The Spin State of 2P/Encke

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Defining the spin state….

- To fully define a spin state we need to know 8 quantities:
    - Direction of total angular momentum vector, **M**/|M
    - The angular velocity at time t_0, $\boldsymbol{\omega}(t_0)$
    - Two ratios of moments of inertia
    - The orientation of a principle axis at time t_0

- For a fully relaxed rotator these reduce to 5 quantities:
    - Direction of the rotation pole, **M**/|M|
    - The sense and period of rotation, $2\pi / |\boldsymbol{\omega}|$
    - The orientation of a non-polar principal axis at t_0

- What we may be able to estimate from the ground and CONTOUR:
    - **M**/|M| (from evolution of coma structures)
    - $\boldsymbol{\omega}$ (from periodicities (up to 2) in lightcurve)
    - **Orientation of long axis at time t_0** (phase of lightcurve; CONTOUR images)
    - **Ratios of inertia** (lightcurve amplitudes, CONTOUR images - from nucleus shape with assumption of homogeneity)

Data on 2P/Encke relevant to spin…

- **Images (Direction of M/**|M| **; Location of active areas) :**
  - **Sekanina's (1987, 1988, 1991) hypothesis**: ***The axis of the fan is in effectively the projection of the spin vector.*** Fans occur when vents are located in the general vicinity of the sunlit pole of a comet nucleus whose (rapid) spin axis is oriented near the orbital plane. Observations of many fan orientations over many orbital geometries between 1868 and 1984. Yield active active areas in both north (55 deg) and southern –75) hemispheres. Pole precession: ~1 deg/orbit.
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  - **Festou and Barale (2000).** Extension of Sekanina's hypothesis to gaseous isophotes and a detailed model of atmospheric outflow. Reanalysis of Spinrad and Djorgovski's Oct 10, 1980 image yields RA=198^0, Dec=0^0 (within a few degs), active area at ~50deg.

