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

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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 $(\mathcal{L} \supset g_{a\gamma\gamma} a \mathbf{E} \cdot \mathbf{B})$
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

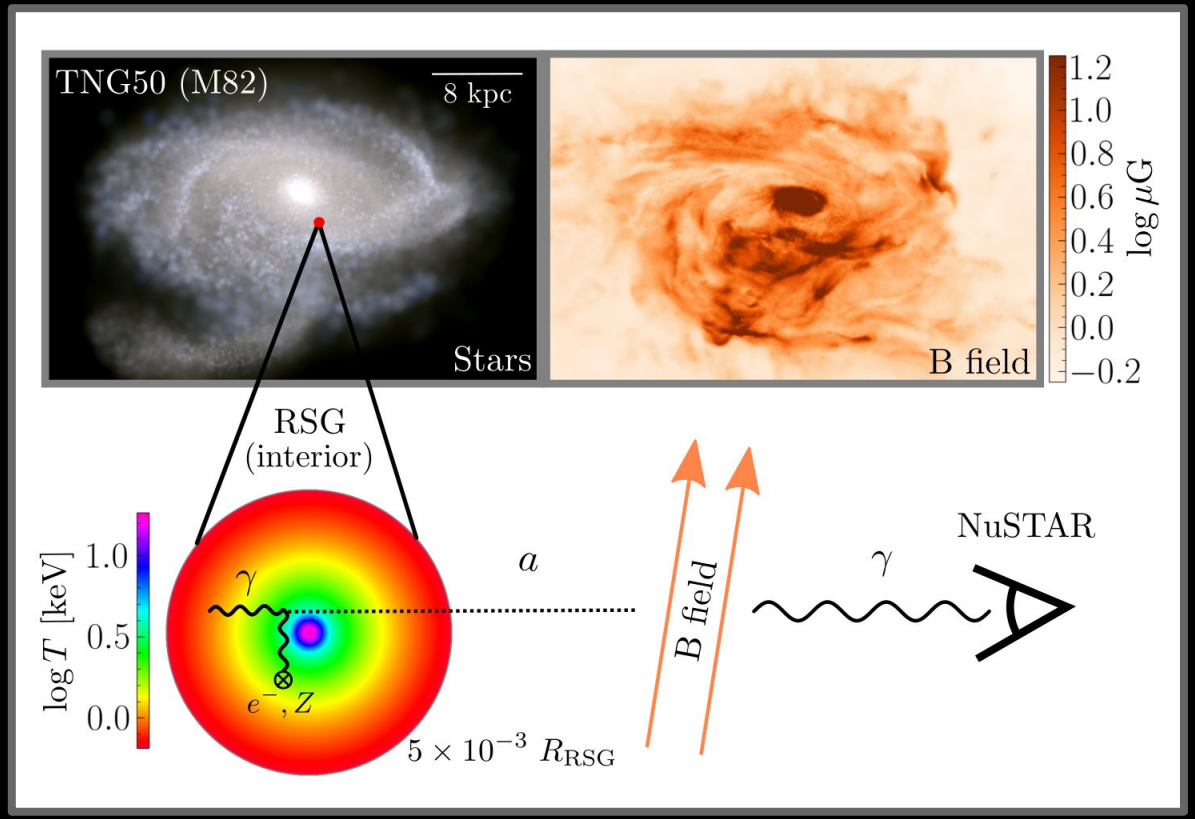
- Starburst Galaxy
- Indications of Strong B-fields

