Variability of Disk Emission in Transitional Disk Systems

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ABSTRACT

Spectral energy distributions (SEDs) of pre-main-sequence (PMS) stars are commonly used as a diagnostic of disk structure and to measure the successful fit of a circumstellar disk model to the target environment. However, assembling a full set of SED data relevant to the study of a circumstellar environment requires observations from UV to millimeter wavelengths, necessitating observations by multiple facilities and typically resulting in multiple epochs of data being stitched together to cover the wavelength range. We investigate the variability of disk emission from the Herbig F star SAO 206462, discuss adjustments to model parameters to fit the "low" and "high" states, and suggest possible physical explanations. We are conducting a more extensive investigation of transitional disk systems (HD 100453A and other objects) to examine the prevalence of the disk emission variability phenomenon. We also emphasize the importance of the Spitzer IRS and IRAC data base and the warm Spitzer IRAC mission to this project.

INTRODUCTION

One of the defining characteristics of pre-main sequence (PMS) disk systems is the infrared (IR) excess emission above the photospheric light which dominates the spectrum at $\lambda > 1\mu m$. The shape of this IR spectral energy distribution (SED) has been used to infer the degree of dust grain growth and settling in protoplanetary disks and to distinguish between geometrically flat disks, constant opening angle disks, flared disks, transitional disks, and debris disks. However, inferring these characteristics from the SED alone is problematic since different combinations of dust size distributions, opacities, inclinations, and disk geometries can produce similar SEDs. By studying systems which are sufficiently near us to be resolved either by interferometric or high contrast imaging techniques, one can provide important checks on the interpretation of unresolved disk data for more distant systems such as the many disks detected by the Spitzer Space Telescope.

As a further complication, the typical SED is assembled from a set of non-contemporaneous UV to millimeter observations obtained from multiple facilities. If one accounts for inter-facility systematic errors, these SEDs are acceptable for static systems. However, in the past 2 years, an abundance of studies have clearly shown that these systems are very dynamic, changing on time scales of weeks to a few years, and one can no longer describe the objects using a model based on a single epoch of data. Sitko et al. (2008) have demonstrated that emission from the inner edge of the dust disk in HD 163296 and HD 31648 changes on time scales of a year (Figs. 1 and 2), and the simplest interpretation of their SEDs would indicate that the distance of the inner dust wall expanded in 2002. Interferometry with the Keck telescope by Tannirkulam et al. (2008) confirmed that in 2003, the inner dust wall had increased by about 20 percent compared to other epochs.

FACILITIES: HST (NICMOS) HST (STIS) HST (ACS) FUSE ROSAT ISO (ISOPHOT) SST (IRS) SST (MIPS) IRTF (SPeX) IRTF (BASS) GEMINI-S (PHOENIX) SUBARU (CIAO)

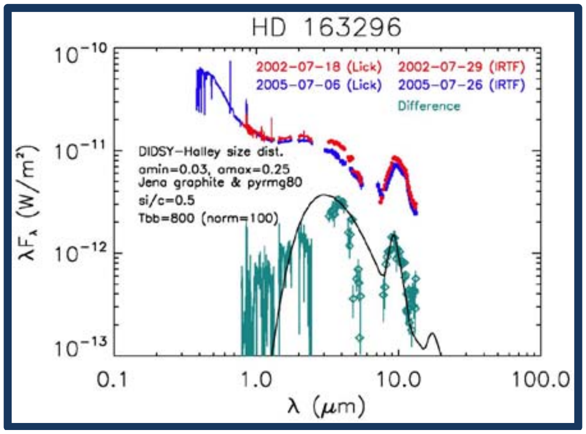

Figure 1: Two epochs of Vis-IR observations of HD 163296. The shorter wavelength set is from the VNIRIS spectrograph on the Lick 3m Shane telescope, while the data longward of 3 μm were obtained with BASS on NASA's IRTF telescope. The difference in flux levels between epochs is shown in the lower portion of the figure. From Sitko et al. (2008).

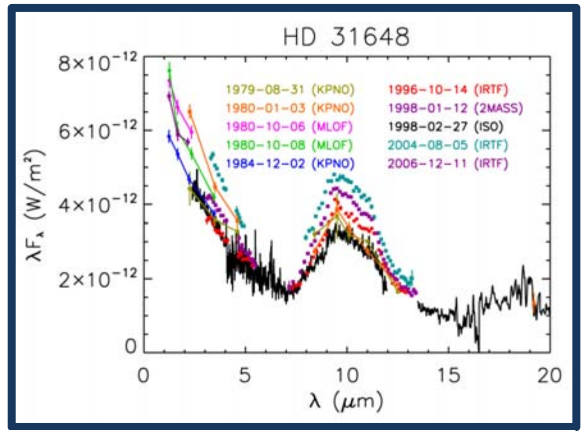

Figure 2: Ten epochs of infrared observations of HD 31648. From Sitko et al. (2008).

SCIENTIFIC RATIONAL

- Planets form and migrate in protoplanetary disks.
- Massive planets are capable of clearing the inner few tens of AU of a planetary system.
- For some BPMG disks (~12 Myr) with warm dust, it has been hypothesized that the warm dust is the product of impacts (Lisse et al. 2008a,b) associated with planet formation.
- Warm dust resulting from collisions should be very dynamically active. Radiation pressure and disk and stellar winds should rapidly drive the material outward by ~1 AU on a timescale of a few weeks (Rhee et al. 2007) causing temperature variations in the NIR excess.
- A composition and/or inclination difference from inner disk to outer disk also suggests non-primordial (second generation) dust in the inner disk.
- A massive body orbiting within the inner disk of a system may produce ***periodic*** NIR variability.

