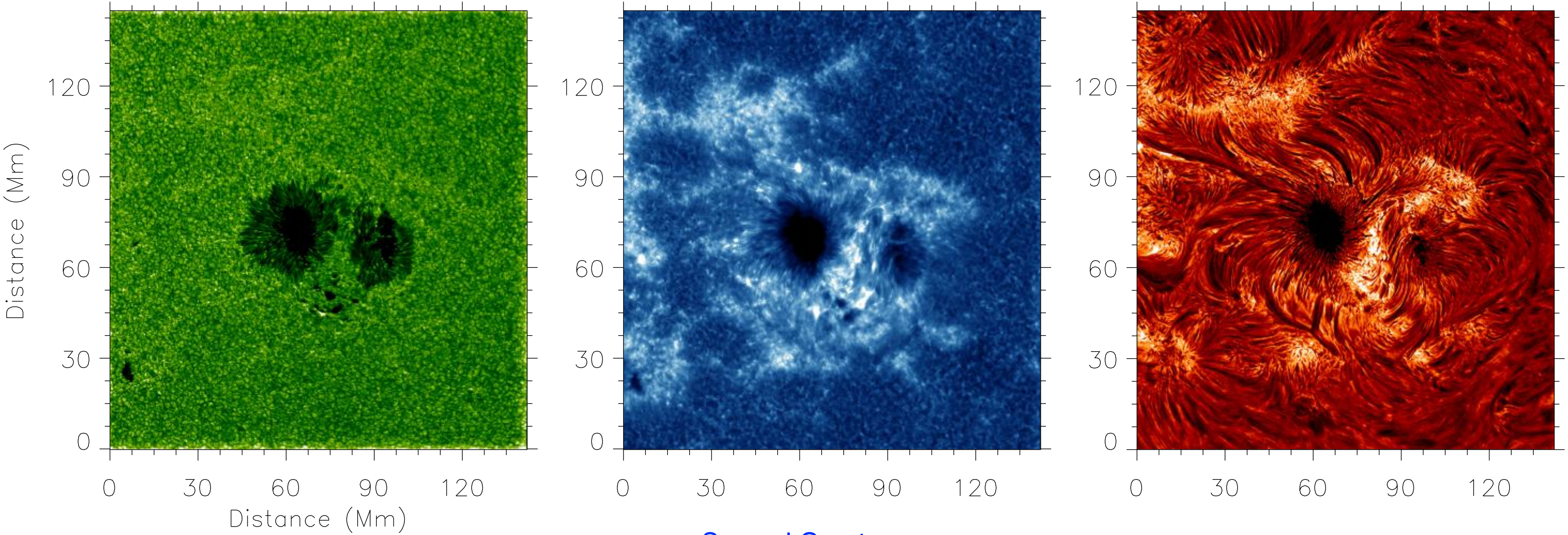
Alfvén Wave Dissipation in the Solar Chromosphere



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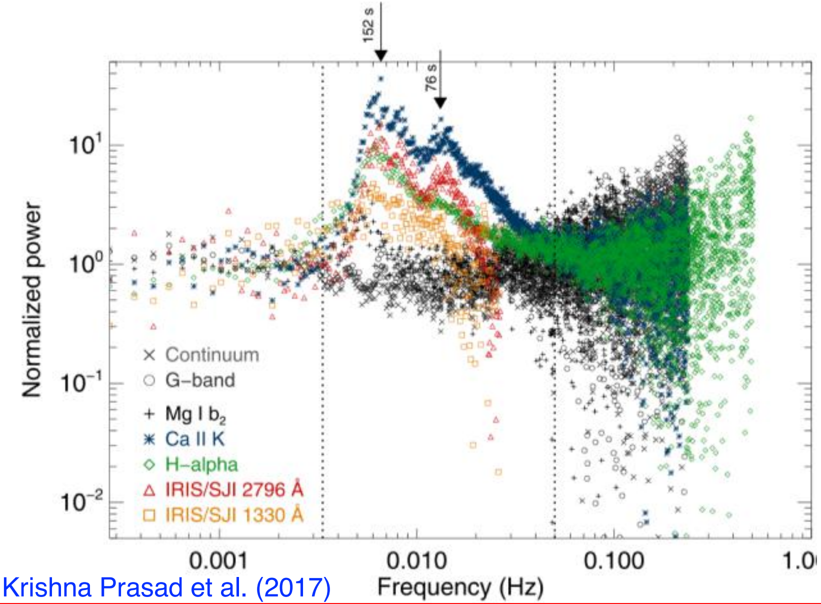
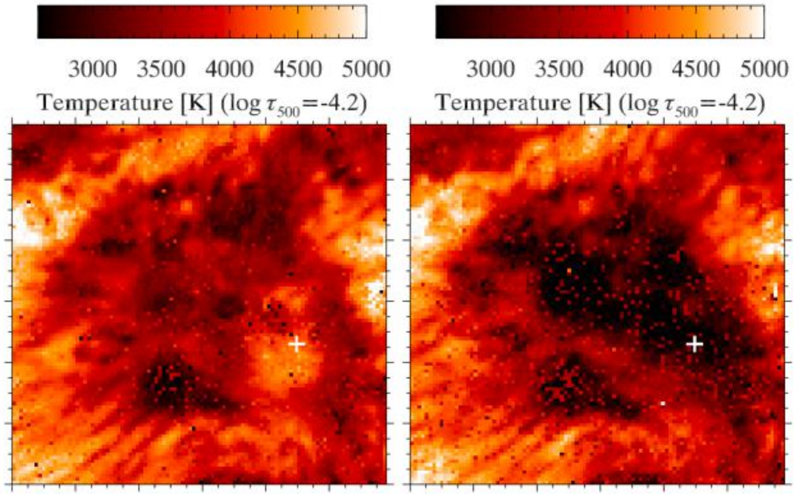
Wave Dissipation

