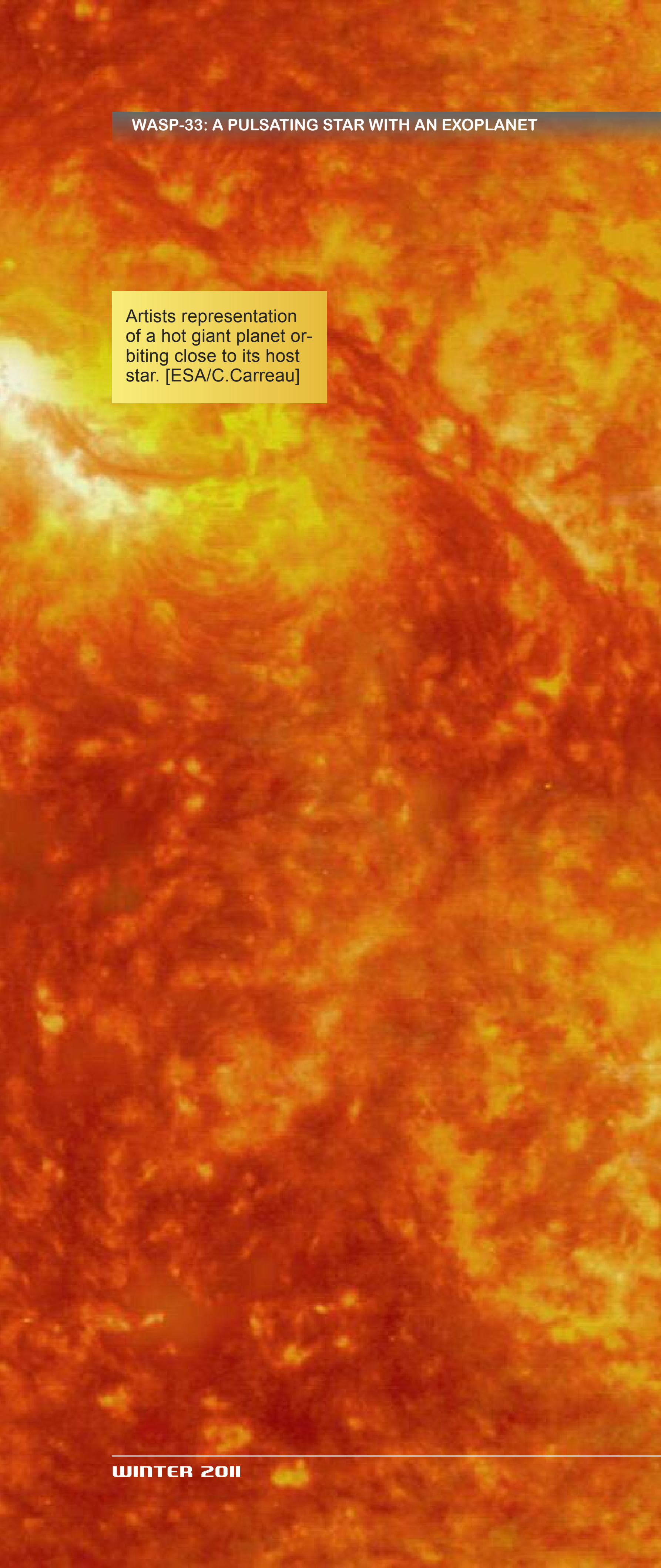
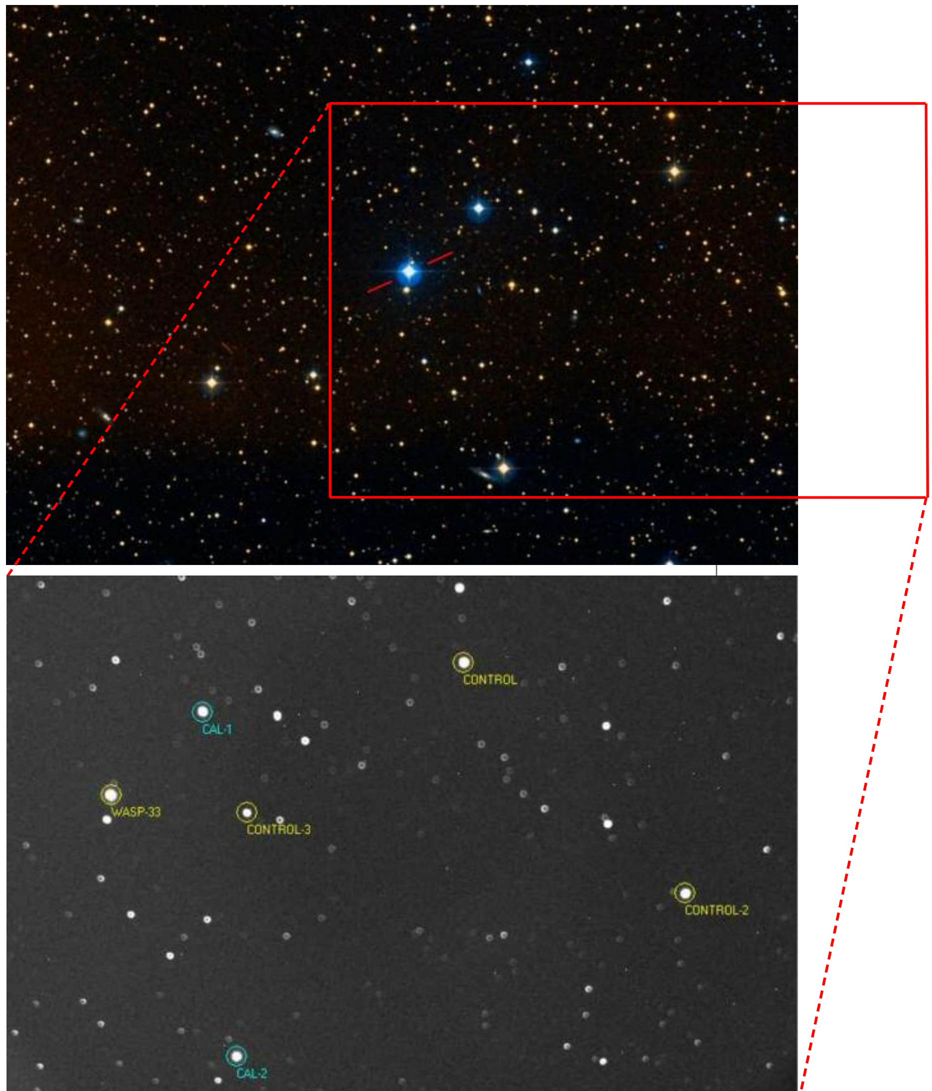
WASP-33: a pulsating star with an exoplanet



