Searching for Magnetic Monopoles

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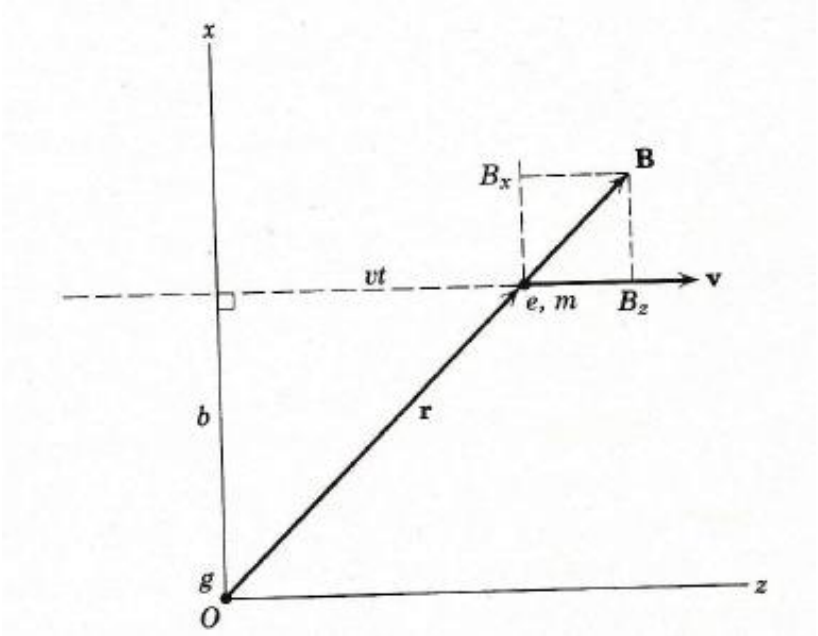
Why I believe in them

Our search for them

Why we may not be able to see them

Why I believe in Magnetic Monopoles(MMs)

1. They would rationalise the quantisation of charge and angular momentum .
2. They are needed in grand unified theories ('tHooft and Polyakov) – but massive of order 10^{16} GeV.



Y axis into slide

Dirac's Argument - Take a MM at origin and charged particle with charge passing with velocity v. (NB magnetic field of a monopole, $B=g/r^2$)

At time t feels force $F_y = e\ v \times B = evB_x = evb\ g/r^2\ b/r$

Substitute in $r= (v^2t^2+b^2)^{1/2}$

Gives momentum kick= $\Delta p_y = F_y\ dt$

Integrate over time t gives $\Delta p_y=2eg/b$

Angular momentum imparted $\Delta L_z = b\ \Delta p_y =2eg$

But this should be quantised = $nh/2\pi$

i.e. $g=nh/4\pi e$ where n is an integer.

Dirac turned the argument round – if a MM exists and we know about quantised angular momentum from quantum mechanics then we can predict the quantisation of electric charge.

'tHooft (1999 Nobel prize-winner) and Polyakov showed that the unification of electroweak and quantum gravity leads naturally to MMs.