- Damping – reduction in wave power and energy – has been observed
- Dissipation – conversion of energy into plasma heat - elusive



Krishna Prasad et al. (2017)

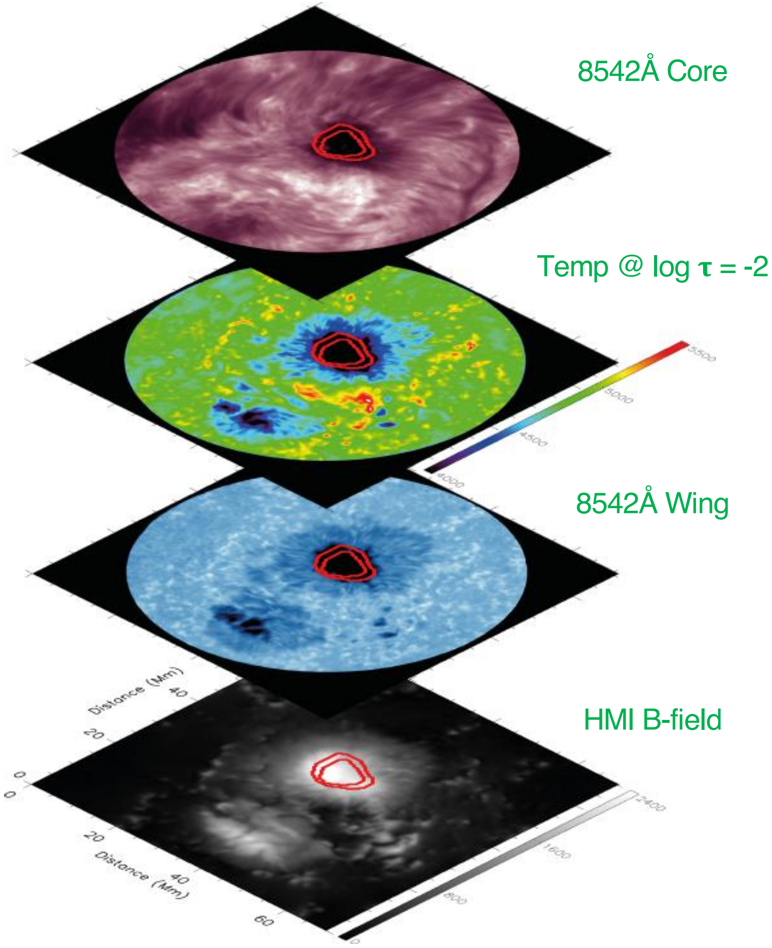
- Umbral Flashes are a macroscopic example of compressible wave dissipation
- Can this be identified for Alfvén waves? Utilising their efficient guiding into the chromosphere



de la Cruz Rodriguez et al. (2013)

