Signal-to-noise calculations including sky, readnoise and dark current

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I have added some new capabilities to my simulator:

- define a circular aperture for photometry
- calculate the number of sky photons falling within the aperture
- calculate the readnoise and dark current contributions within the aperture
- calculate the signal-to-noise ratio for a star

This is still a primitive tool: it assumes that all the star's light falls within the aperture. I also use a single aperture size for light of all wavelengths; in real life, since the PSF would increase at longer wavelengths, one would choose a different aperture size for each passband. Nonetheless, its results may be useful for some planning purposes.

The values below assume:

- pixel size 10.5 microns in visible, 18.0 microns in IR
- aperture radius of 0.40 arcseconds
- readnoise 4 electrons per pixel in visible, 20 electrons in IR
- dark current 0.0005 electrons per pixel per second in visible, 0.04 electrons per pixel per second in IR
- star falls near middle of annulus in focal plane

I follow Howell's article on "Two-Dimensional Aperture Photometry" in the calculation of signal, noise, and signal-to-noise ratio within the aperture.

For each exposure time, the table contains three columns -- one each for a star of spectral class A0V, G0V and M0V -- and rows showing the signal-to-noise ratio for stars of magnitude V=15, V=20, V=25 through each of the passbands. The uncertainty in a magnitude measurement can be estimated from the signal-to-noise ratio like so:

```
                          1.0
     mag_uncertainty  =  ---------------
                         signal_to_noise
```

So, for example, a star with signal-to-noise of 50 would have an uncertainty of about 0.02 magnitudes.

Tables with signal-to-noise ratios

Here is the output in tabular form; I'll present graphs later in this document.

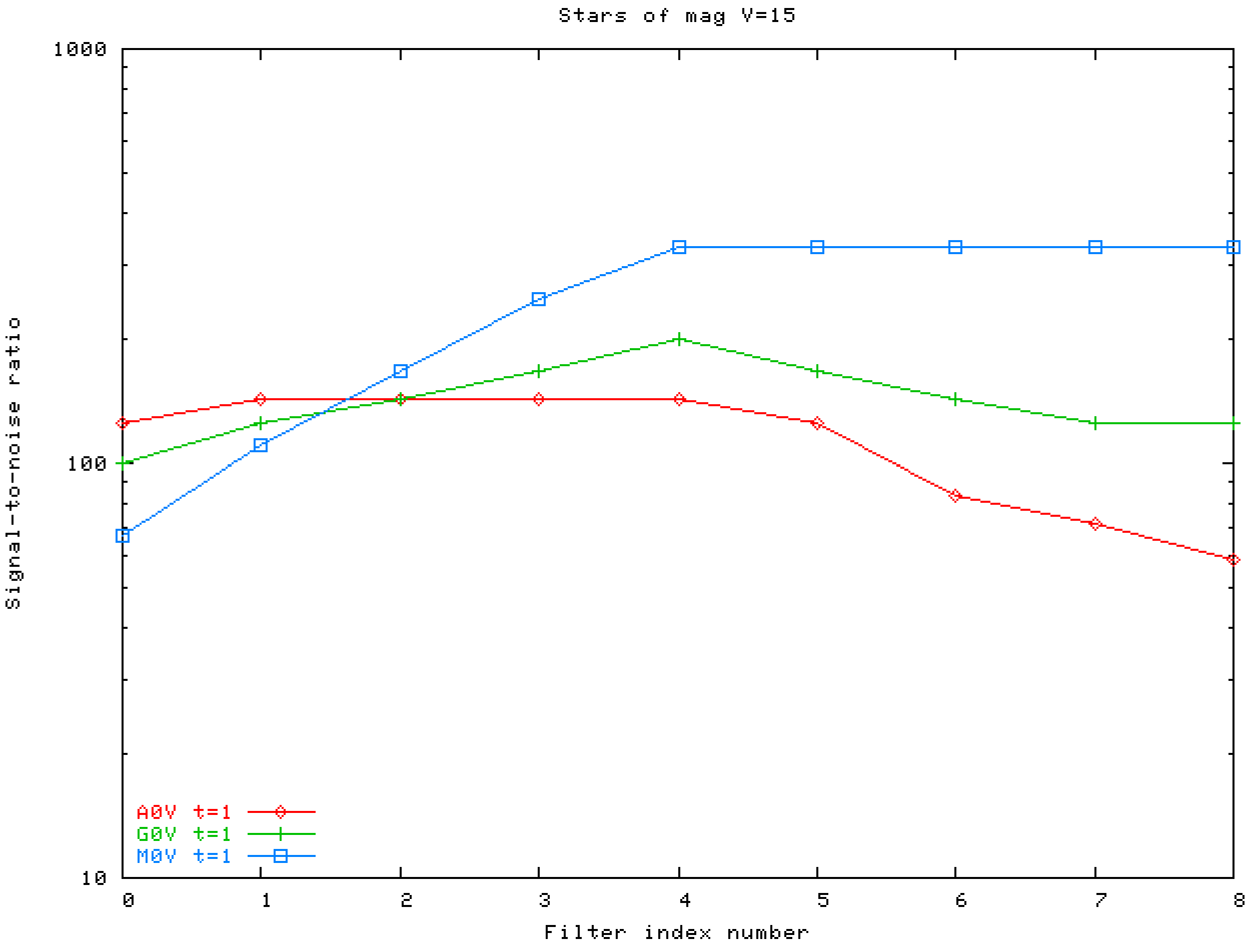
- stars with V=15, exposure = 1 second
- stars with V=15, exposure = 10 seconds
- stars with V=20, exposure = 1 second
- stars with V=20, exposure = 10 seconds
- stars with V=20, exposure = 100 seconds
- stars with V=25, exposure = 10 second
- stars with V=25, exposure = 100 seconds

