鹿林天文台 SLT 望遠鏡的鹿林彗星觀測結果

林忠義 [1], 林宏欽 [2], 葉泉志 [3], 林啓生 [2], Luisa M. Lara[1],
葉永烜 [2], 夏志浩 [4], 蕭翔耀 [2], 林建賢 [2]
[1.] Instituto de Astrofisica de Andalucia – CSIC, Granada, Spain
[2.] 國立中央大學天文研究所
[3.] 中國中山大學環境科學與工程學院
[4] 香港大學物理系

摘要

來自於歐特雲並擁有著逆行軌道(傾角~178度，軌道傾角大於90度稱之逆行)的鹿林彗星(C/2007 N3)是一顆長週期的綠色彗星。它所呈現的綠色代表著從彗星核心正噴出大量的氣體，例如氰(CN)與雙原子碳(C_2)。這顆彗星於2009年1月10日到達近日點，並於2月24日通過近地點(0.411AU)。其實早在2007年7月11日發現鹿林彗星後（當時彗星距離太陽有6.36AU，離地球也有5.65AU的距離），我們就開始利用當初發現它的鹿林天文台SLT望遠鏡密切地持續觀察此彗星的發展。經分析SLT長期觀測資料，可粗略獲得鹿林彗星的灰塵粒子產生率($A(\theta)f\rho$)與日心距離的關係圖。此外，我們也在2008年年底發現了不尋常的反向彗尾！經由影像分析後，發現彗星中的噴流結構似乎與灰塵分子產生率有某種關連性，而這線索或許能幫我們瞭解彗星的彗核在這段監測期間所發生的變化，例如彗核爆發伴隨著噴流產生等現象。

The observations of Comet C/2007 N3 (Lulin) from SLT at Lulin Observatory

Zhong-Yi Lin[1], Hung-Chin Lin[2], Quan-Zhi Ye[3], Chi-Sheng Lin[2], Luisa M. Lara[1],
Wing-Huan Ip[2], Chih-Hao Hsia[4], Hsiang-Yao Hsiao[2], Chien-Hsien Lin[2]
[1.] Instituto de Astrofisica de Andalucia – CSIC, Granada, Spain
[2.] Institute of Astronomy, NCU, Taoyuan, Taiwan
[3.] School of Environmental Science and Engineering, Sun Yat-Sen University, China
[4]Department of Physics, Hong Kong University, Hong Kong, China

Abstract

The green comet C/2007 N3 (Lulin) is a new Oort cloud comet which has retrograde orbit (inclination = 178°). It reached its perihelion on January 10, 2009, and the closest distance to Earth was 0.411 AU on February 24. Soon after its discovery on July 11, 2007, the coma activity of comet Lulin was monitored closely by SLT 41-cm telescope until April 2009. After long time monitoring of comet Lulin the dust production rates ($A(\theta)fp$) was estimated. We discovered the anti-tail in the end of Dec. 2008 and this anti-tail were last for quite a while due to an effect of the orbital geometry. We also found the coincidence between the jet activity and the peak of $A(\theta)fp$ values and this is a clue for us to realize what happens in dust coma of comet Lulin.

關鍵字 (Keywords)：彗星(Comets)、噴流（Jets）、塵埃（Dust）、鹿林彗星（C/2007 N3 (Lulin)）

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1. Comet Lulin discovery and LUSS program

On July 11 2007, the night was the same as the other nights, the assistant, Lin Chi-Sheng, opened the SLT dome (16” Ritchey-Chrétien telescope at the Lulin Observatory) after the mid-night when the sky condition became good for observation. Then he started to follow the observation plan (LUSS, Lulin Sky Survey) made by Quan-Zhi Ye from Sun Yat-Sen University at the Mainland China and took a large number of images. Ye, as usual, reduced the data in the day-time. Fortunately, he identified the new object from three of the photographs (Figure 1) and soon made a report to MPC (Minor Planet Center). Initially, it was described to be the 19.1^m asteroidal object, but new images taken by Young (IAUC 8857) three days after the discovery revealed the presence of a faint coma. The new comet was named "Comet Lulin" (its official designation is comet C/2007 N3, IAUC 8857) and it is also the first

