

Spectropolarimetry: a tool for characterisation of exoplanets

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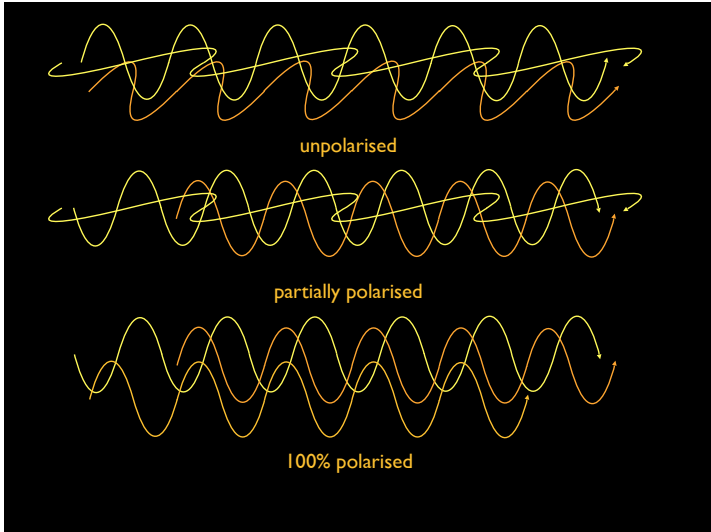
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Polarisation I

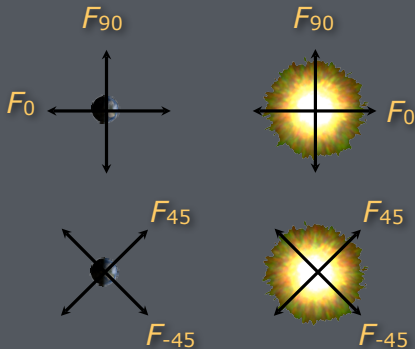


Polarisation II



Image credit: <http://www.tiffen.com/hi-res/Polarizer-Compare.jpg>

How to measure the polarisation



$$F = F_{90} + F_0$$

$$Q = F_{90} - F_0$$

$$F = F_{45} + F_{-45}$$

$$U = F_{45} - F_{-45}$$

Advantages of using polarimetry to characterise exoplanets

- The signal of an exoplanet is often lost in the glare of the parent star.
- Integrated over the stellar disk, light from solar-type stars is virtually unpolarised.
- Polarimetry can be used to distinguish between the signal from the star and planet, since light reflected by the planet will be polarised.
- The degree of polarisation of the reflected light appears to have a different sensitivity to the structure and composition of the atmosphere than the flux.
- Unlike the flux, the polarisation is independent of the planet's size, and the distance to the star and the observer.

Polarisation of the Venusian clouds

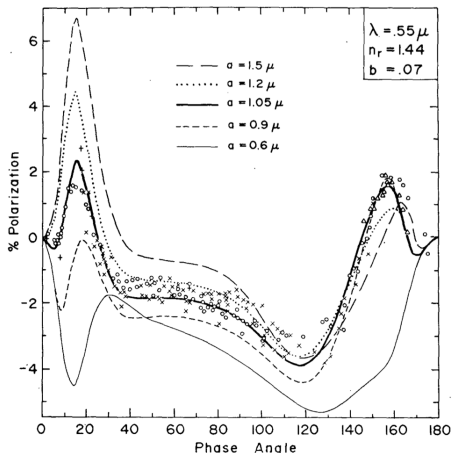


Image credit: Hansen, J. E., & Hovenier, J. W. 1974, J. Atmosph. Sci., 31, 1137

- Polarisation observations are more sensitive to cloud particle properties than intensity measurements.
- Different curves show models with different effective radii. The points on the graph represent observations ranging from 1929 till 1971.

