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A VIEW OF YOUNG CIRCUMSTELLAR DISKS WITH THE GTC

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RESUMEN

Las estrellas jóvenes están rodeadas de discos circumestelares de polvo que pueden formar sistemas protoplanetarios. Se necesitan observaciones en el IR cercano y medio de alta resolución para medir la emisión térmica de esos discos y determinar sus propiedades físicas. En esta contribución nos tratamos específicamente a la variabilidad en los discos y a los discos en los sistemas binarios, e indicamos el potencial y las limitaciones que podríamos esperar del GTC.

ABSTRACT

Young stars are surrounded by circumstellar dust disks from which planetary systems will eventually form. To observe the thermal emission of those disks and to elucidate their physical properties high spatial resolution observations in the near and mid-infrared are needed. In this contribution we address the specific points of disk variability and disks in binary systems, and point out the potential and the limitations we can expect of the GTC.

Key Words: **STARS: PROTOSTELLAR AND PROTOPLANETARY DISKS**

1. INTRODUCTION

Disks are found on many different scales in astronomy, from spiral galaxies to rings around planets, and are currently the subject of intensive investigations in astrophysics. This contribution deals with disks surrounding young stars.

Disks form as a natural byproduct of star formation. Protostellar disks are formed by gas and dust and play a pivotal role in the formation of stars and in the formation and evolution of planetary systems. Disks transfer material from the collapsing cloud onto the central forming star and also represent the reservoir of material from which planets form. Thus, to understand how our Solar System formed and to account for the diversity of planets recently discovered we require the understanding of the protostellar/-planetary disks seen in pre-main sequence (PMS) stars and how they evolve to the debris disks around main-sequence (MS) stars. This latter step is, for instance, fundamental to understanding exo-zodies, which will have very important implications for future space missions such as *DARWIN* and *TPF*, both aimed at characterizing the physics and chemistry of Earth-like planets around stars.

Disks are found around stars over the whole stellar mass spectrum (from OB stars to brown dwarfs), and all evolutionary ages (from Class 0 objects to MS stars). The sizes of disks extend from few stellar radii to $\approx$ 1000 AU and their masses ranges from $\sim 10\ M_{\odot}$ to $\sim M_{\rm Moon}$. One of the nicest example is represented by the young MS star β Pic, which is surrounded by a debris disk replenished by multiple collisions of large solid comet-like bodies; the presence of a planet is also suggested by observations (e.g., Lecavelier des Etangs 2000, and references therein). An important point concerning planetary systems and planets around stars is related to disk statistics, i.e., the number of circumstellar disks around stars. Thus, the time survival of the disks when the star arrives at the main sequence and the survival of those disks (or the replenishment of dust) while the star is on the main sequence are important issues. A recent near-IR study demonstrates that most stars in PMS clusters have lost their original disks after $\sim$ 6 Myr (Haish, Lada, & Lada 2001). Further, recent works based on *ISO* data show that a significant fraction of MS stars—even a few as old as the Sun—still have disks (Habing et al. 2001). Thus, observational results provide relevant clues and put severe constraints on disk evolution and planet-building models.

Observational evidence for disks around stars has been obtained through many techniques and observational facilities, e.g., 4 and 10 m class optical/IR telescopes, SMM and radio telescopes (the JCMT, VLA, etc.), space observatories (*HST*, *IRAS*, *ISO*), etc. There is no doubt that the new and future large facilities (e.g., VLTI, ALMA, *NGST*, *Darwin*/TFP,

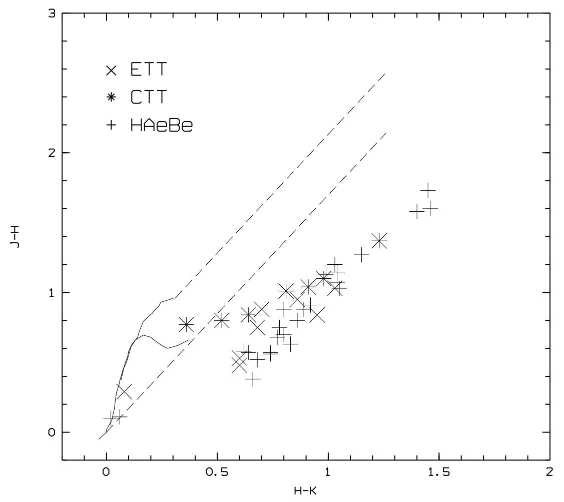

Fig. 1. Two-color diagram of pre-main sequence stars, taken from Eiroa, Garzón, & Alberdi (2001). Solid lines represent main sequence and giant stars. Dashed, lines represent the band of reddening vectors of these stars. PMS stars are located to the right of this band, which is interpreted as the near-IR excess caused by the disks.

