# 13783 - Thermal evolution of old neutron stars

Cycle: 22, Proposal Category: GO

(UV Initiative)

(Availability Mode: SUPPORTED)

**INVESTIGATORS**



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|---|---|---|
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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) PSR-J2144-3933 | ACS/SBC | 2 | 17-Oct-2014 21:40:37.0 | yes |
| 06 | (1) PSR-J2144-3933 | ACS/SBC | 2 | 17-Oct-2014 21:40:39.0 | yes |
| 02 | (2) PSR-B0950+08 | ACS/SBC | 1 | 17-Oct-2014 21:40:40.0 | yes |
| 07 | (2) PSR-B0950+08 | ACS/SBC | 2 | 17-Oct-2014 21:40:40.0 | yes |
| 03 | (3) PSR-J2124-3358 | ACS/SBC | 2 | 17-Oct-2014 21:40:41.0 | yes |
| 08 | (3) PSR-J2124-3358 | ACS/SBC | 2 | 17-Oct-2014 21:40:42.0 | yes |
| 04 | (1) PSR-J2144-3933 | WFC3/UVIS | 1 | 17-Oct-2014 21:40:43.0 | yes |
| 05 | (3) PSR-J2124-3358 | WFC3/UVIS | 1 | 17-Oct-2014 21:40:44.0 | yes |

13 Total Orbits Used

**ABSTRACT**

We propose the first observational study of the thermal evolution of old neutron stars (NSs) through far-UV observations of three nearby pulsars in the age range from 17 Myr to 6 Gyr. The cooling history of younger NSs is being mapped out in the X-rays, providing important information on the properties of the super-dense matter in the NS interiors. However, only one old NS, millisecond PSR J0437-4715, has so far revealed its thermal emission, which has been detected with HST in the far-UV. The observed high temperature of about 1.5*10^5 K unavoidably requires a heating mechanism to operate in the old NS interiors. Two possible heating mechanisms have been identified, but their relative importance and parameters, which depend on poorly understood properties of the NS matter, are currently unclear. The proposed program will discriminate between the competing heating models and help constrain the properties of matter under extreme physical conditions, such as neutron and proton superfluidity and frictional forces between the superfluid vortices and the crustal solid.

Observations of the far-UV surface emission of old NSs, undetectable from the ground, is the only way to establish their long-term thermal evolution (cooling curves) and so probe the cooling/heating mechanisms and the properties of matter at super-high densities. Therefore, the UV capabilities of the HST offer a unique opportunity to carry out such a study, which will be a long-lasting legacy of HST.

**OBSERVING DESCRIPTION**

To measure the temperatures for the chosen sample of old pulsars, we will image the targets with the ACS/SBC detector, the most sensitive detector in the FUV range. To increase the number of souce counts and eliminate the contribution of the Ly-alpha geocoronal emission, we will employ the F125LP filter (1250 - 1700 A) with the SHADOW orbit requirement. We have checked that the shorter SHADOW F125LP exposures yield a larger SNR than longer exposures without the SHADOW requirement with any other SBC filter thanks to the lower air-glow background. We will fill the non-shadow parts of the SHADOW obits with F140LP (1400 - 1700 A) exposures; this narrower filter is used to cut off the geocoronal oxygen lines, which make no contribution in the shadow parts.

The brightness temperatures will be deduced from the measured FUV fluxes. The spectral flux Fnu is proportional to T * nu^2 * (R/d)^2 * 10^{-0.4*Anu} in the Rayleigh-Jeans regime, where R is the NS radius as seen by a distant observer (the radii should be similar for all NSs, for a given EOS and similar masses), d is the distance, and Anu is the extinction, which can be inferred from the radio pulsar dispersion measure and the hydrogen column density found in the X-ray observations.

For the exposure time estimates, we require the detection limits to be slightly lower than the values predicted by realistic heating models for the corresponding pulsar ages. In the cases where a non-negligible contribution from the magnetospheric emission is possible, we assume the FUV flux close to the conservative lower limit on the magnetospheric flux, because deeper observations would not provide tighter constraints on the thermal emission.

We calculated the exposure times needed for detection of the FUV fluxes with the aid of ACS ETC, requiring the detection at the SNR = 4 - 5 level in the 0.1" radius aperture, close to optimal one for very faint targets. These calculations showed that we will need 4 orbit exposures for the pulsars J2144-3933 and J2124-3358, and a 3 orbit exposure for PSR B0950-08. To reduce the dark current instrumental background, which starts growing dramatically at about 3 hours after turning the SBC on because of increasing instrument temperature, we request 2 visits (of 1 or 2 orbits duration) for each of the targets, and request to schedule the visits after the SBC has been off for a while and cooled down.

To evaluate the contribution of the magnetospheric spectrum, we will measure the fluxes of the pulsars (except for B0950+08, the only one in our sample that has already been detected with HST) with the broad WFC3/UVIS F475X  filter (3800 - 6000 A), which provides the optimal trade-off between the width and sensitivity. Using the ETC, we found that one orbit per target would suffice to obtain useful limits. To have enough stars for precise astrometry, we will image the field on the entire UVIS detector. To mitigate CTE effects on our very faint targets, we move them towards ampifier C, close to the center of UVIS2-C512C subarray. We will use the WFC3-UVID-DITHER-BOX pattern in each of the 2 orbits.

