CANADA-FRANCE-HAWAII TELESCOPE

WIRCAM
Science Requirements

Doc. No. WIRCAM-3-CFHT

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Change Record

Issue/Rev.	Date	Section/Parag. affected	Reason/Initiation/Documents/Remarks
0.1	21 July 2001	All	TOC (JLB)
0.2	7 August 2001	All	All sections (JLB & TF)
0.3	17 August 2001	All	Added section on sensitivity (JLB)
0.4	30 August 2001	All	Improved sensitivity section Added sky coverage section (JLB)

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Contents

Part I

Introduction

1 Scope

The scope of this document is to present the high level scientific requirements for the CFHT wide-field infrared camera, WIRCAM.
These requirements are driven by the scientific cases for the camera, which have been prepared with contributions from the following people: J.-F. Le Borgne, J. Bouvier, D. Crampton, T. Davidge, R. Doyon, K. Hodapp, A. Lançon, A. Omont, R. Pelló, J.-P. Picat, A. Robin, G. Soucail.

2 Applicable Documents

[1]

[2]

[3]

3 Abbreviations and Acronyms

DEC	Declination
FWHM	Full Width at Half Maximum
IR	Infrared
PSF	Point Spread Function
RA	Right Ascension
TBC	To be confirmed
TBD	To be defined

4 Glossary

Part II

WIRCAM General Characteristics

The scientific cases that were examined lead to a pure imaging instrument, optimised for the J, H and K photometric bands (1 to 2.5 microns), and with best-effort performance over the I and/or z photometric band (0.8 to 1 1 micron).

An extension to the thermal infrared, while interesting for some programs (such as star formation studies), was eliminated early on, as leading to a significantly more complex instrument on a number of issues (operating temperature, thermal baffling, IR light leaks, etc...). Similarly, a multi-object spectroscopic mode could in principle be usefully added to the camera, but this was considered incompatible with a fast-track instrument development.

5 Telescope Interface

To be added, discussion about Cassegrain versus Prime.

6 Detector Choice

The analysis of the scientific cases indicate that, for an assumed 60% quantum efficiency, a 4kx4k pixel format is a strict minimum. They would greatly benefit from a 6kx4k format or/and a better quantum efficiency (which are largely interchangeable). Such formats can be obtained with 4 or 6 2kx2k chips,

7 Readout overheads

Scaling from the measured CFHT-IR background shows that the time to fill the larger WIRCAM pixels to half of their linear range is 40 s for the J band, and only 15 s for the K' band, for winter conditions. Deep K band exposures will necessarily be built up by coadding individual short exposures of at most 15 s. A very strong requirement is thus that WIRCAM be efficient for such short exposures. We consider that the maximum acceptable overhead is 10%, and therefore set a goal of less than 1.5 s for the total overhead for one image. Some degradation of the readout noise characteristics is acceptable, within reason, to achieve this goal.

8 Image Scale and Field of View

The pixel scale has to be a compromise between the conflicting requirements of maximizing the instantaneous field of view without unduly degrading the image quality CFHT is known for. The optimum

Seeing	0.25"pix	0.30"pix
0.35"	0.39"	0.41"
0.40"	0.44"	0.45"
0.45"	0.48"	0.50"
0.50"	0.53"	0.54"
0.55"	0.57"	0.59"
0.60"	0.62"	0.64"
0.65"	0.67"	0.68"
0.70"	0.72"	0.72"

Table 1: Full width to half maximum for a seeing disk broadened by 0.25" and 0.3" pixels.

compromise is in the 0.25 to $0.30''$/pixel interval. Pixel scales smaller than $0.25''$would oversample the images under most atmospheric conditions and would exagerately restrict the field of view for the scientific cases that WIRCAM wants to address. A pixel scale of $0.30''$/pixel would cover the total unvignetted field of view of the F/8 focus, The lenses for the $0.30''$/pixel scale are more difficult to manufacture and the instrument bigger, but still within reason (TBC). Significantly larger pixels do not appear optically feasible.

Even the smaller of the two pixel scales will undersample the K-band images on the best nights ($0.4''$images have been obtained on several occasions with CFHT-IR). The instrument and its analysis software must therefore be prepared to perform sub-pixel dithering. This is most easily implemented on an instrument that has a tip-tilt correction and can thus very accurately generate a regular grid. It is also feasible, with more complex software, for quasi-random offsets. Once the infrastructure for sub-pixel dithering is in place, sampling considerations no longer drive the pixel size choice. Instead, it is purely determined by how much broadening of the PSF by the detector pixels is deemed acceptable. Table 1 demonstrates that the additional broadening caused by the larger 0.3" pixels is fairly small, even for exceptionally good seeings. The balance between the 45% larger field of view and the modest broadening of the PSF makes the 0.30" pixel scale our preferred choice.

9 Fast guiding

A fast tip-tilt compensation system is required to compensate for the telescope errors (tracking, vibrations and windshaking) and, partially, for atmospheric tilt fluctuations. This compensation can be achieved by adding to the field corrector a plane-parallel plate, controlled on two axes with a typical bandwidth of 5 Hz, in a design similar to the MegaPrime one. Using one of the corrector lenses as the correcting element is not desirable as this would introduce displacement and distortion of the pupil. The error signal for the correction can be provided either by CCD sensors located at the periphery of the field lenses, or by fast readout of a small sub-raster of the science detector.

10 Wavelength Range

11 Filters selection

12 Image Quality

13 Astrometric Accuracy

14 Photometric Accuracy

Part III

WIRCAM Performances

15 Sensivity

The following section gives a preliminary estimation of the WIRCAM performances at the Cassegrain F/8 focus in term of sensitivity for the following filters:

- broad-band J, H, K, Kp filters
- narrow-band HeI, FeII, Brα filters

15.1 Assumptions

15.1.1 Atmosphere

Table 2 gives the assumed atmospheric transmission and sky emission for the different IR bands. The sky emission includes both the OH airglow and the thermal emission for all bands. The thermal emission is however negligible below 2 μm. We do not give here a detailed analysis of the relative influence of the single OH lines on the sky emission for the 1–2.5 μm narrow-band filters. Table 2 also gives the flux from a magnitude zero star above the atmosphere for the different IR bands (from McLean, 1997).

Band	Sky transmission	Sky emission (mag./"^{2})	Flux (Wcm$^{-2}\mu$m^{-1})
J	0.90	16.0	2.90 10^{-13}
H	0.90	13.9	1.08 10^{-13}
K	0.90	13.5	3.80 10^{-14}
Kp	0.90	13.5	4.32 10^{-14}

Table 2: Atmospheric parameters in the infrared for Mauna Kea

15.1.2 Telescope

We have assumed the following characteristics for the CFHT mirrors (Table 3). An operating temperature of 275 K (12 C) has been considered.

Element	Transmission	Emissivity
M1	0.87	0.10
M2	0.94	0.05

Table 3: Optical characteristics of the CFHT mirrors

15.1.3 Camera

Table 4 summarizes the WIRCAM foreseen characteristics based on the current conceptual design. The overall transmission has been computed as the transmission of the filters multiplied by the transmission of the optics.

Filter	λ_0 (μm)	$\Delta\lambda$ (μm)	T	Pixel scale (")
J	1.25	0.16	0.65	0.25
H	1.65	0.29	0.65	0.25
K	2.20	0.34	0.65	0.25
Kp	2.12	0.34	0.65	0.25
HeI	1.083	0.010	0.48	0.25
FeII	1.644	0.016	0.48	0.25
Br γ	2.166	0.022	0.48	0.25

Table 4: WIRCAM optical characteristics

15.1.4 Detector characteristics

The current assumptions regarding the characteristics of the detector are summarized in Table 5. Please note that these characteristics are still preliminary and will therefore need to be confirmed.

Parameter	Value	Comment
Readout noise	50 e-	fast read-out mode
Dark current	1 e-/s	goal is 0.1 e-/s
Full well capacity	70000 e-	1% linearity range
Mean quantum efficiency	75%	
Operating temperature	35 K	

Table 5: Characteristics of the Rockwell HAWAII-2 detector

15.2 Simulation

The basic equations used for the simulation are given hereafter

$$SN = \frac{\frac{S_{obj}}{N_{pix}} \; N_{im} \; t_{el}}{\sqrt{2\;((\frac{S_{obj}}{N_{pix}} + (S_{bck}\; pix\_sc^2) + DC)\; t_{el} + RN^2)\; N_{im}}}$$

and

$$mag = -2.5\; \log \frac{S}{\frac{1}{h\;c}\; F_{\lambda 0}\; \tau\; \eta\; A\; \lambda 0\; \Delta\lambda}$$

where

- SN is the signal to noise ratio
- S_{obj} is the signal from the object in electrons/s
- S_{bck} is the signal due to the background in electrons/arcsec^2/s
- N_{pix} is the number of pixels collecting the flux from the object
- N_{im} is the number of images
- t_{el} is the elementary integration time in s
- pix_sc is the pixel scale in arcsec/pixel
- DC is the detector dark current in electron/s
- RN is the detector readout noise in electron
- $F_{\lambda 0}$ is the flux from a zero magnitude star above the atmosphere in J/s/m^2/μm
- τ is the integrated transmission of the system
- η is the detector quantum efficiency
- A is the collecting area in m^2
- $\lambda 0$ is the filter central wavelength in μm
- $\Delta\lambda$ is the filter spectral bandwidth in μm

The consecutive steps of the simulation are summarized hereafter.

- The instrumental thermal background is calculated by adding the contributions of the telescope mirrors and other optical components. Each element is considered as a blackbody and its radiance is computed for the operating temperature of 275 K and the wavelength of observation. The actual contribution of each element is function of its emissivity, its location on the optical beam, its projected area and the integrated transmission of all following elements.
- The integrated background is determined by adding the instrumental background and the sky emission. It is expressed in terms of equivalent magnitude/"^{2} for each band.
- The integration times needed to reach the BLIP (Background Limited Imaging Performance) mode and to saturate the detector are computed for each band.
- The magnitude per square arcsecond reached as a function of the total integration time and the desired S/N ratio is then computed for each band. The elementary integration time is set to fill about half of the detector full well capacity for each band.
- The magnitude reached for a point-like seeing-limited source (flux concentrated in the seeing disk and measured in an aperture of 1.2 $\times$ seeing) is finally determined.

Filter	Mag./$''^2$
J	16.0
H	13.9
K	12.7
Kp	13.1
HeI	15.2
FeII	13.9
Br γ	12.9

Table 6: Equivalent background magnitudes

15.3 Integrated background

Table 6 gives the equivalent background magnitude (sky and instrument) for each filter.

15.4 BLIP and saturation times

Table 7 gives the integration times per frame needed to reach the BLIP mode for each filter. Saturation times are also given for the different filters.

Filter	BLIP time (s)	Saturation time (s)
J	12.0	333.0
H	2.0	55.0
K	1.2	34.0
Kp	1.5	43.0
HeI	140.0	3730.0
FeII	47.0	1290.0
Br γ	28.0	782.0

Table 7: Integration times per frame to reach BLIP mode

15.5 Sensitivities

15.5.1 Extended objects

Figure 1 gives the WIRCAM limiting magnitudes per square arcsecond (S/N = 5) as the function of the total integration time for an extended source. The limiting magnitudes are determined in the cases of broad-band and narrow-band imaging.

15.5.2 Point-like objects

Figure 2 gives the WIRCAM limiting magnitudes (S/N = 5 in 1 hour) as a function of the wavelength for a seeing-limited source. The limiting magnitudes are determined in the cases of broad-band and

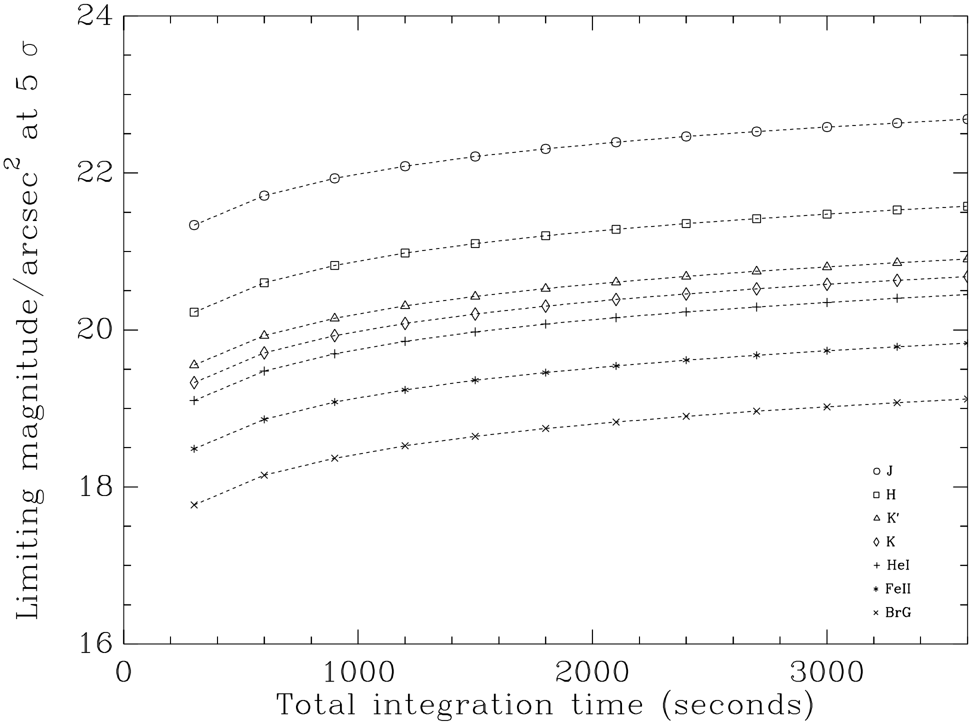


Figure 1: WIRCAM limiting magnitudes per square arcsecond for extended sources.

narrow-band imaging. A median seeing of $0.65''$ at $0.5\ \mu$m (typical value for Mauna Kea) has been considered. Photometry is obtained on an aperture corresponding to $1.2 \times$ FWHM of the seeing at the considered wavelength.

16 Observing efficiency

16.1 Saturation

Figure 3 and 4 give the saturation times per individual images for WIRCAM as a function of the star magnitude respectively for the cases of broad-band and narrow-band imaging. The value of the brightest pixel is calculated assuming a Gaussian distribution for the seeing-limited images at the considered wavelengths. The background is also taken into account.

16.2 Efficiency versus integration time

Figure 5 gives the observing efficiency as a function of the integration time per individual image, taking into account a 2 seconds total read-out time for the whole array in double correlated sampling mode.

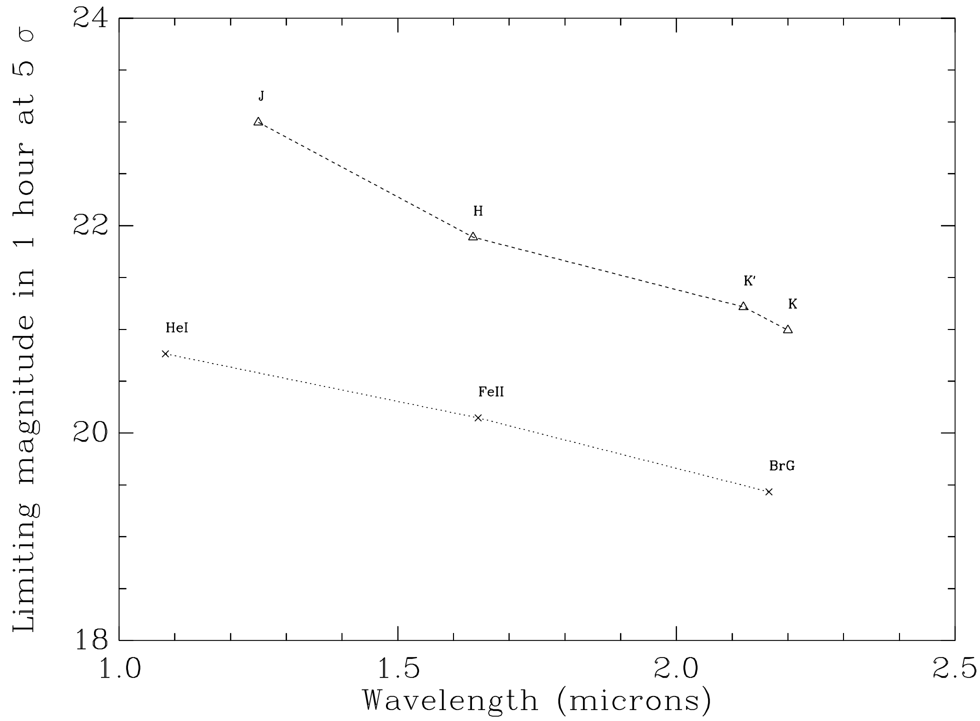


Figure 2: WIRCAM limiting magnitudes for a seeing limited source in 1 hour.

