16648 - Atmospheric Evolution and Loss of a Recently Discovered Low-Density Ultra-Short Period Super-Earth

Cycle: 29, Proposal Category: GO

(UV Initiative)

(Availability Mode: SUPPORTED)

INVESTIGATORS

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VISITS

Visit	*Targets used in Visit*	*Configurations used in Visit*	*Orbits Used*	*Last Orbit Planner Run*	*OP Current with Visit?*
03	(1) UCAC4-666-026266	STIS/CCD STIS/NUV-MAMA	1	02-Dec-2022 12:00:42.0	yes
02	(1) UCAC4-666-026266 WAVE	STIS/CCD STIS/FUV-MAMA	4	02-Dec-2022 12:00:44.0	yes
01	(1) UCAC4-666-026266 WAVE	STIS/CCD STIS/FUV-MAMA	4	02-Dec-2022 12:00:46.0	yes

9 Total Orbits Used

ABSTRACT

Super-Earth characterization continues to be a particular focus of the field given that it is the interface between terrestrial planets and gas-dominated planets. The implications of this division reverberate in planet formation, planetary interiors, and the origins and evolution of planetary atmospheres. A recently discovered ultra-short period exoplanet, TOI-1685b, is the lowest density super-Earth to orbit a small, low-mass star. Its low density and small host star, make it an ideal candidate for extended atmosphere characterization and a measurement of super-Earth mass loss. TOI-1685b has a relatively hot atmosphere, which makes it an excellent target for measuring atmospheric hydrogen escape, particularly given its close orbit, deep within the stellar wind of its host star. Measurements of hydrogen escape provides constraints on the evolution of the planetary atmosphere. We propose spectroscopic observations of two planetary transits to measure the stellar Lyman-alpha emission line and search for signatures of an extended hydrogen atmosphere. The Lyman-alpha line is also the dominant source of UV emission for cool stars, and thereby has a tremendous impact on planetary atmospheres. These observations, along with a short near-UV observation of MgII, the second most dominant emission line, will provide a vital characterization of the stellar inputs into all of the planetary atmospheres in this system. Observations of hot and largely cloud-free atmospheres, particularly of super-Earths like the one requested in this proposal, are an important step in planning future observations of temperate planetary atmospheres.

OBSERVING DESCRIPTION

We plan to use STIS with the G140M grating and 52"x0.1" aperture in order to observe R ~ 10,000 spectra of Lyman-alpha at 1215.67 Angstroms in time-tag mode for two transits of TOI-1685b. Observing two transits will allow the pre-, in-, and post-transit phases to be fully sampled. Due to Hubble's visibility restrictions, a single HST visit composed of 4 orbits will include 92% of the 0.96 hour transit, and 1 or 2 pre- or post-transit observations depending on the chosen schedule. Observations far from first and fourth contact are important in case the escaping material is very extended, similar to what is observed for GJ436 b (Ehrenreich et al. 2015). A NUV E230M exposure is also planned in order to observe the second strongest UV stellar emission line in cool stars, MgII at 2796 and 2803 Angstroms. These observations are important in reconstructing the ISM absorption that dominates the Lyman-alpha profile. This is a step that is often ignored and simplistic assumptions must be made to interpret the stellar profile. This visit has no scheduling constraints and can be taken at any time.

The target is the newly discovered planetary system transiting TOI-1685. It is relatively bright, and among the very best super-Earths with which to do these atmospheric follow-up observations. It stands alone among similar short-period super-Earth exoplanets, as a very low density planet. TOI-

1685b is an ultra-short period exoplanet, with an orbital period of only 0.67 days! Therefore, there are ample opportunities to obtain in-transit observations, even with the geocoronal constraint discussion below.

The narrow slits and spectral resolution capabilities of STIS are necessary to observe the Lyman-alpha profile without overwhelming contamination by geocoronal emission (see below). The resolving power of the G140M grating has been demonstrated to be sufficient to resolve the line and detect extended atmospheres of small exoplanets (e.g., GJ436b; Kulow et al. 2014, Ehrenreich et al. 2015). We also propose a single orbit to use the medium resolution E230M grating to observe the MgII emission profile and interstellar absorption. This information is critical to estimating the intrinsic stellar emission profile of Lyman-alpha, as well as constraining the influence of interstellar absorption.

The narrow aperture sizes of STIS are critical in order to minimize the contamination by the geocoronal Lyman-alpha emission (an important component of the observations that prevent this experiment from being performed with COS). Depending on the time of year, the Earth's motion can Doppler shift the geocoronal line into the stellar emission and contaminate our measurement. Our target will require a timing constraint for observations to be taken between 8 Jun and 2 Dec, to ensure that the geocoronal line is in the core of the ISM absorption.

