Determination of the Spin State of a Cometary Nucleus From Remote Observations: Application to 9P/Tempel 1, 1P/Halley, & 2P/Encke

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Determination of Cometary Spin States:

Overview –

- To learn about cometary nuclei from Earth-based remote observations the spin state must be determined.
- Several cometary nuclei may be in excited spin states.
- How may such a spin state be determined from remote observations?
- Application to comets of space exploration interest – 9P/Tempel 1, 1P/Halley, and 2P/Encke.

Conclusions –

- The spin state of 1P/Halley is excited and known
- The spin state of 10P/Tempel 2 may be known; Sekanina's hypothesis on the origin of sunward fans needs testing.
- The spin states of other comets are not known
- 9P/Tempel 1 and 2P/Encke are challenging cases……

Value of Knowledge of Spin States

- Interpretation of coma phenomena in terms of the properties of active sources on the nucleus.
- Understanding observed orbital evolution under the influence of non-gravitational forces and what it tells us about processes on the nucleus.
- Knowledge of excited spin states can put constraints on mass distribution in the nucleus and its shape.
- Preparation for spacecraft encounters

Reviews –

Sekanina, Z. (1981), Whipple, F.L. (1982), Wallis, M.K. (1984), Belton, M.J.S (1991), Jewitt (1997)

Spin speak…..

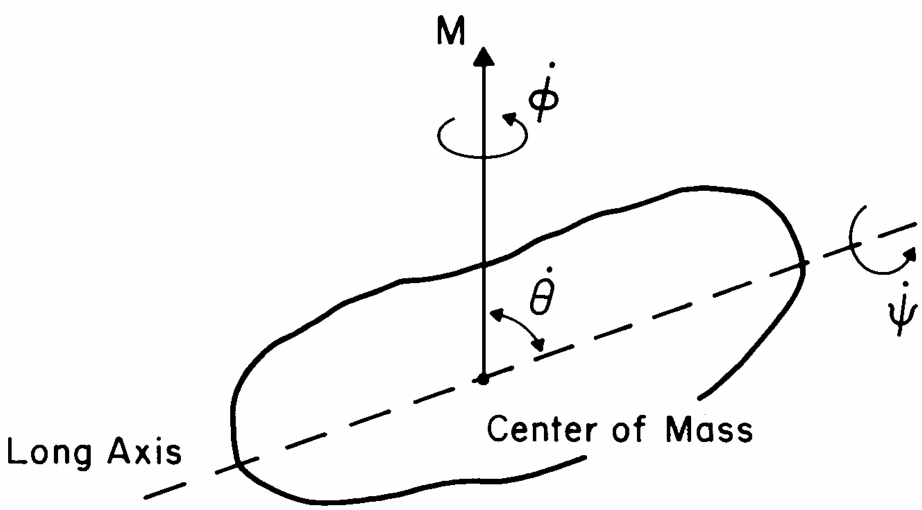


Fig. 1. The observer's view of the component rotations of a nutating cometary nucleus.