TARGET SELECTION

- We are investigating transitional (Najita et al. 2007) and pre-transitional (Brown et al. 2007; Espaillat et al. 2008) disks with:
  - Meeus Group I SED
  - low current accretion rate ($< 10^{-8}$ $M_\odot$ yr^{-1}) as determined from Brγ or FUV
  - evidence for variable warm dust
- Class prototype is SAO 206462 (see Fig. 3 & next section).

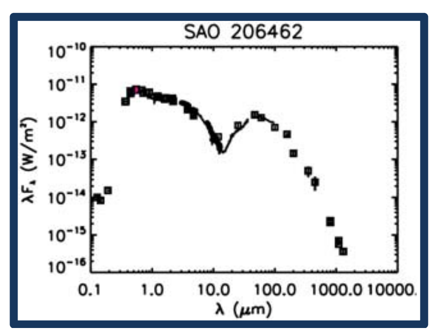

Figure 3: The full SED of SAO 206462 using a limited set of near-IR data. The strong near-IR excess is indicative of dust in the inner disk. The valley near 10 μm suggests a discontinuity between the inner and outer dust disk. From Grady et al. (2009).

SAO 206462 (Grady et al. 2009)

- SAO 206462 (HD 135344B) is a single Herbig Fe star.
- The outer disk is gas-rich (Dent et al. 2005) and detected in scattered light (Fig. 4a).
- An eccentric cavity exists at r=45 AU (SMA; Pontoppidan et al. 2008; Fig 4b).
- The inner disk contains dust (large NIR excess in Fig. 3) & gas (van der Plas et al. 2008).
- Accretion continues onto the star at 3×10^{-9} $M_{\odot}$ yr^{-1} (Garcia Lopez et al. 2006).
- A simple "gapped" disk is expected to be short lived and to have inner-outer disk coplanarity.
- Recent mid-IR interferometric observations (Fedele et al. 2008) find that the inner dust disk does not share the low inclination ($i=11^{\circ}$) of the outer disk, suggesting second generation dust.
- By combining archival data with new observations, we have found unexpected, large amplitude changes in both the NIR excess and the temperature of the excess for SAO 206462 (Fig. 5).
- The 2008 data suggest that significant temp. changes occur on timescales as short as 6 weeks.
- Modeling of the SED variability with Whitney Monte-Carlo Radiative Transfer Code suggests the warm dust has been displaced from 0.08 AU to 0.2 AU.
- It is likely that SAO 206462 hosts a planetesimal belt undergoing active collisions and is a young multi-planet system.

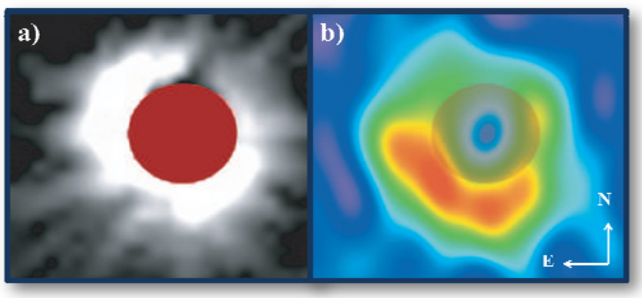

Figure 4: Comparison of (a) PSF-subtracted NICMOS 1.1 µm scattered light coronagraphic imagery with (b) SMA 850 µm continuum imagery of SAO 206462 (Pontoppidan et al. 2008). The r=0.3″ region occulted in the NICMOS imagery is shown as a filled circle in the NICMOS imagery and a shaded circle against the SMA data. The cavity, which is eccentric, is entirely occulted in the NICMOS data. The image scale is 1.6″ x 1.6″. From Grady et al. (2009).

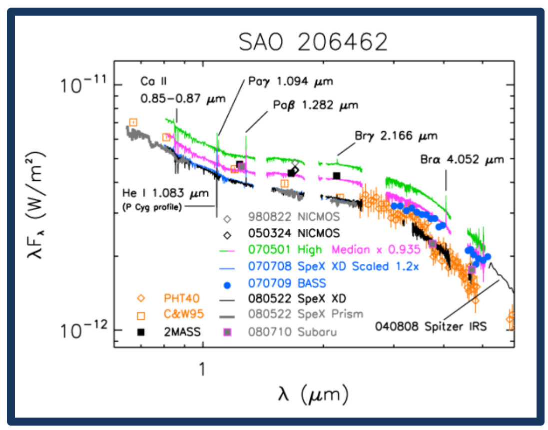

Figure 5: The full set of near- and mid-IR data for SAO 206462 spanning 15 years, color-coded by epoch of observation. Significant NIR temporal variation is detected, well above the 5% systematic errors. From Grady et al. (2009).

NEXT STEPS

- Focus on systems with characteristics described in the Target Selection section above.
  - We have identified several candidates and plans are underway for photometric monitoring of additional systems to identify more candidates.
  - For this sample, silicate emission is rare, PAH emission is common and appears to avoid the inner disk cavity.
- Assemble multi-epoch SEDs from the literature and archives.
  - Utilize the Spitzer IRS and IRAC database.
- Supplement the resulting SEDs with new epochs of accurate observations.
  - Ground based monitoring programs searching for NIR variability and periodicity
  - Warm Spitzer IRAC program for synoptic observations
  - Supported by sub-mm and IR interferometry

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