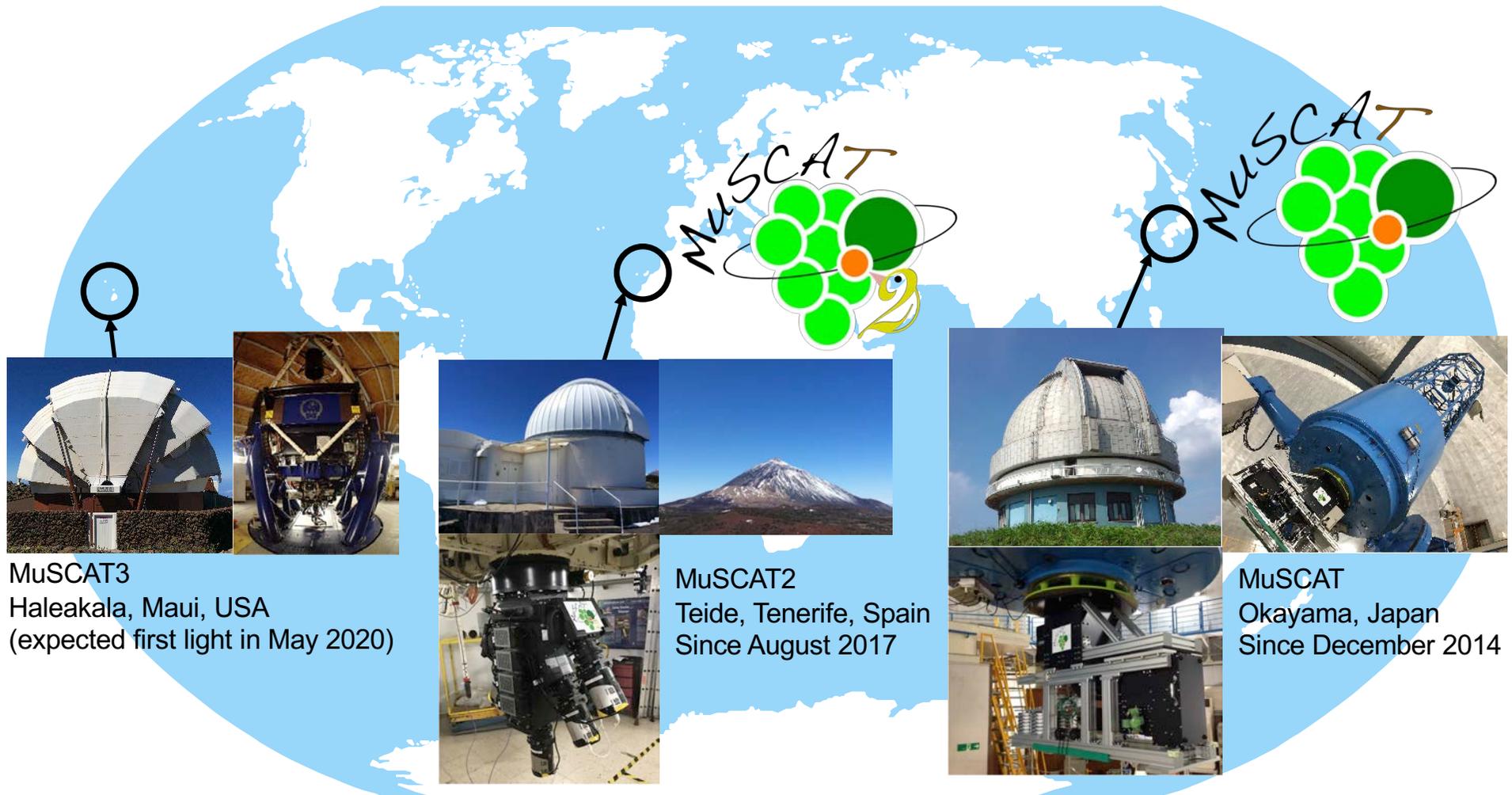


MuSCAT1/2/3: Global Multi-Color Photometric Monitoring Network for Exoplanetary Transits

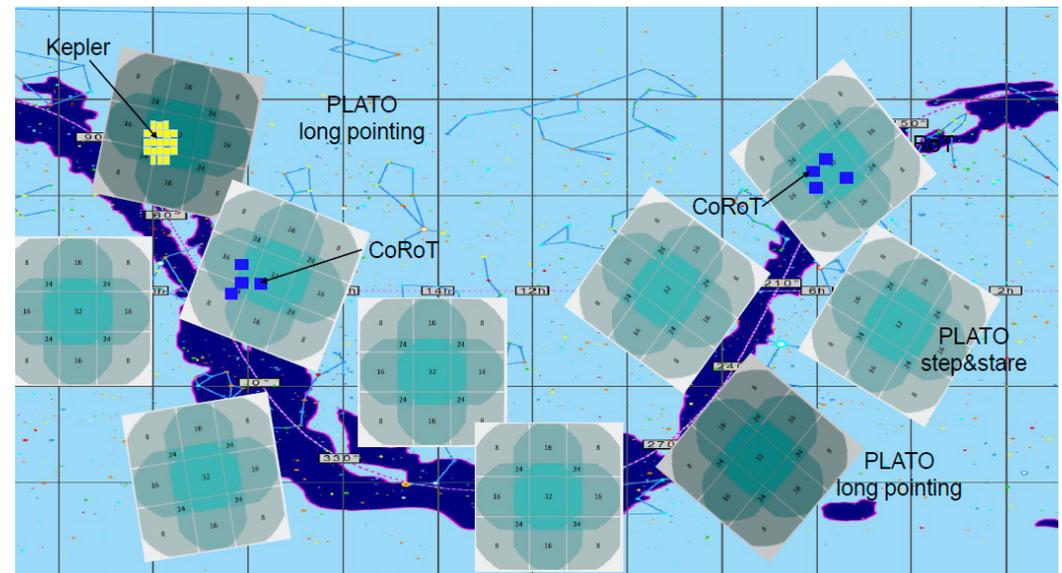
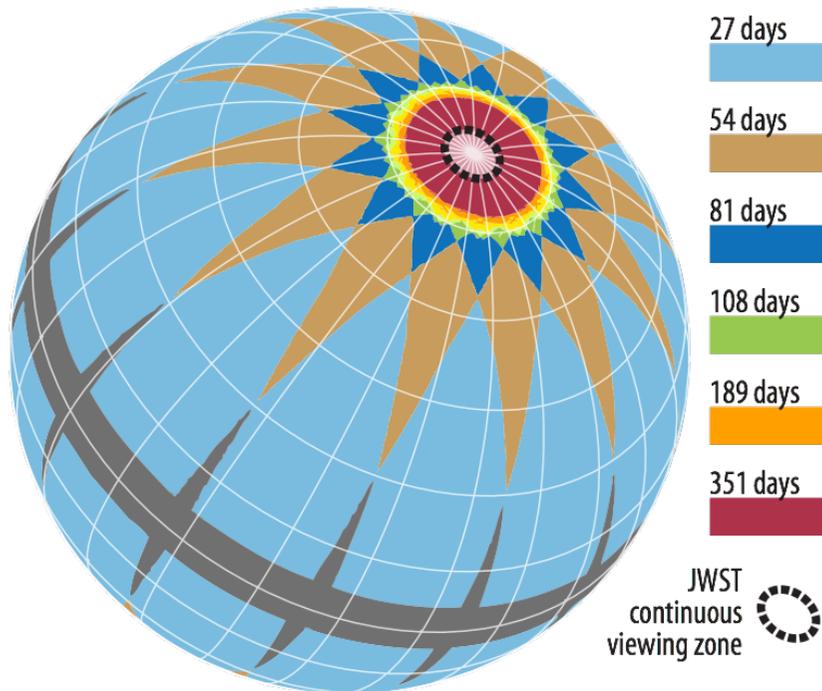


