

Can torques save primordial black hole spikes?

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In collaboration with F. Scarcella,
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2606:25031

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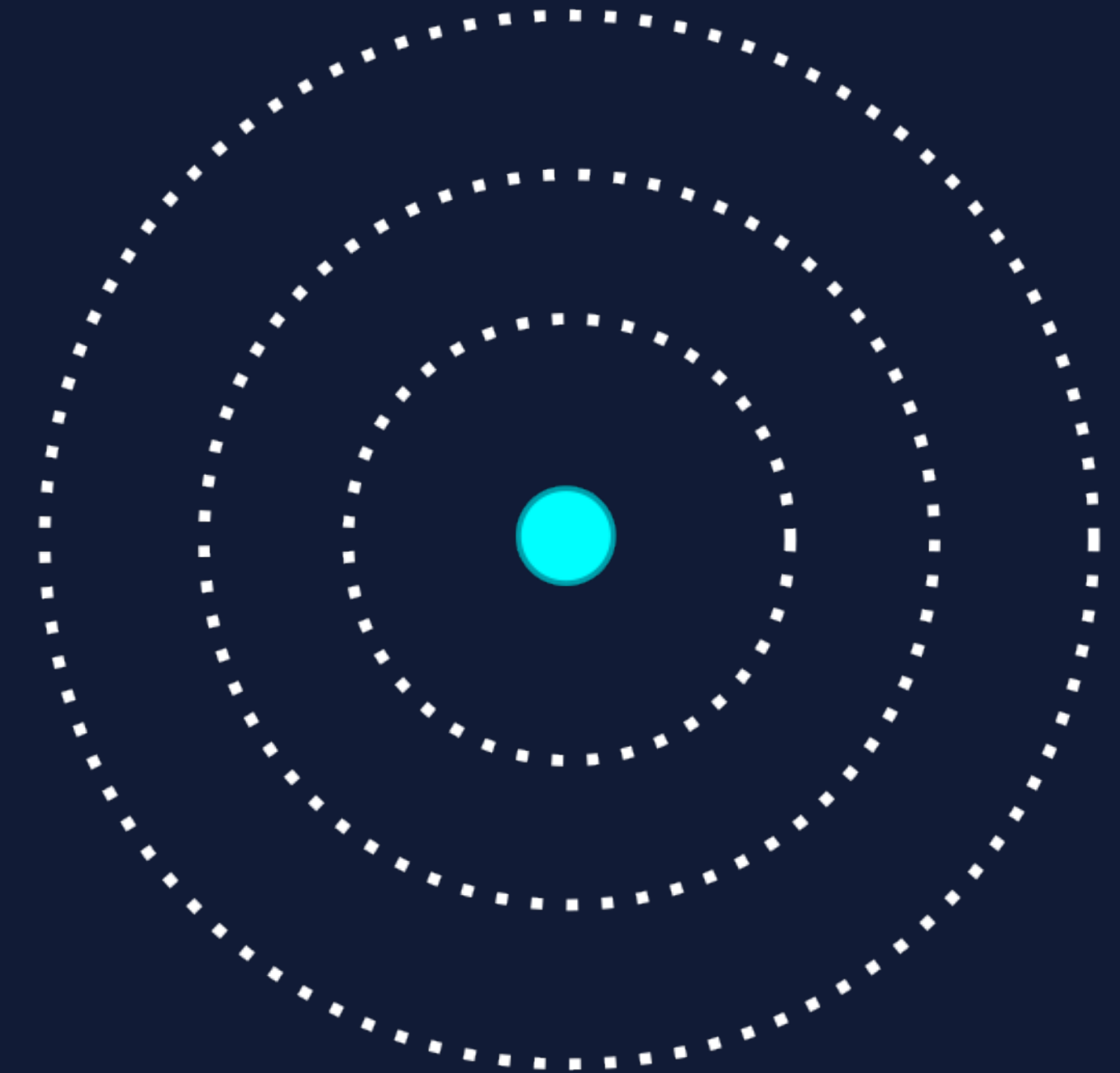


The long story short

- * In arXiv:2606.25031 we study the possibility that **light Primordial black holes (PBHs)**, $M_\ell \approx [10^{17} - 10^{28}] \text{ g}$ could form **dense structures**, similar to **Dark Matter (DM) spikes**, around a heavier PBH, $M_h \approx [1, 10^3] M_\odot$
- * Traditionally, this scenario has been investigated assuming **particle DM**
- * PBHs with masses $M_\ell \approx [10^{17} - 10^{23}] \text{ g}$ could constitute the **entirety** of DM
- * If the spike does not form, light PBHs may instead **accrete** onto the central black hole, **potentially** helping seeding **supermassive black holes (SMBHs)** and producing interesting signals such as **gravitational waves (GWs)**.

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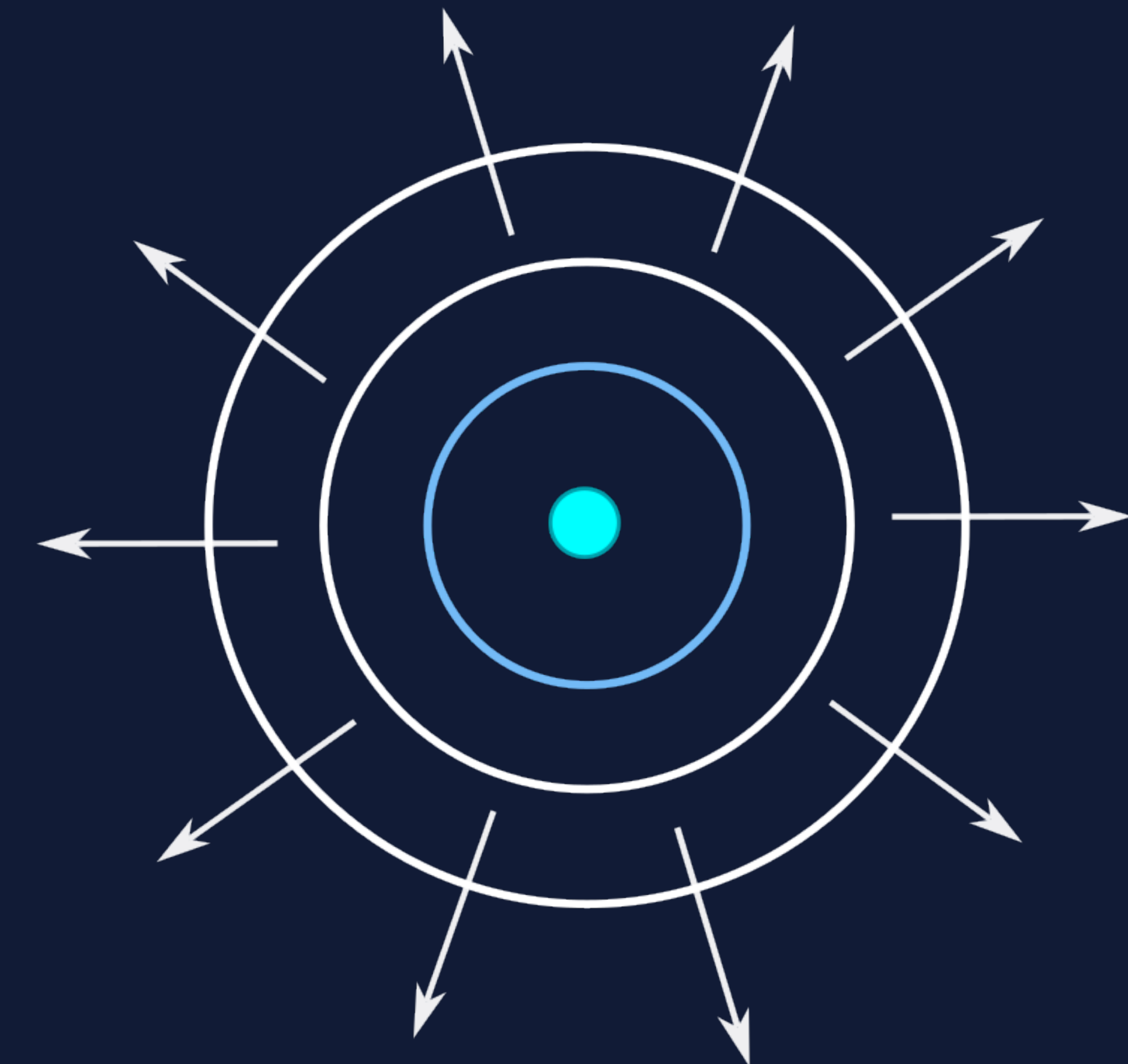
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♦ **Turnaround:** $\dot{r} \approx 0$

$$r_{\text{ta}}^3 = 2 G M t_{\text{ta}}^2 \quad \rho_{\text{ta}} \propto r_{\text{ta}}^{-9/4}$$

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- * **Cascade process**: inner shells are dominated by the PBH gravitational pull, external shells are still following Hubble's flow