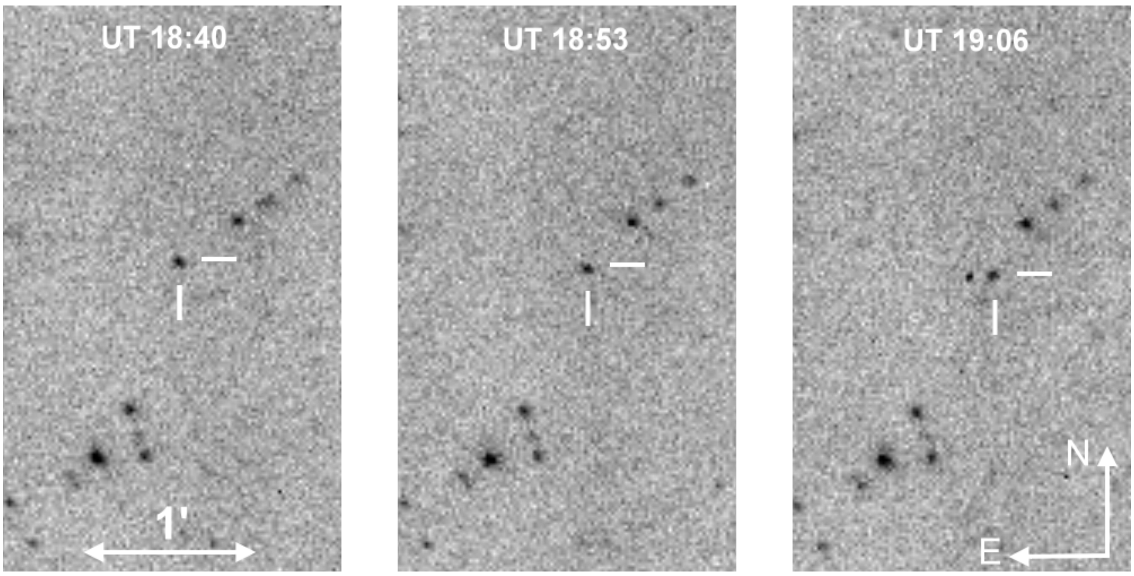

Fig. 1: Three images of comet Lulin taken on July 11, 2007 when comet was at 6.36AU from the Sun and 5.65AU from the Earth reveal an asteroidal object. It was clearly moving compared with background stars. The FWHM for asteroidal object (3.1") is larger than that for field stars (2"~3") but no cometary feature found on the moment. In the figure, North is to the top and East is to the left. The FOV in all images is 2.0' × 3.3 '.

one discovery in Taiwan by using the local telescope at the Lulin Observatory who gave the name to this new comet. The discovery of comet Lulin was part of the major achievements made in the LUSS project that was planned to explore the various populations of small bodies in the solar system, especially on studying Near-Earth asteroids (NEA) that might present serious damage to the Earth. Since the start of the program, LUSS, in March 2006, it has been about 800 asteroids, a few fragments named AK, AM and AN from comet 73P/Schwassmann-Wachmann 3B, one comet (Lulin) and one NEA found in this program. Among the 800 asteroids, more than ten have been officially coded and entitled by the team in Taiwan, including “Lulin”, “Jhongda”, “Chengbruce”, “Shenchunshan”, “Wensayling”, “Mapihsia”, ”Gueiren”, “Tsou”, ”Chiayi”, “Nantou”, “Yushan” and “Kaohsiung”.

The SLT 41cm Telescope (16” Ritchey-Chrétien telescope) which is the main telescope of LUSS program was installed by the Institute of Astronomy of National Central University in March 2005 on the summit of Mt. Front Lulin (120d 52' 25" E, 23d 28' 7" N, H = 2862 m) in central Taiwan. The CCD imaging camera is attached to the Cassegrain focus of the telescope. The CCD camera named U42 was manufactured by Apogee Instruments, Inc. The specifications of the camera can be found in the website of Apogee Instruments Inc and here we list parts of its essential parameters in Table1. The focal length in SLT is 2,500mm (with 0.75x reducer), resulting in a pixel scale of 1.1" per pixel. The field of view of this system is 38' × 38'. The CCD is cooled by using thermoelectric cooling and the system can reach an operative temperature of -20deg. Acquisition of the CCD image is done using the software “MaxIm DL” provided by the Diffraction Limited Inc. running on Windows operating system. More detail of this software can be seen in the following website.
(http://www.cyanogen.com/index.php)

2. Orbital of comet Lulin

Comet Lulin reached its perihelion on January 10 2009, at a distance of 1.211AU from the Sun and approached the Earth reaching its nearest point (0.411AU) to us on February 24 2009. The orbit of comet Lulin is very nearly a parabola and also occupies a very

Table 1. Specifications of the CCD camera U42 as provided from Apogee Instruments Inc.

