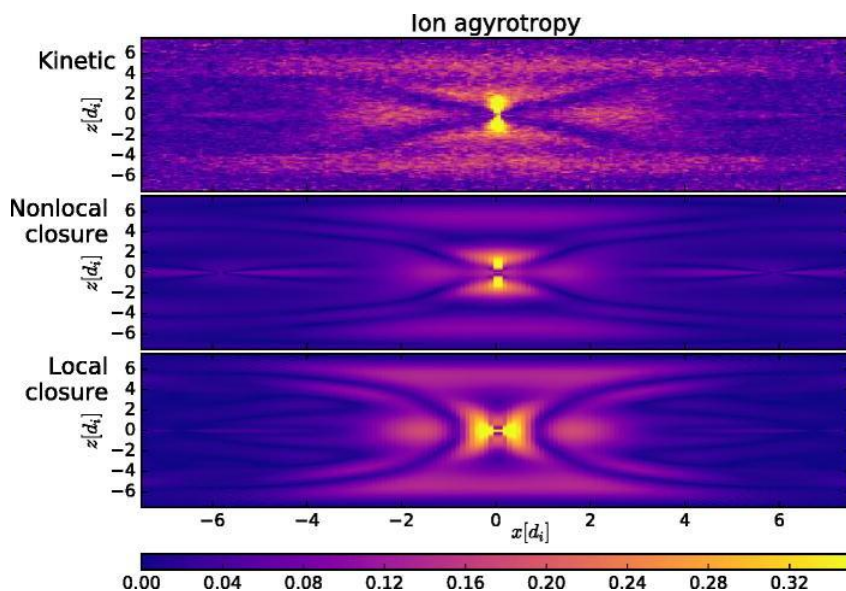


July 2018

## Advanced Simulations Capture the Dynamics of Solar Flares, Northern Lights and Space Storms

New simulations capture the physics of magnetic reconnection, the explosive breaking apart and snapping together of the magnetic field lines in plasma that occurs throughout the universe.



Comparison of the ion agyrotropy between the (top) kinetic, (middle) nonlocal-fluid, and (bottom) local-fluid models. The detailed structure of the ion-pressure tensor is captured by the newly developed “non-local” closure, leading to a potentially more economical way of simulating certain kinetic processes in plasmas.

### The Science

Spurred on by the interest in space weather, such as solar flares and the Northern Lights, and by the success of collisionless fluid closures developed for the numerical simulation of magnetically confined fusion plasmas, a research team from Princeton Plasma Physics Laboratory (PPPL) has implemented a much-improved method for describing nonlocal particle heating in so-called fluid simulations of the plasma in the Earth’s magnetosphere, which treat the plasma as a flowing liquid rather than a collection of millions, billions or even trillions of particles

The nonlocal and collisionless damping of fluctuations by particles in plasmas (hot ionized gases) is described by a recently introduced method for truncating the otherwise infinite hierarchy of fluid equations with a sophisticated “closure”, which leads to a finite set of equations. They applied a so-called ten-moment system to simulations of collisionless magnetic reconnection, the process by which magnetic fieldlines break and explosively snap back to together, by modifying the Hammett-Perkins closure used for plasma turbulence, and they demonstrated that this approach accurately describes both collisionless ion damping and the

anisotropic ion pressure tensor, both of which are needed for accurate magnetic reconnection simulations.

### The Impact

Previous simulations used fluid codes, because this leads to a simplified description of reconnection that takes place in the vastness of space, where widely separated plasma particles rarely collide. However, this collisionless environment also produces kinetic effects, effects which derive from the “discreteness” of individual particles, that traditional fluid models cannot normally capture.

Remarkably, the new mathematical methods developed allow fluid codes to accurately approximate some discrete particle kinetic effects, and thereby create a more detailed picture of the reconnection process.

The energy transferred from the magnetic field to the ionized plasma during reconnection depends critically on complex ion motion and the evolution of the ion pressure tensor.

The new results agree better with kinetic models than the previous simulations. This could extend understanding of reconnection to regions of space such as the magnetosphere, the magnetic field that surrounds the Earth, and provide a more comprehensive view of the universal processes involved in reconnection, leading to better understanding of the impact of space weather on Earth.

### Summary

More accurate kinetic closures for fluid equations have been developed. These can be applied to understand the process of reconnection, an important process that is ubiquitous in magnetized plasmas. These closures allow simulating, in an economical way, the physics that is beyond standard ideal or resistive models of magnetized liquids, i.e. magnetohydrodynamics (MHD).

The research team has successfully demonstrated the new model with idealized examples, and with larger magnetic reconnection simulations. While the adapted ten-moment fluid system provided better simulation of the ion pressure tensor and of the rate of plasma island convergence as compared with fully kinetic simulations, additional ion dynamics such as meandering ion orbits caused by the complex electric and magnetic fields in the reconnection region are not included by the model, and further developments are needed to fully simulate global reconnection phenomena in space weather.

### Contact

Ammar Hakim  
PPPL  
ahakim@pppl.gov

## Participating Institutions

Princeton Plasma Physics Laboratory, Princeton University  
Department of Astrophysical Sciences  
Princeton, NJ 08540

## Funding

This work is supported by the DOE grant DESC0006670, the NASA grant NNX13AK31G, the NSF grant AGS-1338944, and the NASA Living With a Star Jack Eddy Postdoctoral Fellowship Program, administered by the University Corporation for Atmospheric Research.

## Publications

J. Ng, A. Hakim, A. Bhattacharjee, A. Stanier and W. Daughton, "[Simulations of anti-parallel reconnection using a nonlocal heat flux closure](#)", *Physics of Plasmas*, **24**, 082112 (2017). [DOI [10.1063/1.4993195](#)]