Disk-Mania and the Formation of Planets

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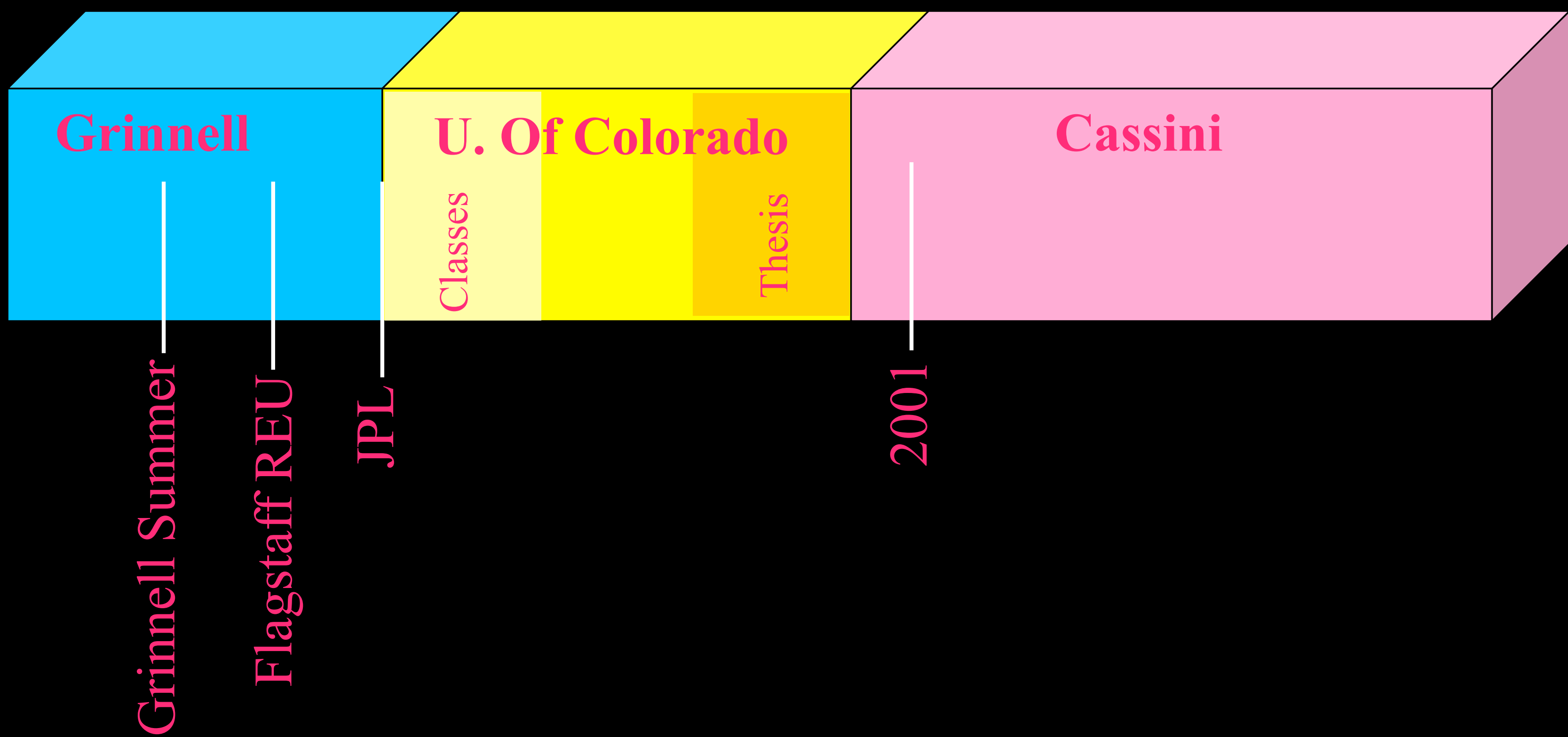
13-Mar-2001


