NASA-CR 80197 IN-90 CR 6P.

FINAL REPORT

NASA GRANT NAG8-048

Dates of Grant: May 15, 1986 - May 15, 1987

John R. Ray

Department of Physics and Astronomy

Clemson University

Clemson, South Carolina 29634-1911

(NASA-CR-180654) [THE ROLE AND BEHAVIOR OF SPIN IN GRAVITATIONAL PHYSICS] Final Report, 15 May 1986 - 15 May 1987 (Clemson Univ.) 6 p Avail: NTIS HC A02/MF A01 CSCL 03B

N87-25140

G3/90 Unclas 0080199

FINAL REPORT

1. SCOPE AND BACKGROUND

The role of spin in gravitational physics is of great importance from the point of view of building realistic models of astrophysical objects and in discussing cosmological models. The treatment of spin in gravitational physics has often been treated in a heuristic manner. As an example, we mention the Weyssenhoff theory of spinning matter which has often been added on to gravitational theories in an ad hoc manner. The resulting theory is then used to estimate the effects of spin on physical processes. On the experimental side, the only planned experiment to test the role of spin in gravitational physics is the NASA Gyroscope Experiment (GP-B). This experiment tests a complex of ideas in gravitational physics involving the role and behavior of spin. There are many scientists that feel that Einstein's general relativity does not incorporate spin in a correct manner and will need modification.[1] Thus, the GP-B experiment is of critical importance.

Ray and Smalley[2-9] have embarked upon an extensive study of the treatment of spin in gravitational physics. In the initial phase of this work they have shown how spin can be introduced into any Lagrangian based theory of gravitation. The metric variation of the Lagrangian in the theory leads to an improved energy-momentum (Ray-Smalley) tensor which represents the source term in the gravitational field equations. We emphasize that this inclusion of spin may be carried out in any theory of gravity that is based on a variational principle.

This self-consistent variational principle has already been used by a number of workers to address several important questions in gravitational physics. For example, recent work by Gasperini[10] has shown how the improved energy-momentum tensor, in the Einstein-Cartan theory, leads to the prediction of an inflationary phase in the expansion of the universe at an early epoch. This inflation is driven by the spin density contribution to the improved energy-momentum tensor. In a more detailed study, Bradus, Fennelly and Smalley[11] have shown how the improved energy-momentum tensor leads to power law expansion in an anisotropic Bianchi I model universe. As another example, Tsoubelis[12,13] has presented an exact solution, in the Einstein-Cartan theory, produced by a cylinder of matter with a net spin polarization along its symmetry axis. In this solution the intrinsic spin density gives rise to frame dragging (Lense-Thirring) terms in the external gravitational field. This Lense-Thirring or inductive component of the gravitational field is one of the concepts that will be tested in the GP-B experiment. This solution solves a long standing issue in the Einstein-Cartan theory and shows that gravitational effect of spin are of the same form as orbital angular momentum.

In summary, we have developed a self-consistent method of introducing spin into any gravitational theory. This theory has been used to answer several questions associated with the behavior of spinning matter in gravitational theories.

2. RESEARCH ACCOMPLISHED UNDER GRANT

The goal of the work is the construction of a theory general enough to be used to investigate spin effects in astrophysical objects and cosmology, and also as a basis to discuss the theoretical ideas tested by the gyroscope experiment.

One of the problems we are working on at the present time is the inclusion of electromagnetism into the self-consistent variational principle for spinning matter. In our first work on this subject we have shown how consistency relations appear in the present treatments of this problem.[8] This work was carried out under the present grant. One problem we still face is to include the effects of the electromagnetic field properly in the thermodynamics of the spinning fluid since this plays a crucial role in the self-consistent variational principle and the resulting improved energy-momentum tensor. We hope to finish this work in the near future. This will give us a self-consistent theory of spinning matter coupled with electromagnetism, which may be used in building models of pulsars and spinning quasars.

Another result that we have obtained during this grant is to show that the self-consistent theory may be formulated in the case when one deals with a fluid in which particle production processes occur.[9] Particle production processes occur in fluids when the temperature is greater than the rest masses of the particles. Since this condition is often satisfied in astrophysical fluids this theory will allow the effects of spin to be incorporated in models of this class of astrophysical objects. In a related process, one can also consider the effect of changes of state in neutron stars in which highly condensed fluids change from fluid to superfluid or conducting to superconducting states.

Another general problem we have worked on and solved during the present grant is the correct derivation of the Raychaudhuri equation in the case of spinning matter.[14] This is an important result since the Hawking-Penrose singularity theorems depend in an important way on this equation. We now have a rigorous way to bring spin into the singularity theorems of Hawking-Penrose. This could have important consequences for our basic view of cosmology. Also on the cosmological problem we have recently studied the procedure of spin averaging in homogeneous cosmological models and found that the effects on inflation are larger than the results in the literature.[10,15]

As a final point we have also now to carry out the self-consistent formulation of the spinning fluid in general relativity.[16]

References

1. Letter from C. N. Yang to James M. Beggs dated December 5, 1983, "The proposed Stanford experiment is especially interesting since it focuses on the spin. I would not be surprised at all if it gives a result in disagreement with Einstein's theory."

2. J. R. Ray and L. Smalley, Phys. Rev. Lett. 49, 1059 (1982).

3. J. R. Ray and L. Smalley, "Spinning Fluids in General Relativity", Phys. Rev. D 26, 2619 (1982).

4. J. R. Ray and L. Smalley, "Perfect Fluids in the Einstein-Cartan Theory", Phys. Rev. D 26, 2615 (1982).

5. J. R. Ray and L. Smalley, "Spinning Fluids in the Einstein-Cartan Theory", Phys. Rev. D 27, 1383 (1983).

6. J. R. Ray and L. Smalley, "Spinning Fluid Energy-Momentum Tensors in the Einstein-Cartan Theory", Ann. N.Y. Acad. Sci. 422, 378 (1984).

7. L. Smalley and J. R. Ray, "Geometrization of Spin and Proof of the Weyssenhoff Fluid Conjecture", Gen. Rel. Grav. 18, 549 (1986).

8. J. R. Ray and L. Smalley, "Consistency Relations for Spinning Matter in Gravitational Theories", Phys. Rev. D 34, 3268 (1986).

9. J. R. Ray and L. Smalley, "Equation of State Spinning Fluids in the Einstein-Cartan Theory", Phys. Rev. D 35, 1185 (1987).

10. M. Gasperini, Phys. Rev. Lett. 56, 2873 (1986).

11. J. C. Bradas, A. J. Fennelly and L. Smalley, "Torsion as a Source of Expansion in a Bianchi I Universe in the Self-Consistent Einstein-Cartan Theory of a Perfect Fluid with Spin Density", submitted for publication.

12. D. Tsoubelis, Phys. Rev. Lett. 51, 2235 (1983).

13. D. Tsoubelis, Phys. Rev. D 30, 1632 (1984).

14. A. J. Fennelly, J. P. Krisch, J. R. Ray and L. L. Smalley, preprint.

15. J. R. Ray and L. L. Smalley, in preparation.

16. J. R. Ray, L. L. Smalley and J. P. Krisch, Phys. Rev. D 35, 3261 (1987).