Dispersal of Planet-Forming Disks around Low Mass Stars

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Collaborators: F. Adams, K. Dullemond, U. Gorti, D. Johnstone, S. Lizano, F. Shu

Recent reviews: Hollenbach et al (2000), Clarke (2002), Hollenbach & Adams (2004), Johnstone et al (2004), Yorke (2004), Hester & Desch (2005), Bally et al (2005), Richling et al (2006), Dullemond et al (2006)

Star Formation through Cosmic Time
KITP, UC Santa Barbara
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Observational Background

1. Disks initially have mass ~0.1 M_*

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

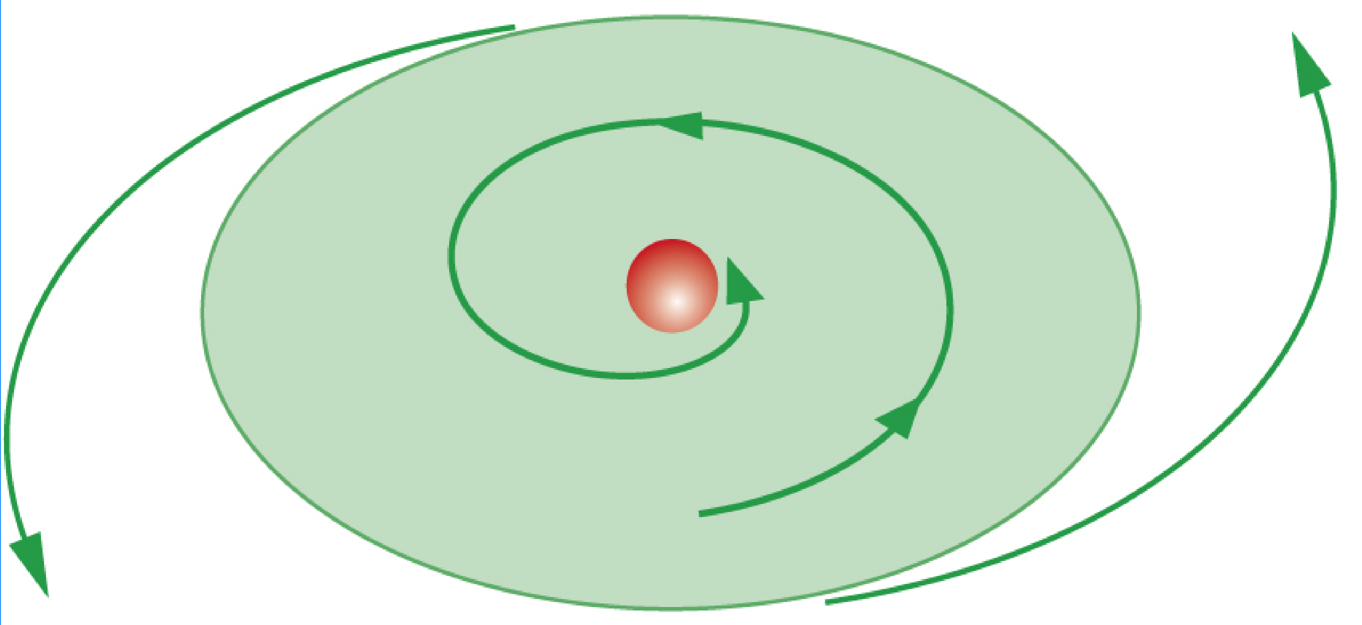
3. Dust mass in outer disk also greatly diminished in same time

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

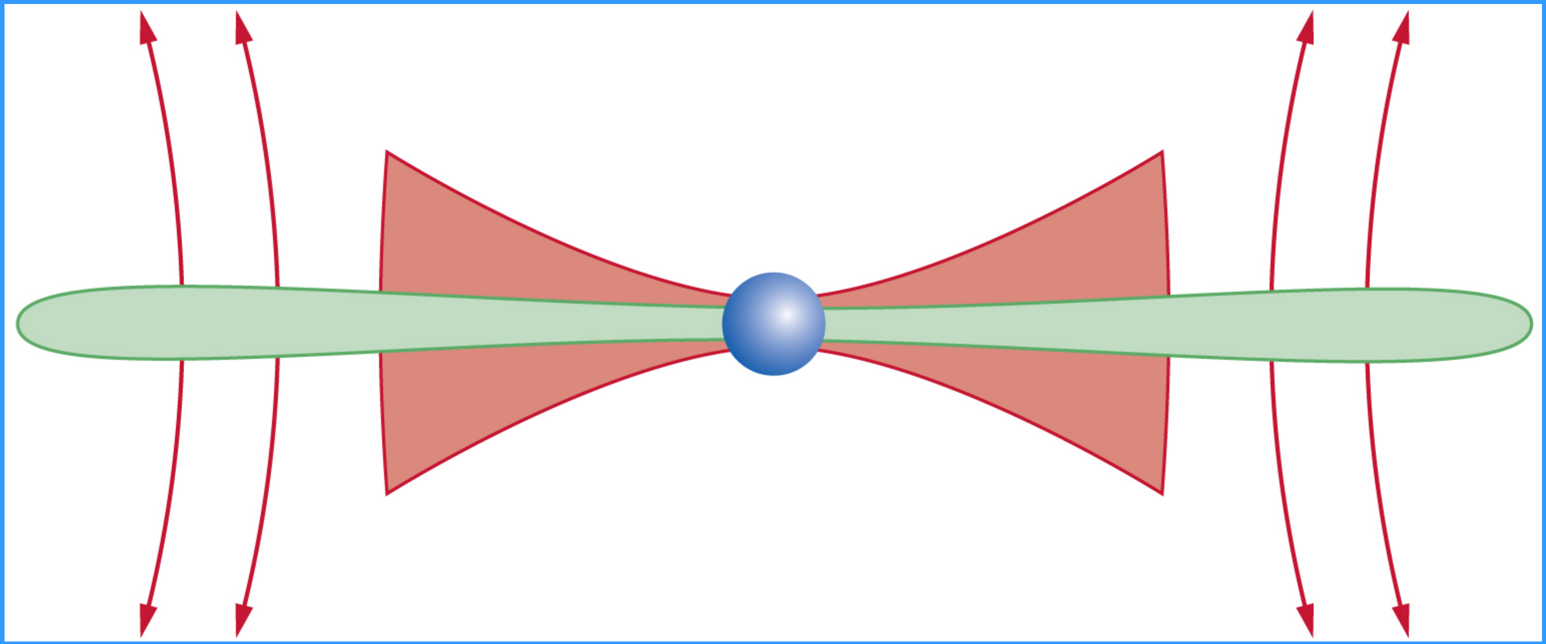
Hartmann et al (1998), Calvet et al (2000), Muzerolle et al (2005), (Clark et al (2001), Matsuyama et al (2003), Ruden (2004), Alexander et al (2006a,b), Hueso & Guillot (2006)



