EP 15: Astrophysics III

Time: Friday 13:30–16:00 Location: ZHG101

Invited Talk EP 15.1 Fri 13:30 ZHG101

Nucleosynthesis of heavy elements in the hot and dense plasmas of explosive astrophysical environments — •Daniel Siegel — Universität Greifswald

Gravitational-wave and multi-messenger astronomy shed light on the astrophysics of black holes and neutron stars and also allow for unique probes of fundamental physics. I will discuss recent results on how the mergers of neutron stars as well as other explosive systems such as the death of massive, rotating stars (collapsars) give rise to the formation of heavy elements in the universe. In particular, I will discuss recent results at the interface of numerical relativity, relativistic astrophysics, neutrino physics as well as nuclear astrophysics, and highlight how multi-messenger astronomy may lead to answers of a 70-year old fundamental question in physics: How does the Universe create its heaviest elements?

EP 15.2 Fri 14:00 ZHG101

Time-dependent modeling of radiative processes in pulsar wind nebulae generated by neutron-star mergers — •Eric Schneider[1], Michael Müller[1], and Daniel Siegel[1,2] — [1]Institute of Physics, University of Greifswald, Greifswald, Germany — [2]Department of Physics, University of Guelph, Guelph, Ontario, Canada

Emission from pulsar wind nebulae (PWNe) and the thermal emission of kilonovae (KN) have traditionally been studied as separate phenomena, associated with distinct astrophysical origins. A pulsar wind nebula is composed of a relativistic leptonic plasma powered by a pulsar typically found in supernova remnants. The leptons cool down through a variety of radiative processes, giving rise to distinct non-thermal emission. A KN is a thermal electromagnetic transient driven by the radioactive decay of neutron-rich nuclei, which are synthesized by the rapid neutron-capture process in the dense plasma outflows from neutron star mergers.

Recent models suggest PWNe may also form in binary neutron star mergers, driven by long-lived remnant neutron stars. These PWNe differ from their supernova counterparts because of their high compactness and high photon densities, requiring new theoretical approaches.

We present a unified model for PWNe evolution and electromagnetic emission, together with a generalized KN model that incorporates the presence of a PWN. We generate a catalog of combined non-thermal and thermal emission to aid interpretation of future merger observations and to constrain properties of merger remnants.

EP 15.3 Fri 14:15 ZHG101

Neutrino-cooled accretion disks around massive black holes and their potential as sites for r-process nucleosynthesis — •Javiera Hernández Morales and Daniel M. Siegel — Institute of Physics, University of Greifswald

The astrophysical origin of about half of the elements heavier than iron, synthesized through rapid neutron-capture (the r-process), is still uncertain. Among proposed sites—neutron-star mergers and collapsars—a common scenario is the formation of a black hole surrounded by an accretion disk. A necessary condition for the r-process to occur in outflows from such disks is a neutron-rich environment, which these disks can achieve through neutrino-cooling. However, the minimum rate at which a black hole needs to accrete to activate this mechanism is still an open question. We employ a one-dimensional, general-relativistic model of accretion disks with weak interactions to explore the parameter space of black-hole mass, accretion rate, and α-viscosity, and study the effect of these parameters on the accretion flow and the presence of neutron-rich material. We find that disks with larger accretion rates reach a lower proton fraction Y_e, with neutron-rich plasma extending over increasingly wider ranges in radii. We show that the characteristic accretion rates that describe the efficiency of cooling, the opaqueness to neutrinos and the trapping of neutrinos in the accretion flow follow power-law relations with black-hole mass and α-viscosity. Our results suggest that disks around black holes with masses ranging from $\sim 3M_\odot$ to $\sim 10^3 M_\odot$ could launch neutron-rich outflows and thus be possible sites for the nucleosynthesis of the heaviest elements in the Universe.

