

# Axion Quark Nuggets: A Recipe for a Glowing Milky Way?

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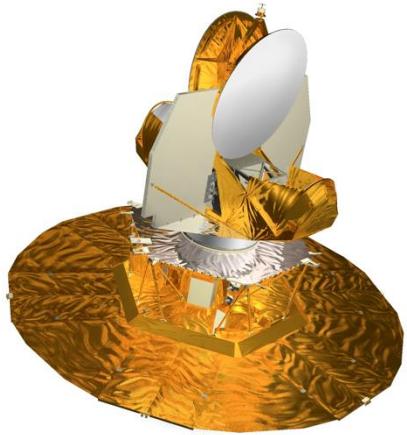
UCB Nuclear Engineering

Feb 27, 2025

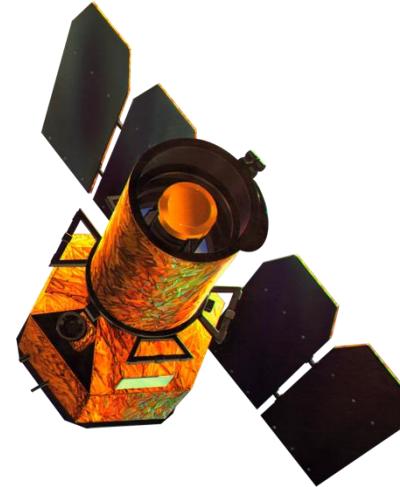


# Mysterious Galactic Glow at Different Frequencies

- WMAP & GALEX made full-sky observations in radio and ultraviolet



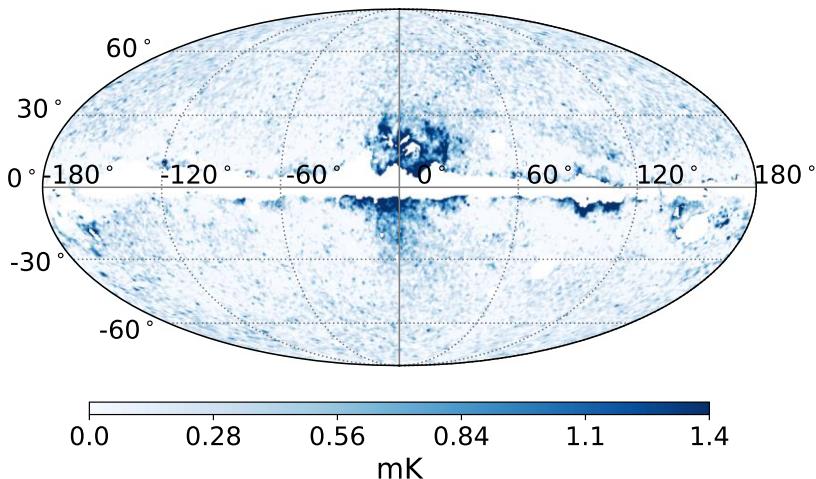
Wilkinson Microwave Anisotropy  
Probe (WMAP) spacecraft  
23-94 GHz



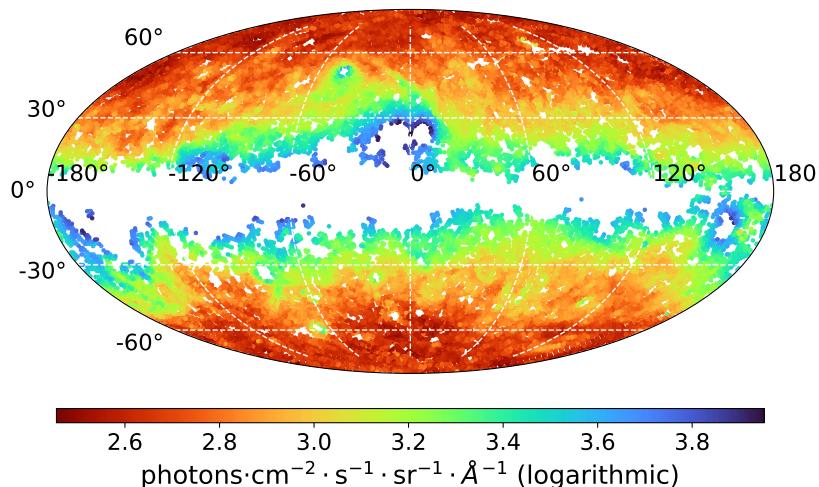
Galaxy Evolution Explorer (GALEX)  
1350-2800 Å

# Mysterious Galactic Glow at Different Frequencies

- Excesses in Galactic radiation were identified, the source(s) of which remain unexplained



