ORIGINS OF THE REGULAR SATELLITES OF JUPITER AND SATURN. I. MOSQUEIRA, NASA Ames Research/SETI.

In the nucleated instability model of planet formation most of the mass of solids resides in planetesimals of size greater than 1 km [1, 2]. Planetesimals may dissolve in the envelopes of the forming giant planets, thus enhancing the planet's metallicity [3]. Most of this high-Z mass delivery takes place before the cross-over time, when the mass of the gaseous envelope grows larger than that of the core. This stage is then followed by a dilution during runaway accretion, depending on the amount of gas accreted during this brief phase of the planet's growth [4]. The giant planet then reaches its final mass, shedding angular momentum as its envelope collapses, a circumplanetary disk forms and planetesimals in its feeding zone undergo a period of intense collisional grinding. In the Jupiter-Saturn region the collisional timescale for kilometer-sized objects is similar to the ejection timescale, so that a fraction of the mass of solids will be fragmented into objects smaller than a 1 km [5, 6]. The mass contained in planetesimal fragments in the meter (the gas-decoupling size) to kilometer mass range can be delivered to the circumplanetary disk by inelastic or gravitational collisions taking place in the Hill sphere of the planet [7, 8, 9, 10], or by ablation through the subnebula gas disk [11, 12]. At any rate, reprocessing of planetesimals and of their trapped volatiles [13, 14] needs to be explicitly considered in interpreting observations of Titan [15, 16] and the medium-sized, icy Saturnian satellites [17, 18, 11].

Given the similarities in the bulk properties of the regular satellites of Jupiter and Saturn, a unified satellite formation model is justified. Yet, the differences between the two satellite systems are also significant. In particular, unlike the Galilean satellites, the densities of the Saturnian satellites exhibit no trend as a function of radial distance from the central object. In order to frame these observations, we will discuss two different satellite formation models that span the range from a gaseous to a gas-poor circumplanetary disk, treat planetesimal dynamics explicitly, and are based on different assumptions regarding the turbulent state of the subnebula at the time of satellite formation. In the gaseous, solids-enhanced minimum mass (SEMM) model [19, 10] the subnebula turbulence is taken to decay as Roche-lobe gas inflow ebbs, and satellite survival hinges on gap-opening by the largest satellites [20]. This model is backed up by recent laboratory [21] and numerical [22] results that strongly suggest that hydrodynamical turbulence cannot transport angular momentum efficiently in Keplerian disks[1]. Realistic, albeit preliminary, scenarios will be discussed that lead to the formation of such a disk in a relatively short timescale, account for the angular momentum budget of the regular satellites, and ultimately provide a connection to the spin angular momentum of the planet. On the other hand, assuming that turbulence drives the continued evolution of the subnebula, we have developed a gas-poor planetesimal capture (GPPC) model that can account for the mass and angular momentum budgets of the regular satellites of Jupiter and Saturn [8]. This model addresses a late-phase in which an already dense circumplanetary disk collisionally captures infalling planetesimal fragments. Neither model relies on specific choices for the turbulence parameter; both models tie in with giant planet formation, and encompass a sufficiently broad observational sample.

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[1] For accretion disks to accrete onto the central object, angular momentum must be transported outwards. While sufficiently magnetized, differentially rotating disks are known to be subject to a local instability or MRI [23], significant portions of the disk may have ionization that is too low for MRI to be effective, creating a ``dead zone" [24]. The extent of the active region is sensitive to the presence of dust particles and other parameters. On the other hand, in the absence of an MHD mechanism, one would have to resort to a purely hydrodynamic mechanism. It is well known that hydrodynamic Keplerian disks are stable to linear perturbations. A number of studies have suggested transient growth bypass excitation leading to non-linear behavior that is not subject to linear stability analysis [25, 26, 27]. However, simulations [22] and laboratory experiments [21] cast doubt on the ability of purely hydrodynamic turbulence to transport angular momentum efficiently in Keplerian disks even for high Reynolds number [28]. The task at hand is not just to excite turbulence but also to sustain it. Although the evidence that such disks are laminar is not conclusive because the Reynolds numbers in astrophysical disks are much larger than those accessible to computers or experiments, there is presently no reason to suppose that nearly inviscid flows are unphysical in all regimes of interest. At present we lack a mechanism that can sustain turbulence in a dense, mostly isothermal subnebula. In order to sidestep this problem, one is forced to postulate a low-density gas disk *ab-initio*, and invoke MRI turbulence. But the presence of dust complicates the situation even in the low density case. Adopting $\alpha \sim 10^{-3}$ for the subnebula involves *three* independent assumptions and is unjustified.

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