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EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

Bright Object Protection Considerations for M Dwarf Flare Events

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Bright Object Protection for Photon-Counting Detectors

Photon-counting detectors on HST have always had bright object protection (BOP) policies in place to eliminate over-illumination of the detector, which can lead to detector damage.

- At high enough levels, leads to detector shutdown, potentially a decrease in quantum efficiency or catastrophic failure, interrupts a carefully built week's worth of planned observations
- At lower levels, extracts charge from the detector and limits the useful lifetime of the detector (c.f. gain sag on COS)

New policy defines an acceptable risk at 10^{-4}, whereas the old policy would not have allowed observations that might have violated limits at maximum.

This is discussed in several ISRs, notably:

Clampin, Kraemer, Kinney STIS ISR 1995-01

Clampin & Kinney, STIS ISR 1996-021

Leitherer et al. STIS ISR 1996-024

Leitherer, Baum, Clampin STIS ISR 1996-028

Leitherer et al. COS ISR 2002-01

Walborn et al. ACS ISR 2006-04

Osten COS ISR 2017-01 (also STIS ISR 2017-02)

Count Rate Limits

Table 7.8: Absolute MAMA Count Rate Limits

STIS IHB

Target	Limit Type	Mode	Channel	Screening Limit
Non-variable	Global	All modes other than 1st-order spectroscopy	FUV & NUV	200,000 counts/s
Non-variable	Global	1st-order spectroscopy	FUV & NUV	30,000 counts/s
Non-variable	Local	Imaging	FUV & NUV	100 counts/s/pix
Non-variable	Local	Spectroscopy	FUV & NUV	75 counts/s/pix
Irregularly Variable	Global	All modes other than 1st-order spectroscopy	FUV & NUV	80,000 counts/s[1]
Irregularly Variable	Global	1st-order spectroscopy	FUV & NUV	12,000 counts/s[2]
Irregularly Variable	Local	Imaging	FUV & NUV	100 counts/s/pix[3]
Irregularly Variable	Local	Spectroscopy	FUV & NUV	75 counts/s/pix[4]

1 Applies to the phase when the target is brightest.
2 Applies to the phase when the target is brightest.
3 Applies to the phase when the target is brightest.
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Table 10.1: COS Count Rate Screening Limits

COS IHB

Detector	Source type	Type of limit	Limiting count rate (counts/s)
FUV	predictable	global	15,000 per segment [1]
		local	0.67 per pixel [2]
	irregular	global	6,000 per segment [1]
		local	0.67 per pixel[2]
NUV	predictable	global	170,000 (imaging) or 30,000 per stripe (spectroscopic)[1]
		local	50 per pixel[3] (imaging) or 70 per pixel (spectroscopic)
	irregular	global	68,000 (imaging) or 12,000 per stripe (spectroscopic)[1]
		local	50 per pixel (imaging) or 70 per pixel (spectroscopic)

1 The global count rate limit for observations using TIME-TAG mode is 30,000 counts/s

2 This local count rate screening limit is not applicable to the 1055 and 1096 cenwaves of the COS G130M grating. For these modes the limiting count rate is 0.2 count/s/pixel for both source types.

3 For imaging acquisitions, a count rate of 360 count/s in the 9×9-pixel box surrounding the target (as computed by the COS Imaging Acquisition ETC) represents an equivalent safe upper limit.

4.1.3 Special Restrictions on Observations with COS, STIS/MAMA and ACS/SBC

The COS, STIS/MAMA, and ACS/SBC instruments employ photon counting detectors and are vulnerable to damage through exposure to bright sources. Consequently, there are a number of restrictions on the use of these configurations. All targets and field objects within the appropriate field of view must pass bright-object safety reviews (see Section 5.1 of the Primer). All Phase I proposals must include a discussion of the safety of the proposed targets and fields in the Description of the Observations (see Section 9.2), based on the relevant Instrument Handbook sections and calculations with the appropriate APT and ETC tools.

Observations of variable sources

Proposals to observe variable objects with the COS, STIS/MAMA, or ACS/SBC detectors must pass bright-object checking before they can be scheduled (see Section 5.1 of the Primer). Proposers should assume the maximum flux values for targets unless there are specific reasons for adopting other values (for example, time constrained observations of periodic variables at flux minima); the justification for adopting alternative flux values should be given in the 'Special Requirements' section of the proposal (see Section 9.3).

