# 12270 - Proper Motion of Leo I: Constraining the Milky Way Mass

Cycle: 18, Proposal Category: GO

(Availability Mode: SUPPORTED)

**INVESTIGATORS**



| *Name* | *Institution* | *E-Mail* |
|---|---|---|
| **Dr. Sangmo Tony Sohn (PI)** | **Space Telescope Science Institute** | **tsohn@stsci.edu** |
| Dr. Roeland P. van der Marel (CoI) | Space Telescope Science Institute | marel@stsci.edu |
| Dr. Steven R. Majewski (CoI) | The University of Virginia | srm4n@virginia.edu |
| Ms. Gurtina Besla (CoI) | Harvard University | gbesla@cfa.harvard.edu |



**VISITS**

| *Visit* | *Targets used in Visit* | *Configurations used in Visit* | *Orbits Used* | *Last Orbit Planner Run* | *OP Current with Visit?* |
|---|---|---|---|---|---|
| 01 | (1) LEO-I-DSPH | ACS/WFC<br>WFC3/UVIS | 2 | 18-Aug-2010 15:41:12.0 | yes |
| 02 | (1) LEO-I-DSPH | ACS/WFC<br>WFC3/UVIS | 2 | 18-Aug-2010 15:41:14.0 | yes |
| 03 | (1) LEO-I-DSPH | ACS/WFC<br>WFC3/UVIS | 2 | 18-Aug-2010 15:41:15.0 | yes |

6 Total Orbits Used

**ABSTRACT**

The mass of the Milky Way is one of the most poorly established Galactic parameters. One important reason for this problem stems from the uncertainty about the bound/unbound status of one particular object, Leo I, which has an unusually large radial velocity (v_hel = 283 km/s) at extreme distance (261 kpc). We propose to resolve this issue by measuring at high-precision the absolute proper motion of Leo I with HST. ACS/WFC F814W data that can be used as first epoch already exist in the archive. For the second epoch data, we request to obtain 6 more orbits with

the same instrument and filter, yielding a 5 year time baseline. With proven techniques that use many compact background galaxies as astrometric reference sources, the predicted transverse velocity accuracy is only 26 km/s at the distance of Leo I. Our results will be accurate enough to address whether or not Leo I is bound. We will then perform new equilibrium modeling of the Milky Way satellite system to obtain an improved estimate of the Milky Way mass. We will also perform new N-body simulations of Leo I, constrained by the measured velocity, to fit simultaneously the orbit, extra-tidal features, and unusual star formation history. This will independently constrain the Milky Way mass. Only HST can achieve the required accuracy, and considerable progress can be made on these important issues with only a small investment of HST time.

**OBSERVING DESCRIPTION**

To measure absolute PM of Leo I, we will use compact background galaxies in the field of view (FOV) as stationary reference sources. We will measure the average motion of stars in Leo I between epochs 1 and 2 with respect to these reference sources. Our analysis techniques and expected accuracies are described in the Phase I proposal. First epoch ACS data are available as part of previous observing programs by PI T. Smecker-Hane (Proposal 10520). The present project will obtain the second epoch data.

The first epoch ACS data were obtained in two filters (F435W and F814W) to make deep color magnitude diagrams that reach well below the main sequence turn-off of Leo I. The available broad-band colors and depth are sufficient for separating Leo I stars, foreground stars, and background galaxies to first order. For the second epoch it is therefore sufficient to take data in only one of the filters. However, our analysis shows that the first epoch data are neither deep nor well-dithered enough to build high signal-to-noise and high resolution templates for the background galaxies. We will therefore use our deeper second epoch F814W data for building the templates.

We will observe Leo I with the F814W filter using the same pointing and orientation used for the first epoch data. Individual exposures will be sub-pixel dithered and will last half an orbit. We will use customized dither patterns designed by Jay Anderson (STScI) to maximize the pixel phase coverage. We require that all of our images be obtained in a 21 day window so that they can be treated as single epoch data for astrometric analysis.

During our second epoch observations, the WFC3/UVIS camera will be pointed ~6 arcmin away in the outer halo of Leo I. We will observe this field with F438W and F814W filters to construct a color-magnitude diagram of the outer halo. This will be used to determine stellar population gradients and the stellar halo density profile to constrain formation and evolutionary scenarios.

