IMAGING OF THE STRUCTURE AND EVOLUTION OF THE COMA MORPHOLOGY OF COMET HALE–BOPP (C/1995 O1)

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Abstract. Imaging of coma morphology of Comet Hale–Bopp from pre-perihelion through perihelion to post-perihelion is presented. Broad band images from 1996 and late 1997 show nearly radial jets streaking out from the nucleus. During both 1996 and late 1997, the brightest jets are approximately in a northern/northeastern direction. The slight curvature present in these radial jets is consistent with radiation pressure effects. Narrow band images around perihelion show two distinctive pictures of the CN and the continuum coma morphology. Spirals are clearly seen in the CN images but not in the continuum where structure is confined to the sunward side. The CN structure is consistent with continuous outgassing of the source of CN from the nucleus during both day and night.

Keywords: Comets — Hale–Bopp C/1995 O1, jets, dust, CN

1. Introduction

Since its discovery in 1995 (Hale and Bopp, 1995) at a heliocentric distance of 7 AU, comet Hale–Bopp has been monitored extensively. We will present our imaging observations from the Kitt Peak 0.9 m, the WIYN[1] telescope and from CTIO during pre-perihelion, near perihelion and post-perihelion. Our images will complement what is already published in the literature (e.g., Rauer et al., 1997) as well as in these proceedings (e.g., Lederer et al., 1997–1999). We will discuss the evolution of the coma morphology and the differences between CN and continuum observations around perihelion.

2. Observations

We observed Comet Hale–Bopp with broad band and narrow band filters during several periods between June 1996 and December 1997 covering a heliocentric

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TABLE I

Observational and geometric circumstances and telescope information

Date	r^1	Δ^2	β^3	$PA_{\odot}^4$	ImS[5]	Telescope	PixS[6]
June 26 ’96	3.97	2.98	4	39	2720	KPNO-0.9 m	0.68
August 10 ’96	3.49	2.74	13	284	1320	CTIO-1.5 m	0.44
September 6 ’96	3.18	2.85	18	275	1252	CTIO-1.5 m	0.44
September 27 ’96	2.93	2.97	20	269	1172	KPNO-0.9 m	0.38
March 13–15 ’97	0.97	1.34	48	166	225	WIYN	0.20
April 1–2 ’97	0.91	1.36	47	206	229	WIYN	0.20
April 14–16 ’97	0.95	1.51	41	233	254	WIYN	0.20
April 18–19 ’97	0.97	1.57	38	238	264	WIYN	0.20
April 23 ’97	0.99	1.64	35	245	276	WIYN	0.20
May 5–6 ’97	1.10	1.85	27	263	311	WIYN	0.20
November 21 ’97	3.48	3.37	16	126	1824	CTIO-0.9 m	0.40
December 17 ’97	3.77	3.60	15	163	1562	CTIO-0.9 m	0.40

[1] Heliocentric distance in AU.
[2] Geocentric distance in AU.
[3] Earth-comet-sun angle in deg.
[4] Position angle of the sun in deg.
[5] Image size in 10^3 km.
[6] Pixel size in arcsec .

range from 4 AU pre-perihelion through perihelion to 3.8 AU post-perihelion at different telescopes. Table I lists the observational and geometrical circumstances of the comet and the telescope information for our observations. The WIYN images had to be taken during twilight at high airmasses (2.5–4.0) and were tracked with cometary rates. NASA Hale–Bopp filters for CN ($\lambda = 3871$ Å, FWHM = 57 Å) and blue continuum ($\lambda = 4449$ Å, FWHM = 62 Å) were used for obtaining these images. The KPNO-0.9 m images were tracked at cometary rates as well while the CTIO observations were tracked siderially with short integration times, so that we would not trail the comet more than the seeing disk. Broad band R filters were used for both KPNO-0.9 m and CTIO images.

3. Coma Morphology

The coma morphology changed from jets to arcs between pre-1997 and perihelion (April 1, 1997). It then changed again between perihelion and late 1997 from arcs to jets. Representative enhanced images from our observing runs (Table I) from 1996, from near perihelion in 1997, and from late 1997 are shown in Figures 1, 2 and 3, respectively. Qualitatively, both 1996 and late 1997 images were similar.

Nearly radial jets were seen in the June, August and September 1996 images as well as in the November and December 1997 images.

