Quasi-periodic Oscillations in Si IV Doppler Velocity During an M-6.5 Class Solar Flare

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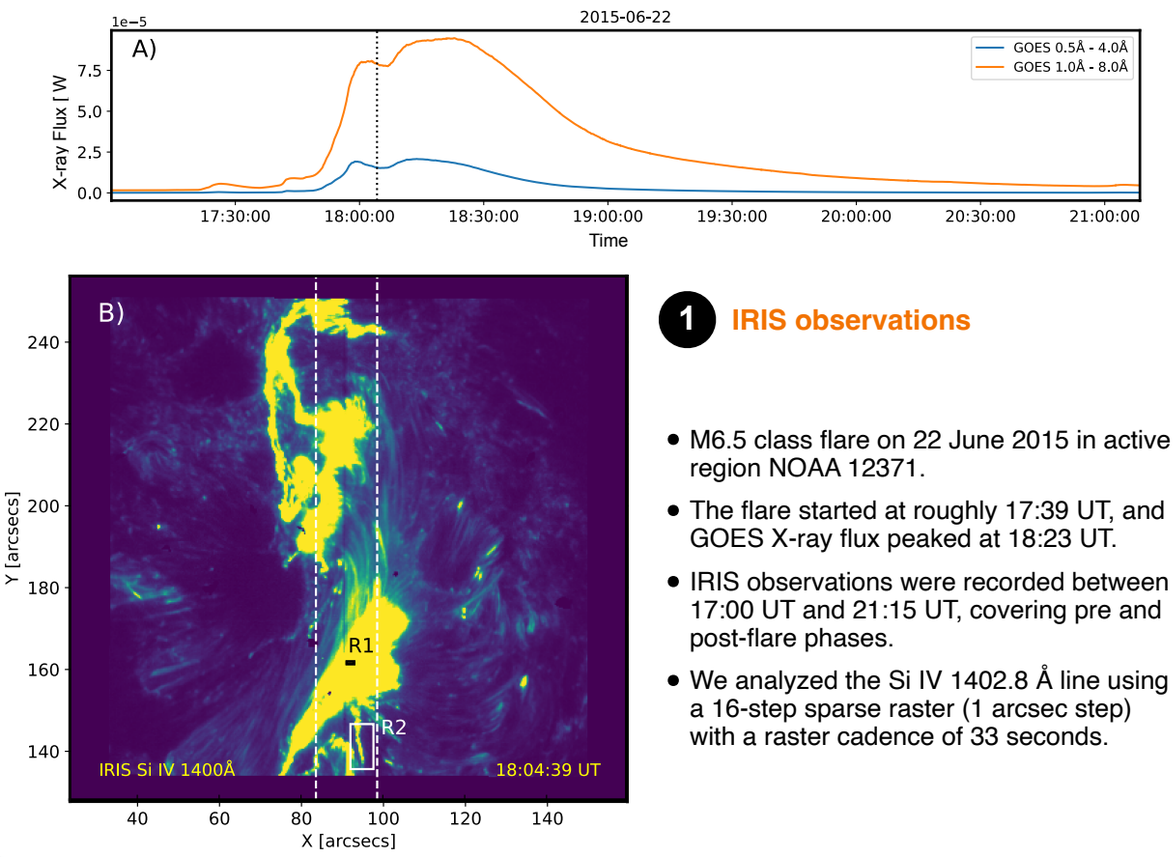
Quasi-periodic oscillations (QPOs) observed in the solar chromosphere and transition region during flares offer valuable insights into the atmospheric response to sudden energy releases and the evolution of the magnetic field. We analyzed an M-6.5 class flare observed by the Interface Region Imaging Spectrograph (IRIS), emphasizing QPOs in the Doppler velocity measured in the Si IV line at the flare ribbons. Our findings reveal variations in the periods of oscillatory signals during different phases of the flare. Specifically, during the flare's impulsive phase, Doppler velocity oscillations with a periodicity of approximately 5 minutes were observed. Pre-flare oscillations exhibited maximum power at around 3 minutes. However, during the gradual decay phase of the flare, longer-period oscillations (~8-12 minutes) were detected in and around the flare ribbons. We interpret the shift to a 5-minute periodicity during the impulsive phase as indicative of a change in the formation height of the Si IV line, corresponding to a deeper atmospheric layer responding to the local acoustic cut-off frequency. Additionally, the extended-period oscillations observed during the decay phase may be attributed to a reorientation of the magnetic field, which could become more inclined post-flare.



