



17769 - The UVOIR portrait of PSR J0030+0451, the key millisecond pulsar

Cycle: 32, Proposal Category: GO

(UV Initiative)

(Availability Mode: SUPPORTED)

INVESTIGATORS

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Dr. George G. Pavlov (PI) (Contact)	The Pennsylvania State University
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Luis E. Rodriguez (CoI)	Pontificia Universidad Catolica de Chile
Denis Gonzalez-Caniulef (CoI) (ESA Member)	Institut de Recherche en Astrophysique et Planetologie

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) PSRJ0030+0451	ACS/SBC	1	15-Sep-2025 13:00:29.0	yes
02	(1) PSRJ0030+0451	WFC3/UVIS	1	15-Sep-2025 13:00:30.0	yes
03	(1) PSRJ0030+0451	WFC3/IR	1	15-Sep-2025 13:00:30.0	yes
05	(1) PSRJ0030+0451	WFC3/IR	1	15-Sep-2025 13:00:30.0	yes
04	(1) PSRJ0030+0451	ACS/SBC	1	15-Sep-2025 13:00:31.0	yes

5 Total Orbits Used

ABSTRACT

Proposal 17769 (STScI Edit Number: 2, Created: Monday, September 15, 2025, 12:00:31PM Eastern Standard Time) - Overview

PSR J0030+0451 is a nearby single radio, X-ray and gamma-ray millisecond pulsar, which has never been studied in the UV-optical-IR (UVOIR). This pulsar turned out to be the best target for measuring neutron star mass and radius with the X-ray NICER mission, using the effects of bending of photon trajectories in a strong gravitational field. Such measurements are very important for understanding the equation of state of the superdense matter in neutron star interiors, determined by strong interactions of hadrons. The mass and radius are obtained from the analysis of the pulsations of thermal soft X-ray emission coming from "hot spots" on the neutron star surface, heated by relativistic particles precipitating from the pulsar's magnetosphere along the magnetic field lines. The pulse shape (hence the inferred mass and radius) critically depend on the positions of the heated regions and the temperature distribution over the neutron star surface. To understand this distribution, one should analyze not only soft X-ray but also far-UV (FUV) pulsations. Such pulsations could be detected with HST, but one should know the average thermal FUV flux to determine the needed exposure. We propose a short exploratory program to estimate the average neutron star surface temperature from measuring UVOIR fluxes in three bands. The estimated temperature will be compared with the predictions of neutron star cooling/heating models, which will give us independent constraints on properties of the superdense matter.

OBSERVING DESCRIPTION

To measure the FUV flux and estimate the neutron star temperature in PSR J0030+0451, we will employ ACS/SBC, the most sensitive detector in the FUV range. To eliminate the contribution of the geocoronal emission and maximize the FUV sensitivity, we will use the F125LP filter (cuts off geocoronal Ly-alpha) in the SHADOW parts of the orbit (1820 s for J0030), and the F140LP filter (cuts off all the geocoronal lines) in the rest of the orbit (500 s).

We choose the ACS/SBC exposure time from the requirement that a temperature of $T = 0.5E+5$ K, which corresponds to the flux density of 10 nJy at 1438 Å, to be detectable at >3 sigma level. From an analysis of archived ACS/SBC F125LP observations we found that two SHADOW orbits (shadow exposure of 3640 s) would be required. A similar estimate is obtained with the ACS ETC: $S/N = 3.0$ for an aperture circle radius of 0.2 arcsec; $(S/N)_{\text{optimal}} = 5.3$ (ETC Request ID: ACS.im.1930247). In the shorter non-shadow parts of the orbits (1000 s exposure) we will firmly detect the pulsar with the F140LP filter if its flux density exceeds 60 nJy (ACS.im.1930268). To minimize the effects of the SBC "thermal glow", we request the SBC observations to be taken in two one-orbit visits. We have checked that there are no bright objects in the SBC field of view that could violate the Bright Object Protection limit.

As some old pulsars show a nonthermal power-law component in the optical, it is important to subtract its contribution into the FUV range from the detected FUV flux in order to measure the temperature. To do this, we need observations in two additional bands covering a broad wavelength range. Optimal filters for this goal are FWC3/UVIS F475X (3800 - 6000 Å) and FWC3/IR F110W (0.9 - 1.4 microns). Thanks to the high sensitivity of

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these detector/filter combinations, 1 orbit in each band would detect very faint sources (or provide very low upper limits).

