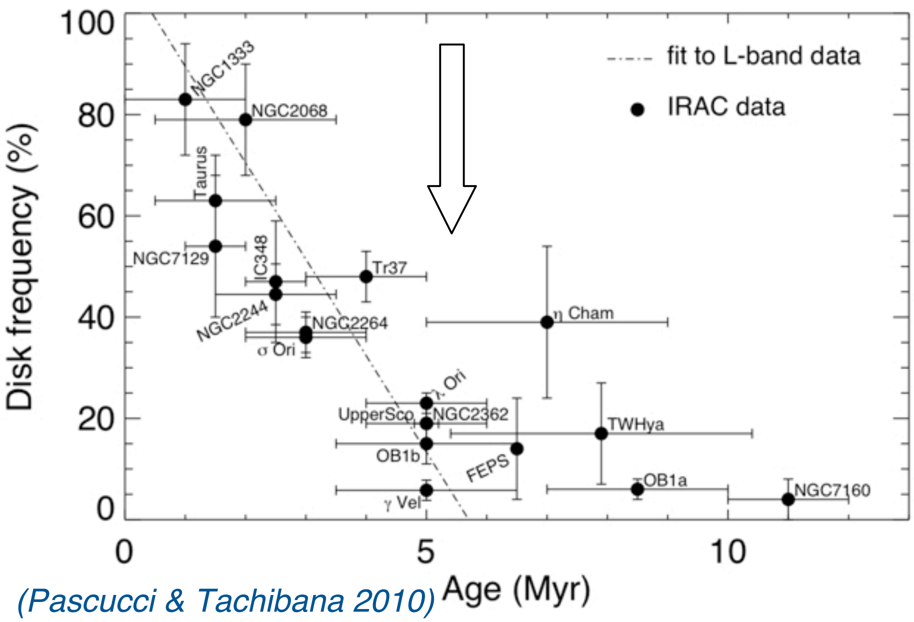
FUV/X-ray/EUV Photoevaporation in Viscously Accreting Disks

Uma Gorti
(NASA Ames/SETI)

Collaborators: Kees Dullemond (MPIA), David Hollenbach (SETI)

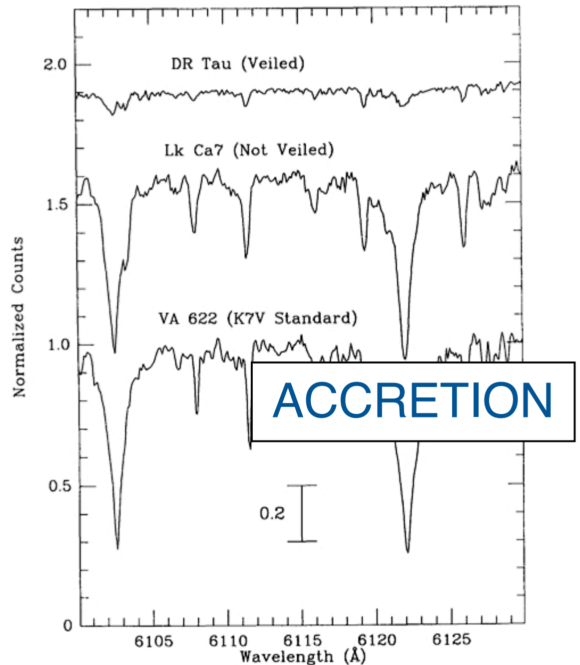
DISK DISPERSAL

Disk Lifetimes ~ 5 Myrs



(Pascucci & Tachibana 2010)

Disks are short-lived; hence must be dispersed by some mechanism.