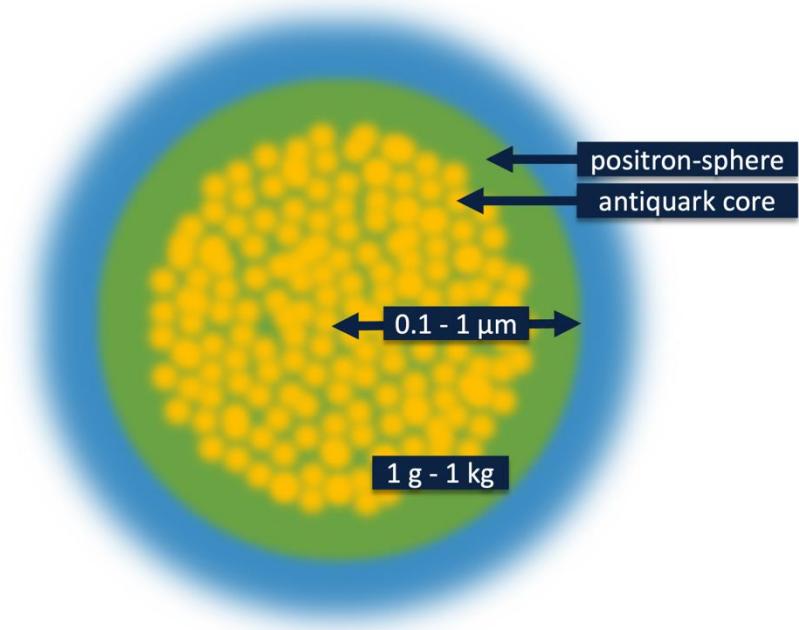
WMAP "haze" K-band (33 GHz)



GALEX FUV diffuse background (1350-1750 Å)

# Dark Matter – Axion Quark Nuggets (AQNs)

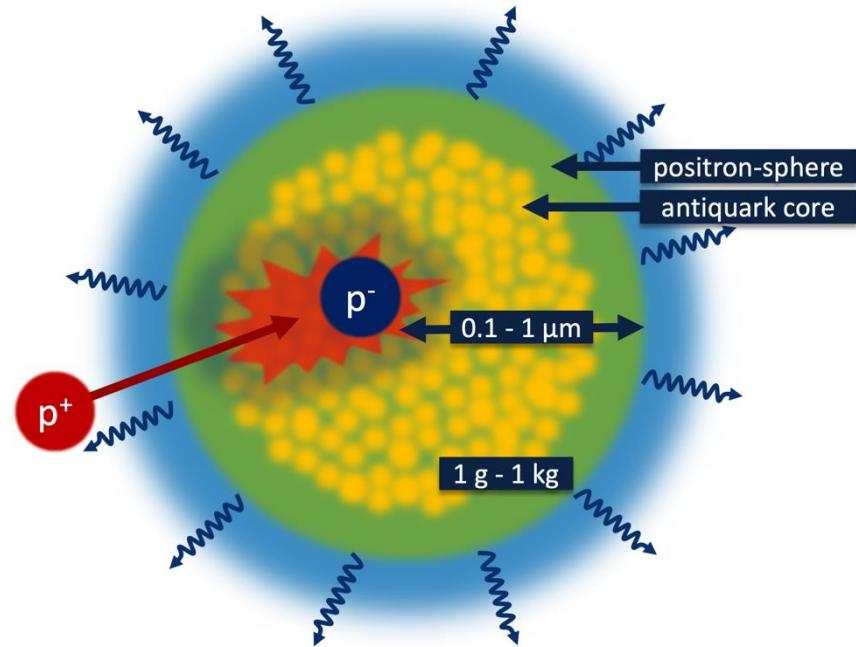
- Proposed dark matter candidate
- Large composite object of nuclear density
- Exists in **matter** and **antimatter** variants
- Direct observation **highly improbable** due to large mass and low number density
- Formed from ordinary quarks during QCD phase transition – collapse of axion domain wall



Antinugget model

# Axion Quark Nuggets (AQNs) – Annihilation with Regular Matter

- Baryons in our Galaxy can **collide** with antimatter AQNs and **annihilate with antiquarks**: produces  $\sim 2$  GeV of energy
- Part of the energy heats up the positron-sphere, causing it to **radiate** in a broadband radiation spectrum
- Radiation may explain observed mysterious excesses

