**Constraining dust extinction in galactic HII regions: description of the proposed programme**

**Introduction**

The interstellar medium (ISM) is known to host a significant amount of dust grains that contribute to the extinction of stellar light (Draine, 2003). HII regions, ionized by the intense ultraviolet radiation from newly formed massive stars of spectral types O or B, are embedded within giant molecular clouds (GMCs). Consequently, these regions are expected to contain substantial amounts of dust. Extinction is quantified as: $A_\lambda = 2.5\log_{10}(F_{0,\lambda}/F_\lambda)$, where $F_{0,\lambda}$ and $F_\lambda$ represent the intrinsic and observed fluxes, respectively. Extinction is often expressed as a function of the color excess, or reddening, $E(B-V)$, and the extinction curve $k(\lambda)$, through the relationship:

$$A_\lambda = k(\lambda)\,E(B-V).$$

Reddening provides a measure of the column density of dust, while the extinction curve reflects the microphysics of dust absorption and it is commonly parameterized by the total-to-selective extinction ratio $R_V = A_V/(A_B - A_V) = A_V/E(B-V)$. Several extinction curves have been proposed in the literature to account for varying physical conditions, grain chemical compositions, grain sizes, and environmental factors. The most widely adopted models include the Cardelli extinction law (Cardelli et al., 1989) and the Calzetti law (Calzetti et al., 2000).

IC 5146, commonly known as the Cocoon Nebula, is a nearby Galactic HII region located in the constellation Cygnus, at a distance of $\sim 800 \pm 50\,\mathrm{pc}$. It is located at the eastern extremity of a 2°-long dark filament that has been mapped in CO and CS (Herbig & Dahm, 2002). The emission/reflection nebula is ionized by the narrow-line B0.5 V single star BD+46° 3474, which has a surface temperature of approximately 32,500 K and a radius of $\sim 5.4R_\odot$ (Rojas et al., 2014). The nebula surface brightness ranges between $10^{-16}$ and $10^{-14}\,\mathrm{erg\,s^{-1}\,cm^{-2}\,arcsec^{-2}}$ in H$\alpha$ emission. The electron temperature of $T_e \sim 10^4\,\mathrm{K}$ and hydrogen number density of $n_H \sim 10^2\,\mathrm{cm^{-3}}$ for IC 5146, derived from collisionally excited lines (CELs), are typical of HII regions (Rojas et al., 2014). Because it's rather simple spherical geometry, suggesting the nebula is ionized by the central star only, it is a good target for quantifying dust extinction in dusty galactic environments (target will be at zenith around 23:00 in Milan the last week of October 2024).

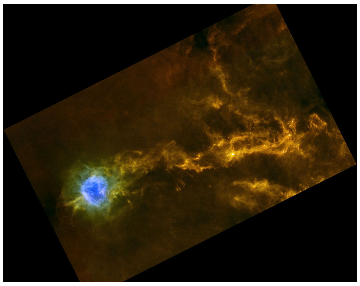


Figure 1: Optical view of the IC 5146 HII region (left) and the same region observed by ESA's Herschel Space Telescope in sub-mm (right). The Herschel SPIRE RGB 250, 350, 500 $\mu$m image captures the larger giant molecular cloud in which IC 5146 is embedded.

**Proposed Plan**

We propose to constrain the dust amount $E(B-V)$ in IC 5146 in three independent ways, the first two direct and the third indirect.

- **Balmer decrements:** This method allows us to estimate the column depth by comparing the ratio of H$\alpha$ emission over H$\beta$ emission. At typical conditions of $T \sim 10^4\,\mathrm{K}$ and $n_e \sim 10^2\,\mathrm{cm^{-3}}$ and for Case B recombination, the intrinsic line ratio $H\alpha/H\beta$ is 2.86 (Osterbrock, 1989). However, dust extinction, which is highly selective toward blue/UV wavelengths, raises this value. Reddening is related to the Balmer decrement by:
$$E(B-V) = \frac{2.5}{k(\lambda_{\mathrm{H}\beta}) - k(\lambda_{\mathrm{H}\alpha})}\log_{10}\left(\frac{H\alpha/H\beta}{2.86}\right)$$

This method was originally developed to study dust extinction in galaxies (Domínguez et al., 2013), but it can also be applied to nebulae.

- **Spectral fitting of embedded stars:** A second way to estimate the extinction is to fit the spectra of the stars embedded within the Nebula, starting from BD+46° 3474, with black-body + extinction models. Gaia DR3 (Data Release 3) offers the Sampled XP Spectra (low-resolution prism-dispersed spectra) of several stars within IC 5146, as well as the estimated surface temperature. The only assumption to be made is the stellar radius, for which we will rely on easy MS scale relationships.

