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THE EVOLUTIONARY STATUS OF UX ORIONIS–TYPE STARS

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ABSTRACT

We present measurements of 1.3 mm continuum emission from a sample of UX Ori stars (UXOrs). The UXOrs are pre–main-sequence stars, typically of intermediate mass, and they are distinguished from other pre–main-sequence stars by their large photometric and polarimetric variations that are thought to be due to variable extinction by circumstellar dust. Transient optical and UV redshifted absorption lines are a second defining characteristic, and have been interpreted in terms of the disruption of infalling cometary bodies. Our new millimeter fluxes are used to derive masses of circumstellar dust, $M_{\rm CSD}$. We combine these measurements with data from the literature to examine a sample of 30 pre–main-sequence systems with spectral types F0–B9, i.e., Herbig Ae stars, about half of which display UXOr characteristics. We find no systematic differences in $M_{\rm CSD}$ between the two groups of stars. Moreover, no statistically significant correlation between $M_{\rm CSD}$ and stellar age is found, and the amplitude of photometric variability appears to be independent of age. We propose that UXOr phenomena do not characterize a more evolved environment. They are probably common to the majority of stars in our sample, but are observed only when the line of sight is close to the equatorial plane of an aspheric circumstellar nebula.

Subject headings: circumstellar matter — infrared: stars — stars: pre–main-sequence

1. INTRODUCTION

UX Ori–type stars (UXOrs) have attracted considerable attention in the last few years. The stars in this group are typically found among Herbig Ae stars, i.e., pre–main-sequence stars of intermediate mass, with a few objects of spectral types F, G, and K. They are characterized by large visual photometric variability that is attributed to variable extinction by clouds of dust surrounding a given star in a comparatively flattened geometrical configuration. Such an interpretation follows from the results of photopolarimetric monitoring of these stars (Grinin et al. 1991; Grinin 1994), and has been discussed by Thé (1994), Herbst, Herbst, & Grossman (1994), Hutchinson et al. (1994), Gahm et al. (1993), Grady et al. (1996), and Eaton & Herbst (1995). Transient absorption lines in optical and UV spectra suggest, for a large fraction of UXOrs, the presence of material falling into the star at high velocities (∼100–200 km s^{-1}; Grady et al. 1996, 1997; Grinin et al. 1994, 1996; de Winter 1996). The current interpretation of these spectra (Grinin et al. 1994, 1996; Grady et al. 1996), although not unique (Sorelli, Grinin, & Natta 1996), is that the infalling gas is produced at least partly by the evaporation of solid bodies (protocomets or planetesimals) in star-grazing orbits.

Time-variable, redshifted absorption in several metal lines has been observed in the much more evolved star β Pic and similarly interpreted in a series of papers (see Lagrange-Henry 1995 and references therein) as due to the infall of evaporating, comet-like bodies. On the other hand, and in contrast to β Pic, UXOrs show some of the classical features of pre–main-sequence stars, such as strong Hα in emission together with large IR excesses (they have all been detected by *IRAS*; Weintraub 1990) that have been ascribed to thermal emission from circumstellar accretion disks (Hillenbrand et al. 1992).

If indeed UXOrs are in a transitional status between young, accreting pre–main-sequence stars and the more evolved Vega-like systems, then they are highly suited to the study of the dissipation of circumstellar disks and the formation of large bodies. However, alternative possibilities have been suggested, and in particular it may be that the geometrical orientation of the system with respect to the observer plays the most important role in determining the presence or absence of observable UXOr characteristics in a pre–main-sequence star (Grinin at al. 1991; Grinin & Rostopchina 1996).

The best way to discriminate between these possibilities and to ascertain the true evolutionary status of UXOrs is to measure the amount of circumstellar dust present in the systems and compare it to the values in normal Herbig Ae stars. Zuckerman & Becklin (1993) find that the mass of dust in small grains, as measured by the submillimeter or millimeter flux, is a sharply decreasing function of time from pre–main-sequence to main-sequence stars, and they attribute this effect to the coagulation of grains from typical interstellar sizes to larger (planetesimal) bodies. If UXOrs are intrinsically different from normal Herbig Ae stars because their circumstellar environment is more evolved toward the formation of large bodies, then we expect them to have smaller amounts of circumstellar (CS) dust, which, possibly, correlates with the age of the star.

