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NOTES FOR THE OBSERVER

by T. P. Prabhu

Supernovae

A supernova event is a stellar explosion of the highest degree in which most of the star disrupts releasing an amount of energy comparable to the radiation output of the entire galaxy. If such an event takes place a hundred parsecs away, the apparent brightness of the supernova would rival that of the full moon. Among the very few galactic supernovae recorded in the history of mankind, probably the closest encounter was two kiloparsecs away—the event of 1054 A.D. which resulted in the Carb nebula. The two other supernovae that were well observed—one by Tycho Brahe in 1572 and the other by Johannes Kepler in 1604—exploded six and ten kiloparsecs away, respectively.

There are only seven definite recordings of galactic supernovae in the last two millennia—those of AD 185, 393, 1006, 1054, 1181, 1572 and 1604. A very young supernova envelope (Cassiopeia A) detected in the radio region might have resulted from an event noticed by Flamsteed in 1680, but the evidence is not conclusive. On the other hand, we now know that between three and ten supernovae must be occurring in the Galaxy in every century. Supernovae are the final events in the lives of stars of short and intermediate life-spans, and hence tend to form close to the galactic disc which is extremely dusty. Our own location in the galactic plane allows us to study optically only a small region of the disc, thus explaining why so few supernovae have been discovered. Even so, it is difficult to understand the lack of optically detectable supernovae over the past three centuries when the astronomical awareness has only been increasing. It is hence highly probable that the next galactic supernova would be detected within the lifetime of the present generation of astronomers (S. van den Bergh 1975 : *Ap. Sp. Sci.* **38**, 447). It is, therefore, imperative for every astronomer to acquaint himself with the problems of supernovae and the techniques of their observations, so that no time is lost in accumulating all the relevent information on this transient and rare event.

The radio part of electromagnetic spectrum suffers very little loss due to interstellar dust. We can therefore observe almost the entire galaxy in the radio band. If frequent radio surveys of the entire band of the Milky Way are undertaken in future, it is quite likely that we will discover several supernovae that may not be very bright in the optical region (W. T. Sullivan 1982 : *Publ. Astr. Soc. Pacific* **94**, 901).

Since a supernova reaches an exceptional brightness at maximum light, it can be seen even at the distances of external galaxies, If the supernova rate is once in a few decades in an individual galaxy, we should expect one every year in a sample of a few dozen galaxies. The number of galaxies that can be observed with the telescopes of small and moderate size is more than an order of magnitude higher. Indeed, the extragalactic supernovae have been recorded at least since 1885, initially as chance discoveries, but later as a result of systematic patrols. Supernovae were probably seen even earlier, by Bulliald in 1664 in M31, by Argelander in 1855 either in NGC 2941 or in NGC 2943, and by Argelander again in 1856 in NGC 968; but the association of these observations with supernovae has been in doubt. The event of 1885 was discovered by Hartwig in M31. This supernova was designated nova S Andromedae in the days when no distinction was made between novae and supernovae. This was the second confirmed variable in Andromeda as the name implies; the first one—R Andromedae (long-period variable of 409-day period, 6–15 mag)—had been known since 1858. S Andromedae exploded at a time when the Henry Draper survey was in progress, and thus also got an HD designation (HD 3969). Currently, the extragalactic supernovae are designated by the year of explosion followed by the letter of alphabet in lower case, in the chronological order of the date of the event. The name of the galaxy is specified as an additional information. The extragalatic supernovae discovered until 1935 appear in table 1, based on the information from the *General Catalogue of Variable Stars* (Kukarkin *et al.*). The list contains 21 confirmed supernovae and three possible ones.

Table 1 shows what was already apparent in 1935: There were 21 chance discoveries of (confirmed) supernovae in 50 years, implying that a systematic search to a fainter magnitude should yield many more supernovae. Fritz Zwicky advocated such a systematic patrol, and soon put it into operation. Due to his efforts and their continuation by several observatories, we now know over 500 extragalactic supernovae. The current discovery rate is about a dozen supernovae brighter than sixteenth magnitude, and also a few fainter ones, every year. And the sky patrol is by no means complete!

