Axion streams and implications for haloscopes

O'Hare, GP & Redondo, PRL 133 (2024) 8, 081001 [arXiv:2311.17367 [hep-ph]]
Eggemeier, O'Hare, GP, Redondo & Wong, PRD 107 (2023) 8, 083510 [arXiv:2212.00560 [hep-ph]]

Giovanni Pierobon, UNSW Sydney

19th Patras Workshop, Patras, September 16-20, 2024

Goal:
Describe axion DM distribution on sub-galactic scales,
relevant for *all post-inflationary* axion searches

Results:
Address minicluster “worst-case” scenario
where all axions are bound in clumped objects

Present a first numerical study
of the **stream density** in the Solar neighbourhood

Post-inflation timeline

PQ phase transition

Cold axion production

Number density conserved

Today

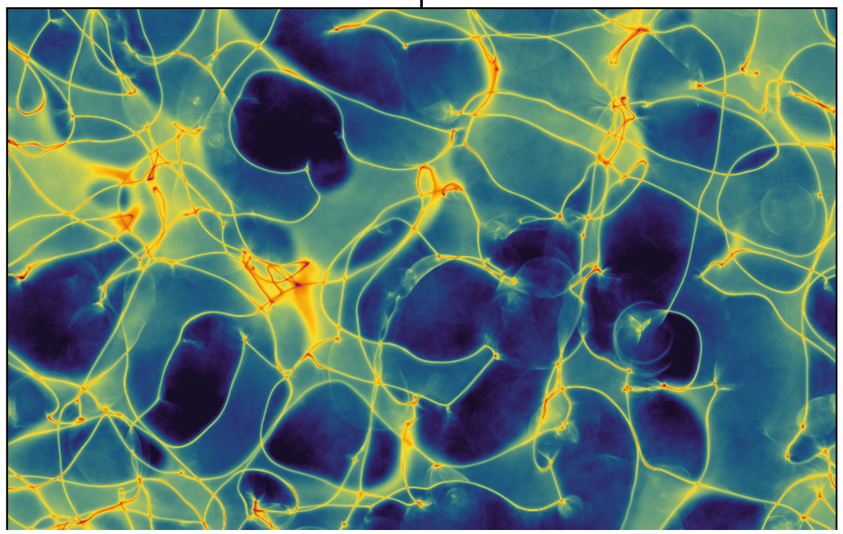
$z \sim 10^{25}$

$z \sim 10^{12}$

$z = 0$

Inflation

$z \sim 10^{13}$



