Colloques internationaux du C.N.R.S.
N° 263 - L'ÉVOLUTION DES GALAXIES ET SES IMPLICATIONS COSMOLOGIQUES

WHITE HOLES OF TYPES II AND III

K. Lake & R.C. Roeder
Scarborough College and
David Dunlap Observatory,
University of Toronto

Nous donnons une discussion qualitative des trous blancs dans le contexte d'un espace de Schwarzschild au sein d'un univers de Robertson-Walker (ce sont les solutions fondamentales de trous trouvées par Schücking et al.). Nous montrons que les configurations d'expansion (trous blancs) peuvent être classées en types I, II ou III suivant la région de l'espace de Schwarzschild dans lesquelles elles s'étendent à partir de la région IV. Nous discutons plusieurs propriétés des différents types, et montrons que si le trou est de type II ou III, la radiation reçue par un observateur peut avoir un décalage vers le rouge intrinsèque non lié au décalage cosmologique.

(a) Classical White Holes

The "White Hole" (hereinafter abbreviated as W.H.) or "Lagging Core" was introduced in 1964 by Novikov and 1965 by Ne'eman in their investigations of explosively expanding configurations which might be related to the quasar phenomenon. The process envisaged was somewhat the opposite of the process of collapse which is widely believed to lead to the existence of "Black Holes". Both processes can be exhibited with maximum clarity in the conformal diagram of the extended Schwarzschild manifold due to Penrose, as indicated in Fig. 1. Details of the conformal technique are given by Hawking and Ellis (1973) and Lake (1976, for $\Lambda \neq 0$).

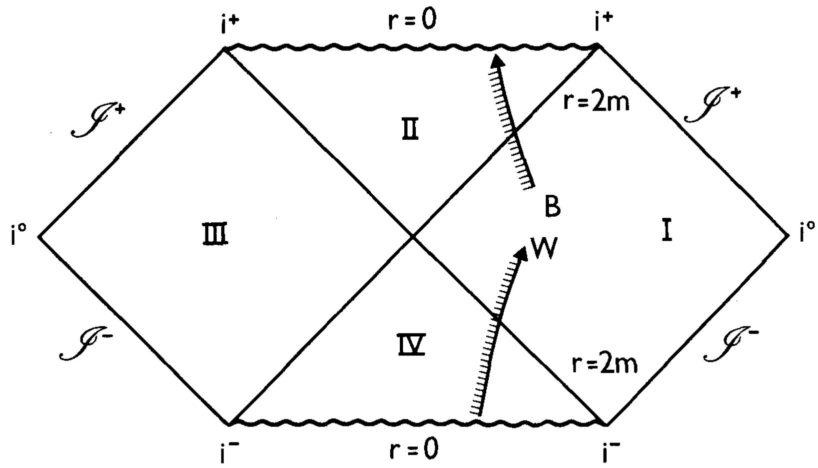

Fig. 1: The conformal diagram of the extended Schwarzschild manifold, assuming $\Lambda=0$. Curves B and W are the world lines of particles on the surfaces of configurations which are undergoing collapse and expansion, respectively. The hatching indicates where suitable interior solutions must be used.

In the case of gravitational collapse (assuming spherical symmetry) the world line of a particle on the surface of the collapsing configuration is simultaneously a radial, timelike geodesic of both the interior and exterior metrics and is represented in the diagram by B. The hatching to the left of B indicates that this part of the extended Schwarzschild manifold is not present since this is the interior of the configuration where a suitable interior metric, e.g. a section of Robertson-Walker, (hereinafter R-W) must be used. The classical W.H. is represented by the curve W which is a radial, timelike geodesic of both the vacuum and interior metrics and is the world line of a particle on the surface of the W.H. To the left of W we have the interior of the configuration which is again usually represented by an expanding "dust ball" with a section of the R-W metric. This classical W.H., which might well be called a Type I W.H. because it expands into the region I of the Schwarzschild manifold,has been widely discussed in recent years, in particular by Szekeres (1973), Eardley (1974) and Narlikar and Apparao (1975).

