The ULF wave foreshock boundary: Cluster observations

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Abstract

In the upstream region of the bow shock, the interaction of backstreaming ions with the incoming solar wind gives rise to a number of plasma instabilities from which ultra-low frequency (ULF) waves can grow. Due to the finite growth rate, it is expected that the region of ULF wave activity is spatially localized in the ion foreshock. Observational evidence of the ULF wave foreshock boundary has accumulated over the last three decades. Among other things, it has been shown that the geometrical characteristics of the boundary are very sensitive to the interplanetary magnetic field (IMF) cone angle. In the present work, we aimed at revisiting the properties of the ULF wave foreshock boundary. For this purpose, we use the first three years of magnetic field data from the flux gate magnetometer (FGM), and the plasma densities and velocities from the hot ion analyzer (HIA) low-geometry factor side on board RUMBA (SC 1). We use a specific and accurate criterion for the determination of boundary crossings, and a 3-D structure bow shock model to reconstruct the foreshock geometry. In particular, our criterion is used to qualitatively measure the differences between the magnetic field in the wave and no-wave zones, taking into account possible rotations of the IMF. A new identification of the ULF wave foreshock boundary is presented and it is compared with previous results reported in the literature as well as with theoretical predictions.

Identification of Earth's ULF waves boundary crossings

During Cluster's excursions into the solar wind, we looked for intervals with low-frequency waves in the magnetic field components. In particular, we identified 213 beginnings (or endings) of intervals with ULF waves for years 2001, 2002 and 2003. Figure 1 shows two clear examples of crossings. For each of the 213 crossings, we extracted the physical variables from the CAA (Cluster Active Archive).

