OPTICAL MONITORING OF VARIABLE SOURCES FROM SPACE: THE OMC ONBOARD INTEGRAL

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ABSTRACT

The high-energy ESA mission INTEGRAL, which is to be launched in the year 2001, will carry an Optical Monitoring Camera (OMC) onboard designed for the study of the optical behaviour of gamma-ray targets. The OMC will additionally provide the needed tool for analysing the photometric V variations of many sources from space in the field of 5° × 5°. These sources will of course also have simultaneous X-ray and gamma-ray measurements.

Key words: space astrometry; optical photometry; variability; CCD detector.

1. INTRODUCTION

The photometric information provided by Hipparcos and Tycho, with limiting magnitudes 12.4 and 11.5, respectively, has been found to be very rewarding in the study of many types of variable stars. Light curves with more than 100 points and a median photometric precision in V_T of 0.06 mag have been produced for a large number of stars in addition to the measurement of their astrometric properties.

The OMC, onboard INTEGRAL mission, will observe the optical emission from the prime targets of the gamma-ray instruments with the support of the X-ray monitor. This capability will provide invaluable diagnostic information on the nature and the physics of the sources over a broad wavelength range.

The currently defined operational modes will allow relatively long and continuous monitoring periods of up to two weeks in comparison with Tycho and Hipparcos, which were combined measurements taken at very different epochs to build the light curves. On the other hand, the time resolution of the OMC will be down to few seconds, allowing the study of short period events. The magnitude limit of the OMC is close to $V = 19.5$ mag for low background noise. The same median photometric accuracy of Tycho will be obtained with the OMC for variable sources of $V = 14$ mag using 15 s integrations, or $V = 16$ mag using 2 min integrations.

The expected number of variable stars within the OMC field of view at low galactic latitudes is close to 25 including eclipsing binaries, pulsating and eruptive stars. Among them, of particular interest will be the monitoring of flare stars within radius of 100 pc, with astrometric distances. A number of around 10^4 flares per year is expected to be measured by the OMC.

In addition to its operation as a scientific instrument, the OMC will provide accurate pointing information to the high energy instruments. For this purpose, to select the monitoring windows from the CCD chip to be transmitted to the ground station, and to standarize the photometric measurements, the Hipparcos and Tycho catalogues will be used by the OMC.

2. SCIENTIFIC OBJECTIVES

The two main scientific objectives of the OMC are:

- to monitor during extended periods of time the optical emission of all high-energy targets within its field of view, simultaneously with the gamma- and X-ray instruments. This will allow the determination of the optical lightcurves for comparison of variability patterns with the hard X-ray and gamma-ray measurements;
- to provide simultaneous and calibrated standard V filter photometry of the high-energy sources. This will allow the comparison of their behaviour with previous or future ground-based optical observations;

But, the OMC will also be able:

- to provide the brightness and positioning of the optical counterparts of gamma-ray or X-ray transients detected by the other instruments taking place within its field of view;
- to monitor optically variable sources within its field of view in a serendipitous way which may require long periods of continuous photometry for their physical interpretation, allowing to deliver at the end of the mission a catalogue of

thousands of variable sources with a well calibrated optical monitoring, covering periods of minutes to weeks and months;

- to search for optical flares or transient events occurring in stars catalogued as variables or previously unknown as such;
- as a by-product, the OMC will provide every few seconds the pointing of the platform with an accuracy around 10 arcsec. This information will be used for improving the on-ground image reconstruction capabilities of the high-energy instruments.

3. CAMERA DESIGN

The Optical Montoring Camera (OMC) consists of an optical system focused onto a large format CCD detector working in frame transfer mode (Figure 1). The optics is based on a refractive system with entrance pupil of 50 mm, focal length of 154 mm, and a field of view of 5 × 5 square degrees. A double Gauss system with radiation resistant glasses has been adopted. After optimisation of the main aberrations, high resolution has been reached while keeping reasonable manufacturing tolerances.

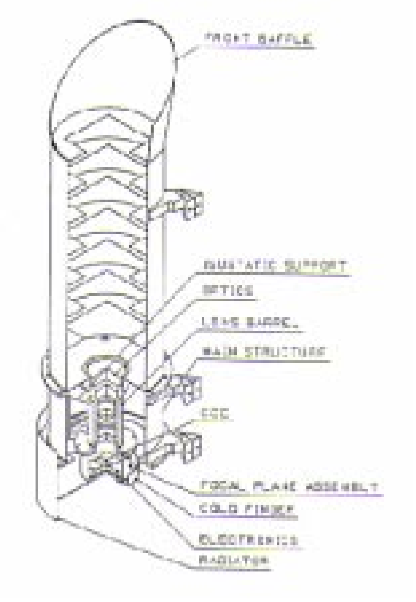

Figure 1. Layout of the OMC camera unit.

