Equilibrium figures

- Historical aspects
  - Collisions + reaccumulation
  - Rubble piles - Agrégats gravitationnels
  - Long spin period, elongated bodies, LASPA
    - Stars, planets and satellites spheroidal
    - Asteroids tri-axial ellipsoids, sometimes very elongated
  - What size barrier for rubble piles?

Gravity

- Different cases in this school

- small g
  - the granular systems on Earth,
    experiments and natural
- micro µg
  - granular and regolith on surface
    close to spin barrier v_esc, or not so close
- capital G
  - self gravitating bodies
    body scale > grain scale

Equilibrium figures

- Observations
- Shape models
  - Farinella
  - Magnusson
  - Holsapple
- Spin barrier
  - Rubble piles
  - Other forces in play ?

Triaxial Equilibrium Ellipsoids among the Asteroids?

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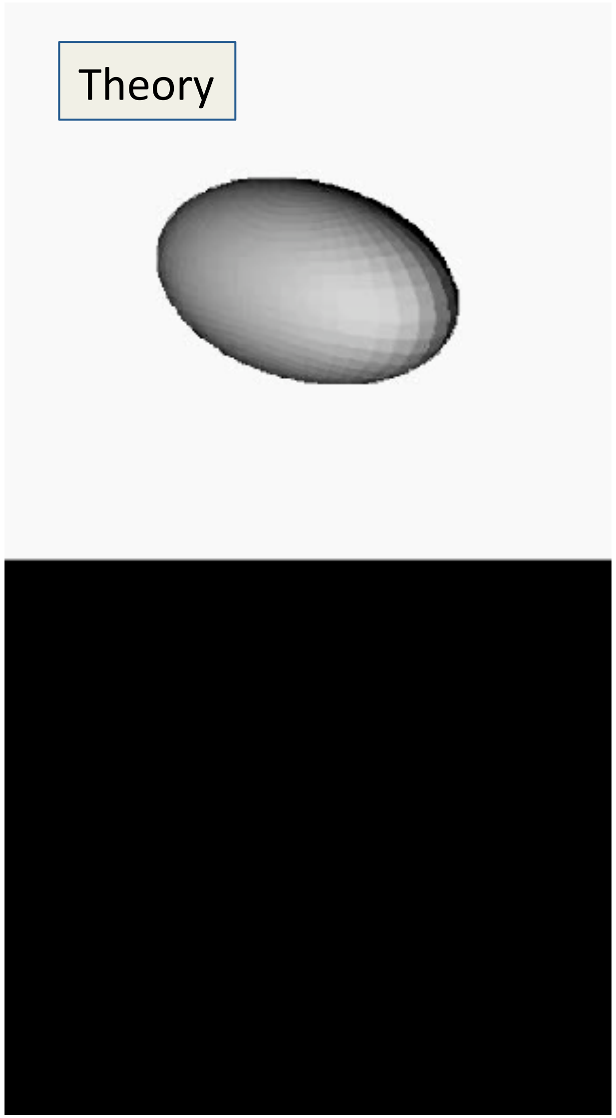
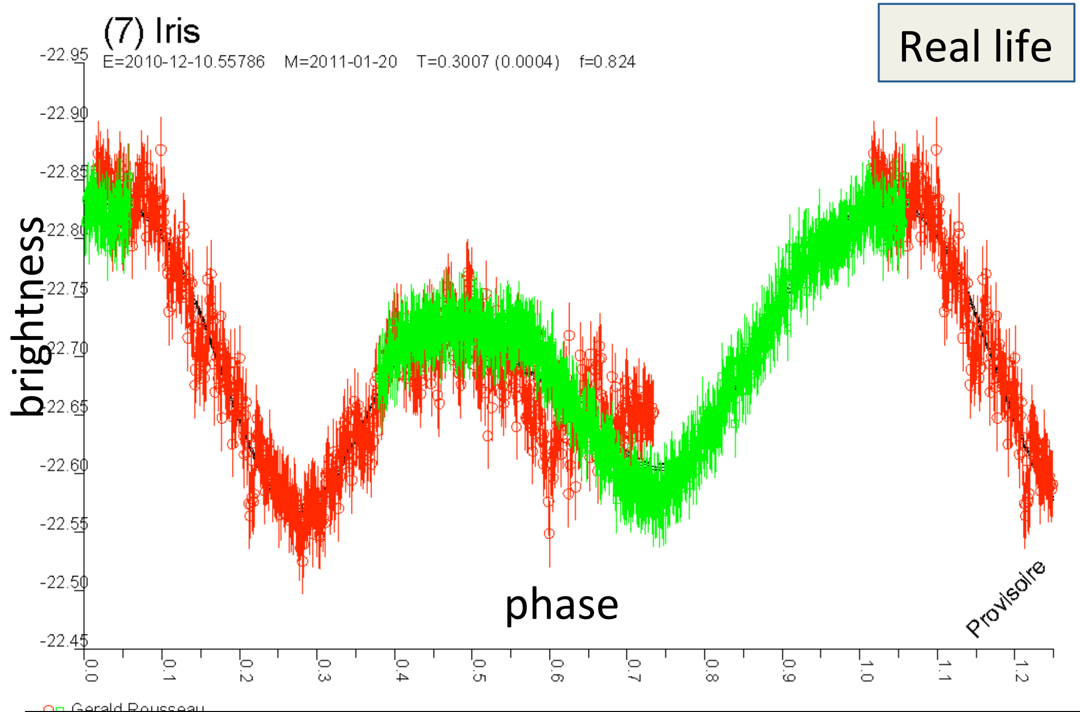
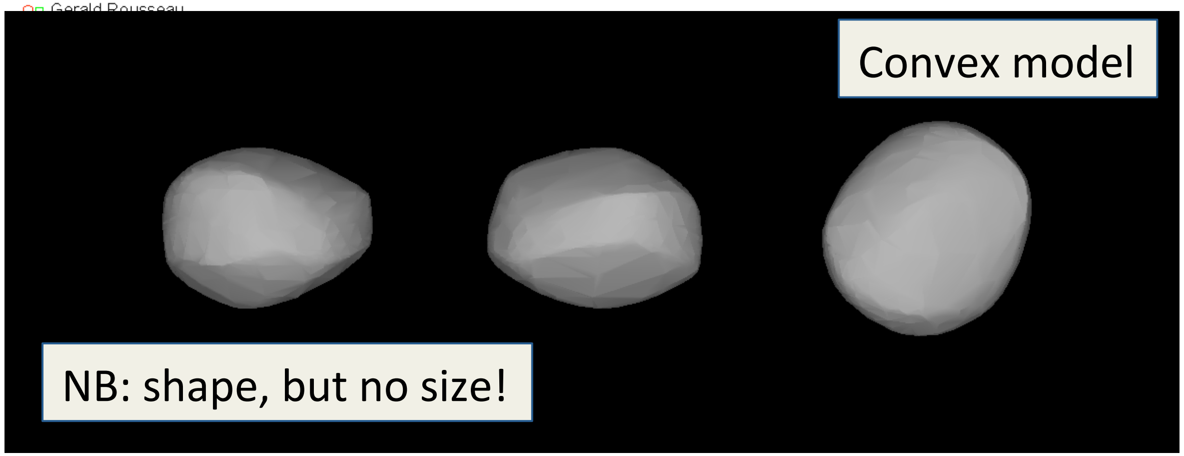
Received October 17, 1980; revised January 27, 1981

