Protoplanetary disks of T Tauri binaries in Orion: Prospects for planet formation

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Abstract. Dusty protoplanetary disks surrounding young low-mass stars are the birthplaces of planets. Studies of the evolutionary timescales of such disks provide important constraints on the timescales of planet formation. Binary companions, however, can influence circumstellar disk evolution through tidal interactions. In order to trace protoplanetary disks and their properties in young binary systems, as well as to study the effect of binarity on circumstellar disk lifetimes, we have carried out spatially resolved spectroscopy for several low-mass binaries in the well-known Orion Nebula Cluster. Brγ emission, which we detect in several systems, is used as a tracer for the presence of an active accretion disk around a binary component. We find a paucity of actively accreting secondaries, and hence, evidence that in a binary system it is the lower mass component that disperses its disk faster.

1 Introduction

Circumstellar proto-planetary disks are not only an inevitable product of the low-mass star formation process, but they are also the most important prerequisite for the formation of life. It is the dust and gas content of such disks out of which planetary systems are born. Therefore, investigations of the composition and evolution of proto-planetary disks around young low-mass stars, is directly linked to our understanding of planet formation, and ultimately elucidating the process that has been responsible for the formation of our own solar system.

The overall lifetime of circumstellar disks, and hence the upper limit on planet-building timescales, has been determined to approximately 10-6 Myr for stars in low stellar density regions and stellar clusters respectively (Cieza et al. 2007; Carpenter et al. 2006; Haisch et al. 2001). These findings are based on infrared observations that measure, for stellar groups of different age, the fraction of stars with circumstellar disks as identified by their near- and mid-infrared excess. One of the dominant processes driving disk evolution in single stars seems to be photoevaporation from the central stellar source (Cieza et al. 2008), suggesting that more luminous stars loose their disks faster. Indeed, studies of large samples of roughly coeval stars spanning a range in mass from \( \sim 0.1 \text{M}_\odot \)
Petr-Gotzens, Daemgen, & Correia

found that lower mass stars retain their disks for a longer time than higher mass stars (Kennedy & Kenyon 2009).

On the other hand, many stars are members of a binary or multiple system, and for nearby solar-like stars the binary fraction is even as high as $\sim 60\%$ (e.g. Duquennoy & Mayor 1991). Hence tidal truncation is expected to be an additional important parameter that should govern the lifetime of a circumstellar disk around each individual binary component. Theoretically, one expects that the truncation radius of the outer circumstellar disk scales with the binary separation and with the components’ mass as $R_t \sim 0.3 - 0.5 \times a$, with $a$ being the binary separation and its factor varying with the system’s mass ratio (Armitage et al. 1999; Papaloizou & Pringle 1977). Because the truncation of the disks should limit the amount of disk material that can be accreted, reduced disk lifetimes are expected for binaries, and in particular for systems with smaller separations, and for less massive stars. The presence of a stellar component may also lead to shorter disk accretion timescales for stars in binary systems as compared to single stars.

2 Goal of this study

The goal of this study is to determine the presence of a circumstellar protoplanetary disk around each individual component of a sample of close binary stars in the $\sim 1$Myr old Orion Nebula Cluster. Thereby, we wish to investigate if, and how, the evolutionary timescales of disks around young stars being members of a binary depart from those determined for single stars. The following diagnostics have proven to be very good indicators for the presence of a disk: (i) photometric excess emission at K- and L-band reliably traces the presence of a warm inner disk (e.g. McCabe et al. 2006), and (ii) Br$_\gamma$ emission at 2.16$\mu$m indicates magnetospheric accretion from a circumstellar disk onto the central young star (e.g. Muzerolle et al. 2001).

In this contribution we focus on spectroscopic observations only and discuss our search for Br$_\gamma$ emission in spatially resolved, low-mass ($< 2M_\odot$) binaries located in the Orion Nebula Cluster (ONC). At a distance of $\sim 440$ pc the ONC is the closest region of active low- and high-mass star formation. Most of the stars in the field of our Galaxy, and most likely our sun as well, were formed in OB star clusters as those present in Orion.

3 Observations and data reduction

A total of 22 ONC binaries have been observed with K-band adaptive optics spectroscopy at Gemini Observatory, using NIFS (spectral resolution of R$\sim 5000$), or at ESO’s VLT, using NACO (R$\sim 1400$). Both instruments provide a wavelength coverage of $\sim 2.05 - 2.45\mu$m. The larger data subset (16 targets) was obtained with the NACO instrument. The range of separation of the binary components is $0.26'' - 1.1''$, which corresponds to about 110-500 AU at the distance of the ONC.

After standard data reduction of the 2-dim spectral images (flat fielding, sky subtraction, bad pixel correction) IRAF/apextract was employed to extract the spectrum of the primary and secondary of each binary. The spectra were
Figure 1. Spectrum of the primary and secondary component of the 0.5″ binary JW876. Each spectrum is plotted together with a template dwarf spectrum from the IRTF spectral library. Both components clearly show Brγ in emission.

Further cleaned from telluric lines through division by standard star spectra of spectral types B0-B9V, which had been observed close in airmass and time. Before the division, Brγ absorption in the standard star spectra was removed by interpolation, allowing us to probe all science target spectra for Brγ-emission, that is indicative for active accretion. Furthermore, spectral typing was achieved by matching the spectra with templates from the IRTF Spectral Library (Rayner et al. 2009 in prep., Cushing et al. 2005). To find the best template, as well as the corresponding best reddening and veiling/excess values, a range of A_V and K-band excess were applied to all spectral templates. Then, a minimum chi^2 was used to fit the modified templates with the science spectra. As an example, we show in Figure 1 the result for the binary JW876.

4 First Results

The first evaluation of the reduced spectra provided spectral types for almost all binary components. The large majority of the stars are of K and M spectral type, as expected for young low-mass objects at the age of 1 Myr. Our preliminary analysis suggests Brγ-emission lines in several of the binary components. In detail, we find that a fraction of ~80% of the target systems show any sign of an active accretion disk, i.e. most of the binaries possess at least one component with a clear signature of Brγ-emission. The numbers of pairs where both components show Brγ-emission and where only one component shows Brγ (so-called mixed-pairs) are roughly equal, and we conclude that mixed-pairs are common.
Quite intriguingly, only one system was found in which only the secondary seems to have an active accretion disk. This finding is apparently not due to an observational bias in the sense that the detection of the Br\(_\gamma\) emission line is more difficult in secondaries, because they are usually the less massive and later spectral type component: in Figure 2 we show that for those systems observed in this study the presence of Br\(_\gamma\) emission is not a function of spectral type. It is evident from the data, although not yet statistically significant, that binarity influences disk evolution, even for binaries as wide as our ONC targets, all of which have separations >100 AU. The under-representation of active accretion disks among secondaries hints at disk dissipation working faster on (potentially) lower mass secondaries, leading us to speculate that secondaries are possibly less likely to form planets. A similar result has been reported by White & Ghez (2001).

![Figure 2](image)

Figure 2. Distribution of spectral types for stellar components that do show Br\(_\gamma\) emission (solid bars) and that do not show Br\(_\gamma\) emission in their spectrum (hatched bars).

In the context of the latter, we further note an interesting observational result: Almost 40 of all the extra-solar planets discovered to date reside in wide binary systems where the component separation is larger than 100AU (large enough that planet formation around one star should not strongly be influenced by the companion star). But for all these systems an extra-solar giant planet is found only around one star, never around both stars of the binary system (see Desidera & Barbieri 2007), and in 95% of the cases it is the primary component that hosts the extra-solar planet.

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