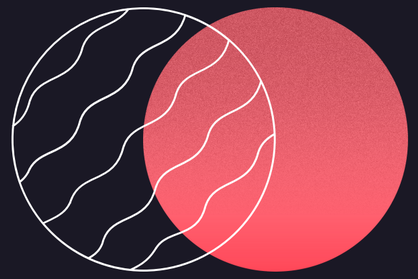

A self-consistent wave description of axion minicluster and their survival in the galaxy

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FIPS Workshop

Motivation

→ Axion provides an elegant solution for the strong CP problem + DM

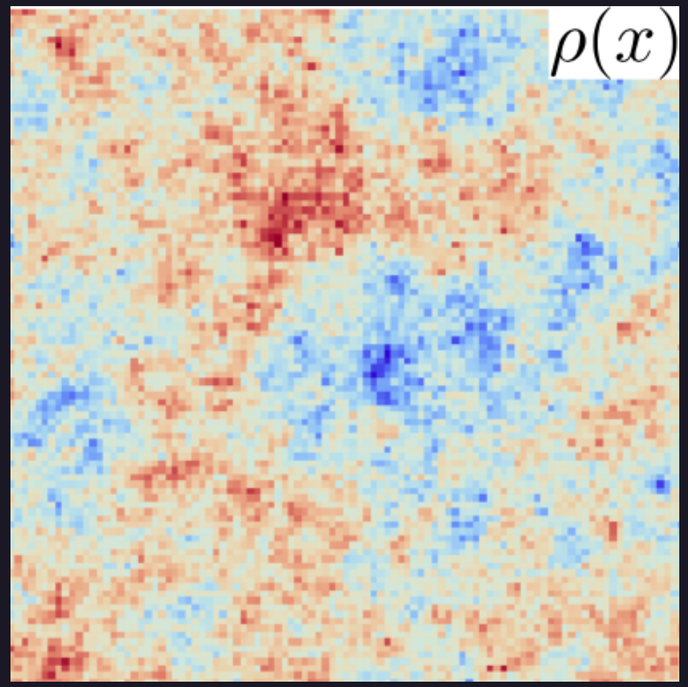
Misalignment Mechanism

→ Pre-inflation scenario: axion field initially homogeneous

→ Post-inflation scenario: axion field initially inhomogeneous. Different values in causally disconnected regions

Motivation

Post-Inflation Scenario



A. Pargner thesis

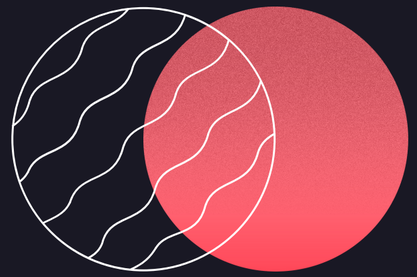
→ Provides a very rich phenomenology:

Domain walls, cosmic strings, axion stars, axion miniclusters

→ Are those objects still present?

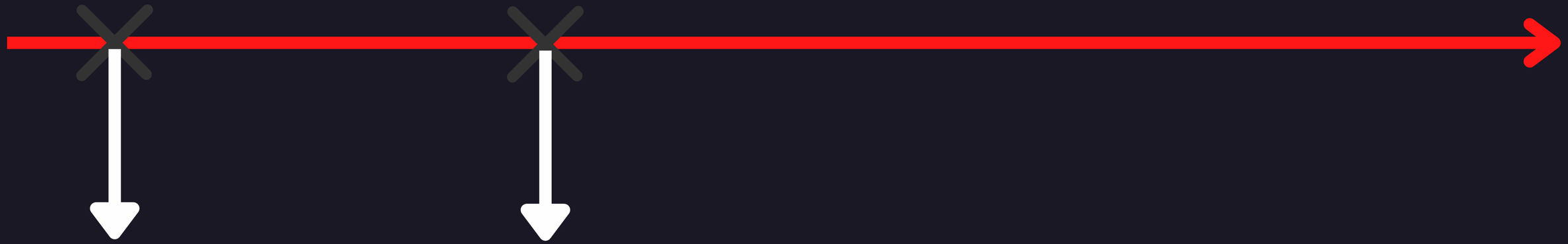
Would affect drastically direct detection

Where are the miniclusters?