Table 1. Extragalactic supernovae discovered before 1935

Designation*	Old name	Galaxy NGC	Galaxy type	Supernova maximum magnitude
1885a	S Andromedae	224	Sb I-II	5.4
1895a	VW Virginis	4424	SBa III	11.1
1895b	Z Centauri	5253	I0 pec	7.5
1898		224	Sb I-II	<10
1901a	Nova Cancri	2535	Sc pec	⩽14.7
1901b	Nova Leonis	4321	Sc I	12.1
1907a		4674	SB0/a pec	⩽13.5
1909a	SS Ursae Majoris	5457	Sc I	12.1
1912a		2841	Sb I	<16.3
1914a		4321	Sc I	<14.0
1915a		4527	Sbc II	13.0
1915		3338	Sc II	<14.4
1916a	RS Piscium	251	Sc	⩽14.5
1917a	Nova Cephei	6946	Sc I	12.9
1919a	Nova Virginis	4486	E0 pec	11.5
1920a		2608	SBb II	10.5
1921a		4038/9	SBm/Sm	—
1921b		3184	Sc II	10.7
1921c		3184	Sc II	11.0
1922	Nova Virginis	4486	E0 pec	—
1923a	Nova Centauri	5236	Sc I-II	13.5
1926a		4303	Sc I	12.6
1926b		6181	Sc I	<14.2
1934a		4719	SBb	13.4

*Supernovae without the alphabetical designations are the ones which were not confirmed.

The most basic information on a supernova is its spectral type, because it is only spectroscopically that a supernova can be classified into one of the two distinct types. Apart from the spectroscopic differences between type I and type II supernovae, the two classes behave differently in their photometric properties and their distribution in the plane of the galaxy, and occur with different frequencies in different types of galaxies. The two kinds of supernovae may therefore have different kinds of precursor stars. Unfortunately spectral types are not known even for a fifth of the supernovae discovered so far. A classification spectrum of a supernova can be obtained only immediately after its discovery before the supernova fades away. Many a times supernovae are discovered in the western sky in the evening, making a followup rather difficult after a few weeks. Also, two weeks are lost during the first month after discovery because of a bright moon. Thus a spectrum of a supernova is best obtained very soon after its discovery. The telegram service of the International Astronomical Union gives a quick information on the discovery of a supernova. However, a spectrum can be obtained only if the observatory treats it as a priority program, and makes the telescope available for it immediately.

Certain firm inferences can be drawn even from a few scores of supernovae whose types are available. The frequency of supernovae—irrespective of the type—increases from the spirals of Hubble types Sa to Sc, and also from the less luminous to the more luminous ones.

The same correlation holds good with the galaxian colour too. All these parameters represent the current rates of star formation in galaxies. Thus it would appear that the supernova rate is correlated with the present rate of star formation indicating that all supernovae originate from the young population of stars. Supernova rate is also very high in de Vaucouleurs I0 (or Sandage's Irr II) galaxies which appear to be forming stars at a very high rate, scattered over the entire galaxy giving it an irregular appearance. The star formation probably results from a recent acquisition of an abundant supply of gas (nouvean-riche spendthrifts !). This fact again indicates that the supernova precursors are young stars. On the other hand, type I supernovae have occurred in several elliptical galaxies, which have produced no type II so far. Now, ellipticals are believed to be systems of old stars, containing insufficient cool gas to currently form stars. This would lead us to a conflicting idea that the progenitors of type I supernovae are old, low-mass stars. Since classified supernovae in I0 galaxies are all of type I, it has been suggested that type I supernovae are the death throes of intermediate mass stars and the ellipticals with supernovae formed stars 10^8 years ago (Y. Oemler & B. M. Tinsley 1979 : *Astr. J.* **84**, 985). However, no convincing evidence has appeared so far that elliptical galaxies have experienced a burst of star formation recently. Accurate spectrophotometric work on these galaxies can help to resolve this problem.

While highlighting the need for spectroscopic information on supernovae, one should not neglect the importance of photometry. The shape of the light curve provides constraints on the models of supernova explosion. It also appears that the maximum luminosity of a supernova (particularly of type I) is fairly constant for all supernovae and hence may be treated as an extragalactic distance indicator. Another—probably more optimistic—idea is that the rate of decline of light is a luminosity indicator. Supernovae have already been used as standard candles, but with a rather lower degree of confidence. Indeed, we have taken a full turn since the arguments put forward in the beginning of this century that "spiral nebulae" were a part of the Galaxy since the few supernovae known at that time were taken to be similar to the galactic novae; the existence of a higher degree of explosion was apparent only after the first indications of the extragalatic distance scale became apparent. Before we may rely on the supernovae as distance indicators, we need to test the constancy of their maximum light—and in case there is an intolerable intrinsic dispersion in the absolute magnitudes at maximum—correlate the departure from the mean with other photometric and spectroscopic parameters. Of course, the most basic requirement is that more supernovae in nearby galaxies be discovered before they reach maximum, and that their light curves be monitored constantly. This would help in improving our understanding of the peak brightness–rate of decline relationship.

