

Large Particles in Young Circumstellar Discs

Henry B. Throop
U. Colorado / LASP

John Bally
U. Colorado / CASA

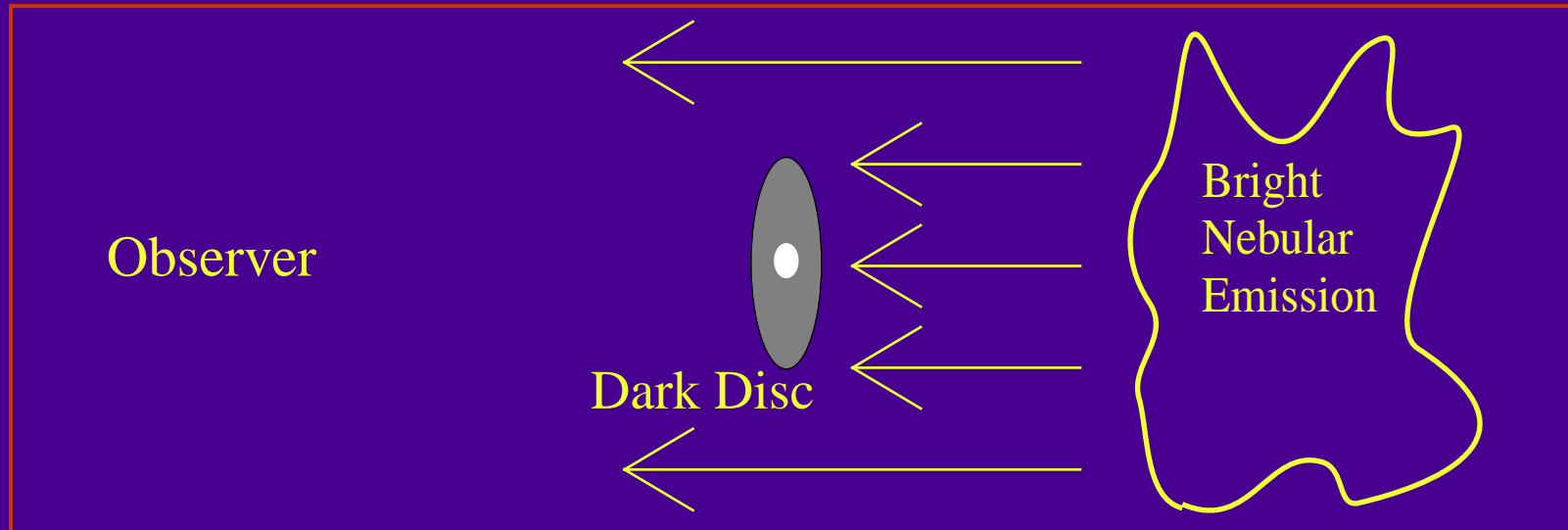
Larry W. Esposito
U. Colorado / LASP

Mark J. McCaughrean
Astrophysikalisches Institut Potsdam

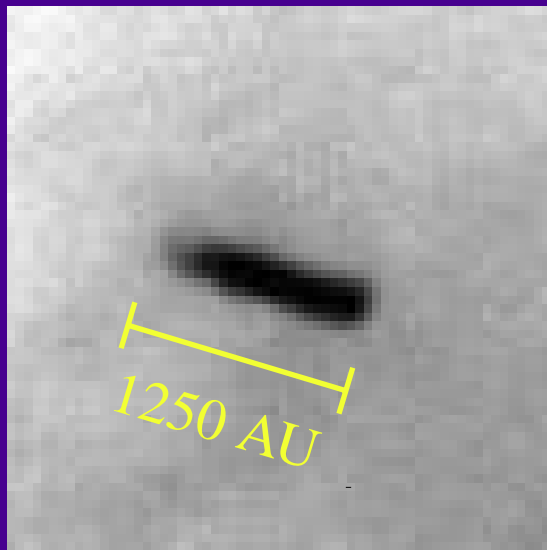
Orion Protoplanetary Discs Observations

- Discs seen in silhouette against bright background
- Variety of sizes, inclinations ($a = 50\text{--}1000$ AU, $\theta = 0 - 90$ deg)
- Stellar ages $\sim 10^6$ yr; $\theta_1\text{C}$ UV photoionization age $\sim 10^5$ yr
- Central star visible in face-on discs
- Disc image illuminated by HII-region background, not central star
- Peak optical depth $\gtrsim 100$
- 70+ silhouettes found in Orion proplyds; surround $\sim 10\%$ of young stars
O'Dell & Wen 1994, McCaughrean & O'Dell 1996

