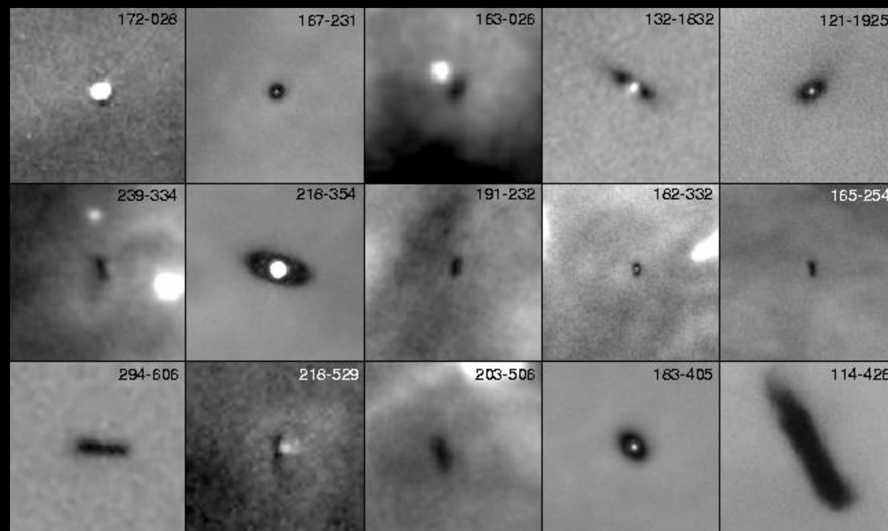
Planetesimal Formation in Dense Star Clusters: Hazard or Haven?



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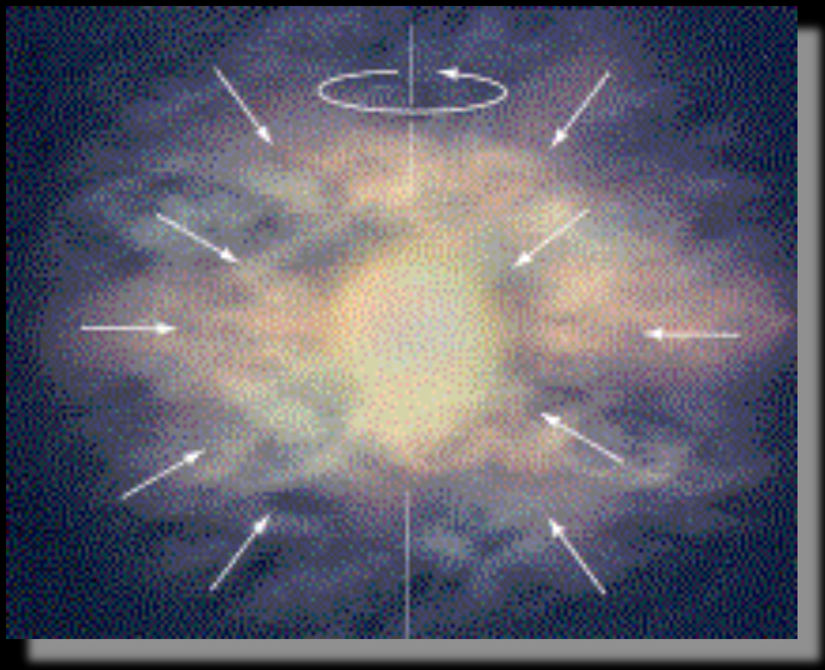
Where Do Most Stars Form?

