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Decayless kink oscillations as self-oscillations

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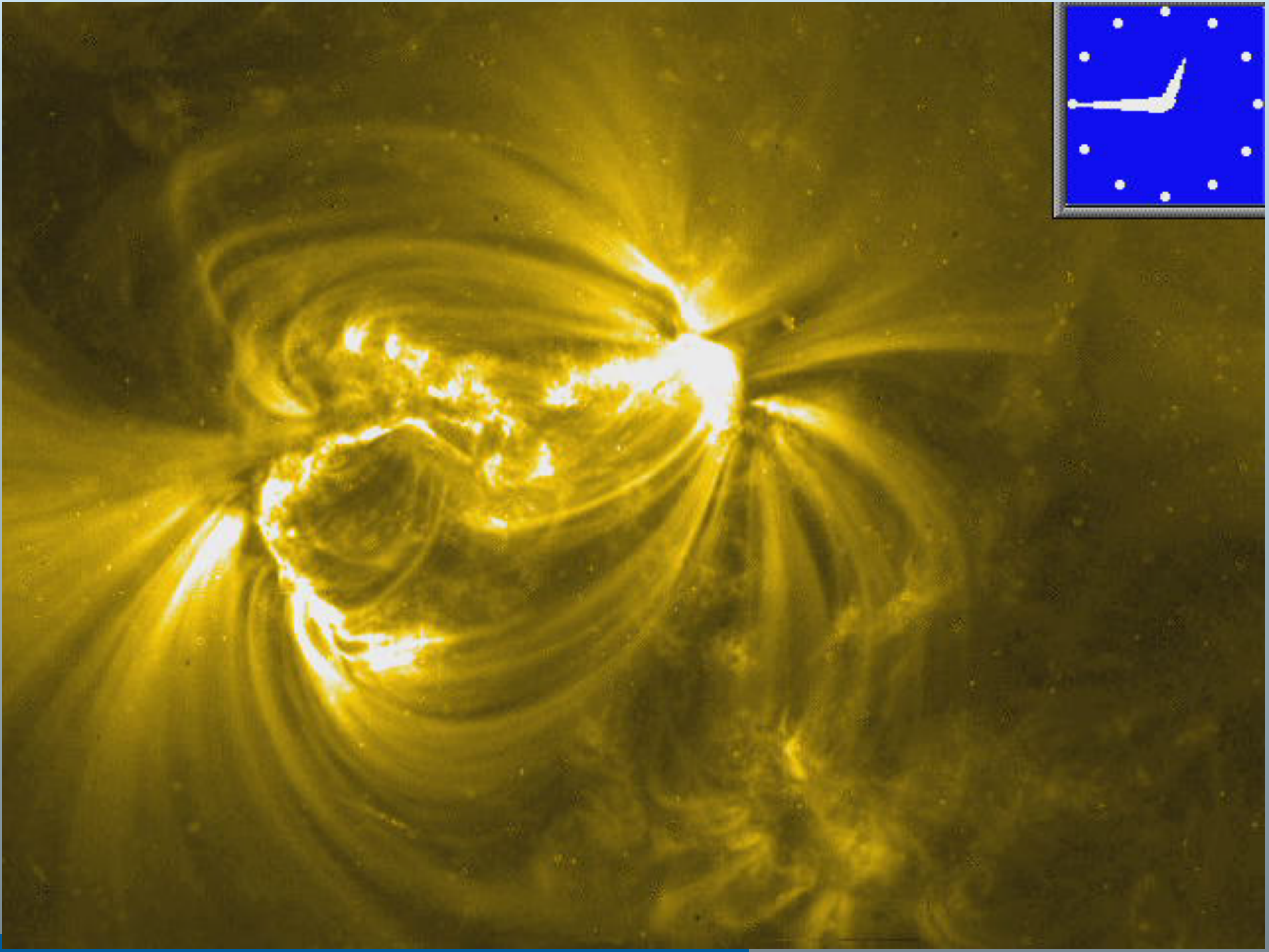
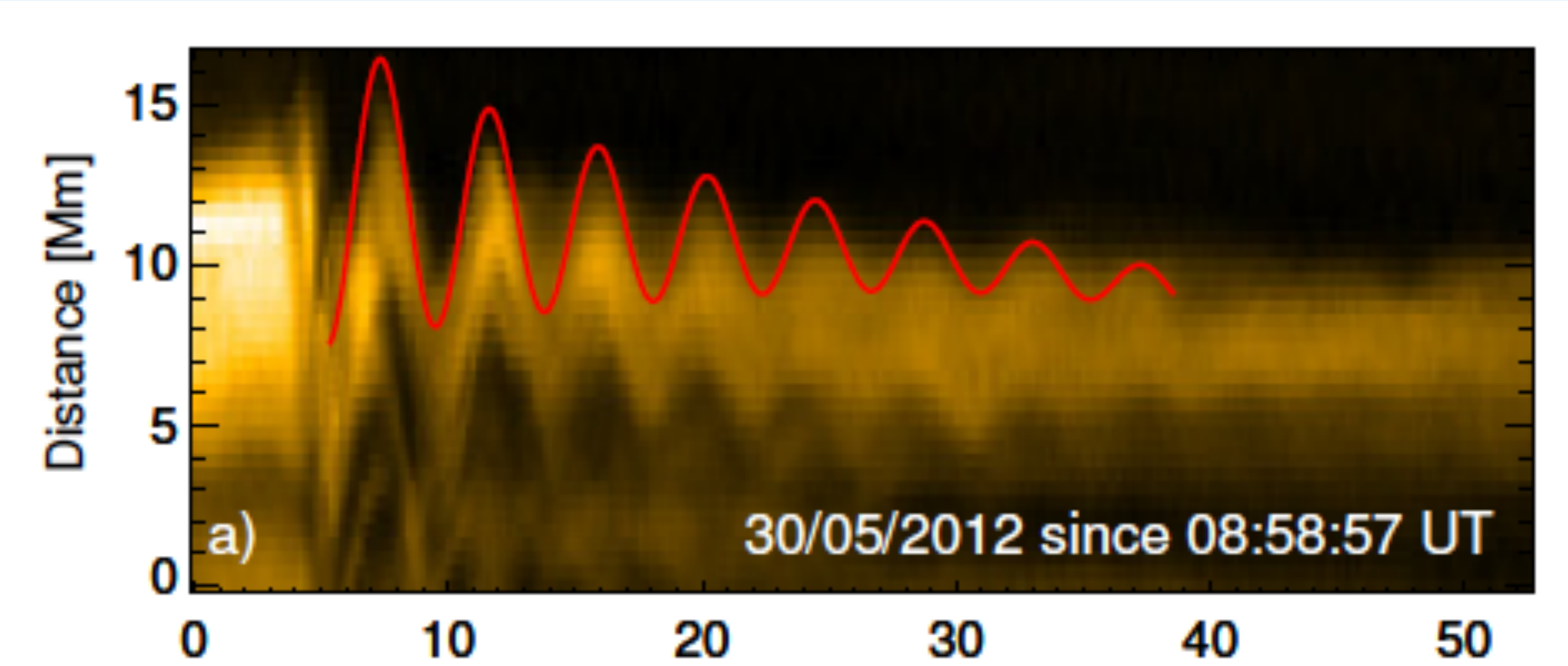
Anfinogentov, S., Nisticò, G., and Lee, D.-H.

Kink modes of coronal loops:



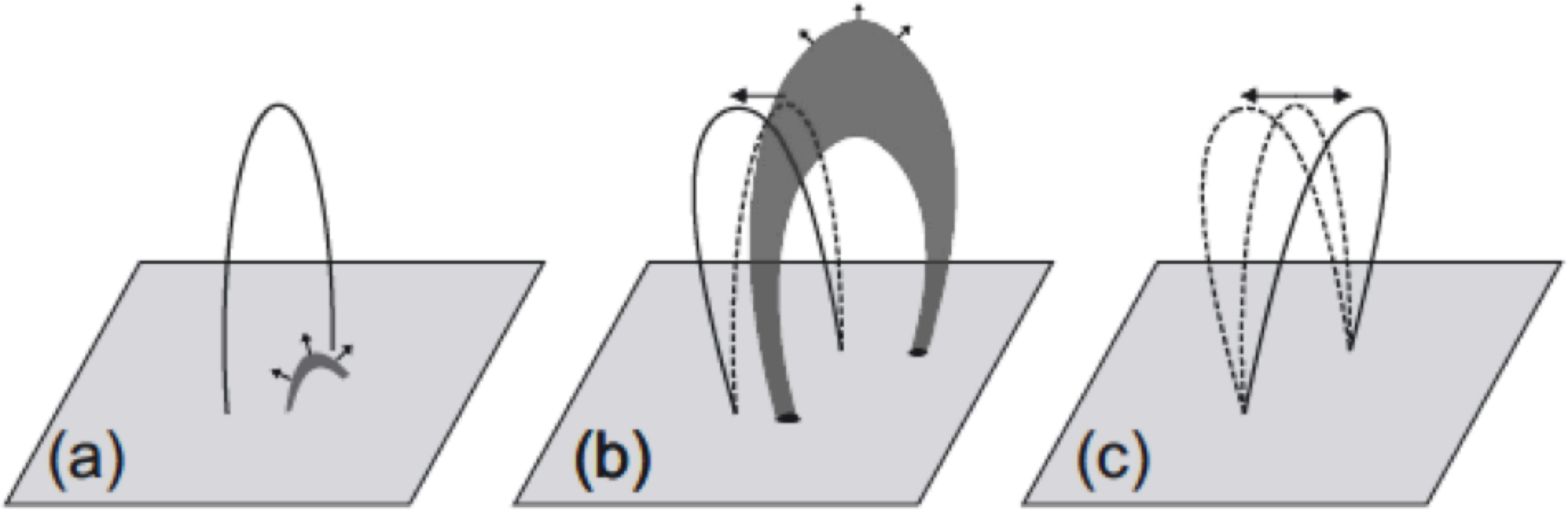
First observation: 14/08/1998
(EUV, TRACE)



