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COMPUTED LUMINOSITIES FOR T TAURI AND RELATED OBJECTS

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RESUMEN

Datos adicionales y mejorados en conjunción con hipótesis más realistas sobre la extinción han permitido calcular nuevas luminosidades de once objetos de la familia T Tauri. Se consideran tanto las luminosidades espectroscópicas como las fotométricas, en algunos casos éstas son diferentes. La discrepancia puede salvarse si la extinción que afecta a estas estrellas es peculiar con un alto cociente de la absorción total a selectiva. Los valores recalculados dan buena representación de las luminosidades que tienen los objetos. Su posición en el diagrama de Hertzprung-Russell es consistente con los resultados de otras investigaciones, la cual se ha usado para estimar las masas y edades de estas estrellas.

ABSTRACT

Improved and additional data for the T Tauri-like objects, with more realistic assumptions concerning extinction, allow us to calculate new values for the luminosities of eleven stars. Both the spectroscopic and photometric luminosities are considered; in several cases, they are found to disagree. These discrepancies may be resolved if the extinction affecting these stars is peculiar, with a large value of the ratio of total to selective absorption. The recalculated values of the spectroscopic luminosities then give a good representation of the luminosities of the objects. The stars are located in the Hertzsprung-Russell diagram; their positions are consistent with previous investigations and have been used to estimate the objects' masses and ages.

Key words: T TAURI OBJECTS—LUMINOSITY—EXTINCTION.

I. INTRODUCTION

In order to calculate the luminosity of a star from its photometric observations, one needs some knowledge of the intrinsic colors and extinction of the star. The T Tauri and related objects have several properties which complicate the determination of their luminosities: ultraviolet and infrared excesses, peculiar spectra, variability, and large amounts of extinction which may be both interstellar and circumstellar.

Mendoza's (1966, 1968) earlier approach was to make such assumptions as to ensure the existence of the newly discovered infrared excesses; therefore he chose the latest available spectral types and assumed all the extinction of the stars to be interstellar. Imhoff (1973) attempted to derive the physical properties of the stars and their circumstellar shells; she adopted Herbig and Rao's (1972) spectral types and assumed all extinction to be circumstellar.

Now it has become possible to make a more definitive study of the luminosities of T Tauri and related objects. Recent interest in these stars has resulted in a number of improvements of the basic spectroscopic and photometric data. In addition, a more realistic consideration of the extinction affecting these stars is presented in this paper.

The following discussion will begin by considering the observational data available and the assumptions adopted for the T Tauri stars. Likewise the techniques of calculation and the resultant luminosities are examined, concluding with the implications of this work with regard to the extinction affecting the stars. It is necessary to consider this work in some detail to ensure that each step in the derivation of the luminosities is clear and reasonable and to delineate its relationship to other research going on in the field.

II. OBSERVATIONAL DATA AND ASSUMPTIONS

The most complete list of spectral types for T Tauri-like stars is the catalogue of Orion population stars by Herbig and Rao (1972). The spectral types adopted here are, for the most part, those from the Herbig and Rao catalogue. Two exceptions are the spectral types for R Mon and R CrA; for these stars the spectral types assigned by Mendoza (1970) and Mendoza *et al.* (1969) will be employed.

Only two stars have been given luminosity classes; SU Aur has been designated as III (Herbig and Rao 1972) and FU Ori as I-II (Herbig 1966). R Mon, R CrA, and V1057 Cyg may be inferred to be supergiants or bright giants from their spectral characteristics and from previous photometric luminosities (Mendoza 1970, 1971*b*; Mendoza *et al.* 1969).

The four most luminous stars will be assumed here to be supergiants; the differences in the results if they are somewhat less luminous should be small. V380 Ori appears to be close to the main sequence and has been assumed to be a dwarf; since it is an early type star differences due to a somewhat higher luminosity will be minimal. Previous photometric reductions (Mendoza 1968; Imhoff 1973) show that the remaining stars fall above the main sequence in the region of the subgiants in color-magnitude diagrams; therefore, subgiant luminosities have been chosen for these stars.