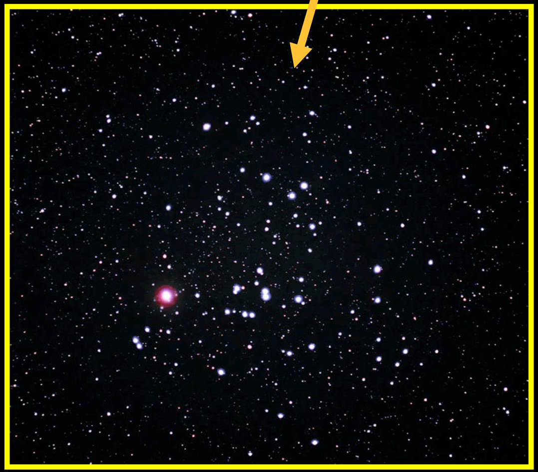
- Mass range of molecular clouds: few $M_{\odot}$– 10^6 $M_{\odot}$
- Mass spectrum of molecular clouds: $dn/dM \sim M^{-1.6}$

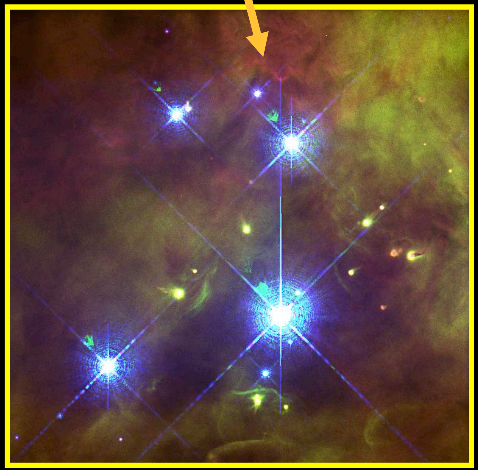
➔ Most of the mass is in the largest GMCs



Regions of Star Formation

	Open Clusters	Dense Clusters
# of stars	10^1 - 10^3	10^3 - 10^4 10^4 stars in last 10 Myr (Orion)
OB stars	No	Yes
Distance	140 pc (Taurus)	450 pc (Orion)
Fraction of local stars which form here	10-30%	70-90%? (Lada and Lada 2003)
Dispersal lifetime		10 Myr (SN)
% of stars with disks		80%? (Smith et al 2005)



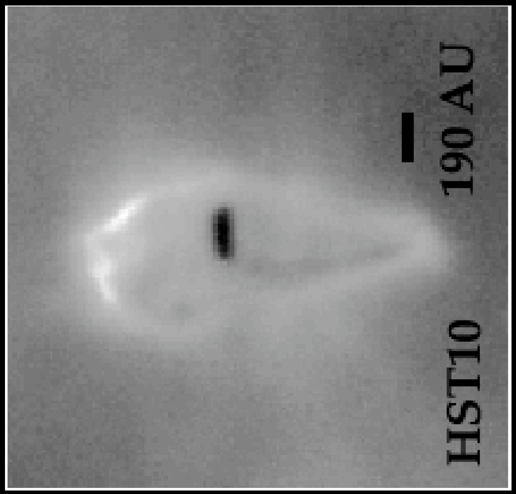


How does Cluster Environment affect Disk Evolution?

- Photoevaporation from external, massive stars
  - 10^5 L_{sun} from O stars at cluster core
  - F ~ 10^4 - 10^6 G_0
  - Truncates disks on Myr timescales
- Close stellar encounters
  - 2,000 stars in 0.5 pc^3
  - Mean stellar separations ~ 10,000 AU
- Interaction with GMC gas
  - Bondi-Hoyle accretion onto stars?
- UV, X ray chemistry
  - Total UV dose is thousands of ionizing photons per (dust) molecule, in first 10 Myr.

Photo-Evaporation (PE)

- FUV/EUV flux from O stars heats and removes H_2 / H from disks.
  - Small dust grains can be entrained in outflow and removed.
- Mass loss rates:
  $dM/dt \sim 10^{-6} - 10^{-8}\ M_{sun}/yr$.
  (Johnstone et al 1998)
- Mass loss rate depends on disk size, distance from external O star.
- MMSN disks surrounding most Orion stars can be truncated to a few AU in Myr.
  - Dust in disks can be retained: sharp outer edge with large grains (Throop et al 2001)
- If you want to build Jupiter in Orion, you must make it fast ! (e.g., Boss)



