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THE LOW-MASS IMF IN THE ρ OPHIUCHI CLUSTER[1]

D. M. WILLIAMS,[2] F. COMERÓN,[2,3] G. H. RIEKE,[2,4] AND M. J. RIEKE[2]
dougw@as.arizona.edu, fcomeron@mizar.ub.es, grieke@as.arizona.edu,
mrieke@as.arizona.edu
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ABSTRACT

We compare the methods for estimating the masses of young, embedded stars developed by Comerón et al. (1993) and by Strom et al. (1995) and show them to be in good agreement. Spectra in the 2 μm region of six low-mass objects are also in agreement with the mass estimates using these methods. The spectrum of a brown dwarf candidate can be used to place an upper limit on its mass of 60% of the minimum required for hydrogen burning. This limit is independent of the photometric analysis, which we update in this paper to make use of new calculations of brown dwarf evolution. This new analysis indicates a mass for this object of roughly 40% of the minimum hydrogen-burning mass, supporting the possibility that it is a young brown dwarf.

The initial mass functions (IMFs) obtained for low-mass stars in the ρ Ophiuchi cloud cores by Comerón et al. (1993) and by Strom et al. (1995) also agree well. The data have been combined to increase the statistical weight of the determination of the IMF. The IMF between 0.03 and 1 $M_{\odot}$ can be fitted satisfactorily by a power law with index in linear mass units of ~ -1.1, or in logarithmic mass units of ~ -0.1.

Subject headings: infrared: stars — open clusters and associations (ρ Ophiuchi) — stars: low-mass, brown dwarfs — stars: luminosity function, mass function

1. INTRODUCTION

Improvements in detector technology in the near-infrared have made possible extensive surveys of the young stellar populations embedded in interstellar clouds. However, methods to analyze these new data to obtain estimates of the characteristics of the low-mass cluster members have lagged behind the observational advances. One approach was proposed by Comerón et al. (1993) (hereafter CRBR) and used to determine the initial mass function in the ρ Ophiuchi embedded cluster. Recently, a second method has been developed by Strom, Kepner, & Strom (1995) (hereafter SKS) and used on the same cluster. We show that the results of these two approaches are in close agreement over the considerable range of mass where they should both be expected to yield good estimates.

Only the technique of CRBR is at present capable of estimating the masses of substellar objects. We test this method further with new K-band spectra of six sources considered by them to be candidate low-mass objects. The spectra appear to confirm the essential assumptions made by CRBR. The properties of these sources have been updated with the improved models of stellar interiors of Burrows et al. (1993). All of these results support the source characteristics assigned previously and indicate that at least one of the candidate very low mass objects is possibly a young brown dwarf.

The initial mass functions derived for the ρ Oph population by SKS and CRBR are in close agreement. We have therefore combined the data from both works to improve the statistical significance with which the IMF is determined. It appears that the IMF is roughly flat (in logarithmic mass units) through the low-mass region (i.e., between 0.03 and 1 $M_{\odot}$).

2. MASS DETERMINATION IN THE STELLAR RANGE

CRBR developed a method that, for the first time, integrated theoretical models of low-mass objects and multiband infrared photometry of embedded sources to provide internally consistent estimates of the mass and extinction of each member of an embedded cluster. In their method, a suite of trial stellar spectra was calculated for a range of assumed temperature, reddening, and degree of infrared excess; the appropriate luminosities were determined from the theoretical models. One of these trial spectra was adopted for an embedded source if a fit to multiband photometry reproduced accurately both the colors and the brightness of the source; sources with either poor fits or strong excess emission were rejected. In the accepted cases, a mass was assigned from the theoretical model used for the trial spectrum.

SKS have recently described another technique that is similar in philosophy but differs significantly in execution. They compare the embedded stars with other, previously studied stars and determine a subset whose HK spectrum is dominated by photospheric emission. Stars with strong excess emission are rejected at this first stage. The accepted sources are dereddened according to their $J-H$ colors to determine their J luminosities. The masses are determined by comparing the J luminosities with the predictions of theoretical models.

Each of these methods has advantages. The approach of SKS is more closely tied to stellar observations and makes the dependence on theoretical models more explicit by not having to invoke them until the final stage. However, it is not applicable to possible substellar objects, for which there is as yet no observational database. The greater dependence of the method of CRBR on the models could lead to larger errors. However,

[1] Observations reported here were obtained at the Multiple Mirror Telescope Observatory, a facility operated jointly by the University of Arizona and the Smithsonian Institution.

[2] Steward Observatory, University of Arizona, Tucson, AZ 85721.

[3] Departament d'Astronomia i Meteorologia, Universitat de Barcelona, Av. Diagonal, 647, 08028 Barcelona, Spain.

