Time Variable Photo-Evaporation of Protoplanetary Disks

Henry Throop (SwRI)

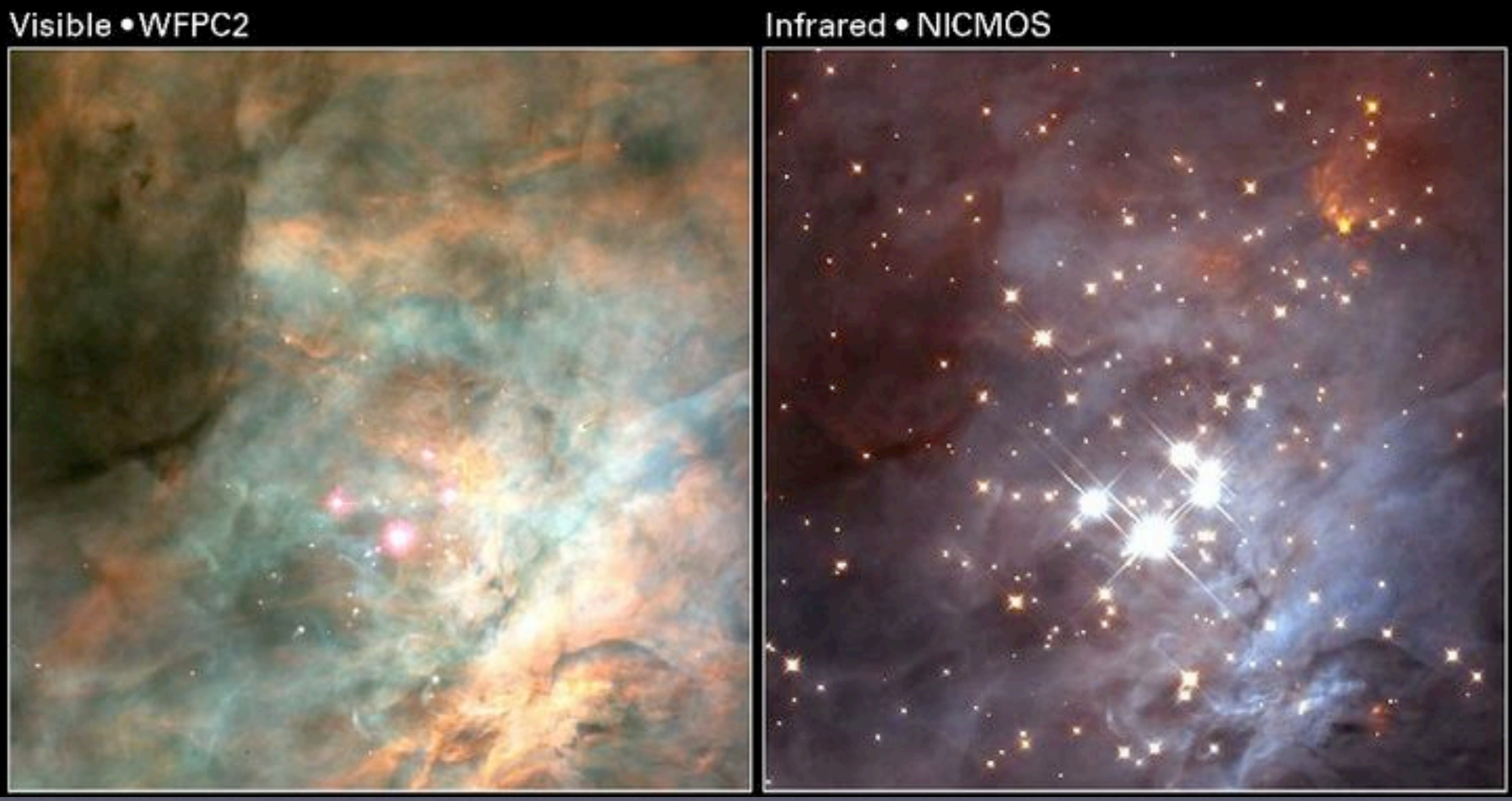
John Bally (U. Colorado)

Takeaway: Photo-evaporation alters the disk structure in essentially unpredictable ways, because it is controlled by motions of thousands of stars. This makes for a great diversity of disk masses and sizes, even for disks formed at the same time in the same cluster.

Photo-evaporation controls disk structure in large clusters, where nearly all stars form.

