Grain processing in YSO disks

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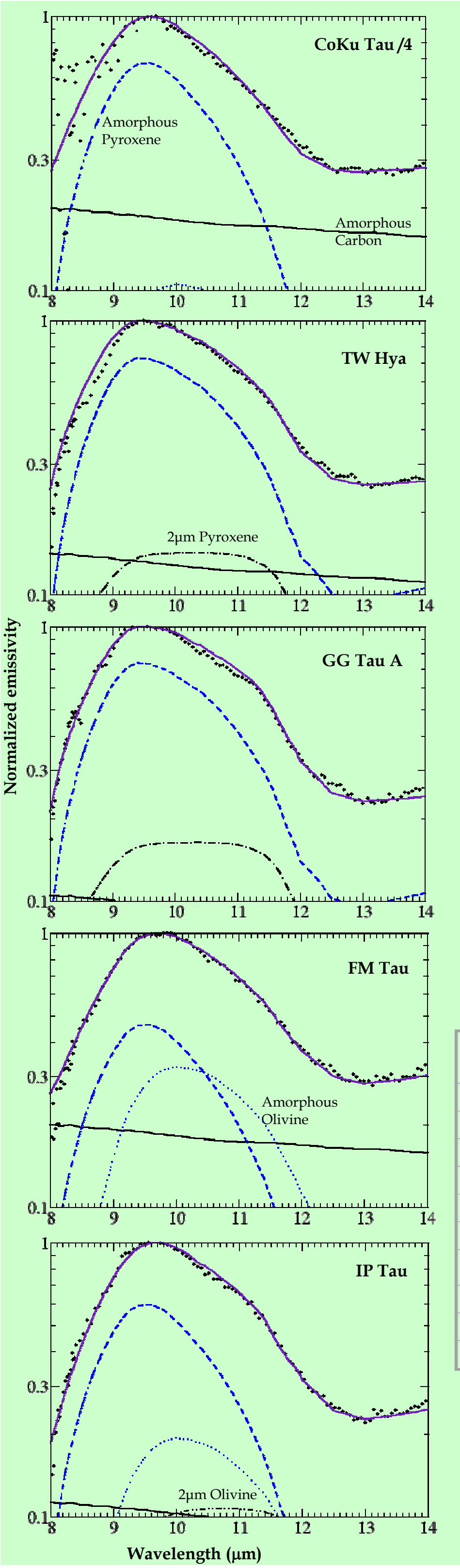

Abstract

Forrest et al. 2004, Furlan et al. 2004, and Uchida et al. 2004 presented Spitzer Infrared Spectrograph observations of Class II Young Stellar Objects in Taurus and in the TW Hydra Association, respectively. All of the sources have broad 10 micron silicate emission features. Each one has a unique shape, indicating variation in composition and crystallinity of the silicate grains in the circumstellar disks of these YSOs. One of the sources, CoKu Tau /4, which apparently has very little disk material out to ~10 AU,has a very smooth and narrow 10 micron emission feature, indicating thesilicate grains composing its disk are amorphous and simple. The spectraof the other sources, all of which have fuller accretion disks, have more structured 10 micron features, indicating the presence of larger grains and/or crystalline silicates, which are believed to arise from processing of amorphous silicates. This processing apparentlyhas not occurred for CoKu Tau /4, where the observable dust is cool(~126K). The dust emissivity is derived from the observed spectra and compared to grain models. For CoKuTau /4, nonspherical amorphous olivine and pyroxene grains are indicated. These grains are believed to be unprocessed material; as such, they represent a primordial mixture from which to base the silicate emission modeling for other sources. For the sources with more complexity, crystalline pyroxenes, forsterite, and larger grains are necessary to fit the spectra.