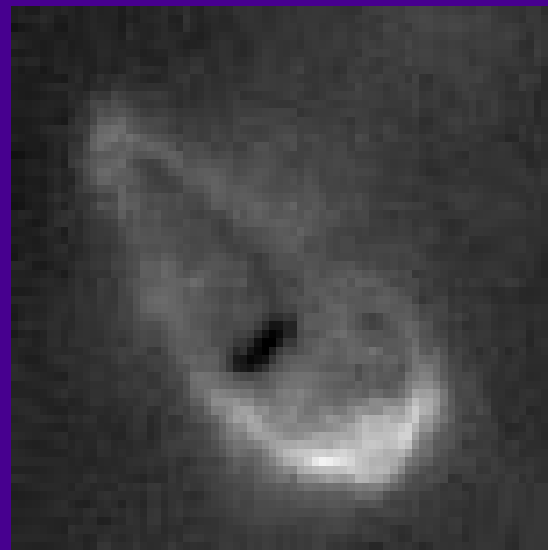
- Observed disc size, shape is function of intrinsic morphology, PSF, and particle scattering properties.



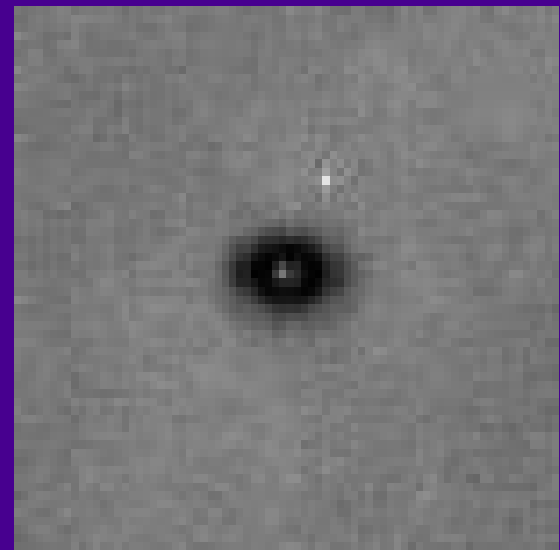
Proplyd Images



114-426
WFPC2, 0.5 μm



HST10
WFPC2, 0.66 μm



HST16
WFPC2, 0.66 μm

Current Analysis:

29 images, 3 discs, $\lambda = 0.25 - 2 \mu\text{m}$, FOC / WFPC2 / NICMOS

I. Particle Size Observations

We have obtained lower limits for the particle sizes in the proplyds by modeling the wavelength-dependence of the silhouette sizes. Radial brightness profiles are measured by taking median brightness levels along concentric isophotes. The brightness profiles are then modeled with multiple scattering Mie calculations to constrain particle sizes. Longer wavelengths probe larger particle sizes, as $Q_{\text{sca}} \sim (r/\lambda)^4$.

We find:

- Disc sizes, profiles show no wavelength trend; *i.e.*, no measurable color

$$R = A_V/E(B-V) \sim 50; \quad \text{color index } \beta_{\text{abs}} \lesssim 0.1$$

- Disc achromaticity at edge requires $\langle r \rangle \gtrsim 10 \mu\text{m}$;

Lack of color is consistent with large $\langle r \rangle$, cm-km.

