17134 - Testing the Limits of Mass Transfer Stability With A Post-Mass-Transfer Binary In M67

Cycle: 30, Proposal Category: GO

(UV Initiative)

(Availability Mode: SUPPORTED)

INVESTIGATORS

Name	*Institution*
Dr. Emily Leiner (PI) (Contact)	**Illinois Institute of Technology**
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Dr. Meng Sun (CoI)	Northwestern University

VISITS

Visit	*Targets used in Visit*	*Configurations used in Visit*	*Orbits Used*	*Last Orbit Planner Run*	*OP Current with Visit?*
01	(1) WOCS14020	COS/FUV COS/NUV	2	21-Jun-2023 15:00:20.0	yes
02	(1) WOCS14020	COS/FUV COS/NUV	2	21-Jun-2023 15:00:20.0	yes
06	(1) WOCS14020	COS/FUV COS/NUV	2	21-Jun-2023 15:00:21.0	yes

Visit	*Targets used in Visit*	*Configurations used in Visit*	*Orbits Used*	*Last Orbit Planner Run*	*OP Current with Visit?*
03	(1) WOCS14020	COS/FUV COS/NUV	2	21-Jun-2023 15:00:22.0	yes
04	(1) WOCS14020	COS/FUV COS/NUV	2	21-Jun-2023 15:00:22.0	yes
05	(1) WOCS14020	COS/FUV COS/NUV	2	21-Jun-2023 15:00:23.0	yes
07	(1) WOCS14020	COS/FUV COS/NUV	2	21-Jun-2023 15:00:24.0	yes

14 Total Orbits Used

ABSTRACT

Many important systems result from mass transfer (MT) in low-mass binaries including double white dwarf (WD) binaries and Type Ia supernovae. A key uncertainty in modeling these systems is whether the MT will be unstable, resulting in a common envelope that dramatically shrinks the binary orbit. In particular, theory suggests that most MT from an RGB donor should be unstable, but observations reveal many systems that challenge this hypothesis. Here we target WOCS 14020, a main sequence-WD binary in open cluster M67. The orbital period of 359 days suggests the system evolved through stable MT from an RGB donor star. WOCS 14020 is uniquely poised to test the limits of MT stability; the primary main-sequence star is one of the lowest mass outcomes of MT in the cluster, and canonical MT models predict MT on to lower mass accretors to be increasingly unstable. We request 10 orbits of COS FUV spectroscopy to measure the WD mass and cooling age in this system, which together define the evolutionary state of the donor star during MT. Further, WOCS 14020's membership in M67 provides many important constraints that are not usually available in modeling post-MT binaries. Together, this will allow us to construct an unusually detailed evolutionary history for WOCS 14020, and explore whether non-conservative mass transfer models yield stable MT evolution and reproduce the observed system. The results will be an important test of whether non-conservative MT models can empirically match the extent of the post-MT population of a benchmark open cluster. The precise WD mass and age measurements required are only possible with FUV spectroscopy, a capability unique to HST.

OBSERVING DESCRIPTION

We propose 10 orbits of FUV COS spectroscopy of the Lyman-alpha region of WOCS 14020, a post-mass-transfer main sequence-white dwarf binary in the open cluster M67 with an orbital period of 359 days. Using this spectrum we will measure the effective temperature and surface gravity

of the WD, breaking the degeneracy between temperature and surface gravity with the known distance to M67. We can then use these measurements to constrain the mass, radius, and cooling age for the WD component, allowing us to model the formation history of this system in exceptional detail.

The main sequence component of WOCS 14020 is a G-type main-sequence star with a temperature of 5990 K. This temperature is cool enough that the Wien tail of the SED drops off rapidly in the UV, and thus FUV spectroscopy will be dominated by the flux from the white dwarf (WD) companion. We can be confident that the WD will be detectable with COS based on previous HST/ACS/SBC FUV photometry in the derived bandpasses of F140N and F150N along with F165LP (HST-GO 16244; PI Mathieu). The derived fluxes are 9.37e-17 erg s-1 cm-2 A-1 in F140N, 1.18e-16 erg s-1 cm-2 A-1 in F150N, and 1.12e-16 erg s-1 cm-2 A-1 in F165LP. The FUV photometry shows a clear photometric excess above the flux expected from the WOCS 14020 main sequence component alone, compelling evidence that a detectable, hot WD is present. Photometric fits are degenerate between temperature, mass, and radius, and therefore the photometry cannot well constrain the WD mass and core composition. However, the photometric detections allow us to calculate COS exposure times by scaling possible WD spectral models to the observed FUV fluxes. For the ETC calculations presented here, we adopt a spectral model that combines a 0.39 Msun, 12,250 K WD and a 5990 K main sequence star, reddened to match the M67 reddening of E(B-V)= 0.041, and normalized to the observed V-band and HST FUV photometry. We note that the true mass and temperature of the WD may differ somewhat from these chosen values, but because we can scale to the observed FUV photometry the exposure time calculated should yield sufficient S/N across the range of plausible white dwarf parameters.

We propose to observe WOCS 14020 with COS using the G140L grating with a central wavelength setting of 1105 Angstroms, providing a spectral range of 1130-2000 A and a spectral resolution of ~0.6 A. This encompasses the Lyman-alpha absorption line at 1216 A, which is essential to determining the WD temperature and gravity. A 407-minute integration with COS will yield a S/N ~ 10 in the wing of Lyman-alpha at 1280 A, after binning to ~1.5 As. This is the signal level necessary to fit WD atmospheres to models in previous studies (e.g. Landsman et al. 1997, Gosnell et al. 2015). Although higher S/N is possible by binning G130M spectra, we require the widest wavelength coverage possible for our fitting purposes, which is provided by the G140L grating.