## Visit

**Proposal 13783, j2144sbc (01), implementation** Sat Oct 18 01:40:45 GMT 2014

**Diagnostic Status: No Diagnostics**

Scientific Instruments: ACS/SBC

Special Requirements: (none)

*Comments: Since the target is very faint, we need the SBC to be cool during the observation to minimize the dark current. Therefore, we request to schedule the visit after the SBC has been off for a while and cooled down.*

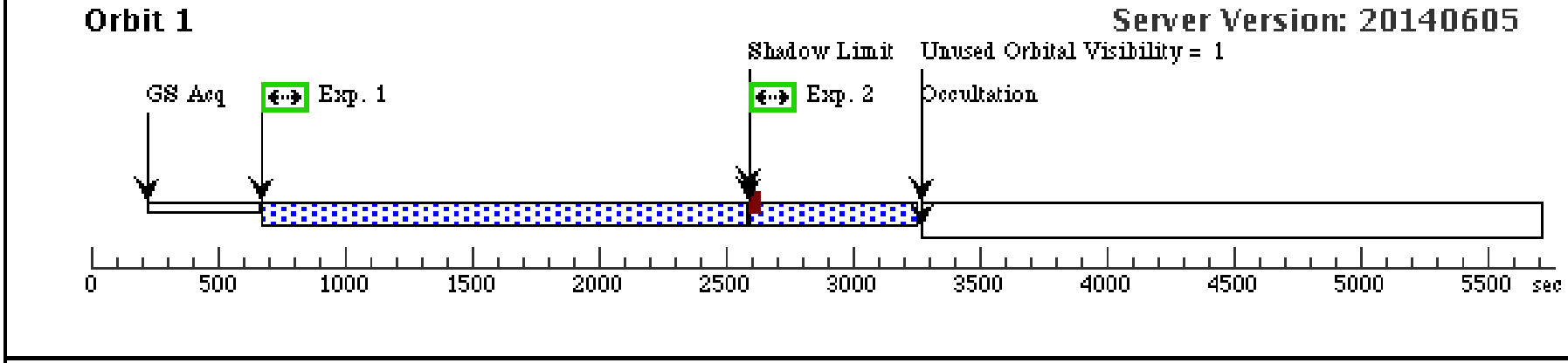
## Fixed Targets

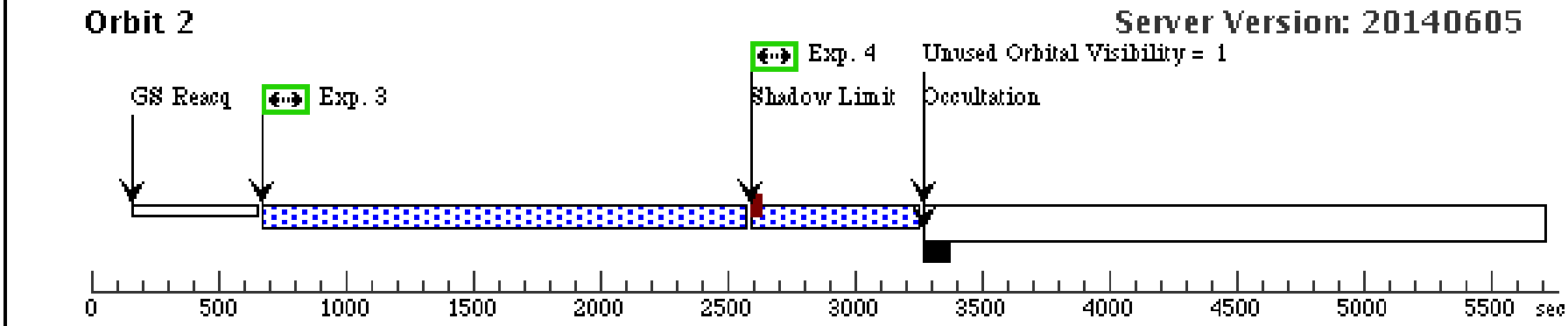
| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (1) | PSR-J2144-3933 | RA: 21 44 12.0190 (326.0500792d)<br>Dec: -39 33 58.16 (-39.56616d)<br>Equinox: J2000 | | V=28+/-2 | Reference Frame: ICRS |

## Exposures

| # | Label (ETC Run) | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | (ACS.im.62 0178) | (1) PSR-J2144-3933 | ACS/SBC, ACCUM, SBC | F125LP | | SHADOW | | 1835 Secs (1839 Secs)<br>*[==>1839.0 Secs ]* | <br>***[1]*** |
| 2 | (ACS.im.61 20180) | (1) PSR-J2144-3933 | ACS/SBC, ACCUM, SBC | F140LP | | | | 616 Secs (616 Secs)<br>*[==>]* | <br>***[1]*** |
| 3 | (ACS.im.62 0178) | (1) PSR-J2144-3933 | ACS/SBC, ACCUM, SBC | F125LP | | SHADOW | | 1840 Secs (1856 Secs)<br>*[==>1856.0 Secs ]* | <br>***[2]*** |
| 4 | (ACS.im.62 0180) | (1) PSR-J2144-3933 | ACS/SBC, ACCUM, SBC | F140LP | | | | 600 Secs (617 Secs)<br>*[==>617.0 Secs ]* | <br>***[2]*** |

Orbit Structure



## Visit

**Proposal 13783, j2144sbc2 (06), implementation** Sat Oct 18 01:40:46 GMT 2014

**Diagnostic Status: No Diagnostics**

Scientific Instruments: ACS/SBC

Special Requirements: (none)