There are problems inherent in assigning spectral types to the T Tauri and related objects. Their spectra are peculiar, not only in the presence of emission lines but in the strengths and profiles of the absorption lines as well. Assignment of a spectral type is difficult and inexact; thus few attempts have been made to designate luminosity classes to the stars. There is, in addition, evidence of spectroscopic change in these variable stars. V1057 Cyg experienced profound changes in its spectral characteristics, from an advanced T Tauri spectrum of perhaps type K0 to that of a luminous A1 star (Herbig 1958; Herbig and Harlan 1971), accompanying an increase in brightness of 5 magnitudes. Since the outburst, the spectrum has become later in type (Herbig 1973). R Mon has also apparently experienced some changes. Joy (1960) gave its spectral type as Ge; however, a recent spectrogram (Mendoza 1970) shows clearly a luminous A-type spectrum. The General Catalogue of Variable Stars (Kukarkin *et al.* 1958) likewise lists the spectral type as A-Fpe. Finally, T Tauri itself appears to vary normally over several spectral subclasses (Weston and Aller 1955). Some of the discrepancies in assigned spectral types in the literature may therefore be due to spectral variability.

The intrinsic color $(V-R)_0$ may be adopted for each star according to its assumed spectral and luminosity types. The color $(V-R)$ is used in this discussion rather than the commonly used $(B-V)$ color because continuous and line emission significantly contaminate the observed B magnitudes for these objects. The intrinsic color $(V-R)_0$ for each star was taken from Johnson's (1966) table of intrinsic colors. In several cases, however, the adopted spectral and luminosity classes are not given in Johnson's tables. For SU Aur (G2 III), its $(V-R)_0$ was estimated from the average of the observed $(V-R)$ colors of several G2 III stars given in Johnson *et al.*'s (1966) photometry of bright stars. The colors of the subgiants were derived from the average of the giant and dwarf colors; a check with Johnson *et al.*'s (1966) data for individual subgiant stars showed this procedure to be quite reliable.

Since the T Tauri objects occur in nearby stellar associations, their approximate distances are known. The distances adopted here are the same as those used in a few previous investigations (Mendoza 1966, 1968; Low *et al.* 1970; Imhoff 1973; Knacke *et al.* 1973); however, it should be noted that a number of distance determinations for each region exists. For instance, values for the Orion region range from 380 to 500 parsecs (Strand 1958; Sharpless 1962; Johnson 1965). The distance determination for the North America Nebula complex is especially in doubt, ranging from 420 to 1980 psc (see Goudis and Meaburn 1973); a conservatively small distance of 700 psc was chosen here.

TABLE 1
ADOPTED DATA

Object	Sp	$(V-R)_0$	r(psc)	Remarks
RY Tau	G5	0.62	150	1
T Tau	K1	0.75	150	1
SU Aur	G2	0.63	150	2
RW Aur	G5	0.62	150	1
GW Ori	G5	0.62	400	1
V380 Ori	A1	0.08	400	1
FU Ori	F2	0.26	400	3
R Mon	A5	0.12	700	3
R CrA	A5	0.12	150	3
T CrA	F0	0.30	150	1
V1057 Cyg	A5	0.12	700	3

Notes to Table 1:

1. Intrinsic color for subgiants.
2. Intrinsic colors for giants.
3. Intrinsic colors for supergiants.

A summary of the adopted spectral types, intrinsic colors, and distances is given in Table 1. The luminosity classes, indicated under "Remarks", play a role only in the choice of intrinsic colors and so do not necessitate that the stars must be of the given luminosities. Only stars for which adequate spectroscopic and photometric data exist are listed; thus only eleven stars are considered here.

In general, Mendoza's (1968, 1970, 1971*a*) photometric observations out to 5 microns have been used in the extinction and luminosity calculations. For four stars, 5 micron observations from other investigators were employed. Data from Rieke *et al.* (1972) and Knacke *et al.* (1973) were used for V1057 Cyg and T CrA, since no M-magnitudes for these stars were observed by Mendoza. GW Ori and R CrA exhibited discordant values most likely due to the variability of the stars; in these two cases, the most reasonable values at 5 microns as compared to the observations at other wavelengths were chosen. To convert the magnitudes to fluxes the appropriate flux calibration must be known. For Mendoza's (1968, 1970, 1971*a*) photometry, Johnson's (1966) calibration was employed for all magnitudes through L except H; Low's (1970) calibration was applied to M. No calibration for the H magnitude has yet been published so that some interpolation is required. For all other investigators, the referenced flux calibrations were used.

