EPSC Abstracts
Vol. 11, EPSC2017-21, 2017
European Planetary Science Congress 2017

Stellar atmospheres behind transiting exoplanets

Dainis Dravins (1), Hans-Günter Ludwig (2), Erik Dahlén (1), Martin Gustavsson (1) and Hiva Pazira (1,3)

(1) Lund Observatory, Box 43, SE-22100 Lund, Sweden, dainis@astro.lu.se (2) Zentrum für Astronomie der Universität Heidelberg, Landessternwarte Königstuhl, DE–69117 Heidelberg, Germany (3) Present address: Department of Astronomy, AlbaNova University Center, SE–10691 Stockholm, Sweden

Abstract

Atmospheric studies of transiting exoplanets require stellar background spectra to be known along the transit path while detection of 'true' Earth analogs require stellar microvariability to be well understood. Hydrodynamic modeling of stellar atmospheres is feasible for various stars but such models and their ensuing spectra have been tested in detail only for the Sun with its resolved surface features. Using exoplanet transits, we extend such spatially resolved spectroscopy to also other stars. During a transit, successive stellar surface portions become hidden and differential spectroscopy between various transit phases provide spectra of small surface segments temporarily hidden behind the planet. Such retrievals of spatially resolved stellar spectra have now been achieved for the planet-hosting stars HD 209458 (G0 V) and HD 189733A (K1 V).

1. Exoplanets and stellar spectra

Detailed knowledge of stellar spectra is required not only to study stellar atmospheres per se, but also to identify subtle differences to them that are caused by exoplanets. Chemical signatures in exoplanet atmospheres may be identified from the difference between an observed spectrum with an exoplanet in transit and the background stellar spectrum. This background spectrum, however, is not that of the stellar flux integrated over the full stellar disk, but that from the projected position on the stellar disk behind the planet. Thus, there is a need to know the varying stellar signal along the exoplanet transit path.

A major challenge is to find 'truly' Earth-like planets, with sizes and orbits comparable to those of the Earth, around stars similar to the Sun [1]. However, the diminutive signals induced by such a planet in stellar radial velocity or in photometric transit amplitudes are very much smaller than stellar intrinsic variability, demanding a detailed understanding of the latter. Some calibration might be possible by correlating fluctuations in stellar irradiance with simultaneous changes in radial velocity. This could become feasible from hydrodynamic models, but their validity must of course be verified.

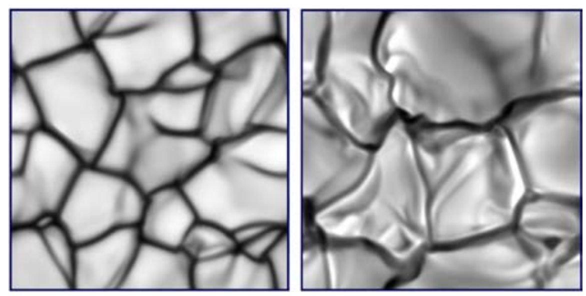

Fig. 1. Hydrodynamic models of different stellar atmospheres [2] predict intensity patterns on the surfaces of white dwarfs (left) and red giants.

2. Exoplanet transit spectroscopy

Spatially resolved stellar spectra can be obtained by using exoplanets as probes, scanning across the stellar surface. During a transit, an exoplanet covers successive segments of the stellar disk and differential spectroscopy between each transit phase and that outside transit, can provide spectra of each particular surface segment that was temporarily hidden.

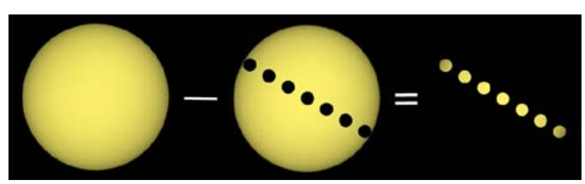

Fig. 2. The differences between stellar flux recorded outside, and during exoplanet transit, yield signatures from the temporarily hidden stellar surface segments.