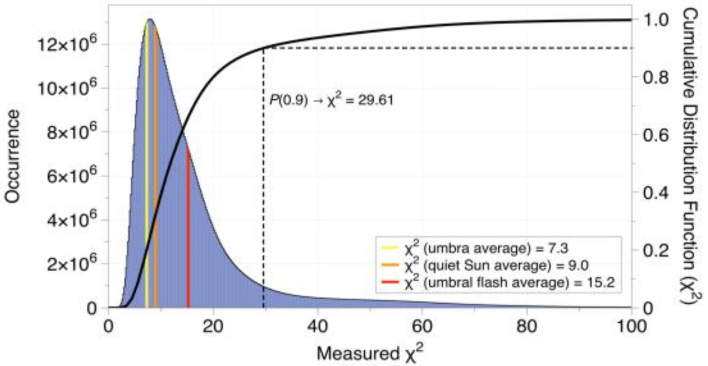
Data Products

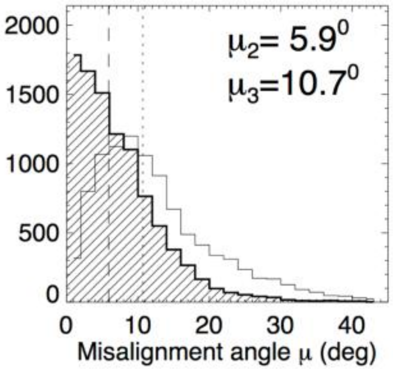
- Fine balance in spectral imaging
- Full Stokes imaging = poorer resolution
- Particularly important for chromsopheric shocks (Felipe et al. 2018)
- IBIS 8542Å Stokes-I observations of sunspot on 24th August 2014
- Purely spectral imaging allowed for 27 wavelength points to be sampled every 5.8s
- However, this meant plasma parameters must be derived in another manner

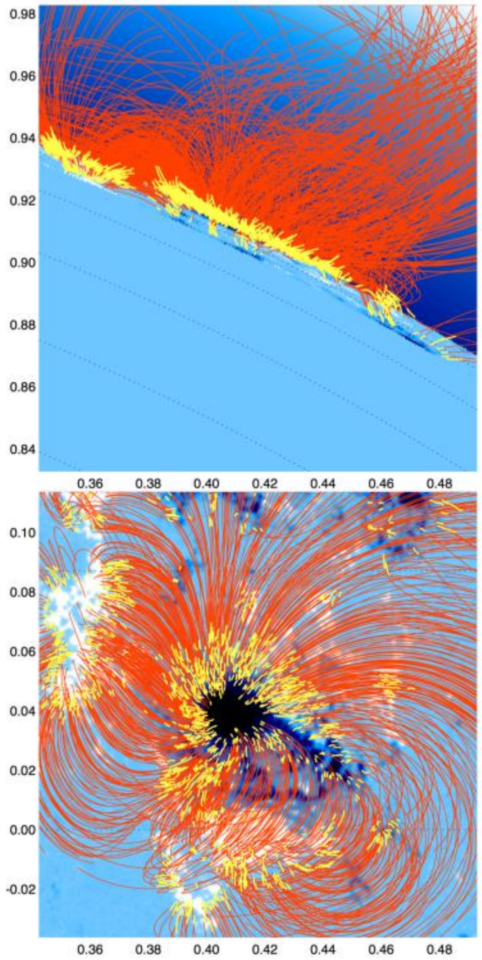


Probing the Sunspot

- Thermal stratification of FOV inferred using *CAlcium Inversions using a Spectral ARchive* (CAISAR; Beck et al. 2015), a fast inversion routine
- Magnetic field geometry derived from Non-Linear Force Free Field extrapolations (Wiegelmann et al. 2008) of HMI magnetograms
- Verified through comparison with simultaneous H-alpha images (Aschwanden et al. 2016)