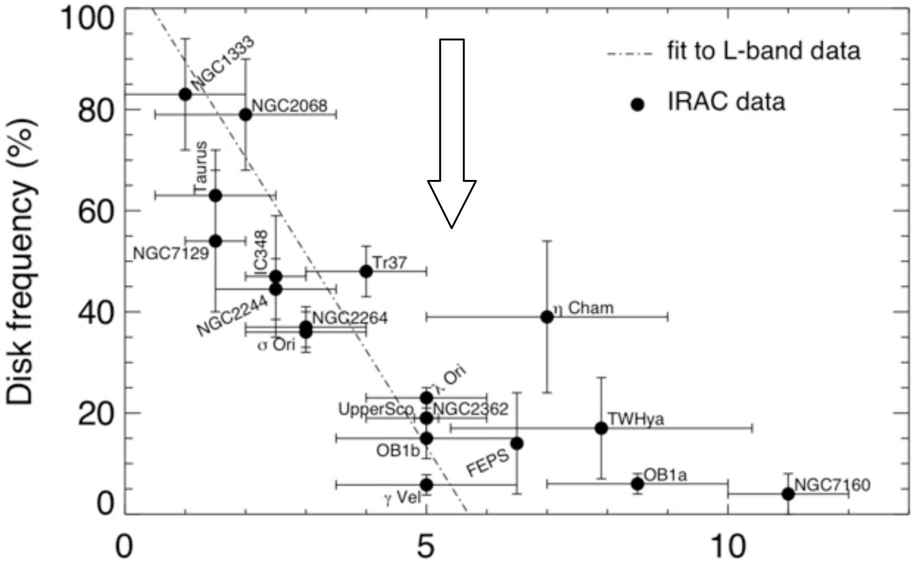


(Hartigan et al. 1991)

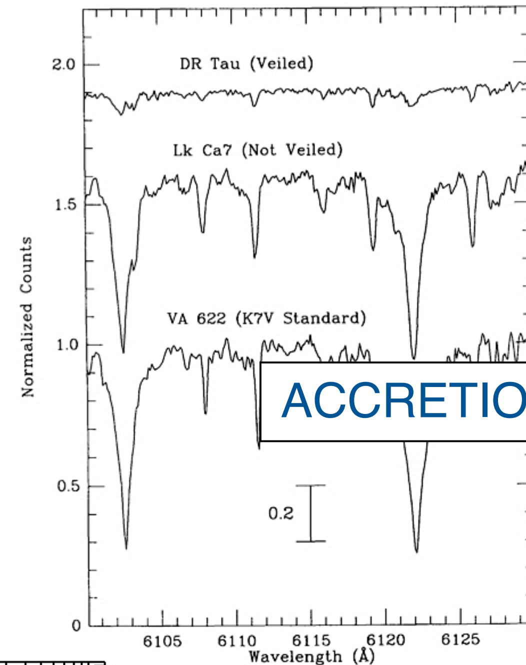
DISK DISPERSAL

Disks are short-lived; hence must be dispersed by some mechanism.

Disk Lifetimes ~ 5 Myrs

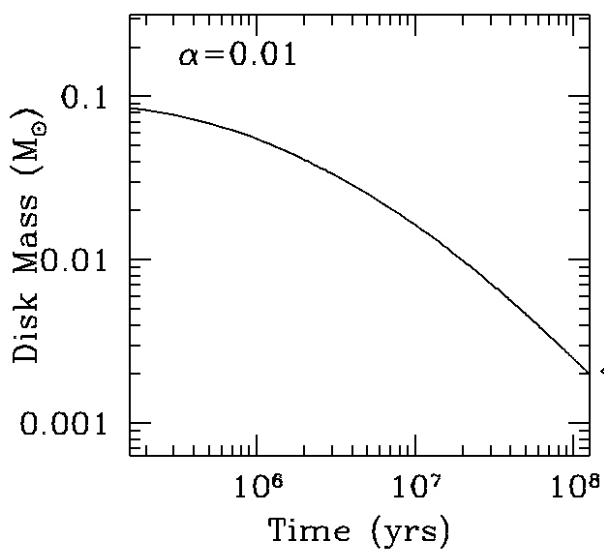


(Pascucci & Tachibana 2010)



ACCRETION

(Hartigan et al. 1991)