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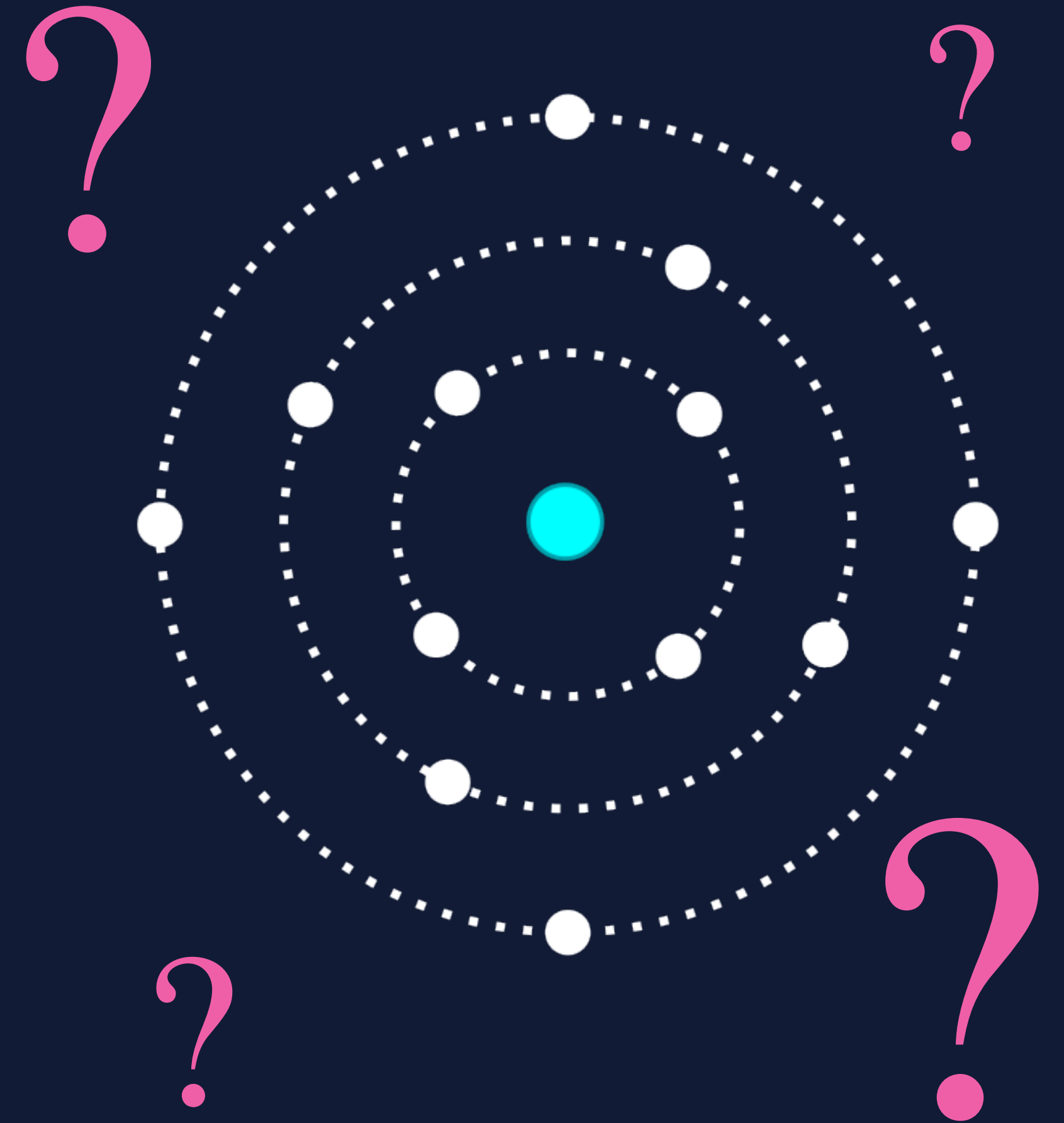
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* After free-fall time, a prominent dark-matter **spike** has developed around the PBH!



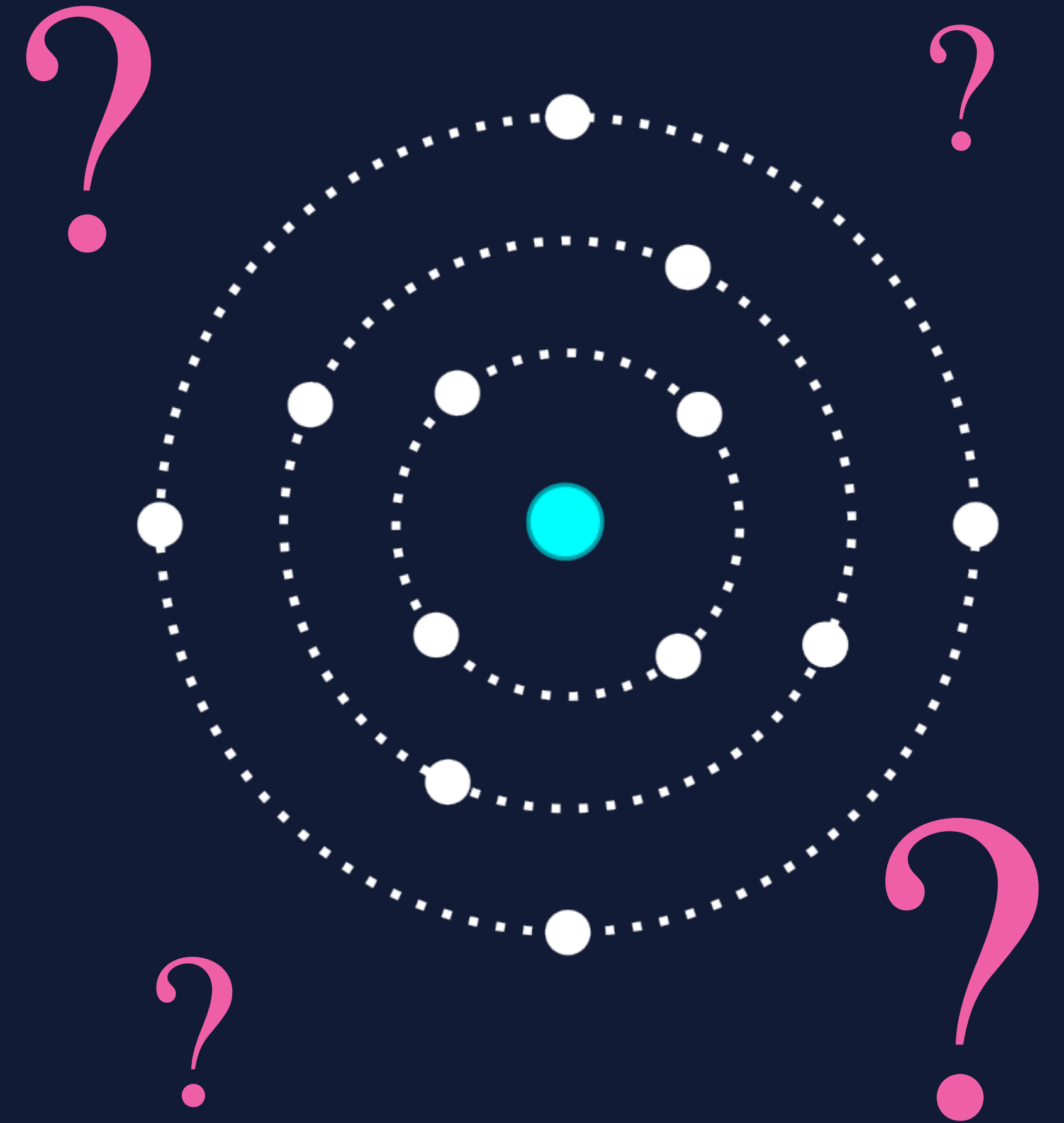
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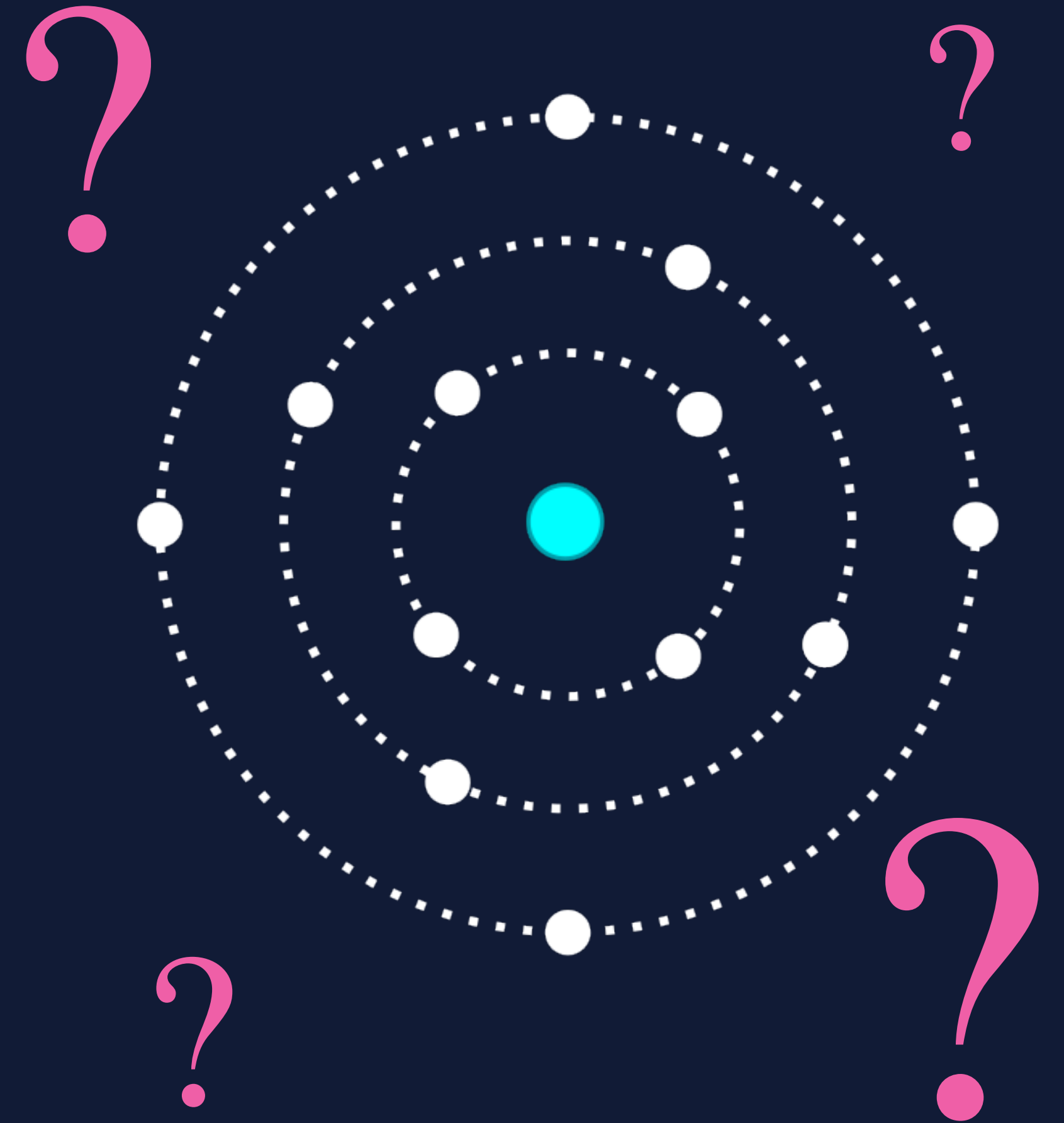
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- * PBHs are not expected to be born with significant peculiar velocities
- * If they do not acquire substantial angular momentum after turnaround, they will simply be accreted by the central PBH

★ **No** PBH density **spike** may form!



