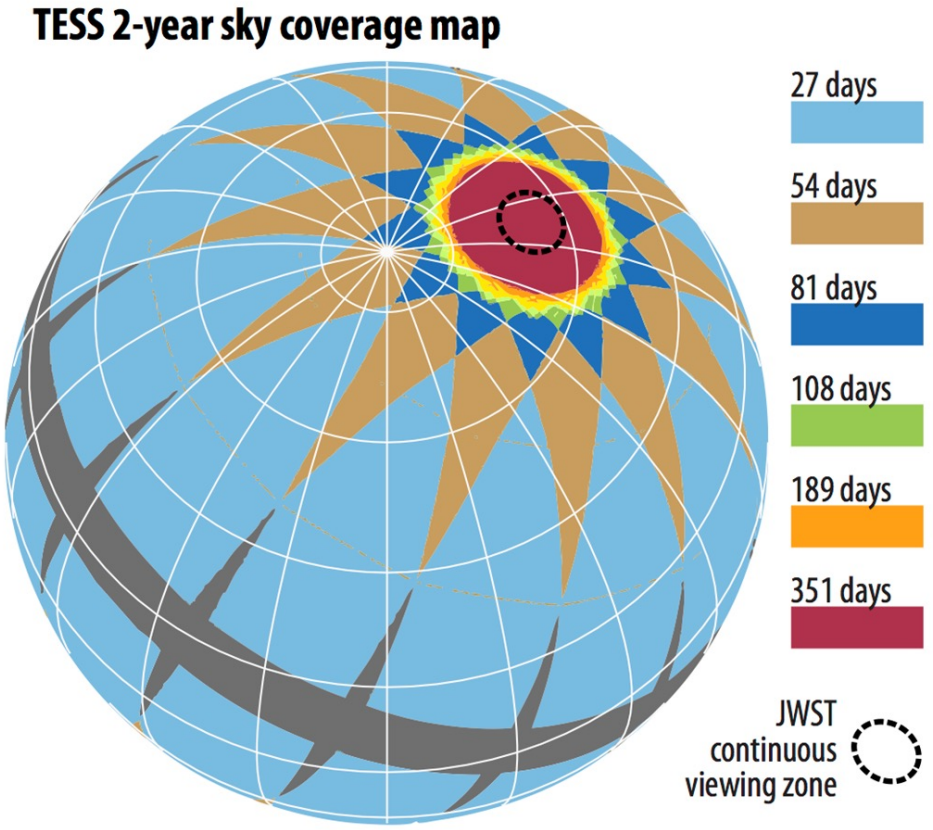
Subaru IRD TESS Intensive Follow-up Project

(Progress reports of S19A-069I, S20B-088I)