[4] Department of Planetary Sciences, University of Arizona, Tucson, AZ 85721.

their approach integrates the fitting of substellar objects into the procedure in a consistent fashion, so it is useful for examining the behavior of the IMF below the bottom of the main sequence.

CRBR carried out extensive tests to show that their method was robust against the expected uncertainties of the theoretical models. However, with the new method developed by SKS, it is now possible to perform a more critical test by comparing the results of the two approaches directly. This comparison is based on independent data sets as well as different modeling approaches, so it gives a true reflection of the net differences including contributions from photometric errors and source variability as well as modeling approaches. Figure 1 shows the derived masses for all objects in common between the two studies. In the spirit of the correlation of infrared excess with age used in the fitting of CRBR, we have used the older mass value from SKS for the class III objects and the younger mass value for the single class II object, 2407.7−2726 (whose ID in CRBR was 2407.3−2735).

Although the close agreement in Figure 1 is noteworthy, it must be remembered that both of these approaches still require calibration against independent measures of the nature of the embedded sources, such as optical and infrared spectra. In addition, the timescales used by CRBR and SKS for the embedded objects differ by about a factor of 2. As a result, one would expect CRBR to derive systematically slightly larger masses than SKS; there is hint of this effect in the comparison, but perhaps not as strongly as expected. Finally, it must be emphasized that the two techniques of photometric modeling are designed to be useful in a statistical sense and to facilitate selection of interesting sources for follow-up. The derived properties of any single source should be interpreted cautiously.

3. SPECTRA OF LOW-MASS OPHIUCHUS SOURCES

3.1. *Approach*

Below the bottom of the main sequence we do not have an independent confirmation of the photometric modeling of CRBR. The agreement with SKS at higher masses and simple continuity arguments would suggest that it should be reasonably trustworthy there also. However, as an independent test, we have obtained spectra of six low-mass objects to compare their properties with the predictions of the modeling.

Because the brown dwarf candidates in the ρ Oph cloud are very young, their temperatures should be similar to those of older cool stars. As a result, we can compare their spectra and those of embedded very low mass stars with features expected from observations of nearby, evolved stars. Spectral sequences in the near-infrared based on the equivalent widths of lines sensitive to effective temperature and gravity are comparatively easier to establish than in the visible range for late-type stars (Kleinmann & Hall 1986; Kirkpatrick et al. 1993; Davidge & Boeshaar 1993; Jones et al. 1994).

The main features in the *K* band correspond to the Na I blend near $\lambda = 2.207$ μm and molecular bandheads due to

