Two New Very Hot Jupiters in the FLAMES Spotlight

Radial velocity follow-up of 41 OGLE planetary transit candidates carried out with the multi-object spectrograph FLAMES on the 8.2-m VLT Kueyen telescope has revealed the existence of Jupiter-mass companions around two transit candidates. They are extremely close to their host stars, orbiting them in less than 2 days.

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For centuries, the brightness variations of the star Algol inspired the superstitions and fears of ancient cultures. The Ancient Arabs referred to Algol as the Al-Ghul, which means "The Ghoul" or "Demon Star", and Ri'B al Ohill, the "Demon's Head" while for the Greeks its behaviour was attributed to a pulsing eye of the Gorgon Medusa. John Goodricke in 1782 was the first to explain correctly the Algol variability by assuming the existence of a darker companion which eclipses the brighter star of a binary system. The binary nature of Algol was confirmed in 1889 by Hermann Carl Vogel who found periodic Doppler shifts in the spectrum of Algol A (spectral class B8V), and the overlaying spectrum of the companion, Algol B, of type Am. In March of this year, photometry and spectroscopy working in tandem again led to the discovery of two new giant planets belonging to the (still rare) family of the very hot Jupiters.

Since the pioneering discovery of 51Peg B by Mayor and Queloz in 1995, more than 120 extra-solar planets have been discovered so far. Almost all of them have in common the fact that their presence was revealed by radial velocity surveys, which consist in the monitoring of the periodic wobble of the spectral lines of the host star caused by the gravitational influence of its planet. Nonetheless, similar to the anecdotal example of Algol, planets can also reveal their existence by the imprints left in the light curve of their host stars. In order for a planetary transit to happen, the angle between the plane where the planet lies and the imaginary line joining our telescope to the host star should be close to zero. The probability of such alignment is roughly proportional to the ratio of the radius of the host star to the size of the orbit of the planet. This probability lies at 0.5% for planets orbiting at 1AU and rises up to 10% for those orbiting at 0.05AU. Looking at orbital properties of the extra-solar planets known to date around solar-like stars, we see that only 0.7% of them orbit at distances smaller than 0.05AU (which corresponds to an orbital period less than 4 days). If we further assume that 50% of stars are binaries for which planets are not expected to exist, we end up with the conclusion that in a sample of 3000 stars we should find only one planetary transit! Adding the fact that astronomical nights have a finite length (i.e, we only observe at night!) and that not all nights are clear nights, we can certainly consider the figures presented above as optimistic. Thus in reality, the probability of observing a transit is much smaller than 1/3000. Another important issue is the accuracy of the photometric measurement. Given the relative size of the planetary disc as compared to the stellar one, the observations of planetary transits are somewhat challenging and require a photometric precision of the order of a few millimagnitudes. The bottom line is simple: in order to find planets through photometric transits we need to be able to observe with high accuracy, for a long time, a huge number of stars.

This is exactly what the OGLE (Optical Gravitational Lensing Experiment) team has accomplished. Started more than one decade ago, the OGLE program was originally designed to detect microlensing events via photometric monitoring of a huge number of stars (of the order of millions of stars) in the Galactic bulge and Magellanic Clouds. OGLE not only found hundreds of microlensing events but also contributed to many other fields. In particular the second phase of the OGLE survey (Udalski et al. 2002) detected 62 short-period multi-transiting objects located in the direction of the constellation of Carina for which planets could be the root cause.

FLAMES: the relevance of the ThAr technique in a 8-m class telescope

Although the shape of the light dip in the light curve can already give suspicions concerning the nature of the transiting object, its final characterization demands however spectroscopic measurements from which radial velocities will be derived, such as is done in the ongoing radial velocity surveys aimed to look for extra-solar planets. The amplitude of the radial velocity variations observed in the host star depends essentially on the mass of the planet and the size of its orbit around the host star. Typically for Hot Jupiters like 51Peg, these variations are around a hundred meters per second. These require the ability to monitor the shifts of the stellar spectra with an accuracy of about 10 m/s, i.e., to put it in terms of pixels, we need to be able to detect displacements of a spectrum on a CCD at a level of a hundredth of a pixel. Due to variations in the refractive index of air related to changes in atmospheric pressure and temperature, shifts of even a few hundred m/s per night might occur. To put it simply, all objects observed on a given night will show amplitudes at a hundred m/s level due only to the changes in the ambient conditions. Other systematic effects have to be added to this radial velocity error such as mechanical flexures, centring errors, etc.

Many of these problems were solved using fibre fed spectrographs, where one fibre is fed with the light from the object and a second fibre, called the simultaneous calibration fibre, receives light from a ThAr lamp. Comparing the ThAr emission line spectrum taken in parallel with the scientific observation with the one done in the beginning of the night, we can measure how much the spectrograph has shifted at a given time. This shift is then used to correct the shift of the fibre illuminated by the stellar light. This technique has been shown to be extremely successful in obtaining highly accurate radial velocities. The high-resolution spectrograph HARPS recently installed at the 3.6-m telescope at La Silla/ESO is state-of-the-art in the use of the simultaneous calibration technique. It can measure radial velocities to a precision of 1m/s!