$$\xi_n(t) = A e^{-\gamma_n t^n} cos(\omega t + \phi) ,$$

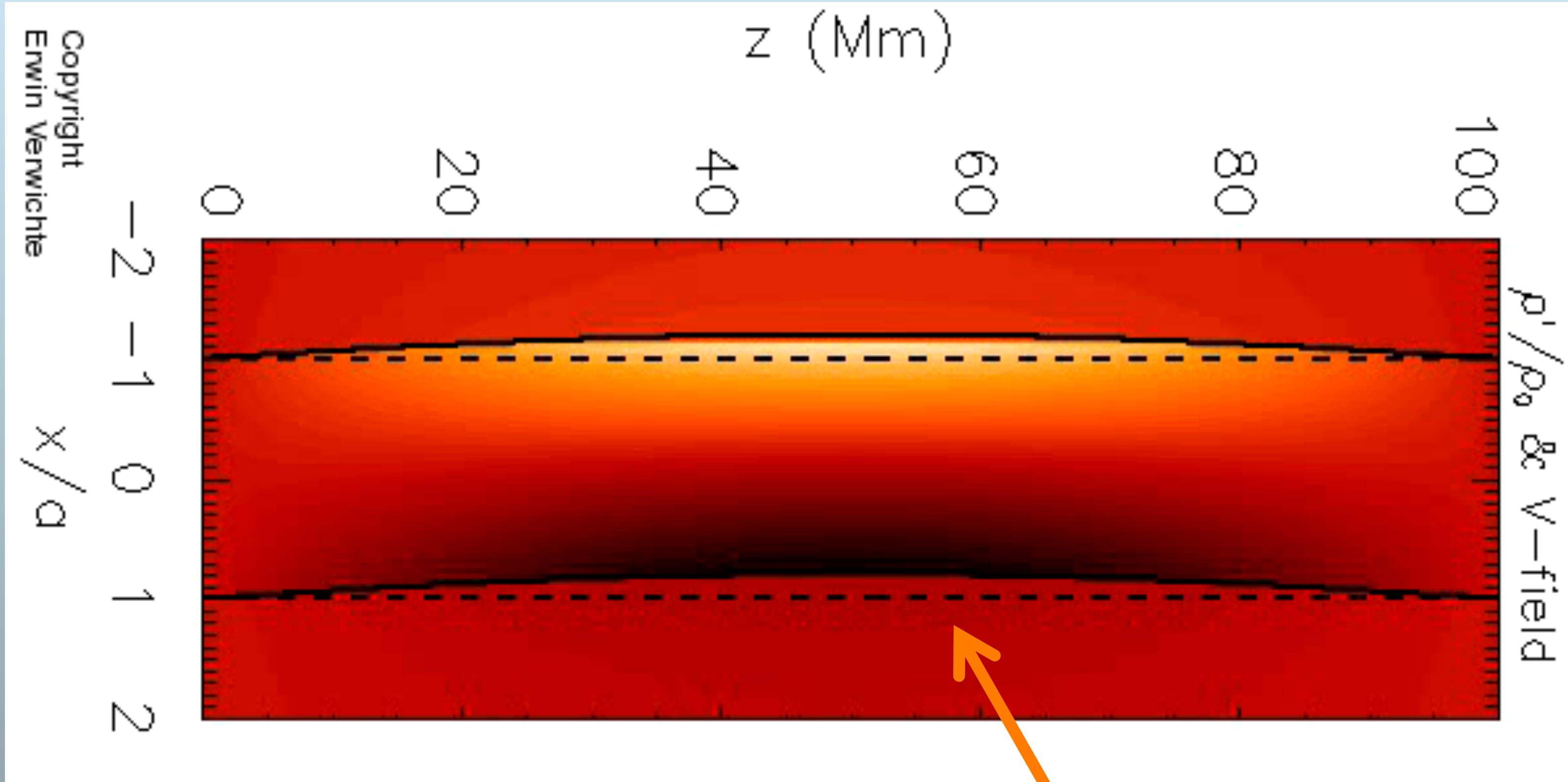
- Oscillation period,
- Decay time

The most common scenario of the excitation is a low coronal eruption:



Zimovets & Nakariakov, A&A 577, A4, 2015;
Goddard et al. A&A 585, A137, 2016:
A comprehensive catalogue of **58 kink oscillation events** observed with SDO/AIA: **169 kink-oscillating loops**

Kink (m=1) modes:



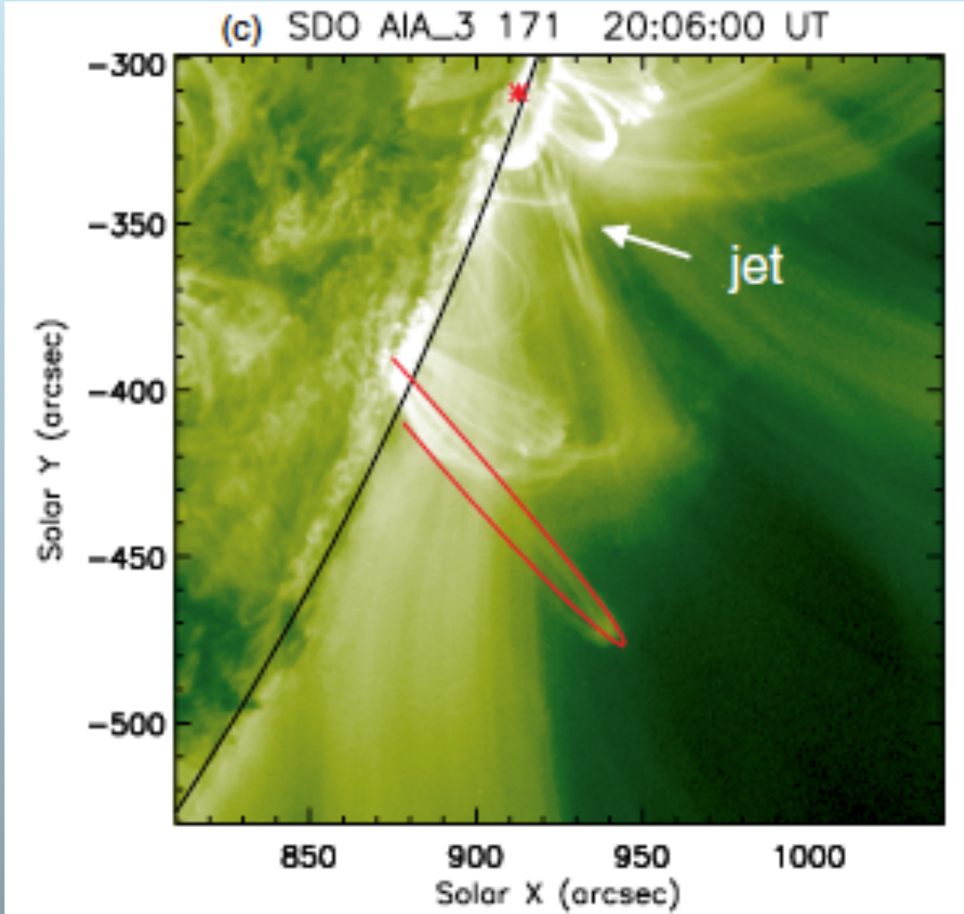
This mode is essentially compressive, and must not be confused with Alfven.
(while, sometimes it is called “Alfvénic”)

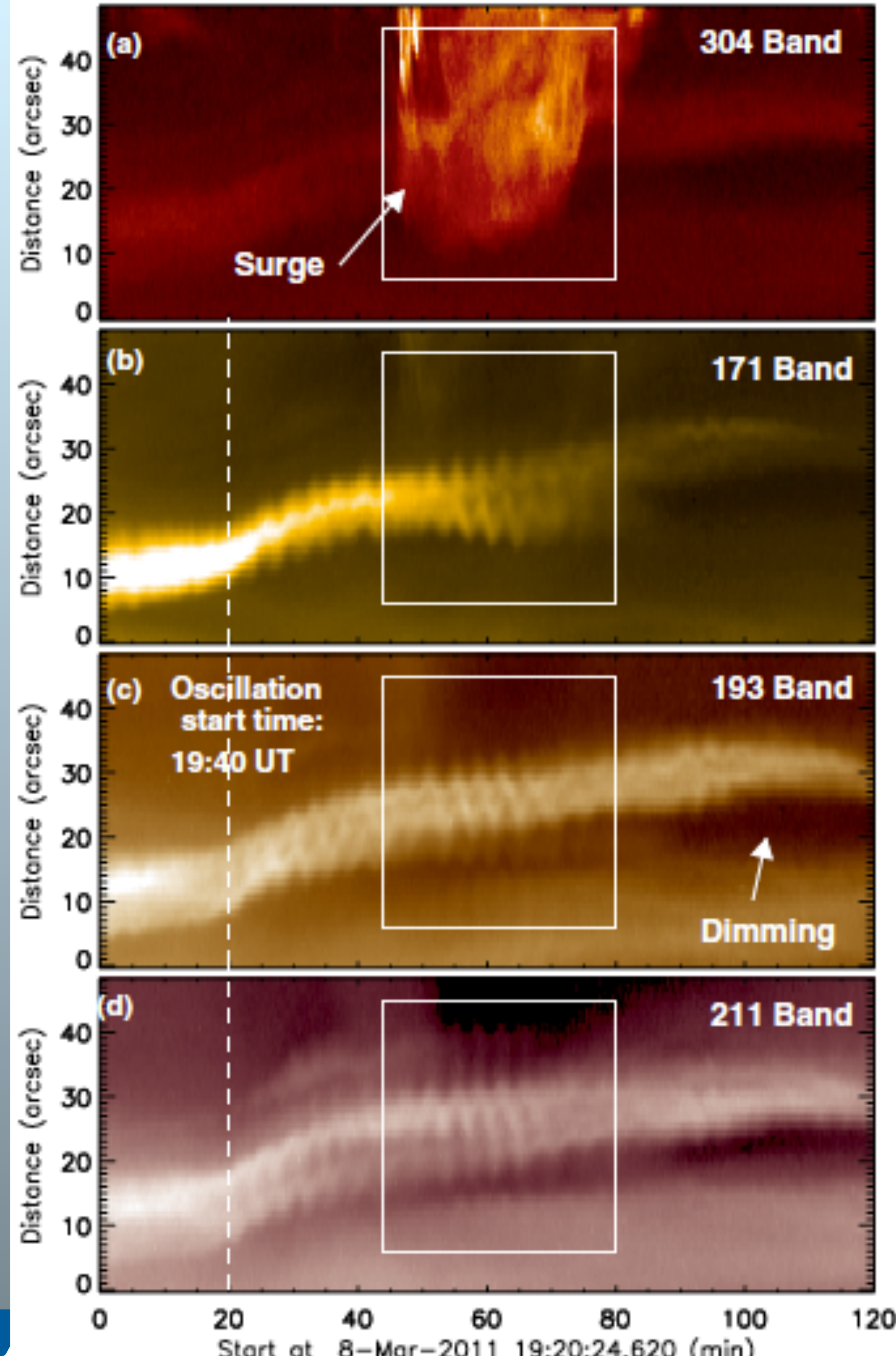
Kink mode: $P_{kink} = 2L / C_K$

Kink speed: $C_K = \left(\dfrac{\rho_0 C_{A0}^2 + \rho_e C_{Ae}^2}{\rho_0 + \rho_e} \right)^{1/2}$;