Energy projection of the axion field from **lattice simulations**

Domain walls and strings

$$m_a = \frac{\rho_{\rm DM}}{n_a} \longrightarrow$$

Goal: find axion number density
axion dark matter mass (**frequency)**

Post-inflation timeline

PQ phase transition

Cold axion production

Number density conserved

Gravitational collapse

Today

$z \sim 10^{25}$

$z \sim 10^{12}$

$z = 0$

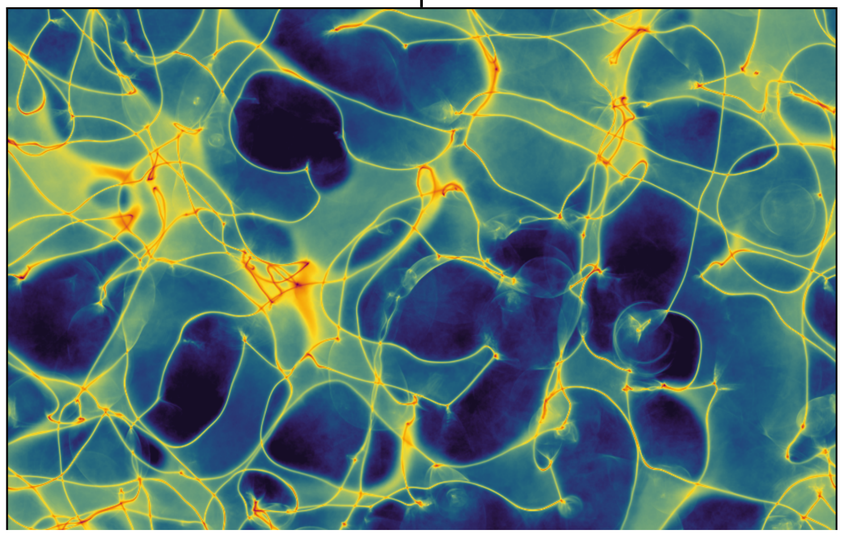
Inflation

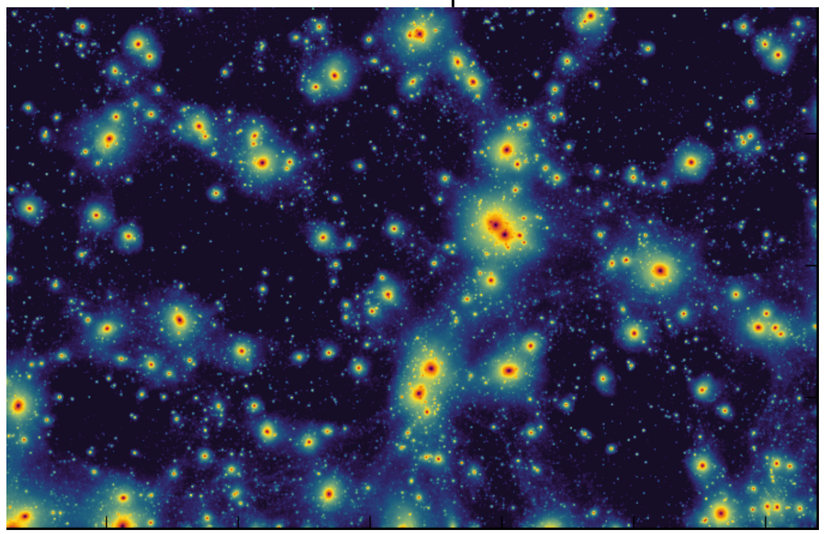
$z \sim 10^{13}$

$z \sim 10^{2}$

Energy projection of the axion field from **lattice simulations**

Domain walls and strings





Energy projection of the axion field from **N-body simulations**

Miniclusters and their halos

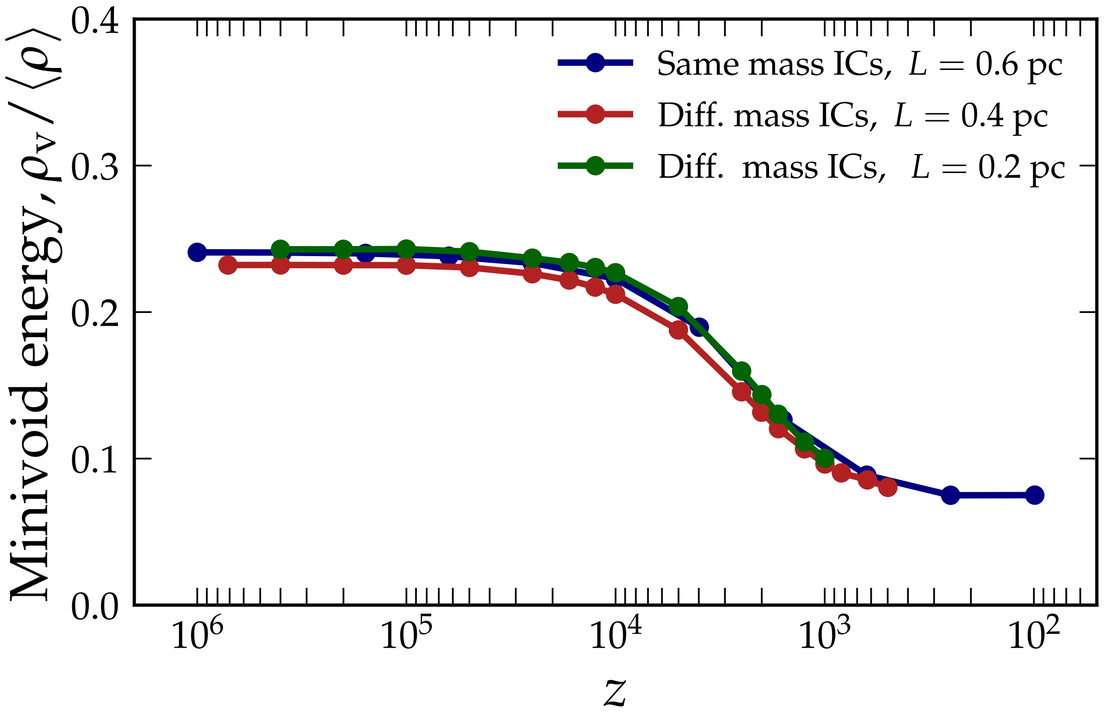
$$m_a = \frac{\rho_{\rm DM}}{n_a} \longrightarrow$$

