Spatially resolved vorticity in supergranulation with helioseismology (and LCT)

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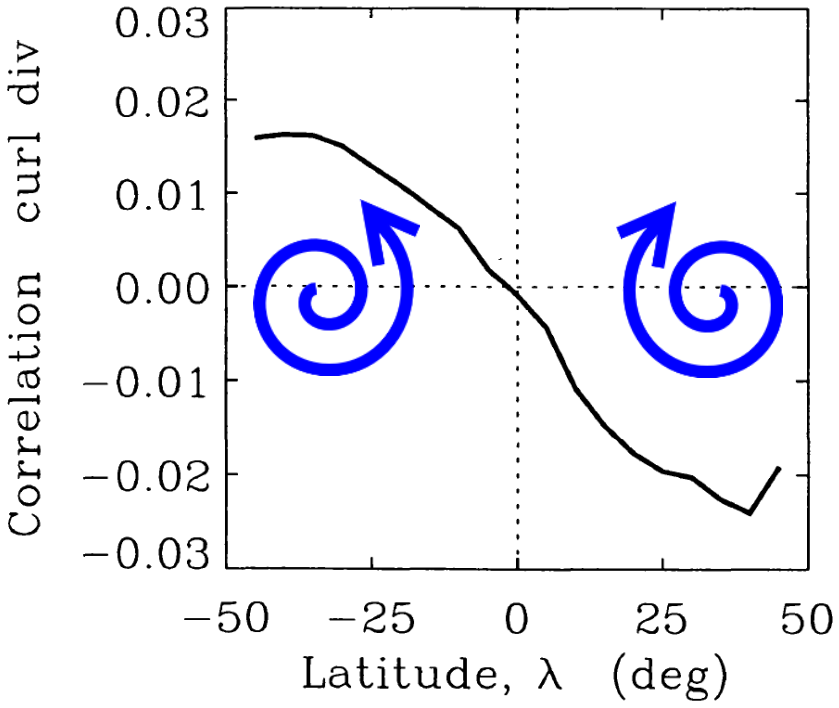
GÖTTINGEN

AstroFiT
Astrophysical Flow Instabilities and Turbulence

MPS

Motivation

- Known non-zero correlation $\langle \mathrm{div}_h \mathrm{curl}_z \rangle$ in supergranular flows
- Probably due to Coriolis force acting on convective flows
- How does the circular flow component look in detail?
  → Resolve spatially



Gizon & Duvall 2003

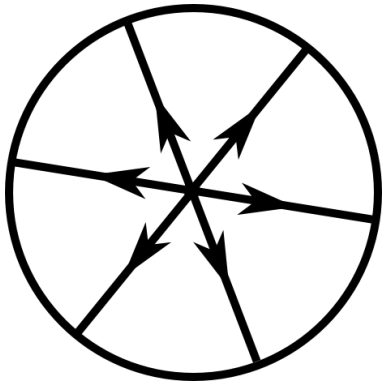
(using f modes in MDI Dopplergrams)

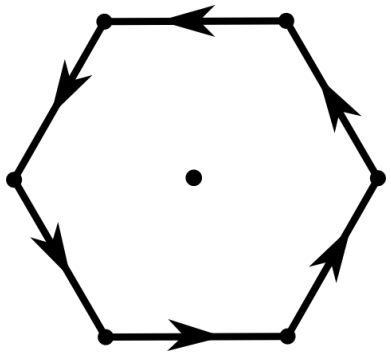
Data and measurement geometries

- HMI Dopplergrams ~ 180 x 180 Mm²
- Tracked for 24h each (around central meridian)
- Remapped using Postel's projection
- Latitudes $-60°, -40°, -20°, 0°, 20°, 40°, 60°$
- 1 May – 28 August 2010
- Select modes: f and p_1

Divergence -sensitive travel times

τ^{oi}





Vorticity -sensitive travel times

$\delta\tau^{\circlearrowleft}$

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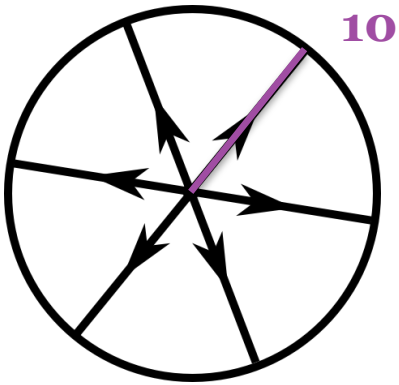

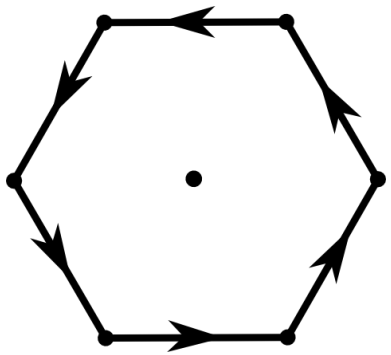

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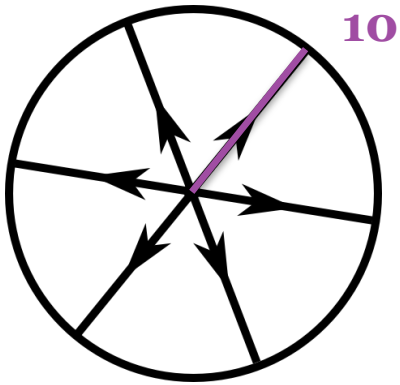

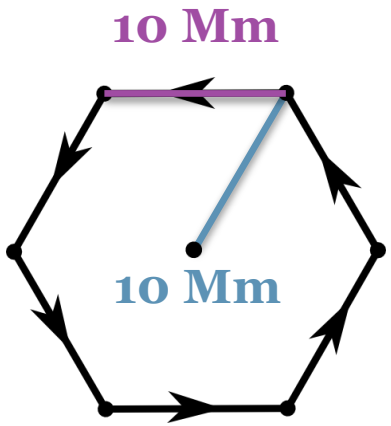

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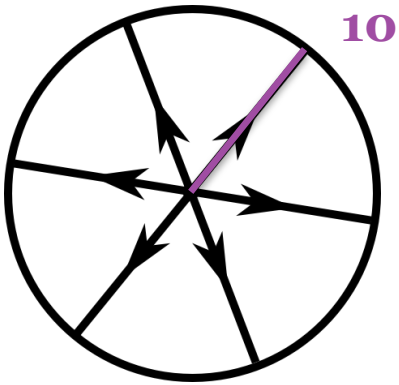

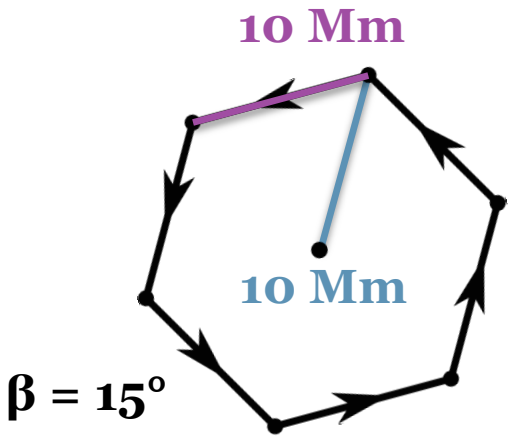

Vorticity -sensitive travel times

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Divergence -sensitive travel times

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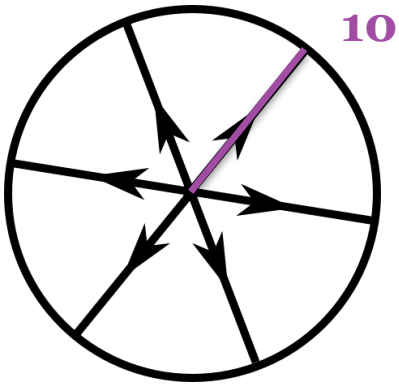

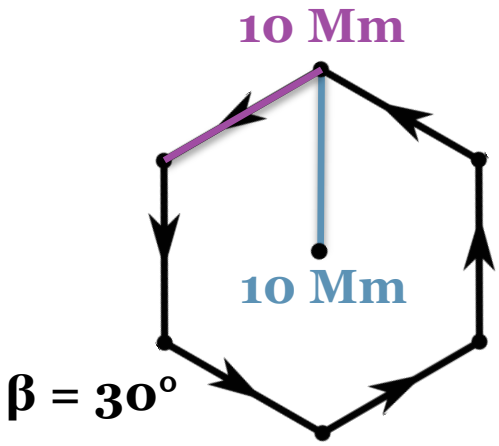

Vorticity -sensitive travel times

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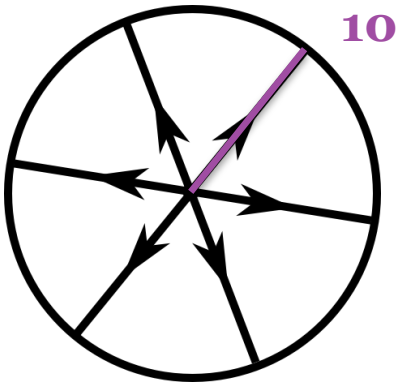
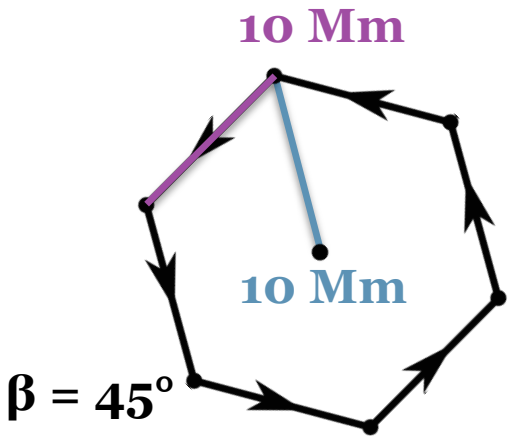




