A Note on Radio Map Units

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The basic unit of radiative intensity is I_ν, the specific intensity or brightness. Consider a given ray, and construct an area dA normal to it. Consider all rays passing through dA whose direction is within a solid angle $d\Omega$ of that ray. The energy crossing dA in a time dt in a frequency range $d\nu$ is defined as

$$dE = I_\nu \; dA \; dt \; d\Omega \; d\nu.$$

This has units of ergs s^{-1} cm^{-2} ster^{-1} Hz^{-1}. If we integrate over the solid angle, we get the flux density S_ν. A standard unit of flux density in radio astronomy is the Jansky, where 1 Jy = 10^{-26} W m^{-2} Hz^{-1} = 10^{-23}ergs s^{-1} cm^{-2} Hz^{-1}. From Wikipedia: "Since the Jansky is obtained by integrating over the whole source solid angle, it is most simply used to describe point sources...for extended sources, the surface brightness is often described with units of Jy per solid angle."

If we have a blackbody emitter (such as the CMB, or any optically thick thermal source), then the intensity is specified just by the temperature as

$$I_\nu = B_\nu(T) = \frac{2h\nu^3/c^2}{\exp(h\nu/kT) - 1}.$$

In radio astronomy we often characterize the brightness at a certain frequency as the temperature of a blackbody having the same brightness at that frequency. We identify $I_\nu = B_\nu(T_b)$, where T_b is the brightness temperature. In the Rayleigh-Jeans limit ($h\nu << kT$), then

$$I_\nu = \frac{2\nu^2}{c^2} kT_b.$$

CMB maps will often give maps in terms of a differential CMB temperature:

$$\Delta T_{CMB} = \frac{\Delta I_\nu}{(dB_\nu/dT)_{T_0}},$$

where $T_0 = 2.7255$ K and ν is the observing frequency. This linearized definition deviates from the true variation in the blackbody temperature in the bright regions of high frequency (217, 353 GHz in Planck) maps.

The Planck 545 and 857 GHz channels are given in intensity units (MJy sr^{-1}) assuming a reference spectral energy distribution $I_\nu = I_0 \times (\nu_0/\nu)$.