Grinnell
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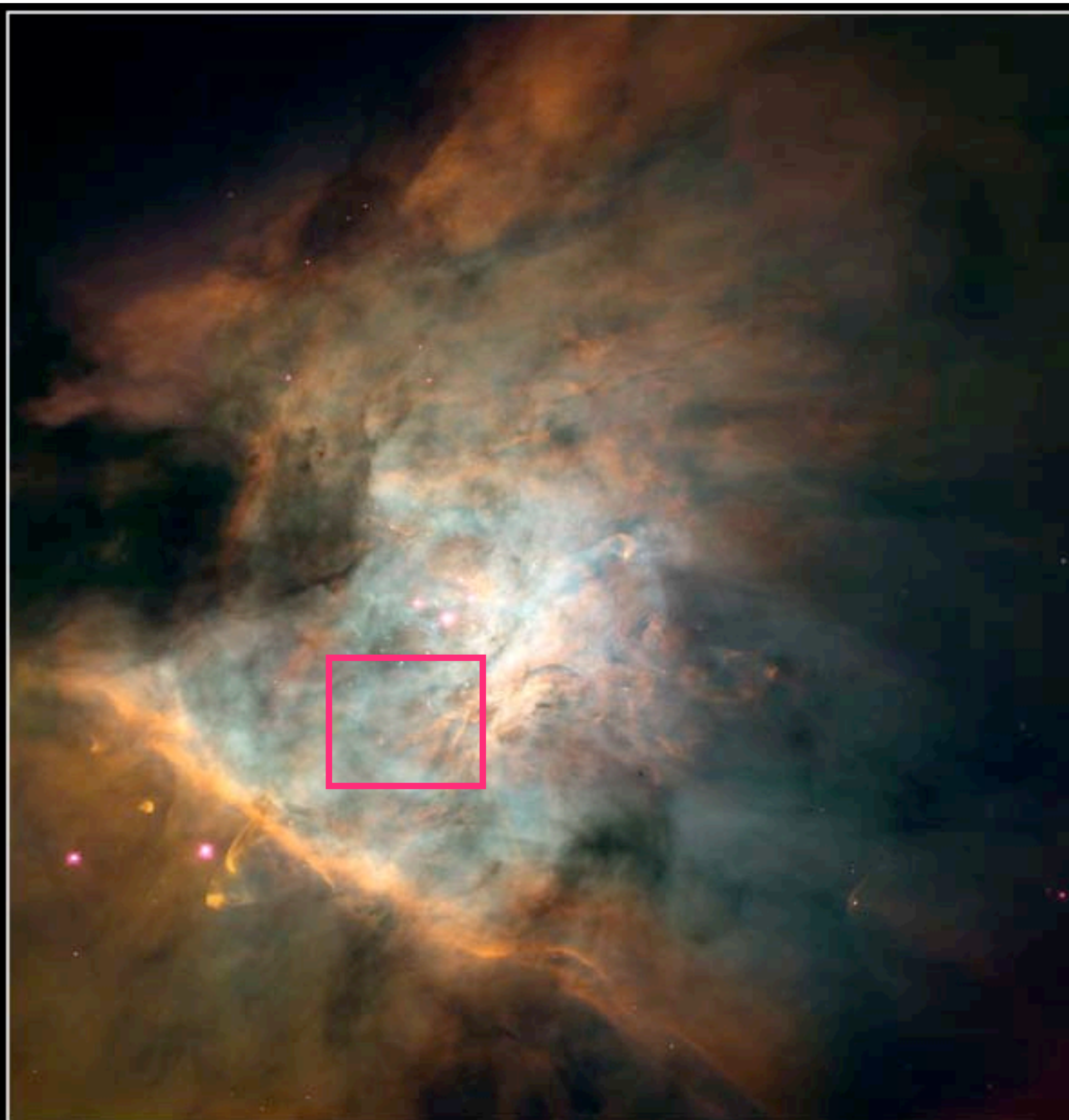
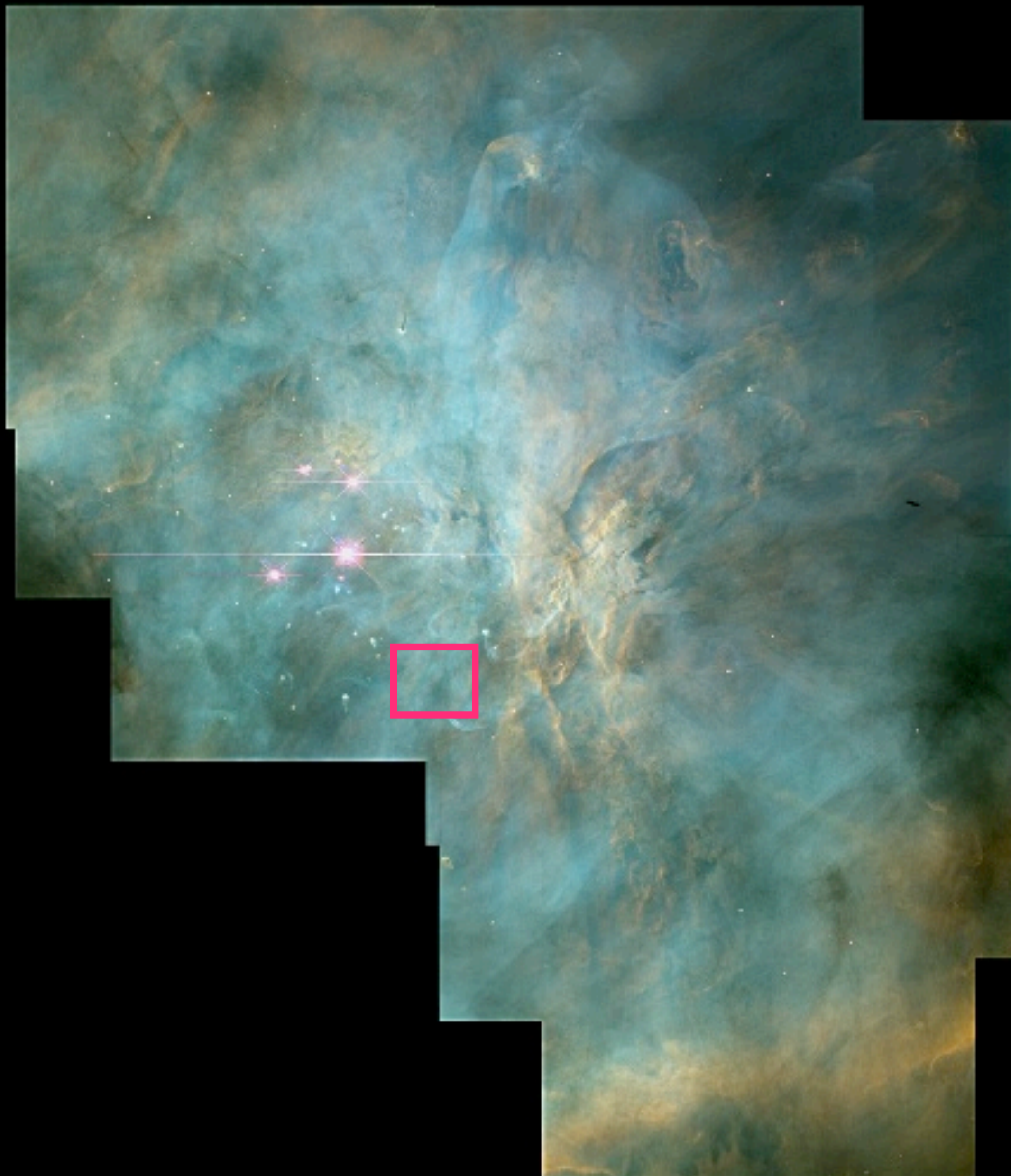