M87

- Massive Elliptical
- Extended Virgo Cluster B-fields

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

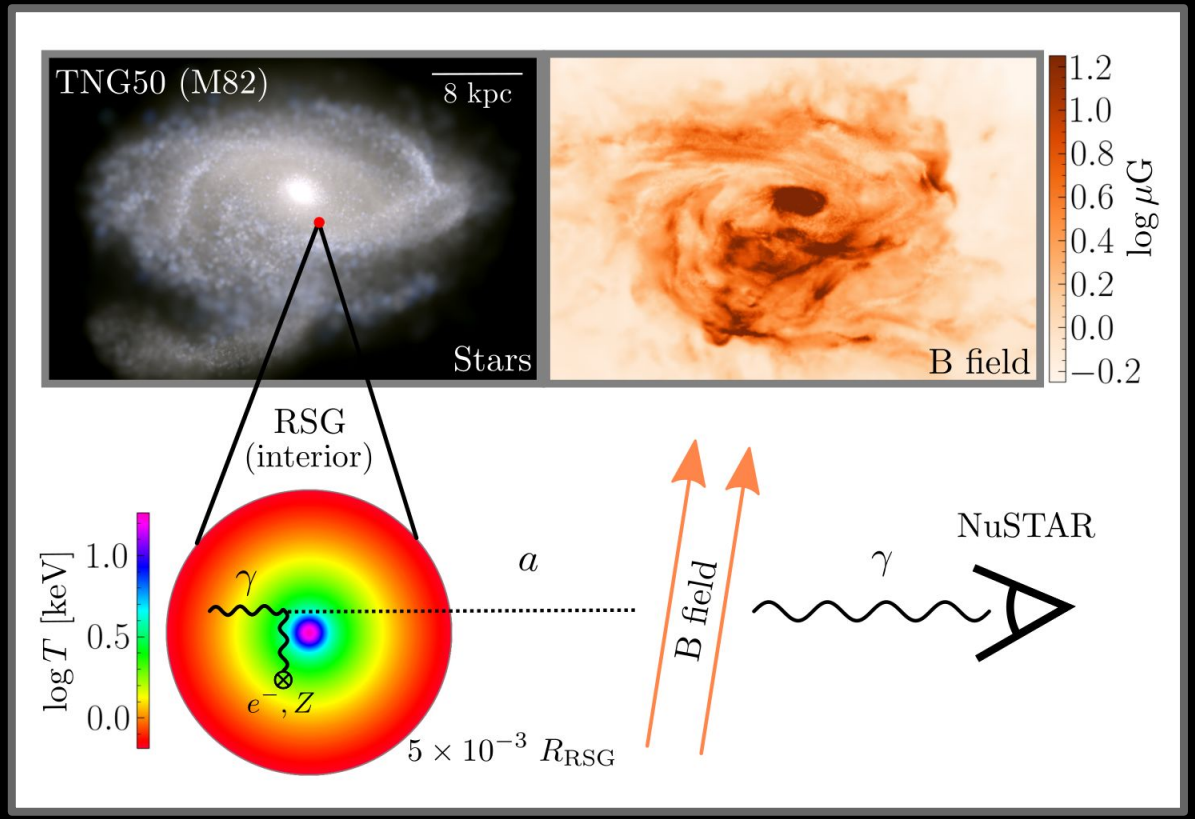
Searching for Axions with NuSTAR:



Searching for Axions with NuSTAR:

Axions produced via Primakoff in stellar interiors

$g_{a\gamma\gamma}$



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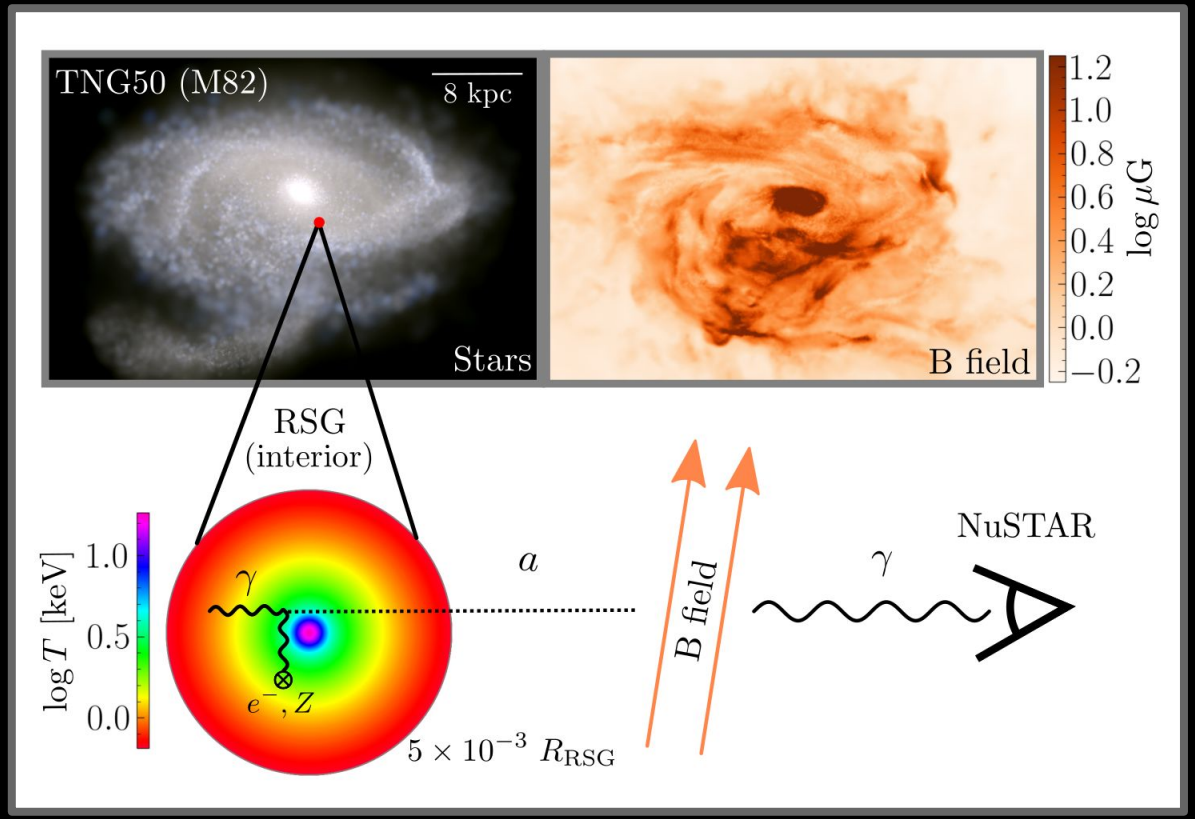

