13630 - Time-Resolved Ultraviolet Spectroscopy of the Missing Link Pulsar/LMXB PSR J1023

Cycle: 21, Proposal Category: GO/DD

(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?*
01	(1) V-AY-SEX	COS/FUV COS/NUV	5	08-Apr-2014 21:29:53.0	yes
02	(1) V-AY-SEX	STIS/CCD STIS/NUV-MAMA	3	08-Apr-2014 21:30:16.0	yes

8 Total Orbits Used

ABSTRACT

PSR J1023 is one of only three known ``missing link'' binary pulsars. These systems have been observed to switch at least once between a milli-second pulsar (MSP) state and a low-mass X-ray binary (LMXB) state. PSR J1023, in particular, was originally classified as an LMXB, but later (re-)discovered as a diskless 1.7 ms MSP. In June 2013, the system transitioned back to its X-ray- and optically bright LMXB state. There is an ongoing extensive X-ray, radio and optical monitoring campaign, but the critical ultraviolet (UV) waveband has so far remained largely unexplored. Since the system could return to a long-lasting low state at any time, and since the UV capability offered by HST may not be available for much longer, we here request DD time to obtain time-resolved UV spectroscopy of this system before it fades into the MSP state again. These observations will allow us to: (i) measure the spectral energy distribution of the accretion disk; (ii) search for evidence of an accretion disk wind; (iii) search for UV variability, including UV pulsations on the neutron star spin period; (iv) determine the reddening and extinction towards the system, and hence its luminosity and mass accretion rate.

OBSERVING DESCRIPTION

We will visit PSR~J1023 twice with HST. The first visit will consist of 5 consecutive HST orbits ($\simeq$~2 binary orbits), during which we will carry out time-resolved FUV spectroscopy with the COS/G140L instrument/grating combination. We will use the 1105~\AA\ setting for all of these observations to achieve continuous wavelength coverage between 1121~\AA\ and 2148~\AA. The TIME-TAG mode of COS will provide a maximum time resolution of 32~ms, too slow to resolve the NS pulse period of 1~ms, but fast enough to capture variability on the dynamical time-scale within the accretion disk. COS is preferred to STIS in the FUV despite its lower time resolution, due to its much higher sensitivity in this waveband.

The second visit will consist of 3 consecutive HST orbits ($\simeq$~1 binary orbit), during which we will obtain time-resolved NUV spectroscopy with the STIS/NUV-MAMA/G230L instruments/detector/grating combination. This gives continuous wavelength coverage between

1570~\AA\ and 3180~\AA\ at a maximum time resolution of 150~μs. In the NUV, We will therefore be able to carry out a search for very fast variability, including the NS pulse period

NUV photometry obtained by {\em Swift}/UVOT shows that $NUV \simeq 16.5$ and $U \simeq 16.4$, where the NUV measurement corresponds to the UVW1 filter -- which has a central wavelength of $\lambda \simeq 2600$~\AA\ -- and where both magnitudes are in the Vega-based UVOT photometric system (Takata et al. 2013; Poole et al. 2008). In the Takata et

al. (2013) model of the overall SED of PSR~1023, the UV waveband is dominated by an accretion disk component with a characteristic temperature of $T \simeq 8500$~K. Based on these numbers, and allowing for overheads, we estimate that our 5 HST orbits of FUV spectroscopy will yield a combined spectrum with $S/N \simeq 10$ per resolution element @

1500~\AA. Similarly, our 3 orbits of NUV spectroscopy will yield a combined spectrum with $S/N \simeq 40$ per resolution element @ 2200~\AA. In the FUV, the total expected source counts and count rates are $\simeq 10^5$ and $\simeq$ 8~c/s; in the NUV, the corresponding numbers are $\simeq 10^6$ and $\simeq$ 170~c/s. In folding the NUV data on the NS pulse period, we will therefore be able to achieve $S/N \simeq 100$ in 0.1 phase bins, yielding sensitivity to signals at the percent level.

