Campagne 2020 Contrats Doctoraux Instituts/Initiatives

Proposition de Projet de Recherche Doctoral (PRD)

Appel à projet IPhyInf - Initiative Physique des infinis 2020

Intitulé du Projet de Recherche Doctoral : Charged particle dynamics in solar wind coherent structures

Directeur de Thèse porteur du projet (titulaire d'une HDR) :

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Unité de Recherche :
Intitulé : LESIA, Obsrevatoire de Paris
Code *(ex. UMR xxxx)* : UMR 8109

Ecole Doctorale de rattachement de l'équipe & d'inscription du doctorant : ED127-AstronomieAstrophysiqueIdF

Doctorants actuellement encadrés par le directeur de thèse (préciser le nombre de doctorants, leur année de 1ere inscription et la quotité d'encadrement) : 1, 2017, 50%

Co-encadrant :

NOM : **Petrukovich** Prénom : **Anatoly**
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Unité de Recherche :
Intitulé : Space Research Institute of Russian Academy of Sciences (IKI, Moscow)
Code *(ex. UMR xxxx)* :

Ecole Doctorale de rattachement : ED127-AstronomieAstrophysiqueIdF
Ou si ED non Alliance SU :

Doctorants actuellement encadrés par le co-directeur de thèse (préciser le nombre de doctorants, leur année de 1ere inscription et la quotité d'encadrement) : 0

Cotutelle internationale : ☐ Non ☒ Oui, précisez Pays et Université : **Russie, Space Research Institute of Russian Academy of Sciences (IKI, Moscow)**

Description du projet de recherche doctoral *(en français ou en anglais)*

3 pages maximum – interligne simple – Ce texte sera diffusé en ligne

Détailler le contexte, l'objectif scientifique, la justification de l'approche scientifique ainsi que l'adéquation à l'initiative/l'Institut.
Le cas échéant, préciser le rôle de chaque encadrant ainsi que les compétences scientifiques apportées. Indiquer les publications/productions des encadrants en lien avec le projet.
Préciser le profil d'étudiant(e) recherché.

Context:

The solar wind is a supersonic plasma stream frozen into an interplanetary magnetic field accelerated away from the Sun. Solar wind measurements at a wide range of distances from the Sun show that radial evolution of ion temperature significantly differs from the adiabatic expansion (Cranmer et al., 2009, Elliott et al., 2016). It means that there must be gradual heat input into the solar wind plasma that begins in the corona and extends far out into interplanetary space (Parker 1963; Leer et al. 1982; Tu & Marsch 1995; Goldstein et al. 1995; Marsch 1999; Hollweg & Isenberg 2002; Cranmer 2002; Matthaeus et al. 2003). Solution of the solar wind heating problem is extremely important both for understanding the structure of the heliosphere and for adequately describing the atmospheres of distant stars. The modern theories suggest that turbulence [Bruno & Carbone 2013] and emerged coherent structures [e.g., Greco et al. 2009, Alexandrova 2008, Lion et al. 2016] can significantly contribute to the solar wind heating, but there is no well accepted concept for a mechanism responsible for such heating.

Scientific objectives:

The aim of this PHD project is to study coherent structures in the turbulent solar wind (e.g., current sheets, shocks, vortices) and their role in ions and electrons dynamics. To approach this problem, the candidate will combine multi-satellite data analysis at 1 AU with NASA/MMS and ESA/Cluster missions, theoretical models, and numerical simulations. The results will be then applied to understand new measurements of the NASA/Parker Solar Probe (PSP) and ESA/Solar Orbiter (SOLO) missions closer to the Sun.

First of all, we will determine the dominant coherent structures in the turbulent solar wind and the solar wind behind the Earth's bow-shock (the so-called magnetosheath). This work will be based on magnetic field measurements at different scales and in 4 points in space in order to separate time and space variations (crucial for the coherent structures identification). This analysis is possible with Cluster in the free solar wind and with MMS in the Earth's magnetosheath. Second, we will do an analysis of ion and electron distribution functions within the dominant coherent structures using high resolution particle measurements on MMS in the Earth's magnetosheath.

