Activity report based on time used on PDC, Kebnekaise, and C3SE of 2018 and 2019

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In this activity report, I describe and list some highlights of the 30 papers that all acknowledge SNAC. Out of those, 7 are submitted, 5 accepted, 9 published in 2019, and another 9 published in 2018. For the calculations, we use the code Runko and the Pencil Code, both of which are hosted on github (https://github.com/natj/runko and https://github.com/pencil-code). The 3-digit numbering of the papers coincides with that of my full list of publications on http://www.nordita.org/~brandenb/pub. All the papers quoted below acknowledge SNAC.

1 Shock and turbulence in collisionless astrophysical plasmas

Many astrophysical plasmas are extremely diluted and, hence, appear almost collisionless. In order to investigate such a plasmas that are beyond the validity regime of MHD, we in Nordita have developed a new open-source particle-in-cell (PIC) simulation code Runko [1]. Main focus of the code is to perform self-consistent fully-kinetic studies of non-thermal particle acceleration in collisionless plasmas.

Turbulence in astrophysical plasmas is ubiquitous appearing in systems such as solar wind all the way to galaxy cluster scales. By using massively-parallel PIC simulations, we have studied the formation and evolution of turbulence in magnetically-dominated diluted plasmas [1]. This work helped us, for the first time, understand how the large-scale energy in the plasma is transferred from one state (large magnetic field perturbations) to other forms (small turbulent motion and subsequently non-thermal particle populations).

Under a strong radiation field (such as close to black holes) the turbulence dynamics is altered due to strong radiative cooling. In order to understand the non-linear behavior of turbulent plasma in such a strong radiation environment, we have performed pioneering radiative kinetic turbulence simulations [2]. This in turn, will help us understand, for example, particle acceleration and heating of diluted plasmas near black holes and neutron stars.

The kinetic turbulence is also known to depict a copious creation of intermittent, very energetic, and localized space regions with strong currents. By using our first-principles simulations, we are, for the first time, starting to trace the statistics and dynamics of these sheet-like structures (forthcoming paper [3]). Such understanding is important as it can be used to parameterize the efficiency of particle acceleration and dissipation strength of diluted plasmas.


There are currently two papers that are close to being submitted. We list those separately below.

Figure 1: Left: spectra of $h_0^2 \Omega_{GW}(f)$ and $h_c(f)$ along with the LISA sensitivity curves in (i) the 6-link configurations with $5 \times 10^9$ m arm length and (ii) the 4-link configurations with $2 \times 10^9$ m arm length after 5 years duration. The dash-dotted lines indicate the slopes $1$ and $-8/3$ in the upper panel and $-1/2$ and $-7/3$ in the lower. Right: similar, but for Runs hel1–3, noh2, and ac1. Note the similarity in the low-frequency tail for $f < 3 \text{mHz}$. Adapted from Ref. [401].


2 Gravitational waves and early universe magnetic fields

An important upcoming activity involves the computation of the stochastic gravitational wave background from the Big Bang. Those can be measured in future with LISA and the pulsar timing array. Our first paper on the numerical method is described in Ref. [393]. In [401], we compare the resulting primordial gravitational wave signal with the sensitivity curves for LISA; see also Figure 1.

We have continued studying the chiral magnetic effect [364,384] as well as the chiral vortical effect [392]. We have also studied new aspects of decaying turbulence in the early universe with magnetic helicity [383] and with cross helicity [377].


### 3 Sunspot formation and radiation transport

Sunspots reveal properties of the underlying magnetic field through their geometrical arrangement in three- and four-spot configurations. This was revealed through our work in Ref. [376]. We have now performed simulations showing the spontaneous flux concentrations from the negative effective magnetic pressure instability beneath a radiative stellar surface [361]. We have also studied the formation of magnetic bipoles in rotating turbulence with coronal envelope [379]. In a more general paper in a special issue describing the Pencil Code, we have also studied the time step constraint in radiation hydrodynamics [396].


### 4 Dynamo action in the Sun

Linear polarization, as characterized by the Stokes $Q$ and $U$ parameters, is coordinate-dependent. A coordinate-independent characterization is provided by the parity-even and parity-odd $E$ and $B$ mode polarizations that are routinely used in cosmology. Their cross-correlation can also reveal information about magnetic helicity, but only if the system is inhomogeneous. This was shown in our new work of Ref. [380] using data of local numerical simulations. More recent work has extended this now to global simulations [390].

We have also continued using simulations to reveal subsurface properties of the Sun’s magnetic field using simulations [394]. Its small-scale [366] and large-scale [365] properties have been subjects of separate investigations of last year.
5 Particles in Turbulence

We have now completed 4 papers on the subject of multi-dimensional condensation and coagulation [373,382,398,399]. They show the importance of local energy dissipation in determining the speed of coagulation [373]. We have produced realistic models of cloud droplet growth due to supersaturation fluctuations in stratiform clouds [382]. We also have performed work that includes the effects of condensation, in addition to coagulation [398]. Finally, we have characterized the importance of fluctuations in dilute systems [399]. This led to the PhD thesis of Xiang-Yu Li, who finished in September 2018.

6 Small-scale dynamo turbulence and ambipolar diffusion

In an attempt to clarify the nature of large-scale dynamo action, we have discovered efficient quasi-kinematic large-scale dynamo growth as the small-scale dynamo saturates [402]. We have
conducted two investigations of dynamos and MHD systems at large magnetic Prandtl number: one that can be applied to galaxy clusters and the solar corona where we now argue that heating occurs not on current sheets, as usually believed, but viscously [387]. In the cooler interstellar medium, ambipolar diffusion becomes important and we have now conducted two-fluid simulations [386]. As an additional off-spring of earlier work, we have completed this year a detailed investigation on varying the forcing scale in low Prandtl number dynamos [367]. It will provide an important benchmark for future studies.


7 Astrobiology and chemical reactions

With the Pencil Code, we can perform simulations of chemical reactions. One important application is hydrogen combustion which can lead to detonation. In [395], we have produced high-resolution studies of this process. Chemical reactions also play a role in origin-of-life studies. In [388], we have studied the effect of fluctuations in accomplishing reactions that drive the system toward a homochiral state without the explicit effects of autocatalysis or enantiomeric cross-inhibition.


**Academic achievements**

In September 2018, Dr Xiang-Yu Li successfully defended his PhD thesis at the University of Stockholm in the Meteorology department with Gunilla Svensson as the main supervisor. This project was supported by a grant from the Norwegian Research Council to Nordita with Brandenburg as the PI. Furthermore, in January 2019, Dr Illa R. Losada successfully defended her PhD thesis at the University of Stockholm in the Astronomy department. This project was supported by a VR grant with Brandenburg as the PI.

From July to December 2019 Nordita was hosting John Hope (University of Bath, UK) as a master student intern to work on a Master’s thesis project on collisionless shock simulations with Joonas Nttil as a main supervisor. Additionally, Maarja Kruuse (Univ. Tartu; Estonia) has been a visiting PhD. fellow in the astrophysics group focusing on kinetic turbulence simulations as one part of her PhD. thesis with Joonas Nätilä as a host. Both projects have been heavily relying on computational resources by SNAC and will the acknowledge it in the forthcoming academic theses.