DID COSMOLOGY TRIGGER THE ORIGIN OF THE SOLAR SYSTEM? H.-J. Blome[1] and T. L. Wilson[2], [1]University of Applied Sciences, Hohenstaufenallee 6, 52066 Aachen, Germany, [2]NASA, Johnson Space Center, Houston, TX 77058.

Introduction: It is a matter of curious coincidence that the Solar System formed 4.6 billion years ago around the same epoch that the Friedmann-Lemaitre (FL) universe became Λ-dominated or dark-energy-dominated, where Λ is the cosmological constant [1]. This observation was made in the context of known gravitational anomalies that affect spacecraft orbits during planetary flyby's [2] and the Pioneer anomaly [3], both possibly having connections with cosmology.

In addition, it has been known for some time that the Universe is not only expanding but accelerating as well [4,5]. Hence one must add the onset of cosmological acceleration in the FL universe as having a possible influence on the origin of the Solar System.

These connections will now be examined in greater detail.

The Modified Kepler Problem: For the FL model of Big Bang cosmology, we have shown [1,3] that Newton's law for the Kepler problem involving motion about a mass M is modified by an additional term

$$\ddot{\vec{r}} = -\frac{GM}{r^2}\hat{r} + \frac{\ddot{a}}{a}\vec{r} \quad , \qquad (1)$$

using spherical coordinates (r,θ,φ). The extra term is a tidal term created by the Riemann curvature tensor. It includes $\ddot{a}$ and $\dot{a}$ representing respectively the acceleration and velocity of a, where a is the FL scale factor of expansion, and the dots correspond to differentiation with respect to time. (1) can be re-expressed in terms of the Hubble parameter $H=\dot{a}/a$ and the deceleration parameter q

$$\ddot{\vec{r}} = -\frac{GM}{r^2}\hat{r} - qH^2\vec{r} \qquad (2)$$

where q is defined as $q = -\ddot{a}a/\dot{a}^2$, and $q \rightarrow q_o$ represents the value of q today. The effects of q and H in (2) can be visualized as depicted in Figure 1.

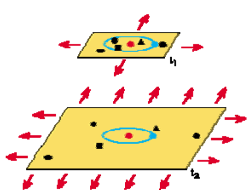

Figure 1. Local tidal expansion of Keplerian conic in space-time.

Tidal Triggering of Nebula Formation: Collapse of a nebular cloud to form the Solar System likewise involved tidal forces. Foremost was the Jeans instability [6] which causes collapse of interstellar gas clouds and eventual star formation. That introduces the notion of the Jeans mass, defined as the critical mass a volume of space can contain before it will collapse under the force of its own gravity. Such a cloud begins to collapse when it lacks sufficient gaseous pressure to balance the force of its own gravity. This can include Λ-induced negative pressures known in cosmology.

There exist many factors, then, that contribute to nebular collapse. These include cosmological tidal perturbations depicted in Figure 1 and 2, near-by supernovae explosions that can force additional matter into the nebular cloud, and passing stars and galaxies that introduce gravitational perturbations in the cloud.

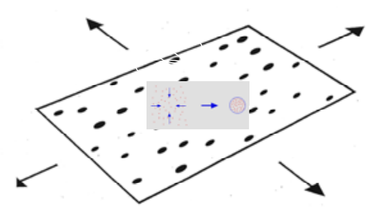

Figure 2. Tidal triggering of nebular cloud collapse.

Such tidal triggering mechanisms [7-10] notably can involve *compressive* radial tidal forces that excite the onset of Jeans instability [11] as well as negative cosmological pressures introduced by Λ.

Cosmological Dynamics: The Hubble term qH^2 in (2) will prove to be the center of focus as the universal interaction term that must be involved in the tidal dynamics of nebular collapse. In order to understand and visualize cosmological dynamics during the origin of the Solar System, several items from FL cosmology need to be presented.

The analytic solutions for flat accelerating FL models with $\Lambda \neq 0$ are well-known [5]

$$a(t) = a_o \sqrt[3]{\Gamma(\cosh y - 1)} \qquad (3)$$

where $y=t/\tau$ with $\tau=(3\Lambda c^2)^{-1/2}$, $\Gamma=\Omega_m/\Omega_\Lambda$, and Ω_m and Ω_Λ are the contributions of baryonic matter m and Λ to the closure parameter Ω, respectively. The age of the FL universe t_o, q, and qH^2 are given by

$$t_o = \frac{2}{3H_0\sqrt{\Omega_\Lambda}} \operatorname{arcsin} h\left(\frac{\Omega_\Lambda}{\Omega_0}\right) = 13.8x10^9 \, years \qquad (4)$$

$$q = \left(\frac{2-\cosh y}{1+\cosh y}\right) \qquad (5)$$

$$qH^2 = \left(\frac{2-\cosh y}{1+\cosh y}\right)\left(\frac{1}{3\tau}\frac{\sinh y}{\cosh y - 1}\right)^2 \quad . \qquad (6)$$

The FL scale factor a in (3) is given in Figure 3. The age of the FL universe in (4) can be read for $a=1$ (today, $t=t_o$), as being 11.6, 13.8, 15.0, and 17.8 Gyr, for the values of Ω_Λ shown as 0.5, 0.71, 0.8, and 0.9, respectively. H_o is actually taken as 71 $kms^{-1}Mpc^{-1}$.

