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The creation and development of an international observational project on a search for extrasolar planets, based on Transit Timing Variations (TTVs). The first results of WASP-4b, TrES-5b and other exoplanets investigations.

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To obtain the most reliable and quality data used for further search and analysis of TTV signals since 2012 international observation campaign centered at Pulkovo Observatory (St. Petersburg, Russia) had been starting. For today the international campaign-project has more than 30 professional and amateur observatories, located in different places of the world (Russia, Finland, Italy, Spain, France, UK, Czech Republic, Slovakia, Cyprus, Greece, Turkey, Armenia, Uzbekistan, USA, Canada, Argentina, Cook Islands). The campaign participants carry out observations with the use telescopes from 20 cm to 2.6 meters.
Based on carefully selected observational data for several exoplanets frequency analysis were carried out and periodograms of data were constructed.

For WASP-4b, TrES-5b TTVs were found and estimated periods and amplitudes of the variations. Such estimates enable us to predict existence of new exoplanet candidates in known planetary systems with the using N-body modeling.

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Constraints on circumbinary planet orbits from Kepler single transit events

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Abstract

All the known transiting circumbinary planets orbit very close to coplanar with their host binaries. But circumbinary systems are not, a priori, limited to this configuration; misaligned systems are likely to exist, and their discovery and characterisation of would shed light on the dynamical history of planets on circumbinary orbits, and on the possible migration mechanisms that might be acting on such complex systems.

We have identified candidate misaligned circumbinary systems within Kepler data. These candidates show single, non-periodic transits that can be used to place constraints on possible orbital configurations for the third body for given binary star parameters. We have developed tools to identify and model possible planetary orbits, and will present preliminary results for representative binary star cases that illustrate our ability to constrain the planet's orbital period and inclination.

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Discovery of WASP-85 Ab: A Hot Jupiter in a Visual Binary System

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Abstract

We report the discovery of the transiting hot Jupiter exoplanet WASP-85Ab. Using a combined analysis of spectroscopic and photometric data, we determine that the planet orbits its host star every 2.66 days, and has a mass of 1.09+/-0.03 M_Jup and a radius of 1.44+/-0.02 R_Jup. The host star is of G5 spectral type, with magnitude V=11.2, and lies 125+/-80 pc distant. We find stellar parameters of T_eff=5685+/-65 K, super-solar metallicity ([Fe/H]=0.08+/-0.10), M_star=1.04+/-0.07 M_sun and R_star=0.96+/-0.13 R_sun. The system has a K-dwarf binary companion, WASP-85B, at a separation of approximately 1.5". The close proximity of this companion leads to contamination of our photometry, decreasing the apparent transit depth that we account for during our analysis. Without this correction, we find the depth to be 50 percent smaller, the stellar density to be 32 percent smaller, and the planet radius to be 18 percent smaller than the true value. Many of our radial velocity observations are also contaminated; these are disregarded when analysing the system in favour of the uncontaminated HARPS observations, as they have reduced semi-amplitudes that lead to underestimated planetary masses. We find a long-term trend in the binary position angle, indicating a misalignment between the binary and orbital planes. WASP observations of the system show variability with a period of 14.64 days, indicative of rotational modulation caused by stellar activity. Analysis of the Ca ii H+K lines shows strong emission that implies that both binary components are strongly active. We find that the system is likely to be less than a few Gyr old. WASP-85 lies in the field of view of K2 Campaign 1. Long cadence observations of the planet clearly show the planetary transits, along with the signature of stellar variability. Analysis of the K2 data, both long and short cadence, is ongoing.

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The GAPS Programme with HARPS-N at TNG: first results and perspectives

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Abstract

GAPS (Global Architecture of Planetary Systems) is an Italian nation-wide long-term program dedicated to the exploitation of the scientific opportunity offered by the installation of the HARPS-N spectrograph at *Telescopio Nazionale Galileo* (TNG) in the summer of 2012. GAPS has been formulated as a balanced combination of discovery and characterization observations. The project goals are: i) studying the frequency of low-mass planets as a function of stellar mass, stellar metallicity, density of the stellar environment, as well as ii) characterizing known planetary systems, detailing the properties of their star(s), planet(s) and the architecture of the planetary orbits. All this information is mandatory to constrain models for the formation and evolution of planetary systems and to assess planet habitability. We shall report on the main results obtained up to date and discuss the perspectives for the development of the program.