Name	
CCD	E2V CCD42-40
Array Size (pixels)	2048 × 2048
Pixel Size	13.5 × 13.5 microns
Imaging Area	27.6 × 27.6 mm
Linear Full Well (typical)	100K electrons
Peak QE (550 nm)	>90%
AD Conversion	16 bits
Sampling	700 kHz @ 16-bit digitization

Table 2. The orbital elements of comet Lulin

Element	Value	Unit
e	0.999995	
i	178.373562	degree
node	338.530972	Degree
peri	136.857744	Degree
q	1.212259	AU
Tp	Jan. 10.639, 2009	UT

e: the eccentricity;
i: the inclination of the orbital planes to the ecliptic plane ;
node: longitude of the ascending node;
peri: the angular distance of perihelion from the ascending node;
q: the perihelion distance in astronomical units;
Tp: the time of perihelion passage.

low-inclination orbit of about 1.6° from the ecliptic plane. More detail ephemeris of comet Lulin can be seen in Table 2.

The low inclination orbit is always found in short-period comets, i.e. Jupiter Family Comets (JFCs), and they are believed to originate in the Edgeworth-Kuiper belt, which surrounds the Sun at distances between about 30 AU (the distance of Neptune) and 50 AU. On the other hand, long-period comets (LPCs), i.e. comet Lulin, are thought to originate in a spherical cloud of debris that surrounds the Sun at distances between 20,000 and 100,000 AU. However, the orbit of the comet Lulin is unique to compare other LPCs. The retrograde orbit means that comet orbits the Sun in the opposite direction to the planets, or clockwise from above the Sun's northern pole. Although the retrograde orbit for comets is not unusual, i.e. the most famous comet Halley also orbits backwards, the retrograde orbit is currently a puzzle. One possible explanation is the tidally-driven precession (Levison et al. 2006) when comets orbited in a disk-shaped inner Oort cloud (2,000~20,000AU) where is located in between a spherical outer Oort Cloud and Kuiper belt. Another probability is that when comets ejected from the Solar system by planetary perturbation, some comets might have a retrograde orbit.

3. Observation and data reduction

Comet Lulin was monitored from July 2008 to April 2009, for a total 33 observing nights, at Lulin Observatory by using Beseel R filter. The data reduction followed standard procedures. In outline, the procedure began with dark-frame subtraction and flat field correction of all frames. Then the night sky contribution was subtracted. To convert the measured counting rates into physical units in R filter, we observed both Landolt standard star field and the stars selected from ESO's catalog of optical spectrophotometric standard stars. The step by step for converting can be seen in following description. First, we need to have the transmission curves for both Bessel R filter and CCD (U42) and the information, flux ($erg\ cm^{-2} s^{-1}\ \mathring{A}^{-1}$) vs. wavelength ($\mathring{A}$), for the flux standard star, for example GD71, (the former transmission curves can be measured and given in TFTC (Thin Film Technology Center), NCU and the later flux information can be downloaded directly from ESO's website). And then we used this information above to get the theoretical flux in Bessel R filter. For GD71, the value is about 120,000 $erg\ cm^{-2}$. Second, we measured the extinction coefficient form Landolt standard star field to make sure the weather condition and at the same time we observe the spectrophotometric standard stars (GD71) in difference airmass. The extinction coefficient can be used and normalized the optical spectrophotometric standard stars to the air-mass 1. Until now, we can easily measure how many counts are there in optical spectrophotometric standard stars at the air-mass 1. In other words, we could have the total counts (~1,300) of GD71. Finally, we got the converted factor which can convert the counts into the real flux between theoretical flux and instrumental counts. The factor also called count rate in our calculation is in the range from 89 to 93. Generally speaking, if we know how many counts there are in cometary coma with fixed projected distance (10,000km), we can use this value to multiply and get real flux in cometary coma.