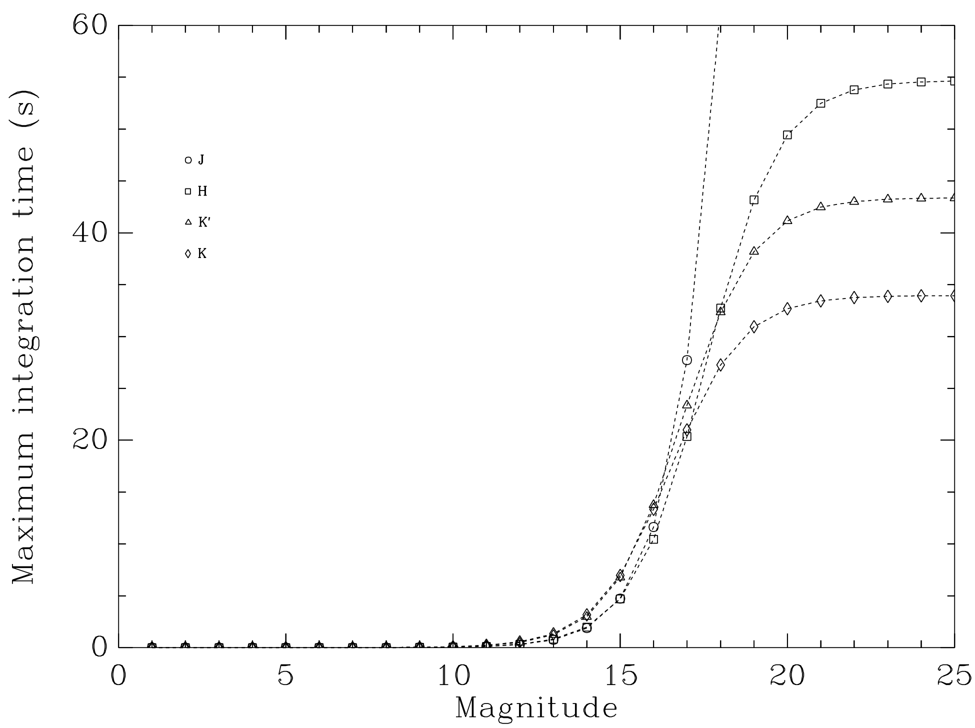


Figure 3: WIRCAM saturation times for broad-band imaging.

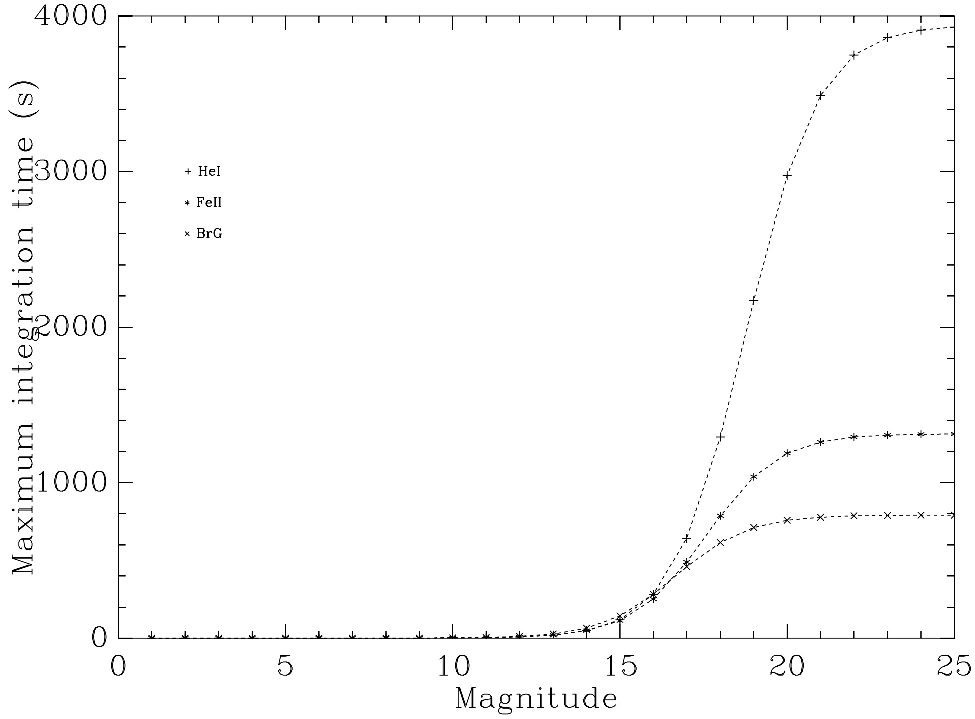


Figure 4: WIRCAM saturation times for narrow-band imaging.

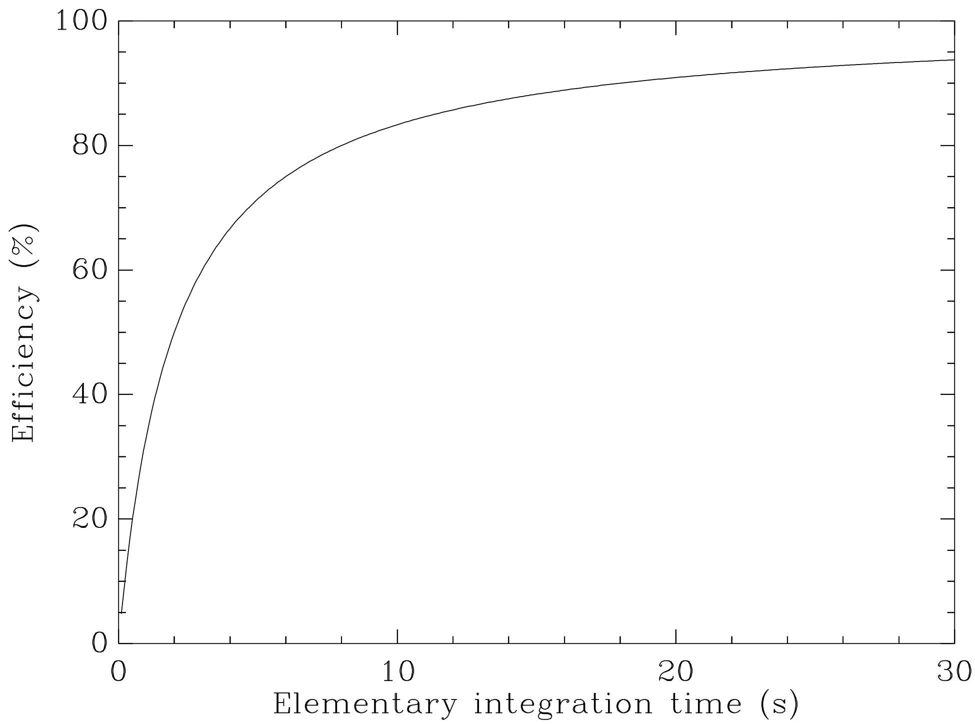


Figure 5: WIRCAM observing efficiency versus integration times.

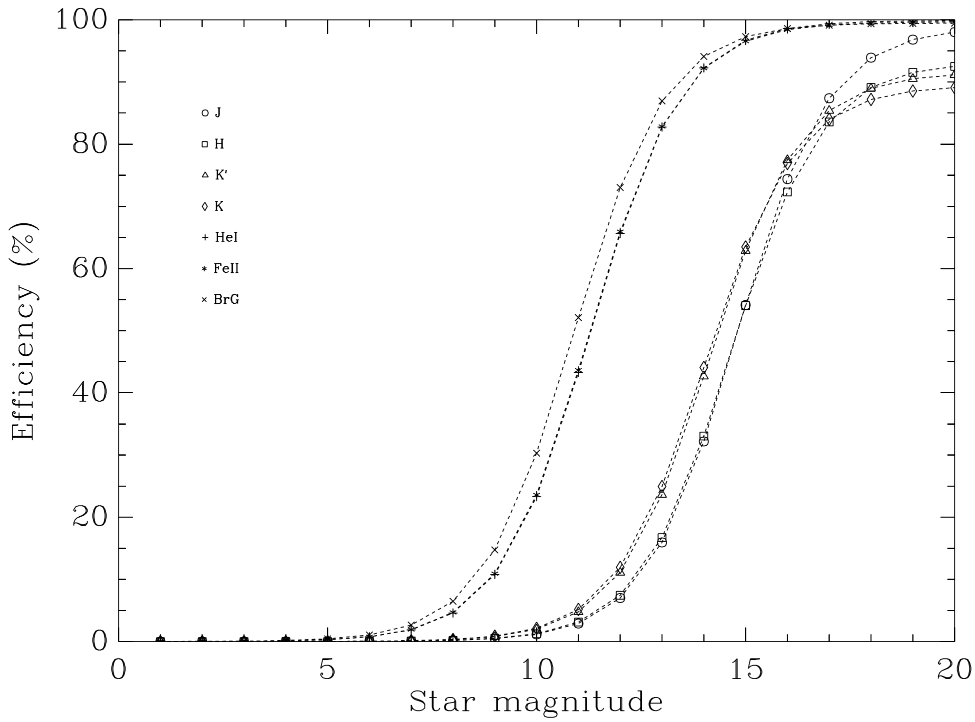


Figure 6: WIRCAM observing efficiency versus star magnitude.

16.3 Efficiency versus magnitude

Figure 6 gives the observing efficiency as a function of the object magnitude taking into account a 2 seconds total read-out time for the whole array in double correlated sampling mode and using half of the linearity range of the detector for the combined object and background signal. The calculated efficiency is per individual frame, no dithering has been considered yet.

17 Speed for Wide-Field Surveys

Part IV

Operation Considerations

Part V

Data Reduction Considerations

A Sky coverage

A.1 Statistical approach

The following figures give the expected sky coverage for on-chip guiding with WIRCAM in the I, J and K bands, as well as derived sky coverage for two narrow-band filters. The values for the narrow-band filters were obtained by rescaling the star counts in J and K by the respective integrated transmission of the filters (HeI with respect to J and H2 with respect to K). The sky coverage has been computed from 36 different regions of the Galaxy.

The star counts have been computed from the so-called "Besançon galactic model" (Robin & Crezé, 1986; see also http://www.obs-besancon.fr/www/modele/descrip_ang.html), which is a synthetic model of the Galaxy. At a given galactic longitude and latitude, the model provides the density of stars that can be observed in a wavelength band as a function of magnitude. If we assume that the position of the stars follow Poisson statistics, we can then compute the probability to find at least one star within the field of view of the camera, a ($a = 17.07'$ for the $0.25''$/pixel scale). The probability is given by

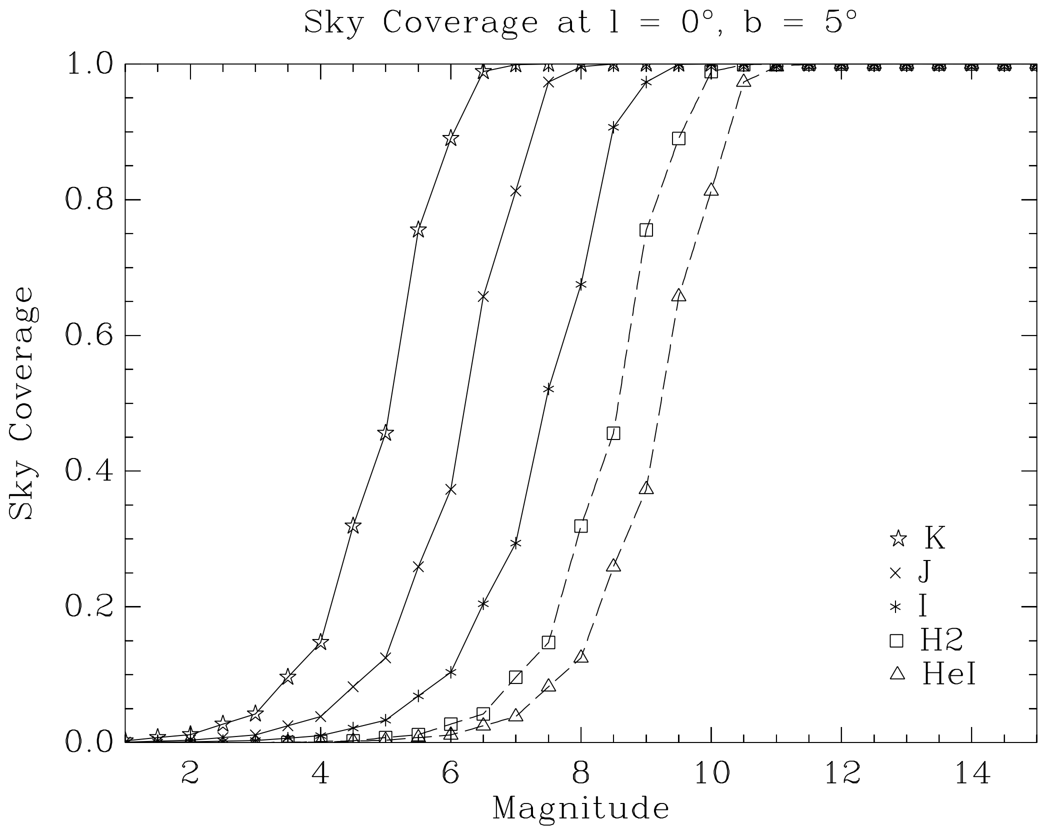
$$P_{N_{stars}>0}(m, a) = 1 - e^{\frac{-\pi a^2 \eta(m)}{60^2}}$$

where $\eta(m)$ is the density of stars brighter than magnitude m per square degrees in the considered region of the Galaxy.

Sky coverage computations based on a subsample of the public 2MASS Second Incremental Data Release (http://www.ipac.caltech.edu/2mass/) seem to lead to comparable sky coverage values for galactic latitudes greater than $+80°$.

A.2 Star forming regions

cf. Jerome's estimations, to be added here.


