Science & Applications of Plasma-Based Accelerators

Session on Plasma Astrophysics (May 18, 2022)

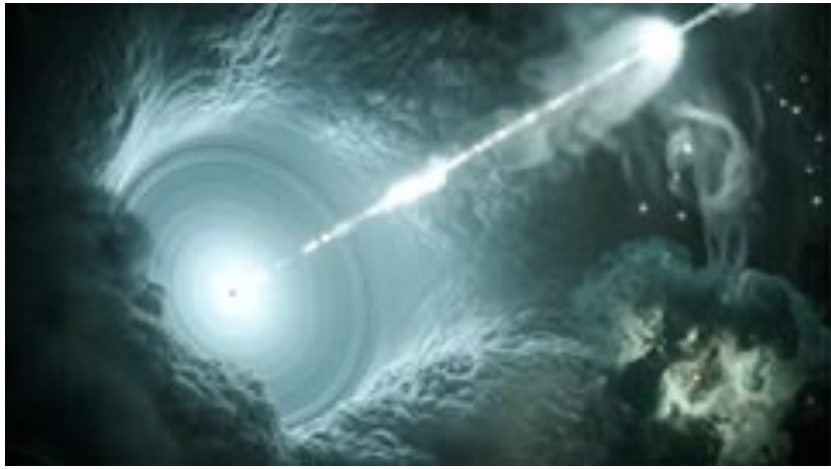
Frank Jenko
Max Planck Institute for Plasma Physics, Garching
TU Munich & UT Austin

Plasma Astrophysics (Convener: Frank Jenko)

09:00 – 09:05	Frank Jenko	**Introduction**
09:05 – 09:35	Frederico Fiuza	**Cosmic-Ray Driven Instabilities**
09:35 – 10:05	Tony Bell	**The Surprising Effectiveness of Cosmic Ray Acceleration**
10:05 – 10:30	**Discussion**	

The golden age of plasma astrophysics

- Most of the visible Universe is in a **turbulent, magnetized plasma state**
- Many key open questions in **astrophysics** and **astroparticle physics** involve **plasma physics**, from the acceleration and propagation of high-energy **cosmic rays** to the role of **turbulence** and **magnetic fields** in the formation of galaxies, stars, and planets…
- Highlight: **multi-messenger astronomy** (combine information from electromagnetic radiation, cosmic rays, neutrinos, and gravitational waves to investigate high-energy processes in the Universe)

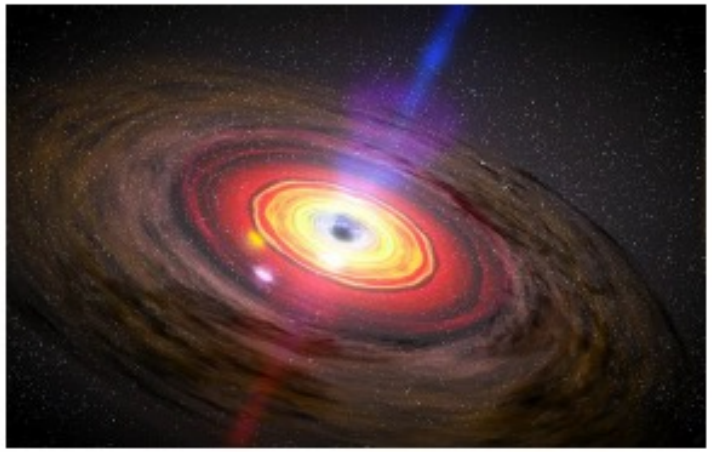


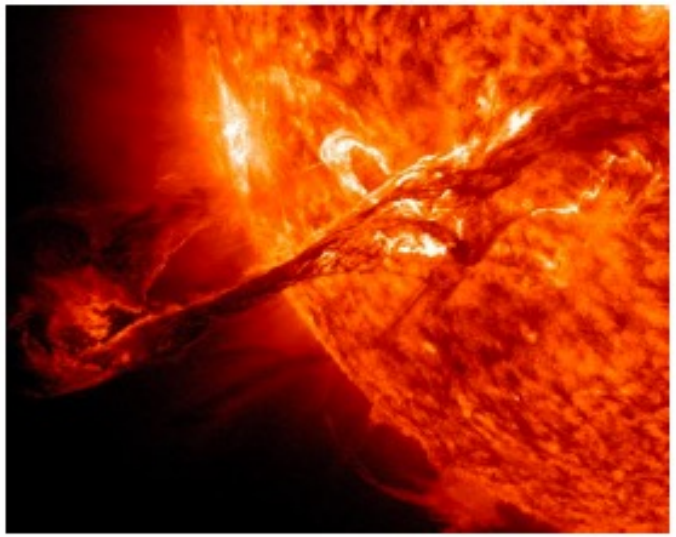
- Confluence of new capabilities in **observation/experiment & theory/simulation**

