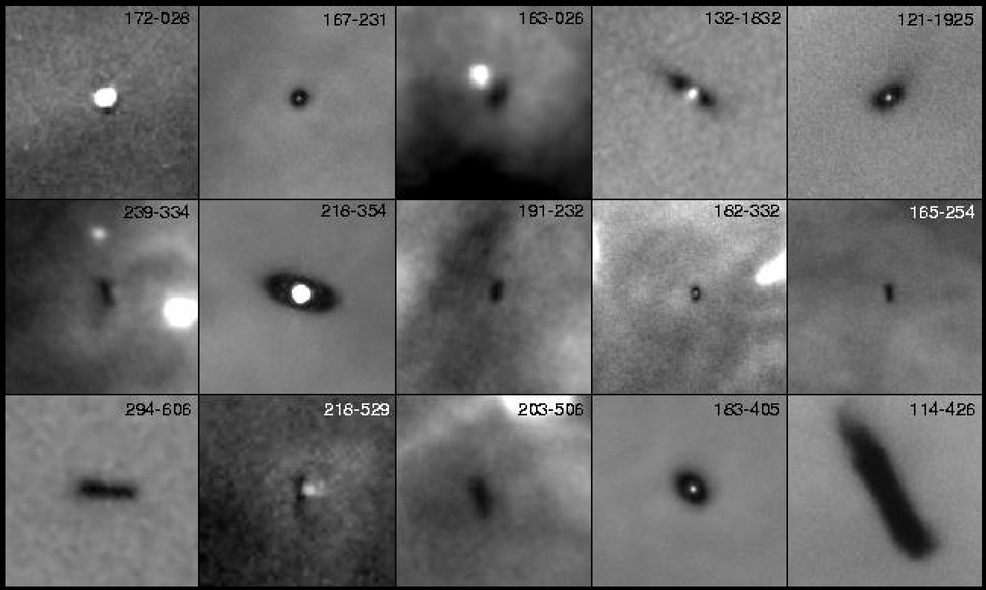
Can Photo-Evaporation Trigger Planetesimal Formation?



Henry Throop
SWRI

John Bally
Univ.Colorado / CASA

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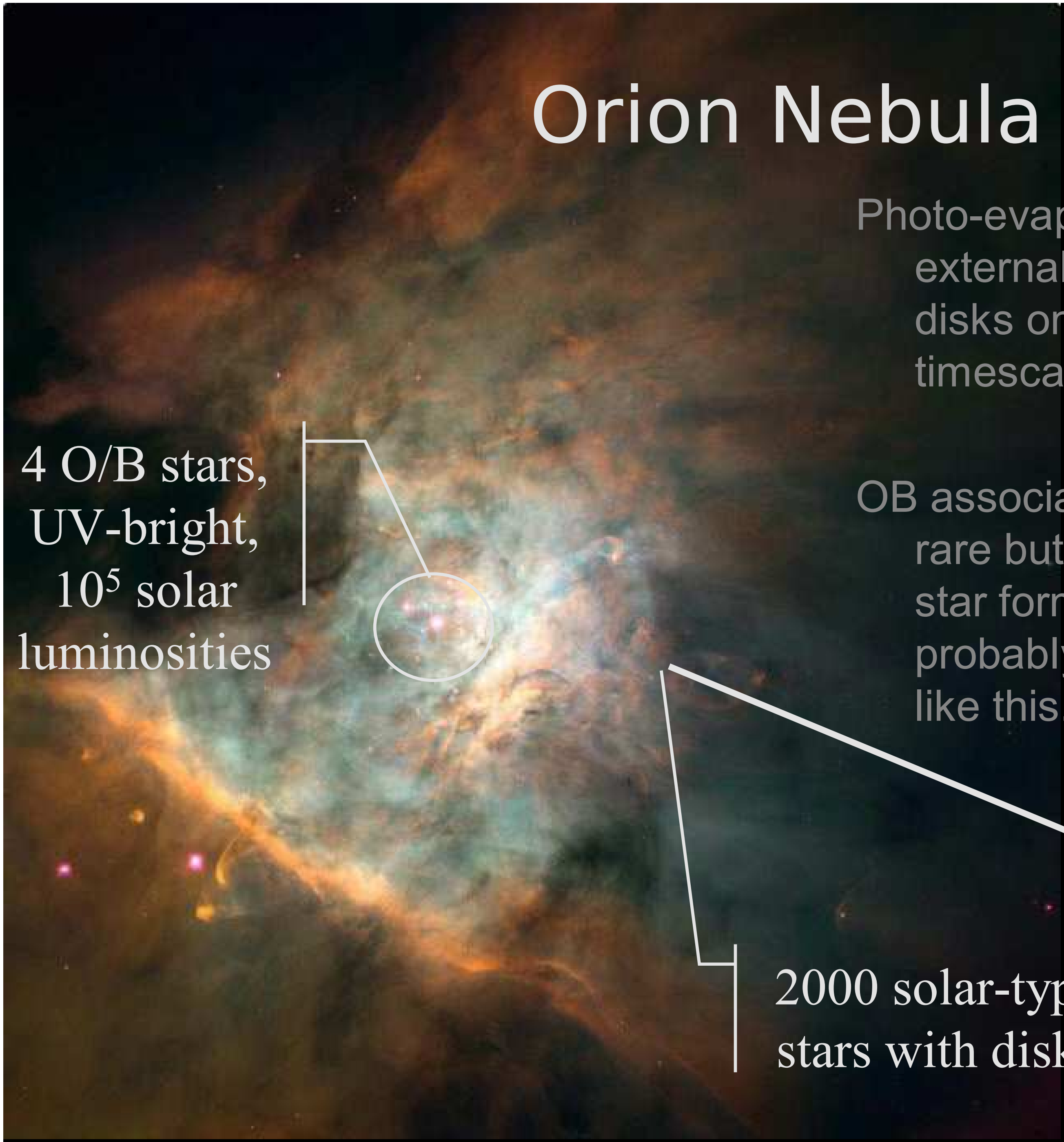
Orion Nebula

