**FINAL SCIENTIFIC/TECHNICAL REPORT**

DOE Award #: DE-FG02-99ER54543

Sponsoring Program Office: Office of Science, U.S. Department of Energy

Name of Recipient: University of Iowa

Project Title: "Correlations and Fluctuations in Weakly Collisional Plasma"

Name of Principal Investigator: Frederick Skiff

Time Period: 07/01/1999 – 06/30/2017

November 15, 2017

## Executive Summary

Plasma is a state of matter that exhibits a very rich range of phenomena. To begin with, plasma is both electrical and mechanical – bringing together theories of particle motion and the electromagnetic field. Furthermore, and especially important for this project, a weakly-collisional plasma, such as is found in high-temperature (fusion energy) experiments on earth and the majority of contexts in space and astrophysics, has many moving parts. For example, sitting in earth's atmosphere we are immersed in a mechanical wave field (sound), a possibly turbulent fluid motion (wind), and an electromagnetic vector wave field with two polarizations (light). This is already enough to produce a rich range of possibilities. In plasma, the electromagnetic field is coupled to the mechanical motion of the medium because it is ionized. Furthermore, a weakly-collisional plasma supports an infinite number of mechanically independent fluids. Thus, plasmas support an infinite number of independent electromechanical waves. Much has been done to describe plasmas with "reduced models" of various kinds. The goal of this project was to both explore the validity of reduced plasma models that are in use, and to propose and validate new models of plasma motion.

The primary means to his end was laboratory experiments employing both electrical probes and laser spectroscopy. Laser spectroscopy enables many techniques which can separate the spectrum of independent fluid motions in the ion phase-space. The choice was to focus on low frequency electrostatic waves because the electron motion is relatively simple, the experiments can be on a spatial scale of a few meters, and all the relevant parameters can be measured with a few lasers systems. No study of this kind had previously been undertaken for the study of plasmas. The validation of theories required that the experimental descriptions be compared with theory and simulation in detail.

It was found that even multi-fluid theories leave out a large part of the complexity of plasma motion. Reduced descriptions were found to fail under most circumstances. A new technique was developed that enabled a measurement of the phase-space resolved ion correlation function for the first time. The wide range of plasma dynamics possible became clear through this technique. It was found that collisionless (Vlasov) theory has a large field of application even when the plasma is weakly-collisional. A new approach, the kinetic wave expansion, was proposed, tested and found to be very useful for describing electrostatic ion waves. This project demonstrated a new way of looking at the "degrees-of-freedom" of plasmas and provided significant validation tests of fluid and kinetic plasma descriptions.

### Summary of work

The funding period covers 17 years of work. A brief summary will be given of the scope of the work accomplished followed by a list of publications, invited talks, and contributed papers.

### Experimental facilities

The first task was to construct and test new experimental facilities. Much of the construction cost was paid for by the PI's start-up funding, but everything was designed for the purposes of the project being summarized here and the student and PI time used for construction and testing were supported by the project. Initially, the project supported a post-doc, but for the remaining years the project was performed by the PI with undergraduate and graduate students with occasional outside collaborators.

