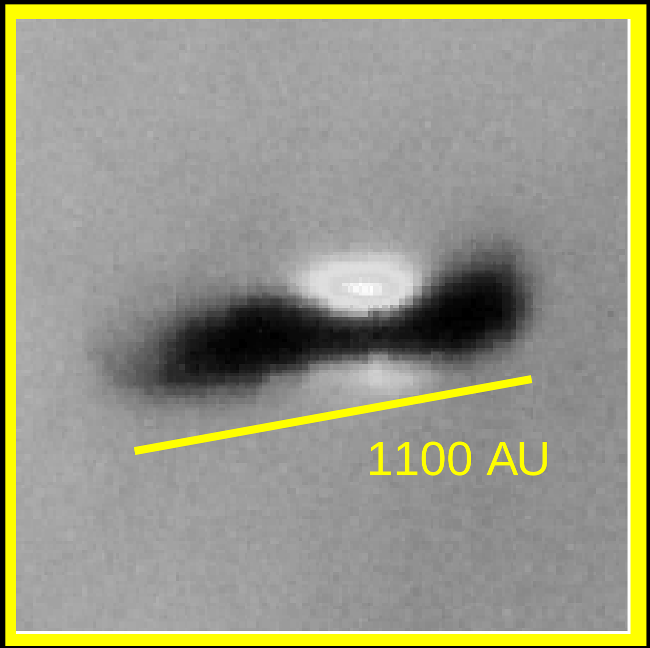
Sandcastles in the Wind: Particle Growth in Externally Illuminated Young Circumstellar Disks

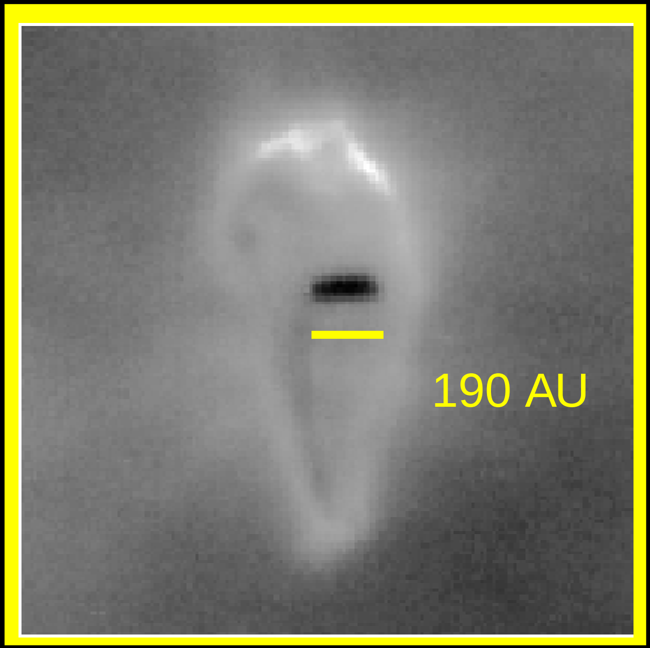
Henry Throop (U. Colorado / LASP)
John Bally (U. Colorado / CASA)
Larry Esposito (U. Colorado / LASP)

January 12, 2000 / AAS Atlanta

Introduction & Observations

HST PC Images in Orion





- Majority of circumstellar disks in Orion are observed to be photoevaporating
- Majority of stars form in Orion-like regions, in externally-illuminated environments
  (e.g., Lada 1998, Hillenbrand et al 1998)
- Disk evolution models have not previously considered UV photoevaporation effects
- Q: **Can we evolve from disk to planets in presence of a strong UV field?**

Disk Evolution Model

We model evolution of grain size distribution in large, young circumstellar disks in Orion under processes of:

Grain Growth

- Grain **coagulation** with collisional velocities of Mizuno *et al* 1988
  - Velocities determined by turbulent convection
  - Fully-sticking particles

Grain Loss

- **Photosputtering**
  - UV photons eject ice molecules, $(dr/dt)_{ice}$ ~ μm/year (Westley et al 1995)
- **Photoevaporation** (Johnstone, Hollenbach, Bally 1998)
  - Heated 10^3 K gas Jeans-escapes disk, entraining small particles in outflow
  - Large particles are safe against entrainment
  - $r_{entrain}$ = 100 μm at 100 AU

- Three-component disk compostion
  - H_2 + silicate + ices; $m_{gas} / m_{dust} = 100$

- Disk is vertically, azimuthally homogeneous

- Turbulence maintained by vertical thermal gradient; shuts off for thermal opacity < 1

$\Sigma \sim R^{-2}$	$R = 10 – 400$ AU	$L_{UV} = 10^5 L_{sun}$	$\alpha = 10^{-2}$
$T \sim R^{-3/2}$	$n(t_0) = n(ISM)$	$D_{UV} = 0.15$ pc	$d = 450$ pc

---

- Observed age of disks ~ 10^{5-6} yr (Hillenbrand et al 1998)
- Observed age of UV source Θ_1 Ori C ~ 10^{4-5} (Bally et al 1998)

- Integrate n(r, R, t) numerically
- Turn on UV source after delay time t_{UV}

Results of Numerical Models

- Outer edges are truncated by loss processes
  - Consistent with steep mass distributions ($\Sigma \sim R^{4\text{-}5}$) observed at outer edge
  - Particle growth is slower at outer edge, $r_{peak} \sim t^2 R^{1/2}$
- Entire gas disk blown away in $t \sim 10^6$ yr

- Ices are depleted at outer edge

- Disk must have 'head start' time of $\sim 10^4$ years to inhibit significant loss at outer edges
- Particles inward of 100 AU grow to > 0.1 mm in 10^4 years and are safe against loss

- High optical depth, fast evolution protects particles inward of 100 AU

- Simultaneous formation of O stars, disk-bearing stars is inconsistent with planet formation in outer edges

Conclusions

- Disks evolution cannot be considered only in isolated environments
  - Majority of solar-type stars may form in OB associations
- UV processes significantly affect disk evolution, and make growth of large particles in large disks difficult
- Steeply-terminated outer disk edges due to photoevaporation are consistent with observations of Orion disks (McCaughrean & O'Dell 1996)
- Timescales are consistent with observations of large particles in Orion disks (Throop et al 1998)
- Timing between the start of coagulation and the onset of photoevaporation is critical to disk survival & evolution