16688 - Towards a 1% local determination of the Hubble constant: quantifying stellar association bias in the distance scale anchor galaxy NGC4258

Cycle: 29, Proposal Category: GO

(UV Initiative)

(Availability Mode: SUPPORTED)

INVESTIGATORS

Name	*Institution*	*E-Mail*
Dr. Richard I Anderson (PI) (ESA Member) (Contact)	**Ecole Polytechnique Federale de Lausanne**	**richard.anderson@epfl.ch**
Dr. Adam Riess (CoI) (AdminUSPI)	The Johns Hopkins University	ariess@stsci.edu
Dr. Stefano Casertano (CoI)	Space Telescope Science Institute	stefano@stsci.edu
Dr. Zoi Spetsieri (CoI) (ESA Member)	Ecole Polytechnique Federale de Lausanne	zoispetsieri@gmail.com

VISITS

Visit	*Targets used in Visit*	*Configurations used in Visit*	*Orbits Used*	*Last Orbit Planner Run*	*OP Current with Visit?*
01	(1) NGC4258	ACS/WFC WFC3/UVIS	1	07-Feb-2022 11:00:13.0	yes
02	(1) NGC4258	ACS/WFC WFC3/UVIS	1	07-Feb-2022 11:00:13.0	yes
03	(1) NGC4258	ACS/WFC WFC3/UVIS	1	07-Feb-2022 11:00:14.0	yes
04	(1) NGC4258	ACS/WFC WFC3/UVIS	1	07-Feb-2022 11:00:15.0	yes

4 Total Orbits Used

ABSTRACT

The tension among recent early- and late-Universe determinations of Hubble's constant (H0) is one of the potentially most consequential open problems in astrophysics. Specifically, the present-day measurement based on a well calibrated empirical distance ladder differs by 8.3 +/- 2.0% (at 4.2 sigma) from the cosmology-dependent H0 value derived from the Planck mission's observations of the Cosmic Microwave Background. It is now crucial to demonstrate the accuracy of the distance ladder by scrutinizing even presumably small systematic errors to either resolve or intensify the tension, whereby the latter could place fundamental physics at the verge of a breakthrough.

We propose to exploit HST/WFC3's unique UV capabilities to validate and improve the late-Universe H0 measurement based on Cepheid variable stars and type-Ia supernovae (SNeIa). WFC3/UVIS F300X observations of Cepheids in the crucial anchor galaxy NGC4258 will quantify the occurrence of Cepheids in or near their natal (cluster) environments. This will allow us to improve the stellar association bias correction currently applied to the distance ladder by a) comparing clustering frequency, type, and magnitude among all distance ladder anchor galaxies (NGC4258, Milky Way, LMC); b) comparing Cepheid clustering properties between NGC4258 and the SNeIa host M101 under nearly identical observing conditions; c) increasing clustering statistics to investigate their dependence on Cepheid properties. Coordinated parallel observations of a new halo field will accurately calibrate the tip of the red giant branch (TRGB) luminosity and improve the TRGB's ability to serve as a Cepheid-independent first distance ladder rung.

OBSERVING DESCRIPTION

We propose deep HST/WFC3 UV imaging in the broad-band F300X passband targeting the field containing > 100 of NGC 4258's known Cepheids, cf. Fig. 3. HST's unique ability to provide deep UV imaging is essential to this project and F300X is the most suitable passband, providing sufficient depth to discover even low-mass, low-luminosity associations that would require a much larger time investment in other UV passbands. The immediate objectives of these primary observations include:

1. conducting anchor-to-anchor and anchor-to-host comparisons of Cepheid clustering statistics as explained in the Scientific Justification above;
2. increasing the sample of known clustered Cepheids beyond the Local Group to measure the mean brightening due to clustering among CDL constituents, investigate its dependence on Cepheid properties (e.g. pulsation period, color, amplitude) and to add diversity to the galaxy environments sampled;
3. optimizing Cepheid selection criteria to minimize H0 bias due to physical association;
4. quantifying the contribution of clustering to the broader problem of crowding;

Hence, the requesetd observations will significantly improve the understanding of how Cepheids associate with their natal environments and the ability to correct the CDL-based H0 measurement from stellar association bias.

We further propose coordinated parallel ACS/F606W and ACS/F814W observations whose immediate objective is to calibrate the absolute magnitude of the TRGB in a previously unobserved field in NGC4258's Western halo. This is will allow to test conflicting results based on an Eastern field and to understand possible variations in apparent TRGB magnitude. The deep imaging of this field is likely to find future application for the calibration of Mira stars as distance tracers in the JWST era (Huang et al. 2019).

