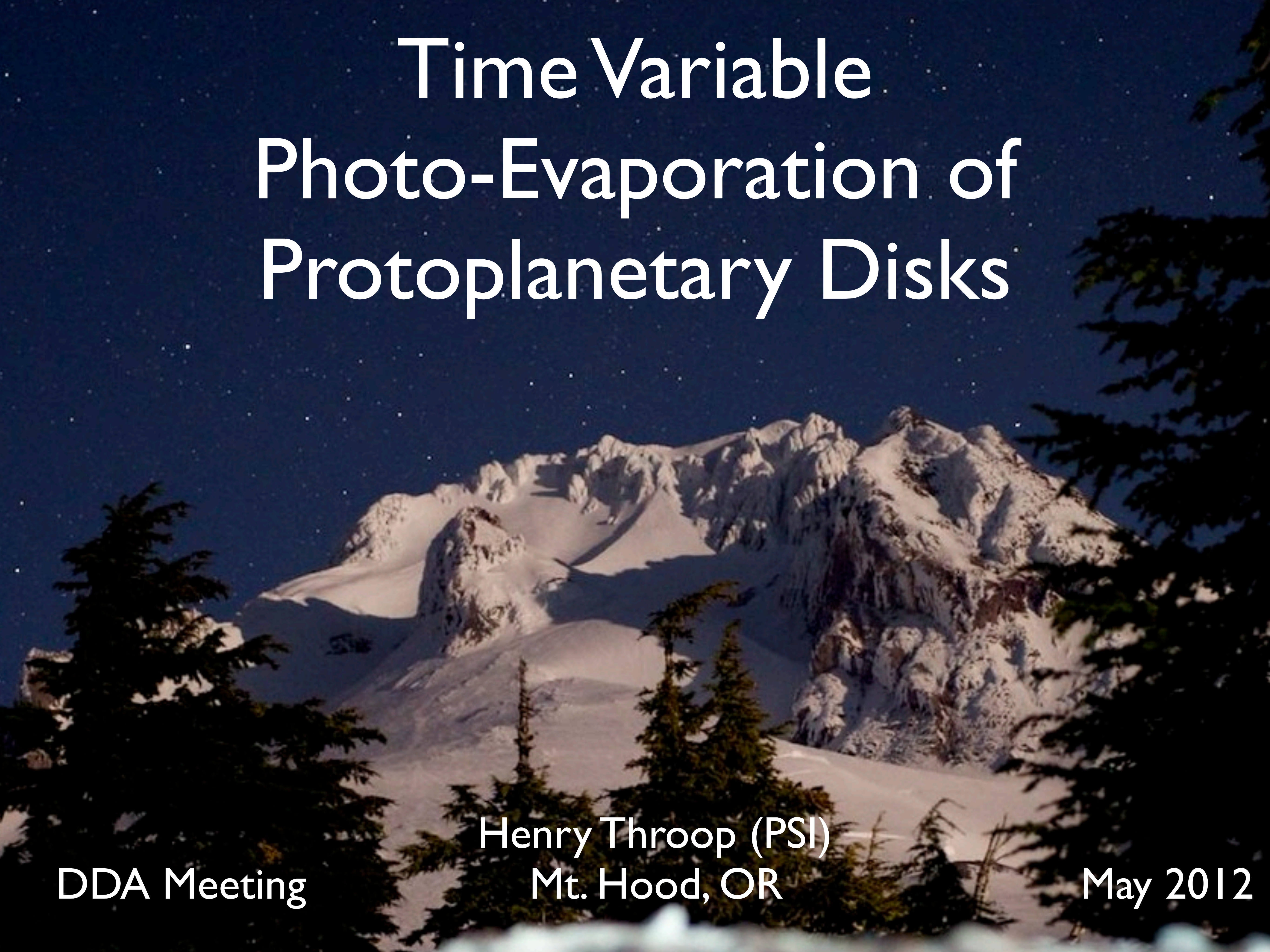
Time Variable Photo-Evaporation of Protoplanetary Disks



Henry Throop (PSI)

