TABLE III

TEMPERATURE CALIBRATION FOR NORMAL GIANTS

T_e*	T_c*	b-y	B-V	$(V-I)_C$	$(R-I)_C$	(V-K)*	MK*
5000	4980	0.55	0.89	0.93	0.433		G7 III
4750	4730	0.60	0.98	1.00	0.461	2.31	K0 III
4500	4460	0.68	1.11	1.11	0.510	2.60	K2 III
4250	4140	0.80	1.26	1.28	0.600	2.96	K3 III
4000	3890	0.90	1.43	1.53	0.735	3.47	K5 III
3750	3560	1.00	1.62	1.97	1.025	4.24	M2 III
3500	3160			2.76	1.570	5.42	M4.5 III
3250	2580			3.80		6.84	M6 III

*From Ridgway, Joyce, White, Wing (1979)

TABLE IV

ABSOLUTE CALIBRATION OF PHOTOMETRY

Filter band	λ_0	Absolute flux density for mag = 0.00 F_ν
U	0.36 μ	1.81×10^{-23} W m^{-2} hz^{-1}
B	0.44 μ	4.26×10^{-23}
V	0.55 μ	3.64×10^{-23}
R_C	0.64 μ	3.08×10^{-23}
I_C	0.79 μ	2.55×10^{-23}
104	1.04 μ	2.00×10^{-23}
K	2.2 μ	6.49×10^{-24}

of $(B-V) = 0$.

VI. Instrumentation Considerations

A. *Filters*

The broad-band *UBVRI* passbands are defined by colored-glass combination filters and the sensitivity cut-off of the photocathodes. The filters not used are similar to those discussed by Bessell (1976), the changes permitting closer alignment to Cousins' natural system (see Appendix 1 for details).

These filters are

U	1 mm UG 2	+ $CuSO_4$
B	1 mm BG 12	+ 2 mm GG 385 + 1 mm BG 18
V	2 mm GG 495	+ 1 mm BG 18
R	2 mm OG 570	+ 2 mm KG3
I	3 mm RGN 9	.

The red-leak-blocking $CuSO_4$ filter can either be a liquid cell described in Paper 1, or a solid crystal filter obtainable from Interactive Radiation, New Jersey.

Most astronomical detectors used for precision observations are optimized for the faintest objects and are run at a fixed maximum gain setting. This mode of operation invariably results in many objects being too bright to measure directly, because of the possibility of detector damage or because of nonlinearities at high counting rates. A practical solution to this general problem is the use of neutral density filters. Many such absorbing filters commonly available are not very neutral, but show quite different attenuation with wavelength and have therefore not been used much in quantitative work. However, some metallic-alloy-coated, fused-silica filters manufactured by Oriel can be selected with constant attenuation to within 3% from 0.3 μ to 1 μ. Such filters would cause no effective wavelength shifts and only small reproducible zero-point shifts in the derived broad-band colors. Care should be taken, however, to avoid problems associated with light reflected from the filter.

B. *Photometric Methods*

It is possible that traditional Fabry-imaging photometry of individual objects will be increasingly replaced by multi-image filter photometry or by computer synthesis of color indices from digital spectra. In the first technique, many stars will be observed simultaneously in one color with an area detector at the focus of a direct camera; in the second, many colors will be "observed" simultaneously for one object with an area detector at the focus of a spectrograph camera.

The advantages of traditional photometry are simplicity, linearity, large dynamic range, high sensitivity, stability, and precision. The disadvantages are a requirement of photometric skies, a restriction to single-star observation, and an inability to work accurately with the small apertures necessary in crowded or high-sky-background fields. Area detectors admirably overcome these disadvantages but have great difficulty

matching the advantages, most importantly the precision and dynamic range. Synthesized indices from digital spectra can be measured with precision over a restricted dynamic range but wide wavelength coverage is usually limited by the grating blaze efficiency and off-axis vignetting of the spectrograph. The unique advantage of digital spectra however lies in the versatility of being able to compute color indices in any photometric system, as well as having spectral line and band information.

VII. Detector Systems

In Figure 11 are shown the relative spectral sensitivity curves (on a linear scale) for examples of three types of detectors currently in use: photomultipliers, imaging electronic detectors, and hypersensitized Kodak photographic plates (Kodak 1973). Also shown (plotted in units of Rayleighs per Å) is the smoothed (~ 100 Å) night-sky spectrum (Broadfoot and Kendall 1968), the brightness of which effectively limits the signal-to-noise ratio of ground based photometry of faint astronomical objects.

