Silicate Evolution in Brown Dwarf Disks

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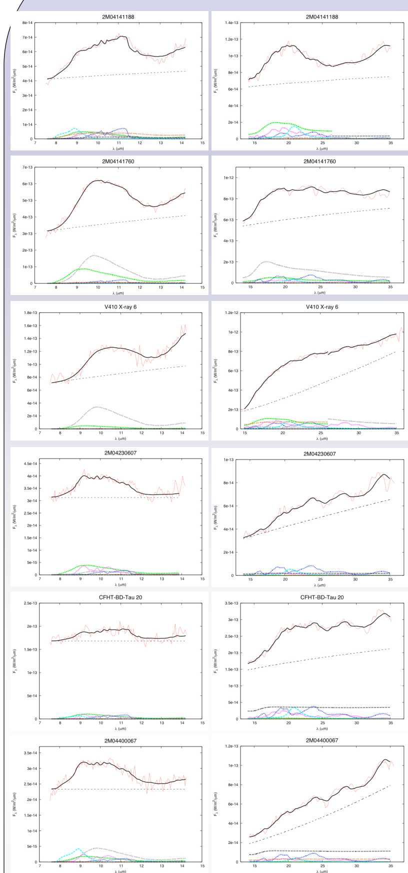
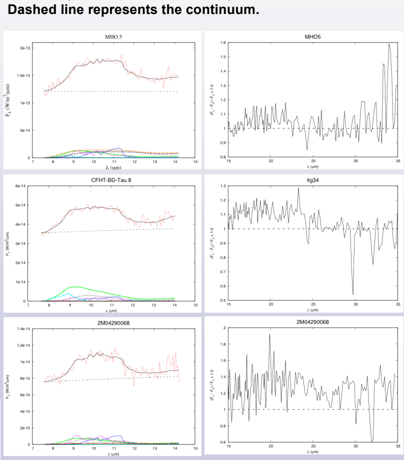
We present a compositional analysis of the 10μm and 20μm silicate emission features for brown dwarf disks in the Taurus and Upper Scorpius star-forming regions. The strengths in the 10μm and 20μm features are similar for most disks, except three cases where the disk has flared up at longer wavelengths. For most sources, we find nearly equal fractions for the large-grain and crystalline mass fractions, indicating both processes to be active in these disks. The crystallinity levels in the disk show a slight increase towards larger disk radii. The grain growth levels do not show any particular trend with the radial distance. The disk structure in both the inner and outer regions is found to be more effected by the crystallinity level in the disk. The median crystalline mass fraction for the Taurus brown dwarfs is found to be a factor of ~2 higher than the median for the higher mass T Tauri stars in this region. A (weak) anti-correlation between the X-ray emission strength and the extent of crystallinity in the disk is observed, suggesting X-rays to be an important dust amorphization agent.

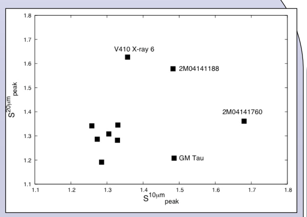
10mu vs. 20mu Features



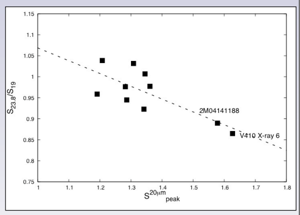
Model-fits to the 10μm and 20μm silicate emission features. Colors represent: red--observed spectrum; black--model fit. Dashed line represents the continuum.



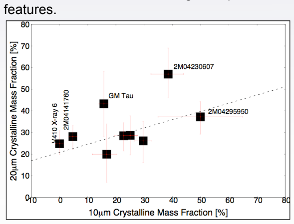
The three 'outlier' cases, that show prominent emission at 10mu, but flat 20mu spectra. Significant grain growth and dust settling has occurred at larger radii for these disks.



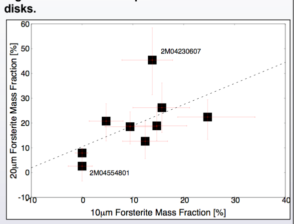
No correlation is observed between the strength in the 10mu and 20mu features. Other than the few flared cases, the strengths are clustered around ~1.3.



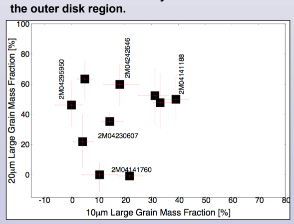
The strengths and shapes of the 20mu features are correlated. The two flared disks 2M0414 and V410 show strong amorphous features.



A slight increase in the crystalline mass fractions is observed in the outer disk (~1 AU) compared to the inner (~0.1 AU) regions. This indicates efficient diffusion of crystalline material from the warm/inner region to the cold/outer parts in these sub-stellar disks.

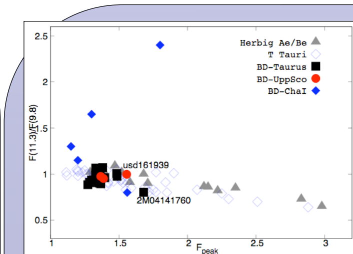


The increase in crystallinity observed in the outer disk region is mainly due to an increase in the forsterite mass fraction. The enstatite mass fraction is found to be nearly constant at ~15% in the outer disk region.



