



# 14623 - A Novel Measurement of Turbulence and Bulk Flows in the Hot Halo of M87

Cycle: 24, Proposal Category: GO

(UV Initiative)

(Availability Mode: SUPPORTED)

## INVESTIGATORS

<i>Name</i>	<i>Institution</i>	<i>E-Mail</i>
<b>Dr. Mike Anderson (PI) (ESA Member) (Contact)</b>	<b>Max-Planck-Institut fur Astrophysik</b>	<b>michevan@mpa-garching.mpg.de</b>
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## VISITS

<i>Visit</i>	<i>Targets used in Visit</i>	<i>Configurations used in Visit</i>	<i>Orbits Used</i>	<i>Last Orbit Planner Run</i>	<i>OP Current with Visit?</i>
01	(1) M87-FILAMENT (2) M87-FILAMENT-OFFSET	COS/FUV COS/NUV	3	09-Nov-2016 11:27:01.0	yes
02	(1) M87-FILAMENT (2) M87-FILAMENT-OFFSET	COS/FUV COS/NUV	3	09-Nov-2016 11:27:03.0	yes
03	(1) M87-FILAMENT (2) M87-FILAMENT-OFFSET	COS/FUV COS/NUV	3	09-Nov-2016 11:27:04.0	yes
04	(1) M87-FILAMENT (2) M87-FILAMENT-OFFSET	COS/FUV COS/NUV	3	09-Nov-2016 11:27:05.0	yes
05	(1) M87-FILAMENT (2) M87-FILAMENT-OFFSET	COS/FUV COS/NUV	2	09-Nov-2016 11:27:06.0	yes

14 Total Orbits Used

## **ABSTRACT**

Decades of observational and theoretical effort have focused on understanding the velocity structure of the hot gaseous halos ( $T > 10^7$  K) suffusing galaxy clusters, groups, and massive ellipticals. The turbulence and bulk flows in these media transport energy, mass, and metals from the nucleus into the diffuse halo, and they provide important non-thermal pressure support which is crucial to understand for accurate hydrostatic mass modeling. The Hitomi X-ray mission was intended to measure these motions in massive clusters, but it was only able to observe one system, and its calorimeter does not have sufficient resolution for lower-mass systems like the Virgo Cluster. As an alternative, we have identified a forbidden ground-state transition in highly ionized Iron -- [Fe XXI] at 1354.08 Å -- which traces plasma in a narrow range around  $10^7$  K (1 keV). With the sensitivity and spectral resolution of COS, this line can be used to measure the velocity structure of the hot halo gas directly. In a recent paper, we examined archival COS G140L spectra of an FUV-bright filament system projected 1.9 kpc from the center of M87 and found tentative (2-5 sigma) evidence of [Fe XXI] emission. This region also has deep X-ray observations which confirm the presence of 1 keV plasma, and the expected [Fe XXI] signal from the X-ray observations is consistent with our FUV measurement. Here we propose follow-up observations using the G130M grating in order to confirm this detection and to measure the velocity structure of the line with 50 km/s precision. Observing this unique line will allow us to measure directly the turbulence and bulk flows in the hot ambient medium of M87.

## **OBSERVING DESCRIPTION**

We will use the same observing procedure as the COS observations in proposals 12271 and 13439, namely taking an NUV ACQ/IMAGE of the nucleus of M87 (called M87-FILAMENT-OFFSET here and in those proposals) and then using that image to point towards the filament (which is about 20" away from the nucleus and called M87-FILAMENT).

It is important to make sure to use the nucleus of M87 for target acquisition and not the knots in the jet which are located  $\sim 0.85$  arcsec to the NW.

