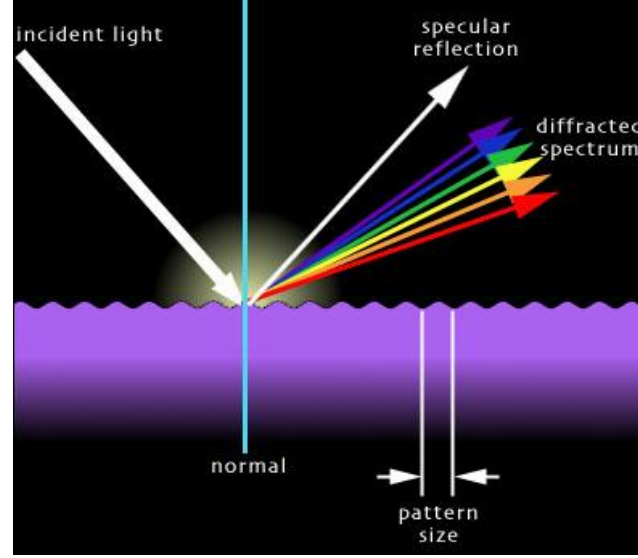
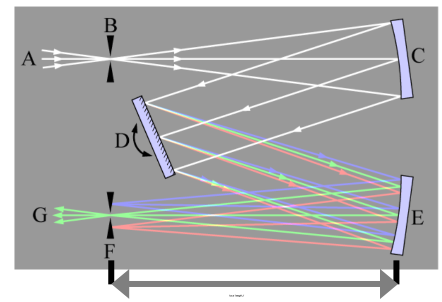
Spectral Measurement Using a Monochromator, Thermopile Detector, and Lock-In Amplifier

September 18, 2012





The University of Toledo
R. Ellingson and M. Heben

Where are We, Where we are Going? (the next three weeks and beyond)

- ✓ Igor (or comparable), LabView
- ✓ Properties of the Sun
- ❑ Understand Components in Optical Measurement System
    - ❑ Physics
    - ❑ Role in experiments
- ❑ Set Them Up!
    - ❑ Bread Board Layout
    - ❑ Interface to Computer
    - ❑ Develop software
- ❑ Characterize output of lamp/monochromator (three weeks)
- ❑ Onward to reflection, transmission, absorption, QE, J/V, and a host of other interesting measurements!

Lab Due Dates, and other Info

Previously – Due on Monday before the lab, noon.

Rationale – wanted students to look at lab report requirements/topics early, so we could help if needed

Now – Due on Tuesday, by Lab time

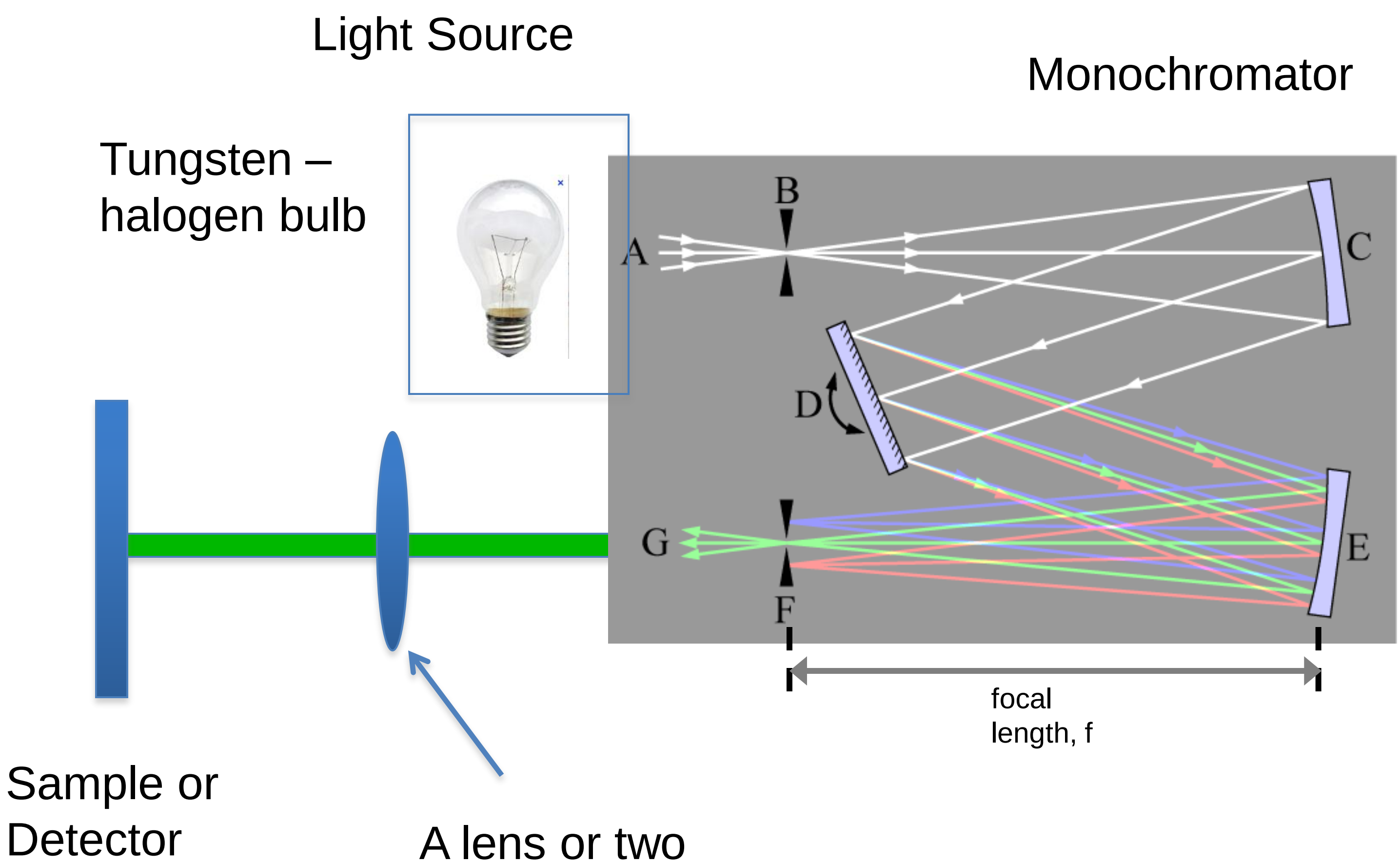
Think about your report and potential stumbling blocks early! Interface with group members early!