Because cool stars (even late-A and early-F stars) are emission line sources in the far-UV, estimating expected S/N for our planned spectra requires first estimating Lyman-alpha and MgII fluxes, which we can do by extrapolating from previously observed stars. Chromospheric line fluxes (such as MgII and Lyman-alpha) are related to X-ray fluxes (Ayres et al. 1995). Wood et al. (2005) provide Lyman-alpha spectra for many stars, which serve as the comparison stars for our purposes here.

While we do not have a direct X-ray observation of TOI-1685, we are able to use the observed rotation period and scaling relations from Mamajek & Hillenbrand (2008) and Linsky et al. (2013, 2014), which results in a log L_X estimated to be 27.0. We estimate that over a single transit, approximately 2,880 seconds after accounting for overheads, that a S/N in the blue wing of the Lyman-alpha profile at 1215.3 Angstroms will be 23.2 per resolution element. Across the entire observed Lyman-alpha profile, the S/N will be ~ 100, and capable of detecting levels of 10%-50% seen for GJ436b (Kulow et al. 2014, Ehrenreich et al. 2015), even accounting for the difference in planetary and stellar size.

We request observations of two transits for several reasons. First, to fully sample the transit curve and the pre- and post-transit periods. Second, to increase the S/N in order to be sensitive to small Lyman-alpha planetary absorption levels. Finally, two transits will enable a test of variability on the planetary absorption (as was found for HD189733b taken in a similar observing mode; Lecavelier des Etangs et al. 2012), any variability in the pre- or post-transit absorption, or variability in the stellar flux.

We plan to correct for telescope ``breathing'' which can generally be modeled as a low order polynomial by using time-tagged data to create a time series of exposures for each individual orbit (Ehrenreich et al. 2012, Bourrier et al. 2013). This effect is important at the 20% level, well above the expected pre-transit absorption level. Four orbits per visit should allow us to adequately model the breathing effect and remove it from each orbit.

Another potentially important systematic effect is the ramp-up in measured flux seen for some STIS observations (Sing et al. 2011, Bourrier et al. 2013). The ramp-up effect tends to produce systematically lower flux values for the first orbit of a visit. However, it is not clear that this effect is always important for the instrument setup we have chosen. Ehrenreich et al. (2012) do not observe this effect in either of their two visits. In fact, even the breathing effect seems not to be present in the data form their second visit. Bourrier et al. (2013) do observe the ramp-up effect in the first orbit of their observations.

The E230M MgII exposure is expected to obtain a S/N of 11.1 per resolution element on wing at half-maximum of the stellar emission profile. This is sufficient to characterize the stellar emission line profile shape (used to help estimate the intrinsic Lyman-alpha profile shape), and even measure the ISM absorption (used to help characterize the ISM absorption in the Lyman-alpha profile). This has been demonstrated on several nearby targets observed with comparable S/N (e.g., Redfield & Linsky 2002, 2004).

The proposed star has a UV spectrum characterized by minimal continuum, but strong emission lines. For this reason, it falls far short of the global brightness limit. The emission lines for our target also falls far short of the local brightness limit. The two emission lines of interest in this proposal (Lyman-alpha and MgII) are also the brightest, and therefore, the procedure given above for estimating the S/N near their peaks is also utilized to test for brightness limit violations.

Visit

Proposal 16648, Visit 03, completed Fri Dec 02 17:00:46 GMT 2022

Diagnostic Status: No Diagnostics

Scientific Instruments: STIS/NUV-MAMA, STIS/CCD

Special Requirements: (none)