- stars with V=25, exposure = 1000 seconds

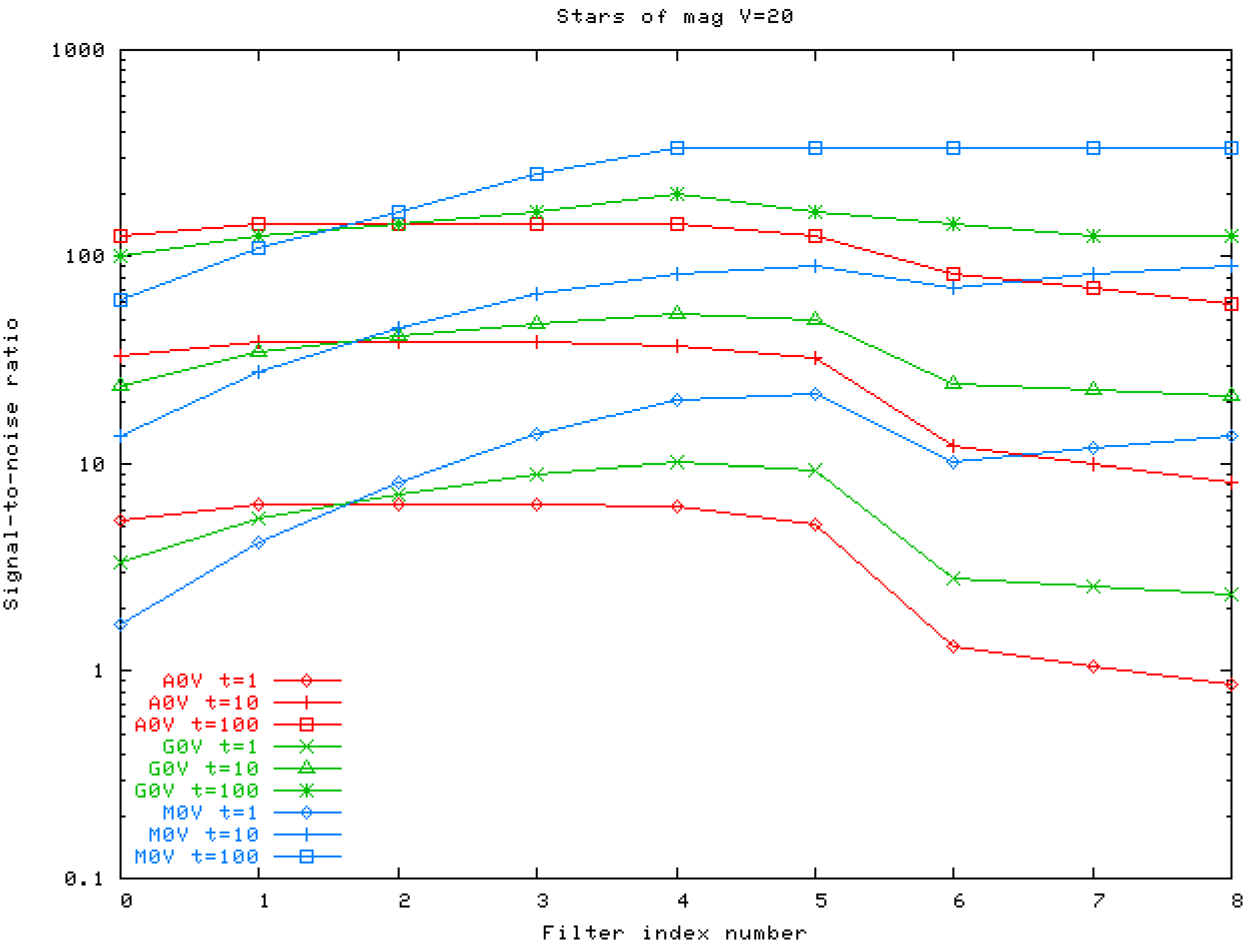
Signal-to-noise as a function of filter index

The graphs below show the signal-to-noise ratio (logarithmic) for each of the 9 SNAP filters. My numerical output doesn't provide meaningful numbers for S/N greater than 1000 (uncertainties less than 0.001 mag), and I've included only data which falls in an interesting portion of parameter space.

