Acoustic Power Absorption in Sunspots and Quiet-Sun from Hankel-Fourier Transform on HMI and AIA Data

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Braun, Duvall, & LaBonte (1987): in polar coordinates (r,θ) waves can be decomposed into components of the form:

$$\Psi_m(r,\theta,t) = e^{i(m\theta+t\omega)} [A_m(k,\omega)\, H^{(1)}_m(kr) + B_m(k,\omega)\, H^{(2)}_m(kr)]$$

A_m and B_m are complex coefficients describing power and phase of waves traveling radially inward and outward.

$H^{(1)}_m$ and $H^{(2)}_m$ are Hankel functions of the 1st and 2nd kind.

"raw" absorption coefficient $\alpha_m = 1.0-|B_m(k,\omega)|^2/|A_m(k,\omega)|^2$

with background removed $\alpha_m = 1.0-(|B_m(k,\omega)|^2-N_m(k,\omega))/(|A_m(k,\omega)|^2-N_m(k,\omega))$

used Dopplergram in Fe I 8688 A line (formed near the temperature minimum region)

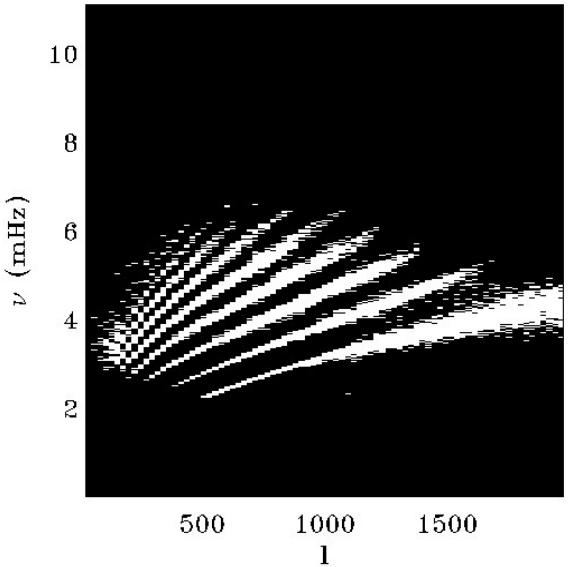
Braun, Duvall, LaBonte, et al. (1992) used intensitygrams in Ca_{II} K line (temperature minimum region)

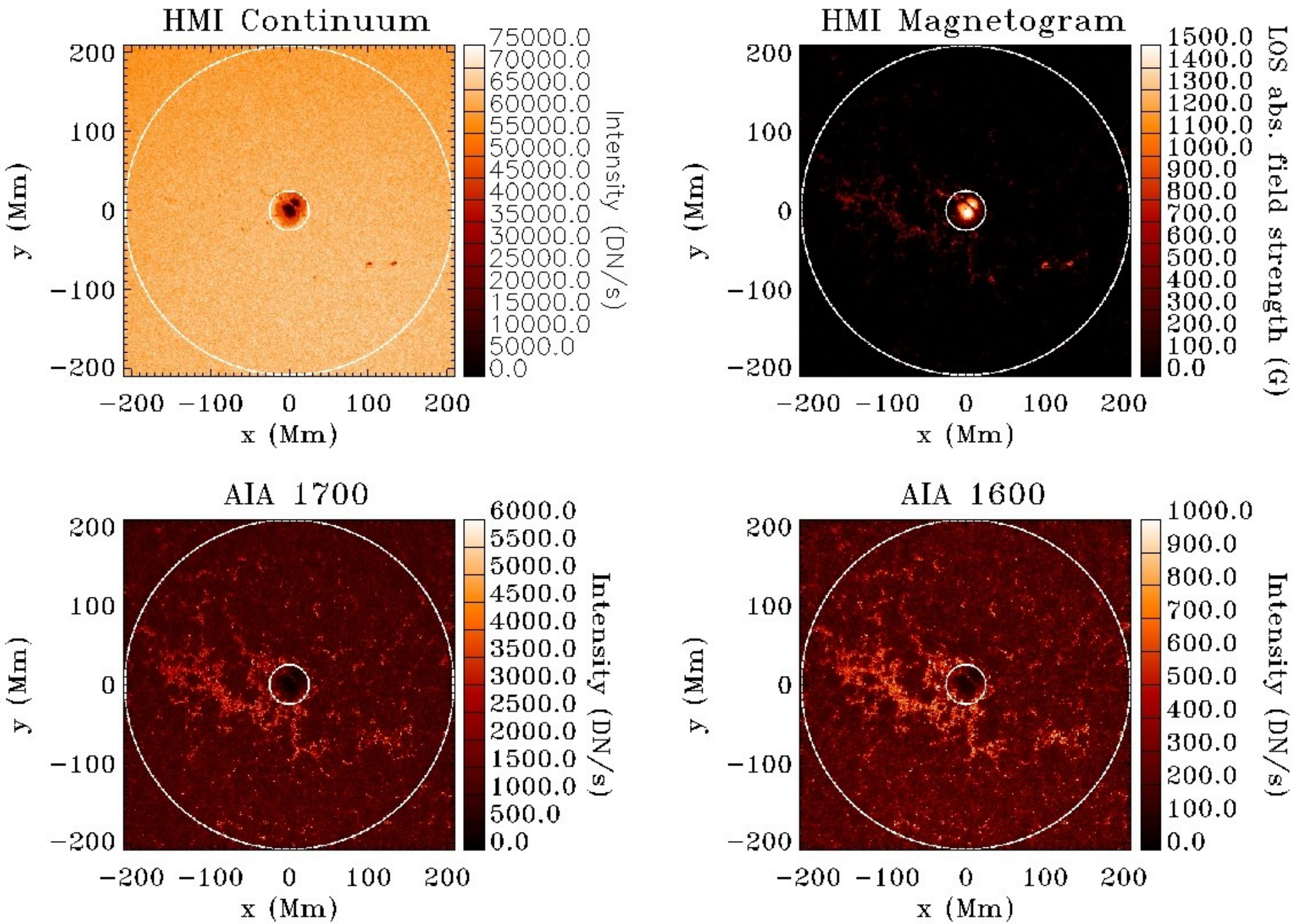
Bogdan, Brown, Lites, & Thomas (1993) used Dopplergrams of Fe I 5576 A line (formation height about 320 km, Bruls, Lites, & Murphy, 1991)

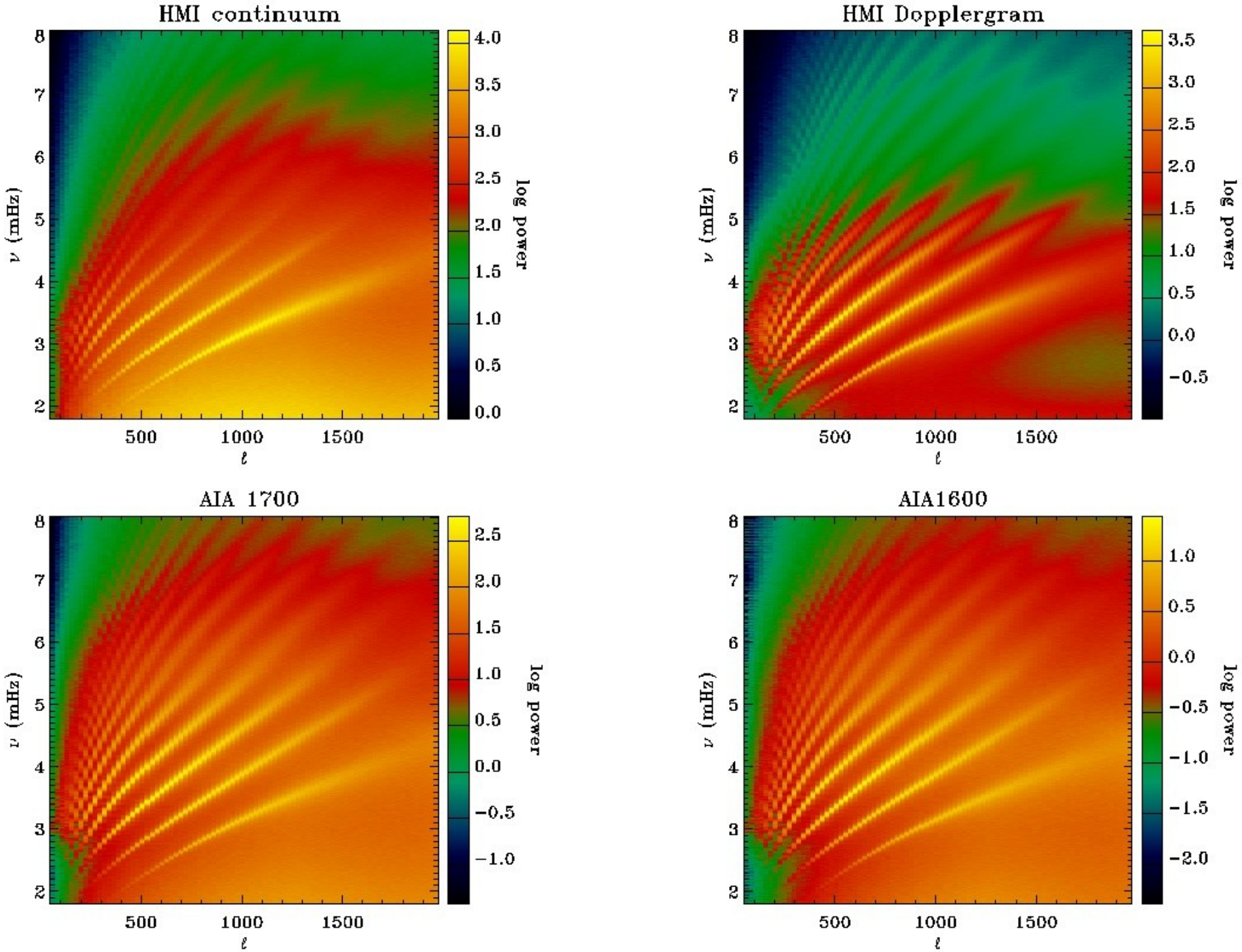
Braun (1995) used used intensitygrams in Ca_{II} K line (temperature minimum region)

Braun & Fan (1998) used Dopplergrams from MDI and GONG to measure meridional circulation

- Hankel-Fourier decomposition applied to 15 sunspots observed with HMI and AIA
- sunspots tracked for 62.5 hours at Carrington rotation rate and with Postel projection (mtrack)
- spatial resolution: 0.09° or 1.09 Mm
- Rmin=25 Mm, Rmax=209 Mm
- azimuthal order m in the range [-46,+46]
- no pre-processing of datacubes
- HMI continuum intensity, HMI Dopplergram, AIA 1700 A and AIA 1600 A (z~0, 150, 360, and 430 km), and for some cases HMI line-core intensity (z~250 km)
- to remove background power: at each k, a 5-order polynomial is fitted to log(power) after the f- and p-mode mask is applied to remove mode power.
- a f- and p-mode mask is applied to select mode power.




