THE DUST RING AROUND AC HER

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ABSTRACT

We have used the Keck I telescope to obtain images at 11.7 μm and 18.7 μm of AC Her, a post-AGB spectroscopic binary. The source is resolved into two spots separated by about 0.″6 which can be explained as emission from particles associated with an edge-on dust ring with a radius of approximately 300 AU that is oriented approximately North-South. We propose that the ring is mainly composed of particles that are larger than 200 μm in radius which are orbiting the binary, while the infrared emission that we observe is emitted by small grains with sizes less than than 1 μm which are not gravitationally bound and, instead, are flowing out in a wind from the ring. We propose that collisions among the larger ring-particles produce the smaller wind-particles. Whether most of the 10^{30} g of dust orbiting AC Her ultimately is expelled in a wind or coalesces into macroscopic objects is unknown.

Subject headings: stars: AGB and post-AGB; circumstellar matter; winds-outflows

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Note

1. INTRODUCTION

The usual explanation for dust around evolved giants is that these stars are ejecting material in a wind (Habing 1996). However, during the past few years, evidence has accumulated that at least a few evolved giants have acquired long-lived orbiting disks of dust and molecular gas (see Jura & Kahane 1999). These long-lived disks probably are formed when a wind is focused and de-accelerated by a binary companion to the mass-losing star (Waters et al. 1993).

The physical evolution of orbiting dusty disks is key for understanding the origin of planets. While most efforts to understand planet formation are directed towards dusty disks around young stars, the dust disks around post main sequence stars may also lead to planet formation. One of the first steps in planet formation is the coagulation of micron-size dust particles into macroscopic objects. We are therefore interested in the size distribution of orbiting solids and determining under what conditions macroscopic particles grow.

RV Tau stars are pulsational variables in transition between the Asymptotic Giant Branch and the Planetary Nebula phase (Jura 1986). Of the approximately 100 such stars that are known, AC Her is one of the brightest (m_V ranging between 7.2 mag and 8.4 mag, Shenton et al. 1992, Zsoldos 1993) and nearest members of this class. It is a strong infrared source with IRAS measurements for $F_\nu(12\ \mu\mathrm{m})$ ranging from 18 Jy to 44 Jy (Shenton et al. 1992), and therefore it possesses a large amount of circumstellar matter. The optical and infrared light curves are well described by circumstellar dust around a non-radial pulsator (Shenton et al. 1992). A goal of this paper is to understand better the origin and evolution of this circumstellar material.

Van Winckel et al. (1998) have found that AC Her is a binary with a 1194 day period. They argue that AC Her possesses a long-lived circumbinary orbiting disk for two reasons. First, as also found by Giridhar, Lambert & Gonzalez (1998) this star has

low abundances of refractory elements such as calcium, but solar abundances of volatile elements such as nitrogen and oxygen. This abundance pattern can be explained if the star has accreted gas but not dust from a long-lived disk (Waters, Trams & Waelkens 1992). In this picture, radiation pressure keeps the grains from falling onto the star while the gas can accrete. Second, the infrared spectrum of the dust around AC Her displays strong emission produced by crystalline silicates which can be understood if there is a long-lived disk in the system so that annealing has time to occur (Molster et al. 1999) A further indirect argument that there is a long-lived disk around AC Her is the detection of relatively strong continuum emission at 272 GHz which can be most easily understood if there are unusually large particles which have had the opportunity to grow (Shenton, Evans & Williams 1995). Finally, Jura & Kahane (1999) have argued that AC Her possesses an orbiting disk since the spectrum of the circumstellar CO emission presented by Bujarrabal et al. (1988) is unusually weak relative to the 60 μm flux and is very unusually narrow with a FWHM < 5 km s^{-1}.

As part of a program to study dust around evolved stars, mid-IR images of AC Her have been acquired. In section 2 the properties of the star are described while in section 3 we present our observations. In section 4, we describe our estimates for the physical properties of the circumstellar environment while in section 5 we present a model for the circumstellar dust. In section 6 we give our conclusions.