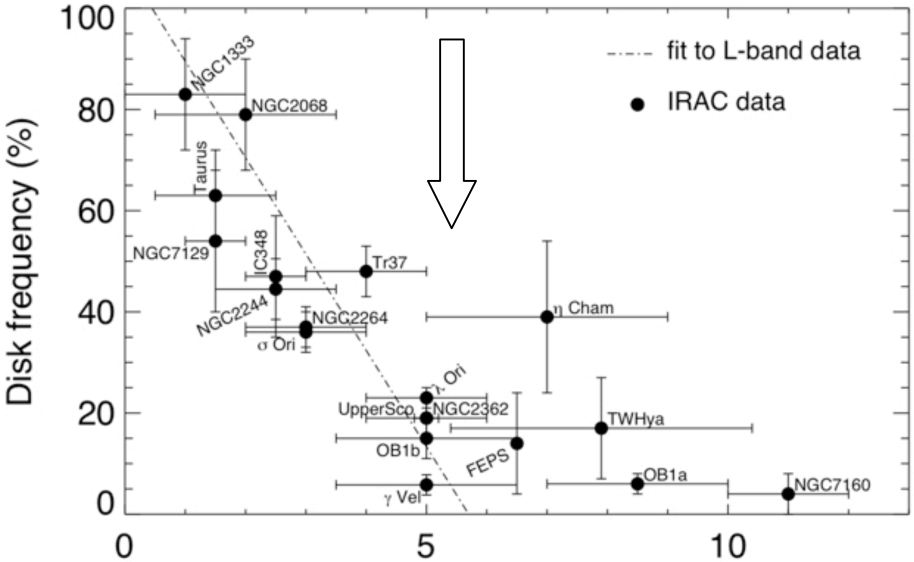


Optically thick disk persists for $> 10^8$ years.

$M_{disk} > 10^{-3}\ M_o$

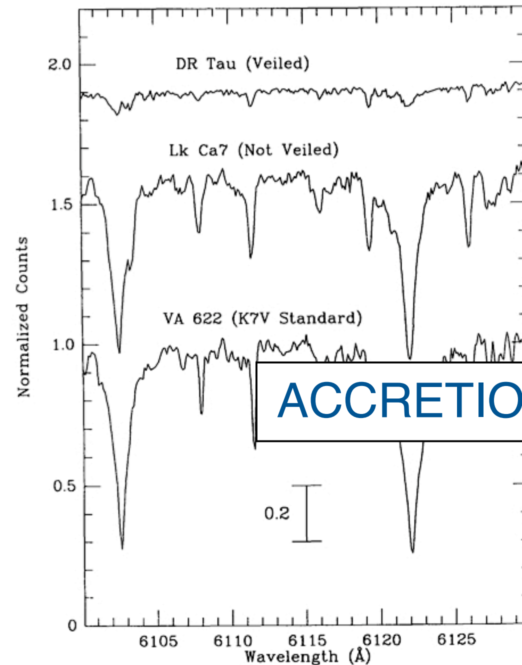
DISK DISPERSAL

Disk Lifetimes ~ 5 Myrs



(Pascucci & Tachibana 2010)

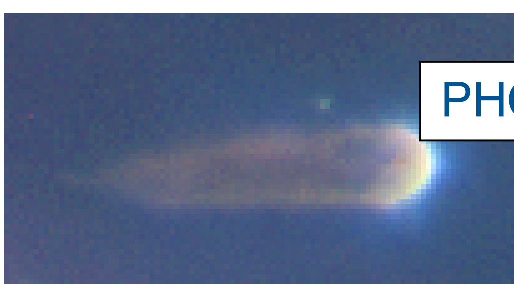
Disks are short-lived; hence must be dispersed by some mechanism.



ACCRETION

(Hartigan et al. 1991)

Cannot disperse inner disk

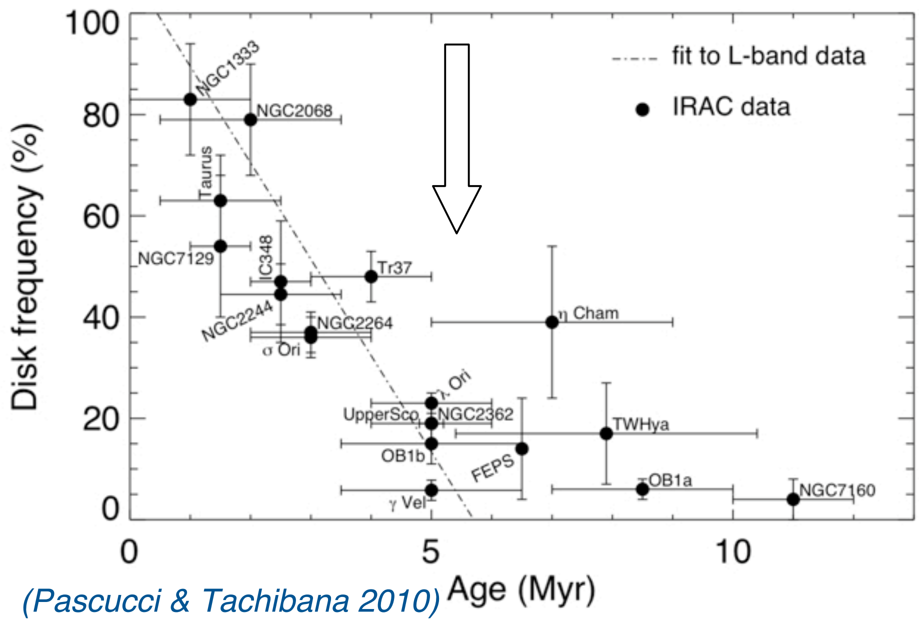


PHOTOEVAPORATION

Optically thick disk persists for > 10^8 years.