HMI Continuum
Intensity (DN/s)
75000.0
70000.0
65000.0
60000.0
55000.0
50000.0
45000.0
40000.0
35000.0
30000.0
25000.0
20000.0
15000.0
10000.0
5000.0
0.0
HMI Magnetogram
LOS abs. field strength (G)
1500.0
1400.0
1300.0
1200.0
1100.0
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
AIA 1700
Intensity (DN/s)
6000.0
5500.0
5000.0
4500.0
4000.0
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
AIA 1600
Intensity (DN/s)
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
x (Mm)
y (Mm)
200
100
0
−100
−200


HMI continuum
HMI Dopplergram
AIA 1700
AIA1600
ν (mHz)
ℓ
log power

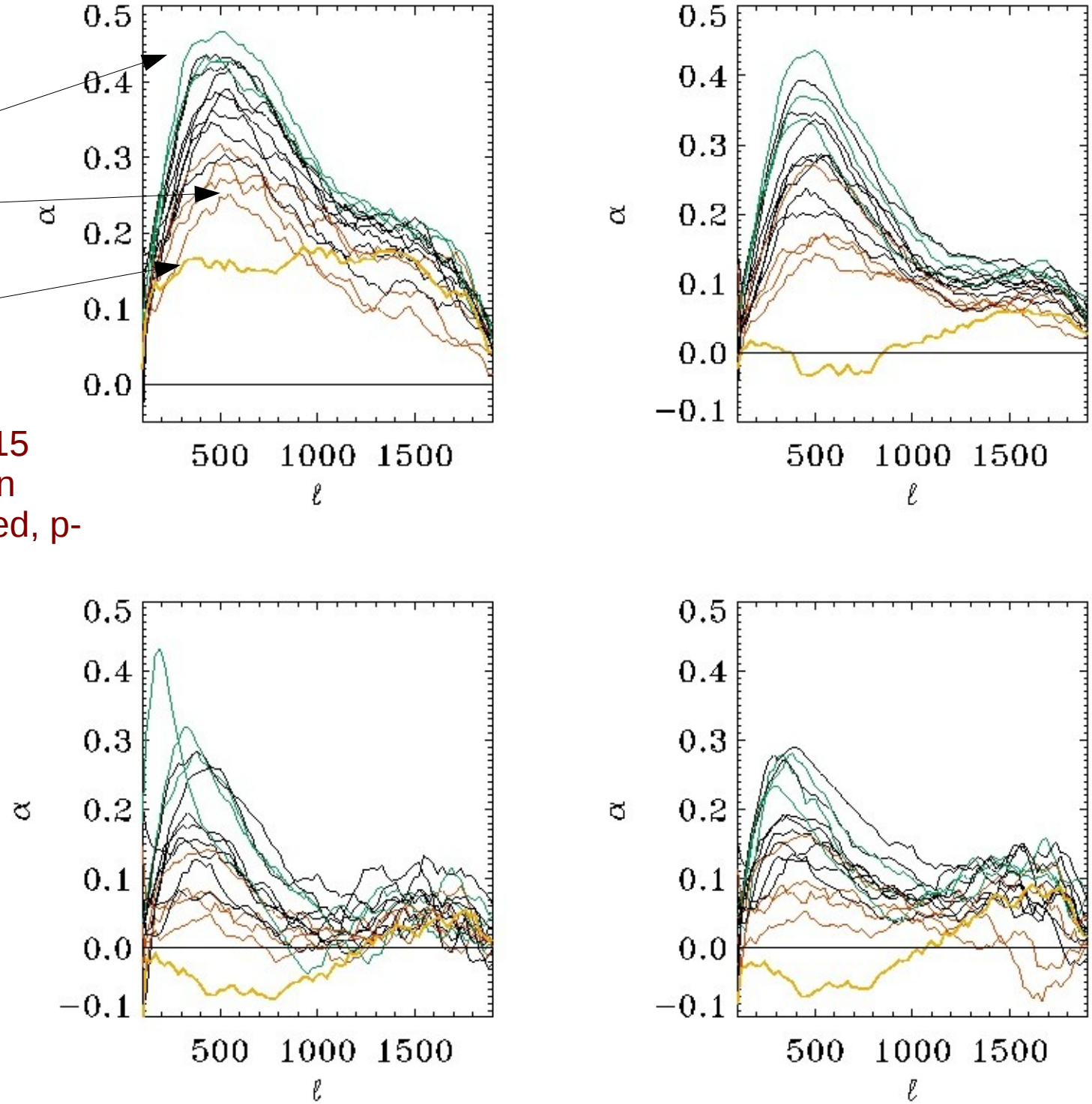
In a 1986 Mm^2 disk:

$\sum |B_{los}|\, dS > 8.4e21$ Mx

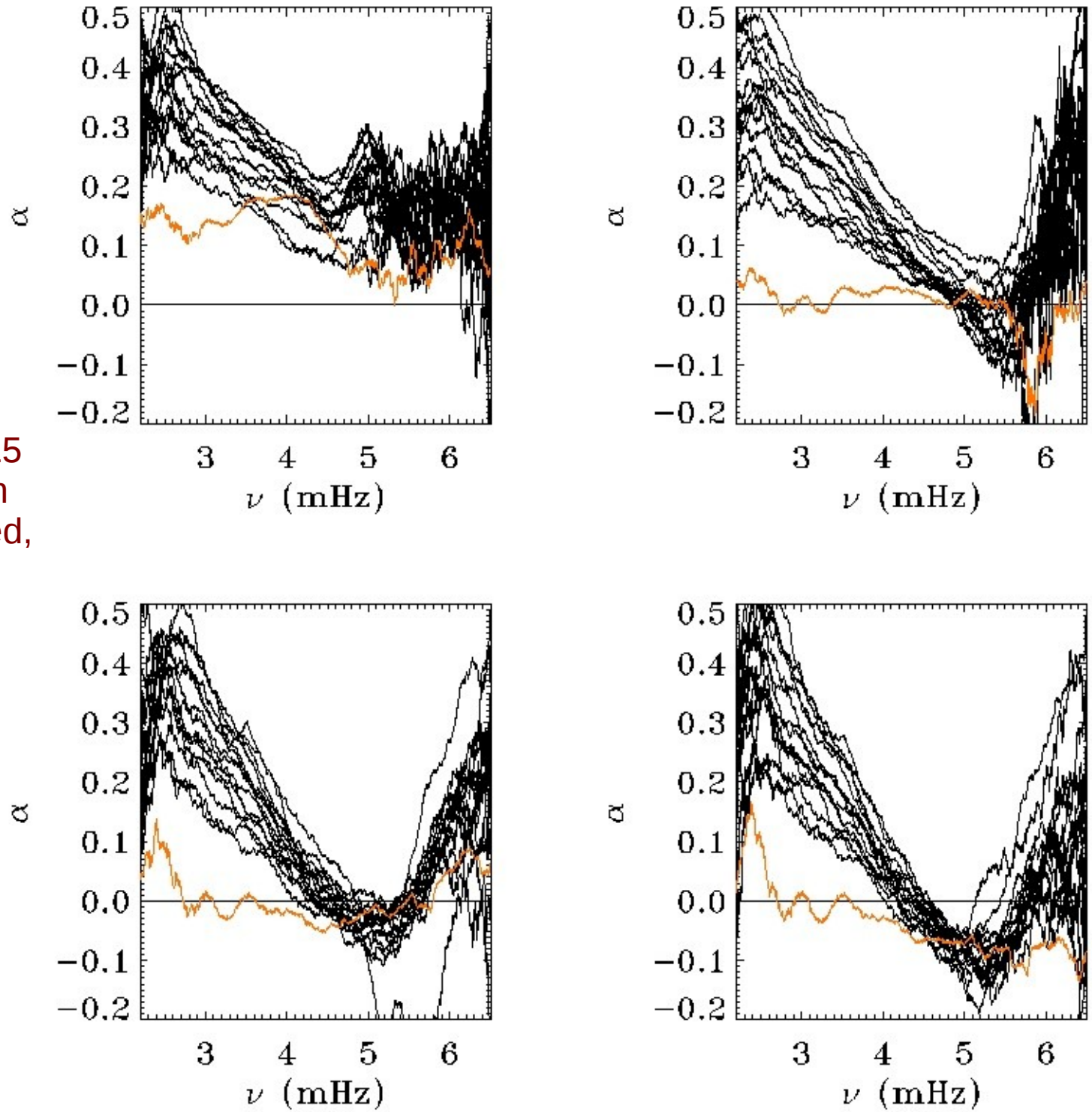
$\sum |B_{los}|\, dS < 2.1e21$ Mx

$\sum |B_{los}|\, dS = 7.3e19$ Mx

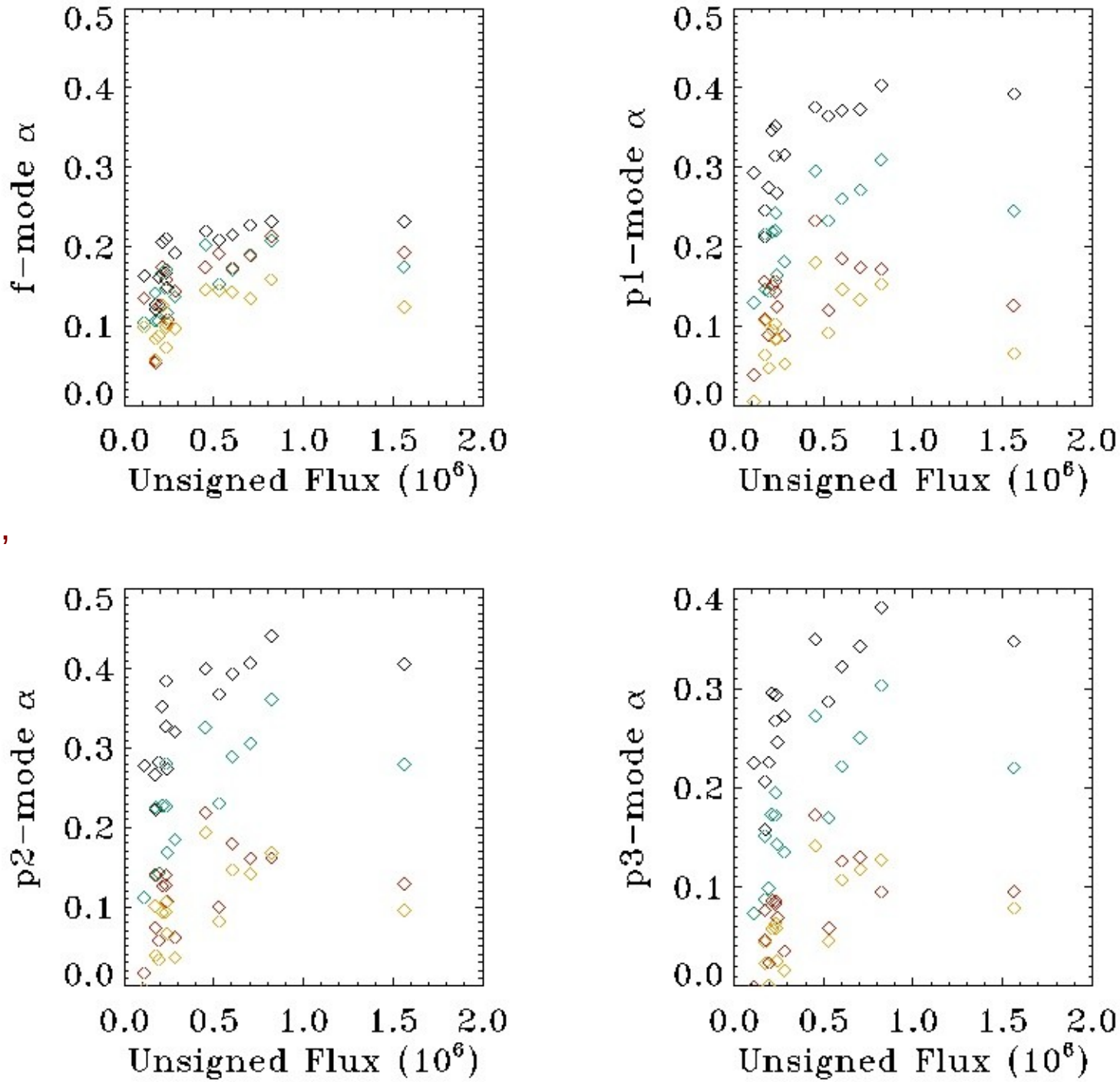
m-averaged absorption in 15 sunspots and in a quiet Sun region; background removed, p- and f-mode mask applied



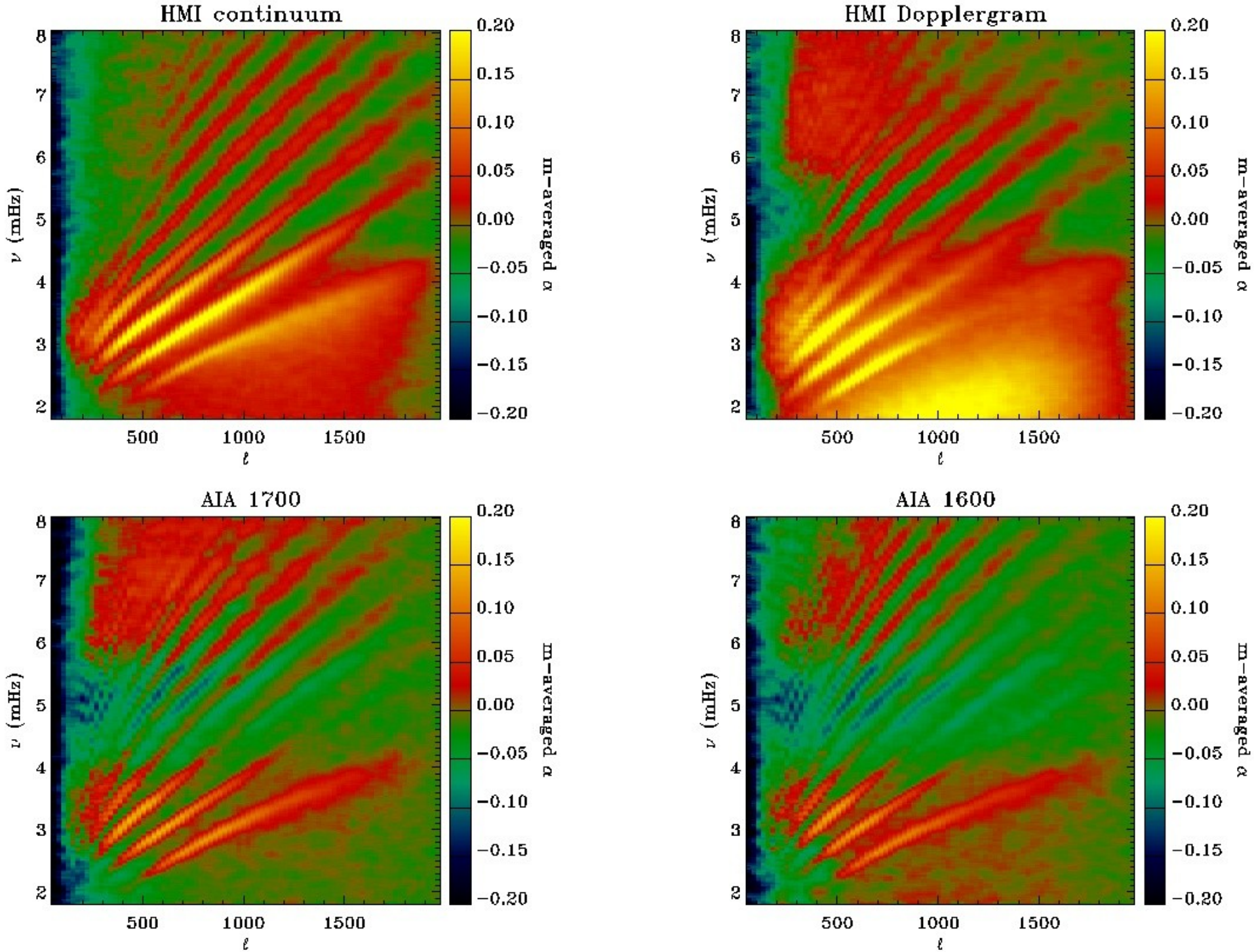
m-averaged absorption in 15 sunspots and in a quiet Sun region; background removed, mask applied



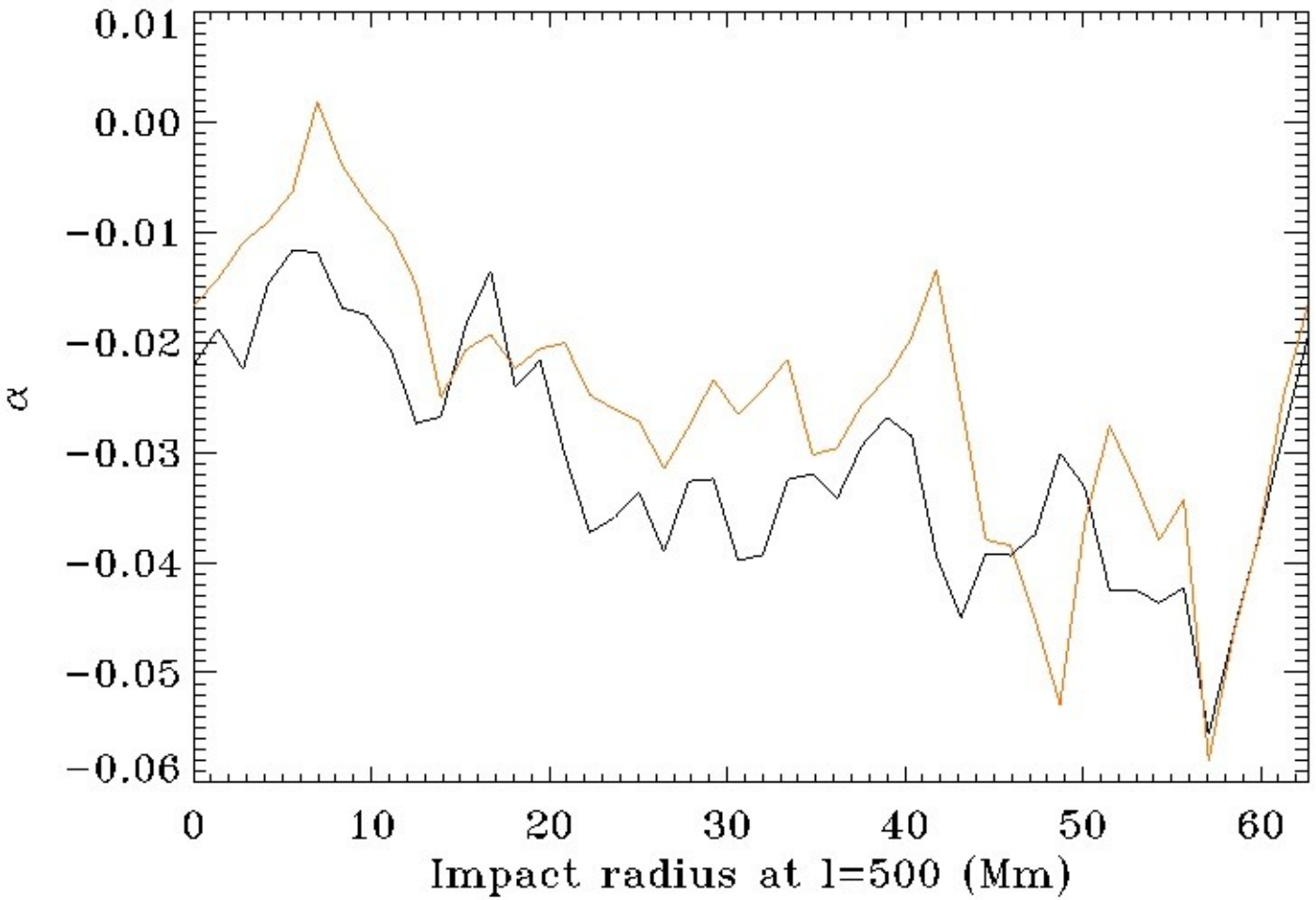
m-averaged absorption in 15 sunspots and in a quiet Sun region; background removed, mask applied