Late policy will be strictly enforced!

Next Lab Report Due October 3 – 1st day after Fall Break

First Quiz on September 25

The “Set-Up”

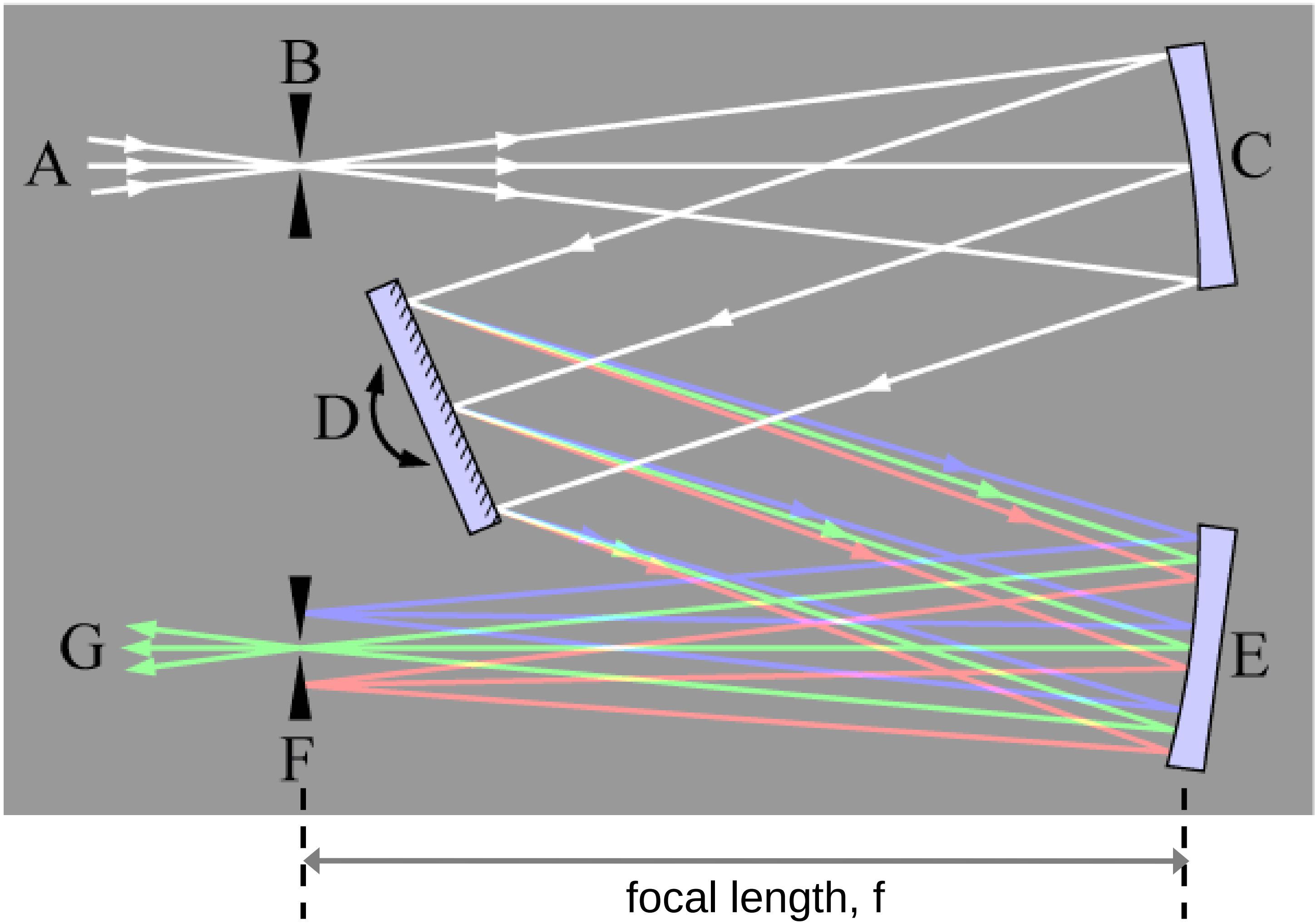


Samples – semiconductor layers, transparent conductive layers, PV devices
Detectors – calibrated thermopile, photodiode

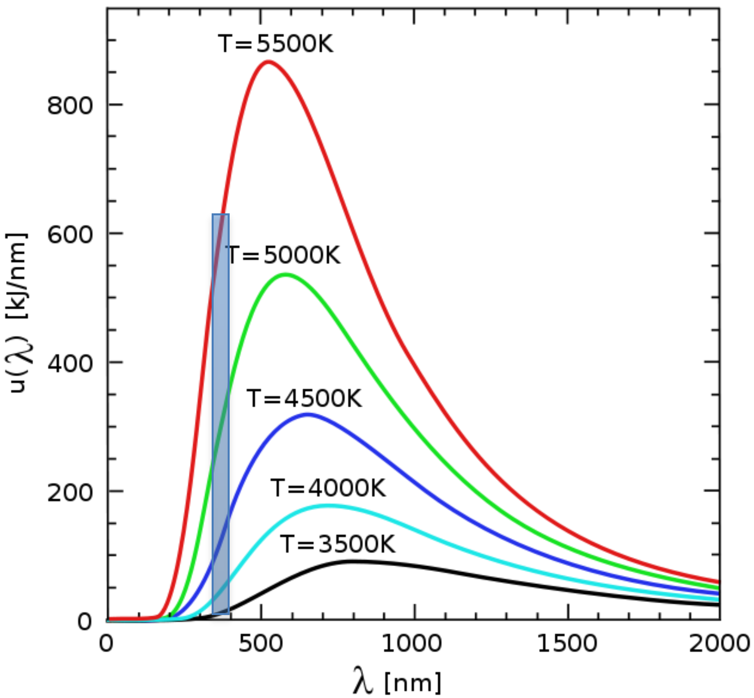
Spectral Products, CM110 1/8th meter monochromator

Feature	Value
Design:	Czerny-Turner, dual-grating turrets
Focal Length:	110mm
f/#:	3.9
Beam Path:	Straight through standard, right angle provided on request.
Wavelength Drive:	Worm and wheel with microprocessor control and anti-backlash gearing. Bi-directional. Usable in positive or negative grating orders.
Wavelength Precision:	0.2nm
Wavelength Accuracy:	± 0.6nm
Slewing Speed:	>100nm/second
