Large-Amplitude Oscillations in Prominences

M. Luna[1,2]

[1] Instituto de Astrofísica de Canarias, Canary Islands, Spain
[2] Universidad de La Laguna, Canary Islands, Spain

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Introduction: Large-Amplitude Oscillations (LAOs)

What are Large-Amplitude Oscillations in Prominence?

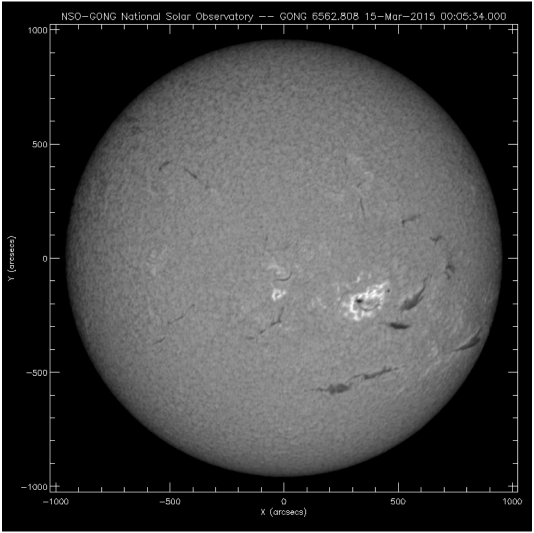
- Large-Amplitude Oscillations (LAOs) in prominences are periodic movements with velocities larger than $> 20\ km\, s^{-1}$ (Oliver & Ballester, 2002, see also reviews by Tripathi et al. 2009 and Arregui et al. 2012).
- LAOs are, in principle, non-linear oscillations.
- A large portion of the prominence/filament moves in phase.
- Two polarizations are possible: longitudinal and transverse motions with respect to the filament spine (magnetic field).
- The triggers are solar energetic events: distant or closer flares, jets, eruptions, or internal destabilization processes in the filament.

Large-amplitude oscillations in the literature

- Historically, prominences undergoing these movements were called “winking filaments”. These were described early in the 20th century by Dyson (1930) but systematically studied by Ramsey and Smith (1966). The next publication is Eto et al. (2002).
- While the literature about small-amplitude oscillations is extensive (Arregui et al., 2012) the LAOs are less widely reported and their nature is poorly understood.

Relevance of LAOs: large-amplitude prominence seismology

LAOs are perfect to probe the hard-to-measure prominence plasma and magnetic field structure.


NSO–GONG National Solar Observatory –– GONG 6562.808 15–Mar–2015 00:05:34.000
1000
500
0
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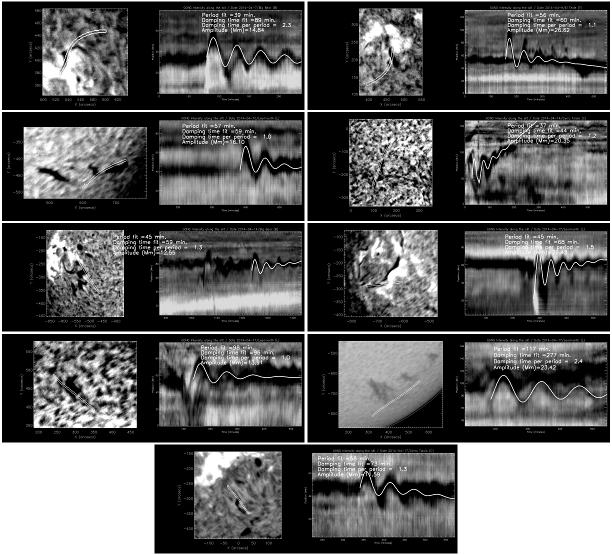
X (arcsecs)

Are large-amplitude oscillations common?

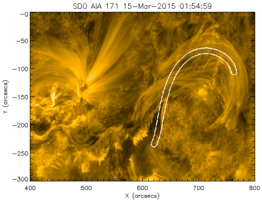


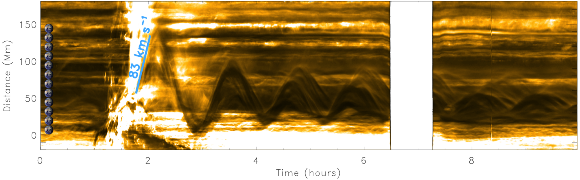
From GONG network.

Theoretical interpretation of Large-Amplitude Longitudinal Oscillations (LALOs)

Theoretical considerations on LALOs

- These kind of LAOs were first reported by Jing et al. (2003).
- The LALO motions are characterized by velocities larger than $20km/s$ (up to $100km/s$) with displacements of up to 140 Mm.
- The displacements are almost parallel to filament spine $\sim$ filament magnetic field according to current models (longitudinal).
- The LALOs have periods of $\sim$1 hour and damps in few periods ($1-4$ periods) indicating strong damping.
- The accelerations involved are large $\sim 100m/s^2$ similar to the solar surface gravity ($g = 274m/s^2$).
- Apparently the trigger is an energetic event close to the filament.

