Surface Magnetic Field Effects on Acoustic Waves.

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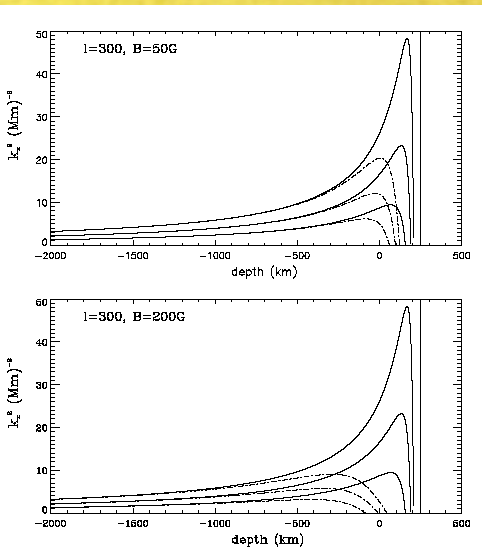
HELAS
European Helio- and Asteroseismology Network

Running Order

- Magnetic fields affect acoustic waves on all levels
  - Stellar Cunha 2005, 2006, global, local
- Active Region Helioseismology
  - Subsurface imaging
- Showerglass Effect & Penumbral Acoustic Anomaly
  - To what degree?
- What is the mechanism?
  - Mode conversion and scattering
- How HELAS can help

Evidence of Magnetic Effects

- Locally
  - Suppression of p-mode amplitude
  - Scatter of p-modes by magnetic field Gizon, Hanasoge, Birch 2006
  - Frequencies change in AR's with evolution Howe, Komm, Hill, Haber, Hindman 2004
  - Phase/amplitude of eigenfunction is changed Jain, Haber, Zweibel 1996
  - Horizontal field lowers turning point - interpreted as sound speed increase? Jain 2006
  - Penumbral NCP has l.o.s dependence Muller, Schlichenmeier, Steiner, Stix 2002
  - Showerglass effect Lindsey & Braun, 2005a, 2005b
  - Cookie cutter method Korzennik 2006

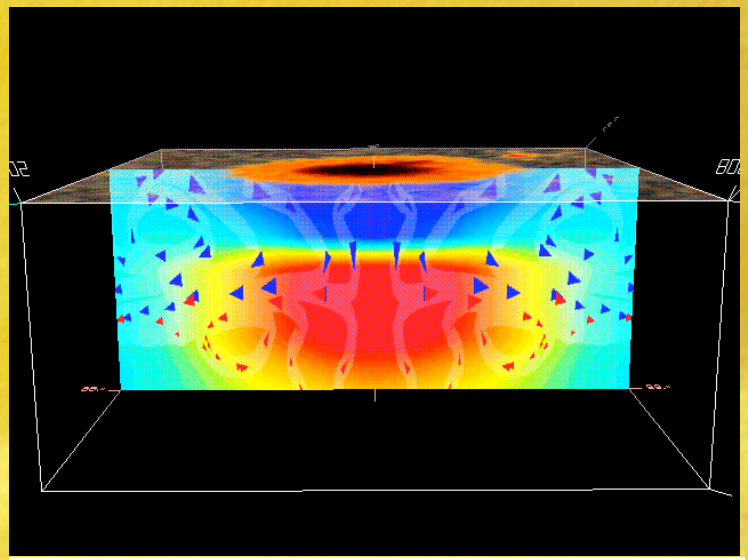


Jain 2006

Imaging Active Regions

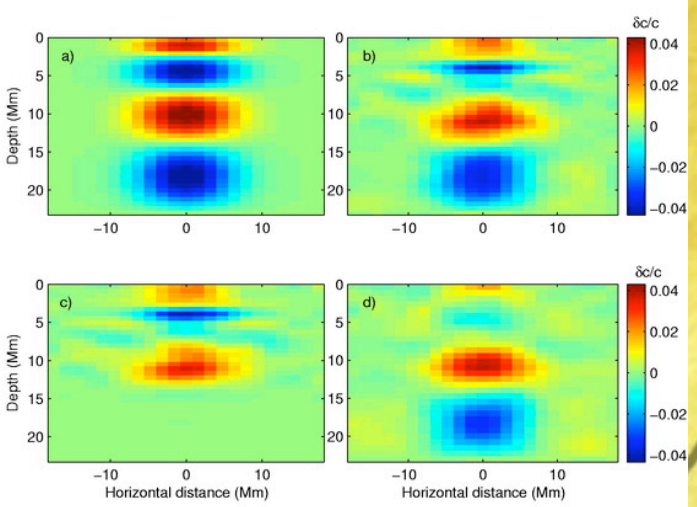
- Sound speeds beneath sunspots
  - Subsurface sunspot sound speed map

    Zhao & Kosovichev



  - Using Time-Distance. Cropping the travel time in the umbra does not significantly alter results.

