Characterizing ultra-cool dwarfs on the search for exoplanets the SPECULOOS project & the Trappist-1 system

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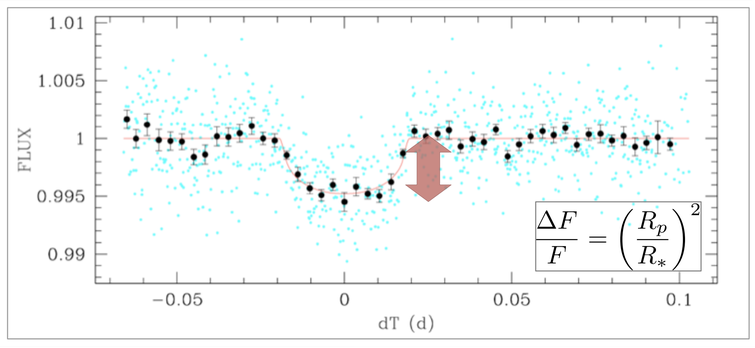
Ultra-cool dwarfs & transiting exoplanets

- Ultra-cool dwarf stars (UCDs) (M6-M9) are the smallest, dimmest, coolest and most abundant stars in our galaxy
  - M_*=0.07 — 0.10 $M_\odot$, R_*=0.09 — 0.15 $R_\odot$
  - Teff=2,000 — 2,600 K, logg = 5.0 — 5.5
- High probability of detecting small planets
- Studying the host star sets the physical constraints for exoplanets and for the potential to sparkle life

- The SPECULOOS project will search for transiting exoplanets
- This is a survey targeting the nearest UCDs with four 1-m robotic telescopes at Paranal, Chile
- This concept has been tested with the Trappist-South and North telescopes



Trappist-1e transit. Combined light-curve observed with "Europa" and "Io" telescopes

Trappist-1 system

Seven earth-sized planets orbiting a M8 dwarf at 12 pc

Gillon et al. 2016, Nature 533, 221 | Gillon et al. 2017, Nature 542, 456

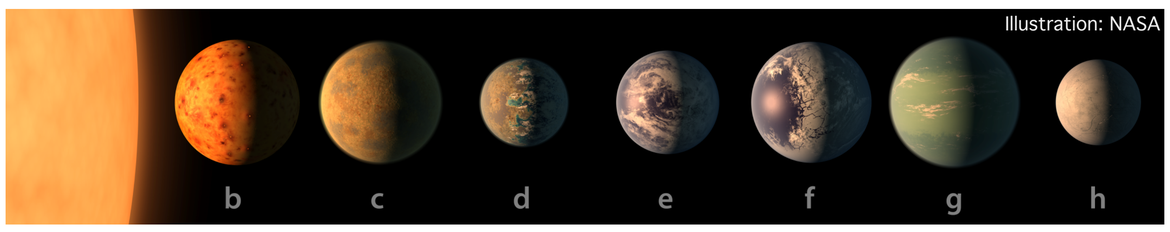
Planets

- 3 planets in the Habitable Zone
- Assuming Earth-like atmospheres these could harbour liquid water oceans on their surface

Host star

2MASS J23062928 – 0502285

- Stellar parameters from observations and from combining observations and stellar models
  - L_*=(0.000524 ± 0.000034)$L_\odot$, ρ_*= $50.7^{+1.2}_{-2.2}\rho_\odot$
  - [Fe/H]= 0.04 ± 0.08, Age > 500 Myr
  - M_*=(0.082 ± 0.011)$M_\odot$, R_*=(0.116 ± 0.006)$R_\odot$, Teff= 2,555 ± 85 K



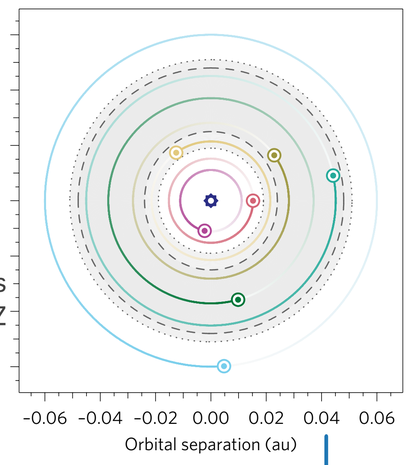
Kepler-2 mission

Luger et al. 2017, Nat. Astron, 1, 0129

data-analysis from the K2 campaign 12

7-planet resonant chain

- Trappist-1 h period confirmed: 18.77 days
- No additional planets detected
- 3-body orbital-resonance



View from above at the date when the first transit was obtained. The grey region is the surface liquid water HZ

Low-activity, middle-aged, late M-dwarf

- Flare rate above 1% of the continuum: 0.26 events/day
- Stellar rotational period: 3.3 days
- Stellar age: 3 — 8 Gyr

K2 data. Long cadence (texp = 30 min)

Super flare one in 78 days (K2 data length)

Stellar models for UCDs and the Trappist-1 star

CLES Code Liégeois d'Évolution Stellaire

Scuflaire et al. 2008, Astrophys. Space. Sci.316, 83

Stellar evolution code developed at the University of Liege

Updated CLES

Fernandes et al. in prep.

