# Investigating Flares and Solar Global Oscillations in Mg II from GOES-16 EXIS


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## Introduction

### Geostationary Observational Environmental Satellite 16 (GOES-16)

- Launched November 19, 2016
- The Extreme Ultraviolet and X-Ray Sensor (EXIS) gives high cadence data for x-ray (1 sec) and MUV (3 sec) emissions.

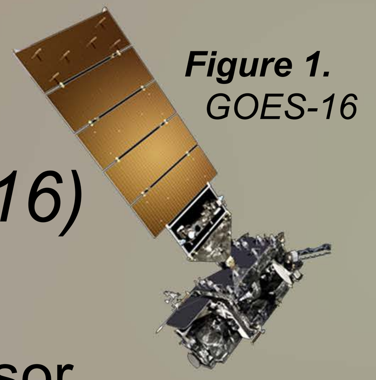


**Figure 1.** GOES-16

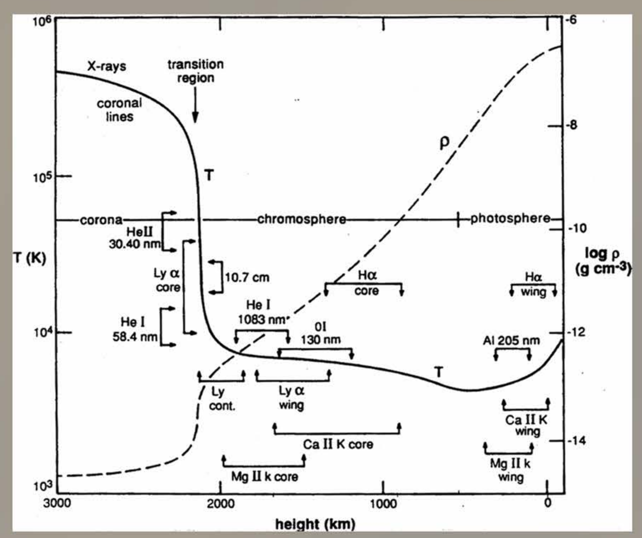


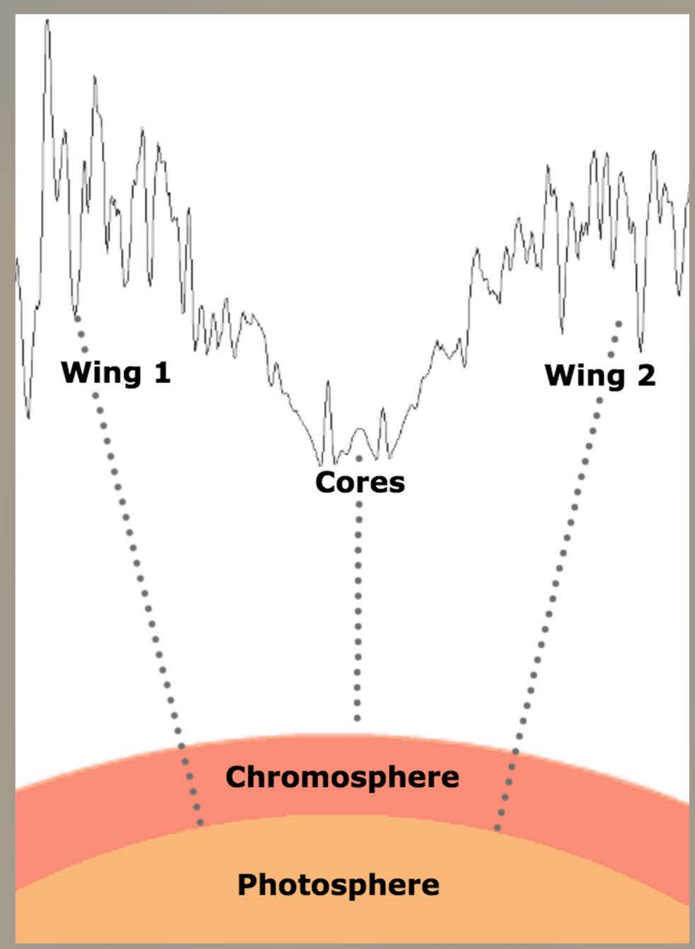
**Figure 2.** *This plot shows the formation heights of various spectral features, as well as their associated temperature and pressure ranges.*

*Note that the Mg II core forms in the chromosphere, the Mg II wing in the photosphere, and x-rays in the corona.*

### Spectral Lines

- The Mg II index is the ratio of the Mg II h core and k core to the Mg II wings.
- The wings sample the photosphere while the cores sample the chromosphere, as seen in Figure 3.
- Mg II cores are much more sensitive to changes than the wings.
- Magnesium II emits in the middle ultraviolet (MUV).