- **Strömgren model:** The third, indirect method for estimating $E(BV)$ involves using the Strömgren radius for HII regions. This radius represents the point where the rate of hydrogen gas photoionizations by the central star ionizing photons balances the rate of recombinations. It marks the boundary where a sharp transition occurs from fully ionized to neutral gas, defining the edge of the HII region and the point where $H\alpha$ luminosity drops to zero. Dust absorption reduces the number of photoionizing photons, leading to a contraction of the nebula (Petrosian et al., 1972; Raga & Lora, 2015). The relationship is expressed by:

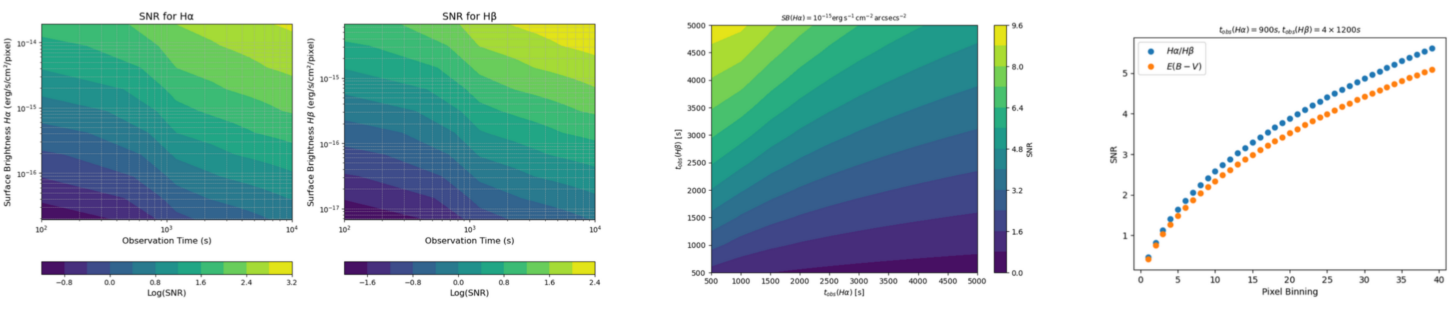
$$S_* e^{-\tilde{k}E(B-V)/1.086} = \alpha_B n_H^2 \frac{4\pi}{3} R_S^3$$

where $S_*$ is the ionizing photon rate, $\alpha_B$ is the Case B recombination coefficient, and $n_H$ is the hydrogen number density. In the case of zero dust absorption, the formula for the Stromgren radius reduces to the usual: $R_S = (3S_*/4\pi\alpha_B n_H^2)^{1/3}$

**Technical Requirements**

We expect the nebula to be sufficiently bright in H$\alpha$ to achieve a reasonable signal-to-noise ratio (SNR) of 5 under typical Milan atmospheric conditions with an exposure time of 900 seconds. This assumes the use of a narrow-band filter and pixel rebinning of 40, based on the specifications of the TOBI telescope and its detector.

In contrast, the surface brightness in H$\beta$ can be at most 1/2.86 of that in H$\alpha$. Additionally the H$\beta$ filter is approximately three times broader than the H$\alpha$ filter and collects more noise from the sky. Due to this factors an observation time exceeding 5000 seconds is required to achieve a reasonable SNR greater than 5. Alternatively, a more substantial rebinning will be necessary to compensate for the lower signal. Figure 2a illustrates the predicted SNR for various exposure times and nebula surface brightnesses, assuming typical Milan atmospheric conditions and a fixed rebinning factor of 50. Figure 2b shows the scaling of the signal to noise ratio for the derived $E(B-V)$. To achieve a sufficient SNR, the key factor is the H$\beta$ flux: observations in the H$\beta$ filter must be conducted for at least five times the duration of H$\alpha$ observations. Additionally the SNR can be optimized with appropriate rebinning, as demonstrated in Figure 2c.




(a) (b) (c)

Figure 2: **a**: estimated SNR for a range of H$\alpha$ and H$\beta$ surface brightness and observing time. Pixel binning is kept fixed at 50. **b**: estimated SNR for $E(B-V)$, for a range of integration times in H$\alpha$ and H$\beta$ and fixed estimated nebular surface brightness and binning factor of 50. **c**: estimated SNR for $t(H\alpha) = 900$ s, $t(H\beta) = 5000$ s and different rebinnings.

References: Draine 2003, ARAA, 41, 241; Cardelli et al. 1989, ApJ, 345, 245; Calzetti et al. 2000, ApJ, 533, 682; Herbig Dahm 2002, AJ, 123, 304; Rojas et al. 2014, ApJ, 797, L18; Petrosian et al. 1972, ApJ, 173, L67; Raga Lora 2015, ApJ, 814, L10.