Fixed Targets

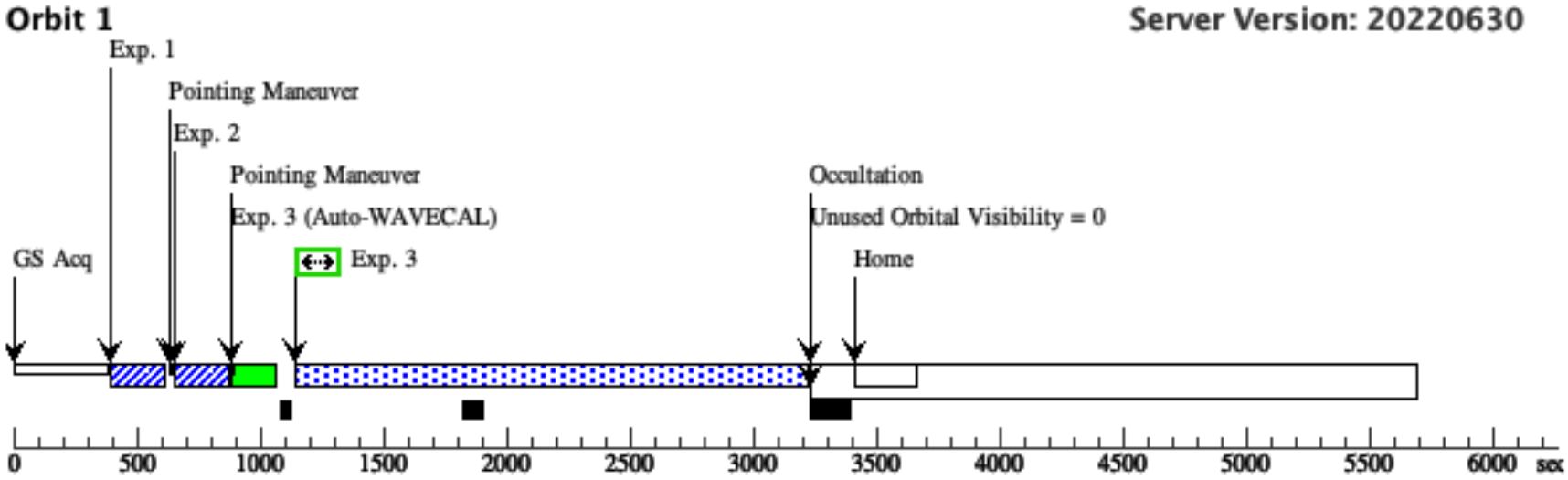
#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	UCAC4-666-026266	RA: 04 34 22.5509 (68.5939621d) Dec: +43 02 13.31 (43.03703d) Equinox: J2000	Proper Motion RA: 37.76220114208268 mas/yr Proper Motion Dec: -87.0623864067154 mas/yr Parallax: 0.026589300033944568" Epoch of Position: 2015.5 Radial Velocity: -43.401 km/sec	V=13.378+/-0.03 TYPE=M3V, E(B-V)=0, F-LINE(2796)=0.028e-12, W-LINE(2796)=0.35, F-LINE(1215)=0.074e-12, W-LINE(1215)=0.6	Reference Frame: ICRS

Comments: This object was generated by the targetselector and retrieved from the SIMBAD database. Position, parallax, and proper motion are taken from GAIA DR2.
Category=STAR
Description=[EXTRA-SOLAR PLANETARY SYSTEM, M V-IV]
Extended=NO

Exposures

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	ACQ (STIS.ta.1530005)	(1) UCAC4-666-026266	STIS/CCD, ACQ, F28X50LP	MIRROR	ACQTYPE=POINT		Sequence 1-3 Non-Int in Visit 03	0.4 Secs (0.4 Secs) *[==>]*	 ***[1]***
	Comments: SNR = 170.5034 *Brightest Pixel = 9,948.58 e*								
2	ACQ/PEAK (STIS.ta.1530013)	(1) UCAC4-666-026266	STIS/CCD, ACQ/PEAK, 52X0.1	MIRROR			Sequence 1-3 Non-Int in Visit 03	0.5 Secs (0.5 Secs) *[==>]*	 ***[1]***
	Comments: SNR = 161.9657 *Brightest Pixel = 12,051.95 e* *Global Source Counts = 65,743.661 e*								
3	SCIENCE (STIS.sp.1530401)	(1) UCAC4-666-026266	STIS/NUV-MAMA, TIME-TAG, 0.2X0.2	E230M 2707 A	BUFFER-TIME=690		Sequence 1-3 Non-Int in Visit 03	2068 Secs (2068 Secs) *[==>]*	 ***[1]***
	Comments: SNR = 14.9377 *Brightest Pixel = 99.74 e*								

Orbit Structure



Visit

Proposal 16648, Visit 02, implementation

Fri Dec 02 17:00:47 GMT 2022

Diagnostic Status: No Diagnostics

Scientific Instruments: STIS/CCD, STIS/FUV-MAMA

Special Requirements: BETWEEN 03-DEC-2022:00:00:00 AND 05-JAN-2023:00:00:00; Period 0.6691403 D AND ZERO-PHASE HJD2458816.22615