**Figure 3.** *Time series shown over formation locations*




### Helioseismology

- Just as seismology probes Earth's interior, helioseismology is used to infer properties about the internal structure and mechanics of the Sun.
- This study uses acoustic waves (p waves) to examine global solar oscillations (global modes) from disk-integrated spectral lines.
- Two well-studied global modes are oscillations lasting approximately 3 and 5 minutes.
- Using wavelet analysis, the power of each frequency can be identified from time series.

## Solar Flares

### Flare Peak Time Delay

- Flares peak in MUV 151 ± 25 seconds on average before in x-ray. (Figure 4)
- In fact, flares can be seen in Mg II on average 31 ± 10 seconds before He 304. See Figure 2 for formation heights and temperatures.

### Long Duration Flares

- Figure 4 shows one pair of flares that demonstrates how regular flares have a sharp peak and rapid decline.
- The Long Duration Events (LDEs), which are flares lasting more than 30 minutes, have gradual declines.

### Physical Explanation

- The time delays give clues to the time evolution of solar flares and the timing of heating in various layers of the solar atmosphere. (Figure 5)

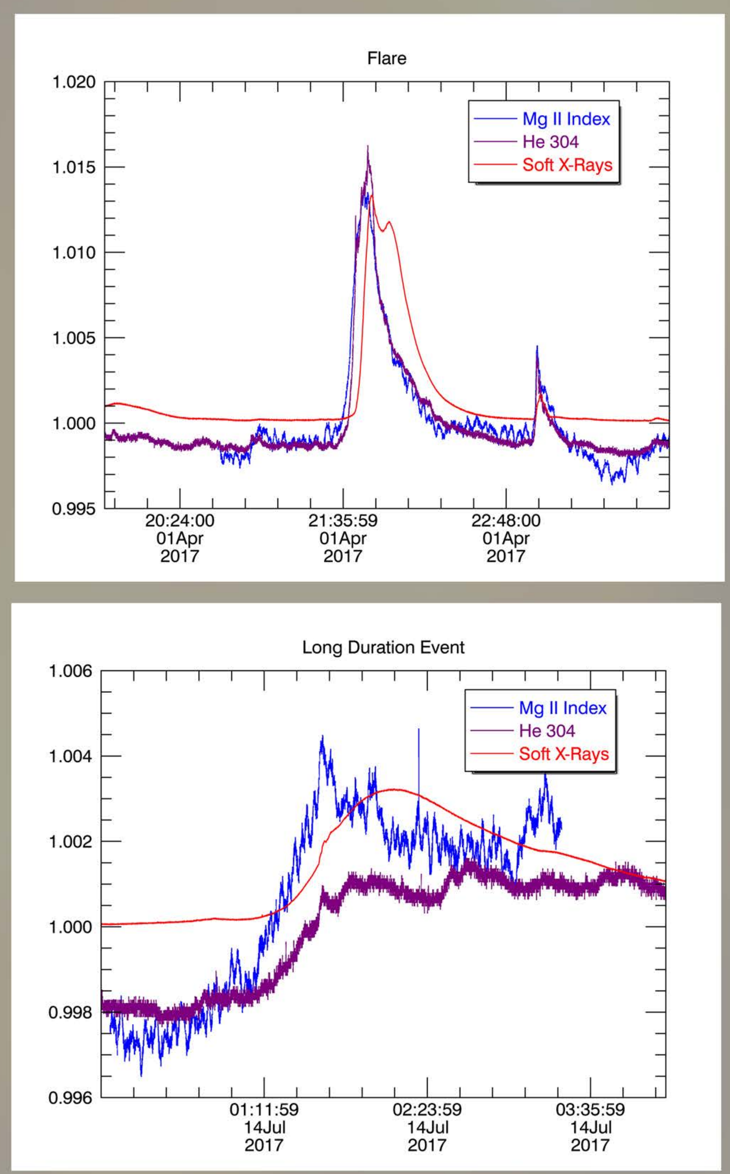



**Figure 4.**
*Upper: The April 1, 2017 M4.4 class flare peaks first in Mg II, then in He 304 ~97 seconds later, and then in soft x-rays another ~109 seconds later.*
*Lower: The July 14, 2017 M2.4 class LDE flare peaks first in Mg II, then in He 304 ~204 seconds later, and then in soft x-rays another ~618 seconds later.*