The target position and proper motion are both very well known from Gaia, so target acquisition can be carried out with NUV imaging instead of a search pattern. Gaia coordinates have uncertainties less than 0.1 mas.

M67 has a total of 52 minutes of visibility per orbit. Including guide star acquisition, target acquisition, and overheads we have requested a total allocation of 10 orbits. These orbits will be divided into five visits of 2 orbits each to protect the detector of COS and aid in scheduling. We will use all four FP-POS positions during each visit.

There are no special timing considerations for these observations and no expected risks to the COS detectors. The target is a binary system, and the primary star in the binary is a G-type main sequence star with no large flares detected in Kepler/K2 observations. The binary system is too wide (Porb= 359 days) for there to be ongoing accretion or outbursts, and the HST UV photometry is also consistent with an older (~300 Myr), quiet WD system. The star's location within the central regions of a well-studied old open cluster ensures that nearby sources are well-characterized, and all are older inactive stars. No nearby bright or flaring sources will present a risk. The BOT tool returns one source as a Health/Safety issue (Object ID: N8X7000767) with a spectral type of **O5V**. This is actually our target which is a G type star (5990 K) with a white dwarf companion, and is not a threat to the detectors.

We do not anticipate significant adverse impacts on this program if HST is reduced to 2-gyro mode. We do not have any timing or orientation restrictions and current schedulability is high, so we expect this program would continue to be schedulable under reduced gyro operations.

Visit

Proposal 17134, Visit 01, completed Wed Jun 21 19:00:24 GMT 2023

Diagnostic Status: No Diagnostics

Scientific Instruments: COS/FUV, COS/NUV

Special Requirements: (none)

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	WOCS14020	RA: 08 52 3.4887 (133.0145362d) Dec: +11 47 48.09 (11.79669d) Equinox: J2000	Proper Motion RA: -11.073 mas/yr Proper Motion Dec: -3.248 mas/yr Parallax: .0014567" Epoch of Position: 2016	V=14.693+/-0.143 NUV= 19.56, F150N= 1.18e-16 cgs, E(B-V)= 0.041	Reference Frame: ICRS

Comments: Coordinates and proper motions from Gaia DR3
Category=STAR
Description=[BLUE STRAGGLER, G V-IV]
Extended=NO

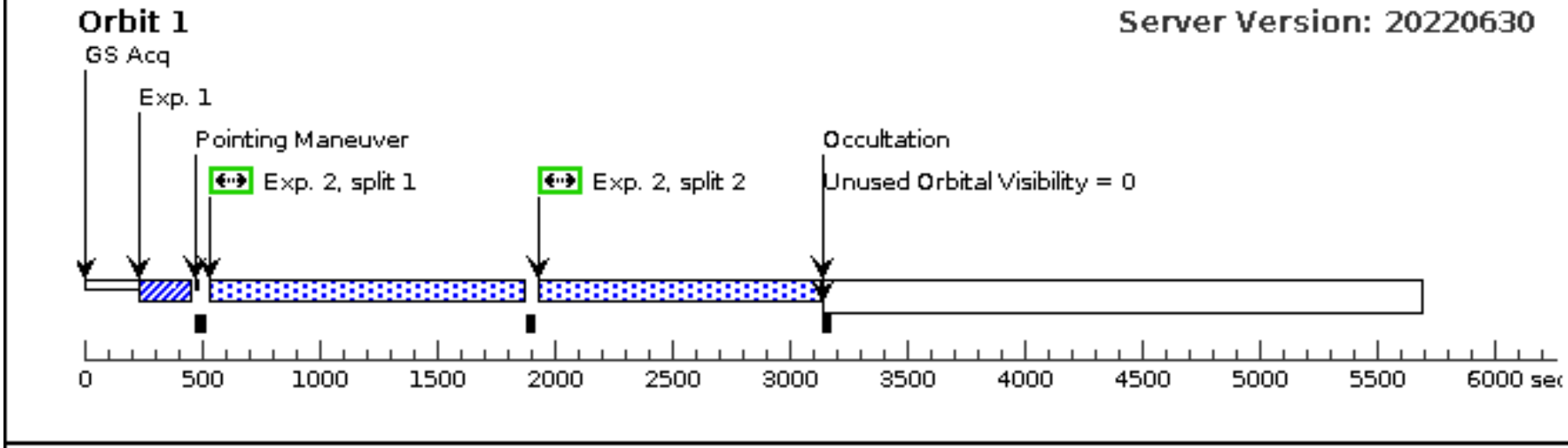
Exposures

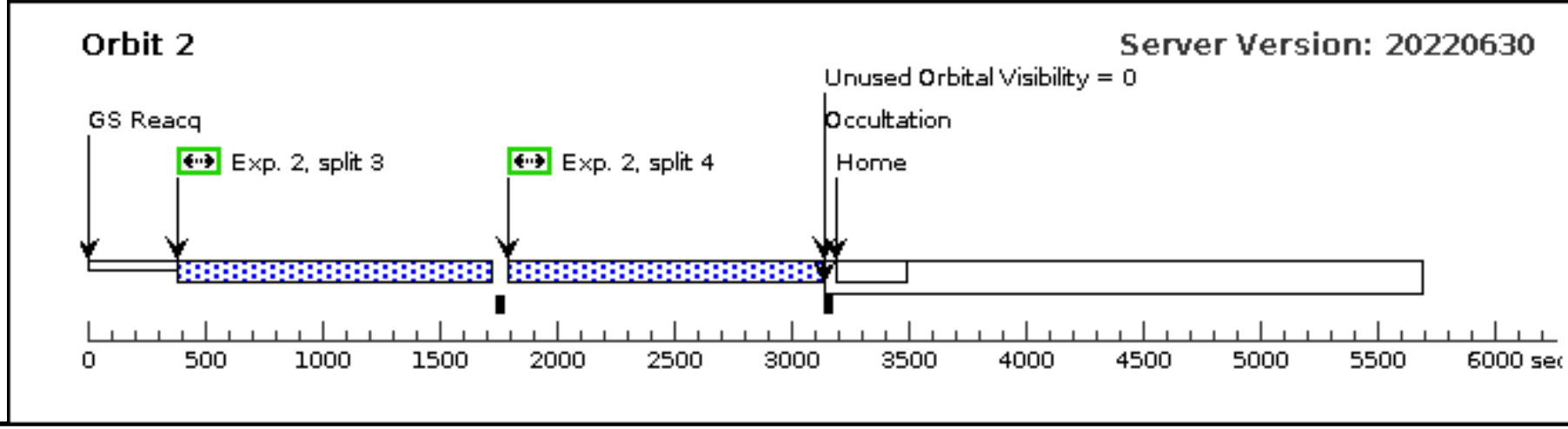
#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	Target Acquisition (COS.ta.1814496)	(1) WOCS14020	COS/NUV, ACQ/IMAGE, PSA	MIRRORA				5.0 Secs (5 Secs) *[==>]*	 ***[1]***