Convert to hard X-rays in galactic/cluster magnetic fields

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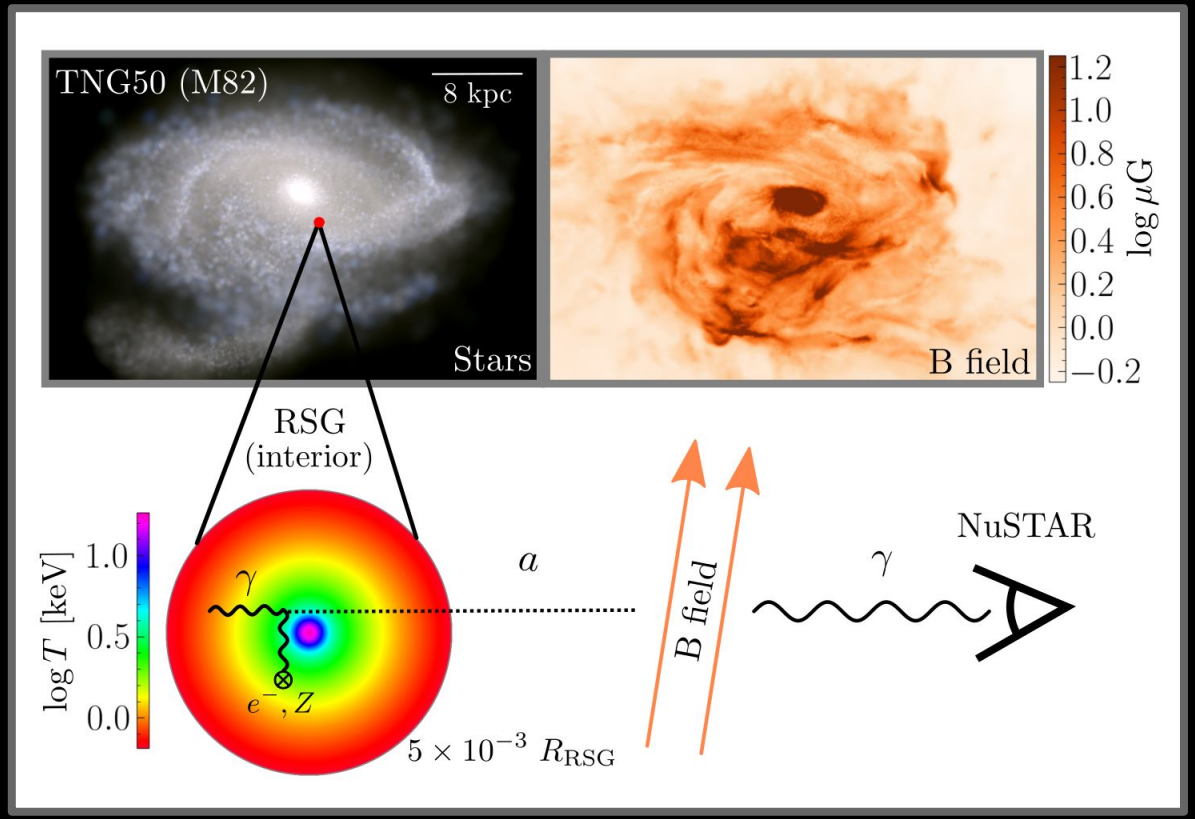


Axions produced via Primakoff in stellar interiors

$g_{a\gamma\gamma}$

Observed by the NuSTAR telescope

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

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

Axion Luminosity from Stellar Populations of M82/M87

Conversion Probability for Axion-Photon Conversion

Signal Model Ingredients

Axion Luminosity from Stellar Populations of M82/M87

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

Conversion Probability for Axion-Photon Conversion

Signal Model Ingredients

Axion Luminosity from Stellar Populations of M82/M87

Primakoff Process

Stellar Profiles (MESA)

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

- Temperature
- Density
- Abundances

Conversion Probability for Axion-Photon Conversion

Signal Model Ingredients

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

Conversion Probability for Axion-Photon Conversion

Signal Model Ingredients

Axion Luminosity from Stellar Populations of M82/M87

Primakoff Process

+

Stellar Profiles (MESA)

+

Stellar Population Models (Obs.)

