Optimal Resolutions for Optical and NIR Spectroscopy Through Atmospheric Emission Lines

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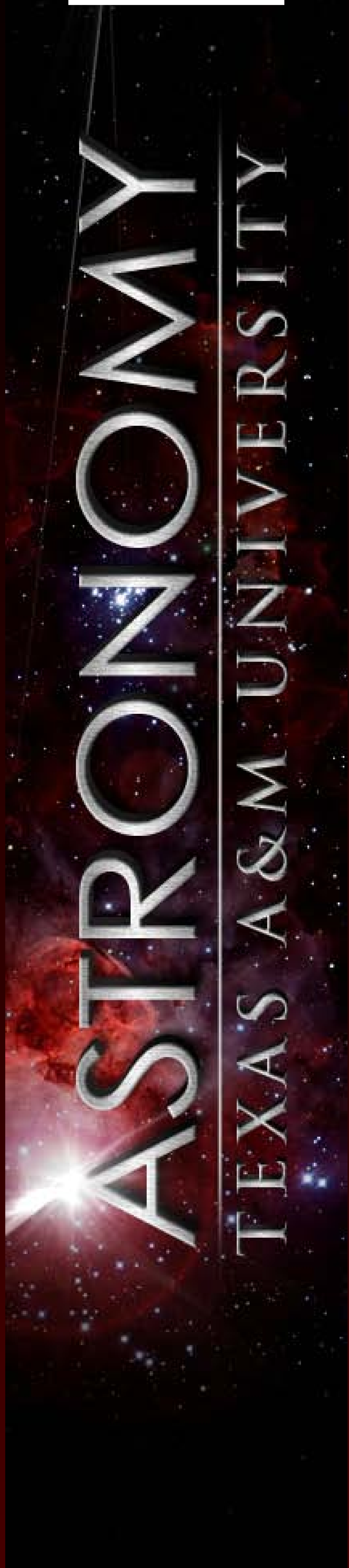
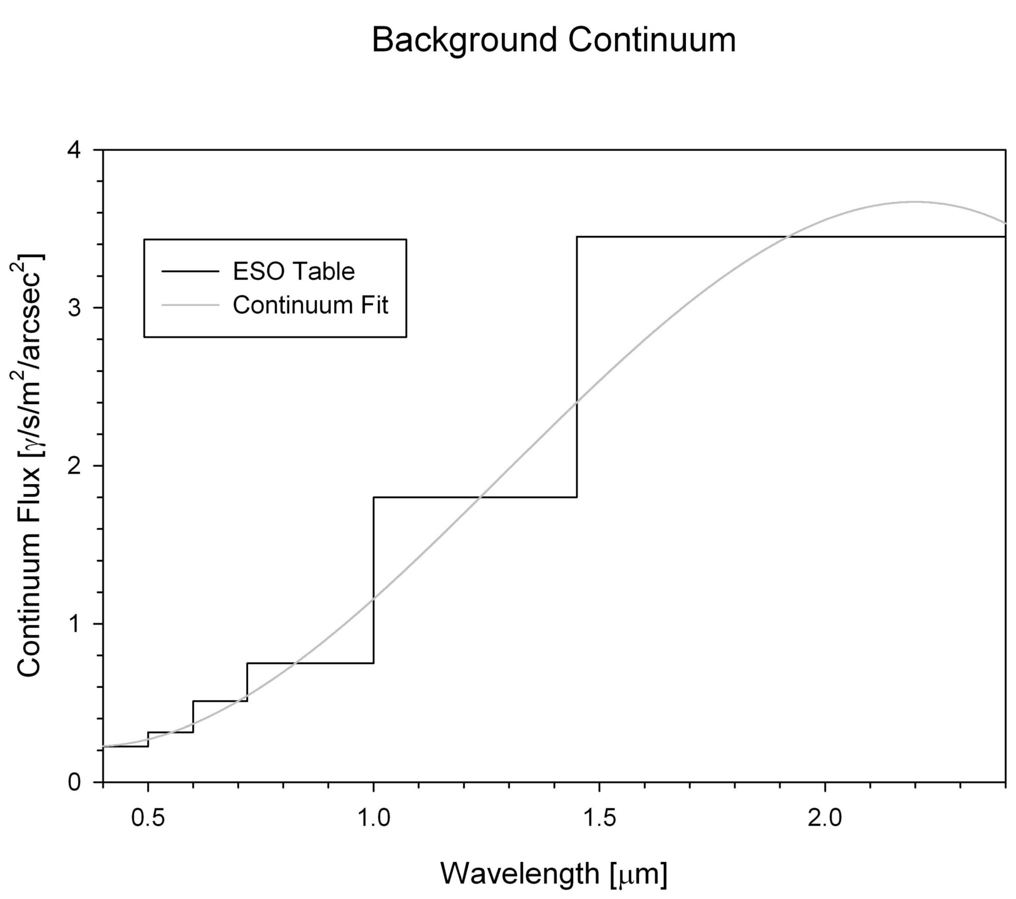


