Cross-Talk Fermilab 6/28/11 1/

There is a large population of NRFs around the galactic center

- a.) Bright in Radio
- b.) Perpendicular to Galactic Plane
- c.) Long and thin
- d.) Sometimes tangled
- e.) Hard polarized spectrum
    - a. Polarization => synchrotron
    - b. Polarization >= 60% in multiple filaments

What does polarized synchrotron emission imply?

For a single electron in a constant B-field, synchrotron will be entirely polarized.

Depolarization

a.) Power law lepton spectrum

$p_0 = (3\gamma + 3) / (3\gamma + 7)$ (Le Roux, 1961)

b.) Faraday Rotation – rotation of light in magnetic field

c.) Random Magnetic Fields
$P \sim p_0 * B_{ord}^2 / B_{tot}^2$

$^{=}$ for power laws $\gamma = 1$

d.) These depolarizing forces add – so observations of polarization put a lower limit on magnetic field order

Magnetic Mirroring

An electron entering a region with an ordered magnetic field will exit the region on timescale equivalent to the gyroradius

$R_g = 1.1 \times 10^{-7}$ pc (E / 10 GeV) (100 μG / B)
$= 3 \times 10^{8}$ m

$T_g \sim 1$ sec

Even in the case of only ~1% ordered magnetic field, the rejection time for GeV particles is ~ 1000 seconds

$T_g \ll T_{sync}$

Result: Polarization => Magnetic Field Order => Electrons inside the NRFs are not externally produced

Hard Spectra of NRFs

NRFs have very hard synchrotron spectra with very fast turnover:

Radio Arc has $Sv \sim +0.3$
Where $Sv = erg / cm^2 / s / Hz$

Northern Thread:
$Sv \sim -0.5$ from 1.4 to 4.8 GHz
$Sv \sim -2.0$ from 4.8 to 8.3 GHz

For a power law electrons we have:

$p = 2\alpha - 1$

where α is the synchrotron energy spectrum and p is the electron injection spectrum.

Supernova remnants have $p \sim 2.4$ so $\alpha < -0.6$ – which is at odds with observation.

Monoenergetic Electron Spectrum

Lesch, 1988 postulated a monoenergetic electron spectrum

Necessary energy ~ 7 GeV !!

Spectrum of monoenergetic electron spectrum can replicate both the rising and rapidly falling synchrotron spectra observed

Previous Models:

Magnetic Reconnection regions form on edges of filamentary arcs:

Can explain both strong magnetic fields and particle acceleration (offset between synchrotron energy loss and energy gain)

BUT, several problems:

1.) Why is the electron injection spectra identical in all filaments?
2.) Acceleration may not be efficient enough to produce GeV particles in any case
3.) Intensity of electron acceleration may vary wildly

Dark Matter as an electron injector

Leptophilic dark matter candidates naturally produce a sharply peaked (non-power law) spectrum

We use 8 GeV DM
(H&G) as a template

dn/dE between 0.0 and -0.5, with 2/3 of energy in a delta function at 8 GeV

Intensity of Electron Injection:

Unlike astrophysical scenarios, dark matter limits fine tuning for the total intensity of injected leptons

The dark matter injection spectrum can be written as:

$$\Phi_{DM} = 4.5 \text{ x } 10^{31} \,(8 \text{ GeV} / M_{DM})^{2} \,(<\sigma v>/3\text{x}10^{26} \text{ cm}^{3}\text{s}^{-1}) \\ (r / 100 \text{ pc})^{-2.5} \,(v / 1 \text{ pc})^{3} \text{ ann / s}$$

In order to calculate the total electron population, we multiply this by dn/dE and then also take into account the time in which the electrons are confined within the filaments.

However, this value is very uncertain – so we take an alternate route:

The synchrotron energy loss time for 8 GeV electrons is given by:

$$T = 6.6 \text{ x } 10^{12} \,(8 \text{ GeV} / E) \,(100 \,\mu\text{G} / B)^{2}$$

We define a parameter τ which defines the ratio between the synchrotron energy loss time and the containment time for 8 GeV

Make correction $E^{-0.33}$ in the containment time (Kolmogorov Spectrum)

Astrophysical mechanisms usually assume $\tau \sim 1$. We make a similar assumption for dark matter scenarios.

=> Diffusion constant $\sim 5 \times 10^{26}$ cm^{2}s^{-1}
Galactic avg. $\sim 5 \times 10^{28}$ cm^{2}s^{-1}

Tau controls two important parameters:

a.) Synchrotron Exhaustion (electron spectrum)

b.) Total intensity (percentage of total electron energy lost to synchrotron)

  a. $\tau = 1$ corresponds to ~48%

Explaining Different NRFs:

In order to explain the different spectra of NRFs, we must employ differences in the magnetic field strength and τ

Peak of Synchrotron spectrum $\sim$ B

Larger τ leads to softer synchrotron spectra

Galactic Trends

In dark matter scenario – the intensity of the electron injection varies as r^(-2.5).

This trend should be observed in the synchrotron from NRFs as a function of their distance from galactic center (20 pc – 120 pc => 2 orders of magnitude)

There are many complicating factors (NRF magnetic fields, filament depths, confinement times – but the size of the correlation may yield interesting results in population studies.

One parameter we can control for is length:

a.) Flux / length – For complete confinement
b.) Flux / length^2 – For free propagation through filament
c.) Flux / length^3 – For diffusive propagation through filament

We scan distributions at 330 MHz and 1.4 GHz, and find opposite results.

Interpretations:

DM naturally creates the right intensity for NRFs if $\tau \sim 1$ (can't go much higher, but could go much lower)

DM naturally creates a reasonable spectra (magnetic fields closely match equipartition results)

DM predicts the r^{-2} correlation between galactic center distance and Flux

However, a few thorny issues:

Diffusion constant must be much lower in NRFs with low magnetic fields (a possible prediction of Alfven)

τ is a rather arbitrary parameter

Further observations necessary:

1.) Larger study of populations, including different frequencies can help isolate DM contribution

2.) Theoretical models of diffusion in ordered magnetic fields could provide bounds on τ