# Waves and Oscillations in Umbral and Penumbral Regions of Sunspots

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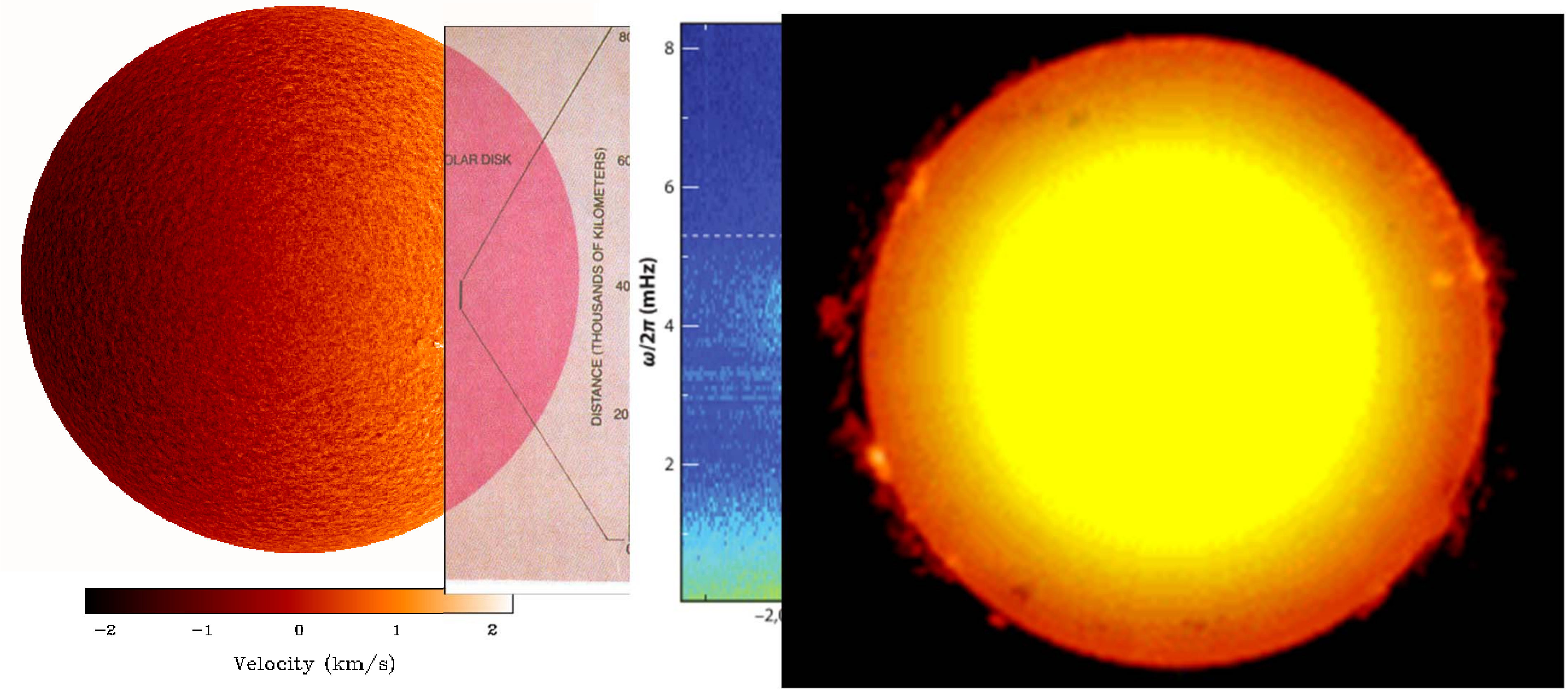
# Background and Motivation

**Photospheric Oscillations:**

- Leighton et al. 1962: five minute oscillations at the photosphere
- Theoretical interpretation: Ulrich 1970, Leibacher and Stein 1971
- Observationally confirmed by Deubner 1975 and others

