An analysis of comet brightness behaviour from ASSA observations

T P Cooper *
PO Box 14740, Bredell, 1623
tpcoope@mweb.co.za

M Begbie
songbird@mweb.co.zw

Summary: Since the Director took over the Comet and Meteor Section of ASSA in 1992, there has been a slow growth in observing comets. This interest was certainly fuelled by the appearance of comet Hale-Bopp, which as a result of its brightness was rather well observed, but there have been several other comets lately which have become reasonably bright. The Director has also presented several workshops with the intention of training observers in the methods of observing comets. This paper analyses the brightness observations of the eight brightest comets observed by ASSA members in the last decade.

General brightness behaviour of comets

It can be shown that the average brightness behaviour of most comets can be represented by the power law equation:

$$m_1 = H_0 + 5 \log \Delta + 2.5n \log r \quad (1)$$

where m_1 = total cometary magnitude
H_0 = absolute magnitude of comet at $\Delta = r = 1$ AU
Δ = geocentric distance of comet
r = heliocentric distance of comet

The heliocentric magnitude of the comet is then given by:

$$m_1 - 5 \log \Delta = H_0 + 2.5n \log r \quad (2)$$

Thus a plot of heliocentric magnitude versus log r takes the form of a straight line, the slope of which yields the value of n, the rate at which the comet brightens or fades relative to its distance from the Sun, also called the photometric constant. The intercept at log $r = 0$

** Director, Comet and Meteor Section, Astronomical Society of Southern Africa*

Paper presented at the 6th ASSA Symposium, held in Johannesburg 2004 October 14–16.

yields H_0. Now, we often find that once these plots are constructed, the brightness behaviour before perihelion, and hence the form of equation (1), differs from that after perihelion. In general, the value of n is found to be around 4, but typical long period comets have $n < 4$ and comets with $P < 30$ yr generally have $n > 5$ (Green 1997:31). The use of the power law equation enables a prediction of future brightness behaviour of a comet, and to see how a comet's brightness deviates from this semi-empirical law based on the inverse square law of light over several apparitions. It can also cautiously be used to compare the behaviour of different comets.

Actual brightness behaviour

The derivation of the pre- and post-perihelion parameters of equation (1) give only the average brightness behaviour of the comet. It does not portray the subtle night-to-night variations that are often observed, or even macro-changes in brightness which might occur as the comet approaches to, or recedes from, the Sun. These changes are best seen by closer scrutiny of the light curve itself over short time scales. The values of H_0 and n can then be determined for various arcs of the comets orbit.

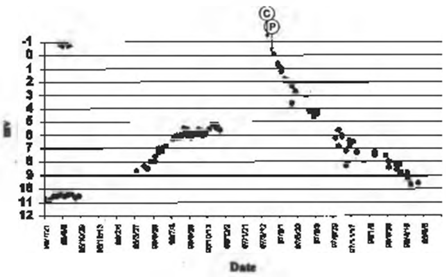

Figure 1(a). Observed m_1 versus date for comet C/1995 O1 Hale-Bopp.

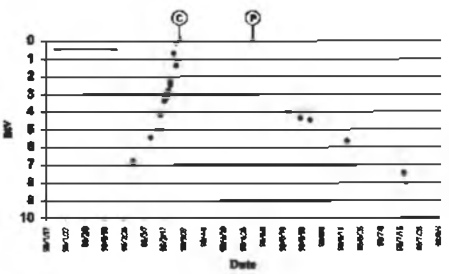

Figure 1(b). Observed m_1 versus date for comet C/1996 B2 Hyakutake.

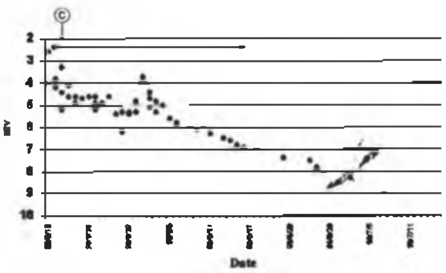

Figure 1(c). Observed m_1 versus date for comet C/1998 J1 SOHO.

