INTERFACE AND SHEAR INSTABILITIES

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(1)

Challenge How does the magnetic field affect stability and dynamical behavior of astrophysical systems (Dense Molecular Clouds, Supernovae, Sulernova Remnants, Jets and Outflows…)? Can we apply HED physics techniques to address this question?

Existing research capabilities The critically important role of the magnetic field in the behavior of astrophysical systems has been broadly recognized and in some cases supported by direct observations (radio interferometers and singledishes, e.g., CARMA, SMA, EVLA, APEX, GBT; ground based telescopes with polarimeters to measure Zeeman effect). Techniques have been developed for introducing dynamically-significant magnetic fields to HED experiments and directly measure them (proton deflectometry).

Gaps Direct observations are sparse or non-existent: we lack sufficent collecting area to do large survey work; existing facilities could do a few objects in each category as a typical PI experiment; need specific detailed model predictions in some cases -- at the level of synthetic observations. In HED experiments, only few attempts have been made to imitate effect of magnetic fields in astrophysics. Another gap includes funding for the experiments and facility time as they are quite costly. While there exist many codes, there are certainly gaps in current codes to be applied to these types of problems that need to be identified.

Opportunities In observations: ALMA (much more collecting area and very high resolution); LMT (25-meter singledish mm-wave telescope), currently under construction. In laboratory experiments: use the capabilities of HEDP facilities (NIF, Z, Omega…), combined with advanced diagnostic capabilities. Broaden collaboration between observers, modelers, and experimenters.

(2)

Challenge Can we apply HED physics techniques, both experiments and simulations, to NIF-based laboratory astrophysics experiments relevant to interface and shear instabilities in radiation controlled astrophysical systems?

Existing research capabilities Smaller scale HEDP facilities which cannot reach the regimes of the radiation-dominated processes. Some multidimensional simulation codes exist.

Gaps While there exist many codes, they often do not meet the specific needs of specific problems. Smaller scale facilities cannot achieve regimes a radiation pressure dominated regime. There exist limited diagnostics on NIF. Funding and facility time as they are both currently sparse.

Research opportunities NIF can achieve new regimes that can be relevant to instabilities occurring in astrophysics. Larger and more complex geometries can be used on NIF. More extensive participation in inter-disciplinary meetings

Collaborations with astronomers and astrophysicists in laboratory experiments from inception through execution. Take a long-term view in addressing the community integration and young researcher influx problems by establishing a program to involve astro students and postdocs in laboratory astrophysics efforts. Can we find more cross-fertilization in diagnostic development, etc, as well as conceptual guidance and simulation?

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Challenge Understand the interaction of the solar wind with geomagnetic field through the smallest scales: Characterize the role of kinetic effects and magnetic reconnection in the non-linear development of Kelvin-Helmholtz instabilities (KHI) and interchange instabilities (II), and their impact for the efficiency of plasma mixing, transport, and energy propagation.

Existing Research Capabilities Fluid scale constellation (e.g., ESA-NASA Cluster) and local single satellite missions (e.g., Geotail, THEMIS), have characterised the development of i) non-linear KHI at the magnetopause, including the potential importance of secondary magnetic reconnection inside non-linear KHI vortices, and (ii) II in dipolarisation fronts in the plasmasheet. 3-D non-linear simulations have examined these effects in the fluid domain in global magnetospheric simulations, or at the kinetic scale in simplified geometries and/or in limited spatial domains.

Gaps Observational capabilities from satellites for understanding non-linear KHI and II development are mostly limited to fluid scales and/or single point measurements, and in general exclude the kinetic regime. Extended phase mission operations often focus on science targets where closure can be gained from measurements from a single platform or mission. Science targets requiring multiple mission and hence multi-point measurements (e.g., as a "great observatory") are often de-emphasized or lacking. Kinetic 3-D simulations are not generally possible at global magnetospheric scales. Local simulations are often limited by simplifications such as periodic boundary conditions, by less realistic geometries, or by limited spatial/temporal resolution and limited domain.