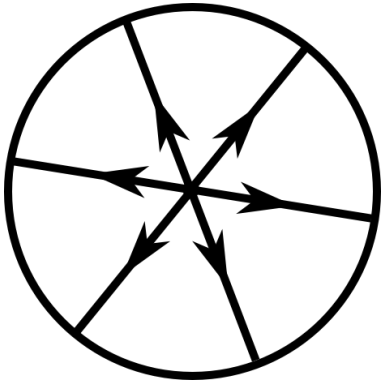
Vorticity -sensitive travel times

$\delta\tau^{\circlearrowleft}$

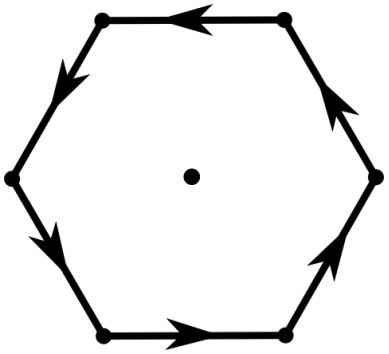
Example travel-time maps

Divergence -sensitive travel times

τ^{oi}

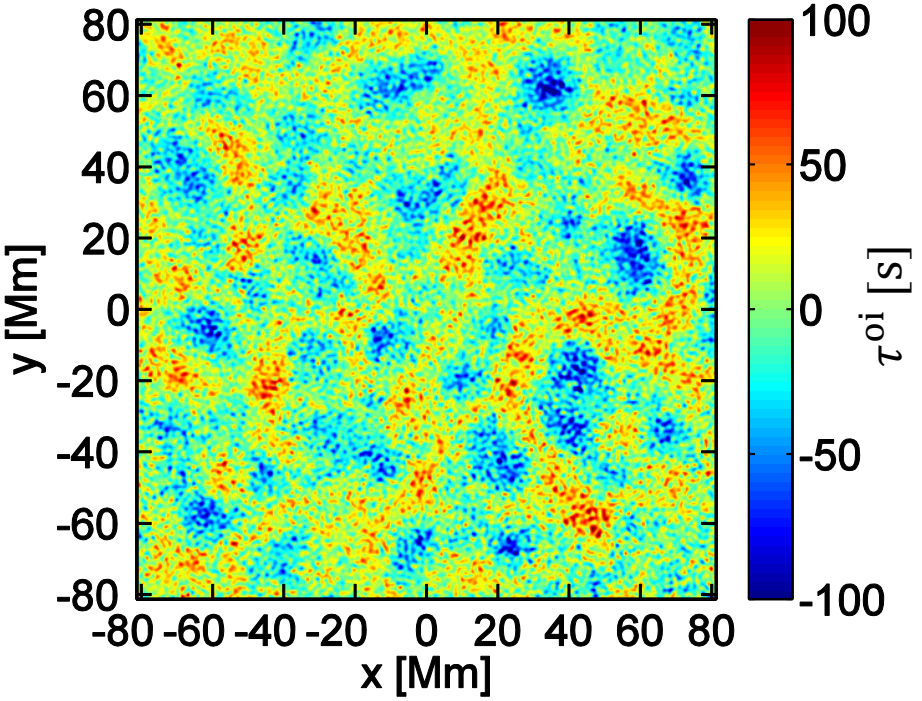


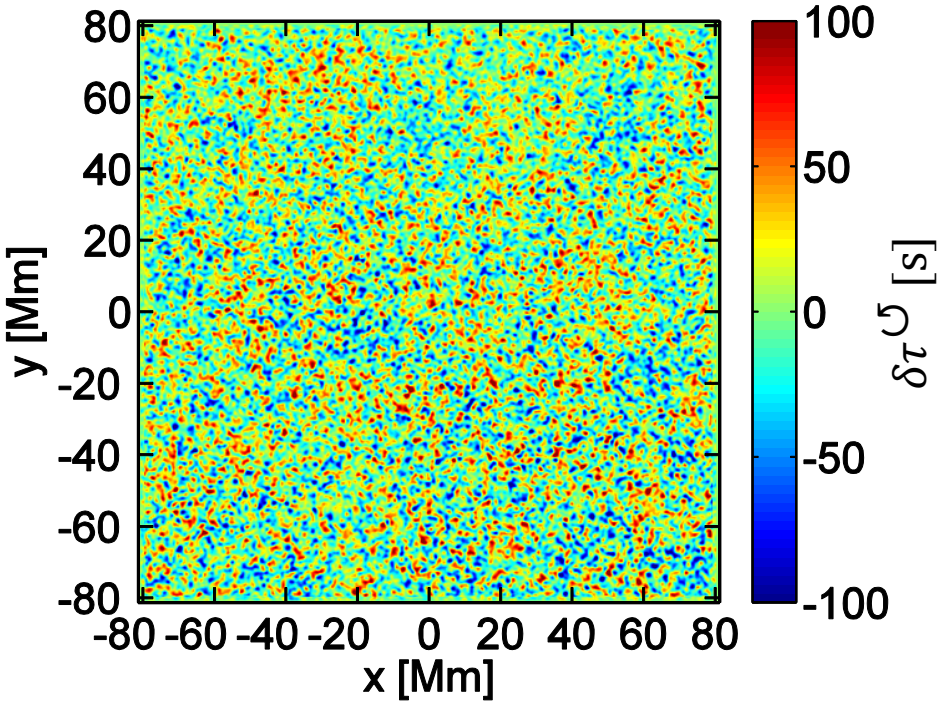
40°
f mode
8h



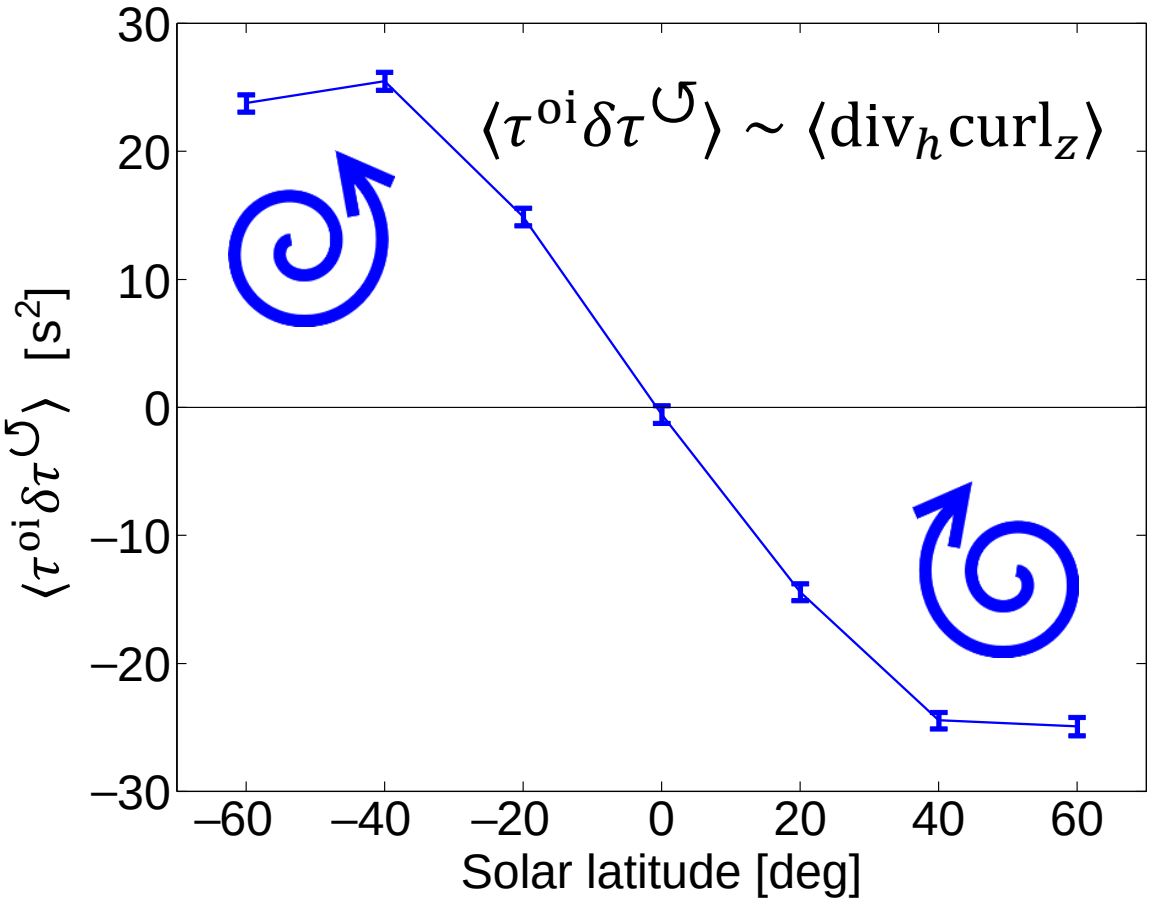
Vorticity -sensitive travel times

$\delta\tau^{\circlearrowleft}$





$\langle \mathrm{div}_h \mathrm{curl}_z \rangle$ vs. latitude

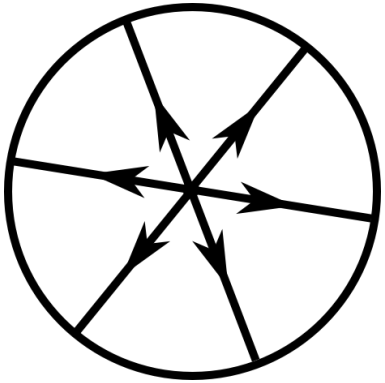


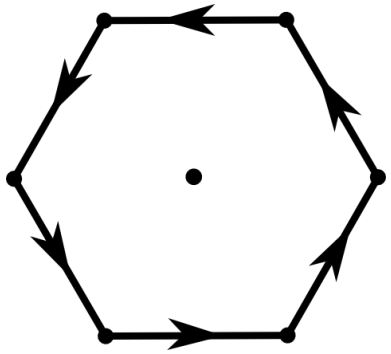
Langfellner et al., A&A, accepted

Example travel-time maps

Divergence -sensitive travel times

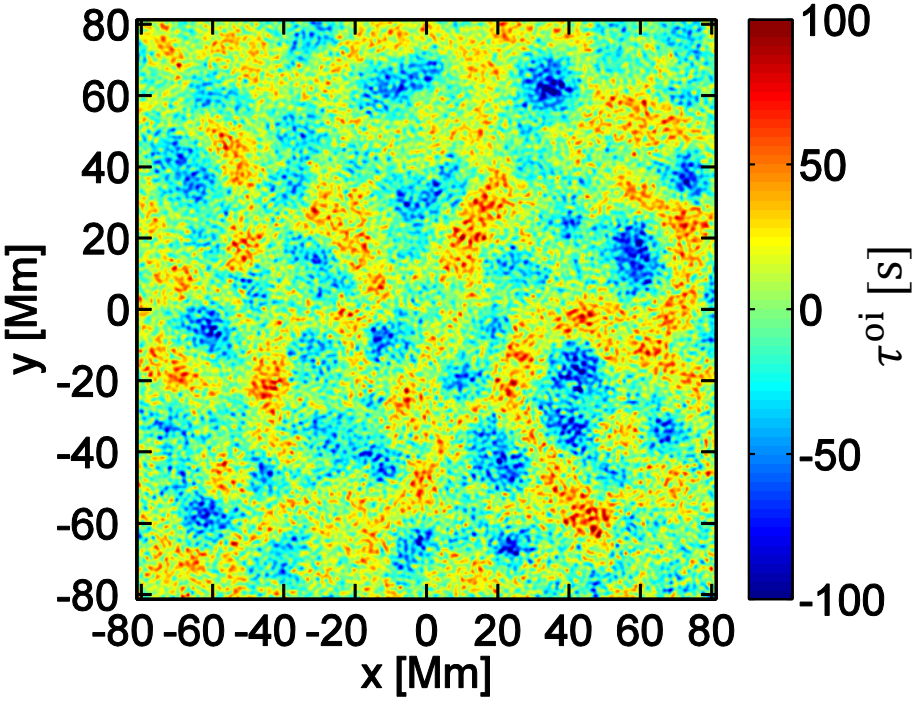
τ^{oi}

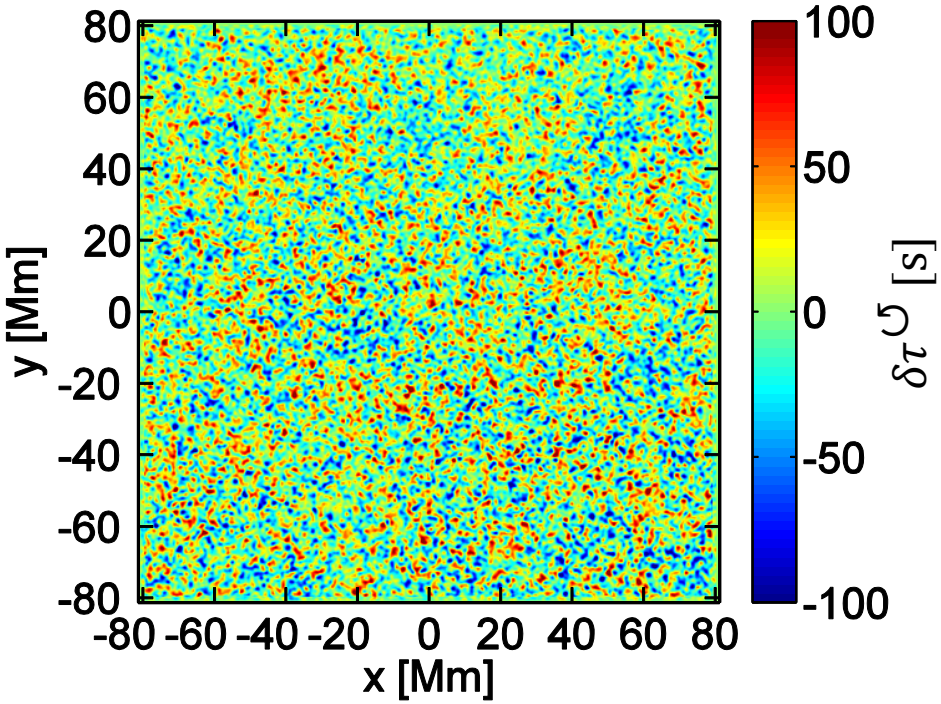




Vorticity -sensitive travel times

$\delta\tau^{\circlearrowleft}$





Example travel-time maps

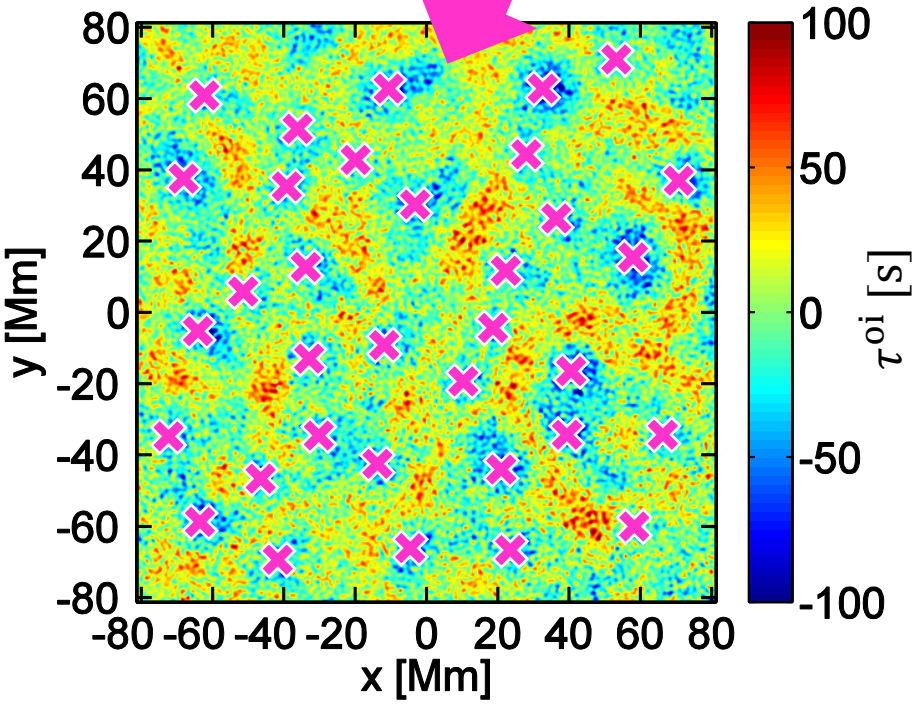
Divergence -sensitive travel times

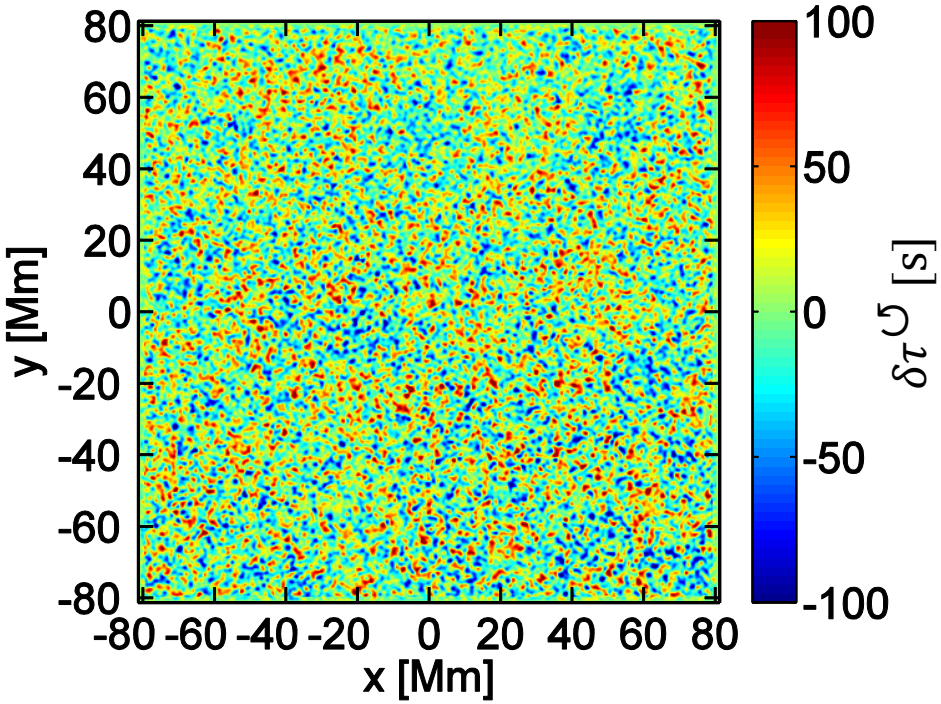
τ^{oi}

Find positions of supergranules

Vorticity -sensitive travel times

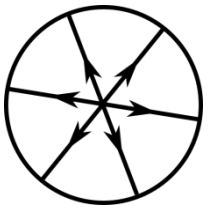
$\delta\tau^{\circlearrowleft}$



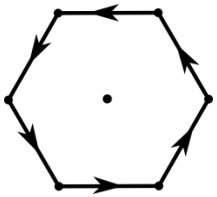


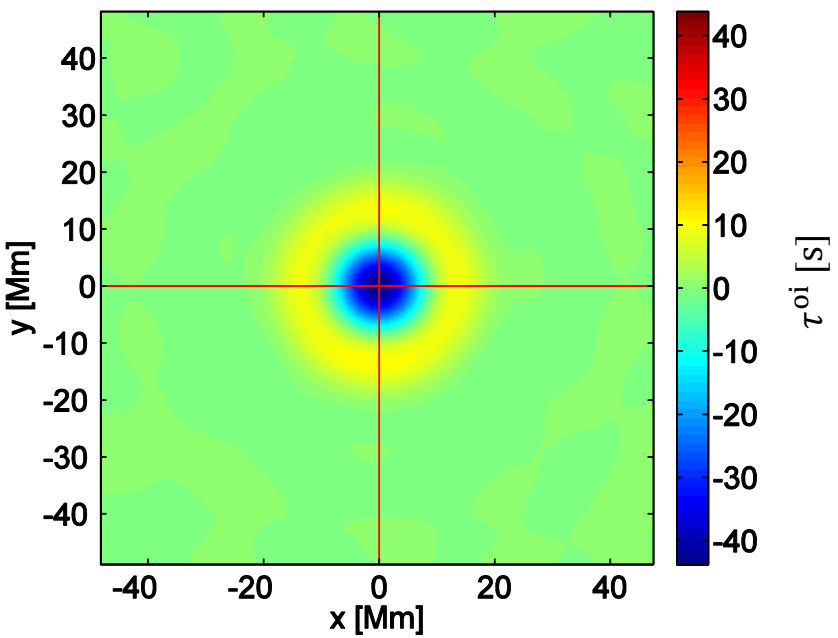
The average supergranule

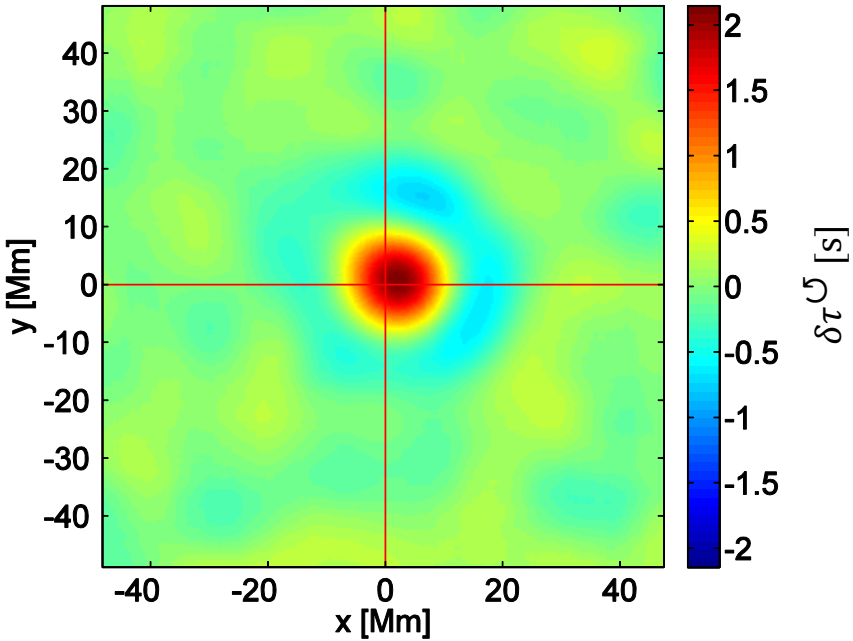
- Shift maps so supergranules are on top of each other
- Average over ~3,000 supergranules (many maps)