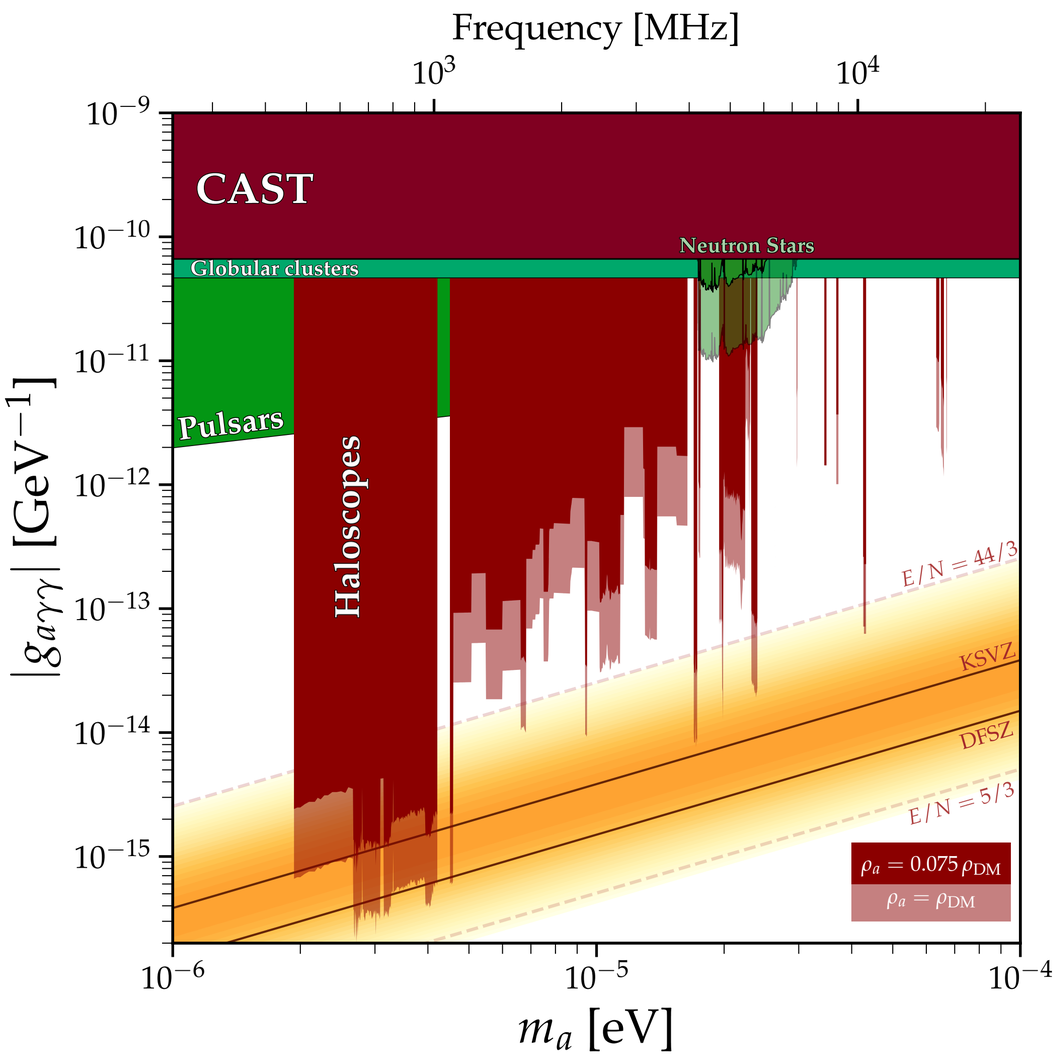
Goal: find axion number density
axion dark matter mass (**frequency)**