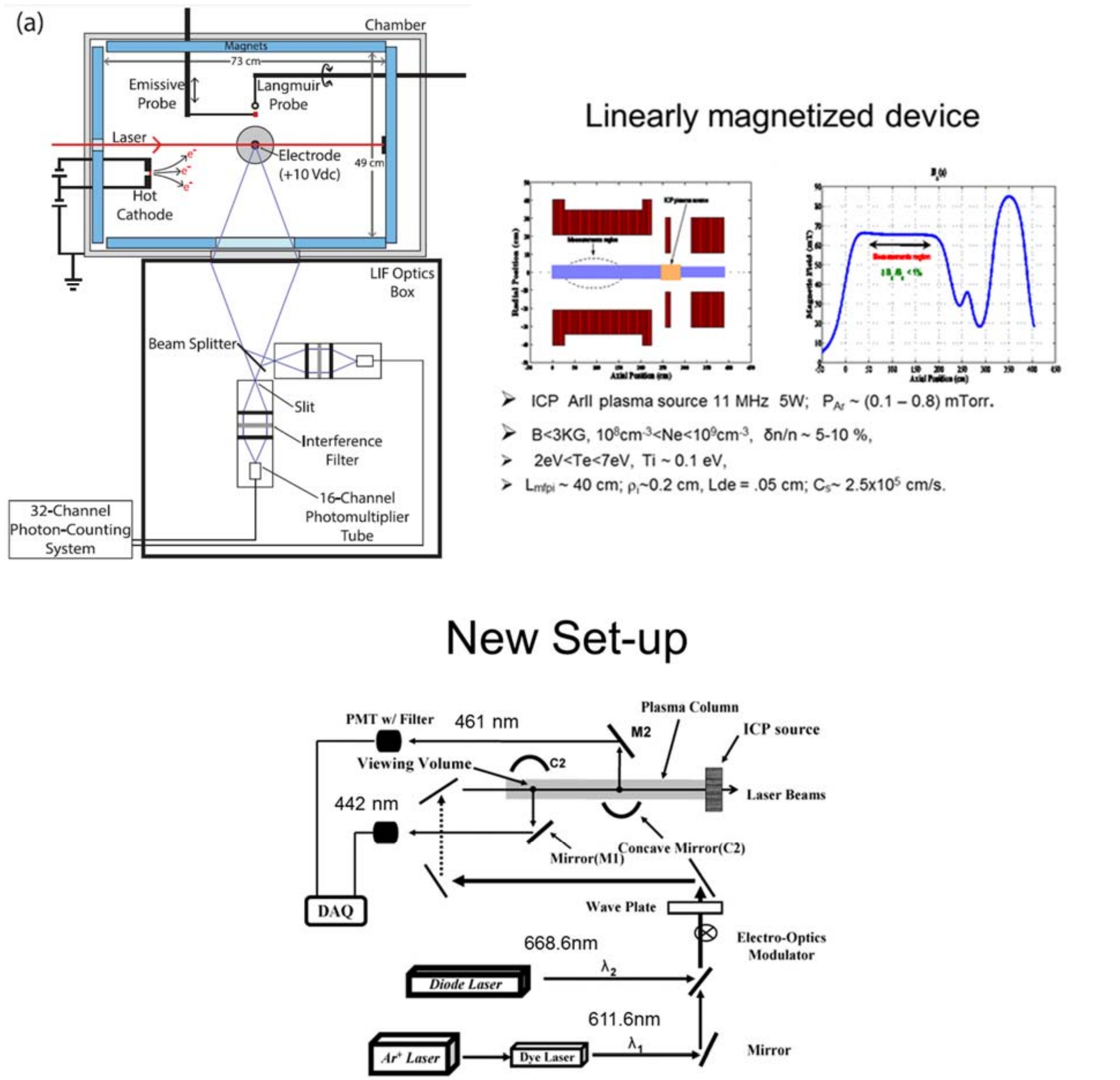


Figure 1. Major experimental facilities constructed for the project. Top left – unmagnetized plasma chamber, right – magnetized chamber, bottom – laser systems.

The experimental facilities were designed to optimize the signal from laser spectroscopic diagnostics. The unmagnetized plasma chamber is outfitted with a large window port enabling remote imaging of a small viewing volume with sub-Debye length spatial resolution. The magnetized plasma chamber has two parallel optical periscopes on motorized carriages which facilitate imaging and two-point correlation studies with sub-Debye length and sub-Larmor radius spatial resolution. In the magnetized plasma chamber the magnetic field is uniform and constant to 0.1% The laser systems developed include single frequency dye, two single frequency diode, and one narrow-band home-made diode-pumped Nd-YLF lasers together with many associated measurement systems purchased or built and in some cases designed by the PI together with students. Sketches of the major experimental facilities using in the project are shown in Figure 1.

**Workforce development**

In addition to the one post-doc who was involved in the construction and initial operation of the new facilities, 21 undergraduate students and fourteen graduate students were trained in experimental plasma physics and laser spectroscopy during the project nine of whom were PhD students under my direction. Funding generally supported the PI and one or two graduate students at any one time. Some students were paid through the project, some worked on projects for course credit, and some participated through collaboration. Training of students was a significant part of the project activities.

**New experimental observables**

Part of the effort in validation involved new types of measurements. The most significant new measurement was of phase-space resolved two-point correlation functions:

$$C(\vec{x}_1, \vec{x}_2, \vec{v}_1, \vec{v}_2; \tau) = \langle \delta f(\vec{x}_1, \vec{v}_1, t) \delta f(\vec{x}_2, \vec{v}_2, t - \tau) \rangle_t$$

Equation 1

The process starts with optimization of the laser spectroscopic (laser-induced fluorescence - LIF) signal. Even after reaching a LIF signal to noise of 1000, further efforts are needed to resolve the correlation function. Averaging over large data sets is required and this requires stabilization of the experiment over run periods of many days. From the correlation function, arrays of power spectra and cross-power spectra were measured. Additionally higher-order correlation functions (involving the product of three fluctuation amplitudes and two independent delay times as opposed to equation 1 with one delay time and two fluctuating amplitude). Higher-order correlation functions permit the calculation of higher-order spectra such as bispectra and bicoherence which indicate three-wave coupling. These quantities had not been experimentally acquired previously in a plasma.

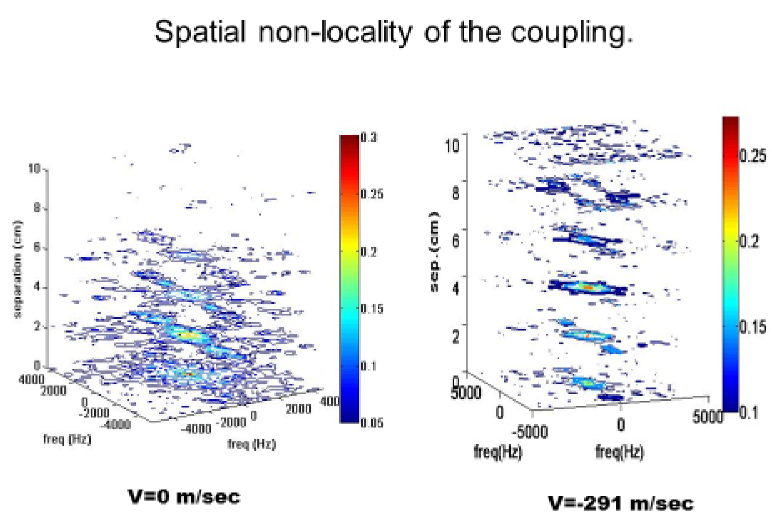


Figure 2. Typical plots of higher-order spectra obtained from LIF.