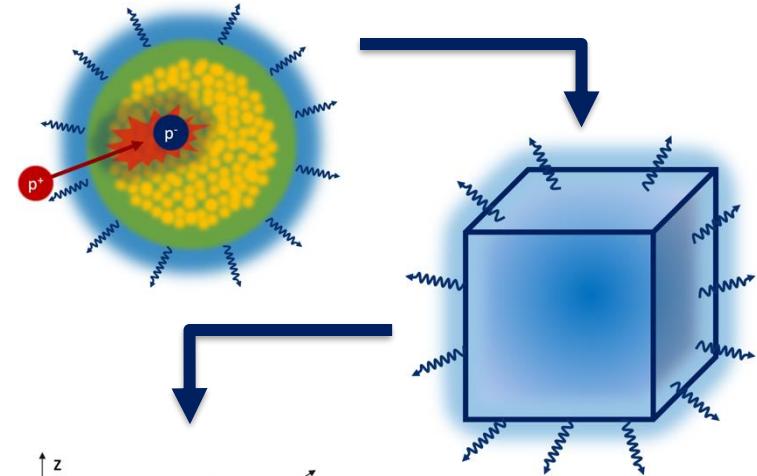


Proton Annihilation with Antinugget

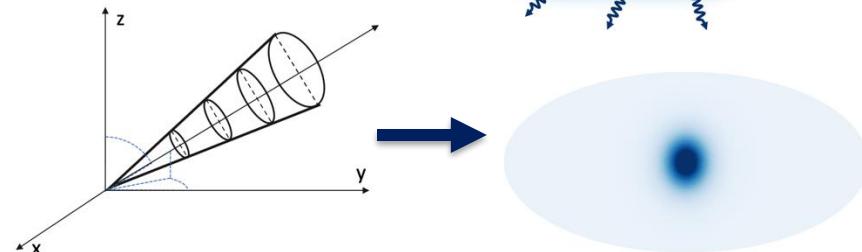
# Axion Quark Nugget Annihilation Simulation

**Goal:** Simulate expected signal from AQN annihilations. **Compare** with observed excesses.

1. AQN's **spectral surface emissivity** from an annihilation is described analytically.



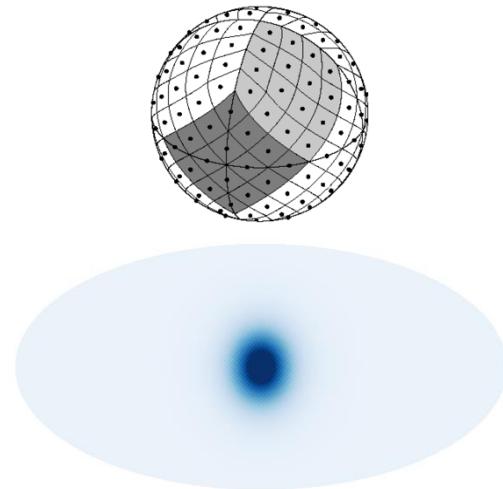
2. Local **spectral spatial emissivity** from AQNs in a volume element can be calculated.



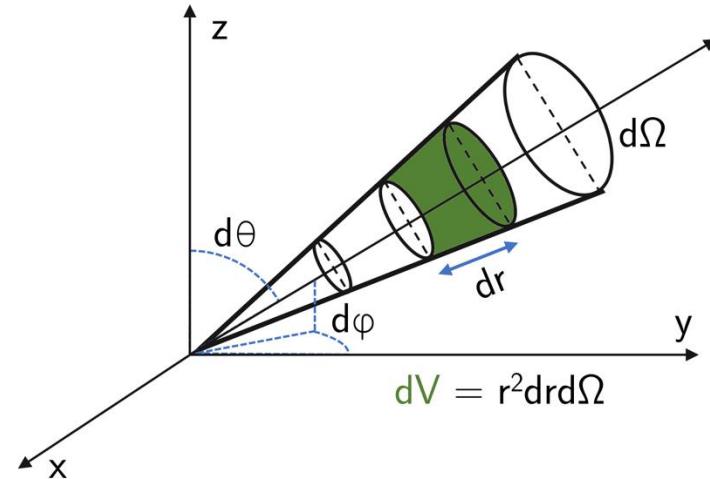
3. The volume elements are integrated along sightlines making up a full-sky image.

# Axion Quark Nugget Annihilation Simulation

**Goal:** Simulate expected signal from AQN annihilations. **Compare** with observed excesses.



For each pixel in the sky...

