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

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Dark Matter – Axion Quark Nuggets (AQNs)

HEAVY COMPOSITE DM

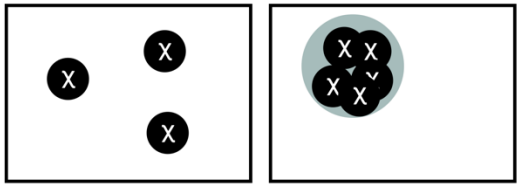
Consider a simple model of fermionic DM coupled by a scalar field

$$\mathscr{L} = \frac{1}{2}(\partial\varphi)^2 + \bar{X}(i\gamma^\mu\partial_\mu - m_X)X + g_X\bar{X}\varphi X - \frac{1}{2}m_\varphi^2\varphi^2 + g_n\bar{n}\varphi n + \mathscr{L}_{SM},$$

Diluted dark matter has a freeze-out abundance that scales with ζ^{-1}

This abundance of dark matter leads to very large $\varphi - X$ composites

see also e.g.
Wise Zhang '14
Krnjaic Sigurdson '14
Hardy Lasenby March-Russell '14
Detmold McCullough Pochinsky '14
Gresham Lou Zurek '17
Coskuner, Grabowska, Knapen, Zurek '18
Acevedo, JB, Goodman '20



Models of quark matter forming during 1st order PT

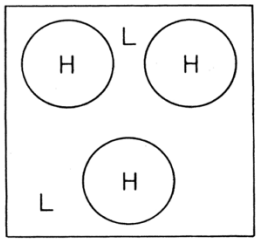


FIG. 3. Isolated shrinking bubbles of the high-temperature phase.

see e.g.
Witten '84
Zhitnitsky '02
Asadi, Kramer, Kuflik, Slatyer, Smirnov '21

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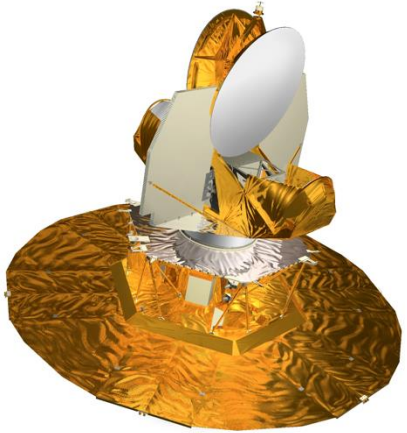
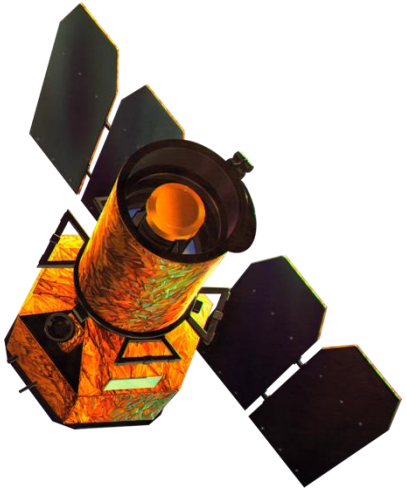
As previewed in Joseph Bramante's talk yesterday…

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



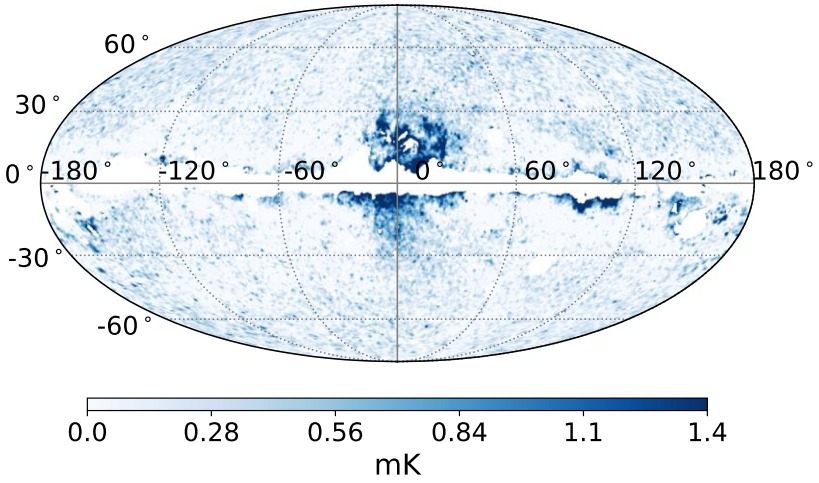
Galaxy Evolution Explorer (GALEX)