The images in broad band R in Figures 1 and 3 were azimuthally renormalized for each radius to enhance the jet features thus preserving the relative brightnesses among jets. Most stars were removed before the renormalization (except for the June 1996 image where there were too many stars). The rings are artifacts caused by background stars that have not been removed. In the images, white corresponds to higher brightness levels as in the jets. Alternate enhancement techniques such as spatial filtering methods (e.g., Larson and Slaughter, 1992) bring out local enhancements such as fainter jets showing a porcupine like structure (e.g., Manzini et al., 1996) but do not preserve the relative brightness information. As we use the brightest jets to constrain the rotational state of the nucleus (Samarasinha et al., 1997–1999), the azimuthal renormalization is the appropriate enhancement technique. The brightest jets are approximately directed towards the northern/northeastern direction for both 1996 and late 1997 images. The respective position angle of the brightest jet near the nucleus is approximately 0°, 0°, 35°, and 30° for the June, August, September 6, and September 27, 1996 images, while for the November and December 1997 images they are 355° and 15°. The position angles of the brightest jets are not coinciding with the sun direction. The jets are slightly curved (especially in the November 1997 image) and the direction of curvature for jets in each image is consistent with the direction of the solar radiation pressure (Table I).

Figure 2 shows a representative time series of some of the enhanced CN and continuum images. The images were first convolved with a gaussian of standard deviation $\sigma = 15$ pixels (corresponding to 3 arcsec) which was the optimal kernel size to bring out the coma structures. The originals were then divided by the convolved images to produce the enhanced images. Again, white denotes the brighter structures. While the structure in the continuum images is present only in the sunward side, the CN images show structure both in the sunward and anti-sunward sides. These CN spirals were first reported by Birkle and Bohnhardt (1997). Lederer et al. (1997–1999) also note a similar spiral pattern for OH, C_2, C_3, and NH. This is consistent with continuous outgassing of the source of CN from the nucleus with a production rate during the cometary night at about 10% of the peak rate during the cometary day. The CN is likely to be produced in situ in the coma from its precursor. The CN images presented here are not continuum subtracted as we do not have information to deduce their continuum contamination. The separation and repeatability of the arcs in the sunward side of the continuum images suggest a projected dust velocity of $\approx$0.4 km s^{-1}, measured on March 13–15, 1997 at a position angle of 180°. The apparent curvature of the arcs during the whole observing period suggests counterclockwise rotation. Furthermore, faint structures can be seen in the sunward side of the continuum images showing the same repetitive pattern as the bright arcs. An extensive discussion of the implied spin state from these images is presented in Samarasinha et al. (1997–1999). To summarize, we found three cases

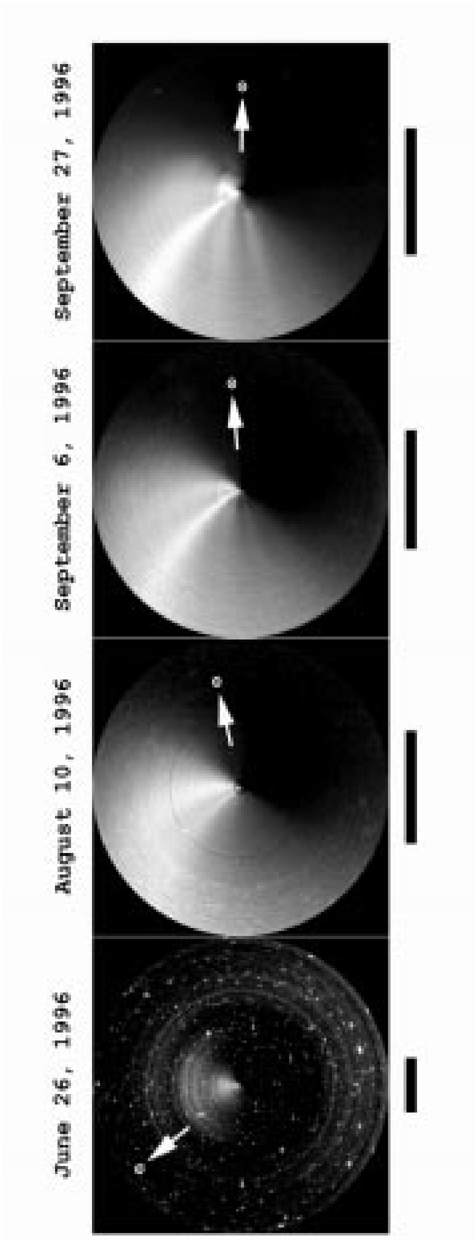

Figure 1. The enhanced images show the coma morphology of comet Hale–Bopp in 1996. In all the images north is to the top and east is to the left. The direction to the sun is shown with white arrows. The scale bar at the bottom of the images corresponds to 500,000 km.

