# *Results of the intensive program* S23A-067I

(and the whole TESS follow-up project)

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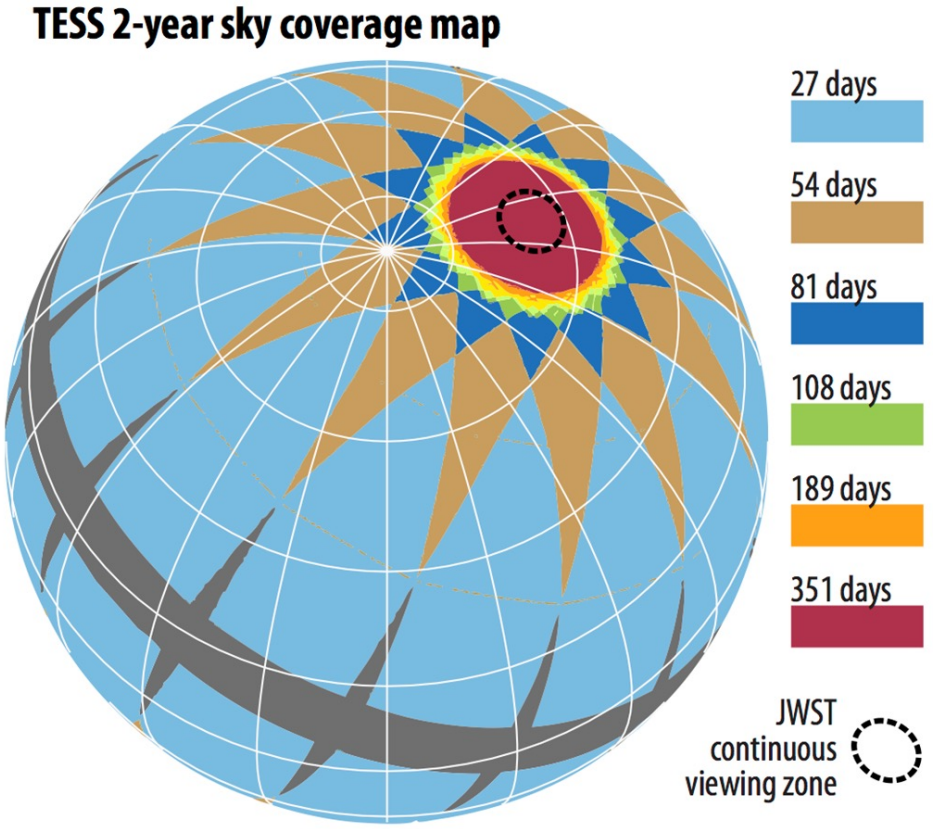
# TESS Introduction

