Waves and Turbulence: Summary and Connections With Other Topics

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Nature and Properties of Turbulent Cascades

- Do turbulent systems in nature exhibit "universal" behavior?

  Not necessarily. For example, magnetic and velocity fluctuations in the solar wind have different exponents that evolve with distance from the Sun. Two-fluid, compressibility, kinetic effects invalidate incompressible MHD model.

- Does MHD turbulence have "universal" regimes akin to HD? Possibly, as seen from recent theory and simulations, but the issue remains open.

  ---Anisotropic Iroshnikov-Kraichnan versus Goldreich-Sridhar

  ----Balanced and imbalanced turbulence, weak and strong

Some Connections with Other Topics

- Connections with the problem of turbulent magnetic reconnection. Does the reconnection rate become independent of the dissipation mechanism? If yes, do we need turbulence to obtain reconnection rates independent of the dissipation mechanism? Or are secondary plasmoid instabilities in a pre-turbulent plasma enough? What role do such processes play in energy conversion in jets and lobes?
- Connections to the dynamo effect: turbulence complicates the artificial separation of mean field and fluctuations. Turbulence can amplify or quench mean-field flows, and so must be treated on an equal footing with them, in order to satisfy conservation relations.

Dissipation, Particle Acceleration and Heating, and the Role of Coherent Structures

- On what scales does dissipation and heating occur? At ion scales? Electron scales? In between ion and electron scales, is there wave dispersion, cascade, dissipation? Where is entropy generated and how?
- Is linear Vlasov theory in homogeneous systems a good guide for damping in the nonlinear regime? Or is the damping mediated by nonlinear coherent structures such as reconnecting current sheets?

Kinetic Simulations for Plasma Astrophysics

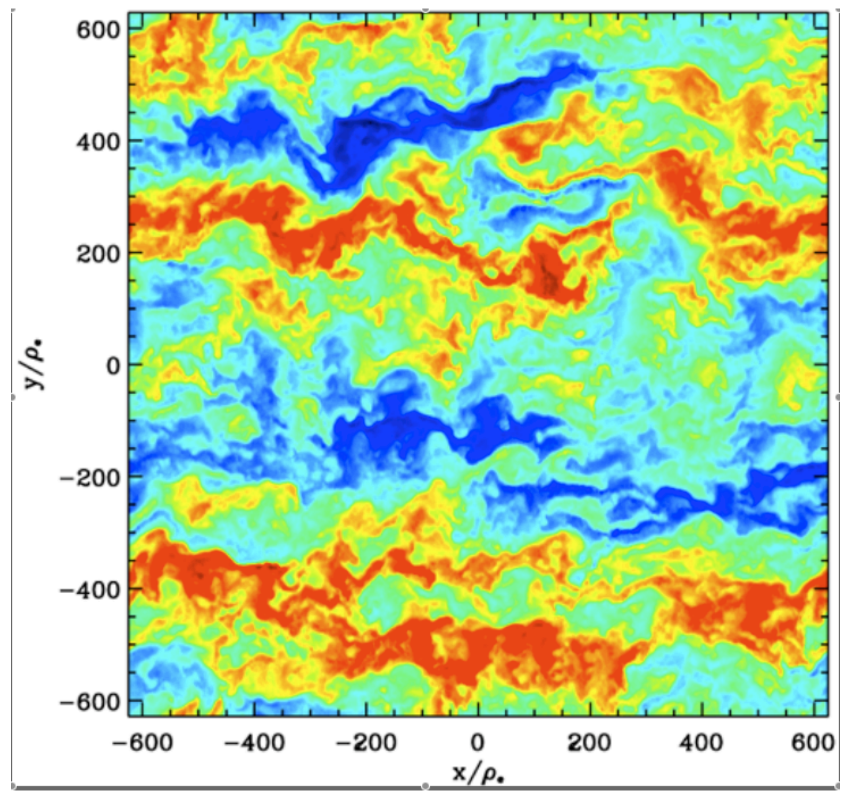
- Exponential growth in computer power means new questions can be investigated that were previously impossible.
- Advances in theoretical & computational techniques in fusion & astrophysics provides opportunities for cross-fertilization
- Traditional PIC (Lagrangian) simulations have been useful for studying important astrophysical & fusion phenomena
- "Continuum" (Eulerian) algorithms (direct "Vlasov solvers") have low noise & can also be useful for some problems, even in 6D. Both PIC & continuum codes need same spatial resolution for fields, but 3-D velocity integrals to calculate currents done more efficiently (asymptotically) w/ 2cd-order integration on a regular grid than PIC's Monte-Carlo random sampling of velocity space.
- Relative efficiency in reality highly problem dependent. Different algorithms provide useful cross-check.

Gyrokinetic simulations for plasma astrophysics

Gyrokinetic equations developed in fusion: Vlasov equation averaged over fast gyration of particles, no need to resolve Debye length & plasma frequency (unlike standard PIC). Continuum & PIC algorithms used.

