Il Cielo come Laboratorio, 29
A.S. 2010-2011

# Star Formation Rate in the galaxy M51

Arianna Cattapan, Anna Pegoraro, Yi Hang Zhu

Liceo Scientifico Eugenio Curiel, Padova (PD)

**Abstract.** The purpose of this experience is to calculate the Star Formation Rate (SFR), which represents the number of solar masses created per year ($M_\odot$/yr), for the galaxy M51. We also calculated the number of ionizing photons emitted each second, and the theoretical number of stars needed to ionize the whole gas if all of them belonged to the spectral classes O5 or B1.

## 1. Introduction

The Whirlpool galaxy was discovered on October, 13th 1773 by the French astronomer Charles Messier and classified in his catalogue as M51 (see Fig. 1). This is a face-on spiral galaxy of type Sc, which forms an interacting pair of galaxies with its neighbour, NGC5195.

In elliptical galaxies, the higher density of the proto-galaxy let the galaxy form stars roughly at the same time. Instead, spiral galaxies are characterized by an ongoing star formation. This is due to the fact that the density of the proto-galaxy is low, and the gas cools down slowly and concentrates in the centre of the galaxy. The disk cools down even slower, and therefore it keeps forming new stars continously. As a consequence, to determine the SFR in spiral galaxies can be made by looking for regions where stars are forming, that are characterized by strongly visible H$\alpha$ and H$\beta$ lines.

## 2. Observational data

In the night of February, 23rd 2011, we observed M51 with the Asiago Galileo Telescope (122-cm), which has a Newton-Cassegrain configuration. The spectra were acquired usgin the B&C spectrograph with the slit positioned in two different ways: the first one along the direction E-W (PA = 90$^o$), the second one along the major axis of the galaxy (PA = 45$^o$), see Fig. 2.

The astronomic coordinates of the galaxy are: R.A.=13h 29m 54s, dec=47$^o$ 11' 60"; the Whirlpool galaxy is in the costellation of Canes Venatici.

## 3. Work description

The software IRAF (Image Reduction and Analysis Facility) was used to analyse the spectra of our galaxy, (Fig. 3). The H$\alpha$ line had to be identified among the emission lines, to select the regions to be studied. In spiral galaxies, like our galaxy, these regiones are located in the arms and in the bulge. The bulge has the highest peak, while the left and right regions represents the arms of M51 (see Fig. 4). The second peak from the left might correspond to a star located between us and the galaxy.

**Fig. 1.** The galaxy M51, or Whirlpool galaxy. Image from National Optical Astronomy Observatory, NOAO.

For each region we need to calculate the flux of the H$\alpha$ and H$\beta$ emission lines. Through the ratio of the two

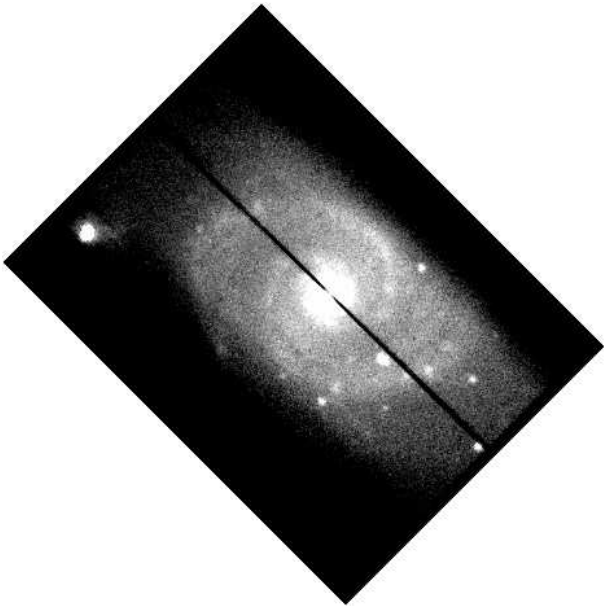

**Fig. 2.** Image of the position of the slit along the major axis of the galaxy, taken with the telescope-guiding-CCD camera.