**Survey of results**

In addition to new discoveries of plasma kinetic modes and nonlinear couplings between modes – some of which are still not fully explained, the goal of validation was a major preoccupation of the project. We will provide some examples here. The multi-fluid theory of the ion-acoustic wave makes simple predictions for the real and imaginary part of the ion plasma response. When the phase is adjusted to the phase of the local density perturbation the eigenfunction for the ion response should be mostly real and invariant with respect to translation in space. Figure 3 shows that this was observed to not be the case for observed monochromatic plasma excitations. The two figures show two measurements of the ion wave function resolved in space and velocity and separated by 1 cm in space. The imaginary parts are not small and the two figures are very different. This is a dramatic failure of the fluid theory.

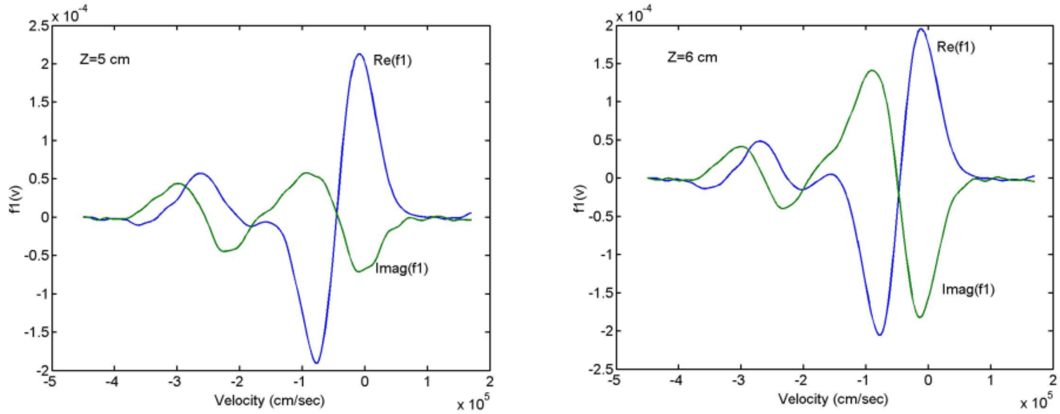


Figure 3. Ion wave functions resolved in phase-space at two adjacent locations.

However, if one takes the measured data it is possible to directly compute terms of the kinetic (Vlasov) equation and to compare them. An example of this is shown in figure 4. This approach can be extended to computations of wave energy and of nonlinear terms which is ongoing research.

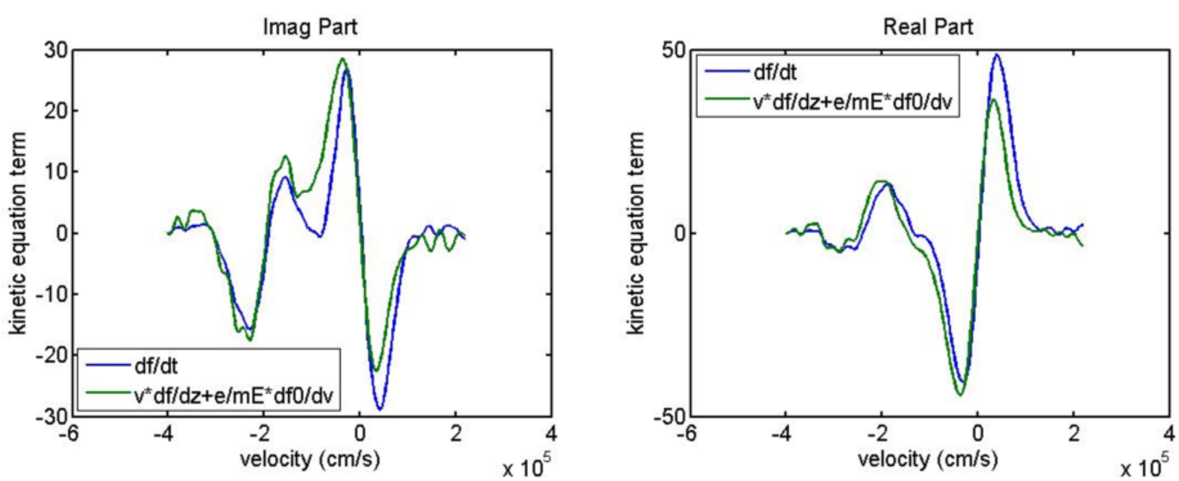


Figure 4. Sample validation of the Vlasov description of the ion-acoustic wave.

Probably one of the most surprising validations has to do with computation of the Morrison G-transform (projection on to Case-Van-Kampen modes). Using this analysis it is possible to reconstruct wave fields over a region based on a measured distribution function at a single point. An example of this is shown in Figure 5. The figure on the left shows a direct comparison of wave fields determined in two different ways experimentally. One way is to directly measure the perturbed ion density. The other technique involves a measurement of the perturbed ion distribution function at a single location and application of an integral transform to find the amplitudes of the continuous spectrum. What is surprising is that collisions are a singular perturbation of the theory so one might expect all trace of the continuous spectrum to be gone. This study showed the robustness of the Vlasov description.

