Phenomenology of axion miniclusters

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Outline

- Miniclusters origin
- Miniclusters and Fast Radio Bursts
- Miniclusters and direct detection

Dense axionic structures

There are two types of dense axionic clumps in the Galaxy:

- Miniclusters

$$M \sim 10^{-12}\, M_\odot$$

- Minihalos

$$10^{-12}\, M_\odot \lesssim M \lesssim 10^{7}\, M_\odot$$

They have different origin, properties, and implications.

Other structures of interest:

- Tidal streams
- Infall caustics

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Density of a clump

Initially

$$\delta\rho_a/\rho_a \equiv \Phi$$

Clump separates from cosmological expansion at $T \approx \Phi\, T_{\rm eq}$, therefore minicluster density today

$$\rho_{\rm mc} \approx 140\Phi^3(1+\Phi)\bar{\rho}_a(T_{\rm eq})$$

Valid for both miniclusters ($\Phi \gtrsim 1$) and minihalos ($\Phi \ll 1$)

They originate from different initial perturbations

- Minihalo $\leftarrow$ usual density perturbation, like galaxy
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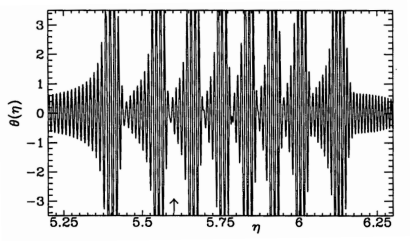
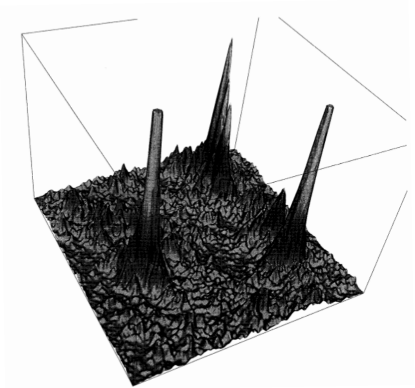
Miniclusters

- Before axion mass turns on: $\theta \approx$ const on a horizon scale.
- After: $\delta\theta \sim \pi$. Axion self-coupling is non-negligible. Non-linear objects form with $M \sim 10^{-12}\, M_{\odot}$.

Minicluster Formation

Field vs time in the center of a future minicluster. It starts as an oscillon.

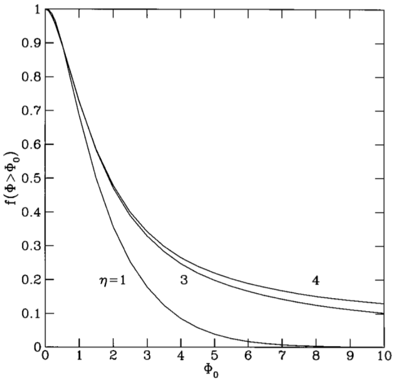




Spatial distribution of energy density. The height of the plot $\Phi = 20$.

E.Kolb & IT, Phys.Rev. D49 (1994) 5040

Minicluster Formation



Mass fraction in miniclusters with $\Phi > \Phi_0$ as a function of Φ_0.

E.Kolb & IT, ApJ 460 (1996) L25

Bose-condensation

Relaxation time is enhanced in axionic halo due to large phase space density

$$t_R^{-1} \sim \lambda_a^2 \rho_a^2 v_e^{-2} m_a^{-7}$$

IT, Phys. Lett. B 261 (1991) 289

Miniclusters with $\Phi > 30$ Bose condense, forming "Bose-stars"

E.Kolb & IT, PRL 71 (1993) 3051

Radius of the star $\sim 300\ \mathrm{km}$, light propagates across of it in $1\ \mathrm{ms}$.

Fast Radio Bursts and Axion Miniclusters

FRB - mysterious astrophysical phenomena

- Short radio flash, 1 ms
- Cosmological origin, $z \sim 1$
- Energy release $10^{38} - 10^{40}$ ergs
- Huge brightness temperature $T_B \sim 10^{36}$ K
- Rate: $\sim 10^4$ events/day for the whole sky.