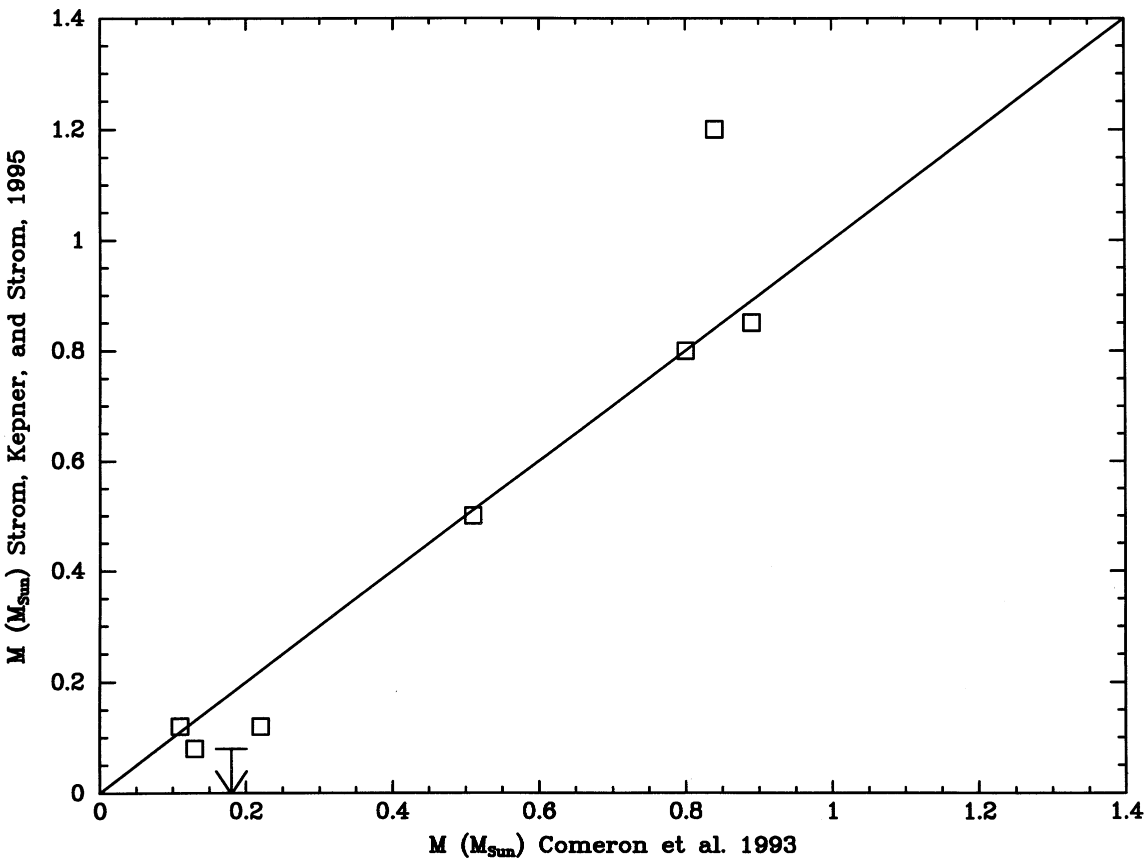

FIG. 1.—Comparison of mass estimates of CRBR and SKS for all objects in common between the two studies. We have used the older mass estimates from SKS for the class III objects, and the younger mass estimate from SKS for the single class II object.

^{12}CO at $\lambda = 2.294$ μm and longer wavelengths. Weaker features due primarily to the Fe I lines at $\lambda = 2.226$ μm and $\lambda = 2.239$ μm and the Ca I blend near $\lambda = 2.263$ μm may also be present.

Atmospheric models of Mould (1978) predict that the equivalent width of the Na I blend increases with decreasing temperature between spectral types G and M, but is rather insensitive to surface gravity. However, the observations show no clear dependence on temperature, as already remarked by Mould (1978) and Jones et al. (1994). On the other hand, the strength of the first ^{12}CO bandhead at $\lambda = 2.294$ μm is found to be well correlated with temperature, increasing as one proceeds to later spectral types. For the coolest stars, a broad absorption band due to H_2O steam in the stellar atmosphere produces a decrease in flux at the short-wavelength end of the band. Other features observable in the 2 μm window are found to be rather insensitive to temperature and surface gravity, according to both models and observations.

3.2. *New Observations and Data Reduction*

Spectra in the 2 μm region of Ophiuchus sources were obtained with the Steward Observatory 2.3 m Bok Telescope and the Multiple Mirror Telescope. M dwarf comparison stars were observed with the 1.5 telescope. In all cases, we used the spectrometer described by Williams et al. (1993) with its 75 lines per mm grating, providing a spectral resolution $\lambda/\Delta\lambda = 800$. The observations of the ρ Ophiuchi sources were carried out on 1993 May 9–11, 1994 May 23, 1994 July 19, and 1995 April 10, and all the field stars except vB 10 were observed on 1993 September 7–8. Observations of vB 10 were made on 1993 October 29.

The spectra were reduced using IRAF tasks and specially designed IRAF scripts. Sky emission lines were removed from our spectra by subtracting from each frame the average of the adjacent ones in time. Atmospheric absorption features were eliminated by ratioing the spectra to those of bright B to G-type stars, observed close to our sources in both position and time and reduced by an identical procedure. At our resolution and signal to noise, the only noticeable intrinsic feature of these comparison stars in the 2 μm region is the strong Brackett γ absorption at $\lambda = 2.166$ μm, which produces a false Brγ emission in the spectra presented in this paper. The resulting spectra were wavelength-calibrated using OH sky emission lines (Oliva & Origlia 1992). The spectra of the Ophiuchus sources are shown in Figure 2. All spectra have been smoothed to a resolution of $\lambda/\Delta\lambda \sim 175$ to increase the ratio of signal-to-noise. The noise increases for wavelengths longer than $\sim$2.25 μm because of thermal background.

The observations of Oph 2320.8−1721 lead us to conclude that it was significantly (by a factor of 1.5–2) fainter on 1994 July 19 than for our previous photometry and spectroscopy. Although this conclusion is based on the spectrophotometry, it is reinforced by the much greater equivalent width of H_2 when we believe the source was faint. Since the H_2 originates in a surrounding, extended nebulosity which should have been transmitted equally on all occasions by our spectrometer slit on the 2.3 m telescope, the simplest explanation for the increase in equivalent width is that the source continuum had become fainter.

Our data on M dwarfs were reduced identically to the spectra of the sources in ρ Oph. Equivalent widths of the most relevant feature for all sources are listed in Table 1. The estimated uncertainties in the listed equivalent widths based on the signal-to-noise ratios are around 5% for Gl 725A, Gl 725B, Gl 873, and vB 10, around 10% for Wolf 922, Ross 248, and L789-6. The features in our spectra are in good agreement with the other studies cited in the preceding section. The only exception to the expected trends discussed in the preceding section within our data is Ross 248. However, this star is known to possess a high space velocity characteristic of Population II objects. Its low metallicity is also suggested by the relative weakness of other lines as compared to stars of similar spectral types; the weak ^{12}CO and other lines are therefore expected. We are therefore confident in using the extensive set of comparisons made possible by these studies in classifying the ρ Oph sources.

