Exploring the nearest ultra-cool dwarfs for terrestrial exoplanets

Artem Burdanov
(on behalf of SPECULOOS consortium)

Massachusetts Institute of Technology

4th Zeldovich virtual meeting – 11 September 2020
Exploring the nearest ultra-cool dwarfs (UCDs) for terrestrial exoplanets

Artem Burdanov (burdanov@mit.edu)

Talk outline

Introduction

What are ultra-cool dwarfs (UCDs)?
Why is it worth searching for transiting exoplanets around UCDs?

Main part

Photometric searches for terrestrial exoplanets transiting UCDs

Summary
What are ultra-cool dwarfs (UCDs)?

- UCDs – dwarf stars and brown dwarfs with $T_{\text{eff}} < 2700$ K
- Luminosity $\lesssim 0.001 L_{\odot}$
- Spectral type – later than M6, including L, T, and Y dwarfs (Kirkpatrick 2005; Cushing et al. 2011)
What are ultra-cool dwarfs (UCDs)?

- Mass $\lesssim 0.1 \, M_\odot$
- Radius $\sim 0.08 - 0.13 \, R_\odot$
What are ultra-cool dwarfs (UCDs)?

Spectral Energy Distribution (SED) of Sun and TRAPPIST-1 star (spectral type M8)

Figure from O'Malley-James and Kaltenegger 2017
What are ultra-cool dwarfs (UCDs)?

- Fully convective and well-mixed
- Main-sequence lifetime: >1000 Gyr
- > 5 : 1 UCDs:G dwarfs in the 8 pc sample (Kirkpatrick et al. 2012)
Known planets around UCDs

don direct imaging: 3
 microlensing: 9
 radial velocity: 2
 astrometry: 1
 transit photometry: 7

Known planets around UCDs
Transit photometry is a powerful discovery method and characterization technique.

- Orbital inclination
- Stellar density, which affects the shape of the transit light curve
- Orbital period (semi-major axis) if at least two consecutive transits were observed
- Highly complimentary by the radial velocity method

\[ \Delta F_{\text{tra}} \approx \left( \frac{R_p}{R_*} \right)^2 \]
Transit spectroscopy

Figures from de Wit & Seager (2014) and Sedaghati et al. (2017)

Many gas giants are objects of these studies

WASP-19 b

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Amplitude of the signal for major spectral features

Transit depth must be large!

Transit depth $< 0.01\%$

Transit depth $\sim 1\%$

Sun

Ultra-cool dwarf

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Figure 4.1: The dotted blue line is the probability of transit, dashed red line is the transit depth, and the black line is the number of transit (or occultations) that are observable for an Earth-like planet with an equilibrium temperature of 255 K as a function of the host star’s mass. Image from Triaud et al. (2013).
Habitable zone of main sequence stars

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Atmospheric characterization of terrestrial exoplanets

James Webb Space Telescope (launch in Oct 2021)

European Extremely Large Telescope (first light in 2025)

Searches for transiting planets around UCDs

Peters Automated InfRared Imaging TELeScope (PAIRITEL) survey: 13 UCDs in 2004 and 2005 for a period of 10 months (Blake et al. 2008). **No transit detections.**

Precision $\sim$1-2% / 5 min

ex-2MASS survey reflector (1.3-m telescope)
Searches for transiting planets around UCDs

• Since 2011, prototype survey with TRAPPIST (TRAnsiting Planets and PlanetesImals Small Telescope) 60-cm robotic telescope at La Silla observatory (Chile)

• Targets: 50 brightest southern ultra-cool dwarfs + 30 M6-type stars
7 Earth-sized planets transiting an ultra-cool star TRAPPIST-1 at 12 parsec (Gillon et al. 2016, 2017)

Figures from Gillon et al. 2017
the TRAPPIST-1 system

Atmospheric characterization with the next generation of telescopes!

Search for habitable Planets
EClipsing ULtra-cOOL Stars
Main concept

Observing ~1200 brightest ultra-cool dwarfs (Kmag ≤ 12.5)

Main goal

Probe with ≥70% efficiency their inner habitable zone for transiting exoplanets of Earth-size and below

More details in Delrez et al. 2018, Murray et al. 2020, Sebastian et al. 2020 (in review), Burdanov et al. 2018
How to reach the goal?

- Ultra-cool dwarfs are distributed uniformly across the sky ➔ targeted survey

- Possible transits can be rather short ➔ continuous monitoring of targets

- Ultra-cool dwarfs are faint in optical range ➔ large telescope + near-IR-optimized CCD

- Efficient exploration of habitable zone ➔ observing of each target up to 20 nights
SPECULOOS survey

SPECULOOS targets: spatial distribution (Aitoff projection)

Image credit: Adam Burgasser
Figure 2. Histograms of the SPECULOOS targets as a function of their spectral type (left) and $K$-band magnitude (right).

Figure from Delrez et al. 2018
The core of SPECULOOS

- Four 1-m robotic telescopes at ESO Paranal observatory (Chile): operational since January 2019
- One 1-m robotic telescope at Teide observatory (Spain): operational since June 2019
- One 1-m robotic telescope at the National Astronomical Observatory of Mexico (Mexico): operational since mid-2019

SPECULOOS survey

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Hardware

- All SPECULOOS telescope are identical (1-m RC) and robotic
- 6.25-m diameter wide-slit
- NTM-1000 direct drive mounts (no meridian flip)
- 1-m diameter primary mirror (F/2.3) + 28-cm diameter secondary at a relative distance of ~1.6 m, resulting in a combined F/8
- Optical tube assembly made of steel, aluminium and carbon fibre components
- Focusing by a motorized axial motion of the secondary mirror
- Raw aluminium coating
Hardware

- Andor iKon-L thermoelectrically-cooled camera with a near-IR-optimized deeply depleted 2K×2K e2v CCD detector (13.5 μm pixel size)

- CCD is operated at -60°C and 1MHz readout mode with a dark current of ∼0.1 e−/s/pixel

- 12′×12′ FOV, pixel scale of 0.35”/pixel

- FLI filter wheel with Sloan-g’, -r’, -i’, -z’ filters, and special exoplanet filters “I + z” and “blue-blocking”

- Boltwood II weather station + SBIG all sky camera

Figure from Delrez et al. 2018
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Photometric precision – SPECULOOS vs. TESS

Figure from Murray et al. 2020
- Eclipsing brown dwarf binary with a period $20.902 \pm 0.006 \, \text{d}$ (which happened to be double-lined); See Triaud, Burgasser, Burdanov et al. 2019
- Quite a few follow-up observations of NGTS, TESS, K2 candidates (e.g. K2-315b Niraula et al. 2020)
Other photometric surveys

• EDEN transit surveys: started 2 years ago, no detections

• ExTrA transit survey: being commissioned, no detections

• Kepler/K2: no detections (see Sestovic and Demory 2020)

• Spitzer: Search for transits in Spitzer archival data of 44 nearby BDs (He et al. 2017), no detections

• Spitzer: Search for exoplanets transiting equator-on UCDs. One unconfirmed candidate (Spitzer Proposal ID #14257)

• Tamburo & Muirhead 2019: Design Considerations for a Ground-Based Search for Transiting Planets around L and T Dwarfs
Summary

• Planetary population around UCDs is mostly unexplored

• Transiting planets around UCDs are favorable targets for atmospheric research with JWST and E-ELT

• Only one transiting system around UCD is found so far (7 terrestrial planets in the TRAPPIST-1 system)

• SPECULOOS survey has started its operations (one brown dwarf eclipsing binary is found), photometric performance is very promising

• More surveys are expected to explore UCDs for transiting planets