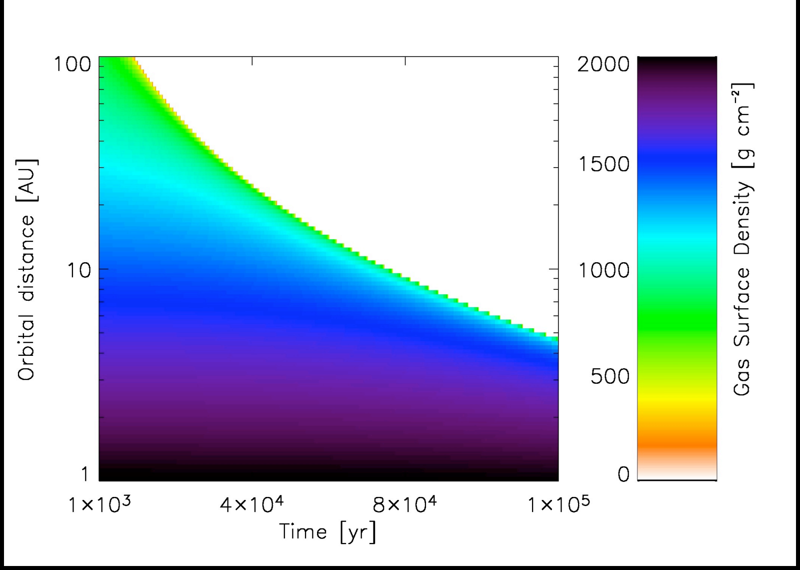
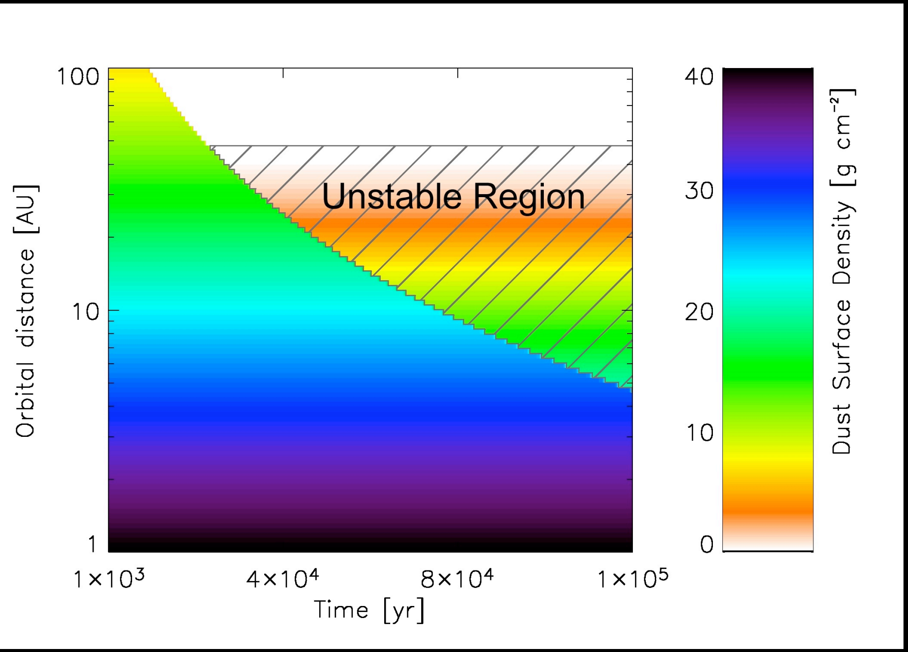


Photo-evaporation is a major hazard to planet formation…

… but all hope is not yet lost!

