FORMATION AND PROGENITORS OF MASSIVE STARS

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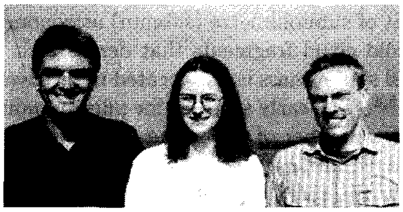

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Earliest stages of massive stars - though difficult to observe - gain increasing interest in observational astronomy due to the advent of new technical developments. To address the question of progenitors, an overview on recent millimetre surveys is given. Particularly, regions with of methanol masers - which are regarded as signposts for massive star formation - harbour sources of different evolutionary stages as witnessed by various combinations of infrared, millimetre and radio emitting objects within the same volume. Certainly, better spatial resolution is required to disentangle the individual sources and to probe their evolutionary stage. The question of formation, i.e. the debate of accretion vs. collision, is reviewed by analysing the most prominent massive protostar candidates and by zooming into a recently discovered source within M 17. Here, a deeply embedded infrared object is surrounded by a huge flared rotating disk; all evidence collected so far points toward a massive protostar that is currently born through disk accretion.

Keywords: Stars: formation, ISM: jets and outflows

1 Introduction

The formation of stars is one of the great miracles in astrophysics. Nevertheless, the birth of low-mass stars has been investigated in great detail during the last decades and it looks that both theory and observation have agreed on a common scenario: stars form from dense clumps in molecular clouds by accretion of material from an envelope and - at later stages - from a disk. The formation process of massive stars is considerably more difficult in all aspects: i) Massive star formation involves large outflows, winds and radiation pressure, which makes it hard to believe that it is simply a scaled-up version of the low-mass formation scenario (e.g. Wolfire & Cassinelli 1987) [1]. ii) Our theoretical understanding and the current computational capabilities are far from a proper treatment of all processes that contribute to the interaction between radiation, gas and dust. Nevertheless, recent model calculations indicate that the formation by accretion from a massive circumstellar disc onto a central protostar might be feasible (Norberg & Maeder 2000, Yorke & Sonnhalter 2002) [2,3]. Given that most massive stars are found in stellar clusters and associations, Bonnell, Bate & Zinnecker (1998) [4] have suggested an alternative scenario where the coalescence of low- to medium-mass protostars leads to the formation of massive stars. iii) Observationally, massive stars are rare and their birth places are usually rather distant. Because their formation occurs on short time scales, the probability of catching a birth in the act is extremely low. Despite of the mentioned obstacles, a variety of observational evidence for massive star formation has been recognised during recent years. In the first part of this review, the latest attempts of finding progenitors of high-mass stars are described while the second part deals with the question whether there is unique signature for accretion with massive stars.

2 Progenitors of high-mass stars

Without doubt, it is the merit of submillimetre (submm) astronomy to have discovered the first true protostars, i.e. dense, cold cloud fragments that derive their luminosity by accretion and where the majority of the final stellar mass is still located in an envelope and/or disk (e.g. André et al. 1993, Chini et al. 1993) [5,6]. The early searches for pure submm emitting massive protostars were less successful although a number of pre-stellar cloud cores could be found which might at some later stage may collapse into high-mass stars (e.g. Mezger et al. 1988) [7]. The reason for this failure is likely due to the short evolutionary times scales of massive pre-stellar cores: high-mass stars reach the main sequence, form (ultra-)compact HII regions and develop ionised winds before all of the material in the envelope has fallen in.

Obviously, the aim is to find high-mass protostars before they form ultracompact HII regions (UC HIIs). One of the most promising strategies is to study regions with maser emission. While OH masers appear to be associated with HII regions, H_2O (collisional pumping) and CH_3OH (radiative pumping) masers seem to occur with early stages, when molecular outflows produce shocks within dense and warm gas. As a consequence a number of millimetre (mm) surveys have been performed (e.g. Beuther et al. 2002a, Sridharan et al. 2002) [8,9]. A recent attempt in this field has been performed by Nielbock et al. (in prep.): Based on a radio continuum and methanol maser survey near southern UC HIIs (Walsh et al. 1998) [10], a subsample of 37 infrared and radio-quiet maser sites have been observed at 1.2 mm. All investigated regions contain a wealth of new mm sources, many of which are neither coinciding with UC HII regions nor masers. As it is well established that high-mass stars tend to be embedded in stellar clusters and associations, it seems that this agglomeration is already introduced at an early stage of formation, at least on large scales.