There are no safety concerns for the COS or STIS detectors. In the NUV, the existing Swift/UVOT observations (taken in the current high state) show that the system is nowhere near bright enough to threaten detector damage. No empirical data exists so far in the FUV, but even the most extreme plausible extrapolation from the NUV to the FUV -- assuming that both NUV and FUV emission lie on the Rayleigh-Jeans tail of the disk spectrum ($F_{\lambda} \propto \lambda^{-4}$) -- yields local and global count rates that remain well below the bright object limits (by about a factor of 7). We will use an imaging target acquisition with Mirror B as the best compromise between efficiency and instrument safety. With this set-up, a 1~m ACQ/IMAGE target acquisition exposure yields $S/N \simeq 30-60$ depending on the detailed SED shape, and the count rate in the brightest pixel never exceeds $\simeq 8$~c/s, well below the bright object limit.

REAL TIME JUSTIFICATION

PSR J1023 is one of only three confirmed ``missing-link" binary pulsars among the $\simeq$250 known millisecond pulsars (MSPs). These systems have been observed to switch at least once between an MSP state and a low-mass X-ray binary (LMXB) state. PSR J1023, in particular, was originally classified as an LMXB (Bond et al. 2002; Thorstensen \& Armstrong 2005), but later (re-)discovered as a diskless 1.7~ms MSP (Archibald et al. 2009).

In June 2013 (i.e. well after the deadline for HST Cycle 21), PSR~J1023 transitioned back to its bright LMXB state (Stappers et al. 2013ab; Kong 2013; Patruno et al 2013; Patruno et al. 2014). This has triggered an extensive X-ray, radio and optical monitoring campaign (PI: Hessels), but the

critical ultraviolet (UV) waveband has so far remained largely unexplored. Since the system could return to a long-lasting low state at any time, and since the UV capability offered by HST may not be available for much longer, we request DD time to obtain time-resolved UV spectroscopy of this system before it fades again.

ADDITIONAL COMMENTS

The target has been observed with Swift/UVOT during its current LMXB state. For this Phase II submission, we have carried out pipeline analyses of all UVOT observations in the last month. We find that, during this time, U (3500A) ~ 16.1, UVW1 (2600A) ~ 15.0 - 15.5, UVM2 (2250A) ~ 15.6 and UVW2 (2030A) ~ 16.9. All of these numbers are in Vegamags. The corresponding flux densities are F(3500) ~ 1.6e-15 erg/s/cm2/A, F(2600) ~ 3.2e-15 - 5.3e-15, F(2250) ~ 3.8e-15, F(2030) ~ 1.3e-15. There is evidence for variability at the ~ 1 mag level both from the two observations we have in UVW1 and also from the SED. Two of the data points (W1 and M2) are from a single day and suggest a fairly flat SED (in F_lambda).

The system's SED in the present has been modelled as an 8500K blackbody by Takata et al. (2013). Our ETC calculations are based on adopting this SED, with the normalization set to a range of 1e-15 - 5e-15 at 2200 (FUV). We take 2e-15 as our default value. For bright object checks, we also consider an extreme model, in which the spectrum is maximally steep (i.e. FLAM ~ lambda^(-4)), with the normalization set to 5e-15 at 2600 A. These numbers should be sufficient to understand and replicate our calculations.

