What to look for in the seismology of solar active regions

Surface magnetic effects

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and
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Thanks also to Hannah Schunker (Monash/MPI)

Sept 26 2006, HELAS Workshop, Nice

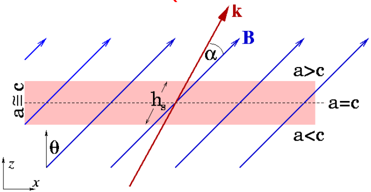
Outline

SOHO 19/GONG 2007 Seismology of Magnetic Activity
July 9-13 2007
Monash University, Melbourne
www.soho19.org, soho19@sci.monash.edu.au
Scientific Organizing Committee
Local Organizing Committee
esa
MONASH University

Five major effects

There are five major effects on a helioseismic wave emerging from beneath a strong magnetic region:

1. Mode conversion/transmission (fast-to-slow and vice versa): attack angle α



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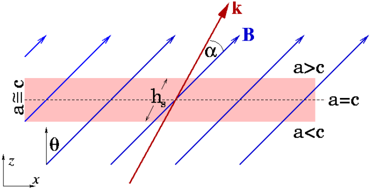

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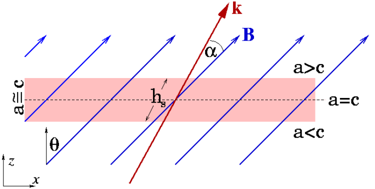

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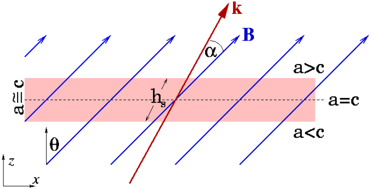

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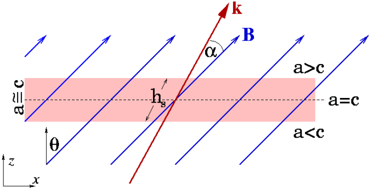

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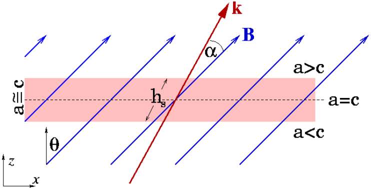

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Consider each in turn . . .

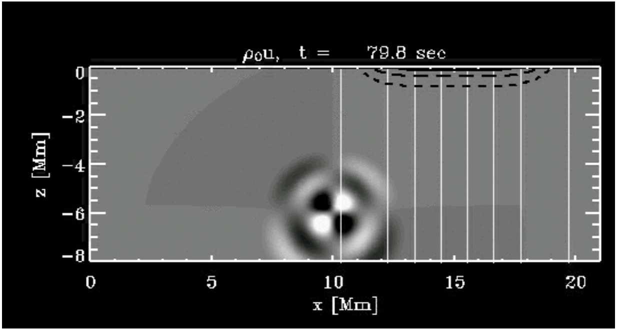
Basic References

Based on Schunker & Cally (2006) and the general ray transmission/conversion theory of Tracy, Kaufman & Brizard (2003).

- Cally, P., Phil Trans Roy Soc A 364, 333 (2006)
- Jefferies, S., McIntosh, S., Armstrong, J., Bogdan,T., Cacciani, A. & Fleck, B., ApJ 648, L151 (2006)
- Schunker, H. & Cally, P., MNRAS 2006 (in press)
- Tracy, E., Kaufman, A. & Brizard, A., Phys Plasmas 10, 2147 (2003)

Mode conversion/transmission: numerical experiment

Acoustic source at 6 Mm depth



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$$T = \exp\left[-\pi K h_s \sin^2 \alpha\right]_{a=c}, \tag{1}$$

where $K = |\mathbf{k}|$ is the wavenumber, α is the attack angle, and $h_s = [d(a^2/c^2)/ds]^{-1}_{a=c}$ is the thickness of the $a \approx c$ layer, and s is arclength along the direction of $\mathbf{k}$. [Modified slightly by acoustic cutoff, which is ignored in this formula for simplicity]