Most dust and gas spirals in but some spreads out

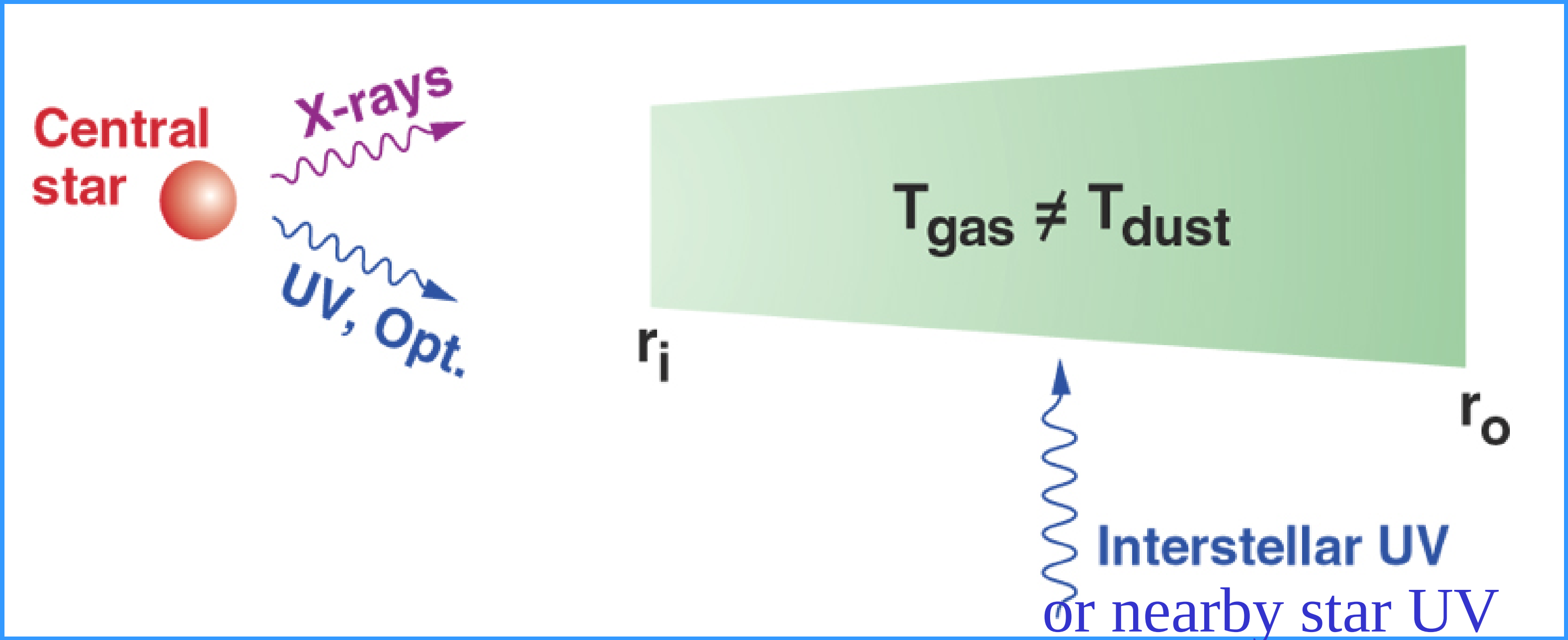
Photoevaporation by Central Star

Hollenbach et al (1994), Shu, Johnstone, & Hollenbach (1994), Yorke & Welz (1994, 1996), Richling & Yorke (1997), Kessel et al (1998), Richling & Yorke(2005), Alexander et al (2006), Gorti & Hollenbach (2007)



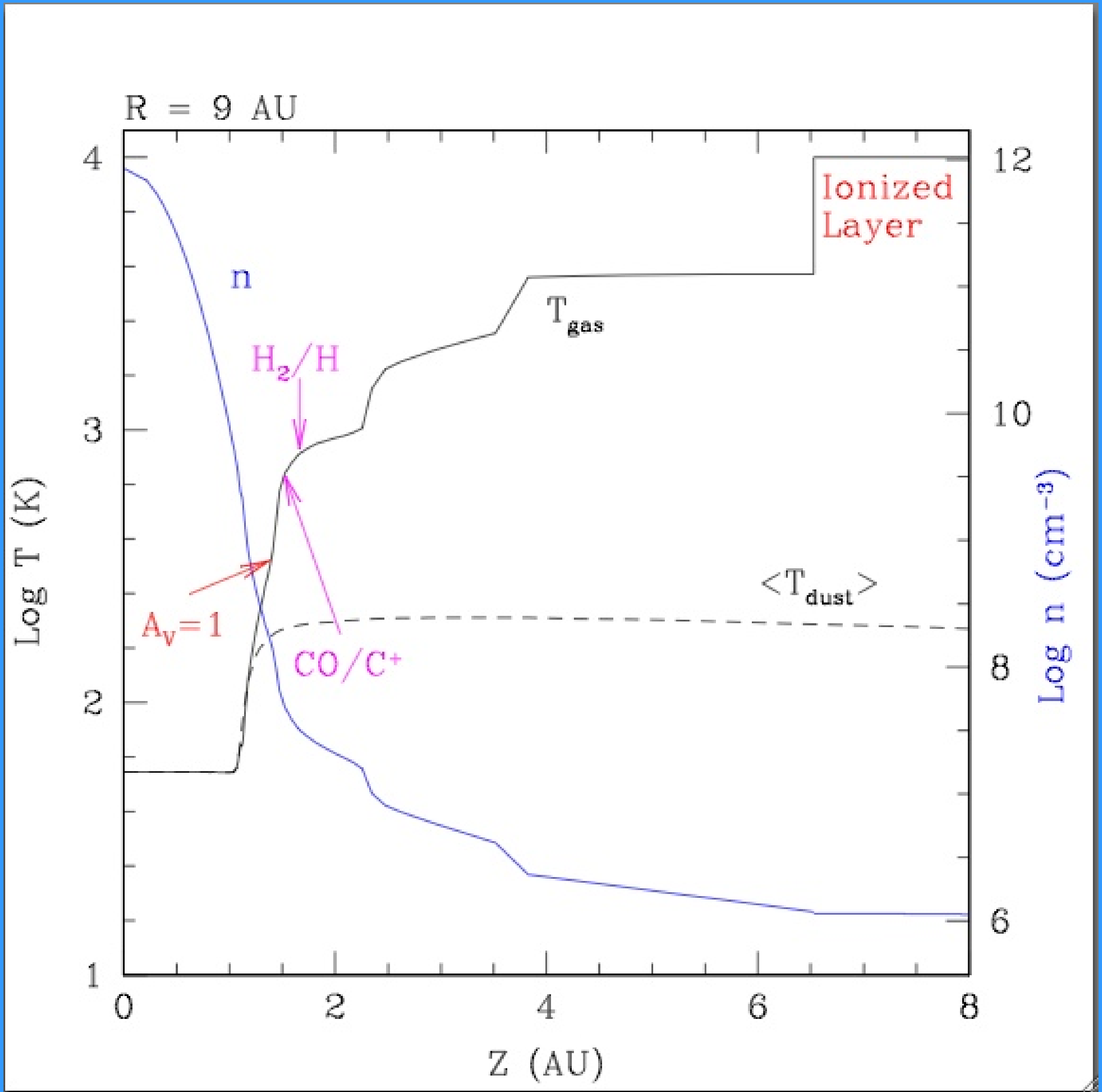
Flow to ISM | cold disk (green), hot surface (red) | Flow to ISM