Visit

Proposal 13630, FUV (01), implementation Wed Apr 09 01:30:26 GMT 2014

Diagnostic Status: Warning

Scientific Instruments: COS/NUV, COS/FUV

Special Requirements: BETWEEN 14-APR-2014:00:00:00 AND 28-APR-2014:00:00:00

Diagnostics

(FUV (01)) Warning (Orbit Planner): INEFFICIENT ORDERING OF FP-POS POSITIONS

(FUV (01)) Warning (Orbit Planner): INEFFICIENT ORDERING OF FP-POS POSITIONS

(FUV (01)) Warning (Orbit Planner): INEFFICIENT ORDERING OF FP-POS POSITIONS

(FUV (01)) Warning (Orbit Planner): INEFFICIENT ORDERING OF FP-POS POSITIONS

Fixed Targets

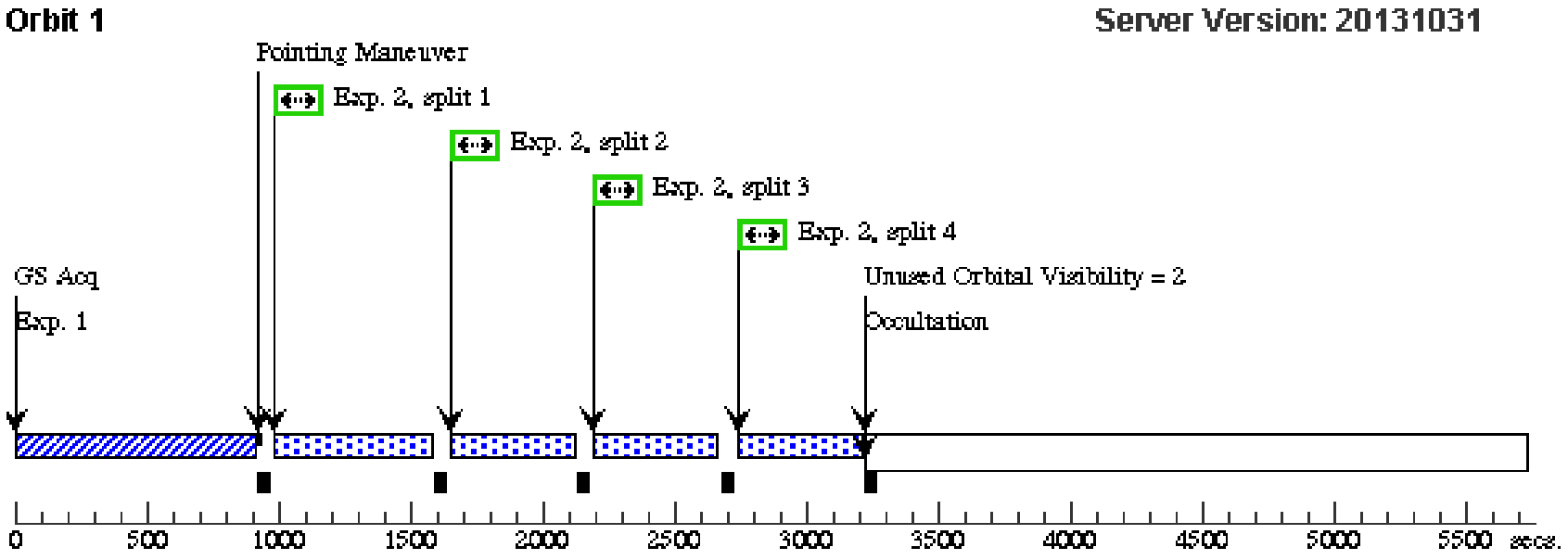
#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	V-AY-SEX Alt Name1: PSR-J1023+0038	RA: 10 23 47.6870 (155.9486958d) Dec: +00 38 41.15 (.64476d) Equinox: J2000	Proper Motion RA: 10 mas/yr Proper Motion Dec: -16 mas/yr Epoch of Position: 2008.92	V=17.26	Reference Frame: ICRS

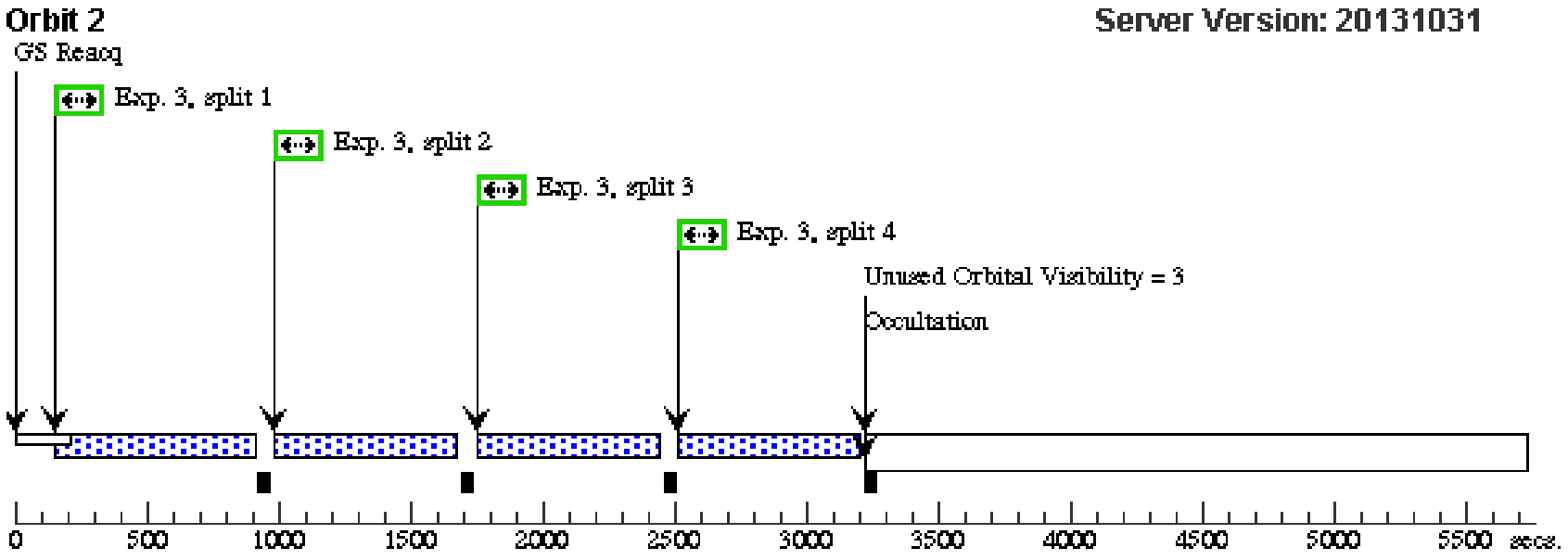
Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.This object was generated by the targetselector and retrieved from the SIMBAD database.

