INFRARED ARRAY CAMERA (IRAC) COLORS OF YOUNG STELLAR OBJECTS
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ABSTRACT
We compare the infrared colors predicted by theoretical models of protostellar envelopes and protoplanetary disks with initial observations of young stellar objects made with the Infrared Array Camera (IRAC) on the Spitzer Space Telescope. Disk and envelope models characterized by infall and/or accretion rates found in previous studies can quantitatively account for the range of IRAC colors found in four young embedded clusters: S140, S171, NGC 7129, and Cep C. The IRAC color-color diagram ([3.6]–[4.5] vs. [5.8]–[8.0]) can be used to help distinguish between young stars with only disk emission and protostars with circumstellar envelopes.

Subject headings: infrared: stars — stars: formation — stars: pre–main-sequence

1. INTRODUCTION
It has now been several decades since the first observations of infrared (IR) excess emission from young stars (Mendoza 1966, 1968). The excess emission is well above that expected from reddened stellar photospheres and originates from the dusty circumstellar disks and envelopes surrounding young stars. For these reasons, IR color–color diagrams have proven to be excellent tools for identifying and classifying young stellar objects. In general, young stars are found in three regions in the near-IR (HJKL) diagrams. Objects with accretion disks (Class II) fall on the classical T Tauri (CTT) locus or along the reddened CTT locus, and objects whose emission is dominated by infalling envelopes (Class I) fall redder of the reddened CTT locus. Stars having disks with large inner holes are found in the region corresponding to reddened main-sequence stars (Meyer et al. 1997). In an exhaustive study of star formation in the Taurus molecular cloud, Kenyon & Hartmann (1995) combined ground-based near-IR photometry with IRAS fluxes to derive spectral indices for Class I and II sources and to show that there is a smooth progression in IR colors from disk-dominated Class II to envelope-dominated Class I. They, along with others (Lada et al. 2000) also showed that the K-L color index is a more effective measure of near-IR excess than H-K and is better for distinguishing Class I from Class II sources.
The Infrared Array Camera (IRAC) on Spitzer (Werner et al. 2004; Fazio et al. 2004) has the potential to extend our understanding of disk evolution and star formation by detecting optically obscured, deeply embedded young stars and protostars, the emission from their disks, and, at earlier stages, from their infalling envelopes. The great advantage of IRAC over ground-based telescopes is its sensitivity in the 3–8 μm bands that contain relatively little contribution from stellar photospheres as compared to disks and envelopes. It is important that we understand this new color space and how to use it to identify young stars of various evolutionary classes. This contribution presents a preliminary interpretation of the IRAC color-color diagram, using predictions of existing models for disks and envelopes and adopting values for parameters which are well understood from star formation studies of nearby regions like the Taurus molecular cloud. These models define clearly separated regions in the IRAC color-color diagram. IRAC observations of four young clusters (Mgeath et al. 2004) are consistent with the model predictions.

2. MODELS
Models in the disk grid were calculated according to the procedures of D’Alessio et al. (1998, 1999, 2001). In brief, the disk is assumed to be steadily accreting at a rate $\dot{M}$ onto a star of age $t$, mass $M$, radius $R$, and effective temperature $T_{\text{eff}}$. The material in the disk consists of gas and dust, with the standard mass ratio ($M_{\text{dust}}/M_{\text{gas}} = 10^{-2}$), well mixed and uniformly distributed. The dust mixture is that proposed by Pollack et al. (1994) and has a size distribution $n(a) da \propto a^{-3.5} da$ between limiting sizes $a_{\min}$ and $a_{\max}$. The disk is heated by viscous dissipation and by irradiation from the central object, and viscosity is calculated with the $\alpha$ prescription (Shakura & Sunyaev 1973). Models are truncated at the dust destruction radius $R_{\text{d}}$, where the disk is optically thick and is used as a blackbody at $T_{\text{eff}}$. The truncation radius is set by the dust destruction temperature $T_{\text{d}}$ (Megeath et al. 2004, in preparation). The truncation radius is set by the sum of the stellar and accretion luminosities (Muzerolle et al. 2003), and the dust destruction temperature is set at 1400 K, the sublimation temperature of silicates at characteristic densities of the inner disk. The wall at $R_{\text{w}}$, which has a fixed height of four scale heights, emits as a blackbody at this temperature (Natta et al. 2001; Muzerolle et al. 2003; P. D’Alessio 2004, in preparation). The equations of disk structure are solved including these heating sources to yield the detailed radial-vertical structure. The emerging spectral energy distribution (SED) is calculated by ray-by-ray integration of the transfer equation for each line of sight. Using these procedures, we have constructed an extensive grid of disk models that cover the following range of parameter space: $T_{\text{eff}} = 4000–10,000$ K for