Choice of F300X photometric band and exposure time estimation The F300X passband on WFC3/UVIS is best suited for this project because its significantly higher throughput compared to F275W or F336W leads to better detectability of low-mass young stellar populations. Its cut-off at the Balmer jump renders it furthermore less sensitive to the Cepheids than F336W or F390W. We are particularly interested in low-mass clusters and dispersed young associations that are not sufficiently bright to lead to changes in light curve morphology or amplitude, hence the request for deep UV observations.

NBODY simulations show that the minimum total cluster mass to form a >10 d Cepheid is approximately 150 -200Msun (F. Dinnbier, private communication). To estimate suitable exposure times, we have estimated the impact of coeval clusters on Cepheid colors, amplitudes, and mean magnitudes using stellar isochrones and synthetic populations computed in HST/WFC3 filter passbands via the CMD 3.2 web interface (Chen et al. 2015). All isochrones and populations are computed assuming solar metallicity and for three ages (30, 50, 100 Myr), representative of Cepheids with three different periods (3, 8, 17d) assuming period-age relations from Bono et al. (2005). To determine the effects of blending on Cepheid properties, we sum the fluxes of one Cepheid (where isochrone crosses instability strip) with the coeval cluster population composed of Main Sequence stars only (none of the randomly populated synthetic populations with M < 2000Msun contained evolved stars). For a 10d Cepheid in a 200 Msun cluster, we find an F300X apparent magnitude of mF300X ~ 24 mag at NGC 4258's distance.

Using the HST ETC, we estimate that we can detect such low-mass clusters with a signal-to-noise ratio of > 3.2 in a total of 10210 s (4 orbits) for such a low-mass cluster with a diameter typical of open clusters 0.215" (8 pc at 7.6 Mpc). Cluster populations will be more than 3 mag brighter than the Cepheid in this case, ensuring that the Cepheid would be subdominant. Another smoking gun for an association with young stars will be the blue F300X - F555W color near 0mag or bluer. As the bottom panel shows, such a low-mass cluster will brighten the apparent magnitude by ~0.03 mag, leading to a 1.5% distance bias for such an individual example.

To suppress Cepheid detectability at phases near maximum UV brightness, we propose to spread the observations across two visits comprising two orbits each, separated by at least 5 days per visit (total of 4 orbits). The same strategy was adopted in GO-15946 targeting F300X obserations of M101. Each visit will be structured as a WFC3-UVIS-DITHER-BOX pattern in order to better sample the PSF and for cosmic ray rejection.

Visit

Proposal 16688, Visit 01, scheduling Mon Feb 07 16:00:15 GMT 2022

Diagnostic Status: No Diagnostics

Scientific Instruments: WFC3/UVIS, ACS/WFC

Special Requirements: ORIENT 223D TO 233 D

Patterns

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

Fixed Targets

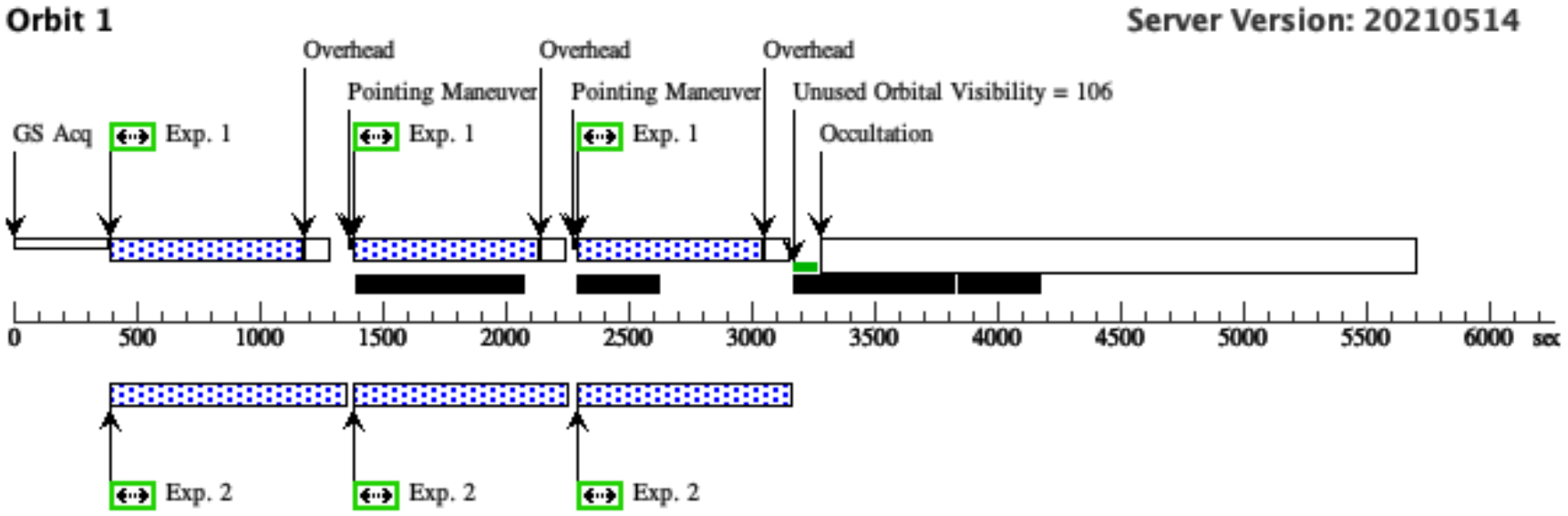
#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	NGC4258	RA: 12 18 49.5600 (184.7065000d) Dec: +47 19 45.45 (47.32929d) Equinox: J2000	Epoch of Position: 2015.5	V=8.41	Reference Frame: SIMBAD

