The impact of vorticity waves on the shock dynamics in core-collapse supernovae

Ernazar Abdikamalov

Convective perturbations arising from nuclear shell burning can play an important role in propelling neutrino-driven core-collapse supernova explosions. In this work, we analyze the impact of vorticity waves on the shock dynamics and the post-shock flow using the solution of the linear hydrodynamics equations. We show that the entropy perturbations generated by the interaction of the shock with vorticity waves may play a dominant role in generating buoyancy-driven turbulence in the gain region. We estimate that the resulting reduction in the critical luminosity is 17-24%, which approximately agrees with the results of three-dimensional neutrino-hydrodynamics simulations.

Magnetic suppression of corotational instabilities in thick accretion disks

Matteo Bugli

Geometrically thick tori with constant specific angular momentum are prone to a global non-axisymmetric hydrodynamic instability, known as Papaloizou-Pringle instability (PPI), which can redistribute angular momentum and also lead to an emission of gravitational waves. It is, however, not clear yet how the development of the PPI is affected by the presence of a magnetic field and by the concurrent development of the magnetorotational instability (MRI). We present a numerical analysis using three-dimensional GRMHD simulations of the interplay between the PPI and the MRI considering, for the first time, an analytical magnetized equilibrium solution as initial condition. In the purely hydrodynamic case, the PPI selects as expected the large-scale m = 1 azimuthal mode as the fastest growing and non-linearly dominant mode. However, when the torus is threaded by a weak toroidal magnetic field, the development of the MRI leads to the suppression of large-scale modes and redistributes power across smaller scales. If the system starts with a significantly excited m = 1 mode, the PPI can be dominant in a transient phase, before being ultimately quenched by the MRI. Such dynamics may well be important in compact star mergers and tidal disruption events.

New insights on the low T/W instability in shocked accretion flows

Thierry Foglizzo

The phase of stalled shock during the collapse of a rotating stellar core is potentially unstable to both the prograde spiral mode of SASI and the low T/W instability. A perturbative analysis is used to better understand and disentangle these processes. We find some major differences between the classical low T/W instability in an isolated neutron star and the extrapolation of this mechanism to an accreting proto neutron star. Characterizing the mechanisms at work can help define the parameter space where these instabilities are strongest in view of identifying their gravitational wave signature and their impact on the explosion mechanism.

How to form a millisecond magnetar? Magnetic field amplification in protoneutron stars

Jérôme Guilet

Extremely strong magnetic fields of the order of 10^{15} Gauss are required to explain the properties of magnetars, the most magnetic neutron stars. Such a strong magnetic field is expected to play an important role for the dynamics of core-collapse supernovae, and in the presence of rapid rotation may power super-luminous supernovae and hypernovae associated to long gamma-ray bursts. The origin of these strong magnetic fields remains, however, obscure and most likely requires an amplification over many orders of magnitude in the protoneutron star. One of the most promising agents is the magneto-rotational instability (MRI), which can in principle amplify exponentially a weak initial magnetic field to a dynamically relevant strength. I will describe our current understanding of the MRI in protoneutron stars and show recent results on the impact of physical conditions specific to protoneutron stars such as neutrino radiation, buoyancy and large magnetic Prandtl number.

The development of neutrino-driven convection in core-collapse supernovae: 2D vs 3D

Remi Kazeroni

A toy model is used to study the non-linear conditions for the development of turbulent motions in the gain region when convection is linearly stabilized by advection, in 2D and in 3D. Our simulations indicate that a buoyant perturbation of density is able to trigger self-sustained convection only in cases close enough to the threshold of linear stability. Our model enables to investigate various physical arguments that had been proposed to explain the impact of dimensionality on the onset of the explosion. In 3D, an efficient mixing to small scales induces an increase of the neutrino heating efficiency in a runaway process. Such a phenomenon is absent in 2D and this could suggest that the tridimensional nature of the flow may foster the explosion as seen in some recent ab initio studies. Similarly our simulations point out that an improved numerical resolution enhances the phase mixing which may ease the onset of explosion.

Status of 3D core-collapse supernova modeling with improved neutrino physics and the multi-messenger predictions

Kei Kotake

Abstract: We will report results from our 3D core-collapse supernova models, where not only a neutron-star (NS) but also a black-hole (BH) forming progenitor is employed. We also discuss how we can extract the information of the NS-forming or BH-forming mechanism based on a detailed analysis of the neutrino and GW signatures.

Blandford-Znajek process in dynamically evolving space-times

Jens M. Mahlmann, P. Cerdá-Durán, M. A. Aloy

We report on our on-going efforts to study the Blandford-Znajek process by means of force-free electrodynamic simulations of magnetospheres around rotating black holes. The problem splits naturally in two steps. In the first one, we obtain equilibrium, axially-symmetric magnetospheres around Kerr black holes. For that, we solve numerically the Grad-Shafranov equation. Among the possible magnetostatic configurations we focus our research on the ones which may be more suitable for extraction of energy from the ergospheric region of the black hole. More specifically, we focus on configurations like, e.g., split monopoles or paraboloid shaped magnetospheres, which may result into collimated plasma outflows. In the second step, we evolve the the initial equilibrium models employing the Einstein Toolkit. We have developed our specific modules for the integration of the General Relativistic Force-Free Electrodynamics equations. These modules consider an augmented system of equations that includes three extra scalar variables to account for the charge continuity as well as for the cleaning of numerically built up magnetic monopoles. Since some of the initially set up magnetospheres develop current sheets, we will carefully examine several strategies to account for the time evolution of the loci where the force-free conditions break down in the computational domain.

