Leading Axion-Photon Sensitivity with NuSTAR Observations of M82 and M87

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University of California, Berkeley
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with Benjamin Safdi
arXiv:2404.14476

Image: NASA, ESA, and The Hubble Heritage Team (STScI/AURA)

Key Highlights:

1. New axion-photon constraints using NuSTAR observations of M82/M87 galaxies
2. Use of full galaxies as a probe of axion physics

A Tale of Two Galaxies

M82

M87

Images: NASA, ESA, and The Hubble Heritage Team (STScI/AURA)

A Tale of Two Galaxies

M82

M87

- Starburst Galaxy
- Indications of Strong B-fields

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A Tale of Two Galaxies

M82

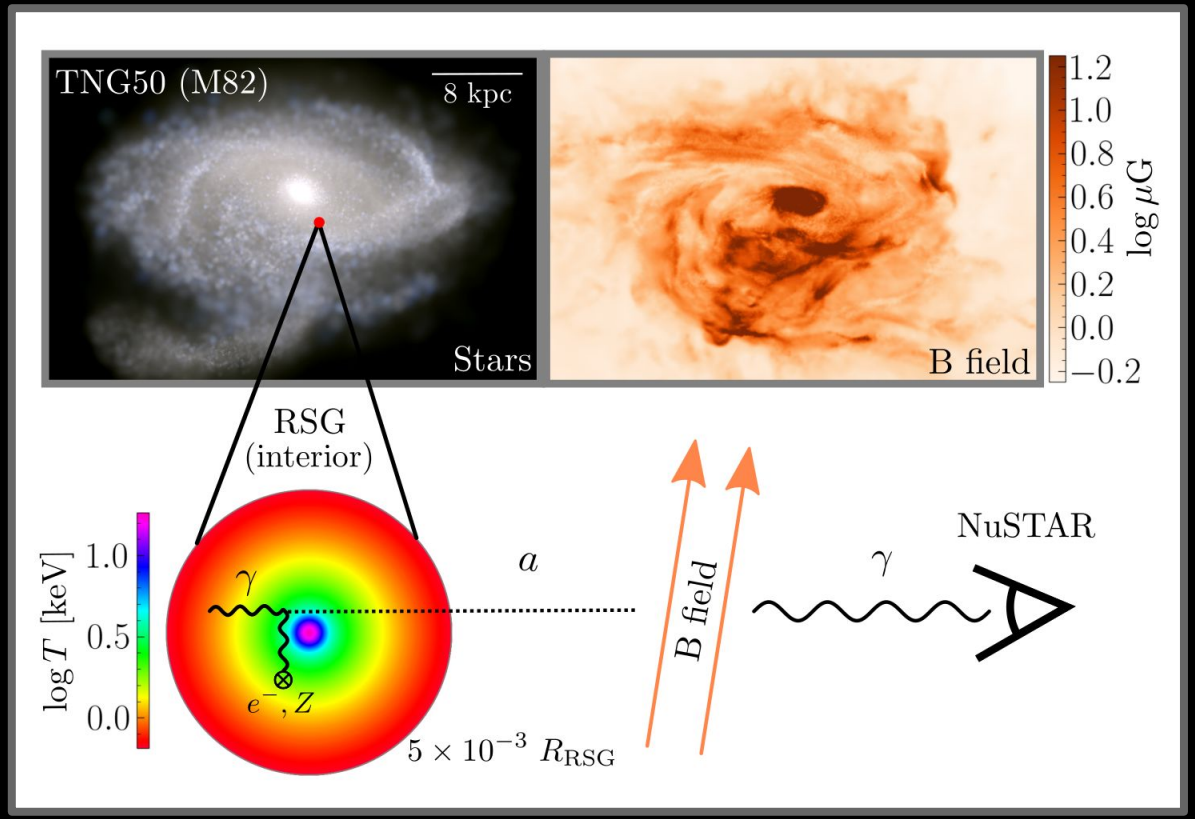
- Starburst Galaxy
- Indications of Strong B-fields

M87

- Massive Elliptical
- Extended Virgo Cluster B-fields

Images: NASA, ESA, and The Hubble Heritage Team (STScI/AURA)

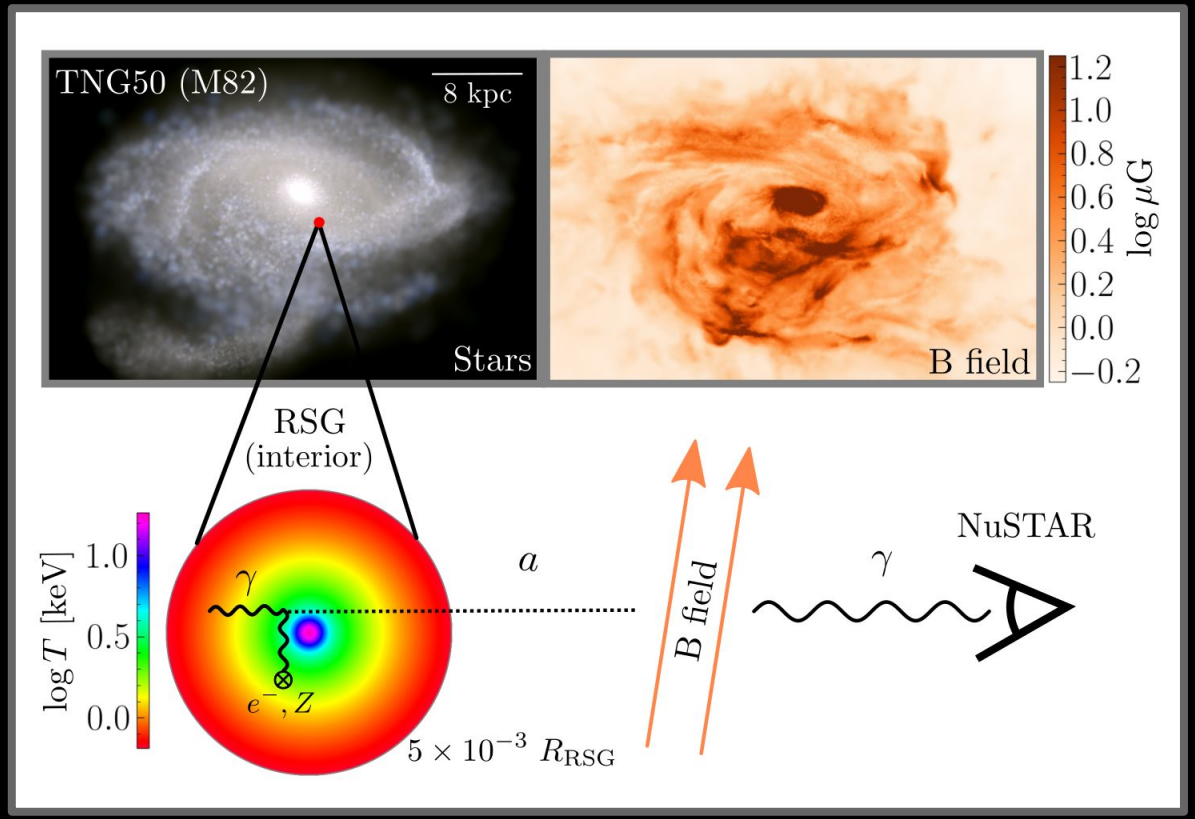
Searching for Axions with NuSTAR:



Searching for Axions with NuSTAR:

Axions produced via Primakoff in stellar interiors

$g_{a\gamma\gamma}$



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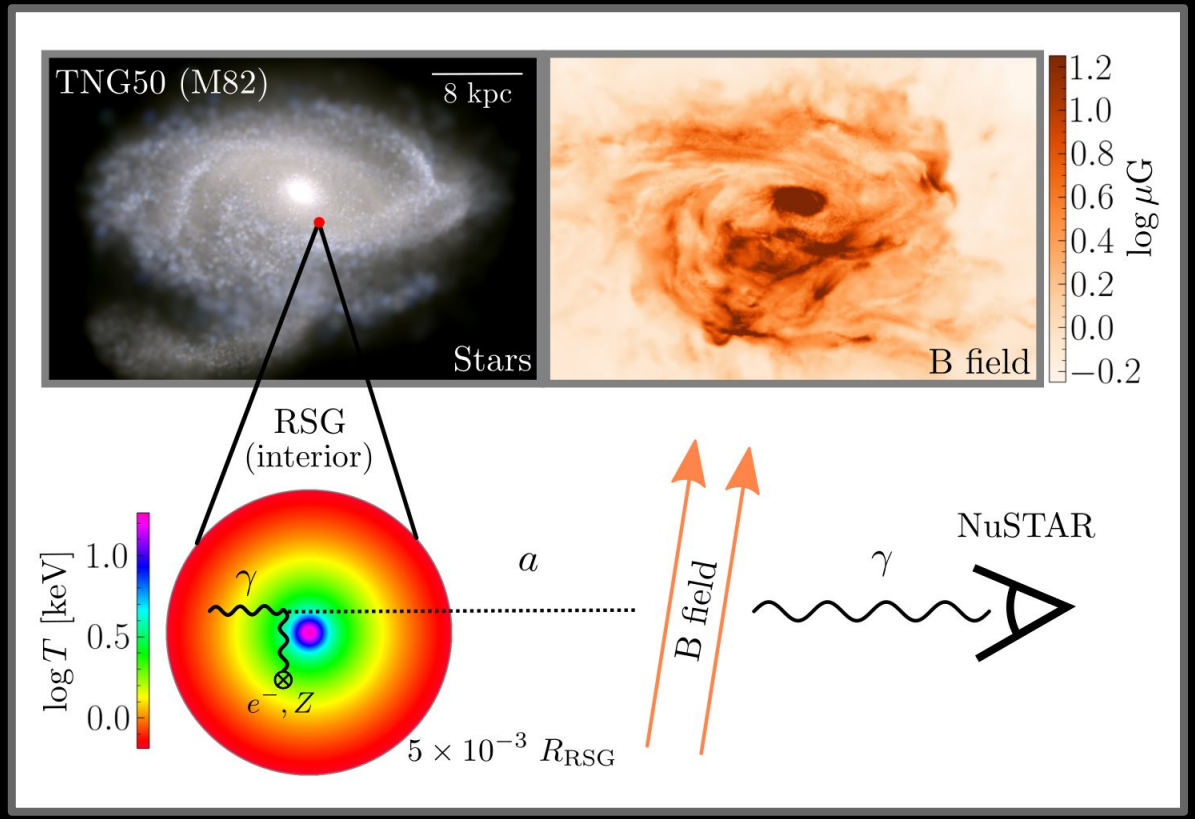

Convert to hard X-rays in galactic/cluster magnetic fields

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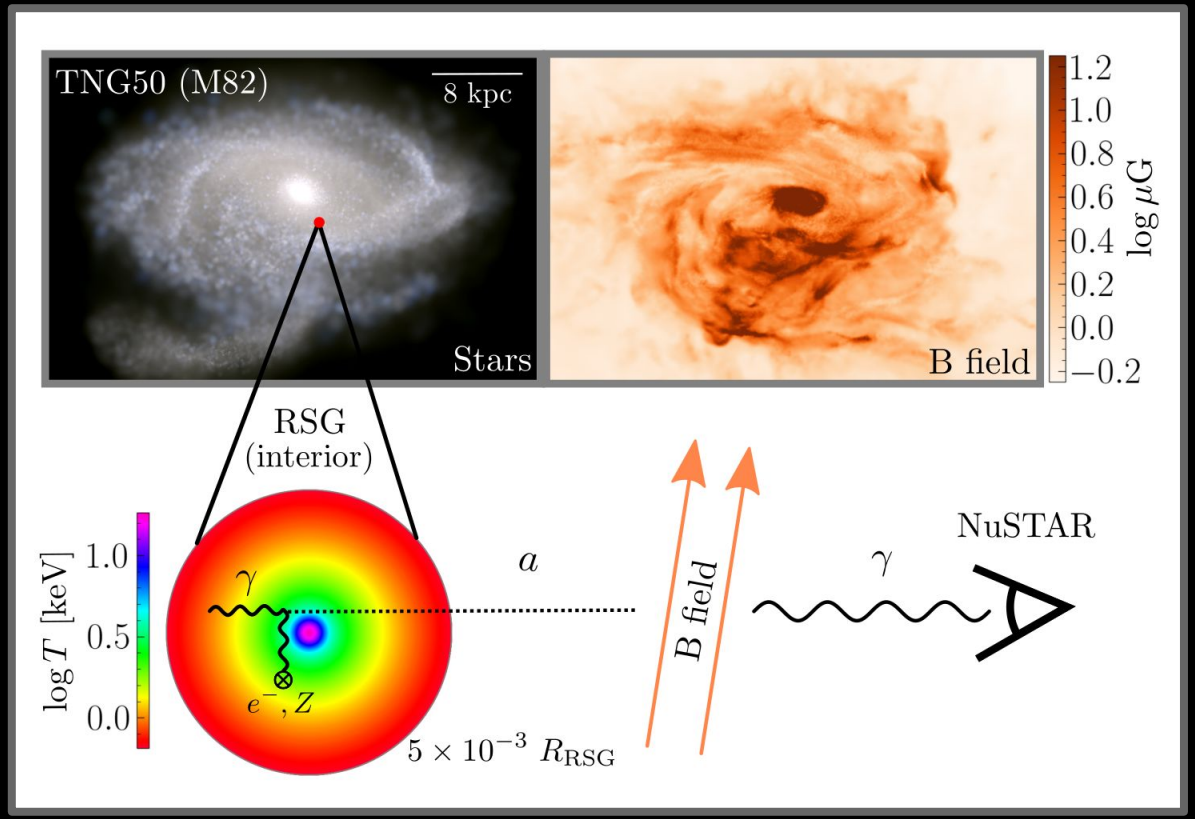

Axions produced via Primakoff in stellar interiors

$g_{a\gamma\gamma}$

Convert to hard X-rays in galactic/cluster magnetic fields

Observed by the NuSTAR telescope

Axion Signal Model Ingredients

$$\frac{dF}{dE}(E) = P_{a\to\gamma}(E)\,\frac{1}{4\pi d^2}\,\frac{dL_a(E)}{dE}$$

Axion-Photon Conversion Probability

Distance

Total Axion Luminosity from Stars

Signal Model Ingredients (1/2)

