XMM Instrument Modes and Operation

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ABSTRACT

We briefly describe the major instrument modes of operation from which the Guest Observer may select. We highlight how these may be utilised within the context of the integrated Observatory operations, and consider some of the major features and constraints. Finally some overall science-driven observation scenarios are considered, and the typical instrument mode selections which map onto these are summarised.

1. Introduction

The full complement of the instruments of XMM will normally operate simultaneously. This very powerful feature does, however, require the Guest Observer to consider the specification of *six* instrument settings for each observation. This work describes how a limited set of basic modes can satisfy most scientific requirements, and limit the amount of information that must be assimilated to achieve this.

1.1. Observatory Issues

- The selection of the Prime Instrument for an observation defines the requested pointing direction, but it should be noted that the RGS is an on-axis instrument only, and in case an offset-pointing is considered for some reason this would compromise RGS data quality.
- An on-axis target might be observed in a special mode which censors part of the focal plane image field, but it should be recalled that we still obtain data from peripheral areas: this maximises the serendipitous science.
- Each instrument has imaging and timing modes to choose from, with window sizes and time resolutions to suit the science goals. These modes also allow the count rate capability to be optimised
- Count rate capability can also be affected by telemetry (eg. 150 - 1500 events/sec is the range for EPIC, depending on mode)
- Filter wheel choices can be made based on scientific necessity, but there are also some lifetime/calibration degradation trade-offs

2. RGS Modes

The *Spectroscopy* mode will be used for most observations. This provides a 5 s time resolution, where all 9 CCDs are read out, providing energy resolved dispersion data. Figure 1 is representative of a RGS dispersed spectrum image obtained in Spectroscopy mode.

The major alternative the GO might consider is the *High Time Resolution* mode. This is implemented with a 16 ms readout slot for each CCD. So for readout of a full spectrum ~150 ms time resolution is provided. Note that in order accurately to determine the absolute timing accuracy and vignetting corrections, a short SPECTROSCOPY exposure needs to be associated with HTR exposures, in order to determine the spectrum location. Generally pile-up will never be a problem in RGS, except for the very brightest of emission lines. For such cases the appropriate CCD may be read out a multiple number of times per overall cycle.

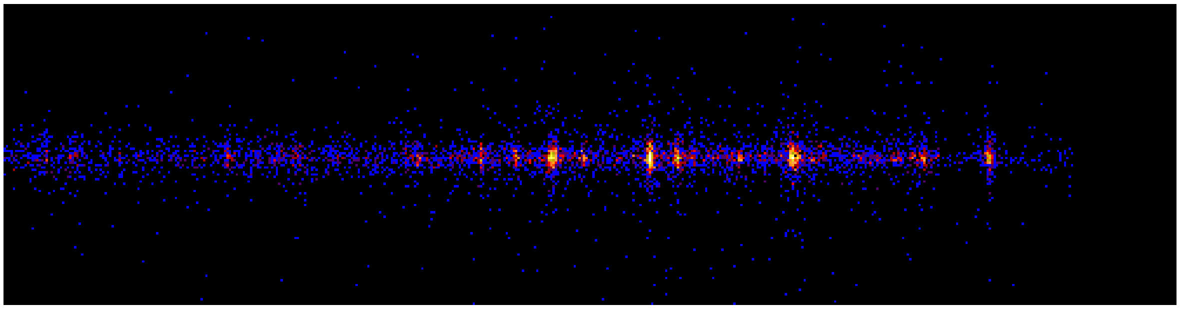


Fig. 1.— Dispersed spectrum from a typical coronal stellar source. Wavelength increases from right to left from about 7 to 35 Angstroms

3. EPIC Modes

3.1. Pile-Up

A major driver for choosing between EPIC modes is the pile-up limit for count rate capability. As a rule-of-thumb, the errors in spectral fitting due to pile-up, exceed the goals for the calibration budget at a piled-up fraction of only a few % (Ballet in press, Lumb et al SPIE 1998). We are developing methods to mitigate these effects by calibration analysis, data and event extraction tools etc., but the observer should be aware that these may not guarantee the science goals are met.

The Users' Handbook quotes count rates which produce 1% pile-up, but there is no simple "pile-up limit" - the data simply become lost or the apparent spectrum changes. For example, Figure 2 shows a simulation for a $E^{-1.7}$ spectrum that is observed at varying count rates in EPIC MOS, and shows how the fitting is affected by pile-up. Taking the results of such simulations, we expect that ≤3 - 4% pile-up should be achieved in order to maintain the calibration goals.