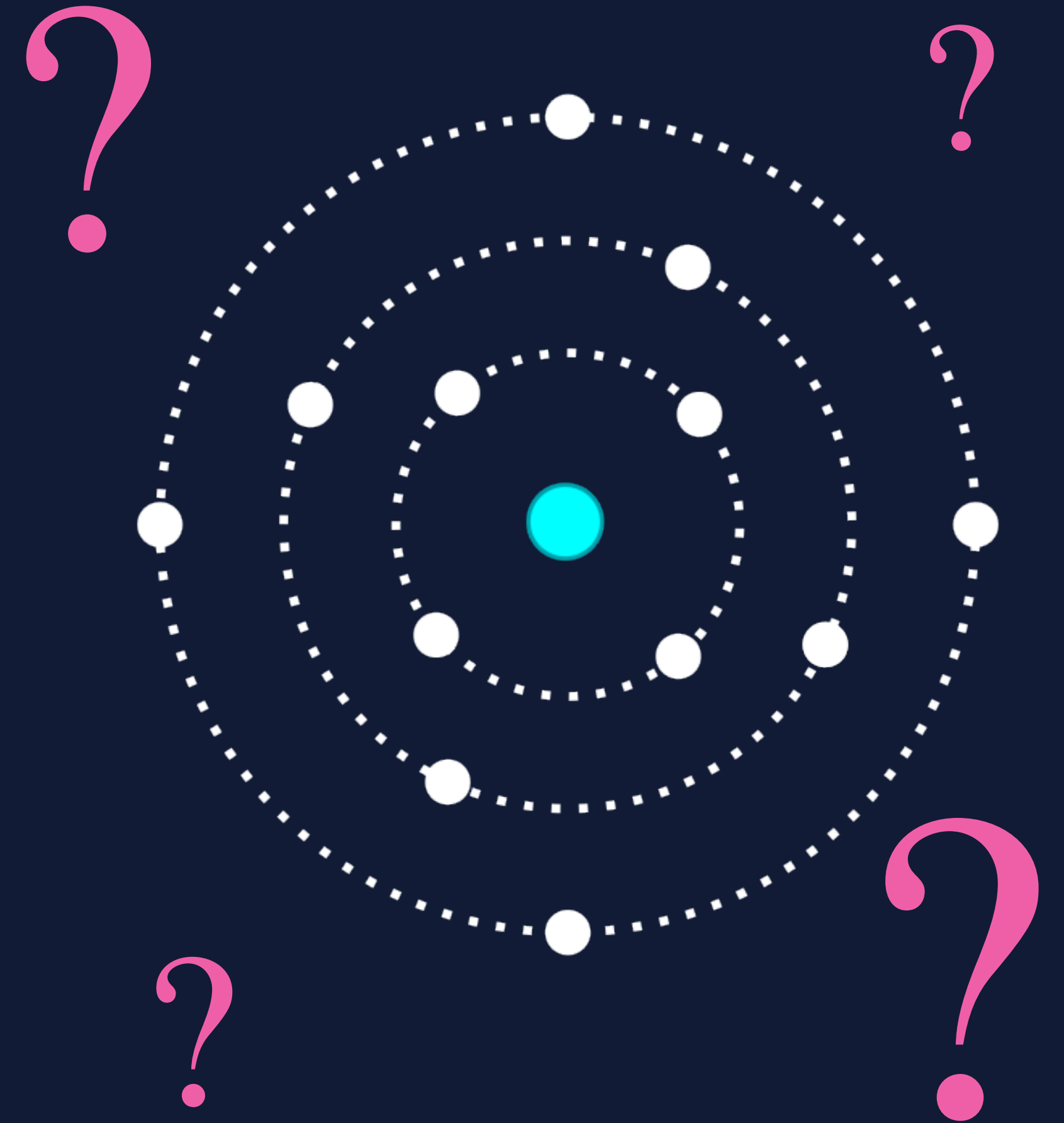
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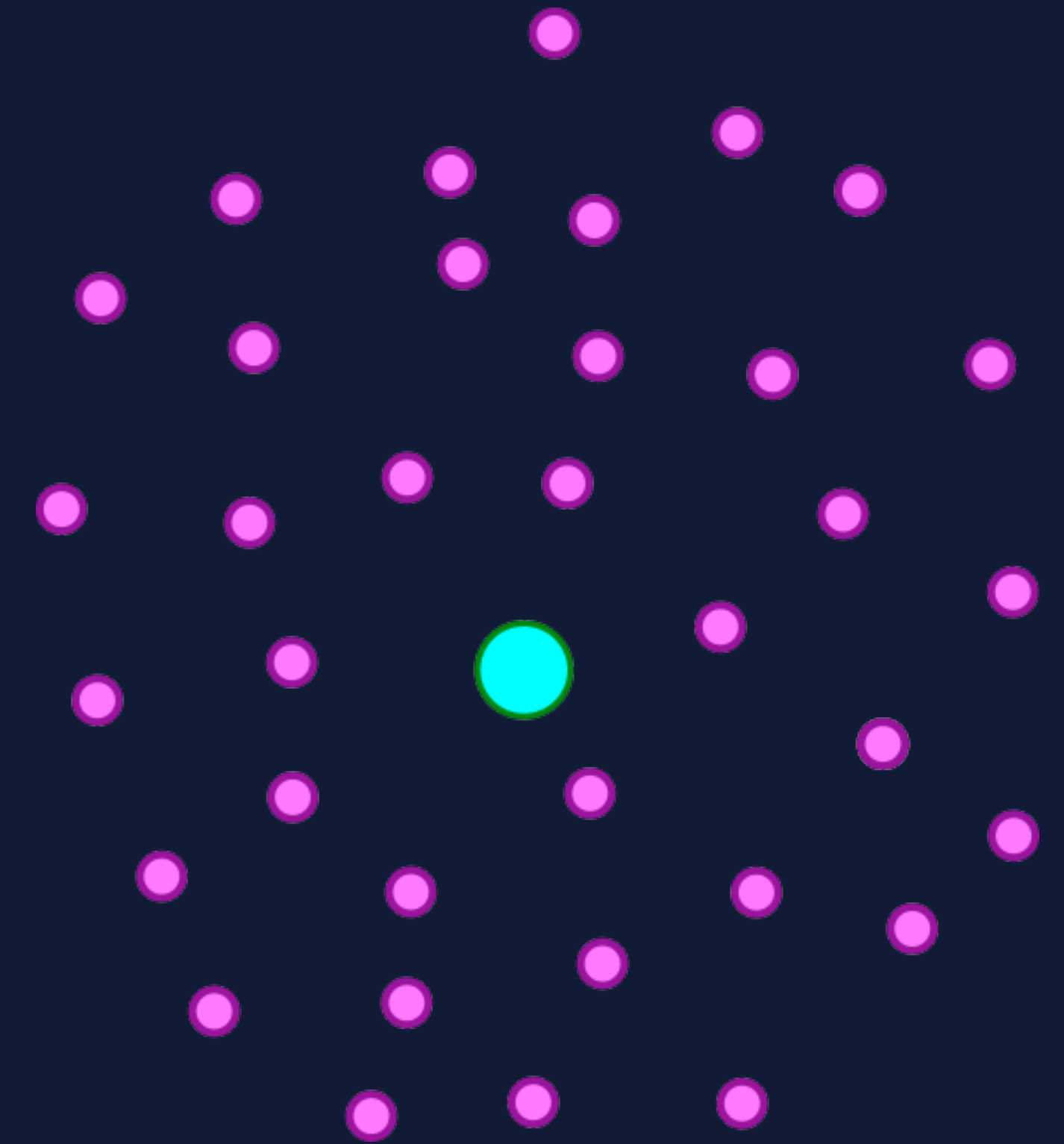
Key question

What mechanisms could generate sufficient torque to prevent the accretion & allow a spike to form?