$$f(x,t) = \int A(k,\omega) e^{i(kx+wt)} dk\, dw$$



# Background and Motivation

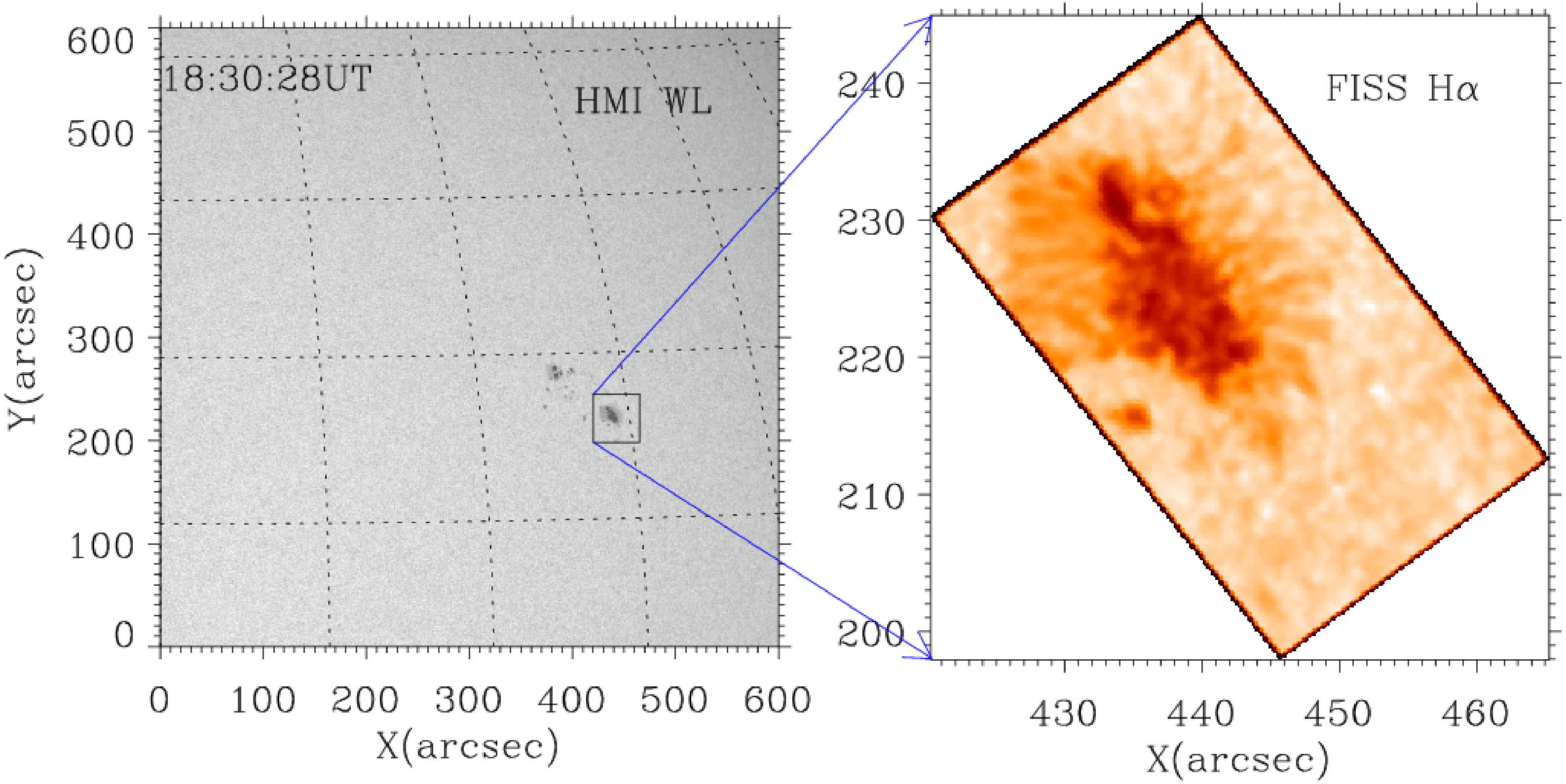
## Chromospheric Oscillations:

- quasi-harmonic fluctuations of velocity and brightness in the K-line of Ca II (Jensen & Orrall, 1963, and others)
- not well understood

