N87-15063

Grain Processes In Massive Star Formation

Mark G. Wolfire - NASA/Ames and Joseph P. Cassinelli - U. of Wisc.-Madison

Observational evidence suggests that stars greater than 100 $M_\odot$ exist in the Galaxy and LMC (Humphreys and Mc Elroy 1984, De Jager 1980), however classical star formation theory (Larson and Starrfield 1971, Kahn 1974) predict stellar mass limits of only ~60 $M_\odot$. A protostellar accretion flow consists of inflowing gas and dust. Grains are destroyed as they near the central protostar creating a dust shell or cocoon. Radiation pressure acting on the grains can halt the inflow of material thereby limiting the amount of mass accumulated by the protostar. We first consider rather general constraints on the initial grain to gas ratio and mass accretion rates that permit inflow. We further constrain these results by constructing a numerical model. Radiative deceleration of grains and grain destruction prcesses are explicitly accounted for in an iterative solution of the radiation-hydrodynamic equations.

At the outer boundary grains see the infrared field emitted by warmer grains in the shell's interior. The outward radiative force must be less than the inward gravitational force

$$\Gamma = \left|\frac{\text{radiation}}{\text{gravity}}\right| = \frac{k_F L/4\pi r^2 c}{GM/r^2} < 1 \tag{1}$$

where k_F is the flux mean of the dust opacity. We here approximate k_F by $k_B(\mathrm{T_{rad}})$, the Planck mean of the radiation pressure coefficient, where $\mathrm{T_{rad}}$ is some characteristic temperature of the incident radiation field. The maximum of $\mathrm{T_{rad}}$ has been chosen to be 2000 °K since we believe that grains at the cocoon's inner edge will be destroyed before they can be heated to such a temperature. The opacity is calculated using an assumed grain model. As a standard we use the Mathis, Rumpl, Nordsieck (1977) (MRN) grain model which consists of graphite and silicate grains ranging in size between $a_- = 0.005\ \mu$m and $a_+ = 0.25\ \mu$m and is distributed in size as $a^{-3.5}$. Since the wavelength of the incident infrared light is generally larger than the grain size, the dominant source of opacity comes from the larger grains where most of the mass resides. We find infall onto a 100 $M_\odot$ core is allowed, for a wide range in $\mathrm{T_{rad}}$, if the total grain number abundance is reduced by a factor of 4 relative to the standard MRN grain model and graphite grains larger than 0.2 times the MRN maximum size grains are depleted.

At the shell's inner edge, the outward radiation pressure must be less than the dynamic pressure of infalling material. If all of the stellar radiation field is absorbed in a thin region at the inner edge of the dust shell, r_1, then it is necessary that

$$\left|\frac{\text{radiation pressure}}{\text{dynamic pressure}}\right| = \frac{L/c}{\dot{M} v_{ff}(r_1)} < 1 \tag{2}$$

where $\dot{M}$ is the mass accretion rate and $v_{ff}(r_1)$ is the free-fall velocity at r_1. We estimate the dust destruction radius by equating radiative heating by the central star to radiative cooling at the grain sublimation temperature. We use the largest graphite grain size that satisfies the outer boundary condition, $a_+ = 0.05\mu$m, and assume here $T_{sub} = 1800$ °K. Since the free-fall velocity is the largest possible inflow velocity we get an estimate of the minimum rate of mass inflow necessary for accretion to continue. We find that inflow onto a 100 $M_\odot$ core requires a mass accretion rate of $> 10^{-3}$ $M_\odot$ yr^{-1}.

Proper estimates of limits on $\dot{M}$ and initial grain conditions require us to account for the deceleration of the flow between shell boundaries due to radiation pressure and to calculate grain destruction processes acting in the inflow. Processes of sublimation and vaporization by grain-grain collisions is considered for graphite and silicates plus surface reactions for graphites. We use the method of Wolfire and Cassinelli (1986) to calculate the grain temperatures and radiation field throughout the accretion flow. The rate of destruction depends on the grain composition, size, temperature, and inflow speed, therefore different grains are destroyed at different radial distances.

Accretion onto a 100 $M_\odot$ core was maintained for $\dot{M} = 5 \times 10^{-3}$ and a grain to gas ratio of 1/8 the standard Galactic value. This is a higher mass inflow and lower grain abundance than that estimated by the simple boundary conditions. The additional constraints are a result mainly of the deceleration of the inflow from the infrared radiation emitted by grains near the shell's inner edge that was not accounted for in the boundary conditions.

Silicate grains are destroyed by sublimation. About half of the mass of graphite grains are removed by surface reactions and half by sublimation. Vaporization by grain-grain collisions are found to be negligible.

These findings seem to suggest that star formation by spherical accretion requires rather extreme preconditioning of the grain and gas environment.

References

Humphreys, R. M. , and Mc Elroy, D. B. 1984, *Ap. J.*, **284**, 565.

De Jager, C. 1980, *The Brightest Stars*, (Dordrecht: D. Reidel).

Kahn, F D. 1974, *Astr. Ap.* , **37**, 149.

Larson, R. B. , and Starrfield, S. 1971, *Astr. Ap.* , **13**, 190.

Mathis, J. S. , Rumpl, W. , Nordsieck, K. H. 1977, *Ap. J.* , **217**, 425 (MRN).

Wolfire, M. G. and Cassinelli, J. P. 1986, to be published in Nov. 1 *Ap. J.*.