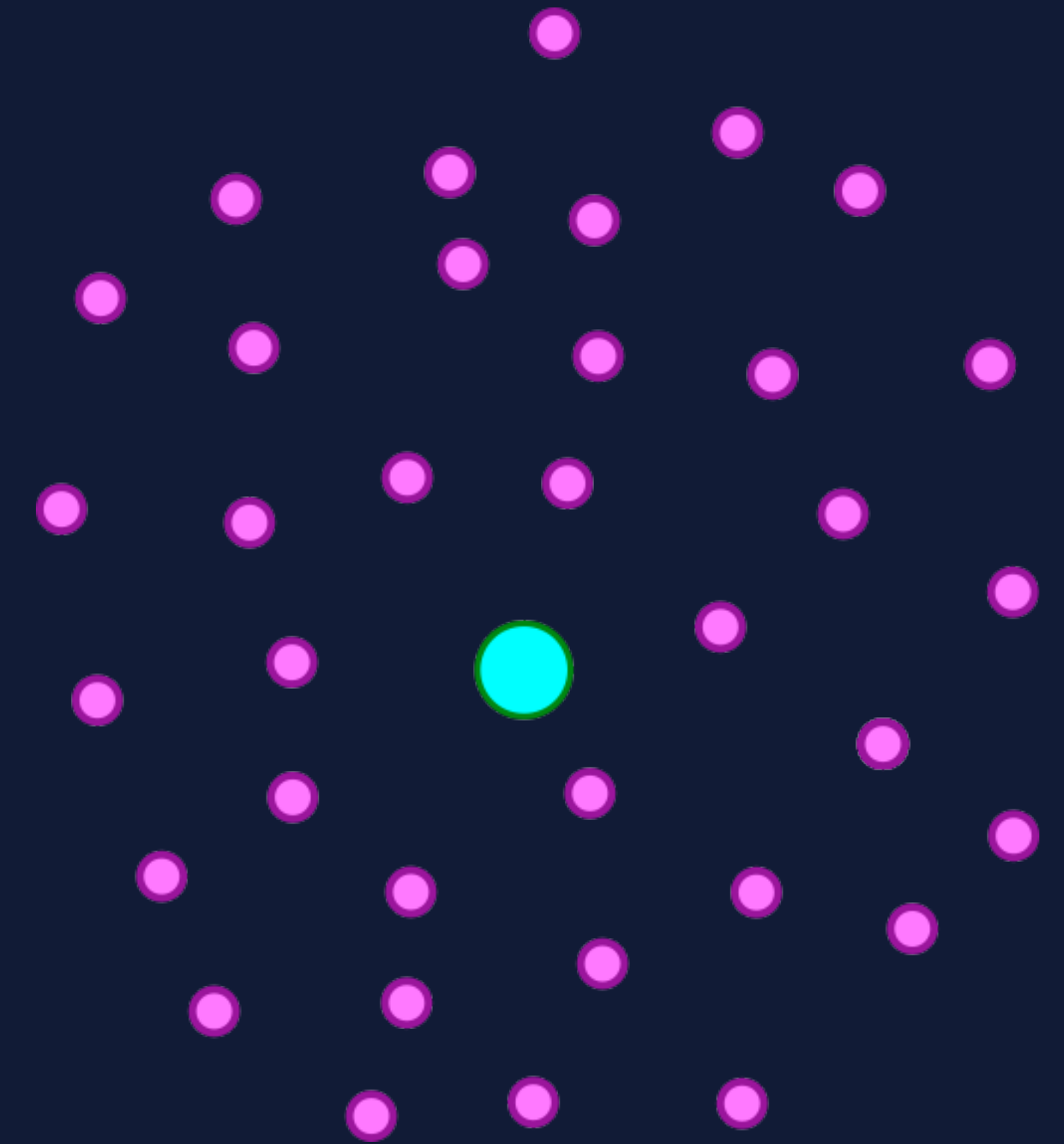
Physical setup

- ✱ We consider a population of light PBHs (IPBHs), with masses $m \in [10^{-16}, 10^{-5}] M_{\odot}$, around a central heavy (hPBH) PBH, $M \in [1, 10^3] M_{\odot}$ (QCD + SMBH seeds)



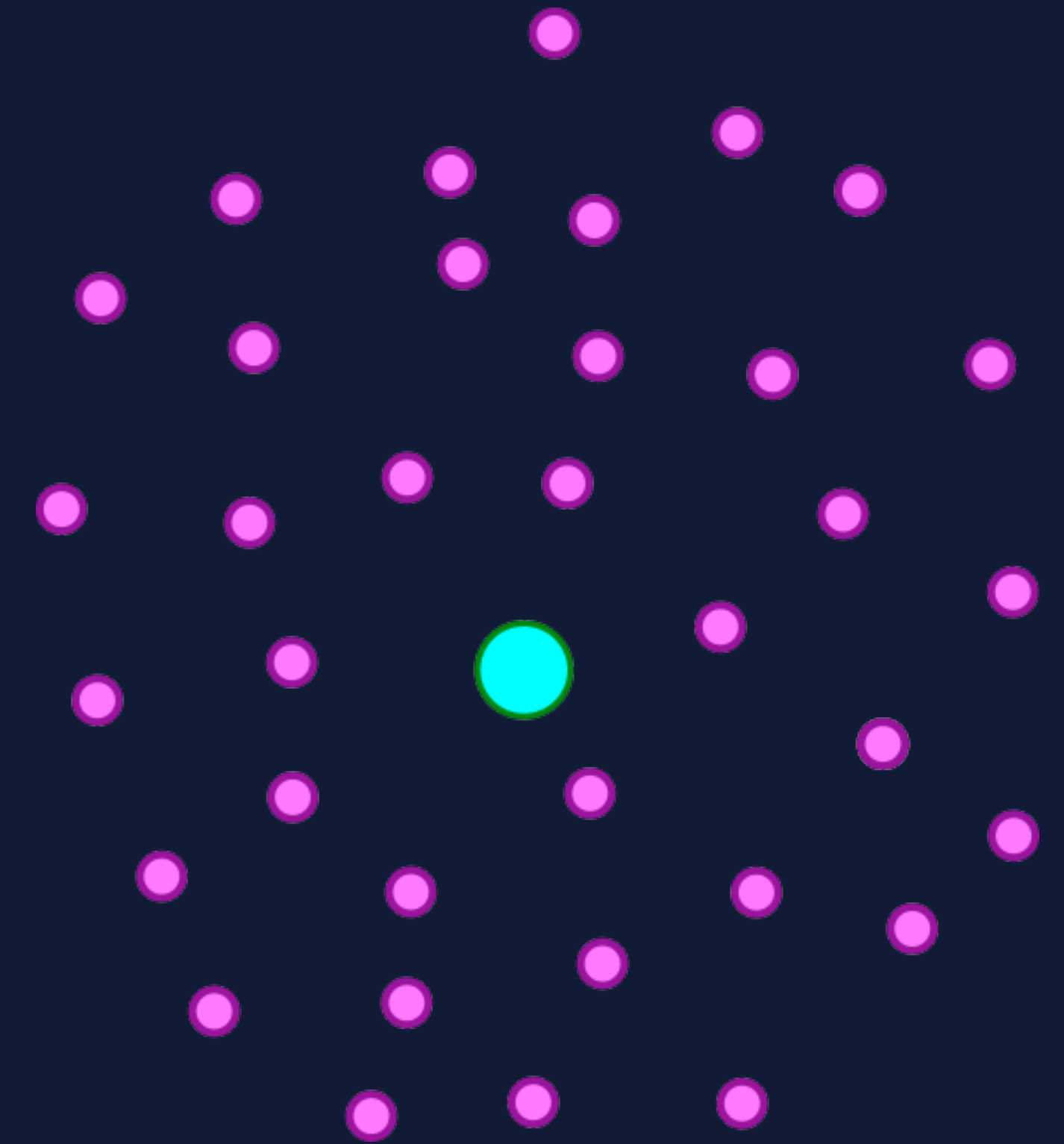
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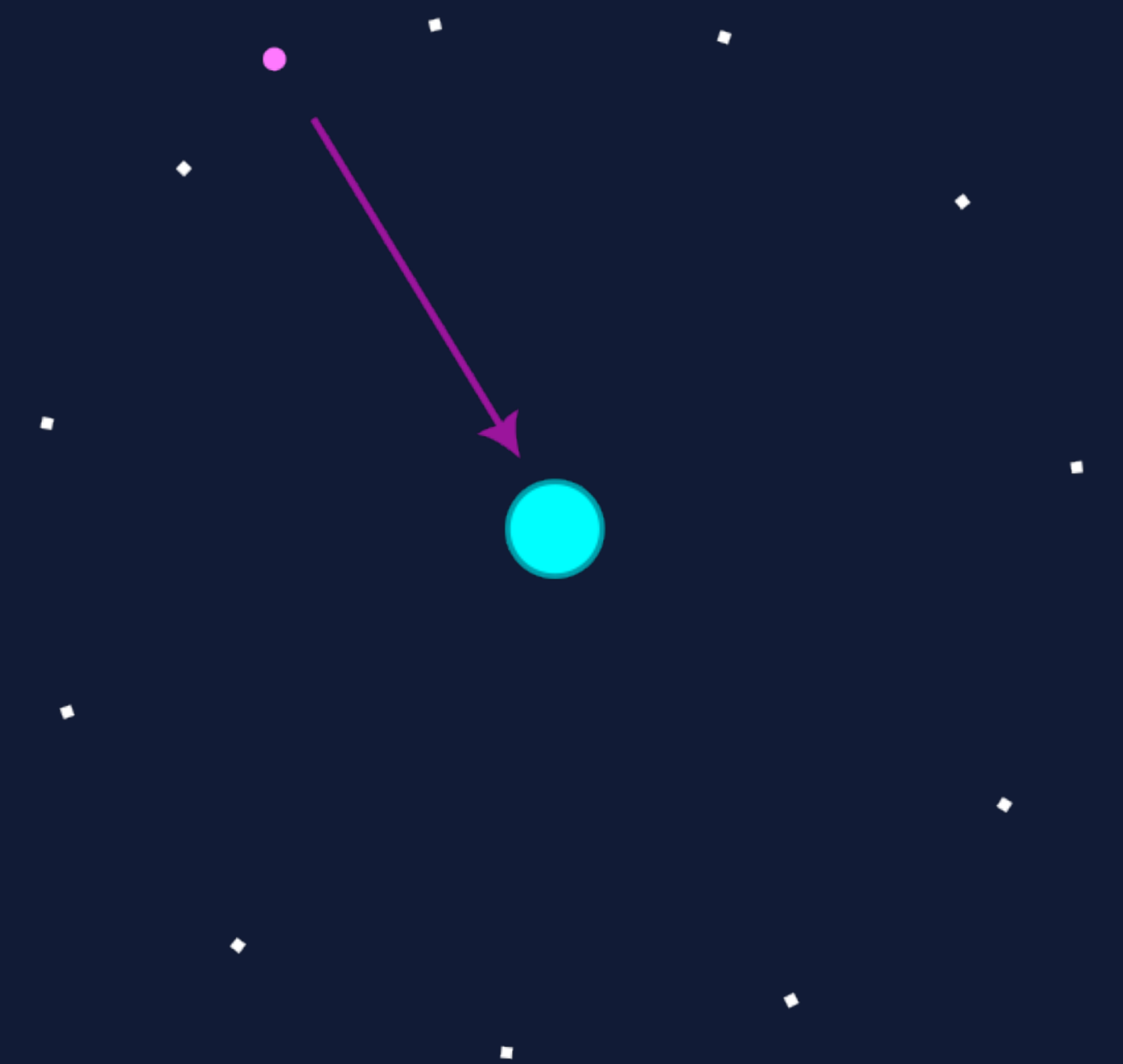
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- ✱ The IPBHs constitute the dominant DM component, while the hPBHs are a subdominant population
- ✱ The evolution of IPBHs around the heavy PBH closely follows that of WIMPs until decoupling from the Hubble flow