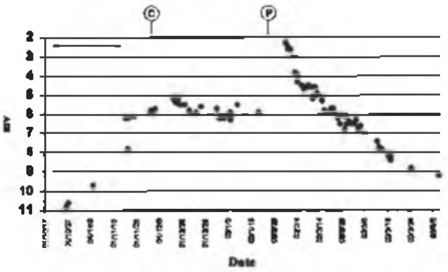

Figure 1(d). Observed m_1 versus date for comet C/2000 WM1 LINEAR.

Date of close approach to Earth is shown as a circled C, and the date of perihelion as a circled P. The double headed arrow in the upper left corner represents a period of 30 days.

Whether a known periodic comet or a comet approaching the Sun from the Oort Cloud or Kuiper Belt for the first time, comets approach the Sun from deep space, where they reside in a frozen and almost inactive state. As they approach the Sun they come under the influence of solar radiation and the solar wind, resulting in sublimation of the outermost layers of the nucleus to form a coma, and driving these volatiles and released dust into the tail. A comet's actual brightness behaviour is characterised by a number of factors, including size and composition of its nucleus, activity, geometry regarding distance from the Earth and Sun, and distance from the Sun at perihelion, and the time of closest passage to the Sun in the comet's orbit. It is not the intention of this paper to discuss these factors, only the observations of the brightness behaviour by amateurs. It is up to our members to contribute accurate observations of cometary magnitudes to enable astronomers to study the behaviour of comets and their interactions with the solar system in greater detail.

Comet brightness estimation

The visual estimation of the brightness of a comet is based on comparison with objects of known brightness. It is useful for accurate estimation of comet brightness that the observer

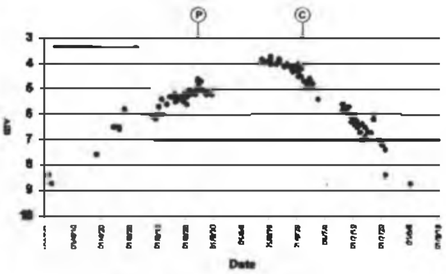

Figure 1(e). Observed m_1 versus date for comet C/2001 A2 LINEAR.

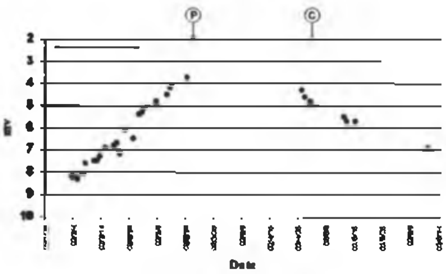

Figure 1(f). Observed m_1 versus date for comet C/2002 C1 Ikeya-Zhang.

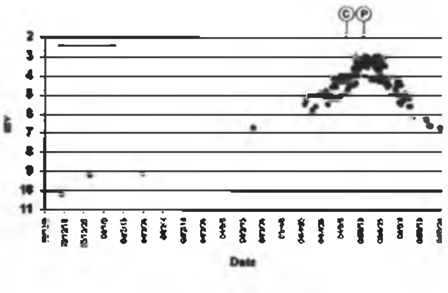

Figure 1(g). Observed m_1 versus date for comet C/2001 Q4 NEAT.

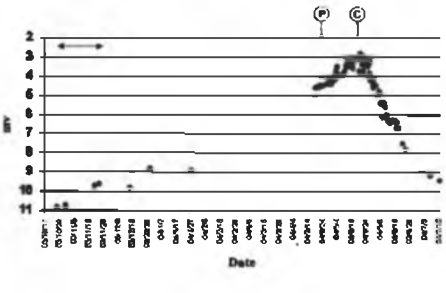

Figure 1(h). Observed m_1 versus date for comet C/2002 T7 LINEAR.

Date of close approach to Earth is shown as a circled C, and the date of perihelion as a circled P. The double headed arrow in the upper left corner represents a period of 30 days.

is first fully conversant with the methods used in the estimation of brightness of variable stars. The latter is based on the step method of Argelander (Hoffmeister et al. 1985:274). The observer selects two stars of similar brightness to the object to be estimated, one brighter and one fainter. The observer divides the difference between the two comparison stars into a convenient number of steps, and estimates the brightness of the object as the number of steps from each of the comparison stars. For example, two stars are selected of magnitude 8.2 and 8.9. The number of steps between them is selected as 7. The observer estimates the object as slightly closer to 8.2 than 8.9, and then decides it is 3 steps from 8.2 and 4 steps from 8.9. The estimate is thus given as 82(3)V(4)89, and the derived magnitude is 8.5. This process is repeated if possible with two or three sets of comparison stars to improve the accuracy of the observation.