1350-2800 Å

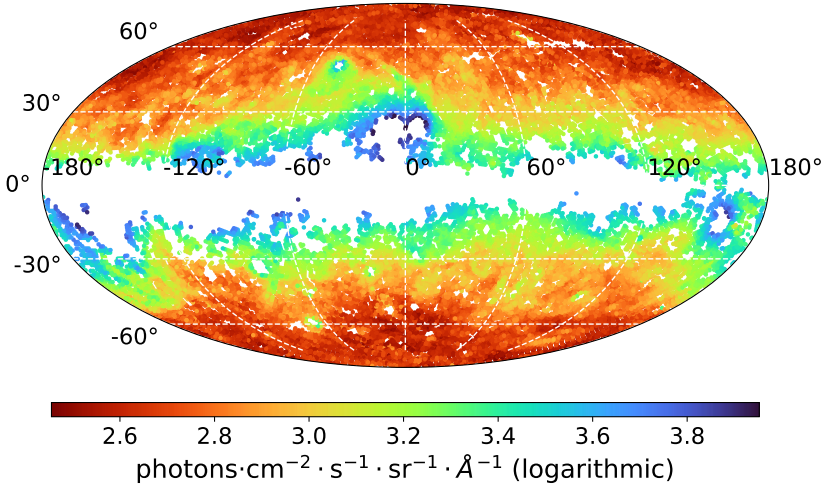
https://wmap.gsfc.nasa.gov/
https://science.nasa.gov/toolkits/spacecraft-icons

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)

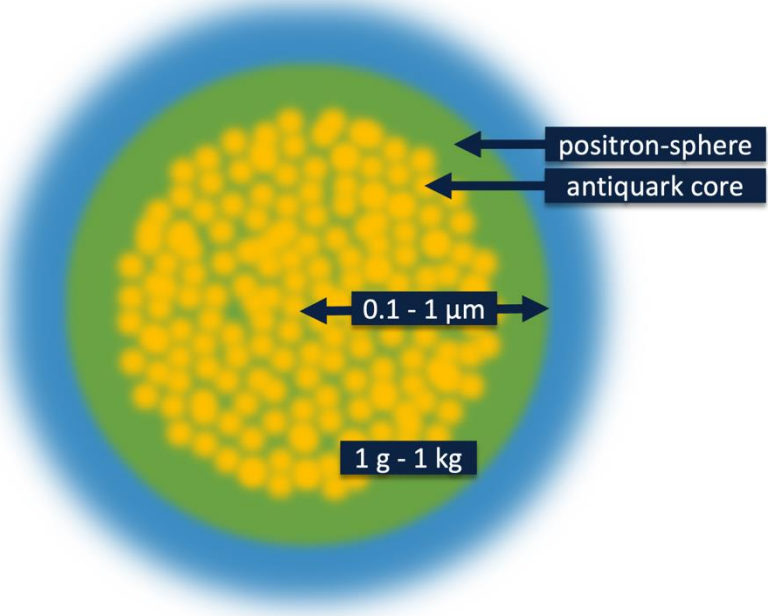


GALEX FUV diffuse background (1350-1750 Å)

Plots with data from [1] and [2]

