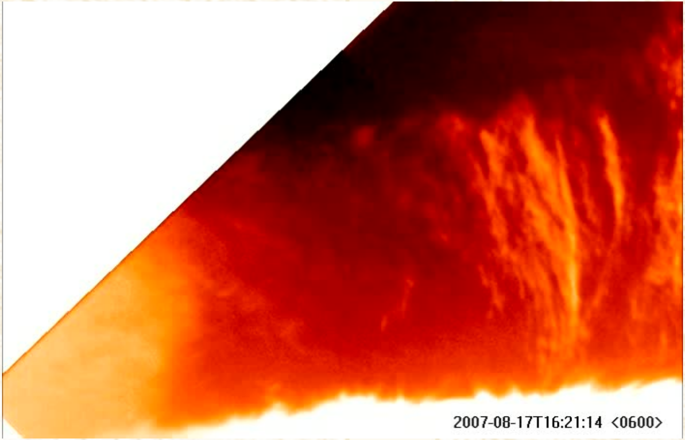
Dynamics of descending plasma knots in solar prominences

R. Oliver, R. Soler, J. Terradas,
T. Zaqarashvili, M. Khodachenko

Physics Department,
University of the Balearic Islands,
Spain

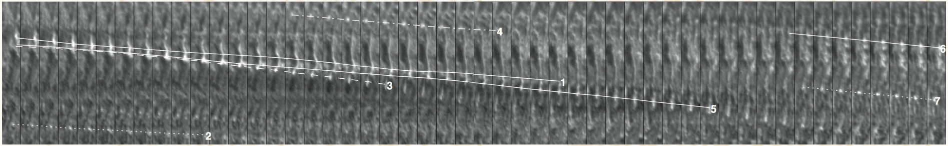
Falling prominence knots



Hinode SOT – Chae (2008)

Falling prominence knots

Time-height diagram (Chae 2010): stack of 50 Hα slices taken with 25 s cadence. Vertical size is 35,000 km. Several prominence knots descend vertically at a roughly constant speed.

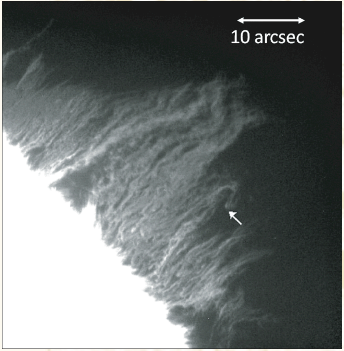


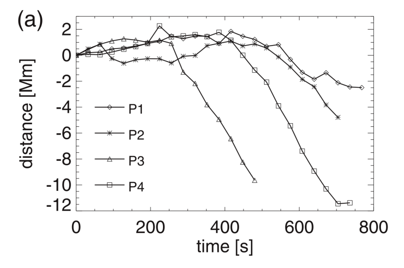
Features of falling prominence knots:

- Motions along vertical path.
- Knots have either roughly constant velocity (in the range 10–60 km s^{-1}) or small acceleration (100 m s^{-2}) compared to that of gravity.

Falling prominence knots

- Knots ejected from the top of a hedgerow prominence.
- Maximum vertical knot velocities: 6–30 km s^{-1}





Ca II H – Hinode SOT

Hillier et al. (2011)

Falling prominence knots

- How do they originate?
- Do prominence knots move across a presumed horizontal magnetic field?
- Why do they have small or even no acceleration?

Falling prominence knots

- How do they originate?
- Do prominence knots move across a presumed horizontal magnetic field?
- Why do they have small or even no acceleration?

Aim: to investigate the dynamics of dense knots falling in quiescent prominences.

Model: assumptions

We do not include...

- The knot formation process,
- non-ideal effects (conduction, cooling),
- magnetic field.

Model: assumptions

We do not include. . .

- The knot formation process,
- non-ideal effects (conduction, cooling),
- magnetic field.

Then, what do we include!?

- Hydrodynamic time evolution of a formed blob in the coronal environment,
- adiabatic changes of state,
- motions in the vertical direction.

Model: equations

- Three unknowns ρ, p, v.
- z-axis is vertical.
- The unknowns only depend on t and z.

