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

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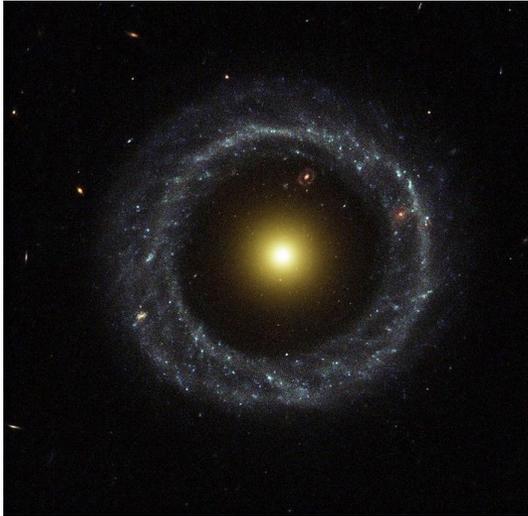MG16, July 2021
Based on papers

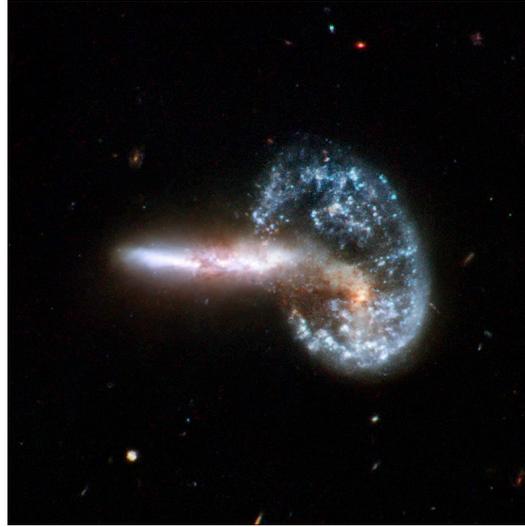## 1. Ring galaxies

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 proccess)

NGC2275, accretion?

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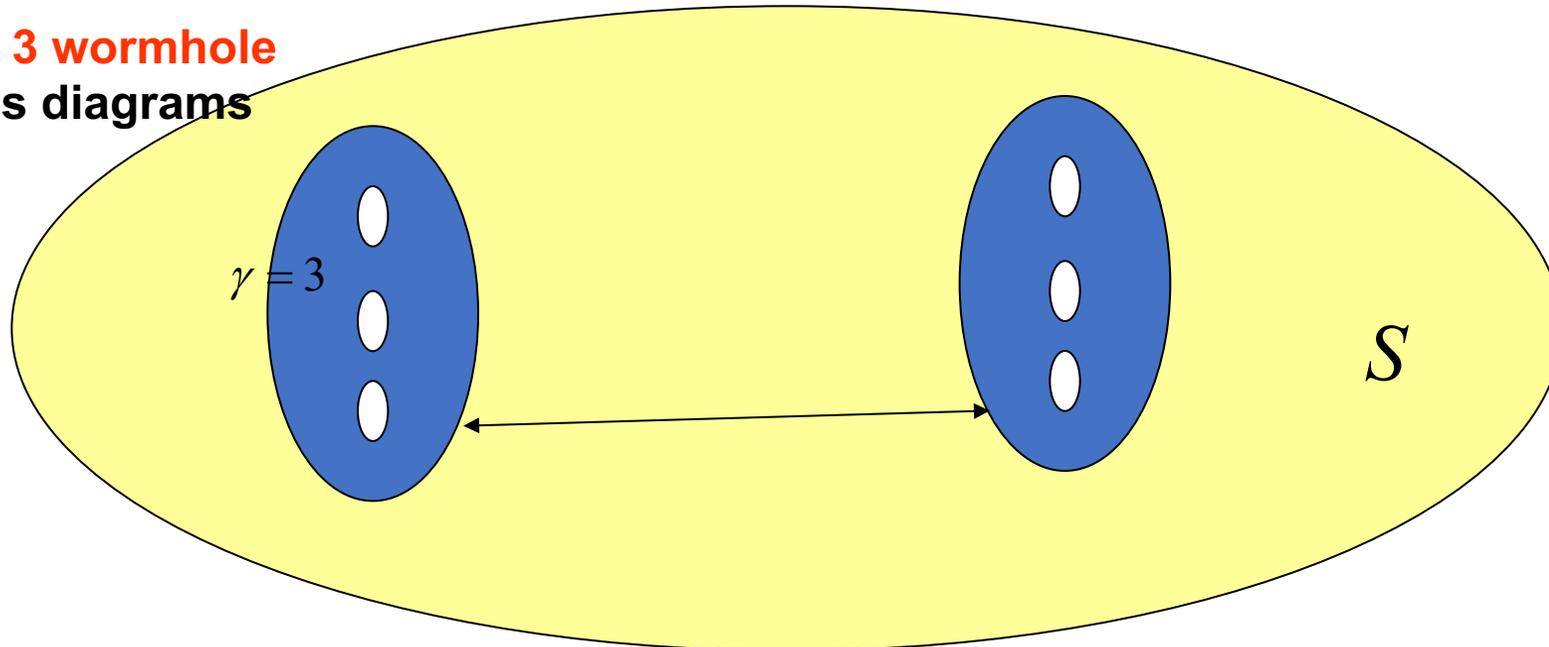
2. Topological structure of a general wormhole