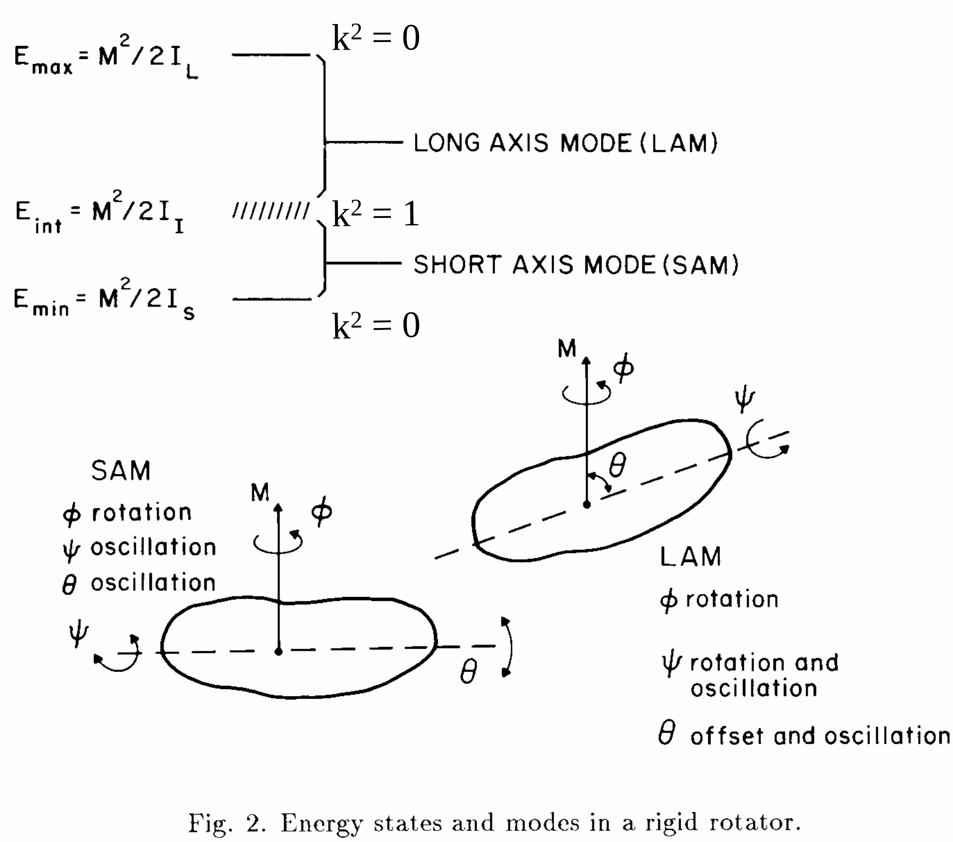


Fig. 2. Energy states and modes in a rigid rotator.

From Belton 1991

<u>Comets for which the Spin State is known:</u>

With known spin state:

– **1P/Halley**	3.69 d	7.1 d	Belton et al (1991); Samarasinha & A'Hearn (1991)

Possibly with known pole position and *periodicitie*s (hrs)

– *10P/Tempel 2*	8.94		Sekanina 1991; Mueller & Ferrin (1996)
– **2P/Encke**	15.08	8.7	Sekanina (1988); Luu & Jewitt (1990); this work.

With known periodicity:

– 31P/Schwassmann-Wachmann 2	5.8 hrs		Luu & Jewitt (1992)
– 95P/Chiron	5.9		Bus et al (1989)
– 107P/Wilson-Harrington	6.1		Osip et al (1995)
– C/Hyakutake	6.23		Schleicher et al (1998)
– C/Hale-Bopp	11.30		Farnham & Schleicher (1997)
– 28P/Neujmin 1	12.68		Campins et al (1987)
– 49P/Arend-Rigaux	13.46		Millis et al (1988)
– **29P/Schwassmann-Wachmann 1**	14.0	32.3	Meech et al (1993)
– 21P/Giacobini-Zinner	19.0		Leibowitz & Brosch (1986)
– C/IRAS-Araki-Alcock	51.36		Sekanina (1988)
– 109P/Swift-Tuttle	67.5		McDavid & Boice (1995)

Spin-states we need to know:

– **9P/Tempel 1**	107.5 or 18.2 or 10.7	Meech & Belton (unpub)
– **46P/Wirtanen**	7.6, 6 (?)	Bauer et al (1996); Lamy et al

Bold: complex ?
Italics: time variable

Spin Determinations are not straightforward……

- **Can the nucleus spin state be fully derived from *Earth-based* remotely sensed observations alone?**

– Photometric periodicities	Millis & Schleicher (1986)
– Periodic coma structures e.g. jets, arcs	Hoban et al (1988)
– Thermal-IR light curves	Campins et al (1987)
– Coma fans	Sekanina (1979, 1988, 1991)
– Evolution of non-gravitational forces	Whipple & Sekanina (1979); Królikowska et al (1998)
– Dependence of lightcurve amplitude on phase. Lightcurve epochs.	Magnusson et al (1989)