Axion Luminosity from Stellar Populations of M82/M87

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Primakoff Process $\frac{dL_a(E)}{dE}$

Signal Model Ingredients (1/2)

Axion Luminosity from Stellar Populations of M82/M87

Primakoff Process

Stellar Profiles (MESA)

$$\frac{dL_a(E)}{dE}$$

- Temperature
- Density
- Abundances

Signal Model Ingredients (1/2)

Axion Luminosity from Stellar Populations of M82/M87

Primakoff Process

Stellar Profiles (MESA)

Stellar Population Models (Obs.)

$$\frac{dL_a(E)}{dE}$$

- Temperature
- Density
- Abundances

- Metallicity
- SFH
- IMF
- # of Stars

Signal Model Ingredients (1/2)

Axion Luminosity from Stellar Populations of M82/M87

Primakoff Process

$$\frac{dL_a(E)}{dE}$$

+

Stellar Profiles (MESA)

- Temperature
- Density
- Abundances

+

Stellar Population Models (Obs.)

- Metallicity
- SFH
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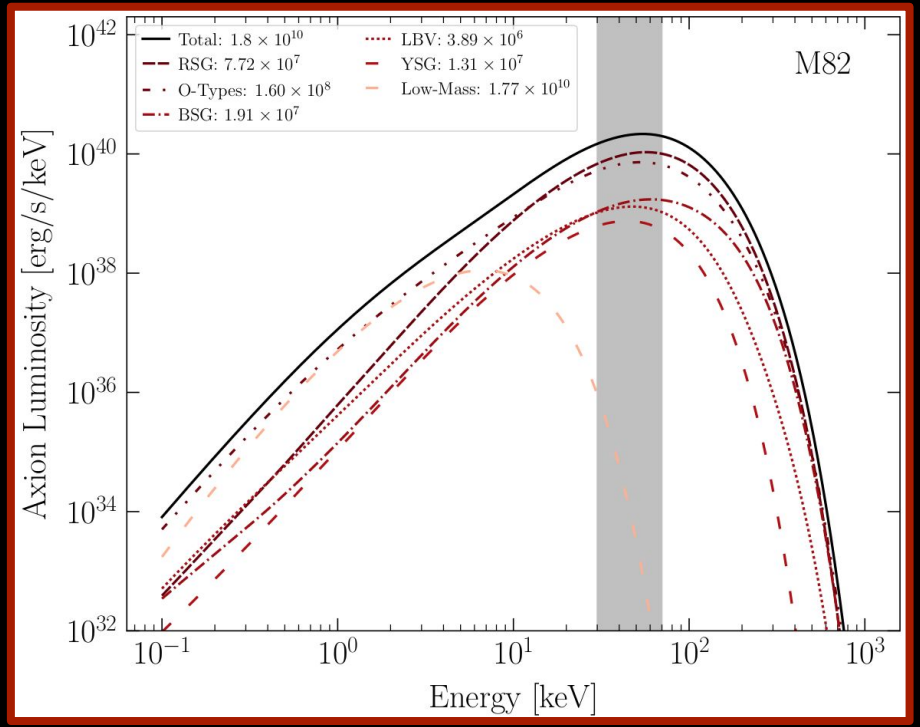
- # of Stars

=

Total Axion Luminosity Spectra

- Dominated by Supergiants and O-Types, generally
- M82: starburst = excellent for axions!



Signal Model Ingredients (2/2)

Conversion Probability for Axion-Photon Conversion

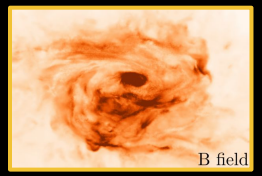
Signal Model Ingredients (2/2)

Conversion Probability for Axion-Photon Conversion

Axion Mass m_a

+

Magnetic Fields



+

Free-electron Densities n_e

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Conversion Probabilities $P_{a\to\gamma}$

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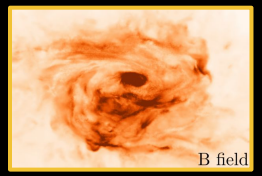

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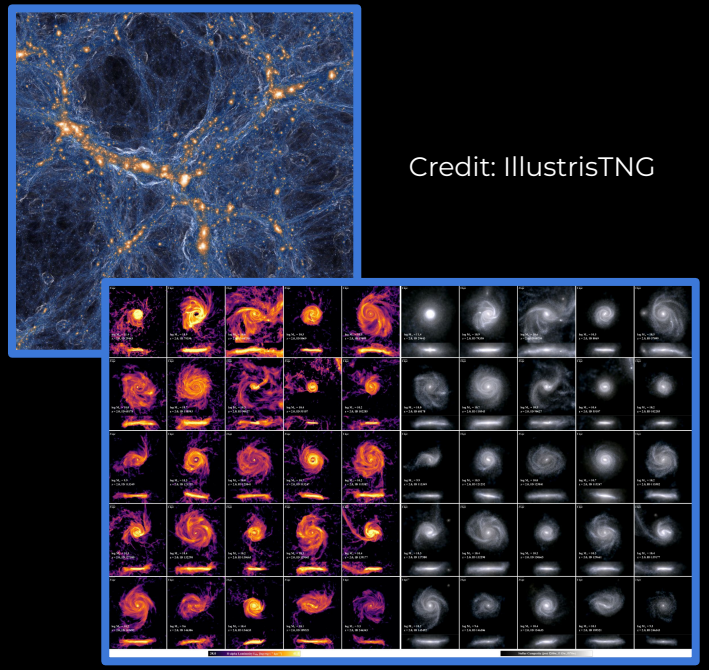
IllustrisTNG TNG50/300 Simulations



Credit: IllustrisTNG

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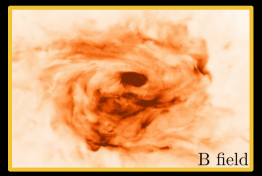

