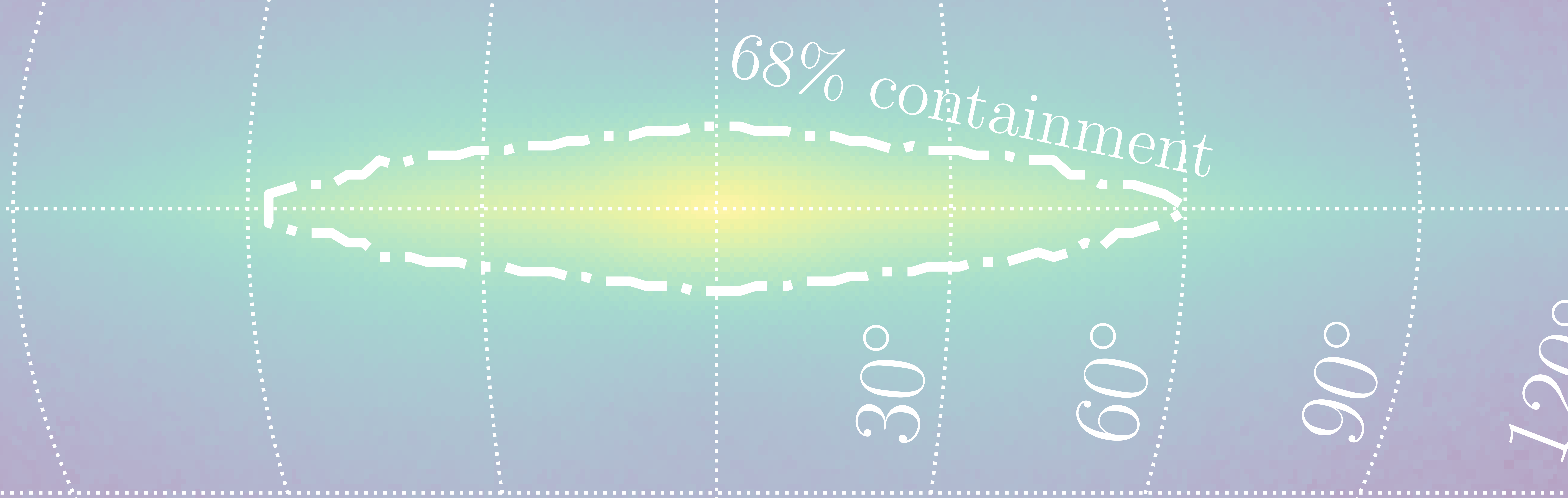
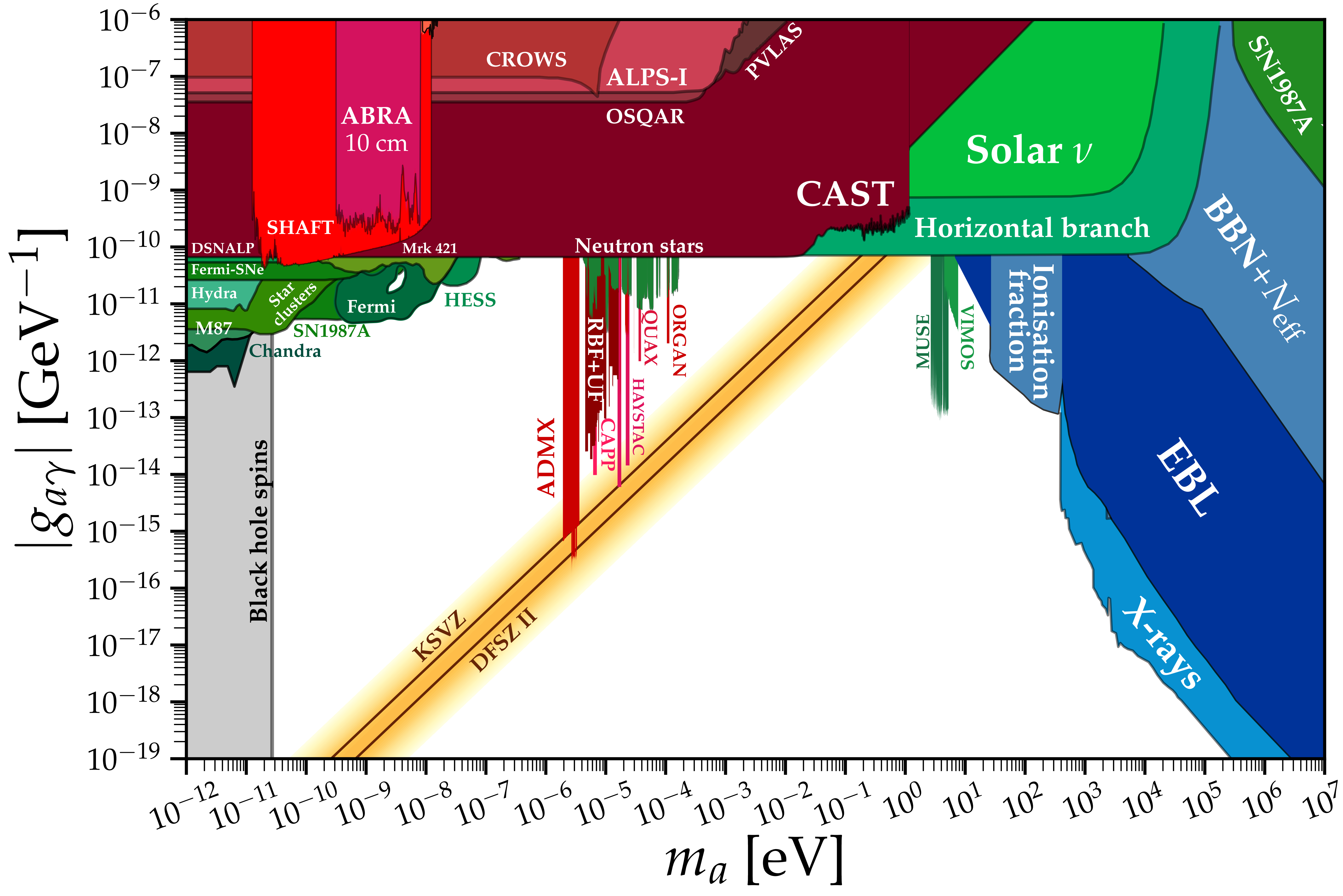
Axion Miniclusters
Interacting with Neutron Stars



Thomas Edwards with Bradley Kavanagh, Luca Visinelli, Samuel J. Witte, Dion Noordhuis, & Christoph Weniger
Oskar Klein Centre (2011.05377, 2011.05378, 2104.07670, github.com/bradkav/axion-miniclusters)

Axions

[https://cajohare.github.io/AxionLimits/]



Axions are a pseudo-Goldstone boson of a symmetry, called the Peccei-Quinn (PQ) symmetry

They were originally introduced to solve a fine tuning issue in QCD called the **strong-CP problem**

Turns out, axions also act as a perfect dark matter candidate

$$\mathcal{L} \propto g_{a\gamma\gamma} a \mathbf{E} \cdot \mathbf{B}$$

[Dine, Fischler, and Srednicki 1981, Weinberg 1978, Peccei and Quinn 1977, Wilczek 1978, ...]

Axion Cosmology

[Buschmann et al., 1906.00967]

Since the axion is produced non-thermally through the misalignment mechanism, the distribution of background axions sensitively depends on the time at which the PQ symmetry breaks

PQ field broken before or during inflation

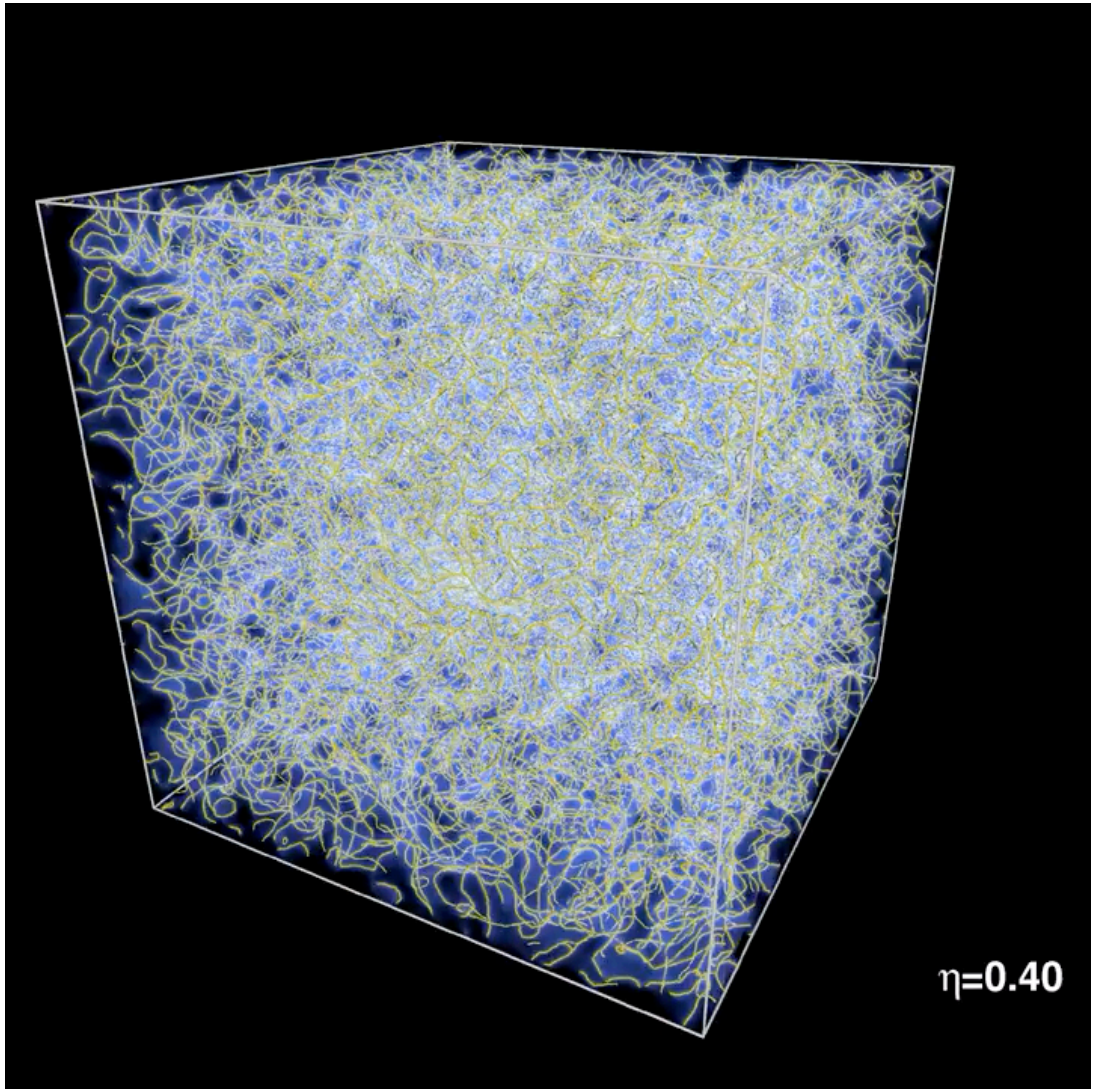
↓

Single mean background density of axions

PQ field broken after inflation

↓

Topological defects that lead to axion **miniclusters**



Overview:

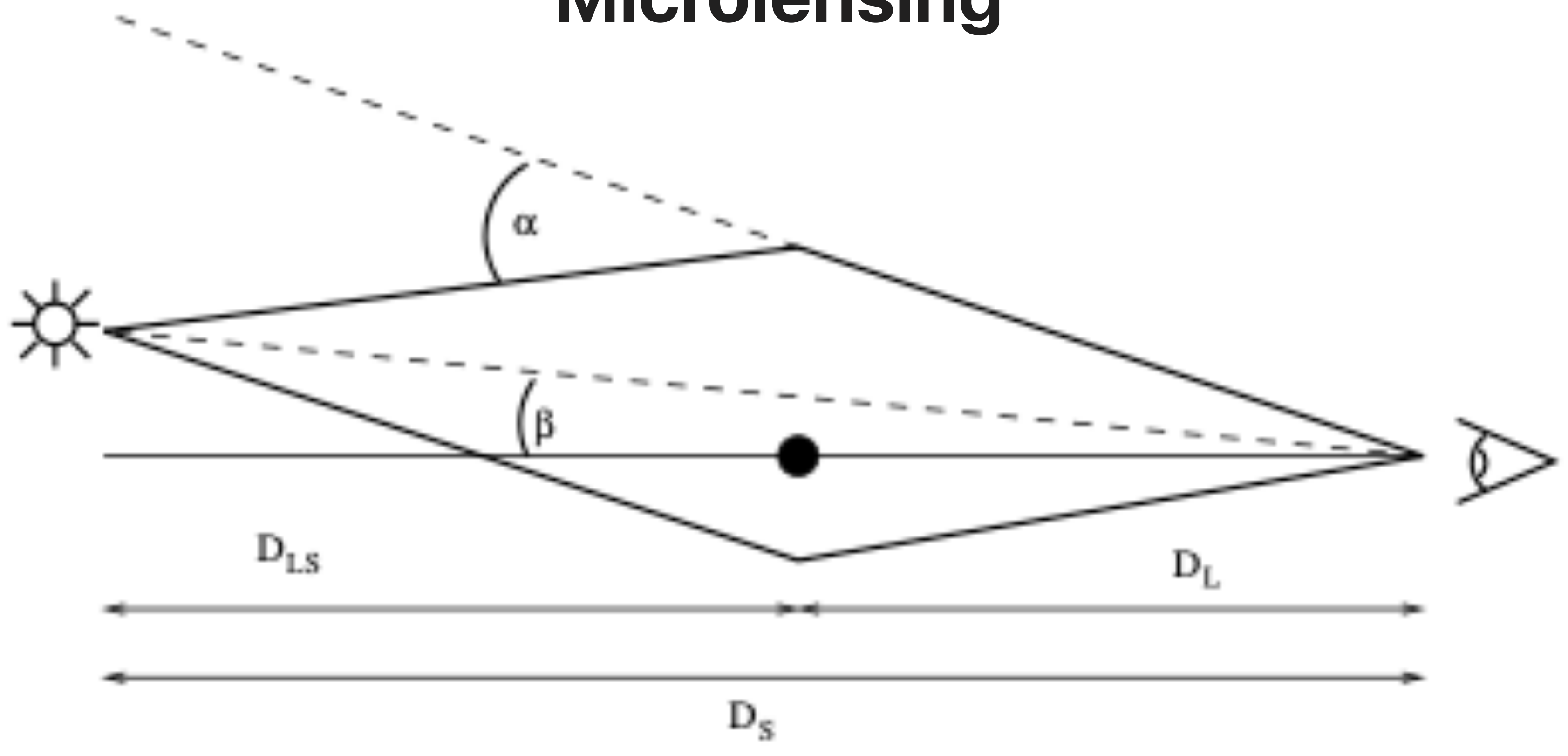
1. Axion Miniclusters in the Milky Way
2. Miniclusters Interacting with Neutron Stars

Overview:

1. Axion Miniclusters in the Milky Way
2. Miniclusters Interacting with Neutron Stars

Why?

Microlensing



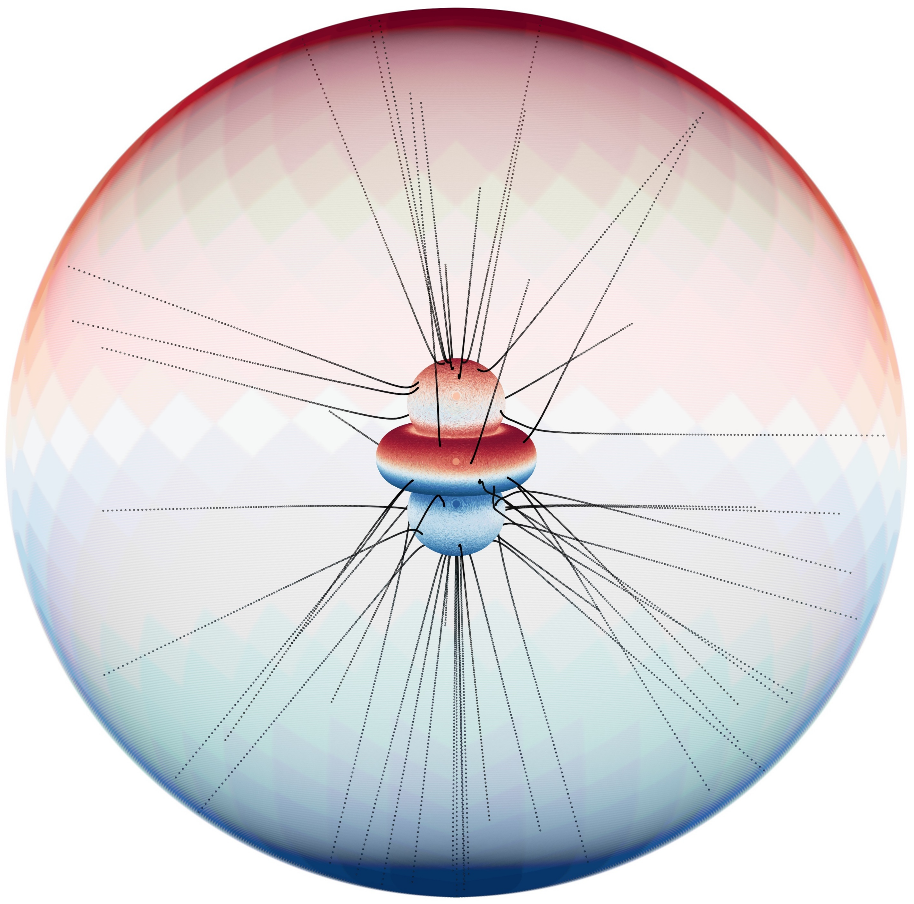
[Fairbairn et al., 1707.03310]

[Ellis et al., 2204.13187]

Direct Detection

[ADMX Collaboration, 1910.08638]

Indirect Detection



[Witte, **TE**, Noordhuis, Weniger: 2104.07670]