    Hughes, Rajaguru, Thompson 2005

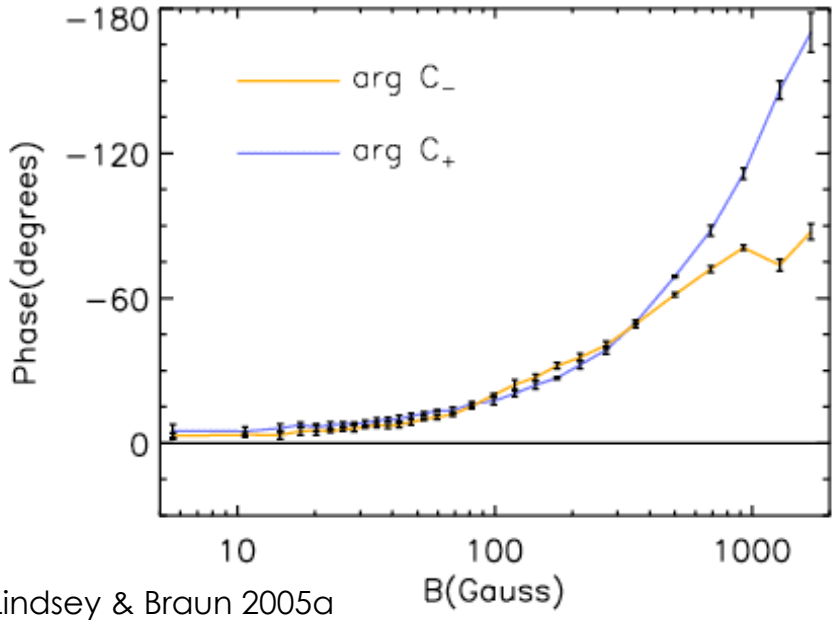


Local Near-Surface Effects

- Showerglass effect Lindsey & Braun 2005 a,b

$$C_- = \left\langle \hat{\psi} \hat{H}_-^{\,*} \right\rangle_{\Delta\nu}$$

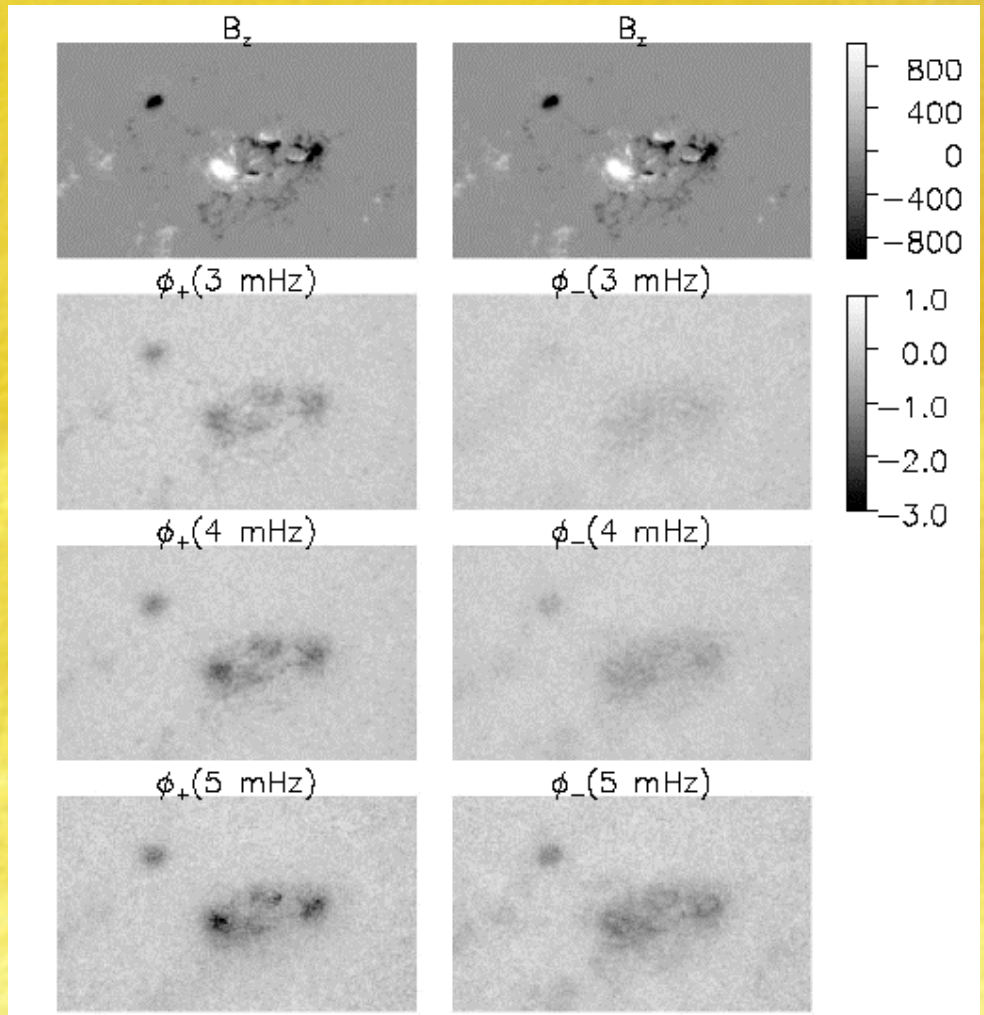
$$C_+ = \left\langle \hat{H}_+ \hat{\psi}^* \right\rangle_{\Delta\nu}$$