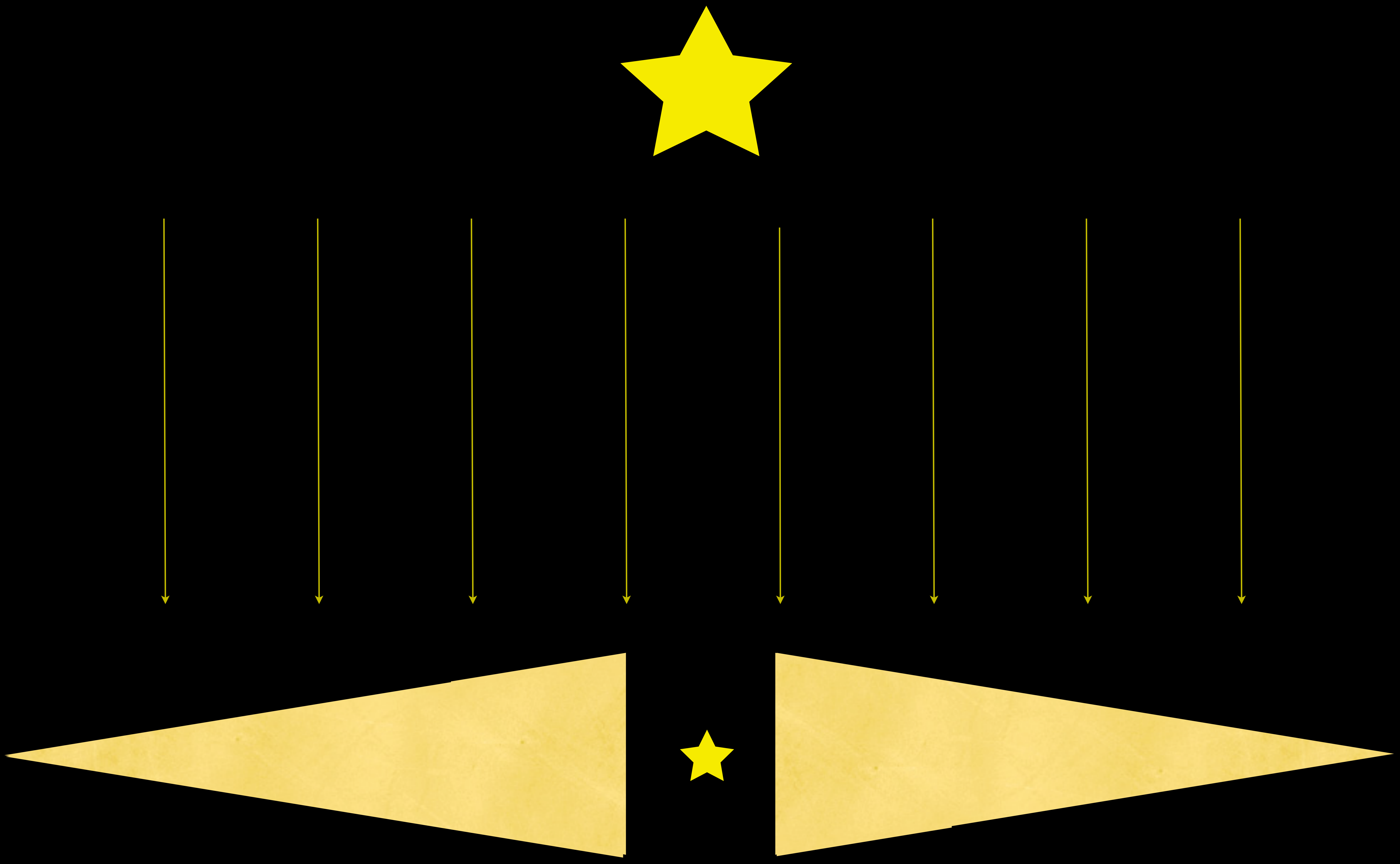
30 Doradus: 100+ O/B stars

Photo-evaporation controls disk structure in large clusters, where nearly all stars form.



Orion Trapezium: 7 O/B stars

Photo-evaporation from external O stars removes disks in 10^5-10^6 years.