Photo-Evaporation Triggered Instability

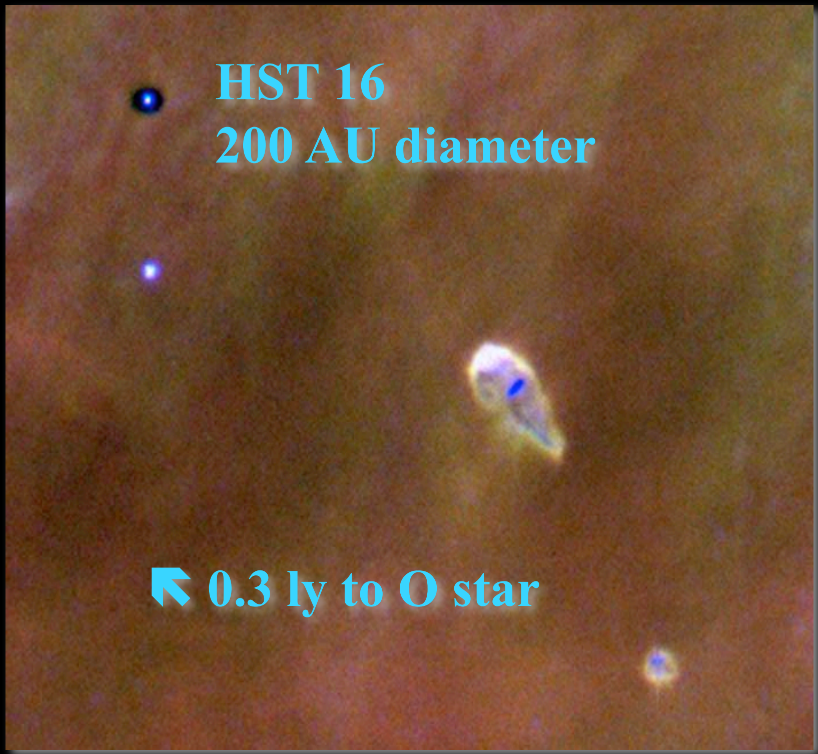
- Gravitational collapse of dust in disk can occur if sufficiently low gas:dust ratio (Sekiya 1997; Youdin & Shu 2004)
  - $\Sigma_g / \Sigma_d < 10$
  - (I.e., reduction by 10x of original gas mass)
- PE removes gas and leaves most dust
  - Grain growth and settling promote this further
- Dust disk collapse provides a rapid path to planetesimal formation, without requiring particle sticking.



Throop & Bally 2005

Close Approaches

- Typical distances today ~ 10,000 AU
- C/A strips disks to 1/3 the closest-approach distances (Hall et al 1996)
- Question: What is the minimum C/A distance a disk encounters as it moves through the cluster for several Myr?