An attempt was made to combine the photometric results from various investigators for observations at wavelengths longward of 5 microns rather than choose any one set of data. An estimation was made of the representative fluxes at wavelengths from 8.5 to 22 microns for each star from the observations of Low (1970), Low *et al.* (1970), Cohen and Woolf (1971), Rieke *et al.* (1972), Cohen (1973*a*, *b*, *c*), and Knacke *et al.* (1973). In addition, the fluxes were extrapolated to zero at 30μ; the values of the far infrared fluxes are unknown and are assumed here to be small enough so as not to significantly affect the results. A summary of the adopted observations to 5 microns is given in Table 2a; the estimated fluxes from 8.5 to 22 microns are listed in Table 2b.

A method for estimating the emission line contamination in the B and R magnitudes of the T Tauri stars is outlined by Imhoff (1973). The values of the corrections δB may be calculated by scaling them from the values for two stars examined by Aveni (1966), using Herbig's emission indices (Herbig and Rao 1972) and Kuhi's (1968) $H\alpha$ emission indices as indicators of the emission line strength. Similarly the corrections δR may be estimated from Kuhi's (1970) examples and his $H\alpha$ indices. For V1057 Cyg, a Herbig emission index of 2 was estimated from the description of the star's spectrum in Herbig and Rao's (1972) catalogue so that δB and δR could be estimated. The emission corrections, which may then be applied to the observed photometry, are listed in Table 3.

The extinction affecting the T Tauri objects may be calculated using the color excess $E(V-R)$, the difference between the observed $(V-R)$ color corrected for emission line contamination and the adopted intrinsic color $(V-R)_0$. In order to derive the visual extinction A_v or the extinction at any other wavelength from the $E(V-R)$ excess, one must adopt an extinction law. Van de Hulst's curve No. 15 (Johnson 1968, Table 12) is used as representative of a normal extinction law. As will be seen in the next section, a peculiar law that yields a significantly larger extinction from a given $E(V-R)$ than Van de Hulst's law is also required; such a law is that given for NGC 2244 by Johnson (1968, Table 21). The color excesses for these two extinction laws are given in Table 4. From Van de Hulst's curve,

TABLE 2a

0.3 – 5μ PHOTOMETRY

Object	V	U–V	B–V	V–R	V–I	V–J	V–H	V–K	V–L	V–M	Remarks
RY Tau	10.46	1.72	1.11	1.11	2.05	2.76	3.76	4.93	6.32	7.2	
T Tau	10.25	1.97	1.22	1.10	1.97	2.86	3.62	4.43	5.83	7.8	
SU Aur	9.09	1.30	0.89	0.74	1.30	1.88	2.52	3.27	4.15	5.6	
RW Aur	10.40	0.35	0.60	0.78	1.50	2.31	3.25	3.71	4.89	5.3	
GW Ori	9.75	1.30	1.00	0.88	1.50	2.08	2.77	3.64	4.71	5.4	1
V380 Ori	10.31	0.29	0.52	0.73	1.41	2.11	3.11	4.23	5.57	6.7	
FU Ori	8.94	2.41	1.41	1.22	2.17	3.04	3.80	4.35	5.13	5.6	
R Mon	11.85	0.37	0.61	0.89	1.60	2.96	4.29	6.37	8.57	10.0	
R CrA	10.74	0.66	0.56	1.02	2.64	2.72	5.82	7.42	8.93	9.6	2
T CrA	11.67	1.16	0.84	1.05	2.15	3.13	4.03	5.02	6.57	7.0	2
V1057 Cyg	9.47	1.81	1.23	1.21	2.35	3.51	4.34	4.84	5.50	6.4	3

Notes to Table 2a:

1. 5μ photometry by Cohen (1973*b*).
2. 5μ photometry by Knacke *et al.* (1973).
3. 5μ photometry by Rieke *et al.* (1972).

