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Erratum: "A Multiple Scattering Polarized Radiative Transfer Model: Application to HD 189733b" (2016, ApJ, 817, 32)

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A normalizing factor of π was not applied to several model runs as a result of a coding bug. The error affects plots in Figures 4–14 in the original article; the magnitudes of the intensity and polarization curves are too large by π. The corrected figures are given below.

We thank Jeremy Bailey, Lucyna Chudczer, and Kim Bott for pointing out a discrepancy between their model results and ours, leading to the discovery of this error.

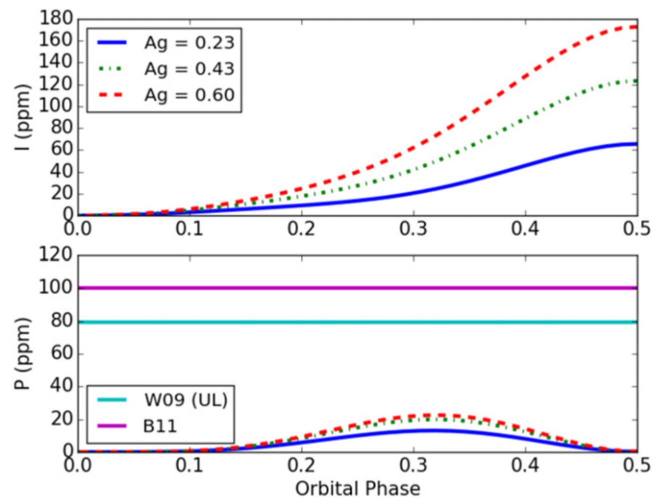

Figure 4. Variation in the degree of polarization for reflected light from HD 189733b with changes in geometric albedo for a semi-infinite, purely Rayleigh scattering atmosphere. *I* and *P* are normalized to direct starlight. The B11 and W09 lines indicate the amplitude of observations from Berdyugina et al. (2011) and the upper limit for non-detection from Wiktorowicz (2009). Orbital phase 0 is mid-transit and 0.5 is mid-eclipse.