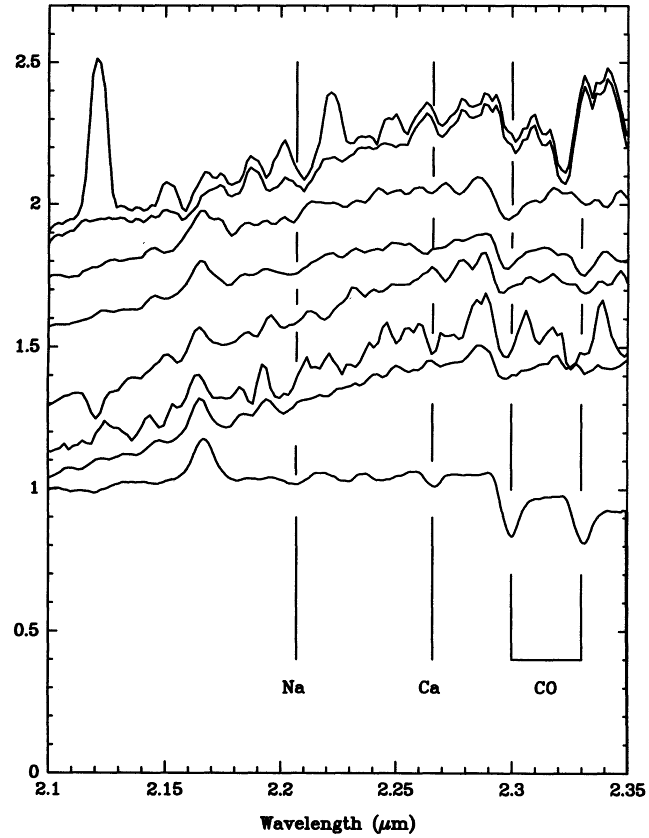

FIG. 2.—*K*-band spectra of Ophiuchus objects. The spectrum of Oph 2320.8−1721 is presented at the top of this plot with and without subtraction of the features due to Brγ absorption in the spectrum of the reference star, and to interstellar H_2 gas. The other spectra are, in descending order: Oph 2326.5−1958, Oph 2320.0−1915, Oph 2320.8−1708, Oph 2404.5−2152, Oph 2317.3−1925, and vB 10. The lower boundary of the frame corresponds to zero flux for the lowermost spectrum.

3.3. *Spectral Properties of Low-Mass Sources*

The spectra of the embedded Ophiuchus objects displayed in Figure 2 confirm them to be cool, low-luminosity objects when compared to the spectra of field stars. The continuum slope of these sources is mostly due to the wavelength dependence of the intervening dust extinction which heavily obscures them. Although the much lower signal-to-noise ratios in these spectra make the equivalent widths entered in Table 1 rather uncertain (errors are of order 40%), bands characteristic of the photospheres of cool stars, particularly the first CO overtone, can be recognized in all of them (see Table 1).

TABLE 1

EQUIVALENT WIDTHS OF SOME LINES AND BLENDS

Star	Spectral Type	Spectral T_{eff}	Na I λ2.207	Ca I λ2.263	^{12}CO λ2.294
Gl 725A[a]	M3 V	3600	5.2	2.1	4.3
Gl 725B[a]	M3.5 V	3500	4.2	2.8	5.0
Gl 873[a]	M3.5 V	3500	5.6	3.7	5.8
Wolf 922[b]	M4 V	3375	5.0	3.5	6.0
Ross 248[b]	M5 V	3200	5.0	3.0	3.0
L789-6[b]	M5 V	3200	7.0	3.0	7.0
vB 10[a]	M8 V	2875	2.6	3.8	25.1
Oph 2320.0−1915[c]	...	...	5(?)	4(?)	16
Oph 2320.8−1708[c]	...	...	4(?)	...	16
Oph 2326.5−1958[c]	...	...	2	2	24
Oph 2317.3−1925[c]	...	...	...	...	15
Oph 2404.5−2152[c]	...	...	11(?)	5	19
Oph 2320.8−1721[c]	...	...	12	...	16

[a] Equivalent width errors ~5%.
[b] Equivalent width errors ~10%.
[c] Equivalent width errors ~40%.