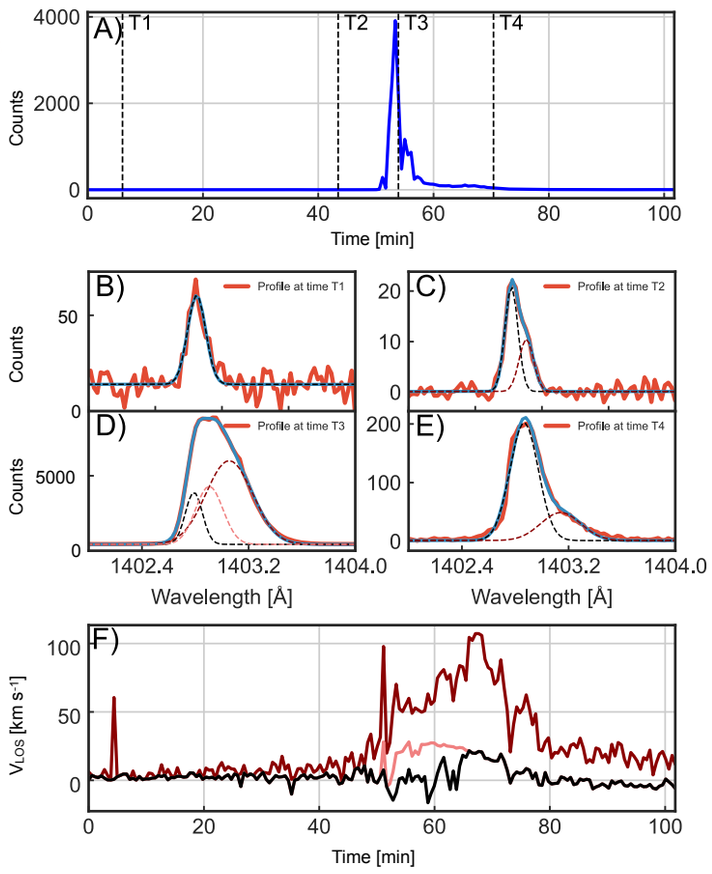
1 IRIS observations

- M6.5 class flare on 22 June 2015 in active region NOAA 12371.
- The flare started at roughly 17:39 UT, and GOES X-ray flux peaked at 18:23 UT.
- IRIS observations were recorded between 17:00 UT and 21:15 UT, covering pre and post-flare phases.
- We analyzed the Si IV 1402.8 Å line using a 16-step sparse raster (1 arcsec step) with a raster cadence of 33 seconds.