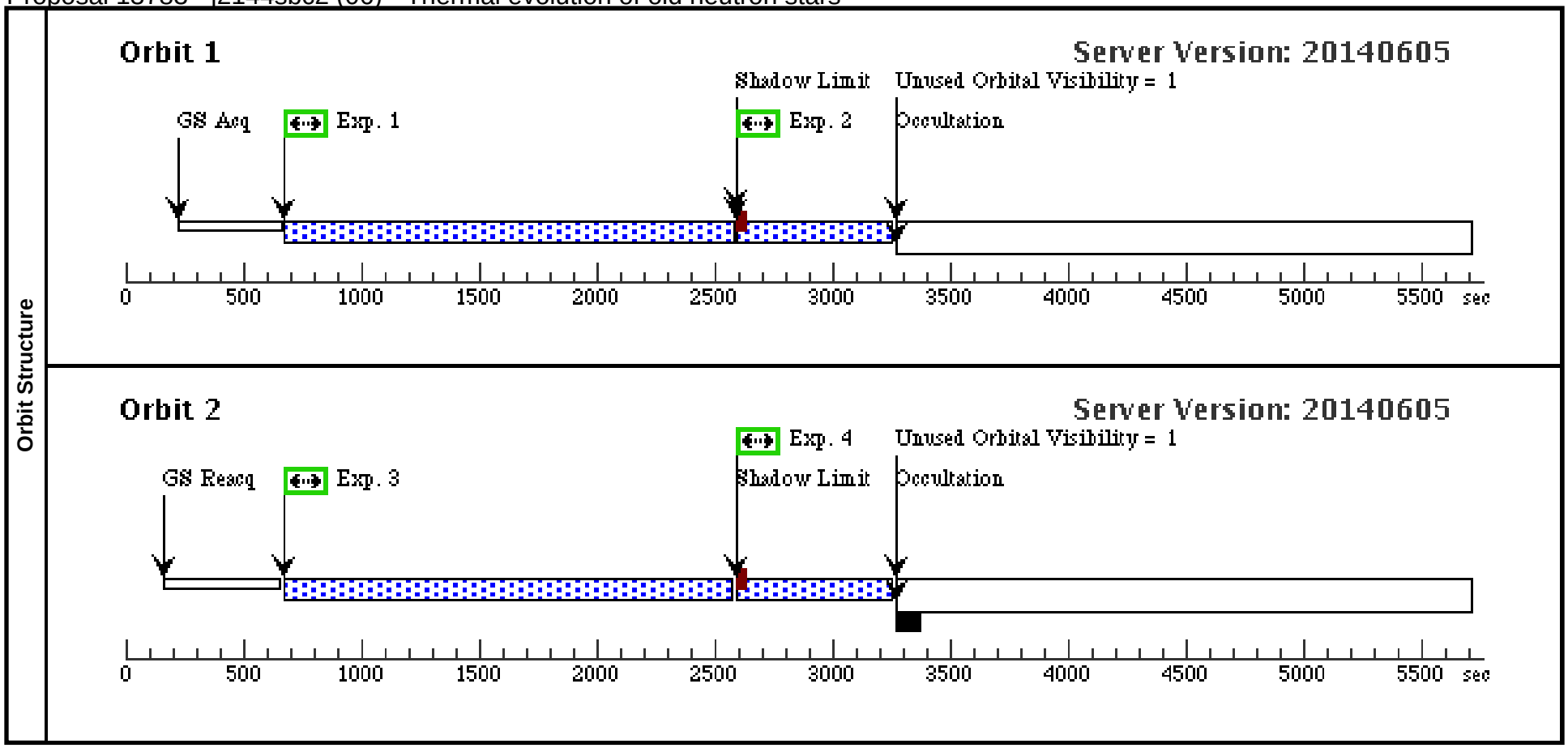
*Comments: Since the target is very faint, we need the SBC to be cool during the observation to minimize the dark current. Therefore, we request to schedule the visit after the SBC has been off for a while and cooled down.*

## Fixed Targets

| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (1) | PSR-J2144-3933 | RA: 21 44 12.0190 (326.0500792d)<br>Dec: -39 33 58.16 (-39.56616d)<br>Equinox: J2000 | | V=28+/-2 | Reference Frame: ICRS |

## Exposures

| # | Label (ETC Run) | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | (ACS.im.62 0178) | (1) PSR-J2144-3933 | ACS/SBC, ACCUM, SBC | F125LP | | SHADOW | | 1835 Secs (1839 Secs)<br>*[==>1839.0 Secs ]* | <br>***[1]*** |
| 2 | (ACS.im.62 0180) | (1) PSR-J2144-3933 | ACS/SBC, ACCUM, SBC | F140LP | | | | 616 Secs (616 Secs)<br>*[==>]* | <br>***[1]*** |
| 3 | (ACS.im.62 0178) | (1) PSR-J2144-3933 | ACS/SBC, ACCUM, SBC | F125LP | | SHADOW | | 1840 Secs (1856 Secs)<br>*[==>1856.0 Secs ]* | <br>***[2]*** |
| 4 | (ACS.im.62 0180) | (1) PSR-J2144-3933 | ACS/SBC, ACCUM, SBC | F140LP | | | | 600 Secs (617 Secs)<br>*[==>617.0 Secs ]* | <br>***[2]*** |


Orbit Structure
Orbit 1
Server Version: 20140605
Shadow Limit
Unused Orbital Visibility = 1
GS Acq
Exp. 1
Exp. 2
Occultation
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
sec
Orbit 2
Server Version: 20140605
Exp. 4
Unused Orbital Visibility = 1
GS Reacq
Exp. 3
Shadow Limit
Occultation
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
sec

## Visit

**Proposal 13783, b0950sbc (02), implementation** Sat Oct 18 01:40:46 GMT 2014

**Diagnostic Status: No Diagnostics**

Scientific Instruments: ACS/SBC

Special Requirements: (none)

*Comments: Since the target is very faint, we need the SBC to be cool during the observation to minimize the dark current. Therefore, we request to schedule the visit after the SBC has been off for a while and cooled down.*

