Suggestions for Survey/Default UV Observing with the Optical/UV Monitor on XMM

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ABSTRACT

I discuss possibilities for acquiring serendipitous ultraviolet observations using the Optical/UV Monitor on XMM. I briefly describe the science goals for acquiring this data and make suggestions for optimizing the observations to these ends. I discuss pointed and diffuse background levels and potential safety issues for the instrument. I conclude that the UV bands potentially offer the most useful serendipitous science data, but that at least two color imaging of each field is highly recommended to maximize the ability to discriminate between sources. Wid field of view coverage, either by binning or image mosaic is preferred in most cases.

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1. Introduction

Two main areas have been mentioned for acquiring serendipitous UV data with the Optical/UV (OM) monitor on XMM. One is to do a slew survey and the other is to prescribe a default mode of observing for XMM which would be used when the XMM observer has not specified a mode. The main questions are whether there is significant science to be gained from these activities and to evaluate the impact of implementing either of these programs as part of general XMM operations. I concentrate here on the science case and solicit input on the difficulty or ease of implementing this program from an operations point of view which may be added in subsequent revisions.

I describe in this report some of the science which could be done with suitable UV data from the Optical monitor, the backgrounds and noise sources which will affect these measurements and some safety issues for the experiment. At the end I conclude with some recommendations and specific courses of action for pursuing these observations.

1.1. Technical documents referenced

XMM-PS-TN-26 - Constraints on the OM Window Configuration - R. Much

2. Science

Independent of monitoring the X-ray targets which OM was designed to do, the most useful and interesting data that will come from the OM will come from images taken with the UV filters and the UV grism. The data gathering potential of the OM at visual wavelengths does not compare favorably with groundbased instruments owing to its smaller size. The main uses of the OM in the visual will be monitoring and identification of X-ray sources. At UV wavelengths not accessible from the ground, there is much less data available, and significant contributions independent of the X-ray instruments may be made.

There are three UV filters, called UVW2, UVW1 and UVM2, with central wavelengths 1900 Å, 2100 Å and 2500 Å respectively, with bandwidths of a few hundred Å. The maximum field of view of the OM is square, 17 minutes on a side and is digitized by the detector and electronics to 2048 by 2048 pixels, making a pixel size of 0.5". The instrumental resolution is just over 1". Because of memory and telemetry limitations the maximum allowed exposure window is roughly 700 by 700 pixels. Hence the maximum size exposure at full resolution would only cover about 10% of the area of the full field. One has the option of binning pixels together to cover more of the available sky area, at the cost of poorer pixel resolution. Binning may be applied by either the detector electronics or the DPU; which makes sense operationally is being discussed at this time but binning at any of the following levels will be possible. Binning by a factor of 2 in each direction would yield 1" digitization pixels and a field 11.62 arcminutes on a size. Binning by a factor of 4 in each direction yields 2" pixels and covers the whole 17' x 17' OM field of view. Hereafter, I will use 'full field' to mean the latter selection of binning and field size. Another option to cover more of the available OM field of view is to take separate exposures, each covering part of the the field, although only a fraction of the total available observing time could be alloted to each subsection, leading to a brighter limiting magnitude in the image. A complete description of windowing constraints is given in R. Much's technical note XMM-PS-TN-26.

It is useful to categorize the kinds of UV science to be done as Galactic or extragalactic.

The distinction is that for extragalactic observations, Galactic point source and diffuse emissions are essentially noise in the observation, whereas for Galactic science, the same emissions could be the primary targets of interest. As a result, the most useful extragalactic pointings will be ”out of the galaxy”, i.e. at high N or S galactic latitudes. At lower latitudes, the large number of Galactic sources will pose a formidable barrier to extracting extragalactic data. For these reasons, the Galactic coordinates of a given observation will be the strongest input in the recommendations given in Section 6.

A brief description of some of the science which can be done with UV data from the optical monitor follows. It is pointed out where certain kinds of observations are favored. One conclusion that should be stated here is that more than one color observation of any given field will be very useful and possibly essential for object identification and stellar background identification.

2.1. Galactic Science

2.1.1. Measuring and understanding UV stellar populations

While our understanding of visual emissions from the Galactic stellar population is fairly mature, the UV emissions are not as well understood. Some reasons for this is that the most massive stars and several types of evolved stars emit preferentially in the UV. Extinction by dust is also strongest in the UV, complicating the picture. Figure 1, taken from Cohen et. al 1994, shows the fit of a UV stellar population model to stellar number count data at 1500 A at two locations in the galaxy (Figure not in e-version draft). Note that data does not go fainter than 14th magnitude and there are significant differences between the model and the data in the higher galactic latitude fit. This paper was based on observations at just 13 galactic locations. Similar work has been pursued by Brosch et al., in a number of papers (e.g. Brosch et al. 1995). More OM full-field images at many galactic locations would significantly improve the data available for this work since they would be at much higher resolution and sample many more Galaxy locations. Even short exposures of the OM will go several magnitudes deeper than current UV data sets. This will make it possible to take exposures in more than one UV filter to test models at different wavelengths.