EP 15.4 Fri 14:30 ZHG101

Ignition of weak interactions and r-process outflows in massive, 'super-collapsar' accretion disks — •Aman Agarwal[1] and Daniel Siegel[1,2] — [1]Institute of Physics, University of Greifswald, D-17489 Greifswald, Germany — [2]Department of Physics, University of Guelph, Guelph, Ontario, Canada, N1G 2W1

The core collapse of rapidly rotating massive ($\sim 10M_\odot$) stars ("collapsars") and the resulting hyperaccreting black holes represent a leading model for the central engines of long-duration gamma-ray bursts (GRBs) and promising sources of neutron-rich plasma outflows for r-process nucleosynthesis. We perform three-dimensional general-relativistic magnetohydrodynamics simulations to explore the neutronization of accretion flows from progenitors with masses above the pair-instability mass gap to the regime of massive PopIII stars (black-hole mass range $M_\bullet \sim 80 - 1000\ M_\odot$). We find that neutron-rich accretion flows develop above an "ignition" accretion rate $\dot{M}_{\rm ign}$, which, in good agreement with analytical estimates, scales as $\dot{M}_{\rm ign} \propto M_\bullet^{4/3} \alpha_{\rm eff}^{5/3}$ up to $M_\bullet \sim 1000 M_\odot$, with $\alpha_{\rm eff}$ being the effective Shakura-Sunyaev disk viscosity. We discuss the implications of very early r-process enrichment through such astrophysical events in the light of recent detections of massive stars by the James Webb Space Telescope and reflect upon their potential as multi-messenger sources of both electromagnetic ("super-kilonovae") and gravitational waves for third-generation gravitational-wave detectors.

EP 15.5 Fri 14:45 ZHG101

Signatures of Exploding Supermassive PopIII Stars at High Redshift — •Cédric Jockel — Max Planck Institute for Gravitational Physics, Potsdam, Germany

Recently, supermassive black holes (SMBHs) of ~ 100 million solar-masses have been discovered at high redshifts of $z \sim 9 - 11$. These large masses so early in the universes history pose severe challenges to our understanding of SMBH formation. One possible formation channel is the direct collapse of rapidly accreting PopIII stars that form in large collapsing halos of primordial gas and grow up to a million solar masses. Our recent studies and also work by other groups show that they eventually collapse and produce powerful supernova-like explosions of 10^{55} erg that last over 10 years. Modelling the observational signatures and prospects of their explosions will give us crucial insight on the early stages of SMBH formation. In this talk, I present our recent work on the observability of these supermassive star explosions including the computation of the luminosity, photometry and colour evolution. In our model, we study the scenario where massive ejecta are released during the collapse and explosion and interact with the surrounding dense cloud via shocks. These shock interactions power emissions of up to $\sim 10^{45-47}$ erg/s in the source frame and lead to easily observable signals in JWST and EUCLID. Due to the long explosion timescale of over 10-15 years, the transients will be observed over a period of a few hundred years due to redshift and might be confused photometrically with persistent high-redshift sources such as little red dots.

EP 15.6 Fri 15:00 ZHG101

Beobachtungskampagnen und theoretische Modellierung von Lichtkurven verschmelzender Schwarzer Löcher — •Julian Sommer — Ludwig-Maximilians-Universität München, München, Deutschland

Schwarze Löcher mit Massen von mehreren Dutzend bis Hunderten Sonnenmassen werden vorwiegend in den Regionen aktiver Galaxienkerne, genauer gesagt in den Akkretionsscheiben supermassiver Schwarzer Löcher, vermutet. Die Interaktion des Verschmelzungsprodukts mit dem umliegenden Gas kann zu elektromagnetischen Signaturen führen, die sich in Form von Flares äußern. Die Dauer eines solchen Flares kann sich über Tage bis Wochen erstrecken und lässt sich als Lichtkurve beschreiben. In diesem Vortrag werden erste Ergebnisse der theoretischen Modellierung solcher Lichtkurven vorgestellt und mit unseren Beobachtungen verglichen, um das Verhältnis zwischen Theorie und Praxis zu analysieren. Unsere Beobachtungskampagnen zu Gravitationswellendetektionen durch LIGO/Virgo/KAGRA werden mit dem 2,1-Meter-Wendelstein-Teleskop durchgeführt, das sowohl den 3KK-Imager als auch den Wide-Field-Imager nutzt.