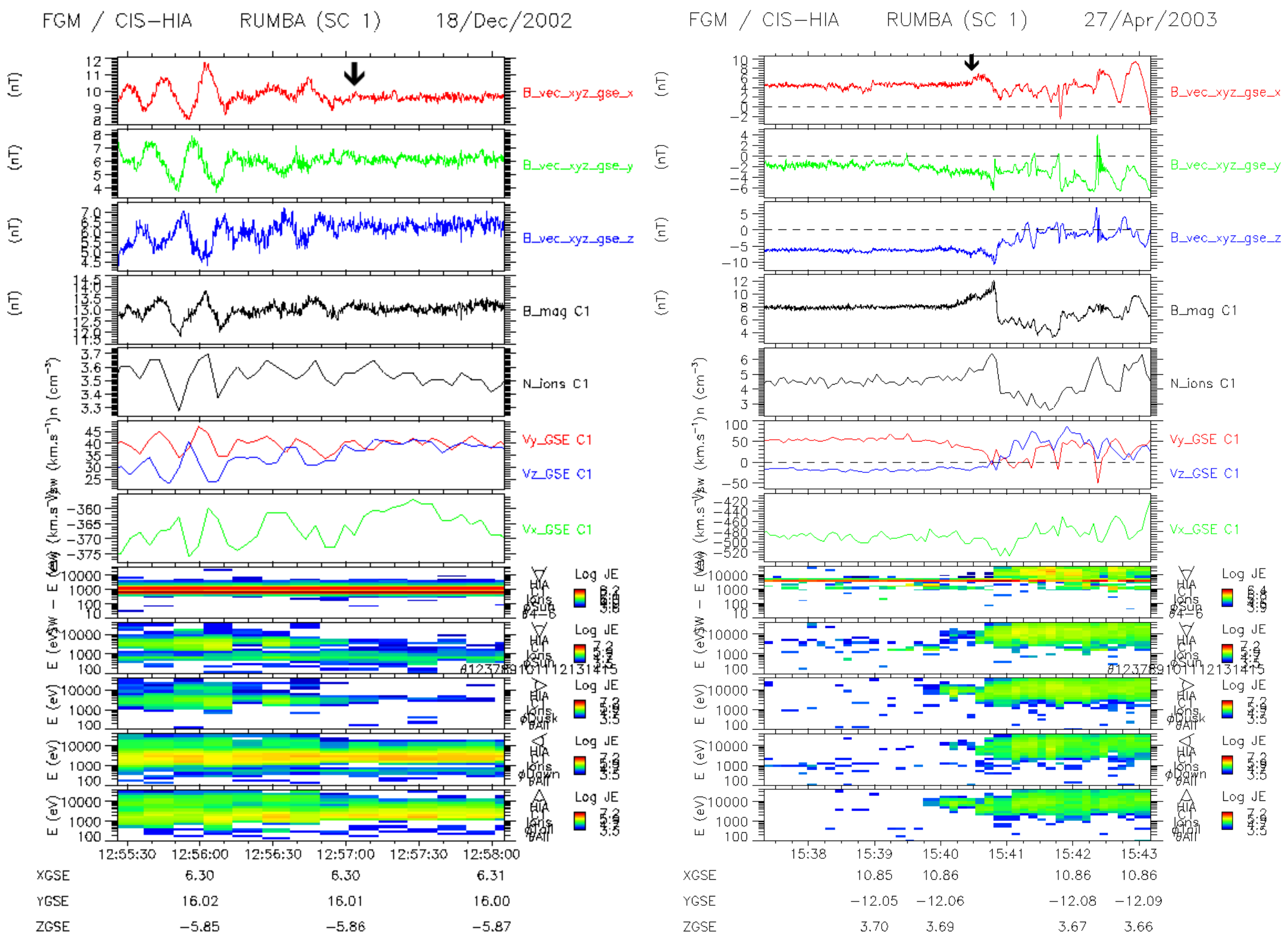

Figure 1: Two examples of ULF waves region crossing (black arrow corresponds to the crossing time). By definition, α is the angle between the mean magnetic field in the upstream region (no waves) and in the downstream region (waves). Left example: $\alpha = 2°$. Right example: $\alpha = 38°$

Data selection criterion

The ULF wave foreshock boundary by definition exists under quasi-stationary IMF conditions. In order to identify this boundary, we studied the level of IMF rotation for every crossing using the angle α between the mean magnetic field in the upstream region (no waves) and in the downstream region (waves).

