# 16783 - Improved Masses for Critical Cepheid Binaries

Cycle: 29, Proposal Category: GO

(UV Initiative)

(Availability Mode: AVAILABLE)

**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?* |
|---|---|---|---|---|---|
| 1A | (1) V-V1334-CYG<br>WAVE | STIS/CCD<br>STIS/FUV-MAMA | 1 | 26-Jul-2021 11:01:48.0 | yes |
| 1B | (1) V-V1334-CYG<br>WAVE | STIS/CCD<br>STIS/FUV-MAMA | 1 | 26-Jul-2021 11:01:50.0 | yes |
| 3A | (3) V-SU-CYG<br>WAVE | STIS/CCD<br>STIS/FUV-MAMA | 1 | 26-Jul-2021 11:01:51.0 | yes |

| *Visit* | *Targets used in Visit* | *Configurations used in Visit* | *Orbits Used* | *Last Orbit Planner Run* | *OP Current with Visit?* |
|---|---|---|---|---|---|
| 3B | (3) V-SU-CYG<br>WAVE | STIS/CCD<br>STIS/FUV-MAMA | 1 | 26-Jul-2021 11:01:52.0 | yes |

4 Total Orbits Used

**ABSTRACT**

Cepheids play an important part in the Hubble Constant tension, and in evolutionary calculation benchmarks, which include comparisons with LMC Cepheids. In some cases, they lead to exotic end-stage objects. An important HST UV legacy is the measurement of the Cepheid masses, the fundamental parameter in stellar evolution. The HST high resolution E140H spectra requested in this proposal (a unique capability of HST) will measure the orbital velocity amplitude of hot companions of three Cepheids, V1334 Cyg, S Mus, and SU Cyg. This can be combined with recent infrared interferometry with the Very Large Telescope Interferometer (VLTI) and CHARA which has resolved the systems, providing visual orbits to augment the spectroscopic orbits. From this combination both masses and distances for the Cepheids have been derived, which already challenge current evolutionary tracks, even those incorporating rotation and core convective overshoot on the main sequence. The observations detailed in this proposal will improve the orbital solution through more accurate orbital velocity amplitudes of the hot companions. In addition for SU Cyg the phasing of the short period orbit of the companion will be more precise. The requested observations are predicted to yield mass solutions accurate to a few percent. These will be the most accurate Cepheid mass determinations available to quantitatively test the underlying physics at this stage.

**OBSERVING DESCRIPTION**

The goal of this program is to obtain STIS FUV E140H spectra of the blue companions of V1334 Cyg, S Mus, and SU Cyg to measure their orbital velocity at several phases and thereby significantly improve our knowledge of the masses and distances of both components. Specifically, for each target, two observations separated by a few days will be made near both orbital velocity maxima and minima to derive the orbital velocity amplitude of the companion. Each observation takes one orbit resulting in spectra with S/N 20 or better (per 2 pixel resolution element). For SU Cyg, the two spectra at each orbital extremum are requested to be separated by by 1.9 to 2.3 days days which will provide a strong constraint on the short period orbit of the companion (Fig. 5), while for the other targets a 2 to 6 day spacing was requested in the phase 1. For SU Cyg, the hot companion itself is a close binary which requires timing constraints on both the long and the short period orbits; we constrain the phase of the long period orbit for the 1st observation at each epoch using a BETWEEN special requirement, and of the short period by specifying the phase required at the start of the visits. For other systems, with only one orbital period, we simply use the phase constraint.

Observations of S MUS were completed in the first cycle (PID 16208) of this multi-cycle proposal and so in this second cycle, we only need to complete addidtional observations of V1334 Cyg and SU Cyg.

Updates to the orbital parameters for SU Cyg have resulted in some minor shifts to the scheduling windows relative to the orginal phase 1 proposal, but these amount to changes of only a few days and do not reduce the overall schedulability.

Likewise reconsideration of the V1334 orbit has caused us to shift our requested phase window for this Cycle's observations from the originally requested orbital phase of 0.24 to 0.37 to instead use 0.25 to 0.38.

The purpose of this program is to obtain additional radial velocity measurements of three stars already observed in previous programs, and so all of these targets have previously been observed by STIS using the exact same configurations we will be using here. While the Cepheids themselves are variable, at these FUV wavelengths we are observing not the cepheids themselves, but rather their main-squence B star companions which are not noticeably variable. Also note that Cepheids have little chromospheric activity so the Lyman alpha brightness and flares are not of any concern.