In the case of aperiodic variables that are either known to undergo unpredictable outbursts, or belong to classes of objects that are subject to outbursts, the proposer must determine whether the target will violate the bright object limits during outburst. If a violation is possible, the proposer must outline a strategy that will ensure that the target is safe to observe with COS, STIS/MAMA, or ACS/SBC.

A description of how you plan to deal with bright object checking for variable sources must be included in the 'Special Requirements' section of the proposal (see Section 9.3).

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Observers interested in proposing for UV observations of cool stars should keep in mind the possibility that low mass stars may undergo extreme enhancements during stochastically occurring flares. Proposers must demonstrate the health and safety of their targets under these extreme conditions.

In the case of aperiodic variables that are either known to undergo unpredictable flares or outbursts, or belong to classes of objects that are subject to flaring or outbursts, the proposer must determine whether the target will violate the bright object limits during outburst. If a violation is possible, the proposer must outline a strategy that will ensure that the target is safe to observe with COS, STIS/MAMA, or ACS/SBC.

A description of how you plan to deal with bright object checking for variable sources must be included in the 'Special Requirements' section of the proposal (see Section 9.3).

Overlight Limits on Detectors Subject to Health & Safety Restrictions

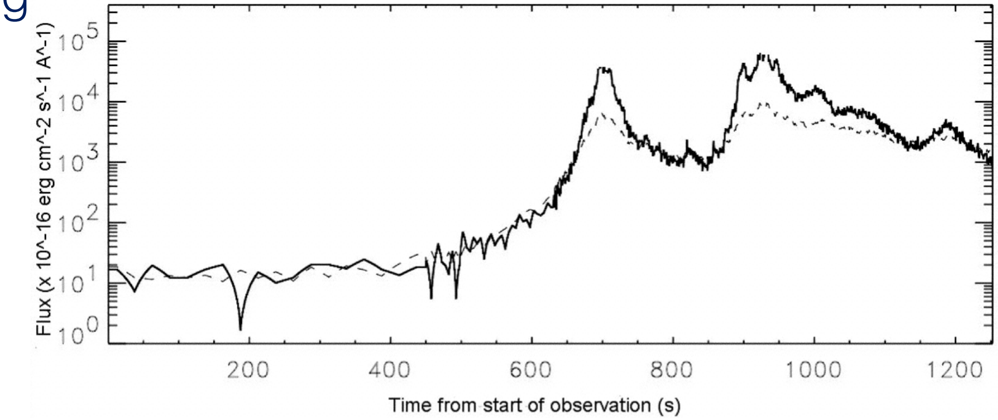
- Hardware and software protection mechanisms to protect from accidental overlight conditions. These mechanisms do not guarantee full protection
- All targets must be screened prior to being cleared for the LRP
- Different limits for non-variable objects and irregularly variable objects; limit for latter is 40% of former to account for uncertainty
- Local Count Rate Limit
    - threshold test over binned area *at beginning of exposure*
    - if the test fails, external shutter commanded to close
- Global Count Rate Limit
    - *continuous monitoring* of number of photons during exposure
    - if the limit is exceeded the high voltage is turned off

Extreme Flares on M Dwarfs

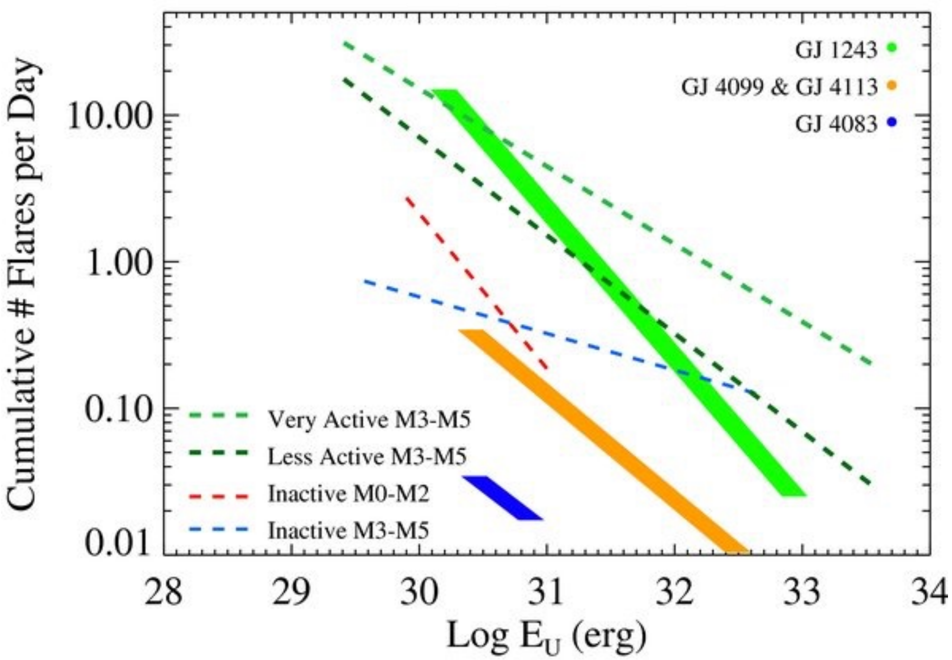
M dwarfs are subject to irregular and unpredictable flaring outbursts. A sampling of recently reported extreme events:

- Robinson et al. (2005) M4V ΔNUV =-7.5 mag
- Osten et al. (2010) M4V Δmag=>-4.7 in white filter, safing of Swift UVOT due to overlight conditions
- Kowalski et al. (2010) M4.5V ΔU=-5.8mag occurring ~once per month
- Schmidt et al. (2014) M8V ΔV=-9
- Schmidt et al. (2016) L0 ΔV<-11

Robinson et al. (2005) large NUV flare with a factor of 1000 flux increase



Flares are not Limited to Magnetically Active M Dwarfs



Hawley et al. (2014)

- Even inactive stars produce flares
- Extreme flares are a continuation of a population of lower level flare enhancements
- The distribution of flare frequency with integrated energy is a power-law
- Hilton (2011) parameterized the flare frequency as a function of magnetic activity status (based on Hα equiv. width) and broad M spectral type bins (early, middle, late)

M Dwarfs are increasingly popular targets for HST

The number of M dwarfs for COS Cycle 24 is greater than the number observed up to this cycle

- From Cycles 17-23, a total of about 20 M dwarfs have been observed with COS
- In Cycle 24 alone there are ~36 M dwarf targets with COS (~170 orbits), out of 863 GO COS orbits in this cycle

M Dwarfs are increasingly popular targets for HST

The need to protect the detectors remains foremost. Users must demonstrate health and safety of their observations, as they always have.

- Additional language inserted into C25 CfP about low-mass star flares
- Strict interpretation of policies would rule out any observations of M dwarfs, since it requires clearance at maximum light
  - This has not been applied uniformly in the past
  - Level of information provided by PIs on detector H&S varies greatly
  - Recognition that extreme flares are expected to be rare, and level of extremeness varies with magnetic activity level and spectral type
  - Risk level of 10^{-4} is used so that with ~100 of these in the remaining lifetime of COS, the chance of an overlight condition is only ~1 percent

Clear and Consistent Guidelines for Evaluating M Dwarf Safety

Osten COS ISR 2017-01 (also STIS ISR 2017-02)

- Use latest research constraining flare rate as a function of magnetic activity status and spectral type
- Assess flare enhancement expected to occur on a flare with 10^{-4} probability
- Use this to establish corresponding global & local count rates
- If the results exceeds detector shutdown limits (much higher than screening limits), observation cannot occur

	flight software global limit (cps)	flight software local limit (cps pix^{-1})
STIS and COS/MAMA	770,000	150 (STIS, dep. on mode) 200 (COS)
COS/XDL	60,000 per segment	2.7

Clear and Consistent Guidelines for Evaluating M Dwarf Safety

Osten COS ISR 2017-01 (also STIS ISR 2017-02)

Information needed:

Targets need to have cleared quiescent screening based on steady flux levels

- Stellar spectral type
- Distance
- Quiescent U band magnitude
- Hα equivalent width. EW (Hα) >1 Å indicates magnetically active star. If unknown, assume worst case
- Stellar radius

Osten's ISR provides directions for how to compute local and global count rates under the extreme flare case.

Mitigation Strategies

Osten COS ISR 2017-01 (also STIS ISR 2017-02)

For targets which fail the screening based on target acquisition (COS):

- Use Bright Object Aperture
- Use Primary Science Aperture dispersed light target acquisition
- Use an offset pointing image acquisition, for reasonably bright nearby stars which are themselves safe to observe

For targets which fail screening based on science exposures:

- Switch off detector segment causing overlight condition
- Switch to a target which passes screening with the same COS configuration
- Switch to STIS configuration which is safe

Implementation in Cycle 24

Framework developed Nov.-Dec., implemented by contact scientists for existing Cycle 24 observations

- 36 targets in current pool affected, 2/3 for science exposures
- Most affected programs still in implementation, awaiting input from PI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