Lindsey & Braun 2005a

Local Near-Surface Effects

- Penumbral Acoustic Anomaly



Lindsey & Braun 2005a

Local Near-Surface Effects

- How **significant** is the penumbral phase deviation?
- Is it dependent on magnetic field **inclination**?
- What **is** the penumbral acoustic anomaly?

Local Near-Surface Effects

- Ingression Correlation, 5 mHz

$$C = \left\langle \hat{H}\_(\bar{r},\nu)\hat{\psi}^{*}(\bar{r},\nu) \right\rangle_{\Delta\nu}$$

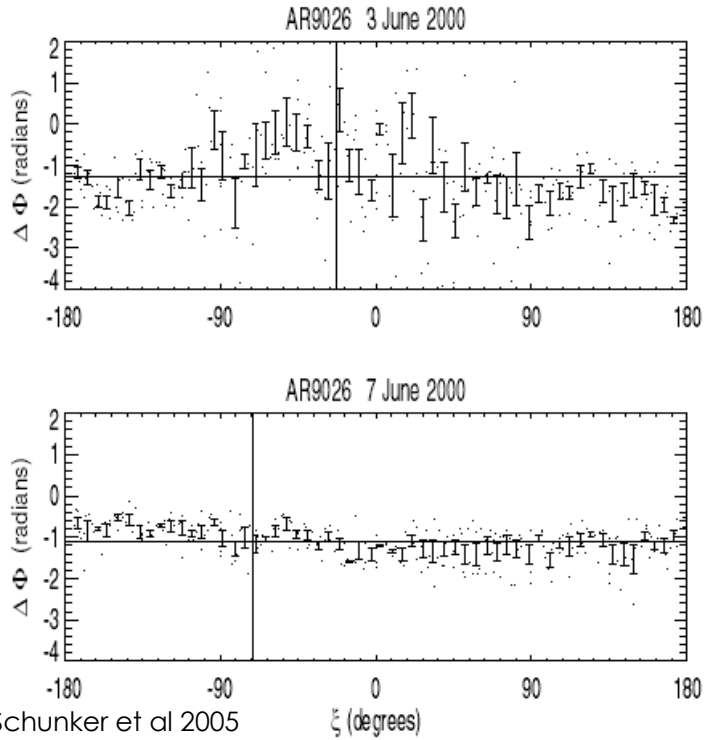
- ψ : Observed surface Doppler signal at the focal point
- $H\_$: Ingression at the focal point
- $\Delta\nu$: 1 mHz bandwidth

$$\delta\phi = \arg\left(\left\langle \hat{H}\_(\bar{r},\nu)\hat{\psi}^{*}(\bar{r},\nu) \right\rangle_{\Delta\nu} \right)$$

$$|C| = \sqrt{\left(\left\langle \hat{H}\_(\bar{r},\nu)\hat{\psi}^{*}(\bar{r},\nu) \right\rangle_{\Delta\nu} \right)^{2}}$$

