VPH GRATING STUDY

We have studied the theoretical performance of VPH gratings in configurations similar to those in the current two-arm concept for GMACS. We can demonstrate that these gratings should work with good efficiency in these configurations. The study was a first look at the proposed gratings for GMACS to identify any problems that might require another iteration on the proposed suite of gratings. Where working angles exceed 40 degrees, both polarizations are shown, otherwise the efficiencies are in unpolarized light. Film parameters were selected to be within the known realm of manufacturability. This study does not include any optimization of fringe tilt or attempt to control Littrow ghosts; these steps can be completed in a future optimization when the basic parameters are settled. Table 1 shows the configurations of the spectrograph considered in the simulations. The principal interesting parameters are the camera-collimator angle (which must meet the Bragg condition) and the VPH grating line density and resulting resolution.

Table 1: Spectrograph configurations simulated for VPH grating throughput

2448mm collimator, 300mm camera (*f*/1)								
	Camera-Collimator angle (°)	Detector	VPH grating (l/mm)	Center wavelength (nm)	Dispersion (nm)	Wavelength range (nm)	Resolution at center wavelength
Blue	37	6144×6160	1325	480	0.21	370-590	2330
Red	37	6144×6160	820	767	0.33	589-945	2300
Blue	82	6144×6160	3285	400	0.066	365-435	6050
	82	6144×6160	2765	475	0.078	433-517	6050
	82	6144×6160	2390	550	0.091	501-599	6060
Red	82	6144×6160	2000	655	0.11	597-713	6025
	82	6144×6160	1700	775	0.13	707-843	6085
	82	6144×6160	1425	920	0.15	838-1002	6032

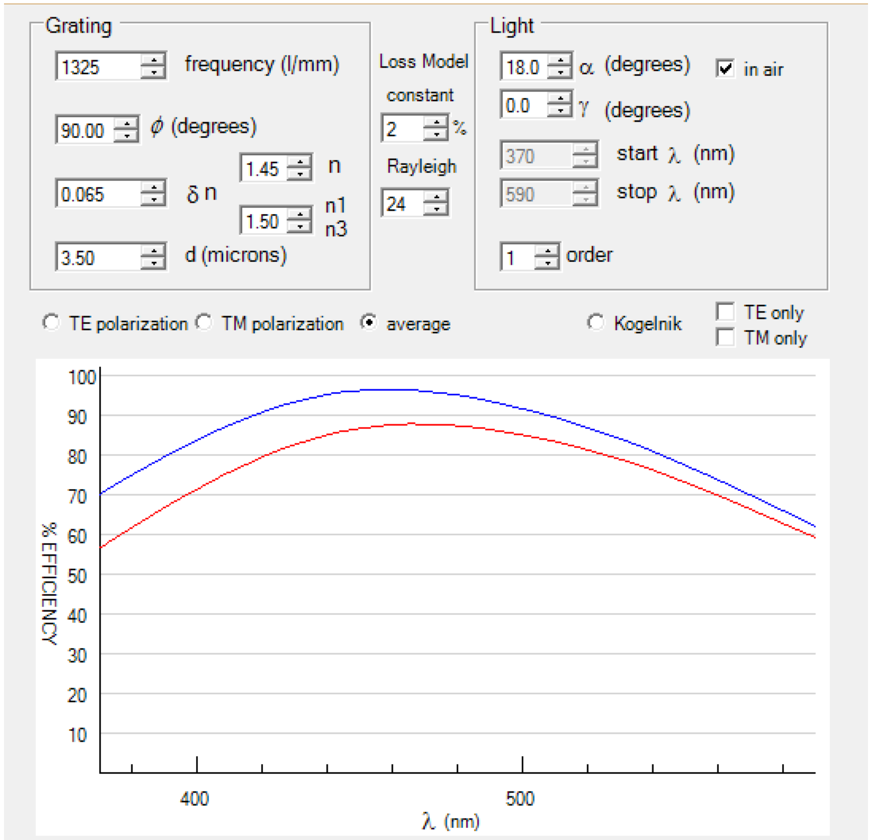

Figure 1: 1325 l/mm blue grating (R~2300) with parameters as shown. The blue curve shows theoretical efficiency for 18 degree operating angle, and the red curve shows likely realized efficiency after surface and other grating losses.

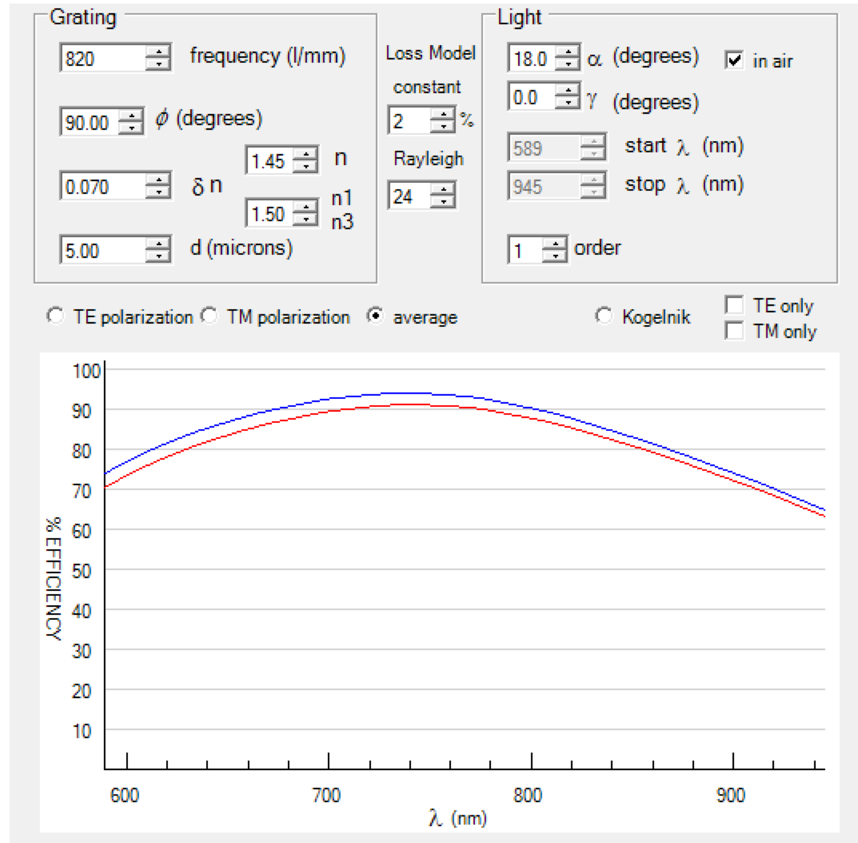

Figure 2: 820 l/mm red grating (R~2300) with parameters as shown. The blue curve shows theoretical efficiency for 18 degree operating angle, and the red curve shows likely realized efficiency after surface and other grating losses.

The two low resolution gratings have line densities, thicknesses, and index modulations that fall well within the production capabilities of known vendors. The 300 mm size is challenging, but should be possible with moderate upgrade of existing equipment. Performance should be excellent throughout the wavelength regions.

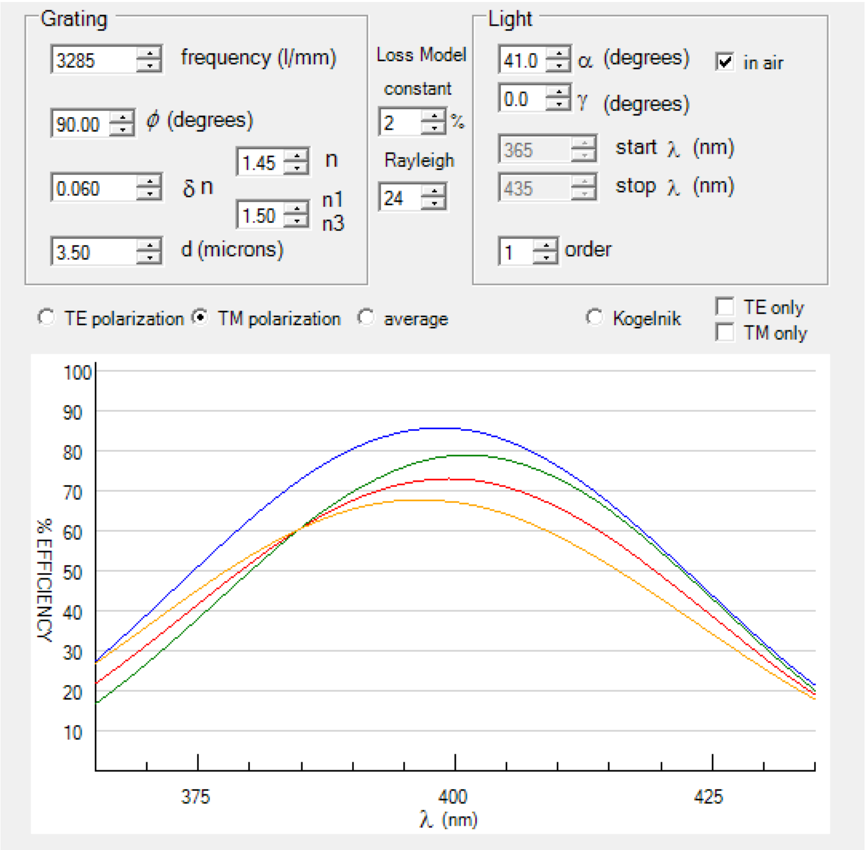

Figure 3: 3285 l/mm Blue grating (R≈6050) with parameters as shown. The blue curve shows theoretical efficiency for 41 degree operating angle, and the red curve shows likely realized efficiency after surface and other grating losses. The orange and green curves show the separate TE and TM polarizations that were averaged to make the red curve.

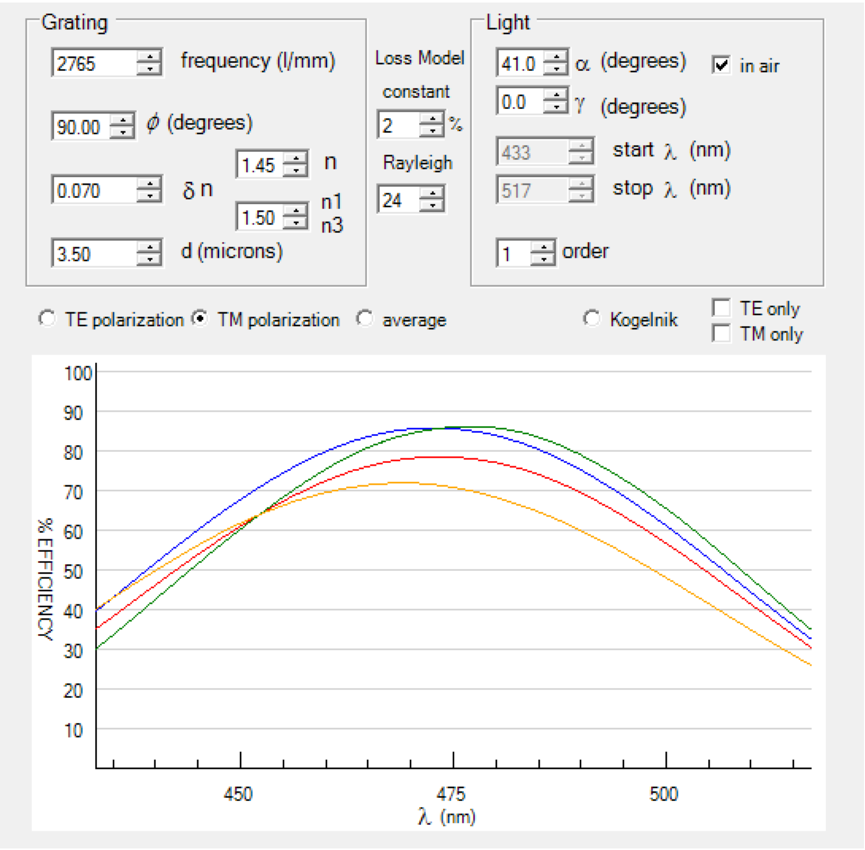

Figure 4: 2765 l/mm Blue grating (R≈6050) with parameters as shown. The blue curve shows theoretical efficiency for 41 degree operating angle, and the red curve shows likely realized efficiency after surface and other grating losses. The orange and green curves show the separate TE and TM polarizations that were averaged to make the red curve.

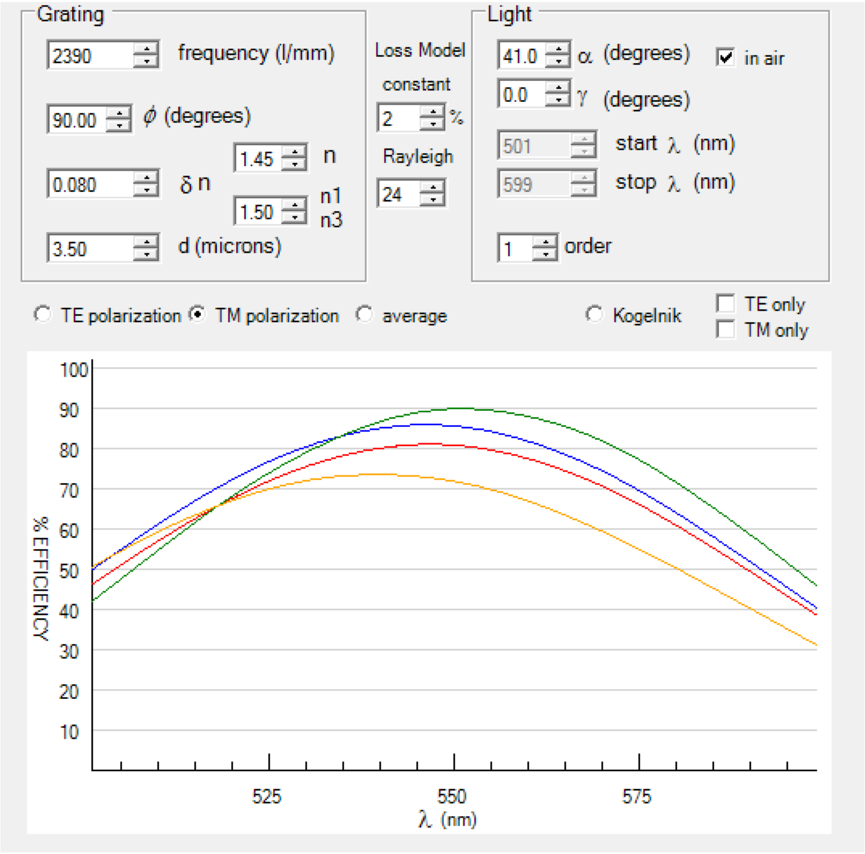

Figure 5: 2390 l/mm Blue grating (R≈6050) with parameters as shown. The blue curve shows theoretical efficiency for 41 degree operating angle, and the red curve shows likely realized efficiency after surface and other grating losses. The orange and green curves show the separate TE and TM polarizations that were averaged to make the red curve.

These higher-resolution gratings are at the lower thickness limit that Syzygy has successfully produced. Prototypes should be produced using the target process to verify scatter performance at the actual line densities. Even at these densities, the bluest grating suffers from limited bandwidth. However, a large grating is not likely to be completely uniform and this effect has not been included in the model. Restricting the uniformity to a low value make the average over the pupil broader, with a lower peak efficiency, if that is desirable

As a cost saving measure, one grating at the average line density of these three and variable camera angle could be used. The model in Figure 6 shows what the performance of this grating would look like in unpolarized light.

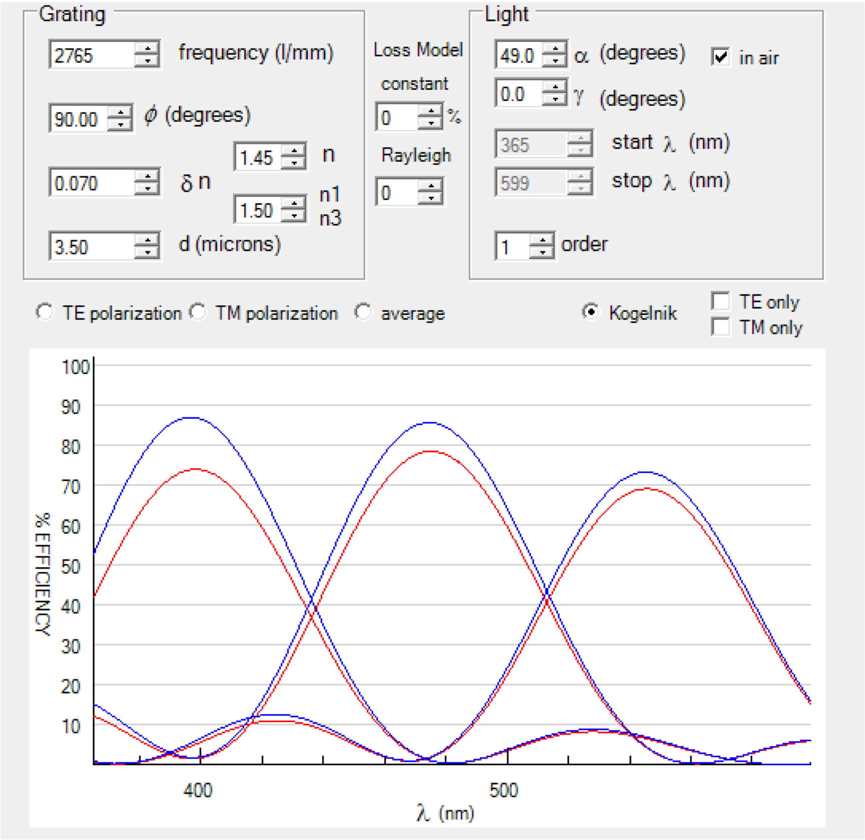

Figure 6: 2765 l/mm Blue grating (R≈6000) with parameters as shown. The blue curves now show theoretical efficiencies for 33, 41, and 49 degree operating angles, and the red curve shows likely realized efficiency after surface and other grating losses.

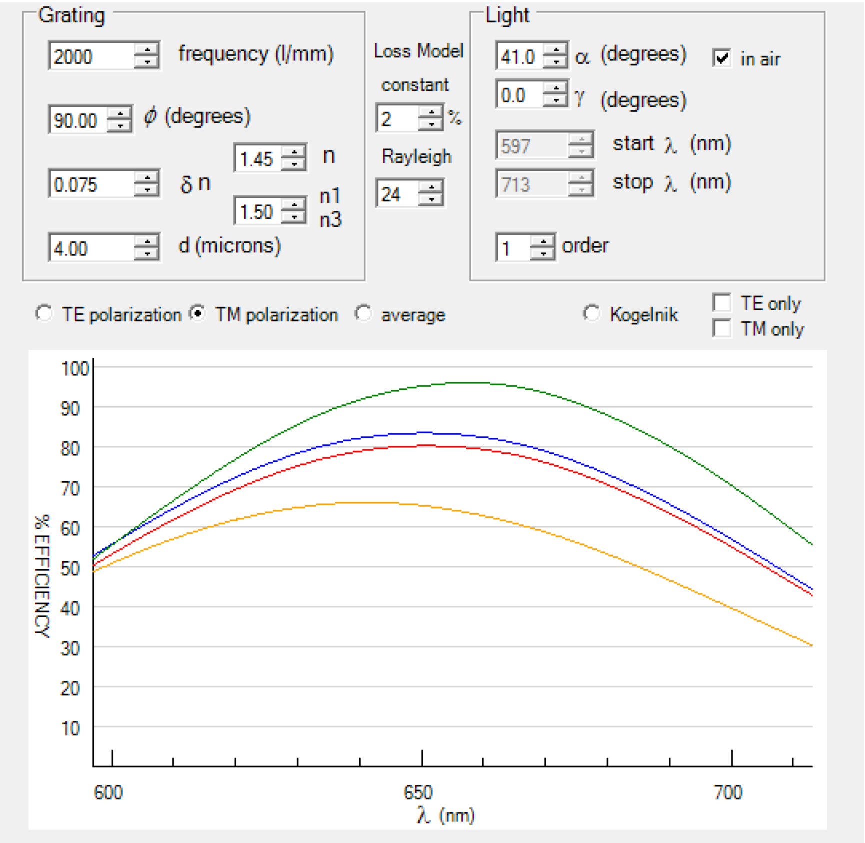

Figure 7: 2000 l/mm Red grating (R≈6025) with parameters as shown. The blue curve shows theoretical efficiency for 41 degree operating angle, and the red curve shows likely realized efficiency after surface and other grating losses. The orange and green curves show the separate TE and TM polarizations that were averaged to make the red curve.

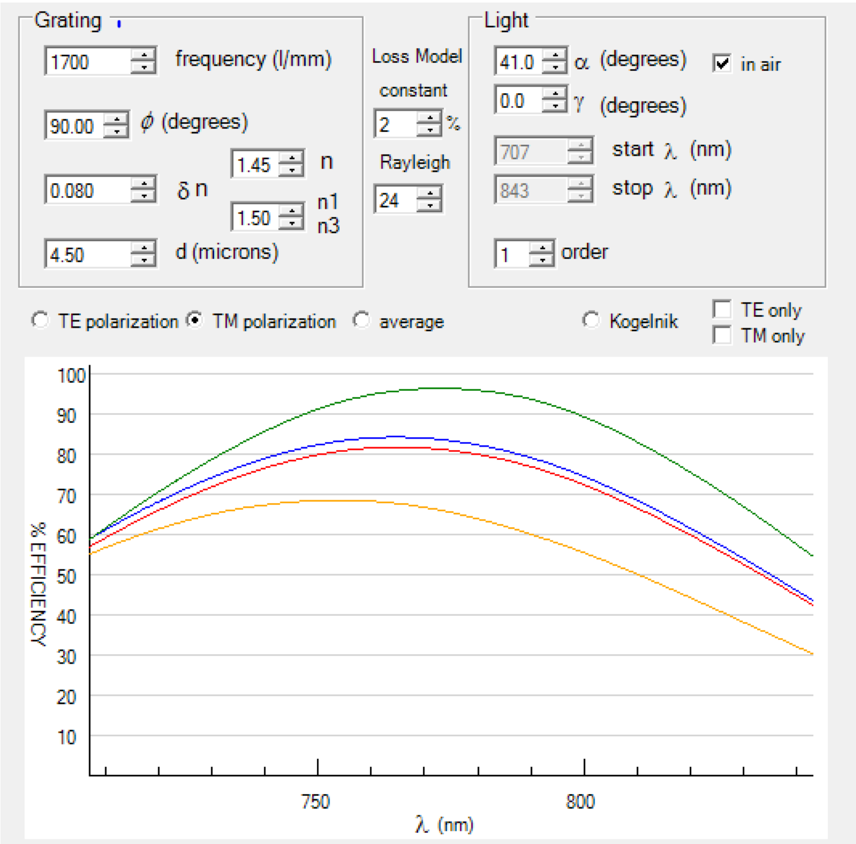

Figure 8: 1700 l/mm Red grating (R≈6025) with parameters as shown. The blue curve shows theoretical efficiency for 41 degree operating angle, and the red curve shows likely realized efficiency after surface and other grating losses. The orange and green curves show the separate TE and TM polarizations that were averaged to make the red curve.

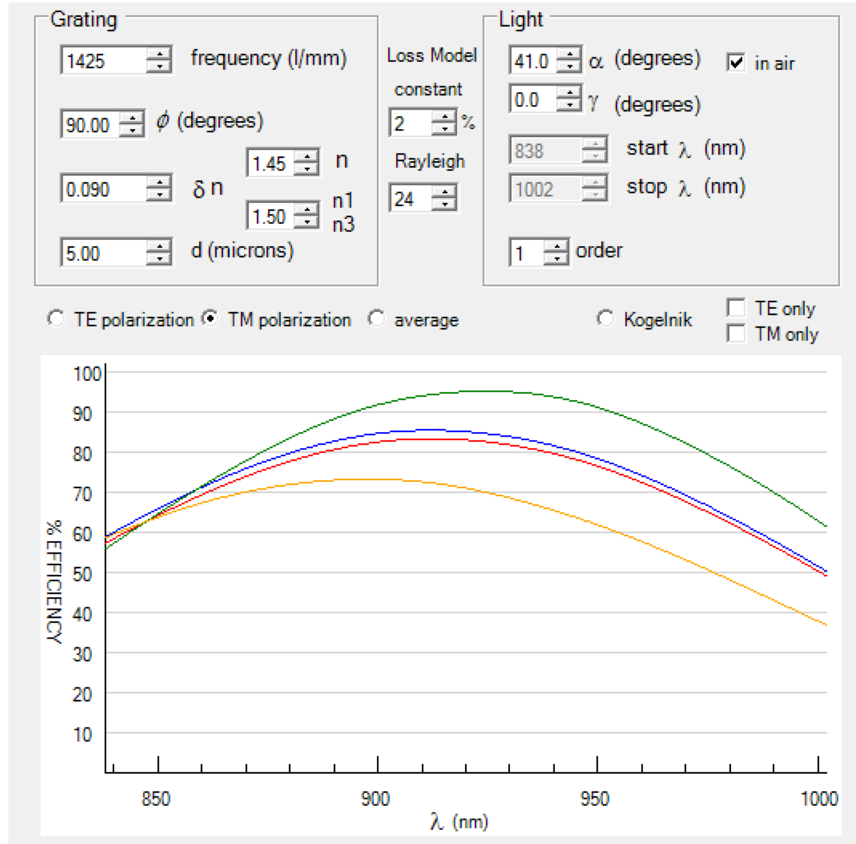

Figure 9: 1425 l/mm Red grating (R≈6025) with parameters as shown. The blue curve shows theoretical efficiency for 41 degree operating angle, and the red curve shows likely realized efficiency after surface and other grating losses. The orange and green curves show the separate TE and TM polarizations that were averaged to make the red curve.

The red gratings are in the range of parameters Syzygy has produced, except for the highest line density. We do find that films are harder to modulate as the line density increases, so a prototype should be produced to check the process.

Once again, as a cost saving measure, one grating at the average line density of these three and a variable camera angle could be used. The model below shows what the performance of this grating would look like in unpolarized light. It is not as attractive as the blue version because the working angle must go very high to reach the 920 nm center wavelength of the reddest setup.

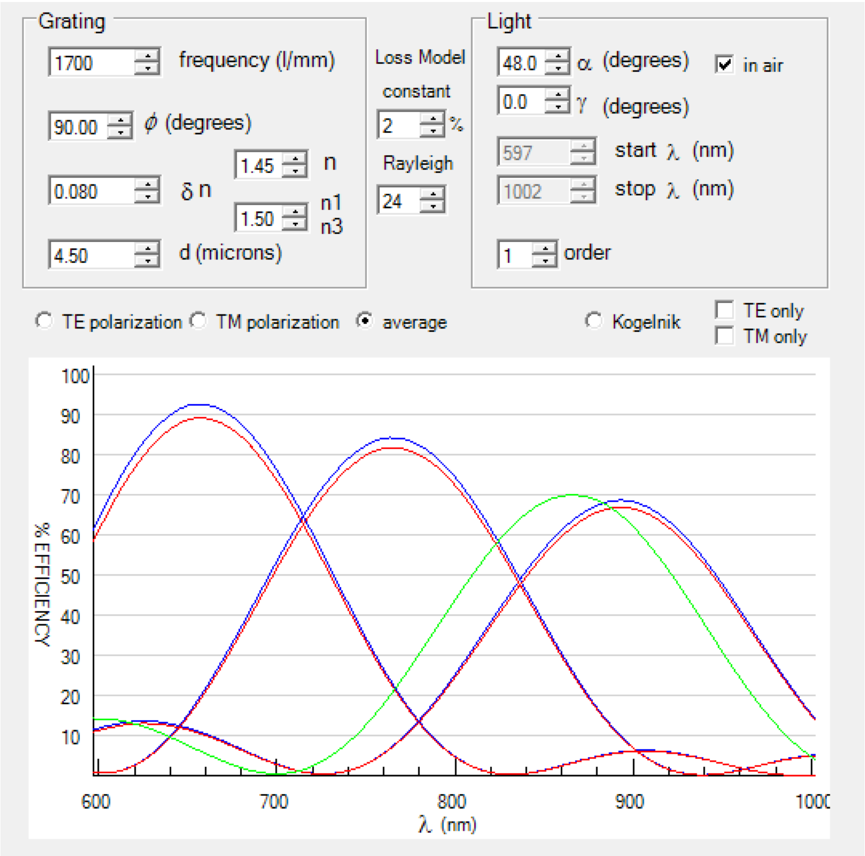

Figure 30: 1700 l/mm Red grating (R≈6000) with parameters as shown. The blue curves now show theoretical efficiencies for 34, 41, and 50degree operating angles, and the red curve shows likely realized efficiency after surface and other grating losses. Ignore the green curve, it got added by accident and didn't want to remake the figure (it is a 48 degree red-like curve if that's interesting).

These simulation show that VPH gratings can achieve good performance in nearly all anticipated configurations. The gratings will be challenging to produce, since the size is large and several of the line densities are high. We plan to pursue the creation of prototype gratings in the next phase of the project.

We note that as the camera-collimator angle increases the grating efficiency drops. This is shown most clearly in Figure 11, where the calculated efficiency peaks at only 70% (barely better than some reflection gratings!) at a camera-collimator angle of 100 degrees. This suggests that GMACS probably should be restricted to less than ~90 degrees, which ultimately restricts the maximum resolution of the instrument to roughly less than 6000.