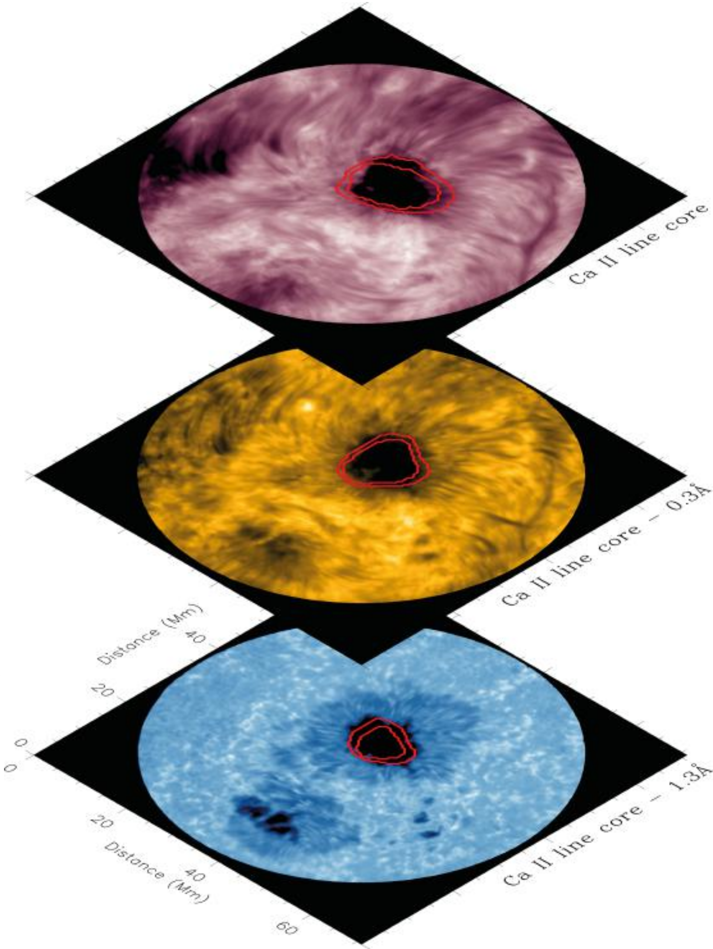




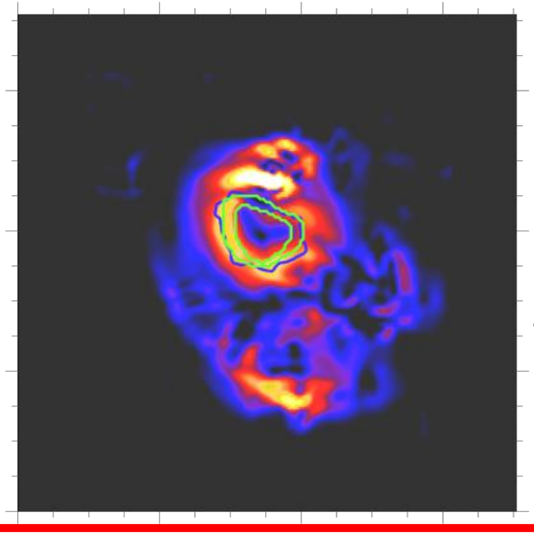


Suitability of the Sunspot

- Plasma parameters reveal wave conduit properties of the sunspot
- Magnetic and gas pressure calculations highlight that $\beta = 1$ mode conversion region exists within umbra
- Encourages a multitude of wave modes to co-exist



- Negative Alfvén speed gradient steepen Alfvén waves (Hollweg et al. 1982)
- Observed at umbra-penumbra boundary
- Implies a region capable of dissipating incompressible modes



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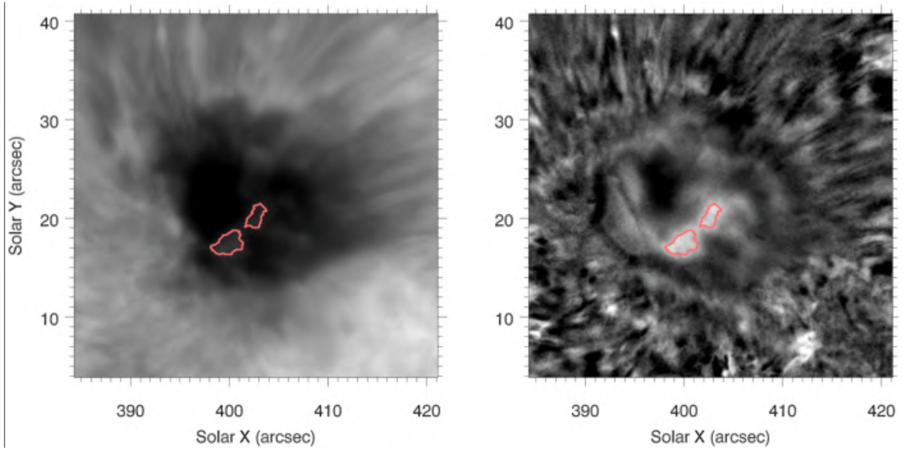
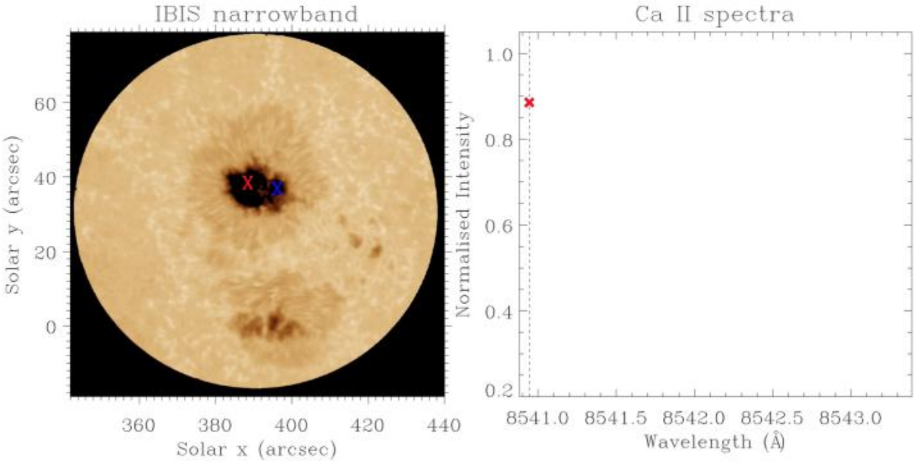
Detecting Shocks