Sky Coverage at l = 0°, b = 5°
Sky Coverage
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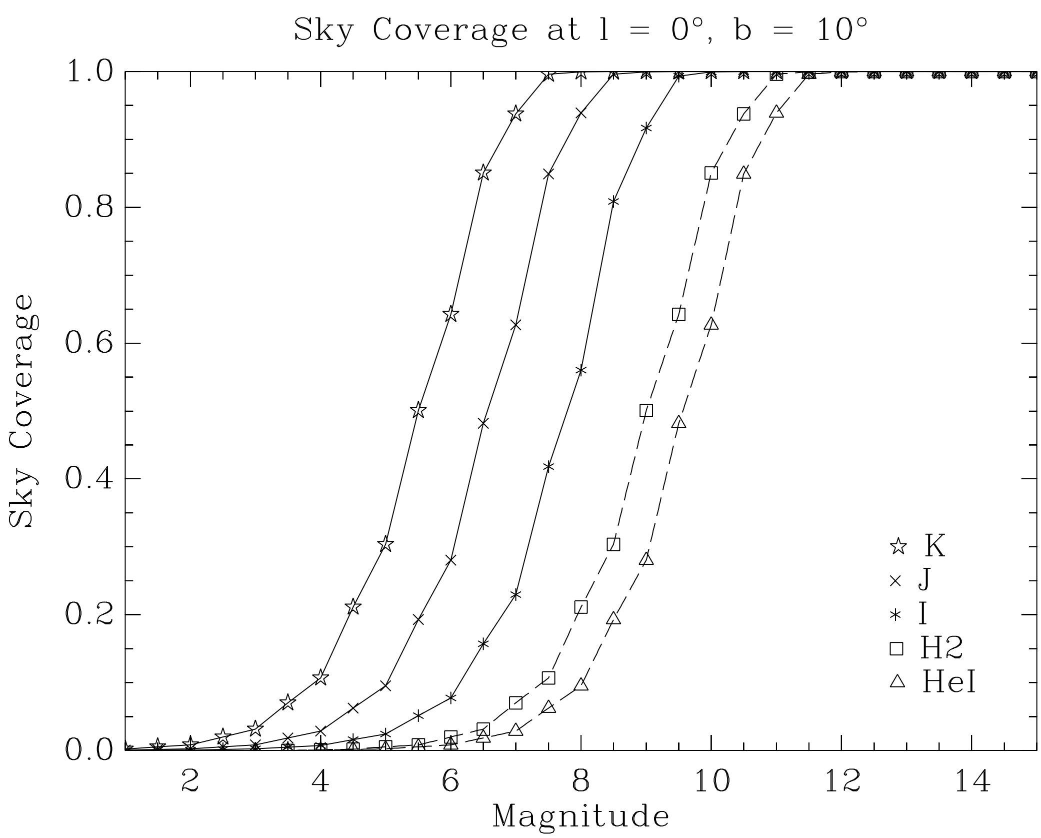
12
14
K
J
I
H2
HeI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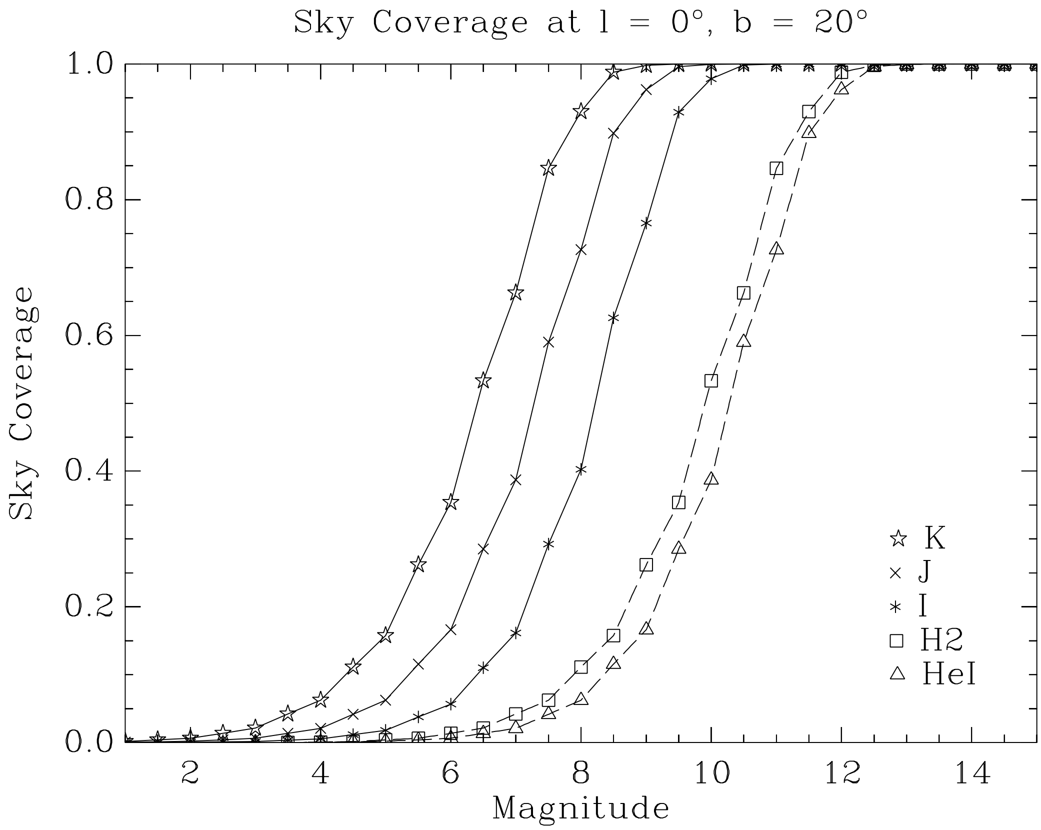
K
J
I
H2
HeI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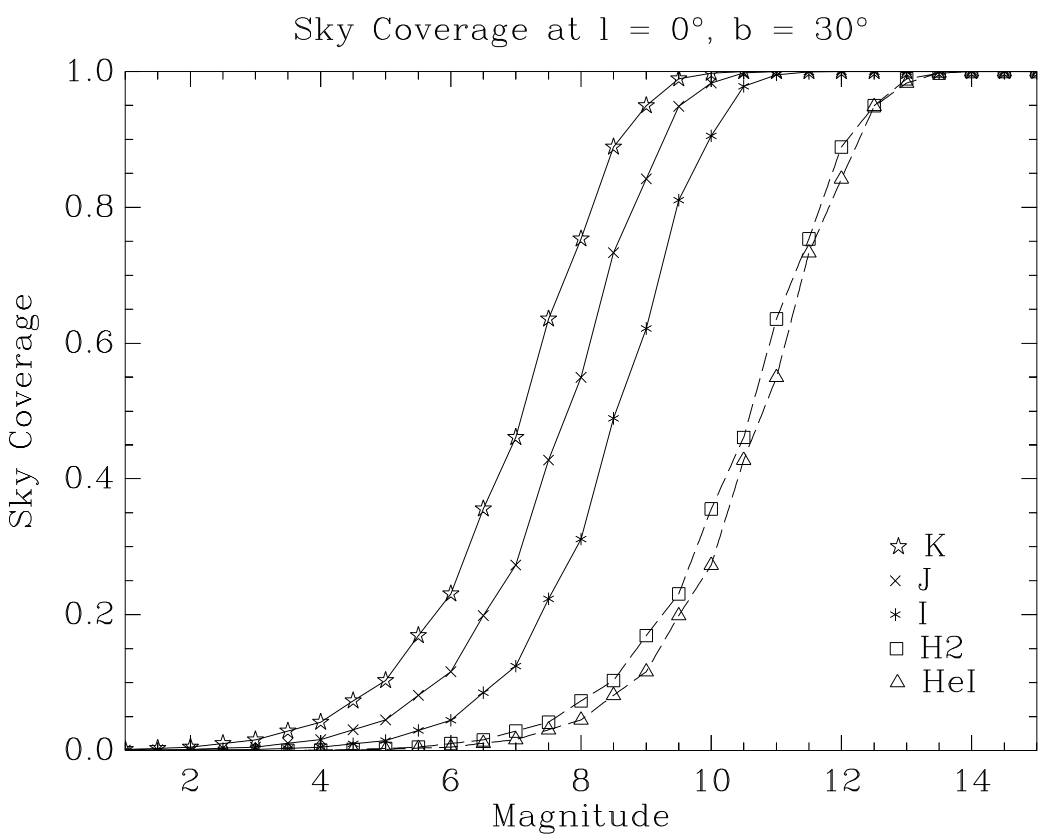
Sky Coverage
Magnitude
K
J
I
H2
HeI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Sky Coverage
Magnitude
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H2
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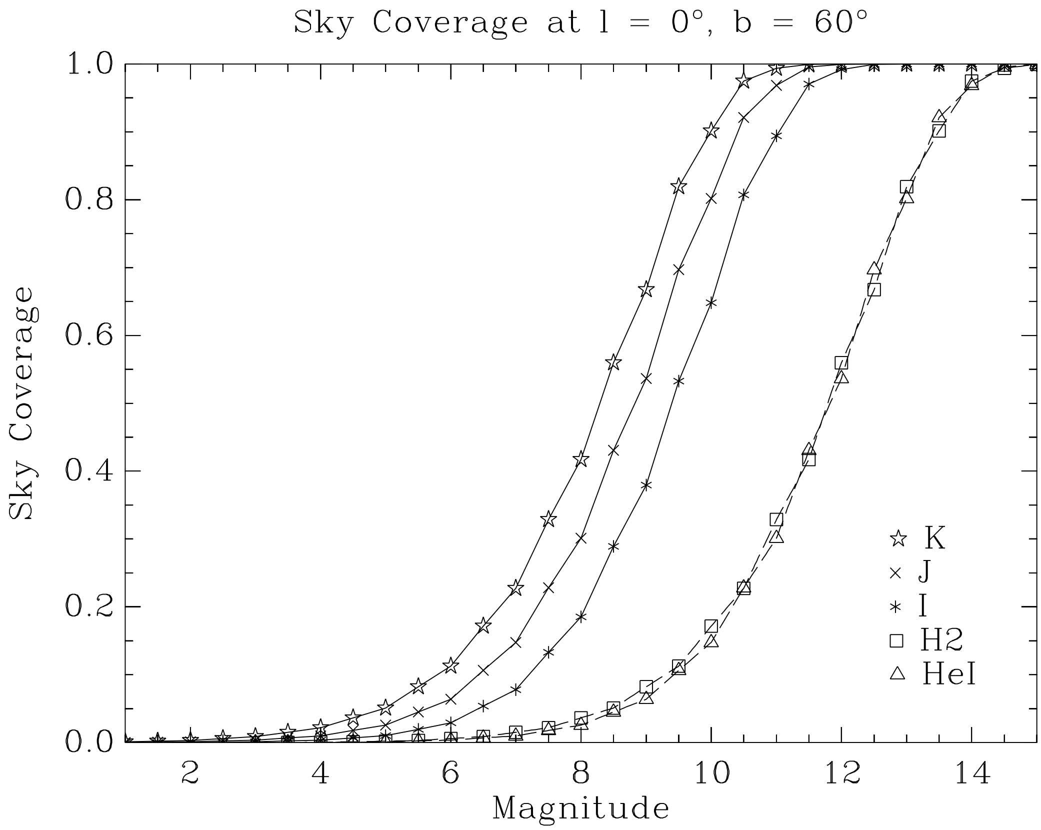
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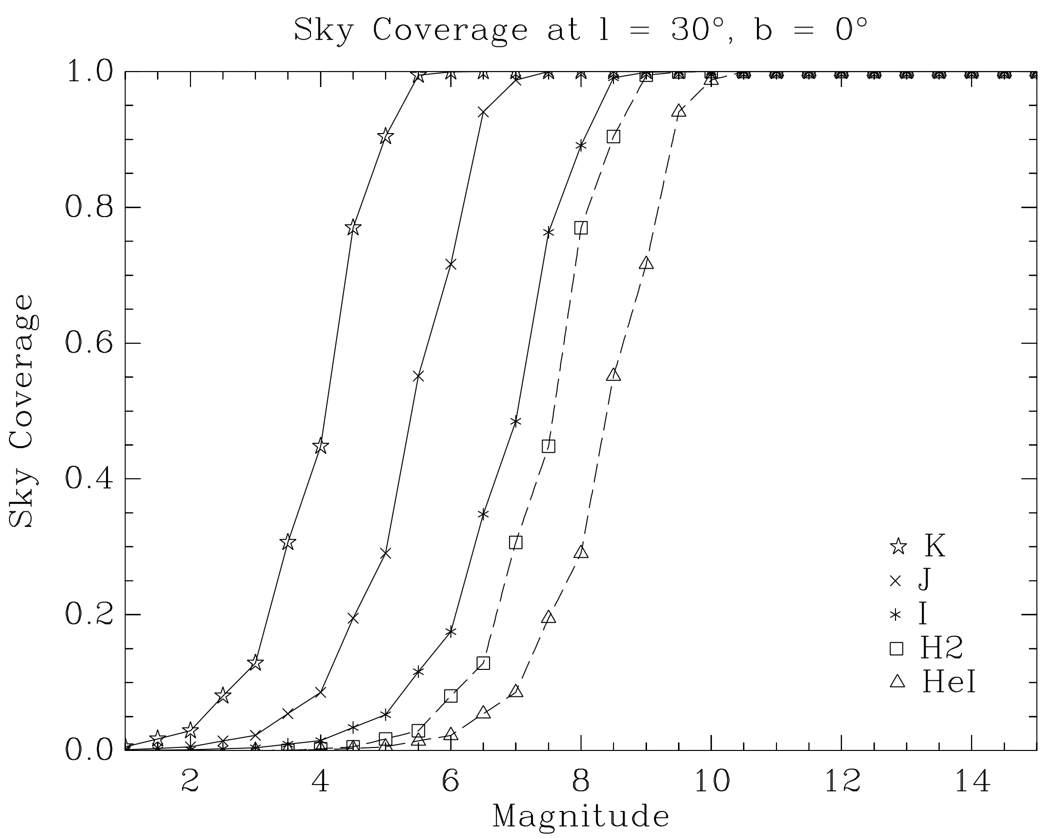
Sky Coverage
Magnitude
K
J
I
H2
HeI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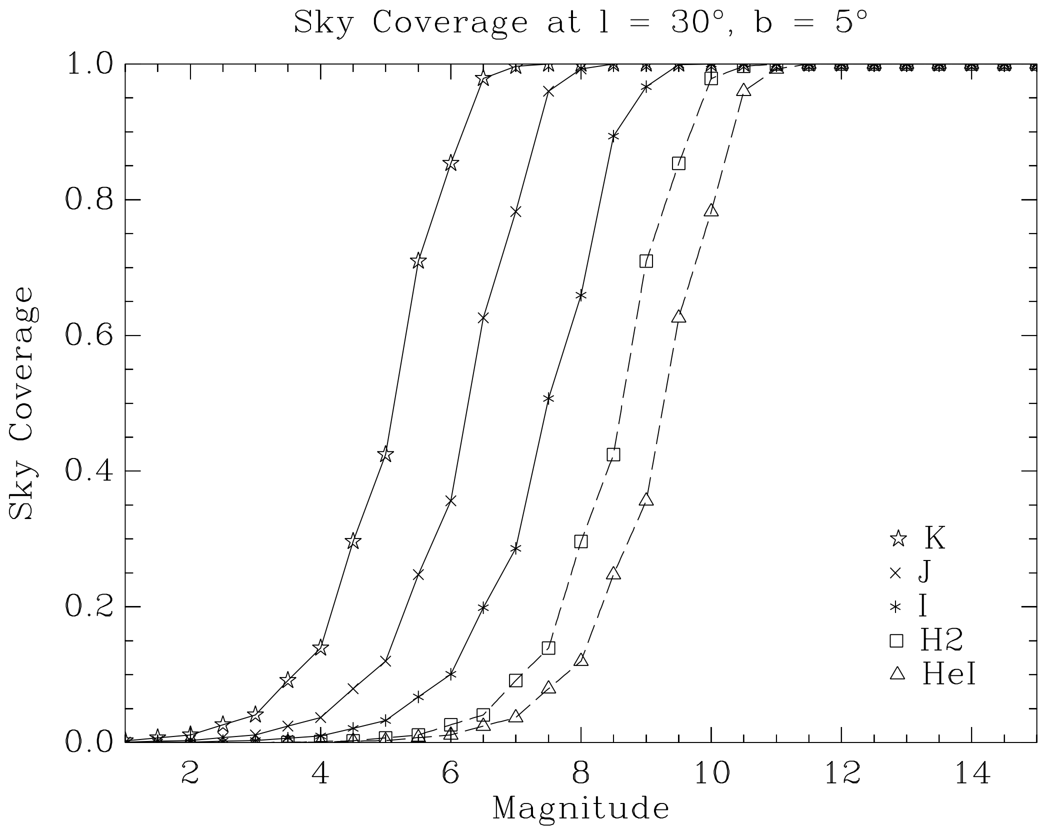
Sky Coverage
Magnitude
K
J
I
H2
HeI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Sky Coverage
Magnitude
K
J
I
H2
HeI
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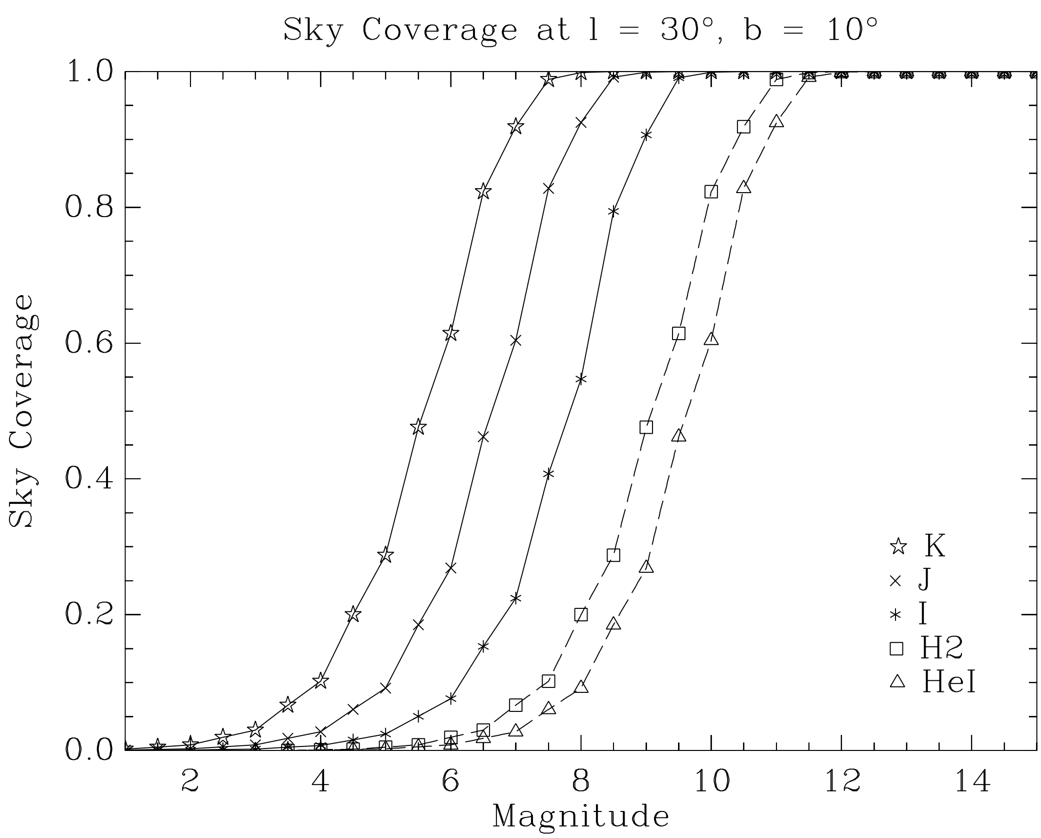
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Sky Coverage
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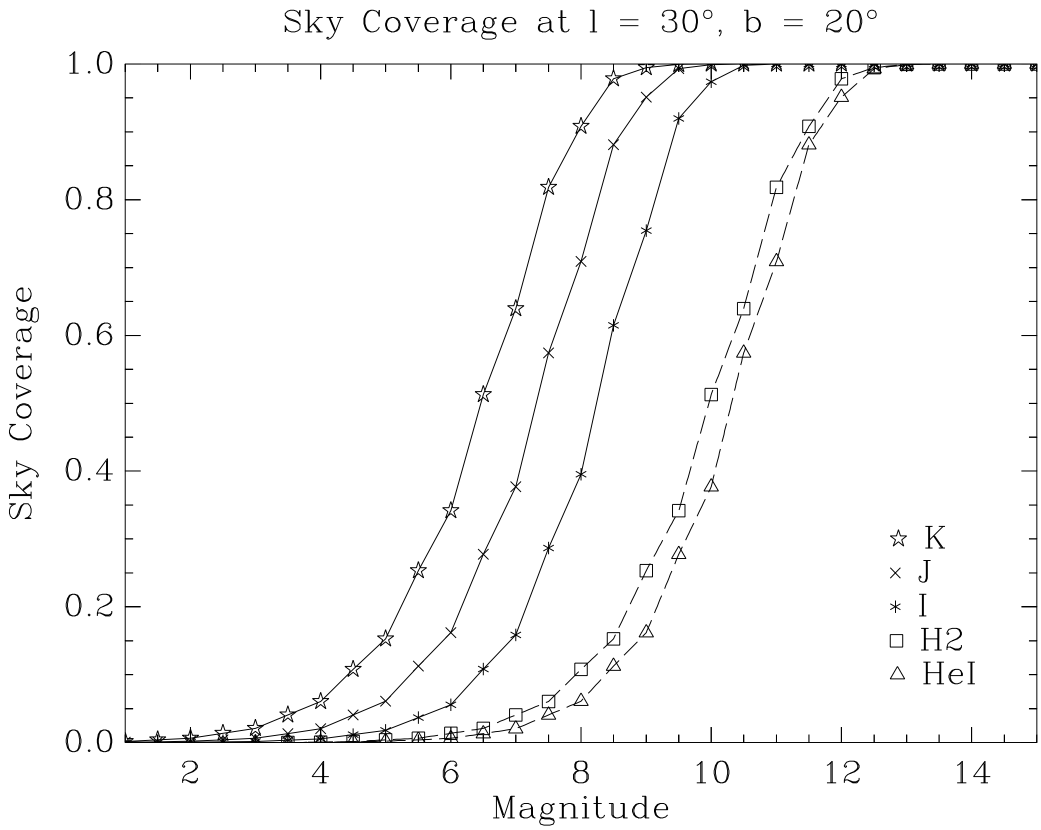

