Differential Atmospheric Effects

An important problem that cannot be neglected when performing multi-object spectroscopy is the differential refraction of the atmosphere. This is a *differential* effect in the sense that the atmospheric refraction index, and hence the direction of propagation of the light from a given star, changes with both zenith distance and wavelength.
The consequences for astronomical observations are therefore two-fold:

- An acromatic effect, due to the fact that the refraction index at a given wavelength changes — non-linearly — with the zenital distance. This is very important when observing with large fields, because stars in different position within the CCD can have significantly different zenital distances, and therefore do not move in a coherent way across the sky, making it impossible to guide on the whole field.
- A chromatic effect, due to the fact that the refraction index changes with wavelength. The result of this is that the red and the blue part of the spectrum do not hit the CCD at the same position, and therefore a part of the star spectrum can fall outside the slit or the fibre hole. This effect is important only when observing over a wide spectral range, especially if in the blue. This effect is fairly constant across the field, and can be compensated by the use of Atmospheric Dispersion Correctors (ADC). The latter, however, is only available for ARGUS observations.

The acromatic effect, being differential across the field, and strongly dependent on the actual zenit distance of the observed sky region, cannot be compensated. It is therefore extremely important to be aware of its amplitude in different observing conditions, in order to correctly program the observations.
A comprehensive formula that takes into account all the parameters affecting the size of the differential atmospheric refraction has been given by Filippenko (1982, PASP, 94, 715). According to its calculations, the refraction index, n, of the atmosphere at a certain wavelength, λ, is given by:

$$n(\lambda) = 10^{-6} \times \left[64.328 + \frac{29498.1}{146 - \lambda^{-2}} + \frac{255.4}{41 + \lambda^{-2}}\right] \times \left[\frac{P\left[1 + (1.049 - 0.0157T) \times 10^{-6}P\right]}{720.883(1 + 0.003661T)}\right]$$

where P is the atmopheric pressure in mm Hg (557.25 for Paranal) and T is the temperature in $^{\circ}C$ (11.5 for Paranal). Once the refraction index is properly determined, the displacement of the observed astronomical object, with respect to its position “without” atmosphere is

$$dr(\lambda) = n(\lambda) tan(z)$$

where z is the zenith distance of the object.

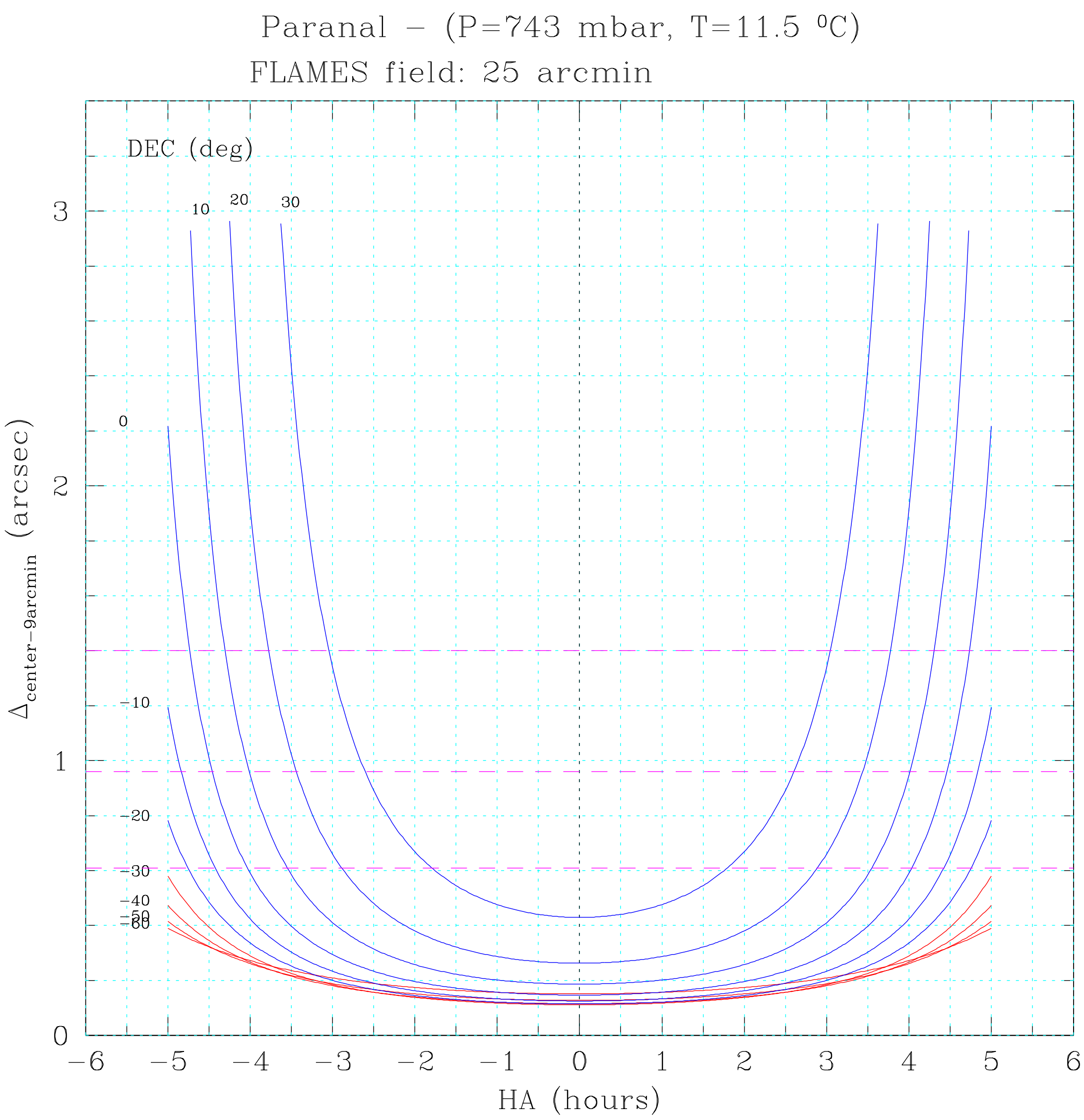

Figure 1: Distance between the field center and an object located 9 arcmin away from it, as a function of hour angle and declination of the field. The dashed horizontal lines indicate are the loci of constant 2, 2.5 and 3 airmasses, from bottom to top, respectively.

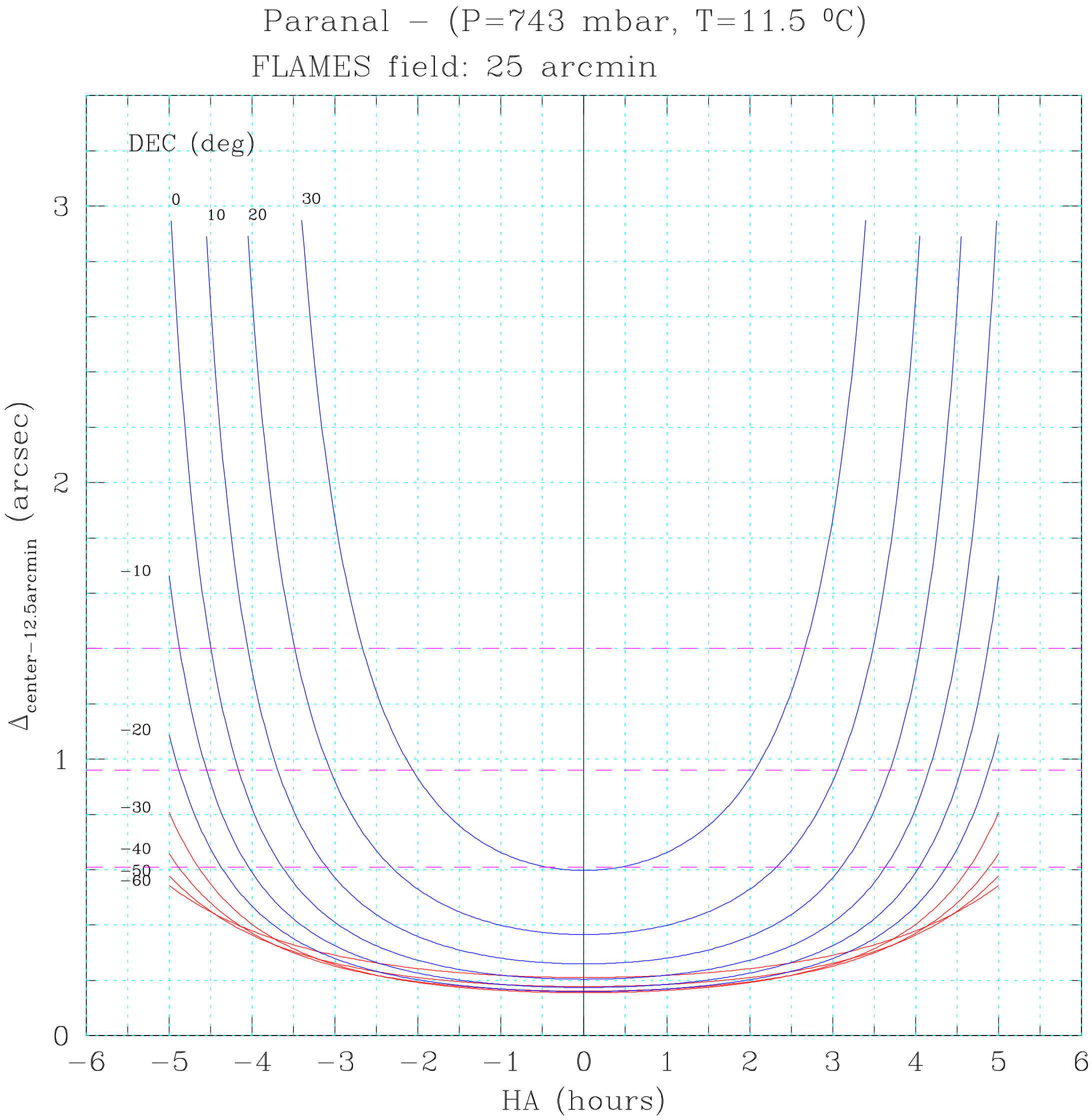

Figure 2: Same as Fig. 1 but for an object located at the very edge of the field (12.5 arcmin from the center).

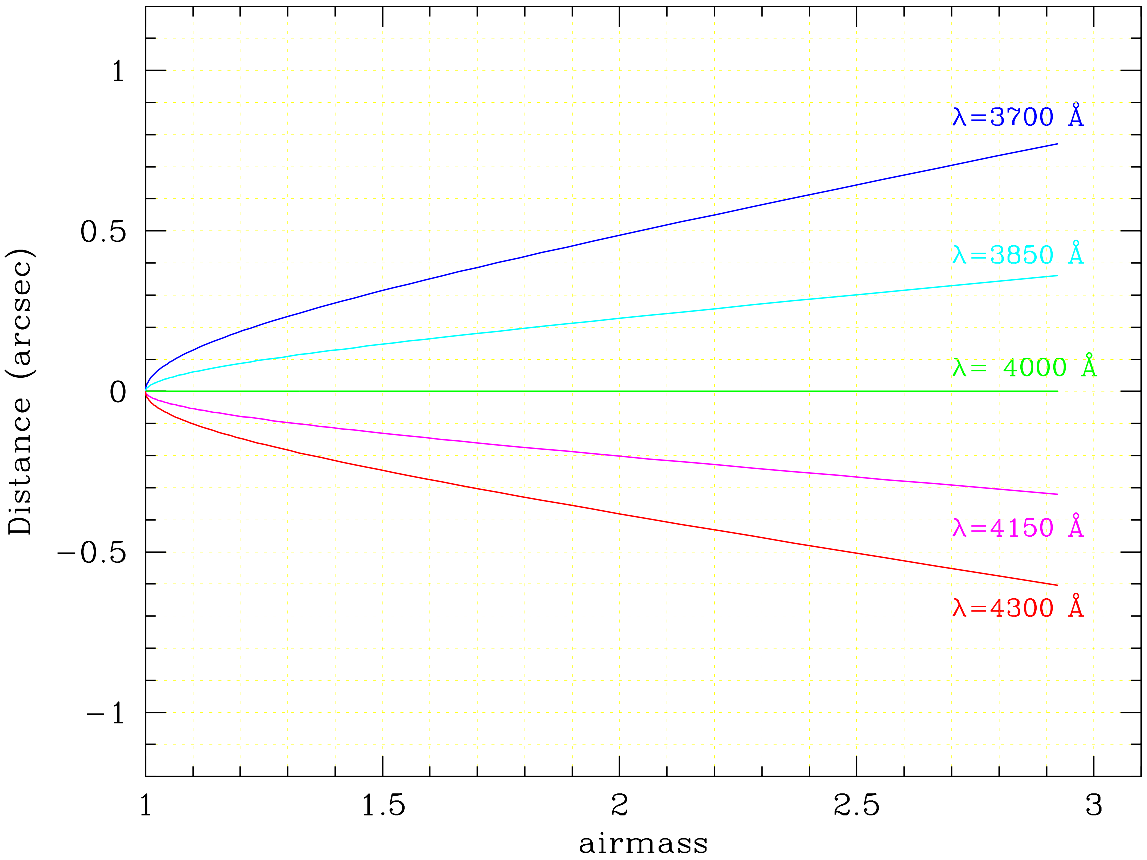

Figure 3: Relative displacement between the central wavelength λ=4000 Åand nearby wavelengths covered by a typical GIRAFFE gratings.

The problem when observing with large field of views is that an object at the field corner will have a zenith distance $z\prime$ different from one at the field center, hence its observed position will be displaced with respect to the "real" one by a different quantity. The size of this difference goes like $tan(z) - tan(z\prime)$ and therefore varies non linearly with the zenith distance of the whole field. Since the telescope is guiding with respect to the center of the field, this effect causes distortions at the field edges, that change shape with time as the observed field moves across the sky.
Figure 1 illustrates the size of this effect for an object located 9 arcmin away from the field center, as a function of the hour angle of the observations and the target declination. Each curve corresponds to a different declination, and indicates the size of the relative motion between the center of the field and the object, at various hour angles. The 9 arcmic distance has been chosen as the radius enclosing about one half of the field area. For comparison, Fig. 2 shows the same effect on a star located at the edge of the frame, i.e., at 12.5 arcmin

from the field center. The effect is obviously non linear with the distance from the field center, getting rapidly worse towards the edges.
Figures 1 and 2 refer to a central wavelength of 4000 Å. Due to the dependence of the refraction index upon wavelength, the effect would be significantly smaller in the red than in the blue. The central λ of the observations is be given as input in the OBs, in order to allow telescope guiding on the same wavelength. However, different regions of the spectrum will be displaced with respect to the central one, and for large displacements they may fall ouside the fibre hole. Figure 3 illustrates the distance between a central wavelength of 4000 Åand four other wavelengths in a typical GIRAFFE spectrum covering a range of 600 Å. Two bluer wavelengths (3700 and 3850 Å) show positive displacement with respect to the central one (i.e., the offset with respect to their theoretical position is larger) while two redder wavelengths (4150 and 4300 Å) show negative displacements.
The FLAMES Fibre Positioner is designed to calculate the *mean* position of each object during the exposure, knowing the field coordinates and the time of the observation. However, as shown in Fig. 1, when the field is close to the horizon the variation of airmass is extremely rapid, causing the position of an object close to the field edge to change by up to 2 arcsec in one hour exposure. For this reason, it is extremely important to carefully plan the duration of each single exposure, in order to minimize the flux losses due to the fact that **objects far away from the field center may move away from their fibre in the course of long exposures**.
Observers should make sure that their observations are confined in the flat part of the curves shown in Fig. 1. For instance, fields at declinations below -30 can be observed continuously for 3-4 hours before and after their culmination. On the contrary, fields at declination between 0 and 30 can be observed for no longer than ~ 1 hour, and as close as possible to zero hour angle.
In order to allow the Fibre Positioner to calculate the mean position of each object during the exposure, it is necessary to fix the time of the observation when configuring the plate. If the observation is then delayed, it might occur that the plate configuration is not anymore appropriate for that field. For this reason, when configuring a plate, a “validity” parameter is calculated, a function of the target declination, which establish for how long the plate configuration is still appropriate for the given field. Execution of the OB is not allowed if the plate validity is expired.