Fixed Targets

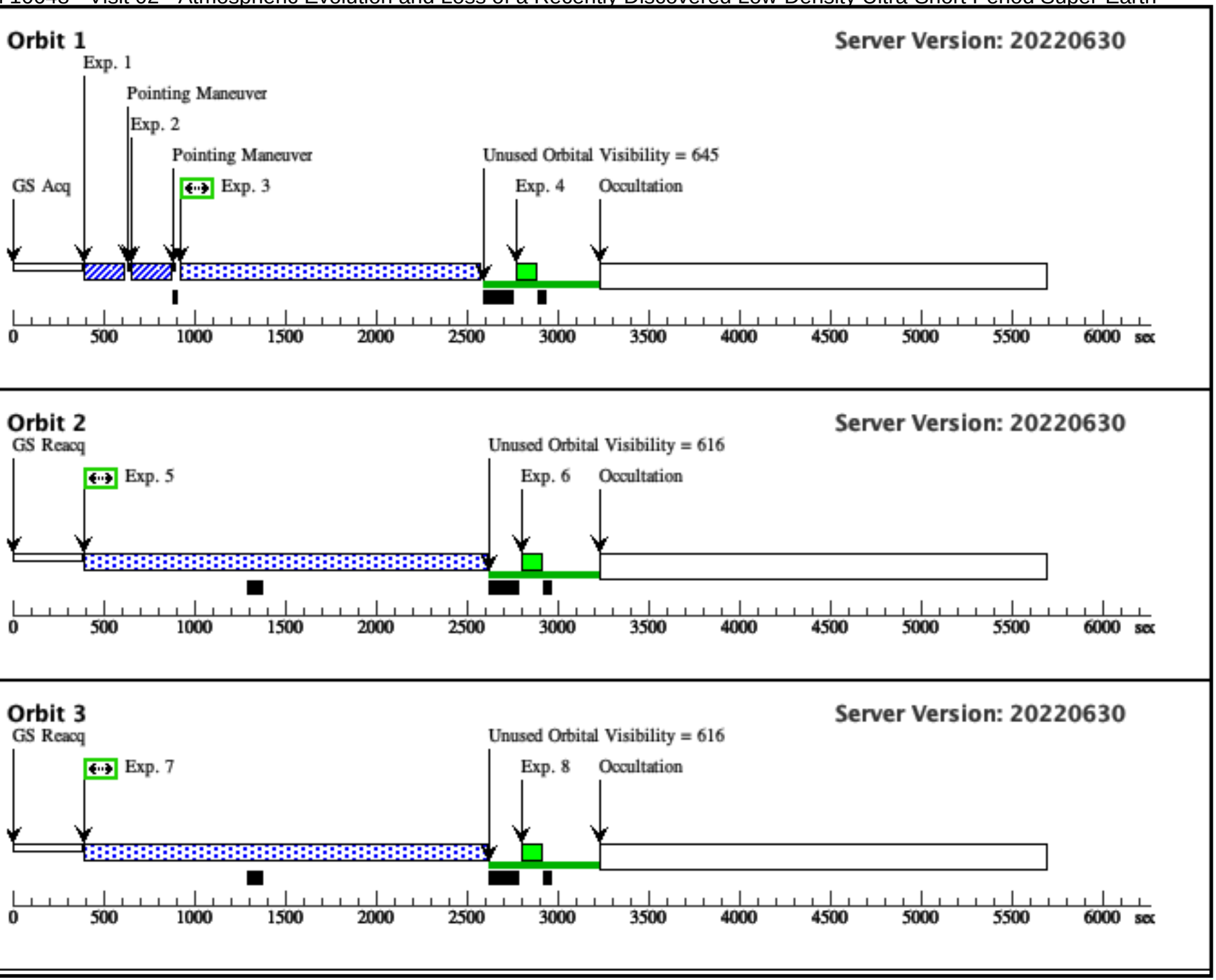
#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	UCAC4-666-026266	RA: 04 34 22.5509 (68.5939621d) Dec: +43 02 13.31 (43.03703d) Equinox: J2000	Proper Motion RA: 37.76220114208268 mas/yr Proper Motion Dec: -87.0623864067154 mas/yr Parallax: 0.026589300033944568" Epoch of Position: 2015.5 Radial Velocity: -43.401 km/sec	V=13.378+/-0.03 TYPE=M3V, E(B-V)=0, F-LINE(2796)=0.028e-12, W-LINE(2796)=0.35, F-LINE(1215)=0.074e-12, W-LINE(1215)=0.6	Reference Frame: ICRS