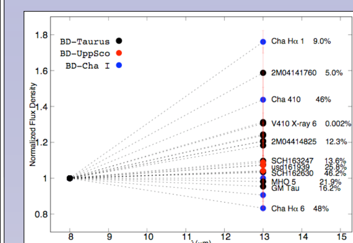
No particular trend is observed for the grain growth levels in the inner and outer disk regions. This large dispersion is mainly caused by the varying (and different) slopes of the disks at 10 and 20mu. For four sources, the large-grain mass fraction has increased by at least a factor of 2 in the outer disk region. The rest show comparable mass fractions of ~40-50% in the inner and outer disk regions.

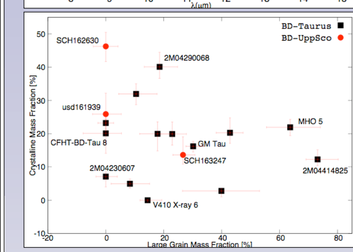
Strength vs. Shape



• Flatter features are observed for the brown dwarfs compared to solar-type stars in Taurus (Sargent et al. 2009) and Herbig Ae/Be stars (van Boekel et al. 2005).
• Similar strengths and shapes are observed for the brown dwarfs in the Taurus and UppSco regions, and these mainly cluster around F_{peak} ~ 1.3 *and F11.3/F9.8 ~ 1*.
• 2M04141760 and usd161939 show more narrow, peaked features than the rest, which is consistent with a >70% sub-micron amorphous silicate mass fractions estimated for these objects.

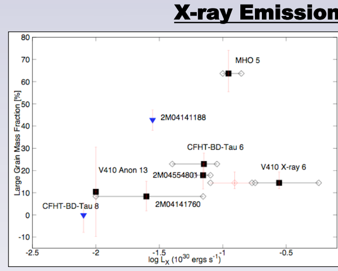
Disk Structure vs. Mass Fractions

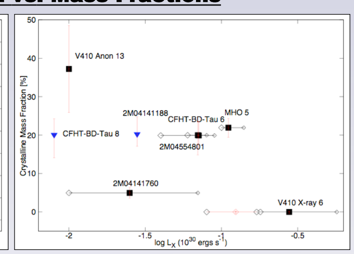




• The Taurus brown dwarfs show a variety in disk structures, from a flared (e.g., 2M04141760) to a flat (e.g., GM Tau) disk geometry.
• All of the UppSco brown dwarfs have flat disk structures.
• No correlation is observed among the Taurus brown dwarfs between the extent of dust settling in the disk and the crystalline mass fractions (noted next to the object name in the figure).
• The UppSco brown dwarfs do show some dependence; SCH162630 with a 46% crystalline mass fraction shows a more flattened disk structure than SCH163247 that has a 13.6% crystalline fraction.
• No correlation is observed between the grain growth and crystallization processes. Most brown dwarfs show nearly equal fractions of large-grain and crystalline silicates, indicating both processes to be active in these disks.
• The mean crystalline mass fraction for the ~5 Myr UppSco brown dwarfs is 29%, which is a factor of ~2 higher than the mean for the ~1 Myr Taurus brown dwarfs. This is consistent with a picture of increasing dust processing with age.

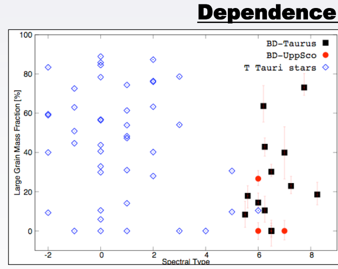
X-ray Emission vs. Mass Fractions

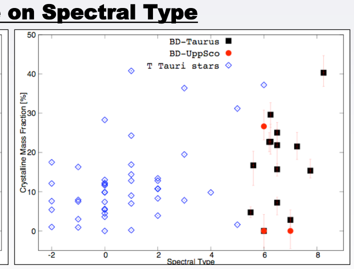




• Among the Taurus brown dwarfs, an increase in the grain growth levels is observed towards increasing X-ray luminosity. X-ray ionisation may induce turbulence in the disk (e.g., Ilgner & Nelson 2006). Increasing X-ray irradiation would thus result in more active turbulent mixing in the disk. This would decrease the level of sedimentation and a higher fraction of large-grains would be detected in the upper disk layers, as probed by the silicate emission feature.
• For the case of crystallization, stronger X-ray emission seems to remove crystalline silicates from the disk surface layers. This effect is more notable for the cases of V410 X-ray 6 and V410 Anon 13. Amorphization by ion irradiation may be a possible explanation, as has been suggested to explain the absence of crystalline silicates in the ISM (e.g., Bringa et al. 2007).

Dependence on Spectral Type





The value of -2 in these figures indicates a SpT of K7, -1 is K5, while 0-9 are M0-M9. A similar spread in the grain growth and crystalline levels are observed among the T Tauri stars (Sargent et al. 2009) and brown dwarfs in Taurus. The mean large-grain mass fraction is ~30% for the brown dwarfs, comparable to the 44% found for the earlier type stars. The median crystalline mass fraction for the brown dwarfs is a factor of ~2 higher than the earlier types. This is consistent with the flatter features observed for the brown dwarfs compared to higher mass stars, due to a higher degree of dust processing.

References: Bringa et al. 2007, ApJ, 662, 372; Ilgner & Nelson 2006, A&A, 445, 223; Riaz 2009, ApJ, 701, 587; Sargent et al. 2009, ApJS, 182, 477; van Boekel et al. 2005, A&A, 437, 189

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