At 40° solar latitude

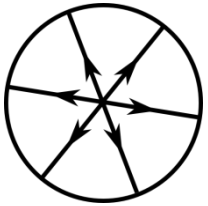






The average supergranule

- Convert travel times into velocities (using a constant factor)



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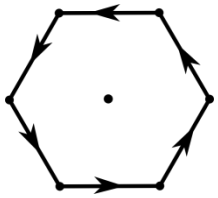

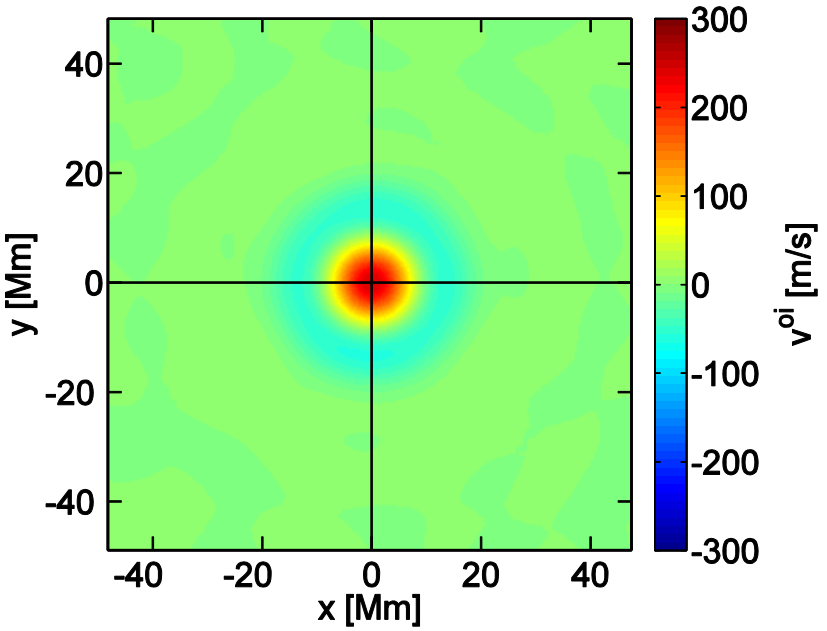

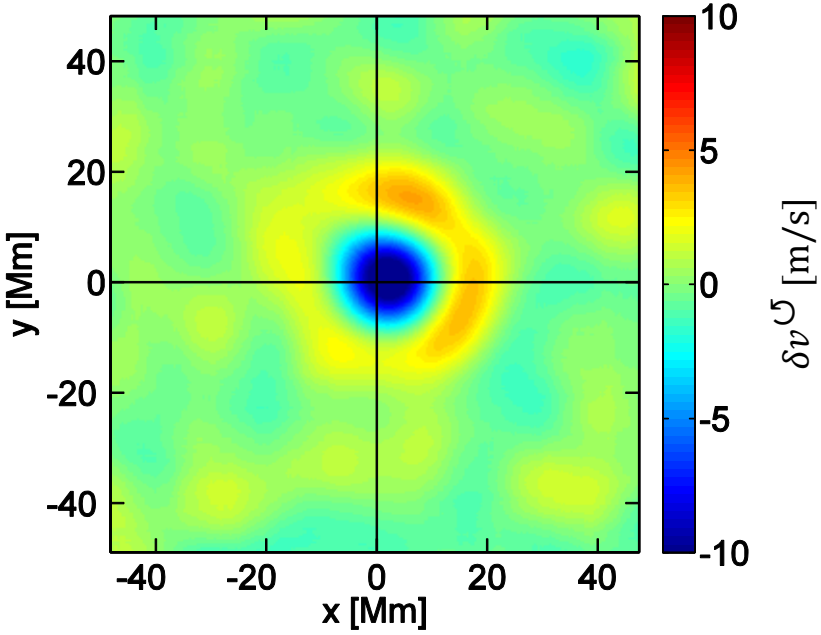

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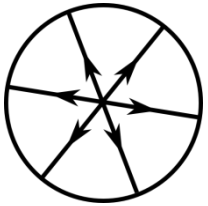

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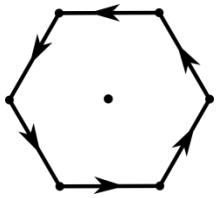
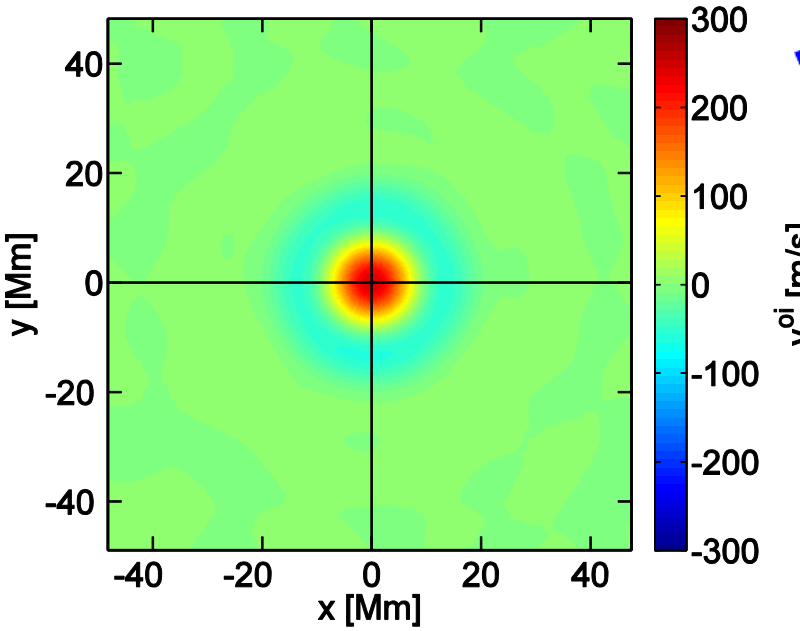
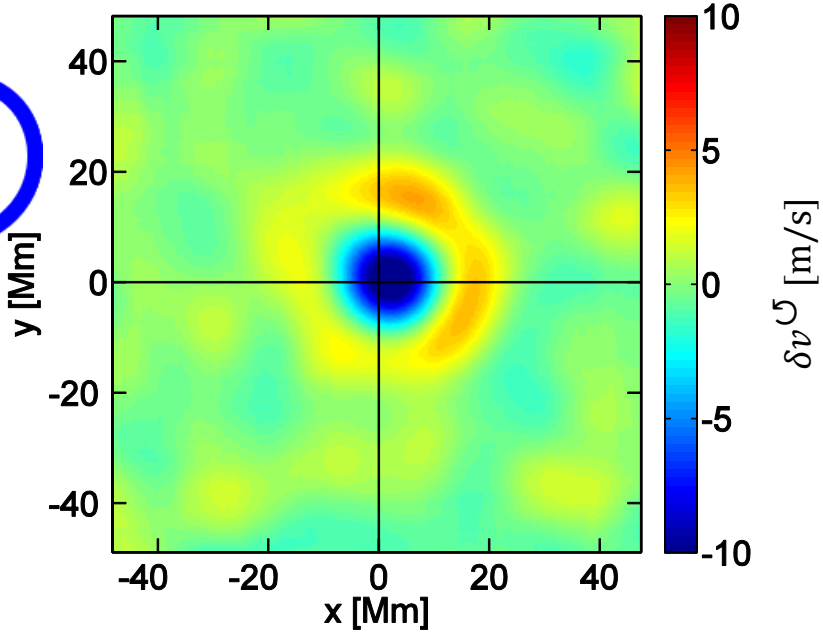
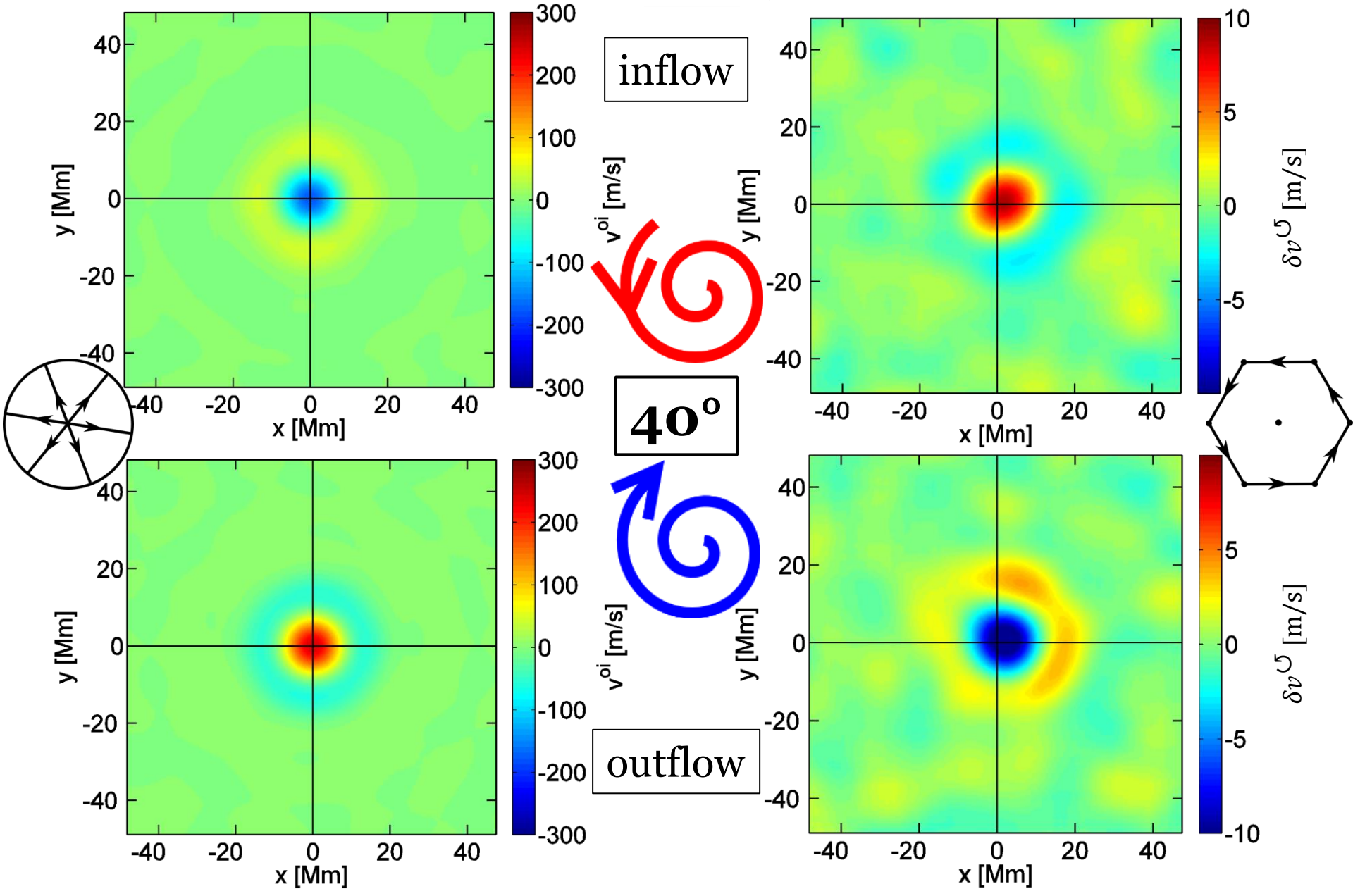
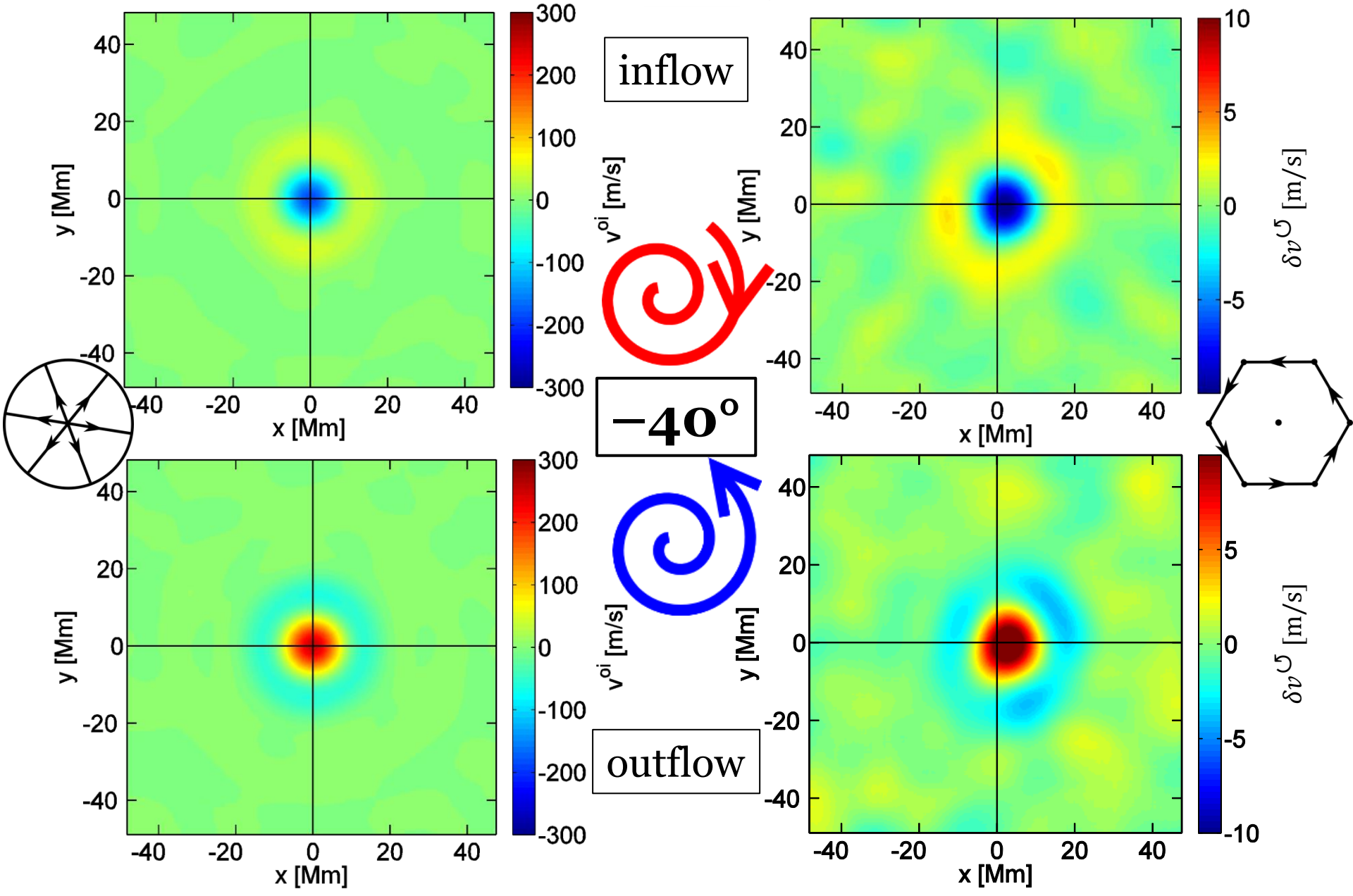
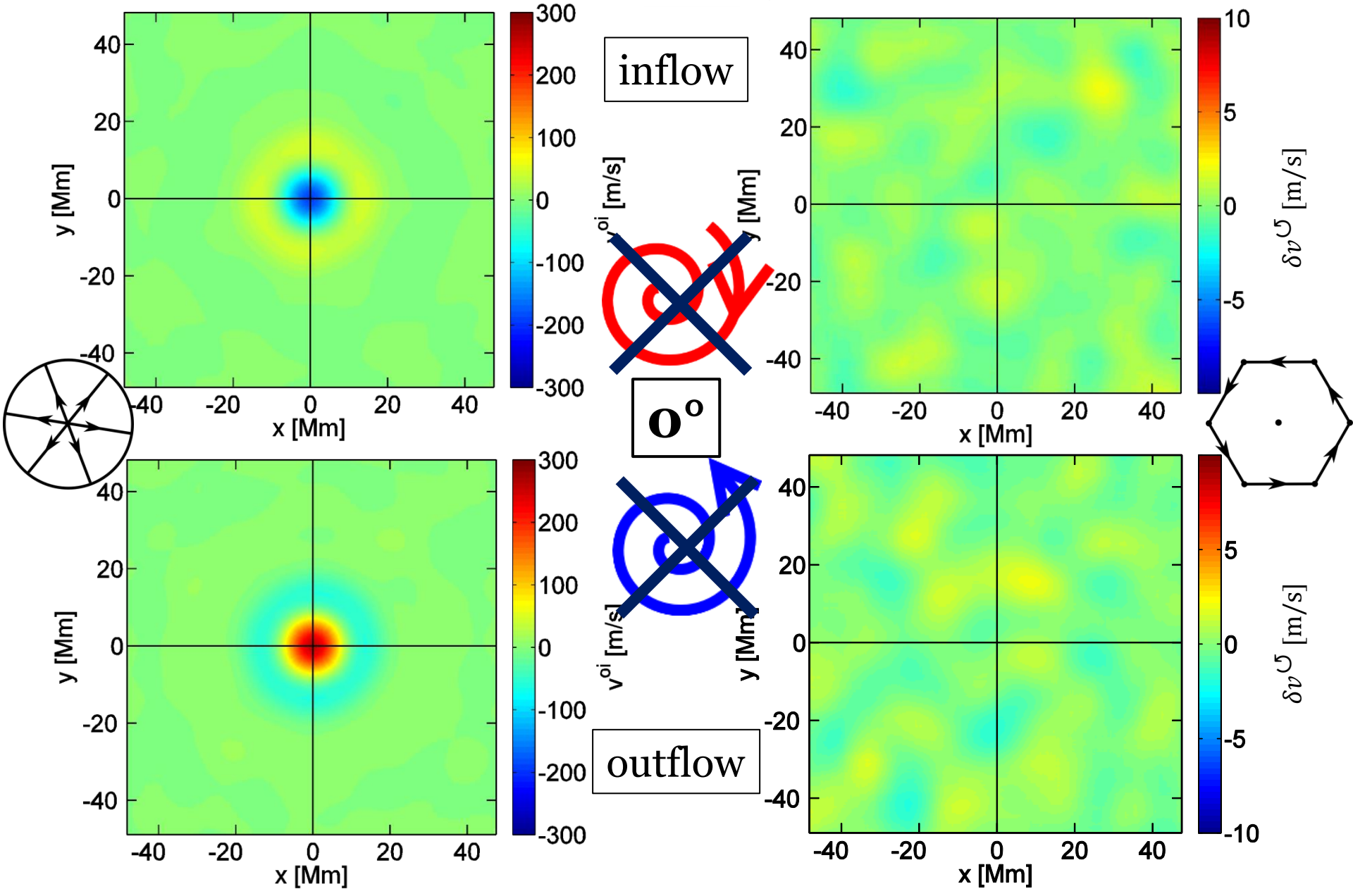




