# 14732 - 2MASS J00423991+3017515: An AGN On The Run?

Cycle: 24, Proposal Category: GO

(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) 2MASS-J00423990+3017514 | WFC3/UVIS | 3 | 09-Nov-2016 11:53:09.0 | yes |

3 Total Orbits Used


**ABSTRACT**

We have discovered a peculiar AGN, 2MASS J00423991+3017515, in a local (z=0.14), disturbed galaxy whose optical spectrum has multiple broad lines that are consistently offset from the narrow line emission and host galaxy absorption by 1530 km/s. The morphology of the host galaxy and spectral properties thus suggest this AGN may be a recoiling supermassive black hole (SMBH). Gravitational-wave recoil kicks result from the coalescence of two SMBHs and have implications for the early growth of high-redshift quasars and SMBH-galaxy co-evolution. We propose high-resolution imaging in the NIR, optical, and UV with the WFC3 camera on Hubble and high-resolution X-ray imaging and spectral follow-ups with the ACIS camera on Chandra to determine if the source of the kinematically-offset broad line emission is also spatially offset from the nucleus of the host galaxy. We request 3 orbits with Hubble and 8 ksec with Chandra to conduct these follow-up observations. If a single, spatially offset AGN is detected, this source will be strongest candidate for a recoiling AGN candidate discovered to date, providing a new, indirect constraint on SMBH spin evolution and merger rates.

**OBSERVING DESCRIPTION**

Observing Plan: We will study the active galaxy 2MASS J00423991+3017515 to determine if the accretting SMBH is a recoiling black hole. With the three HST orbits allocated in our Cycle 24 award, we will execute the following observing program. We will study the host galaxy structure with the F814W filter, the diffuse, narrow line [OIII] emission with the F547M filter, and localize the UV and offset $H\alpha$ emission with the F225W and FQ750N filters.

The first part of our program is the modeling of the host galaxy structure using observation with the F814W filter in the NIR to map the old stellar population. Primarily, this will be used to determine the nucleus of the host galaxy where the surface brightness peaks. Using the publicly available GALFIT package, we will decompose the galactic components of the old stellar population observed in the F814W filter and be able to identify sub-structure in the host galaxy down to $0.1$ kpc scales.

Additionally, we will observe the [OIII] emission with the F547M filter to map the narrow-line emission region in the galaxy. This filter will capture the narrow line [OIII] emission from the galaxy, as well as the narrow and offset broad $H\beta$ lines. The narrow-line emission in our source is observed at the same redshift as the host galaxy absorption, which implies the emission originates from highly ionized gas at rest in the host galaxy. Hence, we must also understand the spatial structure of this gas and its relationship to the underlying stellar population targeted with F814W filter observation. Mapping the emission lines will localize the ionized gas and constrain the global kinematics of the system. If we see two nuclei, this will help determine whether the nuclei are in a pre-merger inspiring phase, or whether one is an empty merger-remnant nucleus and one is an offset AGN.

We also plan to use UV imaging with the F225W filter to localize the thermal emission of the accretion disk and narrow-band optical imaging with the FQ750N filter to target the kinematically offset broad $H\alpha$ emission we detected in our optical spectrum. The advantage of using the F225W filter is that the short UV wavelengths also maximize the resolution of the telescope, allowing us to more precisely locate the AGN. In addition, to confirm the recoil scenario, we must demonstrate that any spatial offset of the AGN is associated with the broad line velocity offset seen in the quasar spectrum. The FQ750N filter, quite fortunately, coincides with the observed wavelength of the rest-frame broad $H\alpha$ emission. This filter is also very narrow (70 angstroms) so it will be dominated by the offset broad line emission with a minimal contribution from the narrow line [NII] and $H\alpha$ emission. The ability to localize the source of broad line emission is unique to our program. If the AGN is displaced in a recoil, the X-ray, UV, and narrow-band image we propose will be coincident, thereby providing strong evidence of an offset SMBH.