Both Szekeres and Eardley have claimed that radiation could be present on the spherical surface $r=2m$ with $1+z=0$; i.e. it would contain photons blueshifted to infinitely high energy. For this reason they have argued that any ball of particles attempting to expand through $r=2m$ into region I will be either unable to do so or will be blown to pieces upon encountering this "blue sphere". However K. Lake and I have subsequently

https://doi.org/10.1017/S0252921100053951 Published online by Cambridge University Press

pointed out that this argument is completely vitiated if one realizes that such radiation would have to come from past timelike infinity (i^- in Fig. 1), and truncates the vacuum manifold by terminating it on a cosmic background, e.g. the simple vacuole or "Swiss Cheese" procedure first described by Schücking (1954). If we assume that the universe began with a "Big Bang", then i^- of region I is necessarily removed and so any photons present on the horizon r=2m must of necessity have finite energy (Lake and Roeder, 1976). Since one can envisage, particularly in an open universe, expanding configurations described by sections of the R-W metric with k=0 or -1 (in Newtonian terms these have zero or positive total energy) it seems quite possible that such W.H.'s would neither recollapse nor be "blown to pieces". Such a situation is illustrated schematically in Fig. 2 where U represents the world line of a particle on the boundary between the universe and the Schwarzschild vacuum and W the world line of a particle on the boundary between the W.H. and the Schwarzschild vacuum.

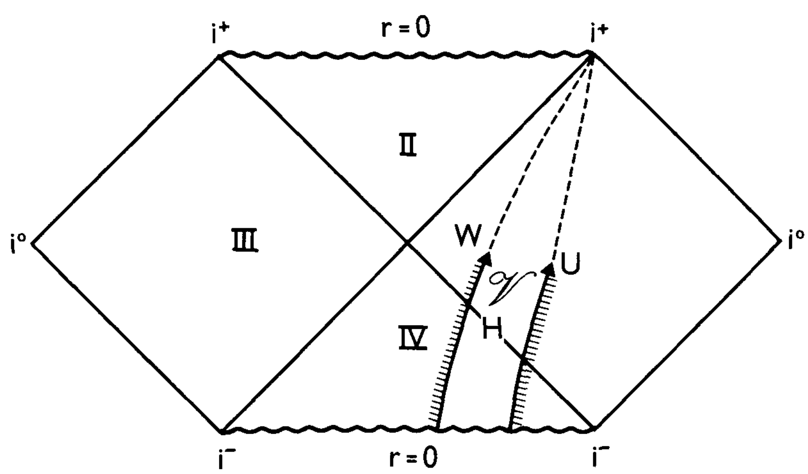

Fig. 2: The removal of past timelike infinity (i^-) by setting the White Hole in a vacuole in a "Big Bang" universe.

To the left of W and to the right of U we have sections of R-W metrics with k=0 or -1. In this case the vacuum section consists only of V, the empty space between the exploding configuration and the universe. In fact, if we consider the simplest case in which both the W.H. and the universe are described by R-W metrics with k=0, then it can be shown that radiation emitted by U and received by W as it passes the horizon H will be received with 1+z=1; i.e. there is no frequency shift whatsoever! There are then obviously no blueshifted photons to be used for the Szekeres-Eardley argument.

(b) White Holes of Types II and III

The extension of the W.H. concept will now be obvious from the figures

https://doi.org/10.1017/S0252921100053951 Published online by Cambridge University Press

already presented. We can draw the curves representing the world lines of particles on the surfaces of Type II and Type III W.H.'s as shown in Fig. 3.

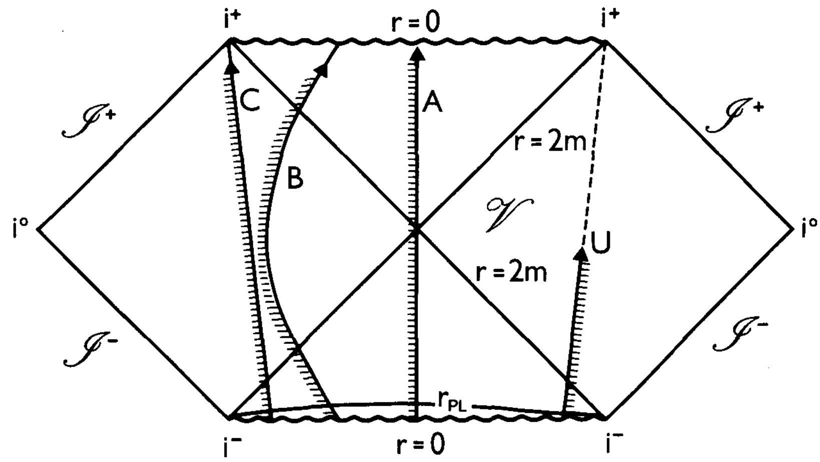

Fig. 3: White Holes of Types II and III indicated schematically by curves A,B,C. See text for details.

