High-Energy Astrophysics Group

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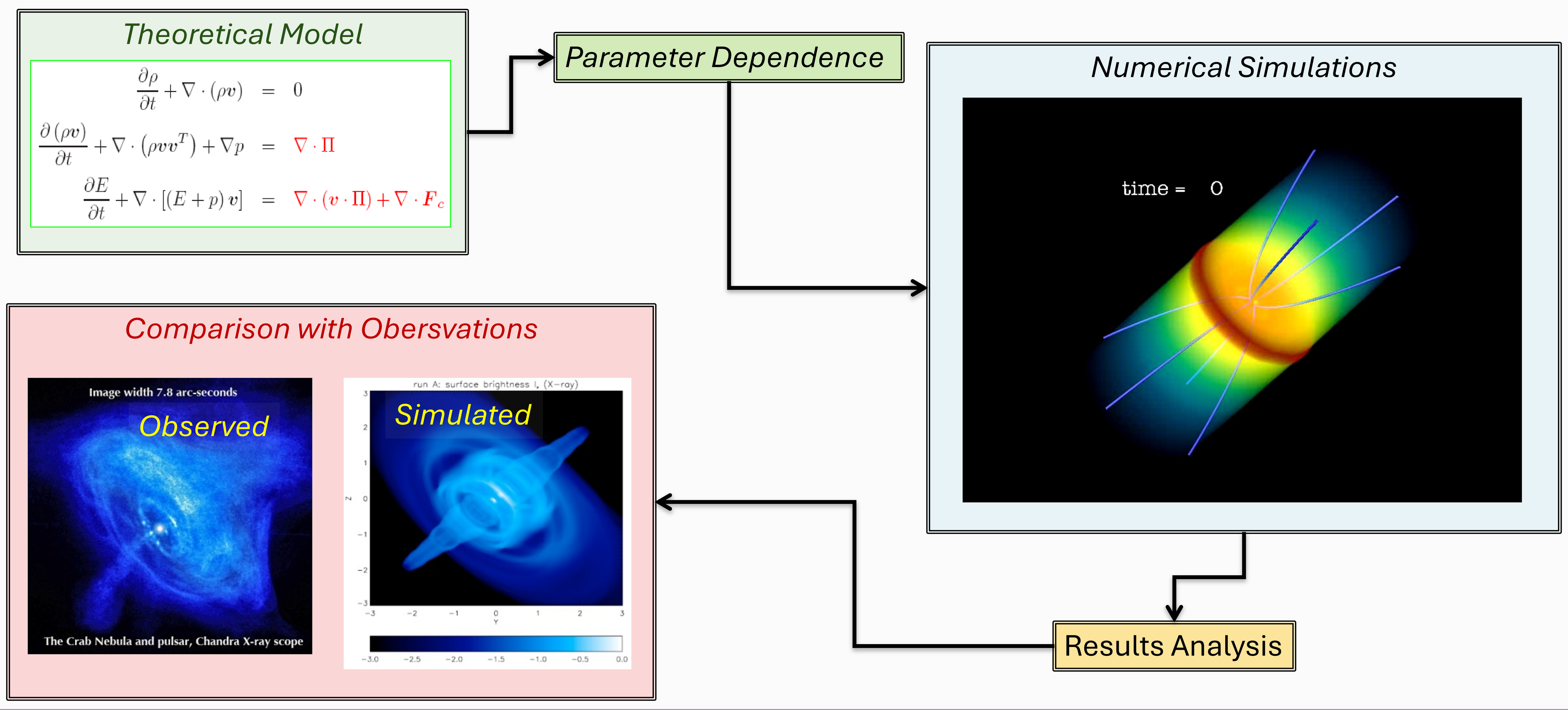
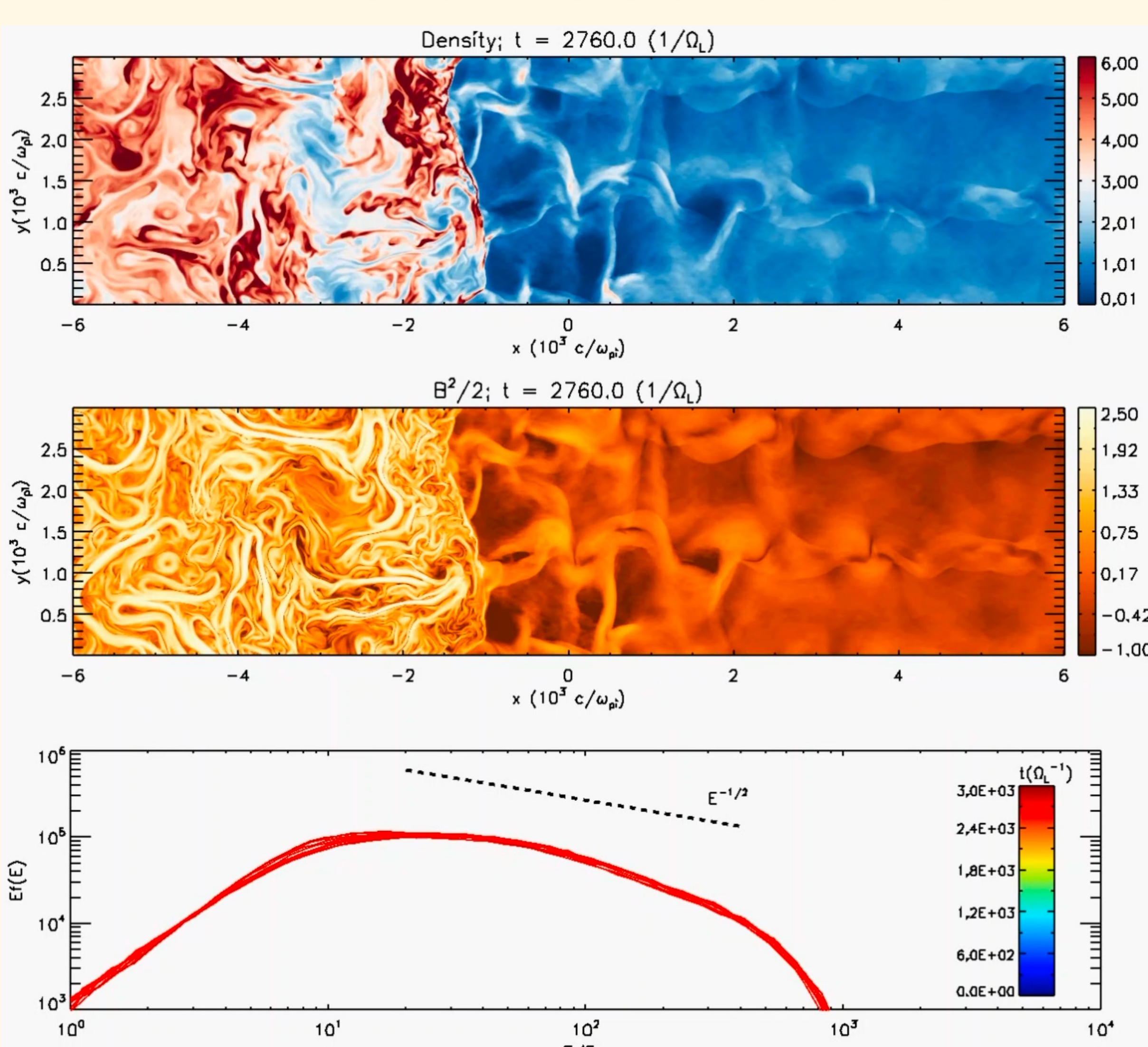
The high-energy astrophysics group focuses on the most powerful astrophysical environments in the Universe and it has a long-standing tradition here at the Physics department.
By means of advanced numerical simulations, we investigate the origin, dynamics and non-thermal emission of highly-energetic phenomena connected to the physics of relativistic jets from Active Galactic Nuclei (AGN), Pulsar Wind Nebulae (PWN) and Gamma Ray Burst (GRB), among others.
These involve understanding the behavior of plasma at extreme densities and temperatures, high velocities, enormous magnetic fields, and strong gravity. Understanding these extreme environments is crucial to interpreting the bizarre energetic phenomena that occur in such objects, and it is is currently experiencing an explosion in data quality and in the level of sophistication of the modeling.