Norio Narita (Astrobiology Center), on behalf of MuSCAT1/2/3 team

Ongoing/Future Space Transit Survey Missions

TESS (2018-2022+): >90% of sky

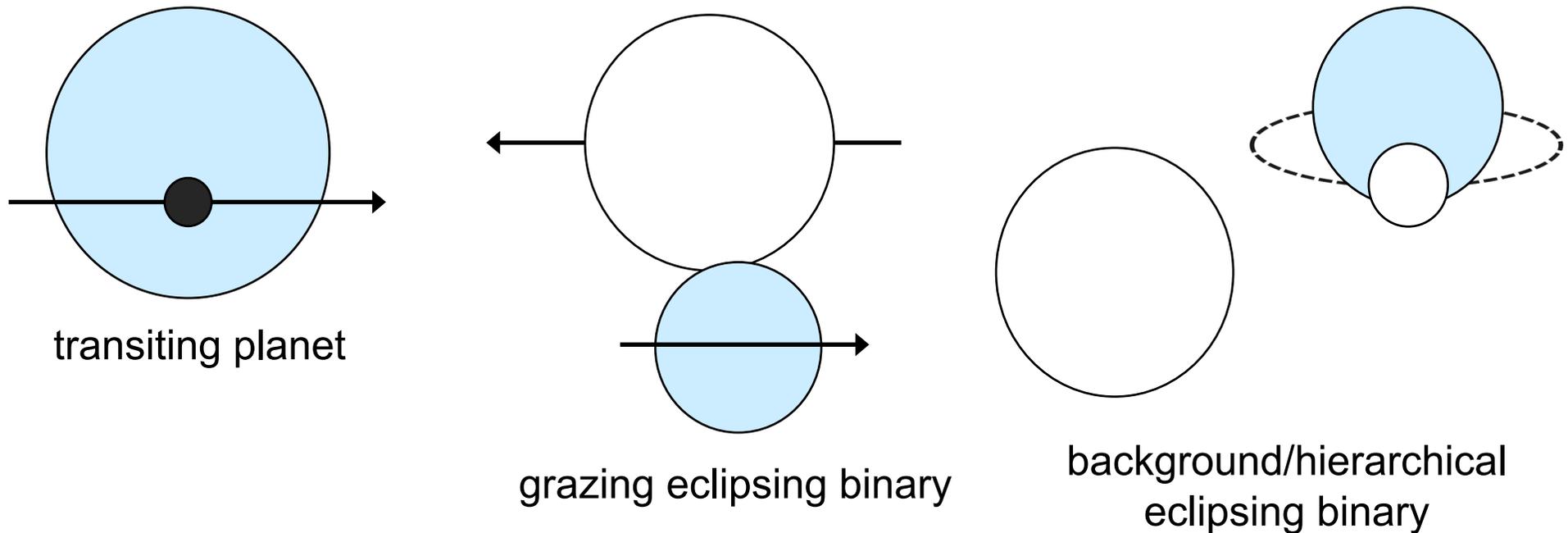
PLATO (2026-2030+): ~25% of sky



Thousands of “candidates” of transiting planets will be discovered.