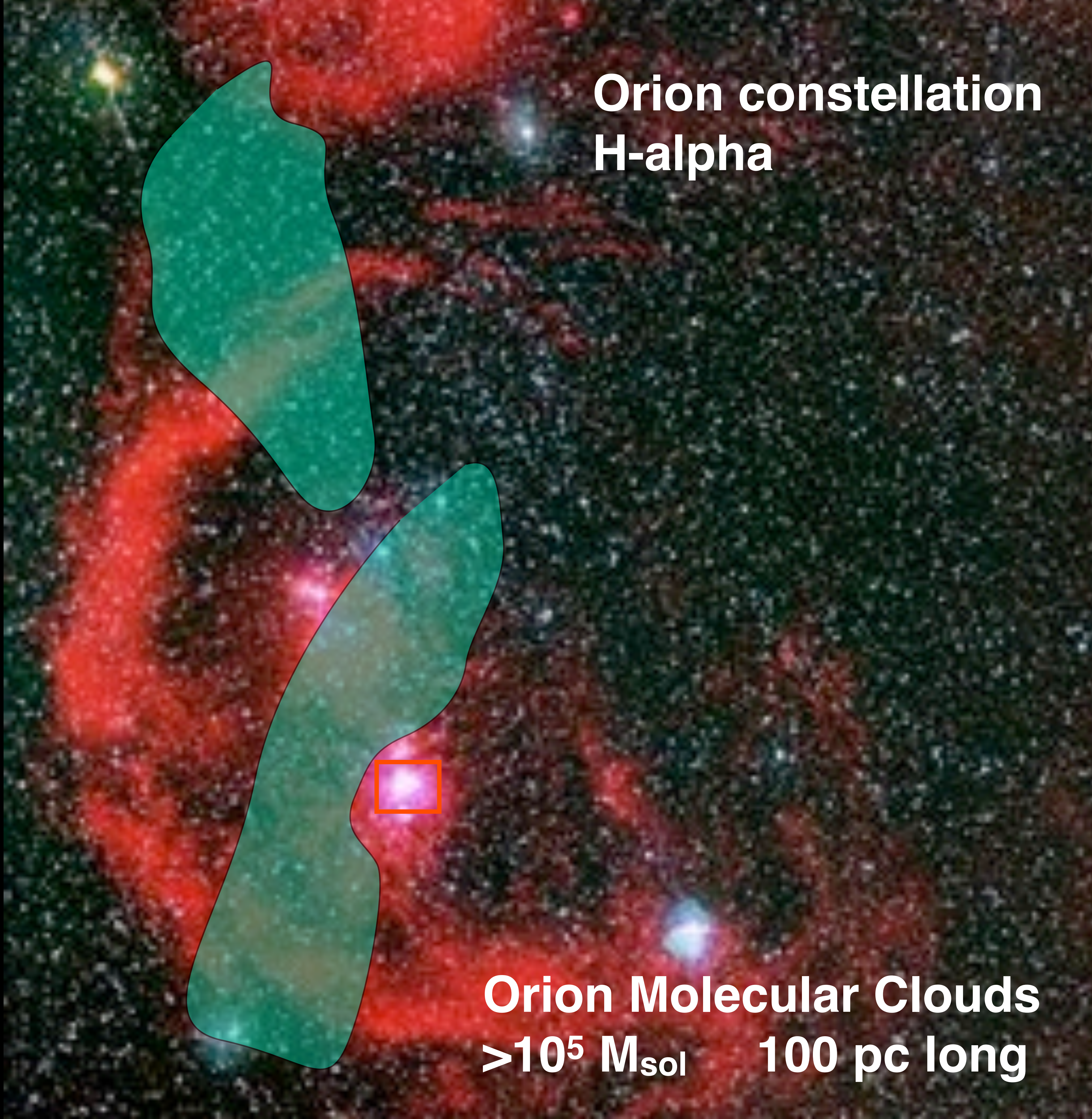
DDA Meeting

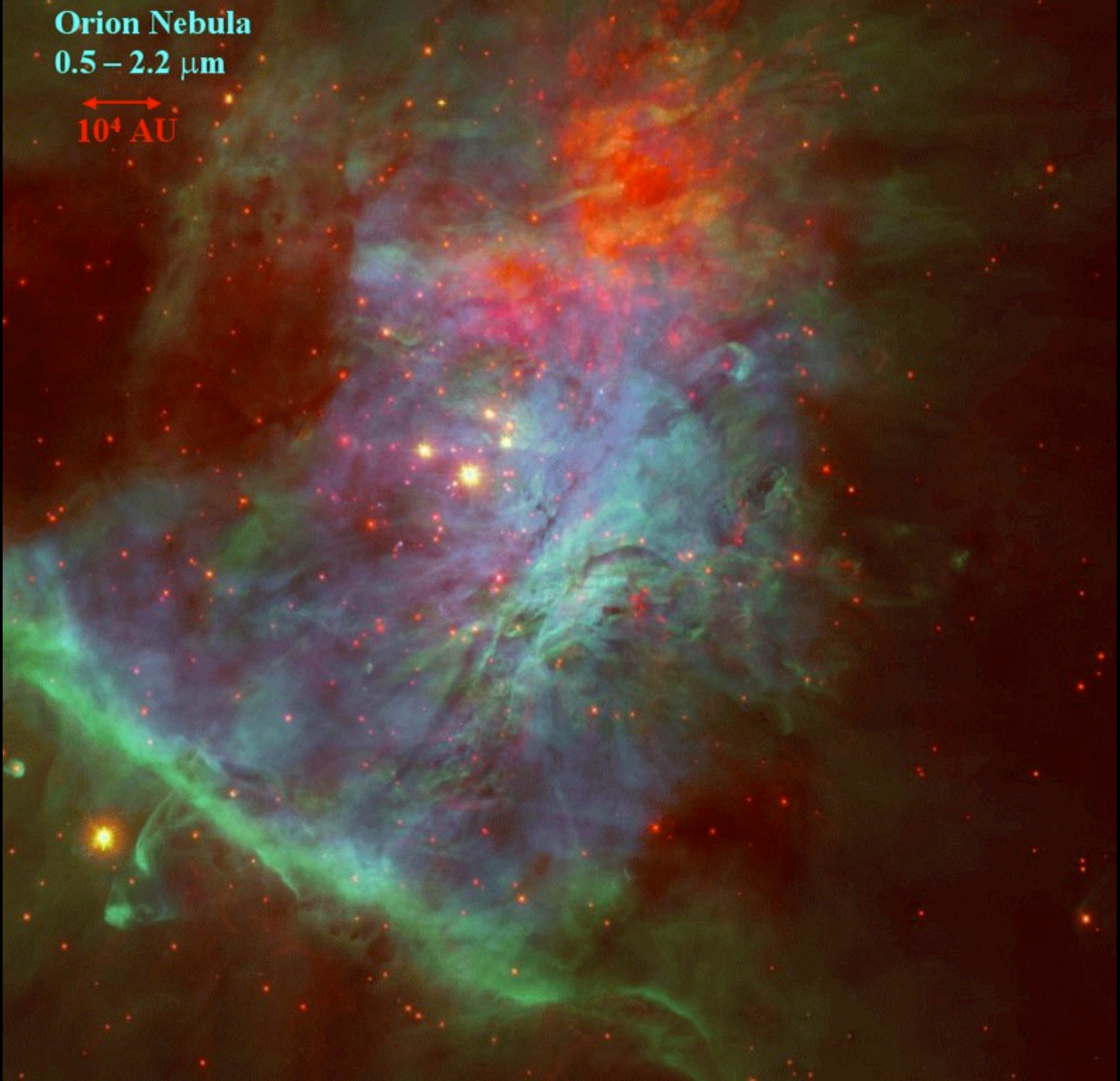
Mt. Hood, OR

May 2012


Orion Constellation
(visible light)

