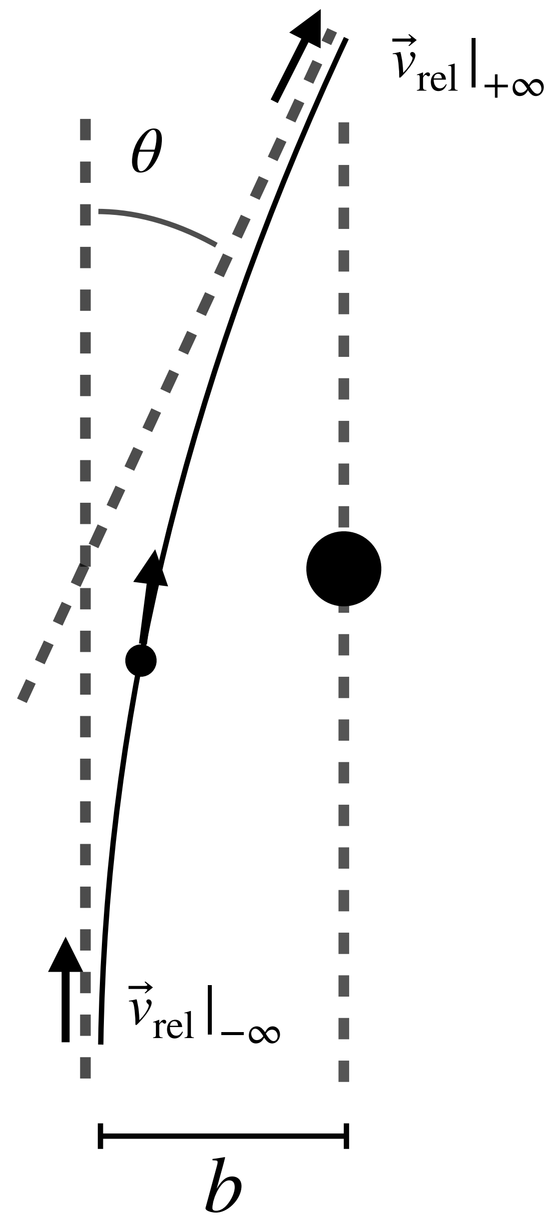

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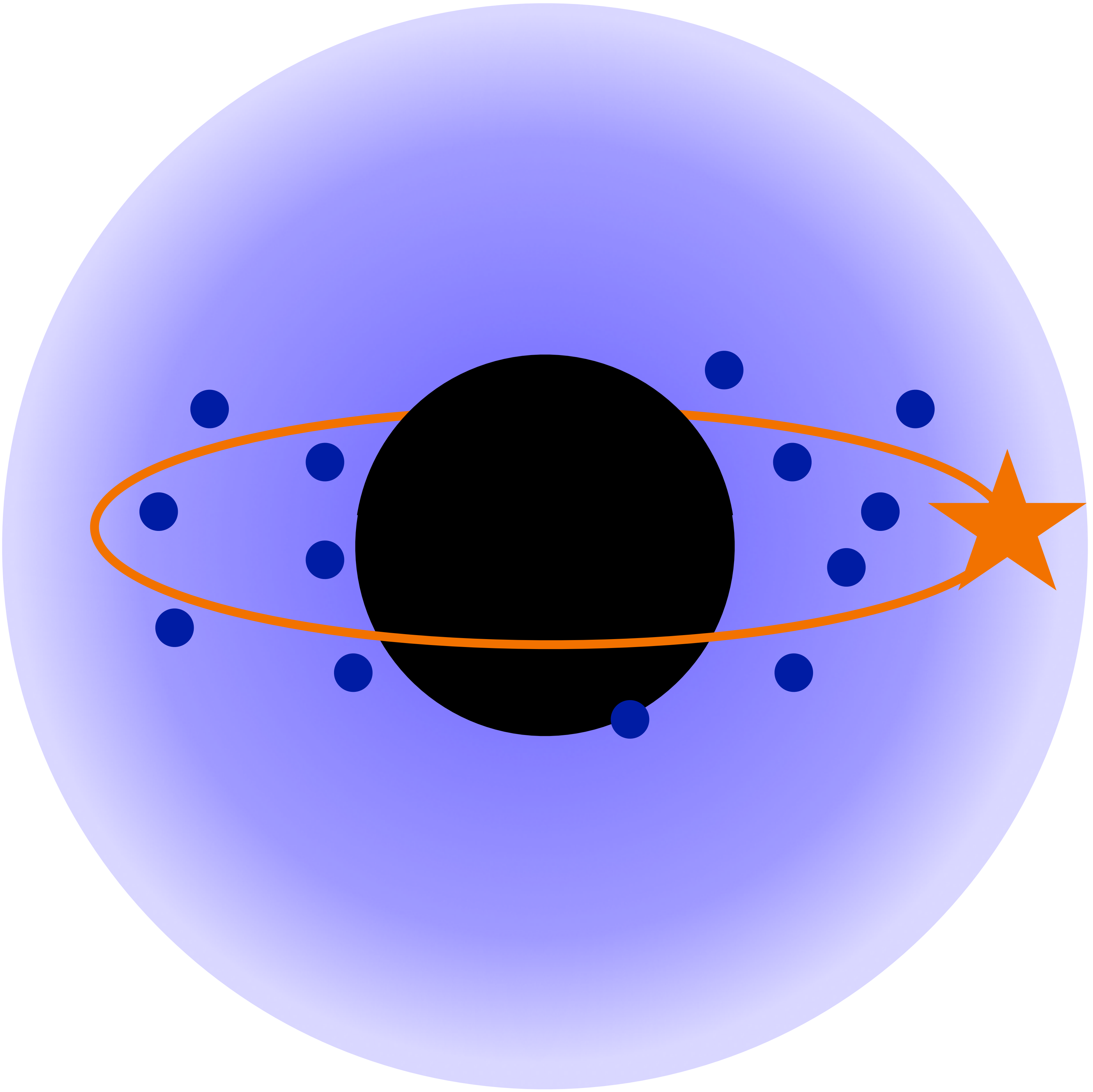

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Energy injection → $\rho_{\rm DM}$ depletion → drag $\mathscr{F}_{\rm DF}$ reduced

reduction of

“feedback”

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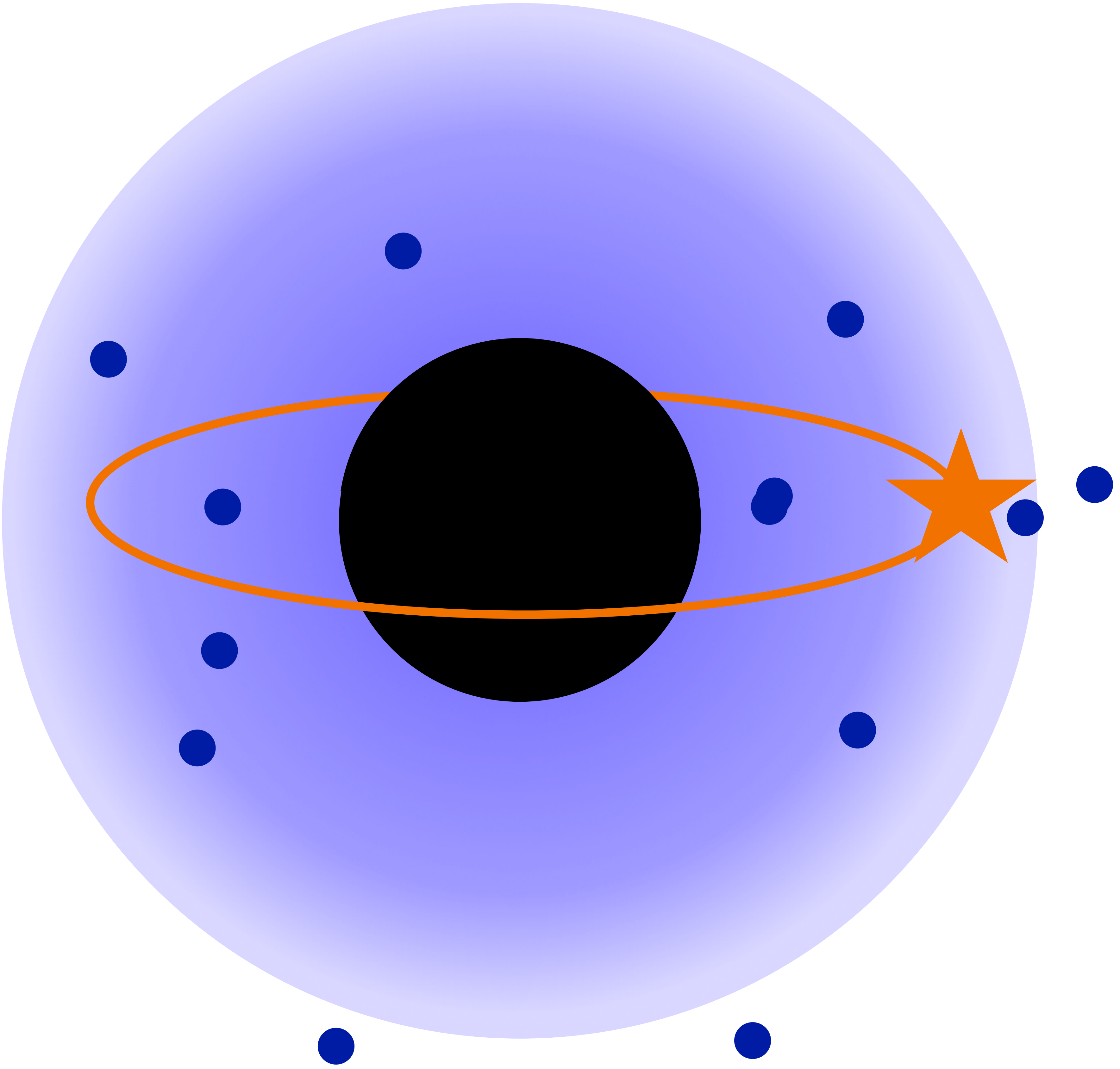