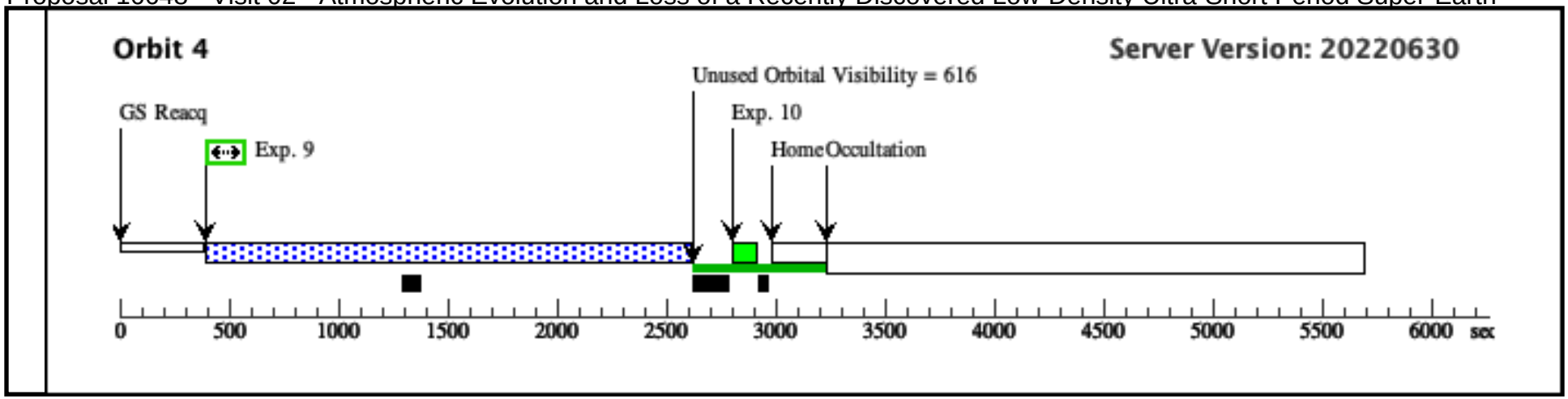
Comments: This object was generated by the targetselector and retrieved from the SIMBAD database. Position, parallax, and proper motion are taken from GAIA DR2.
Category=STAR
Description=[EXTRA-SOLAR PLANETARY SYSTEM, M V-IV]
Extended=NO

Exposures

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	ACQ (STIS.ta.1530005)	(1) UCAC4-666-026266	STIS/CCD, ACQ, F28X50LP	MIRROR	ACQTYPE=POINT	PHASE 0.8630 TO 0.8864	Sequence 1-4 Non-Int in Visit 02	0.4 Secs (0.4 Secs) *[==>]*	***[1]***
	Comments: SNR = 170.5034 *Brightest Pixel = 9,948.58 e*								
2	ACQ/PEAK (STIS.ta.1530013)	(1) UCAC4-666-026266	STIS/CCD, ACQ/PEAK, 52X0.1	MIRROR			Sequence 1-4 Non-Int in Visit 02	0.5 Secs (0.5 Secs) *[==>]*	***[1]***
	Comments: SNR = 161.9657 *Brightest Pixel = 12,051.95 e* *Global Source Counts = 65,743.661 e*								
3	SCIENCE (STIS.sp.1530020)	(1) UCAC4-666-026266	STIS/FUV-MAMA, TIME-TAG, 52X0.2	G140M 1222 A	BUFFER-TIME=900; WAVECAL=NO		Sequence 1-4 Non-Int in Visit 02	1500 Secs (1500 Secs) *[==>]*	***[1]***
	Comments: SNR = 14.5615 *Brightest Pixel = 52.78 e* *Global Count rate = 235.075 e/s*								
4	GO WAVE CAL	WAVE	STIS/FUV-MAMA, ACCUM, 52X0.2	G140M 1222 A			Sequence 1-4 Non-Int in Visit 02	*[==>]*	***[1]***
5	SCIENCE (STIS.sp.1530067)	(1) UCAC4-666-026266	STIS/FUV-MAMA, TIME-TAG, 52X0.2	G140M 1222 A	BUFFER-TIME=900; WAVECAL=NO		Sequence 5-6 Non-Int in Visit 02	2200 Secs (2200 Secs) *[==>]*	***[2]***
	Comments: SNR = 16.6843 *Brightest Pixel = 69.30 e* *Global Count rate = 235.075 e/s*								
6	GO WAVE CAL	WAVE	STIS/FUV-MAMA, ACCUM, 52X0.2	G140M 1222 A			Sequence 5-6 Non-Int in Visit 02	*[==>]*	***[2]***
7	SCIENCE (STIS.sp.1530067)	(1) UCAC4-666-026266	STIS/FUV-MAMA, TIME-TAG, 52X0.2	G140M 1222 A	BUFFER-TIME=900; WAVECAL=NO		Sequence 7-8 Non-Int in Visit 02	2200 Secs (2200 Secs) *[==>]*	***[3]***
	Comments: SNR = 16.6843 *Brightest Pixel = 69.30 e* *Global Count rate = 235.075 e/s*								
8	GO WAVE CAL	WAVE	STIS/FUV-MAMA, ACCUM, 52X0.2	G140M 1222 A			Sequence 7-8 Non-Int in Visit 02	*[==>]*	***[3]***
9	SCIENCE (STIS.sp.1530067)	(1) UCAC4-666-026266	STIS/FUV-MAMA, TIME-TAG, 52X0.2	G140M 1222 A	BUFFER-TIME=900; WAVECAL=NO		Sequence 9-10 Non-Int in Visit 02	2200 Secs (2200 Secs) *[==>]*	***[4]***
	Comments: SNR = 16.6843 *Brightest Pixel = 69.30 e* *Global Count rate = 235.075 e/s*								
10	GO WAVE CAL	WAVE	STIS/FUV-MAMA, ACCUM, 52X0.2	G140M 1222 A			Sequence 9-10 Non-Int in Visit 02	*[==>]*	***[4]***

