A planet of an A-star: HD15082b

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Abstract. Most of the known transiting extrasolar planets orbit slowly rotating F, G or K stars. In here we report on the detection of a transiting planet orbiting the bright, rapidly rotating A5 star HD15082 (WASP-33b, V=8.3, m sin i = 86 km s⁻¹), recently made by SuperWASP. Time resolved spectroscopic observations taken during transit show a hump caused by the planet crossing the line profile. From the analysis of the spectra, we derive the radius of the planet and find that it is orbiting retrograde in respect to the spin of the star. Because of its small distance from an A5 star (the orbital period of only 1.22 days), the equilibrium temperature of the planet is estimated to be 2700 K. The planet thus is one of the hottest planets known, which makes it relatively easy to detect it in the IR. We thus tried to detect it using the TNG but did not succeed.

Keywords: Luminosities; magnitudes; effective temperatures, colors, and spectral classification; Main-sequence: intermediate-type stars (A and F); Extrasolar planetary systems Photometric and spectroscopic detection; coronographic detection; interferometric detection
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THE IMPORTANCE OF STUDYING CLOSE-IN PLANETS OF A-STARS

Studies of transiting extrasolar planets are of key importance for understanding the nature of planets outside our Solar System, because they allow to derive their mass, diameter and their density. The more than 100 transiting planets discovered up to now thus give us a wealth of information about the structure and evolution of extrasolar planets. However, almost all of them are orbiting slowly rotating F, G or K stars. Our knowledge about the planets of earlier type stars thus is very limited.

It would however be very interesting to study planets of early type stars, particularly transiting ones. According to theory, the frequency of massive planets depends on the mass of the star. The frequency is expected to be higher for stars of higher mass than for stars of lower mass. Observations of planets of giant stars seem to confirm this result (Johnson et al. 2010; Kennedy & Kenyon 2008). However, it is not easy to determine the mass of a giant star, let alone to estimate which mass it had when it was still on the main sequence. It would thus be important to confirm this results by detecting planets of stars more massive than the sun but which are still on the main sequence.

By comparing the properties of close-planets of A-stars with those of late-type stars, we can learn a lot about the interaction between stars and planets. Close-in planets of G and K-type stars often have radii that are too large for their mass. Such objects
are usually called “inflated” planets. It is generally believed that this kind of inflation is caused by the interaction between stars and planets. The discovery of CoRoT-9b supports this idea, since this planet is not inflated, because it always has a relatively large distance from its host star (Deeg et al. 2010).

Close-in planets are heated by tidal interaction and the radiation from their host stars. It has however, been shown that even if we take these effects into account, it is still difficult to explain the large sizes of the planets that are observed (Baraffe et al. 2003; Guillot et al. 2010). One possibility would be the presence of an additional planet in an eccentric orbit. Such a planet would cause an eccentric orbit of the inner planet, which would in turn lead to an increased amount of tidal heating. While this mechanism is very attractive, it is unlikely that it works in all cases.

In order to better understand the interaction between stars and planets, it would be ideal if we could simply exchange the central stars with stars of different types, keeping all other parameters constant. Since this is impractical, we observe systems containing stars of different types instead. Since A-type stars are much hotter than G-type stars, their planets will receive correspondingly more photons in the visual regime. Whether this is also the case in the EUV and the X-rays is not obvious. The amount of radiation which the planet receives in this wavelength regime is important, because the evaporation of the atmosphere of a planet depends on the amount of radiation it receives shortward of the Ly-\(\alpha\) line. In the classical view, A-stars do not have an outer convection zones and thus do not have chromospheres, or a coronae. Although there is now growing evidence that this classical view is not strictly true, the chromospheres and coronae of A-stars are certainly not like those of later type stars (Simon & Landsman 1997a; Simon et al. 2002; Hempel et al. 2005; Schröder & Schmitt 2007). The stellar wind of an A-star is also different from that of G-type star. It has been suggested that A-stars have only a radiatively driven winds (Babel 1995). Thus, if the unknown heating mechanism of close-in planets is related to either the coronae, the stellar winds, or the magnetic fields of the host stars, the amount of inflation would be different for planets of an A- and G-stars.

In order to better understand the interaction between close-in planets and their host stars, it is thus important to study close-in planets of A-stars. In here we report on the detection of a transiting planet orbiting the bright, rapidly rotating A5 star HD15082 (WASP-33).

The discovery of HD15082b was presented by Cameron et al. (2010). Because the detection and the properties of the planet were already described in detail in this article, we will just briefly summarize the results in here.

