Similarities of magnetoconvection in the umbra and in the penumbra of sunspots

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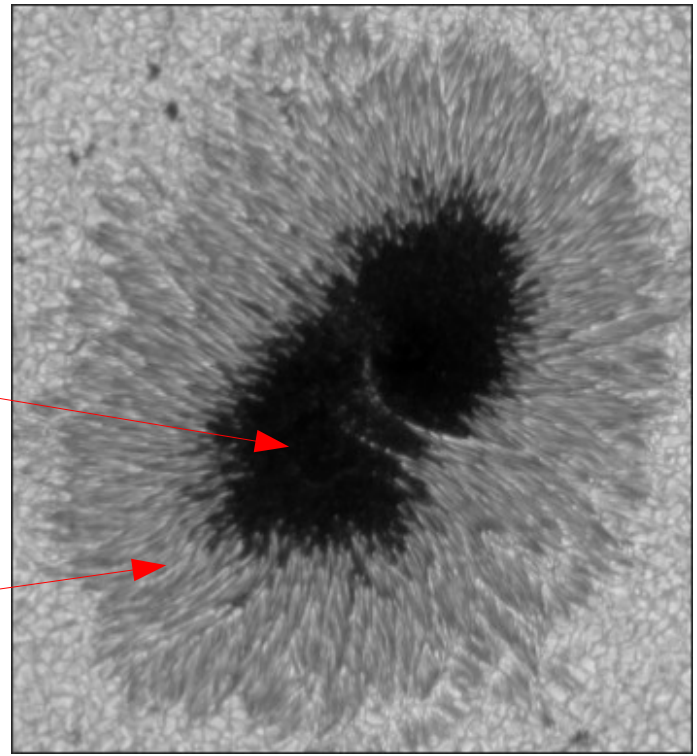
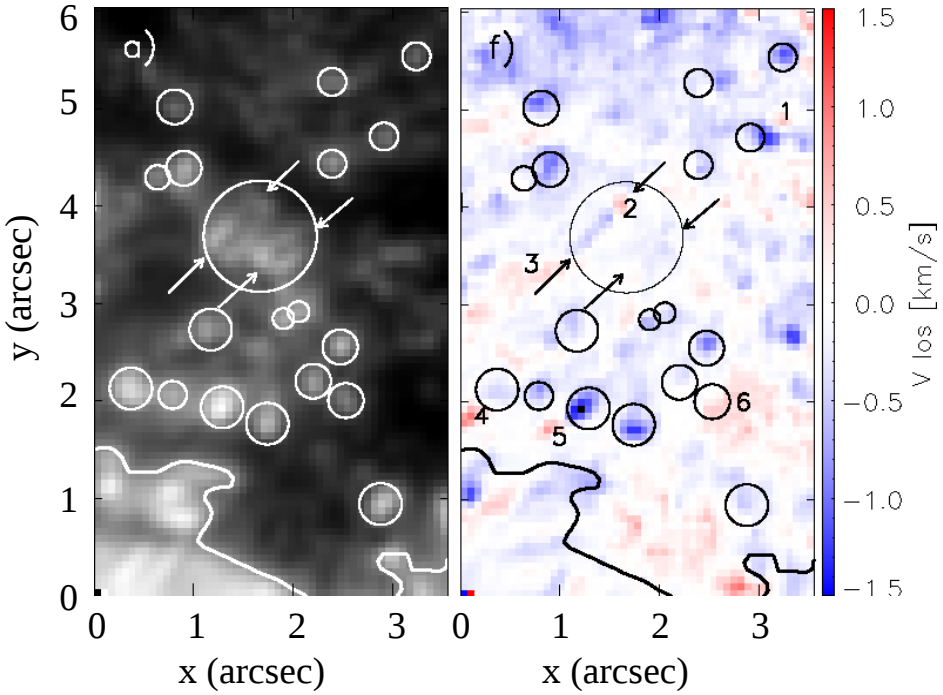
Introduction

- Questions:
  - Why do sunspots have a penumbra?
  - Why is there a sharp boundary between the umbra and the penumbra?
- Both, the umbra and the penumbra exhibit magnetoconvection
  - Umbra: Umbral dots
  - Penumbra: Penumbral filaments



