



## 2319 - TOI-178: the best laboratory for testing planetary formation theories

Cycle: 1, Proposal Category: GO

### INVESTIGATORS

<i>Name</i>	<i>Institution</i>	<i>E-Mail</i>
<b>Dr. Matthew Hooton (PI) (ESA Member)</b>	<b>University of Bern</b>	<b>matthew.hooton@space.unibe.ch</b>
Chloe Fisher (CoI) (ESA Member)	University of Bern	chloe.fisher@csh.unibe.ch
Prof. Yann Alibert (CoI) (ESA Member)	University of Bern	yann.alibert@space.unibe.ch
Dr. Nathan Hara (CoI) (ESA Member)	University of Geneva-Department of Astronomy	nath.hara@gmail.com
Prof. Kevin Heng (CoI) (ESA Member)	University of Bern	kevinheng@gmail.com
Dr. Adrien LELEU (CoI) (ESA Member)	University of Geneva-Department of Astronomy	leleu.adrien@gmail.com
Dr. Enric Palle (CoI) (ESA Member)	Instituto de Astrofisica de Canarias	epalle@iac.es
Dr. Thomas G. Wilson (CoI) (ESA Member)	University of St. Andrews	tgw1@st-andrews.ac.uk
Dr. Vardan Adibekyan (CoI) (ESA Member)	Universidade do Porto	vardan.adibekyan@astro.up.pt
Dr. Romain Allart (CoI) (CSA Member)	Universite de Montreal	romain.allart@unige.ch
Dr. Carlos Allende-Prieto (CoI) (ESA Member)	Instituto de Astrofisica de Canarias	callende@iac.es
Dra. Susana Cristina Cabral Barros (CoI) (ESA Member)	Universidade do Porto	susana.barros@astro.up.pt
Dr. Nicolas Billot (CoI) (ESA Member)	Observatoire de Geneve	nicolas.billot@unige.ch
Gwenael Boue (CoI) (ESA Member)	Observatoire de Paris	gwenael.boue@obspm.fr
Dr. Vincent Bourrier (CoI) (ESA Member)	Observatoire de Geneve	vincent.bourrier@unige.ch
Dr. Alexis Brandeker (CoI) (ESA Member)	Stockholm University	alexis@astro.su.se
Dr. Giovanni Bruno (CoI) (ESA Member)	INAF, Osservatorio Astrofisico di Catania	giovanni.bruno@inaf.it
Prof. Alexandre C. M. Correia (CoI) (ESA Member)	University of Coimbra	acor@uc.pt
Prof. Brice-Olivier Demory (CoI) (ESA Member)	University of Bern	brice.demory@csh.unibe.ch
Prof. David Ehrenreich (CoI) (ESA Member)	Observatoire de Geneve	david.ehrenreich@unige.ch
Nestor Espinoza (CoI) (US Admin CoI)	Space Telescope Science Institute	nespinoza@stsci.edu
Dr. Luca Fossati (CoI) (ESA Member)	Space Research Institute, Austrian Academy of Sciences	luca.fossati@oeaw.ac.at

<i>Name</i>	<i>Institution</i>	<i>E-Mail</i>
Dr. Malcolm Fridlund (CoI) (ESA Member)	Sterrewacht Leiden	fridlund@strw.leidenuniv.nl
Jonas Haldemann (CoI) (ESA Member)	University of Bern	jonas.haldemann@space.unibe.ch
Sergio Hoyer (CoI) (ESA Member)	Laboratoire d'Astrophysique de Marseille	sergio.hoyer@lam.fr
Dr. Daniel Kitzmann (CoI) (ESA Member)	University of Bern	daniel.kitzmann@csh.unibe.ch
Dr. Baptiste Lavie (CoI) (ESA Member)	Observatoire de Geneve	baptiste.lavie@unige.ch
Dr. Monika Lendl (CoI) (ESA Member)	Observatoire de Geneve	monika.lendl@unige.ch
Brett M. Morris (CoI) (ESA Member)	University of Bern	brett.morris@space.unibe.ch
Dr. Hugh Osborn (CoI) (ESA Member)	University of Bern	hugh.osborn@space.unibe.ch
Dr. Mahmoudreza Oshagh (CoI) (ESA Member)	Instituto de Astrofisica de Canarias	moshagh@iac.es
Dr. Carina Persson (CoI) (ESA Member)	Chalmers University of Technology	carina.persson@chalmers.se
Francisco Jose Pozuelos-Romero (CoI) (ESA Member)	Instituto de Astrofisica de Andalucia (IAA)	pozuelos@iaa.es
Dr. Nuno C Santos (CoI) (ESA Member)	Institute of Astrophysics and Space Sciences (IA)	nuno.santos@astro.up.pt
Jean Schneider (CoI) (ESA Member)	Observatoire de Paris	jean.schneider@obspm.fr
Dr. Alessandro Sozzetti (CoI) (ESA Member)	INAF - Osservatorio Astrofisico di Torino	alessandro.sozzetti@inaf.it