in low-β : $C_K = C_{A0} \sqrt{\dfrac{2}{1 + \rho_e / \rho_0}}$

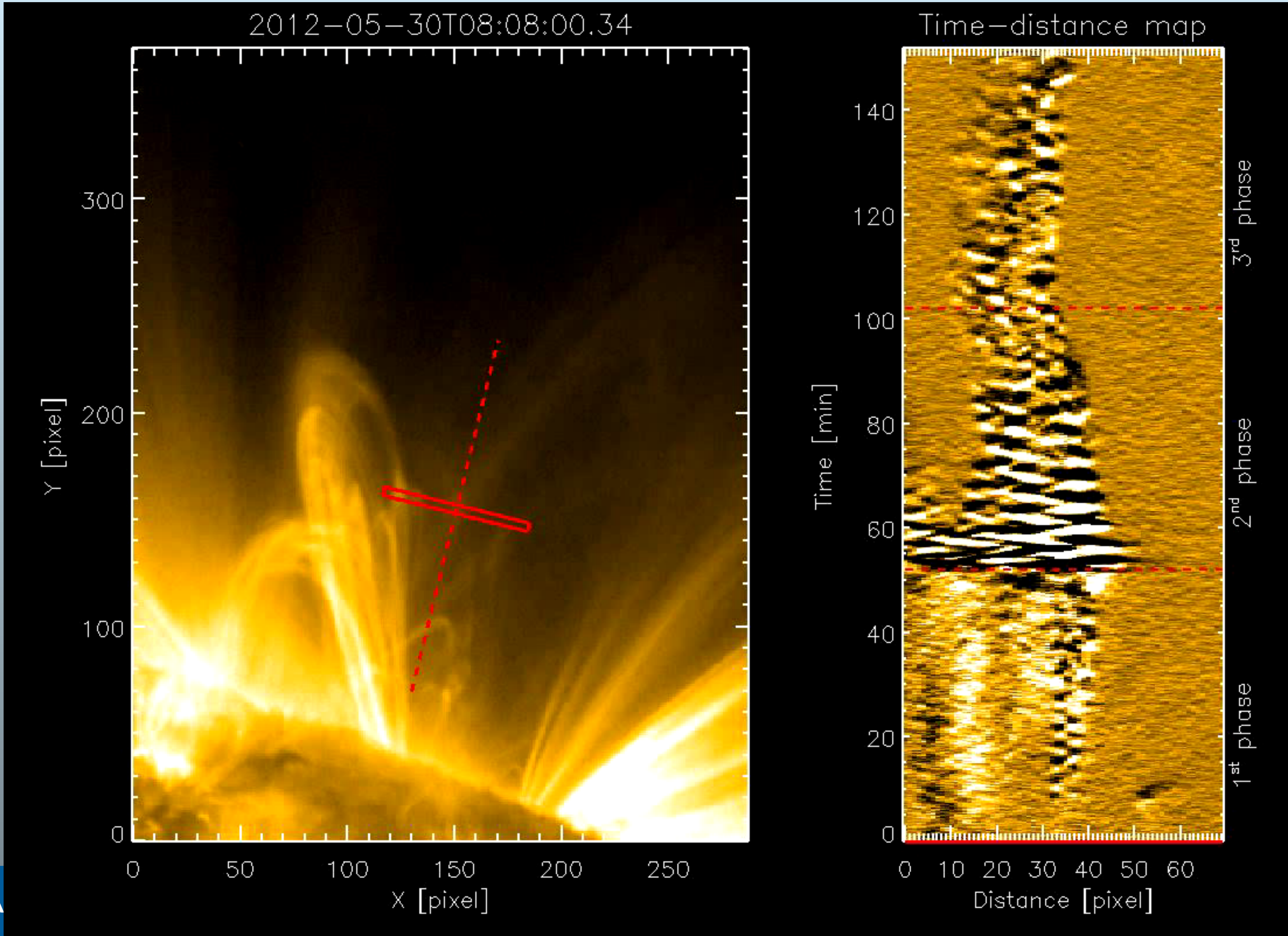
New regime: Decayless





Wang et al. ApJ 751, L27, 2012

An oscillatory pattern occurs before the onset of the main oscillation:

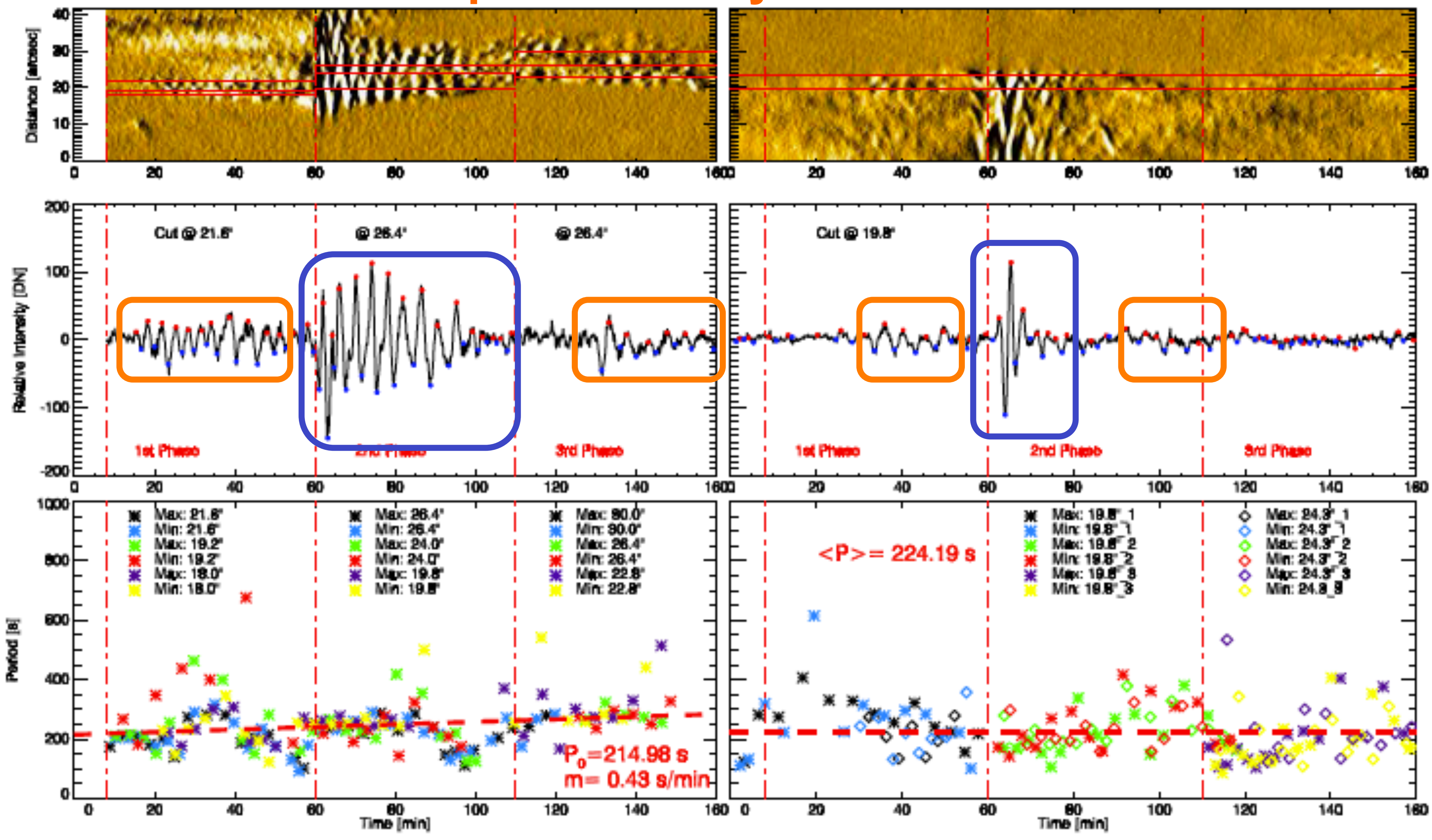


Nistico et al. A&A 552, A57, 2013

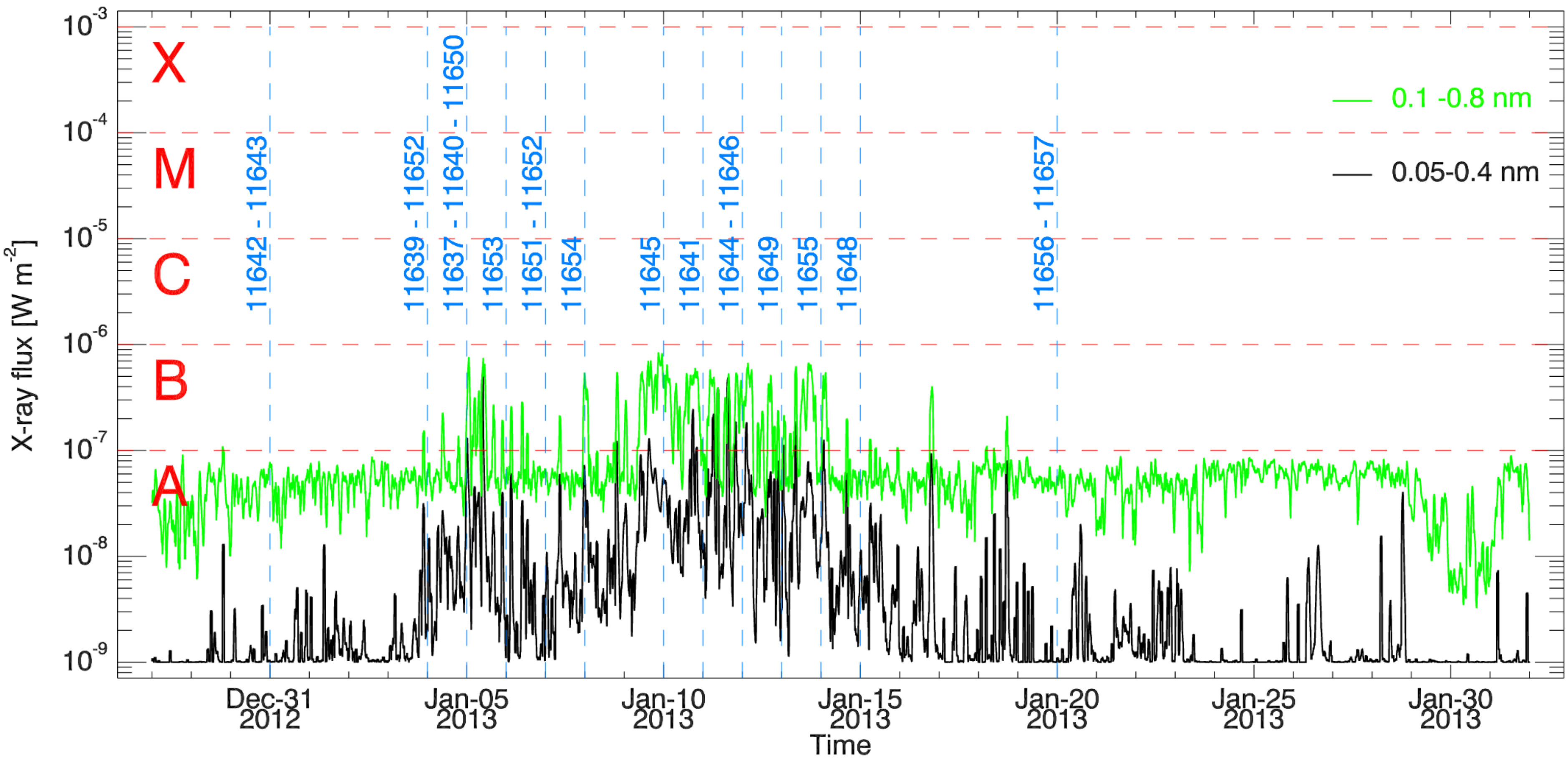
WA

Two regimes: **high amplitude damped**, **low amplitude decayless**

The same period

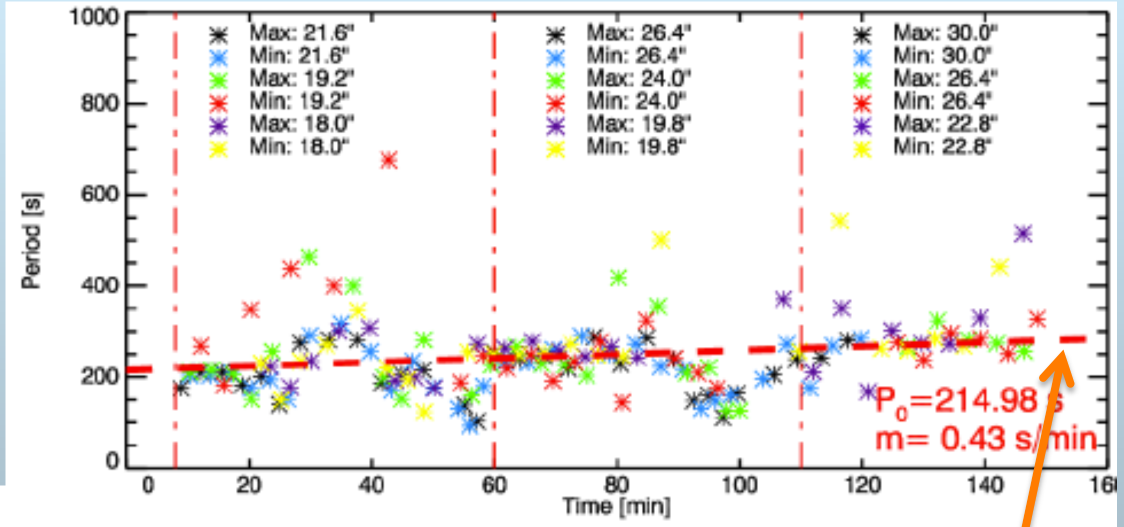


Nistico et al. 2013



Anfinogentov et al., *Astron. Astrophys.* **583**, A136, 2015

What about the increase in the period with the growth of the loop height?



Mass conservation and constant cross section

$$L \rightarrow L + dL$$
$$\rho \rightarrow \rho / (1 + dL/L)$$
$$P \sim L \rho^{1/2} / B$$
$$P = P_0 + dP = P_0 (1 + dL/L)^{\frac{1}{2}} / (1 + dB/B)$$

Assuming dB=0 the loop height increasing from 51 to 84 arcsec, we have

$$P = 1.28 P_0 \quad 275\, s$$

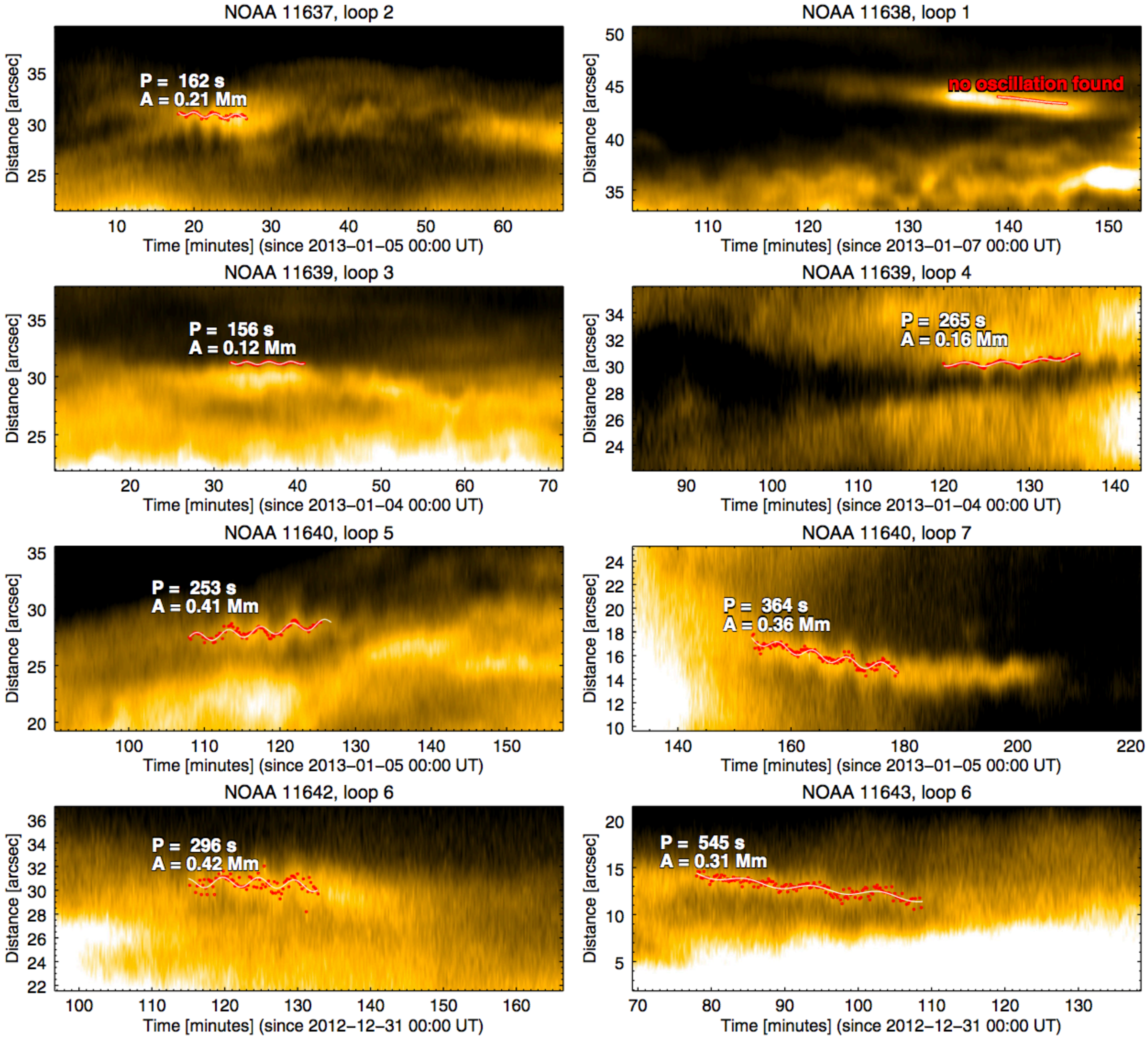
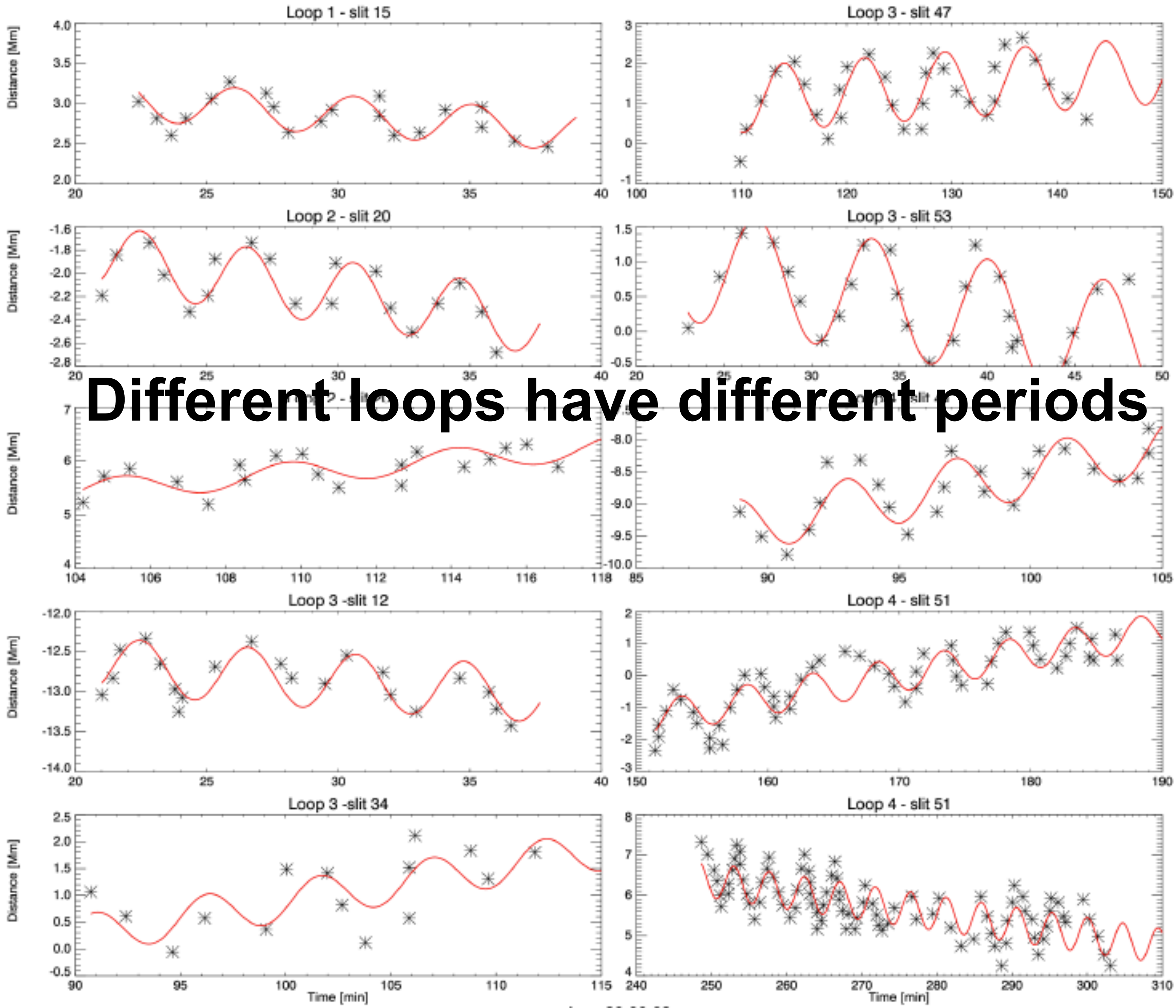


Fig. 4. Time-distance maps of the oscillating loops found in the analysed active regions. The most noticeable oscillations are fitted with a sine function to define their period and amplitude. Red dots indicate the positions of the loop centres estimated by the Gaussian fitting. The white

