The Discovery of a Photoevaporated Circumbinary Disk in the Orion Nebula

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Introduction

Binaries represent a typical product of the gravitational collapse of cores with high angular momentum. In fact, the majority of stars in star-forming regions are expected to be in binary or multiple systems (e.g. Duchene 1999).

There can be three disks in a young binary system: two circumstellar disks and a circumbinary one (Lin & Papaloizu 1993). Disks have been detected around many spectroscopic binaries, but direct imaging of disks around wide binary systems, either circumstellar or circumbinary is much rarer.

We report on the discovery of a photoevaporated circumbinary disk seen in silhouette against the bright nebular background of the Orion Nebula.

Observations

The data presented here are part of the ACS exposures from the *HST Treasury Program on the Orion Nebula Cluster.*

An area of ~ 450 square arcmin nearly centered on the Trapezium Cluster was mapped with ACS/WFC using 5 filters: F435W (Johnson *B*), F555W (Johnson *V*), F658N (*Hα*), F775W (Cousins *I*), F850LP (*z-band).*

The ACS images have been visually inspected and a catalog of 219 circumstellar disks has been compiled (Ricci et al. 2008).

In Figures 1 and 2 we show that source 124-132, a photoevaporated disk ~ 1.5 arcmin north of Trapezium with a diameter of > 100 AU, harbors two point-like sources with a projected separation of ~ 60 AU.

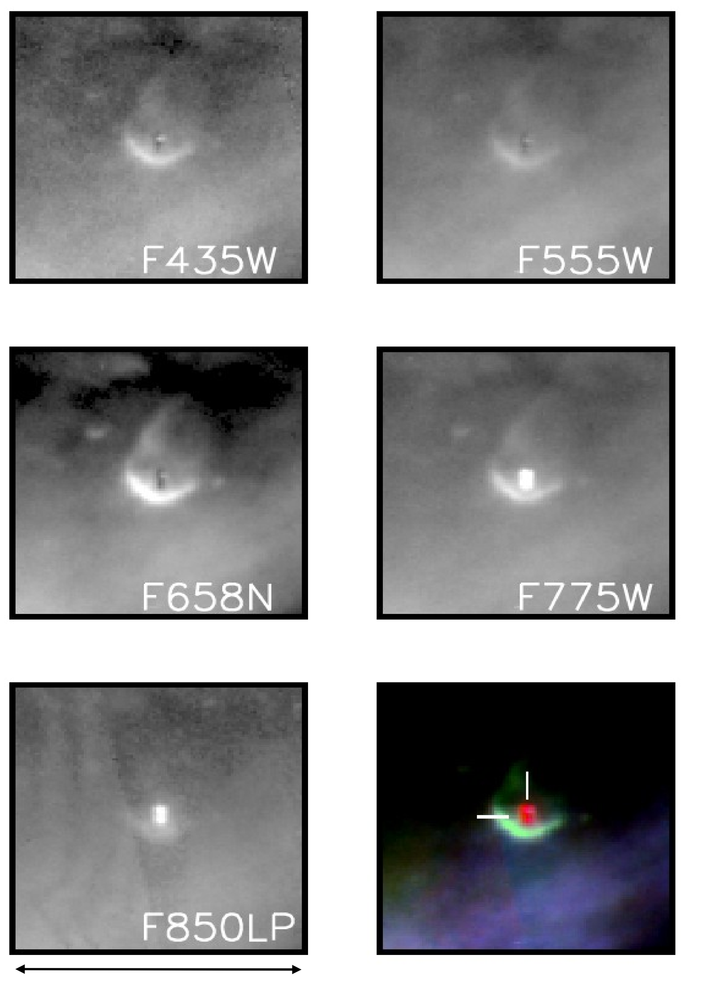

Fig. 1 – ACS/WFC images of 124-132. The color picture at the bottom-right is a composite of the 5 ACS filters. At shorter wavelengths (F435W and F555W) the point-like source remains visible to the west of the disk axis, suggesting that the silhouette disk is slightly tilted with the western (right) side toward us. The F658N image shows that the point-like source is not centered on the dark disk axis, but shifted approximately 2 pixels (0.1") to the north, away from the ionizing front. Since the brightness of the ionization front does not allow us to trace the full extension of the disk to the south, this asymmetry is probably real. More interestingly, at longer wavelengths (F775W and F850LP) two point-like sources appear resolved along the disk axis.