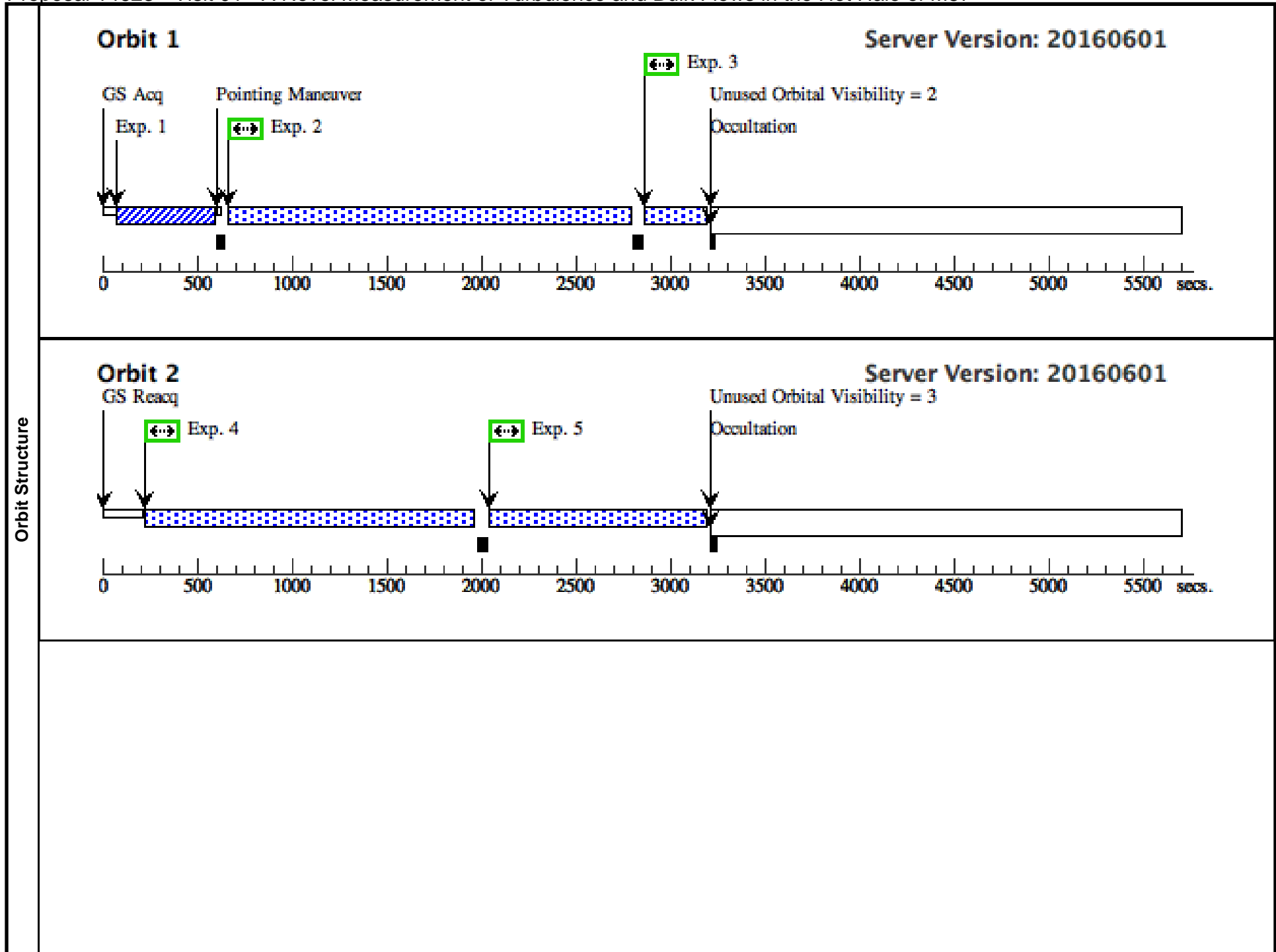
Proposal 14623 - Visit 01 - A Novel Measurement of Turbulence and Bulk Flows in the Hot Halo of M87