2. STELLAR PROPERTIES

The primary star, a pulsational variable with a chaotically-changing period near 75.4 days (Kollath et al. 1998), dominates the optical luminosity of AC Her. Following Shenton et al. (1992), we adopt a mean radius, R_*, and temperature, T_*, of 25 R$_\odot$ and 6500 K, respectively. These results imply an average luminosity, L_*, of 1000 $L_\odot$ and, therefore, from

the observed fluxes (Shenton et al. 1992), the distance to AC Her, D_*, is $\sim$ 750 pc, if there is no interstellar extinction, consistent with the lower bound from the *Hipparcos* data of a distance of 560 pc. If the luminosity is 1000 $L_\odot$ and if there is 1 mag of visual extinction, then the distance is 470 pc. The uncertainty by as much as a factor of 2 in the distance does not qualitatively affect our interpretation described below of the data, although our estimates of the radius and mass in the circumbinary dust ring around AC Her would be altered some.

The luminosity of the star and the fraction of light reprocessed through the circumstellar dust are uncertain because the amount of interstellar extinction is not well measured, because the circumstellar extinction curve is not well known and because it is possible that there might be some very warm dust in the system which emits at wavelengths as short as 1.6 μm. The $(V - K)$ color of this star is variable, and it has been as large as 2.5 mag (Goldsmith et al. 1987). This color is significantly redder than the value of (V-K) expected for a 6500 K giant (Bessell & Brett 1988), and therefore it seems likely that there is a significant amount of extinction. Bergeat et al. (1999) fit a standard interstellar extinction curve with E(B-V) = 0.17 mag to the data and additionally suggest that there may be large circumstellar grains and/or a non-spherical distribution with a nearly face-on disk. Our analysis described below supports the picture that there are large grains, but, if anything, the system is more nearly edge-on rather than face-on. Although uncertain, we estimate from the observed visible/near infrared/IRAS fluxes that about $\sim$10% of the light from the central binary is re-processed through the circumstellar dust. The spectral energy distribution from the dust in the IRAS data is such that F_ν peaks at 25 μm and the black-body color temperature of the flux ratio $F_\nu(12\mu m)/F_\nu(25\mu m)$ ranges from 220 K to 250 K at different phases (Shenton et al. 1992).

Since no light from the secondary star has been separated from that of the bright

primary, indirect methods must be used to infer the secondary's properties. Below, we suggest that the morphology of the infrared image is consistent with our viewing an edge-on ring, and we assume that sin $i = 90°$ where i is the inclination of the dust ring which we assume is the same as the inclination of the binary orbit. The orbit has an eccentricity of 0.12 and a projected semi-major axis of 1.39 AU (Van Winckel et al. 1998). If the luminous primary has a mass, M_p, of 0.60 $M_\odot$, as is characteristic of many post-AGB stars (Habing 1996), and since the measured mass-function, $M_s^3/(M_p + M_s)^2$, is 0.25 $M_\odot$, then the inferred mass of the secondary star, M_s, is 0.78 $M_\odot$. Thus the total mass of the binary is about 1.4 $M_\odot$.

For the estimated mass and average radius of the primary, then log $g = 1.4$, somewhat larger than the value of log $g = 0.5 \pm 0.5$ derived by Van Winckel et al (1998). However, the radius may vary by as much as a factor of 1.5 from the average during the pulsations (Shenton et al. 1992) which leads to excursions in log g by 0.35.

3. OBSERVATIONS

Our data were obtained on 1999 May 31 (UT) and 1999 27 August (UT) at the 10m Keck I telescope using the Long Wavelength Spectrometer (LWS) which was built by a team led by B. Jones and is described on the Keck web page. The LWS is a 128 × 128 SiAs BIB array with a pixel scale at the Keck telescope of 0.″08 and a total field of view of 10.″2 × 10.″2. We used the "chop-nod" mode of observing, and 2 different filters: 11.2 - 12.2 μm during May and 18.4-18.9 μm during August. We observed as standard stars α CrB and γ Aql for the 11.7 μm calibrations and α Aql (Altair) for the 18.7 μm calibrations. The weather during the May night was variable with considerable cirrus cover, and for these data, we did not attempt to measure absolute fluxes. The weather during the August night was excellent. The data were reduced at UCLA using standard LWS routines. From the

standard stars, the FWHM at 11.7 μm and 18.7 μm were measured to equal $\sim$0.″35 and $\sim$0.″45, respectively.