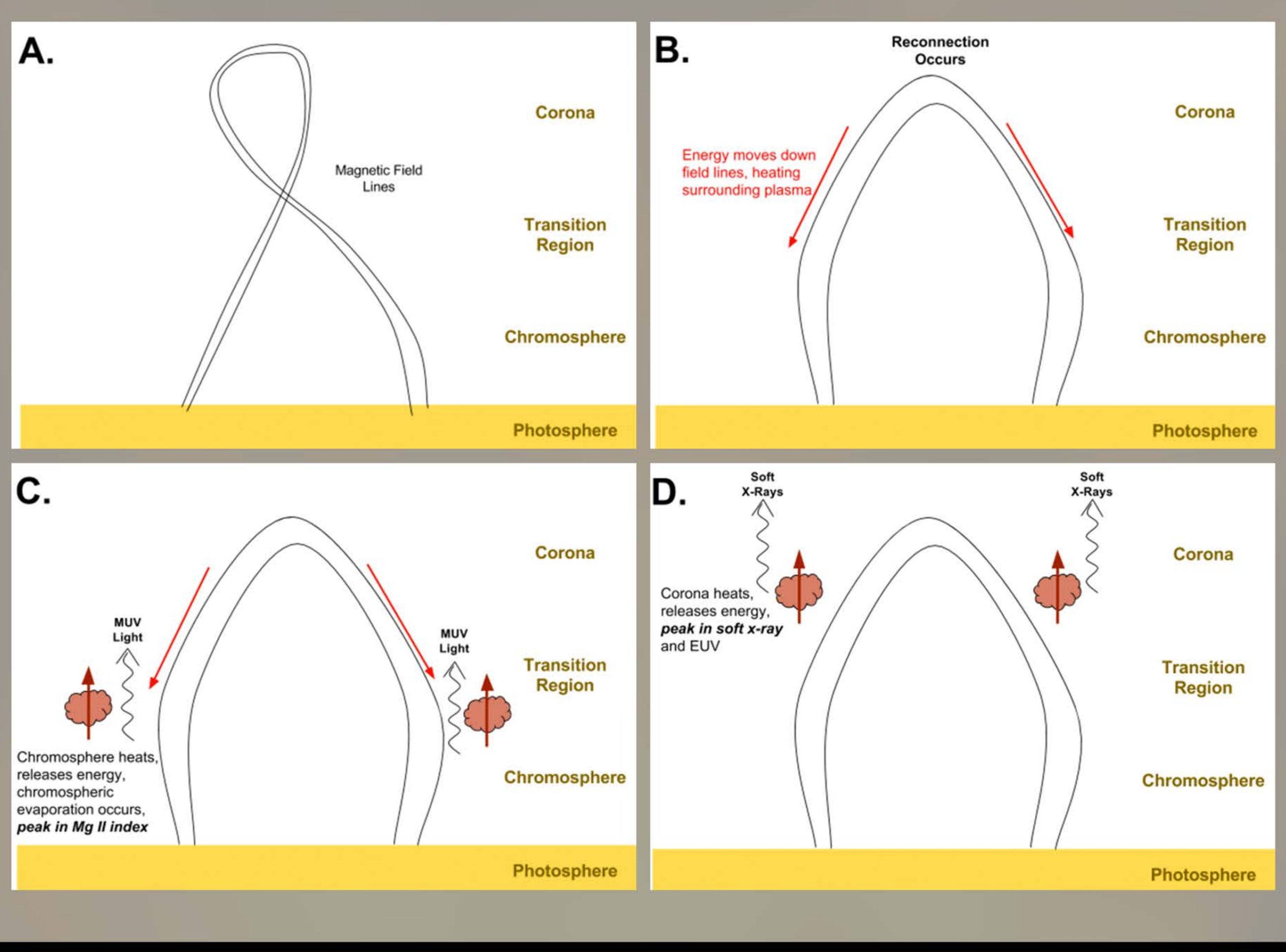



**Figure 5.**
*A. Magnetic field lines are twisted before the flare occurs.*
*B. Magnetic reconnection occurs. Energy moves down the field lines into the transition region and chromosphere.*
*C. The plasma heats, and the flare is seen in the Mg II cores. The transition region then heats to a higher temperature (Figure 2) and the flare is seen in He 304.*
*D. Finally, the corona heats to the high temperatures needed for the soft x-ray flare signature to be seen.*