Stray Light:	$<10^{-5}$
Slits:	Standard Set includes; 0.125mm, 0.15mm, 0.30mm, 0.6mm, 1.2mm and 2.4mm x 4.0mm. For other sizes, consult SP.
Max Resolution:	<1nm w/1200G/mm grating and standard slits
Gratings:	One to two gratings. (30 x 30mm) must be purchased. See Appendix A for options
Software:	Demonstration control program and LabView driver included.
Power:	UL listed 110/220V power pack
Interface:	RS232 standard
Warranty:	One year
Options:	• Hand-held control module with function keys and display for local control • IEEE-488 interface • Interface cables • Gold optics See options and accessories

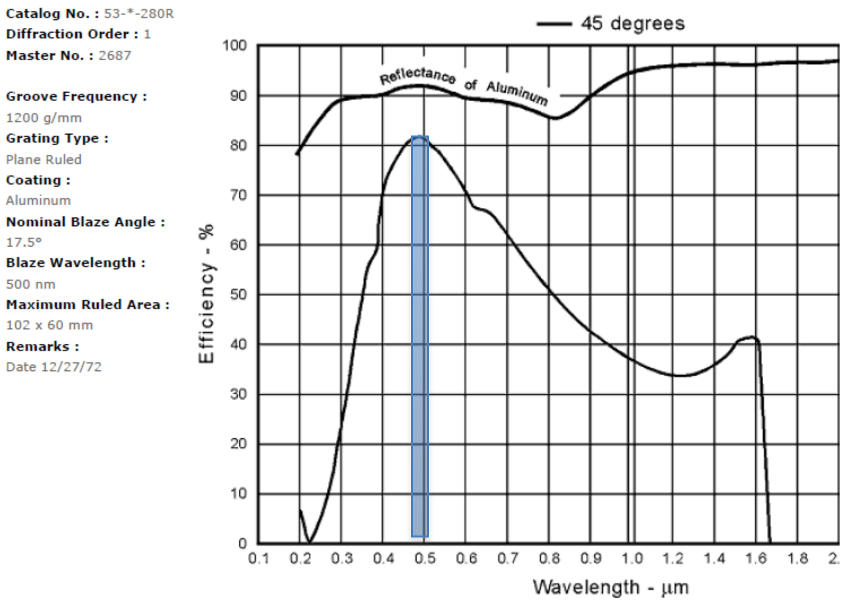
Czerny-Turner Monochromator



Characterize lamp/monochromator output (photon flux) at the sample plane (three week duration)