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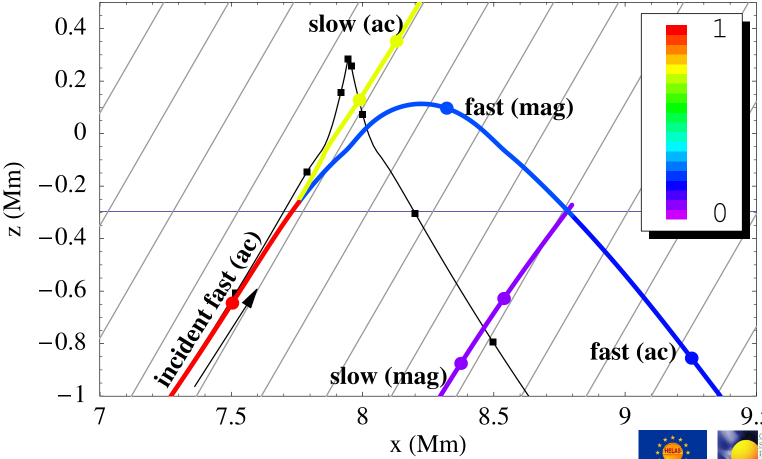
Mode conversion/transmission: $\theta = 30°$

$B = 2$ kG, frequency 5 mHz



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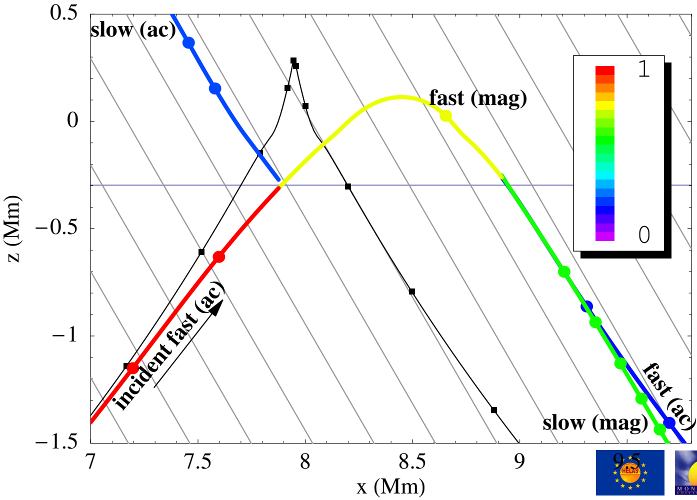
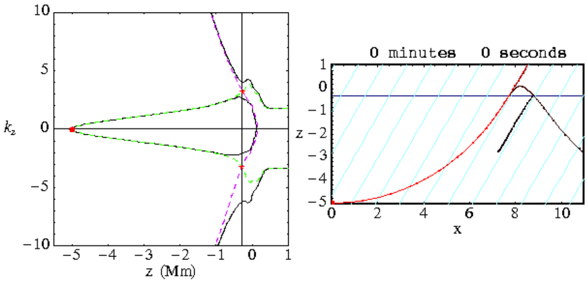


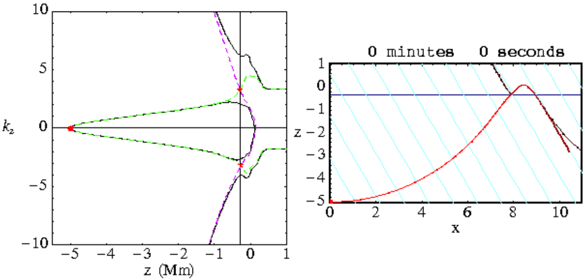
Mode conversion/transmission: $\theta = 30^\circ$ movie

Small attack angle $\Rightarrow$ strong acoustic transmission



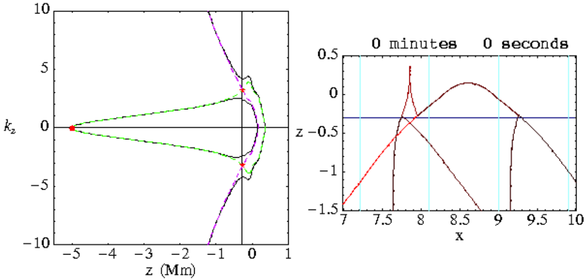
Mode conversion/transmission: $\theta = -30^\circ$ movie

Large attack angle $\Rightarrow$ weak acoustic transmission, strong downward slow leakage



Mode conversion/transmission: $\theta = 0^\circ$ movie

Acoustic wave reflected by cutoff. Further conversion on downward path $\Rightarrow$ extra fast branch