History of axion miniclusters

$T \approx 100\mathrm{MeV}$ $t \approx 17\mathrm{Myr}$

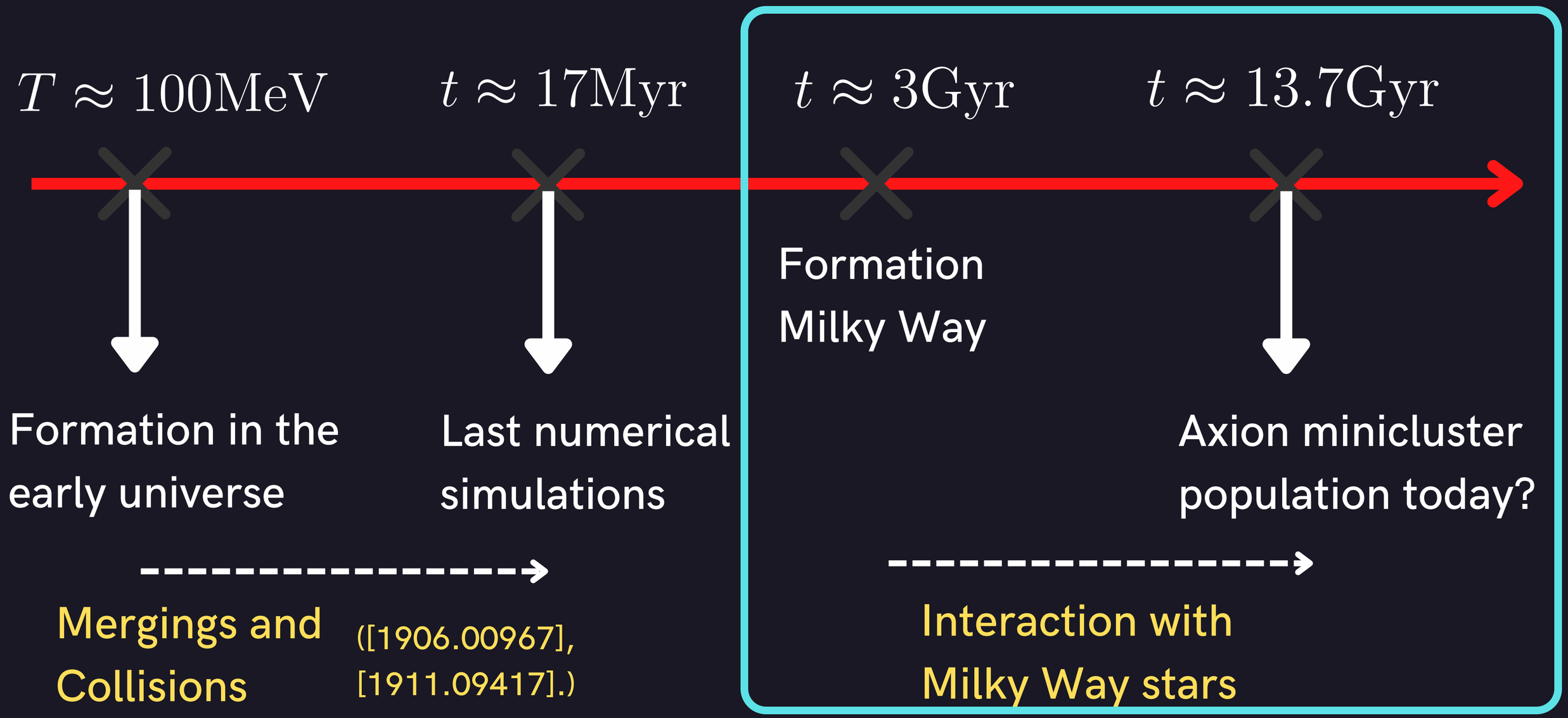


Formation in the early universe

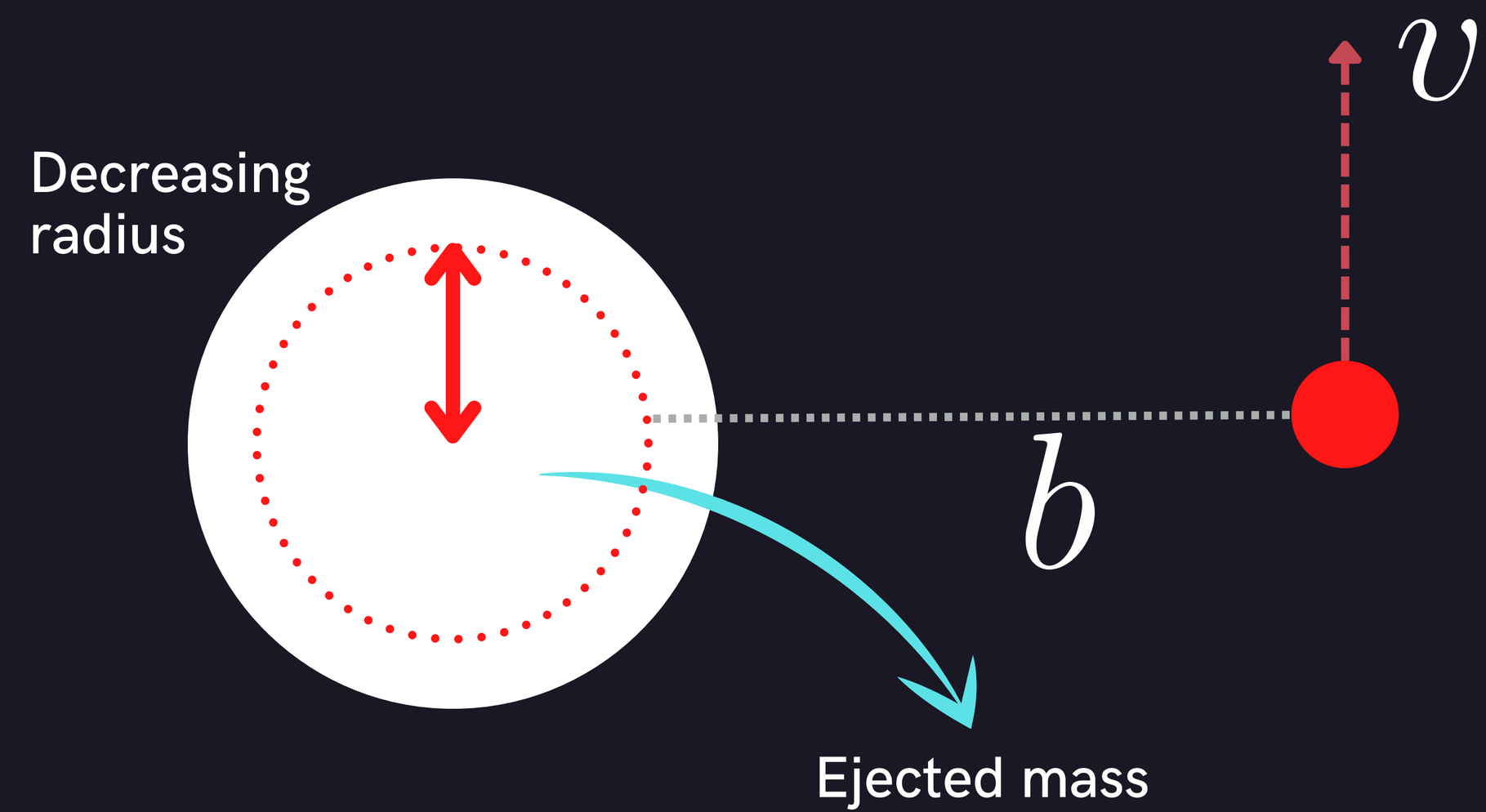
Last numerical simulations

Mergings and Collisions ([1906.00967], [1911.09417].)