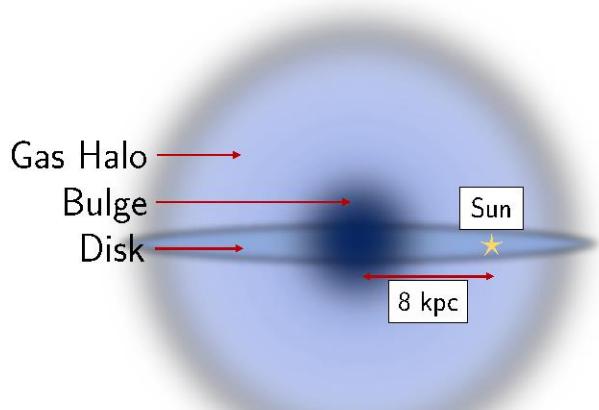


add up contributions to the signal along sightline

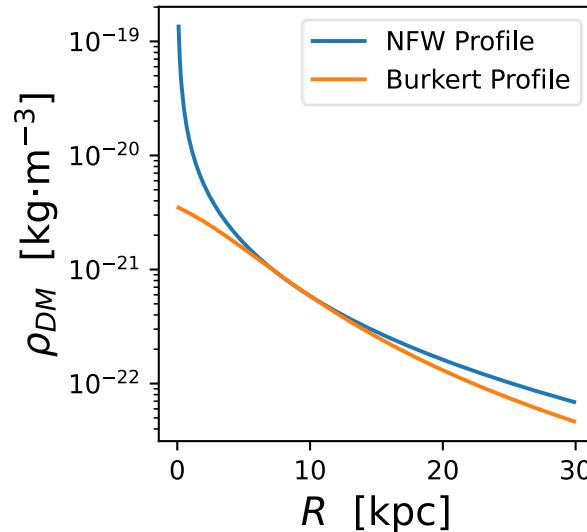
Requires detailed models of **gas** and **dark matter distributions** in our Milky Way.

# AQN Annihilation Simulation – Models

- Can't use observational data directly – not all density is accounted for, especially ionized gas
- Started with analytical models, but these were insufficient, especially in UV



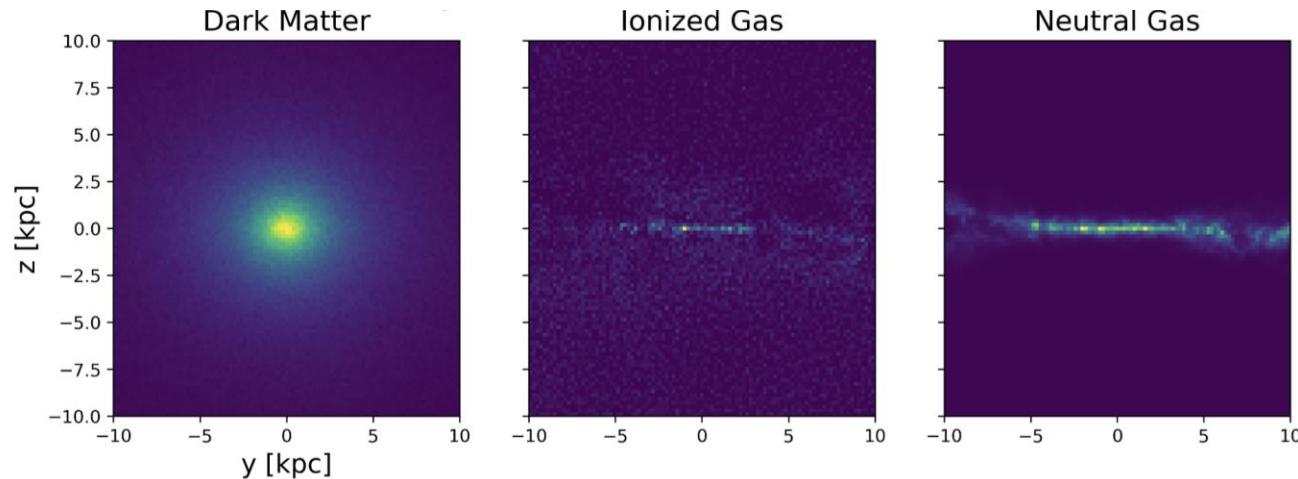
Disk-Bulge-Halo model of visible matter



Two analytical dark matter density models

# Galaxy Simulations – Feedback In Realistic Environments (FIRE)

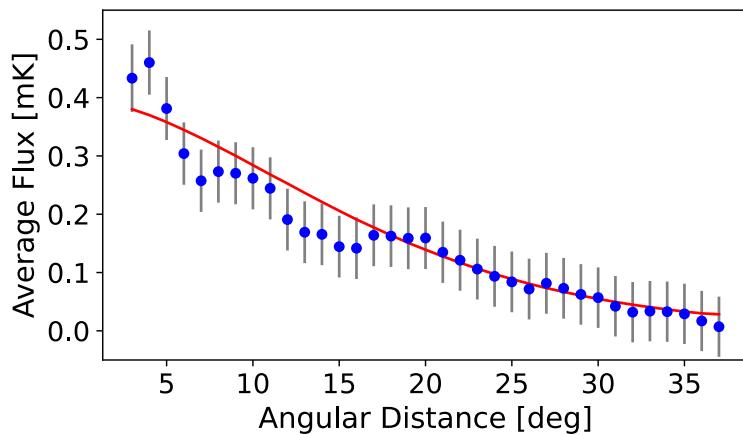
- Milky Way-like galaxy simulation used instead:
- FIRE's Latte suite: cosmological hydrodynamic simulations of Milky Way-like galaxies
- Particle data converted into density fields using Voronoi tessellation



