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EDITORIAL
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Editorial: Improving the Understanding of Kinetic Processes in Solar Wind and Magnetosphere: From CLUSTER to Magnetospheric Multiscale Mission

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Editorial on the Research Topic

Improving the Understanding of Kinetic Processes in Solar Wind and Magnetosphere: From CLUSTER to Magnetospheric Multiscale Mission

The most common matter state in the Universe is plasma (Krall and Trivelpiece, 1986). In the Heliosphere, these plasmas are almost collisionless, magnetized, and quasi-neutral and can mimic a large number of astrophysical plasmas that can only be observed remotely, e.g., the interstellar medium, astrophysical shocks and jets, accretion disks, cluster of galaxies etc.

Single-point space missions have described many properties of near-Earth and heliospheric plasmas by using both *in situ* measurements and remote sensing observations. From the first observations by the *Mariner* mission of turbulent solar wind flow (Neugebauer and Snyder, 1966; Neugebauer and Snyder, 1967), and the first computing of power spectra of alfvénic fluctuations (Coleman, 1968), or pioneering observations of large-scale magnetic structures (Burlaga et al., 1977) from the *Explorer 43* mission, both making single space observations, the community has advanced a lot in knowledge of plasma phenomena.

However, analyses of space plasma using *in situ* data from single spacecraft suffer from a spatio-temporal ambiguity, viz., the difficulty of disentangling temporal and spatial variations. This issue is acute for magnetofluid turbulence in the solar wind where it is very difficult to deduce the three-dimensional properties of the turbulent fluctuations from single spacecraft data (Goldstein et al., 2015). A full and realistic description of our plasma environment requires measurements able to determine the three-dimensional, time-dependent features observed in this turbulent system. Indeed, only multi-spacecraft observations are able to exhibit a connection between space and time: the same physical observables are measured not only at different points in space but also at different instants in time. *Cluster* was the first mission (Escoubet et al., 1997; Escoubet et al., 2001), and until data began to flow from the *Magnetospheric Multiscale Mission* (MMS), it was the only mission designed to describe the three-dimensional structure of plasma phenomena in geospace. To achieve this, *Cluster*, launched in the summer of 2000 and currently still in operation, consists of four identical spacecraft flying in a tetrahedral configuration, thereby making it possible to distinguish between spatial and temporal variations.

Beyond detailed analysis of the electromagnetic field and plasma characteristics, thanks to the robust experiments on board the four spacecraft, the goal of the *Cluster* mission has been to

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exploit multi-point observations to compute spatial gradients. The curlometer analysis technique (Dunlop et al., 1988; Dunlop et al., 2002a; Dunlop and Eastwood, 2008) allows a direct estimation of the total current density from $\nabla \times \mathbf{B}$, using high-resolution magnetic field measurements. The same technique can be applied to velocity field measurements, i.e., $\nabla \times \mathbf{V}$, to resolve flow vorticity (Chanteur, 1998; Harvey, 1998). Therefore, *Cluster* has contributed to determine currents and vorticity in various regions of the Earth's magnetosphere (Dunlop et al., 2016), such as in the magnetotail (see, e.g., Runov et al., 2006; Nakamura et al., 2008; Shen et al., 2008; Narita et al., 2013), in the magnetopause (see, e.g., Dunlop and Balogh, 2005; Panov et al., 2006), in the inner magnetosphere (see, e.g., Vallat et al., 2005; Shen et al., 2014), as well as in the solar wind (see, e.g., Eastwood et al., 2002; Gurgiolo et al., 2010).

Four-spacecraft measurements have been also used to estimate the normal and the speed of a discontinuity (Russell et al., 1983; Dunlop et al., 2002b), by using the so-called timing method. Recently, the timing method has been used to study structures at ion scales in the solar wind turbulence (Perrone et al., 2016; Perrone et al., 2017). Further, measurements from the four satellites, in the appropriate configuration, have allowed to calculate the dispersion relation of several waves ubiquitous in the geospace environment (Narita et al., 2003; Narita and Glassmeier, 2005) by using the wave telescope or k-filtering technique (Pinçon and Lefeuvre, 1991; Motschmann et al., 1996; Glassmeier et al., 2001; Glassmeier, 2003).

Cluster observations have been also used to study turbulence of the plasma which surrounds our local geospace environment. In particular, turbulence correlation scales have been estimated in both Earth's plasmasheet (Vörös et al., 2005; Weygand et al., 2005) and solar wind (Matthaeus et al., 2005; Weygand et al., 2007). Moreover, for the first time, it has been possible to describe the three-dimensional properties of the inertial range of interplanetary turbulence at ion scales (Narita et al., 2011a; Narita et al., 2011b), where intermittency starts to manifest itself. Further, thanks to high-resolution magnetic field data, *Cluster* has allowed to study turbulence toward electron scales in the solar wind (Alexandrova et al., 2009; Sahraoui et al., 2009), where dissipation should take place.

Finally, *Cluster* data have elucidated aspects of reconnection that occurs in the solar wind, magnetosheath, and magnetosphere. For example, multi-point measurements allowed to unambiguously determine the characteristics of the near-Earth's reconnection line on the ion scale (Runov et al., 2003), and to lead to a significant progress in understanding the microphysics of this processes, revealing the subsequent both adiabatic and non-adiabatic particle energization (Retinò et al., 2007; Sundkvist et al., 2007).

In March of 2015, the MMS, consisting of four identical spacecraft, similar to *Cluster*, was launched, providing multi-point measurements in near-Earth space (Burch et al., 2016a). The spacecraft are flying at significantly smaller separations, down to ~ 5 km, while the instruments are providing high-time resolution plasma data, as well as three-dimensional electric field measurements, allowing for an unprecedented investigation of kinetic processes. The *MMS* instruments are able directly to observe the electron diffusion region at the Earth's magnetopause and magnetotail, thus adding critical insight into the physics of magnetic reconnection (Burch et al., 2016b; Torbert et al., 2018). *MMS* observations enabled the study of the statistical properties of turbulence and the associated energy cascade in near-Earth space from the inertial range down to proton and electron scales (Bandyopadhyay et al., 2018; Chhiber et al., 2018). Intermittent structures at kinetic scales have been identified, revealing the existence of electron-scale current sheets, similar to what was previously observed at ion scales (Greco et al., 2016; Yordanova et al., 2016). Furthermore, *MMS* makes it possible to resolve electron-scale regions of active magnetic reconnection, while more recent studies have investigated their role in kinetic-scale turbulence (Phan et al., 2018; Stawarz et al., 2019), providing new insight into the dissipative processes at kinetic scales. The novel measurements lead to the developments of new techniques that examine the complex structure of the plasma velocity distribution functions, shedding a new light into the kinetic physics behind turbulent dissipation (Servidio et al., 2017).

The main motivation in organizing this special issue in Frontiers of Astronomy and Space Sciences, twenty years after the first multi-point observations, is to give an overview of the achievements in the understanding of kinetic processes in both the Earth's magnetosphere and the solar wind as well as to present the current efforts of the scientific community in this field. This special issue collects mainly papers on observations in turbulent space plasmas. Contributions from numerical studies are also present to support the observational evidences and improve the understanding of turbulent collisionless plasmas.

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