## Global Solar Oscillations

### Periodogram Analysis

- The 3 and 5 minute oscillations vary in both period and power over time in agreement with previous results.[1]
- Looking at periodograms for quiet days when there were no active regions on the sun, there is a correlation between saddle points in the wing and peaks in the core periodogram. There is a delay in time and period shortening associated with this correlation (Figure 7).

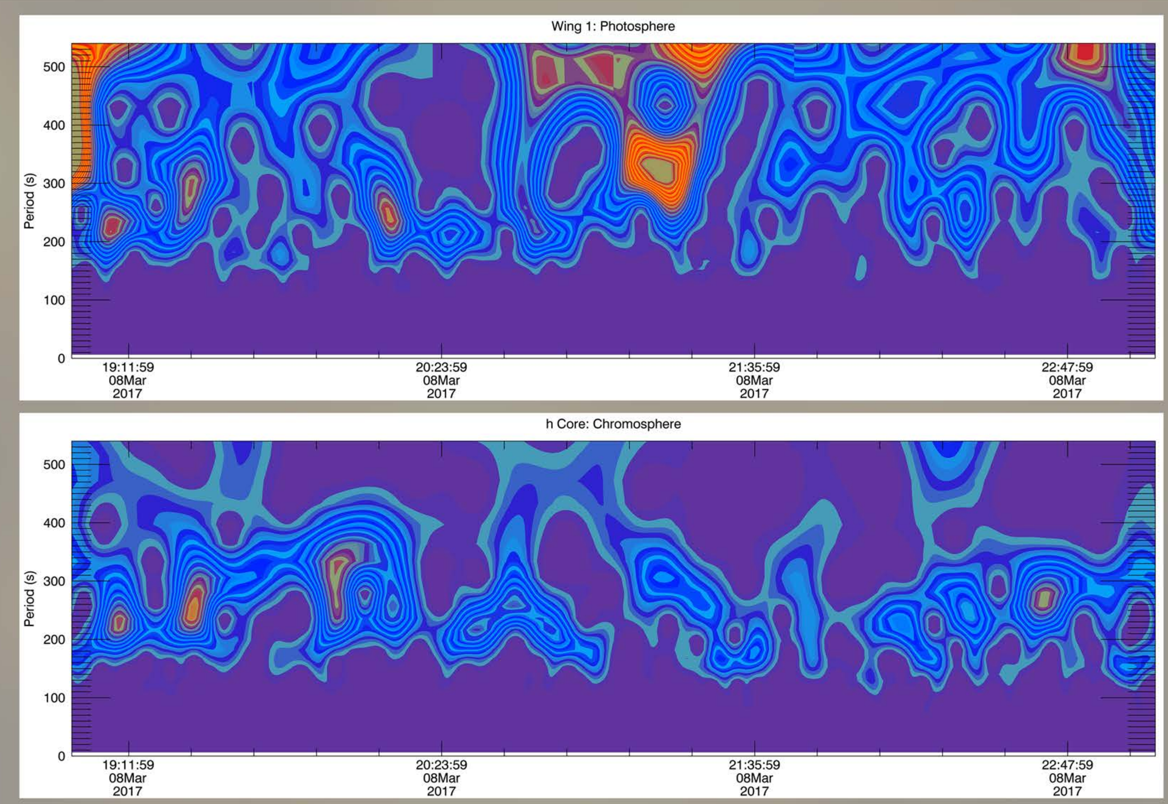



**Figure 6.**
*A set of photospheric and chromospheric periodograms for ~4 hours of a quiet day. Similar periodograms were constructed for other active and quiet days.*