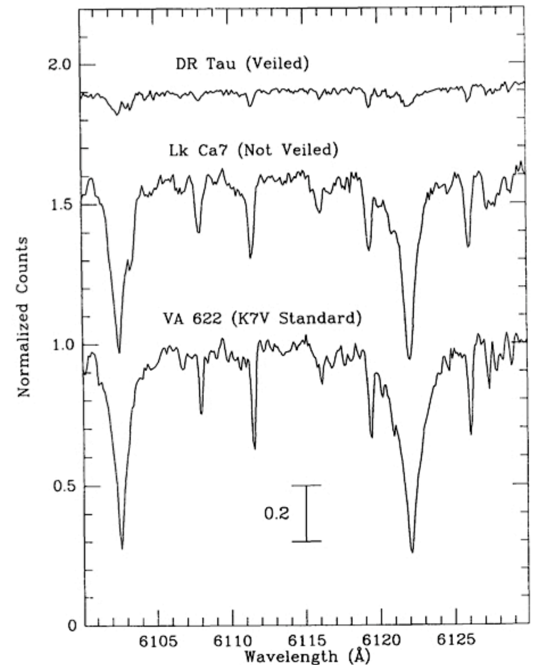
DISK DISPERSAL

Disk Lifetimes ~ 5 Myrs

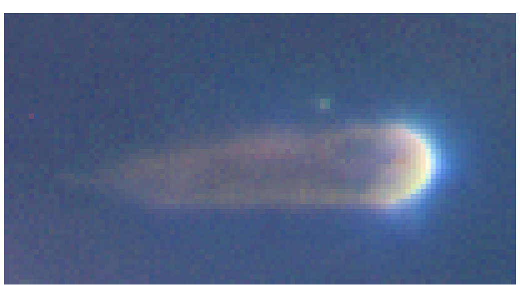


(Pascucci & Tachibana 2010)

Disks are short-lived; hence must be dispersed by some mechanism.



(Hartigan et al. 1991)



ACCRETION + PHOTOEVAPORATION

EUV ($h\nu$ >13.6eV), FUV (6eV< $h\nu$ <13.6EV) and X-ray ($h\nu$ >100eV) photoevaporation of a viscously evolving disk by the central star.

EUV

- Unknown - likely 10^{-3} L_{bol} ~ 10^{40-41} s^{-1}
- Easily absorbed - N(HI) ~ 10^{17} or N_H ~ 10^{20} cm^{-2}
- Long dispersal timescales under typical conditions