Orion Nebula Mosaic HST • WFPC2

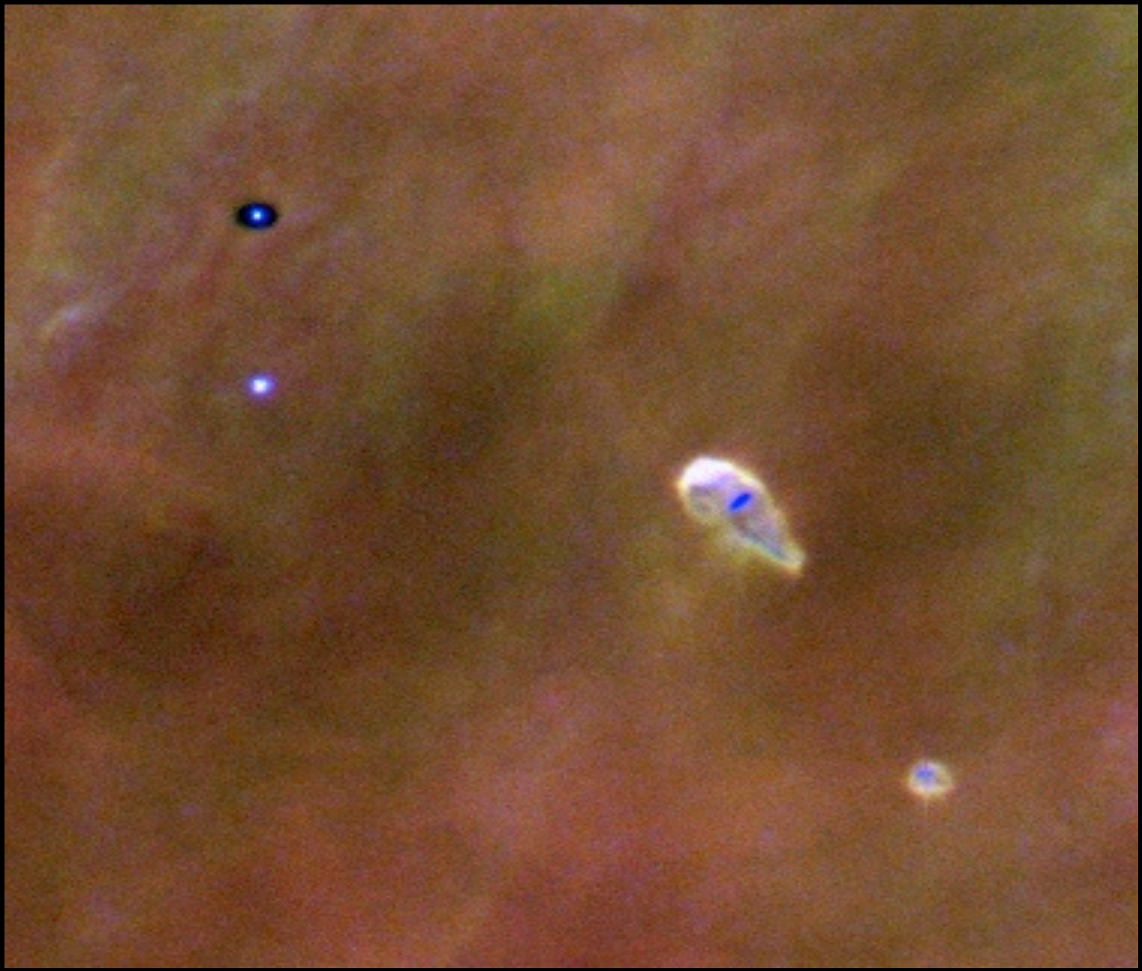
PRC95-45a • ST ScI OPO • November 20, 1995
C. R. O'Dell and S. K. Wong (Rice University), NASA



Orion Nebula

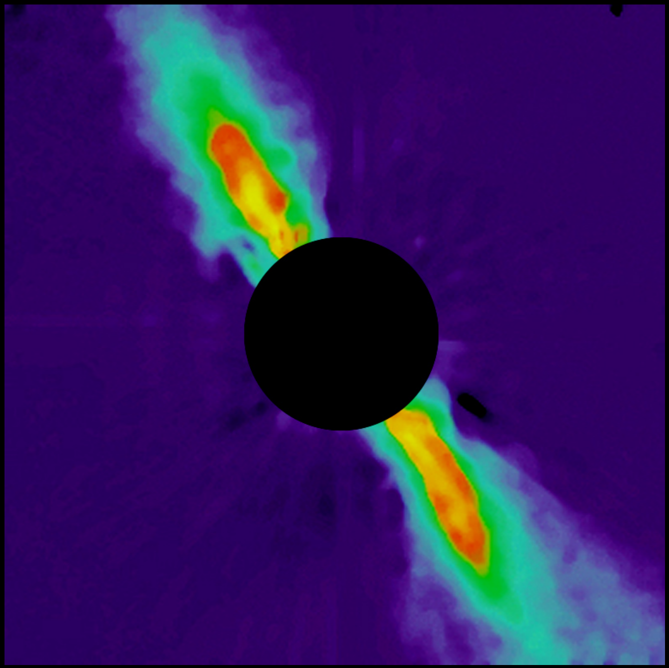
- Closest bright star-forming region to Earth
- Distance ~ 1500 ly
- Age ~ 10 Myr
- Radius ~ 1 ly
- Mean separation ~ 100 AU
- 20,000 young stars
- 100,000 solar luminosities