Plasma physics – connecting the dots

Fusion plasmas

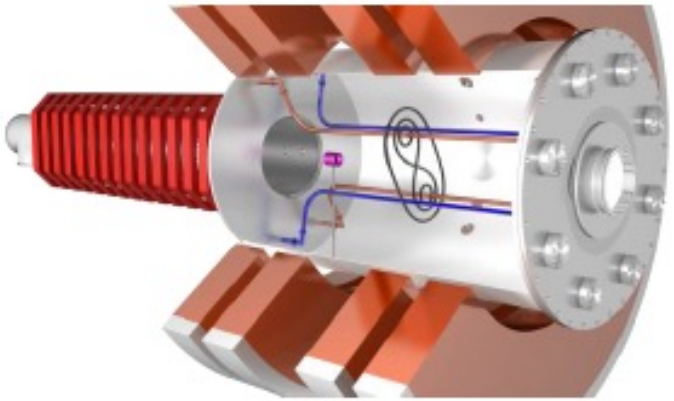
Astrophysical plasmas





Space plasmas

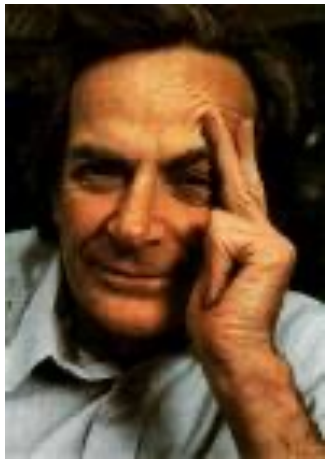
Laboratory plasmas



FEYNMAN'S REMARKS

Seemingly disparate complex non-equilibrium systems can actually be closely connected!

A „provocative" statement by **Richard Feynman**:



„It is actually quite possible for a physicist to retain a broad knowledge of the physical world rather than to become a specialist in some narrow area."

He gives three reasons:

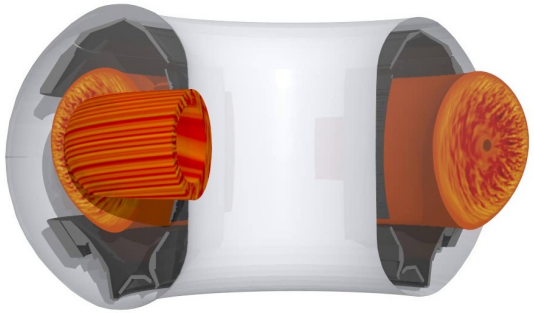
- Same **physics principles** connecting different kinds of phenomena
- Same **fundamental laws** underlying these phenomena
- Same **equations** (and analytical / numerical techniques to solve them)

Richard Feynman, Lectures on Physics, Vol. II, Ch. 12

A recent example

Building bridges between the lab and nature

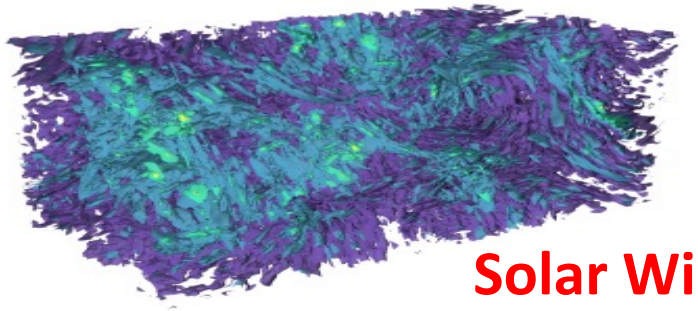
Tools originally developed for fusion research are exported to plasma astrophysics



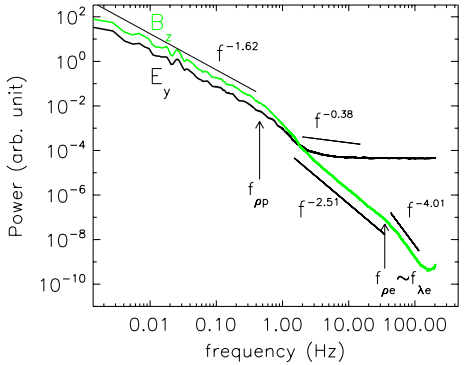
genecode.org

EXASCALE COMPUTING PROJECT

GENE code



Solar Wind



How does plasma turbulence dissipate energy at the (kinetic) tail of the MHD cascade?