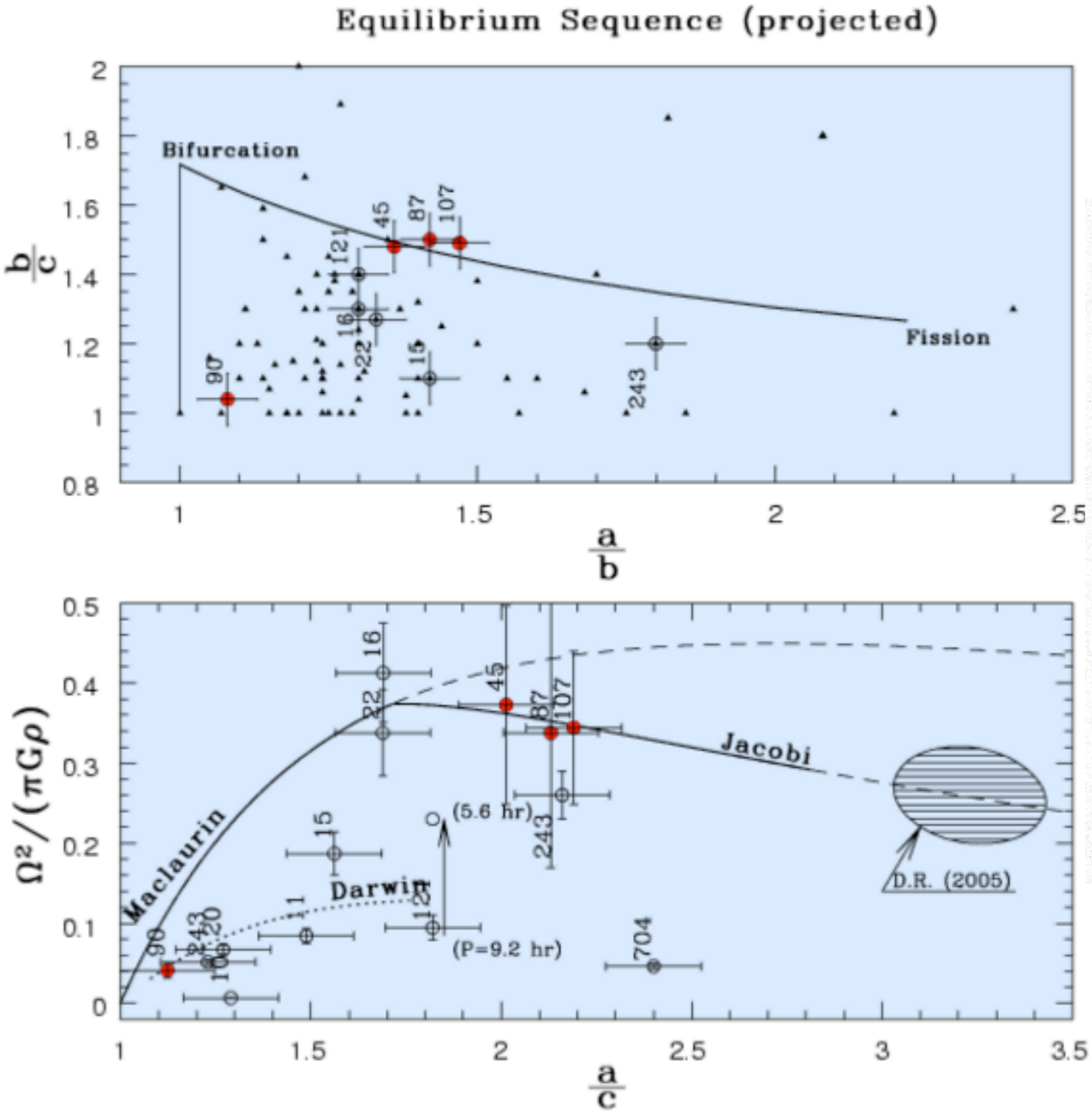
Shapes from LC

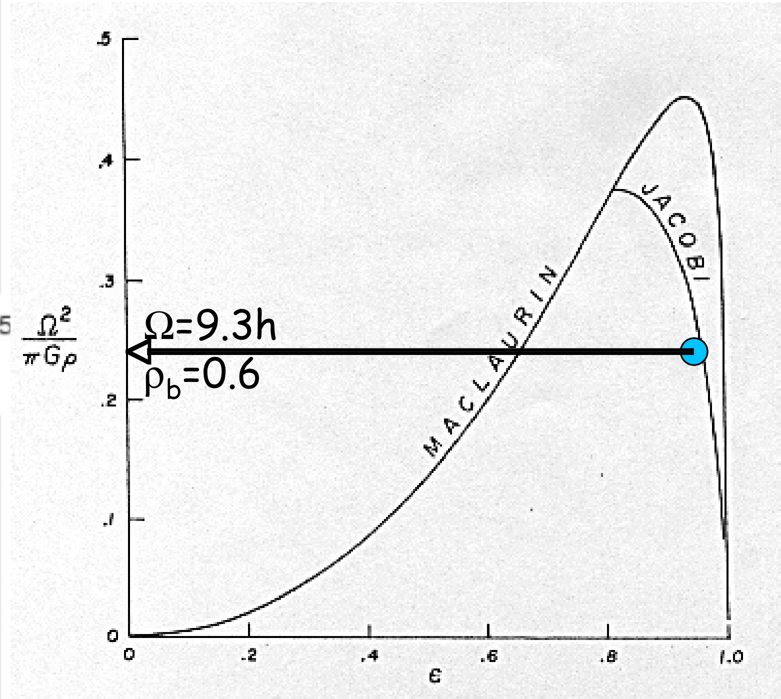






