Photo-evaporation of proto-planetary disks

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Outline

- Introduction
- Viscous accretion
- Photo-evaporation
- Results
- Conclusion
- Future work

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Introduction

- Photoevaporation by the central source (from high mass stars to TTSs)
- Planet migration by gas disk – planet gravitational interaction
- Disk removal mechanisms:
  - Viscous accretion
  - Photoevaporation
  - Stellar encounters
  - Stellar winds
  - Planet formation

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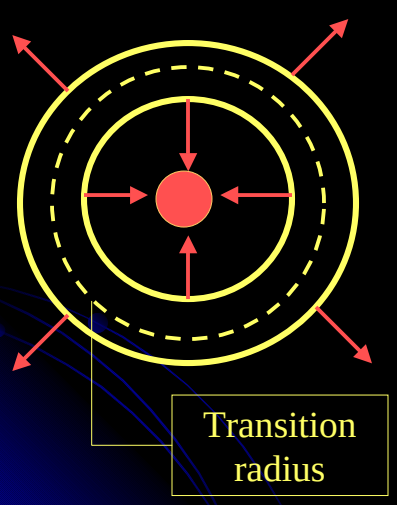
Viscous Accretion



- Outward angular momentum transport
- Angular momentum conservation: inner material moves closer to the central star and outer material spreads out.
- Not possible to remove the entire disk

