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SpS1-Circumstellar disks & their evolution: Dust

Carol A. Grady[1]

[1]Eureka Scientific & Goddard Space Flight Center, Greenbelt, MD 20771 USA
email: Carol.A.Grady@nasa.gov

Circumstellar disks are an intrinsic part of star formation and are also where planets form, migrate, and where the materials capable of producing life-bearing worlds are produced. The most flamboyant signatures of the presence of disks are at infrared through millimeter wavelengths, where thermal emission from dust dominates the system light. The discovery and characterization of the emission from such disks has been a major activity for ground-based observatories and space missions (IRAS, ISO, MSX, AKARI, and *Spitzer*), and continues with the newest generation of infrared (IR) capabilities.

Spectral Energy Distributions (SEDs): The presence of excess light compared with the stellar photosphere not only demonstrates the presence of circumstellar material, but its shape offers insight into its spatial distribution of dust. There is a rapid decay in disk frequency over the first 5 Myr, consistent with the formation time for large asteroids, and dating of Saturn (Pascucci & Tachibana 2009). Association average SEDs indicate grain growth to 10× interstellar sizes by 1-2 Myr (Bouwman *et al.* 2008; Sargent *et al.* 2009). The frequency of *transitional* disks, those with warm dust deficits relative to the average SEDS, indicating cleared lanes or cavities, increases over 2-5 Myr (Brown, 2009).

After 8-12 Myr, disk fractional IR luminosities (F_{IRE}/F_*) are $\leqslant 10^{-3}$, and warm dust becomes rare (Moór *et al.* 2009). Overall F_{IRE}/F_* drops with age, but with a large dispersion, permitting identification of *debris* disks which have undergone recent collisional activity (Wyatt 2008). Debris disk SEDs fall into two classes: those which can be fit by discrete blackbody components, indicating material confined to particle belts or rings, and those with more continuous dust distributions (e.g. disks) (Morales *et al.* 2009). Now the SED data can be combined with locations of Jovian-mass planets to map the planetary system architecture (Chen *et al.* 2008; Reidemeister *et al.* 2009).

Solid-State Features: Spectral features due to grains with radii $\leqslant 10\mu$m are often seen. Absorption is typical of either embedded objects, or stars which are viewed with sight lines passing near the (high inclination) disk midplane. Otherwise, emission is seen.

Ices and Polycyclic Aromatic Hydrocarbons (PAHs): Water and simple molecular ices are seen in young stellar object (YSO) and high inclination disk spectra (Boogert *et al.* 2008; Pontoppidan *et al.* 2008; Gibb *et al.* 2004). Crystalline ice was detected in emission for a few stars by ISO (e.g. Malfait *et al.* 1999), and more recently in debris disks (Chen *et al.* 2008; Lisse *et al.* 2008). Water ice has been detected in reflectance spectra for a Herbig F star disk (Honda *et al.* 2009), but has not been seen in Herbig Ae star disks (Debes *et al.* 2008). Emission in a suite of mid-IR bands identified with PAHs is typical of Herbig Ae stars (Keller *et al.* 2008), is less common in T Tauri stars (Geers *et al.* 2006) and is not seen toward low-mass embedded YSOs (Geers *et al.* 2009). The PAH emission can extend over ≈100 AU of the disk (Habart *et al.* 2006; Geers *et al.* 2007).

Dust: A wealth of silicate, oxide, and other dust features are commonly observed in the spectra of Herbig Ae, T Tauri, and some debris disks. Recent work in this area has focussed on establishing typical grain sizes, degree of silicate crystalinity, and chemistry for intermediate-mass, T Tauri stars, and brown dwarfs using *Spitzer* IRS data. In addition to the distinct features, broader emission components can be identified using mineral libraries based on Solar System objects. There have been efforts to compare the mineralogy of the inner disks with outer disks from integrated light spectra (Sargent *et al.* 2009). Mid-IR interferometry demonstrates that silicate crystallinity drops with radius for Herbig Ae and bright T Tauri disks (Leinert *et al.* 2004; van Boekel *et al.* 2006). Chemical inventories of dust are now available for a few debris disks (Lisse *et al.* 2008).

Transient Phenomena: Variable solid-state emission has now been reported for Herbig Ae (Sitko *et al.* 2008) and T Tauri stars (Woodward *et al.* 2004). Increased silicate crystallinity during EX Lup's outburst demonstrates that significant grain processing occurs in the inner disks of pre-main-sequence stars (Ábrahám *et al.* 2009). Debris disk transient phenomena include large F_{IRE}/F_*, crystalline water ice, and species indicating hypervelocity impacts (Chen *et al.* 2008; Lisse *et al.* 2009).

The Future: *Herschel*, SOFIA, and SPICA will study crystalline water ice features, crystalline silicates, and hydrous silicates, providing an expanded set of mineral and ice diagnostics. ALMA observations will permit verification of disk structures inferred from modeling of SEDs. JWST, as well as providing high contrast imaging, will also enable spatially-resolved spectroscopic studies of small grains. In tandem with ground-based facilities, there will be new disk identifications from AKARI and WISE data, and more synoptic studies. The disk chemical inventories will facilitate systematic studies of whether *stellar* compositional peculiarities are inherited from their molecular cloud.

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