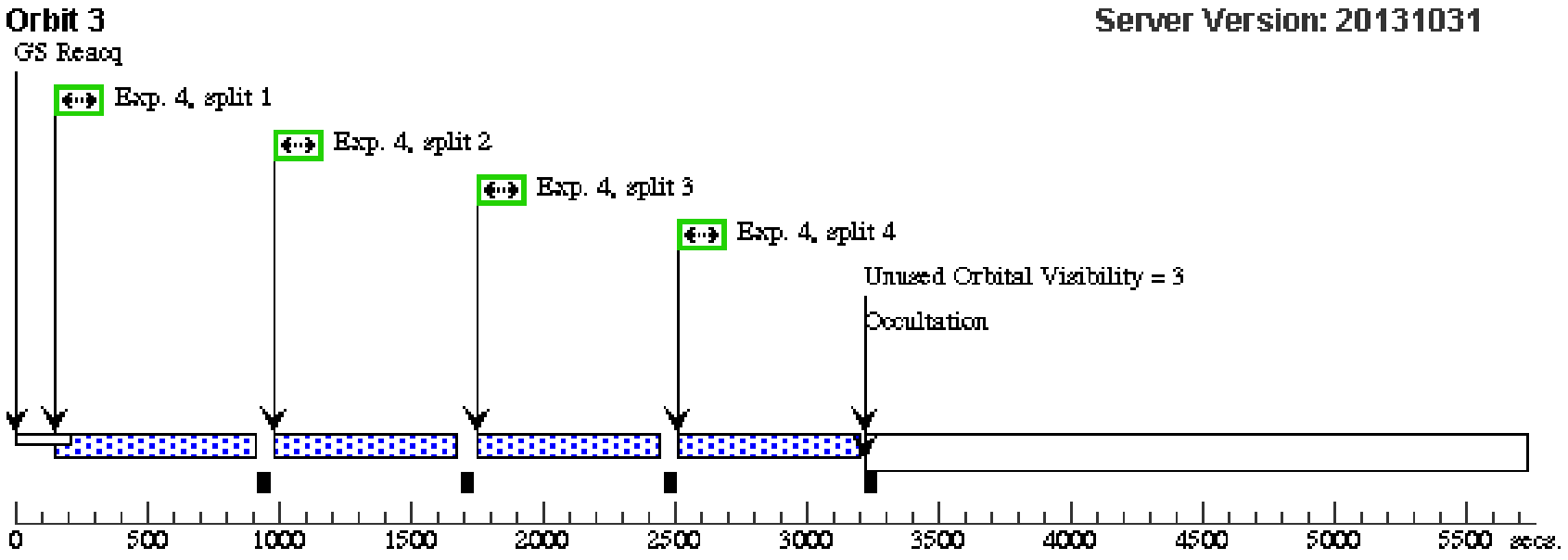
Exposures

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	FUV-TARG-ACQ (COS.ta.574206)	(1) V-AY-SEX	COS/NUV, ACQ/IMAGE, PSA	MIRRORB		GS ACQ SCENARIO BASE1B3		240 Secs (240 Secs) *[==>]*	***[1]***
2	FUV-1 (COS.sp.574245)	(1) V-AY-SEX	COS/FUV, TIME-TAG, PSA	G140L 1105 A	BUFFER-TIME=1350; FP-POS=ALL; FLASH=YES			300 Secs (1680 Secs) *[==>420.0 Secs (Split 1)]* *[==>420.0 Secs (Split 2)]* *[==>420.0 Secs (Split 3)]* *[==>420.0 Secs (Split 4)]*	***[1]***
3	FUV-1 (COS.sp.574245)	(1) V-AY-SEX	COS/FUV, TIME-TAG, PSA	G140L 1105 A	BUFFER-TIME=1950; FP-POS=ALL; FLASH=YES			300 Secs (2568 Secs) *[==>642.0 Secs (Split 1)]* *[==>642.0 Secs (Split 2)]* *[==>642.0 Secs (Split 3)]* *[==>642.0 Secs (Split 4)]*	***[2]***
4	FUV-1 (COS.sp.574245)	(1) V-AY-SEX	COS/FUV, TIME-TAG, PSA	G140L 1105 A	BUFFER-TIME=1950; FP-POS=ALL; FLASH=YES			300 Secs (2568 Secs) *[==>642.0 Secs (Split 1)]* *[==>642.0 Secs (Split 2)]* *[==>642.0 Secs (Split 3)]* *[==>642.0 Secs (Split 4)]*	***[3]***
5	FUV-1 (COS.sp.574245)	(1) V-AY-SEX	COS/FUV, TIME-TAG, PSA	G140L 1105 A	BUFFER-TIME=1950; FP-POS=ALL; FLASH=YES			300 Secs (2568 Secs) *[==>642.0 Secs (Split 1)]* *[==>642.0 Secs (Split 2)]* *[==>642.0 Secs (Split 3)]* *[==>642.0 Secs (Split 4)]*	***[4]***
6	FUV-1 (COS.sp.574245)	(1) V-AY-SEX	COS/FUV, TIME-TAG, PSA	G140L 1105 A	BUFFER-TIME=1950; FP-POS=ALL; FLASH=YES			300 Secs (2568 Secs) *[==>642.0 Secs (Split 1)]* *[==>642.0 Secs (Split 2)]* *[==>642.0 Secs (Split 3)]* *[==>642.0 Secs (Split 4)]*	***[5]***

