Limiting Magnitudes and Exposure Time Estimation

Lick Observatory rules of thumb for limiting magnitudes of the various telescopes and instruments are given below. NB: Depending on the program targets and seeing, limits may be more or less restrictive.

Nickel Direct Imaging	V ~ 21
Nickel Spectrograph	V ~ 16
Shane PFCam Direct Imaging	V ~ 24
Shane Kast Spectrograph	V ~ 20
Shane Hamilton	V ~ 14
Shane Gemini Direct	K ~ 20
Shane Gemini Spectrograph	K ~ 16
Shane AO Natural Guide Star	R ~ 13
Shane AO Laser Guide Start	R ~ 16
Shane AO ShARCS	K ~ 18
CAT Hamilton	V ~ 10

Estimating exposure times can be difficult, as it depends on the telescope, instrument configuration, seeing, and sky background (including moon phase). Many observatories have exposure time estimators for their instruments, however, Lick has not yet implemented any. Some of our instruments do have calculated zeropoint magnitudes, m_{zp}, which tell you at what magnitude you detect 1 e-/sec at the detector and sky magnitudes (mag/arcsec^2). For the direct images you can combine this with plate scale, sky background magnitude, seeing to calculate and exposure time.

$$\frac{S}{N} = \frac{Nt}{\sqrt{Nt + n_{pix}(N_S t + N_R^2)}},$$

where N is the e-/sec from the source, t is the exposure time in seconds, N_S is the e-/sec/pix from the sky and N_R is the RMS readout noise per pixel.

N can be calculated from the zeropoint magnitude:

$$N = 10^{-0.4(m_{obj} - m_{zp})},$$

where m_{obj} is the magnitude of the object and m_{zp} is the zeropoint magnitude. Sky background, m_{sky}, is generally given in units of mag/arcsec^2, so one needs to convert that into e-/sec/pix at the detector:

$$N_S = 10^{-0.4(m_{sky} - m_{zp})} p^2,$$

where p is the plate scale in arcsec/pixel. npix depends on the seeing or desired aperture for photometry, according to one's science program.

Using the above, one can solve for the exposure time for a given S/N ratio:

$$t = \frac{n_{pix}N_S + N + \sqrt{(n_{pix}N_S + N)^2 + 4N^2N_R^2n_{pix}/sn^2}}{2(N^2/sn^2)},$$

where sn is the desired signal to noise ratio.

For example, let's look at PFCam V-band imaging: $V_{zp} = 25.03$,
V_{sky}=20.88mag/arcsec2, N_R=4.1 e-/pix, and plate scale p=0.37 arcsec/pixel.
If the target is V=15 and you want a S/N=100 for your data calculate the exposure time.
Let's assume that the seeing is 1.5 arcsec FWHM.

$n_{pix} = \pi\,(1.5/p)^2 = 51.6$ pix
$N = 10^{-0.4(15-25.03)} = 10280.2$ e-/sec
$N_S=10^{-0.4(20.88-25.03)}\,p^2 = 6.26$ e-/sec/pix

Plugging in these values yields t=1.1 sec.

Exposure time rules of thumb for various Lick instruments to get reasonable signal-to-noise (e.g. S/N ~ 100):

Instrument	**V**	**Approx. Exposure Time**
Shane Kast Spectrograph	16	20 minutes
CAT Hamilton	7	30 minutes
Nickel Direct	12	40 seconds

A technique for estimating exposure times on the fly for a given night is to measure the signal-to-noise of a short exposure of a bright target and then scale appropriately for fainter targets.

There is an exposure time estimator now available for the Kast Spectrograph at
http://etc.ucolick.org/web_s2n/kast