Relic magnetic wormholes as possible source of toroidal magnetic fields in galaxies

Kirillov A.A. Savelova E.P.
1. Ring galaxies

Ring galaxies are the most curious objects. RGs are considered to be produced by scattering with small galaxies, the bar rotation (Lindblad resonance), or the accretion of a cold gas from outside the galaxy. Example is Mayall's object.

The Hoag’s object

The Mayall’s object.
(impact process)

NGC2275, accretion?

The Hoag’s object has too symmetric form. Ideal doughnut form. Analogous form have stable torus-like wormholes !!!
2. Topological structure of a general wormhole

Einstein equations do not fix topology
\[ R_{ik} - \frac{1}{2} g_{ij} R = T_{ik} \]

\[ ds^2 = N^2 dt^2 - g_{\alpha\beta} \left( dx^\alpha + N^\alpha dt \right) \left( dx^\beta + N^\beta dt \right) \]

Initial conditions
\[ \left( g_{\alpha\beta}, \pi^{\alpha\beta} \right)_{t=0} \quad \chi \in S \quad \Rightarrow \quad \left( g_{\alpha\beta}(t), \pi^{\alpha\beta}(t) \right) \]

In GR topology of \( S \) is fixed by onset (Geroch theorem 1967)

**Genus 3 wormhole**

Hegor’s diagrams
3. Stable relic wormholes

a) Spherical genus 0 wormhole

\[ \gamma = 0 \]

requires exotic matter or modification of GR

Whs are unstable! Non-static can exist but collapse too fast. Lobo 2006

\[ S \]

Wormhole throat

b) Genus 1 (torus) wormhole

\[ \gamma \geq 1 \]

does not require exotic matter

Non-static stable! KS 2016
a) Illustration of stability. Billiard on Lobachevsky plane (open Friedman model)

\[ dl^2 = \frac{4dr^2}{(1-r^2)^2}, \]

\[ \chi = 0 \]

\[ \chi = -\pi \]

\[ \chi = \pi \]

\[ \chi = 3\pi \]

Shortest geodesic

\[ dl^2 = \frac{1}{\cos^2 \theta} \left( \left( \frac{a}{2\pi} \right)^2 d\chi^2 + \sin^2 \theta d\phi^2 + d\theta^2 \right) \]
b) upper complex half-plane. More general example

Upon gluing along $g_{\pm}$ transform to Closed geodesic lines

The equal parts of the two geodesics

Parts of geodesic lines which end at the absolute

Repeating such a procedure we may insert an arbitrary number of handles

The space of a constant negative curvature

The Lobachevsky space with a handle on it
c) The simplest stable 3d wormhole

using the axial symmetry of space

add to the above 2d wormhole an angle

Rotation of L-plane around the 0z axis

Their subsequent cosmological evolution is governed by the Freedman equations

$$ds^2 = dt^2 - a^2(t)dl^2$$

$$dl^2$$ -- is the Lobachevsky space with a set of wormholes
3. Magnetic fields of wormholes. Harmonic forms

\[ \nabla_i F^{ij} = 0, \quad \nabla_i \varepsilon^{ijkl} F_{kl} = 0 \]

\[ t = 0 \]

\[ \text{rot} \vec{B} = 0, \quad \text{rot} \vec{E} = 0, \]
\[ \text{div} \vec{B} = 0, \quad \text{div} \vec{E} = 0, \]

Spherical wormhole. Dipole field

Fictitious magnetic charges \( Q_m \)

Bronnikov 2018
Torus-like stable wormhole $\gamma = 1$

Two types of magnetic fields

a) Magnetic charge
Dipole field

\[ B \]

\[ Q_m \]

Analogous electric lines

b) Electric (fictitious) current
Toroidal field

\[ B \]

\[ j \]
4. Possible effects of relic wormholes

a) Accelerator of charged particles
(Kirillov, Savelova, EPJC, 80, 45 2020)
b) Formation of ring-type clumps of baryons 
(Kirillov, Savelova, EPJC, 2020)

\[ Z = Z_{\text{rec}}, R(Z), L(Z) \]

1) \( R(0) \sim 1 \text{Mpc} \)
\[ \delta_b(Z_{\text{rec}}) \sim 4, 8 \times 10^{-3} \]

2) \( R(0) \sim 15 \text{Kpc} \)
\[ \delta_b(Z_{\text{rec}}) \sim 0.32 \div 0.8 \]

3) Smaller Wormholes
\( R(0) < \text{Kpc} \)
collapse before recombination
c) Formation of toroidal magnetic fields in galaxies

After recombination magnetic field of a wormhole do not interact with baryons! They are independent.

1) Relic wormhole collapses into magnetized black hole \( R(0) < 15 \text{Kpc} \)
2) Relic wormhole expands $R(0) > 1\text{Mpc}$ \hspace{1cm} $\delta_b(Z_{\text{rec}}) \ll 10^{-3}$

Outer ring forms homogeneous toroidal field in the center
Thanks for attention!