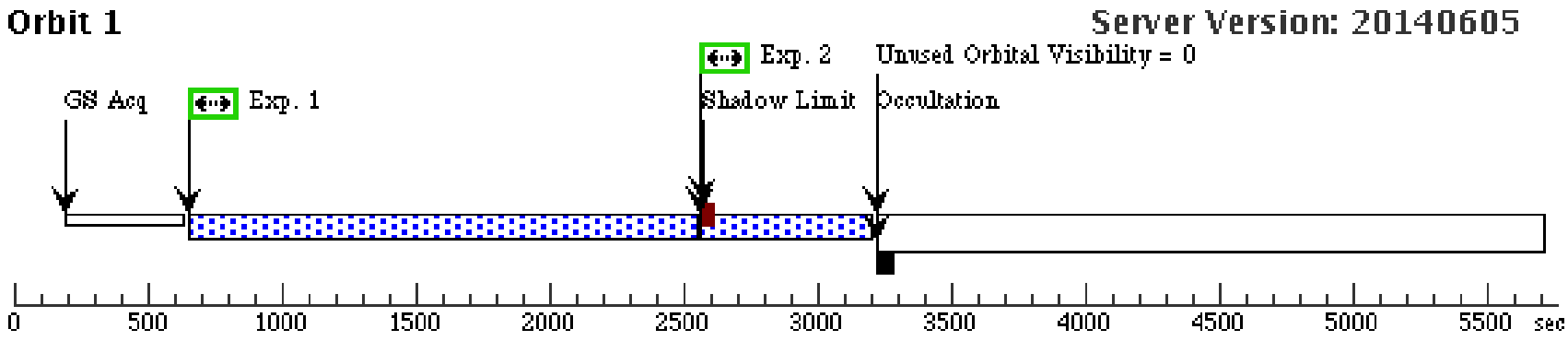
## Fixed Targets

| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (2) | PSR-B0950+08 | RA: 09 53 9.3060 (148.2887750d)<br>Dec: +07 55 36.51 (7.92681d)<br>Equinox: J2000 | | V=27.1+/-0.3 | Reference Frame: ICRS |

## Exposures

| # | Label (ETC Run) | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | (ACS.im.62 0183) | (2) PSR-B0950+08 | ACS/SBC, ACCUM, SBC | F125LP | | SHADOW | | 2800 Secs (1836 Secs)<br>*[==>1836.0 Secs ]* | <br>***[1]*** |
| 2 | (ACS.im.62 0184) | (2) PSR-B0950+08 | ACS/SBC, ACCUM, SBC | F140LP | | | | 592 Secs (592 Secs)<br>*[==>]* | <br>***[1]*** |

## Orbit Structure



## Visit

**Proposal 13783, b0950sbc2 (07), implementation** Sat Oct 18 01:40:46 GMT 2014

**Diagnostic Status: No Diagnostics**

Scientific Instruments: ACS/SBC

Special Requirements: (none)

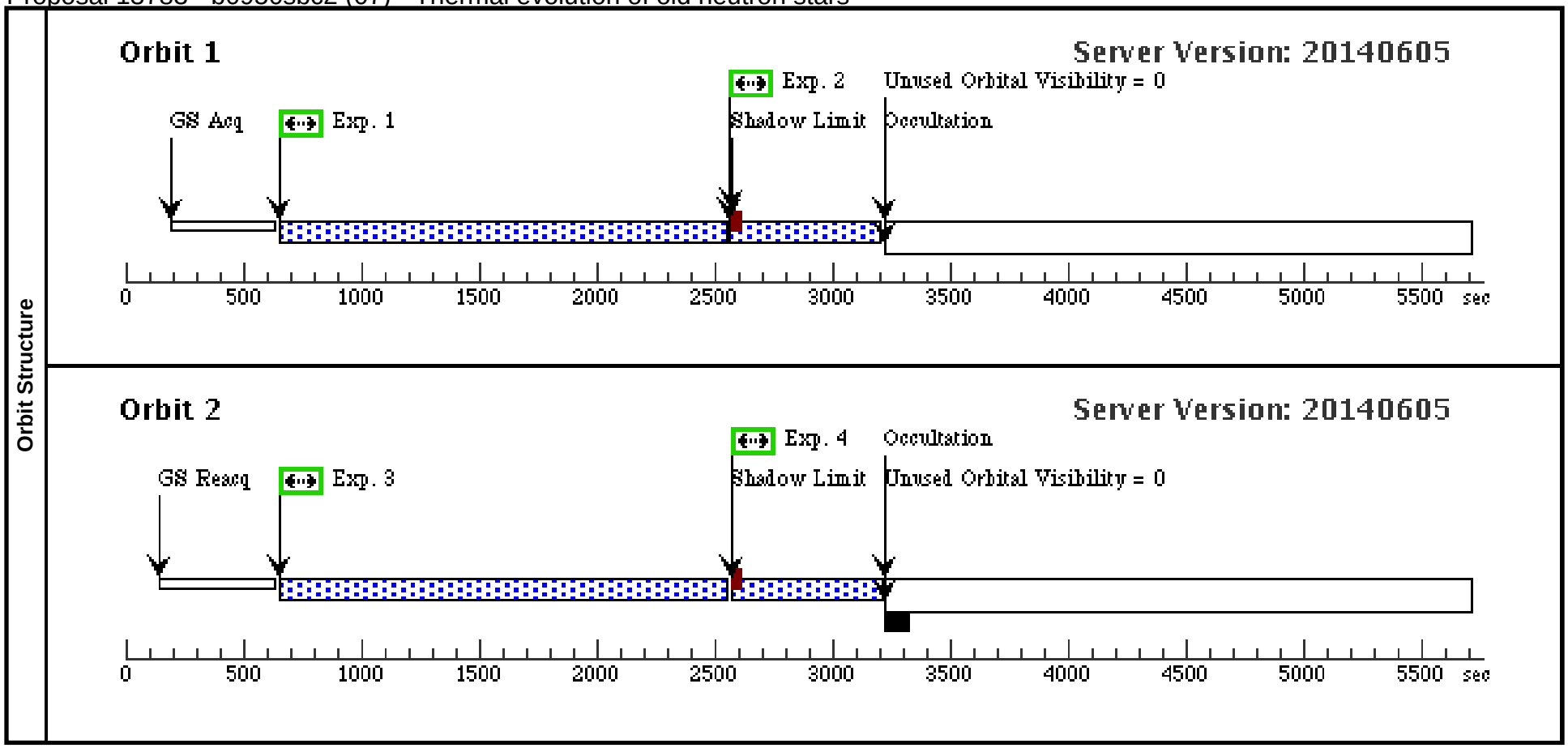
*Comments: Since the target is very faint, we need the SBC to be cool during the observation to minimize the dark current. Therefore, we request to schedule the visit after the SBC has been off for a while and cooled down.*

