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Metallicity and Infrared Debris disks: ISO Evidence for Anti-correlation

M.L. Edwards[1] and R.E. Stencel[1]

Abstract. University of Denver (DU) executed a NASA key project that acquired a magnitude limited sample of 66 stars from the Infrared Space Observatory (ISO) mission, looking for infrared signatures indicative of planet formation around nearby stars. Age and abundance data has been obtained from the literature to supplement the infrared photometry performed by the ISO satellite in the interest of discovering correlations between infrared excesses, ages, and chemical abundances. There are two possible scenarios other than the null possibility where disk stars are identical chemically to non-disk stars. Either the disk will enhance the metal content of the star through accretion or it will lower the metalicity of the parent star by acting as a sink for iron and other heavy elements. The most likely scenario is that young stars with disks will show evidence of a low abundance pattern as the heavy elements in the protostellar cloud form regions of higher density, thus making their own regions of gravitational collapse independent of the main stellar mass. Then as these planetesimals collapse into the parent star the abundances return to more normal levels as time passes, perhaps even increasing the abundances to unusually high levels. The strongest conclusion from the University of Denver ISO sample is that infrared excesses decrease slowly over time regardless of sample choice. This means that dust disks are persistent features of a star, so persistent that a mechanism for replenishing the dust is necessary in order to explain the strength of dust found around older stars.

1. Introduction

Stencel and Backman (1994) executed a NASA key project that acquired a magnitude limited sample of 66 stars from the Infrared Space Observatory (ISO) mission, looking for infrared signatures indicative of planet formation around nearby stars. Age and abundance data has been obtained from the literature to supplement the infrared photometry performed by the ISO satellite in the interest of discovering correlations between infrared excesses, ages, and chemical abundances. There are two "pollution" scenarios, in contrast to the scenario where disk stars are identical chemically to non-disk stars. Either the disk will enhance the metal content of the star through accretion or it will lower the metallicity of the parent star by acting as a sink for iron and other heavy ele-

[1]University of Denver, Department of Physics and Astronomy, www.du.edu

ments. The most likely scenario is that young stars with disks will show evidence of a low abundance pattern as the heavy elements in the protostellar cloud form regions of higher density, thus making their own regions of gravitational collapse independent of the main stellar mass. Then as these planetesimals collapse into the parent star the abundances return to more normal levels as time passes.

2. Correlations of Infrared Excess with Age

Habing et al. (1999) suggest a sharp fall off in the incidence of dust disks around stars older than 400 Myrs. The University of Denver ISO project data set does not contain enough stars older than this to secure any real conclusions about the rates of disk dissolution. However, it seems that Habing et al. are simply having difficulty detecting disks around older stars. Spangler et al. (2001) support this interpretation, reporting seven stars containing stars with measurable excesses older than 400 Myr. This is not a significantly smaller number than their detections for younger clusters. They also report a power-law relationship between t and age with an index of -1.76. This compares well with the power-law, as found from the data set, of -1.52 0.39. The similarity in the two results is surprising considering the small number of points in both analysis and the significantly different natures of the sample sets, average values from clusters in Spangler et al (2001) and nearby field stars in the University of Denver Key Project sample. The conclusion is that infrared excesses decrease slowly over time regardless of sample choice. This means that dust disks are persistent features of a star, so persistent that a mechanism for replenishing the dust is necessary in order to explain the strength of dust found around older stars. Exactly what this replenishment mechanism is remains unclear, although a simple collision replenishment model could explain the observed data.

3. Correlations of Metallicity with Infrared Excess

This work also attempted to observe a correlation between t and metallicity. In a graph of t vs. metallicity for the sample, a slight decrease in t with increasing metallicity is arguable, especially if the solar values listed for the Zodical light are included (Backman et al. 1995). Presuming the correlation exists and is universal, one then requires an explanation of β Pictoris unusually high metallicity for its bright disk. The easiest explanation for this increased metallicity involves a recent encounter with a nearby star or molecular cloud. This could have injected dust into the system and increased its metallicity. It is also possible that β Pictoris simply formed in a very iron rich molecular cloud, perhaps due to a recent nearby supernova. If there is a trend of decreasing dust luminosity with increasing metallicity, it supports the view that metallicity is strongly linked to disk evolution. This is the type of correlation that would be seen if metals are trapped in the disk and are slowly deposited onto the star, as the disk material falls into the star. If the trend exists, a star through time must have its metallicity enriched by a factor of roughly thirty, based on the factor of 30 difference in metallicity between BD Phe and the sun. According to Carroll and Ostlie (1996), 10% of the suns mass, 1.989×10^{32}g, lies in the atmosphere and convective zone. For solar-type stars, this is the region that must be enriched in order to increase the measured abundance of the star. The mass of iron in this region of the sun is around 9.3×10^{27}g, this makes the mass of iron that must be gleaned from some source to enrich the star by a sufficient amount around 2.9×10^{26}g. This is equivalent to 3.9 Moon masses. Disk masses cited in the literature range from $10^{-4} - 10^{4}$ Moon masses (Backman & Parece 1993, Stencel & Backman 1994). Thus it is possible, if the accretion mechanism is very efficient, that this enrichment is from disk depletion alone. However, the accretion mechanism alone does not seem to be responsible for the increased iron abundance in stars with old disks. HD 82934 has detectable amounts of lithium-6 in its atmosphere, which is attributed to the recent consumption of a Jupiter type planet (Santos 2000). If we estimate there is approximately an earth mass of Iron in a Jupiter class planet, for the sake of argument, and that the planetary accretion method is 1% efficient in depositing material from the star in the photosphere, then only one such consumption event is required to supply the observed enrichment. Obviously less efficient mechanisms would require more consumption events. Details to be found in Edwards (2001, Masters Thesis, University of Denver, available on request).

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