EVOLUTION OF DUST SHELLS AND JETS IN THE INNER COMA OF COMET C/1995 O1 (HALE–BOPP)

O. LARDIÈRE
Observatoire de Haute-Provence, F-04870 Saint-Michel-l'Observatoire, France

S. GARRO and J.-C. MERLIN
Astroqueyras, 4 allée des Hortensias, F-75014 Paris, France

(Received 4 February 1998; Accepted 2 April 1999)

Abstract. Comet Hale–Bopp was observed with the 80 cm reflector + CCD at the Haute-Provence observatory (OHP) and with the 62 cm reflector + CCD at the Saint-Véran observatory (Queyras, France). The morphology of the shells was followed from their first appearence on 1997 Jan. 30, until their disappearance on May 9. These shells spread from the nucleus region with a velocity in agreement with a nuclear rotation period of about 11.33 hours. We report also a short and bright dust ejection on May 8. CN images show a long spiral jet in the tailward side invisible on continuum images. The circumnuclear structures have been followed at Saint-Véran from Apr. 5 to Apr. 11, 1997 with a high spatial resolution (200 km/pixel). We have followed the emergence of a recurrent linear polar jet. Measurements of its expansion show a constant acceleration of material with typical expansion velocity of 1 km/s. The CCD frames show the interconnection between spiral jets and the successive shells.

Keywords: Comets: individual: C/1995 O1 Hale–Bopp, dust shells, spiral jets

1. Introduction

Comet C/1995 O1 (Hale–Bopp) was discovered visually by Alan Hale and Thomas Bopp (1995) on 1995 July 23 at more than 7 AU from the Sun. This comet is recognized as one of the greatest comets ever seen for a period of more than five centuries, with an absolute magnitude of -0.8, coming in third position after comet Sarabat of 1729 (-3.0) and the Great Comet of 1577 (-1.8) (Kidger, 1995). Since only a few weeks after discovery, comet Hale–Bopp has exhibited strong jet activity and it was of peculiar interest to follow up its inner structure around perihelion time (1997 Apr. 01) with long focus reflectors.

2. Observations and Data Processing

The inner structure of comet Hale–Bopp has been regularly observed during 40 nights from January 1997 until May 1997 at the Haute-Provence observatory (OHP) with the CCD of the 80cm reflector (T80) equipped with broadband filters

Earth, Moon and Planets **78:** 205–210, 1997.
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(B, V, R and I) and IHW filters (CN, mid and red-continuum). A one week mission at the Saint-Véran station (french Hautes Alpes) was also scheduled from 1997 April 05 to 11 for high resolution observations with the 62 cm reflector (T62)[1] where 433 unfiltered CCD frames, totalizing 9h51 m of observations, have been taken. Typical exposure times were from 0.5 s with the T62 to 10 s and 40 s on the T80 with continuum and CN filters respectively. In order to enhance cometary inner features, a standard data processing (i.e., bias subtraction and flat fielding) followed by rotational-shift-difference (RSD) algorithm (Larson and Sekanina, 1984) was performed with ESO-MIDAS software. Position angles (p.a.) of jets have been measured from processed images by means of an 1D-gaussian fitting of the jet section obtained from a sum of lines of polar-images centered on the cometary nucleus.

3. Dust Shells

On 1997 January 30, an astonishing periodic shell-shape structure in expansion was found for the first time on images taken with the OHP T80 (IAUC No. 6560) and processed by the RSD algorithm. This expanding shell-shaped feature[2] caused by the rotation of the nucleus was confirmed later by other observers who have measured a rotation period of about 11.47 hr (Lecacheux et al., 1997). These shells have been regularly observed at OHP until their disappearence on May 9, 1997. Measurements made on over three months show that the mean projected expansion velocity of the dust shells is about 0.37 km/s in the sunward direction. This value may be compared with the result given by the formula derived by Whipple (1978), $v = 0.535\ r^{-0.6}$ km/s : the speed of expansion of the shells should be 0.56 km/s at an heliocentric distance r of 0.93 AU. The projected separation between shells varies from 12,000 km on Feb. 1997 to 20,000 km on May 1997 with a mean value of about 15,100 km consistent with other results (Rousselot et al., 1997). Considering a radial outflow of the dust with a constant velocity near the nucleus, the ratio between the separation distance and the expansion velocity of arcs gives a nucleus spin-period of about 11.33 hours. Our measurements have also revealed that the outer shells are gradually more confined than the inner shells. This result shows that the expansion velocity of dust shells is inversely proportional to the distance from nucleus.

[1] This telescope is to the disposal of amateurs by means of the non-profit association Astroqueyras.