Transferring this methodology to comets brings the first problem, in that comets generally do not look like stars, but have a certain angular diameter and degree of diffuseness. The second problem is that comets are not uniform in their appearance; one comet may appear large and highly diffuse, while another may have a small compact coma, appearing sharper and more stellar, especially in small instruments. Several methods have been developed in order to compare the brightness of comets with stars, generally by defocusing the stars so that their light is also distributed over an area approximating that shown by the coma.

In the VSS method, also known as the In-Out method, the stars are defocused so that the size of their out-of-focus image appears the same as the in-focus comet. The light of the star is thus spread out over the same angular size as the coma. The brightness of the in-focus coma is compared to the brightness of the out-of-focus stars. This method is well-suited to diffuse comets.

In the VBM method, also known as the Out-Out method, the comet and comparison stars are defocused by the same amount and the brightness of the defocused images are compared. The method is well-suited to comets which show a high degree of condensation. It should not be used for comets with degree of condensation (DC) lower than 7 or 8, and preferably only on comets with DC = 8 or 9.

In the Morris method, also known as the Modified Out method, the comet is defocused sufficiently that any faint outer coma is rendered invisible, leaving the more condensed inner condensation with a more uniform brightness profile. The comparison stars are then defocused to the same apparent size. The method is seen as an overlapping methodology between the VSS and VBM methods.

Skilled observers will adapt to a methodology suited to the morphology of the comet. What is important is that the method used is specified, and that suitably qualified magnitude reference stars are used. Only in this way can the quality of visual comet brightness data be maintained.

The comets observed

The light curves of the eight brightest comets observed by ASSA members over the past decade are shown in Figures 1(a)–(h). These plot observed m_1 versus date, with each point representing a single observation, except comet C/1995 O1 where each point is the average of 10 day bins. The date of close approach to Earth is shown as a circled C, and the date of perihelion as a circled P. The double headed arrow in the upper left corner represents a period of 30 days and is intended to indicate the scale of the plot. These comets all reached magnitude 4 or brighter.

The brightness behaviour for each comet was determined in Figures 2(a)–(h). For each point, the authors determined the values of log Δ and log *r*. We then plotted heliocentric magnitude versus log *r* for each comet, and the values of H_0 and *n* were derived from the intercept of the graphs (at log $r = 0$) and the slope of the straight lines respectively. Solid points and lines represent the behaviour before perihelion, while open circles and dashed lines represent that after perihelion. The overall results are given in Appendix 1, and summarised in Table 1.

Table 1. Summary of photometric parameters of the observed comets.

Comet	*q*	H_0	*n*	range of heliocentric distances
1995 O1	0.92	−1.5	3.9	before perihelion (r = 7.1–4.8 AU)
		−0.2	3.0	before perihelion (r = 4.8–2.1 AU)
		−0.5	3.5	after perihelion
1996 B2	0.23	5.2	3.3	overall
1998 J1	0.15	6.3	2.4	after perihelion
2000 WM1	0.56	7.7	3.2	before perihelion
		6.4	5.4	after perihelion
2001 A2	0.78	7.4	4.9	before perihelion
		7.1	4.6	after perihelion
2002 C1	0.51	6.5	3.1	overall
2001 Q4	0.96	5.5	2.2	overall
2002 T7	0.62	6.1	2.8	before perihelion
		5.2	2.8	after perihelion

Key: *q* = perihelion distance (AU)

Comet C/1995 O1 Hale-Bopp

With around 400 individual observations, this comet was probably the best ever covered by ASSA members. The brightness behaviour is shown in Figure 1(a) and was described in detail by Cooper (1998). The comet was discovered on 1995 July 22, and shows uninterrupted coverage by ASSA members from 1995 July 28 (magnitude 10.8) to 1998 May 30 (magnitude 9.7) apart from two periods when the comet was too close to the Sun for observation. The light curve shows a regular increase from $r = 7.1$ to 4.8 AU, with $n = 3.9$, followed by a slower increase in brightness between $r = 4.8$ and 2.1 AU, with $n = 3.0$. This slowing was attributed to the later-than-expected volatilisation of water vapour, taking over from carbon monoxide as the primary brightness driver. The comet was not visible from southern Africa between r = 2.1 AU and perihelion. After perihelion the comet showed a regular fading behaviour with n = 3.5. From the derived values of H_0, comet Hale-Bopp was clearly one of high intrinsic brightness. The data derived from Figure 2(a) indicate the comet brightened and faded at similar rates before and after perihelion.

