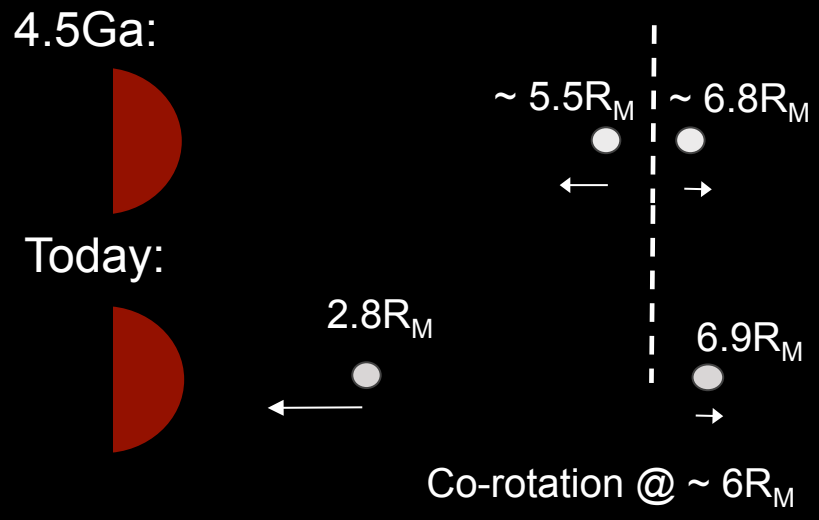
On an impact origin of Phobos-Deimos

Robin M. Canup and Julien Salmon

Southwest Research Institute

Phobos/Deimos properties

- Moons are very small compared to Mars (total mass 10^{19} g)
- Spectra resemble outer asteroid belt material *(e.g., Fraeman et al. 2014)*, and perhaps Mars in some respects *(e.g., Guiranna et al. 2011)*
- Nearly circular, co-planar orbits; Phobos has tidally evolved inward



(sizes not to scale)

Origin remains uncertain

1) Intact capture
   - Motivated primarily by spectra
   - But difficult to reconcile with nearly circular orbits

2) *In situ* formation from a disk
   - Impact with Mars could form disk *(e.g., Craddock 2011)*
   - But impacts that produce very low mass disks would not place material into orbits as distant as Deimos
   - A low-mass, compact disk could spawn moons, but they will be lost to inward tidal evolution *(Rosenblatt & Charnoz 2012)*

Requirements for impact origin

1) A big impact

- Mars may not have experienced the protracted stage of giant impacts that Earth did based on earlier formation time

  ~ 1 to 10 Myr for Mars *(e.g., Nimmo & Kleine 2007)*

  ~ 50 to 100 Myr for Earth *(e.g., Touboul et al. 2007)*

- But, Mars' 25-hr day implies impact by object with ~ few % of Mars' mass *(e.g., Dones & Tremaine 1993)*