Norio Narita (UTokyo) & 37 Co-Is

TESS Introduction

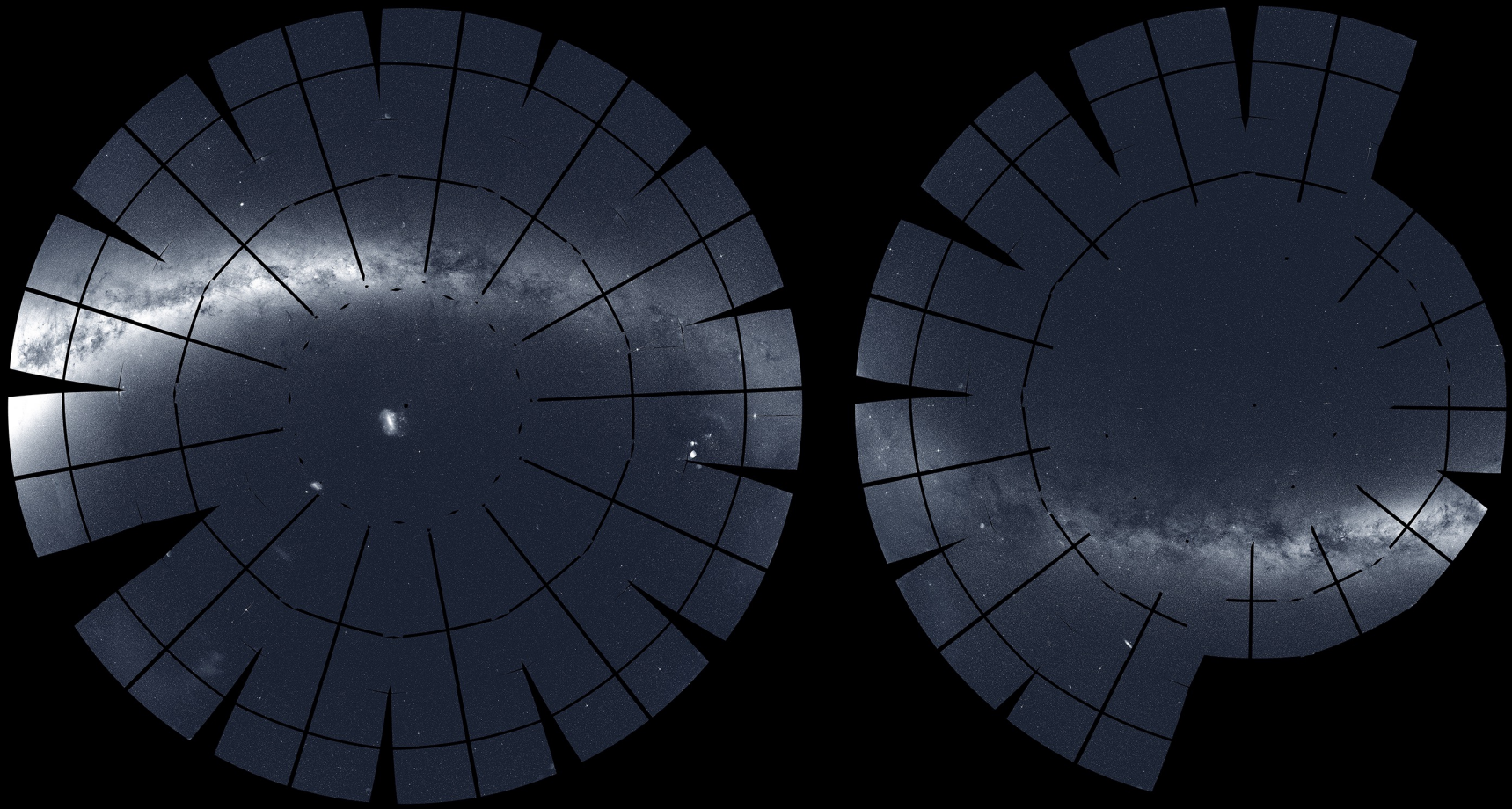
Launched on April 18, 2018



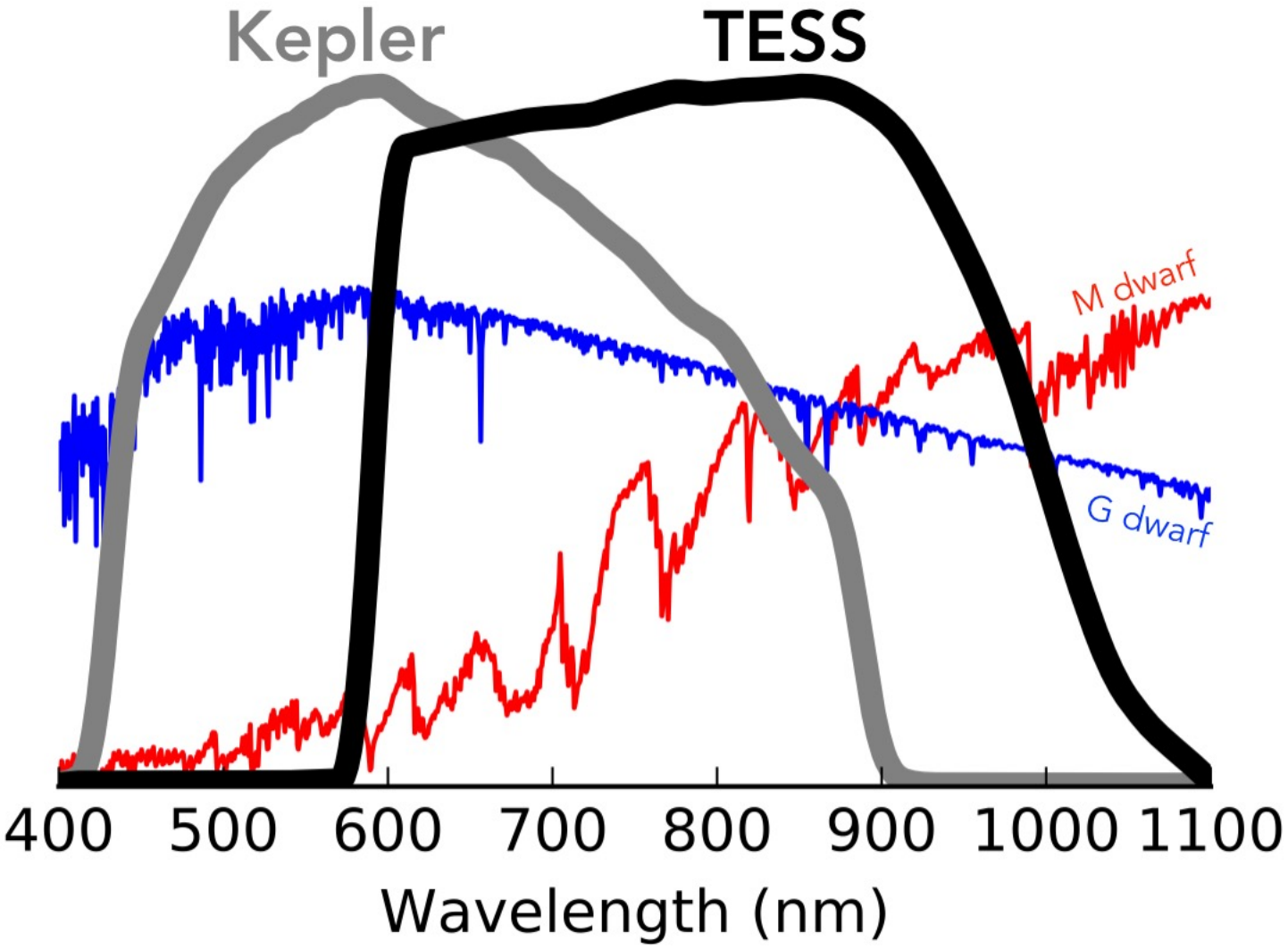
Observing 24 deg x 96 deg FoV ("sector") at a time for 27.4 days