History of axion miniclusters



Interaction with stars in the MW



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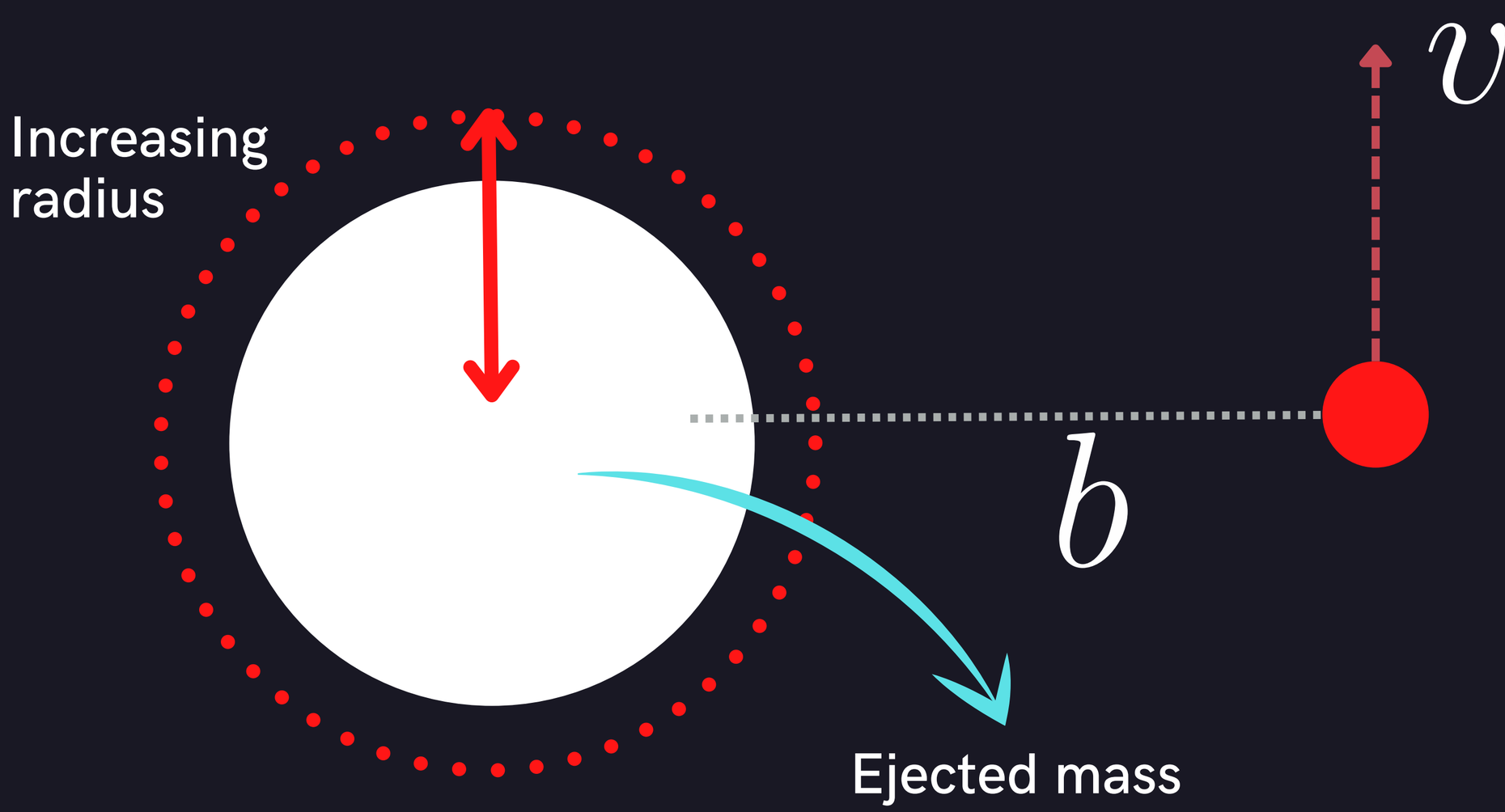
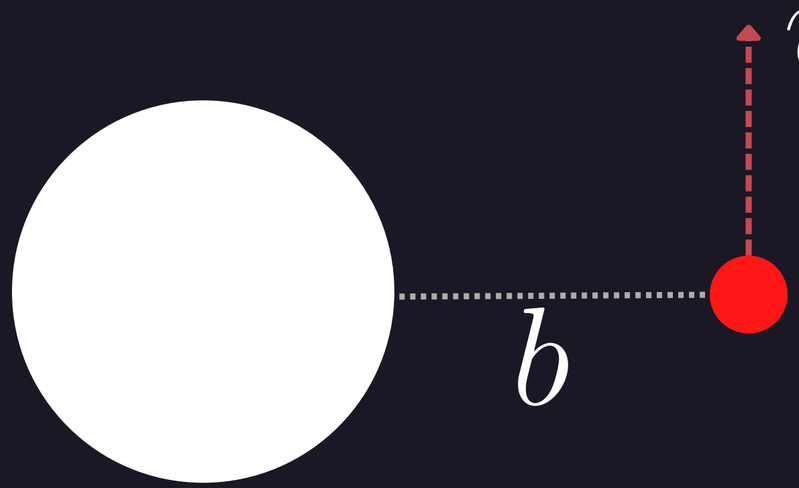


How to know if they survived?

1

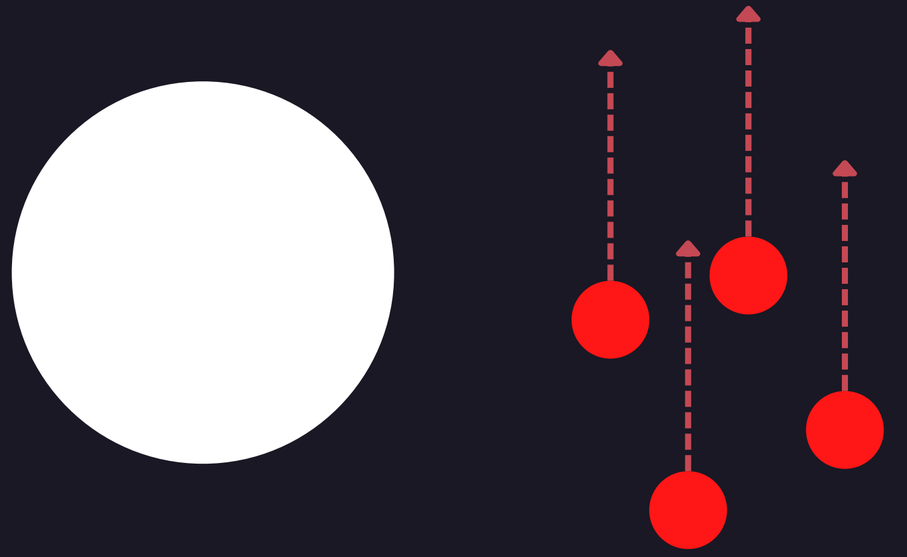
- Characterize the minicluster

2



- How does it interact with a star

3



- Simulate all the interactions in its lifetime

How to know if they survived?

1. *How to characterize the minicluster?*

→ Axions are described by a classical field

$$i\partial_t\psi = \left(-\frac{\nabla^2}{2m_a} + m_a\phi(r)\right)\psi$$

$$\nabla^2\phi = 4\pi G m_a |\psi|^2$$

→ Wave function for a given density and potential profile?

How to know if they survived?

1. *How to characterize the minicluster?*

$$i\partial_t\psi = \left(-\frac{\nabla^2}{2m_a} + m_a\phi(r)\right)\psi$$

$$\nabla^2\phi = 4\pi G m_a |\psi|^2$$

→ Fixed potential, density and distribution function $\{f, \phi, \rho\}$

→ Solve analytically using WKB approximation

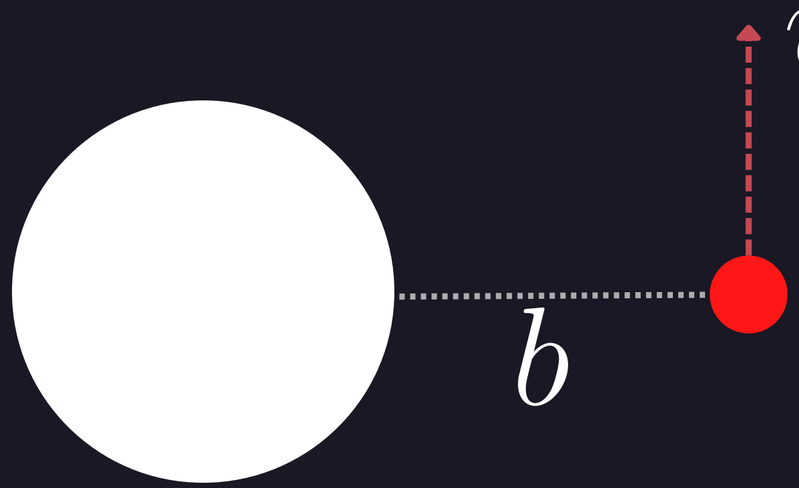
- $\psi(r,t) = \sum_{nlm} C_{nlm} R_{nl}(r) Y_{lm}(\theta,\phi) e^{-iE_n t}$
  - $C_{nlm} = \sqrt{(2\pi)^3 f(E_n)\, g_l(E_n)\, dE_n}\; e^{i\phi_{nlm}}$

How to know if they survived?