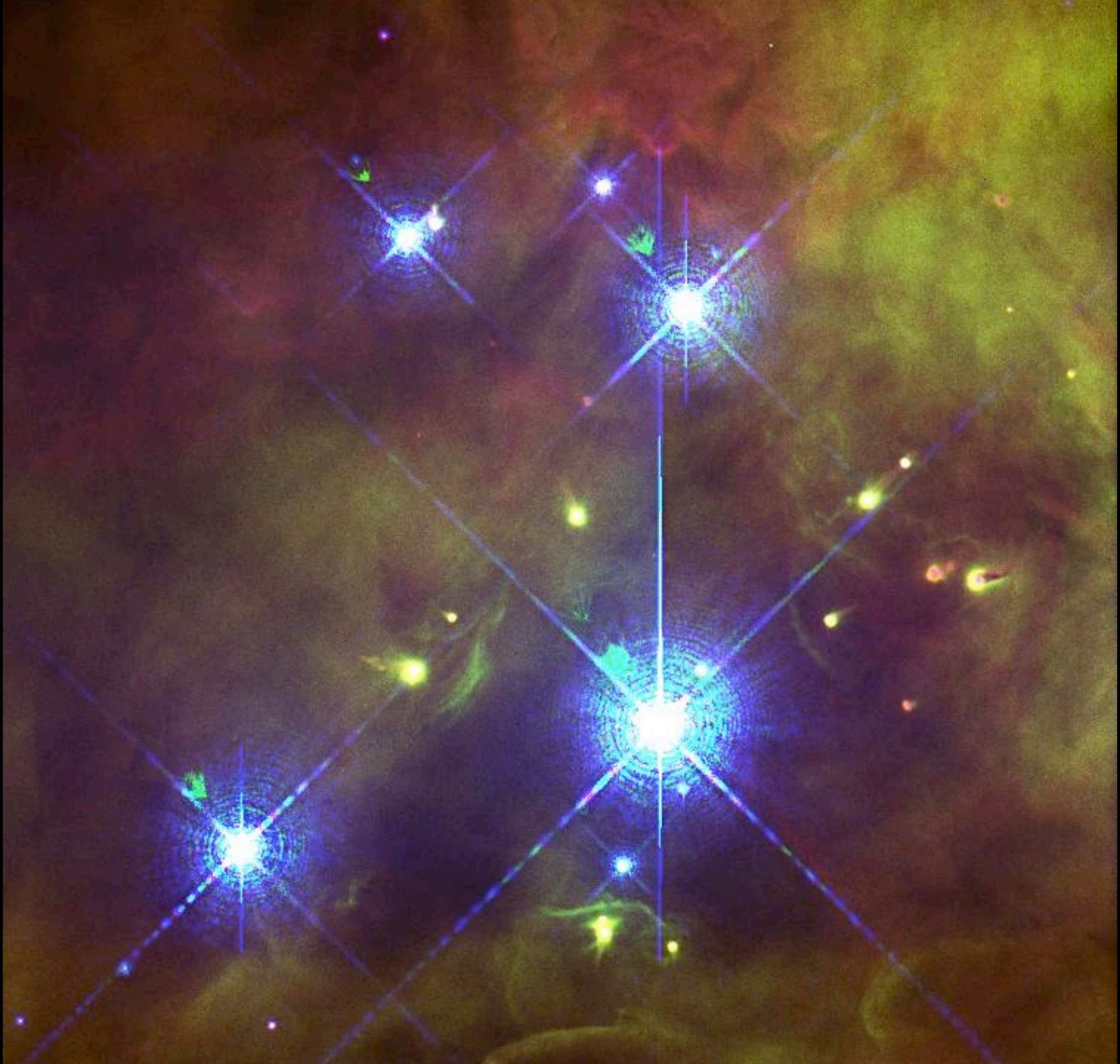

Orion constellation
H-alpha


Orion constellation
H-alpha
Orion Molecular Clouds
>10^5 M_sol   100 pc long

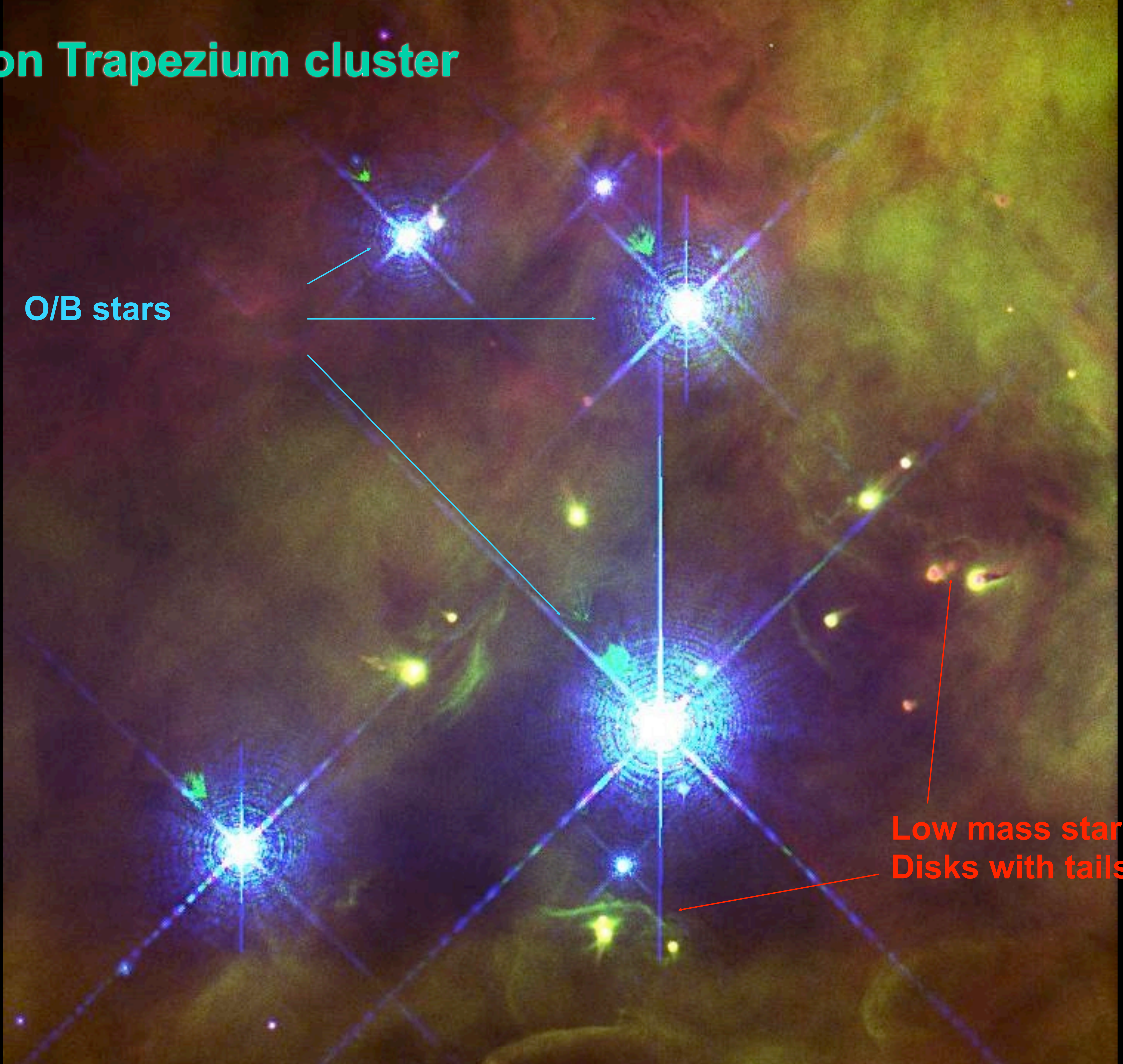

Orion Nebula
0.5 – 2.2 μm
10⁴ AU

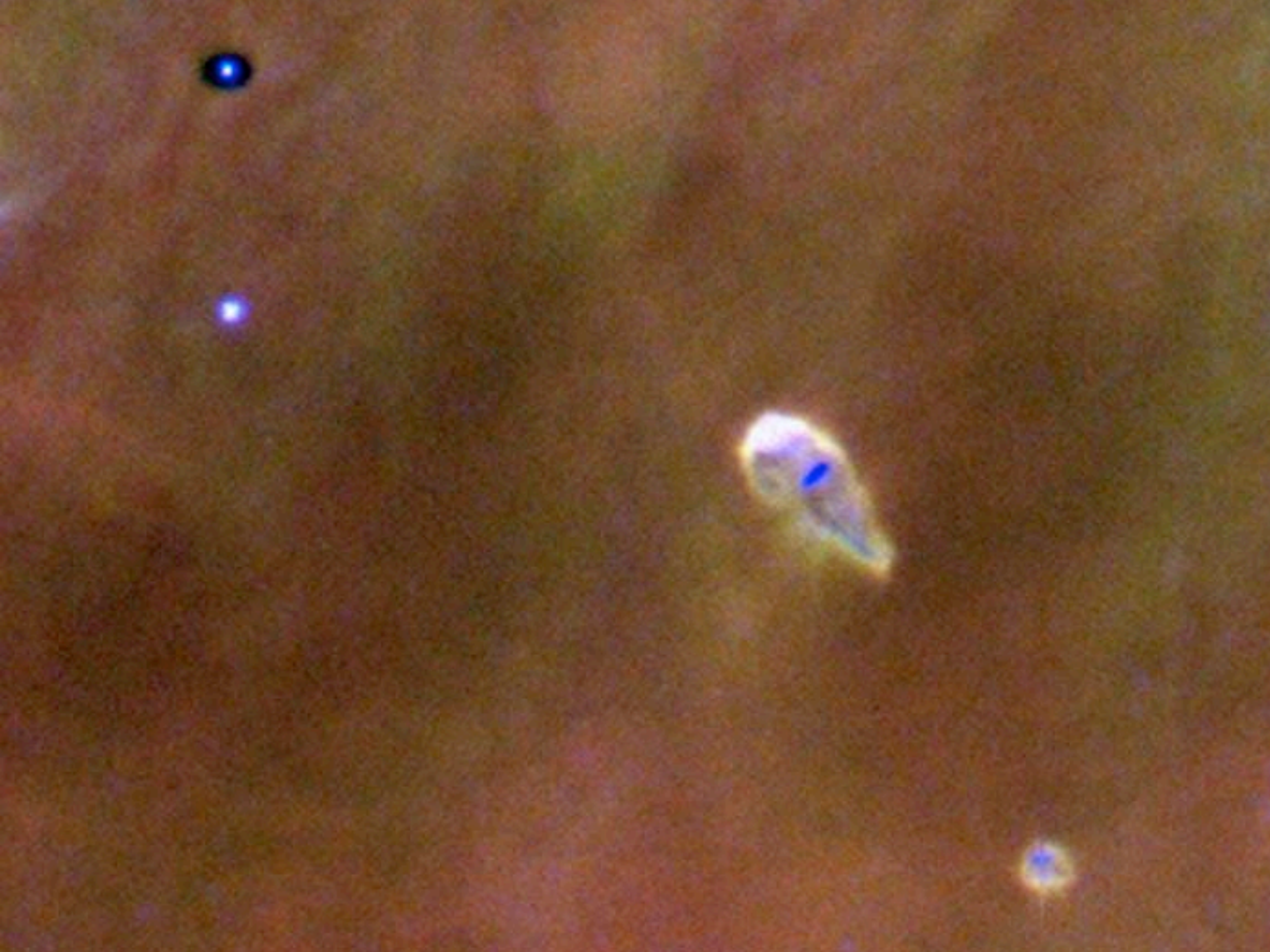
Orion Star Forming Region

- Closest bright star-forming region to Earth
- Distance ~ 1500 ly
- Age ~ 10 Myr
- Radius ~ few ly
- Mean separation ~ 10^4 AU