**REAL TIME JUSTIFICATION**

N/A

**CALIBRATION JUSTIFICATION**

N/A

**ADDITIONAL COMMENTS**

N/A

## Visit

**Proposal 12270, Visit 01, implementation** Wed Aug 18 19:41:17 GMT 2010

**Diagnostic Status: No Diagnostics**

Scientific Instruments: ACS/WFC, WFC3/UVIS

Special Requirements: ORIENT 314.0D TO 315.0 D; GROUP 01,02,03 WITHIN 21D

*Comments: This is the first visit for imaging the Leo I Dwarf Spheroidal Galaxy. Two orbits are required to complete this visit. Since our goal is to measure proper motions of stars in the target galaxy, our orientation is set to exactly match the previous observations of PID 10520. We adopt a customized dither pattern designed by Jay Anderson (STScI) to optimally cover the pixel phase using the POS-TARG special requirements. For each visit we will do a set of 4-point dithering.*

## Fixed Targets

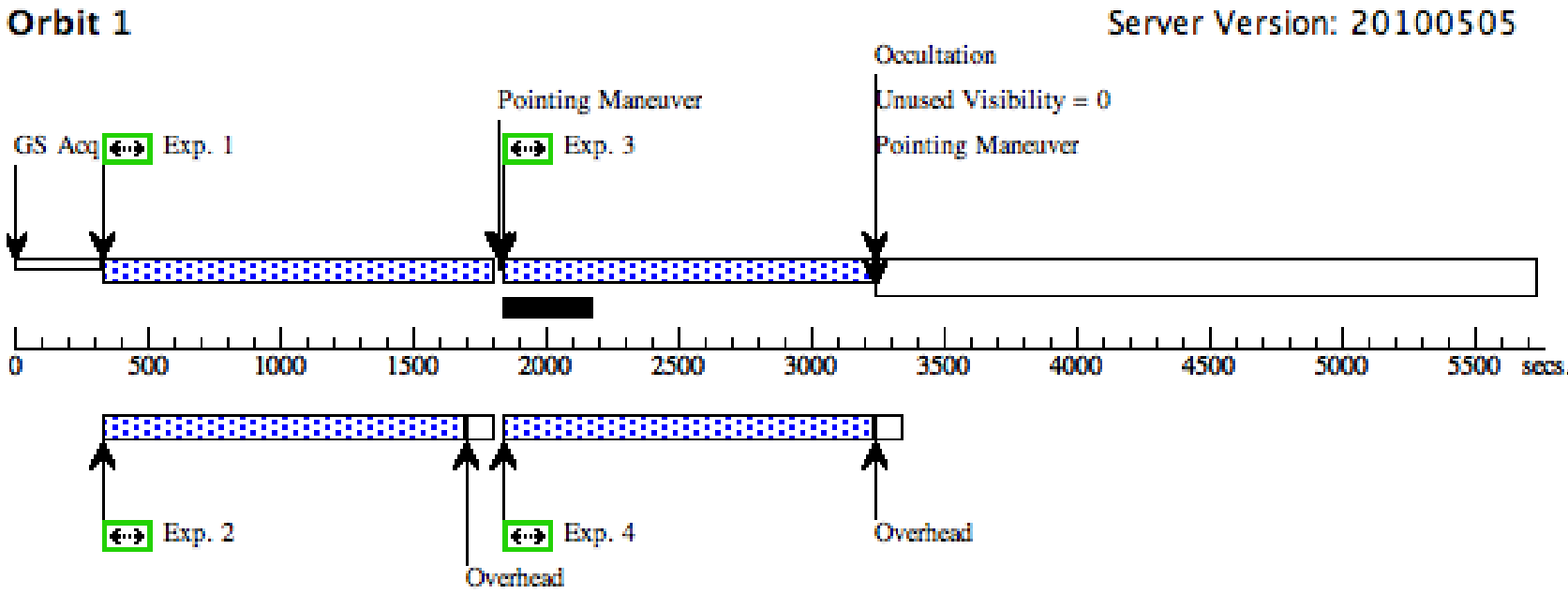
| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (1) | LEO-I-DSPH | RA: 10 08 22.5000 (152.0937500d)<br>Dec: +12 18 6.00 (12.30167d)<br>Equinox: J2000 | | V=11.2 | Reference Frame: ICRS |