We display in Figure 1 the 18.7 μm image; the 11.7 μm image was qualitatively similar. At both wavelengths, there are two distinct spots with an approximately north-south alignment which are separated from each other by about 0″6. There is a hint in the data that the separation of the two peaks at 18.7 μm is larger than at 11.7 μm, but given the uncertainties in the point spread functions at the two wavelengths, we cannot be certain of this result. While there are two distinct peaks at both wavelengths, there is no evidence for any extended emission in our images. Also, the sum of the 18.7 μm fluxes in the two point-source spots appears to add to the total expected from the IRAS photometry.

4. DUST SPATIAL DISTRIBUTION

The infrared luminosity of the dust is powered by absorbing light from the central stars, and as shown by Shenton et al. (1992) and Bergeat, Knapik & Rutily (1999), more than 99% of the emission from AC Her at 18.7 μm arises from circumstellar dust. The 18.7 μm image shown in Figure 1 can be explained with two possibilities: (1) there is an edge-on ring or (2) there is a bipolar outflow. On the basis of the existing spectrum of the circumstellar CO emission, we argue that it is much more likely that there is an edge-on ring. Both from the relative weakness of the 12 μm IRAS flux and our direct spatial imaging, it appears that there is relatively little dust near the star and thus currently the star does not possess a massive wind.

We show in Figure 2 the relative intensity of the 18.7 μm image along a cut through the two IR peaks compared with a model of the expected intensity. The model is an edge-on ring with a relative thickness, ΔD, compared to its radius, D, of 5%, and this model is

convolved with a Gaussian beam with a FWHM of 0.″45. As shown in the Figure, a ring with a radius of 0.″40 matches the data reasonably well. This inferred ring diameter of 0.″80 is greater than the apparent separation of the two peaks because convolving the telescope beam with the ring makes the source appear smaller than its real diameter.

With a distance to the star of 750 pc, our interpretation of the infrared image implies a physical radius of the circumbinary ring of ~300 AU. At this radius, if the total mass of the binary, M_*, is 1.4 $M_\odot$ and if we ignore the outward force exerted by radiation pressure on the grains, the predicted velocity of material in a circular orbit around the central binary is 2.0 km s^{-1}, consistent with the upper limit of 2.5 km s^{-1} to the observed CO line half-width (Bujarrabal et al. 1988). Because the observed line is much narrower than what is observed around most other mass-losing red giants and because the line width agrees very well with what is expected from the interpretation of the mid-IR image as an orbiting ring of material, it is likely that this is a gravitationally bound system.

Since ~0.1 of all the energy emitted by the primary star is re-processed through circumstellar dust, the circumstellar region must subtend about 10% of the sky around the central binary. The half-thickness of the ring must be ~30 AU, but our angular resolution is insufficient to be able to measure this structure.

The referee, Dr. T. J. Jones, has pointed out that the circumbinary ring should produce a net polarization in the integrated light from AC Her. Since ~10% of the light from the star is processed through the ring, dust scattering models (Whitney & Hartmann 1992, Wood et al. 1998) can explain the ~1% net polarization that is observed (Henson, Kemp & Kraus 1987, Nook, Cardelli & Nordsieck 1990). Because the star may exhibit non-radial pulsations (Shenton et al. 1992), the polarization might be partly produced by radiative transfer in the atmosphere as well as circumstellar scattering. Nook et al. (1990) observed AC Her at 6 different times and they report position angles of the mean polarization at 5773

Å as ranging between 15° and 38°. Henson et al. (1987) report 37 measurements of the polarization with a greater total range of position angle, but, again, typical values near 30°. The observed position angle of the polarization does not clearly relate to the approximate value of 0° for the orientation of the ring on the sky. The unknown contribution of the interstellar polarization plus the orientation of the putative nonradial pulsations may at least in part account for the complex time-varying polarization of the system.

