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Wormholes with entrances close to each other

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Contents

Abstract. Theoretical and observational evidence is examined to verify the hypothesis put forward by N S Kardashev that some of the double images of galactic nuclei can be entrances to the same wormhole.

Keywords: wormholes, Einstein's general theory of relativity, multiverse

1. Introduction

The notion of wormholes in general relativity has been known for a century [1]. Since the 1930s, the problem of wormholes has been actively debated from different standpoints. The topic has been especially lively discussed in the last few decades (see the references in [2]).

In [3, 4], we put forward the hypothesis that some astrophysical objects, for example, nuclei of some galaxies, could be wormhole mouths. We have investigated the observational consequences of this hypothesis. In [2], a new concept of wormholes was proposed that treats the question of wormholes from a somewhat different standpoint. In the last decade, intriguing observations of double galactic nuclei have been made [5, 6]. This paper aims to revisit the wormhole hypothesis in light of new theoretical and observational discoveries. We suggest examining the possible interpretation of some images of double galactic nuclei in terms of close mouths of one wormhole.

Wormholes have not been discovered to date. Unlike black holes (BHs), which had been hypothetical for a long time but were discovered by astrophysicists and have been thoroughly studied, wormholes remain hypothetical. Kip Thorne writes: "Whereas black holes are an inevitable consequence of stellar evolution... there is no analogous, natural way for a wormhole to be created" [7, p. 491]. "On the other hand, there are reasons to believe that natural wormholes exist at the submicroscopic level in the form of the so-called quantum foam" [8]. "...There is a chance that... some of the microscopic wormholes can spontaneously grow to human or larger scales, and this had occurred during incredibly rapid 'inflationary' expansion of the Universe" [8]. The evolution of quantum foam is governed by quantum gravity. However, no generally recognized theory of quantum gravity exists. Quantum gravity tunnels pass outside our space–time in the so-called hyperspace. It is assumed that a microtunnel emerges when some singularities in two different places of the universe meet each other in hyperspace. According to Thorne [7, p. 491], "...it is hard to understand how two of them could meet each other in the vast reaches of hyperspace, so as to create a wormhole." As mentioned above, there is no theory of this process as yet, and we can only rely on guesses and intuition.

In addition to the guess that the centers of some galaxies could be wormhole mouths, we conjecture that under certain conditions the probability of the emergence of two mouths of a wormhole at a relatively close distance in the universe might be higher than their emerging far away from each other. Based on this assumption, we hypothesize that in the centers of some galaxies there can be two nearby mouths of a wormhole. In this paper, we consider new theoretical studies of wormholes and discuss how astrophysical observations could test new hypotheses. We discuss new images of double galactic nuclei and their possible interpretation.

2. Different types of wormholes

The properties of different types of wormholes were analyzed in [2]. It was proposed that three types of wormholes be distinguished: (1) static wormholes, (2) space-like wormholes, (3) time-like wormholes. For simplicity, we consider spherical wormholes.

Static wormholes represent a quasistatic or stationary tunnel in hyperspace, connecting two mouths located in one universe or even in two different universes of the multiverse model [9]. Like wormholes of the second type, they are space-

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like. They differ from the second type of wormholes in that the latter are highly dynamic and could be nontraversable. However, as noted above, both type-1 and type-2 wormholes are space-like, and in this paper we combine them into one class-I, space-like wormholes, while time-like wormholes are referred to as 'class-II wormholes'. In time-like wormholes, time flows along the tunnel, and they can be traversable in one direction only: from past to future. When both mouths of a time-like wormhole are in one universe, they can simultaneously serve as a time machine [10]. This does not lead to any problems with the causality principle (see [11, 12]) but, of course, could result in peculiar physical processes [13]. Here, we try to find possible wormhole candidates among galactic nuclei from astrophysical observations. Therefore, we mainly focus on type-I wormholes, because they differ most strongly from entrances to black holes.

We note that class-I wormholes are the classic examples of the wormhole models that initiated their studies. In what follows, we deal with class-I wormholes and only mention class-II wormholes whenever necessary.

