Name: ______________________________
Partner(s): ______________________________
Date: ______________________________

Creating a ***Virtual*** Instrument (establishing the "Pixels as Platform" Paradigm)

Notions of Dispersion:

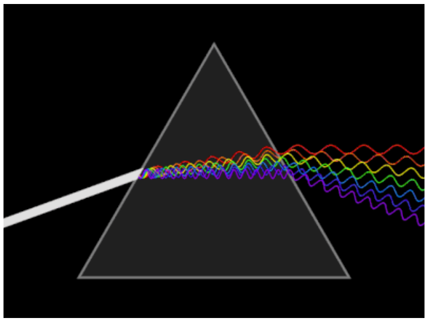


Fig. 1. A glass prism is said to disperse white light into its constituent colors. Transverse *momenta* at an interface leads to a transverse spatial separation of different wavelength components. Explain why, with *dispersion* higher frequencies are deflected most, but for *diffraction* the higher frequencies see the least displacement. [***Clickable*** GIF: Fandom.com]

The transverse dispersion illustrated in Fig. 1 is somewhat different from the longitudinal pulse dispersion that occurs inside an optical fiber:

Fig. 2. An optical fiber's refractive index is frequency dependent, so the various energies comprising a pulse travel at different speeds, resulting in asymmetric pulse stretching with concomitant reduction in amplitude: the pulse has been *dispersed* by the medium. [***Clickable*** simulation + code: Jacopo Bertolotti]

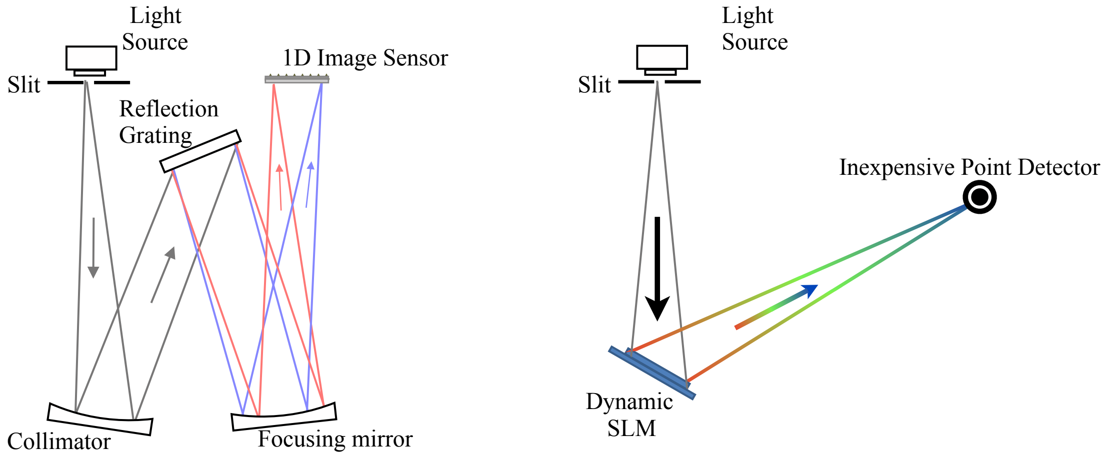


Fig. 3. Left: A grating spectrometer of traditional "W-shaped" layout involves purchase, assembly, and alignment of a number of special optical elements and their associated mounting hardware. Right: Today's lab creates an SLM version.

Optical spectrometers play an important role in AstroPhysics, in Atomic Physics, in Chemistry, and Biomedical Engineering, and in Materials Science (*e.g.*, dissolve a tiny bit of some part, spray the solution into a plasma, and you can get part-per-trillion sensitivities to impurities). The key component is typically a diffraction grating, which is a slab containing a surface with some sort of periodic modulation, in the aperture function, the reflectivity, or in the phase delay imparted to a beam. (The grating is then said to be a transmission grating, reflection grating, or phase grating, respectively.)

Suppose that we start with a diffraction grating (of whatever type), characterized by a period, d, and consider its action upon a particular wavelength, λ. We expect brightness at angles θ_m:

$$d \sin \theta_m = m\lambda$$

where m is the diffractive order. Clearly, for a given order (say $m = 1$), shorter wavelengths (*i.e.*, higher frequencies) are found at smaller angles. In the traditional spectrometer illustrated on the left side of Fig. 3, the output of the spectrometer is optically processed such that distinct (enough) wavelengths fall onto different pixels of a detector.