We separated the sources into 4 different groups according to their spectral properties at IR, mm and radio wavelengths; in addition, we calculated the 1.2 mm luminosity $L_{1.2}$ for every mm source. The groups comprise the following objects: UCHIIs and radio continuum sources (group A), masers without radio continuum emission and not classified as UCHIIs (group B), infrared sources detected by IRAS or MSX without being associated with masers, UCHIIs or radio continuum emission (group C), and finally pure mm sources (group D).

Group A sources are equally distributed between $1 < L_{1.2}\,[\mathrm{L}_\odot] < 10$, and contain the five most luminous objects of the entire sample with $L_{1.2} > 20\,\mathrm{L}_\odot$. This is obviously due to the content of young massive stars that ionise and densify their immediate surroundings. The mm continuum flux might be contaminated by free-free emission. Group B sources are also fairly equally distributed below $10\,\mathrm{L}_\odot$, while only two objects are slightly more luminous. It is likely that this group represents the immediate predecessors of the UCHIIs. Group C only populates the low luminosity regime significantly below $10\,L_\odot$. The IR emission points toward the presence of relatively warm and compact sources which could be evolving pre-main sequence (PMS) stars

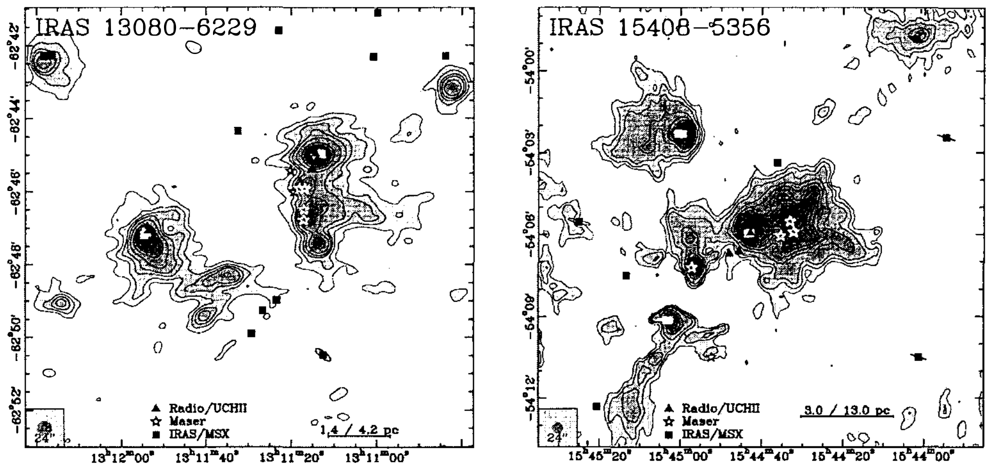

Figure 1: Composite images of methanol maser regions around the IRAS sources 13080-6229 and 15408-5356 mapped at 1.2 mm; known masers are marked by a star. The images display the typical, highly structured regions with lots of embedded compact sources.

- probably of low mass - or accreting massive protostars. Group D sources strongly peak at luminosities below $1\,L_{\odot}$. These objects probably either contain young low-mass protostars or starless clouds. This suggests that high and low-mass stars are forming in a common area.

Fig. 1 shows that the potential regions of high mass star formation are extremely confused and that the various sources (IR, mm, UCHIIs, masers) appear right next to each other. Given that the distance is uncertain in many cases, the absolute luminosity is not unique; furthermore, due to the low spatial resolution of the FIR data the source of luminosity remains questionable. Finally, one has to be aware of the fact, that the linear sizes of many mm cores is of the order of $0.1 - 1$ pc which is comparable to galactic HII regions and clusters.

3 Accretion vs. collision

As mentioned in the beginning, there is an ongoing debate about the formation scenario of massive stars. While the collision idea cannot be verified observationally, the accretion hypothesis can in principle be checked by searching for massive stars with disks. Bipolar molecular outflows are a spectacular manifestation of ongoing star formation and are probably intensely related to the accretion process. They provide a mechanism for accretion disks to shed angular momentum thereby permitting matter in the disk to migrate to the central protostar. Therefore, the period of intense mass loss coincides with the accretion phase of the protostar and is believed to occur over a large stellar mass range. Among others, Shepherd & Churchwell (1996) [11] showed that bipolar outflows are very common also in regions of massive star formation. Moreover the relation between bolometric luminosity of the protostar and the mechanical luminosity of the flow, its momentum flux, and its mass outflow rate smoothly extends from low-mass stars (Cabrit & Bertout 1992) [12] into the high-mass regime. Beuther et al. (2002b) [13] corroborated qualitatively this result but showed simultaneously that the mass entrainment rates are not a unique function of the embedded luminosity. A general problem with these statistical studies is the distance uncertainty with many of the sources and the question whether the observed IRAS luminosity is due to a single object or a cluster of stars.