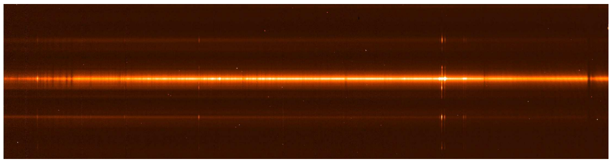

**Fig. 3.** Spectrum of M51 along the major axis, taken with the B&C spectrograph of the Galileo telescope. Image elaborated by DS9.

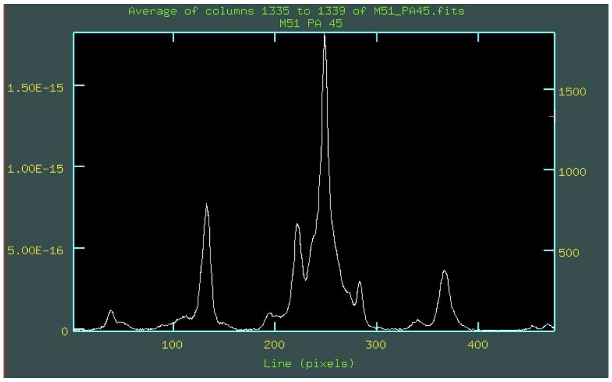

**Fig. 4.** H$\alpha$ regions of the spectrum directed E-W. The peaks correspond to the arms of the galaxy. Image obtained with the IRAF package.

fluxes it is possible to obtain the reddening ($A_V$), which is the visual absorption of electromagnetic radiation by the gas.

$$A_V = \frac{\log\left[2.86 \times \frac{F(H\beta)}{F(H\alpha)}\right]}{-0.1386}$$

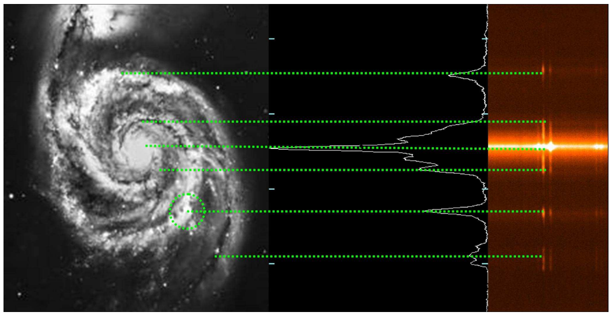

**Fig. 5.** Correlation between the H$\alpha$ regions of the spectrum and the image of the galaxy.

where 2.86 is the theoretical value of the H$\alpha$ to H$\beta$ intensity ratio. The mean reddening is $A_V$=1.42; and it was used to find the real H$\alpha$ flux:

$$I(H\alpha) = I(H\alpha^{obs}) \times 10^{0.4\times A(H\alpha)} \tag{1}$$

The redshift was calculated for the bulge only, since it is not effected by the galactic rotation:

$$z = \frac{\lambda_{obs} - \lambda_e}{\lambda_e}$$

where as $\lambda_{obs}$ we used the wavelength of the H$\alpha$ line of the bulge, and $\lambda_e$ is the rest-frame wavelength of the same line, $\lambda_e$ = 6563 Å. From the redshift, we evaluated the distance by adopting Hubble's law, where Hubble constant ($H_0$) is considered equal to 75 km s$^{-1}$ Mpc$^{-1}$.

$$D = \frac{c \cdot z}{H_0} \ [\text{ Mpc}] \tag{2}$$

To derive the luminosity of the H$\alpha$ line we applied the following equation:

$$L(H\alpha) = 4\pi D^2 \cdot I(H\alpha) \ [\text{ erg s}^{-1}]$$

where D is the distance calculated from eqn. (2), and I(H$\alpha$) is the intensity obtained from eqn. (1).

The SFR in each region was estimated through the Kennicutt's law:

$$SFR = 7.9\text{x}10^{-42} L(H\alpha) \ [\text{ erg s}^{-1}]$$

where D is the distance calculated from eqn. (2), and I(H$\alpha$) is the intensity obtained from eqn. (1).