- Running mean subtracted maps used to detect shocked plasma
- Intensity threshold of 2.2σ above the mean defined a flash pixel
- 555,792 spectra associated with shocks identified

- Typical morphology of Umbral Flashes observed, ‘sawtooth’ pattern with strong blueshift
- Improved resolution allowed for greater sampling of shock morphology





Shock Populations

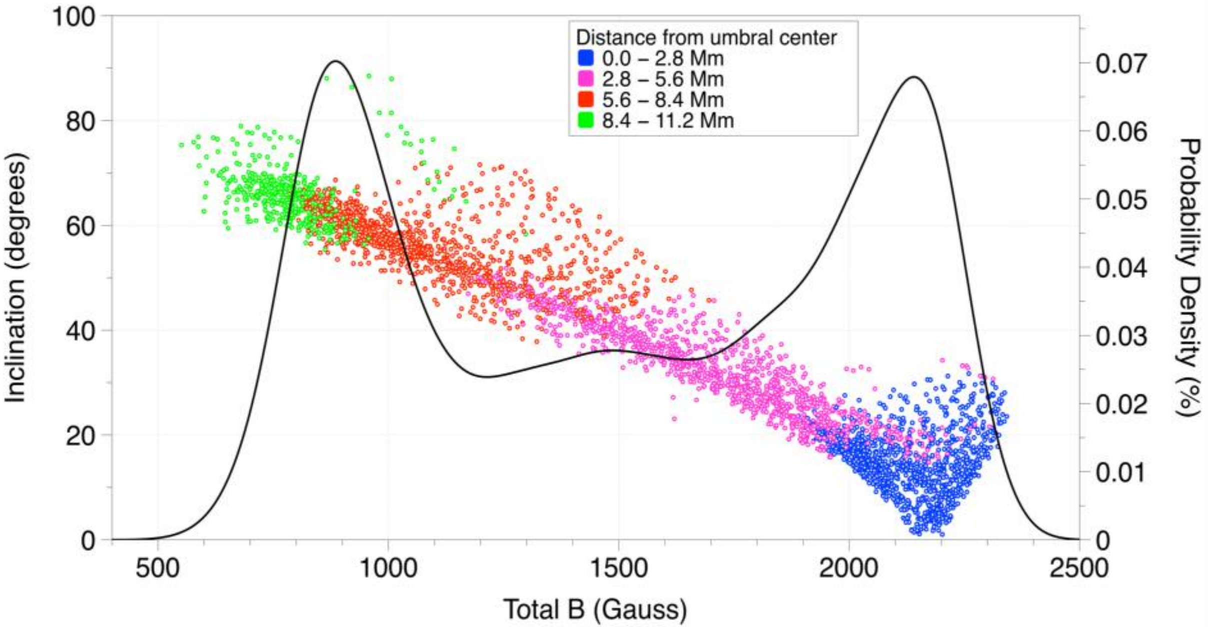
Comparing the occurrence of shock pixels with magnetic field geometry revealed two clear populations, as a function of radius from spot centre

