FINAL REPORT FOR NSF-DOE PROGRAM IN BASIC PLASMA PHYSICS

DOE grant # DE-FG02-06ER54885

E. R. Tracy PI

William and Mary Grant: 737451

Title: Waves in Plasmas

Significant scientific results:

During the three-year period of the grant we made significant progress on the following problems:

* (With A. S. Richardson) Quadratic corrections to the metaplectic formulation of mode conversions. In this work we showed how to systematically deal with quadratic corrections beyond the usual linearization of the dispersion matrix at a conversion. The linearization leads to parabolic cylinder functions as the local approximation to the full-wave behavior, but these do not include the variation in amplitude associated with ray refraction in the neighborhood of the conversion. Hence, the region over which they give a good fit to the incoming and outgoing WKB solutions is small. By including higher order corrections it is possible to provide a much more robust matching. We also showed that it was possible, in principle, to extend these methods to arbitrary order.

* (With A. N. Kaufman, A. S. Richardson and N. Zobin) A new normal form for mode conversion. This is based upon our earlier NSF-DOE-funded work on ray helicity. We have begun efforts to apply these new ideas in practical ray tracing algorithms. This work is still in progress.

* (With A. S. Richardson, N. Zobin and D. Johnston) Group theoretical foundation of path integrals and phase space representations of wave problems. Using the symbol theory of N. Zobin, we developed a new understanding of path integrals on phase space. The initial goal was to find practical computational tools for dealing with non-standard mode conversions. Along the way we uncovered a new way to represent wave functions directly on phase space without the intermediary of a Wigner function. We are exploring the use of these ideas for numerical studies of conversion, with the goal of eventually incorporating kinetic effects. This work is still in progress.

* (With A. N. Kaufman and Y. Xiao) Wave packet studies of gyroresonance crossing. In earlier work, Huanchun Ye and Allan Kaufman -- building upon ideas due to Lazar Friedland -- had shown that gyroresonance crossings could be treated as a double conversion. This perspective is one we have used for many of our papers since then. We are now performing a detailed numerical comparison between full-wave and ray tracing approaches in the study of minority-ion gyroresonance crossing. In this study, a fast magnetosonic wave -- supported by a majority-ion species such as deuterium -- crosses the resonance layer associated with a minority species, such as hydrogen. By using wave packets instead of harmonic solutions, it becomes easy to see the evolution in k-space of the minority-ion disturbance, and the time delay for emission of the reflected fast-wave packet. This work is still in progress.

* (With A. N. Kaufman, A. J. Brizard, A. S. Richardson and N. Zobin) Iterated conversion in a cavity. When mode conversion occurs in a cavity where rays are trapped, multiple conversions will occur and the resulting absorption profile will typically have a complicated spatial dependence due to overlapping interference patterns. The goal of this work is to develop fast and efficient ray-based methods for computing the cavity response to external driving, and to compute the spatial absorption profile. We have introduced a new approach that allows us to visualize in great detail the underlying iterated ray geometry, and should lead to simpler methods for identifying parameter values where global changes occur in the qualitative response (e.g. global bifurcations). This work is still in progress.

Significant senior collaborators on this grant: Nahum Zobin (W&M Math), Allan Kaufman (LBNL and UC Berkeley), Steve Richardson (MIT), Alain Brizard (Saint Michael's College).

The PI and Nahum Zobin received some summer support in 2007 and 2008. The senior collaborators listed above received local support during research visits. Otherwise funds were primarily used to support PhD students and for travel by the PI and students to conferences.

PhD students supported on this grant: Yanli Xiao, David Johnston, Steve Richardson, and for a brief time Dun Zhang and Jeremy Weeden.

Yearly summaries:

2009 Refereed Journal Publications

"Allan Kaufman's contributions to plasma wave theory," E. R. Tracy and A. J. Brizard, invited review for KaufmanFest07, J. Phys.: Conference Series 169 (2009) 012008.

"Application of the transfer entropy to gappy time series," C. W. Kulp and E. R. Tracy, Phys. Lett. 373A (2009) 1261-1267.

2009 Conference papers

"KaufmanFest07: Plasma Theory, Wave Kinetics, and Nonlinear Dynamics," A. J. Brizard and E. R. Tracy, conference report, J. Phys.: Conference Series 169 (2009) 012001.

2009 Contributed talks and posters. Posters were presented at the following conferences:

Sherwood Fusion Theory Meeting, March 30-April 2, Boulder, CO.

