VENERA-9 MAGNETIC FIELD MEASUREMENTS IN THE VENUS WAKE:
EVIDENCE FOR AN EARTH-LIKE INTERACTION

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Abstract. Venera-9 magnetic field measurements in the Venus wake provide additional support for the hypothesis that Venus has an intrinsic planetary field. The observed field is in the direction expected for a northward moment, and is similar to that observed in equivalent locations in the terrestrial magnetosphere, both in its temporal and spatial behavior. In particular, Venera-9 appears to have observed a plasma sheet expansion, field-aligned currents, and tail-field dipolarization.

Estimates of the upper limit of the magnetic moment of Venus have for many years been declining: Mariner 2 measurements produced a limit of 5x10^-2 of the terrestrial moment (ME) (Smith et al., 1965); Mariner 5 measurements, a limit of 5x10^-3 ME (Bridge et al., 1967); Venera-4 measurements, a limit of 3x10^-4 ME (Dolginov et al., 1968); and Mariner 5 and Venera-4 in combination, an upper limit of 10^-4 ME (Dolginov et al., 1969). However, recently this trend has reversed. The most recent measurements of Venera-9 have been interpreted as giving an upper limit of 2.5x10^-4 ME (Dolginov et al., 1976), while the Venera-4 data have been reinterpreted in terms of an upper limit of 8x10^-4 ME with a strong indication of the presence of a planetary field (Russell, 1976). Dolginov et al. derive their limit of 2.5x10^-4 ME from magnetic measurements in the wake of Venus. Since they do not know their spacecraft field in this preliminary report, their limit is based on the fact that the field in the wake is not very different from the interplanetary field. However, since the field strength of the interplanetary medium near Venus is close to 10^7 (Bridge et al., 1967; Dolginov et al., 1969), since the magnitude of the difference vector between the interplanetary field at closest approach is roughly 7x10^7, and since the distance at closest approach, 1500 km, corresponds to an attenuation of the surface field by a factor of 1.9, the extrapolated upper limit to the surface field should in fact be \( \sim 1.9 \times 10^7 \gamma \) or \( \sim 32 \gamma \), which is consistent with the Venera-4 reevaluation based on the radial pro-

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file of the field down to 200 km (Russell, 1976a).

The above argument of course is predicated on total ignorance of the spacecraft field levels and assumes the simple superposition of fields. We feel we can improve upon this technique. It is the purpose of this paper to point out that estimates of the correct zero levels for Venera-9 can be made with some confidence, to within about \( \pm 3 \gamma \). When this is done, a consistent physical picture arises in which the solar-wind interaction with Venus strongly resembles the terrestrial interaction with a tail, a plasma sheet and field-aligned currents bounding the current sheet.

Furthermore, the direction of the field in the tail is in the direction expected for the northward moment inferred from the Venera-4 as it was on the Mariner 5 traversal through the tail (Russell, 1976b). Thus the Venera-9 data, like the Venera-4 data, support the hypothesis that Venus has an intrinsic dipole moment.

Choosing the Correct Zero Levels. The key to the correct physical interpretation of the Venera-9 results is the choice of the proper zero levels. Figure 1 shows the Venera-9 data of Dolginov et al. and the trajectory of the spacecraft in solar-cylindrical coordinates. The dashed horizontal lines on the By and Bz panels show our choice of the correct zero levels for these measurements. The choice of the By zero level is the most difficult one. Our only clues are the sum across the shock and the field strength in the wake region. Since there is no net positive increase in this field component from the interplanetary medium into the magnetosheath (the highly fluctuating region) and since the shock crossing is on the flanks of the magnetosheath, we assume that the field is positive, i.e., sunward in both the interplanetary medium and the magnetosheath. If the correct zero level were more negative than plotted the Bx component in the wake region would become larger. With the original baseline it is roughly 14\( \gamma \) at 0648 Moscow Time. This is slightly larger than the field observed in the wake region at larger distances by Mariner 5 (Russell, 1976b). Thus, it is unlikely that the
zero level could be much more than a few gammas more or less than the original baseline.