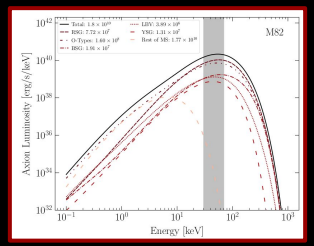
=

Total Axion Luminosity Spectra

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

- Temperature
- Density
- Abundances

- Metallicity
- SFH
- IMF
- # of Stars



Conversion Probability for Axion-Photon Conversion

Signal Model Ingredients

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Stellar Profiles (MESA)

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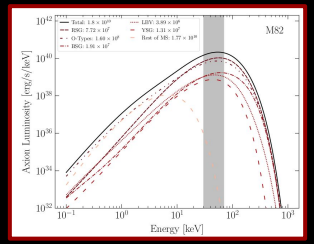
Stellar Population Models (Obs.)

- Metallicity
- SFH
- IMF
- # of Stars

Total Axion Luminosity Spectra



Conversion Probability for Axion-Photon Conversion

Axion Mass m_a

Signal Model Ingredients

Axion Luminosity from Stellar Populations of M82/M87

Primakoff Process

+

Stellar Profiles (MESA)

+

Stellar Population Models (Obs.)

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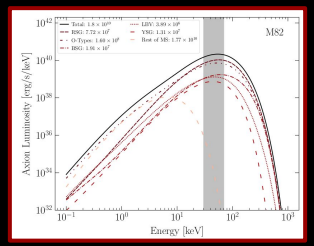

Conversion Probability for Axion-Photon Conversion

Axion Mass m_a

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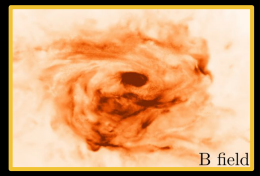
Magnetic Fields



+

Free-electron Densities n_e

=

Conversion Probabilities

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

Signal Model Ingredients

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Primakoff Process

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Stellar Profiles (MESA)

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Stellar Population Models (Obs.)

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Total Axion Luminosity Spectra

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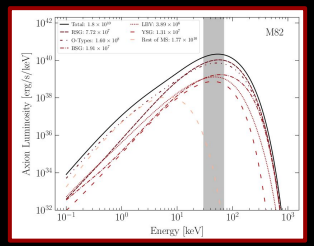

Conversion Probability for Axion-Photon Conversion

Axion Mass m_a

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Magnetic Fields

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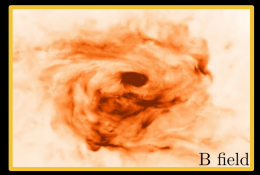

Free-electron Densities n_e

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Conversion Probabilities

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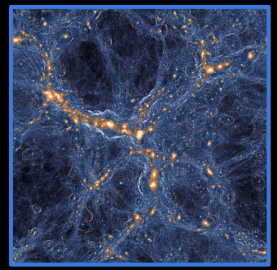
IllustrisTNG TNG50/300 Simulations



Credit: IllustrisTNG

Signal Model Ingredients

Axion Luminosity from Stellar Populations of M82/M87

Primakoff Process

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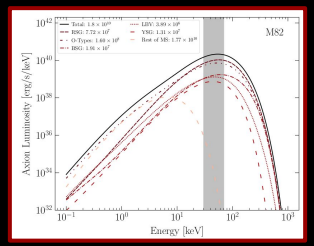

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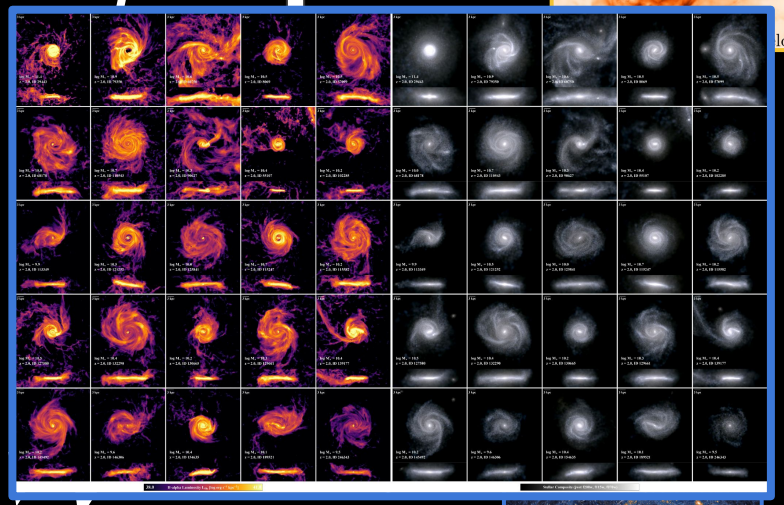
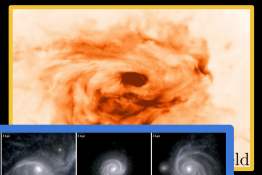
Magnetic Fields