- Mass continuity:

$$\frac{\partial \rho}{\partial t} = -v\frac{\partial \rho}{\partial z} - \rho\frac{\partial v}{\partial z}$$

- z-component of the momentum equation:

$$\rho\frac{\partial v}{\partial t} = -\rho v\frac{\partial v}{\partial z} - \frac{\partial p}{\partial z} - g\rho$$

- Energy equation:

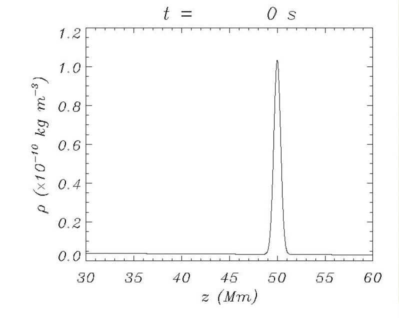
$$\frac{\partial p}{\partial t} = -v\frac{\partial p}{\partial z} - \gamma p\frac{\partial v}{\partial z}$$

Model: initial state

- In the initial state the vertical speed is zero: $v(z, t = 0) = 0$.
- The background pressure and density are vertically stratified (uniform initial temperature, T_0):

$$p(z, t = 0) = p_0 e^{-z/H}, \quad \rho(z, t = 0) = \rho_0 e^{-z/H}, \quad H = \frac{2RT_0}{g}$$

- A concentrated density enhancement is added:

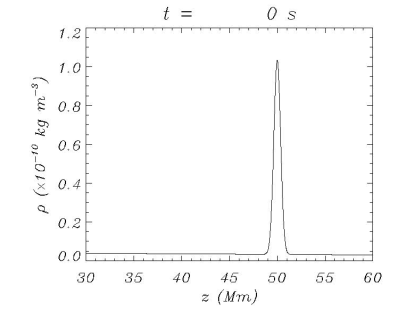


Model: initial state

- In the initial state the vertical speed is zero: $v(z, t = 0) = 0$.
- The background pressure and density are vertically stratified (uniform initial temperature, T_0):

$$p(z, t = 0) = p_0 e^{-z/H}, \qquad \rho(z, t = 0) = \rho_0 e^{-z/H}, \qquad H = \frac{2RT_0}{g}$$

- A concentrated density enhancement is added:

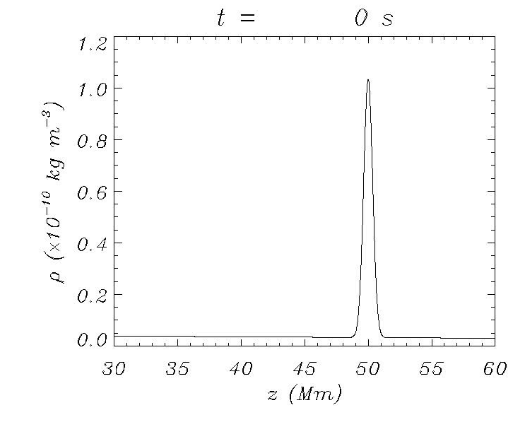


Parameter values:
$H = 120$ Mm
$\rho_0 = 5 \times 10^{-12}$ kg m^{-3}
$z_0 = 50$ Mm
$\rho_{b0} = 10^{-10}$ kg m^{-3}

Simulation time: 1000 s

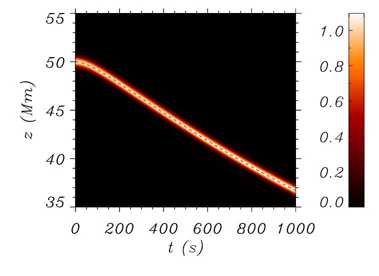
Density

- The condensation keeps its density and shape as it falls.
- If the knot were to fall with the acceleration of gravity, it would reach $z = 0$ at $t \simeq 540$ s.



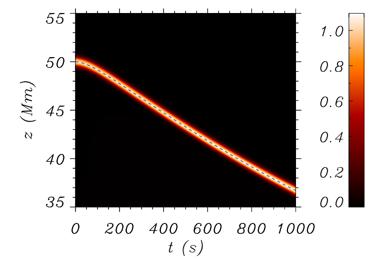
Height and velocity

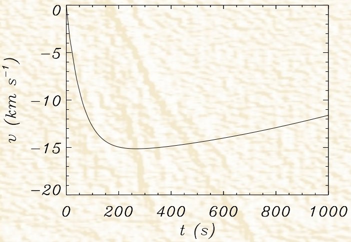
- Height–time diagram of density (colour scale in units of 10^{-10} kg m^{-3}).



Height and velocity

- Height–time diagram of density (colour scale in units of 10^{-10} kg m^{-3}).

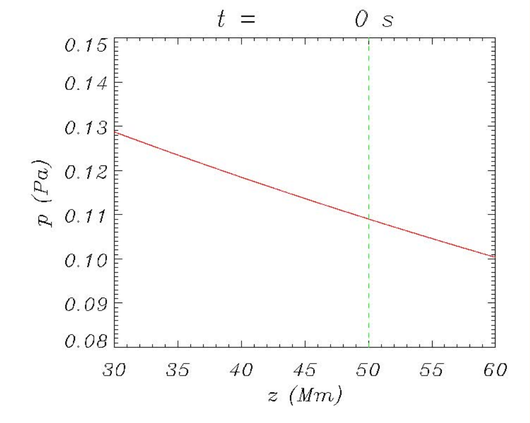




- Initial acceleration phase lasts $\simeq$ 200 s.
- Knot then attains a roughly constant speed $\simeq$ 15 km s^{-1}.