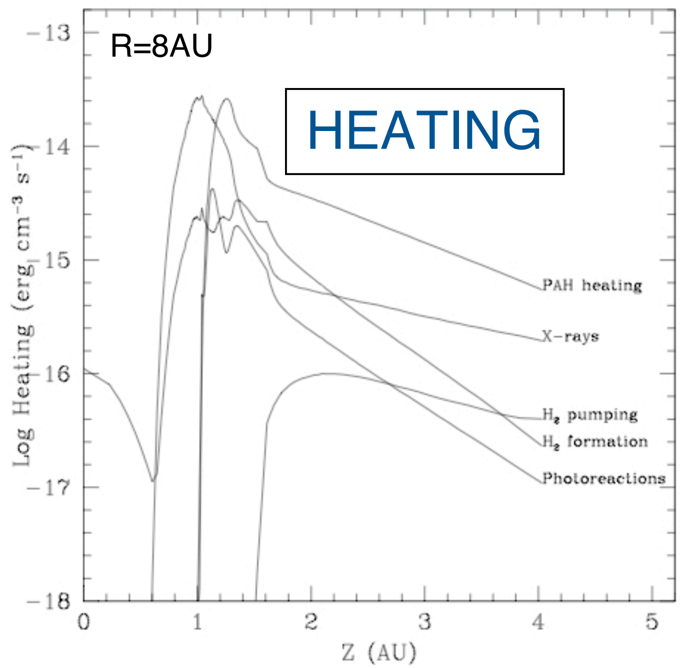
X-rays

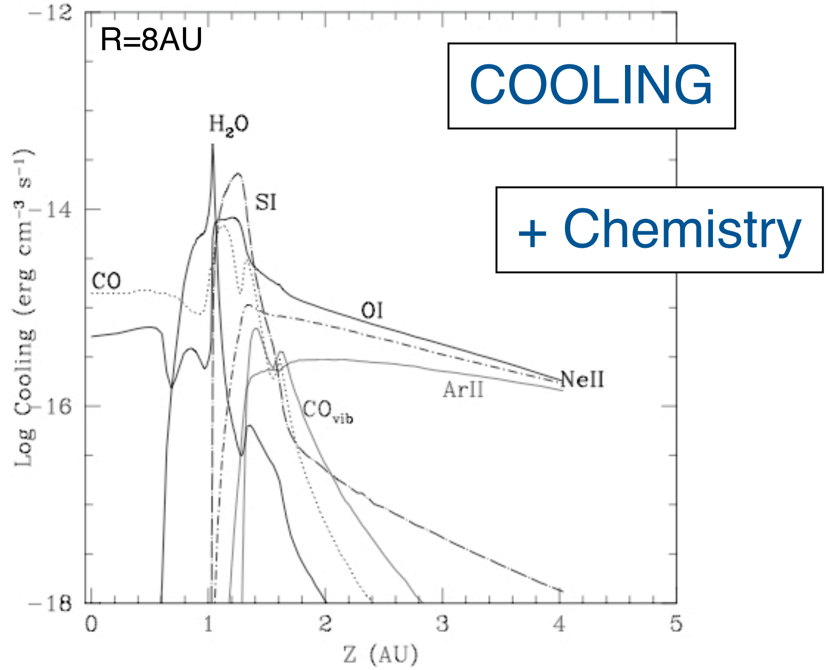
- Measured ~ 10^{-3} L_{bol}
- Young stars are active, hence L_X high
- Hard X-rays can penetrate N_H ~ 10^{22-23} cm^{-2}

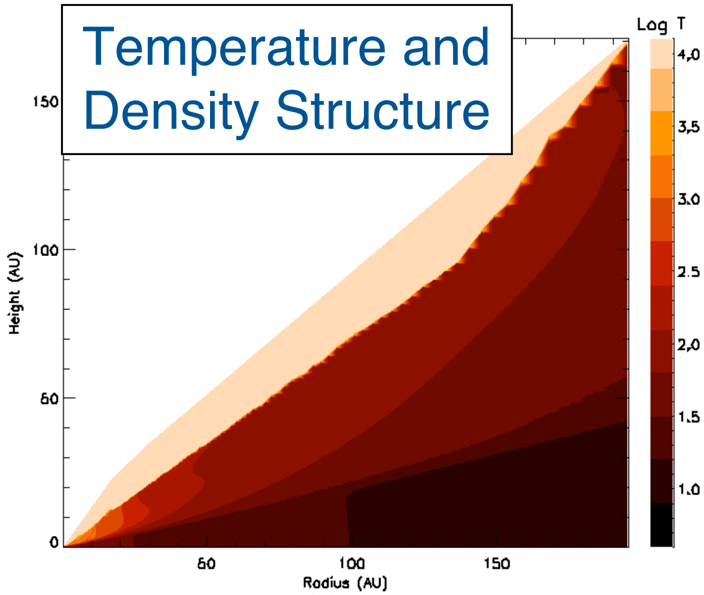
FUV

- Accretion shocks result in high FUV
  Time-dependent, L_{FUV} ~ 0.1 - 10^{-3} L_{bol}
- Chromospheric FUV also high ~ 10^{-3} L_{bol}
- Intermediate mass stars have high photospheric FUV
- Can penetrate to deep disk layers (depending on dust opacity)

GAS AND DUST DISK MODELS (Gorti, Dullemond & Hollenbach 2009)