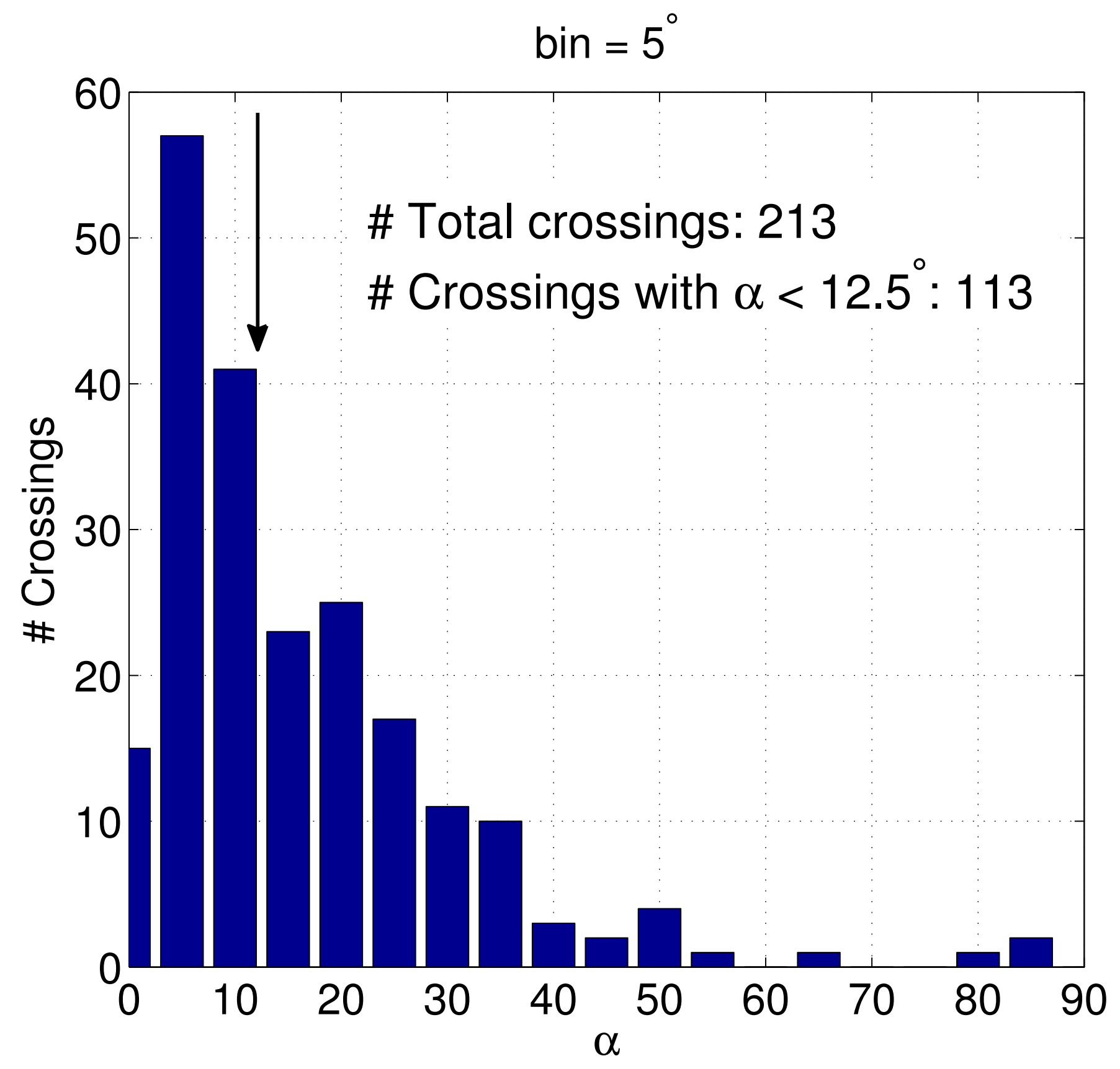

Figure 2: Histogram of α for the 213 identified crossings

According to Figure 2, the histogram has a pick for small values of α. As a result the quasi-stationary IMF criterion was set to $\alpha < 12.5°$ (arrow in Figure 2). Figure 1 shows two examples, one with an $\alpha = 2°$ corresponding to a crossing under quasi-stationary IMF conditions, and another with $\alpha = 38°$ corresponding to a rotation of the IMF direction.

References

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- Farris, M. H., Petrinec, S. M., Russell, C. T., 1991. The thickness of the magnetosheath: Constrains on the polytropic index. GRL 18, 1821-1824.
- Skadron, G., Holdaway, R. D., Lee, M. A., 1988. Formation of the Wave Compressional Boundary in the Earth's Foreshock. JGR 93, 11354-11362.

Solar Foreshock Coordinates

Greenstandt and Baum (1986) introduced the so-called *solar foreshock coordinates* (SFC). For each crossing, in or out of the ULF wave foreshock under quasi-steady IMF conditions, we use the bow shock physical model from Farris et al. (1991). Assuming $\mathbf{v}_{\rm sw} \parallel \hat{\mathbf{x}}_{\rm GSE}$, we calculate the SFC in the $\mathbf{v}_{\rm sw}$-$\mathbf{B}$ plane (see Figure 3) as:

$$\mu = \frac{(y_o - y_i)}{\mathrm{sen}\theta_{\rm Bx}} \qquad (1)$$
$$\nu = \frac{(y_o - y_i)}{\tan\theta_{\rm Bx}} + x_i - x_o$$