Different loops have different periods



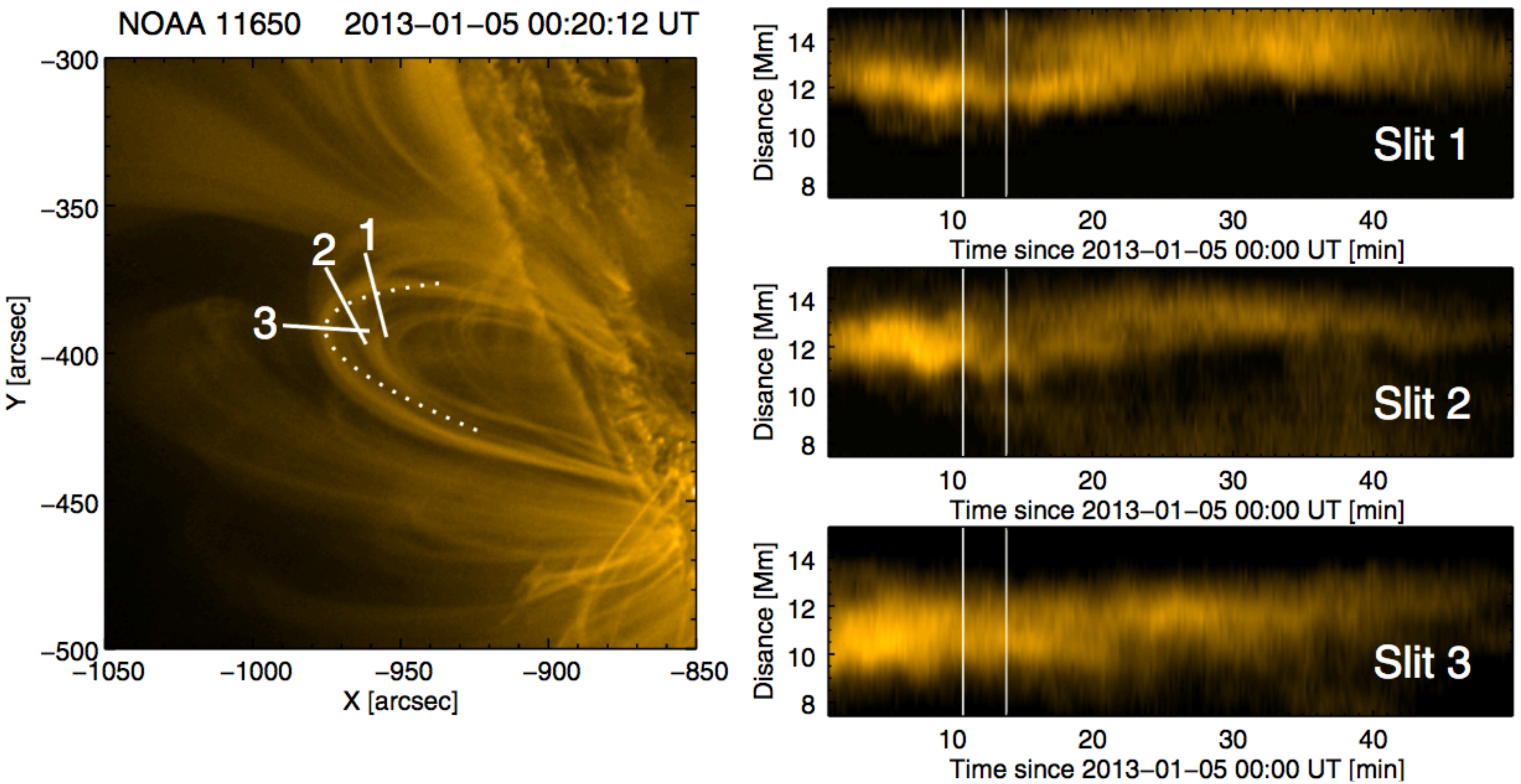


Fig. 7. Illustration of the in phase oscillation of different loop segments. The 171 Å image of the active region NOAA 11650 taken on 5 January 2015 00:20:12 UT is presented in the *left panel*. The oscillated loop is highlighted with a dotted line. Bold white lines show three slits used for

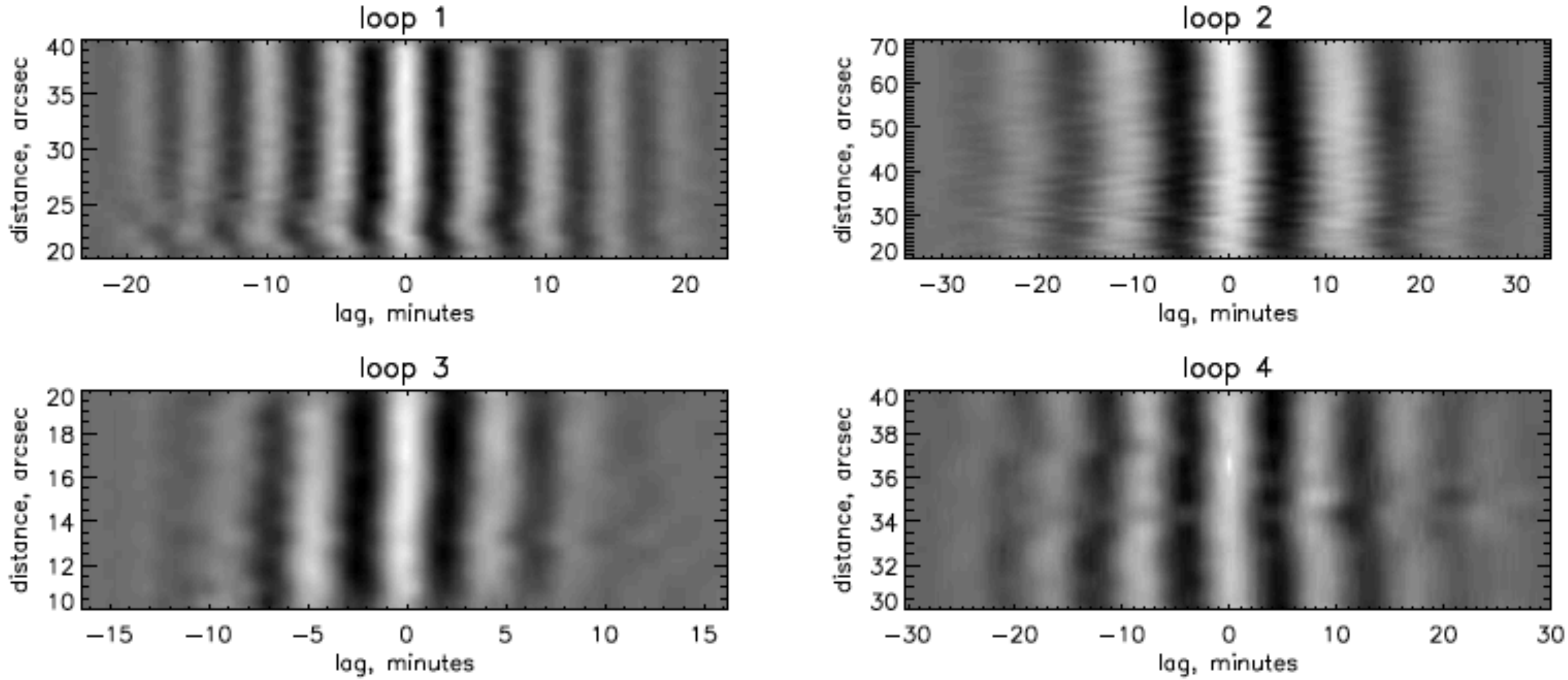
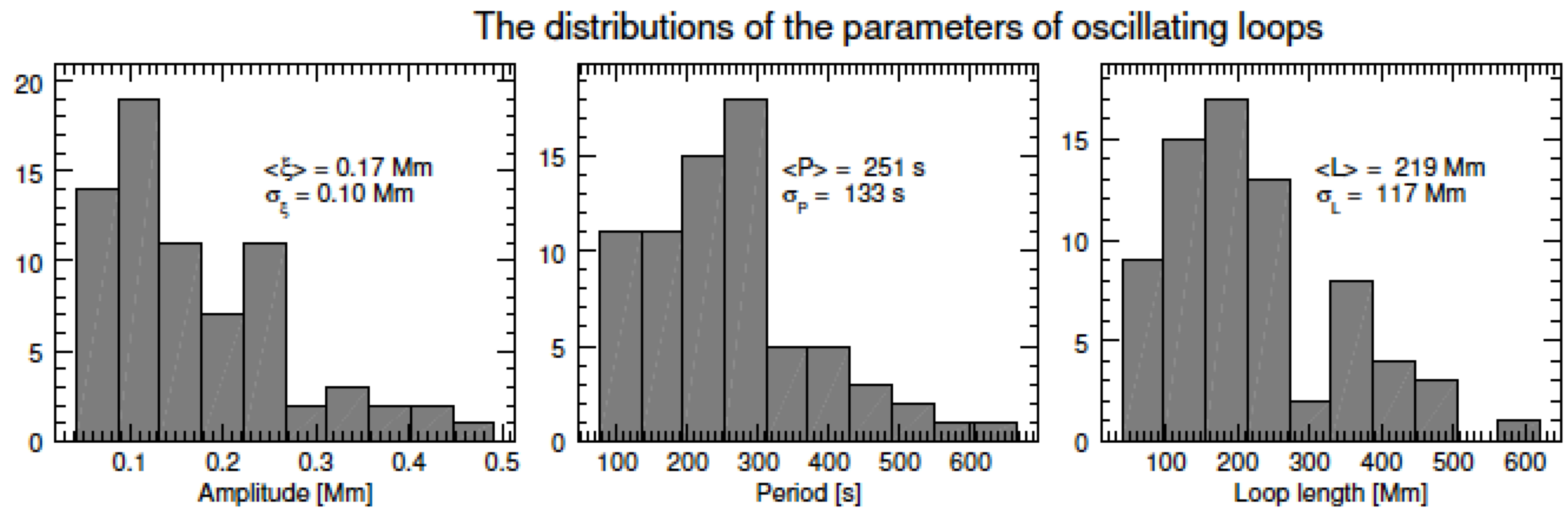


Fig. 5. Cross-correlation plots for loop 1 (upper panel) and loop 2 (lower panel). Vertical axis corresponds to the distance along the loop. Horizontal axis shows the time lag relatively to the reference location.

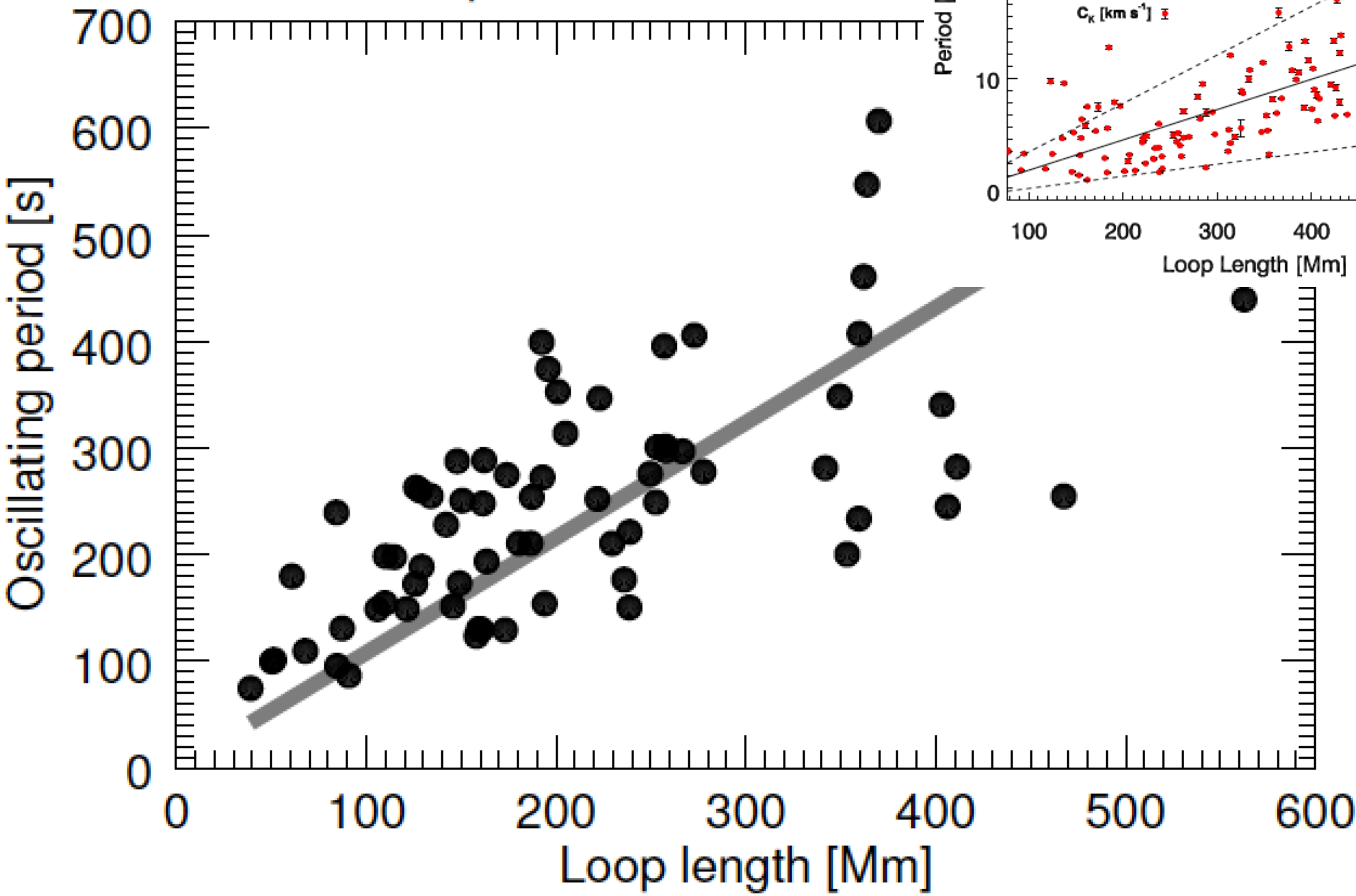
Oscillation phase is constant along the oscillating loops – the oscillations are standing.