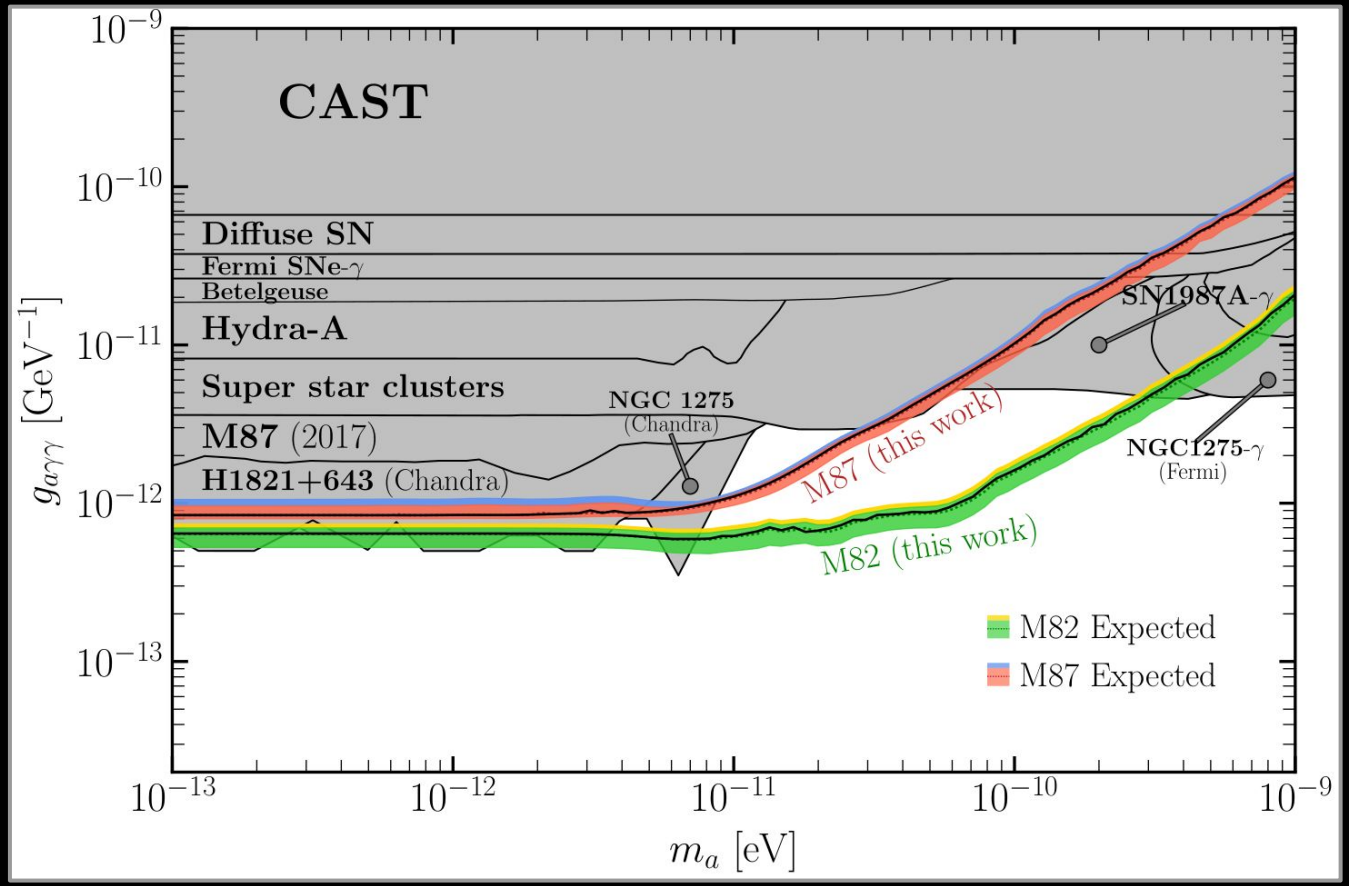




IllustrisTNG TNG50/300 Simulations

Credit: IllustrisTNG

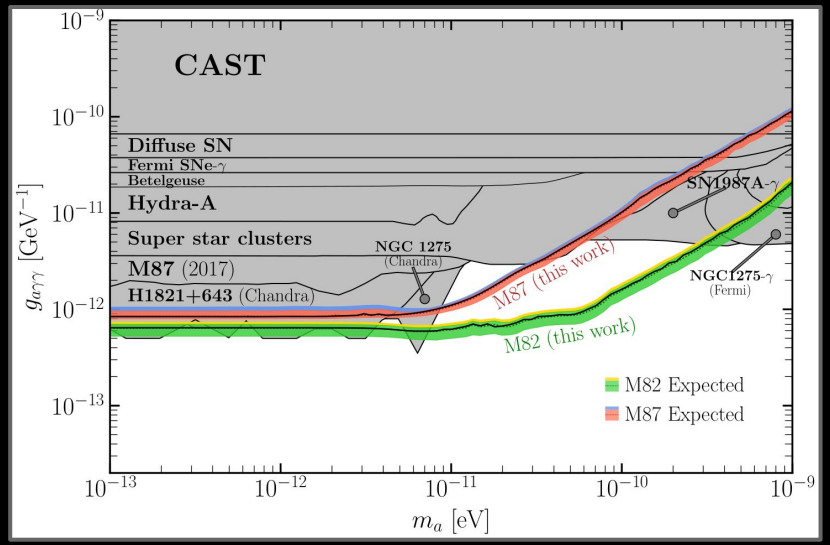
No evidence for axions from NuSTAR = Upper limits on coupling



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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