Einstein equations do not fix topology $R_{ik} - \dfrac{1}{2} g_{ij} R = T_{ik}$ $\Longrightarrow$ $\begin{cases} \dfrac{dg_{\alpha\beta}}{dt} = \dfrac{\delta H}{\delta \pi^{\alpha\beta}} \\[2mm] \dfrac{d\pi^{\alpha\beta}}{dt} = -\dfrac{\delta H}{\delta g_{\alpha\beta}} \end{cases}$

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

Initial conditions $\left(g_{\alpha\beta}, \pi^{\alpha\beta}\right)_{t=0}$ $\quad x \in S$ $\Longrightarrow$ $\left(g_{\alpha\beta}(t), \pi^{\alpha\beta}(t)\right)$

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

Genus 3 wormhole
Hegor's diagrams
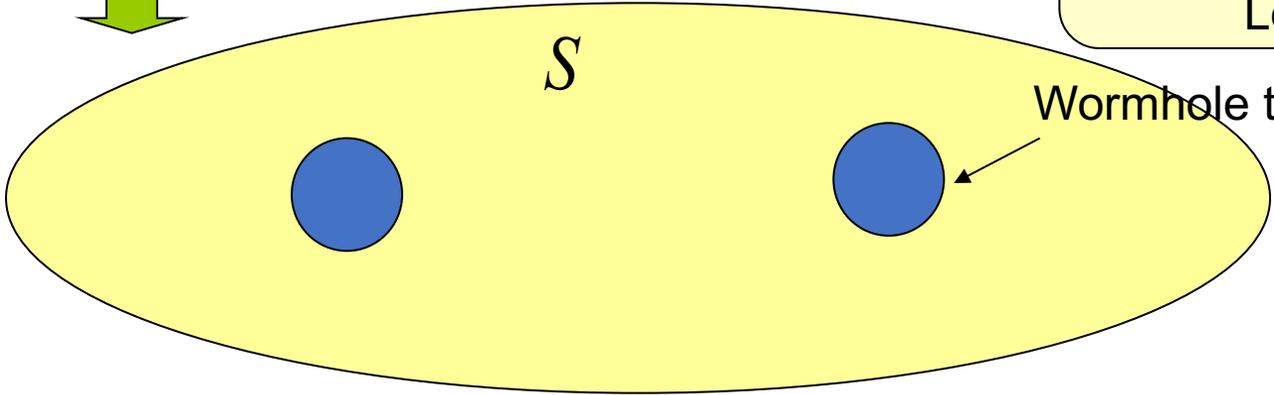

$\gamma = 3$

S

3. Stable relic wormholes

a) Spherical genus 0 wormhole → requires exotic matter or modification of GR → Whs are unstable! Non-static can exist but collapse too fast. Lobo 2006, etc.
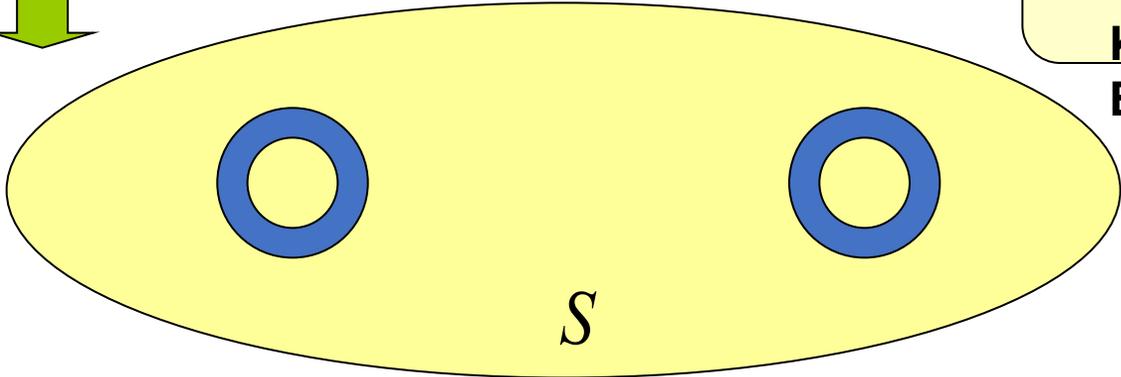
$\gamma = 0$

