Waves and Turbulence: Major Opportunities

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Members of the Working Group

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- T. Carter, UCLA
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- P. Diamond, UCSD
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With valuable input from
G. Hammett,
J. Sarff, M. Goldstein

Five topics

- Nature and properties of turbulent cascades
- Dissipation mechanisms and particle acceleration and heating
- Turbulence in inhomogeneous plasmas and interactions with mean fields
- Coherent structures in turbulence
- Role of laboratory experiments and observations

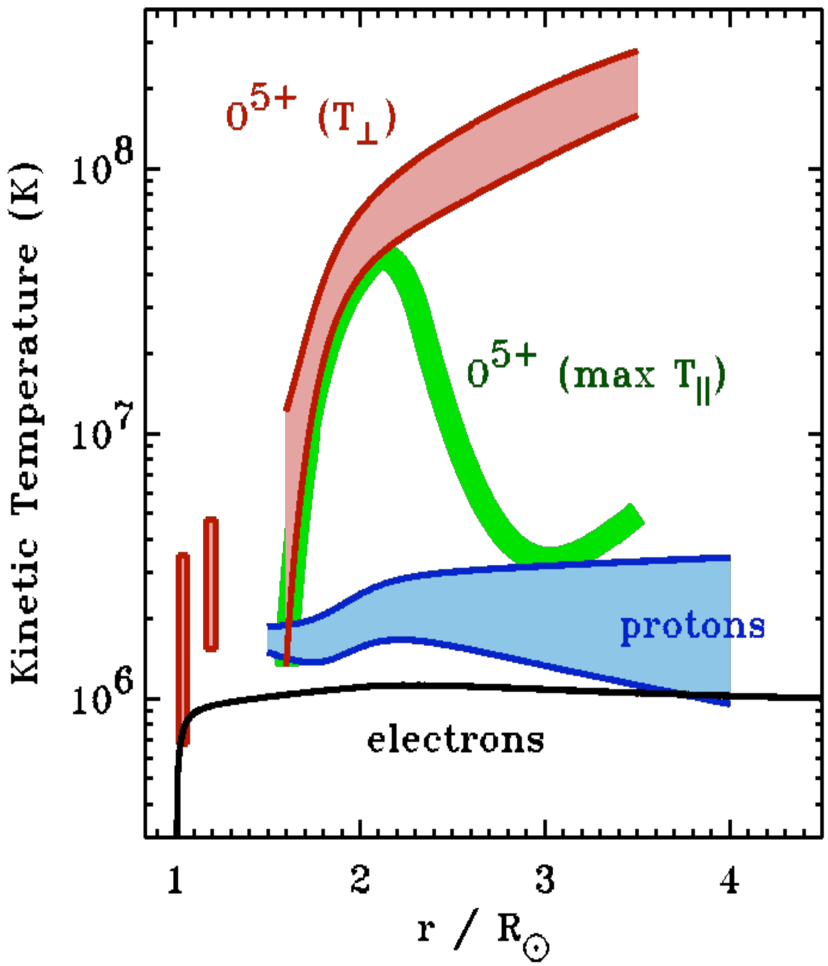
These topics are overlapping, and synergistic.

Waves and Turbulence

Our objective is to propose challenges that cut across laboratory, astrophysical, and space plasmas, as well as funding agencies (DOE, NASA, NSF). They incorporate and synthesize important fundamental issues identified in our group.

Challenge 1	Existing Research Capabilities	Gaps	Opportunities
Understand and predict turbulent particle heating	In situ satellites, ground and space-based telescopes and arrays, laboratory experiments, medium-scale MHD, two-fluid, hybrid, and gyrokinetic turbulence simulations, simple phenomenological models	Experimental / computational results that discriminate between multiple theoretical models, better understanding of anisotropic turbulence in MHD, two-fluid, and fully kinetic/gyrokinetic models, interaction of turbulence with larger-scale inhomogeneities	More comparative experimental and theoretical studies in laboratory and space/astrophysical plasmas, better diagnostics of energy apportionment between electrons and ions, development of more refined phenomenological models, holding coordinated *working* workshops