Orbit Structure

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3000
3500
4000
4500
5000
5500
6000
sec

Visit

Proposal 16648, Visit 01, implementation Fri Dec 02 17:00:47 GMT 2022

Diagnostic Status: No Diagnostics

Scientific Instruments: STIS/CCD, STIS/FUV-MAMA

Special Requirements: BETWEEN 25-NOV-2022:00:00:00 AND 04-JAN-2023:00:00:00; BETWEEN 29-JUL-2023:00:00:00 AND 25-DEC-2023:00:00:00; Period 0.6691403 D AND ZERO-PHASE HJD2458816.22615

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	UCAC4-666-026266	RA: 04 34 22.5509 (68.5939621d) Dec: +43 02 13.31 (43.03703d) Equinox: J2000	Proper Motion RA: 37.76220114208268 mas/yr Proper Motion Dec: -87.0623864067154 mas/yr Parallax: 0.026589300033944568" Epoch of Position: 2015.5 Radial Velocity: -43.401 km/sec	V=13.378+/-0.03 TYPE=M3V, E(B-V)=0, F-LINE(2796)=0.028e-12, W-LINE(2796)=0.35, F-LINE(1215)=0.074e-12, W-LINE(1215)=0.6	Reference Frame: ICRS

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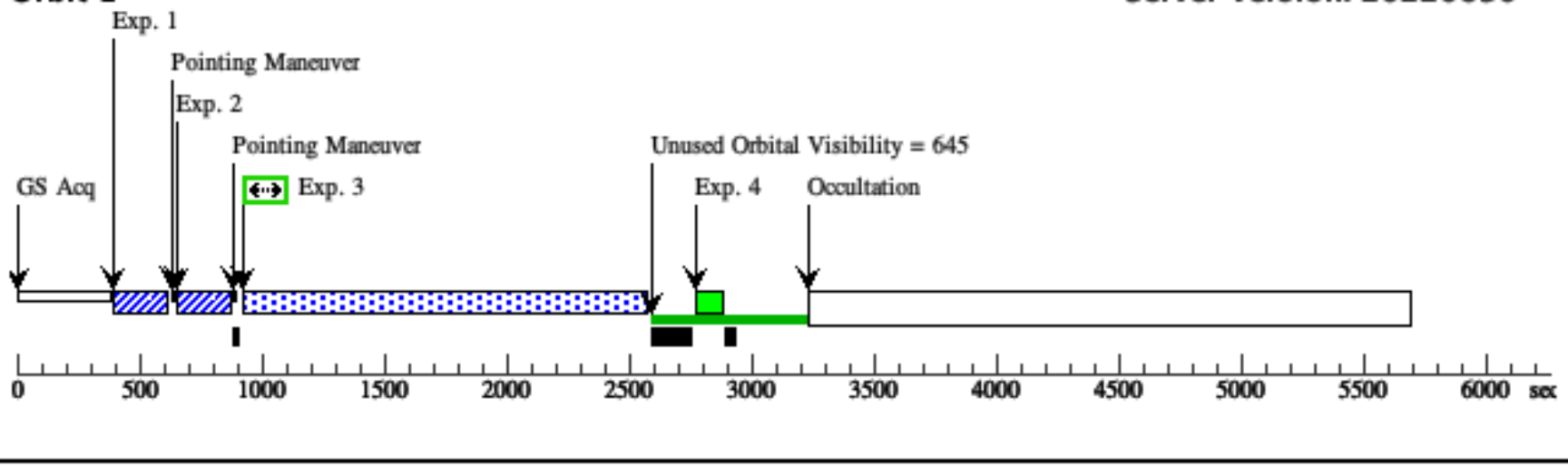
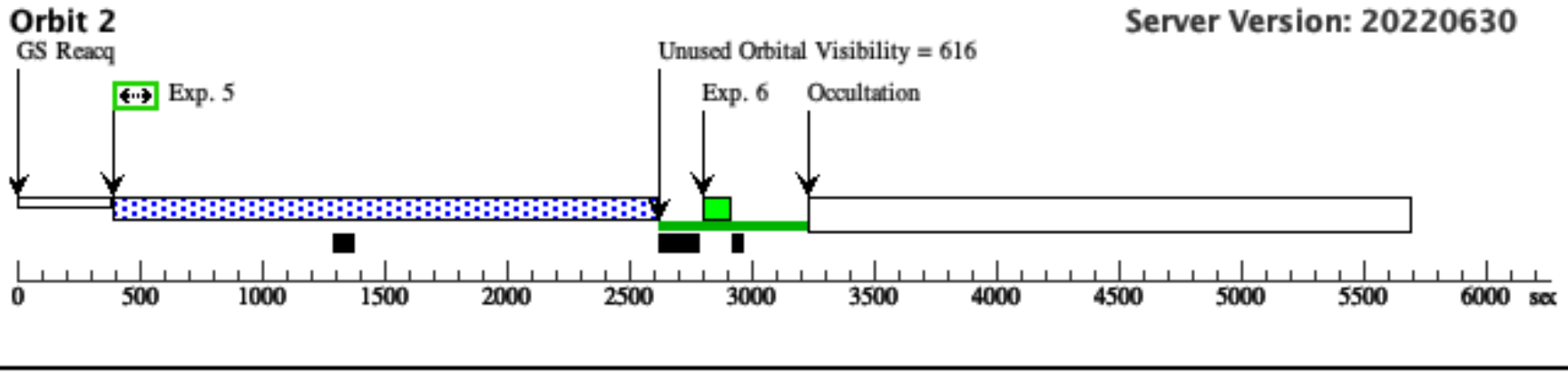
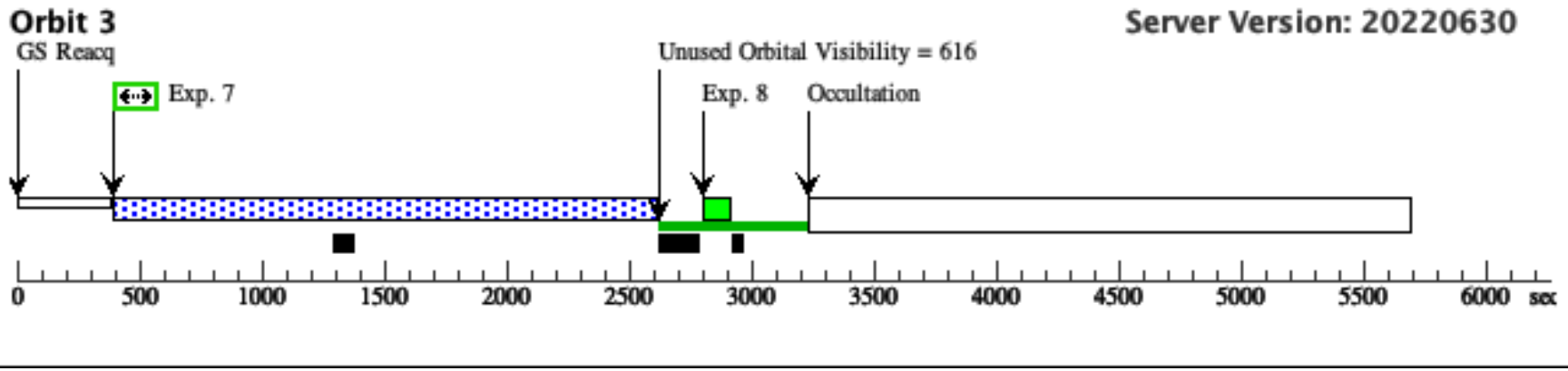
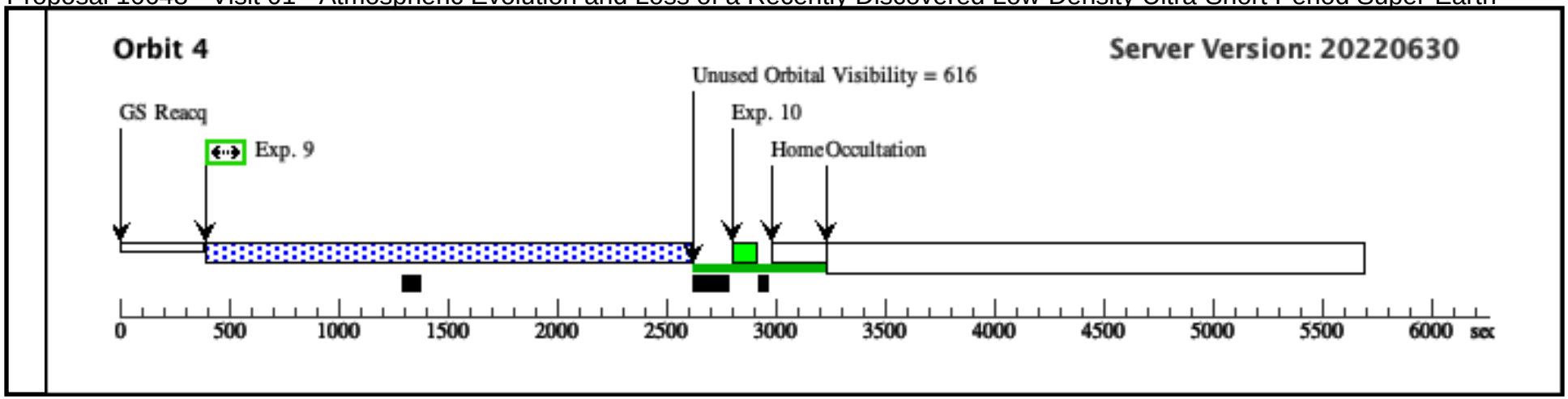
