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FINAL Progress report on DOE project DE-FG02-07ER54940

"Studies of HED Plasmas with Self-Generated Magnetic Fields"

(PI: M.V. Medvedev)

The objective of this research project is the development of theoretical, semi-analytical and numerical frameworks for studies and diagnostics of the electromagnetic turbulence in laboratory HED experiments and in astrophysical sources. More specifically, it is aimed at modeling the electron dynamics and radiation emission in sub-Larmor-scale magnetic fields.

High-amplitude sub-Larmor-scale electromagnetic turbulence is ubiquitous in high-energy density environments, such as laboratory plasmas produced by high-intensity lasers, e.g., NIF, Omega-EP, Trident, and others, and in astrophysical and space plasmas, e.g., at high-Mach-number collisionless shocks in weakly magnetized plasmas upstream regions of quasi-parallel shocks, sites of magnetic reconnection and others. Studies of plasmas and turbulence in these environments are important for fusion energy sciences and the inertial confinement concept, in particular, as well as to numerous astrophysical systems such as gamma-ray bursts, supernovae blast waves, jets of quasars and active galactic nuclei, shocks in the interplanetary medium, solar flares and many more. Such turbulence can be of various origin and thus have rather different properties, from being purely magnetic (Weibel) turbulence to various types of electromagnetic turbulence (for example, whistler wave turbulence or turbulence produced by filamentation or Weibel-type streaming instability), to purely electrostatic Langmuir turbulence. In this project we use analytical and numerical tools to study the transport, radiative, and magneto-optical properties of plasmas with sub-Larmor-scale turbulence. We discovered the connection of transport/diffusion properties to certain spectral benchmark features of (jitter) radiation produced by the plasma and radiation propagation through it. All regimes, from the relativistic to non-relativistic, were thoroughly investigated and predictions were made for laboratory plasmas and astrophysical plasmas. Thus, all the tasks outlined in the proposal were fully and successfully accomplished.

Scientific results

Here we highlight just a few main results obtained for the duration of the project; see the list of papers and presentations for more details.

As a part of the project, the Plasma Physics Group at the University of Kansas led by the PI has developed, debugged and verified of the parallel "transport+radiation" (T+R) code devoted to the study of inter-relation of various transport properties (such as diffusion) of plasma micro-turbulence to its radiative properties, namely the spectral emissivity by charged test particles, relativistic through trans-relativistic, through fully non-relativistic regimes. Understanding such an interrelation has a tremendous importance for the *remote sensing* diagnostic tool of strong electromagnetic turbulence. Such turbulence generated in plasmas by Petawatt-scale laser experiments (NIF, Omega-EP, etc.), e.g., the recently produced non-relativistic collisionless shocks at NIF, by means of either collecting radiation from the plasma particles driving the instability or by launching a weak probe beam of electrons though this plasma and collecting radiation from them. The main idea is as follows. The electromagnetic fields sub-Larmor turbulences vary on scales much smaller than the characteristic curvature radius of particles' paths, so that the particle orbits are never well-defined Larmor circles. Because of the random

phases of fluctuations, the particle paths diffusively diverge due to pitch-angle diffusion. Radiation simultaneously produced by these particles is not synchrotron or cyclotron (magneto-bremsstrahlung), but, instead, carries information about the spectrum of turbulent fluctuations.

For the duration of the project, our group has successfully developed, debugged and verified the aforementioned 3D numerical code and made a number of scientific runs. We have studied the pitch-angle diffusion in random static magnetic fields which spectrum extends well below the Larmor scale of test electrons. We have also computed radiation from these electrons. Generally, when the electromagnetic fields vary on scales much smaller than the characteristic curvature radius of particles' paths, their orbits are random and diffusively diverge due to pitch-angle diffusion.

In parallel with the code development and numerical experiments, the theory, which relates the diffusion coefficient to the properties of the underlying magnetic turbulence, has been developed for the first time. The theory is the outcome of the outcome of the sophisticated and extensive analysical analysis of the plasma transport and radiative properties in numerous regimes and turbulence types. We considered the entire range from non-relativistic, to trans-relativistic, to ultra-relativistic particle/plasma regimes. We considered magnetostatic (pure Weibel), electrostatic (Langmuir) and fully electromagnetic (represented by the whistler more) plasma micro-turbulence. In all cases, the pitch-angle and energy diffusion coefficients were accurately computed and compared with numerical simulations. The agreement of the analytical and numerical results is remarkably good. At the same time, we analytically computed the radiation spectra produced by plasma particles and compared them with our numerical results obtained simultaneously with the transport results. We confirmed the existence of the jitter regime (both in large and small deflection angle cases) and the transition to the conventional synchrotron and the newly found "pseudo"-cyclotron regime. Overall, the results are impressive' they've been published in a long series of papers and conference presentations. Some of the results are highlighted here in Fig. 1.

