

# M-Dwarf BOT Procedures

## COS UV Detectors

Andrew Fox

COS team

August 2017

# Motivation

*“M dwarfs are subject to irregular and unpredictable flaring outbursts, which may increase the FUV and NUV light by possibly large factors”*

These training slides provide guidance for PIs on implementing policies on M-dwarf BOT clearance documented in COS ISR 2017-01 by R. Osten:

[http://www.stsci.edu/hst/cos/documents/isrs/ISR2017\\_01.pdf](http://www.stsci.edu/hst/cos/documents/isrs/ISR2017_01.pdf)

# M-dwarf clearance procedures

Table 2: Maximum U band magnitude increases ( $\Delta U$ ) corresponding to flare energies listed in Table 1.

Activity level	Spectral Type						†
	M0-2		M3-5		M6-9		
inactive	P=10 <sup>-2</sup>	-0.07	P=10 <sup>-2</sup>	-0.07	...		
	P=10 <sup>-3</sup>	-1.1	P=10 <sup>-3</sup>	-1.1	...		
	P=10 <sup>-4</sup>	-2.3	P=10 <sup>-4</sup>	-2.3	...		
active	P=10 <sup>-2</sup>	-1.8	P=10 <sup>-2</sup>	-1.8	P=10 <sup>-2</sup>	...‡	
	P=10 <sup>-3</sup>	-2.3	P=10 <sup>-3</sup>	-4.6	P=10 <sup>-3</sup>	-1	
	P=10 <sup>-4</sup>	-2.8	P=10 <sup>-4</sup>	-8.0	P=10 <sup>-4</sup>	-2.8	

† Almost all late M dwarfs are considered active; West et al. (2008).

‡  $\Delta U$  for flare energy  $E_U$  too small, out of range of validity using data from larger flares.

This table shows the maximum U-band magnitude increase as a function of flare probability and spectral type.

Mid M-dwarfs (M3-5) have the largest flares, with  $\Delta U=-8$

# Information needed per star

In order to clear M-dwarf observations, start by gathering this information:

- **U-magnitude** (Johnson system)
  - If unavailable on SIMBAD calculate from B or V using the colors listed here for the given spectral type:  
[http://www.pas.rochester.edu/~emamajek/EEM\\_dwarf\\_UBVIJHK\\_colors\\_Teff.txt](http://www.pas.rochester.edu/~emamajek/EEM_dwarf_UBVIJHK_colors_Teff.txt)
- **H $\alpha$  equivalent width**
  - $EW(H\alpha) > 1 \text{ \AA}$  indicates magnetically active
  - Table 1 in Newton et al. (2017) has  $EW(H\alpha)$  of  $\sim 3000$  northern M-dwarfs. Check for your target:  
<http://adsabs.harvard.edu/abs/2017ApJ...834...85N>
  - If unavailable, assume it is active

If the observation covers Ly  $\alpha$ , the following two items are also needed:

- **Distance to star in pc**
  - $d[\text{pc}] = 1/\text{parallax ["}]$
- **Stellar radius**
  - see table on next slide

# Table of M-dwarf data

Sp. Type	Temperature (K)	Radius ( $R_{\odot}$ )
M0	3800	0.62
M1	3600	0.49
M2	3400	0.44
M3	3250	0.39
M4	3100	0.26
M5	2800	0.20
M6	2600	0.15
M7	2500	0.12
M8	2400	0.11
M9	2300	0.08

from Kaltenegger & Traub (2009)

Note:  $1 R_{\odot} = 6.96 \times 10^{10} \text{ cm}$ ;  $1 \text{ pc} = 3.09 \times 10^{18} \text{ cm}$

# Overall procedure

The next slides describe how to clear M-dwarf COS observations. The following steps are used:

- 1a) clear ACQUISITION in quiescent case (magnitude  $U$ )
- 1b) clear SCIENCE in quiescent case (magnitude  $U$ )
- 2a) clear ACQUISITION in flaring case (magnitude  $U + \Delta U$ )
- 2b) clear SCIENCE in flaring case with continuum only
- 2c) clear SCIENCE in flaring case with emission lines added

In each case the count rates are compared to the flight software limits.