Circumstellar disks in Orion



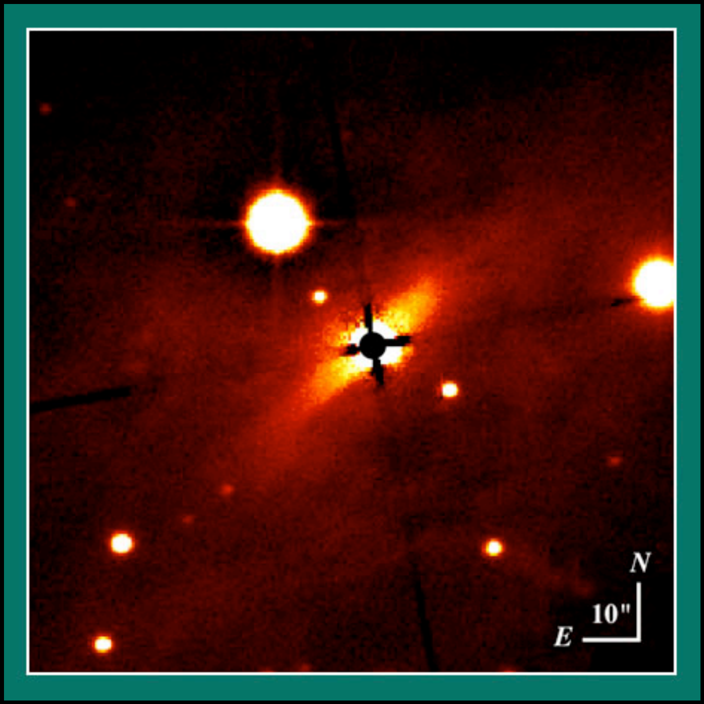
- Size, mass, comparable to our solar system
- Central star comparable to Sun
- Extremely young, ~ 1 Myr
- Lit from outside by bright stars of Orion nebula

Dust disks are common in the universe!

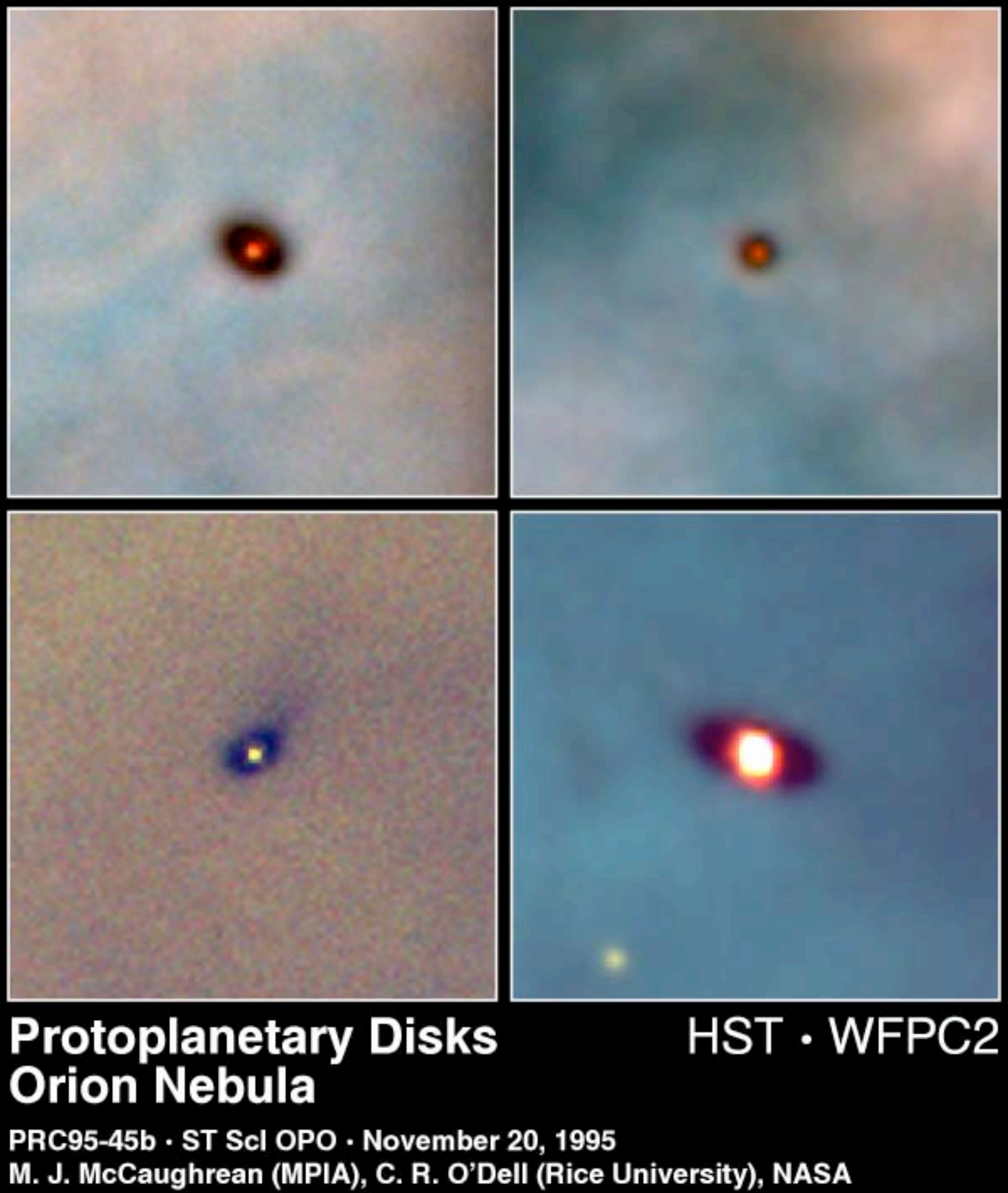


Beta Pictoris
1000 AU
Old - 1 Byr?