Transiting Planets and False Positives

Eclipsing binaries may mimic transit-like dimming



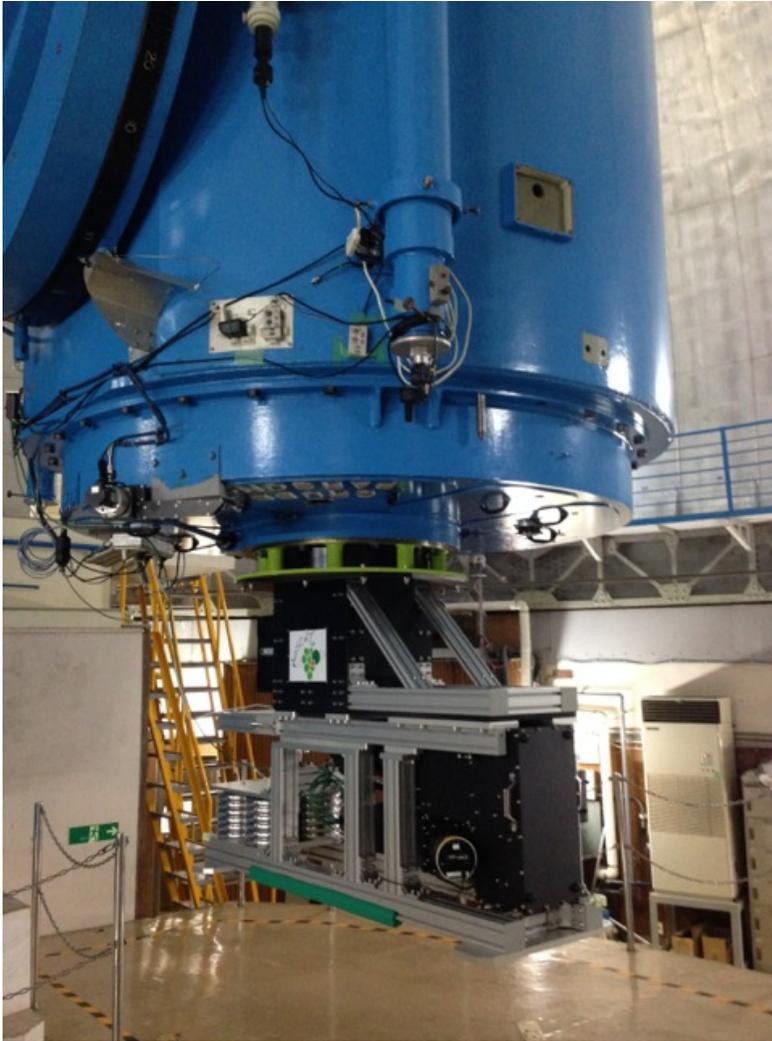
Validation/Confirmation methods

Multi-color transit photometry to see wavelength dependence

AO/speckle/ imaging to exclude contamination

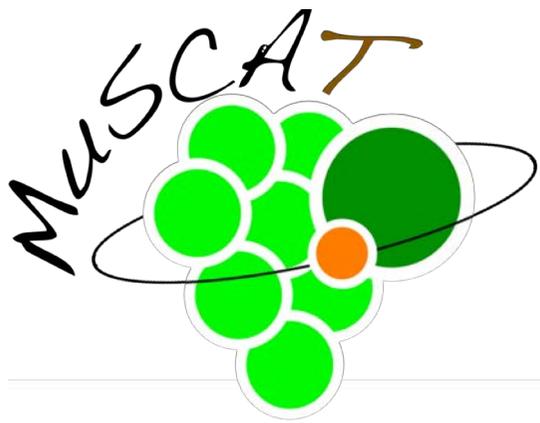
Recon spectroscopy and RV measurements

MuSCAT on Okayama 1.88m telescope

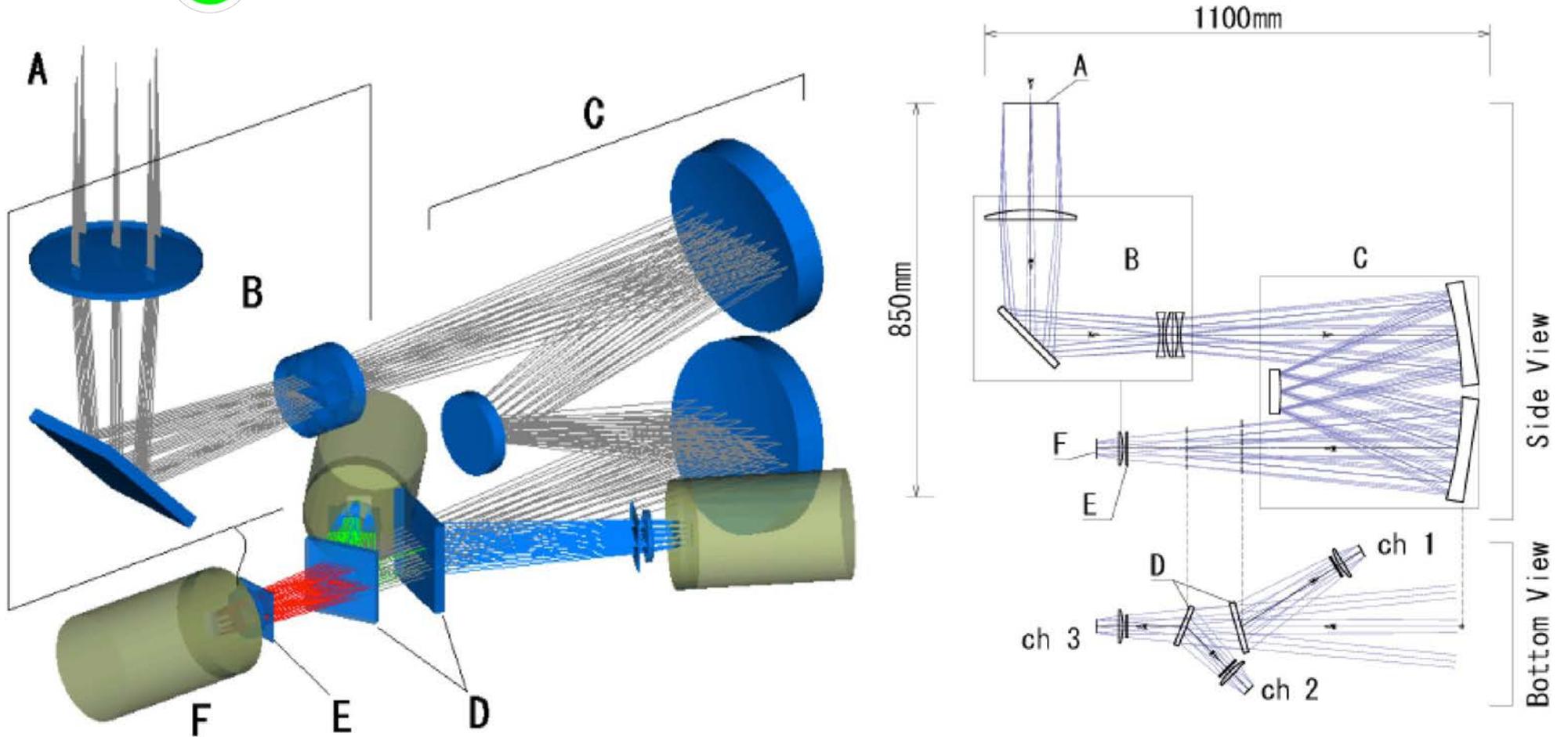


Picture on 2015 March 3

- Multicolor Simultaneous Camera for studying Atmospheres of Transiting exoplanets (MuSCAT)
- Development started since 2013, first light commissioning was done on the night of Dec 24, 2014
- Blue (g: 400-550nm)、red (r: 550-700nm)、NIR (z_s : 820-920nm) simultaneous imaging



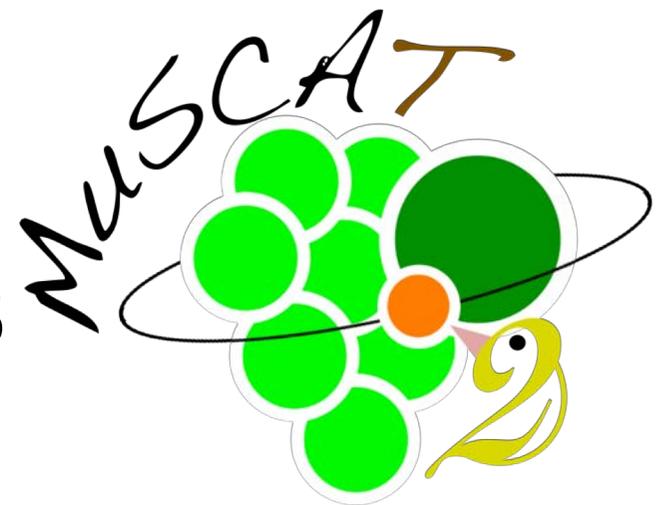
Optical Design



Narita et al. (2015)

