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Assessment Phase Payload Study

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1 PREAMBLE

1.1 SCOPE

This document presents a summary of the construction of a new bright M dwarf catalogue (by Frith & Pinfield and collaborators), which is combined with a recent catalogue from the literature (Lepine & Gaidos 2011) to provide an optimal M dwarf list of potential EChO targets. Current constraints from radial velocity surveys are then used to simulate a Super-Earth planet population around these M dwarfs and the results examined in the context of EChO observations. In addition a brief summary is presented of an ongoing programme of high resolution spectroscopy to place inclination constraints on these M dwarfs, so as to prioritise them for targeted transit searching. Through a collaboration with the LCOGTN and Apache teams a plan exists to fast-track the full process of transit discovery around EChO M dwarfs.

1.2 PURPOSE

The reason for this document to exist is to explore the future prospects for EChO targets consisting of Super-Earths transiting M dwarf stars, and present a summary of some ongoing work in this area.

1.3 APPLICABLE DOCUMENTS

AD #	APPLICABLE DOCUMENT TITLE	DOCUMENT ID	ISSUE / DATE
1			
2			
3			

1.4 REFERENCE DOCUMENTS

RD #	REFERENCE DOCUMENT TITLE	DOCUMENT ID	ISSUE / DATE
1			
2			
3			

2 INTRODUCTION

Four planets are currently known to transit M dwarfs, GJ1214b, GJ3470, GJ436, and KOI-254. With the exception of the Kepler system (Johnson et al. 2012), the host stars are all bright in the near-infrared (K=6.1-8.8) and the systems are thus good targets for characterization by EChO. Two of these were discovered using the radial velocity (RV) method (GJ3470b and GJ436b; Gillon et al. 2007; Bonfils et al. 2012) and have masses similar to Neptune (~15-20Mearth), while GJ1214b was discovered by the M-Earth survey using the transit method (Charbonneau et al. 2009), and has a mass of 5.9 Mearth. GJ1214 is currently the only known system with a Super-Earth transiting an M dwarf, however, there is a lot of community effort ongoing to change this situation.

RV survey teams now routinely target new planet systems for transit follow-up, so this source of bright M dwarf transits will continue to steadily confirm new transits. But it is the transit method itself that holds the greatest potential for identifying new M dwarf planet transits in the coming years, with Super-Earths very much the focus. There is much work underway to identify these systems using ground-based transit surveys that target individual bright M dwarfs for full-phase light curve follow-up in red optical bands. MEarth is one such survey (Charbonneau et al. 2008), with others including APACHE (Giacobbe et al. 2012) and the Los Cumbres Global Telescope Network (Shporer et al. 2011), whose collective goal is to identify the transiting planets around the brightest M dwarfs in the sky.

At the same time work has been underway to maximize the number of bright M dwarfs known, so that they can be targeted for a range of exoplanet studies. Previously M dwarf populations had been identified as high proper motion samples, but this naturally introduced a significant level of incompleteness (e.g. a proper motion sample with >150mas/yr is 50% incomplete for M dwarfs at 40pc distance). Lepine & Gaidos (2012) have used the Super-Blink proper motion survey to identify M dwarfs with J<10 and proper motion >40mas/yr, while the author of this technical note has been involved in the creation of a new bright M dwarf catalogue using the PPMXL absolute proper motion catalogue. This catalogue specifically targets the K<9 brightness range high-lighted by the work of Tessinyi et al. (2012) who explored how missions like EChO might characterize the atmospheres of transiting planets.

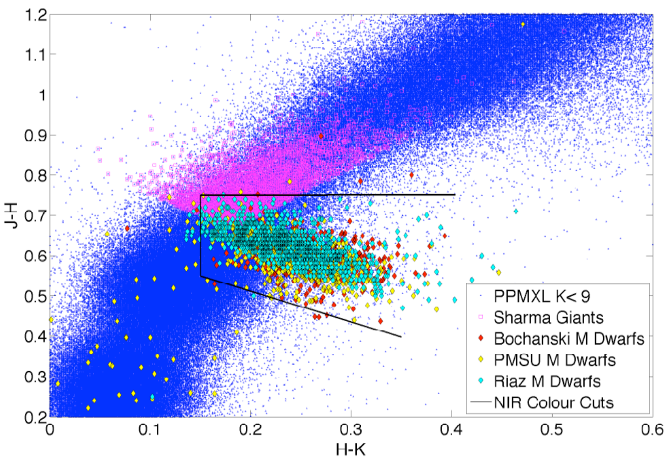
In Sections 3.1 and 3.,2 a summary is presented of the construction of the new bright M dwarf catalogue. In Section 3.3 a simulation is described that predicts the numbers and properties of planets transiting M dwarfs that we may expect to find in the next few years – the future EChO M dwarf targets. Section 3.4 summarises ongoing efforts to expedite the discovery process through spectroscopic follow-up.

