Revista Mexicana de Astronomía y Astrofísica, **27**, 153-156 (1993)

CALIBRATION OF HST NARROW BAND FILTERS USING THE ORION NEBULA

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RESUMEN

Se calibraron imágenes del Telescopio Espacial Hubble en tres filtros con líneas de emisión Hα, [O III] y [N II]. Se determinó la sensibilidad del CCD comparando regiones dentro de las imágenes del TEH con el brillo superficial correspondiente de la Nebulosa de Orión, medido con observaciones desde Tierra. Se hicieron las correcciones para el contínuo en cada filtro. Fué necesario corregir la imagen [N II] por una contribución en Hα. También se determinó la dependencia de la sensibilidad del CCD de imagen a imagen.

ABSTRACT

HST images in three emission line filters: Hα, [OIII] and [NII] have been calibrated. The CCD sensitivity was determined by comparing regions within HST frames with the corresponding surface brightness determined from ground based Orion Nebula observations. Corrections for continuum within each filter were made. It was necessary to correct the [NII] image for an Hα contribution. The frame-to-frame dependence of CCD sensitivity was also determined.

Key words: **ISM: INDIVIDUAL OBJECTS (ORION NEBULA) — TECHNIQUES: IMAGING**

It is important to calibrate the absolute sensitivity of the WF/PC emission line filter set, since changes of interference filters with time are common. Also calibration of the filters done before launch did not duplicate the optical configuration of the WF/PC. Calibration after launch is practical from Orion Nebula images as it is a bright and well studied emission line source.

Calibration is based on the relation between the HST observed signal N and the nebular surface brightness S by:

$$N_{\rm line} = A \cdot \Omega \cdot t \cdot s_\lambda \cdot (T_{\rm line} \cdot S_{\rm line} + EW \cdot S_\lambda) \qquad (1)$$

Where:

N(DNs) is the recorded signal in Data Number.
A(cm^2)is the effective area of the telescope system.
Ω(steradians) is the solid angle subtended by one pixel of the detector.
t(sec) is the exposure time.
s_λ(DNs/Photon) is the wavelength response of the telescope-camera-detector system.
$T_{\rm line}$ is the transmission of the filter at the designated line.
$S_{\rm line}$(photons $\cdot$ cm^{-2} $\cdot$ sec^{-1} $\cdot$ steradian^{-1}) is the surface brightness of the nebula in the line.
EW(Å) is the Effective Width of the filter(EW $= \int_0^\infty T_\lambda d\lambda$).
S_λ(photons $\cdot$ cm^{-2} $\cdot$ Å^{-1} $\cdot$ sec^{-1}steradian^{-1}) is the surface brightness of the nebula in the continuum.

In order to assess the relative role of each term, we can rewrite (1) as:

$$N_{\rm line} = A \cdot \Omega \cdot t \cdot s_\lambda \cdot T_{\rm line} \cdot S_{\rm line} \cdot (1 + \frac{EW}{T_{\rm line}} \cdot \frac{1}{W_{\rm line}}) \qquad (2)$$

Where $W_{\rm line}$ is the ratio of emission line to continuum at the emission line. Approximate values of the filter constants($T_{\rm line}$ and EW) were determined by the prelaunch calibration(Griffiths et al. 1989).

The ground based Orion Nebula images we used were from "An Emission Line Survey of Galactic HII Regions"(Hester et al. 1991), including six calibrated emission line filters Hα, [OIII], [NII], [SII], Hβ, [OII] and three broad band images at 4805Å, 5103Å, 6450Å. The continua and three emission lines Hα, [OIII], [NII] were used in our study. The surface brightness in the continuum at each emission line was obtained by extrapolating or interpolating the three broad band images.

The HST images were all made with the Wide Field Camera of the Hubble Space Telescope. The region imaged is shown in Figure 1. We have the set of exposures made on 13 and 14 August, 1991, including a 200 sec exposure for the Hα (F656N) filter, a 300 sec exposure for the [OIII] (F502N), 600 sec exposures for [NII] 658.3nm (F658N), [OI]+[SIII] (F631N), [SII] (F673N), and a 10 sec exposure for the wide band F555W filter. The images were mask corrected, A-to-D corrected, bias level corrected, bias corrected, preflash corrected, dark current corrected, and flat field corrected using Space Telescope Science Data Analysis System tasks executed from within IRAF first. Then cosmic ray cleaning was done with images both using IRAF tasks and by hand. At this stage, the calibration process was done before the deconvolution.