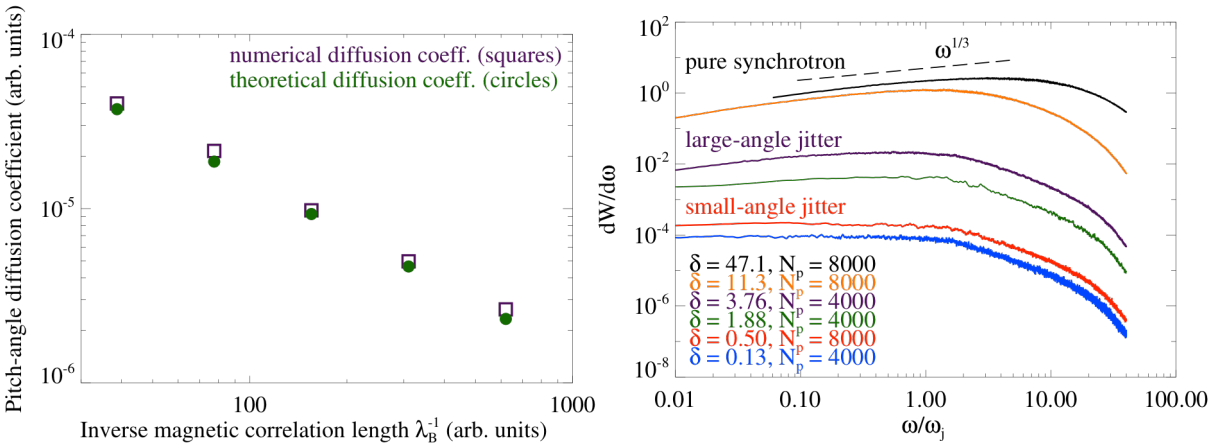

Figure 1. (Left) Pitch-angle diffusion coefficient, $D_{\alpha\alpha}$ vs the inverse of magnetic field correlation scale, λ^{-1}. Relevant simulation parameters include: $\gamma = 3$, $N_p = 1000$, $k_{min} = 8\pi$, 16π, 32π, 64π, and 128π, $k_{max} = 10k_{kmin}$ (for each k_{kmin}), $\langle \delta B^2 \rangle^{1/2}/B_0 = 0.1$, $\Omega_{ce} = 1$, $\chi \approx 0.02$, and $\mu = 4$. For each data point, the theoretical and numerical results differ only by a small factor of order one. *(Right)* Radiation spectra with variable jitter parameters. As can be seen, if the jitter parameter, δ, is less than one – the radiation spectrum is restricted to the small-angle jitter regime. As δ becomes greater than one, a transition occurs to the large-angle jitter regime, and then the synchrotron spectrum (with its distinctive 1/3 slope) emerges as δ becomes much greater than one. The Lorentz factor is equal to five in each case.

The results provide a unique way to remotely diagnose high-energy-density plasmas, both in astrophysical systems and laboratory experiments, including the nonrelativistic collisionless shock experiments at NIF and Omega-EP. Particularly, we collaborated with the simulation group led by Prof. Nishikawa of the University of Alabama, Huntsville. We worked on Relativistic-Particle-In-Cell simulations of the Weibel and Kelvin-Helmholtz instabilities in relativistic jets and the dynamics of magnetic reconnection, and the self-consistent radiation production in the jets. The results were also represented in papers, numerous conferences and proceedings.