We present in this paper new data obtained with the 30 m IRAM telescope for a group of UXOrs with well-studied optical spectra that show clear evidence for both variable circumstellar extinction and the infall of material. We combine our results with millimeter data existing in the literature and obtain a sample of 30 pre–main-sequence stars of spectral type A (about half of which were classified as UXOrs by Grinin 1994 or Herbst et al. 1994). Although this sample can be increased further, it is sufficient to show

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TABLE 1

Millimeter Fluxes of the Target Stars

HBC (1)	Source (2)	Spectral Type (3)	D (pc) (4)	$F_{1.3\ \mathrm{mm}}$ (mJy) (5)	M_{CSD} ($10^{-5}\ M_{\odot}$) (6)
84	CO Ori	F8	460	<4	<5.5
169	BF Ori	A5	460	6 ± 2	8.3
193	LkHα 208	F0	1000	<5	<33
318	BM And	K5	440	<6	<7.6
329	VX Cas	A3	760	<6	<23
430	UX Ori	A3	460	23 ± 2	32
686	WW Vul	A0	370	10.5 ± 1	9.4
736	SV Cep	A0	715	7 ± 2	23

that the circumstellar dust mass in UXOrs and normal Herbig Ae stars is of the same order of magnitude, and that there is no correlation between this quantity and the UXOr nature of a star. We discuss briefly the implications of this result for the evolution of circumstellar disks around intermediate-mass stars.

2. OBSERVATIONS

We selected a sample of eight stars among those classified as UXOrs by Herbst et al. (1994) or with evidence of infall according to Grinin at al. (1994, 1996) and Grady et al. (1996); see Table 1. The observations were carried out with the MPIR 19 channel bolometer at $\lambda = 1.3$ mm on the IRAM 30 m telescope on 1997 March 24. We used the standard ONOFF observing mode, switching with the wobbling secondary with a throw of 46″ and a period of 0.5 s. The main-beam width is about 11″. Pointing and focus were checked and updated regularly by observations of Uranus and other standard pointing sources. The pointing was good to 2″–3″ or better. The atmospheric opacity was monitored by tipping the antenna every 1–2 hr; the zenith opacity varied between 0.15 and 0.47.

The calibration was done using Uranus (35 Jy beam^{-1} assuming $T_B = 96$ K) as a primary calibrator and NGC 7538 (5.5 Jy peak flux density) as a secondary calibrator. The data were reduced using the NIC software. The results are shown in Table 1, which gives in column (1) the Herbig & Bell (1989, hereafter HBC) catalog number, in column (2) the name of the object, in column (3) the spectral type, in column (4) the distance, and in column (5) the measured fluxes and the 1 σ uncertainty. Upper limits are 3 σ. None of the sources are found to be extended relative to our beam.

3. RESULTS

The mass of circumstellar (CS) matter can be computed for each source assuming that the millimeter flux is due to thermal emission by optically thin dust as

$$M_{\mathrm{CSD}} = F_{1.3\ \mathrm{mm}} \frac{D^2}{\kappa_{1.3\ \mathrm{mm}} B_{1.3\ \mathrm{mm}}(T_d)} \tag{1}$$

or

$$\frac{M_{\mathrm{CSD}}}{M_{\odot}} = 1.28 \times 10^{-6} \left(\frac{D}{140\ \mathrm{pc}}\right)^2 F_{1.3\ \mathrm{mm}}(\mathrm{mJy})\ , \tag{2}$$

where we have taken $\kappa_{1.3\ \mathrm{mm}} = 1$ cm^2 g^{-1} of dust (Pollack et al. 1994), $T_d = 50$ K. Equation (2) gives the mass of CS dust only. If gas and dust are in the normal interstellar ratio 100:1, then the total mass of CS matter is 100 M_{CSD}.

The value of M_{CSD} for the eight stars in our sample is given in Table 1, column (6). In order to investigate the amount of circumstellar matter in UXOrs, we have extracted from Table 1 the six stars of spectral type about A and added all the pre–main-sequence stars of the same spectral type (actually, from B9 to F0), for which we could find millimetric fluxes in the literature. M_{CSD} has been recomputed for the entire sample using equation (2). The choice of a narrow range of spectral types avoids possible systematic effects due to a dependence of M_{CSD} on the stellar mass; spectral type A is the most common among UXOrs (Bibo & Thé 1991). The properties of the stars are listed in Table 2, which gives in column (1) the HBC number, in column (2) the name of the source, in column (3) the spectral type, in column (4) the distance, in column (5) the 1.3 mm flux, and in column (6) M_{CSD}. References are given in the table. With the exception of two stars, they are included in the Finkenzeller & Mundt (1984) list of Herbig Ae/Be stars or classified as pre–main-sequence by Thé, de Winter, & Pérez (1994). The two additional stars (HD 34282 and HD 142666) have been identified as pre–main-sequence by Bogaert & Waelkens (1991).