## OBSERVATIONS

<i>Folder</i>	<i>Observation</i>	<i>Label</i>	<i>Observing Template</i>	<i>Science Target</i>
TOI-178 NIRSPEC BOTS				
	1	TOI-178d	NIRSpec Bright Object Time Series	(1) TOI-178
	2	TOI-178g	NIRSpec Bright Object Time Series	(1) TOI-178
	3	TOI-178b	NIRSpec Bright Object Time Series	(1) TOI-178

## ABSTRACT

The atmospheric characterisation of multiple exoplanets in the same system can provide a window into the processes that underpinned their formation and evolution. The planetary C/O ratios are of particular interest as they encode information about where the planet formed with respect to different ice lines, but precise measurements of this using current instrumentation have proved challenging. Recent observations have revealed that the nearby late K-type star TOI-178 hosts a compact system of at least six transiting exoplanets with  $R < 3$  Earth radii, five of which form a chain of Laplacian resonances. Alongside the fact that the large planet-to-planet density variations present in the system appear difficult to theoretically explain, its resonant chain and large atmospheric signal sizes provide a well-constrained laboratory to test the main formation theories. We propose to use JWST/NIRSpec in BOTS mode with the G395M grating to observe single transits of TOI-178 b, d, and g, providing an atmospheric

characterisation of planets that span the full range of known orbital separations from the host. Amongst other things, our mock retrievals suggest that the strong constraints that we will be able to place on the abundances of H<sub>2</sub>O, CO, CO<sub>2</sub>, and CH<sub>4</sub> will enable a precise derivation of the C/O for each planet. The combination of these measurements will facilitate the first detailed observational study using the C/O to test whether multiple planets in the same system formed in situ or migrated to their current positions.

## **OBSERVING DESCRIPTION**

We are proposing to conduct a small programme of ~ 24.85 hr including overheads to observe single transits of TOI-178 b, d, and g using NIRSpec in Bright Object Times Series (BOTS) mode and the default S1600A1 slit. We will use the G395M grating with the F290LP filter and the SUB2048 subarray. This provides resolving power of 1000 with wavelength coverage spanning 2.87-5.10 microns.

For each planet, we calculated the visit duration (or dwell time) for JWST observations of transiting exoplanets, given by  $T_{\text{dwell}} = 0.75 \text{ hr (detector settling)} + \max(1 \text{ hr, } T_{14}/2) \text{ (before transit)} + T_{14} \text{ (transit)} + \max(1 \text{ hr, } T_{14}/2) \text{ (after transit)} + 1 \text{ hr (timing window)}$ , where  $T_{14}$  is the total transit duration. Taken together, this ensures that both the transit and sufficient out-of-transit baseline are acquired, that the detector has sufficient time to settle, and the observation is sufficiently long to provide flexibility with the scheduling window. Respectively for planets b, c, and d, the transit durations of 1.65, 2.28, and 2.19 hr result in visit durations of 5.40, 6.31, and 6.13 hr.

For our observations, we set the number of groups per integration to be the maximum that ensures that none of the pixels in the detector exceeds 80% of its full well capacity. For TOI-178 ( $K_{\text{mag}} = 8.656$ ) with the NRSRAPID readout mode and the SUB2048 subarray, this occurred at 7 groups per integration. To cover the calculated visit durations, we used single exposures with 2697, 3150, and 3060 integrations for planets b, d, and g, respectively. At the resolution element corresponding to a wavelength of 3.95 microns, this achieves a SNR of 157 per frame, which corresponds to a precision on the transit depth of 267, 237, and 241 ppm. In practice, we will combine the data into wavelength bins to achieve an SNR that is sufficiently high to robustly detect the expected molecular features at these wavelengths.