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Typical planet radii - theory versus transits

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Abstract

We compare planetary radii determined for exoplanets to a statistical theory of planets in orbit around A,F,G and K-stars and with periods of less then 128 d. We calculate planets that fit into stable protoplanetary nebulae of stars with masses of 0.8 to 2 times the solar mass. We apply overall detection efficiency onto the theoretical results to obtain theoretical planetary mass and radius distributions and compare this theoretical properties to the ones observed by selected space-transit-mission in the probabilistic mass-radius diagram.

5. Equations

Below, you will find examples of two equations. You should use an equation editor of your word-processing program in order to include your equation(s). The equation number should be placed at the right side of the column and all equations should be consecutively numbered.

$$a^2 + b^2 = c^2 \quad (1)$$

$$E = m \times c^2 \quad (2)$$

6. Summary and Conclusions

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Acknowledgements

The Acknowledgements section should not be numbered. Here, you may include all persons or institutions which you would like to thank. We recommend that the abstract is carefully compiled and thoroughly checked, in particular with regard to the list of authors, **before** submission.

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Finding Planets Orbiting Bright Stars with SuperWASP-South

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Abstract

Over the past decade the Wide Angle Search for Planets (WASP) project has been at the forefront of the ground-based hunt for transiting planets. In that time, WASP has found many systems that push the boundaries of our understanding of planet formation and evolution. In recent years both the North and South installations have changed their observing strategies with the aim of discovering rarer objects to further fill gaps in our knowledge and test current theory. Here we look at the performance and potential of the new WASP-South instrument, which we modified to target brighter stars. We also present some new discoveries from this brighter, southern campaign.

1. Introduction

The next chapter of SuperWASP's already successful career is aimed at finding analogues of HD 209458 b [5, 3] and HD 189733 b [2] in the southern hemisphere. These two examples of planets orbiting exceptionally bright stars, both $V_{mag} \sim 7.7$, boast the most robust and stunning discoveries in the field of transiting hot-Jupiters. These include the detection of atmospheric chemical constituents [4, 8, 9], strong signatures of Rayleigh and Raman scattering [1] and even detection of the planetary radial velocity [7]. Such discoveries are made easier by the larger signal-to-noise ratio achievable with bright stars.

The dearth of southern sky counterparts to these two planets, illustrated in figure 1, is the motivation behind shifting WASP-South to observe brighter stars. The bright targets we expect to find soon will allow us to investigate more deeply the diversity and similarities between planetary systems. The availability of the VLT and soon the E-ELT in the southern hemisphere will enable more detailed study than ever before of these bright targets.

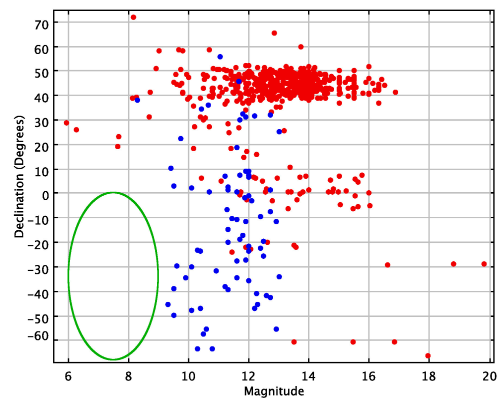

Figure 1: Plot of transiting planet host star magnitude against declination for SuperWASP (blue) and other surveys (red). The green ellipse highlights the lack of planets discovered above 9^{th} magnitude in the southern hemisphere. Data from exoplanets.eu.

2. First Results

In July of 2012 we replaced the lenses on WASP-South with smaller aperture lenses to monitor brighter stars without saturating. An example of the new photometric performance for a typical search field are shown in figure 2. The new data are compared to a similar field from a night with similar conditions using the previous lenses. The minimum precision needed to find hot-Jupiters orbiting sun-like stars is $\sim 1\%$.The previous setup achieves this for stars between magnitudes 9 and 12. The new setup can do the same for magnitudes 6 to 10.

An example of the signals the new instrument can detect is shown in figure 3. We show the lightcurve of a new eclipsing binary with very shallow primary and secondary eclipses. The primary eclipse has a depth of $\sim$ 4mmag, equivalent to a 0.6 R_{Jup} orbiting a sun-like star. The shallower depth of the secondary eclipse shows we can detect even smaller objects.