Even giant planets cover no more than ~1% of any solar-type star, enabling high spatial resolution but demanding very precise observations. Simulations of spectral signatures indicate that ratios between line profiles during various transit phases may change by ~0.5 %, requiring very high signal-to-noise ratios of ~5,000 or more to enable spectral reconstructions [3].

Such S/N ratios are not yet realistic for individual spectral lines, but can be achieved for cool stars by averaging over numerous lines with similar parameters. From observations of HD 209458 with the ESO VLT UVES spectrometer at a spectral resolution $\lambda/\Delta\lambda \approx 80{,}000$, photospheric Fe I line profiles have thus been retrieved at several center-to-limb positions [4]. For HD 189733A (K1 V), analogous results were obtained using data from the ESO HARPS spectrometer.

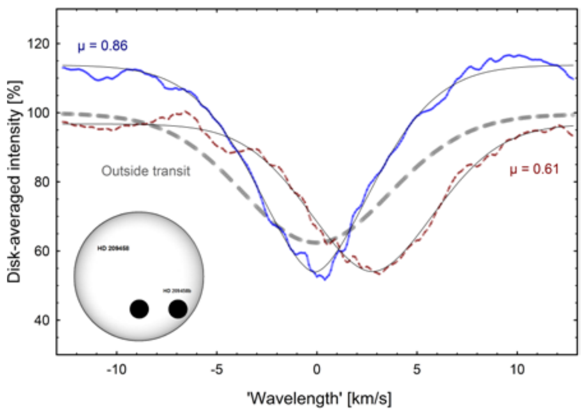

Fig. 3. Reconstructed Fe I line profiles on HD 209458. Spatially resolved lines are not subject to rotational broadening and are substantially deeper than in the disk-averaged spectrum outside transit (dashed gray). During transit, the profiles shift towards longer wavelengths, illustrating both stellar rotation at the latitude of transit and the prograde orbital motion of the exoplanet. The solid blue curve is from exposures near stellar disk center, dashed dark-red curve is from closer to the stellar limb. Due to limb darkening, the local intensity close to disk center is higher, and that further away lower than the average. The planet size and disk positions are to scale.

Retrieved line profiles are compared to synthetic ones. Hydrodynamic 3-D models predict, and current observations confirm, that photospheric absorption lines become broader and shallower towards the stellar limb, reflecting that horizontal velocities in stellar granulation are greater than vertical ones. Additional types of hydrodynamic 3-D signatures will become observable with high-resolution spectrometers at large telescopes.

3. Summary and Conclusions

For bright host stars with large transiting planets, spatially resolved spectroscopy is practical already now. Although still perhaps somewhat noisy, this – as far as we are aware – does represent the first case of high-resolution spectra obtained from precisely picked-out small areas across stellar surfaces.

This method is likely to become much more applicable already in the near future since additional observable targets are likely to be found. Numerous surveys, both from the ground and from space, are monitoring brighter stars for possible exoplanet transits. This is of high priority for exoplanet studies since their observability strongly depends on the host star brightness. Given the known statistics of exoplanet occurrence, it is highly likely that suitable transiting planets will soon be found around also brighter hosts. Observational data for stellar studies will then be obtained concurrently with those for the exoplanets themselves.

Acknowledgements

This study used data from the ESO Science Archive Facility. HGL acknowledges support by the Sonder-forschungsbereich SFB881 'The Milky Way System' (subproject A4) of the German Research Foundation (DFG). DD acknowledges stimulating stays as a Scientific Visitor at the European Southern Observatory in Santiago de Chile.

References

[1] Fischer, D. A., Anglada-Escude, G., Arriagada, P., et al. 2016, Publ. Astron. Soc. Pacific **128**, 066001

[2] Freytag, B., Steffen, M., Ludwig, H.-G., et al. 2012, J. Comp. Phys., **231**, 919

[3] Dravins, D., Ludwig, H.-G., Dahlén, E., & Pazira, H. 2017a, Astron. Astrophys., submitted.

[4] Dravins, D., Ludwig, H.-G., Dahlén, E., & Pazira, H. 2017b, Astron. Astrophys., submitted