Properties and Signatures of ALP Stars in the Milky Way

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Universität Hamburg
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DESY.

Axions

QCD Axion:

- Solves strong CP problem of QCD, $m_a \approx 26\,\mu\text{eV}$
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ALPs:

- Similar DM candidates: axion-like particles (ALPs) with 10^{-12} eV $\leq m_a \leq 10^{-3}$ eV
- Both provide rich *potentially observable* substructure

$\longrightarrow$ Try to detect/exclude axion dark matter using small-scale structure!

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- Extremely dense objects $\rho_\star \sim 10^{23}\ \mathrm{GeV/cm^3}$
- Very promising for detection, need to **infer AS properties** for predictions!

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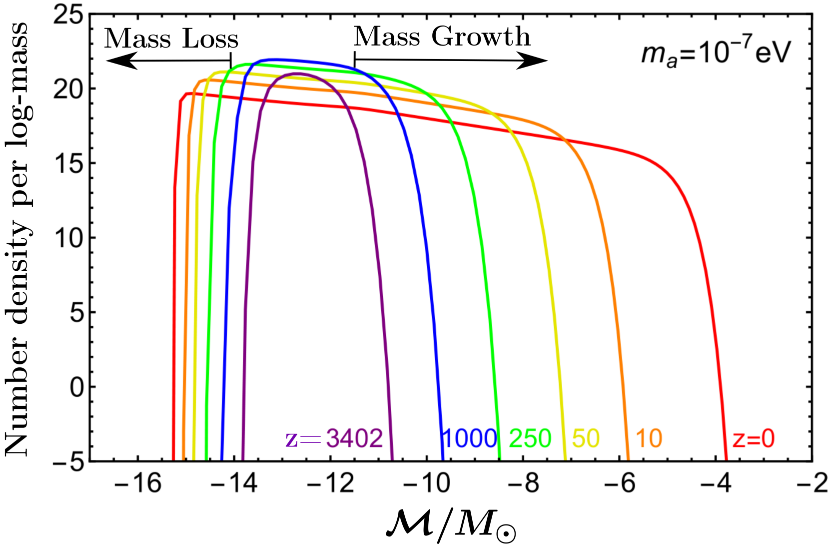
- Properties and linear evolution roughly known
  - Initial conditions from cosmological evolution of axion field
  - Evolution from linear mass growth (Press-Schechter theory)

Minicluster Evolution



[1]

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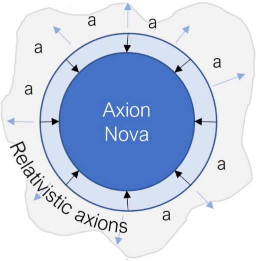
- Calculate collision rates with astrophysical sources $\longrightarrow$ DM signals

Detecting Axion small-scale Structure

Axion Stars

- Relativistic Axion bursts *(Axion novae/Bosenovae)* for $M_\star \geq M_{\star,\mathrm{Nova}}$



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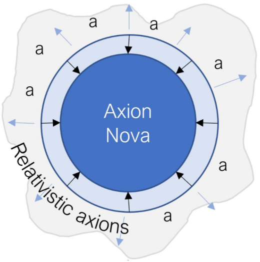

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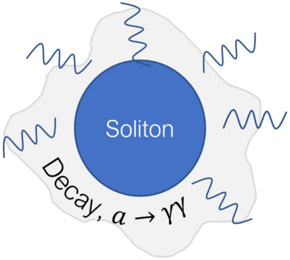

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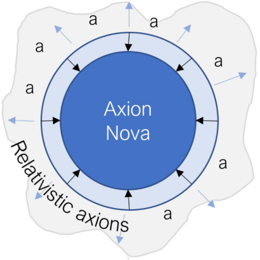
Miniclusters & Axion Stars:

- AS/MC-NS encounters
- Lead to resonance when $\omega_p \simeq m_a$
- Requires $\omega_p \gtrsim m_a$ and active NS magnetic field