In total, the sample contains 30 stars for which we have an estimate of the amount of CS dust, M_{CSD}. Which of these stars are UXOrs? In principle, the UXOr phenomenon is defined by evidence that photometric variability is due to variable extinction by CS matter. The clearest evidence is provided at present by simultaneous photopolarimetric observations over long time intervals, and is available only for about 10 stars (indicated by "y" in column [7] of Table 2). To increase the statistical significance of our sample, we make use of three other indicators, which are generally associated with the UXOr phenomenon, even if not exclusively. The first of these is the amplitude of the photometric variability in the V band, ΔV. As discussed in Herbst et al. (1994), values of ΔV of the order of 1 mag or larger cannot be easily explained by surface stellar activity, but are likely due to variable extinction. The adopted values of ΔV and references are given in column (8). They are more reliable when the observations cover a large interval of time. In fact, the values of ΔV for some of the objects studied by Grady et al. (1996) that are not included in the HBC should be confirmed by further observations. It should also be kept in mind that a large ΔV may be associated with FU Ori processes, i.e., it could be due to large increases in mass accretion rate through circumstellar disks; only the pattern of the variability with time can discriminate between the two cases. To the best of our knowledge, our sample does not include FU Ori stars.

A second characteristic that is usually associated with UXOrs is spectroscopic evidence for accretion, from optical and/or UV spectroscopy. This information is available for a large number of stars. In column (9) we have indicated with a "y" those that show accretion and with an "n" those that show only evidence of wind or nothing.

We define in column (10) the type of Hα profile, following Grinin & Rostopchina (1996) and Grady et al. (1997). We denote with "S" those sources showing profiles with a single, symmetric component, with "D" those that have two components, and with "P" classical P Cygni profiles. Grinin & Rostopchina (1996) show that there is a statistical correlation between the Hα profile and the values of ΔV, with double-peaked Hα profiles more common in objects with large ΔV.