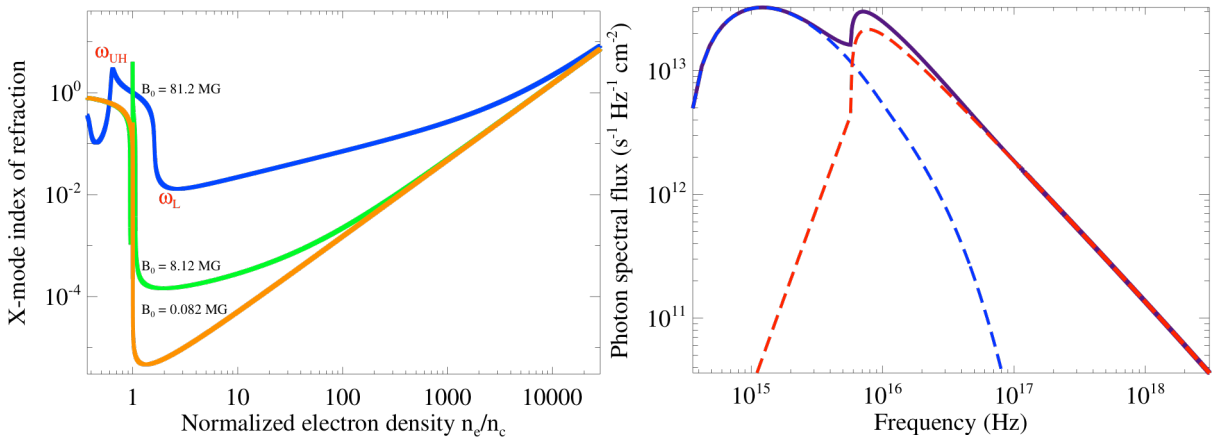

Figure 2. (Left) Index of refraction for the X-mode as a function of depth (in terms of the electron density). Here, three solutions for which $\delta B/B_0 = 0.1$ are plotted with a variable B_0. As expected, the solution approaches the O-mode profile for $B_0 \rightarrow 0$. *(Right)* The photon spectral flux (i.e., the spectral energy flux divided by the photon energy, ω) in a Laser-plasma experiment. We see that the majority of the radiation flux is at frequencies slightly below the frequency, ω_{jn} , i.e., Weibler frequency (i.e., the jitter radiation frequency in Weibel turbulence). Blue – predicted jitter radiation; red – predicted bremsstrahlung radiation.

Another very interesting discovery we are very excited to highlight here concerns with the "quasi"-collisional effects in micro-turbulent plasmas and their effect on the electromagnetic radiation propagation. We discovered that the effective pitch-angle diffusion coefficient represents the effective "quasi"-collision frequency, which substantially modify optic and magneto-optic properties of plasmas, such as anomalous Faraday rotation, anomalous absorption and anomalous plasma transparency. For example, the X-mode index of refraction as a function of the distance into the solid density target in a laser-plasma experiment is shown in Fig. 2a. Obviously, plasma becomes anomalously transparent near the critical surface (where reflection is expected to occur) and the suppression of plasma reflectivity depends on the amplitude of micro-turbulence. We also evaluated the emitted radiation in a typical laser-plasma experiment (as example, we chose the experiment at Tata Institute of Fundamental Research). Our study, illustrated in Fig. 2b demonstrates that the quasi-collisions cause the jitter radiation production (blue curve) and that this part of the spectrum probes plasmas near the critical surface. The standard Bremsstrahlung radiation, though energetically dominant, peaks at a different part of the spectrum – hence it does not "swallow" the jitter signal – and probes the inner, densest parts of the plasma. These results were published/submitted in a series of three recent papers. These results open up a novel radiative diagnostics of high-energy density plasmas produced at NIF, Omega and other facilities.

The results of the PI research performed together with his students and collaborators were reported in conferences, workshops, seminars and colloquia. A number of presentations are done by the PI's graduate students on seminars at KU, as well as at conferences: APS DPP, AAS and APS April meetings. A more complete list of publications and presentations done by the PI and his group is given below.

Publications, conference talks, etc.

For the duration of the project, our group has performed strong and active research along the lines outlined in the research proposal. In particular, **25 papers** (16 refereed) directly related to the project have been published, are in press, or submitted, see below. Our scientific results obtained for the duration of the project and directly related to the project have also been broadly disseminated in the plasma physical, plasma astrophysical and pure astrophysical communities via seminars and colloquia, conference talks, poster presentations and discussions. The PI presented **12** ***invited talks*** *at international conferences*, **15** ***invited colloquia and seminars***; he and his group have also made **42** ***oral and poster presentations*** *at international conferences.* The list of colloquia/seminars, conference talks and presentations is given below.