BD +31 643
Orbits binary star
500 AU
10 Myr?



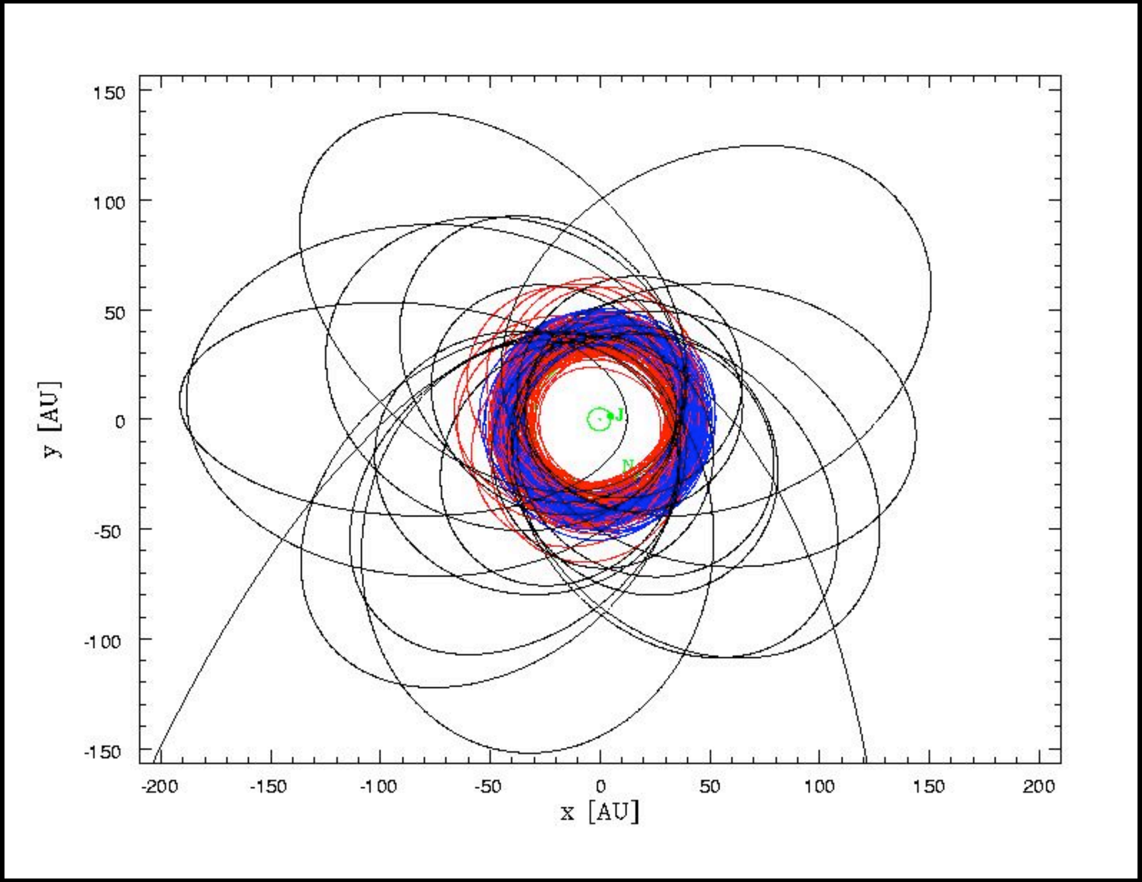
Zodiacal dust
Surrounds Sun
2-2000 AU?
5 Byr



Orion Disks

- Size scales 50-1000 AU
- Dozens of disks
- We see them by their dust
- Disks are in silhouette, lit from behind
- Central stars usually visible
- Young - age ~ 1 M yr
- No planets - yet?

Structure of our Solar System



0-3 AU: Terrestrial planets (rocky)

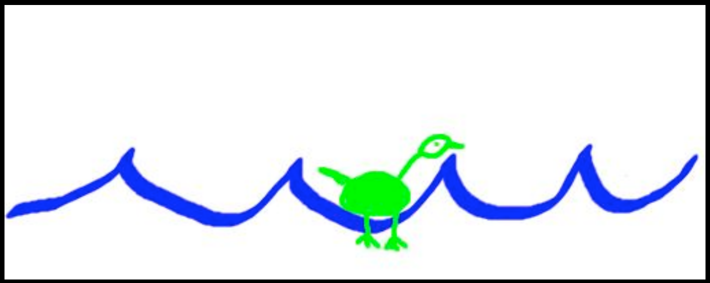
5-40 AU: Jovian planets (gas giants)

40-200 AU: Kuiper Belt, Pluto (icy)

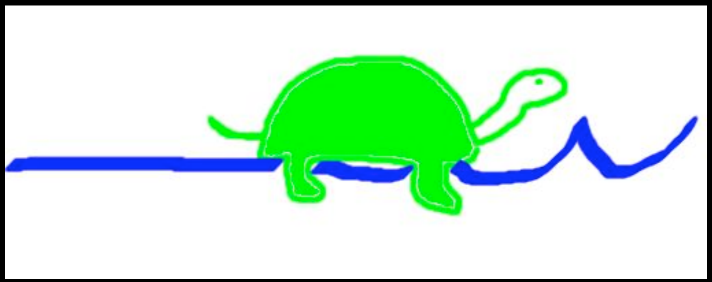
-200,000 AU? : Oort cloud (icy)