TABLE 2

PROPERTIES OF HERBIG Ae STARS

HBC (1)	Name (2)	Spectral Type (3)	D (pc) (4)[a]	$F_{1.3\ \mathrm{mm}}$ (mJy) (5)[b]	M_{CSD} ($10^{-5}\ M_{\odot}$) (6)	Photopolarimetric Observations (7)[c]	ΔV (mag) (8)[d]	Infall (9)[e]	Hα (10)	Age (10^{6} yr) (11)
78......	AB Aur	A0	140 (1)	103 (1)	13	...	0.12 (1)	n (1)	P, S	3
94......	HK Ori	A5	460 (2)	<100 (2)	<138	...	0.78 (2)	y (1)	D	6
154......	T Ori	B9	460 (2)	88 (3)	122	...	1.5 (2)	y (1)	D	0.1
164......	V380 Ori	A1	460 (2)	8 (3)	11	...	0.6 (3)	n (1)	S	1
169......	BF Ori	A5	460 (2)	6 (4)	8.3	y (1)	2.8 (3)	y (2)	D	2
170......	RR Tau	B9	510 (3)	<20 (2)	<34	y (1, 2)	4.1 (4)	y (3)	D	0.6
193......	LkHα 208	F0	1000 (2)	<5 (4)	<33	...	1.4 (5)	...	D	7
246......	CU Cha	A0	180 (2)	451 (5)	95	...	0.2 (6)	...	...	4
273......	KK Oph	A6	160 (2)	50 (2)	8.4	...	1.7 (3)	y (4)	D	>10
282......	VV Ser	B9	440 (2)	<20 (2)	<25	y (3)	1.4 (3)	y (1)	D	0.6
287......	TY Cra	B9	130 (2)	130 (2)	14	...	0.6 (1)	...	...	>10
310......	BD +46°3471	A0	900 (2)	<20 (2)	<106	...	0.07 (7)	n (1)	...	0.1
313......	LkHα 233	A5	880 (2)	<40 (2)	<202	...	1.0 (7)	...	...	4
325......	V376 Cas	F0	600 (2)	38 (6)	89	...	2.8 (7)	...	...	6
329......	VX Cas	A0–A3	760 (4)	<6 (4)	<23	y (1)	2.8 (3)	y (3)	D	3
439......	UX Ori	A3	460 (2)	23 (4)	32	y (1)	2.9 (3)	y (5)	D	3
451......	HD 245185	A0–A5	400 (2)	44 (7)	46	...	0.12 (8)	...	S	5
464......	CQ Tau	A8	140 (5)	221 (7)	28	y (1)	2.0 (3)	y (3)	S	8
552......	NX Pup	A1	450 (2)	20 (3)	26	...	1.4 (9)	y (1)	D	4
619......	V856 Sco	A0	210 (1)	20 (3)	5.8	y (4, 5)	1.7 (7)	y (1)	D	0.6
686......	WW Vul	A0	370 (6)	10.5 (4)	9.4	y (1)	2.7 (3)	y (3)	D	>10
736......	SV Cep	A0	715 (7)	7 (4)	23	y (6)	2.8 (3)	...	D	4
....	HD 100546	B9	103 (1)	465 (3)	32	...	0.08 (6)	y (1)	D	>10
....	HD 104237	A4	116 (1)	92 (3)	8.1	...	0.1 (6)	n (1)	D	2
....	HD 163296	A0–A2	122 (1)	780 (1)	76	...	0.1 (6)	y (1)	P, S	5
....	HD 150193	A0	150 (1)	45 (7)	6.6	...	0.2 (6)	n (1)	P	5
....	HD 34282	A0	547 (8)	183 (8)	298	...	2.4 (10)	...	...	1
....	HD 142666	A8	114 (8)	180 (8)	13	...	1.1 (10)	n (1)	...	10
....	MWC 480	A2–A3	160 (5)	360 (7)	60	...	0.0 (8)	...	...	6
....	MWC 758	A3–A5	150 (5)	72 (7)	11	...	0.15 (8)	...	...	6

[a] Column (4): (1) van den Ancker et al. 1997; (2) Hillenbrand et al. 1992; (3) Wenzel 1972; (4) Shevchenko 1989; (5) Mannings & Sargent 1997; (6) Rossiger & Wenzel 1972; (7) Friedemann, Reimann, & Guertler 1992; (8) Sylvester et al. 1996.

[b] Column (5): (1) Mannings 1994; (2) Hillenbrand et al. 1992; (3) Henning et al. 1994; (4) this paper; (5) Henning et al. 1993; (6) Osterloh & Beckwith 1995; (7) Mannings & Sargent 1997; (8) Sylvester et al. 1996 (fluxes at 1.1 mm; we have assumed $\kappa_{1.1\ \mathrm{mm}} = 1.2\kappa_{1.3\ \mathrm{mm}}$).

[c] Column (7): (1) Grinin 1994; (2) Kardopolov & Rspaev 1989; (3) Kardopolov, Rspaev, & Pavlova 1991; (4) Bessel & Eggen 1972; (5) Hutchinson et al. 1994; (6) A. N. Rostopchina 1997, private communication.

[d] Column (8): (1) Herbst et al. 1994; (2) Shevchenko et al. 1993; (3) Grinin & Rostopchina 1996; (4) Rostopchina, Grinin, & Okazaki 1997; (5) Shevchenko 1989; (6) Grady et al. 1996; (7) Thé et al. 1994; (8) de Winter 1996; (9) HBC; (10) Bogaert & Waelkens 1991.

[e] Column (9): (1) Grady et al. 1996; (2) Welty et al. 1992; (3) Grinin et al. 1996; (4) Hamann & Persson 1992; (5) Grinin et al. 1994.

Figure 1 shows the values of M_{CSD} as a function of ΔV for the stars in Table 2. In panel *a* we identify those stars for which photopolarimetric observations exist; in panel *b* we consider the presence or absence of accretion; in panel *c* we display the type of Hα profile. The plots show the already-known result that accretion and double-peaked Hα profiles are preferentially found in objects with large values of ΔV. However, and this is the main result of this paper, there is *no* indication that the mass of circumstellar matter, as inferred from the observed millimetric fluxes, correlates with *any* of these characteristics. Survival analysis tests for censored data[6] give a 67% probability that a correlation between M_{CSD} and ΔV is absent. In practice, *there is no evidence that the UXOr nature of a star depends on the amount of CS matter*.

