Numerical simulations of large-amplitude oscillations in flux rope solar prominences

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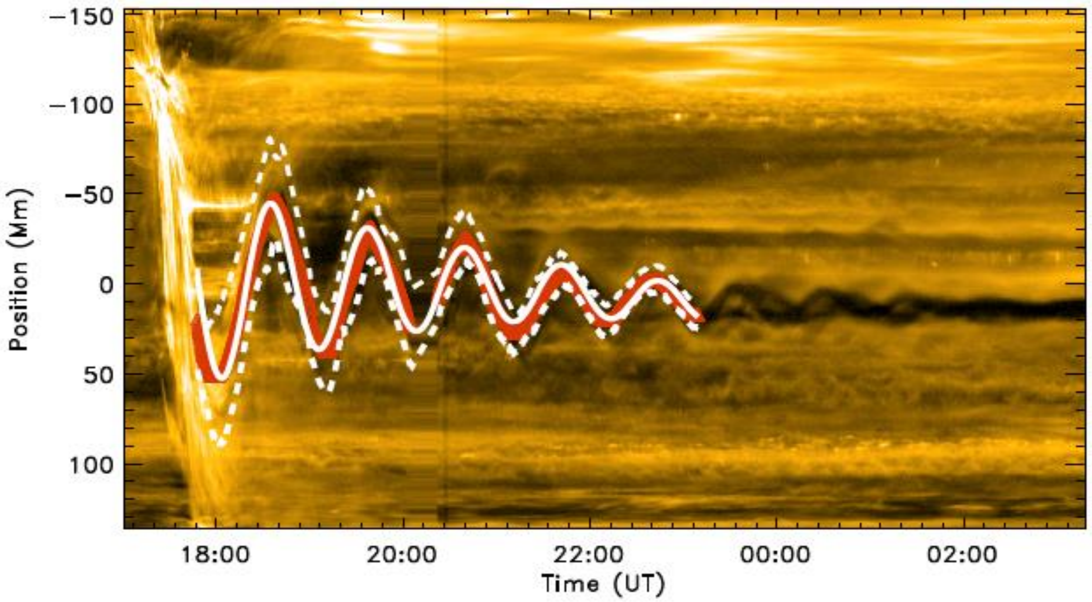
This study is based on the 2.5D numerical simulations of the large-amplitude oscillations (LAOs) in the flux rope solar prominences. The prominence models with two different values of the initial shear angle and the density contrast were considered. In order to investigate the possible normal modes of the structure, the prominence was perturbed with the horizontal and vertical disturbances. To study the mechanism of the external LAOs triggering, we used the disturbance placed out of the flux rope. The transverse and longitudinal oscillation periods do not show a strong dependence on the shear angle and the density contrast. The external perturbation excites the oscillations of both polarizations, and their properties are a mixture of those excited by purely horizontal and vertical driving.

