TAG: PATT

LIVERPOOL TELESCOPE
APPLICATION FOR TELESCOPE TIME

Ref: PL/17B/xxx

Semester: 17B **Duration (Semesters):** 1 **PROGID:**

Applicants (PI First)	Institution	email
John Southworth	**Keele University, UK**	**astro.js@keele.ac.uk**
Amaury Triaud	Univ. Cambridge, UK	aht34@cam.ac.uk
Oliver Turner	Geneva Obs., Switzerland	oliver.turner@unige.cl
David Martin	Geneva Obs., Switzerland	david.martin@unige.clk
Pierre Maxted	Keele University, UK	p.maxted@keele.ac.uk
Sam Gill	Keele University, UK	s.gill@keele.ac.uk

Title: Understanding the mass-radius-luminosity relationship for the lowest mass stars

Abstract:

M-dwarfs are prime targets for exoplanet surveys because the planets in the habitable zones of these stars have comparativly short-period orbits and are much easier to detect and characterise than planets around more massive stars. However, understanding exotic planetary systems around M-dwarfs like TRAPPIST-1 and GJ 1132 is frustrated by our poor understanding of low mass stars. There are few well-characterised M-dwarfs that can be used to establish an empirical mass-radius-luminosity relation. Our low mass eclipsing binary (EBLM) program has discovered over 200 binaries composed of F/G + M stars, for we have measured their masses and radii from existing photometry and high-precision radial velocities. We now need one more set of observations: light curves of their secondary eclipses from which we can measure the luminosity and $T_{\rm eff}$ of the M-dwarf components and thus improve the M-dwarf mass-radius-luminosity relation.

TIME REQUESTED

This semester (hours): 17
Total (hours): 17
Min. Useable %: 47
Sky Brightness: N/A
Photometric:
Seeing (arcsec): Any
Constraints: FIXED/PHASED **Group Cadence (days):**
ToO: **ToO Likelihood (%):**

Which month(s) of the year would you ideally like your observations taken?

Jan Y Feb Mar Apr May Jun Jul Y Aug Y Sep Oct Y Nov Y Dec

Instrument(s)		Details
IO:O		**Filters**
IO:I		**Filters**
RINGO3		
RISE	Y	
SPRAT		
FRODOSpec		**Gratings**
Other*		

Always consult the Call for Proposals and LT web-pages before applying to use ANY instrument.

ltpattv0p6.sty - 0123456789

Summary of Progress on previous related LT Programmes:
N/A

List of previous related and unrelated LT Publications:

Lam et al., A&A, 2017, 599, 3: *From dense hot Jupiter to low-density Neptune: The discovery of WASP-127b, WASP-136b, and WASP-138b*

Faedi et al., A&A, submitted, 2016 (arXiv:1608.04225): *WASP-86b and WASP-102b: super-dense versus bloated planets*

Hay et al., MNRAS, 2016, 463, 3276: *WASP-92b, WASP-93b and WASP-118b: Three new transiting close-in giant planets*

Barros et al., A&A, 2016, 593, 113: *Discovery of WASP-113b and WASP-114b, two inflated hot-Jupiters with contrasting densities*

Hellier et al.., AJ, 2015, 150, 18: *Three WASP-South transiting exoplanets: WASP-74b, WASP-83b & WASP-89b*

Anderson et al.., ApJ, 2015, 800, 9: *The Well-aligned Orbit of Wasp-84b: Evidence for Disk Migration*

Related Proposals: LCO: WHT: INT: ESO:**Y** Other:

Details of related/complimentary proposals to this or other facilities:
ESO: High-resolution optical images of eclipsing binaries with low-mass companions from the WASP survey – PI: Pierre Maxted – Instrument: SPHERE – High resolution images to account for faint blended objects affecting the eclipse depths. No scheduling constraints.