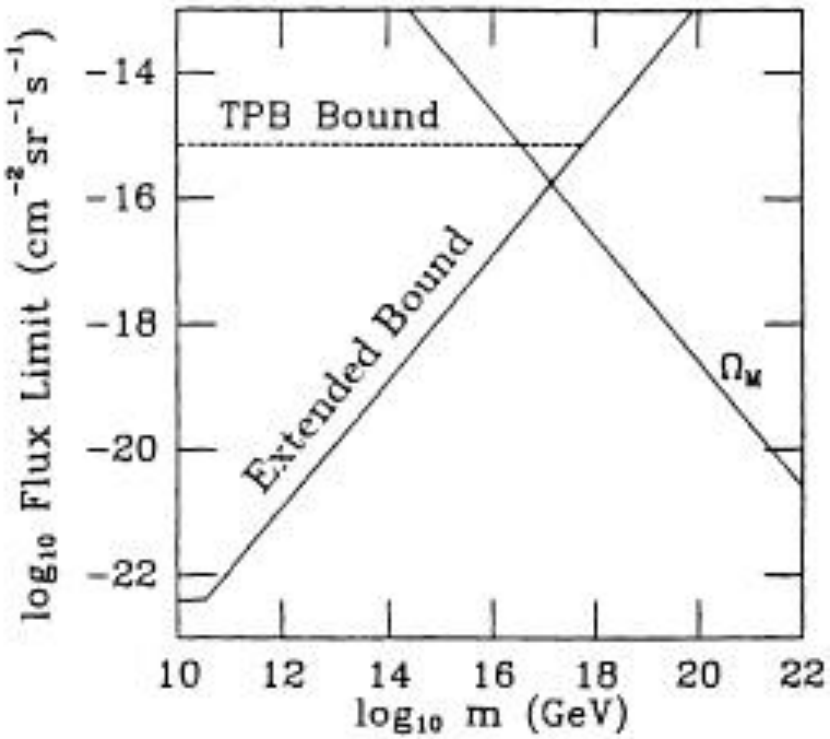
With such strong theoretical expectation MMs should exist.

However, they have never been detected despite many searches (masses < TeV scale otherwise seen at colliders).

Natural Limit – the Parker Bound

- Comes from the demand that the density of MMs should not short circuit the Galactic magnetic field (GMF)

i.e. ½ B.H >> J_m.B t t ~ time taken to regenerate GMF ~ 10^8 years (Tarlé et al)



Our Latest Search.

Idea from Philippe Mermode – look in volcanic rocks which come from a depth where gravitational force down = upward force from Earth's magnetic field.

Earth's crust semi-molten at this depth and any trapped monopoles will drift to this equilibrium point. i.e. they will be concentrated there.

Take volcanic rocks from Iceland and pass them through a SQUID magnetometer.

Pass sample through superconducting coil. Monopole leaves a persistent current – dipoles current goes to zero.

Apparatus.