Physical setup

- ✱ After turnaround, the IPBH shells will start free-falling towards the central PBH



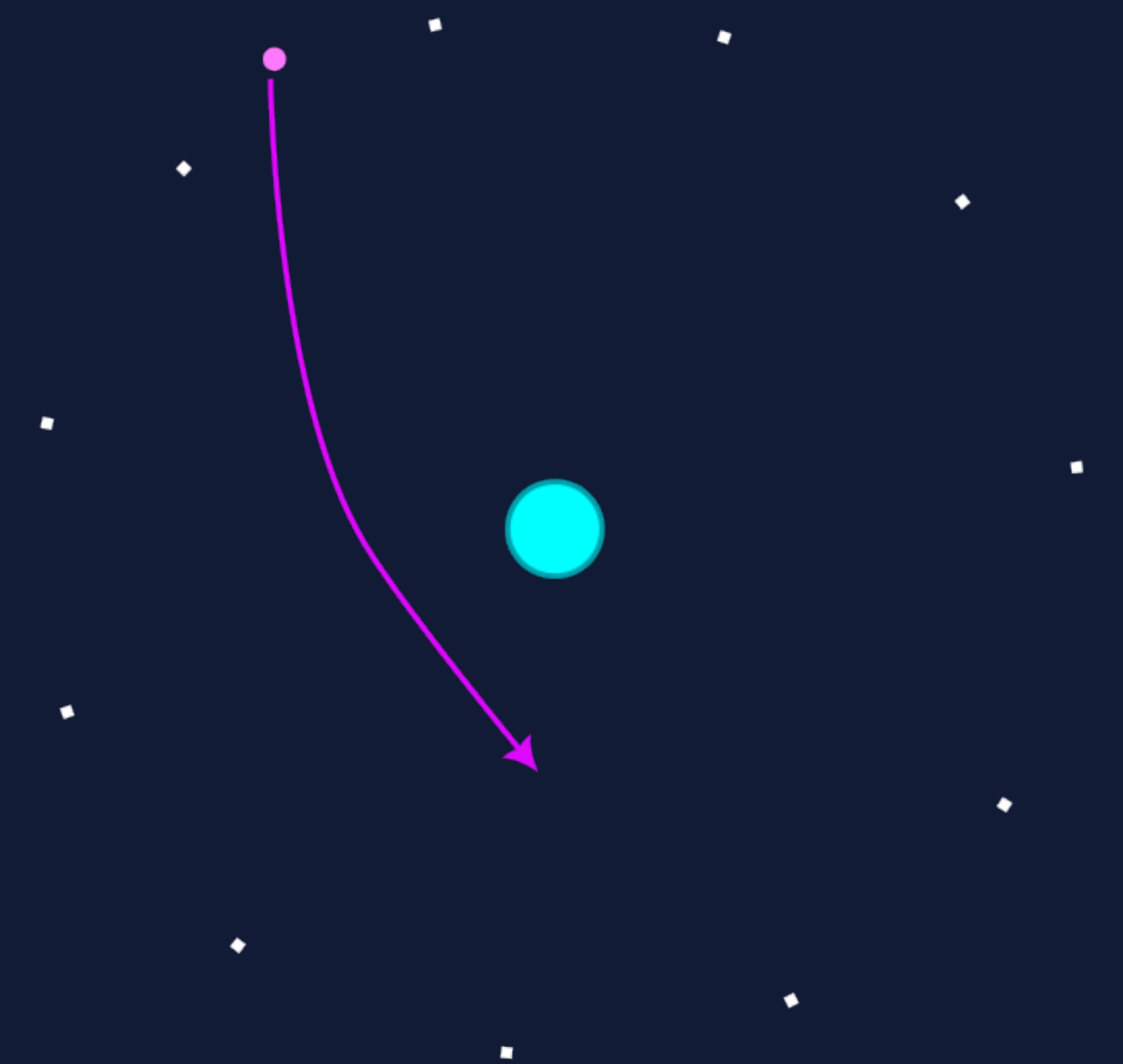
Physical setup

- ✱ After turnaround, the IPBH shells will start free-falling towards the central PBH
- ✱ If mechanisms to generate torque exist, the final (reduced) angular momentum will be

$$\ell = \int dt \frac{\tau(t)}{m} = \int \frac{dr}{v_{ff}(r)} \frac{\tau(t)}{m}$$

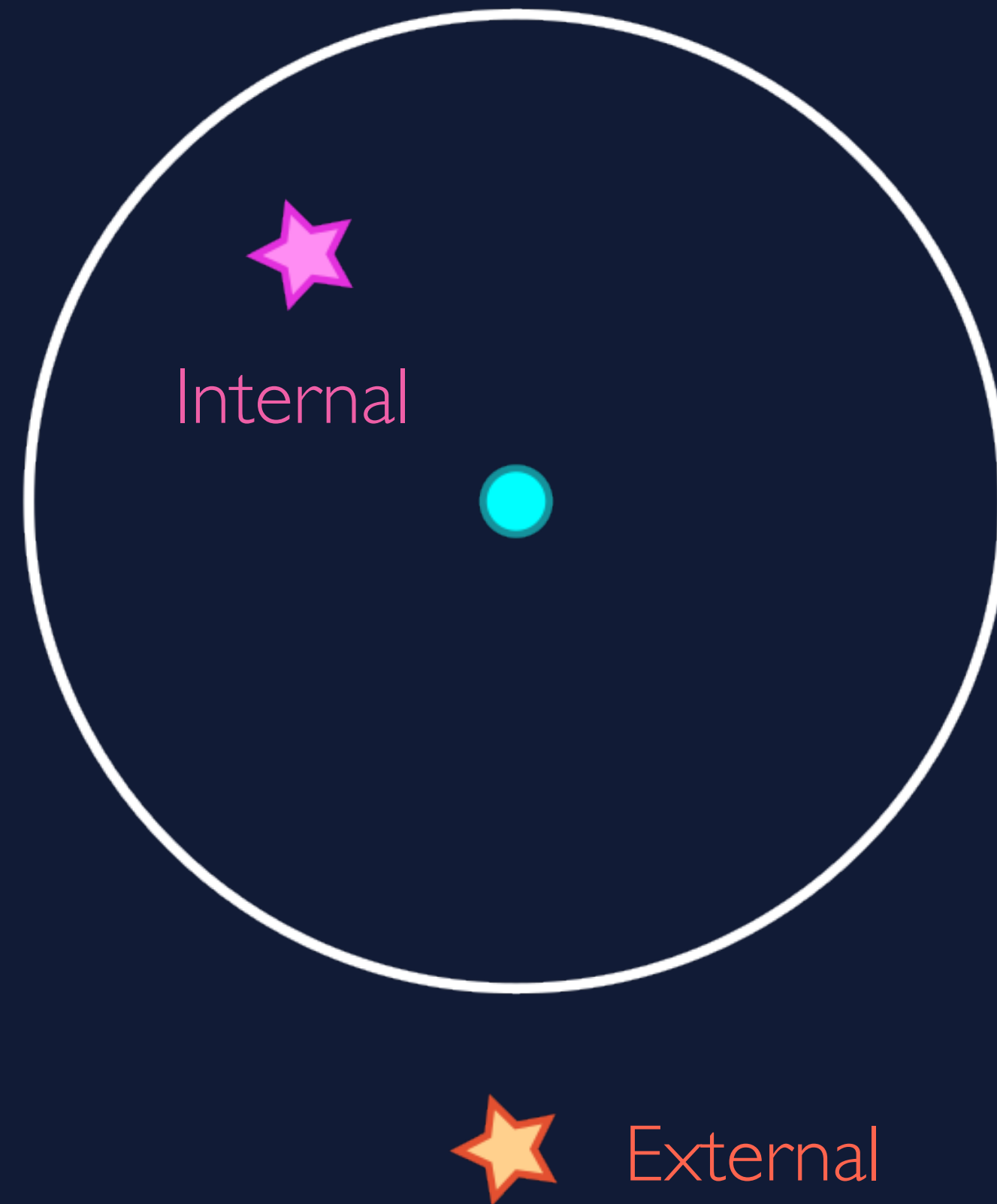
where v_{ff} is the free-fall velocity

- ✱ If $\ell > \ell_{\text{escape}} = 4GM/c$ the PBH escapes capture, and a spike can form!