Plot shows orbits of known Kuiper Belt Objects ('planets' beyond Pluto)

Light Scattering



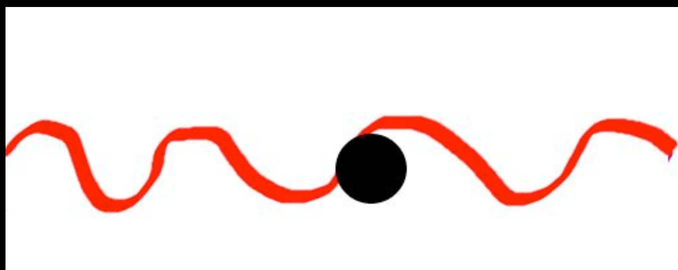
If wavelength > obstruction size,
wave passes through



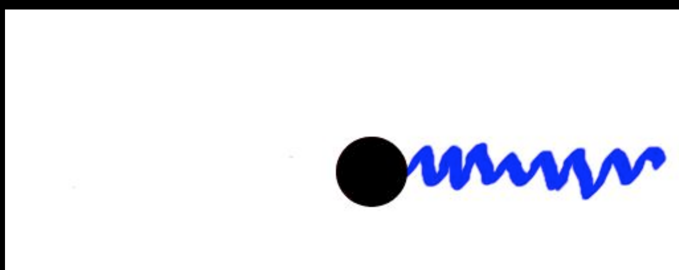
If wavelength < obstruction size,
wave is blocked

Scattering of almost everything in the universe depends primarily on ratio radius/wavelength.

Light Scattering in Orion Disks



If wavelength > dust radius, light passes through

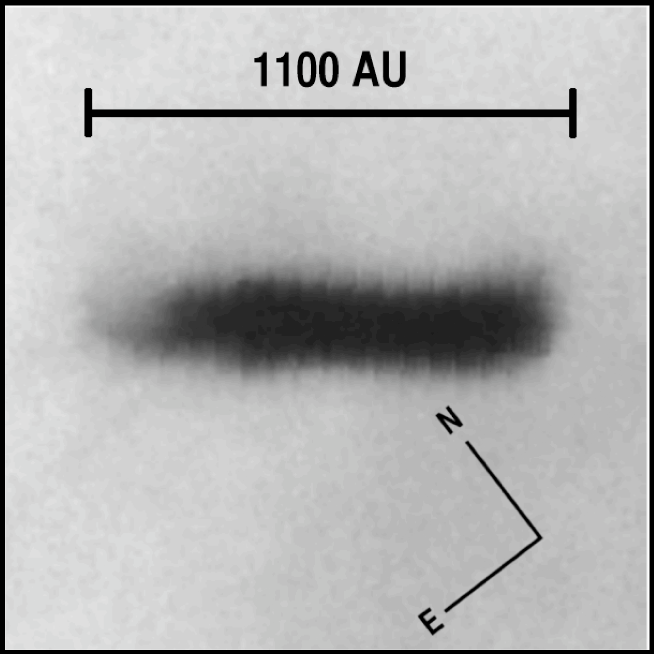


If wavelength < dust radius, light is blocked

By seeing what light passes through and what gets blocked, we can measure the dust size!

This requires a light source behind the dust. In Orion, this is easy: the Orion Nebula emits at many wavelengths!

Orion Disks in Different Colors



656 nm (green light)

1870 nm (near-IR)

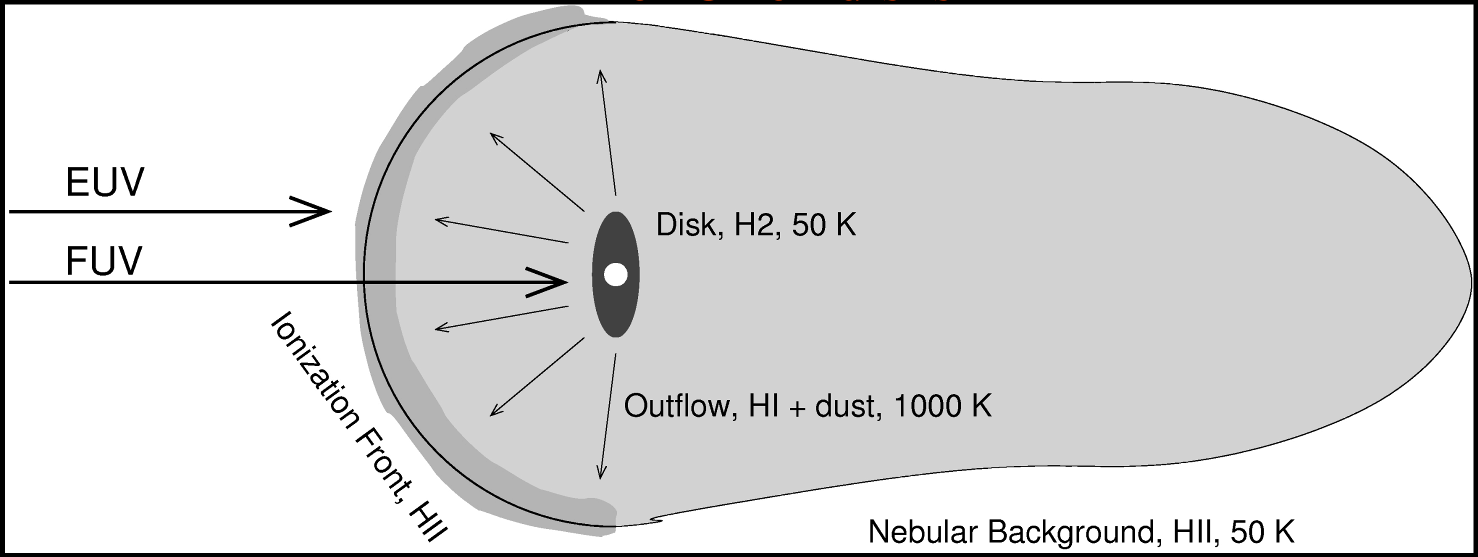
- Disk shrinks vertically with longer wavelength
  - Particles at poles are small
- Disk remains same total diameter
  - Particles in main part of disk are large!!
- Particles have begun to stick together and grow to micron sizes or larger.
- First observation of grain growth in a young circumstellar disk