Umbral dots

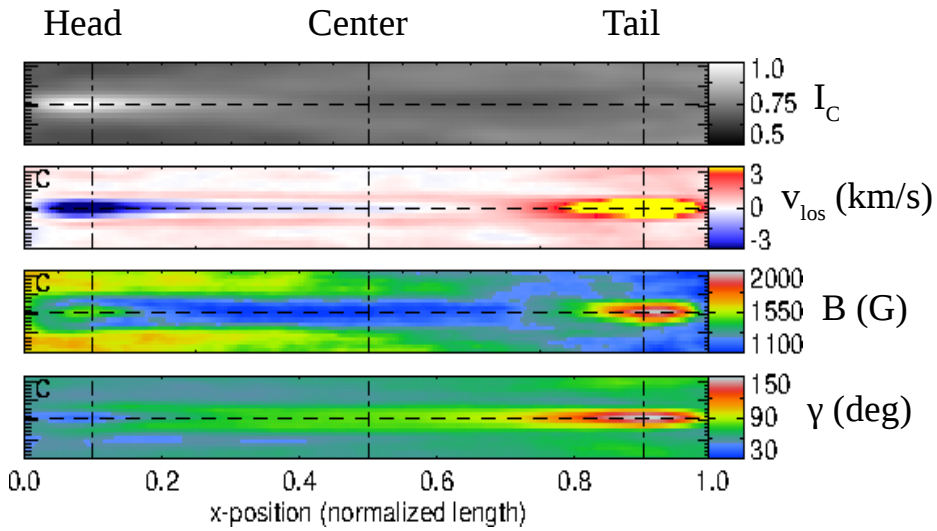
- Central umbral dots:
  - Within the central parts of the umbra
  - Roundish shape
  - Diameter ~ 200 – 300 km
  - Central upflow
- Peripheral umbral dots:
  - Close to the boundary to the penumbra
  - More elongated shape



Adapted from Ortiz et al. (2010)

Penumbral filaments

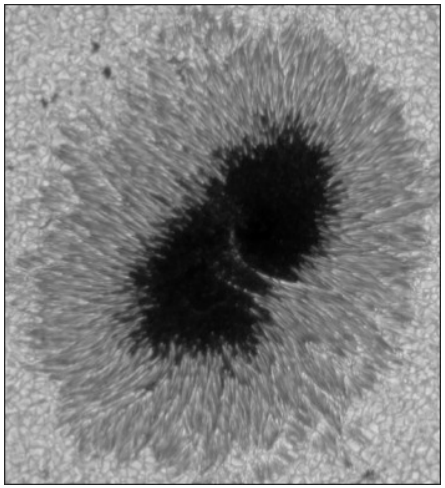
- Length 3 – 7 Mm
- Elongated shape
- Flow along the penumbral filament
- Separated in head, center, tail



Adapted from Tiwari et al. (2013)