Technical Justification and Exposure Estimates for HST WFC3 Imaging: Our HST observations are fairly standard, the biggest concern to our science results is the saturation of the bright AGN. The main constraints on our observations come from two bright stars near the galaxy. Saturation of the AGN is unavoidable when we image the host galaxy structure and, therefore, must be corrected for in our image reduction. We will thus employ two observing strategies with the WFC3 camera on HST.

For the point source imaging, we will observe for a total of 1800 s in the F225W filter and 300 s in the FQ750N filter. The F225W observations will be split between three dithered images to improve the sampling of WFC3's PSF and allow for the removal of cosmic rays and detector artifacts. The FQ750N observation will be consist of medium depth exposures (150s), taken with two dithered images. The AGN is optically bright with an integrated $H\alpha$ flux of $~2\times10^{-12}$ ergs cm$^{-2}$ s$^{-1}$. The UV brightness in the UVW2 filter on the Swift UVOT camera is $2\times10^{-16}$ ergs cm$^{-2}$ s$^{-1}$ \AA$^{-1}$ (18.6 mag). Given the brightness in each band, underexposure is not a concern, but overexposure is since saturation of the CCD pixels will degrade the telescope PSF. Hence, the exposures times were determined by making the most conservative estimate that the emission comes from one point source with 50% of the observed flux falling within the PSF of the telescope. Additionally, AGN are highly variable, so our target total count values are kept to less than half of the saturation value (67,000 ADU) to allow for change in brightness. Using the online ETC as a guide, for an individual exposure of 180 seconds with the FQ750N filter we expect ~10,200 counts per exposure for ~20,400 total counts between the dithered image. For an individual exposure of 600 seconds with the F225W filter we expect ~4,200 counts per exposure for ~12,600 total counts between the three dithered images.

2MASS J00423991+3017515 is moderately bright, V-band magnitude of 17.4, with much of its emission coming from the bright AGN. We will use the long exposures with the F547M and F814W filters to resolve the host galaxy structure will, hence, inevitably saturate any point sources in the image. This is a common issue when observing AGN with HST and, like previous studies, we will use a series of three exposures with graduated exposure times to maximize the dynamic range of our observations. For the F547 filter, two sets of 30 s, 240 s, and 480 s exposures will be taken. For the F814W filter, two sets of 60s, 300s, and 720s will be taken. Dithering will only be done between sets of exposures so the telescope pointing is the same for each set of graduated exposures. The linear nature of CCDs allows us to clip saturated pixels and replace them by the same pixels from a shallower image in a given exposure set that have been scaled by the exposure time ratio. Once the two sets of images at each pointing are corrected for saturation, they will then be combined to improve WFC3's PSF, remove cosmic rays and detector artifacts. As we did with the exposure time estimations for the F225W and FQ750N filters, the short exposure time was determined by adopting the most conservative assumption all the emission originates from the point source to ensure there is no saturation. The intermediate exposure times were chosen so the moderately bright host galaxy features would be captured and any point sources would be near saturation. This exposure allows for the extrapolation of the area

around the saturated regions that might be affected by bleeding from neighboring pixels. The long exposure time is needed to resolve the fainter structure of the galaxy on the smallest scales. In total,our program has 1500 s worth of exposure time and an expected of SNR~280 in the F547M filter observations and 2,160s of exposure time and an expected SNR~520 in the F814W observations.

To deal with the two bright stars near 2MASS J00423991+3017515, we have designed our observations to place the brightest star off of the detector. The other star will be placed on the detector and inevitably "bleed," however, there is a ~440 pixel buffer between the star and the galaxy. With our exposures, we expect the charge bleed to spill over into 20 pixels, in the most extreme case. We have also chosen a narrow range of observing orientations to ensure the diffraction spikes from the telescope internal supports do not cross our galaxy, which could impact our analysis.

Since much of our program relies on precision astrometry, we will observe the galaxy in the "B" quadrant. The FQ750N filter can only be observed in this quadrant, thus we will observe all of the filters in this quadrant so the galaxy position on the chip can be held constant between filters. Additionally, the positioning is such that ghosting from the telescope from bright stars will not occur.