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)



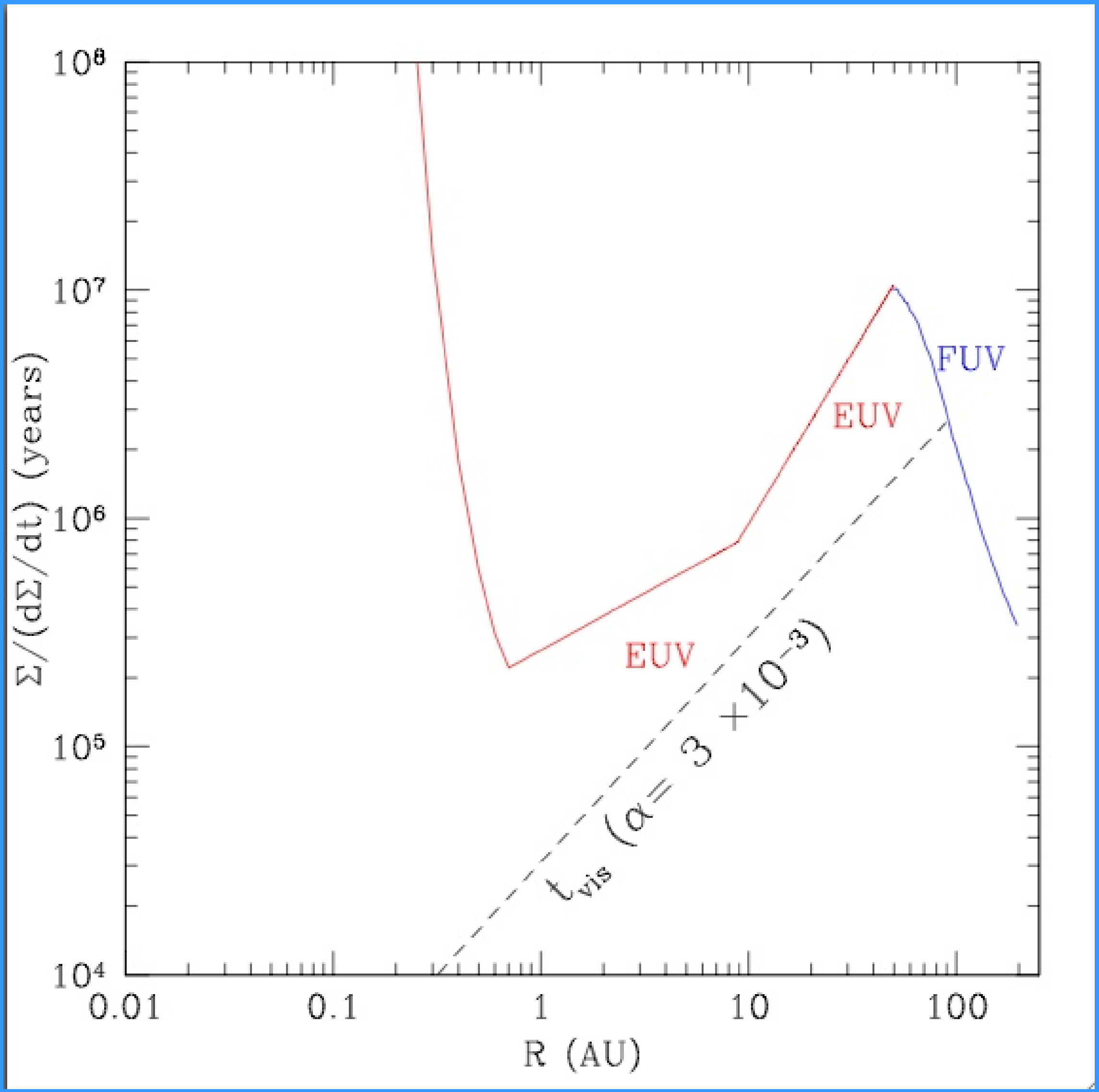
$M_* = 1\ M_\odot$,

$L_* = 2.3\ L_\odot$,
$L_X = 6 \times 10^{-4}\ L_\odot$,
$L_{EUV} = L_X$,
$L_{FUV} = 0.28\ L_\odot$