In UVIS/ F475X we put the target in the UVIS2-C512C-CTE subarray near the chip readout to maximize the CTE. According to ETC (WFC3UVIS.im.1930279), we would detect 13 nJy (at 4850 Å) for a flat f_{ν} continuum in 2232 s science exposure, using the WFC3-UVIS-DITHER-BOX, with $S/N = 3.0$ at $r = 0.1$ arcsec, $(S/N)_{\text{optimal}} = 4.4$.

In WFC3/IR/F110W ($\lambda = 1.15$ micron; exposure 2397 s) we will use the WFC3-IR-DITHER-BOX and readout parameters SAMP-SEQ = STEP100, NSAMP = 12. According to ETC (WFC3IR.im.1930295), we will detect a 22 nJy target with $S/N = 3.0$ at $r = 0.15$ arcsec, $(S/N)_{\text{optimal}} = 3.5$.

We will use the optical image for astrometry based on the Gaia catalog, and then co-align the FUV and optical images for the FUV astrometry.

Proposal 17769 - fuv1 (01) - The UVOIR portrait of PSR J0030+0451, the key millisecond pulsar

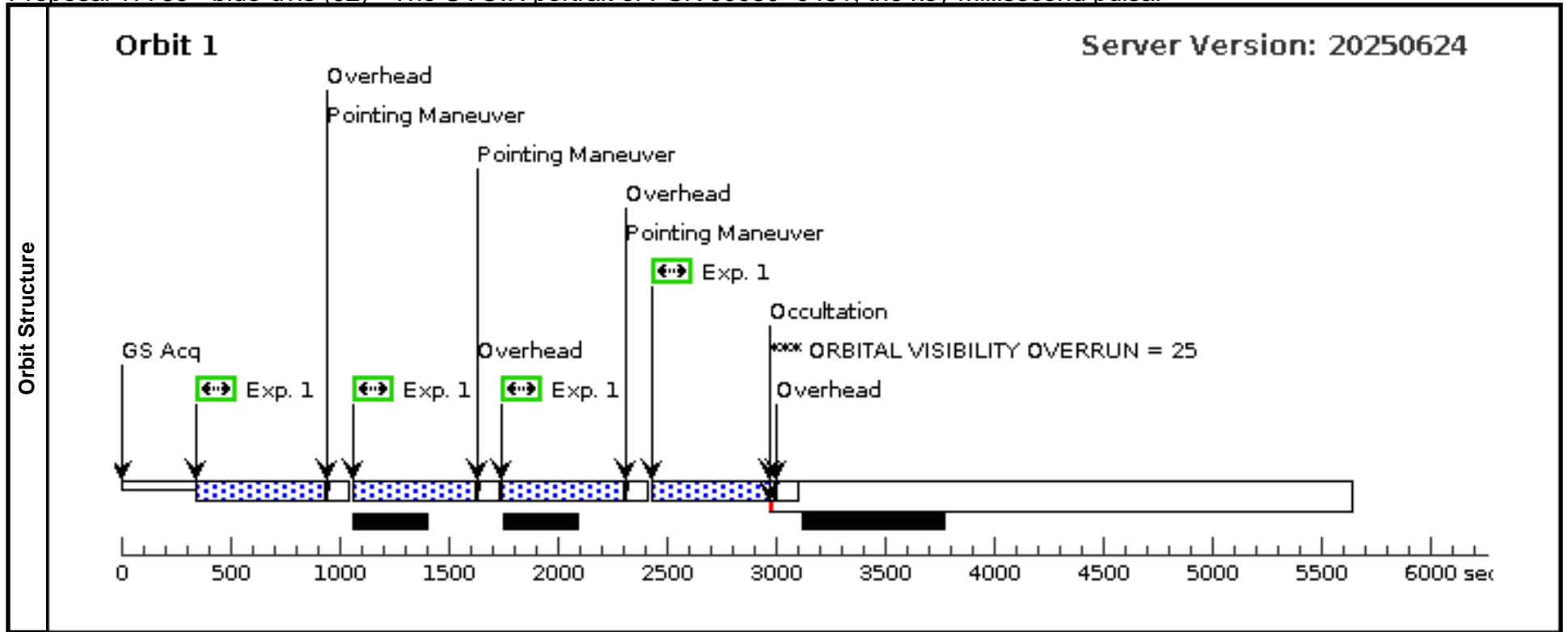
Mon Sep 15 17:00:31 GMT 2025

Visit	Proposal 17769, fuv1 (01), scheduling Diagnostic Status: Warning Scientific Instruments: ACS/SBC Special Requirements: (none)									
	(fuv1 (01)) Warning (Orbit Planner): ORBITAL VISIBILITY OVERRUN									
Fixed Targets	#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous				
