Rotational Disruption of Cometary Nuclei

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with the aid of Derek Richardson, Bill Bottke, and Stephen Lowry

Statistics of Splitting: Weissman (1980)

(somebody ought to update this)

- Dynamically new comets   10%
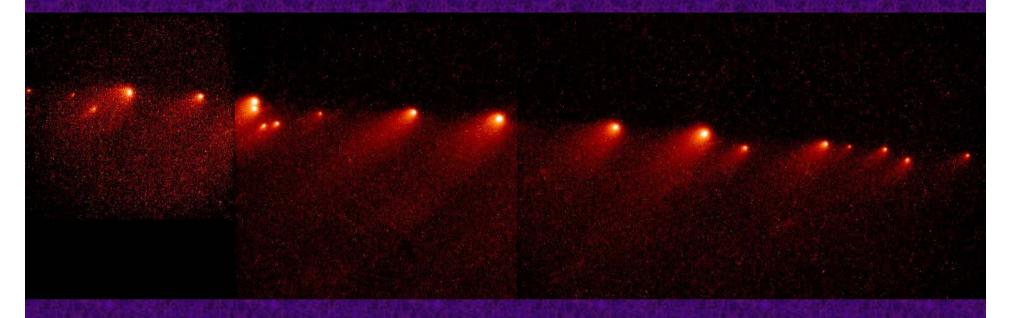
- Returning long-period comets   4%

- Short-period comets   1%

- Splitting rate appears to be correlated with dynamical age

- No correlation observed with perihelion distance, time before or after perihelion, inclination, etc.

- Best dynamical model of long-period comets from the Oort cloud (Weissman 1979) included 15% of LP comets that never split

Why Do Comets Split?

• Tidal disruption: fairly obvious – passage through Roche limit: Shoemaker-Levy 9, Kreutz sun-grazer family

• Random disruption: unknown

• Most common event is comet shedding of one or more fragments at velocities of a few meters/second

