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VISUAL EXTINCTION OF HII-REGIONS IN NGC2403 DERIVED FROM PASCHEN-TO-BALMER LINE RATIOS

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Visual extinction of HII-Regions in NGC2403 derived from Paschen-to-Balmer line ratios.

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Abstract

Investigation of extragalactic HII-regions requires precise correction for the attenuation of the light due to the local dust extinction, which also has implication on the discussion of transparency of disk galaxies; still an unsettled question. Errors on the visual extinction can be reduced by using line pairs with a large separation in wavelength, e.g. short-wave Balmer and near-IR Paschen lines. Here we present results from two-channel spectrophotometry covering 3950–4900 Å and 8500–11000 Å of a number of HII-regions in NGC2403.

Introduction

Observations of galaxies rely on correction for the effect of dust on the internal spectral energy distribution and in general, interstellar extinction remains one of the most serious sources of systematic error in visible and UV measurements of HII-regions and star forming regions in galaxies. Usually, the total visual absorption, A_V, is determined by comparison of the emergent flux ratio at two distinct wavelengths for which the intrinsic ratio is known

$$A_V = \frac{2.5R\log(\frac{R_o}{R_p})}{F(\lambda_2) - F(\lambda_1)} \tag{1}$$

where R_o and R_p are the observed and the predicted case B recombination ratio[1] for the two lines, respectively and $F(\lambda) = \frac{A_\lambda - A_V}{A_B - A_V}$ the normalized extinction curve. Most often H_α/H_β has been used for this purpose, but while it is easy to observe it has the drawback of a short wavelength interval. Clearly, uncertainties on A_V can be greatly reduced if λ_1 and λ_2 are separated by a long interval over which the extinction has a large effect.

To accomplish this it has been suggested to use ratios of emission lines from the Balmer and Paschen line series[2,3] like P_γ/H_δ and P_δ/H_ϵ, that can be observed with modern CCD's provided a correct subtraction of the many sky emission lines in the near-IR region is carried out. These line pairs originate from the same upper level in the hydrogen atom, n = 6 and n = 7, but since they consist of multiplets they are not completely independent of the physical conditions in the emission regions as is often stated. For values found in HII-regions, though, the dependence on T_e and n_e is weak and introduces only an uncertainty on A_V of ± 0.1 mag comparable to the overall uncertainty originating from the errors on R_o and these line pairs offer the best combination over a wide wavelength range. Thus, we aim at measuring the line flux from some of the shortest Balmer lines and as many Paschen lines as possible with special emphasize on the n=7 pair to derive very precise values for the visual extinction of Giant Extragalactic HII-regions (GEHR).

Observations

Observations were performed at the 2.5-m Nordic Optical Telescope, La Palma, with the 4′ long-slit Århus-Tromsø Low Dispersion Spectrograph on January 1/2 1994. This spectrograph consists of two channels optimized for the red and blue part of the spectrum with a dispersion of 7.5 Å/pix and 2.0 Å/pix, respectively. Exposures of $P_{14} - P_\delta$ and $H_\epsilon - H_\beta$ were taken simultaneously in the two channels ensuring that all lines are influenced by exactly the same conditions in order to obtain very precise relative spectrophotometry.

region	$\Delta\alpha$	$\Delta\delta$	extrac. aperture (″)	total exp. (s)
1	+10	+32	10.0x2.2	3600
2	-45	+55	5.8x2.2	1200
3	+96	+35	26.7x2.2	3600
4	-186	+45	8.3x2.2	1200

Table 1. Journal of observations with the numbering of HII-regions in NGC2403 following Fierro et al.[4]. Offsets are from galactic nucleus east and north being positive.

For flux calibration and correction for the atmospheric H_2O absorption band at $\lambda = 8900 - 9800$ Å[5] the spectrophotometric standard stars HD19445, HD84937[6] were observed several times during the night.

Reductions and analysis

The images were reduced with standard IRAF packages including flat fielding, illumination correction, rectifying of the 2-dimensional frames and atmospheric extinction correction appropriate for La Palma. Spectra of Cd/Hg- and Cs-spectral lamps were taken just prior to and right after the observations. The extraction apertures were set to cover the whole region and the sky background was sampled over a large part of the frame around the regions to increase S/N of the OH-sky emission lines. In many cases the optimal extraction technique does not seem to do a good job,

probably due to the extended and complicated structure of the emission regions, and instead cosmic ray events were rejected by applying a routine that fits polynomials at every pixel accounting properly for RON, gain and the spectral nature of the frame.