Starting from south sky (2018-2019 July) relative to the ecliptic plane and observing north in the second year (2019-2020 July)

TESS Primary Mission View

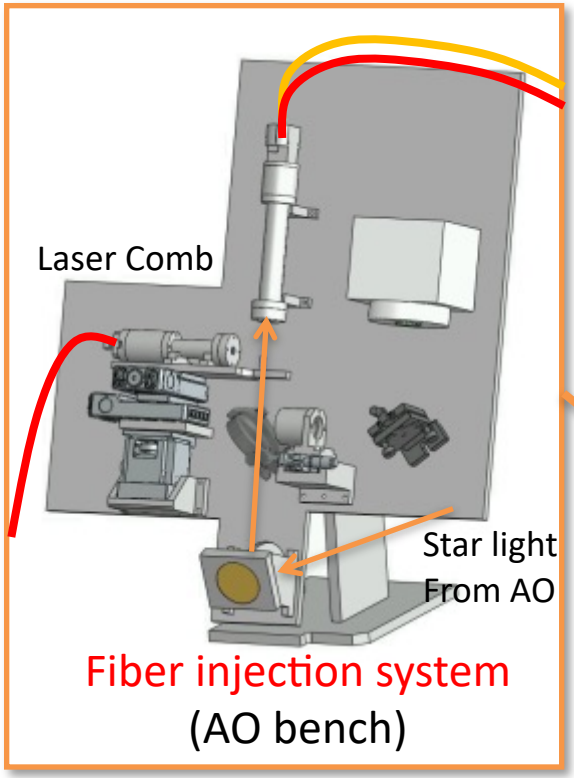


Comparison of TESS and Kepler bandpass

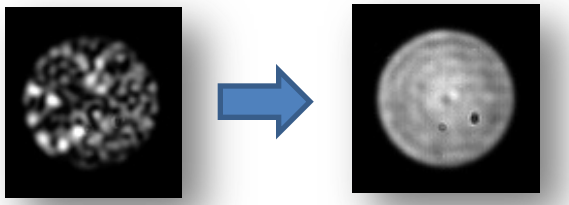


TESS is more favorable for nearby M dwarfs

Overview of the IRD instrument

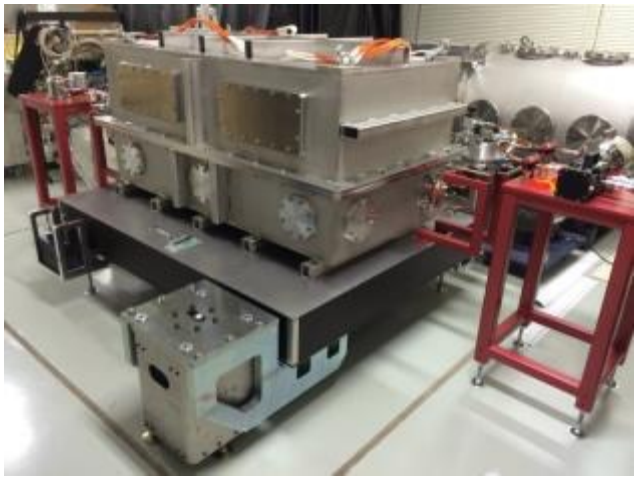


Fiber injection system
(AO bench)

