



# 16769 - The Missing Piece of the IC 10 X-1 Puzzle: What is the Mass of the Black Hole?

Cycle: 29, Proposal Category: GO  
(Availability Mode: SUPPORTED)

## INVESTIGATORS

| <i>Name</i>                              | <i>Institution</i>                      | <i>E-Mail</i>                         |
|--|---|---------------------------------------|
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| Dr. Andre-Nicolas Chene (CoI)            | NOIRLab - Gemini North (HI)             | andrenicolas.chene@gmail.com          |

## 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) NAME-IC-10-X-1           | COS/FUV<br>COS/NUV                  | 2                  | 13-Oct-2021 17:00:15.0        | yes                           |
| 02           | (1) NAME-IC-10-X-1           | COS/FUV<br>COS/NUV                  | 2                  | 13-Oct-2021 17:00:16.0        | yes                           |
| 03           | (1) NAME-IC-10-X-1           | COS/FUV<br>COS/NUV                  | 2                  | 13-Oct-2021 17:00:16.0        | yes                           |
| 04           | (1) NAME-IC-10-X-1           | COS/FUV<br>COS/NUV                  | 2                  | 13-Oct-2021 17:00:17.0        | yes                           |

| <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> |
|--------------|------------------------------|-------------------------------------|--------------------|-------------------------------|-------------------------------|
| 05           | (1) NAME-IC-10-X-1           | COS/FUV<br>COS/NUV                  | 2                  | 13-Oct-2021 17:00:17.0        | yes                           |

10 Total Orbits Used

## **ABSTRACT**

IC 10 X-1 belongs to the extremely rare class of Wolf-Rayet + black hole binary stellar system, and is a valuable laboratory for understanding massive star evolution, black hole formation, and the effects of X-ray irradiation on stellar winds - but only if we know the mass of the black hole. Black hole masses in these systems have proven notoriously difficult to measure with ground-based optical spectroscopy; only Hubble FUV spectroscopy currently capable of achieving a black hole mass measurement, as was demonstrated for the twin system NGC 300 X-1 (HST program #15999). With a well-constrained orbital period (1.45175d), full X-ray coverage with Chandra, XMM-Newton, and NuSTAR, and copious quantities of archival Gemini spectroscopy available, FUV spectroscopy that samples the binary orbital period is the only missing piece of the black hole mass-puzzle for IC 10 X-1. We request 10 orbits with COS/G140L to constrain the mass of the black hole in IC 10 X-1, which will have far-reaching consequences for understanding black formation and for constraining future evolutionary pathways (including the possibility of compact object-merger events) of massive binary stellar systems.