TABLE 1

MEAN J, H, AND K EXCESSES (IN MAGNITUDES) ESTIMATED FROM SIMULTANEOUS OPTICAL AND NEAR-IR OBSERVATIONS DURING OCTOBER 1998 (EIROA ET AL. 2002)

Object	E_J	E_H	E_K
CW Tau	0.9	1.5	2.4
RY Tau	0.4	0.9	1.5
DR Tau	0.0	0.5	1.3
UX Ori	0.2	0.8	1.6
RY Ori	0.1	0.4	0.9

and also the GTC) will, by devoting a considerable fraction of their time to the understanding of this subject, make major contributions.

A large amount of papers and reviews on disks have appeared during the last few years. An excellent summary of the state of the art—physics, chemistry, evolution, etc.—is presented in *Protostars & Planets IV* (ed. Mannings, Boss, & Russell (2000). In this much more modest contribution, I would like to briefly address two specific points, disk variability and binarity, bearing in mind the GTC and its planned IR instrumentation.

2. DISK VARIABILITY

The near-IR excess observed in young PMS stars is attributed to the contribution of the circumstellar disks (see Figure 1 as an example). However, quantifying the excesses is not trivial since the stars, T Tauri and HAe stars, vary in the optical and in the near IR. These variations are largely produced by the PMS photosphere and simultaneous optical and IR photometry are essential to get an idea of the actual excess caused by the dust disks.

An estimate of the near-IR excess produced by the disks in a number of PMS stars has been carried out by Eiroa et al. (2002), whose results are partly reproduced Table 1. A value of 0.7 mag in any of the excesses (columns 2–4 in Table 1) means that the star and the disk contribute equally to the observed near-IR flux. The table shows that most of the observed K fluxes in these stars come from the disks and that the $H-K$ color temperatures are around 1000–1500 K, i.e., the excesses are dominated by thermal emission of hot dust located very close to the stars.

In addition, the analysis of the simultaneous optical and near-IR variability leads us to conclude that the bulk of the near-IR variability is produced by physical phenomena in the disk yielding to significant changes of the hot dust thermal emission. Remarkable is that the timescale of this variability can be very short, e.g., hours or few days, and that the variability amplitude can be very large, e.g., several tenths of magnitude. This is a challenge for disk models. Further, some mid-IR measurements of PMS stars also show pronounced variations: the M and N brightnesses of UX Ori vary by 0.9 and 0.6 mag, respectively, in data just taken 8 days apart (Hutchinson et al. 1994). Thus, high spatial resolution observations (imaging, interferometry) are needed in order to have a chance to see directly variations in the very close surroundings of PMS objects and to elucidate the physics behind them. Is such a work possible with the GTC? The theoretical diffraction limits of the GTC at 2.2 and 10 μm are $\sim$50 and 250 mas respectively.

The expected radii of the near-/mid-IR thermal disks around PMS, Herbig Ae, and T Tauri stars are in the range between tenths to a few AU (1 AU corresponds to 10 mas at a canonical distance of 100 pc). Indeed, interferometric observations of some PMS stars at 2.2 μm indicate characteristic sizes for the hot-dust emitting circumstellar environment of few mas (e.g., Millan-Gabet et al. 2001), while nulling interferometry at 10 μm provides upper limits of 131 mas in three HAe stars (Hinz, Hoffmann, & Hora 2001). Thus, it seems unrealistic to expect to resolve

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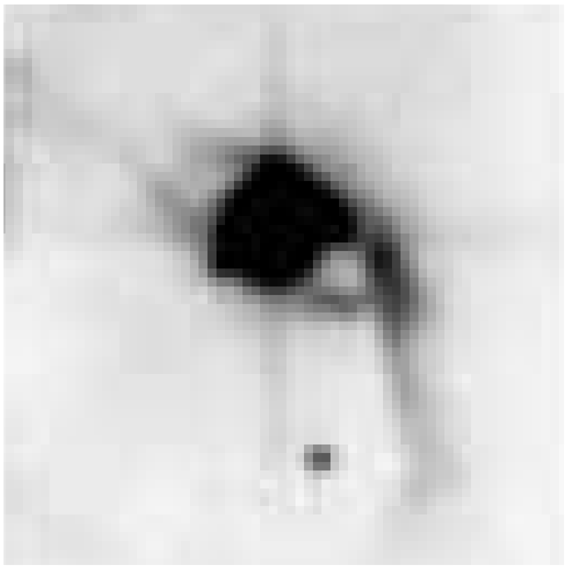