Orbit Structure



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GS Reacq
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Exp. 4, split 3
Exp. 4, split 4
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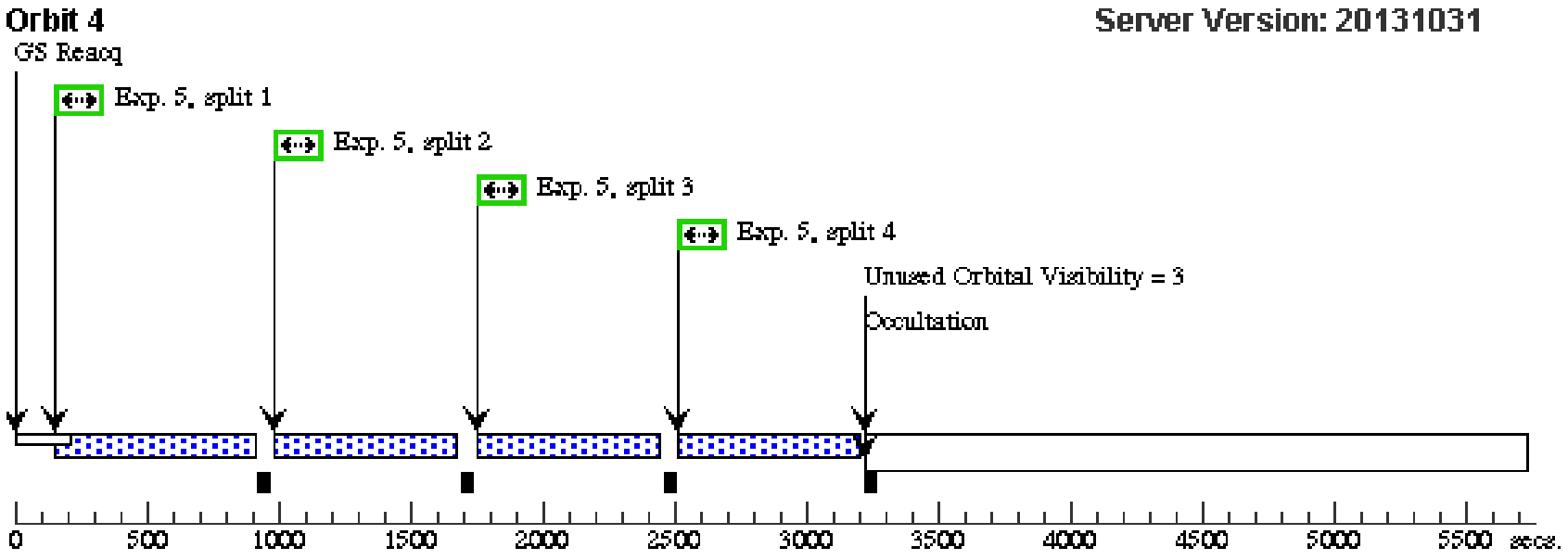
secs.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Exp. 5, split 3
Exp. 5, split 4
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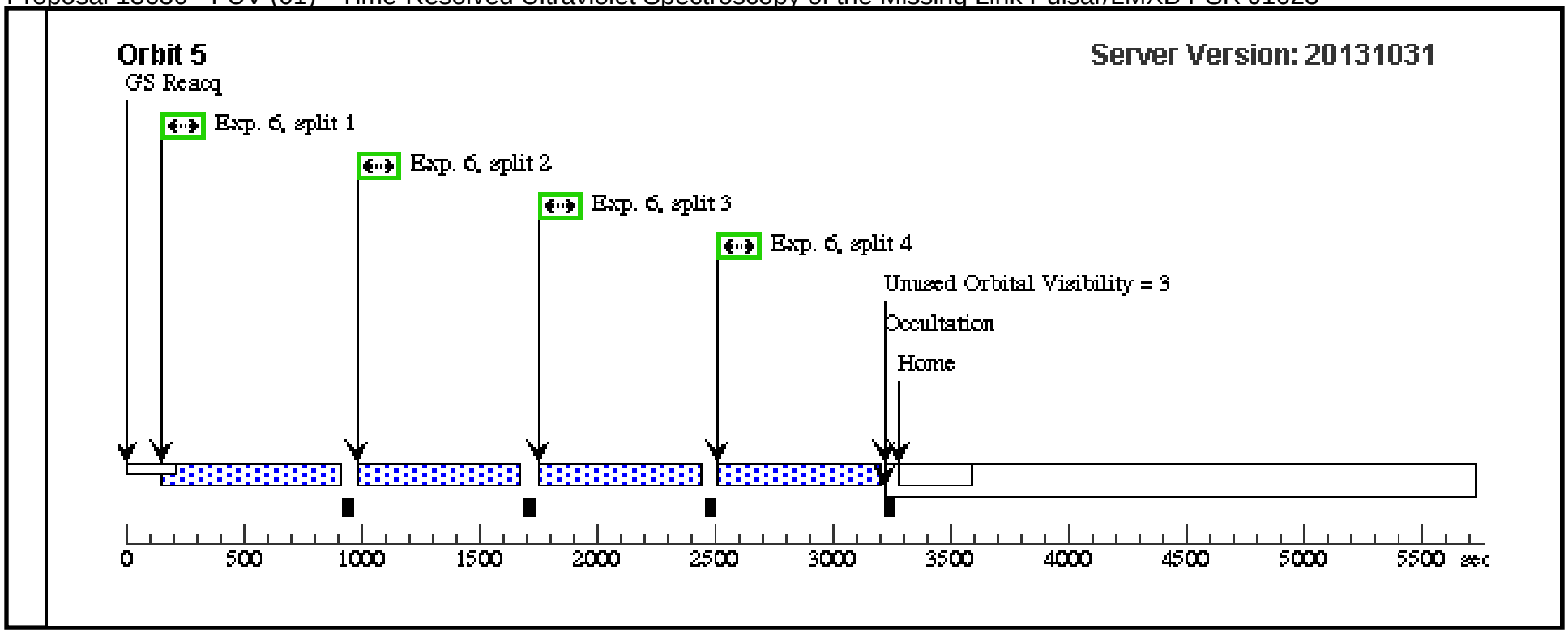
Orbit 5
Server Version: 20131031
GS Reacq
Exp. 6, split 1
Exp. 6, split 2
Exp. 6, split 3
Exp. 6, split 4
Unused Orbital Visibility = 3
Occultation
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1500
2000
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4500
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5500
sec