There are small number of well investigated candidates which are regarded as massive young stellar objects (YSOs) being associated with disks and/or outflows; if true these cases would indicate that high-mass star formation is indeed a continuous extension of the well-known low-mass accretion. Without aiming at completeness some of the most famous templates will be reviewed briefly by discriminating between firm observational evidence and - sometimes far reaching - interpretation.

3.1 Outflow sources

S 106 Historically, the first, spectacular massive outflow source was S 106; this bipolar HII region is excited by an O7 - O9 ZAMS star (Gehrz et al. 1983) [14] called S 106 IR. The bipolar structure of the ionised gas was explained in terms of a slight asymmetry in the density distribution of a mass loss envelope (Felli et al. 1984a) [15]. The two lobes are separated by a dark lane which was initially interpreted as a large-scale molecular disk. However, Stutzki et al. (1982) [16], Barsony et al. (1989) [17] and Schneider et al. (2002) [18] falsified this suggestion and concluded that there is no molecular gas disk in S 106.

HH 80-81 Marti et al. (1993) [19] investigated the Herbig-Haro complex HH 80-81 where a compact radio continuum source, H_2O maser emission and the bright infrared object IRAS 18162-2048 point toward massive star formation within the region. Placed at a distance of 1.7 kpc the IRAS luminosity implies the presence of a $1.7 \cdot 10^4 L_\odot$ star or a cluster of stars (Aspin & Geballe 1992) [20]. Assuming that this luminosity is due to a single ZAMS star it would be a B0 and would create ionisation far in excess of that observed. There is a highly collimated outflow but no disk.

G9.62+0.19 G9.62+0.19 is a well-studied region of massive star formation with a number of extended, compact and ultracompact HII regions. Hofner et al. (2001a) [21] detected a high-velocity molecular outflow and concluded from the mass and energetics of the outflowing gas that a luminous central object must be the driving source in the region. Again, there is no direct evidence for an accretion disk and the driving candidate cannot be assigned uniquely.

IRAS 20126+4104 IRAS 20126+4104 is another massive YSO. With a bolometric luminosity corresponding to a ZAMS spectral type of about B0, the absence of strong radio continuum emission indicates that IRAS 20126+4104 is likely in an evolutionary stage prior to that of an ultracompact HII region. A bipolar jet/outflow is centred on a dense gas clump oriented perpendicular to the flow. However, there are multiple jets suggesting multiplicity of the central source. Likewise, only limits on the presence of an accretion disk can be given (Hofner et al. 2001b) [22].

HW2 The star forming region Cepheus A contains three embedded YSOs (Curiel et al. 2002) [23] as well as a bubble of expanding water masers. It was suggested that one of these radio continuum sources is the embedded YSO powering the water maser structure, but its nature is still unknown. Since this source appears unresolved in the 7 mm map, the size of the HII region or the protostellar disk (and/or envelope) is below 30 AU. HW2 may actually be a small cluster of YSOs in formation.

3.2 Disk candidates

While the above examples do only provide evidence for outflows there are also some objects where "accretion disks" have been claimed.

G192.16-3.82 The largest circumstellar disk hitherto quoted has a diameter of 130 AU and is associated with the potential massive protostar G192.16-3.82 (Shepherd et al. 2001) [24]; this is about the size of the disks detected around low-luminosity protostars. Looking into detail, the central mass of $8-18\,M_\odot$ is derived indirectly from the CO mass outflow and from the luminosity of an IRAS source which includes everything: stellar, accretion and outflow luminosity. Both conversions into a spectral type and then into a stellar mass include large uncertainties and assume a ZAMS relationship between L_{bol} and T_{eff} that may not hold for YSOs. Likewise, the mass estimates for the disk are uncertain due to contamination by free-free emission; the disk mass could be even lower than $3\,M_\odot$ if the emission is partially due to ionised gas. Finally, there is the question of multiple stars. From models of the radio emission Shepherd et al. (2001) [24] conclude that the protostar is a binary system. In addition, they state with respect to the spectral type B2 that this designation represents an upper limit, because lower mass stars in a cluster may also contribute to dust heating.

IRc2-I The high-mass protostar IRc2-I in the BN/KL region in Orion has been claimed to have disk of 80 AU (Plambeck et al. 1990) [25]; Wright et al. (1995) [26] even talk of 1000 AU. In contrast, Greenhill et al. (1998) [27] show that the SiO emission of IRc2-I within 60 AU is not due to a disk but that the region is dominated by a conical bipolar outflow, rather than the expected disk. A slower outflow, close to the equatorial plane of the protostellar system, extends to radii of 1000 AU and contradicts the disk interpretation by Wright et al. (1995) [26].