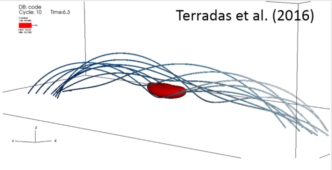




- Possible restoring forces: magnetic origin, gas pressure gradients, or gravity.
- In Luna & Karpen (2012) we modeled LALOs with relation to the geometry of the magnetic structure and the process responsible of the origin of prominence mass:

The restoring force

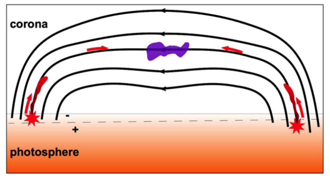
The magnetic structure (skeleton) has dips capable of cool plasma support.



We identified and modelled longitudinal LALOs as the motion of the prominence threads along the dipped magnetic field lines that support the cool mass.

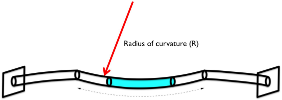
The damping mechanism

Evaporation-condensation model: the coronal heating evaporates the chromospheric plasma that flows along the field lines and condenses (thermal instability) in the corona (Antiochos & Klimchuk, 1991).



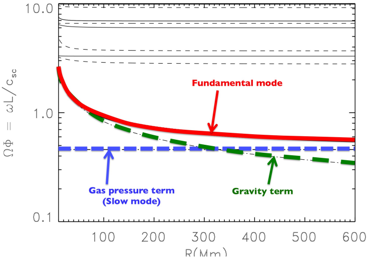
We found that mass accretion by the prominence threads can explain the LALOs strong damping.

- Hyder (1966), Kleczek & Kuperus (1969) modelled LAOs based on the magnetic field as the restoring force. Probably working for transverse case.
- Later, Jing et al. (2003, 2006) and Vršnak et al. (2007) considered their LALO observations in terms of these models.
- In Luna & Karpen (2012) we identified that the restoring force is mainly the projected gravity along the dipped field lines with a small contribution of the gas pressure differences.



- In Luna, Díaz, & Karpen (2012) we found the normal modes,

$$-\frac{\omega}{c_{\mathrm{sc}}}\,\mathrm{cotg}\left[\frac{\omega}{c_{\mathrm{sc}}}(L-l)\right] = -\frac{l g_0}{c_{\mathrm{sp}}^2 R}\left(\frac{\omega^2 R}{g_0}-1\right)$$
$$\times\frac{M\left(1+\frac{1}{2\gamma}-\frac{\omega^2 R}{2\gamma g_0},\,\frac{3}{2};\,\frac{\gamma g_0 l^2}{2Rc_{\mathrm{sp}}^2}\right)}{M\left(\frac{1}{2\gamma}-\frac{\omega^2 R}{2\gamma g_0},\,\frac{1}{2};\,\frac{\gamma g_0 l^2}{2Rc_{\mathrm{sp}}^2}\right)}\,.$$

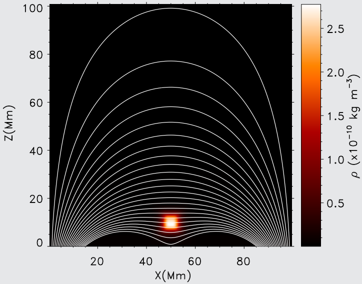


- The frequency of the fundamental mode can be approximated as

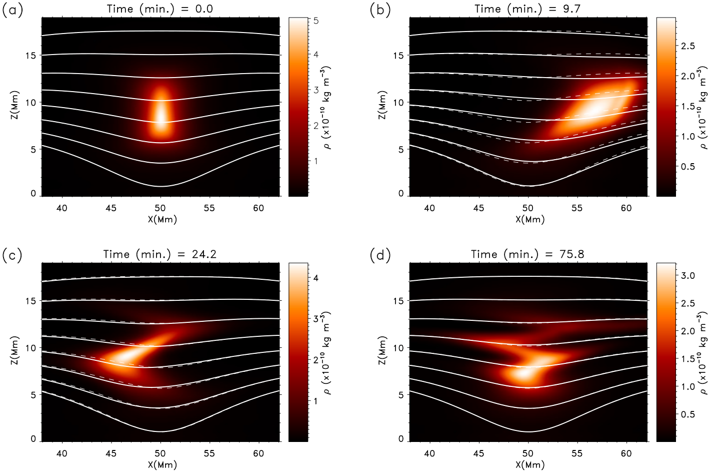
$$\omega_{fund}^2 = \frac{g_0}{R} + \frac{c_{sc}^2}{l(L-l)\chi}$$

- See also Zhang et al. (2012) and the nice parametric study by Zhang et al (2013).

- In previous works the oscillations are in 1D rigid field lines.
- The motion of the heavy plasma produces dynamical changes in the magnetic structure.
- The longitudinal and the transverse motion are probably coupled.