5. MODELS

Although we suggest that there is an orbiting dust ring around AC Her, we do not present a detailed physical model to describe the history and evolution of this system. At the moment, the best we can do is sketch some possibilities while recognizing that there are many large uncertainties.

5.1. Overview of the Origin and Evolution of the Observed, Currently-Orbiting Ring

Mastrodemos & Morris (1998, 1999) have developed models for dusty winds from evolved binaries. For a model with an orbital period of 1636 days, they predict a very flattened outflow and an accretion disk around the secondary star, but they do not predict an orbiting circumbinary ring. Their model therefore fails, for example, to predict the narrow circumstellar CO line that is observed from AC Her.

Bjorkman & Cassinelli (1993) have shown that an orbiting disk may be formed from the wind of a hot, rotating star. The disk is created because the stream lines from the "northern" and "southern" hemispheres intersect, and the gas flows moving along these lines collide, shock and dissipate enough kinetic energy that the material becomes compressed

and the radial outflow is greatly slowed or even reversed (Owocki, Cranmer & Blondin 1994). It may be possible that these models for winds from rotating stars can be extended to the winds from cool AGB stars (Ignace, Cassinelli & Bjorkman 1996) when the primary is "spun-up" by a companion (Livio & Soker 1988) to induce an appreciable amount of rotation. Extending the models of Mastrodemos & Morris for dusty winds to include the effects of rotation by the mass-losing star may explain the presence of an orbiting circumbinary disk. The models developed by Bjorkman & Cassinelli (1993) describe model disks that are much closer to the central star than the ring that is currently observed around AC Her. We hypothesize that there was a putative progenitor-ring that evolved into the currently observed dust distribution.

It is quite likely that the particles in the currently orbiting ring are very different from the particles that were present when the progenitor-ring first formed. That is, while the particles that are ejected in a red giant wind, typically have radii near 0.1 μm (Jura 1996), we argue below that the particles in the ring orbiting AC Her have radii near 200 μm. These large grains can be formed by coagulation of the smaller particles during grain-grain collisions (Chokshi, Tielens & Hollenbach 1993). If the bound circumstellar material was derived from a rotating star, then we would expect that the initial radius of the progenitor-ring might be a "few" AU. This size for the progenitor is much smaller than the 300 AU radius of the observed ring around AC Her. Therefore, in order to explain the observed morphology of the circumstellar matter, there must have been a major expansion of the progenitor-ring with time. When the progenitor-ring was formed, the gas may have been gravitationally bound, but the individual dust particles would tend to be driven into the interstellar medium because they were so small that the outward radiation pressure was greater than the inward gravitational force. While the dust was being driven outwards, grain-grain collisions occured, with the consequence that some of the particles adhered to each other and eventually formed large enough particles which could remain gravitationally

bound to the system.

We can make a very rough estimate of the size particle that might result from grain-grain collisions in the progenitor-ring by assuming that the grains grew until the collision time was comparable to the progenitor-ring dissipation time. If the characteristic size of a dust particle in the ring is denoted as a, then the mass, m_{gr}, of a spherical grain is $4\pi\rho_s a^3/3$ where ρ_s denotes the density of the solid material. The mass in the progenitor-ring at any phase of its evolution, M_{ring} may be crudely estimated as

$$M_{ring} = (dM_{dust}/dt)_{trap}\, t_{dyn} \tag{1}$$

where dM_{dust}/dt denotes the mass loss rate in dust from the central star that is trapped into the progenitor-ring and t_{dyn} denotes the characteristic dynamic time for the flow out of the progenitor-ring. We adopt $t_{dyn} = D/V_{ring}$ where D is the radius of the progenitor-ring and V_{ring} is the flow speed of the dust across the progenitor-ring. Both D and V_{ring} may be functions of time. We assume that the density, n, of dust particles in the progenitor-ring is given by:

$$n \approx M_{ring}/(m_{gr}\, D^3) \tag{2}$$

If we estimate a mean time between collisions of two particles in the progenitor-ring, t_{col}, as $(n\,\pi a^2\, V_{ring})^{-1}$, then $t_{col} < t_{dyn}$ as long as:

$$a < (dM_{dust}/dt)_{trap}/(D\,\rho_s\, V_{ring}) \tag{3}$$

For an AGB star with a high rate of mass loss, the total mass loss rate of dust commonly is near 2×10^{-7} $M_\odot$ yr^{-1} (Habing 1996, Jura 1996). Although the fraction of the wind that is focused into the ring is unknown, assume for the moment that it is 50% so that $(dM_{dust}/dt_{trap}) = 10^{-7}$ $M_\odot$ yr^{-1}. The characteristic outflow speed from the progenitor-ring is uncertain because the gas has been shocked and lost a large amount of its kinetic energy. Very crudely, since the wind speed before the gas was shocked might have been 10 km s^{-1}

(Habing 1996), we estimate that $V_{ring} \sim 1$ km s^{-1}. With $D = 5$ AU and $\rho_s = 3$ g cm^{-3}, then $a \leq 0.3$ cm. Although this argument is very approximate, it does show that relatively large grains might have formed by coagulation during the formation of the progenitor-ring.

Besides radiation pressure on the grains pushing them outwards before they grow large enough to be gravitationally bound, there are at least four additional mechanisms which might be important for the progenitor-ring's expansion. 1. AGB stars are variable. Therefore, there may be times when the luminosity of the central star is sufficiently high that the force exerted by radiation on the grains can episodically drive the matter outwards. (Saslaw 1978) 2. As the primary star continues to lose mass, the material in the orbiting progenitor-ring can expand away from the central binary because it is less tightly gravitationally bound. 3. The material in the progenitor-ring may be magnetically linked to the central star and be driven outwards in a magnetohydrodynamic flow. 4. There may be a third, more distant star in the system as may be the case with the orbiting disk in the Red Rectangle (Jura & Turner 1998). Which, if any, of these mechanisms is important is still unknown.

5.2. Particle Size Distribution: The Ring and its Wind

We propose that there are two distinct populations of grains around AC Her: the ring-particles and the wind-particles, and they each have a characteristic size distribution. We have observed that most of the mid-IR flux is emitted by grains at about 300 AU from the central stars. A black body particle at distance, D, would have a temperature, T_{gr} of

$$T_{gr} \;=\; 0.707\, T_* \, (R_*/D)^{1/2}. \tag{4}$$

With the values of T_* and R_* given above, then $T_{gr} \approx 91$ K at $D = 300$ AU. This temperature is much too low to explain the observed emission at 12 μm which, as mentioned

above, exhibits a color temperature between 220 and 250 K (Shenton et al. 1992). If the particles are spheres of radius a, then in order to be warm enough to emit at mid-IR wavelengths at 300 AU from the star, the particles must have $a < 1$ μm.

Because of the strong outward force by radiation pressure, small grains are not gravitationally bound to the system, and it seems likely that these IR-emitting "small" grains are being ejected in a wind. We propose that these "small" grains have large grain "parent-bodies" in the orbiting ring. For grains orbiting the star, the inward gravitational force must be larger than the outward force by radiation pressure. If a denotes the particle radius, then:

$$a > 3L_*/(16\pi G M_* c \rho_s) \tag{5}$$

If $\rho_s = 3$ g cm^{-3}, then $a > 200$ μm in the regions that are optically thin. Evidence for relatively large grains located near AC Her is given by the measured submillimeter flux at 272 GHz (Shenton, Evans & Williams 1995). We propose that at 300 AU from the central binary, there are both warm grains with $a < 1$ μm and gravitationally bound orbiting grains with $a > 200$ μm.