# Step 1: “Quiescent” ETCs

- ETCs with the quiescent magnitude need to be run for the acquisition (1a) and science (1b) exposures.
- For M-dwarf template in the ETC, *use actual data whenever available* (user-supplied spectrum)
  - make sure the input spectrum overlaps the passband of the chosen setting
- Otherwise use black body or Kurucz model (but these do not have chromospheric emission lines) normalized to GALEX NUV (or U) magnitude

# Step 2: “Flare” ETCs

The Flare ETCs follow the guidelines in the ISR, which are:

- NUV observations:
  - Black body at  $T=9000$  K normalized to  $U=U_{\text{quiescent}}+\Delta U$
- FUV observations:
  - Black body at  $T=9000$  K normalized to  $U=U_{\text{quiescent}}+\Delta U$
  - add C IV and Si IV emission from equations 2 & 3 in ISR
  - add Ly  $\alpha$  emission from equation 4 in the ISR

If any ETC calculation exceeds the flight software (FSW) local or global limits listed in the table on next slide (i.e. if there is a  $10^{-4}$  chance of safing the detector), **the observation cannot proceed.**

Flare ETCs have to be performed separately for the acquisition (2a) and science exposures, with continuum (2b) and then with emission lines added (2c). See examples that follow



# Flight Software (FSW) Limits

Detector	FSW global limit (cts/sec)	FSW local limit (cts/sec/pix)
COS/MAMA (NUV)	770 000	56.25
COS/XDL (FUV)	60 000	2.7

**Use these limits** for comparing to all M-dwarf ETC calculations.  
Note the FSW limits are higher than the standard screening limits.

# Example: HIP 17695

- target=HIP 17695 (M3.0V)
- $U=14.052$   $B=13.048$   $V=11.537$  (SIMBAD)
- No  $H\alpha$  EW so assuming active case
- GALEX NUV=18.52
- $T_{\text{eff}}=3400$  K
- $U_{\text{flare}}=U+\Delta U$  where  $\Delta U=-8.0 \rightarrow U_{\text{flare}}=6.05$
- $d=16$  pc,  $R=0.39 R_{\odot}$

In the following slides we go through the ETC calculations for this target.

# 1a) QUIESCENCE ACQ. ETC (ASSUMING NUV IMAGING)

Requested Signal/Noise Ratio = 40.000

gives: Time = 2.4308 seconds

Exposure time calculation **HAD WARNINGS.**

WARNING MESSAGE: Total count rate per pixel 91.3762 exceeds bright limit 50.

## Plots

☐ Input Target Spectrum☐ Throughout☐ Observed Target Spectrum

Detailed Information	Count rate (counts/s)	Total counts (counts)	Associated noise (counts)
Counts (box of 9 x 9 pixels)			
Source	658.322	1,600.23	40.00
Background	0.095	0.23	0.48
Sky	0.028	0.07	0.26
Dark Current	0.067	0.16	0.40
Total in selected region	658.417	1,600.46	40.01
Brightest Pixel (single exposure)	91.376	222.12	
Count rate entire detector	1,531.731		
Extraction region			
box of 9 x 9 pixels			
Area (pixels)	81.00		
Fraction of flux	1.00		
Fraction of flux in brightest pixel	0.14		
Effective Wavelength	3923.56 Å		

**Instrument name:** COS

Mode: ACQ/IMAGE

Detector: NUV

Mirror: Mirror A

Aperture: Primary Science Aperture

**Target: [point source]**

Spectrum: Black body at 3400.0K

Extinction E(B-V): None

Normalization: Renormalized to abmag = 18.52 in filter Galex/NUV

Redshift: None

Emission Lines: None

USE USER-SUPPLIED SPECTRUM WHENEVER POSSIBLE

SWITCH TO MIRRORB NEEDED  
SINCE LOCAL RATE IS >50

Exposure time (seconds) = 1,800.0000 at wavelength 1310.00 Å  
gives: SNR = 0.0003 (per resolution element)

Table of Source and Noise Counts per Pixel

Plots

Total Counts Signal-to-noise Input Target Spectrum Throughout Observed Target Spectrum

Detailed Information	Count rate (counts/s)	Total counts (counts)	Associated noise (counts)
Counts (box 57 pixels high)	(1 pixel)	(8 pix resel)	
Source	3.098e-08	3.35e-04	0.02
Background	1.585e-04	1.71	1.31
Sky	2.389e-11	2.58e-07	5.08e-04
Dark Current	1.585e-04	1.71	1.31
Total in selected region	1.585e-04	1.71	1.31
Brightest Pixel (single exposure) (at 1306.70 Å)	0.004	8.08	
Brightest Pixel in Segment A (at 1306.70 Å)	0.004		
Brightest Pixel in Segment B (at 1191.09 Å)	2.570e-06		
Count rate entire detector	100.690		
Count rate Segment A	57.573		
Count rate Segment B	43.117		

Buffer Time (sec) 23,428

For APT purposes, the recommended buffer time should be 2/3 of the buffer time calculated above. Please refer to Chapter 5.4 in the COS Instrument Handbook for more details.