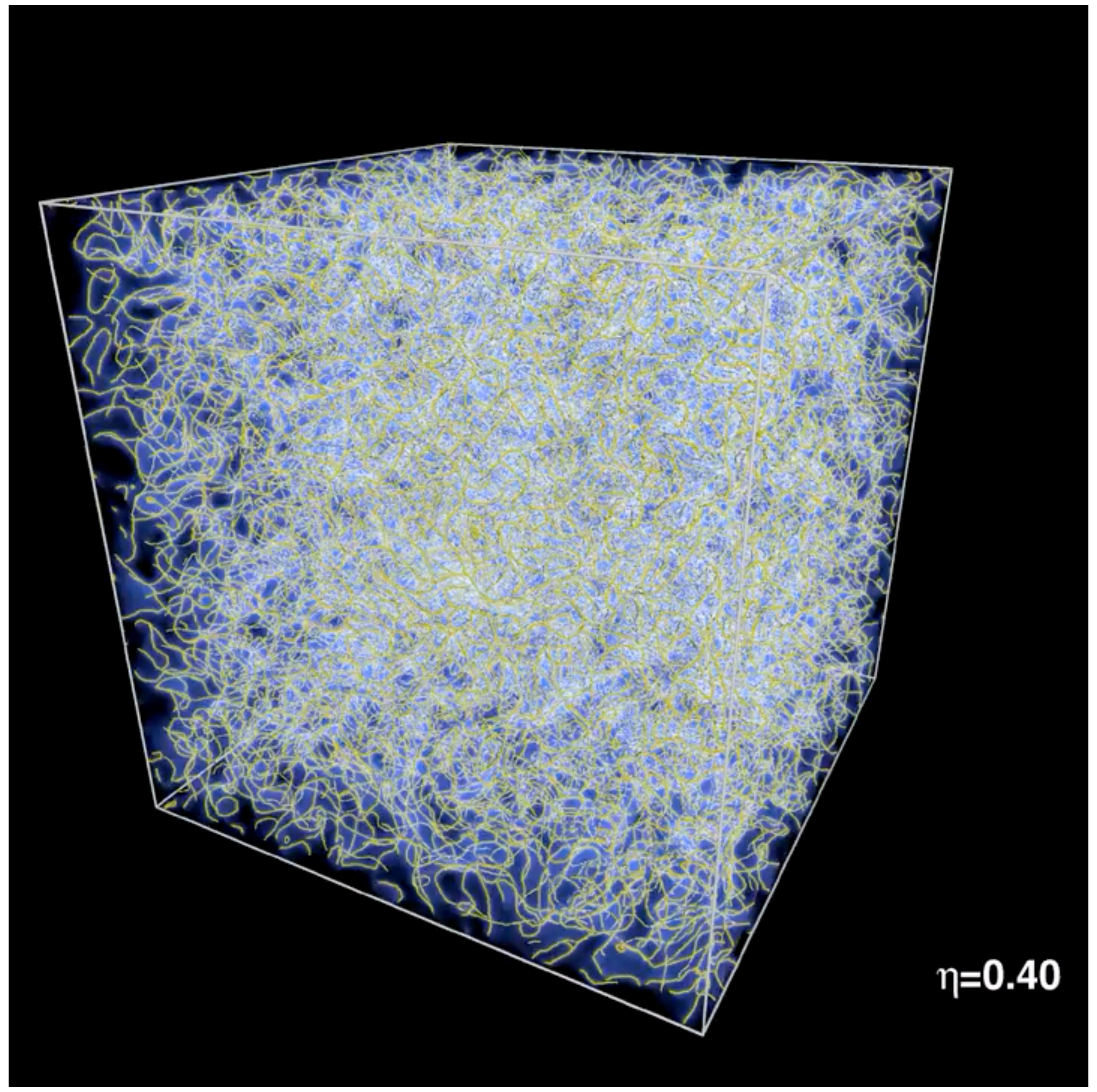
Getting to our Galaxy

Milky Way Formation

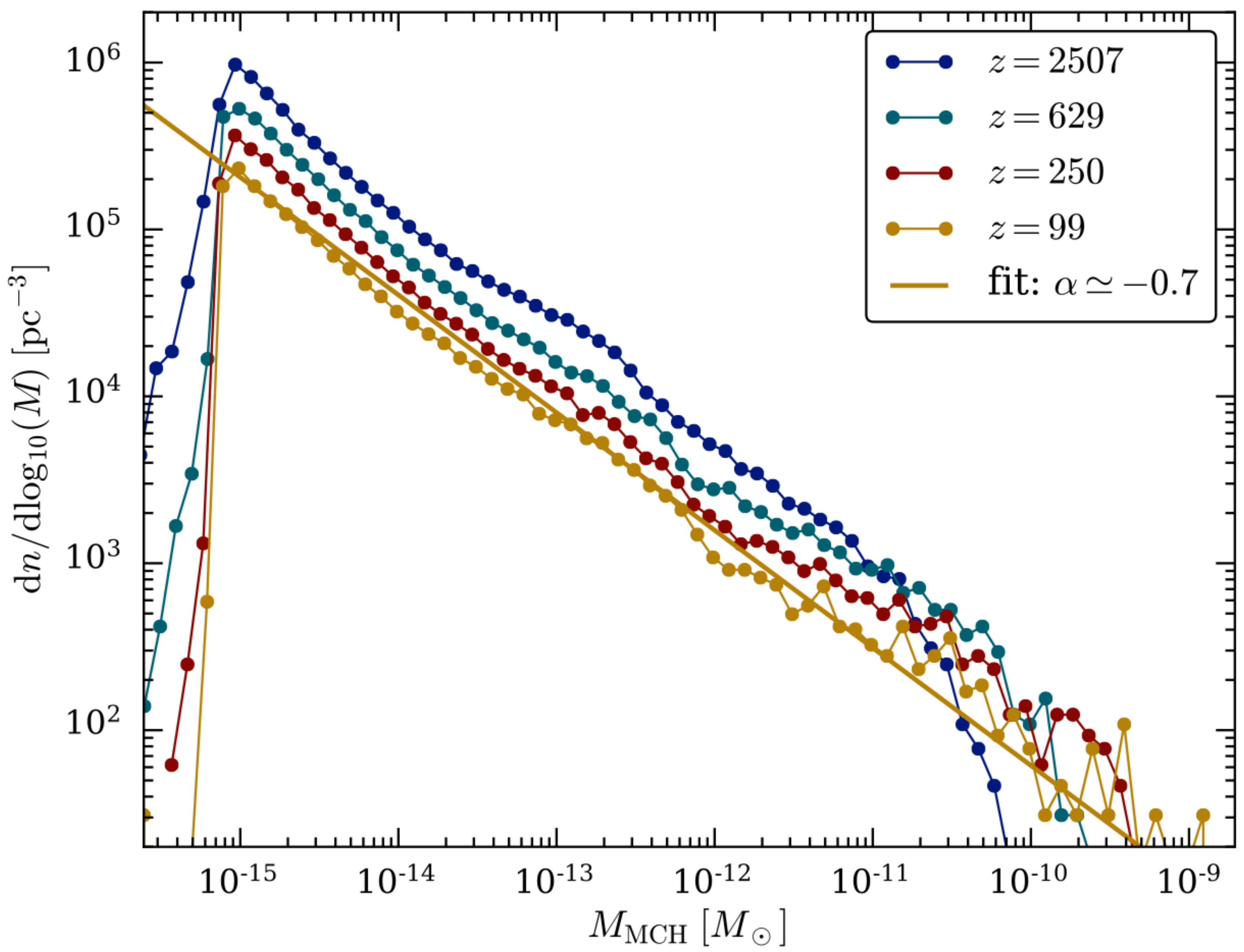
$z_{eq} \sim 3400$ | $z \sim \mathcal{O}(10)$ | $z \sim 0\,(\text{Today})$

Redshift (z)

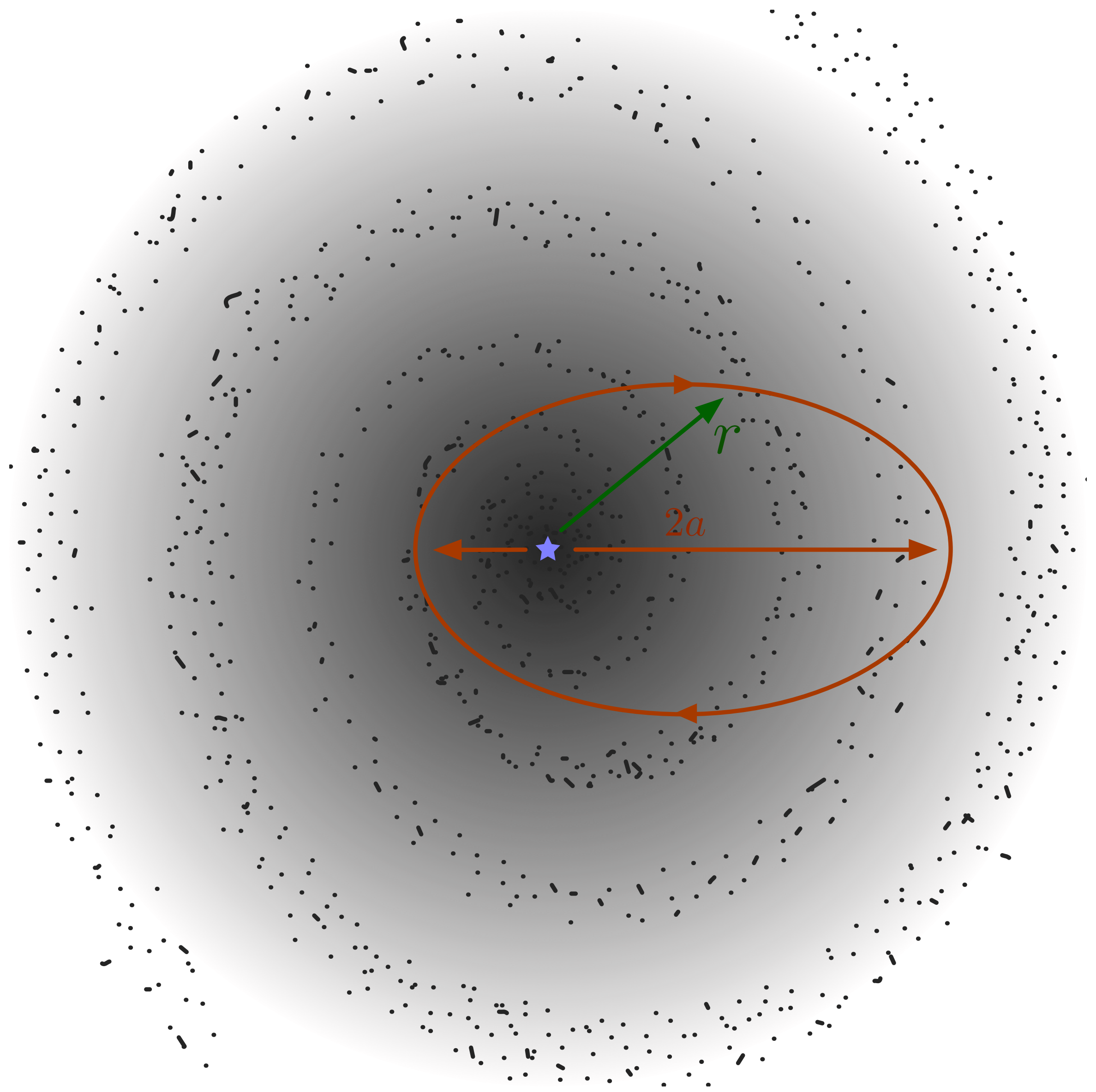
[Buschmann et al., 1906.00967]



[Eggemeier et al., 1911.09417]



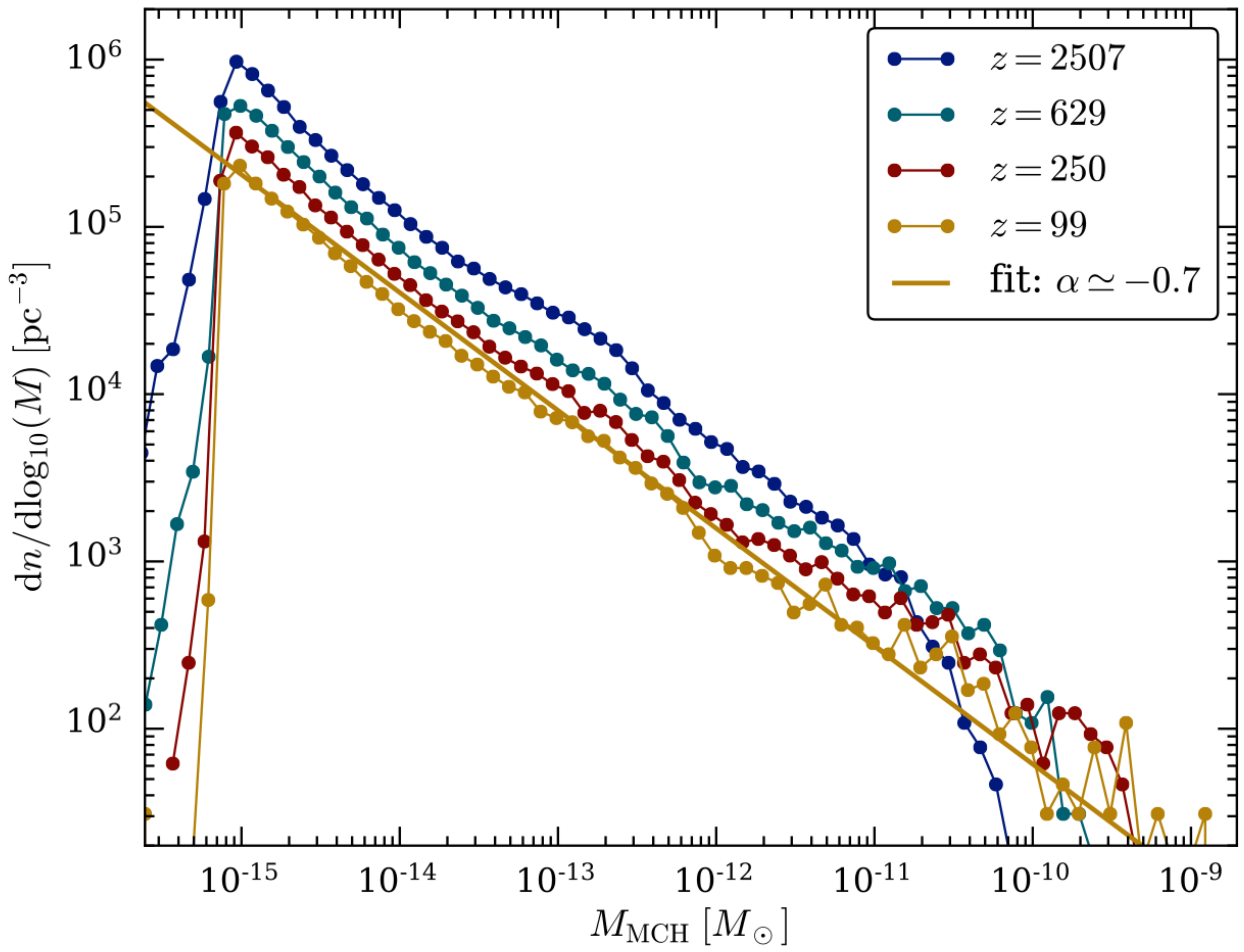
[Kavanagh, **TE**, Visinelli, Weniger, 2011.05377]



Halo Mass Function

[Eggemeier et al., 1911.09417]