Azimuthal Dependence

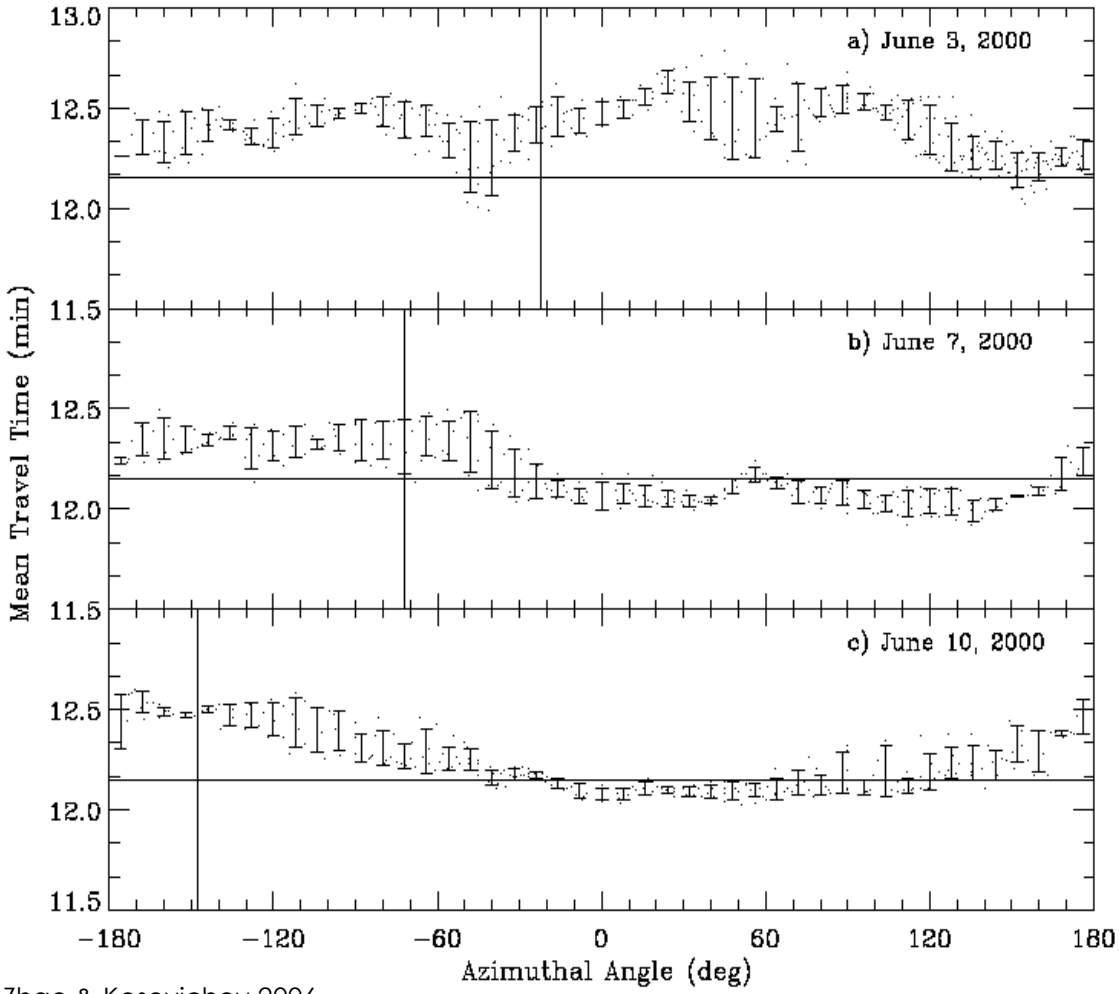
- Schunker et al 2006



Schunker et al 2005

~30 secs ~12 secs ➔

Zhao & Kosovichev 2006

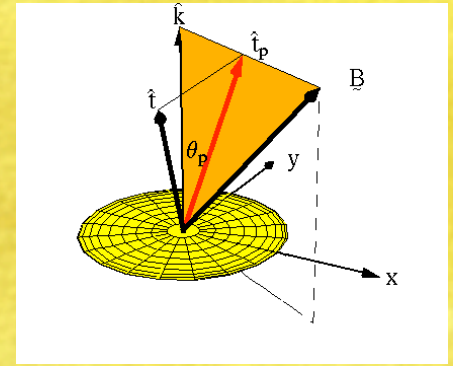