The CCD (1024 × 2048 pixels) uses one section (1024 × 1024 pixels) for imaging and the other for frame transfer before readout. The frame transfer time will be around 0.8 ms so that the need for a mechanical shutter is avoided. The selected chip for the OMC is EEV CCD 47-20, with an imaging area of 13.3 × 13.3 mm and 1024 × 1024 pixels. It requires a full qualification program for space applications which will be carried out by the OMC consortium. The CCD head will be cooled by means of a passive radiator to an operational temperature of $-90°$ C. The OMC camera includes also the CCD readout electronics, the necessary power conditioning electronics and the corresponding interface with the standard dedicated DPE (Data Processing Electronics) of the spacecraft. The readout will allow the extraction of only given sections from the CCD intead of the complete frame in order to permit, when needed, fast monitoring or the comparison of subframes. The scientific performance and additional parameters of the OMC are summarized in Table 1.

4. PHOTOMETRIC PERFORMANCES

The photometric accuracy and limiting magnitude are critical functions of design parameters like the aperture, optical throughput, readout noise, source confusion, pixel size, etc. By photometric accuracy we understand the minimum variation of a given source that can be measured at 3σ level.

With the current OMC design, we will be able to measure variations in V smaller than 0.1 mag for objects brighter than 18 mag and smaller than 0.02 mag for objects brighter than 16 mag. The limiting magnitude of the OMC depends mainly on the amount of background light produced by the stellar contribution and scattered sunlight. At 3σ level, for a minimum level of expected background (outside the galactic plane), the limiting magnitude will be $m_{\rm V} = 19.2$ mag for 10 integrations of 100 s each. This will be the standard observing mode of the camera. For maximum expected background level, within the galactic plane, the limiting magnitude will not go further than $m_{\rm V} = 18.4$ mag.

In Table 2, we show the expected error expressed in magnitudes of a measurement for given integration times and magnitudes. These values have been derived from the signal-to-noise ratio obtained by comparing the expected count rate from the target source and the uncertainties in the total counts, dark counts and read-out noise. Concerning the levels of the background, minimum and maximum values were considered in Table 2 for the stellar and zodiacal light contributions. What we learn from this table is that very good V photometry can be performed with the OMC for objects of different brightness. For the faintest optical sources to be observed by INTEGRAL, around magnitude V = 19 mag, measurements with enough accuracy can be obtained in a relatively short span of time compared to that devoted to the high-energy observations. Several individual points can be produced during the gamma-ray measurements in the optical and thus light variations as small as 0.3 magnitudes can be detected in those objects. In brighter sources, like many of the objects to be observed by INTEGRAL, fast photometry can be obtained with the OMC as well as very accurate photometry of few mmag. In Figure 2, we show the limiting magnitude that can be achieved for different exposures times (assuming that up to ten images are added to increase the signal to noise ratio). Curves are shown both for the best and the worst expected background levels.

The values presented for the photometric accuracy (Table 2) and the limiting magnitudes also include the effect of source confusion (Figure 3), since the stellar contribution to the background was used to determine the expected number of counts per pixel and the noise of the measurements. Consequently,

Table 1. OMC Scientific performances

Parameter	Baseline value
Field of view	$5^\circ \times 5^\circ$
Aperture	50 mm
Focal length	154 mm (f/3.1)
Optical throughput	> 90 per cent at 550 nm
Straylight reduction factor (within UFOV)	$< 10^{-4}$ (for diffuse background)
Point spread function	> 70 per cent of energy within 1 pixel
CCD pixels	1024 × 2048 (1024 × 1024 image area) (13 × 13 μm per pixel)
Image area	13.3 × 13.3 mm
Angular pixel size	17.6 × 17.6 arcsec^2
CCD Quantum efficiency	90 per cent at 550 nm
Full well capacity	150 k electrons per pixel
Frame transfer time	~0.2 ms
Time resolution	> 1 s
Typical integration times	10 – 100 s
Wavelength range	V filter (centered at 550 nm)
Limit magnitude (10 × 100 s, 3σ)	19.7 (V)
Sensitivity to variations (10 × 100 s, 3σ)	$\Delta < 0.1$ for mag. < 16
Average number of stars per pixel ($m_V < 19.5$)	0.6 (full sky); 2.0 ($b = 0^o$) < 0.1 ($b > 40^o$)