We next examined the possibility that M_{CSD} depends on the age of a star. We determined ages comparing the position of the star in the H-R diagram to the isochrones of Palla & Stahler (1993). For each star we obtained the effective temperature T_* from the spectral type (Cohen & Kuhi 1979). The luminosity was then computed by fitting a blackbody of temperature T_* and varying radius to the dereddened V-band magnitude and distance. For variable stars, we have used the V magnitude in the brightest state, assuming that the variability is due to circumstellar extinction. The position of the stars of our sample on the H-R diagram is shown in Figure 2, and the derived ages are given in Table 2, column (11). The uncertainty on the age estimate of any individual star can be quite large, especially for those objects for which the distance is uncertain. Nevertheless, on average they should be reliable enough for our purpose, and we plot on the lower panel of Figure 3 M_{CSD} against stellar age. We find no correlation across the range 10^5–10^7 yr, over which we have observations, with a probability of 76% that the null hypothesis is true. *The dusty environment of pre–main-sequence A-type stars does not show any significant variation during much of the pre–main-sequence evolution of the star.*

Finally, we have checked whether UXOrs are typically older than normal Herbig Ae stars by looking for a correlation between the age and ΔV. We found no such trend,

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[6] Using ASURV Rev. 1.2 (LaValley, Isobe, & Feigelson 1992), which implements the methods presented in Isobe, Feigelson, & Nelson (1986).

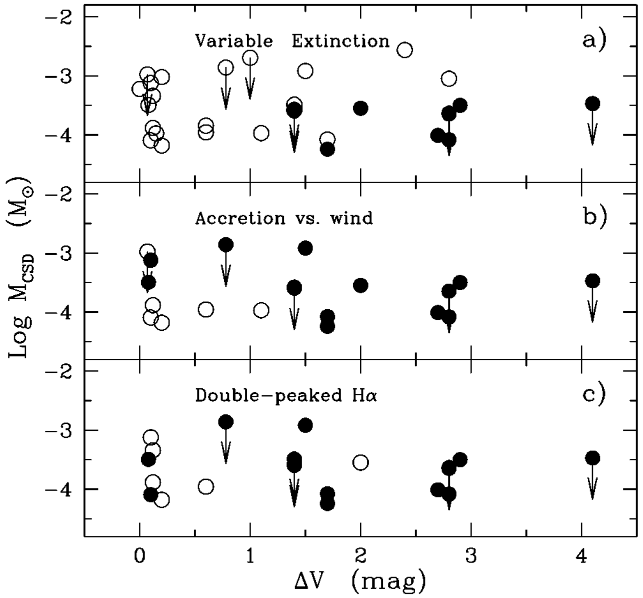

FIG. 1.—(*a*) Mass of circumstellar dust $M_{\rm CSD}$ as a function of the amplitude of the photometric variability ΔV in the V band in magnitudes. Filled circles refer to objects where ΔV is due to variable circumstellar extinction according to photopolarimetric data; open circles refer to objects for which this information is not available. Arrows indicate upper limits. (*b*) Same data for objects with (*filled circles*) and without (*open circles*) spectroscopic evidence of accretion. (*c*) Objects with double-peaked Hα profiles (*filled circles*) and with other kinds of profiles (single, P Cygni) (*open circles*).