From MuSCAT to MuSCAT2

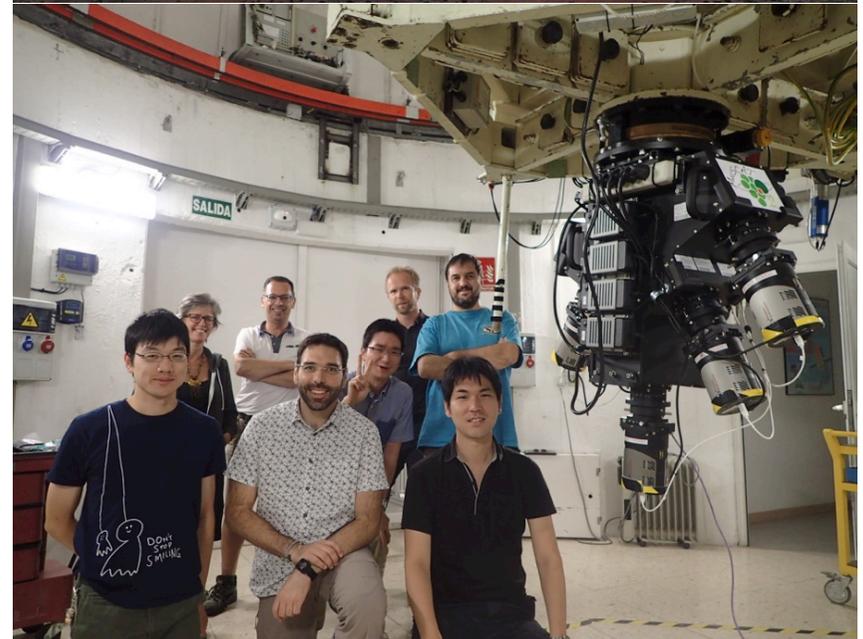
- **Enric Palle at IAC (Spain)** offered a possibility to install a new instrument on TCS 1.52m telescope in Teide observatory, Tenerife, Canaries in 2015
- **Weather success ratio of 70%** at the Teide observatory (cf. 30% at Okayama)
 - Also plenty of unoccupied nights
- Research budget was provided by Astrobiology Center, Japan since 2016



MuSCAT2 on TCS 1.52m@IAC

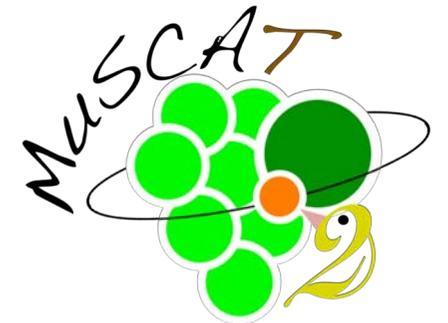
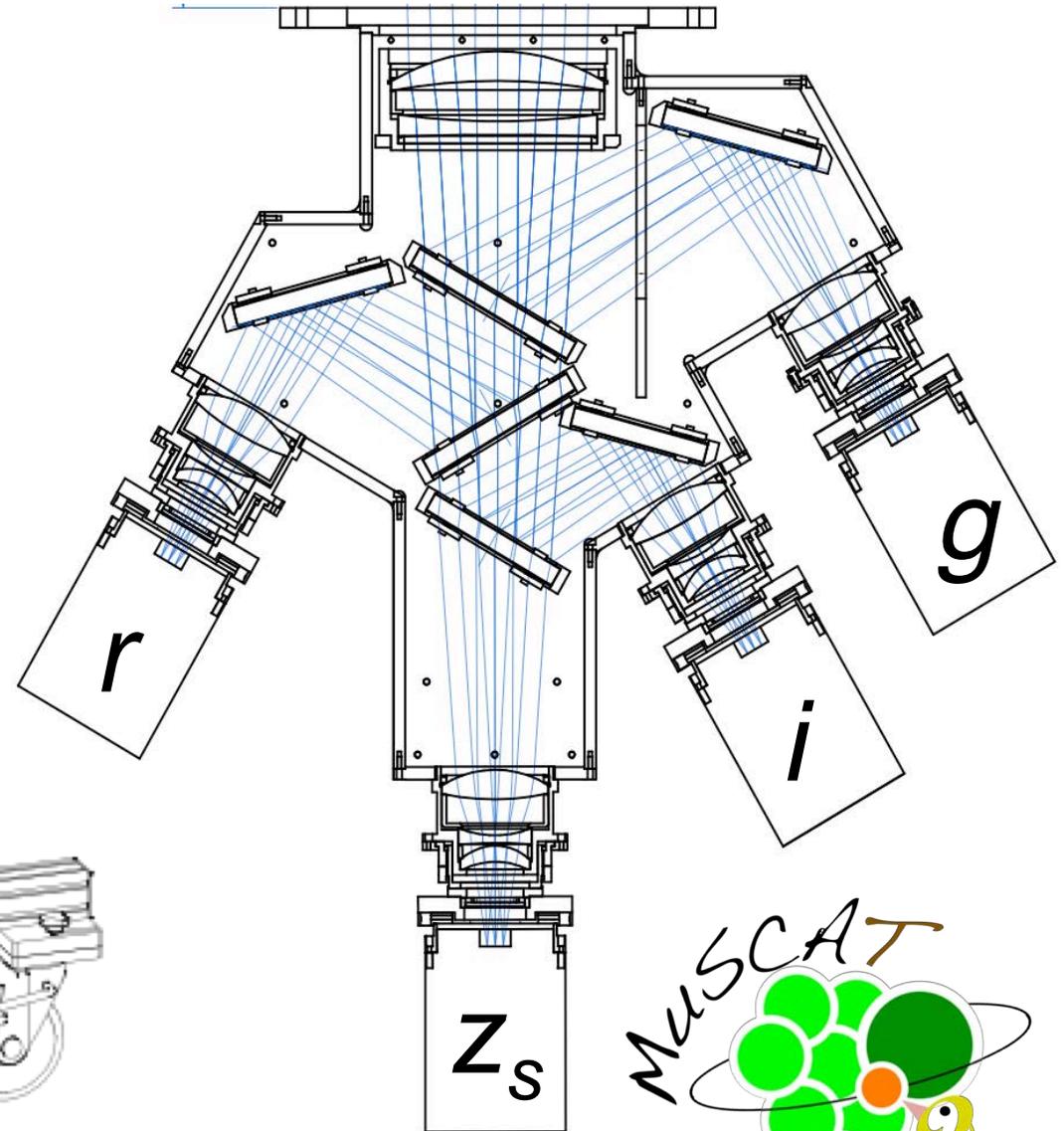
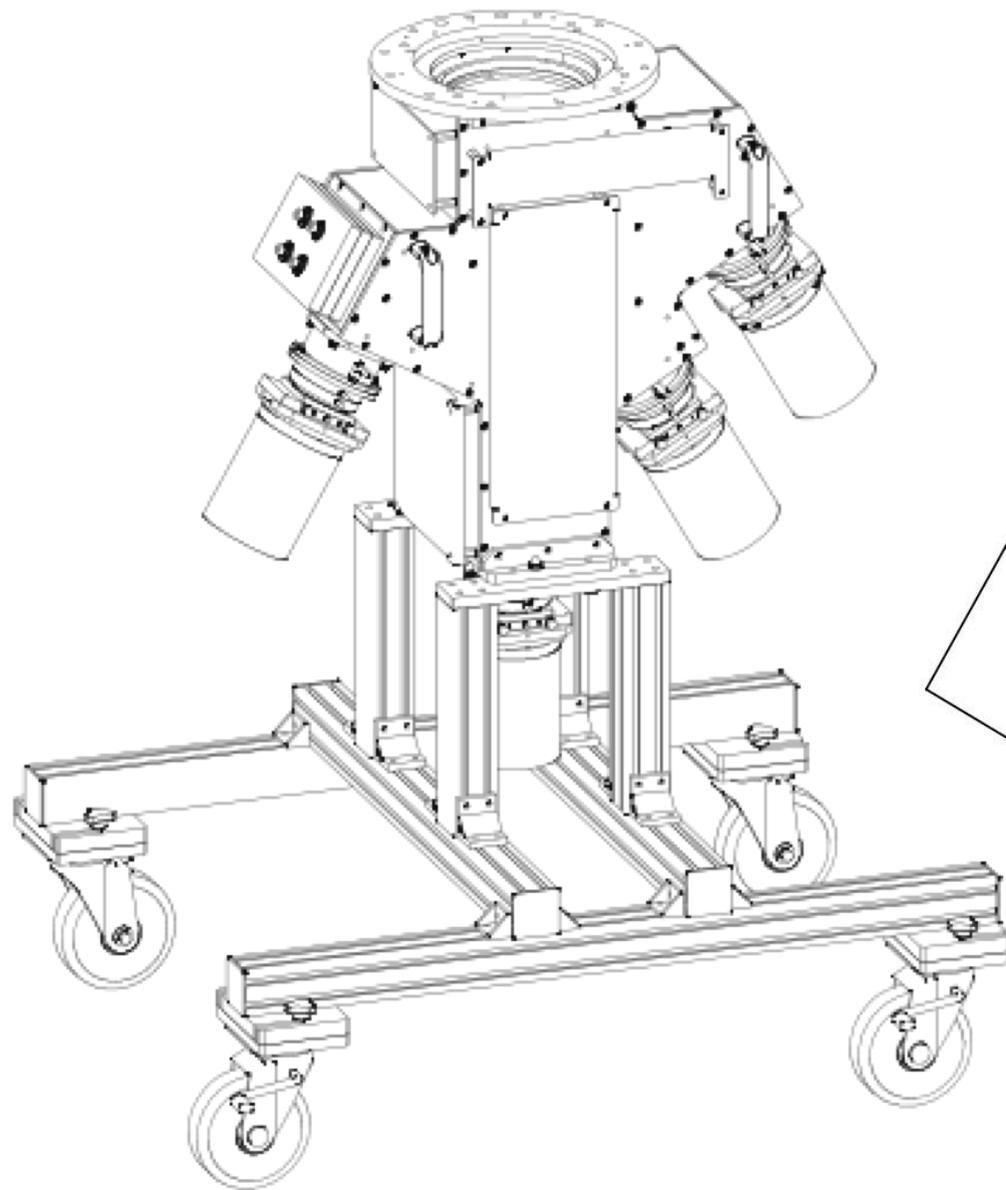