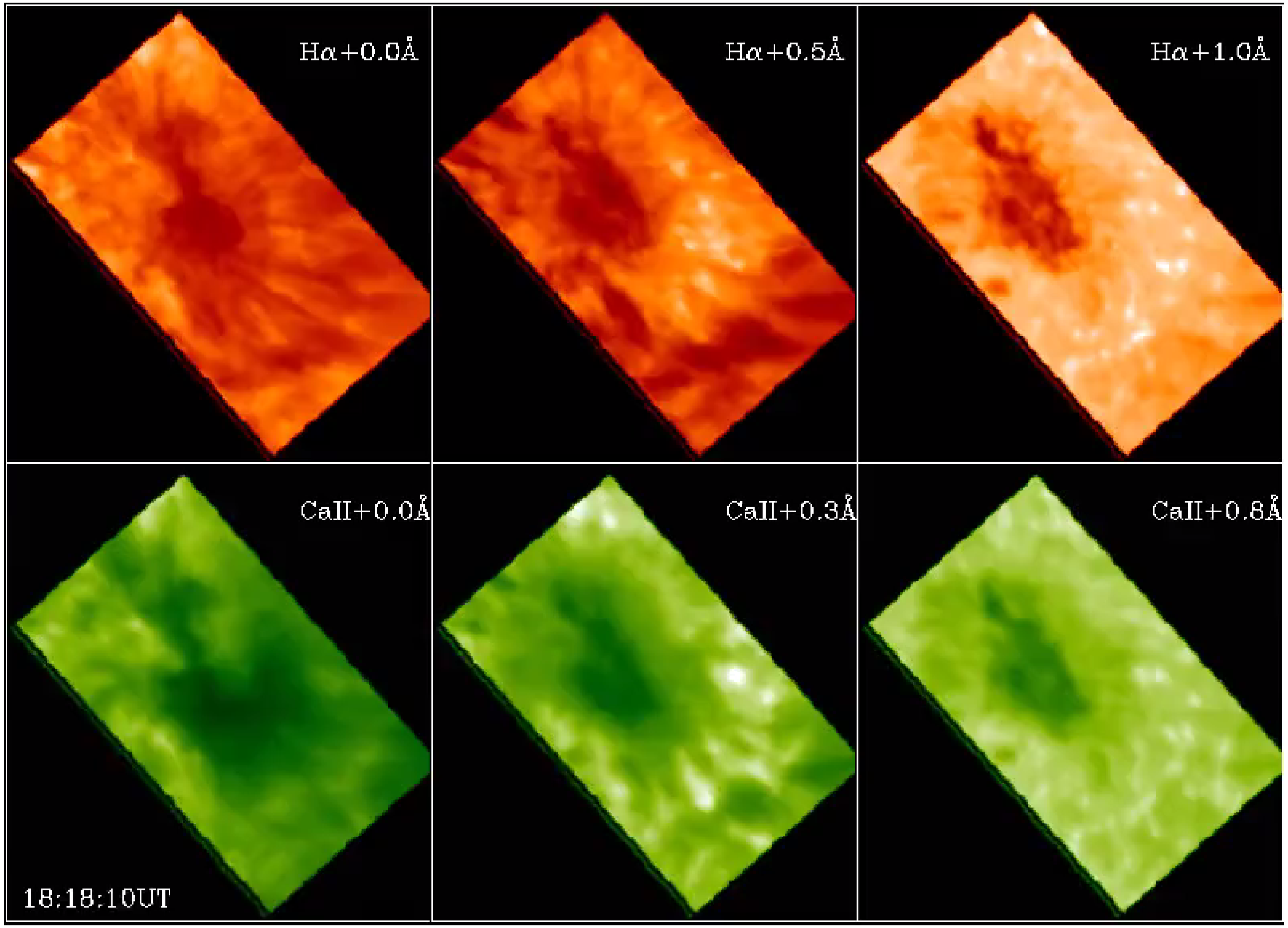
## Why do we study?

- waves and associated oscillations: properties of the region from which they originate and through which they propagate
- sunspot oscillations have close association with activities of active regions
- chromospheric and coronal heating
- local helioseismology uses the oscillation properties

# FISS Observations of AR NOAA 11242, 30 June 2011




- ➢Fast Imaging Solar Spectrograph (FISS), a backend instrument of the 1.6m *New Solar Telescope* at Big Bear Solar Observatory



Hα+0.0Å
Hα+0.5Å
Hα+1.0Å
CaII+0.0Å
CaII+0.3Å
CaII+0.8Å
18:18:10UT

# Umbral-Flashes

## Observations:

- ➢ first discovered by Beckers and Tallant (1969) in Ca II H and K filtergrams and spectrograms observations of a sunspot.

## Theory:

- ➢UF brightening occurs in the local umbral gas during **the compressional phase of a magneto-acoustic wave** (Havnes, 1970)

# Umbral-Flashes

For magneto-acoustic waves, wave velocity

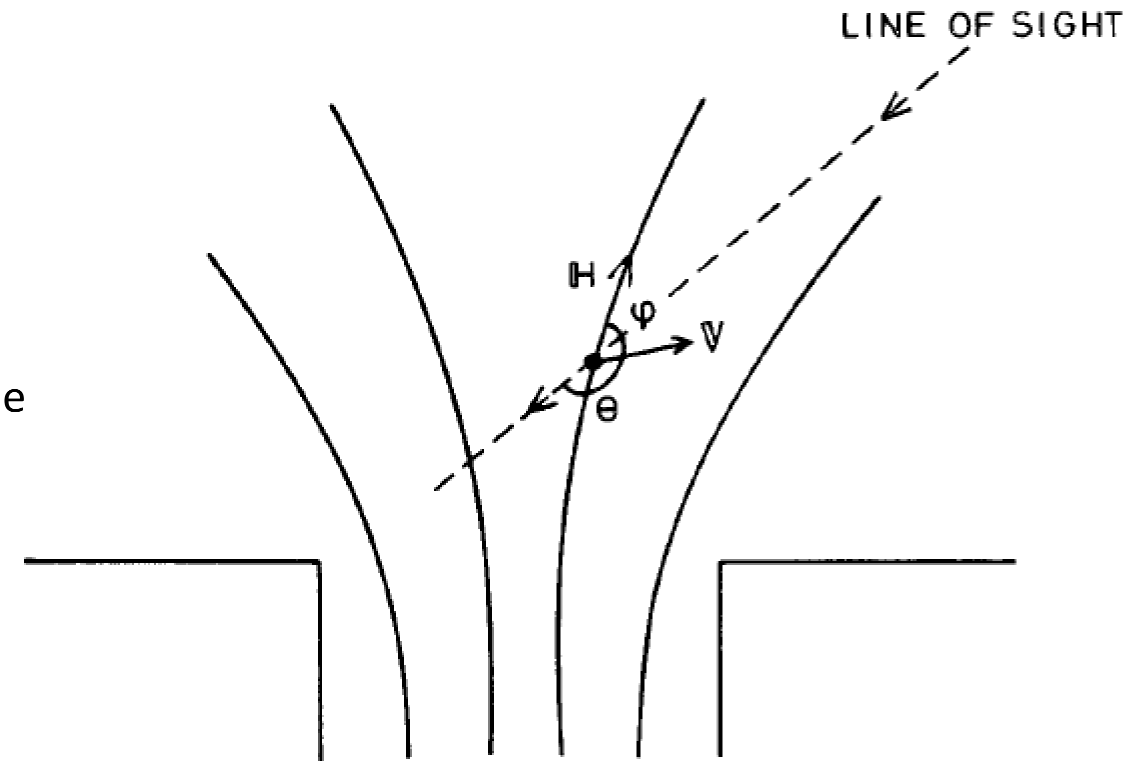
$$V = \frac{V_A}{\sqrt{2}} \sqrt{1 + r \pm \sqrt{(1+r)^2 - 4r\cos^2\varphi}}, \qquad r = \left(\frac{V_s}{V_A}\right)^2$$