## Visit

**Proposal 14732, J00423991 (01), implementation** Wed Nov 09 16:53:11 GMT 2016

**Diagnostic Status: Warning**

Scientific Instruments: WFC3/UVIS

Special Requirements: ORIENT 56D TO 84 D

## Diagnostics

(FQ750N_180s (01.007)) Warning (Form): POS TARG & PATTERN should be used carefully with WFC3 quad filters to avoid placing the target on the vignetted part of the field of view or moving it to another quadrant.

## Patterns

| # | Primary Pattern | | Secondary Pattern | Exposures |
|---|---|---|---|---|
| (1) | Pattern Type=WFC3-UVIS-DITHER-LINE<br>Purpose=DITHER<br>Number Of Points=2<br>Point Spacing=0.145<br>Line Spacing= | Coordinate Frame=POS-TARG<br>Pattern Orientation=46.84<br>Angle Between Sides=<br>Center Pattern=false | | (1-6), (7) |
| (2) | Pattern Type=WFC3-UVIS-DITHER-LINE-3PT<br>Purpose=DITHER<br>Number Of Points=3<br>Point Spacing=0.135<br>Line Spacing= | Coordinate Frame=POS-TARG<br>Pattern Orientation=46.84<br>Angle Between Sides=<br>Center Pattern=false | | (8) |

## Fixed Targets

| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (1) | 2MASS-J00423990+3017514 | RA: 00 42 39.9000 (10.6662500d)<br>Dec: +30 17 51.40 (30.29761d)<br>Equinox: J2000 | | V=17.4 | Reference Frame: ICRS |

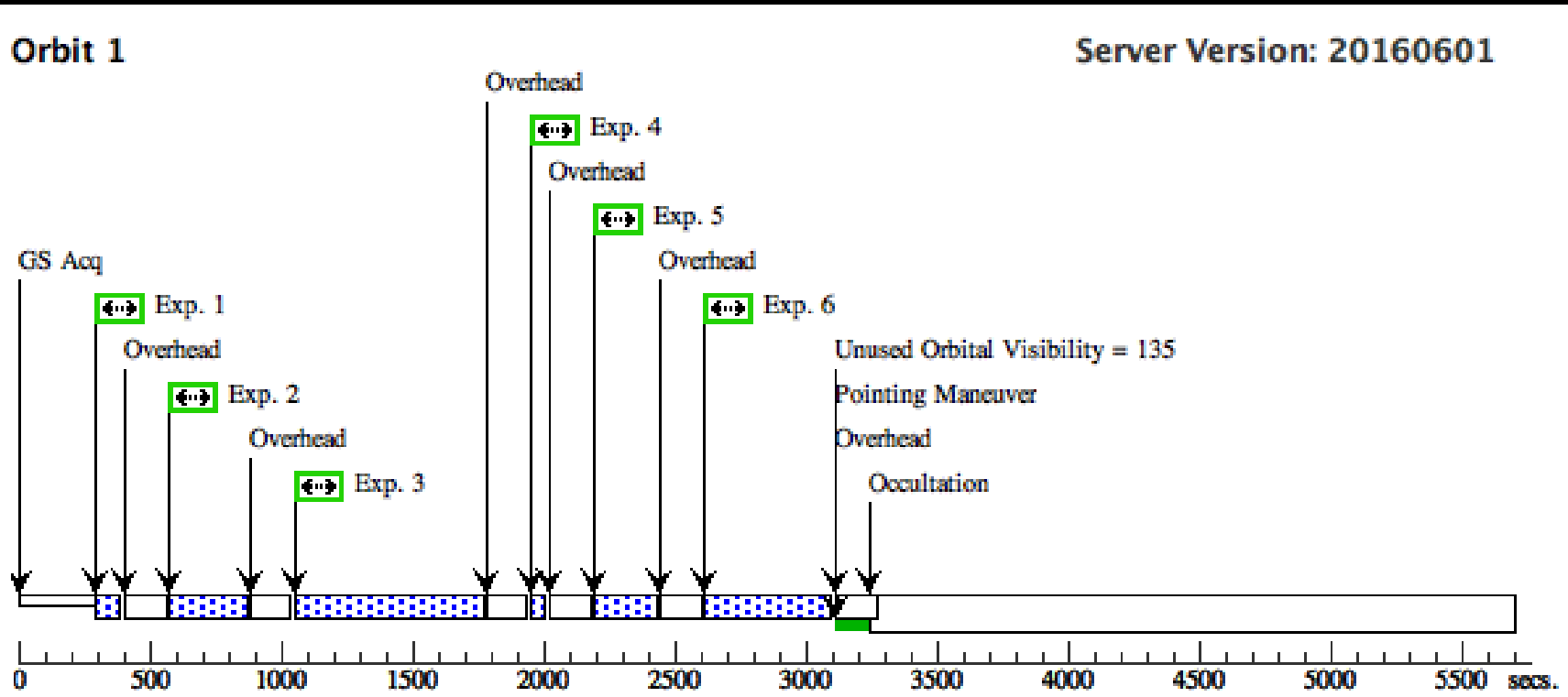
*Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.*