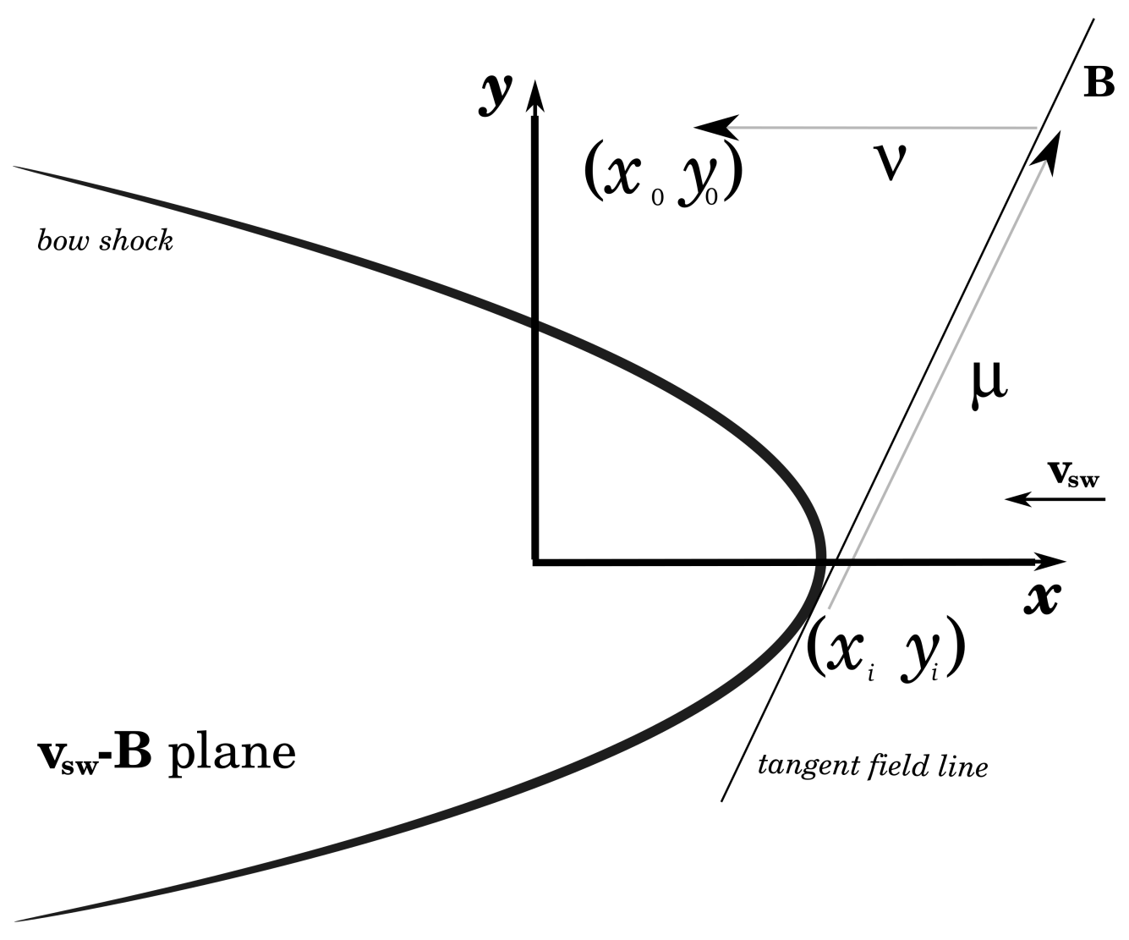

Figure 3: Schematic representation of the solar foreshock coordinates

where $\theta_{\rm Bx} = \mathrm{acos}^{-1}(\mathbf{B}\cdot\hat{\mathbf{x}}_{\rm GSE}/\mathrm{B})$ is the IMF cone angle, (x_i, y_i) is the intersection point between the tangent IMF line and the bow shock fit, while (x_o, y_o) is the observation point (Cluster's crossing location).