Population 1

Weak B-field

Small density gradient

Inhibits magneto-acoustic shocks



Population 2

Strong B-field

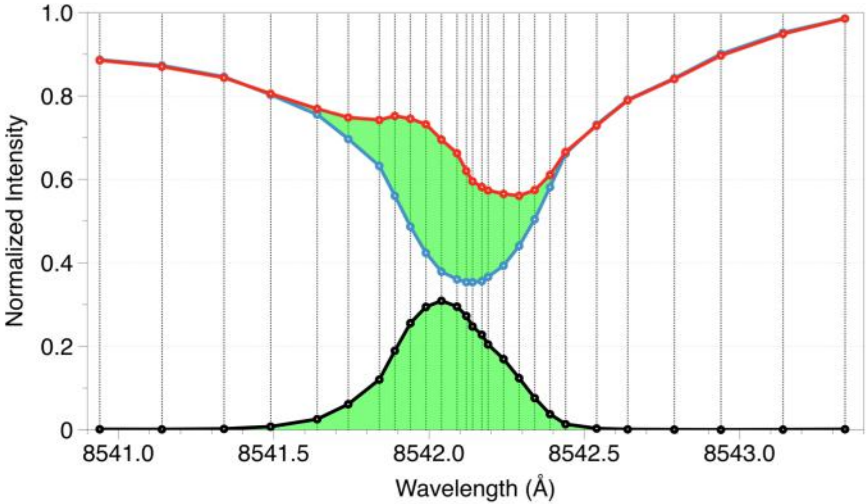
Large density gradient

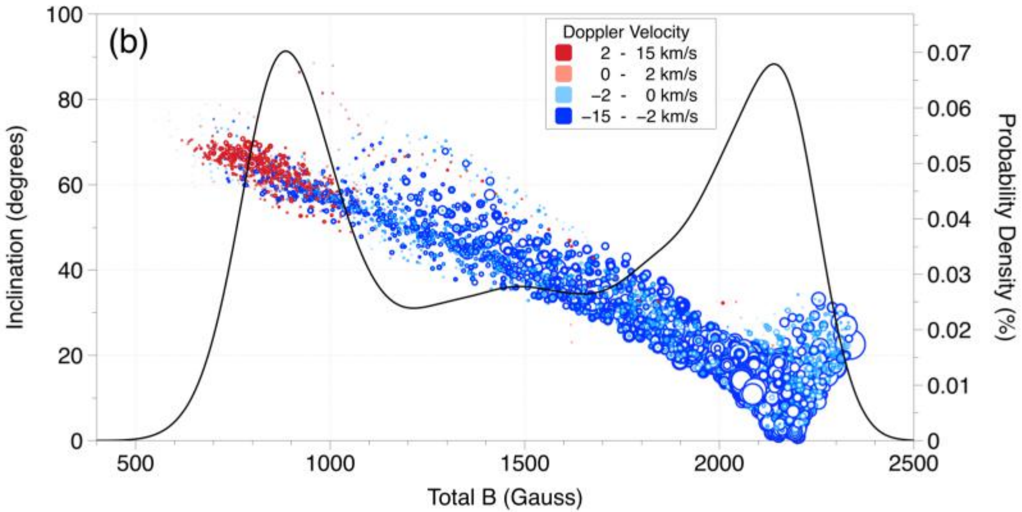
Consistent with UFs

Shock Velocities

- Population 1 can be distinguished from UFs by their LOS velocity signatures
- Resultant profiles reveal the shocked plasma component of the spectral profile

- Population 2 are entirely upflows
- However, Population 1 shows an intermix (~35% downflows)
- Positive signature of Alfvén wave steepening





