

FINAL REPORT ON
NASA GRANT NGL 16-001-043
FOR RESEARCH ON WAVES IN PLASMAS
(December 1, 1966 - November 30, 1988)
by
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I. Brief Overview

This grant for research on waves in plasmas extended continuously over a twenty-two year period. The original proposal was submitted to NASA by Profs. D. C. Montgomery and D. A. Gurnett on May 26, 1966, with Prof. Montgomery as PI. The proposal was subsequently funded with a starting date of December 1, 1966. The original purpose of the grant was to provide a broad base of support for research on waves in plasmas at the University of Iowa, including specifically the theoretical work of Prof. Montgomery and the space experimental work of Prof. Gurnett. The funds obtained were used mainly to provide support for graduate students, summer faculty salaries, and other activities of a general nature that were not supported by other contracts or grants, such as publication of review papers and travel to international conferences. This general arrangement continued until Prof. Montgomery left the University of Iowa in 1976. The grant activities were then reorganized with Prof. Gurnett becoming the PI effective on September 1, 1977. Two additional Co-Investigators, Profs. N. D'Angelo and C. K. Goertz, were added. Under this new arrangement, Prof. Goertz was responsible for theoretical studies and analysis, and Prof. D'Angelo conducted various laboratory studies and investigations. This combination of investigators was important to the success of the grant because it provided a well balanced representation of space experimental, laboratory experimental, and

theoretical studies of waves in plasmas. Over a period of several years the funding was eventually increased to the point that a full time research scientist was also supported under this grant. This situation continued up to the time that the grant was terminated on November 30, 1988. The total funding of NGL 16-001-043 over the twenty-two year period of the grant was \$2,626,173. A year-by-year breakdown of this funding is given in Section II.

During the twenty-two year period of this grant, a total of 397 research papers were supported completely or in part by this grant. A complete listing of these papers is given in Section IV. Of the research that has been accomplished by this grant, probably the most notable aspect is the strong involvement of graduate students. During the twenty-two year period of this grant a total of 57 graduate thesis projects were supported completely or in part by this grant. A complete listing of these students and the degrees awarded is given in Section III. The strong involvement of graduate students is attributed mainly to the flexibility provided by a broadly-based grant which allowed a wide latitude in assignment of research projects, without restrictive program constraints such as often exist in contracts connected with specific spacecraft projects. Also, the steady and consistent level of funding allowed us to make student appointments without serious concern about having to cancel appointments in mid-year, or in the middle of a thesis project.

Overall, we regard this grant to be very successful, both from a research point of view, and from the graduate education point of view.

II. Funding History of NGL 16-001-043

<u>Time Period</u>	<u>Amount</u>
December 1, 1966 - November 30, 1967	\$44,989
December 1, 1967 - November 30, 1968	49,997
December 1, 1968 - November 30, 1969	75,000
December 1, 1969 - November 30, 1970	75,000
December 1, 1970 - November 30, 1971	78,000
December 1, 1971 - November 30, 1972	70,000
December 1, 1972 - November 30, 1973	66,000
December 1, 1973 - November 30, 1974	64,000
December 1, 1974 - November 30, 1975	68,000
December 1, 1975 - November 30, 1976	59,000
December 1, 1976 - November 30, 1977	85,000
December 1, 1977 - November 30, 1978	90,000
December 1, 1978 - November 30, 1979	101,000
December 1, 1979 - November 30, 1980	125,000
December 1, 1980 - November 30, 1981	186,316
December 1, 1981 - November 30, 1982	165,000
December 1, 1982 - November 30, 1983	165,000
December 1, 1983 - November 30, 1984	180,000
December 1, 1984 - November 30, 1985	180,000
December 1, 1985 - November 30, 1986	241,150
December 1, 1986 - November 30, 1987	216,000
December 1, 1987 - November 30, 1988	241,721
Total Funding	<hr/> \$2,626,173