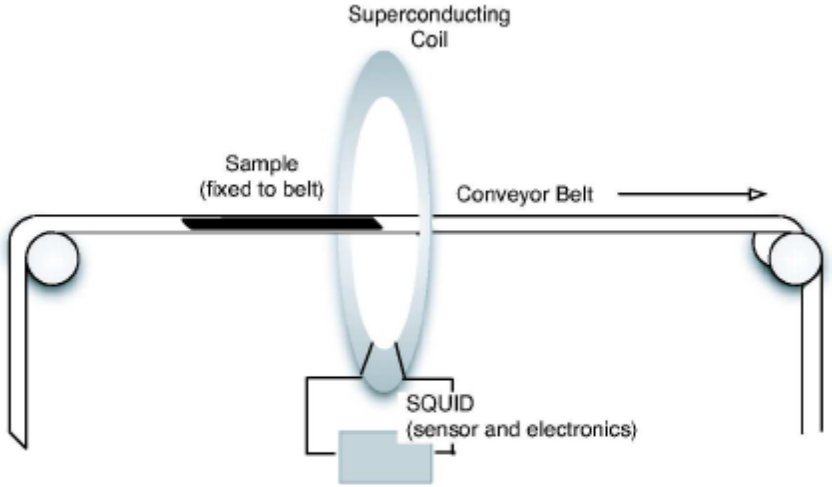
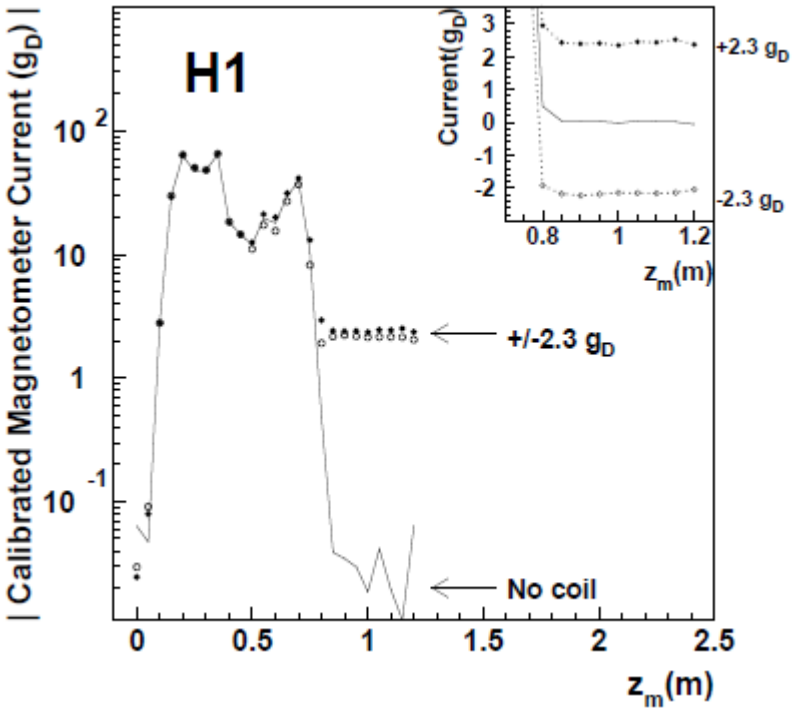
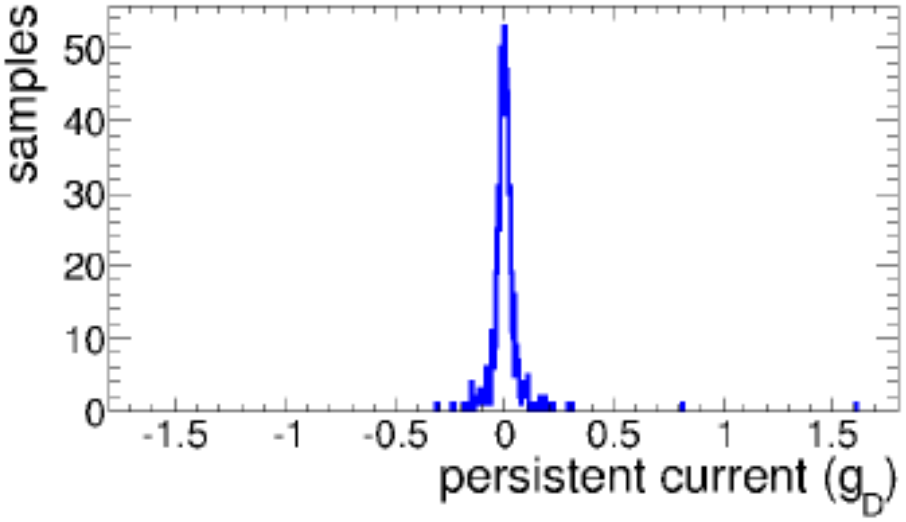


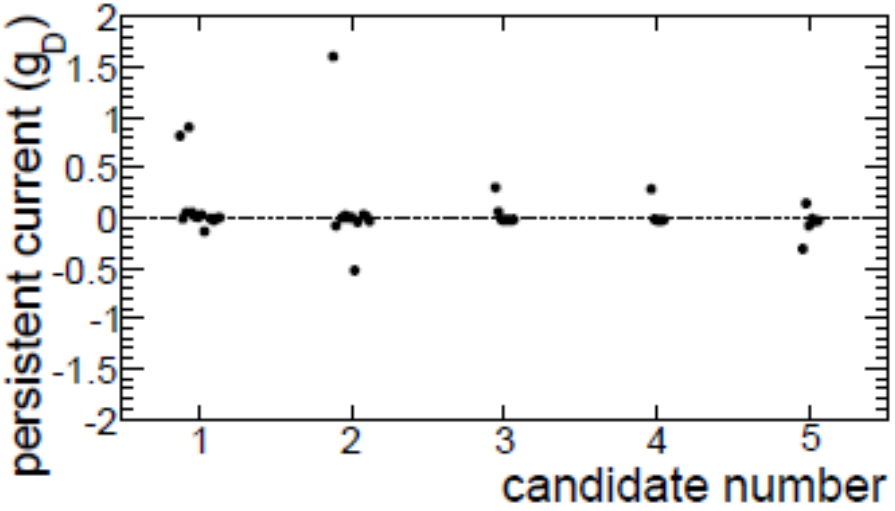
Figure 1: The schematic diagram shows the principle of the method. The conveyor belt travelled in steps of typically 5 cm until the sample traversed completely the superconducting coil. At each step the conveyor belt stopped for 1 sec before the current in the superconducting coil (magnetometer current) was read to avoid the effects of eddy currents. The time for each step was typically 3 secs.