Polarisation of Earth

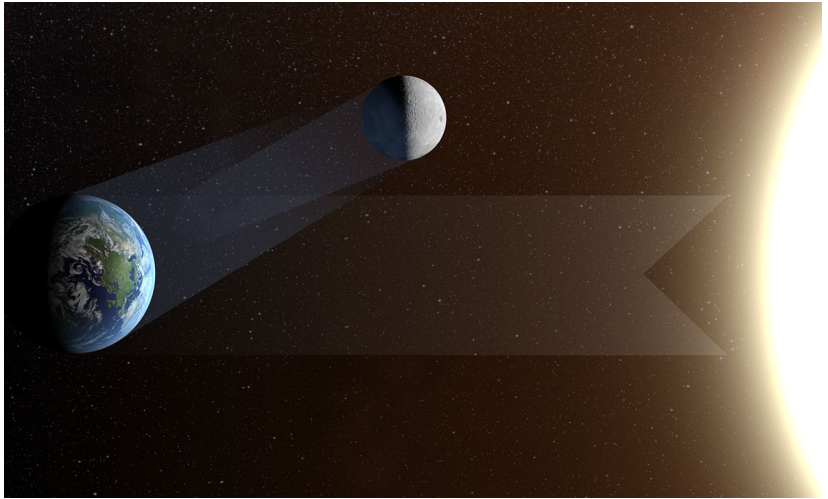
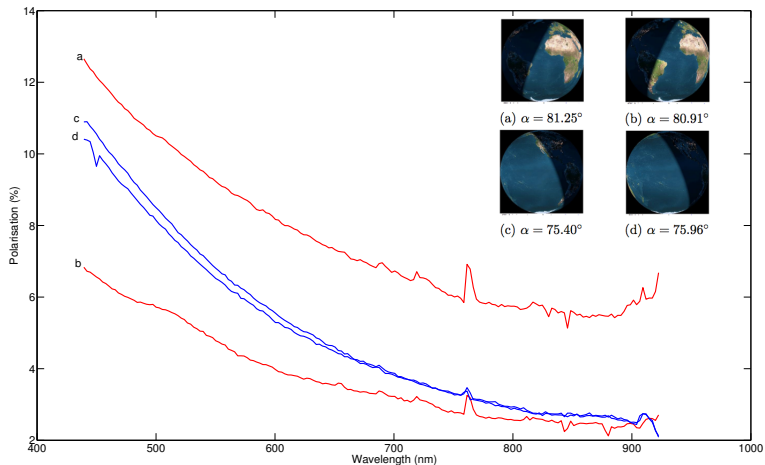


Image Credit: ESO

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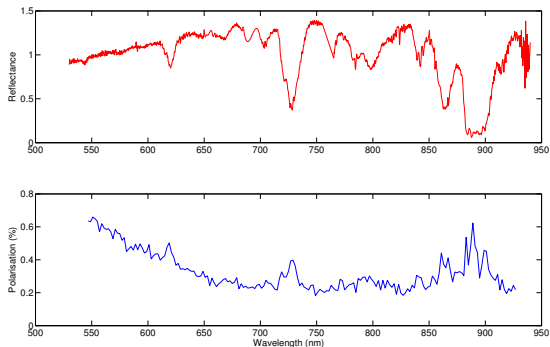
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Earthshine



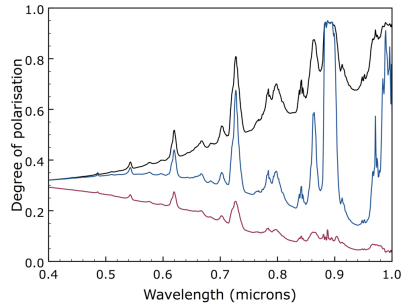
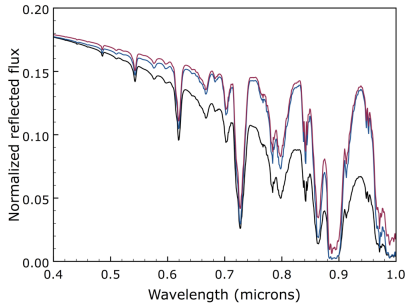
For a recent study of earthshine, see: *Sterzik M. F., Bagnulo S., Palle E., 2012, Nature, 483, 64*

Spectropolarimetry of Saturn



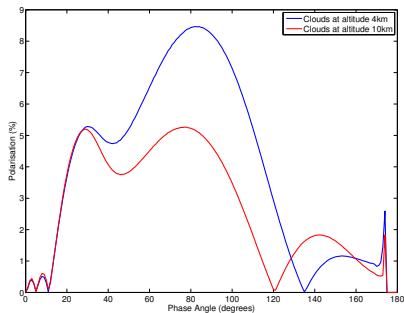
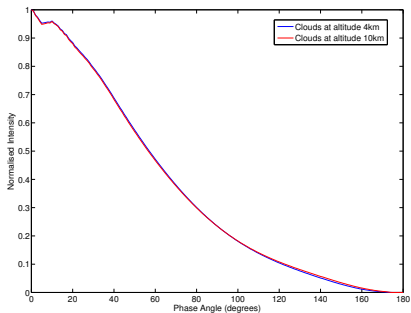
- The top figure shows the reflectance spectrum of Saturn, with strong absorption in several methane bands around 620nm, 728nm, and 890nm.
- The same features also manifest themselves in the polarisation spectrum, shown in the lower figure.

