

# Astronomical Observing Techniques 2016:

## Exercises on Atmospheric Effects

(Due on 22 February 2016 at 11:15)

February 8, 2016

### 1 Airmass

The flux of a star is reduced by absorption in the Earth's atmosphere:  $I = I_0 e^{-\tau}$ , with  $\tau = A \int \rho(z) \kappa(z) dz$ .  $A$  is the airmass,  $\kappa$  the absorption coefficient and  $z$  the altitude. The airmass is given by  $1/\cos(\theta)$ , with  $\theta$  the zenith angle. The optical depth,  $\tau$ , is difficult to calculate in practice as  $\rho(z)$  and  $\kappa(z)$  are not precisely known. Show that we can find  $I_0$ , i.e. the flux before the star light enters the Earth's atmosphere, if we carry out two measurements of the received flux ( $I_1$  and  $I_2$ ) at different airmasses ( $A_1$  and  $A_2$ ), assuming the properties of the atmosphere do not change between the two measurements.

### 2 Sky Background

1. Calculate the spectral radiance (at zenith) of the sky background in the L band ( $3.4\mu\text{m}$ ). Assume that the optical depth is  $\tau = 0.15$ , which is much smaller than 1. Use wavelength units and assume that the average temperature of the atmosphere is  $T = 250$  K.
2. Calculate the sky brightness in  $\text{mag arcsec}^{-2}$ . For  $\text{mag}_L = 0$ , the spectral irradiance is  $8.1 \cdot 10^{-11} \text{ W m}^{-2} \mu\text{m}^{-1}$ .

### 3 Refraction

The direction of light passing through the atmosphere changes because of the changing index of refraction with height. The amount of change is given by Snell's law:  $n_1 \sin(z_1) = n_2 \sin(z_2)$ . Let  $z_t$  be the true zenith angle,  $z_0$  the observed zenith angle,  $z_i$  the observed zenith angle at layer  $i$  in the atmosphere,  $n_0(\lambda)$  the index of refraction at the surface, and  $n_i(\lambda)$  the index of refraction at layer  $i$  ( $i = 1 \dots N$ ).

1. Show that the refraction only depends on the index of refraction near the Earth's surface.
2. We define astronomical refraction,  $R$ , to be the angular amount that the object is displaced by the refraction of the Earth's atmosphere. Derive the following approximation to the refraction  $R(z_0)$  as a function of the observed zenith angle  $z_0$ :

$$R = (n - 1) \tan(z_0)$$

(Hint: Use  $\sin(u \pm v) = \sin(u) \cos(v) \pm \cos(u) \sin(v)$  and  $R \ll 1$ ).

3. How large is this effect for an object observed at a zenith angle of  $45^\circ$ ? Take a typical index of refraction of 1.00029.
4. We want to observe a source in the L band ( $\lambda = 3.45\mu\text{m}$ , bandwidth = 472 nm) with a diffraction-limited 15-m telescope. Do we need to worry about distortion due to the dispersion for a zenith angle of  $45^\circ$ ? And for  $85^\circ$ ? Hint: the diffraction limit of a telescope is given by  $1.22\lambda/D$ .