# Mini-workshop of Relativistic Jets and Related High-Energy Phenomena

Monday, 1 March 2021 - Wednesday, 3 March 2021

Tsung-Dao Lee Institute (East wing of Pao Yue-Kong Library)

# Book of Abstracts

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# Shear acceleration in large-scale jets

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I'll introduce my recent work on shear particle acceleration in large-scale jet, and its application to the observed FR I/II X-ray jets.

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# Analytical Model of Magnetically Dominated Jets and Winds: Jet Launching, Acceleration, and Collimation

**Author:** Liang Chen[1]

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Jets/winds are ubiquitously in association with different celestial objects. However, most of previous theoretical studies of them rely on numerical calculations, not being able to provide a more convenient way for understanding rather abundant observational results. Now we have obtained a general analytical solution for describing a magnetically dominated jet/wind, through separating the "core" equation (which maintains the radial dynamic equilibrium of jet, constructed 1960s) into rotating and non-rotating terms, finding that each of the two-term equations can be solved analytically, and the two solutions match each other very well. This solution is consistent with known theoretical results and numerical simulations, and can be used to interpret main observational results, such as jet shape configuration, acceleration profile (from non-relativistic to relativistic), and polarization pattern etc. Furthermore, the solution is applicable to, e.g., limb-brightening (a hollow jet), periodical signals (a helical jet), and "complex" proper motion pattern (a stratified jet) etc. I this talk, I will present the details of the theory, examples of comparing with observations, and a variety of predictions (Ref. Chen & Zhang, 2021, ApJ, 906, 105).

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# Kink Instability in Relativistic Jets

**Authors:** Omer BrombergN[one]; Jordy DavelaarN[one]; Alexander A. PhilippovN[one]; Chandra Bahadur SinghN[one]

The evolution of kink instability in a force-free, nonrotating jet of high magnetization has been studied using MHD and PIC simulations. The main dissipation mechanism is identified as reconnection of magnetic field lines and the dissipation rate is found to be consistent with the expansion velocity of the kink mode, which drives the reconnection. We present the implications for particle acceleration in astrophysical jets related to GRBs and AGNs.

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## Toward a Full MHD Jet Model of Spinning Black Holes. Kinematics and Application to the M87 Jet

**Author:** Lei Huang[1]

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We investigate the magnetohydrodynamical structure of a jet powered by a spinning black hole, where electromagnetic fields and fluid motion are governed by the Grad–Shafranov equation and the Bernoulli equation, respectively. When a steady and axisymmetric jet structure is assumed, the global solution is uniquely determined with the prescribed plasma loading into the jet and the poloidal shape of the outmost magnetic field line. We apply this model to the jet in the center of the nearby radio galaxy M87, and we find that it can naturally explain the slow flow acceleration and the flow velocity stratification within 10ˆ5 gravitational radii from the central black hole. In particular, we find that the extremal black hole spin is disfavored by the flow velocity measurements if the plasma loading into the jet is dominated by the electron-positron pair production at the jet base.

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## Neutrinos and gravitational waves from magnetized neutrino-dominated accretion discs with magnetic coupling

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Gamma-ray bursts (GRBs) might be powered by black hole (BH) hyperaccretion systems via the Blandford-Znajek (BZ) mechanism or neutrino annihilation from neutrino-dominated accretion flows (NDAFs). Magnetic coupling (MC) between the inner disc and BH can transfer angular momentum and energy from the fast-rotating BH to the disc. The neutrino luminosity and neutrino annihilation luminosity are both efficiently enhanced by the MC process. In this paper, we study the structure, luminosity, MeV neutrinos, and gravitational waves (GWs) of magnetized NDAFs (MNDAFs) under the assumption that both the BZ and MC mechanisms are present. The results indict that the BZ mechanism will compete with the neutrino annihilation luminosity to trigger jets under the different partitions of the two magnetic mechanisms. The typical neutrino luminosity and annihilation luminosity of MNDAFs are definitely higher than those of NDAFs. The typical peak energy of neutrino spectra of MNDAFs is higher than that of NDAFs, but similar to those of core-collapse supernovae. Moreover, if the MC process is dominant, then the GWs originating from the anisotropic neutrino emission will be stronger particularly for discs with high accretion rates.