Low end controlled by the Jeans mass at formation time



Hierarchical structure formation governs the most massive halos

Cut-off at around

$M_{\mathrm{AMC}} \sim 10^{-5}\, M_\odot$

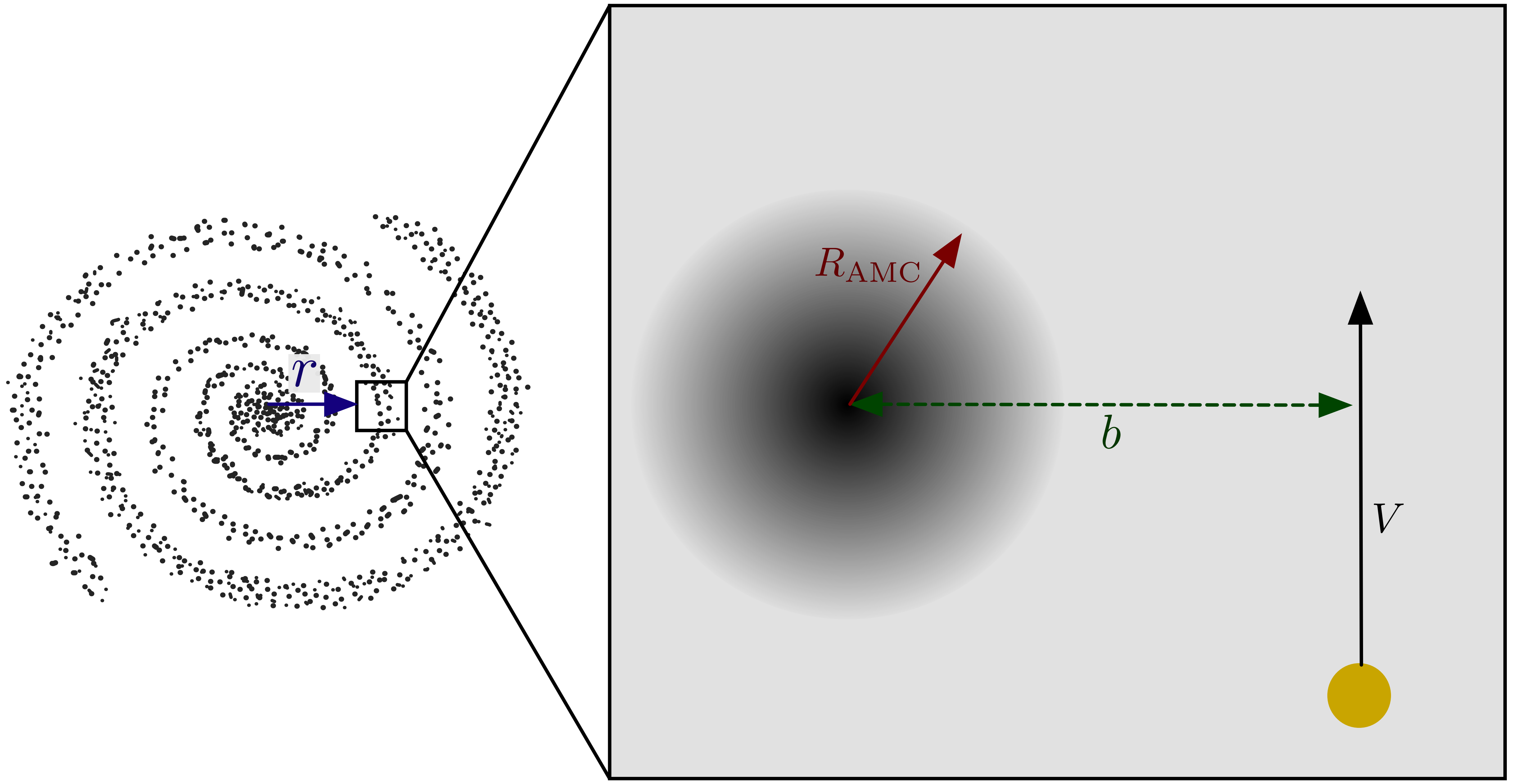
[Fairbairn et al., 1707.03310]

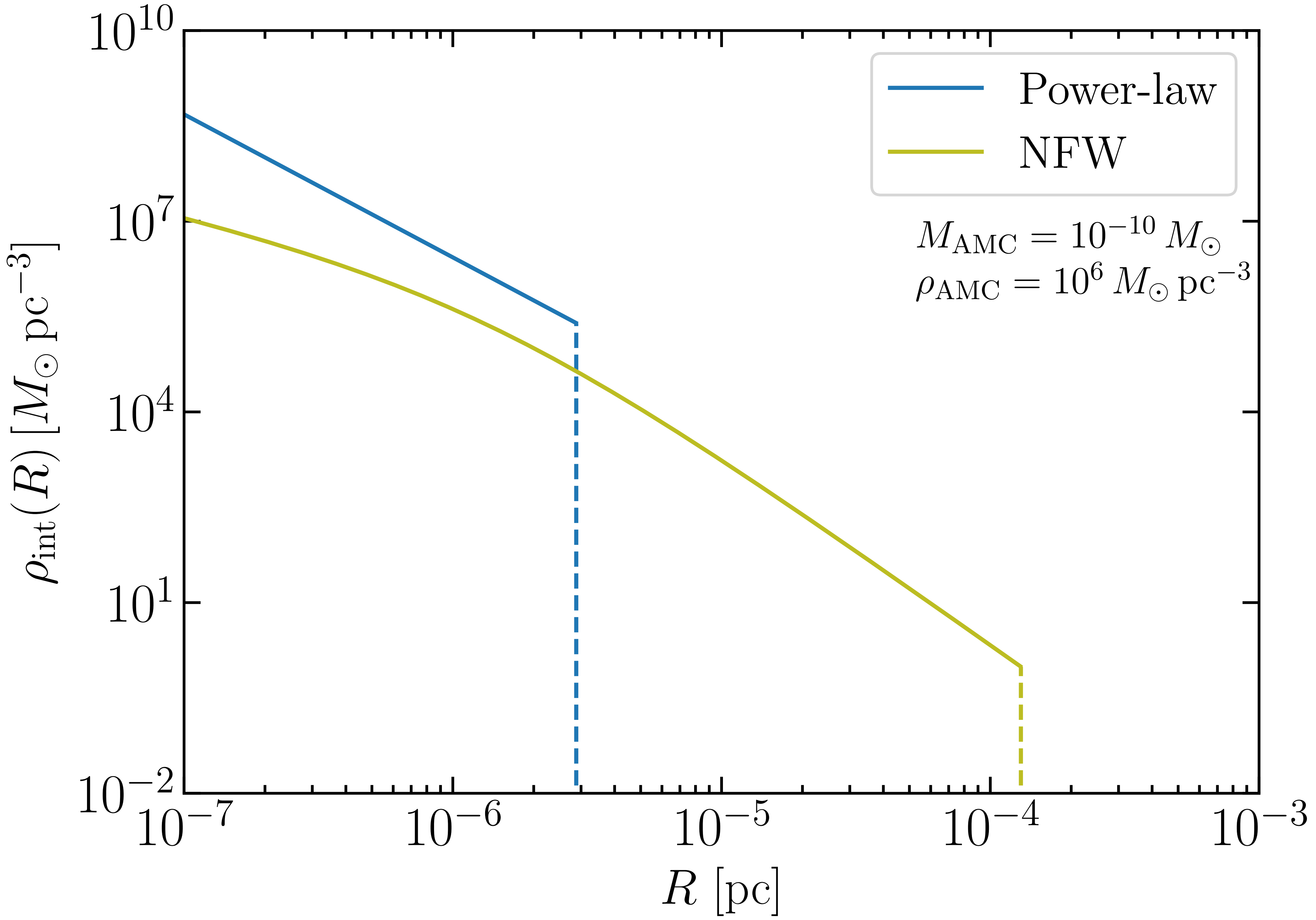
Note that I will report results using this HMF, but our results can **easily be recast to different slopes and functional forms**

[github.com/bradkav/axion-miniclusters]

Minicluster Stellar Interactions

The most important tidal interactions are **with stars**

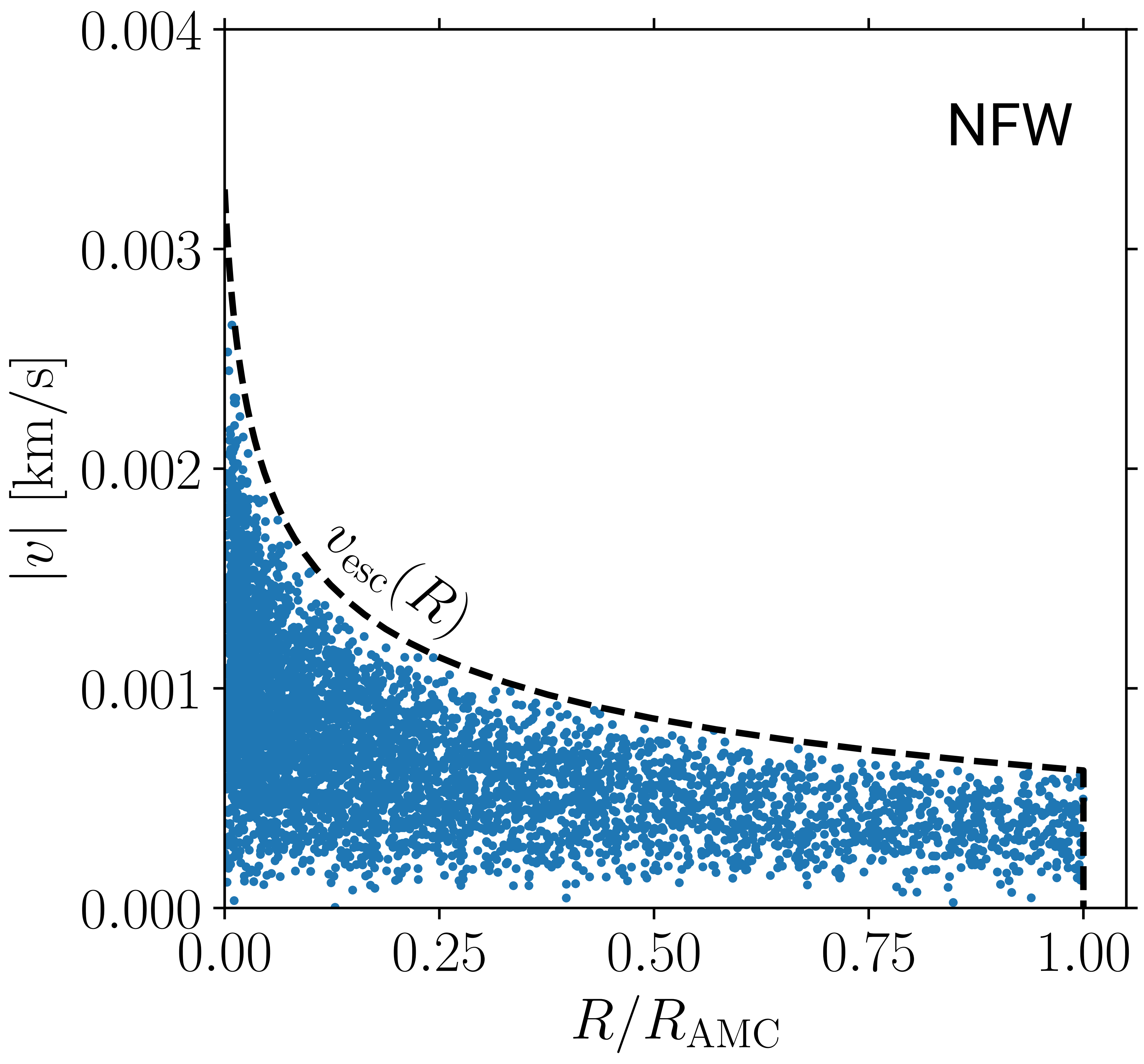




[Kavanagh, **TE**, Visinelli, Weniger, 2011.05377]