## Fixed Targets

| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (2) | PSR-B0950+08 | RA: 09 53 9.3060 (148.2887750d)<br>Dec: +07 55 36.51 (7.92681d)<br>Equinox: J2000 | | V=27.1+/-0.3 | Reference Frame: ICRS |

## Exposures

| # | Label (ETC Run) | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | (ACS.im.62 0183) | (2) PSR-B0950+08 | ACS/SBC, ACCUM, SBC | F125LP | | SHADOW | | 2800 Secs (1836 Secs)<br>*[==>1836.0 Secs ]* | <br>***[1]*** |
| 2 | (ACS.im.62 0184) | (2) PSR-B0950+08 | ACS/SBC, ACCUM, SBC | F140LP | | | | 592 Secs (592 Secs)<br>*[==>]* | <br>***[1]*** |
| 3 | (ACS.im.62 0183) | (2) PSR-B0950+08 | ACS/SBC, ACCUM, SBC | F125LP | | SHADOW | | 1856 Secs (1856 Secs)<br>*[==>]* | <br>***[2]*** |
| 4 | (ACS.im.62 0184) | (2) PSR-B0950+08 | ACS/SBC, ACCUM, SBC | F140LP | | | | 590 Secs (590 Secs)<br>*[==>]* | <br>***[2]*** |


Orbit Structure
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GS Acq
Exp. 1
Exp. 2
Shadow Limit
Unused Orbital Visibility = 0
Occultation
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500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
sec
Orbit 2
Server Version: 20140605
GS Reacq
Exp. 3
Exp. 4
Shadow Limit
Occultation
Unused Orbital Visibility = 0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
sec

## Visit

**Proposal 13783, j2124sbc (03), implementation** Sat Oct 18 01:40:46 GMT 2014

**Diagnostic Status: No Diagnostics**

Scientific Instruments: ACS/SBC

Special Requirements: (none)

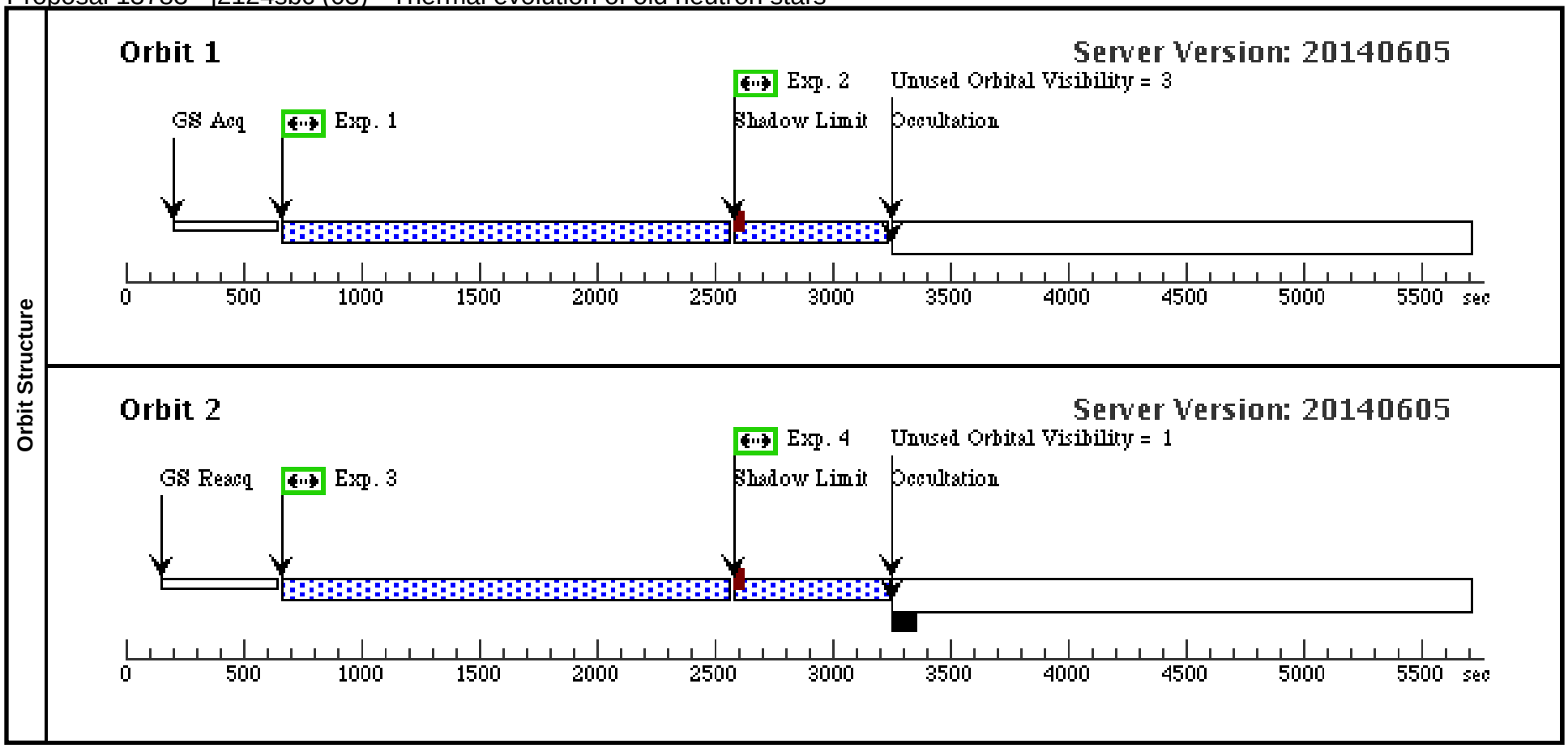
*Comments: Since the target is very faint, we need the SBC to be cool during the observation to minimize the dark current. Therefore, we request to schedule the visit after the SBC has been off for a while and cooled down.*