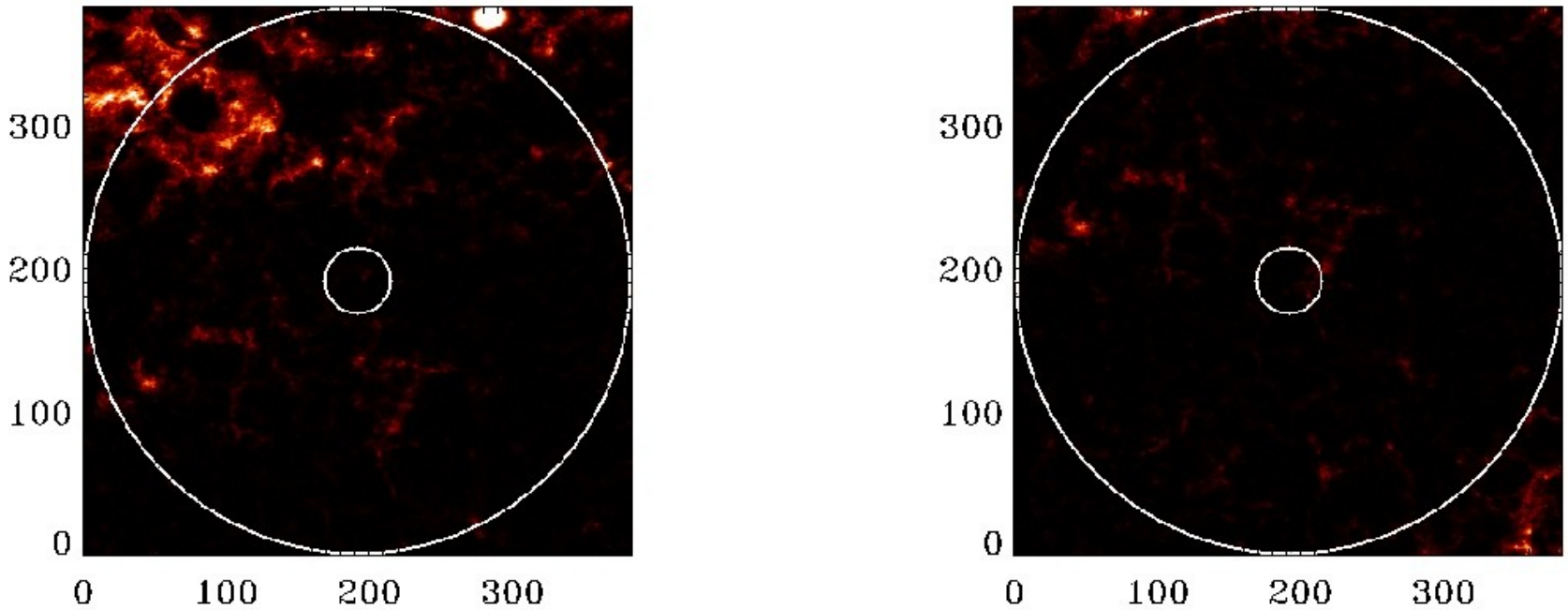
m-averaged power absorption in 15 sunspots



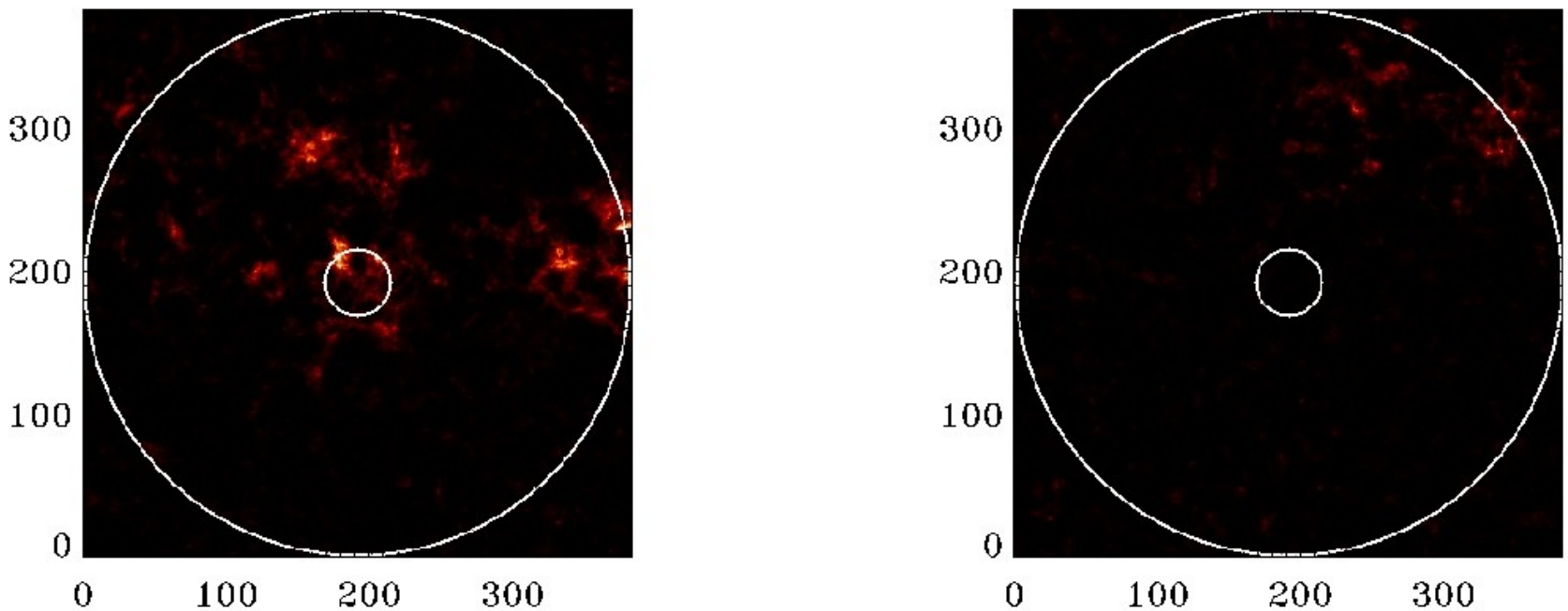
Absorption coefficient for 2 sunspots as a function of impact radius (m/k) at *l*=500 in ν=4.5-5.5 mHz, for AIA 1600