In summary, a quick discovery, a quick spectrum, and continuous photometric monitoring of extragalactic supernovae would open up new vistas of knowledge on the nature of the supernovae, on the nature of star formation in galaxies and on the extragalactic distance scale. The experience gained in the field would also keep us in readiness for a much more informative event—the next Galactic supernova !

The radio supernova in M106

Sullivan's prophecy mentioned above has almost come true—not in our Galaxy, but in NGC 4258 (= M106), an Sc type spiral in Canes Venatici, in the outskirts of the Coma cluster of galaxies about 20 Megaparsecs away from the earth. A team of radio astronomers—R. Davies & A. Pedlar from U. K., J. M. van der Hulst & G. D. van Albada from Holland and E. Hummel from Germany—found a compact radio source in one of the spiral arms of the galaxy while observing with the very large array in 1982 January. The source was not seen on the Westerbork radio maps of 1979 June, nor in 1974–75. Its intensity was reduced by half in late 1982. P. Wild of Switzerland, re-examining the supernova patrol plates, found a faint star (17th mag) in this position on a plate taken in 1981 November. It appears that it was indeed a supernova, not detected optically since it was heavily obscured by dust and thus did not stand out in contrast with the bright spiral arm. In addition to strengthening Sullivan's case for radio survey of supernovae in our Galaxy, this discovery also casts doubts on the frequency of supernovae estimated from optical surveys of external galaxies. Probably many supernovae embedded in dusty spiral arms go undetected.

Evans's supernova in M83

Reverend Robert Evans, an amateur astronomer in Australia has yet another supernova to his credit. He discovered on July 3 a supernova in NGC 5236 (= M83) at a magnitude of 13. The importance of this discovery lies in the fact that Evans caught it well before maximum. This early discovery has led to a quick follow up not only in the optical region, but in x-rays (through recently launched Exosat), the ultraviolet (IUE), the infrared (IRAS) and in the radio regions. The observations covering such a wide range in wavelenghts and beginning two weeks before maximum are expected to unravel several mysteries of supernova phenomenon.

Unfortunately, this supernova has occurred when the north-western monsoon is strong over the Indian peninsula, and it will soon be lost to the sun's glare, for a few months before it becomes an early morning object. A low-dispersion spectrogram obtained by me using the Kavalur 102-cm telescope through moonlit clouds on July 18.6 UT when the supernova was close to its maximum brilliance, shows broad absorptions at 4200, 4700, 5200 and 5700 superposed over a blue continuum. These are the very features that appear in emission in the post-maximum spectra.

Shells of novae

The outer envelope of a nova is ejected explosively at the time of an outburst. The optical spectrum after outburst until minimum is dominated by this envelope. The nova spectrum before and at maximum light resembles that of a supergiant except for a high expansion velocity indicated by the absorption lines. The velocities range from a few hundred to a few thousand kilometres per second in different novae. As this envelope expands, the absorption spectrum changes over to P Cygni profiles (which are characterized by redward emission and blue-shifted absorption); when the optical thickness in the lines reduces considerably, we will see the emission-line spectrum of the shell superposed on the spectrum of the nova remnant. This is the final 'nebular stage' in the development of a nova spectrum.

The photosphere of a nova attains the largest radius around maximum light. Thereafter, it begins to recede as the optical thickness of the envelope decreases. Thus the photosphere lags behind the expanding envelope. Consequently, the blackbody radiation coming from the photosphere declines with time, while the contribution of the free-free and free-bound transitions to the continuum light increases. This phase is termed the free-free expansion phase. The light in the optical continuum decreases linearly during this phase. Once the envelope has become an optically thin shell, the light decreases quadratically with time. Dust grains form in the envelopes of slow novae during this phase, resulting in a deep minimum (due to obscuration) in the optical curve. This energy is reradiated as the infrared radiation from heated dust. Observations in the near-infrared region of the spectrum help in distinguishing the different phases—the blackbody expansion phase, the free-free expansion phase and (in some novae) the dust formation phase.

The continuum during the blackbody expansion phase may be fitted to a blackbody spectrum to obtain the angular radius of the photosphere

$$\theta(t) = 1.0 \times 10^{11} \; (\lambda F_\lambda)^{1/2}_{\max} \; T^{-2}$$

for θ in arcseconds, temperature T in Kelvin and λF_λ in watts cm^{-2}. The wavelength range of at least 0.35–3.5 μm (or *UBVRIJKL* bands) is necessary to define the blackbody spectrum. From these estimations of angular velocity, one can obtain the distance D to the nova from the relation

$$\frac{d\theta}{dt} = \frac{v_{\mathrm{exp}}}{D}$$

in absolute units. Here v_{exp} is the expansion velocity of the photosphere, which is the same as that of the envelope in this phase. This is a well-known method due to Walter Baade.

