Comments on: "Stellar Refraction: A Tool to Monitor the Height of the Tropopause from Space"

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31 October 1975

Schuerman *et al.* (1975) have proposed using spacecraft observations of the atmospheric refraction of stars occulted by the Earth to infer atmospheric density profiles; particularly, to determine the height of the tropopause. I wish to point out that 1) closely related techniques have been used to study other planets' atmospheres, 2) the sensitivity is limited by an effect not considered by Schuerman *et al.* (1975), and 3) effects due to turbulence can be estimated, and are more serious than these authors indicate.

The basic problem was treated by Pannekoek (1903), Fabry (1929) and Baum and Code (1953) who all assumed a constant-temperature atmosphere. Although the angular refraction observable in other planets' atmospheres was found to be small, Fabry (1929) pointed out that large refractions would be observable at the Moon if it had an appreciable atmosphere; this case is quite similar to the proposal of Schuerman *et al.* (1975).

A major effect, not mentioned by Schuerman *et al.* is the attenuation of the star's light by differential refraction (defocusing) in the atmosphere. This attenuation is a factor of 2 at the level where the angular ray deviation (twice the horizontal refraction) equals the angular subtense of one scale height, as seen by the observer. For the 440 km orbital altitude used in the example by Schuerman *et al.* (1975), this occurs at about 16 km height in the atmosphere. At typical tropopause heights near 11 km, atmospheric defocusing would attenuate the star by a factor of 3, or 1.2 stellar magnitudes. This reduces the number of available stars by about a factor of 4. The problem is in fact more serious than this because still deeper regions must be reached to identify the kink in the refraction curve at the tropopause.

In the past this effect has been used to infer the atmospheric scale height. The detailed numerical inversion of the light curve to obtain temperature profiles was first done by Kovalevsky and Link (1969) and a general discussion of the method is given by Wasserman and Veverka (1973).

Finally, consider the effects of turbulence. Because most of the observed telescopic twinkling of stars comes from heights in the range 5–20 km, we can estimate the effects of turbulence fairly accurately in this region. The root-mean-square angular deviation due to this part of the atmosphere is on the order of 0.2 arcsec for a vertical path (Young, 1970). For a horizontal path, the effective path length is about 70 times longer and so is the mean-square angular deviation. This gives about 1.6 arcsec rms image motion, which is considerably larger than Schuerman *et al.*'s estimate ("substantially lower" than 1 arcsec), though not large enough to invalidate their method, which requires only 6 arcsec resolution.

Turbulence also produces intensity scintillation or "twinkling." The theory of scintillations during occultation of a star by a planetary atmosphere has been developed by Young (1976). Without going into the intricacies of the theory, the reader can readily see that if *vertical* transmission through this region produces moderately strong scintillations, then *horizontal* transmission must produce extremely strong scintillations. Quantitative calculations bear this out: If the temperature structure function remains roughly constant throughout this region, strong ("saturated") scintillations should begin at ray heights between 40 and 50 km, as seen from a height of 440 km.

These phenomena place additional constraints on the technique proposed by Schuerman *et al.*, and should be included in a quantitative assessment of its practicality.

Acknowledgment. I thank James E. Hansen of the Goddard Institute for Space Studies for bringing this paper to my attention. This work was supported by Grant NGR-001-117 from the National Aeronautics and Space Administration.

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