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Rotation state of comet 46P/Wirtanen

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Abstract

46P/Wirtanen is a short-period comet that made a sensational Earth flyby last December. Here we present the results of spectral time series analysis of HCN J(3–2) observed with the Atacama Pathfinder Experiment telescope. We have detected strong short-term line variations, evidently produced by the nucleus rotation, which show excited rotation with a period of $\sim$ 9 hr at the epoch of the observations and the rate of change of ~ 0.5 min day^{-1}. The acceleration efficiency is an order of magnitude smaller than expected from a model, which is why the body is protected from rapid rotational disruption for some time, and thus it can be classified as another 'Lucky Survivor' comet.

1. Introduction

While approaching the Sun, cometary ices start sublimating, often creating torques, which drive the angular acceleration and/or complex rotation of the nucleus. The former effect can be described by a simple model [1][6][7], where the rate of change in frequency $\mathrm{d}f/\mathrm{d}t$ is given by:

$$\mathrm{d}f/\mathrm{d}t = \frac{15}{16\pi^2}\frac{v_\mathrm{s}Q_\mathrm{tot}}{R_\mathrm{V}^4\rho}\kappa, \qquad (1)$$

where v_s is the gas sublimation velocity, Q_tot is the (mean-diurnal) production rate of all gaseous species, R_V is the volume-equivalent nucleus radius, ρ is the nucleus bulk density, and κ is the dimensionless effective moment arm, which is a measure of acceleration efficiency. The rotational acceleration can eventually result in centrifugal disruption, when the nucleus reaches a critical rotation period of $\sim$ 3 hr. From the above equation we can immediately see that for comets with small radii the rotation changes are fast, resulting in a quick disruption. Thus the small Jupiter Family comets can only survive if their κ is much less than the model-predicted value $|\kappa| \sim 5\%$ [6]. This effect was already observed in comet Hartley 2, whose small radius of 0.58 km is coupled with an extremely small κ value of -0.04% [3].

The target of our investigation is comet 46P/Wirtanen — a periodic, Jupiter Family comet, with an estimated nucleus radius of 0.7 km. This small comet was observed to have very high water production rates during past returns and thus it was a perfect candidate to study the rotation characteristics of small hyperactive comets.

2. Observations

The visibility prospects of our target were extremely good. After passing the perihelion on December 12, the comet approached the Earth down to 0.077 AU on December 16 placing it among the brightest Earth-skirting short-period comets in modern history.

One of the best rotation-period tracers available for active comets is the HCN molecule [2][3], which can be conveniently observed via rotational transitions. Our earlier experience leaned us towards HCN J(3–2) at 265.886 GHz, which is the brightest line in the millimeter spectrum of comets and has been successfully used to investigate short-term line variations.

The observations were performed using the Atacama Pathfinder Experiment (APEX) telescope on 16 nights between 29 October and 23 November 2018.

3. Nucleus rotation

We analyzed our data with two different techniques: (*i*) Dynamized Structural Periodicity Analysis (DSPA) [1], which allows to determine the rotation frequency simultaneously with the frequency time-derivative, and the simpler (*ii*) Structural Periodicity Analysis (SPA) for determining a constant rotation frequency. Both of these techniques are readily applicable to cometary spectra and have previously demonstrated an excellent sensitivity in providing very accurate rotation parameters of the nucleus of comet 103P/Hartley 2 [3].

The DSPA technique was applied to the entire data set from APEX and revealed the best single-peaked solution for the rotation period of $\sim$ 9 hr at the epoch of the observations and the rate of change in the period of ~ 0.5 min day^{-1}. However, the best global solution (Fig. 1) is found to be very close to the third multiple of the above solution, which means that the rotational pattern repeats best every three rotation cycles.

These results were verified with the simpler SPA technique, which we applied to a shorter, high-S/N data set to minimize the influence of rotation period changes. The resulted periodogram (Fig. 2) shows two independent solutions for the frequency marked as A and B. These solutions generate all the other minima as the other solutions are multiplications of the A and B periods (or whole fractions of the A and B frequencies). The fact that B/2 ($\sim$ 9 hr) solution is much deeper than B confirms the results from DSPA and suggests that this is the real rotation period of the comet (later referred to as C). Furthermore, the deepest minimum is at B/8 = C/4 = A/9, consistent with the excited rotation state, which has two fundamental modes A and B converging every 8 cycles in B and 9 cycles in A. Thus, this time the global solution is slightly better for the fourth multiple of the rotation period C. This difference is natural, though, given that the two data sets have different effective epochs.

The results of our analysis are consistent with other rotation-period determinations for this comet [4][5].

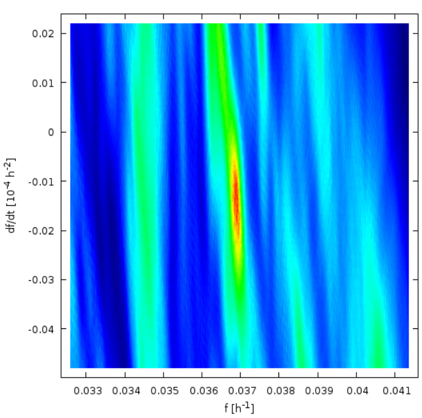

Figure 1: DSPA periodogram.

4. Summary and conclusions

The rotational parameters of comet Wirtanen turn out to be very similar to those of comet Hartley 2. For both comets, the excitation of the rotation state had the best repetitiveness every three rotation cycles and the rate of change in the rotation frequency was much smaller than expected. Despite being nearly twins in terms of physical parameters, the estimated κ value of about -0.5% for comet Wirtanen is an order of magnitude higher than for comet Hartley 2, but still an order of magnitude smaller than expected from models and observed for larger comets. This, and the negative sign of angular acceleration, protect comet Wirtanen from very rapid disruption in near future, making it another example of a 'Lucky Survivor' comet [3].

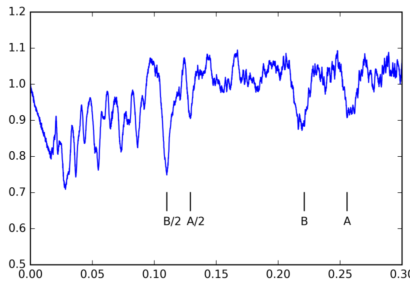

Figure 2: SPA periodogram.

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