[2] Animations showing the expansion of shells are available on our web site: http://www.obs-hp.fr/~lardiere/e_halebopp.htm.

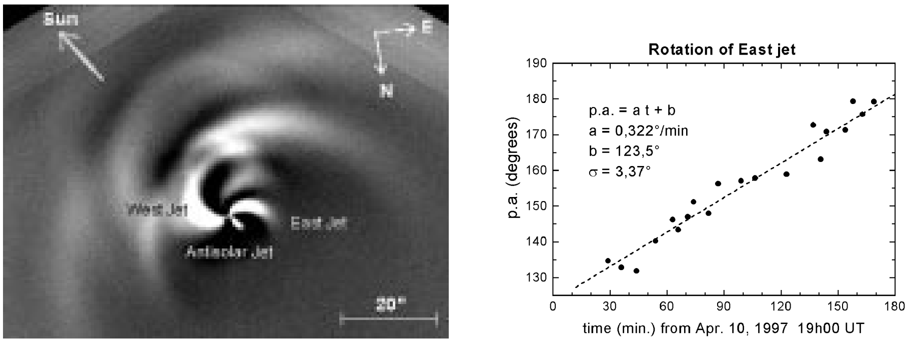

Figure 1. Image obtained on 1997 April 10 with the Saint-Véran T62 showing the jets discussed in this paper. At right, the evolution of the position angle of the East jet. A constant rotation velocity of about 0.3 degrees/min can be seen.

4. Spiral Jets

Continuous observations started on January 1997 with the OHP T80 show that the spiral jets appeared in March 1997. The rotation of the East spiral jet has been measured on co-added images taken with the T62 and processed by the RSD algorithm (Figure 1). An angular speed of 0.32°/min has been deduced on several consecutive nights. This implies an apparent rotation period of 18.3 hours. According to the rotation period determined at that time (11.35 hours) (Jorda et al., 1997), this indicates that the East jet was probably situated at a high cometocentric latitude or that projection effect is very strong. On T62 frames, we have noted a slow apparent rotation of the West spiral jet, probably due to a discrete active zone or cluster of zones permanently exposed to the Sun light around perihelion time. The presence on the North-West side of the nucleus of at least four very sharp spiral jets, with a width at the subarcsecond level, is seemingly crediting the thesis that it existed as much discrete active zones and may explain the apparent non evolution of this place at a lower resolution. Such highly collimated structures are typical of dust jets. The animation of the complete set of higher resolution processed images taken at Saint-Véran clearly shows the connection between spiral jets (West jet in particular) with the shells.[3] The connection is visible not only for the first shell nearer to the nucleus but also at least for the two next ones.

5. CN Jets

Contrary to continuum images, CN images (Figure 2) taken from April 17 to April 22, 1997 with the OHP T80, reveal the presence of the long spiral-shaped jet on the tailward direction, early detected on 1997 February by K. Birkle and H. Boehnhardt (IAUC No. 6583). This CN feature, well-described by gaseous emission from

[3] see our web site: http://www.obs-hp.fr/∼lardiere/st-veran.htm.

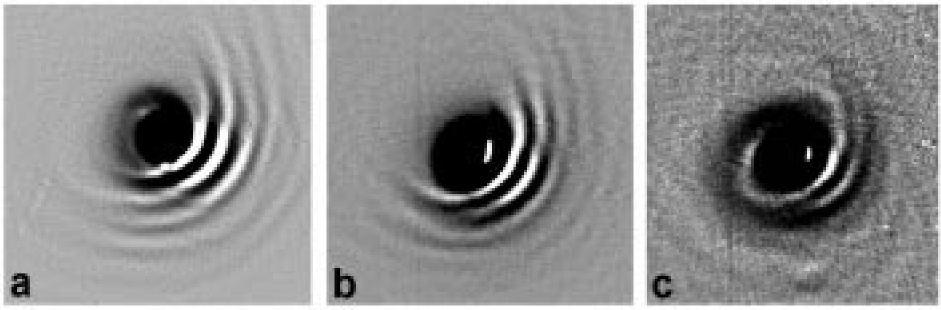

Figure 2. Images obtained with the OHP T80 on 1997 April, in V broadband on Apr. 14 (a), in mid-continuum band (b) and CN band (c) on Apr. 18. A long gaseous spiral-shaped jet located on the tailward side is visible on broadband and CN images. Field of 3 arcmin., North is left, East is up.

small dust particules, is also visible on images taken with broadband filters (B, V and R) which transmit several other gaseous emission lines, implying that CN is not the only gas to be still active on the tailward side (Lederer et al., 1997). Further measurements on CN images and numerical modeling of CN features could also provide some additional constraints for the rotational state of the nucleus (Samarasinha et al., 1997).