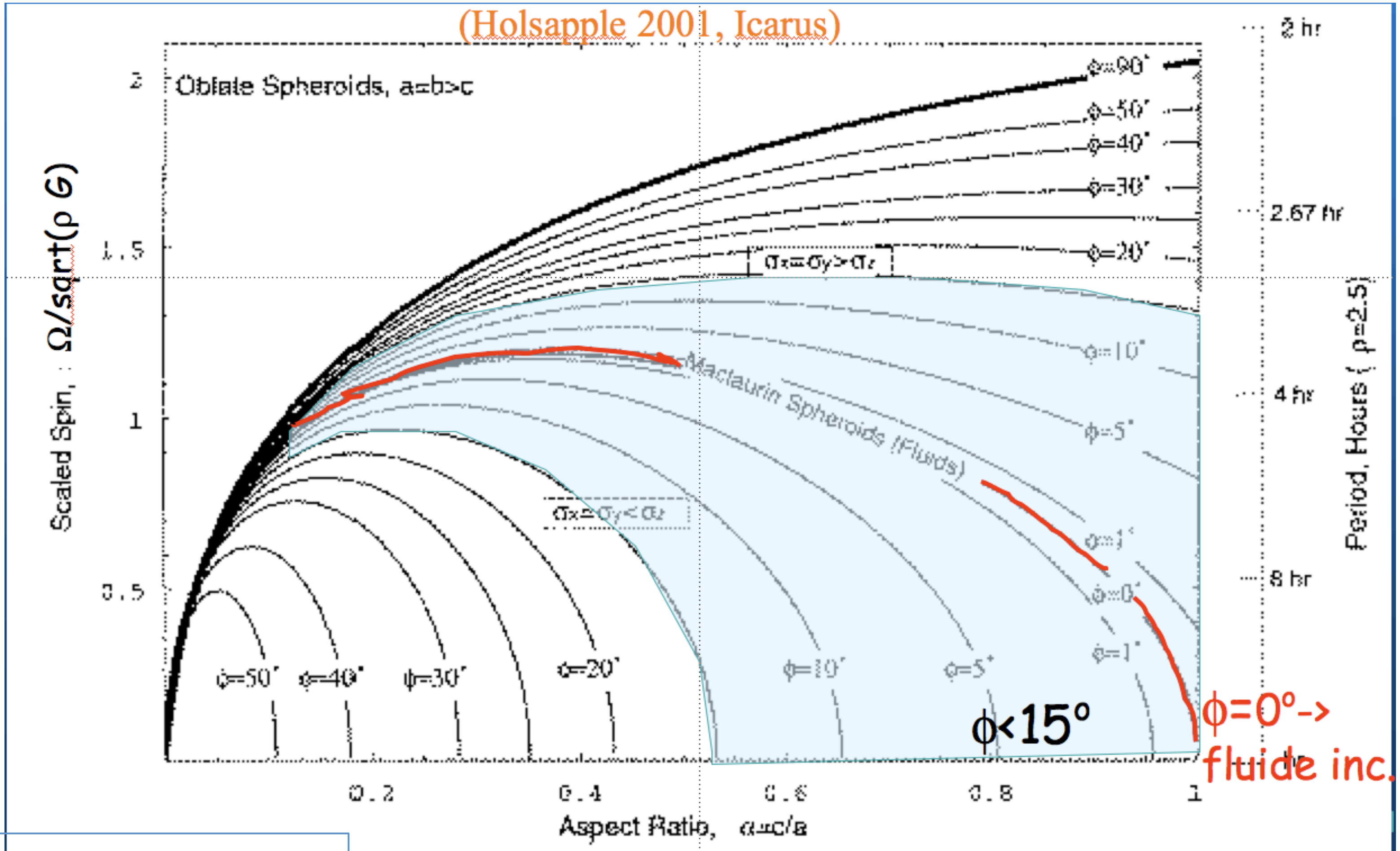
- Hydrostatic equilib. (incomp. fluid) not valid