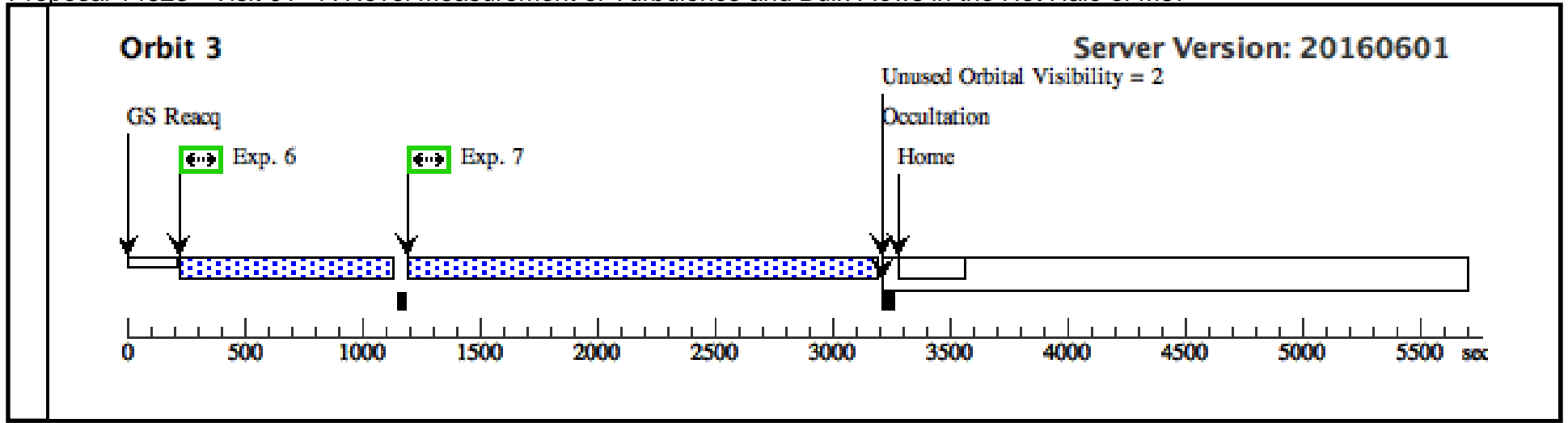
Wed Nov 09 16:27:07 GMT 2016

<b>Visit</b>	<b>Proposal 14623, Visit 01</b> <b>Diagnostic Status: Warning</b> Scientific Instruments: COS/FUV, COS/NUV Special Requirements: (none)					
<b>Diagnostics</b>	(Exposure 2 (Visit 01)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details. (Exposure 3 (Visit 01)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details. (Exposure 4 (Visit 01)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details. (Exposure 5 (Visit 01)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details. (Exposure 6 (Visit 01)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details. (Exposure 7 (Visit 01)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.					
<b>Fixed Targets</b>	<b>#</b>	<b>Name</b>	<b>Target Coordinates</b>	<b>Targ. Coord. Corrections</b>	<b>Fluxes</b>	<b>Miscellaneous</b>
	(1)	M87-FILAMENT	RA: 12 30 50.9900 (187.7124583d) Dec: +12 23 25.50 (12.39042d) Equinox: J2000		V=16.7+/-0.5	Reference Frame: ICRS
	<i>Comments: Extended=YES</i>					
(2)	M87-FILAMENT-OFFSET	RA: 12 30 49.4230 (187.7059292d) Dec: +12 23 28.04 (12.39112d) Equinox: J2000		V=16	Reference Frame: ICRS	
<i>Comments: this is the nucleus of M87 Extended=NO</i>						

Proposal 14623 - Visit 01 - A Novel Measurement of Turbulence and Bulk Flows in the Hot Halo of M87

Exposures	#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
	1	(COS.ta.823 245)	(2) M87-FILAMEN T-OFFSET	COS/NUV, ACQ/IMAGE, PSA	MIRRORB				100 Secs (100 Secs)	
									[==>]	[1]
	2	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;	FP-POS=1	1950 Secs (1950 Secs)	
									[==>]	[1]
	3	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;	FP-POS=2	280 Secs (280 Secs)	
									[==>]	[1]
	4	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;	FP-POS=2	1695 Secs (1695 Secs)	
									[==>]	[2]
	5	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;	FP-POS=3	1100 Secs (1100 Secs)	
								[==>]	[2]	
6	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;	FP-POS=3	865 Secs (865 Secs)		
								[==>]	[3]	
7	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;	FP-POS=4	1950 Secs (1950 Secs)		
								[==>]	[3]	





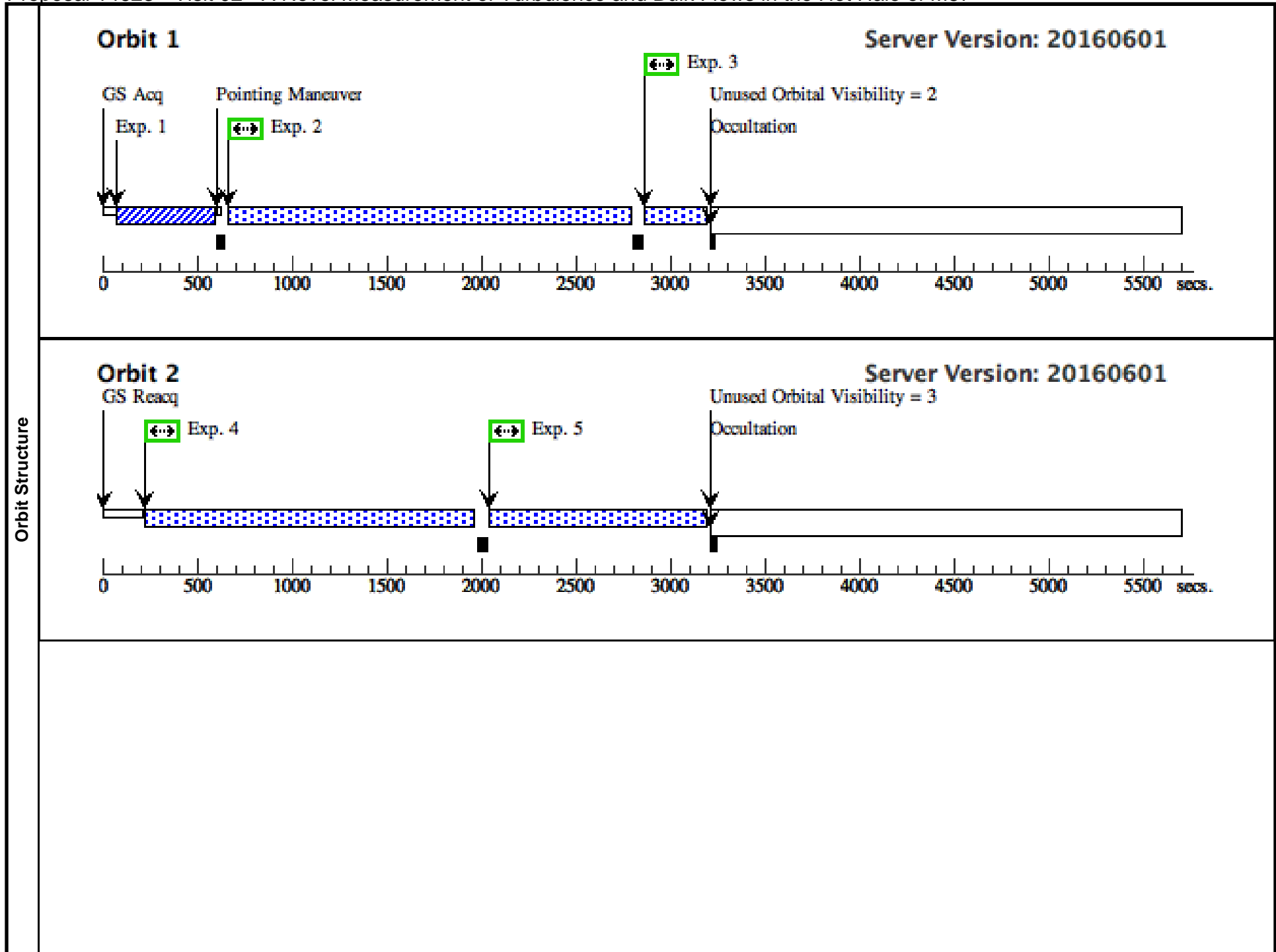
# Proposal 14623 - Visit 02 - A Novel Measurement of Turbulence and Bulk Flows in the Hot Halo of M87