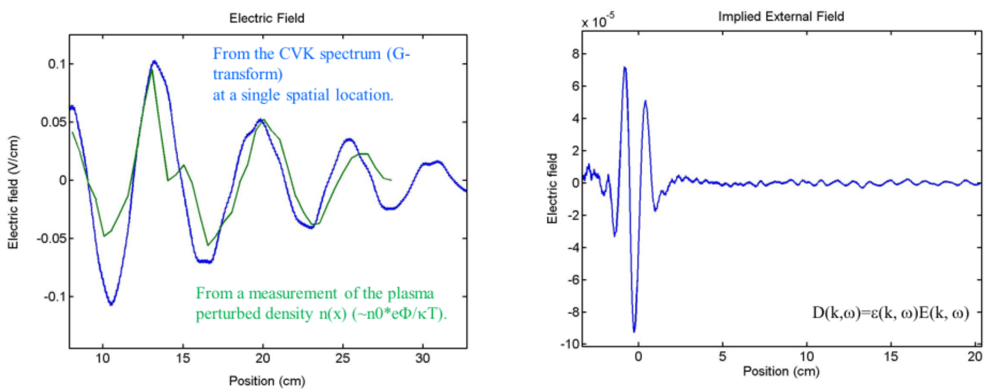


Figure 5. Predictions of wave fields and externally applied fields from the CVK spectrum using the Morrison G-transform.

From the measured data it is also possible to compute moments and to verify the satisfaction of continuity (which may be better thought of as a test of the experimental technique). This is not the same thing as a test of fluid theory. One such test is shown in Figure 6.

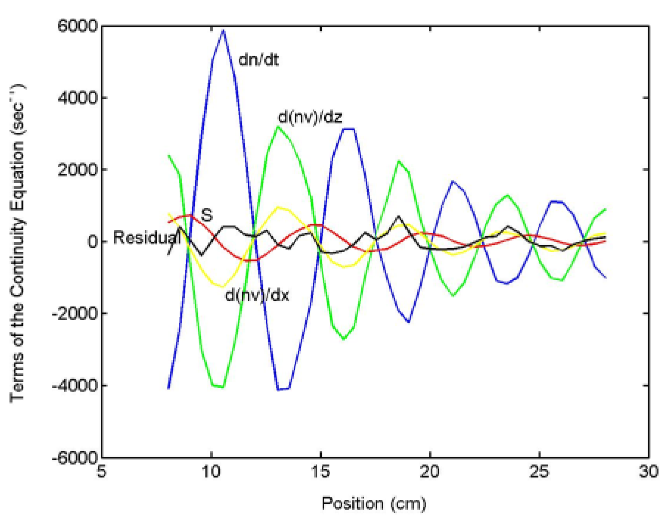


Figure 6. Test of the first-moment of the kinetic equation. The curve labeled S is a term caused by charge-exchange collisions.

Although we were not able to compute a complete nonlinear theory, many nonlinear phenomena were observed and reported. Figure 7 shows a contour plot of the nonlinear second-order ion response at 92 kHz to two waves at 32 and 60 kHz respectively. The data have been Fourier transformed in space to enable a v-phase axis. The red lines correspond to wave-particle resonances.

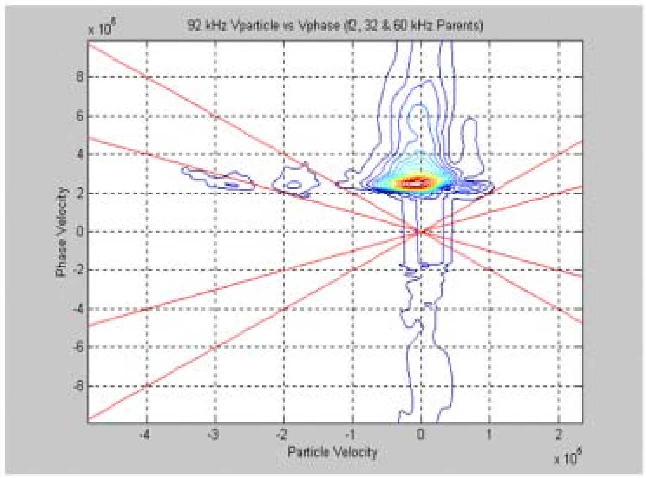


Figure 7. V-phase – V-particle plots of the nonlinear second-order ion response.

The process of making quantitative comparisons and of data requires attention to a wide array of possible systematic effects. This involves making a very accurate model of the LIF measurement process. A significant quantity of work was focused on the effects of optical pumping – which can also be used as a diagnostic technique as the means for “optical tagging”.

The most difficult measurement, and the crowning achievement of this project, was the successful implementation of incoherent wave detection using the two-point correlation technique. This is a way to discover the active degrees of freedom in the ion motions without assuming a particular theory. The technique is statistical in nature. If one measures the quantity in equation 1 for the two spatial coordinates being equal and for velocities over a square grid, then once this square array has been Fourier transformed over the delay time – the matrix is Hermitian with respect to the velocity indices. The rank of this matrix is then the observed number of active wave modes. Sean Mattingly, one of the most recent students, did a thesis on this and was invited to speak at the 2017 DPP meeting. His paper was also selected by the editor of Physics of Plasmas for a press release. Figure 8 shows on the left, the diagonal of the correlation matrix which can be normalized such that it equals the Kruskal-Oberman energy density. This is the kinetic wave energy of the ions according to the Vlasov theory and has not been measured for incoherent fluctuations previously. The plot on the right shows the power spectra of the eigenvalues of the correlation matrix which pertain to the independent fluctuations of different plasma modes. Much remains to be done in understanding plasma dynamical behavior, but the project successfully began the detailed phase-space validation of plasma wave descriptions.

