Axion Quark Nuggets Versus Excess Galactic Radio Background

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References

Summary

An annihilation interaction within the Axion Quark Nugget (AQN) dark matter model could explain the excess in Galactic radio background observed by WMAP and Planck[1].

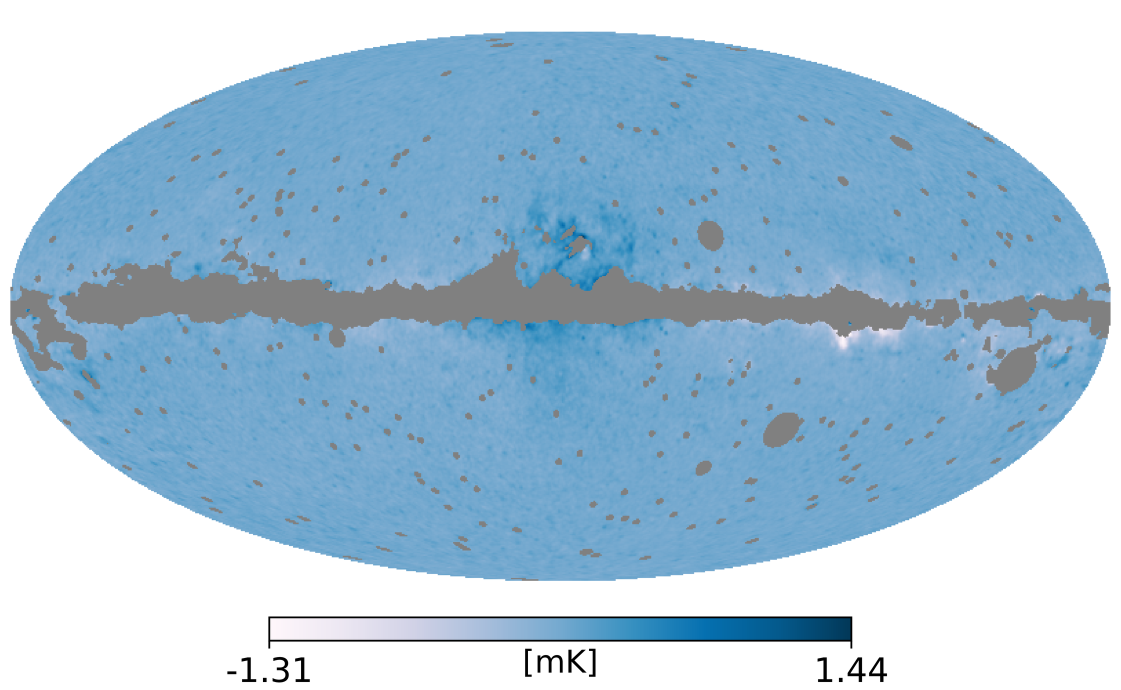
Observations

The Wilkinson Microwave Anisotropy Probe (WMAP) was launched by NASA to observe the Cosmic Microwave Background (CMB) (2001-2010). It made full-sky observations of microwave radiation in 5 bands (23-94 GHz)[2].

The data was contaminated with microwave foreground, accounted for with models of:

1. Sychrotron
2. Free-Free
3. Dust (spinning, thermal)

These physical models resulted in an **excess**, the **WMAP haze**[3].



WMAP haze K-band (33 GHz), full-sky. The strongest signal is seen closest to the Galactic centre, where visible and dark matter densities are highest.