*Comments: The BOT tool returns one source as a Health/Safety issue (Object ID: N8X7000767) with a spectral type of **O5V**. This is actually our target which is a G type star (5990 K) with a white dwarf companion. The ETC run shows the global count rate is 1,449.751 cts/s, well below the global maximum.*

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
2	Science Integration (COS.sp.1814497)	(1) WOCS14020	COS/FUV, TIME-TAG, PSA	G140L 1105 A	FP-POS=ALL; BUFFER-TIME=10275			1000 Secs (4882 Secs) *[==>1152.0 Secs (Split 1)]* *[==>1152.0 Secs (Split 2)]* *[==>1289.0 Secs (Split 3)]* *[==>1289.0 Secs (Split 4)]*	 ***[1]*** ***[2]***

Orbit Structure





Visit

Proposal 17134, Visit 02, failed Wed Jun 21 19:00:24 GMT 2023

Diagnostic Status: No Diagnostics

Scientific Instruments: COS/FUV, COS/NUV

Special Requirements: (none)

Fixed Targets

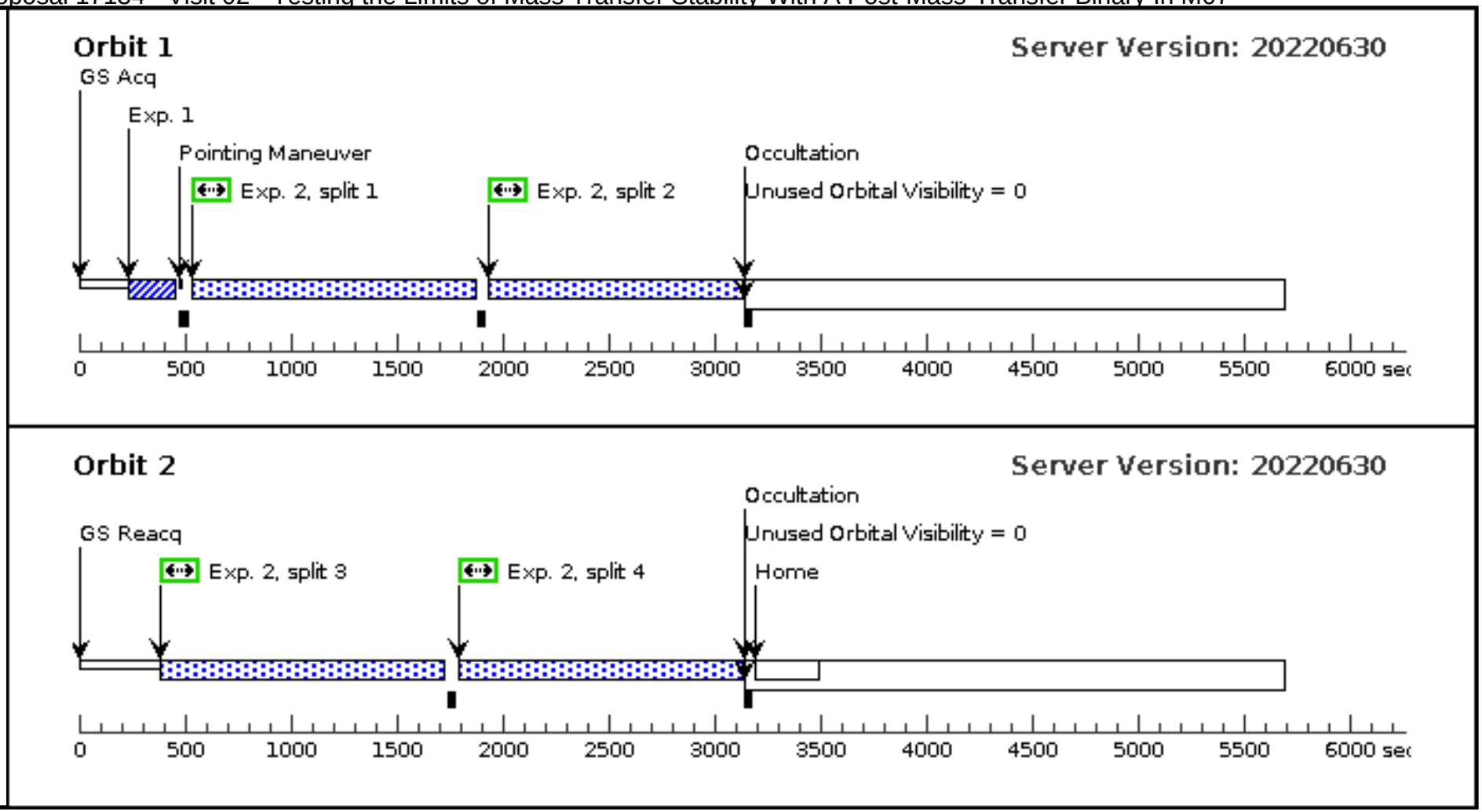
#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	WOCS14020	RA: 08 52 3.4887 (133.0145362d) Dec: +11 47 48.09 (11.79669d) Equinox: J2000	Proper Motion RA: -11.073 mas/yr Proper Motion Dec: -3.248 mas/yr Parallax: .0014567" Epoch of Position: 2016	V=14.693+/-0.143 NUV= 19.56, F150N= 1.18e-16 cgs, E(B-V)= 0.041	Reference Frame: ICRS