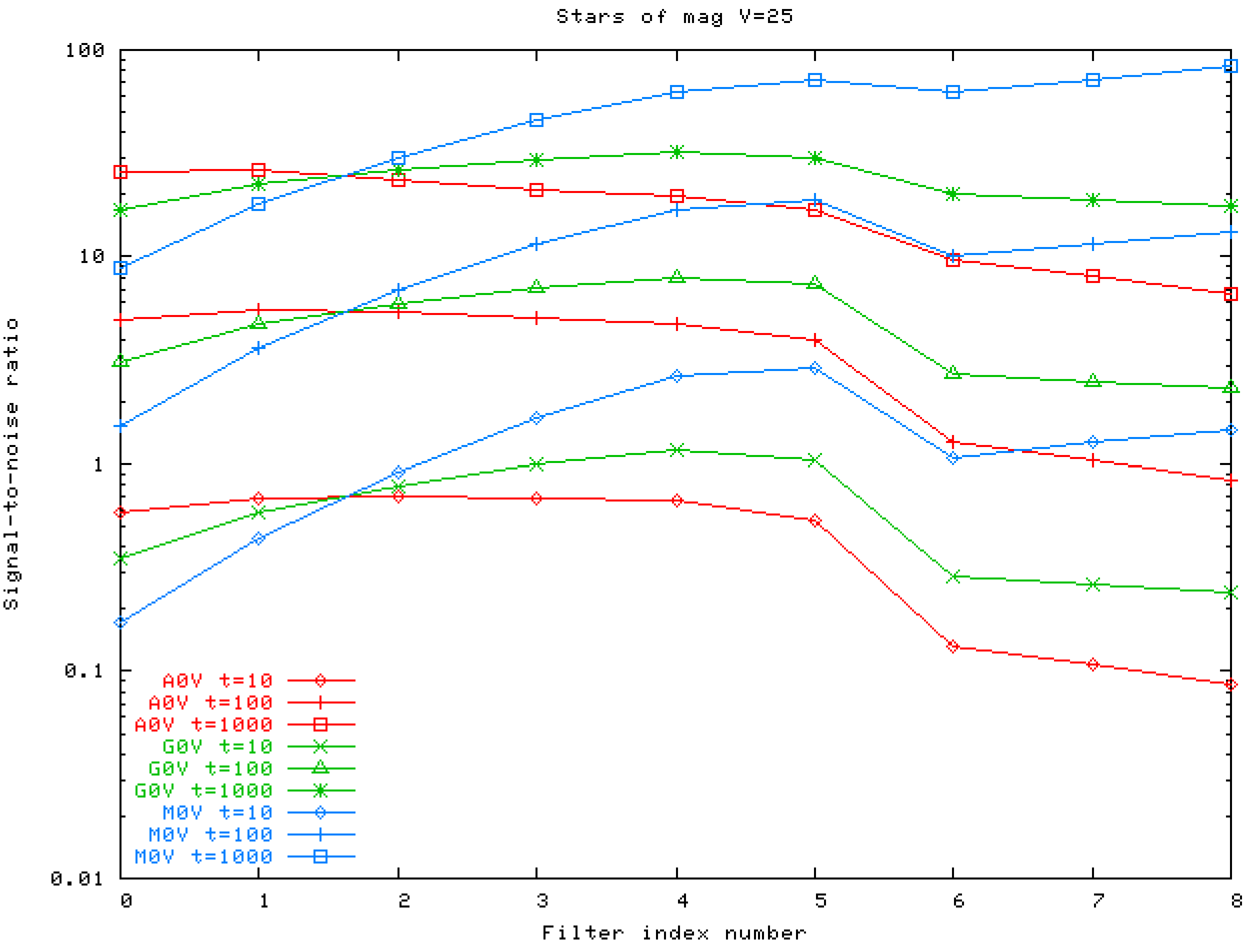
Stars with magnitudes V=15:



Stars with magnitudes V=20:



Stars with magnitudes V=25:



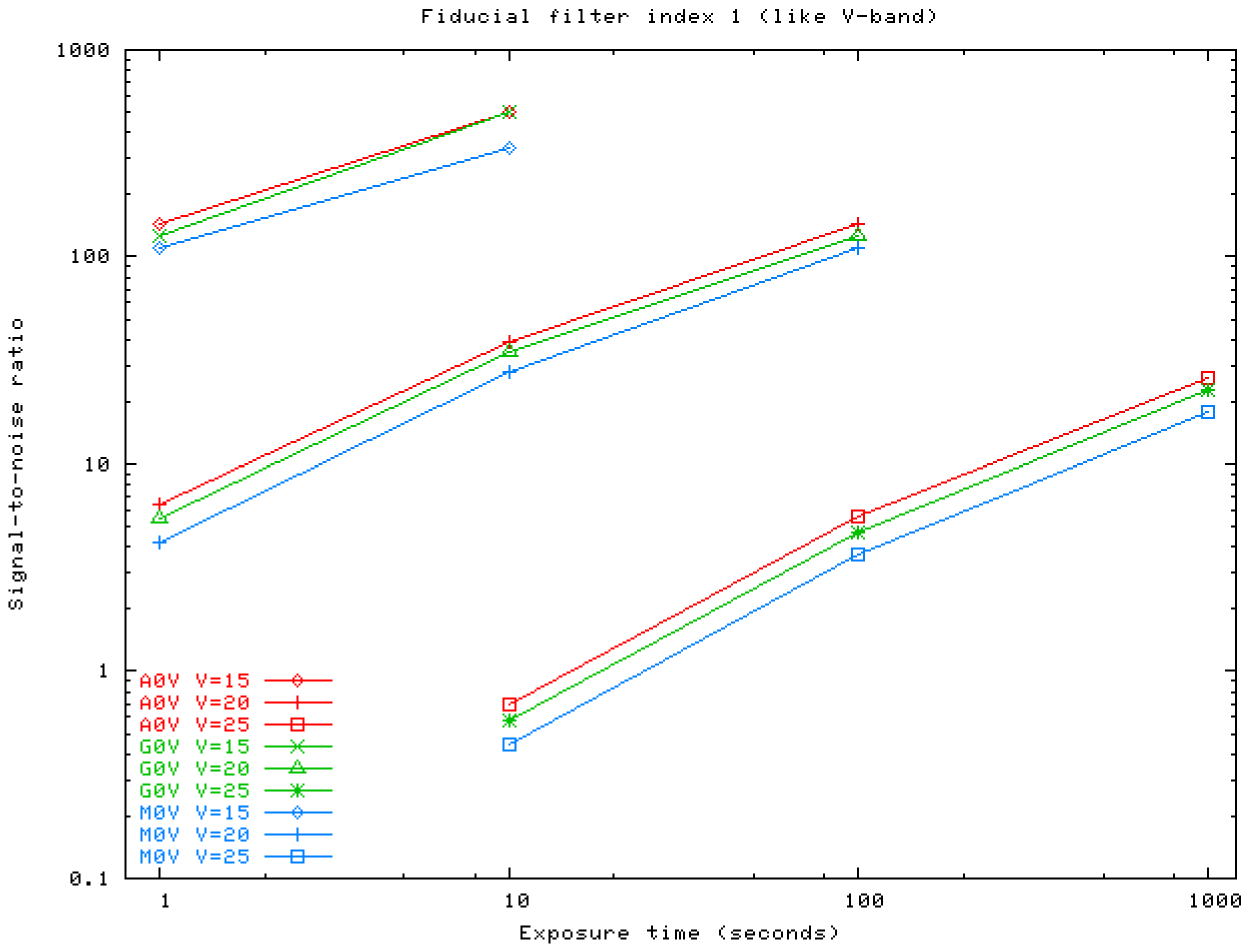
Signal-to-noise as a function of exposure time

We can also plot the signal-to-noise ratio as a function of exposure time. In the graphs below, I choose only three filters from the entire set; in my notation, the indices run from 0 to 8.