2 Doppler velocity measurements

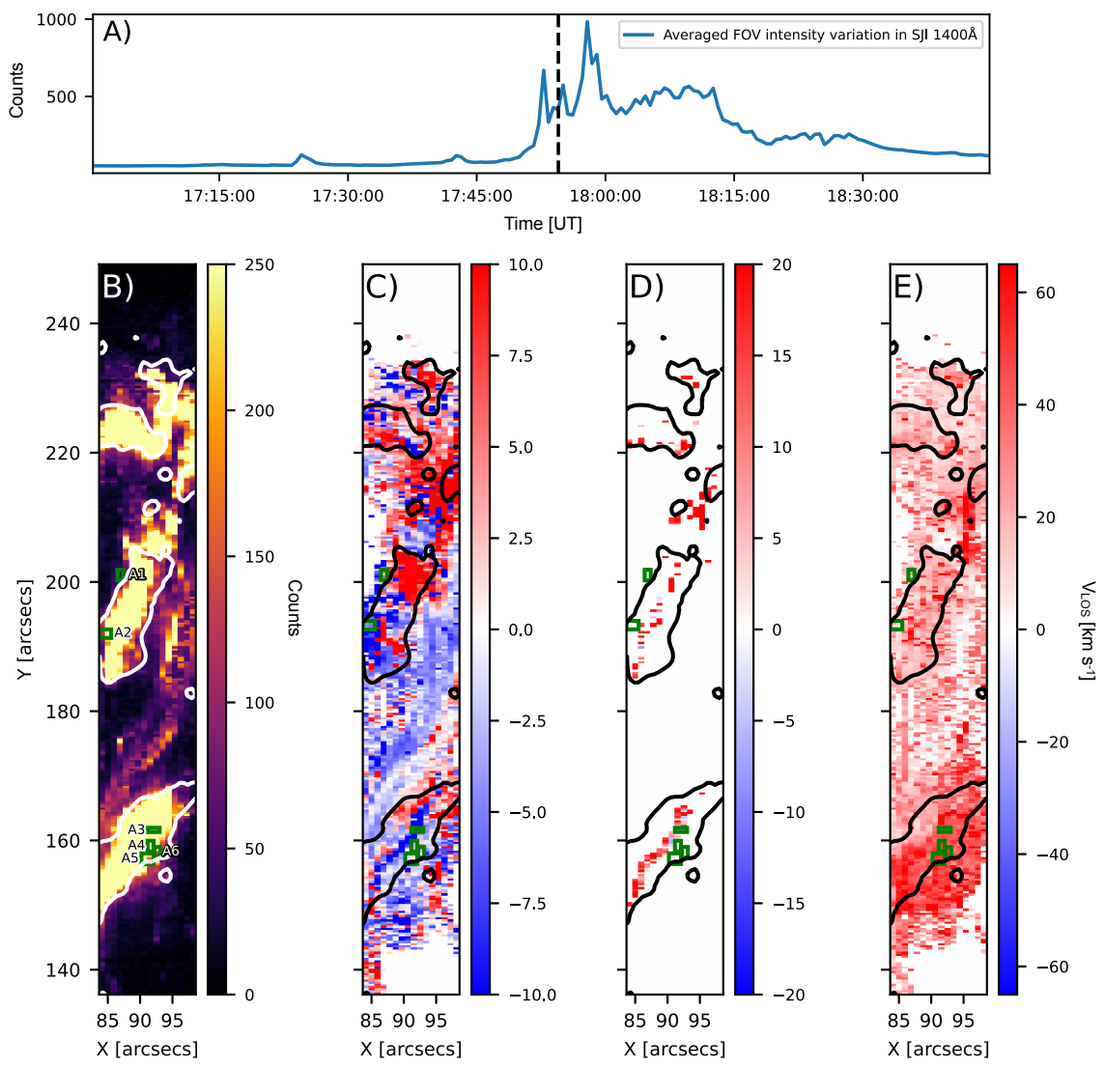
- During the evolution of the flare, the Si IV line exhibited asymmetries, indicating the presence of multiple Doppler-shifted components.
- We applied Principal Component Analysis (PCA) and k-means clustering to classify the observed spectra.
- Based on the shapes of the classified cluster centers, we chose to fit one, two, or three Gaussian profiles to measure the Doppler velocities.
- Panels B-E display the Si IV spectra from a single pixel within the flare ribbons at different times during the observations.
- The evolution of Doppler velocities, obtained through multi-Gaussian fitting, is presented in panel F.