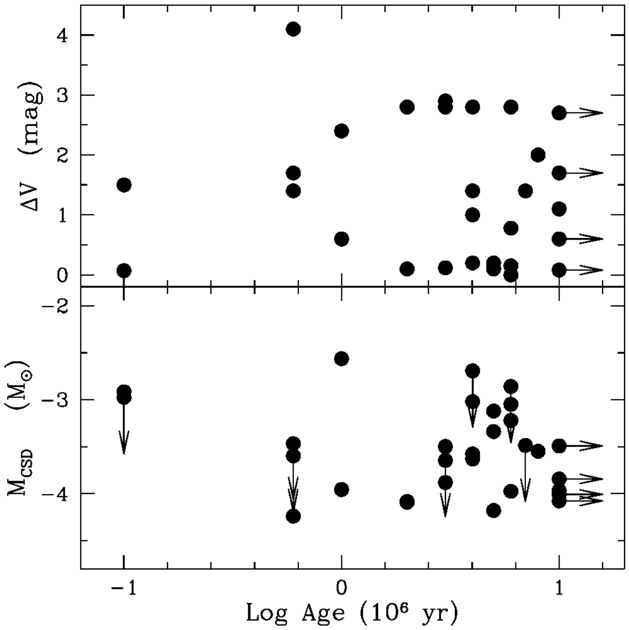

FIG. 3.—*Upper panel:* ΔV as function of the age of the star. Arrows indicate lower limit in age. *Lower panel:* Log of $M_{\rm CSD}$ as a function of the stellar age. Arrows indicate upper limit in $M_{\rm CSD}$ or lower limit in age.

with a 46% probability that such a correlation is absent (see Fig. 3*a*). *UXOrs are, on average, not older than normal Herbig Ae stars.*

4. DISCUSSION

The CS mass values derived from millimetric fluxes measure the amount of dust in relatively small grains, with radii less than a few millimeters (Pollack et al. 1994). Since the emission at these wavelengths is optically thin, $M_{\rm CSD}$ is the total mass of the CS dust, whatever its geometrical configuration. Moreover, it is unlikely that differences in age or geometry can introduce large systematic biases, unless most of the dust is in the form of very large particles.

Therefore, the lack of any correlation between $M_{\rm CSD}$ and the various UXOr characteristics, together with the fact that there is no correlation between the age of the star and either the amount of circumstellar material or the "activity" of the star as measured by ΔV, all strongly suggest that the UXOr nature of a star is caused by geometry only, with UXOr stars simply being viewed more equator-on than their (ostensibly) less active counterparts. In other words, *there is no intrinsic difference between normal Herbig Ae stars and UXOrs.*

If this is indeed the case, we must accept the idea that the CS environment of all pre–main-sequence A-type stars is somewhat different from the standard, simplified description in terms of a homogeneous, geometrically thin disk possibly surrounded by a homogeneous, almost spherically symmetric envelope (Hillenbrand et al. 1992; Natta et al. 1993; Miroshnichenko, Ivezic, & Elitzur 1997). The main feature of the CS matter is its clumpy and nonhomogeneous nature. Polarization and extinction data suggest a star that is surrounded by a geometrically thick, optically thin dusty envelope with a rather large opening angle, which contains condensations of higher optical depth, in orbit around the star. The dust in this envelope is not very different from interstellar dust. Polarization data of some objects, WW Vul in particular (unpublished data), are consistent with the presence, inside this larger envelope, of a geometrically thin, optically thick circumstellar disk. In this case, the lack of near-infrared emission (Hillenbrand et al. 1992) and the quasi-symmetric forbidden-line profiles in most Herbig Ae stars (Corcoran & Ray 1997) indicate the presence of large inner holes in the disk. However, gas is often, although

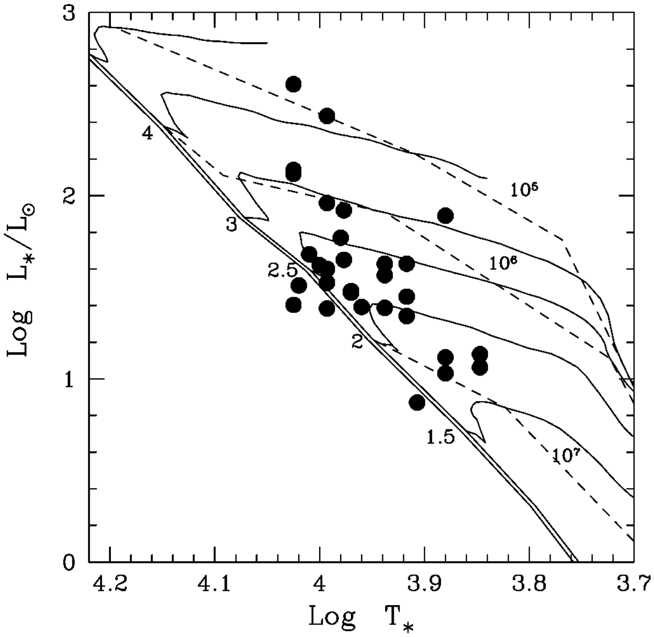

FIG. 2.—Location of the stars on the H-R diagram. The solid curves show the evolutionary tracks of stars of different masses (as labeled on the zero-age main sequence); the dashed lines are the isochrones for 10^5, 10^6, and 10^7 yr (from Palla & Stahler 1993).

sporadically, present inside the cavity, as evidenced by the occurrence of high-velocity redshifted absorption components in various metal lines. It is possible that extended, optically thin regions surrounding the central disks are, in fact, disk atmospheres (see Chiang & Goldreich 1997 for a discussion of disk atmospheres surrounding T Tauri stars).