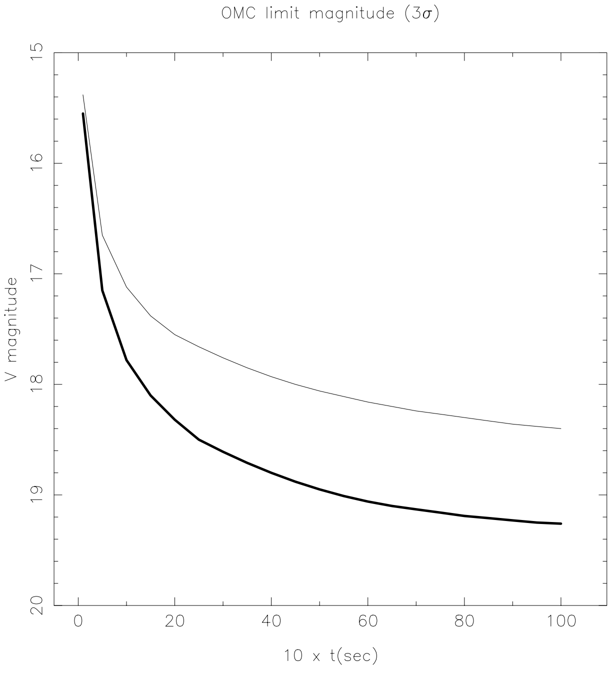

Figure 2. OMC limit magnitude as a function of exposure time, computed for highest (top line) and lowest (bottom line) background levels.

there is a close relation between the numbers obtained above and the number of stars per pixel at the limiting magnitude, also referred to as source confusion.

Table 2. Photometric accuracy of the OMC versus magnitude. Top: minimum background level; bottom: maximum background.

Time(s)	8	10	12	14	16	18
1	0.015	0.037	0.101	0.356	-	-
10	0.005	0.012	0.030	0.080	0.285	-
50	-	0.005	0.013	0.035	0.112	-
100	-	-	0.009	0.025	0.080	0.40
5x100	-	-	0.004	0.011	0.036	0.17
10x100	-	-	0.003	0.008	0.025	0.12
50x100	-	-	0.001	0.003	0.011	0.05

Time(s)	8	10	12	14	16	18
1	0.015	0.037	0.104	-	-	-
10	0.005	0.012	0.031	0.097	-	-
50	-	0.005	0.014	0.042	0.191	-
100	-	-	0.010	0.030	0.135	-
5x100	-	-	0.004	0.013	0.060	0.36
10x100	-	-	0.003	0.010	0.043	0.25
50x100	-	-	0.001	0.004	0.019	0.11

5. THE OMC CATALOGUE

The OMC will primarily monitor all the main targets observed by the high-energy instruments. But, the OMC will also study all the targets of interest in its field of view within its photometric range. To optimize its operations, a catalogue will be compiled before launch containing:

- all known optical counterparts of gamma-ray sources;
- all known optical counterparts of X-ray sources;
- all known AGNs;

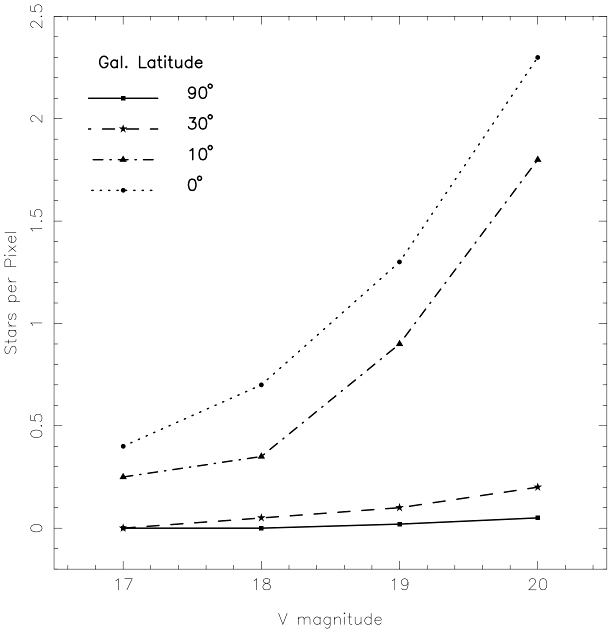

Figure 3. OMC source confusion as a function of galactic latitude.

- all known late-type stars;
- all known erupting variable stars, including novae and cataclysmics;
- additional variable objects which might require optical monitoring;
- any other source of interest discovered during the mission lifetime.

Hipparcos and Tycho reference stars will also be included for positioning and photometric calibration.

The OMC Catalogue will therefore provide a complete set of optical lightcurves of thousands of objects. These lightcurves will have been obtained in an homogeneous way, covering both large and short time periods, and will be futhermore simultaneous to the X-ray and gamma-ray lightcurves.

During the mission, additional sources of interest will be added to the catalogue: newly discovered optical counterparts of high-energy sources and newly discovered supernovae, novae and erupting variables. In addition, every transient event detected with both JEM-X and OMC will be added regularly. The photometry of the standard stars observed by the instrument will also be checked regularly to reject possible variables which previously were unknown.

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