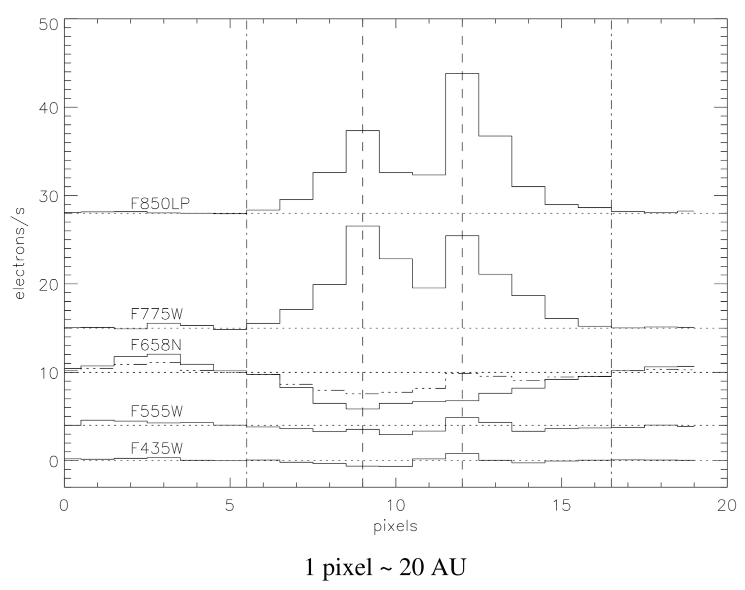

Fig. 2 – North-south cuts (north to the right) through the disk diameter for the 5 ACS filters (solid lines). An offset has been added to the counts in each filter (horizontal dotted lines). The horizontal dash-dot line for the F658N filter is the adjacent column to the west. The position of the sources is marked by the vertical dashed lines, whereas the limits of the disk are indicated with vertical dash-dot lines.

Photometric Analysis

To constrain the nature of the two sources, we derived an estimate of their magnitudes integrating the counts in a 3-pixels diameter aperture and using the filter and color dependent aperture corrections from Sirianni et al. (2005).

Figures 3 and 4 show that the observed magnitudes of source N can be reproduced by two different combinations (black stars in the diagrams) of A_V, Log(L_{acc}/L_{phot}) and stellar mass for each R_V.

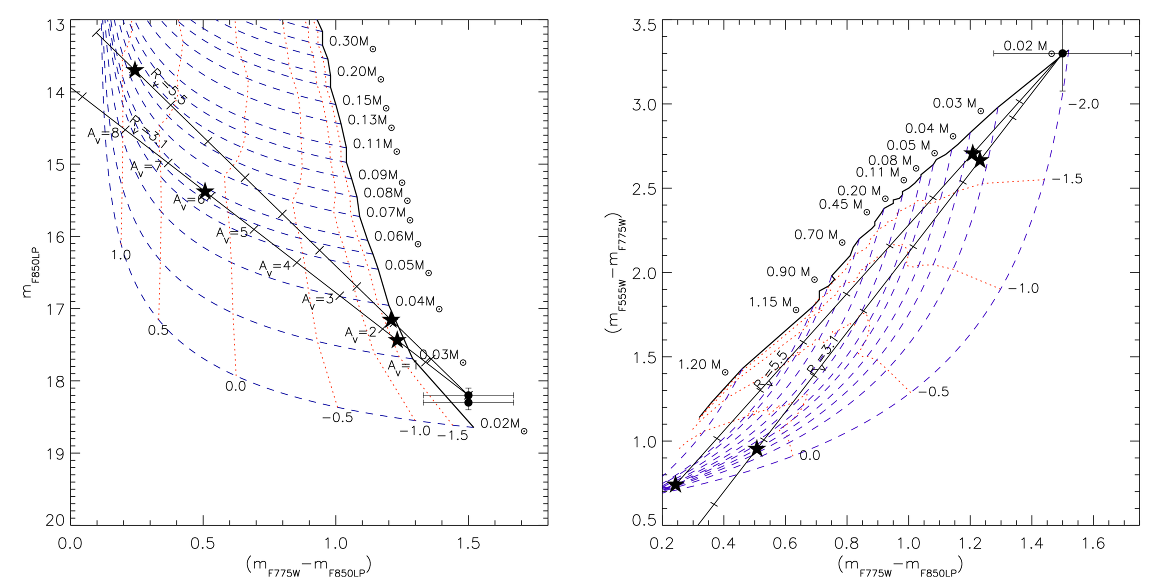

Fig. 3 – Color-magnitude (left) and color-color (right) diagrams for both sources and source N only respectively (black points). Solid curves represent the Baraffe/NEXTGEN 1 Myr isochrone while blue dashed lines give the displacement due to accretion for different values of Log(L_{acc}/L_{phot}). For the accretion spectra we combined 3/4 of optically thick black body emission at T_{eff}=7000 K from the shock region and 1/4 of optically thin emission at the same temperature and with density n = 10^8 cm^{-3} from the pre-shock region (Calvet & Gullbring 1998). Dereddening vectors corresponding with increasing A_V are shown for two values of the reddening parameter R_V. The stars represent the solutions for the position of Source N compatible with the photometric data.