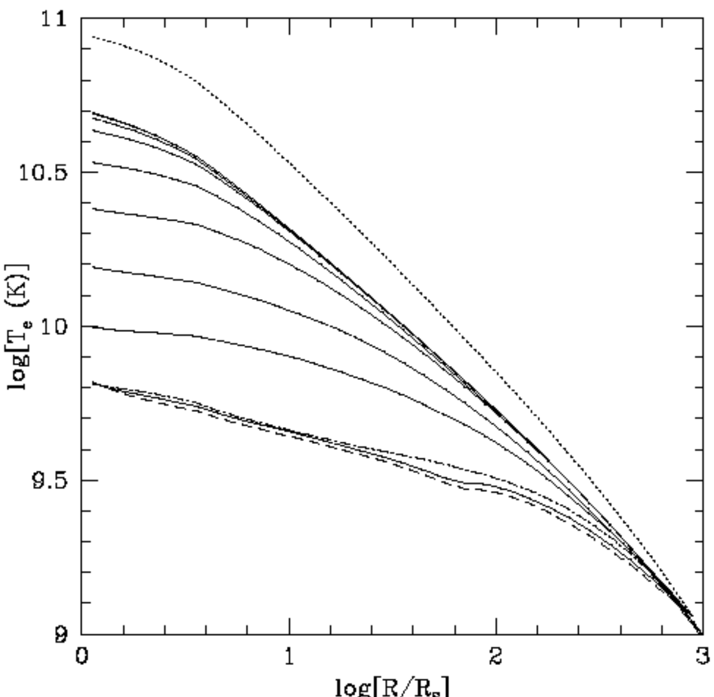
Coronal temperatures (UVCS)



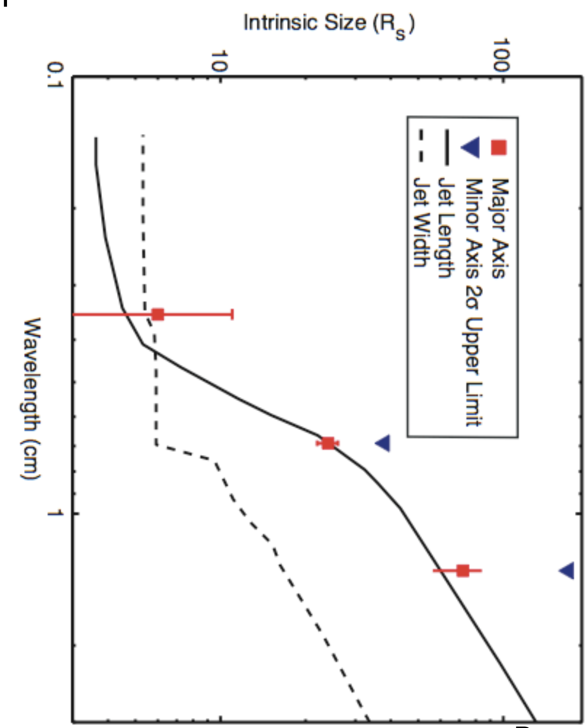
$$
\left\{ \begin{array}{ccc} T_{\text{ion}} \gg & T_p & > T_e \\ (T_{\text{ion}}/T_p) & > & (m_{\text{ion}}/m_p) \\ T_\perp & \gg & T_\parallel \\ u_{\text{ion}} & > & u_p \end{array} \right\}
$$

S. Cranmer, J, Kohl (UVCS)

Improved Observations Will Provide Stronger Tests of Simulations of Accretion Disk Turbulence & Heating



