Formation of Crystalline Dust Grains in Protoplanetary Disks: Observational Evidence for the Destructive Effect of X-Rays

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High-energy irradiation of the circumstellar material might impact the structure and the composition of the protoplanetary disk and hence the process of planet formation. Here, we present a study on the possible influence of the stellar X-ray emission on the crystalline structure of the circumstellar dust. The dust crystallinity is measured for 42 class II T Tauri stars in the Taurus star-forming region using a decomposition fit of the 10 μm silicate feature measured with the Spitzer IRS instrument. We then correlate the X-ray luminosity of the central object with the crystalline mass fraction of the circumstellar dust and find an anti-correlation for objects within an age range of 1.2 to 3 Myr. We conclude that X-rays may destroy the crystalline structure of circumstellar dust.

Introduction

The study of the dust of circumstellar disks and its evolution is crucial for the overall understanding of the processes in the disk and the formation of planets. We still are not able to verify observantly the theories of how the dust evolves from the small, amorphous shaped grains of the interstellar medium to the larger sized, partly crystalline grains abundantly present in circumstellar disks of young solar like objects[1,2]. The initial conditions and many properties of the environment and the central object might be responsible for the shape and the characteristics of the final products, the processed dust and planets, however no[1,3] or only weak[4,5] indications have been found so far between the properties of the disk and those of the central object.

In this study we focus on connections between the stellar object and the dust composition and address in particular the question on weather high energetic irradiation such as X-rays or high-energy particle fluxes have some effect on the dust grain structure as suggested from laboratory measurements using high doses of ion irradiation[6].

Results

Figure 2 shows a fitted spectrum of AA Tau which is representative for the entire sample. The only fit parameters are the relative abundance and the slope of the radial temperature distribution T(r) and hence a unique and global solution can be determined consistently.

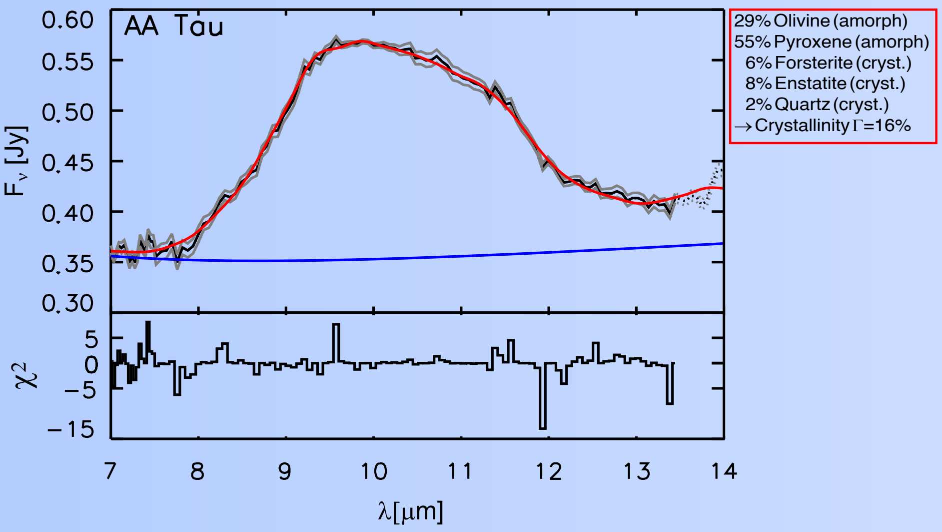

Fig2: Example of an IRS spectrum of AA Tau and corresponding uncertainties (black and gray lines). The resulting fit function of the 10 μm silicate feature is shown as a red line and the abundance of the various silicates is shown in the legend, respectively. The continuum background used for the fit function is shown in blue. In the lower part of the figures the resulting χ^2, multiplied with the sign of the deviation, is shown.

We correlate the crystalline mass fraction Γ with the X-ray luminosity L_X. Figure 3 shows this correlation for the objects selected by their age being older than 1.2 Myr and younger than 3 Myr.

Sample + Method

We use a sample of 42 Class II T Tauri stars located in the Taurus-Auriga star forming region. These targets show a significant emission of the 10 μm silicate feature from the warm dust located at the surface of the inner disk. These objects appear in two recent surveys, one obtained with the XMM Newton X-ray observatory[7] and the other with the InfraRed Spectrometer (IRS)[2,3] onboard the Spitzer Space Telescope.