Disk Photo-Evaporation

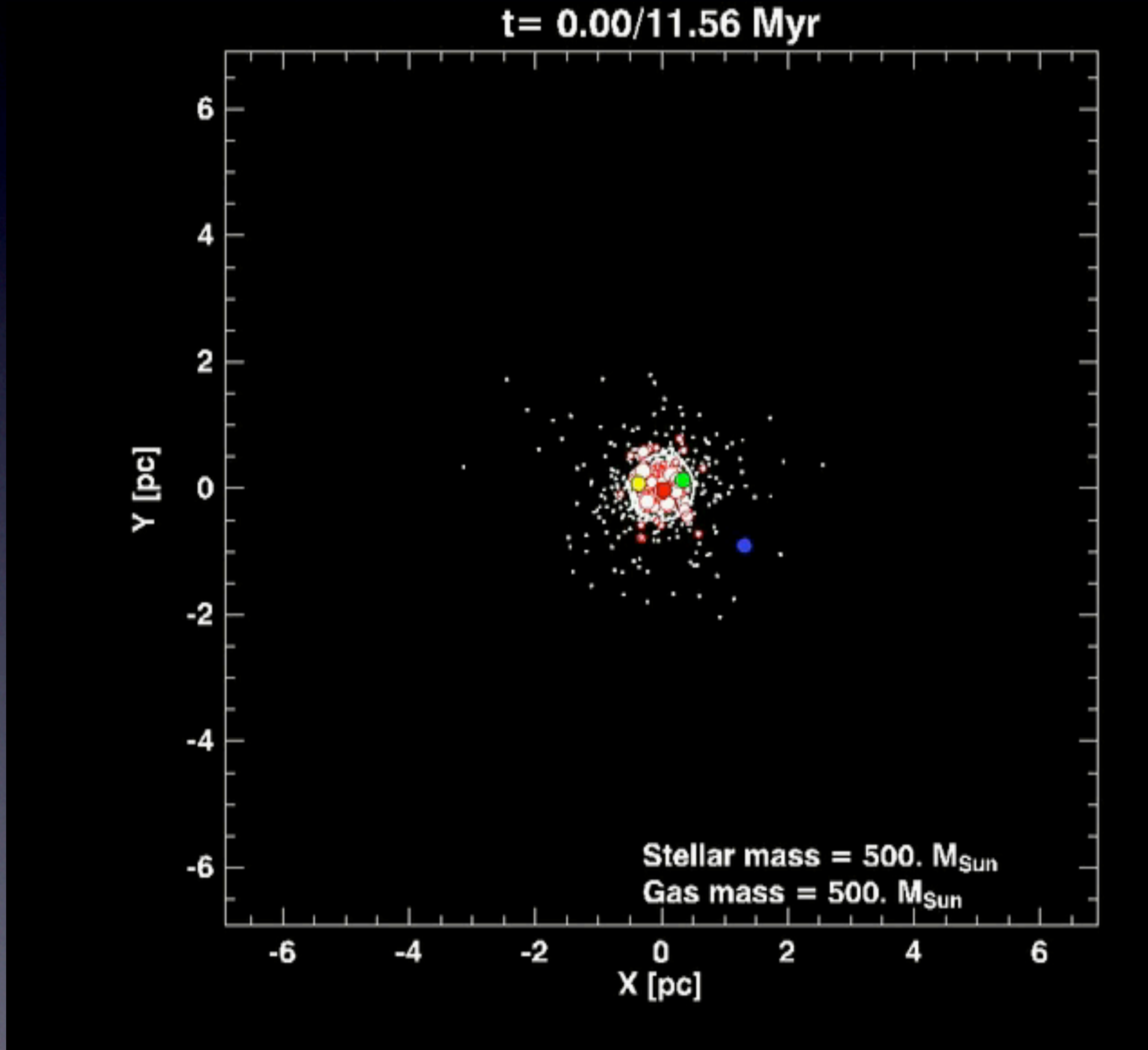
Mass loss rate from disk: $\frac{dM}{dt} = 4\pi\, r_d^2\, v_0\, n_0\, m_H$

Disk surface gas density	n_0
Gas velocity	$v_0 \sim T^{1/2} \sim (F_{\mathrm{UV}})^{1/2} \sim R$
Gas mass	m_h
Disk radius	r_d
Distance from O star	R