Goal: find axion field distribution
axion dark matter **amplitude**

Axion minivoids

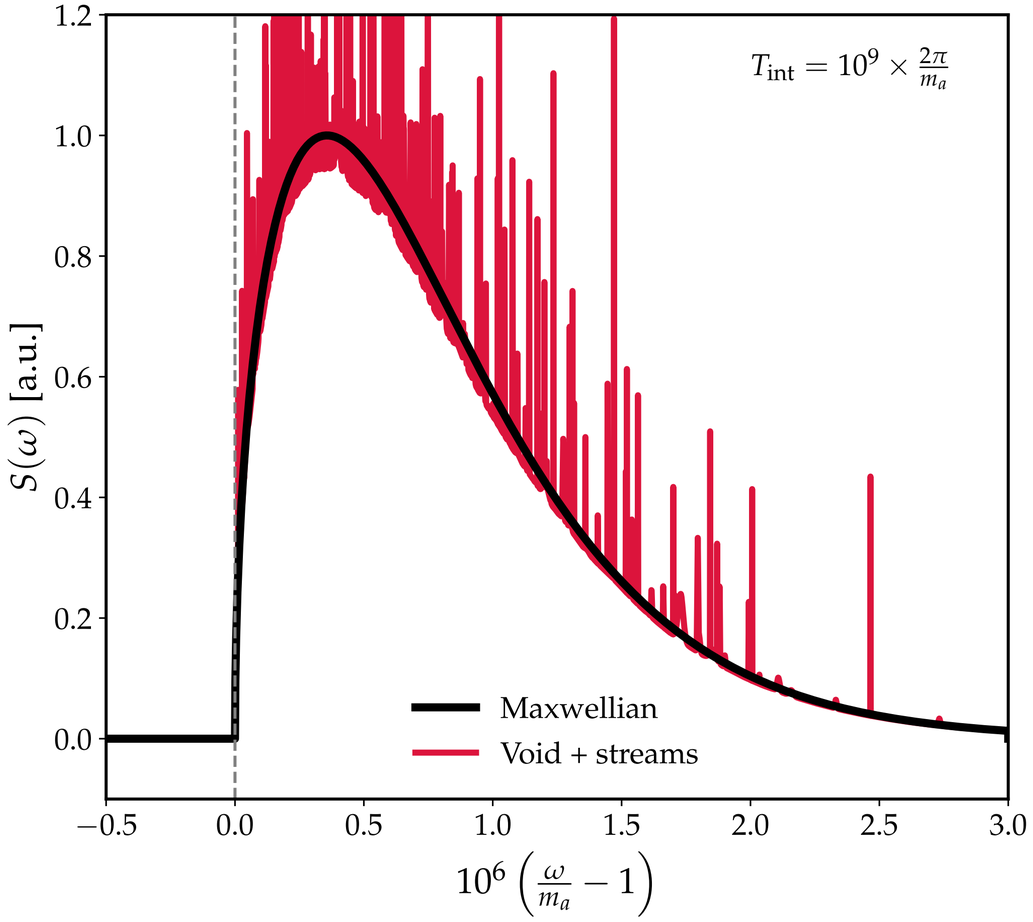
- Most of DM axions (~80%) are bound in MC at the end of the simulation, while occupying **1% of the volume**
- Minivoids (~pc size) largely take the simulation volume, stable at $z \sim 10^2$
- Density in minivoids is ~10% of the large-scale average value
  worst case scenario

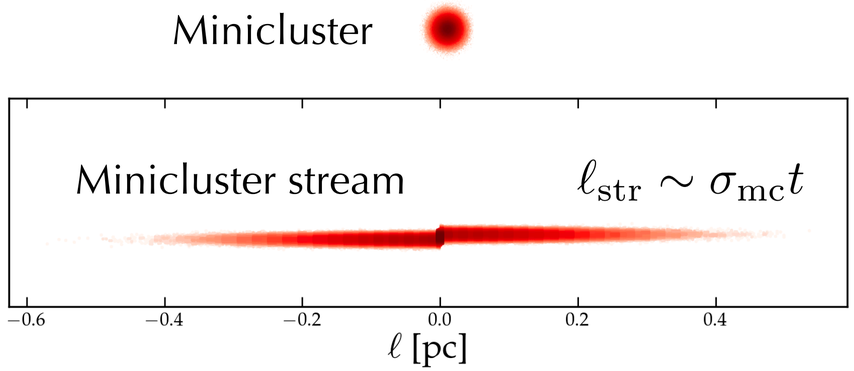




Eggemeier, O'Hare, GP, Redondo & Wong, [2212.00560]