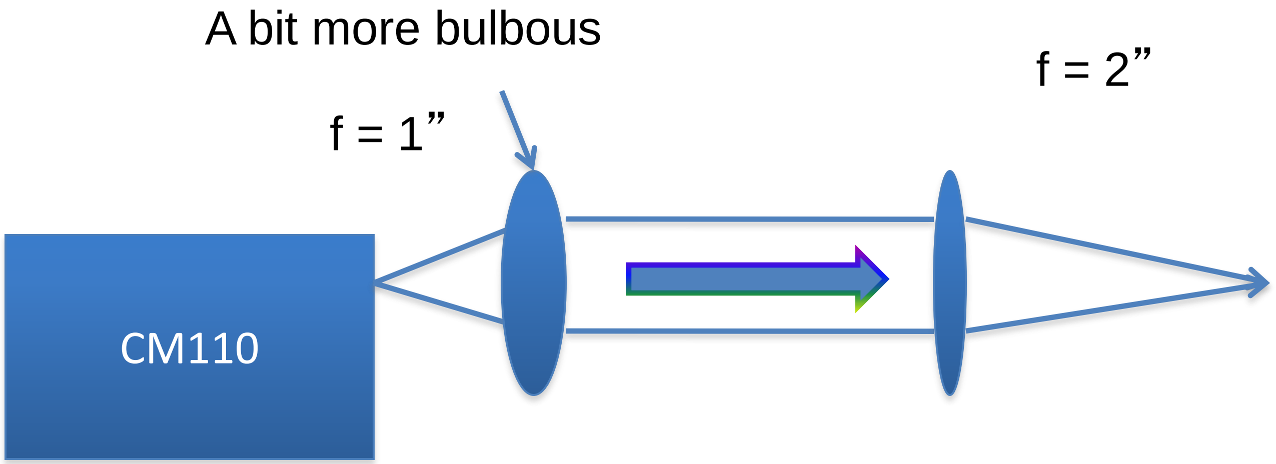
X



How many Photons/s/nm are incident at the sample plane?

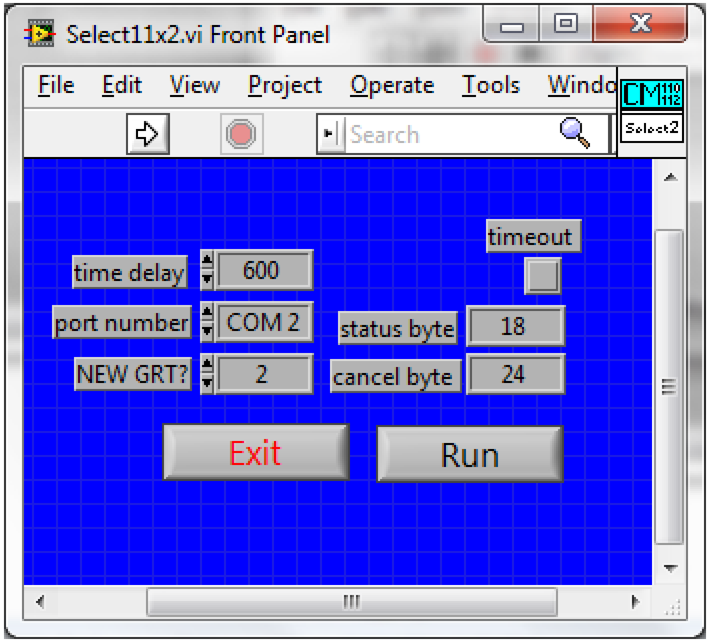
You have two lenses per set-up

1) Both 1” diameter
2) One has a focal length of 1”
3) The other has a focal length of 2”



Details on the CM110 monochromator

- Note that the CM110 has a double-grating turret -- one side has our 1200 g/mm grating (make sure you know what g/mm means); the other side has a flat aluminum mirror. The "Select11x2.vi" enables you to select the turret to be in position 1 or 2 (one is the grating, the other the mirror).
- You'll get the brightest output when selecting the mirror (output only at 0 nm, where it is specularly reflecting); using the grating, you'll get a blend of wavelengths out when set to 0 nm (m = 0), and you can select a specific wavelength.