	(1)	PSRJ0030+0451	RA: 00 30 27.4216 (7.6142567d) Dec: +04 51 39.72 (4.86103d) Equinox: J2000		V=29	Reference Frame: ICRS				
Comments: Category=STAR Description=[NEUTRON STAR, PULSAR] Extended=NO										
Exposures	#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
	1	(ACS.im.19 30256)	(1) PSRJ0030+0451	ACS/SBC, ACCUM, SBC	F125LP		SHADOW; GS ACQ SCENARI O BASE103		1820 Secs (1820 Secs) [==>]	[1]
	2	(ACS.im.19 30273)	(1) PSRJ0030+0451	ACS/SBC, ACCUM, SBC	F140LP				500 Secs (500 Secs) [==>]	[1]
Orbit Structure	Orbit 1 Server Version: 20250624									
	<p>The diagram illustrates the timing of observations relative to the pulsar's occultation. The x-axis represents time in seconds from 0 to 6000. Key events are marked: GS Acq (Green Arrow) at approximately 200s, Exp. 1 (Green Arrow) at 500s, Exp. 2 (Green Arrow) at 2400s, Shadow Limit (Green Arrow) at 2400s, and Occultation (Black Arrow) at 3000s. A shaded blue and white checkered region from 500s to 3000s represents the occultation period. A text label 'ORBITAL VISIBILITY OVERRUN = 14' is positioned near the occultation event.</p>									

Proposal 17769 - blue-uvis (02) - The UVOIR portrait of PSR J0030+0451, the key millisecond pulsar