TABLE 2b

INFRARED FLUXES (10^{-15}w/cm$^2\mu$)

Object	8.5μ	11μ	12.8μ	18μ	22μ	Remarks
RY Tau	.055	.050	.026	.026	.020	1
T Tau	.079	.052	.060	.075	.053	1
SU Aur	.023	.015	.014	.011	.008	1
RW Aur	.008	.005	.004	.002	.001	1
GW Ori	.016	.012	.012	.016	.008	1, 2
V380 Ori	.027	.016	.010	.009	.013	2, 3
FU Ori	.020	.018	.014	.017	.011	2, 3
R Mon	.160	.094	.076	.108	.068	2, 3, 4
R CrA	.500	.300	.250	.150	.119	5
T CrA	.030	.027	.025	.022	.019	5
V1057 Cyg	.108	.095	.085	.055	.043	6

Notes to Table 2b:

1. Fluxes by Cohen (1973*b*).
2. Fluxes by Cohen (1973*c*).
3. Flux at 22μ by Low (1970).
4. Flux at 22μ byLow *et al.* (1970).
5. Fluxes by Knacke *et al.* (1973).
6. Fluxes by Rieke *et al.* (1972).

$A_v = 3.81\ E(V - R)$; however, from the extinction law for NGC 2244, $A_V = 7.04\,E(V - R)$, so that the peculiar law results in a derived extinction nearly twice that from the normal law.

It is assumed that the infrared excess observed in the T Tauri-like objects is due to a spherical dust shell reemitting stellar energy. In this case, the stellar energy absorbed by the grains equals that emitted in the infrared in the line of sight of the observer. Although such a simplification makes calculations tenable, it is neither the only possibility nor necessarily, the most realistic.

TABLE 3

EMISSION LINE CONTAMINATION ESTIMATES

Object	δB	δR
RY Tau	0ᵐ05	0ᵐ02
T Tau	0.10	0.03
SU Aur	0	0
RW Aur	0.11	0.03
GW Ori	0.05	0.02
V380 Ori	0.15	0.04
FU Ori	0	0
R Mon	0.10	0.03
R CrA	0.05	0.02
T CrA	0	0
V1057 Cyg	0.05	0.02

III. RESULTS

There are two methods by which the luminosities of the T Tauri and related objects may be calculated from the above information. The first, termed the spectroscopic luminosity, is designated L_{spec}; here the luminosity is calculated from the object's bolometric magnitude,

$$M_{bol} = m_v - A_v - 5 \log d + 5 + BC.$$

The apparent magnitude m_v may be taken to be the observed V magnitude, A_v is derived from $E(V - R)$ and the appropriate extinction law, d is the adopted distance of the star, and BC is the bolometric correction appropriate to a star of the given spectral and luminosity types, listed by Johnson (1966). The model of a T Tauri object implicit in this treatment is that of a relatively normal star affected by an amount of extinction A_v which may be both interstellar and circumstellar.

The photometric luminosity, designated L_{phot}, is derived from the fluxes measured over a range of wavelengths. Here

$$L_{phot} = 4\pi d^2 \int_0^\infty F(\lambda) d\lambda$$

where d is the adopted distance to the star and $F(\lambda)$ is the flux at wavelength λ, which may be corrected for extinction. The integral over all wavelengths may be approximated by an appropriate integration scheme; the third degree spline integration method (Mendoza 1974) was used for these calculations, with the fluxes at 0 and 30 microns set to zero. This technique allows an easy duplication of our results.

Two limiting cases concerning the photometric luminosity may be considered. The observed luminosity L_{obs} is calculated from the observed magnitudes with no corrections for extinction. L_{obs} is the minimum luminosity the object can have. The observed luminosity would also be representative of a T Tauri object if it were not affected by interstellar extinction, since radiation absorbed by the circumstellar shell will be reradiated and observed in the infrared.