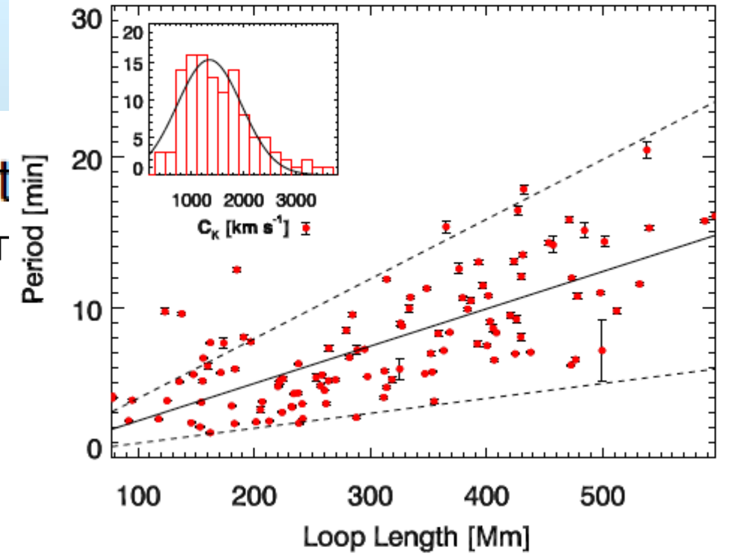
Decayless regime of kink oscillations:

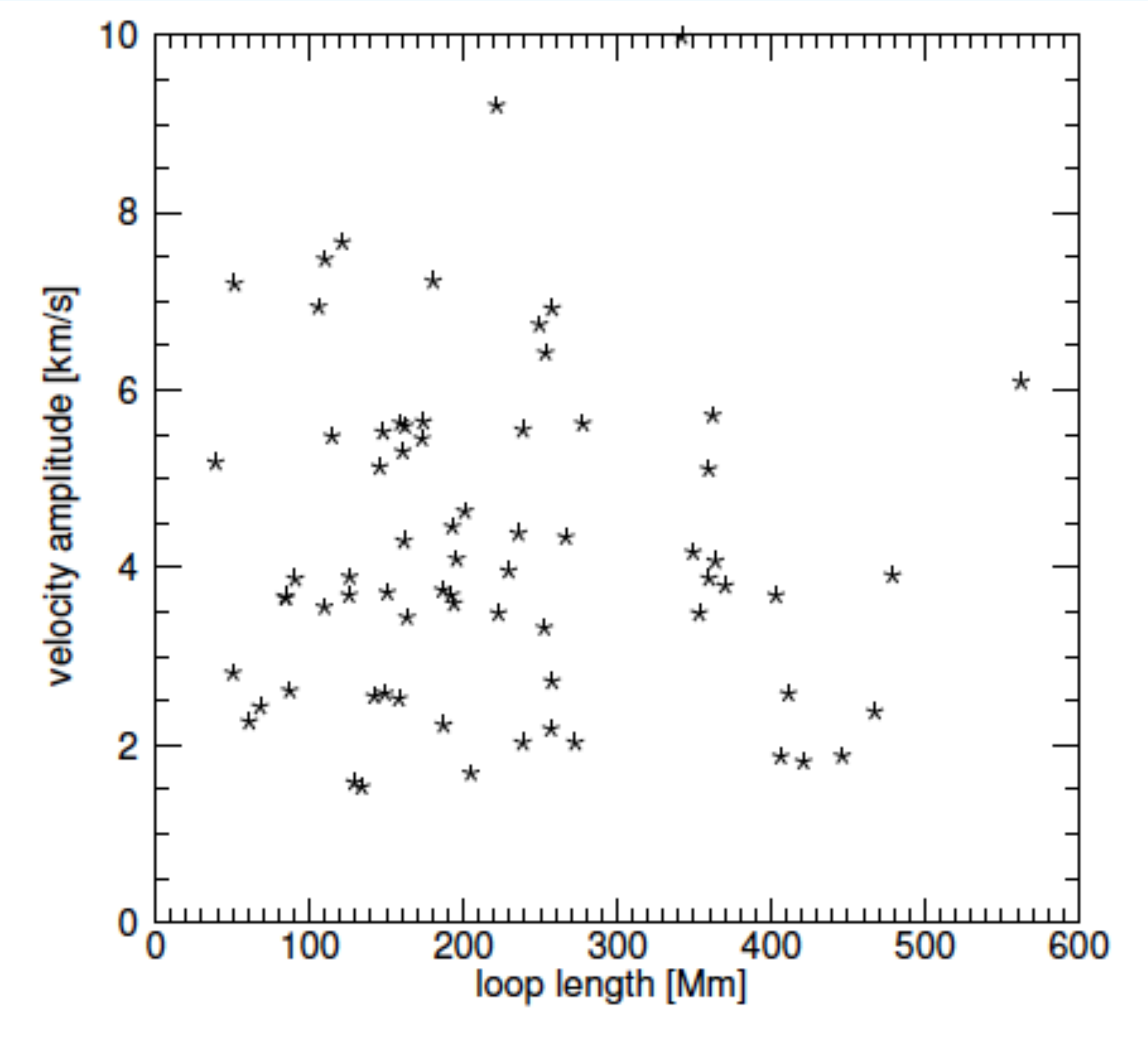


Anfinogentov et al., *Astron. Astrophys.* **583**, A136, 2015

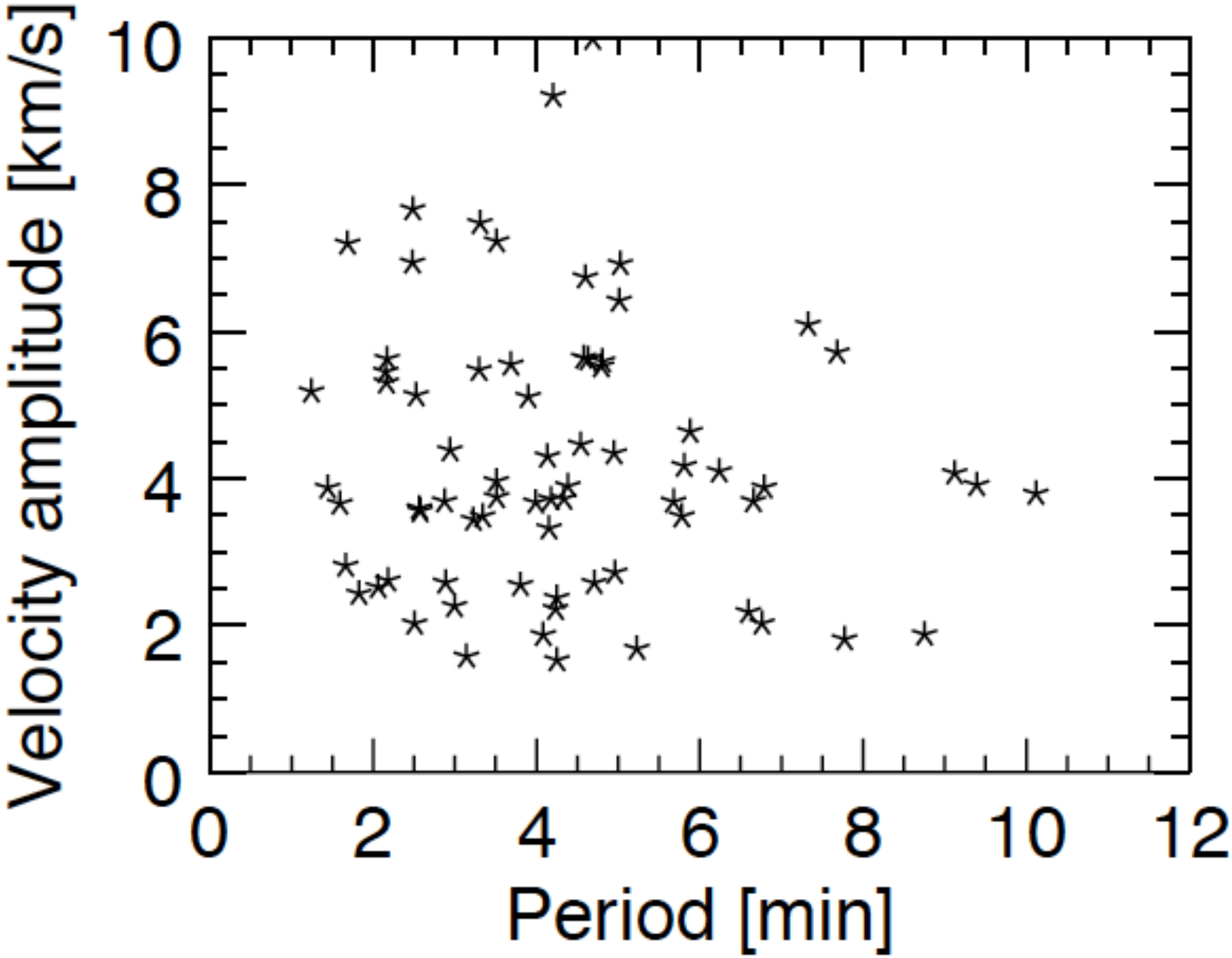
The parameters of oscillat







velocity amplitude [km/s]
loop length [Mm]
0
2
4
6
8
10
0
100
200
300
400
500
600


Velocity amplitude [km/s]
0
2
4
6
8
10
0
2
4
6
8
10
12
Period [min]