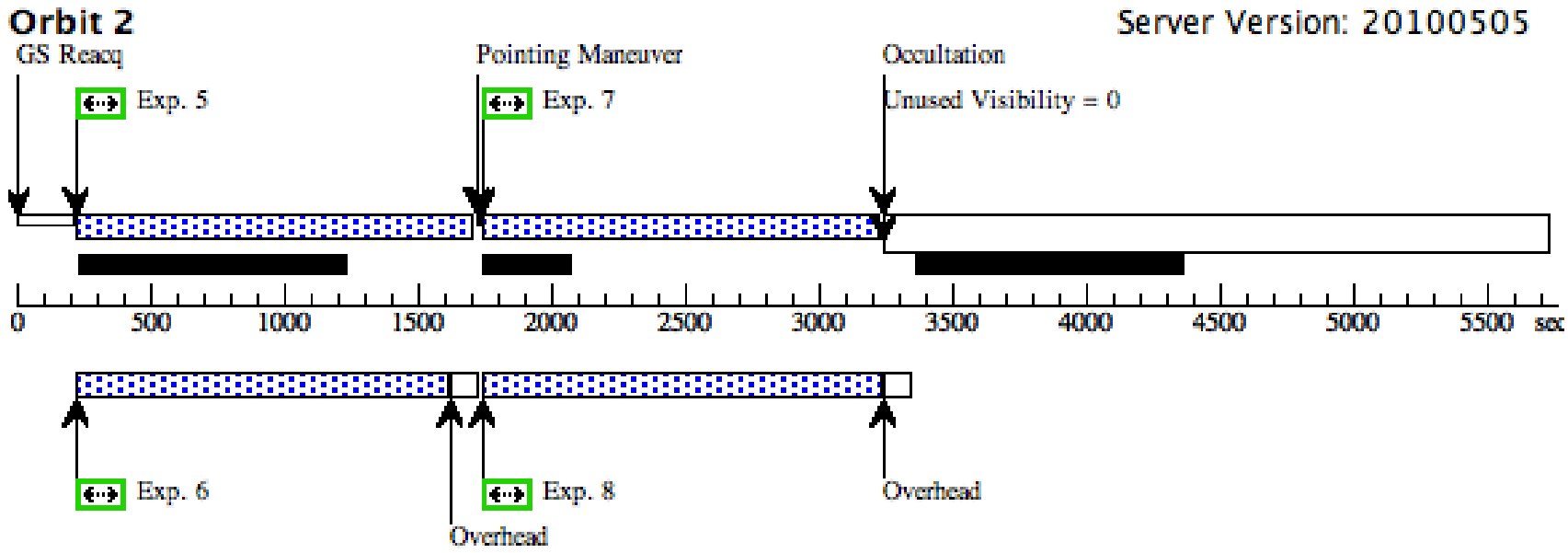
*Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.*