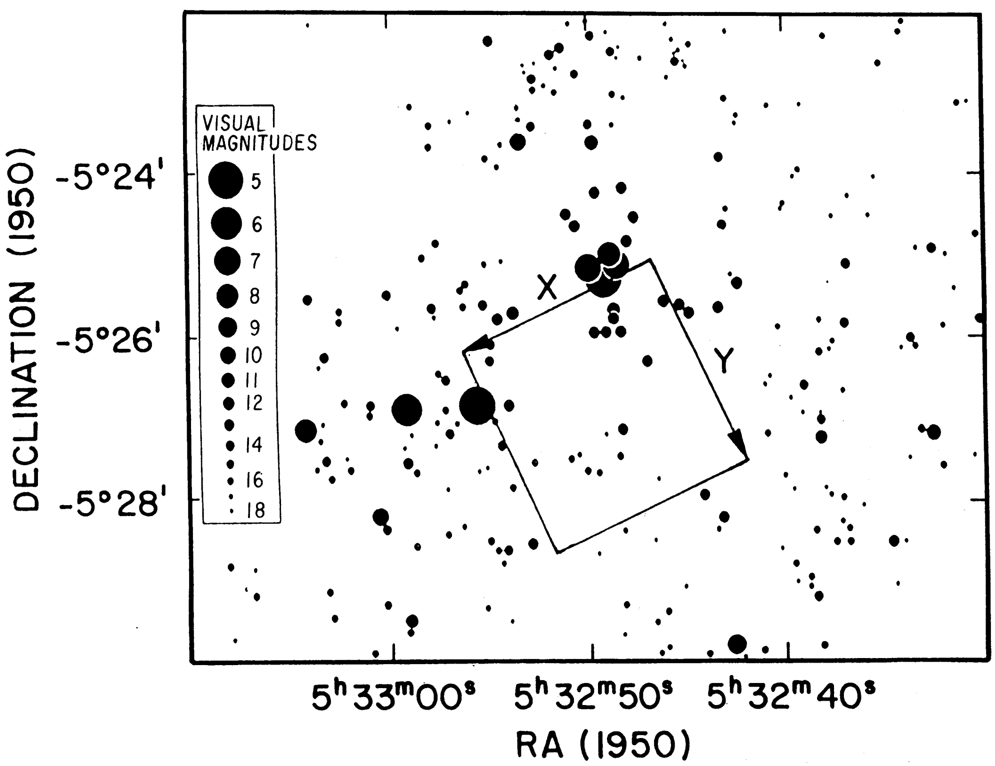

Fig. 1. — HST Orion Nebula observation field of view.

Determination of the role of contamination by the continuum was done using the prelaunch characteristics for EW and $T_{\rm line}$, and values derived from the north quadrant of the HST field for $W_{\rm line}$, as shown in Table 1. Finally, three emission line filters (Hα, [OIII] and [NII]) were chosen to be calibrated, because the continuum in each filter was no more than a few percent, which was not the case for either [SII], [OI]+[SIII] or the wideband filter F555W. The large amount of continuum contribution in the three latter filters made it impossible to do accurate subtraction.

Absolute calibration was done for the Hα filter. For the north quadrant(or the second frame of HST images), the average observed signal was 401.5 DNs, the corresponding emission line surface brightness from the ground based image was 3.40×10^{10}photons $\cdot$ cm^{-2} $\cdot$ sec^{-1} $\cdot$ steradian^{-1}, the continuum at Hα was 2.00×10^7photon$\cdot$cm$^{-2}\cdot$A$^{-1}\cdot$sec$^{-1}\cdot$steradian^{-1}. Applying these numbers to equation (2), we found the derived $A\cdot\Omega\cdot t\cdot s_\lambda\cdot T_{line} = 1.15\times10^{-8}DNs\cdot$photon$^{-1}\cdot$cm$^2\cdot$sec$\cdot$steradians. Removing the solid angle corresponding to the HST pixel size of 0.102" × 0.102" and the exposure time of 200 seconds, gave $A\cdot s_\lambda\cdot T_{line} = 234DNs\cdot$photon$^{-1}\cdot$cm^2. For the Hα filter, we have measured the detector counts in neighboring regions of the four frames, and our results showed that sensitivities of the frames are equal within the measurement error of about 2%. The prelaunch published result(Table 5.1.1 from Griffiths et al. 1989), and comparison of a stellar post-launch calibration(MacKenty et al. 1992) indicate that the first CCD chip is more sensitive than other three chips. Thus, the flat-fields were actually normalized in a way to compensate for the difference.