S

Wormhole throat

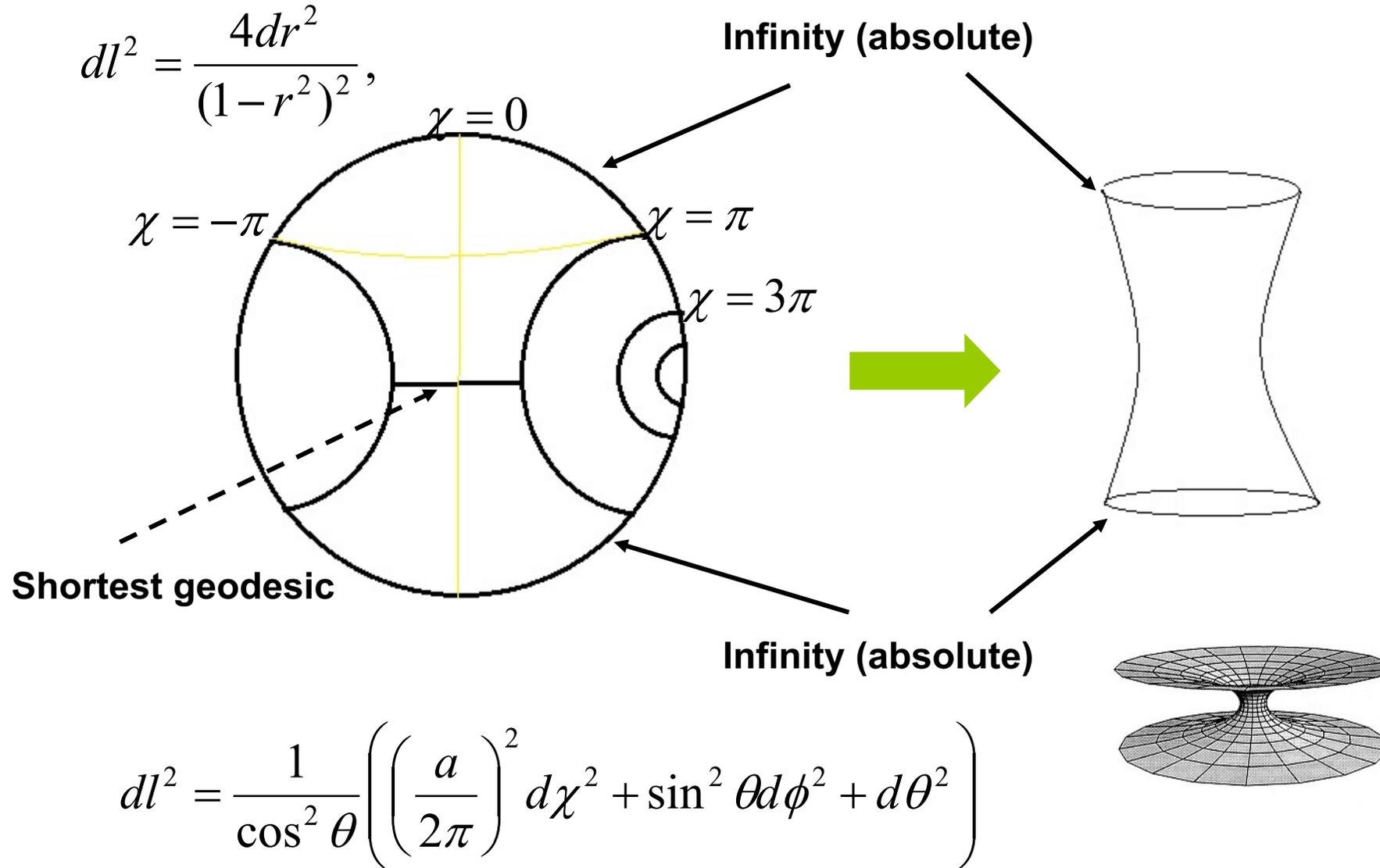b) Genus 1 (torus) wormhole → does not require exotic matter

Non-static stable! KS, IJMP D, 25, 2016, Epjc, 80, 2020

$\gamma \geq 1$

S

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

$\chi = 0$

Infinity (absolute)

$\chi = -\pi$

$\chi = \pi$

$\chi = 3\pi$

Shortest geodesic

Infinity (absolute)

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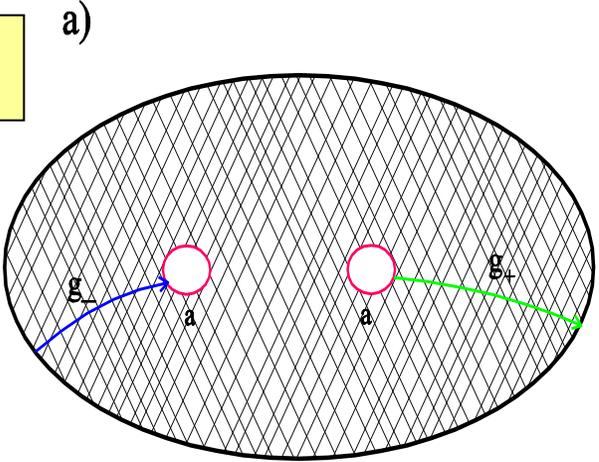
b) upper complex half-plane. More general example
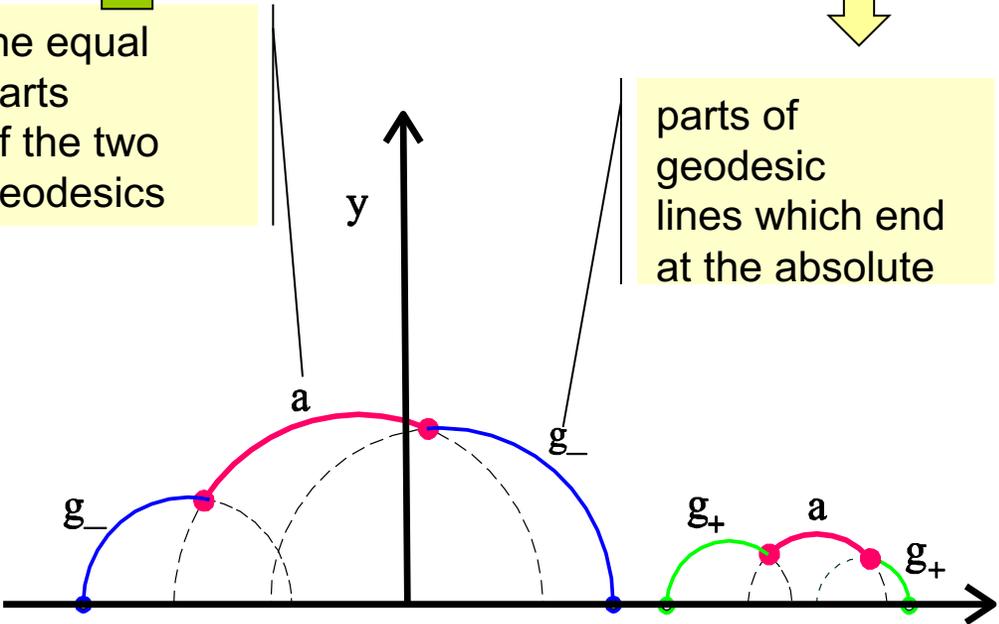
a)

