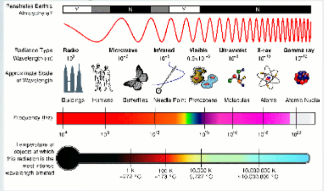
Introduction to Near Infrared Astronomy

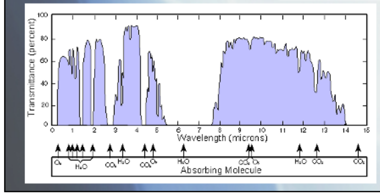
Observational Astronomy Workshop

Elinor Gates

Infrared Regime

Near: 0.7 - 5µm
Mid: 5 - 40µm
Long: 40 - 350µm





Major atmospheric absorption bands from O_2, H_2O, CO_2

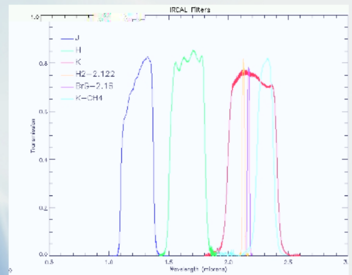
IR spans from about 700nm to 350um. Usually wavelengths to 900nm or 1000nm are considered optical as they are easily detected by visible sensitive CCD detectors.

NIR spans from roughly 900nm to 5um. Mid-IR 5um to 40um. Long 40um to 350um. Boundaries are not precise (e.g. mid/long break between 25 and 40um).

Broadband filters are designed to match the high NIR transparency regimes of the atmosphere.

Broad Band Filters

- J 1.11-1.42μm
- H 1.48-1.76μm
- K 2.02-2.41μm
- K′ 1.95-2.29μm
- K_s 1.99-2.31μm
- K_l 2.05-2.42μm
- L 3.20-3.81μm
- L′ 3.49-4.08μm
- M 4.54-5.16μm
- M′ 4.67-4.89μm

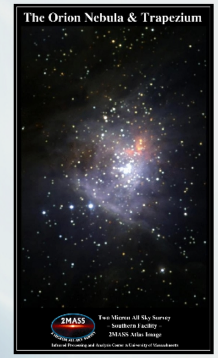


Bandpasses given for IRTF filter set (except K-long filter) - there is some variation, but IRTF' s are typical.

Nice summary of Mauna Kea filters and atmospheric bandpasses at http://irtfweb.ifa.hawaii.edu/IRrefdata/paper_I.pdf

Science Drivers

- Star Forming Regions
- High Redshift Objects (AGN, galaxies)
- Cool Objects (Brown Dwarfs, Planets)
- Dust Disks
- Dust Obscured Objects



Detectors

- Optical uses Silicon CCD devices
- NIR uses HgCdTe, InSb, or InGaAs CMOS detectors
- CMOS = Complementary Metal-Oxide-Semiconductor

- CMOS Advantages:
  - Fast readout
  - Less waste heat
  - Non-destructive reads - each pixel has its own charge-to-voltage conversion
  - Up to 100 times less power required than for CCDs
- CMOS Disadvantages:
  - On chip electronics limit area available for light capture
  - Less uniformity
  - More read noise
  - Less dynamic range

Other technologies for detecting photons in both optical and NIR are available, but CCDs and CMOS detectors are the most commonly used.

Nice comparison of CCD vs CMOS at http://www.teledynedalsa.com/en/learn/knowledge-center/ccd-vs-cmos/ and https://www.edmundoptics.com/knowledge-center/application-notes/imaging/understanding-camera-sensors-for-machine-vision-applications/

CMOS Read Modes

- Non-destructive reads allows flexibility in how to read the chip
- Single
- CDS - Correlated Double Sampling
- Multireads
  - Fowler Sampling
  - Up the Ramp Sampling

Fowler Sampling:

Read chip N times at beginning and N times at end of exposure

$$\sigma_r' = \sigma_r \sqrt{4/N}$$

Up the Ramp Sampling:

Read chip at N intervals during the exposure

$$\sigma_r' = \sigma_r \sqrt{12/N}$$

Fowler and Gatley (1990 ApJ 353:L33)

IR Systems often shutterless

Single read - Erase chip at beginning of exposure, read a single time when exposure complete.

