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Star formation : circumstellar environment around Young Stellar Objects

Manoj Puravankara*
Inter-University Centre for Astronomy and Astrophysics, Pune - 411007, India

Abstract. In this thesis we have undertaken a detailed study of the evolution of young circumstellar disks from the early pre-main sequence phase to the main sequence phase. We have used several observational diagnostics of the disks such as emission-lines, infrared excess and polarization, and have followed their evolution in time. From our study, we show that the accretion activity in intermediate mass young stars declines rapidly and is terminated in about 3-5 Myr. The inner disk is found to dissipate on similar timescale. Further, we show that the optical depth of the circumstellar dust disks decreases steadily with increasing stellar age from the early pre-main sequence phase to the late main sequence phase.

Keywords : circumstellar matter — stars: formation — stars: pre-main sequence — stars: activity — stars: evolution

1. Introduction

One of the major successes of modern star formation theory has been the prediction that the circumstellar disks are natural by-products of the star formation process (e.g. Shu et al. 1987). There is now overwhelming observational evidence for the presence of such disks around a majority of young pre-main sequence (PMS) stars (e.g. Beckwith and Sargent 1996; Mannings and Sargent 1997; Weinberger et al. 2002; Eisner et al. 2003). The observed peculiarities of these young stars are generally attributed to their circumstellar environment (e.g. Hartmann 1998; Natta et al. 2000).

In the early PMS phase, young stars actively accrete matter from the surrounding

*e-mail:manojp@iucaa.ernet.in

disk (e.g. Hartmann 1998). As the star evolves, the disk accretion rate goes down and eventually the accretion is terminated. By the time the central stars reach the main sequence, young circumstellar disks surrounding them lose most of the material due to planet formation and other disk dispersal processes. In the standard model of planet formation, the dust grains with sizes typical of interstellar dust settle down to the disk mid-plane and stick together to grow into rocky planetesimals (e.g. Weidenschilling and Cuzzi 1993). The disk is depleted of smaller grains and this lowers the opacity of the reprocessing disk. Planetesimals grow further to earth-like planetary bodies by coalescence and eventually accrete gas in the outer disk to form giant planets (e.g. Pollack et al. 1996). When the disk has become sufficiently gas-free, so that it is dominated by grain dynamics, the planetary mass objects can gravitationally perturb kilometer-sized planetesimals sending them into highly eccentric orbits. Collisions between these planetesimals then replenish the disk with 'second generation dust' which is observed around many main sequence stars (e.g. Lagrange et al. 2000). At least 15% of main sequence stars are surrounded by such optically thin debris disks (Lagrange et al. 2000).

A detailed study of the disk evolution is critically important to our understanding of the planet formation and other disk dispersal mechanisms and their associated timescales. In this thesis, we have undertaken a study of the the circumstellar environment around young stellar objects from an evolutionary perspective. The evolution of the circumstellar material around these stars from the early pre-main sequence phase to the late main sequence phase is investigated. We have restricted our study to intermediate mass young stars as they are relatively poorly studied.

2. Evolution of disk accretion in pre-main sequence stars

One of the most important observational characteristics of young pre-main sequence stars is the presence of a variety of emission lines in their spectra. (Herbig 1960; Cohen and Kuhi 1979; Corcoran and Ray 1998; Vieira et al. 2003; Hernández et al. 2004). Emission line activity in these stars is widely believed to be accretion driven (e.g. Hartmann 1998; Muzerolle et al. 2004). We have carried out optical spectroscopic observations of about 60 Herbig Ae/Be stars (HAeBe), which are intermediate mass young stars, with the 1m and 2.34m telescopes at Vainu Bappu observatory, Kavalur and with the 2m Himalayan Chandra telescope at the Indian Astronomical Observatory, Hanle, India. We also extracted near-infrared (NIR) J, H and K magnitudes of HAeBe stars in our sample from 2MASS All-Sky Point Source Catalogue. We find a tight correlation between the Hα equivalent width (W($H\alpha$)) and the intrinsic colour excess due to circumstellar disks $\Delta(H-K)$ (obtained by subtracting the photospheric $(H-K)$ colour and the contribution due to interstellar reddening from the observed $(H-K)$ colour) for the intermediate mass HAeBe stars.This correlation found between the strength of emission lines and continuum near-infrared excess emission strongly suggests a physical connection between the origin of emission lines and inner accretion disks.