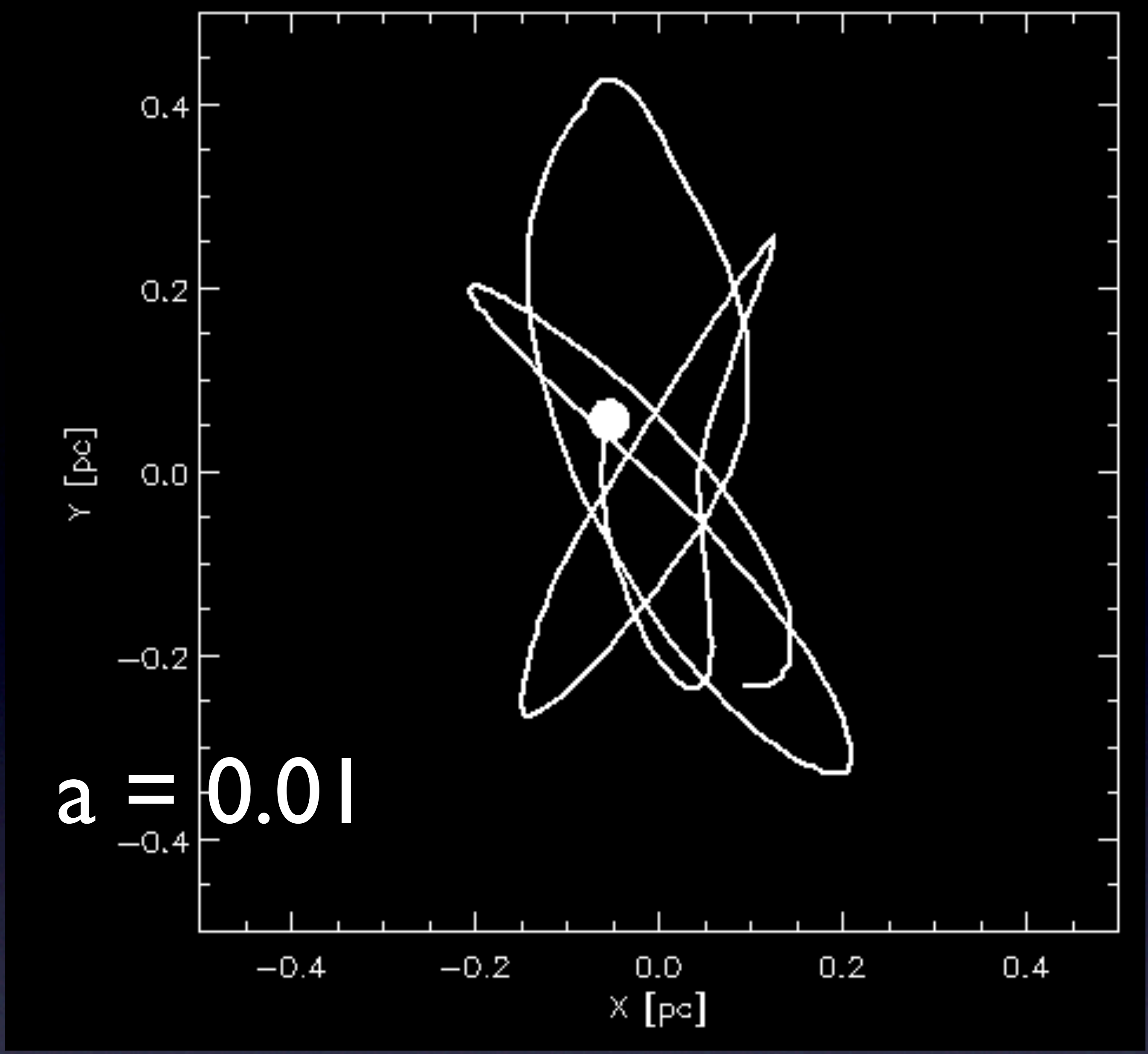
Virtually all previous PE models assume static stellar positions: *R* ~ 0.1 pc ~ 20,000 AU.

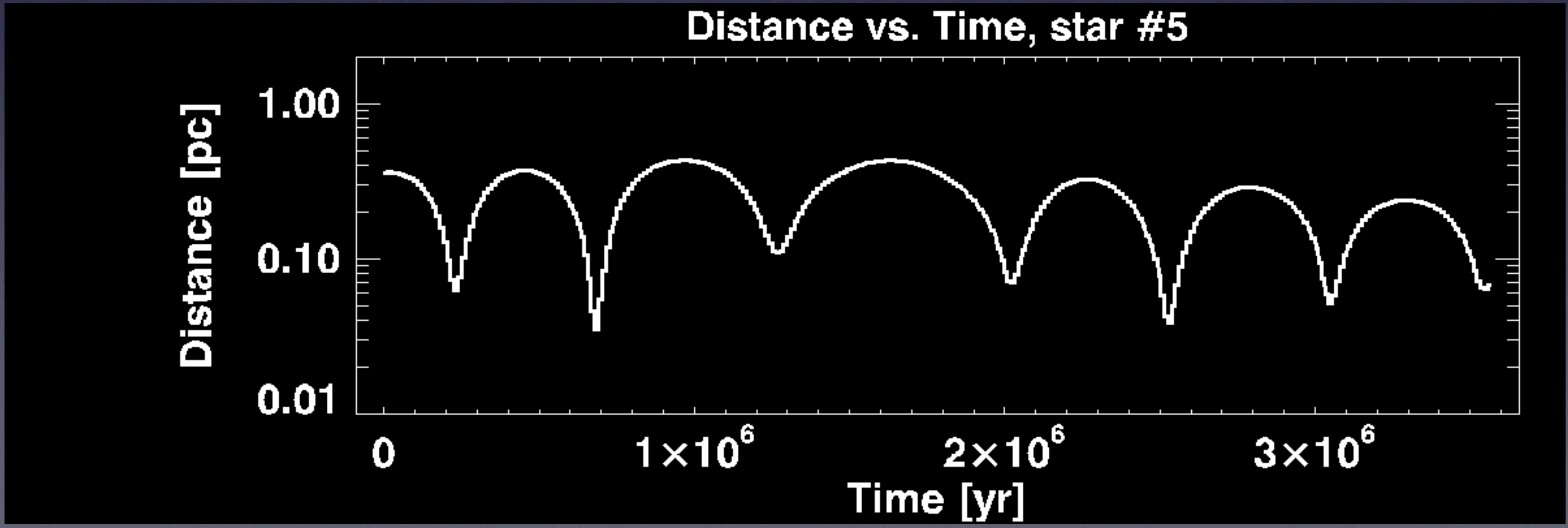
But we know that stars move quickly, with many cluster crossings in first several Myr.

We performed N-body simulations to look at how distance between disks and external O star changes over few Myr.