FUV = 912-2000 A
EUV = <912 A
Xray = 0.5-10 keV

Applications: Photoevaporation as Function of r

$M_* = 1\ M_\odot, \quad M_d = 0.1\ M_\odot$



$L_* = 2.3\ L_\odot,$

$L_X = 5\times10^{-4}\ L_\odot,$

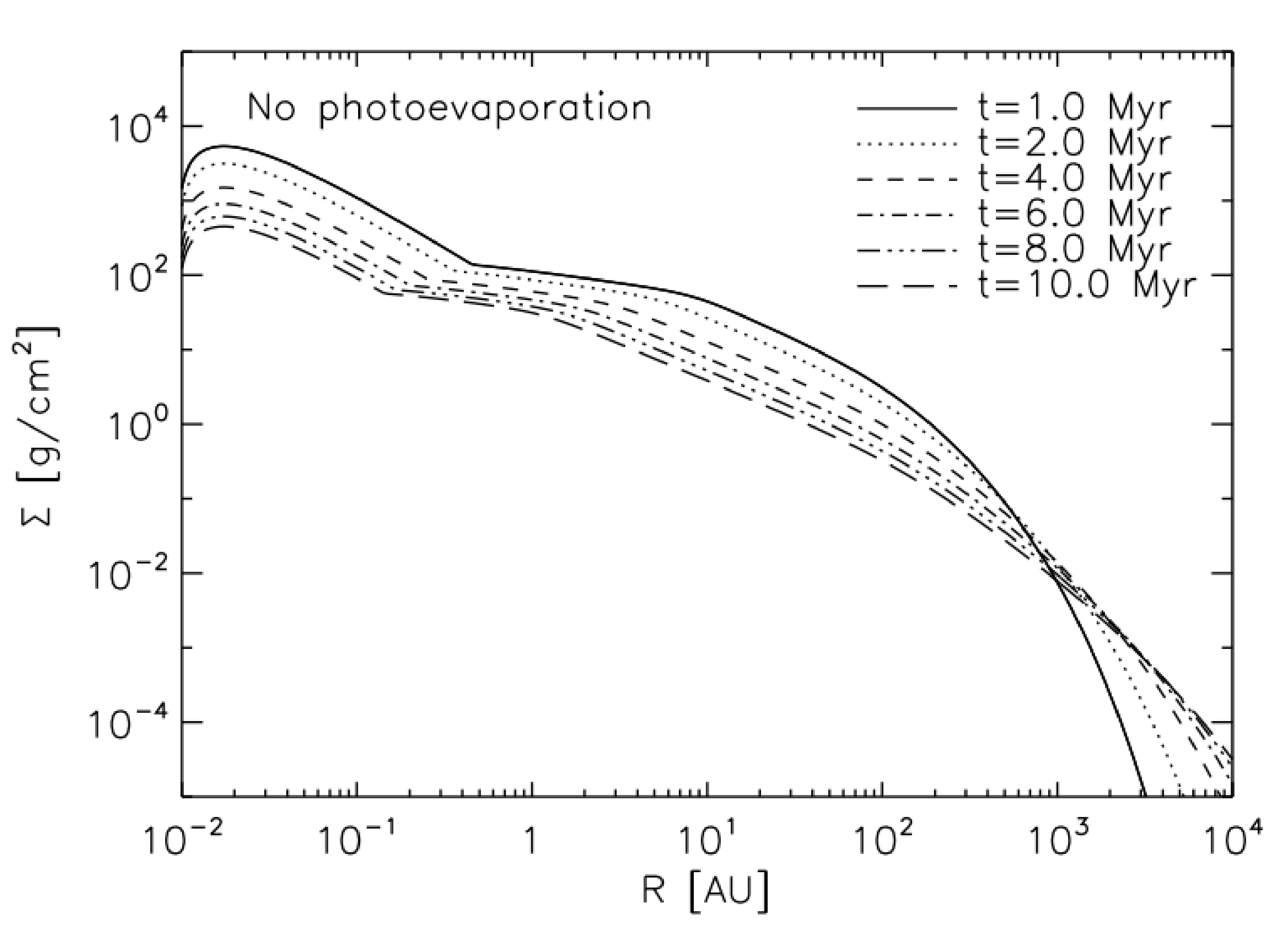
$L_{FUV} = 5\times10^{-4}\ L_\odot$

$L_{EUV} = 5\times10^{-4}\ L_\odot$

"FUV" = FUV + Xrays

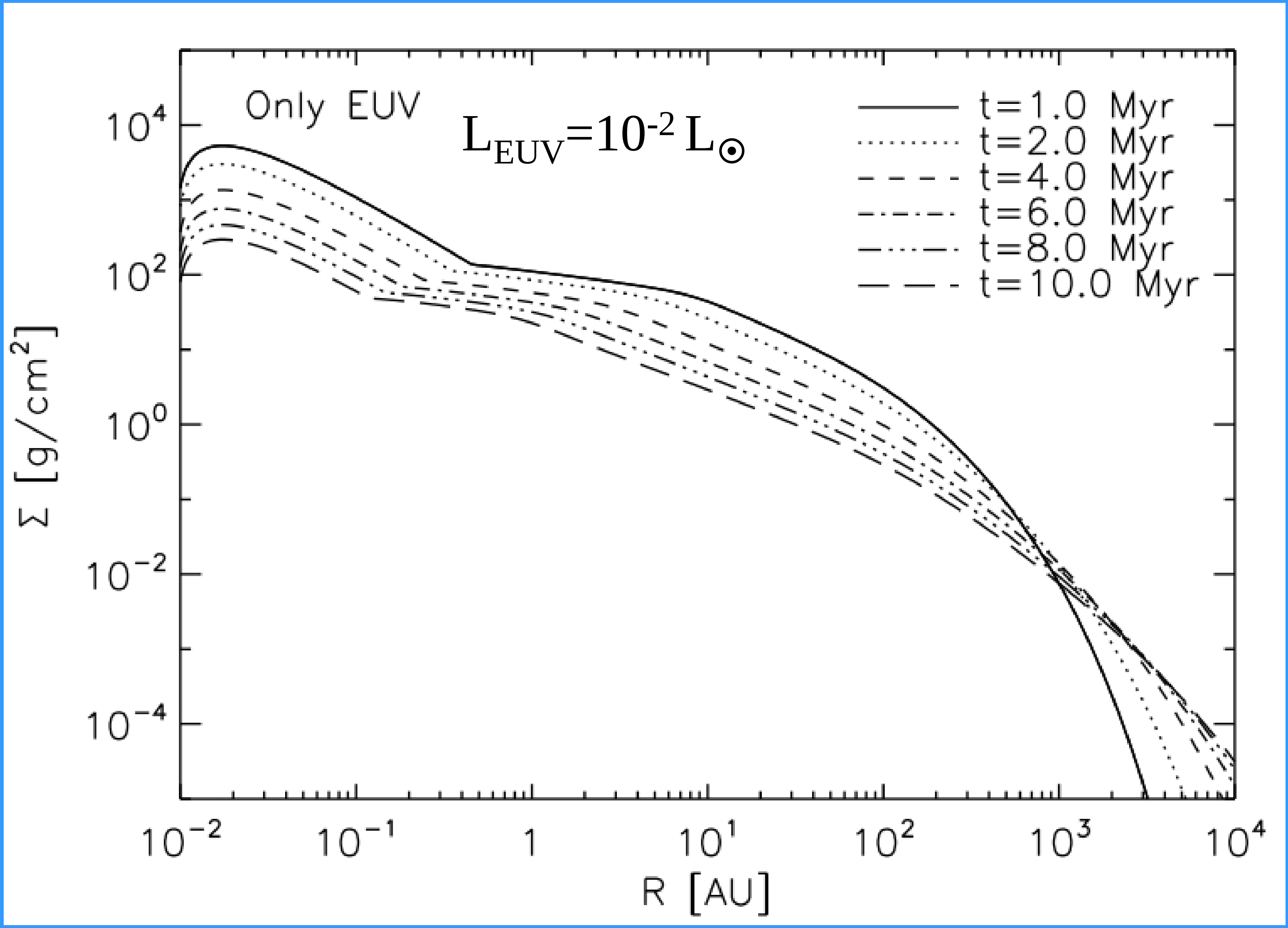
Very new results of Dullemond, Hollenbach, & Gorti