ESO: Secondary eclipse measurements of eclipsing binaries with low-mass companions from the WASP survey – PI: Pierre Maxted Instument: HAWK-I – Same science goals as this proposal. If awarded time for both, observations will be scheduled so as to cover as many objects as possible.

TARGET LIST:

Our target list comprises four low-mass eclipsing binaries discovered by the WASP survey. Each requires high-quality photometry of a secondary eclipse for an accurate determination of the parameters of the M-dwarf component.

Primary	Period (days)	$R_{\rm mag}$ Pri.	$R_{\rm mag}$ Sec.	Sp. Type Pri.	Mass Sec. ($R_{\rm Sol}$)	Depth (ppm)	Eccentricity	Duration (hr)
J0353+05	6.862	10.85	18.82	G6	0.156	650	0.0011 ± 0.00012	2.3
J0526+04	4.031	11.7	19.59	F6	0.206	700	≤ 0.005	2.3
J1013+01	2.8923	11.78	18.78	G6	0.156	1580	≤ 0.009	1.6
J2027+03	3.8397	11.17	18.18	F8	0.261	1570	≤ 0.003	2.3

The observable secondary eclipses for each target occur on the following dates:
J0353+05: 2017-11-09; 2018-01-02
J0526+04: 2018-01-05; 2018-01-09; 2018-01-12
J1013+01: 2018-01-01; 2018-01-30
J2027+03: 2017-07-03; 2017-07-27; 2017-08-23; 2017-10-12

SCIENTIFIC CASE:

M-dwarfs are prime targets for exoplanet surveys because the planets in the habitable zones of these stars have orbits periods of a few weeks or months, and they are much easier to detect and characterise than planets around more massive stars. Surveys like NGTS and TESS are targeting M-dwarfs for exactly these reasons. Understanding exotic planetary systems around M-dwarfs like TRAPPIST-1 and GJ 1132, as well as those soon to be discovered, is made more complicated by our poor understanding of low-mass stars. There are few well-characterised M-dwarfs that can be used to establish an empirical mass-radius-luminosity relation for these stars (see Fig. 1). The few M-dwarfs for which we do have reliable mass and radius estimates are not well matched by stellar models (Fig. 1) for reasons that are not well understood.

Whilst searching primarily for planets transiting Sun-like stars, the Wide Angle Search for Planets (WASP, Pollacco et al. 2006) has discovered many eclipsing binary systems. Over 200 of these are composed of an F/G-type primary with an M-dwarf secondary. These objects are under investigation as part of our low-mass eclipsing binary (EBLM) project (Triaud et al. 2013; Gómez Maqueo Chew et al. 2014.; Triaud et al. in prep). We have already obtained good spectroscopic data for most of these objects and so have characterised the orbit and mass of the M-dwarf secondaries (Triaud et al. in prep.). We have a long baseline of observations with WASP and time available on other instruments to characterise the primary eclipses and thus their radii. However, we lack the observations needed to characterise the secondary eclipses and so measure the luminosity of these key systems. **We propose to make observations using RISE's new I+Z band filter to characterise the secondary eclipses of four F/G + M binaries to complete the observations needed to refine the mass-radius-luminosity relationship for low-mass stars.**

The surface brightness of an F/G-type star can be predicted to an accuracy of about 2% based on its optical colours or some other estimate of $T_{\rm eff}$ (Graczyk et al. 2017). As the area eclipsed during both primary and secondary eclipse is the same in systems with circular orbits, the eclipse depth ratio lets us measure the surface brightness ratio. Systems with eccentric orbits require additional observations (high-precision radial velocity measurements) which we already possess, so can also be included in this analysis straightforwardly. Since we can determine the $T_{\rm eff}$ of the F/G primary star, the secondary eclipse depth gives a robust measure of the brightness temperature of the M-dwarf at the wavelengths where the observations were obtained. This brightness temperature can be converted to an estimate of $T_{\rm eff}$ for the M-dwarf.