Artists representation of a hot giant planet orbiting close to its host star. [ESA/C.Carreau]

Since the discovery of the first extrasolar planet in 1995, the great advances in instrumentation and techniques have continuously increased the number of known planets and have given us the possibility to study their properties. Ultimately, we are looking for habitable planets similar to our Earth, but some exotic systems, such as WASP-33, are still revealing new mysteries and giving us some clues about how planets interact with their host stars.

At the end of February 2011, the list of known exoplanets contained 529 objects. Many of them are Hot Jupiters: giant planets that orbit very close to their host stars. Thus, they are totally inhospitable to life as we know it, due to the very high temperatures on their surface. Nowadays, most of the scientific projects and space missions related to exoplanet research focus on two main perspectives: the search for habitable exoplanets and the characterization of the atmospheres of known exoplanets.
On the other hand, exoplanet research, especially that related to the transit method (see page 108) has many links with one of the branches of stellar astrophysics that is currently in full swing: asteroseismology. Asteroseismologists work on the study of the internal structure of pulsating stars by interpreting the frequency spectra of their surface oscillations. For example, δ-Scuti variable stars usually show both radial and



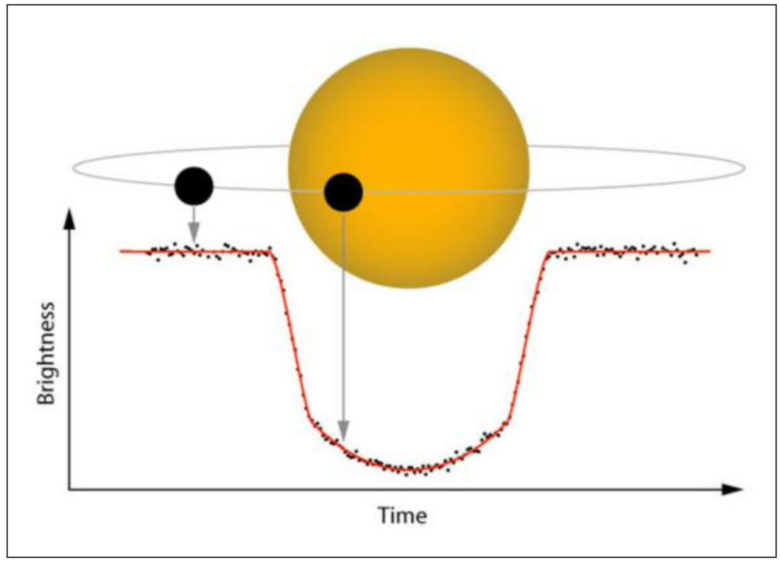
The star WASP-33 is located in the eastern part of the constellation of Andromeda. Its surface temperature, higher than our Sun's, makes it appear bluish in some pictures. The field is rich in stars, making it easy to select comparison objects with which to study the variations in brightness of WASP-33 via differential photometry.