Mon Sep 15 17:00:31 GMT 2025

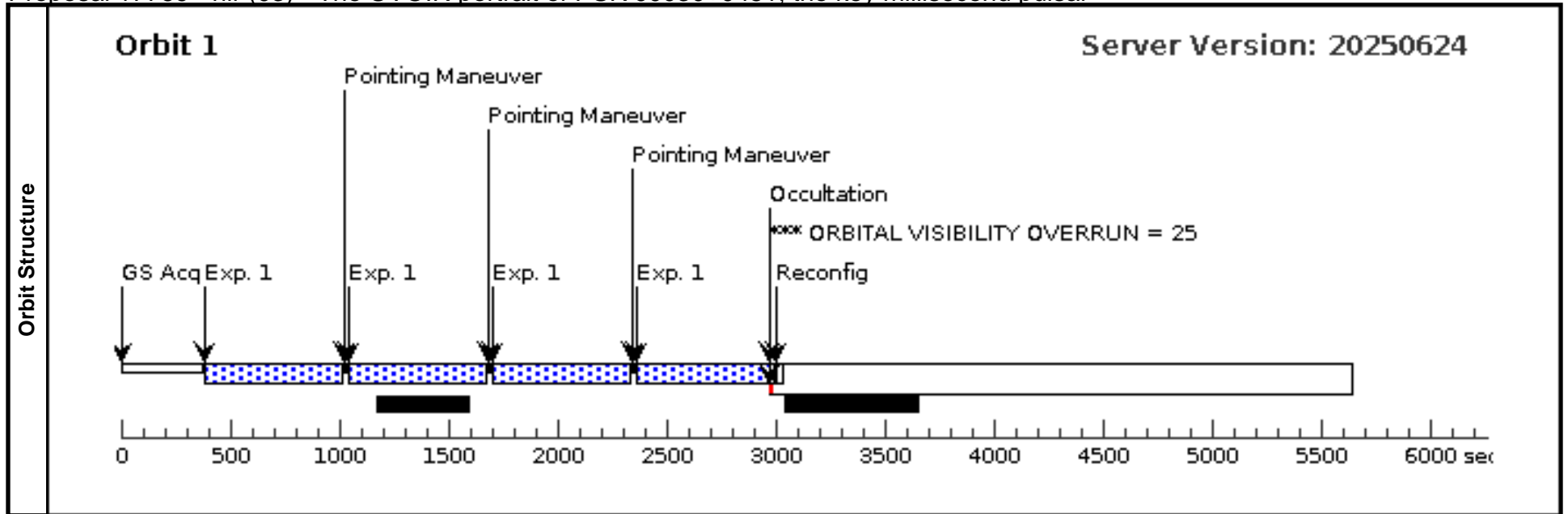
Visit	Proposal 17769, blue-uvis (02), completed Diagnostic Status: Warning Scientific Instruments: WFC3/UVIS Special Requirements: (none)										
	(blue-uvis (02)) Warning (Orbit Planner): ORBITAL VISIBILITY OVERRUN										
Diagnosics											
Patterns	#	Primary Pattern				Secondary Pattern				Exposures	
	(2)	Pattern Type=WFC3-UVIS-DITHER-BOX Purpose=DITHER Number Of Points=4 Point Spacing=0.173 Line Spacing=0.112				Coordinate Frame=POS-TARG Pattern Orientation=23.884 Angle Between Sides=81.785 Center Pattern=false				(1)	
Fixed Targets	#	Name	Target Coordinates		Targ. Coord. Corrections		Fluxes		Miscellaneous		
	(1)	PSRJ0030+0451	RA: 00 30 27.4216 (7.6142567d) Dec: +04 51 39.72 (4.86103d) Equinox: J2000				V=29		Reference Frame: ICRS		
Comments: Category=STAR Description=[NEUTRON STAR, PULSAR] Extended=NO											
Exposures	#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]		Orbit
	1	(WFC3UVI S.im.1930279)	(1) PSRJ0030+0451	WFC3/UVIS, ACCUM, UVIS2-C512C-CTE	F475X			Pattern 2, Exps 1-1 in blue-uvis (02) (2)	558 Secs (2232 Secs) [=>(Pattern 1)] [=>(Pattern 2)] [=>(Pattern 3)] [=>(Pattern 4)]		[1]



Proposal 17769 - nir (03) - The UVOIR portrait of PSR J0030+0451, the key millisecond pulsar

