Motion magnification in solar imaging data sequences in the sub-pixel regime

S. Zhong[1], T. Dukenfield[2], V. M. Nakariakov[1], S. Anfinogentov[3]

[1] Centre for Fusion, Space and Astrophysics, Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom
[2] Centre for mathematical Plasma Astrophysics, Department of Mathematics, KU Leuven, Celestijnenlaan 200B bus 2400, B-3001 Leuven, Belgium
[3] Institute of Solar-Terrestrial Physics SB RAS, Irkutsk 664033, Russia

Background

Low amplitude decayless kink oscillations of coronal loops:

1. Averaged displacement amplitude is 0.17 Mm (~0.4 pixel in AIA resolution).
2. Oscillation parameters at loop segment far from the maximum amplitude location are hardly obtained.
3. Unknown reason for persistent oscillation. Do density and intensity profiles evolve during the oscillation?

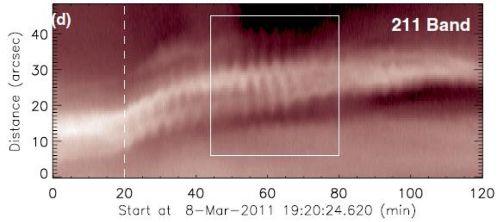
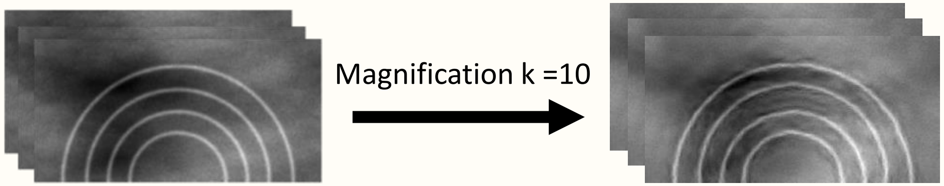


Fig.1 Decayless kink oscillation of coronal loop (Wang+ 2012)

2D dual-tree complex wavelet transform (DTCWT)-based motion magnification (MM) [1] (Anfinogentov & Nakariakov, 2016):

1. amplifies subtle quasi-periodic motions in image sequences or videos.
2. gives linear scaling of the magnified amplitude with the original amplitude when input amplitude ≤ 1 pixel.
3. the magnification is independent of the oscillation period in a broad range of the periods.



Contact: Sihui.Zhong@warwick.ac.uk

[1] https://github.com/Sergey-Anfinogentov/motion_magnification

NAM2021 poster: Motion magnification in solar imaging data sequences in the sub-pixel regime

Motivation

1. To consider the performance of the MM method in the highly sub-resolution regime. To assess the reliability of the MM outcomes at the oscillating segments sufficiently far from the maximum amplitude location, which is necessary for the determination of the parallel structure of a kink oscillation and detection of higher parallel harmonics.
2. To explore the effect of the steepness of the transverse profile on the MM performance.

Method

1. Create artificial image sequence, imitating oscillating semi-circular loops in optically thin emission. Transverse profiles with different steepness are constructed.
2. Apply MM with various magnification factors k.
3. Analyse the results of 2.

- Radial motion: $\xi = \xi_0 \sin\theta \cos(\frac{2\pi}{P} t + \varphi)$, where ξ_0, P, φ are constant. $\xi_0 \ll 1$ pixel.
- Density: $\rho = \rho_{0p} \exp(-(\frac{s^2}{2w^2})^p)$, where $s^2 = \left|\sqrt{(x^2+y^2)} - R\right|^2 + z^2$, w=10 pixel, *p* is steepness index. ρ_{0p} varies to make mass of loop constant.
- Intensity (x-y plane) : $I = \int_{LOS} \rho^2 ds$