Context of the research

Time-distance diagram in 171 Å.
Luna et al. 2017

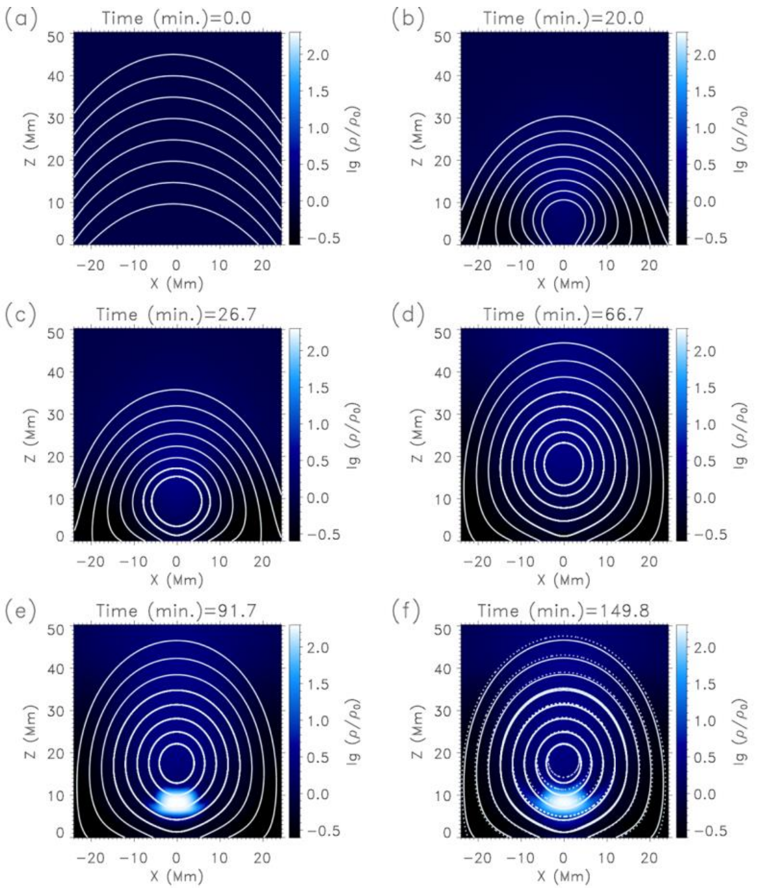


- Large-amplitude oscillations (LAOs) are prominence motions with velocity amplitudes larger than 20 km s^{-1} (see review Arregui et al. 2018).
- There are observed the longitudinal and transverse LAOs with respect to the magnetic field (see reviews Tripathi et al. 2009; Arregui et al. 2018).
- Many observations suggest that LAOs can be triggered by external perturbation (see, e.g., Gilbert et al. 2008; Shen et al. 2014b).
- Theoretical studies show that the main restoring force is gravity projected along the magnetic field, and the period depends on the radius of curvature of the dipped magnetic field lines. (Luna & Karpen 2012; Luna et al. 2016; Zhou et al. 2018).
- The restoring force of the transverse oscillations has a magnetic origin. Corresponding period shows dependence on the structure's parameters, such as prominence width or density (Terradas et al. 2013; Adrover-González & Terradas 2020).

In this work, we aim to understand how the properties of the LAOs depend on different parameters of the structure (i.e., density contrast and shear angle), and to study the mechanism of the external triggering of the LAOs.