Thermopile Detector (Dexter Research, Model 2M)

Parameter	Min	Typical	Max	Symbol	Units	Comments
Active Area size		2 x 2		AA	mm	Hot junction size, per element.
Element Area		4		A	mm^2	
Number of Junctions		48				Per element.
Number of Channels		1				Per detector package.
Output Voltage	200	250	300	V_s	µV	DC, H=330µW/cm^2 (3)
Signal-to-Noise Ratio	12,739	19,531	33,333	SNR	√Hz	DC, SNR=V_s/V_n
Responsivity	15.2	18.9	22.7	$\mathfrak{R}$	V/W	DC, $\mathfrak{R}=V_s/HA$ (2)
Resistance	5	10	15	R	kΩ	Detector element
Temperature Coefficient of $\mathfrak{R}$		-.36			%/°C	Best linear fit, 0° to 85°C (1)
Temperature Coefficient of R		-.2			%/°C	Best fit, 0° to 85°C (1)
Noise Voltage	9.0	12.8	15.7	V_n	nV/√Hz	$V_n^2=4kTR$
Noise Equivalent Power	.40	.68	1.03	NEP	nW/√Hz	DC, NEP= V_n HA/V_s (2)
Detectivity	1.9	3.0	5.0	D*	10^8cm√Hz/W	DC, D*=V_s/ V_n H√A (2)
Time Constant		85		$\mathcal{T}$	ms	Chopped, -3dB point (1)
Field of View		38°/95°		FOV	Degrees	See Assembly Drawings for FOV Description.
Package Type		TO-5				Standard package hole size: ∅.150"
Operating Temperature	-50		100	T_a	°C	

General Specifications: Flat spectral response from 100nm to > 100µm. Linear signal output from 10^{-6} to 0.1W/cm^2. Maximum incident radiance 0.1W/cm^2, damage threshold ≥ .5W/cm^2

Notes: **(1)** Parameter is not 100% tested. 90% of all units meet these specifications. **(2)** A is detector area in cm^2. **(3)** Test Conditions: 500K Blackbody source; Detector active surface 10cm from 0.6513cm Diameter Blackbody Aperture.

Goals of this Unit

1) Build an optical set-up to permit development of a LabView program to acquire (directly into the DAQ board), plot, and store signals from the thermopile detector. The detector is to be excited by the chopped output of the CM110 monochromator. Determine the time constant of the detector, and identify the gas used for packaging. Useful resources are under "Effects of Encapsulation Gas on Thermopile Detectors" and "Thermopile Time Constant Determination" at the http://www.dexterresearch.com/?module=Page&sID=technical-library

2) Acquire plot and store data from the thermopile using the lock-in technique. Compare to data from (1), and understand how the measured voltage relates to the thermopile's response.

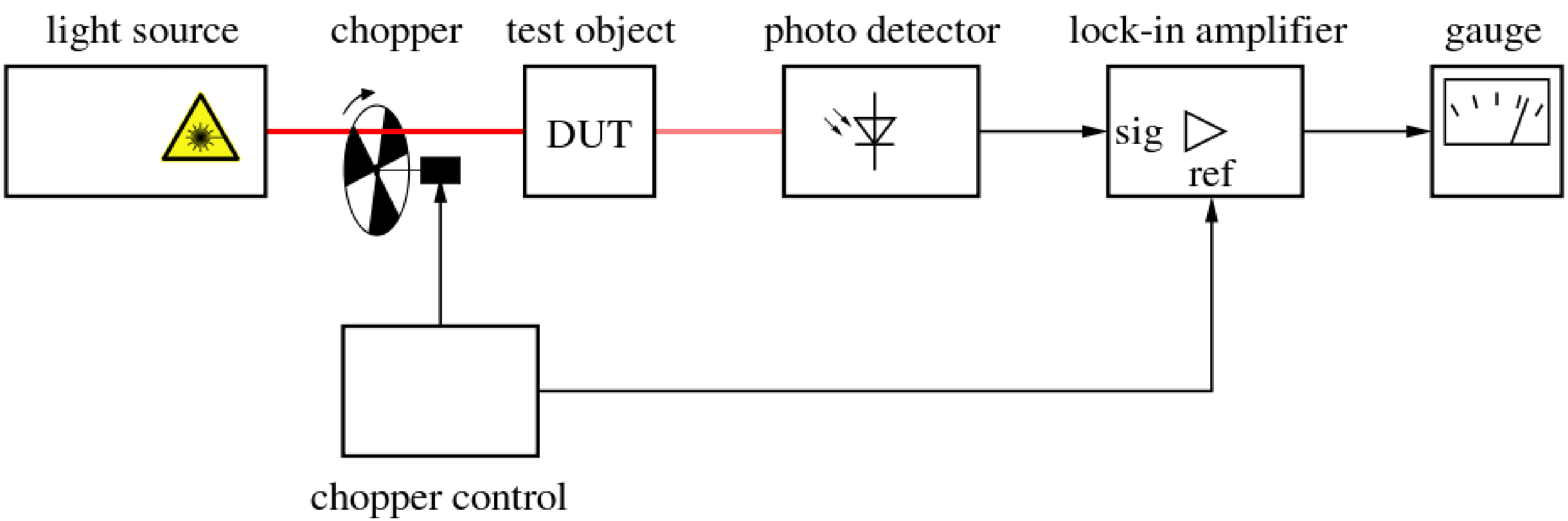
3) Develop a program to measure, plot and store the output of the monochromator, in terms of # of photons/nm-cm2-s, as function of wavelength, for various lamp powers, and several slits widths. How does your measured spectrum compare to a Black Body spectrum? How does your measured spectrum compare to the AM 1.5 spectrum? Use Igor Pro to develop a correction file to convert measured spectrum into either BB or AM 1.5.