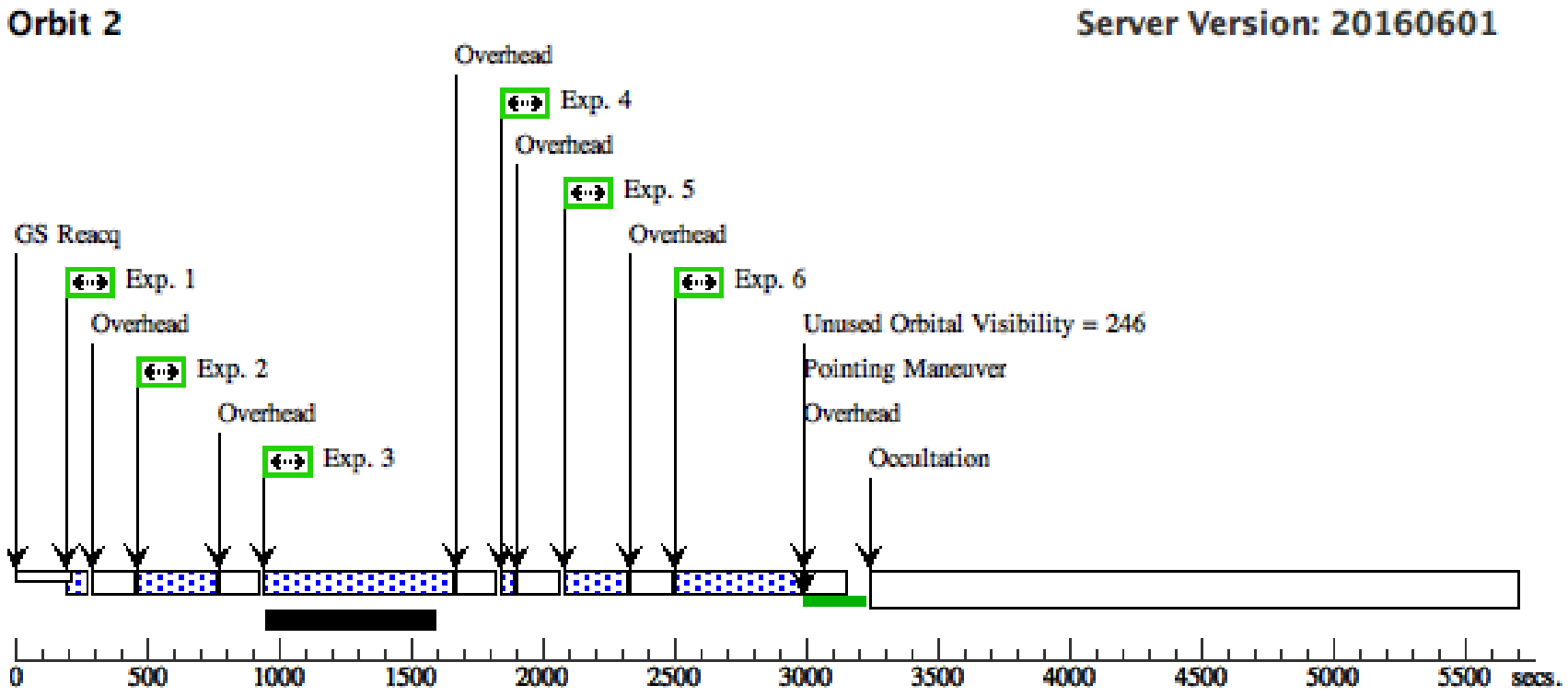
*Care was taken to place galaxy in the unvignetted region of the detector for the observations with the FQ750N filter to avoid the "quad edge effects."*
*Extended=YES*