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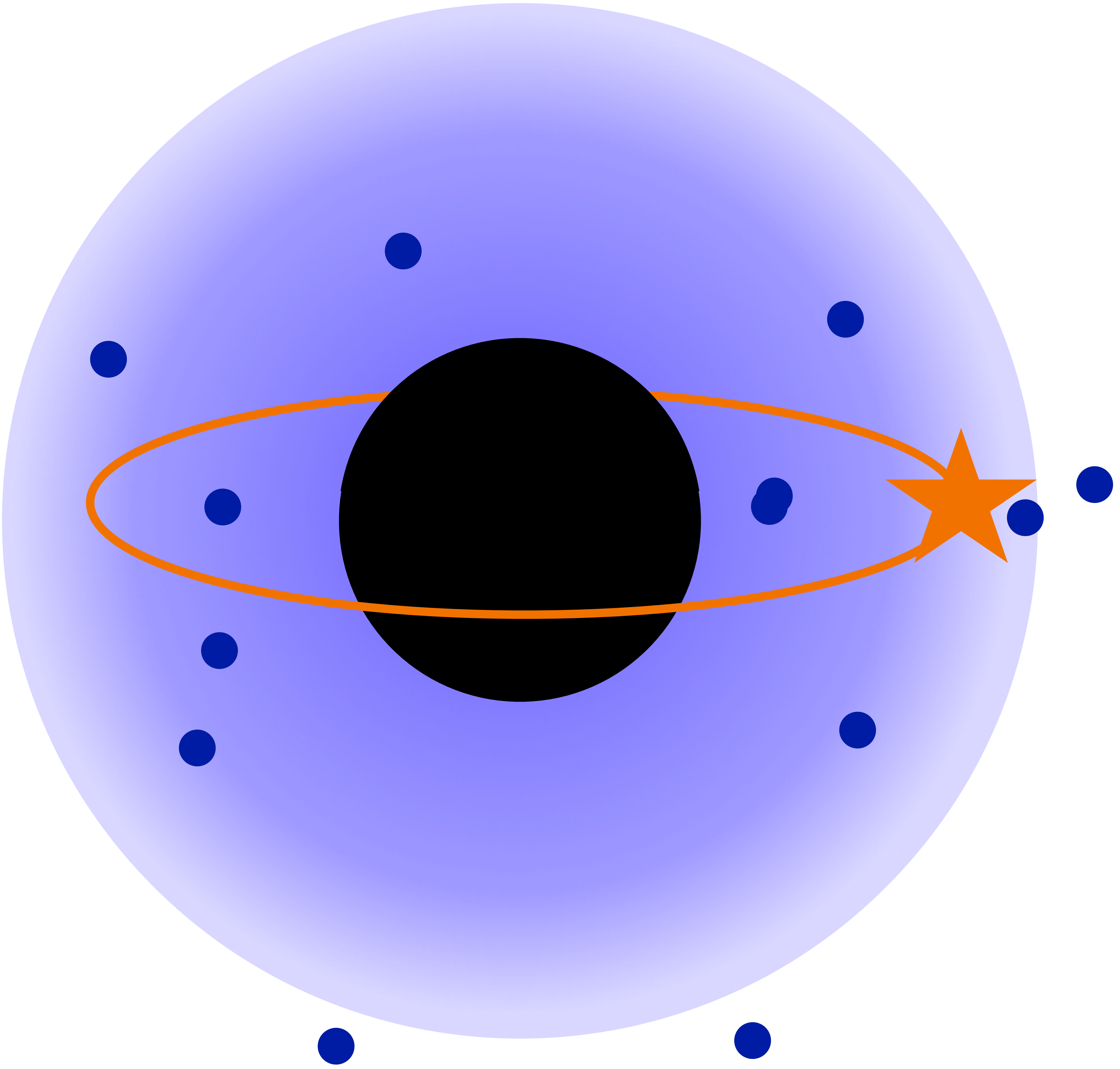

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We perform **simulations to follow the evolution** of the 3 systems

NbodyIMRI

Kavanagh et al. 2402.13762

- Star + BH + DM pseudo-particles
- Newtonian gravity ($r_{\rm orb} \sim 10^5 r_S$)
- Star, BH "feel" each other & DM particles
- DM particles "feel" star & BH (softened)

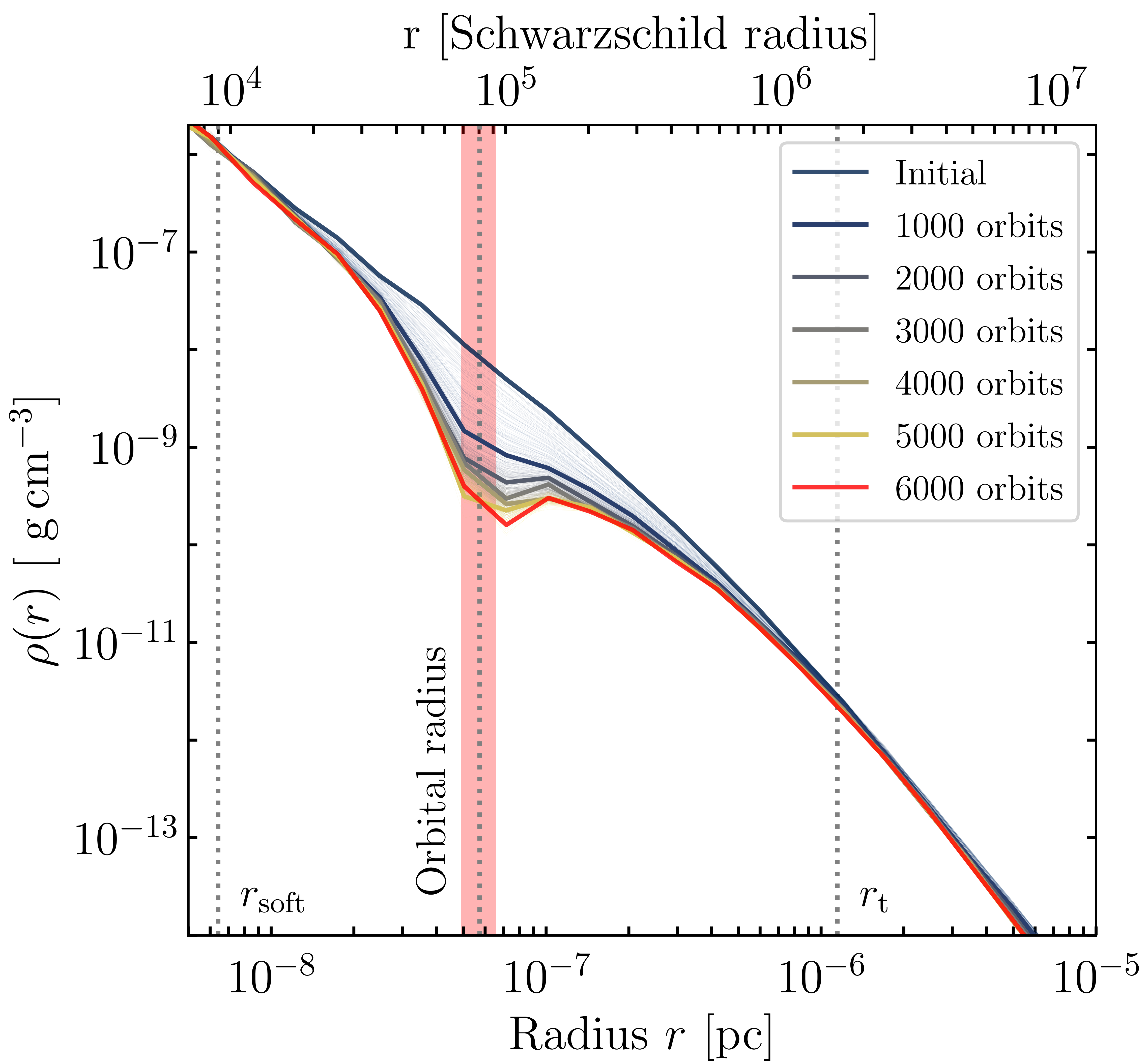
[github.com/bradkav/NbodyIMRI]

***Purely gravitational** energy loss mechanism*

Simulations with NbodyIMRI
[github.com/bradkav/NbodyIMRI]