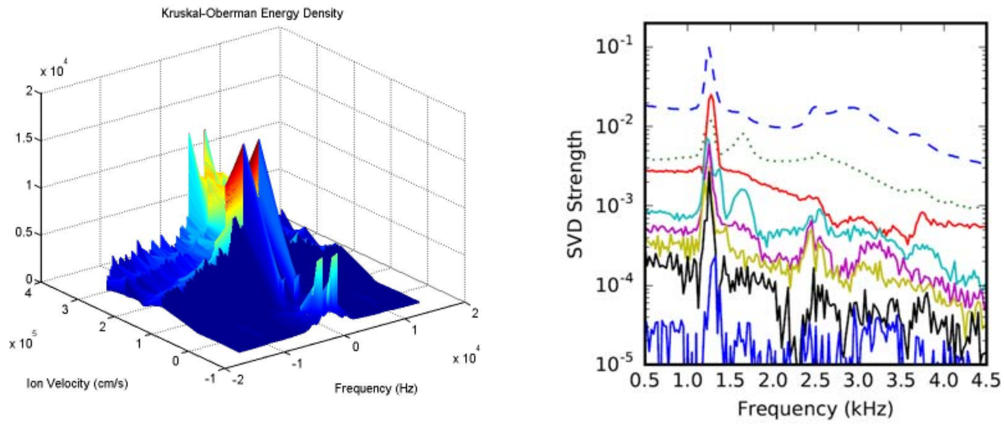


Figure 8. The left frame is the diagonal of the velocity correlation matrix (real and positive definite) normalized to be equal to the Kruskal-Oberman energy density. The frame on the right is a power spectrum of the eigenvalues of the matrix showing the frequency dependence of the many independent active plasma modes.

**Articles**


1. Kinetic Modes in a Hot Magnetized and Weakly Collisional Plasma, S. De Souza-Machado, M. Sarfaty, and F. Skiff, Physics of Plasmas **6**, 2323 (1999).
2. Kinetic Eigenmodes and Discrete Spectrum of Plasma Oscillations in a Weakly Collisional Plasma, C. S. Ng, A. Bhattacharjee, and F. Skiff Phys. Rev. Lett. **83**, (1999) pp1974-1977.
3. Wave-particle interaction, F. Skiff, C. S. Ng, A. Bhattacharjee, W. A. Noonan and A. Case, Plasma Physics and Controlled Fusion, **42** Supplement 12B (2000) ppB27-B35.
4. Ion dynamics in nonlinear electrostatic structures, F. Skiff, G. Bachet, F. Doveil, Phys. Plasmas **8**, (2001) pp3139-3142.
5. Weakly damped acoustic-like ion waves in plasmas with non-Maxwellian ion distributions, H. Gunell and F. Skiff, Phys. Plasmas **8**, (2001) pp3550-3557.
6. Experimental Studies of the propagation of electrostatic ion perturbations by time-resolved laser-induced fluorescence, Phys. Plasmas **8**, (2001) pp3535-3544.
7. Non-linear Optical Tagging Diagnostic for the Measurement of Fokker-Planck Diffusion and Electric fields, N. Claire, M. Dindelegan, G. Bachet, and F. Skiff, Rev. Sci. Instrum. **72**, 4372 (2001).
8. Coherent detection of the complete linear electrostatic response of plasma ions using laser-induced fluorescence, F. Skiff, IEEE Transactions on Plasma Science (2002).
9. Electrostatic degrees of freedom in non-maxwellian plasma, F. Skiff, H. Gunell, A. Bhattacharjee, C. S. Ng, and W. A. Noonan, Physics of Plasmas **9**,1931 (2002).
10. Electrostatic fluctuations in plasmas with distribution functions described by simple pole expansions, H. Gunell and F. Skiff, Physics of Plasmas **9**, 2585 (2002).
11. Ion soliton observation with laser-induced fluorescence, N. Claire, G. Bachet, and F. Skiff, Physics of Plasmas **9**, 4887 (2002).
12. Complete spectrum of kinetic eigenmodes for plasma oscillations in a weakly collisional plasma, C. S. Ng, A. Bhattacharjee, and F. Skiff, Phys. Rev. Lett. (2004).
13. Mini-conference on laser-induced fluorescence in plasmas, F. Skiff and J. Bollinger, Phys. Plasmas **11,** 2972 (2004).
14. Measurement of Asymmetric Optical Pumping of Ions Accelerating in a Magnetic-Field Gradient, X. Sun, E. Scime, M. Miah, S. Cohen, and F. Skiff Phys. Rev. Lett. **93**, (2004).