Cross-correlation of two spectra of the same star taken at different times is the most robust way to measure velocities of the STIS spectra (yielding the sharpest correlation peak and the least sensitivity to data processing such as smoothing). This is an ideal approach for binary stars, since the full orbital velocity amplitude can be measured directly by obtaining spectra at orbital velocity minimum and maximum. Details of the requested timing were justified in the Special Requirements section of the 16208 phase 1 proposal.

Because the wavelength/velocity accuracy is the most important objective of this program, in our phase 1 we had requested extra deep wavecals. After consultation with the STIS team, we decided 34s was the appropriate wavecal exposure length. We request 34s wavecals instead of the default 25s to compensate for the expected fading of the lamp since the last time the default was adjusted. To ensure that the accuracy of the faint FUV wavecal lamp is not degraded by a high dark current, it would be best if these visits could be scheduled as the first STIS FUV MAMA observation in a given SAA free period, as this avoids the dramatic increase in dark current that occurs when the FUV MAMA high voltage has been on for more than an orbit or so. This is especially important for SU Cyg as the ISM lines in that target cannot be used to verify the velocity zero point to the required accuracy.

## Visit

**Proposal 16783, V1334 Epoch 2a (1A), implementation** Mon Jul 26 15:01:52 GMT 2021

**Diagnostic Status: No Diagnostics**

Scientific Instruments: STIS/CCD, STIS/FUV-MAMA

Special Requirements: Period 1932.8 D AND ZERO-PHASE HJD2453316.75

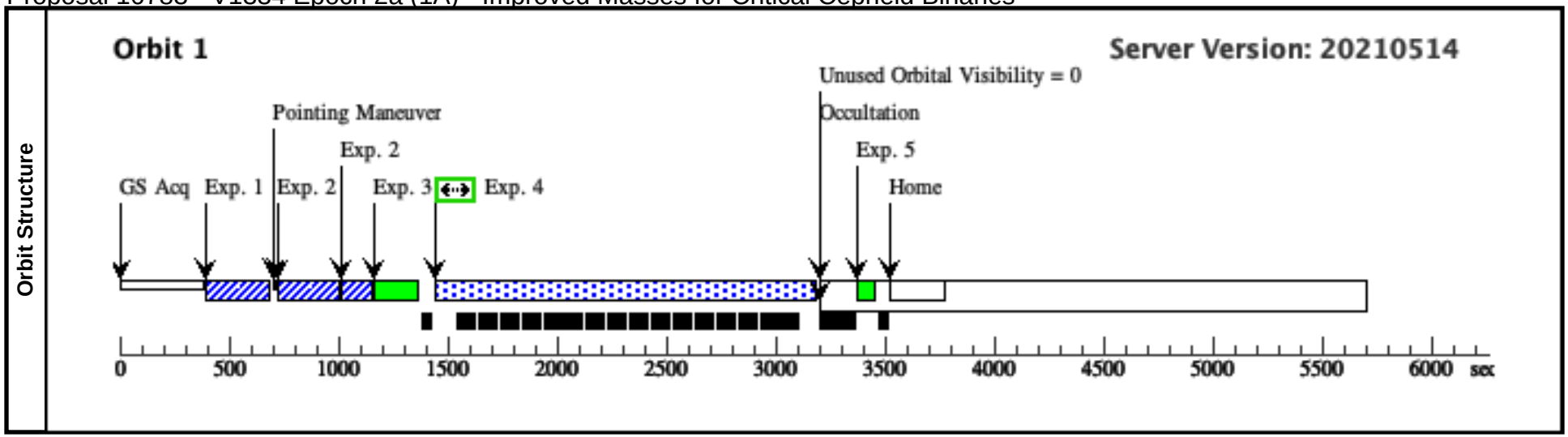
## Fixed Targets

| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (1) | V-V1334-CYG | RA: 21 19 22.1822 (319.8424258d)<br>Dec: +38 14 14.87 (38.23746d)<br>Equinox: J2000 | Proper Motion RA: 3.1743915473177853E-4 sec of time/yr<br>Proper Motion Dec: 3.26E-4 arcsec/yr<br>Parallax: 0.0011506"<br>Epoch of Position: 2015.5 | V=5.882<br>SpT=F1II+B7.0V | Reference Frame: ICRS |

*Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.*
*Category=STAR*
*Description=[B6-B9.5 V-IV, CEPHEID, COMPOSITE SPECTRAL TYPE, F0-F2, PULSATING VARIABLE]*
*Extended=NO*

## Exposures

| # | Label (ETC Run) | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | F25ND3 ACQ (STIS.ta.466076) | (1) V-V1334-CYG | STIS/CCD, ACQ, F25ND3 | MIRROR | | PHASE 0.250 TO 0.38 | Sequence 1-5 Non-Int in V1334 Epoch 2a (1A) | 0.2 Secs (0.2 Secs)<br>*[==>]* | *[1]* |
| 2 | G230LB ACQ/PEAK (STIS.sp.1444996) | (1) V-V1334-CYG | STIS/CCD, ACQ/PEAK, 0.2X0.09 | G230LB<br>2375 A | | | Sequence 1-5 Non-Int in V1334 Epoch 2a (1A) | 1 Secs (1 Secs)<br>*[==>]* | *[1]* |
| | *Comments: Need to allow for variability of the Cepheid in the NUV.*<br>*1s gives 559,000 e- from source as calculated from IUE spectra, would need 46s to saturate.* | | | | | | | | |
| 3 | wavecal | WAVE | STIS/FUV-MAMA, ACCUM, 0.2X0.09 | E140H<br>1271 A | | | Sequence 1-5 Non-Int in V1334 Epoch 2a (1A) | 34 Secs (34 Secs)<br>*[==>]* | *[1]* |
| 4 | E140H 1271 V1334 Cyg (STIS.sp.1444987) | (1) V-V1334-CYG | STIS/FUV-MAMA, TIME-TAG, 0.2X0.09 | E140H<br>1271 A | WAVECAL=NO;<br>BUFFER-TIME=99 | | Sequence 1-5 Non-Int in V1334 Epoch 2a (1A) | 1728 Secs (1728 Secs)<br>*[==>]* | *[1]* |
| | *Comments: ETC predicts global rate of 18958 cnts/s using IUE LGAP spectra*<br>*Observed GLOBRATE from previous 4 STIS/E140H/1271/0.2x0.09 observations ranges from ~ 16400 to 17900 cnts/s;*<br>*Count rate variations are believed to be entirely due to focus driven throughput variations of 0.2x0.09 aperture.*<br>*So while the minimun buffer time doesn't provide a lot of margin for time-tag mode, the history of previous observations gives us confidence we won't overfill the buffer.* | | | | | | | | |
| 5 | wavecal | WAVE | STIS/FUV-MAMA, ACCUM, 0.2X0.09 | E140H<br>1271 A | | | Sequence 1-5 Non-Int in V1334 Epoch 2a (1A) | 34 Secs (34 Secs)<br>*[==>]* | *[1]* |


Orbit Structure
Orbit 1
Server Version: 20210514
Unused Orbital Visibility = 0
Pointing Maneuver
Occultation
Exp. 2
Exp. 5
GS Acq
Exp. 1
Exp. 2
Exp. 3
Exp. 4
Home
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
sec