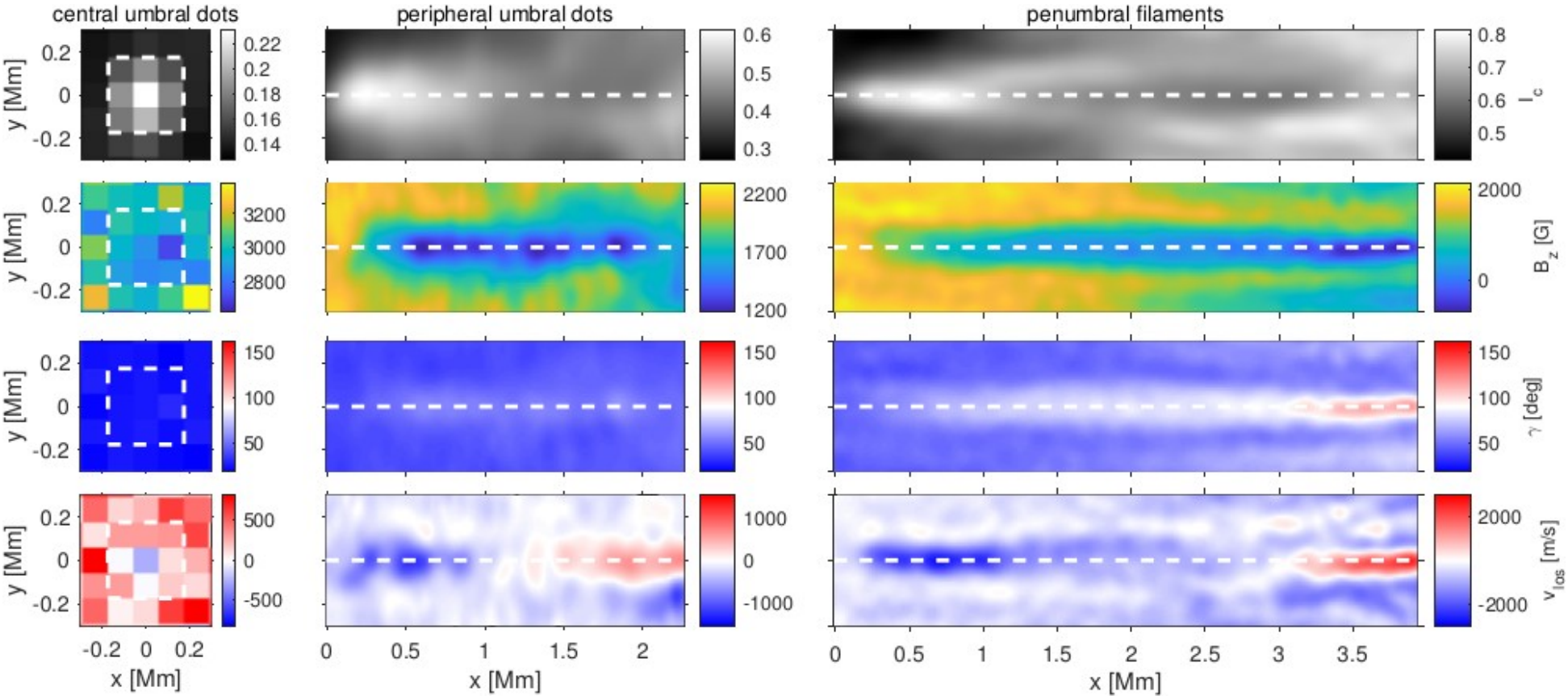
This study

- Goal of this study: How do the properties of convective elements vary within sunspots?
- Generate and compare ensemble averages of the different types of convective elements
  - Based on Hinode observations of a sunspot
  - Spectropolarimetric inversion using SPINOR (Frutiger et al. 2000; van Noort 2012), use I_C and B_z,γ, v_{los} at $\tau = 1$
  - Compare central umbral dots, peripheral umbral dots, penumbral filaments
  - Manually select individual features, then average them (following approach by Tiwari et al. 2013)



AR 10923:
- Observed on 14 November 2006
- Heliocentric angle: 8°
- Area: 2700 Mm^2