NGC 7538 S-a This potential massive YSO close to a site of OH and H2O masers is embedded in an elongated cloud core (Sandell et al. 2003) [28]. The mm continuum has revealed a resolved elliptical source of about 14" × 8" while the line emission yields a source size of 11" × 7" at the position of the OH and H2O masers. The velocity gradient along the major axis of the elliptical source is interpreted as a rotating disk. Though the molecular line studies indicate both rotation and outflow, the velocity structure of the entire system is extremely confused and there is no direct evidence for a disk. The luminosity of the source of $2 \cdot 10^4\,L_\odot$ has been determined from data at 57, 100 and 1000 μm and corresponds to regions of 30", 55" and 60", respectively, with a positional accuracy of 15". Thus, the FIR observations do not have enough spatial resolution or positional accuracy to confirm that the luminosity originates from the OH/H_2O masers.

Orion 114-426 The largest silhouette disk so far is known as Orion 114-426 (McCaughrean et al. 1998) [29] and has a diameter of about 1000 AU and a mass of $\geq 5 \times 10^{-4}\,M_\odot$; however, its central star is likely a low-mass object of about $1.5\,M_\odot$ rather than a massive protostar.

To summarise, all above candidates - apart from Orion 114-426 - provide only indirect evidence for a disk and all of them do not show a direct signature for ongoing accretion. Furthermore, it is highly uncertain whether the observed outflows originate from a massive protostar or from low-mass companions. Likewise, the inferred luminosities which are mainly based on large-beam FIR data and/or CO outflows may originate from single stars and/or clusters. Thus, although there is growing evidence that massive stars are associated with outflows that probably originate from an accretion process through a disk there is not a single clear-cut case so far to uniquely support the accretion scenario for high-mass stars.

3.3 The first massive accretion disk?

In the following, the most recent example for the formation of a massive protostar through disk accretion is described. It has been discovered by Chini et al. (2004) [30] and comprises all constituents expected from a massive protostellar source: i) a uniquely defined central source, ii)