## Visit

**Proposal 16783, V1334 Epoch 2b (1B), implementation** Mon Jul 26 15:01:52 GMT 2021

**Diagnostic Status: No Diagnostics**

Scientific Instruments: STIS/CCD, STIS/FUV-MAMA

Special Requirements: AFTER 1A BY 2 D TO 6 D

## Fixed Targets

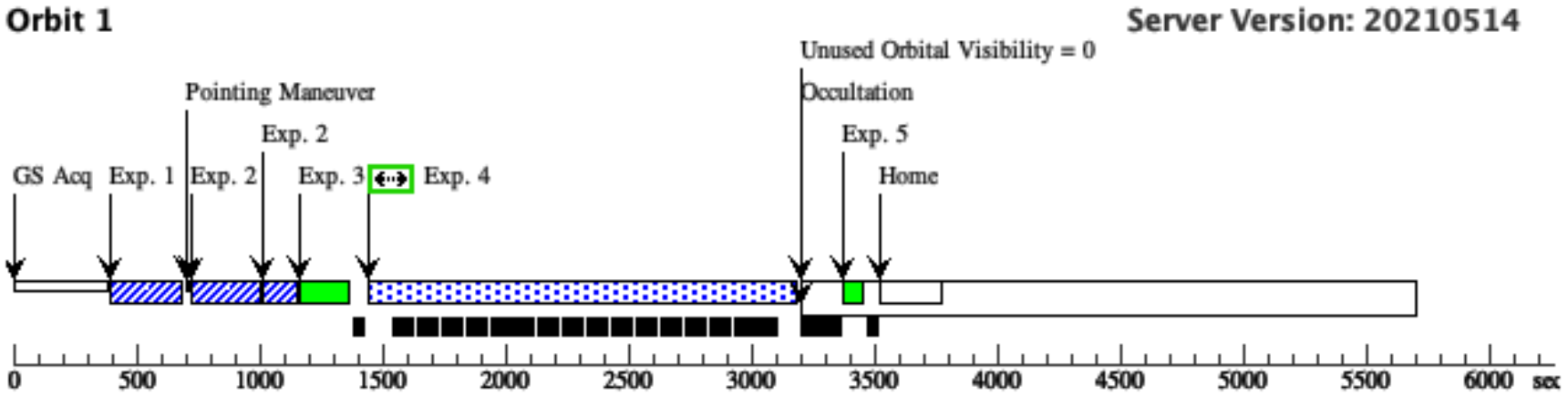
| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (1) | V-V1334-CYG | RA: 21 19 22.1822 (319.8424258d)<br>Dec: +38 14 14.87 (38.23746d)<br>Equinox: J2000 | Proper Motion RA: 3.1743915473177853E-4 sec of time/yr<br>Proper Motion Dec: 3.26E-4 arcsec/yr<br>Parallax: 0.0011506"<br>Epoch of Position: 2015.5 | V=5.882<br>SpT=F1II+B7.0V | Reference Frame: ICRS |

*Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.*
*Category=STAR*
*Description=[B6-B9.5 V-IV, CEPHEID, COMPOSITE SPECTRAL TYPE, F0-F2, PULSATING VARIABLE]*
*Extended=NO*

## Exposures

| # | Label (ETC Run) | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | F25ND3 ACQ (STIS.ta.466076) | (1) V-V1334-CYG | STIS/CCD, ACQ, F25ND3 | MIRROR | | | Sequence 1-5 Non-Int in V1334 Epoch 2b (1B) | 0.2 Secs (0.2 Secs)<br>*[==>]* | ***[1]*** |
| 2 | G230LB ACQ/PEAK (STIS.sp.1444996) | (1) V-V1334-CYG | STIS/CCD, ACQ/PEAK, 0.2X0.09 | G230LB<br>2375 A | | | Sequence 1-5 Non-Int in V1334 Epoch 2b (1B) | 1 Secs (1 Secs)<br>*[==>]* | ***[1]*** |
| | *Comments: Need to allow for variability of the Cepheid in the NUV.*<br>*1s gives 559,000 e- from source as calculated from IUE spectra, would need 46s to saturate.* | | | | | | | | |
| 3 | wavecal | WAVE | STIS/FUV-MAMA, ACCUM, 0.2X0.09 | E140H<br>1271 A | | | Sequence 1-5 Non-Int in V1334 Epoch 2b (1B) | 34 Secs (34 Secs)<br>*[==>]* | ***[1]*** |
| 4 | E140H 1271 V1334 Cyg (STIS.sp.1444987) | (1) V-V1334-CYG | STIS/FUV-MAMA, TIME-TAG, 0.2X0.09 | E140H<br>1271 A | WAVECAL=NO;<br>BUFFER-TIME=99 | | Sequence 1-5 Non-Int in V1334 Epoch 2b (1B) | 1728 Secs (1728 Secs)<br>*[==>]* | ***[1]*** |
| | *Comments: ETC predicts global rate of 18958 cnts/s using IUE LGAP spectra*<br>*Observed GLOBRATE from previous 4 STIS/E140H/1271/0.2x0.09 observations ranges from ~ 16400 to 17900 cnts/s;*<br>*variations are believed to be entirely due to focus driven throughput variations of 0.2x0.09 aperture.*<br>*So while the minimun buffer time doesn't provide a lot of margin for time-tag mode, the history of previous observations gives us confidence we won't overfill the buffer.* | | | | | | | | |
| 5 | wavecal | WAVE | STIS/FUV-MAMA, ACCUM, 0.2X0.09 | E140H<br>1271 A | | | Sequence 1-5 Non-Int in V1334 Epoch 2b (1B) | 34 Secs (34 Secs)<br>*[==>]* | ***[1]*** |