Zhao & Kosovichev 2006

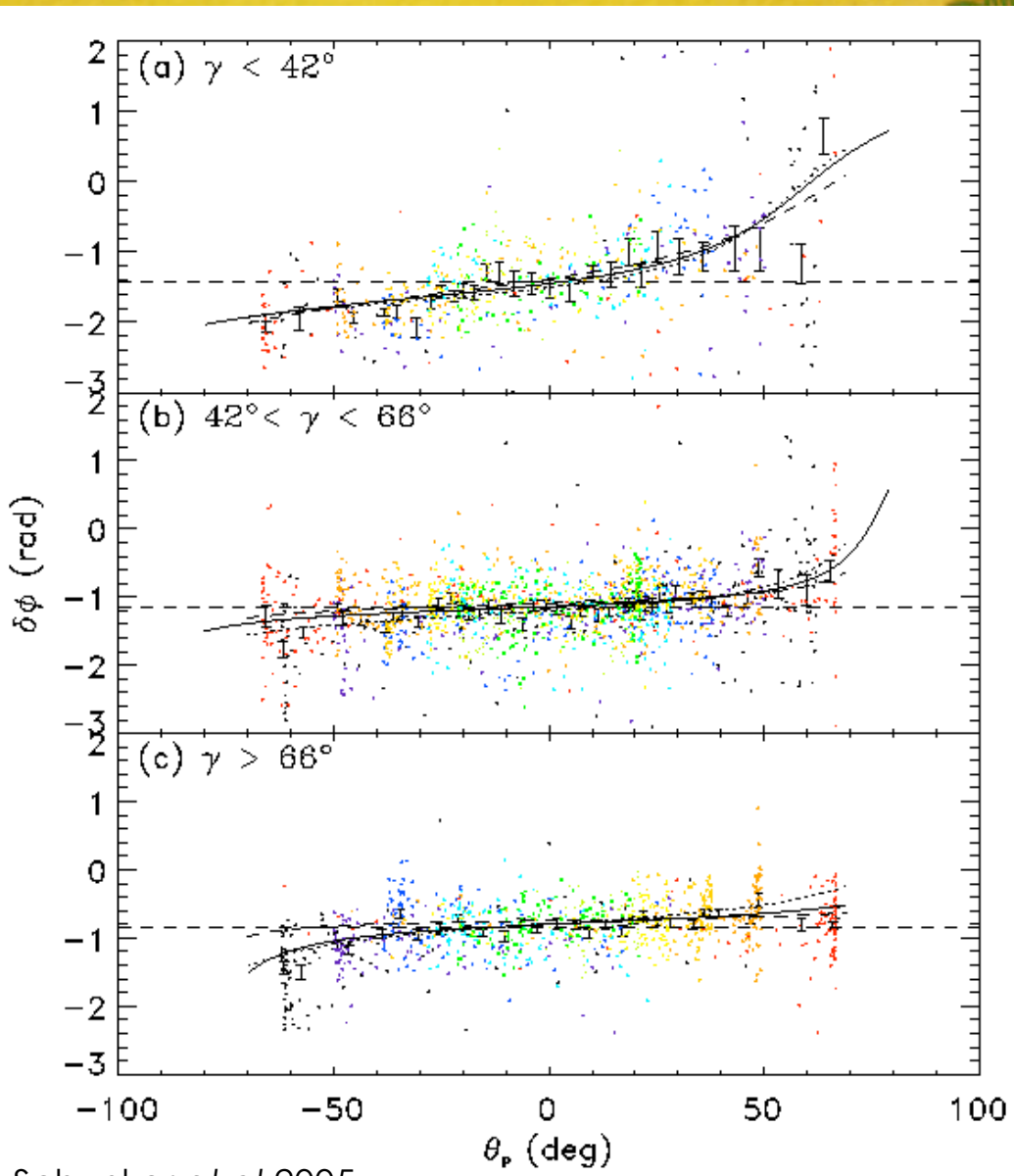
Line of Sight Dependence

$\delta\phi$ vs. θ_p

- θ_p
  - B: magnetic field vector
  - t: line-of-sight vector
  - k: radial vector