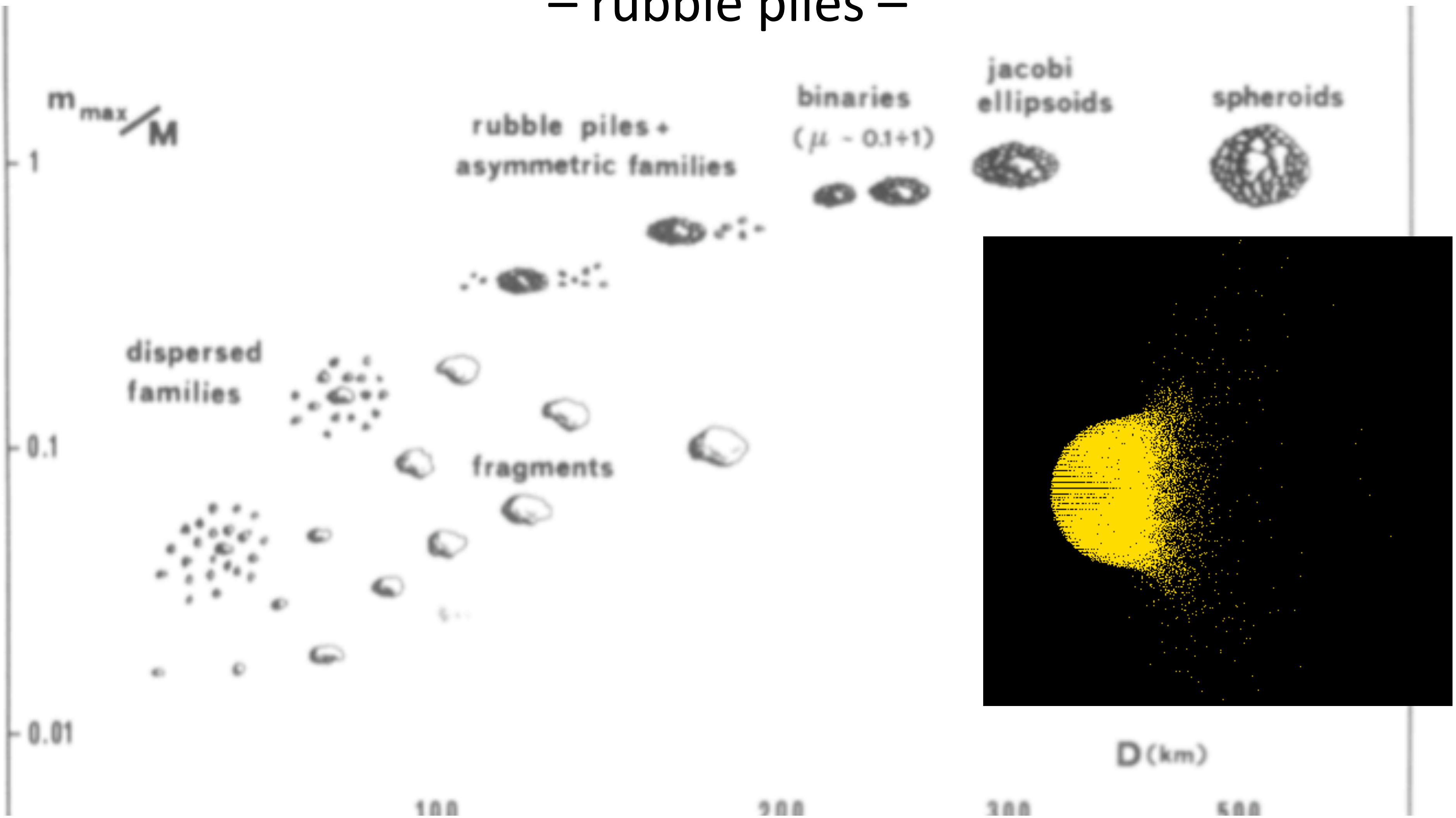
Iinferred density of Ausonia

Mohr-Coulomb

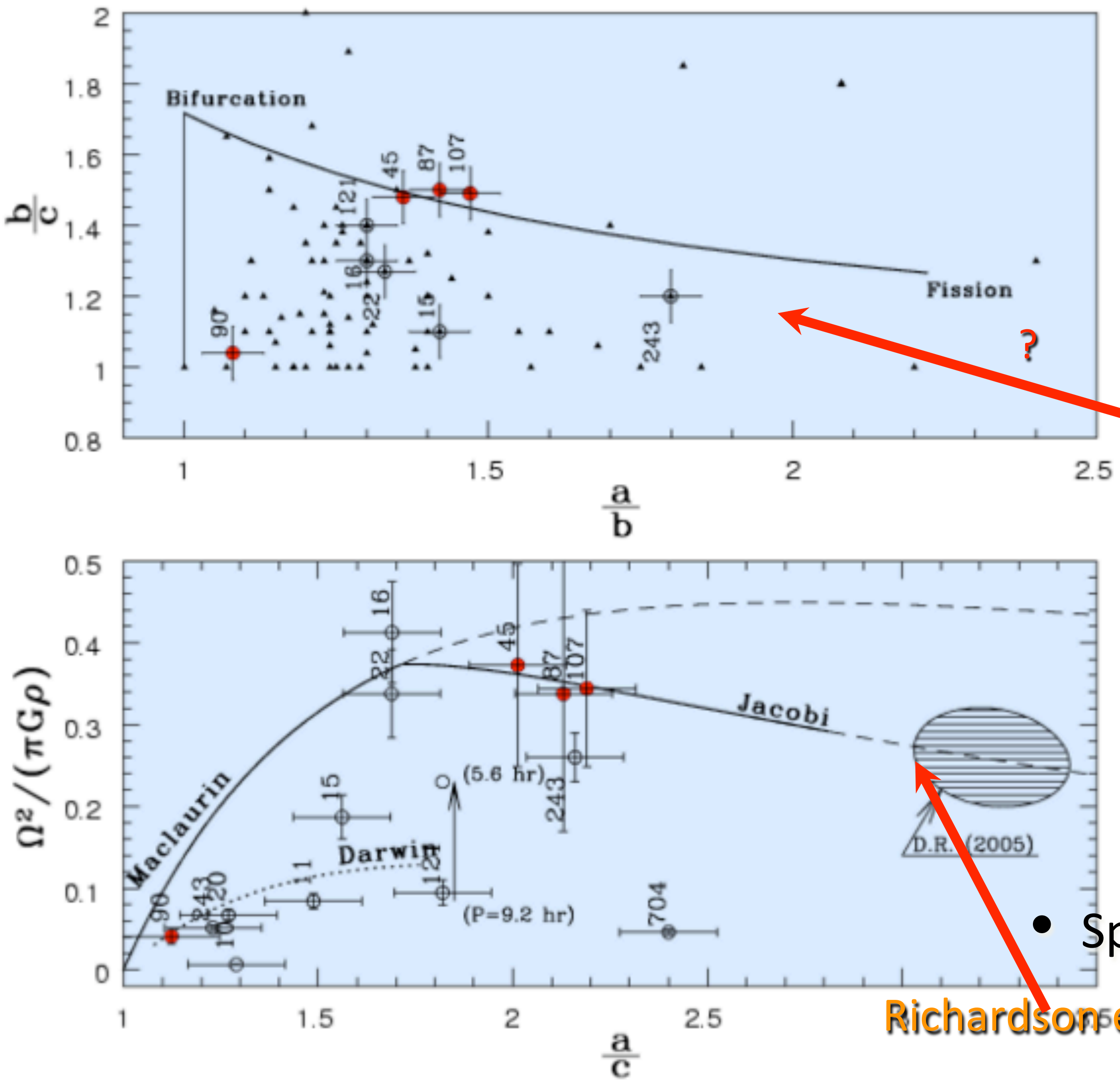


Equilb. +stability

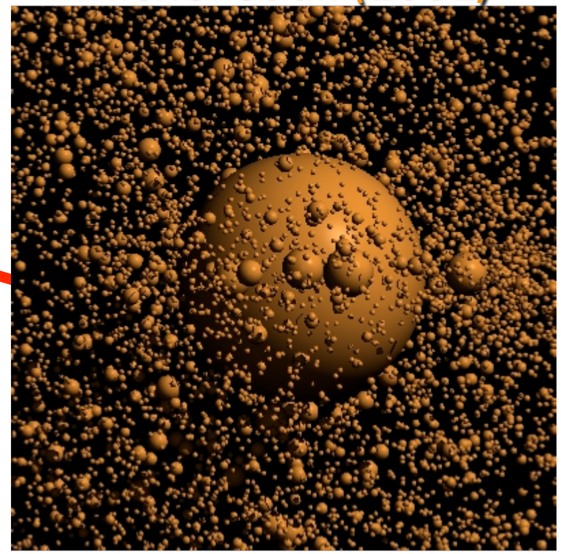
Farinella et al. 1982
Asteroids as outcome of catastrophic collissions
– rubble piles –



• Final result of re-accumulation?



Michel et al. (2001)



- shape not of interest in original simulations

- Spin-up + mas loss

Richardson et al. (2005)

Equilibrium figures

- Binary asteroids
  - Detection, study, not easy
  - MBB, TNB, NEB, Trojans and Centaurs

- Origin - can be diverse
  - Fission (in two)
  - breakup
  - Re-accumulation
  - Others (capture, …)
  - « The story of the black sheep »