$M_* = 1\ M_\odot$, $M_d = 0.1\ M_\odot$, $\alpha = 0.01$ + no photoevaporation



Very new results of Dullemond, Hollenbach, & Gorti

$M_* = 1\ M_\odot$, $M_d = 0.1\ M_\odot$, $\alpha = 0.01$ + EUV photoevaporation



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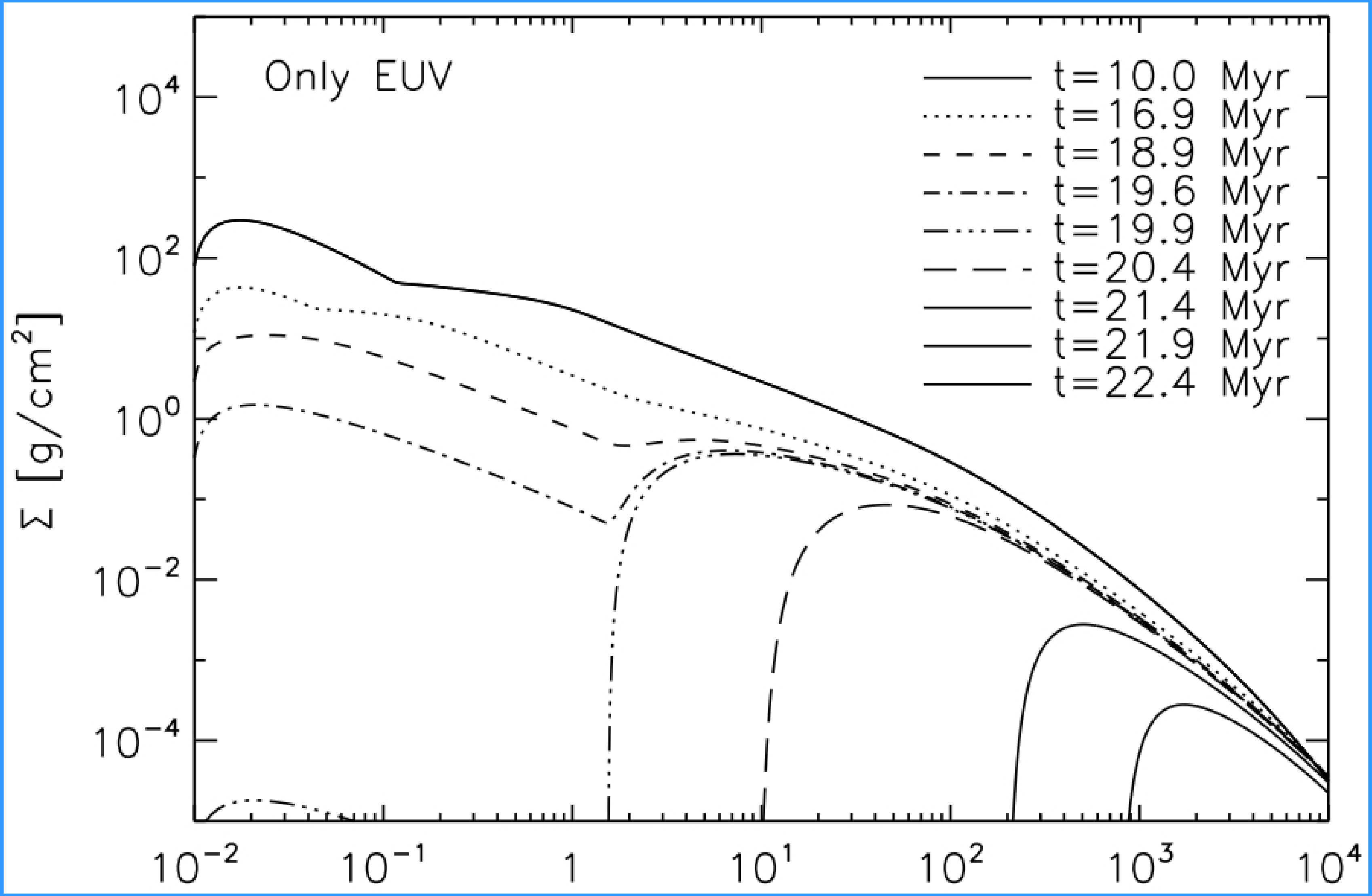
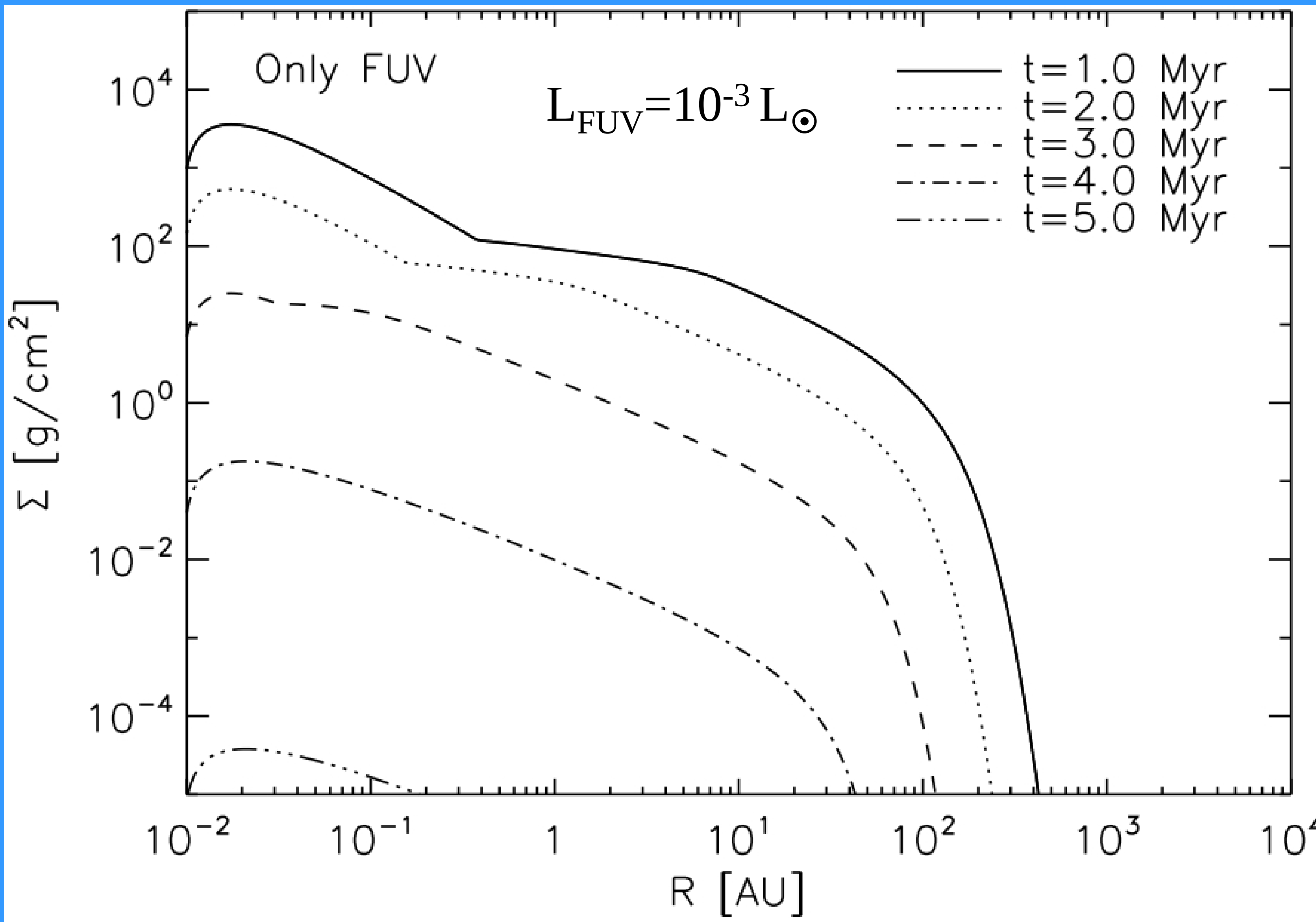