Classes of torque

Two classes, depending if the source of torque is inside or outside each turnaround shell



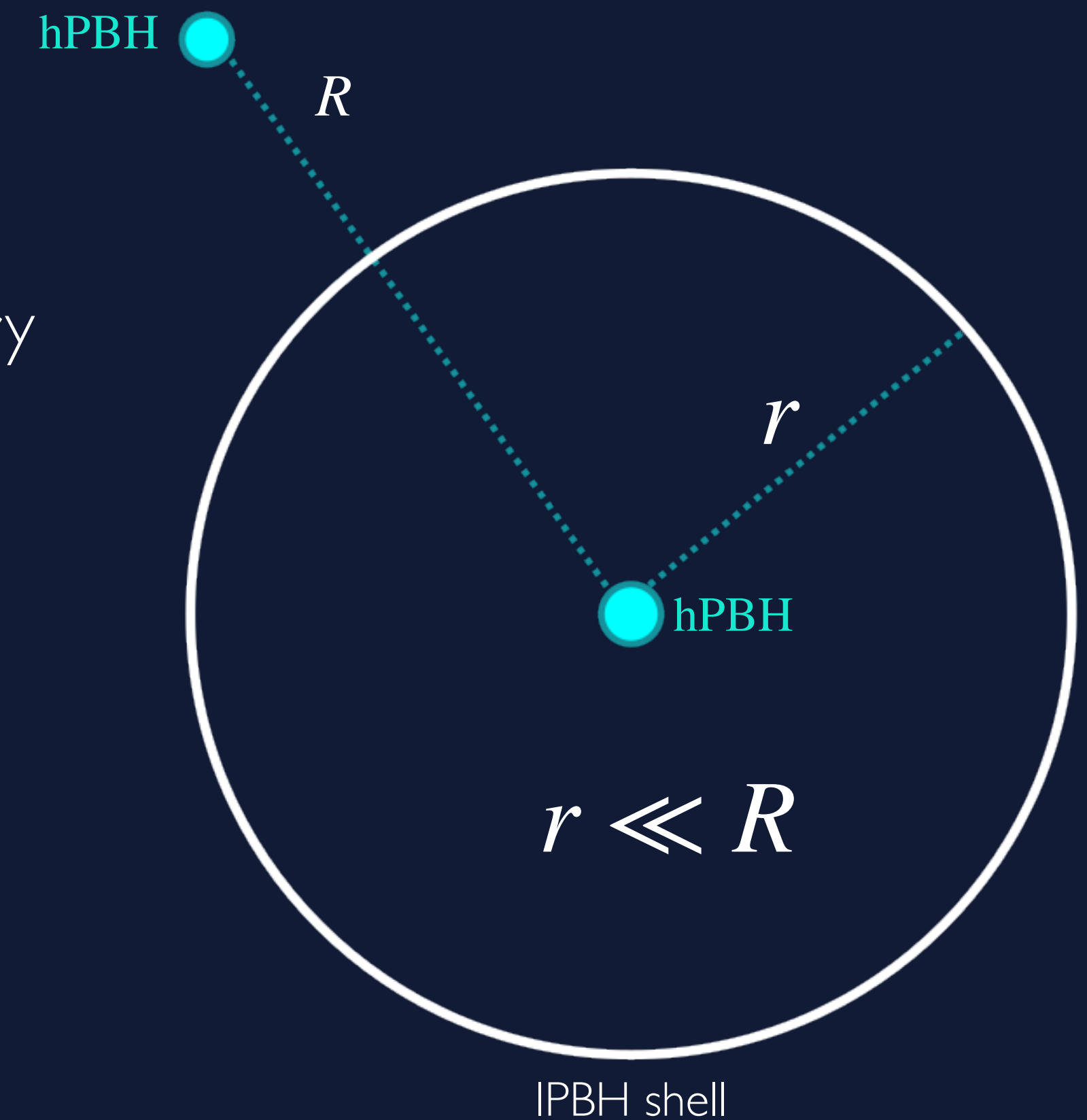
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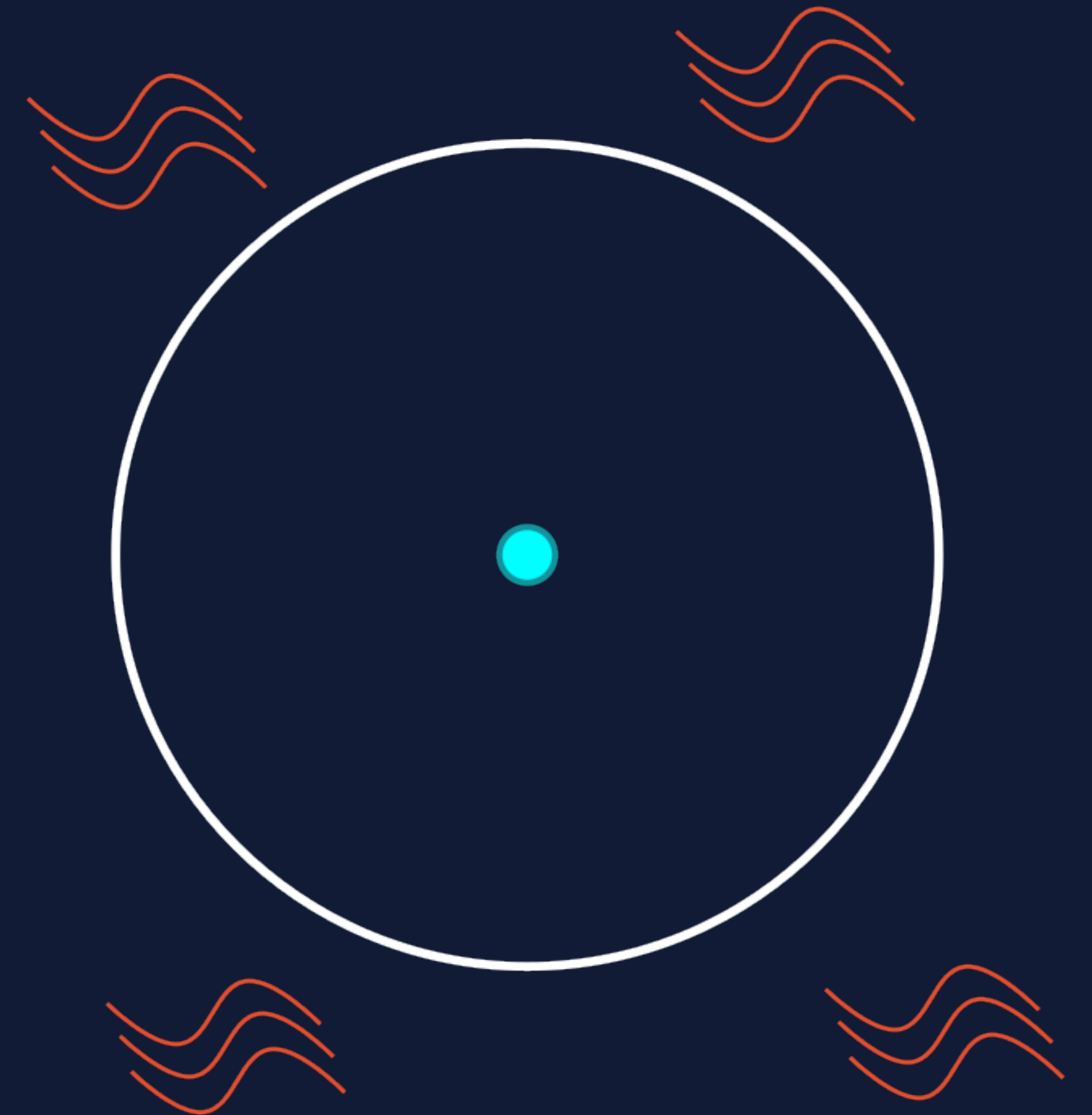
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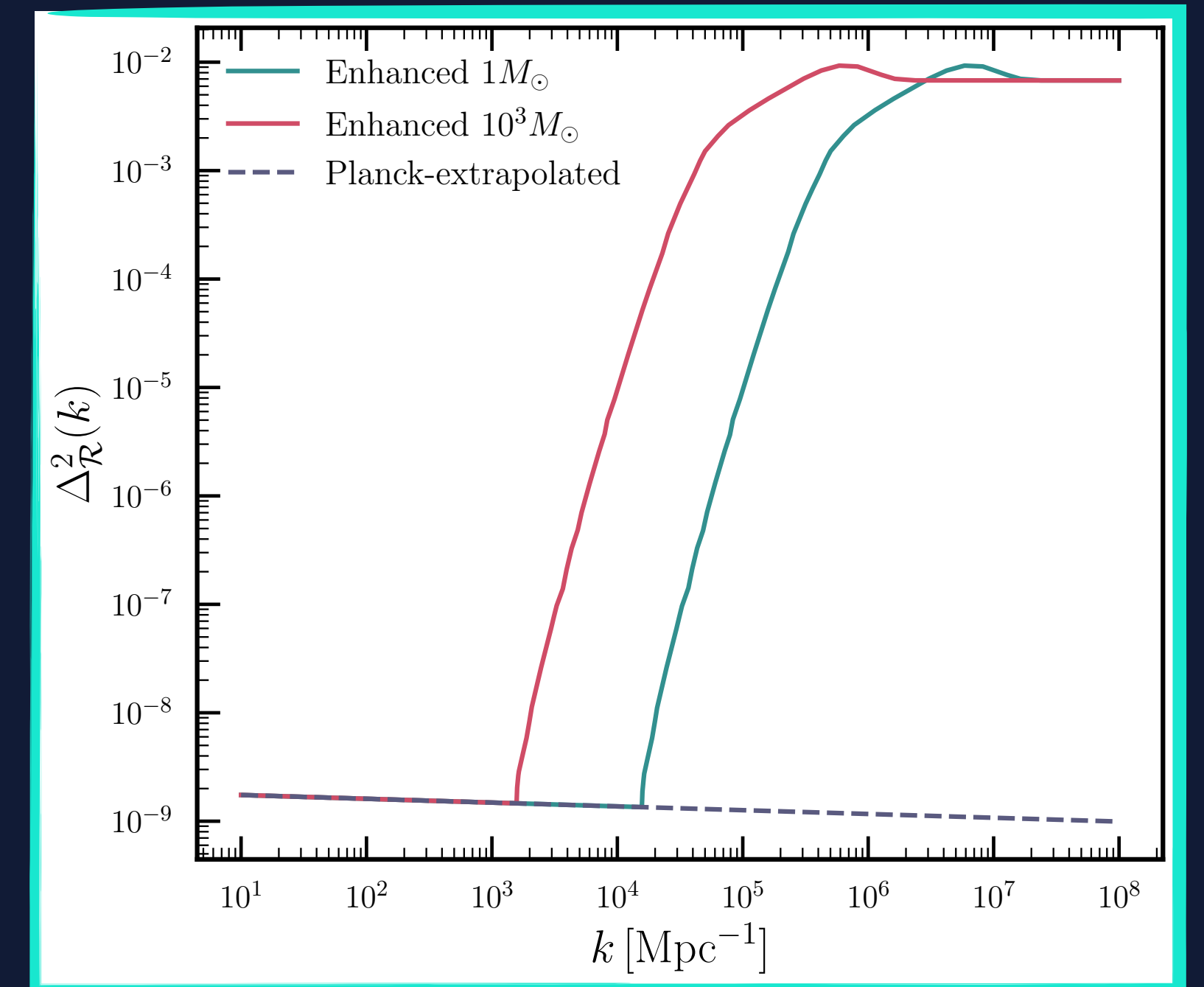
- 1) Far-away external hPBHs
- 2) Cold dark matter large-scale adiabatic density perturbations