Black → Stationary
Pink → Moderate downflow
Red → Strong downflow



3 Doppler velocity maps

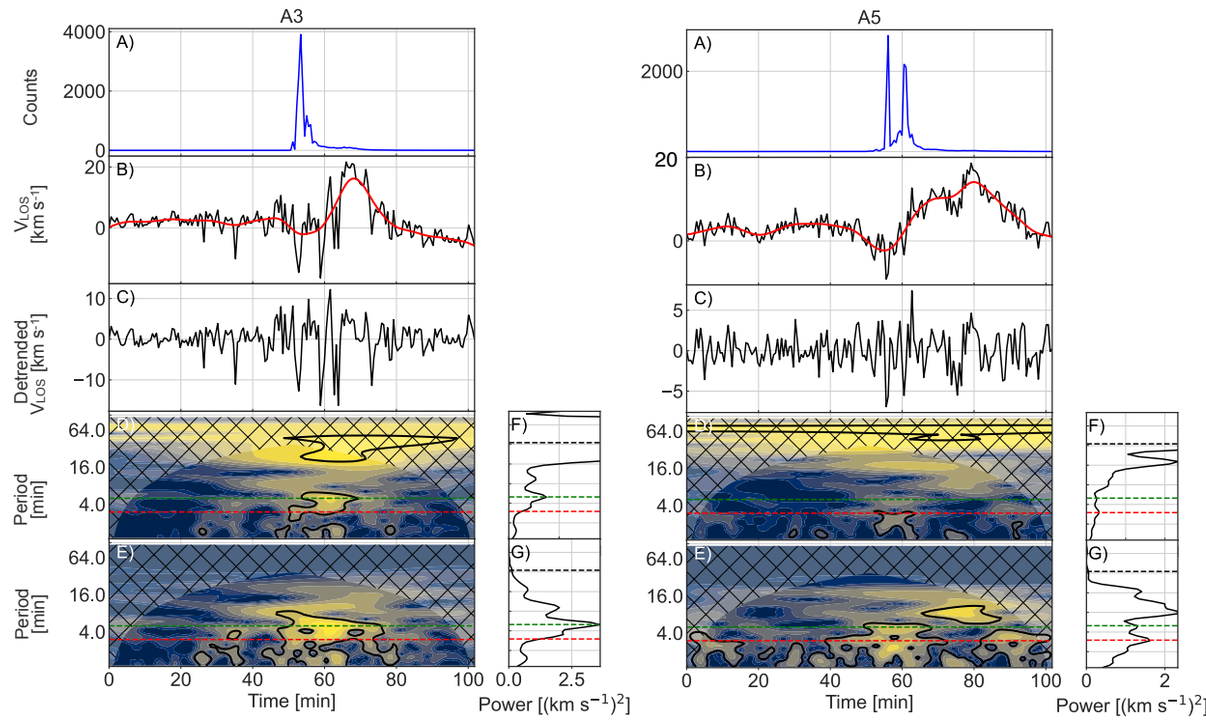
Panels C, D, and E show Doppler velocity maps for the stationary, moderate, and strong downflow components.