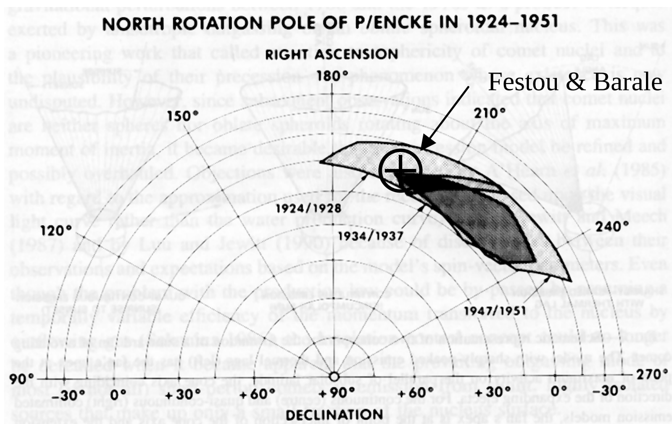
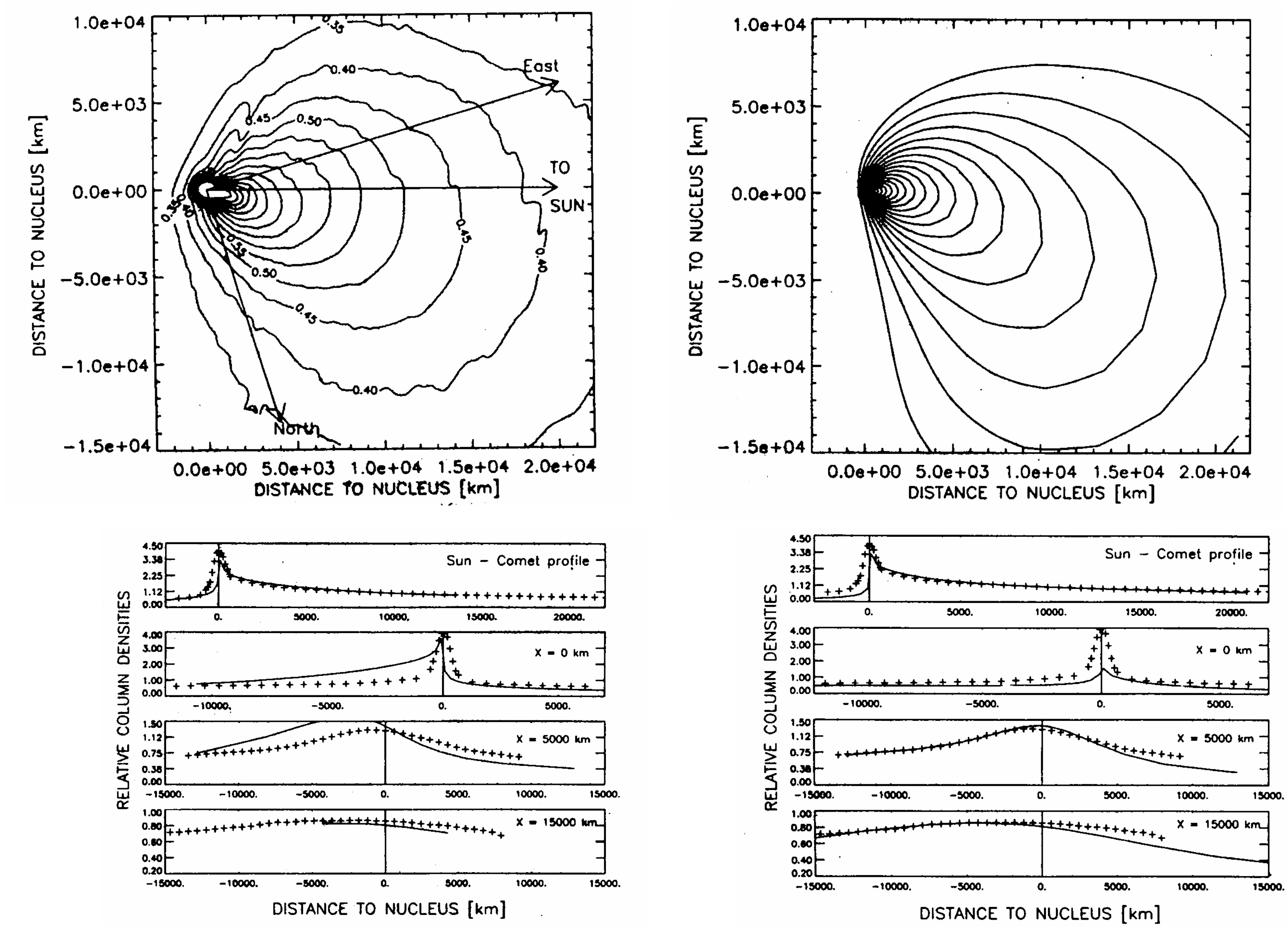
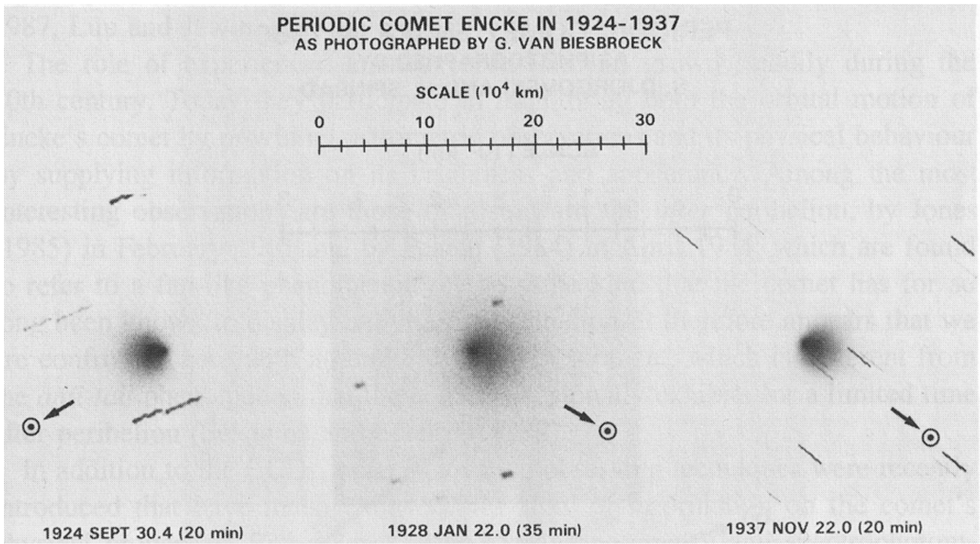