Equilibrium figures

Dobrovolskis (1982) stresses in tri-axial bodies

Shear stress

Tresca

$|\tau|_{max} = (\sigma_1\text{-}\sigma_3)/2 > S_o$

Friction

$|\tau| = S_o - \tan(\phi)\,\sigma$

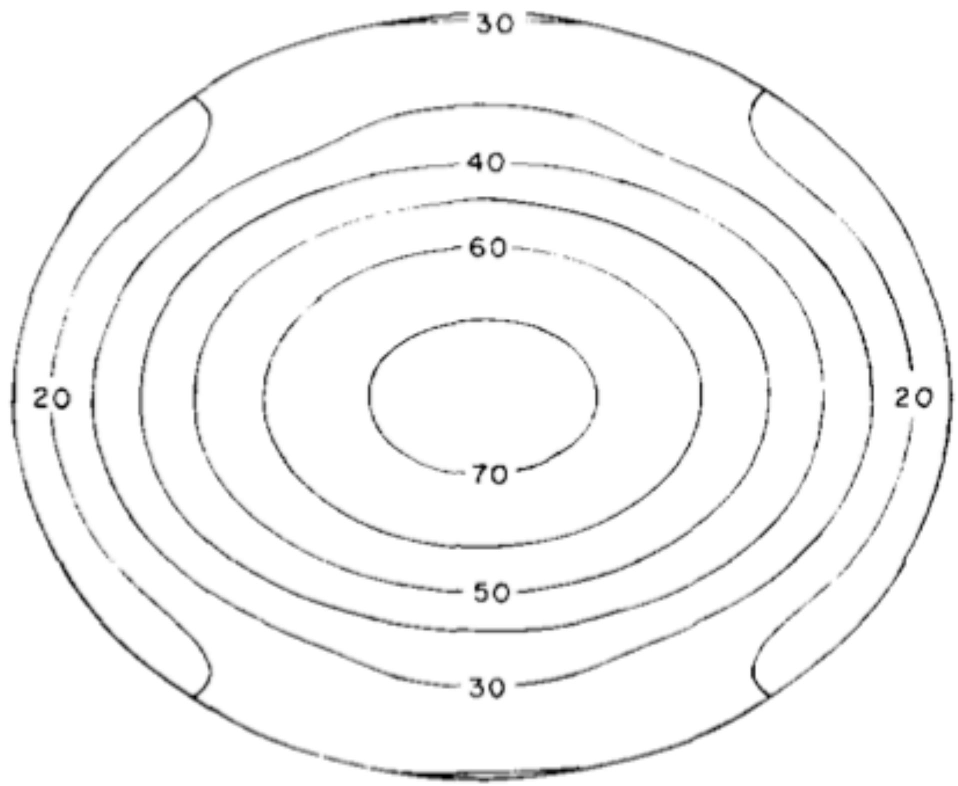


FIG. 4. Contour map of the maximum shear stress $|\tau|_{max}$ (in millibars) over an equatorial section of Phobos.

Canup (2005)
giant impact + reaccumulation

SEARCH ARTICLES

A Giant Impact Origin of Pluto-Charon

Robin M. Canup

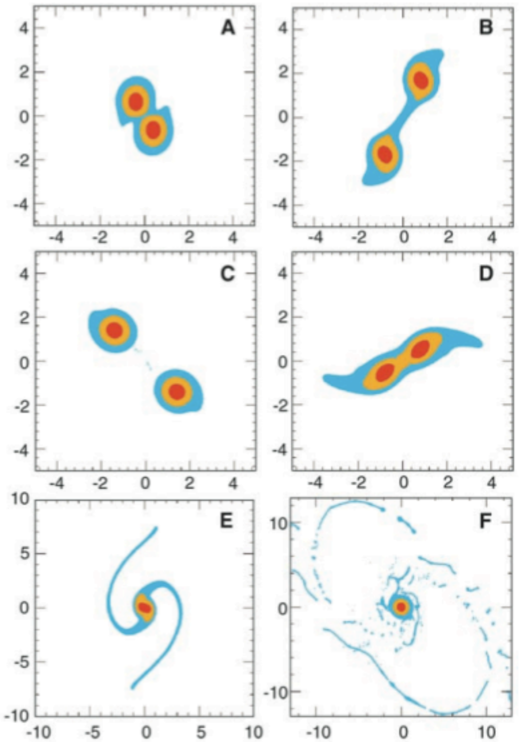


Fig. 1. Time series of a potential Pluto-Charon–forming impact yielding a planet-disk system (run 70 in table S1 with N = 120,000 particles). Results are shown looking down onto the plane of the impact at times t = 1.3, 3.2, 7.5, 11.8, 14.5, and 24.6 hours; units shown are distance in 10^3 km. Color indicates material type (blue, water ice; orange, dunite; red, iron), with all of the particles in the 3D simulation overplotted in order of increasing density. The impacting objects are identical—both are predifferentiated into 40% ice mantles and 60% rock cores by mass with initial surface temperatures set to 150 K, increasing with depth (7) to a central temperature ≈800 K. After an initially oblique impact in the counterclockwise sense (A), the two objects separate (B and C) before recolliding. After the second collision, the denser cores migrate toward the center, as a bar-type mode (36) forms in the rapidly rotating merged objects (D). From each end of the bar emanate spiral structures (D and E), whose self-gravity acts to transport angular momentum from inner to outer

an ice mantle, rock core, and i
and (iii) SIM: 50% serpentine
ice in an undifferentiated mixt
jects range from uniform to h
tiated, with rock mass fractio
and 86% and bulk densities be
2.5 g/cm^3.

I modeled a variety of imp
all capable of providing an an
tum within the range for Plu
collision of two nonspinning
objects delivers a normalized
mentum (*16*)