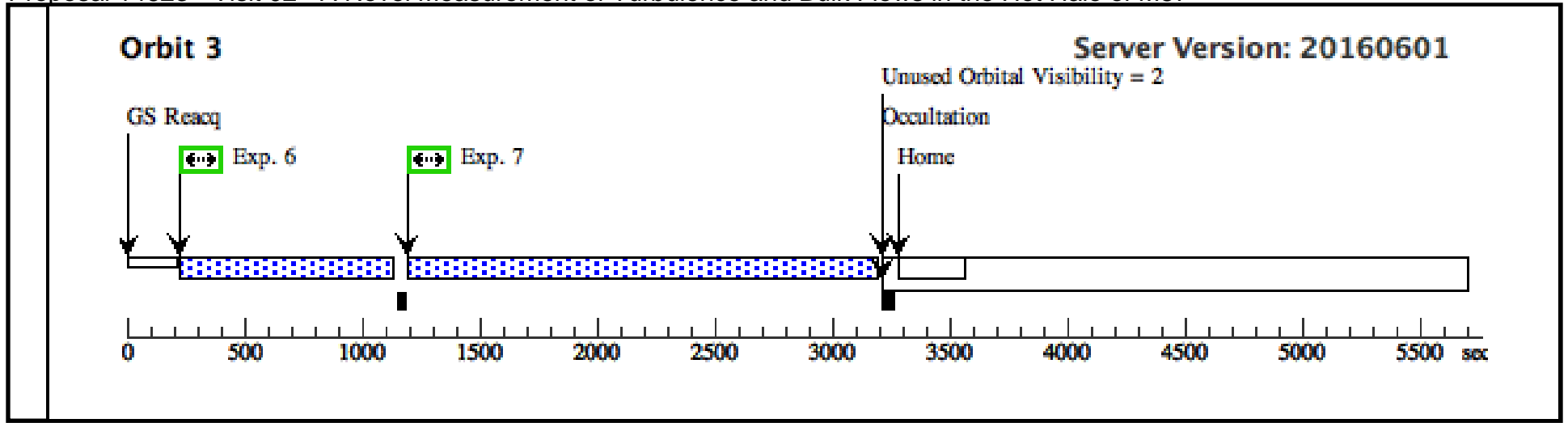
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<b>Visit</b>	<b>Proposal 14623, Visit 02</b> <b>Diagnostic Status: Warning</b> Scientific Instruments: COS/FUV, COS/NUV Special Requirements: (none)					
	<b>Diagnostics</b>	(Exposure 2 (Visit 02)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.				
(Exposure 3 (Visit 02)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
(Exposure 4 (Visit 02)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
(Exposure 5 (Visit 02)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
(Exposure 6 (Visit 02)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
(Exposure 7 (Visit 02)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
<b>Fixed Targets</b>		<b>#</b>	<b>Name</b>	<b>Target Coordinates</b>	<b>Targ. Coord. Corrections</b>	<b>Fluxes</b>
	(1)	M87-FILAMENT	RA: 12 30 50.9900 (187.7124583d) Dec: +12 23 25.50 (12.39042d) Equinox: J2000		V=16.7+/-0.5	Reference Frame: ICRS
	<i>Comments: Extended=YES</i>					
(2)	M87-FILAMENT-OFFSET	RA: 12 30 49.4230 (187.7059292d) Dec: +12 23 28.04 (12.39112d) Equinox: J2000		V=16	Reference Frame: ICRS	
<i>Comments: this is the nucleus of M87 Extended=NO</i>						

Proposal 14623 - Visit 02 - A Novel Measurement of Turbulence and Bulk Flows in the Hot Halo of M87

Exposures	#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
	1	(COS.ta.823 245)	(2) M87-FILAMEN T-OFFSET	COS/NUV, ACQ/IMAGE, PSA	MIRRORB				100 Secs (100 Secs)	
									[==>]	[1]
	2	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;		1950 Secs (1950 Secs)	
							FP-POS=1		[==>]	[1]
	3	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;		280 Secs (280 Secs)	
							FP-POS=2		[==>]	[1]
	4	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;		1695 Secs (1695 Secs)	
							FP-POS=2		[==>]	[2]
	5	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;		1100 Secs (1100 Secs)	
						FP-POS=3		[==>]	[2]	
6	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;		865 Secs (865 Secs)		
						FP-POS=3		[==>]	[3]	
7	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;		1950 Secs (1950 Secs)		
						FP-POS=4		[==>]	[3]	