TCS 1.52m telescope
Teide observatory, Tenerife, Spain
 $28^{\circ} 18' 01.8''$ N, $16^{\circ} 30' 39.2''$ W
2386.75m
middle of Mount Teide (3718m)



First light on August 24, 2017

Mechanical and Optical Designs of MuSCAT2



From MuSCAT2 to MuSCAT3

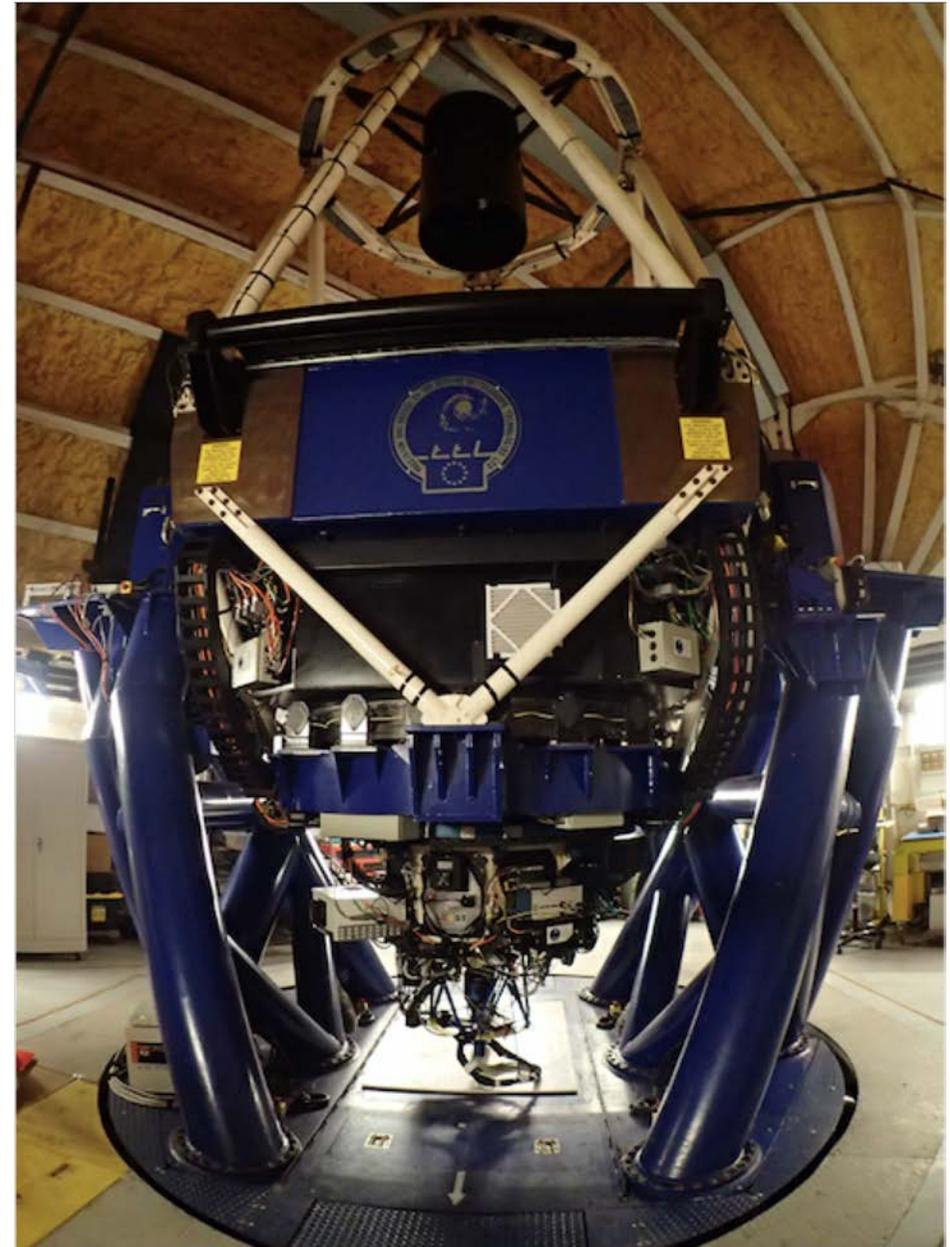
- We got a research funding for MuSCAT3 in late-June 2018
 - Grant-in-Aid for Scientific Research on Innovative Areas: research area A03 (PI: Masahiro Ikoma, co-I: Norio Narita)
 - Additional funding provided by Astrobiology Center, JSPS KAKENHI, and JST PRESTO (PI: Norio Narita)

We searched for a host 1-2m class telescope in the US to establish **the global multi-color network**