Empty wormholes are nonstatic [2]. Gravity of the strongly curved space–time tends to squeeze the tunnel into a line singularity. To stabilize the tunnel, it has to be filled, for example, with exotic matter with the energy density $\epsilon < 0$. The antigravity of matter with $\epsilon < 0$ balances the gravity of curved space. As a result, a static model can be constructed. Such models can be stable or unstable under small perturbations.

The masses of the mouths of class-I wormholes can be arbitrary, not equal to each other for any pair, and even negative. The entrances (which are also exits) are not surrounded by an event horizon, unlike BHs, and do not have any sharp boundaries; they can be used to enter and exit. Wormholes can be traversable in both directions for matter and radiation. A radial magnetic field can also pass through the tunnel, its space topology keeping the field from expansion. The exits then look like magnetic monopoles with opposite signs. We note that in the absence of elementary magnetic monopoles in nature, such magnetic field configurations cannot exist in black holes.

We stress the following fact: in the absence of elementary magnetic monopoles, radial magnetic fields can exist not only in wormholes but also in some other hypothetical objects. For example, the collapse of a wormhole with a magnetic field results in the formation of BHs with a residual magnetic field. However, these objects would then be connected by a singularity resulting from the collapse [14]. In the Reissner–Nordstrom solution, entrances and exits of the object have a radial magnetic field. However, as was shown in [2], these are mouths of time-like wormholes. More complicated cases are possible. We stress that all these objects are related to wormholes. Observations of such objects would be equivalent to the discovery of wormholes or results of the wormhole evolution.

The main observational proof that a compact object is the mouth of a wormhole and not a BH can be as follows (see [15]):

1. The magnetic field quite close to the mouth is a monopole one (taking the above stipulations into account). Estimates (see [16, 17] and below) show that the maximum magnetic field at the mouth of a wormhole is

$$H \approx 3 \times 10^{10} \left(\frac{3 \times 10^{14}\,[\mathrm{cm}]}{l} \right) [\mathrm{G}]\,. \tag{1}$$

2. The possibility of matter outflow from the mouth, i.e., the observation of blue-shifted radiation from the outflow near the mouth, which is impossible for BHs.

3. The fundamental possibility of seeing other regions of our universe or even other universes through the tunnel, suggesting the appearance of a specific shadow from a wormhole with small-size details.

4. The fundamental possibility of seeing the interior of a wormhole and the space outside its opposite mouth suggests observation of possible radiation variability on time scales shorter than the size of the exit divided by the speed of light.

The observational properties listed above are sufficient but not necessary. We note in conclusion that the structure of tunnels of time-like wormholes is much more complicated, comprising, in particular, Cauchy horizons and infinite pieces of space–time not belonging to our universe. Therefore, processes beyond the Cauchy horizons depend on conditions both in our universe and in these additional structures (see [2]).

3. Close mouths of a wormhole

The main goal of this paper is to scrutinize the hypothesis that some double galactic nuclei can represent mouths of a single wormhole. In this section, from the theoretical standpoint, we consider observational properties that can be expected from such an object.

We recall that one of the possible characteristics of a wormhole is the radial magnetic field piercing it from one mouth to the other. The mouths then appear like magnetic charges with opposite signs, and close exits form a magnetic dipole. We consider its properties.

We examine the simplest model: a zero-mass wormhole [18–21] with a magnetic field [17].

The metric ($c = 1$, $G = 1$) is given by

$$\mathrm{d}s^2 = \mathrm{d}t^2 - \mathrm{d}R^2 - r^2(\mathrm{d}\theta^2 + \sin^2\theta\,\mathrm{d}\phi^2)\,, \qquad r^2(R) = l^2 + R^2\,, \tag{2}$$

where $q = \mathrm{const}$ is the radius of the wormhole throat. The energy–momentum tensor includes two parts:

(1) that of the radial magnetic field

$$T^0_{0\,\mathrm{magn}} = T^1_{1\,\mathrm{magn}} = -T^2_{2\,\mathrm{magn}} = -T^3_{3\,\mathrm{magn}} = \frac{q^2}{8\pi r^4}\,, \tag{3}$$

with the remaining $T^m_{n\,\mathrm{magn}} = 0$; q characterizes the magnetic field intensity;

(2) the part due to exotic dust

$$T^0_{0\,\mathrm{d}} = \frac{q^2}{4\pi r^4}\,, \tag{4}$$

with the remaining $T^m_{n\,\mathrm{d}} = 0$.