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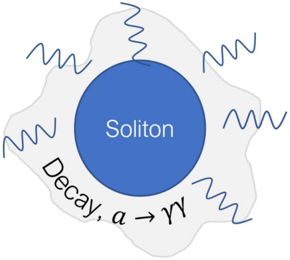

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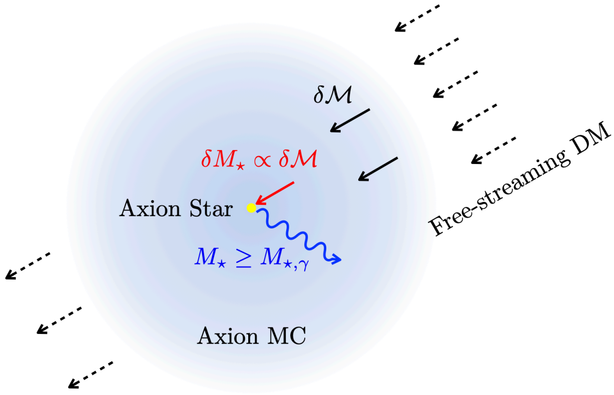
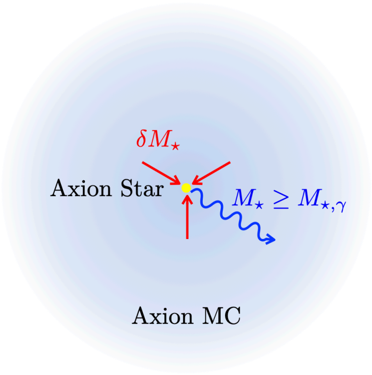
- Plasma resonance criterion yields only ~ 1 /decade signals
- MC-MC mergers can occur as often as 10^3 /yr
- Could lead to both axion novae and radio conversion
- All of the above **without including AS accretion**

Accretion Models

External Accretion:



Internal Accretion: [4]



Preliminary Results

- Models give predicted radio background $\longrightarrow$ compare with observed backgrounds
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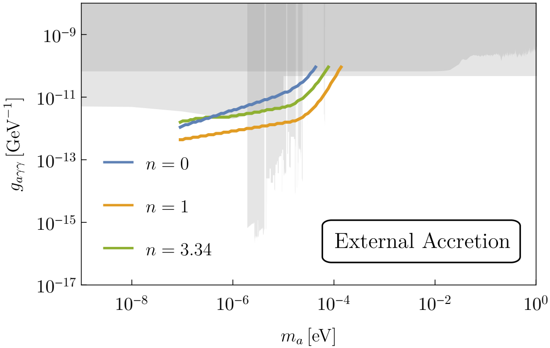

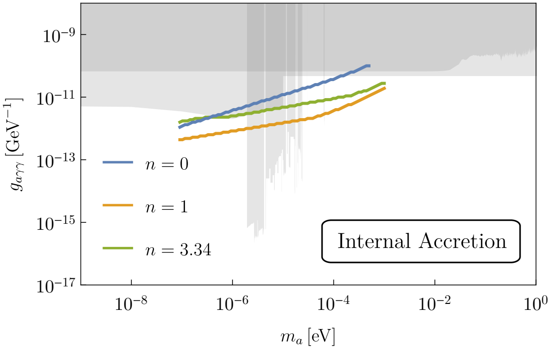

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  - Frequent MC-MC merger rates *(both of the above)*
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    - Frequent MC-MC merger rates *(both of the above)*
- **Without considering long-time AS accretion and non-linear theory**
- Even more possibilities including accretion
- E.g. new model of AS accretion with resonant photon emission

Thank you for your attention!

