



17202 - Does MWC 656 host a black hole or stripped helium star? FUV spectroscopy will tell.

Cycle: 30, Proposal Category: GO

(UV Initiative)

(Availability Mode: SUPPORTED)

INVESTIGATORS

<i>Name</i>	<i>Institution</i>	<i>E-Mail</i>
Dr. Kareem El-Badry (PI) (Contact)	California Institute of Technology	kelbadry@caltech.edu
Prof. Charlie Conroy (CoI)	Harvard University	cconroy@cfa.harvard.edu
Dr. Julia Bodensteiner (CoI) (ESA Member)	European Southern Observatory - Germany	julia.bodensteiner@eso.org
Dr. Tomer Shenar (CoI) (ESA Member)	Universiteit van Amsterdam	t.shenar@uva.nl
Dr. Thomas Rivinius (CoI) (ESA Member)	European Southern Observatory - Germany	triviniu@eso.org
Dr. Douglas Russell Gies (CoI)	Georgia State University Research Foundation	dgies@gsu.edu
Dr. Luqian Wang (CoI)	Yunnan Astronomical Observatory, CAS	wangluqian@ynao.ac.cn
Dr. Kevin Burdge (CoI)	Massachusetts Institute of Technology	kburdge@mit.edu
Dr. Ylva Goetberg (CoI)	Carnegie Institution of Washington	ygoetberg@carnegiescience.edu

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) HD-215227 WAVE	STIS/CCD STIS/FUV-MAMA	1	11-Jan-2023 00:00:15.0	yes
02	(1) HD-215227 WAVE	STIS/CCD STIS/FUV-MAMA	1	11-Jan-2023 00:00:16.0	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>
03	(1) HD-215227 WAVE	STIS/CCD STIS/FUV-MAMA	1	11-Jan-2023 00:00:16.0	yes
04	(1) HD-215227 WAVE	STIS/CCD STIS/FUV-MAMA	1	11-Jan-2023 00:00:17.0	yes

4 Total Orbits Used

ABSTRACT

We propose multi-epoch STIS FUV spectroscopy of the only Be star + black hole binary candidate, MWC 656. These observations will reveal the nature of the Be star's elusive companion: a black hole, or an intermediate-mass (~ 3 Msun) stripped helium star. Either scenario would be extraordinary: intermediate-mass stripped stars are the main progenitors of stripped-envelope supernovae, X-ray binaries, and merging neutron stars, yet they have remained elusive for decades; the black hole would be in the mass gap and would be the only known X-ray faint high-mass X-ray binary containing a black hole. Our proposed observations will unambiguously distinguish between these two scenarios, as the UV spectrum of a massive stripped star will be very different from that of a black hole accretion disk. FUV spectra will also constrain the spectral type, mass, and RV variability of the Be star more reliably than has been possible with optical data, which are strongly contaminated by the Be star's circumstellar disk.

OBSERVING DESCRIPTION

We propose to obtain 3 orbits of STIS MAMA high dispersion UV spectroscopy of MWC 656, a bright ($V=8.8$, GALEX FUV ~ 9.0) binary system. The FUV magnitude is estimated based on the spectral type and optical/IR SED. The extinction is low ($E(B-V) \sim 0.2$), so the expected FUV magnitude is reasonably well-constrained, and is also constrained from the measured TD-1 UV flux. 3 separate single-orbit visits are required, with a typical inter-visit spacing of 15 days, to resolve the RV variations of both components over the course of the 60-day orbital period. The expected RV variations of the Be star are ~ 20 km/s between visits, while those of the companion are ~ 100 km/s. Both will be readily detectable with our proposed instrumentation, which will yield RVs precision of ~ 0.5 km/s for the companion, and ~ 3 km/s for the Be star.