In addition to the stellar features, emission at $\lambda = 2.121$ μm from shocked H_2 (Brand 1993) can be easily recognized in the spectrum of Oph 2320.8−1708 and Oph 2320.8−1721. This feature is extended along the slit position (i.e., in the north/south direction) for Oph 2320.8−1721 and therefore originates in the surrounding medium. A similar explanation is likely for the feature in Oph 2320.8−1708. Fainter H_2 emission can also be distinguished in the spectrum of Oph 2320.8−1721 at $\lambda = 2.073$, 2.154, and 2.223 μm. These nonphotospheric features, plus the already mentioned false Brγ emission, have been artificially removed from the unsmoothed spectrum of Oph 2320.8−1721 by linearly interpolating the adjacent continuum; the cleaned spectrum is displayed in Figure 2.

3.4. *Discussion*

Our fitting procedure was discussed in detail by CRBR, who used the theoretical evolutionary tracks computed by D'Antona & Mazzitelli (1985). We have updated this work by using the more recent models of Burrows et al. (1993). These models can be expected to produce more accurate results, mainly through an improved treatment of the boundary condition represented by the stellar atmosphere based on the models of Lunine et al. (1989). The revised fits are listed in Table 2, which includes fits for a broad variety of possible ages. The best-fitting near-infrared spectral index n (Adams, Lada, & Shu 1987) is found to be fairly independent of the chosen isochrone, and the same value has been used for all the isochrone fittings of each object, selected from a fit to the source assuming it is on the deuterium-burning main sequence.

Although five of the sources are indicated to be close to the stellar/substellar limit, only Oph 2320.8−1721 is indicated to be in the substellar range by an amount that exceeds the likely uncertainties of the method. The temperatures of all five very low mass sources are fitted to be just under 3000 K, in good agreement with the depth of the CO bands in their spectra. Oph 2320.0−1915 is fitted with a temperature somewhat above 3000 K and may be more massive than estimated by CRBR. If fits are made which force the source to have no infrared excess ($n = -3.0$), then the masses are increased slightly except for that of Oph 2320.8−1721, which rises to 0.07 $M_\odot$ if it is more than 2 Myr old. However, for this forced fit the residuals are unacceptably large. Thus, the new fits reinforce the conclusions by CRBR that these objects are very low mass stars or are substellar and our spectra are in good agreement with this conclusion. Since the temperature that would be assigned from the spectra is consistent with the modeling, we would have reached similar conclusions about all these sources if we had started with the spectrally determined temperatures and dereddened them accordingly before computing luminosities.

Oph 2320.8−1721 is a dim and rather blue object, with a noticeable infrared excess at longer wavelengths. No fits to its colors are possible for masses in the stellar range, unless either the excess is overridden or it has an age in excess of 30×10^6 yr, which is at least 10 times larger than the estimated age of the ρ Ophiuchi cluster population (Wilking, Lada, & Young 1989; Greene & Meyer 1995). However, the infrared excess characteristic of very young objects and the variability of the source argue against that possibility.

The spectrum of Oph 2320.8−1721 provides a number of new insights relevant to the modeling that leads us to identify this object as a candidate brown dwarf. The possibility that the object is a background red giant that is seen through a thin spot in the cloud, or is some other chance interloper, was previously argued against on statistical bases. The spectrum and other data reinforce the probable cloud membership of this source in a number of ways. First, the CO absorption bands are weak for a typical cool red giant. Second, the association of a small cloud of H_2 with the source indicates that it is embedded in the ρ Oph molecular cloud. Third, the apparent variability of the source is consistent with it being a very young object, but would be unexpected for an interloping M dwarf or background red giant. Finally, the probable weak infrared excess detected by Rieke & Rieke (1990) at 10 μm again indicates the source is likely to be young and embedded in the cloud.

A critical assumption in the modeling of CRBR is that the near-infrared colors apply to the photosphere of the object. The CO absorption bands in all of these sources confirm that assumption, at least in the 2 μm region. At shorter wavelengths, some very young T Tauri stars have strong blue excess emission from an accretion zone that veils the normal stellar spectral features. This behavior is accompanied by very strong Brγ emission (Giovanardi et al. 1991). Since the false Brγ we observe in Oph 2320.8−1721 (and in the other sources) is no stronger than expected from the absorption in our calibration star, we conclude that such a strong blue excess is unlikely for this source (and for the others as well).