- Local, unevolved Orion region has primordial particle size $\sim 0.2 \mu\text{m}$

Particles have grown to $\gtrsim 10^5$ x original mass in $\sim 10^6$ y

- Accretion timescale is consistent with inner disc evolution models

Ruden & Pollack 1991: $t_{\text{coll}} \sim 1$ y

II. Disc Structural Modeling

We use a 3D 7-parameter model to simulate the observed disks. For each disk, a Monte Carlo code generates $N \sim 10^5$ model images spanning the parameter space. These model images are PSF-convolved compared directly with the data images. Regions of good fit ($\chi^2 < 1$) and a best-fit solution are shown for each disc.

Disk model: 3D cylindrically-symmetric disks projected into image plane with single-scattering, large-particle model applied.

$$\Sigma(r) \sim r^{-k} \quad (r_1 < r < r_2)$$

$$\Sigma(r) = 0 \quad (r < r_1; r > r_2)$$

$$\rho(z) \sim |1 - z/z_2| > 0$$

Structural Modeling Results

| Disc | Inner disc cutoff r_1 [AU @ d=450 pc] | Outer disc cutoff r_2 [AU] | Vertical half-height z_2 [AU] | Power law exponent k | Inclination θ [deg] | Edge-on optical depth τ_{\max} | Inferred disk lower- limit mass (M_{solar}) (d) |
|---------|--|---------------------------------|------------------------------------|------------------------------|-------------------------------|---|---|
| HST10 | 27+- 27 | 95 +- 5 | 20 +- 7 (a) | 3.5 +- 2.5 | 82+- 7 (a) | 150 +- 100 | 5 e-4 |
| HST16 | 54 +- 36 | 202 +- 45 (b) | 45 +- 22 | 4.9 +- 1.3 (b) | 45 +- 5 | 60 +- 40 | 2 e-3 |
| 114-426 | 13+- 13 | 720 +- 45 | 99 +- 45 (c) | 2.9 +- 1.1 | 79 +- 8 (c) | 150 +- 100 | 1.3e-2 |

a,b,c: Parameter pairs vary together; see plots for relationships

d: Extreme lower limit: assumes no macroscopic ($> 10 \mu\text{m}$) particles; $M_{\text{gas}}/M_{\text{dust}} = 150$.

Disc radial exponents are steep enough ($k = 3-5$) s.t. discs are self-terminating. Discs which are not UV-illuminated (*i.e.*, not subject to photo-evaporation) are still opacity-terminated, suggesting that termination is due to transport, grain growth, or initial conditions. The k are generally higher than that measured in inner disc regions ($k=1-2$, *e.g.*, Beckwith *et al* 1990).

III. Disc Evolution

UV photoevaporation of disks may play a strong role in disk evolution. The photosputtering timescale for ice dust $t_{sputter} (1\mu\text{m})$ and the inner-disc grain collision time t_{coll} (Ruden & Pollack 1991) are of comparable times, $t \sim 1\text{-}10$ yr. Both processes are fast, and the slight dominance of one over the other may have significant implications for planetary formation statistics. If the Trapezium is typical of star-forming regions, the processes seen here are likely to be highly relevant to planetary formation elsewhere.