Calibration monopole (a long thin solenoid) size 2.3 g_D



Results





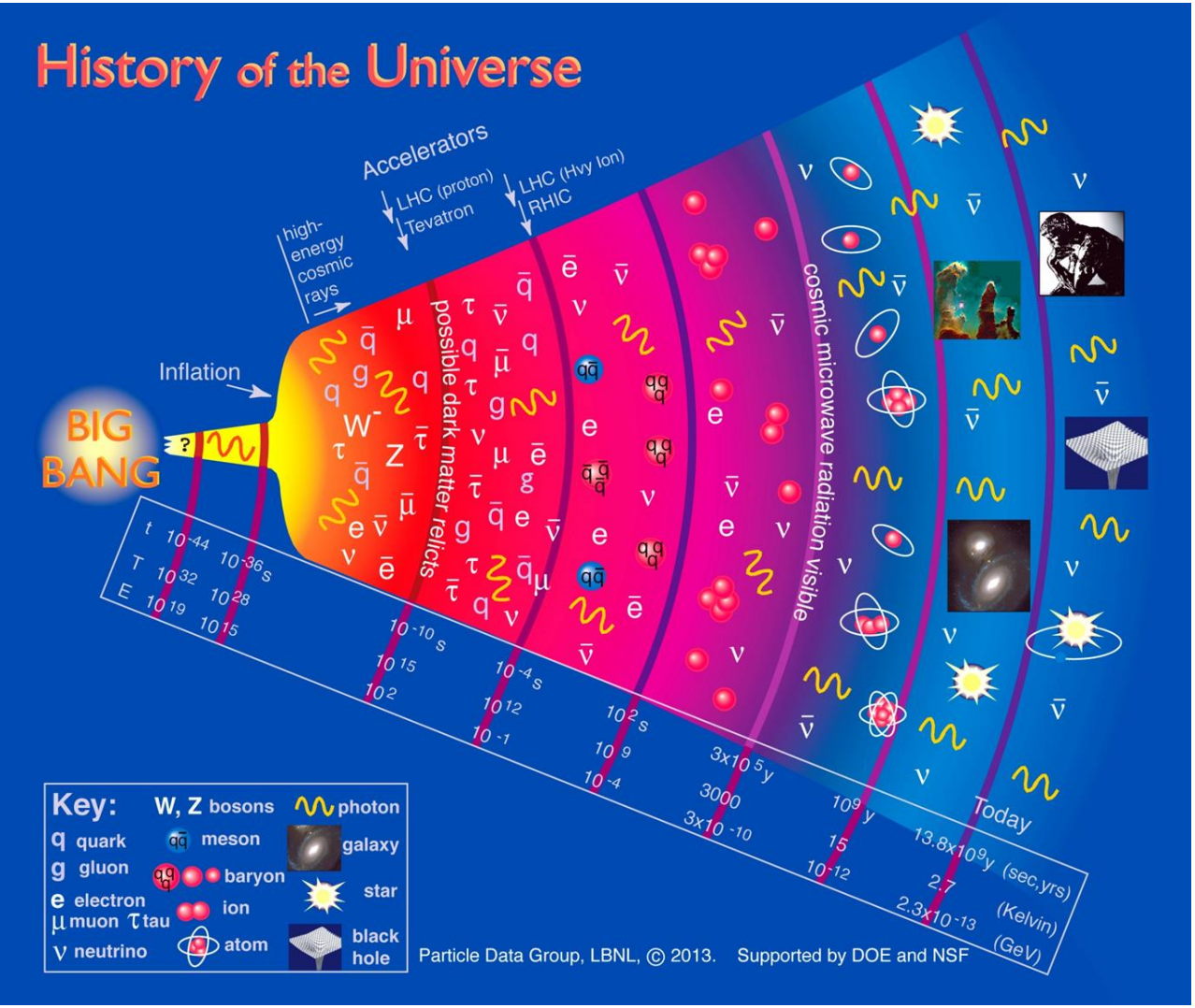
Occasional flux jumps occur – repeat the readings to see if it really is a MM.