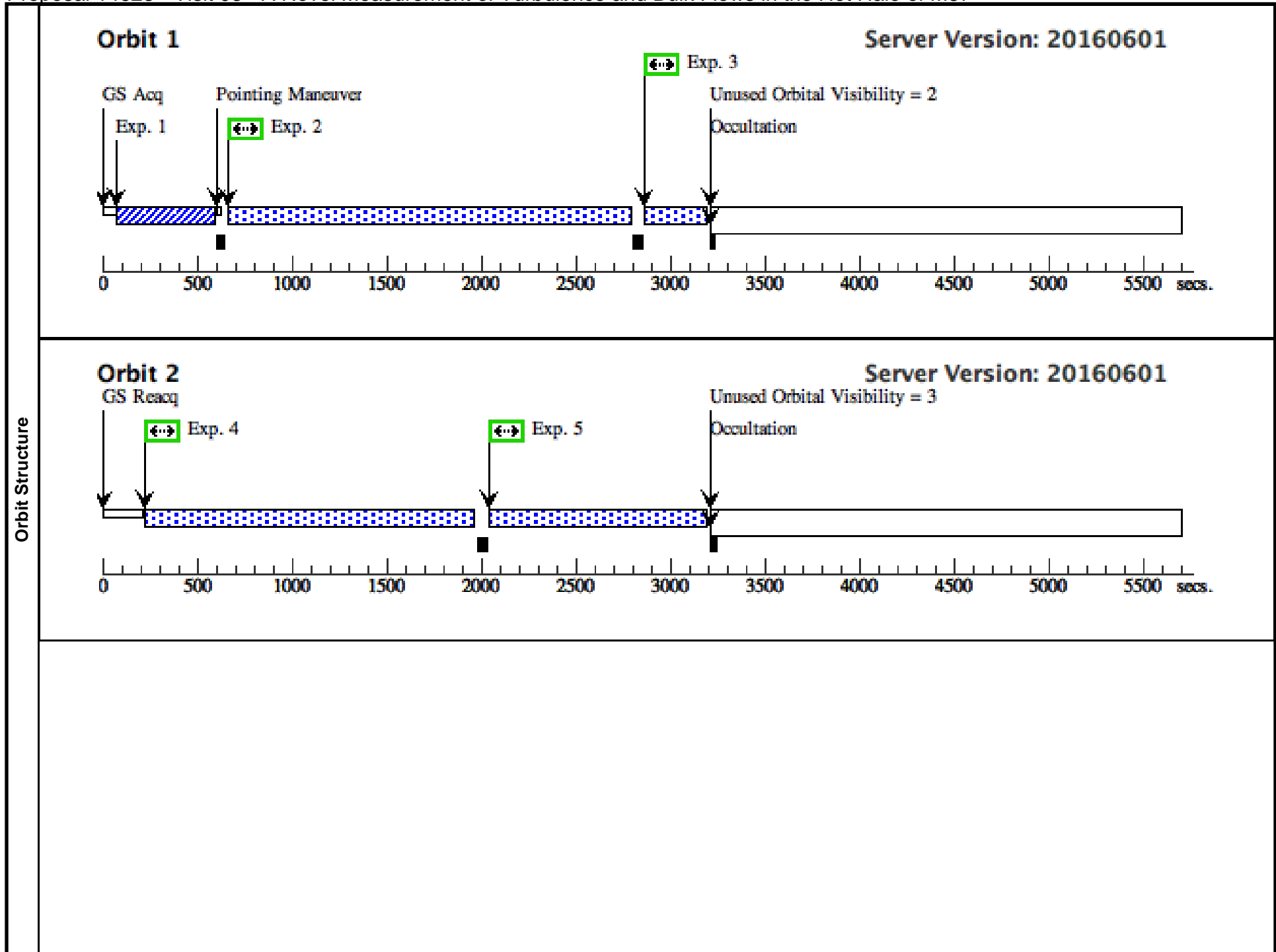
Proposal 14623 - Visit 03 - A Novel Measurement of Turbulence and Bulk Flows in the Hot Halo of M87