Mon Sep 15 17:00:31 GMT 2025

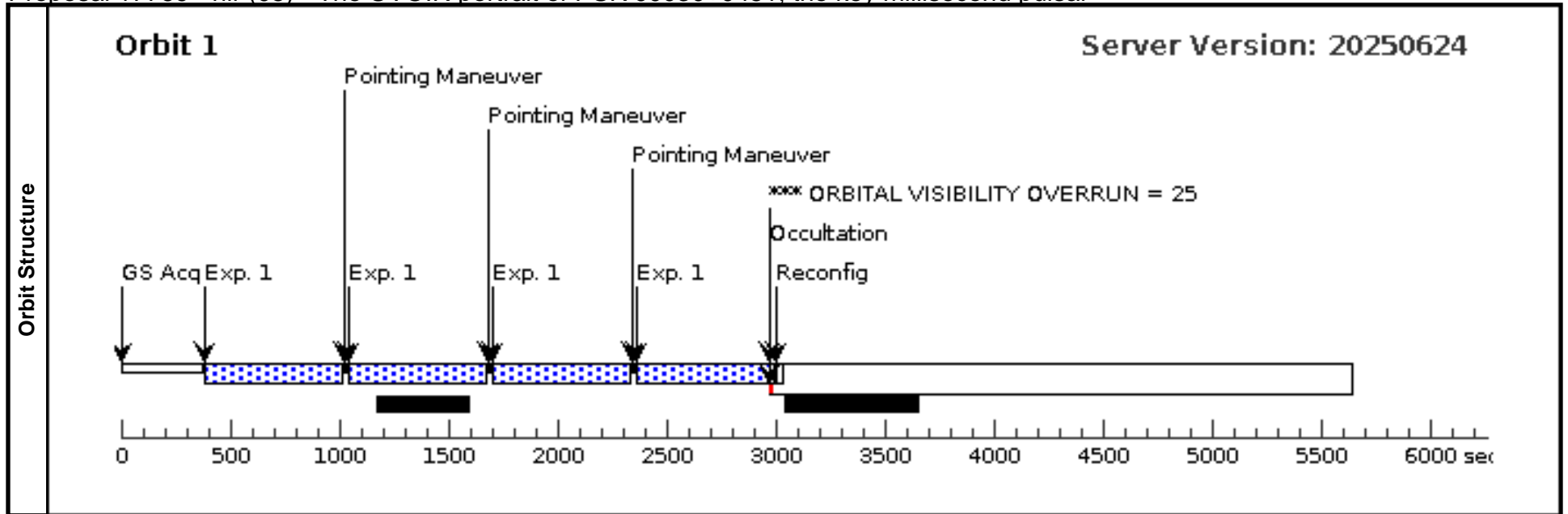
Visit	Proposal 17769, nir (03), failed Diagnostic Status: Warning Scientific Instruments: WFC3/IR Special Requirements: (none)										
	(nir (03)) Warning (Orbit Planner): ORBITAL VISIBILITY OVERRUN										
Diagnosics											
Patterns	#	Primary Pattern				Secondary Pattern			Exposures		
	(1)	Pattern Type=WFC3-IR-DITHER-BOX-MIN Purpose=DITHER Number Of Points=4 Point Spacing=0.572 Line Spacing=0.365		Coordinate Frame=POS-TARG Pattern Orientation=18.528 Angle Between Sides=74.653 Center Pattern=false					(1)		
Fixed Targets	#	Name	Target Coordinates	Targ. Coord. Corrections		Fluxes	Miscellaneous				
	(1)	PSRJ0030+0451	RA: 00 30 27.4216 (7.6142567d) Dec: +04 51 39.72 (4.86103d) Equinox: J2000			V=29	Reference Frame: ICRS				
Comments: Category=STAR Description=[NEUTRON STAR, PULSAR] Extended=NO											
Exposures	#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]		Orbit
	1	(WFC3IR.im.1930295)	(1) PSRJ0030+0451	WFC3/IR, MULTIACCUM, IR	F110W	SAMP-SEQ=STEP100; NSAMP=12		Pattern 1, Exps 1-1 in nir (03) (1)	599.232292 Secs (2396.929 Secs) [=>(Pattern 1)] [=>(Pattern 2)] [=>(Pattern 3)] [=>(Pattern 4)]		[1]



Proposal 17769 - nir (05) - The UVOIR portrait of PSR J0030+0451, the key millisecond pulsar

Mon Sep 15 17:00:31 GMT 2025

Visit	Proposal 17769, nir (05) Diagnostic Status: Warning Scientific Instruments: WFC3/IR Special Requirements: (none)										
	(nir (05)) Warning (Orbit Planner): ORBITAL VISIBILITY OVERRUN										
Diagnosics											
Patterns	#	Primary Pattern				Secondary Pattern				Exposures	
	(1)	Pattern Type=WFC3-IR-DITHER-BOX-MIN Purpose=DITHER Number Of Points=4 Point Spacing=0.572 Line Spacing=0.365				Coordinate Frame=POS-TARG Pattern Orientation=18.528 Angle Between Sides=74.653 Center Pattern=false				(1)	
Fixed Targets	#	Name	Target Coordinates		Targ. Coord. Corrections		Fluxes		Miscellaneous		
	(1)	PSRJ0030+0451	RA: 00 30 27.4216 (7.6142567d) Dec: +04 51 39.72 (4.86103d) Equinox: J2000				V=29		Reference Frame: ICRS		
<i>Comments:</i> Category=STAR Description=[NEUTRON STAR, PULSAR] Extended=NO											
Exposures	#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]		Orbit
	1	(WFC3IR.im.1930295)	(1) PSRJ0030+0451	WFC3/IR, MULTIACCUM, IR	F110W	SAMP-SEQ=STEP100; NSAMP=12		Pattern 1, Exps 1-1 in nir (05) (1)	599.232292 Secs (2396.929 Secs) [=>(Pattern 1)] [=>(Pattern 2)] [=>(Pattern 3)] [=>(Pattern 4)]		[1]