These two observational steps will be done at LESIA/Paris Observatory (Meudon) under the supervision of Milan Maksimovic and in collaboration with Olga Alexandrova. The observational results will be then the basis of the modeling and numerical simulations, which will be done in IKI (Moscow) with Anatoly Petrukovich, in collaboration with Anton Artemyev in UCLA (Los Angeles, USA). Main theoretical approaches include perturbation theory for resonant Hamiltonian systems and theory of adiabaticity destruction in Hamiltonian systems with separatrices. Using these approaches, efficiency of ion and electron scattering by coherent structures of different configurations will be investigated. Numerical simulations of ion and electron interaction with coherent solar wind structures will include massive test particle simulations and self-consistent hybrid simulations.

The final step will be comparison of 1 AU observations with the new measurements in previously unexplored regions made by the Solar Orbiter and Parker Solar Probe closer to the Sun.

Justification of the scientific approach:

In order to understand the solar wind evolution and heating, we propose here to do the data analysis of Cluster and MMS at 1 AU, SOLO at 0.3-1AU and Parker Solar Probe at 0.05-0.3 AU. Note that the instrumentation is quite different on the four space missions.

Approaching the Sun, the conditions are such that important constraints have been made on the instruments and data telemetry for PSP and SOLO. The most sensitive instrument ever measuring turbulent fluctuations at kinetic scales (where one expects particle-turbulence interactions) is Cluster/STAFF (search coil magnetometer), which can resolve ion and electron scales at 1 AU. MMS has been designed for the Earth's magnetosphere studies (including solar wind between the bow-shock and the magnetopause, i.e., within the magnetosheath) and it provides the highest cadency for ion and electron distribution functions, but also less sensitive magnetic measurements at kinetic scales. PSP and SOLO have less sensitive search coil magnetometers than Cluster/STAFF, the particle instruments have lower cadency than MMS. Both missions are composed of a single spacecraft (which makes it impossible to separate time and space variations), by opposition with Cluster and MMS.

To resume, using multi-satellites Cluster and MMS, we will be able to separate between time and space variations and fully characterize coherent structures. High quality measurements of turbulent fluctuations and particle distributions at 1 AU will allow a detailed modeling. Then, using our knowledge at 1 AU, we will be able to interpret properly PSP and SOLO measurements closer to the Sun.

It is crucial to have a strong observational and theoretical background thanks to the study proposed here to interpret correctly the new observations of PSP and SOLO and advance our understanding of solar wind physics.

Adequation to "Initiative Physique des Infinis"

This project is in full adequation with the "Initiative Physique des Infinis" as far as it aims to better understand the behavior of (charged) particles in (turbulent space) plasmas.

The problem of turbulence is one of the open problems in modern physics. Here we address the electromagnetic turbulence in astrophysical collisionless plasmas, where the usually (collisional) dissipation is not efficient. This problem covers a very large range of scales, from ~ 1AU to very small (for astrophysics) ~ 1km. Precisely, from the propagation of magnetic structures over Sun-Earth distance (scales ~ 1 AU), to scales of turbulence/particles interaction (~1-1000 km).

The aim of the project is to understand physical processes which govern in the complex turbulent space plasmas and their impact on the solar wind expansion in the Heliosphere. Thanks to the proposed collaboration between LESIA and IKI, the candidate will use the diversity of approaches (theory, modeling, data analysis of different spacecrafts in the Heliosphere).

The student will participate in doctoral schools devoted to plasma physics (from laboratory to astrophysics, like the one organized every 2 years in 'Ecole de Physique des Houches', e.g., http://geoffroy-lesur.org/plasmas2017/) and to satellite data mining.