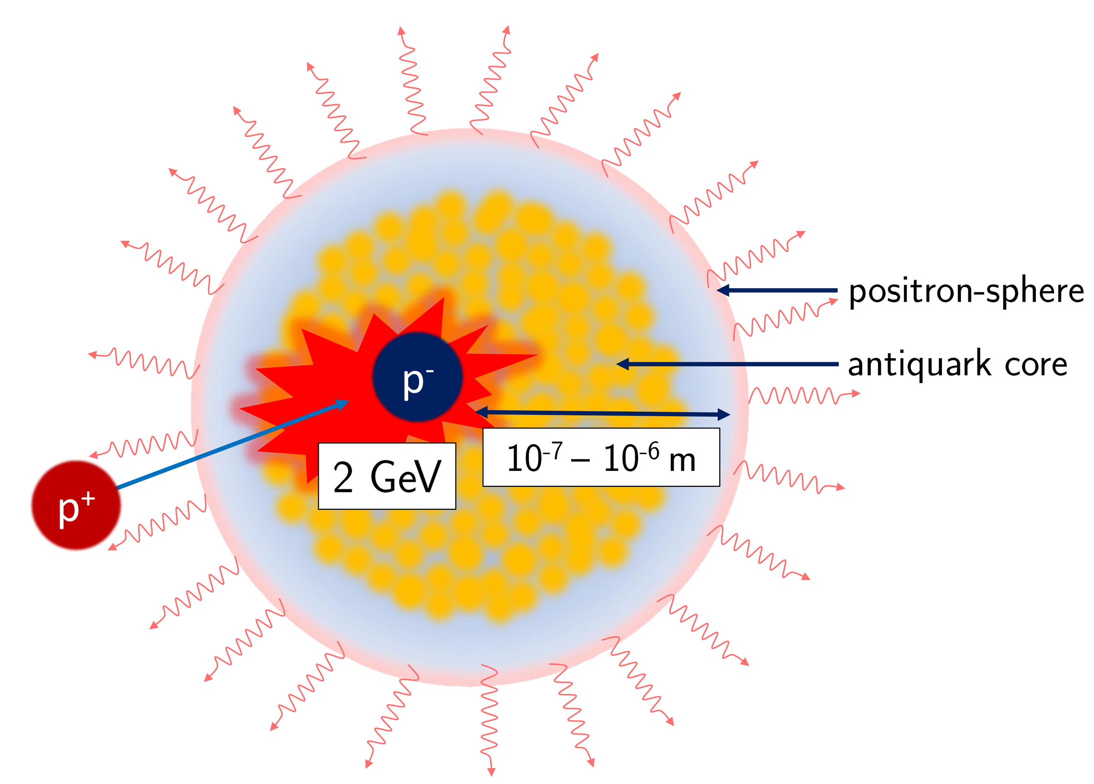
The flux at each angular distance from the Galactic centre was averaged, effectively simplifying the data from 2-D to 1-D.

Theory

Axion quark nuggets (AQNs) are a proposed dark matter candidate in the form of large composite objects of nuclear density[4]. They exist in both **matter** and **antimatter** variants.

Direct observation, or observation through electromagnetic fields is highly improbable because of their **large mass** and extremely **low number density**.

Baryons (mainly free protons) can collide with antimatter AQNs and **annihilate** with the antiquarks in the core.



Proton annihilation with antinugget. Antiquark core in color superconducting phase (yellow), inside a positron-sphere (blue). A portion of the 2 GeV of available energy is thermalized, heating the positron-sphere, causing it to radiate in a broadband radiation spectrum.

Part of the radiated spectrum may explain the excess radiation observed by WMAP, unexplained by other dark matter models[5].

Goal: **Simulate** radio signal from AQN annihilations in the Milky Way, **compare** with WMAP haze.

Implementation

An AQN's **spectral surface emissivity** from an annihilation is described analytically[5].

From this the local **spectral spatial emissivity** from AQNs in a volume element can be obtained:

$$\mathrm{d}\epsilon_\omega(\vec{\mathbf{r}}) = \mathrm{d}\epsilon_\omega\left(T\left(n_{\mathrm{bar}}(\vec{\mathbf{r}})\right), n_{\mathrm{AQN}}(\vec{\mathbf{r}})\right),$$

There is a dependence on the **local baryon density** $n_{\mathrm{bar}}(\vec{\mathbf{r}})$ through the AQN temperature T, and on the **dark matter density** $n_{\mathrm{AQN}}(\vec{\mathbf{r}})$. Models for both are needed.