MuSCAT2
Teide, Tenerife, Spain
Since August 2017

MuSCAT
Okayama, Japan
Since December 2014

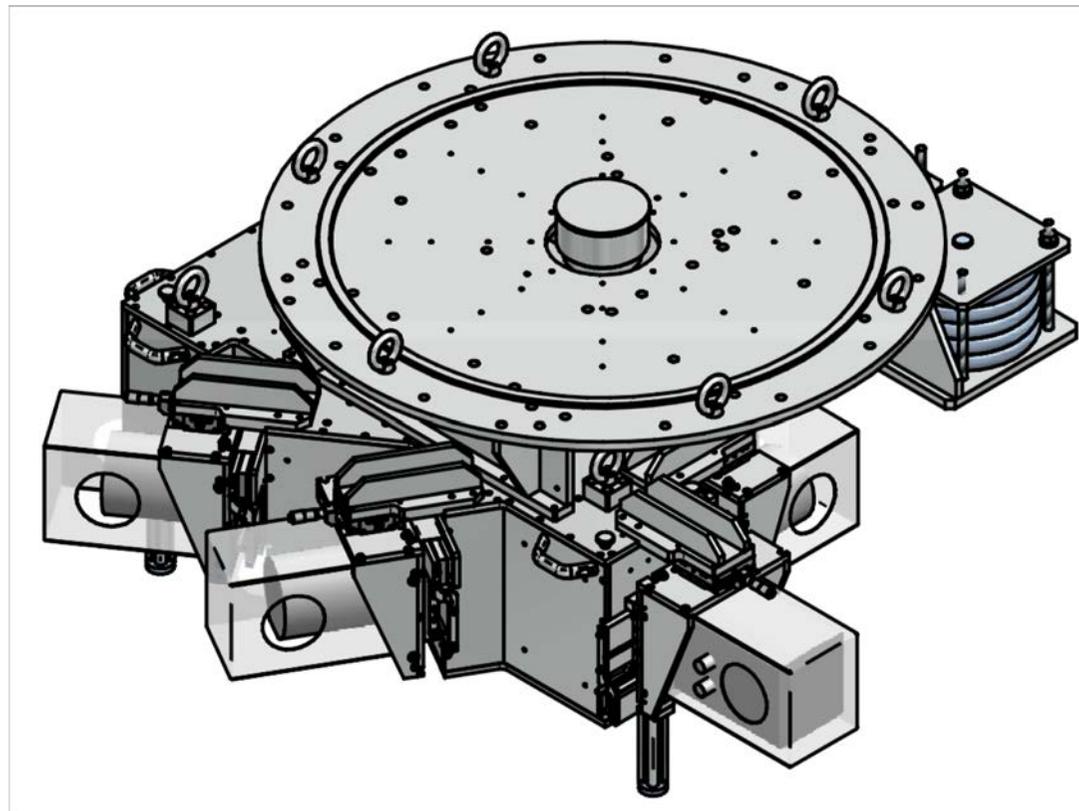
FTN 2m telescope@Haleakala, Maui



2m Faulkes Telescope North
(operated by Las Cumbres Observatory)
Haleakala, Maui, USA
 $20^{\circ} 42' 27.0''$ N, $156^{\circ} 15' 21.6''$ W
at the top of Haleakala (3,055m)

Current Status and Plan of MuSCAT3

- An MoU between Astrobiology Center and Las Cumbres Observatory was signed by both directors
- Mechanical design is now fixed (below)
- We plan to install MuSCAT3 to the FTN 2m telescope in **May 2020**



	MuSCAT1 on OAO 1.88m tel.	MuSCAT2 on TCS 1.52m tel.	MuSCAT3 on FTN 2m tel.
Primary mirror	1.88m	1.52m	2.0m
Location	34° 34' 37" N 133° 35' 38" E 372m	28° 18' 02" N 16° 30' 39" W 2387m	20° 42' 27" N 156° 15' 22" W 3055m
FoV	6.1' x 6.1' (with 1k CCD)	7.4' x 7.4' (with 1k CCD)	9.1' x 9.1' (with 2k CCD)
Clear sky ratio	~30%	~70%	~70%
Pixel scale	0.36" / pix	0.45" / pix	0.27" / pix
Readout time	0.58 sec	0.58 sec	2.3 sec
# of nights/yr	100-150	~300	TBD
# of channels	3 (g, r, z)	4 (g, r, i, z)	4 (g, r, i, z)

MuSCAT1/2/3: Global Multi-Color Photometric Monitoring Network for Exoplanetary Transits

The image features a world map with three callouts pointing to the locations of MuSCAT observatories. Each callout includes a logo and a photograph of the observatory. The logos consist of the word 'MuSCAT' in a stylized font above a cluster of green circles of varying sizes, with a small orange circle in the center. The first callout points to Haleakala, Maui, USA, showing a large white dome and the telescope structure. The second callout points to Teide, Tenerife, Spain, showing a white dome and a photograph of Mount Teide. The third callout points to Okayama, Japan, showing a white dome and the telescope structure.

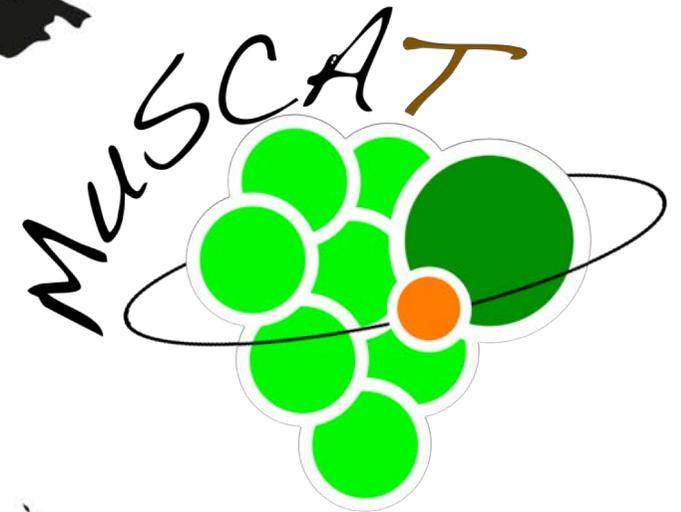
MuSCAT3
Haleakala, Maui, USA
(expected first light in May 2020)

MuSCAT2
Teide, Tenerife, Spain
Since August 2017

MuSCAT
Okayama, Japan
Since December 2014

Possible Future: Night always falls on MuSCATs?