An image near the plane of the Galaxy to 22nd magnitude or fainter will be very crowded. Here, the problem is much more likely to be stellar confusion than a lack of serendipitous sources. For images near the Galactic plane, not binning, or binning only 2x2 should be considered to reduce the limitations of source confusion while a greater field of view covered by taking separate mosaic images. The preferred binning factor and exposure time for each mosaic piece should be determined by the time needed to reach the confusion limit. Thes question should be decided by detailed simulations. Before these are completed, my guess is that 2x2 binning represents a reasonable compromise to maximizing the area covered while minimizing source confusion. For exposure times greater than 8000 seconds, no binning and a mosaic of 4 exposures in two filters would cover the area while minimizing confusion.

The slew survey would be very useful for contributing to this type of investigation.

2.1.2. Measuring Galactic diffuse radiation

The primary source of diffuse radiation in the galaxy is starlight scattered from dust in the interstellar medium. This radiation has been studied in an attempt to understand the distribution, scattering and absorption properties of the dust and other emission mechanisms that give rise to it, such as hot gas or H_2 fluorescence. The dust-to-gas ratio is also investigated. A well-developed model for this emission has been produced by A. Witt (publication in preparation) and all-sky predictions for the emission have been produced. However, these predictions have gone untested over the vast majority of the sky because the amount of sky that has been observed in the UV is so small. The UV wavelength of the model predictions is 1600 Å.

The data desirable for this type of study are full frame images in the short wavelength OM UV filter (UVW2). Separating the stellar emission from the diffuse emission will be possible in images binned 2" x 2", and the wide field coverage is desirable. The resolution of most diffuse surveys is much larger than 2", so the loss of resolution should be inconsequential for this work. At low Galactic latitudes, the diffuse emission is quite bright, and short exposures are capable of measuring it to high precision. This allows more than one filter to be covered.

For a low-latitude direction, one can measure the diffuse brightness with the OM to a statistical uncertainty of less than 2% in 500 s in the UV filters. For high latitude fields where the diffuse intensity is lower, one will measure the diffuse brightness to about 4% in 1000 s in the UV filters. The times will be much shorter at V. These accuracies would be very adequate for diffuse studies, and supports taking exposures in more filters where possible. We note that the minimum exposure time for an OM exposure is about 1000 s, owing to the time it takes to telemeter an image to the ground.

The slew survey would be very useful for contributing to this type of investigation.

2.2. Extragalactic science

2.2.1. Measuring UV properties of nearby galaxies

The basic observational properties of nearby galaxies have not been well established in the ultraviolet. Recent systematic studies (e.g. Deharveng et al. 1994) of these properties use databases of only a few hundred galaxies. The UV - visible spectral energy distribution of galaxies is one of the fundamental observables for galactic astronomy; measuring this observable at the present time for different types of galaxies is significant constraint in studies of galaxy evolution.

There have been only a few UV instruments that have gathered a significant number of measurements on nearby galaxies. Systematic correlation of the UV properties with the optical properties, typically using an optical galaxy catalog such as RC3, reduces the usable set of galaxies by half or more. When the galaxy set is further subdivided into RC galaxy types, this may leave only a few galaxies in certain subtypes. Hence, there currently exists an inadequate galaxy database on which to base firm statements about galactic UV observables. This lack is especially important because for studies of distant galaxies, which are typically measured in optical/near IR bands, the light emitted from the galaxy started out in the ultraviolet.

Observations of individual galaxies to 1150 Åare proceeding with the Hubble Space telescope. OM can contribute if we identify all the galaxies serendipitously in the field of XMM observations and measure their UV properties. A similar program has been carried out by Hill et al. 1997 using HST WFPC images. While the HST has a much larger collecting area than OM, the UV efficiency of WFPC is less than OM, and OM's larger field of view make it competitive for this work.

2.2.2. Measuring the evolution of more distant galaxies

Light received from galaxies near 1500 Å is primarily from B and A stars. Since these stars do not live very long, the UV light from galaxies is an indicator of the current rate of star formation in galaxies, and in general, the UV brightness of galaxies has been diminishing with time. When galaxies with significant redshift are observed, this star-formation sensitive band will be visible in different OM ultraviolet bandpasses, allowing direct measurements of the amount of galaxy evolution that has occurred. Another advantage to working in the ultraviolet compared with the visible band is that the stellar source background is signifigantly lower, by about a factor of 10, making the job of separating galaxy light from stars significantly easier.