How can we have a decayless monochromatic oscillation of a damped oscillator?

$$\frac{d^2 a(t)}{dt^2} + \delta \frac{da(t)}{dt} + \Omega_K^2 a(t) = f(t)$$

If *f(t)* is be **periodic**:

e.g. leakage of 3-min umbral oscillations

(Sych et al. A&A **505**, 791, 2009)

P-modes? Not likely, as they are not harmonic enough

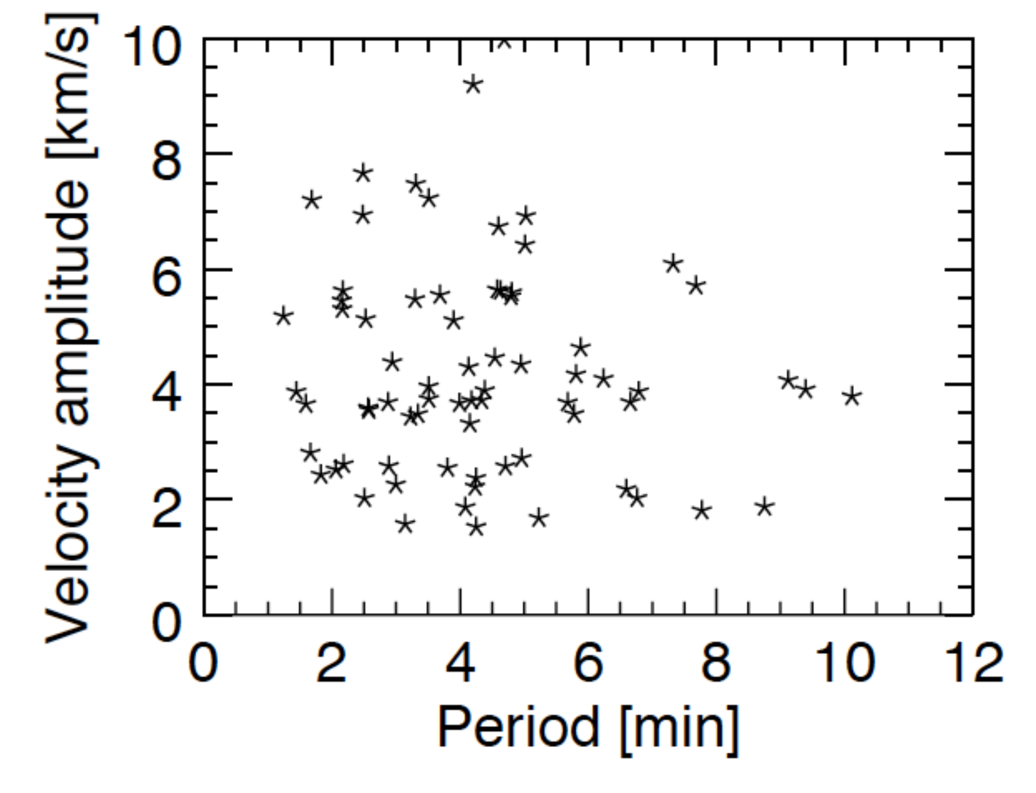
- The saturated amplitude of driven oscillations is

$$a(\omega_{\text{driver}}) \propto \left|\Omega_K^2 - \omega_{\text{driver}}^2\right|^{-1}$$

- The frequency of the driven oscillations is ω_{driver},

- **But**, no signature of resonance:

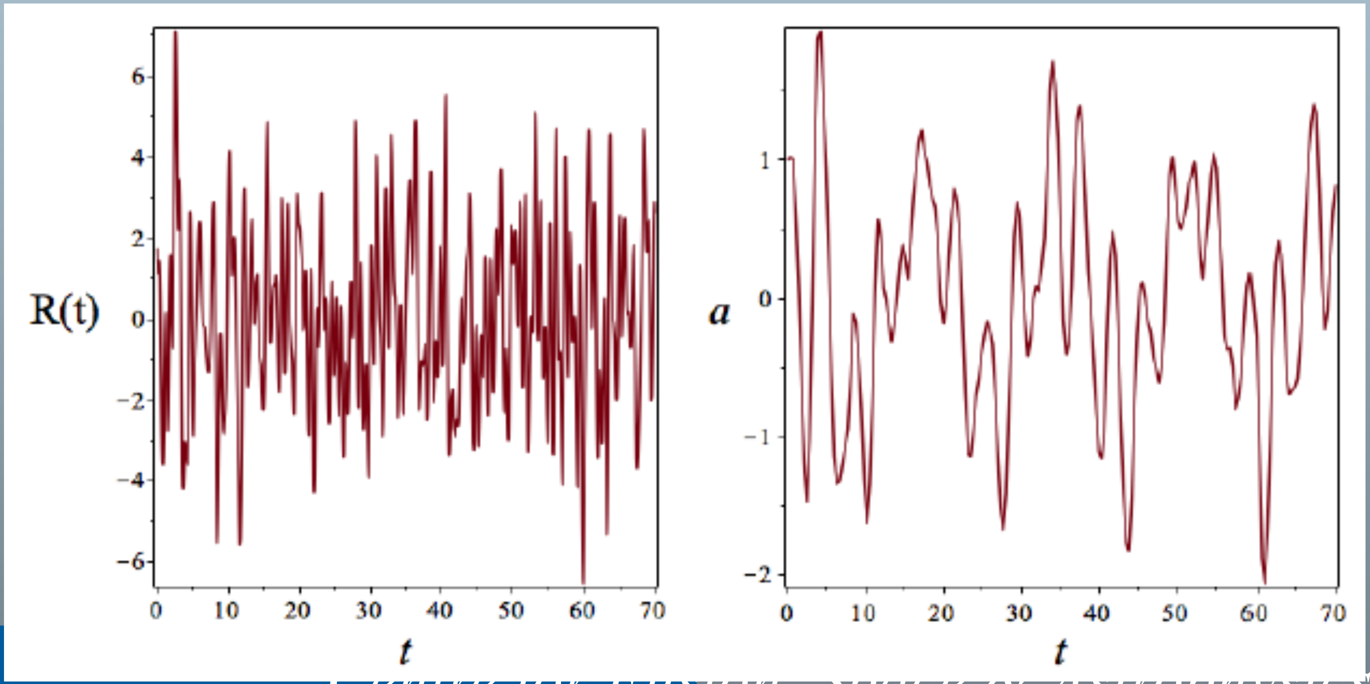
- very broad range of periods: (neither 3 min, nor 5 min)



$$\frac{d^2a(t)}{dt^2} + \delta \frac{da(t)}{dt} + \Omega_K^2 a(t) = R(t)$$

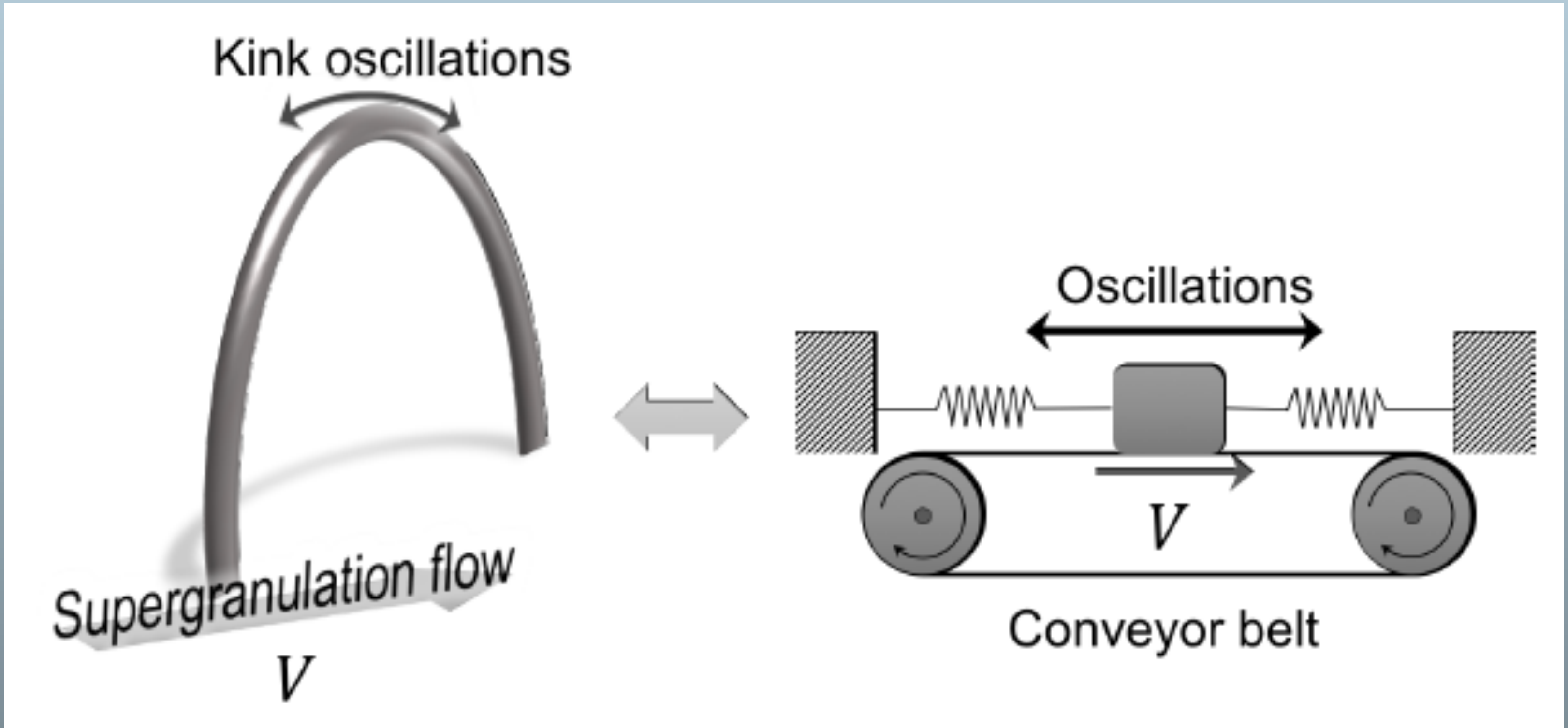
What if *f(t)* is **random**, e.g. granulation flows?

Randomly driven oscillations:



Undamped kink oscillations can be **self-oscillations**:

In contrast with driven oscillations, a self-oscillator itself sets the frequency and phase with which it is driven, keeping the frequency and phase for a number of periods.



In a self-sustained oscillator (self-oscillator), the driving force is controlled by the oscillation itself
so that it acts in phase with the velocity, causing a negative damping that feeds energy into the vibration:

no external rate needs to be adjusted to the resonant frequency.