The sky is divided into pixels. For each pixel, the local spectral spatial emissivity is calculated for volume elements along a sightline. These elements are summed to produce the flux emanating from this pixel.

Dark Matter Distribution

A Burkert profile was used for the dark matter distribution[6]. Unlike the Navarro–Frenk–White (NFW) profile, the dark matter number density does not diverge as the Galactic centre is approached:

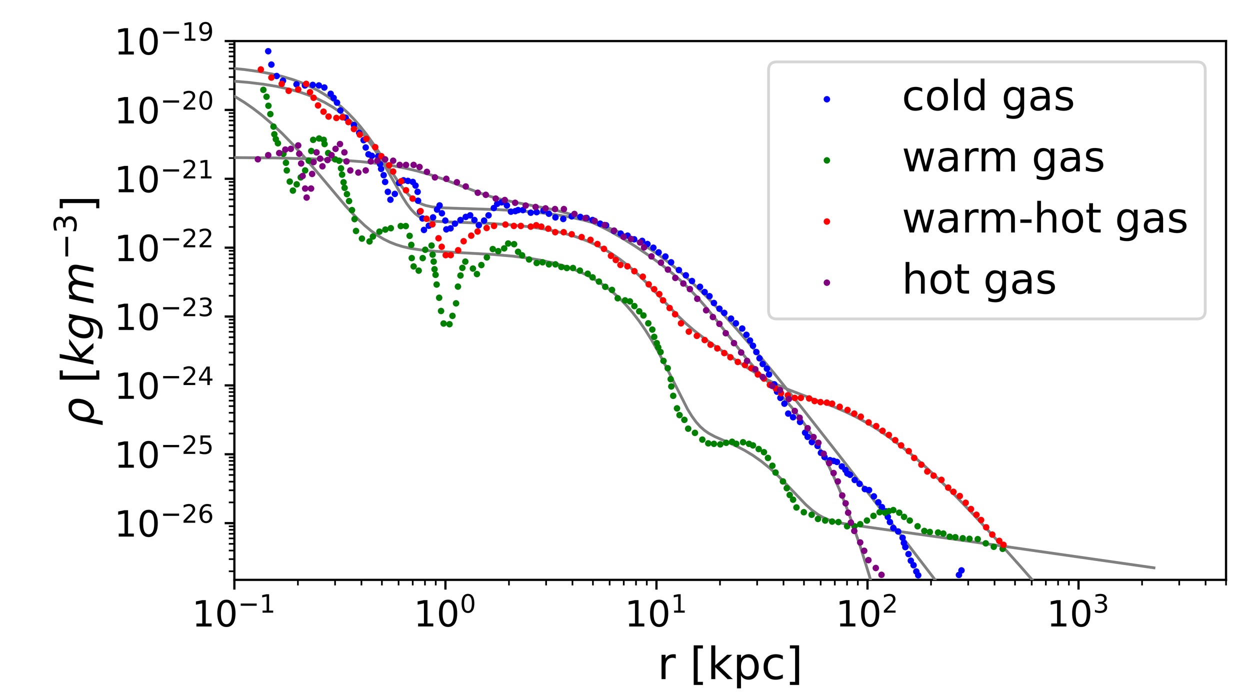
$$\rho_{\mathrm{DM,\ BURK}}(\vec{\mathbf{r}},\ \rho_0,\ r_0) = \frac{\rho_0\, r_0^3}{(r+r_0)(r^2+r_0^2)},$$

where $r = |\vec{\mathbf{r}}|$, r_0 is the scale length, and ρ_0 is the central density $\rho_0 = v_h^2/4\pi r_0^2 G$ where v_h is the characteristic velocity.

Visible Matter Distribution

If the temperature of the baryon gas is high enough, AQNs can become **ionized**, increasing their effective capture radius.