**Exposures**

| # | Label | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | F814W_060s | (1) 2MASS-J00423990+3017514 | WFC3/UVIS, ACCUM, UVIS1-2K2B-SUB | F814W | FLASH=11 | | Pattern 1, Exps 1-6 in J00423991 (01) (1) | 60 Secs (120 Secs) | |
| | | | | | | | | *[==>(Pattern 1)]* | ***[1]*** |
| | | | | | | | | *[==>(Pattern 2)]* | ***[2]*** |
| 2 | F814W_300s | (1) 2MASS-J00423990+3017514 | WFC3/UVIS, ACCUM, UVIS1-2K2B-SUB | F814W | FLASH=5 | | Pattern 1, Exps 1-6 in J00423991 (01) (1) | 300 Secs (600 Secs) | |
| | | | | | | | | *[==>(Pattern 1)]* | ***[1]*** |
| | | | | | | | | *[==>(Pattern 2)]* | ***[2]*** |
| 3 | F814W_720s | (1) 2MASS-J00423990+3017514 | WFC3/UVIS, ACCUM, UVIS1-2K2B-SUB | F814W | | | Pattern 1, Exps 1-6 in J00423991 (01) (1) | 720 Secs (1440 Secs) | |
| | | | | | | | | *[==>(Pattern 1)]* | ***[1]*** |
| | | | | | | | | *[==>(Pattern 2)]* | ***[2]*** |
| 4 | F547M_030s | (1) 2MASS-J00423990+3017514 | WFC3/UVIS, ACCUM, UVIS1-2K2B-SUB | F547M | FLASH=12 | | Pattern 1, Exps 1-6 in J00423991 (01) (1) | 30 Secs (60 Secs) | |
| | | | | | | | | *[==>(Pattern 1)]* | ***[1]*** |
| | | | | | | | | *[==>(Pattern 2)]* | ***[2]*** |
| 5 | F547M_240s | (1) 2MASS-J00423990+3017514 | WFC3/UVIS, ACCUM, UVIS1-2K2B-SUB | F547M | FLASH=11 | | Pattern 1, Exps 1-6 in J00423991 (01) (1) | 240 Secs (480 Secs) | |
| | | | | | | | | *[==>(Pattern 1)]* | ***[1]*** |
| | | | | | | | | *[==>(Pattern 2)]* | ***[2]*** |
| 6 | F547M_480s | (1) 2MASS-J00423990+3017514 | WFC3/UVIS, ACCUM, UVIS1-2K2B-SUB | F547M | FLASH=6 | | Pattern 1, Exps 1-6 in J00423991 (01) (1) | 480 Secs (960 Secs) | |
| | | | | | | | | *[==>(Pattern 1)]* | ***[1]*** |
| | | | | | | | | *[==>(Pattern 2)]* | ***[2]*** |
| 7 | FQ750N_180s | (1) 2MASS-J00423990+3017514 | WFC3/UVIS, ACCUM, UVIS-QUAD-SUB | FQ750N | FLASH=11 | | Pattern 1, Exps 7-7 in J00423991 (01) (1) | 180 Secs (360 Secs) | |
| | | | | | | | | *[==>(Pattern 1)]* | ***[3]*** |
| | | | | | | | | *[==>(Pattern 2)]* | |
| 8 | F225W_600s | (1) 2MASS-J00423990+3017514 | WFC3/UVIS, ACCUM, UVIS1-2K2B-SUB | F225W | FLASH=11 | | Pattern 2, Exps 8-8 in J00423991 (01) (2) | 600 Secs (1800 Secs) | |
| | | | | | | | | *[==>(Pattern 1)]* | |
| | | | | | | | | *[==>(Pattern 2)]* | ***[3]*** |
| | | | | | | | | *[==>(Pattern 3)]* | |