Mass Loss

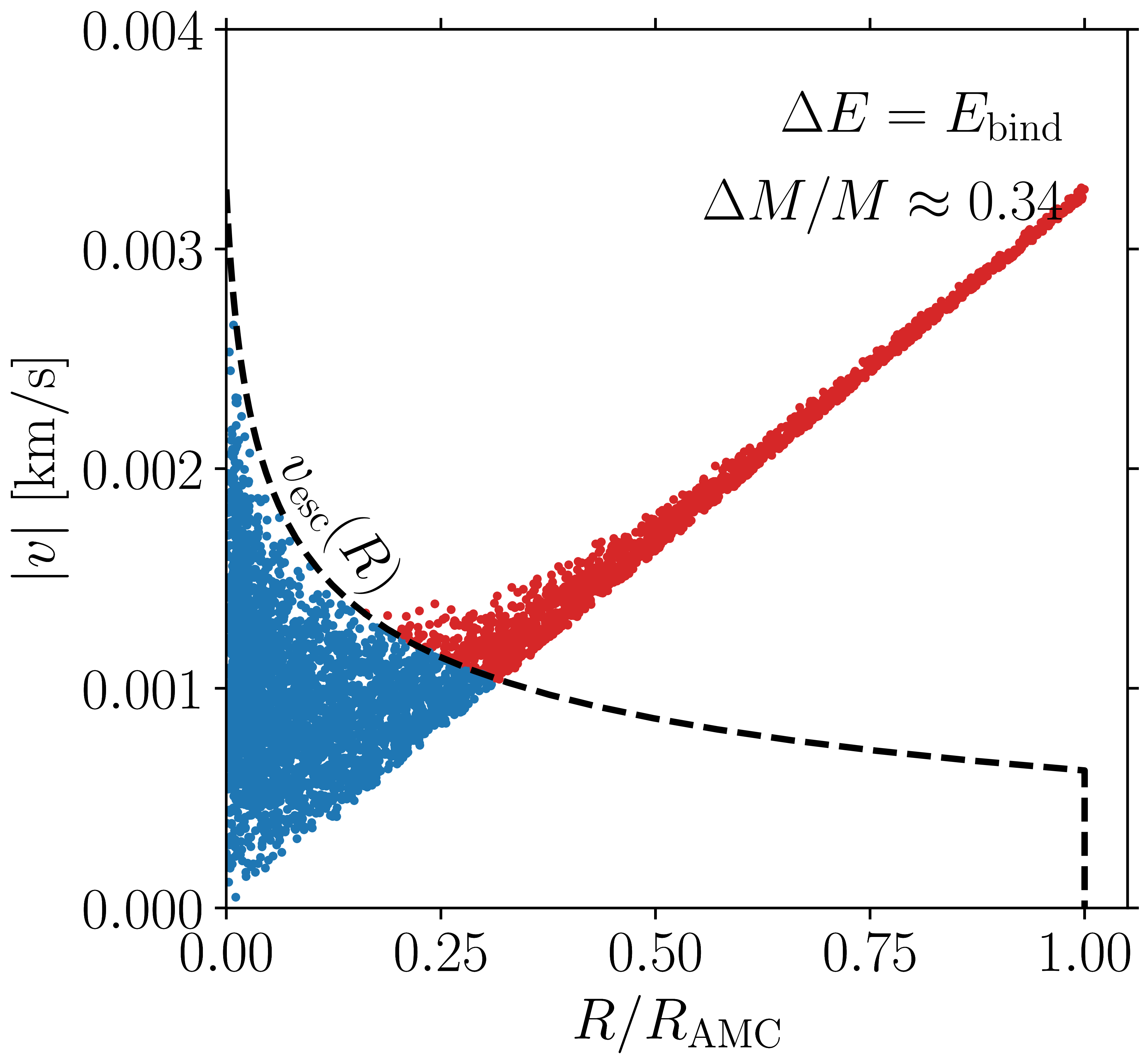
Describe the AMC with a self-consistent distribution function $f(\mathcal{E})$
(obtained using Eddington's formula)



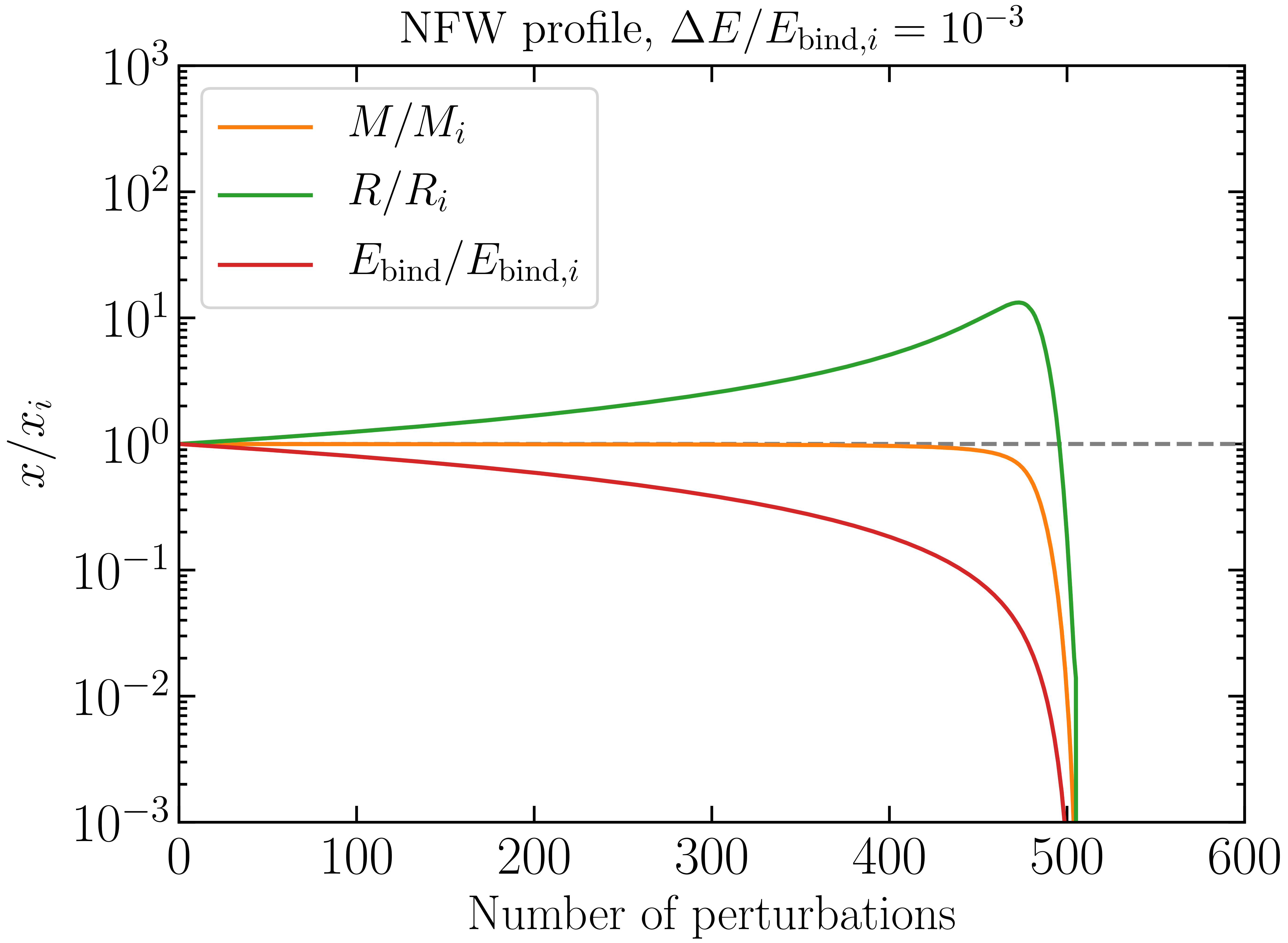
Perturb

$$\Delta E \approx \left(\frac{2GM_\star}{b^2 V}\right)^2 \frac{M_{\mathrm{AMC}}\langle R^2\rangle}{3}$$

[Green & Goodwin, astro-ph/0604142]



Repeated Interactions



Monte Carlo

Generate sample of AMCs (with correct density distribution but *log-flat* mass function)

Sample orbital parameters (e, ψ)

Compute number of stellar interactions:

$$N = \int_0^{T_{\mathrm{MW}}} \mathrm{d}t \, n_\star(t) V_{\mathrm{AMC}}(t) \cdot \pi b_{\mathrm{max}}^2$$

Sample interaction properties (V, b) and perturb AMC

AMC not disrupted

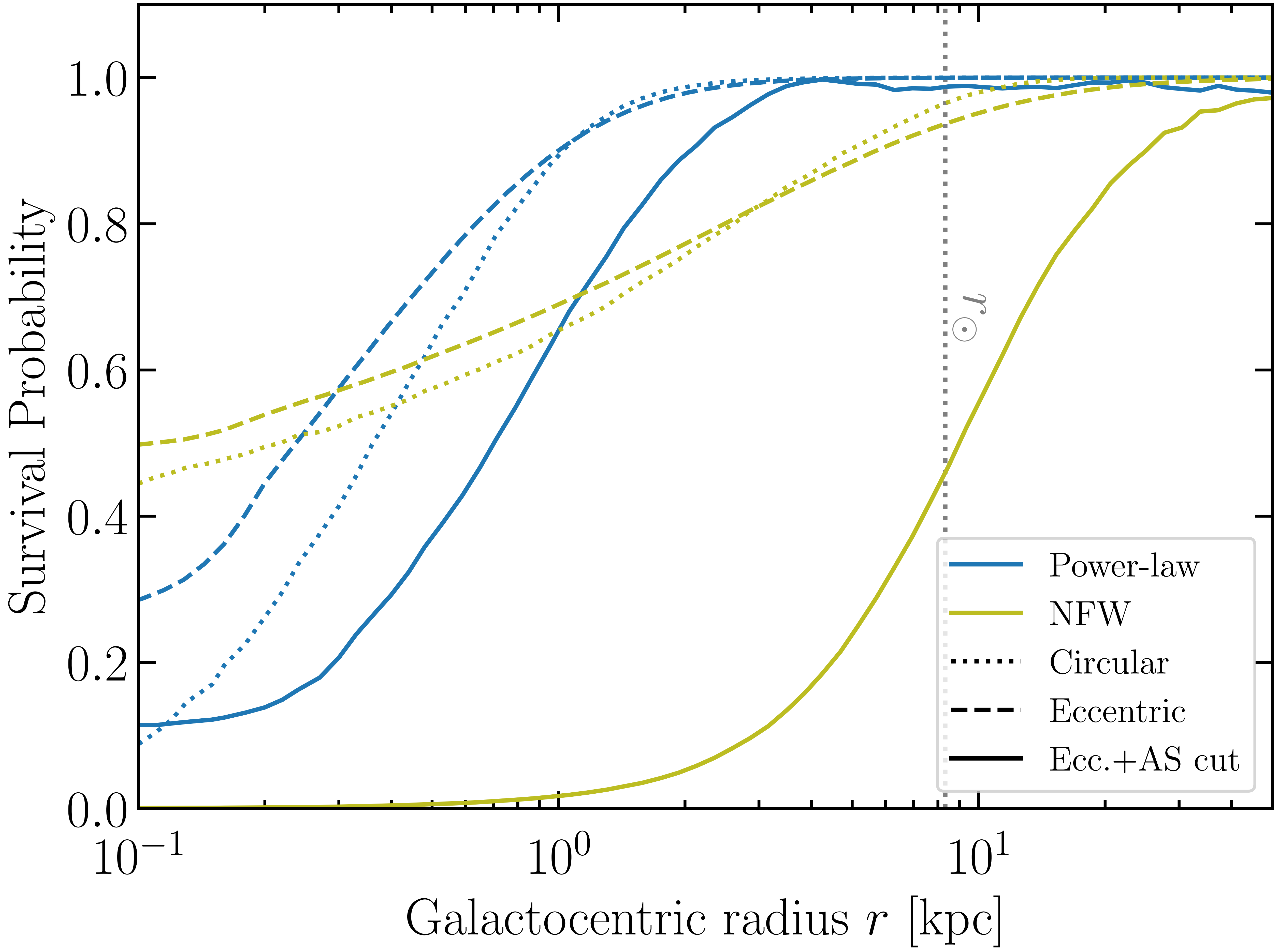
AMC disrupted

Remove AMC from simulation

Collect surviving AMCs and reconstruct true properties

[Kavanagh, **TE**, Visinelli, Weniger, 2011.05377]

