Star Formation Rate at $z = 0.2$ derived from Hα luminosities: constraint on the reddening

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Abstract. We discuss the relative merits of using UV and Hα as star formation indicators from galaxy surveys. In particular, comparing UV and Hα in the CFRS gives a limit of a factor 2.5 for the UV(2800 Å) extinction from dust, using the conversion factors of Madau et al. 1998 (Salpeter IMF, 0.1–125 M⊙). Our strong correlation between B and Hα argues for a universal IMF slope. The Hα LF at $z = 0.2$ shows a faint end slope of $\alpha = -1.35$, which is consistent with fading of short bursts of star formation. We also discuss the contribution of AGN to UV and Hα luminosities.

1. Luminosity density and star formation rate

The cosmological evolution of the star formation rate (SFR) can be inferred from the luminosity density of the galaxy population seen at different redshifts (Madau et al. 1998). Indeed the luminosity density history traces the global evolution of the galaxy population, or in other words, of the whole content of galaxies (gas, stars, dust, active galactic nucleus (AGN), supernovae remnants, etc.), and not simply of the stellar population. Recovering the genuine shape of the SFR history is essential to differentiate between scenarios of galaxy evolution and formation. Extensive studies of nearby galaxies have shown that the UV, FIR, radio continuum and Hα line fluxes are closely connected (Buat 1992), even though these radiations are produced by different physical processes. Thus they originate from a common photoionizing spectrum. Retrieving the absolute photoionizing flux depends crucially on the understanding of these processes.

2. Dust extinction of UV and Hα emission

Assuming there is no AGN, the galactic UV continuum radiation directly traces the UV stellar spectra. From the Lyman break (912 Å) to $\sim 3500$ Å, the emissivity of the starburst galaxy population becomes less dominated by the relatively massive, young stars (O, B types, $T \geq 10^4$ K, $M \geq 10$ M⊙, $t_{MS} \sim 10^7$ yr), while it becomes more dominated by the intermediate mass stars (A type, $M = 2 - 5$ M⊙, $t_{MS} \sim 10^8$ yr). The emissivity of the more quiescent galaxy population (i.e. ellipticals) may be dominated by massive, old stars ($t \gg 10^9$ yr), but other possibilities, of which some are non stellar, have been proposed to account for the UV rise seen in these galaxies. Assuming there is no AGN, the Hα(λ6563 Å) fluxes come from the hydrogen gas surrounding very massive,
short-lived stars (OB type, $T \sim 60,000$ K, $M > 10 M_\odot$, $t_{MS} \sim 10^6$ yr). The gas is directly excited by far-UV stellar photons shorter than 912 Å, and its recombination produces spectral emission lines. Of the Balmer lines, Hα is the most proportional to the far-UV stellar spectra, because it is the easiest to ionize, and is barely, if at all, affected by the stellar absorption due to old stars. Moreover, it does not depend on the metal fraction present in the gas, or on the hardness of the ionizing stellar spectrum (which is the case for metal lines e.g. [O II]λ3727).

The global contribution of these stellar populations depends mainly on the shape of the initial mass function (IMF) and its mass cut-off, the average age and metallicity, and the luminosity function (LF) of the galaxy population considered. Uncertainties arise for ellipticals, for which the UV source is not fully understood. Also Hα fluxes for galaxies dominated by an old stellar population are likely to be affected by stellar absorption. However, in the studies of global evolution of the galaxy population, the starburst galaxies dominate the UV radiation, and so the remaining galaxies are unlikely to affect the general results.

Recovering the absolute SFR from UV continuum and Hα line flux measurements depends on the dust extinction, which is subject to debate. Indeed massive-star formation occurs in dusty molecular clouds; most of the UV radiation is reprocessed by dust and emitted in the far infra-red. Hα, and UV fluxes arise from relatively late stages of star formation ($\gtrsim 10^6$ yr), when the star-forming region becomes less opaque. In the optical, different extinction laws behave similarly, thus retrieving the original Hα fluxes is not a major problem. In the UV, which is more dust affected, they can differ by a large factor. Thus, it leads to large uncertainties in the absolute UV radiation. But, long-lived stars as traced by the near-UV, sit in less obscured regions than short-lived stars as traced by Hα. This is corroborated by the fact that extinction measurements from the UV stellar continuum are found to be no larger (as expected by any extinction laws) than from the optical Hα/Hβ decrement. Consequently, the observed near-UV is dominated by intermediate mass stars not only because they are more numerous and longer-lived than massive stars, but also because they are much less dust obscured. In summary, Hα and near-UV radiations emerge in average from different environments within a galaxy, because each is dominated by different stellar populations and time scales (see e.g. Calzetti et al. 1994). Nevertheless, they are tightly correlated (Buat et al. 1987) - asserting the universality of the upper IMF limit.