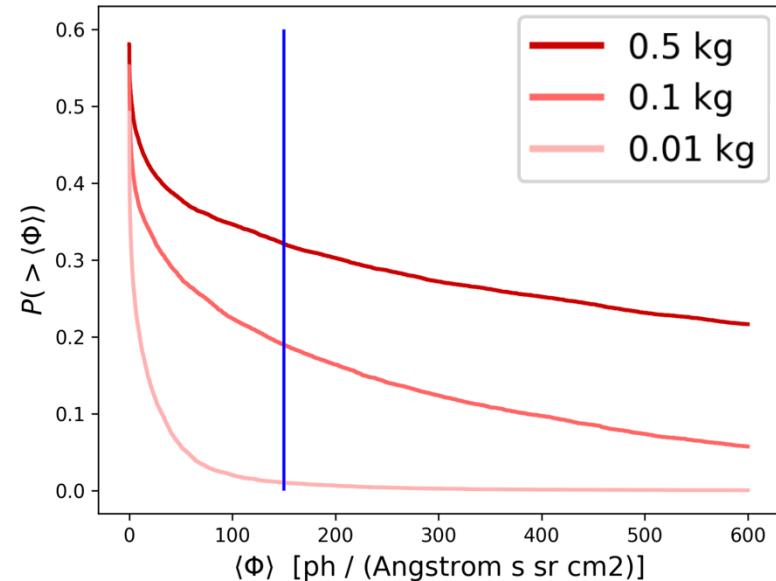
Densities calculated from FIRE's m12i galaxy simulation

# AQN Annihilation Simulation – First Results

- Initial results show a **potential match in signal amplitude and distribution** in radio, and **in signal amplitude** in UV



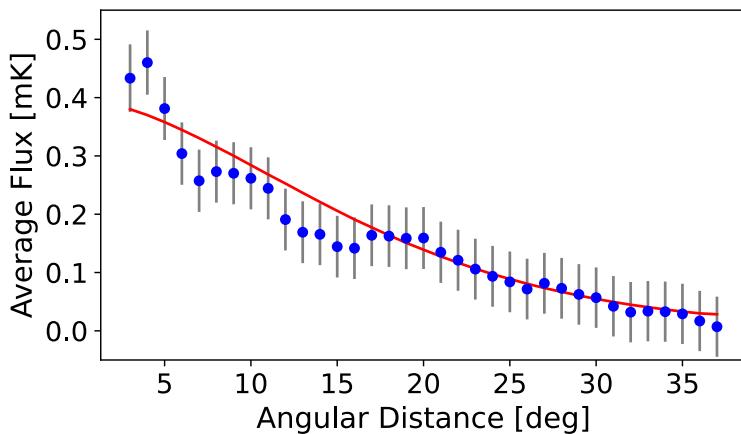
Radio AQN annihilation flux and WMAP haze flux. Results of MCMC analysis.



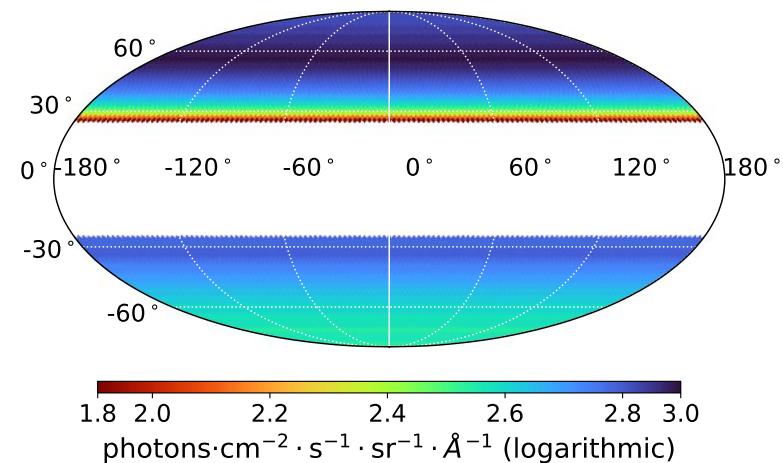
FUV AQN annihilation for different masses using flux using FIRE m12i simulation.