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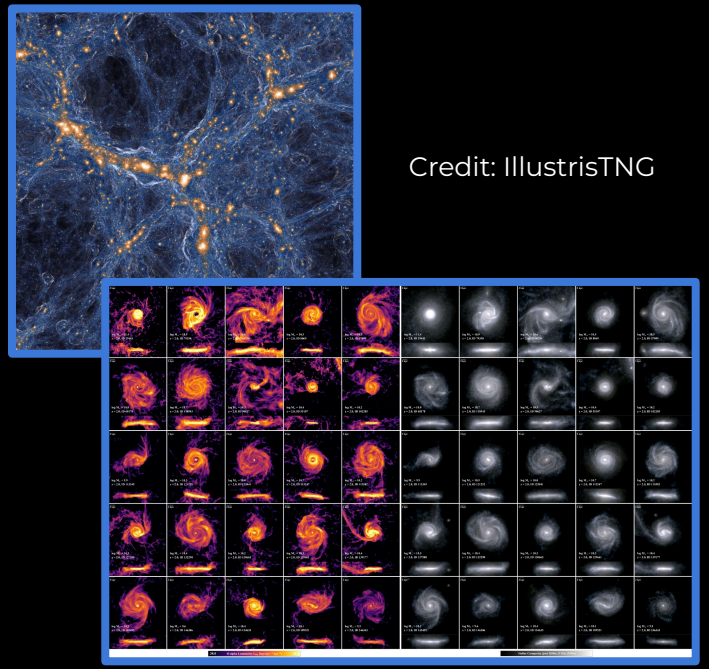
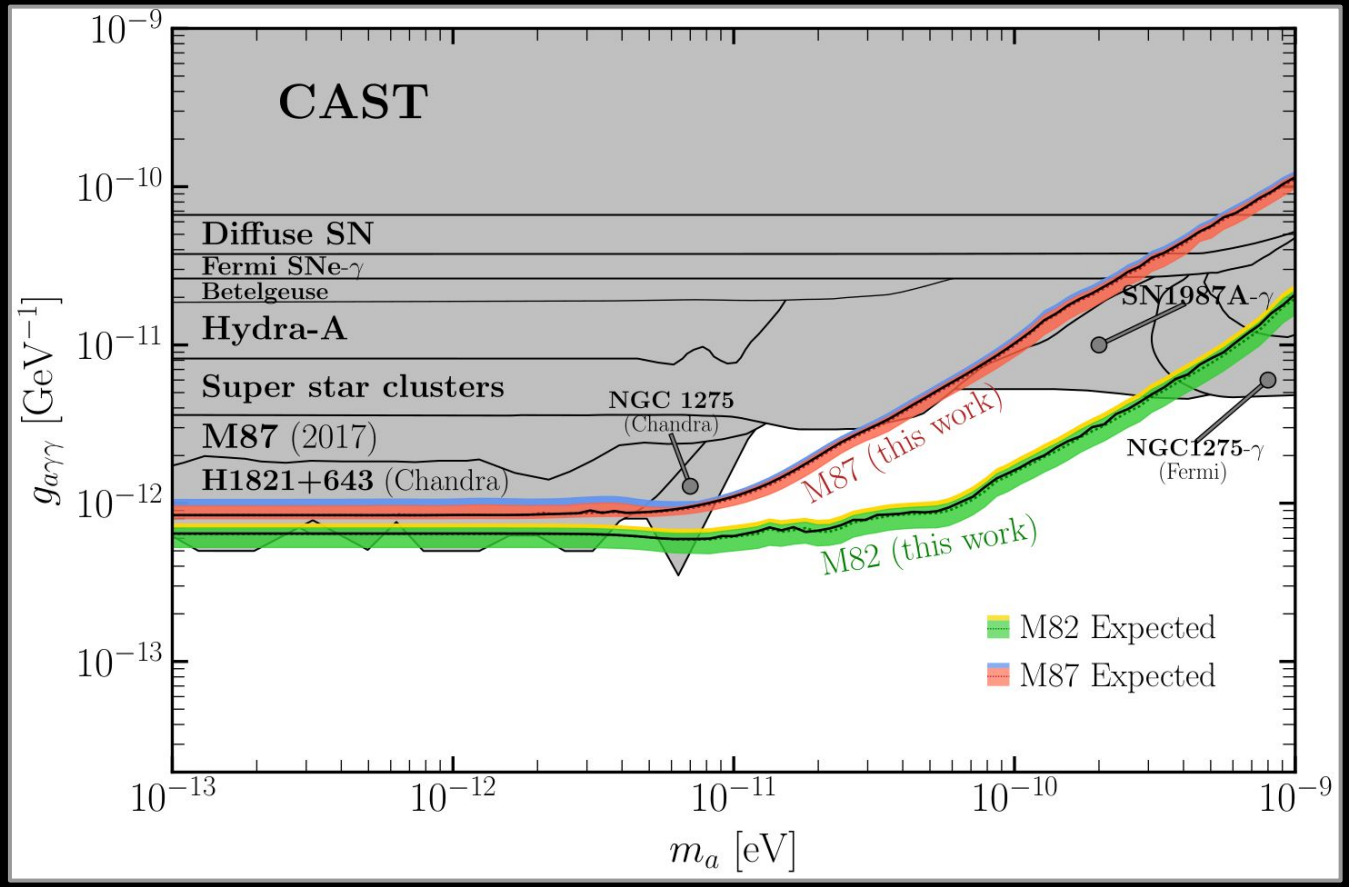


Credit: IllustrisTNG

The variability in galaxy candidates and magnetic fields = largest source of uncertainty in our analysis

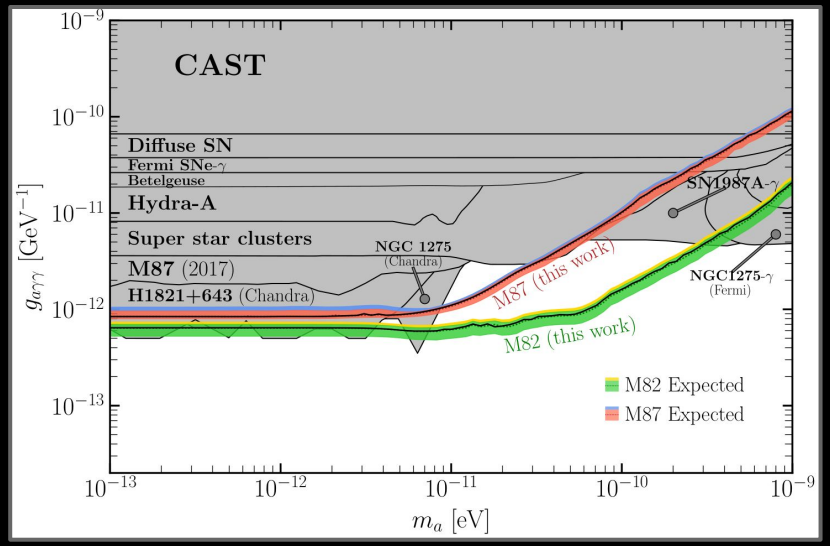
No evidence for axions from NuSTAR = Upper limits on coupling



Previous Limits: C. O'Hare

Conclusion and Outlook

- Leading constraints on the axion-photon coupling from X-ray observations of all stars in M82/M87



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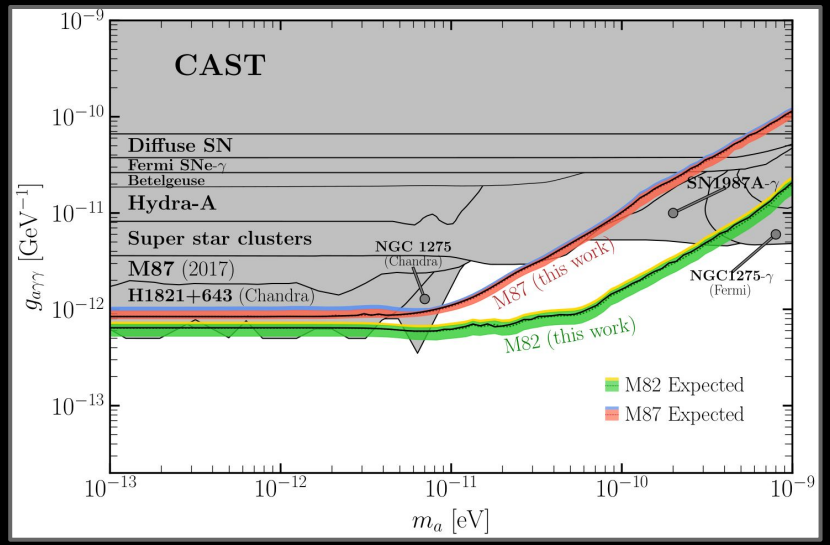

