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

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

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

MuSCAT2
Teide, Tenerife, Spain
Since August 2017

MuSCAT
Okayama, Japan
Since December 2014
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

- 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
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
28º 18' 01.8" N, 16º 30' 39,2" W
2386.75m
middel 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.
FTN 2m telescope@Haleakala, Maui

2m Faulkes Telescope North
(operated by Las Cumbres Observatory)
Haleakala, Maui, USA
20° 42’ 27.0“ N, 156° 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
<table>
<thead>
<tr>
<th></th>
<th>MuSCAT1 on OAO 1.88m tel.</th>
<th>MuSCAT2 on TCS 1.52m tel.</th>
<th>MuSCAT3 on FTN 2m tel.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary mirror</td>
<td>1.88m</td>
<td>1.52m</td>
<td>2.0m</td>
</tr>
<tr>
<td>Location</td>
<td>34° 34’ 37” N 133° 35’ 38” E 372m</td>
<td>28° 18’ 02” N 16° 30’ 39” W 2387m</td>
<td>20° 42’ 27” N 156° 15’ 22” W 3055m</td>
</tr>
<tr>
<td>FoV</td>
<td>6.1’ x 6.1’ (with 1k CCD)</td>
<td>7.4’ x 7.4’ (with 1k CCD)</td>
<td>9.1’ x 9.1’ (with 2k CCD)</td>
</tr>
<tr>
<td>Clear sky ratio</td>
<td>~30%</td>
<td>~70%</td>
<td>~70%</td>
</tr>
<tr>
<td>Pixel scale</td>
<td>0.36” / pix</td>
<td>0.45” / pix</td>
<td>0.27” / pix</td>
</tr>
<tr>
<td>Readout time</td>
<td>0.58 sec</td>
<td>0.58 sec</td>
<td>2.3 sec</td>
</tr>
<tr>
<td># of nights/yr</td>
<td>100-150</td>
<td>~300</td>
<td>TBD</td>
</tr>
<tr>
<td># of channels</td>
<td>3 (g, r, z)</td>
<td>4 (g, r, i, z)</td>
<td>4 (g, r, i, z)</td>
</tr>
</tbody>
</table>
MuSCAT1/2/3: Global Multi-Color Photometric Monitoring Network for Exoplanetary Transits

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  - 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 ~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

Fukui et al. (2016b)
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