4. Data analysis and results

4.1 Imaging

The imaging is processed to enhance the coma structure by using a radial and azimuthal masking. The method was briefly described in following. The mean radial brightness profile of the cometary coma, averaged over all azimuthal angles, was determined in the first step. Then, the comet image was divided by the mean brightness profile to enhance deviations from the mean coma (Lin et al. 2007).

Jet feature appearance was found on August 2 2008 first in our images when we start the monitoring proposal. The jet is spiral-like not straight and its position angle measured from north through east is nearly perpendicular to the anti-solar direction (Figure 2b). This phe-

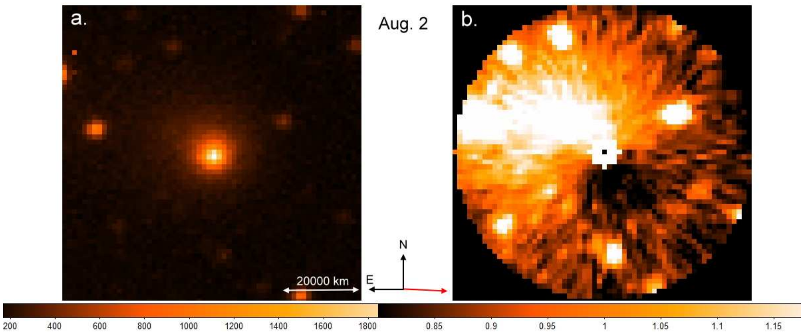

Fig. 2: Images of comet Lulin was taken on August 2, 2008. The left one (a) was the original image acquired with R filter and shows a nearly circular coma. The right one (b) enhanced by azimuthally median masking showing clearly curved jet. The orientation is given in the figure and the red arrow represents the direction of Sun. The FOV is 1.1' × 1.1' corresponding to 79,000 × 79,000 km.

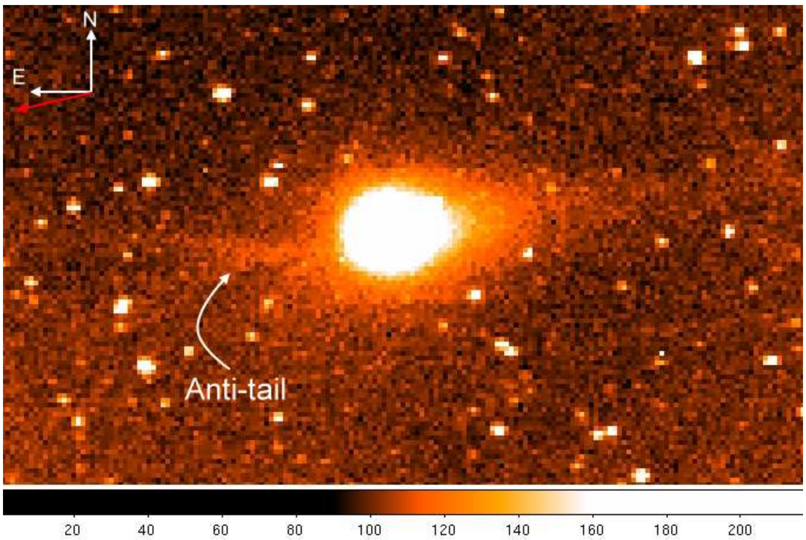

Fig. 3: Comet Lulin represents its anti-tail in sunward direction on December 21, 2008. This unusual tail was last for a while and it, at least, did not fall away during our observation from December 2008 to April 2009. The orientation is given in the figure and the red arrow represents the direction of Sun. The FOV is 12' × 7.5' (1.12×10^6 km × 6.7×10^5 km).

nomenon, curved jet, might be caused by the rotational effect from the cometary nucleus. The position angle of jet feature was changed due to the orbital of comet and it changed from 20 to 90 degree during the time from the beginning to the end of August 2008. Unfortunately, the data of comet Lulin by using SLT is not enough to estimate the rotation period of comet.