EP 15.7 Fri 15:15 ZHG101

Probing the effects of magnetic fields on ultra-high energy

cosmic ray arrival directions at the Pierre Auger Observatory — •Berenika Čermáková for the Pierre-Auger-Collaboration — Karlsruhe Institute for Technology, Karlsruhe, Germany

When ultra-high-energy cosmic rays (UHECRs) travel from sources to Earth, they are deflected by extragalactic and galactic magnetic fields. Since the deflection depends on the charge of the nuclei, UHECRs with very high magnetic rigidity propagate almost ballistically. Consequently, when detected on Earth, the arrival directions point near their origin. Hence, backtracking the high-rigidity UHECRs could set a limit on different source classes.

However, indirect detection of UHECRs poses challenges in obtaining information about their energy and mass simultaneously. Machine learning-based mass estimators show the potential to improve the reconstruction of mass-sensitive variables, such as the depth of the shower maximum.

In this contribution, we investigate the effect of the galactic magnetic field on the propagation of the UHECRs using neural network-based mass estimators. We test different scenarios of source distributions. In particular, we present the developed methodology to test the hypothesis that sources follow the distribution of matter in space, hence the Supergalactic plane. We use data from the Pierre Auger Observatory.

EP 15.8 Fri 15:30 ZHG101

Precise Reconstruction of Neutrino Event Energy Using Deep Learning — •Severin Magel, Chiara Bellenghi, Elena Manao, and Rasmus Ørsøe for the IceCube-Collaboration — Technical University of Munich, TUM School of Natural Sciences, Department of Physics, James-Franck-Straße 1, D-85748 Garching bei München, Germany

The first ever 5σ detection of an astrophysical neutrino source has long been chased by neutrino telescopes like IceCube and KM3NeT. Achieving a high statistical significance in detecting these sources is partially limited by the precision of variable reconstructions for the incoming neutrino direction and energy. We investigate the potential of state-of-the-art deep learning architectures like Graph Neural Networks (GNN) and transformers to improve classical algorithms and obtain a more precise neutrino energy prediction. We force the model to recognise general patterns in the detector response by training it on all signatures left in the detector by the different neutrino interaction channels. This pre-trained architecture is then fine-tuned for the reconstruction of specific neutrino events that are eventually used in various analyses not limited to the search for an astrophysical neutrino sources. In this presentation, I will outline the technical challenges and the physics-oriented results from these efforts.

EP 15.9 Fri 15:45 ZHG101

Simulation-based inference has its own Dodelson-Schneider effect (but it knows that it does) — •Jed Homer[1,2], Oliver Friedrich[1,2,3], and Daniel Gruen[1,2,3] — [1]University Observatory, Faculty of Physics, Ludwig-Maximilians-Universität, Scheinerstr. 1, 81677 Munich, German — [2]Munich Center for Machine Learning (MCML) — [3]Excellence Cluster ORIGINS, Boltzmannstr. 2, 85748 Garching, Deutschland.

Making inferences about physical properties of the Universe requires knowledge of the data likelihood. A Gaussian distribution is commonly assumed with a covariance matrix estimated from a set of simulations. The noise in such estimates causes two problems: it distorts the parameter contours, and it adds scatter to the location of those contours. For non-Gaussian likelihoods, an approximation may be derived via Simulation-Based Inference (SBI). It is often implicitly assumed that parameter constraints from SBI analyses are not affected by the same problems as parameter estimation, with a covariance matrix estimated from simulations. We investigate whether SBI suffers from effects similar to those of covariance estimation in Gaussian likelihoods. SBI suffers an inflation of posterior variance that is equal or greater than the analytical result in covariance estimation for Gaussian likelihoods for the same number of simulations. The assumption that SBI requires a smaller number of simulations than covariance estimation for a Gaussian likelihood analysis is inaccurate. Despite these issues, we show that SBI correctly draws the true posterior contour given enough simulations.