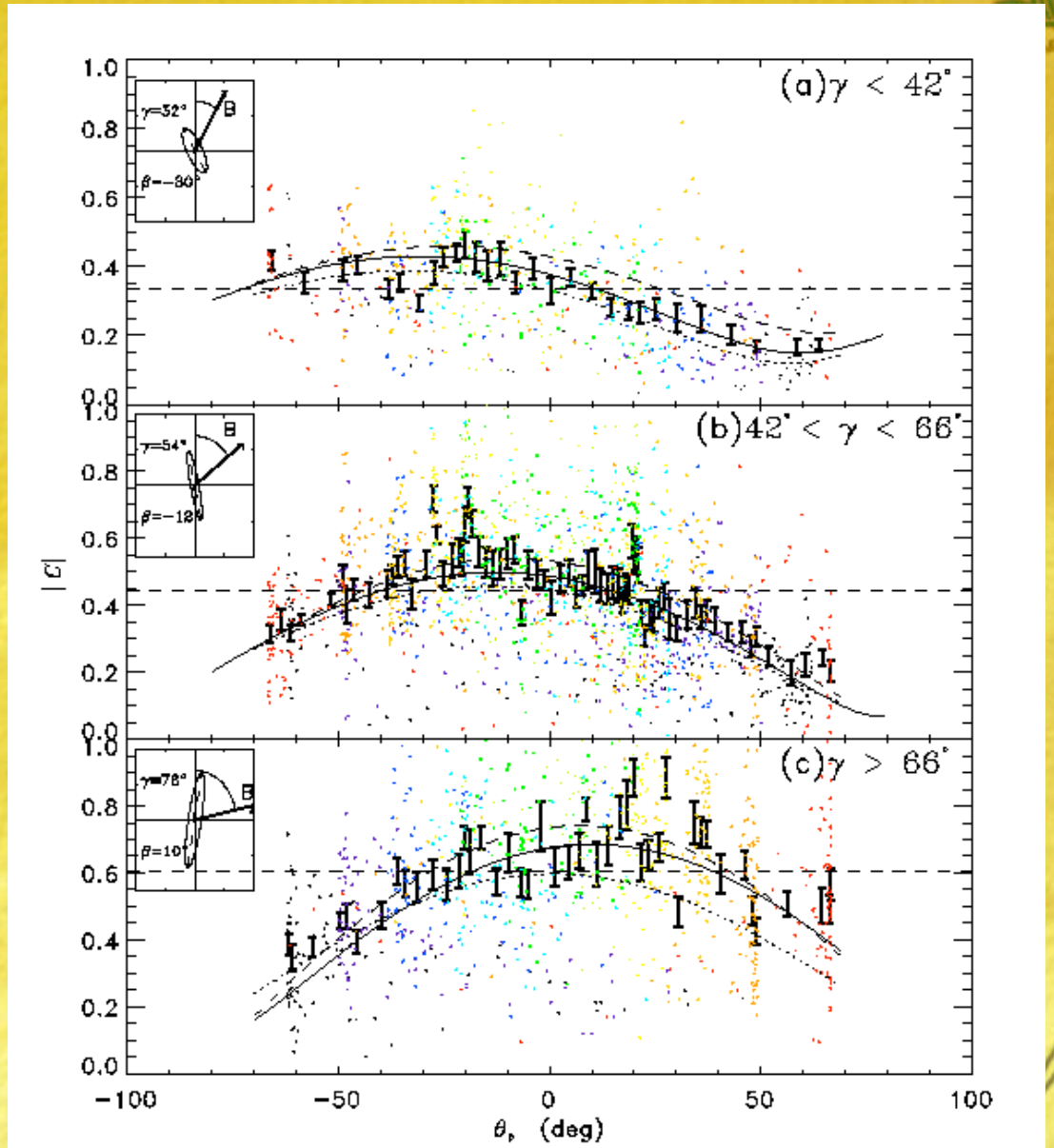
Significant variation of $\delta\phi$!



Schunker *et al* 2005

Line of Sight Dependence

$|C|$ vs. θ_p



Local Near-Surface Effects

- Consistent results for another sunspot in AR9057, and at 3 & 4 mHz

- Small γ, Stronger *B* (inner penumbra)
  - lower eccentricity
  - smaller deviation angle (δ, angle between **v** & *B*)
  - larger inclination from vertical (β)