# AQN Annihilation Simulation – First Results

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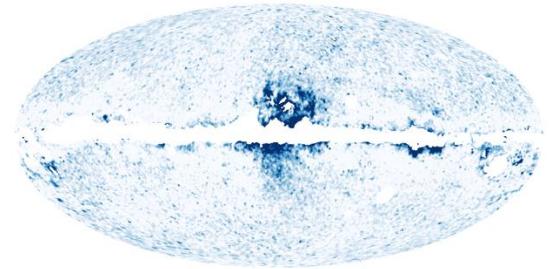
Radio AQN annihilation flux and WMAP haze flux. Results of MCMC analysis.



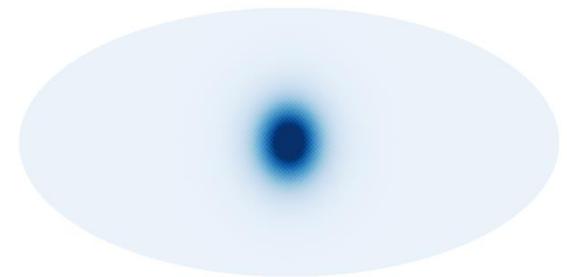
FUV AQN annihilation flux using radially averaged data from FIRE m12i simulation.

# Axion Quark Nuggets and Galactic Glow – Conclusion

- Mysterious excess radiation observed in our Milky Way across multiple frequency bands
- Excess could be explained by **(anti) Axion Quark Nugget dark matter annihilations**
- **Compare** simulated annihilation signal with mysterious excesses
- Initial simulations show a **match in signal amplitude and distribution**
- **The AQN model may have the unique ability to explain multiple observed Galactic excesses within the same dark matter framework**



WMAP Galactic Excess



Sample Simulated Result

# Axion Quark Nuggets and Galactic Glow – Conclusion

- **The AQN model may have the unique ability to explain multiple observed Galactic excesses within the same dark matter framework**
- This AQN annihilation interaction can be investigated at different scales – papers published for Galaxy clusters and Large Scale Structures

F. Majidi, X. Liang, L. Van Waerbeke, A. Zhitnitsky, M. Sekatchev, J. Sommer, K. Dolag, T. Castro. **The Glow of Axion Quark Nugget Dark Matter: (I) Large Scale Structures.** JCAP, August 2024.

<https://arxiv.org/abs/2406.12122>

J. Sommer, K. Dolag, L. Böss, I. Khabibullin, X. Liang, L. Van Waerbeke, A. Zhitnitsky, F. Majidi, J. Sorce, B. Seidel, E. Hernández-Martínez. **The Glow of Axion Quark Nugget Dark Matter: (II) Galaxy Clusters.** A&A September 2024.

<https://arxiv.org/abs/2406.17946>

M. Sekatchev, X. Liang, L. Van Waerbeke, A. Zhitnitsky. **The Glow of Axion Quark Nugget Dark Matter: (III) The Milky Way UV Background.** A&A September 2024. <https://arxiv.org/abs/2406.17946>

