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Response to Comment on "A Large Excess in Apparent Solar Oblateness Due to Surface Magnetism"

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Our analysis of satellite data from the Reuven Ramaty High-Energy Spectroscopic Imager revealed a strong correlation with a magnetic proxy, leading to an anomalous increase of the solar oblateness. We modeled this effect to yield an oblateness measurement of an assumed underlying nonmagnetic Sun. Kuhn *et al*. note that this measurement could be confused with a systematic spatial brightness variation. The existing data on this are ambiguous.

We thank Kuhn *et al*. (*1*) for their comments, with which we agree in principle but not in detail. Our study (*2*) explicitly recognized the cross talk between the edge location and brightness as they potentially vary around the limb, when using a simple threshold detection as we have done. We quantified this cross talk for the well-known process of gravity darkening ("ellipticity dimming") due to centrifugal effects from the known surface rotation. As we noted, "[t]he RHESSI observations are differential measurements of the radius based on a simple fixed-brightness threshold… This necessarily results in crosstalk between limb position and brightness…Because of this cross talk, it is necessary to make a correction (prolate, 0.03 milli–arc sec) for ellipticity dimming as a result of Von Zeipel's theorem…We make the further strong assumption, discussed in detail in the SOM, that no other global brightness variation presently needs to be considered" (*3*–*5*) [figure 1B in (*2*) and supporting online material for (*2*)].

There is no problem with this assumption unless there is an axisymmetric quadrupole term in limb brightness that is many times larger than that required by Von Zeipel's theorem. Although such a large nonrotational quadrupole term may well exist (*4*, *6*), it is a very difficult measurement and we do not feel that the existing observations have established it well enough to use quantitatively. Our RHESSI data are also extremely suitable for measuring slow variations of solar surface intensity. We have not yet completed a brightness analysis, but our preliminary looks do not show a significant quadrupole intensity variation. The α term in (*1*) also appears not to have a significant axisymmetric quadrupole term and also differs drastically from that observed by Rast *et al*. (*6*). We certainly agree with Kuhn *et al*. (*1*) that a detailed analysis of the photospheric intensity distribution, including the brightness at the extreme limb, is important to carry out and the results will certainly have broad importance in solar and stellar physics. The possible brightness variations include not only the classical limb-darkening function but also several other interesting possibilities associated with interior or surface structures.

The details of the new MDI data analysis cannot be understood in detail from the material presented in (*1*). This difficulty is compounded by the very different instruments and methods; a definitive comparison would require a much more detailed presentation. To correct for the limb brightness variation presented in the inset in figure 1 in (*1*), and to simulate the RHESSI analysis, the identified "bright pixel data" from MDI is used to mask the data to derive an estimated oblateness bias. In the RHESSI analysis, an external and independent data set (EIT 284A) is used to mask magnetic activity. This measure has much greater contrast than the MDI brightness itself, and the "RHESSI-style" analysis method used by Kuhn *et al*. (*1*) cannot sufficiently mask against weak magnetic elements. It therefore tends to overestimate the oblateness. Our masking method uses the asymptotic behavior of the measured oblateness versus data fraction and does not rely on an oblateness measurement at a fixed level of data deletion as stated in (*1*). The asymptotic value is approximately 0.6 milli–arc sec lower than any estimated value at the plateau of the measured oblateness versus data fraction. Also at times of very little photospheric magnetic flux, the images from the Extreme Ultraviolet Telescope (EIT) on the Solar and Heliospheric Observatory (SOHO) (e.g., for 20 March 1997) still show clear structures (especially at the W limb). These are presumably the source of the major peaks in the α profile shown in the inset in figure 1 in (*1*). This sort of low-level activity will certainly perturb the limb signatures but would not have any visibility in the facular magnetic field. Finally, we note that the 0.6 milli–arc sec bias suggested in (*1*) would certainly differ for the different instruments and reduction methods, and it is only speculation to imagine that it would be different between 1997 and 2004.

Our report (*2*) clearly stated how the RHESSI data measure the oblateness of the quiet, presumably nonmagnetic Sun. We acknowledge the possibility of contamination by an axisymmetric quadrupolar brightness variation at the limb. The brightness variation as described by Kuhn *et al*. (*1*) would unfortunately make the RHESSI measurement overestimate the oblateness. Our reported oblateness would then have to be corrected to a still smaller value, in conflict with earlier measurements and theoretical predictions (*5*).

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References and Notes

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