• HST imaging shows many more smaller fragments may be involved

• Suggested mechanisms
  – impacts (e.g., Harwit, 1968) – probability too low
  – volatile gas pockets (e.g., Whipple, 1963)
      – unlikely in low density, porous nucleus
  – rotational spin-up due to torques from asymmetrical outgassing (e.g., Davidsson, 1999, 2001)
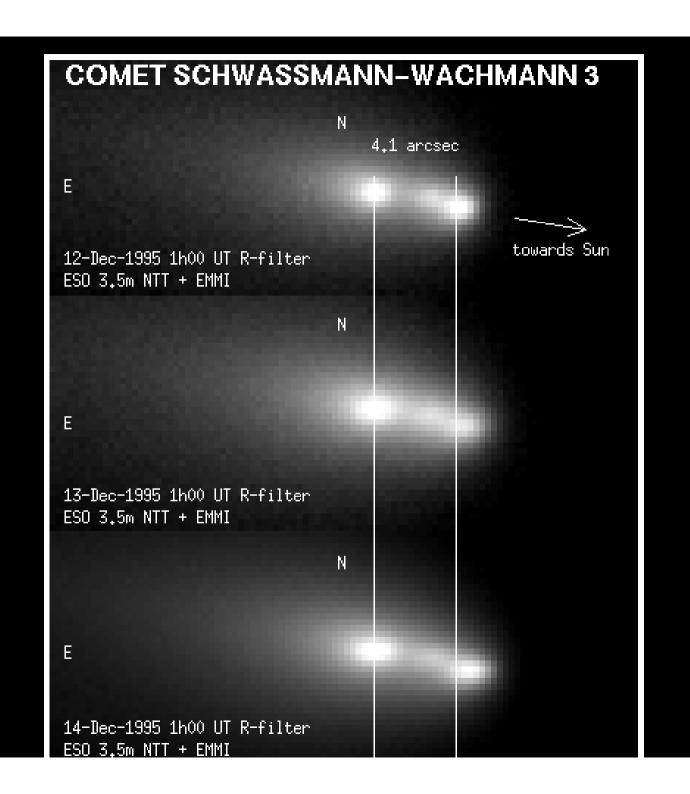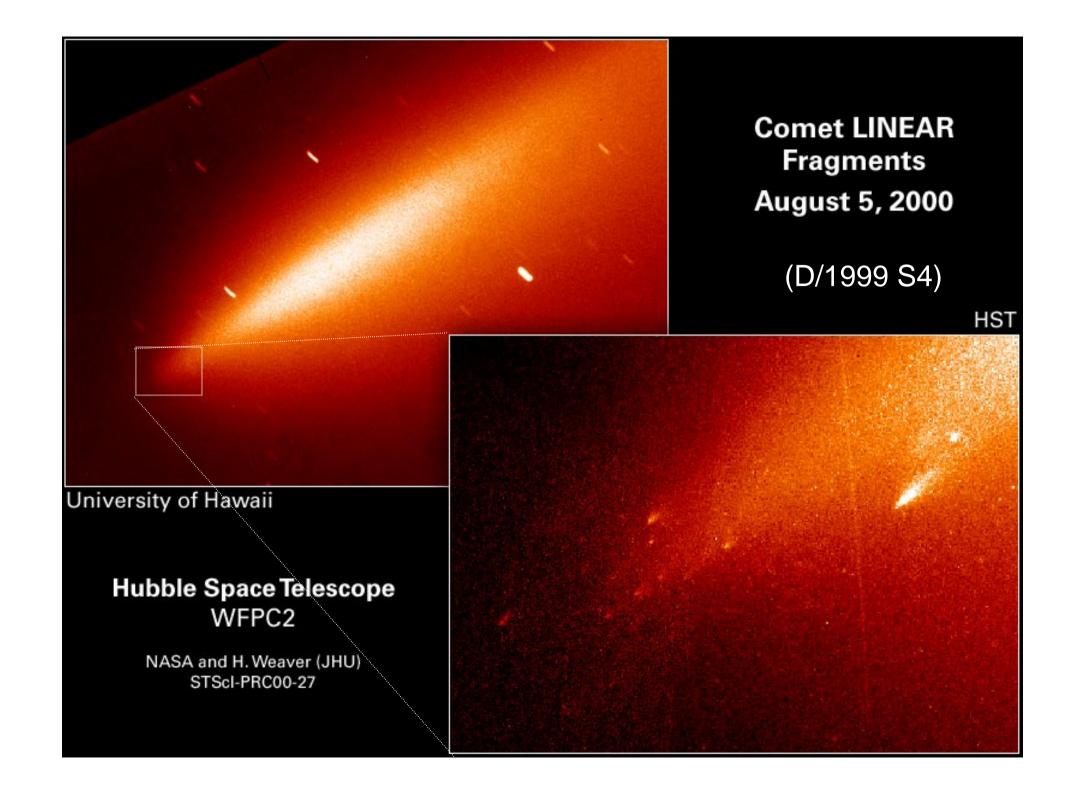
Comet Shoemaker-Levy 9: Tidal Disruption

- Chain of 21 comets discovered in eccentric orbit around Jupiter in March, 1993

- 1992 perijove passage at 1.6 R_J – tidally disrupted comet

- Fragments impacted Jupiter in July, 1994

- Probably captured into orbit ~ 1929. Previous orbit was probably a Centaur object, similar to 29P/SW-1
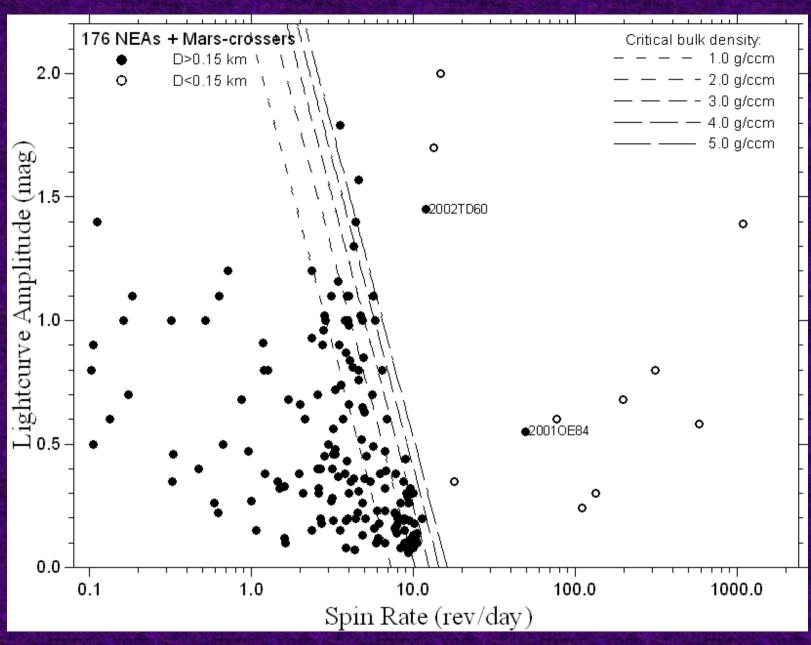
Comet 73P/SW-3 Fragment B: Random Disruption