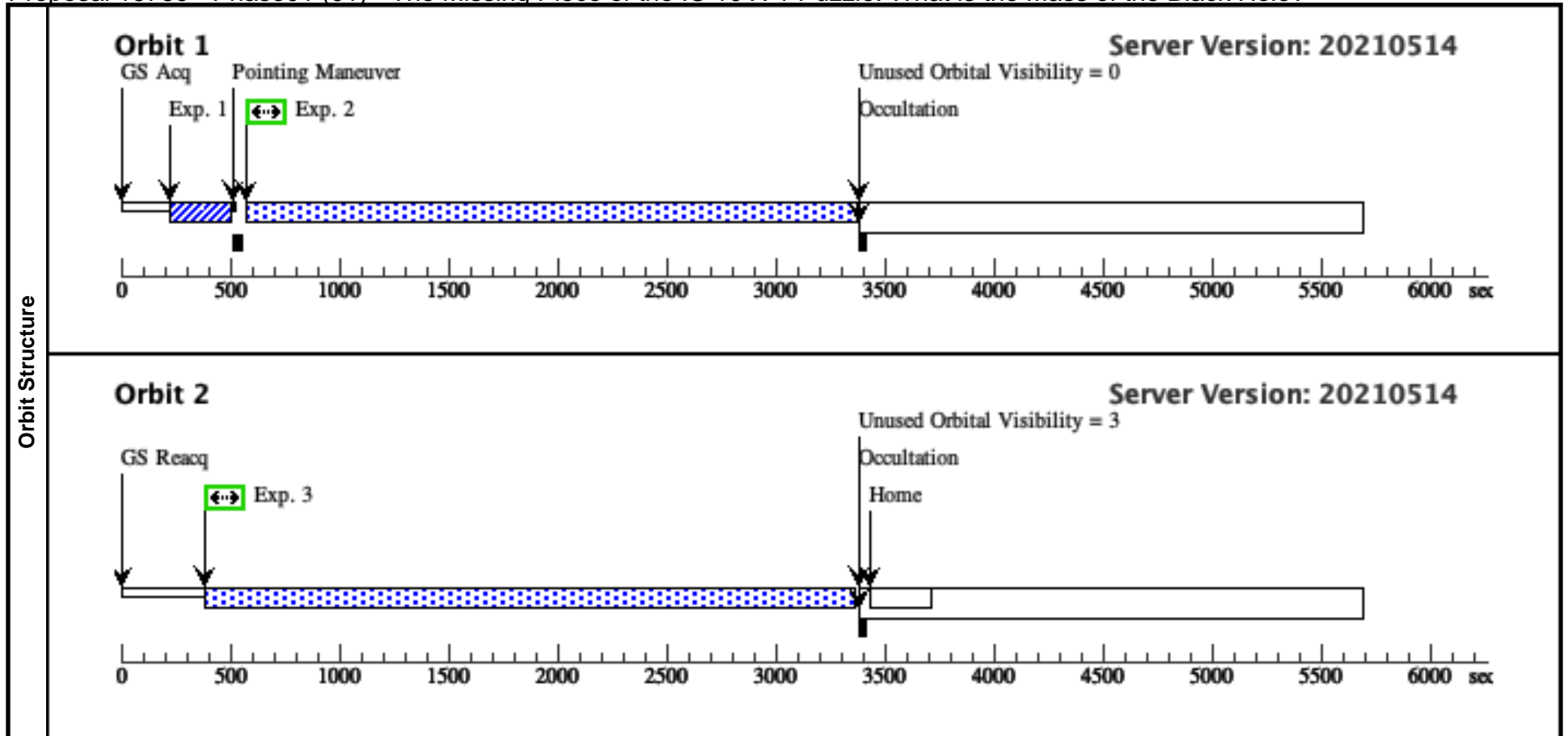
## **OBSERVING DESCRIPTION**

We will collect COS spectra for the Wolf-Rayet + black hole binary IC 10 X-1 at five different orbital phases (with 2 orbits per visit). The instrument settings for all four visits is identical: IC 10 X-1 (5 x 2 orbits): COS/FUV G140L. The best measurement of the binary orbital period is 1.45175 +/- 0.00001 d, with a zero-point time corresponding to phase=0.5 (e.g., the deepest part of the X-ray dip) on MJD 54040.87. The Hubble visits should roughly sample the entire binary orbital period, although they need not be taken during a single orbital cycle. However, to keep the orbital phase uncertainty to a minimum, all HST visits should be completed within roughly two months of one another.

Proposal 16769 - Phase01 (01) - The Missing Piece of the IC 10 X-1 Puzzle: What is the Mass of the Black Hole?