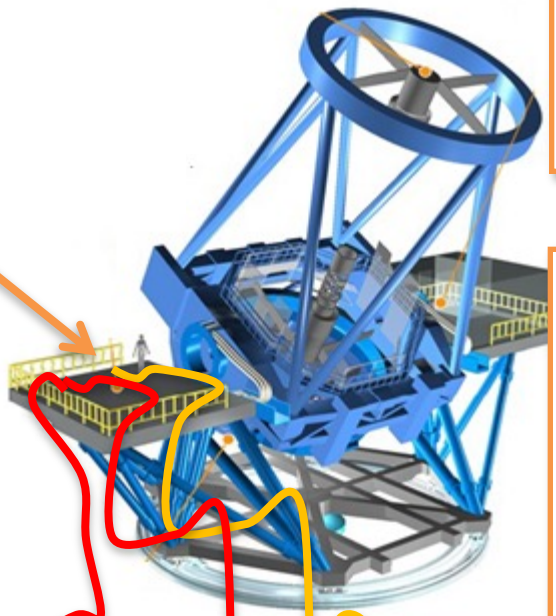


Mode scrambler

Resolution: R=70000
Wavelength: 0.97-1.75um
Cryo: 60K (detector), 200K (optics)



Spectrometer system
(Coudé room)

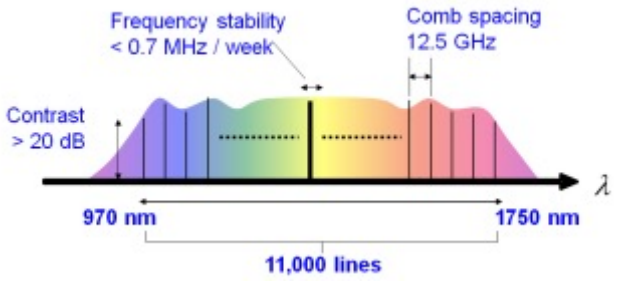


Fiber
(Comb)

Fiber
(star)

spectrometer

Coudé Room



Laser frequency comb
(IR Observing floor)

MuSCAT network for efficient planet validation

MuSCAT3
Haleakala, Maui, USA
Since September 2020

MuSCAT2
Teide, Tenerife, Spain
Since August 2017

MuSCAT
Okayama, Japan
Since December 2014

What we proposed

- Determine precise (20% uncertainties) masses of 10+ small planets (less than 2.5 R_{Earth}) around mid-late M dwarfs (less than 3500 K) discovered by TESS with Subaru IRD
  - Thereby uncover the mass-radius-period relation of small planets around mid-late M-dwarfs
  - Test latest planet formation theories (including core accretion, giant impacts, and subsequent atmospheric escape) for mid-late M dwarfs by observations
  - Identify good targets for further atmospheric / orbital characterizations (as our targets are transiting planets)
  - (If any) pursue potentially habitable planets delivered by TESS

Numbers of allocated nights and success rate

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

- Major TAC/referees' concern: IRD is a shared-risk instrument and TESS observations have just started.
- TAC comments: The Subaru TAC decide to allocate only for the next three semesters as a pilot program. We hope that the pilot observations from S19A to S20A will be useful for the subsequent proposal for S20A and beyond.
- 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)