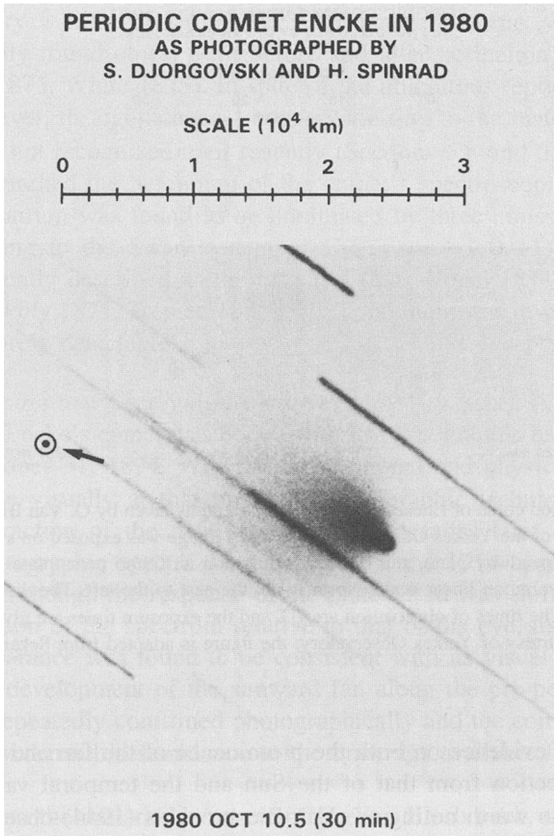
FIG. 8—Constraints on the position of the rotation pole of Encke's comet from observed orientations of the fan. Based on the combined common solutions for the apparitions 1924–1928, 1934–1937, and 1947–1951. (Reproduced from Sekanina 1988b.)

Festou & Barale's (2000) fit to Spinrad & Djorgovski's Image Data:



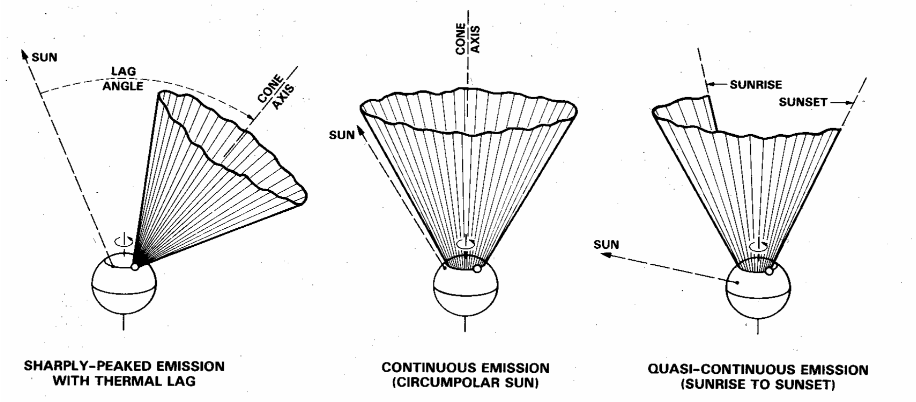
Types of images used by Sekanina (1988)……