Comments: Coordinates and proper motions from Gaia DR3
Category=STAR
Description=[BLUE STRAGGLER, G 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	Target Acquisition (COS.ta.1814496)	(1) WOCS14020	COS/NUV, ACQ/IMAGE, PSA	MIRRORA				5.0 Secs (5 Secs) *[==>]*	 ***[1]***
*Comments: The BOT tool returns one source as a Health/Safety issue (Object ID: N8X7000767) with a spectral type of **O5V**. This is actually our target which is a G type star (5990 K) with a white dwarf companion. The ETC run shows the global count rate is 1,449.751 cts/s, well below the global maximum.*									
2	Science Integration (COS.sp.1814497)	(1) WOCS14020	COS/FUV, TIME-TAG, PSA	G140L 1105 A	FP-POS=ALL; BUFFER-TIME=10275			1000 Secs (4882 Secs) *[==>1152.0 Secs (Split 1)]* *[==>1152.0 Secs (Split 2)]* *[==>1289.0 Secs (Split 3)]* *[==>1289.0 Secs (Split 4)]*	 ***[1]*** ***[2]***

Orbit Structure



Visit

Proposal 17134, Visit 06, implementation Wed Jun 21 19:00:24 GMT 2023

Diagnostic Status: No Diagnostics

Scientific Instruments: COS/FUV, COS/NUV

Special Requirements: (none)

Comments: Repeat of Visit 2 observation (HOPR 92484)

Fixed Targets

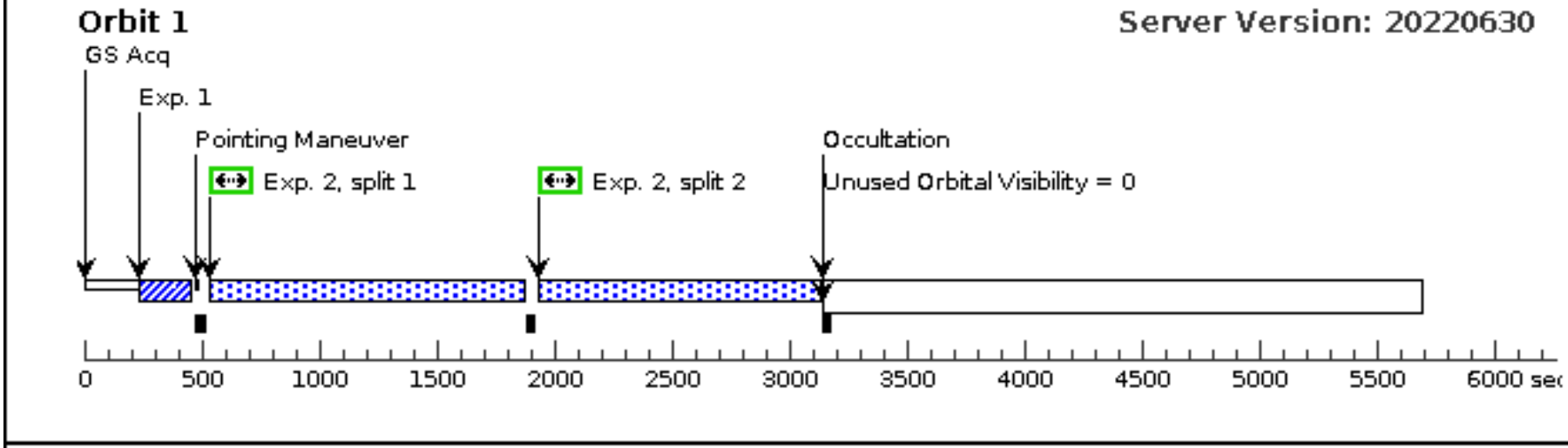
#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	WOCS14020	RA: 08 52 3.4887 (133.0145362d) Dec: +11 47 48.09 (11.79669d) Equinox: J2000	Proper Motion RA: -11.073 mas/yr Proper Motion Dec: -3.248 mas/yr Parallax: .0014567" Epoch of Position: 2016	V=14.693+/-0.143 NUV= 19.56, F150N= 1.18e-16 cgs, E(B-V)= 0.041	Reference Frame: ICRS