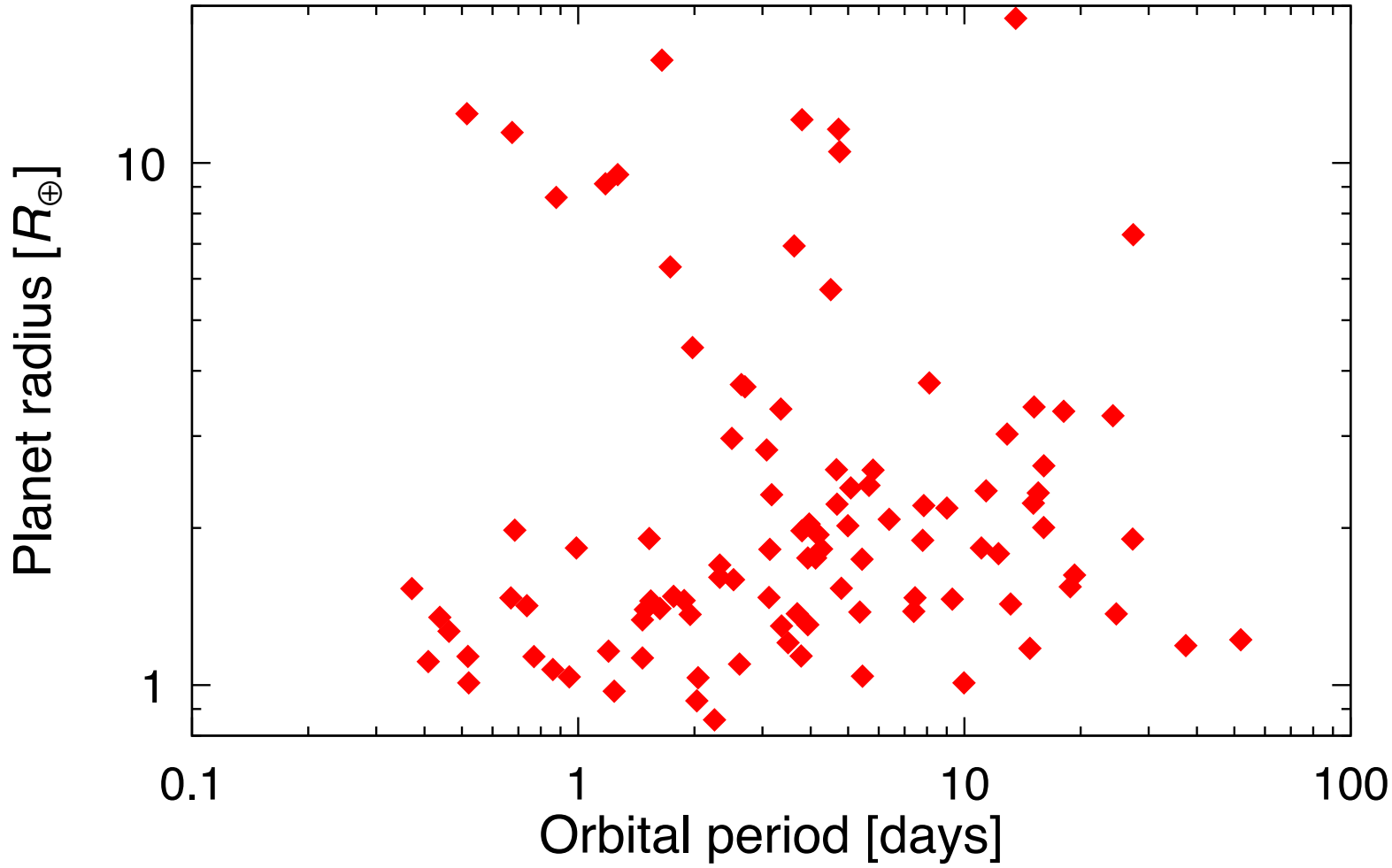
- 20A: 4 nights -> 0 night (all nights lost due to weather and COVID)

- 3.5 successful nights in total / 14 allocated nights (25% success rate)

cf. TESS candidate planets around stars T_{eff} < 3500K

TESS has discovered 100+ candidates as of Feb 2021

50+ candidates are observable from Maunakea with >40 deg elevation



The initial major concern by TAC/referees proved unfounded.

Numbers of allocated nights and success rate

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

- Major TAC concern
  - We are not fully convinced if IRD can achieve an accuracy of the velocity measurements to measure the mass of such possible Earth-mass planets. (…) If the team really plan to measure the mass of earth mass planet and K~1m/s (rather than 2m/s) is essential for your study then please prove this by using the 20B and 21A time. If your main goal is super-earth and sub-neptune and ~2m/s is enough for your scientific goal, then please clarify in the proposal and interview.
- TAC comments
  - TAC recommends to apply again in S21B by showing compelling performance, matured science case and observing program for additional observing nights.