## Exposures

| # | Label | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | leoi-acs-dither1 | (1) LEO-I-DSPH | ACS/WFC, ACCUM, WFCENTER | F814W | CR-SPLIT=NO | POS TARG 0.0000,0.0000;<br>GS ACQ SCENARIO BASE1B3 | Sequence 1-4 Non-Int<br>Prime + Parallel Group 1-2 | 1267 Secs<br>*[==>]* | ***[1]*** |
| 2 | leoi-wfc3-dither1 | (1) LEO-I-DSPH | WFC3/UVIS, ACCUM, UVIS | F814W | CR-SPLIT=NO | | Sequence 1-4 Non-Int<br>Prime + Parallel Group 1-2 | 1326 Secs<br>*[==>]* | ***[1]*** |
| 3 | leoi-acs-dither2 | (1) LEO-I-DSPH | ACS/WFC, ACCUM, WFCENTER | F814W | CR-SPLIT=NO | POS TARG 0.1740,0.1850 | Sequence 1-4 Non-Int<br>Prime + Parallel Group 3-4 | 1267 Secs<br>*[==>]* | ***[1]*** |
| 4 | leoi-wfc3-dither2 | (1) LEO-I-DSPH | WFC3/UVIS, ACCUM, UVIS | F438W | CR-SPLIT=NO | | Sequence 1-4 Non-Int<br>Prime + Parallel Group 3-4 | 1367 Secs<br>*[==>]* | ***[1]*** |
| 5 | leoi-acs-dither3 | (1) LEO-I-DSPH | ACS/WFC, ACCUM, WFCENTER | F814W | CR-SPLIT=NO | POS TARG 0.3232,0.1235 | Sequence 5-8 Non-Int<br>Prime + Parallel Group 5-6 | 1361 Secs<br>*[==>]* | ***[2]*** |
| 6 | leoi-wfc3-dither3 | (1) LEO-I-DSPH | WFC3/UVIS, ACCUM, UVIS | F814W | CR-SPLIT=NO | | Sequence 5-8 Non-Int<br>Prime + Parallel Group 5-6 | 1371 Secs<br>*[==>]* | ***[2]*** |
| 7 | leoi-acs-dither4 | (1) LEO-I-DSPH | ACS/WFC, ACCUM, WFCENTER | F814W | CR-SPLIT=NO | POS TARG 0.1005,0.3305 | Sequence 5-8 Non-Int<br>Prime + Parallel Group 7-8 | 1360 Secs<br>*[==>]* | ***[2]*** |
| 8 | leoi-wfc3-dither4 | (1) LEO-I-DSPH | WFC3/UVIS, ACCUM, UVIS | F438W | CR-SPLIT=NO | | Sequence 5-8 Non-Int<br>Prime + Parallel Group 7-8 | 1466 Secs<br>*[==>]* | ***[2]*** |

Orbit Structure



## Visit

**Proposal 12270, Visit 02, implementation** Wed Aug 18 19:41:17 GMT 2010

**Diagnostic Status: No Diagnostics**

Scientific Instruments: ACS/WFC, WFC3/UVIS

Special Requirements: ORIENT 314.0D TO 315.0 D; GROUP 02,01,03 WITHIN 21D

*Comments: This is the second visit for imaging the Leo I Dwarf Spheroidal Galaxy. Two orbits are required to complete this visit. We request that the orientation be exactly the same as that for Visit 01. We adopt a customized dither pattern designed to optimally cover the pixel phase using the POS-TARG special requirements. For each visit we will do a set of 4-point dithering.*

## Fixed Targets

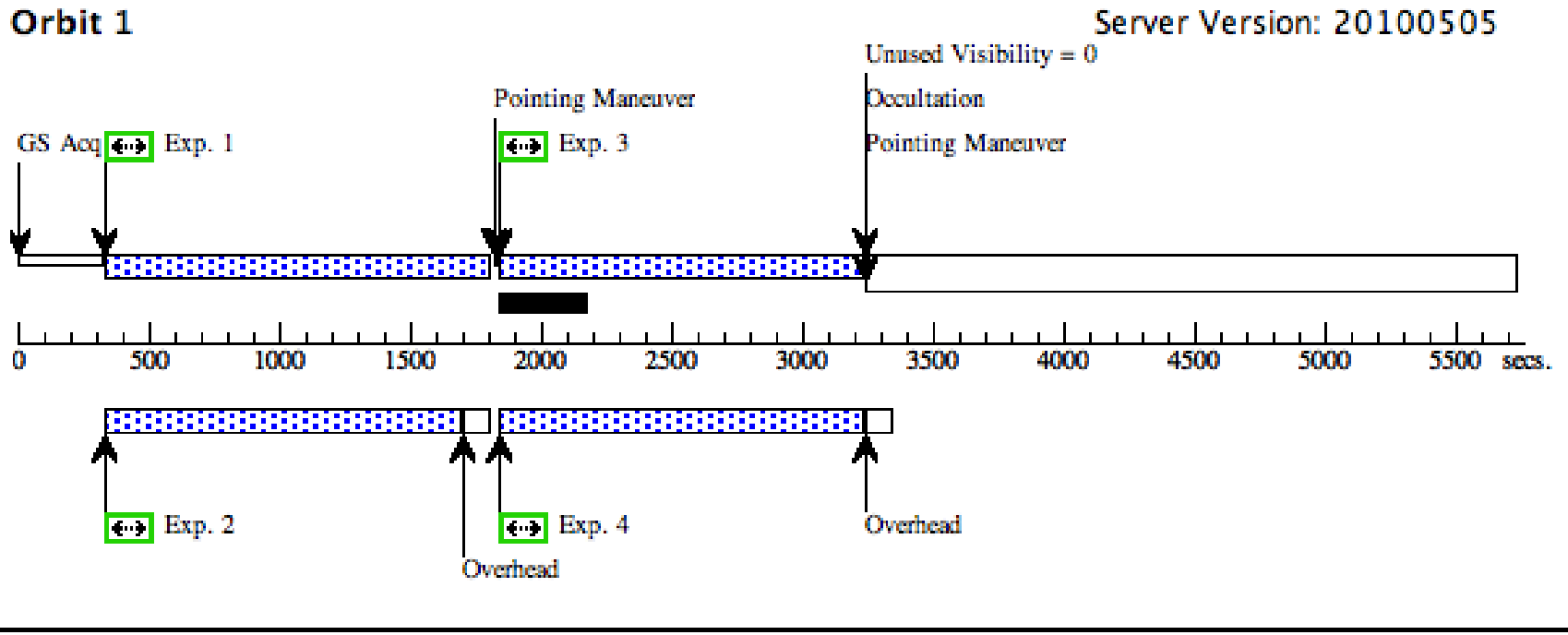
| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (1) | LEO-I-DSPH | RA: 10 08 22.5000 (152.0937500d)<br>Dec: +12 18 6.00 (12.30167d)<br>Equinox: J2000 | | V=11.2 | Reference Frame: ICRS |

