Order Overlap

- A single wavelength constructively interferes in several directions.
- A given direction can receive multiple wavelengths.
Spectral Calibration
Spectral Calibration

TripleSpec Users Guide
Fiber Optics and Fiber Spectroscopy

- Total internal reflection – Refraction going from a high index medium to a low one can only occur over a limited range of angles since $\sin(\theta)$ cannot be greater than one.

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

\[ \sin \theta_c = \frac{n_2}{n_1} \]

http://hyperphysics.phy-astr.gsu.edu/Hbase/phyopt/totint.html
Fiber Optics and Fiber Spectroscopy

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Fiber Optic Spectroscopy

- Sloan Digital Sky Survey Spectroscopy
Fiber Optic Spectroscopy

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Solar Spectrum (just a small portion of the 300 spectra)
Integral Field Units

- Fibers can be bundled tightly to sample a spatial region and map it to a slit.
Fabry Perot Interferometers

• In the end we are most interested in constructing spectral data cubes.
  - Integral field units accomplish this goal by generating a spectrum at every spatial point.
Fabry Perot Interferometers

- In the end we are most interested in constructing spectral data cubes.
  - Alternatively one could take a picture at each discrete wavelength if there was a “filter” narrow enough to isolate each wavelength.
Fabry Perot Interferometers

• Remarkably, if you place two nearly perfectly reflective mirrors (say 99% reflective, 1% transmissive) parallel to one another, you create a resonant cavity that transmits, with high efficiency very narrow wavelength ranges.
  - Filter out the ones you don't want and you have a ultra-narrowband imager.
  - “Newton's rings” is an example of this effect, but with reflectivity of only 4%.

To get constructive interference the transmitted waves have to be in phase.

Since each transmitted wave comes from two passes through the cavity of width “d” the transmission condition is

\[ m \lambda = 2d \]

where \( m \) is an integer.
Fabry Perot Interferometers

\[ \delta \lambda_{FSR} = \frac{\lambda^2}{2d} \]

\[ \Delta \lambda = \frac{\text{FSR}}{\text{Finesse}} \]

\[ \text{Finesse} = \frac{\pi \sqrt{R}}{1 - R} \]

FSR = Free Spectral Range = Separation in wavelength between adjacent peaks
Fabry Perot Interferometers

Free Spectral Range (FSR)

Transmission Through Fabry-Perot Resonator

Optical Frequency Normalized to Free Spectral Range

$F = \text{Finesse}$
- $F = 1$
- $F = 2$
- $F = 5$
- $F = 10$
- $F = 20$
- $F = 50$
- $F = 100$
- $F = 200$
- $F = 500$
- $F = 1000$
The Normal (Gaussian) Distribution

The “Central Limit Theorem” says that any series of measurements with finite variance will tend toward the Gaussian distribution given a large number of samples.

The distribution is characteristic of the experiment itself. The exact peak is “known to nature”.

\[
f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}
\]
Confidence Intervals

- Nature knows the location of the peak, but your measurement is drawn randomly from the Normal Distribution.
  - 1 in 300 times you will get a measurement that is more than three standard deviations from the actual value.
    - Do you want to bet your entire career on that?
    - $5\sigma$ is the rule...
  - A spectrum might consist of 1000 independent point. On average there will be three peaks.
CCD Architecture

Bucket Brigade CCD Analogy

Integration of Photon-Induced Charge

Parallel Bucket Array

Serial Bucket Array

Parallel Register Shift (1 Row)

Serial Register Shift to Output

Converyer Belt

Calibrated Measuring Container

Note that bad things can happen when buckets overflow (saturation).
One can simultaneously use silicon to build circuitry as well as perform the function of converting photons to electrons. Silicon, however, has a cutoff corresponding to a wavelength of ~ 1μm.

Infrared detectors must use other materials, but silicon-based electronics are still required for the readout. The solution is to “wire” infrared sensitive material to a silicon electronics base structure.
Infrared Arrays and Indium Bump Bonds

Charge no longer gets dragged around as it is on a silicon-based CCD. Instead, the electronics directly address the charge in place where the charge collects.

Importantly, the act of readout does not destroy the charge as it does on a CCD. It can be read multiple times (you can watch the image grow on the chip) without any noise penalty.
CCD Drift Scanning

- Since charge shifts systematically in one direction on a CCD as it reads out, an interesting trick involves shifting the charge at the sidereal rate.
  - The CCD reads out continuously without shuttering the light (as opposed to shuttering the light and then waiting minutes for a readout).
CCD Drift Scanning

- Since charge shifts systematically in one direction on a CCD array as it reads out, an interesting trick involves shifting the charge at the sidereal rate.
  - The integration time is limited to the time it takes a star to drift across the chip.
  - Large chips can also see distortion due to the circular path followed by the stars around the pole (especially at high declination).