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Sky Coverage
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H2
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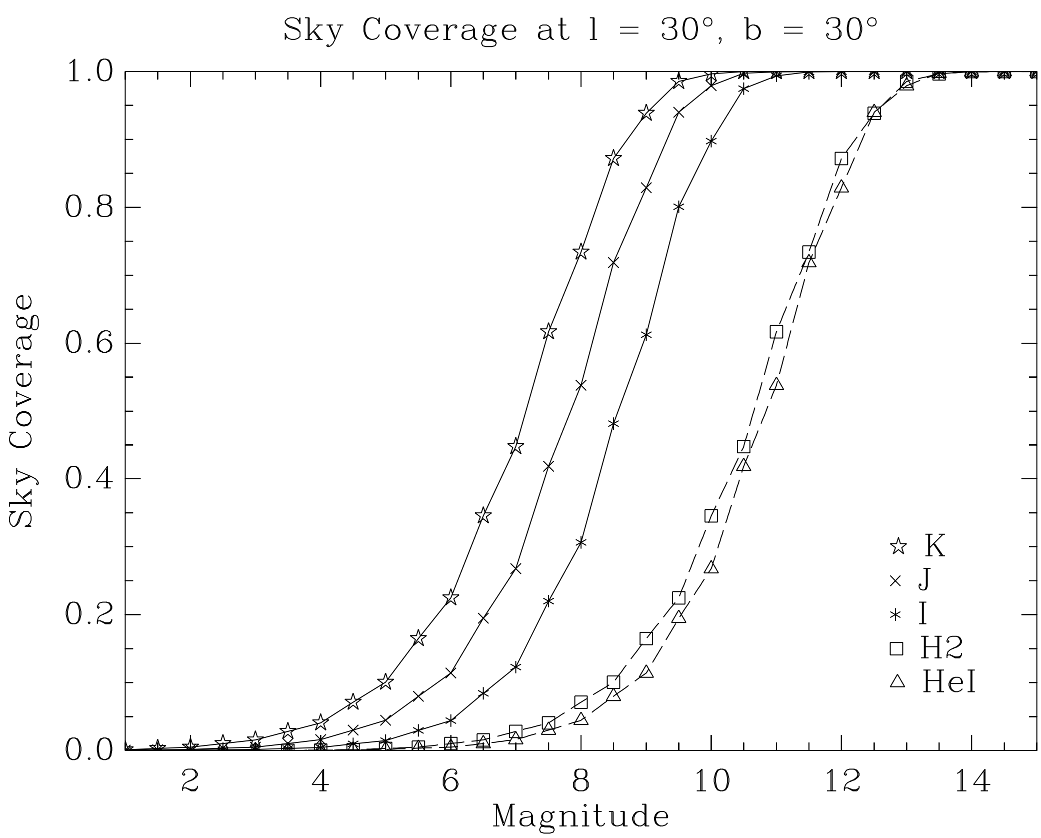