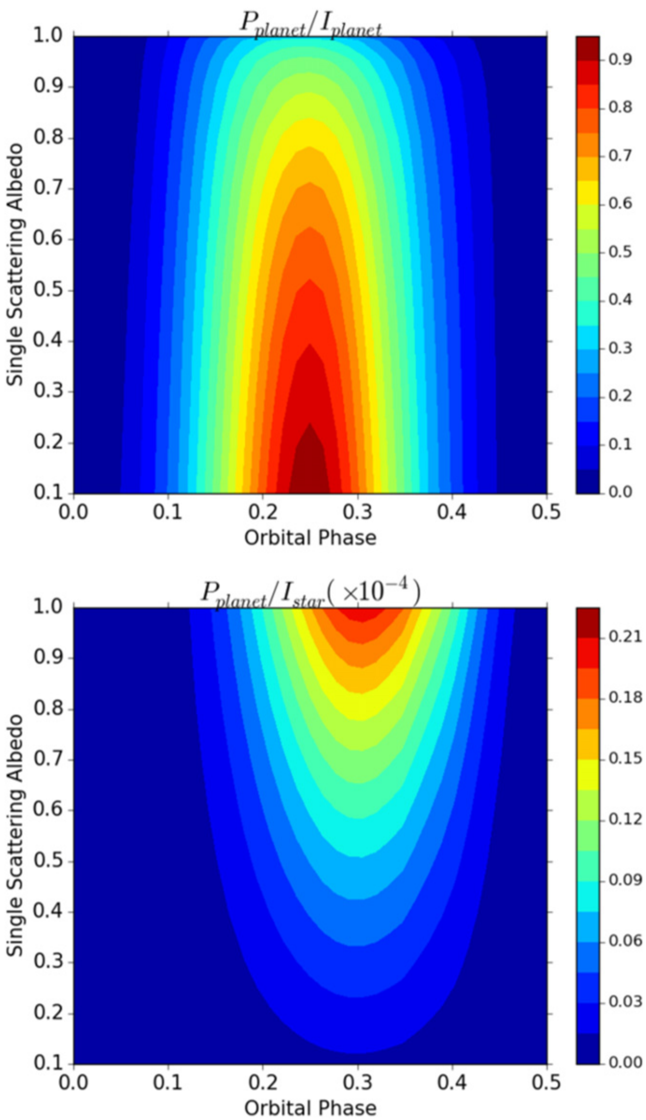

Figure 5. Variation in the degree of polarization as a function of single scattering albedo and orbital phase for a semi-infinite Rayleigh scattering atmosphere normalized to reflected light from the planet (top) and direct starlight (bottom). For the former, the highest degree of polarization occurs at low albedo, while for the latter (which is the observable quantity), it occurs at high albedo.

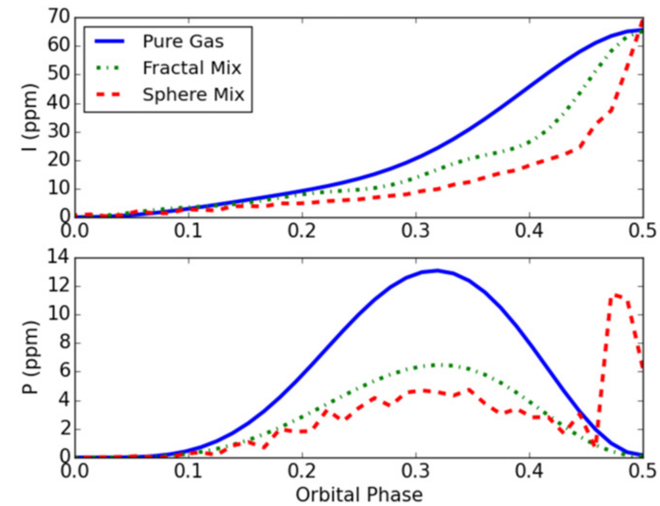

Figure 6. Variation in the degree of polarization from reflected light HD 189733b system with a semi-infinite pure gas and hazy atmospheres. The particle properties are listed in Table 2 of the original paper. The geometric albedo of the planet is forced to remain close to 0.23.

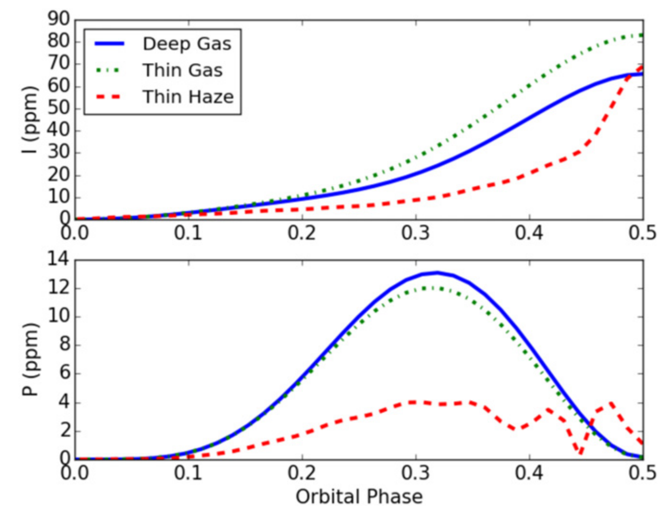

Figure 7. Variation in reflected intensity and the degree of polarization for different atmospheric structures of HD 189733b. The intensity curves for a semi-infinite Rayleigh atmosphere (deep gas), thin, clear gas atmosphere (thin gas) and a hazy atmosphere with spherical particles (thin haze) on top of a cloud layer. The haze and cloud properties are mentioned in Table 2 of the original paper.