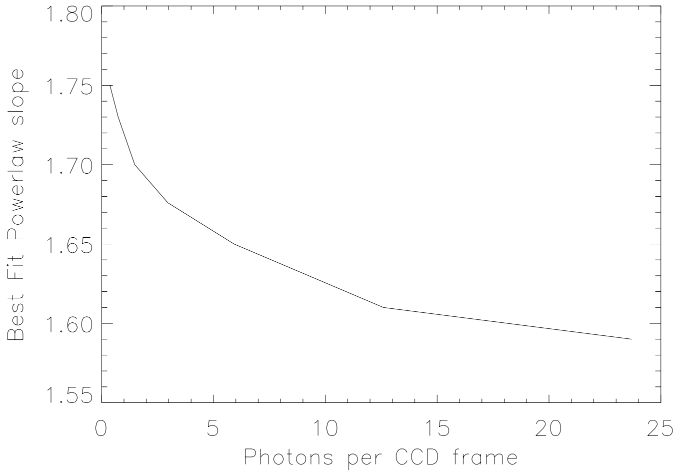


Fig. 2.— Changes in spectral fitting parameters due to pile-up effects from a point source in the EPIC MOS camera

Figure 3 compares pile-up fraction versus flux in EPIC and AXAF ACIS cameras for reference. This shows that in the equivalent full-frame modes, unless corrections are applied, XMM should be more robust against pile-up than AXAF. For both EPIC and ACIS, restriction of a window to accelerate the CCD read out improves the count rate capability, but EPIC preserves its count rate advantage over ACIS. The following sections describe the different modes, and how they perform with respect to pile-up.

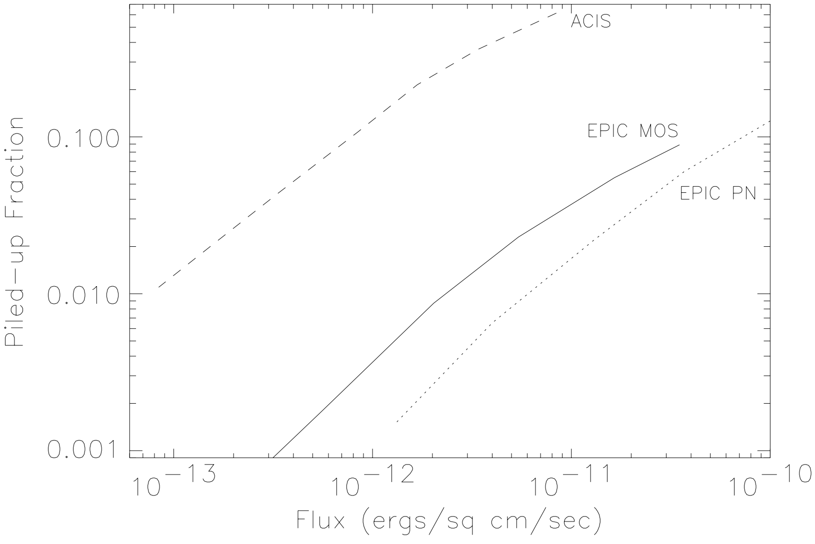


Fig. 3.— Comparing Pile-up in AXAF and XMM instruments

Figure 4 displays the typical images that would be returned from a selection of EPIC PN operation modes. Note the logarithmic scaling is responsible for highlighting a small amount of smearing of out-of-time events in the vertical direction.