In several cases, the expanding shell has been observed photographically in the later stages, when its size becomes optically measurable. The classic example is that of V603 Aquilae (1918) whose shell was photographed three and a half months after maximum light by E. E. Barnard. The expansion rate of the radius of the shell was later determined to be 1 arcsec yr^{-1}. The expansion velocity of 1700 kms^{-1} or 340 A.U. yr^{-1} inferred from the widths of the emission lines yields a distance of 340 parsecs for the nova. Very few classical novae have exploded at such close quarters, another example being DQ Herculis (1934) at a distance of 260 pc.

V603 Aquilae is also important on another account. As soon as its shell was photographed, W. H. Wright obtained slitless spectrograms of the shell in different position angles. He noticed that spectrographic images were symmetric in the position angle 112° and antisymmetric in the position angle 202°. The nova shell obviously possessed an axis of symmetry though not spherical symmetry. Wright continued his observations to obtain a series of slit spectra in these two position angles. The spectra were analysed a few decades later by H. Weaver (1974, *Highlights of Astronomy* **3**, 509) who reconstructed the three-dimensional structure of the nova shell from these data. The detailed model included a polar cap approaching the earth, an equatorial ring and a parallel ring on each side of it, in addition to thinner rings at different latitudes and two diametrically opposite holes.

It now appears that such a model of polar caps and equatorial rings may be a common feature of the majority of nova shells. The only exception to this structure is a rare GK Persei-type envelope which is totally devoid of symmetry. E. R. Mustel & A. A. Boyarchuk (1970, *Ap. Space Sci.* **6**, 183) have photographed such structure in another nearby nova—DQ Herculis. Once the concept of the structure is formulated, one can model the structure simply from the emission-line profiles observed in the nebular stage. The emission lines at this stage exhibit multiple components, which result from a super-position of a double-peaked profiles from each ring, and a single peak from each polar blob. J. B. Hutchings (1972, *M.N.R.A.S.* **158**, 177) has modelled the shells of HR Delphini (1967), LV Vulpeculae (1968) and FH Serpentis (1970) in this fashion (see also I. Malakpur 1973 : *Astr. Ap.* **24**, 125 and T. P. Prabhu 1977 : *Kodaikanal Obs. Bull. Ser. A* **2**, 75).

The expansion velocity of the shell is an important parameter in the reconstruction of the structure of the nova shell. The spectrum of a typical nova shows different absorption syytems with different velocities in different phases of evolution. The different systems may also coexist at a given time. All these velocities may not really represent the expansion velocity of the envelope, but may depict the velocity of a localized region that may contribute maximally to the line spectrum at each epoch. An understanding of these velocity systems is yet to be achieved. It appears that the half-width of the emission lines at half-maximum represents the actual expansion velocity well. The experience with V603 Aquilae and DQ Herculis suggests that the velocity field may be slightly anisotropic, the polar regions travelling faster than equatorial regions, thus giving an ellipsoidal shape to the envelope. Probably, the axial symmetry should be treated more rigorously and the velocity field varied while constructing the models.

If the distance and the interstellar absorption to the nova are estimated, the mass of the shell can be estimated from the observed flux in a Balmer line. The estimated absolute flux leads to the electron density, which, when multiplied by the mass of the hydrogen atom and the emitting volume of the shell, results in the mass of the envelope. The volume of the emitting region involves the estimation of the radius of the shell, its thickness and the 'filling factor' or the fraction of the shell that is filled by the gas. Whereas the former can be inferred from the expansion velocity, epoch after outburst (or directly the observed angular radius) and the distance, the other two are more difficult to guess. Assuming that a tenth of the volume is filled with gas and the thickness of the shell is a tenth of its radius, one obtains masses of the shells in the range of 10^{-5} to 10^{-4} solar masses—decidedly a very small mass compared to the shells of supernovae.

The old nova GK Persei

The old nova GK Persei (1901) is undergoing another of its periodic mild outbursts according to J. Mattei of American Association of Variable Star Observers (*IAU Circulars No. 3840, 3848*). From its normal visual brightness of 13.3 in 1983 April, it rose to 12.5 in early July, and reached 11.5 on July 23. Such outbursts of amplitude 1–3 mag have been recurring in GK Persei every 2–3 years at least since 1966; data are scanty for earlier years, and only two outbursts (one in 1930 and another in 1949) are recorded. The light curve of GK Persei between 1928 and 1978 has been compiled by R. Hudec (1981, *Bull. Astr. Inst. Czech.* **32**, 93) who lists eight outbursts during this period. The 1981 outburst has been reported in *I.A.U. Circular No. 3574.* M. G. Watson & A. Smith (1983: *I. A. U. Circular No. 3850*), using Exosat, have not only detected an x-ray brightening, but also discovered a periodicity of 351 seconds.