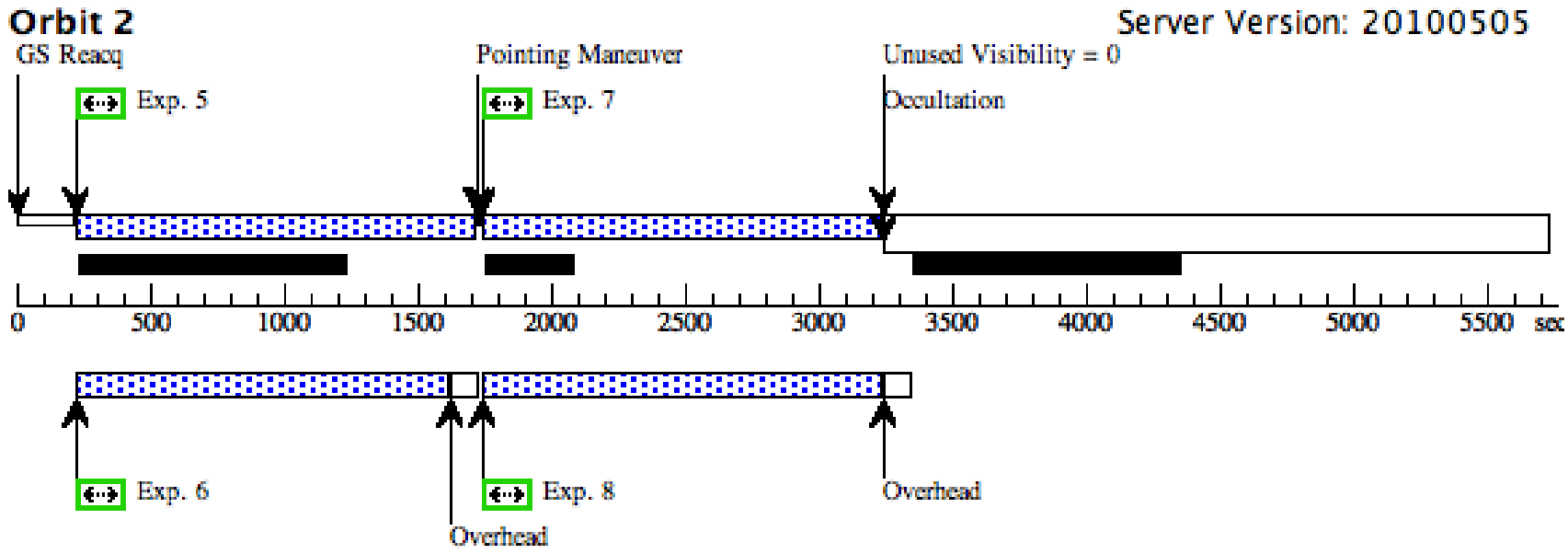
*Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.*

