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Exploration of the molecular gas content of young debris disks

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Abstract. Thanks especially to the ALMA interferometer, there are several new detections of CO gas in debris disks. Based on our own and archival ALMA observations, we found that the presence of CO gas in dust-rich debris disks around young (10–50 Myr) A-type stars is common. Interestingly, similarly dust-rich debris disks around young F-K type stars exhibit significantly lower gas incidence. The main difference between the two subsamples is related to a special population of gaseous debris disks whose total CO gas quantity is comparable to that of the less massive Herbig Ae disks. The origin of gas in these CO-rich debris systems is not fully clarified yet.

Keywords. (stars:) circumstellar matter, radio lines: stars.

While the evolution of dust between the protoplanetary and debris stages is rather well studied, the parallel evolution of gas remained poorly explored (Wyatt *et al.* 2015). In order to better understand this aspect of the transition and the early phase of debris disks' evolution, using ALMA data we explored the CO content of a sample of young (10–50 Myr), cold (<140 K), dust-rich ($L_{\rm disk}/L_* > 5 \times 10^{-4}$) debris systems within 150 pc. By supplementing our own ^{12}CO measurements (for 20 targets) with literature (Lieman-Sifry *et al.* 2016, Marino *et al.* 2016, Matrà *et al.* 2017) and archival ALMA line observations, we gathered data for 44 objects, thereby compiling a nearly complete volume-limited sample of such disks. Their analysis have brought the following results.

Detection rate of CO gas. 11 out of the 17 disks that surround A-type stars harbor CO gas. The high detection rate (∼65%) implies that the presence of CO gas in dust-rich debris disks around young A-type stars is common. Out of the 27 disks that surround F, G, or K-type stars, only two (7.4%) show detectable CO emission. By applying Fisher's exact test we found that the observed difference in the proportions of gas-bearing systems in the two subsamples is statistically significant (see also in Moór *et al.* 2017).

Evolution of gas and dust from the protoplanetary to debris phase. By carrying out ^{13}CO and C^{18}O line observations for seven gas-bearing debris disks – all surround A-type stars – with ALMA, we demonstrated that their ^{12}CO emission is optically thick and their CO mass is a factor of 30–250× higher than that calculated from ^{12}CO measurements alone using an optically thin assumption. In Figure 1 we compared the dust and CO content of the eleven gas-bearing debris disks around A-type stars from our sample with those of known Herbig Ae systems. Consistently with previous findings (e.g. Wyatt *et al.* 2015) we found a pronounced drop in dust mass from primordial to debris disks. On the contrary, the CO gas mass of debris disks show a significantly larger spread and

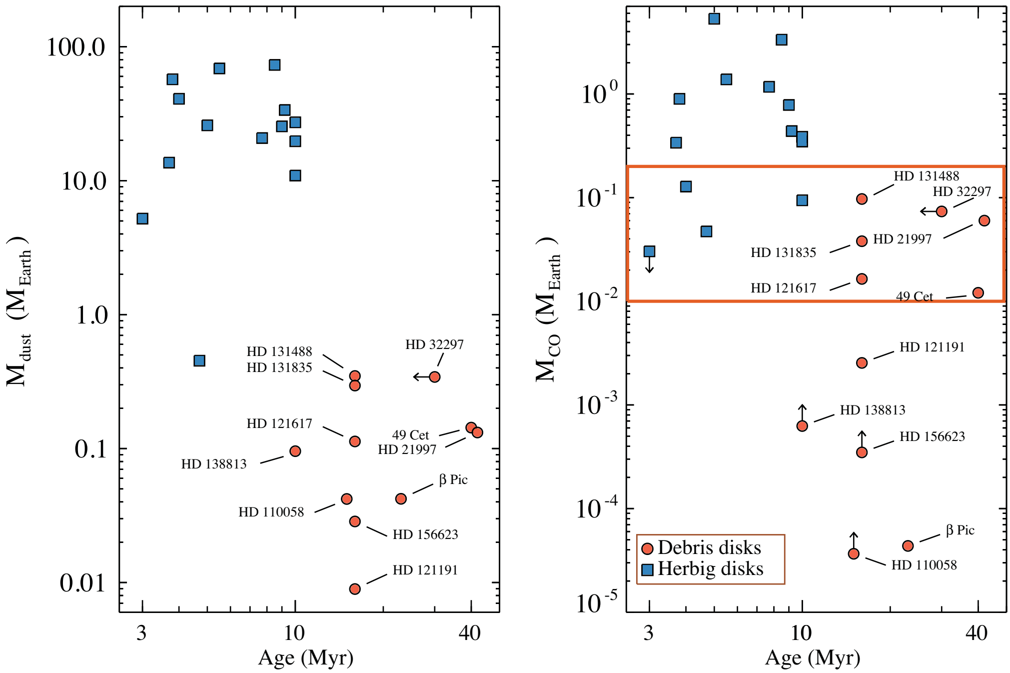

Figure 1. Dust and CO masses of the eleven gas-bearing debris disks around young A-type stars from our volume-limited sample and of some nearby Herbig Ae stars as a function of age. In the right panel the red rectangle highlights those six debris disks whose CO mass is comparable to that of Herbig Ae systems.

there are at least six systems whose CO mass is comparable to that of Herbig Ae disks (see the region highlighted by red in Figure 1).

Origin of gas in debris disks around young A-type stars. Currently there are two viable scenarios to explain the existence of CO gas at protoplanetary level in the debris disks around young A-type stars. One possibility is that they exhibit a hybrid nature: while their dust is secondary and derived from the erosion of planetesimals, the gas component is predominantly leftover from the primordial phase and is dominated by H_2 molecules that provide strong shielding to CO gas (Kóspál *et al.* 2013). Alternatively, Kral *et al.* (2018) recently demonstrated that in debris disks with sufficiently high gas production from icy planetesimals via collisions, shielding by neutral carbon atoms – photodissociation products of the released CO and CO_2 gas – can explain the long lifetime of CO molecules. The currently available observational results are not conclusive enough on the gas origin in these systems. To clarify this question, further observations and application of new approaches are needed (e.g., Kral *et al.* 2018).

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