We will use the E140M grating and MAMA detector with a 0.2×0.2 slit, yielding coverage of the far-UV (1150-1700\AA) with a resolving power of $R = 45,800$. This setup produces spectra with sufficient resolution to measure the radial velocity variations of both components of the binary and to record in detail the narrow lines of the helium star companion, if it exists. We plan to visit the target three times and rebin the spectral dispersion down by a factor of four, for a final $R = 11,450$. (Observing directly with a lower-resolution grating would risk saturating the detector). This is the

Proposal 17202 (STScI Edit Number: 0, Created: Wednesday, January 11, 2023 at 12:00:17 AM Eastern Standard Time) - Overview
same observing setup and approach that was recently successfully used by Wang et al. 2021 to characterize sdO companions to Be stars with FUV flux ratios as low as 1%.

MWC 656 has 55 minutes of orbital visibility in each orbit. After subtraction of 6 minutes for guide star acquisition, 6 minutes for STIS target acquisition, and 8 minutes for STIS science observations overhead, there remain 2000 seconds science exposure time in one orbit. Using the STIS exposure time calculator, we estimate that we will obtain a signal-to-noise ratio of 70 per resolution element at 1425 Å (before rebinning; ≈ 150 after rebinning) in each of the three visits. This exceeds our SNR requirement (to detect a companion that contributes 1% of the FUV flux) by a factor of 4.

Our primary goals are to constrain the effective temperature and radius of both components and to measure the relative amplitude of both components' RV shifts in order to determine the mass ratio. We will perform a cross correlation analysis with model spectra to detect the spectral signals of the Be star and hot companion in order to measure radial velocities for both; observing at multiple epochs is essential for determining the mass ratio. We will fit the composite spectra using a binary spectral model, inferring temperatures and flux ratios for both components. Given the known distance from the precise Gaia parallax, the component radii can be determined from fits of the spectral energy distribution, and masses can subsequently be inferred from evolutionary models.

If the companion remains consistent with a BH, our analysis of the RVs and Be star UV spectrum will significantly improve constraints on both component masses, which we will compare to evolutionary tracks to constrain the system's formation history and expected future evolution. Characterization of additional spectral features from the BH accretion disk in the UV will also improve constraints on the time-averaged accretion rate. If UV spectra instead reveal a stripped helium star companion, analysis of its spectrum will constrain its temperature and luminosity. Comparison of these to evolutionary tracks for stripped stars from Gotberg et al. (2018) will then similarly constrain the system's evolutionary history.

Proposal 17202 - first visit (01) - Does MWC 656 host a black hole or stripped helium star? FUV spectroscopy will tell.

Wed Jan 11 05:00:17 GMT 2023

Visit	Proposal 17202, first visit (01), completed				
	Diagnostic Status: No Diagnostics				
	Scientific Instruments: STIS/CCD, STIS/FUV-MAMA				
	Special Requirements: Period 59.12 D AND ZERO-PHASE HJD2455722.2				

Fixed Targets	#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
	(1)	HD-215227	RA: 22 42 57.2979 (340.7387412d) Dec: +44 43 18.21 (44.72172d) Equinox: J2000	Proper Motion RA: -3.478 mas/yr Proper Motion Dec: -3.159 mas/yr Epoch of Position: 2016.0	V=8.81+/-0.1 TD-1 flux in 156.5 nm band: 6.9 e-12 erg/s/cm^2/Angstrom	Reference Frame: ICRS

Comments: The target is outside the GALEX footprint. However, we have two ways to estimate the UV flux:

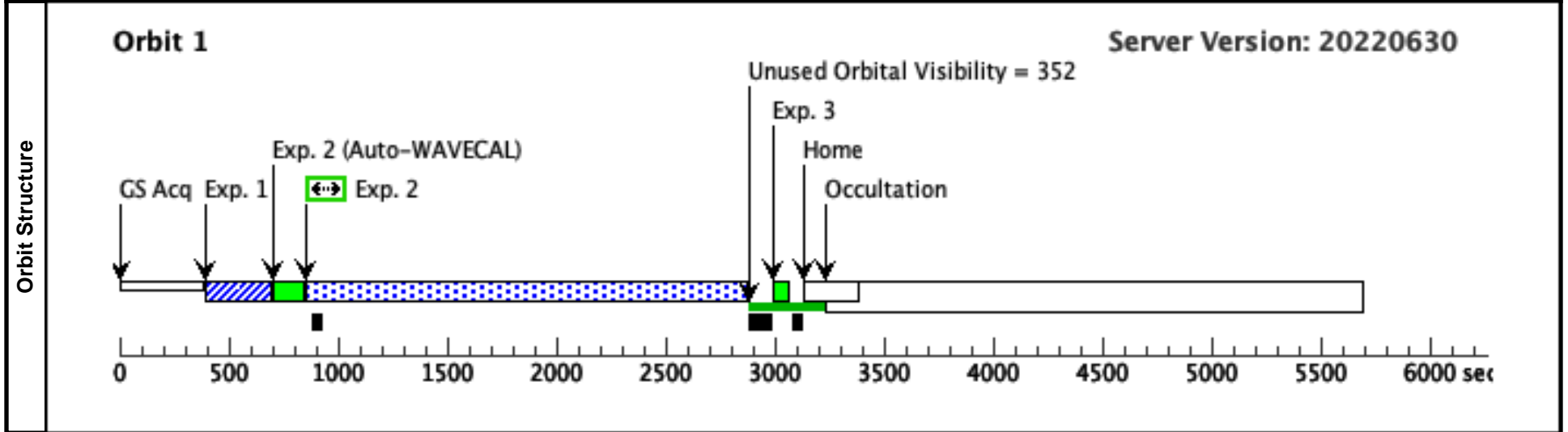
(i) *Assuming a B1.5 III template with $T_{\text{eff}} = 20,000 \text{ K}$, $R = 8 \text{ R}_{\text{sun}}$, $d = 2 \text{ kpc}$, and $E(B-V) = 0.2$ (parameters from Casares et al. 2014; distance from Gaia; extinction from Bayestar dust map), we estimate an FUV flux density ranging from $(6-10) \times 10^{-11} \text{ erg/s/cm}^2/\text{AA}$ over the 1150-1700 AA range.*

(ii) *The target was observed by the TD-1 UV flux survey, which measured a flux density of $(0.69 \pm 0.03) \times 10^{-11} \text{ erg/s/cm}^2/\text{AA}$ at 1565 AA, which is in good agreement with the model assumed in (i).*

For the estimate in (i), the ETC predicts a global count rate of 35,000 counts/s, well below the bright limit of 200,000 counts/s.

Category=STAR
Description=[B0-B2 III-I, BE, INTERACTING BINARY]

Exposures	#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
	1	(1809799)	(1) HD-215227	STIS/CCD, ACQ, F25ND3	MIRROR	ACQTYPE=POINT	PHASE 0.45 TO 0.5	5	1 Secs (1 Secs)	[1]
	2	(1809801)	(1) HD-215227	STIS/FUV-MAMA, ACCUM, 0.2X0.2	E140M 1425 A				2000 Secs (2000 Secs)	[1]
	3		WAVE	STIS/FUV-MAMA, ACCUM, 0.2X0.2	E140M 1425 A				[1]	