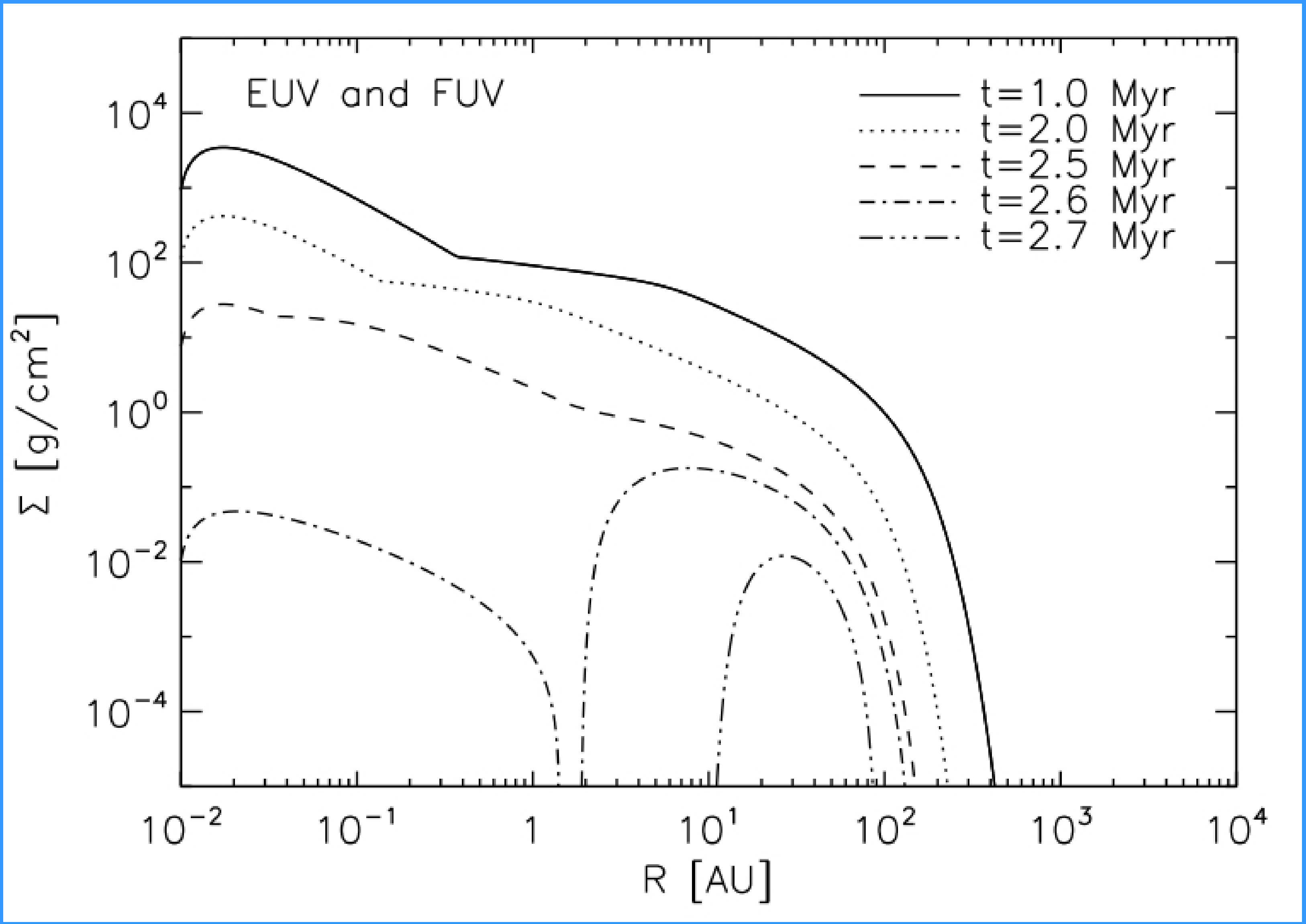
Very new results of Dullemond, Hollenbach, & Gorti

$M_*=1\ M_\odot$, $M_d = 0.1\ M_\odot$, $\alpha = 0.01$ + FUV photoevaporation



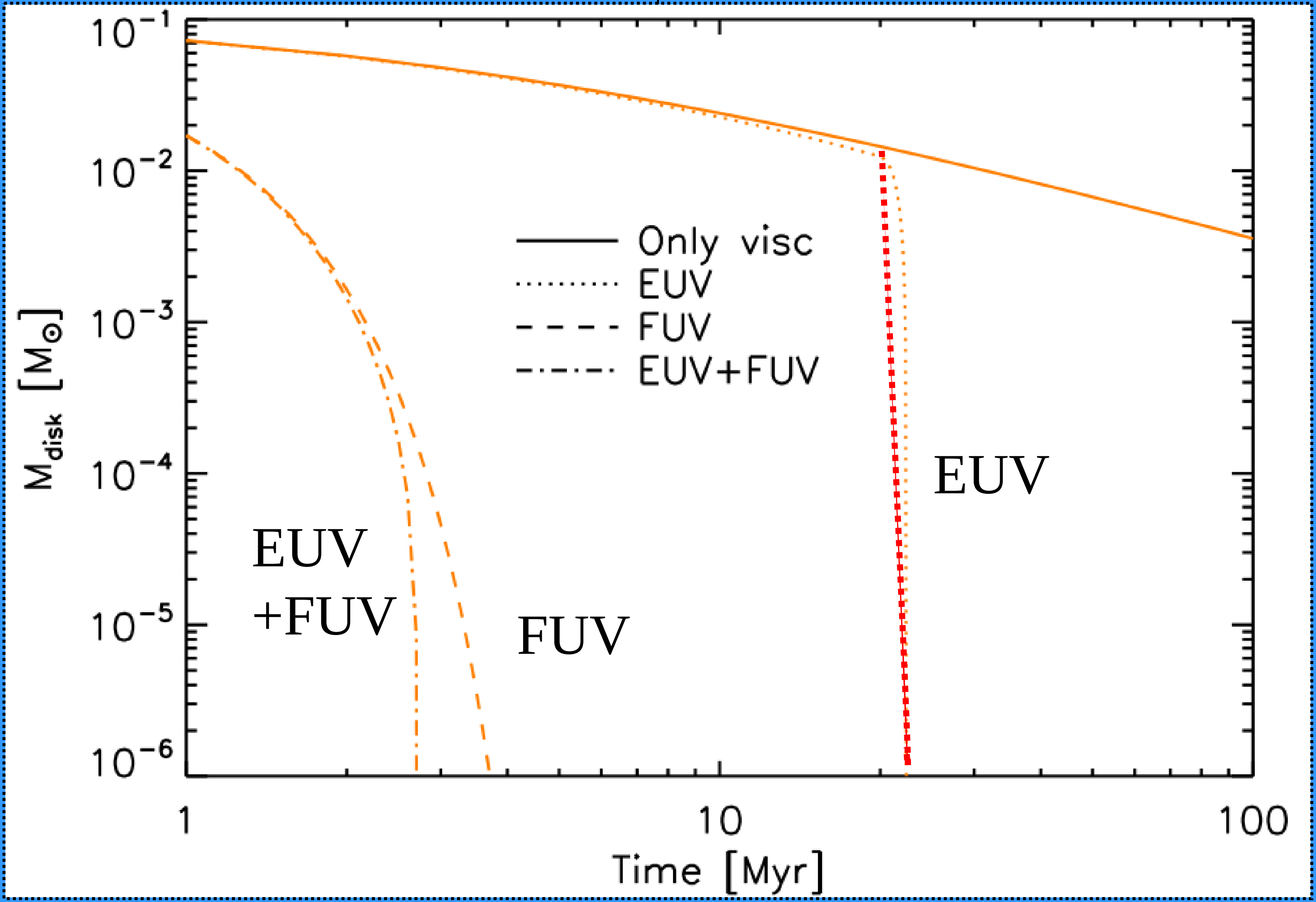
Very new results of Dullemond, Hollenbach, & Gorti