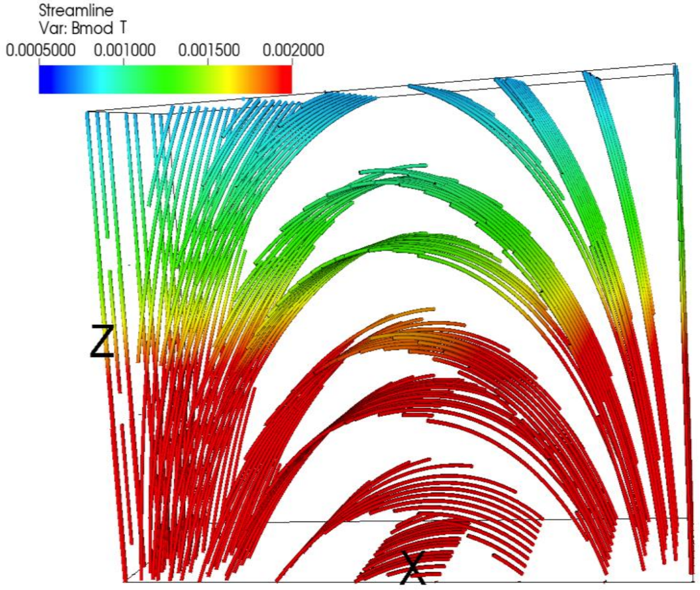
Numerical model

Process of prominence formation



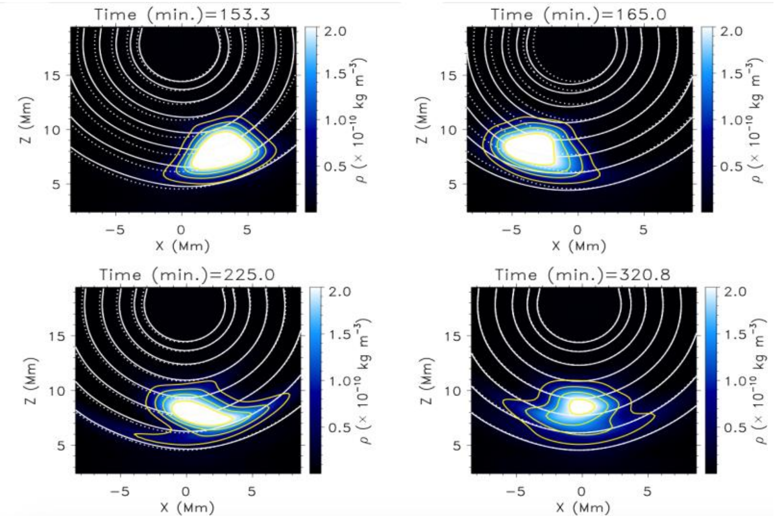
- We solve the ideal MHD equations using the Mancha 3.0 code (Khomenko et al. 2008).
- The initial atmosphere is gravitationally stratified corona.
- The initial magnetic field is the sheared arcade.
- We used the converging motions at the bottom to produce reconnection and initiate flux rope formation.
- Prominence mass was artificially loaded to the dipped part of the formed flux rope.
- After the relaxation process, the prominence was perturbed in the vertical and horizontal directions.
- In order to study the mechanism of the external triggering of the LAOs, we performed an experiment using the disturbance placed out of the flux rope.

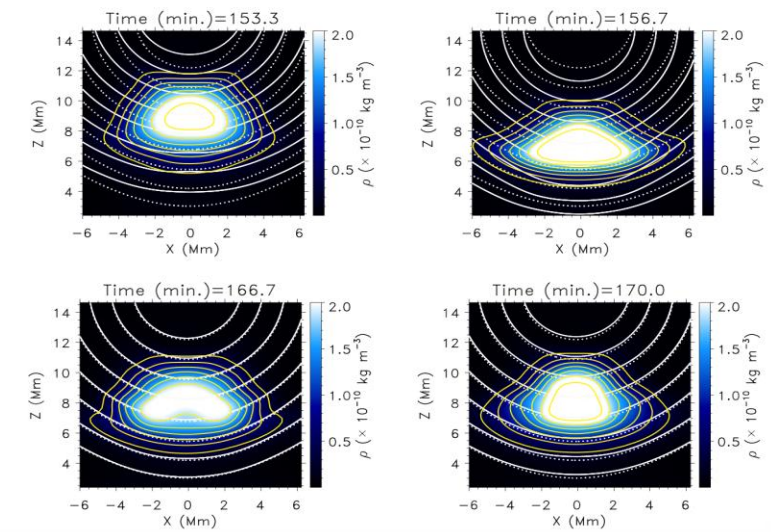
Sheared arcade in 3D perspective. In this work, we considered two values of the shear angle, θ=45°, 60°.