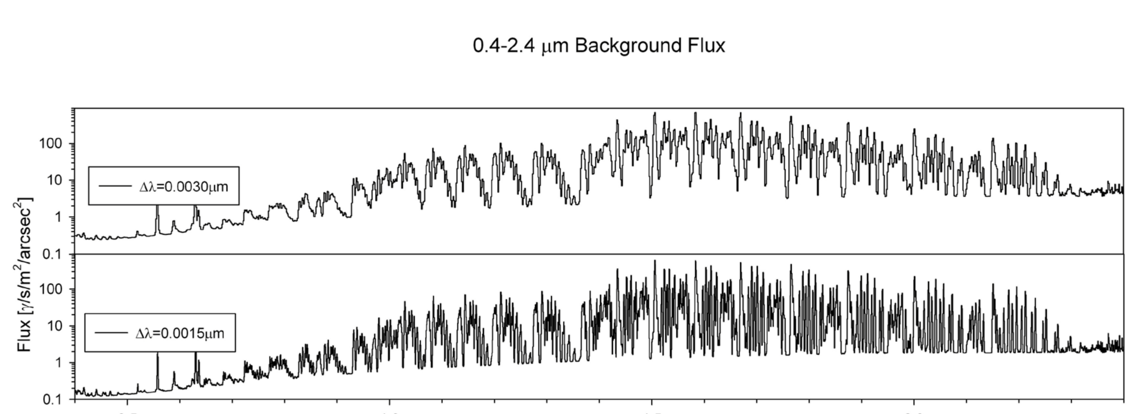
What is the 'best' and why do we want it?

We might want to know what the best resolution is when designing new instruments, preparing observing proposals, or simply working on data analysis. A simple example might be attempting to observe a faint object in the red. At low resolutions you have many emission lines falling on your pixels while at high resolutions your signal is spread out over many pixels resulting in a loss of the Signal-to-Noise Ratio (SNR). Do you want to maximize the number of pixels without emission lines? Or maximize the SNR in a few pixels? Or all pixels? The problem is Quality versus Quantity although the specific science goals will ultimately determine the resolution.



