

## SPICAM Technical Note TN-31

The Calibration factors of the SPICAM UV spectrometer channel.

Version 1.2

*Version 1.2 : Update of G(HT), JF Daloze, 5 December 2007*

*Version 1.1 : Minor corrections, A. Reberac, 20 January 2005*

*Version 1.0 : Initial Issue, Jean-Loup Bertaux , 17 January 2005*

### 1. Introduction

This paragraph is intended to allow to convert the signal of the UV detector (ADUs) into a physical photometric quantity:

- spectral flux (Photons/(cm<sup>2</sup>.s.nm), for a point source
- spectral intensity for an extended source Photons/(cm<sup>2</sup>.s.str.nm),

The detector is a combination of an image intensifier with a CCD. The readout of the CCD is in ADU (Analog to digital Units).

A photoevent is defined as a pulse of light triggered in the phosphor of the intensifier by the creation of a photoelectron at the cathode of the intensifier. It creates in the CCD a number G of ADU (spread over a few pixels). The gain G, defined as the number of ADU/photoevent, can be controlled by the High Voltage put on the MCP of the intensifier. The High Voltage is described by the data parameter HT (in the header of each data record) . This is the so-called “pseudo-counting “ technique.

### 2. Response to a stellar source.

We observe a star with no slit put in place in the spectrometer.

Let  $F_s(\lambda)$  be the spectral flux of a given star (in photons/(cm<sup>2</sup>.s.nm)):

The number of ADU which is recorded in one spectel (spectral pixel) and which is assumed to contain the whole stellar flux (the spectel is the binning of several CCD lines) is:

$$N(\text{ADU}) = F_s(\lambda) S_{\text{ent}} R_{\text{mir}}(\lambda) R_{\text{grat}}(\lambda) QE(\lambda) G \frac{d\lambda}{dt} \quad (1)$$

Where:

$S_{\text{ent}}$  is the area of the entrance of the spectrometer = 16 cm<sup>2</sup>

$R_{\text{mir}}(\lambda)$  is the reflectivity of the parabolic mirror, a function of wavelength  $\lambda$ .

$R_{\text{grat}}(\lambda)$  is the reflectivity of the spherical holographic grating, a function of wavelength

$QE(\lambda)$  is the quantum efficiency of the CsTe cathode of the intensifier (including the loss of the MgF<sub>2</sub> window).

$\frac{d\lambda}{dt}$  = 0.543 nm, the wavelength interval covered by one spectel  
the integration time in seconds.

As is usually done, we define  $S_{\text{eff}}$ , the efficient area of the instrument, as:

$$S_{\text{eff}}(\lambda) = S_{\text{ent}} R_{\text{mir}}(\lambda) R_{\text{grat}}(\lambda) QE(\lambda), \text{ in cm}^2. \quad (2)$$

Therefore, we get:

$$N(\text{ADU}) = F_s(\lambda) S_{\text{eff}}(\lambda) G(\text{HT}) d\lambda dt \quad (3)$$

Consequently, when observing a star, in order to know its spectral flux from a SPICAM UV measurement, we apply the formula:

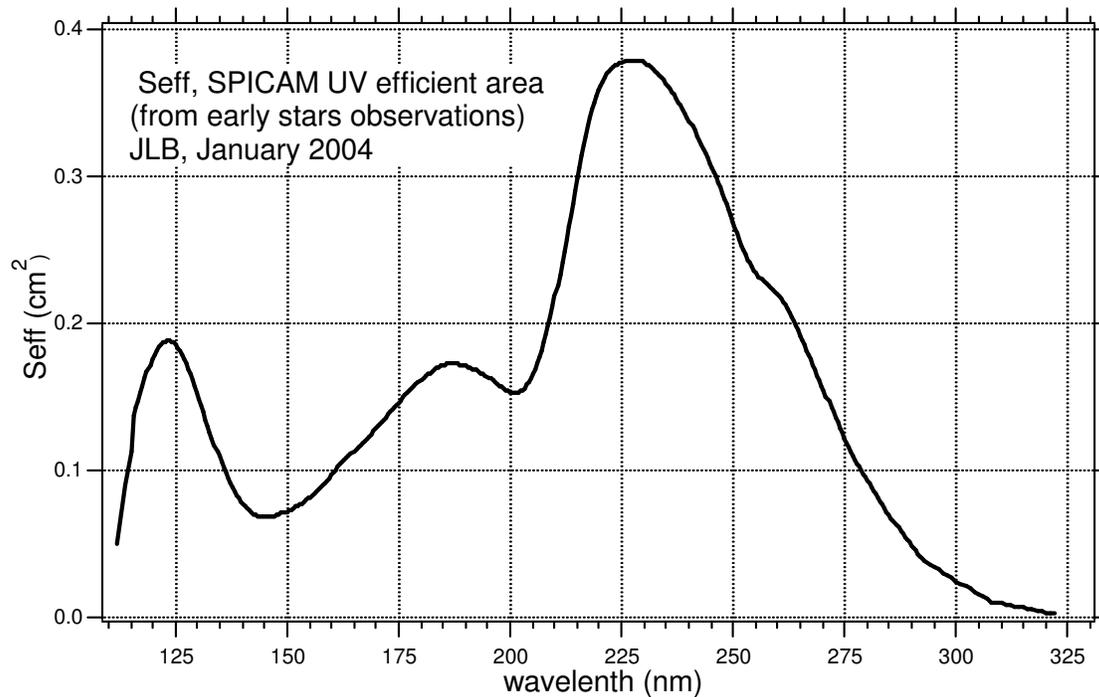
$$F_s(\lambda) = N(\text{ADU}) / (S_{\text{eff}}(\lambda) G(\text{HT}) d\lambda dt) \quad (4)$$

One has to find  $dt$  from header of each data record,  $d\lambda = 0.543$ ,  $S_{\text{eff}}(\lambda)$  is contained in the calibration file `SPICAM_UVSEFF.DAT` and  $G(\text{HT})$  is given as a formula in the documentation `SPICAM_CALIBRATION.TXT` file.