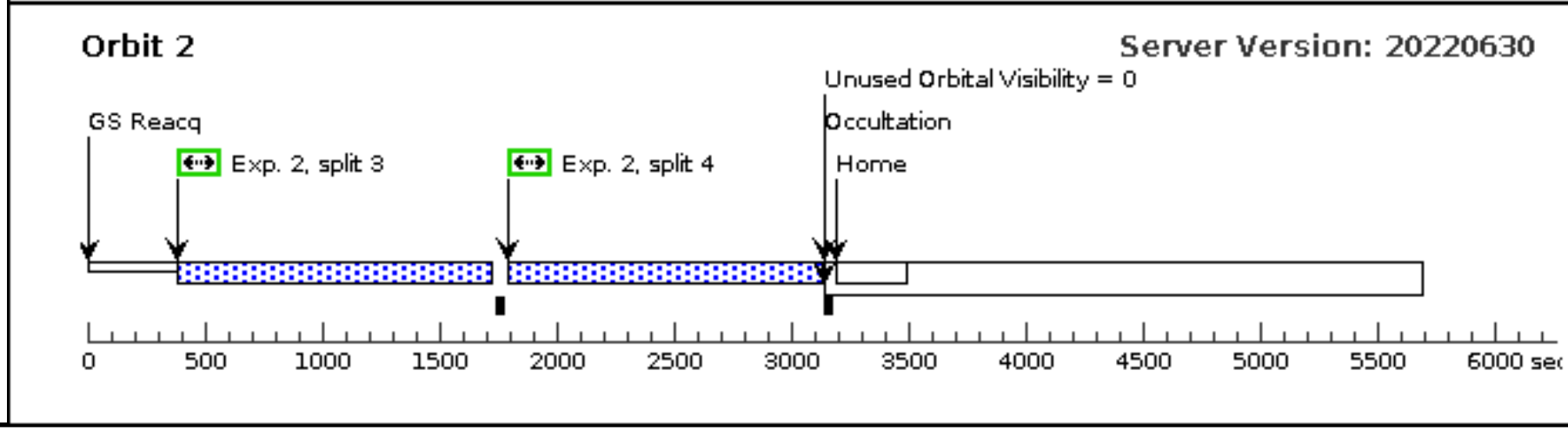
Comments: Coordinates and proper motions from Gaia DR3
Category=STAR
Description=[BLUE STRAGGLER, G V-IV]
Extended=NO

Exposures

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	Target Acquisition (COS.ta.1814496)	(1) WOCS14020	COS/NUV, ACQ/IMAGE, PSA	MIRRORA				5.0 Secs (5 Secs) *[==>]*	 ***[1]***
*Comments: The BOT tool returns one source as a Health/Safety issue (Object ID: N8X7000767) with a spectral type of **O5V**. This is actually our target which is a G type star (5990 K) with a white dwarf companion. The ETC run shows the global count rate is 1,449.751 cts/s, well below the global maximum.*									
2	Science Integration (COS.sp.1814497)	(1) WOCS14020	COS/FUV, TIME-TAG, PSA	G140L 1105 A	FP-POS=ALL; BUFFER-TIME=10275			1000 Secs (4882 Secs) *[==>1152.0 Secs (Split 1)]* *[==>1152.0 Secs (Split 2)]* *[==>1289.0 Secs (Split 3)]* *[==>1289.0 Secs (Split 4)]*	 ***[1]*** ***[2]***

Orbit Structure





Visit

Proposal 17134, Visit 03, completed Wed Jun 21 19:00:24 GMT 2023

Diagnostic Status: No Diagnostics

Scientific Instruments: COS/FUV, COS/NUV

Special Requirements: (none)

Fixed Targets

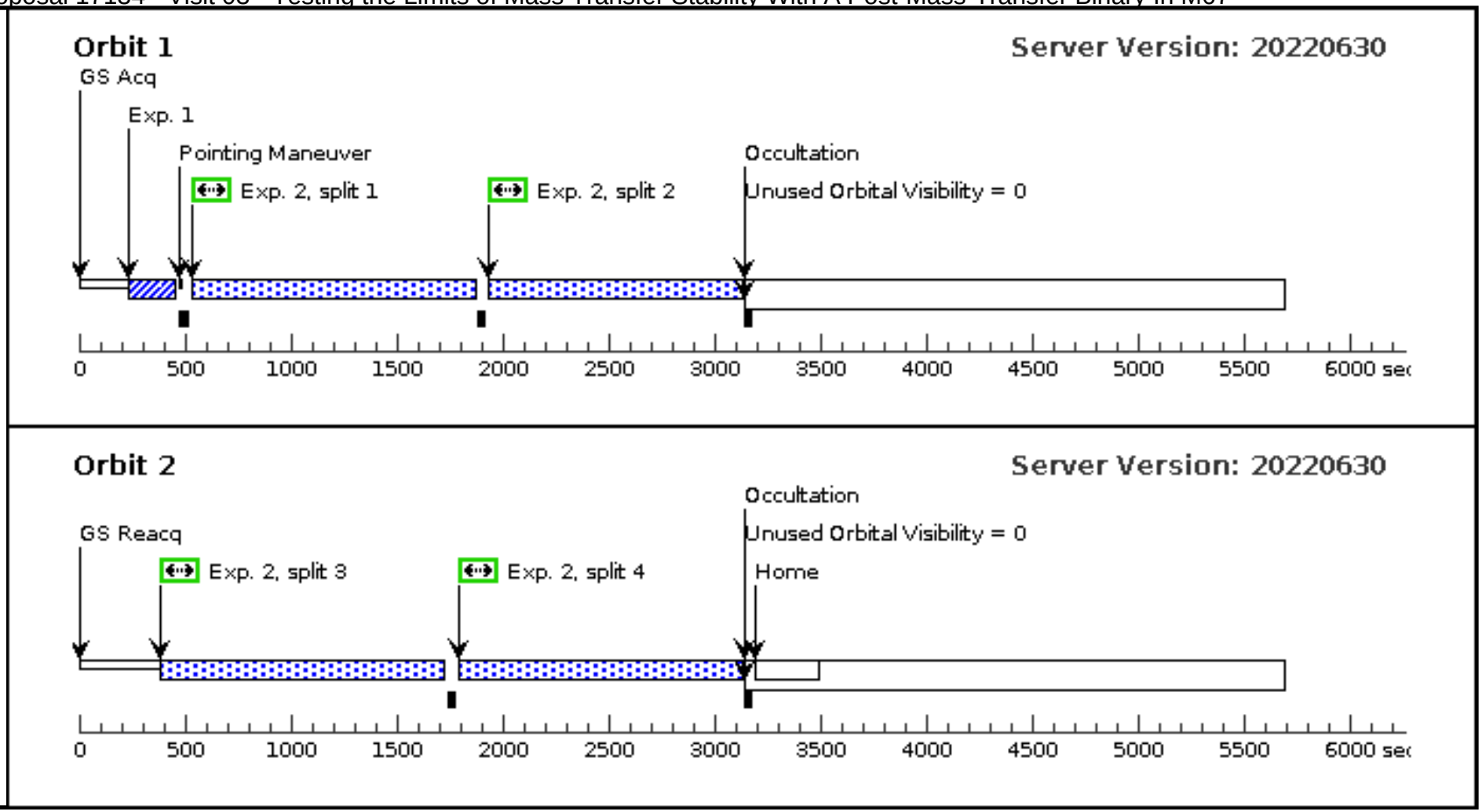
#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	WOCS14020	RA: 08 52 3.4887 (133.0145362d) Dec: +11 47 48.09 (11.79669d) Equinox: J2000	Proper Motion RA: -11.073 mas/yr Proper Motion Dec: -3.248 mas/yr Parallax: .0014567" Epoch of Position: 2016	V=14.693+/-0.143 NUV= 19.56, F150N= 1.18e-16 cgs, E(B-V)= 0.041	Reference Frame: ICRS