Fig. 2. K image of the double source Serpens SVS 20 and its associated circumbinary disk. The size of the image is $41''\!.2 \times 44''\!.5$.

the hot thermal disks surrounding PMS objects with the GTC. However, extended thermal emission at 10 and 18 μm in some debris disks and in some very hot Herbig Be type stars have been detected (e.g., Telesco et al. 2000; Polomski et al. 2002).

Summarizing, although in the near-IR regime it is not expected that the GTC will be capable of resolving thermal disks (even with the planned adaptive optic system), it will likely be extremely useful in the mid-IR window using CANARICAM and its various observing modes (direct imaging, coronography, spectroscopy, and polarimetry).

3. BINARITY

Many young PMS stars are known to be binaries. In these cases, a circumbinary disk and a disk around each component may have been formed. The physics of the disks would be highly dependent on the mass ratio of each component and on their separation.

Figure 2 shows a K image of Serpens SVS 20, a very young double protostellar object, whose components have not yet reached the T Tauri phase. The image is saturated and does not allow us to distinguish between the individual components of the double, which are separated by $\sim$ 1.5 arcsec in the N–S direction. However, an impressive nebulous ring is seen in scattered light around the binary; SVS 20 and its circumbinary disk are reminiscent of theoretical model predictions of binary star formation.

Figure 3 presents the K spectrum (spectral resolution $\sim$ 1000) of each SVS 20 stars. While the brighter, southern component presents a featureless spectrum (at least at this resolution), the northern component has very pronounced Brγ and CO band emissions. Thus, the circumstellar environment around each star of the binary has very different properties (SVS 20 is intriguing in many respects since, in spite of its components having very different brightnesses, their 0.9–5 μm energy distributions are similar—a 900 K blackbody is a good fit for both components—and the 3.1 μm ice optical depths are also similar, $\sim$1 magnitude.

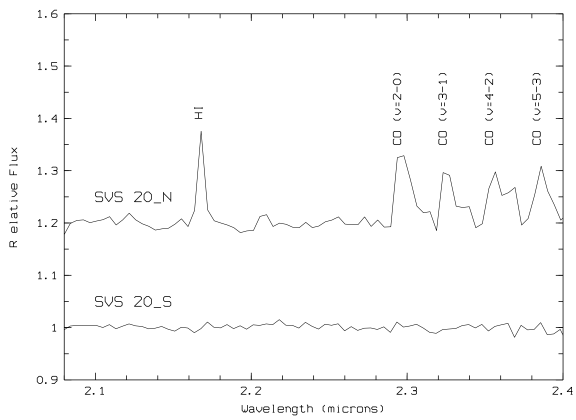

Fig. 3. K-normalized spectra of each component of Serpens SVS 20. The spectral resolution is $R \sim 1000$, although the spectra have been plotted with a lower resolution ($R \sim 500$). SVS 20-N has been displaced by 0.2 relative units for the sake of clarity.

The data of Figures 2 and 3 have been taken with the 2.2 m and 3.5 m telescopes of Calar Alto Observatory. In most cases, however, the separation of PMS binary/multiple stars is small, considerably less than 1 arcsec, and the objects are also much fainter; thus, interferometric observations or larger 10 m class telescopes using adaptive optics systems, like the GTC, are required to study those objects in detail. Some nice work has already been done. For example, Duchene, Ghez, & McCabe (2002) have used the Keck II telescope to obtain K spectra of each star of the close pair T Tau S (0.09 arcsec separation equivalent to 12.9 AU). Their excellent data suggest that each component of the pair is surrounded by an accretion disk with different properties. Undoubtedly, the GTC and its foreseen infrared instruments EMIR and CANARICAM, together with the AO system, will contribute significantly to this exciting field.

4. CONCLUSIONS

The GTC will be a large facility which will produce important results in many fields of astrophys-

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ical research; in particular star formation. In this modest contribution two specific points related to the circumstellar disks around young stars have addressed: disk variability and binarity. We have shown that many exciting results are expected from the GTC and its auxiliary instruments, though we have also pointed out some of the limitations we can realistically expect.

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