Refereed Publications:

1) B.D. Keenan, M.V. Medvedev, **On the (Quasi-)collisionality of Small-scale Electric Turbulence**, *submitted* (2015)

2) B.D. Keenan, M.V. Medvedev, **Particle Transport and Radiation Production in Magnetized Plasmas with sub-Larmor-scale Electromagnetic Fluctuations**, *submitted* (2015)

3) B.D. Keenan, M.V. Medvedev, **Radiation from particles moving in small-scale magnetic fields created in solid-density laser-plasma laboratory experiments**, *Phys. Plasmas*, **22**, 113110 (2015)

4) B. Keenan, A. Ford, M.V. Medvedev, **Quasicollisional magneto-optic effects in collisionless plasmas with sub-Larmor-scale electromagnetic fluctuations**, *Phys. Rev. E*, **92**, 053102 (2015)

5) B. Keenan, A. Ford, M.V. Medvedev, **Transport of and Radiation Production by Trans-relativistic/Non-relativistic Particles Moving Through Sub-Larmor-Scale Electromagnetic Turbulence**, *Phys. Rev. E*, **92**, 033104 (2015)

6) M.V. Medvedev, V.V. Medvedev, **Asymmetric diffusion of cosmic rays**, *Phys. Plasmas*, **22**, 091504 (2015)

7) A. Kamble, A.M. Soderberg, L. Chomiuk, R. Margutti, M. Medvedev, S. Chakraborti, R. Chevalier, N. Chugai, J. Dittmann, M. Drout, C. Fransson, D. Milisavljevic, E. Nakar, N. Sanders, **Radio Observations Reveal a Smooth Environment around the Extraordinary Type Ib Supernova 2012au**, *Astrophys. J.,* **797**, 2 (2014)

8) K.I. Nishikawa, P.E. Hardee, I. Dutan, J. Niemiec, M. Medvedev, Y. Mizuno, A. Meli, H. Sol, B. Zhang, M. Pohl, D.H. Hartmann, **Magnetic Field Generation in Core-Sheath Jets via the Kinetic Kelvin-Helmholtz Instability**, *Astrophys. J.*, **793**, 60 (2014)

9) K.-I. Nishikawa, P. Hardee, B. Zhang, I. Dutan, M. Medvedev, E. J. Choi, K.W. Min, J. Niemiec, Y. Mizuno, A. Nordlund, J. T. Frederiksen, H. Sol, M. Pohl, D. H. Hartmann, **Magnetic field generation in a jet-sheath plasma via the kinetic Kelvin-Helmholtz instability**, *Annales Geophysicae,* **31**, 1535 (2013)

10) B.D. Keenan, M.V. Medvedev, **On Particle Transport and Radiation Production in Sub-Larmor-Scale Electromagnetic Turbulence**, *Phys. Rev. E,* **88**, 013103 (2013)

11) M.V. Medvedev, A. Loeb, **Dynamics of Astrophysical Bubbles and Bubble-Driven Shocks. Fundamental Theory, Analytical Solutions and Observational Signatures**, *Astrophys. J.*, **768**, 113 (2013)

12) M.V. Medvedev, A. Loeb, **On Poynting-Flux-Driven Bubbles and Shocks Around Merging Neutron Star Binaries**, *Mon. Not. R. Astron. Soc*., **431**, 2737 (2013)

13) S. Reynolds, M.V. Medvedev, **Radiative diagnostics for sub-Larmor scale magnetic turbulence**, *Physics of Plasmas* **19**, 023106 (2012)

14) M.V. Medvedev, J.T. Frederiksen, T. Haugboelle, A. Nordlund, **Radiation from sub-Larmor scale magnetic fields**, *Astrophys. J.* **737**, 55 (2011)

15) K.-I. Nishikawa, J. Niemec, M. Medvedev, B. Zhang, P. Hardee, A. Nordlund, J. Frederiksen, Y. Mizuno, H. Sol, M. Pohl, D. Hartmann, M. Oka, G.J. Fishman**, Radiation from relativistic jets in turbulent magnetic fields**, *Advances in Space Research* **47**, 1434 (2011)

16) M. Gedalin, A. Spitkovsky, M. Medvedev, M. Balikhin, V. Krasnoselskih, A. Vaivads, S. Perri, **Relativistic filamentary equilibria**, *J. Plasma Physics* **77**, 193 (2011), doi:10.1017/S002237781000005X

Non-refereed Publications:

1) K.I. Nishikawa, P. Hardee, Y. Mizuno, I. Dutan, B. Zhang, M. Medvedev, E.J. Choi, K.W. Min, J. Niemiec, A. Nordlund, J. Frederiksen, H. Sol, M. Pohl, D.H. Hartmann, A. Marscher, J.L. Gomez, **Radiation from accelerated particles in relativistic jets with shocks, shear-flow and reconnection**, in proceedings of the conference: Innermost Regions of Relativistic Jets and Their Magnetic Fields, Granada, Spain (ed. by J.L. Gómez) EPJ Web of Conferences, **61**, id.02003 (2013)