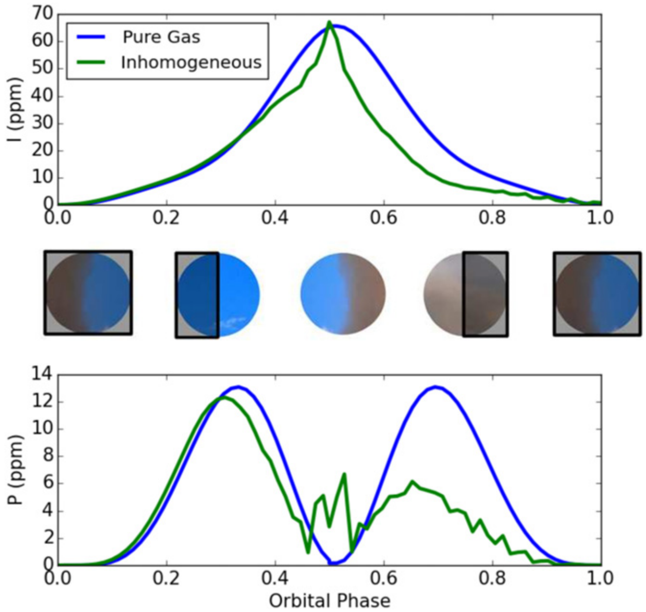

Figure 8. Variation in reflected intensity and the degree of polarization as a planet with an inhomogeneous atmosphere completes one orbit compared to a homogeneous, Rayleigh scattering planet. The spheres on top show the planet as seen from Earth at the phases indicated on the abscissa. The dark blue regions are pure Rayleigh scattering, and the grayish regions contain haze. The portion covered by the box indicates the night side of the planet.

