GALACTIC CENTER PULSAR AS A TEST OF BLACK HOLE EXISTENCE AND PROPERTIES

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ABSTRACT: There is a reasonable chance of finding a (probably X-ray) pulsar in a short-period orbit around the galactic center. Such a pulsar can provide a test distinguishing a central black hole from a supermassive object or spinar. It also makes available a good clock in a region of space in which GM/Rc^2 is much larger than solar system values, thus allowing strong-field tests of general relativity.

The existence of expulsive phenomena, short-lived turbulence, IR source 16, excess mass and a compact radio source at or in connection with the galactic center requires a powerful, massive energy source there (Oort, 1977). The source might be a group of small objects (stars colliding in a relativistic cluster, many SNe and pulsars, etc.) or a single large one (supermassive star, spinar, black hole). Observational tests that might distinguish these two classes are discussed by Trimble (1971) and many others. Tests to tell a black hole from an extended object are harder to come by. A pulsar in a relatively short period orbit around the galactic center can provide such a test. It also makes available a good clock in a region of space in which GM/Rc^2 is much larger than solar system values, thus allowing strong-field tests of general relativity.

We need first to assess the probability of finding a usable pulsar. The $5 \times 10^6\ M_\odot$ associated with the galactic center (Wollman et al. 1976) is 2.5×10^{-5} of the total galactic mass. To see a radio pulsar, we need $L_r \sim 10^{32-33}$ erg s^{-1}, implying $P \sim 10-20$ ms (and search frequency $\gtrsim 10$ GHz Davies et al. 1976) and age ~ 100 yr. An X-ray pulsar must have $L_x \sim 10^{34-36}$ erg s^{-1} to be discovered by the HEAO-B imaging camera. This requires a period ~ 0.1 s and age $\sim 10^{3-4}$ yr for a Crab-like pulsar, or an accretion rate $\gtrsim 10^{14}$ g s^{-1} on a 1 $M_\odot$ neutron star. The accretion can be from a binary companion or from high-density regions of the local ISM. If our galaxy has a supernova rate of 0.1 yr^{-1}, 300 weak X-ray binaries, and 10^8 old neutron stars, and the region that scatters radio

W. B. Burton (ed.), The Large-Scale Characteristics of the Galaxy, 401–404.

waves from the central compact source has 10^{-3} of its volume with 10^3 times its average density of 10^3 cm^{-3} (Backer, 1978), then the probabilities of finding one useful pulsar are about 0.0002 for a young radio object, 0.002 for a young X-ray one, 0.02 for an X-ray binary, and 0.2 to 1.0 for an accreting old neutron star. Davies et al. (1976) suggest that the compact radio source is a young pulsar, in which case the problem is solved.

The value of such a pulsar lies in its clock-like nature, allowing us to determine its orbit and probe the nature of space-time in its vicinity. The potential due to a flattened spinar disc at small r is quite different from that of a black hole, so the shape of the pulsar's orbit can distinguish the two cases. In addition, the parameter GM/Rc^2 to which all classic relativity tests are proportional (see, eg., Ohanian, 1976 for the proportionality constants) can be much larger than its maximum solar system and binary pulsar value of 1-2 X 10^{-6}. Table I summarizes the situation for pulsars 10^4 AU (size of the IR source) to 0.1 AU (Schwarzschild radius for 5 X 10^6 $M_\odot$) from the galactic center. V and P are orbit velocity and period; Tau is the lifetime of the orbit against gravitational radiation; ΔE is the gravitational redshift; $\dot{\theta}$ the "perihelion" advance; and $\Delta\theta$ and Δt the light deflection and excess time delay for em radiation with impact parameter R. Blanks in the table indicate unobservably small values or quantities undefined because there are no stable orbits. Gravitational lens effects will give brightness fluctuations also of order GM/Rc^2, but the details are very sensitive to the angle at which we see the system (Cunningham and Bardeen, 1973).