The relationships between quantities have been extensively studied in the nearby universe. However, we need to ascertain these physical parameters with cosmic time. Clearly the emissivity of galaxies evolves with redshift, but is the stellar content entirely responsible? Or does the dust extinction vary? Does the AGN contribution increase? We need to answer these questions before getting the correct shape of the SFR. This is essential not only for including these processes in evolutionary models, but also for quantifying how much it affects the galaxy selection in deep surveys. Correlating Hα and UV at any redshift is a powerful way to tackle the dust uncertainties.
3. **SFR from Hα at z = 0.2: dust upper limit**

Hα is seen in the optical up to \( z \sim 0.3 - 0.4 \). Prospective instruments in the near infra-red will soon enable systematic studies of Hα and UV radiation within the same galaxy sample at \( z \gg 0.3 \). This will avoid discrepancies inherent to comparing different surveys. With the I-selected CFRS galaxies up to \( z = 0.3 \), we measured the dust-corrected Hα luminosities, and obtained a Hα luminosity function (see Tresse & Maddox 1998 for further details). We used the factors from Madau et al. 1998 (Salpeter IMF, 0.1–125 M\(_\odot\)) to convert our Hα luminosity density at \( \langle z \rangle = 0.2 \) of \( 10^{39.44\pm0.04} \) erg/s/Mpc\(^3\) into a log SFR/M\(_\odot\) yr\(^{-1}\) = \(-1.71 \pm 0.04\). At \( z < 0.3 \), the B-band barely samples the rest-frame UV. Thus we could not compare directly our Hα determination with a UV one without extrapolation, which is likely to introduce untestable uncertainties. However the B-band of CFRS galaxies at \( 0.4 < z < 1.3 \) allowed the determination of the rest-frame near-UV(2800 Å) of \((1 + z)^{3.9\pm0.75}\) (h\(_{50}\) = 1, \( \Omega = 1 \), \( \lambda = 0 \)), as defined in Lilly et al. 1996, then the log SFR/M\(_\odot\) yr\(^{-1}\) from UV(2800 Å) at \( z = 0.2 \) should be \(-2.13 \pm 0.14\). Assuming that all parameters are correct (IMF, stellar populations, no AGN, case B recombination, etc.) and that the slope \( \alpha \) for the star-forming LFs is constant, then the UV(2800Å) fluxes are low by a factor \(~2.5\) (or 1 mag) at \( z = 0.2 \). We interpret this as the dust correction required for these UV measurements. We note that our average dust correction from the Hα/Hβ decrement is A\(_V\) = 1 mag, which is of the same order as we derived for the UV(2800 Å) magnitudes at \( z \simeq 0.2 \). This result is similar to local observations as discussed in Section 2.

4. **Hα luminosities, B-band emissivity, and colors**

We find that B-band luminosities are tightly correlated to Hα luminosities. This is as the correlation between UV and Hα; the B band is still dominated by young stars (type A). This surely reinforces the hypothesis of a universal IMF: for a certain amount of massive OB stars formed, there is always the same among of intermediate mass, type A, stars. We find \( M(B_{AB}) = 46.7 - 1.6 \log L(H\alpha) \), with the luminosities L(Hα) being dust corrected, but not the B magnitudes. If the latter are corrected, according our results, a dust correction of 0.6 mag in average (Seaton’s law assumed) should be taken. This relation implies that surveys at high \( z \), which select preferentially bright, star-forming galaxies, are also likely to pick up only the strongest Hα emitters. We do not find a correlation between Hα luminosities, and the rest-frame colors \((B - R)\). This endorses the idea that Hα production depends mainly on the “instantaneous” star formation, or in other words, on the time scale since the last burst.

5. **The Hα luminosity function**

The Hα LF is related to the number of ionizing photons emitted by massive stars. Since the latter have a short life \(< 10^6 \) yr, their number traces the “instantaneous” SFR. The SFR deduced only from Hα luminosities is very dependent on
the assumed IMF, since only the massive stars are traced. The slope of the Hα LF depends more on the time scale since the last star bursts, rather than on the SFR. A fading process of Hα photons produces a non flat slope. The shallower the IMF, the slower is the fading process, and steeper is the slope (Hogg & Phinney 1997). Because of the tight relation between B or UV magnitudes, and Hα luminosities, the slope in B- and UV-band LFs must be correlated to the slope of the Hα LF. We note that for the luminosity density history (Madau et al. 1998, Lilly et al. 1996), a constant slope for star-forming galaxies has been assumed (α = −1.3) at all redshifts, i.e. a constant fraction of dwarf galaxies has been considered. If the merging rate, and/or the SFR are not constant through cosmic time as predicted, this assumption has to be revised. The SFR history is deduced from the luminosity densities, φ* L*(α + 2); a (1 + z)α evolution in L*, or in φ*, is approximatively equivalent to a slope evolution of α = Γ−1 ((1 + z)Γ(α + 2)) − 2 ≃ α0 + 2/(1 + z)α − 2.

The best fit for our Hα LF is α = −1.35 ± 0.06, φ* = 10^{−2.83 ±0.09} Mpc−3, and L* = 10^{42.13 ± 0.13} erg s−1. We point out that the tight relation found between B or UV magnitudes, and Hα luminosities validates our use of a magnitude-selected survey, like the CFRS, to measure the Hα LF. We did not exclude the AGN galaxies from our sample to be able to compare our result to the CFRS rest-frame UV data (contrarily to Gallego et al. 1995). There are many problems arising if AGN are excluded. In principle, they should be excluded, but in practice, it requires an objective technique to do so at all redshifts, in particular for the narrow-line AGN. Moreover, observing the whole galaxy content (or part of) as done in deep redshift surveys, blurs the objective line-ratio classification because different stellar and dust contents within individual galaxies are sampled, which leads to overlap between AGN and starbursts (see Tresse et al. 1996). In addition, the Hα fluxes observed from an AGN galaxy is produced both by the AGN and the H II regions. The contribution of each ionizing source to the Hα flux is unknown. Thus removing AGN galaxies from a sample underestimates the total Hα flux produced by stars. Conversely including them provides an upper-limit of Hα luminosities produced by stars. Also, if merging processes trigger nuclear activity, then excluding AGN may lead to the exclusion of this class of galaxies.

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