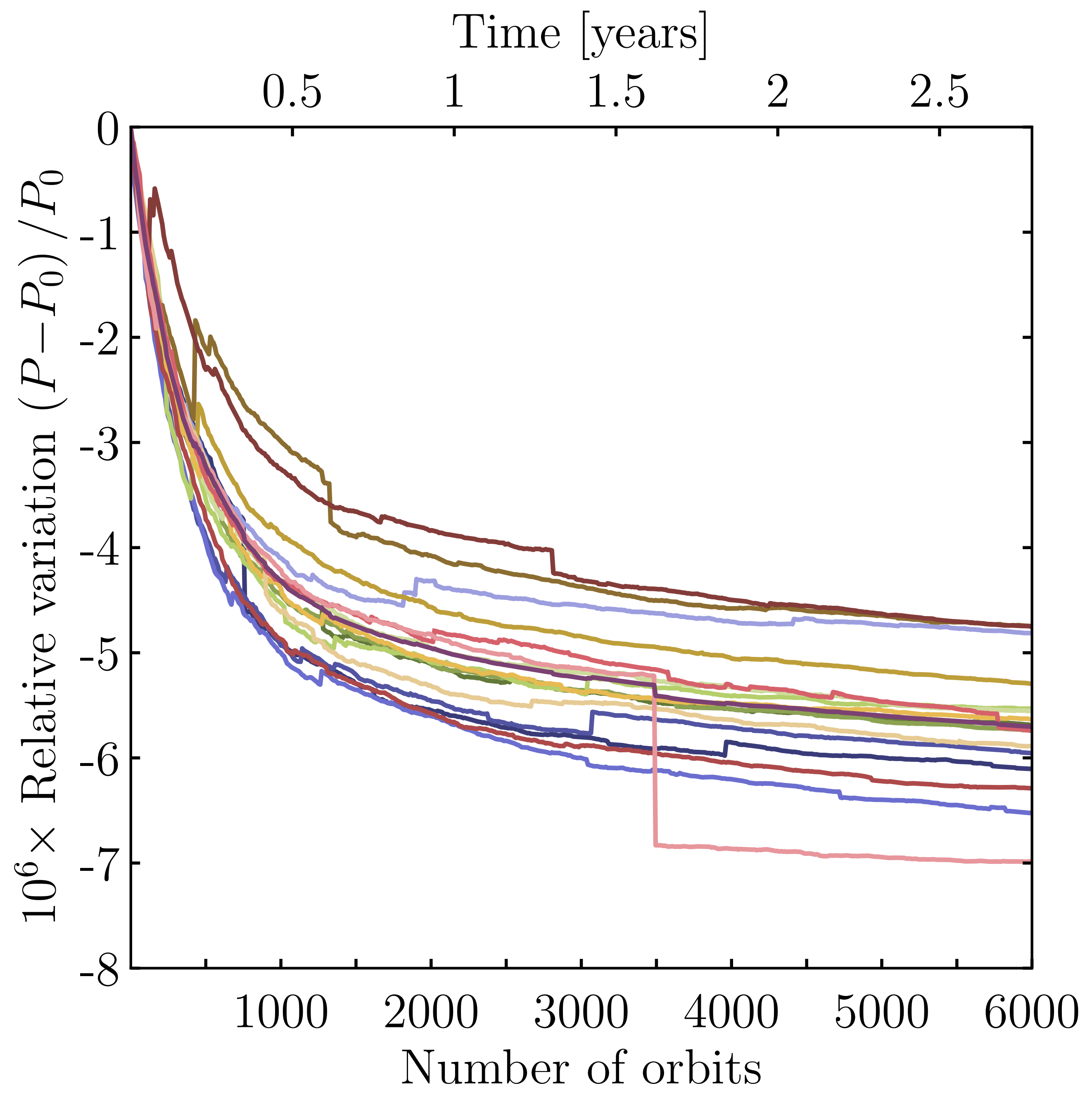
For each of the **3 Xray binary** systems:

- Set masses and orbital parameters of **BH & star** to the **observed values** (circular orbits)
- Vary the **power-law index** $\gamma \in [1.9, 2.4]$
- Initialise (20k) DM pseudo-particles according to **density profile** $\rho_{DM} \propto r^{-\gamma}$
- Evolve system for 6000 orbits
- **16 realisations** for each value of γ
- Every 10 orbits, read the orbital radius and period



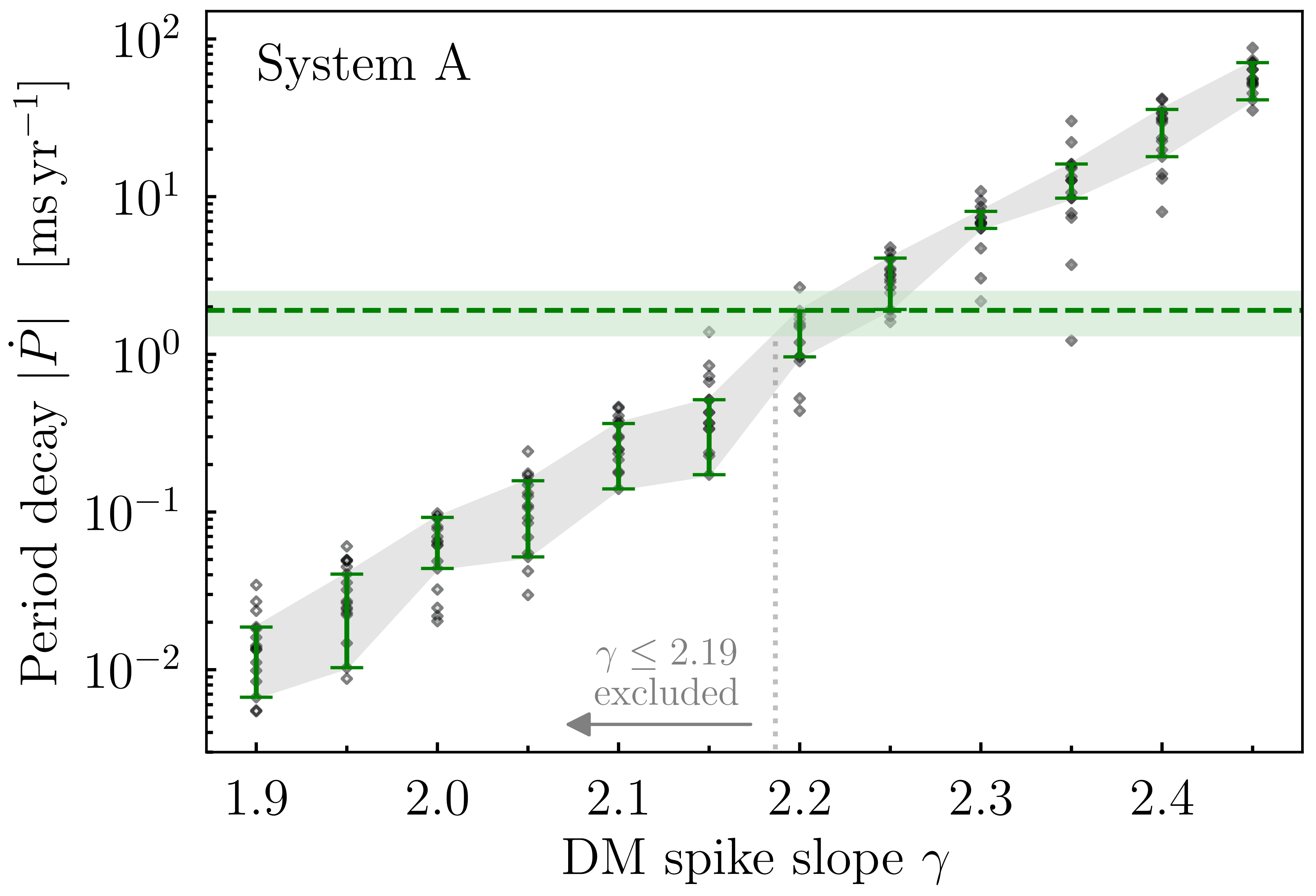
Estimating the rate of decay $\dot{P}(\gamma)$

- Decay of the orbital period slows with time (feedback)