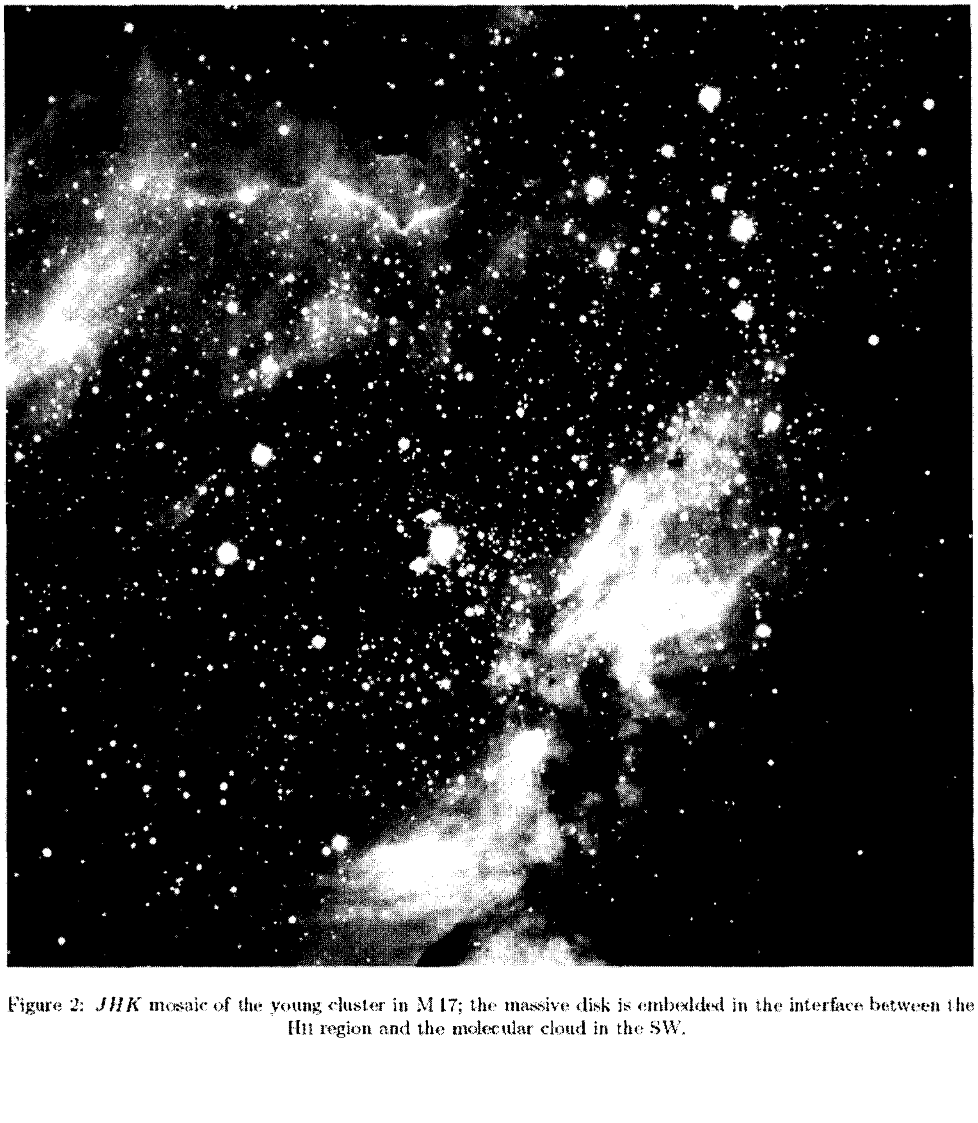

Figure 2: *JHK* mosaic of the young cluster in M 17; the massive disk is embedded in the interface between the HII region and the molecular cloud in the SW.

a massive flared rotating disk, iii) spectral evidence for accretion, iv) a bipolar reflection nebula, and v) a bipolar jet.

Looking into the cradle

The Omega nebula or M 17 is one of the most prominent star forming regions in our Galaxy at a distance of 2.2 kpc (Chini & Wargau 1998) [31]. Fig. 2 shows part of a three-colour infrared mosaic of the area which was the initial observation leading to our investigation. It shows a dense cluster of young stars embedded in clouds of gas and dust. M 17 is extremely young as witnessed by the presence of several high-mass stars which ionise the surrounding hydrogen gas; the total energy output of these stars is almost $10^7\,L_\odot$. Adjacent to its south-western edge, there is a huge cloud of molecular gas which is believed to become a site of future star formation. The interface between the HII region and the molecular cloud is the locus where the radio emission as well as the infrared emission of the area attain their maximum (Felli et al. 1984b) [32]. Nevertheless, despite many attempts no stellar object could be identified to be responsible for this emission. Therefore, it is believed that the radio and infrared emission is not due to an individual stellar source, but rather is the result of a collision between the expanding HII region and the molecular cloud; this leads to a density and temperature enhancement of the interstellar medium and thus to an increase in emission from the boundary layer.

Chini et al. (2004) [30] have recently investigated this interface between the HII region and the molecular cloud by means of unprecedented deep infrared imaging between 1.2 and 2.2 μm in order to penetrate the dust and to search for newly forming high-mass stars. Due the sensitivity of these measurements more than 50 magnitudes of visual extinction became transparent and the faint nebular emission of the HII region could shine through the south-western molecular cloud. Close to the radio and infrared emission peaks a tremendous opaque silhouette appears against the nebular background associated with an hourglass shaped nebula and surrounded by a larger disrupting dust envelope. As outlined in the following, this system complies perfectly with theoretical predictions for a newly forming high mass star surrounded by a huge accretion disk and accompanied by an energetic bipolar mass outflow.

The accretion disk

The most obvious morphological components of the system are two triangular shaped dust lanes that become visible at infrared wavelengths. Fig. 3 is a JHK image showing the silhouette of a flared disk, seen nearly edge-on, and a bipolar nebula. With a radius of about 10.000 AU it is by far the largest circumstellar disk ever detected. Its orientation is parallel to the interface between the HII region and the molecular cloud, indicating that large scale motions and density gradients may have influenced the formation of the disk. When going from the centre towards its outer edges the disk widens substantially. Using the background nebular light as a homogenous source of illumination, the extinction and thus the column density of interstellar matter within the disk can be determined at each point along the line of sight. This analysis reveals three morphological details: starting from a central hole of $4 \cdot 10^{15}$ cm radius, a dense inner torus extends up to $r \sim 3.8 \cdot 10^{16}$ cm and widens with increasing radius from $z \sim 7.9 \cdot 10^{15}$ to $1.8 \cdot 10^{16}$ cm. Further out a flared disk dominates the optical depth extending up to $r \sim 9.9 \cdot 10^{16}$ cm with a thickness z from $1.8 \cdot 10^{16}$ to $4.1 \cdot 10^{16}$ cm. An outer envelope can be traced to about $r \sim 5.3 \cdot 10^{17}$ cm with $1.0 \cdot 10^{17} < z\,[\mathrm{cm}] < 4.0 \cdot 10^{17}$.