III. Theses Supported in Full or in Part by NGL 16-001-043

Armstrong, Thomas P.	Ph.D.	Aug. 1966
Bergeson, John E.	Ph.D.	June 1967
Burns, Thomas B.	M.S.	June 1967
Taylor, William W. L.	M.S.	Aug. 1967
Cauffman, David P.	M.S.	June 1968
Harding, Rollin	Ph.D.	June 1968
Roque, Celso R.	Ph.D.	June 1968
Anderson, Roger R.	M.S.	June 1969
Cauffman, Mavis G.	M.S.	June 1969
Rodriguez, Paul	M.S.	June 1969
Vahala, George M.	M.S.	June 1969
Mosier, Stephen R.	Ph.D.	Jan. 1970
Shaw, Robert R.	M.S.	Jan. 1970
Vahala, George M.	Ph.D.	Jan. 1971
Cauffman, David P.	Ph.D.	May 1971
Shoucri, Magdi	M.S.	May 1972
Williams, James N.	Ph.D.	Dec. 1972
Taylor, William W. L.	Ph.D.	May 1973
Hosford, N. Douglas	M.S.	May 1973
Romesser, Thomas E.	M.S.	May 1973
Hsu, Jang-Yu	M.S.	Dec. 1973
Rodriguez, Paul	Ph.D.	July 1974
Romesser, Thomas E.	Ph.D.	Dec. 1974
Kurth, William S.	M.S.	May 1975
Cheng, Chio-Zong	Ph.D.	July 1975
Seyler, Charles E.	Ph.D.	July 1975
Shaw, Robert R.	Ph.D.	July 1975
Baumback, Mark M.	M.S.	May 1976
Anderson, Roger R.	Ph.D.	Dec. 1976
Fyfe, David E.	Ph.D.	May 1977
Gallagher, Dennis	M.S.	Dec. 1978
Kurth, William S.	Ph.D.	May 1979
Green, James L.	Ph.D.	July 1979
Herink, Kent	M.S.	July 1979
Strayer, Brian	M.S.	May 1979
Reinleitner, Lee A.	M.S.	May 1980
Huang, Cheryl Yu-Yin	Ph.D.	Dec. 1981
Gallagher, Dennis L.	Ph.D.	July 1982
Reinleitner, Lee A.	Ph.D.	July 1982
Fuselier, Stephen A.	M.S.	May 1983
Persoon, Ann M.	M.S.	May 1983
Tokar, Robert L.	Ph.D.	Dec. 1983
Omidi, Nojan	Ph.D.	May 1984

Seery, Joan R.	M.S.	May 1984
Fuselier, Stephen A.	Ph.D.	Dec. 1984
Kustom, Brittan	M.S.	Dec. 1984
Weimer, Daniel R.	Ph.D.	Dec. 1984
Farrell, William M.	M.S.	Dec. 1984
Steinberg, John T.	M.S.	Dec. 1985
Baumback, Mark M.	Ph.D.	May 1986
Cartier, Steven L.	Ph.D.	May 1986
Ma, Ti-Ze	Ph.D.	Aug. 1986
Farrell, William M.	Ph.D.	Aug. 1987
Suszcynsky, David M.	M.S.	May 1987
Steinberg, John T.	Ph.D.	May 1988
Kistler, Allen C.	M.S.	Aug. 1988
Boardsen, Scott A.	Ph.D.	Dec. 1988

IV. Papers and Publications

1. Negative Ion Detection in the Ionosphere from Effects on ELF Waves
S. D. Shawhan
J. Geophys. Res., 71, 5585, 1966.
2. A Satellite Study of VLF Hiss
D. A. Gurnett
J. Geophys. Res., 71, 5591, 1966.
3. Scattering of Energetic Particles by Laboratory Plasmas
D. Montgomery, C. Roque, and I. Alexeff
Phys. Fluids, 9, 2500, 1966.
4. Numerical Studies of the Nonlinear Vlasov Equation
T. P. Armstrong
Phys. Fluids, 10, 1269, 1967.
5. Asymptotic State of the Two-Stream Instability
T. P. Armstrong and D. Montgomery
Journal of Plasma Physics, 1, 425, 1967.
6. Shielding in Anisotropic Plasmas
G. Joyce and D. Montgomery
Phys. Fluids, 10, 2017, 1967.
7. Foundations of Classical Kinetic Theory
D. Montgomery
Lectures in Theoretical Physics, Vol. 9C, ed by W. E. Brittan and A. O. Barut, Gordon and Breach, New York, pp. 15-95, 1967.
8. Controlled Landau Damping of Ion-Acoustic Waves
I. Alexeff, W. D. Jones, and D. Montgomery
Phys. Rev. Lett., 19, 422, 1967.
9. Dispersion of Ion-Acoustic Waves
K. Lonngren, D. Montgomery, I. Alexeff, and W. D. Jones
Physics Letters, 25A, 629, 1967.
10. A Derivation of the Equation of Brownian Motion from the Kinetic Equation for Weakly Interacting Gases
D. Montgomery
Physica, 36, 663, 1967.
11. The Deflection of Charged Particles by a Current-Carrying Plasma
G. Joyce, D. Montgomery, and C. Roque
Phys. Fluids, 10, 2399, 1967.
12. Evolution of a Nonlinear Ion Acoustic Wave
D. Montgomery
Phys. Rev. Lett., 19, 1465, 1967.