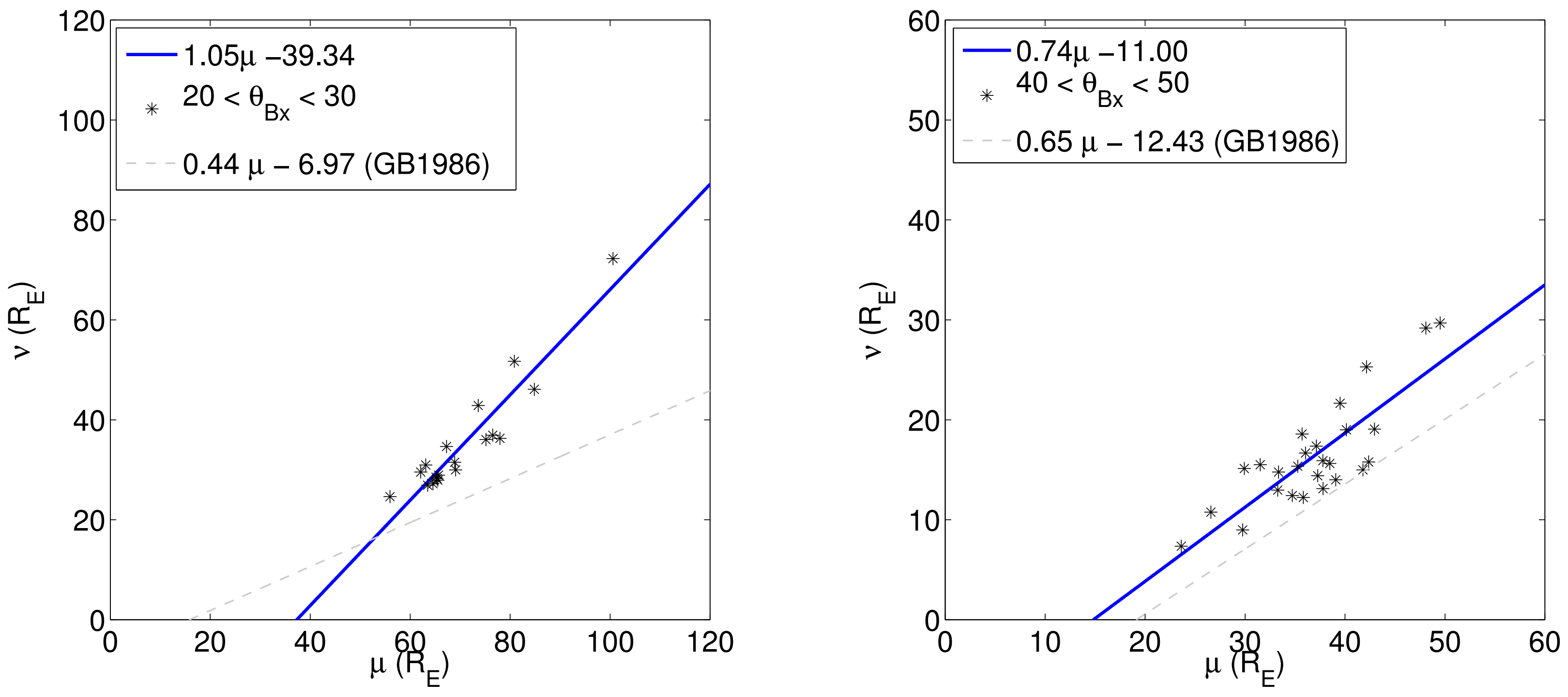

Figure 4: ULF wave foreshock boundary crossings in solar foreshock coordinates.

The location of the ULF wave foreshock boundary was found to depend on the IMF cone angle (Greenstandt and Baum, 1986). We performed a scatter plot of the ULF wave foreshock boundary crossings considering only the cases with a cone angle $40° < \theta_{\rm Bx} < 50$ and $20° < \theta_{\rm Bx} < 30$. Figure 4 shows our best linear fit (blue). For comparison the best linear fit by Greenstandt and Baum (1986) is included (gray).

Conclusions

We used a specific and accurate criterion for the determination of the ULF wave foreshock boundary and a 3-D bow shock physical model to reconstruct the foreshock geometry. Our criterion is used to qualitatively measure the differences between the magnetic field in the wave and no-wave zones, taking into account possible rotations of the IMF. Our preliminary identification of the ULF wave foreshock boundary is compared with that reported by Greenstandt and Baum (1986). For $40° < \theta_{\rm Bx} < 50$ (around Parker's value) our results are compatible to Greenstandt and Baum (1986) in spite of the difference in the selection criteria. We also find that the slope in the μ-ν plane (Figure 4) is sensitive to the value of $\theta_{\rm Bx}$. The observed differences between both works, in particular for $20° < \theta_{\rm Bx} < 30$ might be due to the different bow shock models employed. In addition, for $\theta_{\rm Bx} = 45°$ our boundary forms an angle of 87° with respect to the $\hat{\mathbf{x}}_{\rm GSE}$. This angle is somewhat different from the theoretical prediction reported by Skadron et al. (1988) of 77°. The difference might be due to the fact that Skadron's criterion is based on the compressive component of the fluctuations.

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