3 THE PROSPECTS FOR SUPER-EARTHS TRANSITING BRIGHT M DWARFS

The following section describes how bright M dwarfs were selected in order to be as complete as possible at the low proper motion end. The new catalogue is then compared and combined with the recent catalogue of Lepine & Gaidos (2011). A population of planets is then simulated around M dwarfs with K<9 and their properties considered. In the final section a programme to expedite the discovery of transits is briefly described.

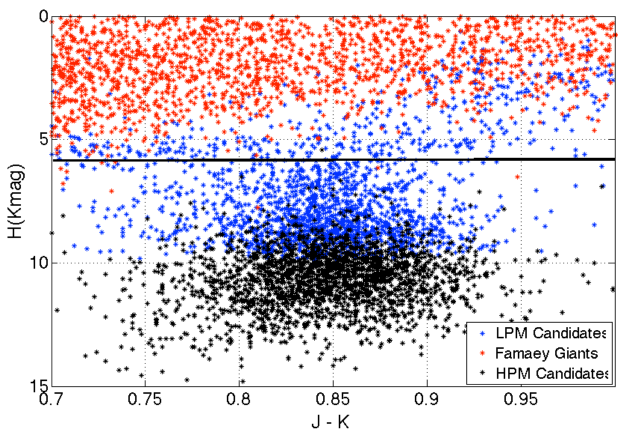
3.1 BRIGHT M DWARF SELECTION TECHNIQUES

The first step is to remove the Galactic plane (between galactic latitudes of +15 and -15). Saturated 2MASS stars were also removed since their photometric uncertainties and large and colour selection will be poor. Next a set of near-infrared colour cuts were applied to select M dwarfs (see the figure below).

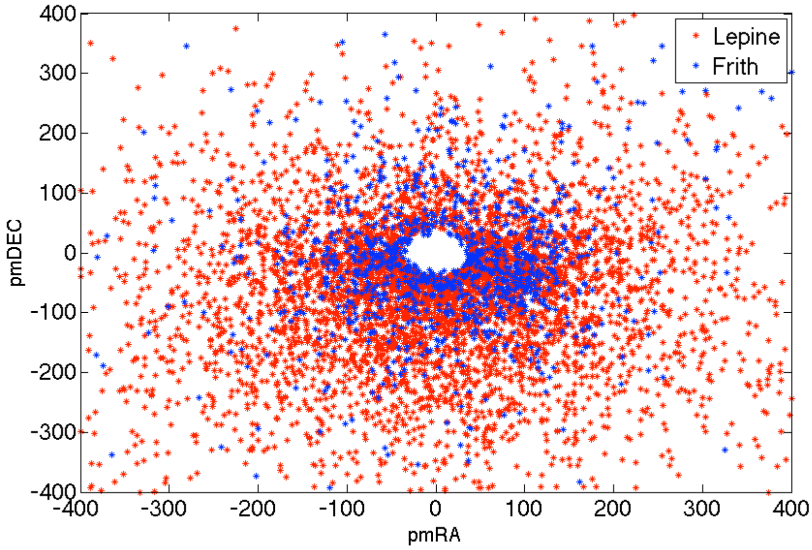


It is important to reject giants and reddened background stars that can contaminate M dwarf colour space, and additional optical/near-infrared cuts were applied to reduce contamination levels further. However, much contamination remains in the sample after all colour cuts are applied.

