Radio-Band and B-Band Luminosity and Brightness of Galaxy NGC 5236

Problem

Compare the radio and B-band intensity with the radio and B-band luminosity of the galaxy NGC 5236.

Hints

Data

Distance in Megaparsecs

$d := 6.9$

$$6.9 \quad (2.1)$$

Number of Centimetres in One Parsec

$pc := 3.086 \cdot 10^{18}$

$$3.086000000\ 10^{18} \quad (2.2)$$

Major Axis in Arcminutes

$ma := 11.2$

$$11.2 \quad (2.3)$$

Minor Axis in Arcminutes

$mi := 10.2$

$$10.2 \quad (2.4)$$

Centre of Radio Band in GHz

$rbc := 1.49$

$$1.49 \quad (2.5)$$

Bandwith in MHz

$bw := 50$

$$50 \quad (2.6)$$

Intensity in mJy per Beam

$ib := 2445$

$$2445 \quad (2.7)$$

Beam Diameter Circular Solid Angle in Arcseconds

$bd := 54$

$$54 \quad (2.8)$$

B-band Magnitude

$mb := 8.51$

$$8.51 \quad (2.9)$$

Pixel Size on Sky in Square Arcseconds

$px := 1$

$$1 \qquad \textbf{(2.10)}$$

Flux Density Calibration for the B-band Filter in units of ergs $cm^{-2}\, s^{-1} Hz^{-1}$

$fc := 4.063 \cdot 10^{-20}$

$$4.063000000\ 10^{-20} \qquad \textbf{(2.11)}$$

Full Width at Half-Maximum for B Filter in micrometres

$\Delta\lambda := 0.098$

$$0.098 \qquad \textbf{(2.12)}$$

Effective Wavelength for the B Filter in micrometres

$\lambda_{eff} := 0.438$

$$0.438 \qquad \textbf{(2.13)}$$

$1 \text{ Jansky} = 10^{-23} \text{ ergs } s^{-1} cm^{-2} Hz^{-1}$

$Jy := 10^{-23}$

$$1.00 \times 10^{-23} \qquad \textbf{(2.14)}$$

Speed of Light in Centimetres per second

$c := 2.9979 \cdot 10^{10}$

$$2.997900000\ 10^{10} \qquad \textbf{(2.15)}$$

Useful Equations

Solid Angle Subtended by Major and Minor Axes in Arcseconds

$\Omega_{gal} = evalf\left(\frac{\text{Pi}}{4} \cdot (ma) \cdot (mi) \cdot \left(\frac{\text{Pi}}{180 \cdot 60}\right)^2 \text{sr}\right) :$

Flux Density

$f_\nu = I_\nu \cdot \Omega_{gal} :$

$\Delta\nu$ for the B-band Filter

$\Delta\nu = \frac{c}{\left(\lambda_{eff}\right)^2} \cdot \Delta\lambda :$

Total Flux

$f = f_\nu \cdot \Delta\nu :$

Luminosity

$L = 4 \cdot \pi \cdot r^2 \cdot f :$

Solution

Calculate the solid angle subtended by the galaxy:

$$\Omega_{gal} = evalf\left(\frac{Pi}{4} \cdot (ma) \cdot (mi) \cdot \left(\frac{Pi}{180 \cdot 60}\right)^2 sr\right)$$

$$\Omega_{gal} = 7.59 \times 10^{-6}\ sr \tag{4.1}$$

Radio Band

Calculate the solid angle of the beam:

$$\Omega_{beam} = evalf\left(\frac{Pi}{4} \cdot (bd) \cdot (bd) \cdot \left(\frac{Pi}{180 \cdot 60 \cdot 60}\right)^2 sr\right)$$

$$\Omega_{beam} = 5.38 \times 10^{-8}\ sr \tag{4.1.1}$$

Convert the specific intensity, which is the flux density per solid angle, to ergs/s.