Orbit Structure



## Visit

**Proposal 16783, SU Cyg Epoch 2a (3A), implementation** Mon Jul 26 15:01:52 GMT 2021

**Diagnostic Status: No Diagnostics**

Scientific Instruments: STIS/CCD, STIS/FUV-MAMA

Special Requirements: BETWEEN 01-MAR-2022:00:00:00 AND 03-APR-2022:00:00:00; Period 4.675083036 D AND ZERO-PHASE HJD2444832.1224

*Comments: To ensure that the accuracy of the faint FUV wavecal lamp is not degraded by a high dark current, it would be best if these visits could be scheduled as the first STIS FUV MAMA observation in a given SAA free period, as this avoids the dramatic increase in dark current that occurs when the FUV MAMA high voltage has been on for more than an orbit or so. This is especially important for SU Cyg as the ISM lines in that target cannot be used to verify the velocity zero point to the required accuracy.*

## Fixed Targets

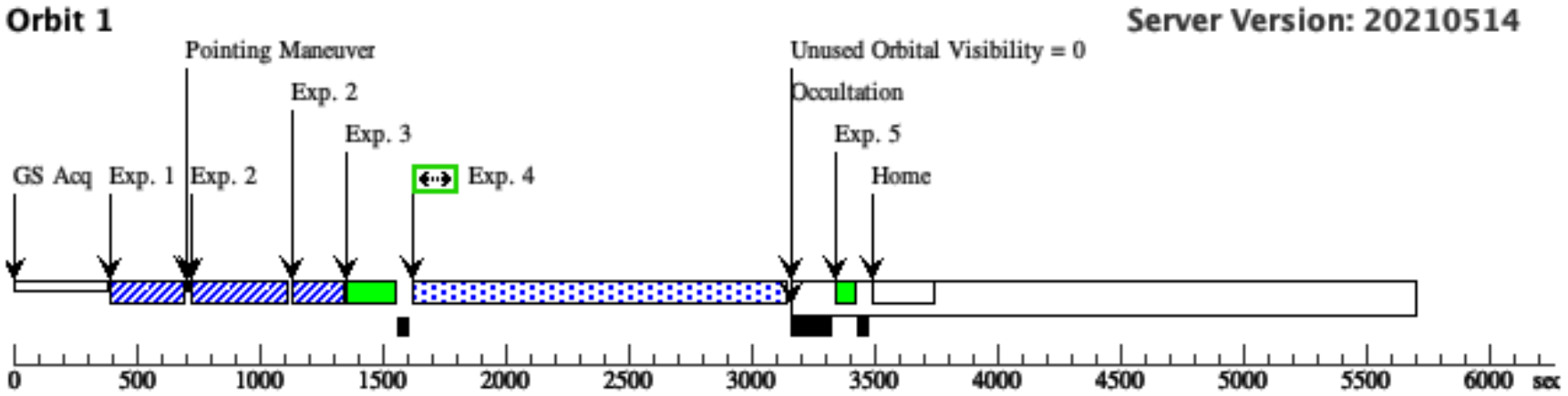
| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (3) | V-SU-CYG | RA: 19 44 48.7343 (296.2030596d)<br>Dec: +29 15 52.85 (29.26468d)<br>Equinox: J2000 | Proper Motion RA: -1.4160645255034498E-4 sec of time/yr<br>Proper Motion Dec: -0.0031549999221169855 arcsec/yr<br>Parallax: 0.0011695"<br>Epoch of Position: 2015.5 | V=6.44<br>SpT=F2Iab:+B8.0V; I=5.84 | Reference Frame: ICRS |

*Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.*
*Category=STAR*
*Description=[B6-B9.5 V-IV, CEPHEID, COMPOSITE SPECTRAL TYPE, F0-F2, PULSATING VARIABLE]*
*Extended=NO*