Streams in the Solar neighbourhood



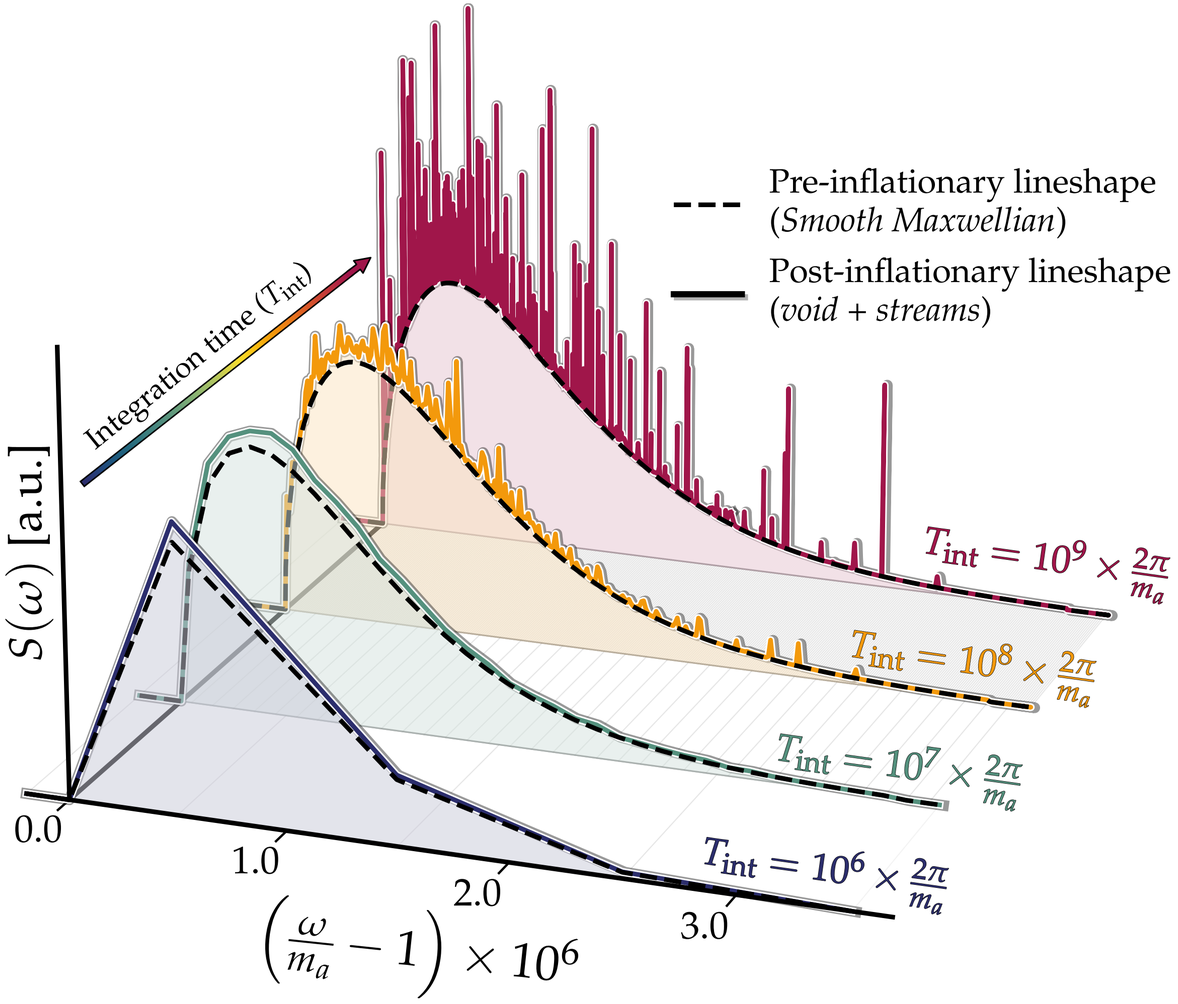


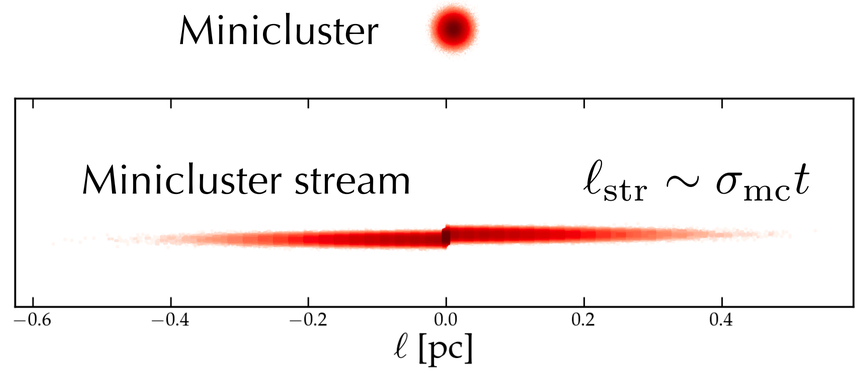
Using information from numerical simulations, we run a Monte Carlo analysis and find:

- $\mathcal{O}(1000)$ overlapping streams at a given point
- Stream-to-void *enhancement* of ~7
- Overall stream energy adds up to ~80% of the measured value of $\rho_{\rm DM}$ (coupling rescaling of ~1.2)
- Narrow lines typically lasting days-years

O'Hare, GP & Redondo [2311.17367]

Streams in the Solar neighbourhood





Using information from numerical simulations, we run a Monte Carlo analysis and find:

- $\mathcal{O}(1000)$ overlapping streams at a given point
- Stream-to-void *enhancement* of ~7
- Overall stream energy adds up to ~80% of the measured value of $\rho_{\rm DM}$ (coupling rescaling of ~1.2)
- Narrow lines typically lasting days-years

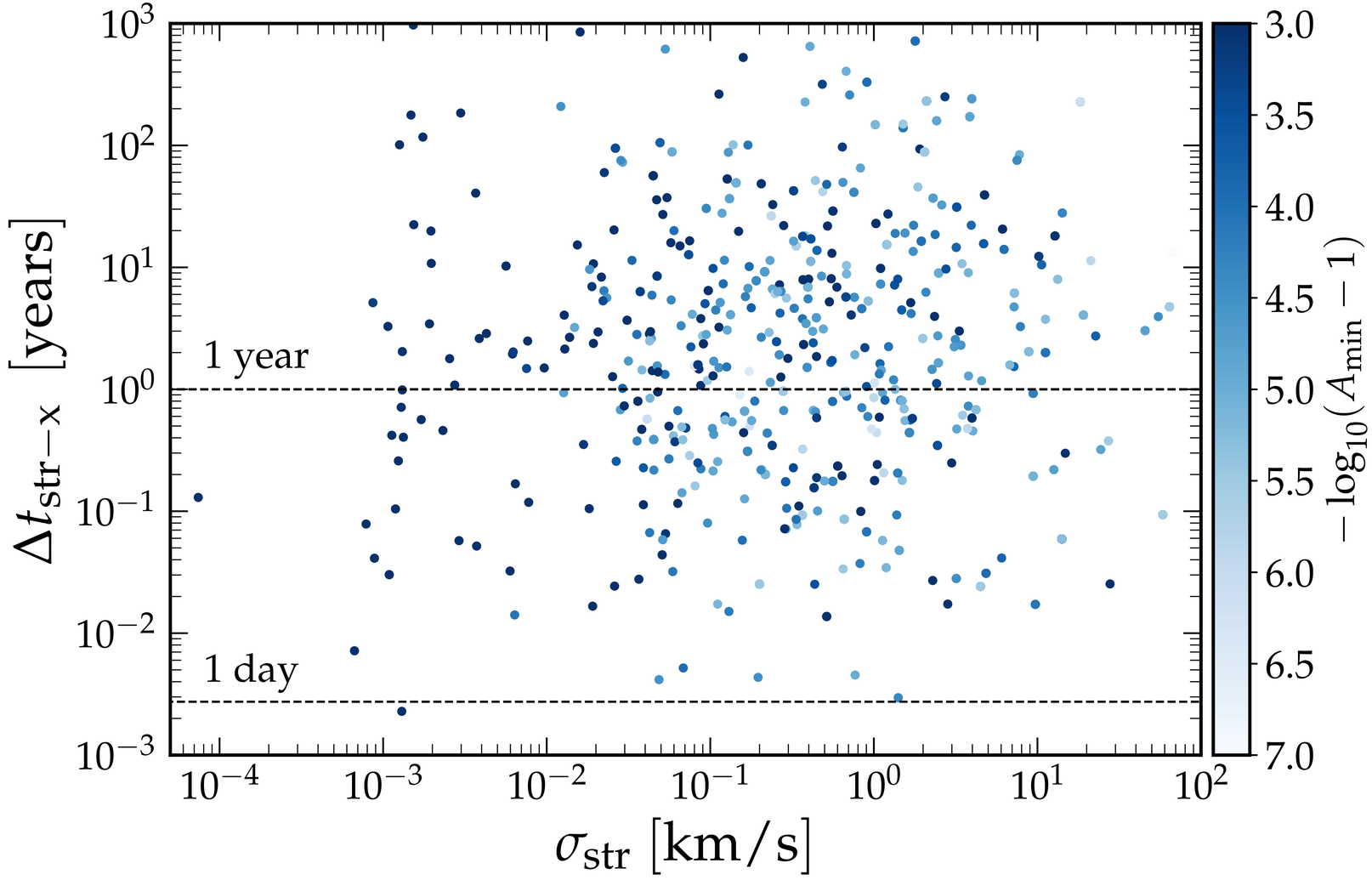
O'Hare, GP & Redondo [2311.17367]