Comments: Coordinates and proper motions from Gaia DR3
Category=STAR
Description=[BLUE STRAGGLER, G 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	Target Acquisition (COS.ta.1814496)	(1) WOCS14020	COS/NUV, ACQ/IMAGE, PSA	MIRRORA				5.0 Secs (5 Secs) *[==>]*	 ***[1]***
*Comments: The BOT tool returns one source as a Health/Safety issue (Object ID: N8X7000767) with a spectral type of **O5V**. This is actually our target which is a G type star (5990 K) with a white dwarf companion. The ETC run shows the global count rate is 1,449.751 cts/s, well below the global maximum.*									
2	Science Integration (COS.sp.1814497)	(1) WOCS14020	COS/FUV, TIME-TAG, PSA	G140L 1105 A	FP-POS=ALL; BUFFER-TIME=10275			1000 Secs (4882 Secs) *[==>1152.0 Secs (Split 1)]* *[==>1152.0 Secs (Split 2)]* *[==>1289.0 Secs (Split 3)]* *[==>1289.0 Secs (Split 4)]*	 ***[1]*** ***[2]***

Orbit Structure



Visit

Proposal 17134, Visit 04, completed Wed Jun 21 19:00:24 GMT 2023

Diagnostic Status: No Diagnostics

Scientific Instruments: COS/FUV, COS/NUV

Special Requirements: (none)

Fixed Targets

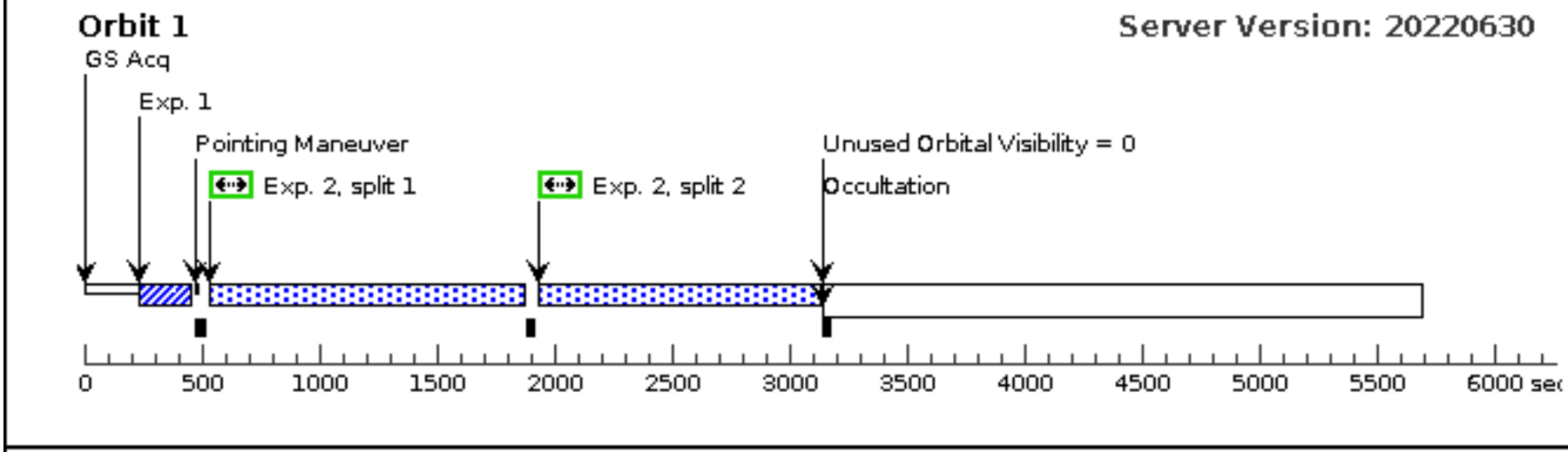
#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	WOCS14020	RA: 08 52 3.4887 (133.0145362d) Dec: +11 47 48.09 (11.79669d) Equinox: J2000	Proper Motion RA: -11.073 mas/yr Proper Motion Dec: -3.248 mas/yr Parallax: .0014567" Epoch of Position: 2016	V=14.693+/-0.143 NUV= 19.56, F150N= 1.18e-16 cgs, E(B-V)= 0.041	Reference Frame: ICRS