Comet C/1996 B2 Hyakutake

This comet was discovered on 1996 January 20. It was observed from March 1 at magnitude 6.8, and brightened rapidly as it slowly crossed Libra. Closest approach to Earth occurred on March 23 at a distance of only 0.1 AU, and about this time the comet headed rapidly northwards, by month-end moving 18° per day and reaching magnitude 0. It was out of view at its brightest, and recovered in the southern morning sky in mid-May. It faded slowly after perihelion on May 1, and was observed until mid-July, located in Volans. The photometric parameters in Appendix 1 are inconsistent due to the small arc over which the comet was observed pre-perihelion. The values in Table 1 are based on the combined behaviour before and after perihelion, and give n = 3.3.

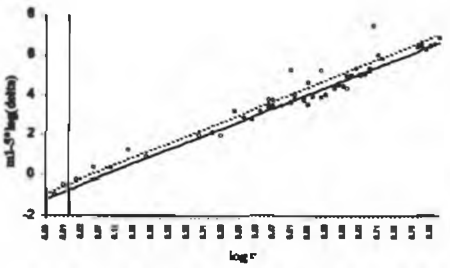

Figure 2(a). Brightness behaviour of comet C/1995 O1 Hale-Bopp. n = 3.5; m_1 = –0.5 + 5 log Δ + 8.8 log r.

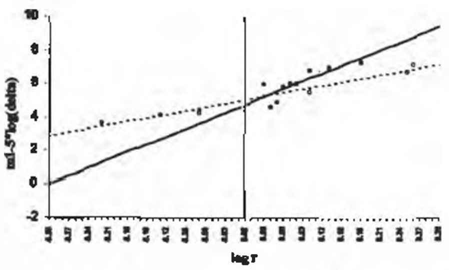

Figure 2(b). Brightness behaviour of comet C/1996 B2 Hyakutake. n = 3.3; m_1 = 5.2 + 5 log Δ + 8.2 log r.

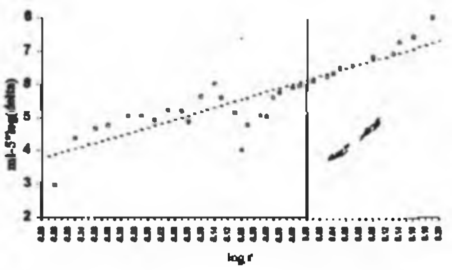

Figure 2(c). Brightness behaviour of comet C/1998 J1 SOHO. n = 2.4; m_1 = 6.3 + 5 log Δ + 6 log r.

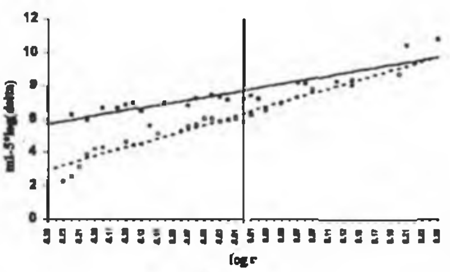

Figure 2(d). Brightness behaviour of comet C/2000 WM1 LINEAR. n = 4.4; m_1 = 7.0 + 5 log Δ + 11 log r.

Comet C/1998 J1 SOHO

This comet was discovered on 1998 May 3 and passed perihelion on May 8. The comet was picked up at magnitude 2–3 on May 18, highly condensed with a narrow tail. It was closest to Earth two days later at a distance of 0.84 AU. The photometric parameters indicate the comet was not intrinsically bright at $H_0 = 6.3$, but it became visually quite bright due to its close perihelion distance. No data is available pre-perihelion, and the rate of fading is relatively slow with $n = 2.4$. The visual light curve in Figure 1(c) is characterised by a short-lived outburst in brightness of amplitude about 1.5 magnitude commencing 1998 June 1.

