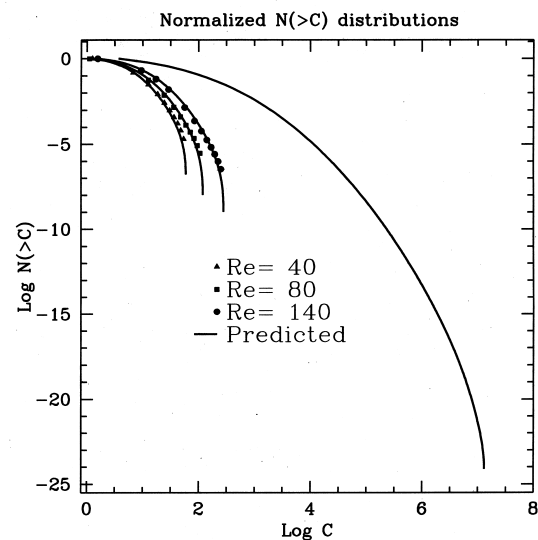


TURBULENT CONCENTRATION: FRACTAL DESCRIPTION, SCALING LAWS, AND GENERALIZED APPLICATIONS TO PLANETESIMAL ACCRETION. J. N. Cuzzi¹, R. C. Hogan², A. R. Dobrovolskis³; ¹Ames Research Center (Space Science Division, 245-3, Moffett Field, CA 94035; cuzzi@cosmic.arc.nasa.gov), ²Symtech, Inc., ³UC Santa Cruz.

We proposed [1] that a plausible level of 3D nebula turbulence in the terrestrial planet region selects chondrule-sized solids (chondrules and nonspherical clastic fragments) for strong concentration, leading to loose "primary aggregates" which, we further hypothesized, then settle *en masse* to the nebula midplane, compacting through a series of stages to become solids. Extrapolations from numerical simulations to nebula conditions led to expected concentration factors of $10^5 - 10^6$ under likely nebula conditions. Since that time, new data on disaggregated chondrule size distributions has been shown to be in excellent agreement with the predictions of our numerical models [2]. In a separate abstract [3] we discuss other comparisons of theory and data on chondrule rims. Here we note two new results.

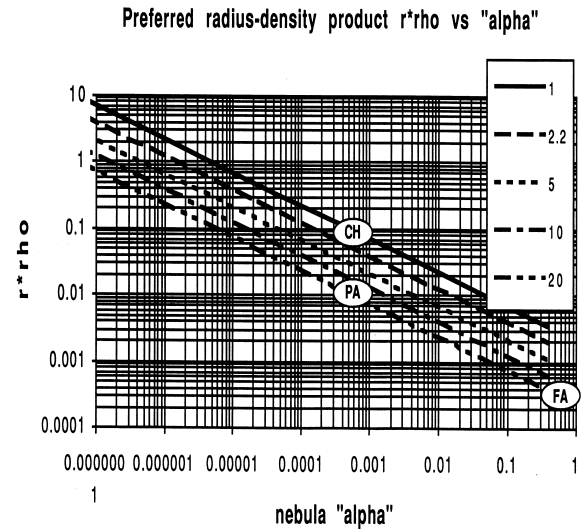
We first note our recent result [4] that the spatial distribution of nebular particle mass density ρ under Turbulent Concentration (TC) has a "multifractal" nature very similar to that of the dissipation of turbulent kinetic energy k , for which a considerable amount of work has been done by turbulence physicists [5]. Multifractal distributions result from cascade processes, and have characteristic scaling functions which predict how the function varies with spatial scale in a statistical sense. The relevant properties of fractals for the case at hand will be described. We use the flow Reynolds number $Re = \alpha c H / \nu$, where α is the usual nebula turbulence parameter, c is sound speed, H is scale height, and ν is molecular viscosity. The shape of the scaling function is not only quite similar for ρ and k , but also displays Re -independence in both cases, leading us to hypothesize that the TC process is, like the transfer of energy down the turbulent inertial range, a cascade process. We have related the multifractal descriptors of ρ to the probability distribution of ρ in the nebula, using only Re as a parameter. We thus avoid mere extrapolation as in our earlier work [1], and the result is more robust. Figure 1 shows the