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## Relativistic Jet Simulations and Modeling in Horizon Scale

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The Event Horizon Telescope has presented the prominent ring feature at the center of giant radio galaxy M87 which is consistent with the size and shape of the lensed photon orbit encircling the "shadow" of a supermassive black hole. I will review theoretical interpretation of EHT results and present recent progress of theoretical modeling beyond EHT.

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## Wind and jet from black hole hot accretion flows

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Hot accretion flows around black holes can produce strong wind. These winds are important not only because they are an important ingredient in accretion dynamics, but also play an important role in AGN feedback. In this talk, we will first briefly review the history of wind study, then focus on introducing the properties of wind such as its mass flux and velocity. These properties are obtained by analyzing the 3D GRMHD numerical simulation data using a virtual particle trajectory approach. At last, we will compare the properties of wind and jet.

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## Episodic ejection in black hole accretion flow

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Observationally we have two types of jet, namely continous jet and episodic jet. The former has been intensively studied while the latter not. The episodic jet is likely associated with flares. In this talk, we will introduce our MHDmodel for the formation of episodic jet. This model was originally proposed by analogy with the coronal mass ejection in the Sun, and most recently confirmed by our 3D MHD numerical simulations. Its possible connection with the flares recently detected in Sgr A* by GRAVITY will also be briefly discussed.

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## Acceleration and Cooling Processes in Outburst Phase of the TeV Blazar W Com

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Curved broad-band spectral distributions of non-thermal sources like blazars are described well by a log-parabolic law where the spectra can be obtained for relativistic electrons by means of a statistical acceleration mechanism whose probability of acceleration depends on energy. In this work we used the curvature parameter of the synchrotron spectra (b) and the peak energy (Ep) to investigate the acceleration and cooling mechanism during outburst phase of the TeV blazar W com. We carried out a detailed time-resolved temporal and spectral study using multi-wavelength data taken by *Swift* and *XMM-Newton* satellites. Similar spectral variation of the main two emission components supports the SSC scenario. During the event, the source showed a significantly positive Ep-b relation, which, incorporating previous theoretical predictions, likely be associated with a magnetic field-driven stochastic process in the jet.

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## Low power radio-detected narrow line Seyfert 1 galaxies in low frequency radio surveys

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Narrow line Seyfert 1 galaxies are found to host powerful relativistic jets. Consider their relatively low black hole mass and high accretion rate, they could play an important role to understand the formation and the evolution of AGN jet. In this talk, I introduce our recent works on NLS1s with the data of new low frequency radio surveys. We compared the jet-disk connections between NLS1s and other jetted AGNs, and found NLS1s show higher jet production efficiency than typical FR II radio galaxies and FSRQs. In addition, we found a sample of NLS1s with much lower radio luminosity in the catalog of LOFAR Two-metre Sky Survey. Interestingly, they follow similar jet-disk connection with their brighter counterparts, as well as blazars. These low power NLS1s could be important on the evolved stage of jets. As the sensitivity get much better in SKA era, the low luminosity end of radio-detected AGNs may change our view of jet evolution and/or radio mode feedback intensively.

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## The optically thick and Eddington-limited wind driven by supercritical accretion onto compact objects

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Supercritical accretion onto compact objects may drive massive winds that are nearly spherical, optically thick, and Eddington-limited. Blackbody emission from the photosphere is the direct observational signature of the wind. Here I show that such a scenario can explain the X-ray emission from the luminous and very soft sources in nearby galaxies, and their broadband spectra via an irradiation model that takes into account the presence of the optically thick wind and radiation transfer in it.

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## A Multi-wavelength Perspective of Outflows from Nearby Low-luminosity AGNs

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Outflows (in the form of jet and/or wind) from weakly-accreting, low-luminosity AGNs are believed to play an important role in the host galaxy evolution. In this talk, I will present our recent work on parsec-scale jets and winds from the nearest known low-luminosity AGNs (including Sgr A, *M31*, M32*and M81*), based primarily on X-ray and radio observations.