The maximum column density of hydrogen inferred from the optical depth at 2.2 μm is $\sim 6 \cdot 10^{22}$ atoms cm^{-2}. Adopting normal interstellar dust properties, this value can be converted into a dust mass; using 140 as a recent number for the gas-to-dust ratio we obtain about $6\,M_\odot$ for the gas inside the inner disk. However, both assumptions of normal dust properties and a normal gas-to-dust ratio may be far from the true conditions in such an extreme environment.

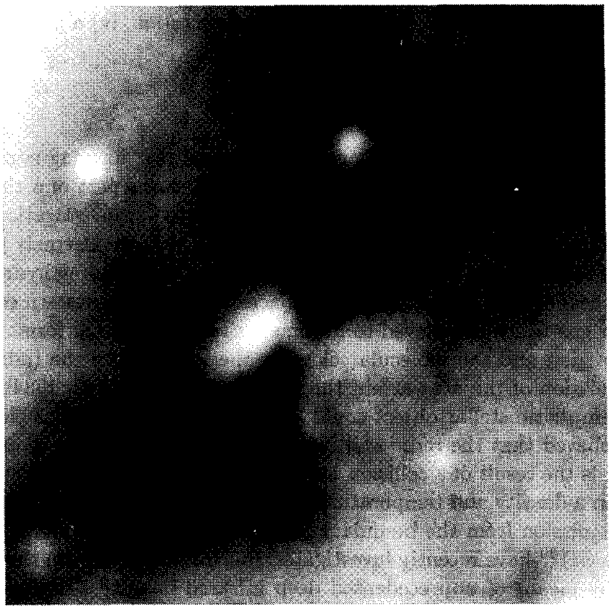

Figure 3: Composite JHK image showing the disk morphology and the associated bipolar nebula.

Further physical properties concerning the mass and the kinematics of the disk and its surroundings have be obtained from mm observations. ^{13}CO data indicate that the disk/envelope system slowly rotates with its north-western part approaching the observer. A velocity shift of 1.7 km/s corresponding to a velocity gradient of about 11 km/s/pc is present over an extent of 30.800 AU. Adopting an abundance ratio of 43 between ^{12}CO and ^{13}CO and a conversion factor of $N_{H_2} = 2.3 \cdot 10^{20}\,cm^{-2}$ per K km/s to derive H_2 column densities from the velocity integrated ^{12}CO intensities a conservative lower limit for the disk mass of 110 solar masses is obtained. Several effects will increase the true disk mass: i) All observed lines are more (^{12}CO) or less (^{13}CO, $C^{18}O$) optically thick. ii) The CO lines may be partly photo-dissociated. iii) The above conversion factor is more compatible with regions of low densities ($n_H \sim 200\,cm^{-3}$) and low temperatures ($T \sim 10\,K$) and thus may not be applicable in a hot dense core environment of a massive star, or in an externally heated and compressed cloud edge such as the M 17 ionisation front. Given that the conversion factor varies with $\sqrt{n}/T$, the disk mass could increase by a factor of three when using $n_H \sim 10^5\,cm^{-3}$, as suggested by the column densities from the optical depth at 2.2 μm and assuming a temperature of $T \sim 100\,K$.

The bipolar nebula and the jets

A sequence of images from 0.4 to 2.2 μm (Chini et al. 2004) [30] depicts a second morphological structure - an hourglass-shaped nebula perpendicular to the plane of the disk where the two lobes show different wavelength dependent intensities. The fact that optical light is detectable throughout the huge amount of foreground extinction can only be explained if the emission is - at least partly - due to reflected light scattered by dust grains. In this case, the extinction which increases roughly inversely with wavelength is compensated by the effect of scattering which varies as λ^{-4}. The nebular light seems to originate from two separate components, a diffuse extended shimmer and a more compact emission in the central region.