Opportunities Coordinate current and future proposed constellation mission operations to cover multiple scales (ion, electron and fluid) at the magnetopause and plasmasheet to target: i) Non-linear KHI development and transport, and “dipolarisation front” interchange instabilities, and ii) the role of such coherent structures in plasma dissipation and turbulence. Future missions include : NASA MMS, JAXA-CSA SCOPE, ESA Cross-Scale, etc. Flight of true constellation class missions using numerous (>~10-100) nano-satellites, with supporting continent scale dense ground arrays (e.g., the proposed NSF Distributed Array of Small Instruments – DASI), would revolutionize research in this area.

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Challenge Stability of current-carrying astrophysical jets: why do they propagate to the distance of tens and more jet radii despite the presence of current-driven and shear-driven instabilities?

Existing research capabilities Subsonic, magnetized plasma jets (measured velocity profiles, plasma structure). Subsonic, magnetized, uniform plasma flows (measured velocity profiles, plasma fluctuations). Supersonic, (un)magnetized plasma jets (measured plasma structure and global velocity, including interactions with plastic)

Gaps Experiments conducted thus far do not have some of important ingredients of astrophysical objects, like the presence of axial magnetic field and significant external density. Paradoxically resilient jets have not been explained by theory and simulations; this may be an indication of incomplete physics included. Anisotropy of transport coefficients not included in numerical modeling.

In many cases, diagnostics were inadequate to make detailed comparisons with models.

Research opportunities Research opportunities are two-fold: 1) Assessment, design, and construction of a next-step (non-HEDP) experiment specifically oriented towards simulations of astrophysical jets; short-term, low-cost effort to extend MFE codes to astrophysics & space physics (open boundary conditions, radiation where necessary). 2) Using HEDP facilities, especially, Z-pinch based, possibly combined with pulsed lasers (the latter capability exists with Z, ZEBRA, and, in future, MAGPIE) and advanced diagnostics.

(5)

Challenge Magnetic reconnection in high-beta plasmas and non-ideal plasmas (stellar interiors, accretion discs, shock-heated stellar winds, dense molecular clouds)

Existing research capabilities Experiments usually limited to ideal, low-beta plasmas

Gaps Little or no information on reconnection under conditions where collision mfp is shorter than the ion (and even electron) dynamic length; little or no information on reconnection in plasmas with beta>1, in particular, reconnection of non-collinear flux ropes

Opportunities Carefully designed experiments on Z, OMEGA, and NIF.

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Challenge

- Develop validated simulation capability for instabilities in complex fluids
    - Problems are computationally intensive
    - Problems span a wide range of scales, and Reynolds number has very weak scaling with computing power: $Re \sim (CPU^*hr)^{1/(d+1)}$
    - Many problems are inherently 3D
- Examples
    - Multiple interacting mixing zones in core collapse SNe
    - Interfacial instabilities in spatially inhomogeneous fluids (SNR)
    - Interfacial instabilities in reacting fluids (TN deflragration)
    - Interfacial instabilities developing over a background of pre-existing turbulent (Type Ia explosion)
    - Effect of differential rotation on instability development in Type II SNe

Existing research capabilities

- Petaflop-scale computers
- Direct numerical simulation (DNS) of 3D RT with Reynolds number up to 32,000; just above the Re~20,000 turbulent mixing transition
- Very high resolution 2D simulations

- Subgridscale models to capture effects of unresolved scales
- Multidimensional multiphysics astrophysics codes

Gaps

- Still just on the threshold for turbulence DNS: Can’t do fully developed 3D turbulence with extended inertial range, transitional flow in the presence of larger scales, transitional flow with multiphysics
- Validation for astrophysics codes (Including subgrid models): Astro codes are not routinely applied to relevant nonlinear-phase experiments

Opportunities

- Exaflop-scale computing (considered feasible this decade) would allow another factor of 10 in Reynolds number, which should allow for unambiguous fully developed RT turbulent mixing
- Integrated “Cradle to Grave” stellar modeling: Better coupling of stellar modeling to explosion modeling, and explosion modeling to remnant modeling
- Collect a set of instability experiments, define and characterize in astro-code-friendly terms, and deliver to the astrophysics community as a tool for code validation