Role of each supervisor and the scientific skills provided:

Milan Maksimovic (DR/CNRS, LESIA): Supervision of spacecraft observations and data analysis. PI of SOLO/RPW instrument, CoI of FIELDS/PSP instrument (PI Stuart Bale, Berkeley), CoI of Cluster/STAFF. Expert of space instrumentation in general and of SOLO, PSP, Cluster in particular. Expert of solar wind modeling.

Anatoly Petrukovich (Director of Space Research Institute of Russian Academy of Sciences (IKI), Moscow, Russia; correspondent member of the Russian Academy of Sciences): Supervision of spacecraft observations and observation/theory comparison. Expert in magnetospheric plasma dynamics and in spacecraft instrumentation.

Olga Alexandrova (ASAD/CNAP, LESIA): Collaboration on the spacecraft observations, data analysis and modeling. Expert of space plasma turbulence and coherent structures. CoI of Cluster/STAFF, CoI of SOLO/RPW.

Anton Artemyev (Associate Researcher UCLA, IKI): Collaboration on the spacecraft observations, theoretical modelling and numerical simulations. Expert in plasma physics theory.

Publications / productions of the supervisors in connection with the project

LESIA team:

1. Maksimovic, Milan; Pierrard, Viviane; Lemaire, Joseph, On the Exospheric Approach for the Solar Wind Acceleration, Astrophysics and Space Science, v. 277, Issue 1/2, p. 181-187 (2001).

2. Maksimovic, M.; Zouganelis, I.; Chaufray, J. -Y et al., Radial evolution of the electron distribution functions in the fast solar wind between 0.3 and 1.5 AU, Journal of Geophysical Research: Space Physics, Volume 110, Issue A9, CiteID A09104, 09/2005

3. Maksimovic, M.; Bale, S. D.; Berčič, L. et al., Anticorrelation between the Bulk Speed and the Electron Temperature in the Pristine Solar Wind: First Results from the Parker Solar Probe and Comparison with Helios, The Astrophysical Journal Supplement Series, Volume 246, Issue 2, id.62, 02/2020

4. O. Alexandrova, A. Mangeney, M. Maksimovic, N. Cornilleau-Wehrlin, J. M. Bosqued, M. Andre, Alfven vortex filaments observed by Cluster in the magnetosheath downstream of perpendicular shock, J. Geophys. Res., Vol. 111, A12208, 2006

5. Alexandrova, O.; Chen, C. H. K.; Sorriso-Valvo, L.; Horbury, T. S.; Bale, S. D., Solar Wind Turbulence and the Role of Ion Instabilities, Space Science Reviews, Volume 178, Issue 2-4, pp. 101-139, 2013.

6. Lion, Sonny; Alexandrova, Olga; Zaslavsky, Arnaud, Coherent Events and Spectral Shape at Ion Kinetic Scales in the Fast Solar Wind Turbulence, The Astrophysical Journal, Volume 824, Issue 1, article id. 47, 13 pp. (2016)

7. Tieyan Wang, Olga Alexandrova, Denise Perrone et al., Magnetospheric

Multiscale Observation of Kinetic Signatures in the Alfvén Vortex, The Astrophysical Journal Letters, Volume 871, Issue 2, article id. L22, 12 pp. (02/2019).

8. Jovanovic, Dusan; Alexandrova, Olga; Maksimovic, Milan; Belic, Milivoj, Fluid theory of coherent magnetic dipolar and quasi-monopolar structures in high-beta plasmas of the Solar wind and of the Earths magnetosheath, eprint arXiv:1705.02913, 2017arXiv170502913J, APJ, 2020, in press

IKI team:

1. Petrukovich A. A., A. V. Artemyev, R. Nakamura, E. V. Panov, and W. Baumjohann. Cluster observations of dBz/dx during growth phase magnetotail stretching intervals. 2013 J. Geophys. Res. 118, 5720–5730, doi:10.1002/jgra.50550, 2013