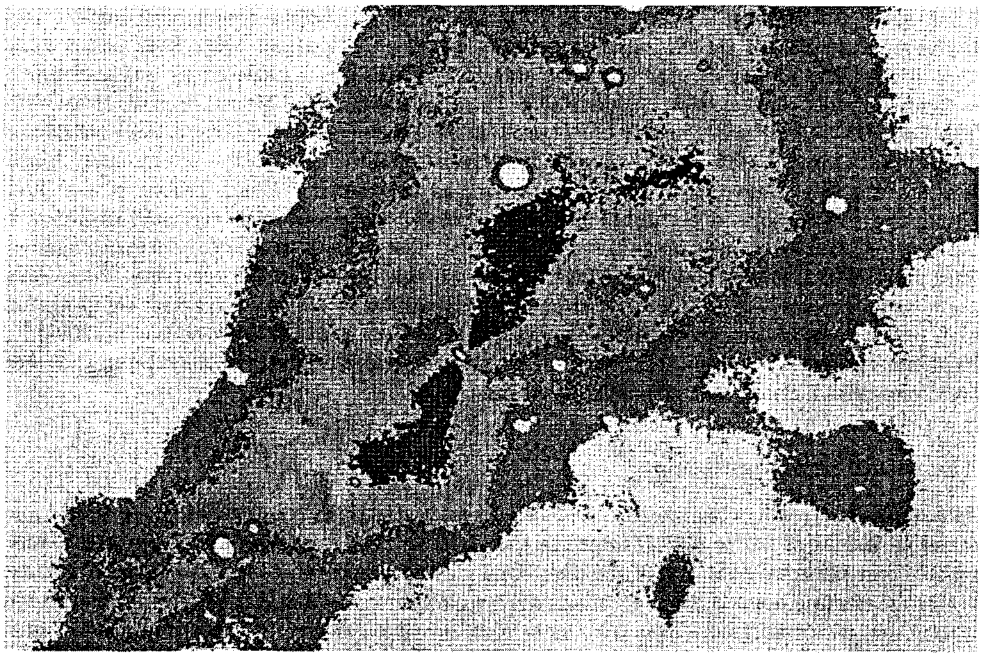

Figure 4: Contrast-enhanced 2.2 μm NACO image that shows the inner disk (blue) and the bipolar jet (red).

Firstly, the diffuse emission - particularly prominent at optical wavelengths - is symmetric and seems to mark the walls of an hourglass shaped cavity. It extends at least up to $5 \cdot 10^17$ cm above the plane of the disk towards both sides with a maximum width of about the same size. The origin of this emission is probably due to scattered light from the walls of the cavities that have been cleared by an energetic mass outflow. From the fact that the NE lobe becomes brighter with increasing wavelength while the intensity of the SW lobe remains almost constant we conclude that the former suffers from more extinction. This suggests a slight inclination of the disk with respect to the line of sight which hides the NE lobe partly behind the disk. Vice versa one is facing the disk slightly from below and thus are looking into the SW cavity. The hourglass morphology of the SW cavity is supported by two curved dusty ejecta that end in typical bow-shocks as a result of their interaction with the ambient medium. This picture is further corroborated by CO data which also trace the walls of both cavities.

Secondly, there is a more compact emission at both sides of the innermost disk. Both blobs show a strong wavelength dependence with the western one being bright in the optical and almost vanishing in the infrared; at about 1 μm the clumps are of equal intensity and attain simultaneously their maximum brightness. Beyond 1 μm the eastern blob becomes stronger by 10% at J and K and by 40% at H. This is in contrast to what one would expect from the pure extinction which is higher along the eastern line of sight due to the inclination of the disk. It is likely that there are intrinsic intensity differences between the two features which may either be caused by an asymmetric outflow or by line emission, particularly in the $H-$band. The eastern outflow shows a pronounced morphology; it seems to originate close to the central object and resembles an precessing jet that turns over shortly after leaving the innermost region; farther out the orientation of the flow axis is almost parallel to the disk plane. The much fainter western flow is more diffuse and has an angle of about 45° with respect to the disk plane (Fig. 4).

A spectrum between 0.4 and 0.9μm (Chini et al. 2004) [30] that covers both cavities and the flows is dominated by the emission lines of Hα, the CaII triplet 8498, 8542 and 8662Å, and HeI 6678Å. In the case of low-mass stars these lines are considered as unquestionable evidence for an ongoing accretion process (e.g. Hartmann et al. 1994, Muzerolle et al. 1998) [33,34]. The CaII triplet was also shown to be a product of disk accretion for both a large sample of TTauri and Herbig Ae/Be stars (Hamann & Persson 1992) [35]. The Hα line is extremely broad and shows a deep blue-shifted absorption as well as an inverse P Cygni profile; blue-shifted absorption components in permitted lines are typically associated with accretion disk-driven outflows (Muzerolle et al. 1998, Calvet 1997) [34,36]. The same is true for forbidden emission lines such as [O I] 6300Å and [S II] 6731Å which are also present in the spectrum. Numerous permitted and forbidden Fe II lines which are velocity-shifted by 120 km/s are clear signposts for high velocity dissociative shocks with velocities of more than 50 km/s (Muzerolle et al. 2001) [37]. In summary, there is a typical TTauri spectrum from two 30.000 AU nebular lobes that are associated with a flared disk of 10.000 AU radius.