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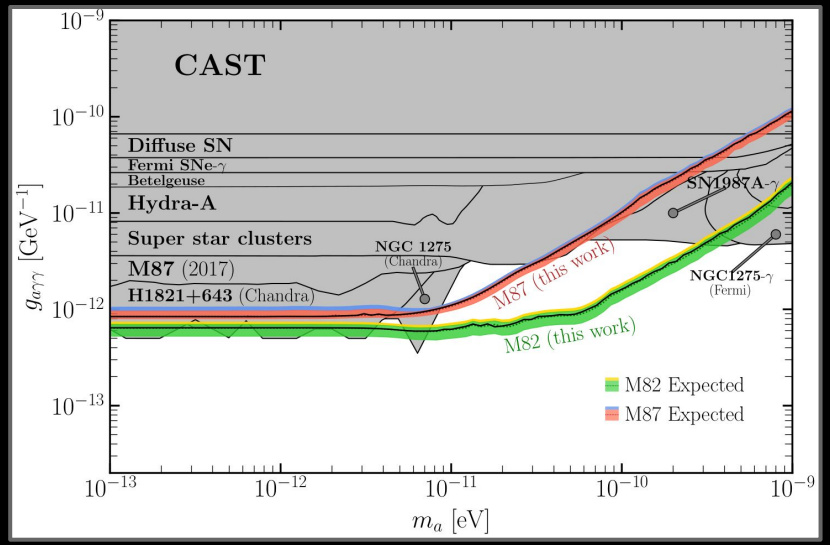
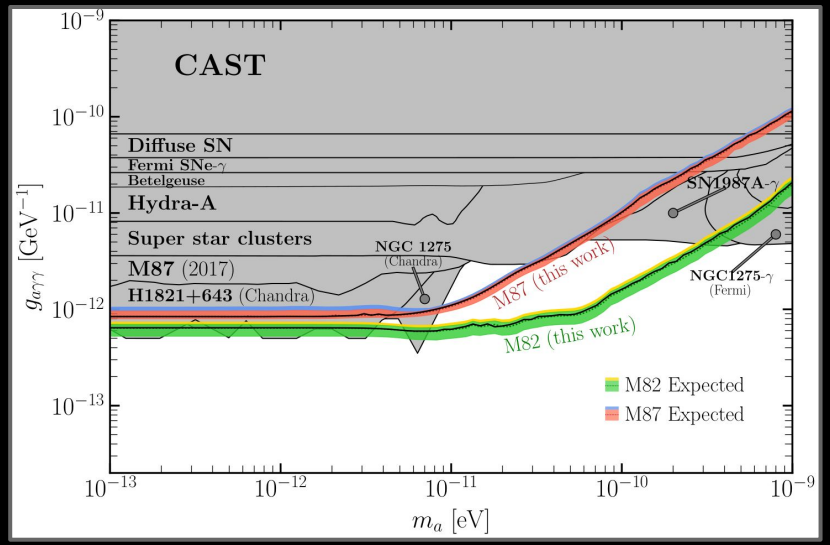
- Magnetic fields dominant source of uncertainty



Conclusion and Outlook

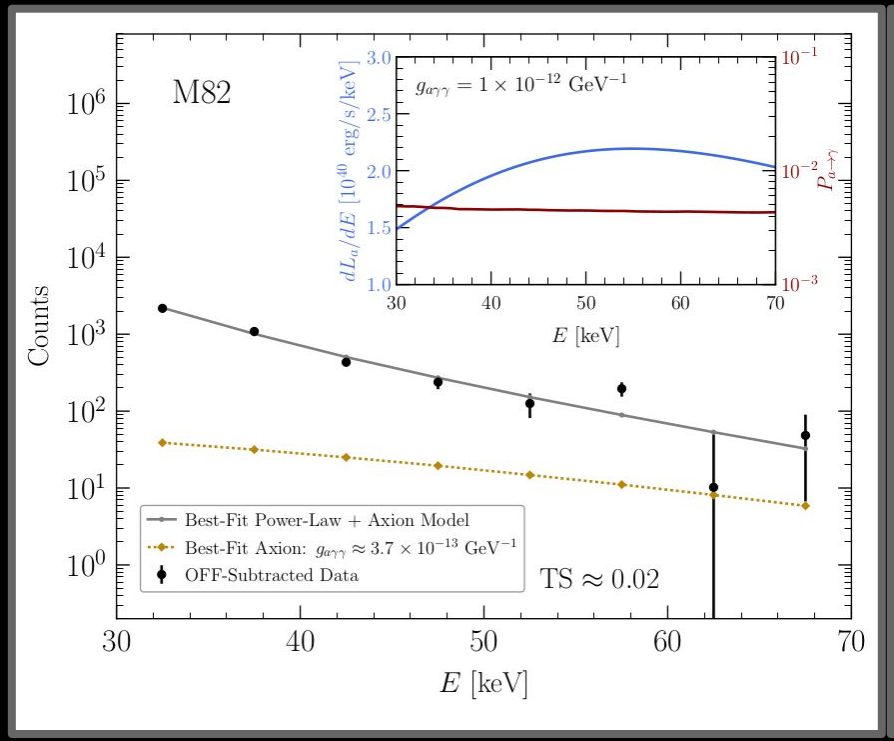
- Leading constraints on the axion-photon coupling from X-ray observations of all stars in M82/M87
- Galaxies as a probe of axion physics
- Magnetic fields dominant source of uncertainty
- Can extend to other galaxies, clusters, and axion-electron and axion-nucleon couplings