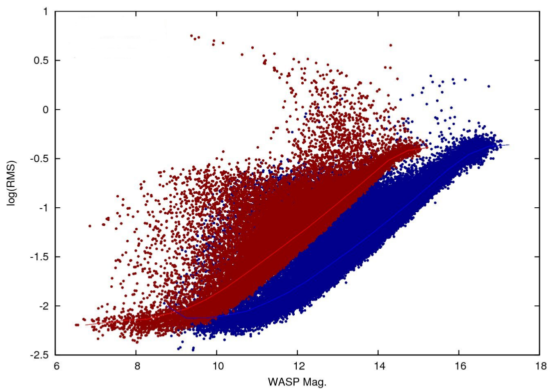

Figure 2: Plot comparing the Log(RMS) as a function of instrumental magnitude of stars from similar fields taken using the old (blue) and new (red) lenses. The median Log(RMS) is overplotted in light blue and light red for the corresponding coloured data. We can see the optimal performance of the two versions of the WASP-South instrument are similar but shifted to a brighter magnitude for the new data.

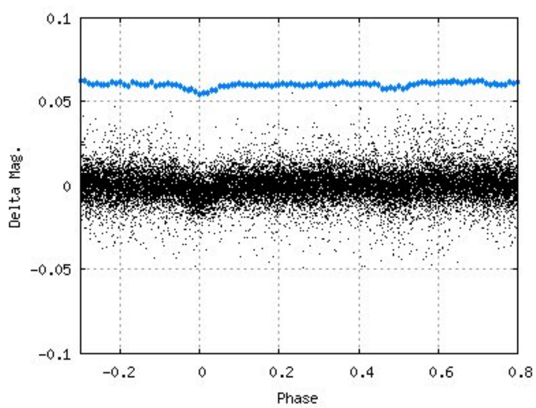

Figure 3: Phase folded plot of the lightcurve of a new eclipsing binary star with primary eclipse visible at phase 0. Secondary eclipse is also apparent at phase 0.5. The recorded depth of the primary eclipse is $\sim$ 4mmag; this is equivalent to a 0.6 R_{Jup} planet transiting a sun like star. The shallower secondary eclipse demonstrates our ability to detect even smaller targets.

3. Summary and conclusions

The new, upgraded WASP-South instrument has now been running for nearly 3 years. In this time we have collected data on stars with visual magnitudes ranging from just brighter than 6^{th} to around 12^{th} across nearly half of the sky. We have re-optimised the reduction pipeline for the new data and will present first results from our new observing strategy including: our operational changes, our assessment of the performance of the new instrument and new discoveries made in our search for rarer, bright objects.

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Constraints on Small-size Planet Occurrence around Nearby Early-to-mid M Dwarfs from the APACHE Project

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Abstract

APACHE [1] is a ground-based photometric survey intended to find planets transiting the closest and smallest main-sequence stars. Here, we try to answer an outstanding question: in light of the bounty of small planets transiting small stars uncovered by the Kepler mission, should APACHE have found one planet so far? We estimate APACHE's ensemble sensitivity to exoplanets by performing end-to-end simulations of observations of ~350 nearby early-to-mid M dwarfs, gathered by APACHE between 2012 July and 2015 August. For 2– 10 R ⊕ planets, we compare this sensitivity to results from Kepler [2] and MEarth ground-based photometric survey [3]. APACHE is sensitive to transits of planets the size of Neptune. In light of this sensitivity, we discuss our lack of detections of transiting Neptunes based on the analysis of the first three years of survey data, and compare our results with known populations of Neptune-sized exoplanets around nearby early M dwarfs, discovered by both radial velocity and transit surveys. Furthermore, we put in context these results with the preliminary statistics of an M-dwarf survey from HARPSN@TNG within the large programme GAPS (Global Architecture of Planetary Systems [4]), focused on targets under monitoring with APACHE.

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Determining exoplanet cloud properties using optical phase curves

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Abstract

Accurate photometry of spatially unresolved exoplanet+star systems is setting key constraints on various aspects of close-in exoplanet atmospheres (geometric albedos, peak brightness offsets, temperatures, occurrence of clouds and haze, etc.) through the investigation of the planetary phase curves [1, 2, 3]. Such work has been enabled by observations of the optical phase curves of hot Jupiters by COROT and Kepler. A theoretical framework to investigate such phase curves and recover the information contained in them has been missing, however. We have set out to establish such a framework, which allows us to connect fundamental properties of the exoplanet atmosphere (cloud spatial distribution, optical depth, cloud particle scattering properties) to the observable phase curves.