non-radial pulsations with periods that may vary between a few hours to days, and, because of this, they can show small photometric variations, often near the detection limit of our telescopes. Therefore, both exoplanet transit searches and pulsating star studies need photometric observations of high precision, and this is the reason why some space missions (such as Kepler or COROT) combine both scientific themes among their objectives. Surprisingly, we still know very few stars hosting exoplanets that also show some type of pulsations (although recent discoveries include μ-Arae and HAT-P-7). Recently, our reasearch group (J. C. Morales, I. Ribas and E. Herrero) from the Institute of Space Sciences (CSIC-IEEC), Barcelona Autonomous University, together with the amateur astronomer Ramon Naves, have discovered the first pulsating δ-Scuti type star with a planet: WASP-33. Although WASP-33 b was discovered back in 2006 using the transit method, high-precision photometric measurements obtained by us have revealed small-amplitude oscillations in the star, making WASP-33 one of the most interesting planetary systems known to date.

Exoplanets and amateur astronomers

During recent years, CCD cameras for astronomy have become more and more available to non-professional astronomers. The equipment employed by enthusiasts of increasing sophistication, together with the amount of information shared through the Internet, are allowing many amateur astronomers to utilize advanced observational techniques, and therefore carry out valuable re-

When a planet transits in front of its host star we can measure a decrease in its apparent brightness. This is usually done with the technique of 'differential photometry': comparing the magnitude of our star with that of others in the same image field. Typically, for a Jupiter-type planet around a star such as the Sun, the decrease in light flux is about 1-2%, and this is measurable with amateur equipment. The example in the image corresponds to a transit of the exoplanet WASP-10 b. [UH/J.Johnson]

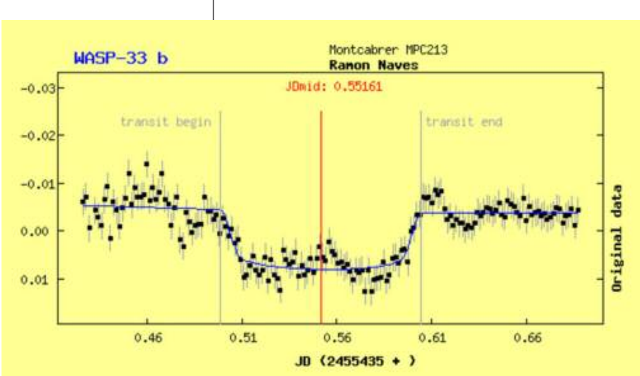


search with their own telescopes. One of the fields in which this is proving important is the photometric observations of exoplanet transits. Nowadays, at the Exoplanet Transit Database (ETD, http://var2.astro.cz/ETD), which is maintained by the Czech Astronomical Society, we can find almost 2000 transit observations, most of them submitted by amateur astronomers. Tools such as ETD allow both professionals and amateurs to share data, and consequently may result in important collaborative projects, such as that leading to the discovery of pulsations in WASP-33 that we describe here.

The graphic below shows a series of photometric data obtained by R. Naves at the Montcabrer Observatory (20 kilometers from Barcelona) during a transit of WASP-33 b on the night of August 26, 2010. The transit is clearly visible, as well as the pulsations, but before explaining the physics of this planetary system, we should address the key factors permitting an amateur astronomer to obtain photometric data of very high quality, with their own equipment: a 30 cm-diameter telescope and an SBIG ST8-XME CCD camera.

Needless to say, an essential factor for success is experience and expertise with the equipment, but there are also some methodological steps that are very important in obtaining good photometric data on exoplanet transits. For instance, a very clear observational plan for the observations is required, and we should also keep in mind that it is necessary to take images for some time before and after the transit to obtain a full curve that can be analysed. A set of tools within the ETD website can be used to calculate which transits will be observable on a certain night, or when a transit of a specific exoplanet will be observable.