Survival Probability



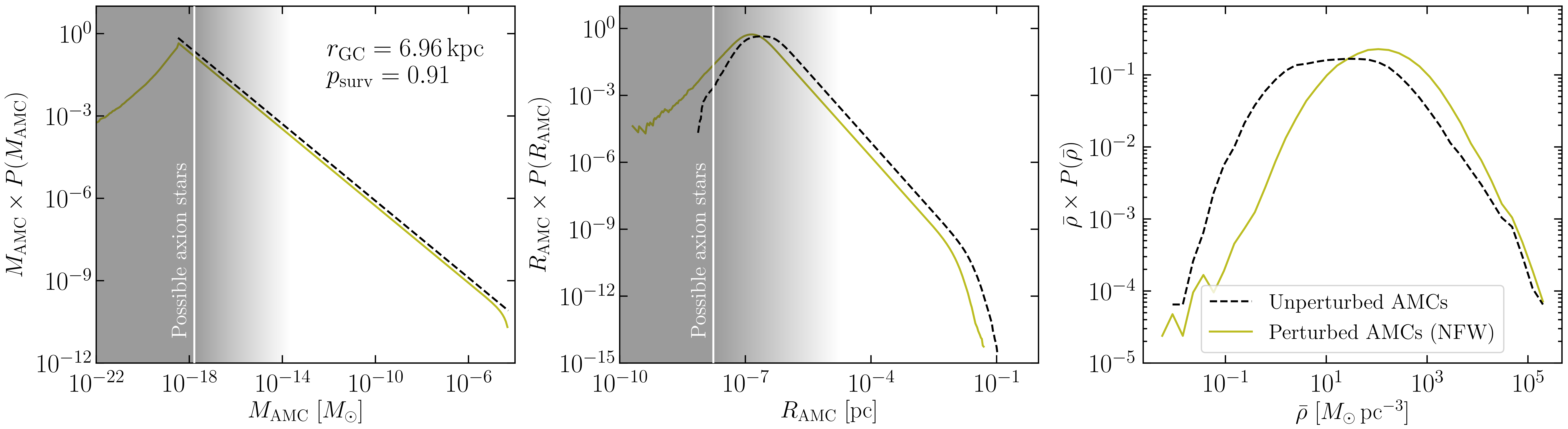
Survival probability at Solar position:

$\mathcal{O}(40\%)$ for NFW profiles

$\mathcal{O}(99\%)$ for PL profiles

[Distributions and tools for re-casting available online: github.com/bradkav/axion-miniclusters]

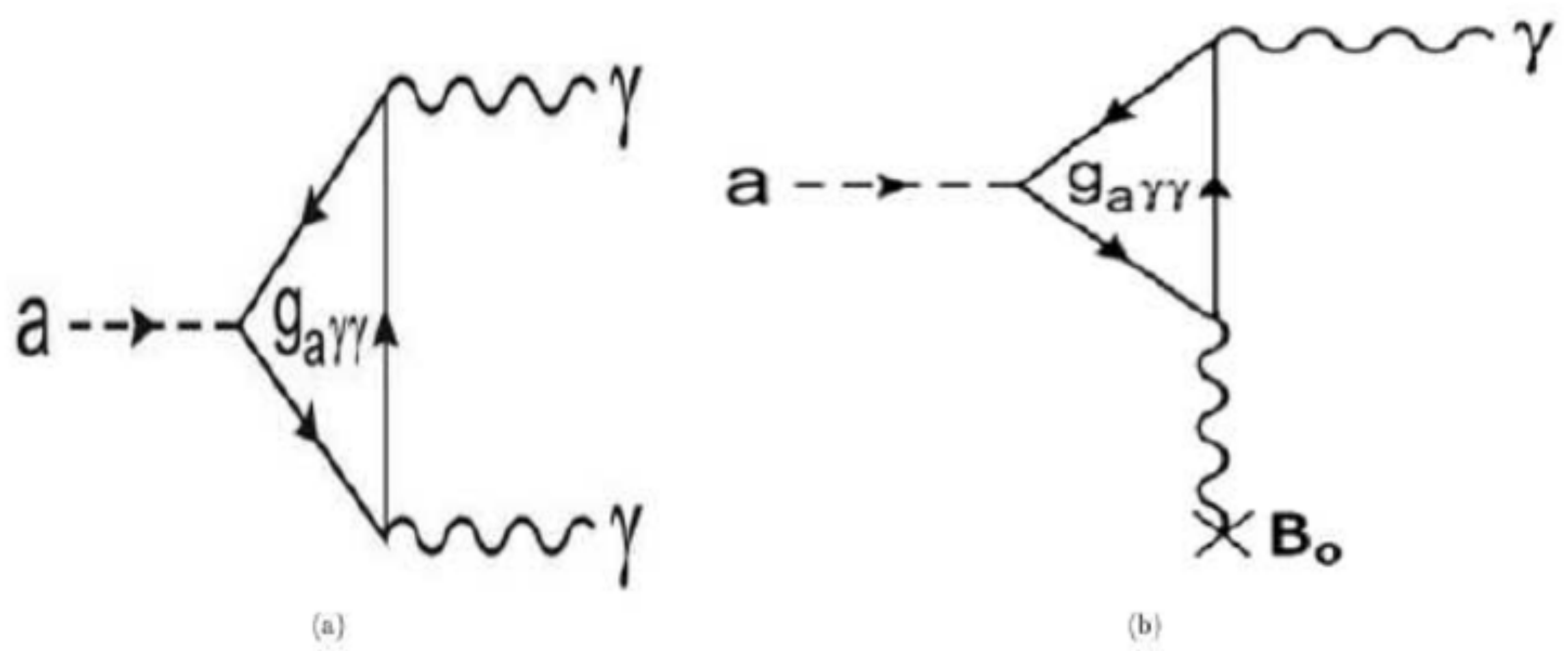
Miniclusters Tend to Lose Mass and Become More Dense



Overview:

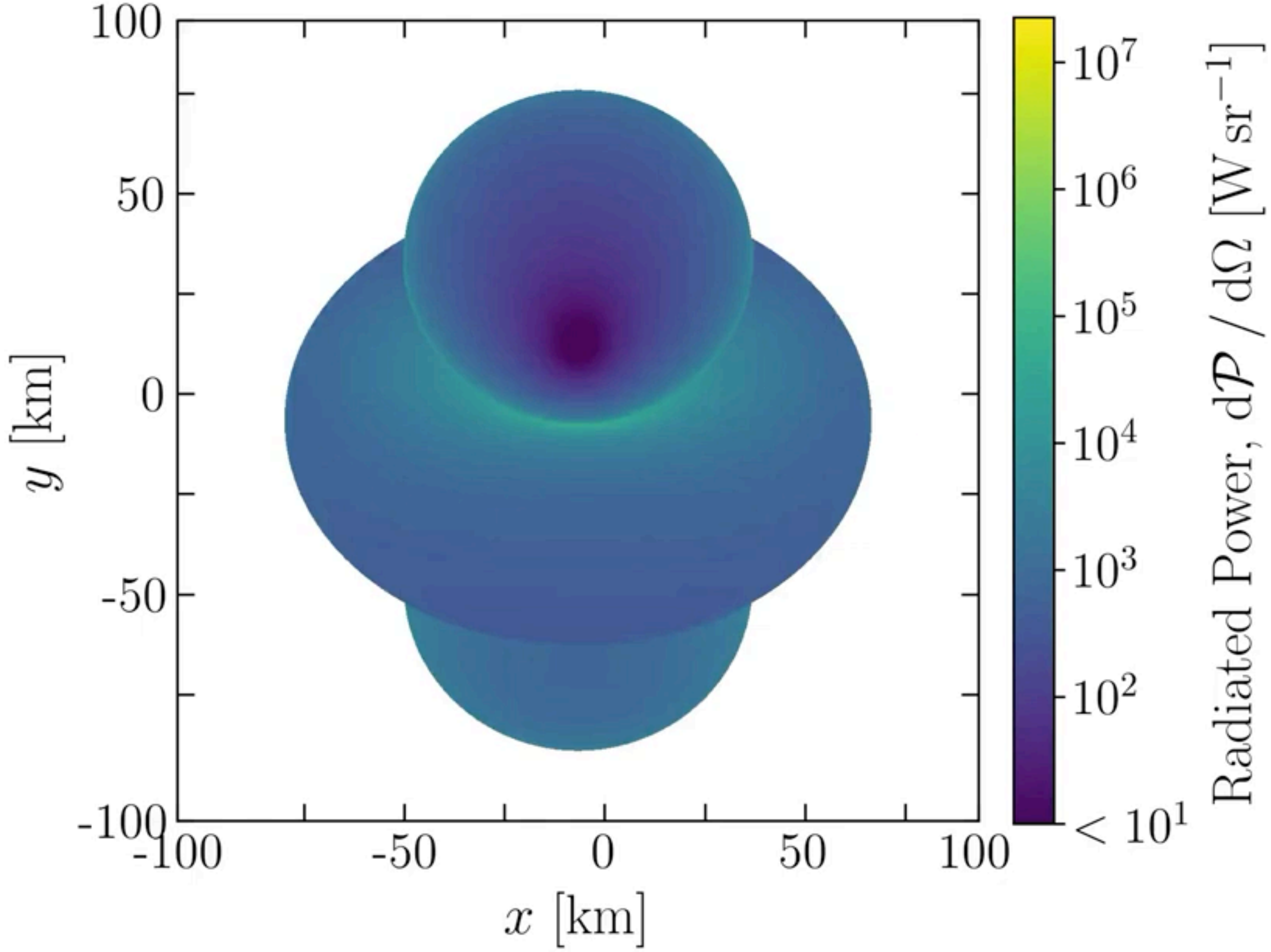
1. Axion Miniclusters in the Milky Way
2. Miniclusters Interacting with Neutron Stars

Axion-Photon Conversion



$$\mathcal{L} \propto g_{a\gamma\gamma} a \mathbf{E} \cdot \mathbf{B}$$

[Sikivie 1983]