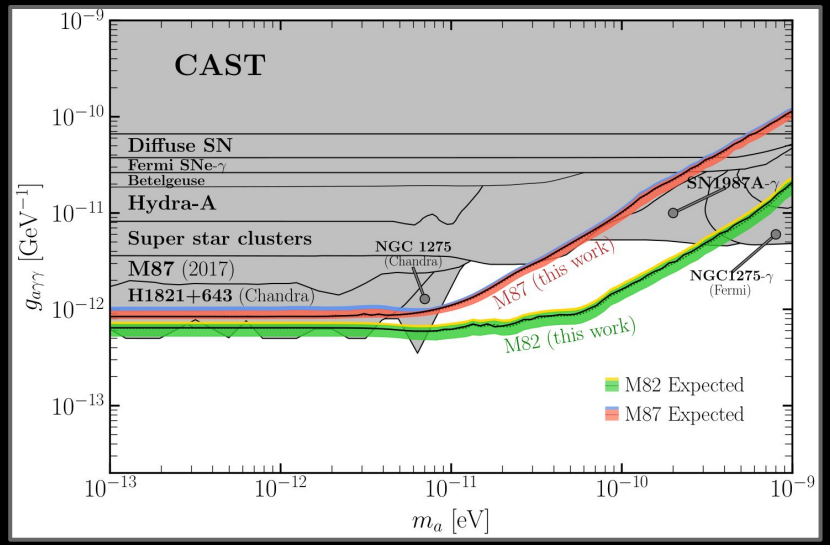
- Galaxies as a probe of axion physics



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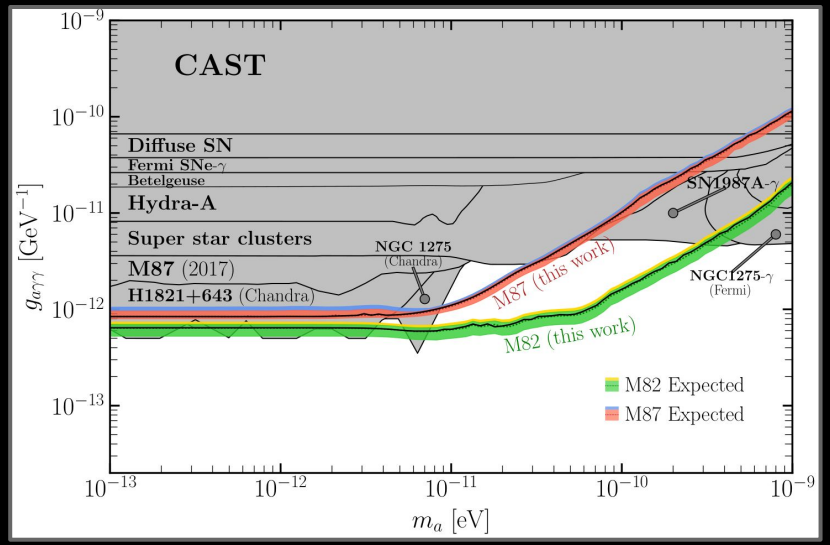
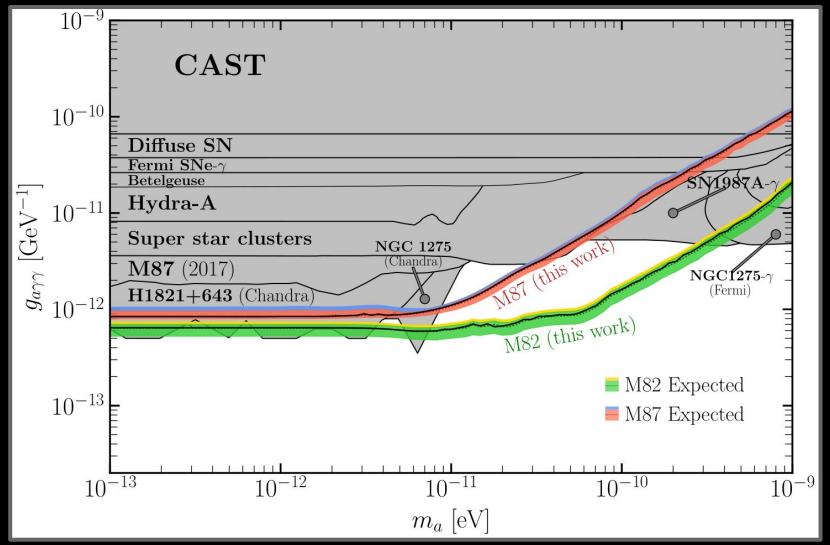
- Magnetic fields dominant source of uncertainty