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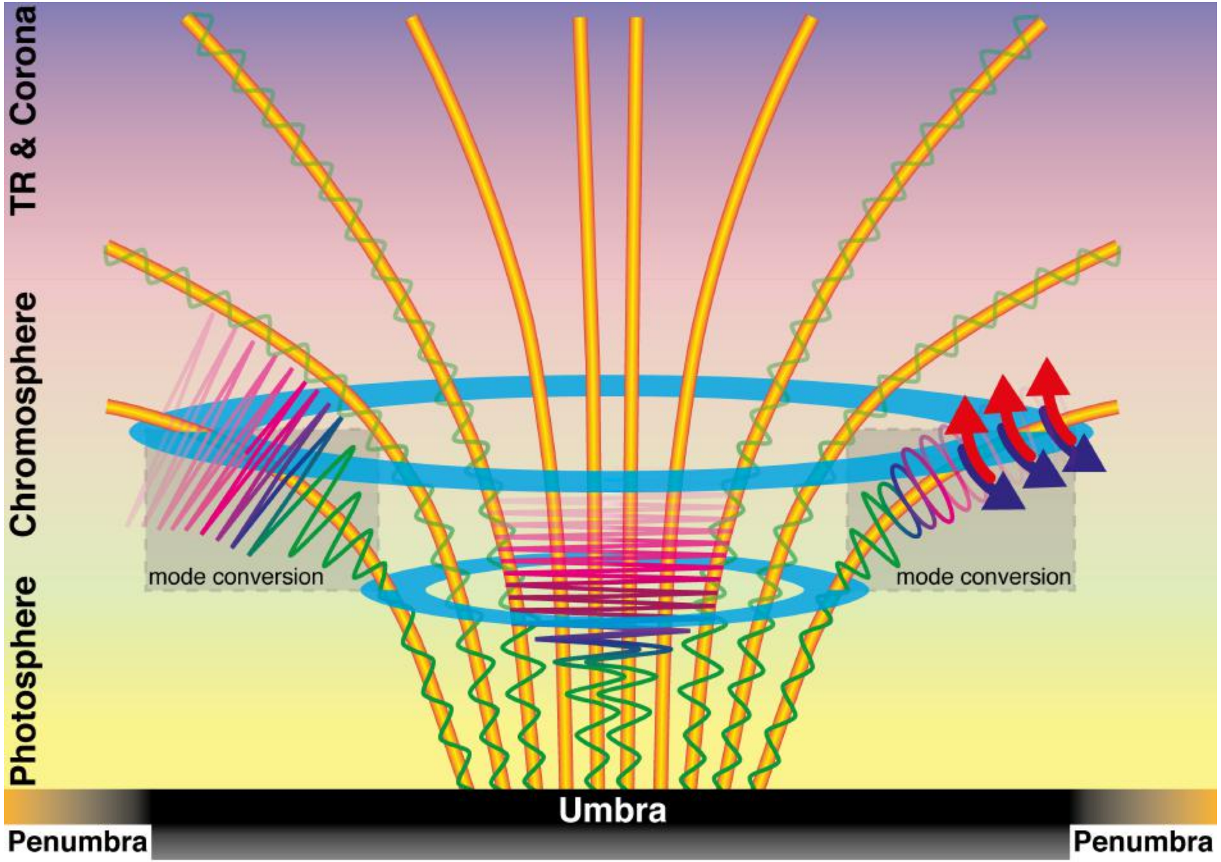
Alfvén Shocks

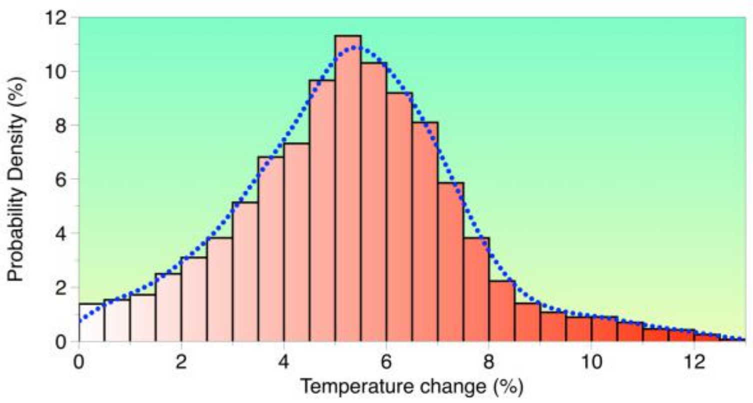
Non-linear Alfvén waves resonantly amplifying magneto-acoustic waves into shocks (Hollweg 1971)