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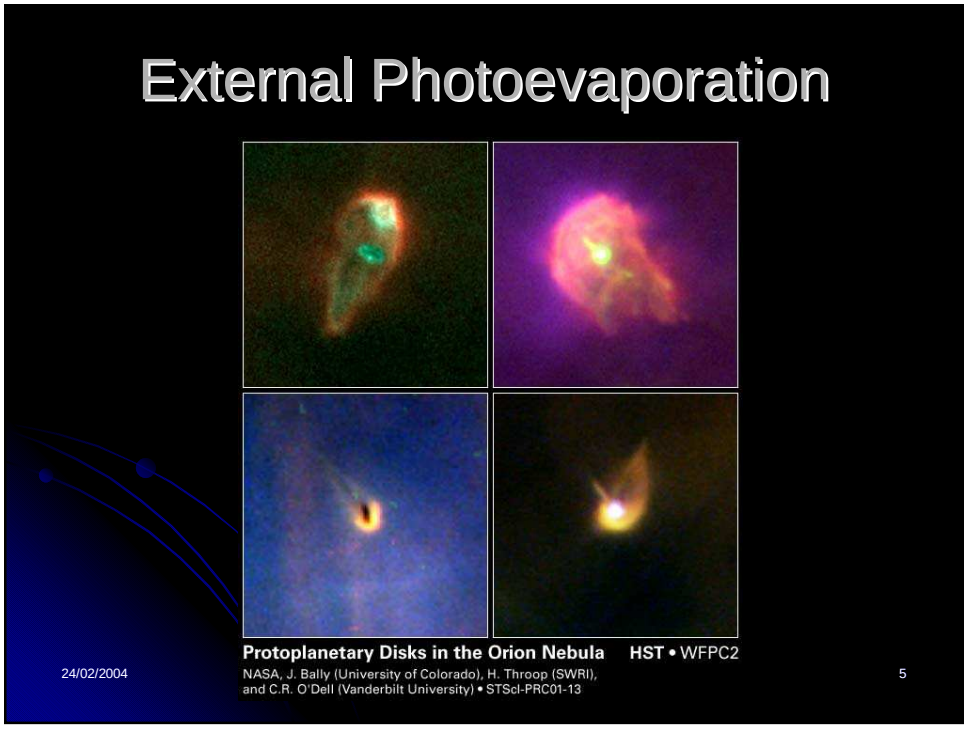
External Photoevaporation
Protoplanetary Disks in the Orion Nebula
HST • WFPC2
NASA, J. Bally (University of Colorado), H. Throop (SWRI),
and C.R. O'Dell (Vanderbilt University) • STScI-PRC01-13
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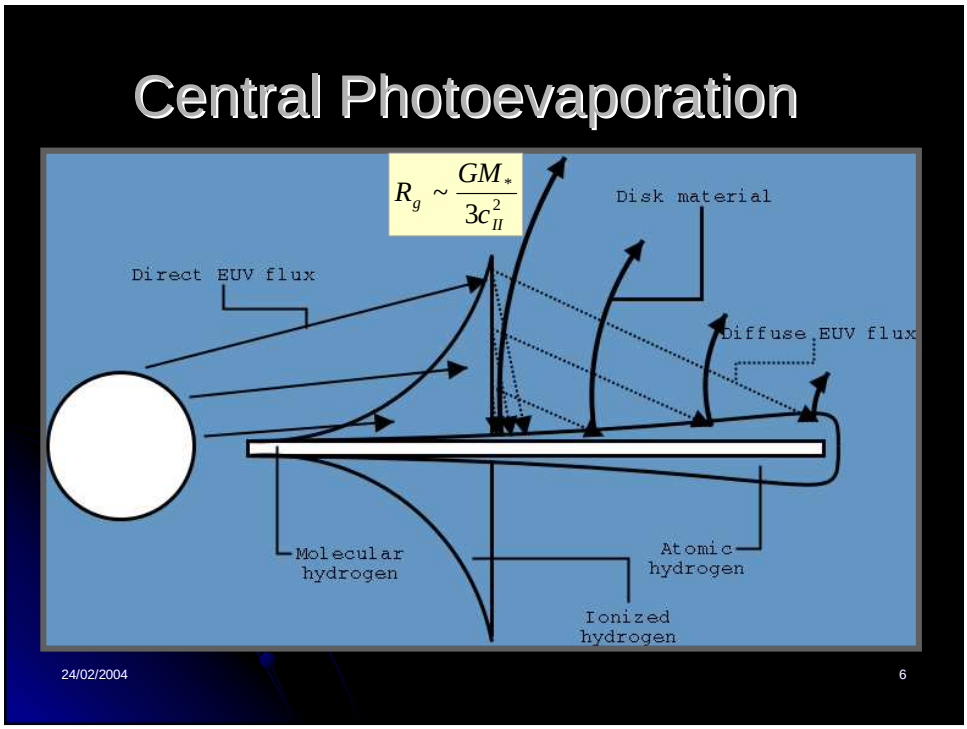
Central Photoevaporation
$R_g \sim \frac{GM_*}{3c_{II}^2}$
Disk material
Direct EUV flux
Diffuse EUV flux
Molecular hydrogen
Atomic hydrogen
Ionized hydrogen
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Gap opening

- When the photo-evaporation time scale approaches the viscous diffusion time scale:

$$\Sigma_{gap} \sim 2gcm^{-2}\left(\frac{\alpha}{10^{-3}}\right)^{-1}\left(\frac{\phi_*}{10^{40}s^{-1}}\right)^{1/2}\left(\frac{R_g}{2.4AU}\right)^{-1}$$

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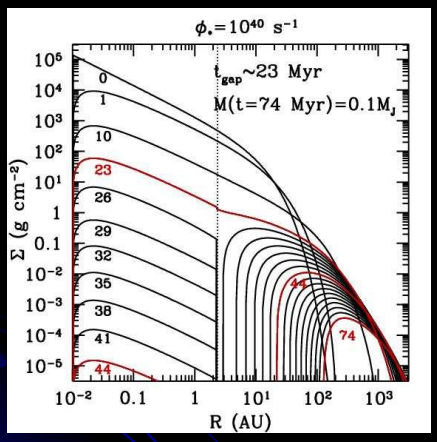
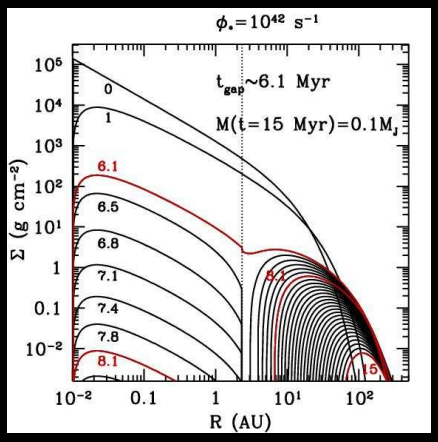
Surface density evolution