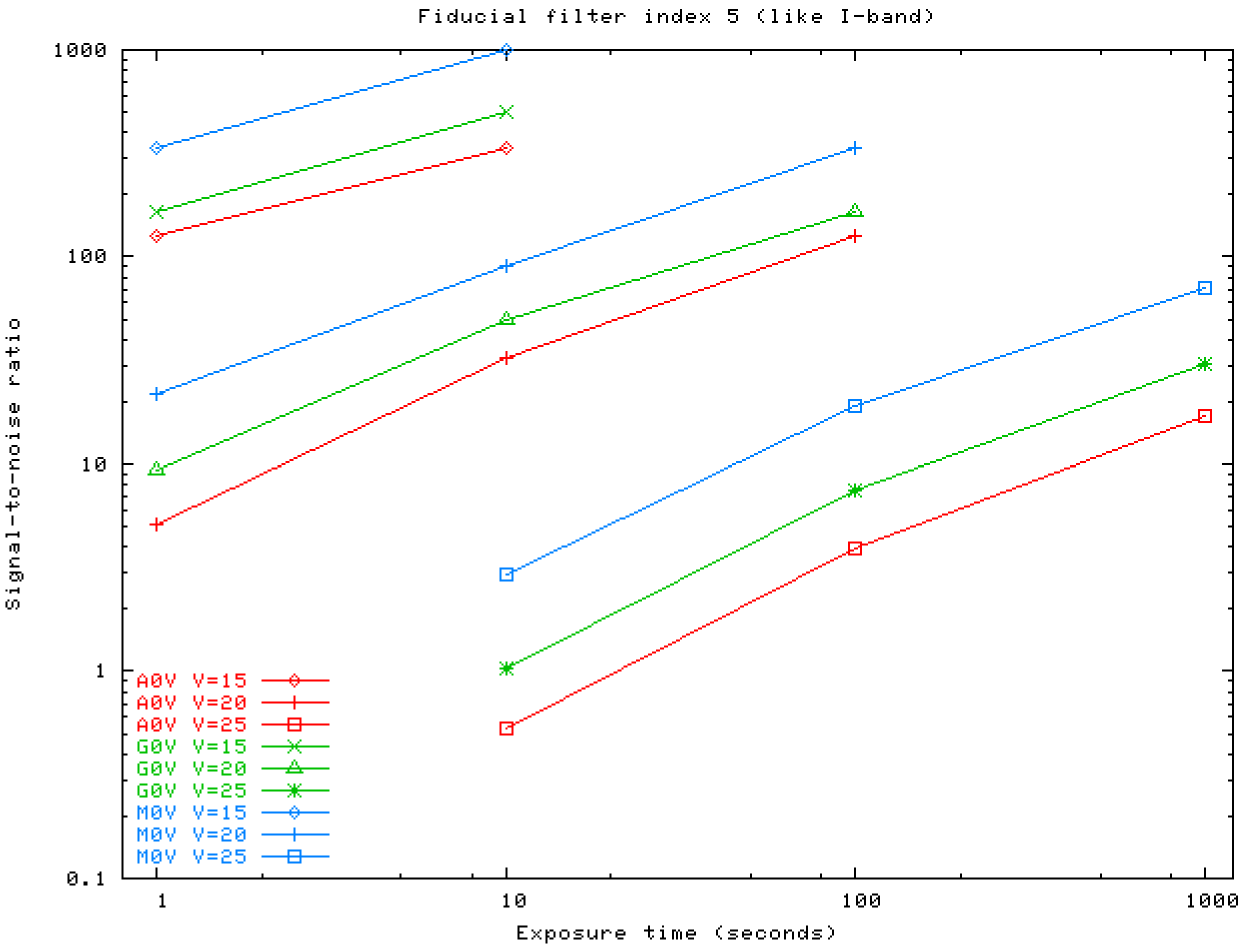
- filter index 1 (similar to V-band), visible CCDs
- filter index 5 (similar to I-band), visible CCDs
- filter index 7 (similar to J-band), IR detectors

Note that the difference in signal-to-noise between stars of the same V-band magnitude, but different spectral types, is small in the blue portion of the visible, rises towards the red, and becomes very large in the near-IR. This occurs simply because I chose to compare stars with the same V-band magnitude; had I chosen stars with the same J-band magnitude, the trends would be reversed.