Encircled energy fraction 1.00

Instrument name: COS  
Mode: spectroscopic  
Detector: FUV  
Central Wavelength: 1280  
Grating: [G140L] Grating (R ~ 2000 - 5,000)  
Aperture: Primary Science Aperture

Target: [point source]

Spectrum: Black body at 3400.0K  
Extinction E(B-V): None  
Normalization: Renormalized to abmag = 18.52 in filter Galex/NUV  
Redshift: None  
Emission Lines: None

USE USER-SUPPLIED SPECTRUM WHENEVER POSSIBLE

## 2a) FLARE ACQ. ETC (ASSUMING NUV IMAGING)

Requested Signal/Noise Ratio = 40.000

gives: Time = 0.0006 seconds

Exposure time calculation **HAD WARNINGS.**

WARNING MESSAGE: Observation countrate 2.55654e+06 exceeds NUV imaging global screening count rate limit of 170000 counts per sec

WARNING MESSAGE: Total count rate per pixel 354726 exceeds bright limit 50.

### Plots

**LOCAL & GLOBAL LIMITS VIOLATED**

☐ Input Target Spectrum

☐ Throughout

☐ Observed Target Spectrum

Detailed Information	Count rate (counts/s)	Total counts (counts)	Associated noise (counts)
Counts (box of 9 x 9 pixels)			
Source	2,555,662.571	1,600.00	40.00
Background	0.095	5.97e-05	7.73e-03
Sky	0.028	1.76e-05	4.20e-03
Dark Current	0.067	4.21e-05	6.49e-03
Total in selected region	2,555,662.666	1,600.00	40.00
Brightest Pixel (single exposure)	354,725.966	222.08	
Count rate entire detector	2,556,535.980		

Extraction region

box of 9 x 9 pixels

Area (pixels) 81.00

Fraction of flux 1.00

Fraction of flux in brightest pixel 0.14

Effective Wavelength 2533.23 Å

**Instrument name:** COS

Mode: ACQ/IMAGE

Detector: NUV

Mirror: Mirror A

Aperture: Primary Science Aperture

**Target: [point source]**

Spectrum: Black body at 9000.0K

Extinction E(B-V): None

Normalization: Renormalized to vegamag = 6.05 in filter Johnson/U

Redshift: None

Emission Lines: None

## 2b) FLARE SCIENCE ETC (CONTINUUM ONLY)

Requested Signal/Noise Ratio = 10.000 at wavelength 1310.00 Å (per resolution element)

gives: Time = 2.5611 seconds

Exposure time calculation **HAD WARNINGS.**

WARNING MESSAGE: Buffer time 42.8531 is less than minimum 80 seconds.

WARNING MESSAGE: Total count rate per pixel 1.18744 exceeds bright limit 0.666667.

WARNING MESSAGE: Segment countrate 5.28e+04 will have a >5 percent reduction in detected countrate due to detector dead-time effects not included in the ETC. See section 4.1.5 of the COS Instrument Handbook for details.

WARNING MESSAGE: Segment countrate 52805.7153265 exceeds segment/stripe global count rate limit of 15000 counts per second for non-variable sources.

### LOCAL & GLOBAL LIMITS VIOLATED

[Table of Source and Noise Counts per Pixel](#)

#### Plots

Total Counts    Signal-to-noise    Input Target Spectrum    Throughout    Observed Target Spectrum

#### Detailed Information

Counts (box 57 pixels high)

Source  
Background  
Sky  
Dark Current

Total in selected region

Brightest Pixel (single exposure) (at 1482.23 Å)

Brightest Pixel in Segment A (at 1482.23 Å)

Brightest Pixel in Segment B (at 1195.45 Å)

Count rate entire detector

Count rate Segment A

Count rate Segment B

PLOT INPUT  
TARGET SPECTRUM  
AND READ OFF FLUX AT  
3650 and 1500 Å,  $f_{3650}$   
and  $f_{1500}$ .