Additional guidance for Part 3

- Include information about calculations and assumptions (step by step).
- Include a comparison of measured data to the AM 1.5 and AM0 spectra in units of #photons/(s-cm^2-nm).
- Specify definition of correction files as AM X(λ)/measured spectra (λ).
- Plot (measured spectra x correction file) for each case versus AM X spectra.

Stanford Research Systems, Model SR510 Lock-In Amplifier

Typical experimental setup for lock-in detection



Stanford Research Systems, Model SR510 Lock-In Amplifier

- Also known as a “phase-sensitive detector”;
- Can extract a signal with a known carrier wave (modulation frequency) from an otherwise very noisy environment;
- Requires a reference signal, which is effectively multiplied by the input signal;
- When a sinusoidally varying signal of frequency ν_1 is multiplied by another sinusoidally varying wave of frequency $\nu_1 \neq \nu_2$, and integrated over many cycles, the result is zero; thus for a noisy signal with a component at the carrier (reference) frequency, the result of long time integration is non-zero;
- Modulation of the signal can be achieved by (using light as a relevant example) an optical chopper (note that our chopper has a “reference” signal output, but pay careful attention to what this signal looks like);
- Practical aspects of an LIA: the need to set the phase correctly (controlled through the Reference Input section); the sensitivity setting; the display; the scaling of the “Output” signal; the role of the Time Constant.

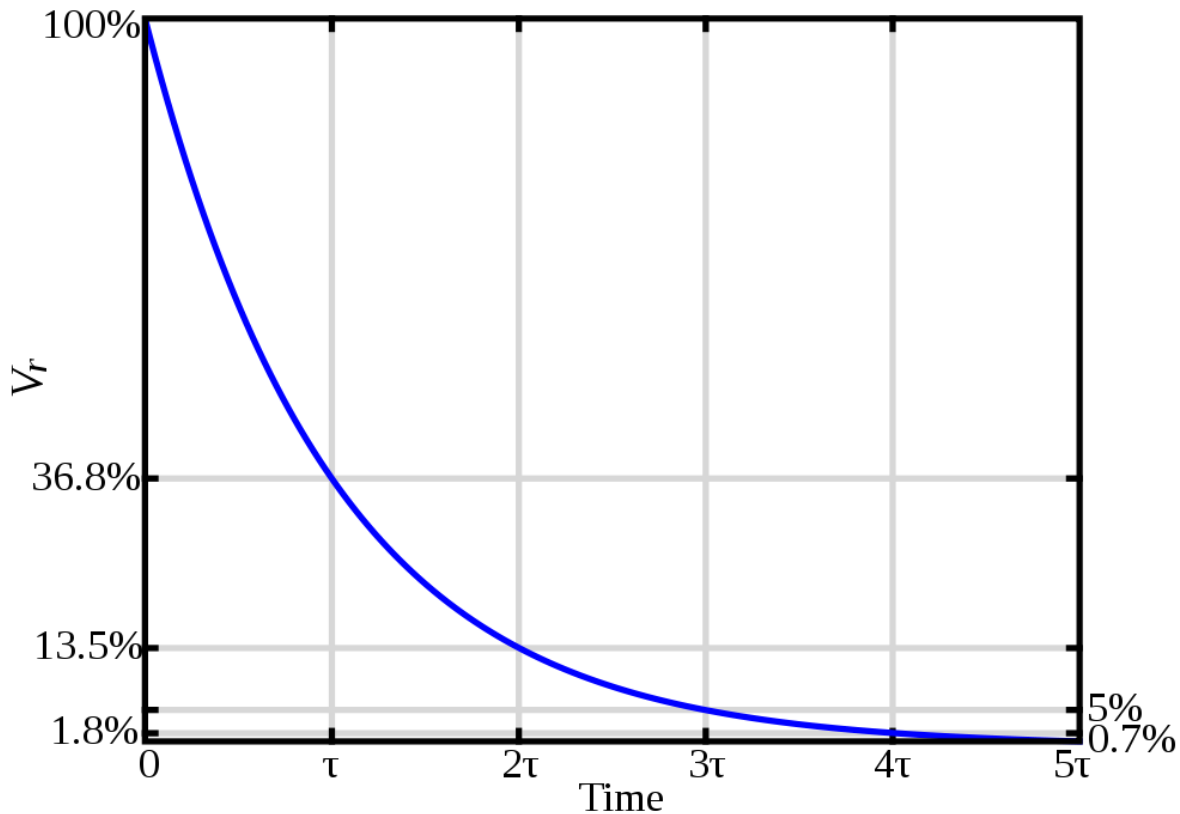
after *Wikipedia: http://en.wikipedia.org/wiki/Lock-in_amplifier*