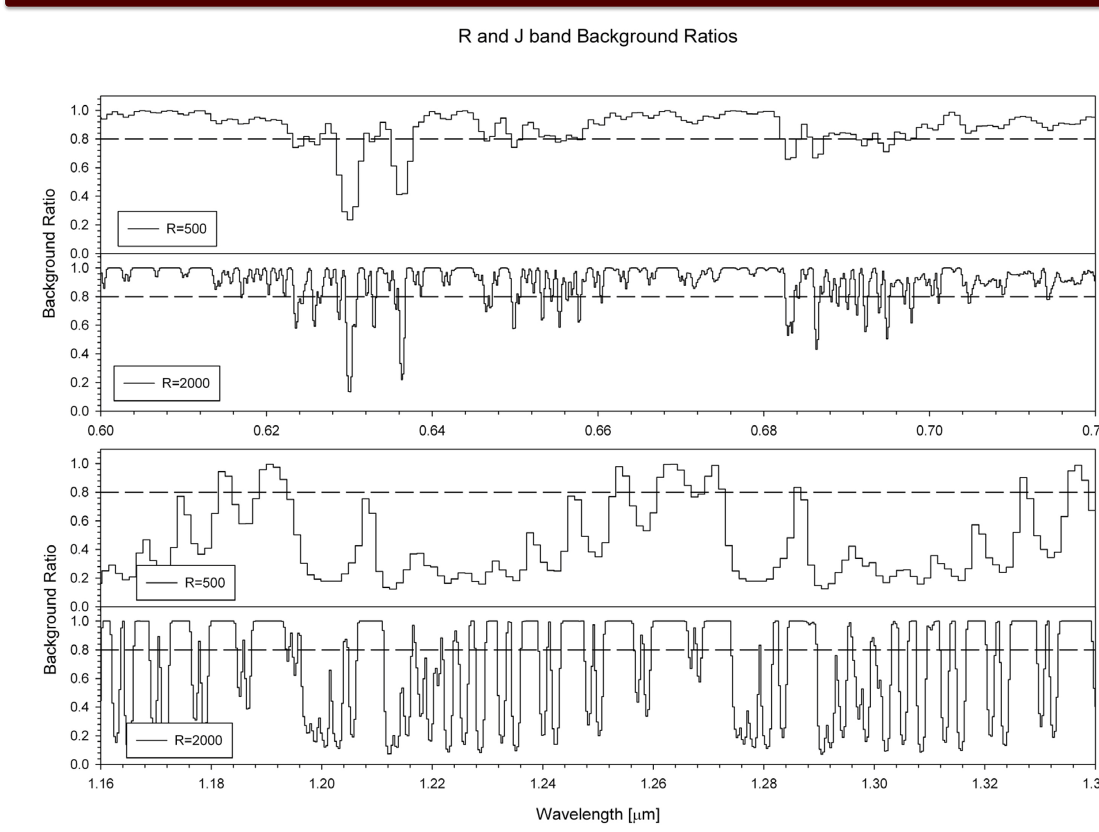
Creating the background spectrum

Starting with the tables and data files available on ESO's E-ELT Design Reference Mission website as a guide, we created our own background sky spectrum model. We began by taking the table of sky continuum values per band pass and converting this step function into a continuous function by fitting a polynomial to the midpoints of each wavelength range as shown above. We then took each of the emission lines, given in integrated flux, and converted them into Gaussians with a full-width-at-half-maximum (FWHM) equal to twice the dispersion of the spectrum. Here the resolution in defined as the FWHM of the emission lines. We then add the emission lines and sky thermal emission to our continuum fit and repeat this process at resolutions ranging from 10-50,000 as demonstrated below.



Abstract

We study the effects of atmospheric emission lines in the background sky on spectroscopic measurements in the 0.4-2.4 micron range at resolutions ranging from 10-50,000 to determine an optimal observing resolution. We build a model of the background sky spectrum and calculate the fraction of pixels free of emission lines in 7 different band passes while varying the resolution. We then discuss the effect of the background emission on the SNR of targets of various magnitudes to determine an 'optimal' resolution at which to observe. Preliminary results show that emission lines have little to no effect in the optical, but that in the wavelengths greater than 1.5 microns the effects of atmospheric emission lines suggest a resolution of at least 2000 is optimal.

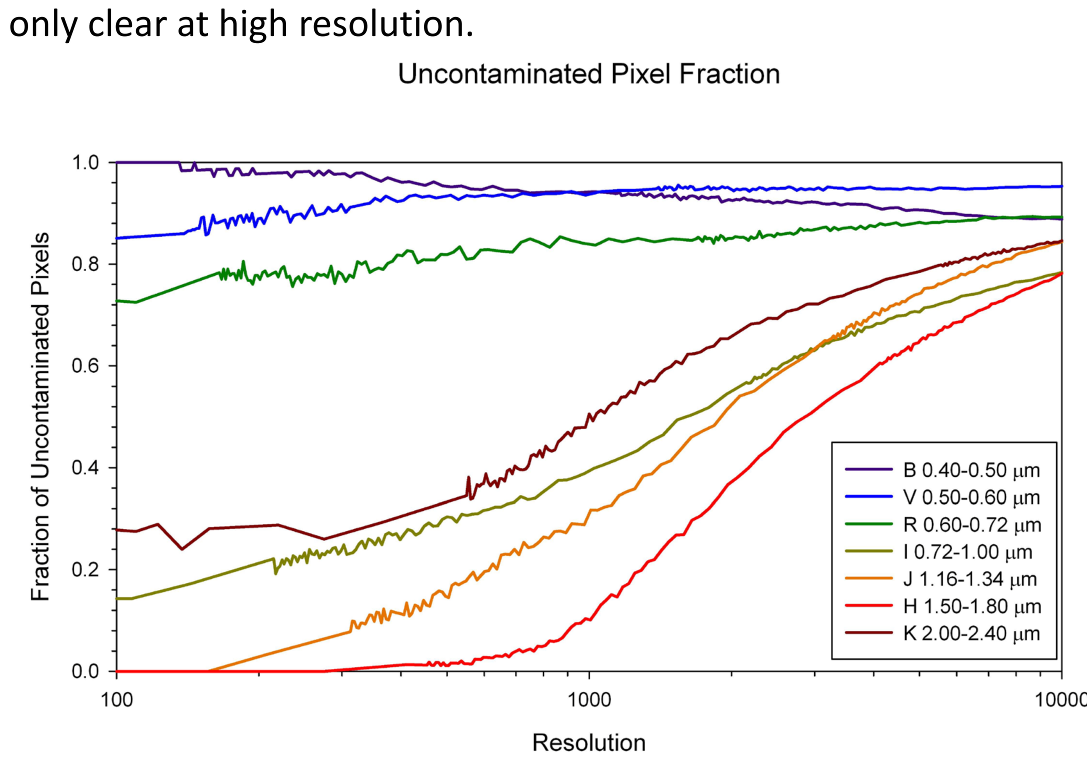


What is a contaminated pixel?

We define a contaminated pixel by taking the square root of the ratio of the continuum to that of the background. A contaminated pixel is defined as having a value of 0.8 or lower.

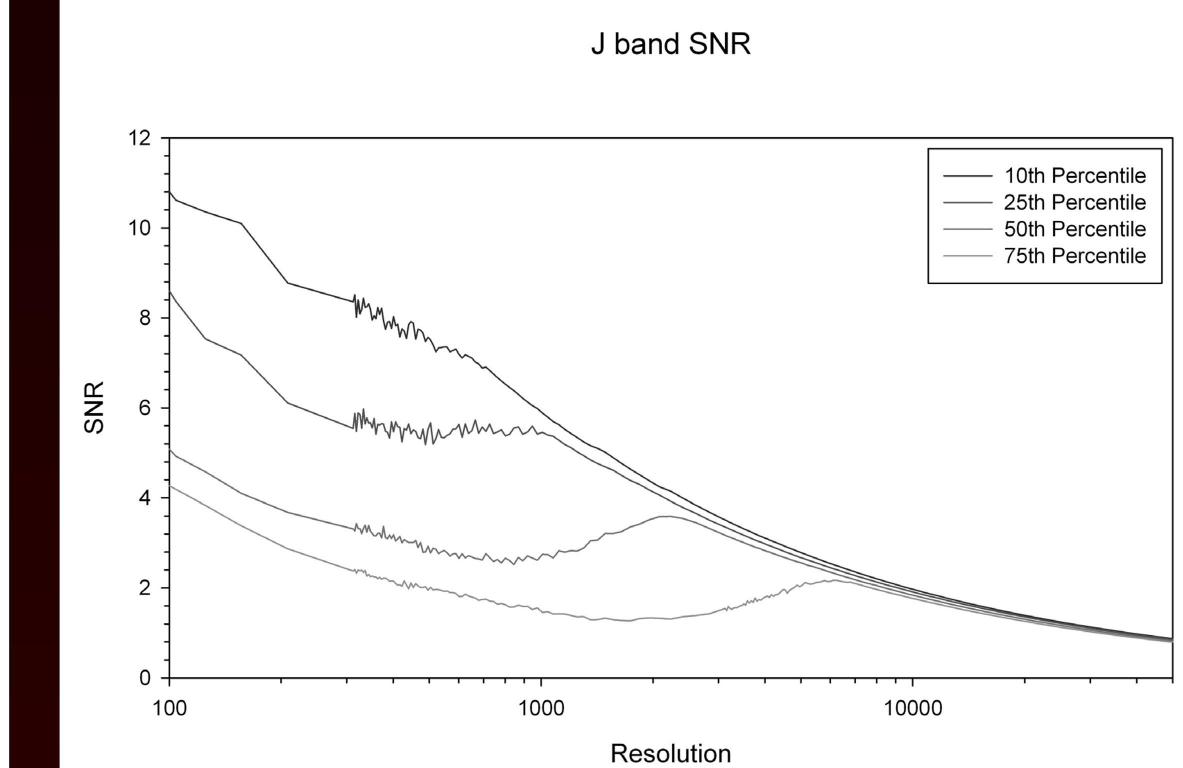
$$\frac{\sqrt{continuum}}{\sqrt{continuum + emission\ lines + thermal}} \leq 0.8$$