Summary

- **Miniclusters, voids and streams** are a *smoking guns* of the post-inflationary axion dark matter scenario
- In the minivoids, the energy density is only 10% of the large-scale measured value, leading to substantial sensitivity suppression in *all* haloscopes
- With current modelling of tidal disruption, we expect the axion DM signal to reach ~80% of the large-scale measured value, with thousands of overlapping streams at each point
- If haloscopes can measure the axion signal with high-enough frequency resolution, streams reveal a spiky lineshape that can *distinguish* pre- and post-inflation axion DM

Additional slides

Stream duration and dispersion velocity



O'Hare, GP & Redondo, [2311.17367]

Cosmological timeline

PQ phase transition

Cold axion production

Number density conserved

Gravitational collapse

Today

Lattice

N-body

Monte Carlo

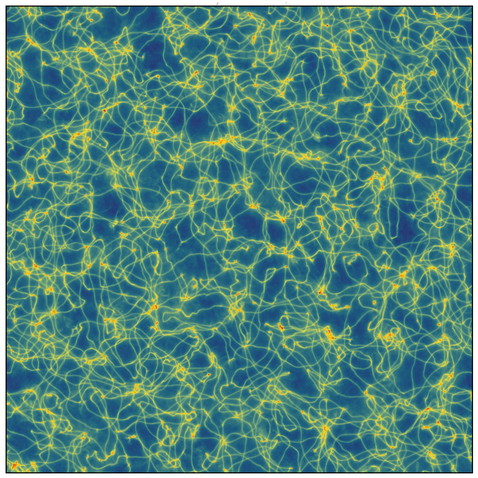
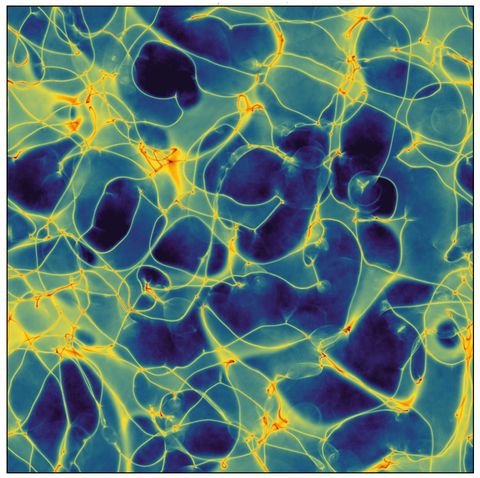
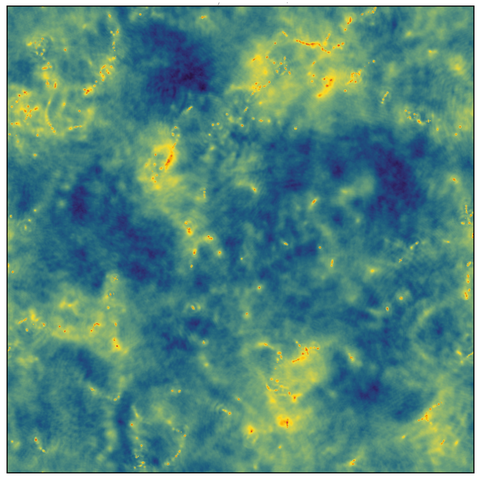
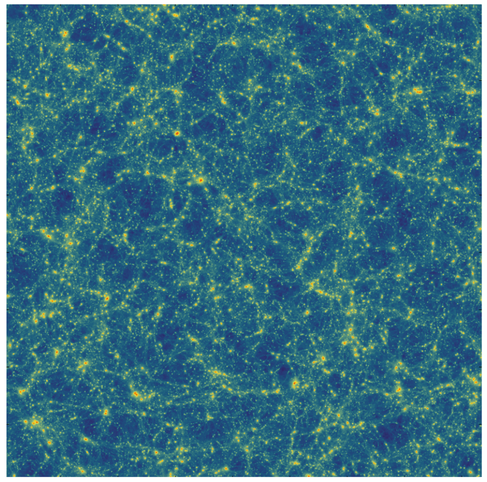
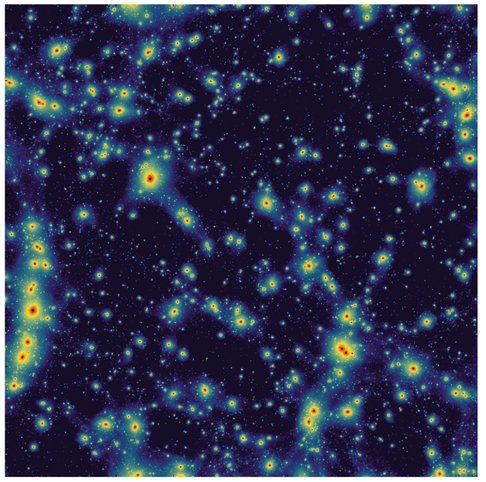
Klein-Gordon (relativistic)
Schrödinger-Poisson (non-relativistic limit)