1	ACQ (STIS.ta.1530005)	(1) UCAC4-666-026266	STIS/CCD, ACQ, F28X50LP	MIRROR	ACQTYPE=POINT	PHASE 0.8630 TO 0.8864	Sequence 1-4 Non-Int in Visit 01	0.4 Secs (0.4 Secs) *[==>]*	***[1]***
	Comments: SNR = 170.5034 *Brightest Pixel = 9,948.58 e*								
2	ACQ/PEAK (STIS.ta.1530013)	(1) UCAC4-666-026266	STIS/CCD, ACQ/PEAK, 52X0.1	MIRROR			Sequence 1-4 Non-Int in Visit 01	0.5 Secs (0.5 Secs) *[==>]*	***[1]***
	Comments: SNR = 161.9657 *Brightest Pixel = 12,051.95 e* *Global Source Counts = 65,743.661 e*								
3	SCIENCE (STIS.sp.1530020)	(1) UCAC4-666-026266	STIS/FUV-MAMA, TIME-TAG, 52X0.2	G140M 1222 A	BUFFER-TIME=900; WAVECAL=NO		Sequence 1-4 Non-Int in Visit 01	1500 Secs (1500 Secs) *[==>]*	***[1]***
	Comments: SNR = 14.5615 *Brightest Pixel = 52.78 e* *Global Count rate = 235.075 e/s*								
4	GO WAVE CAL	WAVE	STIS/FUV-MAMA, ACCUM, 52X0.2	G140M 1222 A			Sequence 1-4 Non-Int in Visit 01	*[==>]*	***[1]***
5	SCIENCE (STIS.sp.1530067)	(1) UCAC4-666-026266	STIS/FUV-MAMA, TIME-TAG, 52X0.2	G140M 1222 A	BUFFER-TIME=900; WAVECAL=NO		Sequence 5-6 Non-Int in Visit 01	2200 Secs (2200 Secs) *[==>]*	***[2]***
	Comments: SNR = 16.6843 *Brightest Pixel = 69.30 e* *Global Count rate = 235.075 e/s*								