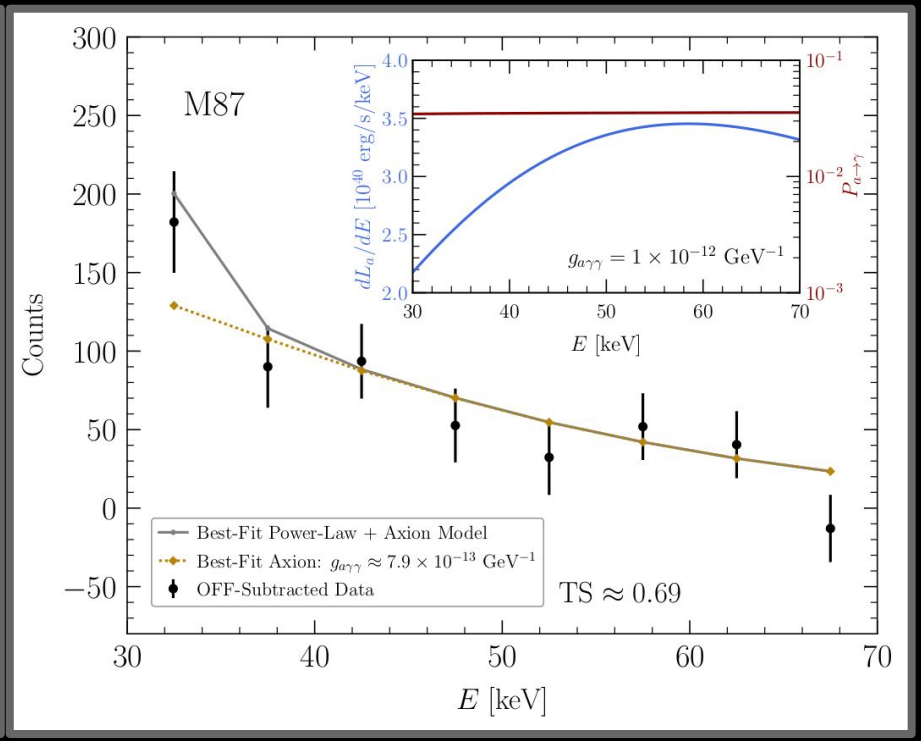


Thanks for listening!

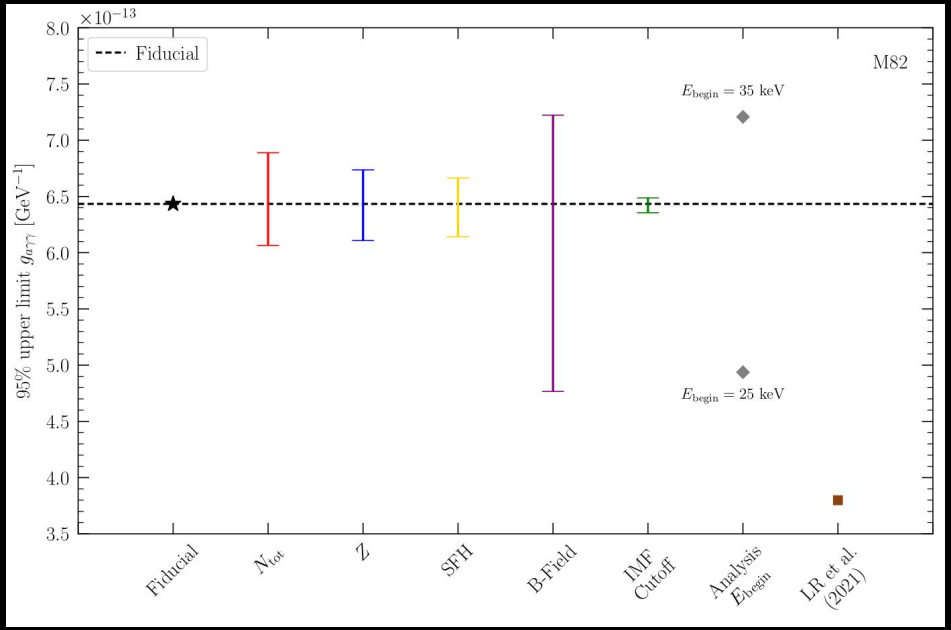
Appendix

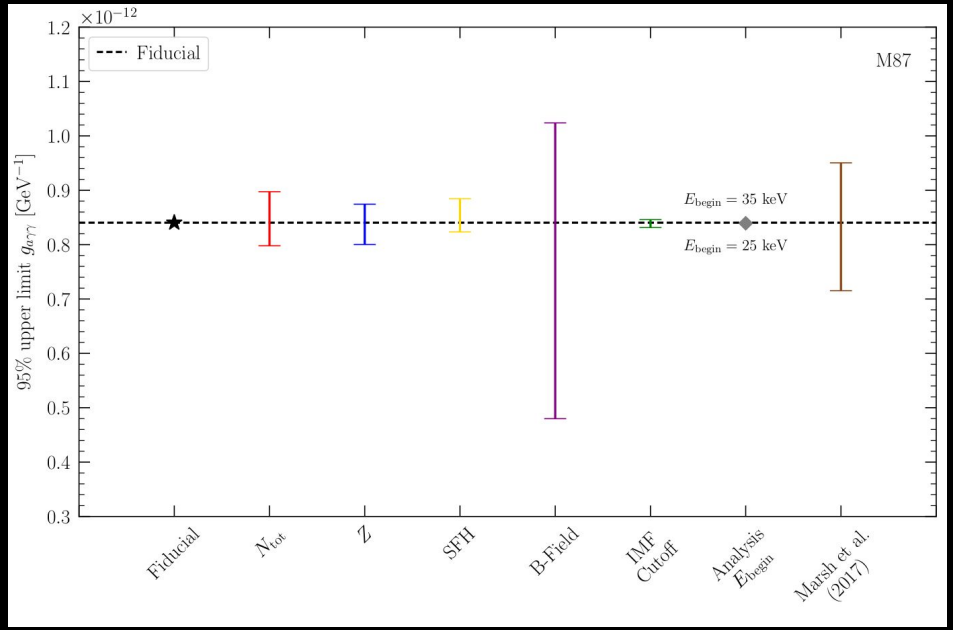
Signal Model + NuSTAR Data Constrains Axion-Photon Coupling