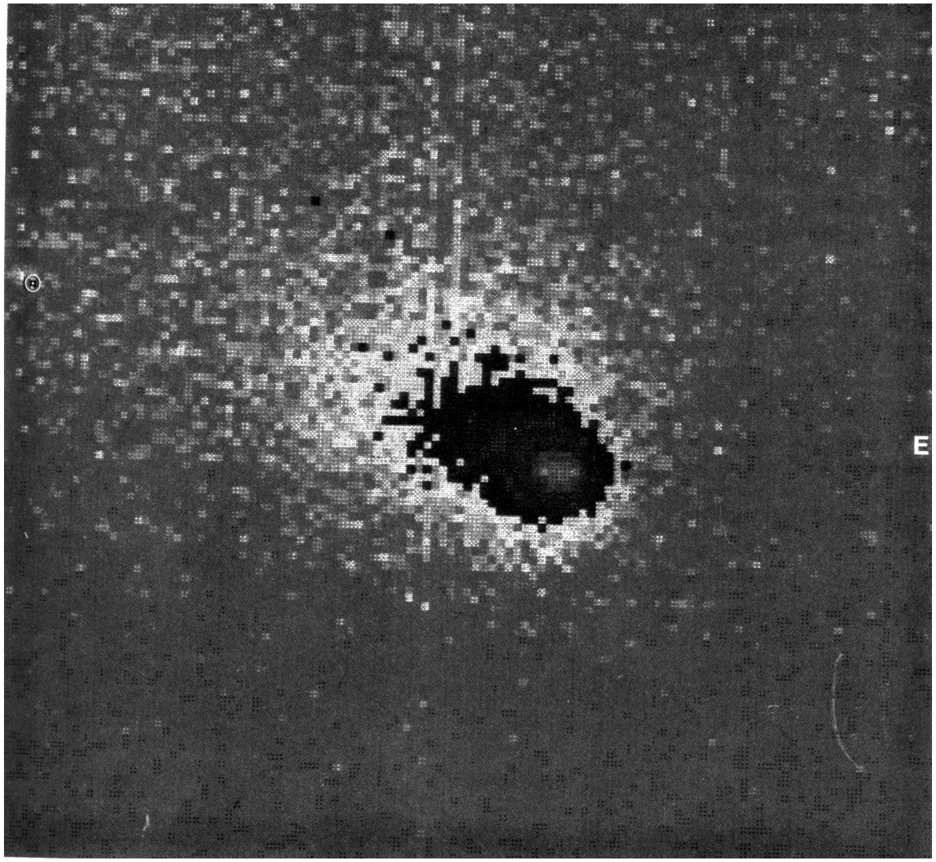
- **2P/Encke and 10P/Tempel 2 appear to indicate that the answer is yes. A test of Sekanina's hypothesis is needed.**

Excited spin: 8 parameters	**Pure spin: 6 parameters needed**

Typical coma fan structure used by Sekanina to determine pole positions.

R- filter image of 10P/Tempel2
By Boehnhardt et al (1990).

30 x 30 arc sec FOV with N at the top. 1 minute exposure.



Sekanina's hypothesis:
Emission fans are the products of ejection events that proceed either continually or quasi-continually from a vent (or vents) located in the general vicinity of the sunlit pole of a comet nucleus whose spin axis is oriented near the orbital plane.