6	GO WAVE CAL	WAVE	STIS/FUV-MAMA, ACCUM, 52X0.2	G140M 1222 A			Sequence 5-6 Non-Int in Visit 01	*[==>]*	***[2]***
7	SCIENCE (STIS.sp.1530067)	(1) UCAC4-666-026266	STIS/FUV-MAMA, TIME-TAG, 52X0.2	G140M 1222 A	BUFFER-TIME=900; WAVECAL=NO		Sequence 7-8 Non-Int in Visit 01	2200 Secs (2200 Secs) *[==>]*	***[3]***
	Comments: SNR = 16.6843 *Brightest Pixel = 69.30 e* *Global Count rate = 235.075 e/s*								
8	GO WAVE CAL	WAVE	STIS/FUV-MAMA, ACCUM, 52X0.2	G140M 1222 A			Sequence 7-8 Non-Int in Visit 01	*[==>]*	***[3]***
9	SCIENCE (STIS.sp.1530067)	(1) UCAC4-666-026266	STIS/FUV-MAMA, TIME-TAG, 52X0.2	G140M 1222 A	BUFFER-TIME=900; WAVECAL=NO		Sequence 9-10 Non-Int in Visit 01	2200 Secs (2200 Secs) *[==>]*	***[4]***
	Comments: SNR = 16.6843 *Brightest Pixel = 69.30 e* *Global Count rate = 235.075 e/s*								
10	GO WAVE CAL	WAVE	STIS/FUV-MAMA, ACCUM, 52X0.2	G140M 1222 A			Sequence 9-10 Non-Int in Visit 01	*[==>]*	***[4]***

Orbit Structure








Orbit 4
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Unused Orbital Visibility = 616
GS Reacq
Exp. 9
Exp. 10
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Occultation
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sec