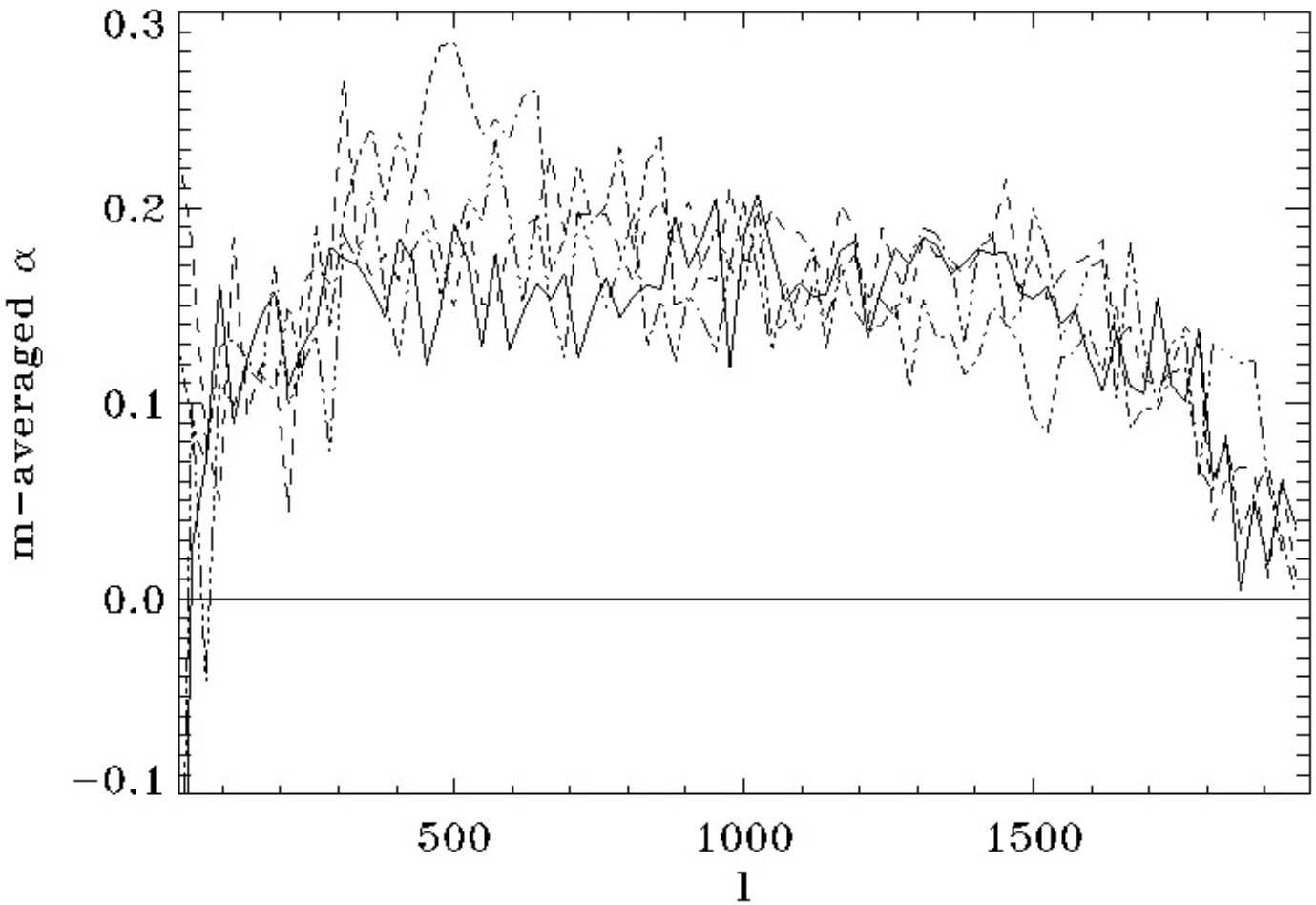
No background removed, mask applied



4 quiet Sun regions: mean abs(B_{los}), colorscale saturated at 250 G

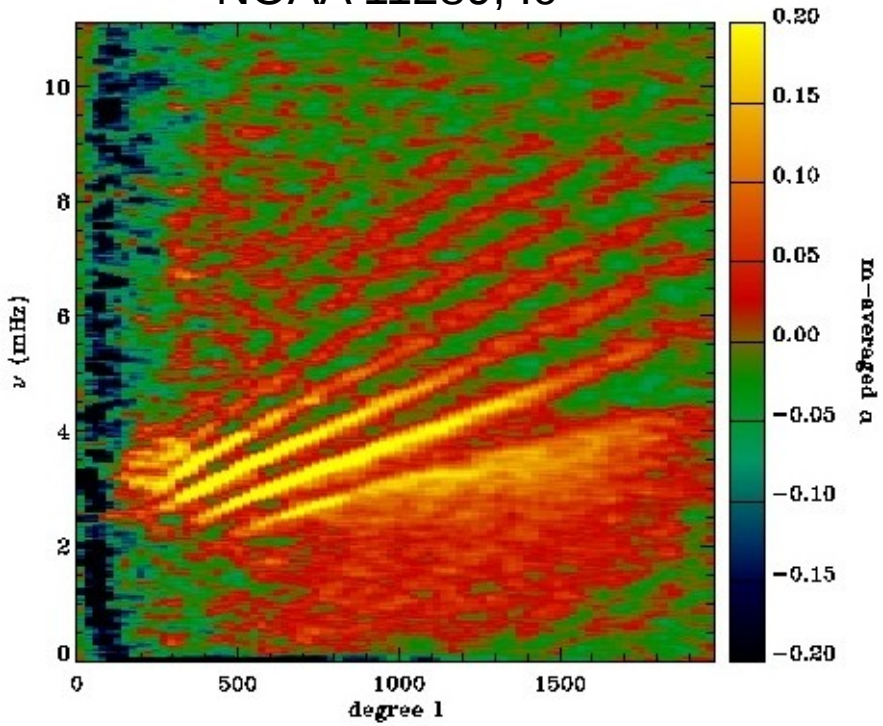


m-averaged absorption coefficient in HMI continuum for 4 quiet Sun regions (un-smoothed curves)



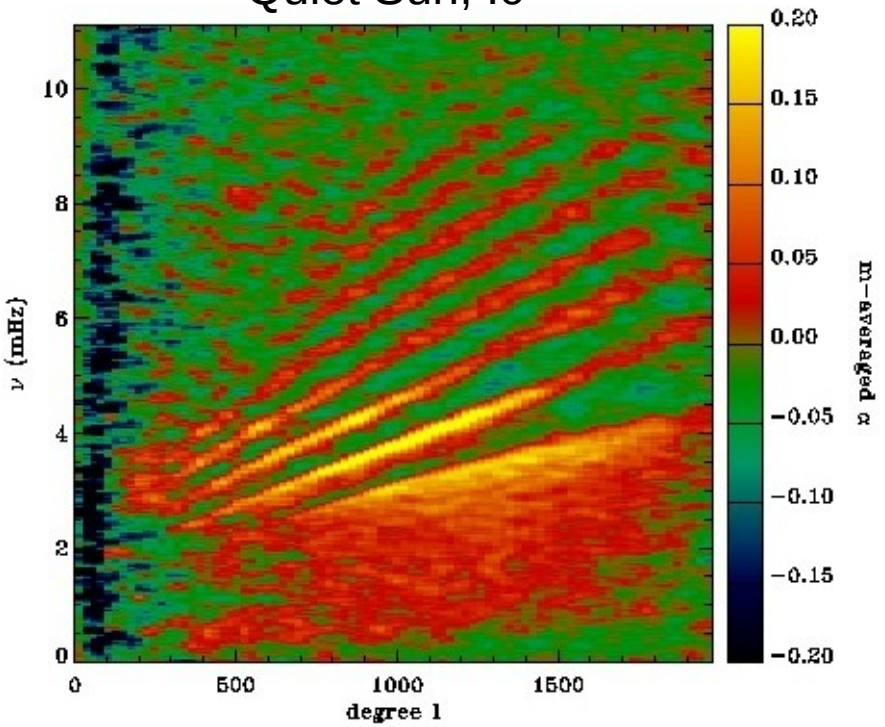
Background removed and f- and p-mode mask applied

NOAA 11289, Ic

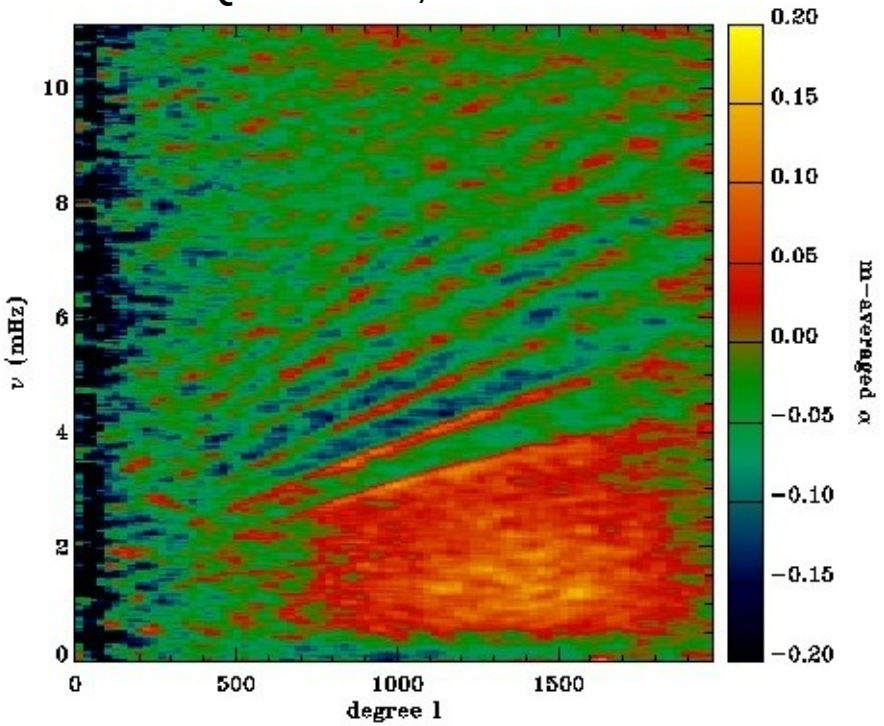


Using Doug Braun's Hankel-Fourier decomposition codes on a quiet Sun region (#1)