We can also derive an upper limit to the mass of Oph 2320.8 − 1721 in a way that is largely independent of our modeling technique. By comparing our spectrum of the source with the sequences determined by us and by Jones et al. (1994), we adopt GL 406 as the warmest permissible M dwarf analog of Oph 2320.8 − 1721. To maximize the luminosity, we assume that the entire J, H, K flux densities are from the photosphere of the source; assuming that the intrinsic colors are identical to those of GL 406, we find an upper limit to the reddening of $A_V \leq 11$. We use this upper limit to compute a lower limit to the absolute, dereddened magnitude of the source, $M_K \geq 6.33$. We then apply the relation between M_K and luminosity for GL 406 (e.g., Kirkpatrick et al. 1993 and references therein) to convert the lower limit on the absolute magnitude to an upper limit on the luminosity, namely $L \leq 0.017\ L_\odot$. Because we have measured Oph 2320.8 − 1721 at J(16.4), H(14.8), K(13.55), L'(12.1), and N(8.7) (CRBR), we can also include in this estimate any possible excess emission, on the conservative assumption that it represents reradiation of a blue excess that is not included in the luminosity based on GL 406. The excess at L' under the assumptions adopted for this limiting calculation is not important energetically. We therefore estimate the additional luminosity as νF_ν, measured at N(10.6 μm). We get an additional 0.004 $L_\odot$, or a total luminosity of $L \leq 0.021\ L_\odot$. Finally, we use this upper limit on the luminosity to derive an upper limit on the mass by taking the age of Oph 2320.8 − 1721 to be 3×10^6 yr, the full age of the embedded cluster, despite the evidence for the relative youth of the object. From model X of Burrows et al. (1993), we find $M \leq 0.05\ M_\odot$.

Greene & Meyer (1995) have recently reported infrared spectroscopy of a number of embedded sources in the ρ Oph cluster. They conclude that all these sources are no more than about 10^6 yr old. This result is surprisingly discordant with the age of the cluster determined previously by optical spectroscopy (e.g., Wilking et al. 1989). It may indicate either that the embedded sources are systematically much younger than the ones visible optically, or that further efforts are needed to reconcile differing age estimators. We note that the discrepancies found by Greene & Meyer (1995) with the masses fitted by CRBR for sources in the low-to-moderate mass range are largely due to the much younger ages they have assigned, as shown by the trend with age in Table 2 for Oph 2320.0 − 1915. However, for the lowest mass objects the masses are virtually independent of age over the possible range, since these objects are all near the deuterium-burning main sequence where their properties change only slowly with age.

In conclusion, the spectra of six low-mass objects are in good agreement with the predictions of the modeling of the photometry. Further confirmation through spectra of additional sources is still needed, but it appears that the method of CRBR is reasonably effective even for the lowest mass objects detected in the ρ Oph cloud.

4. THE INITIAL MASS FUNCTION

As expected from the excellent agreement of the modeling, the initial mass functions derived by CRBR and SKS are also in reasonable agreement as shown by the star counts of Figure 3 (the statement about disagreements in the IMFs in SKS is the result of a misunderstanding). In this figure, the counts of SKS have been normalized by 1.29 to give the same total number of stars in the range $5 > M(M_\odot) > 0.1$. SKS had a slightly more conservative criterion than did CRBR for inclusion of objects with infrared excesses. This difference is perhaps justified in both cases because the photometry of SKS extended only to 2.2 μm, while that of CRBR extended to 3.4 μm and hence allowed more accurate modeling of any excesses. In any case, there appear to be only three objects in this category, not enough to influence the results significantly one way or the other.

Since the two surveys are in such good agreement, we can combine them by averaging the masses derived for sources in common and including all other sources with mass $\geq 0.1\ M_\odot$ from either study (the study of SKS extended to an additional cloud core compared with that of CRBR). For substellar objects, we have renormalized the results of CRBR by the ratio of the number of objects in the combined IMF to that in the IMF of CRBR alone, and we have included the modest completeness correction derived by CRBR to account for the systematic omission of heavily obscured low-mass objects in their survey (the statement by SKS that CRBR did not make such completeness corrections is a misunderstanding). This improved IMF is shown in Figure 4. The error bars in Figure 4 are based on counting statistics of the number of objects in each bin and do not include possible systematic errors. Figure 4 implies strongly that the IMF in the ρ Oph cluster continues into the substellar range without a rapid termination below the bottom of the main sequence. Within the errors, the IMF can be fitted either by a power law of slope ~ -1.1 (linear mass units) or ~ -0.1 (logarithmic units). However, given the possible systematic errors, a modest flattening of the IMF cannot be ruled out.