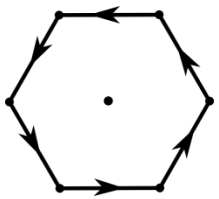



inflow
40°
outflow
v^{oi} [m/s]
$\delta v^{\circlearrowleft}$ [m/s]
x [Mm]
y [Mm]


inflow
−40°
outflow
y [Mm]
x [Mm]
v^{oi} [m/s]
$\delta v^{\circlearrowleft}$ [m/s]
40
20
0
-20
-40
300
200
100
0
-100
-200
-300
10
5
-5
-10

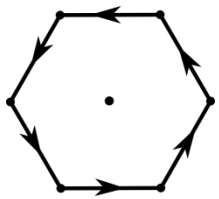

inflow
outflow
y [Mm]
x [Mm]
v^{oi} [m/s]
$\delta v^{\circlearrowleft}$ [m/s]
300
200
100
0
-100
-200
-300
10
5
0
-5
-10
40
20
0
-20
-40

Comparison: f mode / p_1 mode

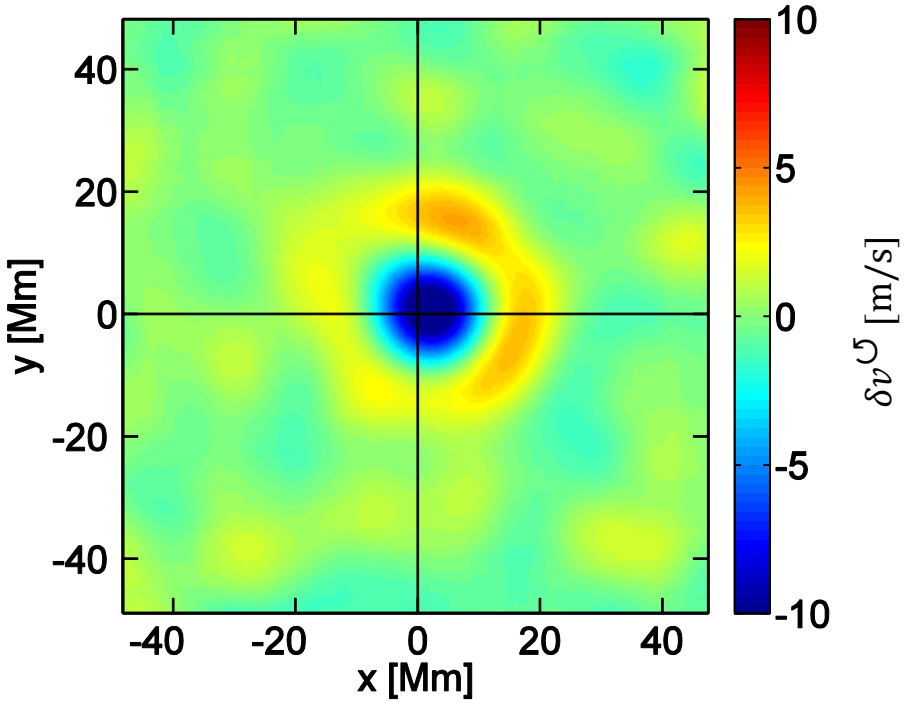


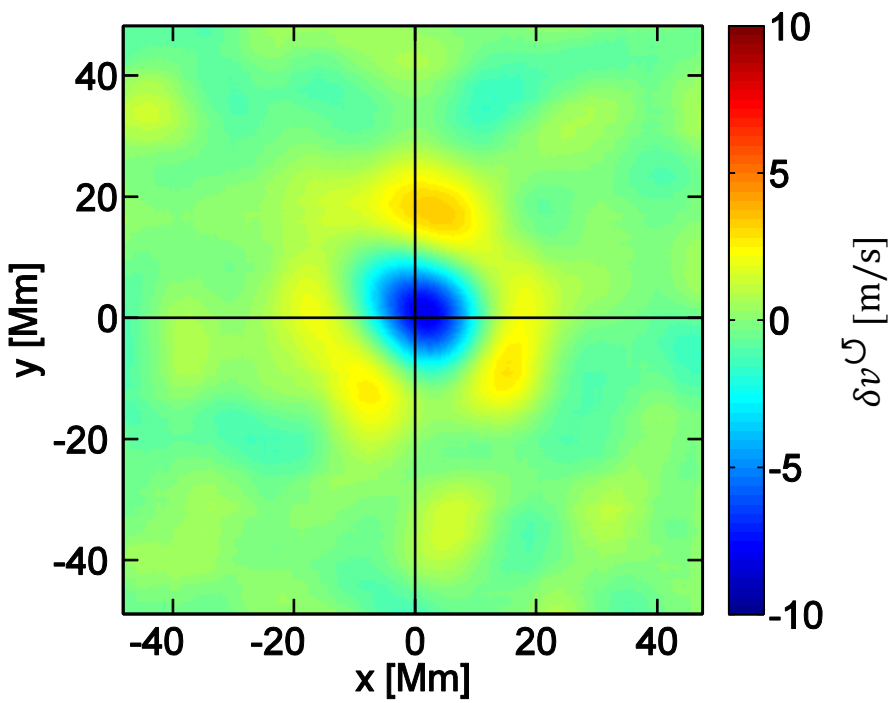
f mode

40°
outflow

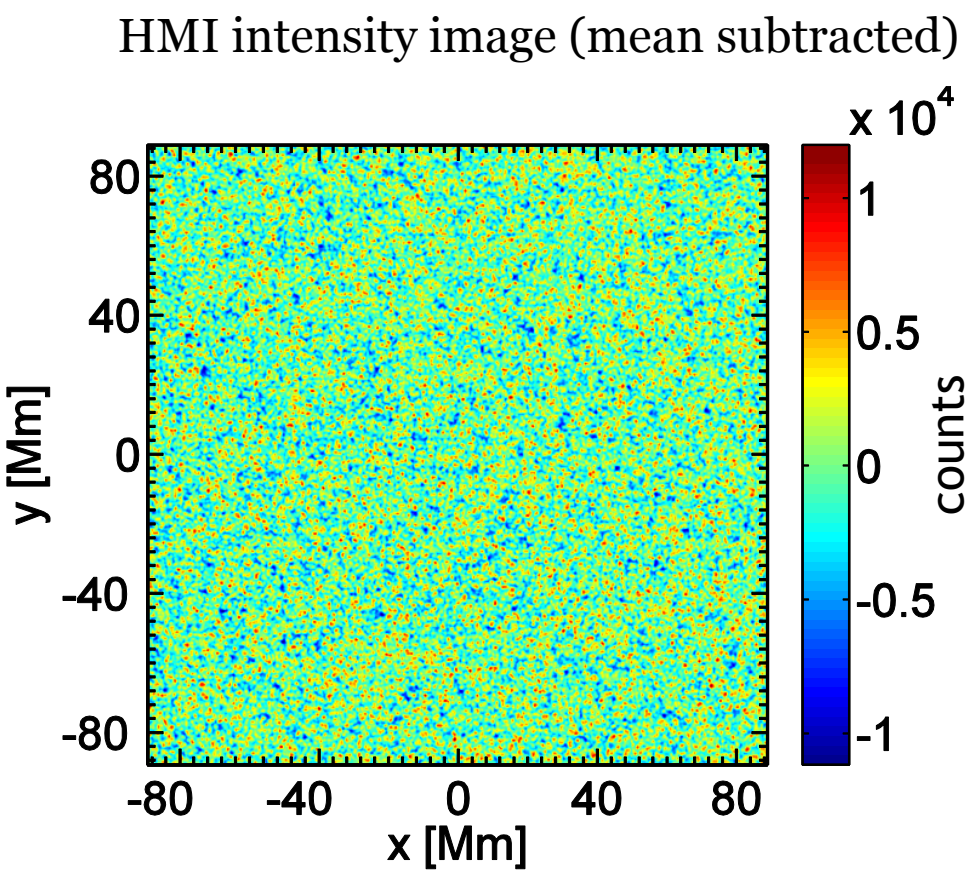


p_1 mode





Local correlation tracking (LCT)

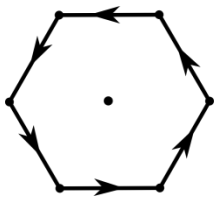


- Granules get advected by larger-scale flows

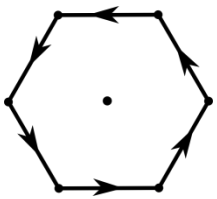
  → Use granules as tracers of supergranule motions

- Cross-correlate image parts at times t and $t + \Delta t$
  → get shift Δx
  → get velocity $v = \frac{\Delta x}{\Delta t}$

Comparison: Time-distance vs. LCT

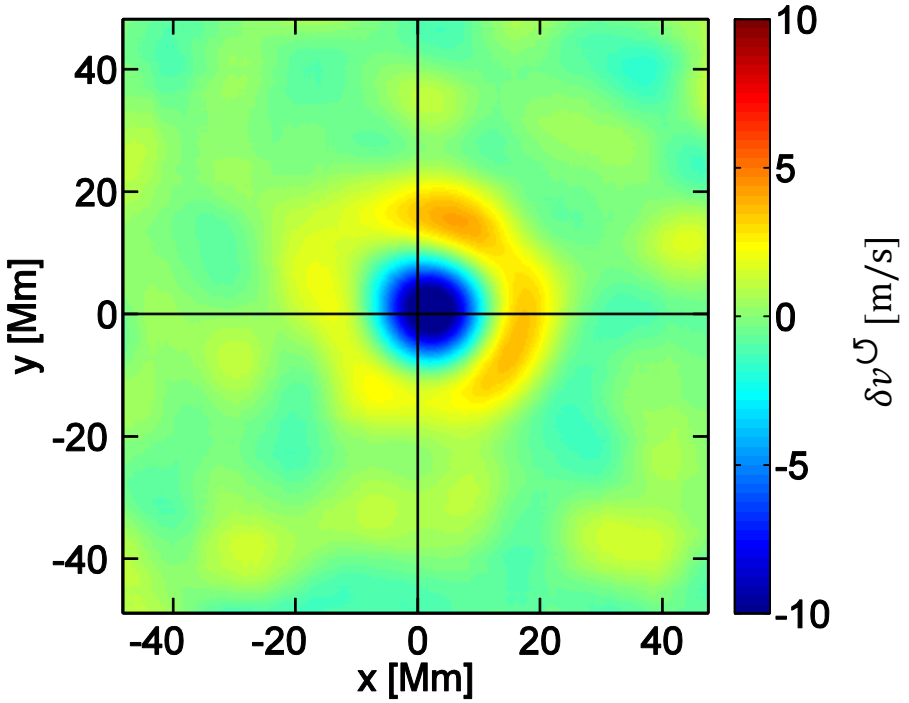


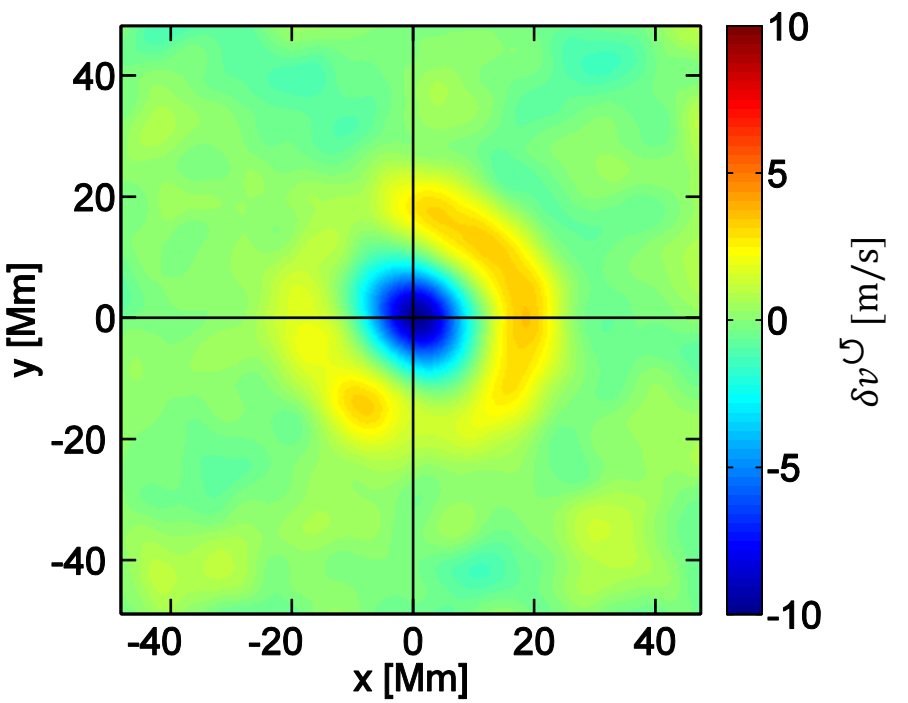
40°
outflow



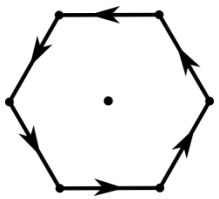
Time-distance (f mode)