Ensemble averages



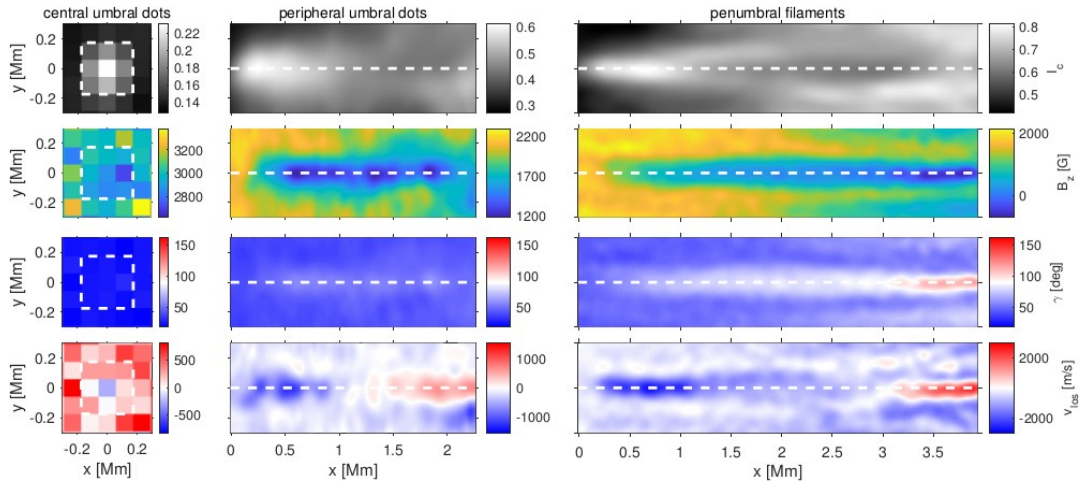
Ensemble averages

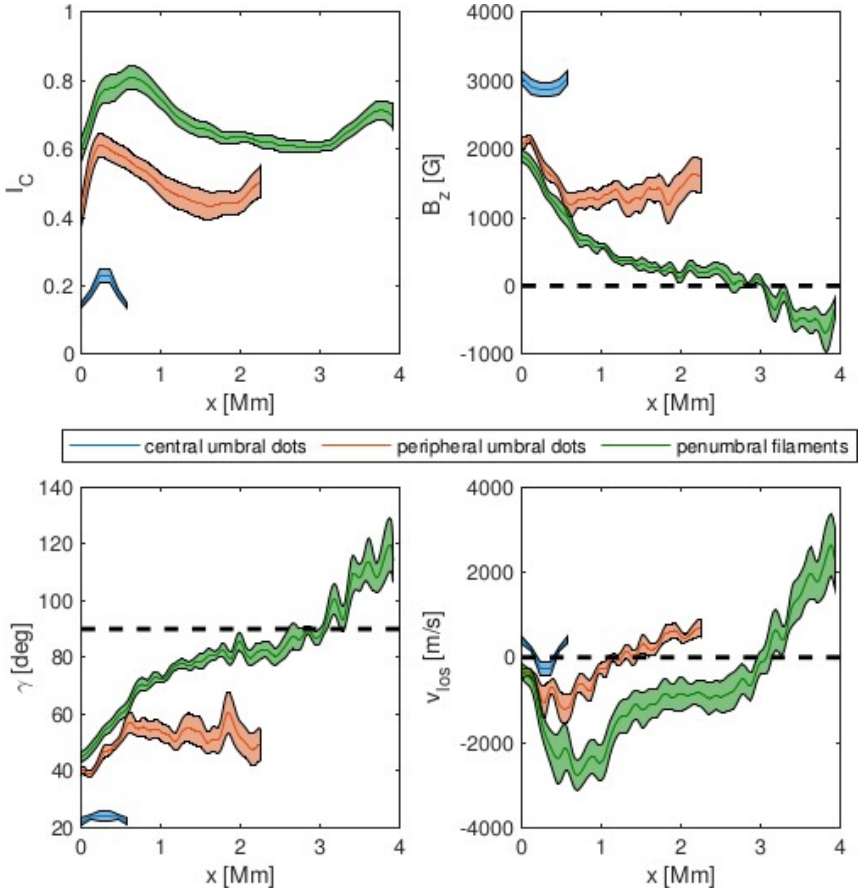
Central umbral dots

Peripheral umbral dots

Penumbral filaments

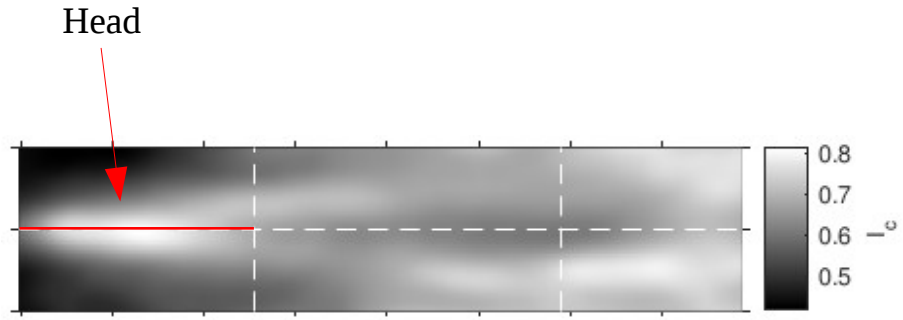
Smooth transition in length, shape, and observables?