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Extracting and Fitting Dust Emissivities

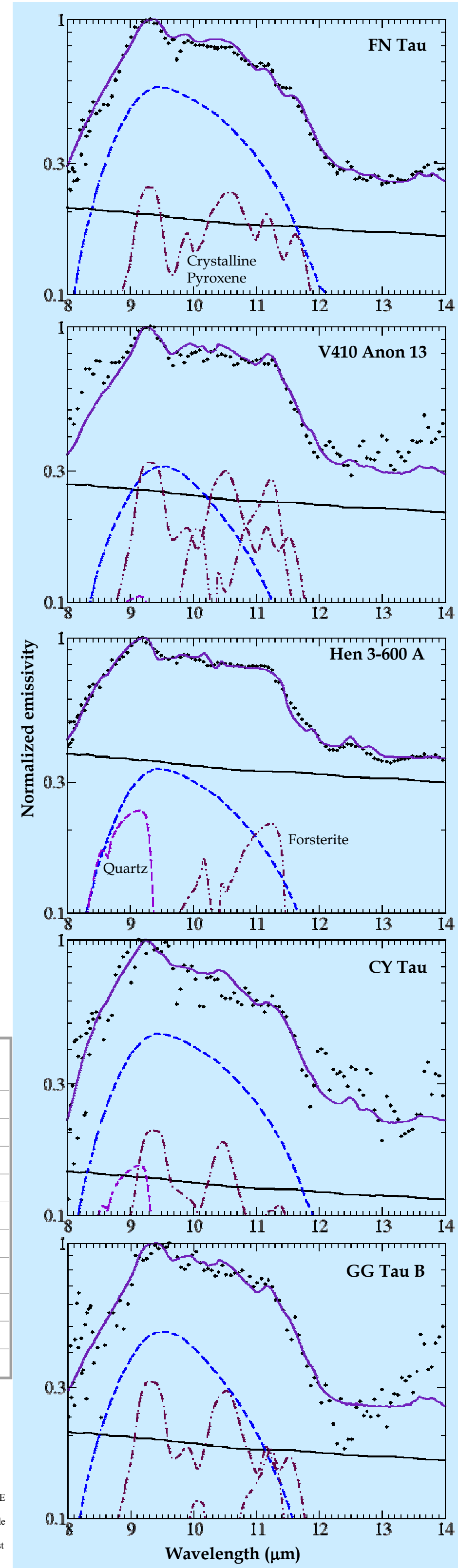
- Fit power law to 5 to 8 μm region of each spectrum, subtract power law from spectrum
- This power law represents optically thick emission from inner disk (Kenyon and Hartmann 1987, Chiang et al. 2001). For CoKu Tau /4, the power law represents the Rayleigh-Jeans tail of the photosphere. There is little disk emission at these wavelengths (D'Alessio et al. 2005)
- Assuming emissivity, ε, is similar to that of Murchison and Vigarano meteorites (Forrest et al. 1976), fit a blackbody by setting $B_{10\mu m}(T)/(B_{20\mu m}(T)*0.6) = F_{resid,10\mu m}/F_{resid,20\mu m}$ and solve for T. For GG Tau B, there were no 20 μm data, so T was artificially set to 255.9K, the temperature for GG Tau A
- Divide residuals by $B_\nu(T)$ (Gillett et al. 1975)
- For optically thin emission, emissivity should be directly proportional to the mass-weighted opacity of each grain species (Forrest et al. 1979)
- Fit the derived emissivity by varying the mass fractions of the various components (see the Table below)