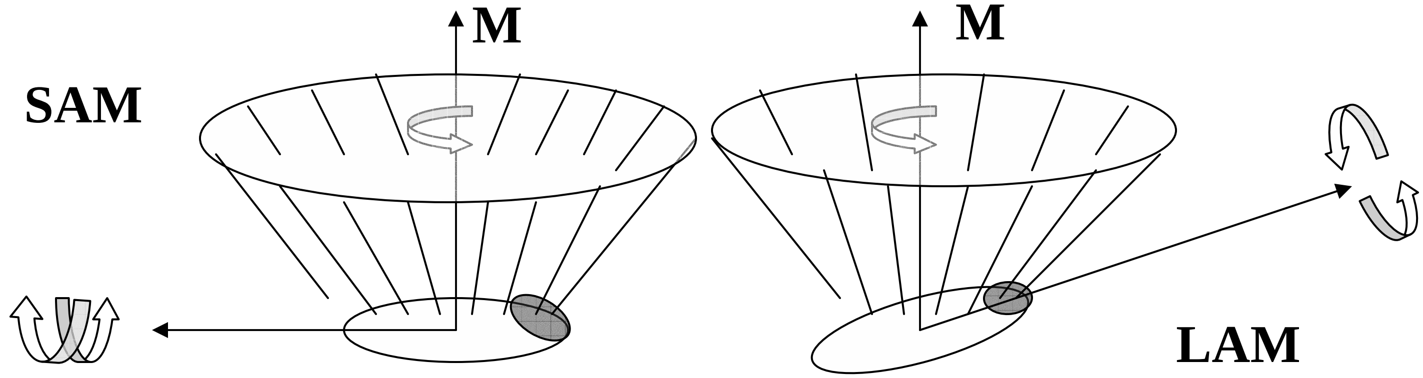


Fan models…….

Sekanina's (1987) fan model:



Suggested modification for elongate nuclei in general spin state:

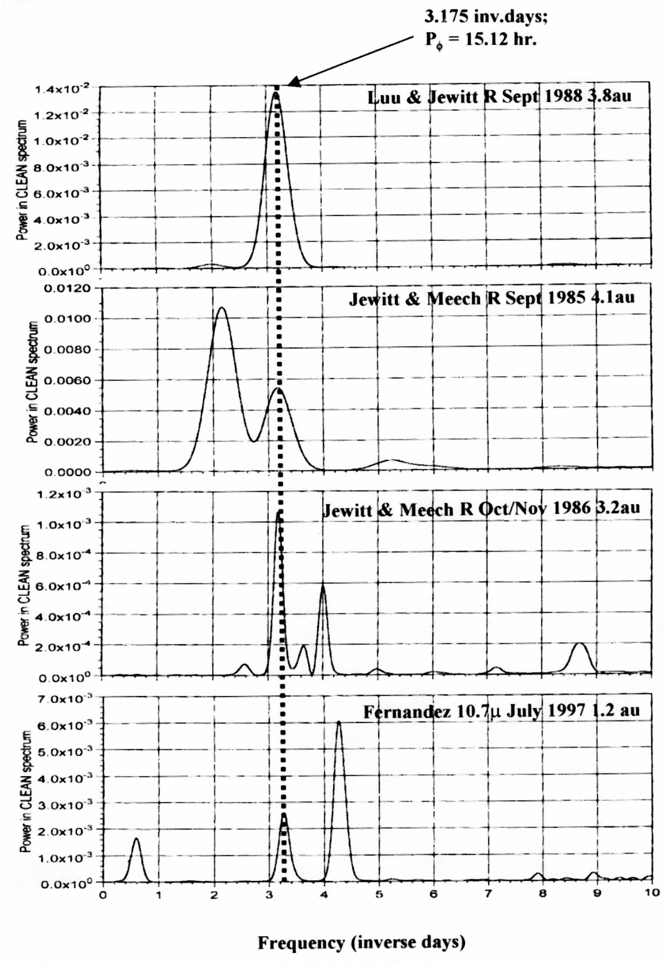


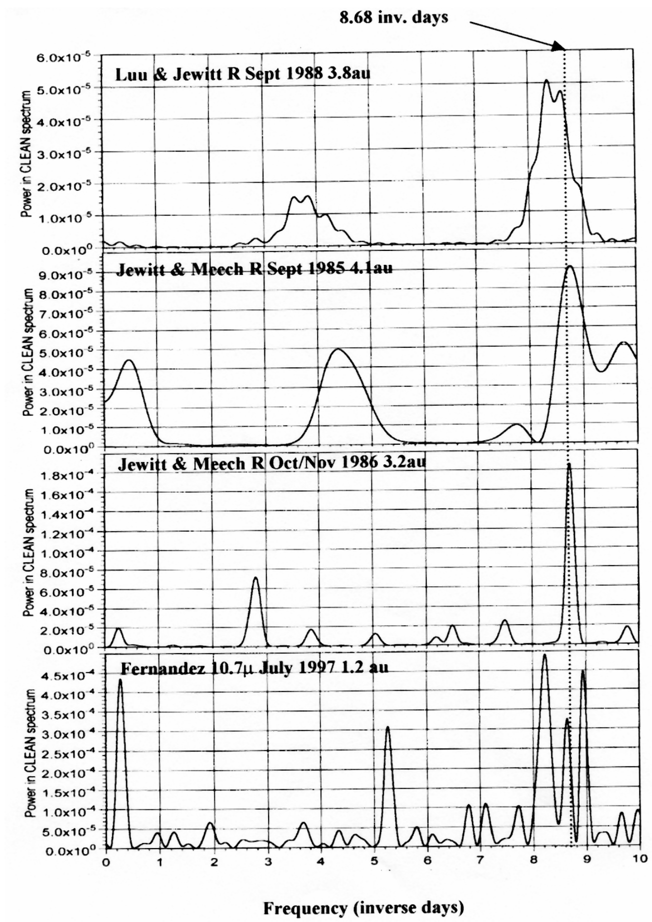
The symmetry axis of the fan is the projection of the angular momentum vector.

Lightcurve data (Periodicities; reference time; constraints on shape) :

Observers	Telescope	λ	Year	Dates	Data points	R(au)
Jewitt & Meech	KPNO 4m	R	1985	Sept. 22-23	25	4.06
Jewitt & Meech	KPNO 2.1m	R	1986	Oct. 30-31; Nov. 01-03	15 47	3.15
Luu & Jewitt	McGraw-Hill 2.4 m	R	1988	Sept. 3,6,7	101	3.83
Fernandez thesis	ESO 3.6m	10.7μ	1997	July 17-19	~50	1.2

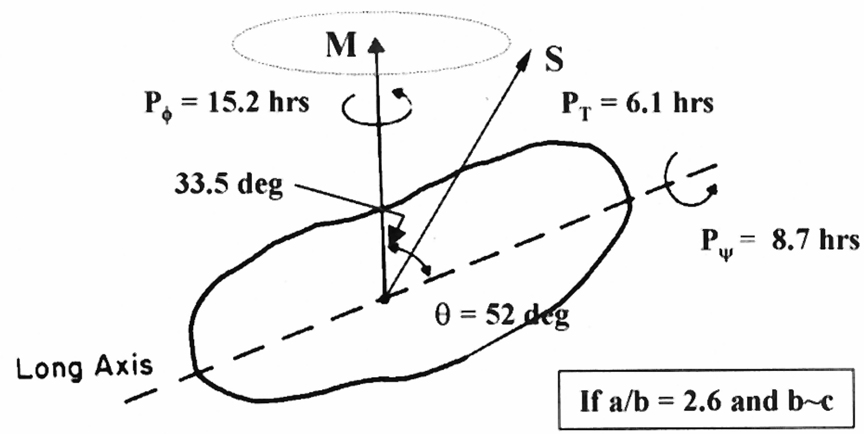
WindowClean analysis of lightcurve data…..





Second Frequency is an unexpected result…..
Implications for an excited spin state:

- Two frequencies: $\omega_1 = 3.175$ inv. Days; $\omega_2 = 8.68$ inv days
- Using model simulations to identify periodicities (Kryszczyńska et al 1999; Meech et al 1993):
  - $\omega_1 = 2/P_\phi$ & $\omega_2 = 2/P_\phi + 2/P_\psi$
  - $P_\phi = 15.2$ hrs
  - $P_\psi = 8.7$ hrs



- SAM or a LAM?
  - For SAM's $P_\psi / P_\phi > 1$ (Samarasinha & A'Hearn, 1991)
  - Must be a LAM…..
  - If $a > b \sim c$ then $a/b > 2.1$ consistent with lightcurve amplitudes
  - If $a/b \sim 2.6$ (Fernandez thesis using Sekanina pole) then: $\theta \sim 52$ deg
  - Total spin period ~6.1hr; spin vector (S) is inclined to angular momentum vector (M) by ~ 33.5 deg and circulates once every 15.2 hrs.