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



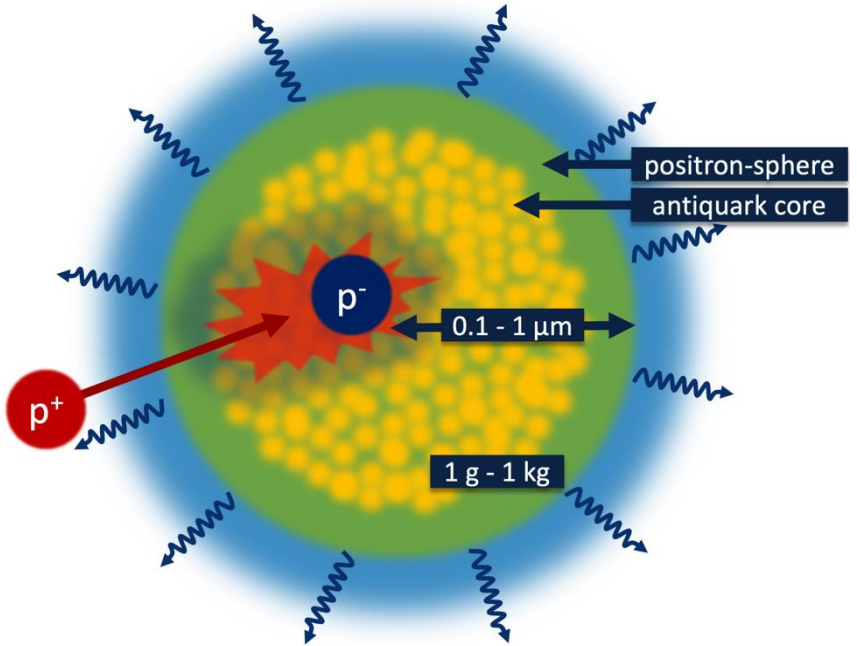
Antinugget model

Axion Quark Nuggets (AQNs) – Annihilation with Regular Matter

- Baryons in our Galaxy can **collide** with antimatter AQNs and **annihilate with antiquarks**: produces ~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

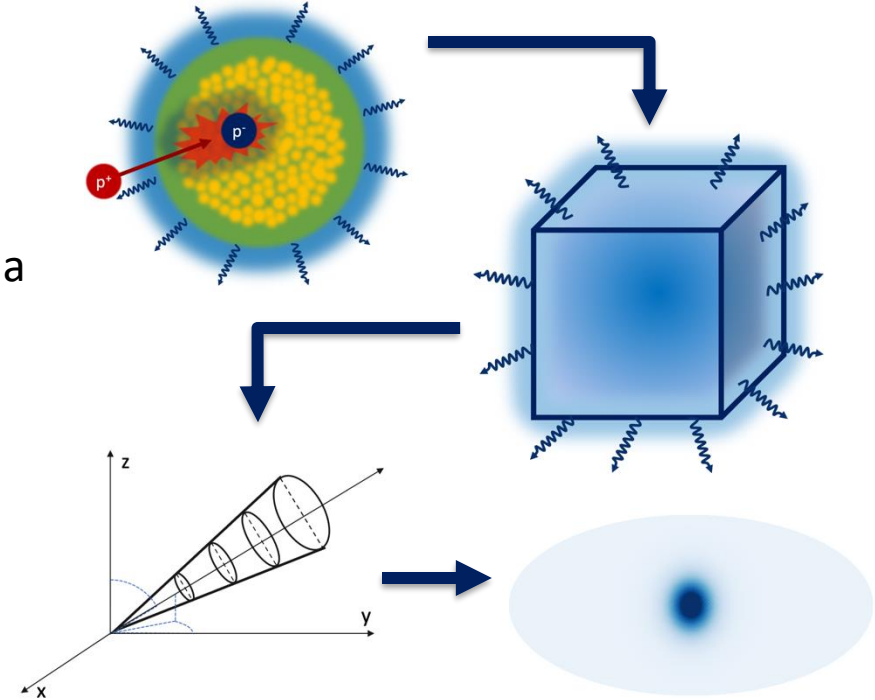
Axion Quark Nugget Annihilation Simulation

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.