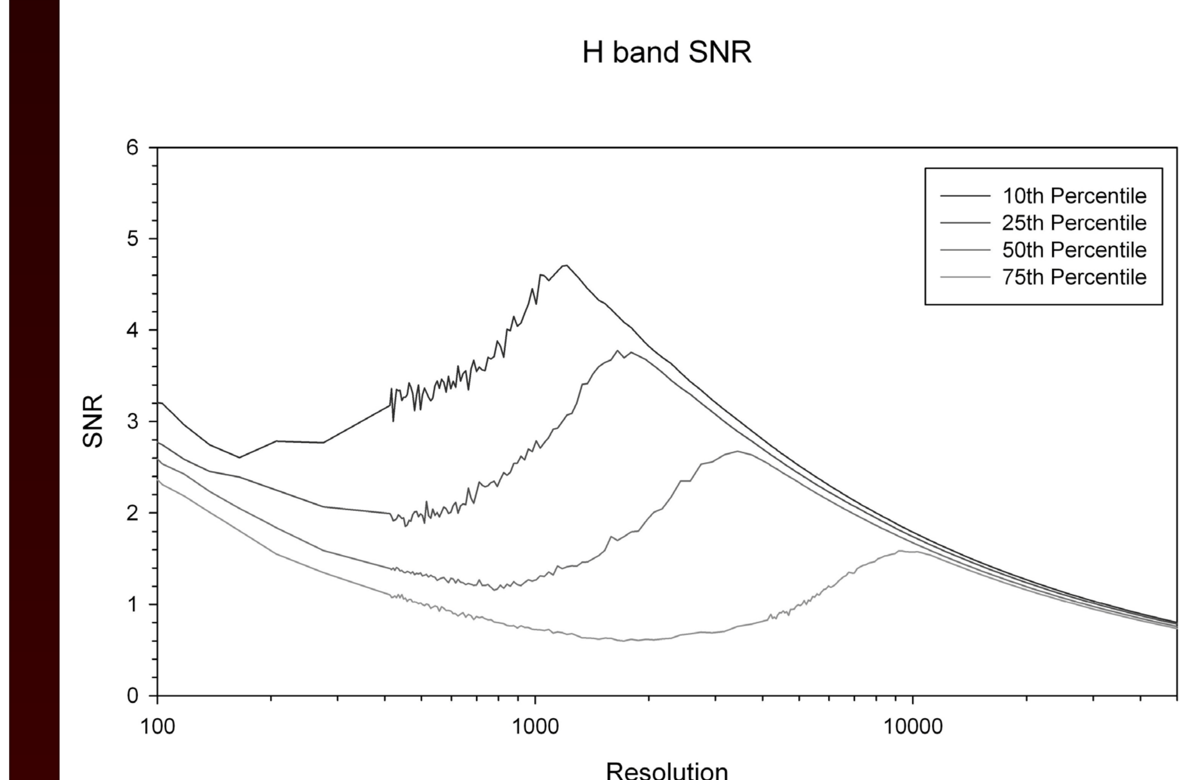
This is preformed on a pixel by pixel basis in each wavelength range. Examples are shown above for the individual pixel values at various wavelengths where the 0.8 value threshold is shown. Pixels above this line are considered uncontaminated. The figure below illustrates the fraction of uncontaminated pixels per resolution in various band passes where the optical bands are free from contamination at all wavelengths, and the longer wavelengths are only clear at high resolution.



Testing the SNR

To test the SNR in each wavelength range we create an idealized 20th magnitude source with constant flux at all wavelengths. We then calculate the SNR in each pixel using the standard SNR equation. The SNR values in each pixel are then rank ordered, and the 10th, 25th, 50th, and 75th percentiles are plotted per resolution. At shorter wavelengths the emission lines are not strong enough to cause the SNR to diverge from a value based solely on the continuum as the background source. At longer wavelengths the effect of the emission lines is more noticeable. In the H band (1.50-1.80 micron), there is even a distinct peak in the SNR as shown below.





Conclusions

At shorter optical wavelengths the strength and density of atmospheric emission lines has little to no effect on the SNR and the SNR is dominated by the continuum. At longer wavelengths the stronger, more frequent emission lines begin to reduce the SNR even at lower resolutions where greater SNR is expected. This causes a peak in the SNR at resolutions around 2000 indicating that at lower resolutions no signal is gained while you still lose spectral resolution. From here we conclude that a resolution of at least 2000 should be used while observing at longer wavelengths.

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