April 18

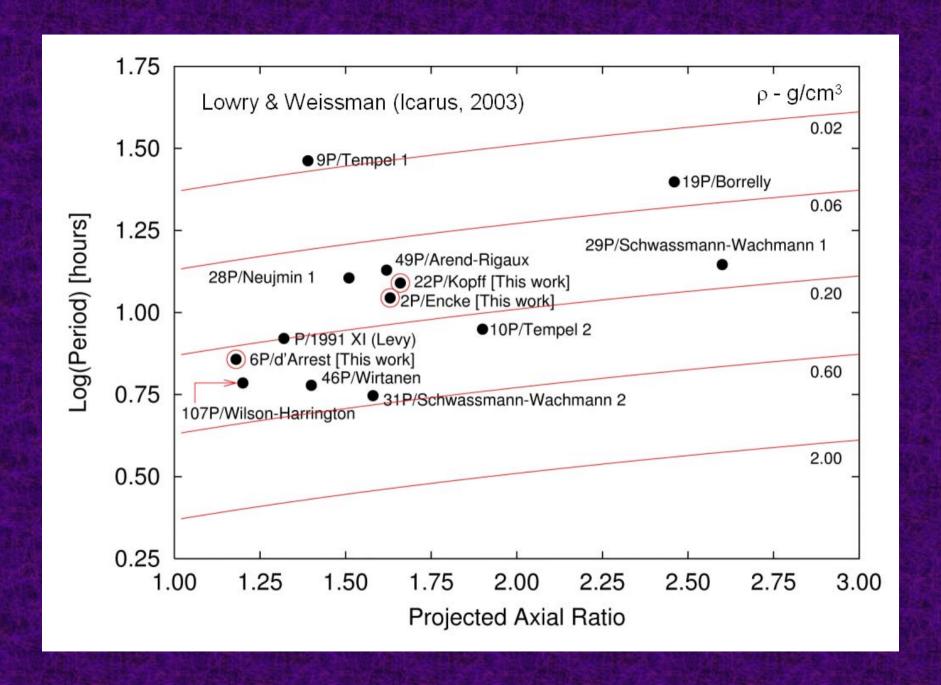April 19

April 20

- SW3 – random disruption event: Comet split into several fragments in 1995. (Also split soon after discovery in 1930)

- Close approach to Earth in 2006 allowed observations of major disruption events while inbound to perihelion

COMET SCHWASSMANN–WACHMANN 3

N
4.1 arcsec
E
towards Sun

12-Dec-1995 1h00 UT R-filter
ESO 3.5m NTT + EMMI

N
E

13-Dec-1995 1h00 UT R-filter
ESO 3.5m NTT + EMMI

N
E

14-Dec-1995 1h00 UT R-filter
ESO 3.5m NTT + EMMI

Comet LINEAR
Fragments
August 5, 2000

(D/1999 S4)