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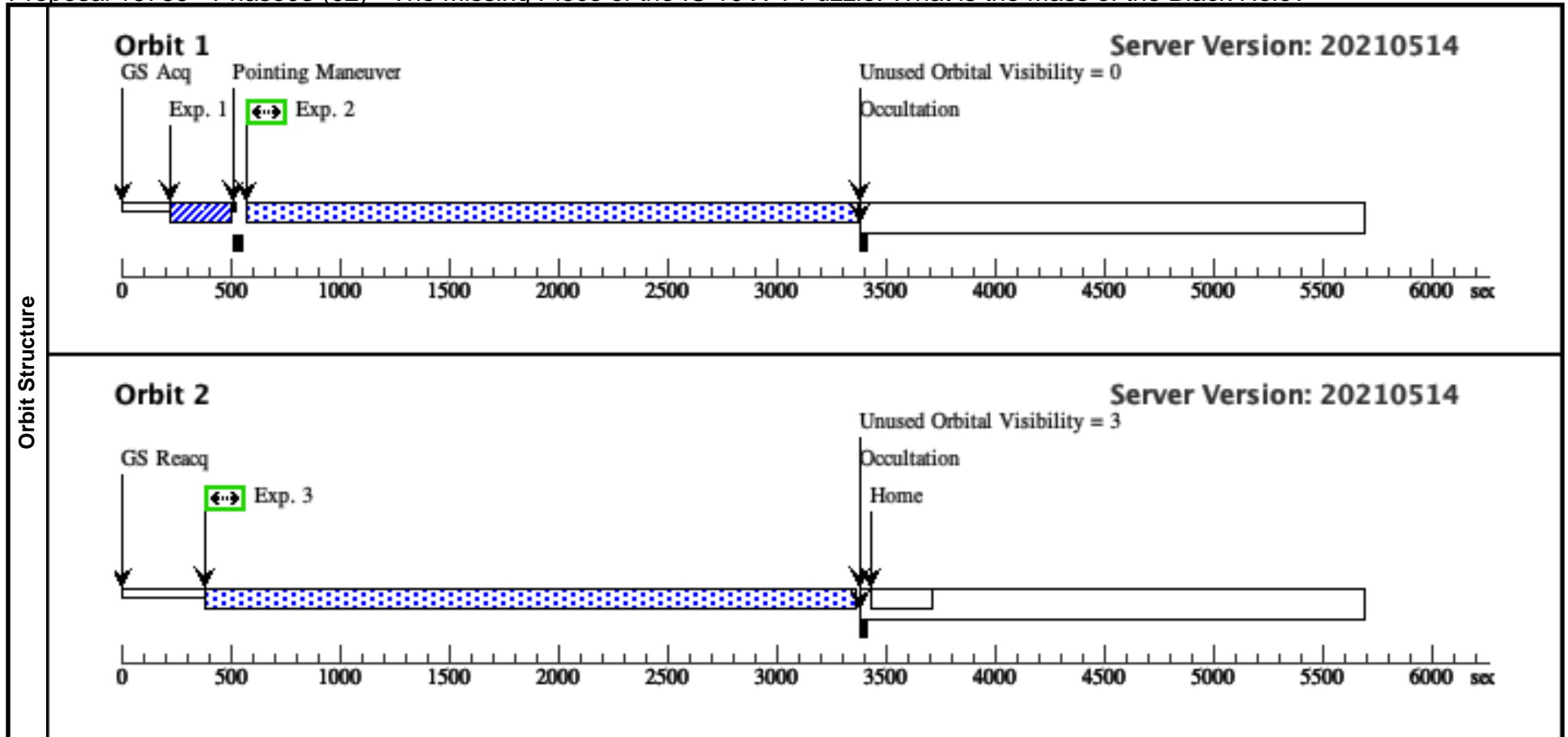
| Visit     | <b>Proposal 16769, Phase01 (01), scheduling</b><br><b>Diagnostic Status: No Diagnostics</b><br>Scientific Instruments: COS/FUV, COS/NUV<br>Special Requirements: Period 1.45175 D AND ZERO-PHASE HJD2454041.37 |                                |                    |   |                           |  |                       |        |  |       |
|-----------|--|--------------------------------|--------------------|---|---------------------------|--|-----------------------|--------|--|-------|
|           | Fixed Targets  | #                              | Name               | Target Coordinates  | Targ. Coord. Corrections  | Fluxes   | Miscellaneous         |        |  |       |
|           |  | (1)                            | NAME-IC-10-X-1     | RA: 00 20 29.0900 (5.1212083d)<br>Dec: +59 16 51.95 (59.28110d)<br>Equinox: J2000 | Epoch of Position: 2015.5 | V=21.5+/-0.2   | Reference Frame: ICRS |        |  |       |
|           | <i>Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.</i><br>Category=STAR<br>Description=[WOLF RAYET - WN]<br>Extended=NO                                      |                                |                    |   |                           |  |                       |        |  |       |
| Exposures | #  | Label (ETC Run)                | Target             | Config,Mode,Aperture  | Spectral Els.             | Opt. Params.   | Special Reqs.         | Groups | Exp. Time (Total)/[Actual Dur.]            | Orbit |
|           | 1  | Phase01_A CQ (COS.ta.152 1938) | (1) NAME-IC-10-X-1 | COS/NUV, ACQ/IMAGE, PSA   | MIRRORA                   |  | PHASE 0.05 TO 0.1 5   |        | 25 Secs (25 Secs)<br>[==>]                 | [1]   |
|           | 2  | Phase01 (COS.sp.152 1 1950)    | (1) NAME-IC-10-X-1 | COS/FUV, TIME-TAG, PSA  | G140L<br>1280 A           | BUFFER-TIME=1.7 e4;<br>FLASH=YES;<br>SEGMENT=BOTH;<br>FP-POS=1 |                       |        | 2280 Secs (2627 Secs)<br>[==>2627.0 Secs ] | [1]   |
|           | 3  | Phase01 (COS.sp.152 1 1950)    | (1) NAME-IC-10-X-1 | COS/FUV, TIME-TAG, PSA  | G140L<br>1280 A           | BUFFER-TIME=1.7 e4;<br>FLASH=YES;<br>SEGMENT=BOTH;<br>FP-POS=2 |                       |        | 2930 Secs (2930 Secs)<br>[==>]             | [2]   |