Comments: This object was generated by the targetselector and retrieved from the SIMBAD database. The coordinates were shifted to the location of the Primary observation target to be observed with WFC3/UVIS.
Category=GALAXY
Description=[SEYFERT]
Extended=YES

Exposures

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	(1529726)	(1) NGC4258	WFC3/UVIS, ACCUM, UVIS-CENTER	F300X	FLASH=14	GS ACQ SCENARIO BASE1BE	Pattern 3, Exps 1-2 in Visit 01 (3) Prime + Parallel Group 1-2 in Pattern 3, Exps 1-2 in Visit 01	420 Secs (2250 Secs) *[==>750 Secs (Pattern 1)]* *[==>750 Secs (Pattern 2)]* *[==>750 Secs (Pattern 3)]*	 ***[1]***
2		(1) NGC4258	ACS/WFC, ACCUM, WFC	F606W			Pattern 3, Exps 1-2 in Visit 01 (3) Prime + Parallel Group 1-2 in Pattern 3, Exps 1-2 in Visit 01	420 Secs (2250 Secs) *[==>750 Secs (Pattern 1)]* *[==>750 Secs (Pattern 2)]* *[==>750 Secs (Pattern 3)]*	 ***[1]***

Orbit Structure



Visit

Proposal 16688, Visit 02, scheduling Mon Feb 07 16:00:16 GMT 2022

Diagnostic Status: No Diagnostics

Scientific Instruments: WFC3/UVIS, ACS/WFC

Special Requirements: SAME ORIENT AS 01; AFTER 01

Patterns

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

Fixed Targets

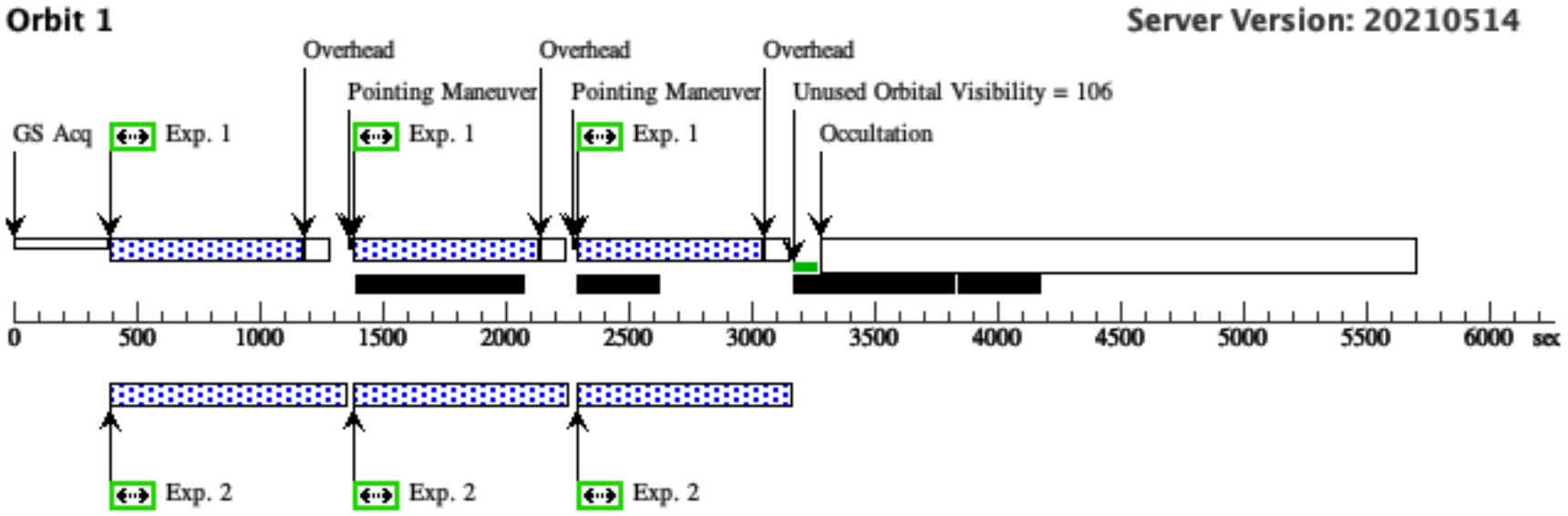
#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	NGC4258	RA: 12 18 49.5600 (184.7065000d) Dec: +47 19 45.45 (47.32929d) Equinox: J2000	Epoch of Position: 2015.5	V=8.41	Reference Frame: SIMBAD