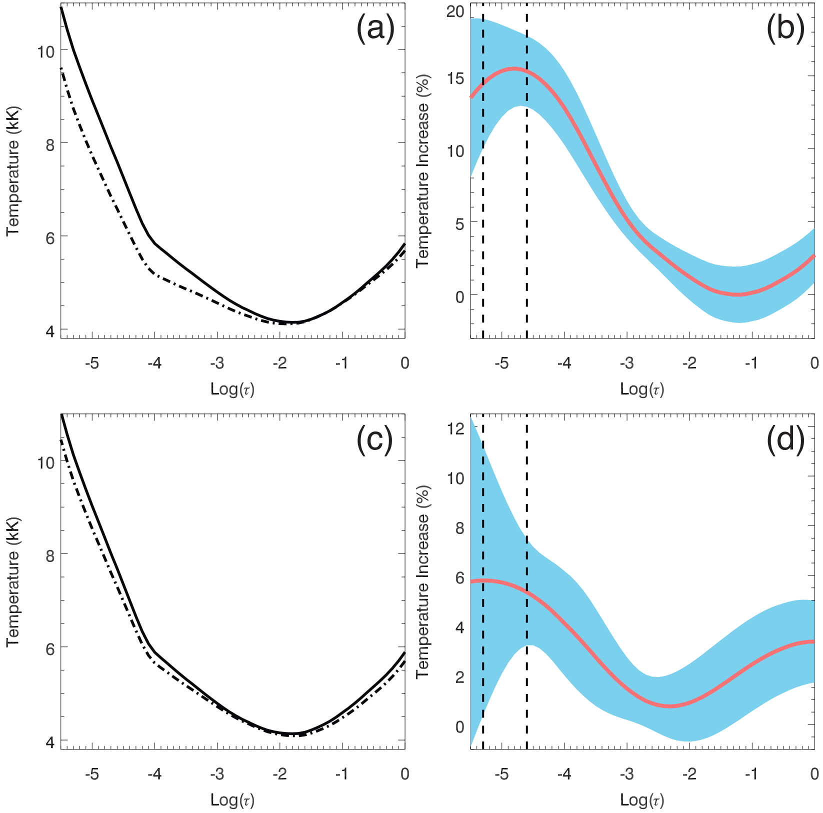


Magneto-acoustic waves converting into elliptically polarised Alfvén waves that form shocks (Montgomery 1959)

Shock Temperatures

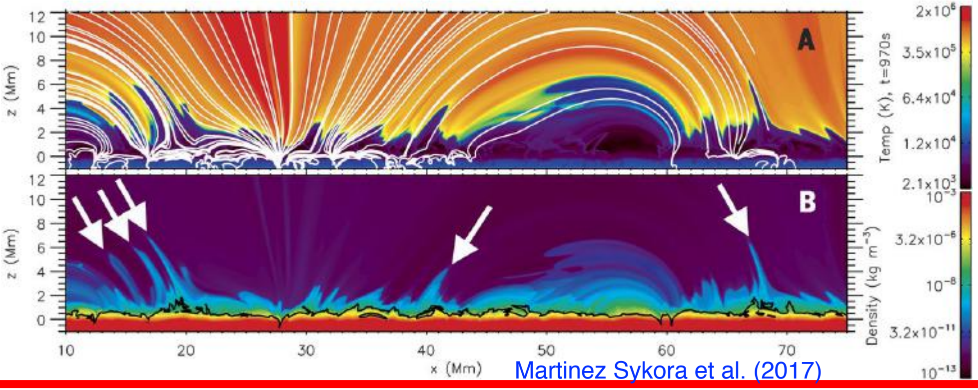
- Temperature outputs reveal the dissipative potential of the shocks
- Typical Umbral Flashes exhibit temperature increase of 15%
- Alfvén shocks exhibit smaller increase of ~6%
- All Alfvén shocks exhibit dissipation



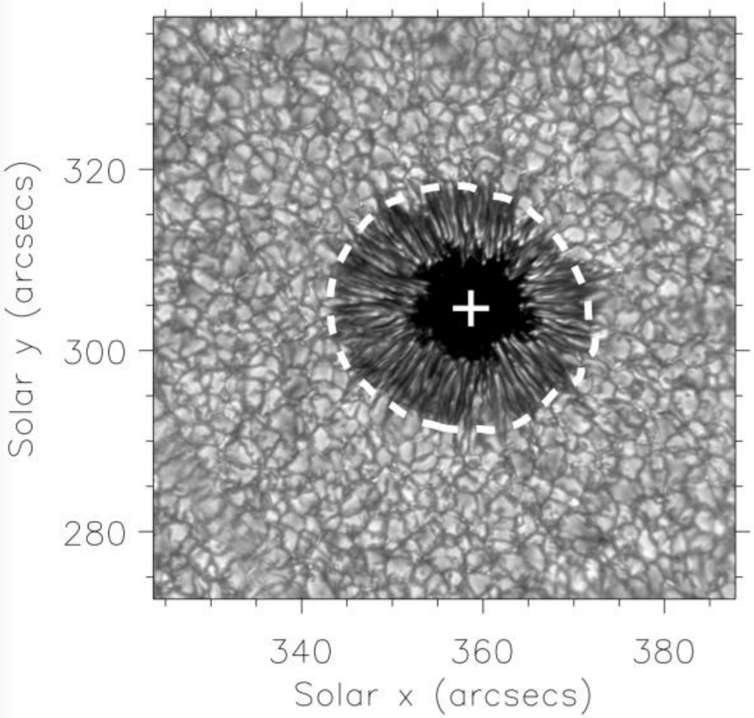


Conclusions

- Observations of the dissipation of Alfvén waves with ~10kW/m^2 energy flux
- B-field geometry and velocity signatures provide proof
- Can this be fulfilled elsewhere? Need a Mach number of at least 0.2
- Further detail in Grant et al. 2018, *NatPh,* **14**, 480



Martinez Sykora et al. (2017)



Jess et al. (2013)

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