It is likely that the emission by the crystalline silicates in the mid-IR is produced by these "small" grains. Qualitatively, it takes a "long" time for the grains to anneal into a crystalline form (Molster et al. 1999). However, it is also likely that the annealing occurs more rapidly near the star when we imagine that the grains are relatively small. The size of the particles when they anneal is not known.

5.3. Mass of the Ring

Having acquired a direct measure of the radius of the ring, the previous estimates of its mass can be improved. Because IRAS measured $F_\nu(100\ \mu\text{m}) = 8.0$ Jy and because Shenton

et al. (1995) measured $F_\nu(0.11\,cm) = 46.6 \pm 13$ mJy within a beam of diameter 19″, then between these two frequencies, F_ν varies as $\nu^{+2.1}$. This frequency variation of the flux is much flatter than characteristic of small grains, and it is likely that the mm-wavelength emission is produced by a distinct population of cold ($T < 100$ K), large particles (Shenton et al. 1995). We propose that the mm-wavelength flux is mainly arises from the large dust particles in the orbiting ring.

If the ring has a radius of 300 AU and is composed of particles that are larger than 0.02 cm in radius, then these particles should have a temperature near 91 K. In the Rayleigh-Jeans limit, the mass of the dust, M_{ring}, is given by the expression:

$$M_{ring} \;=\; (F_\nu\,\lambda^2\,D_*^2)/(2\,k\,T_{gr}\chi_\nu) \tag{6}$$

If $\chi_\nu(0.11\text{ cm}) = 1\text{ cm}^2\text{ g}^{-1}$ (Pollack et al. 1994), then $M_{ring} = 1.2 \times 10^{30}$ g. The sub-mm data are most sensitive to emission by particles whose diameter is less than 0.11 cm; the mass of any larger particles present in the ring is unknown.

5.4. Dust Collisions in the Ring and the Resulting Ring-Wind

We suggest that there are competing processes that occur during grain-grain collisions that affect the evolution of the dust in the ring around AC Her. Following a collision, the particles may coalesce, fragment, produce a spray of small particles or perhaps undergo some combination of these processes. Any small particles which are created will then be driven out of the system by radiation pressure and thus appear as a dust-wind from the ring.

Since the gas to dust ratio around AC Her may be ~100 times lower than found around most AGB stars (Jura & Kahane 1999), the gas is less important in the dust dynamics of this system than in the circumstellar envelopes around most other evolved stars. Separation

of the gas from the dust may have occurred since large dust particles are not well coupled dynamically to the gas.

With a total dust mass of $\sim 10^{30}$ g within a volume of about 3×10^{46} cm^3, the space density of particles whose mean radius is 200 μm and whose matter density is 3 g cm^{-3} is about 3×10^{-13} cm^{-3}. Therefore, the mean time, $(n\,\sigma\,V)^{-1}$, for a particle to collide with another particle at a grain-grain speed of 1 km s^{-1} is about 1000 yr. If these collisions result in some particle destruction, then there may be a spray of small particles ejected from the ring.

One check of this picture is to estimate the mass loss rate in the proposed wind from the ring. If $\overline{\chi}$ denotes the average opacity of the wind particles to the light emitted by the primary, if the wind originates from an inner boundary, D, and propagates into a region as seen from the central binary of solid angle, Ω_{wind}, then from the equation of continuity, the radial optical depth in the wind, τ_{wind}, is:

$$\tau_{wind} \;=\; \int_D^{\infty} (\overline{\chi}\, dM_{wind}/dt)/(\Omega_{wind}\, R^2\, V_{wind}(R))\; dR \tag{7}$$

where V_{wind} is the velocity of the wind particles. If the wind is optically thin, the fraction of the luminosity of the central binary absorbed by the wind, is given by the ratio:

$$L_{wind}/L_* \;=\; \tau_{wind}\, \Omega_{wind}/(4\pi) \tag{8}$$

where L_{wind} and L_* denote the luminosity of the wind and the central binary, respectively.