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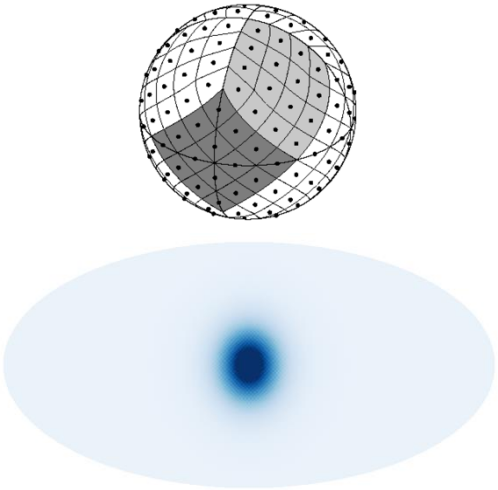
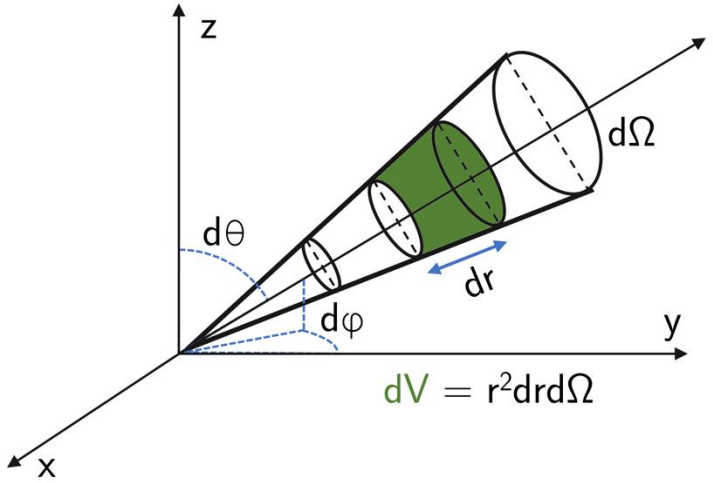


For each pixel in the sky…

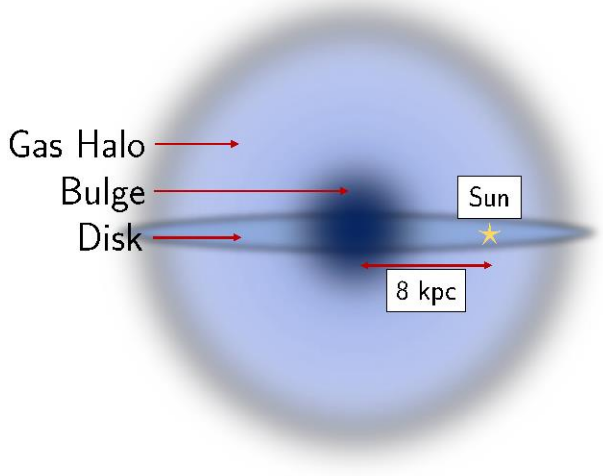


add up contributions to the signal along sightline

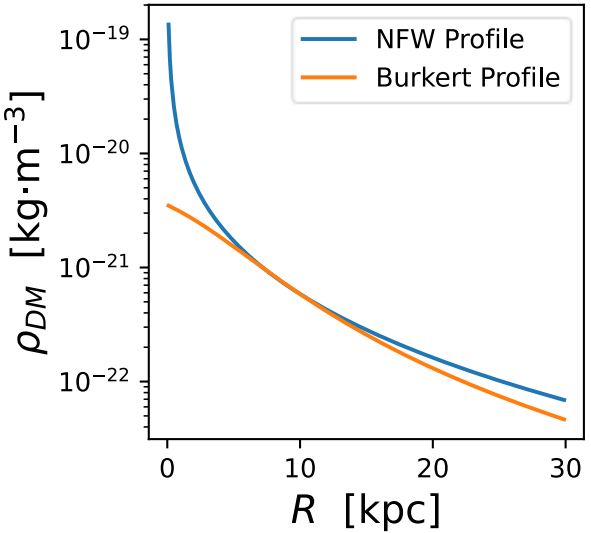
Requires detailed models of **gas** and **dark matter distributions** in our Milky Way.