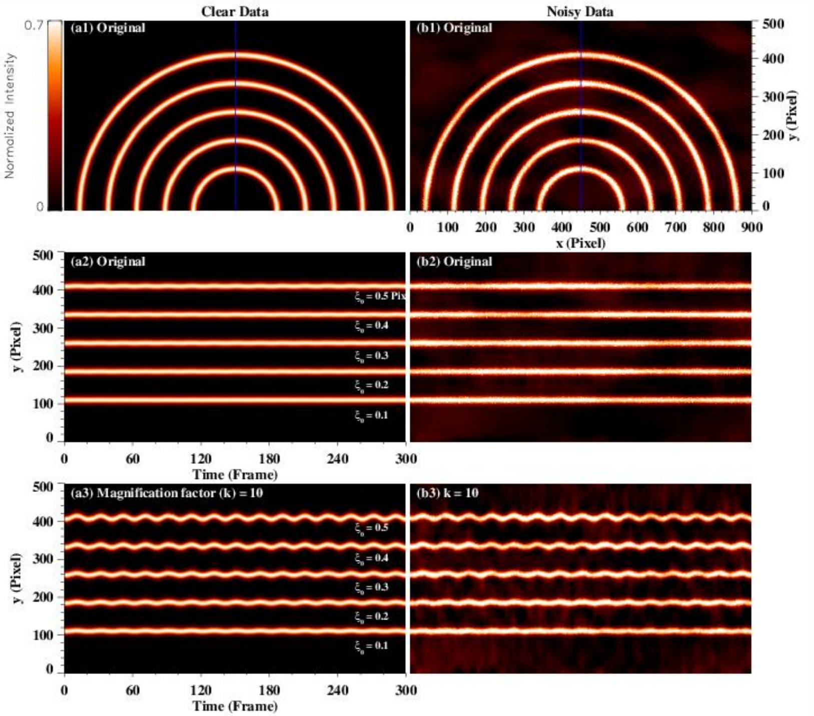


Fig.2 Snapshot of a set of five semi-circular loops undergoing fundamental decayless kink oscillations in the regime with (right) and without (left) background noise.

Contact: Sihui.Zhong@warwick.ac.uk

Result

Dependence on input amplitude:

- We test the applicability of MM for sub-pixel oscillations ($\xi_0 \in [0.01, 0.5]$) of loops with generalized Gaussian profile (*p*=1).
- The MM technique is found to work well on the analysis of sub-pixel oscillations, with the amplitude down to as small as 0.01 pixel, giving linear scaling of the magnified amplitude with the input amplitude (see Fig. 3)

Effect of transverse profile:

- We apply MM to oscillations of loops with different transverse profiles (p=1-50).

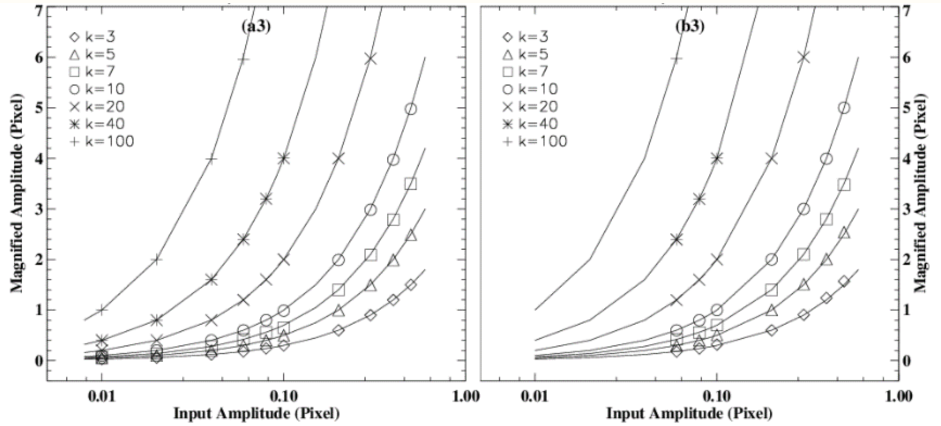


Fig.3 Magnified vs. input displacement amplitude. The solid curves indicate linear scaling.

- After MM, transverse profiles with various steepness are found to be preserved (see Fig.4). But MM creates minor artefact when k and *p* grows.