No repeatable readings seen

Limit on concentration
$< 4\ 10^{-29}$ MM per nucleon at 95% CL

Published in PRL 110 (2013) 121803
(Phillipe Mermode, Dave Milstead, TS plus several others).

Why do we not see MMs in Galaxy



First possible reason

If MMs have $M>10^{15}$ Gev only produced in pre-inflationary Universe.

Volume expansion is of order 10^{65} after inflation, so final concentration becomes very low.

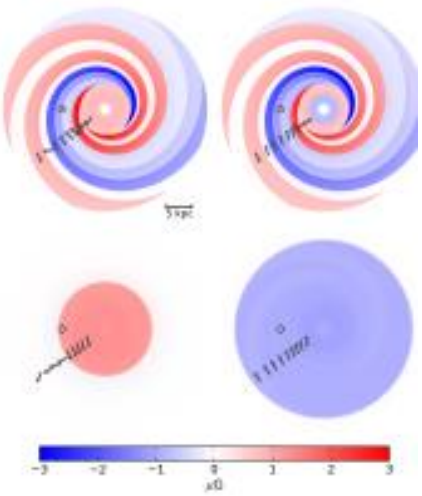
Can MMs be trapped in the Galaxy?

Program to step MMs through gravitational and galactic mag field (GMF).

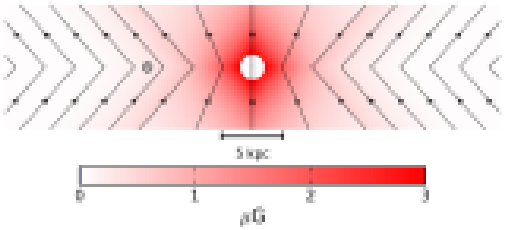
Simulates the forces on a MM – study their trajectories in Galaxy.