Relevant results on 2P/Encke spin…

• Whipple & Sekanina (1979)	P = 6.24 hr; Prograde(?)
• Sekanina (1988, 1991)	Precession ~ 1deg/rev; α = 205; δ = +2 (1950); Vents at ~55 and –70 latitude
• Jewitt and Meech (1987)	P ~ 22.4 hr; a/b > 2/1
• Luu and Jewitt (1990)	P = 15.08 ± 0.08 hr; a/b > 1.8/1
• Fernandez et al (2000)	R = 2.4 ± 0.3 km; 15.2 ± 0.3hr; p=0.05 ±0.02
• Festou * Barale (2000)	α = 198; δ = 0 (within a few degrees)
• Belton (2000, unpublished)	$P\phi$ = 15.12 hr; [$P\psi$ = 8.7hr; θ = 52deg if LAM]

Proposed starting point for CONTOUR studies….

• Sense of spin:	Prograde (?)
• Current direction of **M**	α = 198 ± 10; δ = 0 ±10 deg (1950)
• $P\phi$	15.12 ± 0.1hr
• $P\psi$	Infinite (pure spin) or 8.7 hr (LAM)
• θ	90 deg (pure spin) or 52 deg (LAM)
• Axial ratio (a>b=c)	2.6:1:1
• Mean radius	2.4 ± 0.3km (a = 3.9; b = c = 1.5 km)
• Photometric properties	Hapke* parameters for C-type asteroid

*Hapke parameters for C-type average (Helfenstein & Veverka (1989):

$\varpi_0 =$ 0.037; h = 0.025; S(0) = 0.20; g = -0.47; Θ = 20 deg

(the equivalent geometric albedo is p =0.049)

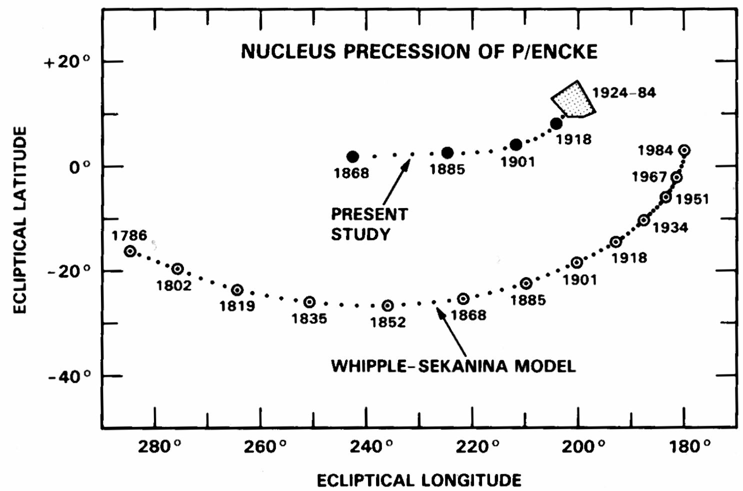
Constraints on the spin state of 2P/Encke

Expectations for the Dec 11, 2003 encounter

What can we learn from the spin state

Spin state changes…..

- **Observations**
  - According to Whipple & Sekanina (1979) and Sekanina (1988, 1991) and based on Sekanina's hypothesis on the nature of cometary fans the *direction* of **M** has changed at a rates of up to 3 deg / rev – but no measurable change in the past 60 years. Change in **M** generally (but not always) imply changes in the the angular velocity vector, ω.



- **Theoretical**
  - In general (but not always), calculations show that jet torques lead to appreciably excited rotational states. The timescale and degree of excitation depend greatly on the strength, orientation, and location of the active regions as well as the size and mass of the nucleus.

Conclusions