upon gluing
along

$g_\pm$ transform to Closed geodesic lines
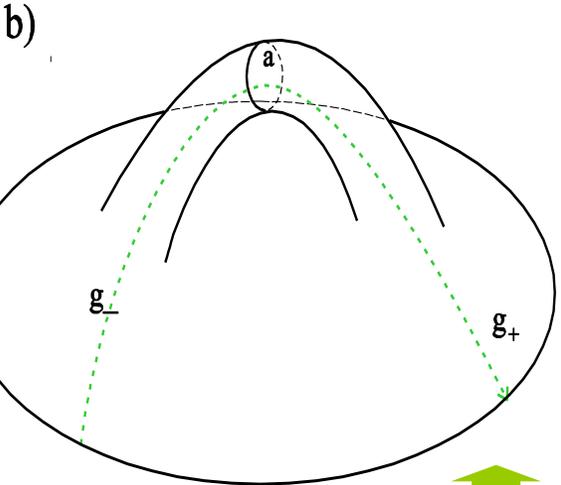
the equal
parts
of the two
geodesics

y

parts of
geodesic
lines which end
at the absolute

the space of a constant
negative curvature

b)

a

g_

g_

g_+

a

g_+

x

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

the Lobachevsky space
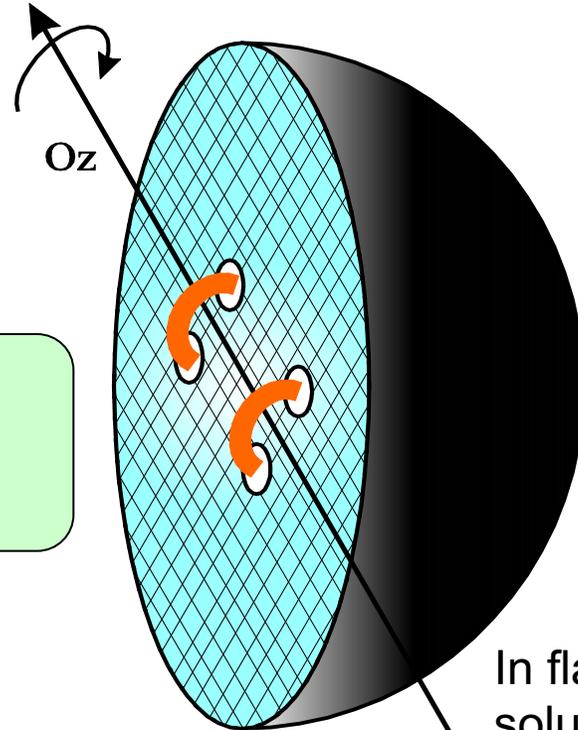with a handle on it

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

Oz

Their subsequent cosmological evolution is governed by the Freedman equations

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

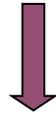dl^2 -- is the Lobachevsky space with a set of wormholes

In flat space axial wormhole solutions without exotic matter were constructed by Bronnikov, et al, PRD 2013, 2019

3. Magnetic fields of wormholes. Harmonic forms

$$\nabla_i F^{ij} = 0, \qquad \nabla_i \varepsilon^{ijkl} F_{kl} = 0$$
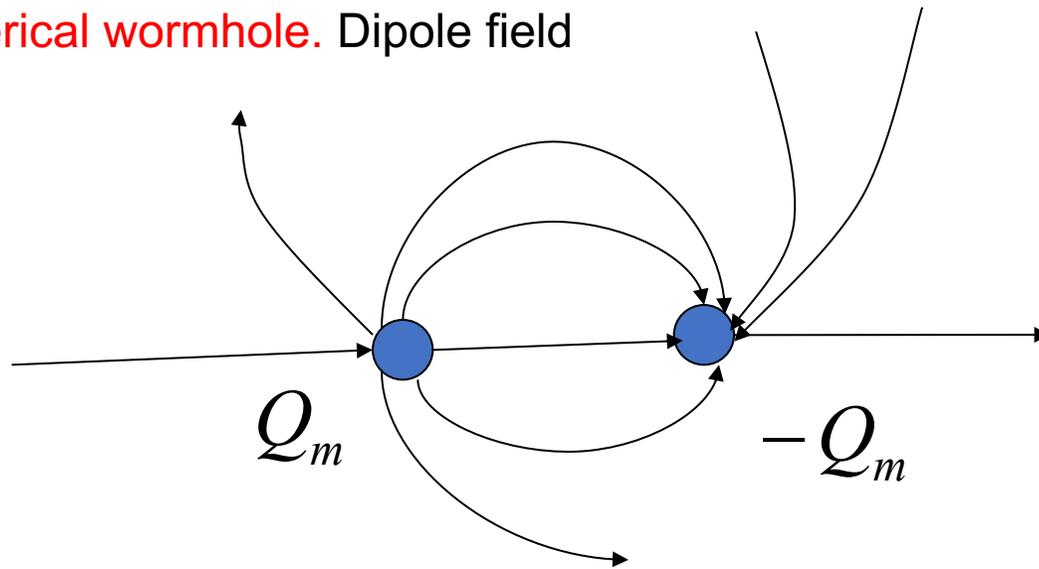
$$\begin{cases} dF = 0 \\ d * F = 0 \end{cases}$$