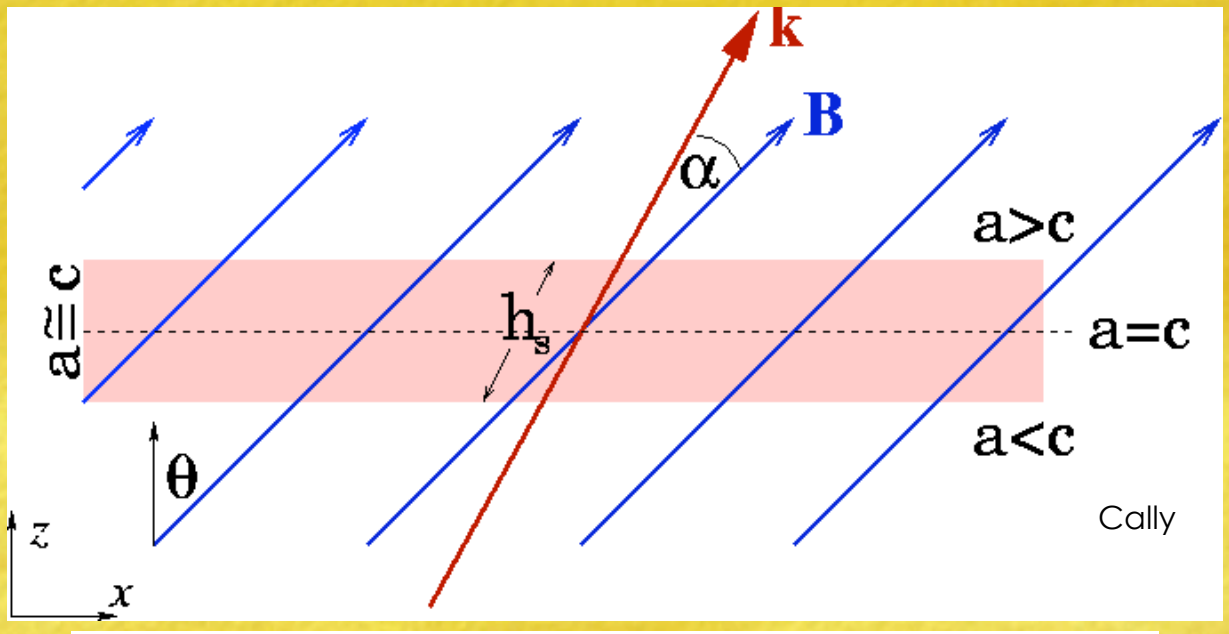
- Bigger γ, Weaker *B* (outer penumbra)
  - high eccentricity
  - larger deviation angle (δ)
  - smaller inclination from vertical (β)

Modeling Acoustic-Magnetic Interactions

- Scattering and mixing of modes Cally et al 1994 , Zhang 1997, Barnes & Cally 2003, Rosenthal & Julien 2004
  - Vertical magnetic field
  - Conversion of f-modes to s-modes
  - Less than 10% of incident modes scatter into f-modes
  - Cannot reproduce observed absorption
- Resonant absorption LaBonte & Ryutova 1993, Tirry 2000
- Mode conversion fits well Cally, Crouch & Braun 2003

What is the Mechanism?

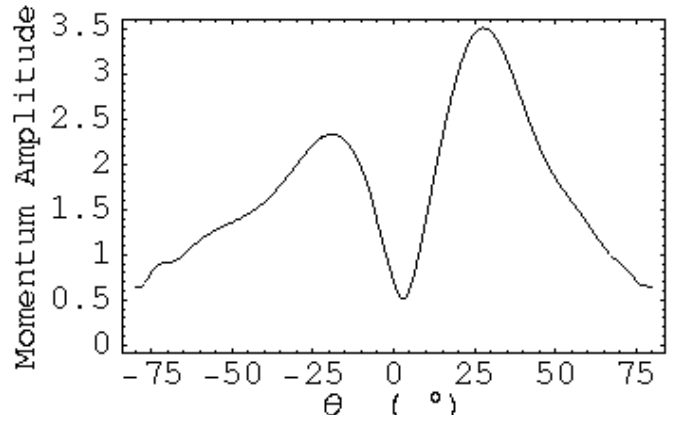
- Mode Conversion/Transmission: slow↔slow/slow↔fast