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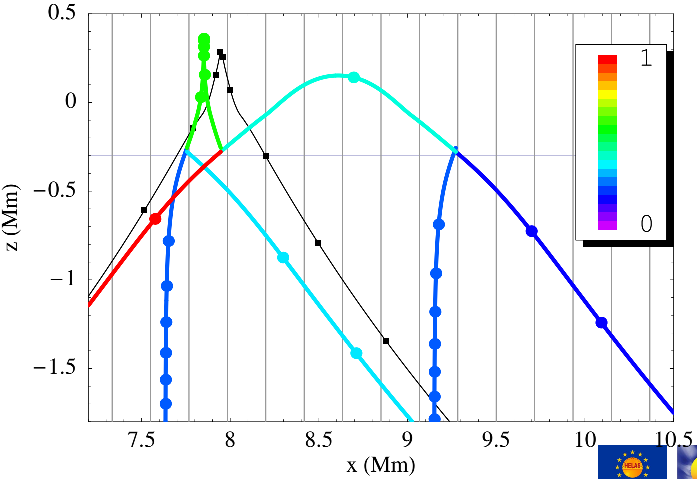
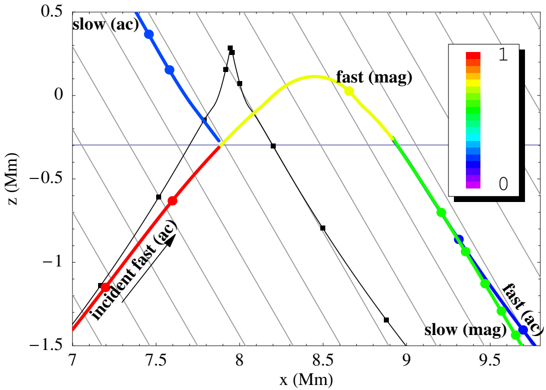


Shortened travel times I

Let's have a look at one of those ray diagrams again, say $\theta = -30°$:



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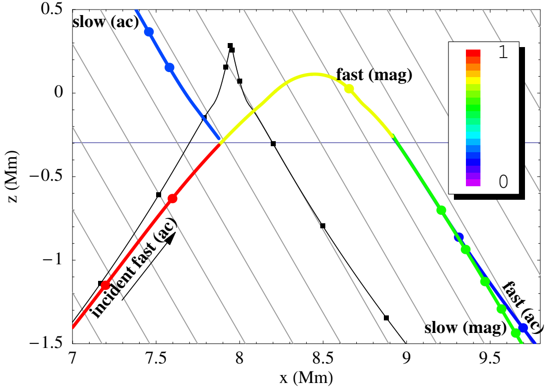
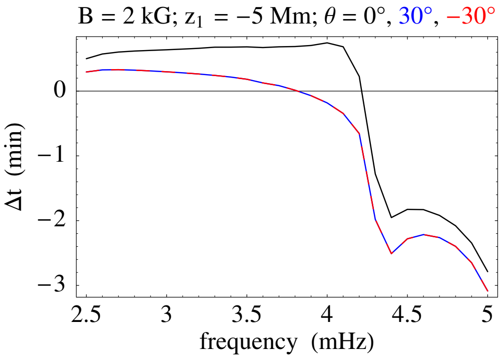


Focus on the continuing fast ray as it refracts back downward off the Alfvén speed gradient to skip once more. Much faster!

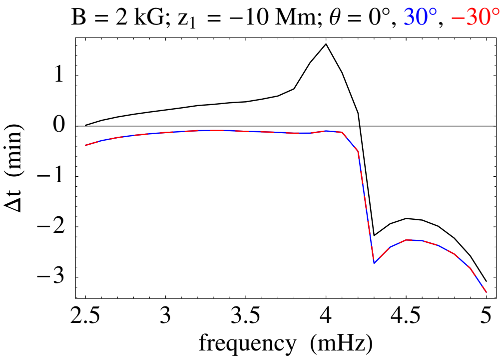
Shortened travel times II

Look at the difference in skip timing (lower turning point to lower turning point) between magnetic and nonmagnetic cases, as a function of frequency:



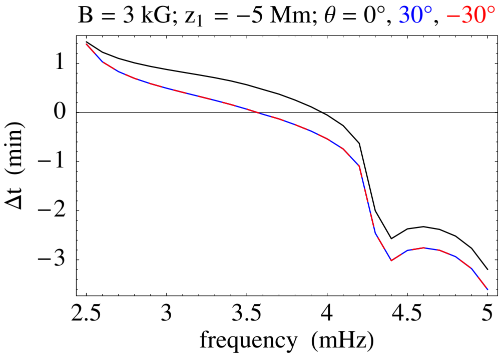
Shortened travel times II

The same but with deeper rays:



Shortened travel times II

And now with stronger magnetic field:



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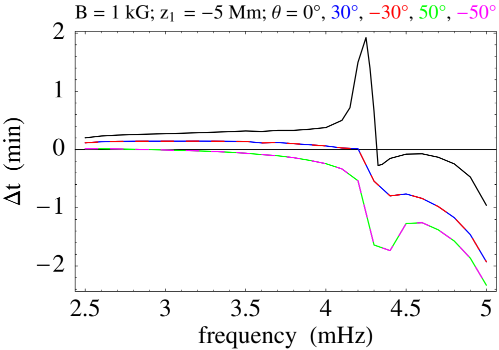

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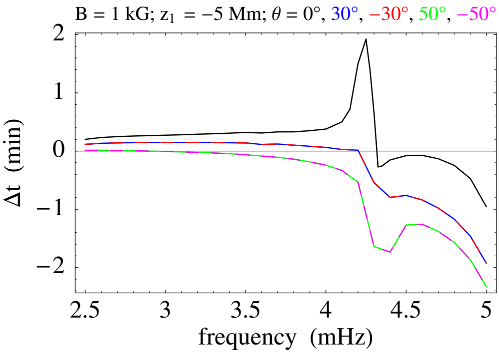
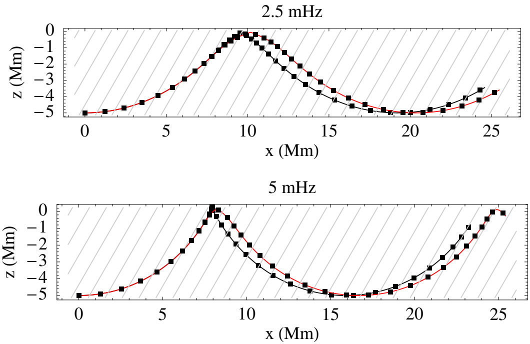


Higher frequency rays are greatly speeded up by the magnetic field!

Skip distances

Beware: skip distance is different for magnetic and nonmagnetic cases!



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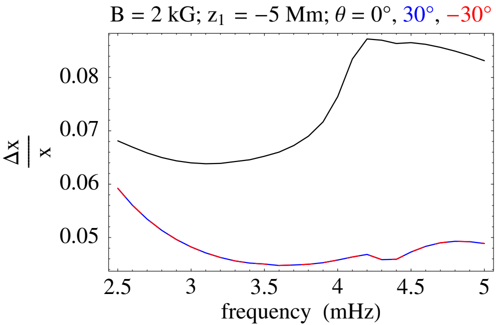

Skip distance lengthened by magnetic field by 4–9% in this case (at all frequencies)

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- Dependence on field inclination θ; stronger effect at higher inclination

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- This allows low frequency acoustic waves to ascend sufficiently inclined magnetic ramps

Magnetic portals

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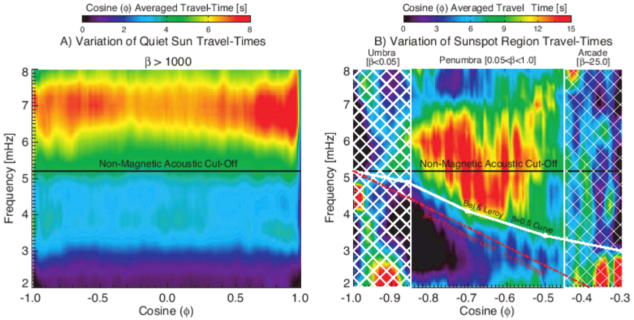