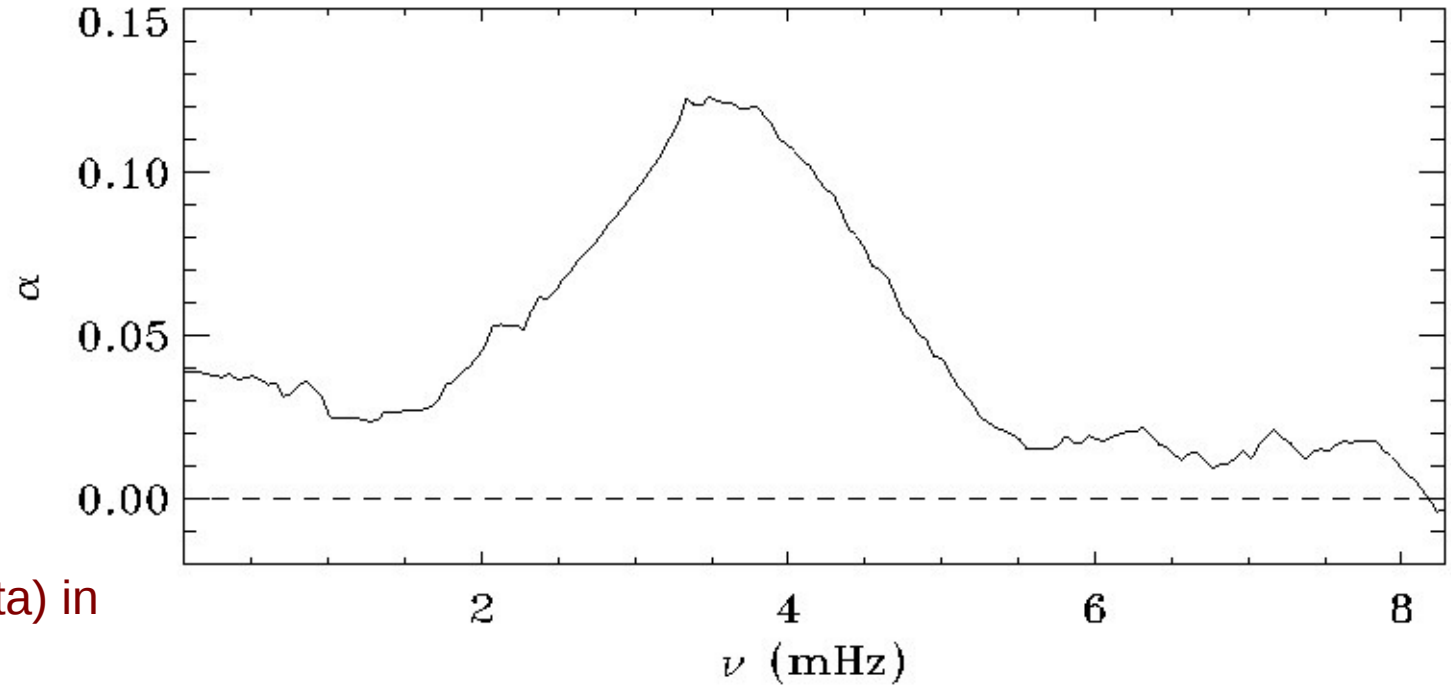
Quiet Sun, Ic

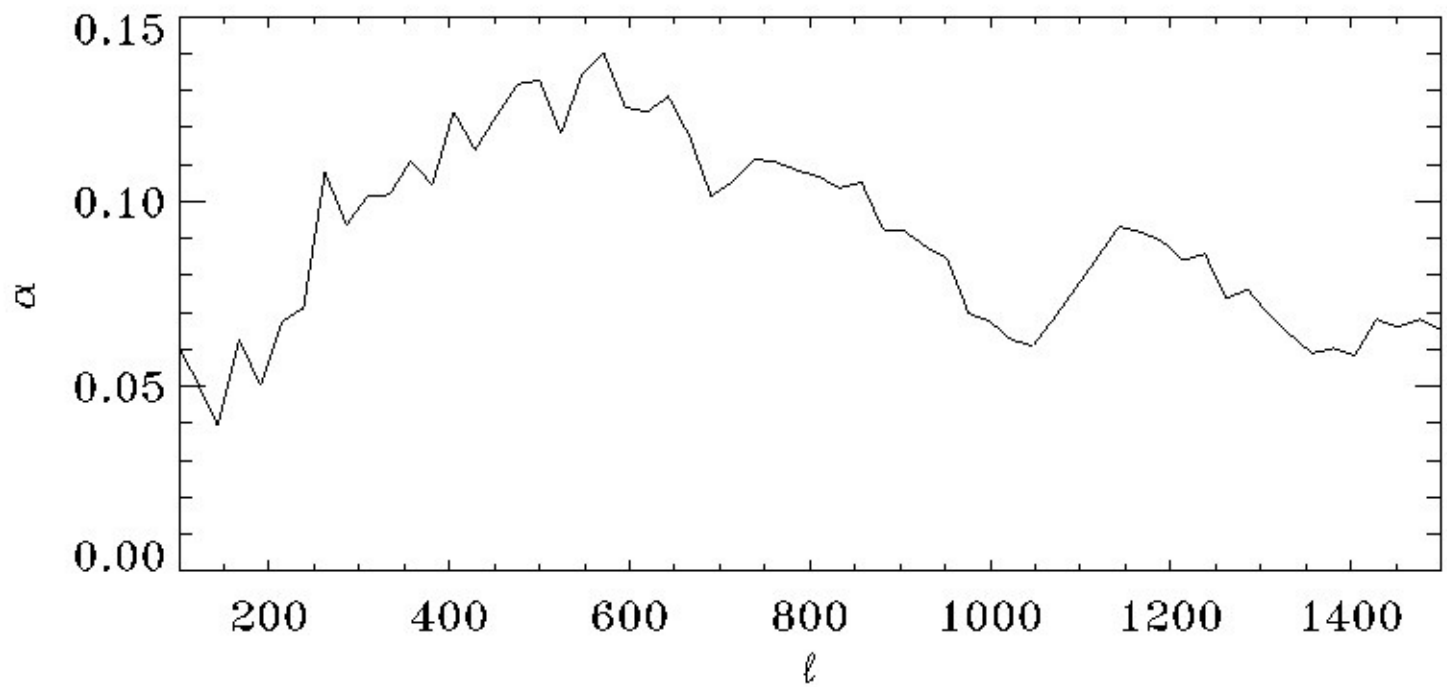


Quiet Sun, line core

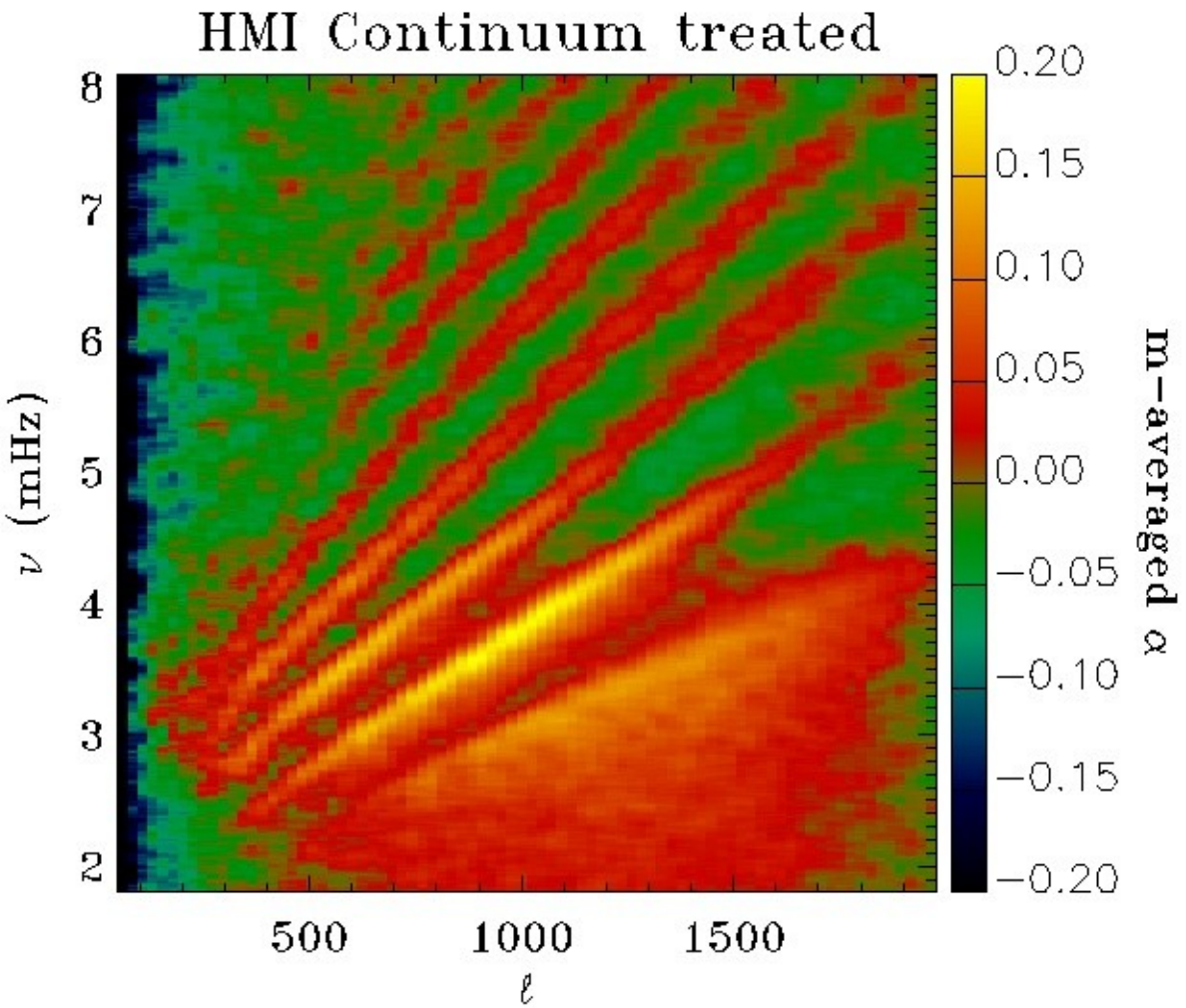


MDI continuum (full disk data) in quiet Sun: m-averaged absorption; no background removed, no mask applied



