Chromospheric resonant cavities in umbrae: unequivocal detection and seismic applications

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Umbral chromospheric oscillations exhibit significant differences compared to their photospheric counterparts. We evaluate two competing scenarios proposed for explaining those observations: a chromospheric resonant cavity and waves traveling from the photosphere to upper atmospheric layers. The oscillatory signatures of both models have been determined from numerical simulations, and they have been compared to observations. We find that a high-frequency peak in the He I 10830 Å power spectra cannot discriminate between both theories, contrary to the claims of Jess et al. (2019, *Nature Astronomy, 4,* 220). In contrast, phase differences between velocity and temperature fluctuations reveal a standing pattern and unequivocally prove the presence of an acoustic cavity above umbrae. Our findings offer a new seismic method to probe sunspot chromospheres through the identification of resonant nodes in phase spectra.

Context of the research

1 Properties of umbral oscillations:

- *Photosphere*: Period ~5 min, amplitude ~200 m/s
- *Chromosphere*: Period ~3 min, amplitude ~5 km/s

2 Models proposed for explaining these differences

- *Chromospheric resonant cavity*: Waves are trapped between the photosphere and transition region.

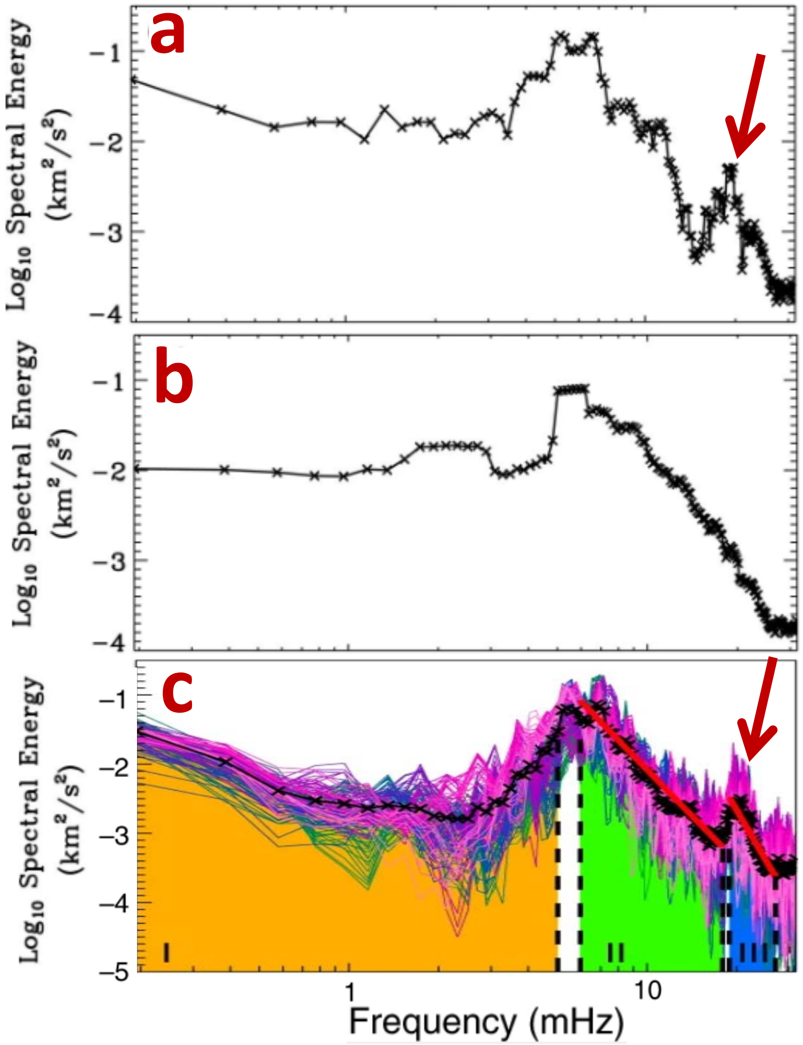
(e.g., Zhugzhda 2008; Botha et al. 2011; Felipe 2019)

- *Propagating waves*: Photospheric waves propagate upwards. 3-minute waves dominate the chromospheric signal due to the spatial attenuation of evanescent waves.