## Exposures

| # | Label (ETC Run) | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | ACQ (STIS.ta.615219) | (3) V-SU-CYG | STIS/CCD, ACQ, F25ND3 | MIRROR | | PHASE 0.95 TO 0.05 | Sequence 1-5 Non-Int in SU Cyg Epoch 2a (3A) | 1.5 Secs (1.5 Secs)<br>*[==>]* | <br>***[1]*** |
| 2 | ACQ/PEAK (STIS.sp.1472320) | (3) V-SU-CYG | STIS/CCD, ACQ/PEAK, 0.2X0.09 | G230LB<br>2375 A | | | Sequence 1-5 Non-Int in SU Cyg Epoch 2a (3A) | 10 Secs (10 Secs)<br>*[==>]* | <br>***[1]*** |
| | *Comments: 358,477 e- from source in 3 s exposure*<br>*1,194,923 e- from source in 10s exposure* | | | | | | | | |
| 3 | E140H 1234 WAVE | WAVE | STIS/FUV-MAMA, ACCUM, 0.2X0.09 | E140H<br>1234 A | | | Sequence 1-5 Non-Int in SU Cyg Epoch 2a (3A) | 34 Secs (34 Secs)<br>*[==>]* | <br>***[1]*** |
| 4 | E140H 1234 SU Cyg (STIS.sp.1444984) | (3) V-SU-CYG | STIS/FUV-MAMA, TIME-TAG, 0.2X0.09 | E140H<br>1234 A | BUFFER-TIME=754;<br>WAVECAL=NO | | Sequence 1-5 Non-Int in SU Cyg Epoch 2a (3A) | 1507 Secs (1507 Secs)<br>*[==>]* | <br>***[1]*** |
| | *Comments: ETC predicts global rate of 2123 cnts/s using IUE LGAP spectra*<br>*Observed GLOBRATE from previous STIS/E140H/1234/0.2x0.09 observations ranges from ~ 1696 to 1897 cnts/s;*<br>*variations are believed to be entirely due to focus driven throughput variations of 0.2x0.09 aperture.* | | | | | | | | |
| 5 | E140H 1234 WAVE | WAVE | STIS/FUV-MAMA, ACCUM, 0.2X0.09 | E140H<br>1234 A | | | Sequence 1-5 Non-Int in SU Cyg Epoch 2a (3A) | 34 Secs (34 Secs)<br>*[==>]* | <br>***[1]*** |

Orbit Structure



## Visit

**Proposal 16783, SU Cyg Epoch 2b (3B), implementation** Mon Jul 26 15:01:52 GMT 2021

**Diagnostic Status: No Diagnostics**

Scientific Instruments: STIS/CCD, STIS/FUV-MAMA

Special Requirements: AFTER 3A BY 1.9 D TO 2.3 D

*Comments: To ensure that the accuracy of the faint FUV wavecal lamp is not degraded by a high dark current, it would be best if these visits could be scheduled as the first STIS FUV MAMA observation in a given SAA free period, as this avoids the dramatic increase in dark current that occurs when the FUV MAMA high voltage has been on for more than an orbit or so. This is especially important for SU Cyg as the ISM lines in that target cannot be used to verify the velocity zero point to the required accuracy.*