- We are interested in the idea proposed by LCO
 - to develop MuSCAT4 to FTS 2m (Australia)
 - to develop MuSCAT5,6... to LCO 1m telescopes
- We are seeking for additional budget

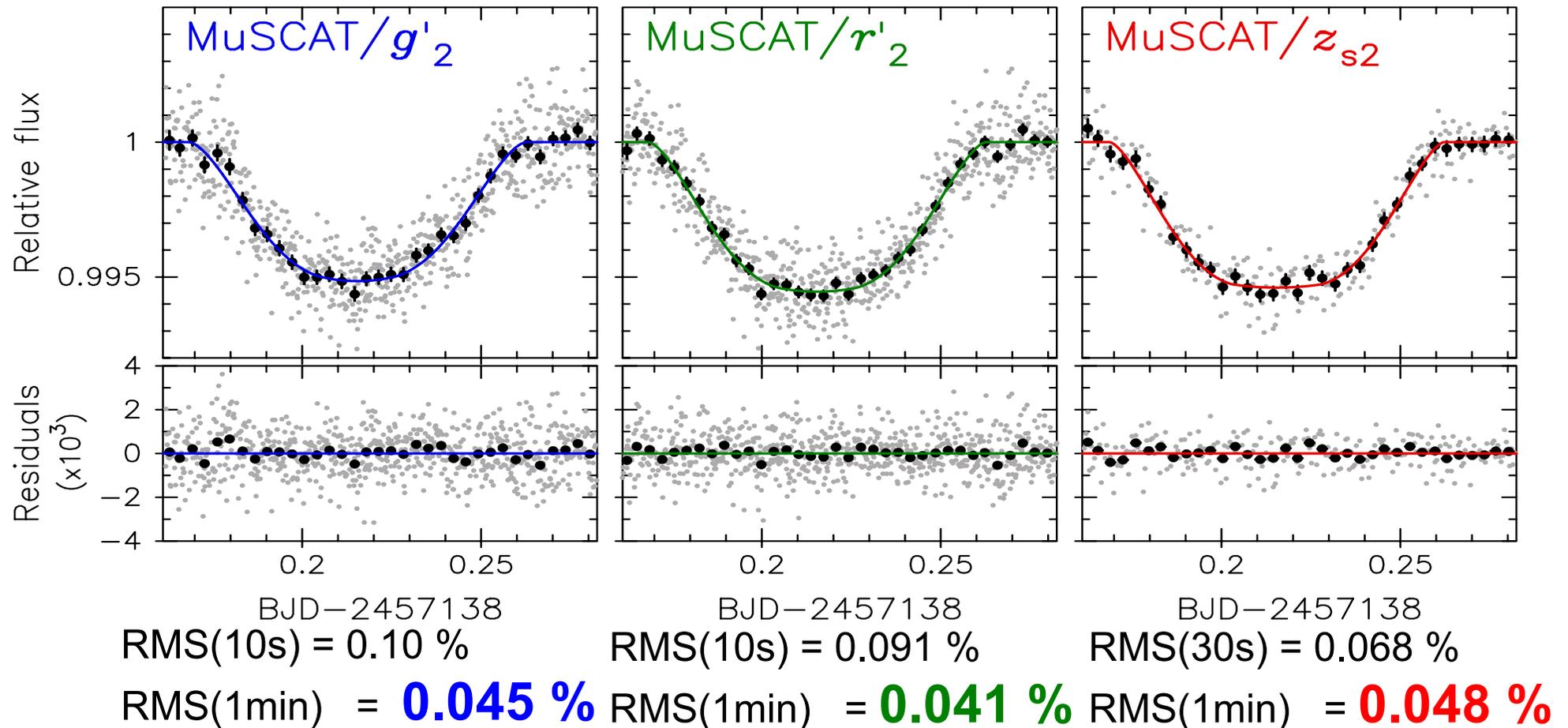


How MuSCATs can support the ARIEL mission

1. Improving transit ephemerides of ARIEL targets to optimize ARIEL observations
2. Supporting pre-selection of ARIEL targets
3. Monitoring stellar variability and optical transits covering ARIEL observations

Demonstration of Precision: MuSCAT

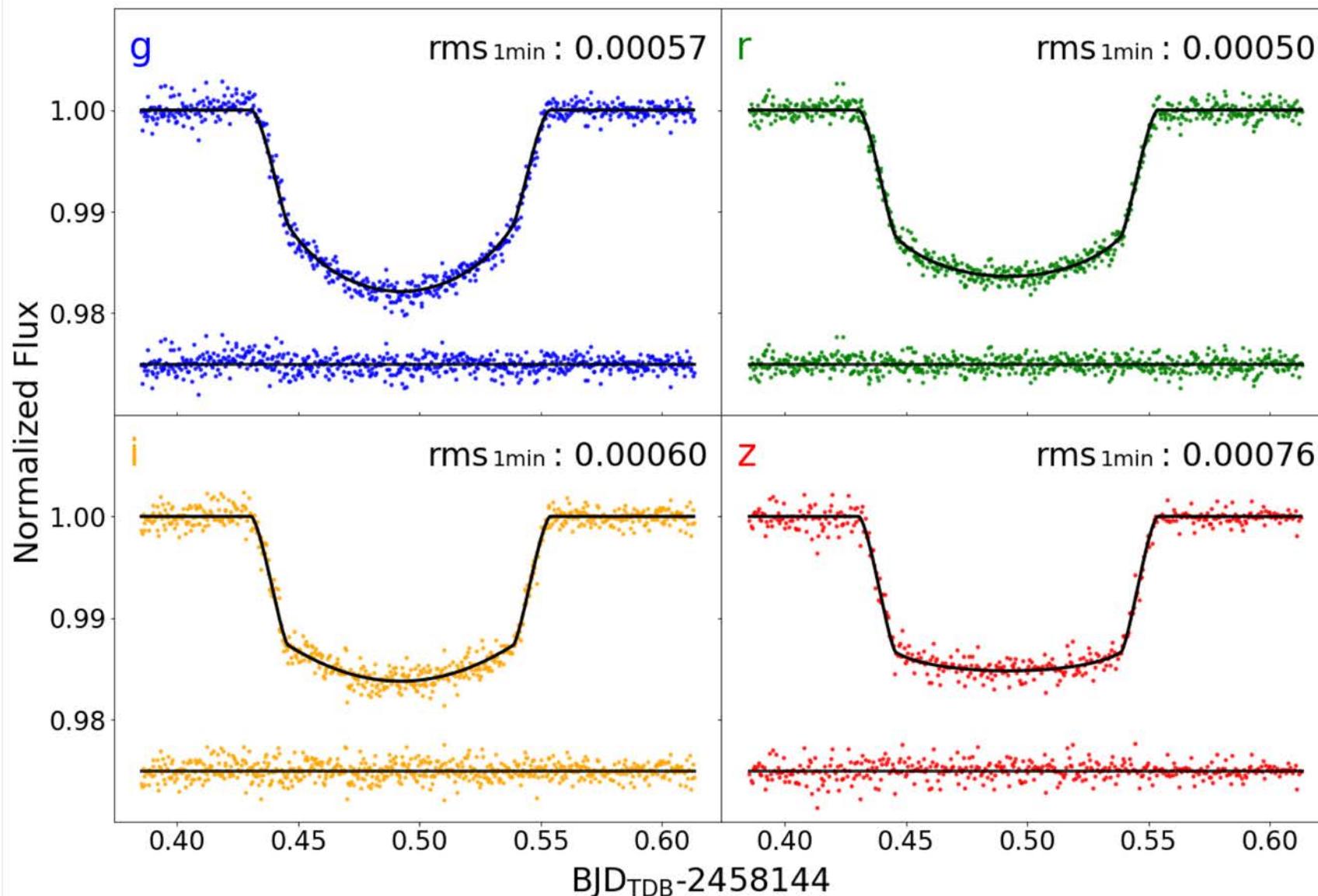
Case for HAT-P-14 (F star, V=10) : Fukui et al. (2016a)