Launched on April 18, 2018

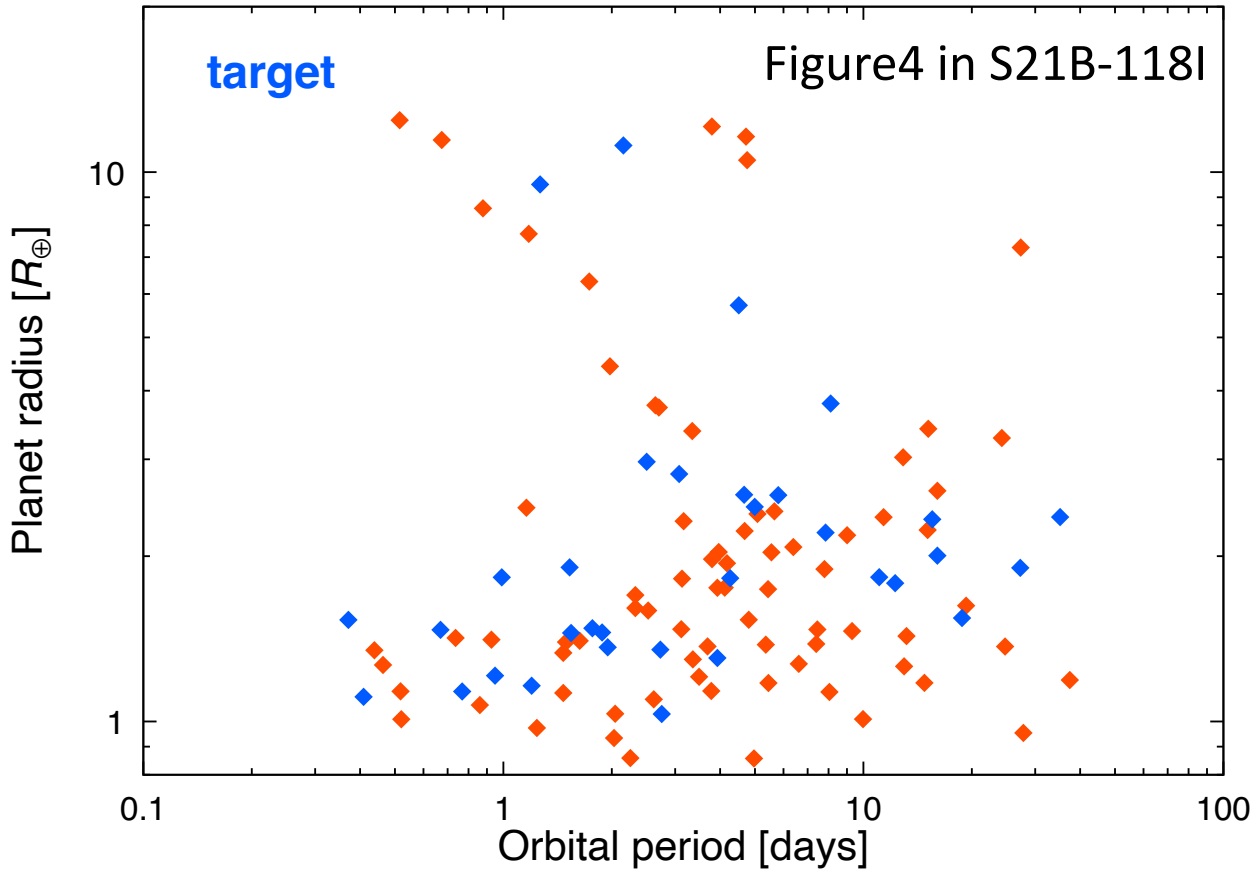

Observing 24 deg x 96 deg FoV ("sector") at a time for 27.4 days

TESS completed the primary mission (2018-2020 July) and

currently the 2nd extended mission (ETM2) is ongoing (2022-2024)

# TESS candidate planets (TOIs) around stars $T_{eff}$ < 3500K

TESS has discovered 100+ TOIs as of April 2021 (250+ by Jan 2023)




In the previous IRD intensive programs (S19A-069I, S20B-088I, S21B-118I),
we have observed ~35 TOIs to characterize
their masses, orbits, and atmospheres with Subaru IRD