If we treat the dynamics of the outflow as an acceleration from rest at an initial radius, D, to the final grain outflow velocity by radiation pressure, and if we ignore the gravity of the central binary, drag resistance by the gas and collisions with other dust particles, then:

$$V_{wind}(R) \;=\; [(\overline{\chi}\, L_*)/(2\,\pi\, c)]^{1/2}\, (1/D \;-\; 1/R)^{1/2} \tag{9}$$

where c is the speed of light. Combining the above:

$$L_{Wind}/L_{Total} \;=\; (dM_{Wind}/dt)\; [(c\,\overline{\chi})/(2\,\pi\, D\, L_*)]^{1/2} \tag{10}$$

Since the opacity of the particles is uncertain, we simply adopt $\overline{\chi} \approx 3/(4\,\rho_s\,a)$. With $a = 0.1$ μm as might occur if the large particles break apart into pieces resembling the initial building blocks, then $\overline{\chi} = 2.5 \times 10^4$ cm^2 g^{-1}. With $D = 300$ AU, $L_* = 1000$ L$_\odot$ and $L_{Wind}/L_{Total} \approx 0.1$. Therefore, from equation (10), $dM_{Wind}/dt = 2 \times 10^{-8}$ M$_\odot$.

The scenario proposed here for the evolution of the dust around the evolved star AC Her is somewhat similar to that proposed by Kenyon et al. (1999) for the material orbiting the very young A star HR 4796. In that case, it is argued that large grains and, eventually, planetesimals grow by coagulation in a protoplanetary disk. Subsequent agitation of the disk material by the planetesimals leads to collisions which puff up the disk and also produce the smaller particles responsible for the infrared emission from this system. Although the situations differ in many respects, in each case there is an initial period of grain growth in a circumstellar system which is followed by the [currently observed] stage in which the products of grain collisions and destruction are observed.

6. CONCLUSIONS

We have acquired 11.7 μm and 18.7 μm images of the dust emission from AC Her. We find that the emission is concentrated into two unresolved spots that are separated by $\sim$0.6$''$. We interpret this result as support for the model that this star possesses a long-lived orbiting ring of material with a radius of about 300 AU, consistent with the unusually narrow profile of the circumstellar CO emission. Stability of the ring against radiation pressure requires dust particles at least 200 μm in size, while the bulk of the mid-infrared radiation appears to come from particles smaller than 1 μm.

We propose the following model for the formation and evolution of the ring around AC Her. Because the star shows no evidence for a currently substantial mass loss, it appears

this is an evolving system rather than one which is in equilibrium. At an earlier epoch, we hypothesize that the mass-loss wind from the red giant primary of this binary system was focused into a progenitor-ring of radii a few AU, within which the particles evolved to be as large as 200 μm in radius. The proposed progenitor-ring expanded with time to its current size, with several different mechanisms possibly being important. At the present epoch, the observed small particles are created by shattering which occurs during collisions of large grains in the ring. It is also possible that particles considerably larger than 200 μm have already formed or are in the process of coagulating within the ring.