Recently adapted to account for low-mass stars

- Include meaningful equation of state [1], [2]
- Adapt public atmosphere model grid: BT-Settl [3]
- Able to choose different metallicities, other than solar
- Compared with low-mass stellar evolution code (BHAC15) [4] with the same input physics (differences less than 1%)
- Testing with M7 binary [5]: M (dynamical [5]) = 0.088 ± 0.001 $M_\odot$
  - M (CLES & [6]) = 0.078 ± 0.03 $M_\odot$ (with [Fe/H] (1σ) = 0.12)
  - M (BHAC15) = $0.048^{+0.012}_{-0.019}$ $M_\odot$

Stellar luminosity and density for CLES and BHAC15 evolution models for 0.08 $M_\odot$ and 0.09 $M_\odot$ with various metallicities, compared to luminosity and density measured for Trappist-1. If Trappist-1 star was 'young': M_* = 0.08 $M_\odot$ would agree with observations

Testing new age

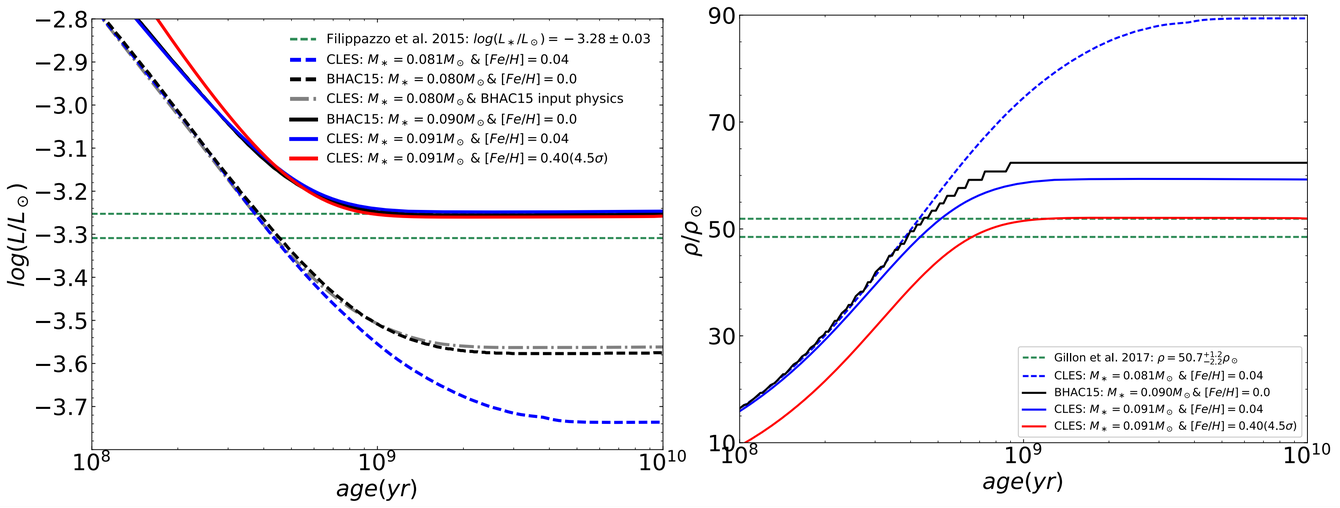
Van Grootel et al. in prep.

Trappist-1 is not a young-star

- Indications of a middle-aged star has recently been constrained in [7] to 7.6 ± 2.2 Gyr

New-mass from stellar models

- M_*=0.09 $M_\odot$, with CLES and also confirmed by BHAC15 for measured luminosity
- Need to increase the metallicity to further account for the stellar density derived from transits



Conclusion and what is next

- UCDs are excellent targets for searching transiting earth-sized planets
- Trappist-1 system was discovered while surveying UCDs
- CLES stellar evolution code is ready to carry-on studies with UCDs
- To account for an age > 7Gyr for Trappist-1, the stellar models suggest a revision of the stellar mass which has an affect on planetary-star relations
- New discoveries made with the SPECULOOS project are potential targets for the Extremely Large Telescopes and the JWST/NASA with further studies on atmospheric characterisation and searching biosignatures
- Continuing working on improving stellar evolution models for low-mass stars

SPECULOOS project

"Europa" and "Io" telescopes at SPECULOOS Southern Observatory at ESO Paranal Observatory, Chile. Credit: P. Annual

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The SPECULOOS project is an international collaboration

Sponsors

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- [4] Baraffe, I., Homeier, D., Allard, F., & Chabrier, G. 2015, A&A, 577, A42
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- [6] Press, W. H., Teukolsky, S. A., Vetterling, W. T., & Flannery, B. P. 1992, Numerical recipes in FORTRAN
- [7] Burgasser & Mamajek 2017, arxiv: 1706.02018