Buffer Time (sec)

42

For APT purposes, the recommended buffer time should be 2/3 of the buffer time calculated above. Please refer to Chapter 5.4 in the [COS Instrument Handbook](#) for more details.

Encircled energy fraction    1.00

Instrument name: COS

Mode: spectroscopic

Detector: FUV

Central Wavelength: 1280

Grating: [G140L] Grating (R ~ 2000 - 5,000)

Aperture: Primary Science Aperture

Target: [point source]

Spectrum: Black body at 9000.0K

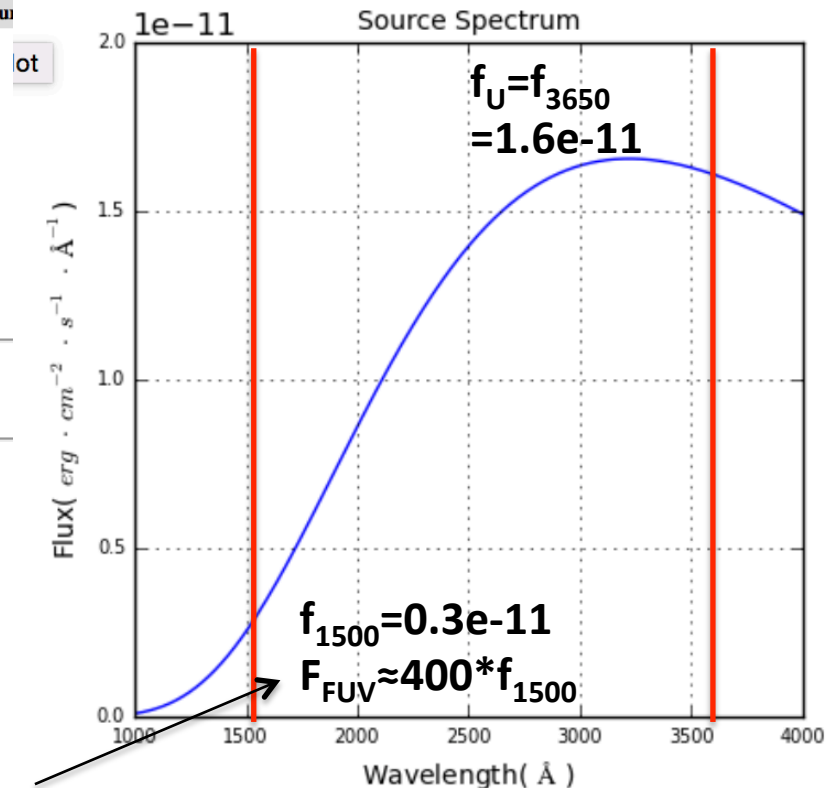
Extinction E(B-V): None

Normalization: Renormalized to vegamag = 6.05 in filter Johnson/U

Redshift: None

Emission Lines: None

Count  
(count)



Factor 400 is because GALEX FUV bandpass is 400 Å wide  
Alternatively, integrate from 1350-1750 Å to get  $F_{\text{FUV}}$

# Calculating line flux (C IV, Si IV, Ly $\alpha$ )

See equations 2-4 in ISR

- $\log f_{\text{C IV}} = 0.32 + 0.92 \log f_{\text{U}}$
- $\log f_{\text{Si IV}} = 2.4 + 1.10 \log f_{\text{U}}$
- $\log f_{\text{Ly}\alpha} = 3.97 + 0.43 \log F_{\text{FUV}} - 1.14 \log (d/R_*)$

Line fluxes ( $f_{\text{C IV}}$ ,  $f_{\text{Si IV}}$ ,  $f_{\text{Ly}\alpha}$ ) are in units of  $\text{erg cm}^{-2} \text{ s}^{-1}$

$F_{\text{FUV}}$  is integrated flux in GALEX FUV bandpass in units of  $\text{erg cm}^{-2} \text{ s}^{-1}$

$f_{\text{U}}$  is flux at 3650 Å in units of  $\text{erg cm}^{-2} \text{ s}^{-1} \text{ Å}^{-1}$

$d$  and  $R_*$  are in same unit

For HIP 17695:

- $\log f_{\text{C IV}} = -9.61 \quad \rightarrow \quad f_{\text{C IV}} = 2.4\text{e-}10$
- $\log f_{\text{Si IV}} = -9.48 \quad \rightarrow \quad f_{\text{Si IV}} = 3.3\text{e-}10$
- $\log f_{\text{Ly}\alpha} = -10.43 \quad \rightarrow \quad f_{\text{Ly}\alpha} = 3.7\text{e-}11$

## 2c) FLARE SCIENCE ETC (CONTINUUM+LINES)

Requested Signal/Noise Ratio = 10.000 at wavelength 1310.00 Å (per resolution element)

gives: Time = 2.5611 seconds

Exposure time calculation **HAD WARNINGS.**

WARNING MESSAGE: Buffer time 31.0882 is less than minimum 80 seconds.

