# RADIATIVE PROCESSES in ASTROPHYSICS

**Problems set 1. Deadline Friday, January 23, 2026.**

1.1 X-ray photons are produced in a cloud of radius $R$ at the uniform rate $\Gamma$ (photons per unit volume per unit time). The cloud is a distance $d$ away. Neglect absorption of these photons (optically thin medium). A detector at Earth has an angular acceptance beam of half-angle $\Delta\theta$ and it has an effective area of $A$.

a. Assume that the source is completely resolved. What is the observed intensity (photons per unit time per unit area per steradian) toward the center of the cloud?

b. Assume that the cloud is complete unresolved. What is the average intensity (in the above units) when the source is in the beam of the detector?

1.2 A supernova remnant has an angular diameter $\theta = 4.3$ arcminutes and a flux at 100 MHz of $F_{100} = 1.6 \times 10^{-19}$ erg cm$^{-2}$ s$^{-1}$ Hz$^{-1}$. Assume that the emission is thermal.

a. What is the brightness temperature $T_b$? What energy regime of the blackbody curve does this correspond to?

b. The emitting region is actually more compact than indicated by the observed angular diameter. What effect does this have on the derived value of $T_b$?

c. At what frequency will this object's radiation be maximum, if the emission is blackbody?

d. What can you say about the temperature of the material from the above results?

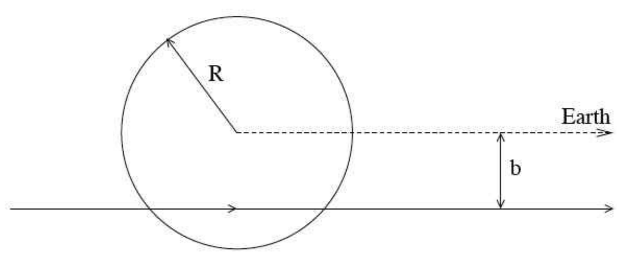


Figure 1: Geometry for exercise 1.3.

1.3 A certain gas emits thermally at the rate $P(\nu)$ (power per unit volume and frequency range). A spherical cloud of this gas has radius $R$, temperature $T$ and is a distance $d$ from Earth ($d \gg R$).

a. Assume that the cloud is optically thin. What is the brightness of the cloud as measured on Earth? Give your answer as a function of the distance $b$ away from the cloud center, assuming the cloud may be viewed along parallel rays with different impact parameters $b$ (i.e. the closest distance from the cloud center to the ray, see Fig. **??**).

b. What is the effective temperature of the cloud?

c. What is the flux $F_\nu$ measured on Earth coming from the entire cloud?

d. How do the measured brightness temperatures compare with the cloud's temperature?

e. Answer parts (a)-(d) for an optically thick cloud.

1.4 In this exercise we examine the radiation from the planet Jupiter.

a. What is the power intercepted by Jupiter from the Sun?

b. We define the albedo $A$ as the ratio of the incident over the reflected flux, $F_{\text{reflected}} = A \times F_{\text{in}}$. Jupiter has $A = 0.52$. What is the amount of energy from the Sun absorbed per second by Jupiter?

c. We approximate the thermal emission by Jupiter as a pure blackbody. Jupiter rotates fast, once per 10 hrs. This is fast enough to even out any temperature differences between the side illuminated by the Sun and the side turned away from the Sun. Jupiter can therefore be approximated as isothermal. What is the equilibrium temperature of Jupiter in the Sun's radiation field?

d. The observed spectrum from Jupiter can be reasonably approximated by a Planck curve. It peaks at about $7.13 \times 10^{12}$ Hz. What temperature do you deduce for Jupiter?

e. A possible explanation for this temperature difference is that it is a remnant from the formation stage of Jupiter. The gravitational energy liberated as the protoplanterary material coalesced into Jupiter, is stored as thermal energy (heat) of the gas deep inside Jupiter's interior. For this gas a specific heat capacity of $2.1 \times 10^7$ erg g$^{-1}$ K$^{-1}$ can be assumed, appropriate for atomic hydrogen. The energy liberated by the temperature decrease of this material contributes energy to the budget that has to be evaluated to calculate Jupiter's surface equilibrium temperature.

If we assume that the power delivered by Jupiter's interior is constant with time, calculate the minimum temperature of the Jupiter's interior at the formation time 4.5 Gyr ago.