1. Methodology

Our framework (García Muñoz & Isaak, *submitted*) relies on a recently devised Pre-conditioned Backward Monte Carlo (PBMC) algorithm [4] that computes the phase curves of inhomogeneous planets without any computational overhead with respect to the solution of homogeneous planets [5, 6]. The calculation proceeds by simulating a number of one-photon numerical experiments. Since it is a backward algorithm, each experiment traces the trajectory of a photon from the observer through the scattering atmosphere. The contribution to the estimated radiation at the observer's location is built up by adding the contributions every time the photon undergoes a collision. The simulation is terminated when the photon is completely absorbed in the atmosphere.

The algorithm includes a scheme to select the photon entry point into the atmosphere based on the local projected area of the 'visible' planet disk. This strategy ensures that all simulated photons contribute to the estimated radiation at the observer's location.

The output of each simulation is the planet-to-star brightness ratio for reflected starlight:

$$F_p/F_\star = (R_p/a)^2 A_g \Phi(\alpha) \qquad (1)$$

where R_p and a are the planet's radius and orbital distance, respectively; A_g is the geometric albedo and $\Phi(\alpha)$ is the planet phase function. By sampling the star-planet-observer phase angle α, we build the synthetic model phase curves that allow us to compare with available exoplanet phase curves.

2. Investigation of cloud properties

In the contribution, we present our framework and use the test case hot Jupiter Kepler 7b to illustrate the cloud properties that can be constrained from optical phase curve measurements, as well as possible degeneracies between key atmospheric parameters. Further, we discuss our findings in the context of upcoming space missions and General Circulation Models.

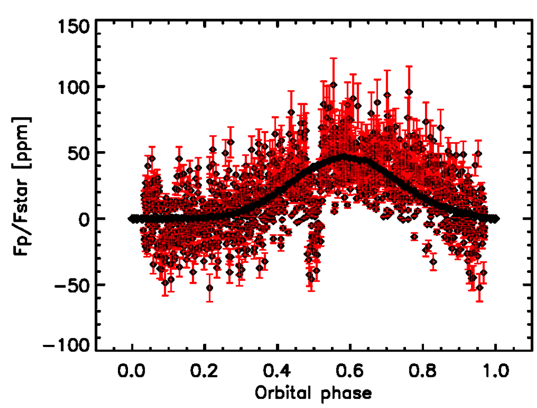

Figure 1: Observed (black diamonds+red bars) and modeled (black symbol) phase curve of Kepler-7b. Measurements are from Ref. [3]. Model fitting of the observations enables us to investigate the information content of the measured phase curve.

3. Outlook

Within coming years, first CHEOPS and TESS and then PLATO will greatly increase the number of available exoplanet phase curves, thus allowing for comparative studies. The devised methodology paves the way for the investigation of exoplanet cloud properties with data to be obtained by these missions. Atmospheric studies of exoplanets with optical phase curves will primarily focus on hot Jupiters, although Neptune-sized planets may also be amenable to such studies.

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Revisiting Spitzer Transit Observations with Independent Component Analysis: New Results for Exoplanetary Systems

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Abstract

Blind source separation techniques are used to reanalyse several exoplanetary transit lightcurves of a few exoplanets recorded with the infrared camera IRAC on board the Spitzer Space Telescope during the "cold" era. These observations, together with observations at other IR wavelengths, are crucial to characterise the atmospheres of the planets. Previous analyses of the same datasets reported discrepant results, hence the necessity of the reanalyses. The method we used here is based on the Independent Component Analysis (ICA) statistical technique, which ensures a high degree of objectivity. The use of ICA to detrend single photometric observations in a self-consistent way is novel in the literature. The advantage of our reanalyses over previous work is that we do not have to make any assumptions on the structure of the unknown instrumental systematics. We obtained for the first time coherent and repeatable results over different epochs for the exoplanets HD189733b and GJ436b [Morello et al.(2014), Morello et al.(2015)]. The technique has been also tested on simulated datasets with different instrument properties, proving its validity in a more general context [Morello et al.(2015b)]. We will present here the technique, and the results of its application to different observations, in addition to the already published ones. A uniform re-analysis of other archive data with this technique will provide improved parameters for a list of exoplanets, and in particular some other results debated in the literature.