Finally, we consider whether the source properties we derive should be preserved after the embedding cloud has dissipated. André & Montmerle (1994) have obtained extensive observations of the circumstellar material in the ρ Oph system at 1.3 mm. They find that the circumstellar material has virtually all been dissipated by the time a source has reached class II, i.e., with a modest infrared excess, so that sources of classes II and

TABLE 2

MODEL MASSES OF OPHIUCHUS SOURCES

Object	n	0.5 Myr	1 Myr	2 Myr	3.5 Myr	8 Myr
Oph 2317.3 − 1925......	−2.5	0.07	0.07	0.07	0.11	0.3
Oph 2320.0 − 1915......	−3.0	0.15	0.15	0.4	0.5	0.8
Oph 2320.8 − 1708......	−2.5	0.08	0.08	0.08	0.2	0.3
Oph 2320.8 − 1721......	−0.5	0.02	0.02	0.03	0.03	0.03
Oph 2326.5 − 1958......	−2.5	0.06	0.06	0.07	0.08	0.2
Oph 2404.5 − 2152......	−2.0	0.05	0.06	0.06	0.06	0.15

NOTE.—These fits are based on the models in CRBR with the improvements discussed in § 3.4. n is the best-fitting near-infrared spectral index (Adams et al. 1987); all masses are in units of $M_\odot$.

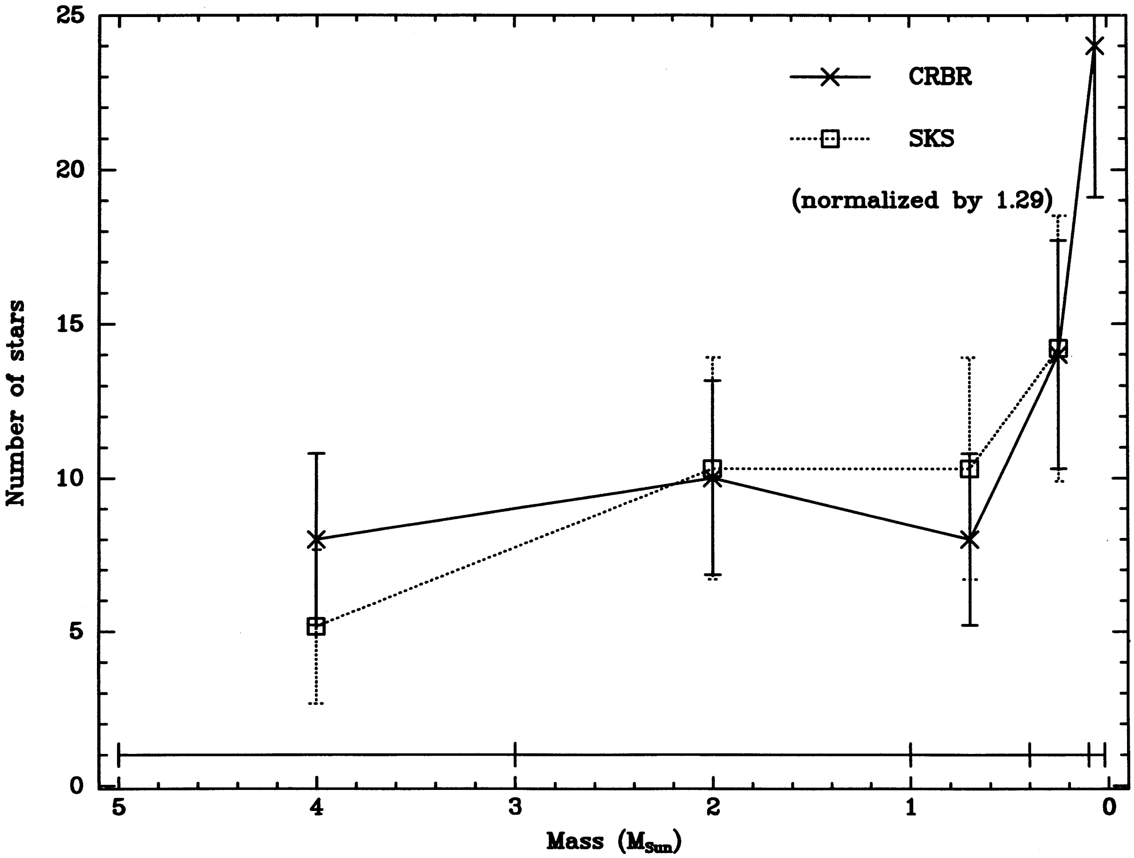

FIG. 3.—Comparison of star counts. The star counts of CRBR and SKS are compared. The bins used are the same as in CRBR and are shown at the bottom of the figure. The counts of SKS have been normalized by 1.29 to give the same total number of stars in the range $5 > M(M_{\odot}) > 0.1$. Note the agreement of the two surveys.

III cannot be expected to accrete significant additional masses of interstellar material. Since the photometric methods of both CRBR and SKS are based only on sources of classes II and III, we conclude that the derived IMF should be representative of the mass distribution in a more mature open cluster. It is also noteworthy that André & Montmerle (1994) observed Oph 2320.8 − 1721 and obtained only an upper limit, so that the very low mass indicated for this object should not be increased by future accretion.