$$J_{col} \equiv \frac{L_{col}}{L'} = \sqrt{2} f(\gamma) b' ($$

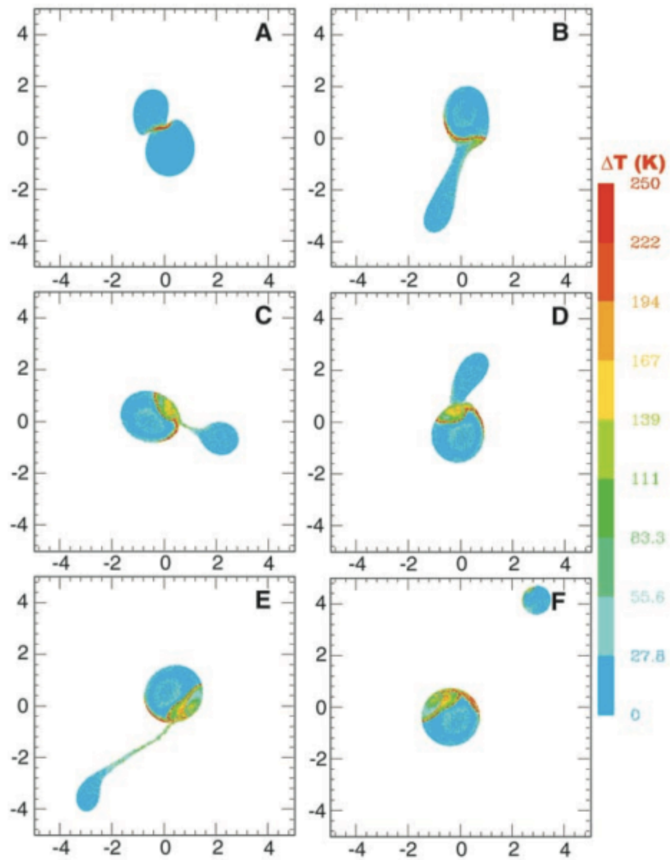
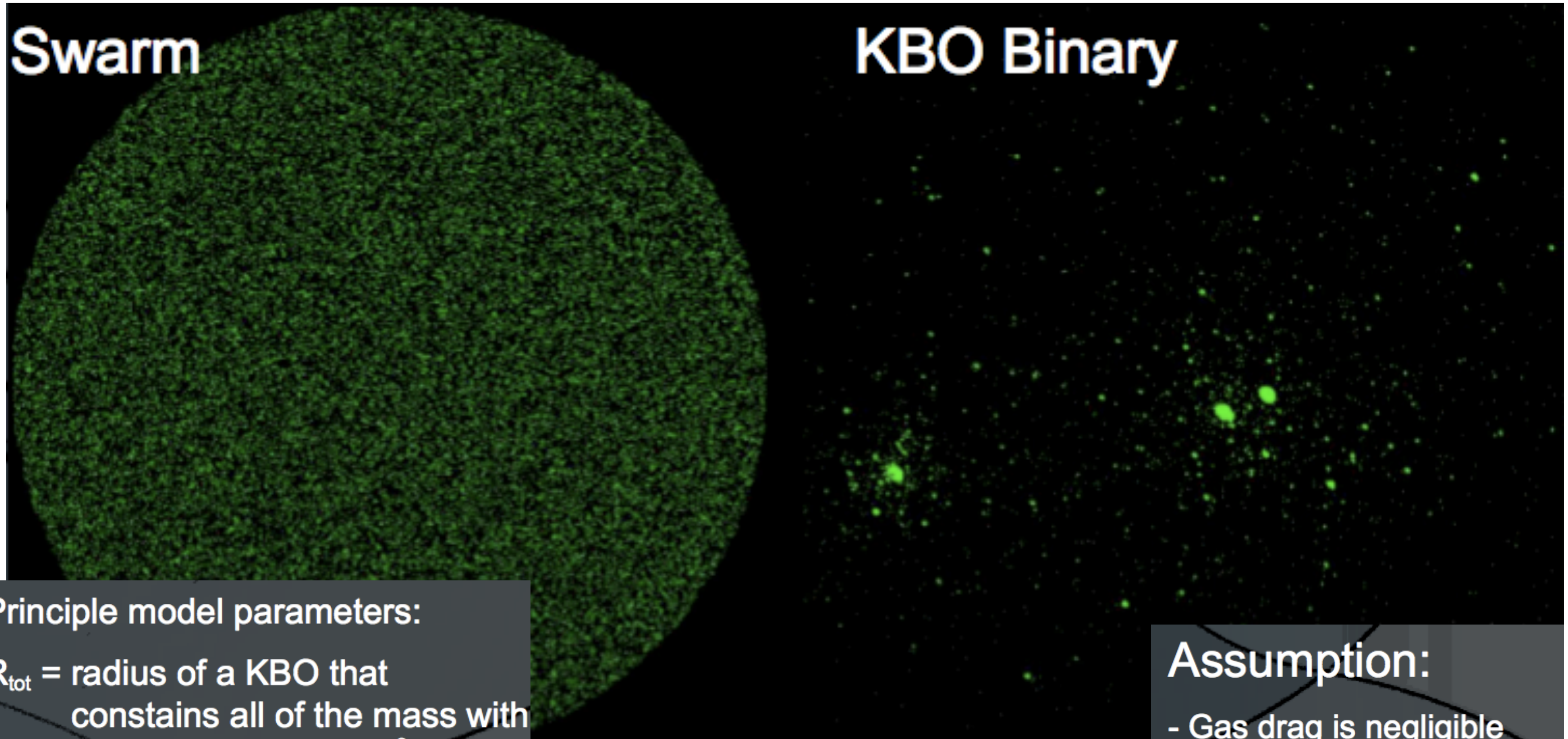


Fig. 2. Time series of a potential Pluto-Charon–forming impact yielding a planet-moon system (run 20 in Table 1 with N = 20,000 particles). Results are shown at times t = 0.9, 3.2, 5.9, 7.5, 11.2, and 27.5 hours; distances are shown in units of 10^3 km and color scales with the change in temperature in kelvin. The impacting objects have uniform serpentine compositions. After an initially very oblique impact with a 73° impact angle (A), the two objects separate (B and C) and during this period the smaller impactor receives a net torque from the distorted figure of the target. After a second, even more grazing encounter (D), an additional portion of the impactor is accreted onto the planet, while the rest self-contracts into an intact moon containing 12% of the central planet's mass that is again torqued by the ellipsoidal figure of the target (D and E) onto a stable orbit with a semimajor axis of 6.5 R_p and an eccentricity of e = 0.5. The final moon in (F) is described by 2232 SPH particles.