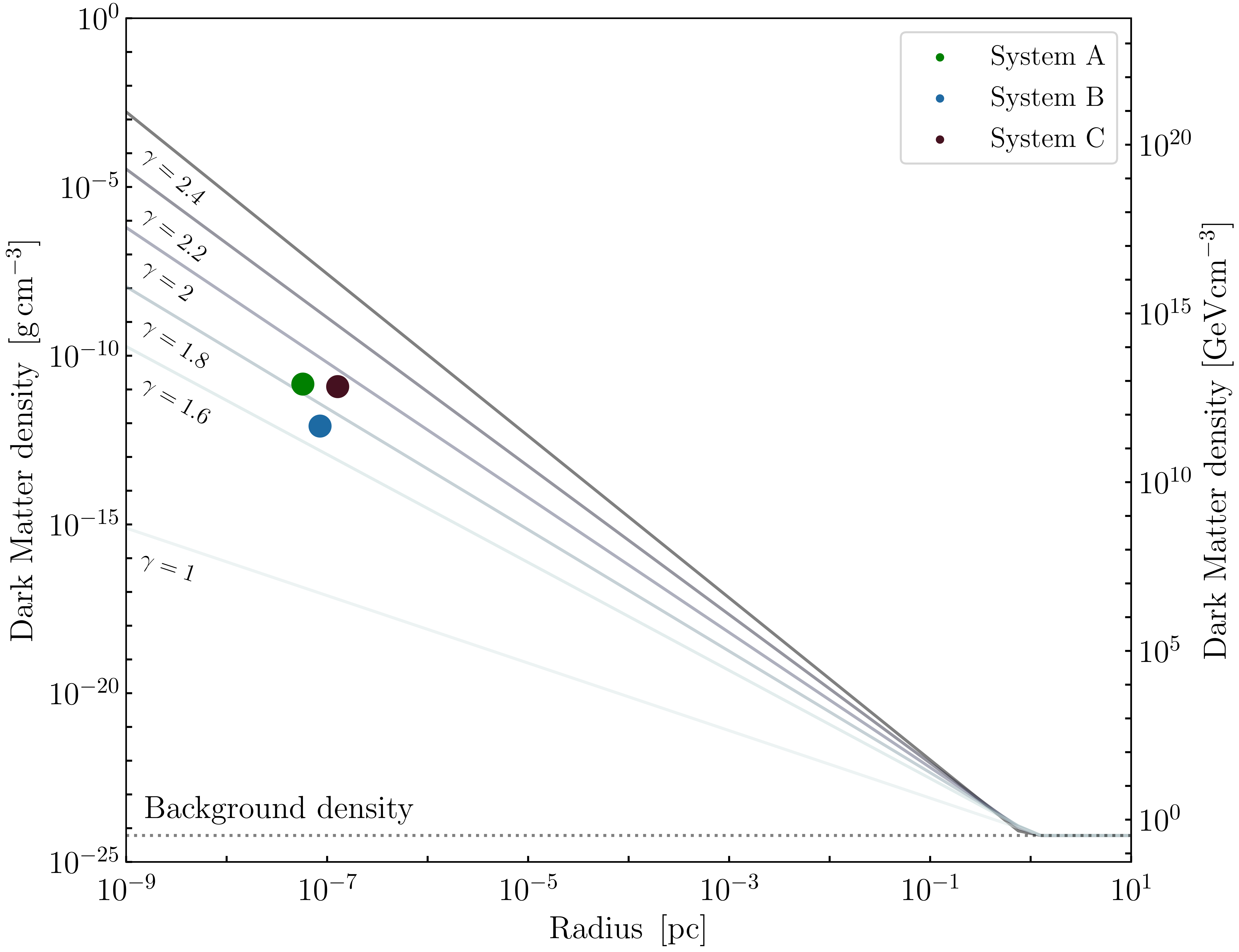
- Estimate derivative $\dot{P} = \langle \Delta P/\Delta t \rangle_{1000\,\text{orbits}}$

- Collect final values of $\dot{P}$ from each realisation, for all values of γ



- Compare with observed $\dot{P}$ value to get $[\gamma]$

Results: constraints on the dark-matter spike profile $\rho_{DM}(r) \propto r^{-\gamma}$



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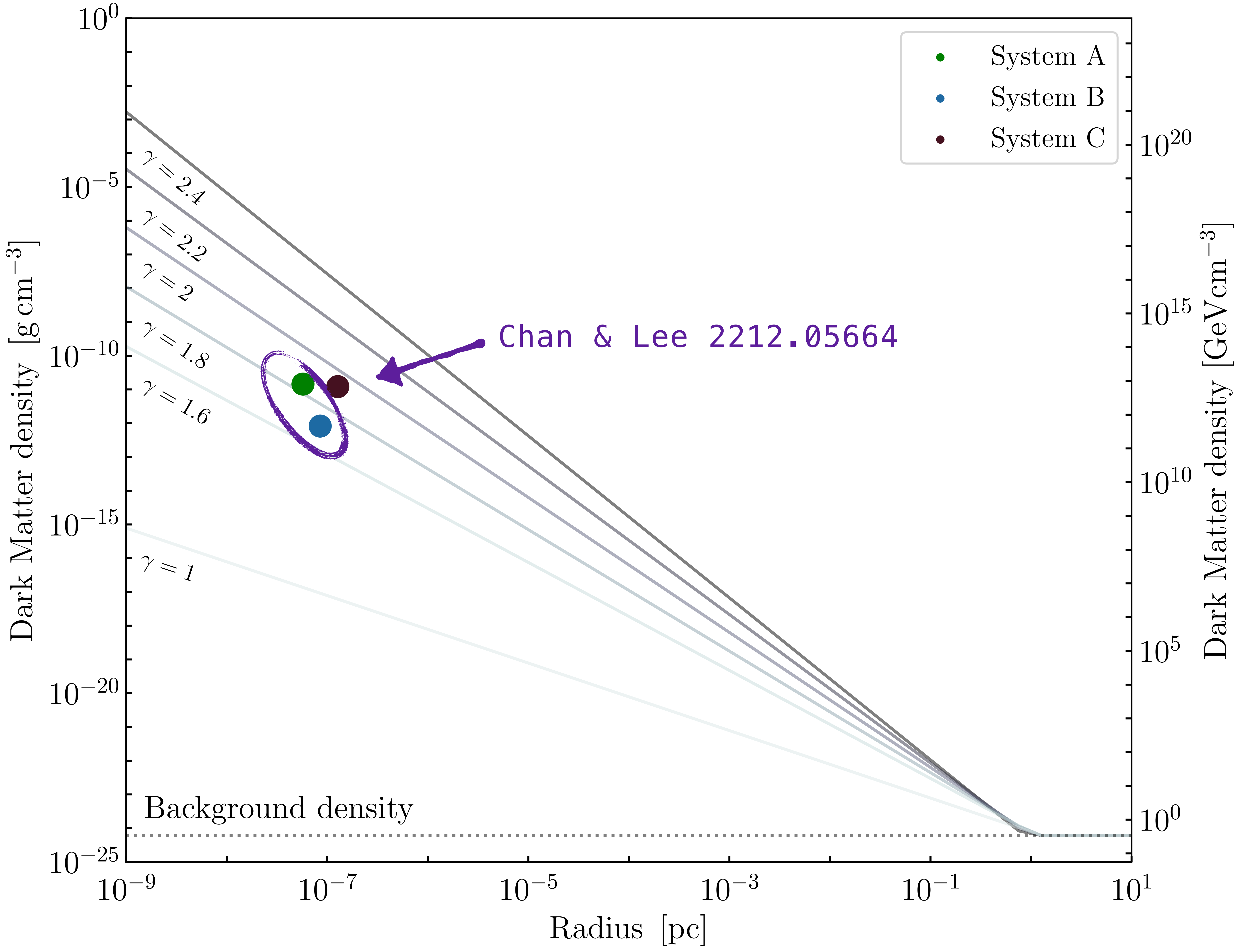

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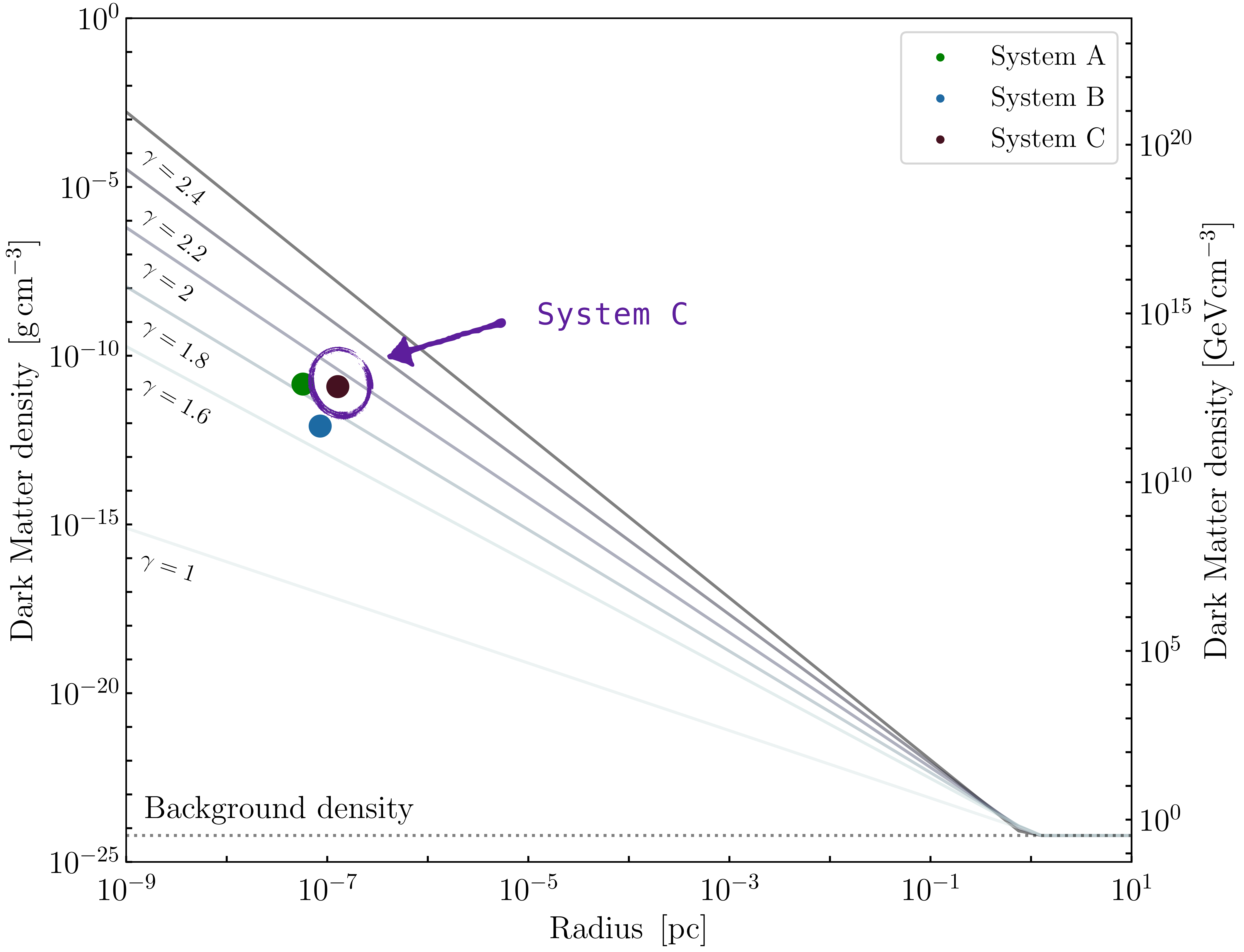