The other limiting case is that all of the extinction of the object is assumed to be interstellar; the observations are then corrected for the total amount of extinction. This particular luminosity will be designated L_{corr}, the corrected luminosity. In the following calculations of L_{corr} no corrections for extinction were made for the fluxes at 8.5 microns and longward; the uncertainty thus introduced is much smaller than that due to the variability of the objects at these wavelengths.

TABLE 4

COLOR—EXCESS RATIOS

Law	$\frac{E_{U-V}}{E_{B-V}}$	$\frac{E_{B-V}}{E_{B-V}}$	$\frac{E_{V-R}}{E_{B-V}}$	$\frac{E_{V-I}}{E_{B-V}}$	$\frac{E_{V-J}}{E_{B-V}}$	$\frac{E_{V-H}}{E_{B-V}}$	$\frac{E_{V-K}}{E_{B-V}}$	$\frac{E_{V-L}}{E_{B-V}}$	$\frac{E_{V-M}}{E_{B-V}}$	$\frac{A_V}{E_{B-V}}$
Van de Hulst*	1.71	1.00	0.80	1.62	2.30	2.59	2.78	2.91	2.95	3.05
NGC 2244	1.71	1.00	0.81	1.65	2.40	2.80	3.14	3.93	4.8	5.7

* Curve No. 15.

The real situation for the T Tauri and related objects must be intermediate between these two limiting cases. The extinction affecting the star is thought to be both interstellar and circumstellar since the objects occur within dark nebulae of large extent and have infrared excesses indicative of nearby circumstellar shells. Thus the previously determined reddening excess $E(V - R)$ is the sum of the interstellar and circumstellar components.

The total extinction is required to calculate L_{spec}, but only the interstellar extinction must be considered to determine L_{phot}. Thus if the proper choices are made for both the interstellar and circumstellar extinction, the spectroscopic and photometric luminosities will be equal. Since the exact proportions of the circumstellar and interstellar components in the total extinction and their appropriate extinction laws are not known, one cannot compute L_{phot} precisely. However, a comparison of L_{spec} with the limiting cases of the photometric luminosity, L_{obs} and L_{corr}, may be revealing. One would expect that, if the object is affected by both varieties of extinction, L_{spec} would lie between L_{obs} and L_{corr}. The relative nearness of L_{spec} to either of the limiting cases could then give some indication of the proportions of interstellar and circumstellar contributions to the extinction.

The quantities L_{spec}, L_{obs}, and L_{corr} were calculated for each star assuming a normal (Van de Hulst's) extinction law and the previously adopted spectral types, intrinsic colors, and distances. An examination of the results reveals that, in over half the stars, L_{spec} does not exhibit the expected behavior; instead L_{spec} is considerably less than L_{obs}, often by about a factor of 2. It has already been stated that L_{obs} is the minimum luminosity that the object can have; therefore, L_{spec} must be in error.

Of all the quantities required to calculate L_{spec}, it was found that only a large error in the extinction calculations can account for the size of the discrepancies found in several of these objects. Such an error could occur if the extinction law corresponding to the dust extinguishing the star were peculiar; for a given $E(V - R)$, the extinction A_v must be much larger than that for a normal extinction law. The peculiar law found for the Orion region by Johnson (1968) does not meet this criterion. Although the ratio of total to selective extinction R is large, the ratio $E(B - V)/E(V - R)$ is small, so that for a given value of $E(V - R)$, A_v is not much larger than that found for a normal extinction law. An extinction law that exhibits the required behavior is the one found for NGC 2244 by Johnson (1968). In the visual region the law is nearly the same as Van de Hulst's (see Table 4), yet R is large. As shown in the previous section, the extinction derived using this law is nearly twice that found using a normal law. It may be noted that the objects-under consideration lie at galactic longitudes for which Johnson (1968) has found large values for R.

Use of the peculiar extinction law can increase the value of L_{spec} sufficiently so that it equals or exceeds L_{obs}, as is physically required, for those stars with discrepant luminosities. One could apply the peculiar extinction law to all the stars under consideration; however, it was decided to assume a normal situation whenever possible. The peculiar law was employed only when the calculations using the normal law were obviously in error. This does not preclude the possibility that a peculiar law applies to additional objects.