Relativistic Parameters for a 1 $M_\odot$ Pulsar a Distance R from a 5 X 10^6 $M_\odot$ Black Hole

R (AU)	$\frac{2GM}{Rc^2}$	V/c (1)	P (2)	Tau (3)	ΔE at 6.6 keV	$\dot{\theta}$ (4)	$\Delta\theta$ (5)	Δt (6)
10^4	10^{-5}	0.003	450 yr	long	-----	$0\overset{\prime\prime}{.}04$ yr^{-1}	4"	700 s
10^3	10^{-4}	0.01	14 yr	long	-----	14" yr^{-1}	40"	800 s
10^2	10^{-3}	0.03	163 d	6X10^{11} yr	-----	$1\overset{\circ}{.}2$ yr^{-1}	7'	900 s
10	10^{-2}	0.1	5.3 d	6X10^7 yr	0.07 keV	$1\overset{\circ}{.}1$ d^{-1}	$1\overset{\circ}{.}1$	1100 s
1	10^{-1}	0.3	3.7 h	6000 yr	0.7 keV	14° h^{-1}	11°	1150 s
0.1	1	1.0	-----	----	$\gtrsim 7$ keV	-----	2π	1245 s

(1) Orbit Velocity
(2) Orbit Period
(3) Lifetime against gravitational radiation
(4) "perhelion" advance
(5) light deflection for impact parameter R
(6) excess time delay for impact parameter R

Requiring observations of two or more of these quantities to give consistent results constitutes perhaps the only strong-field test of general relativity that can be carried out in our lifetimes.

REFERENCES

Backer, D.L. 1968. Astrophys. J. 222, p.L9.

Cunningham, C. and Bardeen, J. 1973. Astrophys. J. 183, p.237.

Davies, R.D., Walsh, D., and Booth, R. 1976. Monthly Notices Roy. Astron. Soc. 177, p.319.

Ohanian, H.C. 1976. "Gravitation and Spacetime" (New York: Norton & Co.)

Oort, J.H. 1977. Ann. Rev. Astron. Astrophys. 15, p.295.

Trimble, V. 1971. Nature 232, p.607.

Wollman, E.R., Geballe, T., Lacy, J., Townes, C., and Rank, C. 1976. Astrophys. J. 205, p.L5.

DISCUSSION

Burke: The existence of apparently separate expanding features in the central region implies recurring activity. How could a black hole produce recurring activity?

Sanders: A black hole might produce recurring activity in the following way: In the central 200 parsecs of the Galaxy the distribution of interstellar material is obviously quite clumpy. If we suppose that within 100 to 200 pc of the center there are 20 to 30 massive molecular clouds and that the velocity distribution of the clouds is completely isotropic with a dispersion of 100-200 km s^{-1}, then a molecular cloud would actually pass through the center every 10^6 to 10^7 years. An encounter between a molecular cloud and a 10^7 $M_\odot$ black hole could produce quite spectacular results even if a very small fraction of the cloud (10^2-10^3 $M_\odot$) is captured by the hole. In this picture accretion is extremely non-steady-state.

Greyber: (1) K. Lo, M. Cohen, et al. point out the possibility of time variations in the flux from the compact radio source coincident with the peak of Sgr A West. (2) The logical possibility of part of the gravitational energy from collapse of the pre-galaxy cloud being stored in coherent relativistic electrons makes possible models other than "spinars" or massive black holes for such radio sources.

Trimble: (1) This means simply that they did not see the 0''001 component, which could have a variety of expanations. (2) You may be right.

Kaufman: The 10% value for the efficiency factor was a value that Fowler pulled out of the air as the best compromise between 1% and 100%. Is there any better justification now for assuming a 10% efficiency?

Trimble: 0.1 mc^2 is approximately the binding energy for a mass m in that last stable circular orbit around a Kerr black hole with the value of a/M (angular momentum per unit mass) that is thought to result from steady-state accretion.

Burke: To the extent that one accepts the conventional interpretation of the 3-kpc expanding arm and to the extent that one accepts Burton and Liszt's model as a temporary phenomenon, there are separated outbursts of large energy from the galactic center, lasting a relatively brief time. This does not seem to be a natural consequence of the kind of black hole models you have discussed here.