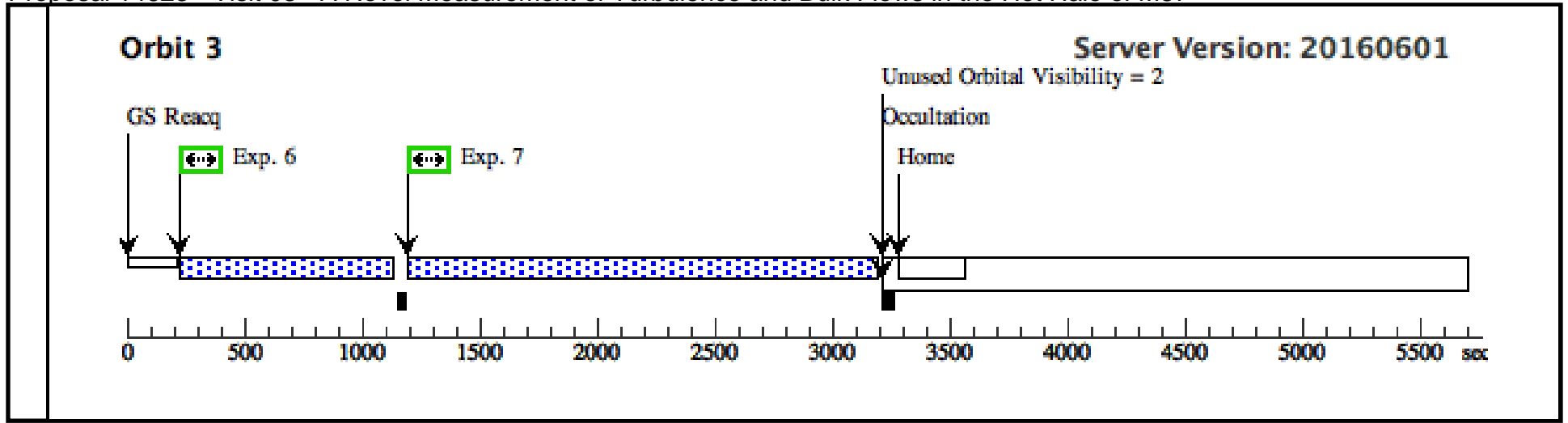
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<b>Visit</b>	<b>Proposal 14623, Visit 03</b> <b>Diagnostic Status: Warning</b> Scientific Instruments: COS/FUV, COS/NUV Special Requirements: (none)					
	<b>Diagnostics</b>	(Exposure 2 (Visit 03)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.				
(Exposure 3 (Visit 03)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
(Exposure 4 (Visit 03)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
(Exposure 5 (Visit 03)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
(Exposure 6 (Visit 03)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
(Exposure 7 (Visit 03)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
<b>Fixed Targets</b>		<b>#</b>	<b>Name</b>	<b>Target Coordinates</b>	<b>Targ. Coord. Corrections</b>	<b>Fluxes</b>
	(1)	M87-FILAMENT	RA: 12 30 50.9900 (187.7124583d) Dec: +12 23 25.50 (12.39042d) Equinox: J2000		V=16.7+/-0.5	Reference Frame: ICRS
	<i>Comments: Extended=YES</i>					
	(2)	M87-FILAMENT-OFFSET	RA: 12 30 49.4230 (187.7059292d) Dec: +12 23 28.04 (12.39112d) Equinox: J2000		V=16	Reference Frame: ICRS
<i>Comments: this is the nucleus of M87 Extended=NO</i>						

Proposal 14623 - Visit 03 - A Novel Measurement of Turbulence and Bulk Flows in the Hot Halo of M87

	#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]		Orbit
<b>Exposures</b>	1	(COS.ta.823 245)	(2) M87-FILAMEN T-OFFSET	COS/NUV, ACQ/IMAGE, PSA	MIRRORB				100 Secs (100 Secs)		
									[==>]		[1]
	2	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00; FLASH=YES; FP-POS=1			1950 Secs (1950 Secs)		
									[==>]		[1]
	3	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00; FLASH=YES; FP-POS=2			280 Secs (280 Secs)		
									[==>]		[1]
	4	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00; FLASH=YES; FP-POS=2			1695 Secs (1695 Secs)		
								[==>]		[2]	
5	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00; FLASH=YES; FP-POS=3			1100 Secs (1100 Secs)			
								[==>]		[2]	
6	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00; FLASH=YES; FP-POS=3			865 Secs (865 Secs)			
								[==>]		[3]	
7	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00; FLASH=YES; FP-POS=4			1950 Secs (1950 Secs)			
								[==>]		[3]	