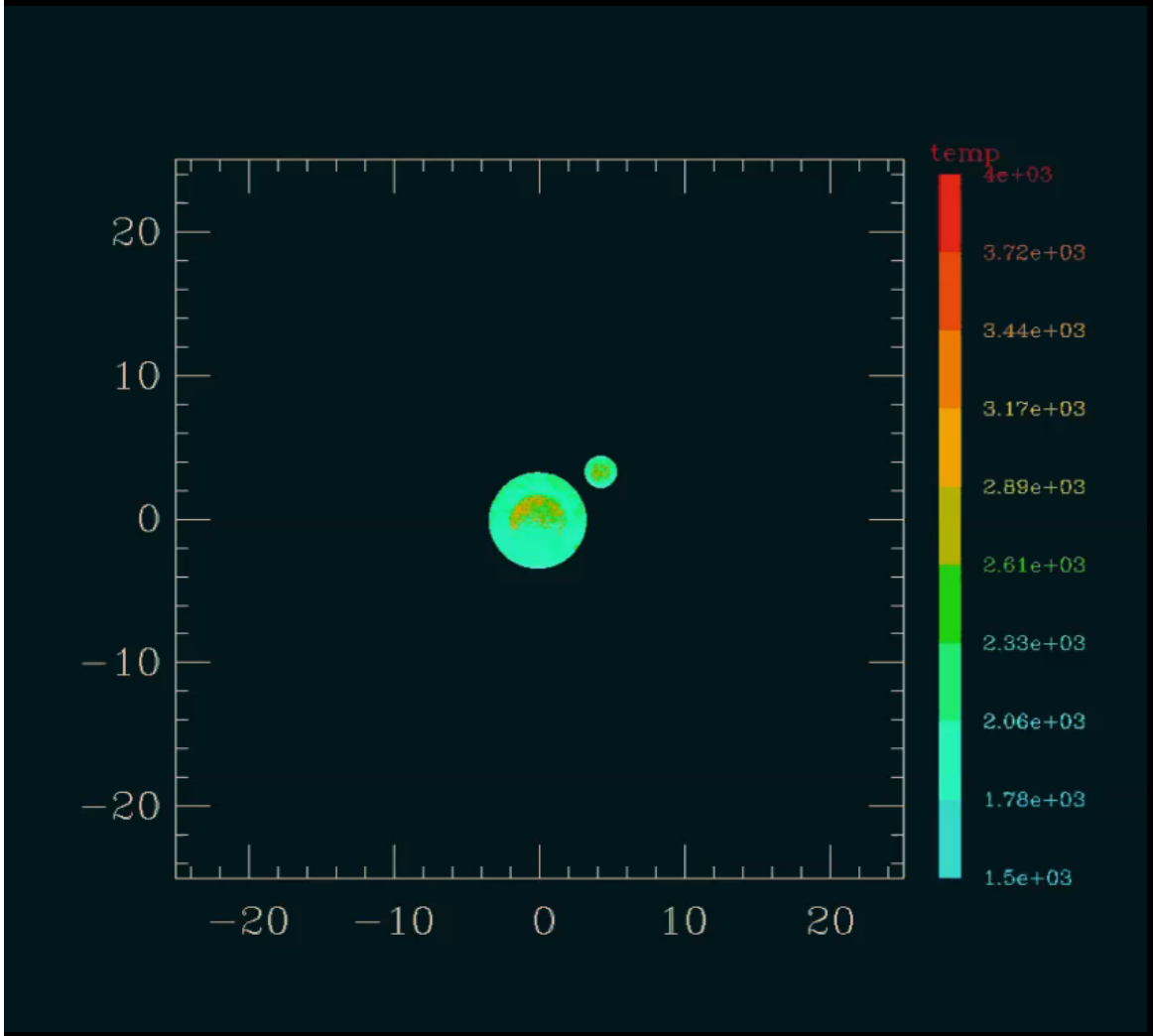
2) Disk mass ≥ mass of Phobos + Deimos

Could have been much larger since inner material would have tidally evolved into Mars

3) Outer disk edge near Deimos

Substantially more extended disk would have produced moons beyond Deimos that are not observed

Example impact generated disk at Mars



- 5×10^5 particle SPH simulation
- 0.03 Mars mass impactor, 45° impact angle, $v_{imp} = v_{esc}$