At φ=90°,

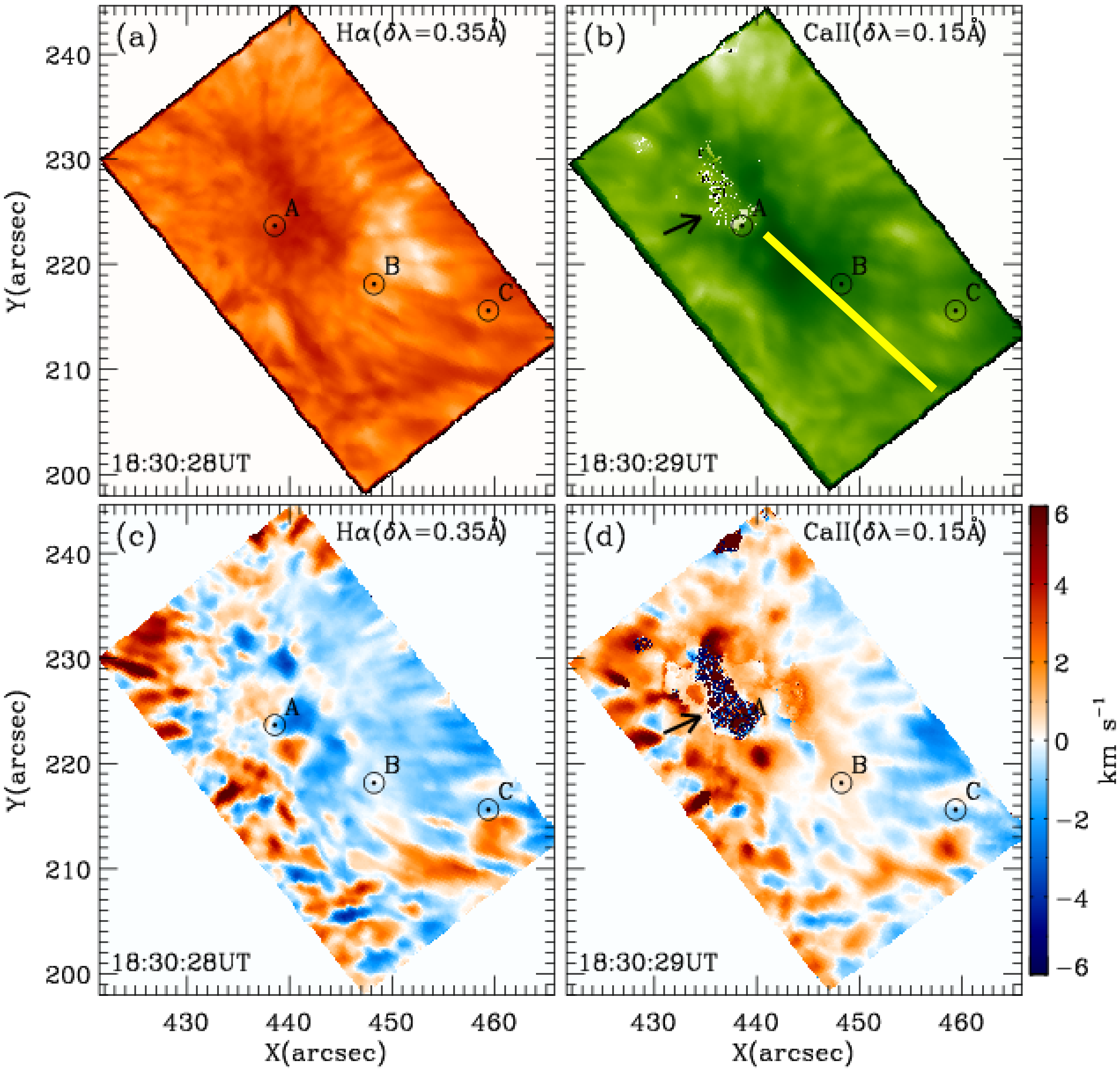
$$V = \sqrt{{V_A}^2 + {V_s}^2}$$

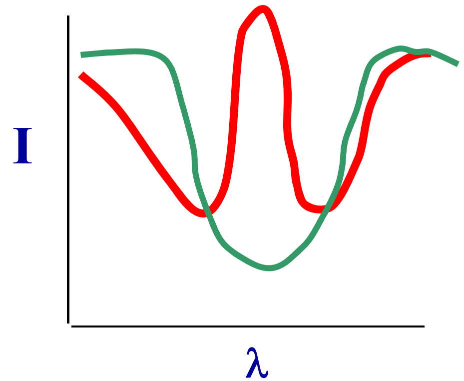
Maximum wavelength shift of line due to MA waves

$$\Delta\lambda_m = \frac{\lambda_0 V \cos\theta}{c} \frac{\Delta\rho_m}{\rho_0}$$