## Fixed Targets

| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (3) | PSR-J2124-3358 | RA: 21 24 43.8440 (321.1826833d)<br>Dec: -33 58 45.21 (-33.97922d)<br>Equinox: J2000 | | V=28+/-1 | Reference Frame: ICRS |

## Exposures

| # | Label (ETC Run) | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | (ACS.im.62 0185) | (3) PSR-J2124-3358 | ACS/SBC, ACCUM, SBC | F125LP | | SHADOW | | 1838 Secs (1838 Secs) | |
| | | | | | | | | *[==>]* | ***[1]*** |
| 2 | (ACS.im.62 0186) | (3) PSR-J2124-3358 | ACS/SBC, ACCUM, SBC | F140LP | | | | 605 Secs (605 Secs) | |
| | | | | | | | | *[==>]* | ***[1]*** |
| 3 | (ACS.im.62 0185) | (3) PSR-J2124-3358 | ACS/SBC, ACCUM, SBC | F125LP | | SHADOW | | 1850 Secs (1850 Secs) | |
| | | | | | | | | *[==>]* | ***[2]*** |
| 4 | (ACS.im.62 0186) | (3) PSR-J2124-3358 | ACS/SBC, ACCUM, SBC | F140LP | | | | 613 Secs (613 Secs) | |
| | | | | | | | | *[==>]* | ***[2]*** |


Orbit Structure
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Server Version: 20140605
GS Acq
Exp. 1
Exp. 2
Shadow Limit
Unused Orbital Visibility = 3
Occultation
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3500
4000
4500
5000
5500
sec
Orbit 2
Server Version: 20140605
GS Reacq
Exp. 3
Exp. 4
Shadow Limit
Unused Orbital Visibility = 1
Occultation
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500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
sec

## Visit

**Proposal 13783, j2124sbc (08), implementation** Sat Oct 18 01:40:46 GMT 2014

**Diagnostic Status: No Diagnostics**

Scientific Instruments: ACS/SBC

Special Requirements: (none)

*Comments: Since the target is very faint, we need the SBC to be cool during the observation to minimize the dark current. Therefore, we request to schedule the visit after the SBC has been off for a while and cooled down.*

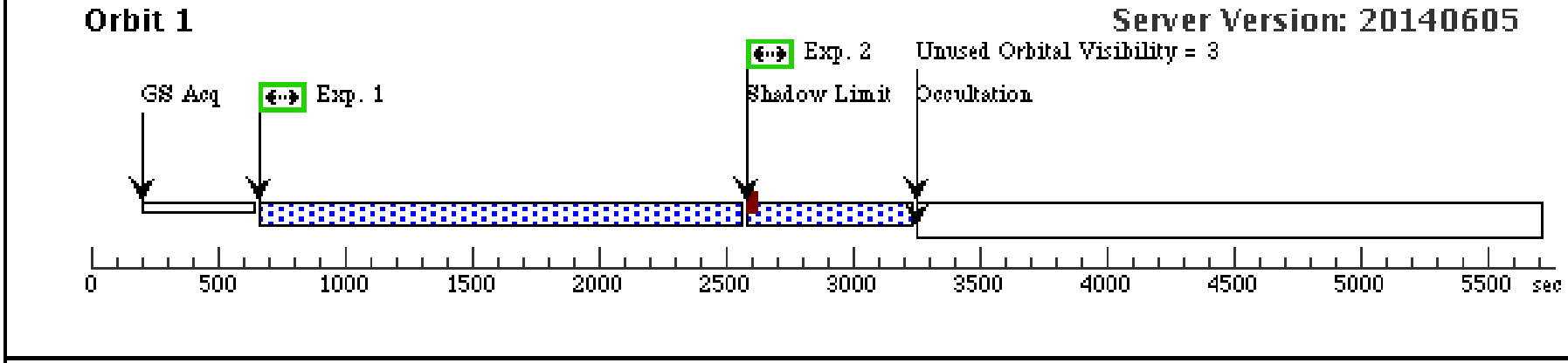
## Fixed Targets

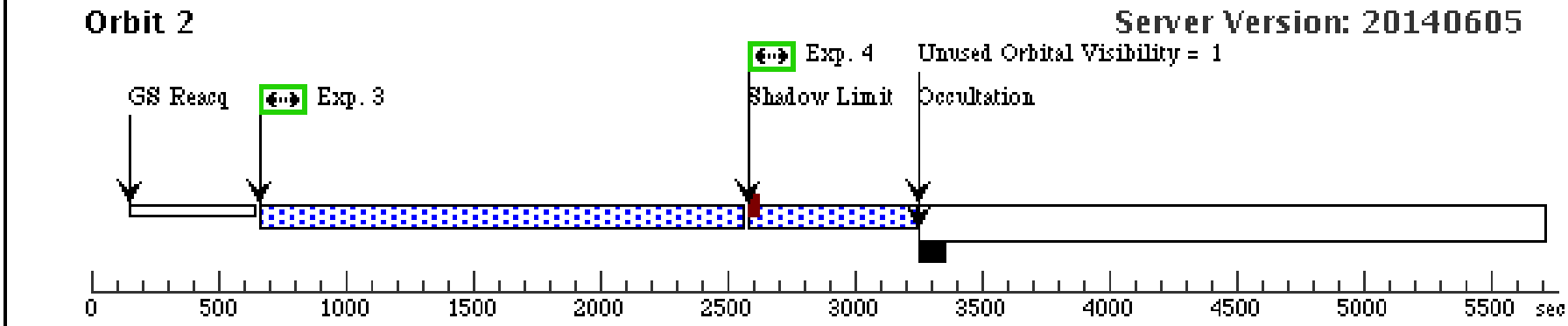
| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (3) | PSR-J2124-3358 | RA: 21 24 43.8440 (321.1826833d)<br>Dec: -33 58 45.21 (-33.97922d)<br>Equinox: J2000 | | V=28+/-1 | Reference Frame: ICRS |