$\tau_\nu \sim R^2/\nu \sim R^2/\alpha c_s H \sim R v_K/\alpha c_s^2 \propto R$ $\quad d\Sigma/dt \propto \phi^{1/2}$

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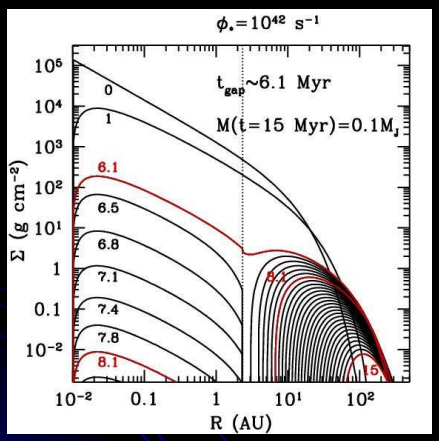
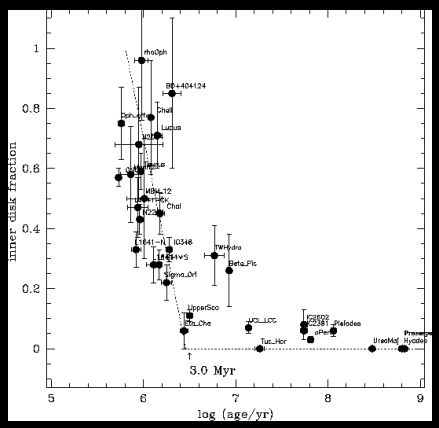
Inner disk life time





Hillenbrand, 2003

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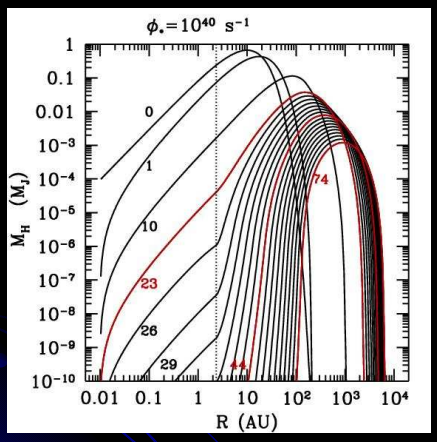
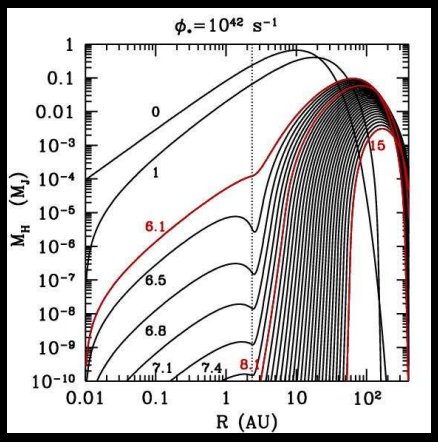
Feeding zone





