Properties of p-mode oscillations observed in strong H-α flares

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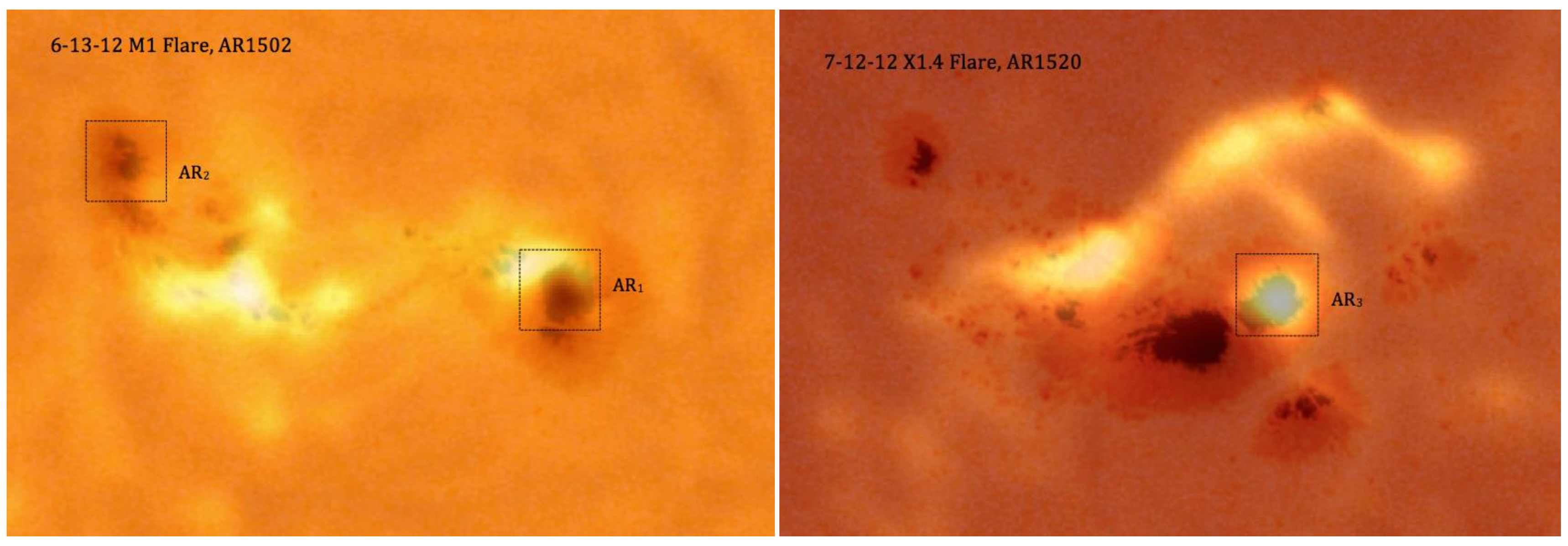
Abstract: We have analyzed H-α intensity images obtained at a 60-sec cadence with GONG to investigate the properties of oscillations in the p-mode frequency band at the location and time of strong X-class flares. For each of three flares, we extracted time series in as many as seven sub regions located at physically distinct positions including the flare core and quiet areas outside the flaring region. The time series were analyzed with a moving power-map analysis to examine power as a function of frequency and time. We find that, in the heart of all three flares, the low-frequency power (~1-2 mHz) is substantially enhanced immediately prior to and after the flare, and that power at all frequencies up to 8 mHz is depleted at flare maximum. This depletion is both frequency and time dependent, which probably reflects the changing depths visible during the flare in the bandpass of the filter. These variations are not observed outside the flaring region. The depletion may indicate that acoustic energy is being converted into thermal energy at flare maximum, while the low-frequency enhancement may arise from an instability in the chromosphere and provide an early warning of the flare onset.