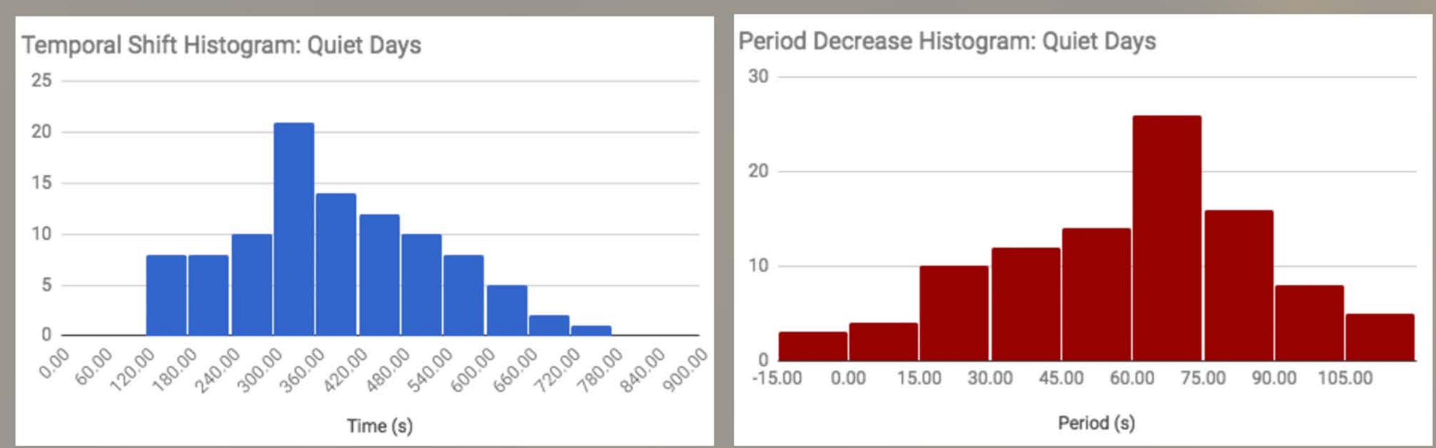



**Figure 7.**
*Left: The histogram shows the time delays between wing saddle points and core peaks. The mode is a 5-6 minute delay.*
*Right: The histogram shows the period shortenings between wing saddle points and core peaks. The mode is a 60 to 75 second delay.*
*The data is from 99 saddle points out of a total 137 taken over roughly 18 hours of periodograms.*

## Conclusions

### Results

- The 3 and 5 minute oscillations vary in both period and power over time.
- A correlation exists between the photospheric saddle points and chromospheric peaks in quiet day periodograms.
- LDEs are distinguishable from flares in Mg II.
- Flares peak in MUV 151 ± 25 seconds on average before in x-ray and 31 ± 10 seconds on average before in He 304.

## References

### Images

**Image Sources:** (1) "Naming a GOES Satellite." GOES-R Has Become GOES-16, National Oceanic and Atmospheric Administration, 30 Nov. 2016. (2) Vernazza, J. E., et al. "Structure of the Solar Chromosphere. III - Models of the EUV Brightness Components of the Quiet-Sun." The Astrophysical Journal Supplement Series, vol. 45, 1981, p. 635. (Background) Public domain.

### Selected References


1. *Abramov-Maximov, V. E., et al. "A Comparison of Parameters of 3-Minute and 5-Minute Oscillations in Sunspots from Synchronous Microwave and Optical Observations." Proceedings of the International Astronomical Union, vol. 4, no. S257, 2008, pp. 95–99.*
2. *Costa, Fatima Rubio Da, and Lucia Kleint. "A Parameter Study for Modeling Mg II h and k Emission During Solar Flares." The Astrophysical Journal, vol. 842, no. 2, 2017, p. 82.*
3. *Delache, Philippe. "Quiet Sun." Space Science Reviews, vol. 29, no. 4, 1981.*
4. *Kerr, G. S., et al. "IRIS Observations of the Mg II h and k Lines During a Solar Flare." Astronomy & Astrophysics, vol. 582, 2015.*
5. *Kumar, Brajesh, et al. "On the Flare Induced High-Frequency Global Waves in the Sun." The Astrophysical Journal, vol. 711, no. 1, Oct. 2010.*
6. *Lemaire, P., et al. "Simultaneous H and K Ca II, h and k Mg II, Lα and Lβ H I Profiles of the April 15, 1978 Solar Flare Observed with the OSO-8/L. P.S.P. Experiment." Solar Physics, vol. 90, no. 1, 1984, pp. 63–82.*