Photo-evaporation (PE) by external O/B stars removes disks on 10^5-10^6 yr timescales.

OB associations like Orion are rare but large – majority of star formation in the galaxy probably occurs in regions like this.



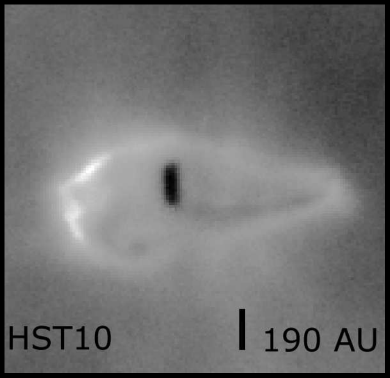


Photo-Evaporation and Gravitational Instability

- Problem: Planetary formation models explain grain growth on small sizes (microns) and large (km) but intermediate region is challenging.

- Youdin & Shu (2002) find that enhancing dust:gas surface density ratio by 10x in settled disk allows gravitational instability of dust grains to form km-scale planetesimals.

- Can photo-evaporation (PE) encourage this enhancement, and thus allow the rapid formation of planetesimals?

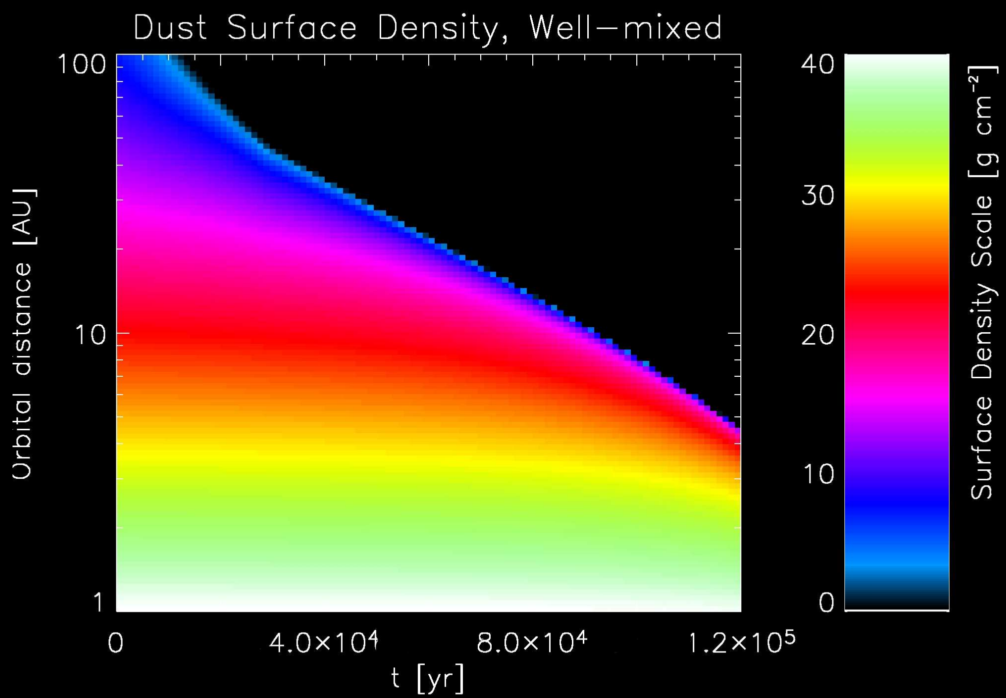
Model of Photoevaporation

- Our model is the first to examine dust and gas separately during photo-evaporation, and is the first to incorporate GI into photo-evaporation calculations.

- 2D code which tracks gas, ice, dust around solar-mass star.