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- 1) Far-away external hPBHs
- 2) Cold dark matter large-scale adiabatic density perturbations
 - depends on the primordial curvature spectra of perturbations
 - 2 cases: CMB-like + PBH enhancement based on 2207:10056 & 2209:05959



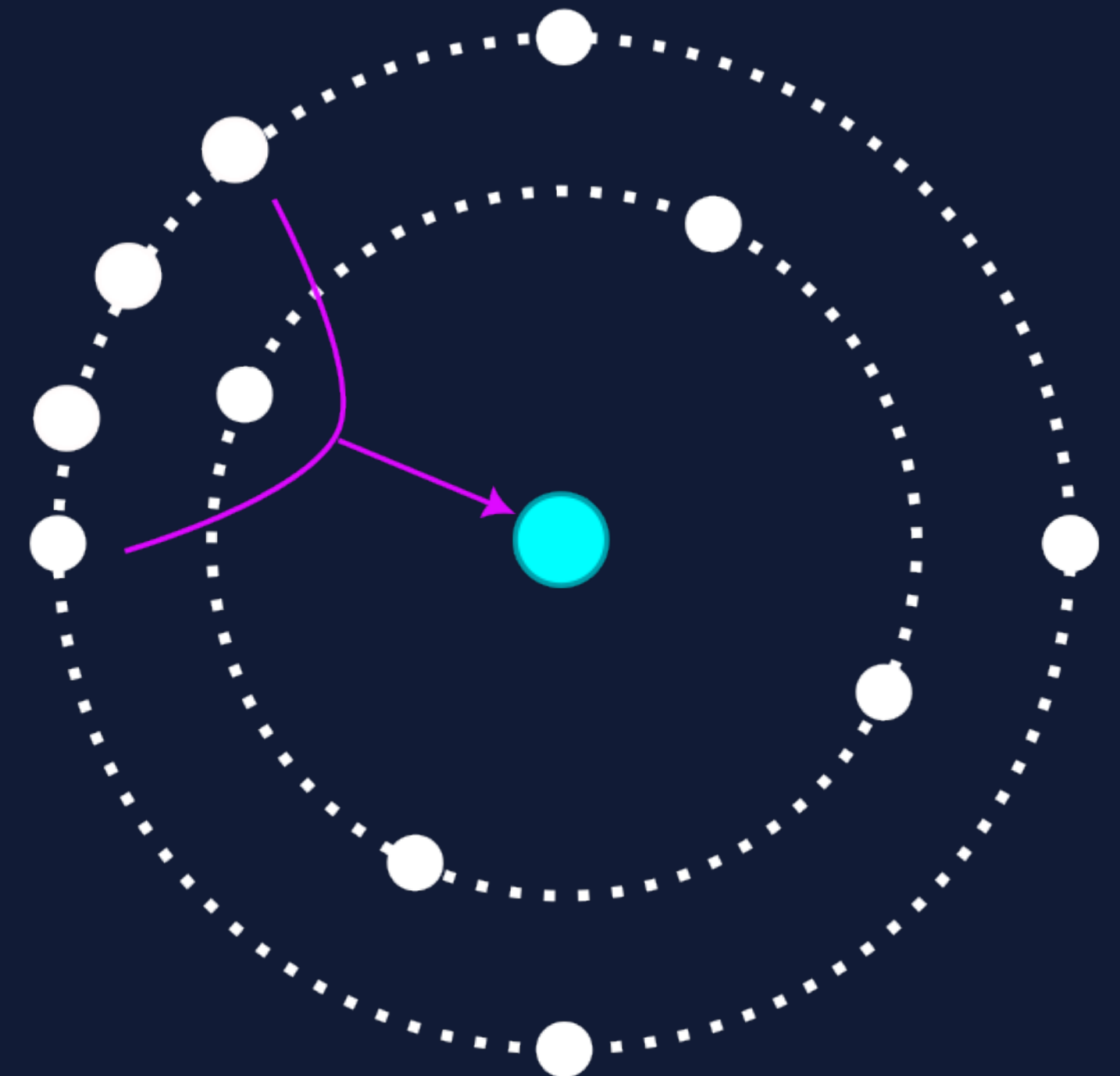
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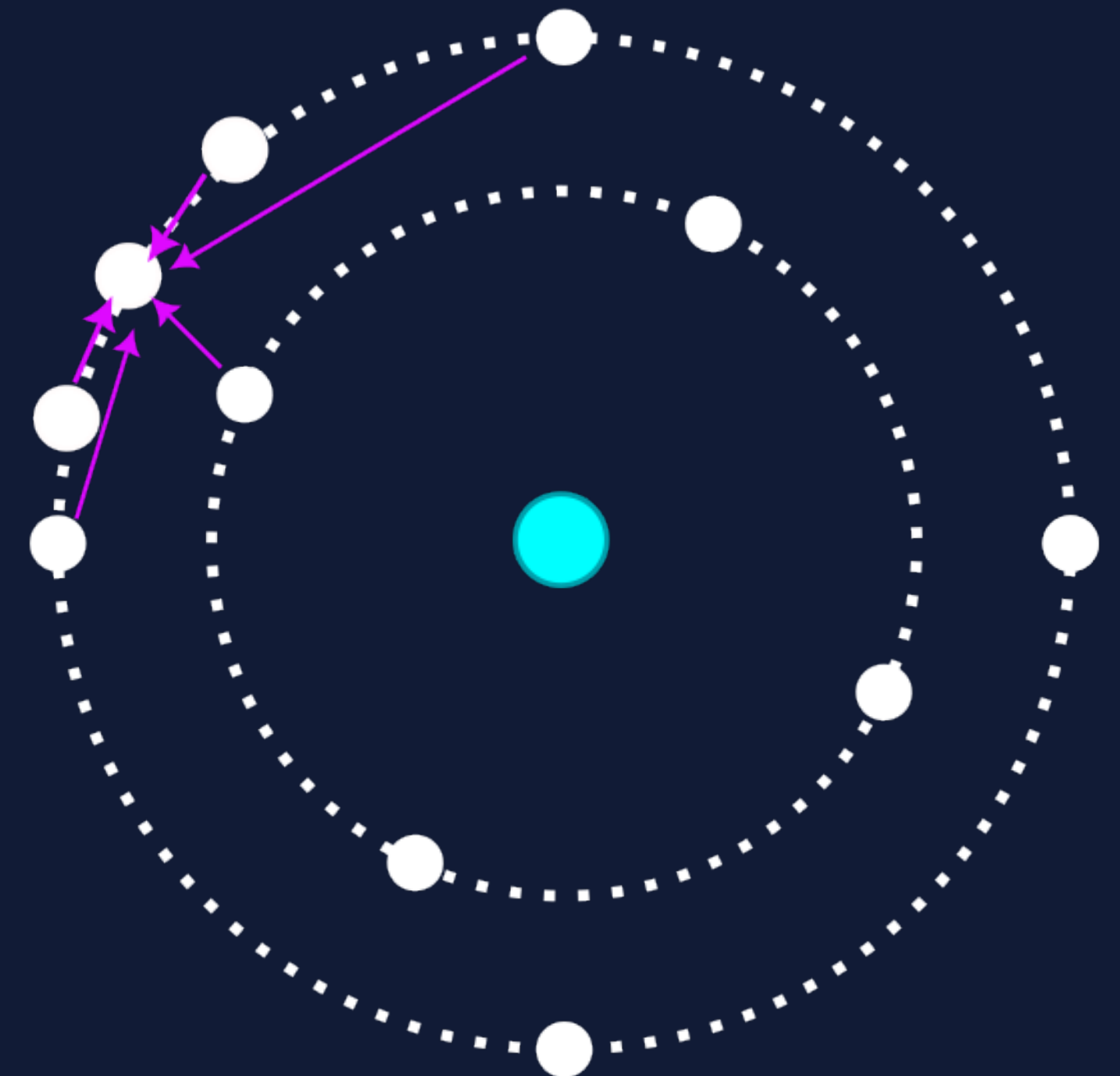
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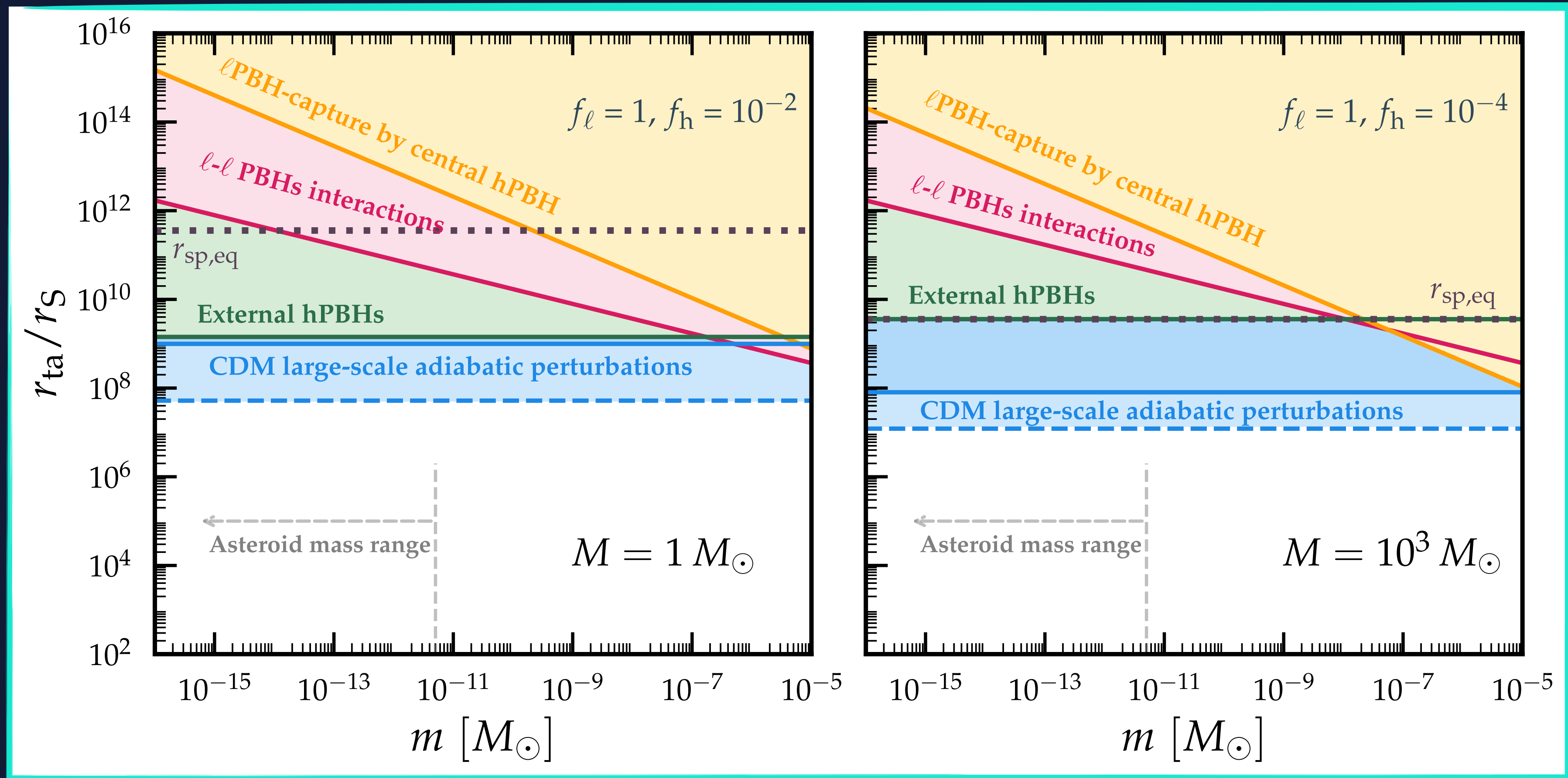
* **Small scale anisotropies** of the gravitational potential inside the shell produce additional forces (hence torque) acting on each PBH independently