LCT

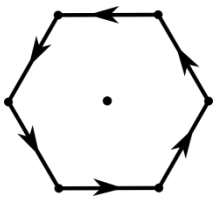




Comparison: Time-distance vs. LCT

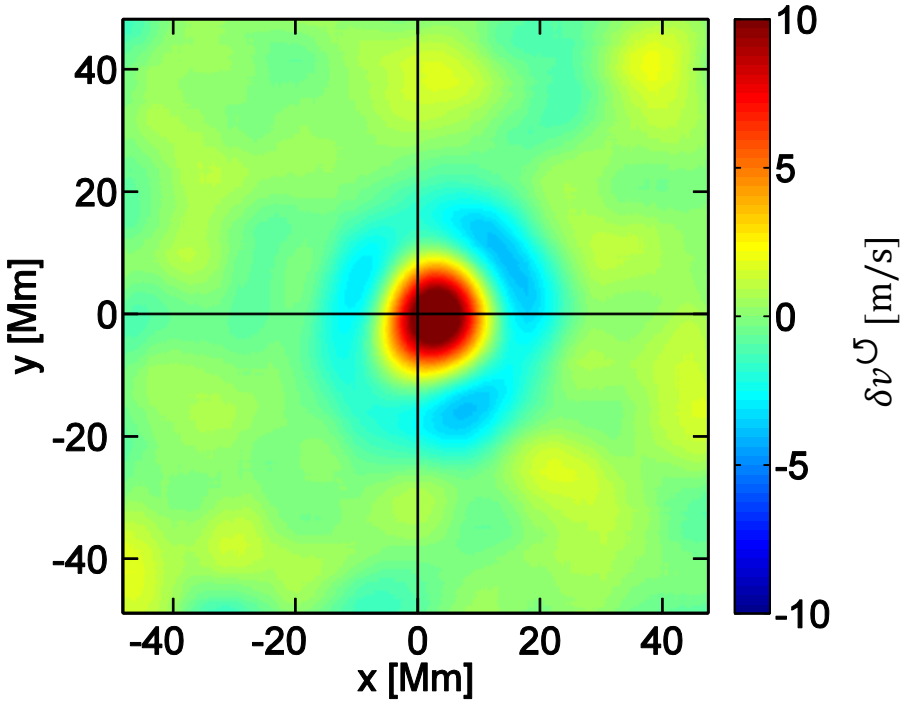


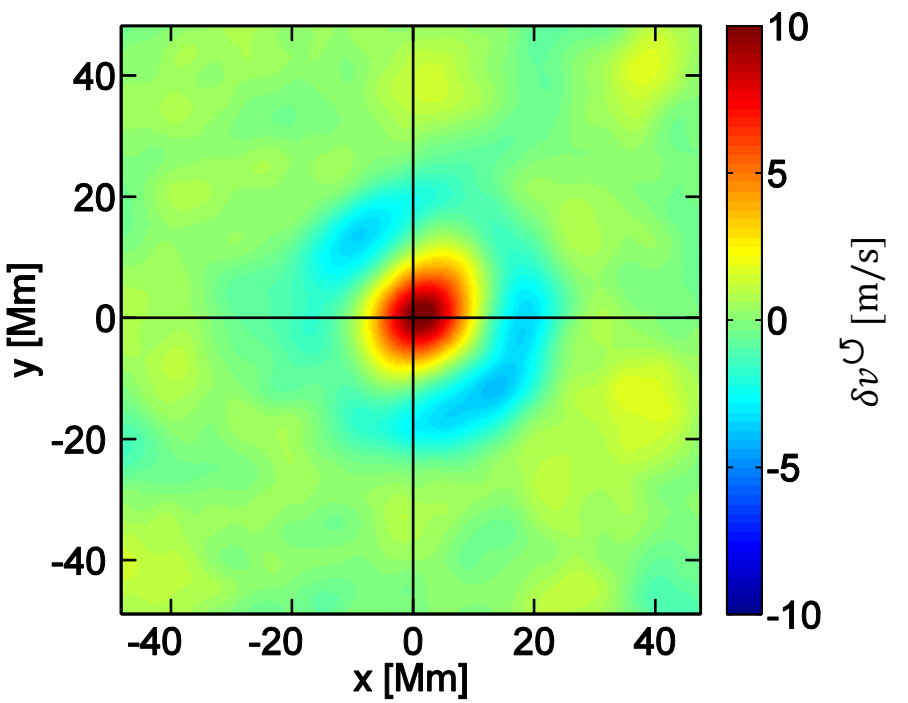
−40°
outflow



Time-distance (f mode)