M_*=1 $M_\odot$, M_d = 0.1 $M_\odot$, α = 0.01 + FUV+EUV photoevaporation



Very new results of Dullemond, Hollenbach, & Gorti

$M_* = 1\ M_\odot$, $M_d = 0.1\ M_\odot$, $\alpha = 0.01$, Mass of disk with time



Summary and Conclusions

1. Photoevaporation is likely the dominant dispersal mechanism for the outer disk (beyond several AU).

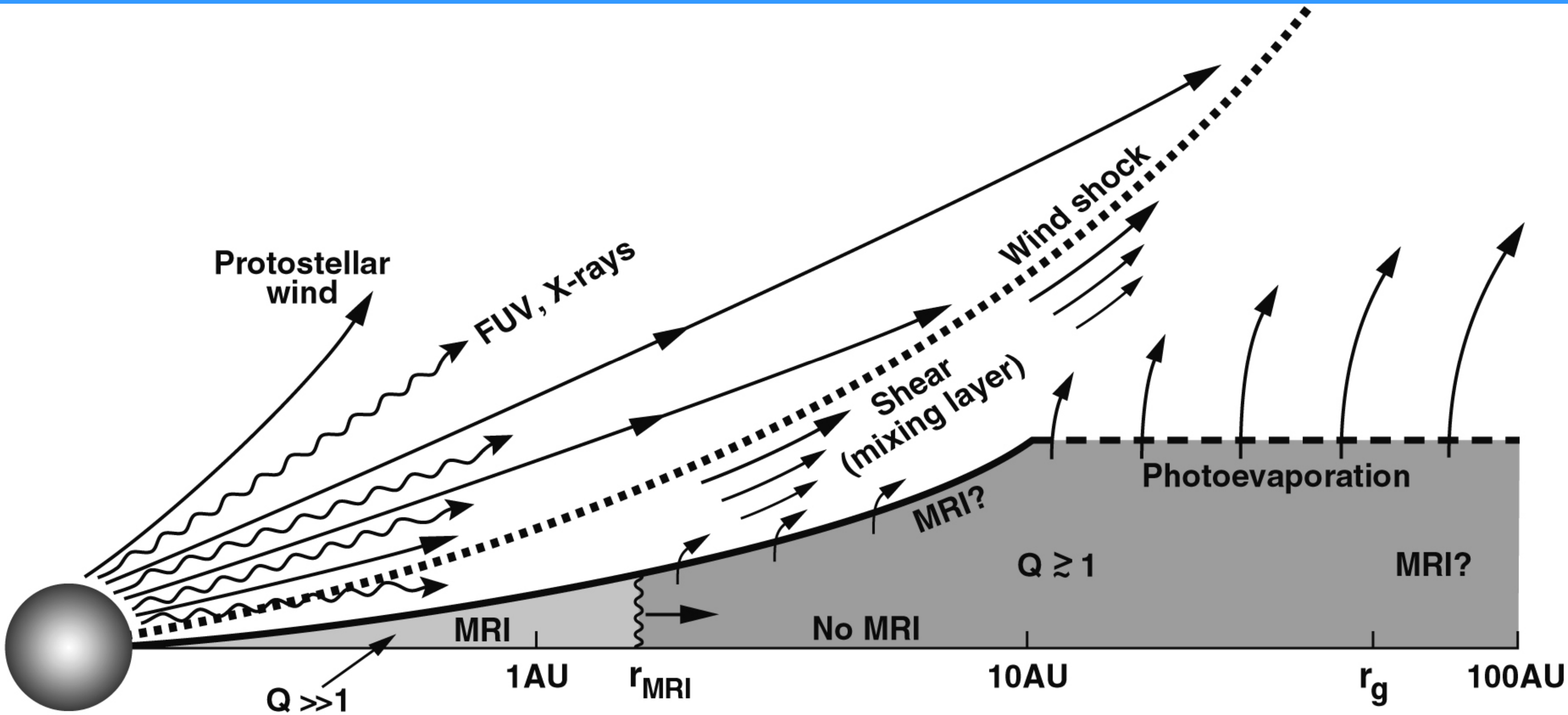
2. Viscous spreading/accretion disperses the inner disk.