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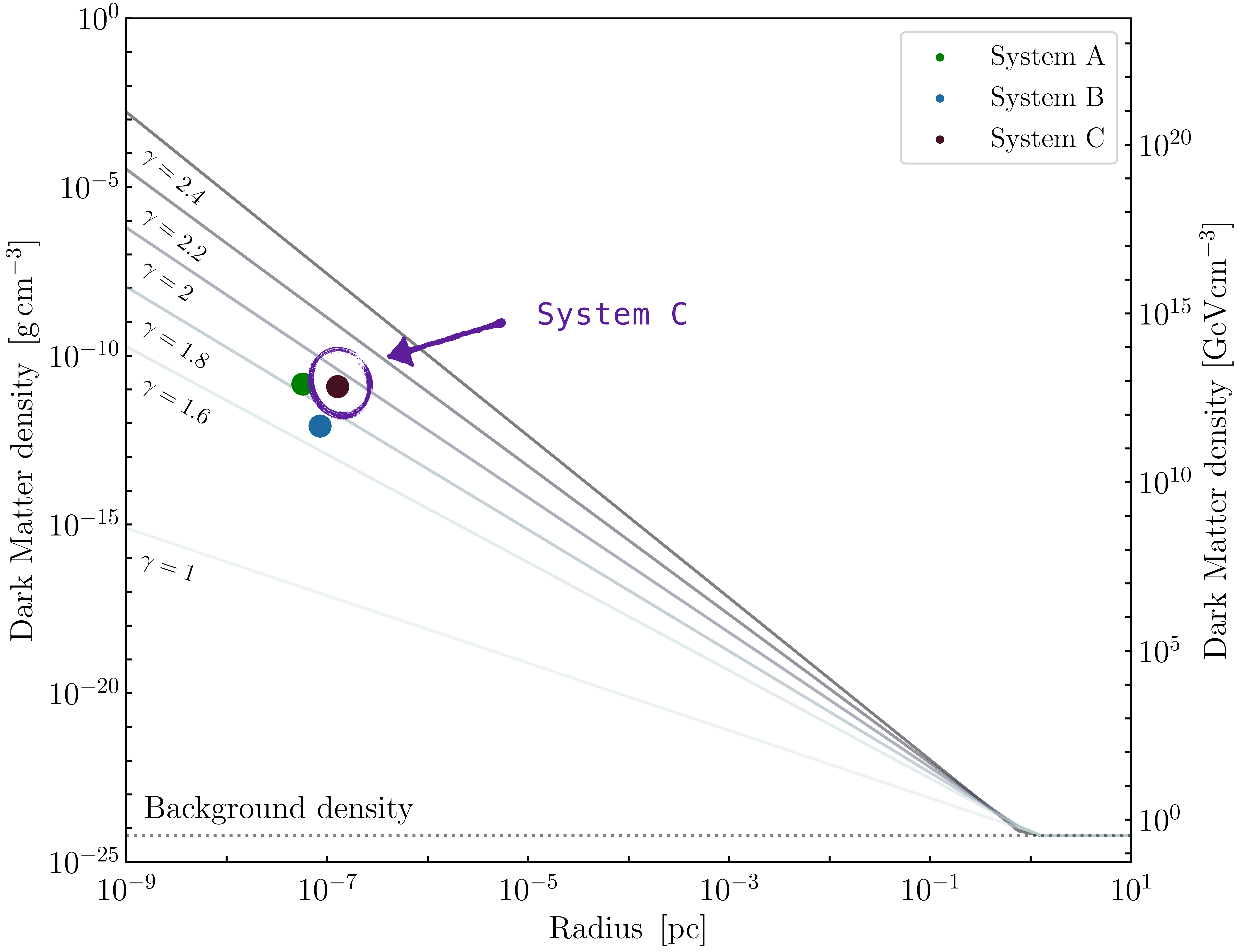
$$\dot{P} \propto -\frac{M_\star}{M_{\rm BH}} P^2 \rho_{\rm DM}$$



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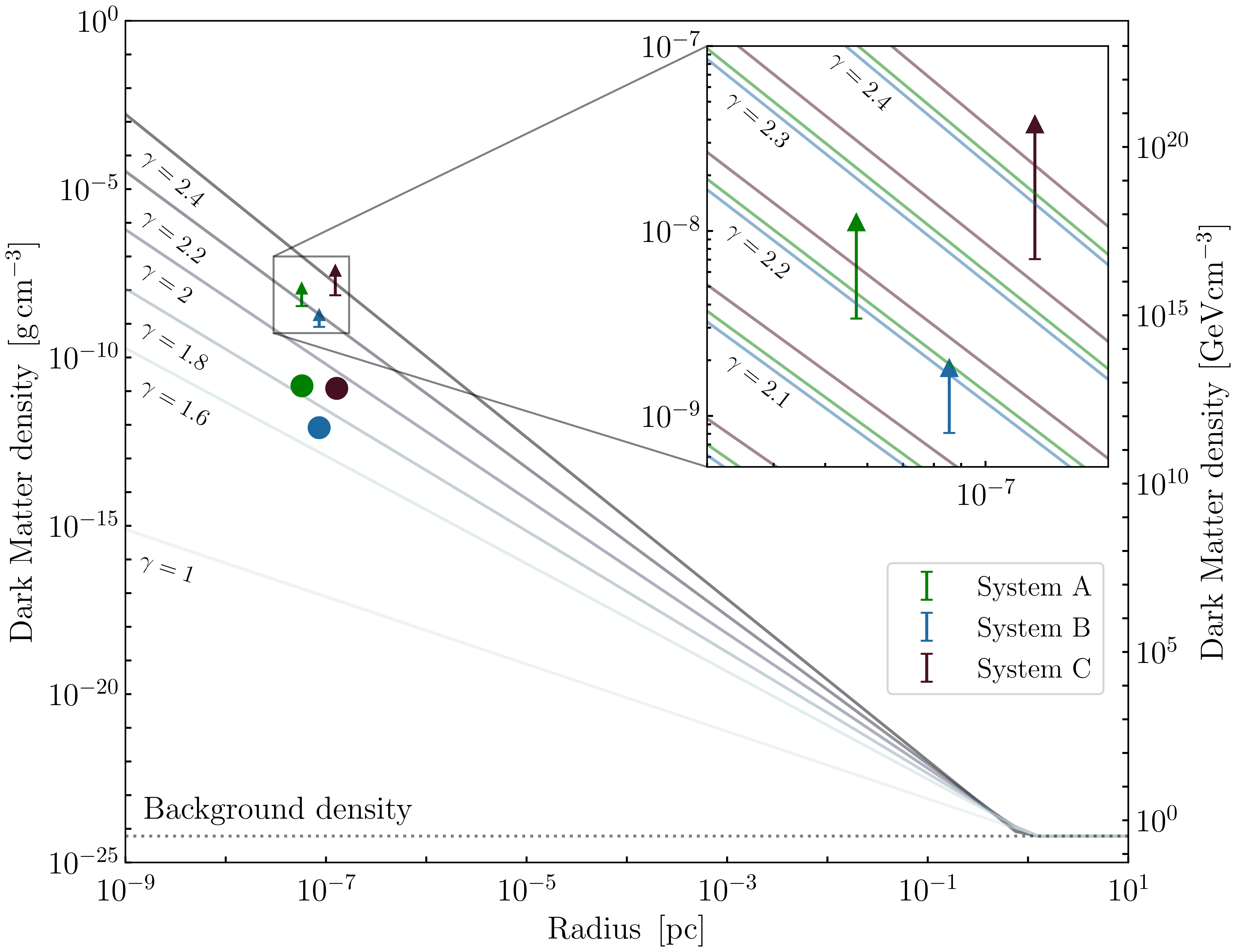