Nesvorny et al. (2008-2010) gravitationnal collapse



Principle model parameters:

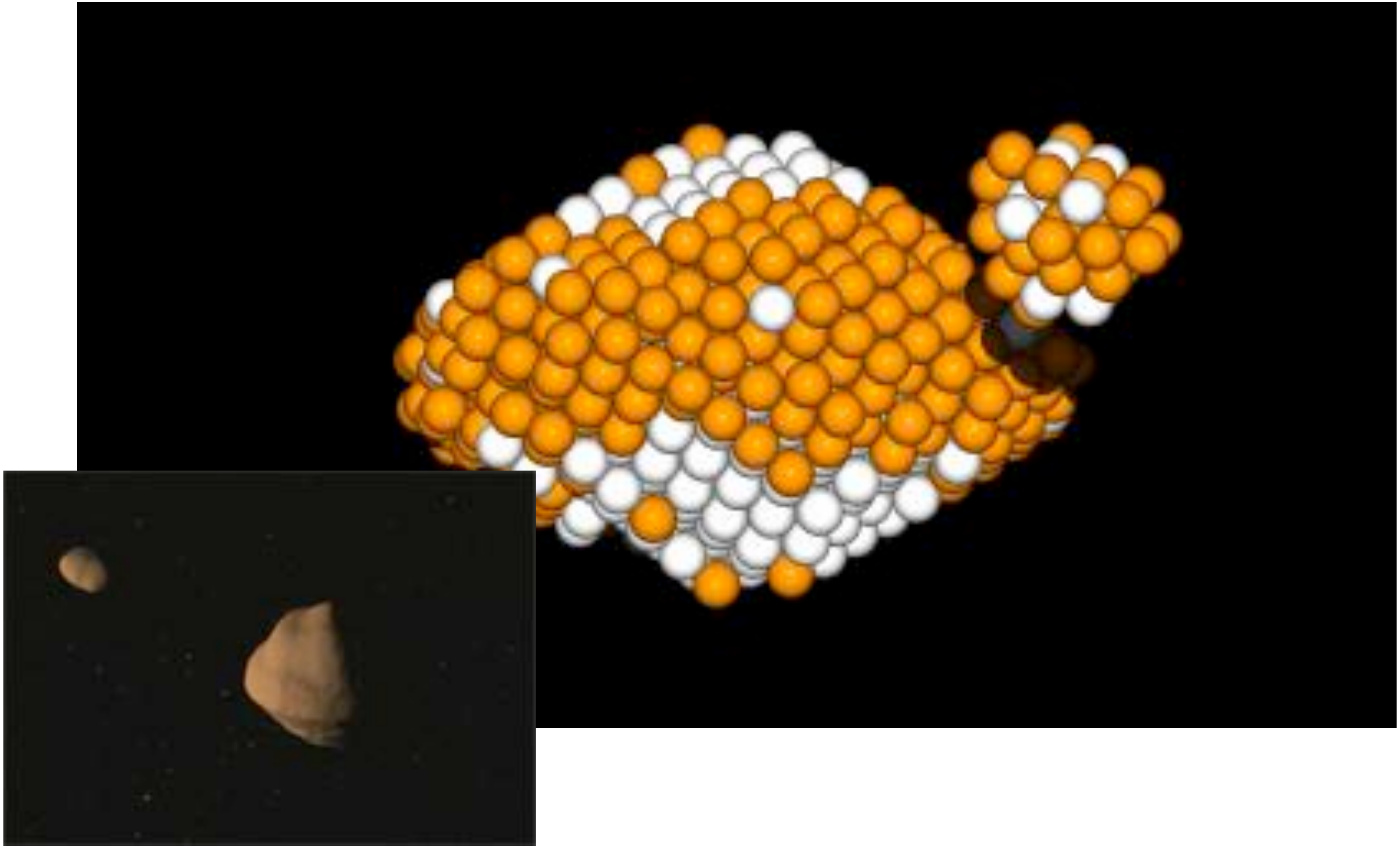
R_{tot} = radius of a KBO that constains all of the mass with a density of 1.0 g/cm^3

Ω = orbital frequency of swarm around its own center of mass

Assumption:

- Gas drag is negligible
- Solar tides are negligible
- Particle sizes ~ 1 meter

Walsh et al. (2008)
Spin-up



Equilibrium figures

- Binaries
  - Mass + volume => density
  - (hydr. equil.) spin+shape => density

  =>Test

  - Spin+shape + J2

  => interior

  - Evolution, tides ?
  - Porosity is uncertain (meteorite analogue)

Shapes & Case studies

- What interior ? what behavior to solicitations (forces, torques, stresses, heat,...)
- What influence of history (tides, collisions, ...)
- Ranges of size different model ?
  - 100m — 10km — 100km

$$P(r) = \frac{2\pi}{3}\rho^2 G R^2 \left(1 - \frac{r^2}{R^2}\right)$$

$$= 1.4\,\mathrm{MPa}\left(\frac{\rho}{10^3\ \mathrm{kg/m^3}}\right)^2 \left(\frac{R}{100\ \mathrm{km}}\right)^2 \mathrm{x} \left(1 - \frac{r^2}{R^2}\right)$$

  - 0.1 Pa to 100 Mpa, pressure at centre
  - visco-plastic and/or visco-elastic ?

Conclusion

1. bad weather on Wednesday