5. CONCLUSIONS

We have reconsidered methods to derive masses of embedded young stars from near-infrared photometry by examining the results obtained for sources in the cores of the ρ Ophiuchi cloud. We find that the two methods proposed for this derivation (CRBR; SKS) are in agreement over the range of 0.1–1 $M_{\odot}$, where both are applicable. In the substellar range, however, only the method proposed by CRBR is applicable. To test its performance on very low mass objects, we have obtained K-band spectra of six sources, including a brown dwarf candidate, and of some field M dwarfs. Comparison with field stars shows that the spectra of the ρ Oph sources display characteristics of the photospheres of cool stars. The constraints on the source temperatures determined from the spectra are consistent with a reanalysis of the photometry presented by CRBR using new evolutionary tracks for low-mass objects, and confirm that the initial hypotheses underlying the analysis procedure developed by CRBR are valid for these sources. An important result is that the low mass previously assigned to Oph 2320.8 − 1721 is supported by the spectrum of this source; the new analysis would suggest a mass of about 0.03 $M_{\odot}$, with an upper limit of 0.05 $M_{\odot}$.

The initial mass functions derived for the ρ Oph embedded cluster by CRBR and by SKS are in agreement. If we combine these IMFs to improve the statistical significance, they show the IMF to rise from low stellar masses into the brown dwarf regime as a power law with index ~ -1.1 (linear mass units) or ~ -0.1 (logarithmic units).

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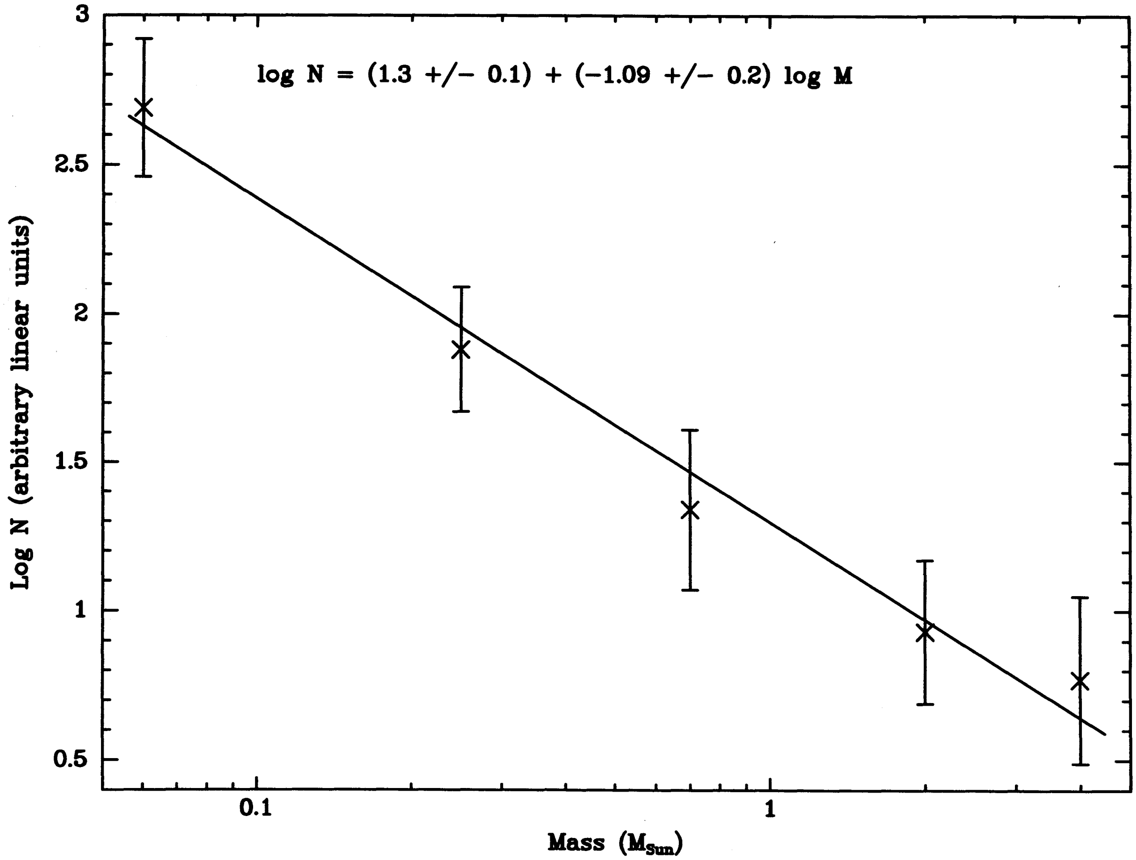

FIG. 4.—The initial mass function for ρ Oph from the merger of CRBR and SKS source counts. The error bars reflect $N^{1/2}$ counting errors. The best fitting power law $[N(M)dM \propto M^n dM]$ has a slope (n) of -1.09 ± 0.2.

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