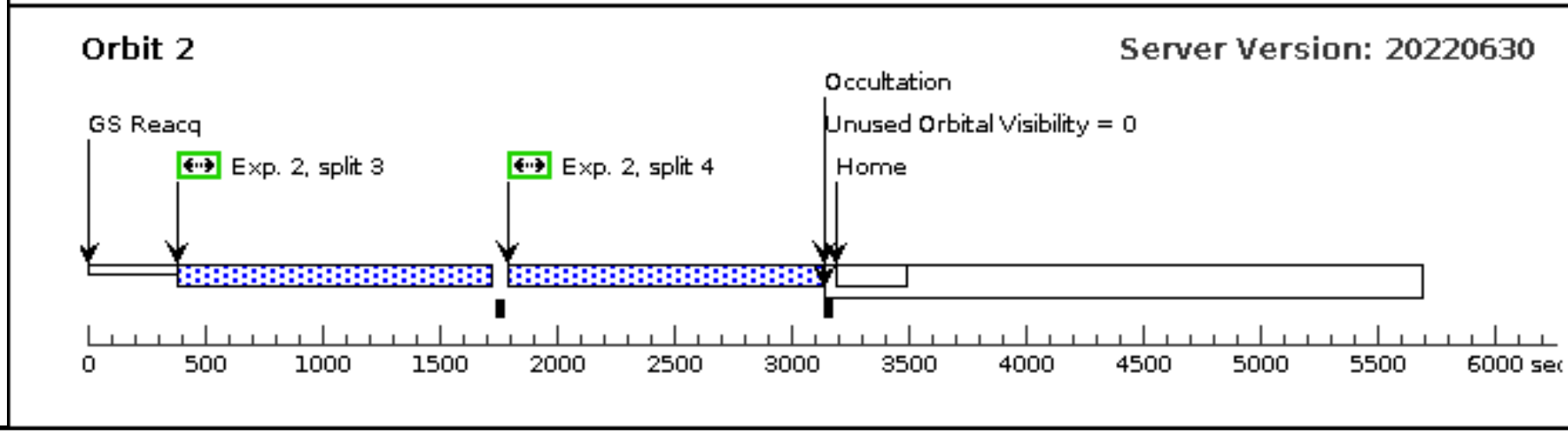
Comments: Coordinates and proper motions from Gaia DR3
Category=STAR
Description=[BLUE STRAGGLER, G V-IV]
Extended=NO

Exposures

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	Target Acquisition (COS.ta.1814496)	(1) WOCS14020	COS/NUV, ACQ/IMAGE, PSA	MIRRORA				5.0 Secs (5 Secs) *[==>]*	 ***[1]***
*Comments: The BOT tool returns one source as a Health/Safety issue (Object ID: N8X7000767) with a spectral type of **O5V**. This is actually our target which is a G type star (5990 K) with a white dwarf companion. The ETC run shows the global count rate is 1,449.751 cts/s, well below the global maximum.*									
2	Science Integration (COS.sp.1814497)	(1) WOCS14020	COS/FUV, TIME-TAG, PSA	G140L 1105 A	FP-POS=ALL; BUFFER-TIME=10275			1000 Secs (4882 Secs) *[==>1152.0 Secs (Split 1)]* *[==>1152.0 Secs (Split 2)]* *[==>1289.0 Secs (Split 3)]* *[==>1289.0 Secs (Split 4)]*	 ***[1]*** ***[2]***

Orbit Structure





Visit

Proposal 17134, Visit 05, failed Wed Jun 21 19:00:24 GMT 2023

Diagnostic Status: No Diagnostics

Scientific Instruments: COS/FUV, COS/NUV

Special Requirements: (none)

Fixed Targets

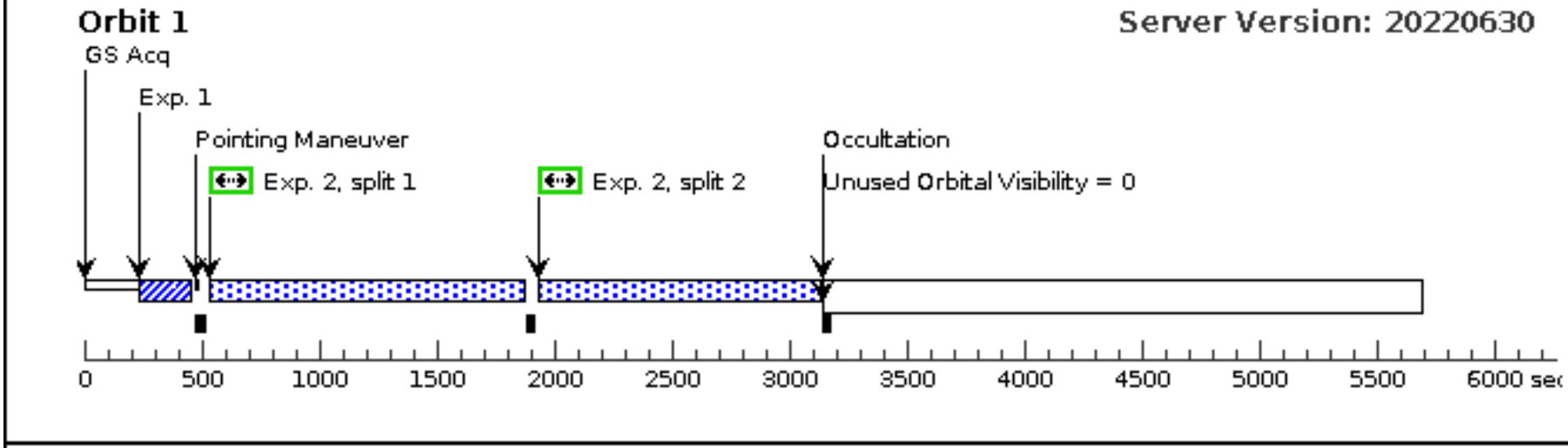
#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	WOCS14020	RA: 08 52 3.4887 (133.0145362d) Dec: +11 47 48.09 (11.79669d) Equinox: J2000	Proper Motion RA: -11.073 mas/yr Proper Motion Dec: -3.248 mas/yr Parallax: .0014567" Epoch of Position: 2016	V=14.693+/-0.143 NUV= 19.56, F150N= 1.18e-16 cgs, E(B-V)= 0.041	Reference Frame: ICRS