N-body sims track individual history of one solar-mass star in Orion-like cluster.

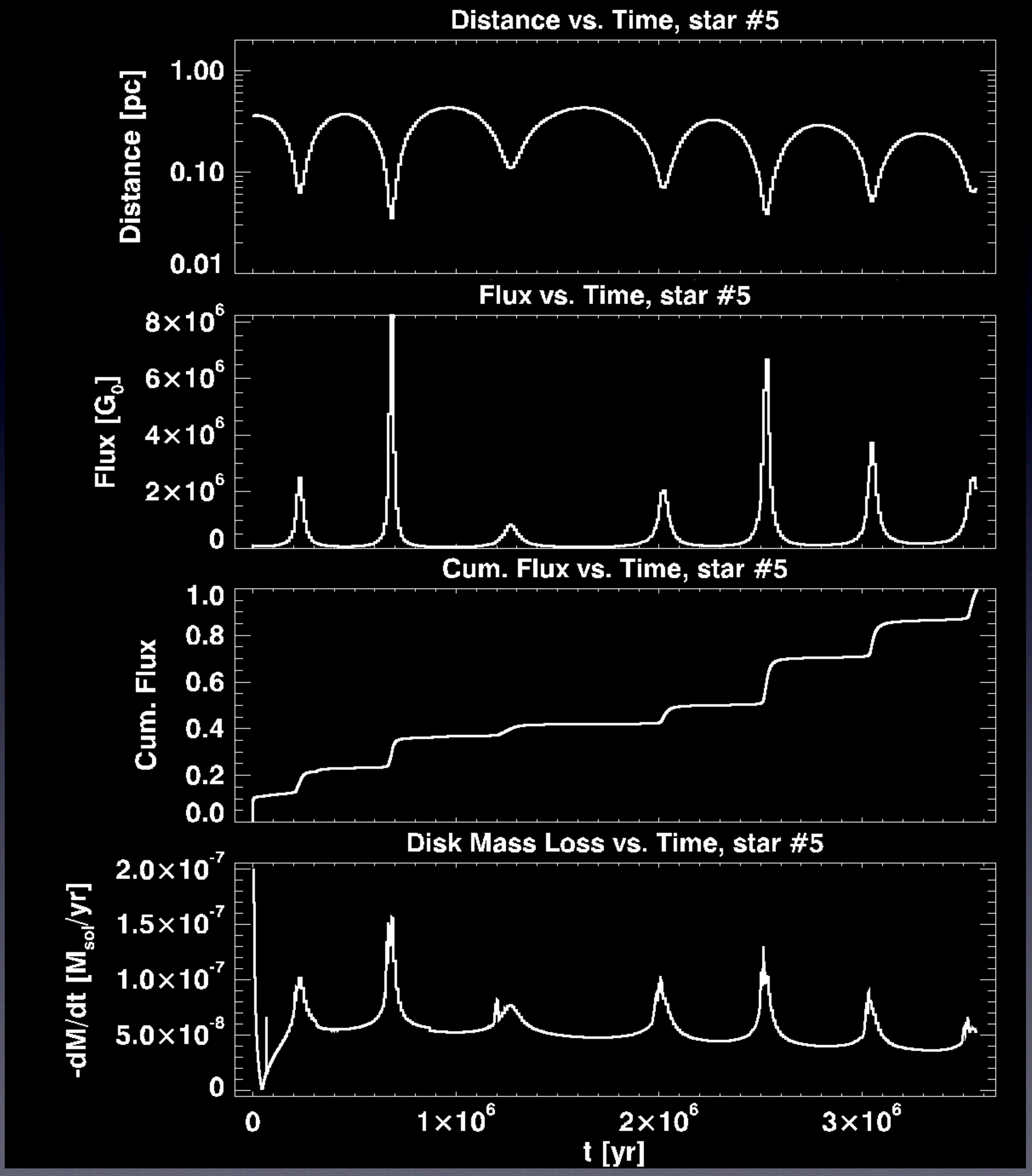


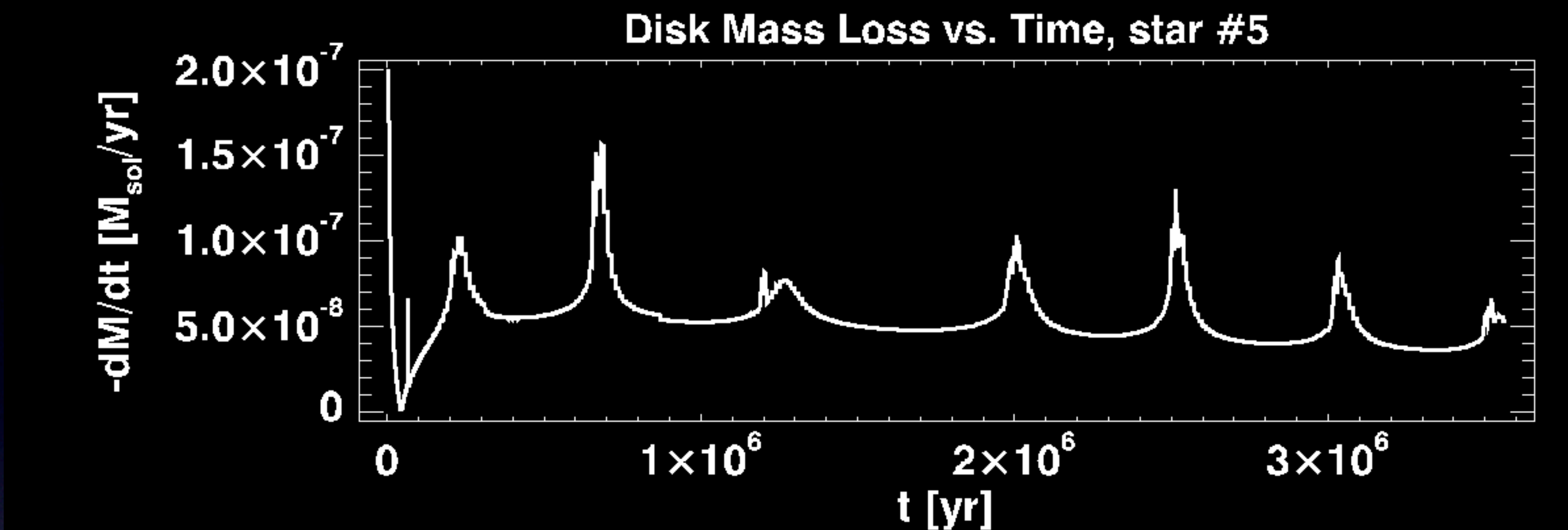