WARNING MESSAGE: Total count rate per pixel 432.505 exceeds bright limit 0.666667.

WARNING MESSAGE: Segment countrate 7.36e+04 will have a >5 percent reduction in detected countrate due to detector dead-time effects not included in the ETC. See section 4.1.5 of the COS Instrument Handbook for details.

WARNING MESSAGE: Segment countrate 73638.1317646 exceeds segment/stripe global count rate limit of 15000 counts per second for non-variable sources.

[Table of Source and Noise Counts per Pixel](#)

**LOCAL & GLOBAL LIMITS VIOLATED**  
**BUFFER TIME ALSO TOO SHORT**

### Plots

☐ Total Counts ☐ Signal-to-noise ☐ Input Target Spectrum ☐ Throughput ☐ Observed Target Spectrum

### Detailed Information

	Count rate (counts/s)	Total counts (counts)	Associated noise (counts)
Counts (box 57 pixels high)	(1 pixel)	(6 pix resel)	
Source	6.508	100.00	10.00
Background	1.585e-04	2.43e-03	0.05
Sky	2.389e-11	3.67e-10	1.92e-05
Dark Current	1.585e-04	2.43e-03	0.05
Total in selected region	6.508	100.00	10.00
Brightest Pixel (single exposure) (at 1393.78 Å)	432.505	1,107.67	
Brightest Pixel in Segment A (at 1393.78 Å)	432.505		
Brightest Pixel in Segment B (at 1195.45 Å)	0.347		
Count rate entire detector	75,880.909		
Count rate Segment A	73,638.132		
Count rate Segment B	2,242.777		

Buffer Time (sec)

31

For APT purposes, the recommended buffer time should be 2/3 of the buffer time calculated above. Please refer to Chapter 5.4 in the [COS Instrument Handbook](#) for more details.

Encircled energy fraction 1.00

**Instrument name:** COS

Mode: spectroscopic

Detector: FUV

Central Wavelength: 1280

Grating: [G140L] Grating (R ~ 2000 - 5,000)

Aperture: Primary Science Aperture

**Target:** [point source]

Spectrum: Black body at 9000.0K

Extinction E(B-V): None

Normalization: Renormalized to vegamag = 6.05 in filter Johnson/U

Redshift: None

**Emission Lines:**

Line at Center 1215.7 Å FWHM 0.5 Å Flux 3.7e-11 Fλ

Line at Center 1393.8 Å FWHM 0.2 Å Flux 3.3e-10 Fλ

Line at Center 1548.2 Å FWHM 0.2 Å Flux 9e-11 Fλ

3 lines added in ETC, note different  
line width for Ly-a (0.5 Å)



# If screening limits are exceeded

- If violation is with COS/NUV ACQ/IMAGE:
  - Investigate offset-star acquisition (if point source within 2 arcmin)
  - Investigate switch to MIRRORB, BOA, or spectroscopic ACQ.
  - Consider a blind pointing (no acquisition) if your observations do not require high flux or wavelength accuracy.
- If violation is with COS SCIENCE:
  - Investigate switch of grating (L to M)
  - Consider substituting a more distant target of same spectral type
  - Consider a switch to STIS. This requires a request to the Telescope Time Review Board (TTRB), submitted online via the Program Status Page under the “Request an observing change” link.
- Target substitutions that do not alter the science goals can be approved within the COS team as minor change requests if no duplication exists. This should be discussed with your Contact Scientist.

# Further Information that can be taken into account when calculating M-dwarf count rates

The following items can be used to clear targets, on a case-by-case basis:

- information about the flare frequency distribution for a particular target
- information about the ISM  $N(\text{H I})$  for a particular target and how that can be used to reduce  $\text{Ly}\alpha$  intensity for a particular target
- information about why the width of the lines should be broader for a particular target

PIs should contact their CS if any of this information is relevant to their program.