The elevation of comet Lulin was getting lower and lower after August and it was not available for observing until the end of December 2008. On Dec. 19, 2009, we detected the anti-tail of comet Lulin in very low elevation. Two days later, we finally took a good quality anti-tail imaging (Figure3). We can see an anti-tail lied on the Sun-ward direction. The anti-tail is actually only part of dust tail and this rare phenomenon is an illusion caused by the viewing geometry as the comet orbits in nearly the same plane at the Earth. This phenomenon is usually rather rare and short duration. The anti-tail of comet Lulin, however, was last for quite a while since we detected in Dec. 2008.

4.2 Dust production rate

$A(\theta)f\rho$, dust production rate, is the product of the dust Bond albedo at a given phase angle, $A(\theta)$, the filling factor of the dust within the aperture, f, and the projected aperture radius, ρ, and was first described by A'Hearn et al (1984) in order to characterize the dust activity of a comet. $A(\theta)f\rho$ is related to a stationary model that assumes a uniform and constant dust expansion within the coma. According to this model the dust column density varies as ρ^{-1}. In this case, $A(\theta)f\rho$ becomes independent of ρ. Afρ measured in cm is given in equation 1

$$A(\theta)f\rho = \frac{(2r\Delta)^2}{\rho}\frac{F_{com}}{F_{sun}} \qquad (1)$$

Here r [AU] is the comet's heliocentric distance, Δ[AU] is the comet's geocentric distance, ρ[cm] is the radius of aperture at the comet (we used 10,000 km in this work), $F_{com}[erg\ cm^{-2}s^{-1}]$ is the measured cometary flux in a continuum filter, and F_{sun} $[erg\ cm^{-2}s^{-1}]$ is the solar flux at 1 AU. The solar flux can be computed by using a high-resolution solar spectrum (Kurucz et al. 1984) for converting and the detail can be found in Lin et al. (2007, 2009). The resulting values are given in Figure 4. The measured $A(\theta)f\rho$ values here are effected by an error of ~10% due to the errors in the absolute flux calibration of the images.

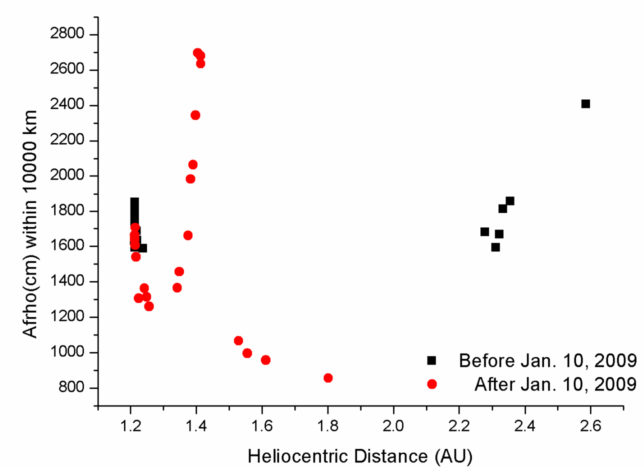

Fig. 4: The variation of *Afρ* with heliocentric distance. The up-limit *Afρ* values within an aperture of radius ρ=10,000 km for the comet Lulin from Aug 2, 2008 (~2.6AU) to Mar. 12, 2009 (~2.1AU). The square symbols (black) are measured in the days before perihelion (~1.2AU) and the circler ones (red) are determined after comet Lulin passed through its perihelion. The uncertainty in our data is 10% due to the errors in absolute flux calibration of the images.