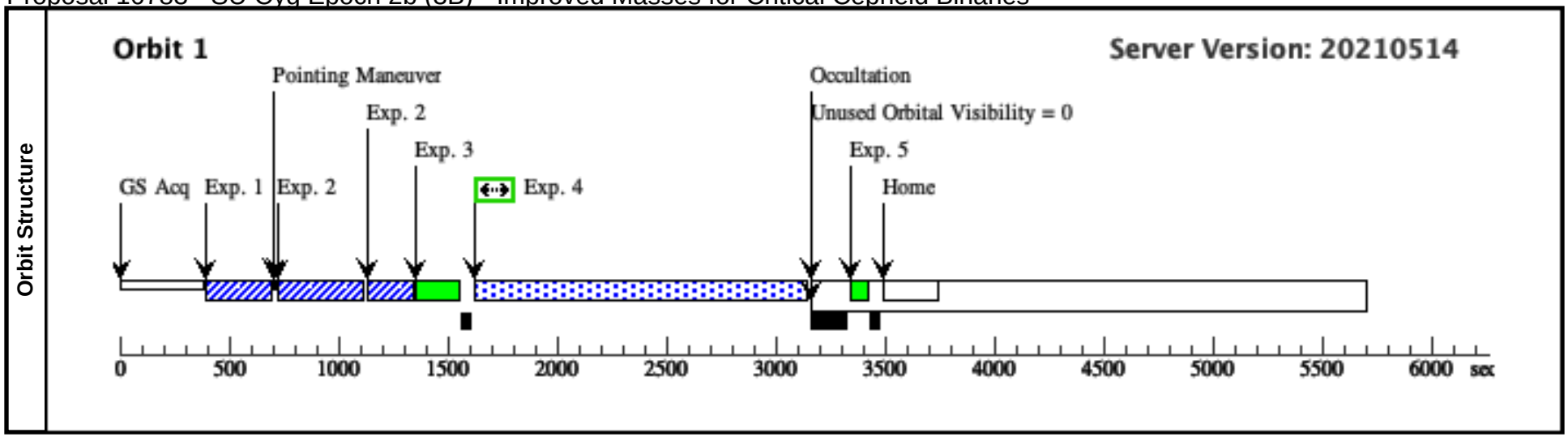
## Fixed Targets

| # | Name | Target Coordinates | Targ. Coord. Corrections | Fluxes | Miscellaneous |
|---|---|---|---|---|---|
| (3) | V-SU-CYG | RA: 19 44 48.7343 (296.2030596d)<br>Dec: +29 15 52.85 (29.26468d)<br>Equinox: J2000 | Proper Motion RA: -1.4160645255034498E-4 sec of time/yr<br>Proper Motion Dec: -0.0031549999221169855 arcsec/yr<br>Parallax: 0.0011695"<br>Epoch of Position: 2015.5 | V=6.44<br>SpT=F2Iab:+B8.0V; I=5.84 | Reference Frame: ICRS |

*Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.*
*Category=STAR*
*Description=[B6-B9.5 V-IV, CEPHEID, COMPOSITE SPECTRAL TYPE, F0-F2, PULSATING VARIABLE]*
*Extended=NO*

## Exposures

| # | Label (ETC Run) | Target | Config,Mode,Aperture | Spectral Els. | Opt. Params. | Special Reqs. | Groups | Exp. Time (Total)/[Actual Dur.] | Orbit |
|---|---|---|---|---|---|---|---|---|---|
| 1 | ACQ (STIS.ta.615219) | (3) V-SU-CYG | STIS/CCD, ACQ, F25ND3 | MIRROR | | | Sequence 1-5 Non-Int in SU Cyg Epoch 2b (3B) | 1.5 Secs (1.5 Secs)<br>*[==>]* | <br>***[1]*** |
| 2 | ACQ/PEAK (STIS.sp.1472320) | (3) V-SU-CYG | STIS/CCD, ACQ/PEAK, 0.2X0.09 | G230LB<br>2375 A | | | Sequence 1-5 Non-Int in SU Cyg Epoch 2b (3B) | 10 Secs (10 Secs)<br>*[==>]* | <br>***[1]*** |
| | *Comments: 358,477 e- from source in 3 s exposure*<br>*1,194,923 e- from source in 10s exposure* | | | | | | | | |
| 3 | E140H 1234 WAVE | WAVE | STIS/FUV-MAMA, ACCUM, 0.2X0.09 | E140H<br>1234 A | | | Sequence 1-5 Non-Int in SU Cyg Epoch 2b (3B) | 34 Secs (34 Secs)<br>*[==>]* | <br>***[1]*** |
| 4 | E140H 1234 SU Cyg (STIS.sp.1444984) | (3) V-SU-CYG | STIS/FUV-MAMA, TIME-TAG, 0.2X0.09 | E140H<br>1234 A | BUFFER-TIME=754;<br>WAVECAL=NO | | Sequence 1-5 Non-Int in SU Cyg Epoch 2b (3B) | 1507 Secs (1507 Secs)<br>*[==>]* | <br>***[1]*** |
| | *Comments: ETC predicts global rate of 2123 cnts/s using IUE LGAP spectra*<br>*Observed GLOBRATE from previous STIS/E140H/1234/0.2x0.09 observations ranges from ~ 1696 to 1897 cnts/s;*<br>*variations are believed to be entirely due to focus driven throughput variations of 0.2x0.09 aperture.* | | | | | | | | |
| 5 | E140H 1234 WAVE | WAVE | STIS/FUV-MAMA, ACCUM, 0.2X0.09 | E140H<br>1234 A | | | Sequence 1-5 Non-Int in SU Cyg Epoch 2b (3B) | 34 Secs (34 Secs)<br>*[==>]* | <br>***[1]*** |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Pointing Maneuver
Exp. 2
Exp. 3
Occultation
Unused Orbital Visibility = 0
Exp. 5
GS Acq
Exp. 1
Exp. 2
Exp. 4
Home
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
sec