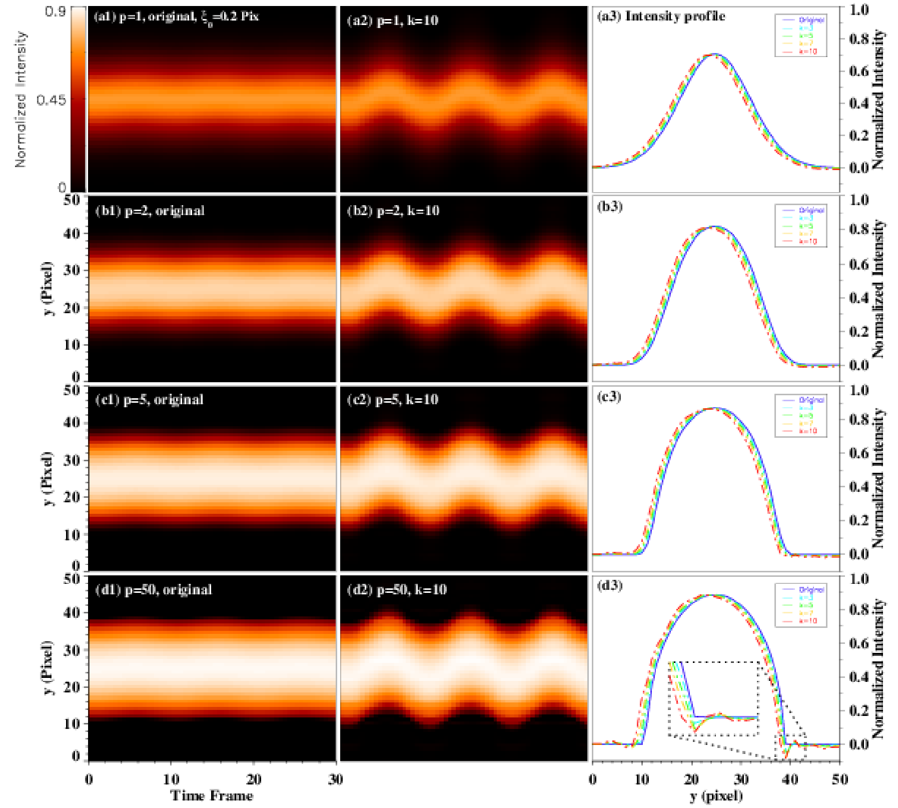


Fig.4 Comparison of the outcomes of motion magnification on kink oscillations of loops with different steepness index *p*.

Contact: Sihui.Zhong@warwick.ac.uk

Effect of transverse profile:

- Steeper profile gives larger visual loop width.
- For a fixed p, FWHM stays the same with various k if k<20 (see Fig.5). For seismological application, high value of k (k>20) is not usually practical.

Artificial artefacts:

- The higher magnification factor, steepness and level of noise would make MM generates more artefacts (see Fig.6).

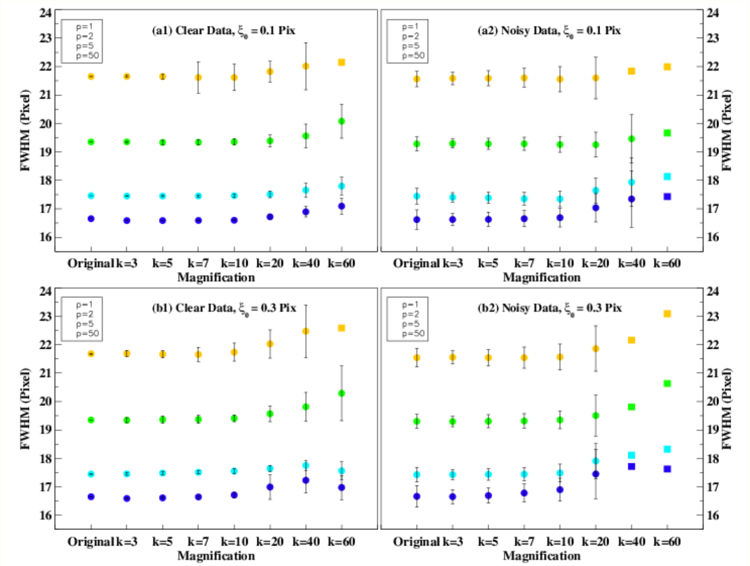


Fig.5 Measured FWHM of oscillating loops with different *p*.

- When k ≤ 20, the visual artefact caused by MM is very minor and should not have a significant impact on the result.

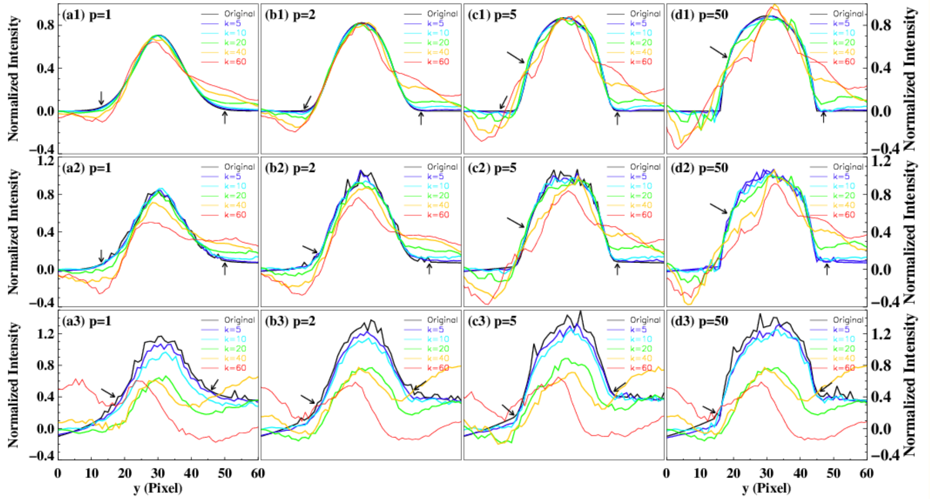


Fig.6 Difference between original and magnified profiles.

Conclusion

1. MM not only magnifies subtle transverse motions, but also preserves transverse profiles of the oscillating structure.
2. **These findings confirm the robustness of the motion magnification technique for applications in MHD coronal seismology.**

Contact: Sihui.Zhong@warwick.ac.uk