13. Response of a One-Dimensional Vlasov Plasma to External Electric Fields
R. C. Harding
Phys. of Fluids, 11, 2233, 1968.
14. Scattering of Charged Particles in a Weakly Turbulent Plasma
C. Roque
Phys. of Fluids, 11, 2471, 1968.
15. Numerical Studies of Turbulent Heating
S. Peter Gary and D. Montgomery
Phys. of Fluids, 11, 2733, 1968.
16. Numerical Studies of Nonlinear Ion Acoustic Waves
T. P. Armstrong and D. Montgomery
Proceedings of A. P. S. Topical Conference on Numerical Simulation of Plasma, Los Alamos, New Mexico, Sept. 18-20, 1968, Report LA-3900.
17. Numerical Study of Charged Particle Heating by Plasma Turbulence
S. P. Gary and D. Montgomery
Proceedings of A. P. S. Topical Conference on Numerical Simulation of Plasma, Los Alamos, New Mexico, Sept. 18-20, 1968, Report LA-3990.
18. Particle Acceleration by Electrostatic Waves with Spatially Varying Phase Velocities
S. P. Gary, D. Montgomery, and D. W. Swift
J. Geophys. Res., 73, 7524, 1968.
19. Oscillations Present in Plasma-Electron Heating by an Electron Beam
I. Alexeff, G. E. Guest, D. Montgomery, R. V. Neidigh, and D. J. Rose
Physical Rev. Lett., 21, 344, 1968.
20. Morphology of VLF Emissions Observed with the Injun 3 Satellite
W. W. L. Taylor and D. A. Gurnett
J. Geophys. Res., 73, 5615, 1968.
21. VLF Electric and Magnetic Fields Observed with the Javelin 8:45 Sounding Rocket
S. D. Shawhan and D. A. Gurnett
J. Geophys. Res., 73, 6549, 1968.
22. The Low Frequency Cutoff of ELF Emissions
D. A. Gurnett and T. B. Burns
J. Geophys. Res., 73, 7437, 1968.
23. Experimental Strong Turbulent Heating
R. V. Neidigh, I. Alexeff, G. E. Guest, W. D. Jones, D. C. Montgomery, D. J. Rose, and W. L. Stirling
Paper CN-24/L-2 at International Atomic Energy Agency Conference on Controlled Fusion, Novosibirsk, U.S.S.R., 1968.
24. Radiation from an Oscillating Magnetic Dipole in a Streaming Plasma
J. E. Bergeson