15. The phase-space-resolved two-point correlation function of ion density fluctuations, A. Diallo and F. Skiff, Physics of Plasmas **12**, 110701 (2005).
16. Bispectral analysis of nonlinear compressional waes in a two-dimensional dusty plasma crystal, V. Nosenco, J. Goree, and F. Skiff, Physical Review **E 73**, 016401 (2006).
17. Weakly Collisional Landau Damping and 3D BGK Modes: New Results on Old Problems, C. S. Ng, A. Bhattacharjee, and F. Skiff, Physics of Plasmas **13**, 055903 (2006).
18. Diagnostics of colllisionless processes in plasmas, F. Skiff, IEEE Transactions on Plasma Science **34**, 1548-1552 (2006).
19. Time-resolved measurements of the density fluctuations in ion phase space, Ahmed Diallo and Frederick Skiff, Physics of Plasmas **13**, 055705 (2006).
20. Observation of coherent nonlinear interactions in the ion velocity distribution function, I. Uzun and F. Skiff, Physics of Plasmas **13**, 112108 (2006).
21. Nonlinear correlations in phase-space resolved fluctuations at drift wave frequencies, F. Skiff Plasma Phys. Contr. Fusion **49**, B259 (2007).
22. Antenna excitation of a drift wave in a toroidal plasma, A. Diallo, P. Ricci, A. Fasoli, I. Furno, B. Labit, S. H. Müller, M. Podestà, F. M. Poli, and F. Skiff, Physics of Plasmas **14**, 102101 (2007).
23. Time resolved LIF with a fast-scanning diode laser, F. Skiff and V. Patel, Journal of Physics: Conference Series **227** (2010).
24. Measurement and interpretation of the velocity space correlation of a laboratory plasma fluctuation with laser induced fluorescence., S W Mattingly, J Berumen, F Chu, R Hood and F Skiff, *JINST* **8** C11015, (2013).
25. Hood, R., Scheiner, B., Hopkins, M. m., Barnat, E. V., Yee, B. T., Merlino, R. L., Skiff, F., Baalrud, S. D. (2016). Ion flow and sheath structure near positively biased electrodes. *Physics of Plasmas*, *23*(11), 113503- 1-9.
26. Velocity space degrees of freedom of plasma fluctuations, Sean Mattingly, and Fred Skiff, Physics of Plasmas 24, 090703 (2017).
27. On determining the fraction of metastable ions produced by direct ionization, F. Chu, S.W. Mattingly, J. Berumen, R. Hood and F. Skiff 2017 JINST 12 C11005

## Invited Lectures

### International

1. Wave-particle interaction, 27th EPS conference on Controlled Fusion and Plasma Physics, Budapest 2000.
2. Chaotic ions and electrostatic ion waves, Fourth International Workshop On Nonlinear Waves and Chaos in Space Plasmas Tromsø, Norway, June 17-22, 2001.
3. Experimental Studies on Plasma Waves and Fluctuations Using Laser-Induced Fluorescence, 10th International workshop on laser-aided plasma diagnostics, Fukuoka Japan, September 2001.
4. Phase-space resolved ion wave fluctuations, International Congress on Plasma Physics, Sydney (2002).
5. Landau damping in weakly collisional plasmas. 7th International Workshop on the Interrelationship between Plasma Experiments in Laboratory and Space, Whitefish (2003).
6. Electrostatic Degrees of Freedom in Weakly Collisional Plasmas, German Science Foundation International Colloquium, "Kinetics of Partially Ionized Plasmas", Greifswald (2004).
7. Nonlinear fluctuations ion the ion phase-space, F. Skiff, 6th International Workshop on Nonlinear Waves and Turbulence in Space Plasmas, Fukuoka Japan (2006).
8. Nonlinear correlations in phase-space resolved fluctuations at drift wave frequencies, European Physical Society conference on Controlled Fusion and Plasma Physics, Warsaw, 2007.
9. Kinetic Modes in nonlinear ion fluctuations, F. Skiff, International Workshop on the Interrelationship between Plasma Experiments in Laboratory and Space, Djurönäset (2009).
10. Applications of the continuous spectrum, F. Skiff, Vlasovia, Marseille (2009).

11. Time resolved LIF with a fast-scanning diode laser, F. Skiff and V. Patel, Laser-Aided Plasma Diagnostics 14, Castelbrando (2009).
12. Measurement of ion phase-space fluctuations using laser-induced fluorescence, F. Skiff, V. Patel, S. Shinohara, and T. Motomura, Japanese Society for Plasma Physics and Fusion Energy, Sapporo 2010.
13. Optical Pumping and particle diagnostics in gas discharge plasmas, F. Skiff, Laser-Aided Plasma Diagnostics 15, Jeju Korea (2011).
14. Adventures in the Science of Tone Quality, F. Skiff and K. Tse, 16th World Saxophone Congress, St. Andrews Scotland, July 10-15, 2012.
15. The 18th Israeli Conference on Plasma Science and its Applications, Experiments on the kinetic degrees of freedom of electrons and ions, Beer Shiva, Israel Skiff, Fred
16. On putting experimental data into the Vlasov-Poisson equations, F. Skiff, Collisionless Boltzmann (Vlasov) equation and modeling of self-gravitating systems and plasmas, CIRM, Luminy Marseille, Oct. 30-Nov. 3 2017.