Measuring the evolution of galaxies requires sampling enough galaxies at different and especially distant redshifts to draw meaningful conclusions about the differences seen. The largest redshifts also provide the most lever arm for measuring evolution. For this reason, deep exposures are preferred for this work. Secondarily, more than one waveband would be useful for color measurements and object discrimination. These considerations argue for a long exposures at the shortest wavelength when XMM is pointing away from the Galaxy, and additional exposures in UVW1 and UVM2 as time allows. A two color approach, with one UV exposure and one B or V exposure will be very helpful in separating galaxies from stars.

2.3. Surveying and identification of X-ray sources

The maximum usefulness of the SSC depends on ending up with a set of combined X-ray and optical/UV observations. There is an argument for taking at least one and possibly two OM full field images at each XMM pointing to maximize survey data. Even short OM exposures of 1 Ks in two colors would be a great help to discover and analyze non-targeted X-ray sources. Using Table 4 of Much et al. 1997, OM should detect objects fainter than B=23 in a 1000 second image with the B filter, with a similar limit at V, and only a slightly brighter limit at the shortest wavelength UVW2 filter. We should think very strongly of *requiring* a short (1000 s or less) full-field B or V observation as a default unless this would seriously degrade an observer's program or EPIC is not functioning in an imaging mode. Note that from the numbers in Section 2.1.2, this exposure would well determine the diffuse intensity. For exposures at low galactic latitude, we could consider covering the entire OM field in an unbinned configuration with several separate exposures if observing time allowed. Each partial OM field exposure need be no longer than 500 or 1000 seconds (XMM minimum exposure time still TBD) depending on the band. The U band is not suitable for this work because the blocker will obscure part of the field.

The case for a second OM color is not quite as strong, but for long observations where the tax would not be severe on a percentage basis, a second observation at UVW2 could be considered. From a serendipitous science viewpoint, UVW2 is the second observation is preferred. Note that both filter images can be combined together to provide maximum sensitivity to faint point sources. For Galactic pointings, source confusion will limit the usefulness of a deeper image, and the exposure time could be reduced to 500 s (or the minimum telemetry time required) per exposure. High resolution is not as important as covering a larger fraction of the EPIC field. The above arguments suggest requiring two colors in a full-field 2" x 2" binned image or a mosaic of 1" images if time allows (these spatial resolutions still well exceed that of EPIC).

The tradeoffs of whether higher resolution vs. deeper images are more useful for Galactic survey images should be decided either by simulation or in-flight experience. What we should do now is establish the tools necessary to routinely acquire binned or unbinned data covering the maximum field of view, given a limiting exposure time.

A final consideration for acquiring survey data is to utilize the OM windowing possibilities to cover more field than the observer requests. For example, if the observer requested only a small window around their prime target, another science window could be set up even at different binning, to cover more of the OM field. The size of the serendipitous window would be limited by total memory to 700 x 700 pixels less the size of the observers window. The filter would be set by the observer. *However, this method of obtaining survey data even where the observer requests OM data may very effectively increase the usefulness of OM.* Technical implementation of this possibilitity should be evaluated by the SOC.

3. Backgrounds

The chief backgrounds in OM images will be from zodiacal light, bright stars, diffuse galactic light, and the instrument. Obviously, depending on what is being studied, a particular source may be a background or desired target. Each of these are location and wavelength dependent, which makes it undesirable to simply set global guidelines for serendipitous observing. However, two main distinctions which can be drawn are whether the observatory is pointing ”in the Galaxy” or ”out of the Galaxy”, and whether an observation is near the plane of the solar system where zodiacal light may be significant.

3.1. Stars

The observed number density of stars drops rapidly as a function of photon energy, i.e. there are a lot more G stars than B stars. This suggests that in areas where stellar confusion is a problem, i.e. in the Galactic plane, UV filters will be substantially less confused. Simulations of OM images can be viewed at http://xmmom.physics.ucsb.edu/xmmom/pseudo_images.html. These simulations indicate that OM fields will be very crowded for most observations. Distinguishing between objects in the fields will almost certainly require more than one color. This will be true both for identification of X-ray sources and for serendipitous UV science. The upshot of this is that *wherever possible, a second OM color should be obtained.* This would most likely mean an exposure at B or V that reaches the same limiting magnitude as the UV image. Because of the response of the OM, this can be accomplished in about 1/2 the time, the exact number TBD following OM calibration.