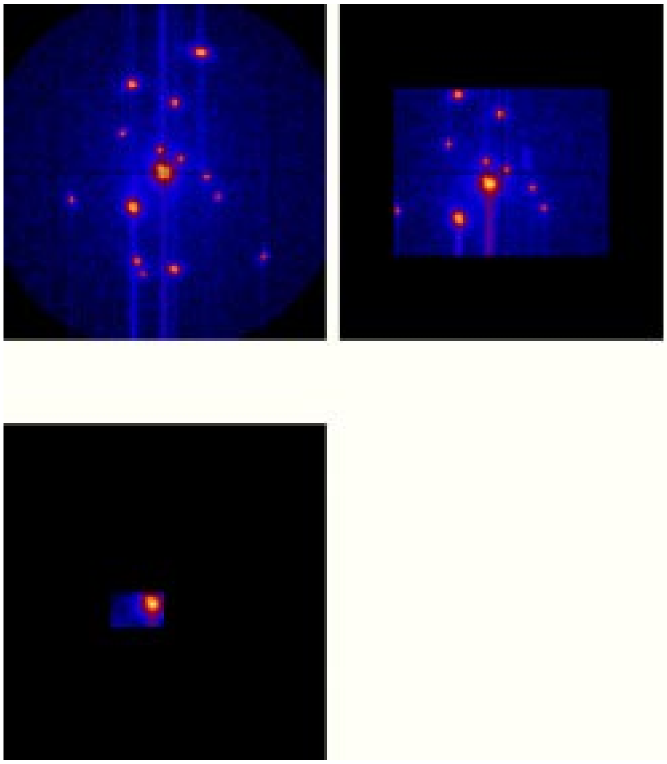


Fig. 4.— Top Left: Full Frame Image of stellar cluster. Top right: Large Window mode of same field -note this now also accounts for expected off-centering of the PN camera. Bottom left: Small Window mode for the bright on-axis object

Figure 5 displays the image that would be returned from a selection of the EPIC MOS Full Window operation mode. The bright source in the centre might require a windowed operation, so Figure 6 displays the typical image that would be returned from a selection of small partial window mode. Note the outer CCDs retain full coverage of the rest of the field.

For FAST mode, only a 1-d image is obtained from the CCD in the timing mode of readout, where the displacement in apparent vertical direction is converted to a time information (Figure 7). Again the remaining CCDs provide coverage of the outer field.

Instrument Mode	No. of CCDs	Total Pixels	Time Resolution	Point Source Flux (mCrab)
Full Window	12	400 x 384	75 ms	2
Large Window	8	200 x 256	45 ms	3
Small Window	1	64 x 64	6 ms	20
Timing	1	1 x 64	40 μs	650
Burst	1	1 x 64	7 μs	6300 (low live time)

Table 1: PN Mode characteristics.

Table 2: EPIC MOS modes summary.

Mode	Pixels (in central CCD)	Time resolution	Point source Flux (m Crabs)
Full Window	600x600	2.7 s	0.25
Partial Window	300x300	1.5 s	0.5
Partial Window	100x100	0.4 s	2
Timing	1x100	1.5 ms	35

3.2. EPIC Filter choices

An optical blocking filter is used to prevent stray and focussed visible light from degrading the noise and energy scale. It is used in conjunction with an on-board offset table calculation.

- The thick filter suppresses optical contamination for point source targets up to m_v of 1 - 4 (MOS) or m_v of 0 - 3 (pn).
- The medium filter blocking is 10^3 less efficient than thick filter, so we expect this filter useful for point sources as bright as m_v = 8 - 10.
- Thin filter blocking is 10^5 less efficient than thick filter, so it is limited to point sources 13 magnitudes fainter than the thick filter

The open filter should only be used when trying to detect the very softest photons in the bandpass. The diffuse zodiacal light alone will produce measurable optical light contamination, compromising the energy response. In addition the CCDs could become contaminated with ice and hydrocarbons on a time scale of about one day, leading to a loss of calibration and a necessity to initiate a bake-out and re-calibration sequence. Therefore observations in the open position are not recommended by the SOC as a *routine* operation. The GO must supply strong scientific arguments that the response to the softest photons around 0.1 keV is crucial for the proposed investigation and, moreover, that the expected visible light contamination is expected to be minimal, by checking the optical catalogues for the source field .