Results. Internal perturbations

Temporal evolution after the horizontal and vertical perturbation





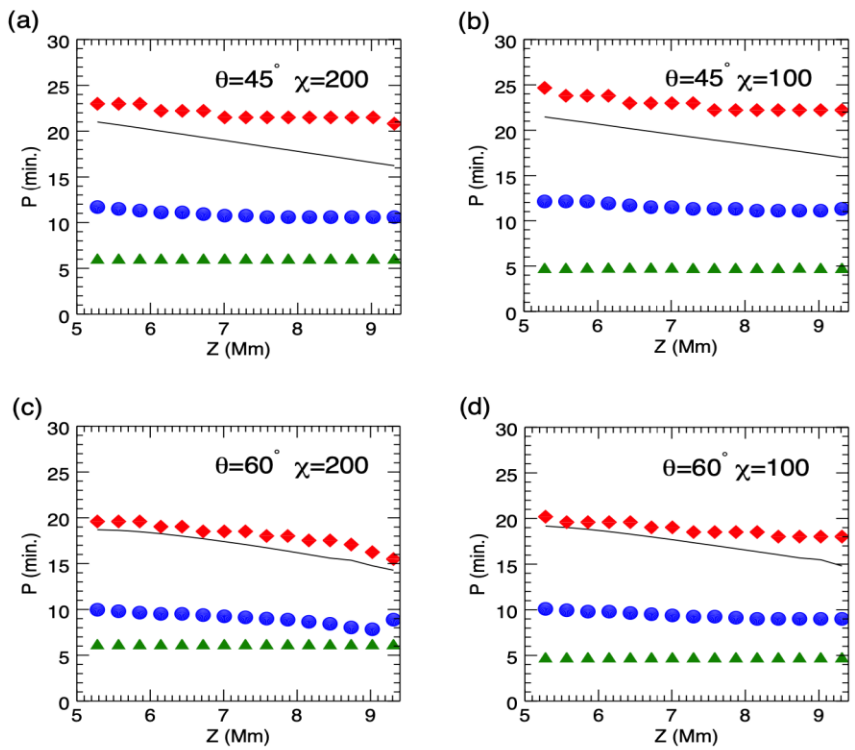
- The period of the longitudinal oscillations (red diamonds) decreases with height and shows a good agreement with the pendulum model (solid line).
- The period of the vertical oscillations (green triangles) does not change with height.
- A comparison between the different models does not show substantial variations of the corresponding periods.

Pendulum period

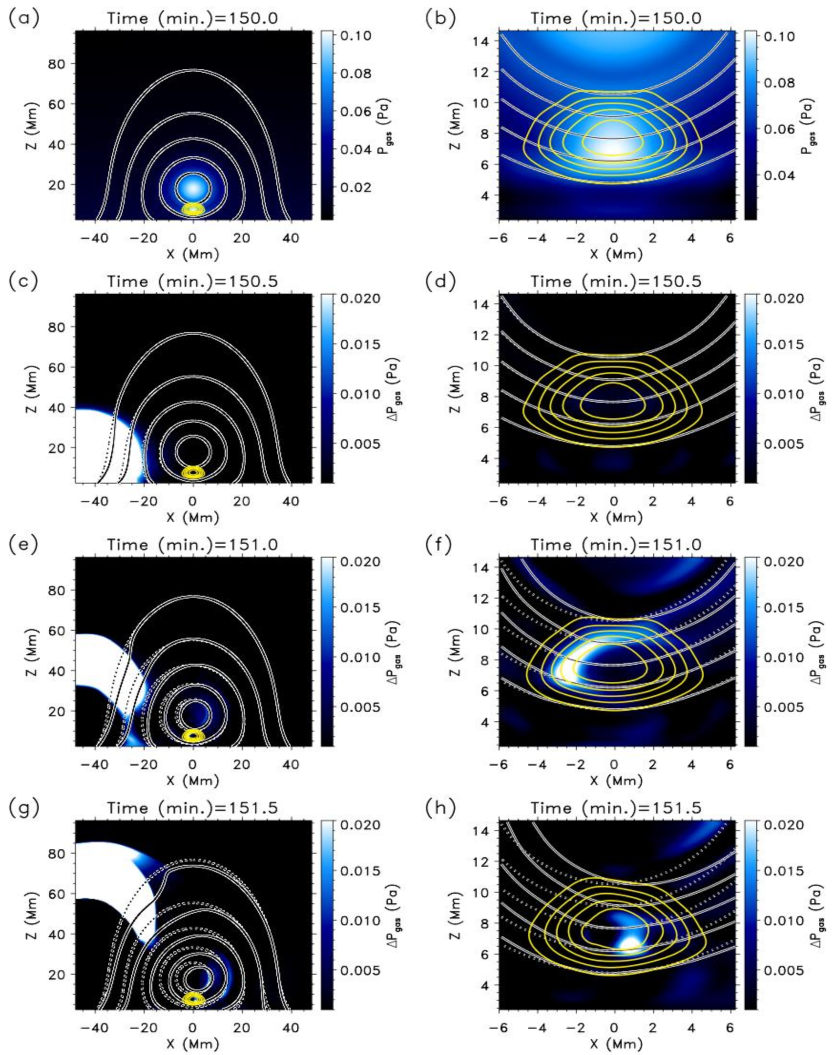
$$P = 2\pi\sqrt{\frac{R}{g}}$$

Periods of the longitudinal and vertical oscillations as a function of height of the magnetic dips.