Table 5 lists the spectroscopic, observed, and corrected luminosities (solar units) that have been

TABLE 5

DERIVED LUMINOSITIES
(solar units)

Object	Spectroscopic	Photometric		Remarks
		Observed	Corrected	
RY Tau	34	12	46	2
T Tau	18	19	33	2
SU Aur	9	10	12	1
RW Aur	4	4	7	2
GW Ori	51	52	71	1
V380 Ori	93	55	220	1
FU Ori	1100	160	910	1
R Mon	1100	660	3300	2
R CrA	330	79	1000	2
T CrA	6	7	13	1
V1057 Cyg	3300	615	4200	1

Notes to Table 5:

1. Color-excess ratios from a normal extinction law (Van de Hulst, see Table 4).
2. Color-excess ratios from a peculiar extinction law (NGC 2244, see Table 4).

here calculated for each star. Where the peculiar extinction law had to be employed, as noted in the last column, both L_{spec} and L_{corr} are the recalculated values. L_{obs} is the same in any instance because no extinction corrections are involved in its calculation. For SU Aur, GW Ori, and T CrA, the agreement of L_{spec} calculated for a normal law was considered to be sufficiently close to L_{obs} not to warrant assuming the peculiar law. In addition, the spectroscopic and corrected luminosities of FU Ori are similar enough to be assumed to be equal within the uncertainties of the calculations; increasing the value of R does not remove the small discrepancy. The large luminosity of V1057 Cyg may be much larger, since its adopted distance is conservatively small.

Although the uncertainties in the calculated luminosities are sizeable, one may make some preliminary remarks concerning the nature of the extinction affecting each object. For those objects in which the spectroscopic luminosity is comparable to the observed luminosity, the extinction may be mostly circumstellar; these stars are T Tau, SU Aur, RW Aur, GW Ori, and T CrA. In the cases where the spectroscopic luminosity is close to the corrected luminosity, the extinction may be largely interstellar; such an instance occurs for FU Ori and perhaps V1057 Cyg. Finally, the intermediate cases indicate comparable amounts of both interstellar and circumstellar extinction; these are RY Tau, V380 Ori, R Mon, and R CrA. One may note that the "classical" T Tauri objects tend to have predominantly circumstellar extinction, the early type objects the intermediate case, and the unusual objects FU Ori and V1057 Cyg mostly interstellar extinction. However, it is not possible to specify the precise amounts of interstellar and circumstellar extinction at present.

IV. DISCUSSION

We have obtained luminosities for eleven T Tauri and related objects. Broad and narrow band photometric observations have been combined with assumed intrinsic colors and a normal extinction law to yield spectroscopic and photometric luminosities. An examination of those luminosities has shown that, for many of the objects, a peculiar extinction law must be adopted in order to reconcile the discrepancies in the calculated luminosities. One may conclude that the final values calculated for the spectroscopic luminosities represent the best available luminosities for the stars.

This investigation has benefited from several improvements of the basic photometric and spectroscopic data. However, its results differ from previous ones primarily in the new treatment of the extinction of the objects and the resultant use of a peculiar extinction law. In general the calculated luminosities lie between those given by the two limiting cases previously considered (Mendoza 1966, 1968; Imhoff 1973), as would be expected. The visual extinction in some objects is found to be nearly double that previously calculated, due to the use of the peculiar extinction law. It may be noted that peculiar extinction with a large value for R has been previously suggested as affecting some young stars by Strom *et al.* (1972) and as descriptive of dark clouds containing young stellar objects (Carrasco *et al.* 1973).