References:

[1]: Fairbairn and Marsh (2019): *Structure Formation and Microlensing with Axion Miniclusters*

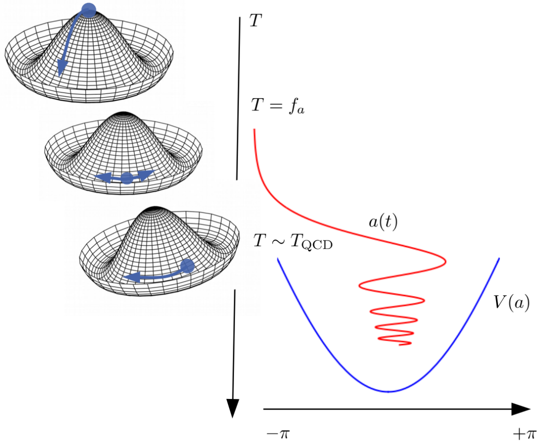
[2]: Du et al. (2024): *Soliton Merger Rates and Enhanced Axion Dark Matter Decay*

[3]: Maseizik and Sigl (2024): *Distributions and Collision Rates of ALP Stars in the Milky Way*

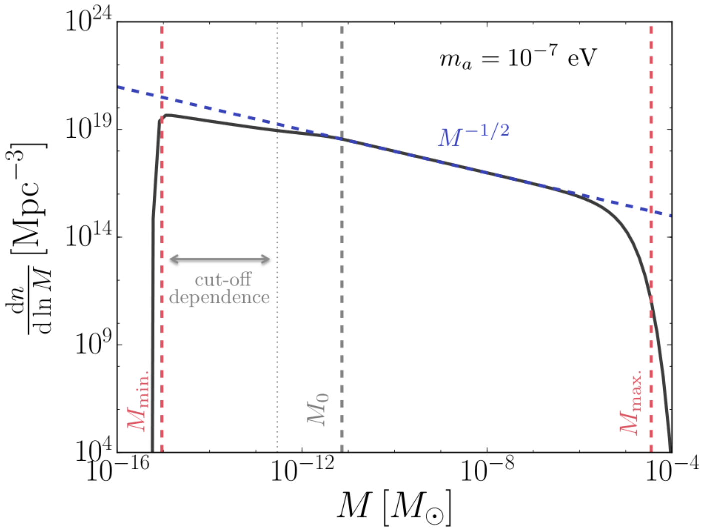
[4]: Dmitriev et al. (2024): *Self-similar Growth of Bose Stars*

Axions & ALPs

- Strong CP problem of QCD, $m_a \approx 26\,\mu$eV
  - possible violation of Charge & Parity symmetry
  - neutron dipole moment $d_n \sim 10^{-16}\,\theta\,e\,$cm
  - experimental measurements show $d_n < 1.8 \cdot 10^{-26}\,e\theta\,$cm $\Rightarrow \theta \lesssim 10^{-10}$
  - Why is $\theta \in [-\pi, \pi]$ so small?
- Solution: PQ Mechanism (Peccei, Quinn)
  - New complex scalar $\phi(x) = \phi_0(x)\,e^{ia(x)/f_a}$
  - Axion $a(x)$ is angular degree of freedom
  - $U(1)$ shift symmetry broken at $T \sim f_a$
  - At $T \sim T_{QCD}$ potential $V(a)$ is generated
  - Axion acquires mass and behaves like CDM
- Similar DM candidates: axion-like particles (ALPs) with $10^{-12}\,$eV $\leq m_a \leq 10^{-3}\,$eV

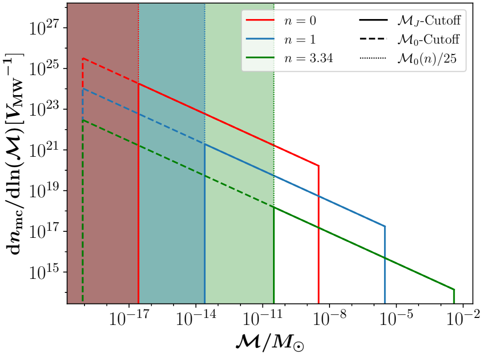


Fairbairn Results



MCMF & ASMF

MCMF:



ASMF: