

# Spectrally-quantified chemical reactivity of optical fluids and materials in the GMACS spectrograph for GMT

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## ABSTRACT

We present a preview of compatibility tests for index-matching fluids with commonly used optical assembly materials. Although we focus on fluid candidates for GMACS, the results of the conducted experiments are applicable to all instruments that use optical index-matching fluids. The experiment presented here aims to identify potentially corrosive matchings of fluids and materials. In the experiment, a material (RTV, polyethylene, delrin, etc.) is submerged in a quartz cuvette of fluid (Cargille liquids, glycerin, etc.). Contamination is observed by using a spectrometer to measure the absorption spectrum at various post-submersion times. The current results have large measurement errors compared to the signal, and no contamination appears to have taken place. We detail the source of these errors and make suggestions for similar future experiments.

**Keywords:** Cargille fluids, index-matching fluids, optical fluids, GMACS, GMT

## 1. INTRODUCTION

### 1.1 GMT

The Giant Magellan Telescope is a ground-based extremely large telescope that is currently scheduled for completion before 2020 at the Las Campanas Observatory in Chile. GMT will consist of seven 8.4m (27.6 ft) diameter primary mirror segments and will have the equivalent resolving power of a 24.5 m (80.4 ft) single primary mirror and the light collecting ability of a 21.4 m (70.2 ft) single primary mirror<sup>1</sup>. This will give GMT over four times the light-gathering ability of Gran Telescopio Canarias which is the ground-based optical telescope with the largest effective mirror area -- same as a 10.4 m (34.2 ft) diameter single primary mirror -- as of the writing of this paper.

### 1.2 GMACS

The Giant Magellan Areal Camera and Spectrograph is a wide-field optical spectrograph for GMT<sup>8</sup>. GMACS will aid GMT in its science goals of observing galaxy assembly, dark energy, first light, and reionization. GMACS is an integral part of GMT and because of this, it is imperative to ensure the integrity of the GMACS spectrograph for the decades that it will be in operation.

### 1.3 Optical Fluids

Recently, several spectrographs have been compromised by the corrosive nature of optical fluids with some materials. Two years after the commissioning of the Robert Stobie Spectrograph (RSS) on the Southern African Large Telescope, astronomers noticed a significant loss of ultra-violet transmission<sup>5</sup>. With great difficulty and time lost, they diagnosed that the optical fluids had corroded the polyurethane bladder<sup>9</sup>. These particles from the corrosion fell into the fluid and blocked UV light.

Furthermore, other astronomers have taken a preemptive approach to this problem. When designing the Deep Imaging Multi-Object Spectrograph (DEIMOS), the team at UCO/Lick Observatory did a preliminary 3-month test of several optical fluid and material candidates for DEIMOS<sup>7</sup>. With their research, they qualitatively identified and avoided many incompatible fluid and material pairs.

In our research, we seek to select index-matching fluids suitable for GMACS and to conduct similar tests as those conducted by the UCO/Lick team. We want to augment these tests by measuring the absorption spectra of the fluids to obtain exact quantitative results. With our research, we hope to ensure the integrity of the GMACS spectrograph and to provide information for future spectrograph instrumentation (Table 1).

Table 1. Many of these fluids and materials are popular for instrument making. (Hilyard, Laopodis, Faber 1999)<sup>2</sup> (Clemens, Crain, Anderson 2004)<sup>3</sup> (Epps, Sutin 2003)<sup>4</sup> (Sheinis et. al. 1999)<sup>5</sup> (Buckley et. al. 2008)<sup>6</sup> (Brown, Fabricant, Boyd 2002)<sup>7</sup>

<b>Fluids and Materials in Other Instruments</b>	
<u>Fluid</u>	<u>Instruments that Use Them</u>
Glycerin	None
Cargille Laser Liquid Code 1075	DEIMOS <sup>2</sup> , SDSS <sup>3</sup>
Cargille Laser Liquid Code 5610	IMACS <sup>4</sup> , ESI <sup>5</sup> , Goodman <sup>6</sup> , RSS <sup>6</sup> , Binospec <sup>7</sup>
<u>Material</u>	
Delrin	ESI
Polyethylene	DEIMOS
Polyurethane	None
Kapton	None
Teflon	RSS
Silicon	LRIS <sup>6</sup> , RSS

## 2. THE EXPERIMENT

### 2.1 Experimental Setup

At its simplest, our setup consist of a light source, the sample, and a spectrometer. The light is provided by a xenon lamp which has an emission spectrum that extends into the UV range (300-450nm) as we require for this experiment. The sample is contained in a 100mm path length, quartz cuvette. Quartz was selected because it is clear in the UV. The spectrometer grating orientation is positioned to maximize the sensitivity in the UV.

We performed several baseline experiments to optimize the UV throughput of our setup: from testing the UV transmission of our fibers to changing the monochromator grating. We included an integrating sphere after discovering the cuvette holder was not coupling properly to the SMA1 fiber.

### 2.2 Procedure

We tested six different materials (delrin, silicone, teflon, kapton, polyethylene, polyurethane) in combination with three different fluids (glycerin, Cargille LL1074, Cargille LL5610). Each material was cut into uniform pieces and submerged in a flask containing a different fluid. Thus there were 18 combinations of fluids and materials to test.

Prior to filling the cuvettes with fluids, we cleaned them with distilled water, acetone, and pressurized nitrogen to remove any residue. Upon filling the cuvettes, we found that air bubbles in the fluids scattered a noticeable fraction of light so we waited for the air bubbles to disperse. After the measurements, we poured the fluids back into there flask to continue aging.

The measurements were performed using the following method. An empty cuvette was placed in the cuvette holder, and its spectra was measured. This measurement served as our control to help remove day to day changes in our setup (for example lamp instability). Then we filled the cuvette with fluid to be tested and recorded a background subtracted spectra. We repeated the measurement for the different material-fluid combinations several times over a period of 3 weeks to record the evolution of the transmission with time.

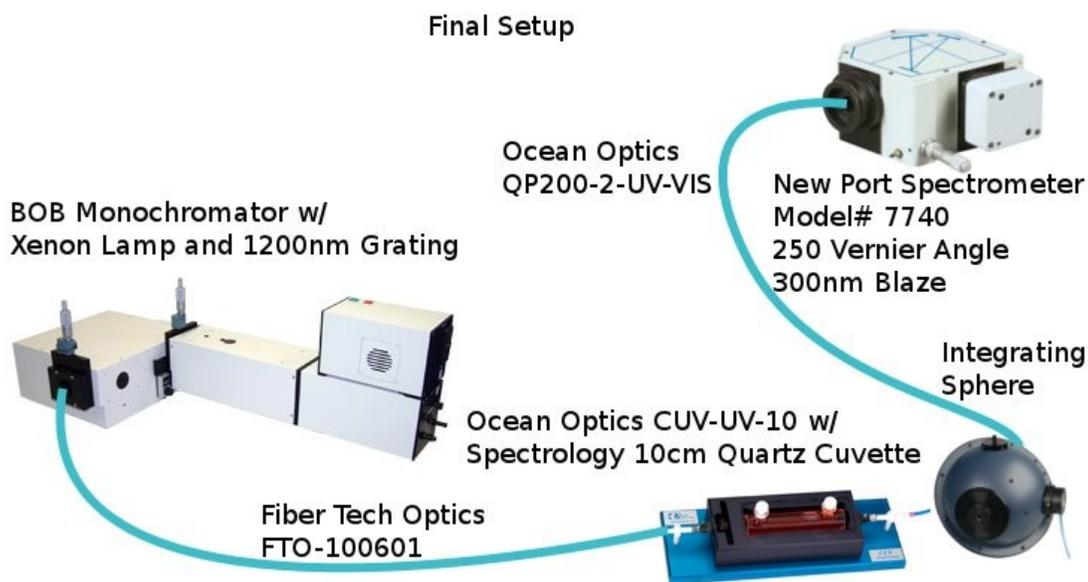


Figure 1. Experimental Setup. Light generated by the lamp is coupled by the monochromator into the fiber. It then passes through the sample and is coupled by the integrating sphere into the second fiber and then the spectrometer where its spectra is measured.

### 3. THE RESULTS

We were not able to detect any effect of the contamination on the transmission spectra of the fluids greater than our experimental uncertainties, thus no quantitative conclusions may be drawn about the chemical reactivity of the materials with the liquids. Our experimental setup uses a relatively long 100mm optical path through the sample under test that complicates fiber coupling and increases the measurements errors. The longer beam path should more than compensate this increase in uncertainty by a 100 fold increase in sensitivity to absorption features in the liquids when compared to previous experiments using a 1mm baseline.

Even though our measurement error did not allow us to detect UV throughput degradation, there is still some information to be gathered by considering a simple binary approach to the data: did it transmit UV light or not. Considering that all combinations of material and fluid transmitted UV about the same, it would seem as though very little reactions occurred under the conditions in which the samples were aged.

It could be that the liquids were not given sufficient time or the proper environment in which to be contaminated. In Nordsieck, Nosan, and Schier 2010, they found the contamination set in after 200-300 hours when the reaction was accelerated by allowing the samples to age in a heated environment (35°C). Our samples were aged at standard temperature and pressure so the reactions happened much slower. Though if there were any small change in the UV throughput, our setup would detect it because of the 100mm long path length used to measure the absorption spectra.

We included the combination of LL5610 and polyurethane in our test as a control sample because it is a pair known to produce contamination. The fact that we did not see a measurable effect in this case indicates that the samples did not have enough time to age.

### LL1074 Spectra After 3 Weeks

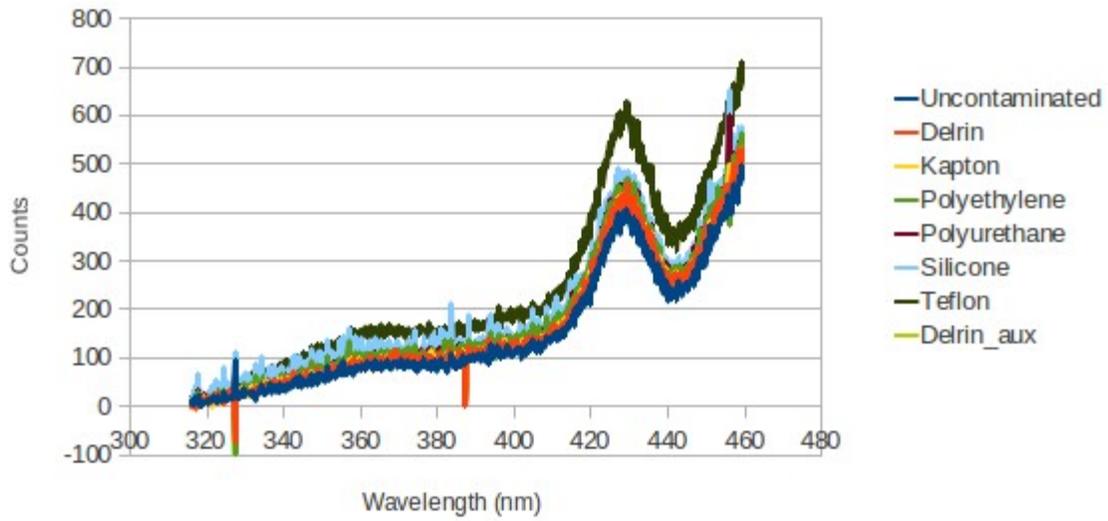


Figure 2. LL1074 Spectra After 3 Weeks. Most of the spectra from contaminated LL1074 have signals greater than the uncontaminated LL1074. This should not be the case.

### LL5610 Spectra After 3 Weeks

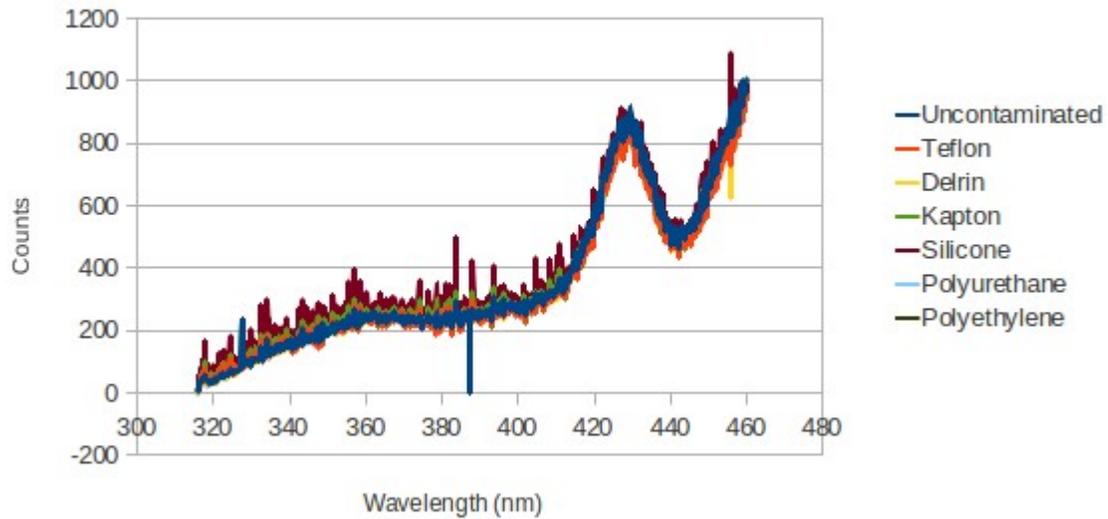


Figure 3. LL5610 Spectra After 3 Weeks. Although it is noisy, it is apparent that few of the samples lost a significant amount of UV transmission.

## Glycerin Spectra After 3 Weeks

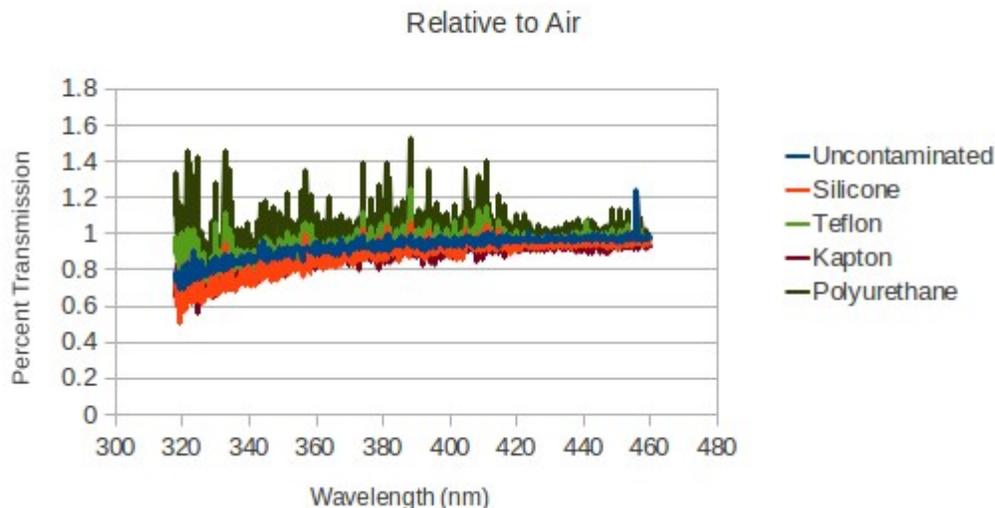


Figure 4. Glycerin Spectra After 3 Weeks: Relative to Air. Although it is noisy, it is apparent that few of the samples lost a significant amount of UV transmission.

### 4. SOURCES OF ERROR

In the process of running this experiment, we found many sources of error, some of which were surprising. After leaving a cuvette of glycerin open to air for a couple of days, we found that a beam of light would be deflected when traveling through the cuvette. After a few simple tests, we deduced that glycerin, which is hygroscopic, had absorbed water from the air and produced a gradient from top to bottom in its refractive index. This deflected the UV light and significantly dropped our throughput.

The long path length of the cuvettes helped to make our setup very sensitive to any absorption but it also introduced many problems. Collimating and coupling the light through the cuvette with the fibers proved difficult which is why we introduced the integration sphere in the setup. Unfortunately, this drops the throughput by a factor of about 1000 which we compensated by increasing the integration time by a factor of 1000.

We took steps to avoid nonlinear detection effects, but this proved to be a challenge because the lamp output and detector sensitivity both change rapidly in the UV region. We made sure to keep the sum of counts from the background and the signal below the nonlinear region. The spectrometer sensitivity dropped to zero near 330 nm. A combination of long integration times and low signal made measurements near 330nm inaccurate.

In an email correspondence, Alan Schier and Kenneth Nordsieck noted that deviations in the dimensions of the cuvette could change the path length. If the cuvettes were not made to be exactly 100mm, then this would introduce more medium to absorb UV. This effect would be much smaller in our experiment because our path lengths are 100 times longer.

### 5. SUGGESTIONS FOR FUTURE EXPERIMENTS

For future experiments, we shall make several suggestions that will reduce measurement error and costs. Although long path length cuvettes provide better sensitivity, the measurement errors associated with them in our experiment made this point moot. Short path length cuvettes reduce the optical coupling problems and require less optical fluid to fill. This reduces the experiments cost significantly as Cargille fluids can cost around \$200 per 8 fluid ounces. Also, the cuvettes we used had small openings perpendicular to the path length. This made cleaning them a challenge with serious consequences. Because the windows of the cuvette were not accessible to clean, it took many acetone baths to remove residuals from the interior of the cuvette. Small cuvettes with openings with accessible windows would eliminate this problem.

The act of pouring the samples from the storage flask into the testing cuvette introduced problems. Each time a transfer was made residual fluids were lost as they coated the inside of the previous container. Also, repeatability was a major concern. We discovered in a few auxiliary tests that small variations in the cuvettes and the cleaning of the cuvettes would produce large measurements errors. To rectify this, we suggest storing the fluid in the same container that it will be tested in.

Even though glycerin is not a viable optical fluid because of its hygroscopic nature, it is two orders of magnitude less expensive than Cargille fluids, and thus it is an excellent sample to use to test the setup for measurement errors and to ensure that the experiment is functioning properly.

Finally, we suggest that the samples either be given ample time to age or be placed in an high temperature environment to accelerate any chemical reactions. The long path length of our setup was unable to detect early onset UV throughput degradation as we supposed it would. Thus to measure the contamination, it is necessary to allow the chemical reaction to come to fruition.

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