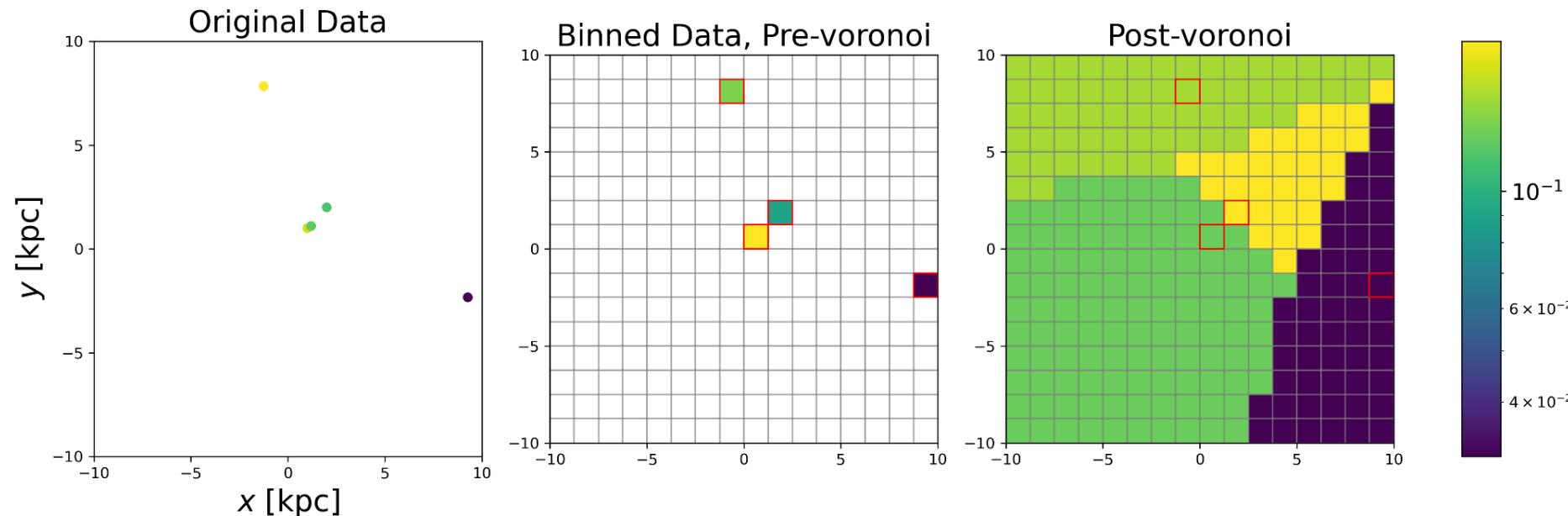


# Thank You



# Voronoi Tessellation Technique

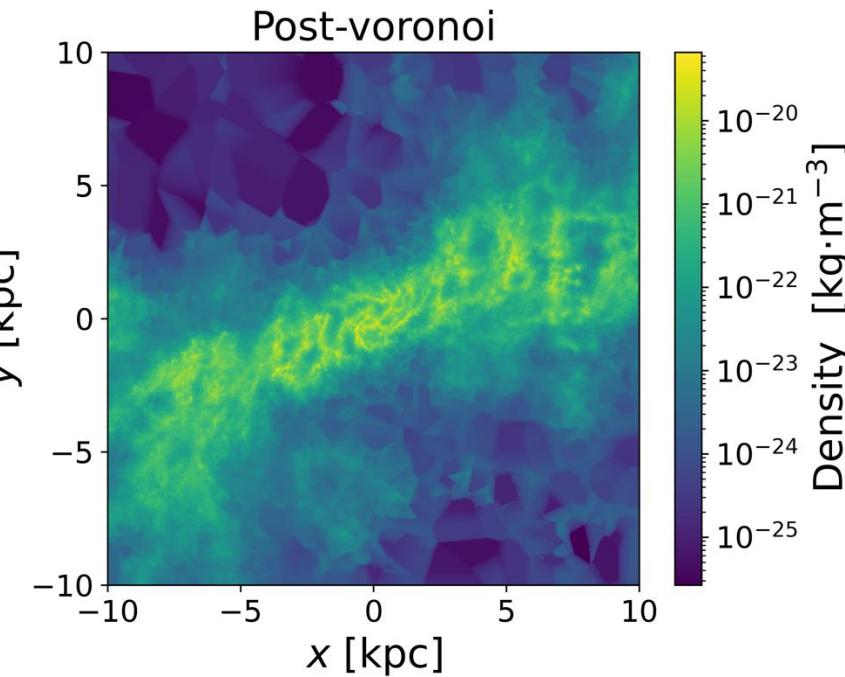
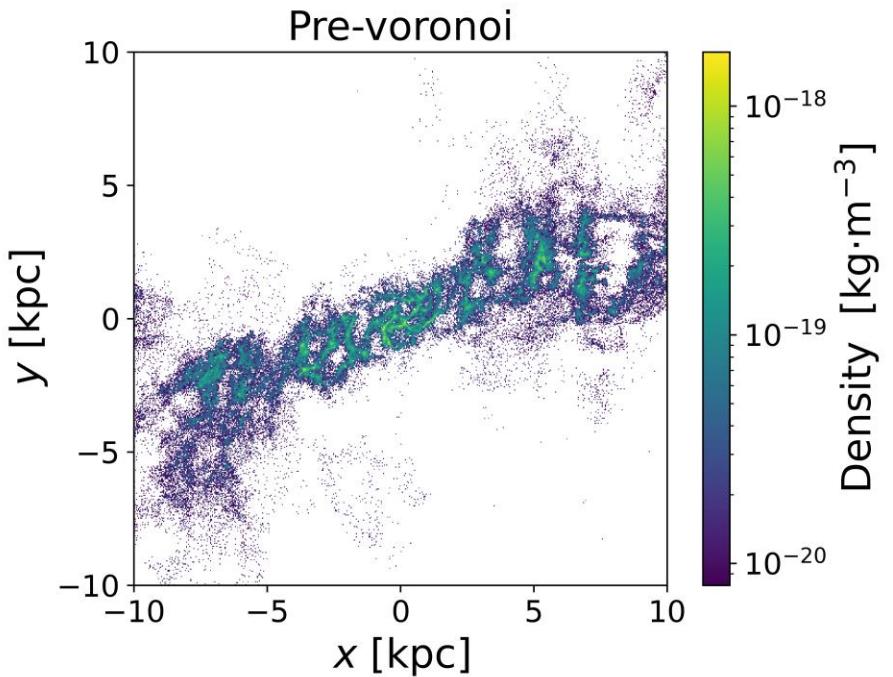
Use Voronoi tessellation to convert **point-like data** into a **density field**.