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

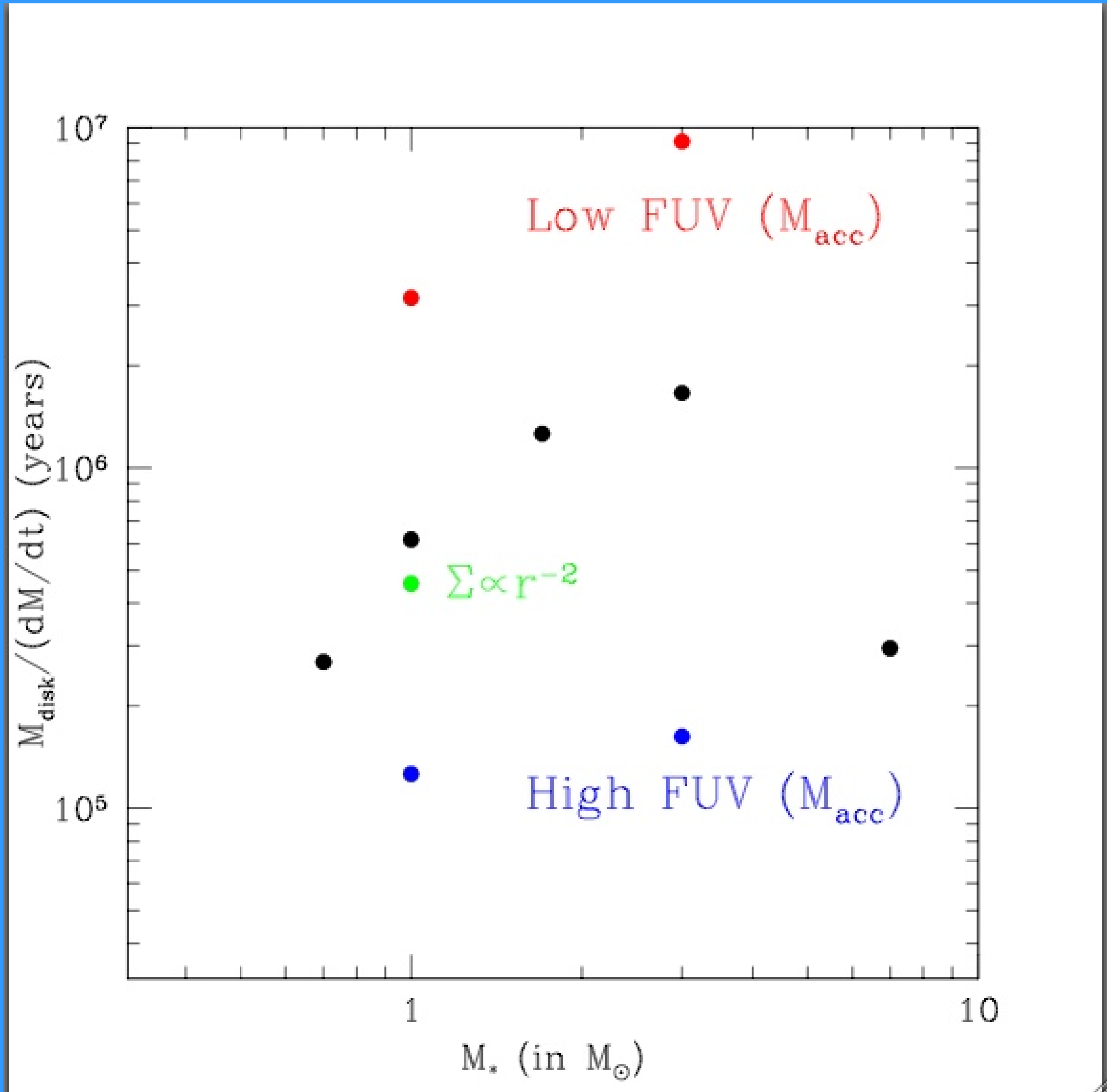
I. Intermediate Disk Evolution



t ~ 10^6 - 10^7 yr

Applications: Lifetimes of Disks, Photoevaporation Only

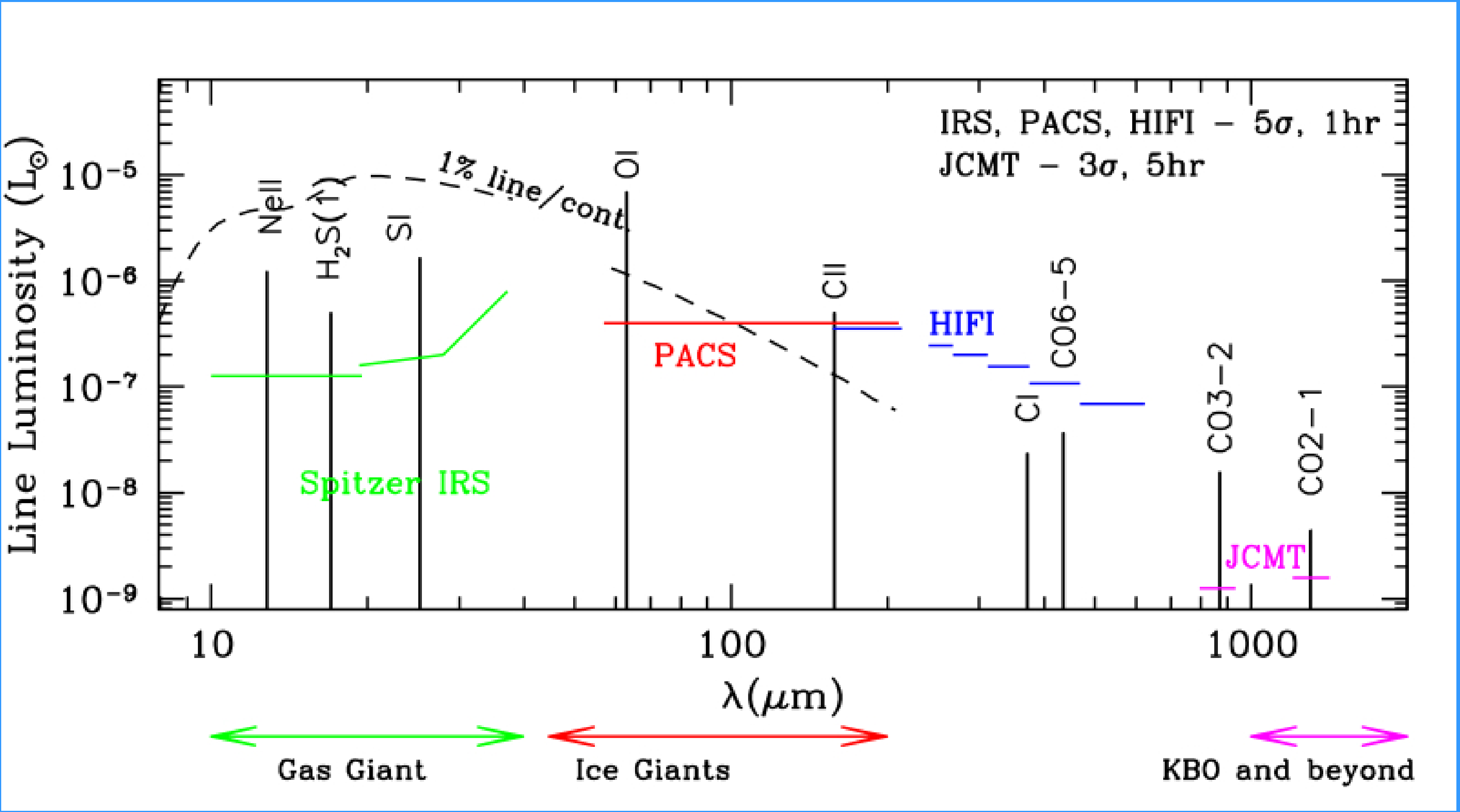
Disk Dispersal versus Central Star Mass, $M_{disk} = 0.03\ M_*$



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)

Hollenbach & Gorti (in prep), Glassgold, Najita, and Igea 2007, Pascucci et al (2007) for observation of [NeII] 12.8um, Geers et al (2007)