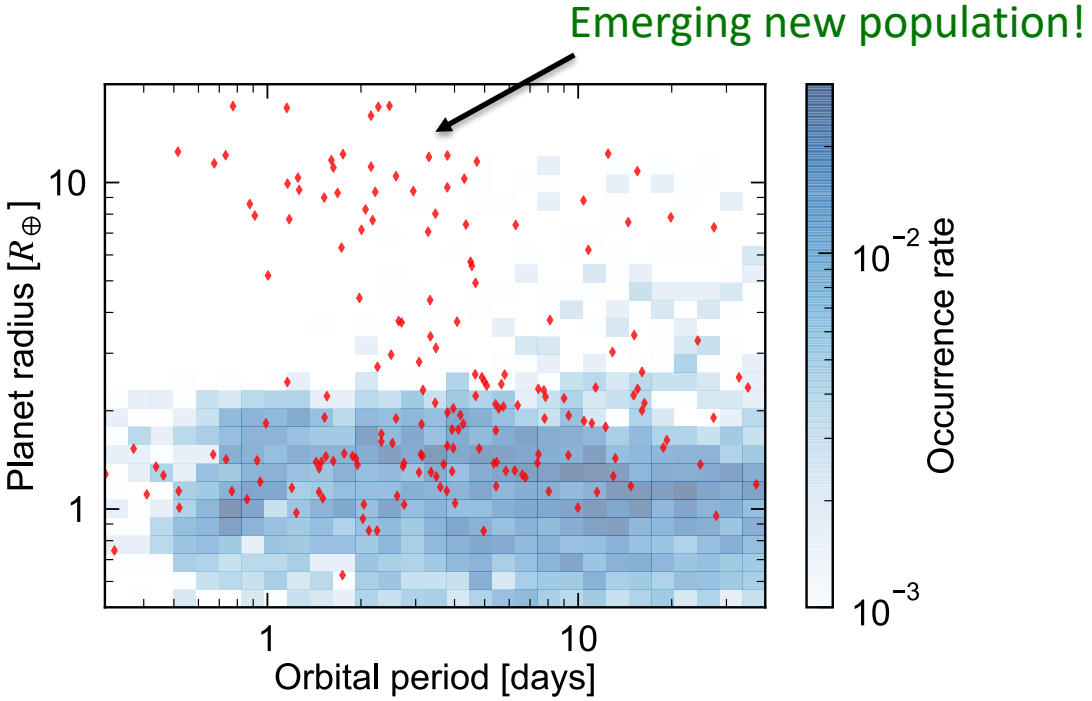
# The latest intensive program S23A-067I

## Purpose of S23A-067I

To gain knowledge which can place crucial constraints on the formation and evolution of planets and planetary systems around mid-late M dwarfs.

### Main targets

- Close-in giant planets
- Eccentric sub-Neptunes
- Multiple planetary systems




Comparison between known TOIs (red dots) around M dwarfs (Teff < 3500K) with the latest theoretical prediction (blue shade) by Kimura & Ikoma (2022).

# Numbers of allocated nights and success rate (23A-23B)

## S23A-067I (25 nights: 2 semesters x 12.5 nights)

- 23A: 12.5 nights -> 2.5 successful nights
- 23B: 12.5 nights -> 2.5 successful nights
- Success rate: 5/25 = 20%

## What we could complete

- Discovery and mass determination of two close-in giant planets
  - TOI-4860b (Triaud et al. 2023)
  - TOI-XXXXb (de Leon et al. in prep.)

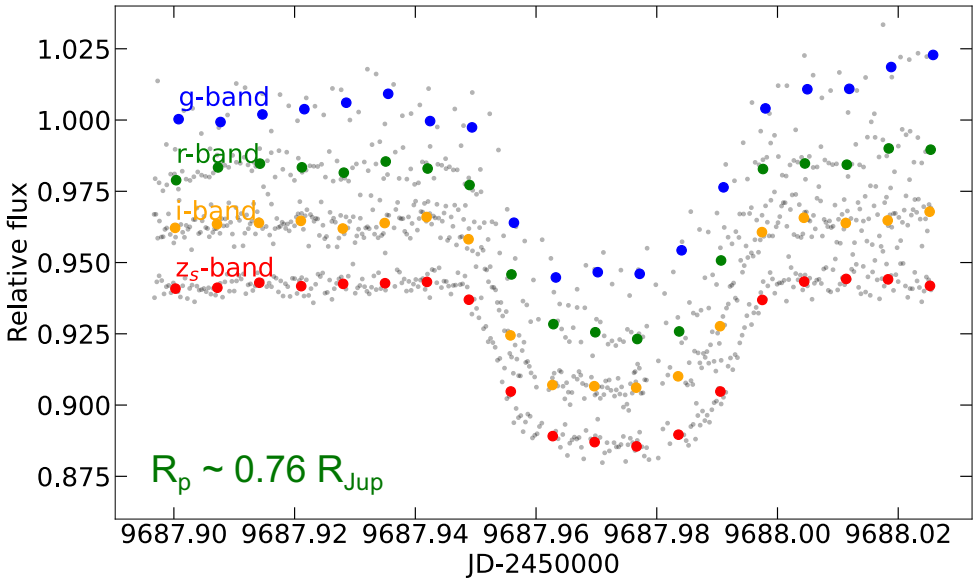
## What we could not complete

- Mass determination of a close-in super-Neptune with an outer planet
- Mass determination of several sub-Neptunes (including eccentric ones) with additional planets