CDS - read chip at beginning of exposure, read again at end of exposure. Subtract the two values.

CMOS Read Modes

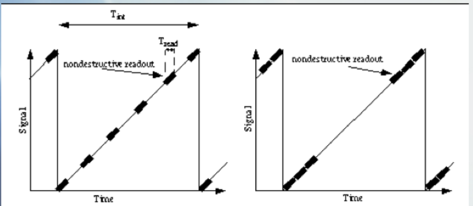


Figure 1 a: Follow up the ramp sampling. Nondestructive readouts are equidistantly distributed along the integration ramp. The slope of the integration ramp is calculated for each pixel by a least squares fit.

Figure 1 b: Fowler sampling. Nondestructive readouts are concentrated at the beginning and at the end of the integration ramp. The slope is calculated by averaging the slope of all Fowler pairs.

Nice on-line reference (and source of above graphic): http://www.eso.org/~gfinger/muc2000/muc2000.html

Note: All reads are included in the integration time.

With very short exposures, the effective dynamic range of the chip may be reduced.

Bias, Dark Current, Sky Background

- Significant Bias Structure
- Significant Dark Current
- Sky Backgrounds High and Variable on short time scales - Dominated by thermal emission and airglow
- Typical Sky Background Magnitudes/arcsec^2:
  - J ~ 15-16
  - H ~ 13-14
  - K ~ 12-13

Objects often fainter than sky background

Sky background levels can vary by up to 100% in a single night and on time scales as short as a minute.

NIR sky background is less at higher latitudes. Also less at higher elevations and lower zenith distances.

Airglow = combined effects of photoionization recombination of ions, chemiluminescence,

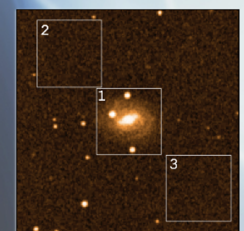
Exposure Time and Co-adds

- Sky background can be high and cause images to saturate long before the desired S/N for the science target has been achieved. This time can be as short as a few seconds depending on bandpass (e.g. K' sky will saturate in 8 seconds with the Shane Gemini Camera).
- Co-add identical short exposures and write to a single file.
- Co-adds usually have less overhead than writing separate files.
- Optimize so that dithers are frequent enough to track changes in sky background, but long enough to maximize S/N.
- This technique is also applicable when preventing bright objects from saturating the device.

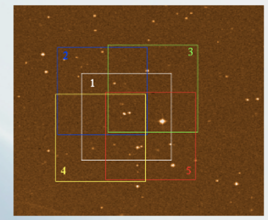
Need to balance exposure time per co-add, number of co-adds with sky background levels and variability, and readout noise for each co-add.

Nodding and Dithering

- Nodding:
  - Subtract Background



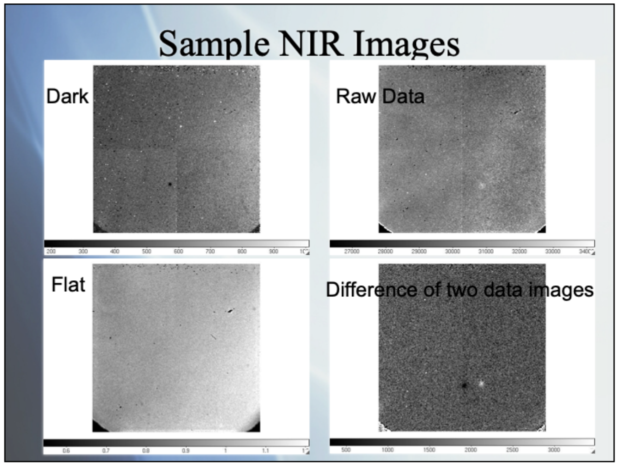
- Dithering
  - Subtract Background
  - Avoid Bad Pixels
  - Remove Cosmic Rays