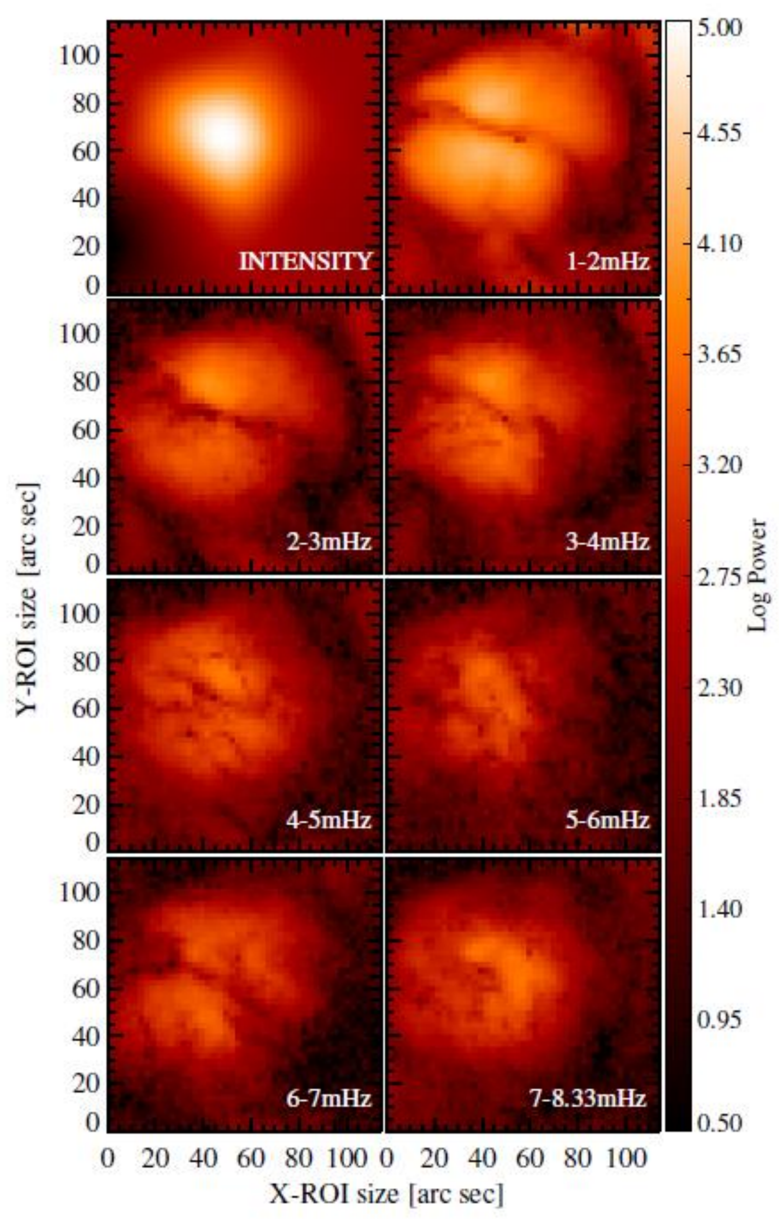
Analysis 1: A moving power-map analysis was applied to regions AR1-3. In this analysis, at each spatial pixel a 60-min time series is extracted and a 1-D FFT is applied to produce a temporal power spectrum at that location. These spectra can be averaged over temporal frequency bands to produce power maps, as seen below. The start time of the time series is then shifted by one minute and the procedure repeated 60 times to build up a power map movie with a 27.8 μHz frequency resolution, 1-min time resolution, and 60-min time extent. The power maps are then averaged over 1-mHz wide bands. An example is shown below for region AR3, covering seconds 1920 to 5520 in the 7200 second time span covered by the analysis. This time span was centered on the time of flare maximum X-ray intensity. The moving power-map analysis was first used by Jackiewicz & Balasubramaniam (2013).