We consider the simplest ideal models and therefore do not discuss stability issues. If the mouths of this model are spatially close to each other, they form a magnetic dipole with zero mass. This and many other observational properties of a wormhole are model-dependent and are determined by its internal structure.

We consider a more complicated model. This is a wormhole similar to that considered in [17]: it has zero mass ($m = 0$) at both mouths. The metric is similar to (2):

$$\mathrm{d}s^2 = \mathrm{d}t^2 - \mathrm{d}z^2 - (z^2 + n^2)(\mathrm{d}\theta^2 + \sin^2\theta\,\mathrm{d}\phi^2)\,, \tag{5}$$

where n is a scalar related to the necessary matter in geometrical units, and $-\infty < z < \infty$. The matter maintaining the staticity of the wormhole consists of

(1) the radial magnetic field with the energy–momentum tensor

$$T_i^k(e) = \frac{Xe^2}{8\pi r^4}\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}, \tag{6}$$

where $r^2 = z^2 + n^2$, X is the proportion of the magnetic field and the proportion of the exotic dust in the total energy density, and e^2 is the magnetic field strength in the throat $z = 0$.

(2) Exotic dust with the density ρ:

$$T_i^k(\rho) = \frac{X\rho}{8\pi r^4}\begin{pmatrix} -2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}, \tag{7}$$

with $-2\rho X = -2e^2 X$ being the dust density in the throat.

(3) An exotic massless scalar field with the characteristic strength $-n^2 = T_0^0(n)$:

$$T_0^0(n) = \frac{(1-X)(-n^2)}{8\pi r^4}. \tag{8}$$

The total tensor T_i^k of all types of matter is

$$T_i^k = T_i^k(e) + T_i^k(\rho) + T_i^k(n). \tag{9}$$

The maximum possible magnetic field for metric (5) corresponds to $X = 1$; the value $X = 0$ corresponds to the absence of the magnetic field.

For a fixed size of a wormhole with the throat $r^2 = n^2$, the maximum possible magnetic field piercing the wormhole is

$$\frac{e}{r^2}, \qquad e^2 = n^2. \tag{10}$$

This model with $m = 0$ is, of course, an idealized case, and it is logical to consider the model with a nonzero mass, as was already done in [3]. We treat the mass as an arbitrary parameter that depends on the wormhole structure. The masses of different mouths can be different and even negative. Of profound interest for us are bound binary systems, and we consider only such binaries. We assume the conditions under which Newtonian gravity can be used. The general Kepler problem, including bodies with negative masses, was considered in [22]. In this paper, we consider similar problems, taking the electromagnetic interaction of oppositely charged mouths into account. To understand the main features, for simplicity we consider binary systems (two mouths of one wormhole) in circular orbits around the common barycenter. The opposite mouths of such a dipole system have equal effective magnetic charges with opposite signs. A similar problem under special conditions was addressed in [3].

Figure 1 schematically shows two mouths of a wormhole with masses m_1 and m_2 with the same charge q, orbiting the barycenter. The orbital separation is $\tilde{R}$. The interaction force is the sum of the Coulomb attraction of the $\pm q$ monopoles and the gravitational attraction of masses m_1 and m_2:

$$F = \frac{Gm_1m_2}{\tilde{R}^2} + \frac{q^2}{\tilde{R}^2} = \frac{Gm_1m_2 + q^2}{\tilde{R}^2}. \tag{11}$$

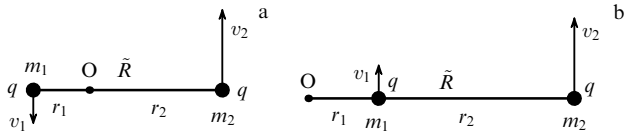

Figure 1. Two mouths of a wormhole with masses m_1 and m_2 in orbit around the barycenter O. (a) Both masses m_1 and m_2 are positive. (b) Mass m_1 is positive and the mass m_2 is negative, with $|m_1| > |m_2|$.