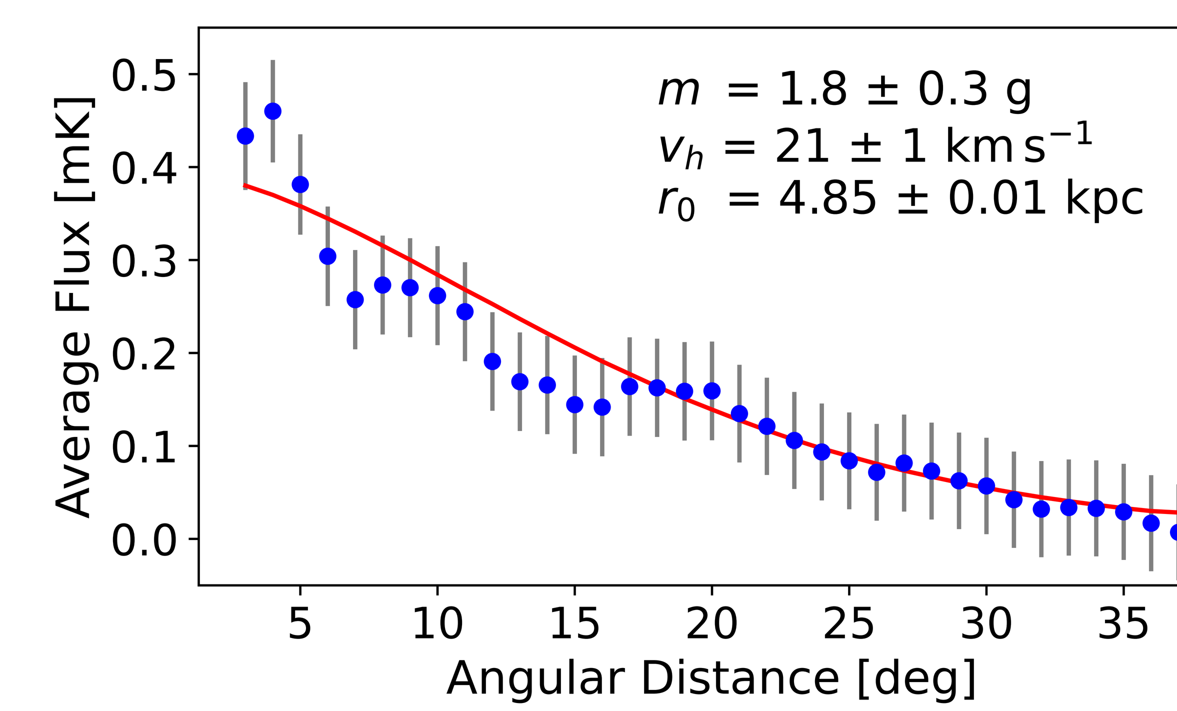
Due to the missing baryons problem, ionized gas distributions from Milky Way-like galaxies were used, rather than from observations.



Fitted mass density distributions of the four hydrogen gas components from the Eris2k Milky Way-like galaxy simulation[7]: The cold neutral gas component ($T_{\mathrm{gas}} < 3\cdot10^4\,\mathrm{K}$) and the warm ($3\cdot10^4\,\mathrm{K} < T_{\mathrm{gas}} < 10^5\,\mathrm{K}$), warm-hot ($10^5\,\mathrm{K} < T_{\mathrm{gas}} < 10^6\,\mathrm{K}$), and hot ($T_{\mathrm{gas}} > 10^6\,\mathrm{K}$) ionized gas components are shown.

Results

An MCMC analysis was used to optimize for AQN mass m and Burkert parameters v_h, r_0.



Simulated AQN annihilation flux and WMAP haze flux against angular distance from the Galactic centre using results from MCMC analysis[1]. **These results are not final**—this establishes a framework for comparing the AQN annihilation signal with the WMAP haze.

Future work includes extensions to other Galactic excesses, and improvements to the dark and visible matter distribution models.