## Exposures

| # | Label | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | leoi-acs-dither5 | (1) LEO-I-DSPH | ACS/WFC, ACCUM, WFCENTER | F814W | CR-SPLIT=NO | POS TARG 0.5030,0.0460;<br>GS ACQ SCENARIO BASE1B3 | Sequence 1-4 Non-Int<br>Prime + Parallel Group 1-2 | 1267 Secs<br>*[==>]* | ***[1]*** |
| 2 | leoi-wfc3-dither5 | (1) LEO-I-DSPH | WFC3/UVIS, ACCUM, UVIS | F814W | CR-SPLIT=NO | | Sequence 1-4 Non-Int<br>Prime + Parallel Group 1-2 | 1326 Secs<br>*[==>]* | ***[1]*** |
| 3 | leoi-acs-dither6 | (1) LEO-I-DSPH | ACS/WFC, ACCUM, WFCENTER | F814W | CR-SPLIT=NO | POS TARG 0.6770,0.2310 | Sequence 1-4 Non-Int<br>Prime + Parallel Group 3-4 | 1267 Secs<br>*[==>]* | ***[1]*** |
| 4 | leoi-wfc3-dither6 | (1) LEO-I-DSPH | WFC3/UVIS, ACCUM, UVIS | F438W | CR-SPLIT=NO | | Sequence 1-4 Non-Int<br>Prime + Parallel Group 3-4 | 1367 Secs<br>*[==>]* | ***[1]*** |
| 5 | leoi-acs-dither7 | (1) LEO-I-DSPH | ACS/WFC, ACCUM, WFCENTER | F814W | CR-SPLIT=NO | POS TARG 0.8262,0.1695 | Sequence 5-8 Non-Int<br>Prime + Parallel Group 5-6 | 1363 Secs<br>*[==>]* | ***[2]*** |
| 6 | leoi-wfc3-dither7 | (1) LEO-I-DSPH | WFC3/UVIS, ACCUM, UVIS | F814W | CR-SPLIT=NO | | Sequence 5-8 Non-Int<br>Prime + Parallel Group 5-6 | 1371 Secs<br>*[==>]* | ***[2]*** |
| 7 | leoi-acs-dither8 | (1) LEO-I-DSPH | ACS/WFC, ACCUM, WFCENTER | F814W | CR-SPLIT=NO | POS TARG 0.6035,0.3765 | Sequence 5-8 Non-Int<br>Prime + Parallel Group 7-8 | 1364 Secs<br>*[==>]* | ***[2]*** |
| 8 | leoi-wfc3-dither8 | (1) LEO-I-DSPH | WFC3/UVIS, ACCUM, UVIS | F438W | CR-SPLIT=NO | | Sequence 5-8 Non-Int<br>Prime + Parallel Group 7-8 | 1462 Secs<br>*[==>]* | ***[2]*** |