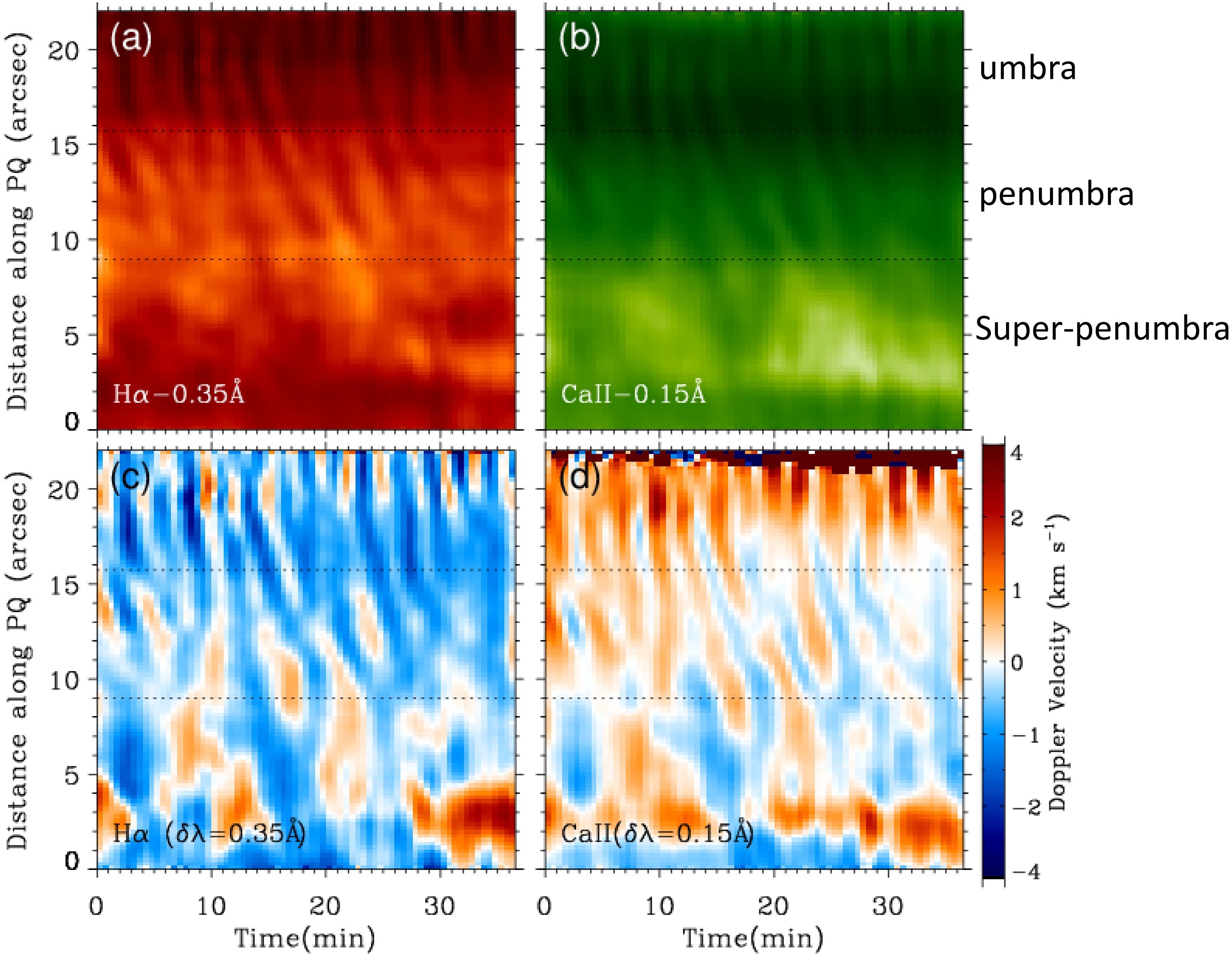
# Chromospheric Dopplergrams




**MDI, GONG, HMI:**
Magnetic and Doppler transients (Maurya et al. 2009, 2011)

# Running Penumbral Waves and Oscillations



# Running Penumbral Waves and Oscillations

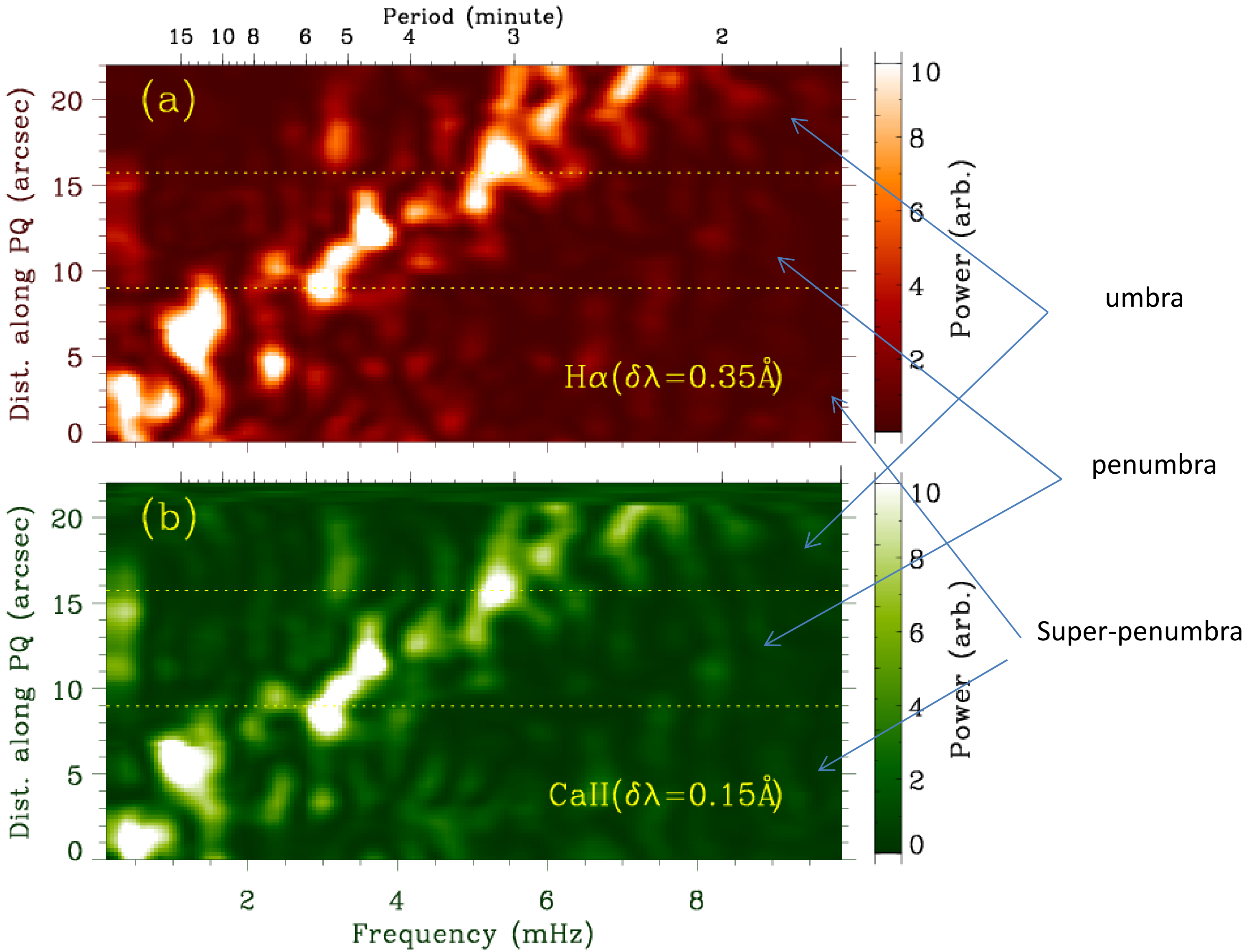
## Observations:

- RPWs were studied first by Zirin and Stein (1972) and Giovanelli (1972), independently, in Hα filtergrams

## Theory:

- Nye and Thomas (1974, 1976): **RPWs are gravity-modified fast magneto-acoustic waves** that are vertically trapped at the photospheric levels. The waves are more nearly acoustic type at the low levels (convection zone), while they are more nearly of Alfvén type at higher levels (photosphere and low chromosphere).

