# Surface waves: Origin of the Evershed phenomenon ?

M. BÜNTE AND S. K. SOLANKI

*Institut für Astronomie, ETH-Zentrum, CH-8092 Zürich*

**Abstract**

Surface waves propagating along the boundary between penumbra and underlying convection zone produce all features of the Evershed effect for a particular spectral line. It is shown, however, that the sign of the net shift and asymmetry depends crucially on the temperature sensitivity of the spectral line under consideration. Hence, the systematic shifts and asymmetries, observed in almost all photospheric lines, cannot be explained by the temperature–velocity correlation of these waves.

## 1. The surface wave model

We have recently suggested that surface waves guided along the boundary between the magnetic penumbra and the underlying non-magnetic convection zone might explain the still enigmatic Evershed phenomenon (Bünte et al. 1993). Detailed computations of the spectral signature of magneto-acoustic gravity surface (MAGS-) waves can qualitatively reproduce all observed features of the Evershed effect in the neutral iron line at 5250.2 Å. In this contribution we present similar calculations for two Fe I lines with different temperature sensitivities.

## 2. Results for different spectral lines

The potential of MAGS-waves to produce a net line shift and/or asymmetry in a spectral line when observed towards the limb lies in the correlation between horizontal velocity and temperature perturbations. Bünte et al. (1993) have studied the neutral iron line Fe I 5250.2 Å and obtained *red*-shifts and asymmetries in the averaged line profiles for waves propagating *towards* the observer.

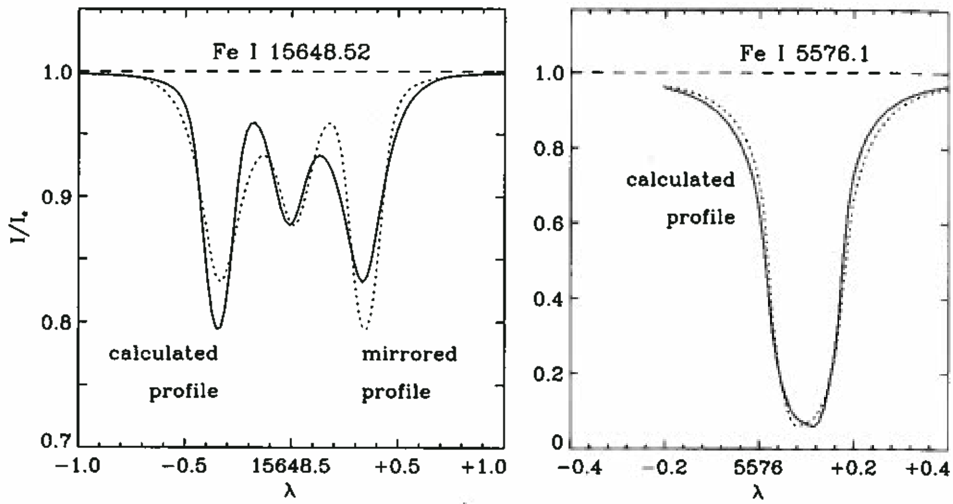


Figure 1: Line profiles (solid) calculated at $\mu = 0.34$ ($\theta = 70°$) in the presence of the 1st harmonic surface mode with $\lambda_x = 700$ km and vertical velocity amplitude $\hat{v}_{1z}(0) = 1$ km/s. Also shown are the mirrored profiles (dotted) to visualize shifts and asymmetries. **a:** Fe I 15648.52 Å; **b:** Fe I 5576.1 Å.

We have computed the averaged line profiles for Fe I 15648.5 Å and Fe I 5576.1 Å, again for waves travelling towards the observer. The resulting profiles are shown in Figs. 1 a & b (solid) along with the mirrored profiles (dotted). Note that the infrared line shows a *blue*-shift, while the profile of Fe I 5576.1 Å is almost *unaffected* by the wave.

The reason for this diverse behaviour of the three spectral lines lies in their different temperature sensitivities. Regions above the crests of a surface wave are heated and move with the wave, while the regions above the throughs are cooled and move in the opposite direction. Consider, then, a wave propagating towards the observer as shown in Fig. 2. The line profiles from the high temperature regions show a blue-shift, while those from the low temperature regions show a red-shift. The net shift and asymmetry of the averaged line profile depends on two effects:

- continuum–velocity correlation (favoring high temp. regions),
- line strength–velocity correlation (usually favoring low temp. regions).

Hence the sign of shift and asymmetry depends on the temperature sensitivity of the spectral line under consideration. The Fe I 5250.2 Å line studied by Bünte et al. (1993) is highly temperature sensitive. Hence the line strength–velocity correlation dominates, the cool regions are favored, and the averaged line profiles show a red-shift and/or asymmetry for waves

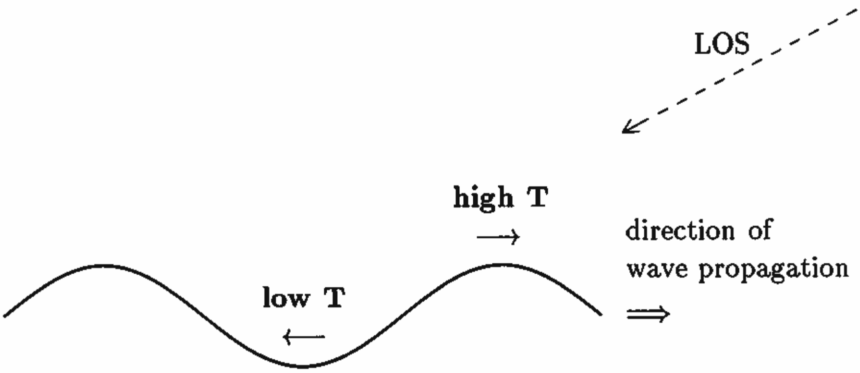


Figure 2: A surface wave propagating horizontally to the right is observed close to the limb, i.e. at a large angle of the line-of-sight (LOS) to the vertical. Regions of increased temperature (high T) are moving *towards* the observer, regions of reduced temperature (low T) move *away* from the observer. The net effect (at low spatial resolution) depends on the temperature sensitivity of the spectral line under consideration.

propagating towards the observer. The infrared line Fe I 15648.5 Å, on the other hand, is comparatively insensitive to temperature changes so that the continuum–velocity correlation dominates. Hence the high temperature domains are favored, and the averaged profile shows a blue-shift (Fig. 1a). Finally, for a line of intermediate temperature sensitivity, like Fe I 5576.1 Å, the correlation effects approximately cancel (Fig. 1b).

## 3. Conclusions

Surface waves have a number of properties that make them attractive candidates for explaining the Evershed phenomenon as discussed in detail by Bünte et al. (1993) for the neutral iron line Fe I 5250.2 Å. In this contribution we have presented calculations for two additional spectral lines, Fe I 5576.1 Å and Fe I 15648.5 Å. The effects of surface waves on these lines are negligible (Fe I 5576.1 Å) or of opposite sign (Fe I 15648.5 Å) as compared with the case of Fe I 5250.2 Å, due to their different temperature sensitivities. Since observations of almost all photospheric lines show shifts and asymmetries of the same sign, they cannot be explained on the basis of a correlation between horizontal velocity and temperature perturbations.

## References

Bünte, M., Darconza, G., Solanki, S.K.: 1993, *Astron. Astrophys.* **274**, 478