Proposal 2319 - Targets - TOI-178: the best laboratory for testing planetary formation theories

#	Name	Target Coordinates	Targ. Coord. Corrections	Miscellaneous
(1)	TOI-178	RA: 00 29 12.4828 (7.3020117d) Dec: -30 27 14.82 (-30.45412d) Equinox: J2000	Proper Motion RA: 0.011596817739502139 sec of time/yr Proper Motion Dec: -0.08725300003789016 arcsec/yr Epoch of Position: 2015.5	
<p><i>Comments: This object was generated by the target selector and retrieved from the SIMBAD database.</i>  <i>Category=Star</i>  <i>Description=[Exoplanets, K stars]</i>  <i>Extended=NO</i></p>				
(2)	2MASSJ00291115-3027561	RA: 00 29 11.1906 (7.2966275d) Dec: -30 27 56.36 (-30.46566d) Equinox: J2000	Proper Motion RA: -2.1579397350383365E-5 sec of time/yr Proper Motion Dec: 2.11E-4 arcsec/yr Epoch of Position: 2015.5	
<p><i>Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.</i>  <i>Category=Star</i>  <i>Description=[F stars]</i>  <i>Extended=NO</i></p>				

Proposal 2319 - Observation 1 - TOI-178: the best laboratory for testing planetary formation theories

Wed Mar 31 00:17:01 GMT 2021

<b>Observation</b>	<p><b>Proposal 2319, Observation 1: TOI-178d</b></p> <p><b>Diagnostic Status: Warning</b></p> <p>Observing Template: NIRSpec Bright Object Time Series</p>																																										
<b>Diagnostics</b>	<p>(TOI-178d (Obs 1)) Warning (Form): Exposure Duration exceeds the limit of 10000.0 seconds. Above this limit it is possible that a High Gain Antenna move may occur during the exposure.</p> <p>(Visit 1:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.</p>																																										
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<b>Special Requirements</b>	<p>Phase 0.97439 to 0.98075 with period 6.5576941 Days and zero-phase 2458747.1464507 HJD</p> <p>Time Series Observation</p> <p>No Parallel</p>																																										

Proposal 2319 - Observation 2 - TOI-178: the best laboratory for testing planetary formation theories

Wed Mar 31 00:17:01 GMT 2021

<b>Observation</b>	<p><b>Proposal 2319, Observation 2: TOI-178g</b></p> <p><b>Diagnostic Status: Warning</b></p> <p>Observing Template: NIRSpec Bright Object Time Series</p>																																										
<b>Diagnostics</b>	<p>(TOI-178g (Obs 2)) Warning (Form): Exposure Duration exceeds the limit of 10000.0 seconds. Above this limit it is possible that a High Gain Antenna move may occur during the exposure.</p> <p>(Visit 2:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.</p>																																										
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<b>Special Requirements</b>	<p>Phase 0.99207 to 0.99408 with period 20.70945955 Days and zero-phase 2458748.02934 HJD</p> <p>Time Series Observation</p> <p>No Parallel</p>																																										

Proposal 2319 - Observation 3 - TOI-178: the best laboratory for testing planetary formation theories

Wed Mar 31 00:17:01 GMT 2021

<b>Observation</b>	<p><b>Proposal 2319, Observation 3: TOI-178b</b></p> <p><b>Diagnostic Status: Warning</b></p> <p>Observing Template: NIRSpec Bright Object Time Series</p>																															
<b>Diagnostics</b>	<p>(TOI-178b (Obs 3)) Warning (Form): Exposure Duration exceeds the limit of 10000.0 seconds. Above this limit it is possible that a High Gain Antenna move may occur during the exposure.</p> <p>(Visit 3:1) Warning (Form): Overheads are provisional until the Visit Planner has been run.</p>																															
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#	Grating/Filter	Readout Pattern	Groups/Int	Integrations/Exp	Exposures/Dith	Total Dithers	Total Integrations	Total Exposure Time	ETC Wkbk.Calc ID																							
1	G395M/F290LP	NRSRAPID	7	2697	1	1	2697	19516.787	57628.4																							
<b>Special Requirements</b>	<p>Between Dates 24-NOV-2020:00:00:00 and 12-DEC-2022:00:00:00</p> <p>Between Dates 14-DEC-2022:00:00:00 and 24-NOV-2050:00:00:00</p> <p>Phase 0.92601 to 0.94777 with period 1.9145567 Days and zero-phase 2458741.63705 HJD</p> <p>Time Series Observation</p> <p>No Parallel</p>																															