# Distribution of Oscillation Power

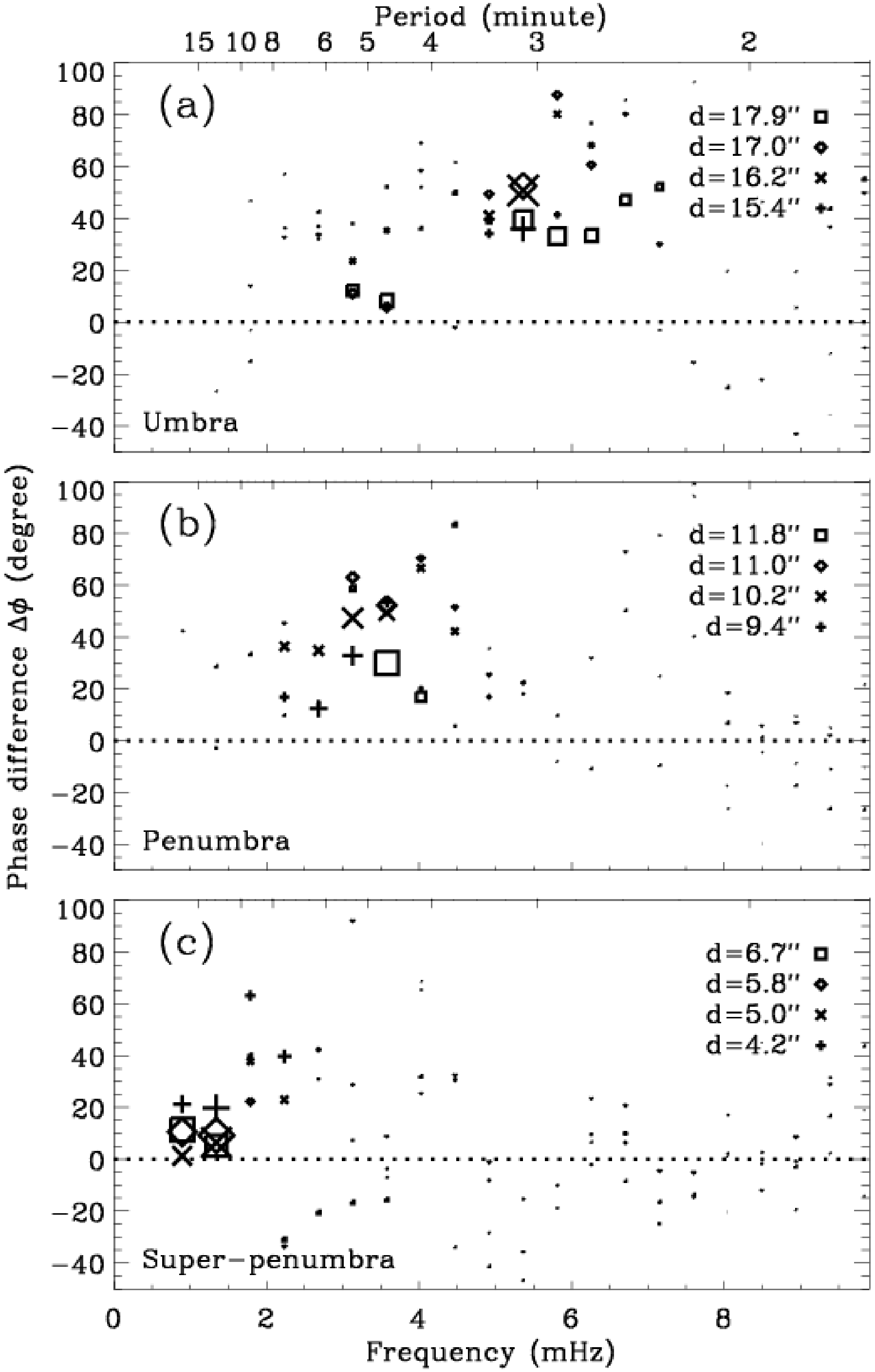



(Maurya et al. 2013, Solar Physics, 288, 73)