Wide-band photometric systems

The idea of the photometric systems originated with the introduction of the photographic plate in astronomical photometry. The early photographic emulsion was sensitive only to the radiation from ultraviolet to blue, as compared to the human eye which is sensitive from violet to red with a peak in the green region. Thus a distinction was made between the photographic and visual systems of magnitudes. As methods were developed to sensitize the photographic emulsion to longer wavelengths, photometric bands such as the photovisual were brought into practice. However the photoelectric photometer was soon to be introduced, which was highly favoured because of its linear response, high detective quantum efficiency and low noise when cooled. Thus the photographic emulsion was redueed to be a detector of secondary importance in photometry, used only when one needed its features of special advantage—the two-dimensional format, and a capacity to integrate over a long duration. The modern photometric systems are defined primarily with respect to the photoelectric photometer. The photographic systems also mimic these standard systems.

Standard photometric systems are generally classified into three groups: wide-band, intermediate-band and narrow-band. The wide-band photometric systems have typical bandwidths of 20% of the central wavelength and the intermediate-band a few per cent. The narrow-band systems with bandwidths of a few tens of Angstroms are used in a study of the strengths of absorption or emission features, individually or in groups. A further improvement in the spectral resolution can be achieved only through low- and high-resolution spectrophotometry.

Several wideband systems have been designed by different groups of investigators. The different wideband colours and indices have been calibrated with varying degrees of success, as indicators of stellar effective temperature, surface gravity, metallicity and the interstellar extinction suffered by the star-light. The different systems have thus been used in a statistical investigation of stars with respect to these properties, in testing theories of stellar and galactic evolution, and understanding the content and distribution of interstellar dust. It should be borne in mind that the best data are obtained at the highest spectral resolutions. Yet, with the advantage of reaching fainter and farther with a given equipment, a judicious choice of a wide-band photometric system can give us the first indication of the solution to an astrophysical problem. We describe a few of the important systems below.

The RGU system

A photographic system still in use, albeit mainly in the studies of stellar statistics, is the *RGU* system due to W. Becker (1946). This system isolates three bands—red (6400 Å), green (4700 Å) and ultraviolet (3700 Å), each about 500 Å wide. The advantage of this system lies in its ability to separate the disc and halo populations, and also the dwarfs and giants in the $(U - G, G - R)$ diagram. These properties make the system an excellent choice for application in star count studies.

The UBV system

The most popular wideband system in photometry is the *UBV* system devised by M. L. Johnson & W. W. Morgan in 1953. This system was originally developed for the RCA 1P21 photomultiplier; but equivalents have been developed for other types of detectors—photographic as well as photoelectric. Johnson & Morgan used Corning 9863 filter to isolate an ultraviolet (U) band of effective wavelength 3650 Å and a bandwidth of 680 Å. They also employed Corning 5030 cemented to a Schott GG 13 filter to isolate the blue (B) band of 980 Å bandwidth at 4400 Å, and Corning 3384 to isolate the visual (V) band of 890 Å bandwidth at 5480 Å. The Johnson & Morgan U band is similar to the one in *RGU* system, except that the former extends little more to the ultraviolet. The G band lies in between the B and V bands. The V band is termed *visual* since it resembles the human eye in its wavelength response.

The *UBV* system was developed mainly for a photometric study of stars classified spectroscopically according to the MKK (W. W. Morgan, P. C. Keenan & E. Kellman) system. Though it is not as sensitive to the luminosity class as the *RGU* system, it can be used with confidence in estimating the spectral type and the interstellar reddening and extinction over a range of colours. Since the B band includes the region 4000–4500 Å which is affected by absorption lines due to metals, the *UBV* system has also been used to define a crude metallicity indicator.

A photometric system is affected not only by the detector and the filter, but also by the telescope and other optics in the path of the starlight, as well as by the local and temporal variations in the characteristics of the atmosphere. (Johnson & Morgan used a reflector telescope at an altitude of 2150 m). It is therefore customary to define a photometric system by a set of standard stars. One may use the filters with slightly different characteristics to offset the differences in the optics and the atmosphere, but one needs to obtain a close agreement with the magnitudes and colours of the primary standard stars. The small differences that may exist between the instrumental and standard magnitudes may be corrected in the reductions of photometric data by using linear relationships of the form

$$\text{Standard magnitude} = a \times \text{instrumental magnitude} + b \times \text{colour of the star},$$