In order to discuss these W.H.'s we have to make full use of the extended Schwarzschild vacuum manifold discovered by Kruskal (1960), an essential feature of which is the existence of region III (sometimes called the "mirror world") in which can occur the same processes as occur in region I. It is important to realize that all four regions are present only in vacuum and that it is impossible for ordinary material particles to pass from region I to III or vice versa, although tachyons (if they should exist) would be able to do so (Honig, Lake, and Roeder 1974). In discussions involving the extended Schwarzschild manifold the observer is conventionally assumed to reside in region I; we shall continue to use this convention. In Fig. 3 we may visualize ourselves as living somewhere to the right of U, in a R-W universe which is matched onto a Schwarzschild vacuum solution V. Curve A, which passes from region IV directly into region II represents the world line of the surface of Type II W.H. Curves B or C which pass from region IV directly to region III do the same for Type III W.H.'s. It can be seen immediately that the Type II W.H. is unique, in that there is only one way to pass directly from region IV to region II. The Type III W.H. with k restricted to +1 (curve B) has been discussed by Szekeres and others (see Zel'dovich (1963)). The matter distributions in each of these W.H.'s, as well as those of type I, are represented by R-W metrics which terminate at some value, χ_B, of the radial comoving coordinate. The distinction between W.H. of types I and III is formulated on the basis of the extrinsic curvature of the boundary surface.

https://doi.org/10.1017/S0252921100053951 Published online by Cambridge University Press

(c) Observational Properties

Narlikar and Apparao have discussed some of the observational properties of a Type I W.H. whose interior metric is R-W with k=+1. We have calculated the redshifts of photons on radial trajectories which would be measured by a stationary observer (at constant r, θ, ϕ) in region I, for all three kinds (k=±1,0) of Type I W.H., for the Type II W.H. and for all three kinds (k=±1,0) of Type III W.H. However, it is immediately obvious from Fig. 3 that any photons emitted by particles on trajectories A,B,C just before they leave region IV will have a very large redshift when received by our stationary observer in region I. An observer further out in the universe beyond U would measure a still larger redshift. This happens because as particles on trajectories A,B,C are about to leave region IV, photons emitted by them into region I will behave similarly to photons emitted by a collapsing object which is about to pass from region I into region II along the curve B of Fig. 1. The big difference, of course, is that as an object passes from region I to region II the observer in region I could jump aboard and become a participator (in principle at least); no observer in region I can jump aboard a distribution whose surface is represented by curve A, B or C in Fig. 3. The events represented by B and C are taking place on the other side of the famous Kruskal throat, events represented by A are taking place in the throat.

The redshifts measured by the stationary observer at r_0 in region I are shown in Fig. 4 for a variety of W.H.'s whose interior metrics are characterized by various values of the curvature constant k (=±1,0) and boundary coordinate χ_B; the parameter M measures the gravitational mass as determined by the stationary observer. An inspection of the figure shows that $(1+z)\to\infty$ as $T_{obs}\to\infty$ not only for Type I W.H.'s with k=+1, but also for all (k=±1,0) Type III W.H.'s and the Type II W.H. If we measure M in units of $10^{12}M_{\odot}$ then the units of T_{obs} in Fig. 4 are approximately 2 M_{12} months.

In Fig. 5 is shown the time interval during which the observer will see the frequency shift change from blue to red for Type III W.H.'s. It will be noted that this happens very fast; again if we use $10^{12}M_{\odot}$ as an example, for Type III W.H.'s with k=-1 or 0, (1+z) changes from 0 to 1 in about 1 week. Thereafter the observer will measure a redshift.

https://doi.org/10.1017/S0252921100053951 Published online by Cambridge University Press

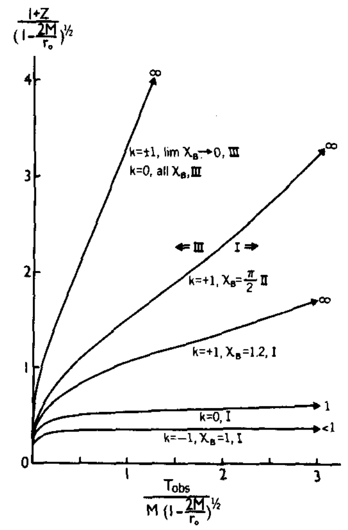

Fig. 4.

