# Statistical analysis of acoustic wave power and flows around solar active regions

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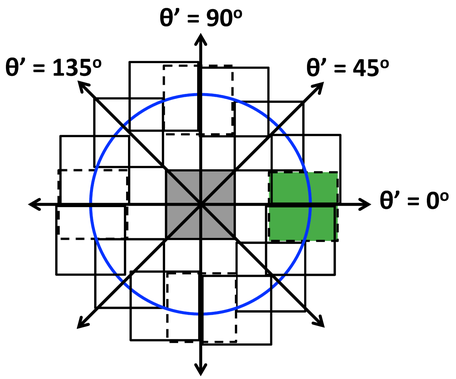
## Abstract

We analyze the effect of a sunspot in its quiet surroundings applying the helioseismic technique, **ring analysis**, on almost **three years of HMI observations** obtained during solar cycle 24 to further study the sunspot structure below the solar surface.

In the center, the grey square represents a five-degree quiet target patch (**MAI < 5 G**). The **white squares** (slightly misplaced) correspond to the outermost positions that a neighboring active tile could be, i.e., their center are at a distance equal or smaller than **8◦ (blue circle)** from the center of grey square.



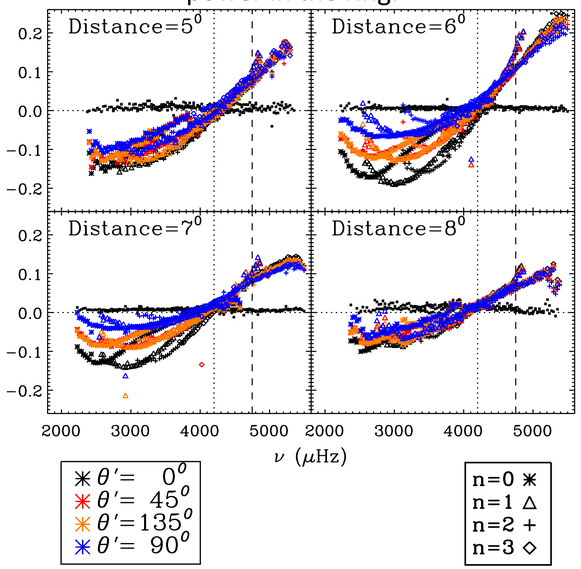

Assuming that the nearby active region is at the **green tile (MAI > 100 G*)**, four different directions θ' in relation to it are represented by arrows.

*A five-degree tile with a Magnetic Activity Index (MAI) larger than 100 G includes NOAA active regions with a total corrected area (USAF/NOAA) as small as 40 millionths of the solar hemisphere.

## Amplitude

The **attenuation** of acoustic waves with **frequencies lower than 4.2 mHz** depends more strongly on the wave direction at a **distance of 6°–7°** from the sunspot center.

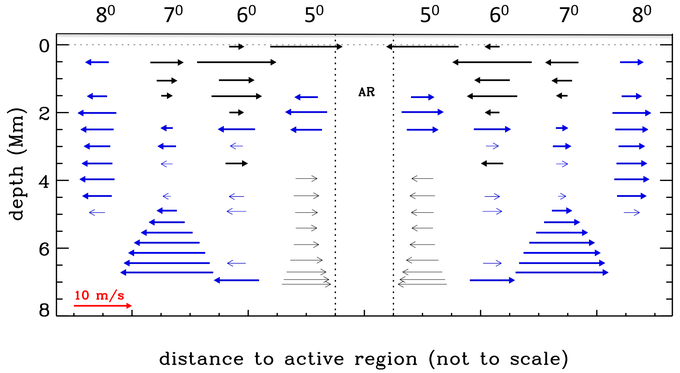
The relative difference of the maximum power in the ring.




The small black squares close to zero are the results for the control set.

The **amplification** of higher frequency waves is **highest 6° away** from the active region and is largely **independent** of the wave's direction.

## Horizontal Flow




Thick arrows are for flows > 2.5σ and thin arrows are for 1.5 – 2.5σ.

For better visualization, outflows are in blue and **inflows in black**, plus the results were duplicated in the left and right side of the active region.

The center of the shell of this circular flow seems to be **centered around 7⁰ from the active region (AR) center**.

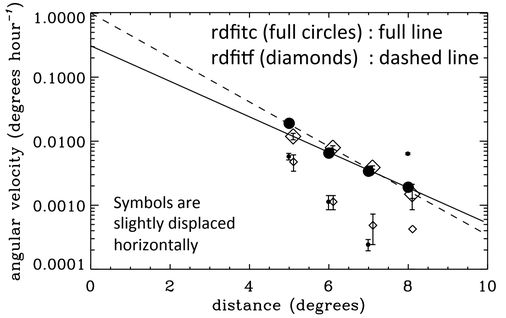
Our results agree with a large-scale circular flow around the sunspot in the shape of a **cylindrical shell** around the sunspot as proposed by Hindman, Haber & Toomre (2009: ApJ 698, 1749**)** supposing a downflow close to the sunspot and a upflow farther away connecting the near-surface inflow and the deep outflow.

## Clockwise Flow.

We observe a mean clockwise flow around active regions, the angular speed of which decreases **exponentially** with distance and has a coefficient close to -0.7 degree$^{-1}$.

Extrapolation of the rdfitc fit (full line) roughly agrees with the average of angular speed obtained by Zheng et al. (2016: ApJ, 826, 6) at the sunspot umbra for all rotating sunspot during almost 40% of our data set.

The small symbols are for the control set.




✧ **For more information see our paper: ApJ 859, id.7 (2018)**

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