- Radius of axion Bose-star 1 ms
- Minicuster mass $10^{-12} M_\odot = 2 \times 10^{42}$ ergs
- Bose-star can explode in a burst of coherent radiation
- We have 10^{24} miniclusters just in a Galaxy

FRBs can be explained by axion star explosions into pure radiation

IT, JETP Letters 101 (2015) 1

A. Iwazaki, PRD 91(2015) 023008

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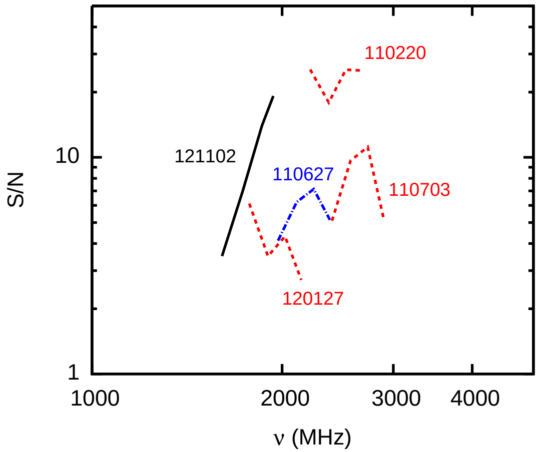
Fast Radio Bursts and Axion Miniclusters

FRB spectra shifted to their rest frame



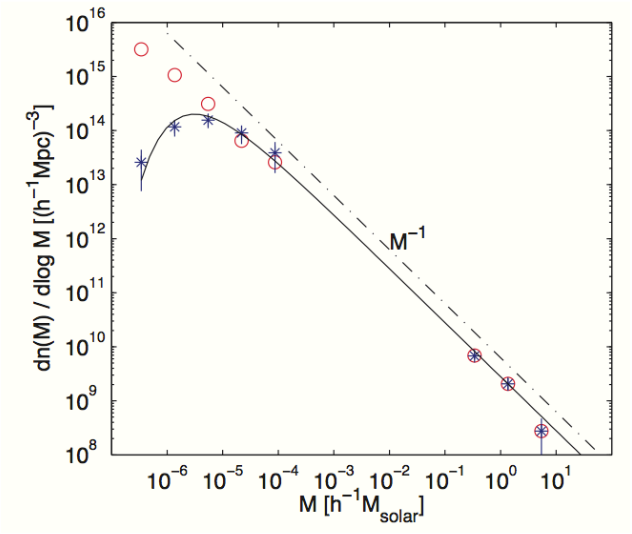
IT, JETP Letters 101 (2015) 1

Minicluster abundance

Typical miniclusters with $\Phi \approx 1$:

- 10^{24} in the Galaxy
- $10^{10}\ \mathrm{pc}^{-3}$ in the Solar neighborhood
- Minicluster radius $\sim 10^7\ \mathrm{km}$
- Direct encounter with the Earth once in 10^5 years
- During encounter density increases by a factor 10^8 for about a day

Minihalo Formation



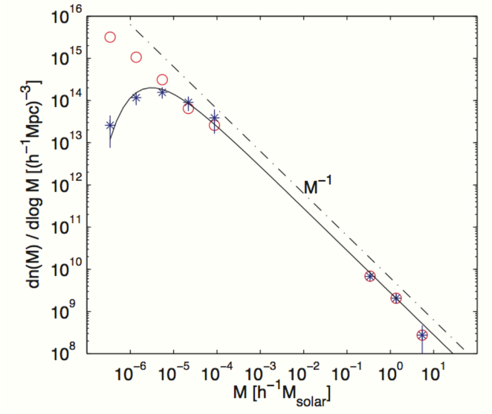
stars - WIMPS

circles - axions

For axions cutoff is at
$10^{-12} M_{\odot}$

J. Diemand, B. Moore, J. Stadel, Nature 433 (2005) 389

Minihalo Formation

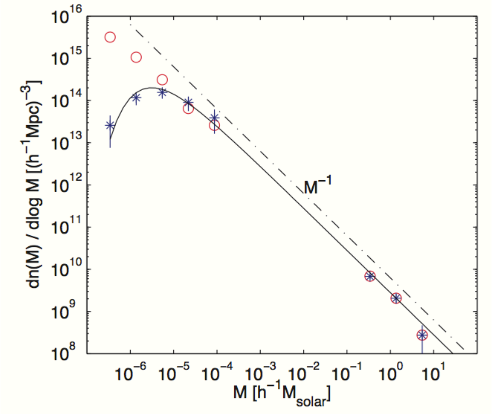


$10^{-6} M_\odot \Longleftrightarrow \Phi = 0.016$:

- $500\ \mathrm{pc}^{-3}$ in the Solar neighborhood
- Direct encounter with the Earth once in 10^4 years
- During encounter density creases by a factor 100 for about 50 years

But those minihalos are tidally destroyed actually

Minihalo Formation



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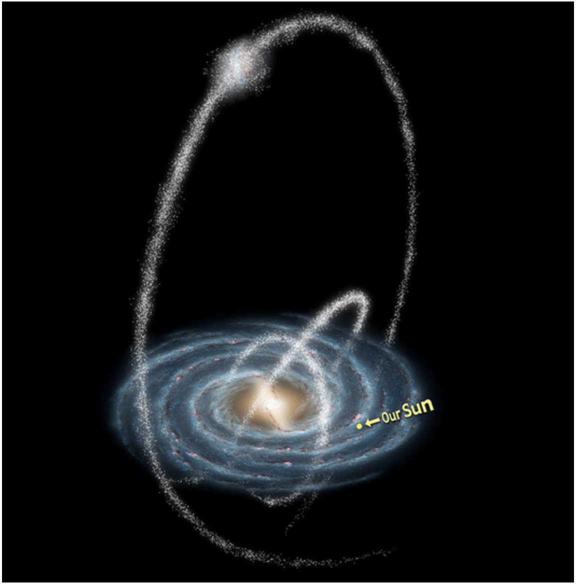
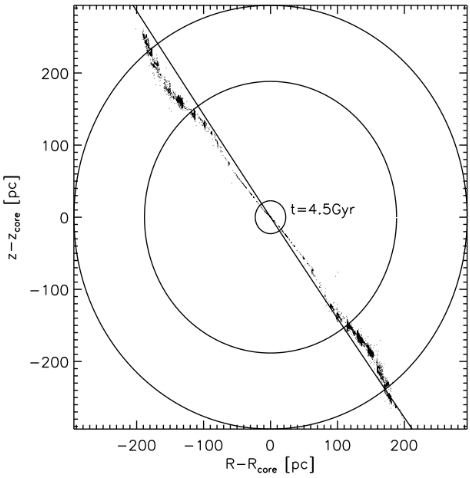
Tidal streams



Minihalo Destruction

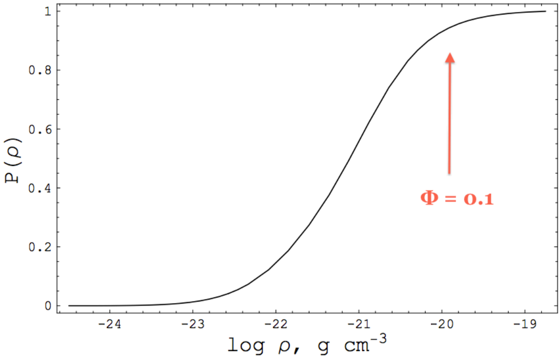


$10^{-6} M_{\odot} \Longleftrightarrow \Phi = 0.016$:

- Length of a stream 10^4 of initial minihalo radius
- Density of a stream 10^{-2} of the local DM density

G. Angus, H. Zhao, MNRAS 375 (2007) 1146

Tidal destruction



V.Berezinsky, V.Dokuchaev, Yu.Eroshenko, et al, PRD 81 (2010) 103529

5% of ministers are destroyed for $\Phi = 0.1$
Practically all of them are destroyed for $\Phi = 0.016$

Crossing tidal streams

	$\Phi \approx 0.1$	$\Phi \approx 1$
Linear increase in 5 Gyr	2×10^4	10^6
Local $\rho/\bar{\rho}_{DM}$	3	100
Signal duration	15 days	1 day
Repeats in	4 years	1 day $\times$ 100 $\times$ F

Density perturbations originating from most abundant miniclusters are of order one with coherence scale of order days. This should lead to a "promising" random density field.

Coinclusions

Axion miniclusters can have interesting phenomenological consequences and the subject requires further thorough studies.

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