Pressure

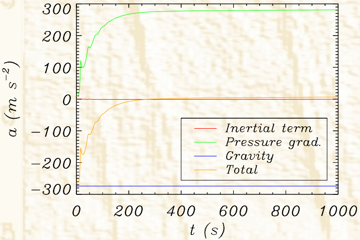
- Sound wave generated at the initial knot position (sound speed $\simeq 235$ km s^{-1}).
- A strong pressure gradient is generated at the knot position.
- Established pressure gradient travels with the knot (its position is given by the green line).

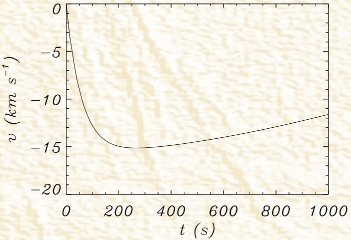


- Pressure structure under and above the knot is rearranged.

Acceleration

$$\rho \frac{\partial v}{\partial t} = -\rho v \frac{\partial v}{\partial z} - \frac{\partial p}{\partial z} - g\rho \quad \Rightarrow \quad \frac{\partial v}{\partial t} = -v\frac{\partial v}{\partial z} - \frac{1}{\rho}\frac{\partial p}{\partial z} - g$$

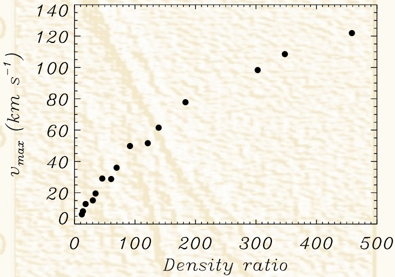




- Inertial term is negligible.
- Pressure gradient builds up and counteracts gravity at $t \simeq 200$ s.

Maximum descending speed

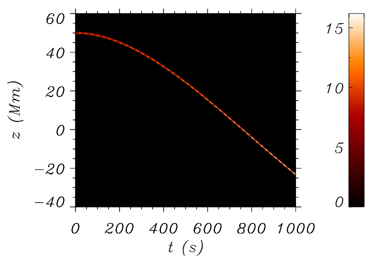
- Similar dynamics are obtained for other parameter values.
- The local coronal density depends on the initial knot height, the coronal density at $z = 0$ and the coronal scale height ($H \propto T_0$).
- The density ratio (initial knot density to local coronal density) determines the maximum falling speed.

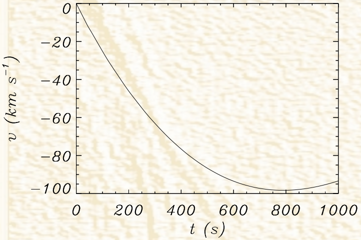


- Observed knot velocities require knot to corona density ratios between 10 and 120.

Larger knot density: height and velocity

- Knot density is 10 times larger.

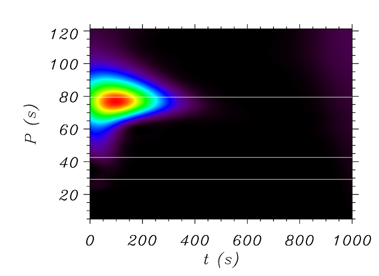


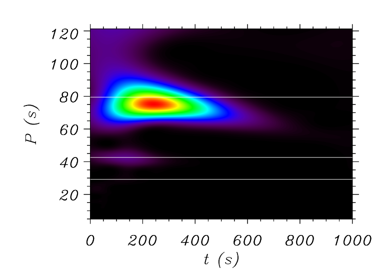


- Initial acceleration phase lasts much longer ($\simeq$ 800 s compared to $\simeq$ 200 s).
- Maximum falling velocity is much higher ($\simeq$ 100 km s^{-1} compared to $\simeq$ 15 km s^{-1})

Larger knot density: sound wave emission

- Knot density and velocity display damped oscillations.
- These oscillations are revealed after fitting and subtracting a third degree polynomial + wavelet analysis.
- Horizontal lines: theoretical periods of leaky sound waves.





Conclusions

Summary of results

- Acceleration phase followed by more or less constant speed.
- Presence of mass condensation leads to a pressure gradient that opposes gravity.
- Maximum falling speed increases with density ratio.
  There is a very good correlation between the two quantities.
- Damped oscillations because of sound wave emission.
  Detectable as periodic changes of the knot density and velocity.