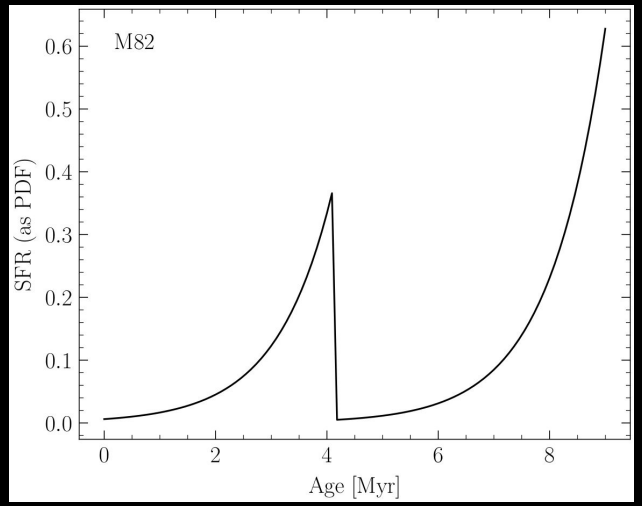


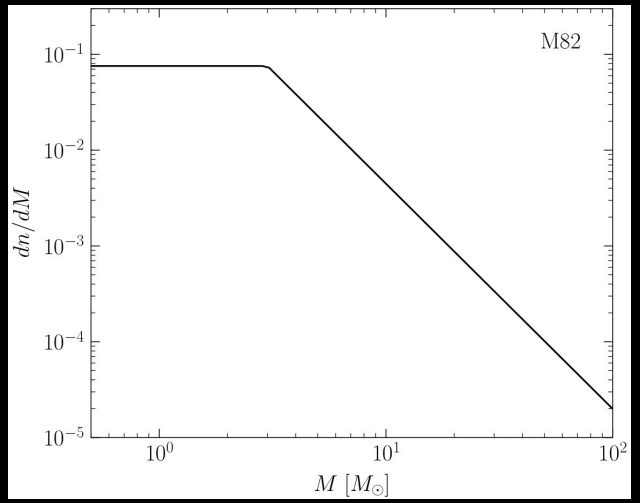
Systematics

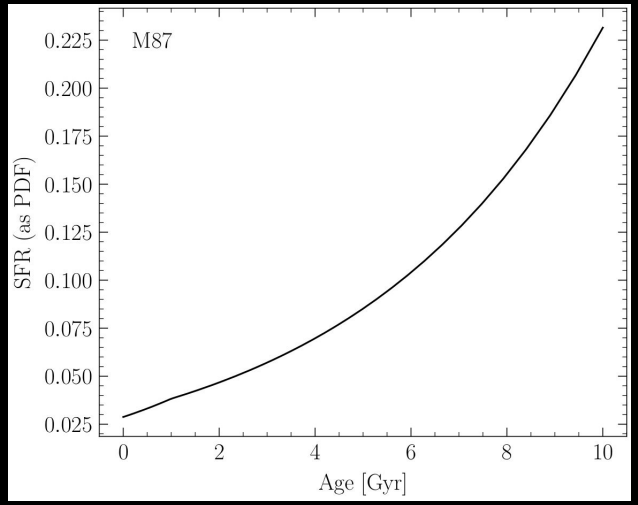


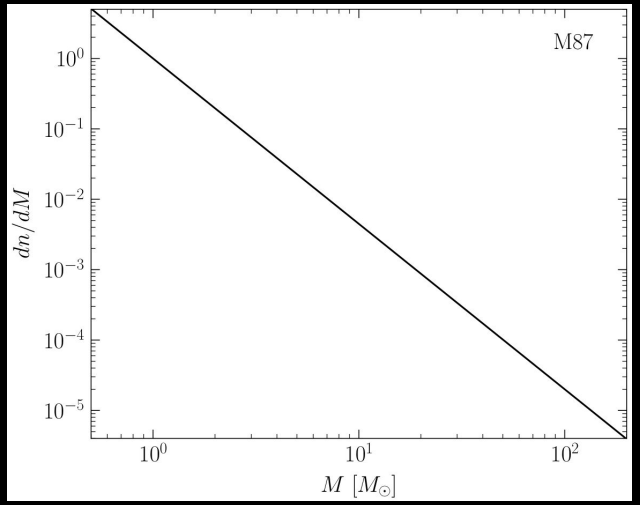


Stellar Population Modeling

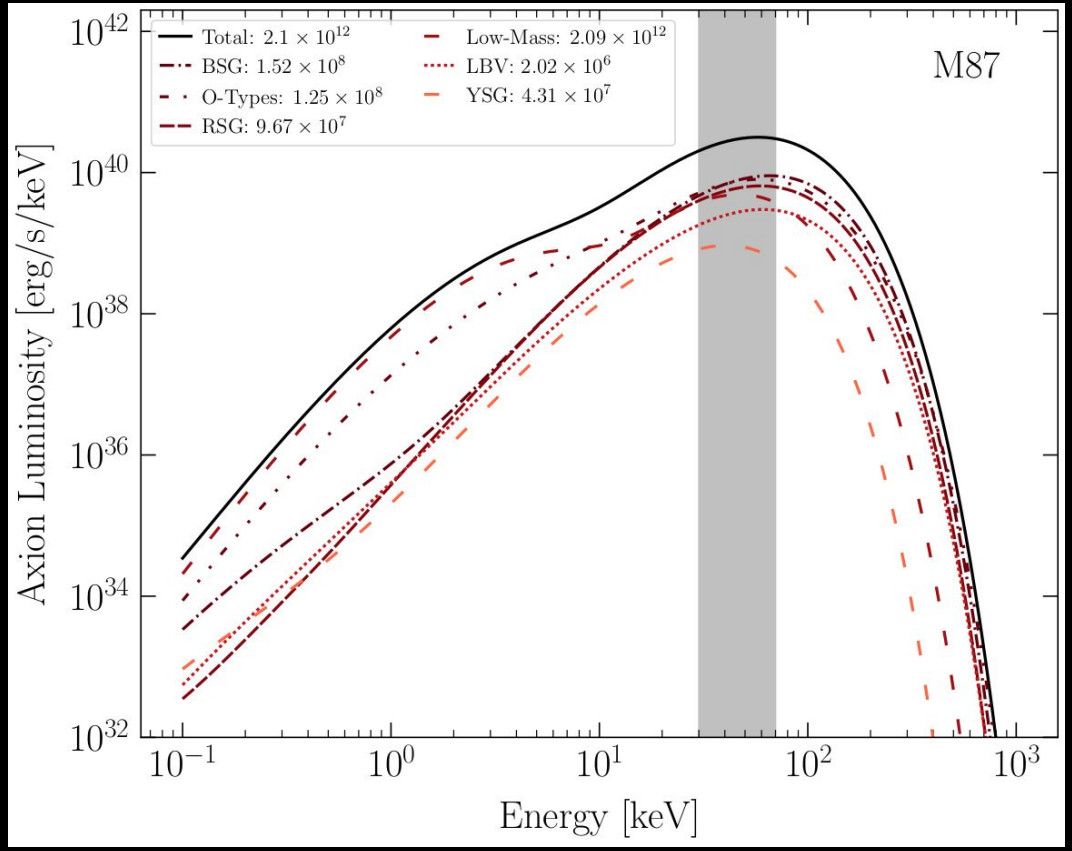




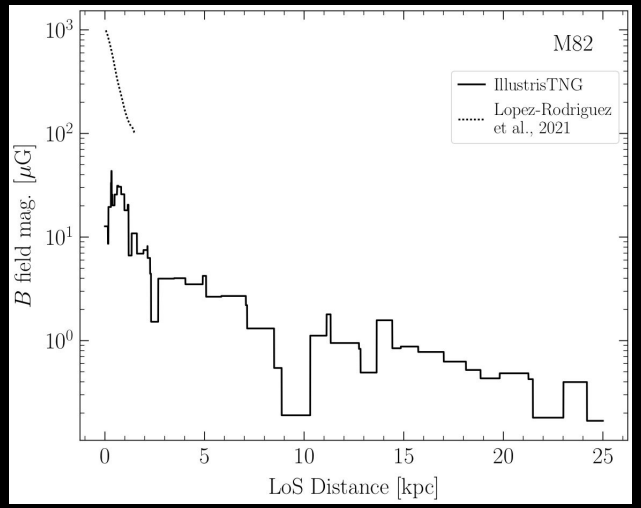