Another essential ingredient for high-precision photometry work is a cor-



Photometry of the WASP-33b transit on August 26, 2010 obtained by R. Naves at Montcabrer Observatory with a 12” Meade LX200 telescope and a SBIG ST8-XME camera. These data alerted us to the possible brightness variations of the star.

rect calibration of the images, with dark, flat and bias frames. Otherwise, the noise resulting from thermal effects from the CCD electronics or the effects of sensitivity differences over the different parts of the sensor could be higher than the transit signal that we want to detect, and therefore prevent any meaningful analysis of the data.

The author at the Joan Oró telescope of the Montsec Astronomical Observatory.

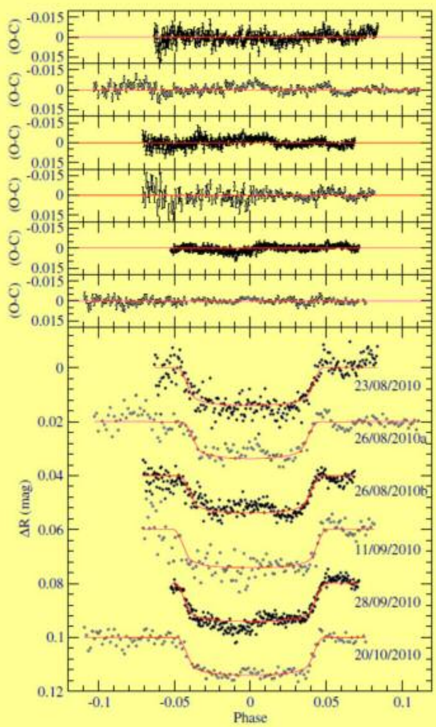
In some cases, when the star under investigation is very bright (typically more bright than magnitude 10, although this depends on the equipment), it is necessary to defocus the telescope a certain amount to spread the light over a large number of pixels, and increase the exposure time of the images, without reaching saturation. This is done to average out atmospheric scintillation effects, which cause variations on the star brightness on very short time scales.

In addition, the light from the star is distributed over a large number of pixels, thus allowing for a better sampling and more precise photometry.

By following such a procedure (developed from our own experience), and by relying on good atmospheric conditions, it is possible to obtain photometric precision of 2 to 3 millimagnitudes with a small telescope and a low-cost CCD. This enables the study of a good fraction of the currently-known transiting exoplanets. These have been essentially the key elements that allowed us to make the discovery of pulsations in the WASP-33 system, since the period and amplitude of the oscillations, which are characteristic of a δ-Scuti type variable, had not been detected in previous measurements.

An interesting star-planet system

WASP-33, also known as HD 15082, is a main sequence star classified as an A5 spectral type, and located in the constellation of Andromeda at a distance of 378 light years. Its size is about 1.5 times that of the Sun, and its surface temperature is on average about 7500 K (compared to the Sun's 5777 K). Its planet, WASP-33 b, is thought to be a giant planet with a mass about 4 times that of Jupiter, orbiting very close to its host star (at 0.02 UA, 3 million kilometers) once every 1.22 days. Moreover, and surprisingly, its orbital motion is retrograde and



Series of transit observations employed for the analysis of the WASP-33 system in our work. The upper panels show the same data after subtracting the curve of the planet transit. The residuals show the small oscillations of δ-Scuti type that are intrinsic to the star. It is evident that the pulsation maxima and minima appear always at the same orbital phases of the planet.

inclined with respect the equator of the star. The star is a fast rotator, with a spin period of 0.85 days, and thus it constitutes a peculiar and very interesting system from a dynamical point of view.

This has prompted its study by several different research groups.

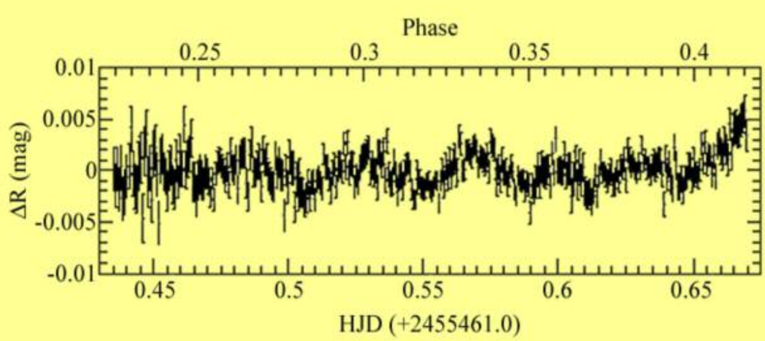
A recent investigation has shown that the day side of the WASP-33 b planet could be at a temperature close to 3000 K, and therefore make it the hottest known planet. This scorching temperature makes the planet definitely uninhabitable, but it also turns it into a very interesting object to be studied, because of the possible properties of its atmosphere and the relationship with its host star. The opening figure shows an artist's impression of a system similar to WASP-33 b and its host star.