Conclusion and Outlook

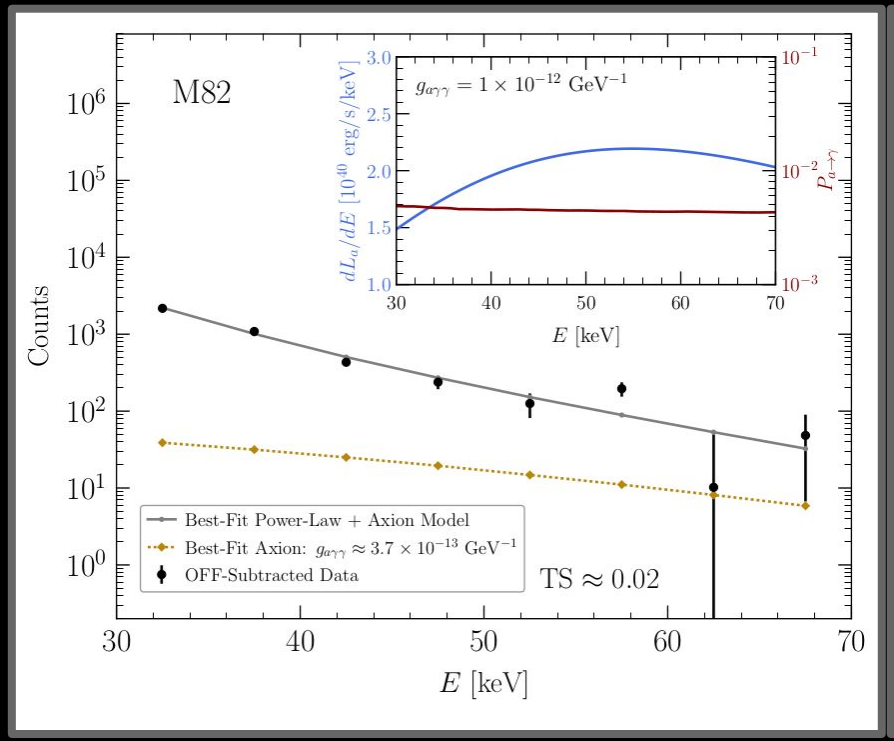
- Leading constraints on the axion-photon coupling from X-ray observations of all stars in M82/M87
- Galaxies as a probe of axion physics
- Magnetic fields dominant source of uncertainty
- Can extend to other galaxies, clusters, and axion-electron and axion-nucleon couplings

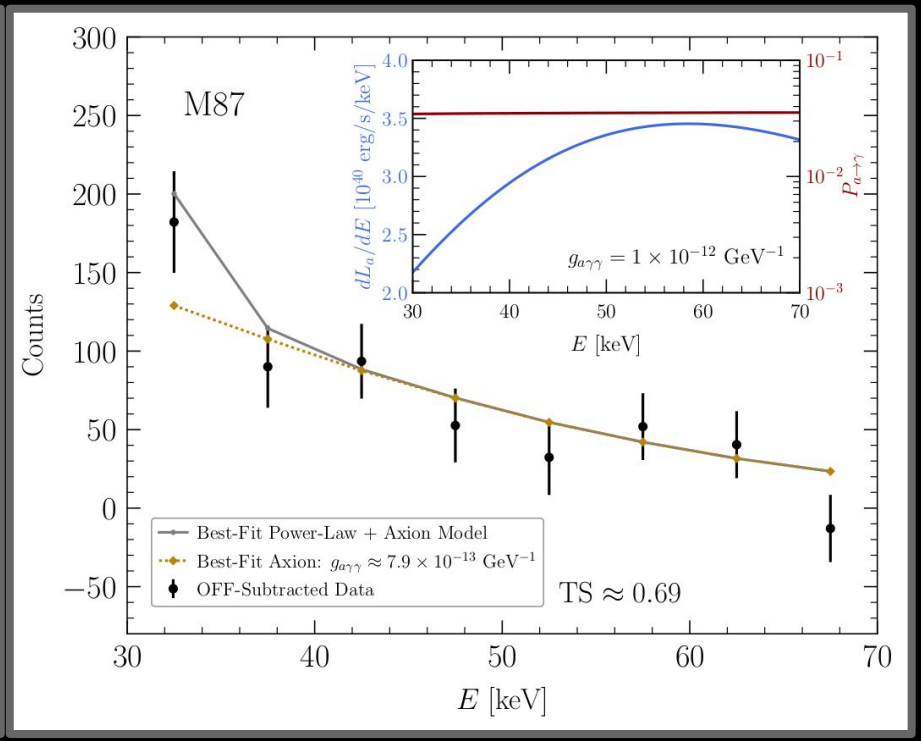


Thanks for listening!