- Processes:
  - Grain growth (microns-cm)
  - Vertical settling
  - Photo-evaporation
  - Dust gravitational instability
- Photo-evaporation heats gas and removes from top down and outside in
  - Gas is preferentially removed
  - Dust in midplane is shielded and retained

Effect of Sedimentation on PE



- Case I: Dust and gas well-mixed (no settling); 0.02 M_{sol}
- Model result: Disk is evaporated inward to 2 AU after 10^5 yr

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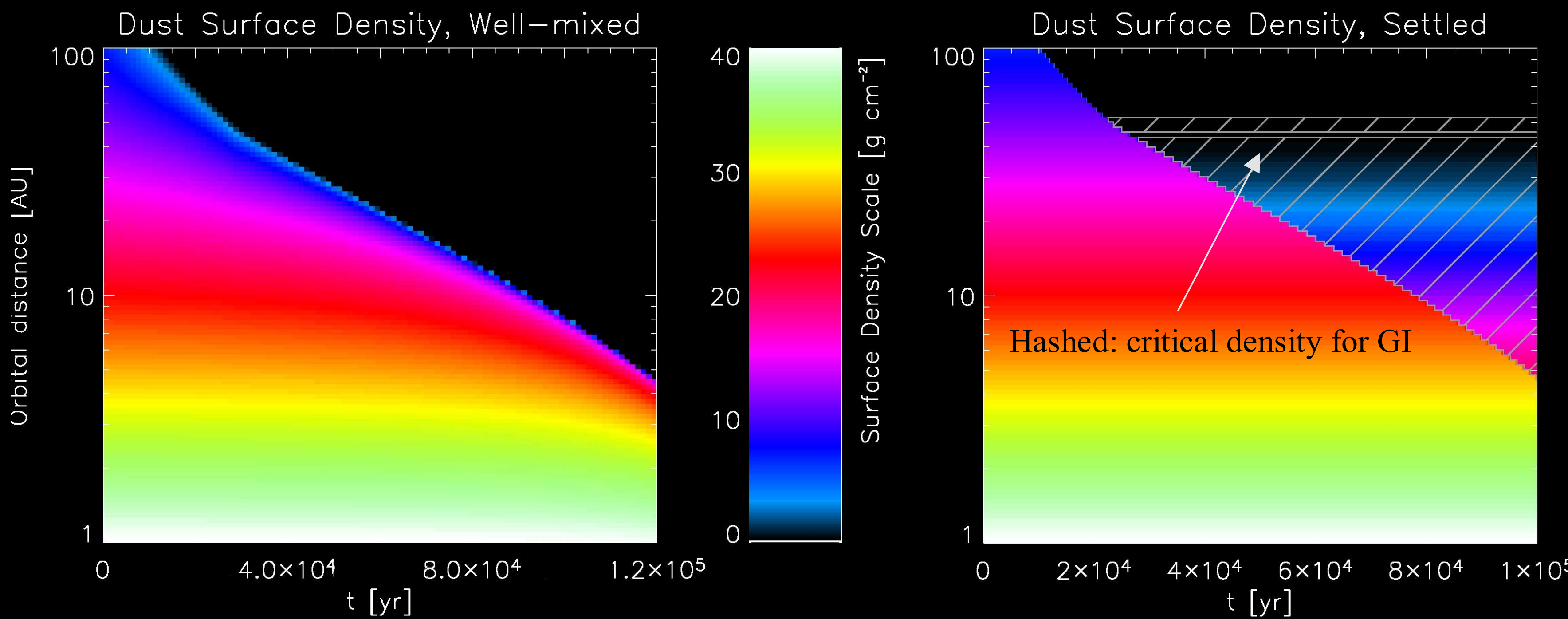

- Case I: Dust and gas well-mixed (no settling); 0.02 M_{sol}
- Model result: Disk is evaporated inward to 2 AU after 10^5 yr

- Case II: Dust grows and settles to midplane
- Model result: Disk is evaporated inward, but leaves significant amount of dust at midplane (40 Earth masses outside 2 AU)
- Dust has sufficient surface density to collapse via GI

Modeling Results

- Photo-evaporation can sufficiently deplete gas in 2-100 AU region to allow remaining dust to collapse via GI.
- Gas depletion depends on a sufficient quiescent period ~ 10^5 yr for grains to settle before photo-evaporation begins.
- Disk settling depends on low global turbulence, and is not assured.

Timeline

0 yr: Low-mass star with disk forms

10^5 yr: Grains grow and settle

10^5 yr: O stars turn on

10^6 yr: Gas disk is lost, allowing planetesimals to form from disk

Conclusions

- Photo-evaporation may not be so hazardous to planet formation after all! In this model, it actually *encourages* planetesimal formation.

- Did Solar System form near an OB association?
  - Rapid gas dispersal may not allow for formation of giant planets.
  - Final distribution of rock, ice, gas may depend strongly on time of O stars to turn on, and speed of disk dispersal.

The End

Star Formation and Photo-Evaporation (PE)

- The majority of low-mass stars in the galaxy form near OB associations, not in dark clouds (ie, Orion is the model, not Taurus)
- PE by FUV and EUV photons removes disks from outside edge inward, on 10^6 yr timescales.
- PE is caused by external O and B stars – not the central star.
- In Orion, typical low-mass star age is 10^6 yr, but O star age is 10^4 yr – disks have had a quiescent period before PE begins.

Implications

- Coagulation models of grain growth have difficulty in the cm-km regime. This model allows for that stage.

- Model explains how planets could be common, in spite of fact that majority of low-mass stars form near OB associations.