N-body sims track individual history of one solar-mass star in Orion-like cluster.

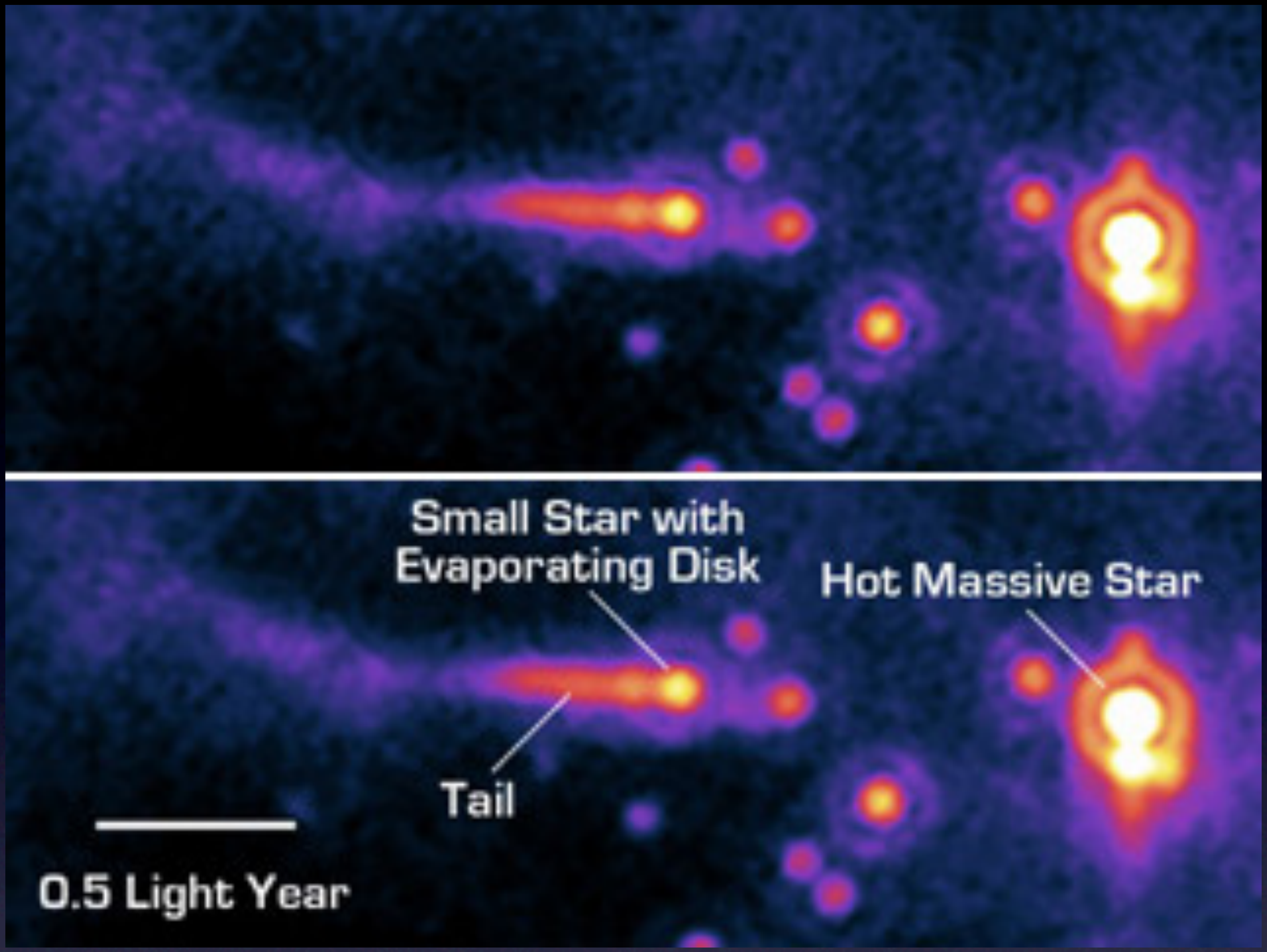
We couple N-body sims, PE, and a viscous disk evolution model:

$M_d = 0.05\ M_\odot$
$r_d = 100$ AU
$\Sigma = -3/2$
$\alpha = 0.01$

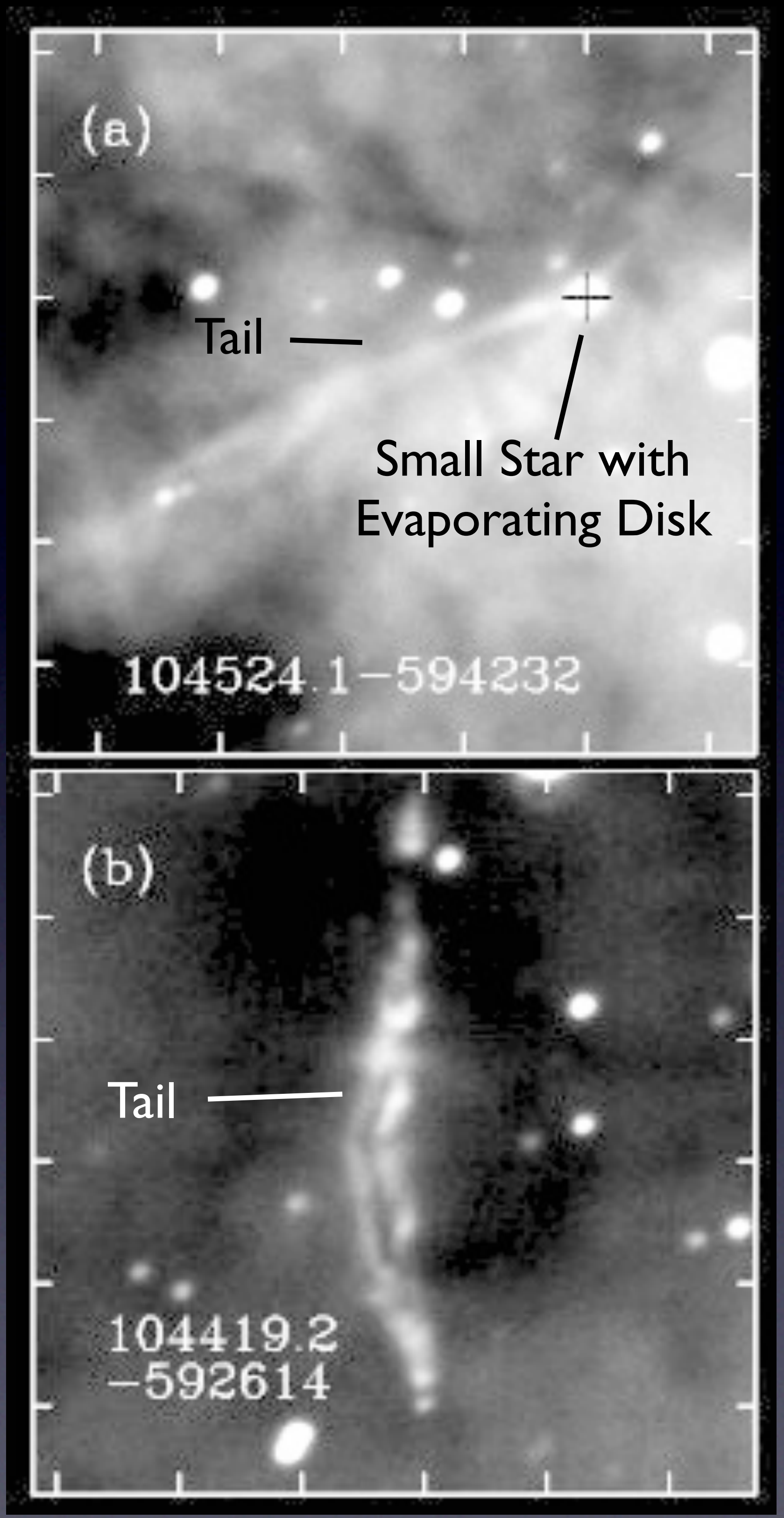




- Photo-evaporation is highly episodic.
- 90% of the UV flux is deposited during 10% of the time.
- Real clusters will have more variability: more O stars, stellar evolution, ISM structure, disk structure, etc.
- Variability causes a diversity of disk structures and masses, *even for disks of the same age and composition formed in the same cluster.*