1. Introduction

Observations of exoplanetary transits are a powerful tool to investigate the nature of planets around other stars. Transits are revealed through periodic drops in the apparent stellar brightness, due to the interposition of a planet between the star and the observer. The shape of an exoplanetary transit lightcurve depends on the geometry of the star-planet-observer system and the spatial distribution of the stellar emission at the wavelength at which observations are taken [Mandel & Agol(2002)]. Multiwavelength transit observations can be used to characterise the atmospheres of exoplanets, through differences in the transit depths, typically at the level of one part in $\sim 10^4$ in stellar flux for giant planets [Brown(2001)]. For this purpose, the diagnostic parameter is the wavelength-dependent factor $p = r_p/R_s$, i.e. the ratio between the planetary and the stellar radii (or p^2, so-called transit depth).

The exoplanet HD189733b is one of the most extensively studied hot Jupiters: the brightness of its star allows spectroscopic characterisation of the planet's atmosphere. Different analyses of the same dataset, including two simultaneous Spitzer/IRAC observations at 3.6μm and 5.8μm, have been used to infer the presence of water vapour in the atmosphere of HD189733b [Beaulieu et al.(2008), Tinetti et al.(2007)], or to reject this hypothesis [Désert et al.(2009)]. GJ436b is a Neptune-sized planet for which the atmospheric composition is very debated in the literature [Stevenson et al.(2010), Beaulieu et al.(2011), Knutson et al.(2011), Knutson et al.(2014)]. Some authors also claimed that stellar variability may affect the observed spectra at a level that it would be impossible to infer any atmospheric properties.

Although stellar activity may significantly affect estimates of exoplanetary parameters from transit lightcurves [Ballerini et al.(2012), Berta et al.(2011)], the method used to retrieve the signal of the planet also plays a critical role. The analyses mentioned above were all based on parametric corrections of the instrumental systematics, and are thus, to some degree, subjective. Recently, non-parametric methods have been proposed to decorrelate the transit signals from the astrophysical and instrumental noise, and ensure a higher degree of objectivity. [Waldmann (2012), Waldmann et al.(2013), Waldmann (2014)] suggested algorithms based on Independent Component Analysis (ICA) to extract information of an exoplanetary atmosphere from spectrophotometric datasets.

We adopt a similar approach to detrend the transit signal from photometric observations by using Point Spread Functions (PSFs) covering multiple pixels on the detector. We apply this technique to re-analyse some observations of primary transits recorded with Spitzer/IRAC. We present a series of tests to assess the robustness of the method and the error bars of the parameters estimated. Critically, by comparing the results obtained from different measurements, we discuss the level of repeatibility of transit measurements in the IR, limited by the absolute photometric accuracy of the instrument and possible stellar activity effects.

2. The algorithm: pixel-ICA

The main novelty of the algorithms we use here is their ability to detrend the transit signal from a single photometric observation of just one primary transit. This is possible because, during an observation, there are several pixels detecting the same astrophysical signals at any time, but with different scaling factors, depending on their received flux, their quantum efficiency, and the instrument PSF. We performed an ICA decomposition over several pixel-lightcurves, i.e. the time series from individual pixels, in order to extract the transit signal and other independent components (stellar or instrumental in nature). Further details are reported in [Morello et al.(2014), Morello et al.(2015), Morello et al.(2015b)].

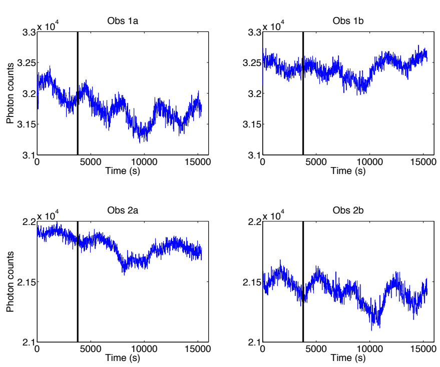

Figure 1: Raw integral light-curves of the four Spitzer/IRAC primary transit observations of GJ436b at 3.6 and 4.5 μm. Data points on the left of black vertical lines have been discarded for the analysis, on a statistical basis. Note that the transit depth is comparable with the amplitude of systematics.