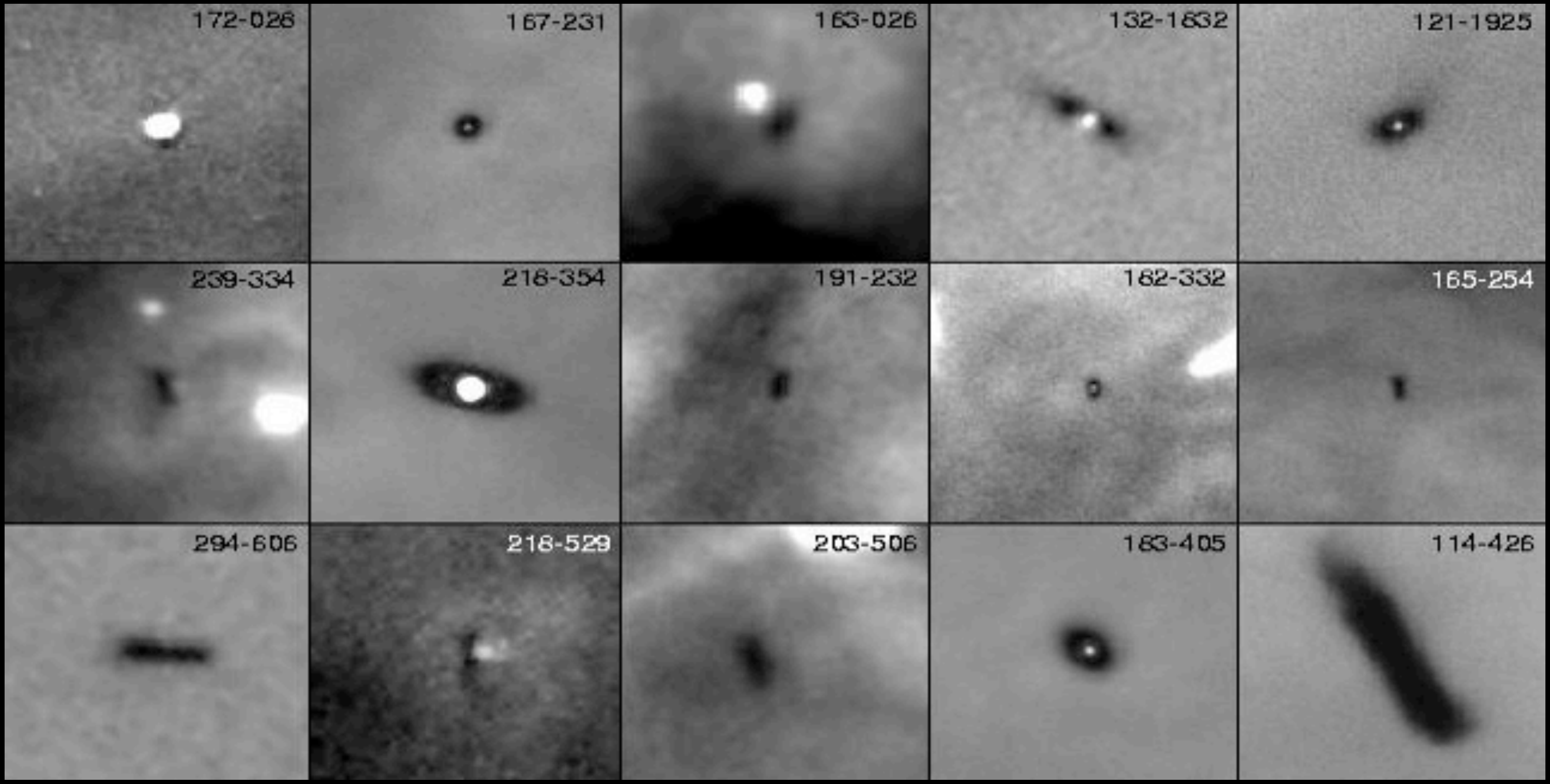


Orion Trapezium cluster





Circumstellar Disks In Orion



- 100+ disks directly observed, diameters 100-1200 AU
- 80%+ of stars in Orion show evidence for having disks

These stars are too distant and young to directly search for planets… but we want to study the environment and processes to understand the planets which would be produced in these dense clusters -- and therefore throughout the galaxy.

Regions of Star Formation

	Large Dense Clusters: Orion	Small Sparse Clusters: Taurus
# of stars	10^3 - 10^4 10^4 stars in last 10 Myr (Orion)	10 - 100
OB stars	Yes	No
Distance	450 pc (Orion)	140 pc (Taurus)
Distance between stars	5000 AU	20,000 AU
Dispersal lifetime	Few Myr	
% of stars with disks	> 80%	
% of stars that form here	70-90%	10-30%

Orion: Hot, Dense, Massive

Most stars form in large clusters.

Taurus: Dark, Small, Cold

Most planet formation models study small clusters.

How does Cluster Environment affect Disk Evolution?

Work we have done involves ...

– UV photo-evaporation from massive stars

– Interaction with cluster gas

– Close stellar encounters

– Organics and UV photolysis from massive stars

Throop 2000; Bally et al 2005; Throop & Bally 2005; Throop & Bally 2008; Moeckel & Throop 2009; Throop & Bally 2010; Pichardo et al 2010; Throop 2011.

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

Photo-Evaporation in Orion

- Disks surrounding solar-type stars are heated by UV-bright stars.
- Gas is heated and removed from disk on 1-10 Myr timescales.
- If disk is removed quickly, we can't form planets!