$$t = 0 \quad \Downarrow$$

$$rot\vec{B} = 0,$$

$$div\vec{B} = 0,$$

$$rot\vec{E} = 0,$$

$$div\vec{E} = 0,$$

Spherical wormhole. Dipole field

Fictitious magnetic charges Q_m

K. Bronnikov 2018

$$Q_m \qquad\qquad -Q_m$$
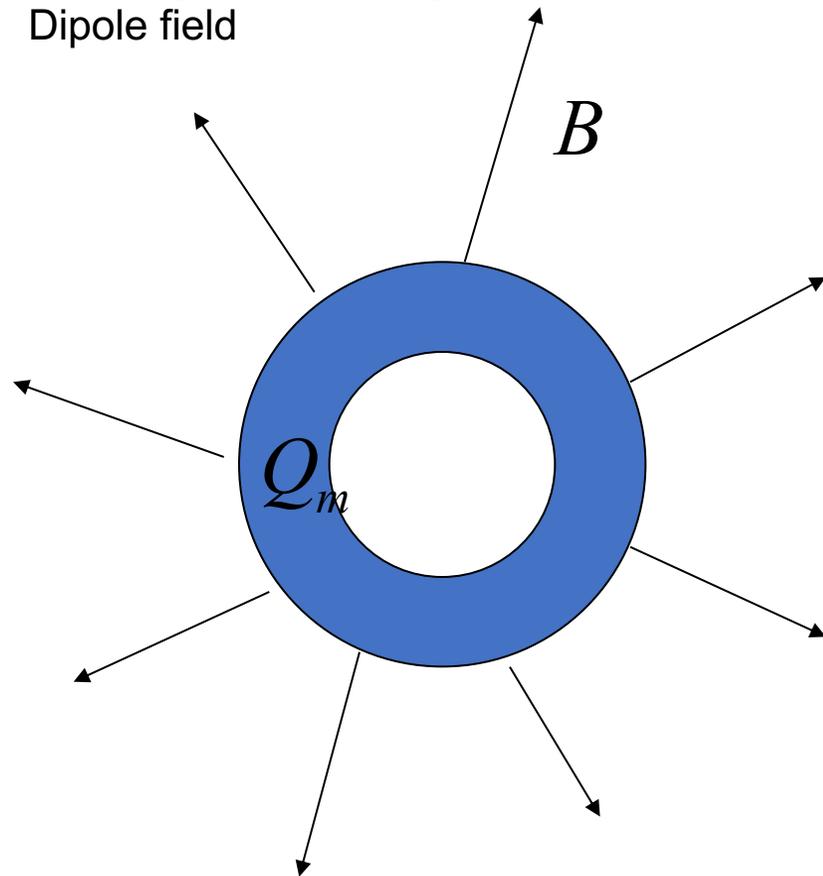
Torus-like stable wormhole $\gamma = 1$

Two types of magnetic fields (Kirillov, Savelova, EPJC, 80, 45 2020)

a) **Magnetic charge**
Dipole field

B

Q_m

b) **Electric (fictitious) current**
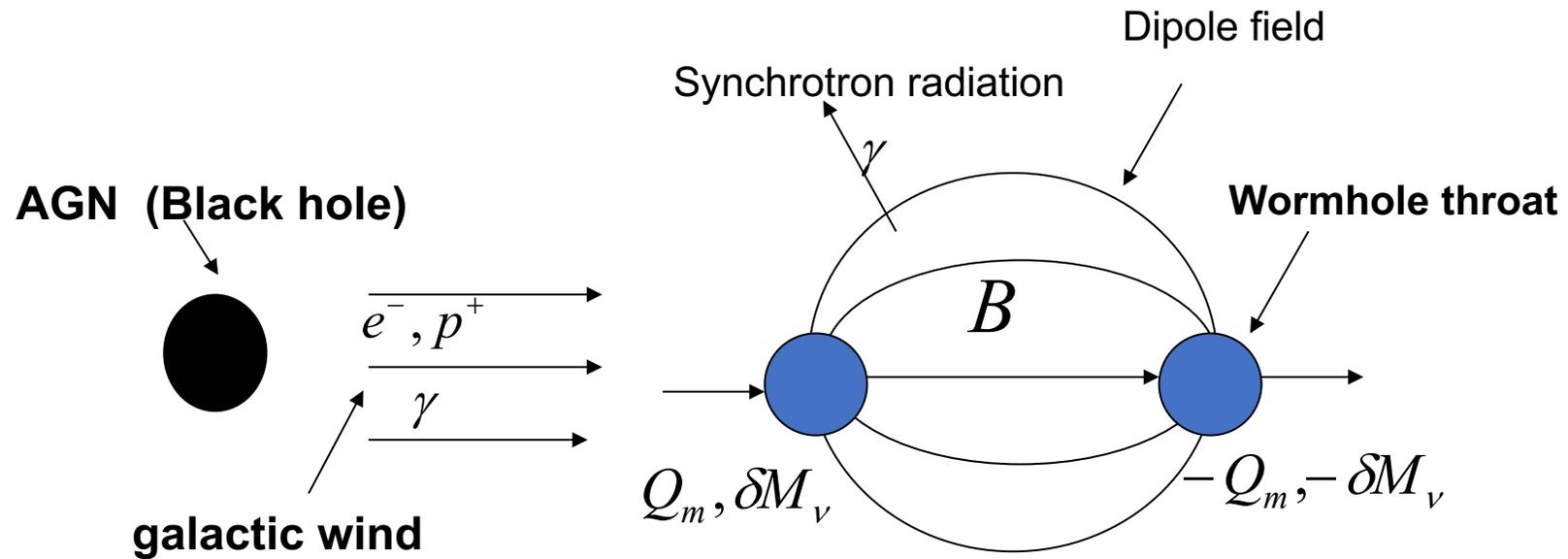Toroidal field