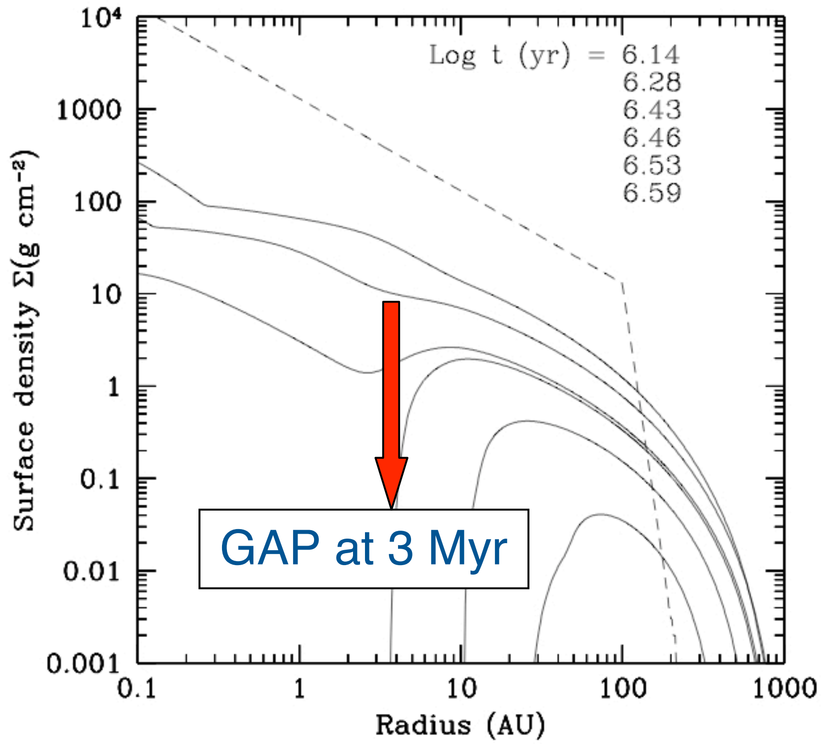




Other Model Features:

- $T_{gas} \neq T_{dust}$ (Dust model is included)
- Viscosity + EUV/FUV/X-ray photoevaporation (Surface Density Evolution)