- 20B: 7 nights -> 5 successful nights (2 nights lost due to weather)
- 21A: 7 nights -> 2 nights in poor weather, 5 nights remaining
- current success rate is ~65%

Publications using the IRD intensive data

Previous results (reported at the last Subaru UM in Kona)

1. TOI562 (Ruque+ 2019)
2. TOI736 (Crossfield+ 2019)

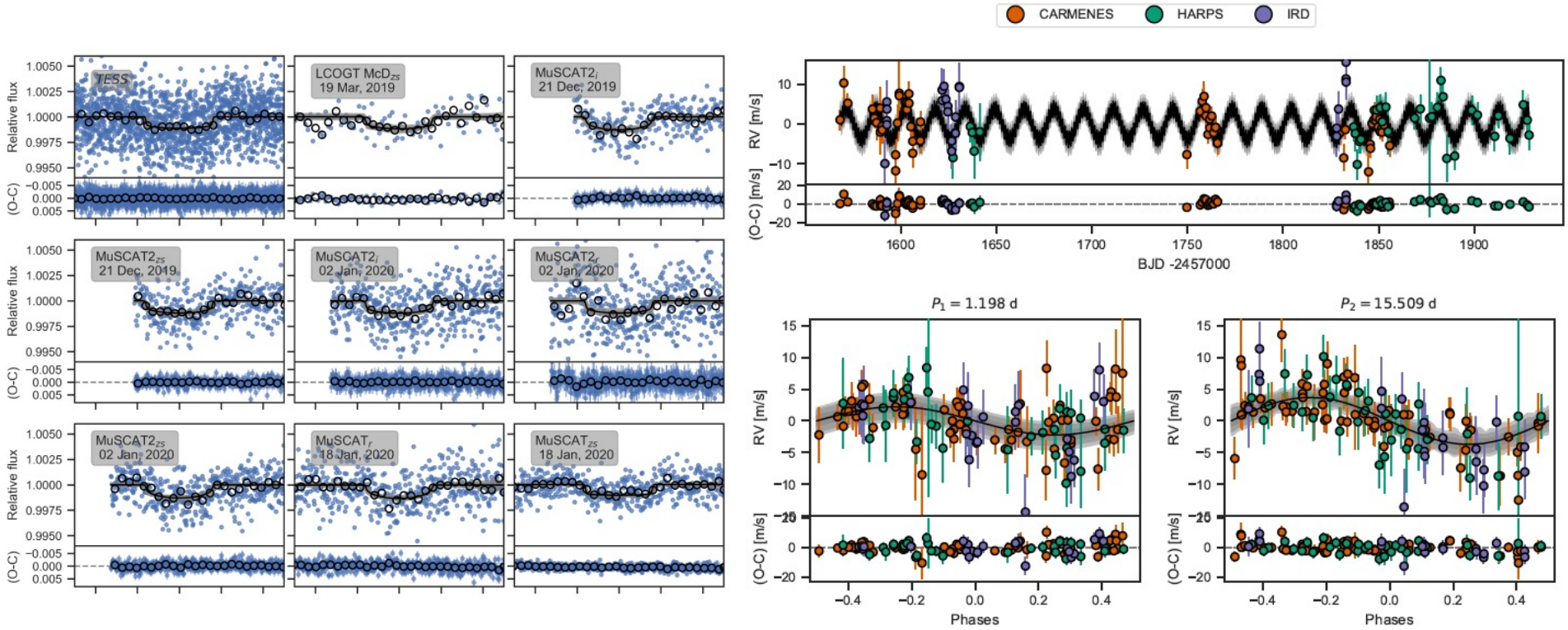
New results

3. TOI2221=AU Mic (Hirano+ 2020): spin-orbit alignment
4. TOI488 (Kemmer+ 2020): mass determination / additional planet
5. TOI732 (Nowak+ 2020): mass determination
6. TOI1640 (Soto+ submitted): mass determination
7. TOI1634 & 1685 (Hirano+ in prep.): mass determination / additional planet?
8. TOI2285 (Fukui+ in prep.): validation / additional planet?
9. TOI1696 (Mori+ in prep.): validation
10. TOI1468 (Chaturvedi+ in prep.): mass determination
11. TOI2221=AU Mic (Cale+ in prep.): mass determination

- ongoing observations for other 10+ systems

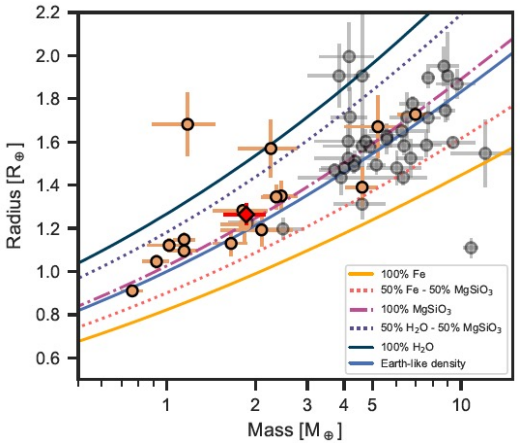
Mass of TOI488.01 and discovery of TOI488.02