Herschel and ALMA studies of supernova remnants

Mikako Matsuura

Shocks in relativistic transverse stratified jets

Zakaria Meliani

We investigate the plasmoid knot formation in stratified relativistic jet by means of relativistic magneto-hydrodynamics simulations. Indeed, astrophysical jets in active galactic nuclei seem to be transversely stratified, with a fast inner jet and a slower outer jet. As it is likely that the launching mechanism for each component is different. In the other hand, the steady and moving knots properties are observed along these jets. With the proposed model, we were able to link the different types of observed knot in various radio load AGN with specific stratified jet characteristics. We showed that the increase energy flux at the outer edge of the jet induces a steady knot near the core and a moving knots at larger distance.

Pulsar glitch models in general relativity

Jerome Novak

Pulsar glitches are often interpreted as angular momentum transfers occurring between two fluids present in the neutron star interior, triggered by the rapid motion of superfluid vortex lines at large scales. We model for the first time all general relativistic effects in a numerical model for glitches. First, we show numerical calculation of stationary configurations of neutron stars composed of a neutron superfluid and a fluid made of charged particles, spinning with different rotation rates. These general relativistic calculations are based on realistic equations of state accounting for entrainment effects between the fluids. These configurations are then used to build a numerical model for pulsar glitches in full general relativity. In particular, we study in details the characteristic time scale associated with the spin-up stage, during which the stellar dynamics are governed by a mutual friction force arising from the interactions between the superfluid vortices and the surrounding fluids. Taking general relativity into account leads to an additional coupling between the fluids through frame-dragging effects and is shown to affect significantly the actual value of the spin-up time scale.

Sterile neutrinos in stellar core-collapse

Tomasz Rembiasz

Sterile neutrinos are additional neutrino species proposed as an extension of the Standard Model to explain discrepancies in the fluxes of the (standard) active neutrinos in baseline experiments. Sterile neutrinos were also put forward as a plausible missing agent in the core-collapse supernova mechanism. To test this hypothesis, we have implemented into the code Aenus a two-moment transport scheme for sterile neutrinos coupled to the hydrodynamics of the gas and the transport of (standard) active neutrinos. I will present results of our recent 1D simulations of a stellar core-collapse with two different models of (heavy) sterile neutrinos, i.e. of Fuller et al. (2009) and Albertus of et al (2015) with masses of 145-200 MeV and 50-80 MeV, respectively. We observe that sterile neutrinos can have a great impact on the post-bounce phase (leading to a successful explosion). With the help of our simulations, we are able to give constraints on the sterile neutrino models.

Supernova neutrinos

Irene Tamborra

Neutrinos are key particles in core-collapse supernovae. Neutrinos revive the stalled shock wave to finally trigger the core collapse and affect the element formation in the neutrino-driven wind. Carrying information from deep inside the stellar core, neutrinos are direct probes of the supernova mechanism. Fascinating recent developments on the role of neutrinos in supernovae are reviewed, as well as our current understanding of the flavor conversions in the stellar envelope. The detection perspectives of the next burst will be also outlined

Towards asteroseismology of core-collapse supernovae with gravitational wave observations

Alejandro Torres

Gravitational waves from core-collapse supernovae are produced by the excitation of different oscillation modes in the proto-neutron star (PNS) and its surroundings, including the shock. In this work we study the relationship between the post-bounce oscillation spectrum of the PNS-shock system and the characteristic frequencies observed in gravitational-wave signals from core-collapse simulations. This is a fundamental first step in order to develop a procedure to infer astrophysical parameters of the PNS formed in core-collapse supernovae. Our method combines information from the oscillation spectrum of the PNS, obtained through linear-perturbation analysis in general relativity of a background physical system, with information from the gravitational-wave spectrum of the corresponding non-linear, core-collapse simulation. Using results from the simulation of the collapse of a 35 M presupernova progenitor we show that both types of spectra are indeed related and we are able to identify the modes of oscillation of the PNS, namely g-modes, p-modes, hybrid modes, and standing-accretion-shock-instability (SASI) modes, obtaining a remarkably close correspondence with the time-frequency distribution of the gravitational-wave modes. The analysis presented in this paper provides a proof-of-concept that asteroseismology is indeed possible in the core-collapse scenario, and it may serve as a basis for future work on PNS parameter inference based on gravitational-wave observations.

Development of a new fourth-order hydrodynamic code for Astrophysics

Annop Wongwathanarat

We report on recent progress in our development of a new hydrodynamic code named APSARA. The code employs a fourth-order finite-volume method for solving the Euler equations in mapped coordinates. APSARA shows fourth-order convergence for test problems with smooth flows, and exhibits less numerical viscosity in the low-Mach number regime than in numerical codes widely used in Astrophysics.