ORIGIN OF PHOBOS AND DEIMOS: A NEW CAPTURE MODEL. S. Fred Singer, Univ. of Virginia; Science & Environmental Policy Project, 1600 S. Eads St, Ste 712-S, Arlington, VA 22202 <singer@sepp.org>

Introduction: The origin of the Martian satellites presents a puzzle of long standing. Conventional hypotheses either violate physical laws or have difficulty accounting for the observed orbits. Both satellites have near-circular and near-equatorial orbits. Phobos' orbit has been observed to shrink (since its discovery in 1877), indicating the influence of tidal perturbations. Extrapolating their orbits backward in time yields nearly identical circular orbits at the synchronous limit, followed by parabolic orbits suggesting capture **[1].** But there is no obvious mechanism for energy dissipation to capture of these small bodies; nor should such capture yield equatorial orbits **[2].**

Contemporaneous formation with the planet Mars is contradicted by dynamics. The obliquity of Mars' axis, about 25 , indicates formation by stochastic impacts of large planetesimals, at least in the last stages of Mars accumulation. But the equatorial orbits of the satellites would require that the obliquity of Mars changed quasi-adiabatically, i.e., very slowly compared to the orbital periods of the moons. This suggests that Mars acquired the moons only after its formation was completed, but it leaves the mechanism uncertain.

With capture and contemporaneous formation both unlikely, we propose a third possibility: Capture of a large Mars-Moon, during or shortly after the formation of the planet, with Phobos and Deimos as its surviving remnants. Arguments are given in favor of such a hypothesis and illustrative examples are shown.

Arguments for a Capture Origin of Phobos and Deimos:

1. Capture of a large body is dynamically easier, since the greater tidal friction is likely to dissipate sufficient kinetic energy to turn an initially hyperbolic orbit into a bound elliptic orbit.

2. A large Mars-Moon ***(M-M)*** would change the angular momentum of Mars in the capture process. Analogous to the Earth-Moon case, our calculations show that M-M's initial orbit would be inclined and even retrograde, but its final orbit would be prograde, near-equatorial, and at the synchronous limit.

3. Capture of M-M from a retrograde orbit would reduce the angular momentum of Mars, dissipate kinetic energy of rotation, and contribute internal heat energy required for melting the planet.

4. The close passage of the Mars-Moon within the Roche limit would have fractured it. Tidal friction would soon drive the largest pieces into Mars, with the smallest pieces remaining as Phobos and Deimos. Phobos is spiraling into Mars now and will disappear in a few million years; but Deimos, beyond the synchronous orbit limit, will survive against tidal friction.

5. The present orbit of Phobos makes it likely that more massive fragments existed in the past and have spiraled into Mars because of by tidal perturbation -- lifetime being inversely proportional to mass. ["If the dinosaurs had had better telescopes, they would have observed them.]

6. The present orbit of Deimos, just beyond the synchronous limit, provides an important clue about its origin

7. There are no ready alternatives to explain the origin of the Martian moons.

A fundamental prediction is that the moons are similar in composition and petrology. While they do not appear to be similar, this difference might be explained by differences in the regoliths covering their surfaces. We need both surface and deep samples to decide this issue, and to investigate whether Phobos and Deimos once formed parts of a larger body, most of which has now disappeared, perhaps by impacting on Mars.

A Sketch of the New Capture Hypothesis: We assume that near the end of the process of Mars assembly from planetesimals one body passed close enough to lose energy by tidal perturbation -- changing its orbit from parabolic to elliptic and so becoming captured. [There are several schemes available that would enhance such an energy loss.] The initial orbit is assumed to be retrograde. Also, the impact parameter is small enough to place the prospective Mars-Moon (M-M) well within the classical Roche limit to cause fragmentation. The pieces re-accrete after passage, but we are now dealing with a rubble pile.

Rather quickly , the orbit becomes prograde and near-equatorial **[3]** and ends up at the planet's synchronous orbit limit **[1].** Simultaneously, the planet undergoes changes in its spin angular momentum (and dissipates kinetic energy of rotation **[4]** into internal heating) in order to keep the vector sum of angular momentum of M + M-M constant.