External Illumination in Orion

- Disks are heated by intense stars in Orion
- Gas heats to 1000K and exceeds escape velocity
- Small grains can be entrained in gas and also lost
- Easiest to lose: small grains at outside edge

External UV light can rapidly destroy disks!

The environment plays a major effect in evolution of Orion disks



Overview of Planetary Formation

I. Cloud of material condenses, star forms
II. Dust grains ⇢ pebbles
III. Pebbles ⇢ terrestrial planets
IV. Terrestrial planets + gas ⇢ Jovian planets
V. Stellar winds ⇢ clear out remaining gas, dust

Total time: 10 Myr (<1% age of current Solar system)

Big question:

We have observational evidence that Orion disks are in Stage II.
Will they get to the other stages and form solar systems?

Evolutionary Modeling of Disks

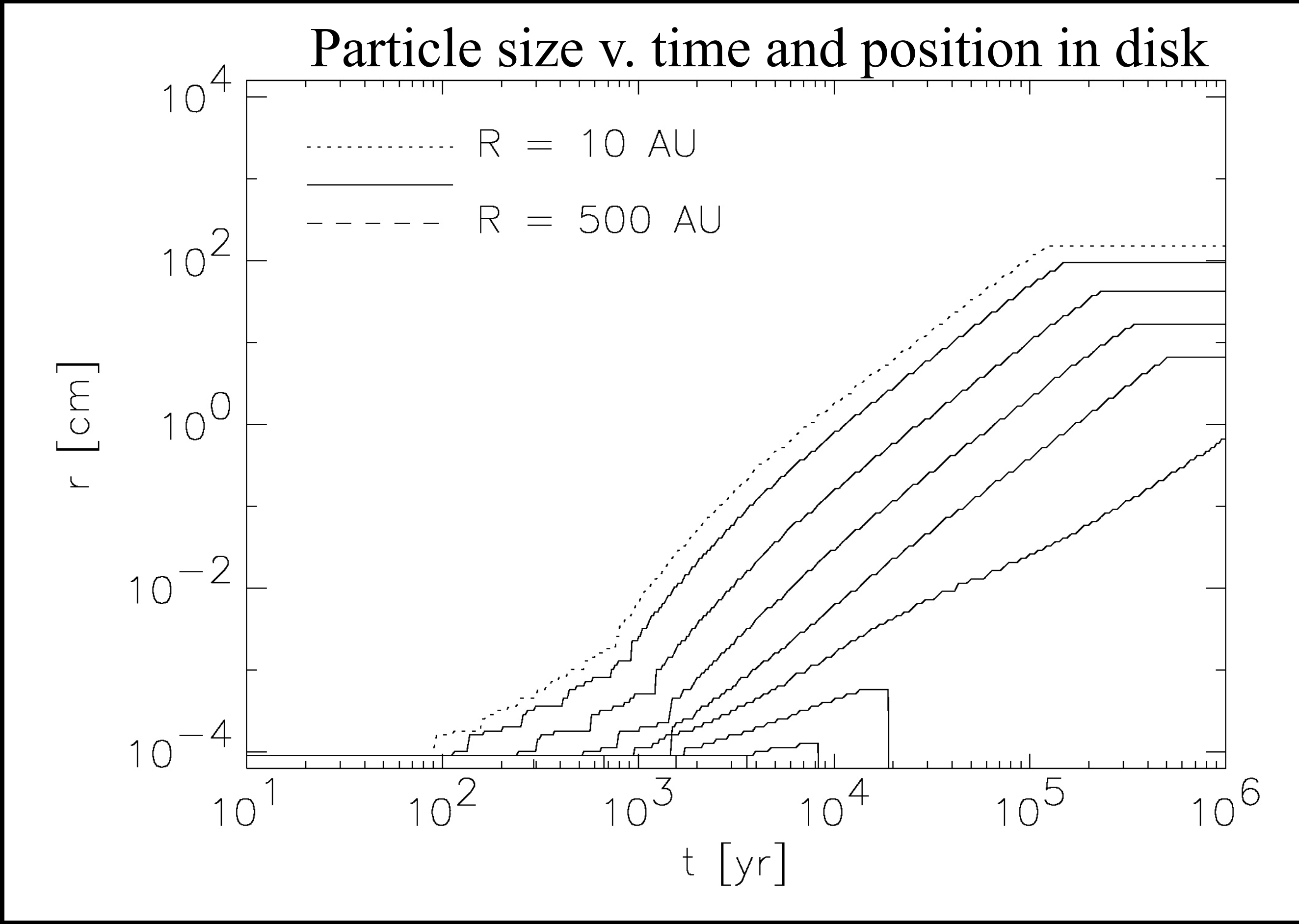
Goal: We want to predict future state of disks based on their current state.

Solution: Put initial conditions and relevant physics together and integrate!