Visit

Proposal 13630, NUV (02), implementation Wed Apr 09 01:30:30 GMT 2014

Diagnostic Status: No Diagnostics

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

Special Requirements: AFTER 01 BY 0 D TO 1 D; BETWEEN 14-APR-2014:00:00:00 AND 28-APR-2014:00:00:00

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
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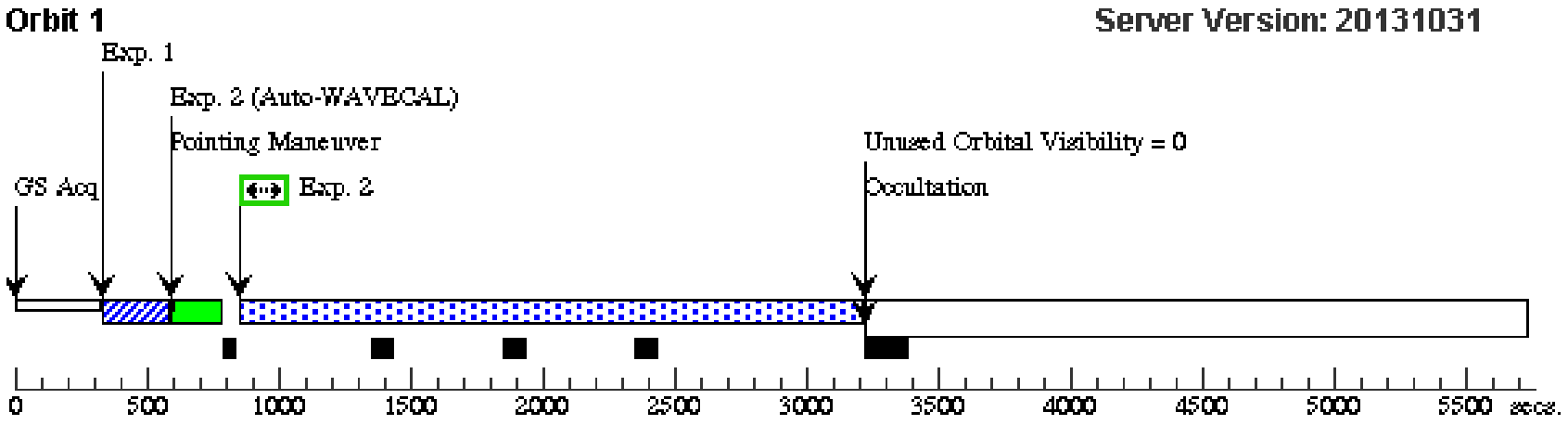
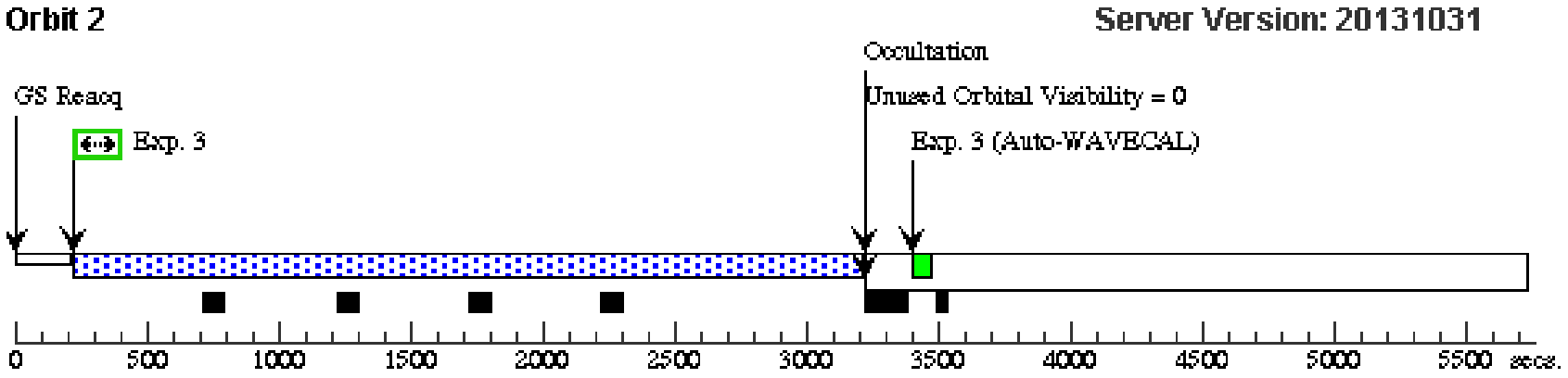
Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.This object was generated by the targetselector and retrieved from the SIMBAD database.