B

j
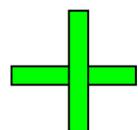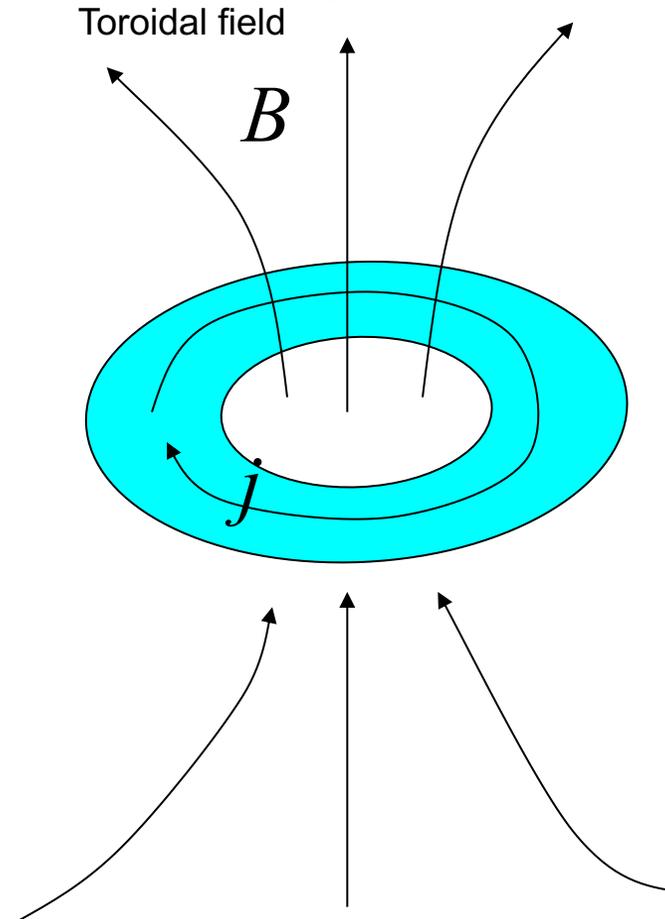
Analogous electric lines

4. Possible effects of relic wormholes

1. Collective effects, scattering on wormholes, KSZ effect, (Kirillov, Savelova, EPJC, 81 263 2021; Astr. Sp. Sci. **364**, 1, 2019; Universe, **4**,35,2018)

2. Effects of individual magnetic wormholes:

    a) Accelerator of charged particles
    (Kirillov, Savelova, EPJC, 80, 45 2020)

b) Formation of ring-type clumps of baryons
(Kirillov, Savelova, EPJC, 80, 810, 2020)

$Z = Z_{rec}$, $R(Z)$, $L(Z)$

1) $R(0) \sim 1 Mpc$

$\delta_b(Z_{rec}) \sim 4, 8 \times 10^{-3}$

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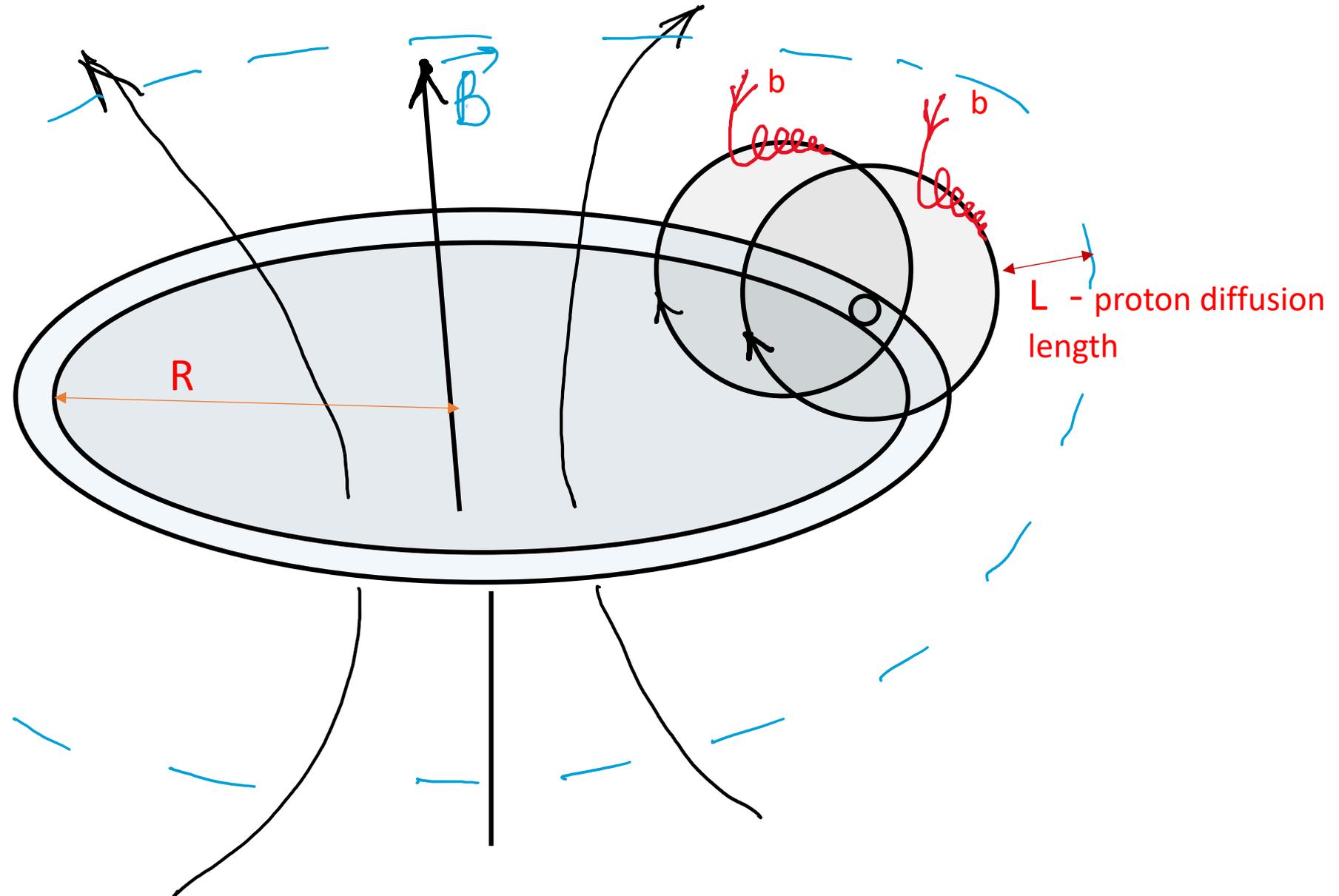
$\delta_b(Z_{rec}) \sim 0.32 \div 0.8$