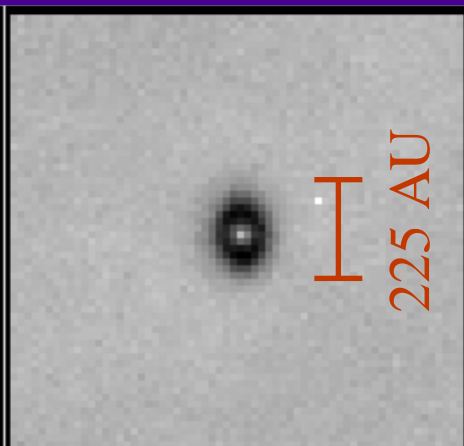
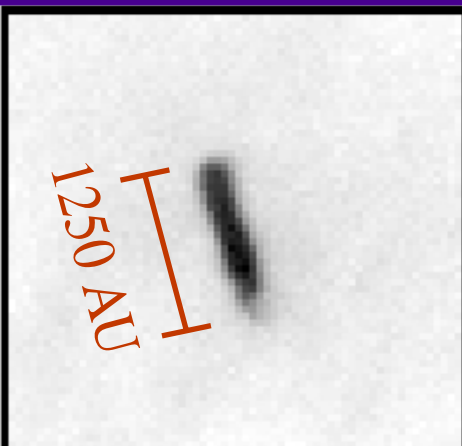
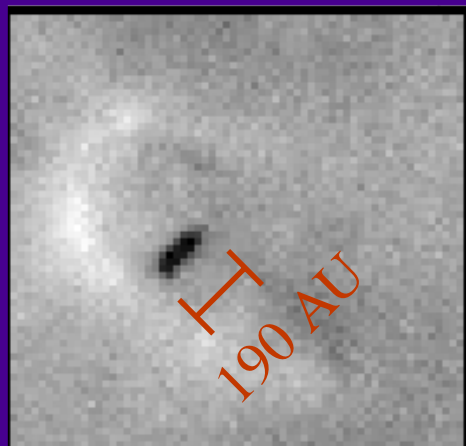
The competition between photoevaporation and coagulation has not been examined previously. We are currently implementing an evolutionary model which will track the size distribution and optical depth of particles at the outer disc edge. Processes modeled include UV photoevaporation of gas and dust, coagulation, and inward radial transport in a convecting young circumstellar disk.

References

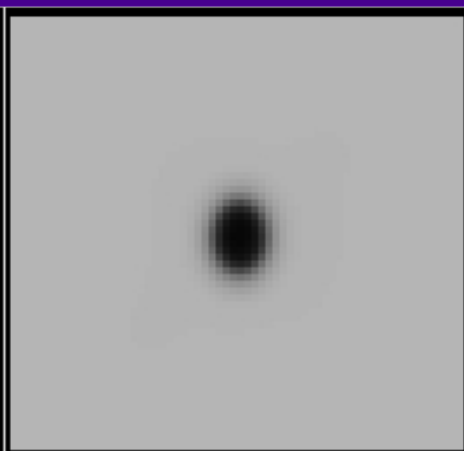
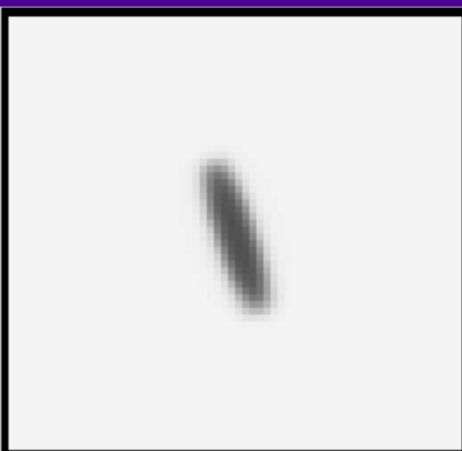
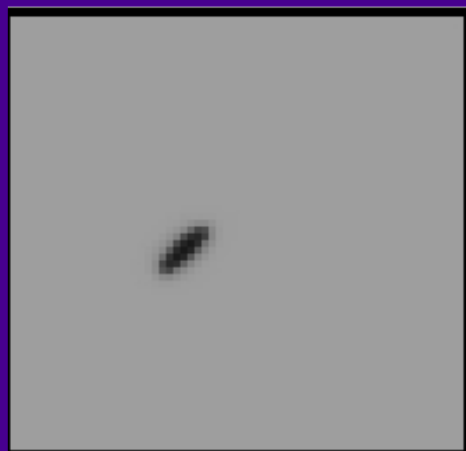
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Conclusions / Future Work

- First visible-light observation and measurement of accretion & large particles in young circumstellar discs
- Particle growth is fast, even at outer disc edge
- Observations needed at longer λ to probe larger particles
- Discs are self-terminated, independent of UV photoevaporation
- UV photoevaporation / photosputtering could inhibit planet formation, depending on balance between processes.
- Modeling of UV-influenced disc evolution in progress



Data



Best-fit
Model

HST10
WFPC2, 0.66 mm

114-426
WFPC2, 0.5 mm

HST16
WFPC2, 0.66 mm