An SLM-based version is illustrated below:

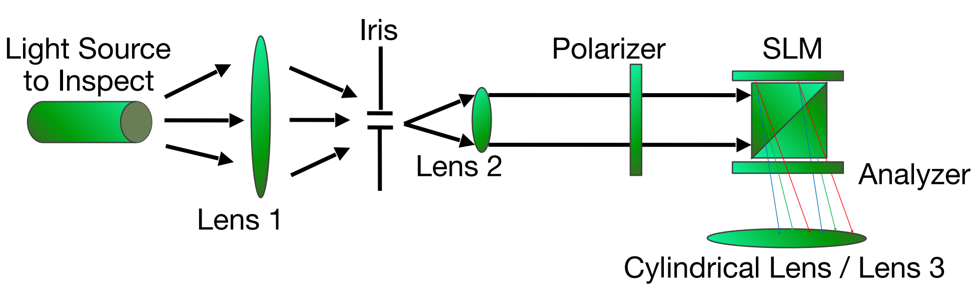


Fig. 4. For today's version, we haven't simplified the setup as much as we could, but this approach is convenient for our next steps.

Take a careful look at Fig. 4, and **describe, in your lab notebook, what you think is going on**.

As requested in the caption of Fig. 1 above, explain why, with *dispersion* (the effect in a glass prism) higher frequencies are deflected most, but for *diffraction* the higher frequencies see the least displacement. — Then go further and make a prediction for which you will see in your experiment with a liquid crystal Spatial Light Modulator.

As the spectrographic signal may be weak at some wavelengths of interest, Lens 1 is shown, in Fig. 4, as a larger aperture lens (*e.g.*, 2-inch diameter), designed to gather more signal; however, depending upon your chosen initiatives, signal strength may not be an issue today (in which case a 1-inch lens would still be fine). Lens 2 aims to collimate the beam, to a diameter that fills the active area of the SLM. **Why does this experiment include an iris? What might that affect?**

1. Use a laser to align the iris, the SLM, and all lenses (including the cylindrical lens) to a common (folded) optical axis.

2. Remove the laser and install the light source to be inspected, positioning it (and Lens 1, as needed) so that the light re-appears on (is ~ focused to) the iris.

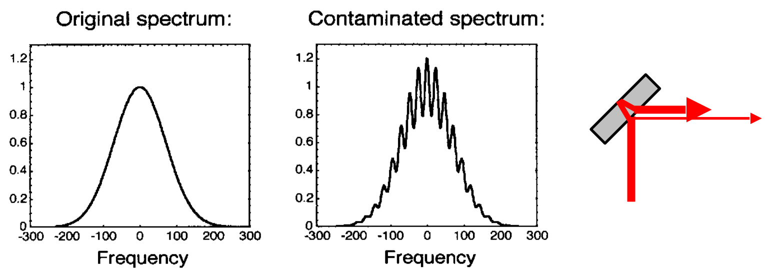
3. Adjust Lens 2 so that the light coming from the iris becomes collimated, enters the SLM, then passes through the cylindrical lens, where it will eventually produce its spectrum on the focal plane. (Since you do have one on hand, you can use a camera rather than the single-pixel photodiode shown in Fig. 3.)

4. Come up with a procedure to capture a spectrum, and analyze the observed results

Questions:

1) What factors determine the spectral *resolution*?

2) Is there any evidence of the kinds of multi-path oscillations discussed in class today, in our second lecture on Fourier Optics, in our example that used the **Shift Theorem**? Why or why not?



Opportunities for Initiative: (come up with your own ideas!)

You could, as *<u>initiative</u>* read about (or watch a YouTube video on), and create notes describing the work of Donna Strickland and Gérard Mourou that was honored by half of the 2018 Nobel Prize in Physics. This work relies upon dispersion to amplify laser pulses safely, prior to recompression of the pulse, a technique that is absolutely foundational to the current golden age of Atomic Physics and many other applications.

Alternatively, you could, as *<u>initiative</u>* read about (or watch a YouTube video on), and create notes describing a new method called Serial Time-Encoded Amplified Microscopy ("STEAM"). — We now find ourselves at the **Dawn of Third Age** of high-speed imaging. Attainable speeds during the First Age were limited by the inertial response of a mechanical shutter. The Second Age bypassed that limit via electronic shuttering (turning circuitry on and off), but was still limited by electronic delays. The new era is demarked by essentially *all-optical* shuttering techniques, and promises to open entirely new worlds of possibilities for inquiry and explanation. — Serial time-encoded amplified imaging / microscopy (STEAM) and sequentially timed all-optical mapping photography (STAMP) are completely different types of optical imaging technology that have led to the recent development of (what was at the time) the world's fastest camera in continuous and burst modes, respectively. This field is evolving very rapidly! Methods such as STEAM and STAMP are poised to enable *you* to develop new classes of instruments with which you can help researchers and engineers to address many kinds of problems. (CAUTION: do not search for videos simply using "STEAM" as a search term; that is unlikely to yield a video about Serial Time-Encoded Amplified Microscopy.)

…Or, you could consider dispersion in the liquid crystal solution of the SLM itself!