This approach has been used for only two F/G + M binaries to-date, KIC 1571511 (Ofir et al. 2012) using *Kepler* photometry and J0113+31 (Gómez Maqueo Chew et al. 2014.) using ground-based photometry in the J-band (Fig. 1). In both cases, the value of $T_{\rm eff}$ derived is approximately 4000 K, much higher than the value of 3350 K expected for stars of this mass ($M \approx 0.15 M_{\odot}$). It is thought that tidal heating of the M-dwarfs, caused by their eccentric orbits, is the cause of the anomalous results for these two objects. As all of our targets have very low eccentricities we do not expect them to be subject to this effect. As a result they will provide useful constraints not only on the mass-radius-luminosity relation, but also on the effects of tidal heating.

The masses and radii of planets are determined from the measured orbital velocity amplitude and transit depth, respectively. Both of these methods only give a ratio of the planetary mass or radius to that of the star. Without improving out knowledge of the physical properties of M-dwarfs, we will not be able to draw robust conclusions about the properties of planets orbiting them. We therefore ask for LT/RISE observations to characterise a significant sample of M-dwarfs in eclipsing binaries, which will enable us to improve the empirical mass-radius-luminosity relation for these objects. LT/RISE has a proven track record of obtaining high-precision time-series photometric follow-up of transiting planets, but in past semesters its $V+R$ filter was not well-suited to obtaining secondary eclipses of systems with M-dwarf components. With the shift to a redder $I+Z$ filter, which means deeper secondary eclipses, this work is now possible with RISE.

TECHNICAL CASE:

Over recent years we have used LT/RISE to obtain numerous high-quality lightcurves of WASP planets (see Fig. 2 and publication list on page 2). RISE was primarily built for obtaining high-quality transit light curves, and has been shown to be highly successful. It can achieve a timing resolution of 1 second (due to its frame-transfer CCD) and has a relatively large field of view. This provides us with a good choice of comparison stars, which is essential for accurate photometry and helps to minimise systematic noise. In addition, the use of a broad $I+Z$ filter this semester gives us the unique opportunity to observe these eclipses which are significantly deeper at longer wavelengths.

We have selected four targets to observe for this application. Target selection was based on choosing the systems with the lowest-mass M-dwarf secondary stars, circular or almost-circular orbits, and which also had secondary eclipses observable with the LT in semester 2017B.

Our time requirement is dictated by the eclipse duration rather than the exposure times. In addition to the duration of each eclipse we require some time before and after (2 hours in total) against which the eclipse depth can be measured. This will allow us to determine the $T_{\rm eff}$ of each M-dwarf component. Using this baseline the light curves can also be decorrelated for dependencies caused by changing airmass, target position, and the FWHM of the PSF. We will defocus the telescope to minimise the effects of flat-fielding errors and detector inhomogeneities (e.g. Southworth et al. 2009), which also means that we have no seeing requirement. We request a total time of 17 hr to be used, corresponding to the duration of the four transits (see Target List) plus two hours of pre- and post-transit observations for each.

The number of viable events for these targets is limited during the semester. As a result we request FIXED time be available for these observations. However we are also used to scheduling observtions with PHASED time and so can make sucessful observations under these conditions. Our minimum usable fraction of 47% (8 hr) represents the time required to obtain a high quality lightcurves J0353+05 and J1013+01, the systems with the lowest mass M-dwarf components.

Using twn lightcurves from a combination of 1.2-m and 0.6-m telescopes, Lendl et al. (2013) were able to measure an occultation depth in the z-band of 352 ± 116 for WASP-19 ($R_{\rm mag} = 12.1$). Our targets are brighter (by a factor of around 1.7) , our smallest predicted eclipse depth is approximately twice as deep and the LT will provide a collecting area of at least a factor 2.7 larger. Thus, we expect to be at least 9 times more sensitive, enabling us to make these detections with a single light curve each.