1

- Characterize the minicluster

2



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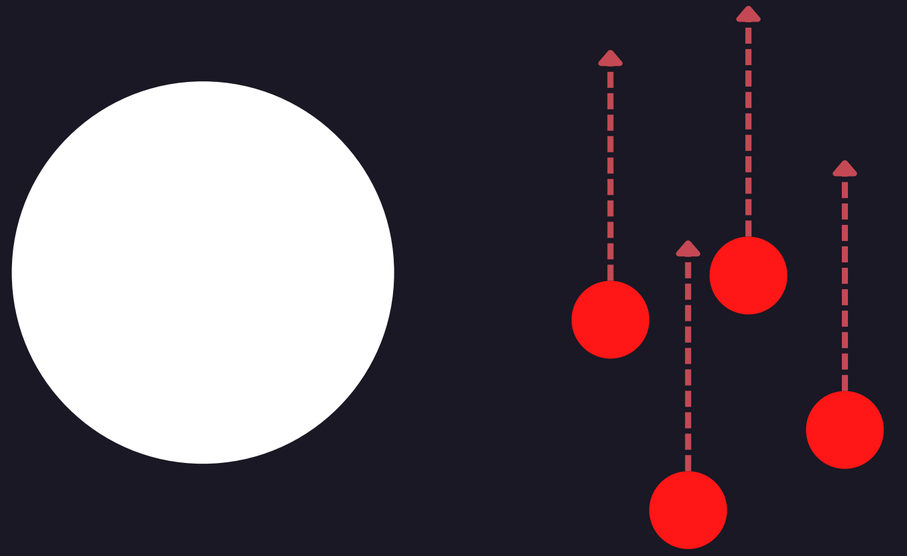


- Simulate all the interactions in its lifetime

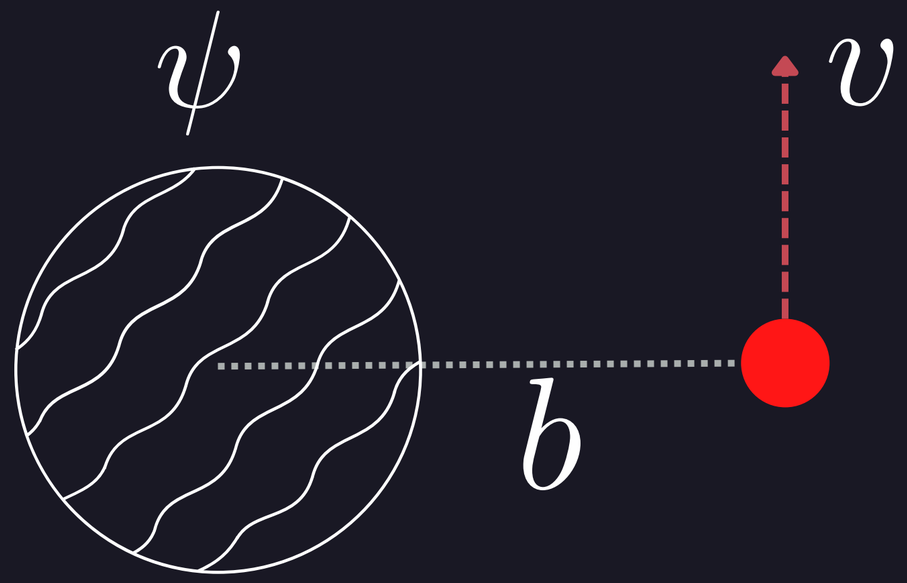
How to know if they survived?

2. How does it interact with a star?

→ The star creates a time dependent perturbation on the minicluster

$$H(t) = H_0 + H_1(t)$$

$$H_1(t) = -\frac{GM_* m_a r^2}{(b^2 + v^2 t^2)^{3/2}} P_2(\cos\gamma(t))$$



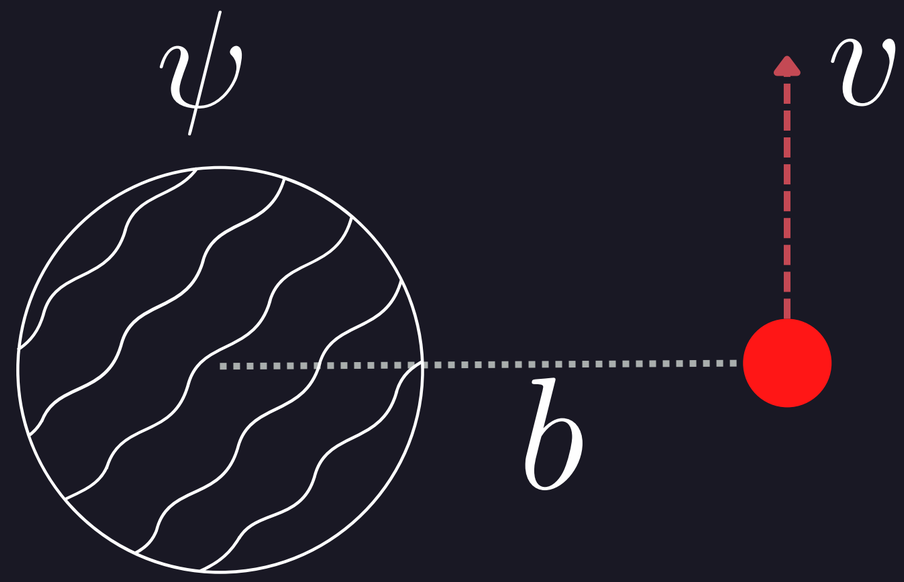
→ Apply QM perturbation theory: transition between energy levels

How to know if they survived?

2. How does it interact with a star?

→ Each energy level is shifted by

$$\delta E(E,l) = \left(\frac{2GM_*}{b^2 v}\right)^2 \frac{m_a}{4} < nl|r^2|nl >$$



→ If $|E| < \delta E(E,l)$ the energy level is removed from the system and generates a variation of the mass

How to know if they survived?