## A UNIQUE STAR/PLANET SYSTEM

The light curve of HD15082b (WASP-33b) obtained by SuperWASP shows a flat-bottomed, planet-like transits recurring every 1.22 d (Christian et al. 2006; Pollacco et al. 2006). Further photometric monitoring with the 0.95-m James Gregory Telescope (JGT) at the St. Andrews University Observatory, the 60-cm telescope of the University of Keele, and 35-cm Schmidt-Cassegrain telescope at the University of London Observatory at Mill Hill confirmed the transit, and allowed to refine the transit-depth and the
transit duration to a higher accuracy.

Because we could not confirm the planet by radial-velocity measurements, we used time resolved spectroscopic observations taken during transit instead. A transiting planet causes a bump that crosses the line-profile during the transit. This bump distorts the line-profile which results in a change of radial-velocity. This change of radial-velocity during transit can even be measured for slowly rotating stars (Rossiter-McLaughlin effect). If such a signature is present and matches the transit geometry deduced from photometry, the presence of a planet is confirmed. Jenkins et al. (2010) have also noted recently that the Rossiter-McLaughlin effect provides a powerful method for distinguishing planets from blends in cases where classical methods of confirmation cannot be used. For rapidly rotating stars, the bump can be seen in the line-profiles directly. We obtained three time-series of spectra during transit with echelle spectrographs. One series was taken with the 2-m-Alfred Jensch telescope at Tautenburg observatory, another one with the 2.7-m Harlan J. Smith Telescope at McDonald Observatory, and a third one with the Nordic-Optical-Telescope (NOT) at the Observatorio del Roque de los Muchachos. We used LSD in order to compute an average line-profile and modeled it with a transiting planet. By modeling the photometric light-curve, and the spectroscopic times-series, we determined the orbital parameters and the radius of the planet to a high accuracy. From the analysis of the spectra, we find that the planet is orbiting retrograde in respect to the spin of the star.

We obtained 29 radial-velocity measurements with the Alfred Jensch telescope in order to measure the mass of the planet. Although an iodine cell was used for the observations, the huge $v \sin i$ of the star of 90 $kms^{-1}$ limited the accuracy of our measurements.

**FIGURE 1.** Mass and density of the planets detected by SuperWASP. HD15082b (WASP-33b) is marked as a circle.
to about 700 $m s^{-1}$. Unfortunately, we could only derive an upper limit for the mass of the planet of 4.1 $M_{Jup}$. Combined with the radius of 1.497 ± 0.045 $R_{Jup}$, this gives us an upper limit for the density of 1.2 $g cm^{-3}$. The planet thus may well belong to the class of low-density planets, which would mean that the evaporation rate could be high. Figure 1 shows the masses and radii for the planets discovered by SuperWASP including HD15082b (marked as a circle).

It thus turns out that the planet has unique properties (Table 1). The orbital separation is only 0.02555 ± 0.00017 AU, or 3.83 ± 0.09 $R_{star}$. Since the star has a temperature of 7430 ± 100 K, this planet receives about five times as much radiation in the visual band than a planet orbiting a solar-like star at the same distance. Simon & Landsman (1997b) studied the emission of many A to F stars at 1900 Å, and find that the relative flux of A-stars is on average higher than that of late type stars. However, the flux at 1900 Å has scatter of ±0.4 mag for stars of the same spectral type. It is thus not easy to estimate how much brighter the HD15082 is at 1900 Å than a solar-like star. It is possible that it is more than 100 times brighter than a G-type star but we can not be certain about that. Even more difficult is it to estimate the flux short-ward of Ly-α ($\lambda = 121.5668 nm$) which is the essential parameter in order to estimate the mass-loss of the planet.

**SPECTROSCOPIC OBSERVATIONS OF THE SECONDARY TRANSIT**

Because the planet is so close to a hot A-type star, at least the side facing the star must be very hot. A simple model leads to a temperature of about 2800 K but the real temperature