# Fourier Phase-difference

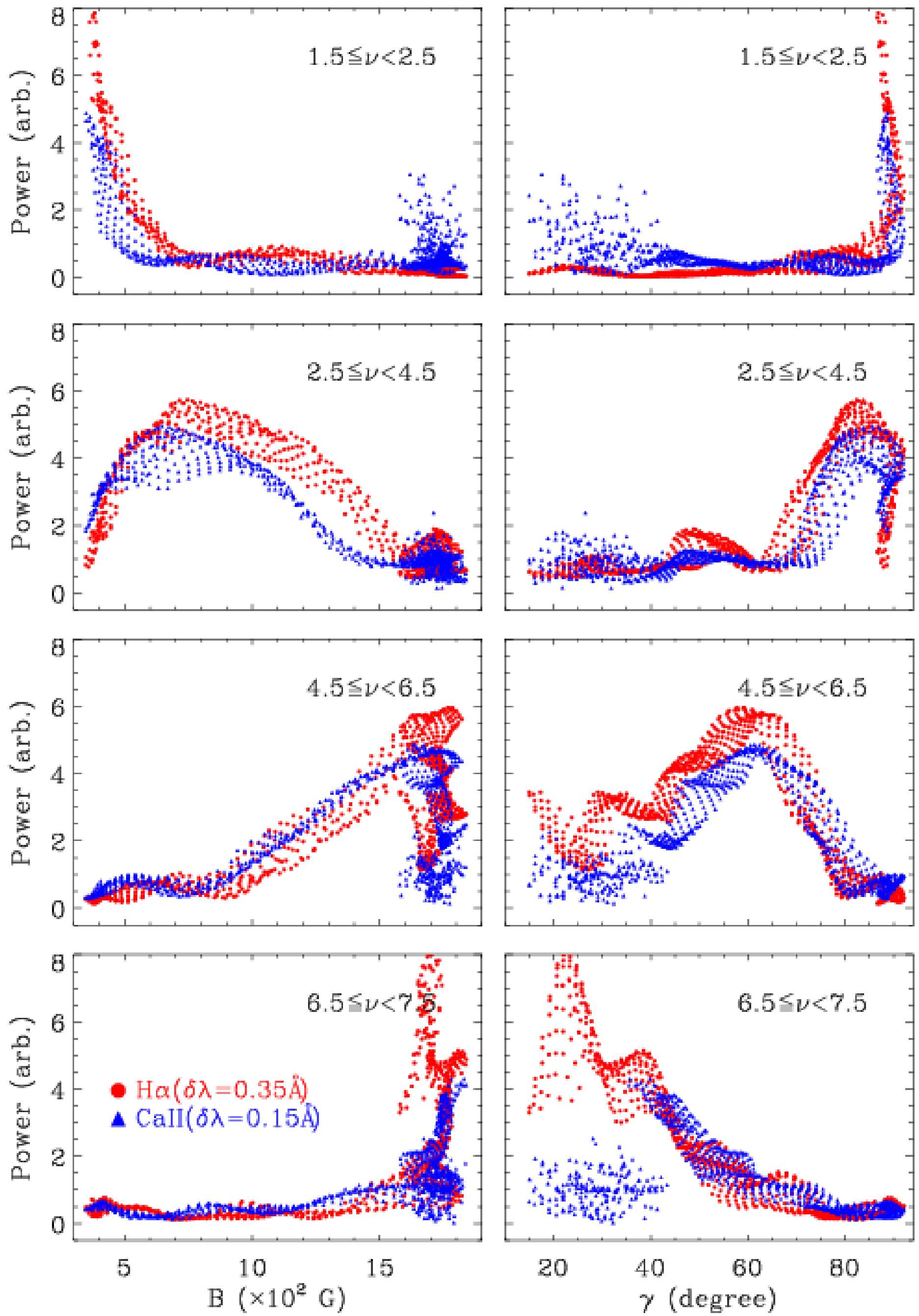
➢phase difference between the Hα (δλ = 0.35 Å) and Ca II (δλ =0.15 Å) Doppler velocities as function of frequency for four locations in the umbra (a), penumbra (b) and super-penumbra (c).

➢The average phase difference in the three and five millihertz frequency bands are around 40° where cross-spectral power is significant.



# Distribution of Oscillation Power

➢oscillation power shows different relations with the magnetic field strength and the inclination in different frequency bands



- MAG waves can propagate upward through T.M. only at frequency above cutoff frequency (Cally et al., 1994)

$$f_c = \frac{g\gamma}{2c_s}, \quad c_s = \sqrt{\frac{\gamma RT}{\mu}}$$

- for MAG waves in the solar atmosphere, $f_c$ will be affected by the B when it is not parallel to the g

$$g = g_0 \cos\vartheta, \quad \Rightarrow f_c \propto \frac{\cos\vartheta}{T}$$

- For example, Umbra: 5.7 mHz (T = 3800, θ=0°), umbral boundary: 5 mHz (T = 3800, θ=30°)

# Summary and Conclusion

- RPWs are better seen in the core of Hα and Ca II,
  - . . . amplitude decreases with λ
  - . . . difficult to distinguish after 0.75Å and 0.50Å, respectively.
  - . . . amplitude decreases from umbra to outward

- RPWs appear as a sort of **continuation of some of the flash waves**. The main difference between the UFs and the RPWs is that the **UFs are best seen in Ca II, while RPWs are best seen in Hα** Dopplergrams.

- suppression of oscillation power at lower frequencies and enhancement at higher frequencies

- frequency of peak power gradually decreases from the umbra to outward

- peak power oscillation frequency seems to be associated with magnetic field and inclination

THANKS