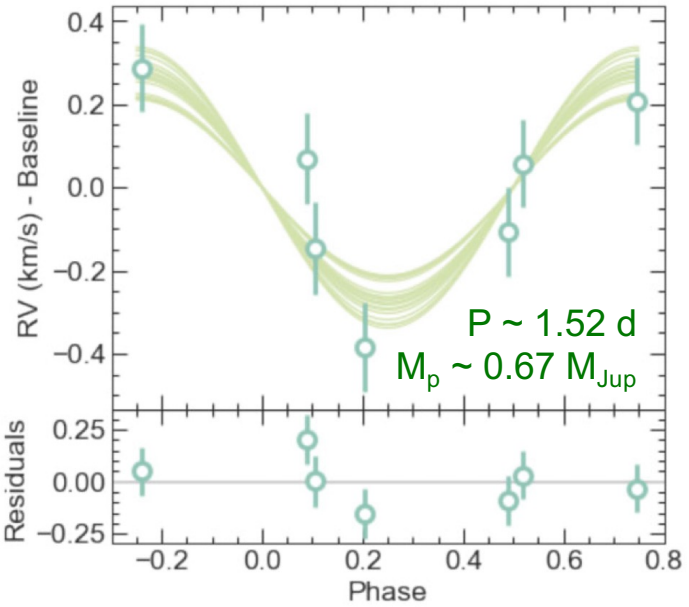
# Discovery and Characterization of TOI-4860b

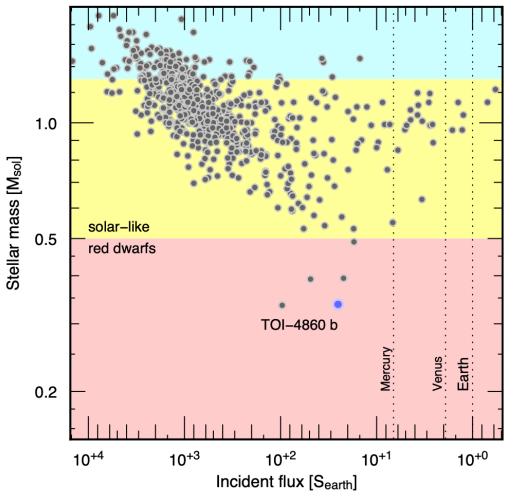
## Discovery of a close-in giant planet around an M4.5 dwarf ($T_{eff}$~3,390K)

### Multi-color transit with MuSCAT3




### RVs with IRD




TOI-4860b is one of the close-in giant planets orbiting lowest mass stars (still sparsely populated)

Triaud et al. (2023)

# Numbers of allocated nights and success rate (19A-21A)

## S19A-069I (3 semesters x 3 nights + 1 compensation night)

- 19A: 3 nights -> 1.5 successful nights (1.5 night lost due to weather)
- 19B: 3 nights -> 1 successful night (2 nights lost due to weather)
- 20A: 3 nights -> 0 night (all nights lost due to weather and COVID)
- 20B: +1 night -> 1 successful night (compensation for COVID)

## S20A-103N (4 nights, thanks to the special rule)

- 20A: 4 nights -> 0 night (all nights lost due to weather and COVID)

## S20B-088I (2 semesters x 7 nights, although requested 6 semesters)

- 20B: 7 nights -> 5 successful nights (2 nights lost due to weather)
- 21A: 7 nights -> 2.5 successful nights (4.5 nights lost due to weather and telescope trouble)

- 11 successful nights in total / 28 allocated nights (39% success, 19A-21A)