$$m < m_H = 2\pi\Sigma R(2r_H) = M_*(2\pi\Sigma R^2/M_*)$$

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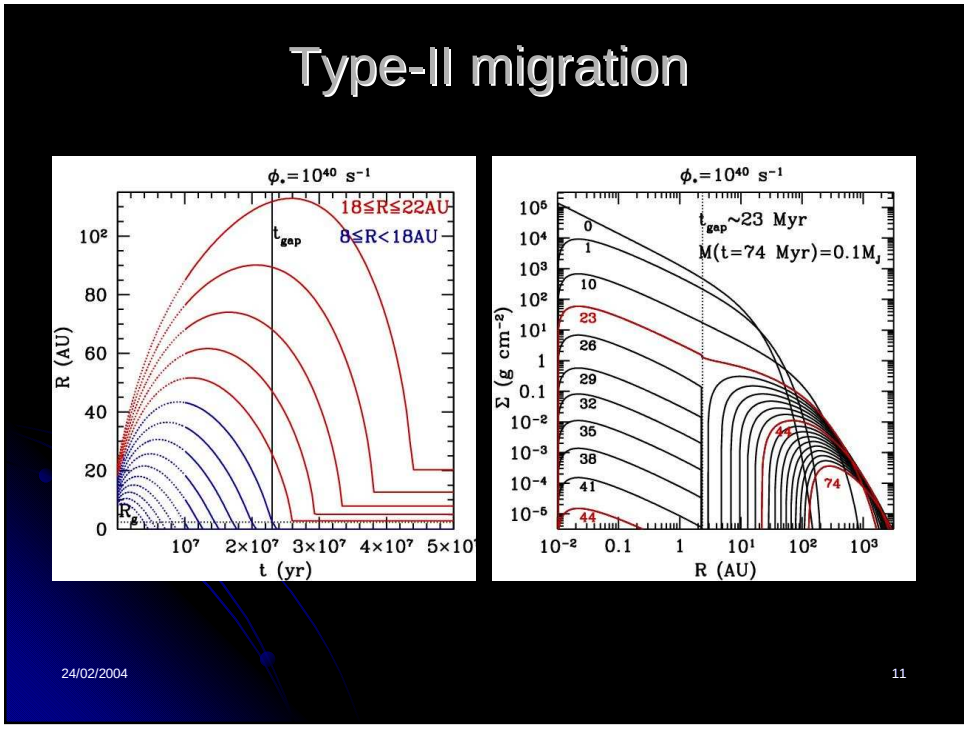
Type-II migration
$\phi_*=10^{40}$ s^{-1}
18≦R≦22AU
8≦R<18AU
t_{gap}
R (AU)
t (yr)
R_g
$\phi_*=10^{40}$ s^{-1}
t_{gap}~23 Myr
M(t=74 Myr)=0.1M_J
Σ (g cm^{-2})
R (AU)
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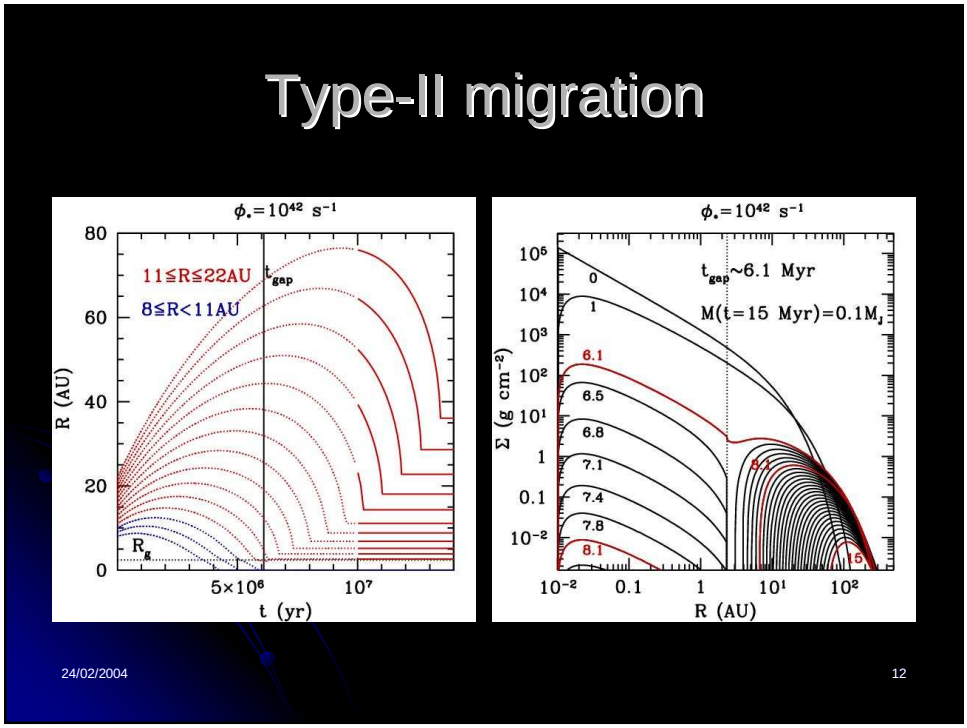
Type-II migration
$\phi_*=10^{42}$ s^{-1}
11≦R≦22AU
8≦R<11AU
t_{gap}
R (AU)
t (yr)
R_g
$\phi_*=10^{42}$ s^{-1}
t_{gap}~6.1 Myr
M(t=15 Myr)=0.1M_J
Σ (g cm^{-2})
R (AU)
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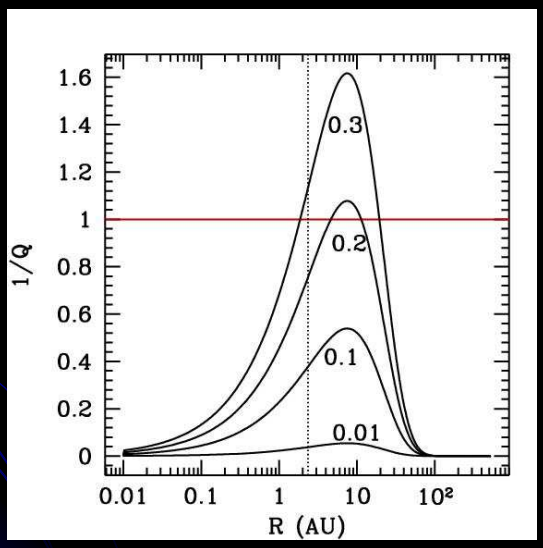
Gas disk instability ?