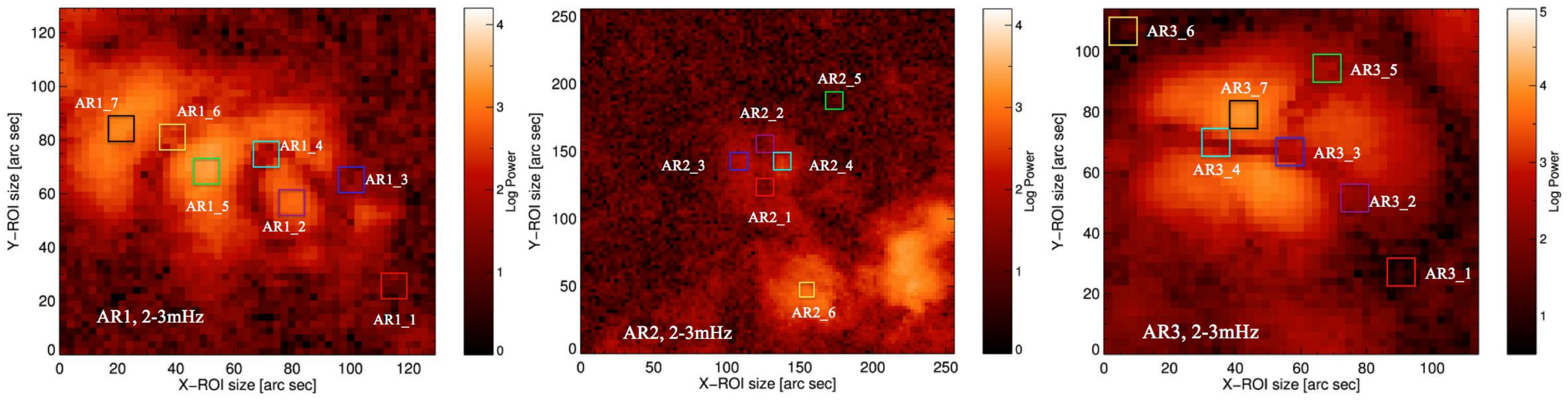
Data: The basic input observations are the 2k x 2k full-disk H-α intensity images obtained with the GONG instruments since 2010. Two large flare events in AR1502 and AR1520 from the summer of 2012 were selected for analysis, with the regions located on the disk close to the central meridian to reduce projection effects. Two subregions from AR1502 and one from AR1520 were analyzed over a two-hour period, centered on flare maximum, as summarized in Table 1 and the images below. The three subregions are each 129 x 129 arcsec in size.

Table 1. Table of observational information of the three data sets.

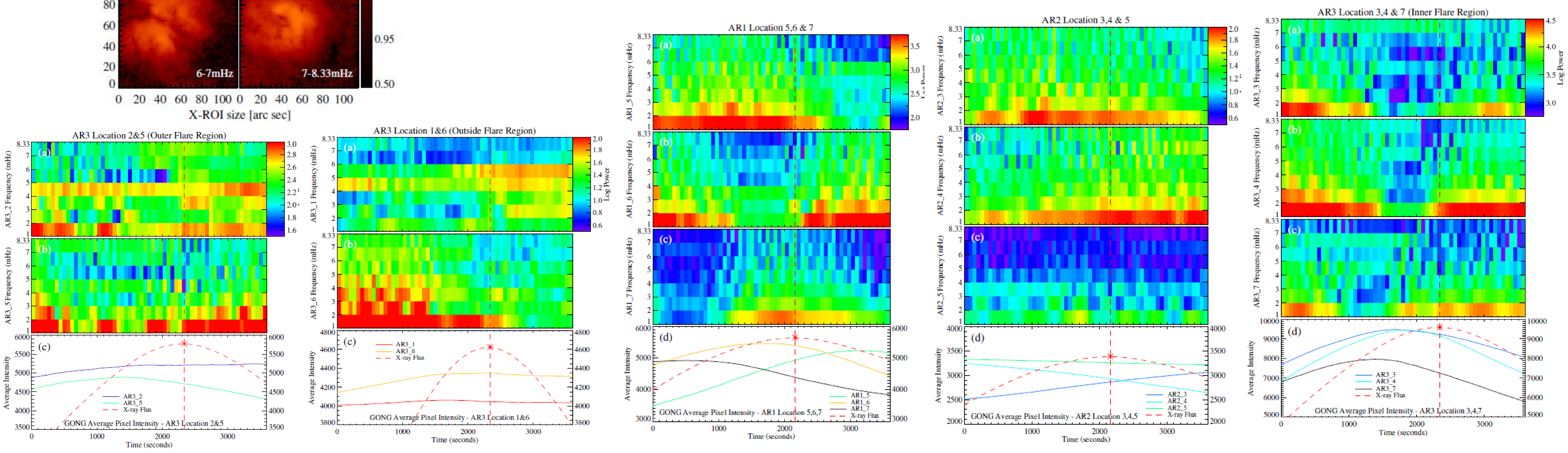
Data Set	Date	Active Region (AR)	Flare Class	Event Time (UT)	Images	GONG Detector	Cadence [s]
AR1	13–Jun–12	AR1502	M1	13:19	121	El Teide	60
AR2	13–Jun–12	AR1502	M1	13:19	121	El Teide	60
AR3	12–Jul–12	AR1520	X1	16:53	121	Cerro Tololo	60