2) K.-I. Nishikawa, P. Hardee, B. Zhang, I. Dutan, M. Medvedev, E.J. Choi, K.W. Min, J. Niemiec, Y. Mizuno, A. Nordlund, J.T. Frederiksen, H. Sol, M. Pohl, D.H. Hartmann, **Radiation from accelerated particles in relativistic jets with shocks, shear-flow, and reconnection**, Fermi Symposium proceedings - eConf C121028 (2012), also published as arXiv:1303.2569

3) K.-I. Nishikawa, B. Zhang, I. Dutan, M. Medvedev, P. Hardee, E. J. Choi, K. W. Min, J. Niemiec, Y. Mizuno, A. Nordlund, J.T. Frederiksen, H. Sol, M. Pohl, D.H. Hartmann, **Radiation from accelerated particles in relativistic jets with shocks, shear-flow and reconnections**, in proceedings of *GRB Symposium,* Malaga, Spain (2012)

4) K.-I. Nishikawa, B. Zhang, E. J. Choi, K. Min, J. Niemiec, M. Medvedev, P. Hardee, Y. Mizuno, Å Nordlund, J. Frederiksen, H. Sol, M. Pohl, D. H. Hartmann, G.J. Fishman, **Radiation from accelerated particles in shocks and reconnections**, in proceedings of *IAU Symposium 279*, *Death of Massive Stars,* Proceedings of the International Astronomical Union, IAU Symposium, Volume 279, p. 371 (2012)

5) K.-I. Nishikawa, , E.-J. Choi, K. Min, P. Hardee, Y. Muzino, B. Zhang, J. Niemiec, M. Medvedev, A. Nordlund, J. Frederiksen, H. Sol, M. Pohl, D.H. Hartmann, J.F. Fishman, **Simulations of Relativistic Jets and Associated Self-consistent Radiation**, Proc. of *Astronum-2011,* ASP Conference Series, Vol. 459. Edited by N.V. Pogorelov, J.A. Font, E. Audit, and G.P. Zank. San Francisco: Astronomical Society of the Pacific, p.143 (2012)

6) K.-I. Nishikawa, B. Zhang, J. Niemiec, M. Medvedev, P. Hardee, Y. Mizuno, E. J. Choi, K. Min, A. Nordlund, J. Frederiksen, H. Sol, M. Pohl, D. H. Hartmann, G.J. Fishman, **Radiation from**

accelerated particles in shocks and reconnections, Proc. of *2011 Swift Symposium,* eConf C110509 (2012)

7) K.-I. Nishikawa, E.J. Choi, K.W. Min, J. Niemiec, B. Zhang, P. Hardee, Y. Mizuno, M. Medvedev, A. Nordlund, J. Frederiksen, D. H. Hartmann, G.J. Fishman, **Radiation from shock-accelerated particles**, Proceedings of the Gamma-Ray Bursts 2012 Conference (GRB 2012), Munich (2012); http://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=152, id.28

8) M.V. Medvedev, S. Pothapragada, S. Reynolds, **Are GRB jets magnetically-dominated, or baryon-rich, or lepton-rich?**, in *Proc of GRB-2010 conference*, (eds., McEnery, Racussin, Gehrels) (2011)

9) K.-I. Nishikawa, J. Niemec, M. Medvedev, B. Zhang, P. Hardee, A. Nordlund, J. Frederiksen, Y. Mizuno, H. Sol, M. Pohl, D.H. Hartmann, G.J. Fishman**, Simulation of Relativistic Shocks and Associated Self-consistent Radiation**, in *Proc of Huntsville workshop: Partially ionized plasmas throughout the cosmos* (2011)

Invited Conference Talks:

1) M.V. Medvedev, **Review: Transport (T-conduction) in the ICM**, *Workshop on ICM Physics and modeling,* Max Planck Inst. for Astrophysics, Garching, Germany (2015)

2) M.V. Medvedev, **Particle acceleration in astrophysical relativistic jets**, *14th Annual International Astrophysics Conference (AIAC-15),* Tampa, FL (2015)

3) M.V. Medvedev, **Particle acceleration in relativistic jets**, *Accelerating Cosmic-Ray Comprehension (ACRC) workshop*, Princeton Univ., Princeton, NJ (2015)

4) M.V. Medvedev, **Could the universe get magnetized by galaxy cluster accretion shocks?**, *APS DPP-14 meeting, mini-conference: The Magnetic Universe -- A Mini-Conference in Honor of Stirling Colgate*, New Orleans, LA (2014)

5) M.V. Medvedev, **Non-standard paradigm of Cosmic Ray propagation**, *COSPAR-2014 General Assembly*, Moscow, Russia (2014)