But the synchronous orbit is unstable **[1]**, with the bulk of M-M ending up within that orbit and Deimos just beyond it. The bulk of M-M now spirals in towards Mars because of tidal perturbations. In the process, it may break up, with the most massive pieces spiraling in most rapidly. Phobos happens to be the smallest fragment and so survived to this day (but will die in a few million years). [If the dinosaurs had had better telescopes, they would have observed these larger fragments that have now disappeared.]

Illustrative Calculations: To illustrate the process, we carry out a simple sample calculation, relying mainly on conservation angular momentum and on published results of orbit evolution under the influence of tidal perturbations **[3,1].**

We start with the present angular momentum of Mars

$$J_M = I_M \, \omega = 1.79*10^{39} \text{ (in CGS units)}$$

We next set this value equal to the sum of the angular momenta of M and M-M when M-M is in a prograde synchronous orbit.

Thus $J_M = I_M \, \omega + m(GM)^{2/3} \, \omega^{-1/3}$

Numerically the equ becomes

$1.79 = 2.5*10^4 \, \omega + 7.8 \, \mu \, \omega^{-1/3}$

where μ=m/M,

with values chosen as $5*10^{-4}$. 10^{-3}, and $2*10^{-3}$.

From this equation we derive values of ω (synchronous angular velocity). period of rotation ***P***, and orbital radius r.

We also express r in terms of the planetary radius ***R*** as

ρ = r/R. [Its present value for Mars is 6.01 Martian radii.]

These values are presented in the Table below.

We now assume for simplicity that capture takes place with an impact parameter of ***2R*** (well within the classical Roche limit) and with an inclination of 180 Subtracting this orbital angular momentum of M-M from the present angular momentum of Mars (which is also the total angular momentum of the system), we can calculate the initial angular momentum J_i and angular velocity ω_i of Mars and the kinetic energy of rotation dissipated as M-M reaches its synchronous prograde orbit (when also the angular velocity of Mars reaches its minimum value).

Discussion: All known hypotheses about the origin of the Martian satellites involve some ad hoc assumptions; some also violate the laws of physics. The hypothesis that they may be the surviving fragments of a once-captured planetesimal requires a minimal number of assumptions and is not contradicted by any physical law. It may also serve to explain other observed features of Mars, such its early melting **[4].** Most important, it leads to definite predictions about Phobos and Deimos; they should be similar -- even though they look different.

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Based on research performed as Visiting Scientist at the Lunar & Planetary Institute in Houston in October 2002

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References:

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[3] H. Gerstenkorn. *Z. Astrophys*. **36**, 245-274 (1955); G.J.F. MacDonald. "Tidal Friction" *Rev. Geophys*. **2**, 467-544 (1964).

[4] S.F. Singer. LPSC 34. Abstract #1146 (2003)

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Parameters for Mars and Satellites (in CGS units)

Mars: Mass $M=6.4*10^{26}$; R_{mean}=3340 *km*; $I=2.5*10^{43}$

Present Values

Rot. period=24.6*hr* (88620 *s*); $\omega=7.1*10^{-5}$; $J_M=1.79*10^{39}$

Assumed values for m/M

μ:	**0.0005**	**0.001**	**0.002**
Values at Synchronous Orbit			
Ang. vel. **ω (**10^{-5}**)**	6.78	6.39	5.53
Period P (*hr*)	25.7	27.3	31.6
ρ=r/R	6.18	6.44	7.1
KE_{rot}/M (10^7)	9	8	6
Initial values for Mars			
Ang mom J_i (10^{39})	1.87	1.94	2.09
Ang vel ω_i (10^5)…	.7.5	7.8	8.4
Period P_i(*hr*)	23.3	22.3	20.7
KE_{rot}/M (10^7)	11	12	14
KE dissipated/M (10^7) ($KE_{init} - KE_{synch}$)	2	4	8

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