Stanford Research Systems, Model SR510 Lock-In Amplifier

- The output from a lock-in amplifier is generally calibrated to indicate the actual signal amplitude (e.g., in Volts).
- However, the measured signal amplitude does depend on the specifics of the Reference signal. For example, for sinusoidal modulation, the output is generally the root-mean-square signal at the modulation frequency, so a factor of $\sqrt{2}$ comes into play – note that you can test this by comparing the actual signal amplitude (as measured by the DAQ analog-to-digital (AI)) to the signal detected by the lock-in amplifier.
- For a non-sinusoidal modulation, the value may be different. What is the shape of our signal modulation? Sinusoidal?

after *Wikipedia: http://en.wikipedia.org/wiki/Lock-in_amplifier*

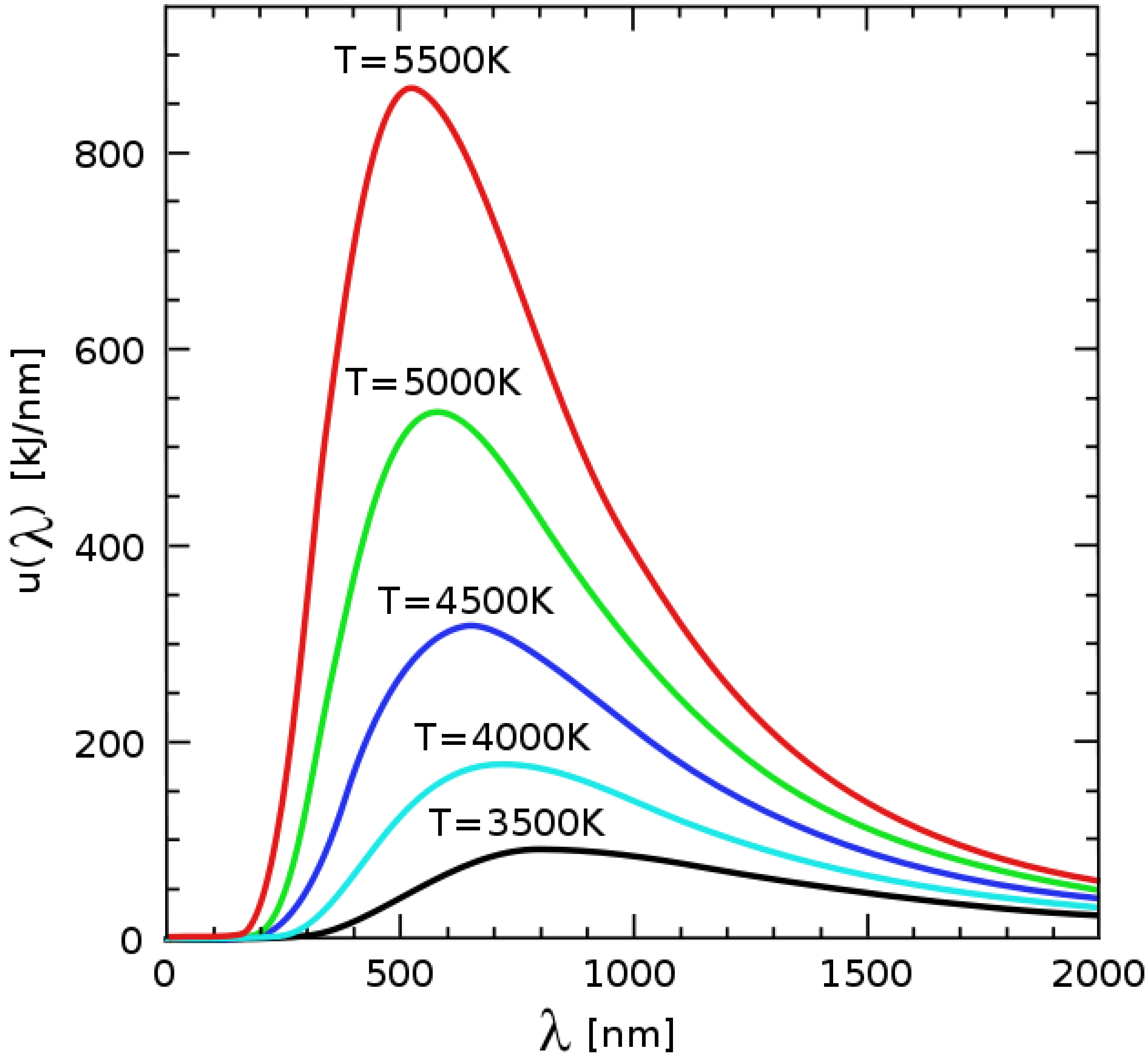
What do we mean by "time constant"?