The choice for the By zero level is less difficult. The basis of the principal technique for choosing zero levels on interplanetary missions is the tendency for near constancy of the field magnitude across discontinuities (Blander, 1973). In figure 1, there is a large discontinuity occurring almost exclusively in the Y-component at the line labelled 3. To maintain a constant field magnitude across this discontinuity, the field change should be centered on zero. Thus, we would choose to draw our zero line through the midpoint of the discontinuity. We note that it is possible for the Y-component to reverse across the shock front on the flanks of the magnetosheath.

Finally, for Bz we note that the field change across the shock is negative, and hence we expect the interplanetary component might be negative also. This is a weak constraint. To pick a specific baseline we assume that the field in the wake region has a zero Z-component under undisturbed conditions. In other words, we assume the solar wind significantly stretches out the field in the wake region.

Although the three components of the position of Venera-9 are not given by Dolginov et al., a sample trajectory for Venera-10 is given by Vaisberg et al. (1976b). The orbit of Venera-9 is quite similar (Vaisberg, personal communication, 1976). The satellite is in the southern hemisphere throughout the wake traversal, and on the dawn side of Venus (in the terrestrial sense) at the shock encounter. We can use this fact as a rough check on our baselines since a positive interplanetary By component naturally leads to a positive By component in the dawn flank of the magnetosheath if By in the interplanetary medium is small. Inspection of figure 1 shows this to be the case. Another check is to calculate the shock normal using the coplanarity theorem (Colburn and Sonett, 1966) which, since it involves a cross product with the upstream field, is sensitive to errors in the baselines. Doing this for the baselines chosen for figure 1, and z2v on either side of these baselines we obtain normals appropriate for crossings in the southern dawn quadrant. Thus, we have moderate confidence that our baselines are approximately correct and we proceed with the interpretation of the wake data based on these baselines.

Interpretation. The data in the Venus wake in figure 1 were taken at a minimum of 1.25 Ry from the center of the planet and ~1 Ry behind the planet. On the earth these would correspond to distances of roughly 12.5 Re and 10 Re respectively if we equate the terrestrial magnetopause nose radius to the Venus

![Figure 1](image_url)
The spatial behavior evident on this pass is also similar to that of the magnetotail. First, as the spacecraft moves from the night time towards the "dawn" flank the By component decreases in strength and Bz decreases, i.e., becomes increasing negative. In other words, the field becomes less "tail-like", and more like a dipole field with its moment opposite that of the earth. The By component which is small in the tail becomes more positive as the magnetopause is reached. This component is in the sense expected for a flaring tail boundary in the lower "dawn" quadrant of the tail. The By component reaches -5\gamma at 0648 MT. Although this brief excursion could be a temporal change, part could also be a spatial change. These data are probably obtained near the center of the tail where the effects of flaring are minimal and the effect of the aberration of the tail by the solar wind maximal. Aberration of a 14\gamma tail field is expected to produce about a -1.5\gamma effect in By.

Discussion. Our examination of the Venera-9 data suggests that Venus has a magnetotail similar in spatial properties and dynamic behavior to the terrestrial tail. The observed direction of the field is in accord with the northward magnetic moment inferred from the Venera-4 data by Russell and others, and with the Mariner 5 data examined by Russell. Furthermore, the "southward" turning of the field during the "plasma sheet" encounter and the increasingly southward field as the dawn-dusk terminator is approached are consistent with a northward "edge" arc.

Gringauz et al. (1976) and Vaissier et al. (1976a) have also published preliminary measurements from Venera-9. They report expected flow velocities and number densities in the magnetosheath and solar wind, but report an absence of flowing plasma in the wake region. Using their electron data, they find a number density of 2 cm^{-3} and an electron temperature of 1.5x10^5 K which is not too dissimilar to measurements in the distant night time magnetosphere.

Finally, we remark that near the planet the "edge-effects" of a tail current system opposes the dipolar field of the planet. In the earth this is manifested by extremely low fields (10-20\gamma) in the midnight magnetosphere from about 7-12 Re. Thus, the perigee position chosen by Dolginov et al. (1976) to measure the planetary moment, not only suffers because of unknown spacecraft fields as outlined in our introduction, it also cannot be used even if the spacecraft fields were known! A correct measurement requires radial profiles to much lower altitudes. Thus, to date the Venera-4 data give our best estimate of the magnetic moment of Venus.
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