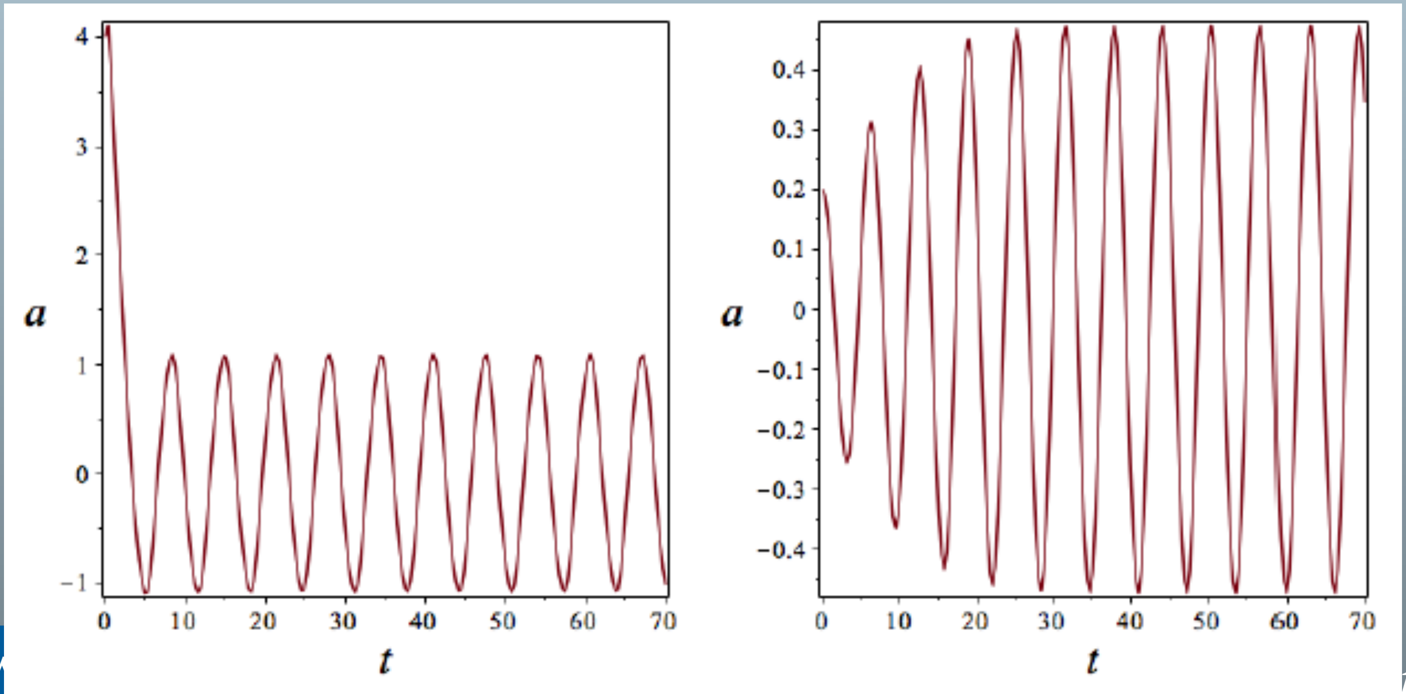
Examples:

- Heart,
- Clocks,
- Bowed and wind musical instruments,
- Devices that convert DC in AC.

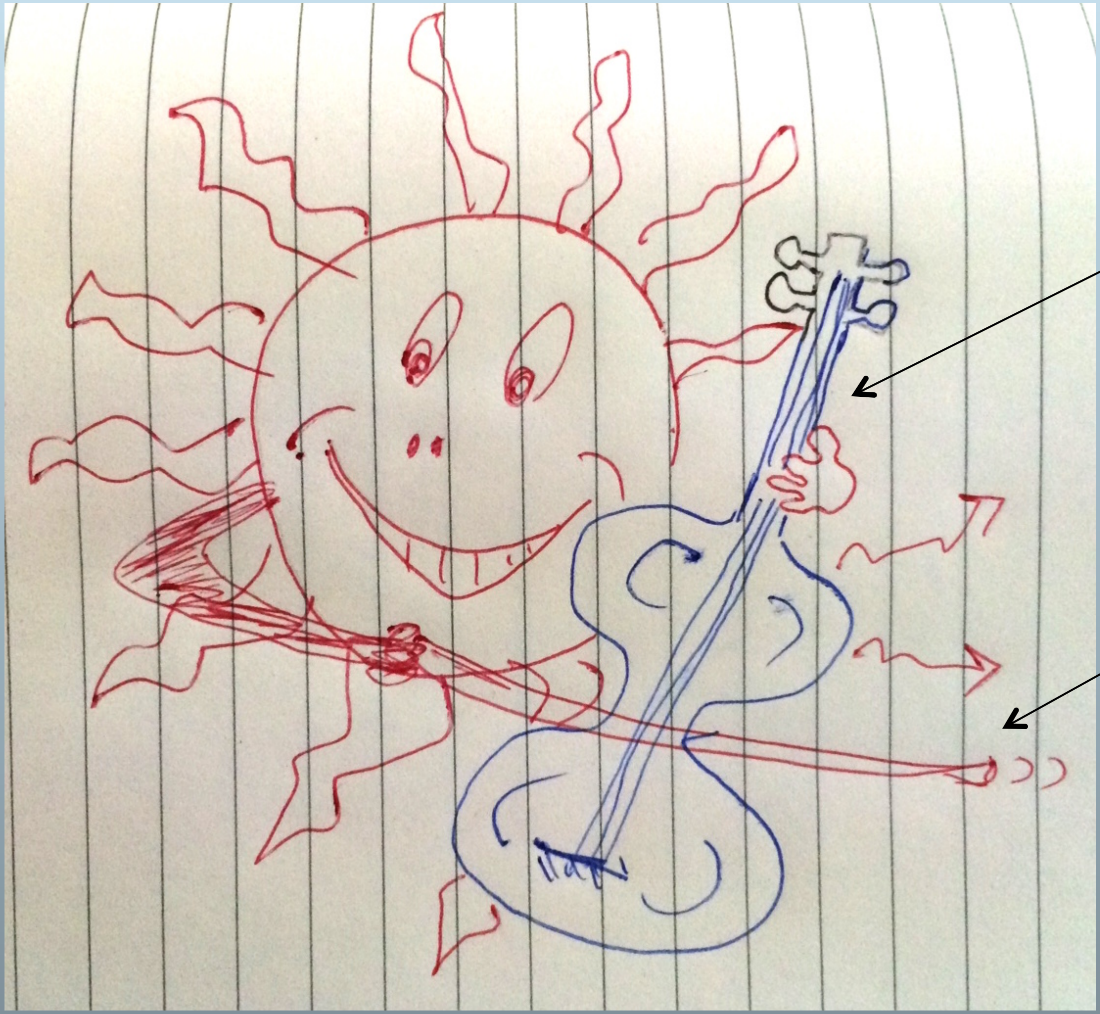
$$\frac{d^2a(t)}{dt^2} + \delta\frac{da(t)}{dt} + \Omega_K^2 a(t) = F\left(v_0 - \frac{da(t)}{dt}\right)$$

Rayleigh Eq.:

$$\frac{d^2a(t)}{dt^2} - \left[\Delta - \alpha\left(\frac{da(t)}{dt}\right)^2\right]\frac{da(t)}{dt} + \Omega_K^2 a(t) = 0$$



Sketch of our model of undamped kink oscillations of loops:



Loops

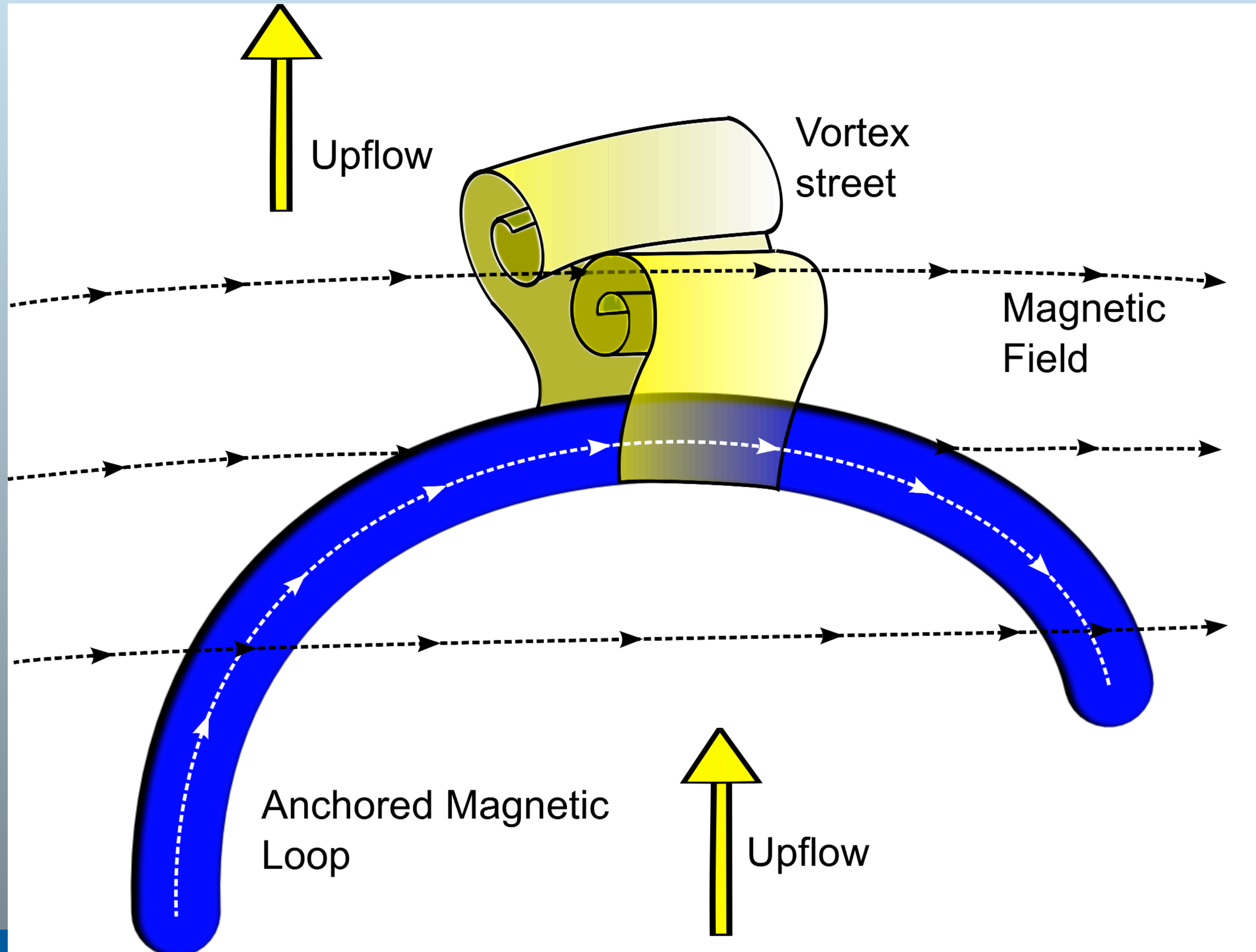
Quasi-steady flows (supergranulation?)

Conclusions

- There is another, decayless and low-amplitude regime of the oscillations.
- The period depends on the loop length.
- The amplitude does not depend on period.
- Broad range of periods.
- Are decayless oscillations **self-oscillations**?

Resonant excitation of kink oscillations by periodic shedding of Alfvenic vortices:

Nakariakov, Aschwanden & Van Doorsselaere, Astron. Astrophys. **502**, 661 (2009); Gruszecki et al. *Phys. Rev. Lett.* **105**, 055004, 2010



OBSERVATIONAL EVIDENCE?