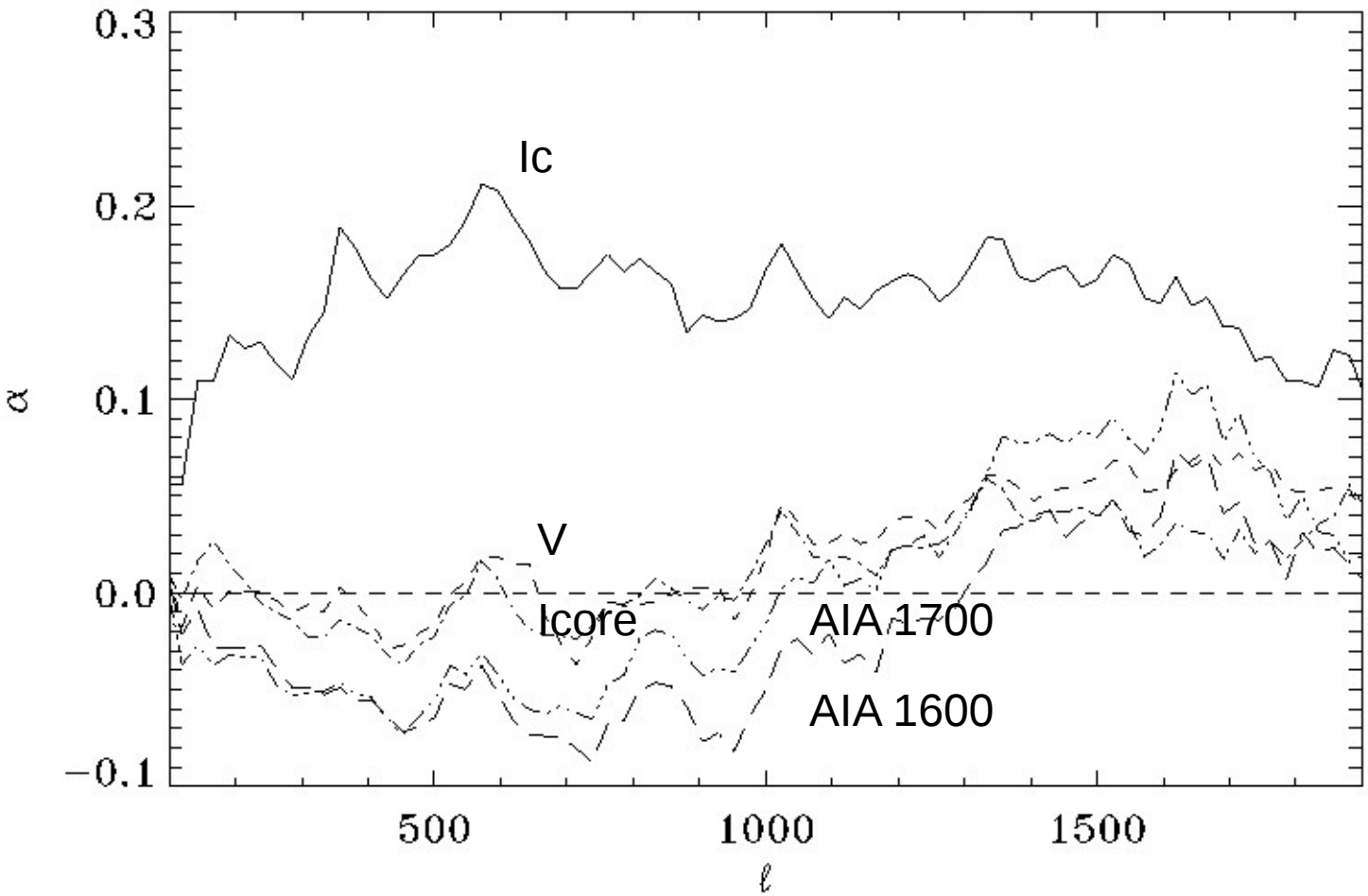


m-averaged power absorption in 3 quiet-Sun regions in pre-processed continuum intensity



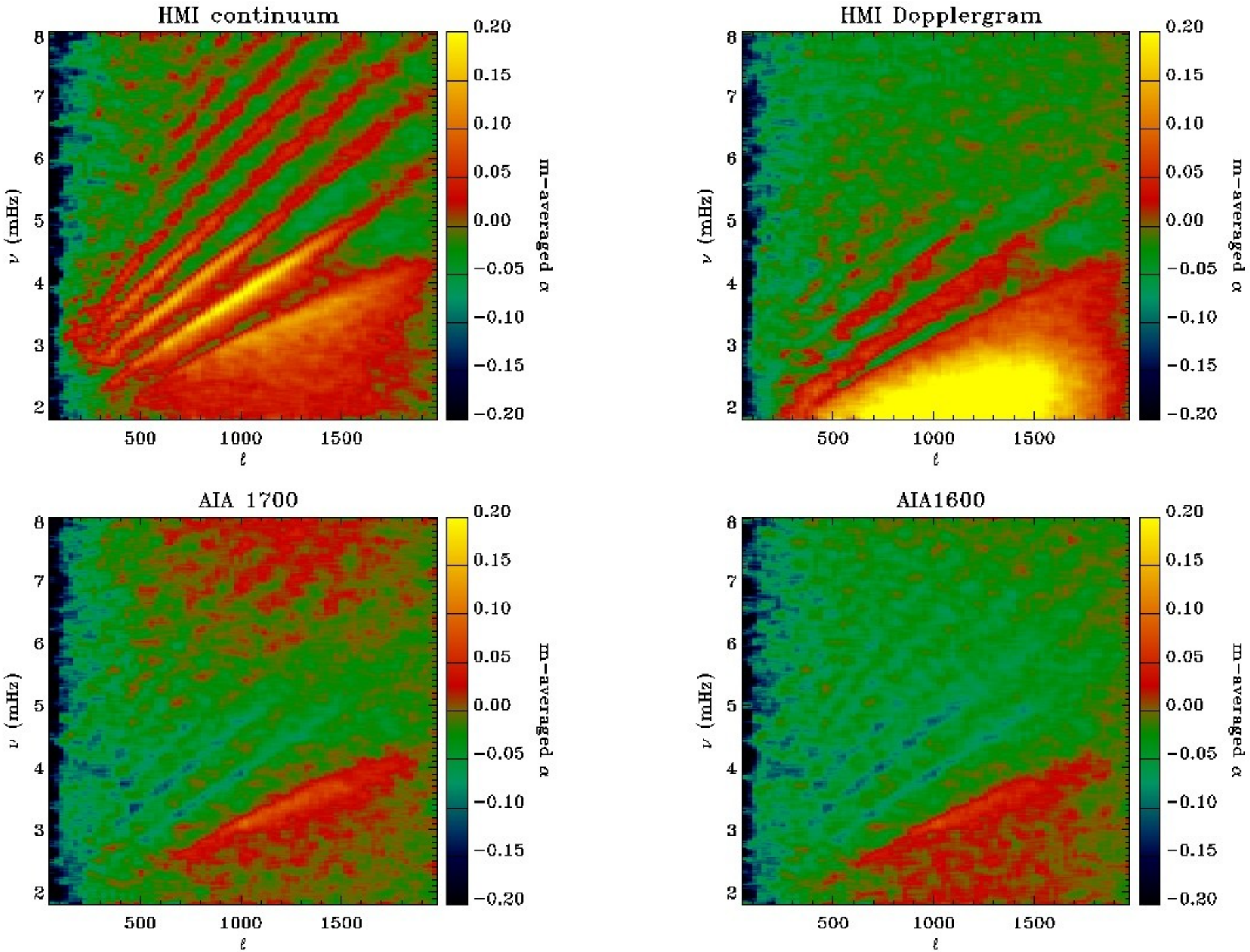
The continuum intensity cube was pre-processed: limb-darkening removed, moving-difference taken (high-pass filter)

m-averaged absorption coefficient in a quiet Sun region (#4, smoothed curves)