2. How does it interact with a star?

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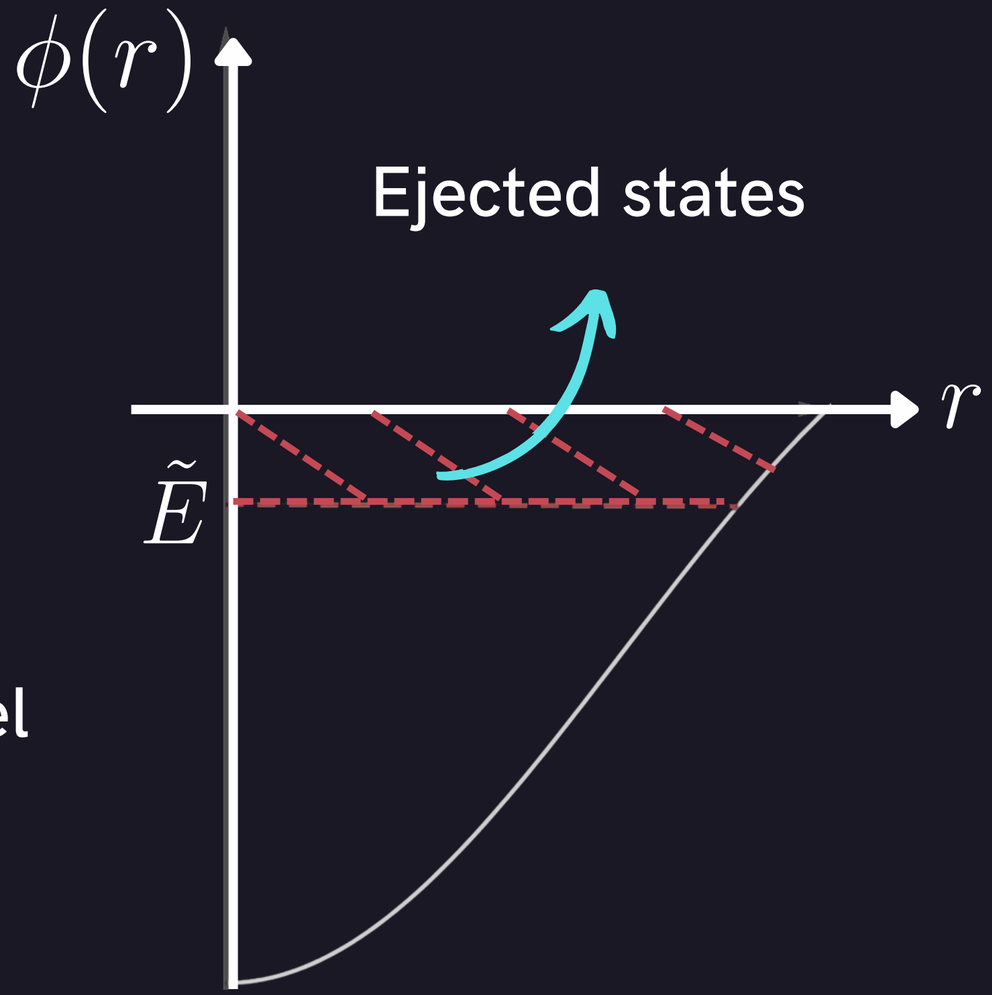
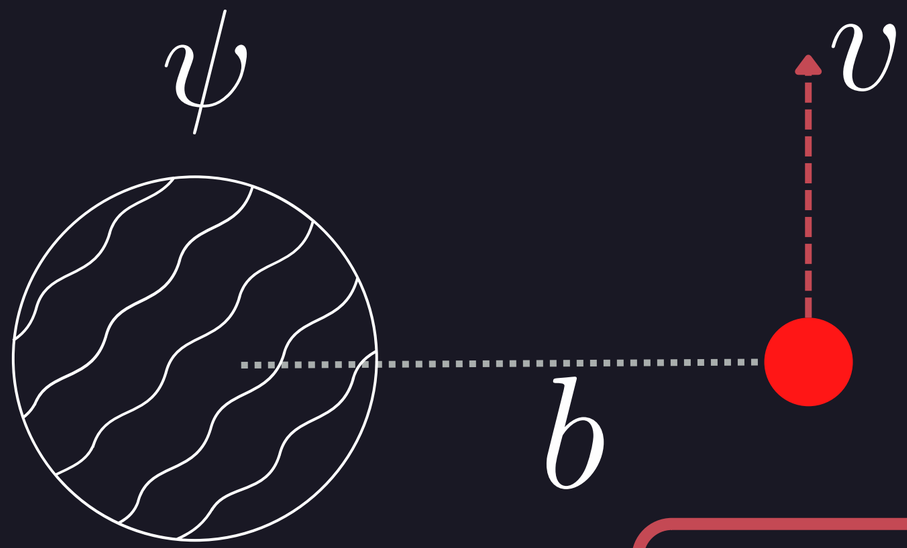


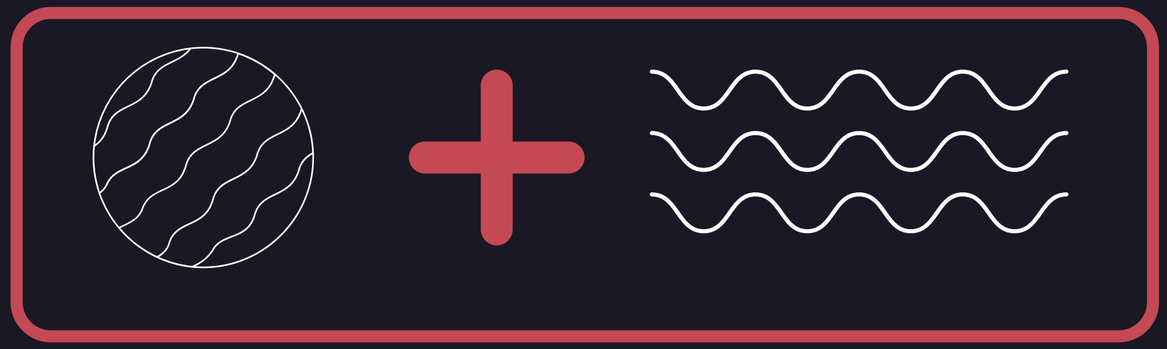
How to know if they survived?