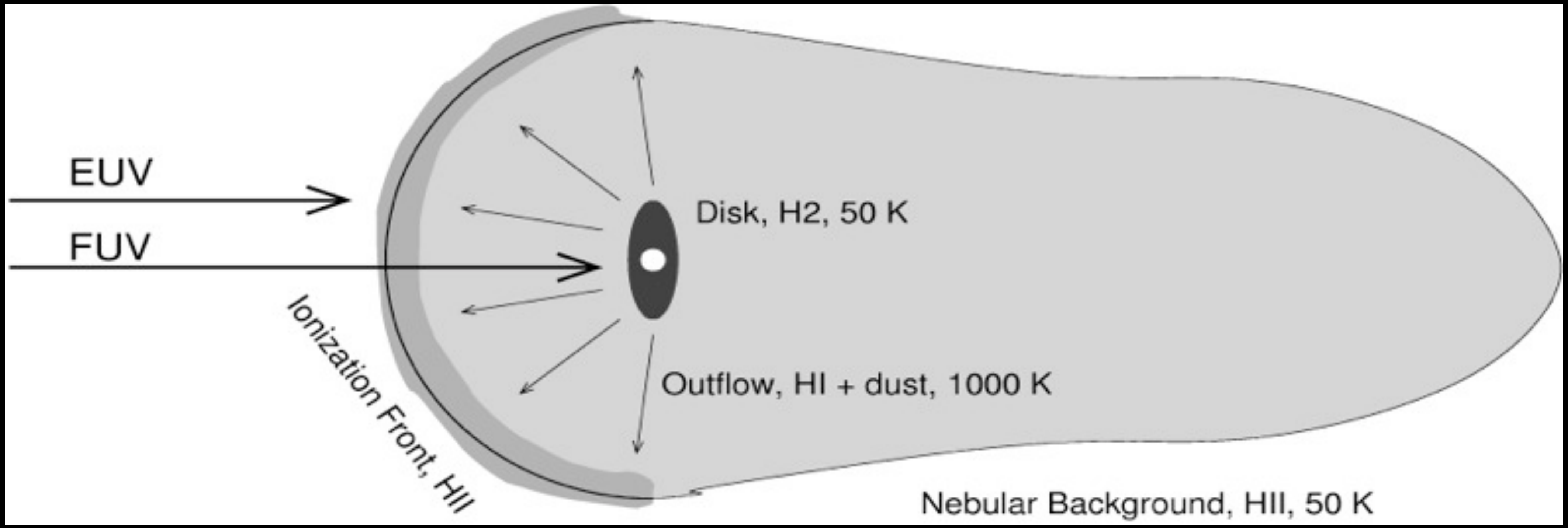
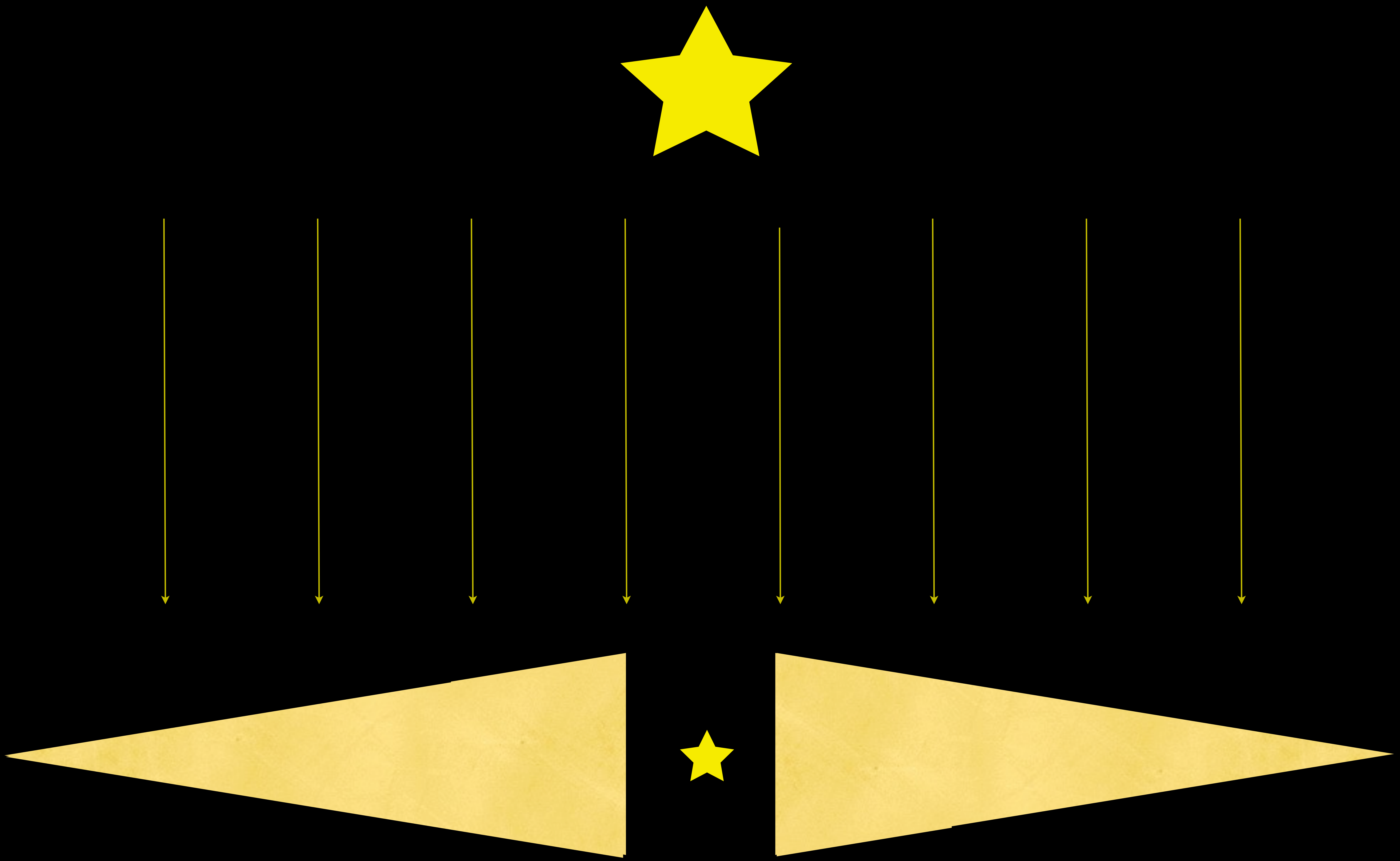
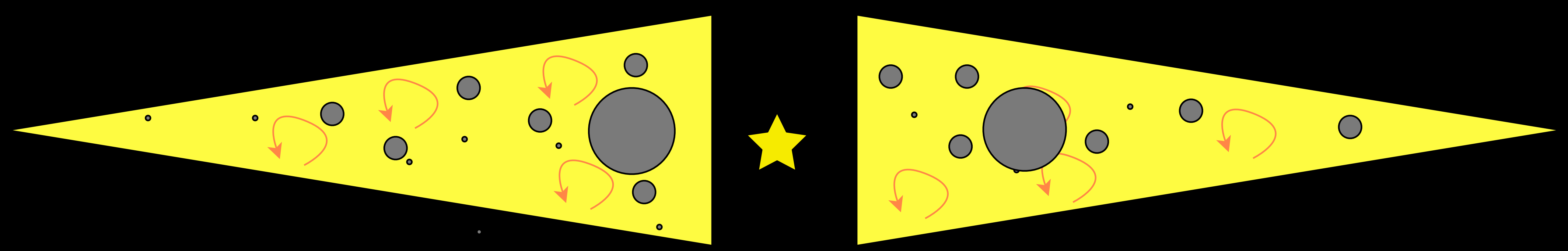


Photo-evaporation from external O stars removes disks in 10^5-10^6 years.



Triggered Planet Formation?

Photo-evaporation removes gas and allows gravitational instability to form planetesimals.