where a and b are constants determined using the standard stars. Such equations are called the transformation equations. A list of primary standard stars in the *UBV* system is given in table 2, taken from Johnson [1963, *Basic Astronomical data* (ed. : K. A. A. Strand) Univ. of Chicago Press, p. 204]. Like all the broadband systems, the *UBV* system is also affected by the intrinsic spectral energy distributions of stars. Thus, one needs to check the performance of one's equipment over a wide range of spectral types. That is why the primary standard stars are chosen over a wide enough range. Yet, these stars are too few in number and some of them may not be available in a given night. A large number of secondary standard stars and photoelectric sequences are now available, and make the photoelectric observations relatively easy. The equatorial *UBVRI* photoelectric sequences of T. J. Moffett & T. G. Barnes (1979, *Astr. J.* **84**, 627) and its parent *UBV* catalogue of equatorial standard stars by A. U. Landolt (1973, *Astr. J.* **78**, 959) are particularly to be recommended.

Table 2. Primary standard stars in the *UBV* system

HD	Name	V	$B-V$	$U-B$	Spectral type
12929	α Arietis	2.00	+1.151	+1.12	K2 III
18331	HR 875	5.17	+0.084	+0.05	A1 V
69267	β Cancri	3.52	+1.480	+1.78	K4 III
74280	η Hydrae	4.30	−0.195	−0.74	B3 V
135742	β Librae	2.61	−0.108	−0.37	B8 V
140573	α Serpentis	2.65	+1.168	+1.24	K2 III
143107	ε Coronae Borealis	4.15	+1.230	+1.28	K3 III
147394	τ Herculis	3.89	−0.152	−0.56	B5 IV
214680	10 Lacertae	4.88	−0.203	−1.04	O9 V
219134	HR 8832	5.57	+1.010	+0.89	K3 V

Other multicolour systems

Among other important broadband systems, we have the 7-colour Geneva photometry due to F. Rufener (1963; see M. Golay 1972: *Vistas Astr.* **14,** 13). The seven bands are U (3460 Å), B (4250 Å), V (5510 Å), B_1 (4020 Å), B_2 (4480 Å), V_1 (5410 Å) and G (5810 Å). A subset of these—$UB_1B_2V_1G$—is at times used as Geneva 5-colour photometric system.

The first attempt at extending the multicolour photometry into the infrared region was due to J. Stebbins & A. E. Whitford (1943, *Ap. J.* **98,** 20) who developed the 6-colour *UVBGRI* system (note that V is for violet and not visual). The effective wavelengths are 3550 Å(U), 4200 Å(V), 4900 Å(B), 5700 Å(G), 7200 Å(R) and 1.03 μm(I). The bandwidths are about 800 Å for the first four bands and 1500 Å for the remaining two bands. G. E. Kron & J. L. Smith (1951, *Ap. J.* **113,** 324) suggested an alternative *RI* system with effective wavelengths of 6800 Å and 8250 Å respectively to supplement the photographic and photovisual bands. The most popular red-infrared system is the *RIJKLMN* system of H. L. Johnson (1965, *Ap. J.* **141**, 923) with effective wavelengths (in μm) of 0.70(*R*), 0.88(*I*), 1.25(J), 2.20(*K*), 3.60(*L*), 5.00 (*M*) and 10.20(*N*). This is now generally used as an extension of the *UBV* system. Observations in the *RI* bands can be carried out using a photomultiplier with S-1 or some S-20 cathodes. The extended-red S-20 photomultipliers are now preferred to the S-1 cathodes becausee of their increased sensitivity, though the infrared response does not extend as far out as that of S-1. Table 3 lists a combination of filters suggested by J. D. Fernie (1974, *Publ. Astr. Soc. Pacific* **86**, 837) for use in conjunction with EMI 9658R.

Table 3. Suggested filters for *UBVRI* photometry with extended-red S-20 photomultiplier (Fernie 1974)

Band	Filters
U	UG2 (2mm) + BG18 (2mm)
B	BG12 (2mm) + BG18 (2mm) +GG 4 (1mm)
V	GG14 (3mm) + BG18 (2mm)
R	OG550 (2mm) + RG6 (1mm)
I	BG3 (1mm) + RG610 (2mm)

The observations in the infrared bands call for a different technique and different detectors. The PbS detector is generally used for *JKL* bands, the InSb detector for *KJLM* bands, and a bolometer for *MN* bands. A *Q* band at 20 μm (bolometer) and an *H* band at 1.6 μm (PbS/InSb) are also at times added to this system. The complete *UBVRIJHKLMNQ* system is sometimes referred to as the *alphabet-soup* system.