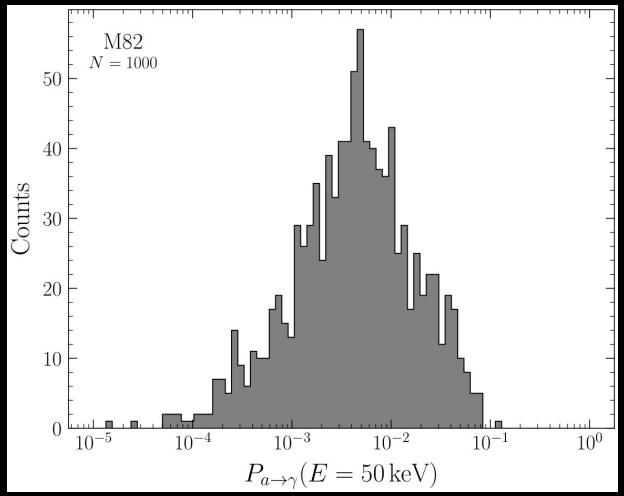


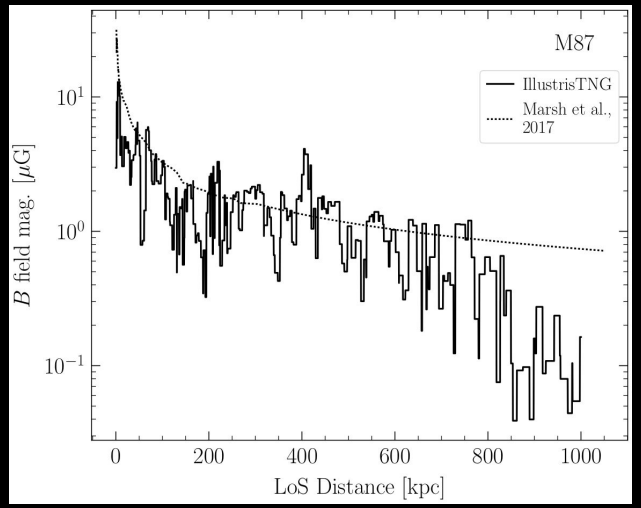
Axion Luminosity for M87

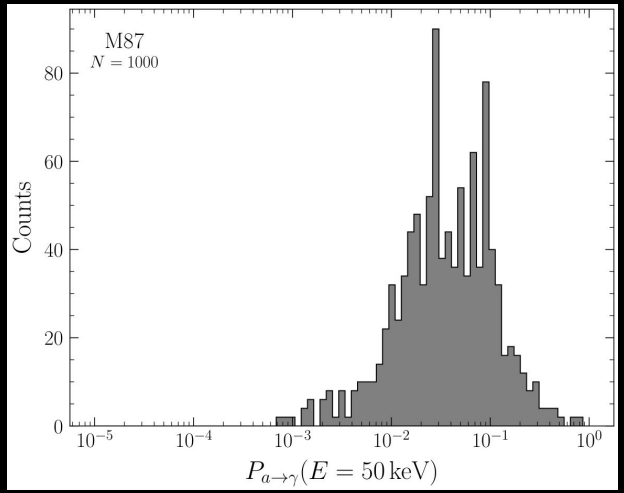
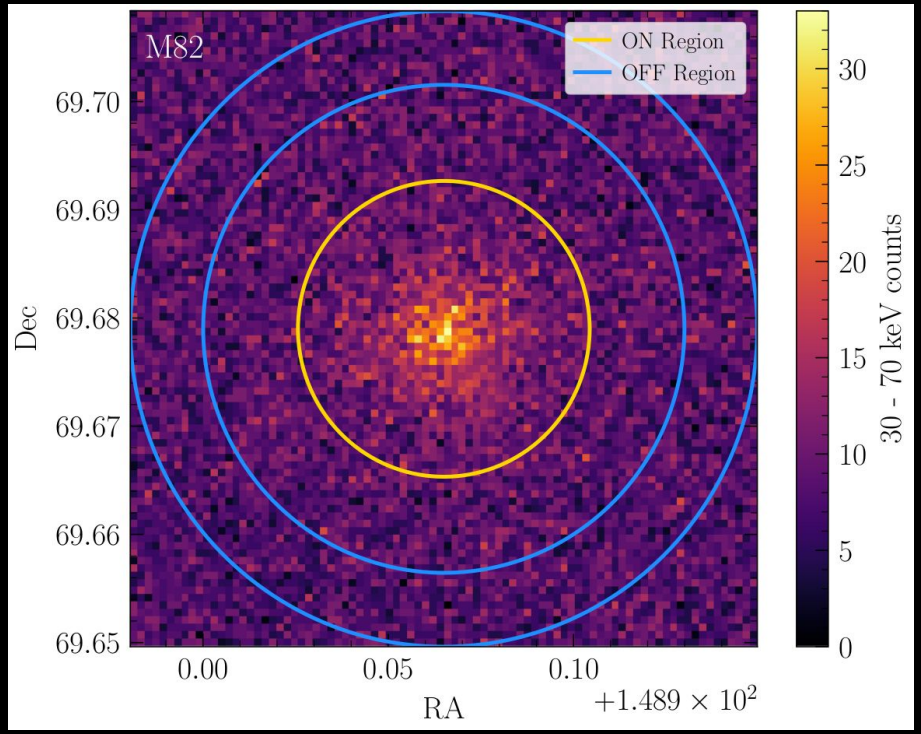
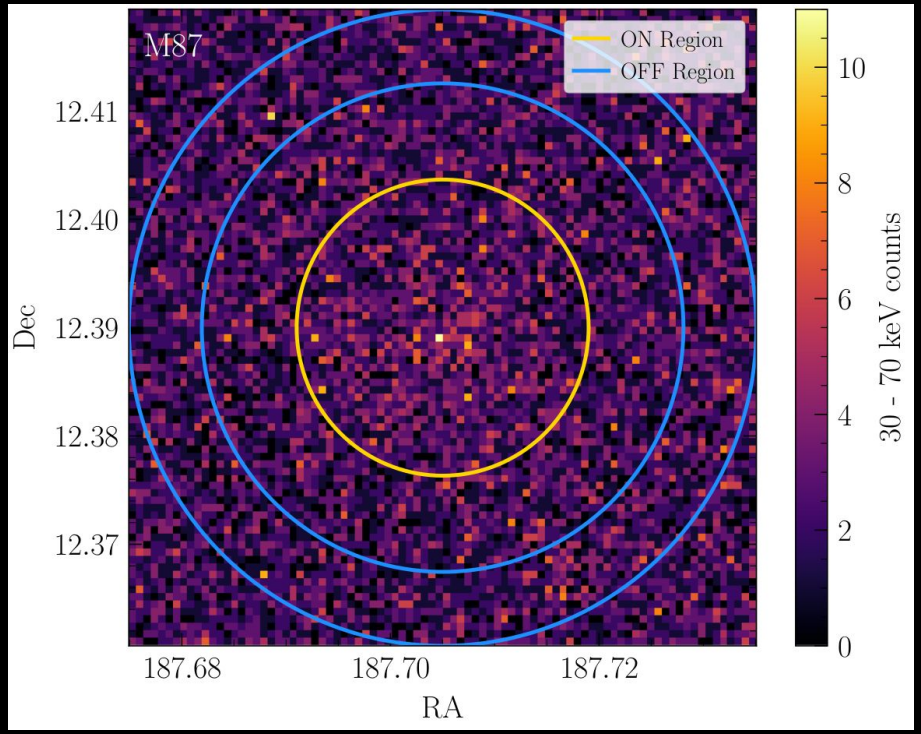


Conversion Probabilities









Spatial Maps