Using the strength of emission lines as a measure of accretion rate we studied the evolution of accretion in intermediate mass HAeBe stars. The equivalent width of the Hα line was taken as an indicator of emission line activity and the pre-main sequence ages were obtained by placing the stars in the HR diagram and comparing with the theoretical evolutionary tracks (Palla and Stahler 1993). We find an overall decrease in W(Hα) with age though at small ages there is a large spread in the Hα equivalent widths. Equivalent width of Hα emission in HAeBe stars is found to fall by a factor of more than two on a timescale of about 2-3 Myr, and the emission disappears in about 5-6 Myr. This timescale is quite similar to the inner disk lifetimes derived from the studies of disk frequencies in young clusters (Haisch et al. 2001). We also find a general decline in the magnitude of NIR colour excess with the PMS age of the star, indicating a gradual dissipation of the inner accretion disks.

3. Lifetimes of inner disks: disk census of OB associations

From the near-infrared K and L band surveys of young embedded clusters it has been shown that the optically thick inner accretion disks ($\leq$ 1 AU) are dissipated rapidly on timescales of a few Myr (e.g. Haisch et al. 2001). However, in these studies, clusters in the age range of 5-30 Myr is only poorly represented. This age range is nevertheless important for disk evolution studies because the transition from optically thick to optically thin disks is believed to take place during this phase. We have carried out a disk census of 12 nearby OB associations which are in the age range of 5 - 50 Myr. We studied the frequencies and lifetimes of inner disks in these associations based on their near-infrared excesses. We find that the fraction of stars with circumstellar disks in these OB associations is very low ($\leq$ 5%). Inner disks have dissipated around most of the stars in these OB associations in about 5 Myr. This is consistent with the disk dissipation timescale being as short as $\sim$ 5 Myr.

4. Transition objects: optically thick to optically thin disks

The next stage of evolution, where the accretion is terminated and the inner disk is being dissipated, is an important phase in understanding the process of disk dissipation and planet formation. Transition from optically thick disks to thin disks is believed to take place sometime during this phase. However, very few such stars are known currently. One of the tasks is to identify young stars in this 'transition phase' where accretion is terminated and the inner disks is getting disrupted. Observationally this is manifested by the lack of near-infrared excess emission and the absence of emission lines in the spectra. We have identified a few such stars and have studied their physical properties in detail. Our studies indicate that the dissipation timescale for the outer disk is slightly longer than that for the inner disk (Manoj et al. 2002).

5. Main sequence debris disks: polarization measurements

As the ‘primordial’ disk gets dissipated, which is accompanied by the formation of planetesimals, the secondary grains are generated due to the collisions between these planetesimals. Several main sequence stars with such ‘secondary’ disks are now known. We have carried out optical polarization observations of the main sequence dusty systems (Vega-like stars) and have studied their polarization properties in detail. From our study we find that Vega-like stars show intrinsic polarization which is is caused by scattering of stellar light due to circumstellar dust distributed in a flattened disk. The absence of any excess reddening in these stars is consistent with the dust grains in their circumstellar disks being relatively large in size. However, in some Vega-like stars that show relatively small infrared excesses but large values of polarization, an additional component of dust consisting of smaller grains with high albedo may also be present (Bhatt and Manoj 2000).

6. Lifetimes and temporal evolution of debris disks

Finally, we have studied the lifetimes and temporal evolution of the dust disks surrounding main sequence stars. The primary difficulty in such a study has been the problem of determining the ages of individual main sequence field stars. Even when several dating techniques are employed, the ages estimated are not always mutually consistent (Zuckerman 2001). To circumvent this problem we used velocity dispersion as an age indicator to constrain the ages of a large sample of main sequence Vega-like stars. Velocity dispersion of a group of stars is known to be a measure of the average age of that group. We have used *Hipparcos* measurements to study the kinematics of Vega-like systems. Velocity dispersion of Vega-like stars is found to be systematically smaller than that of the normal main sequence field stars for all spectral types, suggesting that the main sequence dusty systems, on the average, are younger than the normal field stars. The debris disks seem to survive longer around late type stars as compared to early type stars. Further, we find a strong correlation between fractional dust luminosity ($f_d \equiv L_{dust}/L_\star$) and velocity dispersion of stars with dust disks. Fractional dust luminosity is found to drop off steadily with increasing stellar age from early pre-main sequence phase to late main sequence phase. (Manoj and Bhatt 2005)

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