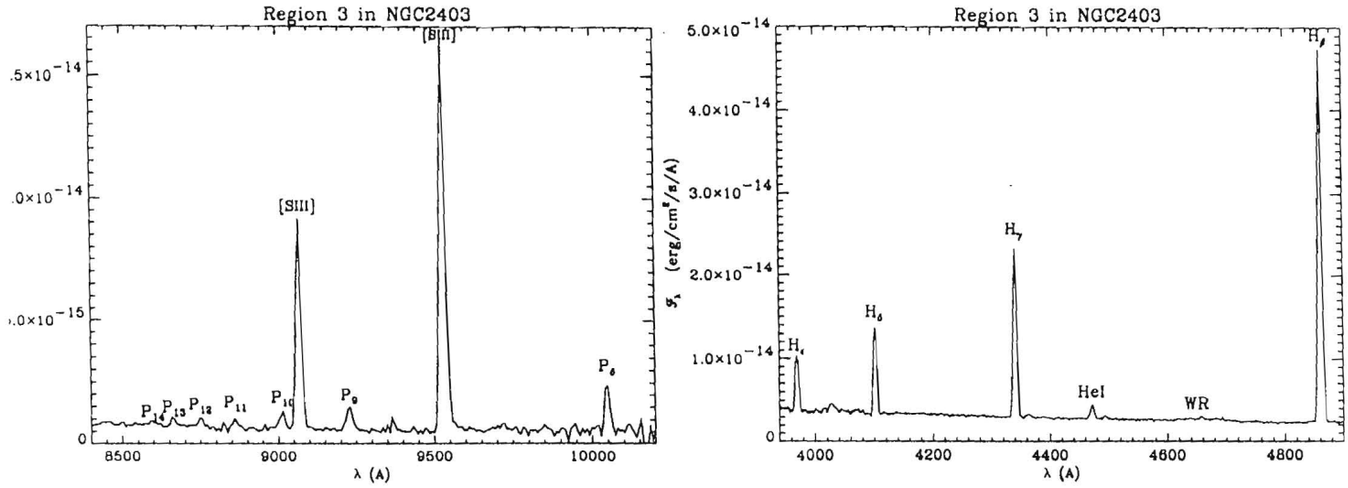

Figure 1. (a) Near-IR spectrum of HII-region 3 in NGC2403. The faint Paschen lines down to P_{14} are clearly identified. At P_{15} we tend to reach the series limit, giving rise to a false continuum, which makes flux measurement unreliable. Some other emission lines are also labeled.
(b) Blue spectrum of the same region showing the 4 strong Balmer emission lines. Note also the broad feature at $\lambda \sim 4650$ Å assigned to Wolf-Rayet stars[6].

The flux in the spectral lines is measured both by simply summing under the line and by fitting a Gaussian profile to the line and integrating under this profile. The two methods give values, that deviate only slightly. In fig. 1.a and 1.b we present the red and blue spectrum of HII-region 3 in NGC2403 and in table 2 the measured line fluxes for all 4 regions are given as well as parameters necessary for calculating A_V. The inferred value for A_V from (1) for all possible line ratios can be found in table 3. We see that for the strongest Paschen lines ($P_{10} - P_\delta$) consistent values are obtained for all 4 regions. The adopted values for A_V are shown in table 4 compared to values found in the literature derived by the Balmer decrement method.