Disk Photo-Evaporation

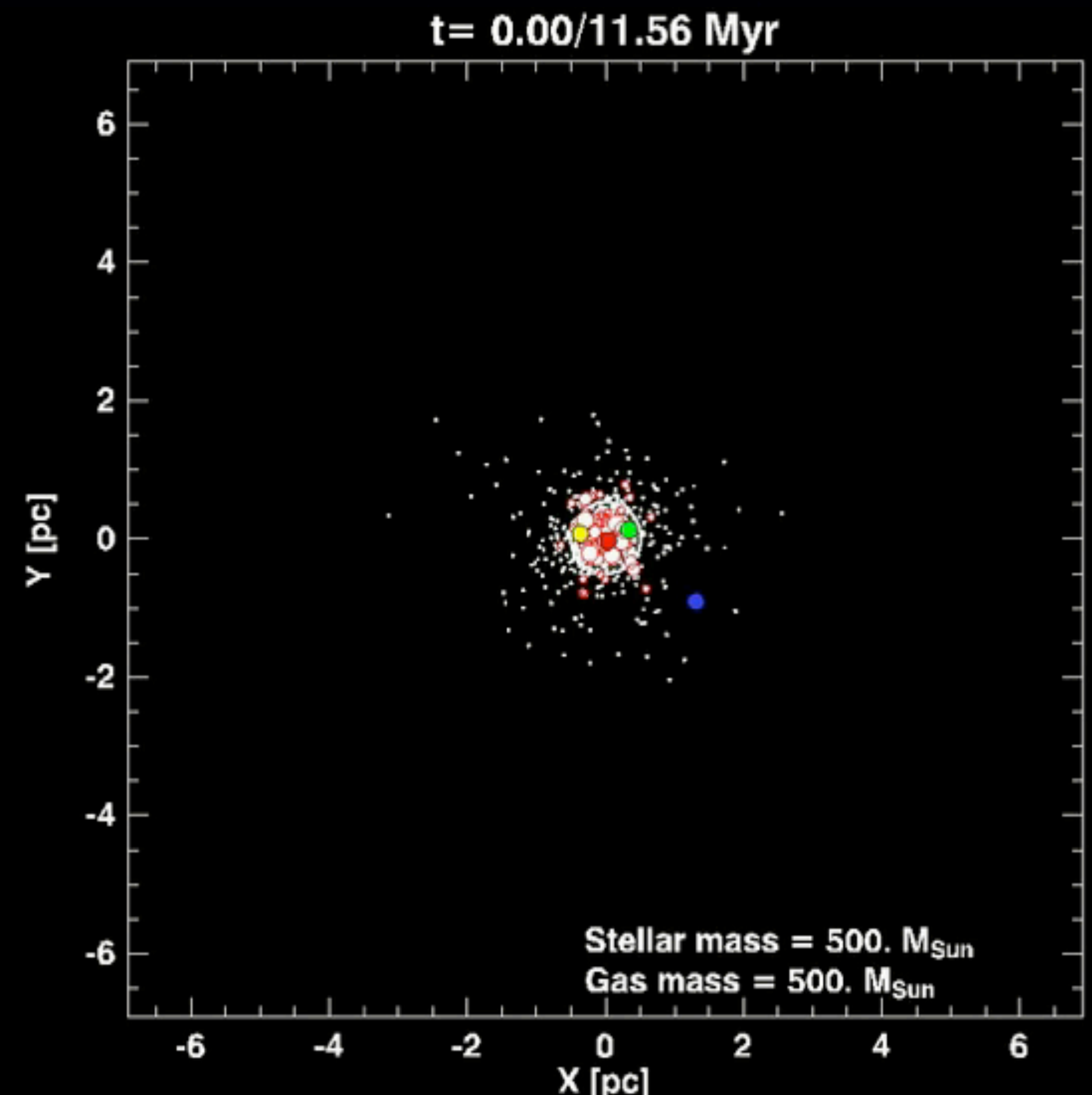
Mass loss rate from disk: $\frac{dM}{dt} = 4\pi\, r_d^2\, v_0\, n_0\, m_H$

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

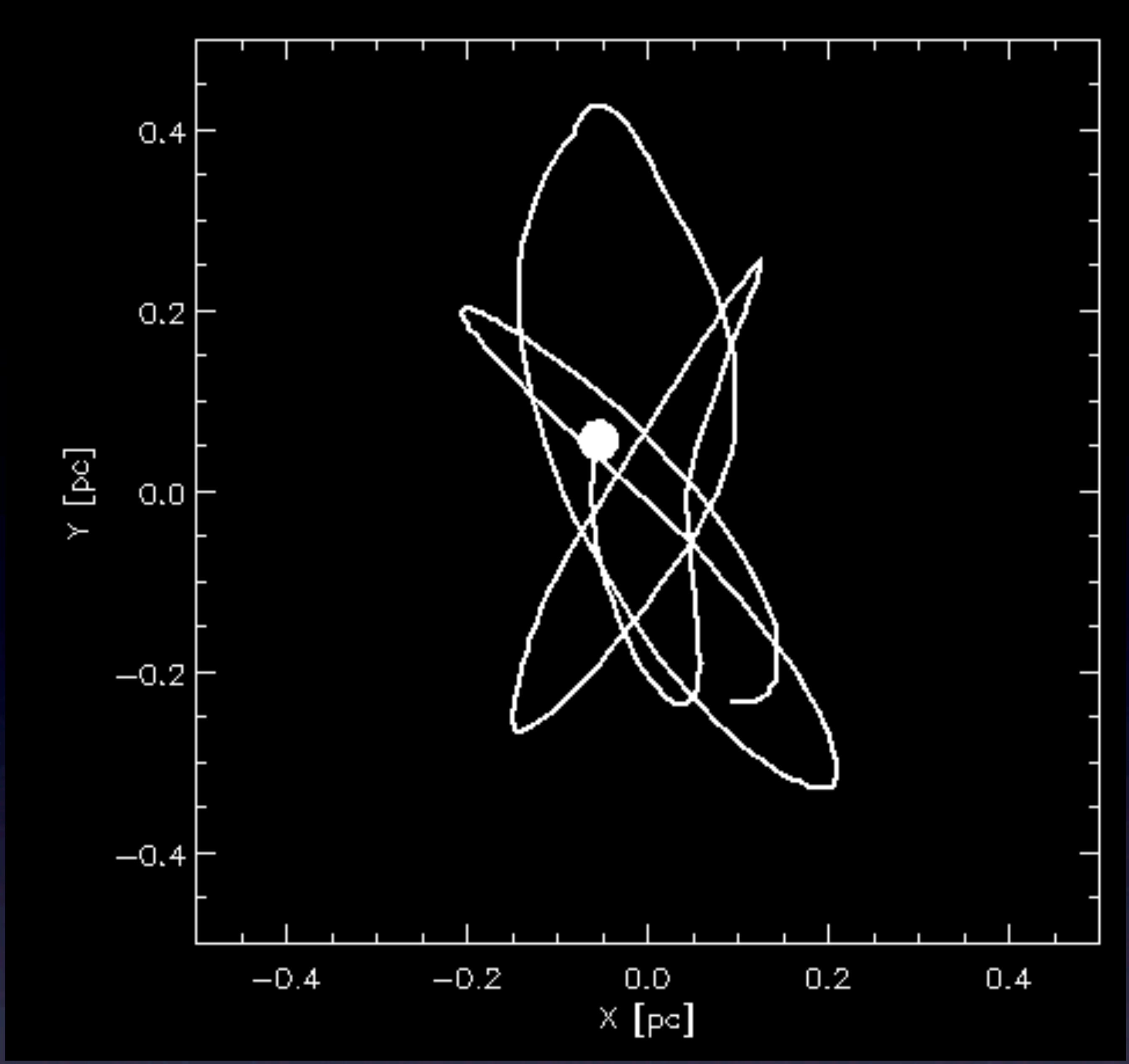
Virtually all previous PE models assume static stellar positions: *R* ~ 0.1 pc ~ 20,000 AU.