Comments: This object was generated by the targetselector and retrieved from the SIMBAD database. The coordinates were shifted to the location of the Primary observation target to be observed with WFC3/UVIS.
Category=GALAXY
Description=[SEYFERT]
Extended=YES

Exposures

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	(1529726)	(1) NGC4258	WFC3/UVIS, ACCUM, UVIS-CENTER	F300X	FLASH=14	GS ACQ SCENARIO BASE1BE	Pattern 3, Exps 1-2 in Visit 02 (3) Prime + Parallel Group 1-2 in Pattern 3, Exps 1-2 in Visit 02	240 Secs (2250 Secs) *[==>750 Secs (Pattern 1)]* *[==>750 Secs (Pattern 2)]* *[==>750 Secs (Pattern 3)]*	 ***[1]***
2		(1) NGC4258	ACS/WFC, ACCUM, WFC	F814W			Pattern 3, Exps 1-2 in Visit 02 (3) Prime + Parallel Group 1-2 in Pattern 3, Exps 1-2 in Visit 02	240 Secs (2250 Secs) *[==>750 Secs (Pattern 1)]* *[==>750 Secs (Pattern 2)]* *[==>750 Secs (Pattern 3)]*	 ***[1]***

Orbit Structure



Visit

Proposal 16688, Visit 03, scheduling Mon Feb 07 16:00:16 GMT 2022

Diagnostic Status: No Diagnostics

Scientific Instruments: WFC3/UVIS, ACS/WFC

Special Requirements: ORIENT 223D TO 233 D; AFTER 02 BY 5 D TO 40 D

Comments: Second pointing > 5 days later in F606W (as Visit01), can be slightly offset from Visit 01

Patterns

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

Fixed Targets

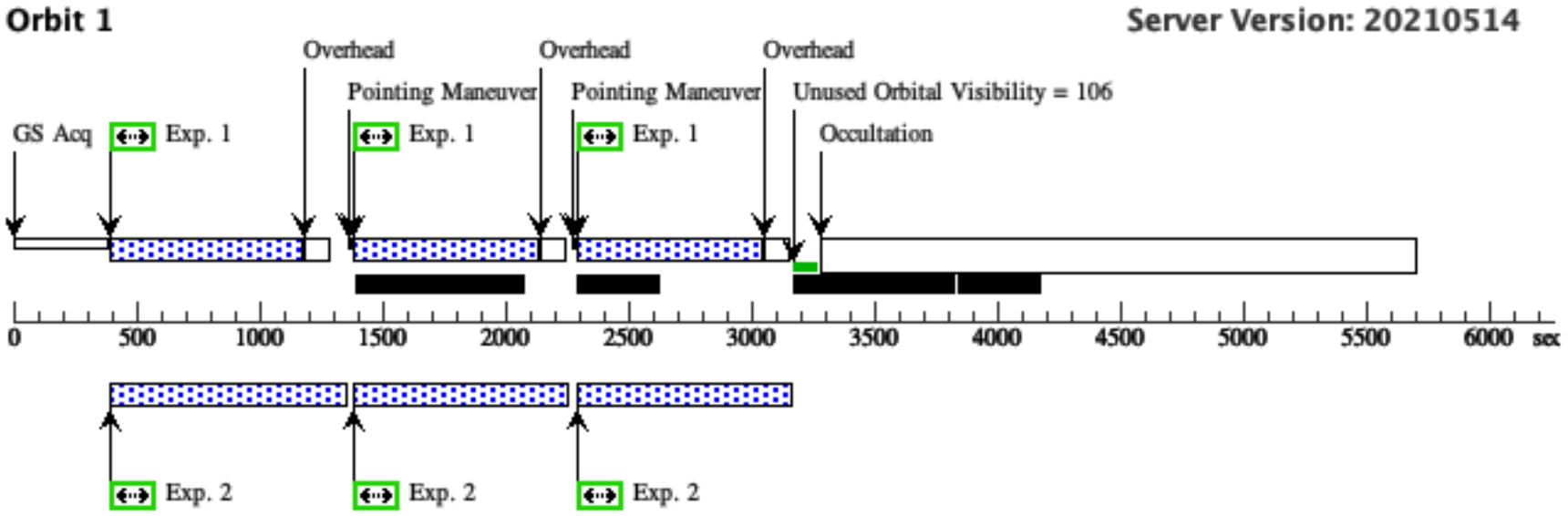
#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	NGC4258	RA: 12 18 49.5600 (184.7065000d) Dec: +47 19 45.45 (47.32929d) Equinox: J2000	Epoch of Position: 2015.5	V=8.41	Reference Frame: SIMBAD