Also because of the high source density we expect in OM images, the grisms will most likely NOT be useful for serendipitous work owing to the difficulty of reducing crowded-field grism data.

3.2. Diffuse Backgrounds

The two main diffuse backgrounds that will affect the detection of point sources are diffuse Galactic light and zodiacal light.

3.2.1. Diffuse Galactic light

Outside of HII regions, DGL arises primarily from starlight scattering off dust in the ISM. It varies strongly with Galactic latitude, being a factor of about 50 times brighter in the Galactic plane than when looking away from the plane. It has only a small wavelength dependence, following the Galactic spectral energy distribution.

Since we are discussing serendipitous observations with pointings determined for other reasons, considering the above properties, this background will be difficult to minimize. It will contribute substantially to noise in observations near the Galactic plane. Suggestions for the *observing* this light are discussed in Section 2.1.2, above.

3.2.2. Zodiacal light

Zodiacal light is sunlight reflected from interplanetary dust and shows a spectrum similar to that of the sun. Since XMM is constrained to point only at large angles from the sun, the variation of zodiacal light across the sky is not dramatic, about a factor of 2-3 from its brightest to its faintest. However, the variation with wavelength is dramatic, as is shown in Table 1. The zodiacal light is a factor of 500 lower in the shortest wavelength band than in the visible and is a factor of 10 lower than the faintest levels of diffuse UV Galactic light.

These data indicate that studies of diffuse emission are best performed in the UV bands, especially UVW2. The lower level of diffuse background in the UV may also improve point source detection, depending on the source spectrum.

4. Safety

The primary safety issue for the OM is whether there are stars in the FOV sufficiently bright in the observing filter to damage the detector. The detector utilizes a microchannelplate-intensified CCD. The intensifier stage is subject to gain and sensitivity losses when small areas of the detector are over-illuminated regardless of whether this portion of the detector is being read out. The exact illumination limits are still being measured and the final stellar magnitude limits will depend on the overall throughput of the OM optical system.

A determination of whether the stellar brightnesses in a field pose a safety threat to the detector will have to be made prior to any OM observation. The considerations for serendipitous exposures are not different than for ordinary observations so we can use and should use the same safety mechanisms that are already in place. Currently, a check is done of the FOV by XMM operators that no star in the field of view exceeds a filter-dependent brightness limit.

Safety determination is equally relevant for serendipitious fields and should certainly be included in this mode of operation.

4.1. OM Detector lifetime issues

The OM detectors will gradually lose sensitivity over time because the gain of the microchannelplates degrades with total charge extracted and the reflectivity and photocathode efficiency are likely to diminish with time. If the nominal plan is be to have OM switched on and observing for each XMM observation, suggesting default modes to maximize the scientific gain from the OM makes the best use of the limited resource of OM detector lifetime. Depending on the rate of degradation experienced during the mission, the science team could consider switching the OM off unless requested by the observation PI. Performing the UV sky survey would be an additional burden on the detector, shortening its overall lifetime by a fractional amount equal to the ratio of slew time to observation time. Rough estimates from the SOC put this number at 10 - 15%. Given the large value in the UV survey, my view is that this additional use of the OM is very worthwhile.

5. Telemetry and Instrument Limitations

For serendipitous observations, one would naturally want to include as much of the OM field of view as possible at the maximum resolution. However, constraints against this ideal scenario arise both from telemetry limititions and processing of images in the OM electronics.

A thorough discussion of these limitations are given by R. Much in XMM-PS-TN-26. An important conclusion of this work is that a maximum of about 490,000 pixels may be acquired in an image cycle. This would translate to a square image of about 700 pixels on a side although this exact format may not be possible. The full OM field is 2048 pixels so that only about one tenth of the area of the detector may be observed at full resolution. By binning pixels four to one, about 1/2 of the area of the full field can be covered in a single exposure.

This size image will take approximately 1000 seconds to telemeter to the ground, thus setting the minimum useful exposure time. It is possible that crowded Galactic fields in visual filters may become highly confused even in 1000 s; an observation time shorter than the telemetry time may be desired in some instances to avoid confusion. Exact recommendations will have to wait until instrument performance is verified in flight.

This pixel limit significantly limits the ability of OM to do serendipitous science. I encourage us to think about ways to increase the spatial coverage possible in OM images.

6. Recommended Observations

The above discussion has covered a variety of topics and many different considerations. Because of the large number of conflicting constraints, it is probably not possible to come up with an *optimum* set of recommendations, but I believe the following are reasonably based on maximizing the science XMM can do.