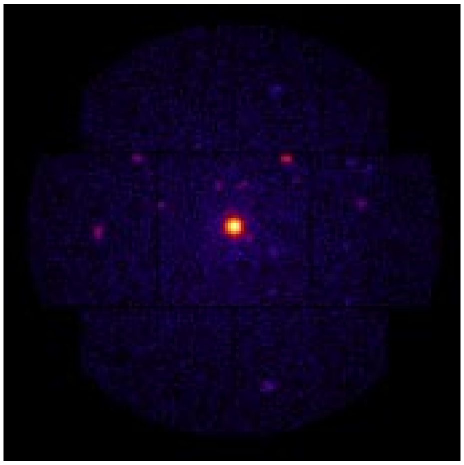


Fig. 5.— MOS Full Window mode

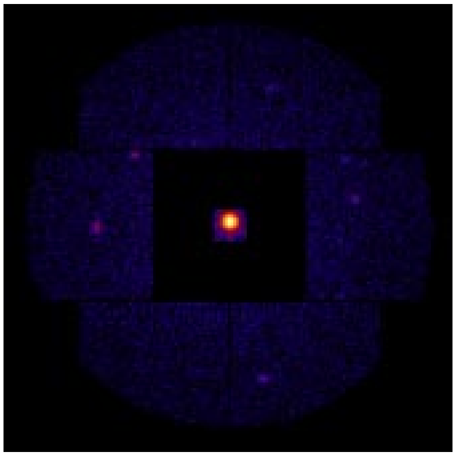


Fig. 6.— MOS Partial Window mode

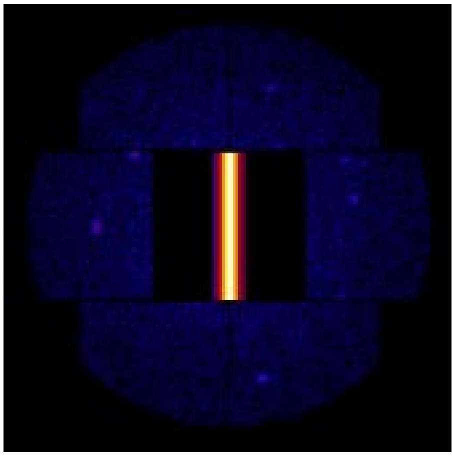


Fig. 7.— MOS Timing mode

4. OM Modes

The basic image mode is implemented by taking sequential windowed areas and filter wheel positions to perform multi-colour photometry covering up to the full 17 arc min field of view

Selected small areas can be programmed for a *Fast* mode, in which time resolved "event lists" are produced at ∼50 ms resolution, simultaneously with an imaging window.

A specific filter wheel sequence must be adhered to, ensuring that the filter wheel rotations are minimised for lifetime reason.

A set of default modes have been defined to satisfy detailed constraints (see for example the technical note on the XMM web site and the Users' Handbook explanation - XMM-PS-TN-26 from $http://astro.estec.esa.nl/XMM/tech/socdoc_top.html$). Figure 8 shows how the default image mode covers the field of view in 5 sequential exposures, while maintaining a small window on a central target of interest.

4.1. OM Modes caveats

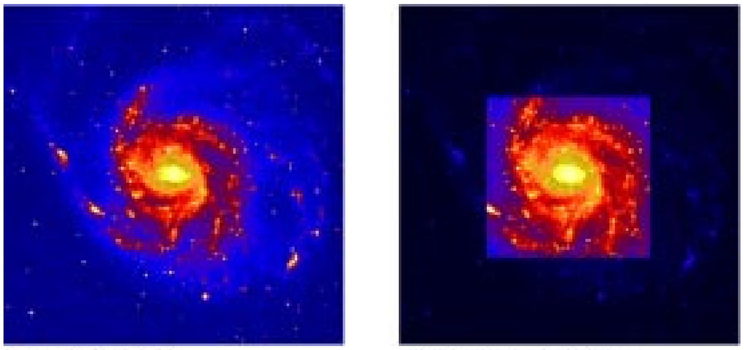
- Setting of arbitrary window sizes and locations is in principle possible. However without a knowledge of spacecraft roll constraints this cannot be easily achieved
- Essentially such requested observations may become fixed-time and inefficient or impractical to schedule
- The photometric linearity is limited by the CCD framing rate, so that stars with count rates greater than ∼10 photons/sec are affected (typically $m_v \sim 13$ -14)
- A safety issue is the photocathode gain degradation, which would depress sensitivity (locally) for exposures following a bright point source. This limit depends critically on filter wheel position, but is typically $\sim m_v = 9$

4.2. OM Filter choices

The filters will be chosen for science driven reasons, such as to obtain multi-colour photometric images. The default exposure time is 1ksec, but the observer may change the required exposure times to suit detection of different spectral types. For example the following table shows the length of time required to make a 5σ detection of an object with $m_v = 23$ mag