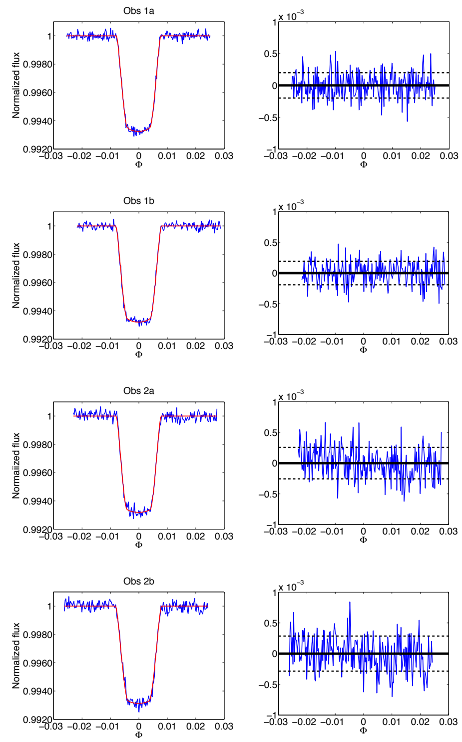

Figure 2: Left panels: (blue) detrended light-curves for the four observations with (red) best transit models overplotted, binned over 7 points; best transit models are calculated with p, a_0, and i as free parameters, and Phoenix quadratic limb darkening coefficients [Morello et al.(2015)]. Right panels: Residuals between detrended light-curves and best transit models; black horizontal dashed lines indicate the standard deviations of residuals.

3. Summary and Conclusions

We have introduced a blind signal-source separation method, based on ICA, to analyse photometric data of transiting exoplanets, with a high degree of objectivity; a novel aspect is the use of pixel-lightcurves, rather than multiple observations.

We have applied the method to reanalyse some Spitzer/IRAC datasets, which previous analyses found to give discrepant results, and obtained consistent parameters from these observations. We suggest the large scatter of results in the literature arises from the use of parametric methods to detrend the signals, neglecting the relevant uncertainties, and correlations.

We investigated the limits of our method on simulated observations.

We are applying this method to obtain robust and uniform results for a list of planets.

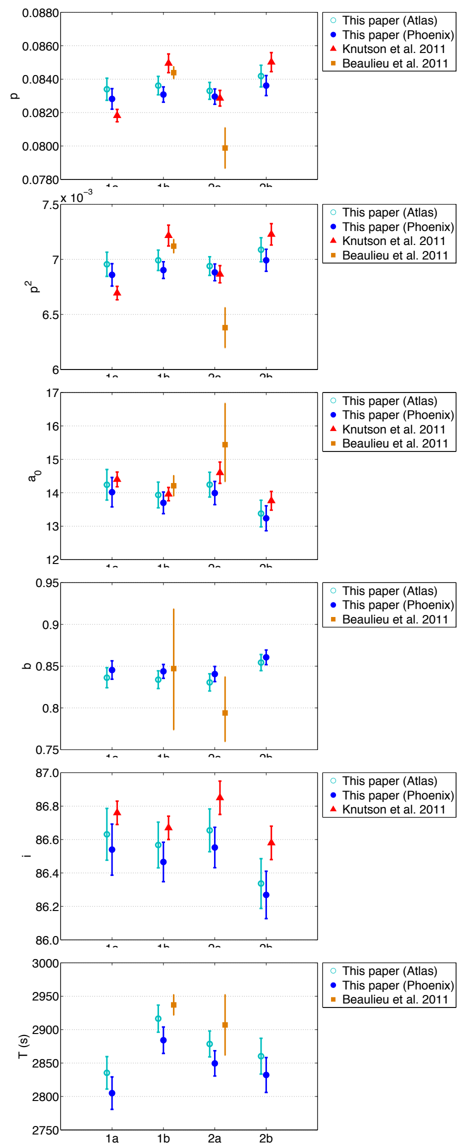

Figure 3: From top to bottom: Comparisons of the parameters p, a_0, and i (left side), p^2, b, and T (right side), obtained in this paper [Morello et al.(2015)] with Atlas stellar model (cyan, empty circles), Phoenix stellar model (blue, full circles), in [Knutson et al.(2011)] (red triangles), and in [Beaulieu et al.(2011)] (yellow squares).

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