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Conclusions

- Viscous accretion + photo-evaporation = efficient disk removal mechanism
- It is possible to halt type-II migration at a few AU. However, type-I migration !!
- If the source of EUV emission is independent of accretion (i.e. high EUV stellar flux), it is possible to halt type-II migration at time scales that are consistent with typical inner disk lifetimes (1-5Myr).
- The maximum surface density for gap opening is weakly dependent on the ionizing flux from the central star

For more details: ApJL 2003, 585, 143; ApJ 2003, 582, 893

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Photoevaporation by external stars

Evaporating proplyds: Johnstone et al. 1998

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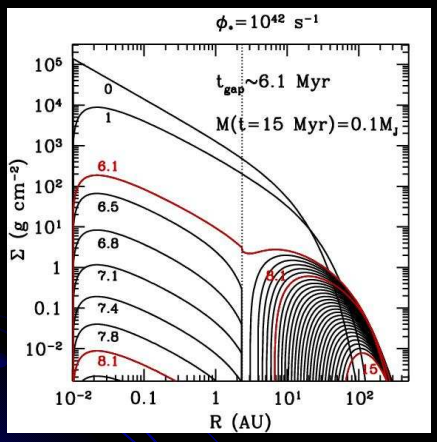
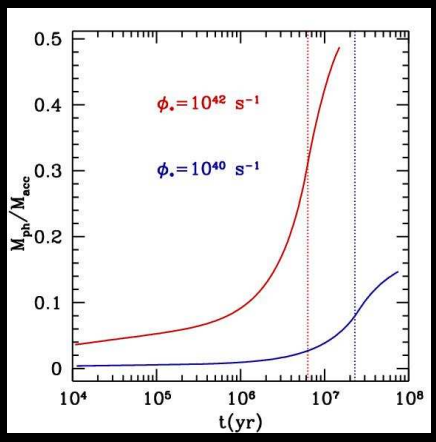
Solid disk stability





Local enhancement of the solid/gas ratio, solid disk instability ? (Youdin & Shu 2002 ApJ, 580; Youdin & Chiang 2004). Disk wind, dust settling time scale

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