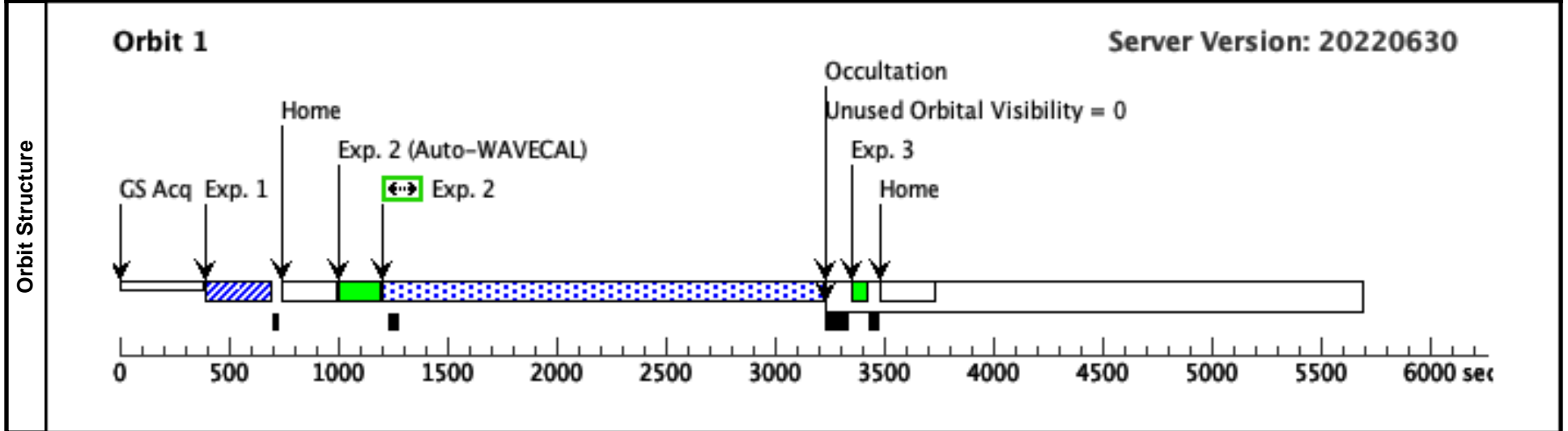
Proposal 17202 - second visit (02) - Does MWC 656 host a black hole or stripped helium star? FUV spectroscopy will tell.

Wed Jan 11 05:00:17 GMT 2023

Visit	Proposal 17202, second visit (02), completed				
	Diagnostic Status: No Diagnostics				
	Scientific Instruments: STIS/CCD, STIS/FUV-MAMA				
	Special Requirements: Period 59.12 D AND ZERO-PHASE HJD2455722.2				

#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	HD-215227	RA: 22 42 57.2979 (340.7387412d) Dec: +44 43 18.21 (44.72172d) Equinox: J2000	Proper Motion RA: -3.478 mas/yr Proper Motion Dec: -3.159 mas/yr Epoch of Position: 2016.0	V=8.81+/-0.1 TD-1 flux in 156.5 nm band: 6.9 e-12 erg/s/cm^2/Angstrom	Reference Frame: ICRS
<i>Comments: The target is outside the GALEX footprint. However, we have two ways to estimate the UV flux:</i>					
<i>(i) Assuming a B1.5 III template with $T_{\text{eff}} = 20,000 \text{ K}$, $R = 8 R_{\text{sun}}$, $d = 2 \text{ kpc}$, and $E(B-V) = 0.2$ (parameters from Casares et al. 2014; distance from Gaia; extinction from Bayestar dust map), we estimate an FUV flux density ranging from $(6-10) \times 10^{-11} \text{ erg/s/cm}^2/\text{AA}$ over the 1150-1700 AA range.</i>					
<i>(ii) The target was observed by the TD-1 UV flux survey, which measured a flux density of $(0.69 \pm 0.03) \times 10^{-11} \text{ erg/s/cm}^2/\text{AA}$ at 1565 AA, which is in good agreement with the model assumed in (i).</i>					
<i>For the estimate in (i), the ETC predicts a global count rate of 35,000 counts/s, well below the bright limit of 200,000 counts/s.</i>					
Category=STAR					
Description=[B0-B2 III-I, BE, INTERACTING BINARY]					

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	(1809799)	(1) HD-215227	STIS/CCD, ACQ, F25ND3	MIRROR	ACQTYPE=POINT	PHASE 0.95 TO 0.0 5		1 Secs (1 Secs) [==>]	[1]
2	(1809801)	(1) HD-215227	STIS/FUV-MAMA, ACCUM, 0.2X0.2	E140M 1425 A		PHASE 0.95 TO 0.0 5		2000 Secs (2000 Secs) [==>]	[1]
3		WAVE	STIS/FUV-MAMA, ACCUM, 0.2X0.2	E140M 1425 A				[==>]	[1]