2. How does it interact with a star?



The star creates a time dependent perturbation

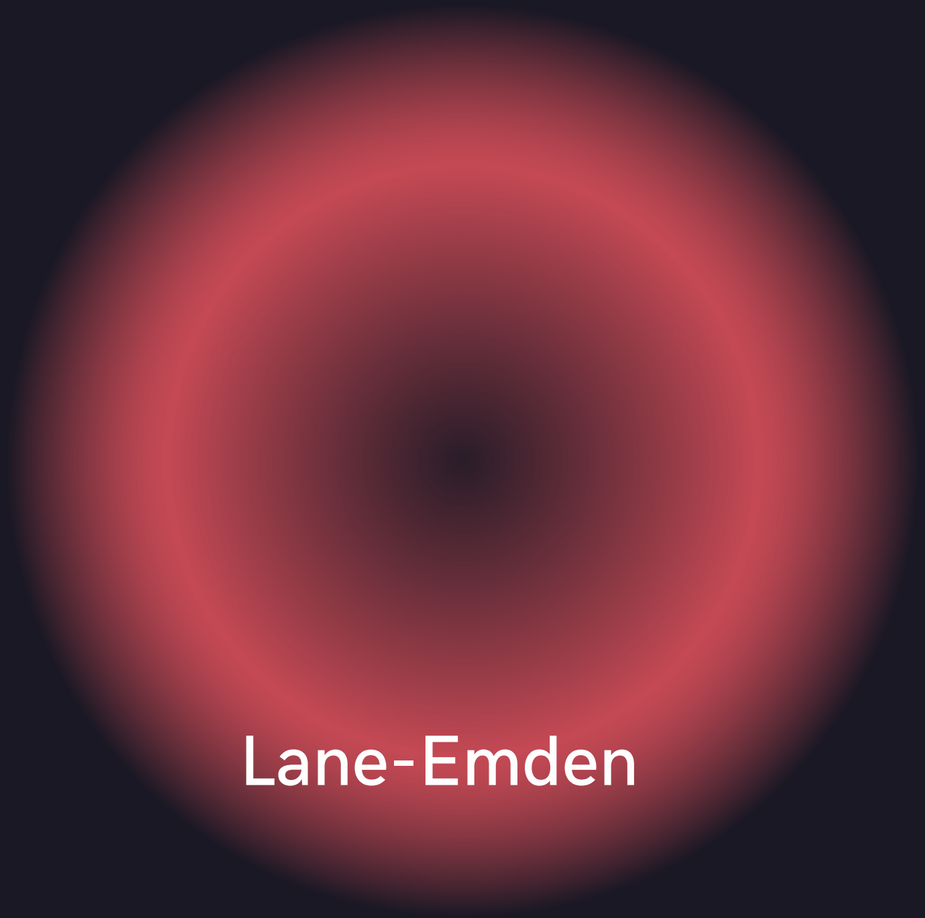
$$H_1(t) = -\frac{GM_* m_a r^2}{(b^2 + v^2 t^2)^{3/2}} P_2(\cos\gamma(t))$$



Final state

How to know if they survived?