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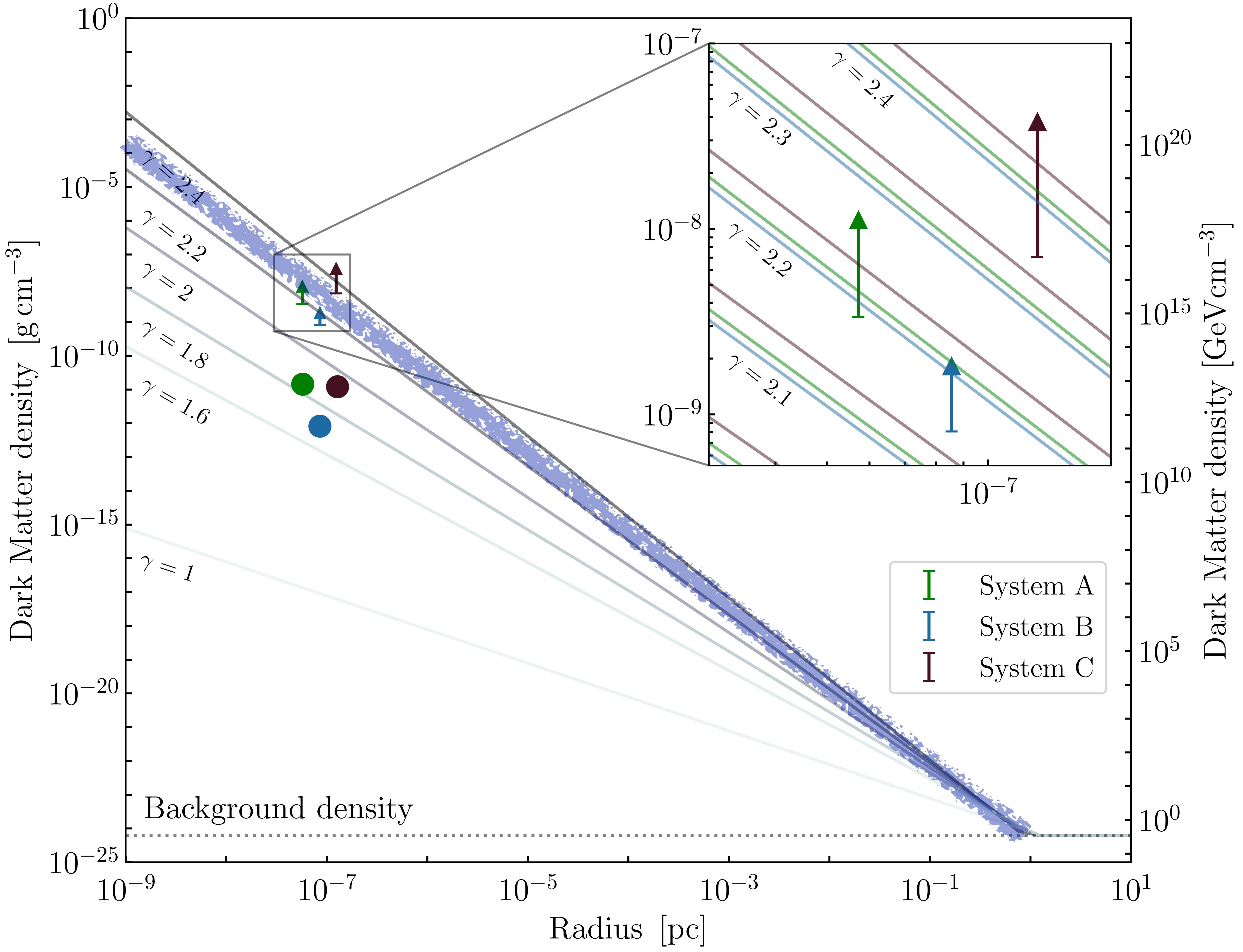


Conclusions

- *“Best fit” spike profiles are* ***consistent across 3 systems and with common spike models***

- ***IF*** *DM spikes were proven to be present, they would be* ***much more common*** *than we presently think*

- ***CAVEAT****: we evolved the systems for* ~ 10 *years, they are* $\gg 10^6$ *years old*

  ($\sim 10^6$ *years:* $1\,\%$ *variation in radius)*

- *Need to model the* ***long-term evolution*** *of DM spike+binary ! (In progress…)*

DM spike modelling

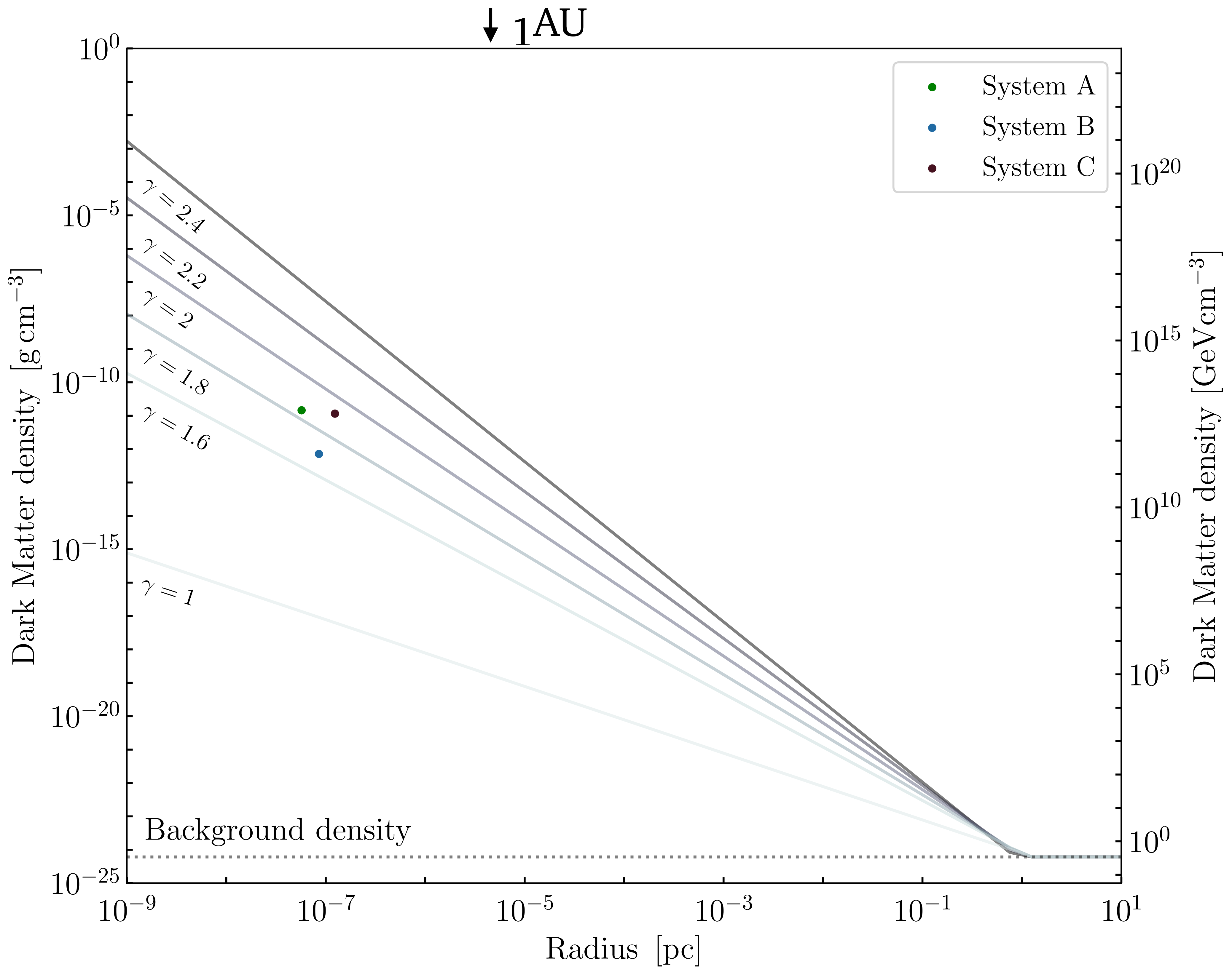
- Power law scaling $\rho_{\rm DM}(r) = \begin{cases} \rho_{\rm sp}(r)\,, & r \leq r_{\rm sp} \\ \rho_{\rm bkg}\,, & r \geq r_{\rm sp} \end{cases}$

- Normalisation: assume background density value recovered at $r_{\rm sp} = 0.2\, r_{\rm in}$, where the gravitational influence radius is

Merritt 2004
Eda et al 1408.3534

$$M_{\rm DM}(\leq r_{\rm in}) = \int_0^{r_{\rm in}} 4\pi r^2 \rho_{\rm DM}(r)\, dr = 2M_{\rm BH}$$

- Velocity distribution through Eddington inversion (assume isotropy)



Spike formation in astrophysical black holes

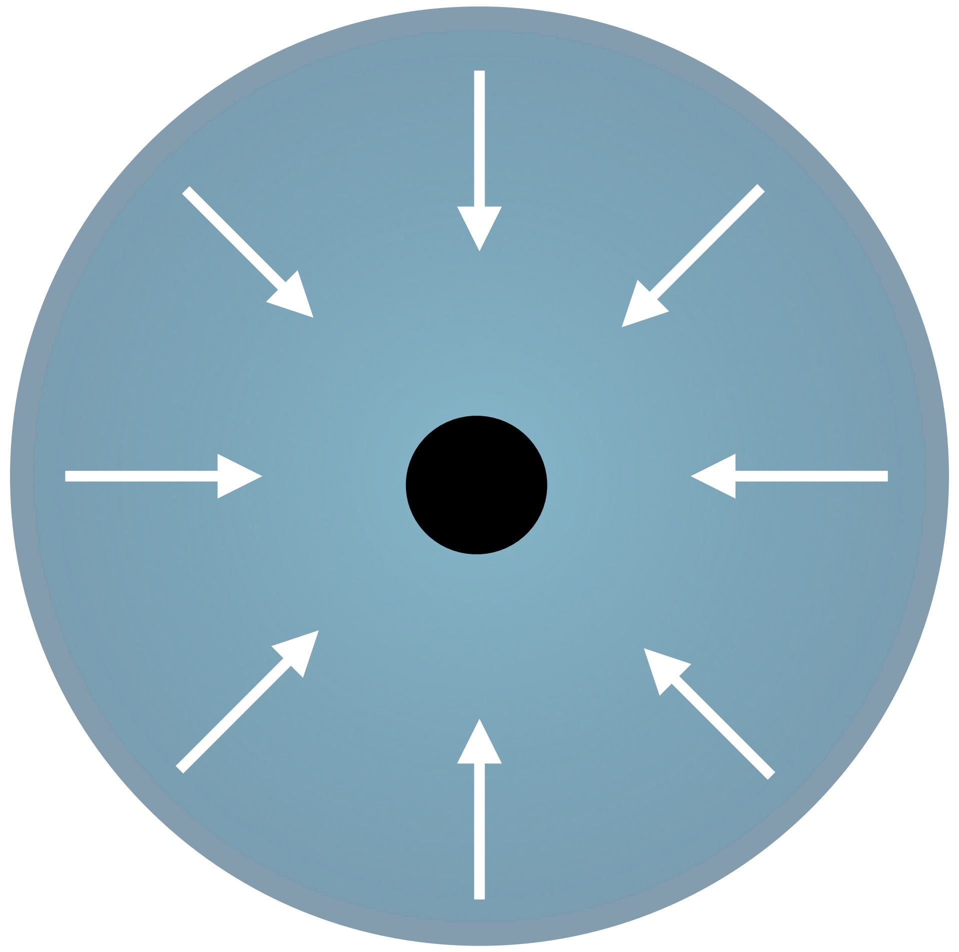
Adiabatic, central BH growth inducing DM halo contraction