HST

University of Hawaii

Hubble Space Telescope
WFPC2

NASA and H. Weaver (JHU)
STScI-PRC00-27

Pravec et al. (2003), In *Asteroids III*

Figure. Lowry & Weissman (Icarus, 2003). Plot of Log(Period) [hours] versus Projected Axial Ratio, with density curves (ρ - g/cm³) labeled 0.02, 0.06, 0.20, 0.60, 2.00. Comets shown: 9P/Tempel 1, 19P/Borrelly, 29P/Schwassmann-Wachmann 1, 49P/Arend-Rigaux, 22P/Kopff [This work], 2P/Encke [This work], 28P/Neujmin 1, 10P/Tempel 2, P/1991 XI (Levy), 6P/d'Arrest [This work], 46P/Wirtanen, 31P/Schwassmann-Wachmann 2, 107P/Wilson-Harrington.
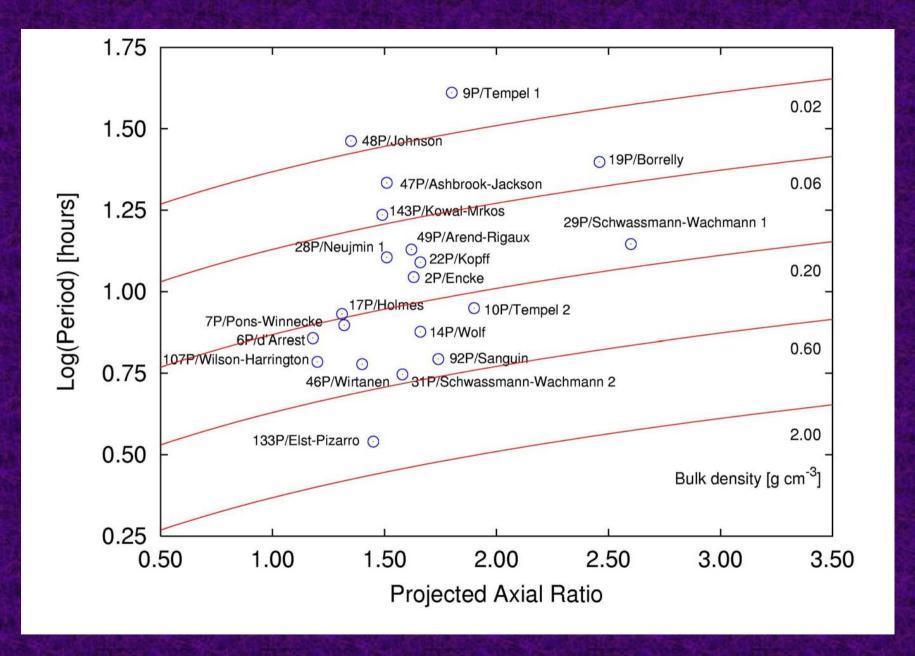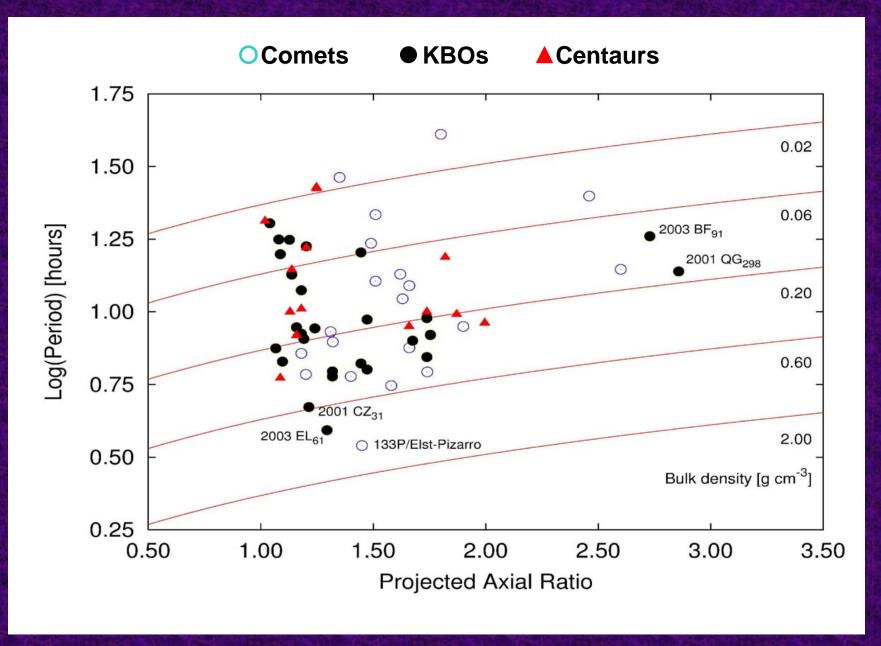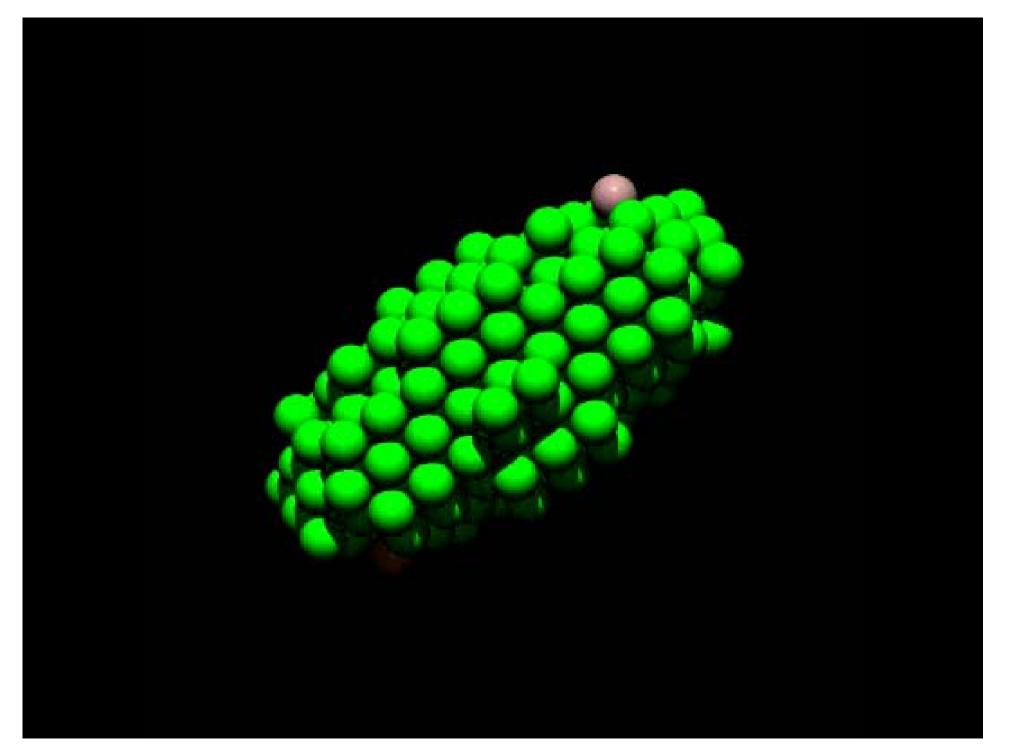
Snodgrass, Ph.D. Thesis, Queen's Univ. Belfast