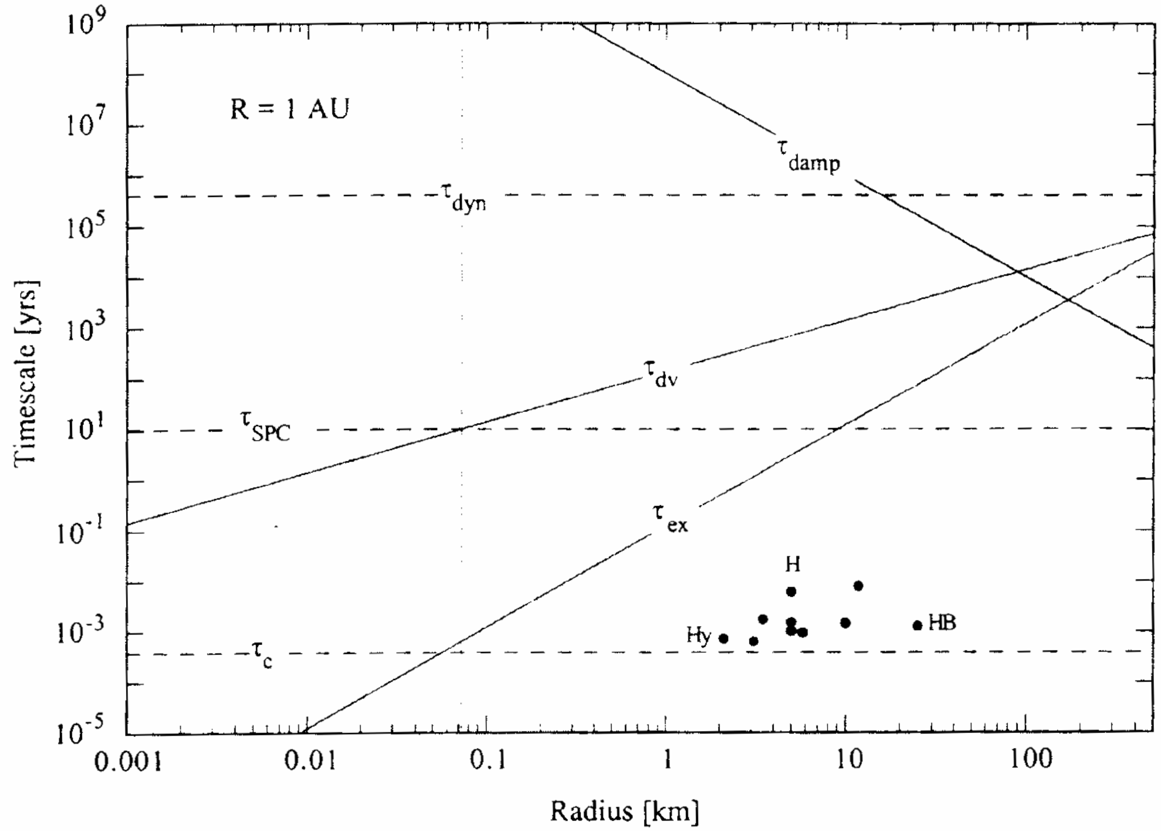
Are comet nuclei in excited spin states common?

- **Discussed by Samarasinha et al (1986, 1995) and Jewitt (1991, 1997)**
- **Jewitt (1997) finds $\tau_{ex} \sim 0.1r^2$ yrs or about 2.5 yrs for a 5 km radius nucleus at 1AU.**
- **Samarasinha (1999) has compared a number of comets with 1P/Halley which is known to be in a excited state: $\tau_{ex} \sim r^4/P^*Q_{H2O}$**

Comet	Effective Radius (km)	Period (d)	Q_{H2O} (Perihelion)	τ_{ex}/τ_{Halley}	Observed spin state
46P/Wirtanen	~0.6	~0.3	$1.3\text{-}2.5.10^{28}$	0.08 - 0.15	?
1P/Halley	5.2	2.8	$1.3.10^{30}$	1	Excited
2P/Encke	3-5	0.63	$4.5.10^{28}$	14 - 110	?
9P/Tempel 1	2.7-3.8	0.5-4.5	2.10^{28}	3 – 104	?
C/Hale-Bopp	~30	0.46	$1.5.10^{31}$	584	Pure
29P/S-W 1	8.6 –15.4	0.58	5.10^{28} (CO)	939-9,655	Excited (?)

- **ROSETTA target, 49P/Wirtanen, is most likely to be in an excited spin state. CONTOUR (2P/Encke) and DEEP IMPACT (9P/Tempel 1) targets are a possibility….**

Timescales for cometary processes (after Jewitt (1997)



τ_{damp} – Damping timescale

τ_{dyn} – Median dynamical lifetime of SPCs

τ_{dv} - Devolatilization timescale

τ_{ex} – Spin excitation time

τ_{SPC} – SPC mean orbital period

τ_c – Max. period with no strength

Excitation in an 2P/Encke orbit.

(Initial period= 2 days; a:b:c = 8:4:3.5; Five active areas; Q = 1.7.10[28] mol/s; Orbit =2P/Encke)