Proposal 16769 - Phase03 (02) - The Missing Piece of the IC 10 X-1 Puzzle: What is the Mass of the Black Hole?

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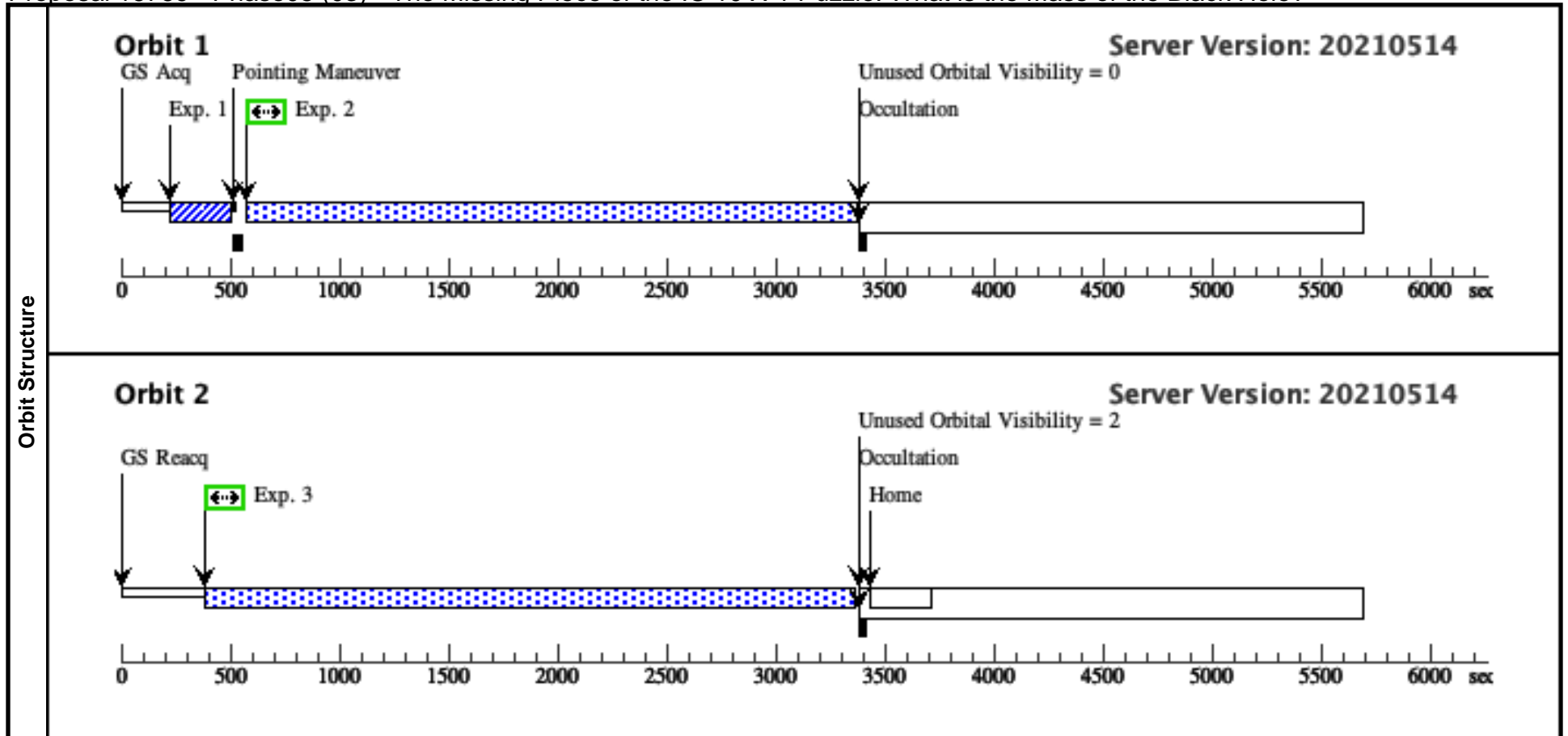
| Visit  | <b>Proposal 16769, Phase03 (02), scheduling</b><br><b>Diagnostic Status: No Diagnostics</b><br>Scientific Instruments: COS/FUV, COS/NUV<br>Special Requirements: Period 1.45175 D AND ZERO-PHASE HJD2454041.37 |  |                           |                         |                       |  |                     |               |  |                |   |                           |              |                       |  |  |  |  |  |
|--|--|--|---------------------------|-------------------------|-----------------------|--|---------------------|---------------|--|----------------|---|---------------------------|--------------|-----------------------|--|--|--|--|--|
|  | 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>NAME-IC-10-X-1</td> <td>RA: 00 20 29.0900 (5.1212083d)<br/>Dec: +59 16 51.95 (59.28110d)<br/>Equinox: J2000</td> <td>Epoch of Position: 2015.5</td> <td>V=21.5+/-0.2</td> <td>Reference Frame: ICRS</td> </tr> <tr> <td colspan="6"> <i>Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.</i><br/> <i>Category=STAR</i><br/> <i>Description=[WOLF RAYET - WN]</i><br/> <i>Extended=NO</i> </td> </tr> </tbody> </table> | #                         | Name                    | Target Coordinates    | Targ. Coord. Corrections                                       | Fluxes              | Miscellaneous | (1)  | NAME-IC-10-X-1 | RA: 00 20 29.0900 (5.1212083d)<br>Dec: +59 16 51.95 (59.28110d)<br>Equinox: J2000 | Epoch of Position: 2015.5 | V=21.5+/-0.2 | Reference Frame: ICRS | <i>Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.</i><br><i>Category=STAR</i><br><i>Description=[WOLF RAYET - WN]</i><br><i>Extended=NO</i> |  |  |  |  |