IRD measured the masses of an Earth-like planet and outer additional planet



Kemmer et al. (2020)

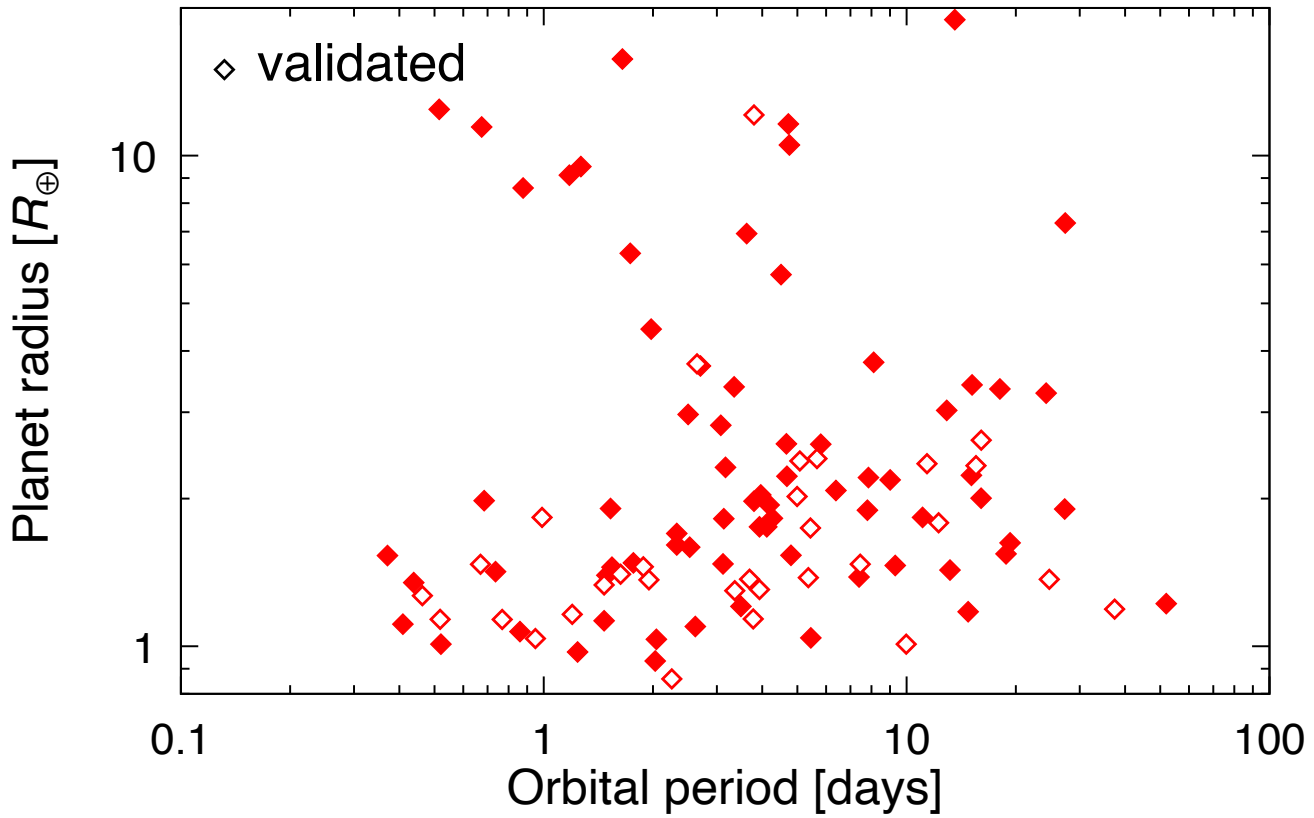
We found the planet b has R_b~1.26 R_{Earth}, M_b~1.86 M_{Earth} (Earth-like planet), K_b=2.21±0.35 m/s, and discovered additional outer planet c at P_c~15.5 d, $Msini_c$~7.4M_{Earth}



