The PI tool proposed for PFIS will be, in its final form, a java application. In order to best take advantage of the object orientation java offers, the PFIS instrument is considered as a set of component subsystems, each of which will become an object within the java program. This object orientated approach has several advantages – its simulation of the instrument will allow the PI tool to operate beyond the scope of other tools examined, in that it will allow the PI to much more information than the basic S/N or exposure time (we presently envisage returning S/N and exposure, along with sky, source, detector and total count information). Also, its modularity makes updates (e.g. from calibration data or future upgrades/repairs) much easier to perform.

The first step in developing these objects is to examine instrument design and decide what the major components of the system are. Then, once these are identified, the actual physics influencing the passage of light through the system is investigated and briefly outlined, so that the foundations are available to allow coding to commence.

1. Instrument components

Since PFIS has so many operating modes, there are several instrumental components that are only used in certain configurations (e.g. the beamsplitter for polarimetry). The following is a list of objects that are always in place for all modes:

- collimator
- camera
- CCD

-not surprising really!

There are then polarimetry components:

- waveplates
- beamsplitter

and the dispersers:

- gratings (and associated filters)
FP etalons (and associated filters)

The last changeable component is the slit mask, which will have various configurations depending on which observing mode is being employed.

2. What happens to light at each component?

This is the question that drives the PI tool – as light (in our case a simulated spectrum or image) passes through the system, various physical processes take place. The tool has to simulate these in order to return output data, and associated S/N or exposure time. The effect of each major component is outlined below, along with a list of inputs that will be required from the PI (and by extension the tool itself) at each stage and any relevant equations. The (E and O) indicated the 2 spectra from polarimetry, explained at the end of this document.

The first task is to convert the input from the SALT tool to useful quantities. Since ultimately we are concerned with counts, it makes sense to deal with photons throughout the detector. The spectrum delivered to the PI tool from SALT is in erg s\(^{-1}\). Dividing by photon energy at each wavelength gives number of photons per second at each wavelength.

2.1 Slit mask

The slit mask is essentially a flux reducer – it removes flux from areas of the field of view that are not required for the observation, and allows pile up of spectra to be avoided in spectroscopy. The flux throughput indicates the amount of light that exits through the slit. Two types of mask are used – field of view masks and slit masks. Our source will either be point or extended, and seeing is assumed to be Gaussian.

Inputs: spectrum (# photons v. wavelength)
slit width
zenith seeing
field angle

Process: multiply by slit throughput

\[
erf(x) = \frac{2}{\sqrt{\pi}} \int_{-\frac{x}{2}}^{\frac{x}{2}} e^{-\frac{t^2}{2}} dt
\]

This is the error function, where \(x\) is the slit width in arcsec, and \(t\) is given by

\[
t = \frac{x}{\sqrt{2} \text{arc}}
\]
In the case of Gaussian seeing at angle \( \theta \) from the zenith, seeing varies from zenith seeing in the following way

\[
FWHM \quad \text{sec}(\theta)^{0.6}
\]

At 37° this term is 1.14 (from the Observers Guide).

The FWHM has to then be converted to \( \theta \)seeing using the following equation (just derived from Gaussian distribution).

\[
\theta_{\text{seeing}} = \frac{\sqrt{8 \ln(2)}}{FWHM}
\]

Then, \( \theta_{\text{tot}} \) is found by adding in the SALT error budget (SEB) in quadrature. The SEB is estimated to be 0.6 arcsec at FWHM. Converting this to sigma too gives

\[
\theta_{\text{tot}} = \sqrt{\theta_{\text{seeing}}^2 + \theta_{\text{SEB}}^2}
\]

Inserting this back into the error function allows the slit throughput to be calculated.

Output: modified spectrum 1

2.2 Optics

Here, the collimator and camera are considered as a single component. Light passing through the lenses and coatings that make up this system undergoes losses at all surfaces, and so a single efficiency curve can be used to describe the whole system, since \( \text{eff}_{\text{tot}} = \text{eff}_{\text{components}} \). The efficiency is a function of wavelength only for an on-axis point source, and will be a function of both wavelength and field angle for an off-axis or extended source. It is likely that this curve will be a text file, allowing for easy update once testing commences on the assembled, coated optics.

Input: modified spectrum 1 or 1a (see polarimetry section at end)

Process: Multiply by efficiency \((F(\text{wavelength, field angle}))\)

Output: modified spectrum 2
2.3a Gratings

Two types of grating are used in PFIS – surface relief and volume-phased holographic gratings. The grating modifies incident light in several ways. The first is the most important – it disperses the light allowing a spectrum to be observed. The dispersion can be considered as either angular i.e. how the angle through which the light is diffracted varies with wavelength. Linear dispersion gives the linear difference between two dispersed wavelengths on a focal surface. In this case, the incident light is collimated, so the LD is given by the angular resolution multiplied by the focal length of the camera, \( f_{\text{cam}} \). Also, the grating has an associated efficiency, which must be included.

Inputs:  
- grating name  
- camera (grating) angle  
- modified spectrum 2

Process:  
multiply spectrum by efficiency (\( F(\text{grating, wavelength, angle, E/O}) \)  
(to get total efficiency, average the E and O components)

Output:  
modified spectrum 3a

2.3b FP

It is suggested that we invite Rutgers to contribute at this point.

Output:  
modified spectrum 3b

2.4 Filters

Filters are used in spectroscopy mode to block unwanted second order light, and in FP mode to allow narrow band observation. The filters have an associated transmission, which is a function of wavelength, and assumed to be constant across the area of the filter. Again, this will be a text file, based on information from the vendor.

Input:  
modified spectrum 3a or 3b

Process:  
multiply by efficiency (\( F(\text{wavelength}) \))

Output:  
modified spectrum 4(E and O)
2.5 CCD

The behaviour of the CCD is rather complex, and has obvious consequences on the final data collected. The quantum efficiency of the detector relates the number of incident photons to the number of output electrons. This is a function of wavelength, and multiplies in the same way as previous efficiencies. The complication for PFIS is that the detector is an array of three CCDs with varying QE properties. Since only certain wavelengths will fall on each chip, the overall efficiency curve for the detector is the sum of the curves for each chip evaluated for the wavelengths that are incident on them. The wavelengths falling on each chip have been calculated previously, and so are available in look-up tables. The PI tool would be required to calculate these based on the input information from the disperser set-up.

A total number of photons per pixel can be calculated assuming a constant linear dispersion – the wavelength range falling on each detector is found by dividing the total range across the detector by the number of pixels – the photon number is then just found by summing the photon arrival rate over each pixel and multiplying by frame exposure time. Finally, the number of counts is calculated by multiplying by the QE of the detector. The spatial extent of the source on the detector is also important, to determine total size on the detector for imaging mode, and to calculate size in the direction perpendicular to dispersion for astronomy. An important thing to think about here

To calculate signal to noise, or exposure time, other characteristics of the CCD are also required.

Inputs:  
- binning  
- speed  
- mode (frame transfer, windowing)  
- modified spectrum 4(E and O)

Process:  
- determine read noise (based on speed)

This is outlined in the document SALT-3196AE0001

\[
T_{\text{readout}} = (\text{rows} \times T_{\text{row}}) + (\text{cols} \times \text{rows} \times (T_{\text{col}} + T_{\text{rows}}))
\]

In this equation, \(T_{\text{row}}\) and \(T_{\text{col}}\) are the readout times for each row and column respectively. This must be adjusted for binning.

S/N calculations – the signal is the number of photons incident on the detector at each wavelength. For total S/N, the photons from both sky and source must be added. Signal noise is given by Poisson statistics, i.e. \(\sigma = \sqrt{N}\), and this must be added in quadrature with other signal noise and detector noise. The detector noise is a consequence of both readout noise, and dark current, although this will be essentially negligible.
Output: S/N or exposure time – various plots

SNR requires calculation of number of photons at detector, which is ultimately governed by the spatial extent of the source on the detector. The size of the source at the focal plane is found using the plate scale of the telescope. This must then be multiplied by the magnification of the PFIS optics to give the size on the detector in mm. This is converted to number of pixels by dividing by the size of one pixel (and to bins by including the binning factor). This size is also used to determine the number of sky photons, so that sky subtraction can be carried out.

One thing that must be noted here is that the distribution of the source photons on the detector is described by a PSF (here we assume a Gaussian), while the sky count is approximately constant across the detector.

3. Polarimetry

The polarimetry submode introduces two spectra – the E and O components of the light - to the rest of the system once the initial light has based through the beamsplitter.

3.1 Waveplate

The waveplates retard the electric component of the incoming radiation by a half, or quarter wave, so that the amount of polarisation present can be studied. The waveplates and blanks have an efficiency that must be included in the over all losses the light experiences.

Inputs: modified spectrum 1  
percent polarisation  
required error binning  
waveplate orientation angle

Process: multiply by efficiency (F(wavelength, field angle)

Outputs: modified spectrum 1a

3.2 Beamsplitter

The beamsplitter separates the E and O components of the incoming light. The prism array has an overall efficiency that will be dependent both on wavelength and field angle, since each of the individual prisms in the array has its own efficiency behaviour. This will be important for extended objects (although this is not a major concern since polarimetric imaging is not great anyway due to poor efficiency in the blue).
Inputs:
modified spectrum 2
field angle

Process:
Ignore E and O dependence initially – assume that it is the same for both. However, if we should decide to include both, we will have an E and O efficiency for the dispersers that will have to be included in subsequent calculations.

Output:
modified spectrum 2E and 2O

It is assumed that all efficiencies listed will be in the form of look up tables, most likely text files.