Dispersal of Planet-Forming Disks around Low Mass Stars

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Star Formation through Cosmic Time
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Observational Background

1. Disks initially have mass $\sim 0.1 \, M_\star$

2. Inner ($<1$ AU) disk gets optically thin in dust in few Myrs

3. Dust mass in outer disk also greatly diminished in same time

4. There are some cases of optically thin inner disk (hole) with optically thick outer disk.

5. Most of initial mass does not go into planets
Mechanisms for Disk Dispersal: Viscous Spreading and Accretion


Most dust and gas spirals in but some spreads out
Photoevaporation by Central Star


Flow to ISM  |  cold disk (green), hot surface (red)  |  Flow to ISM
Photoevaporation by Central Star Models (Gorti & Hollenbach 2004, 2008, and Dullemond, Hollenbach & Gorti 2008)

Need to self-consistently calculate the chemistry, heating and cooling, radiative transfer, vertical and radial structure, and dynamics of flow.
Photoevaporation by Central Star: Model Results
(FUV, EUV+Xrays)

\[ M_* = 1 \, M_\odot, \]
\[ L_* = 2.3 \, L_\odot, \]
\[ L_X = 6 \times 10^{-4} \, L_\odot, \]
\[ L_{\text{EUV}} = L_X, \]
\[ L_{\text{FUV}} = 0.28 \, L_\odot \]

FUV = 912-2000 A
EUV = <912 A
Xray = 0.5-10 keV
Applications: Photoevaporation as Function of $r$

$M_\ast = 1 \, M_\odot$, $M_d = 0.1 \, M_\odot$

$L_\ast = 2.3 \, L_\odot,$

$L_X = 5 \times 10^{-4} \, L_\odot,$

$L_{FUV} = 5 \times 10^{-4} \, L_\odot$

$L_{EUV} = 5 \times 10^{-4} \, L_\odot$

“FUV” = FUV + Xrays
Very new results of Dullemont, Hollenbach, & Gorti

$M_*=1 \ M_\odot, \ M_d = 0.1 \ M_\odot, \ \alpha = 0.01 + \text{no} \ \text{photoevaporation}$
Very new results of Dullemond, Hollenbach, & Gorti

\[ M_* = 1 \, M_\odot, \quad M_d = 0.1 \, M_\odot, \quad \alpha = 0.01 + \text{EUV photoevaporation} \]
Very new results of Dullemond, Hollenbach, & Gorti

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$M_*=1\, M_\odot$, $M_D=0.1\, M_\odot$, $\alpha=0.01+\text{FUV+EUV photoevaporation}$
Very new results of Dullemond, Hollenbach, & Gorti

\[ M_*=1 \, M_\odot, \quad M_d = 0.1 \, M_\odot, \quad \alpha = 0.01, \quad \text{Mass of disk with time} \]
1. Photoevaporation is likely the dominant dispersal mechanism for the outer disk (beyond several AU).

2. Viscous spreading/accretion disperses the inner disk.

3. EUV photoevaporation creates gap at a few AU, then viscous accretion creates inner hole, then EUV rapidly evaporates outer torus from inside out. This only operates, however, once the disk has lost mass and the accretion rate through the disk has fallen to very low values of $\sim 5 \times 10^{-10} M_\odot/yr$. Clarke et al 2002, Alexander et al 2006.

4. Photoevaporation by FUV and Xrays photoevaporates from outside in, and evaporates the main mass reservoir of disk, thus determining their lifetimes.
End
I. Intermediate Disk Evolution

$t \sim 10^6 - 10^7 \text{ yr}$
Applications: Lifetimes of Disks, Photoevaporation Only

Disk Dispersal versus Central Star Mass, $M_{\text{disk}} = 0.03 M_*$
Applications: Model Spectra
Verification of hot gas capable of evaporating
Model Spectrum: $r = 100$ AU optically thick disk
Applications:  Model Spectra and Observations

Observational Diagnostics of ionized (HII) surface and Xray heated region just below it (partially ionized)

Infrared Fine Structure Lines ([NeII] 12.8 um)