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## Compact X-ray jet as hot corona in the black hole X-ray binary MAXI J1820+070 observed with Insight-HXMT

**Author:** Zhang Shuang-Nan[1]

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Insight-HXMT is China ' s first X-ray astronomy satellite and was successfully launched on June 15th, 2017. It made extensive and broad band (1-250 keV) observations of the black hole X-ray binary MAXI J1820+070 during its most recent bright outburst. Timing analysis has found low-frequency quasi-periodic oscillations (LFQPOs) up to above 200 keV, the highest energy from any accreting black hole system. This cannot be explained in the previous models involving disk or extended corona, but is best interpreted as the precession of a compact X-ray jet relativistically moving away from the black hole. Broad band spectral analysis during the outburst revealed strong evolution of the reflection of the hard X-ray emission off the accretion disk. The observed evolution is inconsistent with the previously assumed static corona model from which the hard X-ray photons are produced, but is again best interpreted as relativistically outflowing jet-like hot plasma as the hard X-ray source, fully compatible with the compact X-ray jet revealed by the timing analysis.

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## Opening remark

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## Wind production from thin accretion disk

**Authors:** Weixiao WangN[one]; Defu BuN[one]; Feng YuanN[one]

Strong winds are common phenomena in active galactic nuclei. Although, there are abundant observational data about winds, the launching mechanisms of the winds are still not clear. Two possible drving mechanisms are radiation line force driven and magnetic driven. I will talk about our recent numerical simulation work on the roles of the two mechanisms on driving winds.

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## Blob formation and ejection above accretion flow around massive black hole

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We study the small scale magnetic reconnection above the radiative inefficient accretion flow around massive black hole via 2D magnetohydrodynamics (MHD) numerical simulation, in order to model the blob formation and ejection from the accretion flow around Sgr A$*$. The connection of both the newly emerging magnetic field and the pre-existing magnetic field is investigated to check whether blobs could be driven in the environment of black hole accretion disc. It is found that after the magnetic connection, both the velocity and temperature of the plasma can be comparable to the inferred physical properties at the base of the observed blob ejection. At the beginning of the reconnections, the fluid is pulled toward the central black hole due to the gravitational attraction and the current sheet produced by the reconnection is also pulled toward the same direction, consequently, the resulting outflows move both upwards and towards the symmetry axis of the central black hole. Eventually, huge blobs appear, which supports the catastrophe model of episodic jets (Yuan et al. 2009).

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## Winds and jets from the hot disk around the black holes

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We will discuss self-consistent accretion-ejection solutions in full general relativistic prescription around the black holes and predicated the possible origin of the high energy emissions in the BH sources, like, $\gamma$-rays and neutrinos. We have solved the jet equations of motion along the von Zeipel surfaces computed from the inner part of the hot accretion flow. Interestingly, we obtained many types of the jet solutions, for example, jet solutions with/without internal shock, and failed/bound jet solutions. The shocks in the jet can form for high Kerr spin parameter, $a_s > 0.6$ and jet terminal velocity also increases with the spin and energy of the accretion flow. We believed that the high energy radiations, neutrinos, and variabilities in the jets can be originated from the shocks in the jet as vindicated in the many observational and modeling studies.

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## Astro seminar: Long-term TeV spectra of blazars Mrk 421 and Mrk 501

The High Altitude Water Cherenkov (HAWC) Gamma-Ray Observatory surveys the very high energy sky in the 300 GeV to 100 TeV energy range and it has detected two blazars, Markarian 421 (Mrk 421) and Markarian 501 (Mrk 501). The observations comprises the period between June 2015 and July 2018, resulting in a ˜1038 days of effective exposure. In this talk I will show the time averaged spectral analysis for both sources above 0.5 TeV. Since the observation of gamma radiation from blazars provides information about the physical processes that take place in their relativistic

jets, it is important to study the broad-band spectral energy distribution (SED) of these objects. To this purpose, contemporaneous data from the Large Area Telescope on board the Fermi satellite and literature data, in the radio to X-ray range, were used to build time averaged SEDs that were modeled within a synchrotron self-Compton leptonic scenario to derive the physical parameters that describe the nature of the respective jets.