

## SPICAV Technical Note TN

The Calibration factors of the SPICAV UV spectrometer channel.

A.REBERAC, J.L.BERTAUX and E.DIMARELLIS

26-June-2008

Version 1.0

### 1. Introduction

This document 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:

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

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 MgF2 window).

$d\lambda$  = 0.55 nm, the wavelength interval covered by one spectel

$dt$  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:

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

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

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

One has to find dt from header of each data record,  $d\lambda = 0.55$ ,  $\text{Seff}(\lambda)$  is contained in the calibration file SPICAV\_UVSEFF.DAT and  $G(\text{HT})$  is contained in the calibration files SPICAV\_UVGAIN.DAT.

### 3. Instrument calibration data.

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

The gain of the MCP (Micro Channel Plate) of the image intensifier may be adjusted by TC (telecommand) with a HV level from 350 to 880 volts, commanded by a digital level HT from 0 to 255. When a photo-electron is created in the photocathode (a photo-event), it results in a pulse of light from the phosphor, distributed over a few pixels of the CCD. It is detected by the CCD reading electronics by a number of ADUs (Analog to digital Units).

The gain has been checked in flight with stellar observations, by a statistical method, by determining the mean number of photo-events contained in the whole band devoted to the star signal outside of the atmosphere. The total ADU signal fluctuations are analysed, and the gain G is determined as:

$$G = \text{Var}(S_{\text{ADU}}) / 2 \times S_{\text{ADU}} \quad (5)$$

Where  $S_{\text{ADU}}$  is the mean values of a series of measurements,  $\text{Var}(S_{\text{ADU}})$  is the variance of the series and the factor 2 comes from the non-Gaussian distribution of the number of electrons coming from a single photo-event [Sandel and Broadfoot, 1986].

The file SPICAV\_UVGAIN.TXT gives the gain obtained for all HT values often used with SPICAV.

#### 3.2. Wavelength assignment

The wavelength assignment is determined from several type of observations:

- Lyman-alpha emission line
- NO emission line
- Solar spectrum.

The wavelength is given by:

$$\lambda = -7.64093 \cdot 10^{-6} p^2 - 0.548086 p + 322.515 \quad (6)$$

p is a given pixel.

This is for line 143 in the CCD and at 0 °C as temperature.  
This point will be more fulfilled later on. (cf. E.Villard thesis (under drafting))

### 3.3. Efficient Area

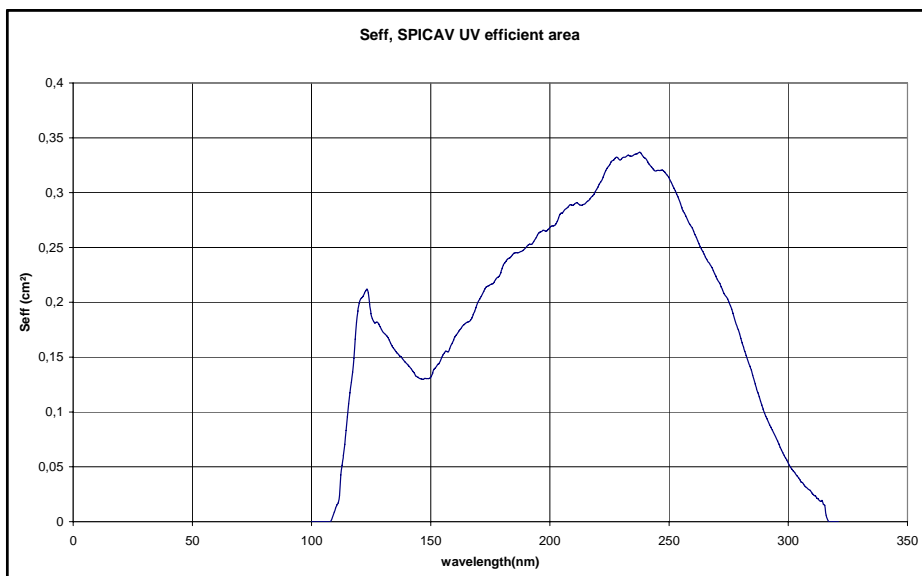
A good knowledge of the absolute sensitivity is necessary for a correct quantitative analysis of emissions measurements.

The overall sensitivity as a function of wavelength can be determined by observing hot stars whose absolute flux is known from Hubble Space Telescope (HST) and IUE observations.

We found out that HST calibration was performed also with IUE collected spectra, and 4 stars by HST are indeed SPICAV targets: Zeta Puppis, Beta Cen, Eta Uma, Zeta Oph.

Therefore, assuming that the HST calibration is correct, the absolute calibration has been based on this quatuor of stars, by comparison (ratio) of the measured spectrum (in ADU) of a star to the HST/IUE absolute spectrum of the same star:

$$Seff(\lambda) = N(\text{ADU}) / (F_{\text{star}}(\lambda) \times G(\text{HT}) \times dt) \quad (7)$$



**Figure 1. Seff, SPICAV UV efficient area. This was based on the quatuor stars listed above.**

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 SiO<sub>2</sub>, opaque below 160 nm. The curve 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 Seff here is representative of a band of 16 CCD lines binned together.

### 3. 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 spectral 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:

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

### 4. 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 spectral (spectral pixel) (the spectral 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):

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

or with the definition of  $S_{\text{eff}}$ :

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

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:

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

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.