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| <i>Comments: This object was generated by the targetselector and retrieved from the SIMBAD database.</i><br><i>Category=STAR</i><br><i>Description=[WOLF RAYET - WN]</i><br><i>Extended=NO</i> |  |  |                           |                         |                       |  |                     |               |  |                |   |                           |              |                       |  |  |  |  |  |
| Exposures  | #  | Label (ETC Run)  | Target                    | Config,Mode,Aperture    | Spectral Els.         | Opt. Params.   | Special Reqs.       | Groups        | Exp. Time (Total)/[Actual Dur.]            | Orbit          |   |                           |              |                       |  |  |  |  |  |
|  | 1  | Phase03_A CQ (COS.ta.152 1938)   | (1) NAME-IC-10-X-1        | COS/NUV, ACQ/IMAGE, PSA | MIRRORA               |  | PHASE 0.25 TO 0.3 5 |               | 25 Secs (25 Secs)<br>[==>]                 | [1]            |   |                           |              |                       |  |  |  |  |  |
|  | 2  | Phase03 (COS.sp.152 1 1950)  | (1) NAME-IC-10-X-1        | COS/FUV, TIME-TAG, PSA  | G140L 1280 A          | BUFFER-TIME=1.7 e4;<br>FLASH=YES;<br>SEGMENT=BOTH;<br>FP-POS=3 |                     |               | 2280 Secs (2627 Secs)<br>[==>2627.0 Secs ] | [1]            |   |                           |              |                       |  |  |  |  |  |
|  | 3  | Phase03 (COS.sp.152 1 1950)  | (1) NAME-IC-10-X-1        | COS/FUV, TIME-TAG, PSA  | G140L 1280 A          | BUFFER-TIME=1.7 e4;<br>FLASH=YES;<br>SEGMENT=BOTH;<br>FP-POS=4 |                     |               | 2930 Secs (2930 Secs)<br>[==>]             | [2]            |   |                           |              |                       |  |  |  |  |  |



Proposal 16769 - Phase05 (03) - The Missing Piece of the IC 10 X-1 Puzzle: What is the Mass of the Black Hole?