2. How does it interact with a star?

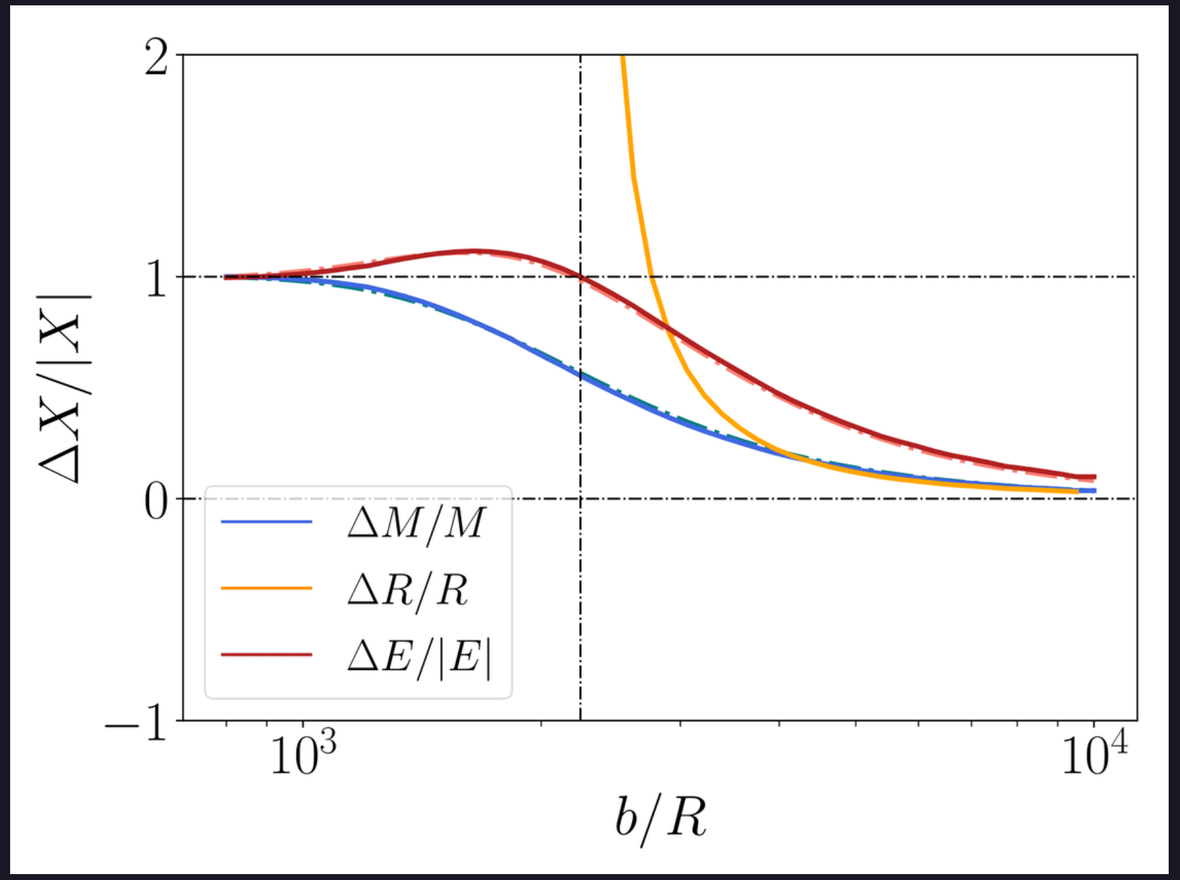


Lane-Emden

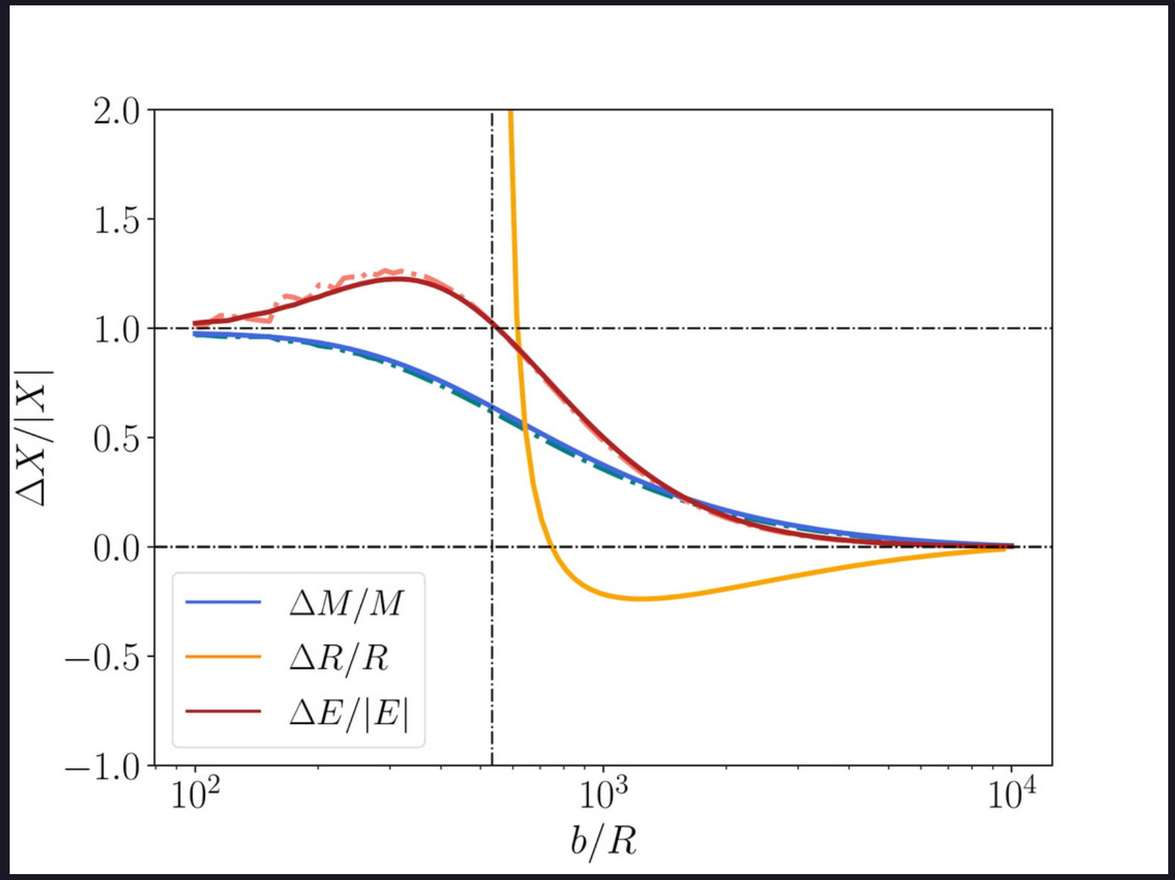
Hernquist

How to know if they survived?

2. How does it interact with a star?



Lane-Emden



Hernquist

How to know if they survived?

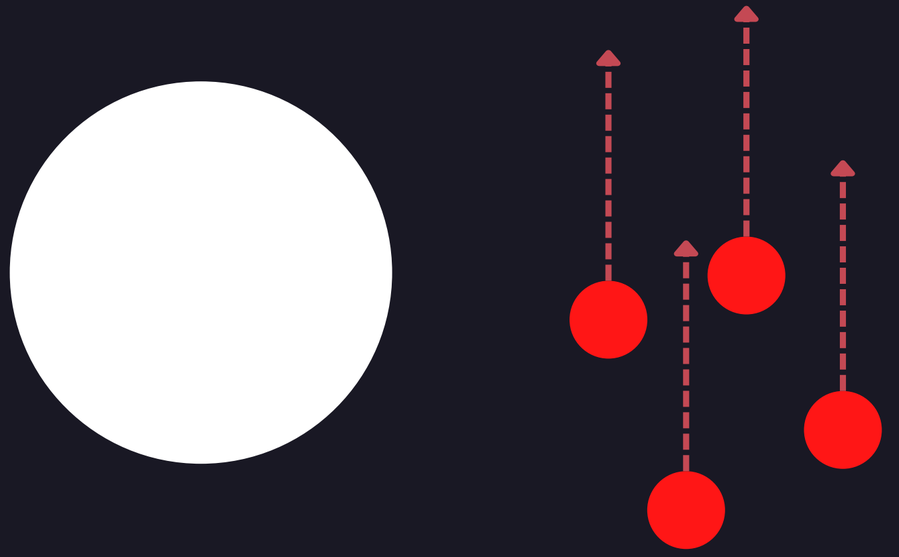
1

- Characterize the minicluster

2

- How does it interact with a star

3



- Simulate all the interactions in its lifetime

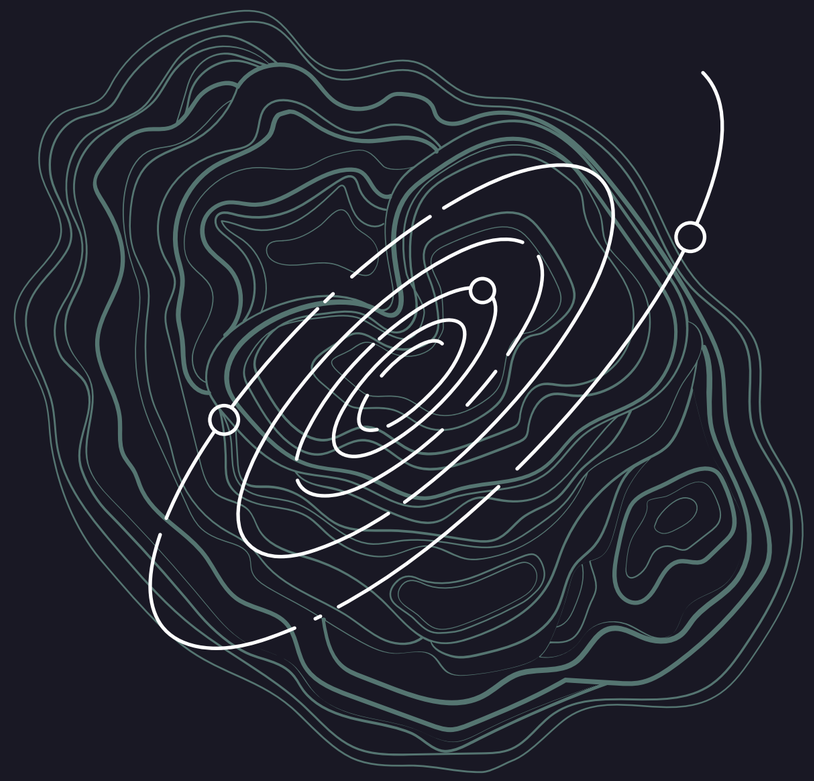
How to know if they survived?

3. Simulate their evolution in the galaxy

Milkay Way is composed of a dark matter halo with an NFW profile

We assume that the dark matter halo is initially fully composed of axion miniclusters

What is their survival at our location?



How to know if they survived?