LCT



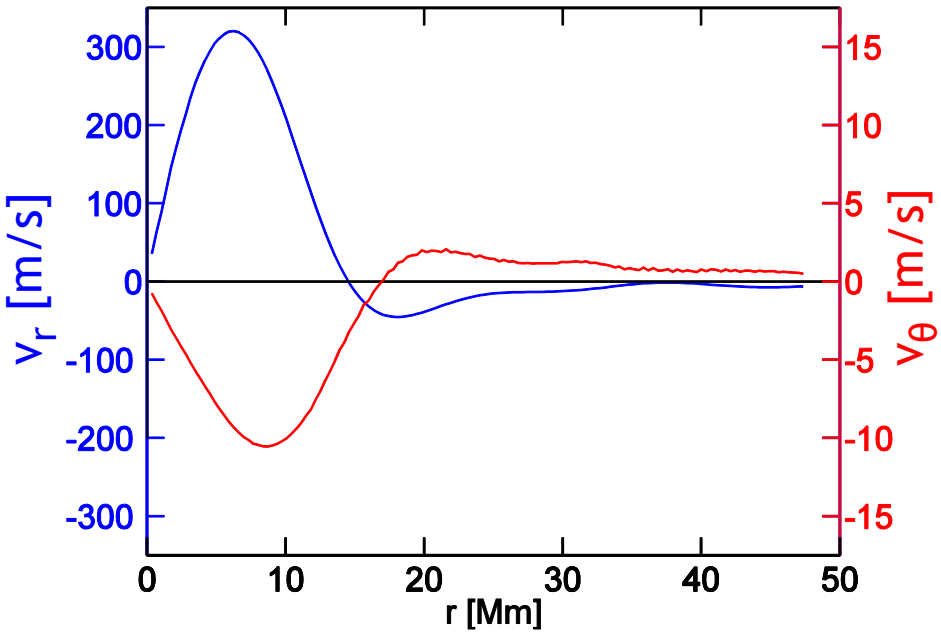


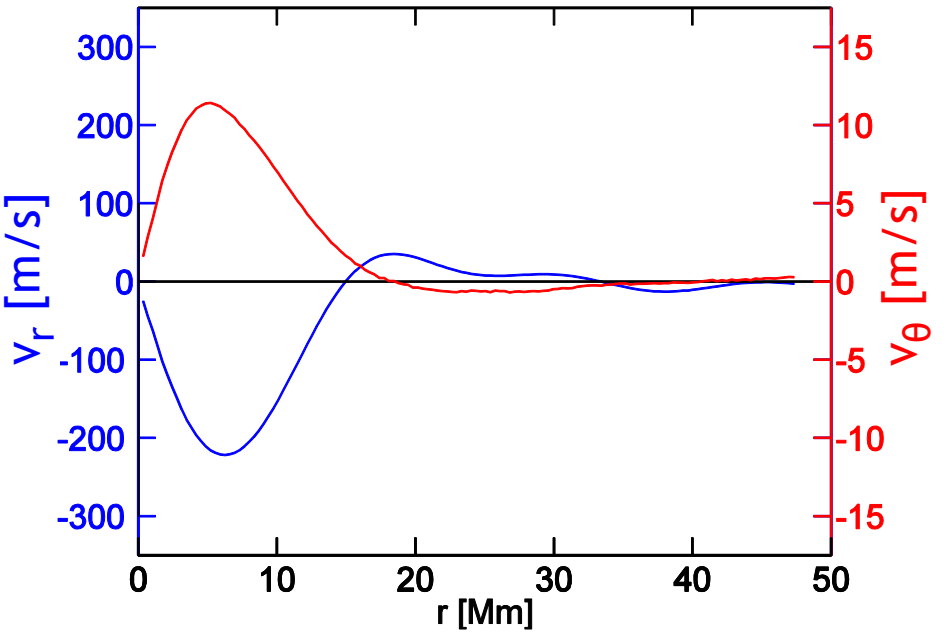
LCT: avg. supergranule flow profiles

outflow

40°

inflow



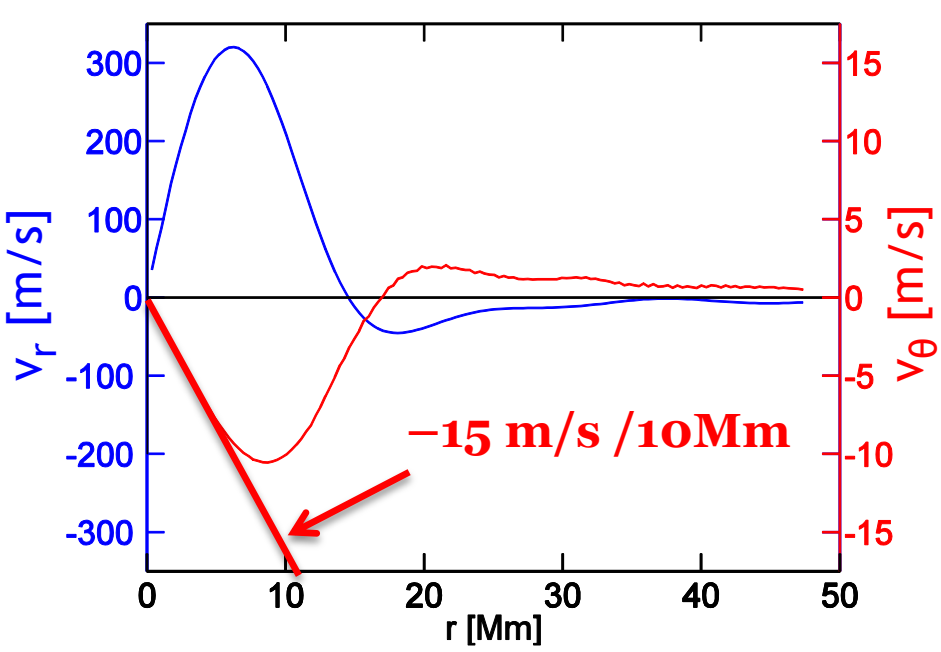


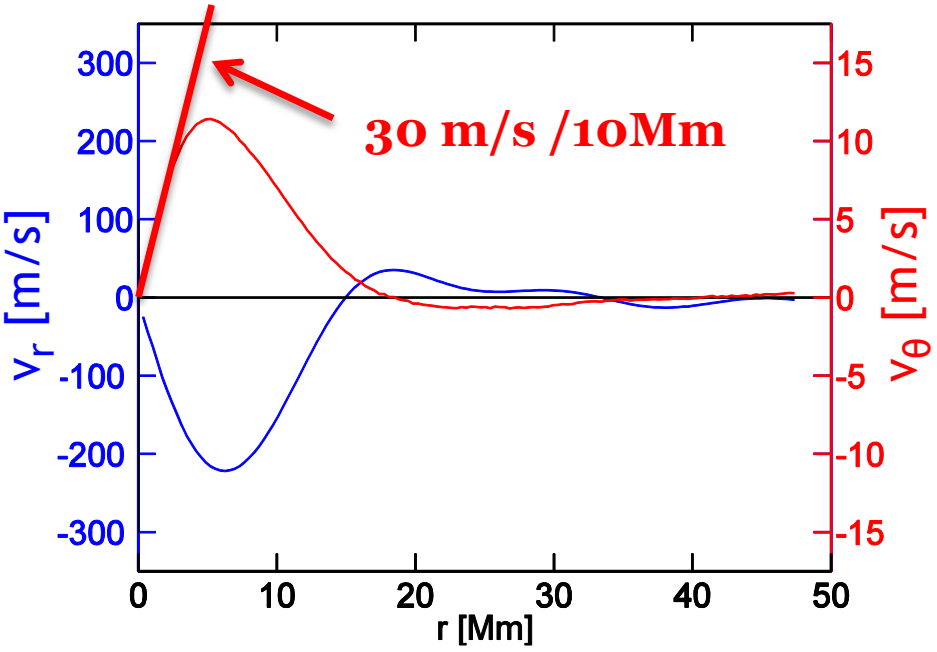
LCT: avg. supergranule flow profiles

outflow

40°

inflow



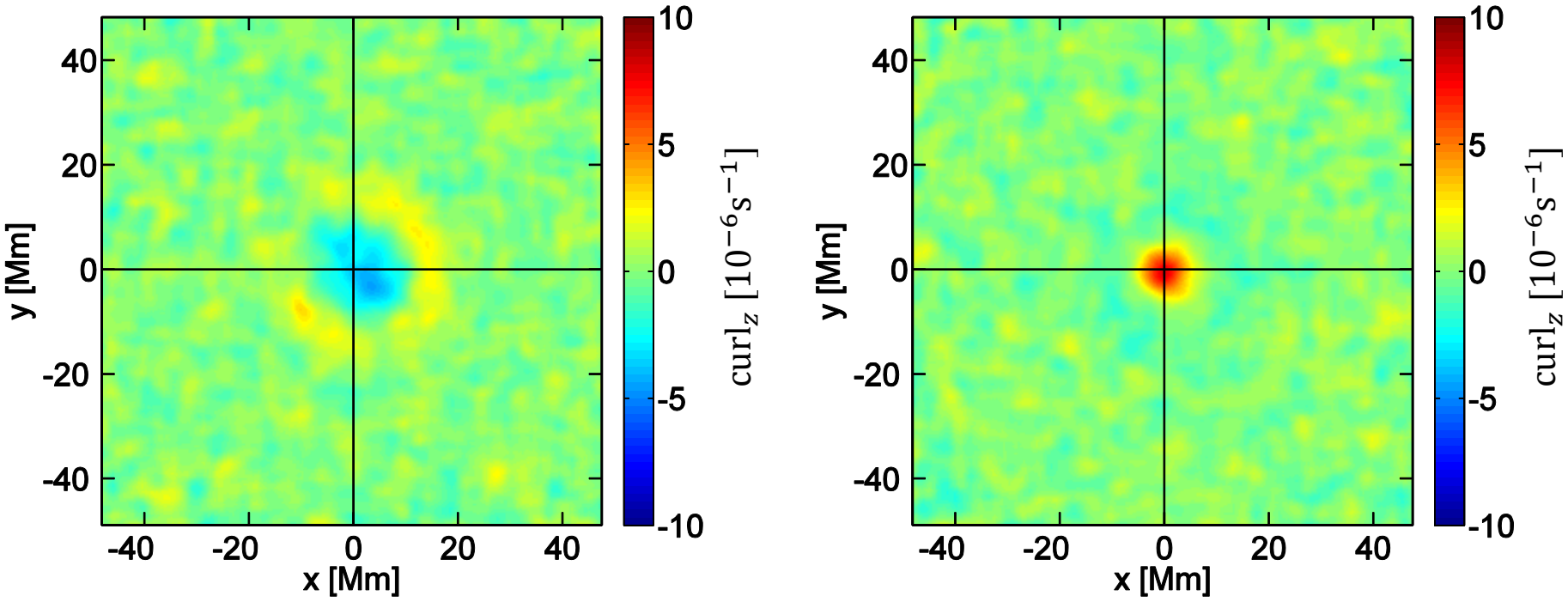


LCT: Spatially resolved curl_z

outflow

40°

inflow

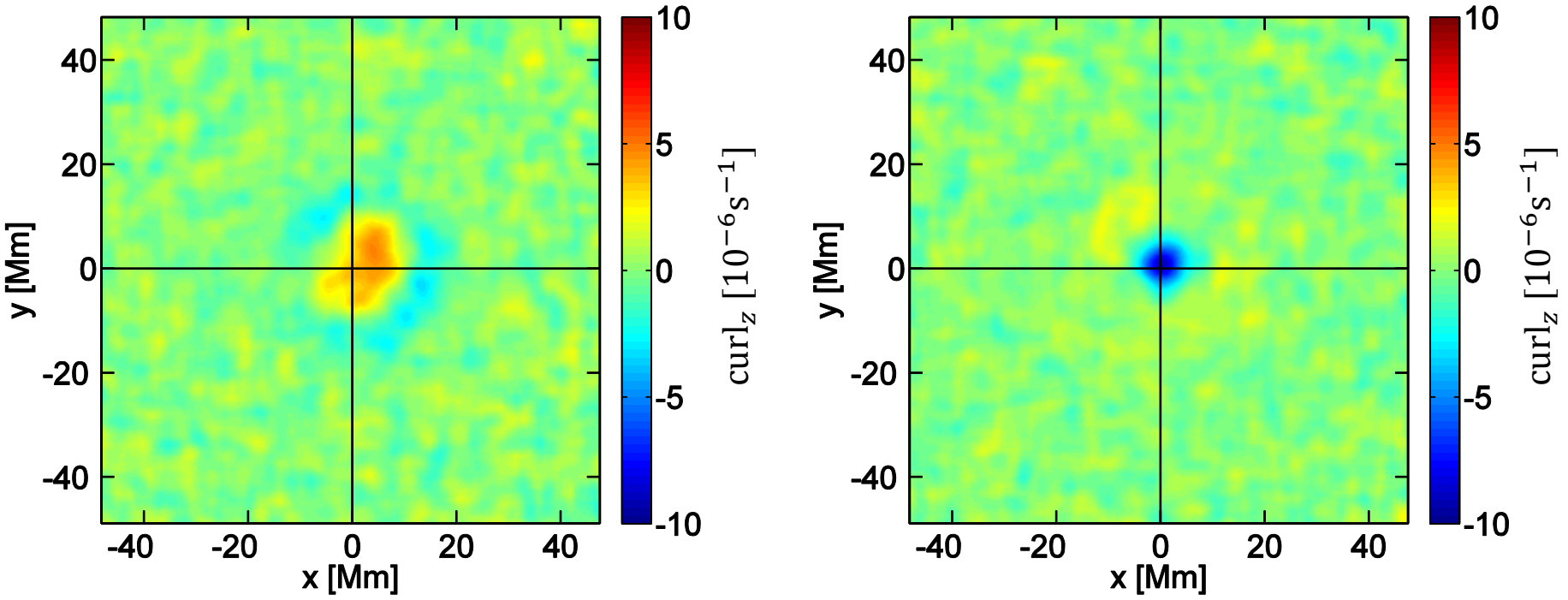


LCT: Spatially resolved curl_z

outflow

$-40°$

inflow



Conclusions

- Circular velocity of the average supergranule measured with time-distance
- Result confirmed by LCT

- Horizontal flow profile measured with LCT
- curl_z spatially resolved with LCT

- Time-distance can provide depth dependence (inversion)

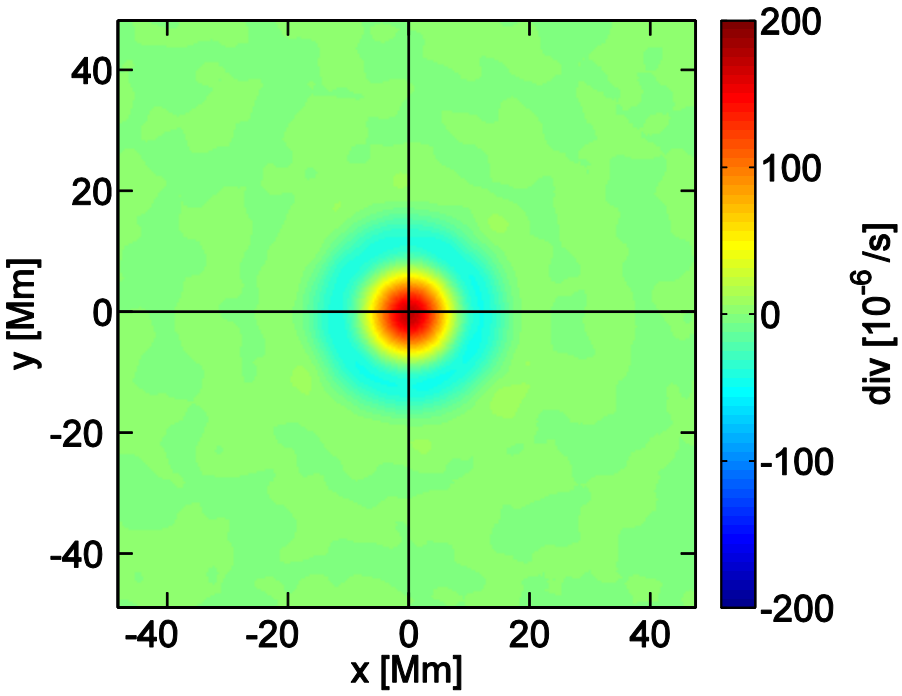
Thank you
for your attention!