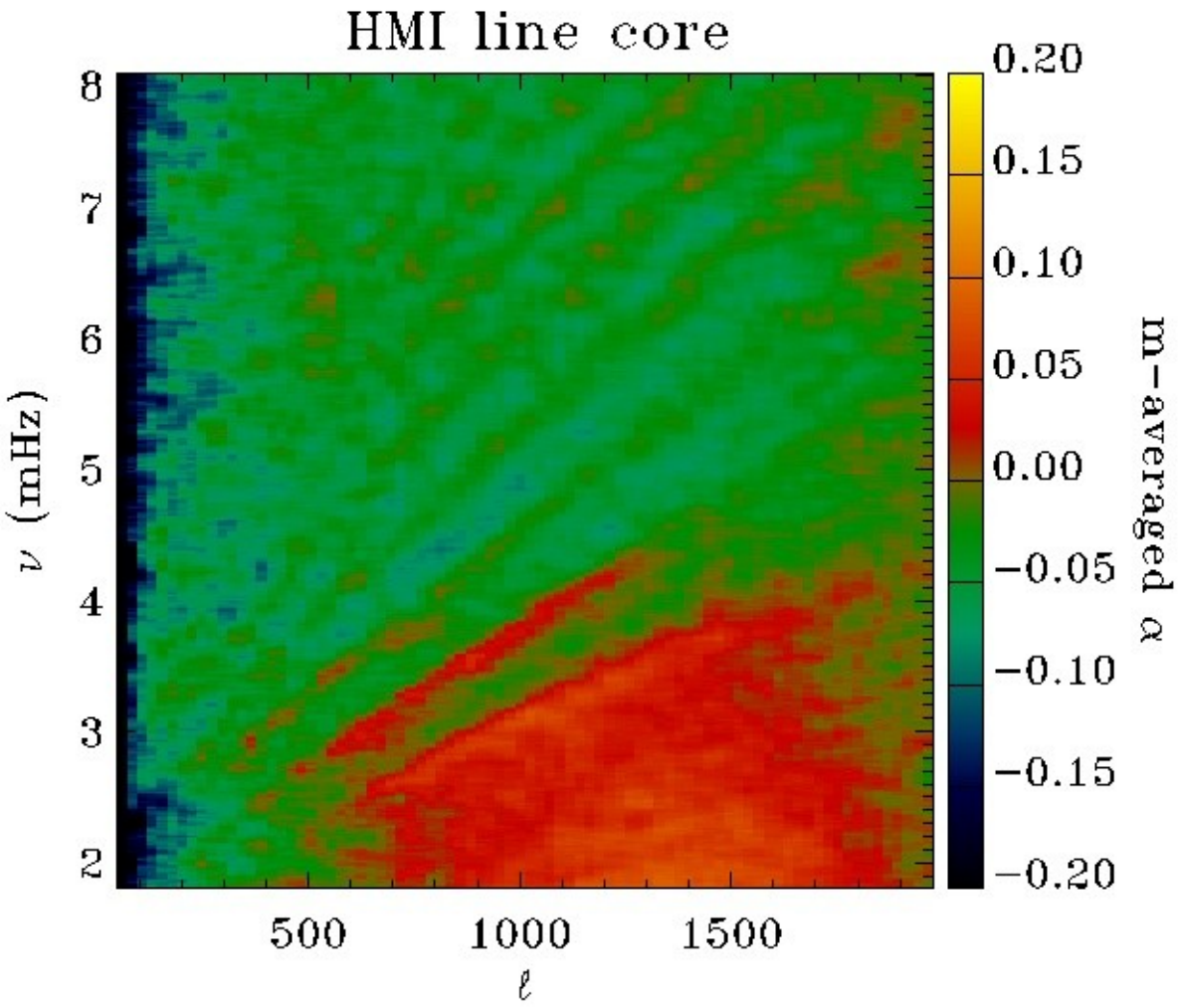


Background removed and f- and p-mode mask applied

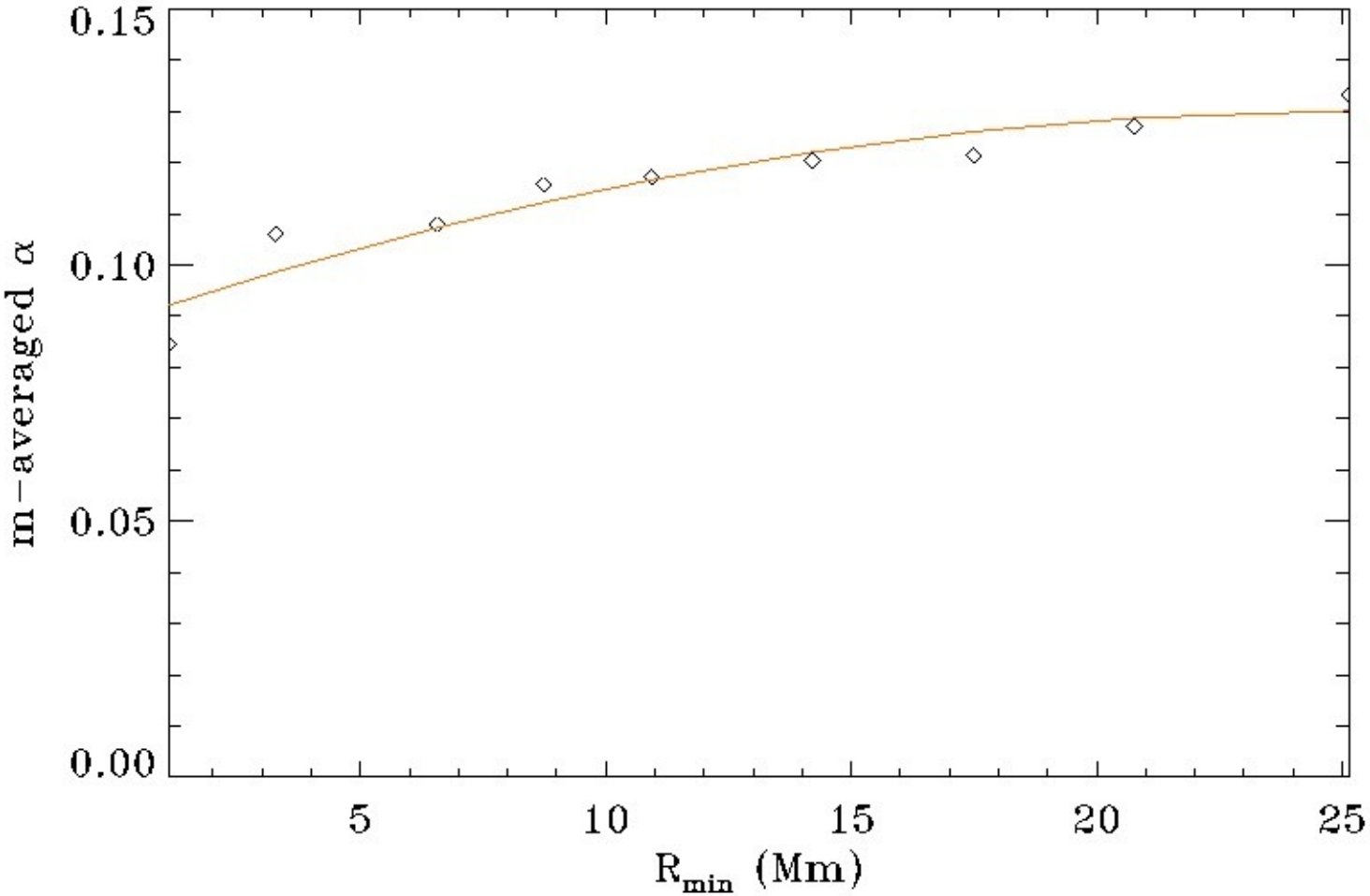
m-averaged power absorption in 3 quiet-Sun regions



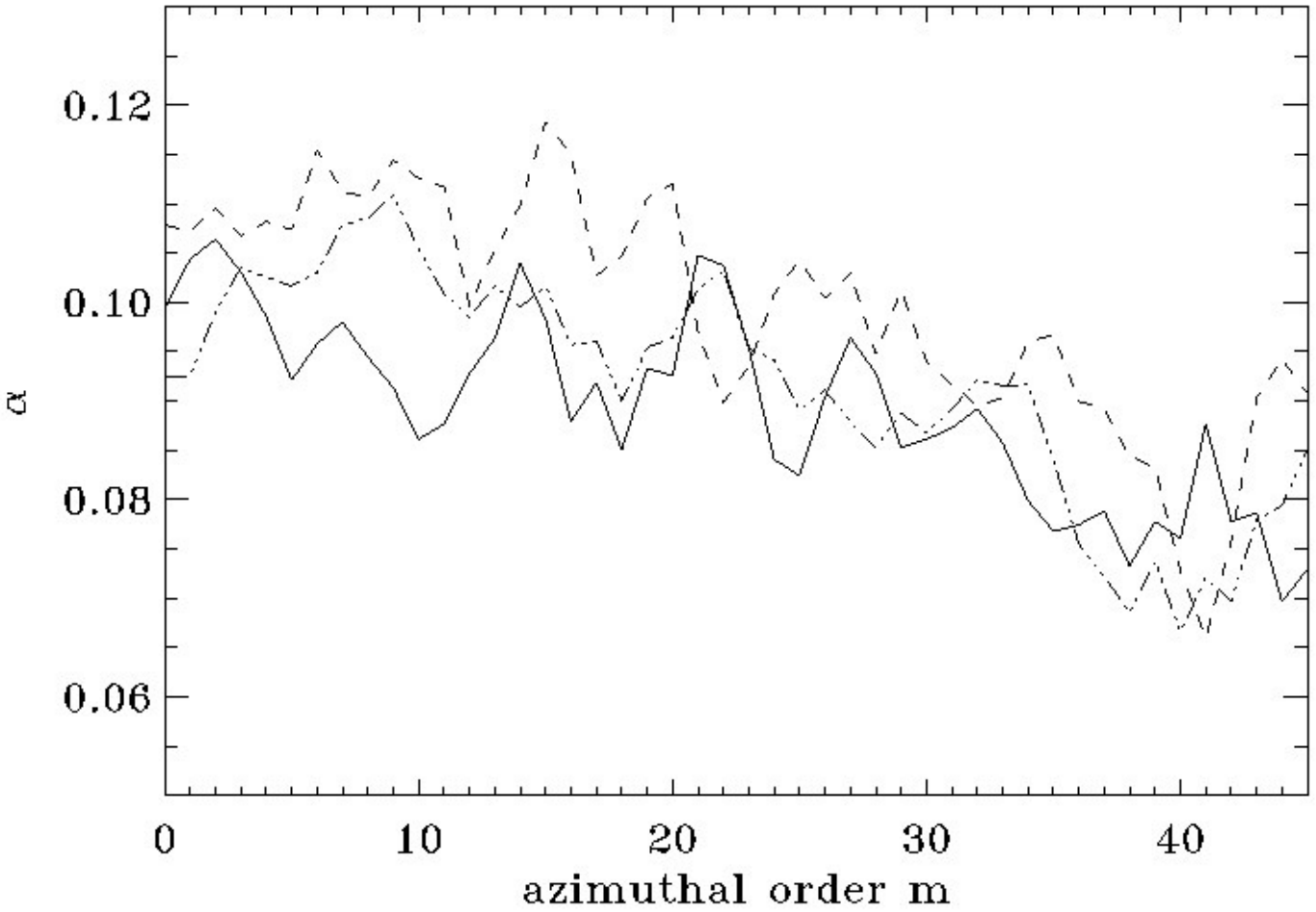
m-averaged power absorption in 3 quiet-Sun regions in line-core intensity



m-averaged power absorption in a quiet-Sun region as a function of Rmin (background removed and f- and p-mode mask applied; -2≤m≤2)



m-averaged power absorption in 3 quiet-Sun regions as a function of m (background not removed but f- and p-mode mask applied; curves smoothed)



Conclusion and Future Work

- f- and p-mode power absorption in sunspot varies with height in atmosphere
- emission at $\nu \geq 4.5$-5 mHz due to seismic halo (fast MAG waves propagating upwards, refracted by magnetic field and emerging in region surrounding the sunspot, Khomenko & Collados, 2009)?
- quiet Sun at continuum level seems to behave like a power absorber, while higher there is emission in the p-mode ridges.
- does explanation by Bogdan et al. (1998) of emission at l=500 still hold?

- calculate phases of Hankel-Fourier decomposition coefficients
- calculate coefficients for line-core data
- run code on R. Stein's simulations (for different heights in atmosphere): looked at 48x48 Mm^2 simulations but difficult to conclude anything. need 96x96 Mm^2.
- run code on temporal subsets of sunspot datacubes (to look at potential center-to-limb variation)
- run code on more sunspots and quiet Sun regions
- run code on Doppler velocity calculated from HMI filters I0-I5 (close to continuum height)