The spectroscopic luminosities derived for the objects may be used with their spectral types to locate their positions in the Hertzsprung-Russell diagram. The qualitative behavior of these stars is not changed from previous investigations. It is reassuring to note the consistency of this behavior with the previously adopted intrinsic colors of the stars. Those four stars assumed to be supergiants or bright giants have bolometric magnitudes from approximately -1^m25 to -3^m75. Those stars considered

TABLE 6

MASSES AND AGES

Object	log Te (°K)	log $\frac{L_{spec}}{L_\odot}$	$\frac{M}{M_\odot}$	t(yrs.)
RY Tau	3.73	1.53	2.7	5×10^5
T Tau	3.68	1.26	2.5	6×10^5
SU Aur	3.72	0.95	2.0	10^6
RW Aur	3.73	0.60	1.5	5×10^6
GW Ori	3.73	1.71	3.0	3×10^5
V380 Ori	3.96	1.97	3.0	8×10^5
FU Ori	3.87	3.04	6.7	4×10^4
R Mon	3.93	3.04	6.5	5×10^4
R CrA	3.93	2.52	4.7	2×10^5
T CrA	3.85	0.78	1.4	8×10^6
V1057 Cyg	3.93	3.52	9.0	3×10^4

to be subgiants fall in that region, with bolometric magnitudes of about $2^{m}5$.

If the effective temperatures of these objects may be derived, their positions in a theoretical H-R diagram may be used to estimate the stars' masses and ages. Mendoza's (1969) calibration of temperature with intrinsic color $(V - R)_0$ was used to derive the objects' temperatures. The masses and ages were then estimated by comparing the positions of the objects to Iben's (1965) pre-main sequence evolution ary tracks. Table 6 lists the derived quantities for each star.

Although this consideration of the luminosities of the T Tauri-like objects is in some ways an improvement over previous investigations, a number of basic questions remain to be answered. It has been implicity assumed, in our choice of the intrinsic colors of the stars, that the objects consist of normal stars surrounded by dust clouds which only minimally affect the stars themselves. Some credence to this assumption is given by Larson's (1969) theoretical results; these indicate that the pre-main sequence star will not be seen, due to its dense circumstellar shell, until it is not far from the main sequence and retains only a residual dust shell. Such a situation seems likely for the "classical" T Tauri stars; however, for objects such as R Mon and R CrA the observed spectrum may arise in the shell rather than the stellar photosphere (Herbig and Rao 1972). In addition, the preliminary results of Buerger and Collins (1973) indicate that the infrared radiation from the circumstellar grains may affect the stellar atmosphere, forming a sort of chromospheric layer which can produce Balmer continuum and line emission.

Our knowledge of the luminosities of the T Tauri-like objects would be considerably improved if there were a precise method of separating the effects of interstellar and circumstellar extinction; at present there is none. In addition, a circumstellar law should differ from an interstellar one due to the importance of scattering and the geometry of the shell. A discussion of this problem has been given by Code (1973). However, though Code's work indicates that R should be decreased, this investigation requires that, in many cases, R must be increased.

The infrared excess has been assumed to be due to reradiation from a spherical circumstellar dust shell. Two other possibilities, which ought to be studied more closely, are considered here only briefly. Strom (1972) has suggested that the infrared excess may be due to hydrogen continous emission from a circumstellar gas cloud. This is likely to contribute to the infrared excess; however, dust emission is probably a more efficient process (Stein 1972).

Another likely possibility is that the distribution of dust near the stars may be aspherical, perhaps disk-like (see Strom, Strom, Yost, *et al.* 1972). A T Tauri star surrounded by a disk of reradiating dust would mimic the behavior noted above. Seen face on, it would have a large observed luminosity due to the contribution from the large infrared emitting area but a small spectroscopic luminosity since the line of sight extinction is small. Seen edge on, the reverse would be true. We would then expect to see a distribution of cases among the T Tauri stars with an inverse relationship between the sizes of the infrared excesses and the visual extinction. An examination of the data in this paper does not indicate that such a relationship holds. In fact, there is a mild indication that the opposite holds true, that is, that greater extinction correlates with large infrared excesses. However, the possibility of such a geometry of the dust cloud should by no means be ruled out.

One may conclude that both the interstellar and circumstellar components of the extinction must be considered in deriving any quantities describing the T Tauri-like objects. Especially, a peculiar extinction law affecting the stars is required in many cases. Useful luminosities for the stars may be derived; however, many basic questions must still be considered.

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