The calibration process is more complicated for the [NII] filter due to the presence of Hα emission line in this filter. The modified N-S relations are:

$$N_{[NII]} = A \cdot \Omega \cdot t \cdot s_\lambda \cdot (T_{[NII]} \cdot S_{[NII]} + EW \cdot S_\lambda + T_{H\alpha} \cdot S_{H\alpha}) \tag{3}$$

$$N_{N[II]} = A \cdot \Omega \cdot t \cdot s_\lambda \cdot T_{[NII]} \cdot S_{[NII]} \cdot (1 + \frac{EW_{[NII]}}{T_{[NII]}} \cdot \frac{1}{W_{[NII]}} + \frac{T_{H\alpha}}{T_{[NII]}} \cdot \frac{S_{H\alpha}}{S_{[NII]}}) \tag{4}$$

Obviously, the calibration of the [NII] filter required a calibrated HST Hα image.

Table 1.

Filter	Ion	$\frac{S_{line}}{S_{H\alpha}}$ [a]	T_{line} [b]	EW(Å) [b]	W^c_{line}	$(\frac{EW}{T_{line}} \cdot \frac{1}{W_{line}})^d$	$\frac{T_{line}\cdot s_\lambda(line)}{T_{H\alpha}\cdot s_\lambda(H\alpha)}$	
F656N	Hα	1	0.39	19	1702.8	0.029	1^b	1^e
F502N	[OIII]	1.30	0.30	29	1485.5	0.065	0.69^b	1.69^e
F658N	[NII]	0.15	$\frac{0.315([NII])}{0.07(H\alpha)}$	20	470.9	0.135	0.80^b	1.05^e
F631N	[OI]+[SIII]	0.001	0.42	29	...	...	...	...
F673N	[SII]	0.018	0.77	50	...	...	...	...
F555W	N/A	N/A	N/A	1205	...	...	...	...

[a]Characteristic line ratios studied by Baldwin et.al. 1991.
[b]Prelaunch values.
[c]HST north quadrant value(see figure 1).
[d]Contribution of continuum.
[e]Post launch values.

The wavelength dependent relative sensitivities were determined by assuming the line surface brightness in the north quadrant were the average of the values of the three positions studied by Peimbert & Torres-Peimbert (1977), and Simpson (1973). Under this assumption, the relative calibration then came from:

$$\frac{s_{\lambda,1} \cdot T_{line1}}{s_{\lambda,2} \cdot T_{line2}} = \frac{N_1}{N_2} \cdot \frac{t_2}{t_1} \cdot \frac{S_{line2}}{S_{line1}} \cdot \frac{(1 + EW_2/(T_{line2} \cdot W_{line2}))}{(1 + EW_1/(T_{line1} \cdot W_{line1}))} \tag{5}$$

One can see from Table 1 that the postlaunch value of $\frac{T_{line}\cdot s_\lambda(line)}{T_{H\alpha}\cdot s_\lambda(H\alpha)}$ is quite different from the predicted prelaunch value, which indicates that the wavelength dependence of the CCD sensitivity has changed after launch and/or the filters have changed.

For the [OIII] filter, the results are: observed signal N=853.9 DNs;

$$A \cdot s_\lambda \cdot T_{line} = 396 \text{ DNs photon}^{-1} \text{ cm}^2.$$

And our results for the [NII] filter are: observed signal N=516.3 DNs;

$$\frac{T_{H\alpha}}{T_{[NII]}} = 0.222, \quad \frac{EW_{[NII]}}{T_{[NII]}} \cdot \frac{1}{W_{H\alpha}} + \frac{T_{H\alpha}}{T_{[NII]}} = 0.259,$$

$$A \cdot s_\lambda \cdot T_{[NII]} = 249 \text{ DNs photon}^{-1} \text{ cm}^2.$$

Finally, the HST Orion Nebula images were calibrated to absolute energy units by using the results shown above and convenient forms of (1)-(4):

$$S_{line} = \frac{N_{line}}{A \cdot \Omega \cdot t \cdot s_\lambda \cdot T_{[line]}} \cdot \frac{1}{1 + EW/(T_{line} \cdot W_{line})} \quad (6)$$

$$S_{[NII]} = \frac{N_{[NII]}}{A \cdot \Omega \cdot t \cdot s_\lambda \cdot T_{[NII]}} - S_{H\alpha} \cdot (\frac{EW_{[NII]}}{T_{[NII]}} \cdot \frac{1}{W_{H\alpha}} + \frac{T_{H\alpha}}{T_{[NII]}}) \quad (7)$$

This work was done using HST WF/PC team engineering observations and was analyzed under GTO contract NAG5-1626.

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