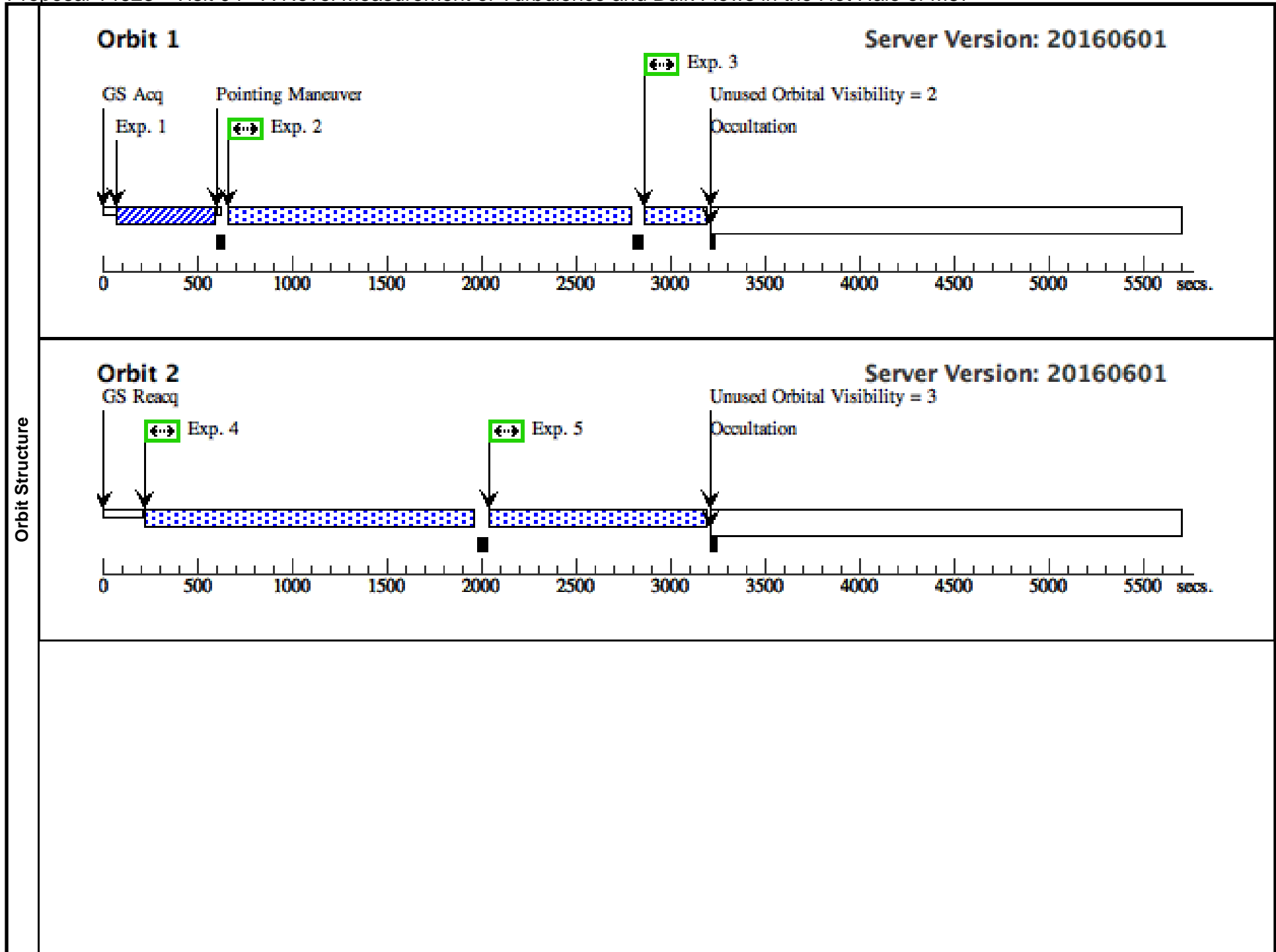
Proposal 14623 - Visit 04 - A Novel Measurement of Turbulence and Bulk Flows in the Hot Halo of M87