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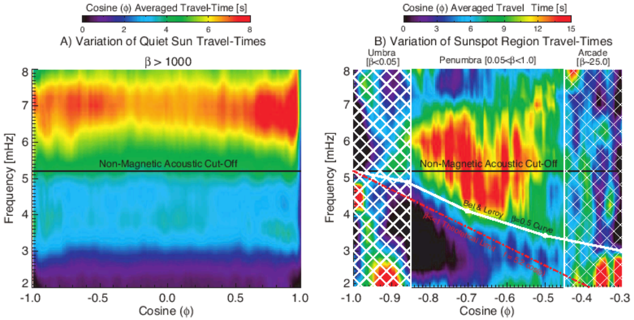

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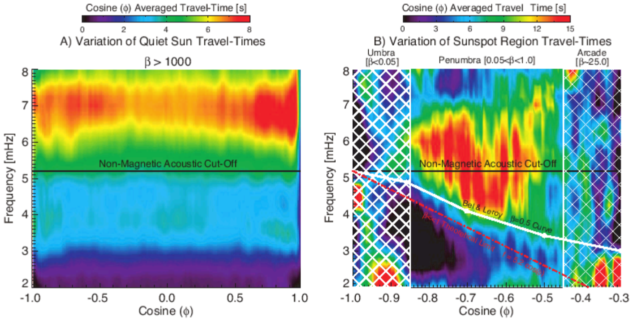

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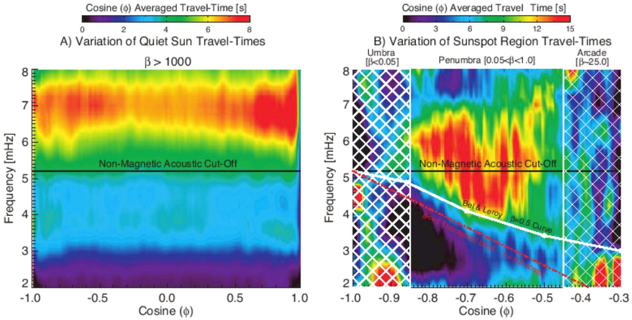

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- **Wave mechanical experiment** to see if it's true. Place an acoustic driving plane at z=-4 Mm which launches 5 mHz waves with $k_x > 0$ such that the acoustic cavity has natural base at $z_1 = -5$ Mm ($k_x \approx 1.35$ Mm^{-1}). Radiation boundary conditions at top (for fast and slow waves) and bottom (slow wave only). Now monitor the acoustic wave energy flux high in the atmosphere:

Directional acoustic filter – experiment

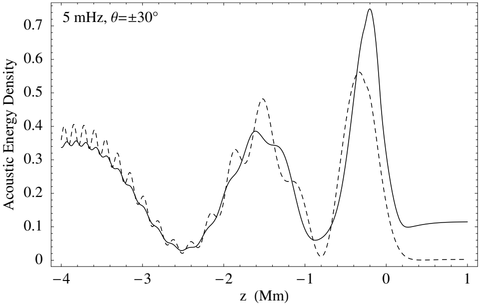

Figure: Acoustic wave energy density as a function of height for $\theta = \pm 30^\circ$ for 2 kG field. Full curve: $\theta = 30^\circ$; dashed curve: $\theta = -30^\circ$. From wave mechanical experiment, not ray theory.

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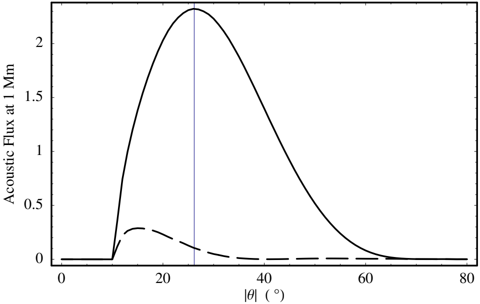

Figure: Vertical acoustic wave energy flux high in the atmosphere as a function of magnetic field inclination θ for 2 kG field. Full curve: $\theta > 0$; dashed curve: $\theta < 0$. From wave mechanical experiment, not ray theory. The zero flux at low inclination is due to the acoustic cutoff making the slow (acoustic) wave evanescent. The ramp effect opens up the atmosphere to travelling wave penetration once $\cos\theta < \omega/\omega_c$.

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- As expected from ray theory (attack angle)

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- Modelling suggests that at SOHO/MDI heights, this effect is far from complete
- High resolution simultaneous observations at a variety of heights would be very useful (e.g., Jefferies; more to come from new UK camera?)

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THE END

See you in Melbourne

Brunt-Väisälä and Cutoff frequencies