$z \sim 10^6$

Vlasov-Poisson (collisionless)
Non-relativistic CDM

$z \sim 99$

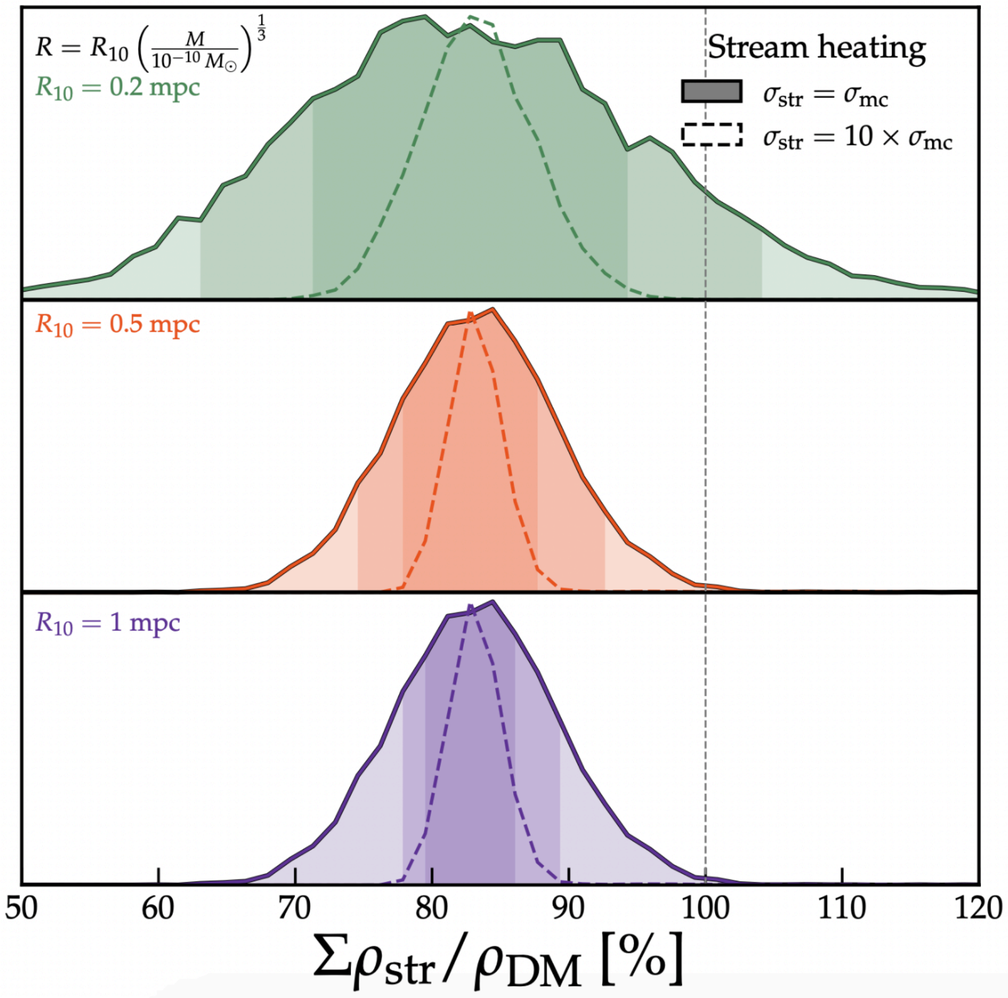
Minicluster orbits
Stellar encounters

jaxions
(J. Redondo, A. Vaquero)
github.com/veintemillas/jaxions

gadget-4
(V. Springel)
wwwmpa.mpa-garching.mpg.de/gadget4/

Axion streams at solar position



O'Hare, GP & Redondo, [2311.17367]