The arrival of FLAMES (Fibre Large Array Multi-Element Spectrograph) to Kueyen in 2003 opened the doors of the VLT to the world of accurate radial velocities. Using the UVES-fibre link, FLAMES allows for the simultaneous observations of seven objects whose spectra are recorded in the red-arm CCD mosaic of UVES along with the emission line spectrum of the ThAr which is fed into an eighth fibre. The radial velocity accuracy is around 30–50 m/s. Work is in progress to bring these figures down to a 10–20 m/s level which requires a refinement in the reduction software to deal with this particular mode and a better characterization of the other possible sources of systematics effects (again at a level of a hundredth of a pixel).

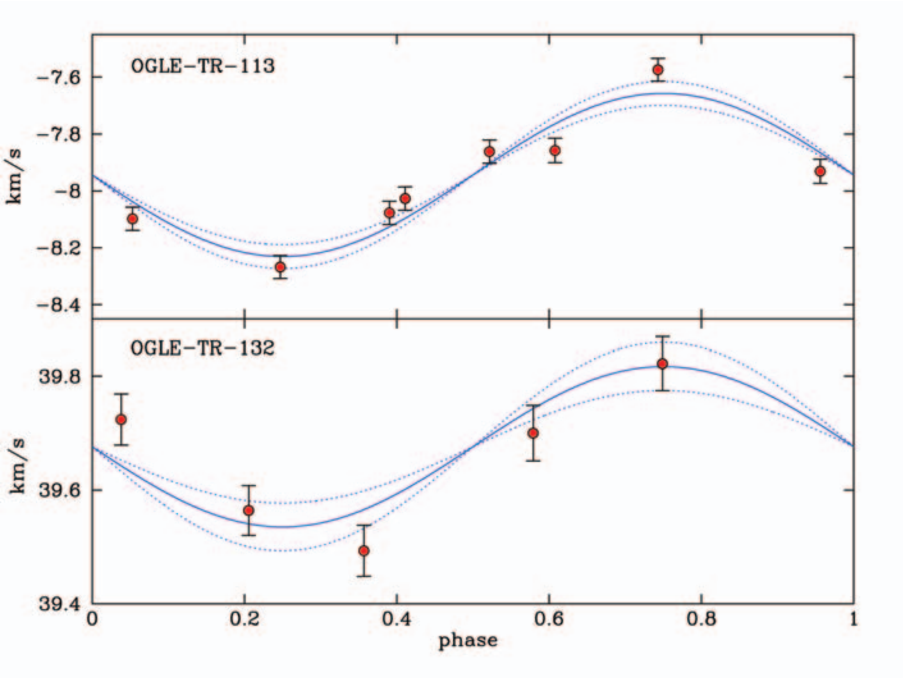

Figure 1. Phase-folded radial velocity measurements of OGLE-TR-113 and OGLE-TR-132 with the respective orbital solution (solid line). The dotted lines correspond to fit curves for lower and upper 1-sigma intervals in the semi-amplitude K of the radial velocity curve which is directly related to mass of the planet; the larger the semi-amplitude K, the more massive the planet is.

Very Hot Jupiters

The association of the collecting power of a 8-m class telescope with the simultaneous calibration technique makes FLAMES a superb instrument to look for extra-solar planets around faint stars such as the transit candidates found by OGLE, which have visual magnitudes around 16.

Thus, during eight consecutive half-nights in March 2004, Kueyen pointed towards the constellation Carina and the UVES red-arm CCD mosaic gradually received the light of the 41 OGLE top transit candidates. The data were reduced and analysed during the second half of each night. Objects showing large radial velocity variations (to a km/s level) as expected for the case of spectroscopic binaries, or showing large rotation as a sign of orbital synchronization resulting from tidal effects, were excluded. A few days later, when all velocity points collected during the 8 half-nights were analysed together, two new planets emerged from the data – one around OGLE-TR-113 and another around OGLE-TR-132! The phase-folded radial velocities of OGLE-TR-113 and OGLE-TR-132 are shown in Figure 1.

Orbital parameters of the systems and their physical parameters such as radii and masses for the host star and its planet can be

Table 1. Properties of the four known transiting extrasolar planets. Jupiter and Saturn are listed for comparison.

Name	Period (d)	Radius (R_J)	Mass (M_J)
OGLE-TR-56	1.21	1.23 ± 0.16	1.45 ± 0.23
OGLE-TR-113	1.43	$1.08^{-0.05}_{+0.07}$	1.35 ± 0.22
OGLE-TR-132	1.69	$1.15^{-0.13}_{+0.8}$	1.01 ± 0.31
HD209458	3.52	1.35 ± 0.02	0.69 ± 0.06
Jupiter	4332	1	1
Saturn	10756	0.84	0.3