N-Body Dense-Cluster Simulations

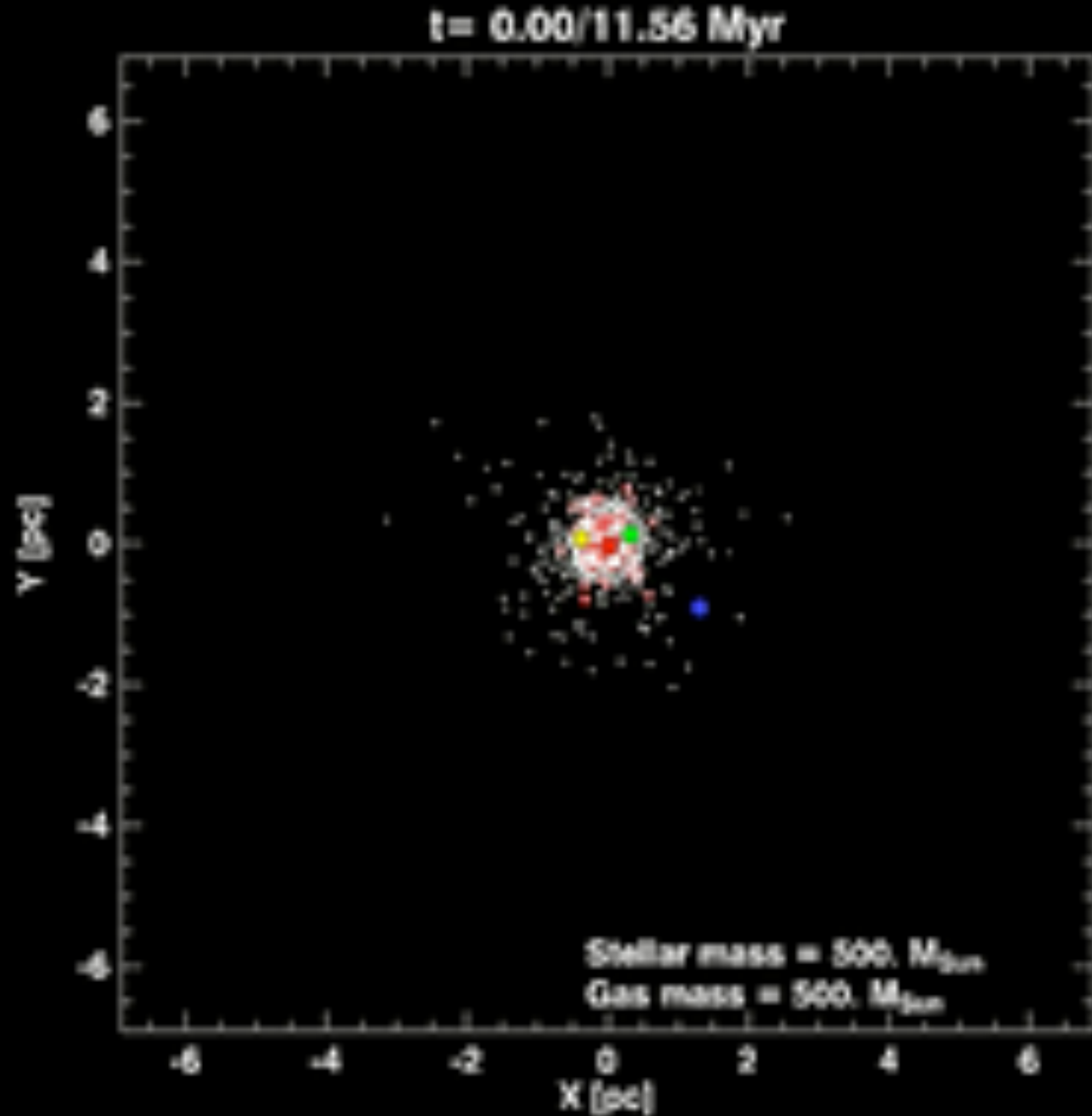
NBODY6 code (Aarseth 2003)

Stars:

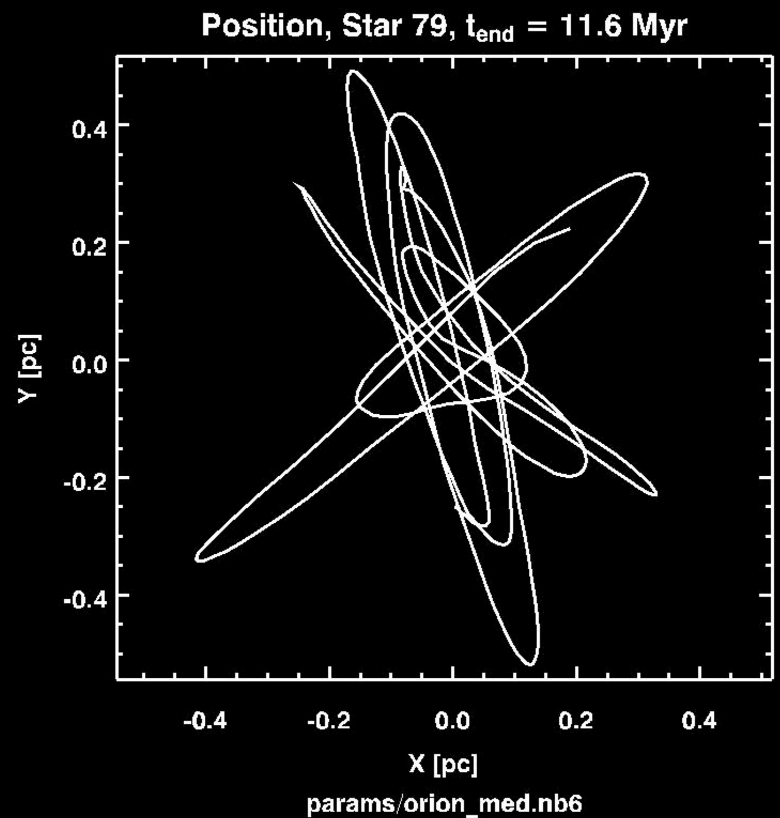
- N=1000
- M_{star} = 500 M_{sun}
- Salpeter IMF
- R_0 = 0.5 pc
- O6 star fixed at center