Orbit Structure

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GS Reacq
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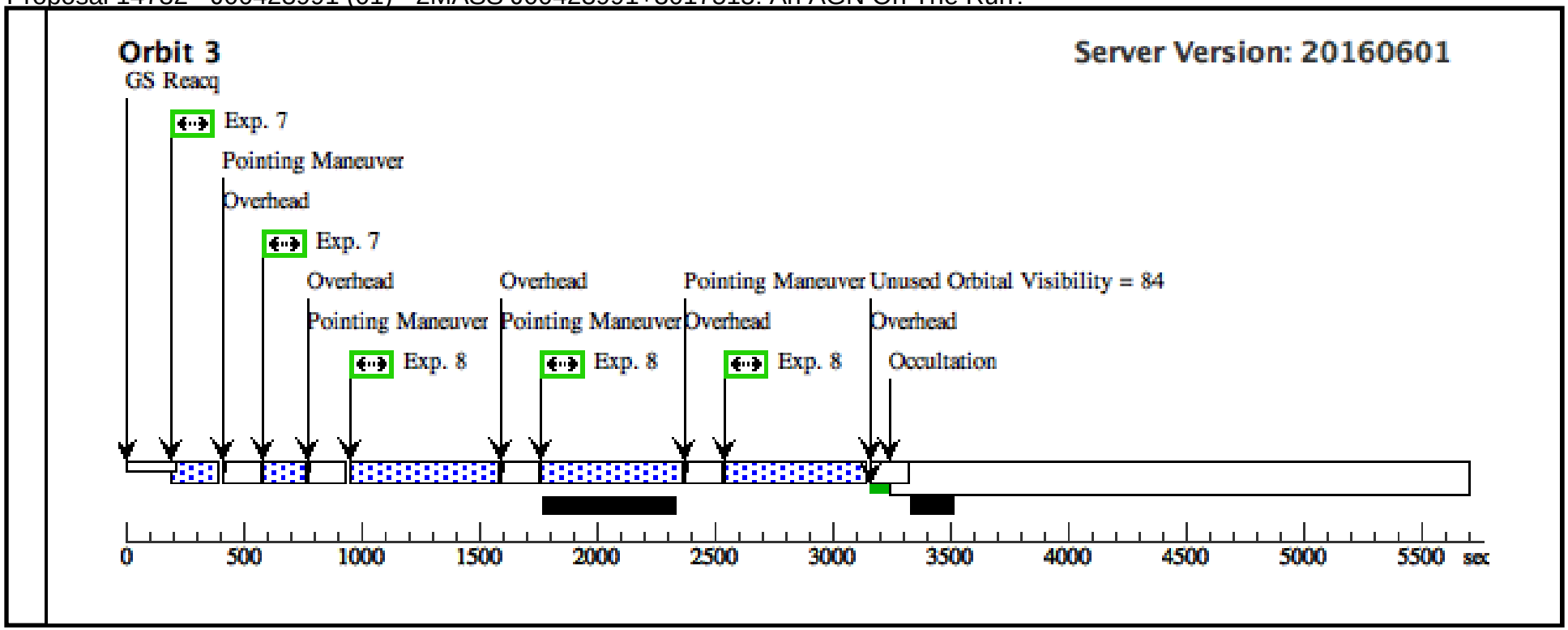
Overhead
Exp. 2
Overhead
Exp. 3
Overhead
Exp. 4
Overhead
Exp. 5
Overhead
Exp. 6
Unused Orbital Visibility = 246
Pointing Maneuver
Overhead
Occultation
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
secs.


Orbit 3
Server Version: 20160601
GS Reacq
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Pointing Maneuver
Overhead
Exp. 7
Overhead
Pointing Maneuver
Exp. 8
Overhead
Pointing Maneuver
Exp. 8
Pointing Maneuver
Overhead
Exp. 8
Unused Orbital Visibility = 84
Overhead
Occultation
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2000
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sec