3) Smaller Wormholes
   $R(0) < Kpc$
collapse before recombination

R

L - proton diffusion length
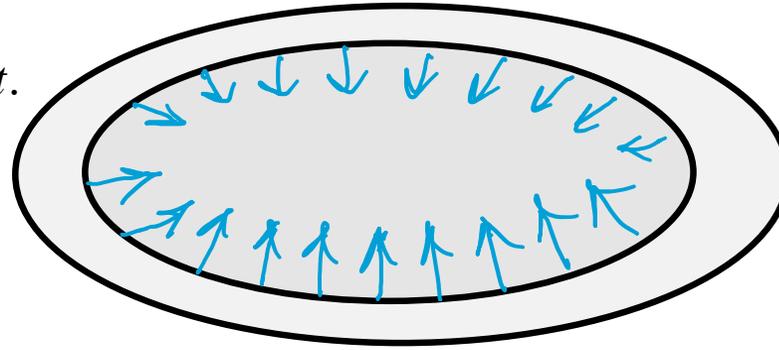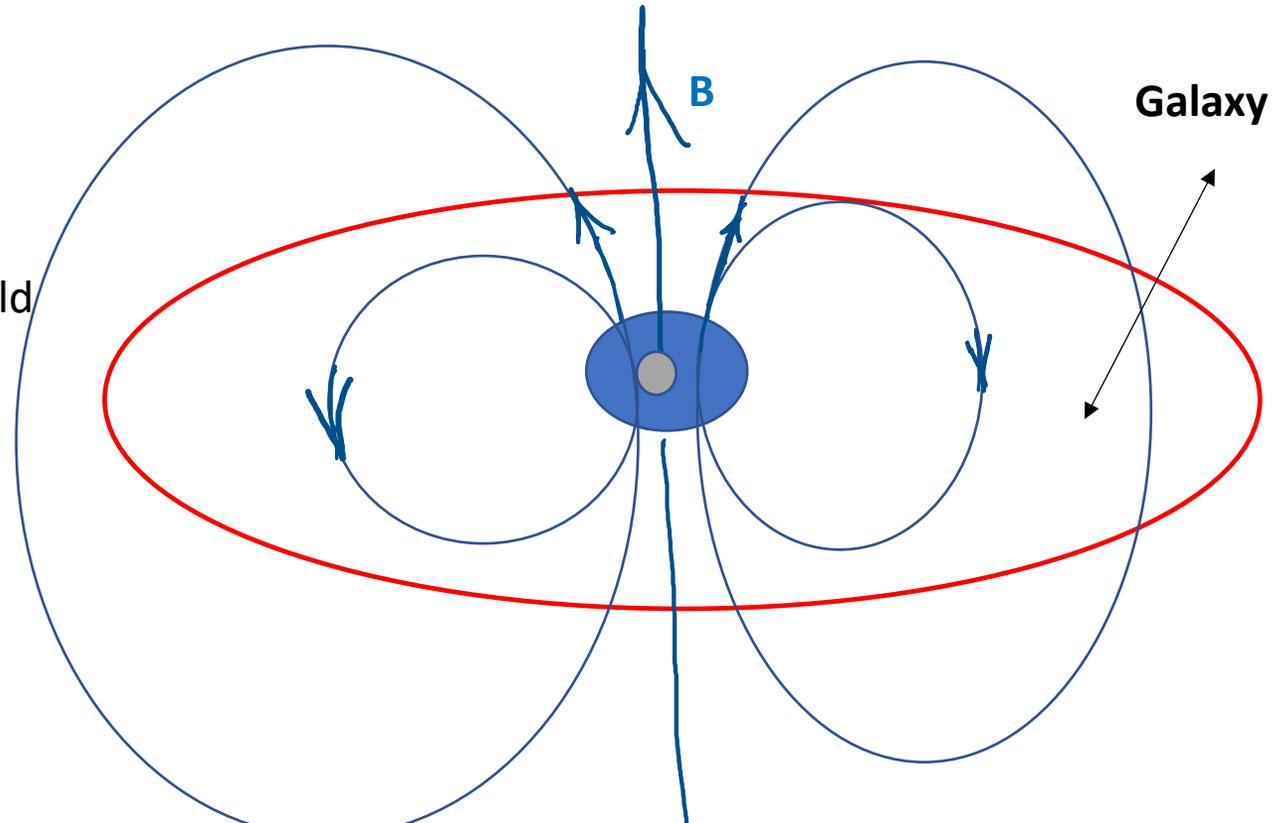
b