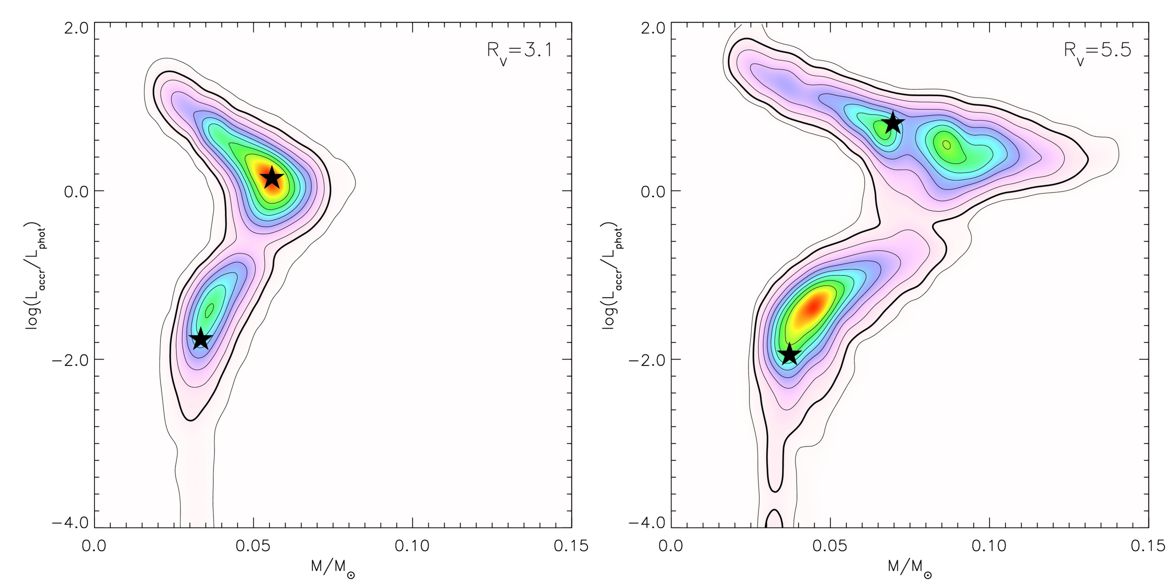

Fig. 4 – Distribution of mass and accretion luminosity for source N, derived from a Monte Carlo simulation done using 10000 trial stars populating a gaussian error distribution for the source N magnitudes. The left and right panels are relative to the R_V = 3.1 and R_V = 5.5 reddening law, respectively. The two areas at the top and bottom of each figure correspond to the high and low solutions.

Mass Accretion Rate

Another clue to the nature of the sources comes from a comparison of our estimated accretion rates with the values found for similar objects (e.g. Muzerolle et al. 2003).

On this basis we exclude the *high* solutions that provide mass accretion rates in excess by 2 orders of magnitudes.

So the most consistent solutions for the two point-like sources (similar photometry) gives M ~ 0.04 M_{Sun}, $\dot{M}$~ 5 x 10^{-11} $M_\odot$ / yr, with A_V ~ 2^m.

Discussion

Whereas our images show the presence of a large-scale circumbinary disk, the presence of mass accretion points to the presence of at least one circumstellar disk.

Theory provides a consistent scenario, predicting that circumstellar and circumbinary disks emerge as outcome of the evolution of the original circumstellar disk in which the binary system formed (Gunther & Kley 2002). Due to the exchange of angular momentum from the binary to the disk, an inner gap developes between the inner and outer disk regions. Material can flow through the gap along spiral arms, feeding the circumstellar disks and therefore sustaining mass accretion into the central stars.

The influence of UV flux from an external source on a circumstellar disk has been studied only for single stars by Robberto et al. (2002), who have shown that extra heating of a disk face produces an increase of the disk flaring angle, leading to photoevaporation and possibly a warping of the system. This may explain why source S remains undetected in our bluest filters: the southern of the disk is the one more directly exposed to the UV flux and the stronger photoevaporation may locally increase the optical depth on this side. Assuming the sources are identical, a line of sight difference in A_V of only 0.3^m would bring source S below our detection limit at the shortest wavelengths while being compatible with the magnitudes observed in the red filters.

Conclusion

We have found a photoevaporated disk in the Orion Nebula that includes a wide binary, with a projected separation between the two point-like sources of ~ 60 AU at the distance of Orion.

From the comparison between the observed magnitudes of the brightest source with those predicted using a 1 Myr Baraffe/NEXTGEN isochrone with different amount of accretion luminosity and extinction we find that a low mass (~ 0.04 M_{Sun}) brown dwarf with mass accretion rate $\dot{M}$ ~ $10^{-10.3}$ M_{Sun}/ yr, typical for objects of this mass, and about 2 magnitudes of visual extinction provides the best explanation to the data.

This is the first observation of a circumbinary disk undergoing photoevaporation and, if confirmed by spectroscopic observations, the first detection of a wide substellar pair still accreting and enshrouded in its circumbinary disk.

References

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