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Instability and Particle Acceleration in Relativistic Jets

Qiana Hunt and Kyle Rettke – College of Science, Physics

Overview

Massive black holes at the heart of Active Galactic Nuclei, and the collapse of supernovae have both been observed to emit relativistic jets – collimated flows of highly ionized gas that are known to travel at apparently super-luminal speeds. TRISTAN, a 3-D particle-in-cell code, was used to simulate the behavior of these jets as they move through an ambient plasma, either with or without initial magnetic fields. Analysis of the simulation results reveals a possible cause of particle acceleration that is seen to occur within jets, as well as the function of instability in promoting particle acceleration and magnetic field generation. Likewise, these simulations show the impact of other properties of the jet in determining the behavior of the jet as it propagates.

Key Findings

- Instability develops as a result of particle interaction within the jet, and between the jet and the ambient plasma
- Instability causes magnetic field generation and amplification
- Magnetic reconnection, a result of instability, causes particle acceleration
- Jet stability is determined by jet composition, and magnetic field strength and orientation
- e^--p^+ jets tend to be more stable than e^--e^+, due to higher particle mass (see Fig. 5 and 6)

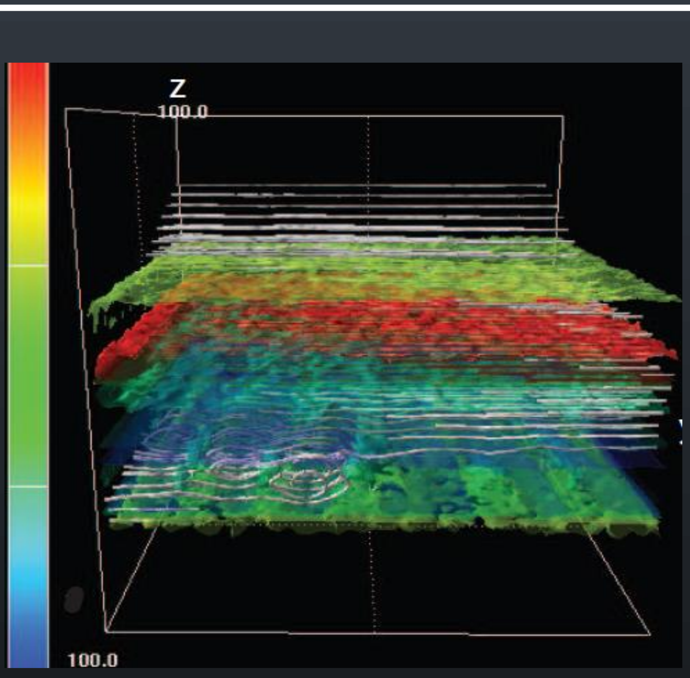

Fig. 1 KKHI Instability in electron-proton (e^--p^+) jet

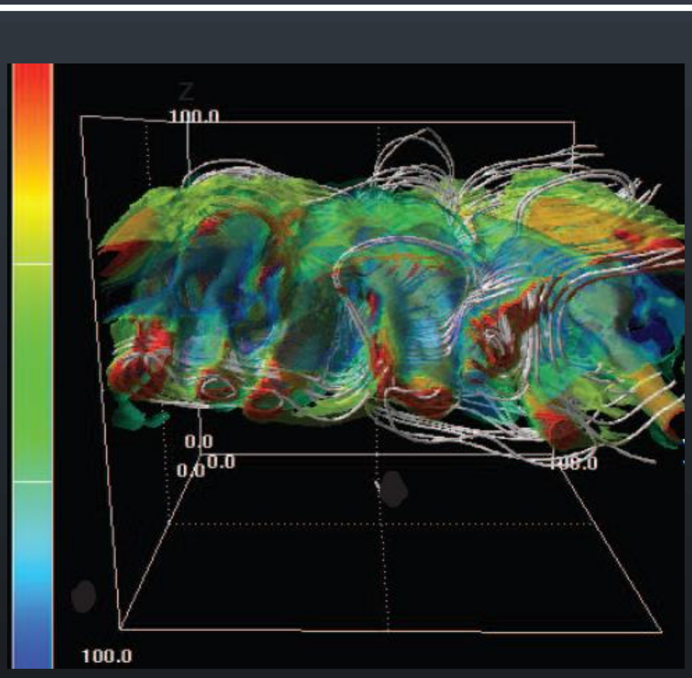

Fig. 2 KKHI Instability in electron-positron (e^--e^+) jet

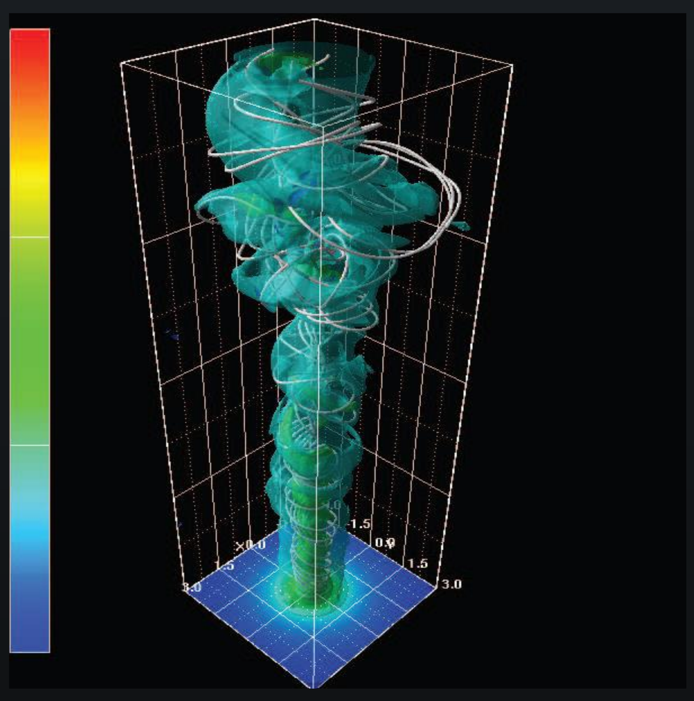

Fig. 3 Kink Instability

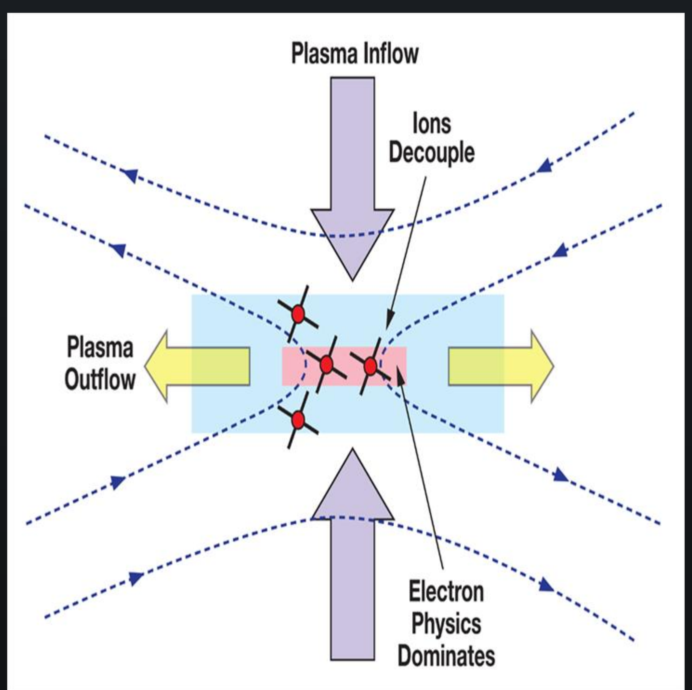

Fig. 4 Magnetic Reconnection, courtesy of nasa.gov

Figures

As the jet propagates, it is subject to several types of instability:

- (Kinetic) Kelvin Helmholtz Instability, (Fig. 1 and 2), occurs due to velocity shears between fluids that create regions of higher and lower density.
- Kink Instability, (Fig. 3), occurs due to the presence of a helical magnetic field. Slight variations in form cause perturbations that eventually unravel the jet. This results in magnetic reconnection.
- Magnetic Reconnection, (Fig. 4), occurs when magnetic field lines splice. Magnetic energy is converted into kinetic and thermal energy, spurring particle acceleration.
- Weibel Instability, (see Fig. 5 and 6), occurs due to particles within the jets moving in opposite directions, which causes current filamentation.