Proposal 17769 - fuv2 (04) - The UVOIR portrait of PSR J0030+0451, the key millisecond pulsar

Mon Sep 15 17:00:31 GMT 2025

Visit	Proposal 17769, fuv2 (04), scheduling Diagnostic Status: Warning Scientific Instruments: ACS/SBC Special Requirements: (none) <i>Comments: We request this visit to be separated in time from the identical visit fuv1 (01) to minimize the "thermal glow" of the detector.</i>																																		
	Diagnostics (fuv2 (04)) Warning (Orbit Planner): ORBITAL VISIBILITY OVERRUN																																		
Fixed Targets	<table border="1"> <thead> <tr> <th>#</th> <th>Name</th> <th>Target Coordinates</th> <th>Targ. Coord. Corrections</th> <th>Fluxes</th> <th>Miscellaneous</th> </tr> </thead> <tbody> <tr> <td>(1)</td> <td>PSRJ0030+0451</td> <td>RA: 00 30 27.4216 (7.6142567d) Dec: +04 51 39.72 (4.86103d) Equinox: J2000</td> <td></td> <td>V=29</td> <td>Reference Frame: ICRS</td> </tr> </tbody> </table>					#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous	(1)	PSRJ0030+0451	RA: 00 30 27.4216 (7.6142567d) Dec: +04 51 39.72 (4.86103d) Equinox: J2000		V=29	Reference Frame: ICRS																		
	#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous																													
(1)	PSRJ0030+0451	RA: 00 30 27.4216 (7.6142567d) Dec: +04 51 39.72 (4.86103d) Equinox: J2000		V=29	Reference Frame: ICRS																														
<i>Comments:</i> Category=STAR Description=[NEUTRON STAR, PULSAR] Extended=NO																																			
Exposures	<table border="1"> <thead> <tr> <th>#</th> <th>Label (ETC Run)</th> <th>Target</th> <th>Config,Mode,Aperture</th> <th>Spectral Els.</th> <th>Opt. Params.</th> <th>Special Reqs.</th> <th>Groups</th> <th>Exp. Time (Total)/[Actual Dur.]</th> <th>Orbit</th> </tr> </thead> <tbody> <tr> <td>1</td> <td>(ACS.im.19 30256)</td> <td>(1) PSRJ0030+0451</td> <td>ACS/SBC, ACCUM, SBC</td> <td>F125LP</td> <td></td> <td>SHADOW; GS ACQ SCENARI O BASE103</td> <td></td> <td>1820 Secs (1820 Secs) [==>]</td> <td>[1]</td> </tr> <tr> <td>2</td> <td>(ACS.im.19 30273)</td> <td>(1) PSRJ0030+0451</td> <td>ACS/SBC, ACCUM, SBC</td> <td>F140LP</td> <td></td> <td></td> <td></td> <td>500 Secs (500 Secs) [==>]</td> <td>[1]</td> </tr> </tbody> </table>					#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit	1	(ACS.im.19 30256)	(1) PSRJ0030+0451	ACS/SBC, ACCUM, SBC	F125LP		SHADOW; GS ACQ SCENARI O BASE103		1820 Secs (1820 Secs) [==>]	[1]	2	(ACS.im.19 30273)	(1) PSRJ0030+0451	ACS/SBC, ACCUM, SBC	F140LP				500 Secs (500 Secs) [==>]	[1]
	#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit																									
	1	(ACS.im.19 30256)	(1) PSRJ0030+0451	ACS/SBC, ACCUM, SBC	F125LP		SHADOW; GS ACQ SCENARI O BASE103		1820 Secs (1820 Secs) [==>]	[1]																									
2	(ACS.im.19 30273)	(1) PSRJ0030+0451	ACS/SBC, ACCUM, SBC	F140LP				500 Secs (500 Secs) [==>]	[1]																										
Orbit Structure <p>The diagram shows a timeline for Orbit 1 from 0 to 6000 seconds. Key events include: GS Acq (0-500s), Exp. 1 (500-1820s), Shadow Limit (2400s), Exp. 2 (2400-2900s), and Occultation (3000s). A shaded region from 500s to 3000s indicates orbital visibility overruns. A text label states 'ORBITAL VISIBILITY OVERRUN = 14'. The server version is 20250624.</p>																																			