Here and below, we assume that $G \neq 1$. The orbital period of this system is

$$T = 2\pi\tilde{R}\sqrt{\frac{m_1m_2\tilde{R}}{(Gm_1m_2 + q^2)(m_1 + m_2)}}, \tag{12}$$

and the linear orbital velocity of the mouth m_1 is

$$v_1 = \sqrt{\frac{m_2(Gm_1m_2 + q^2)}{m_1(m_1 + m_2)\tilde{R}}}. \tag{13}$$

These expressions are valid if both masses are positive. If one of the mouths, for example, m_2, has negative mass, $m_2 < 0$ (as shown in Fig. 1b), there is a constraint on the sign of the denominator in formula (12) for the orbital period T. The denominator must be negative, and if the total mass of the system $m_1 + m_2$ is positive, the inequality $Gm_1m_2 + q^2 < 0$ must hold, restricting the value of the charge:

$$q < \sqrt{-Gm_1m_2}. \tag{14}$$

The same restriction can be obtained from expression (13) for the velocity.

To estimate the lifetime of the system, we assume, for simplicity, equal masses of both mouths. The accelerated motion of charges causes dipole electromagnetic radiation with the intensity [23]

$$I_{\text{em}} = \frac{2}{3c^3}\ddot{d}^2 = \frac{8q^2(Gm^2 + q^2)^2}{3c^3m^2\tilde{R}^4}. \tag{15}$$

The quadrupole gravitational wave radiation is [23]

$$I_{\text{gr}} = \frac{32\,G\mu^2\omega^6\tilde{R}^4}{5c^5} = \frac{64G(Gm^2 + q^2)^3}{5c^5m\tilde{R}^5}. \tag{16}$$

The total energy losses by the system include both electromagnetic and gravitational radiation:

$$I = I_{\text{em}} + I_{\text{gr}} = \frac{8(Gm^2 + q^2)^2}{c^3\tilde{R}^4m}\left(\frac{q^2}{3m} + \frac{8G(Gm^2+q^2)}{5c^2\tilde{R}}\right). \tag{17}$$

The total energy of the system with the electromagnetic and gravitational interactions taken into account is

$$E = -\frac{Gm^2 + q^2}{\tilde{R}}. \tag{18}$$

Then the lifetime of the system, by the order of magnitude, is

$$\tau \approx \frac{E}{I} = \frac{m\tilde{R}^3c^3}{8\,(Gm^2+q^2)\big(q^2/3m+8G(Gm^2 + q^2)/5c^2\tilde{R}\big)}. \tag{19}$$

4. Images of close galactic nuclei

In the preceding section, we theoretically considered the possibility of the existence of close mouths of a wormhole. Here, we present some observational facts supporting this point of view.

If two close mouths of one wormhole have magnetic fields, the field directions near the mouths should be opposite, such that they form a magnetic dipole in the external space. In this case, the radiating plasma would likely extend from one mouth to another. In other cases, such a field structure connecting two objects is impossible, and explanations of a similar visible structure are confusing.

Figure 2 shows the double nuclei of some galaxies.

In Figure 2d, the faint dashed line is an artist's view of a tunnel connecting two nuclei and lying outside our space–time.

5. Conclusion

Observational appearances of a wormhole with close mouths are dependent on the electromagnetic processes in such unusual conditions.

We estimate the magnetic fields near the wormhole mouths. Formula (1) is obtained for the particular wormhole model constructed in [3]. In this model, the magnetic field and exotic dust with $\epsilon < 0$ give rise to antigravity balancing the gravity of the strongly curved space, which makes the model