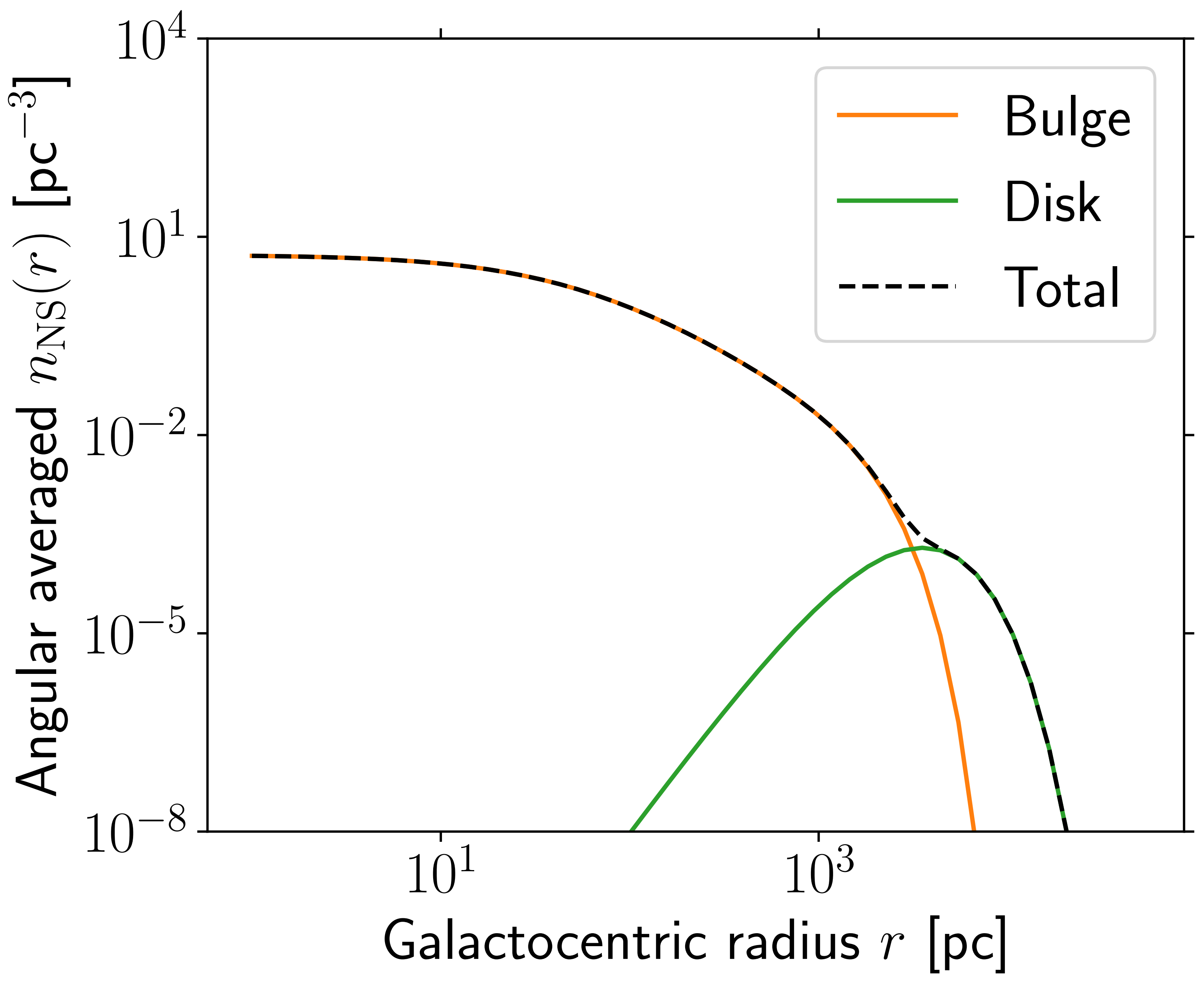
[Leroy, Chianese, **TE**, Weniger, 1912.08815; Hook et al., 1804.03145]

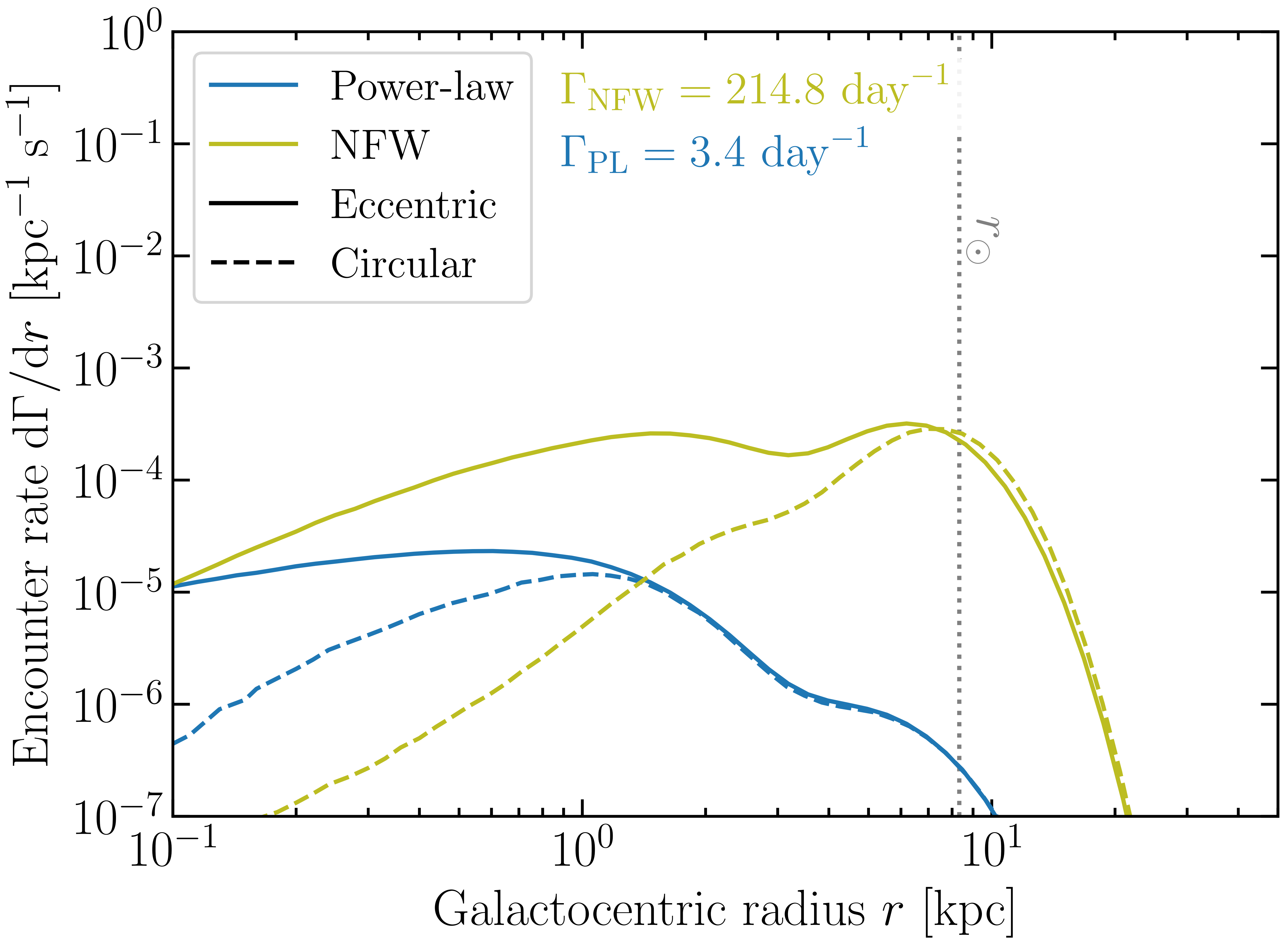
NS-AMC Interactions

We assume there are roughly **10^9 neutron stars in the Milky Way**

B-field distribution assumed to be log-normal with a central value of **10^{12} Gauss**

[Safdi et al., 1811.01020]





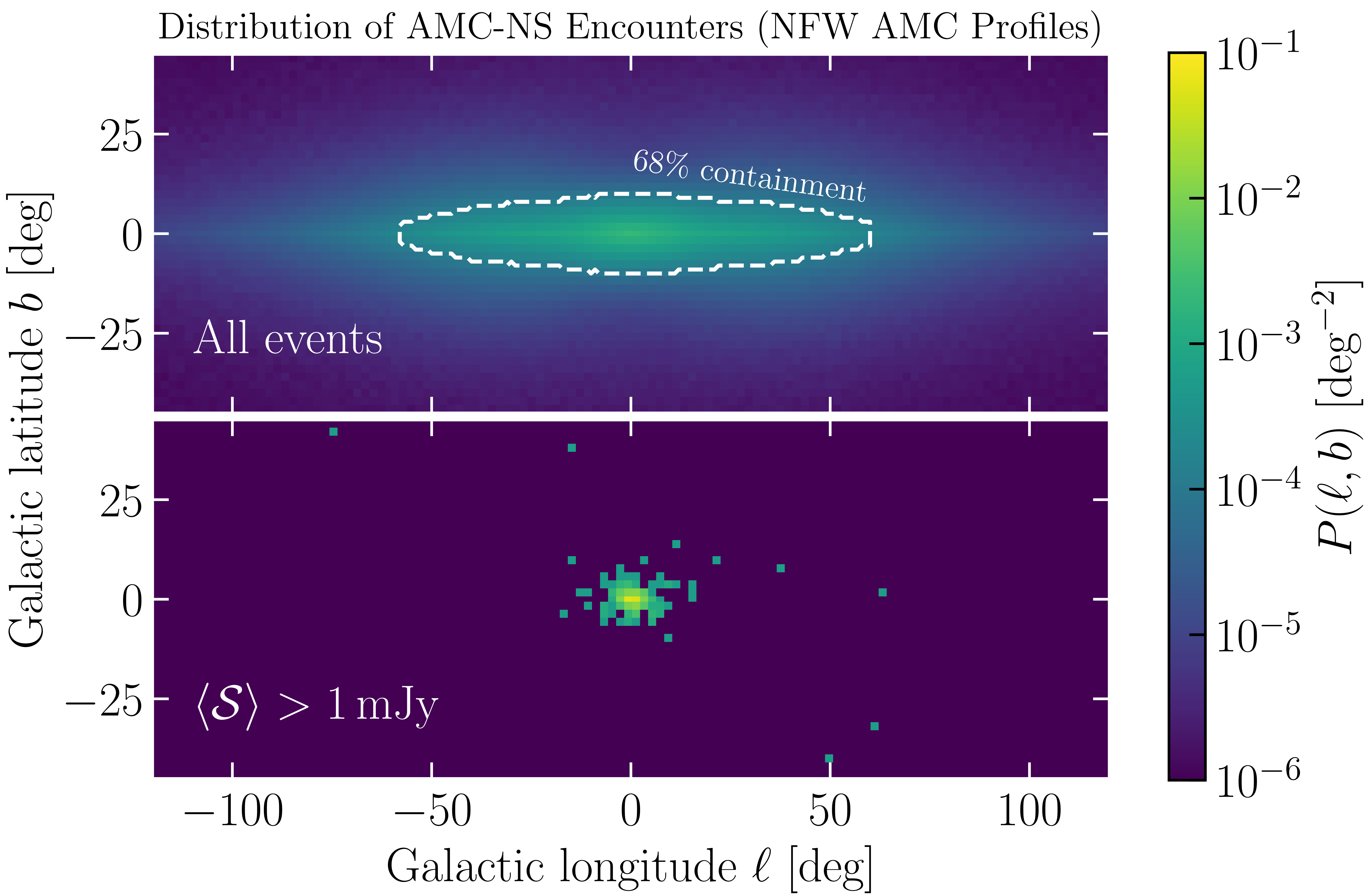
Radio Transients

[**TE**, Kavanagh, Visinelli, Weniger, 2011.05378]