Analysis 2: The power map movies show intriguing dark lanes where p-mode power is apparently suppressed in the flare kernel. In order to examine the temporal behavior of the oscillatory power in these features, as well as in other interesting regions, the power map movies were averaged over a number of small 3 x 3-pixel areas, as shown above. The power as a function of power map start time and frequency for some of these small areas is shown in the set of five images below, along with the GOES X-ray intensity and the GONG H-α intensity as a function of time.



a): AR3_2, b): AR3_5   a): AR3_1, b): AR3_6   a): AR1_5, b): AR1_6, c): AR1_7   a): AR2_3, b): AR2_4. c): AR2_5   a): AR3_3, b): AR3_4, c): AR3_7

Results: The behavior of the power as a function of frequency and time strongly depends on the location of the analysis area and the temporal behavior of the intensity in the area. In the control areas outside of a flare (AR3_1, AR3_6) random variations are observed. This is also the case for flaring regions where the H-α intensity is relatively constant (areas AR3_2, AR3_5, AR 2_3, AR2_4, AR2_5). But in areas where the intensity is strongly varying (AR1_5, AR1_6, AR1_&, AR3_3, AR3_4, AR3_7), a distinctive "V" shape is seen in the color plots. This indicates that the power is suppressed first at the highest frequencies and then, as the H-α intensity increases in the area, the suppression moves to lower frequencies until the time of maximum intensity. At that time, the process reverses with the power levels rebounding first at lower frequencies and then progressing to shorter-period waves. In addition enhanced power at the lowest frequencies of 1-2 mHz is almost always present in the flaring regions but intermittent otherwise.

Discussion: The "V" shape of the power as function of frequency and time in the flaring regions can be understood as a consequence of the nature of the observations and the behavior of the H-α spectral line during a flare. The observations are obtained with a filter that is centered on the wavelength of line core in the quiet Sun. During the course of the flare, the motion of the plasma will change the wavelength of the line due to the Doppler effect, so that the filter bandpass will admit a higher proportion of light from the wings of the spectral line rather than the core. Since the wings of the line are formed at lower heights in the solar atmosphere, and since the peak amplitude of the p-modes shifts to lower frequencies at lower heights, the net effect is to reduce power at high frequencies. This reduction moves to lower frequencies as the flare progresses and the spectral line is increasingly Doppler shifted. When the flare energy decreases, the solar plasma motions die out and the spectral line core moves back towards the center of the filter bandpass, restoring the visibility of the high-frequency power.

In addition to this visibility effect, there may also be a transfer of energy from the oscillations to the flare. This is suggested by the observations in region AR1_7, which seems to undergo an additional suppression of high-frequency power well after the intensity fades. The enhanced low-frequency power in the flaring regions is also interesting, as it may result from some instability in the chromosphere. It would be worthwhile to extend the analysis to times well before the flare to see if the presence of enhanced low-frequency power could be a useful flare forecasting tool. Finally, incorporating magnetic field observations and additional flares into the analysis will allow further understanding of the behavior of p-mode oscillations in the presence of flares.

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