Results

- CoKu Tau /4, TW Hya, GG Tau A: The circumstellar disk of CoKu Tau /4 is believed to be clear of material out to ~10 AU (D'Alessio et al. 2005); evidently, the remaining dust is relatively unprocessed. TW Hya is believed to have a partially cleared-out disk (Calvet et al. 2002). For all three objects, small (Rayleigh-limit) amorphous silicates are predominantly pyroxene. Larger amorphous grains are indicated by the extension of the silicate feature beyond 11 μm. Forsterite is indicated for GG Tau A at 11.3 μm
- FM Tau, IP Tau: Similar to previous, except small amorphous olivine grains are also indicated. Both require forsterite at ~11.3 μm
- FN Tau, V410 Anon 13: Require substantial amounts of crystalline pyroxene $Mg_{1-x}Fe_xSiO_3$, where x ≤ 0.3, as well as amorphous Mg-rich pyroxene. Small amounts of crystalline grains such as forsterite and silica may be needed for V410 Anon 13
- Hen 3-600 A: A rich collection of amorphous and crystalline pyroxenes and olivines and silica
- CY Tau, GG Tau B: Low S/N in the silicate feature for CY Tau and GG Tau B makes determination of grain composition challenging, but both seem to indicate amorphous and crystalline pyroxenes, augmented by small amounts of either crystalline grains or larger amorphous grains.

	Temp (K)	Am. Pyrox %	Am. Oliv. %[3]	Cr. Pyrox %	Forst-erite %	Cr. quartz %[10]	2μ A. Pyrox %[11]	2μ A. Oliv %[12]	Am. Carbon %[13]
CoKu Tau /4	126	54[1]	13.5	0	0	0	0	10	22.5
TW Hya	189	64.6[2]	0	0	0	0	22.3	0	13.1
GG Tau A	256	63.5[2]	0	0	1.9[8]	0	25.1	0	9.5
FM Tau	241	37.7[1]	34.8	0	0.5[9]	0	0	8.1	19
IP Tau	272	48.8[1]	20.9	0	2[9]	0	0	17.4	10.8
FN Tau	216	57.6[2]	0	20.3[4]	0	0	0	0	22.1
V410 Anon 13	240	30.1[1]	0	22.6[5]	15[8]	2.3	0	0	30.1
Hen 3-600 A	211	33.1[2]	6.7	3.3[6]	12.7[9]	4.7	0	0	39.5
CY Tau	250	46.9[2]	0	15.6[7]	3.1[8]	3.1	15.6	0	15.6
GG Tau B	256	45.9[1]	0	21.8[5]	9.4[8]	0	0	0	22.9

[1] Optical constants for amorphous pyroxene $Mg_1Fe_0SiO_3$ come from Dorschner et al. 1995, assuming a Continuous Distribution of Ellipsoids (CDE, described in Zubko et al. 1996)
[2] Optical constants for amorphous pyroxene $Mg_{0.7}Fe_{0.3}SiO_3$ come from Dorschner et al. 1995, assuming CDE
[3] Optical constants for amorphous olivine $MgFeSiO_4$ come from Dorschner et al. 1995, assuming CDE
[4] Opacities for $Mg_{0.9}Fe_{0.1}SiO_3$ come from Chihara et al. 2002
[5] Opacities for $Mg_{0.8}Fe_{0.2}SiO_3$ come from Chihara et al. 2002
[6] Optical constants for 3 crystallographic axes of enstatite, $MgSiO_3$, come from Jäger et al. 1998, assuming CDE
[7] Opacities for $Mg_{0.7}Fe_{0.3}SiO_3$ come from Chihara et al. 2002
[8] Opacities for forsterite, "Fo", come from Koike et al. 2003
[9] Optical constants for 3 crystallographic axes of crystalline olivine $Mg_{1.9}Fe_{0.1}SiO_4$, forsterite, come from Fabian et al. 2001, assuming CDE
[10] Properties for quartz come from Wenrich and Christensen 1996 and Spitzer and Kleinman 1961
[11] Opacities for 2μm radius spheres of amorphous pyroxene $Mg_{0.7}Fe_{0.3}SiO_3$ come from Dorschner et al. 1995, assuming Mie Theory (van de Hulst 1957)
[12] Opacities for 2μm radius spheres of amorphous olivine $MgFeSiO_4$ come from Dorschner et al. 1995, assuming Mie Theory (van de Hulst 1957)
[13] Optical constants for amorphous carbon "ACH2" come from Zubko et al. 1996, assuming CDE



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