				$\left(\frac{\mathcal{F}_\lambda}{\mathcal{F}_{H_\beta}}\right)_o$			
λ	ID	$F(\lambda)$	$\left(\frac{I_\lambda}{I_{H_\beta}}\right)_p$	Reg. 1	Reg. 2	Reg. 3	Reg. 4
3970	H_ϵ	1.469	0.159	0.121	0.119	0.113	
4102	H_δ	1.337	0.260	0.208	0.234	0.209	0.181
4340	H_γ	1.074	0.469	0.406	0.434	0.416	0.410
4861	H_β	0.509	1.000	1.000	1.000	1.000	1.000
8598	P_{14}	-1.490	0.00672			0.013	
8665	P_{13}	-1.513	0.00837			0.016	
8750	P_{12}	-1.542	0.0106	0.018		0.019	
8863	P_{11}	-1.577	0.0138	0.022		0.027	
9015	P_{10}	-1.620	0.0184	0.032	0.031	0.038	0.039
9229	P_9	-1.675	0.0254	0.042	0.039	0.056	0.063
10049	P_δ	-1.857	0.0553	0.098	0.118	0.112	0.195
$\log(\mathcal{F}_\lambda(H_\beta))$				-13.00	-12.85	-12.43	-12.93

Table 2. Numbers relevant for the calculation of the visual extinction of the 4 observed regions in NGC2403. Column 3 lists the normalized extinction function from Cardelli et al.[7] with R=3.1 and column 4 the predicted line intensity relative to H_β as given by Hummer & Storey[1] for adopted values of $T_e = 10^4\,K$ and $n_e = 10^4\,cm^{-3}$. In columns 5-8 we present the observed line flux relative to H_β within the extraction apertures. H_ϵ is blended with the $[NeIII]$ line at 3967.46 Å; and where the S/N is sufficient these are deblended by fitting two Gaussians. The estimated errors on the quoted line ratios are 10 % increasing to 20 % for the weakest lines. The values of $\log \mathcal{F}(H_\beta)$ $(erg/s/cm^2/\text{Å})$ agree well with those found by Fierro et al.[6], but these absolute numbers are naturally very sensitive to the size of the aperture used and the exact position of the slit.

	Region 1					Region 2		
$\lambda_2 \backslash \lambda_1$	P_{12}	P_{11}	P_{10}	P_9	P_δ	P_{10}	P_9	P_δ
H_β	0.83	0.75	0.86	0.78	0.81	0.84	0.68	1.08
H_γ	0.83	0.77	0.86	0.80	0.82	0.76	0.64	0.96
H_δ	0.85	0.80	0.87	0.82	0.83	0.71	0.59	0.89
H_ϵ	0.87	0.81	0.89	0.83	0.85	0.89	0.78	1.06

	Region 3							Region 4		
$\lambda_2 \backslash \lambda_1$	P_{14}	P_{13}	P_{12}	P_{11}	P_{10}	P_9	P_δ	P_{10}	P_9	P_δ
H_β	1.11	1.10	0.93	1.06	1.13	1.22	1.00	1.19	1.39	1.79
H_γ	1.02	1.01	0.88	0.98	1.04	1.11	0.95	1.11	1.27	1.60
H_δ	1.04	1.04	0.92	1.01	1.06	1.12	0.97	1.27	1.41	1.71
H_ϵ	1.14	1.13	1.02	1.10	1.16	1.21	1.06			

Table 3. Calculated A_V for all observed line pairs in the 4 regions from (1) using the values given in table 1. Only region 2 seems to suffer significantly from underlying Balmer absorption due to the stellar content[6], and has been corrected for this by adopting an equivalent width of 1.9 Å[8].

In the same observation run spectra of HII-regions in NGC628 were obtained in a similar manner, the analysis of these will be carried out in the near future.

Region	1	2	3	4
This work	0.83 ± 0.04	0.82 ± 0.16	1.05 ± 0.08	1.4 ± 0.2
Fierro et al. (1986)	0.85 ± 0.24	0.61 ± 0.24	0.97 ± 0.24	0.85 ± 0.24
McCall et al. (1985)			0.71 ± 0.14	

Table 4. Adopted values for A_V compared to results from the Balmer decrement method. Uncertainties in this work include only the standard deviations of the line pairs used in table 2.

Conclusions

We have shown that precise values for A_V of GEHR can be derived from flux ratios of Paschen and Balmer emission lines obtained from simultaneous spectrophotometry of the two wavelength ranges. For the SABcd galaxy NGC2403 which has an inclination of 60° we find values ranging from 0.83 to 1.4 mag. 0.12 mag of this is due to Galactic extinction[9], but the rest must be attributed to extinction internal to NGC2403.

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