Remaining/new frontier targets

Dozens of small candidate transiting planets have been validated,

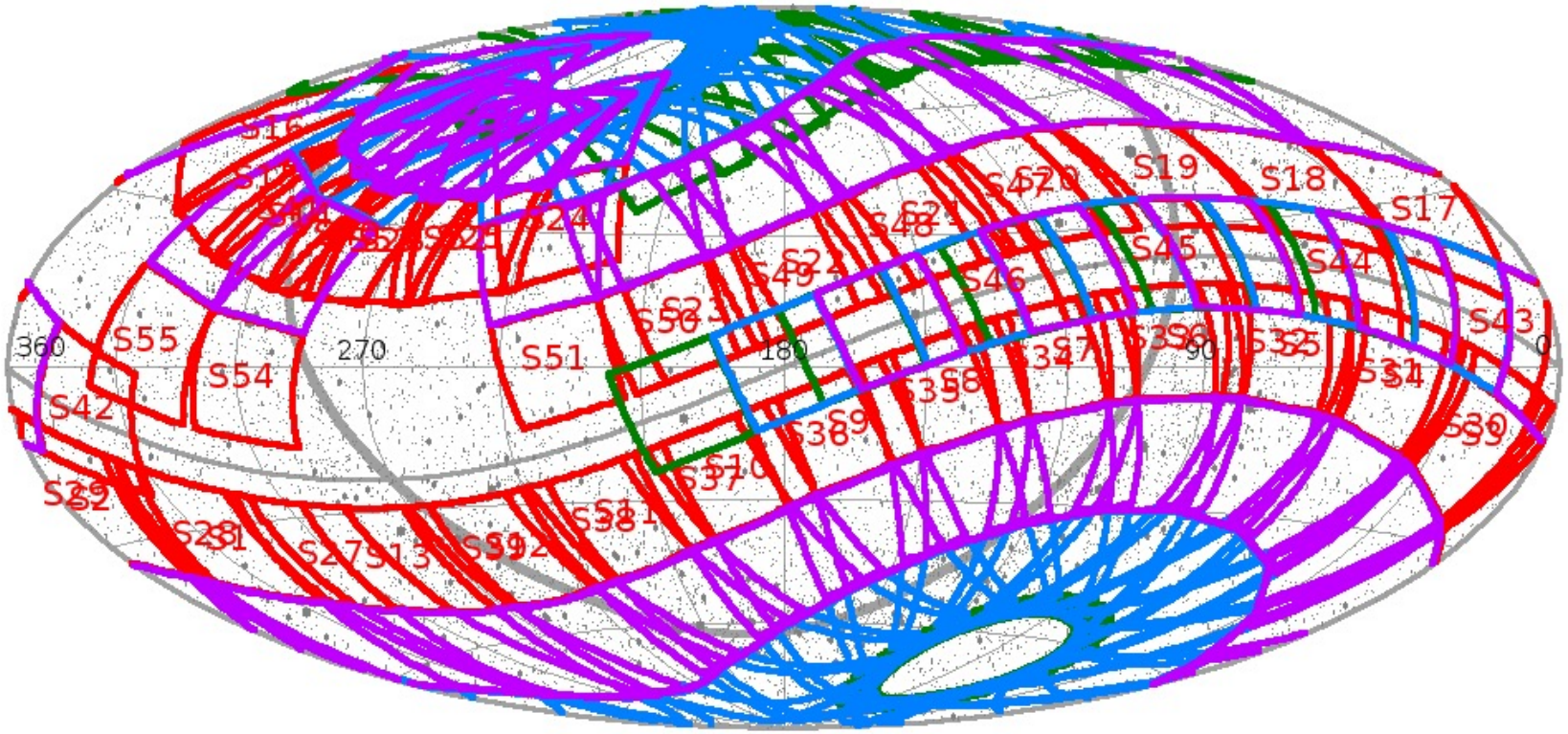
but precise masses have been determined only for <10 planets



Sub-Neptunes (2.5-4 R_{Earth}) and giant planets (>4 R_{Earth}) around M dwarfs are also very interesting, because such planets were rare before the TESS survey and will be suitable for atmospheric characterization

TESS Extended Mission (at least until 2022)

TESS is not over yet



New candidates will be discovered in the new fields,

especially in the ecliptic plane

Summary

- TESS has discovered 100+ candidate transiting planets around mid-late M dwarfs, and we aimed to determine the masses of small transiting planets with Subaru IRD

- Within the allocated nights, we have demonstrated that IRD can determine precise masses of small Earth-like transiting planets (down to $<2\ M_{Earth}$)

- We have dozens of remaining targets which IRD can lead

- Continuation of S20B-088I is strongly desired