6) M.V. Medvedev, **Asymmetric diffusion of Cosmic Rays**, *Workshop on Relativistic Plasma Astrophysics*, Purdue University, West Lafayette, IN (2014)

7) M.V. Medvedev**, Asymmetric diffusion in turbulent plasmas**, *Isradynamics-2014* conference, En Bokek, Israel (2014)

8) M.V. Medvedev**, On Cosmic Ray Propagation in the Heliosphere**, *13th Annual International Astrophysics Conference* (AIAC-13), Myrtle Beach, SC (2014)

9) M.V. Medvedev, **Asymmetric diffusion in turbulent magnetized plasmas with a mean field gradient**, *12th Annual International Astrophysics Conference* (AIAC-12), Myrtle Beach, SC (2013)

10) M.V. Medvedev, **Theory and numerical modeling of radiation from sub-larmor-scale magnetic turbulence**, *International Astrophysics Forum Alpbach, IAFA 2011,* Alpbach, Tyrol, Austria (2011)

11) M.V. Medvedev, **Theory and numerical modeling of radiation from sub-larmor-scale magnetic turbulence**, *Shocks, turbulence and nonlinear systems*, Eilat, Israel (2011)

12) M.V. Medvedev, **Interplay of MHD turbulence and discontinuities in the Solar Wind**, *10th Annual International Astrophysics Conference* (AIAC-10), Maui, Hawaii (2011)

Invited colloquia and seminars:

1) University RUDN (Moscow People's Friendship Univ.), Physics Seminar, *AGN jets (2015)*
2) U. Colorado - Boulder, CIPS seminar, *Asymmetric diffusion in turbulent plasmas (2013)*
3) University RUDN (Moscow), Physics Seminar, *Gamma-ray bursts and shocks (Cosmic nano-physics) (2013)*
4) Aspen Center for Physics, Cosmic Ray Acceleration program, *Relativistic shocks + upstream + downstream (2013)*
5) Aspen Center for Physics, Cosmic Ray Acceleration program, *Asymmetric diffusion and CR transport (2013)*
6) Harvard University, ITC, Luncheon talk, *Poynting-Flux-Driven Bubbles and Shocks Around Merging Neutron Star Binaries (2013)*
7) National Research Center "Kurchatov Institute", Plasma seminar on *Asymmetric diffusion in plasmas (2012)*
8) Pulkovo Observatory (Russia), Seminar on *Shocks in Gamma-Ray Bursts (2012)*
9) University of California, San Diego, CASS Astro and Plasma Seminar, *Theory and numerical modeling of radiation from sub-Larmor-scale magnetic turbulence (2012)*
10) KU Space and Astrophysical Plasma seminar, *Theory and numerical modeling of radiation from sub-Larmor-scale magnetic turbulence (2011)*
11) U. Colorado - Boulder, Physics Colloquium: *A theorist's view of astrophysical relativistic shocks (2011)*
12) U. Colorado - Boulder, JILA Astrophysics seminar: *Soft X-ray background or heliospheric X-ray foreground? Mapping the outer heliosphere (2011)*
13) U. Colorado - Boulder, CIPS Plasma seminar: *Radiation diagnostic of sub-Larmor-scale magnetic fields in high-energy-density plasmas (2011)*
14) Truman State University, Physics Colloquium: *Gamma-Ray Bursts: Cosmic nano-physics at work (2011)*
15) KU Space and Astrophysics Plasma Seminar: *Interplay of nonlinear Alfven waves and discontinuities (2011)*

Conference Presentations:

1) M.V. Medvedev, **On particle acceleration in astrophysical relativistic jets**, *Mini-Conference: Plasma Energization - Interactions Between Fluid and Kinetic Scales -- APS DPP-15 meeting*, Savannah, GA (2015) [oral]

2) M.V. Medvedev, **Regimes of transport (T-conduction) in IGM plasmas**, *APS DPP-15 meeting*, Savannah, GA (2015) [oral

3) B. Keenan, A. Ford, M.V. Medvedev, **On the Observation of Jitter Radiation in Solid-Density Laser-Plasma Laboratory Experiments**, *APS DPP-15 meeting*, Savannah, GA (2015)

4) A. Ford, B. Keenan, M.V. Medvedev, **Modeling electron-positron plasma production around supermassive BHs in AGNs**, *APS DPP-15 meeting*, Savannah, GA (2015)

5) M.V. Medvedev, **How did the universe get magnetized?**, *APS April meeting*, Baltimore, MD (2015) [oral]