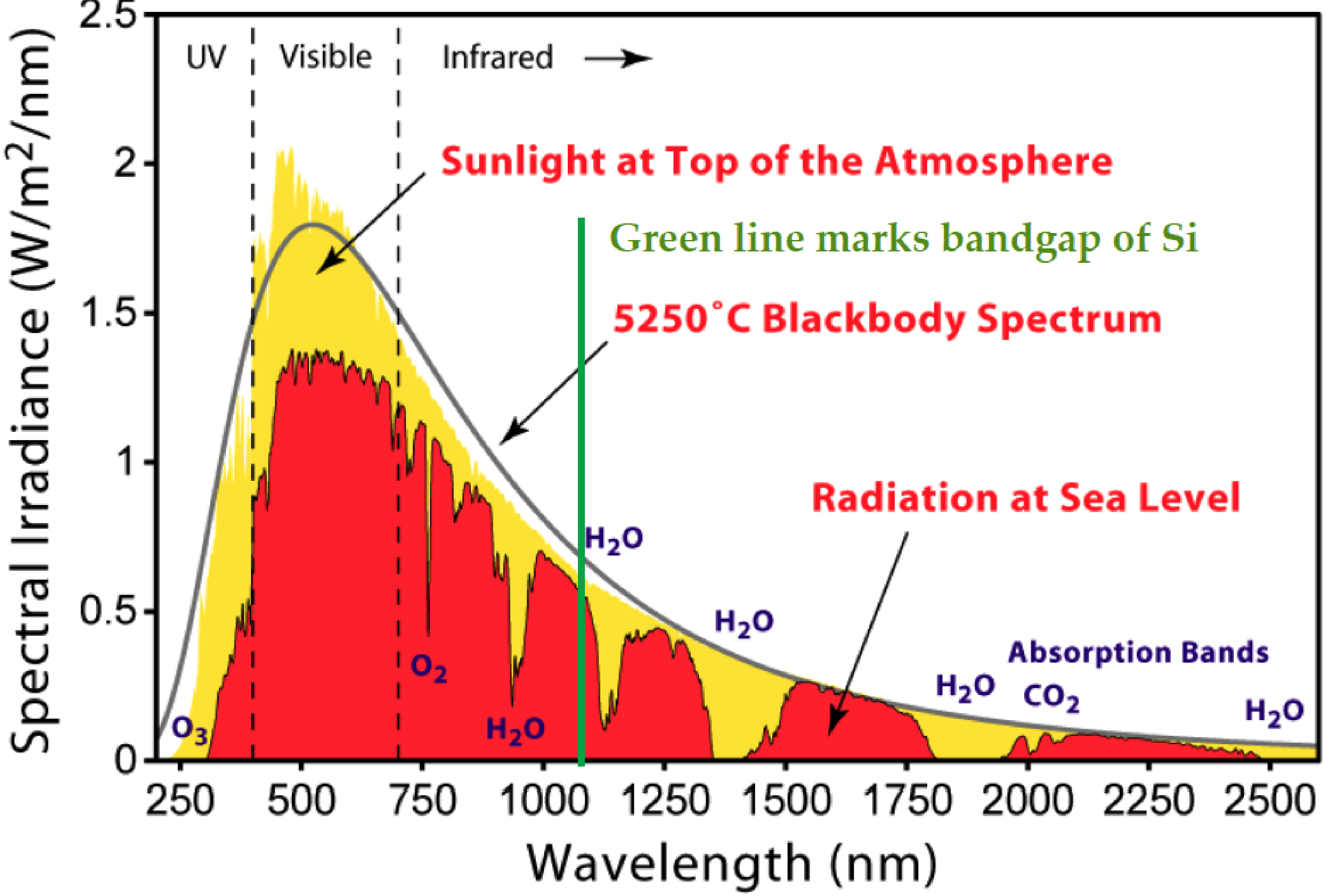
$$V(t) = V_0 e^{-\left(t/\tau\right)}$$

http://en.wikipedia.org/wiki/Time_constant

Spectrometer sensitivity calibration: black body radiation, grating efficiency, detector sensitivity



Solar Radiation Spectrum



Resources:

http://gratings.newport.com/information/handbook/toc.asp

http://www.thinksrs.com/products/SR510530.htm

http://www.dexterresearch.com/?module=Page&sID=technical-library

http://www.pariss-hyperspectral-imaging.com/GratingOrders_Movie/GratingOrders_Movie.html