The nature of the protostar

At the disk centre where one expects the newly forming star there is a relatively compact 2.2 μm emission feature of 240 × 450 AU which is too small to host a cluster. Its major axis differs by 15° from the rotational axis of the disk. One may speculate whether this elongated feature marks the starting point of the precessing massive outflow or whether it originates from a binary system that is currently born from a common accretion disk. Given that there is only a $K-$band brightness for this central object its absolute luminosity is highly uncertain. From extinction values of neighbouring stars it is likely that the disk is deeply embedded in the molecular cloud behind a visual extinction of about 50 magnitudes. The dust within the disk produces another contribution of about 60 magnitudes toward its centre which makes it impossible to obtain any optical information about the protostellar accreting object. Assuming that the central emission is due to direct stellar light an absolute infrared brightness of $K \sim -2.5$ mag is derived. This would correspond to a main sequence star of about 20 $M_\odot$ and a temperature of 35.000 K. An independent mass estimate from dynamical considerations, concerning the rotation of the molecular disk, yields a mass of about 15 $M_\odot$ for the central gravitational object. Due to the fact that the accretion process is still active, and that the gas reservoir of the disk still allows for a substantial mass gain, it is likely that in the present case a massive protostar is on its way to become an O-type star. Theoretical calculations show that an initial gas cloud of 60 to 120 $M_\odot$ evolves into a star between 33 and 43 $M_\odot$ while the remaining mass is rejected into the interstellar medium (Yorke & Sonnhalter 2002) [3].

All presented evidence point toward a massive star that is currently forming via accretion through a disk while the associated energetic mass outflow disrupts the surrounding environment and rejects part of the accreted material into the ambient medium. The observations show - for the very first time - all theoretically predicted ingredients of the star formation process directly and simultaneously in a single object and therefore improve our current understanding of such an event tremendously. The schematic picture of Fig. 5 summaries the individual components as revealed by the different observing techniques and complies perfectly with recent magneto-centrifugal disk/wind models (Hartigan et al. 1995, Hirose et al. 1997) [38,39]. A central protostar - maybe even a binary system - is surrounded by a flared, slowly rotating disk from which it accretes mass along a reconnected magnetospheric field. A considerable fraction of the transferred mass is accelerated from the polar regions of the protostar/disk interface into opposite directions along the open stellar magnetic field. This reconnection-driven jet is further accelerated magneto-centrifugally due to stellar rotation and excavates the ambient medium. Eventually, a bipolar high-velocity neutral wind forms an hourglass like cavity which reflects light from the

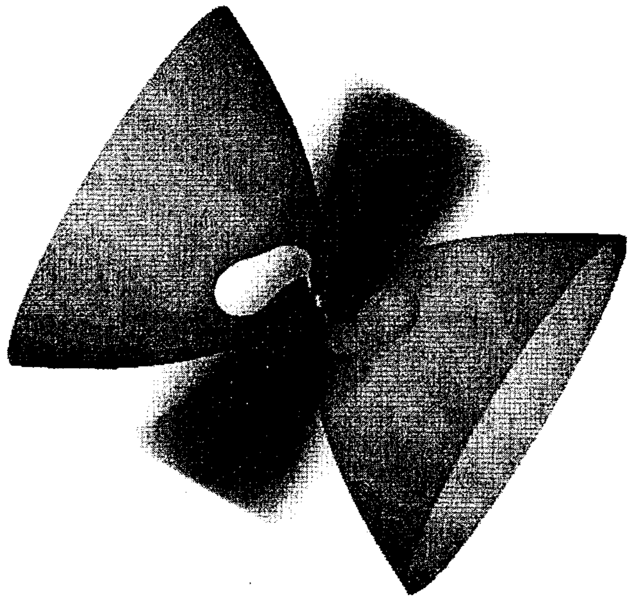

Figure 5: Model of the source outlining the disk (black) seen under an aspect angle of 15°, two nebular hourglass shaped lobes and two precessing jets.

very inner regions of the system. Further out this neutral wind drives the observed molecular bipolar flow.

4 Summary

This review has focused on progenitors of massive stars, i.e. on evolutionary stages between massive pre-stellar cores and UC HIIs. It looks that the current submm/FIR surveys are likely to detect proto-clusters rather than protostars. Though valuable for a first glimpse of where massive star formation occurs in our Galaxy, these surveys will have to be refined by future missions with higher spatial resolution. Some of individual well-known massive protostellar candidates have been reviewed. While there is ample evidence for energetic mass outflows the driving sources are difficult to identify; likewise, their luminosity is highly uncertain - partly due to confusion, partly due to missing photometric data. Nevertheless, the mass and energetics of the outflowing gas point toward luminous central objects as driving sources. The new disk in M 17 seems to be a promising case in favour of the accretion scenario. It is the largest and most massive disk that could be directly observed with sub-arcsecond spatial resolution. Follow-up observations are definitely required to constrain the mass and the luminosity of the forming star.

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