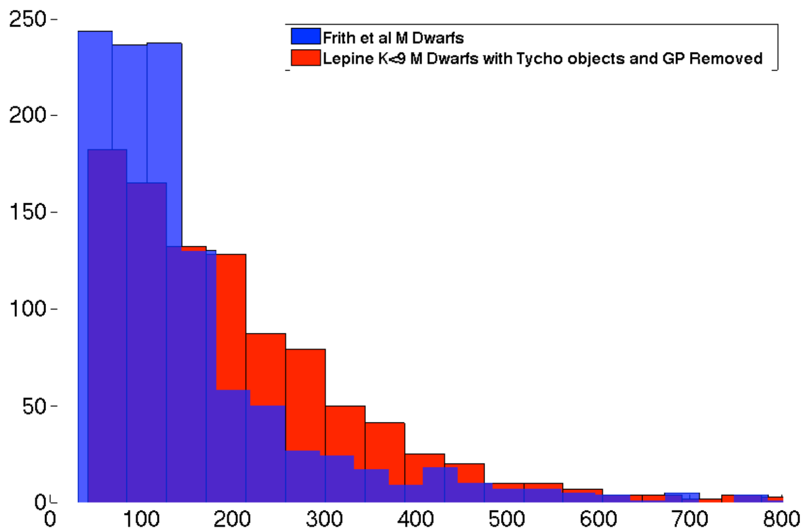
Proper motion and reduced proper motion allows additional means to reject giants and reddened background stars. We required the uncertainty associated with proper motion measurements to be no more than 25%, and then imposed a reduced proper motion criteria. The following figure shows the reduced proper motions of the colour selected sample. The black points are a high proper motion sample of M dwarfs, and the red points are a clean colour selected sample of giant stars. A cut was chosen (black line) to separate dwarfs from giants within the candidate sample.



These proper motion and reduced proper motion criteria probe to lower proper motions than the hard cut-off used in the catalogue of Lepine & Gaidos (2011), as can be seen in the following figure.



The new catalogue and the Lepine & Gaidos are complementary however (see the next histogram). The new search is better at identifying low proper motion M dwarfs where the absolute astrometry of PPMXL will reduced contamination from non moving giants. However, the Lepine & Gaidos catalogue is to be preferred at higher proper motions due to the more complete approach used to construct the high proper motion contingent from the SuperBlink survey.



3.2 ECHO M DWARFS – THE CATALOGUES

Given the complementarity of the two M dwarf catalogues they have been combined together. In the following tables we summarise the main characteristics and important differences of the two catalogues. Also shown are the n umber of bright M dwarfs (with K<9) that are available. This totals 7962 objects.

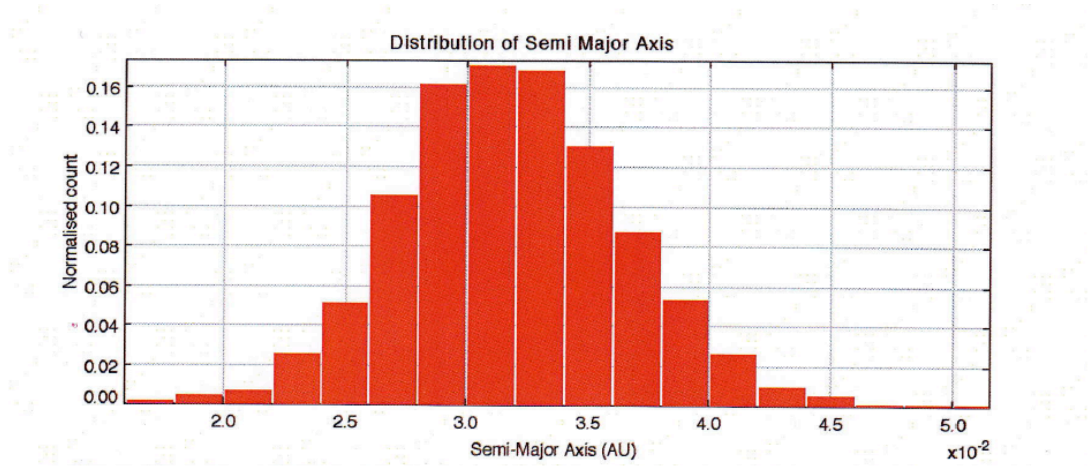
Frith & Pinfield	Lepine & Gaidos
K<9 H-K>0.15 Various optical colour cuts	J<10 H-K>0.1 Limited optical colour cuts
PPMXL (USNO-B+2MASS, ICRS absolute proper motions)	SuperBlink (relative proper motions)
No strict proper motion cut-off	Proper motions >40 mas/yr