cumulative volume fraction occupied by regions with particle concentration factor larger than some value C . In the upper left corner are "data" (triangles, squares, and circles) taken from numerical simulations at three values of flow Reynolds number. The Reynolds numbers shown on the figure are the Taylor microscale versions which are equal to $(15 Re)^{0.5}$; thus for these flows, $Re=100$, 400, and 1300 respectively. The smooth curves in figure 1 are the predicted volume fractions obtained using our Re -independent scaling laws [2]. In these curves, the value of Re is the only variable. The agreement with the data taken directly from each simulation is quite good, and validates the approach.



The smooth curve without points is the prediction for nebula Re ; assuming $\alpha = 10^{-3}$, $Re = 10^9$. Large concentration factors C are seen to occur with interesting probability under plausible nebula conditions - for instance, for $C = 5 \times 10^5$, a fractional volume of 10^{-12} , or one dense zone in a box 10^4 km on a side, is implied. There are many such zones in a column extending through a nebula scale height.

We next point out that the TC process has more general application than merely to chondrules and chondrites. Particles that are selected for strong concentration are those with stopping time equal to the eddy turnover time of Kolmogorov scale eddies [1]. The stopping time t_s is a function of gas density ρ_g and particle internal density ρ_s as well as particle radius: $t_s = r\rho_s/c\rho_g$. Recently Wood [6] noted that turbulent concentration can concentrate even tiny solid grains, which have extremely small t_s , if the Kolmogorov scale eddies have an extremely short overturn time - which can be produced by high nebula Reynolds number (equivalently, " α " close to unity; [1]) - and the gas has an extremely low density. These conditions might prevail at very high altitude in the nebula during the infall stage. In figure 2 we present the general relationships for objects suitable for strong selective concentration in nebula turbulence over a range of α and nebula density, as related to radial location (lines labeled by location in AU) in a standard model [7]. Objects are aerodynamically characterized by the product $r\rho_s$; thus large, low density objects behave like small, high density objects. As examples we define three types of likely particles: solid chondrules (CH), porous aggregates (PA) perhaps representing unmelted "chondrule precursors", and fluffy fractal aggregates (FA) with dimension 2 made from individual micron radius mineral monomers. For FA's, the stopping time is identical to that of a single mineral grain because the density varies inversely with the radius, so the implications (large α , low ρ_g) are much as in [6].



Note that while the terrestrial planet region selects CH type particles for concentration, the outer planet region, with lower gas densities, concentrates PA's instead, even at the same level of turbulence. This is not of trivial interest, since one of the primary obstacles to planetesimal growth is in the meter-size range, where relative velocities from differential gas drag or turbulent forcing are close to disruptive [8]. TC might help growing particles leapfrog this awkward stage in their development. Nominal nebula properties at 5 AU, and concentration factor of 10^6 , produce clumps of PA with an "effective" (unit density) radius of $5f^{0.33}$ meters, where f is the fraction of solids in the most effectively concentrated $r\rho_s$ range.

[1] JN Cuzzi et al., 1996, in "Chondrules and the Protoplanetary Disk"; Hewins, Jones, and Scott, eds. [2] JM Paque and JN Cuzzi 1997, XXVIII LPSC; [3] JN Cuzzi et al., 1998, XXIX LPSC (this volume); [4] RH Hogan et al., 1998, Phys Revs, submitted; [5] Menevaux and Srinivasan 1991, J. Flu. Mech. 224, 429; [6] JA Wood 1997, XXVIII LPSC; [7] JN Cuzzi et al., 1993, Icarus 106, 102; [8] S Weidenschilling and JN Cuzzi 1993, Protostars and Planets III