## Exposures

| # | Label (ETC Run) | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | (ACS.im.62 0185) | (3) PSR-J2124-3358 | ACS/SBC, ACCUM, SBC | F125LP | | SHADOW | | 1838 Secs (1838 Secs) | |
| | | | | | | | | *[==>]* | ***[1]*** |
| 2 | (ACS.im.62 0186) | (3) PSR-J2124-3358 | ACS/SBC, ACCUM, SBC | F140LP | | | | 605 Secs (605 Secs) | |
| | | | | | | | | *[==>]* | ***[1]*** |
| 3 | (ACS.im.62 0185) | (3) PSR-J2124-3358 | ACS/SBC, ACCUM, SBC | F125LP | | SHADOW | | 1850 Secs (1850 Secs) | |
| | | | | | | | | *[==>]* | ***[2]*** |
| 4 | (ACS.im.62 0186) | (3) PSR-J2124-3358 | ACS/SBC, ACCUM, SBC | F140LP | | | | 613 Secs (613 Secs) | |
| | | | | | | | | *[==>]* | ***[2]*** |

Orbit Structure



## Visit

**Proposal 13783, j2144uvis (04), implementation** Sat Oct 18 01:40:46 GMT 2014

**Diagnostic Status: No Diagnostics**

Scientific Instruments: WFC3/UVIS

Special Requirements: (none)

## Patterns

| # | Primary Pattern | | Secondary Pattern | Exposures |
|---|---|---|---|---|
| (2) | Pattern Type=WFC3-UVIS-DITHER-BOX<br>Purpose=DITHER<br>Number Of Points=4<br>Point Spacing=0.173<br>Line Spacing=0.112 | Coordinate Frame=POS-TARG<br>Pattern Orientation=23.884<br>Angle Between Sides=81.785<br>Center Pattern=false | | (1) |

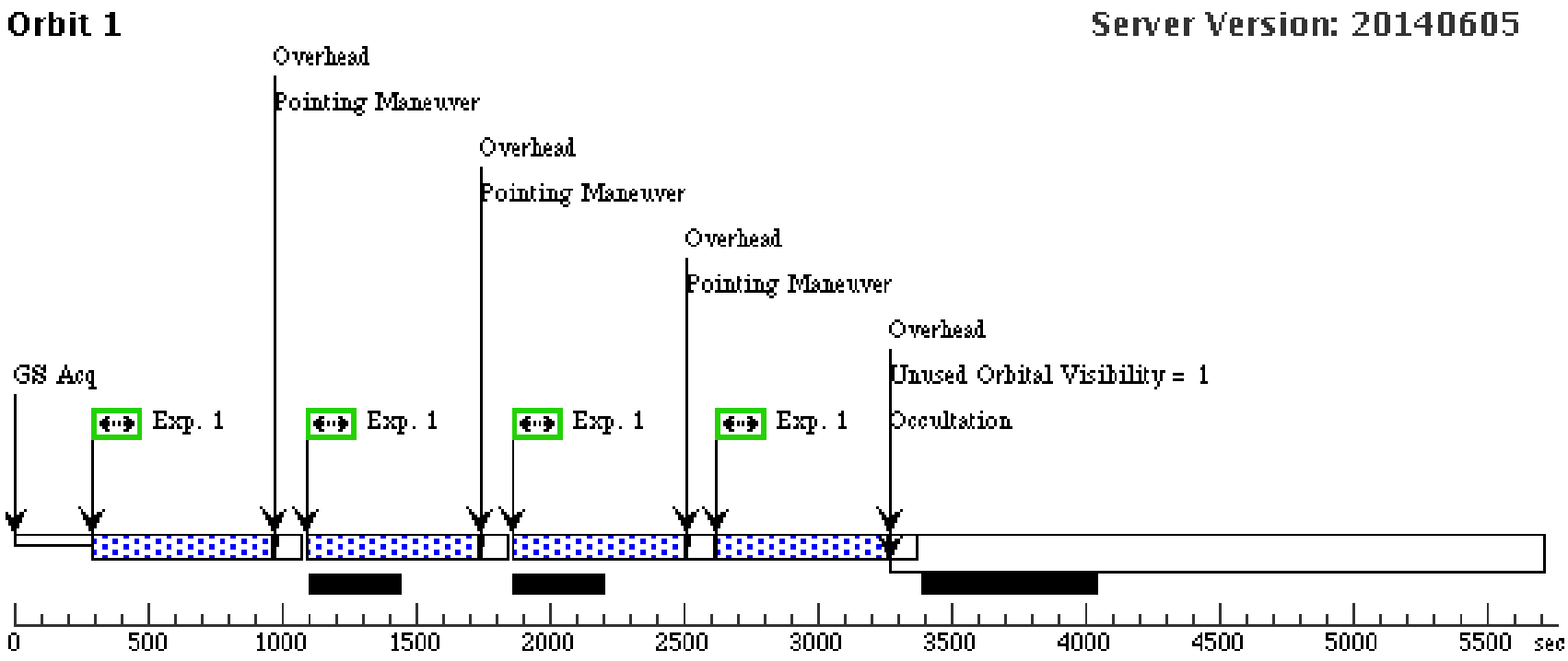
## Fixed Targets

| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (1) | PSR-J2144-3933 | RA: 21 44 12.0190 (326.0500792d)<br>Dec: -39 33 58.16 (-39.56616d)<br>Equinox: J2000 | | V=28+/-2 | Reference Frame: ICRS |