The SFR in each region was estimated through the Kennicutt's law:

$$SFR = 7.9\text{x}10^{-42} L(H\alpha) \ [\text{ M}_\odot \text{ yr}^{-1}]$$

Approximatly, each region has an area given by the rectangle with base (b) corresponding to the slit's width and the height (h) given by the its linear size along the slit. These can be converted in kpc by adopting the following equation and knowing that the CCD scale is 1”/px:

$$b = \frac{k \cdot D}{206265} \ [\text{kpc}]$$

where k is the slit width and is equal to 4.25”

$$h = \frac{px \cdot D}{206265} \ [\text{kpc}]$$

where px=region’s width in arcsec

$$A_{\text{rectangle}} = b \cdot h$$

The total area of the galaxy was approximated to a circle:

$$A_{\text{TOT}} = \left( \frac{\langle D \rangle \cdot r}{206265} \right)^2 \cdot \pi$$

Last, the total SFR was computed multiplying the total area by the mean density of the local SFR.

$$SFR_{\text{TOT}} = \left( \frac{SFR}{\langle A_{\text{rec}} \rangle} \right) \cdot A_{\text{TOT}}$$

The second part of our work was focused on calculating how many ionizing photons are emitted every second from our galaxy. To do this, we used the following relation:

$$Q_{\text{ion}} = 7.3 \times 10^{11} L(H\alpha) \tag{3}$$

Calculated this values, we estimated how many stars belonging to the spectral type O5 should be in the galaxy to produce the amount of ionizing photons calculated.

$$O5stars = \frac{Q_{\text{ion}}}{Q_{O5}}; \qquad Q_{O5} \approx 5 \times 10^{49} \quad [\text{ph/s}]$$

In the same way we estimated the number of B1 stars needed to achieve the same result:

$$B1stars = \frac{Q_{\text{ion}}}{Q_{B1}}; \qquad Q_{B1} \approx 3 \times 10^{45} \quad [\text{ph/s}]$$

## 4. Results

This experience had the aim to estimate the Star Formation Rate (number of solar masses per year, $M_\odot/yr$) of the galaxy M51. We used spectra obtained from the Galileo Telescope of the Asiago Astrophysical Observatory. As second step of this work, we calculated how many ionizing photons are emitted every second from the galaxy, and the theoretical number of stars necessary to ionize the gas if all the stars belonged to the spectral classes O5 or B1.

The Star Formation Rate we estimated for M51 is ~7 $M_\odot$/yr, which means that, in the warmest regions of the arms and in the bulge, every year could be created, on average 7, stars as big as our Sun. The mean SFR in spiral galaxy is about 5 $M_\odot$/yr.

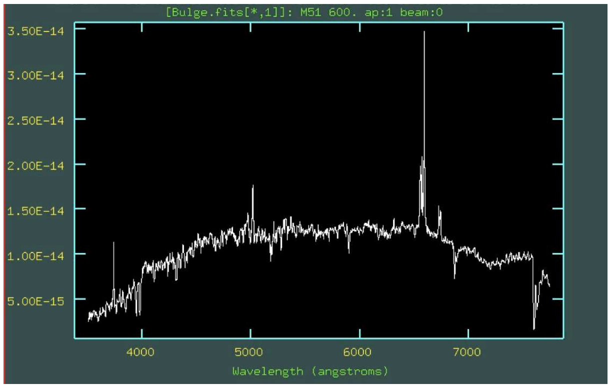

**Fig. 6.** The spectrum of the Whirlpool Galaxy, along direction E-W, in which the gas emission spectrum is superposed to the stellar continuum.

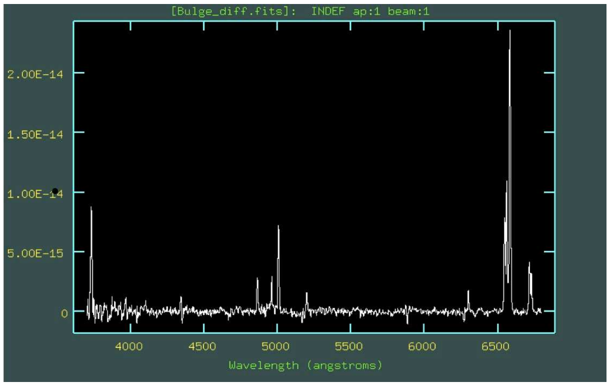

**Fig. 7.** The emission spectrum of the Whirlpool Galaxy, along direction E-W. The underlying stellar spectrum was subtracted by the STARLIGHT task.