Orbit Structure



## Visit

**Proposal 12270, Visit 03, implementation** Wed Aug 18 19:41:18 GMT 2010

**Diagnostic Status: No Diagnostics**

Scientific Instruments: ACS/WFC, WFC3/UVIS

Special Requirements: ORIENT 314.0D TO 315.0 D; GROUP 03,01,02 WITHIN 21D

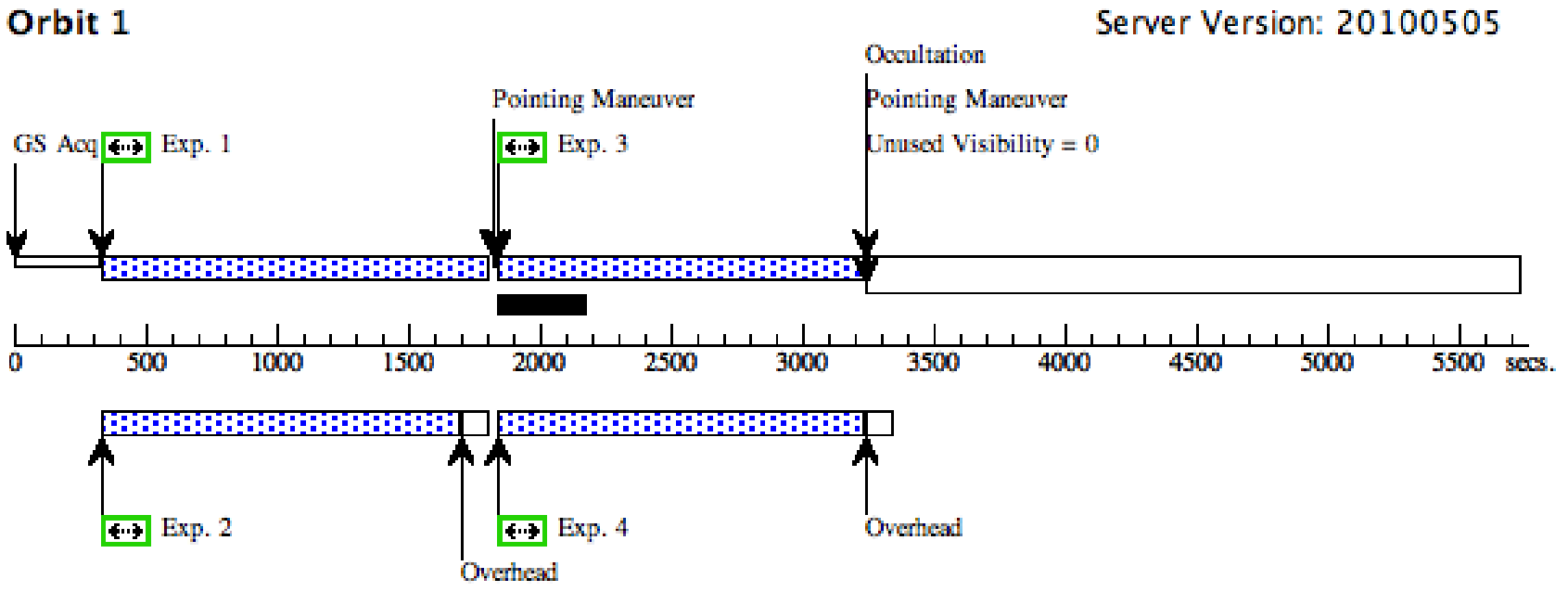
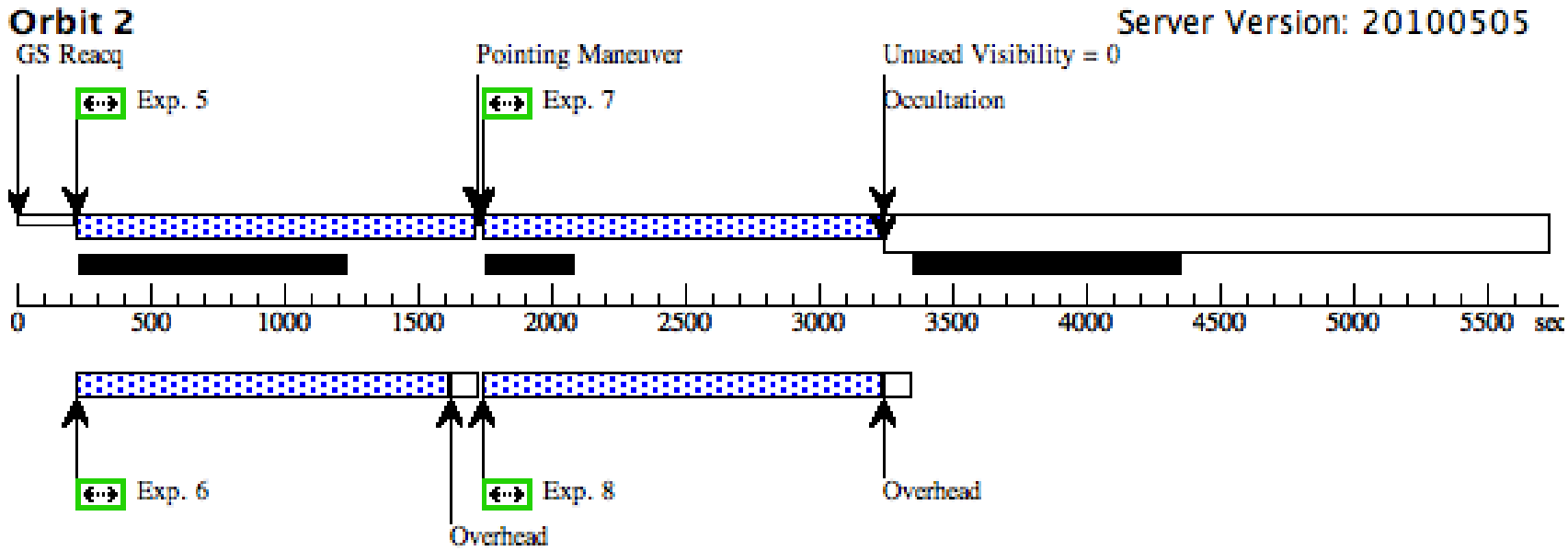
*Comments: This is the third visit for imaging the Leo I Dwarf Spheroidal Galaxy. Two orbits are required to complete this visit. We request that the orientation be exactly the same as that for Visit 01. We adopt a customized dither pattern designed to optimally cover the pixel phase using the POS-TARG special requirements. For each visit we will do a set of 4-point dithering.*