6) A. Ford, B. Keenan, M.V. Medvedev, **Leptonic cascade around Kerr BHs and the formation of relativistic jets**, *APS April meeting*, Baltimore, MD (2015)

7) B. Keenan, A. Ford, M.V. Medvedev, **Relation of the energy and pitch-angle diffusion of charged particles to the emitted radiation in small-scale astrophysical turbulence**, *APS April meeting*, Baltimore, MD (2015)

8) M.V. Medvedev, **On Cosmic Ray Propagation**, *APS DPP-14 meeting, mini-conference: Van Allen 100: Cosmic Ray Transport*, New Orleans, LA (2014) [oral]

9) M.V. Medvedev, A. Ford, B. Keenan, **Theory of the leptonic cascade in magnetospheres of Kerr black holes**, *APS DPP-14 meeting*, New Orleans, LA (2014) [oral]

10) A. Ford, B. Keenan, M.V. Medvedev, **Modeling magnetospheres of spinning black holes**, *APS DPP-14 meeting*, New Orleans, LA (2014)

11) B. Keenan, A. Ford, M.V. Medvedev, **"Pheudo-cyclotron" radiation and transport of non-relativistic particles in inhomogeneous sub-Larmor-scale electro-magnetic fields**, *APS DPP-14 meeting*, New Orleans, LA (2014)

12) M.V. Medvedev, **On Cosmic Ray Propagation**, *AAS meeting*, Boston, MA (2014) [oral]

13) M.V. Medvedev, **Non-standard paradigm of Cosmic Rays diffusion**, *High-Energy Density and Laboratory Astrophysics (HEDLA-2014) meeting*, Bordeaux, France (2014)

14) M.V. Medvedev, **Asymmetric diffusion of Cosmic Rays**, *APS April* meeting, Savannah, GA (2014) [oral]

15) B. Keenan, A. Ford, M.V. Medvedev, **"Pheudo-cyclotron" radiation of non-relativistic particles in small-scale magnetic turbulence**, *APS April* meeting, Savannah, GA (2014)

16) A. Ford, B. Keenan, M.V. Medvedev, **Electron-positron cascade in magnetospheres of spinning black holes**, *APS April* meeting, Savannah, GA (2014)

17) M.V. Medvedev, **Asymmetric diffusion of Cosmic Rays**, *High-Energy Astrophysics meeting HEA-13,* Moscow, Russia (2013) [oral]

18) M.V. Medvedev, A. Loeb, **Formation, dynamics and observational signatures of Poynting-flux-driven bubbles and shocks produced by merging NS binaries and implications for SGRBs**, *Texas Symposium on Relativistic Astrophysics*, Dallas (2013)

19) M.V. Medvedev, **Asymmetric diffusion in turbulent plasmas**, *APS DPP-13 meeting*, Denver (2013) [oral]

20) B. Keenan, M.V. Medvedev, **Radiation production by and transport of non-relativistic particles in plasmas with sub-Larmor-scale magnetic fields**, *APS DPP-13 meeting*, Denver (2013)

21) A. Ford, M.V. Medvedev, **On magnetospheres of spinning black holes**, *APS DPP-13 meeting*, Denver (2013)

22) M.V. Medvedev, A. Loeb, **Poynting-Flux-Driven Bubbles and Shocks Around Merging Neutron Star Binaries**, *APS April* meeting, Denver (2013) [oral]

23) B. Keenan, M.V. Medvedev, **Transport Properties and Radiation Production in Plasmas with Sub-Larmor-Scale Magnetic Turbulence**, *APS April* meeting, Denver (2013) [oral]

24) M.V. Medvedev, A. Loeb, **Dynamics of Astrophysical Bubbles and Bubble-Driven Shocks: Basic Theory, Analytical Solutions and Observational Signatures**, *AAS HEAD* meeting, Monterey, CA (2013)

25) M.V. Medvedev, A. Loeb, **On Poynting-Flux-Driven Bubbles and Shocks Around Merging NS/Magnetar Binaries and Implications for SGRBs**, *AAS HEAD* meeting, Monterey, CA (2013)

26) M.V. Medvedev, B. Keenan, **Magnetic micro-turbulence: relation of electron diffusion to their emitted radiation spectra**, *AAS HEAD* meeting, Monterey, CA (2013)