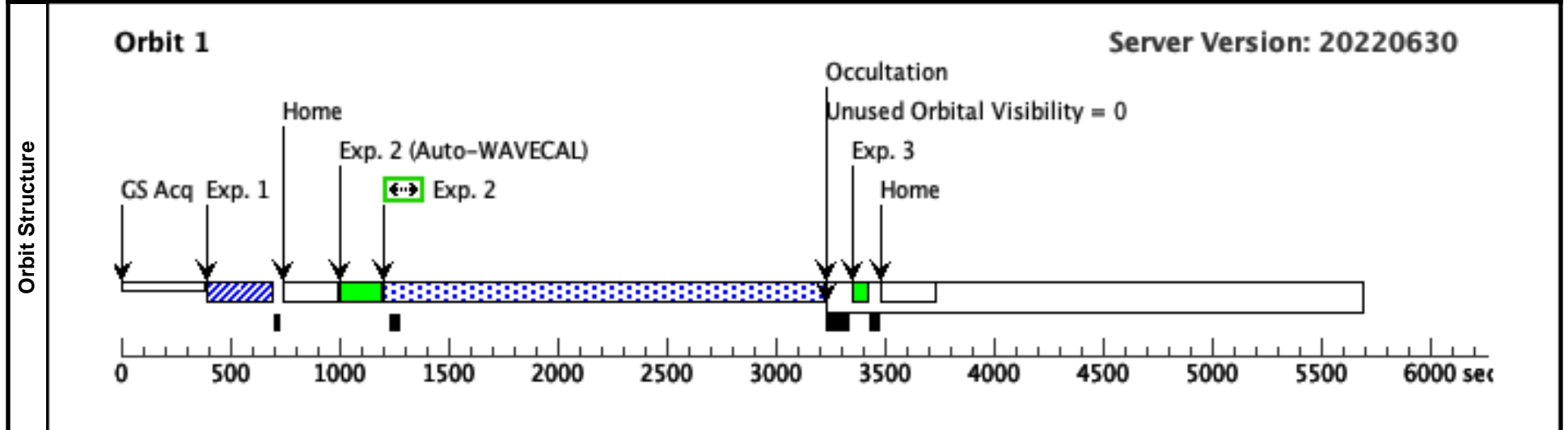
Proposal 17202 - third visit (03) - Does MWC 656 host a black hole or stripped helium star? FUV spectroscopy will tell.

Wed Jan 11 05:00:17 GMT 2023

Visit	Proposal 17202, third visit (03), failed				
	Diagnostic Status: No Diagnostics				
	Scientific Instruments: STIS/CCD, STIS/FUV-MAMA				
	Special Requirements: Period 59.12 D AND ZERO-PHASE HJD2455722.2				

Fixed Targets	#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
	(1)	HD-215227	RA: 22 42 57.2979 (340.7387412d) Dec: +44 43 18.21 (44.72172d) Equinox: J2000	Proper Motion RA: -3.478 mas/yr Proper Motion Dec: -3.159 mas/yr Epoch of Position: 2016.0	V=8.81+/-0.1 TD-1 flux in 156.5 nm band: 6.9 e-12 erg/s/cm^2/Angstrom	Reference Frame: ICRS
<i>Comments: The target is outside the GALEX footprint. However, we have two ways to estimate the UV flux:</i>						
<i>(i) Assuming a B1.5 III template with $T_{\text{eff}} = 20,000 \text{ K}$, $R = 8 R_{\text{sun}}$, $d = 2 \text{ kpc}$, and $E(B-V) = 0.2$ (parameters from Casares et al. 2014; distance from Gaia; extinction from Bayestar dust map), we estimate an FUV flux density ranging from $(6-10) \times 10^{-11} \text{ erg/s/cm}^2/\text{AA}$ over the 1150-1700 AA range.</i>						
<i>(ii) The target was observed by the TD-1 UV flux survey, which measured a flux density of $(0.69 \pm 0.03) \times 10^{-11} \text{ erg/s/cm}^2/\text{AA}$ at 1565 AA, which is in good agreement with the model assumed in (i).</i>						
<i>For the estimate in (i), the ETC predicts a global count rate of 35,000 counts/s, well below the bright limit of 200,000 counts/s.</i>						
Category=STAR						
Description=[B0-B2 III-I, BE, INTERACTING BINARY]						