2. Artemyev A.V., A.A. Petrukovich, A.G. Frank, R. Nakamura, L.M. Zelenyi. Intense current sheets in the magnetotail: Peculiarities of electron physics. 2013. J. Geophys. Res. 118, 2789–2799, doi: 10.1002/jgra.50297

3. Zelenyi L M, Neishtadt A I, Artemyev A V, Vainchtein D L, Malova H V "Quasiadiabatic dynamics of charged particles in a space plasma" Phys. Usp. 56 347–394 (2013); DOI: 10.3367/UFNe.0183.201304b.0365

4. Artemyev A. V., Neishtadt A. I., Zelenyi L. M., Rapid geometrical chaotization in slow-fast Hamiltonian systems. Physical Review E, 89, 060902(R), 2014, doi: 10.1103/PhysRevE.89.06090

5. Artemyev, A.V., Neishtadt, A.I., Zimovets, I.V. et al. Chaotic Charged Particle Motion and Acceleration in Reconnected Current Sheet. Sol Phys 290, 787–810 (2015). https://doi.org/10.1007/s11207-014-0639-y

6. Petrukovich Anatoli, Anton Artemyev, Ivan Vasko, Rumi Nakamura, Lev Zelenyi. Current Sheets in the Earth Magnetotail: Plasma and Magnetic Field Structure with Cluster Project Observations. Space Sci Rev (2015) 188:311–337, DOI 10.1007/s11214-014-0126-7

7. Artemyev Anton V., Vassilis Angelopoulos, Jasper S. Halekas, Alexander A. Vinogradov, Ivan Y. Vasko, and Lev M. Zelenyi, Dynamics of Intense Currents in the Solar Wind, The Astrophysical Journal, 859:95 (11pp), 2018

8. Petrukovich A A, Malova H V, Popov V Yu, Maiewski E V, Izmodenov V V, Katushkina O A, Vinogradov A A, Riazantseva M O, Rakhmanova L S, Podladchikova T V, Zastenker G N, Yermolaev Yu I, Lodkina I G, Chesalin L S "Modern view on solar wind from micro to macro scales" Phys. Usp., 2020, accepted

Student profile

Knowledge of plasma physics. Some knowledge of space physics and heliosphere are desirable, but not obligatory.

We have a potential candidate, Alexander Vinogradov (master degree student at IKI), co-author of the papers [7,8] of the IKI-team-list.

This project is submitted with the agreement of the direction of LESIA and IKI.

Annex: Organization of the co-supervision LESIA/IKI

As far as the PHD will be done in 2 institutes, we find it important to mention the following organization. Regular teleconferences between the two groups will be carried out during the 3 years of the PHD project. Moreover, during the periods spent in Paris, supervisors from IKI will visit LESIA. A workshop will be organized by Paris Observatory at CIAS (https://cias.obspm.fr/) during the first visit. During the periods spent in Moscow, supervisors from the Paris Observatory will visit IKI. These visits are important to maintain regular contact between the two teams and allow good development of the PhD. We plan the following time repartition between two institutions:

2020

01/10/2020 – 31/12/2020: LESIA, Paris Observatory (3 months)

2021

1/01/2021 – 30/06/2021: LESIA, Paris Observatory (6 months)

1/07/2021 – 31/12/2021: IKI, Moscow (3 months)

2022

01/01/2022 – 31/03/2022: IKI, Moscow (3 months)

01/04/2022 – 30/09/2023: LESIA, Paris Observatory (6 months)

1/07/2022 – 31/12/2022: IKI, Moscow (6 months)

2023

01/01/2023 – 30/06/2023: IKI, Moscow (6 months)

01/07/2023 – 30/09/2023: LESIA, Paris Observatory (3 months)

The place of the defense will be discussed during the PhD.

Merci de nommer votre fichier pdf :
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à envoyer simultanément par e-mail à l'ED de rattachement et au programme :
cd_instituts_et_initiatives@listes.upmc.fr avant le 30 mars.