PHYSICAL REVIEW LETTERS **120,** 105101 (2018)

Fully Kinetic Simulation of 3D Kinetic Alfvén Turbulence

Daniel Grošelj,[1] Alfred Mallet,[2] Nuno F. Loureiro,[3] and Frank Jenko[1]
[1]*Max-Planck-Institut für Plasmaphysik, Boltzmannstraße 2, D-85748 Garching, Germany*
[2]*Space Science Center, University of New Hampshire, Durham, New Hampshire 03824, USA*
[3]*Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*

Fully kinetic PIC simulations support GENE results [Told PRL 2015; Bañón Navarro PRL 2016]

Plasma physics for astrophysics: CR propagation

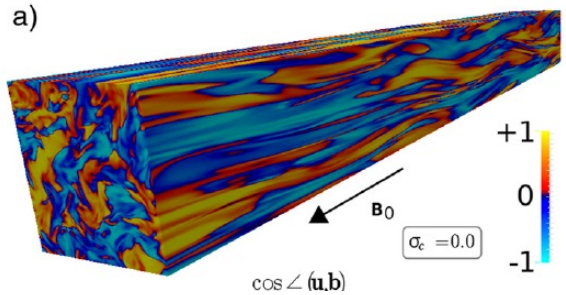
Just an example

The Astrophysical Journal, 711:997–1007, 2010 March 10 doi:10.1088/0004-637X/711/2/997

SCALING THEORY FOR CROSS-FIELD TRANSPORT OF COSMIC RAYS IN TURBULENT FIELDS

T. Hauff[1], F. Jenko[1], A. Shalchi[2], and R. Schlickeiser[2]
[1] Max-Planck-Institut für Plasmaphysik, EURATOM Association, 85748 Garching, Germany
[2] Institut für Theoretische Physik, Lehrstuhl IV: Weltraum-und Astrophysik, Ruhr-Universität Bochum, 44780 Bochum, Germany
Received 2009 October 22; accepted 2010 January 28; published 2010 February 19

The Astrophysical Journal, 811:8 (12pp), 2015 September 20 doi:10.1088/0004-637X/811/1/8



COSMIC-RAY PITCH-ANGLE SCATTERING IN IMBALANCED MHD TURBULENCE SIMULATIONS

Martin S. Weidl[1], Frank Jenko[2], Bogdan Teaca[3], and Reinhard Schlickeiser[4]
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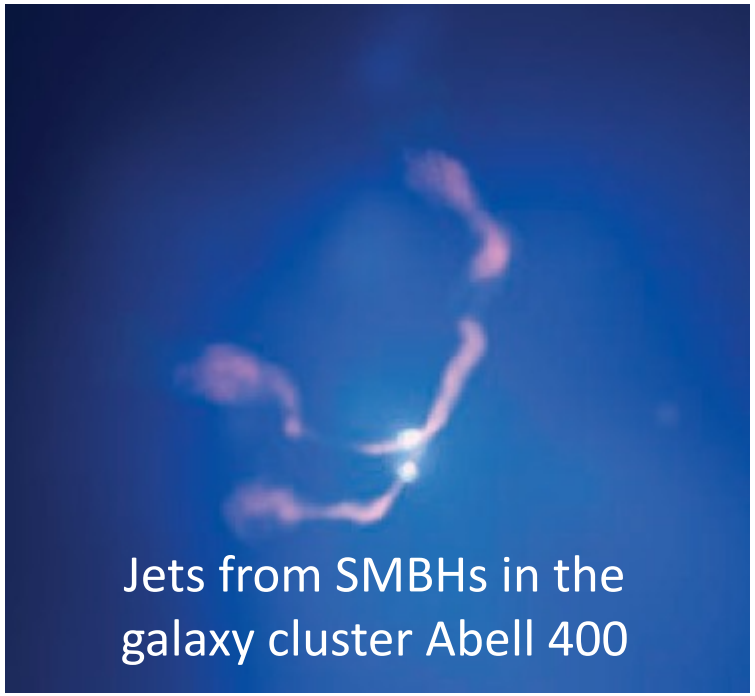
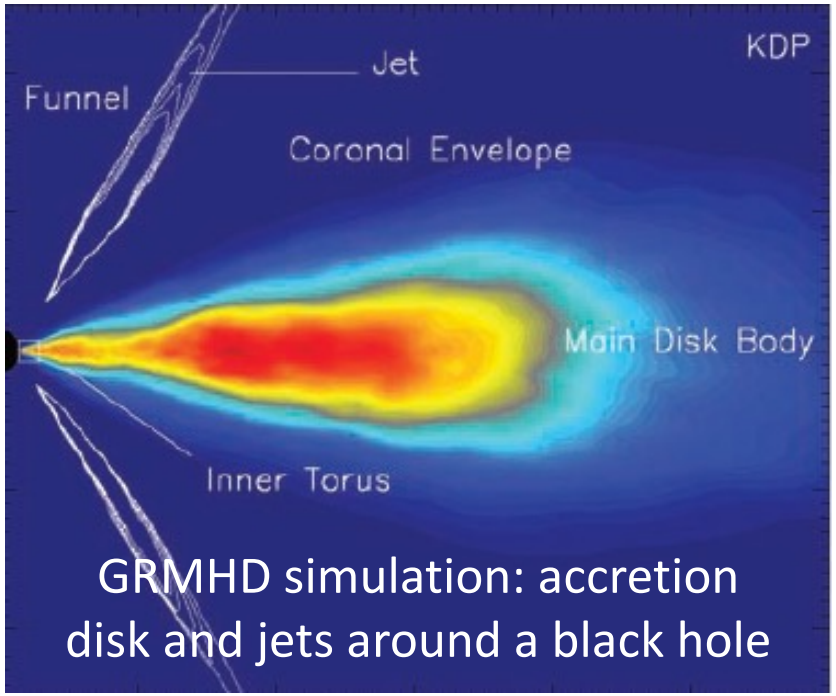
[2] Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA
[3] Applied Mathematics Research Centre, Coventry University, Coventry CV1 5FB, UK
[4] Institut für Theoretische Physik, Lehrstuhl IV: Weltraum- und Astrophysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany
Received 2015 February 19; accepted 2015 August 8; published 2015 September 11