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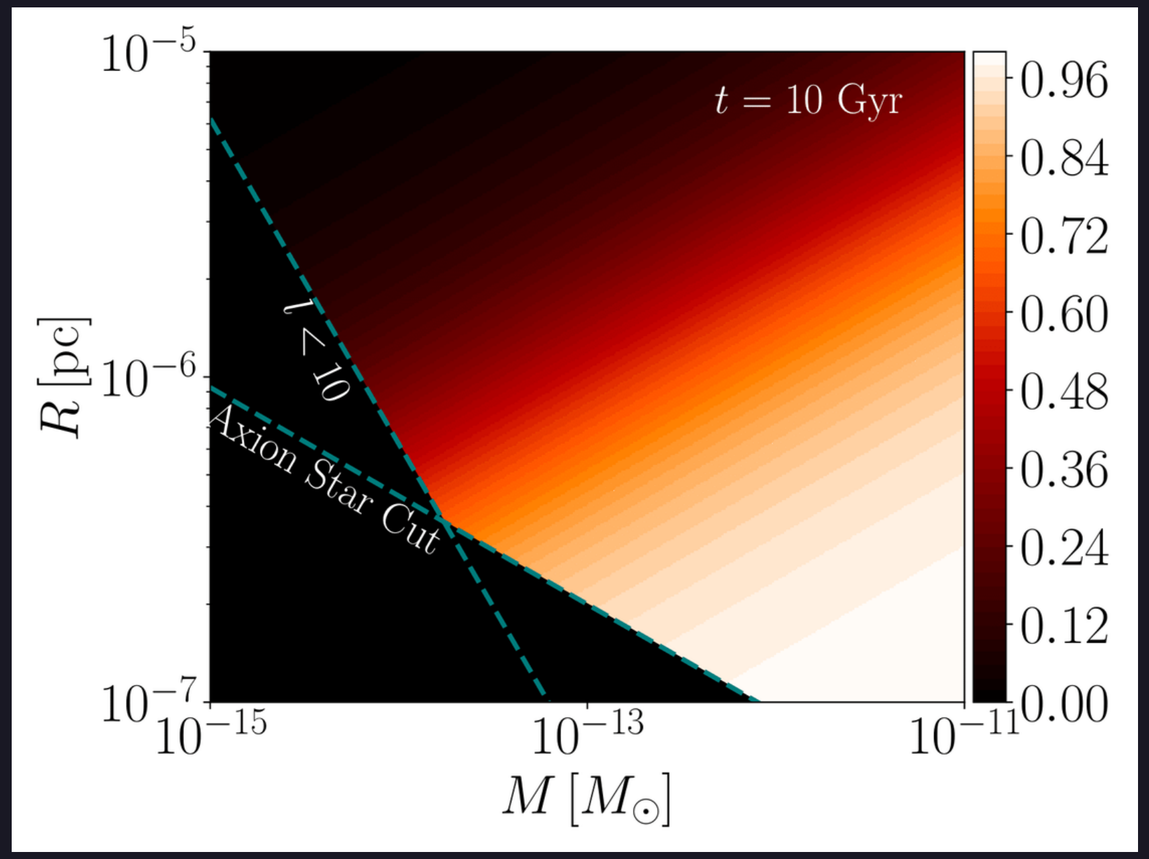
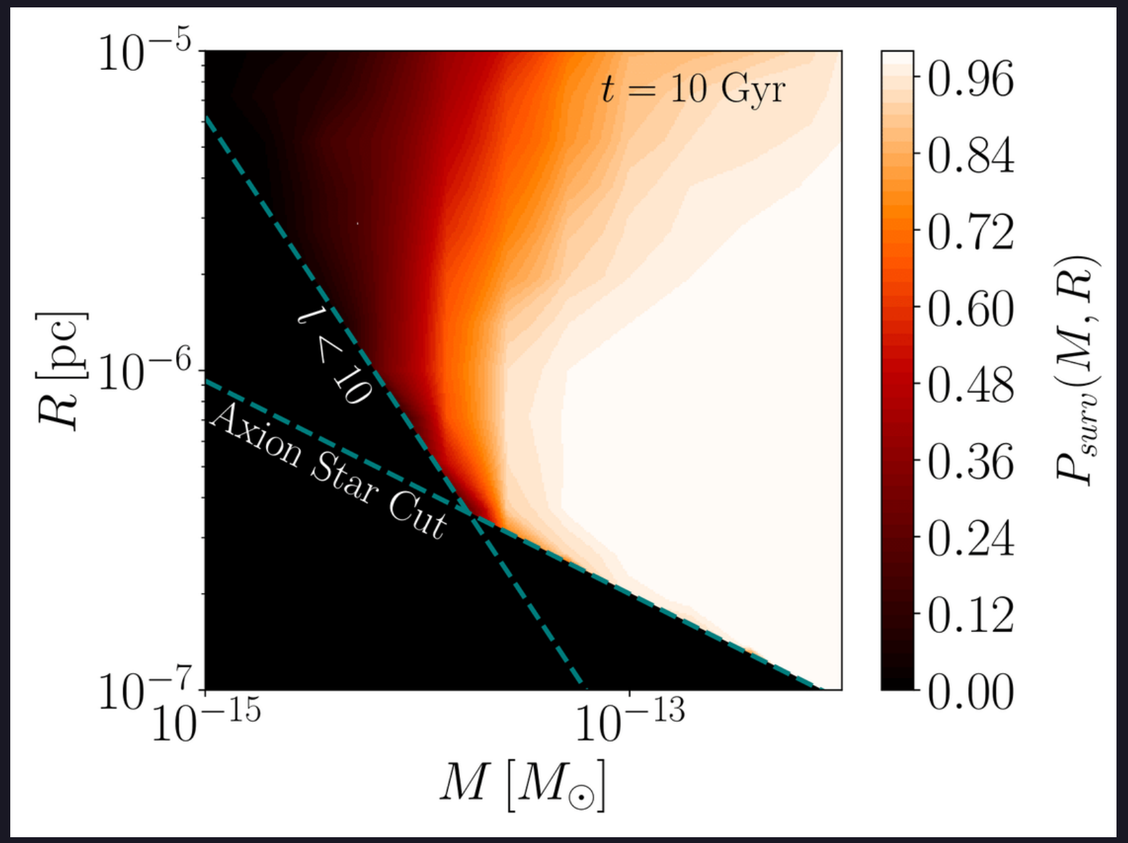


82% Survival

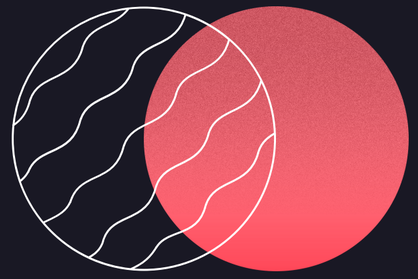


94% Survival

Summary

- Miniclusters are a strong prediction from axion particles appearing after inflation
- Axions should be described through a classical field. We have developed a method to built the wave function for any kind of minicluster profile
- This solution and the QM tools allow us to describe how a minicluster interacts with a star.
- We predict the survival of the miniclusters at our location :strong survival

Thank you!



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