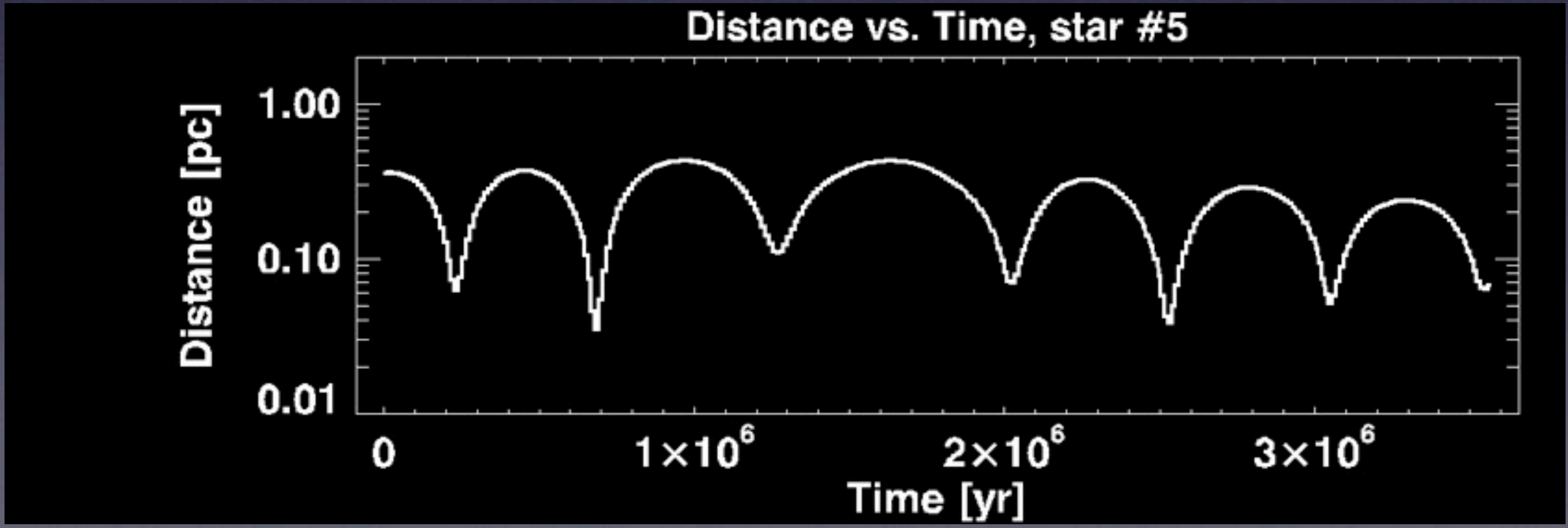
But we know that stars move quickly, with many cluster crossings in first several Myr.

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 solar-mass stars in large Orion-like clusters.