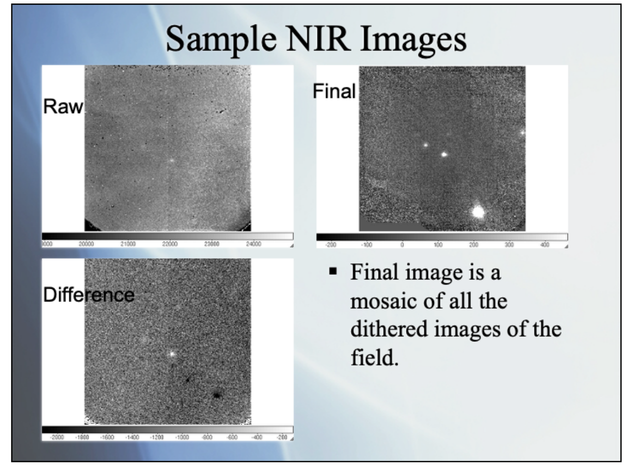
Sky background region should be featureless and near to target. Best to use multiple sky regions in case they are not featureless.

Optimal dithering pattern reference: Berstein, PASP 114:98-111, 2002

Also drizzle techniques: Fruchter & Hook, PASP 114:144-152, 2002

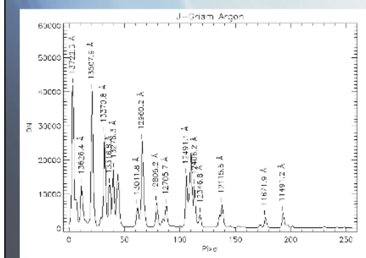


H-band images from Shane Telescope and IRCAL camera



H-band images from Shane Telescope and IRCAL camera

Spectroscopy



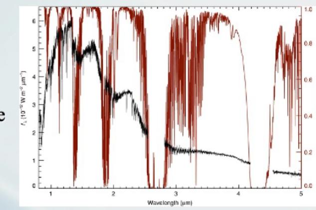
- Dither along slit or nod to sky for sky background subtraction
- Argon arc lamps (may need identical images with lamp off for some bandpasses to account for thermal emission of dome, optics, etc.)
- Telluric absorption lines

Good list of line plots and lists:
http://www.gemini.edu/sciops/instruments/nir/wavecal/index.html
Telluric standards:
http://www.gemini.edu/sciops/instruments/nir/specstandards/index.html

Spectroscopy

Telluric Absorption

Can change on order of minutes. Typically observe an A0 or G2 dwarf to remove telluric absorption features.

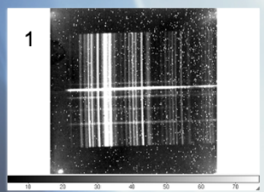


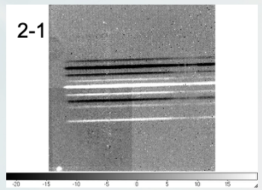
Gl 406 (M6V) with Telluric Absorption overlaid for Mauna Kea.

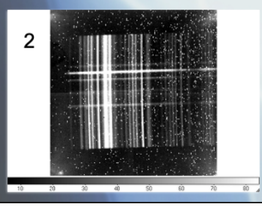
Rayner, J., et al., ApJS 189:289, 2009

AO and G2 stars have relatively few prominent features in the NIR bandpasses, making telluric features more discernable.

Spectral Data







- Dither along slit then difference images to remove sky background emission.

J-band grism images from the Shane Telescope and Gemini Camera

Calibrations/Reductions

- Darks (identify hot pixels) - bias/dark current usually subtracted with sky frames
- Flat Fields
- Flux Standards
- Spectroscopy:
  - Arc lamps
  - Telluric standards
  - Spectral standards

- Reduction Packages:
- IRAF - dimsum
- IDL
  - astro library
  - SIMPLE
- Starlink - GAIA, ORAC-DR
- Python

Spectral data reduction flats (figaro):
http://starlink.eao.hawaii.edu/docs/sun86.htx/sun86.html

IRAF tutorial: http://iraf.noao.edu/tutorials/doslit/doslit.html

Flat Fields

- Twilight flats similar to optical direct imaging - best flats somewhere between 35 and 50% of full well depth.
- Dome flats similar except for some bandpasses (longer than 2 microns) you may need to take additional exposures with the flat field lamp turned off to account for thermal emission of the dome, optics, etc. In data reduction you subtract the 'lamp off' data from the 'lamp on' data as you would subtract a sky frame from a data frame.