References

Baraffe et al., 1998, A&A, 337, 403
Dotter et al., 2008, ApJS, 178, 89
Gómez Maqueo Chew et al., 2014, A&A, 572, 50
Graczyk et al., 2017, ApJ, 837, 7
Lendl et al., 2013, A&A, 552, 2
Ofir et al., 2012, MNRAS, 423, 10
Pollacco et al., 2006, PASP, 118, 1407
Triaud et al., 2013, A&A, 549, 18
Southworth et al., 2009, MNRAS, 396, 1023

FIGURES AND TABLES:

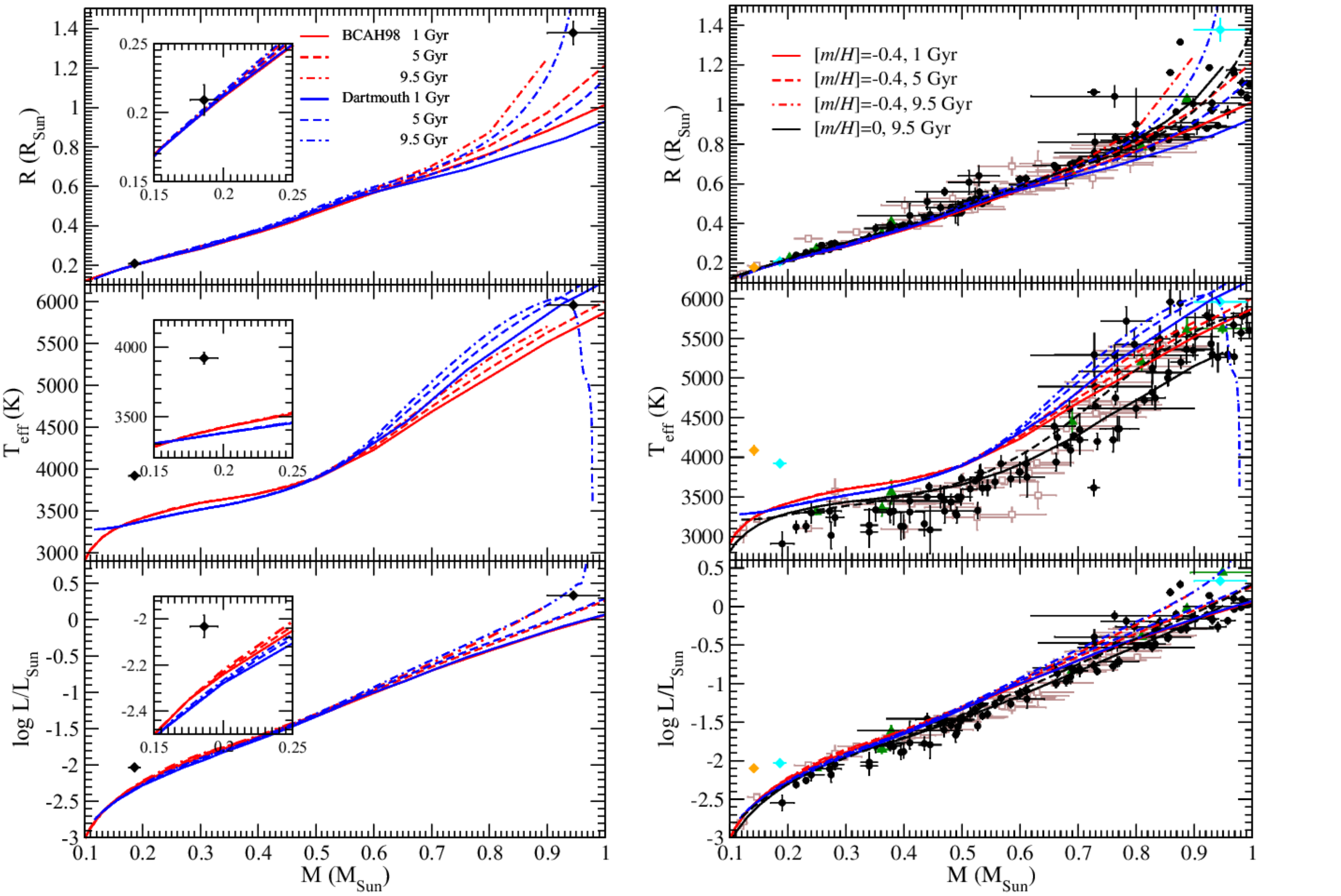

Fig. 1. The mass-radius-$T_{\rm eff}$-luminosity relation for low mass stars from Gómez Maqueo Chew et al. (2014). The left-hand panels show the properties of both components