Sharma et al. ApJ 2007



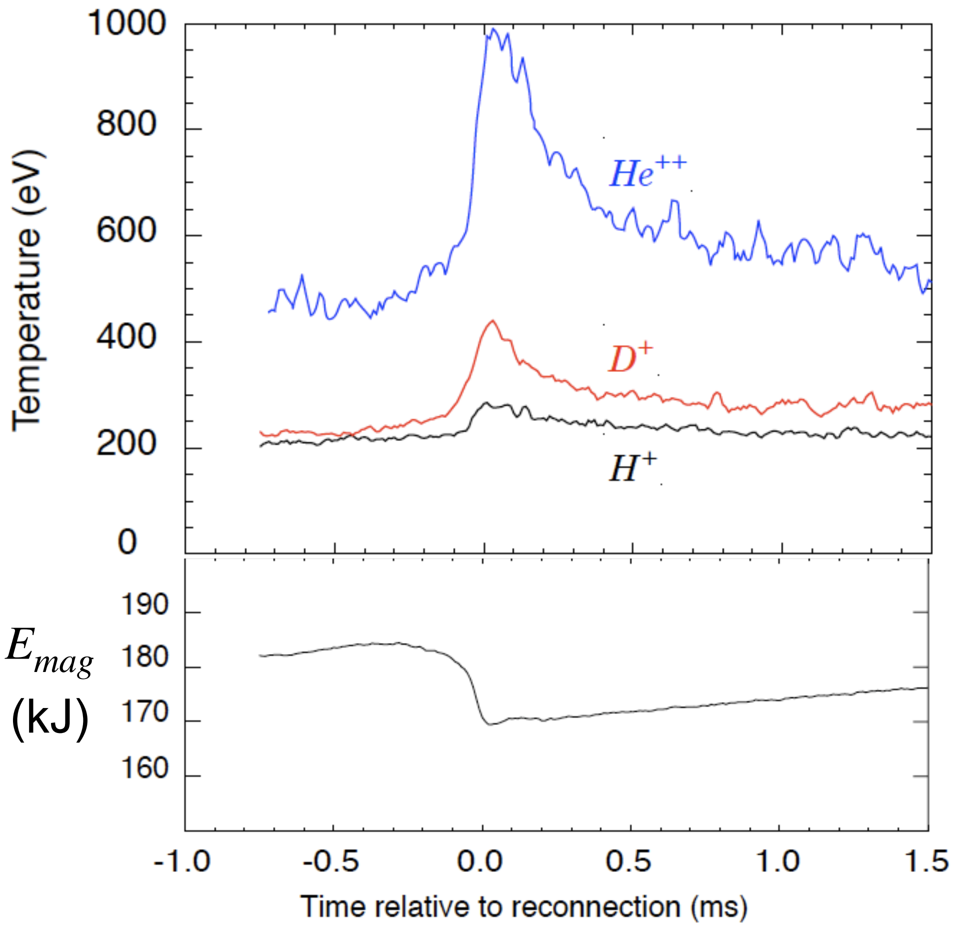
Bower et al. Science 2004

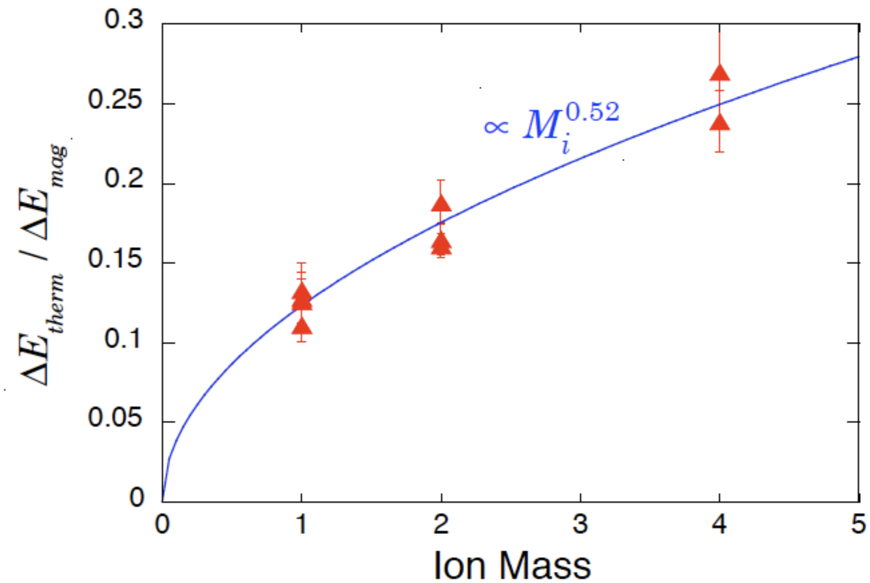
- Left: Electron temperature profile predictions from kinetic MRI turbulence simulations for various assumed accretion rates
- Recent VLBA measurements (right) and Faraday rotation measurements (Marrone et al. 07 ApJ 654, L57) give important tests of simulations, being improved. VLBA soon able to resolve event horizon in the massive black holes at the galactic center of our galaxy and of M87.
- Two very different systems: M87 has large jet & many orders of magnitude more radiation.

General topic of particle heating in turbulence ties together many fundamental plasma problems

- Simulations beginning to predict temperature and density profiles, magnetic field strength, and relative electron and ion heating. Essential to understanding observed luminosity of accretion disks and other astrophysical objects
- In many hot, lower density plasmas such as in radiatively inefficient accretion flows or galaxy clusters, traditional MHD breaks down because of the long mean-free path where kinetic effects can alter the dynamics & heating.
- Braginskii anisotropic viscosity or drift-kinetic-MHD can be used to study this regime, if supplemented w/ models of very small-scale microinstabilities (firehose, mirror, cyclotron) that limit anisotropy & cause particle heating.
- Also need to understand heating from Landau damping at $k_{perp}\ \rho_i > 1$ in the tail of the Alfven wave cascade (some work done with gyrokinetics, not finished).
- Accurate calculation & models hard, test with observations (and experiments?)
- General theme of Multiscale Problems: interactions of widely varying scales Prandtl # dependence of MRI & general dynamos, role of turbulent