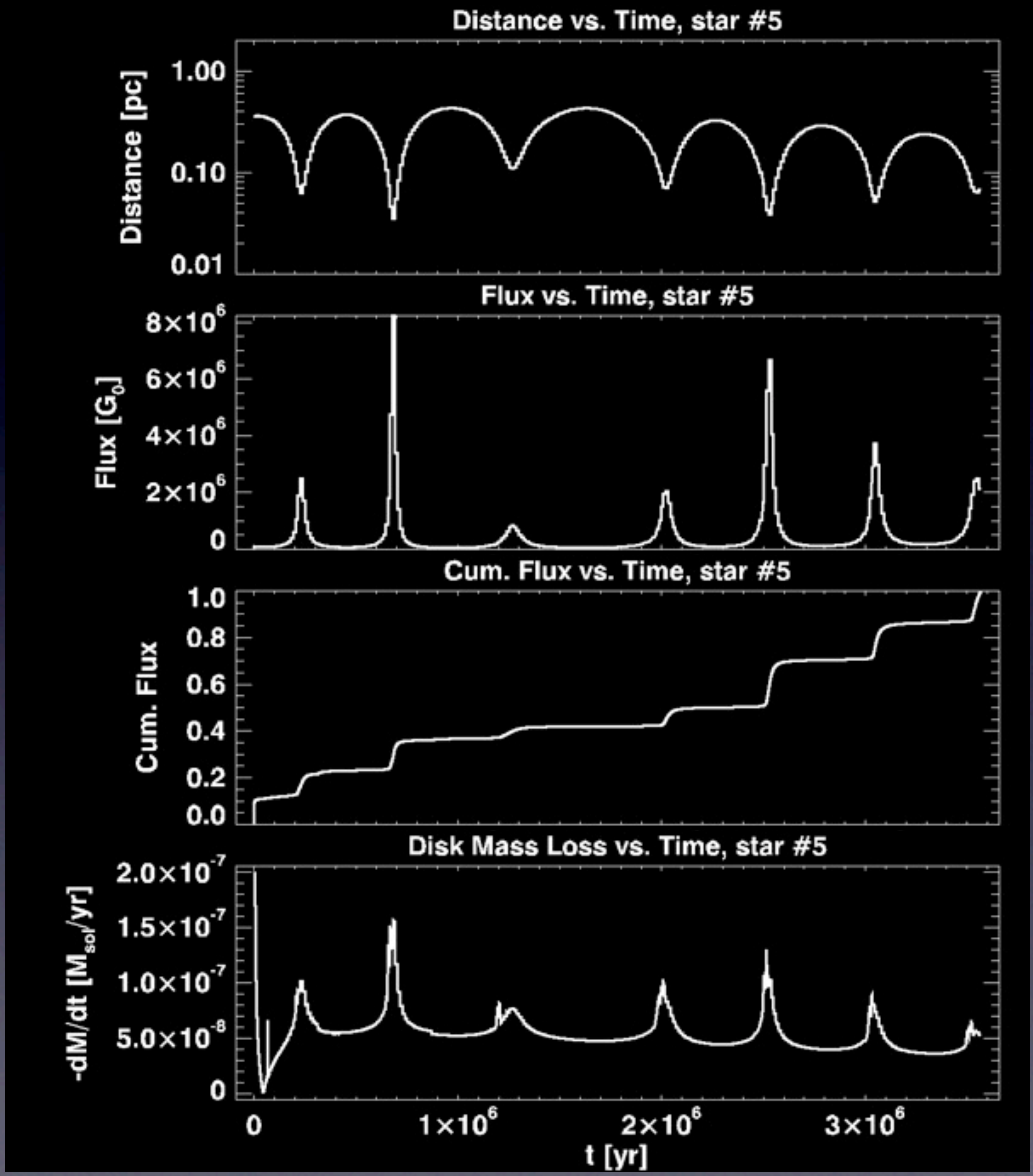


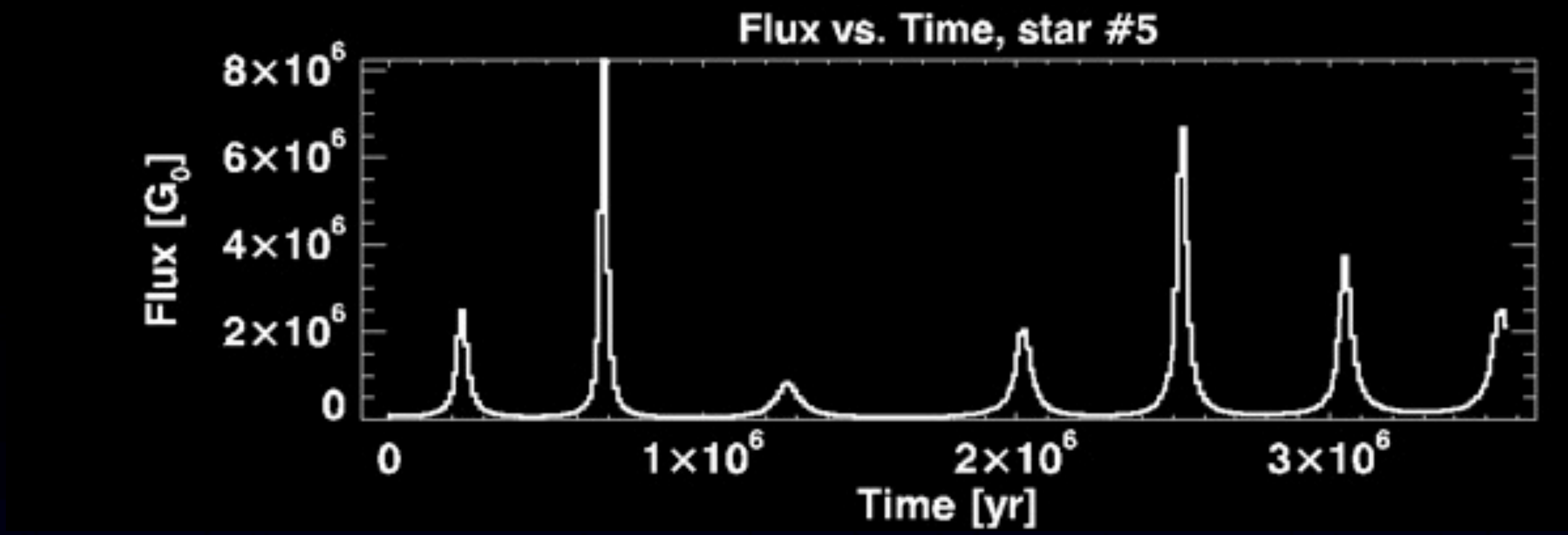


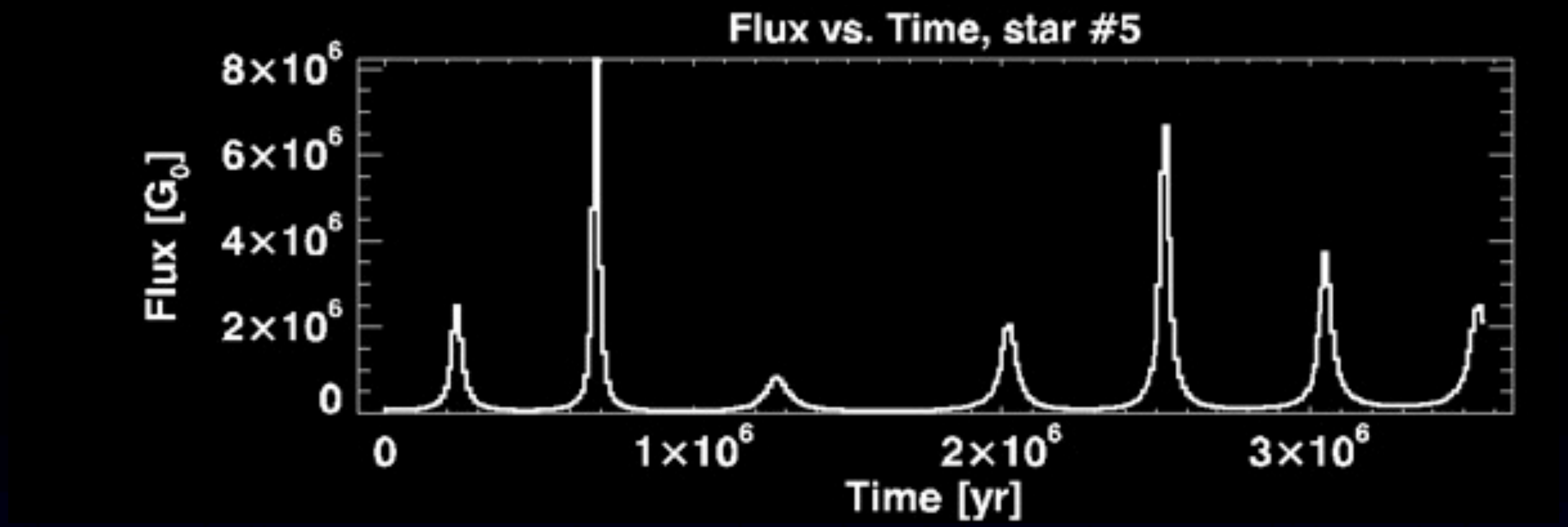
N-body sims track individual history of solar-mass stars in large Orion-like clusters.

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

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




Flux vs. Time, star #5
Flux [G0]
8×10^6
6×10^6
4×10^6
2×10^6
0
0
1×10^6
2×10^6
3×10^6
Time [yr]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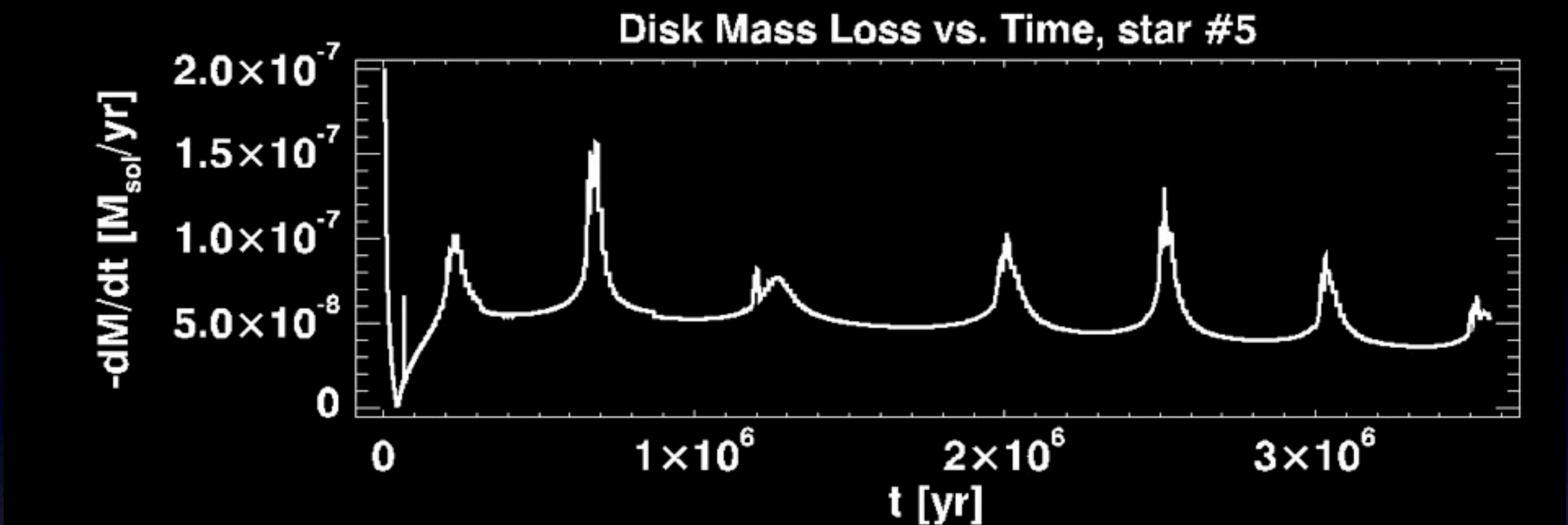

- Photo-evaporation is highly episodic.
- 90% of the UV flux is deposited during 10% of the time.
- Real clusters will have more variability than our models: more O stars, stellar evolution, ISM structure, disk structure, etc.
- Variability causes a diversity of disk structures and masses, *even for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