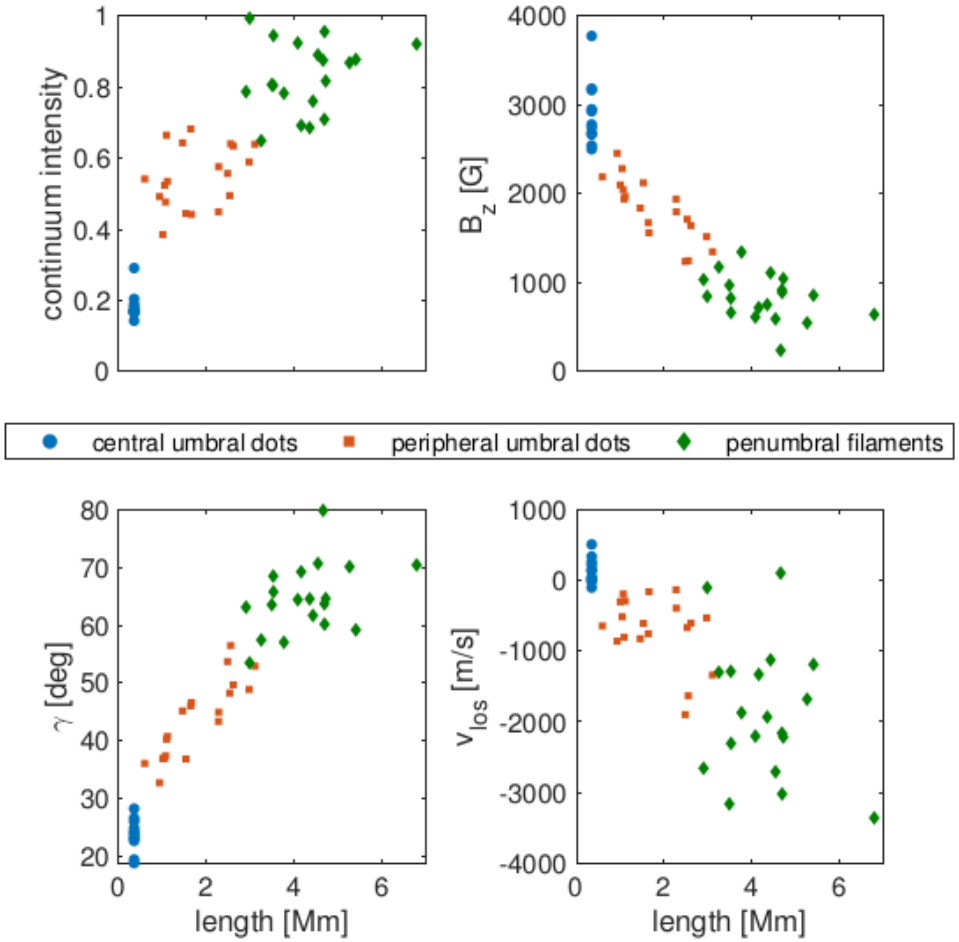




Dependence on the length

- Are the properties of convective elements related to their length?
  - Plot observables versus length for each individual feature
  - Focus on the heads of the features here for brevity
- Smooth dependence of all properties on the length of the features
- No discontinuity between the umbra and the penumbra





Summary and discussion

- Smooth transition from umbral dots to penumbral filaments
- The similarities between peripheral umbral dots and penumbral filaments pose the question why there is such a rapid increase in brightness at the umbra-penumbra boundary:
  - Penumbral filaments are more extended than peripheral umbral dots
  - The intensity of convective elements increases with length

    => The integrated brightness of convective elements increases strongly with length

- What determines the size and elongation of the convective elements?
  - How are they affected by the strength and inclination of the underlying magnetic field?
  - High-resolution spectropolarimetric observations with DKIST of the umbral boundary might allow resolving this question