Astronomical Observing Techniques 2013: Exercises on Atmospheric Effects (Due on 24 September 2013 at 13:00)

September 16, 2013

1 Airmass

The flux of a star is reduced by absorption from the atmosphere: $I = I_0 e^{-\tau}$, with $\tau = A \int \rho(z)\kappa(z)dz$, with A the Airmass, κ the absorption coefficient and z the altitude. The Airmass is given by $1/cos(\theta)$, with θ the zenith angle. The optical depth (τ) is in practice difficult to calculate as $\rho(z)$ and $\kappa(z)$ are not precisely known. Show that if we do two measurements of the received flux (I_1, I_2) at different Airmasses $(A_1; A_2)$ we can find I_0 (assuming the properties of the atmosphere do not change with time).

2 Sky Background

1. Calculate the spectral radiance (at the zenith) of the sky background in the L band (3.4μm), the optical depth $\tau = 0.15$ (you can assume $\tau \ll 1$, use wavelength units). The average temperature of the atmosphere is $T = 250$ K.
2. Calculate the sky brightness in mag arcsec^{-2}, use that for mag$_L = 0$, the spectral irradiance is $8.1*10^{-11}$ W m$^{-2}\mu$m^{-1}.

3 Refraction

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

1. Show that the refraction depends only the index of refraction near the earth's surface.
2. In which direction does an object move by refraction (away or towards the zenith)?
3. We define astronomical refraction, R, to be the angular amount that the object is displaced by the refraction of the Earth's atmosphere. Derive that the refraction as function of observed zenith angle $R(z_0)$ is (approximately) given by $R = (n - 1)\tan(z_0)$. (Hint: you can use that $\sin(u \pm v) = \sin(u)\cos(v) \pm \cos(u)\sin(v)$, and that $r \ll 1$).
4. How large is this effect for an object observed at a zenith angle of 45°? Take a typical index of refraction of 1.00029.
5. Now suppose we want to observe a source in the L band ($\lambda = 3.45\mu$m, bandwidth = 472 nm) with a diffraction limited 15 m telescope. Will you see distortion for a zenith angle of 45°? And for 85°?