Gondolo & Silk astro-ph/9906391

Sadeghian et al. 1305.2619

Ullio et al. astro-ph/0101481

$$\rho(r) \propto r^{-\alpha} \rightarrow \quad \rho(r) \propto r^{-\left\{\gamma = \frac{9-2\alpha}{4-\alpha}\right\}}$$

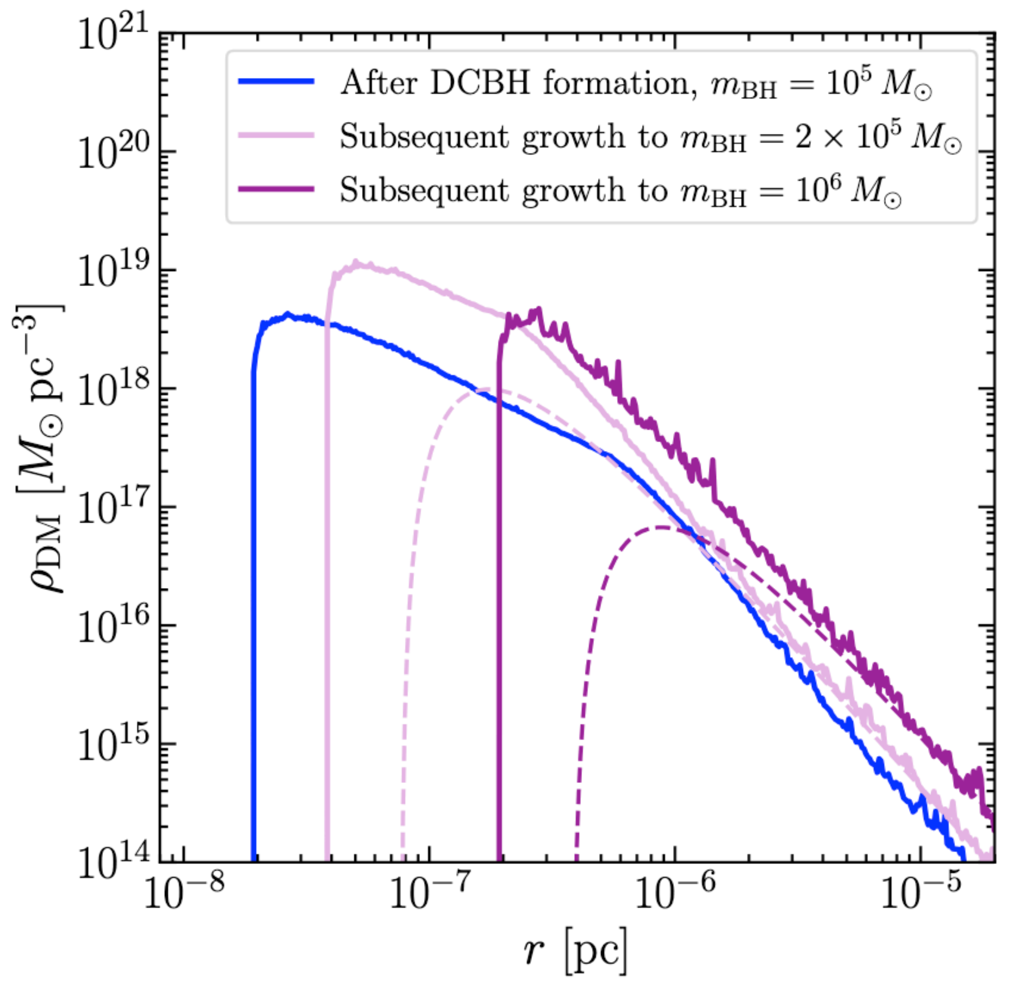


$$0 \leq \alpha \leq 2 \rightarrow 9/4 \leq \gamma \leq 5/2$$

$$\text{NFW}: \quad \alpha = 1 \rightarrow \gamma = 7/3$$

Halo contraction under more realistic description of BH formation process

Bertone et al. 2404.08731

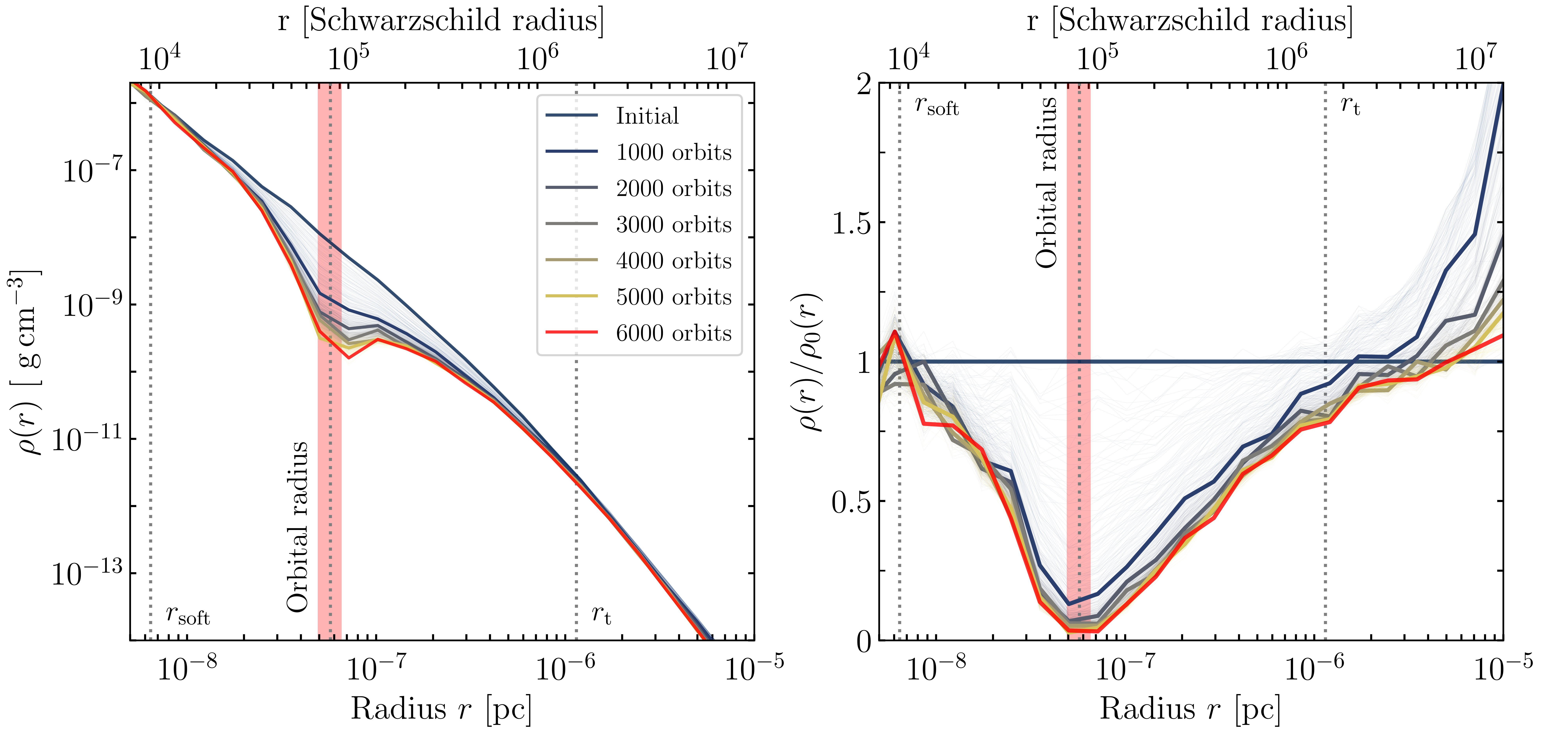


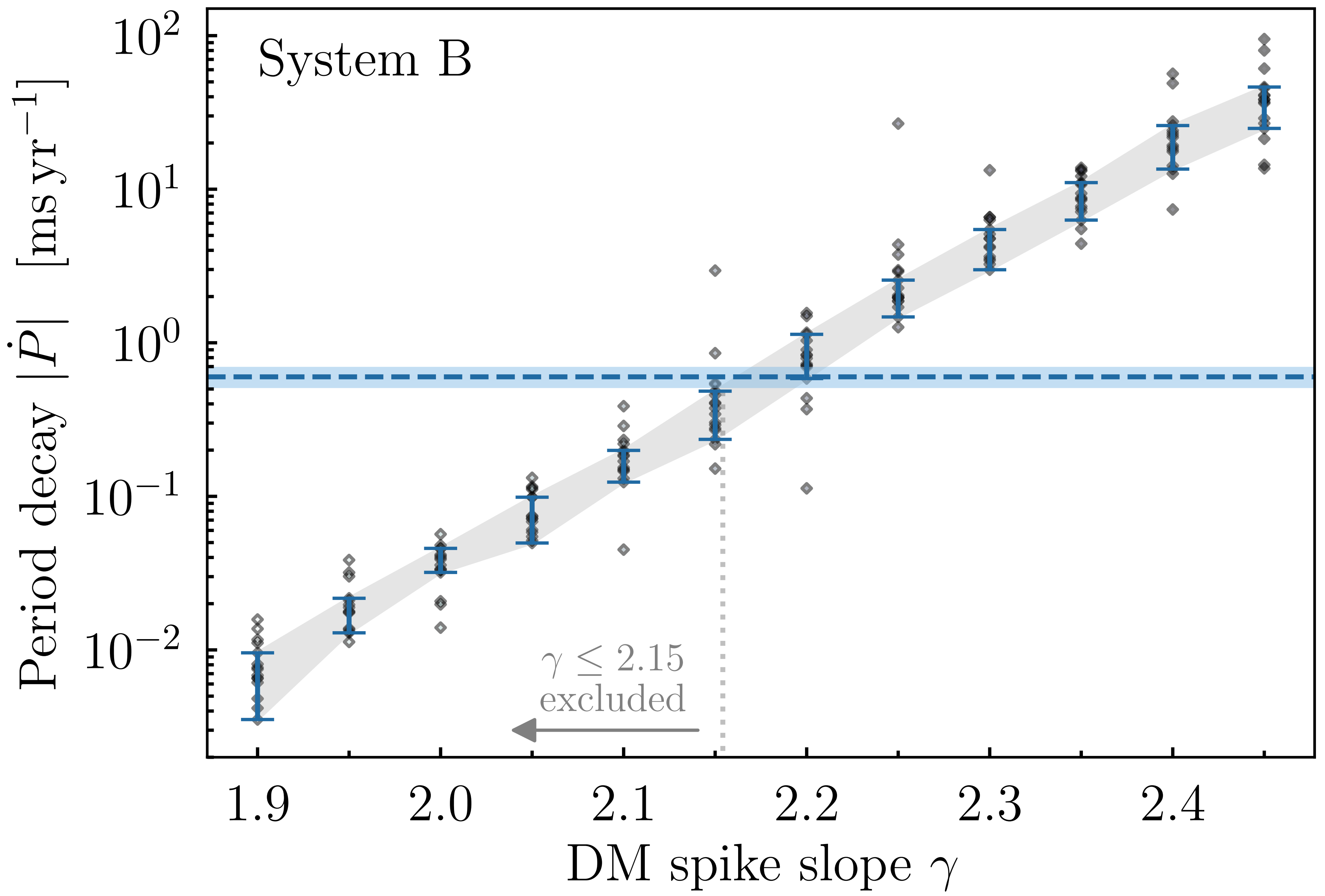
Observations

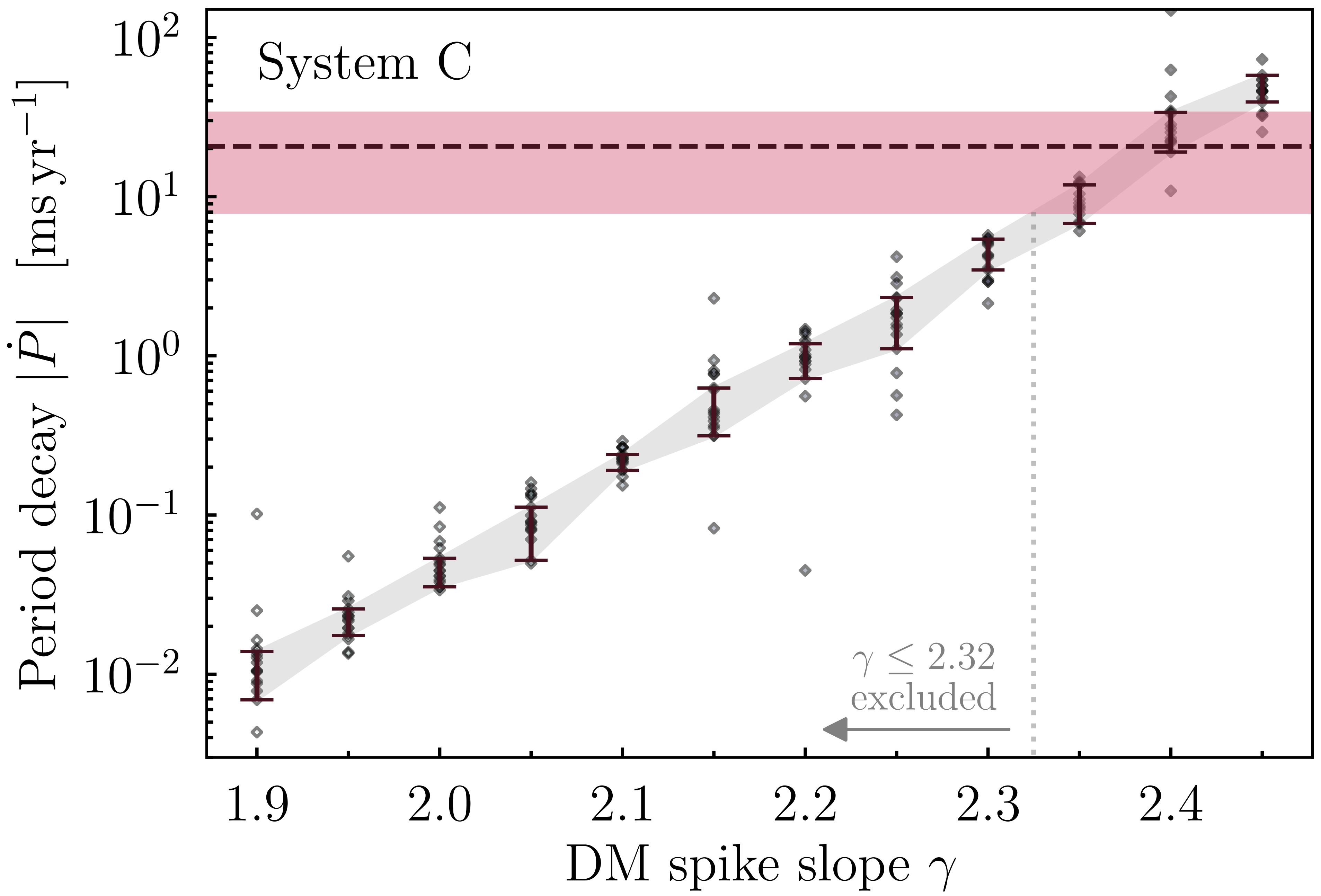
	System A	System B	System C
	XTE J1118+480	A0620-00	NM1991
$M_{\rm BH}$ $[M_\odot]$	$7.46^{+0.34}_{-0.69}$ [46]	5.86 ± 0.24 [59]	$11.0^{+2.1}_{-1.4}$[47]
$M_\star$ $[M_\odot]$	0.18 ± 0.06 [46]	0.40 ± 0.01 [46]	0.89 ± 0.18 [47]
$r_\star$ $[R_\odot]$	0.34 ± 0.05 [47]	0.67 ± 0.02[47]	1.06 ± 0.07 [47]
$q = M_*/M_{\rm BH}$	0.024 ± 0.009 [46]	0.060 ± 0.004 [59]	0.079 ± 0.007 [47]
