Atmospheric dispersion and its effect on high resolution imaging

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The single biggest problem facing any observer wishing to undertake a programme of high resolution photography is the atmosphere. When a good quality, well collimated telescope is used the atmosphere is responsible for nearly all deterioration of the image quality delivered at focus. Astronomical seeing is a very well-documented phenomenon, but with the increasing number of observers employing large aperture telescopes for high resolution imaging, another not so well-known process can affect image quality far more than observers realise. Indeed until recently I had rather underestimated the effect of this phenomenon. This effect is atmospheric dispersion.

Atmospheric dispersion and its effects

The atmosphere imparts many deleterious effects on the light that passes through it. Astronomical seeing (the mixing of air of different temperatures) is undoubtedly the most destructive property when it comes to obtaining high resolution images, however atmospheric dispersion also imparts serious effects, especially when employing large aperture telescopes with the object of interest located well away from the zenith.

Dispersion is the 'smearing out' of light of different colours due to differential refraction as it passes through our atmosphere. The level of dispersion present is related to the wavelength of light and the filter passband. Shorter wavelengths/wider filters are more seriously affected than longer wavelengths/narrower filters. Effectively our atmosphere behaves as a prism, splitting white light into its spectrum of colours. Dispersion is worse the lower in the sky you observe, as the light is passing through more air. For example when observing an object at about 30° altitude you are looking through around twice as much air as you would be at the zenith – a considerable difference.

Pressure, temperature and humidity all affect the amount of dispersion that will occur for a given altitude but, for the typical amateur observer, these secondary effects are very small. The main culprit is the altitude of the object above the horizon, as shown in Figure 1.

Larger aperture telescopes are affected more than smaller ones because of their better resolving power, so the effect of dispersion becomes significant at a higher object altitude. For example, as a 16" (40cm) aperture delivers four times better theoretical resolution than a 4" (10cm) aperture it becomes clear that for this larger telescope to deliver performance to its maximum resolving potential, the object must be located very high above the horizon. Even at an altitude of 60°, around 0.7 arcseconds of dispersion is present from 400–650nm. Since many observers live at latitudes where the planets do not pass close to the zenith it soon becomes apparent that we are often imaging objects well away from the zenith where dispersion has serious potential to degrade image quality.

A typical 6" (15cm) telescope should achieve a performance not hindered by dispersion down to an altitude of around 40° in white light, although when we consider the wide spectral response of CCDs and the resolution possible under excellent seeing it becomes clear we should look at ways to try and overcome dispersion in order to maximise the potential of our telescopes.

Overcoming dispersion

There are ways in which we can overcome the effects of dispersion. The general consensus among observers is that the use of filters eliminates these effects, meaning typical RGB colour imaging 'bypasses' the effect as the filters are passing only a narrow band of wavelengths. However, in reality this is not the case.

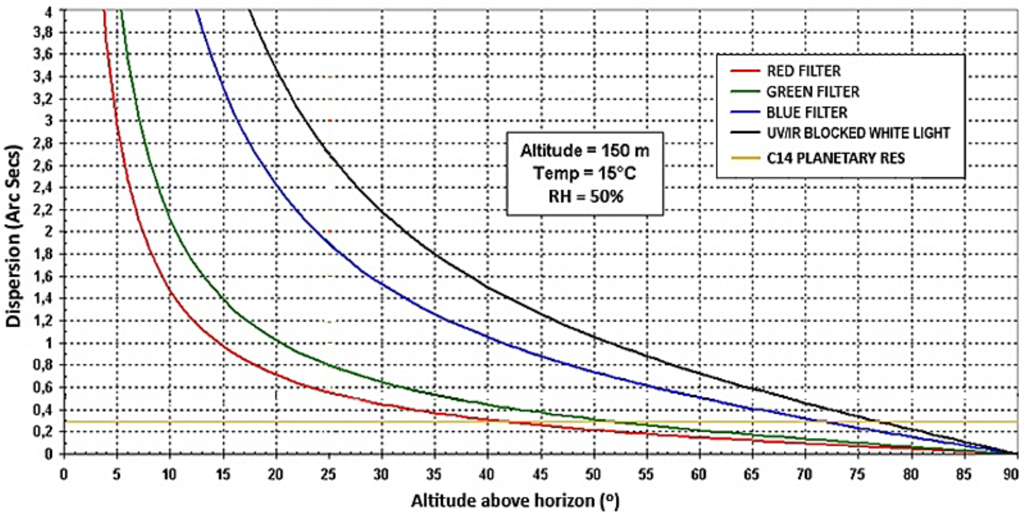

Figure 1. The amount of dispersion plotted against altitude for a given bandwidth of light.[1] The red, green and blue lines show the dispersion for the typical bandwidth of RGB filters (100–150nm). The black line represents UV/IR blocked white light across a 400–650nm range. The yellow line across the graph represents the typical maximum resolving power of a 356mm aperture telescope on planetary bodies.