A. *Photomultipliers*

Table V lists data for three advanced tubes widely used in astronomy. Extended-red S20 photocathodes such as in the selected EMI 9658 *R* or 9659 *B* tubes can be used very successfully for *UBVRI* photometry. The effective wavelengths of the *V*, *R*, and *I* passbands obtained with the extended S20 differs only slightly from those obtained with the GaAs tube (Cousins 1974) and the standard star color indices transform precisely. There may however be small differences between the $(R-I)$ indices of extremely weak-line and strong-line K stars measured with some *R* filters and different cathodes. The 9658 *R* tube has a novel feature, its end window having an internal surface of pyramid-shaped prisms onto which the photocathode is deposited. This apparently increases the quantum efficiency in the 0.3 μ–0.9 μ region without significantly affecting the dark current.

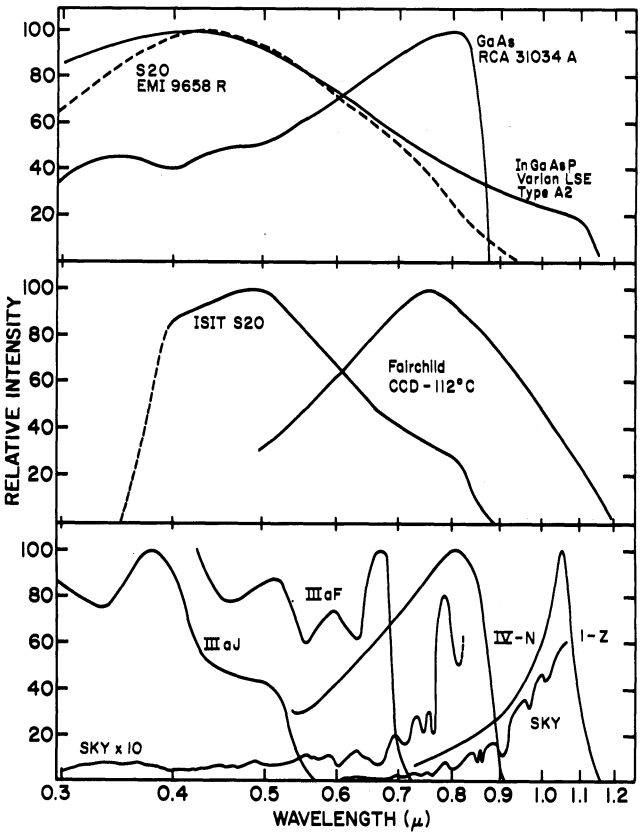

FIG. 11—Relative sensitivity curves for various detectors described in text.

The very red-sensitive RCA 31034 A tube is the "natural" tube of the Cousins *VRI* system and the Eggen-Kron *R,I* system. Cousins uses the tube at $-10°$ C while most other observers use dry-ice cooling at ~ $-78°$ C which produces slightly lower dark counts and a bluer red cutoff. Peculiarities of the tube are the low maximum permitted anode current of 0.1 μÅ (compared to 1 μÅ for the Varian tube and ~ 200 μÅ for the EMI tube) which corresponds to a count rate for some tubes of about 300,000 at a gain of 10^6; a hysteresis in some tubes at currents around 0.1 μÅ; and a poorer absolute sensitivity stability than other photomultipliers (however the relative sensitivity, i.e., color differences, is very stable). The cathode also requires an extremely high vacuum for proper operation, and any gas leakage via the metal pin-glass surfaces will result in sudden cathode destruction. Regular periodic use of the tube at anode currents in excess of 0.1 μÅ will result in slow permanent loss in photocathode sensitivity; experience has shown sensitivity losses of 2–3 over a two-year period.

The Varian tube has a unique solid photocathode with high blue sensitivity like an S20 tube, and a sensitivity beyond 1 μ which is 20 times that of a good Sl tube. It is an ideal tube to use for the Johnson (1966) *UBVRI* system, and could be used for an exact match to the Cousins or Kron *VRI* system with a red-cutoff filter at 0.88 μ. The tube should always be kept at a temperature below $-20°$ C and used at anode currents less than 1 μÅ (~ 3×10^6 Hz at a gain of 10^6), otherwise a slow, permanent loss of cathode sensitivity will result.

For most astronomical problems the more restricted wavelength responses of the GaAs or the extended S20 cathodes are adequate. The Varian tube however, will permit for the first time the measurement of the continuum color (0.75 μ-1 μ) and red-band strengths of faint galactic M dwarfs (Mould and McElroy 1978), and the extragalactic M giants, using narrow-band filters such as those of the Wing (1971) system.