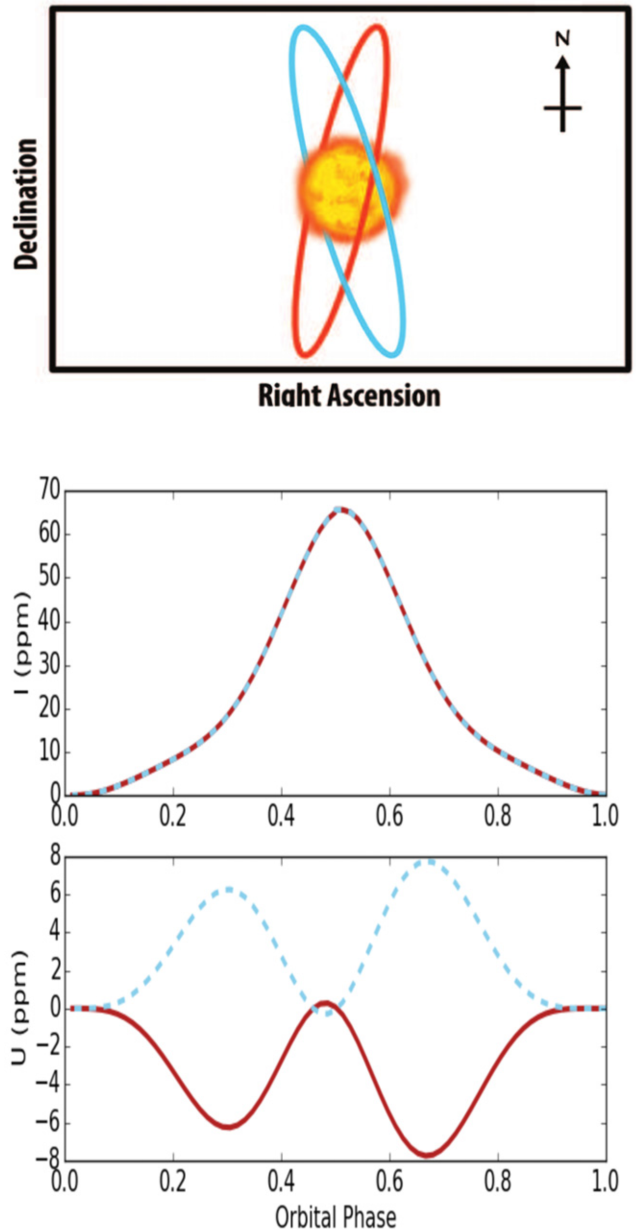

Figure 9. Top panel shows a cartoon of two orbits of inclination close to 90° and longitude of the ascending node 16° (red, solid line) and −16° (blue, dashed line) for the HD 189733b system as seen from Earth. (figure is approximate, not to scale, angles are not accurately depicted.) The arrow indicates the sense of motion of the planet in the orbit and upwards is north in the sky plane of the Earth. These orbits are indistinguishable from photometry alone, but can be separated using polarimetry. The sign of Stokes parameter U changes, while intensity is invariant for this pair of orbits.

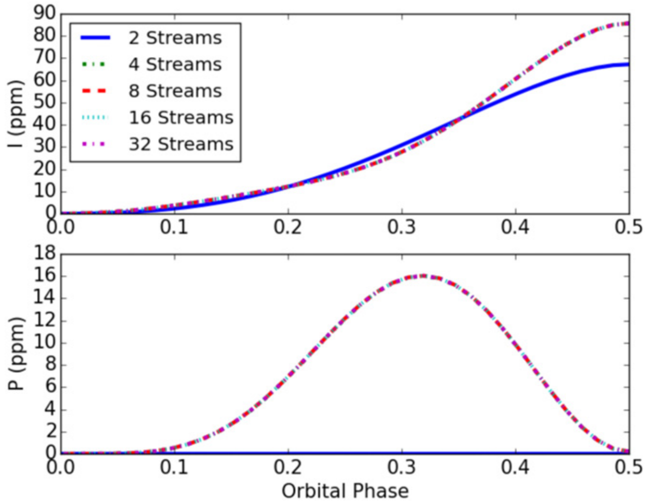

Figure 10. Model outputs for different number of computational streams in the RT model for a Rayleigh scattering atmosphere using 64 quadrature points for disk integration. Four streams at least are necessary to produce polarization, but beyond that results are insensitive to change in streams.

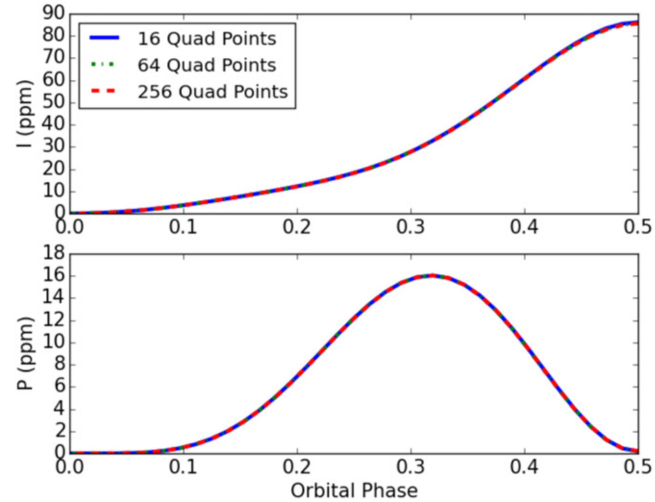

Figure 12. Model outputs for different number of quadrature points for a Rayleigh atmosphere with eight computational streams for RT. Results are insensitive to the number of quadrature points.