Comments: This object was generated by the targetselector and retrieved from the SIMBAD database. The coordinates were shifted to the location of the Primary observation target to be observed with WFC3/UVIS.
Category=GALAXY
Description=[SEYFERT]
Extended=YES

Exposures

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	(1529726)	(1) NGC4258	WFC3/UVIS, ACCUM, UVIS-CENTER	F300X	FLASH=14	GS ACQ SCENARIO BASE1BE	Pattern 3, Exps 1-2 in Visit 03 (3) Prime + Parallel Group 1-2 in Pattern 3, Exps 1-2 in Visit 03	420 Secs (2250 Secs) *[==>750 Secs (Pattern 1)]* *[==>750 Secs (Pattern 2)]* *[==>750 Secs (Pattern 3)]*	***[1]***
2		(1) NGC4258	ACS/WFC, ACCUM, WFC	F606W			Pattern 3, Exps 1-2 in Visit 03 (3) Prime + Parallel Group 1-2 in Pattern 3, Exps 1-2 in Visit 03	420 Secs (2250 Secs) *[==>750 Secs (Pattern 1)]* *[==>750 Secs (Pattern 2)]* *[==>750 Secs (Pattern 3)]*	***[1]***

Orbit Structure



Visit

Proposal 16688, Visit 04, scheduling Mon Feb 07 16:00:16 GMT 2022

Diagnostic Status: No Diagnostics

Scientific Instruments: WFC3/UVIS, ACS/WFC

Special Requirements: SAME ORIENT AS 03; AFTER 02 BY 5 D TO 40 D

Patterns

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

Fixed Targets

#	Name	Target Coordinates	Targ. Coord. Corrections	Fluxes	Miscellaneous
(1)	NGC4258	RA: 12 18 49.5600 (184.7065000d) Dec: +47 19 45.45 (47.32929d) Equinox: J2000	Epoch of Position: 2015.5	V=8.41	Reference Frame: SIMBAD

Comments: This object was generated by the targetselector and retrieved from the SIMBAD database. The coordinates were shifted to the location of the Primary observation target to be observed with WFC3/UVIS.
Category=GALAXY
Description=[SEYFERT]
Extended=YES

Exposures

#	Label (ETC Run)	Target	Config,Mode,Aperture	Spectral Els.	Opt. Params.	Special Reqs.	Groups	Exp. Time (Total)/[Actual Dur.]	Orbit
1	(1529726)	(1) NGC4258	WFC3/UVIS, ACCUM, UVIS-CENTER	F300X	FLASH=14	GS ACQ SCENARIO BASE1BE	Pattern 3, Exps 1-2 in Visit 04 (3) Prime + Parallel Group 1-2 in Pattern 3, Exps 1-2 in Visit 04	420 Secs (2250 Secs) *[==>750 Secs (Pattern 1)]* *[==>750 Secs (Pattern 2)]* *[==>750 Secs (Pattern 3)]*	 ***[1]***
2		(1) NGC4258	ACS/WFC, ACCUM, WFC	F814W			Pattern 3, Exps 1-2 in Visit 04 (3) Prime + Parallel Group 1-2 in Pattern 3, Exps 1-2 in Visit 04	420 Secs (2250 Secs) *[==>750 Secs (Pattern 1)]* *[==>750 Secs (Pattern 2)]* *[==>750 Secs (Pattern 3)]*	 ***[1]***

Orbit Structure