Exposures	#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
	1	(1809799)	(1) HD-215227	STIS/CCD, ACQ, F25ND3	MIRROR	ACQTYPE=POINT	PHASE 0.2 TO 0.3		1 Secs (1 Secs)	
									[==>]	[1]
	2	(1809801)	(1) HD-215227	STIS/FUV-MAMA, ACCUM, 0.2X0.2	E140M 1425 A		PHASE 0.2 TO 0.3		2000 Secs (2000 Secs)	
								[==>]	[1]	
3		WAVE	STIS/FUV-MAMA, ACCUM, 0.2X0.2	E140M 1425 A				[==>]	[1]	



Proposal 17202 - third visit-repeat (04) - Does MWC 656 host a black hole or stripped helium star? FUV spectroscopy will tell.

Wed Jan 11 05:00:18 GMT 2023

Visit	Proposal 17202, third visit-repeat (04)				
	Diagnostic Status: No Diagnostics Scientific Instruments: STIS/CCD, STIS/FUV-MAMA Special Requirements: Period 59.12 D AND ZERO-PHASE HJD2455722.2 <i>Comments: This is a repeat of the visit that failed due to an instrument error.</i>				

Fixed Targets	#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
	(1)	HD-215227	RA: 22 42 57.2979 (340.7387412d) Dec: +44 43 18.21 (44.72172d) Equinox: J2000	Proper Motion RA: -3.478 mas/yr Proper Motion Dec: -3.159 mas/yr Epoch of Position: 2016.0	V=8.81+/-0.1 TD-1 flux in 156.5 nm band: 6.9 e-12 erg/s/cm^2/Angstrom	Reference Frame: ICRS

Comments: The target is outside the GALEX footprint. However, we have two ways to estimate the UV flux:

(i) *Assuming a B1.5 III template with $T_{\text{eff}} = 20,000 \text{ K}$, $R = 8 R_{\text{sun}}$, $d = 2 \text{ kpc}$, and $E(B-V) = 0.2$ (parameters from Casares et al. 2014; distance from Gaia; extinction from Bayestar dust map), we estimate an FUV flux density ranging from $(6-10) \times 10^{-11} \text{ erg/s/cm}^2/\text{AA}$ over the 1150-1700 AA range.*

(ii) *The target was observed by the TD-1 UV flux survey, which measured a flux density of $(0.69 \pm 0.03) \times 10^{-11} \text{ erg/s/cm}^2/\text{AA}$ at 1565 AA, which is in good agreement with the model assumed in (i).*

For the estimate in (i), the ETC predicts a global count rate of 35,000 counts/s, well below the bright limit of 200,000 counts/s.

Category=STAR
Description=[B0-B2 III-I, BE, INTERACTING BINARY]

Exposures	#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
	1	(1809799)	(1) HD-215227	STIS/CCD, ACQ, F25ND3	MIRROR	ACQTYPE=POINT	PHASE 0.2 TO 0.3			1 Secs (1 Secs) [==>]
2	(1809801)	(1) HD-215227	STIS/FUV-MAMA, ACCUM, 0.2X0.2	E140M 1425 A					2000 Secs (2000 Secs) [==>]	[1]
3		WAVE	STIS/FUV-MAMA, ACCUM, 0.2X0.2	E140M 1425 A					[==>]	[1]