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| Visit  | <b>Proposal 16769, Phase05 (03), scheduling</b><br><b>Diagnostic Status: No Diagnostics</b><br>Scientific Instruments: COS/FUV, COS/NUV<br>Special Requirements: Period 1.45175 D AND ZERO-PHASE HJD2454041.37   |  |                           |               |  |                          |              |  |        |                                 |   |                           |                                |                       |  |         |  |                     |  |                            |     |   |                           |                    |                        |              |  |  |  |  |     |   |                           |                    |                        |              |  |  |  |  |     |
|--|--|--|---------------------------|---------------|--|--------------------------|--------------|--|--------|---------------------------------|---|---------------------------|--------------------------------|-----------------------|--|---------|--|---------------------|--|----------------------------|-----|---|---------------------------|--------------------|------------------------|--------------|--|--|--|--|-----|---|---------------------------|--------------------|------------------------|--------------|--|--|--|--|-----|
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| #  | Name   | Target Coordinates   | Targ. Coord. Corrections  | Fluxes        | Miscellaneous  |                          |              |  |        |                                 |   |                           |                                |                       |  |         |  |                     |  |                            |     |   |                           |                    |                        |              |  |  |  |  |     |   |                           |                    |                        |              |  |  |  |  |     |
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| 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>Phase05_A CQ (COS.ta.152 1938)</td> <td>(1) NAME-IC-10-X-1</td> <td>COS/NUV, ACQ/IMAGE, PSA</td> <td>MIRRORA</td> <td></td> <td>PHASE 0.45 TO 0.5 5</td> <td></td> <td>25 Secs (25 Secs)<br/>[==&gt;]</td> <td>[1]</td> </tr> <tr> <td>2</td> <td>Phase05 (COS.sp.152 1950)</td> <td>(1) NAME-IC-10-X-1</td> <td>COS/FUV, TIME-TAG, PSA</td> <td>G140L 1280 A</td> <td>BUFFER-TIME=1.7 e4;<br/>FLASH=YES;<br/>SEGMENT=BOTH;<br/>FP-POS=1</td> <td></td> <td></td> <td>2280 Secs (2627 Secs)<br/>[==&gt;2627.0 Secs ]</td> <td>[1]</td> </tr> <tr> <td>3</td> <td>Phase05 (COS.sp.152 1950)</td> <td>(1) NAME-IC-10-X-1</td> <td>COS/FUV, TIME-TAG, PSA</td> <td>G140L 1280 A</td> <td>BUFFER-TIME=1.7 e4;<br/>FLASH=YES;<br/>SEGMENT=BOTH;<br/>FP-POS=2</td> <td></td> <td></td> <td>2030 Secs (2931 Secs)<br/>[==&gt;2931.0 Secs ]</td> <td>[2]</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                         | Phase05_A CQ (COS.ta.152 1938) | (1) NAME-IC-10-X-1    | COS/NUV, ACQ/IMAGE, PSA  | MIRRORA |  | PHASE 0.45 TO 0.5 5 |  | 25 Secs (25 Secs)<br>[==>] | [1] | 2 | Phase05 (COS.sp.152 1950) | (1) NAME-IC-10-X-1 | COS/FUV, TIME-TAG, PSA | G140L 1280 A | BUFFER-TIME=1.7 e4;<br>FLASH=YES;<br>SEGMENT=BOTH;<br>FP-POS=1 |  |  | 2280 Secs (2627 Secs)<br>[==>2627.0 Secs ] | [1] | 3 | Phase05 (COS.sp.152 1950) | (1) NAME-IC-10-X-1 | COS/FUV, TIME-TAG, PSA | G140L 1280 A | BUFFER-TIME=1.7 e4;<br>FLASH=YES;<br>SEGMENT=BOTH;<br>FP-POS=2 |  |  | 2030 Secs (2931 Secs)<br>[==>2931.0 Secs ] | [2] |
| #  | Label (ETC Run)  | Target   | Config,Mode,Aperture      | Spectral Els. | Opt. Params.   | Special Reqs.            | Groups       | Exp. Time (Total)/[Actual Dur.]            | Orbit  |                                 |   |                           |                                |                       |  |         |  |                     |  |                            |     |   |                           |                    |                        |              |  |  |  |  |     |   |                           |                    |                        |              |  |  |  |  |     |
| 1  | Phase05_A CQ (COS.ta.152 1938)   | (1) NAME-IC-10-X-1   | COS/NUV, ACQ/IMAGE, PSA   | MIRRORA       |  | PHASE 0.45 TO 0.5 5      |              | 25 Secs (25 Secs)<br>[==>]                 | [1]    |                                 |   |                           |                                |                       |  |         |  |                     |  |                            |     |   |                           |                    |                        |              |  |  |  |  |     |   |                           |                    |                        |              |  |  |  |  |     |
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| 3  | Phase05 (COS.sp.152 1950)  | (1) NAME-IC-10-X-1   | COS/FUV, TIME-TAG, PSA    | G140L 1280 A  | BUFFER-TIME=1.7 e4;<br>FLASH=YES;<br>SEGMENT=BOTH;<br>FP-POS=2 |                          |              | 2030 Secs (2931 Secs)<br>[==>2931.0 Secs ] | [2]    |                                 |   |                           |                                |                       |  |         |  |                     |  |                            |     |   |                           |                    |                        |              |  |  |  |  |     |   |                           |                    |                        |              |  |  |  |  |     |