6. Peculiar Features

6.1. Antisolar jet

Among the more spectacular features observed with the T62 was the detection of a rapidly expanding antisolar jet. This linear jet is visible at a steady average p.a. of 34° from April 7 to 10 (Figure 1). The increase of the length has been rendered by a polynomial fit of the second order, indicating an acceleration. The average expansion rate is of 0.8 km/s in the plane of the sky. Such behavior is typical of gaseous emission but emission of dust grains accelerated at gas speed is also possible (Combi, 1997).

6.2. Dust events

Two strong dust events have been reported in addition to standard dust jets and arcs described above and appearing periodicaly at every nucleus rotation. The first dust event that we have observed appears on 1997 March 12.18 UT: continuum processed images show two clusters of dust elongated along the solar-antisolar direction. This dust event is problably associated with an apparent small brightness excess recorded on the same day by photometric observations (Rodríguez et al., 1997). Later, a very similar but brighter dust event has been observed on three consecutive nights in May 1997 (Figure 3). A rapidly growing 90°-bent dust jet

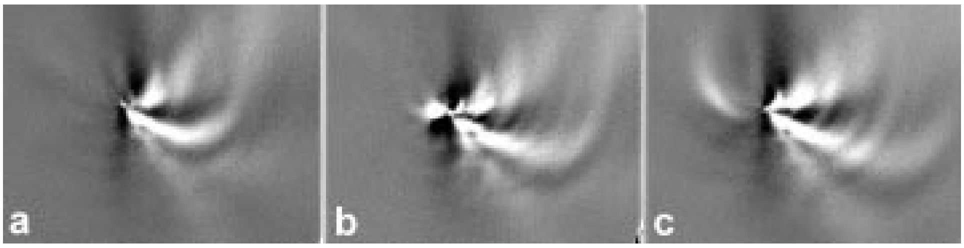

Figure 3. Images obtained on 1997 May 7 (a), 8 (b) and 9 (c) with the OHP T80 and processed by the RSD algorithm. A strong and bright dust event occured on May 8.75 UT near the north side of the nucleus (b). One day later, the dust cluster was visible at over 50,000 km from the nucleus and took the shape of an elongated structure parallel to the radius vector (c). A rapidly growing bent jet is clearly visible in the sunward direction. Its length is 44,000 km on May 7 (a), 82,200 km on May 8 (b), and 103,000 km on May 9 (c). Field of 3′, North is left, East is up.

is also clearly visible in the sunward direction. Similar observations have been reported by Kidger et al. (1996) on a spiral jet observed on August 1995. This 90°-break point is situed on a contact surface beyond which solar wind becomes stronger than the gas pressure within the inner coma. Then, an expansion of this contact surface means that a significant increase in gas production occurs around the nucleus which may also favour dust events from the nucleus.

7. Conclusions

Comet Hale–Bopp has raised the first opportunity of observing a Great Comet with modern post-photographic technologies. The use of highly sensitive and high resolution CCD detectors combined with the intensity of the comet itself authorized high spatial and temporal resolutions with long focus reflectors. The quite far distance of the comet from the Earth has also permitted an unusual long coverage over time.

All of these have been decisive factors for discriminating the nature (gas or dust) of the various features observed within a radius of 70,000 km from the nucleus around perihelion time. Following the very first detection of the dust shells at the OHP on January 30, 1997, the distance between the three first shells have showed to be nearly constant (about 15,000 km at perihelion time) and indicate a rotation period for the nucleus of 11.33 hours. The link between spiral jets and dust shells has been clearly observed at Saint-Véran. The very complex activity of this comet from March to May 1997 has also been accompanied by several dust events detected in continuum band. These events occurred after the apparition of the spiral jets and was seemingly coinciding with brightness surges observed elsewhere. Regarding activity associated with gaseous emissions, we have measured an expansion velocity of the order of 1 km/s in a recurrent rectilinear jet. It is not clear if it is an antisolar jet located on the nucleus pole or a feature turned toward the line of sight. Observations with a CN filter at OHP have also clearly confirmed that CN jets do not coincide with dust jets, as was observed in 1986 in P/Halley. Further investigations have yet to be made in correlation with observations from other places, in particular for confirming the orientation of the various features observed.

Acknowledgements

We wish to thank the Astroqueyras staff, his President, Jacques Boussuge, and the inhabitants of the village of Saint-Véran for their invaluable help during our stay, and the OHP staff for making the 80 cm-telescope readily available to us. We are also grateful to Javier Licandro for useful discussions during the meeting.

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