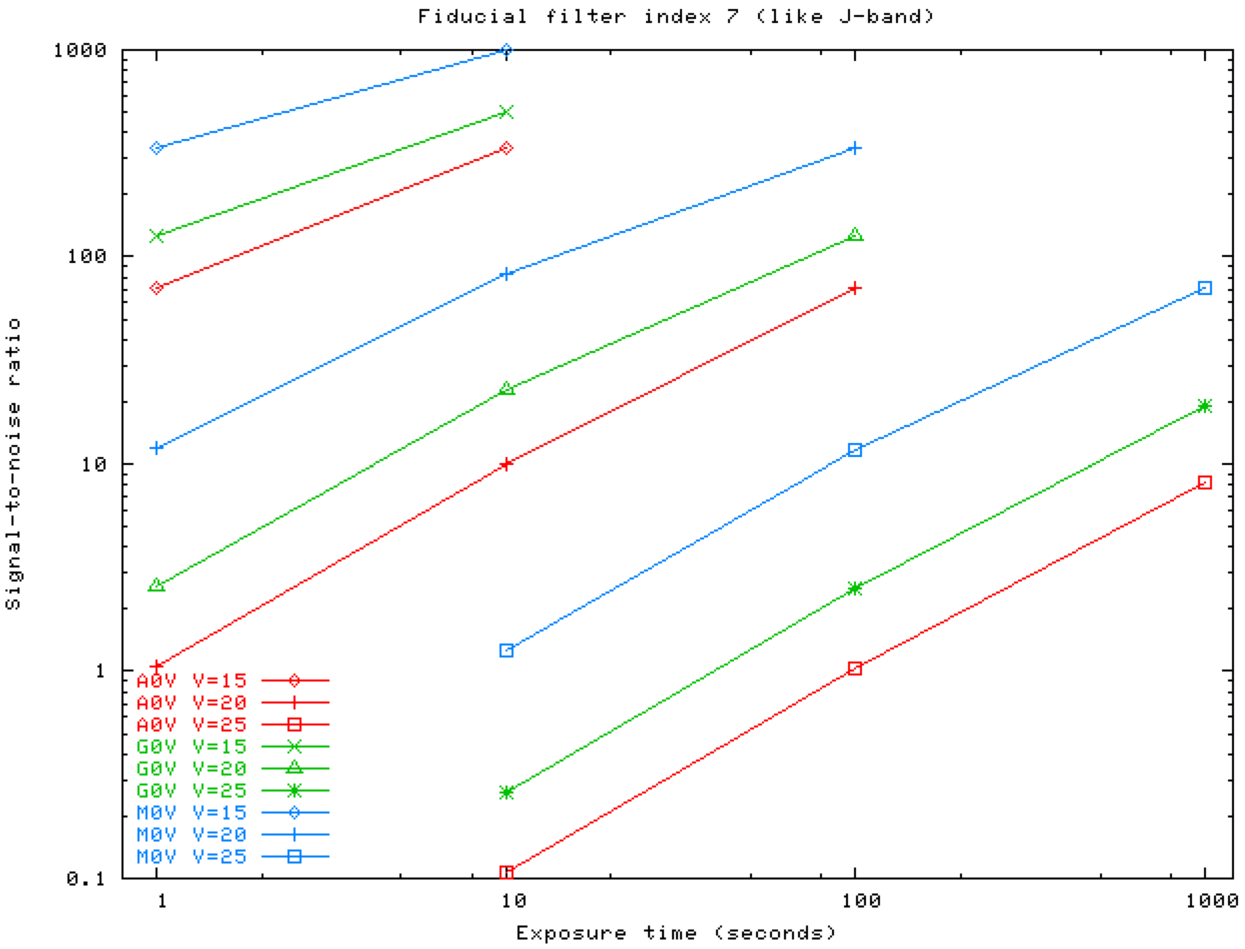
Filter index 1 (similar to V-band):



Filter index 5 (similar to I-band):



Filter index 7 (similar to J-band):



Exposure time at which sky noise equals readout noise

At which exposure time in each filter does the noise from background sky equal the readout noise? Assuming readout noise of 4 electrons per pixel in the visible, and 20 electrons per pixel in the infrared (which is somewhat lower than the IR devices tested so far can provide -- see Tarle's plenary talk from the 2004 Collaboration Meeting -- but somewhat higher than the desired value), I find the following.

Filter	exposure (seconds)
0	443
1	254
2	175
3	127
4	104
5	125
6	1735
7	1977
8	2148

One might conclude that if the actual readout noise is similar to the values I've assumed, and if the exposure times are a few hundreds of seconds,

- our visible images will contain very roughly equal components from sky background and readout
- the readout noise in our IR images will be more important than the sky background