A wideband system especially suited for the observations of galaxies is that due to W. G. Tifft (1961, *Astr. J.* **66**, 390). The bands in this system are designated numerically as 1(3750 Å), 2(4180 Å), 3(4835 Å), 4(5945 Å), 5(6050 Å), 6(7850 Å), 7(8300 Å) and 8(1.0 μm). Tifft has observed with different apertures a large number of galaxies in the first four bands, deriving the various magnitude and colour profiles. These bands are particularly helpful in arriving at crude estimates of metallicity and the relative frequencies of young and old populations.

A relatively more recent wideband photometric system is the Washington CMT_1T_2 system designed by G. Wallerstein and developed by R. Canterna (1976, *Astr. J.* **81**, 228). The *C* band of 1100 Å width at 3910 Å is sensitive to the bands of cynogen (CN); the metallicity sensitive *M* band is at 5085 Å (1050 Å wide). The T_1T_2 bands at 6330 Å (800 Å wide) and 7885 Å (1400 Å wide) are designed to enable an effective temperature calibration through the index $T_1 - T_2$ The system is designed for use with a GaAs detector like the RCA C31034.

Finally, a mention should be made of a recent photographic system. The excellent performance of the fine-grained emulsions IIIa-J and IIIa-F has prompted the photometrists to develop a blue-red photographic system for applications related to the photometry of faint objects, particularly over a wide field. W. J. Couch & E. B. Newall (1980, *Publ. Astr. Soc. Pacific* **92**, 746) discuss such a *JF* system, and also a photoelectric analogue that can help in an accurate calibration of the photographic photometry. The characteristics of this system are given in table 4.

Table 4. The photographic *JF* system (Couch & Newall 1980)

Band	Photographic	Photoelectric EMI 9658 AM(S-20) +	λ_{eff} Å	$\Delta\lambda$ Å
J	IIIaJ + GG 385	GG385 (2mm) + BG 28 (2mm)	4385	1050
F	IIIaF + RG 630	RG630 (3mm) + BG 20 (3mm) + BG 38 (1mm)	6676	500

A photoelectric hour-angle solar guider

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For studying a particular feature on the solar disc, it is necessary to keep the image of the sun fixed with respect to the instrument over the duration of the observations. However, the atmospheric refractions, irregularities in the drive system and the mis-alignment of the polar axis of the coelostat cause the image to drift from its position. The drift due to misalignment of the polar axis can be made negligible by accurately aligning the polar axis. However, the drift of the solar image due to atmospheric refraction and irregularities in the drive system is not easy to correct manually. We have designed an hour-angle guider to apply automatic corrections for drift in the east-west direction.

The hour-angle guider is a system giving a 50 Hz sine-wave output. The frequency of the output signal changes depending upon the direction of the drift of the solar image. The first mirror of the coelostat rotates with half the rotational velocity of the earth with the help of a synchronous motor. If there is any displacement of the image in the east-west direction, the speed of the motor is automatically changed to compensate for the drift.

A block diagram of the hour-angle guider is shown in figure 1. The image position sensor system consists of two photodiodes placed on the eastern and the western limb of the solar image. The relative displacement in the east-west direction of the image

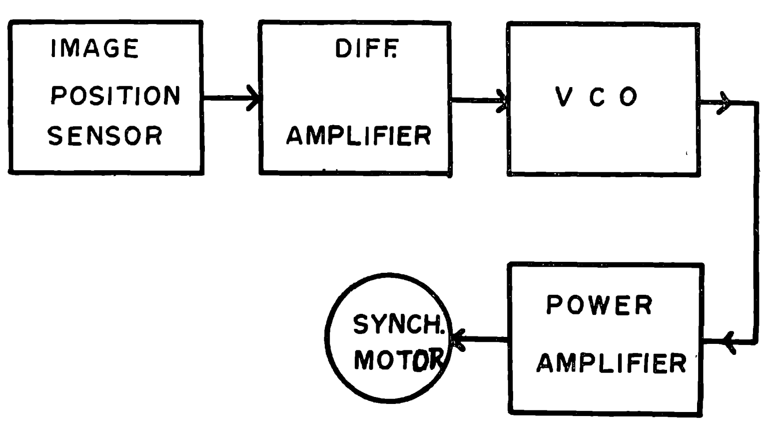

Figure 1. Block diagram of photoelectric hour-angle guider.

with respect to the two diodes produces variations in the light flux falling on the photodiodes, which convert these variations into electrical signals. The outputs are fed into the inverting and noninverting inputs of an operational amplifier which is used as a differential amplifier. The output of the differential amplifier is then applied to the gate of a field effect transister (FET) of a voltage-controlled oscillator (VCO). The channel resistance of the FET changes depending upon its gate voltage. The frequency output of the VCO changes with the change in the channel resistance of FET. The output signal of the VCO is fed to a power amplifier. The required speed control is achieved by driving a synchronous motor with the output of the power amplifier.