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### TABLE 1. Properties of HD15082 and HD15082b

| Parameter          | Value                                              |
|--------------------|----------------------------------------------------|
| Stellar mass       | 1.495 ± 0.031 $M_s/M_\odot$                       |
| Stellar radius     | 1.444 ± 0.034 $R_s/R_\odot$                       |
| Spectral Type      | kA5hA8mF4                                         |
| Distance           | 116 ± 16 pc                                        |
| Teff               | 7430 ± 100 K                                       |
| log g              | 4.3 ± 0.2                                          |
| $v\sin i$          | 90 ± 10 $km s^{-1}$                                |
| [M/H]              | 0.1 ± 0.2                                          |
| $M_B$              | 3.1 ± 0.3                                          |
| $M_V$              | 3.0 ± 0.3                                          |
| $M_J$              | 2.2 ± 0.3                                          |
| $M_H$              | 2.2 ± 0.3                                          |
| $M_K$              | 2.1 ± 0.3                                          |
| Epoch of mid-transit, Tc | 2454163.22373 ± 0.00026 HJD                        |
| Orbital period     | 1.2198669 ± 0.0000012 d                            |
| Orbital separation, a | 0.02555 ± 0.00017 AU                      |
| Projected obliquity, $\lambda$ | 252 ± 2°                      |
| Planet mass        | < 4.1 $M_p/M_{Jup}$                                |
| Planet radius      | 1.497 ± 0.045 $R_p/R_{Jup}$                        |
could even be higher. This is very likely, since the true temperature of HD149026b is also much higher than the calculated temperature using the same simple model (Harrington et al. 2007). If the temperature of HD15082b is 2800 K, it should be possible to detect it.

During the secondary transit of an extrasolar planet, the star occults the planet. Shortly before that moment, the planet is observed at its maximum brightness. Thus, by observing the planet before, during and after the secondary transit, it is possible to determine the amount of radiation coming from the planet alone. Such secondary eclipses have been observed most notably from space (e.g. Charbonneau et al. 2005; Deming et al. 2006; 2007) but have also been detected from the ground (de Mooij & Snellen 2009; Sing & López-Morales 2009).

The other property that makes this object very special is that the host star is unusually bright ($J=7.58, H=7.52, K=7.47$ mag). This opens up the possibility to observe directly the thermal emission of this very hot Jupiter.

Up to now, the temperatures of the planets that have been studied are typically about 1000 K (GJ436b: $712 \pm 36$ K, Deming et al. 2007; TrES-1: $1060 \pm 50$ K, Charbonneau et al. 2005; HD189733b: $1117 \pm 42$ K, Deming et al. 2006; HD209458b: $1130 \pm 150$ K, Deming et al. 2005; HD189733: $973 \pm 33$ K, Knutson et al. 2007). Up to now, there are only two planets for which the evaporation exosphere has been detected: HD209458b, and HD189733b. Observation of the Ly-α line of HD209458b with the HST allowed to estimate the evaporation rate to be of the order of $10^{10}$ g s$^{-1}$ (Lecavelier des Etangs 2009).

In order to learn more about the properties, the evolution and particularly the the evaporation of close-in extrasolar planets it is best to study the most extreme cases. How hot are these planets, and how long can they survive the intensive heat of their host stars? Is it possible that hot Neptunes are the cores of evaporated Jupiters? Observations of HD15082b could answer these questions.

Using 2800 K for the temperature for the planet and $1.5 \pm 0.05 R_{\text{jup}}$ for its radius, we find that the planet has to be brighter than about $m_J = 15.11$, $m_H = 14.8$, $m_K = 14.4$, or $\approx 7$ mag fainter than the star. The problem thus is not the brightness of the planet itself but the brightness difference between the star and the planet. Figure 2 shows the estimated brightness difference between planet and star. For example, in the J-band the planet-to-star flux ratio is about 0.001, corresponding to 1 mmag. Figure 2 shows the expected brightness ratio between the star and the planet. We expect a that the flux of the planet is $\geq 0.1\%$ to $\geq 0.2\%$ in the NIR.

Using the Teleesporio Nationale Galileo (TNG) at the Observatorio del Roque de los Muchachos and its NICS spectrograph have have obtained spectra in and out of transit. We used the IJ-grism which covers the wavelength range from 0.9 to 1.45 $\mu$m. With a slit-width of 1 arcsec, NICS achieves a resolution of $\lambda/\Delta\lambda = 500$. In order to minimize the flux-losses, we opened the slit as far as possible, which is 2 arcsec. The object was observed in-transit for about half an hour and out-of transit for one hour. Unfortunately, the night was partly cloudy which limited the time for which we could observe the object.

The spectra are shown in Figure 3. Unfortunately, due to clouds, we can only derive an upper limit of 1.2% for the relative flux of the planet. This is clearly insufficient for the detection of the planet. The upper limit for the temperature that we can derive is
FIGURE 2. Expected brightness-ratio between the star and the planet.

FIGURE 3. Spectrum of HD15082b (WASP-33b) taken in and out of the secondary transit. The secondary transit of the planet is not detected.

roughly 5500 K. Spectra of higher signal-to-noise ratio or photometric data of sufficient quality are needed in order to detect the secondary eclipse of the planet.
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