$r_{\rm orb}$ $[R_\odot]$	2.54 ± 0.06	3.79 ± 0.04	5.49 ± 0.32
P_0 [day]	0.16993404(5) [46]	0.32301415(7) [46]	0.432605(1) [47]
$\dot{P}$ [ms/yr]	-1.90 ± 0.57 [46]	-0.60 ± 0.08 [46]	-20.7 ± 12.7 [47]

Measurements from Gonzalez Hernandez et al. 2011,2013,2016

Distance from us ~ 1 kpc


r [Schwarzschild radius]
10^4
10^5
10^6
10^7
10^{-7}
10^{-9}
10^{-11}
10^{-13}
$\rho(r)$ [g cm^{-3}]
$r_{\rm soft}$
Orbital radius
$r_{\rm t}$
Initial
1000 orbits
2000 orbits
3000 orbits
4000 orbits
5000 orbits
6000 orbits
10^{-8}
10^{-7}
10^{-6}
10^{-5}
Radius r [pc]
r [Schwarzschild radius]
10^4
10^5
10^6
10^7
2
1.5
1
0.5
0
$\rho(r)/\rho_0(r)$
$r_{\rm soft}$
Orbital radius
$r_{\rm t}$
10^{-8}
10^{-7}
10^{-6}
10^{-5}
Radius r [pc]


System B
Period decay $|\dot{P}|$ [ms yr^{-1}]
10^2
10^1
10^0
10^{-1}
10^{-2}
$\gamma \leq 2.15$
excluded
1.9
2.0
2.1
2.2
2.3
2.4
DM spike slope γ


System C
Period decay $|\dot{P}|$ [ms yr^{-1}]
10^2
10^1
10^0
10^{-1}
10^{-2}
$\gamma \leq 2.32$
excluded
1.9
2.0
2.1
2.2
2.3
2.4
DM spike slope γ

Long term evolution