- Radio Science, 3, 191, 1968.
25. Effects of Electron Temperature Variation on Ion Acoustic Waves
I. Alexeff, W. D. Jones, and D. Montgomery
Phys. Fluids, 11, 167, 1968.
 26. Microburst Phenomena
3. An Association between Microbursts and VLF Chorus
M. N. Oliven and D. A. Gurnett
J. Geophys. Res., 73, 2355, 1968.
 27. Observations of VLF Hiss at Very Low L Values
D. A. Gurnett
J. Geophys. Res., 73, 1096, 1968.
 28. Nonlinear Vlasov Plasmas: Initial Value Problem and Response to an External Field
D. Montgomery
Statistical Physics of Charged Particle Systems, ed by R. Kubo and T. Kihara, Tokyo and New York, Syokabo and W. A. Benjamin, pp. 156-177, 1969.
 29. Fluctuations in Monatomic Gases
D. Montgomery
Phys. Fluids, 12, 804, 1969.
 30. A Simple Gigacycle Correlator
I. Alexeff, R. V. Neidigh, and W. R. Wing
Int. Journ. of Engineering Science, 7, 531, 1969.
 31. Numerical Study of Weakly Unstable Electron Plasma Oscillations
T. P. Armstrong and D. Montgomery
Phys. of Fluids, 12, 2094, 1969.
 32. Quasilinear Theory of the Ion-Wave Instability
David Montgomery and George Vahala
Proc. Third European Fusion Conference and Symposium on Beam-Plasma Interactions, Utrecht, Netherlands, June 23-27, 1969; page 104.
 33. VLF Measurements of the Poynting Flux Along the Geomagnetic Field with the Injun 5 Satellite
S. R. Mosier and D. A. Gurnett
J. Geophys. Res., 74, 5675, 1969.
 34. Shock-like Solutions of the Electrostatic Vlasov Equation
David Montgomery and Glenn Joyce
Journal of Plasma Physics, 3, 1, 1969.
 35. VLF Emissions During Magnetic Storms and their Association with 40keV Electrons
David P. Cauffman and Donald A. Gurnett
J. Geophys. Res., 74, 1144, 1969.

36. Ionospheric Observation of VLF Electrostatic Noise Related to Harmonics to the Proton Gyrofrequency
S. R. Mosier and D. A. Gurnett
Nature, 223, 605, 1969.
37. Initial Observations of VLF Electric and Magnetic Fields with the Injun 5 Satellite
D. A. Gurnett, G. W. Pfeiffer, R. R. Anderson, S. R. Mosier, and D. P. Cauffman
J. Geophys. Res., 74, 4631, 1969.
38. VLF Electric and Magnetic Fields Observed in the Auroral Zone with the Javelin 8.46 Sounding Rocket
D. A. Gurnett and S. R. Mosier
J. Geophys. Res., 74, 3979, 1969.
39. Effects of Bunched Ion Bursts on Apparent Nonlinear Ion Acoustic Waves
Y. H. Ichikawa
Phys. Fluids, 13, 2541, 1970.
40. Discrete Spectra and Damped Waves in Quasilinear Theory
G. Vahala and D. Montgomery
Journal of Plasma Physics, 4, 677, 1970.
41. Recent Rocket Measurements of AC Electric and Magnetic Fields in the Ionosphere
S. D. Shawhan and D. A. Gurnett
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42. Conjugate Photoelectron Impact Ionization
S. D. Shawhan, L. P. Block, and C.-G. Falthammer
J. Atmos. Terr. Physics, 32, 1885, 1970.
43. Propagation of Ion Acoustic Waves in a Magnetic Field
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44. Thermal Relaxation in One and Two Dimensional Plasma Models
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Phys. of Fluids, 13, 1405, 1970.
45. Validity of the Electrostatic Approximation
David Montgomery
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46. Solution of Vlasov's Equation by Transform Methods
T. P. Armstrong, R. C. Harding, G. Knorr, and D. Montgomery
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J. Opt. Soc. of America, 60, 8, 1970.
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D. A. Gurnett
Particles and Fields in the Magnetosphere, 309, Reinhold Book Co., N. Y.
(B. M. McCormac, ed.), 1970.
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D. A. Gurnett and P. Rodriguez
J. Geophys. Res., 75, 1342, 1970.
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D. Montgomery
Book; 400 pp.; published by Gordon and Breach, September, 1971.
52. Parametric Amplification of Alfvén Waves
G. Vahala and D. Montgomery
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53. Kinetic Theory of a Two-Dimensional Magnetized Plasma
G. Vahala and D. Montgomery
Journal of Plasma Physics, 6, 425, 1971.
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55. Kubo Conductivity of a Strongly Magnetized Two-Dimensional Plasma
D. Montgomery and F. Tappert
Phys. Rev. Lett., 27, 1419, 1971.
56. Double Probe Measurements of DC Electric Fields with the Injun 5
Satellite
D. P. Cuaffman and D. A. Gurnett
J. Geophys. Res., 76, 6014, 1971.
57. On the Distributions of Plasmas and Electric Fields over the Auroral
Zones and Polar Caps
L. A. Frank and D. A. Gurnett
J. Geophys. Res., 76, 6829, 1971.
58. Electrical Conductivity of Weakly Turbulent Plasmas
Y. H. Ichikawa and K. Nishikawa
Phy. Fluids, 14, 569, 1971.
59. Comment on Negative Diffusion Coefficients in Quasi-linear Theory
D. Montgomery and S. Bodner
Journal of Plasma Physics, 5, 131, 1971.