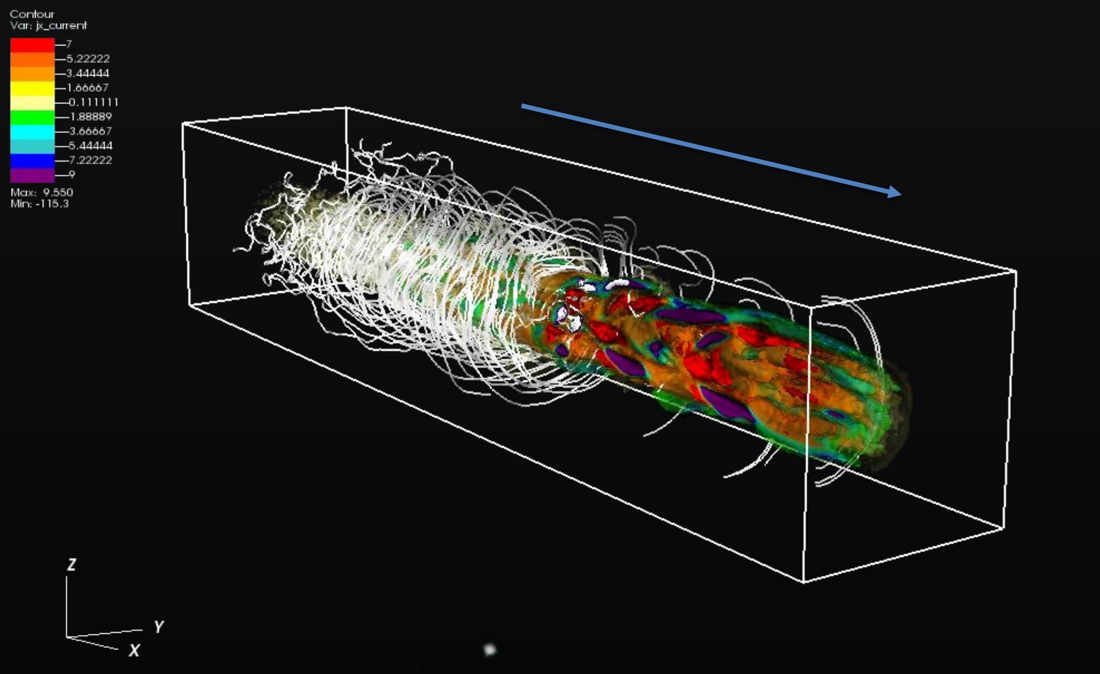

Fig. 5 Propagation of electron-proton (e^--p^+) jet, with current filaments and magnetic field lines

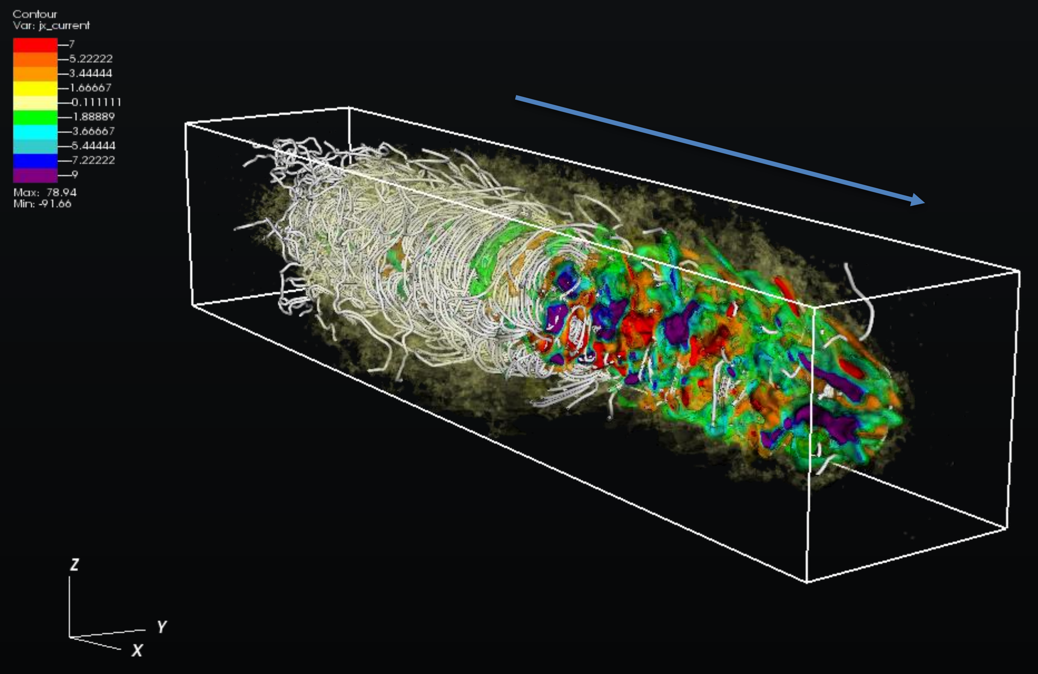

Fig. 6 Propagation of electron-positron (e^--e^+) jet, with current filaments and magnetic field lines

Impact

- Provides explanations for observed jet shapes and for the propulsion mechanisms that allow jets to propagate
- Demonstrates the potential capabilities of 3-D, multi-processor simulations in replicating complex, real-life phenomena

Explanation

In alignment with The American Astronomical Society's mission to enhance scientific understanding of the universe, we hope to better comprehend and explain, through our research, cosmic jet observations.

Images of AGN jets, M87 and Hercules A (above) and Centaurus A (left)
Courtesy of NASA

Acknowledgements

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