## Exposures

| # | Label | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | (1) PSR-J2144-3933 | WFC3/UVIS, ACCUM, UVIS-CENTER | F475X | | POS TARG -71.4,-75.3 | Pattern 2, Exps 1-1 in j2144uvis (04) (2) | 638 Secs (2552 Secs)<br>*[==>(Pattern 1)]*<br>*[==>(Pattern 2)]*<br>*[==>(Pattern 3)]*<br>*[==>(Pattern 4)]* | ***[1]*** |

Orbit Structure



## Visit

**Proposal 13783, j2124uvis (05), implementation** Sat Oct 18 01:40:46 GMT 2014

**Diagnostic Status: No Diagnostics**

Scientific Instruments: WFC3/UVIS

Special Requirements: (none)

## Patterns

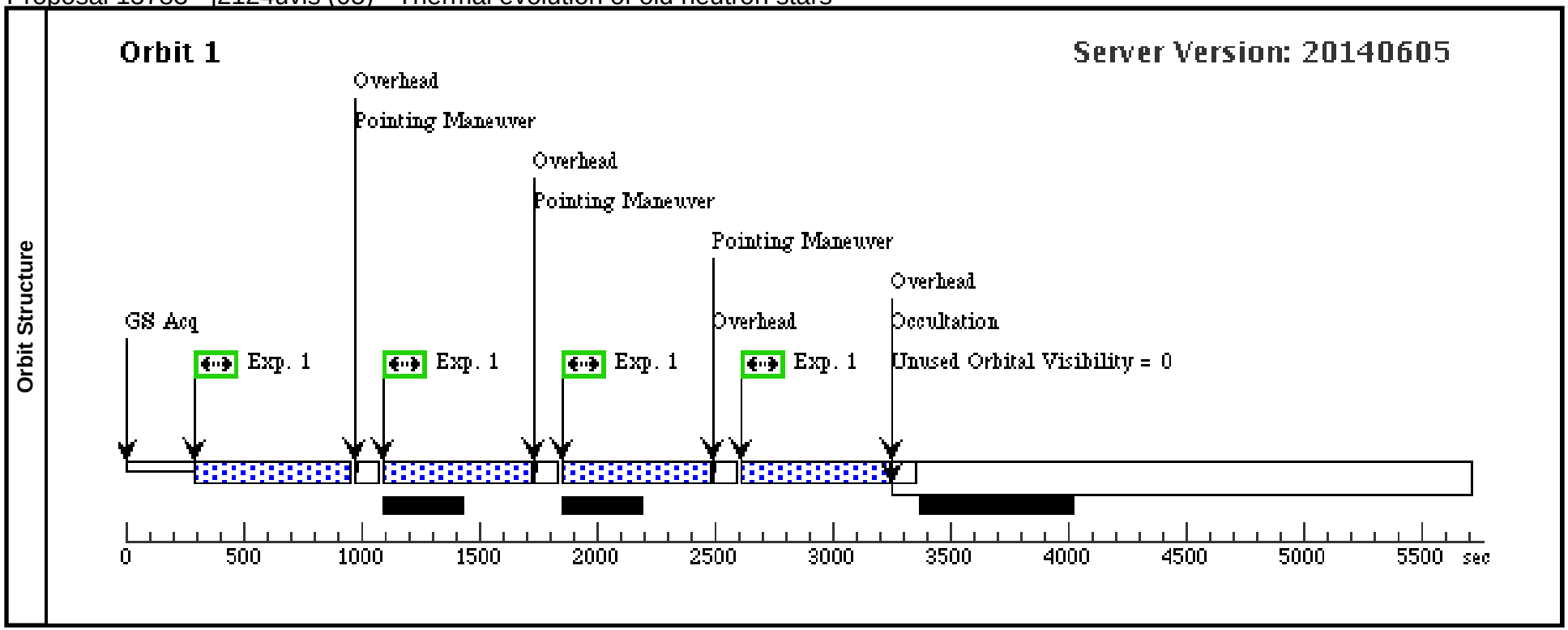
| # | Primary Pattern | | Secondary Pattern | Exposures |
|---|---|---|---|---|
| (2) | Pattern Type=WFC3-UVIS-DITHER-BOX<br>Purpose=DITHER<br>Number Of Points=4<br>Point Spacing=0.173<br>Line Spacing=0.112 | Coordinate Frame=POS-TARG<br>Pattern Orientation=23.884<br>Angle Between Sides=81.785<br>Center Pattern=false | | (1) |

## Fixed Targets

| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (3) | PSR-J2124-3358 | RA: 21 24 43.8440 (321.1826833d)<br>Dec: -33 58 45.21 (-33.97922d)<br>Equinox: J2000 | | V=28+/-1 | Reference Frame: ICRS |

## Exposures

| # | Label | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | (3) PSR-J2124-3358 | WFC3/UVIS, ACCUM, UVIS-CENTER | F475X | | POS TARG -71.4,-75.3 | Pattern 2, Exps 1-1 in j2124uvis (05) (2) | 635 Secs (2532 Secs)<br>*[==>633.0 Secs (Pattern 1)]*<br>*[==>633.0 Secs (Pattern 2)]*<br>*[==>633.0 Secs (Pattern 3)]*<br>*[==>633.0 Secs (Pattern 4)]* | ***[1]*** |


Orbit Structure
Orbit 1
Server Version: 20140605
Overhead
Pointing Maneuver
Overhead
Pointing Maneuver
Pointing Maneuver
Overhead
Occultation
Overhead
GS Acq
Exp. 1
Exp. 1
Exp. 1
Exp. 1
Unused Orbital Visibility = 0
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
sec