$$I_\nu = \frac{ib\ mJy}{5.38 \cdot 10^{-8} sr}$$

$$I_\nu = \frac{4.544609664\ 10^{10}\ mJy}{sr} \tag{4.1.2}$$

$$\frac{rhs(\mathbf{(4.1.2)})}{1000 mJy\ Jy^{-1}}$$

$$\frac{4.544609664\ 10^{7}\ Jy}{sr} \tag{4.1.3}$$

$$I_\nu = \mathbf{(4.1.3)} \cdot 10^{-23} erg\ s^{-1} cm^{-2} Hz^{-1} Jy^{-1}$$

$$I_\nu = \frac{4.544609664\ 10^{-16}\ erg}{sr\ s\ cm^2\ Hz} \tag{4.1.4}$$

Calculating the flux density:

$$f_\nu = rhs(\mathbf{(4.1.4)}) \cdot rhs(\mathbf{(4.1)})\ sr$$

$$f_\nu = \frac{3.450300317\ 10^{-21}\ erg\ sr}{s\ cm^2\ Hz} \tag{4.1.5}$$

Calculating the flux (flux density times bandwidth):

$$f = rhs(\mathbf{(4.1.5)}) \cdot 10^6 \cdot bw Hz$$

$$f = \frac{1.725150158\ 10^{-13}\ \mathrm{erg\ sr}}{\mathrm{s\ cm}^2} \tag{4.1.6}$$

Luminosity at 6.9 Mpc:

$r := \mathrm{d} \cdot 10^6 \cdot pc\mathrm{cm}$

$$2.129340000\ 10^{25}\ \mathrm{cm} \tag{4.1.7}$$

$evalf\left(L = 4 \cdot \mathrm{Pi} \cdot r^2 \cdot rhs(\mathbf{(4.1.6)})\right)$

$$L = \frac{9.829395081\ 10^{38}\ \mathrm{erg\ sr}}{\mathrm{s}} \tag{4.1.8}$$

B-Band

Converting one square arcsecond to steradians:

$evalf\left(px \cdot \left(\frac{\mathrm{Pi}}{180 \cdot 60 \cdot 60}\right)^2\right) \mathrm{sr}$

$$2.350443055\ 10^{-11}\ \mathrm{sr} \tag{4.2.1}$$

Calculating f_ν from equation (10) in the text, using the reference flux from Table 2 in the text:

$solve\left(mb - 0 = -2.5 \cdot \log_{10}\left(\frac{f_\nu}{\mathrm{fc}}\right), f_\nu\right)$

$$1.602680018\ 10^{-23} \tag{4.2.2}$$

This is the flux density (f_ν) within a square arcsecond. Dividing this by the unit solid angle gives the specific intensity:

$I_\nu = \frac{\mathbf{(4.2.2)}}{\mathbf{(4.2.1)}}$

$$I_\nu = \frac{6.818629426\ 10^{-13}}{\mathrm{sr}} \tag{4.2.3}$$

Multiply this times the galaxy's solid angle to obtain the flux density of the galaxy:

$6.818629426\ 10^{-13} \cdot 7.59 \times 10^{-6}$

$$5.175339734\ 10^{-18} \tag{4.2.4}$$

ergs per square centimetre per second per hertz.

From Table 2 in the text, $\Delta\lambda = 0.098$ µm, and λ_{eff} 0.438 µm. Therefore,

$$\Delta\nu = \frac{c}{\left(\lambda_{eff}\right)^2} \cdot \Delta\lambda$$

$$\Delta\nu = 1.531422406\ 10^{10} \tag{4.2.5}$$

in units of hertz.

Therefore, the flux ($f = f_\nu * \Delta\nu$) is:

(4.2.4)$\cdot$*rhs*(**(4.2.5)**)

$$7.925631227\ 10^{-8} \tag{4.2.6}$$

ergs per second per square centimetre. And the luminosity ($4*\pi*r^2*f$) is

$evalf\left(4\cdot \mathrm{Pi}\cdot \left(2.129340000\ 10^{25}\right)^2 \cdot \textbf{(4.2.6)}\right)$

$$4.515790130\ 10^{44} \tag{4.2.7}$$

joules per second.

	INTENSITY ($erg/sr/cm^2/Hz$)	LUMINOSITY (erg/s/sr)
RADIO	$4.545\ 10^{-16}$	$9.827\ 10^{38}$
B-BAND	$6.819\ 10^{-13}$	$4.516\ 10^{44}$

Note that the intensity of the two bands differs by roughly 3 orders of magnitude while the luminosity differs by nearly 6 orders of magnitude.

References

Condon, J. (1987). A 1.49 GHz Atlas of Spiral Galaxies. *ApJS*, Ser 65, 485-541.