Physics included in model:

- Grain growth by sticking
- Turbulence
- Convection & temperature profiles
- Keplerian orbital motion
- Gas drag
- Gas & dust heated by external stars

Evolutionary Modeling Results I



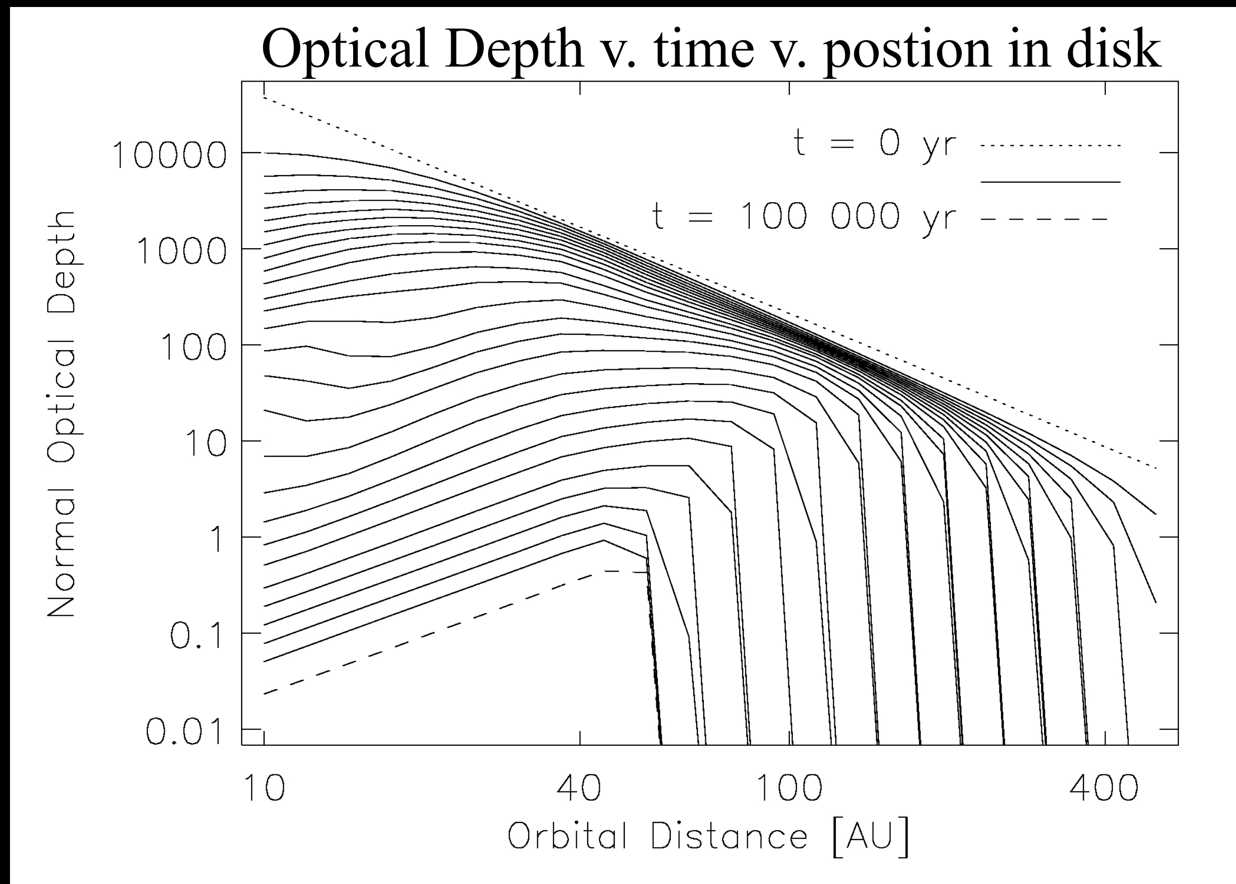
Particles grow rapidly at inner disk edge (meter size in 10^5 yr)

Particles grow slowly at outer disk edge

Evolutionary Modeling Results

'Optical Depth':
~ opacity of disk

(number of times light drops by *e*)



- Gap is formed at inner edge
- Sharp outer edge is made
- Disk shrinks rapidly due to heating from external stars
- Implications for planetary formation?

Implications for Planetary Formation

- Gas, dust in disk are lost in < 1 Myr (!)

- Terrestrial planets
  - Dust ⇢ pebbles ⇢ Earths
  - Can do it quickly in inner disk

- Jovian Planets
  - Earths + Gas ⇢ Jupiters
  - Dust, gas both lost quickly in outer disk
  - To build Jupiters, we must
    - Build Earth-mass cores quickly
    - Attract gas soon after, before lost

Terrestrial planets in Orion are formed frequently
Jovian planets in Orion are formed either rarely or rapidly

If Orion typical, then probabilities apply throughout the galaxy.

Open Problems in Planetary Formation

- Need more resolution!
    - Even at relatively close distance of Orion, best resolution ~ 10 AU

- Need more wavelengths!
    - Will allow us to probe for different-sized particles

- Need better physical & lab models!
    - How do grains *really* stick to each other and grow?
    - How do gases behave in hot, dense environments?

The Really Big Open Questions

- Where do most stars form: is Orion typical or not?
- How long does it take to form Jupiters: 10^3 yr or 10^7 yr?
- What about life?
  - External stars heat and remove gas, but
  - UV also produces lots of organic molecules needed for life!
- How many stars, with habitable planets, with life, are there?

Conclusions

- We have witnessed the first stages in planetary formation directly in Orion.

- Planetary formation can't be considered in a vacuum: the environment is important!

- Planets appear to grow quickly, even in extreme environments.