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



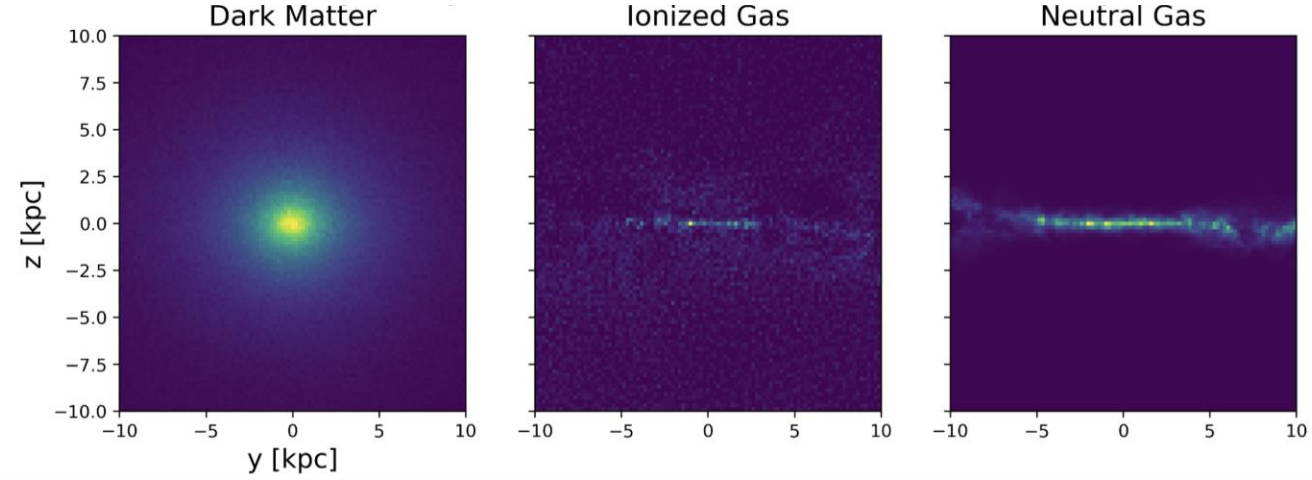
Disk-Bulge-Halo model of visible matter



Two analytical dark matter density models

Galaxy Simulations – Feedback In Realistic Environments (FIRE)

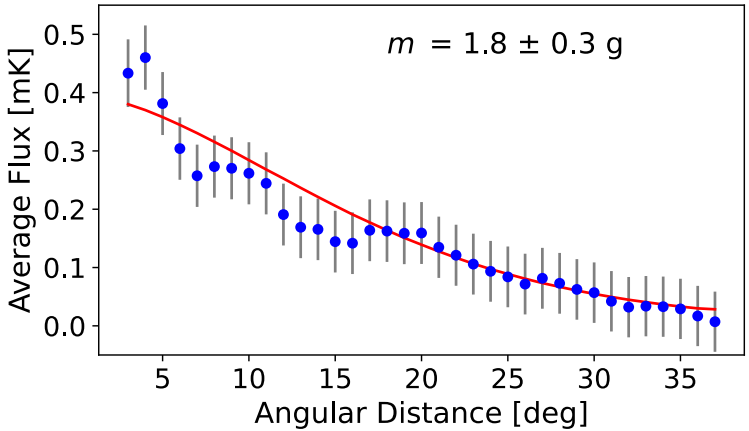
- Milky Way-like galaxy simulation used instead:
- FIRE's Latte suite: cosmological hydrodynamic simulations of Milky Way-like galaxies
- Particle data converted into density fields using Voronoi tessellation



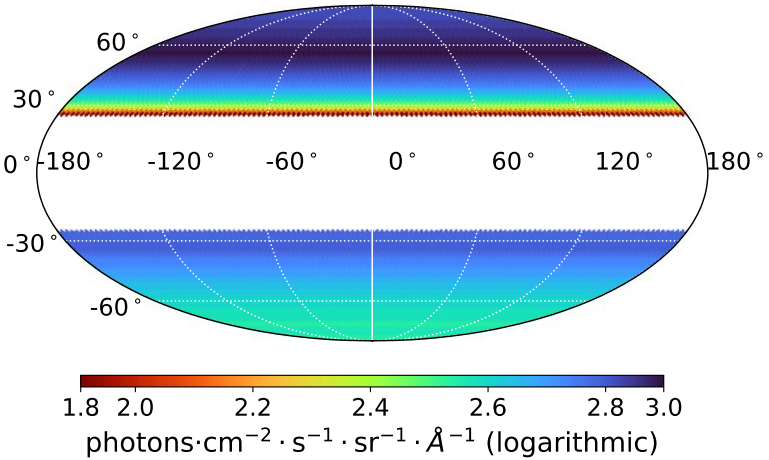
Densities calculated from FIRE's m12i galaxy simulation