### 3. Instrument calibration data.

#### 3.1. Efficient Area

$S_{\text{eff}}(\lambda)$  was obtained from some early star observations, including delta Scorpio. It was prolonged to both ends of the spectrum by using the data sheet from Hamamatsu on  $QE(\lambda)$ , in Igor experiment: `extension calibration spicam UV.pxp`



*Figure 1.  $S_{\text{eff}}$ , SPICAM UV efficient area (from early stars observations by comparison with IUE data base on delta Scorpio essentially (Aurelie Reberac), with extension by Bertaux in December 2003.  $S_{\text{eff}}(\lambda)$  is contained in the calibration file `SPICAM_UVSEFF.DAT`*

### 3.2 Curve of the gain G(HT)

The literature indicates that the number of electrons  $g_p$  coming out from a MCP (for one electron at the entrance) is a function of the High voltage  $V$  applied to the MCP:

$$\ln g_p = a \ln V + b$$

Since the light of the phosphor, and therefore the number of ADU produced in the CCD is proportional to  $g_p$ , we have a relationship of the same form:

$$\ln G(\text{HT}) = a' \ln V + b' \quad (5)$$

The science engineering data (from 0 to 255) to code the level of HT is Htnum:

In Spicam we have the relation:

$$V = 500 + \text{Htnum} * 1.57 \quad (6)$$

We have determined the values of  $a'$  and  $b'$ , and the number of ADU per photoevent  $G(\text{HT})$  is:

$$\text{Gain} = \exp(7.46113 * \ln(500 + 1.57 * \text{HTnum}) - 46.3864) \quad (7)$$

Here is a table for some values often used with SPICAM (when Htnum=0, the intensifier is not operated).

HTnum	G(HT)
0	0
1	1.0
10	1.2
20	1.5
40	2.4
60	3.6
80	5.2
200	37.3

Some caveats:

1. The signal from a star may depend on which portion of the intensifier the image of the spectrum is formed. In particular, there is a portion of the detector which is covered by a window of  $\text{SiO}_2$ , opaque below 160 nm. The curve  $\text{Seff}$  given here is for a star which is centered on the nominal position (as if there was a slit), and we have ignored all sorts of PRNU (Pixel to pixel non uniformity).
2. The signal of a star extends over several lines of the CCD, because of PSF of the parabolic off axis telescope and scattered stray light. The value of  $\text{Seff}$  here is representative of a band of 10 CCD lines binned together. Other values of  $\text{Seff}$  are representative of smaller or large bands (but not very much different).
3. Many more star observations are available; the extensive comparison will be done, from IUE catalogues and from other sources (Rottmann's experiment SOLSYICE/UARS and SOURCE)

#### 4. Extracting the flux and error bar.

In formula (4), the number of ADU is the raw data minus the DC of the CCD. Ignoring the error that could be done there, the Error bar on the number of photoevent comes from a modified Poisson Statistics. From one spectel reading of the CCD given in ADU, the number  $n$  of photoevent for this reading is given by formula (7). The Poisson law gives a  $\sigma = \sqrt{n}$ ; the modified Poisson law comes from the fact that not all photoevent give the same number of ADU, but there is an exponential distribution; as a result, the error is in reality:

$$\sigma = \sqrt{2n} \quad (8)$$

#### 5. Response to an extended source.

Let  $I(\lambda)$  be the spectral intensity of a given extended source (in photons/(cm<sup>2</sup>.s.str.nm)): In practice, the mode of SPICAM operation is with a slit, of width 50  $\mu\text{m}$  or 500  $\mu\text{m}$ , depending on the place on the CCD.

The number of ADU which is recorded in one spectel (spectral pixel) (the spectel is the binning of several CCD lines) depends on the solid angle  $d\omega$  subtended by the lines of the CCD which are binned together to form a band spectrum (which is what is transmitted to TM):

$$N(\text{ADU}) = I(\lambda) \text{Sent} R_{\text{mir}}(\lambda) R_{\text{grat}}(\lambda) \text{QE}(\lambda) G d\lambda dt d\omega \quad (9),$$

or with the definition of  $\text{Seff}$ :

$$N(\text{ADU}) = I(\lambda) \text{Seff}(\lambda) G d\lambda dt d\omega \quad (10).$$

The focal length of the parabolic mirror is  $f=120$  mm. The CCD pixel size is 23  $\mu\text{m}$ .

One line of the CCD subtends a solid angle of  $50 \times 23 / (120000)^2 = 7.986 \text{ e-}08$  steradian.

and 10 times larger for the wide slit.

Therefore, if a measurement is made with a band of  $P$  CCD lines ( $p=1,2,4,8,16,32$ ), the intensity is:

$$I(\lambda) = N(\text{ADU}) / (\text{Seff}(\lambda) G d\lambda dt p d\omega) \quad (11)$$

with units of photons/(cm<sup>2</sup>.s.str.nm).

For those who are more familiar with Rayleigh and KiloRayleigh, remember that :

$$\text{One Rayleigh (R)} = 10^6 / 4\pi \text{ photons}/(\text{cm}^2.\text{s.str}), \quad (12)$$

$$\text{One kiloRayleigh (kR)} = 10^9 / 4\pi \text{ photons}/(\text{cm}^2.\text{s.str}),$$

And one can get from (11) and (12) the spectral intensity in Rayleigh per nanometer.