TIME EVOLUTION OF A VISCOUS PHOTOEVAPORATING DISK



$0.1M_o$ disk around $1M_o$ star

$L_{EUV} = L_X = L_{FUV;Chr.} = 10^{-3}\ L_{bol}$

Viscosity Parameter $\alpha = 0.01$

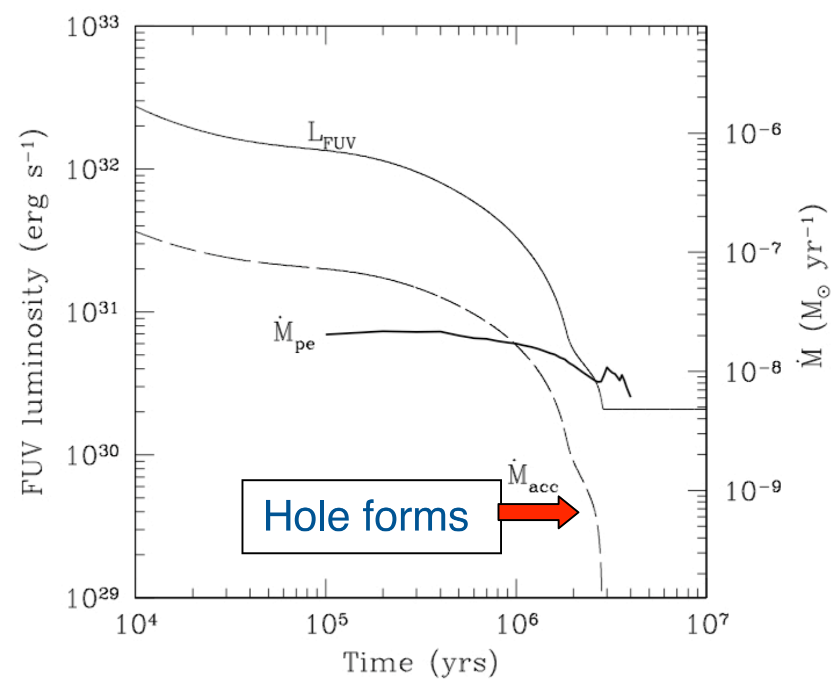
Dust opacity lower than ISM by 10

Attenuating wind accompanies accretion - $dM_{wind}/dt \sim 0.1\ dM_{acc}/dt$

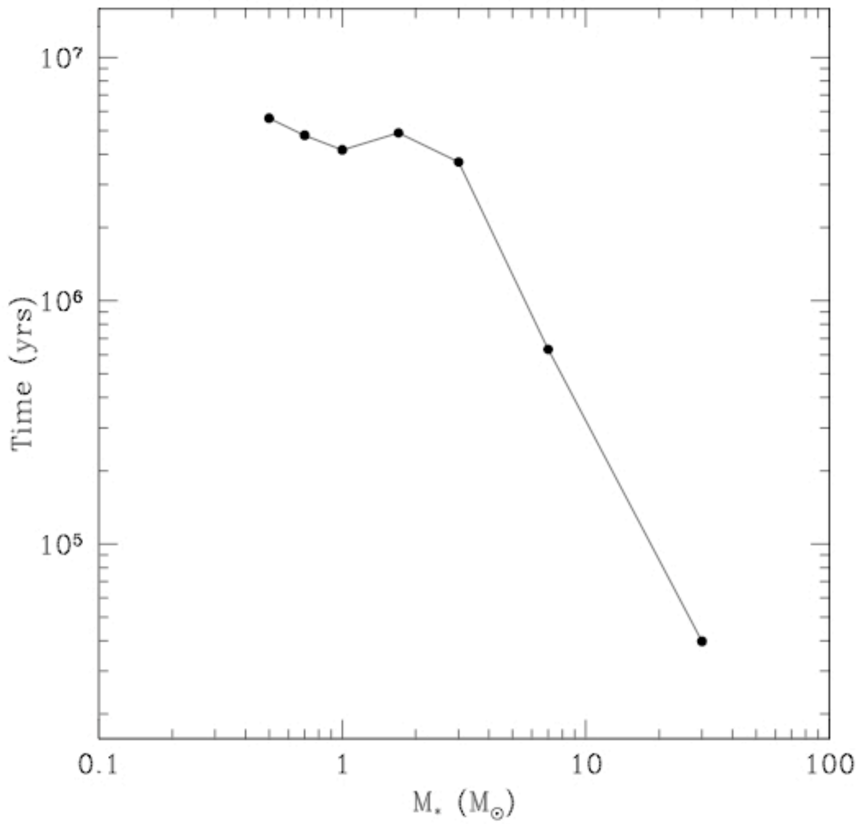
Gap forms in disk (FUV/X-Rays) ~ 3 Myrs

~ 50% mass accreted, ~ 50% dispersed

Disk Lifetime ~ 4 Myrs



Disk Lifetime as a Function of Stellar Mass



Low mass stars ($M_* \sim < 3\ M_o$)
Active chromospheres, high L_X, L_{FUV}
Low M_{disk}, gravity, α (scales with M_*)
$\tau_{disk} \sim$ few Myrs

High Mass stars ($M_* > \sim 3\ M_o$)
Low L_X, but high photospheric UV
Higher M_{disk}, gravity, α

$\tau_{disk} \sim< 10^5$ yrs

DEPENDENCE OF DISK LIFETIMES ON VARIOUS DISK PARAMETERS

- Typical disk+star initial conditions lead to typical disk lifetimes ~ 4Myrs

- Wide dispersion about this value - Many input parameters!!

1. Viscosity Parameter (α) $\Downarrow$ τ_{disk} $\Uparrow$ (Nearly linear)
2. Chromospheric FUV/X-rays $\Downarrow$ τ_{disk} $\Uparrow$ (No gaps for ~ 10^{28-29} erg s^{-1})
3. Soft X-rays (0.2keV) if present, τ_{disk} $\Downarrow$ (See poster by Owen et al.)
4. Dust Evolution: Flaring angle (settling) $\Downarrow$ τ_{disk} $\Uparrow$

   Gas/Dust ratio(grain growth) $\Uparrow$ τ_{disk} $\Uparrow$ ($\Downarrow$ if PAHS)

   PAH abundance (for FUV) $\Downarrow$ τ_{disk} $\Uparrow$

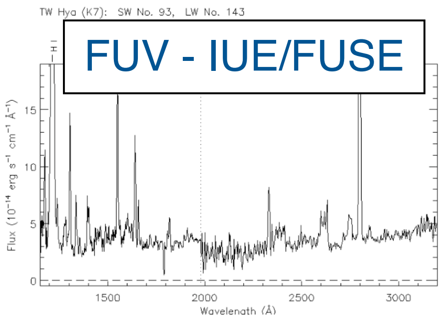
Dust evolution may increase disk lifetimes

Future work will include dust evolution….