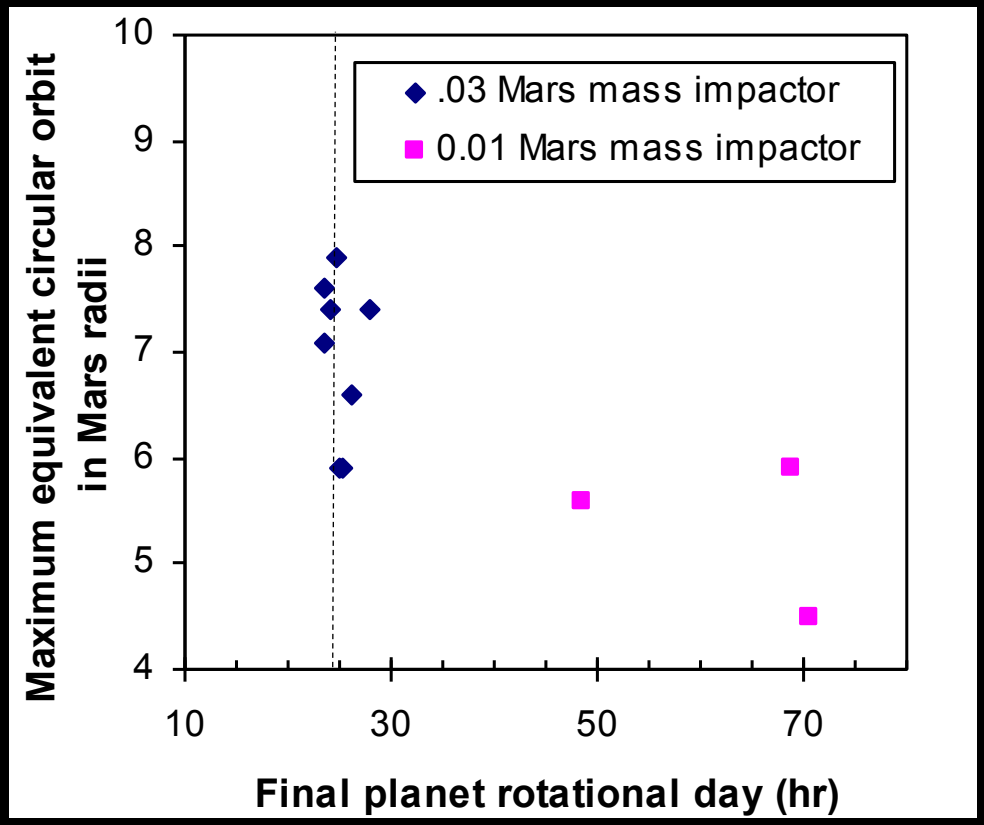
Results:

- Final day: 24-hr
- Disk with 7×10^{-4} Mars masses

Color: Temp in K (blue: 1500 K; red: > 4000K)
Salmon & Canup (2014)

Radial extent of impact generated disks

Impacts consistent with 25-hr day appear associated with disk edge near Deimos' orbit:



Salmon & Canup (2014)