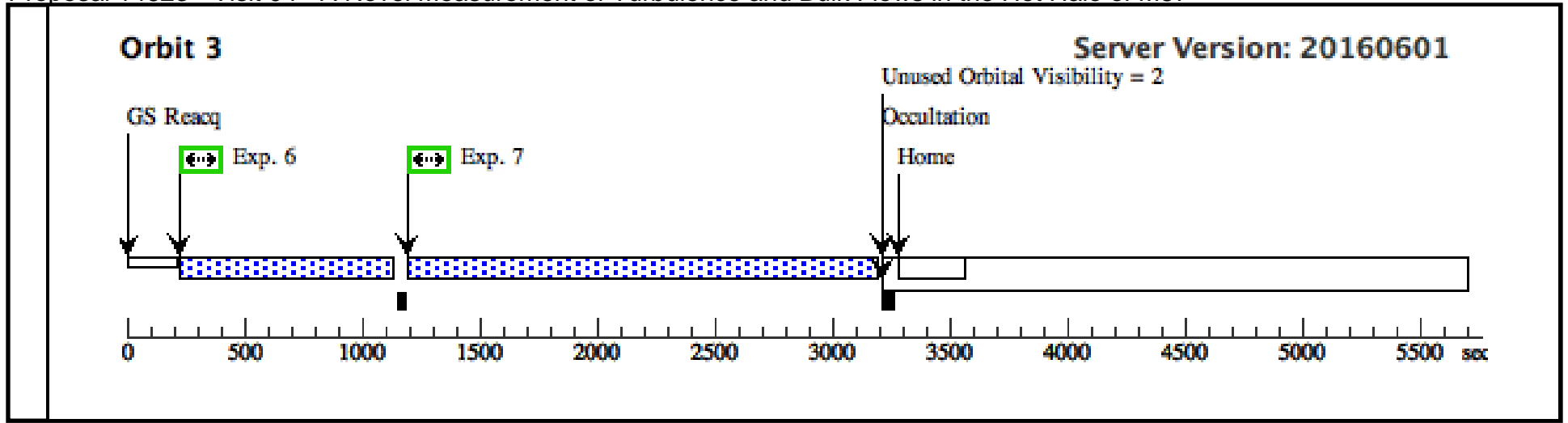
Wed Nov 09 16:27:08 GMT 2016

<b>Visit</b>	<b>Proposal 14623, Visit 04</b> <b>Diagnostic Status: Warning</b> Scientific Instruments: COS/FUV, COS/NUV Special Requirements: (none)					
	<b>Diagnostics</b>	(Exposure 2 (Visit 04)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.				
(Exposure 3 (Visit 04)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
(Exposure 4 (Visit 04)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
(Exposure 5 (Visit 04)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
(Exposure 6 (Visit 04)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
(Exposure 7 (Visit 04)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.						
<b>Fixed Targets</b>	<b>#</b>	<b>Name</b>	<b>Target Coordinates</b>	<b>Targ. Coord. Corrections</b>	<b>Fluxes</b>	<b>Miscellaneous</b>
	(1)	M87-FILAMENT	RA: 12 30 50.9900 (187.7124583d) Dec: +12 23 25.50 (12.39042d) Equinox: J2000		V=16.7+/-0.5	Reference Frame: ICRS
	<i>Comments: Extended=YES</i>					
(2)	M87-FILAMENT-OFFSET	RA: 12 30 49.4230 (187.7059292d) Dec: +12 23 28.04 (12.39112d) Equinox: J2000		V=16	Reference Frame: ICRS	
<i>Comments: this is the nucleus of M87 Extended=NO</i>						

Proposal 14623 - Visit 04 - A Novel Measurement of Turbulence and Bulk Flows in the Hot Halo of M87

Exposures	#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
	1	(COS.ta.823 245)	(2) M87-FILAMEN T-OFFSET	COS/NUV, ACQ/IMAGE, PSA	MIRRORB				100 Secs (100 Secs)	
									[==>]	[1]
	2	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;		1950 Secs (1950 Secs)	
							FP-POS=1		[==>]	[1]
	3	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;		280 Secs (280 Secs)	
							FP-POS=2		[==>]	[1]
	4	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;		1695 Secs (1695 Secs)	
							FP-POS=2		[==>]	[2]
	5	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;		1100 Secs (1100 Secs)	
						FP-POS=3		[==>]	[2]	
6	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;		865 Secs (865 Secs)		
						FP-POS=3		[==>]	[3]	
7	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00;	FLASH=YES;		1950 Secs (1950 Secs)		
						FP-POS=4		[==>]	[3]	





Proposal 14623 - Visit 05 - A Novel Measurement of Turbulence and Bulk Flows in the Hot Halo of M87

Wed Nov 09 16:27:08 GMT 2016

<b>Visit</b>	<b>Proposal 14623, Visit 05</b> <b>Diagnostic Status: Warning</b> Scientific Instruments: COS/FUV, COS/NUV Special Requirements: (none)										
	(Exposure 2 (Visit 05)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details. (Exposure 3 (Visit 05)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details. (Exposure 4 (Visit 05)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details. (Exposure 5 (Visit 05)) Warning (Form): COS FUV PSA science exposures with extended targets have special calibration limitations. See "Errors and Warnings" for more details.										
<b>Fixed Targets</b>	<b>#</b>	<b>Name</b>	<b>Target Coordinates</b>	<b>Targ. Coord. Corrections</b>	<b>Fluxes</b>	<b>Miscellaneous</b>					
	(1)	M87-FILAMENT	RA: 12 30 50.9900 (187.7124583d) Dec: +12 23 25.50 (12.39042d) Equinox: J2000		V=16.7+/-0.5	Reference Frame: ICRS					
<i>Comments: Extended=YES</i>											
(2)	M87-FILAMENT-OFFSET	RA: 12 30 49.4230 (187.7059292d) Dec: +12 23 28.04 (12.39112d) Equinox: J2000		V=16	Reference Frame: ICRS						
<i>Comments: this is the nucleus of M87 Extended=NO</i>											
<b>Exposures</b>	<b>#</b>	<b>Label (ETC Run)</b>	<b>Target</b>	<b>Config,Mode,Aperture</b>	<b>Spectral Els.</b>	<b>Opt. Params.</b>	<b>Special Reqs.</b>	<b>Groups</b>	<b>Exp. Time (Total)/[Actual Dur.]</b>	<b>Orbit</b>	
	1	(COS.ta.823 245)	(2) M87-FILAMEN T-OFFSET	COS/NUV, ACQ/IMAGE, PSA	MIRRORB				100 Secs (100 Secs)		
										[==>]	
										[1]	
	2	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00; FLASH=YES; FP-POS=1				1121 Secs (1121 Secs)	
										[==>]	
									[1]		
3	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00; FLASH=YES; FP-POS=2				1121 Secs (1121 Secs)		
									[==>]		
									[1]		
4	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00; FLASH=YES; FP-POS=3				1404 Secs (1404 Secs)		
									[==>]		
									[2]		
5	(COS.sp.841 246)	(1) M87-FILAMEN T	COS/FUV, TIME-TAG, PSA	G130M 1318 A	BUFFER-TIME=50 00; FLASH=YES; FP-POS=4				1404 Secs (1404 Secs)		
									[==>]		
									[2]		