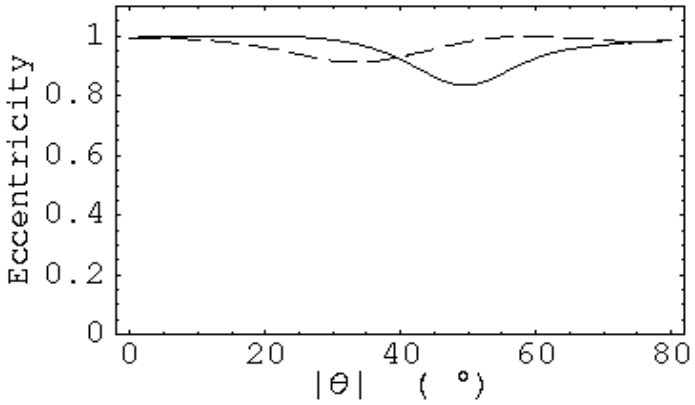


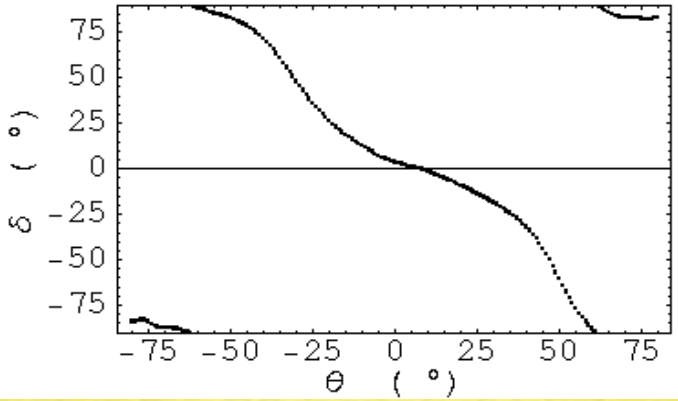
$$T = \exp[-\pi K h_s \sin^2 \alpha]_{a=c}$$

- See **Cally's Talk Tomorrow**, Cally (2005) or Schunker & Cally (2006) for a detailed explanation

Mode Conversion







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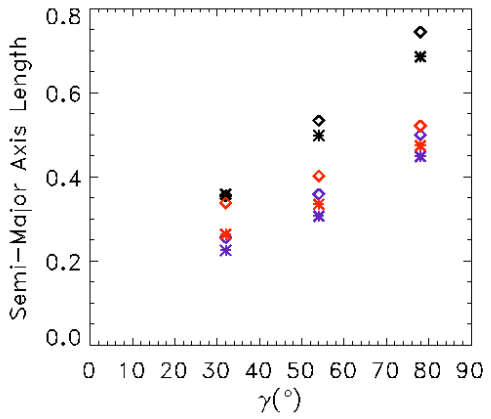
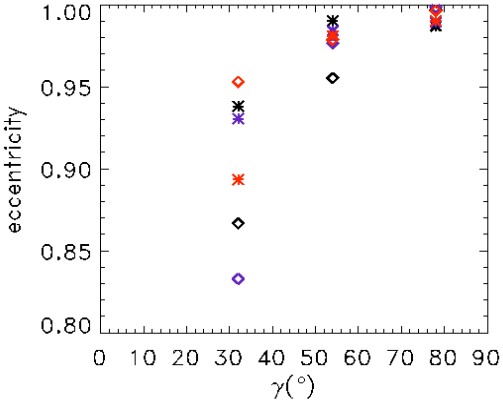
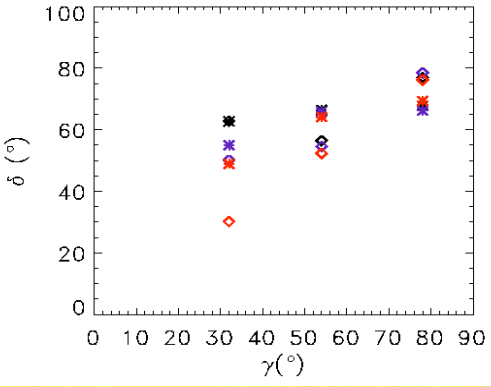
Not bad

✔✔

Observation







Conclusions

- Significant surface effect in penumbra from magnetic field
- Effect is dependent upon line-of-sight
- Surface velocity appears to be dependent on magnetic field inclination *and* strength
- Mode transmission is able to explain aspects of observation - may be the physical mechanism of absorption and phase changes?

Issues & Plans

- What signal are we really observing?
- Atmospherically higher helioseismic measurements will enable further comparison for mode conversion
- Enhanced resolution Dopplergrams and magnetograms will reconcile features (SDO/HMI)
- HELAS can help by sharing results from the many ways of studying magnetic effects
- More realistic models of acoustic-magnetic interactions in sunspots

Help HELAS Help You

- We want to make local helioseismology readily available
  - Collate small, selected data sets - MDI, GONG….
  - As easy as possible - ready to use for analysis
  - Make software available
    - Frank Hill - ring diagrams
    - Charlie Lindsey & Doug Braun - holography, Hankel analysis
    - Tools - Kernels, inversions…

Help HELAS Help You

Please contribute! ***schunker@mps.mpg.de***