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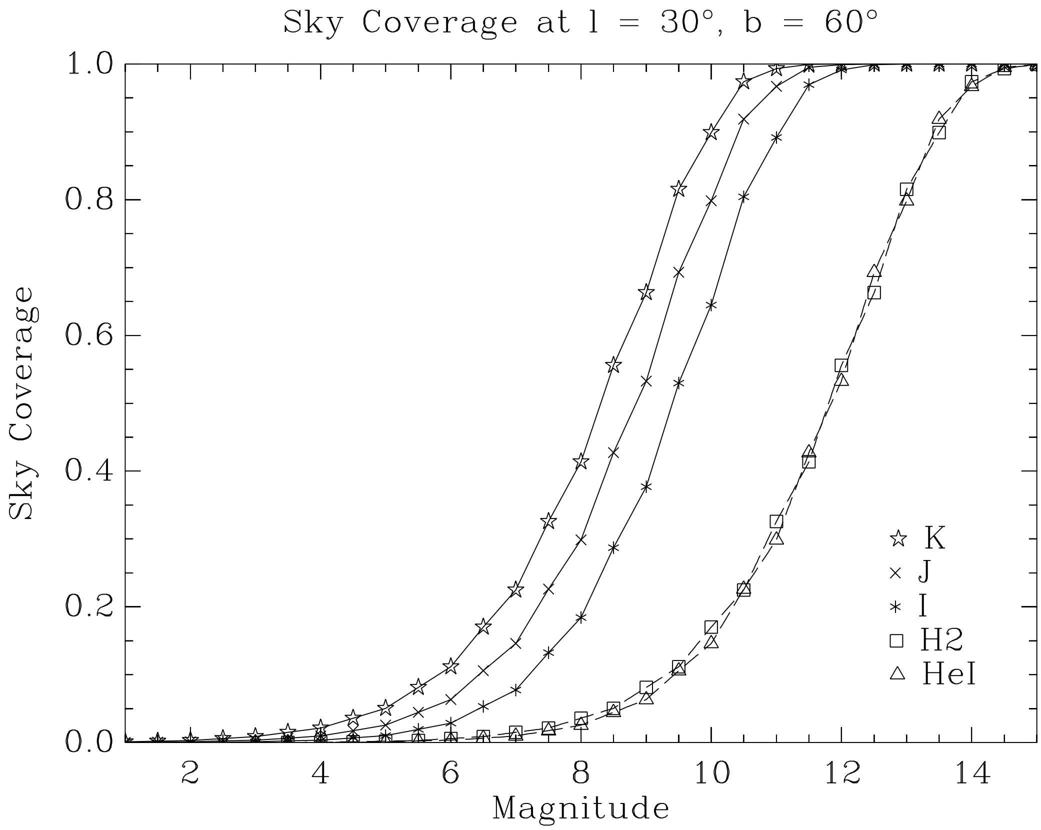
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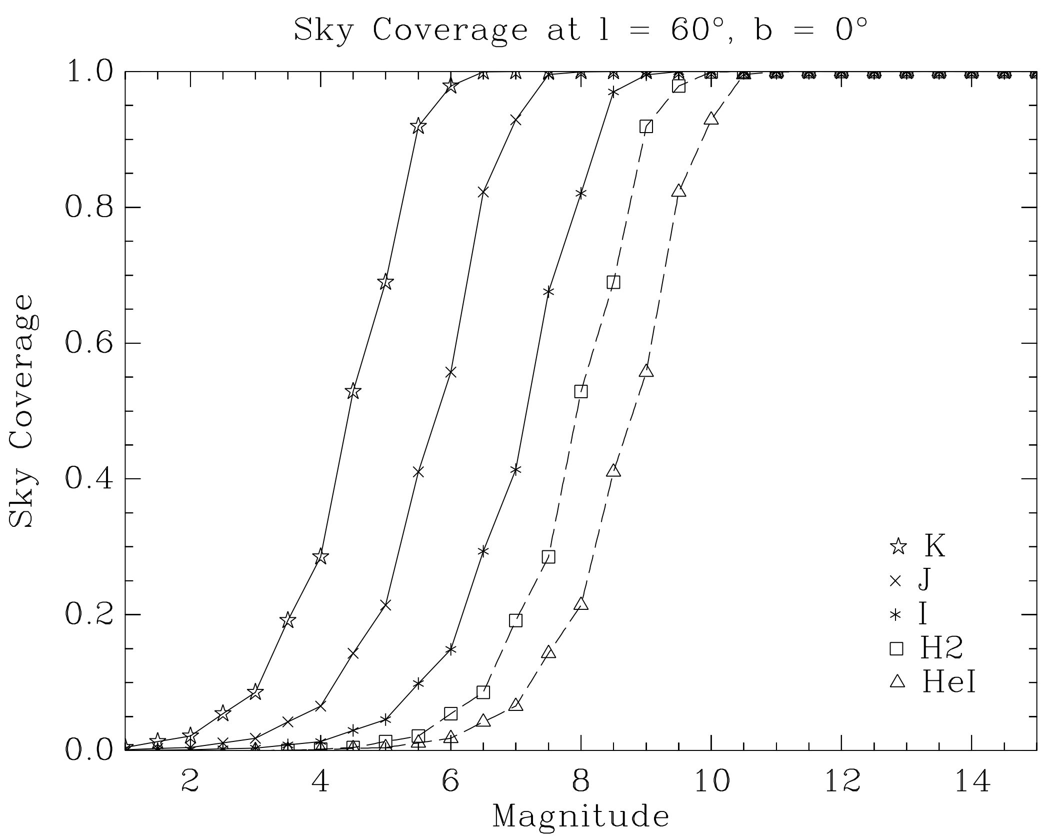
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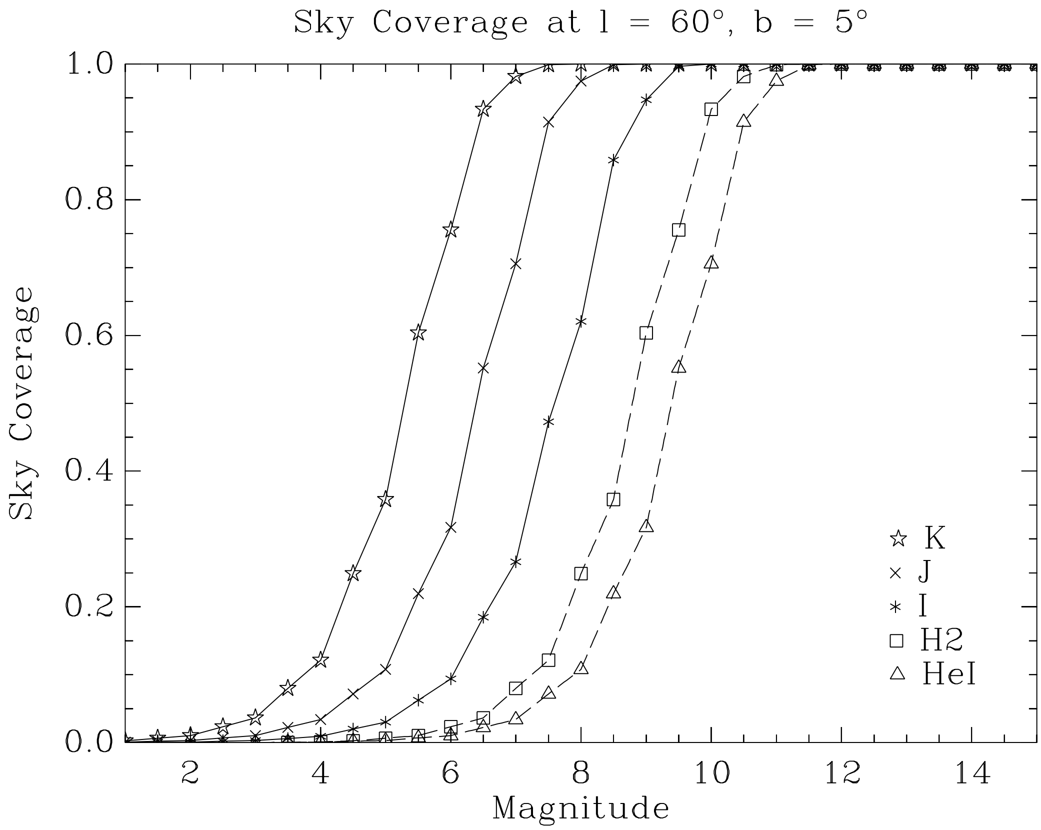
HeI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Magnitude
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H2
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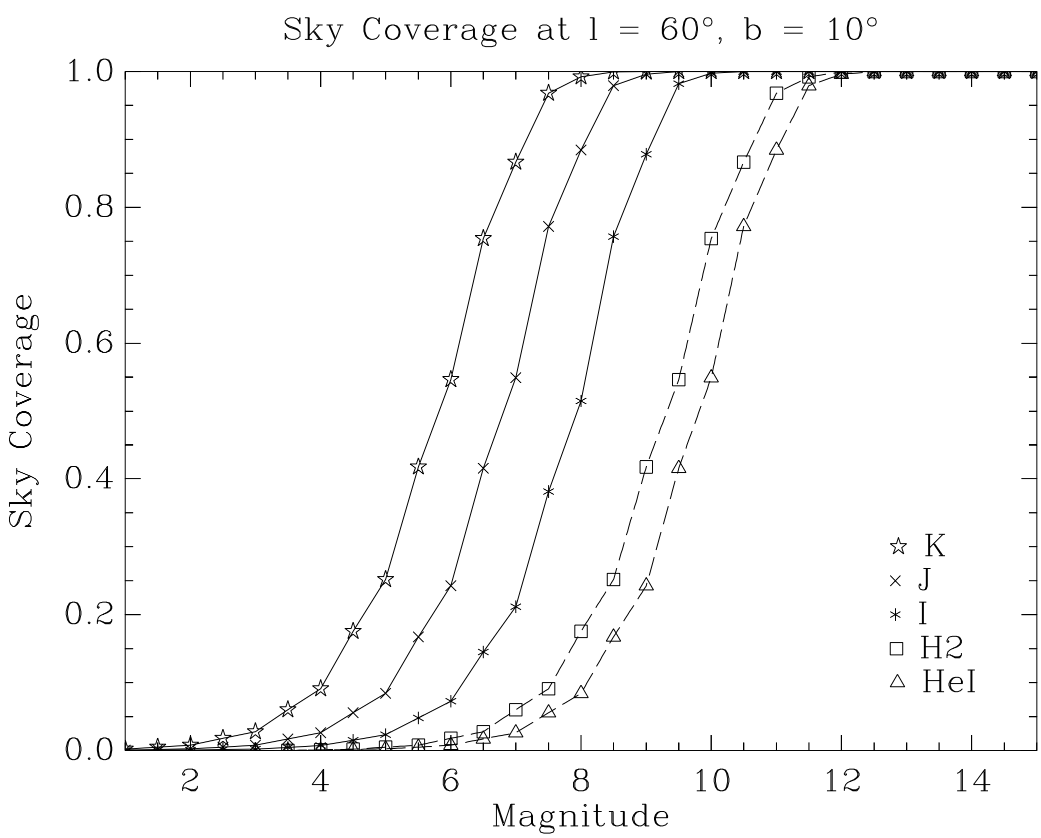
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Sky Coverage
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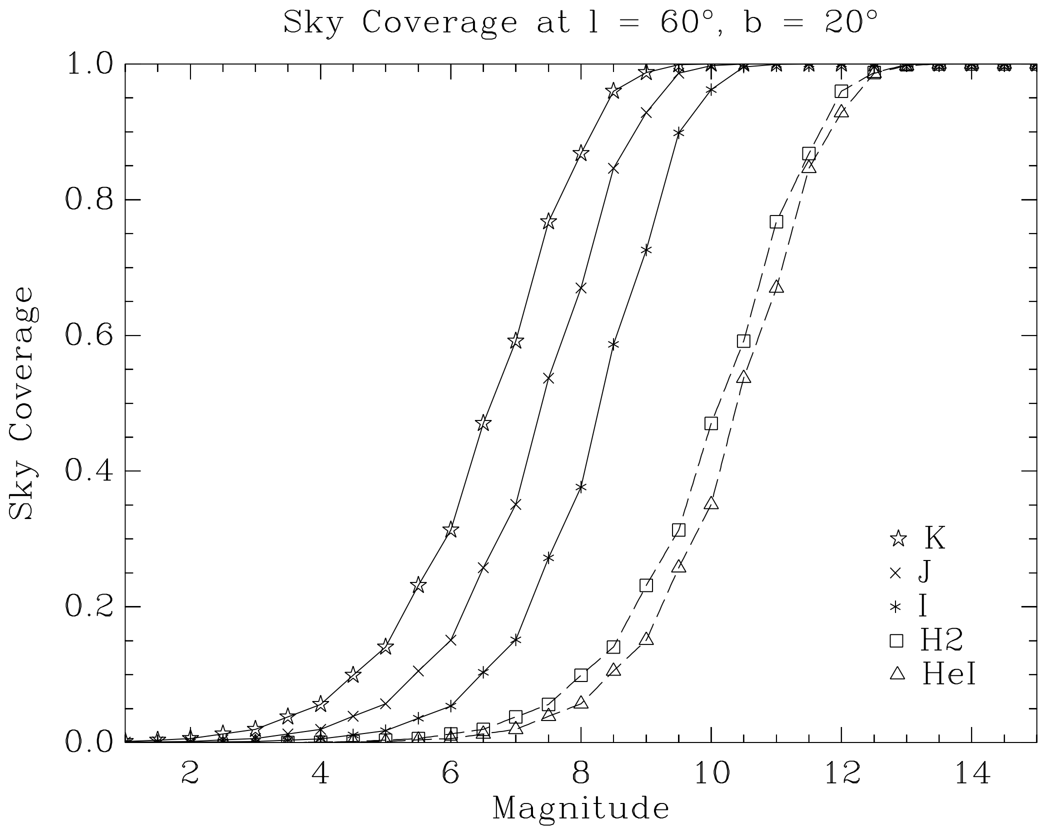
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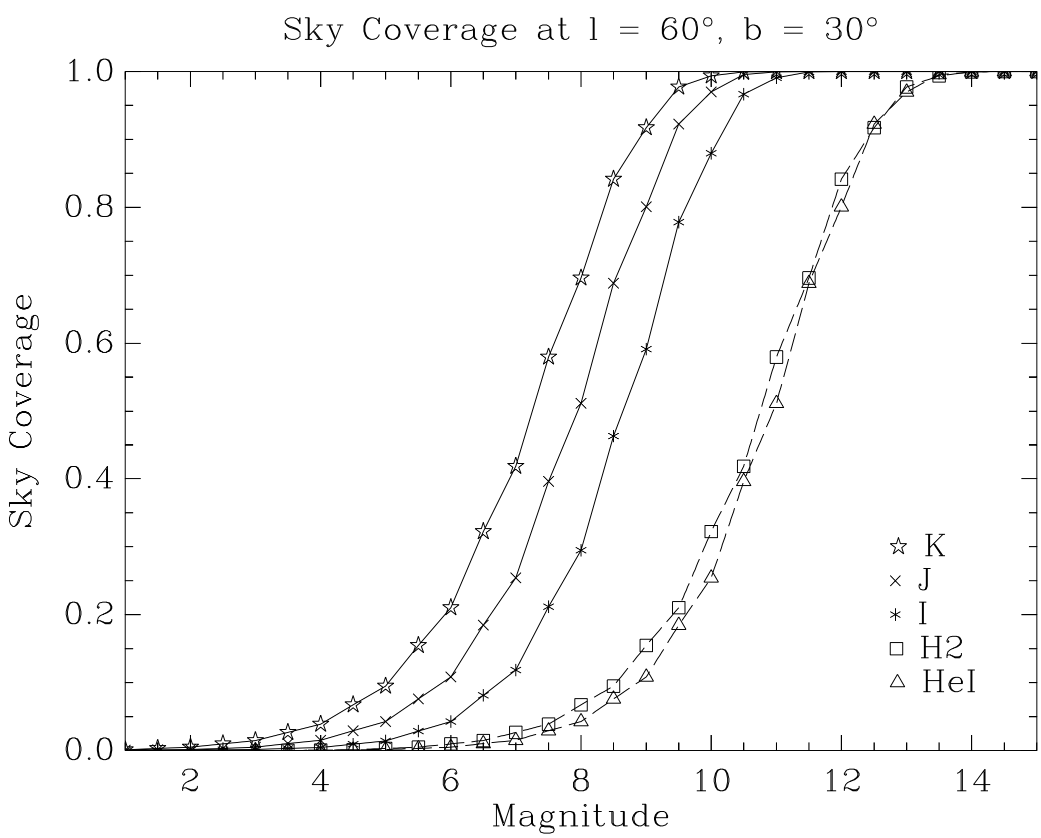