## Fixed Targets

| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (1) | LEO-I-DSPH | RA: 10 08 22.5000 (152.0937500d)<br>Dec: +12 18 6.00 (12.30167d)<br>Equinox: J2000 | | V=11.2 | Reference Frame: ICRS |

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

## Exposures

| # | Label | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | leoi-acs-dither9 | (1) LEO-I-DSPH | ACS/WFC, ACCUM, WFCENTER | F814W | CR-SPLIT=NO | POS TARG 0.1180,0.5180;<br>GS ACQ SCENARIO BASE1B3 | Sequence 1-4 Non-Int<br>Prime + Parallel Group 1-2 | 1267 Secs<br>*[==>]* | ***[1]*** |
| 2 | leoi-wfc3-dither9 | (1) LEO-I-DSPH | WFC3/UVIS, ACCUM, UVIS | F814W | CR-SPLIT=NO | | Sequence 1-4 Non-Int<br>Prime + Parallel Group 1-2 | 1326 Secs<br>*[==>]* | ***[1]*** |
| 3 | leoi-acs-dither10 | (1) LEO-I-DSPH | ACS/WFC, ACCUM, WFCENTER | F814W | CR-SPLIT=NO | POS TARG 0.2920,0.7030 | Sequence 1-4 Non-Int<br>Prime + Parallel Group 3-4 | 1267 Secs<br>*[==>]* | ***[1]*** |
| 4 | leoi-wfc3-dither10 | (1) LEO-I-DSPH | WFC3/UVIS, ACCUM, UVIS | F438W | CR-SPLIT=NO | | Sequence 1-4 Non-Int<br>Prime + Parallel Group 3-4 | 1367 Secs<br>*[==>]* | ***[1]*** |
| 5 | leoi-acs-dither11 | (1) LEO-I-DSPH | ACS/WFC, ACCUM, WFCENTER | F814W | CR-SPLIT=NO | POS TARG 0.4412,0.6415 | Sequence 5-8 Non-Int<br>Prime + Parallel Group 5-6 | 1363 Secs<br>*[==>]* | ***[2]*** |
| 6 | leoi-wfc3-dither11 | (1) LEO-I-DSPH | WFC3/UVIS, ACCUM, UVIS | F814W | CR-SPLIT=NO | | Sequence 5-8 Non-Int<br>Prime + Parallel Group 5-6 | 1371 Secs<br>*[==>]* | ***[2]*** |
| 7 | leoi-acs-dither12 | (1) LEO-I-DSPH | ACS/WFC, ACCUM, WFCENTER | F814W | CR-SPLIT=NO | POS TARG 0.2185,0.8485 | Sequence 5-8 Non-Int<br>Prime + Parallel Group 7-8 | 1364 Secs<br>*[==>]* | ***[2]*** |
| 8 | leoi-wfc3-dither12 | (1) LEO-I-DSPH | WFC3/UVIS, ACCUM, UVIS | F438W | CR-SPLIT=NO | | Sequence 5-8 Non-Int<br>Prime + Parallel Group 7-8 | 1462 Secs<br>*[==>]* | ***[2]*** |

Orbit Structure