60. An Experimental Study of VLF Mode Coupling and Polarization Reversal
P. Rodriguez and D. A. Gurnett
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61. Theory of the Injun 5 VLF Poynting Flux Measurements
S. R. Mosier and D. A. Gurnett
J. Geophys. Res., 76, 972, 1971.
62. Poynting Flux Studies of Hiss with the Injun 5 Satellite
S. R. Mosier
J. Geophys. Res., 76, 1713, 1971.
63. Whistlers with Harmonic Bands Caused by Multiple Stroke Lightning
R. R. Shaw and D. A. Gurnett
J. Geophys. Res., 76, 1851, 1971.
64. Color Spectrograms of VLF Poynting Flux Data
D. A. Gurnett, S. R. Mosier, and R. R. Anderson
J. Geophys. Res., 76, 3022, 1971.
65. Relation of Langevin's Equation to Boltzmann's Equation in the Theory of Brownian Motion
D. Montgomery
Proc. Conf. on Statistical Mechanics (I.U.P.A.P.), Chicago, Illinois, March 29-April 2, 1971, pp. IV.1 - IV.5.
66. Conductivity of a Two-Dimensional Guiding Center Plasma
D. Montgomery and F. Tappert
Phys. Fluids, 15, 683, 1972.
67. Three-Dimensional Plasma Diffusion in a Very Strong Magnetic Field
D. Montgomery, C.-S. Liu, and G. Vahala
Phys. Fluids, 15, 815, 1972.
68. Two-Dimensional Vortex Motion and "Negative Temperatures"
D. Montgomery
Phys. Lett., 39A, 7, 1972.
69. Simulation of the "Negative Temperature" Instability for Line Vortices
G. Joyce and D. Montgomery
Phys. Lett., 39A, 371, 1972.
70. Multiple Soliton Production and the Korteweg-deVries Equation
N. Hershkowitz, T. Romesser, and D. Montgomery
Phys. Rev. Lett., 29, 1586, 1972.
71. Kinetic Theory of a Two-Dimensional Magnetized Plasma Part 2. Balescu-Lenard Limit
G. Vahala
Journal of Plasma Physics, 8, 357, 1972.
72. Quantum Statistical Mechanics of Dense Partially Ionized Hydrogen

- H. E. DeWitt and F. J. Rogers
Physics of the Earth and Planetary Interiors, 6, 51, 1972.
73. ELF Noise Bands Associated with Auroral Electron Precipitation
D. A. Gurnett and L. A. Frank
J. Geophys. Res., 77, 3411, 1972.
74. Sheath Effects and Related Charged Particle Acceleration by Jupiter's Satellite Io
D. A. Gurnett
Astrophys. J., 175, 525, 1972.
75. Direct Observations of Low-Energy Solar Electrons Associated with a Type III Solar Radio Burst
L. A. Frank and D. A. Gurnett
Solar Physics, 27, 446, 1972.
76. VLF Hiss and Related Plasma Observations in the Polar Magnetosphere
D. A. Gurnett and L. A. Frank
J. Geophys. Res., 77, 172, 1972.
77. Injun 5 Observations of Magnetospheric Electric Fields and Plasma Convection
D. A. Gurnett
Earth's Particles and Fields, ed. by B. M. McCormac, Reinhold Book Company (Dordrecht, Holland), 1972.
78. Satellite Measurements of High Latitude Convection Electric Fields
D. P. Cauffman and D. A. Gurnett
Space Sci. Rev., 11, 111, 1972.
79. Negative Temperature States for the Two-Dimensional Guiding-Center Plasma
G. Joyce and D. Montgomery
Journal of Plasma Physics, 10, 107, 1973.
80. Guiding Center Plasma in 2 and 3 Dimensions
D. Montgomery
Bull. Am. Phys. Soc. Ser. II, 18, 1262, 1973.
81. The Equilibrium Properties of a One-Dimensional Kinetic System
J. H. Williams and G. Joyce
Journal of Chemical Physics, 59, 741, 1973.
82. Plasma Wave Observations Near the Plasmopause with the S³-A Satellite
R. R. Anderson and D. A. Gurnett
J. Geophys. Res., 78, 4756, 1973.
83. Sheath Acceleration of Photoelectrons by Jupiter's Satellite Io
S. D. Shawhan, R. F. Hubbard, G. R. Joyce, and D. A. Gurnett
Photon and Particle Interactions with Surfaces in Space, ed. by R. J. L. Grard, D. Reidel Publishing Company, p. 405, 1973.