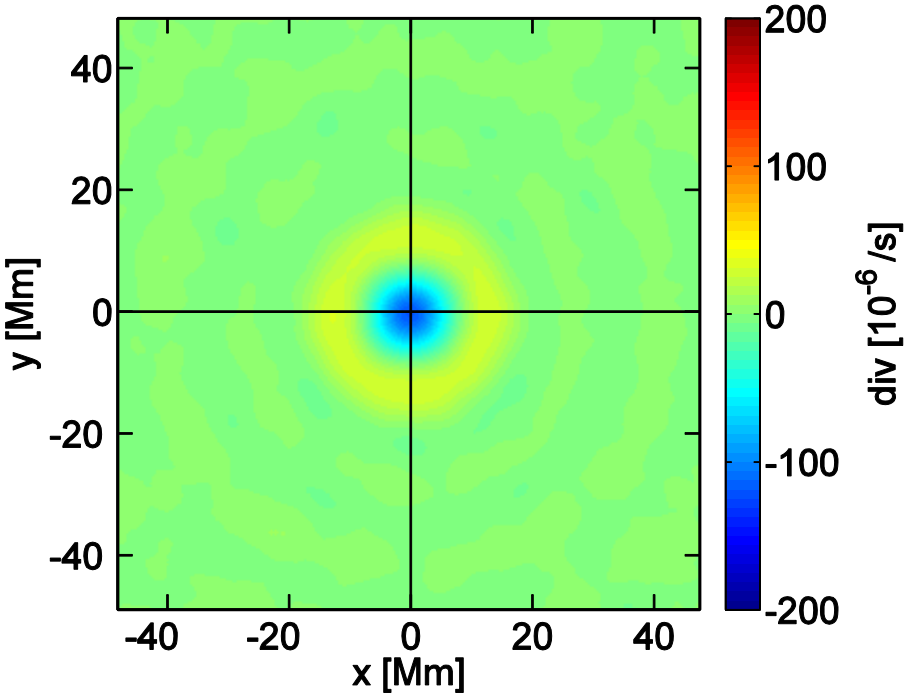
LCT: Spatially resolved div_h

outflow

40°

inflow



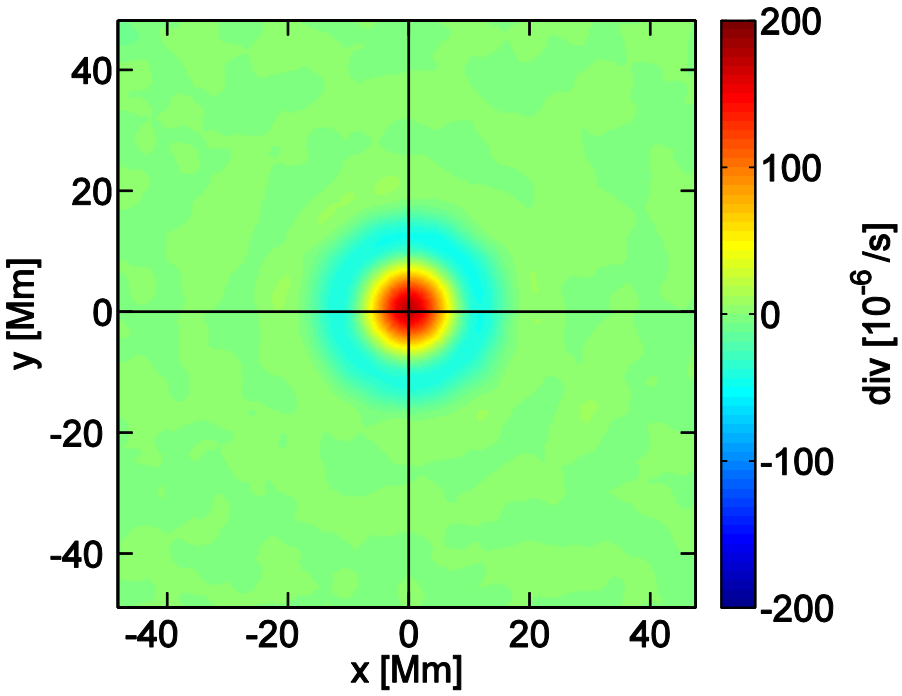


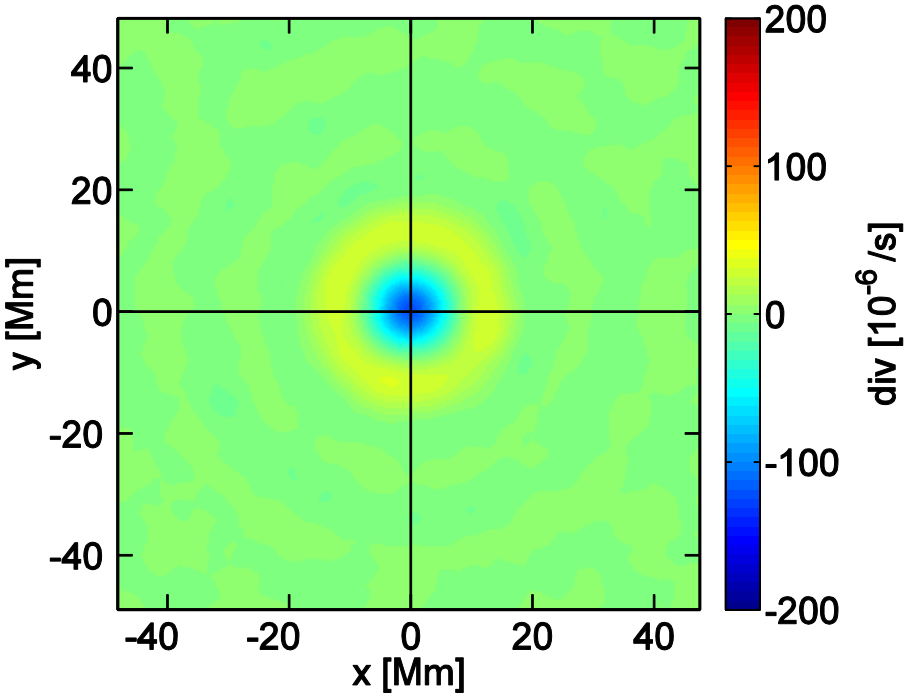
LCT: Spatially resolved div_h

outflow

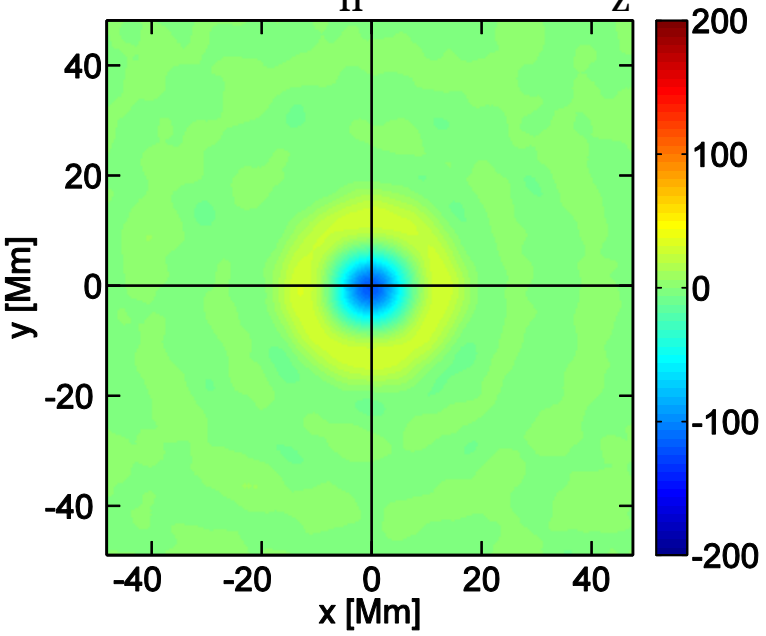
$-40°$

inflow

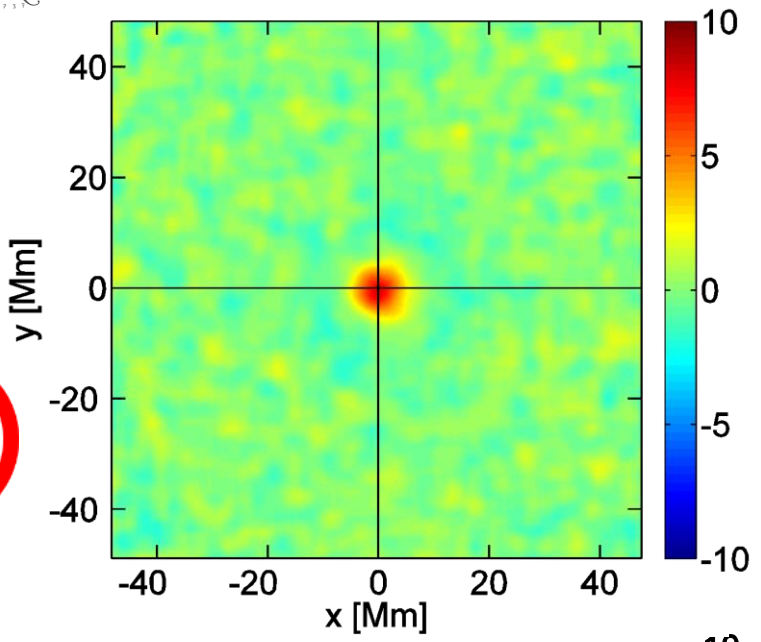




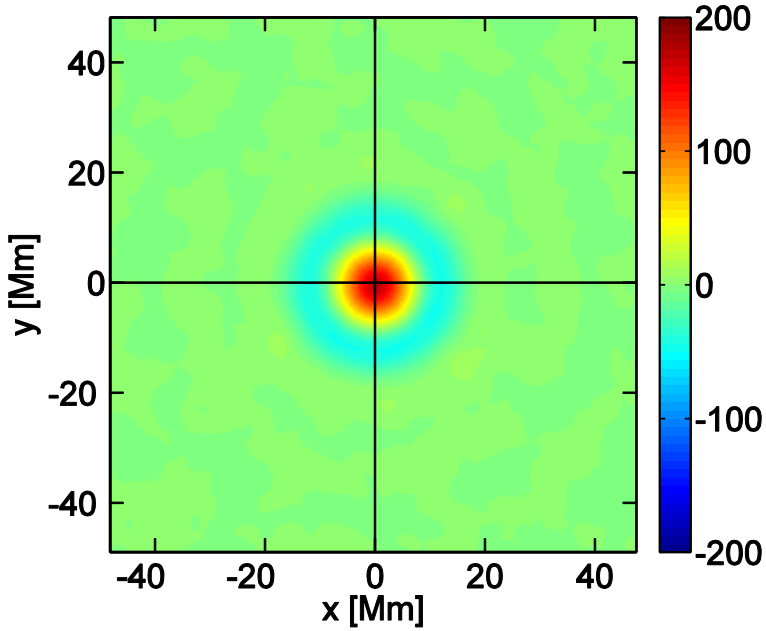
LCT div_h and $curl_z$



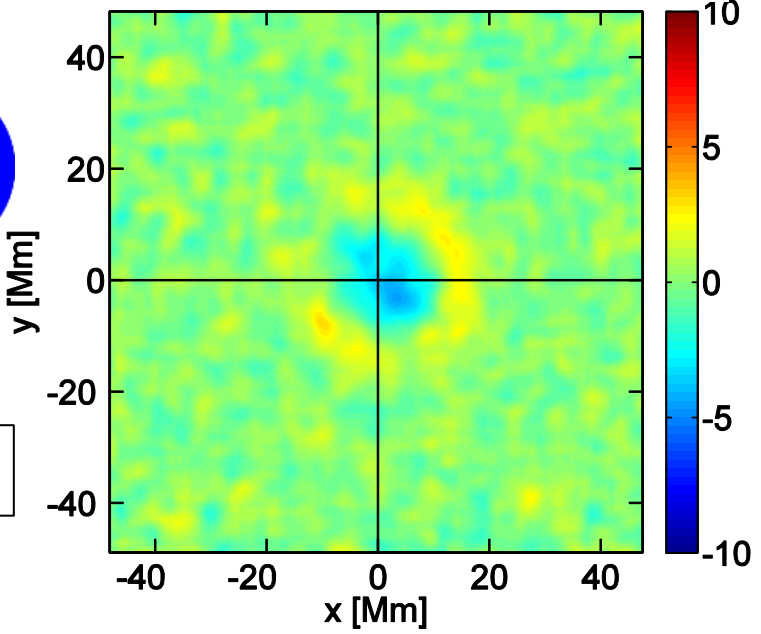
inflow



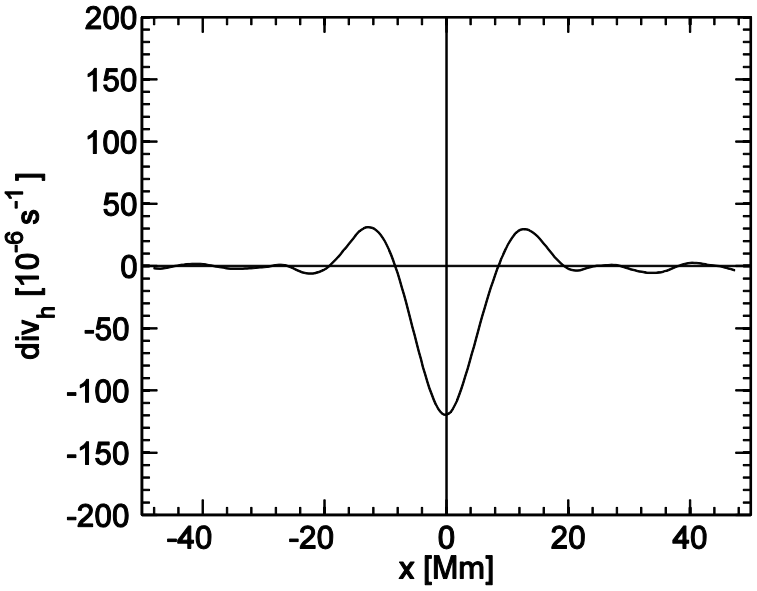
40°



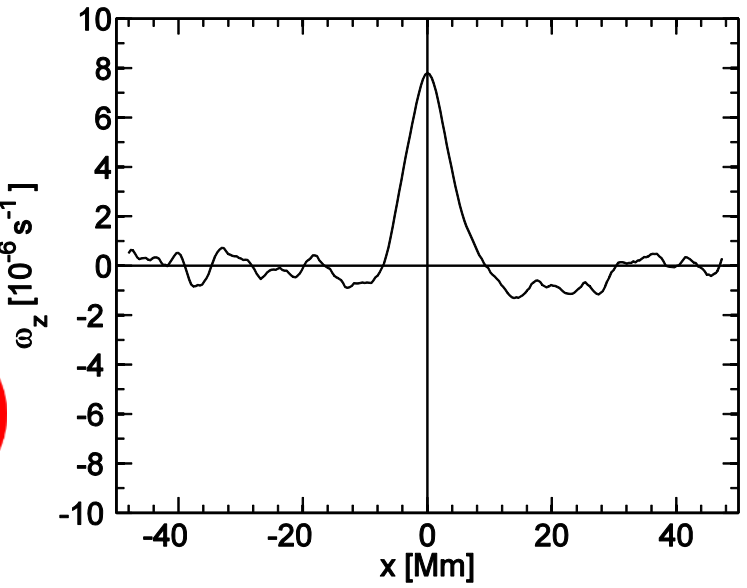
outflow



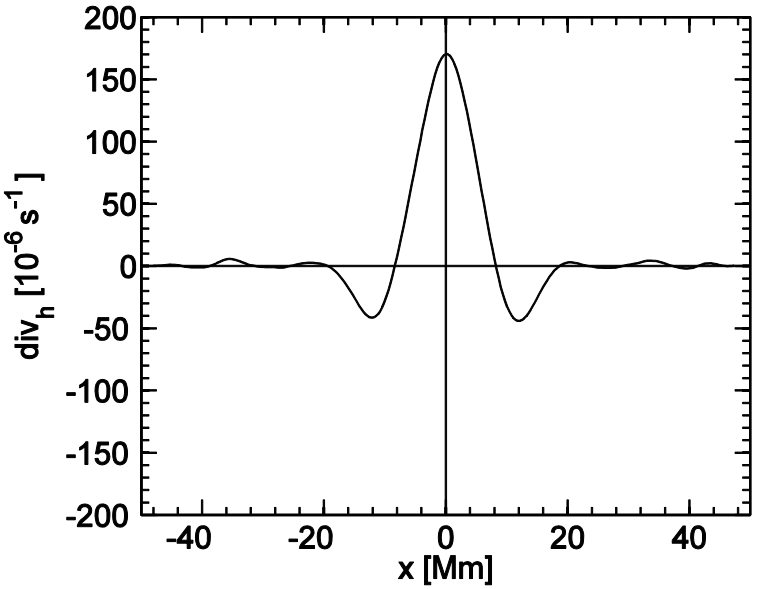
LCT div_h and $curl_z$ cuts y=0



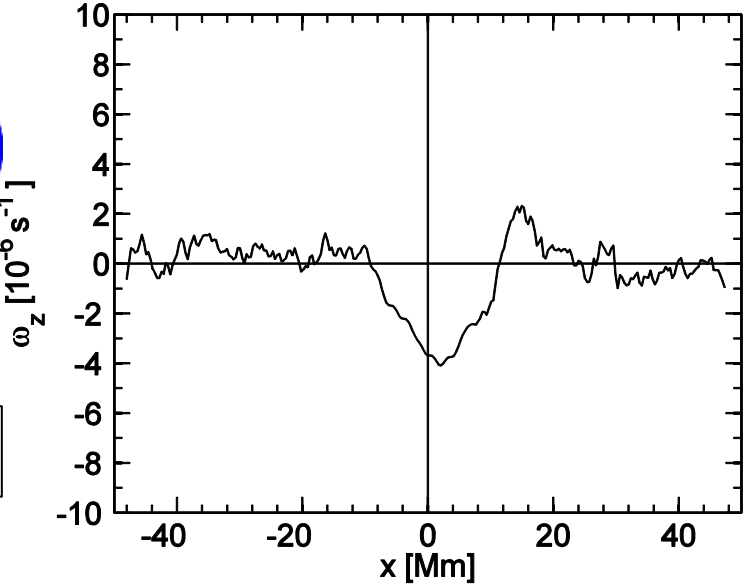
inflow



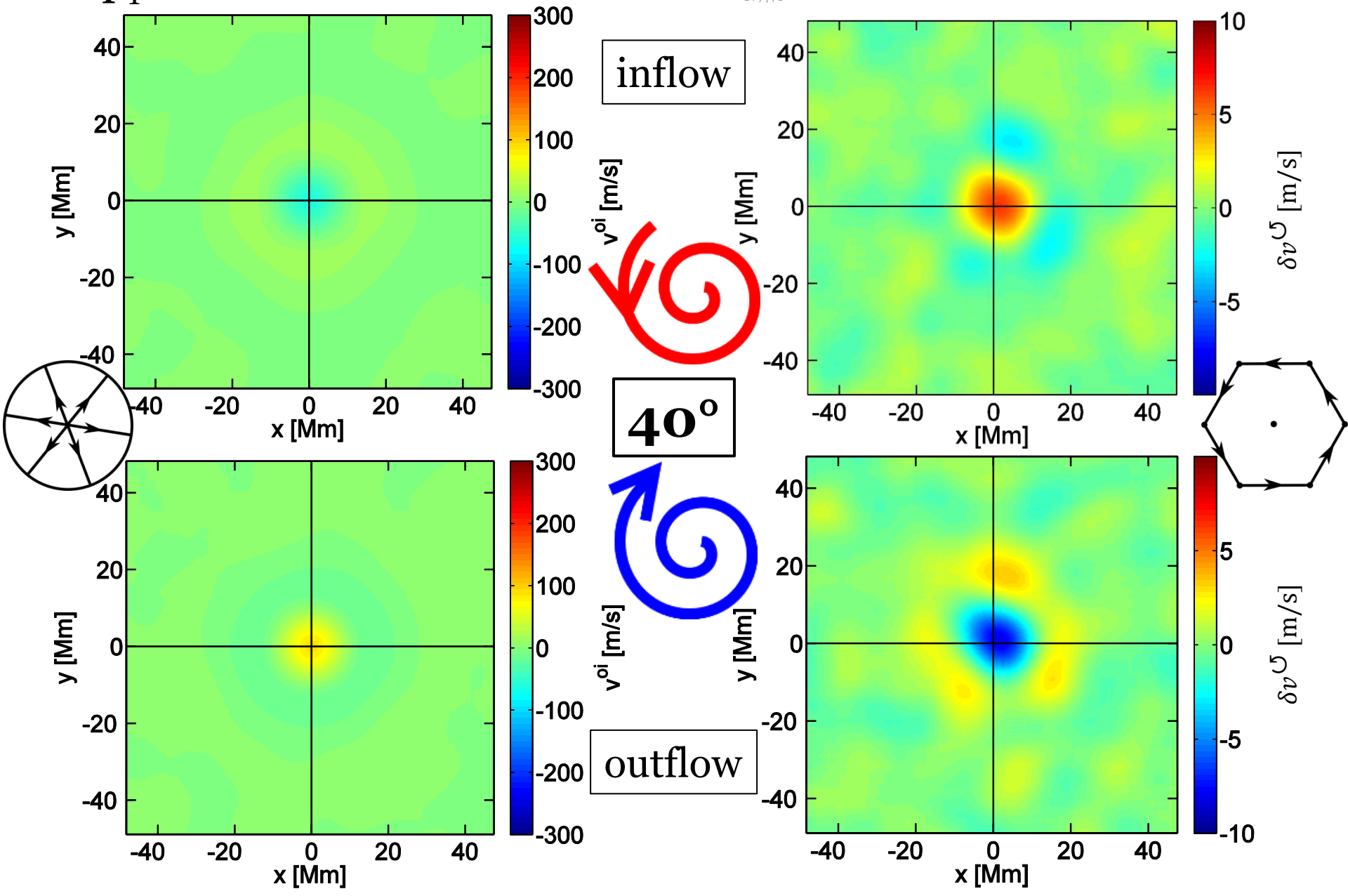
40°



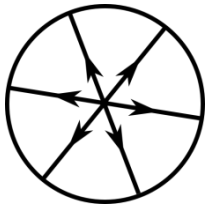
outflow



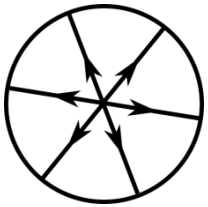
p_1 mode


inflow
40°
outflow
v^{oi} [m/s]
$\delta v^{\circlearrowleft}$ [m/s]
x [Mm]
y [Mm]
300
200
100
0
-100
-200
-300
10
5
0
-5
-10
40
20
0
-20
-40

Comparison: Time-distance vs. LCT

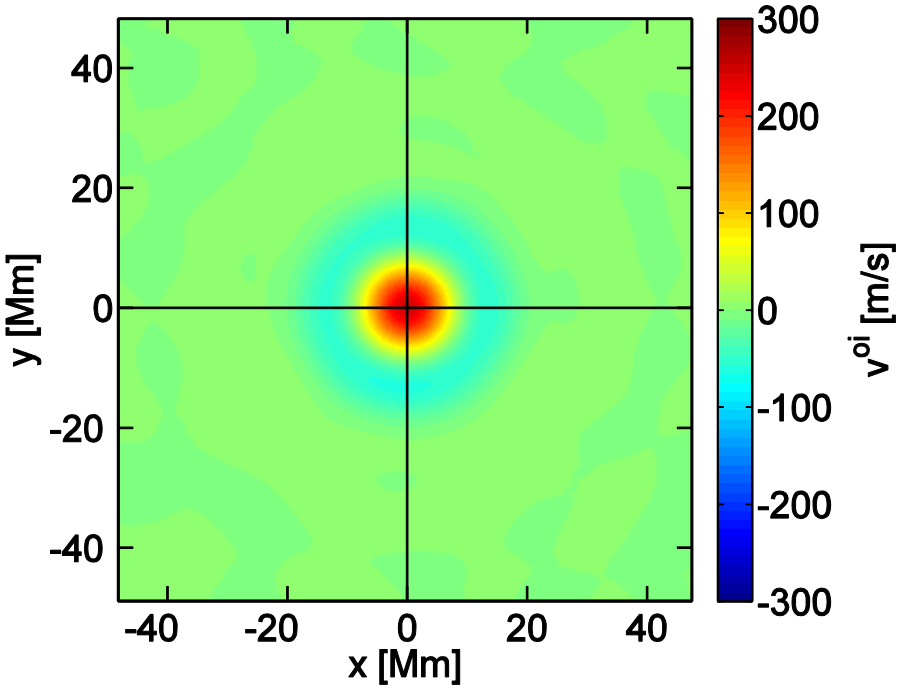


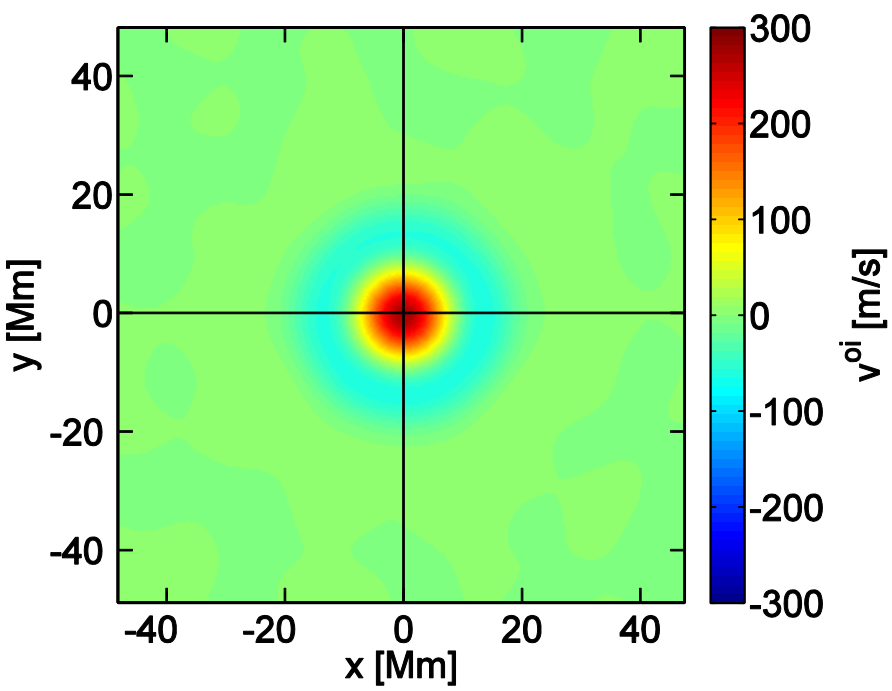
40°
outflow



Time-distance (f mode)