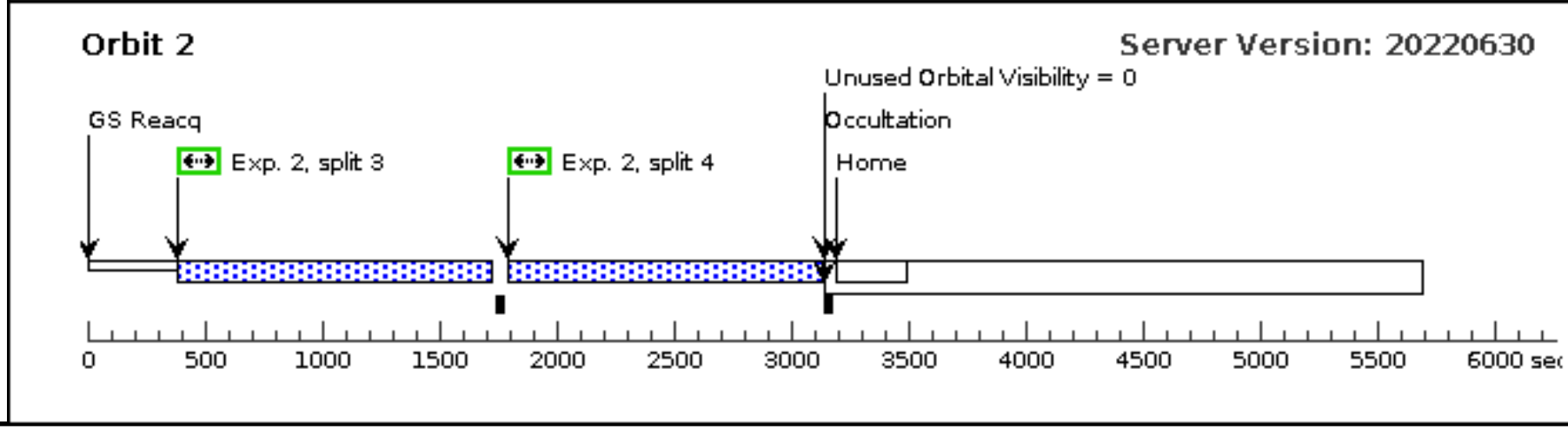
Comments: Coordinates and proper motions from Gaia DR3
Category=STAR
Description=[BLUE STRAGGLER, G V-IV]
Extended=NO

Exposures

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	Target Acquisition (COS.ta.1814496)	(1) WOCS14020	COS/NUV, ACQ/IMAGE, PSA	MIRRORA				5.0 Secs (5 Secs) *[==>]*	 ***[1]***
*Comments: The BOT tool returns one source as a Health/Safety issue (Object ID: N8X7000767) with a spectral type of **O5V**. This is actually our target which is a G type star (5990 K) with a white dwarf companion. The ETC run shows the global count rate is 1,449.751 cts/s, well below the global maximum.*									
2	Science Integration (COS.sp.1814497)	(1) WOCS14020	COS/FUV, TIME-TAG, PSA	G140L 1105 A	FP-POS=ALL; BUFFER-TIME=10275			1000 Secs (4882 Secs) *[==>1152.0 Secs (Split 1)]* *[==>1152.0 Secs (Split 2)]* *[==>1289.0 Secs (Split 3)]* *[==>1289.0 Secs (Split 4)]*	 ***[1]*** ***[2]***

Orbit Structure





Visit

Proposal 17134, Visit 07 Wed Jun 21 19:00:24 GMT 2023

Diagnostic Status: No Diagnostics

Scientific Instruments: COS/FUV, COS/NUV

Special Requirements: (none)

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	WOCS14020	RA: 08 52 3.4887 (133.0145362d) Dec: +11 47 48.09 (11.79669d) Equinox: J2000	Proper Motion RA: -11.073 mas/yr Proper Motion Dec: -3.248 mas/yr Parallax: .0014567" Epoch of Position: 2016	V=14.693+/-0.143 NUV= 19.56, F150N= 1.18e-16 cgs, E(B-V)= 0.041	Reference Frame: ICRS

Comments: Coordinates and proper motions from Gaia DR3
Category=STAR
Description=[BLUE STRAGGLER, G 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	Target Acquisition (COS.ta.1814496)	(1) WOCS14020	COS/NUV, ACQ/IMAGE, PSA	MIRRORA				5.0 Secs (5 Secs) *[==>]*	 ***[1]***
*Comments: The BOT tool returns one source as a Health/Safety issue (Object ID: N8X7000767) with a spectral type of **O5V**. This is actually our target which is a G type star (5990 K) with a white dwarf companion. The ETC run shows the global count rate is 1,449.751 cts/s, well below the global maximum.*									
2	Science Integration (COS.sp.1814497)	(1) WOCS14020	COS/FUV, TIME-TAG, PSA	G140L 1105 A	FP-POS=ALL; BUFFER-TIME=10275			1000 Secs (4882 Secs) *[==>1152.0 Secs (Split 1)]* *[==>1152.0 Secs (Split 2)]* *[==>1289.0 Secs (Split 3)]* *[==>1289.0 Secs (Split 4)]*	 ***[1]*** ***[2]***

Orbit Structure