Owing to the complex nonlinear form of the equations, theoretical models based on astrophysical fluids are approached by means of *numerical simulations*, whose results can ultimately be compared with observations.



Particle Acceleration



At small scales, particle acceleration occurs in localized dissipation regions, typically identified with shock waves, magnetic reconnection sites or turbulence regions, originated as byproducts of large-scale 3D plasma instabilities.
While addressing this topic, we try to give an answers the challenging questions:
"What are the conditions leading to ultra-relativistic energization of electrons / protons ?"
"What is the time-scale for this process and how efficient is it ?"

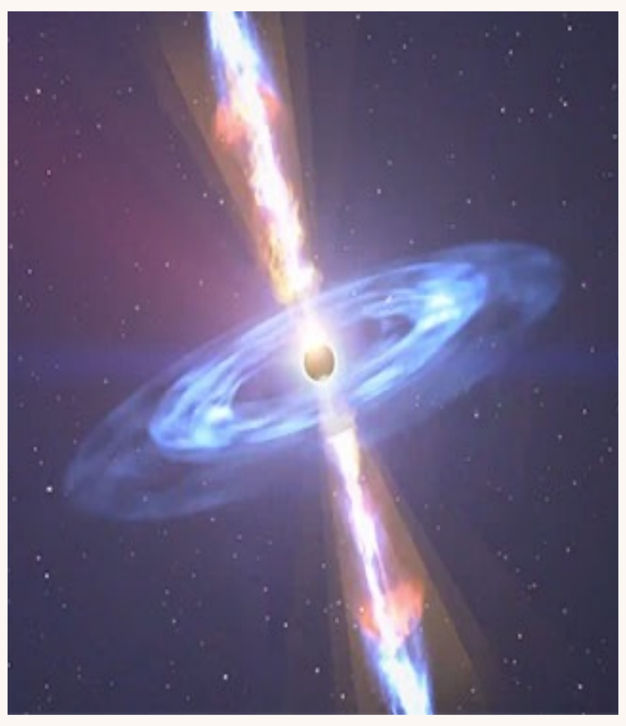
High-Performance Computing

The modelling of astrophysical plasma is deeply connected with our ability to solve the underlying physical equations, which describe the dynamical evolution of plasma under extreme conditions. For this, more advanced numerical methods targeting next generation hardware (e.g. GPU) should be developed.

Jet Propagation

Jets are launched in proximity of compact objects (BH / NS) in the form of collimated relativistic outflows of supersonic plasma, propagating through the external environment. They feature non-thermal emission characterized by synchrotron and inverse-Compton cooling and can survive for thousands of parsecs.

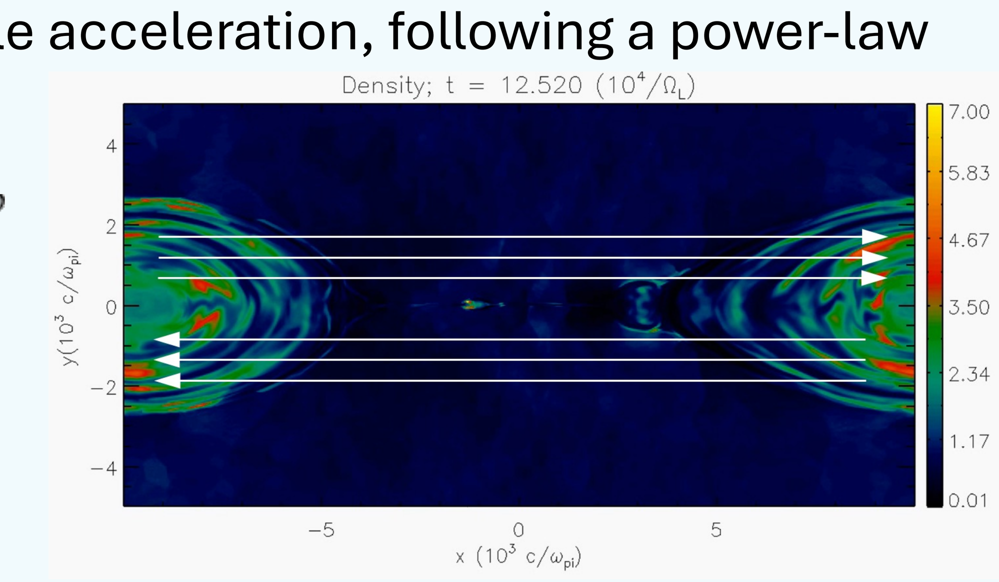
We aim at understanding jet survival against instabilities and how magnetic energy becomes available to energize particles responsible for the observed emission.



Magnetic Reconnection

Magnetic reconnection is a topological rearrangement of magnetic field lines with opposite polarity leading to efficient dissipation of magnetic energy into heat, kinetic energy and particle acceleration, following a power-law

$$\frac{dN}{d\gamma} = N_0 \left(\frac{\gamma}{\gamma_0}\right)^{-p}$$



State-of-the-art 3D models pose a new challenge in describing the dynamics of the tearing mode instability extended both analytically and via numerical simulations the ideal TMI reconnection scenario to full 3D models.