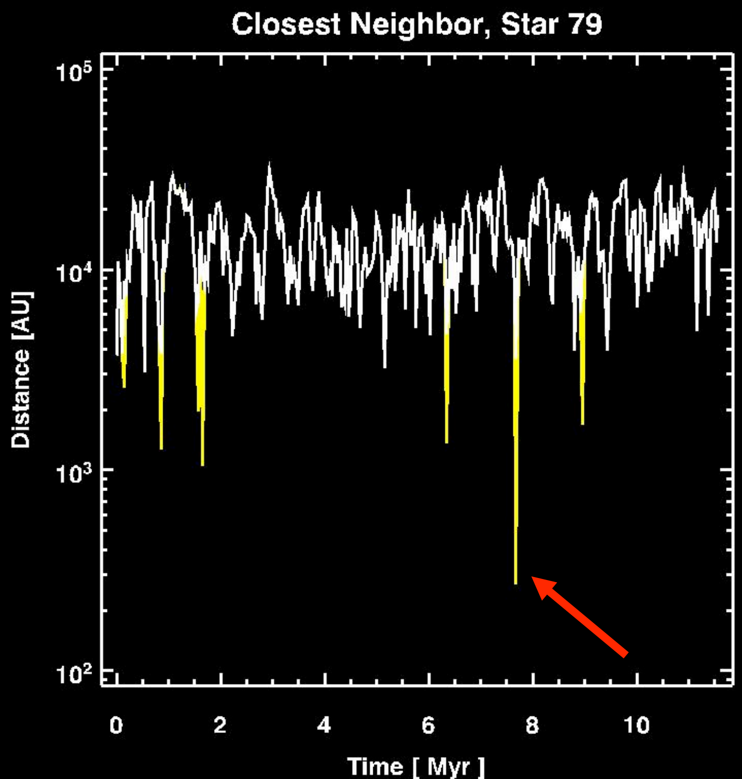
Gas:

- M_{gas} = 500 M_{sun}
- R_0 = 0.5 pc
- Disperses with timescale 2 Myr



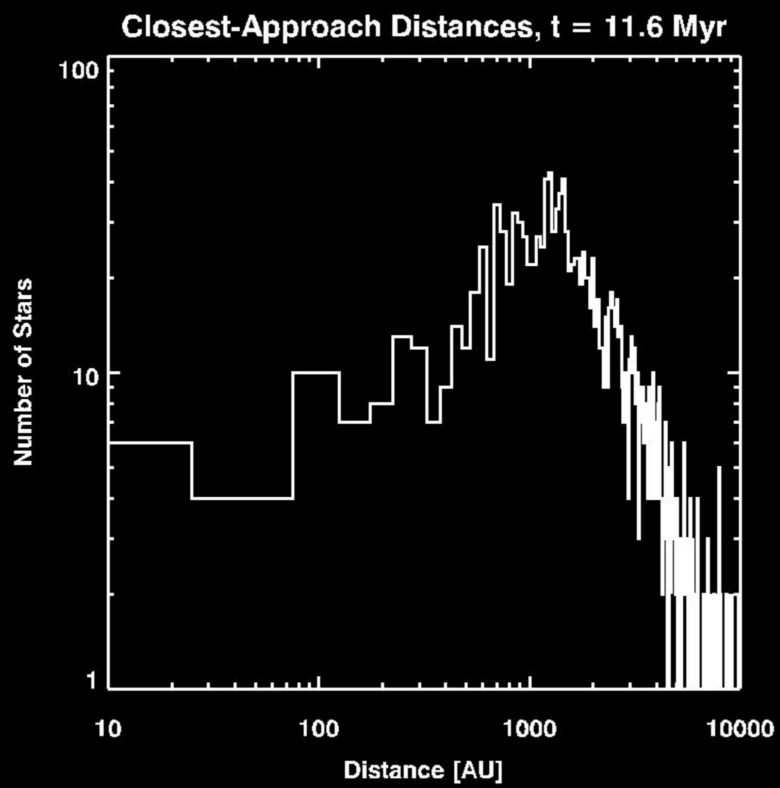
Close Approach History - Typical 1 M_{SUN} Star