$$g_{a\gamma\gamma} = 8 \times 10^{-15}\,\mathrm{GeV}^{-1}$$

$$m_a = 20\,\mu\mathrm{eV}$$

Sky Position

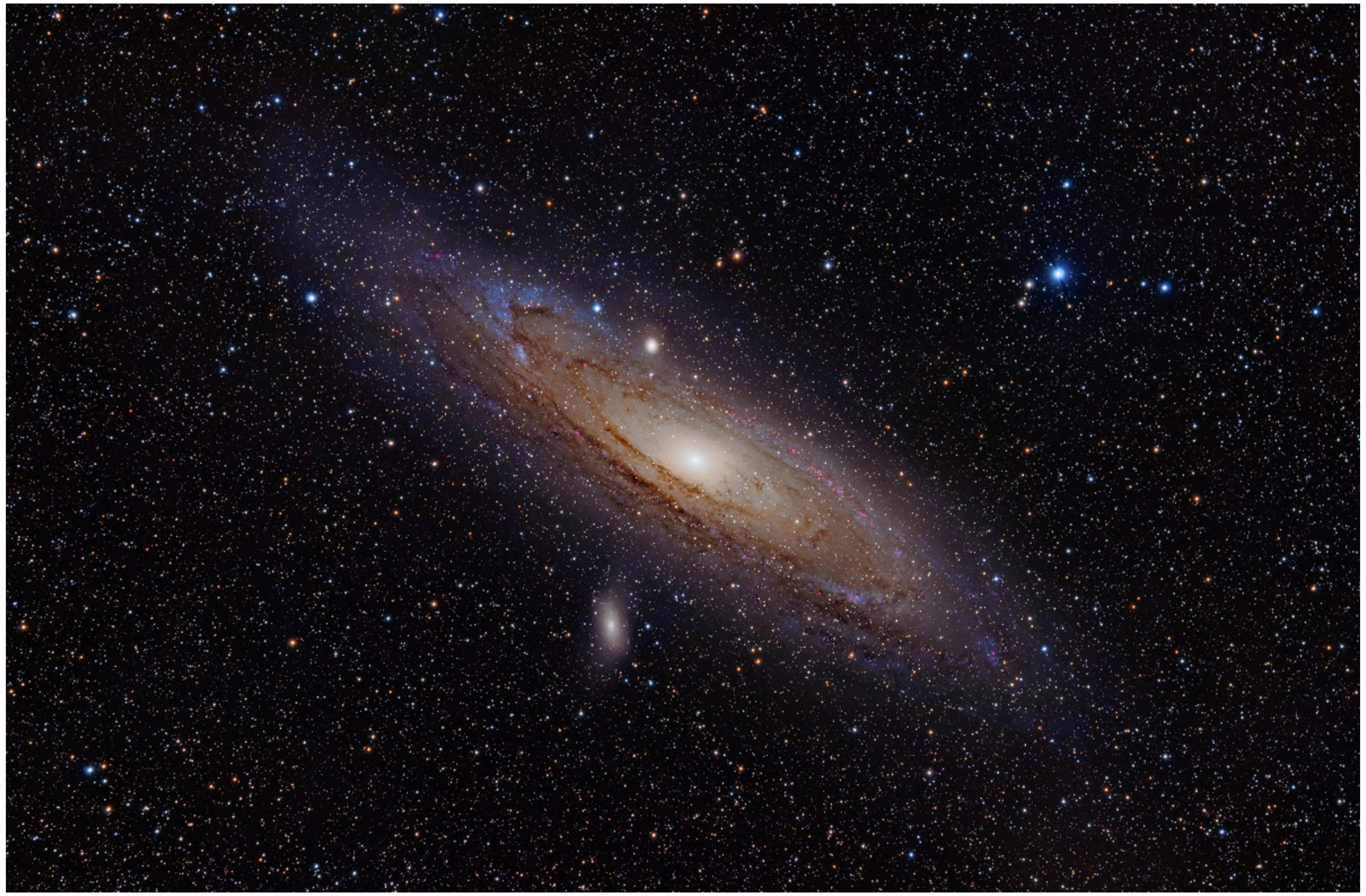


[**TE**, Kavanagh, Visinelli, Weniger, 2011.05378]

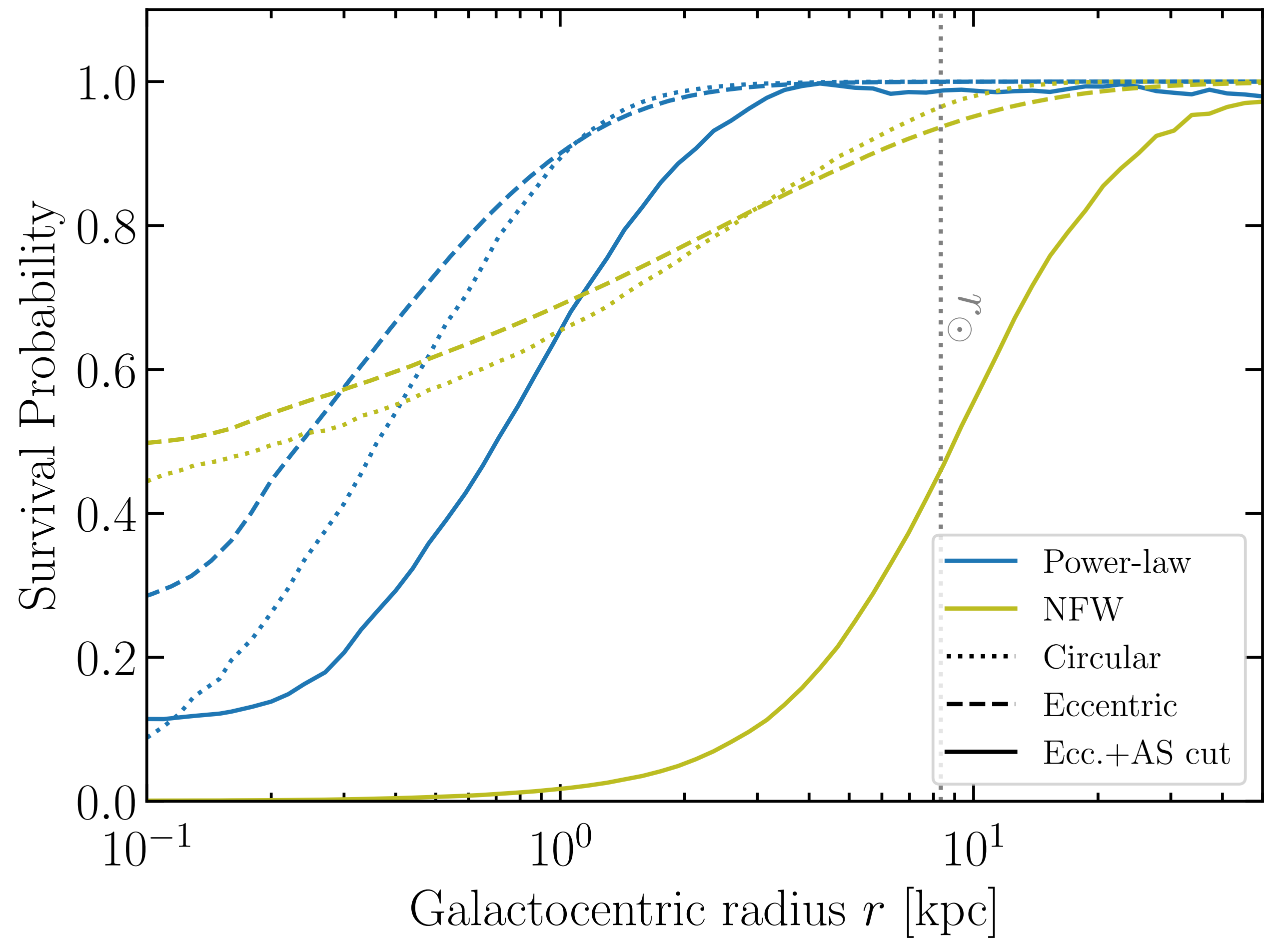
The majority of events come from the **centre of the Galaxy**

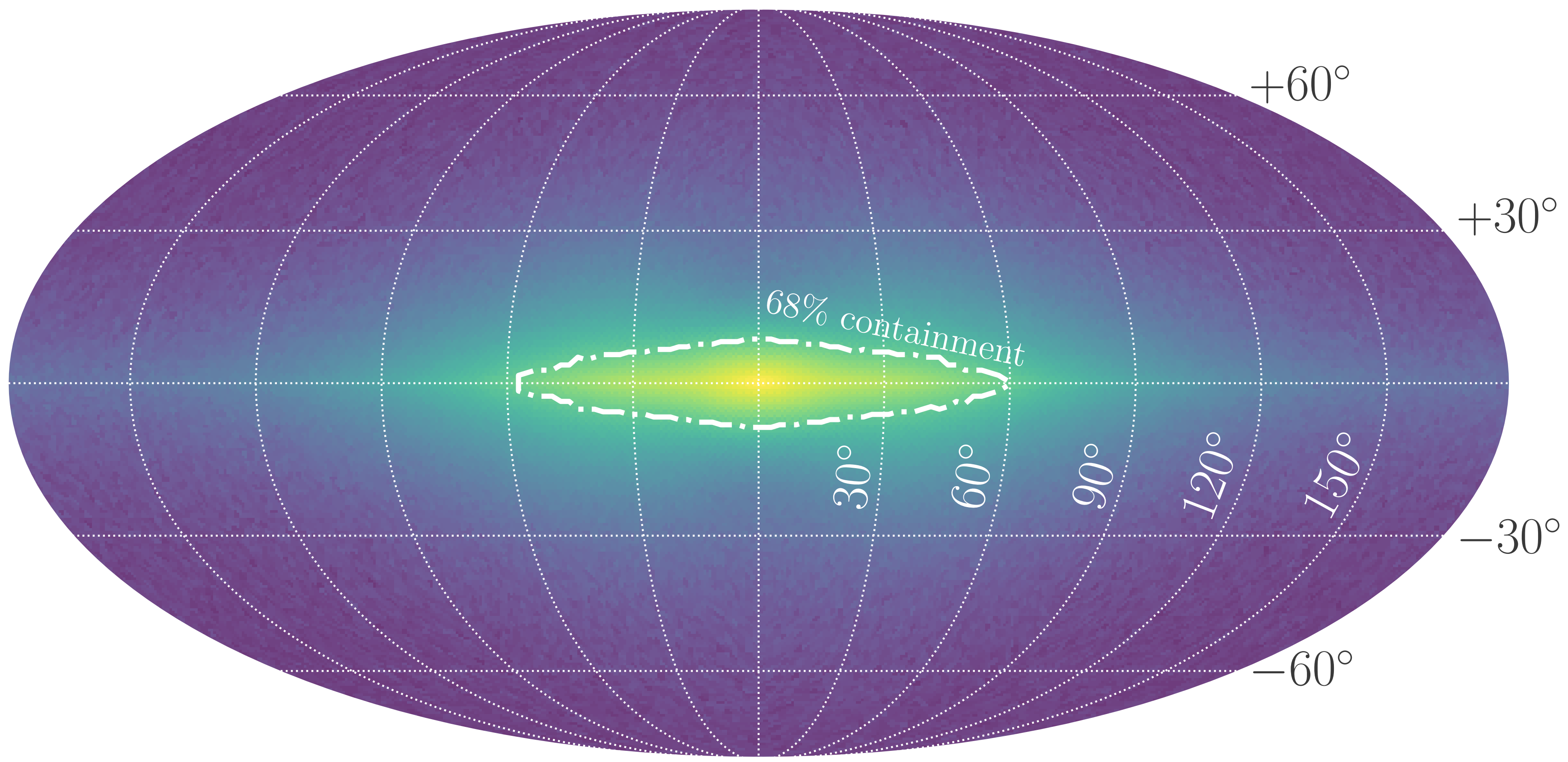
The PL profile distributions are **even more concentrated**

Ongoing Observations



Conclusions





1. Axion miniclusters are **heavily disrupted** by interactions with stars in the Milky Way
2. Minicluster — neutron star interactions can lead to bright radio transients that are potentially **detectable with current radio telescopes**

[Distributions and tools for re-casting available online: github.com/bradkav/axion-miniclusters]