b

c) Formation of toroidal magnetic fields in galaxies

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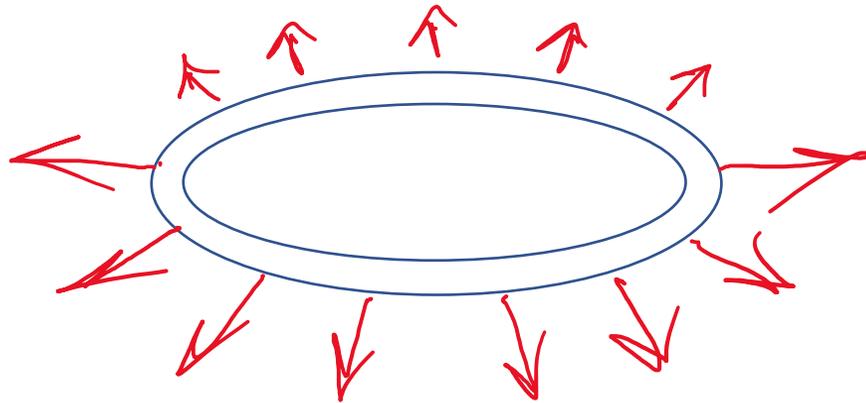*do not interact with baryons! They are independent.*

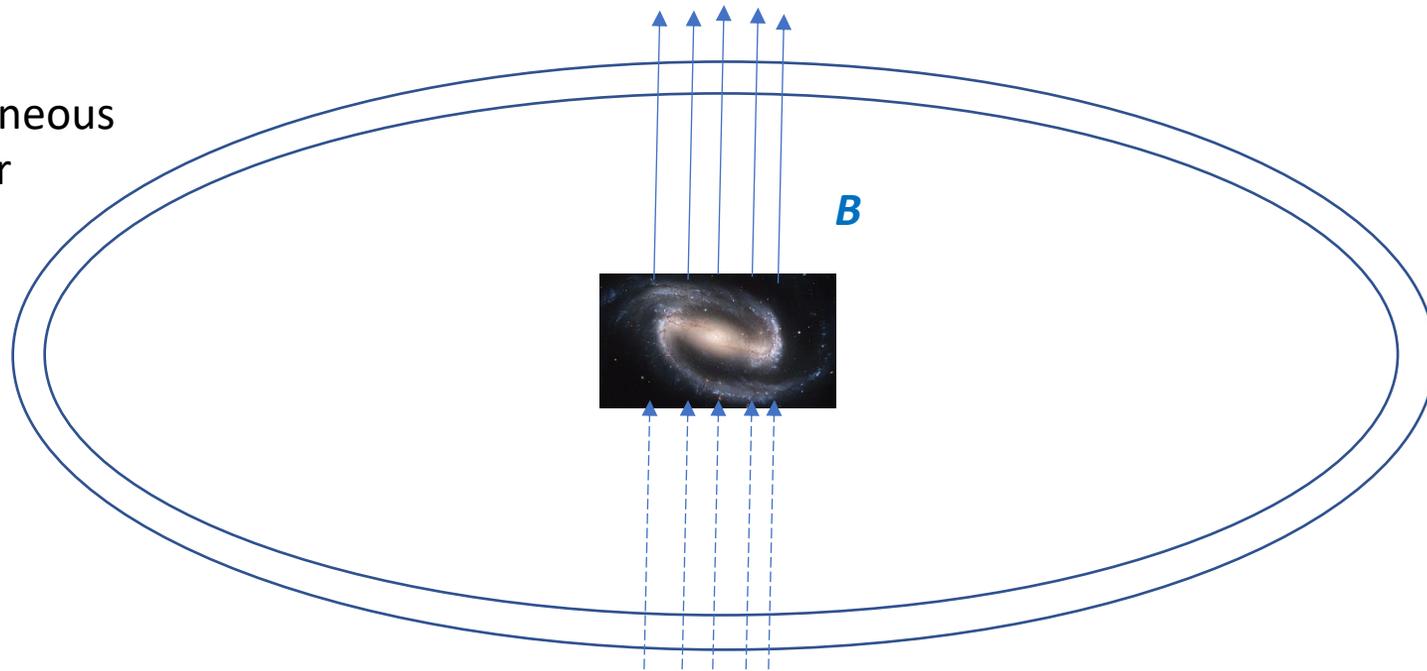1) Relic wormhole collapses into
magnetized black hole $R(0) < 15Kpc$

Magnetic BH in the center
forms inhomogeneous toroidal field

B

Galaxy

2) Relic wormhole expands $R(0) > 1Mpc$ $\delta_b(Z_{rec}) << 10^{-3}$

Outer ring forms homogeneous
toroidal field in the center

B

Overview

1. Objects like stable wormholes should exist and they may have torus-like throats.
2. Magnetic wormholes lead to new observable phenomena (accelerators,
Formation of ring-type structures, specific magnetic fields, etc.).
One possible candidate maybe found by R.P. Noris et al,
"Unexpected circular radio objects at high Galactic latitude" Astr. Soc. Australia 38 (2021) e003

Thanks for attention!