"A study of minority-ion gyroresonance crossing using wave packets", Y. Xiao*, E. R. Tracy and A. N. Kaufman.

"Novel visualization and computational methods for iterated conversion in tokamak RF heating," E. R. Tracy, A. S. Richardson, A. N. Kaufman, N. Zobin and A. J. Brizard.

2008 Journal publications:

"Recirculation in multiple wave conversions", A. J. Brizard, A. N. Kaufman and E. R. Tracy, Physics of Plasmas 15 082115 (2008).

"Quadratic corrections to the metaplectic formulation of resonant mode conversion", A. S. Richardson and E. R. Tracy, to appear in J. Physics A: Mathematical and General.

2008 PhD Thesis

"Topics in mode conversion theory and the group theoretical foundations of path integrals," A. S. Richardson, PhD Thesis, William and Mary, 2008.

2008 Invited talks

"Phase space methods in plasma wave theory", Dynamics Days, January 3-6, Knoxville, TN.

2008 Contributed conference talks and posters (* = presenter)

At the APS-DPP meeting, November 17-21, 2008, Dallas, TX.

"Variational formulation of kinetic-bulk multiple-wave conversion in fusion plasmas," A. N. Kaufman, A. J. Brizard and E. R. Tracy.

"A study of full-wave and ray-tracing methods for two simple models of multidimensional mode conversion," Y. Xiao and E. R. Tracy.

Sherwood Fusion Theory Meeting, April 23-25, Annapolis, MD:

"A new improved normal form for linear conversion," E. R. Tracy, A. N. Kaufman and N. Zobin.

"Recirculation effects in multiple linear conversion," A. J. Brizard, A. N. Kaufman and E. R. Tracy.

"A study of full-wave and ray-tracing methods for a simple model of multi-dimensional mode conversion," Y. Xiao, A. S. Richardson, E. R. Tracy and A. N. Kaufman.

2007 Journal Publications

"Eikonal waves, caustics and mode conversion in tokamak plasmas", A. Jaun, E. R. Tracy and A. N. Kaufman, Plasma Phys. Control. Fusion 49 (2007) 43-67.

"Local fields and asymptotic matching in multidimensional linear conversion", E. R. Tracy, A. N. Kaufman and A. Jaun. Phys. Plasmas 14 (2007) 082102 - 082130.

2007 Conference Proceedings:

(all to appear in the AIP Proceedings for the 17th Topical Conference on RF Power in Plasmas, May 7-9, Clearwater, FL)

"Extended Budden problem associated with an energetic particle population", A. J. Brizard, A. N. Kaufman and E. R. Tracy.

"Higher order corrections in the one dimensional mode conversion problem", A. S. Richardson, E. R. Tracy and A. N. Kaufman

"A new normal form for multidimensional mode conversion" E. R. Tracy, A. S. Richardson, N. Zobin and A. N. Kaufman.

2007 Invited talks

"Protein mass spectrometry: a new window on biological dynamics", UMd, College Park, Nonlinear Dynamics Group Seminar, April 25, 2007.

"Ray-based methods in plasma wave theory", invited talk for KaufmanFest 2007, UC Berkeley, October 2007.

2007 Contributed conference talks and posters (* = presenter)

At the APS-DPP meeting, November 12-16, 2007, Orlando, FL:

"Modified Budden problem associated with an energetic-particle population", A. J. Brizard*, A. N. Kaufman and E. R. Tracy.

"Quadratic effects in mode conversion" A. S. Richardson*, E. R. Tracy and A. N. Kaufman.

"Direct comparison of full-wave and ray-tracing methods for a simple model with mode conversion", Y. Xiao*, A. S. Richardson and E. R. Tracy.

"Path integrals and conversion", N. Zobin, A. S. Richardson* and E. R. Tracy.

"A new normal form for multidimensional conversion", E. R. Tracy*, A. S. Richardson, N. Zobin and A. N. Kaufman.

Sherwood Fusion Theory Meeting, April 23-25, Annapolis, MD:

"Higher order corrections to the metaplectic formulation of linear mode conversion" A. S. Richardson*, E. R. Tracy and A. N. Kaufman. (This won the award for best student poster.)

"A new normal form for multidimensional mode conversion", E. R. Tracy*, A. S. Richardson, N. Zobin and A. N. Kaufman.

Patents: None