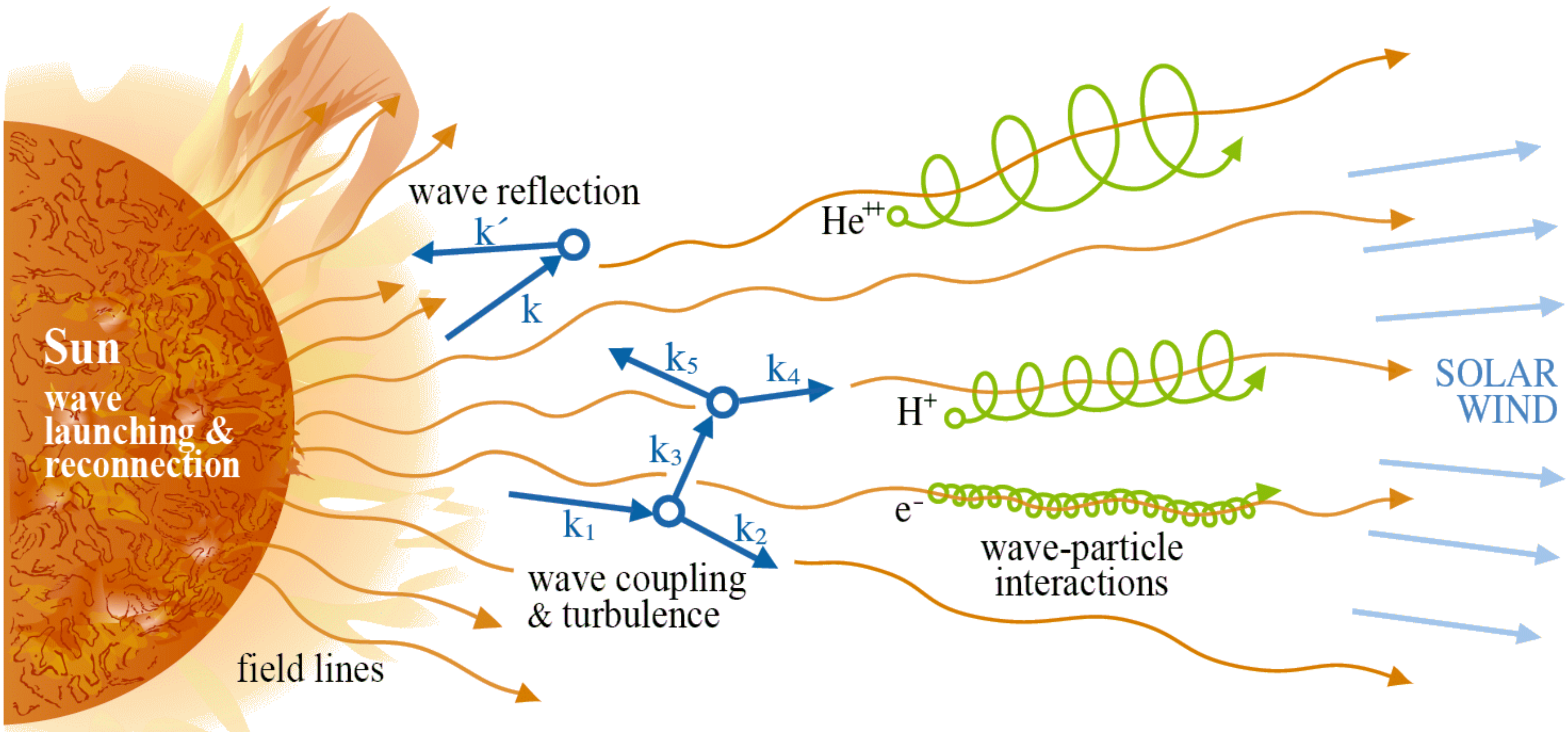
Gyrokinetics beginning to be applied to some astro problems, such as kinetic effects on reconnection w/ guide field, transition from MHD→ kinetic Alfven wave turbulence, relative electron and ion heating in the tail of Alfven wave turbulence at $k_{perp} \rho_i > 1$.

- Example of continuum 5-D gyrokinetic simulation of fusion plasma turbulence w/ 2.5e9 mesh points (Goerler & Jenko, PRL 2008)
  (768 x, 384 y, 16 z, 32 $v_{||}$, 16 μ, 2 species)
  (512 velocity points per spatial grid point)



- 100,000 CPU hours: ~10 hours on 10% of petaflop ORNL Cray XT-5. Proposals to develop exaflop

Example: Kinetic dissipation processes in the solar corona



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

Need for computational sandbox models

- Allow for the most important processes to assert their dominance in the presence of other competing processes. Sacrifice the computational rigor of some of the more focused models, but include a wider range of questions
- Example: not treat the full dynamics of the turbulent eddies, but the treat the cascade as diffusion in k-space, and parameterize dissipation in terms of net heating.

Role of laboratory experiments and observations

- Space observations from past (Voyager, Ulysses, Helios) and present satellite missions (including multi-satellite missions such as Cluster, Themis) provide great opportunities. Solar Probe Plus will continue that tradition.
- Laboratory experiments, such as LAPD, MRX, SSX and fusion experiments (MST, NSTX, other major tokamaks) have and can provide interesting tests of theory and insights.
- New national experiment: low collisionality, large magnetic field, and access to higher beta.

Figure 1. A sketch of the flux tube texture of the solar-wind plasma. Each flux tube contains a different plasma and the flux tubes move independently. A depiction (left) looking at the sides of the tubes indicates that the tubes are tangled about the direction of the Parker spiral. An end view (right) depicts the cross sections of the network of tubes. The scale sizes of the flux tubes correspond to the scale sizes of granules on the solar surface. The median diameter of a flux tube at 1 AU is 5.5×10^5 km.

[Borovsky, 2008]

Fig. 3. 3-D currents of Alfvén waves in a helium plasma rendered as snakes using the graphics package "Maya." For this image, the background magnetic field points out of the page. This image is part of a sequence used in the creation of a 3-D movie in collaboration with Eric de Jong, Steve Levoe, and Shigeru Suzuki from the Jet Propulsion laboratory, Pasadena, CA. The movie was shown in a lecture at the Los Angeles County Museum of Art and demonstrates (if nothing else) a link between science and art.