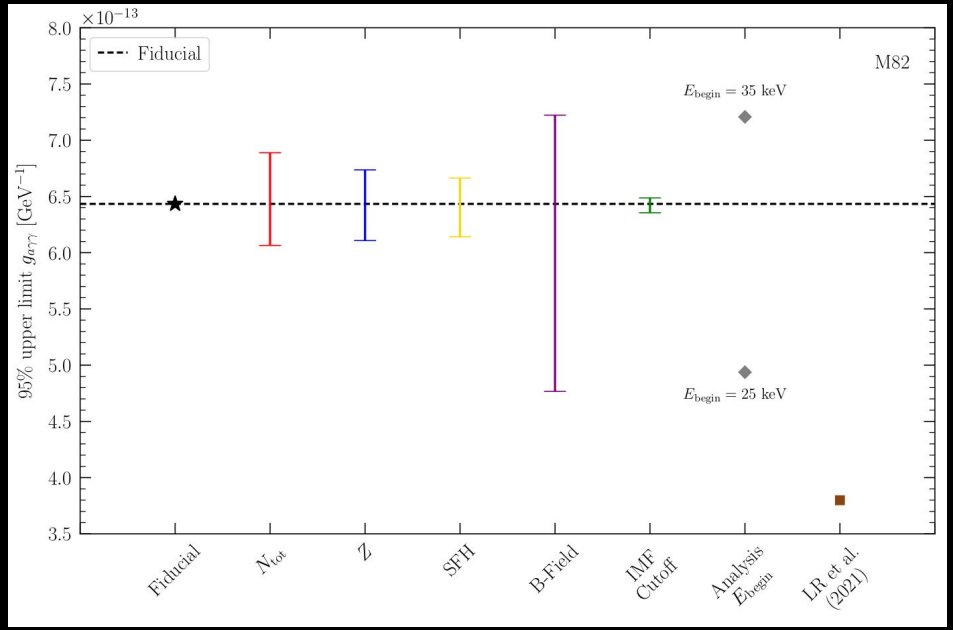
Appendix

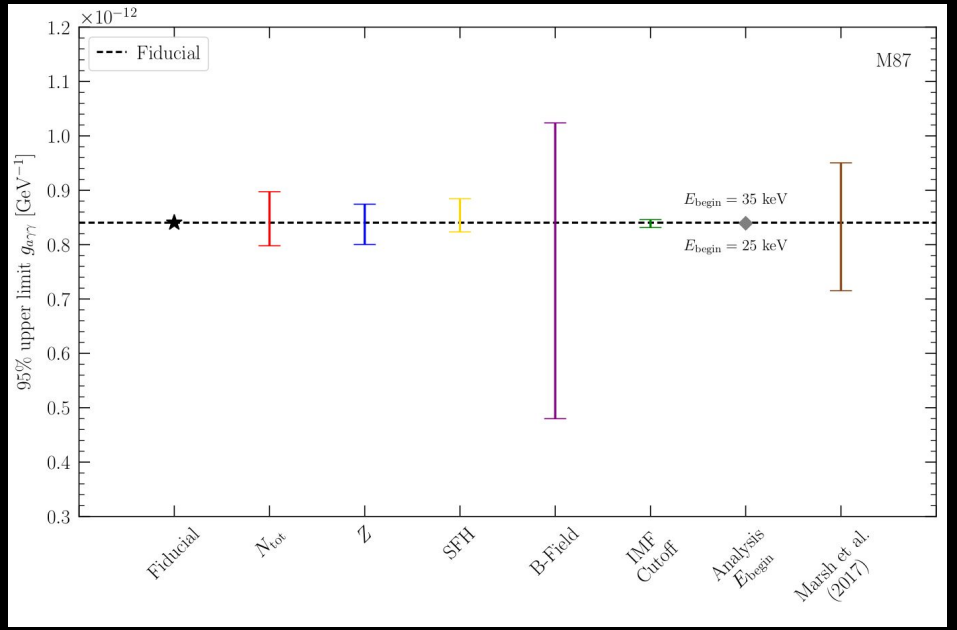
Signal Model + NuSTAR Data Constrains Axion-Photon Coupling





Systematics





Spatial Maps