- 1) Force on the central hPBH from shell anisotropies
- 2) Force on each IPBH from its neighbours



Results

Can torques save IPBH spikes?



Conclusions & outlook

- * Motivated by the analogy with WIMP spikes, we investigated whether **IPBHs** — in the mass range still compatible with constituting part or the entirety of DM — could form **spikes around heavier PBHs** with masses of 1 and $10^3 M_{\odot}$ (QCD peak + SMBH seeds)
- * The innermost shells are accreted, but **most of the shells are “saved”** by CDM adiabatic large-scale density perturbations
- * Our results suggest that **spike formation is possible!**
- * Such spike formation dynamics could also lead to distinctive GWs signatures, providing an additional observational window into multi-scale PBH scenarios
- * Hierarchical mergers in this high density environment might enhance the growth of SMBH seeds!

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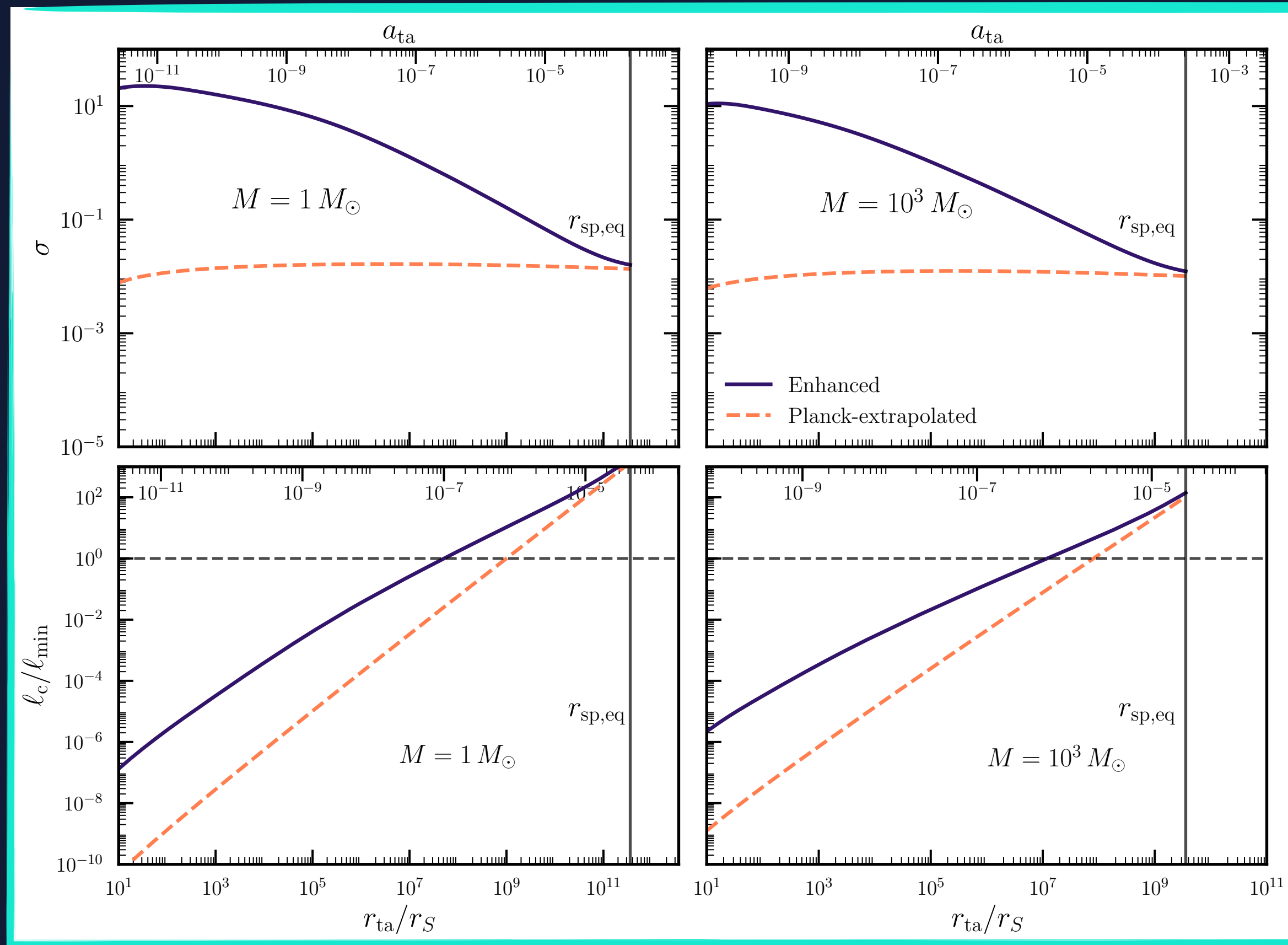
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Thanks!
Questions?



Backup

CDM adiabatic large-scale density perturbations



$$\nabla^2 \delta\Phi = 4\pi G \bar{\rho} \delta_{\text{cdm}}$$

$$\langle T_{ij}^2 \rangle = (4\pi G \bar{\rho})^2 \int \frac{dk}{2\pi^2} k^2 \mathcal{P}_{\text{cdm}}(k) \equiv (4\pi G \bar{\rho})^2 \sigma^2,$$

Evolution with CAMB

- * CAMB is an Einstein-Boltzmann solver that can be used to evolve primordial curvature perturbations to redshift z
- * We use it to evolve the CMB-like baseline curvature spectrum to matter-radiation equality, extracting the CDM component and deriving

$$\mathcal{T}(k, z) = \frac{\Delta_{\text{CDM,CMB}}^2(k, z)}{\Delta_{\mathcal{R},\text{CMB}}^2(k)},$$

- * We use this to evolve the PBH enhanced spectra at scales $k \geq 10^{-4} \text{Mpc}^{-1}$, CAMB's performance worsens

Capture threshold with f_{PBH}