27) K.-I. Nishikawa, P. Hardee, B. Zhang, I. Dutan, M. Medvedev, E. J. Choi, K.W. Min, J. Niemiec, Y. Mizuno, A. Nordlund, J. T. Frederiksen, H. Sol, M. Pohl, D. H. Hartmann, **Magnetic field generation in a jet-sheath plasma via the kinetic Kelvin-Helmholtz instability**, Dynamical processes in space plasmas II, Isradinamic (2012)

28) M.V. Medvedev, A. Loeb, **Electromagnetic bubbles around merging neutron stars**, conference on *High-Energy Astrophysics-2012*, Moscow, Russia (2012) [oral]

29) M.V. Medvedev, A. Loeb, **Formation and dynamics of an electromagnetic bubble during the NS binary inspiral: theory and observational signatures**, *APS Prairie* meeting, Lawrence (2012) [oral]

30) B. Keenan, M.V. Medvedev, **Astrophysical magnetic micro-turbulence: relation of diffusion of relativistic electrons to the emitted radiation spectra**, *APS Prairie* meeting, Lawrence (2012)

31) M.V. Medvedev, **Asymmetric diffusion in turbulent magnetized plasmas with a mean field gradient**, *APS DPP-12* meeting, Providence (2012) [oral]

32) B. Keenan, M.V. Medvedev, **Transport properties and radiation production in plasmas with sub-Larmor-scale magnetic turbulence**, *APS DPP-12* meeting, Providence (2012)

33) M.V. Medvedev, A. Loeb, **Formation and dynamics of an electromagnetic bubble during the NS binary inspiral: theory and observational signatures**, *Nature's particle accelerators* conference, Annapolis (2012) [oral]

34) M.V. Medvedev, J. Frederiksen, T. Haugboelle, A. Nordlund, **Theory and numerical modeling of radiation from sub-Larmor-scale magnetic turbulence**, *High-Energy-Density and Laboratory Astrophysics* conference (HEDLA-2012), Tallahassee (2012)

35) K.-I. Nishikawa, B. Zhang, E. J. Choi, K. Min, J. Niemiec, M. Medvedev, P. Hardee, Y. Mizuno, Å Nordlund, J. Frederiksen, H. Sol, M. Pohl, D. H. Hartmann, G.J. Fishman, **Radiation from accelerated particles in shocks and reconnections**, *IAU Symposium 279*, *Death of Massive Stars: Supernovae and Gamma-Ray Bursts*, Nikko, Japan (2012)

36) M.V. Medvedev, J. Frederiksen, T. Haugboelle, A. Nordlund, **Theory and numerical modeling of radiation from sub-Larmor-scale magnetic turbulence**, *American Physical Society meeting, Division of Plasma Physics,* Salt Lake City, UT (2011)

37) B. Keenan, M.V. Medvedev, **Inter-relation of radiative and transport properties of HED plasmas with small-scale magnetic turbulence**, *American Physical Society meeting, Division of Plasma Physics,* Salt Lake City, UT (2011)

38) S. Reynolds, M.V. Medvedev, **Radiative diagnostics for sub-Larmor scale magnetic turbulence**, *American Physical Society meeting, Division of Plasma Physics,* Salt Lake City, UT (2011)

39) K.-I. Nishikawa, , E.-J. Choi, K. Min, P. Hardee, Y. Muzino, B. Zhang, J. Niemiec, M. Medvedev, A. Nordlund, J. Frederiksen, H. Sol, M. Pohl, D.H. Hartmann, J.F. Fishman, **Simulations of Relativistic Jets and Associated Self-consistent Radiation**, *Astronum-2011*, Valencia, Spain (2011)

40) K.-I. Nishikawa, B. Zhang, J. Niemiec, M. Medvedev, P. Hardee, Y. Mizuno, E. J. Choi, K. Min, A. Nordlund, J. Frederiksen, H. Sol, M. Pohl, D. H. Hartmann, G.J. Fishman, **Radiation from accelerated particles in shocks and reconnections**, *2011 Swift Symposium*, Clemson, SC (2011)

41) M.V. Medvedev, **The effect of quantum evaporation of dark matter halos**, *APS meeting*, Anaheim, CA (2011) [oral]

42) M.V. Medvedev, **Radiation from shocks and magnetic reconnection: A key to the jet composition**, conference on *Prompt GRBs*, Raleigh, NC (2011) [oral]

Personnel, advising, etc.

The PI has worked hard mentoring and leading his graduate students in their research. The progress is strong as always: two students (Brett Keenan and Alex Ford) have successfully passed their Comprehensive Exams (Keenan passes with honors) in November 2013. They continue to work with PI toward their Ph.D. degrees. Last update: Brett Keenan successfully defended his PhD (with honors) in January 2016.