LCT



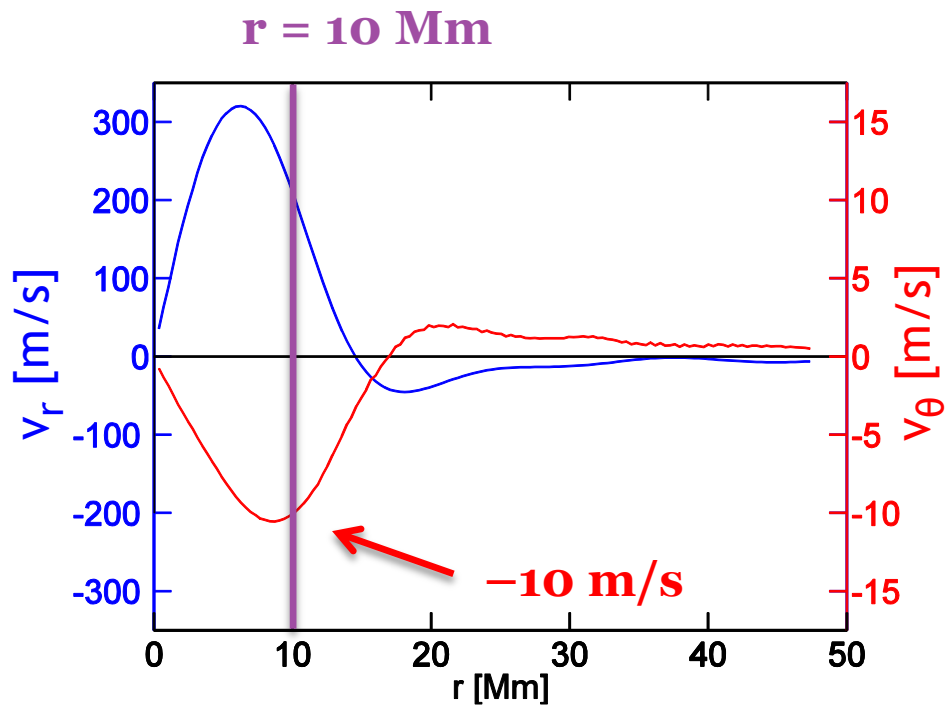


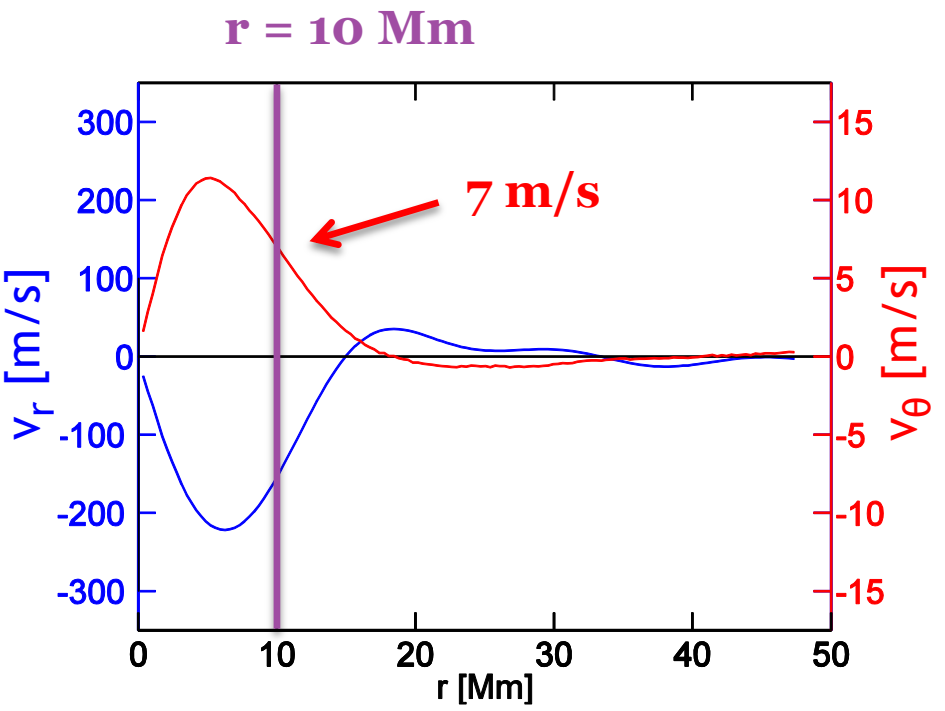
LCT: avg. supergranule flow profiles

outflow

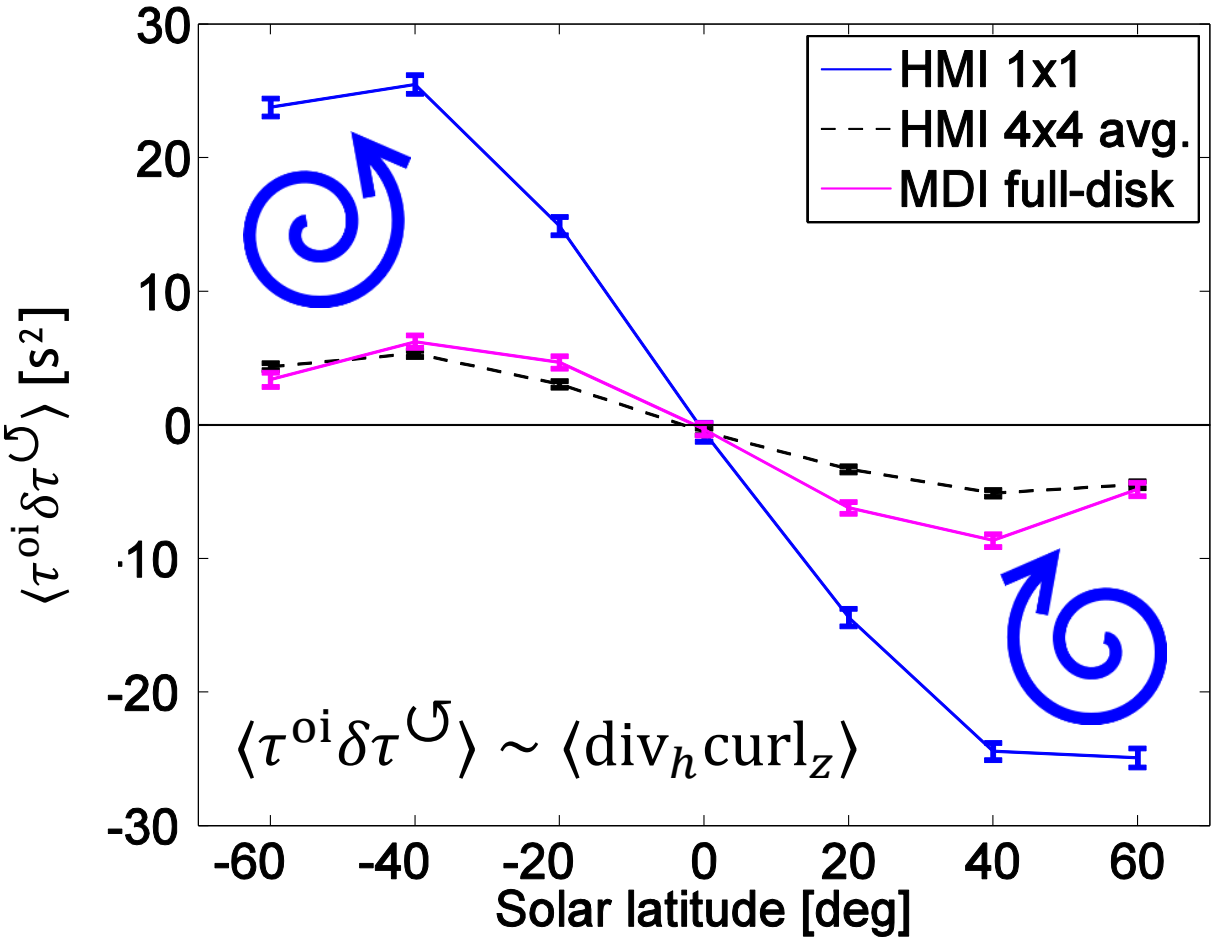
40°

inflow





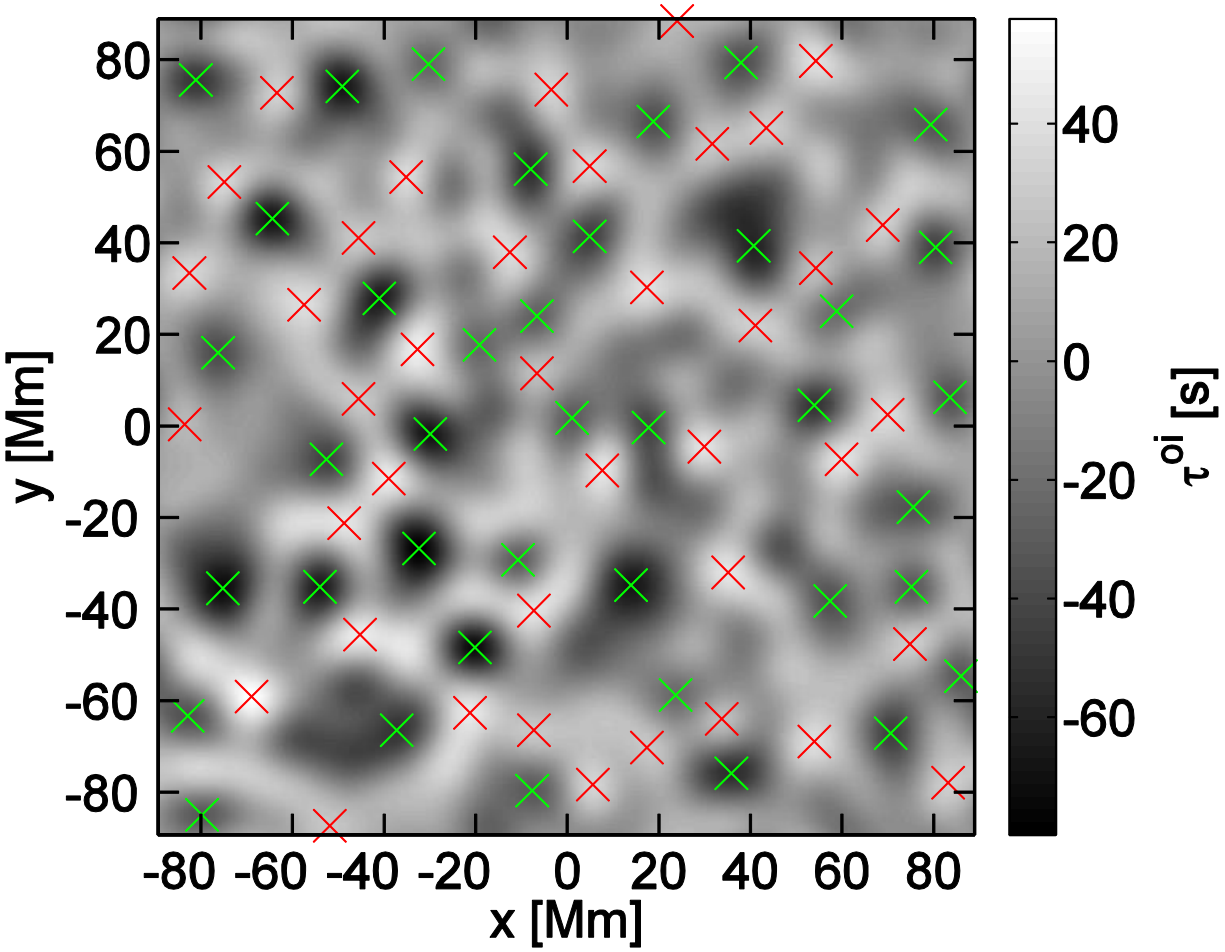
$\langle \mathrm{div}_h \mathrm{curl}_z \rangle$ vs. latitude: HMI and MDI



f mode

Langfellner et al., A&A, accepted

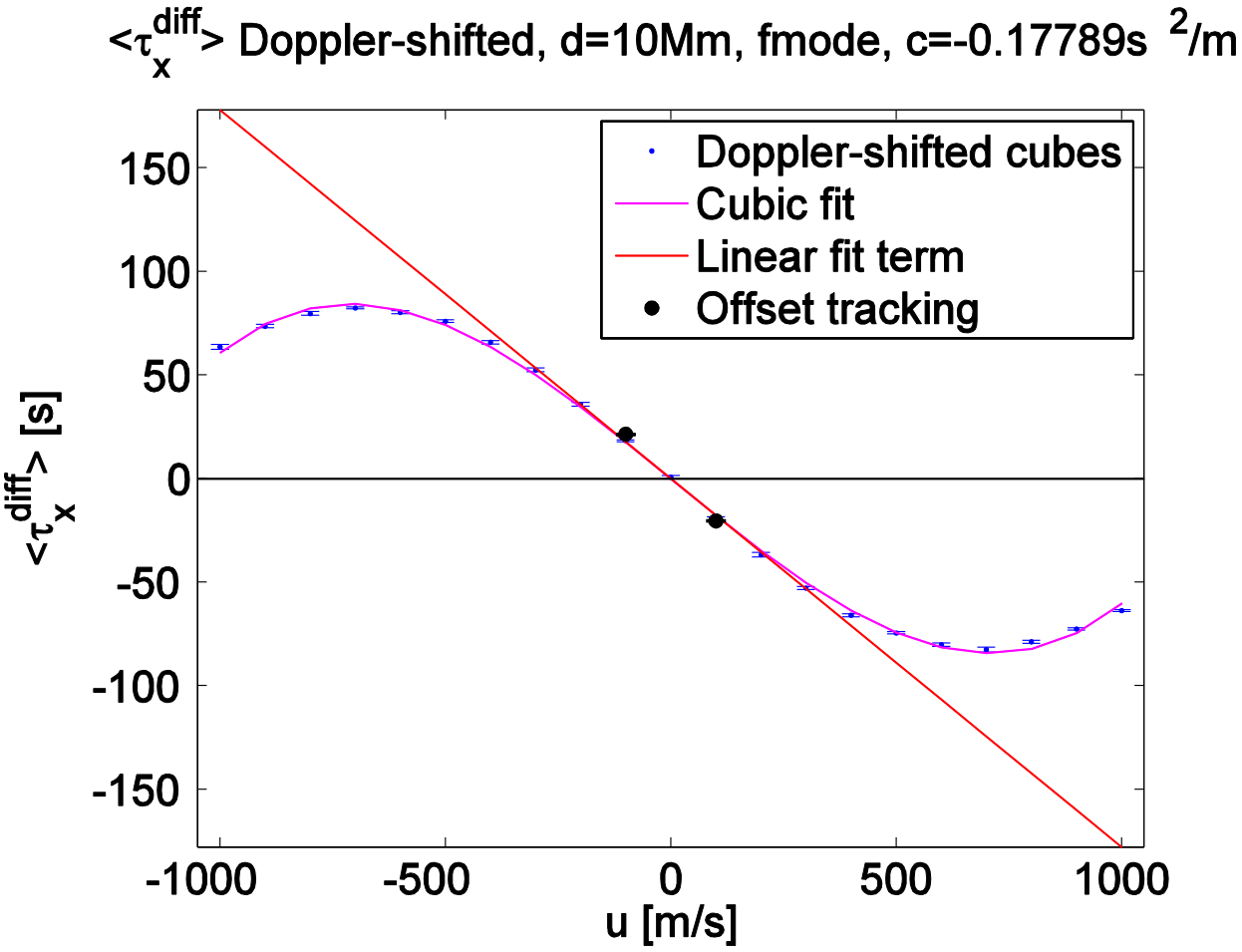
Supergranule identification



f mode
0° latitude

Smoothed:
kR > 300
filtered away

Conversion factor (f mode)



Travel-time power spectra

f mode

τ^{oi} o^{o} $\delta\tau^{\circlearrowleft}$