(e.g., Fleck & Schmitz, 1991; Centeno et al. 2006; Felipe et al. 2010b)

3 Recent claim of a chromospheric cavity

Jess et al. (2019, Nature Astronomy) detected a power peak at 20 mHz in He I 10830 (panel **c**). Simulations of a resonant cavity show a similar peak (panel **a**), but simulations without transition region do not (panel **b**).



Methodologies

Numerical simulations

- MANCHA3D
(Khomenko & Collados 2006; Felipe et al. 2010a)
- Background: model M (Maltby et al. 1986) with 2000 G vertical magnetic field.
- Waves are driven below the photosphere.
- 2.5D, z∈[-1140, 3500] km, Δz=10 km
- Two cases:

(i) With transition region: waves are trapped due to the gradients of the temperature.

(ii) Without transition region: waves can freely propagate upwards.

Observations

He I 10830 Å

- Slit spectropolarimeter (TIP/VTT or GRIS/GREGOR)
- 5 temporal series of sunspots (Centeno et al. 2006; Felipe et al. 2010b; Felipe et al. 2018)

Na I D_2

- GFPI/GREGOR
- Pore (Kuckein 2019)

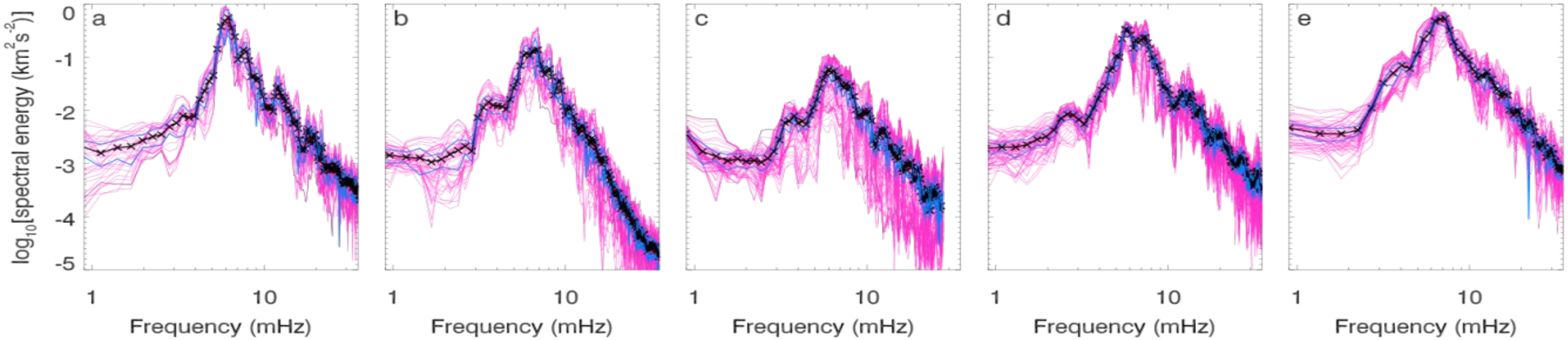
Analysis

- Determination of velocity and temperature/intensity fluctuations
- Power and phase spectra

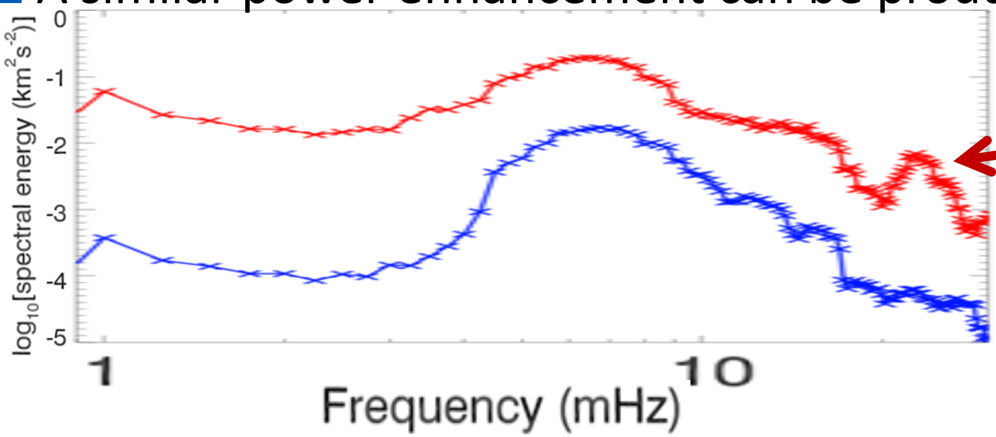
Results

A high-frequency power peak in He I 10830 Å velocity is **NOT** an evidence of a resonant cavity above umbrae. This conclusion is based on two facts:

1 Most sunspots do not exhibit that power peak:



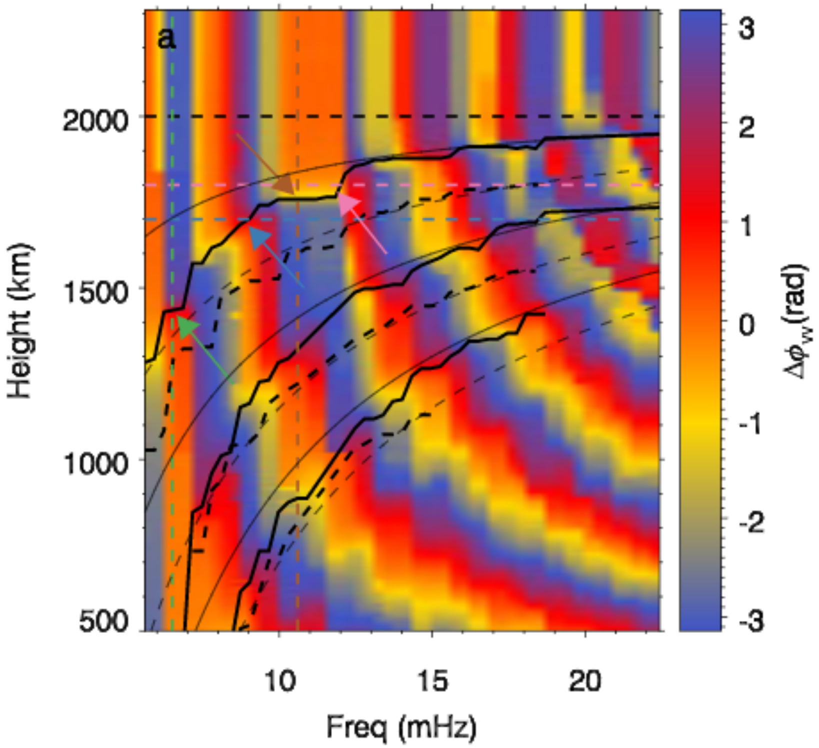
2 A similar power enhancement can be produced without a resonant cavity



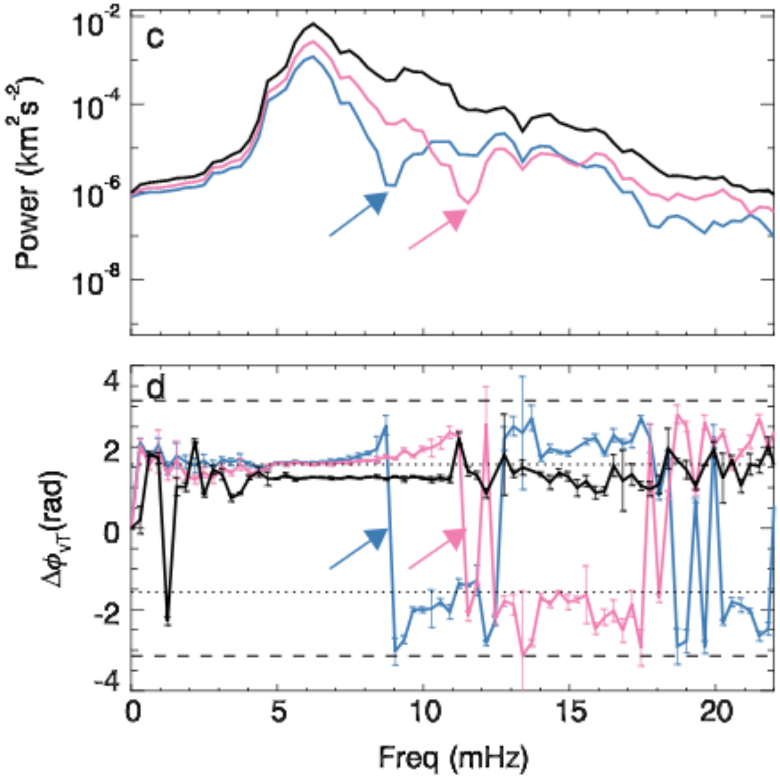
Non-linear effects can generate a power peak ~20 mHz without the presence of a reflecting layer at the transition region.