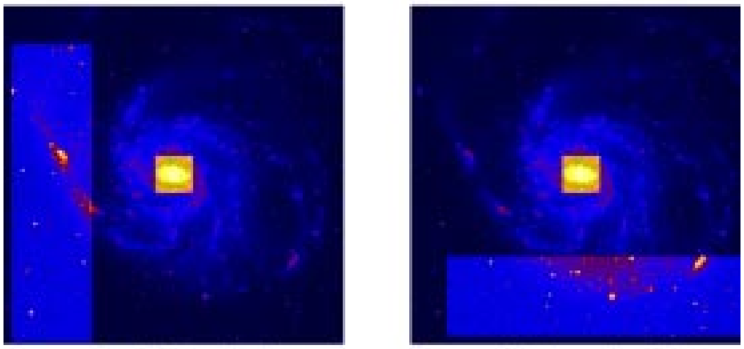
Filter	B0	A0	G0
U	340	2100	6400
B	750	980	2400
V	4300	4400	4700
White	70	370	1300

Table 3: Time to make 5σ detection of a magnitude = 23 star vs. OM filter selections (seconds)



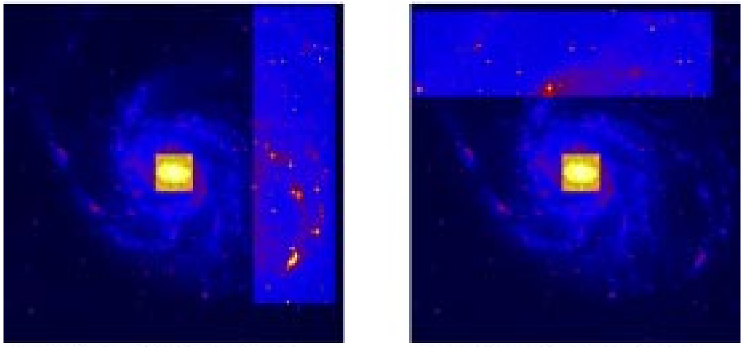
M101 OM Full Field

Exposure 1 – FOV Centre



Exposure 2– left edge+ Centre

Exposure 3– bottom edge+ Centre



Exposure 4– right edge+ Centre

Exposure 5– top edge+ Centre

Fig. 8.— OM Window sequences of default modes

5. Typical Observing Scenarios

The following tables summarise some typical observing scenarios that cover a very wide range of scientific cases, with suggested instrument modes and some key summary parameters.

Table 4: Faint Extended Source Imaging

Instrument	Mode	Time Resolution	Constraints
EPIC PN	Full Window	75 ms	
EPIC MOS	Full Window	2.7 s	
RGS	Spectroscopy	5 s	Energy resolution degraded
			Depending on source extent
OM	Imaging	1000 s (typically)	Choose filter wheel x no. windows

Table 5: Bright Extended Source Imaging

Instrument	Mode	Time Resolution	Constraints
EPIC PN	Full Window	200 ms	Full window + extended integration time
EPIC MOS	Partial Window	1.5 s	5.5 arcmin window
RGS	Spectroscopy	5 s	Resolution degraded
			Depending on source extent
OM	Imaging	1000 s (typically)	Choose filter wheel x no. windows

Table 6: Bright Point Source Imaging

Instrument	Mode	Time Resolution	Constraints
EPIC PN	Small Window	5 ms	4.4 arc min window
EPIC MOS	Partial Window	0.4 s	1.8 arcmin window
	or Timing	1.5 ms	No imaging
RGS	Spectroscopy	5 s	On axis
OM	Imaging	1000 s (typically)	Choose filter wheel x no. windows

Table 7: Bright Point Source with Timing

Instrument	Mode	Time Resolution	Constraints
EPIC PN	Timing	40 μs	No imaging
EPIC MOS	Timing	1.5 ms	Imaging of outer CCDs
RGS	HTR	150 ms	
OM	Fast	50 ms (typically)	Can be in addition to imaging windows

5.1. Points regarding set-up time

The whole observation duration is longer than the sum of the basic set of exposure durations: There are overheads, associated with setting up the instruments. EPIC cameras require time to calculate and set up the offset tables. This is automatic but we note that if the filter chosen is too transmissive, there may be systematic light leak effects, and the process of uplinking replacement or default tables may add additional overheads.

RGS diagnostic data is obtained in a special “Q mode”, so that the offset calculation is not required to be performed. The “HTR” mode *may* need an extra set-up exposure.

The OM requires several minutes between the setting of filter positions and acquisitions for locating the window exposures.

6. References

J Ballet, submitted to **Astron & Astrophys**, 1998

D H Lumb et al, **Proc SPIE** v 3445 in press 1998