From the XMM survey we use only the coronal X-ray luminosity L_X[7]. We use the IRS spectra to decompose the 10 μm silicate emission feature into several components due to amorphous silicates with stoichiometries of Olivine and Pyroxene and the crystalline silicates Forsterite, Enstatite and Quartz at various sizes, using their mass absorption coefficients[4]. From this, we determine the relative abundance and finally the relative crystalline mass fraction Γ. Figure 1 illustrates how we build the model for the total observable flux, based on a two-layer temperature distribution method[8] to fit the observed data.

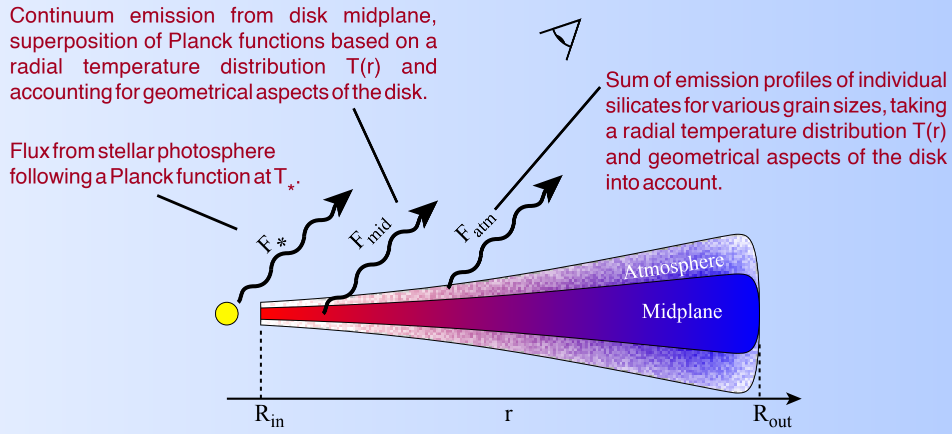

Fig1: Circumstellar disk model describing the observable total flux which is a superposition of the stellar light, F_*, the continuum emission from the disk midplane, F_{mid}, and the emission from the optically thin disk atmosphere, F_{atm}.

We find a significant anti-correlation which leads to the conclusion that X-rays may have a destructive effect on the crystalline structure of dust grains. However, it is more likely that the coronal X-ray emission correlates with other high energetic radiation (protons, electrons and ions) which might be more effective to destroy the crystalline dust structure[6]. The sample selection according to the age supports this model as it explains that for very young disks (<~1 Myr) the dose is insufficient to destroy the crystalline structure of the dust. For older objects (>3 Myr) other effects with longer timescales might be dominant such as radial dust mixing and the reproduction of crystalline dust in the inner disk.

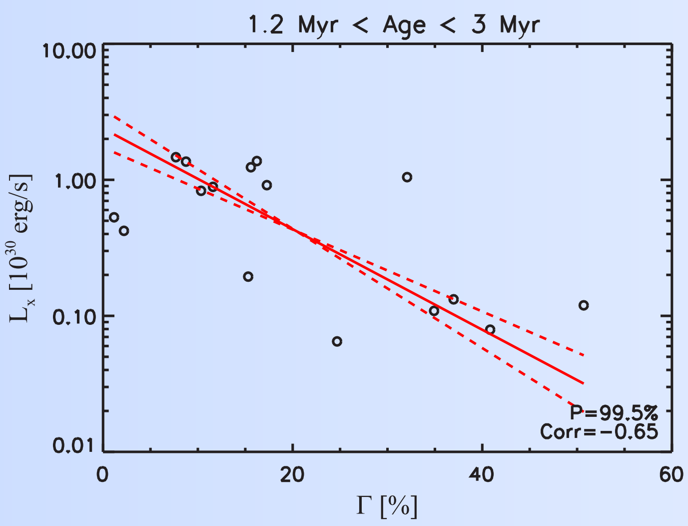

Fig3: X-ray luminosity L_X vs. total crystalline mass fraction Γ for objects of an age within 1.2–3 Myr. The lines represent the OLS bisector regression[9] (solid) with the uncertainties for the slope (dashed).

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