- In Luna, Terradas, Khomenko, Collados, De Vicente (2016) we have studied the LALOs in a 2D structure.
- We have performed numerical simulations with our code MANCHA.
- The magnetic structure has dips (Terradas et al. 2013).
- We have solved the time dependent problem with our code MANCHA.
- The Alfvén modes are not considered.


(a)
Time (min.) = 0.0
(b)
Time (min.) = 9.7
(c)
Time (min.) = 24.2
(d)
Time (min.) = 75.8
Z(Mm)
X(Mm)
ρ ($\times10^{-10}$ kg m^{-3})
0
5
10
15
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45
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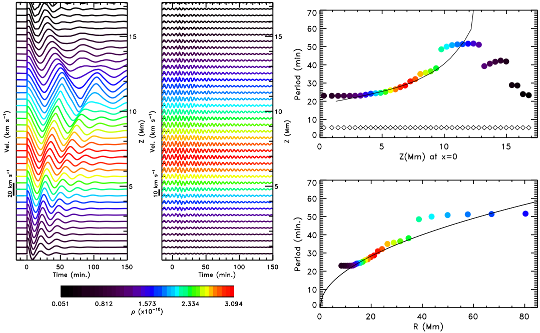
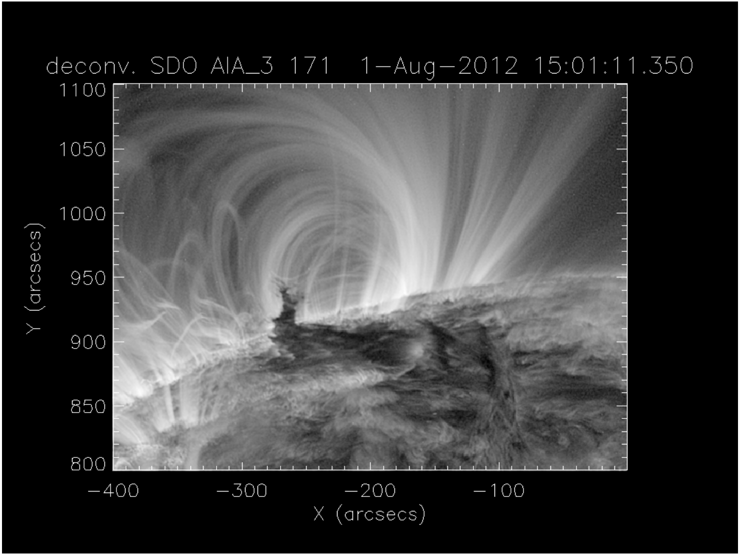


- The periods of longitudinal and transverse oscillations are very different.
- The longitudinal oscillation period depends on the z-position (zig-zag shape). In contrast the transverse oscillations are uniform in the structure.
- The longitudinal oscillations show a significant damping in contrast to the weak damping of the transverse motions.
- We speculate that numerical phase-mixing explain the significant longitudinal damping.
- The longitudinal oscillation periods fit very well the pendulum model of Luna & Karpen (2012).


deconv. SDO AIA_3 171 1-Aug-2012 15:01:11.350
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Y (arcsecs)
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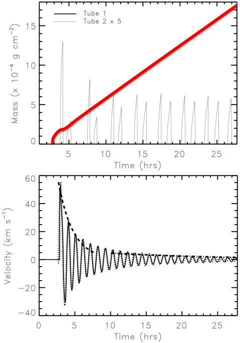
X (arcsecs)

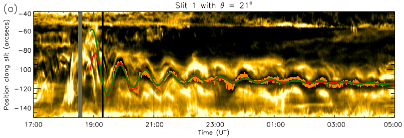
- Several mechanisms have been proposed but not tested.
- In Luna, Karpen & DeVore (2012) we studied the process of formation of prominences (movie).



- In Luna & Karpen (2012) can be explained by the accretion of mass by the prominence threads with a contribution of the non-adiabatic effects. Zhang et al. (2013) found that the radiation has a non-negligible contribution.
- We found that the motion of the thread is

  $$s(t) = s_0 + A\, J_0[\omega(t-t_0)+\psi_0]e^{-(t-t_0)/\tau_\mathrm{w}},$$

  where $\psi_0 = \omega\, m_0/\alpha$ being α the mass accretion rate.
- In Ruderman & Luna (2016) we analytically solved the governing non-linear equations.
- In Luna, Knizhnik, Muglach, Karpen, Gilbert, Kucera, & Uritsky (2014) we estimated the mass accretion rate from observations to a value of $\sim 10^7\, kg/hr$.



Conclusions

- LAOs are perfect tools to probe the hard-to-measure global structure of quiescent prominences.
- LAOs also give information of the trigger.

Future Work

- It is necessary to improve the theoretical modeling.
- It is necessary to increase the number of reported events.
- LAOs have been also observed in erupting prominences.