Use parameterisation of GMF by Farrer and Jansson

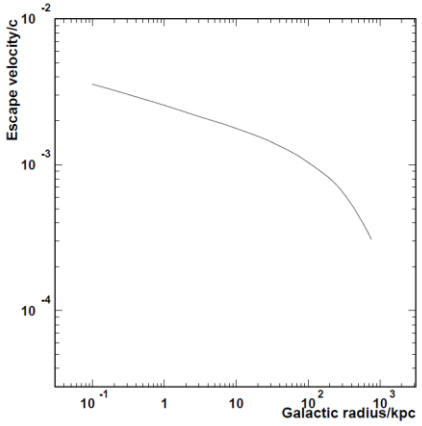
In plane GMF



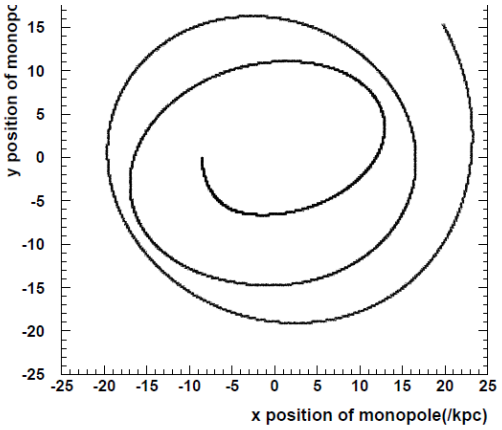
Out of plane GMF



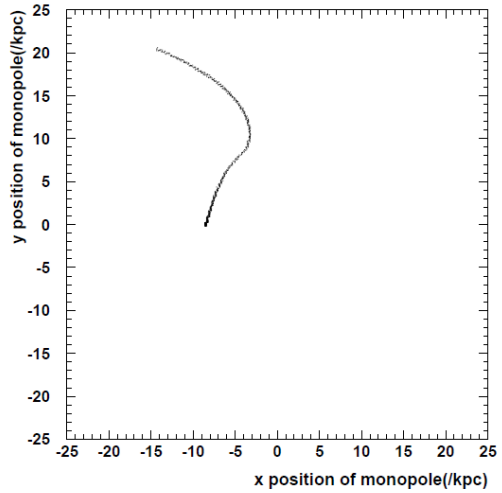
Galactic mass distribution (Fairbairn et al)



GMF throws MMs out of Galaxy quickly.

