15. Intensity normalization for three different programs

It is essential to have the same units of measurement to compare Ventspils RTMC and the other programs – 1) RADMC3D created by C.Dullemond et al. (https://www.ita.uni-heidelberg.de/~dullemond/software/radmc-3d/); 2) Integral_equ (Integral equations for source functions in homogeneous sphere. Rayleigh scattering) created by J.Freimanis and R.Peženkovs.

We use SI system of units:

Speed of light $c = 2{,}99792458 * 10^8 \ \frac{m}{s}$

Planck constant $h = 6{,}62607015 * 10^{-34}\, J * s$

Boltzmann constant $k = 1.380649 * 10^{-23} \ \frac{J}{K}$

Brightness temperature of the surface of the Sun $T_b = 5780\ K$

Frequency for 550[nm] wavelength $\nu = \frac{c}{\lambda} = \frac{2{,}99792458*10^8 \frac{m}{s}}{5{,}5*10^{-7} m} = 5{,}450772 * 10^{14}\ Hz$

Radius of the Sun $r_* = 6{,}96 * 10^8\ m$

Luminosity of the Sun $L_{*tot} = 3{,}828 * 10^{26}\ W$

Outer radius of the dust cloud $r_0 = 20\ AU = 2{,}991957414 * 10^{12}\ m$

Distance between cloud and telescope $\mathrm{r}_{dist.cloud.tel} = 600pc = 1{,}851406548 * 10^{19}\ m$

Distance between star and telescope

$$\mathrm{r}_{dist.star.tel} = 600pc + 20AU = 1{,}851406847 * 10^{19}\ m$$

Telescope is arbitrarily assumed to be ESO VLT, having 8.2 m diameter of the primary mirror, unobscured by the secondary mirror and other structures

We calculate star luminosity for $\nu = 5{,}450772 * 10^{14}\ Hz$ assuming blackbody radiation for the adopted brightness temperature T_b (equation 15.1) :

$$L_{*\nu} = \frac{8\pi^2 r_*^2 h\nu^3}{c^2} * \frac{1}{e^{\frac{h\nu}{kT_b}} - 1} \tag{15.1}$$

$$L_{*\nu} = 4{,}997579 * 10^{11}\ \frac{W}{Hz}$$

To get each pixel value of Ventspils RTMC it is essential to calculate pixel coefficient (equ 15.2):

$$H_{m,\nu.RTMC}^{pix} = \frac{L_{*\nu} * W_{m.RTMC}}{W_{tot.RTMC}}$$

(15.2)

$W_{m.RTMC}$ – number of photons accumulated by corresponding CCD matrix pixel

$W_{tot.RTMC}$ - number of photons emitted by star

$$H_{m,\nu.RTMC}^{pix} = \frac{4{,}997579 * 10^{11} \left[\frac{W}{Hz}\right] * W_{m.RTMC}}{10^{9} * 10^{3}} = W_{m.RTMC} * 0{,}4997579 \quad \left[\frac{W}{Hz}\right]$$

To get each pixel value of Integral_equ it is essential to calculate pixel coefficient using equation 15.3:

$$H_{m,\nu.Integ}^{pix} = \frac{L_{*\nu} * S_{tel}[m^2] * \Omega_m * W_{m.integ.}}{L_{*tot}}$$

(15.3)

S_{tel} – area of the primary mirror of the telescope:

$$S_{tel} = \frac{\pi * D^2}{4} = \frac{\pi * 8{,}2^2}{4} \approx 52{,}8102 \; [m^2]$$

(15.4)

Ω_m – spatial angle corresponding to single pixel of the image, CCD matrix having 200x200 square pixels, cloud radius equals to 98 pixels:

$$\Omega_m = \frac{r_0^2}{r_{dist.star.tel}^2 * (98 * 98)} = 2{,}71929 * 10^{-18} \; [sr]$$

(15.5)

$W_{m.integ.}$ – corresponding pixel value of CCD matrix of Integral_equ program

$$H_{m,\nu.Integ}^{pix} = \frac{L_{*\nu} * S_{tel}[m^2] * \Omega_m * W_{m.integ.}}{L_{*tot}} =$$

$$= \frac{4{,}997579 * 10^{11}\left[\frac{W}{Hz}\right] * 52{,}8102\ [m^2] * \frac{[(20AU\ in\ [m]):98]^2}{((600\ pc + 20AU)\ in\ [m])^2} * W_{m.integ.}}{3{,}828 * 10^{26}[W]}$$

$$= W_{m.integ.} * 1{,}874823 * 10^{-31}\left[\frac{W}{Hz}\right]$$

(15.6)

To get each pixel value of RADMC3D it is essential to calculate pixel coefficient using equation 15.7:

$$H_{m,\nu.RADMC3D}^{pix} = imageI[\dots]\frac{pixsizeX * pixsizeY}{r_{dist.star.tel}^2} * S_{tel}$$

(15.7)

$imageI[\dots]$ - value of corresponding pixel

$$H_{m,\nu.RADMC3D}^{pix} = imageI[\dots]\frac{pixsizeX * pixsizeY}{r_{dist.star.tel}^2} * S_{tel} =$$

$$= imageI[\dots]\frac{[(20AU\ in\ [m]):98]^2}{\big((600\ pc + 20AU)[m]\big)^2} * 528102\ [cm^2] * 10^{-7} =$$

$$= imageI[\dots] * 1{,}43606 * 10^{-19}\left[\frac{W}{Hz}\right]$$

(15.8)