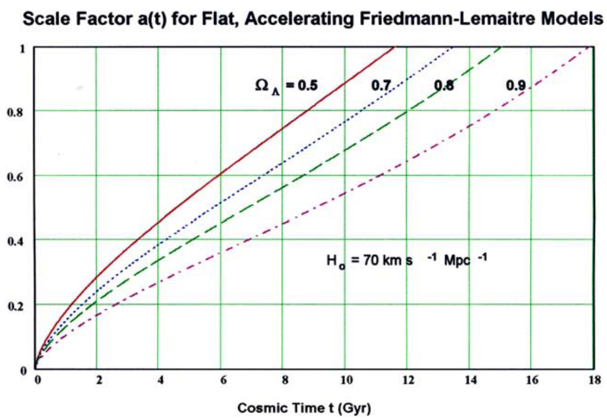

Figure 3. The FL scale factor *a(t)*.

To visualize q, it has been plotted in Figure 4. Throughout the age t_o = 13.8 Gyr of the FL universe, q is seen to vary considerably. This universe even undergoes a coasting transition when q~0 at $t(z^*)$=7.55 Gyr [12] whereupon the sign of q changes and establishes the onset of the accelerating universe. This is the point of inflection (*) occurring at redshift z^*=0.67, with Ω_Λ=0.7 and Ω_m=0.3 and $a^*/a_o = \sqrt{\Omega_m / \Omega_\Lambda} = (1+z^*)^{-1}$.

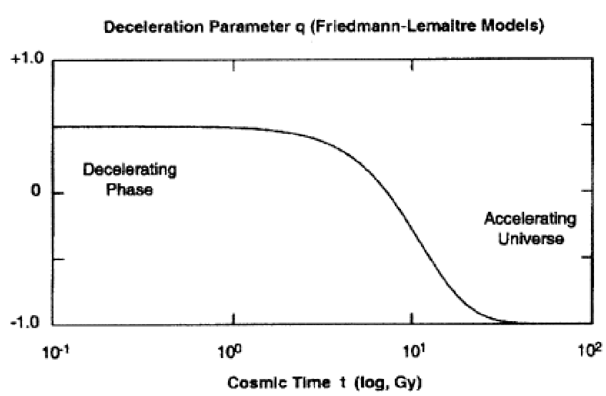

Figure 4. The deceleration parameter q.

The transition to a vacuum-dominated FL universe occurs when

$$\frac{R_\Lambda}{R_o} = \frac{a_\Lambda}{a_o} = \sqrt[3]{\Omega_{m,o} / \Omega_\Lambda} = \frac{1}{1+z_\Lambda} \qquad (7)$$

at the equilibrium redshift $z_{eq}=z_\Lambda$=0.32, noting that $R=ra(t)$. Using (4), this happens at $t_{eq}=t(z_\Lambda)$=10 Gyr.

Summary of the Hubble tidal term: There exist three phases of cosmological evolution in the FL universe. These are defined by $q=q(t)$ in (5), illustrated in Figure 4. (1) First is the early decelerating universe phase when q~+0.5. (2) Second is the rollover phase during which q transitions into a coast (q~0) region and changes sign. (3) Third is the accelerating universe phase that asymptotically continues in perpetuity with $q \sim -1$.

The Hubble tidal term qH^2 in (6) regulates the cosmological dynamics of the fundamental Newton-Kepler equation of motion in (2) at least to the second-order approximation used in deriving the Riemann curvature there [3].

Both the epoch of inflection $t(z^*)$=7.2 Gyr and the time of equilibrium t_{eq}=10 Gyr occurred during the second phase. Further, it is remarkable that these numbers approximately coincide with the origin of the Solar System 4.6 Gyr ago. Clearly the onset of acceleration at 7.2 Gyr could have played a role in triggering the origin of the Solar System at 9.2 Gyr.

Conclusions: The Jeans instability is a classical mechanism introduced in 1902, years before the advent of modern cosmology. Cosmology has since changed our understanding of tidal forces and perturbation theory. One of the most important things to realize is that the physics of q_o and H_o today is not the same as qH^2 was 4.6 Gyr ago when the Solar System formed. One can see this in Figures 3 and 4.

The Hubble tidal term qH^2 in (6) has now been defined and identified as a potentially important feature that played a role during the formation of the Solar System at the onset of acceleration in the FL universe which later became vacuum dominated. This is relevant to the formation of other planetary systems as well.

References: [1] Blome H.-J., Wilson T.L. (2010), *LPS, 41,* 1019. [2] Blome H.-J., Wilson T.L. (2009), *LPS, 40,* 1704. [3] Wilson T.L., Blome H.-J. (2009), *Adv. Spa. Res., 44,* 1345-1353. [4] Perlmutter S. et al. (1999), *Ap. J., 517*, 565. [5] Ries A.G. et al. (2000), *Ap. J., 536*, 62. [6] Jeans J.H. (1902), *Phil Trans. Roy. Soc. A, 199*, 1. [7] M.J. Henriksen, G. Byrd (1996), *Ap. J., 459*, 82. [8] Ballesteros-Paredes J. et al. (2006), *MNRAS, 395,* L81. [9] Torbett M.V. (1986), *MNRAS, 223,* 885. [10] Métivier L. et al. (2009), *EPSL, 278*, 370. [11] Masi M. (2007), *Am. J. Phys., 75*, 116. [12] Blome H.-J., Wilson T.L. (2005), *Adv. Spa. Res., 35,* 111.