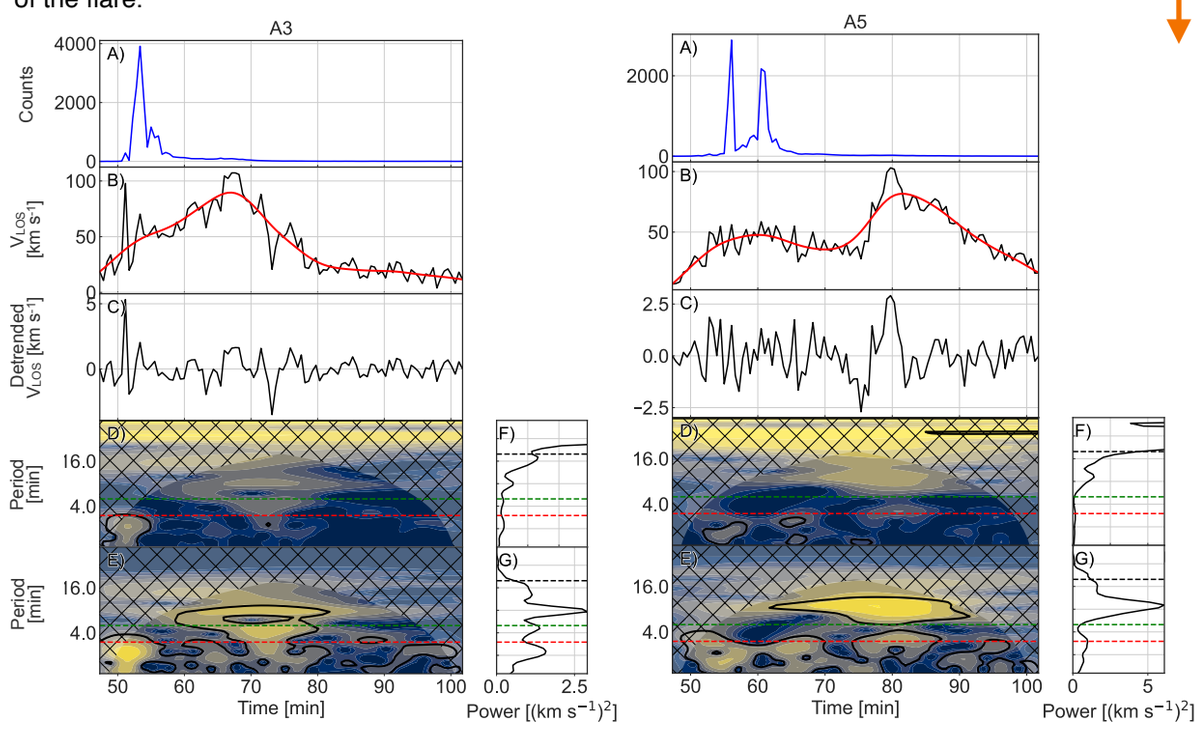


4 Wavelet analysis

Wavelet analysis for the stationary component at two locations within the flare ribbons is presented. The analysis was performed on both the original and detrended velocity variations, with the detrending carried out using Fourier filtering. Locations A3 and A5 exhibit enhanced 5-minute oscillations during the impulsive phase of the flare. Additionally, location A5 shows 10-minute oscillations during the decay phase. These locations, A3 and A5, are marked in panel ❸.

Wavelet analysis for the downflowing component at the same locations is presented below. Enhanced oscillations with an 8-10 minute periodicity were observed following the impulsive phase of the flare.

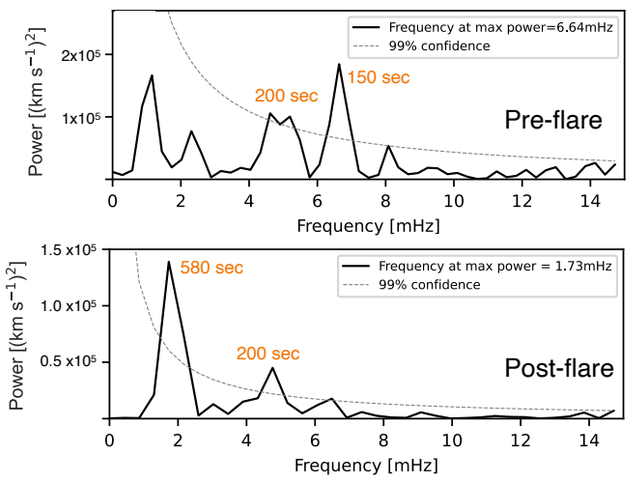




5 Oscillations in sunspot penumbra

The IRIS rasters also cover part of the sunspot penumbra near the flare. Refer to the white box plotted on the IRIS 1400 SJI image in panel ❶. We analyzed oscillations during both the pre-flare and post-flare phases. Before the flare, the penumbra exhibited ~3-minute oscillations. However, after the flare, the dominant oscillatory period shifted to around 10 minutes.

The Doppler velocities were measured by fitting a single Gaussian to the average Si IV profiles within the white box.



Summary

- We analyzed an M-6.5 class flare observed by IRIS, focusing on the quasi-periodic oscillations (QPOs) in the Doppler velocity measured in the Si IV line at the flare ribbons. Our findings reveal variations in the period of oscillatory signals throughout different phases of the flare.
- The QPO analysis was conducted on both stationary and downflowing Doppler components of the Si IV line.
- During the impulsive phase of the flare, we observed enhanced 5-minute oscillations in the stationary component, accompanied by an increased amplitude of the oscillatory signal. Following the impulsive phase, longer period oscillations, approximately 10 minutes, were detected at certain locations.
- In the downflowing component, longer periodicities of 8-10 minutes were prominent during the gradual decay phase of the flare.
- The nearby sunspot penumbra exhibited ~3-minute oscillations prior to the flare, which were replaced by enhanced ~10-minute oscillations after the impulsive phase.
- One possible explanation for the longer-period oscillations is a change in the magnetic field orientation, which may become more inclined following the flare (see Millar et al., 2024, MNRS, 527, 5916).
- The enhanced 5-minute oscillations in the flare ribbons during the impulsive phase may arise from changes in the formation height of the Si IV line, with contributions from deeper atmospheric layers. See Kerr et al., 2019 (ApJ, 187, 23) for a detailed study of the Si IV line formation during flares.