# Numbers of allocated nights and success rate (21B-23B)

## S21B-118I (3 semesters x 10 nights)

- 21B: 11 nights -> 5 successful nights
- 22A: 3 IRD + 3.5 MAROON-X nights -> 1 + 3.5 successful nights
- 22B: 11.5 IRD + 1 MAROON-X nights -> 3 + 1 successful nights

## S23A-067I (2 semesters x 12.5 nights)

- 23A: 12.5 nights -> 2.5 successful nights
- 23B: 12.5 nights -> 2.5 successful nights

## Total success rate (19A-23B: 5 years)

- Success rate (19A-23B in total): 29.5/83 = 35.5%

# Publications using the IRD intensive data

## Published papers (reported in Subaru UM FY2021)

1. TOI562 (Luque+ 2019): validation
2. TOI736 (Crossfield+ 2019): validation
3. TOI2221=AU Mic (Hirano+ 2020): spin-orbit alignment, press release
4. TOI488 (Kemmer+ 2020): mass determination / additional planet
5. TOI732 (Nowak+ 2020): mass determination
6. TOI1640 (Soto+ 2021): mass determination
7. TOI1634 & 1685 (Hirano+ 2021): mass determination, press release
8. TOI2221=AU Mic (Cale+ 2021): mass determination
9. TOI2285 (Fukui+ 2022): validation, press release

# Publications using the IRD intensive data

## Published papers (reported in Subaru UM FY2022)

10. TOI1696 (Mori+ 2022）: validation, sub-Neptune
11. TOI1452 (Cadieux+ 2022): validation, temperate sub-Neptune
12. TOI2136 (Kawauchi+ 2022): validation, helium search, sub-Neptune
13. TOI4306 (Delrez+ 2022): validation, habitable super-Earth, press release
14. TOI5557 (Hirano+ 2023): validation, Earth-sized planet, also observed in openuse&SSP

# Publications using the IRD intensive data

## Published papers (after Subaru UM FY2022)

15. TOI1442,2445 (Morello+ 2023): validation, ultra-short period planets
16. TOI519 (Kagetani+ 2023): mass determination, giant planet
17. TOI4860 (Triaud+ 2023): mass determination, giant planet

## Papers submitted (after Subaru UM FY2022)

18. TOI782, 1448, 2120, 2406 (Hori+ submitted): sub-Neptunes, validation
19. TOI663 (Cointepas+ submitted): multi-transiting planets, validation
20. TOI6008 (Barkaoui+ submitted): ultra-short period planet, validation

# Publications using the IRD intensive data

## Papers in preparation

21. TOIXXXX (de Leon+ in prep.): mass determination, giant planet
22. Helium transmission spectroscopy (Kawauchi+ in prep.)

## Need more data

23. TOIXXXX (Fukuda+): mass determination, super-Neptune
24. TOIXXX, XXX (Ikuta+): inner sub-Neptune + outer planet
25. TOIXXXX (Narita+): inner eccentric sub-Neptune + outer eccentric giant planet
26. TOIXXXX (Fukui+): ultra-short period brown dwarf
27. TOIXXX, XXXX, XXXX: eccentric sub-Neptunes
28. TOIXXXX: mass determination / collaboration with Gemini-N/MAROON-X

22+ publications from 29.5 successful nights

# What we have achieved

- We have discovered (either constrained or determined masses of) 32 planets in 25 planetary systems using the IRD intensive data
  - 14 likely Earth-like planets, including one in the habitable zone
    - TOI562b, TOI736b, TOI488b, TOI732b, TOI1442b, TOI1634b, TOI1685b, TOI2445b, TOI4306b&c, TOI5557b, TOI1442b, TOI2445b, TOI6008b
    - contributing to one of the Science Goals of Subaru Telescope 2.0
  - several super-Earths and sub-Neptunes (favorable for future atmospheric characterization with JWST, Ariel)
  - three close-in giant planets around mid-M dwarfs, which were thought to be very rare (high impact on planet formation models)
- We have also identified several planetary systems with additional outer planets
  - also important for planet formation models