of J0113+31, highlighting the discrepant $T_{\rm eff}$ found for the secondary star. The right-hand panels show the properties of a compilation of low-mass eclipsing binaries. The coloured lines in all panels show the predictions of two recent sets of theoretical stellar evolutionary models.

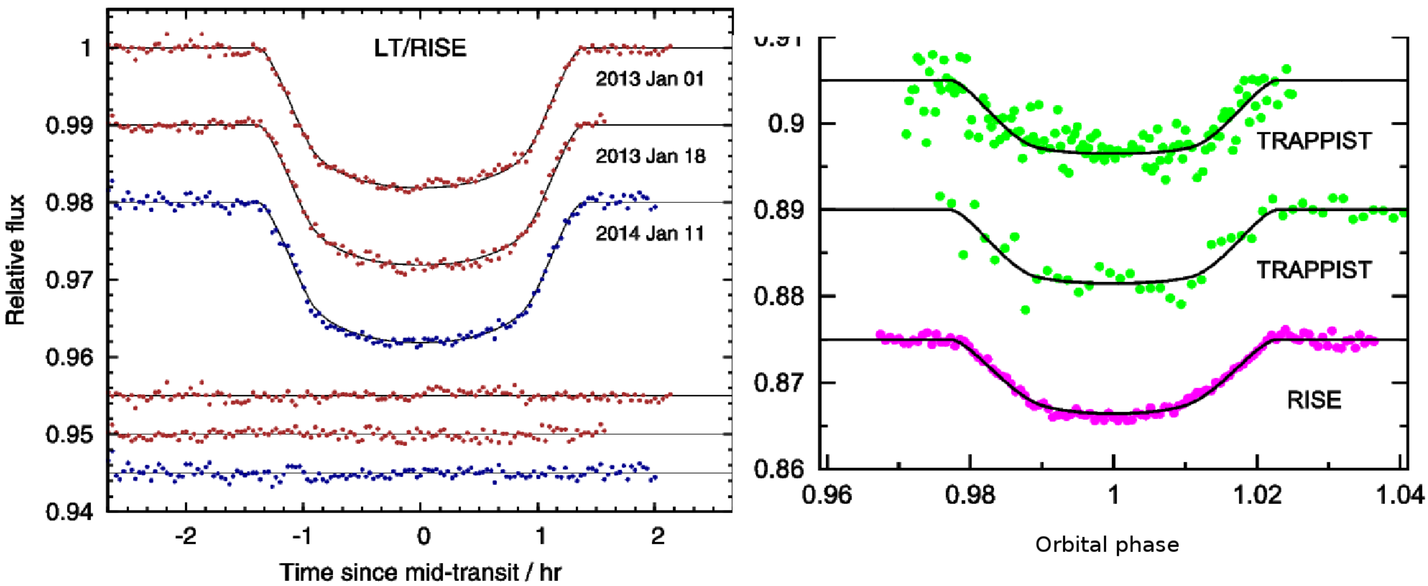

Fig. 2. Example light curves published by our group. The left panel shows three RISE light curves of WASP-84 (fig. 1 from Anderson et al. 2015). The right panel shows one RISE light curve of WASP-74 (base of Fig. 1 from Hellier et al. 2015).