As discussed above the amount of dispersion is dependent on the bandwidth used. Typical RGB filters cover around 100–150nm in bandwidth and a red filter of 100nm bandwidth will be less affected by dispersion than a blue filter of the same bandwidth. Dispersion does have less effect for filtered light compared to unfiltered light as shown in Figure 1. This figure also shows that white light is quite seriously affected by dispersion. For example, if we say the typical highest resolution attained on a planetary target by a 36cm telescope is around 0.25 arcseconds (which in practice is about right from my own imagery), then we can conclude that for a 36cm aperture, to maintain 0.25" resolution unaffected by dispersion, with different filters the altitude of the object above the horizon must be greater than the following:

UV/IR blocked white light:	77°
Astronomik blue filter:	72°
Astronomik green filter:	52°
Astronomik red filter:	42°

It is therefore apparent that dispersion can play a major role in the attempt to obtain high resolution imagery of the planets even when using filters. From typical northern European latitudes the planets only rarely attain an altitude of 60° and, for much of the time, we must work at altitudes much lower than this. Therefore while filters can provide some relief from the effects of dispersion they certainly do not cure the problem. We must turn to another device for this purpose.

Dispersion correctors

Basic correctors that reduce the smearing effects of dispersion have been employed by visual planetary observers for many years.[2] The 19th century astronomer George Airy employed a set of wedge prisms to correct for the effects of dispersion during his observations. In use a prism was orientated so that its dispersion was opposite to that produced by Earth's atmosphere.

Depending upon the altitude of the object more than one prism would be required to exactly nullify dispersion, but it is possible to use two wedge prisms that rotate with respect to one other to provide an adjustable corrector for almost any altitude. This is known as a Risley prism. This type of system is ideal for the observer as it offers an easily adjustable system without the need for multiple single prisms.

Single wedge prism correctors are typically specified as 2° or 4° prisms which will nullify dispersion in unfiltered light for a given altitude. For example a 2° prism will nullify dispersion across the visible spectrum at 65° altitude, while a 4° prism will work at 35° altitude. Adirondack Astronomy in the USA manufactured a set of such prisms which they marketed as Prismatic Atmospheric Dispersion Correctors[4] (PADCs) which could either be used alone or as a pair for adjustable correction. Sadly these have since been discontinued.

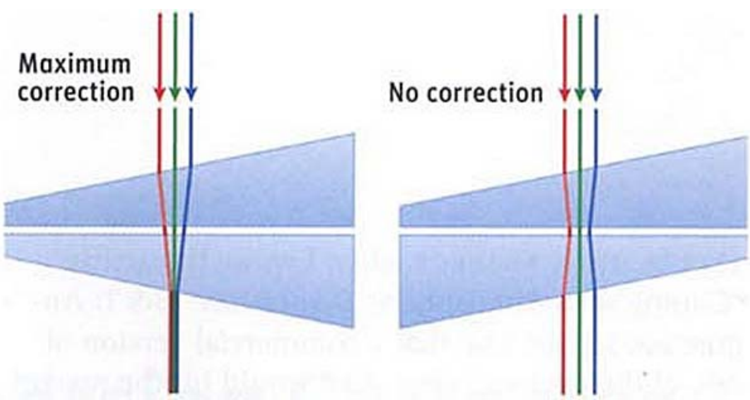

Figure 2. How a wedge prism works to correct light affected by dispersion. This diagram illustrates a Risley prism arrangement.

Figure 3. The two primary dispersion correctors available in recent times: Astro Systems Holland's adjustable corrector and Adirondack's PADC corrector. The PADC is no longer made, however the ASH corrector is still available at the time of writing.

Fortunately, fully adjustable dispersion correctors are now available with a prism pair incorporated into a single convenient unit. Astro Systems Holland (ASH) manufactures such a device which is available to amateurs.[3] This unit is ideally suited to the task of high resolution imaging as it offers easily adjustable correction via a pair of prisms with levers extending out of the device barrel for quick and easy adjustment.