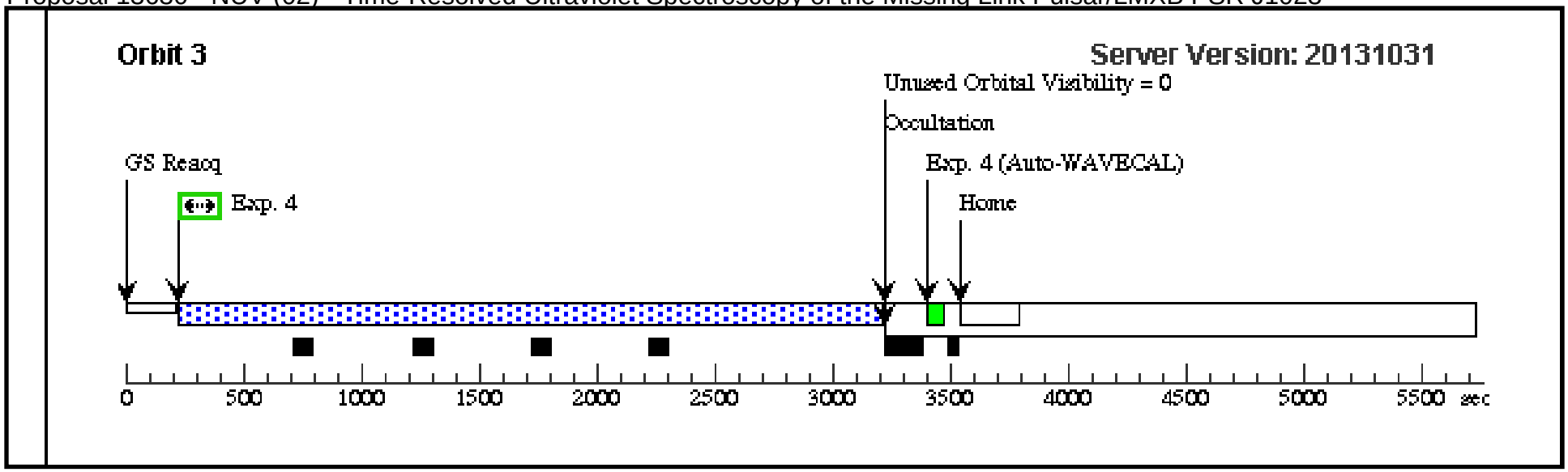
Exposures

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	NUV-TARG-ACQ (STIS.ta.574258)	(1) V-AY-SEX	STIS/CCD, ACQ, 50CCD	MIRROR	ACQTYPE=POINT			1 Secs (1 Secs) *[==>]*	 ***[1]***
2	NUV-1 (STIS.sp.574254)	(1) V-AY-SEX	STIS/NUV-MAMA, TIME-TAG, 52X0.2	G230L 2376 A	BUFFER-TIME=500			500 Secs (2348 Secs) *[==>2348.0 Secs]*	 ***[1]***
3	NUV-1 (STIS.sp.574254)	(1) V-AY-SEX	STIS/NUV-MAMA, TIME-TAG, 52X0.2	G230L 2376 A	BUFFER-TIME=500			500 Secs (2979 Secs) *[==>2979.0 Secs]*	 ***[2]***
4	NUV-1 (STIS.sp.574254)	(1) V-AY-SEX	STIS/NUV-MAMA, TIME-TAG, 52X0.2	G230L 2376 A	BUFFER-TIME=500			500 Secs (2979 Secs) *[==>2979.0 Secs]*	 ***[3]***

Orbit Structure






Orbit 3
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Unused Orbital Visibility = 0
Occultation
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Exp. 4 (Auto-WAVECAL)
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5000
5500
sec