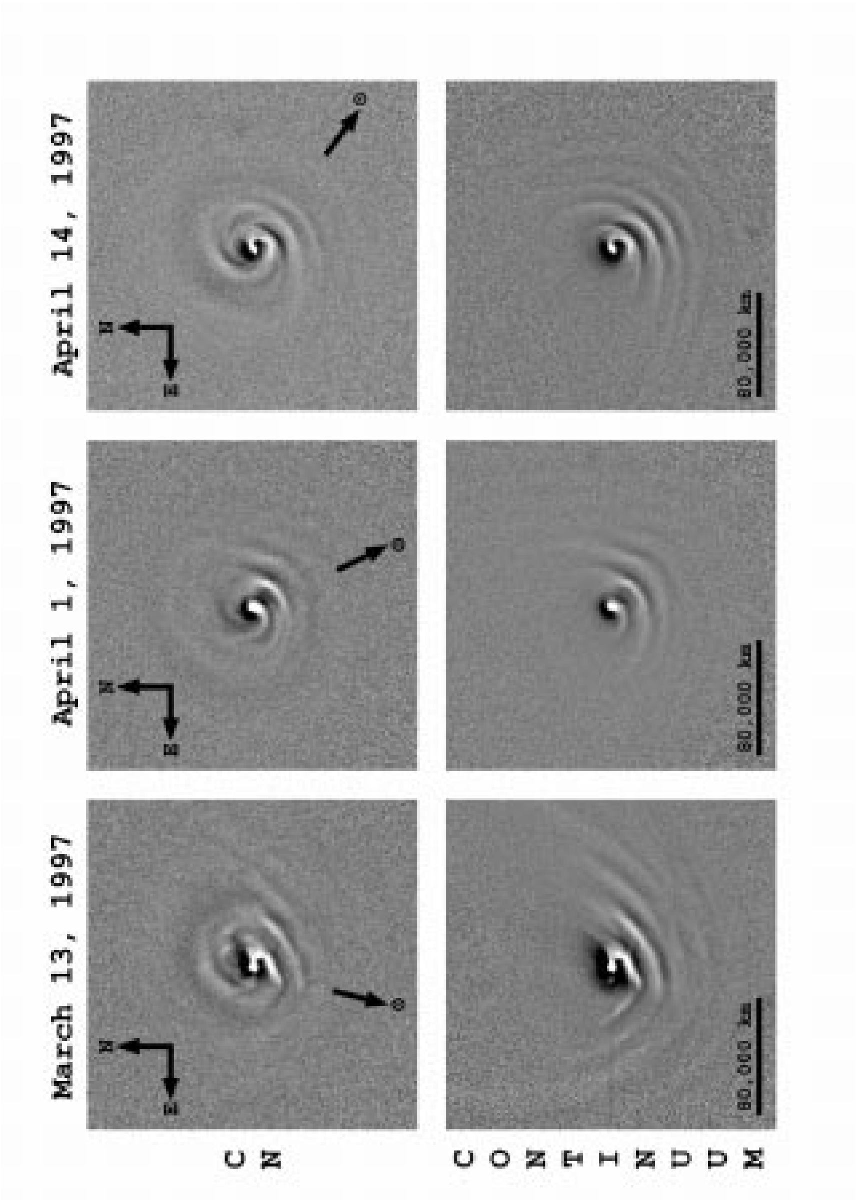

Figure 2. (a) The enhanced images show the coma morphology of comet Hale–Bopp in March/April, 1997. The direction to the sun is shown with black arrows.

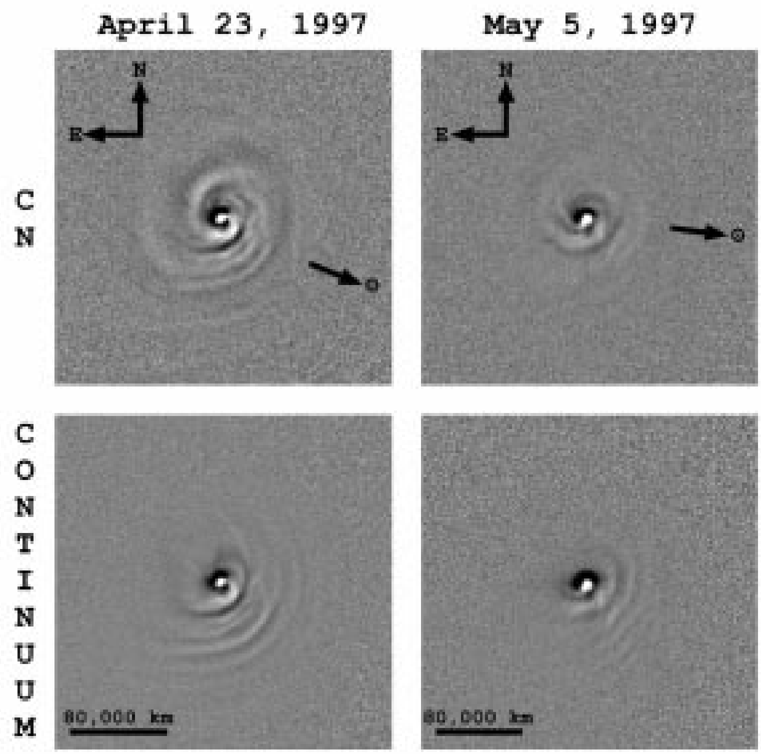

Figure 2. (b) The enhanced images show the coma morphology of comet Hale–Bopp in April/May, 1997. The direction to the sun is shown with black arrows.

of rotational states compatible with near perihelion observations: (1) principal-axis rotation, (2) a complex rotational state with a small precessional angle, or (3) a complex rotational state with a large ratio between the component periods. The WIYN images from May 1997 indicate the beginning of the change in the arc structure to a structure where both arcs and radial jets co-exist as in February 1997 (e.g., Hergenrother and Larson, 1997).