Felipe (2020, Nature Astronomy, accepted)

Results: signatures of a chromospheric cavity



Resonant structure of a umbral chromospheric cavity. Thick solid (dashed) lines indicate the location of velocity (temperature) nodes.



Power (top) and V-T (velocity-temperature, bottom) spectra at z=2000 km (black), z=1800 km (pink), and z=1700 km (blue)**.**

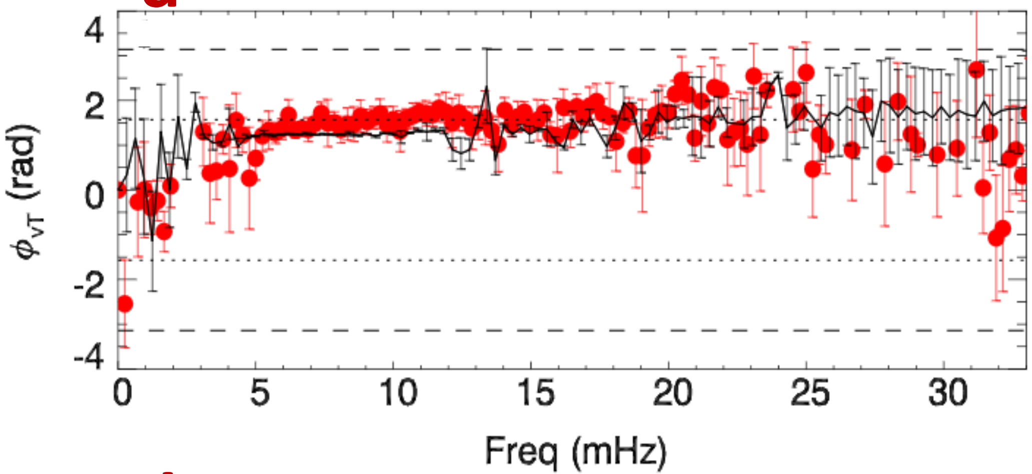
1 Dips in the power spectra at the frequencies where the formation height of the line intersects a velocity nodal plane.

2 V-T phase difference of π/2 rad, with π jumps at the frequencies where the formation height of the line intersects a velocity or temperature nodal plane. Propagating waves show a π rad V-T phase difference.

Impact and prospects for the future

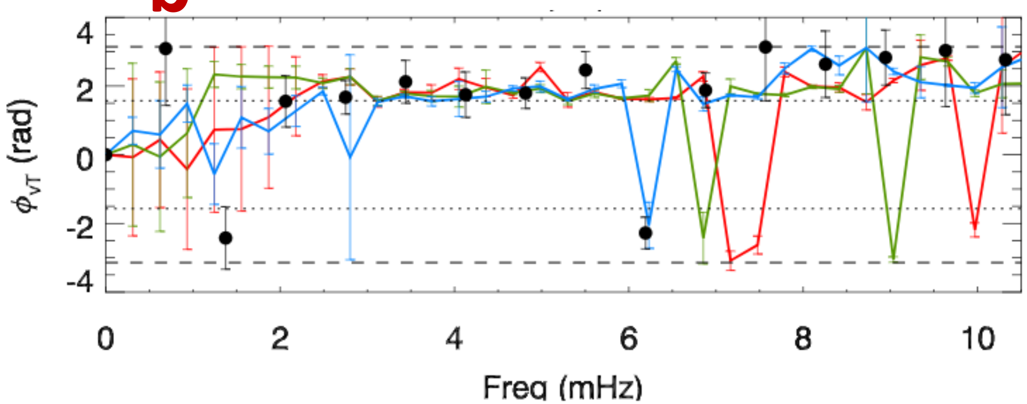
We find unequivocal evidence of the existence of a resonant cavity above sunspot umbrae. V-T spectra measured with the He I 10830 Å triplet (**a**, red circles) and with the Na I D_2 line (**b**, black circles) show a π/2 phase shift.

a



We propose a new seismic analysis to probe umbral chromospheres. The identification of nodes in V-T spectra (phase jumps) can be employed to infer the height of the transition region and sound speed. Na I D_2 measurements (Fig. **b**, black circles) are consistent with a transition region located at z=2600 km (blue).

b



Felipe et al. (2020, submitted to ApJL)