MuSCAT can achieve $\sim 0.05\%$ precision for 10th mag targets
in 60 sec exposure

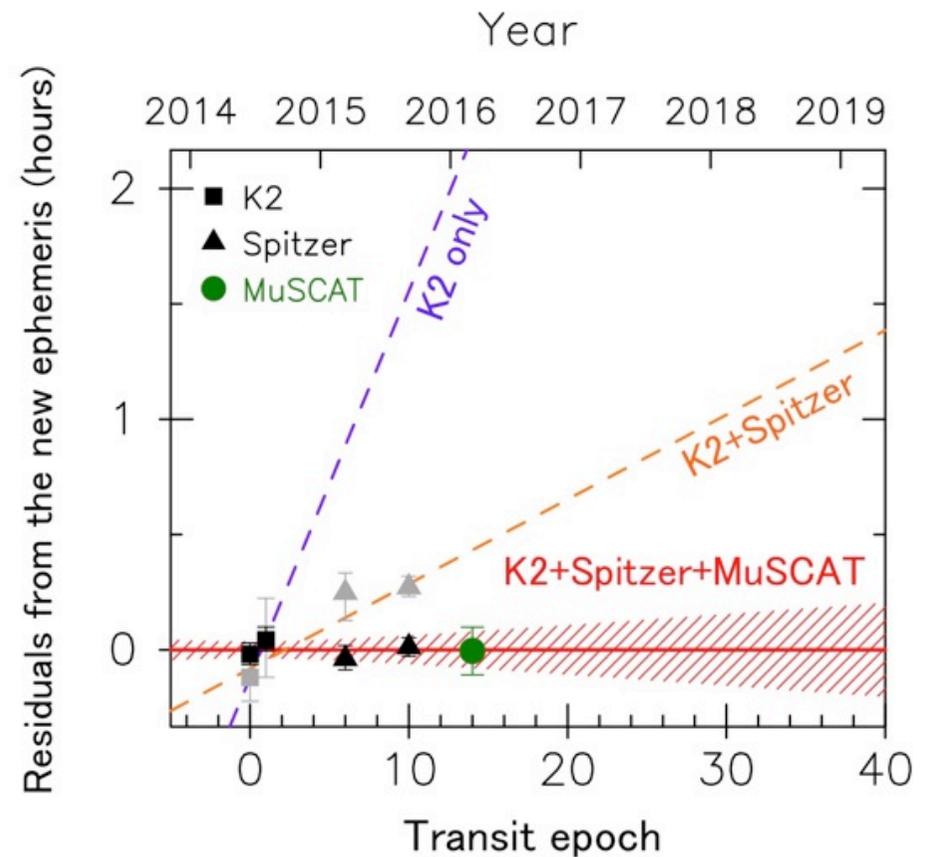
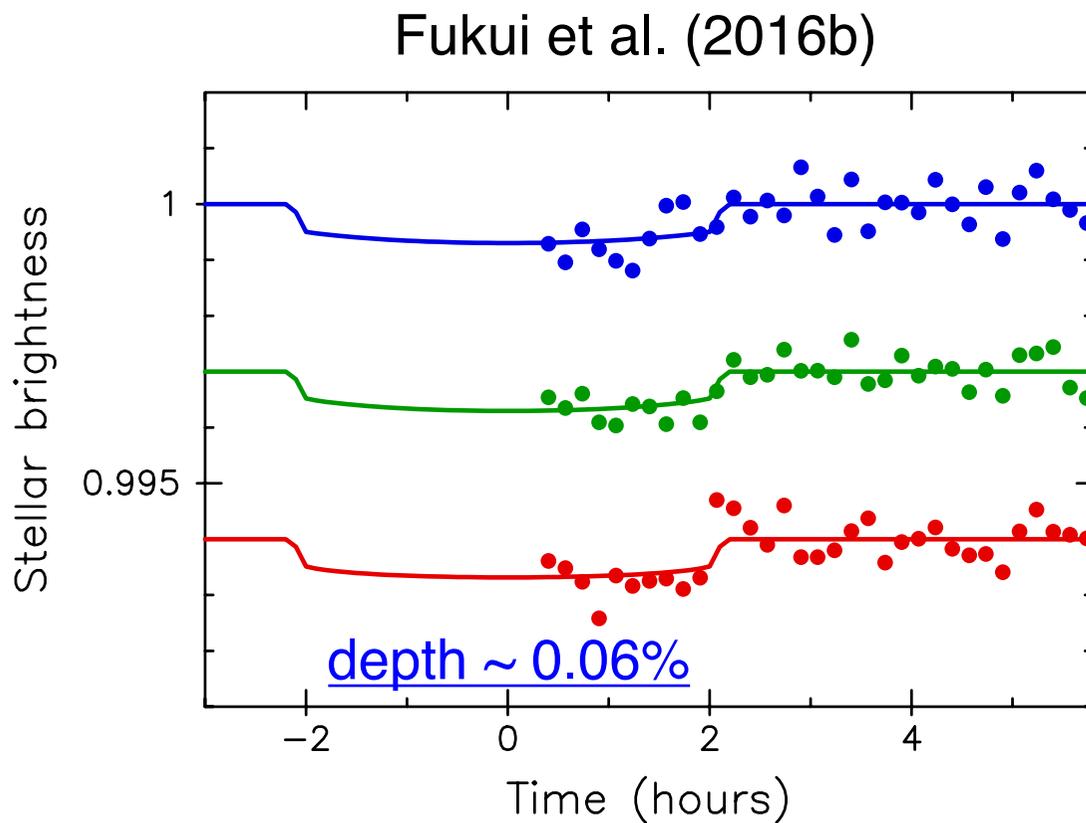
Demonstration of Precision: MuSCAT2

Case for WASP-12 (G star, $V=11.6$) : Narita et al. (2019)



Improvement of the transit ephemeris of K2-3d

High precision multi-color transit photometry gives better transit ephemerides and parameters



This is especially important for TESS planets
for future JWST/ARIEL observations

Japanese Contribution to ARIEL (ARIEL-JP)

A number of Japanese researchers are interested in contributing to the ARIEL mission in both aspects of hardware and science

- Masahiro Ikoma (UTokyo) & his previous/current students
- Keigo Enya, Go Murakami (JAXA)
- Shingo Kameda (Rikkyo)
- Norio Narita (ABC), Akihiko Fukui (UTokyo) & MuSCAT team

Summary

- We have developed MuSCAT1/2/3 for global multi-color transit photometry network
 - MuSCAT4 and more may be available by the ARIEL era
- ARIEL-JP hope to contribute to the ARIEL mission from Japan
- As one of possible contributions from ARIEL-JP, we would like to support the ARIEL mission using MuSCATs