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Modeling of Comet Rotational Spin-up

•   Gutierrez et al. (2002, 2003a, 2003b, 2005), Jorda & Gutierrez (2002), Nieshtadt et al. (2002, 2003), Mysen (2005)

•   For reasonable values of nucleus size, shape, and activity level, change in period can be 0.1–2 hours per perihelion passage

•   Change in pole direction can be ~2–20 degrees per perihelion passage

•   Pole will random walk, resulting in different changes on each perihelion passage

•   Explains observed variations in behavior of non-grav forces for many short-period comets; Also, lack of non-grav forces role in dynamical evolution of long-period comets.

N-Body Simulation of Rubble Pile Nucleus

- 209 particles, each 170 m in radius

- Nucleus is gravitational aggregate – no binding forces

- Nucleus prolate ellipsoid: $4 \times 2 \times 2$ km; $M = 4.7 \times 10^{15}$ g

- Initial bulk density: 0.6 g cm^{-3}; porosity $\approx 48\%$

- Initial spin period: 8 hours

- Two active areas: orange and purple particles, one on each end; active only in sunlight, thermal lag (sun at top, +Y)

- Modeled with PKGRAV program (Richardson et al. 2000)

- Particles "bounce" when they hit, with modest frictional dissipation force both vertically and horizontally

Axis and Spin Stats for Largest Rubble Pile

Predictions of a Rotational Spin-Up Model

- Split comets should be relatively fast rotators
  - C/1999 S4 LINEAR: 5.2 hr (Lisse et al. 2006)
  - C/Hyakutake: 6.27 hours (Schleicher & Osip 2002)

- Split comets should preferentially be small
  - Only 3 split comets with measured radii:
    69P/Taylor: r = 3.6 km; 79P/duToit-Hartley: r = 1.4 km
    C/Hyakutake: r = 2.4 km — typical values

- Split comets may have relatively high nongravitatioanl forces
  - 9 split JFC comets: mean $A_1 = 0.571$, $A_2 = 0.179$
  - 50 JFC comets: mean $A_1 = 0.385$, $A_2 = 0.049$

Conclusions

- Rotational spin-up provides a viable mechanism for explaining random disruption of cometary nuclei

- Disruption events occur randomly as nucleus period crosses some rotational threshold, depending on shape, density, binding strength, activity, asymmetry, etc.

- Ejection velocities ~ meters/sec

- Explains repeated disruption events from some nuclei

- Events can be totally disruptive

- Also explains why some nuclei appear to be rotationally de-spun: e.g., Halley, Tempel 1