Multiwavelength analysis of active star forming regions: The case of NGC 604

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Abstract.
We analyse the integrated ultraviolet and optical spectra of the active star forming region NGC 604. The ultraviolet resonance wind stellar lines, the nebular optical emission lines and the higher order terms of the Balmer series and HeI absorption lines detected are interpreted using evolutionary models optimized for young star forming regions. The evolutionary state and the massive stellar content of the region is derived in a self-consistent way.

Keywords: galaxies: evolution - galaxies: stellar content - ISM: HII regions

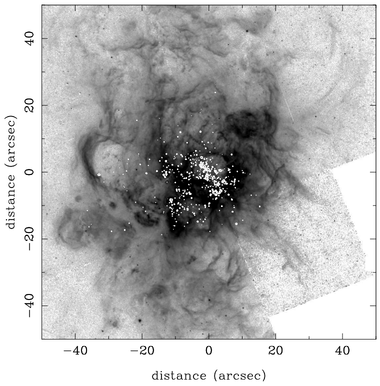
1. Introduction

Active star forming regions (ASFR) are powered by massive stars. These stars dominate the ultraviolet and optical light. They are the main source of ionization, mechanical heating and chemical enrichment of the interstellar gas. Thus, massive stars, and in consequence ASFR as the preferred place where massive stars form, play a relevant role in the evolution of galaxies. Important questions related with ASFR are: what is the stellar content and the evolutionary state in these objects? and how the star formation proceeds?

This contribution deals with diagnostic techniques based on the integrated light of ASFR at UV-optical wavelengths that allow to estimate the stellar content and their evolutionary state in a self-consistent way. To show the potential of the evolutionary synthesis models, we present here the results of applying these techniques to the second brightest HII region in the Local Group, NGC 604. Due to its proximity (distance of 840 Kpc), HST was able to detect the individual stars of the ionizing cluster and estimate the stellar content (Drissen et al, 1993) (Hunter et al, 1996). Thus, NGC 604 is a perfect laboratory where to explore how mature are the evolutionary synthesis models because the results obtained from the integrated light can be compared with those obtained from the studies based on the detection of individual stars. The consistency between the different techniques strengthens their reliability and power when they are applied to determine the stellar content of more distant ASFR.

2. The morphology of NGC 604

NGC 604 has been intensively observed with the WFPC2 camera onboard the *HST*. A composite image (Figure 1a) of the ionized gas and the UV emission indicate that the massive stars are mainly concentrated within the inner 20 arcsec. On contrast, the nebular emission extends out to ~ 200 pc from the center, showing many filaments and shell structures. Surface brightness photometry shows that 75% and 90% of the total Hα flux is contained in the inner 100 and 140 pc radii.



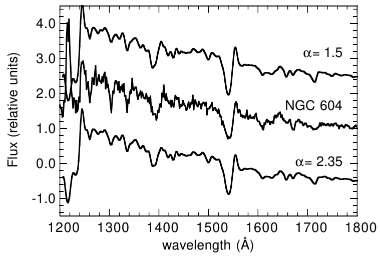


Figure 1. (a): *HST*+WFPC2 (F653N) image in the Hα emission line (grayscale). The ultraviolet emission (F170W) is overlayed in white contours. (b): IUE spectra of NGC 604 de-reddened by E(B-V)=0.1 using LMC extinction, and 3 Myr instantaneous burst models for different assumptions of the IMF slope.

IUE spectra of NGC 604 show that the UV continuum is dominated by absorption lines formed in the wind of massive stars (Figure 1b). On contrast, it shows a nebular emission-line spectrum at optical wavelengths. These spectral characteristics reflect the fact that NGC 604 is powered by massive stars. These stars emit photons with energies of tens of eV which are absorbed and re-emitted in their stellar winds, producing ultraviolet resonance transitions. However, most of the far-ultraviolet photons escape from the stellar winds and they photoionize the surrounding interstellar medium. At the near-ultraviolet, the spectrum corresponding to the central nebular hole shows the higher order terms of the Balmer series and some HeI lines in absorption. These lines form in the photosphere of young stars.

3. The massive stellar content and its evolutionary state

We can estimate the massive stellar content and the evolutionary state of NGC 604 through the modelling of its spectral characteristics at the optical and ultraviolet wavelengths using the evolutionary synthesis technique. A more extended analysis of the data is in González Delgado & Pérez (2000).