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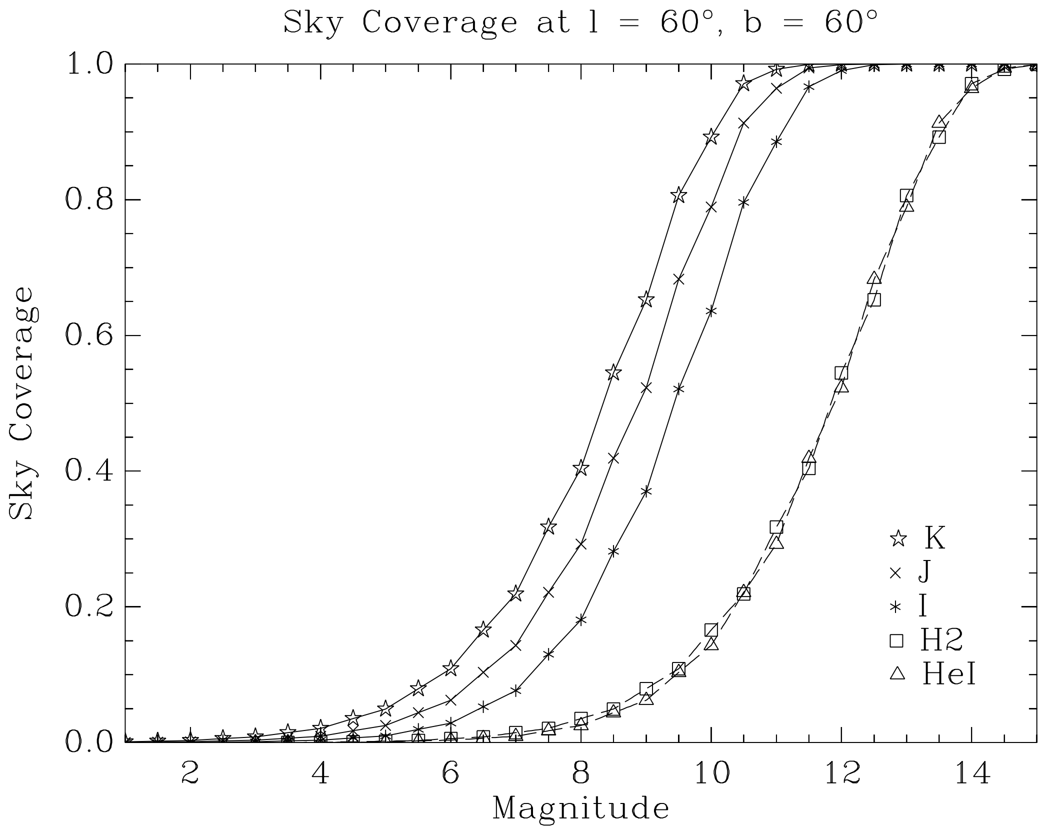
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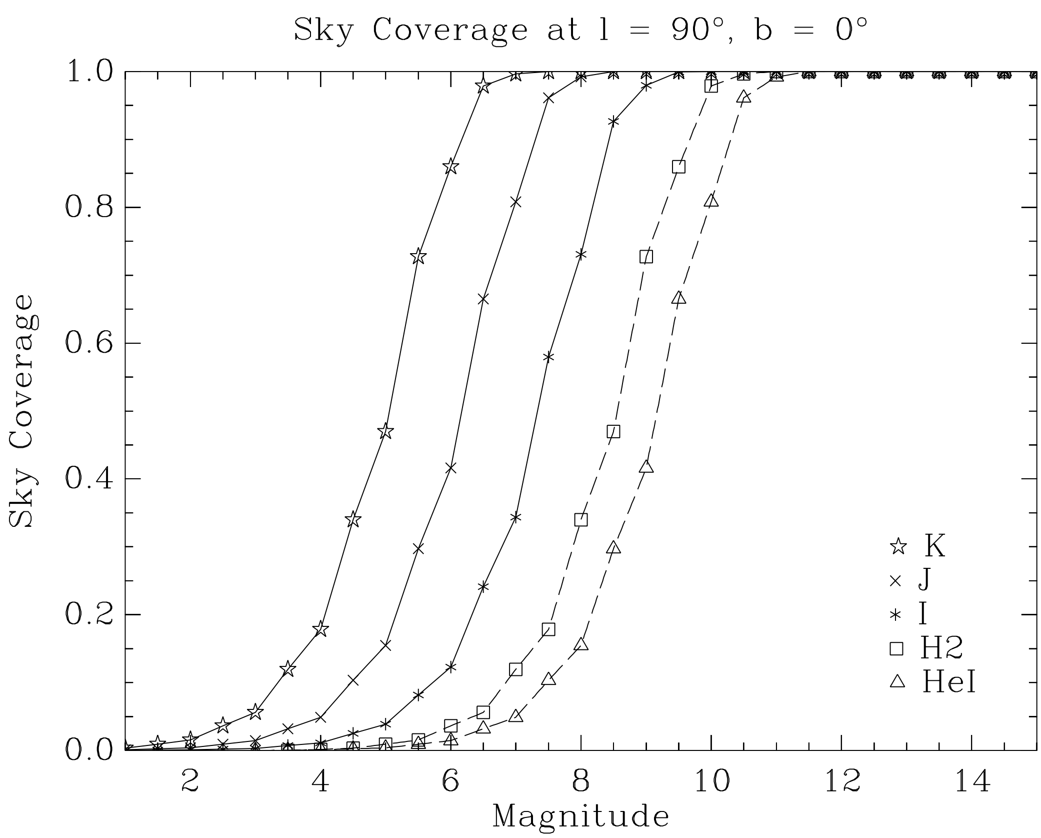
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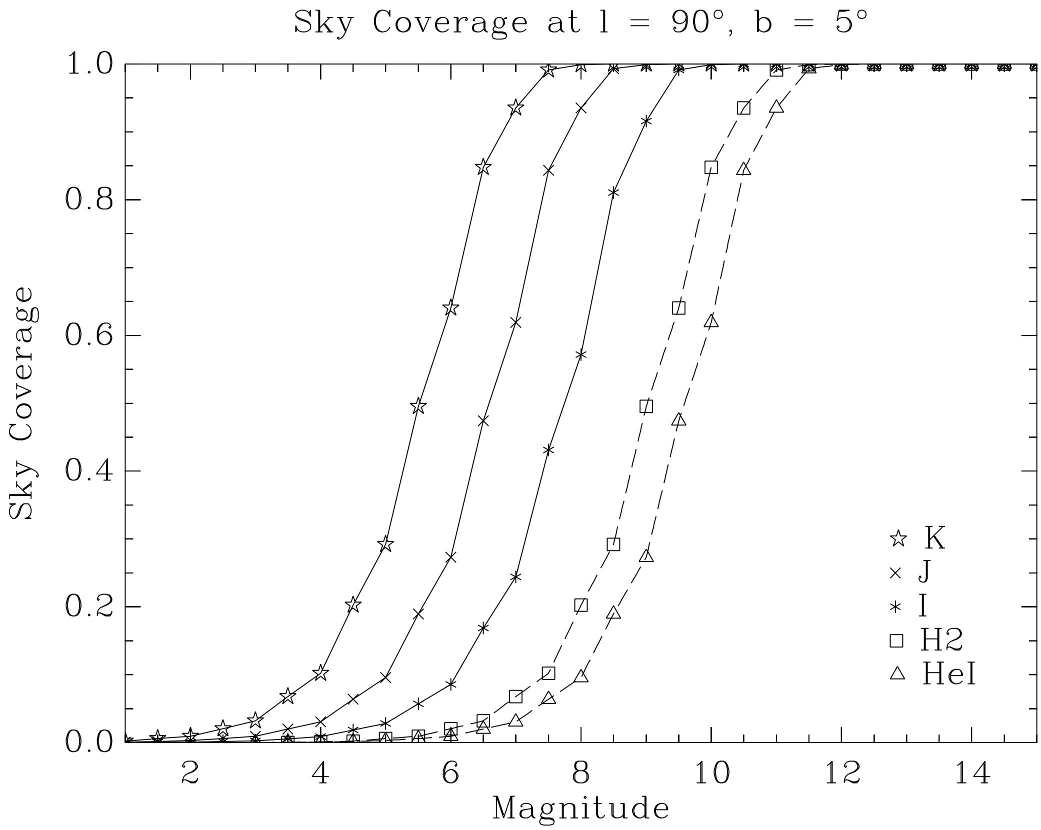
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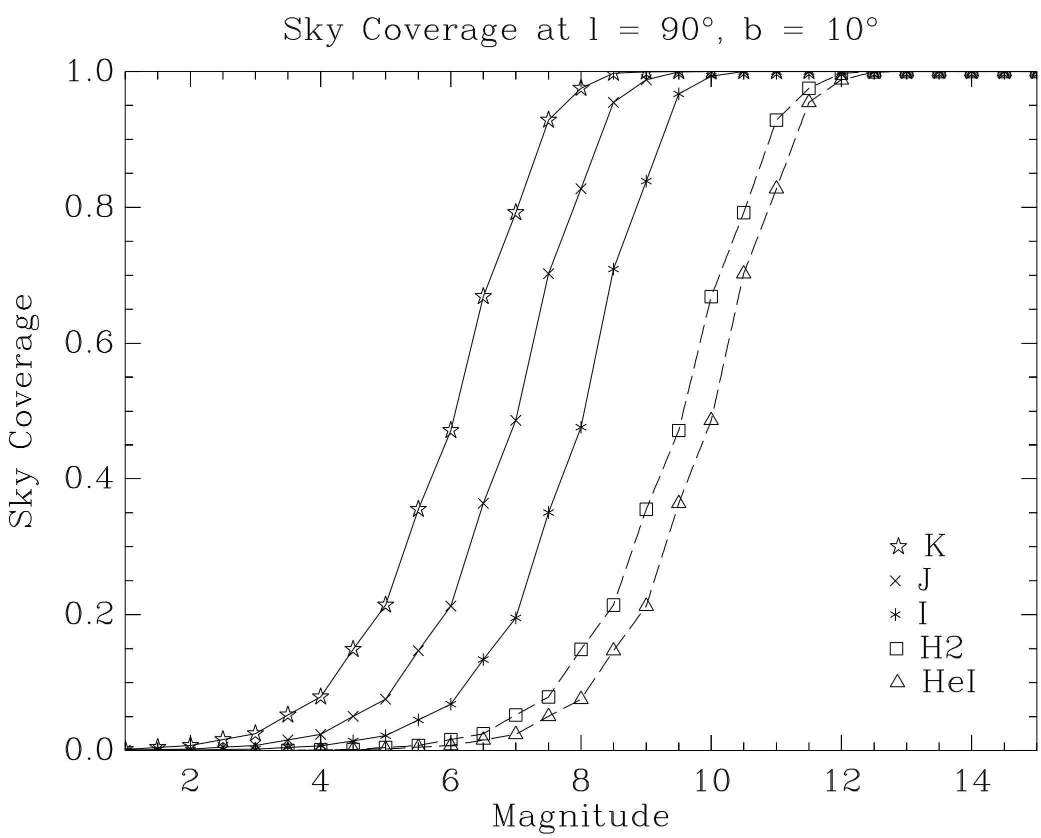
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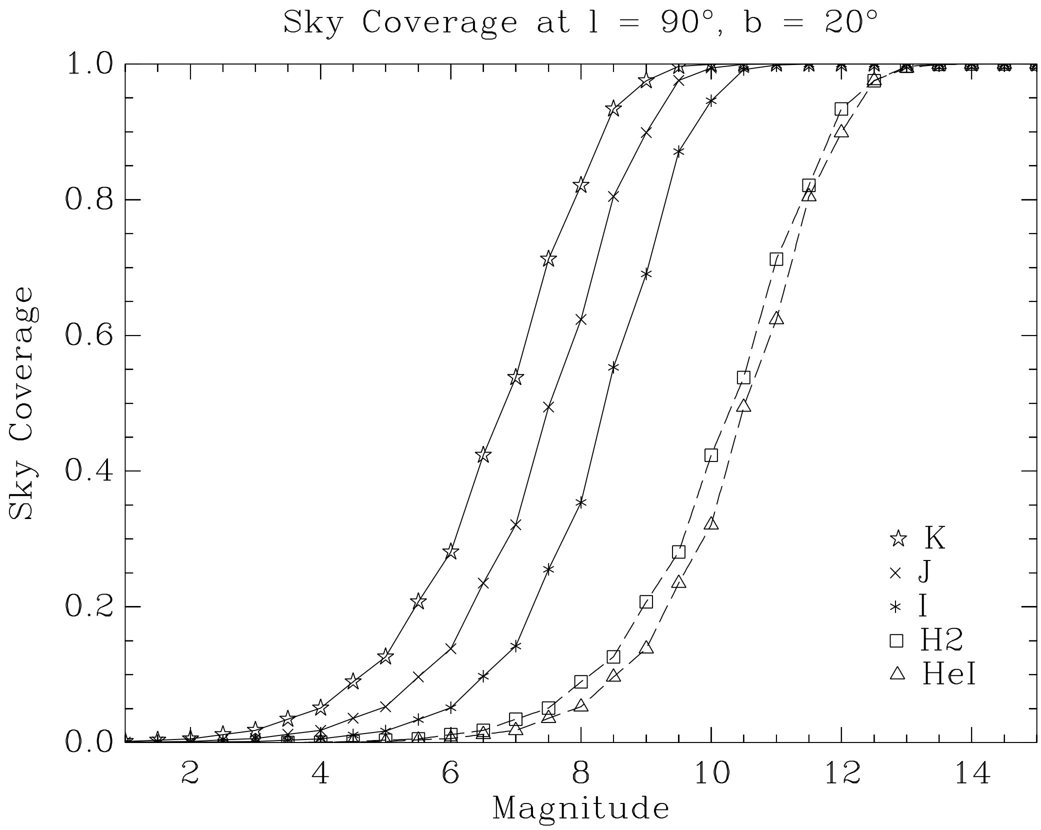
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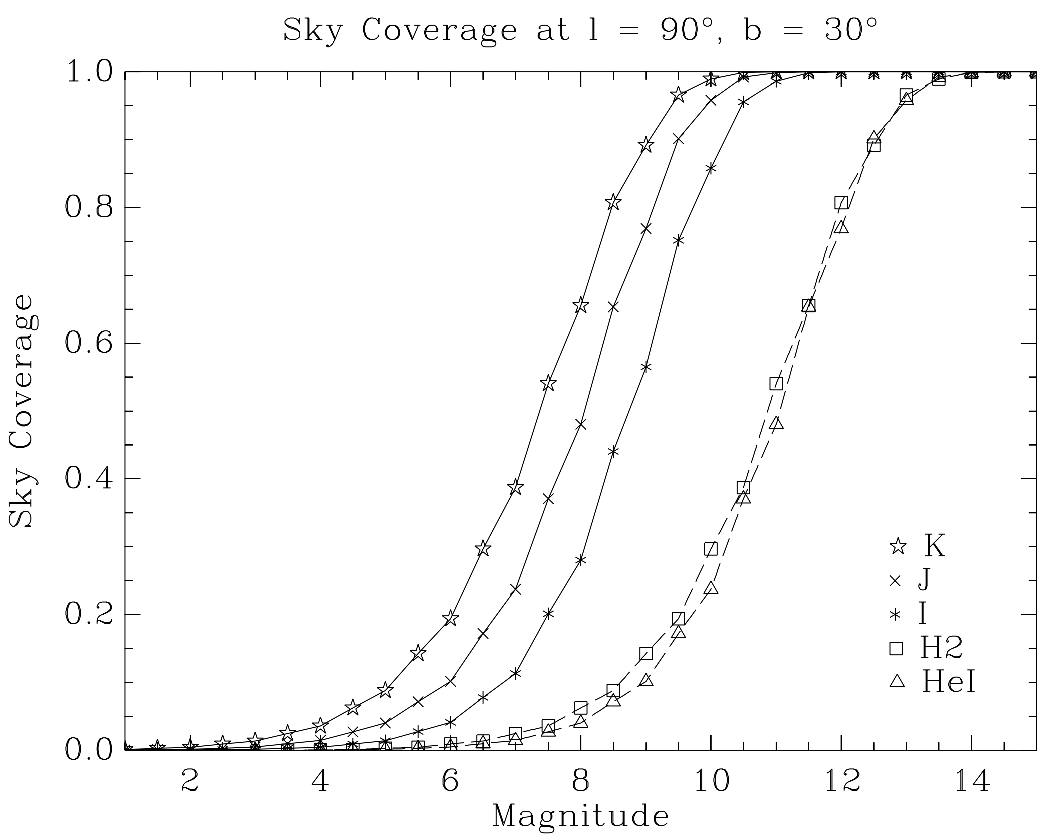
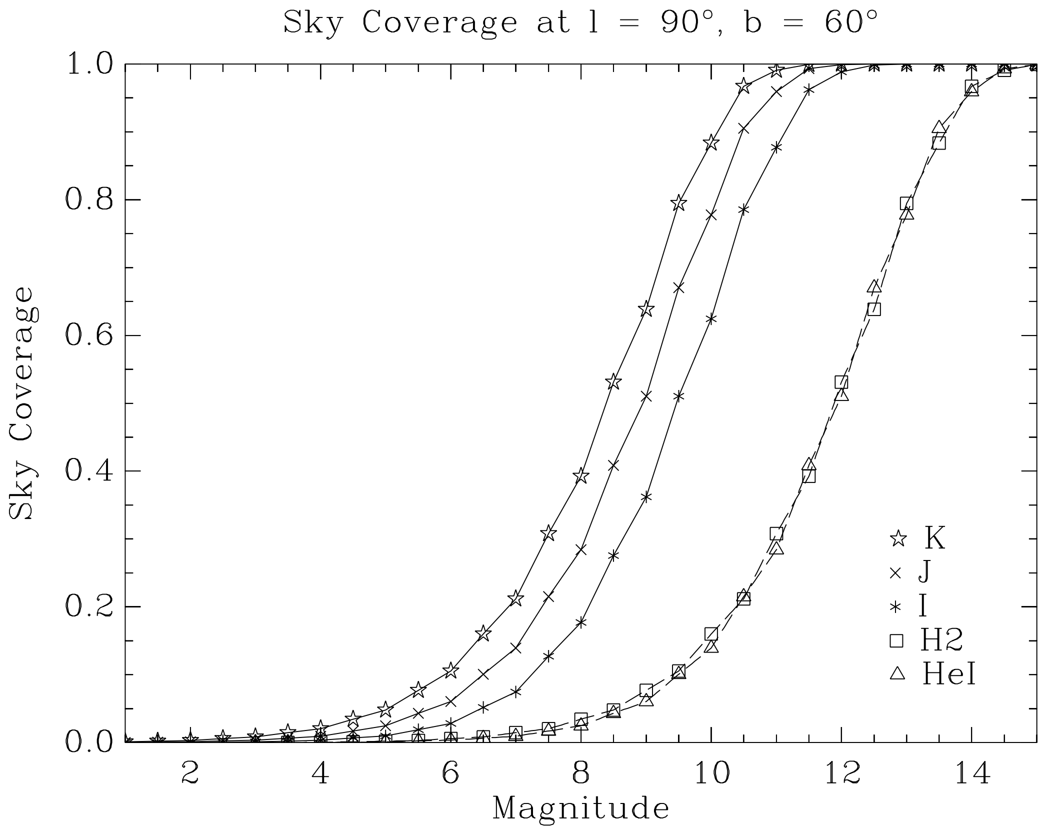
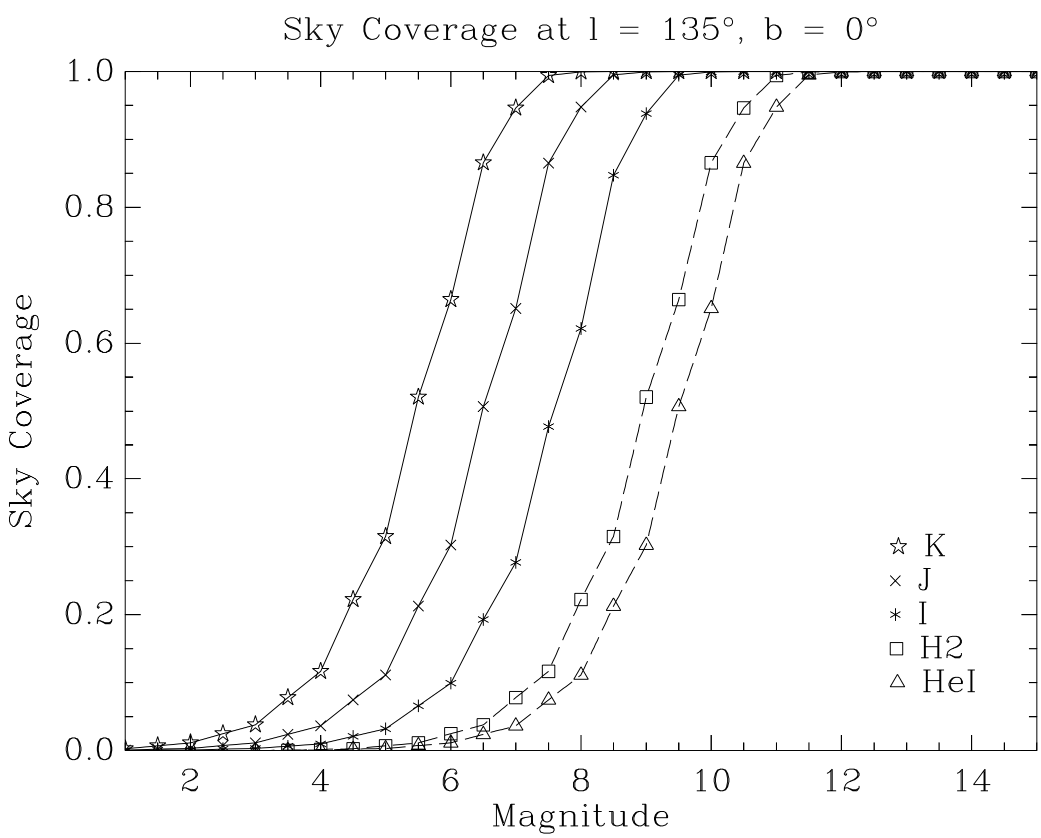
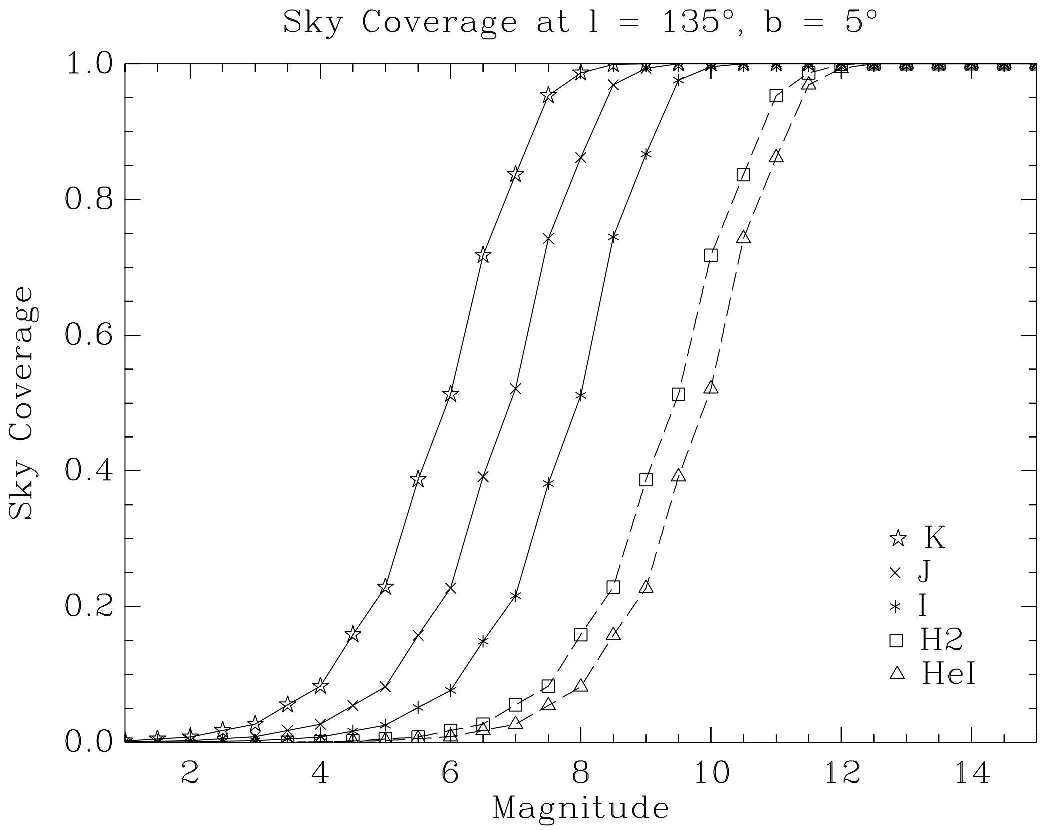
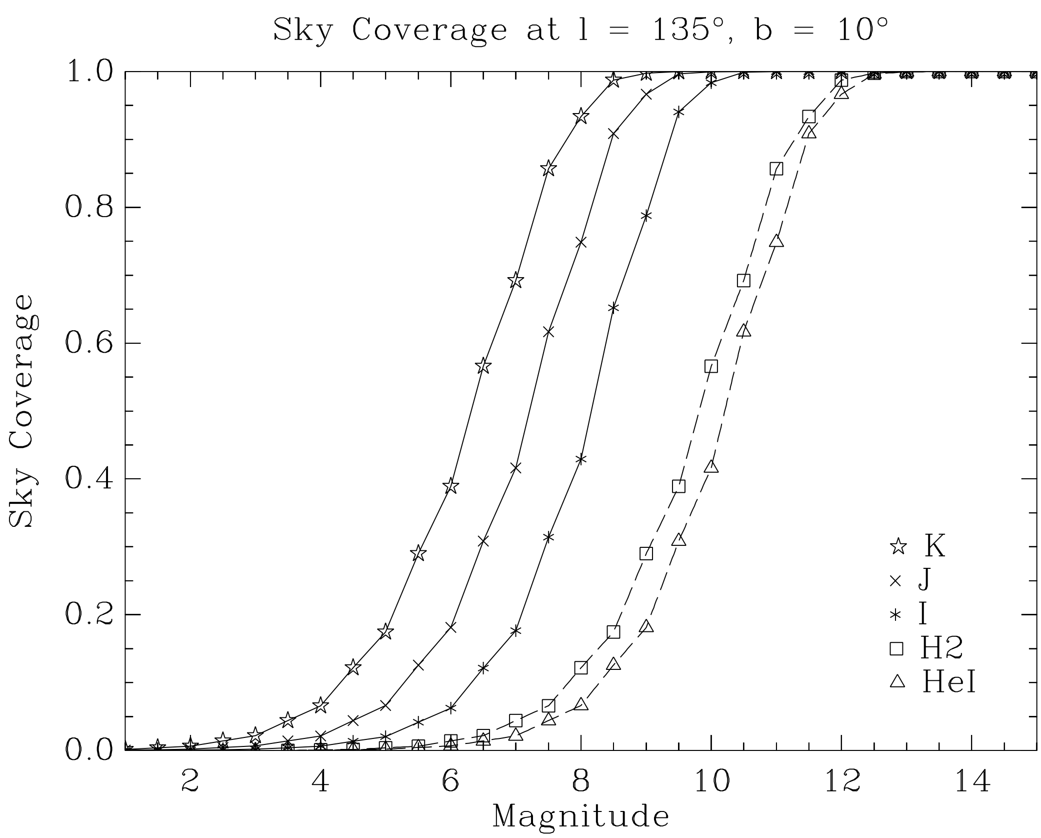
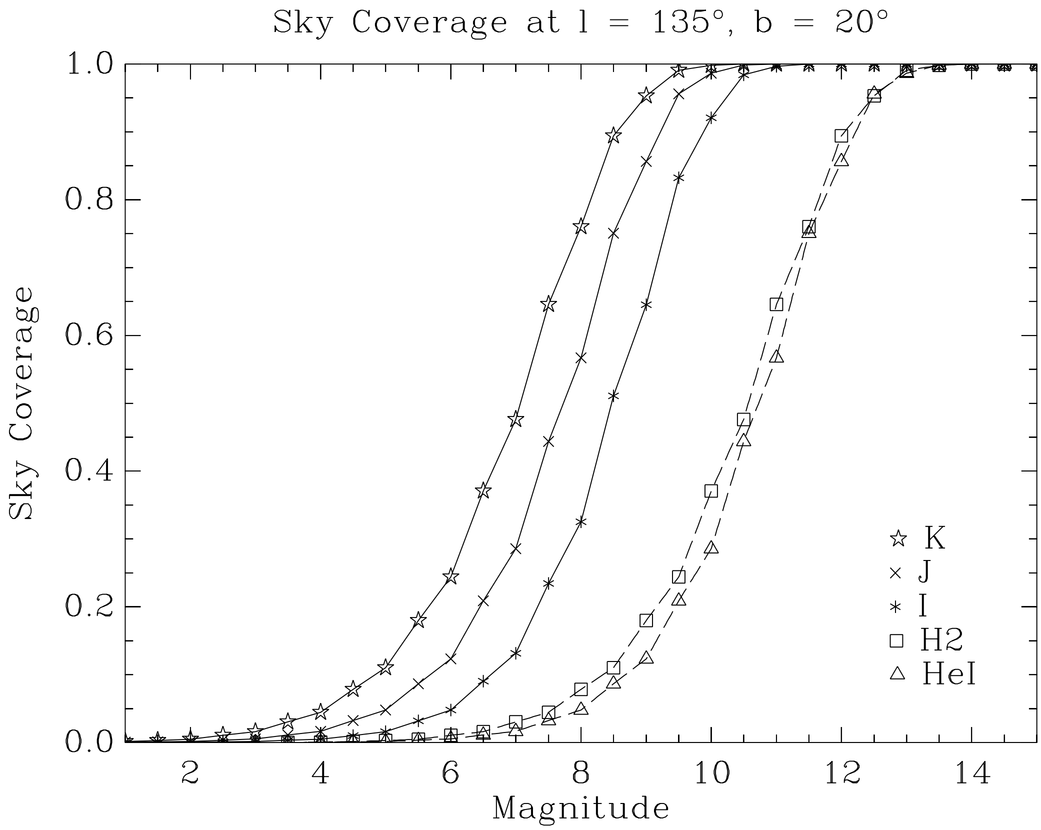