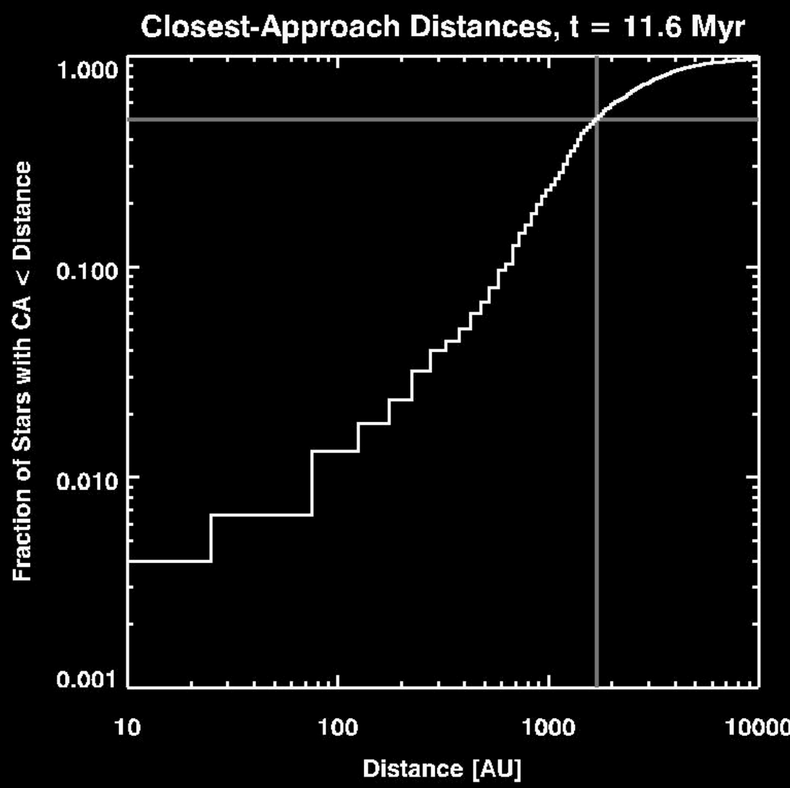




- Star has 5 close approaches at < 2000 AU.
- Closest encounter is 300 AU at 8 Myr
  - Too late to do any damage

