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Quasi-biennial oscillations in the cross-correlation of properties of macrospicules

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Abstract

Jets, whatever small (e.g. spicules) or large (e.g. macrospicules) their size, may play a key role in momentum and energy transport from photosphere to chromosphere and at least to the low corona. Here, we investigate the properties of abundant, large-scale dynamic jets observable in the solar atmosphere: the macrospicules (MS). These jets are observationally more distinct phenomena than their little, and perhaps more ubiquitous, cousins, the spicules. Investigation of long-term variation of the properties of macrospicules may help to a better understanding of their underlying physics of generation and role in coronal heating. Taking advantage of the high temporal and spatial resolution of the Solar Dynamics Observatory, a new dataset, with several hundreds of macrospicules, was constructed encompassing a period of observations over six years. Here, we analyse the measured properties and relations between these properties of macrospicules as function of time during the observed time interval. We found that cross-correlations of several of these macrospicule properties display a strong oscillatory pattern. Next, wavelet analysis is used to provide more detailed information about the temporal behaviour of the various properties of MS. For coronal hole macrospicules, a significant peak is found at around 2-year period. This peak also exists partially or is shifted to longer period, in the case of quiet Sun macrospicules. These observed findings may be rooted in the underlying mechanism generating the solar magnetic field, i.e. the global solar dynamo.

Keywords: Sun: chromosphere; Sun: macrospicules; Sun: solar cycle; Sun: oscillations

1. Introduction

Since their first detection (Bohlin et al., 1975), evolution and generation of macrospicules (MS) have been investigated in several ways. These jets appear and disappear at around 20–40 min timescales and their length and width could be multiple times that of the spicules. The notion of spicules and macrospicules may refer to a possible relation between the two phenomena, however, their behaviour, generation and evolution seem all to be rather different.

Majority of MS studies are based on imaging observations. The early works focus on determining the physical dimensions of the observed jets in intensity maps. The first 25 MS were identified by the spectroheliograph onboard *Skylab* (Bohlin et al., 1975). These results were followed up quickly by the analysis of another two macrospicules and their energy was estimated, by the application of a

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cylindrical assumption of their geometry to be: 3×10^{26} ergs (Withbroe et al., 1976).

Statistical analysis of 32 MS was carried out by Labonte (1979). They found MS jets using various wavelengths such as Hα and D_3 at Big Bear Observatory. Dere et al. (1989) also investigated 10 MS of *Skylab-2* observations at EUV wavelenghts.

In these early works, macrospicules could be divided into two subclasses based on the wavelength of the observation: the EUV macrospicules and Hα macrospicules. Shibata (1982) filled in the gap between the two classes: the author claimed that the main difference between the two classes of jets is the intensity ratio between the macrospicule and the surrounding corona environment.

Improvement of observation technology led to a more complex analysis of these jets. Other physical properties, e.g. temperature and density, became measurable, therefore plenty of new features of MS were found: (i) it has been shown that MS jets are multi-thermal phenomena, which have the potential to be the source of the fast solar wind (Pike and Harrison, 1997); (ii) emission of the two opposite sides along the main axis of the jets are blue and redshifted, therefore MS may be rotating objects ("solar tornadoes") (Pike and Mason, 1998); (iii) the density of MS is around 10^{10} cm^{-3} and their temperature is about $2\text{–}3 \times 10^5$ K (Parenti et al., 2002), and (iv) the energy needed for MS formation could be between 3.66×10^{13} J and 1.46×10^{17} J (Bennett and Erdélyi, 2015).

Numerical simulations of MS were developed side by side with the observations. The first numerical simulation of macrospicules was carried out by Murawski et al. (2011). The authors claimed that chromospheric velocity pulses may have the ability to generate macrospicules.

Furthermore, Loboda and Bogachev (2017) compared observations taken by the TESIS solar telescope and from simulation results of an axially symmetric one-dimensional hydrodynamic method. They found that macrospicules loose ≈12% of their original mass during their lifetime.

Recently, some works claimed to find a possible connection between the properties of MS and the behaviour of the global solar dynamo. For example Gyenge et al. (2015) investigated the spatial distibrution of 101 MS between June 2010 and December 2012. Their longitudinal and latitudinal distribution showed a qualitatively similar pattern, what could be also observed in the case of spatial distribution of the sunspot groups.

Long-term investigation of MS was carried out by Kiss et al. (2017). In their work, basic physical properties of MS (such as length, width, area, lifetime, upflowing velocity) were studied over a 5-year period of observation. A strong oscillatory pattern was discovered with around a two-year period. Particular study of this wave signature was really difficult due to the short time interval of MS selection. The length of operation time of *Solar Dynamics Observatory (SDO)* (Pesnell et al., 2012) and its *Atmospheric Imaging Assembly (AIA)* (Lemen et al., 2012) limited the opportunities to observe jets continuously for a longer period of time, therefore MS are searched for between 01.06.2010 and 31.12.2015. Five years of observation was just not sufficiently long enough for signal processing methods to provide high-enough confidence information about the oscillation.

Therefore the aim of this paper is to extend the database, investigate these oscillation signatures and provide more confidently detailed information about them.

2. Database and methodology

Long-term investigation of MS properties requires a temporally homogeneous database. To achieve this goal, the data provider instrument should meet several requirements such as operation time for multiple years and adequate temporal resolution for resolving MS evolution. SDO was launched in 2010 and its AIA instrument carries out a full-disc image of the Sun at nine different wavelengths. For the database, the 30.4 nm, optically thin, EUV line was used, where MS are clearly visible. Temporal resolution of *SDO/AIA* in 30.4 nm is 12 s, therefore the second criteria listed above is fulfilled. During the research, we used Python and its solar data analysis package, the Sunpy (Mumford et al., 2015).

Detailed information about the criteria of how to define MS and the so-called tetragon assumption are all described in Kiss et al. (2017), we would not repeat them here. However, let us briefly recall the key steps for completeness. We searched MS in a 2-h long observating window on a given day. As the log-normal distribution fitting of several MS property shows in Kiss et al. (2017), the characteristic lifetime of MS is significantly shorter (≈15–16 min) than the temporal length of the observing window. Therefore the entire evolution of these jets can be observed comfortably during these 2 h. For this reason, *SDO/AIA* 30.4 nm observations between 12:00–14:00 on each 1st, 7th, 15th and 24th day of each month since June 2010 (launch of *SDO*) until the end of 2016 are the basis of the data analysis. An advantage of this choice of data selection is that the sampling is homogeneous. This is a required criteria for the application of wavelet analysis.

The application of set of definitions yields the discovery of 342 MS. The data were collected on 312 observing dates, therefore an average of ≈1.1 MS are visible during a two-hour interval at the solar limb in 30.4 nm. Furthermore, the tetragon model assumption provides a rather accurate description of the physical properties (such as area, length, width) of a jet for each *SDO/AIA* observation during MS lifetime. This set of macrospicules is a representative sample.

The maximum values of these properties (maximum length, maximum width, maximum area) in addition with average velocity and lifetime are cross-correlated with each other. Considering the temporal evolution of these distributions, strong oscillatory patterns become visible. This

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