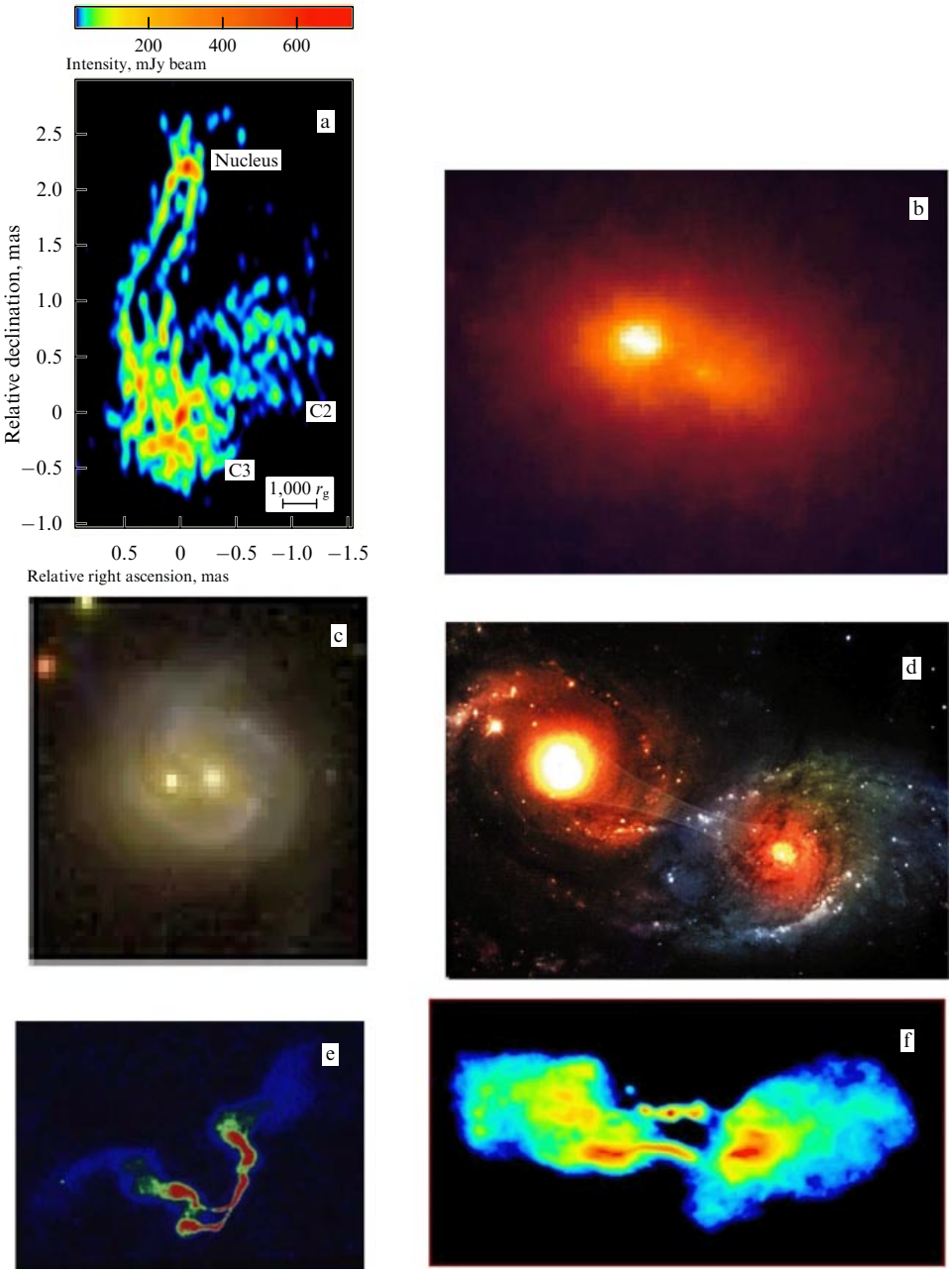

Figure 2. (Color online.) (a) Radio image of the central parsec of 3C84 [24]; (b) double nucleus in M31, https://hubblesite.org/contents/media/images/1993/18/110-Image.html; (c) double nucleus in NGC 3758 [25]; (d) galaxies NGC 2207 and IC 2163 [26]; (e) nucleus of the quasar 3C75; (f) double nucleus of the galaxy NGC 6166.

static. The required magnetic field strength in the wormhole throat should be

$$H \approx \frac{c^2}{G^{1/2} l} \,. \tag{20}$$

We note that for the Reissner–Nordstrom solution [10] describing a type-II wormhole, a similar estimate follows from the condition of its existence [27]:

$$\frac{Ge^2}{c^4} = \frac{G^2 M^2}{c^4} \,. \tag{21}$$

Thus, possible wormholes with close mouths have one more observational feature (see Fig. 2) that can be used in attempts to identify them.

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