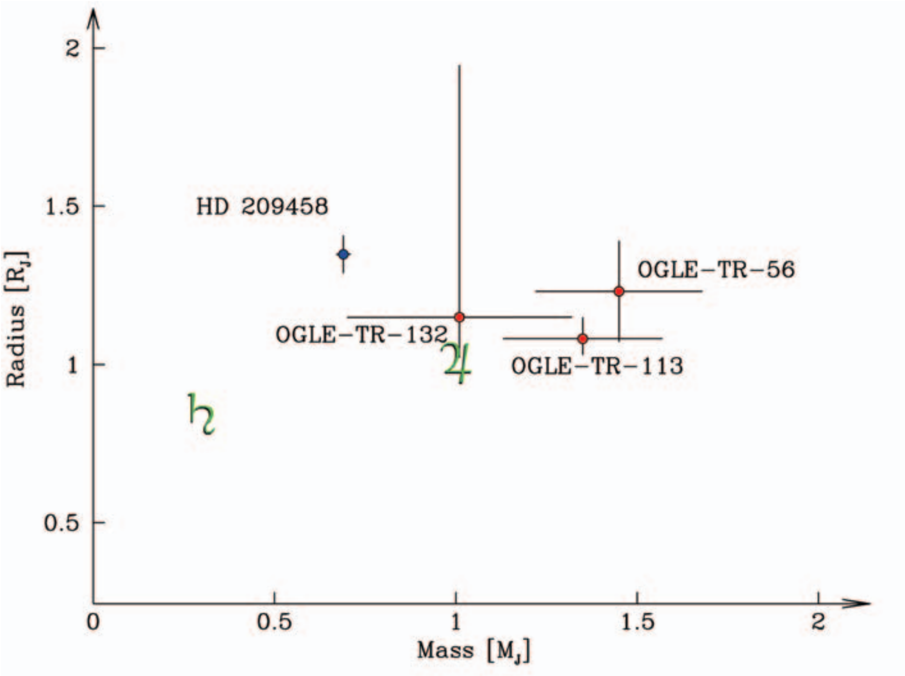

Figure 2. The four known transiting extrasolar planets plotted in the Mass-Radius diagram. The red solid points represent the three planets found by the OGLE survey. HD209458 (Charbonneau et al. 2000) is shown as a blue point. Jupiter and Saturn are indicated for sake of comparison.

derived when the spectroscopic, kinematic and photometric information are analysed together. The stellar spectrum yields the spectroscopic characteristics of the host star such as gravity, effective temperature and metallicity which are needed as input parameters for the combined analysis of the radial velocity curve and light curve which, in turn, contain information about the masses of star-planet system and geometry of the system (i.e., size of the transiting body and orbital inclination, for instance). Orbital periods, radii and masses derived by Bouchy et al. (2004) for OGLE-TR-113 and OGLE-TR-132 are summarized in Table 1. Also indicated in Table 1 are the characteristics of the other two transiting extrasolar planets known to date plus our own giant planets (Jupiter and Saturn). For OGLE-TR-113, the parent star is of the K-type (cooler and less massive than the Sun) and is located at a distance of about 1200 light-years. The orbiting planet is about 35% heavier and its diameter is 10% larger than that of Jupiter. It orbits the star once every 1.43 days at a distance of only 3.4 million km (0.0228 AU). By comparison, in our own solar system, Mercury is 17 times farther away from the Sun. The surface temperature of that planet, which like Jupiter is a gaseous giant, is correspondingly higher, probably above 1800 °C. The OGLE-TR-132 system is about 6000 light-years far from the Sun. This planet is about as heavy as Jupiter and about 15% larger. It orbits an F-dwarf star (slightly hotter and more massive than the Sun) once every 1.69 days at a distance of 4.6 million km (0.0306 AU). The photometric transit observed by OGLE is close to the detectability limit. As a consequence, the derived physical parameters are not as well constrained as for OGLE-TR-132. New photometric observations carried out with FORS2 are on the way to help to better constrain its light curve. In Figure 2 we compare the radii and masses of all four transiting giant planets found so far with Jupiter and Saturn. In spite of their very short orbital periods, they are quite similar to our own Jupiter.

The discovery of OGLE-TR-113 and OGLE-TR-132 shows that in spite of being quite rare, the case of OGLE-TR-56 (Konacki et al. 2003) is not an isolated and bizarre event of Nature. The distribution of orbital periods of the extra-solar planets discovered so far suggests that planets around the Jupiter mass pile up at an orbital period around three days (Udry et al. 2003). The three very hot Jupiters recently found provide evidence that in fact the three days of orbital period does not represent an absolute limit for the existence of giant planets. In addition, the fact that the spectral types of the host stars span from F to K also suggest that very hot Jupiters are possible around different types of stars.

The Future: space missions

The complementarity of the transit and radial velocity techniques now opens the door towards a detailed study of the true characteristics of exoplanets. Space-based searches for planetary transits – like the COROT and KEPLER missions, scheduled to fly in the coming years, will yield hundreds of transit candidates. With instruments like HARPS and FLAMES, the European extra-solar planet community (or the *planet hunters* as the media like to call us) is in an excellent position to take the lead in the ground-based radial velocity follow-up, which will in the future lead to the characterization of other worlds. Hopefully the fruitful tandem started in the 18th century will keep unmasking many other ghouls throughout the sky for years to come!

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