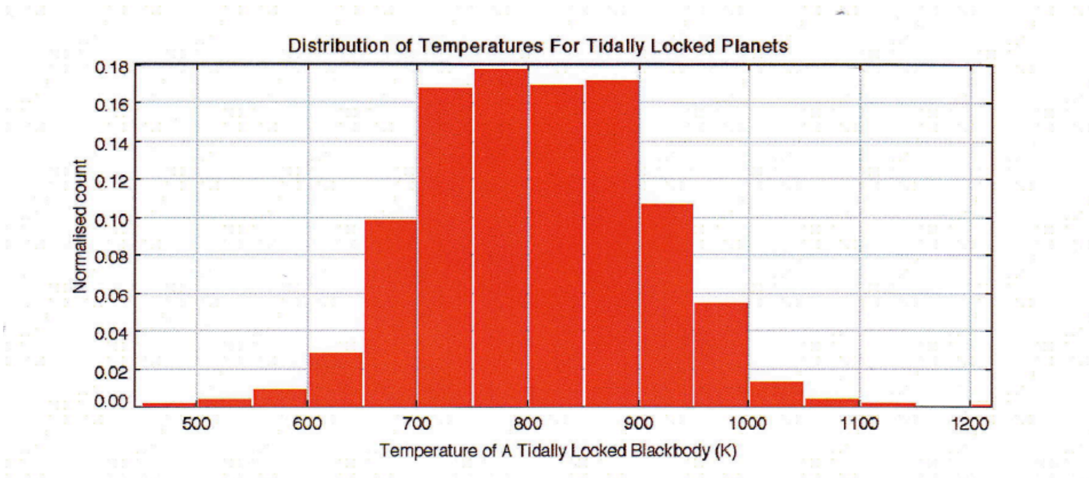
K mag	Lepine Gaidos	Frith & Pinfield	Total
<5	28	1	29
5-6	134	5	139
6-7	466	23	489
7-8	1501	134	1635
8-9	4728	942	5670
<9			7962

3.3 SIMULATED M DWARF PLANETS

To simulate the likely yield of possible transiting planets around the combined sample of bright M dwarfs, a Monte-Carlo simulation was carried out using Super-Earth planet fractions and observed distributions from the known radial velocity population of M dwarf planetary systems. Recent observations from HARPS constrain the M dwarf Super-Earth (1-10 MEarth) planet fraction to be 25-60% (67% confidence) for orbital periods of 1-10 days (Bonfils et al. 2011). Inclination angles were assigned randomly and eccentricities were assigned using a folded Gaussian distribution (with a mean of 0.0 and a standard deviation of 0.3). Predicted transits were then identified with sufficient inclination if a transit depth >0.5% was found. Planet temperatures were calculated assuming a mixture of both tidally locked and rapidly rotating planets (i.e. to account for a range of heat distributions throughout the planetary atmospheres). The simulation was run 100 times to produce a statistical spread for the expected properties.

Typically about 10 transiting planet were found, with the semi-major-axis and temperature distributions shown below.





Considering the hot (800-2000K), warm (350-800K) and HZ (250-350K) planetary temperature definitions put forward by Tessenyi et al. (2012), the predictions clearly show that essentially all the Super-Earths transiting M dwarfs will either be hot or warm, with a roughly even split between these two temperature ranges.

3.4 CAN WE SPEED UP TRANSIT DISCOVERY?

The process of identifying these predicted transiting planets around the known population of bright M dwarfs is a challenge for the next few years. Surveys like MEarth, LCOGTN and Apache are taking the approach of targeting individual M dwarfs with a host of small (0.5-1m) telescopes, and searching for transits in the resulting light curves. There are several important factors to be considered for success;

- The target lists of these surveys need to be optimized to include the brightest M dwarfs from the available catalogues. The LCOGTN and Apache teams are actively involved in the EChO consortium, and are collaborators in the M dwarf programme described here.
- Search methods must be refined/established that are capable of identifying the transit signatures in a high fraction of the light curves of the targeted M dwarfs. The light-curve data is complicated both by intrinsic M dwarf variability and by the nocturnal cadence, atmospheric variations, and instrumental systematics associated with the ground-based observations (e.g. Berta et al. 2012). The latest technique of the MEarth team (Berta et al. 2012) uses a computationally efficient semi-Bayesian approach to explore the vast probability space spanned by the many parameters of the model, naturally incorporating the uncertainties in these parameters into the evaluation of candidate events. Such methods robustly assess the false alarm probability of M dwarf transit

signals and provide a practical route to optimal follow-up and RV confirmation of all the candidates.

- The systems with the highest inclination angles should be identified and targeted as a priority since planets orbiting in a plane perpendicular to the rotation axis will be more likely to transit in such systems. A large programme of low and high resolution spectroscopy is now underway to confirm the spectral types of bright M dwarfs and also measure vsini and activities. The combination of activity with vsini allows one to place constraints on the inclination angle due to the rotation-activity relation for early-mid M dwarfs (e.g. Herrero et al.2012). At this time the programme is targeting the brightest 500 M dwarfs.

In summary, with effective implementation of developing surveys and techniques we can expect to discover at least 10 Super-Earths transiting bright M dwarf stars in the next 5-10 years, adding a diversity of Super-Earth atmospheres to the existing range of targets for the proposed EChO mission.

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