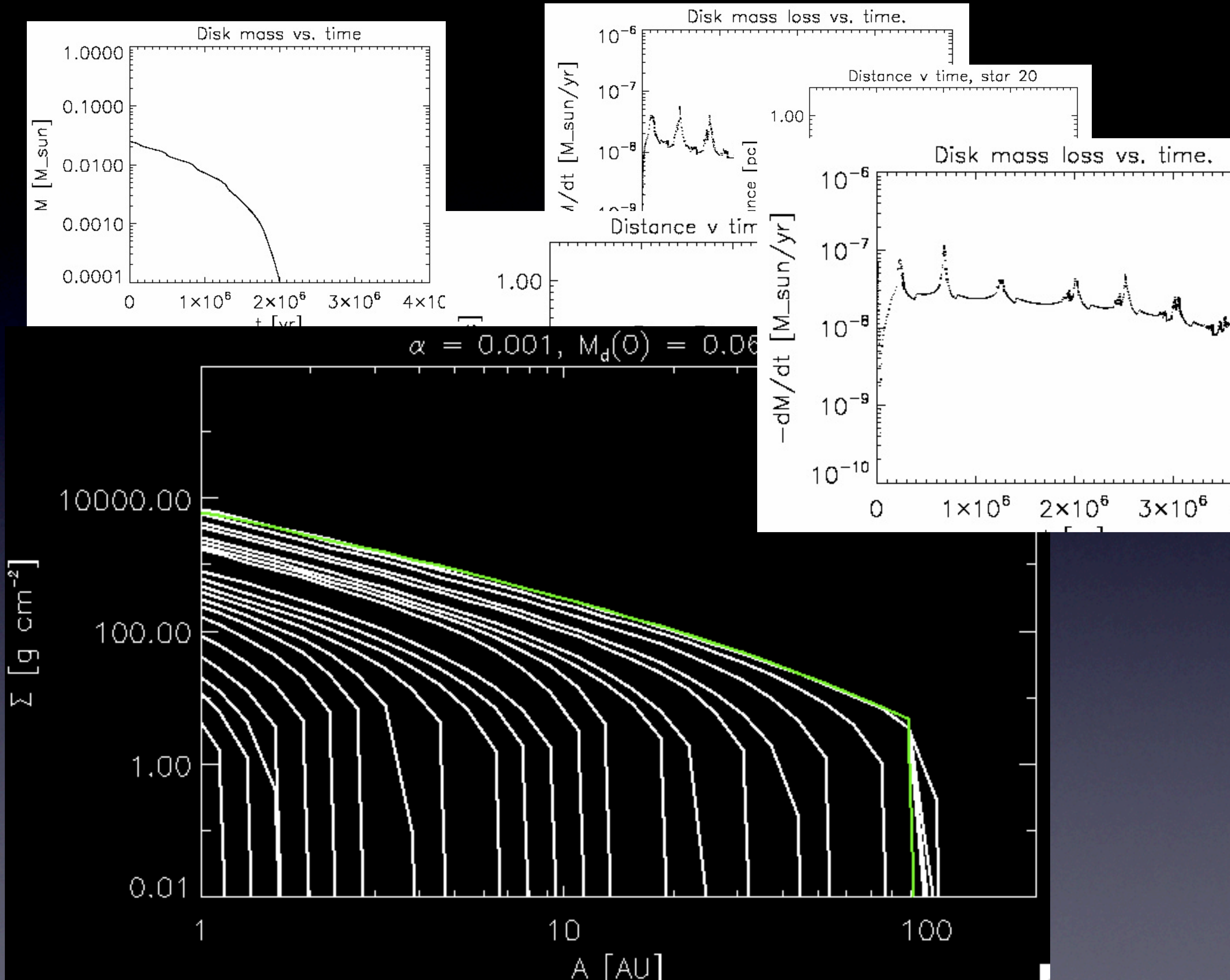
Balog et al. 2007, IC 1396 (Spitzer)



Smith et al 2003; η Carina

Dust tails from observed proplyds show clumpiness that is likely due to time-variable photo-evaporation.

Backup Slides



Disk mass vs. time
M [M_sun]
1.0000
0.1000
0.0100
0.0010
0.0001
0
1×10^6
2×10^6
3×10^6
Disk mass loss vs. time.
Distance v time, star 20
1.00
Disk mass loss vs. time.
-dM/dt [M_sun/yr]
10^-6
10^-7
10^-8
10^-9
10^-10
0
1×10^6
2×10^6
3×10^6
α = 0.001, M_d(0) = 0.06
Σ [g cm^-2]
10000.00
100.00
1.00
0.01
1
10
100
A [AU]