An explanation of the transition from jet features to arc structures between pre-perihelion and near perihelion and the reverse transformation between near perihelion and post-perihelion can be found in the companion paper by Samarasinha et al. (1997–1999). In short, this transition can be explained by three causes: (1) an increased separation between arcs as the heliocentric distance decreases, (2) a changing sun-comet-Earth geometry, and (3) an increased spatial resolution as the geocentric distance decreases.

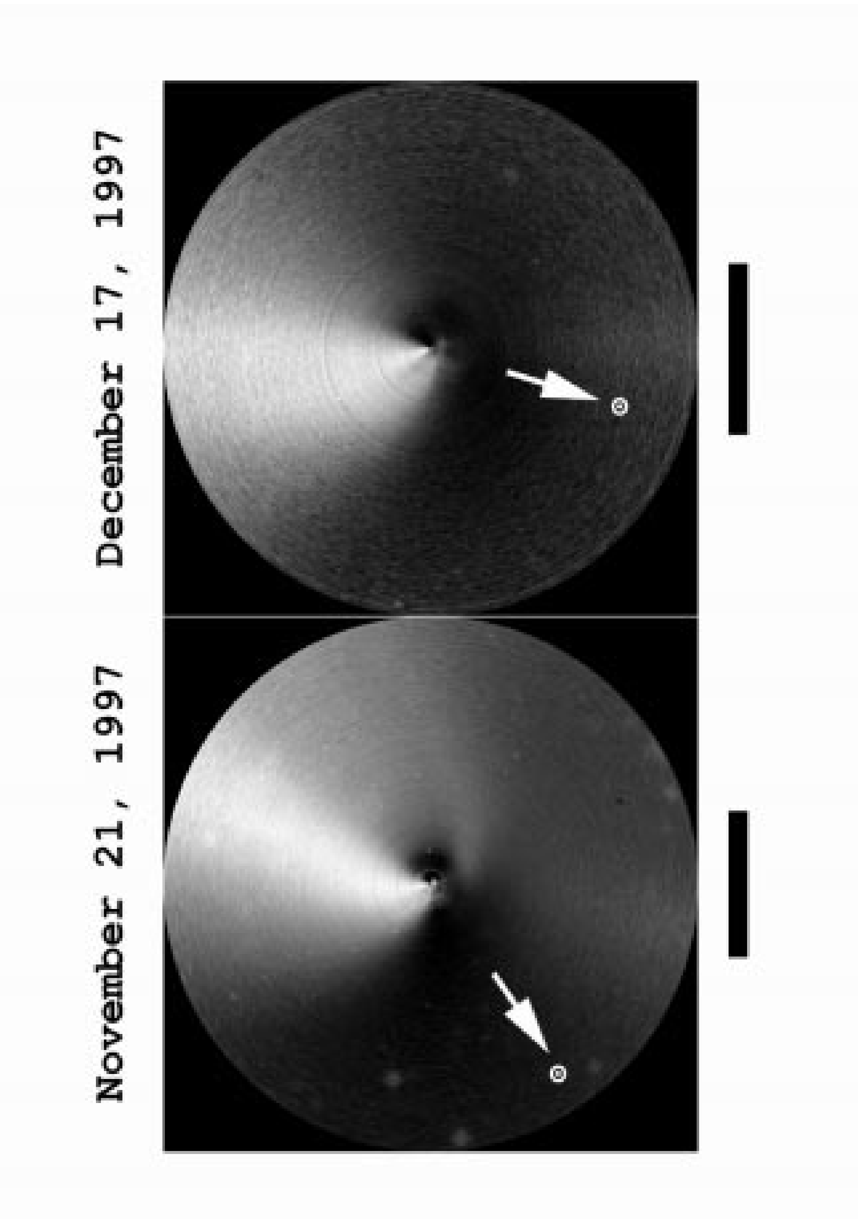

Figure 3. The enhanced images show the coma morphology of comet Hale–Bopp in late 1997. In all the images north is to the top and east is to the left. The direction to the sun is shown with white arrows. The scale bar at the bottom of the images corresponds to 500,000 km.

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