**National**

1. Landau damping in weakly collisional plasmas and galaxies, (presented by A. Bhattacharjee), Sherwood Conference on plasma theory, Los Angeles, March 2000.
2. Electrostatic degrees of freedom in non-Maxwellian Plasma, APS-DPP Long Beach, CA (2001) BAPS 46.
3. Lagrangian and Eulerian pictures of plasma dynamics using LIF, APS-DPP Miniconference on Laser induced fluorescence in plasmas, Albuquerque NM, (2003) BAPS 48, p 179.
4. Evidence of non-linear ion phase-space structures in plasma drift-wave fluctuations, F. Skiff, SIAM mini-symposium on Coherent Structures in Plasmas, Orlando, October (2004).
5. Diagnostics of collisionless processes in plasmas, 2005 workshop on Nonlocal, Collisionless Electron Transport in Plasmas, Princeton NJ August 2-4, (2005).
6. Measurements of ion density fluctuations in phase-space, with A. Diallo, APS-DPP Denver Co, BAPS 50 (2005).
7. Measurement of the perturbed distributions of electrons and ions, F. Skiff, Workshop on the control of distribution functions in low temperature plasmas at GEC 2011, Salt Lake City (2011).
8. Velocity-space cross-correlation matrix measurements and potential applications to space plasmas S. Mattingly and F. Skiff, American Physical Society Division of Plasma Physics Meeting October 23-27, 2017 Milwaukee WI.

**Contributed Papers (conference presentations)**

1. Electrostatic Degrees of Freedom in Weakly-Collisional Plasma. F. Skiff, IPELS conference Kreuth, Germany 1999.
2. Kinetic Eigenmodes and Discrete Spectrum of Langmuir Oscillations in a Weakly Collisional Plasma, C. S. Ng A. Bhattacharjee, and F. Skiff, APS-DPP BAPS **44**, (1999).
3. Longitudinal Kinetic Modes in a Weakly Collisional Plasma, W. A. Noonan, A. Case, and F. Skiff, APS-DPP BAPS **44**, (1999).
4. Using Ion Motion in Waves to Determine Kinetic Equations, F. Skiff, G. Bachet, and F. Doveil, APS-DPP BAPS **44**, (1999).
5. LIF Studies of Three Wave Interaction in a Weakly Collisional Plasma, A. Case, W. A. Noonan, and F. Skiff, APS-DPP BAPS **44**, (1999).
6. Electrostatic Degrees of Freedom in Weakly Collisional Plasma, F. Skiff, US-Japan Workshop on RF Physics,March 14-16, 2000, Princeton University.
7. Experimental studies of BGK ion waves, F. Skiff, W. A. Noonan, A. Case, G. Bachet, and F. Doveil, APS-DPP BAPS **45**, (2000).

8. Non linear optical tagging diagnostic for the measurement of fokker-planck diffusion and electric fields. N. Claire, M. Dindelegan, G. Bachet, and F. Skiff, APS-DPP BAPS **45**, (2000).
9. Acoustic-like waves in non-Maxwellian plasmas, H. Gunell and F. Skiff, IPELS, Hokkaido, Japan, June (2001).
10. Electrostatic Degrees of Freedom in Non-Maxwellian Plasmas, F. Skiff, Transport Task Force, Fairbanks, May (2001).
11. Phase-space resolved ion wave fluctuations, F. Skiff, APS-DPP BAPS **47**, 2002.
12. Measuring velocity resolved ion wave fluctuations using LIF, F. Skiff, 11th International Symposium on Laser Aided Plasma Diagnostics, Les Houches, France (2003).
13. Complete spectrum of kinetic eigenmodes for plasma oscillations in a weakly collisional plasma, C. S. Ng, A. Bhattacharjee, and F. Skiff, APS-DPP BAPS **48**, (2003) p118.
14. Kinetic waves near the drift frequency, F. Skiff, APS-DPP BAPS **48**, (2003) p118.
15. Anomalous phase shifts in drift wave fluctuations, A. Diallo and F. Skiff, APS-DPP BAPS **48**, (2003) p119.
16. Ion soliton observation in plasma with LIF, N. Claire, G. Bachet, and F. Skiff, APS-DPP BAPS **48**, (2003) p210.
17. Potential and velocity profiles of an electrostatic sheath, N. Claire, G. Bachet, U. Stroth and F. Skiff, APS-DPP BAPS **48**, (2003) p212.
18. Anomalous structure in driftwave fluctuations, F. Skiff and A. Diallo, International Conference on Plasma Science, Baltimore, June (2004).
19. Kinetic effects in drift wave fluctuations, A. Diallo and F. Skiff, APS-DPP BAPS **49**, (2004) p117.
20. Analysis of ion phase-space fluctuations, F. Skiff, A. Diallo and I. Uzun, APS-DPP BAPS **49**, (2004) p117.
21. Nonlinear interactions in drift wave spectrum, I. Uzun and F. Skiff, APS-DPP BAPS **49**, (2004) p118.
22. Enhanced optical pumping of ions accelerating in a magnetic field gradient, E. Scime, X. Sun, S. Cohen, and F. Skiff, APS-DPP BAPS **49**, (2004) p170.
23. Onsager's regression hypothesis applied to driftwave fluctuations, F. Skiff, A, Diallo, and I. Uzun, 32nd IEEE International Conference on Plasma Science June 18-23 (2005).
24. Velocity Resolved Ion Density Fluctuations, A. Diallo and F. Skiff, 8th International Workshop on the Interrelationship between Plasma Experiments in Laboratory and Space, Tromso Norway, July 4-8 (2005).
25. Quasicoherent Nonlinear Interactions in Ion Density Fluctuations, I. Uzun and F. Skiff, Abstract:RP1.00103, APS-47th Annual Meeting of the Division of Plasma Physics (2005).
26. A wave absorption measurement of the electron distribution function, F. Skiff, C. Kletzing, D. Thuecks, S. Bounds, and S. Vincena, APS-47th Annual Meeting of the Division of Plasma Physics (2005).
27. Measurements of Dispersion and Damping for Kinetic and Inertial Shear Alfvén Waves, D. Thuecks, C. Kletzing, S. Bounds, F. Skiff, W. Gekelman, and S. Vincena, APS-47th Annual Meeting of the Division of Plasma Physics (2005).
28. Measurement of the two-point correlation function in the ion phase-space, F. Skiff, A. Diallo, and I. Uzun, APS April Meeting BAPS 51:2, C16-6 (2006).
29. Onsager Regression applied to fluctuations of the ion distribution function, F. Skiff, 48th APS-DPP BAPS 51:7,BP1-87 (2006).
30. Laboratory measurements of the electron distribution function via whistler wave absorption, D. Thuecks, F. Skiff, C. Kletzing, S. Bounds, and S. Vincena, 48th APS-DPP BAPS 51:7,CP1-98 (2006).
31. Using Wavelet transforms for improving the conditional sampling results, I. Uzun, F. Skiff, 48th APS-DPP BAPS 51:7,ZP1-78 (2006).
32. Inference of particle-velocity dependent transport from measurements of the ion two-point correlation function, F. Skiff, 11th EU-US Transport Task Force Meeting Sept.4-7 Marseille 2006.