Voronoi tessellation demo using 5 points

# Using Galactic Simulations

Apply the Voronoi tessellation method to simulations of Galaxies similar to our Milky Way



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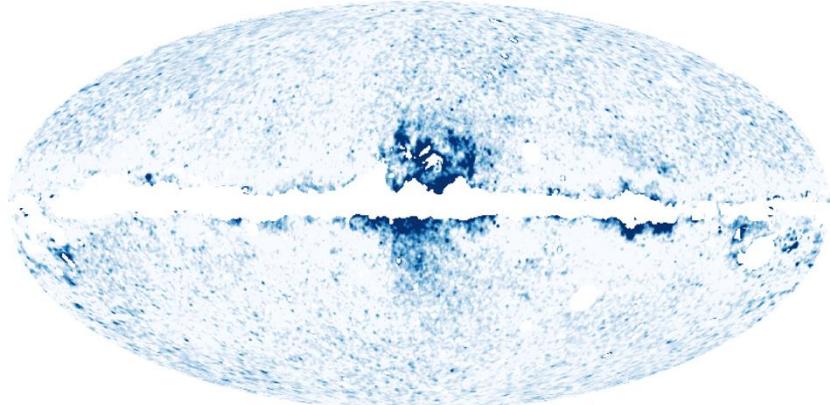
## Axion Quark Nuggets: A Recipe for a Glowing Milky Way?

Program: MSc in Physics

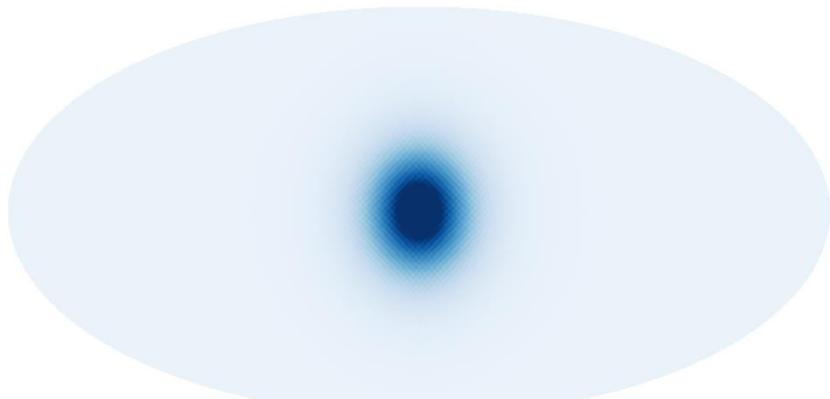
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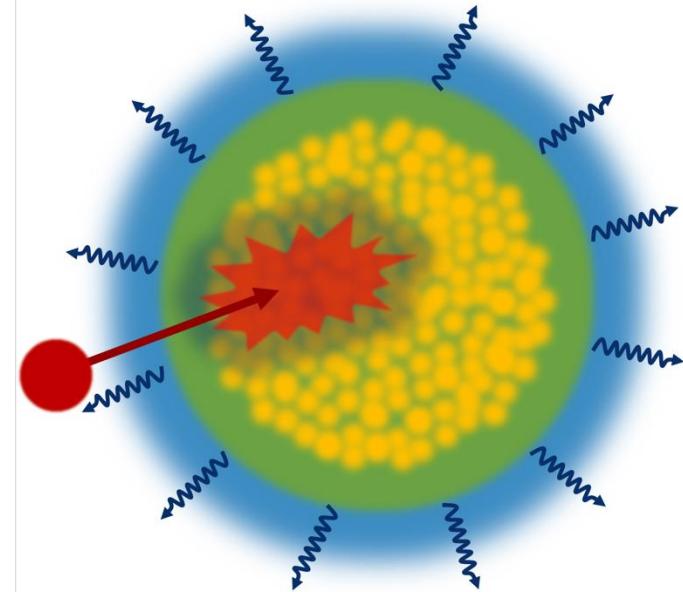
# Mysterious Glow



Sample Simulated Result



# Axion Quark Nugget



Can dark matter explain this  
glow in our Milky Way?

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