Ion heating in MST increases with ion mass, with $T_i > T_e$





G. Fiksel et al., Phys. Rev. Lett. 103, 145002 (2009)

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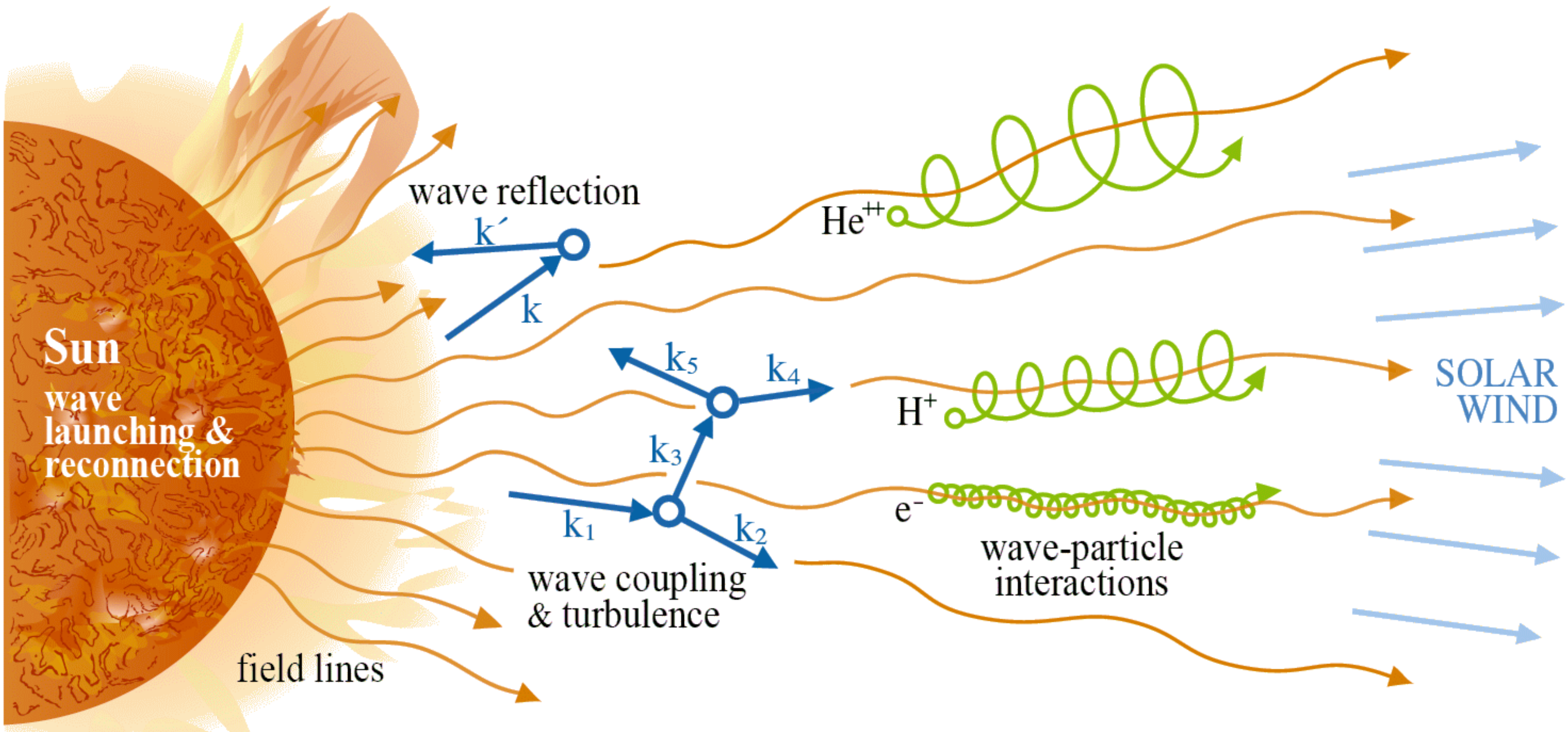
Example: Kinetic dissipation processes in the solar corona



Courtesy: B. Chandran, M. Lee, and K. Donahue, UNH

Waves and Turbulence (continued)

Challenge 2	Existing Research Capabilities	Gaps	Opportunities
Understand, in controlled experiments, specific mechanisms underlying turbulent cascades and heating/ acceleration, develop scaling relations, and validate fluid as well as kinetic computer simulation codes	Basic laboratory experiments (LAPD, MRX, SSX, MST, NSTX) and high-performance computer simulation codes	Experimental results that discriminate between multiple theoretical models, higher-resolution diagnostics/ instruments, experimental studies of relevant wave-wave and wave-particle interactions, cascades, spectra, structure functions, anisotropy, intermittency and coherent structures, flows, and particle heating/acceleration.	A national experimental facility and consortium of institutions (tying in with reconnection and dynamo initiatives)