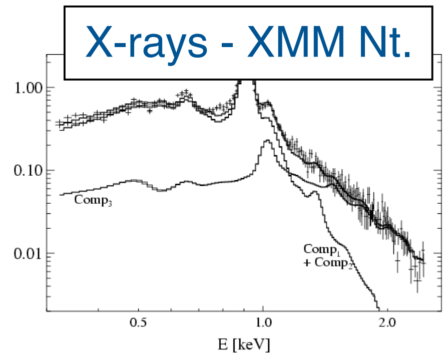
Disk models calculate line emission - Test of n, T structure and photoevap. rates

TW Hya

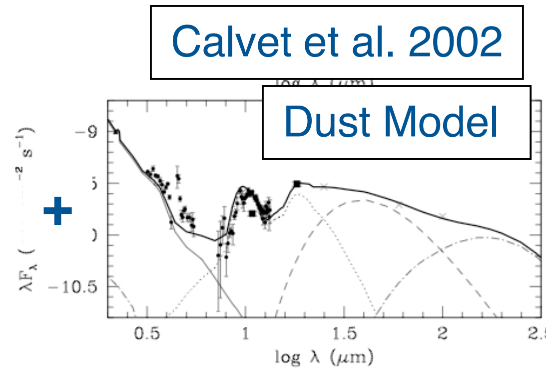
Known Stellar parameters +



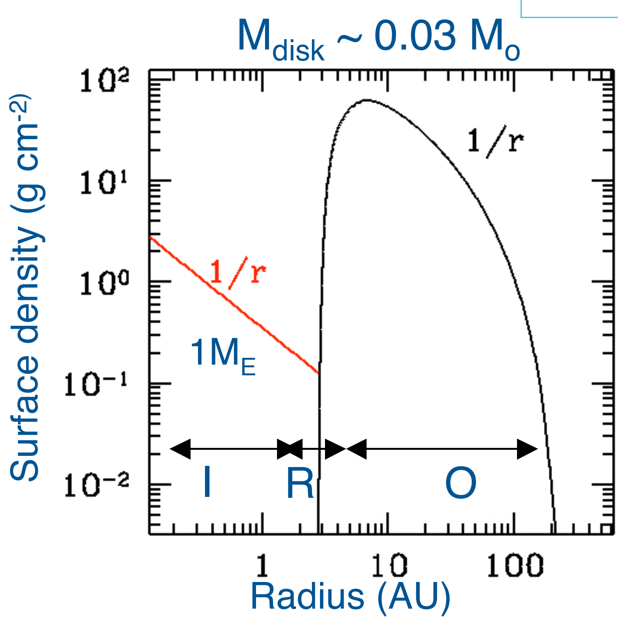
+



+



R=Rim; O=Outer; I=Inner



Comparison of Model Line Luminosities (in $L_\odot$) and Observational Data.

Region	Line	Model	Obs.	Refs.
O	CO 2-1	6×10^{-9}	7.9×10^{-9}	Qi et al. 2006
O	CO 3-2	2.1×10^{-8}	2.4×10^{-8}	Qi et al. 2006
O	CO 6-5	5×10^{-8}	4.6×10^{-8}	Qi et al. 2006
R,I	NeII 12.8μm	6×10^{-6}	4.5×10^{-6}	Ratzka et al. 2007
R,I	H_2 S(2)	4.0×10^{-7}	$5 \times 10^{-7} \downarrow$	Bitner et al. 2008
R,I	H_2 S(1)	1.0×10^{-6}	$6 \times 10^{-7} \downarrow$	Bitner et al. 2008
I	CO vib. (total)	1.7×10^{-5}	$\approx 1.0 \times 10^{-5}$	Salyk et al. 2008
R,I	OI 6300 Å	5×10^{-6}	1×10^{-5}	Edwards, priv. comm.
R,I	OI 5577 Å	7×10^{-7}	1.4×10^{-6}	Edwards, priv. comm.

Preliminary Results!

SUMMARY

- Viscous accretion and photoevaporation by central star are effective in dispersing circumstellar disks (around ~ 0.3-3M_o stars) on timescales of ~ few Myrs.

- FUV and X-rays are more important than EUV or viscosity alone, disk dispersal takes place over a wide range of disk radii. Viscosity depletes the inner Disk ~< 1-2 AU. FUV photoevaporation can deplete the outer disk mass reservoir rapidly. Gaps form at a few AU depending on the level of stellar chromospheric activity.

- Disk lifetimes depend on various parameters, most importantly the disk viscosity and dust evolution. Disk lifetimes depend weakly on stellar mass for low and intermediate mass stars, and are ~ few Myrs for $M_* < 3M_o$; more massive stars lose their disks rapidly ~ few 10^5 years.

- Disk models also predict line emission/spectra from surface layers where photoevaporation occurs. Models can be tested by comparing with observational data. Our models reproduce gas line emission from TW Hya fairly well.