Close Approaches - Entire Cluster

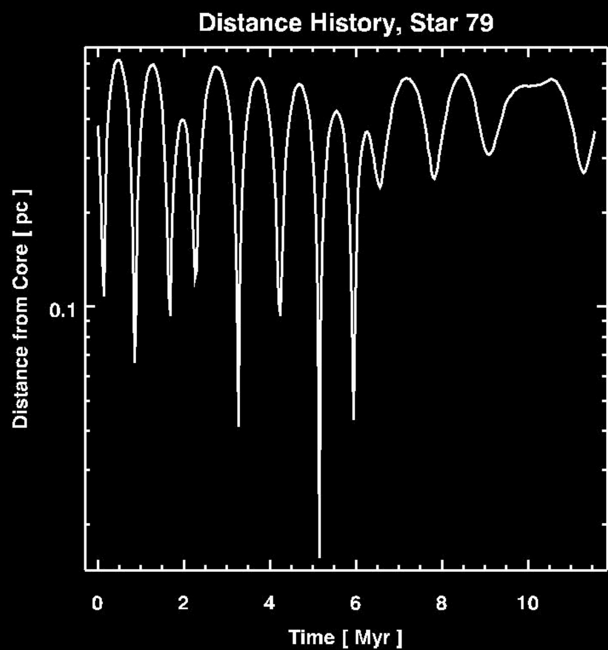


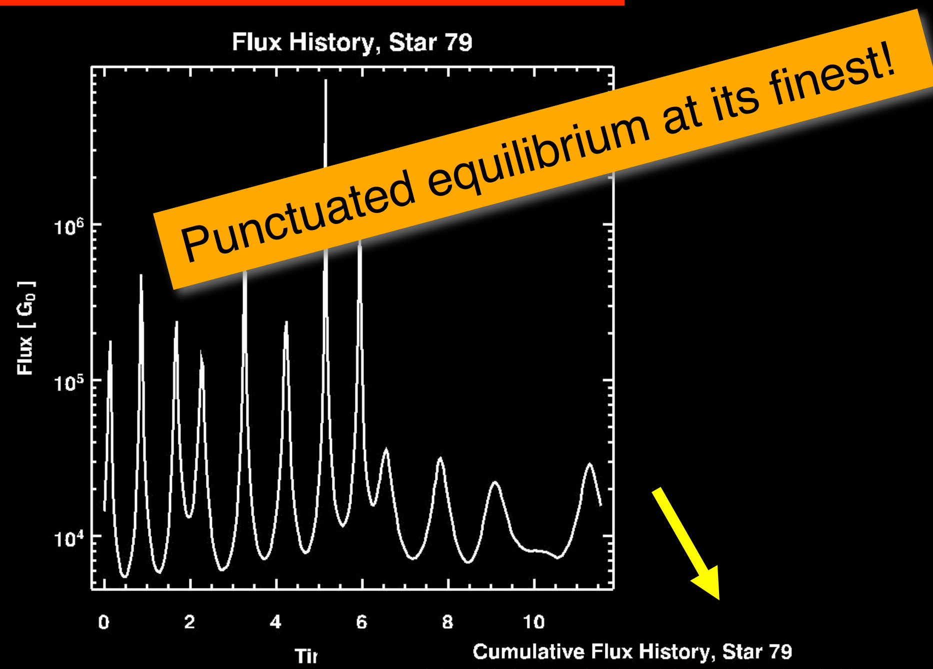


- Typical minimum C/A distance is 1100 AU in 10 Myr
- Significant disk truncation in dense clusters is rare!
  - Only 1% of disks are truncated to 30 AU, inhibiting planet formation

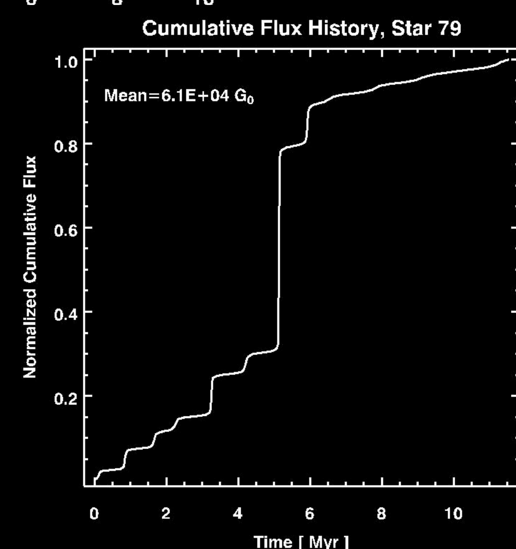
Throop & Bally 2006, in prep

Flux History, Typical 1 M_{SUN} Star





- Flux received by disk varies by 1000x as it moves through the GMC.
- Peak flux approaches 10^7 G_0.
- Most of the flux is deposited during brief but intense close encounters with core.
- There is no `typical UV flux.'
- Disk evolution models assume steady, uniform grain growth, PE, viscous spreading. But if PE is not steady, then other processes dominate and may dramatically change the disk.



What do we know?

- Large fraction of stars forming today are near OB associations, not in open clusters
- PE can rapidly destroy disks
  - Hard to make Jovian planets
- PE can also trigger rapid planetesimal formation
  - Easy to make planetary cores
- Close encounters are unimportant

Where do we go?

- Need better understanding of effect of time-variable PE on disk evolution
- Need better understanding of role of gravitational instabilities: how frequent is it?
- UV, X-ray chemistry in dense clusters unexplored