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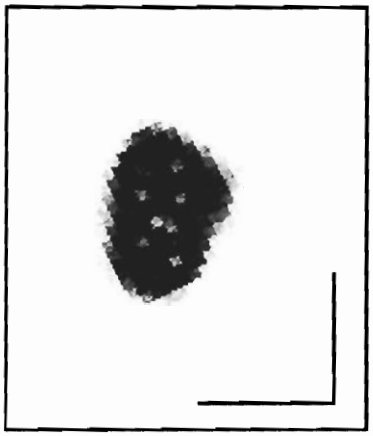
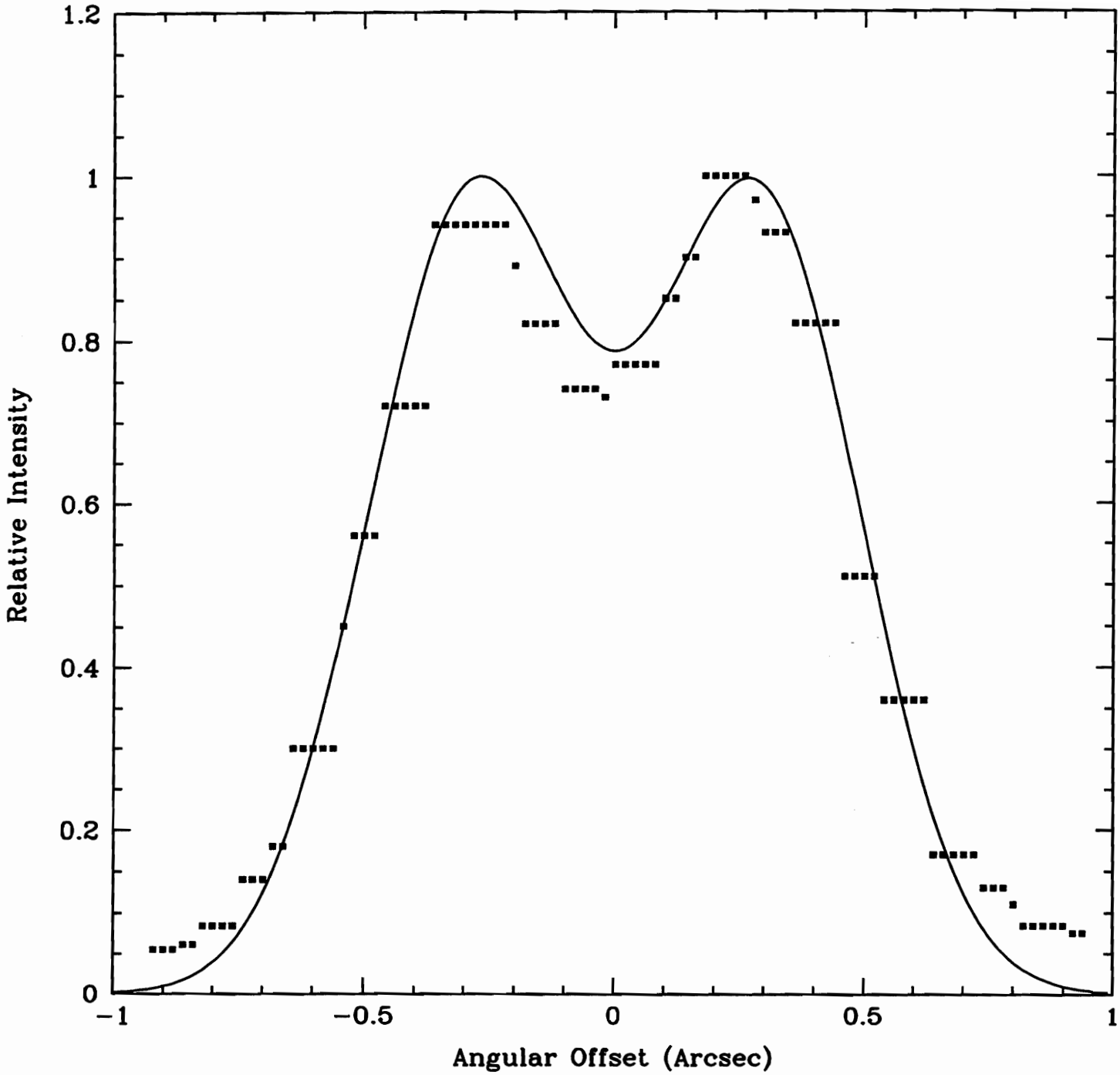
FIGURE CAPTIONS

Fig. 1. The 18.7 μm image of AC Her. North is to the top and and East is to the left; these directions are displayed on the Figure by lines whose lengths are 1" each.

Fig. 2. Plot of a north-south cut through the 18.7 μm image compared with a model of a Gaussian beam with FWHM 0.45″ convoluted with a narrow ring of radius 0.40″.

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0.6
0.4
0.2
0
Relative Intensity
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−0.5
0
0.5
1
Angular Offset (Arcsec)