84. Direct Comparison Between Satellite Electric Field Measurements and the Visual Aurora
D. W. Swift and D. A. Gurnett
J. Geophys. Res., 78, 7306, 1973.
85. Electromagnetic Radiation Trapped in the Magnetosphere Above the Plasma Frequency
D. A. Gurnett and R. R. Shaw
J. Geophys. Res., 78, 8136, 1973.
86. Io-Accelerated Electrons: Predictions for Pioneers 10 and 11
S. D. Shawhan, D. A. Gurnett, R. F. Hubbard, and G. Joyce
Science, 182, 1348, 1973.
87. Observed Relationships Between Electric Fields and Auroral Particle Precipitation
D. A. Gurnett and L. A. Frank
J. Geophys. Res., 78, 145, 1973.
88. Magnetic Field Dependence of Plasma Relaxation Times
D. Montgomery, L. Turner, and G. Joyce
Phys. Fluids, 17, 2201, 1974.
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D. Montgomery, L. Turner, and G. Joyce
Physics of Fluids, 17, 954, 1974.
90. Statistical Mechanics of "Negative Temperature" States
D. Montgomery and G. Joyce
Physics of Fluids, 17, 1139, 1974.
91. Thermal Relaxation of a Two-Dimensional Plasma in a dc Magnetic Field.
Part I: Theory
J.-Y. Hsu, D. Montgomery, and G. Joyce
Journal of Plasma Physics, 12, 21, 1974.
92. Thermal Relaxation of a Two-Dimensional Plasma in a dc Magnetic Field.
Part II: Numerical Simulation
J.-Y. Hsu, G. Joyce, and D. Montgomery
Journal of Plasma Physics, 12, 27, 1974.
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G. Vahala, L. Vahala, D. Montgomery, and G. Joyce
Phys. Fluids, 17, 2298, 1974.
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J.-Y. Hsu and D. Montgomery
Physics Letters, 48A, 39, 1974.
95. Thermal and Suprathermal Plasma Densities in the Outer Magnetosphere
D. A. Gurnett and L. A. Frank
J. Geophys. Res., 79, 2355, 1974.

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D. A. Gurnett and S.-I. Akasofu
J. Geophys. Res., 79, 3197, 1974.
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D. A. Gurnett
J. Geophys. Res., 79, 4227, 1974.
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N. Hershkowitz and T. Romesser
Phys. Rev. Lett., 32, 581, 1974.
99. Electric Field Correlations in the Guiding-Center Plasma
G. Joyce, D. Montgomery, and M. Emery
Phy. Fluids, 17, 110, 1974.
100. Partition Function for a Two-Dimensional Plasma in the Random-Phase Approximation
C. E. Seyler, Jr.
Phys. Rev. Lett., 32, 515, 1974.
101. A Test of Incoherent Cerenkov Radiation for VLF Hiss and Other Magnetospheric Emissions
W. W. L. Taylor and S. D. Shawhan
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T. Romesser and N. Hershkowitz
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N. Hershkowitz and T. E. Christensen
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C. E. Seyler, Jr., Y. Salu, D. Montgomery, and G. Knorr
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P. Rodriguez and D. A. Gurnett

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and Plasma Frequency in the Outer Magnetosphere
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111. The Earth as a Radio Source: The Non-Thermal Continuum
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and Solar Electrons
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Fluids
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