AQN Annihilation Simulation – First Results

- Initial results show a **potential match in signal amplitude and distribution** in radio
- For FUV, local density computations need to be improved to account for scattering and absorption effects



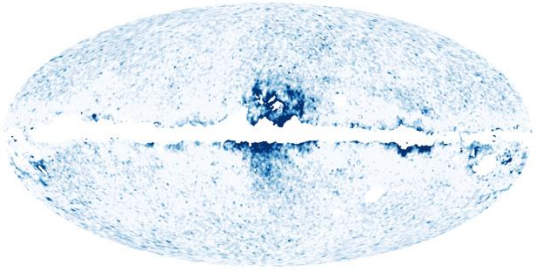
Radio AQN annihilation flux and WMAP haze flux. Results of MCMC analysis.



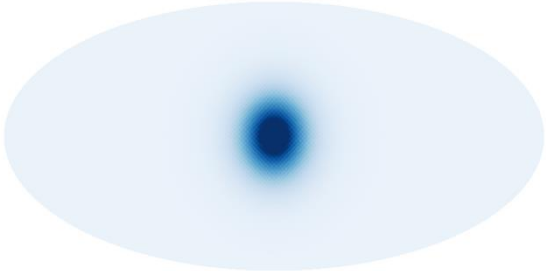
FUV AQN annihilation flux using radially averaged data from FIRE m12i simulation.

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**



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

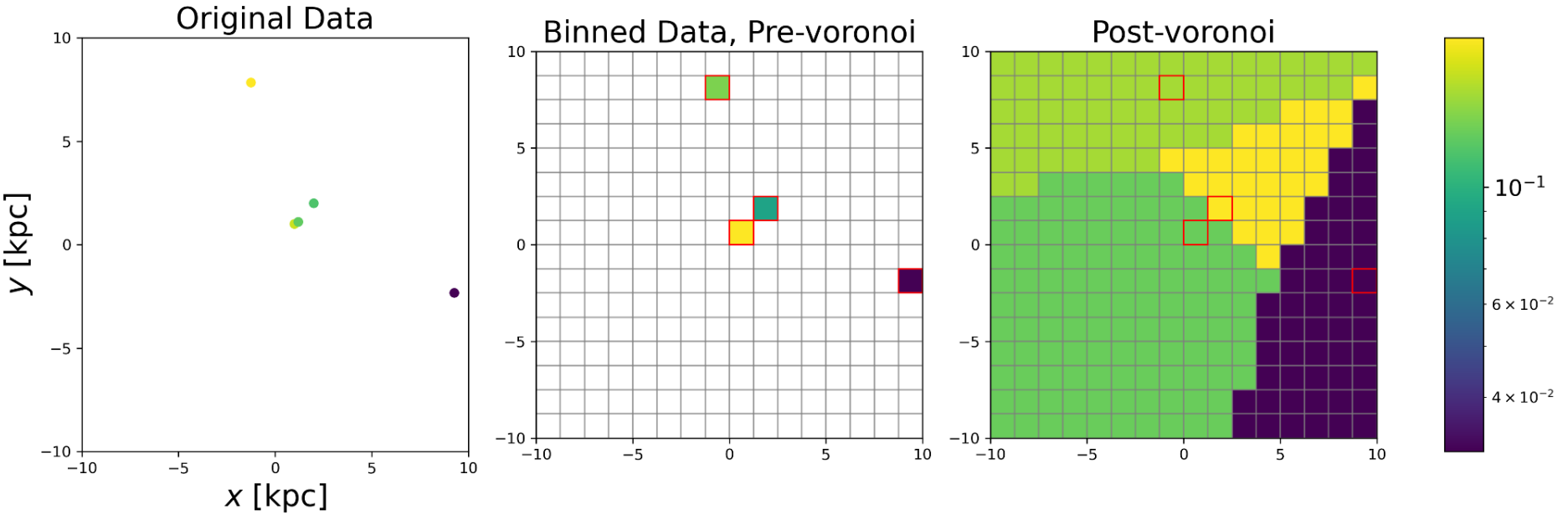
F. Majidi, X. Liang, L. Van Waerbeke, A. Zhitnitsky, M. Sekatchev, J. Sommer, K. Dolag, T. Castro. **The Glow of Axion Quark Nugget Dark Matter: (I) Large Scale Structures**. JCAP, August 2024.
https://arxiv.org/abs/2406.12122