33. Onsager regression in phase-space resolved ion fluctuations, F. Skiff, 49$^{th}$ APS-DPP BAPS 52, GP8-19 (2007).
34. Laboratory experiments on dispersion and damping of kinetic and inertial shear Alfven waves, D. J. Thuecks, C. A. Kletzing, F. Skiff, S. R. Bounds, and S. Vincena, AGU Fall meeting, #SM23B-1401, San Francisco (2007).
35. Ion Phase-Space Fluctuations, F. Skiff, 14$^{th}$ International Congress on Plasma Physics Fukuoka (2008).
36. Measurement of two-point two-velocity correlation functions in the ion phase-space, F. Skiff 50$^{th}$ APS-DPP, BAPS 53, UP6-106 (2008).
37. Tests of collision operators using measurements of shear Alfven wave dispersion and damping, D. THuecks, C. Kletzing, F. Skiff, S. Bounds, and S. Vincena, 50$^{th}$ APS-DPP, BAPS 53, YP6-87 (2008).
38. Measurement of reduced parallel electron distributions using whistler wave absorption. D. Thuecks, F. Skiff, C. Kletzing, and S. Vincena, APS-DPP BAPS 54, GP8-75 (2009).
39. Kinetic Correlations in drift-wave fluctuations, F. Skiff, V. Patel, and S. Shinohara, APS-DPP BAPS 54, GP8-137 (2009).
40. Plasma phase-space fluctuations, F. Skiff, V. Patel, X. Li, and D. J. Drake, GEC- Paris (2010).
41. Design and Use of an Elsässer Probe for projection of Alfvén wave fields according to wave direction, D. J. Drake, C. A. Kletzing, and F. Skiff, GEC- Paris (2010).
42. Laser induced fluorescence diagnostic for the plasma coquette experiment, N. Katz, F. Skiff, C. Collins, D. Weisberg, J. Wallace, M. Clark, K. Garot, C. Forest, APS-DPP, BAPS 55 NP9-70 (2010).
43. Design and use of an Elsasser probe for projection of Alfven wave fields according to wave direction, D. J. Drake, C. A. Kletzing, and F. Skiff, APS-DPP, BAPS 55 PP9-108 (2010).
44. On the measurement of Lagrangian correlation functions in drift-wave fluctuations, F. Skiff, V. Patel, X. Li, S. Shinohara, and T. Motomura, APS-DPP, BAPS 55 TP9-8 (2010).
45. Phase-space correlations in drift wave fluctuation using laser-induced fluorescence system, T. Motomura, F. Skiff, V. Patel, Xing Li, S. Shinohara, Japanese Society for Plasma Physics and Fusion Energy, Sapporo 2010.
46. Alfven wave collisions: the fundamental building block of plasma turbulence, G. Howes, K. Nielson, F. Skiff, C. A. Kletzing, 53$^{rd}$ APS-DPP BAPS 56 (2011).
47. Design and use of an Elsasser probe for analysis of Alfven wave fields in a laboratory plasma, D. J. Ddrake, C. A. Cletzing, F. Skiff, G. Howes, and S. Vincena, 53$^{rd}$ APS-DPP, BAPS 56 (2011).
48. A multi-wavelength LIF detection system, F, Skiff, D. J. Drake, and T. N. Good, 53$^{rd}$ APS-DPP, BAPS 56 (2011).
49. On the interpretation of particle tagging data, F. Skiff and S. Mattingly, APS April Meeting, Atlanta GA March 31-April 3 (2012).
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