The schematic circuit diagram of the photoelectric hour-angle solar guider is shown in figure 2. When the photodiodes (GP 120) receive equal amounts of light flux, the output of the differential amplifier should be zero in ideal case; but in actual practice as the characteristics of the two photodiodes may not necessarily be identical, a

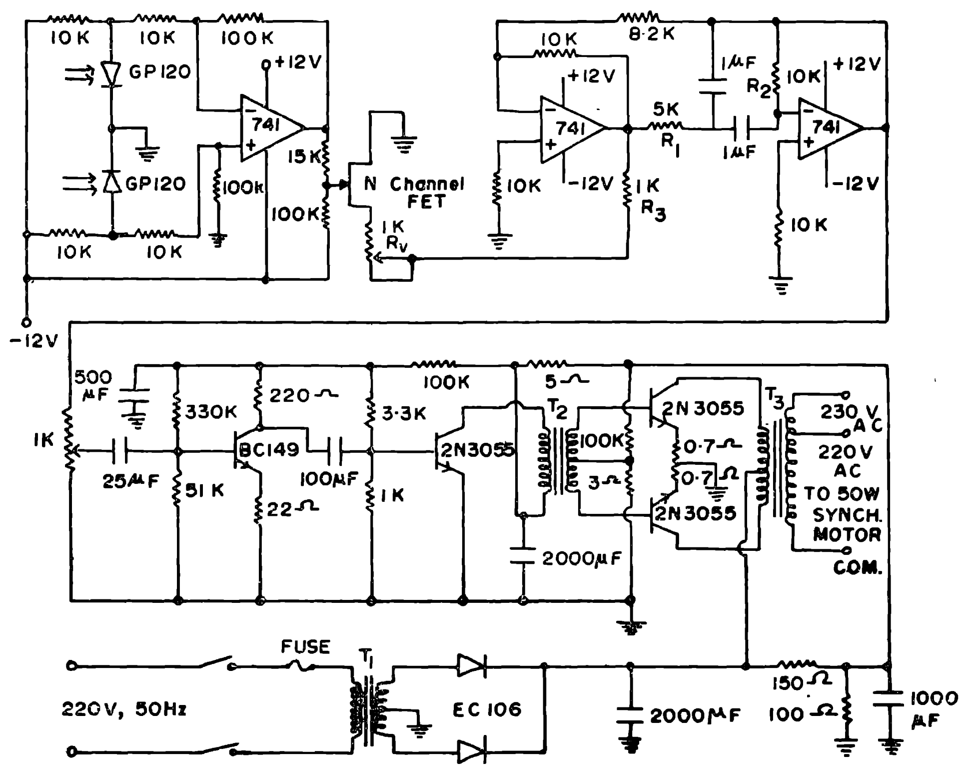

Figure 2. Schematic circuit diagram of the photoelectric hour-angle solar guider.

voltage V_1 appears on the gate of the FET which is responsible for a change in its channel resistance. The resistances R_3, R_V and the channel resistance of the FET are adjusted to control the frequency of the VCO. The frequency of the VCO can be calculated from

$$f = \frac{1}{2\pi C}\sqrt{\frac{R_1 + R'_3}{R_1 R_2 R'_3}},$$

where $R'_3 = R_3 + R_V +$ channel resistance of the FET, and $C = C_1 = C_2 = 1\ \mu$F.

Initially; when the two photodiodes receive equal amounts of light flux, the frequency of the VCO is adjusted to 50 Hz by means of the potentiometer R_V. This 50 Hz signal is amplified by a power amplifier to run a 220V, 50 Hz synchronous motor of the coelostat. If one photodiode receives higher light flux as compared to the other the gate voltage of the FET is either positive or negative with respect to V_1 depending upon the direction of the displacement of the solar image. In case it is positive, the channel resistance of the FET is reduced, and correspondingly the frequency of VCO increases. This causes the synchronous motor to run faster until the photodiodes receive equal amounts of light flux. Similarly, if the other photodiode receives more flux than the first one, the gate voltage of the FET is negative with respect to V_1. The frequency of the VCO would then decrease and consequently the speed of the synchronous motor reduces until both the photodiodes again receive equal amounts of light flux. Thus, the image of the sun is always kept at a fixed position.

The above guider is being used successfully with a 46-cm coelostat for the last two years. A similar instrument can be designed to guide the solar image in declination too, controlling the position of the second mirror of coelostat.

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