The mean quantity of ionizing photons is $8 \times 10^{49}$ ph/s. The number of stars belonging to the O5 spectral class, needed to ionize all the gas is nearly 12. In the same way, the number of stars belonging to the B1 spectral class is nearly $2 \times 10^5$. The second value is higher than the first one because B1 stars are cooler (12000K<T<25000K) and smaller than O5 stars (25000K<T<50000K); therefore more B1 stars are needed to heat the same quantity of gas.

From the other relations it is possible to derive that:

- the redshift of the galactic centre is $z = 0.001545$;
- M51’s distance is $D = 6.1794$ Mpc equivalent to about 20 millions light year (1pc = 3.26 ly);
- the mean value of the reddening is $A_V = 1.419$.

In the bulge, the star density is very high, therefore the observed spectrum is the result of the contribution of the underlying stellar spectrum and of the gas emission spectrum. In order to retrieve the emission spectrum, we had to subtract the modeling stellar spectrum

**Table 1.** The summary results for each regions of M51.

| | $z$ | D | $A_v$ | L | SFR | $Q_{ion}$ | Stars O5 | Stars B1 |
|---|---|---|---|---|---|---|---|---|
| Left Region 1 | 0.00167 | 668.603 | 0.302 | $1.384 \mathrm{x} 10^{38}$ | 0.00109 | $1.010 \mathrm{x} 10^{50}$ | 2.021 | $3.368 \mathrm{x} 10^{4}$ |
| Left Region 2 | 0.00160 | 639.348 | 1.984 | $9.262 \mathrm{x} 10^{38}$ | 0.00732 | $6.761 \mathrm{x} 10^{50}$ | 13.523 | $2.254 \mathrm{x} 10^{5}$ |
| Left Region 3 | 0.00156 | 624.736 | 1.974 | $8.551 \mathrm{x} 10^{38}$ | 0.00676 | $6.242 \mathrm{x} 10^{50}$ | 12.484 | $2.081 \mathrm{x} 10^{5}$ |
| Bulge | 0.00163 | 653.991 | 1.278 | $1.890 \mathrm{x} 10^{38}$ | 0.00149 | $1.379 \mathrm{x} 10^{50}$ | 2.759 | $4.598 \mathrm{x} 10^{4}$ |
| Right Region 2 | 0.00161 | 645.450 | 3.238 | $4.141 \mathrm{x} 10^{39}$ | 0.03271 | $3.023 \mathrm{x} 10^{51}$ | 60.458 | $1.008 \mathrm{x} 10^{6}$ |
| Right Region 1 | 0.00149 | 597.297 | 1.443 | $3.620 \mathrm{x} 10^{38}$ | 0.00286 | $2.642 \mathrm{x} 10^{50}$ | 5.285 | $8.808 \mathrm{x} 10^{4}$ |
| Star | 0.00162 | 649.735 | 0.667 | $2.888 \mathrm{x} 10^{38}$ | 0.00228 | $2.108 \mathrm{x} 10^{50}$ | 4.216 | $7.026 \mathrm{x} 10^{4}$ |

from the observed one, using the STARLIGHT task. Without this subtraction, the H$\alpha$ line intensity would result lower than in reality due to the stellar absorption (see Figs. 6 and 7).

The galaxy's spectrum shoes a weird peak, the second from the left, that might not correspond to a galactic arm. It could be the H$\alpha$ emission of a star located between us and the galaxy. Although, this peak was considered in the calculations. All the results obtained for our galaxy are summarized in Table 1.

## References

http://seds.org/messier/more/m051_noao.html
Lazzari M., Rocchetto M., Vidal I., ”Misura della Star Formation Rate nelle galassie NGC1569, NGC2798 e NGC3227”, Il Cielo come Laboratorio 2006/2007;
http://dipastro.pd.astro.it/osservatorio/telescopio.html