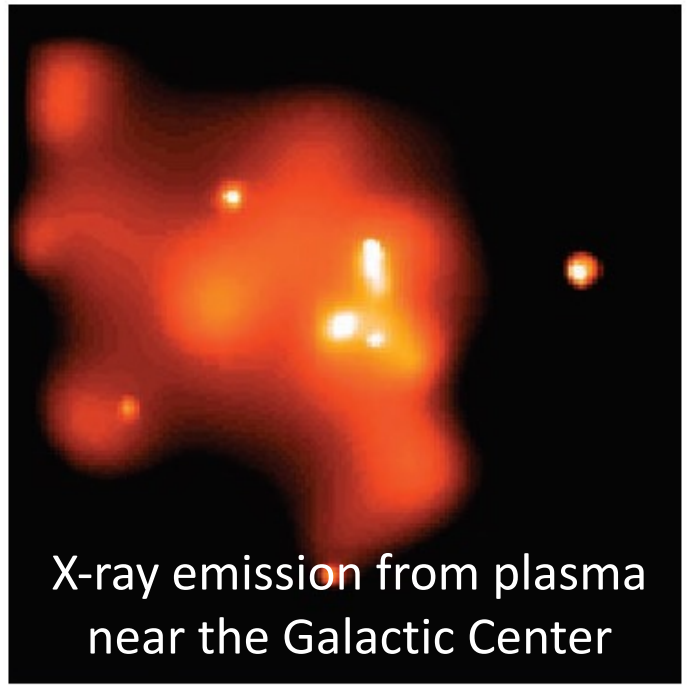
Plasma physics and black holes



Jets from SMBHs in the galaxy cluster Abell 400



GRMHD simulation: accretion disk and jets around a black hole



X-ray emission from plasma near the Galactic Center

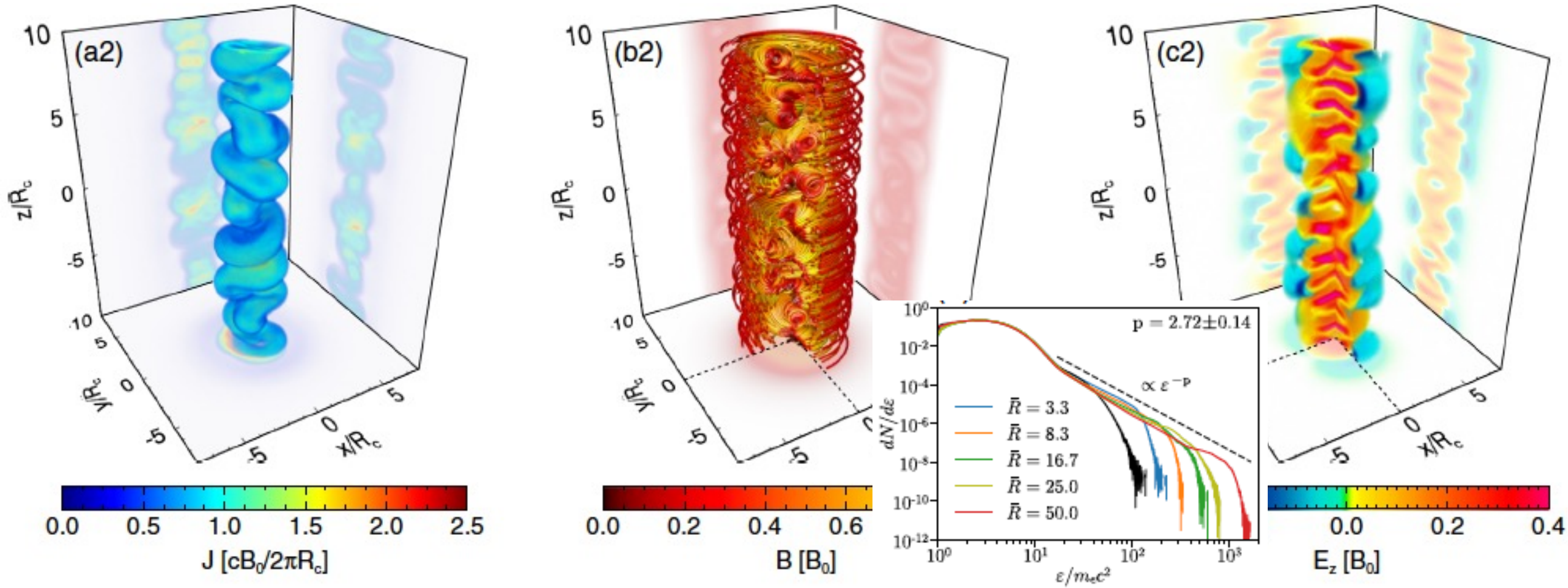
PRL 118, 045001 (2017) PHYSICAL REVIEW LETTERS week ending 27 JANUARY 2017

Accelerating Plasma Mirrors to Investigate the Black Hole Information Loss Paradox

Pisin Chen[1,2,*] and Gerard Mourou[3,†]

UHECRs from relativistic AGN jets? Alves+ PRL 2018

Fully kinetic simulations: magnetized jets are susceptible to helical kink instabilities



My background / home institution:

Max Planck Institute for Plasma Physics (IPP)

- IPP was founded in 1960 by Werner Heisenberg
- IPP has 1100 staff (700/400 at Garching/Greifswald) and operates two large experiments (ASDEX Upgrade, W7-X)
- Focus on fusion energy, but also active in basic plasma physics and plasma astrophysics

Tony Bell

University of Oxford, Imperial College, Rutherford Appleton Laboratory

Awards: Fellow of the Royal Society, Hoyle Prize 2014, Eddington Medal 2016, Alfven Prize 2017, Yodh Prize 2021

Research: particle acceleration by shock fronts; laser-produced plasmas; magnetic field amplification by cosmic rays; QED plasmas; plasma astrophysics

Frederico Fiuza

Theory Group Leader at the High Energy Density Science division at SLAC

Awards: John Dawson Award 2020; Thomas H. Stix Award 2018; DOE Early Career Research Program Award 2017; EPS PhD Research Award 2013

Research: kinetic simulations & HED experiments to explore a wide range of topics in astrophysical and laboratory plasmas, including particle acceleration, magnetic field amplification, collisionless shocks, magnetic reconnection, and fusion energy

Plasma-Based Accelerators: Opportunities

Identifying and understanding cosmic accelerators (UHECRs!)

Bridging laboratory and astrophysical plasmas

- Exploring existing experimental facilities to their full potential
- Simulation as a bridge between experiment and astrophysics
- Possible goals: Understand basic plasma processes, validate codes…

Pushing the (theory) envelope…

- Exascale computing allows for new kinds of simulations
- Plasmas under extreme conditions (GR, radiation, QED…)

Connecting the dots…

- Plasma processes (turbulence, reconnection, dynamos, shocks, radiation…)
- Spatio-temporal scales (mic vs mac)
- Scientific disciplines (plasma physics, astrophysics, space physics, HEP…)