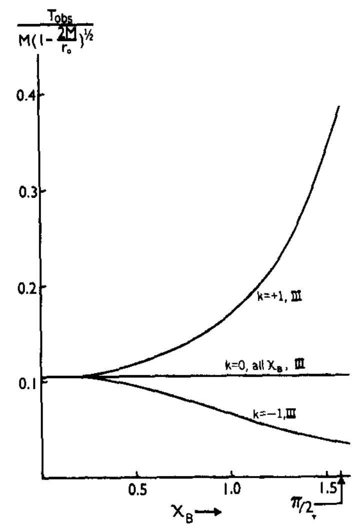

Fig. 5

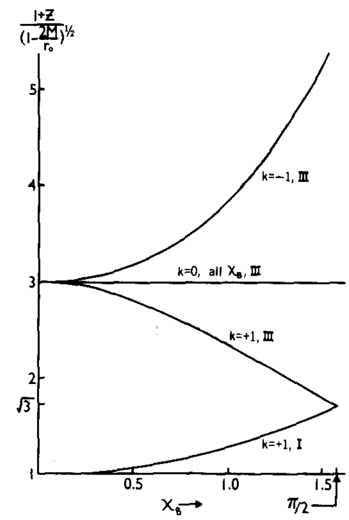

Fig. 6

Fig. 4: Redshifts measured by a stationary observer in region I as a function of his time.

Fig. 5: The time interval for the region I observer to see the frequency shift change from extreme blue to neutral, as a function of the boundary coordinate χ_B, for various Type III W.H.'s.

Fig. 6: The redshift at the time of minimum rate of change of redshift, as a function of the boundary coordinate χ_B, for various W.H.'s.

The value of (1+z) at the epoch when the observer measures the minimum rate of change of (1+z) is shown in Fig. 6 for Type III W.H.'s and some Type I W.H.'s with k=+1. For all Type III W.H.'s the observed rate of change of (1+z) is a minimum when $1+z \geq \sqrt{3}$; for all Type III W.H.'s with k=0, the minimum occurs when 1+z=3. For k=0 and units of $10^{12}M_\odot$ this minimum rate of change is $(\frac{14.2}{M_{12}})$ yrs^{-1}. An additional complication for all W.H.'s is the fact that photons on non-radial trajectories must be taken into account before detailed statements about their appearance can be made. In fact, it appears that radiation from W.H.'s of Types II and III is dominated by photons emitted at the Planck time.

Whether it is compelling or even possible to identify these configurations with any astrophysical objects is not clear at present. It is, however, clear that if these configurations do exist in the universe their spectra will be intrinsically redshifted by a mechanism which has nothing to do with cosmology; it is the gravitational redshift. It should also be pointed out that the masses M associated with Type III W.H.'s by our observer in region I do not measure the proper masses of these configurations, which are significantly larger.

The cosmological model suggested by this picture is a generalization of that considered by Szekeres, viz. a number of Robertson-Walker sections mutually connected by Kruskal throats possibly opening into the centres of certain galaxies, through which energy is interchanged from one section to another.

REFERENCES

Eardley, D. 1974, Phys. Rev. Lett. 33, 442.

Hawking, S. and Ellis, G.F.R., "The Large Scale Structure of Space-time", Cambridge University Press, 1973.

Honig, E., Lake, K., and Roeder, R.C., Phys. Rev. D 10, 3155.

Kruskal, M.D. 1960. Phys. Rev. 119, 1743.

Lake, K. 1976, thesis, University of Toronto.

Lake, K., and Roeder, R.C. 1976. Lett. Nuovo Cimento 16, 17.

Narlikar, J.V. and Apparao, K.M.V. 1975. Astrophys. and Sp. Sci. 35, 321.

Ne'eman, Y. 1965. Astrophys. J. 141, 1303.

Novikov, I.D. 1964. Astron. Zh. 41, 1075.

Schücking, E. 1954. Zs. f. Phys. 137, 595.

Szekeres, P. 1973, Il Nuovo Cimento 17B, 187.

Zel'dovich, Ya. B. 1963, Zurn. Eksp. Teor. Fiz. 16, 732.

DISCUSSION

I. NOVIKOV: I would like to stress that the stable model of a white hole requires a small delay in the expansion($\Delta\tau < \frac{2GM}{c^3}$; M is the mass of the white hole). But we need a large delay in the expansion for the explanation of the explosions of the quasars and/or the other objects ($\Delta\tau \sim 10^{10}$ years $\gg \frac{2GM}{c^3}$). Under this condition all types of the white holes turn into black holes by the quantum process near the singularity (Zeldovich, Novikov, Starobinsky, 1974) and by the matter accretion (Eardley, 1974).

J.-C. PECKER: I admire very much the way in which you are pushing the theory in order to present a new view of the universe. You are careful enough to insist on the very large gap still existing, with the invention of the new white (or black holes), between the mathematical objects and the observed objects. My question is: is there any way, a priori, from your studies to predict statistically how many of these new objects (so far imaginary!) could be found in the observable universe?

R.C. ROEDER: Not yet.

https://doi.org/10.1017/S0252921100053951 Published online by Cambridge University Press