Proposal 16769 - Phase07 (04) - The Missing Piece of the IC 10 X-1 Puzzle: What is the Mass of the Black Hole?

Wed Oct 13 21:00:18 GMT 2021

| Visit  | <b>Proposal 16769, Phase07 (04), scheduling</b><br><b>Diagnostic Status: No Diagnostics</b><br>Scientific Instruments: COS/FUV, COS/NUV<br>Special Requirements: Period 1.45175 D AND ZERO-PHASE HJD2454041.37 |  |                           |                         |                       |              |  |        |  |       |  |   |      |                    |                          |        |               |     |                |   |                           |              |                       |  |  |  |  |  |
|--|--|--|---------------------------|-------------------------|-----------------------|--------------|--|--------|--|-------|--|---|------|--------------------|--------------------------|--------|---------------|-----|----------------|---|---------------------------|--------------|-----------------------|--|--|--|--|--|
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| Exposures  | #  | Label (ETC Run)  | Target                    | Config,Mode,Aperture    | Spectral Els.         | Opt. Params. | Special Reqs.  | Groups | Exp. Time (Total)/[Actual Dur.]            | Orbit |  |   |      |                    |                          |        |               |     |                |   |                           |              |                       |  |  |  |  |  |
|  | 1  | Phase07_A CQ (COS.ta.152 1938)   | (1) NAME-IC-10-X-1        | COS/NUV, ACQ/IMAGE, PSA | MIRRORA               |              | PHASE 0.65 TO 0.7 5  |        | 25 Secs (25 Secs)<br>[==>]                 | [1]   |  |   |      |                    |                          |        |               |     |                |   |                           |              |                       |  |  |  |  |  |
|  | 2  | Phase07 (COS.sp.152 1 1950)  | (1) NAME-IC-10-X-1        | COS/FUV, TIME-TAG, PSA  | G140L 1280 A          |              | BUFFER-TIME=1.7 e4;<br>FLASH=YES;<br>SEGMENT=BOTH;<br>FP-POS=3 |        | 2280 Secs (2627 Secs)<br>[==>2627.0 Secs ] | [1]   |  |   |      |                    |                          |        |               |     |                |   |                           |              |                       |  |  |  |  |  |
|  | 3  | Phase07 (COS.sp.152 1 1950)  | (1) NAME-IC-10-X-1        | COS/FUV, TIME-TAG, PSA  | G140L 1280 A          |              | BUFFER-TIME=1.7 e4;<br>FLASH=YES;<br>SEGMENT=BOTH;<br>FP-POS=4 |        | 2930 Secs (2930 Secs)<br>[==>]             | [2]   |  |   |      |                    |                          |        |               |     |                |   |                           |              |                       |  |  |  |  |  |