Sky Coverage at l = 90°, b = 30°
Sky Coverage
Magnitude
K
J
I
H2
HeI
0.0
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
12
14

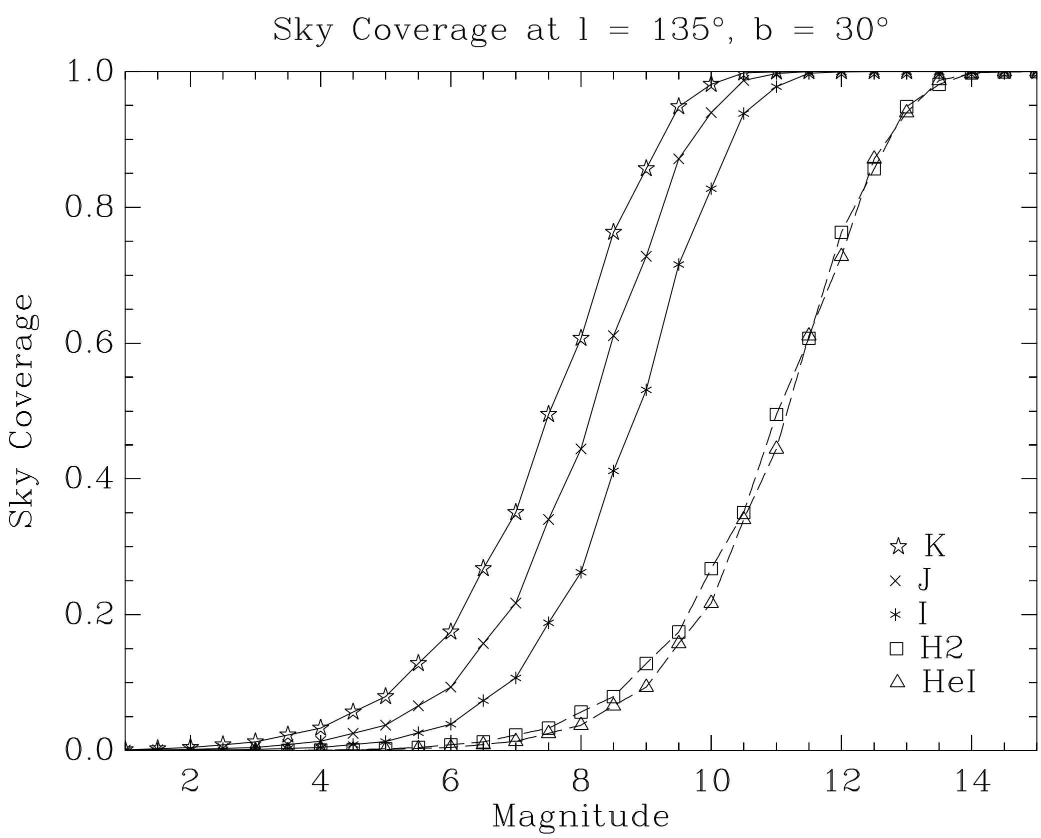

Sky Coverage at l = 90°, b = 60°
Sky Coverage
Magnitude
1.0
0.8
0.6
0.4
0.2
0.0
2
4
6
8
10
12
14
K
J
I
H2
HeI

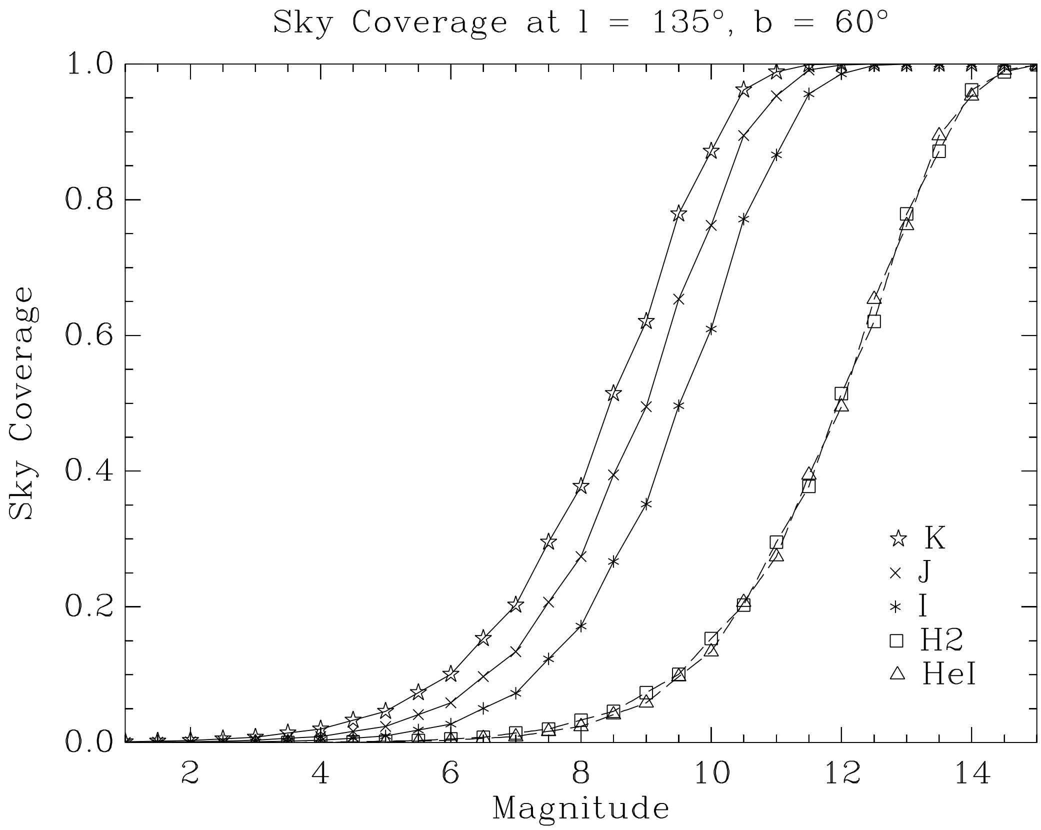

Sky Coverage at l = 135°, b = 0°
Sky Coverage
Magnitude
1.0
0.8
0.6
0.4
0.2
0.0
2
4
6
8
10
12
14
K
J
I
H2
HeI