- Results of 10 SPH simulations

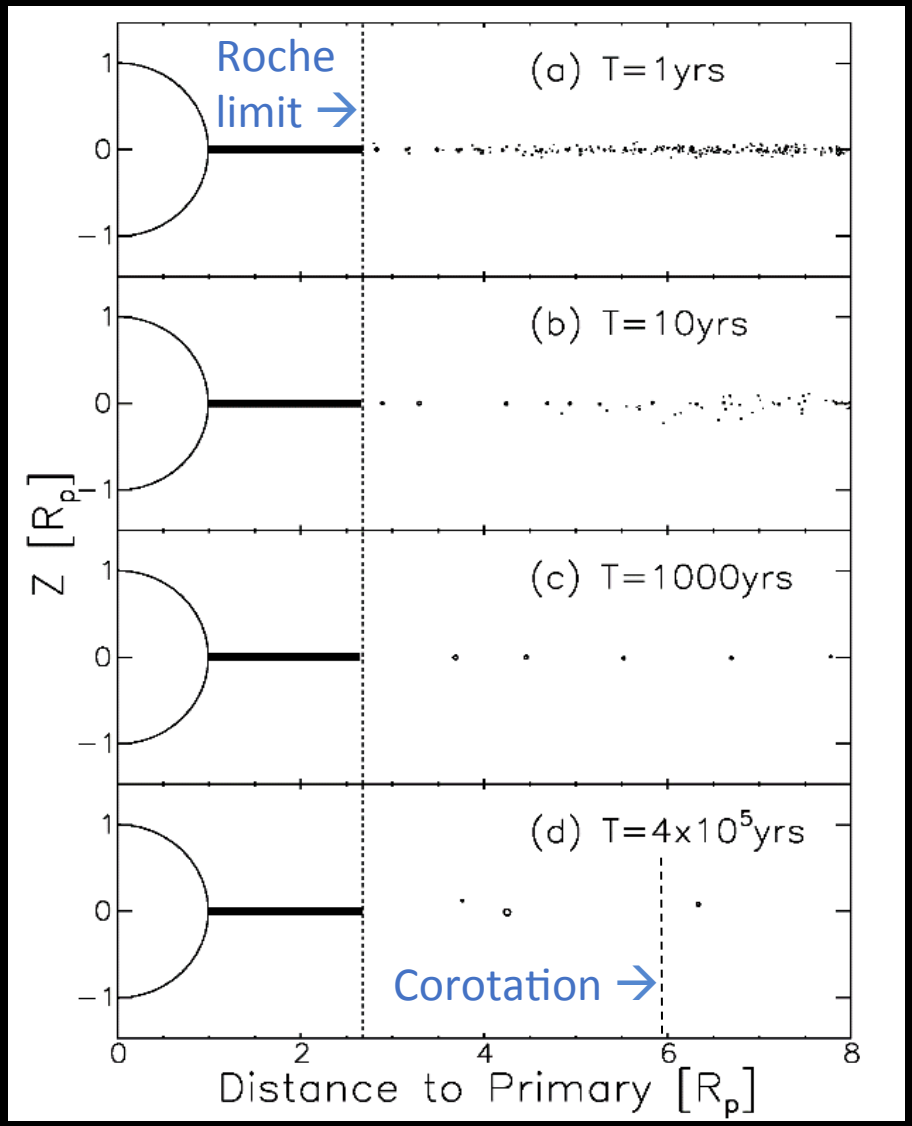
  33° to 55° impact angle

  $1 \leq v_{imp}/v_{esc} \leq 1.2$

- For each run, compute maximum equivalent circular orbit of bound disk material

  $a_{eq} = a(1-e^2)$

Accretion of moons



Concept: Outermost disk accumulates into P/D, while nearly all disk mass produces larger satellites inside co-rotation that are eventually lost

← Schematic/very low resolution simulation

- Salmon & Canup (2012) lunar accretion model
- Initial disk with 10^{-4} Mars masses
- Did not include tidal evolution

Physical implications of an impact origin

1) Moons' composition compared to Mars will be a function of fraction of disk from impactor vs. target
2) Bulk composition of P & D would be similar to each other
3) Rubble pile interiors, due to rapid cooling of disk material and tiny energy of accreting P & D
4) Ice-poor compositions because thermal velocities are ≥ local escape velocity from Mars

$v_{rms} = \sqrt{3RT/\mu}$ → 1.7 km/s [5 km/s] for H_2O [H_2] at 2000K

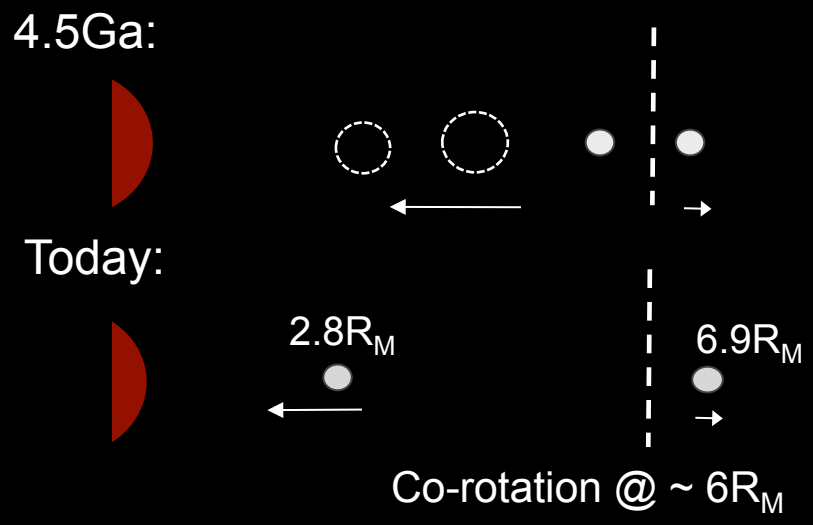
v_{esc} (6 to $7R_{Mars}$) = 1.9 km/s to 2 km/s

Such properties may be constrained by future Phobos/Deimos exploration

Conclusions

- Preliminary models suggest an impact origin is feasible
  - Only a small number of relatively low-resolution simulations so far
    Those here + ten impact simulations in Citron et al. (2015)
  - Additional processes may prove important
    E.g., pre-impact rotation in target, tidal evolution during accretion

- Implies a disk orders-of-magnitude more massive than Phobos & Deimos, with large inner satellites lost to inward tidal decay



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- There is overlap between type of impacts that can produce Mars' rotation and those that could produce the Borealis basin (Marinova et al. 2008; Nimmo et al. 2008).
  - Could be possible (although not required) to form P/D from Borealis impact (e.g., Citron et al. 2015)