I summarize in Table 2 the constraints and indications which the above areas suggest for serendipitous observations and follow these with summary recommendations.

*Full field refers to binning detector pixels 4 to 1, which will typically be accomplished at the DPU level.

I note that these recommendations are based on pre-launch and pre-calibration performance estimates for the OM. This subject should be reviewed after launch to take into account in-flight performance information and periodically thereafter.

7. Comments on UV Sky Survey

1. The UV sky survey could potentially gather a large amount of useful UV data.
2. An OM slew survey would reach about 5 magnitudes fainter than the previous survey.
3. Real-time raw data mode necessary for survey is expected to be implemented in OM-DPU.
4. Should be done early in the XMM mission, while performance of OM detector still good.
5. NASA has selected a UV Small Explorer called GALX, that is expected to launch in September, 2000. GALX will perform a sky survey to magnitude 21 or below, in two UV bands, (roughly comparable to OM UVW2 and UVW1). We have the opportunity to get good results before this mission if we begin early.

8. Summary of Conclusions and Open issues

From the above discussion, we conclude that:

1) Obtaining a UVW2 image and a B or V image would be very useful for serendipitous science

2) In most cases, wider field of view coverage is preferred. This is either an OM image binned to 2" pixels to cover the whole field or a mosaic of shorter exposures with less

Table 1: The relative brightness of the zodiacal light in different OM filters.

Filter	Wavelength (Å)	Normalized Solar Brightness Factor	Zodiacal Light $[ph cm^{-2} s^{-1} \AA^{-1} sr^{-1}]$
V	5500	1	6.6×10^4
B	4200	0.9	4.5×10^4
U	3600	0.53	2.3×10^4
UVW1	2600	0.07	2000
UVM2	2200	0.02	500
UVW2	1900	0.0054	125

Table 2: Summary of discussions for OM serendipitous observations

Consideration	Comments	Argues for
1. UV Galactic stellar populations		full-field* 3 UV filters, shortest first as time allows
2. Study of diffuse emission		full field; UVW2 and UVW1 most useful
3. Nearby galaxies	observe at higher latitudes	long UVW2, UVW1 and short B or V, full field
4. Galaxy evolution	long, deep, high-latitude exposures needed	long UVW2, UVM2; shorter B or V, full field
5. SSC Surveying	shorter exposures ok in Galaxy mosaic unbinned images if time	B (1000s) UVW2 (1000s) full field
6. Stellar discrimination	Two colors essential; not U	
7. Zodiacal light	Avoid with UVW2 and UVM2	
8. Safety	short exposure first?	
9. Telemetry/Memory limits	Bin to cover larger area	
10. Minimize stellar confusion	in Galaxy only	cover maximum area with all exposures $T < 1000s$

binning. An algorithm to decide which method is preferred can be based on the data below.

8.1. Open Issues

There are a number of open issues which need further discussion, simulations or decisions.

1. Should any OM images be *required* for typical XMM observations to maximize survey and serendipitous science?

2. Which is the preferred visual band filter, V or B?

3. Short exposure implementation. Is there a way to implement a 500 sec exposure for the optical filter? This would allow for a higher resolution, non-confused image mosaic in the Galaxy.

3. How would the "OM default mode" observations be implemented?

3.1 An OM default configuration to maximize the serendipitous science can be implemented for the cases where a GO selects from the OM configuration menu "don't care", or uses a window and filter configuration that leaves room for another large serendipitous science window

3.2 To implement the latitude dependent filter sequence we will need a new PHS tool (which calculates the galactic coordinates) and selects the adequate, predefined filter sequence and exposure times.

Table 3: Recommendations for OM serendipitous configurations

Galactic Longitude	Observing Prescription	Exposure Times
$\|l\| < 30$	full-frame: UVW2; B; UVW1; UVM2	30% : 20% : 25% : 25% for $T_{total} \leq 5000s$
	use full or half res. and mosaic field	30% : 20% : 25% : 25% if $T_{total} > 16Ks$
$\|l\| > 30$	full-frame: UVW2; B	70% : 30% if $T_{total} < 30Ks$
	add UVW1 if time	40% : 20% : 40% for $T_{total} > 30Ks$
all?	full-frame: B; UVW2	1000 s; 1000 s

3.3 Should we think of ammending the SSC follow-up tick box to reflect that we should set up the OM to support imaging ID studies via the default configuration?
4. The SSC should input its recommendations for field coverage vs. depth for their expected science, taking into account confusion, loss of information owing to loss of resolution, etc. This document emphasizes UV serendipitous science. If possible, the result should be a simple algorithm the SOC can implement.

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