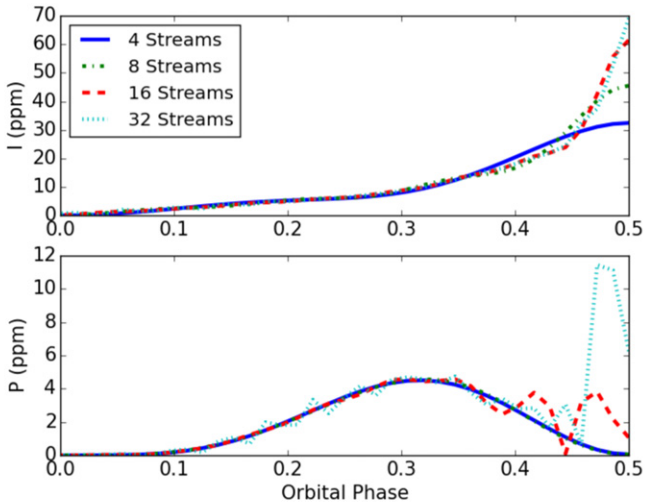

Figure 11. Model outputs for different number of computational streams in the radiative transfer (RT) model for a hazy scattering atmosphere using 64 quadrature points for disk integration. Sixteen streams at least are necessary to produce a rainbow. Hazy models in the paper are run with 32 streams and 256 quadrature points. The inhomogeneous planet uses 1024 quadrature points.

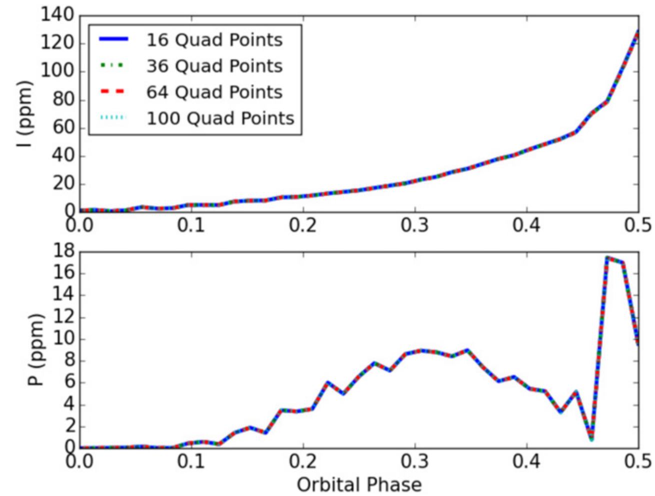

Figure 13. Model outputs for different number of quadrature points for a hazy atmosphere with 32 computational streams for RT. Results are sensitive to the number of quadrature points, but for the purposes of our discussion, the broad features are unchanged. Beyond 16 streams, the rainbow is always visible and the general shape of the curves remains the same in both I and P.

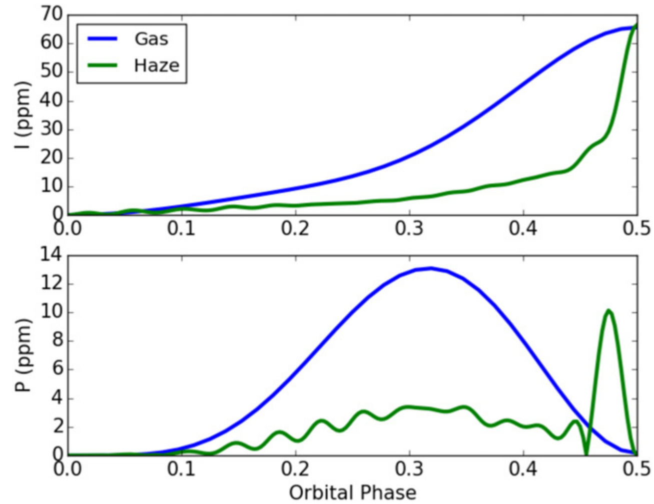

Figure 14. Model outputs for Rayleigh and hazy atmospheres with 32 streams and 256 quadrature points with a resolution of 1° in the orbital phase angle. The orbital phase from 0 to 0.5 is 180°, and a typical resolution for all runs in this paper is 5°. Note the smooth waviness of the hazy curve. We continue to use 5° since it does not miss any major features and has a significantly lower computational cost.

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References

Berdyugina, S., Berdyugin, A., Fluri, D., & Piirola, V. 2011, ApJL, 728, L6
Wiktorowicz, S. J. 2009, ApJ, 696, 1116