The pulsations of the star

WASP-33 became the focus of our interest in early September 2010, when R. Naves contacted us after inspecting his observations at Montcabrer Observatory during a transit, and discovering some interesting sine-wave-like features (see figure at the bottom of page 108). Subsequent observations at the ETD, taken by different observers on several dates, made it clear that the oscillations were not systematic errors caused by atmospheric fluctuations or by instrumental effects. It became evident that they were intrinsic pulsations in the WASP-33 star. Once confirmed, in-depth monitoring was deemed necessary for a full characterization. We employed both the Montcabrer Observatory and the Montsec Astronomical Observatory, with a robotic 80 cm telescope (image on previous page) located in the Catalan Pyrenees. In addition, we also made use of the best quality data found at the ETD. The atmospheric properties (effective temperature and surface gravity) of WASP-33 indicate that it is a candidate for being a δ-Scuti type variable star.

Numerous time series of photometric data showed the oscillations when corrected for the effects of brightness decrease during the planetary transit (see graphic on this page). Measurements taken outside the transit also clearly showed the pulsations (see graphic on next page). Our analysis proceeded with the calculation of a periodogram that yielded a value of 68 minutes for the period, and an amplitude of only one millimagnitude. Both the period and the amplitude confirmed WASP-33 as a pulsating star of δ-Scuti type, being the first one known of this type which hosts a planet.

However, our study went one step further. A tantalising suggestion from our transit observations is that the brightness oscillations of the star always seem to occur at the same orbital phase of the planet, thus indicating some sort of synchronisation with the orbital period. The constancy of the orbital phase of the oscillation pattern is still seen in observations made very recently, after publication of our article, and 150 days after the measurements shown on page 108.



Photometric measurements of WASP-33 obtained from Montsec Astronomical Observatory on September 21, 2010. They show evident magnitude variations.

Star-planet interactions?

The observations discussed above indicate some kind of synchronization between the period of variation of the star and the orbital period of the planet. This conclusion is reached right away from a visual analysis of the transit observations. But a rigorous periodogram analysis amazingly shows that the ratio of the orbital period of the planet and the period measured from pulsations is very close to 26. Unfortunately, at this point we still do not have sufficient precision in the pulsation period to confirm that this is the case.

Many of the known δ-Scuti variable stars belong to binary stellar systems. It has been hypothesized that the companion star, especially if it has a short orbital distance and has an eccentric orbit, may be the cause of pulsations in the variable star. In those cases, the orbital and pulsation periods tend to be synchronized, as has been observed to occur in the binary star HD 209295, in which the principal component is a δ-Scuti.

Current theories explain that this occurs due to resonant tidal forces caused by the companion on the variable star. This has never been observed in a star-planet system.

WASP-33 may be the first example of a new class of system in which a planet induces or alters the pulsation period of its variable host star. Theory seems to indicate that the possibility of this occurring is remote, since the mentioned effects should be too weak, but part of this theory should be reformulated by considering some of the dynamical peculiarities of the WASP-33 system indicated above. We should consider whether, in this case, the proximity of the planet, its retrograde and inclined orbit relative to the stellar spin axis, and the rapid rotation of the star could cause interactions between the star and planet with the consequences that we have observed. Undoubtedly, measurements by professional and amateur astronomers in the next months will be pivotal to solve the mystery of one of the more interesting planetary systems known to date.

Technical details on the discovery of pulsations in WASP-33 can be found in the article "WASP-33: The first delta-Scuti exoplanet host star", E. Herrero, J.C. Morales, I. Ribas and R. Naves, *Astronomy & Astrophysics*, 526, L10, available at www.aanda.org/articles/aa/pdf/2011/02/aa15875-10.pdf.

Enrique Herrero was born in 1986 in Valencia (Spain), and has lived for many years in Lleida. He graduated in Physics at the University of Barcelona in 2009.
After doing a Masters degree in Astrophysics at the same University, today he is doing his PhD in exoplanets and low-mass stars at the Institute for Space Science (CSIC-IEEC).
Since his origins as an amateur astronomer, he has combined his research tasks with dissemination activities in astronomy, very often with works and photos obtained by himself (www.celdenit.com).