The "transitional" status of UXOrs between pre–main-sequence stars on one side, where the circumstellar matter is practically unprocessed interstellar matter (the Herbig Ae stars), and Vega-like stars on the other, with debris disks, no gas, and possibly planets, is not confirmed by this study. This hypothesis was based on the "comet-like" analogy between the accretion phenomena seen in UXOrs and that in β Pic, which would imply that a significant fraction of the circumstellar dust has coagulated into large bodies.

We cannot, however, rule out that some fraction of dust has condensed into larger bodies at a very early stage, i.e., before the star reaches the birthline at about 10^5 yr. Indeed, analysis of multiband millimeter photometric observations of the very young ($t \approx 0.5$ Myr) T Tauri system DO Tau by Koerner, Chandler, & Sargent (1995) yields a surprisingly low value for the grain opacity index (β). At long wavelengths, opacity varies as a power law in frequency, $\kappa_\nu \propto \nu^\beta$. Koerner et al. (1995) obtain $\beta = 0.6$, which is much smaller than the value of 2 typically ascribed to small grains (radius $a \sim 0.1$ μm) in the interstellar medium (ISM; Draine & Lee 1984), and it is less than can be accounted for by changes in the chemical composition of grains (Pollack et al. 1994) or by changes in grain morphology (Wright 1987) during the time elapsed since the formation of the disk. Instead, $\beta = 0.6$ requires that a fraction of the grains contributing to the observed millimeter-wave emission have radii $a \gtrsim 1$ mm (see Mannings & Emerson 1994), the implication being that significant grain growth, by up to 4 orders of magnitude in size, can occur very early in the history of a circumstellar disk, and it may be that some of the material in UXOr and Ae disks has been "lost" to the formation of large bodies even at a comparatively young age.

Zuckerman & Becklin (1993) compare the amount of circumstellar dust in pre–main-sequence, Vega-like, and main-sequence stars and find a sharp decrease with time as t^{-2}, between pre–main-sequence stars and objects with ages $\sim 3 \times 10^8$ yr. Our results indicate that the process of dust coagulation is not a smooth function of time, and that, in particular, no significant decrease of the mass of small grains is seen in the time interval between $\sim 10^5$ and 10^7 yr.

5. SUMMARY

This paper presents observations of the continuum emission at 1.3 mm of a sample of eight pre–main-sequence UXOr stars, i.e., stars which show large photometric variation due to variable circumstellar extinction, together with evidence of mass accretion from UV and optical spectroscopy. We detect four UXOrs and set upper limits for the other four. The amount of circumstellar (CS) dust we derive when we assume that the emission is due to optically thin dust is $M_{\rm CSD} \gtrsim 3 \times 10^{-4}\ M_\odot$ for all eight stars. This corresponds to a CS gas mass $\gtrsim 0.03\ M_\odot$, when a standard gas-to-dust ratio is assumed.

By combining our observations with data from the literature, we have studied a sample of 30 pre–main-sequence stars with spectral types between F0 and B9, i.e., Herbig Ae stars, about half of which exhibit UXOr characteristics. We find no systematic differences in $M_{\rm CSD}$ between the two groups of stars. In addition, no statistically significant correlation between $M_{\rm CSD}$ and stellar age is found. The amplitude ΔV of photometric variability appears to be independent of $M_{\rm CSD}$. UXOr features therefore do not seem to depend either on the amount of dust in the circumstellar environment or on the age of a given star.

This strongly suggests that the UXOr phenomenon does not characterize stars with more evolved environments, in which an increasingly large fraction of the circumstellar dust has coagulated into larger bodies (planetesimals). Instead, the UXOr nature is probably shared by most pre–main-sequence stars (of spectral type A), but is observable only when the line of sight is close to the equatorial plane.

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