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

Thank You

Voronoi Tessellation Technique

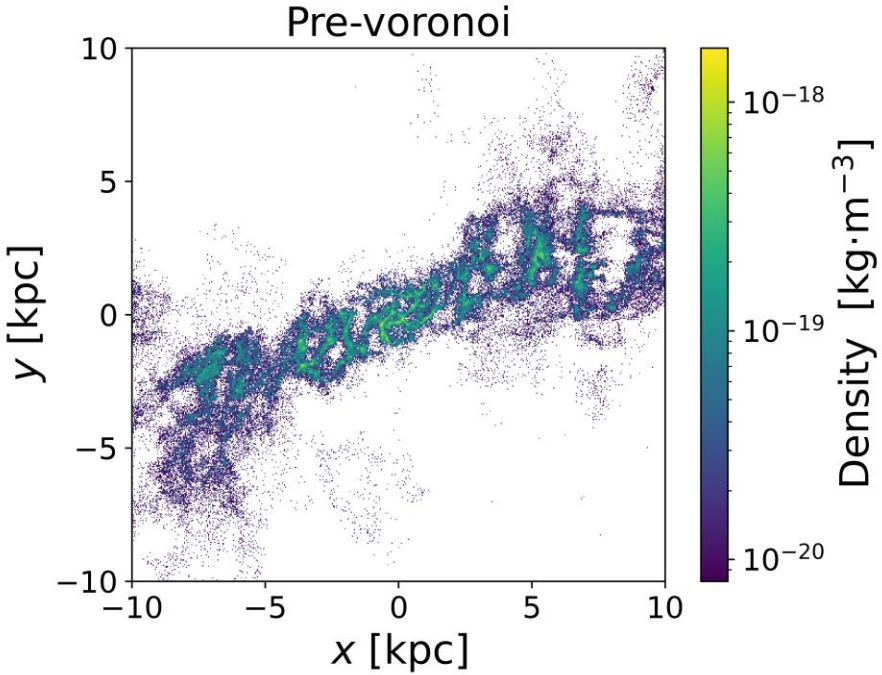
Use Voronoi tessellation to convert **point-like data** into a **density field**.