Typical prices for such correctors are not especially cheap coming in at around the £250 mark for the adjustable ASH corrector. Single prism correctors are less expensive, however I know of no current source for them.

Dispersion correctors in practice – are they worth it?

In theory a corrector sounds as if it should be an essential piece of equipment for the serious planetary observer, but what about in practice under the night sky? My own experience so far is an extremely positive one – so much so it has prompted me to compile this article. I began with an Adirondack 2° single prism which I still have. During the 2011 apparition of Saturn this device enabled me to obtain a notably higher level of image quality despite the mediocre altitude of the planet at just 37° at maximum. It enabled me to use unfiltered light to obtain sharp images, something which would have been impossible without the corrector in place at such an altitude. Even red light images showed a notable increase in sharpness. These positive results prompted me to obtain a fully adjustable dispersion corrector identical to the one detailed earlier.

One tricky problem faced by users of such a device is keeping the corrector aligned properly rotationally with regard to the direction of the dispersion. For example a planet's position angle relative to the local horizon changes as it rises, culminates and sets. This means we must slowly adjust the corrector over time to keep it correctly aligned to counteract the direction of dispersion. This sounds complex but in practice is easily achieved if we know an object's position angle relative to the horizon in our field of view. In practice the corrector needs to be adjusted every 30–60 minutes to keep the orientation of the device optimal for dispersion correction.

In truth there is no simple answer to the question 'Are dispersion correctors worth acquiring?' It depends upon a number of factors. Those using smaller telescopes would not really see much benefit apart from times when the planets are very low in the sky. For those using large apertures a dispersion corrector would appear to be essential equipment when seeking to obtain the best possible image quality.

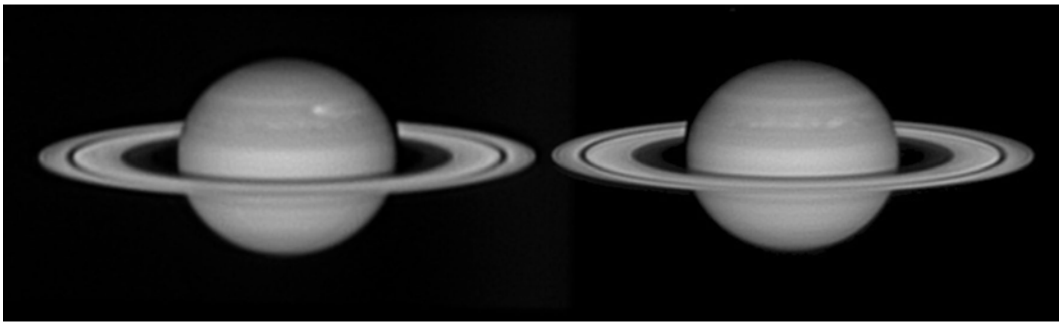

Figure 4. Uncorrected and corrected white light image comparison. These views of Saturn obtained with and without a dispersion corrector clearly reveal the smearing imparted by dispersion upon the uncorrected view.

For those fortunate enough to be located within the tropics it is likely that only a small benefit would be realised since for most of the time the planets are high enough in the sky to be well away from the worst effects of dispersion.

Many observers employ colour cameras for a single shot colour image. These are especially vulnerable to the effects of dispersion, and the figures quoted for white light apply for the amount of dispersion for a given altitude. I would consider a corrector essential for anyone using a colour camera for planetary imaging purposes. Simply re-aligning the colour channels back into line to remove colour fringing does not remove all of the dispersion affecting the image.

For the casual observer the expense of a dispersion corrector may seem rather steep, however for more serious observers it is a very worthwhile investment, especially those employing large aperture telescopes for high resolution imaging or using colour CCD cameras.

Dispersion has been a largely forgotten issue from an amateur standpoint in recent years, however the use of dispersion correctors is on the increase, and in the age of very high resolution imaging many now consider these devices an essential piece of equipment to help coax the best out of their telescopes.

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Conclusions

For those located in the northern hemisphere the years ahead, while very favourable for Jupiter, are not so good for Mars and Saturn, both of which are sinking lower in our skies. Obtaining good quality images of these planets will become increasingly difficult. A dispersion corrector such as those discussed in this article would help greatly to improve both image quality for CCD users and the view in the eyepiece for those observing visually.

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Received 2011 May 02; accepted 2011 June 22

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