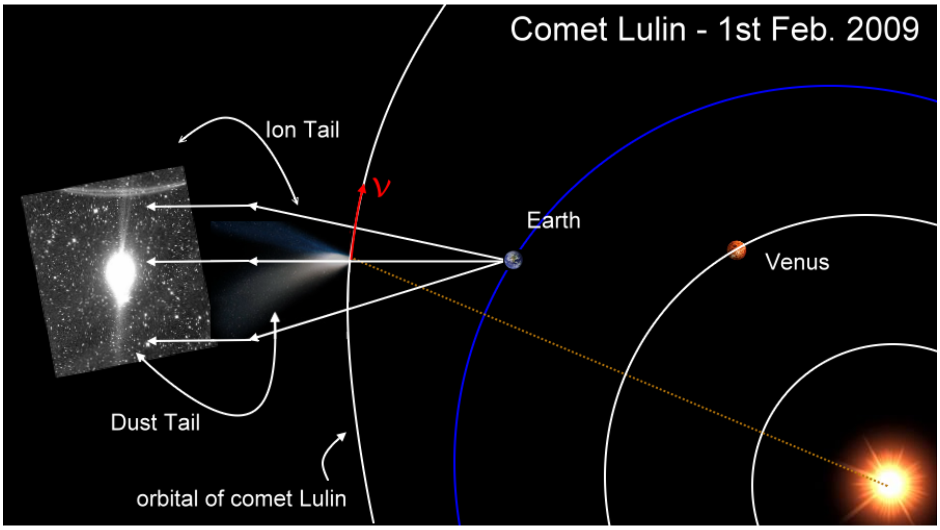

Fig. 5: An illustration for the anti-tail viewed edge-on from Earth on Feb. 1, 2009.

5. Discussion

Anti-tails are rare phenomena in comets but they are mostly observed in some brighter comets, like C/1995 O1 (Hale-Bopp), 2000WM1 (LINEAR), C/2006 P1 (McNaught), C/2007N3 (Lulin) and so on. However, comet Lulin traveled along and crossed the ecliptic plane is unusual in those comets mentioned above. Due to this lucky coincidence of orbital geometry, the anti-tail was last for quite a while. In Figure 5 we can see how the anti-tail (in our case, the composition of anti-tail is an ion tail not the dust tail) caused by an effect of the orbital geometry and our viewing angle here on Earth. Moreover, the anti-tail could be represented by projection effect and neck-line structures (Boehnhardt, 2004). The former one consisted of micron-size dust released over about months before the observations and it would have a needle-like appearance. The latter one is formed by old and heavy grains released long time ago (orders of many months to years) crossing the orbital plane of a comet at 180° of true anomaly from their emission. However, under this hypothesis, we don't see any narrow-like structure, i.e. needle or neck-line in our images. We, therefore, think that the geometry effect is more likely to explain what we saw in our images.

On Aug. 2, 2008, comet Lulin shows a nearly circular coma, about 1 arcmin in diameter, slightly elongated toward West-East (Figure 2a). After image processing, the jet feature was clearly represented (Figure 2b). The $A(\theta)f\rho$, value at this moment is close to ~ 2,400 cm (up-limit) on early August 2008 and we think this high value may be caused by the inner-jet in its coma. The unusual jet structure which is similar to comet Machholz is extremely curved (Lin et al. 2007). Our measurement in $A(\theta)f\rho$ seems obviously to be followed the jet activity and obviously seen in August 2008. When the jet towards to tail-ward direction and was slightly weaker than that in early August, the $A(\theta)f\rho$, value is decreasing from 2,400 to 1,600 (cm) even if comet Lulin is on the way to its perihelion. In fact, there are three peaks during our observations and these phenomena seem to consist with the light curve presented by Dr. Yashida[a]. The unexpected outburst of comet Lulin can be referred to the fresh surface of nucleus. In general, the cometary surface in long-period comets (LPCs) is fresher than that in short-period comets (SPCs) and this fresher surface could evaporate amount of gas as comet approaches the Sun. While ices sublimate on the nucleus, the dust embedded in them is freed and dragged out by the expanding gas. Another possibility is fragmentation to explain unexpected outburst but we didn't detect any fragments behind the main comet during our observations. These unexpected outbursts could give us a clue to realize what the cometary surface is going on. Unfortunately, the broad-band filter set in SLT is not enough to provide the complete information in inner coma, for example the outgassing activities and gas coma developments. We still need the narrow-band filter (i.e. Rosetta filter set in LOT) to make a comprehensive data of comet Lulin.

Acknowledgements

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Note

The formal chinese names of astroids found by LUSS are: Lulin (鹿林), Jhongda (中大), Chengbruce (鄭崇華), Shenchunshan (沈君山), Wensayling (溫世仁), Mapihsia (馬碧霞), Gueiren (歸仁), Tsou (鄒族), Chiayi (嘉義), Nantou (南投), Yushan (玉山) and Kaohsiung (高雄).

[a] http://www.aerith.net/comet/catalog/2007N3/2007N3.html