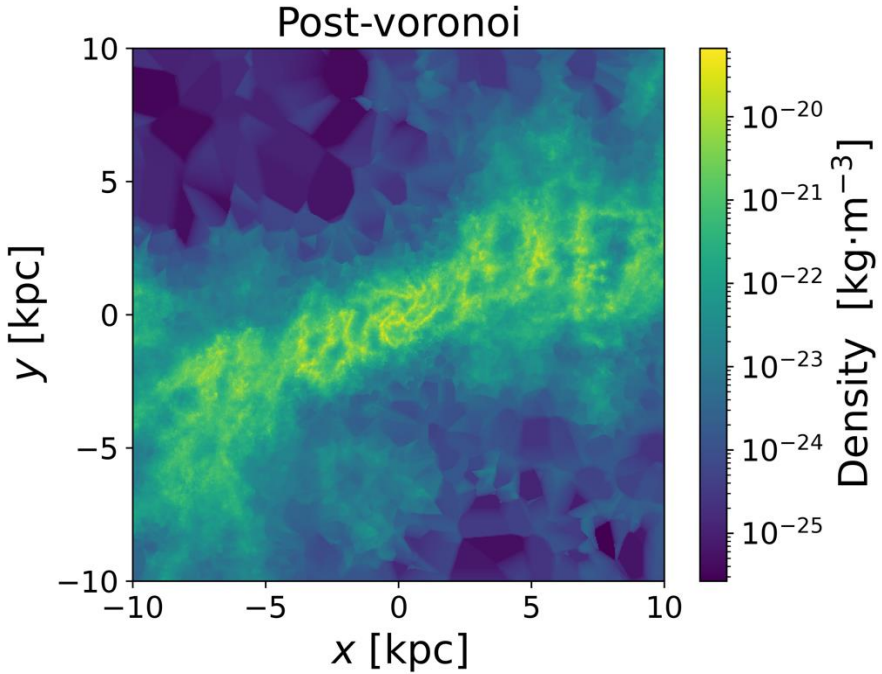


Voronoi tessellation demo using 5 points

Using Galactic Simulations

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





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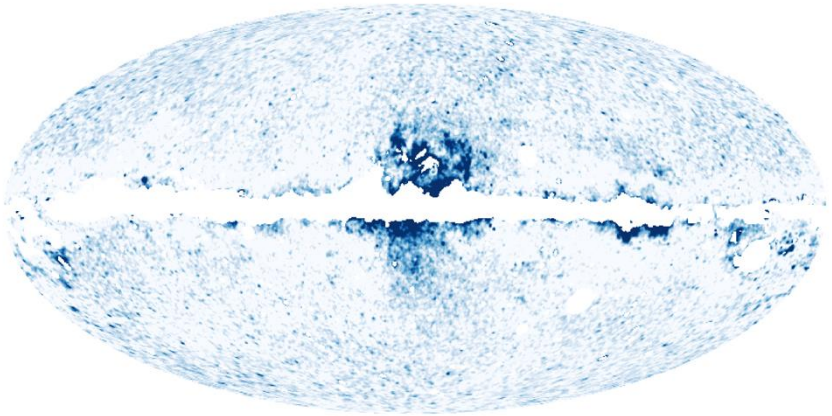
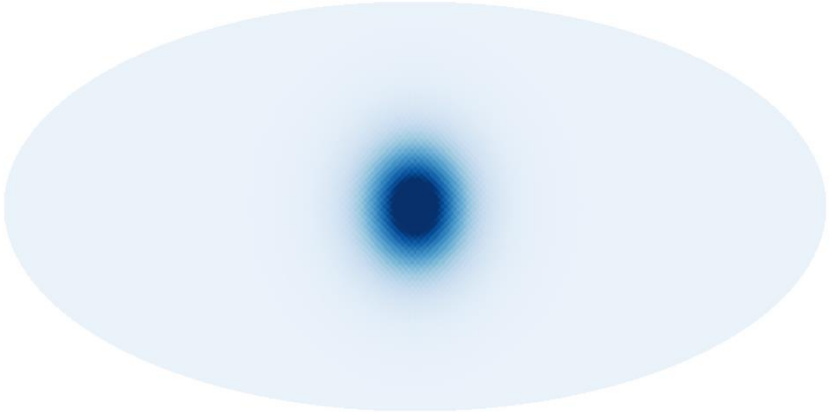
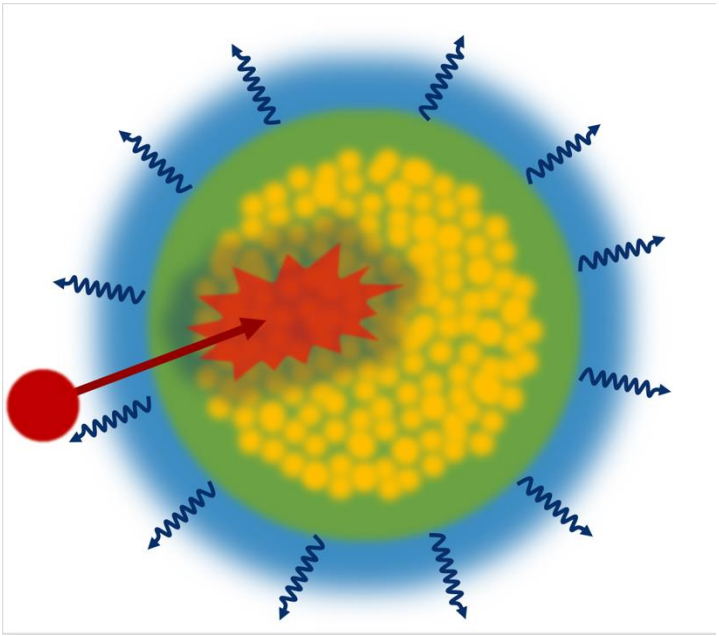
Mysterious Glow



Sample Simulated Result



Axion Quark Nugget



Can dark matter explain this glow in our Milky Way?