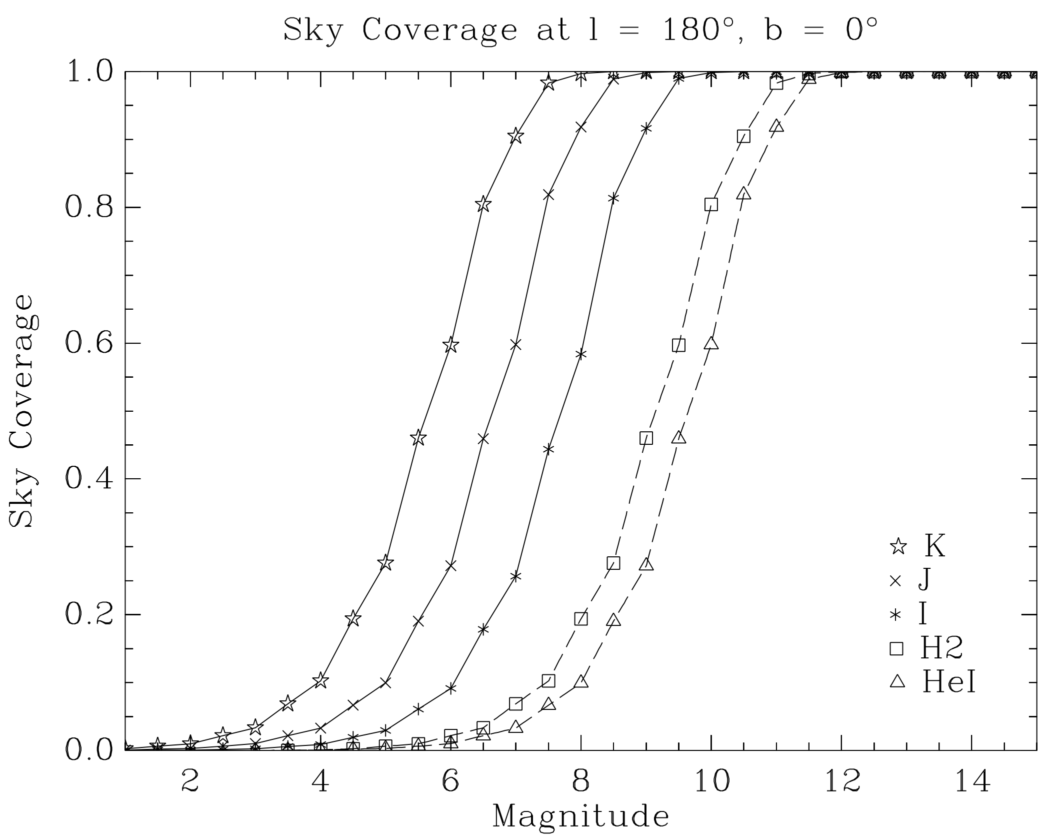

Sky Coverage at l = 135°, b = 5°
Sky Coverage
Magnitude
K
J
I
H2
HeI

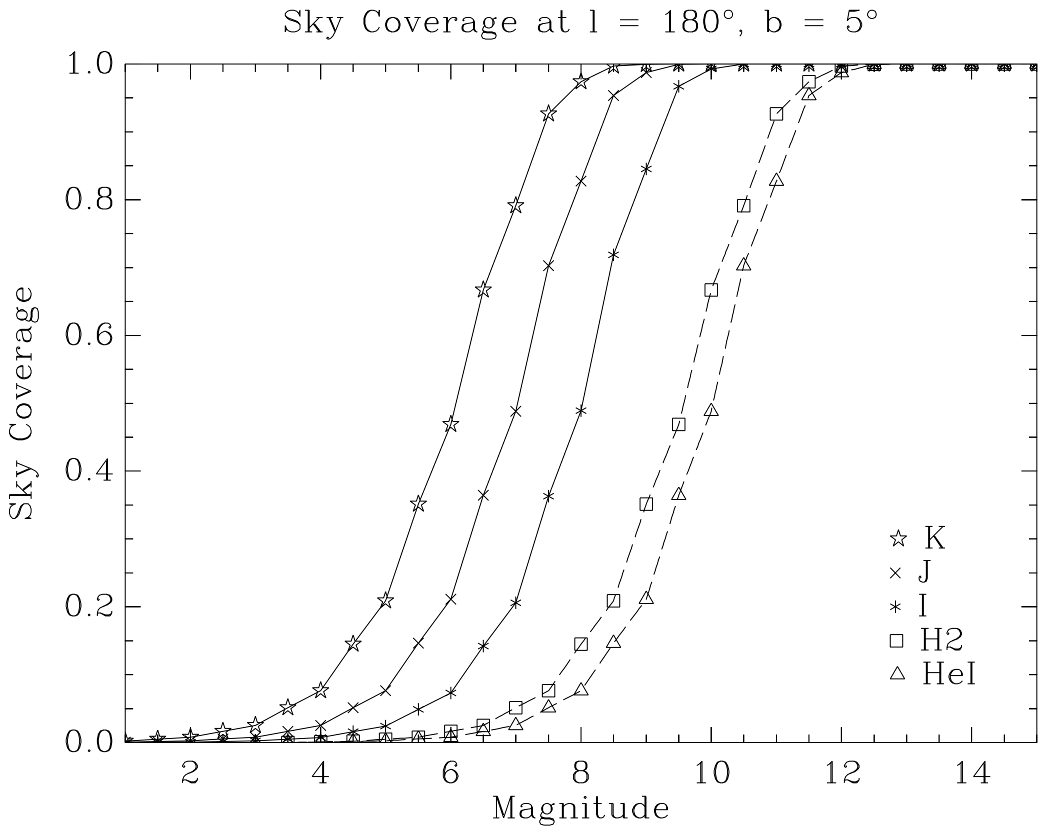

Sky Coverage at l = 135°, b = 10°
Sky Coverage
Magnitude
K
J
I
H2
HeI

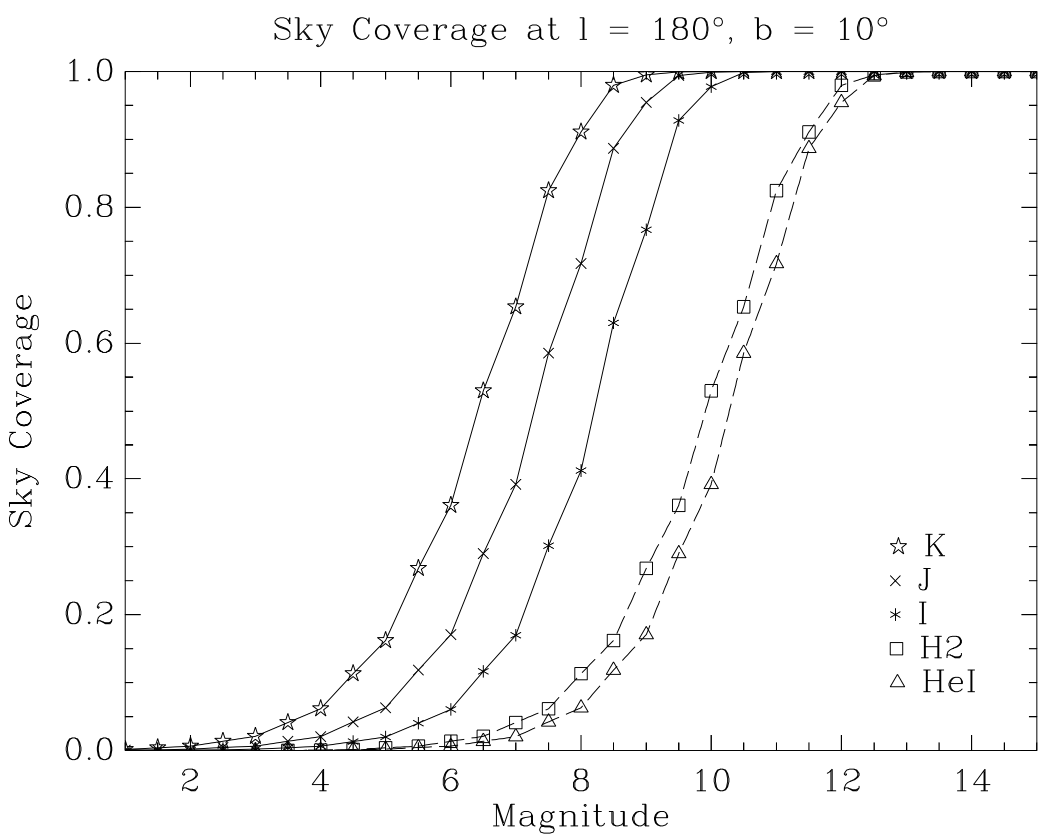

Sky Coverage at l = 135°, b = 20°
1.0
0.8
0.6
0.4
0.2
0.0
Sky Coverage
2
4
6
8
10
12
14
Magnitude
K
J
I
H2
HeI

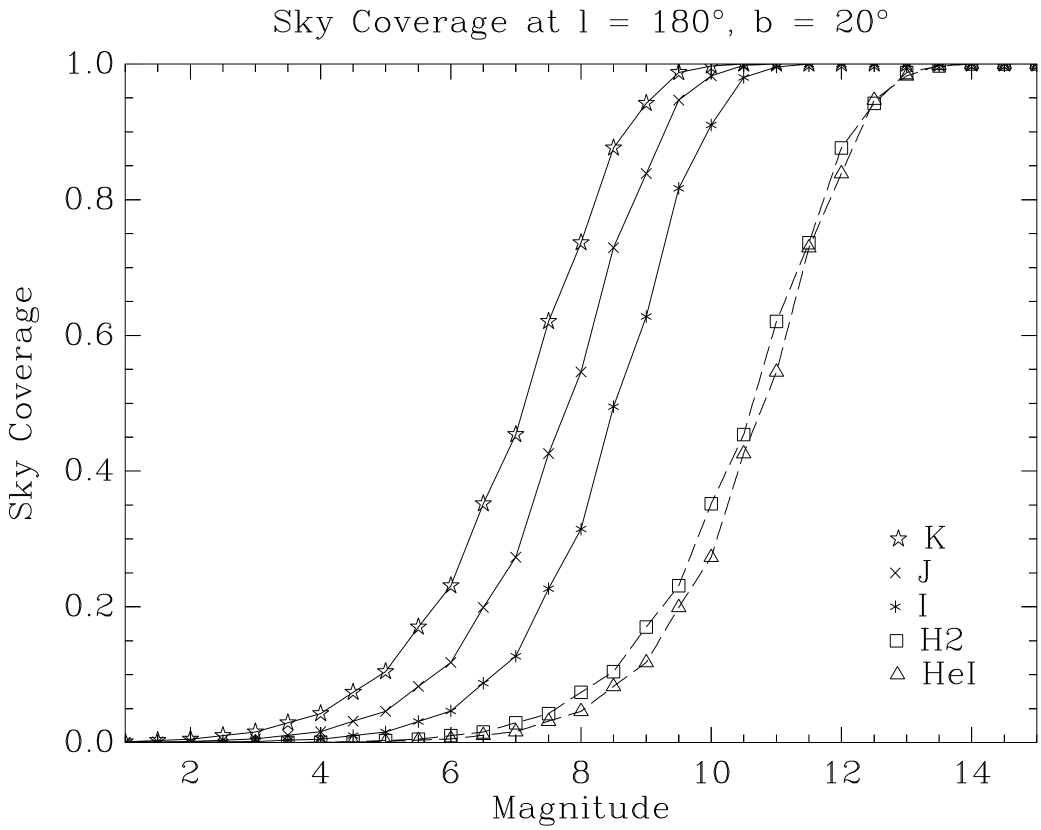

Sky Coverage at l = 135°, b = 30°
1.0
0.8
0.6
0.4
0.2
0.0
Sky Coverage
2
4
6
8
10
12
14
Magnitude
K
J
I
H2
HeI

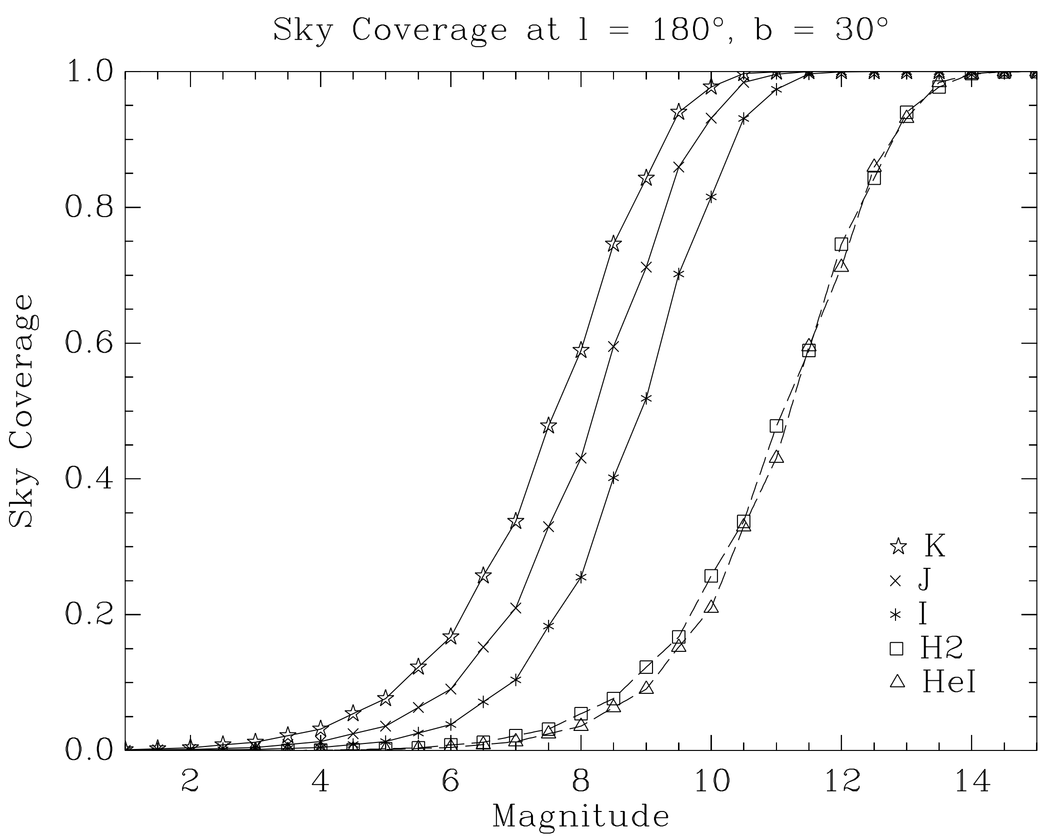

Sky Coverage at l = 135°, b = 60°
Sky Coverage
Magnitude
K
J
I
H2
HeI

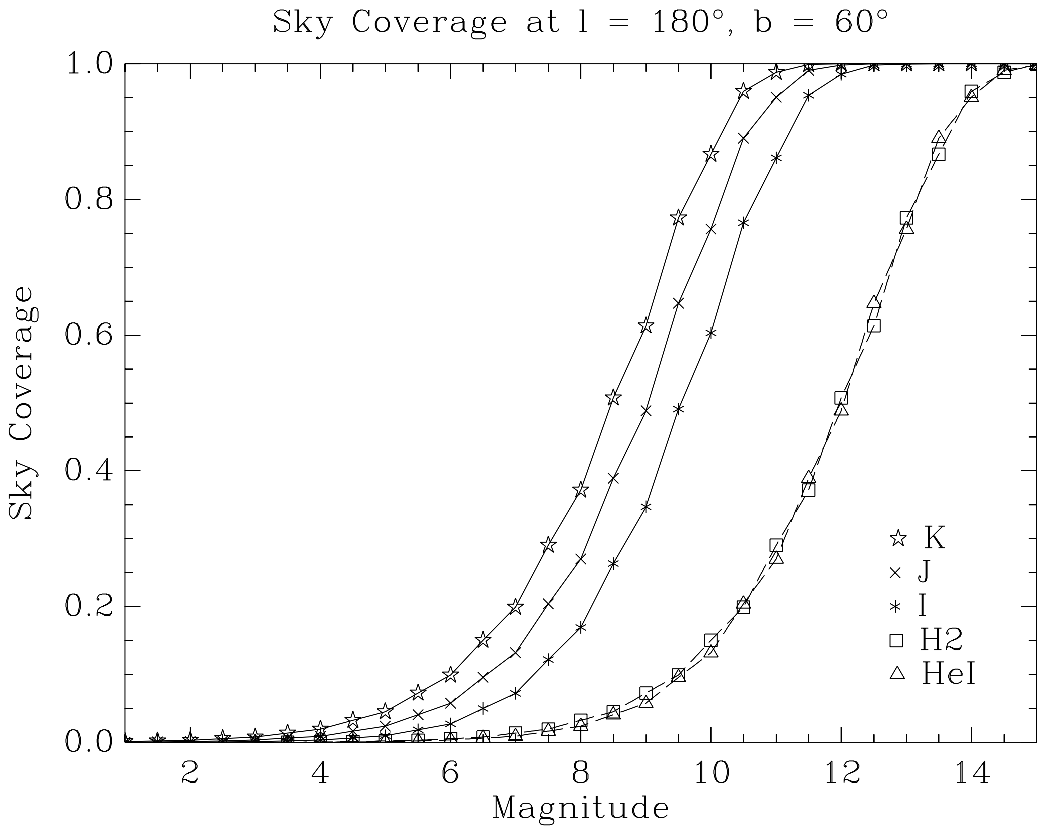

Sky Coverage at l = 180°, b = 0°
Sky Coverage
Magnitude
K
J
I
H2
HeI

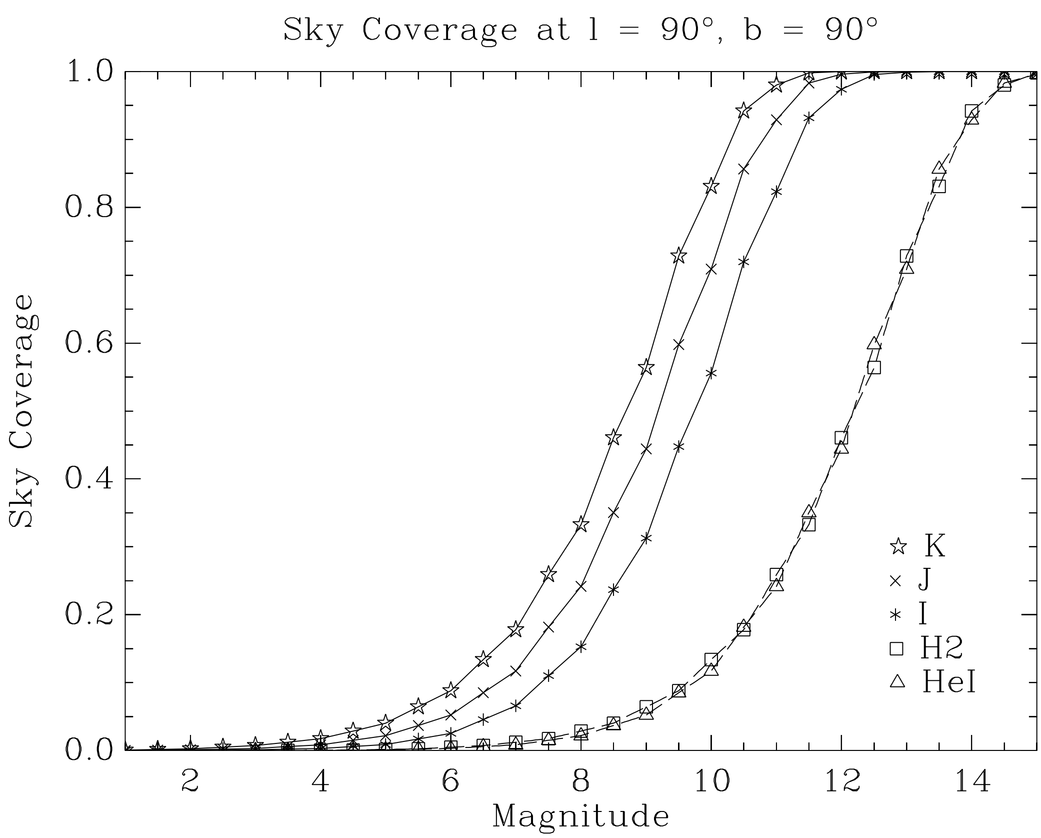

Sky Coverage at l = 180°, b = 5°
Sky Coverage
Magnitude
K
J
I
H2
HeI


Sky Coverage at l = 180°, b = 10°
Sky Coverage
Magnitude
K
J
I
H2
HeI


Sky Coverage at l = 180°, b = 20°
1.0
0.8
0.6
0.4
0.2
0.0
Sky Coverage
2
4
6
8
10
12
14
Magnitude
K
J
I
H2
HeI


Sky Coverage at l = 180°, b = 30°
1.0
0.8
0.6
0.4
0.2
0.0
Sky Coverage
2
4
6
8
10
12
14
Magnitude
K
J
I
H2
HeI


Sky Coverage at l = 180°, b = 60°
Sky Coverage
Magnitude
0.0
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
12
14
K
J
I
H2
HeI


Sky Coverage at l = 90°, b = 90°
Sky Coverage
Magnitude
0.0
0.2
0.4
0.6
0.8
1.0
2
4
6
8
10
12
14
K
J
I
H2
HeI