



# Editorial: Magnetohydrodynamic Waves in the Solar Atmosphere: Heating and Seismology

Tom Van Doorselaere<sup>1\*</sup>, Valery M. Nakariakov<sup>2,3</sup>, Bo Li<sup>4</sup> and Patrick Antolin<sup>5,6</sup>

<sup>1</sup> Department of Mathematics, Centre for mathematical Plasma Astrophysics, KU Leuven, Leuven, Belgium, <sup>2</sup> Department of Physics, Centre for Fusion, Space and Astrophysics, University of Warwick, Coventry, United Kingdom, <sup>3</sup> St. Petersburg Branch, Special Astrophysical Observatory, Russian Academy of Sciences, St. Petersburg, Russia, <sup>4</sup> School of Space Science and Physics, Shandong University, Weihai, China, <sup>5</sup> Department of Mathematics, Physics and Electrical Engineering, Northumbria University, Newcastle upon Tyne, United Kingdom, <sup>6</sup> School of Mathematics and Statistics, University of St. Andrews, St. Andrews, United Kingdom

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## Editorial on the Research Topic

### Magnetohydrodynamic Waves in the Solar Atmosphere: Heating and Seismology

Historically, following the seminal paper on what is now called “Alfvén” waves (Alfvén, 1942), the theoretical understanding of Magnetohydrodynamic (MHD) waves in uniform media of infinite extent rapidly reached substantial sophistication as summarized in the classics by Cowling (1957) and Braginskii (1965). In particular, the role that MHD waves may play in heating the solar atmosphere was pointed out by Cowling as early as in the 1950s (see Cowling, 1962, and references therein). That the structuring in the physical parameters of the solar atmosphere may strongly affect MHD waves was then recognized (e.g., Uchida, 1968; Rosenberg, 1970; Zaitsev and Stepanov, 1975). Even though they paved the way for the now-called “coronal seismology,” most modeling studies (e.g., Uchida, 1970; Edwin and Roberts, 1983; Poedts et al., 1990) focused on utilizing the waves for coronal heating (e.g., Ionson, 1978; Hollweg et al., 1982). This modeling was an endeavoring effort, however, because no observational feedback was available, given the lack of instrumental development at the time. Indeed, some scientists even believed that there were no waves in the solar corona. Despite the lack of observational support, many pioneering papers appeared in this subject area.

Substantial indirect evidence suggesting that MHD waves played a key role in explaining the strong emission and broad non-thermal line widths in the upper chromosphere, transition region and corona already existed from observations with Skylab (Feldman et al., 1988), HRTS (Dere and Mason, 1993), and SUMER (Chae et al., 1998). However, there are two key times in transforming the field of coronal wave studies from its early stages to its current level.

The first key discovery was the direct imaging of coronal waves in the SOHO and TRACE era (late 1990s and early 2000s). This came in three important papers that showed the direct evidence of (1) slow waves in footpoints of coronal loops (Berghmans and Clette, 1999) and (2) transverse kink waves in flaring active regions (Aschwanden et al., 1999; Schrijver et al., 1999). The big impact of these papers is in the fact they provided ample feedback on the earlier models for coronal waves. As a result, these discoveries have triggered an avalanche of observational papers on these types of waves, accompanied with detailed analytical and numerical models. Because direct imaging observations of waves suggested insufficient energy for coronal heating (a topic still under debate, see e.g., Terradas et al., 2018), research focus expanded toward their seismological potential (Nakariakov and Ofman, 2001). With coronal seismology, the aim is to use observed wave properties to obtain physical properties of the coronal structure with which the wave is associated, by the comparison with models.

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Scott William McIntosh,  
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Research (UCAR), United States

### \*Correspondence:

Tom Van Doorselaere  
tom.vandoorselaere@kuleuven.be

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The second key discovery was the realization that MHD waves are truly omnipresent in the solar atmosphere. This was shown explicitly for the first time with the CoMP instrument (Tomczyk et al., 2007), which only narrowly preceded the Hinode observations (De Pontieu et al., 2007). More recently, a comprehensive analysis of EUV movies of the corona demonstrated the omni-presence of decayless kink oscillations of coronal loops, interpreted as natural standing oscillations continuously sustained by some still debated mechanism (Anfinogentov et al., 2015). These papers have transformed the field, because the observed wave events went from rare observations to space-filling in the corona. Furthermore, the current instrumentation allows to spatially, temporally and spectrally resolve individual aspects of waves. As a result, many researchers are once again considering heating aspects of MHD waves in the solar corona, eschewing somewhat the seismology aspect. Still, it has not been conclusively shown if and how these waves contribute to coronal heating (Arregui, 2015; Hinode Review Team et al., 2019, chapter 6.1).

It must be noted that wave based coronal heating theories are aplenty, and that many of those are theoretically able to produce and maintain a corona (for a review see e.g., Priest, 2014). However, the real challenge lies in identifying key observable predictions from these theories that would allow to discriminate them against observations. This challenge implies, on one hand, conducting advanced numerical simulations of the various wave physical processes—a task that requires enormous amount of computing power due to both, the local and global aspects of wave propagation and dissipation in the heterogeneous solar atmosphere. On the other hand, the challenge requires the synthesis of observable quantities (imaging and spectropolarimetry) from the numerical results, targeting specific instruments and observation conditions—a task known as forward modeling, only possible through the continuous development of atomic databases such as CHIANTI (Dere et al., 1997), and forward modeling codes such as FoMo (Van Doorslaere et al., 2016).

The historical perspective shows clear trends in the field of MHD waves in the solar atmosphere, in parallel with the development of instrumentation, data analysis techniques, computing power and numerical modeling codes: first there was a strong focus on wave heating, later a strong emphasis on seismology, and now both heating and seismological aspects

and their combination are on the cutting edge of the ongoing research efforts.

The main motivation in organizing this special issue in *Frontiers of Astronomy & Space Sciences* is the 20th anniversary of the discovery of waves in the solar corona. Celebrating the first aforementioned key discovery, our aim for this issue was to give an overview of the current efforts in the field, through the display of currently ongoing Research Topics. This issue shows that there is a healthy balance between observational and modeling papers in the field of MHD waves in the solar atmosphere, following the larger trend in solar physics. Moreover, the two main directions in the field are reflected very well in this content collection: using the observed MHD waves for coronal seismology and coronal heating. This shows perhaps that a new balance has been found within the community between these two important research directions.

In the current special issue, we see also an accent on the basic understanding of wave phenomena in MHD and beyond. This shows two aspects: (1) Wave behavior in MHD is not completely understood yet at a theoretical level, and (2) a significant effort is now being done to understand what is happening beyond MHD (e.g., two fluids). This opens up potential for even more applications in the solar atmosphere, and indicates that there is a lot of room to expand, perhaps by focusing on the smaller scales that are not accessible by MHD waves.

## AUTHOR CONTRIBUTIONS

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**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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