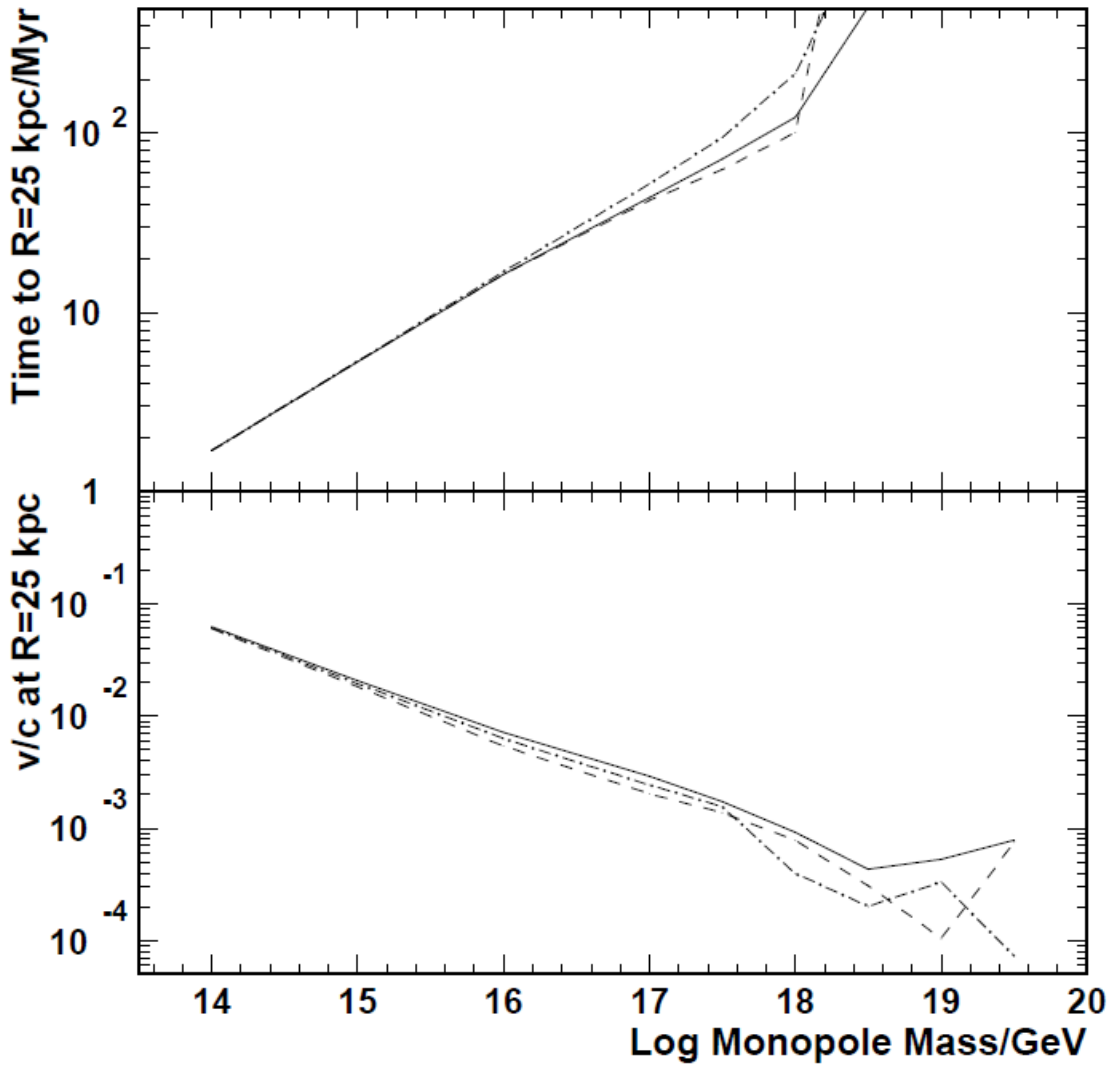


MM in orbit at radius of Solar System but in 1/1000 strength GMF

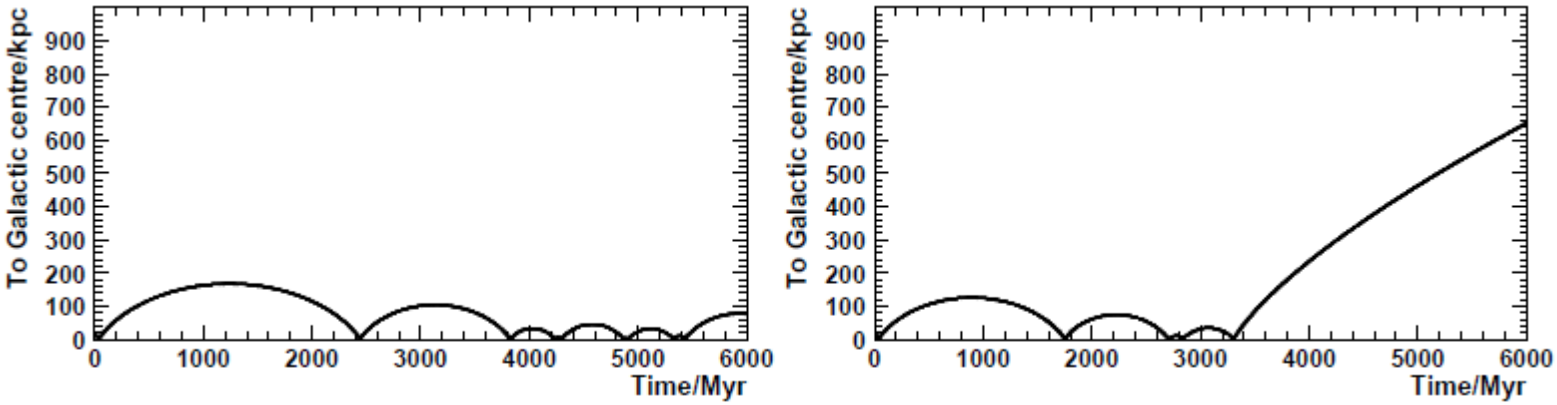


MM in a full strength GMF

Lifetimes of free MMs in Galaxy are short for all starting conditions for Mass < 10^{18} GeV.



For Mass > 10^{18} GeV the MMs spend a large fraction of their time at very large radii i.e. the “bounce” off the GMF up to large radii. Gravitational field then pulls them back.



Conclusions

MMs should exist – given the strong theoretical motivation.

Free MMs may have a low concentration in the Universe due to inflation.

Free MMs are not well constrained to live in the Galaxy at a radius where we can detect them.

Ray of hope – a MM stuck on a dust grain – gravitational field of Galaxy will then overcome tendency of GMF to expel it.

This work is summarised in arxiv:1410.1374 - Non -collider Searches for stable massive particles by S. Burdin, M. Fairbairn, P. Mermode, D. Milstead, J. Pinfold, TS and W. Taylor (to be published in Physics Reports.).