Modelling the polarisation of reflected light from Jupiter-like planets



Plots from *Stam, D. M., Hovenier, J. W., Waters, L. B. F. M. 2004, AA, 428, 663*

Modelling the polarisation of reflected light from ice and water clouds



Previous work involving polarisation of exoplanets

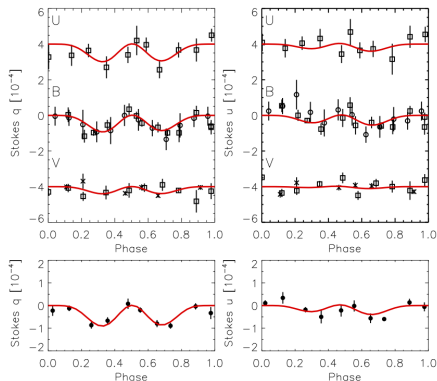


Figure 1. Stokes q and u with $\pm 1\sigma$ error bars for HD189733b. Upper panels: the new UBV measurements are shown by squares and the binned B -band data from B08 by open circles, and the W09 measurements by crosses. The U and V data are shifted in vertical by $\pm 4 \times 10^{-4}$ for clarity. Lower panels: all the U and B data from the years 2006–2008 binned together. The mean error of the binned data is 1.7×10^{-5} and the standard deviation is 1.1×10^{-5} . Curves are the best-fit solutions for the Rayleigh–Lambert atmosphere. The normalized χ^2 of the fit is 1.16.

- Berdyugina et al. (2008)^a claimed to have made the first detection of an exoplanet using polarimetry.
- Subsequent polarisation observations were made by Wiktorowicz (2009)^b, and these could not confirm the detection.
- A further study by Berdyugina et al. (2011)^c reported another detection of the same planet at shorter wavelengths, which is still awaiting confirmation from follow-up observations.

^a Berdyugina et al. 2008, ApJ, 673, L83

^b Wiktorowicz, S. J. 2009, ApJ, 696, 1116

^c Berdyugina et al. 2011, ApJ, 728, L6

SPHERE (Spectro-Polarimetric High-contrast Exoplanet REsearch)

- SPHERE's main goal is to find and characterise giant exoplanets orbiting nearby stars by direct imaging.
- One of its three instruments, ZIMPOL (The Zurich imaging polarimeter), will search for the signature of reflected light from exoplanets through polarimetric imaging.

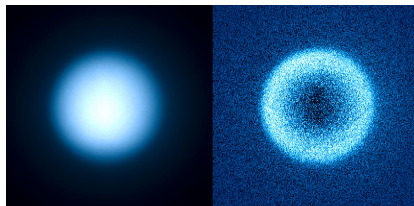


Image of Titan in the optical taken with SPHERE, the left-hand side is a standard intensity image, and the right-hand side shows the polarisation. The flux and polarisation clearly show different behaviours - the flux is similar to that of any spherical body with or without atmosphere, but the behaviour of P indicates that there are different particles high in the atmosphere (seen at the limb) than lower in the atmosphere (visible in the centre of the disk). Image Credit: ESO/J.-L. Beuzit et al./SPHERE Consortium

Summary and Conclusion

- Polarimetry is the study of the polarisation of light, either as a function of phase angle, or wavelength.
- It is a very promising method for the characterisation of exoplanets, due its ability to disentangle the polarised light reflected by planets from the overwhelming unpolarised stellar radiation.
- Polarisation is more sensitive to cloud particle properties than intensity measurements, and features often lost in intensity due to multiple scattering are preserved in the polarisation.
- Polarimetric observations of exoplanets have been difficult to obtain, but new instruments such as SPHERE at the VLT, and planned instrumentation at the future E-ELT should help this field to take off.