3.1. Modelling of optical nebular lines

The emission-line spectrum depends on the radiation field from the ionizing stellar cluster, on the density distribution and chemical composition of the gas. The star formation law, age and massive stellar content of the stellar clusters can be constrained by comparing the observed emission line strengths with the predictions from the photoionization models. The spectral energy distribution (SED) generated by the stellar evolutionary synthesis code Starburst99 (Leitherer et al, 1999) is taken as input to the photoionization code CLOUDY (Ferland, 1997). Other input parameters are the electron density (30 cm^{-3}), abundance (12+log (O/H)= 8.5) and the ionizing photon luminosity (log Q= 51.54 s^{-1}). The observational constraints are the strength of emission-line ratios indicative of the electron temperature ([O III]4363/5007), electron density ([S II]6717/6732) and ionization structure ([O III]5007/[O II]3727, [S III]9069/[S II]6716+6732). Another important observational constraint is the radius of the nebula. The results from the modelling indicate that the nebula is well described by a sphere of inner radius 20 pc and outer radius 110 pc. It is partially filled (filling factor $\simeq$0.1) with ionized gas that is very tenuous (Ne$\simeq$30 cm^{-3}). The nebular emission lines are well accounted for by photoionization if the ionizing cluster formed in an instantaneous burst 3 or 4.5 Myr ago.

3.2. Modelling of the UV and near-UV continuum

The strongest wind stellar features in the spectra of NGC 604 are N V λ1240, Si IV λ1400, C IV λ1550, He II λ1640, and N IV λ1720. The evolutionary state, the star formation law and the IMF can be constrained with these lines because in massive stars the shape of the profile reflects the stellar mass-loss rate, which is related to the stellar luminosity, and thus to the stellar mass. Comparison of the observed spectra with those predicted by Starburst99 indicates that the stellar cluster in NGC 604 must be young and of short duration. The strength of Si IV indicates that it is an instantaneous burst of age between 3 to 5 Myr, because bursts younger than 3 Myr or older than 5 Myr have very few O supergiants, and thus very weak Si IV. On the other hand, from the strength of C IV we can exclude instantaneous bursts with $M_{\rm up} \leq 60$ M$\odot$ and IMF steeper than α=3.0. A 3 Myr instantaneous burst with Salpeter and $M_{\rm up} \geq 80$ M$\odot$ fits well the profile of the wind stellar lines.

The equivalent width of the HeI λ4388, 4026 and 3819 (0.32, 0.55 and 0.26 Å, respectively) absorption lines and the absorption wings of

Table I. Model predictions for massive stars and energy released for an UV continuum luminosity of $log\, L_{1500} = 38.16$ erg s^{-1} Å^{-1}

age (Myr)	α	$M_{\rm up}$ (M⊙)	$log\, Q$ (ph s^{-1})	Mass (10^6 M⊙)	No.O	log P_w (erg s^{-1})
3.0	2.35	80	51.28	0.47	209	37.98
3.0	2.35	120	51.40	0.36	164	38.60
3.0	1.50	80	51.28	0.13	180	38.05

the Balmer lines are also compatible with burst models 3 Myr old, with Salpeter or slighltly flatter IMF.

Further constraints to the evolutionary state come from the ratio of the number Wolf-Rayet to O stars. These quantities are derived from the UV continuum and HeII λ1640 line luminosity. First, the extinction affecting the stellar cluster is estimated comparing the shape of the UV continuum with the SED predicted by the evolutionay synthesis models. The extinction estimated is $E(B-V) = 0.1$ if the LMC extinction law is used to derive the value, or $E(B-V) = 0.2$ if the Calzetti et al (1994) extinction law is used. The ratio WR/O=0.075, is fitted by a 3-3.5 Myr instantaneous burst formed following a Salpeter or flatter IMF.

4. Conclusions

The three techniques applied suggest that the central ionizing cluster in NGC 604 is very young, $\simeq 3$ Myr old, and that the stars in the cluster were formed in an instantaneous burst following a Salpeter (α=2.35) or flatter (α=1.5) IMF, having stars more massive than 80 M⊙. The stellar cluster is able to provide most of the ionizing photons needed to photoionize the whole nebula, and the wind power to form the central shell structure where the cluster core is located. The stellar cluster is affected by an extinction similar to the average extinction that affects the ionized gas. The estimated number of massive stars in the cluster is also in agreement with that derived from previous studies based on the detection of individual stars. These results support the use of these techniques for the interpretation of the integrated light of more distant star forming regions.

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