θ - shear angle, χ - density contrast

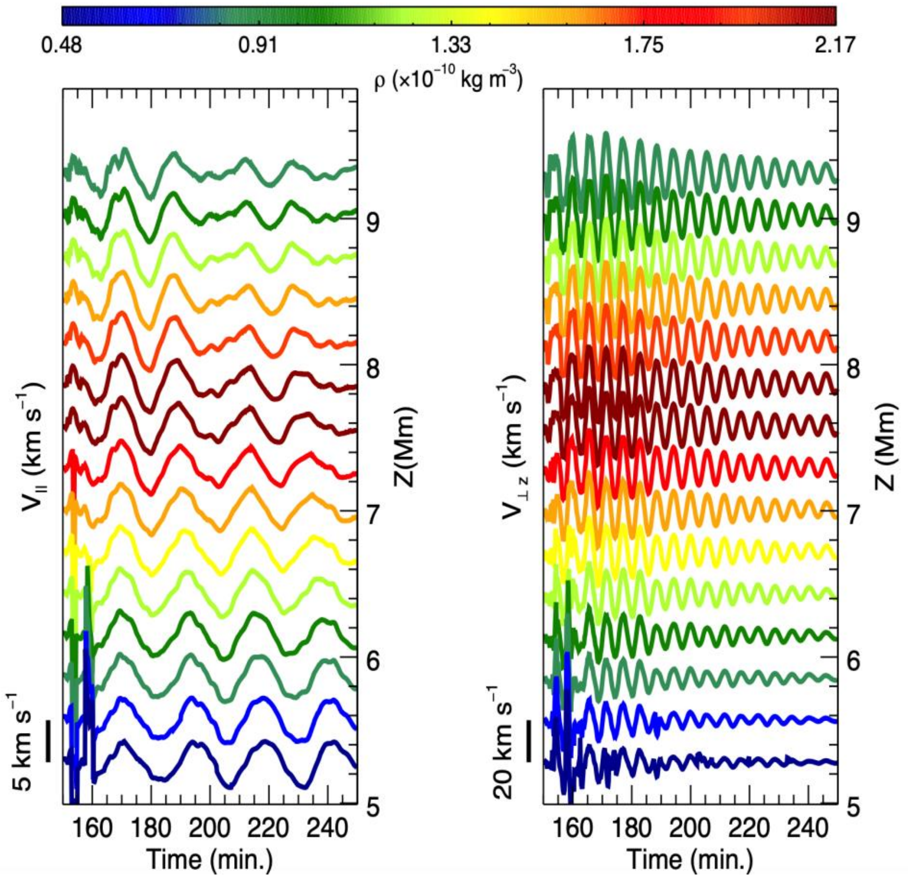


Results. External perturbation



- The external perturbation displaces the flux rope, and, as a consequence, the prominence is also displaced from the equilibrium position.
- The analysis of motions showed the evidence of the excitation of oscillations of both polarizations.
- The vertical motions are coherent in the different prominence layers.
- The longitudinal oscillation period slightly decreases with height that resembles the behavior of the period in the case of purely horizontal driving.

The oscillations in the different magnetic field lines produced by the external perturbation



Conclusions and prospects for the future

- The periods of the longitudinal and vertical oscillations show a weak dependence on the prominence structure parameters, such as the shear angle and the density contrast.
- The period of the longitudinal oscillations decreases with height, showing a good agreement with the pendulum period.
- The period of the vertical oscillations remains constant with height, suggesting a global normal mode.
- The external perturbation displaces the flux rope and excites the longitudinal and vertical prominence oscillations.

Complete study can be read in Liakh et. al 2020 (A&A): **https://doi.org/10.1051/0004-6361/201937083**

Future perspective

- We expect that the 3D prominence model will allow us to investigate further the mechanism of the external triggering of different types of the LAOs.
- It is also desirable to use more realistic external disturbances, such as energy release due to the magnetic reconnection or an eruption of the neighboring prominence.