Comet C/2000 WM1 LINEAR

This comet was originally thought to be an asteroid on discovery on 2000 December 16 at magnitude 18. It was first observed from southern Africa on 2001 October 26 at magnitude 10.8. Visually it brightened rather quickly during November as it crossed Aries, making a close approach to Earth of 0.32 AU on December 2, and thereafter remained at about magnitude 6 for nearly two months. The comet was too low for observation near perihelion, but

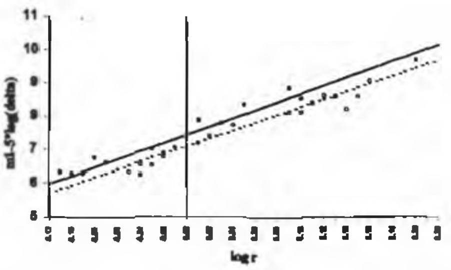

Figure 2(e). Brightness behaviour of comet C/2001 A2 LINEAR. $n = 4.8$; $m_1 = 7.2 + 5 \log \Delta + 12 \log r$.

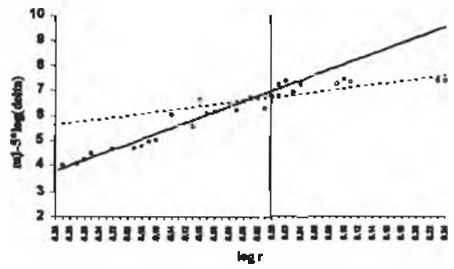

Figure 2(f). Brightness behaviour of comet C/2002 C1 Ikeya-Zhang. $n = 3.1$; $m_1 = 6.5 + 5 \log \Delta + 7.8 \log r$.

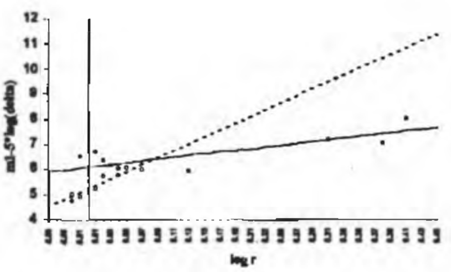

Figure 2(g). Brightness behaviour of comet C/2001 Q4 NEAT. $n = 2.2$; $m_1 = 5.5 + 5 \log \Delta + 5.5 \log r$.

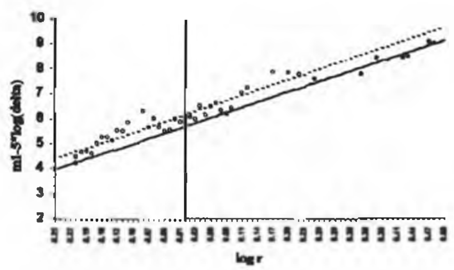

Figure 2(h). Brightness behaviour of comet C/2002 T7 LINEAR. $n = 2.8$; $m_1 = 5.5 + 5 \log \Delta + 7 \log r$.

was located afterwards in the morning sky having brightened to magnitude 2.3. It shows a regular fading behaviour after perihelion. The parameters in Figure 2(d) indicate the comet to be intrinsically fainter with a slower rise before perihelion ($H_0 = 7.7$, $n = 3.2$), and brighter with a more rapid fading after perihelion ($H_0 = 6.4$, $n = 5.4$).

Comet C/2001 A2 LINEAR

This comet was discovered in mid-January 2001 and first observed on April 1 at magnitude 8.4. The visual light curve shows a slightly slower rise to maximum, which occurs between perihelion on May 24 and closest approach on June 30. The rise was punctuated by at least three short outbursts in brightness of small amplitude, caused by splitting events within the comet's nucleus, and at least two of these can be detected in the ASSA data. Immediately after perihelion the comet was too low for observation, and re-emerged in the morning sky at around magnitude 3.7. The derived parameters in Figure 2(e) indicate similar brightness behaviour both before and after perihelion.

Comet C/2002 C1 Ikeya-Zhang

This comet was discovered on 2002 February 1 and first observed on February 3 at magnitude 8.2. The period before perihelion was quite well covered, but the period after perihelion was covered only by Zimbabwean observers due to the northerly declination of the comet. Due to the sparse observations after perihelion, no comparison of behaviour before and after perihelion is made and the values in Table 1 are based on the combined behaviour, and give $n = 3.1$.

Comet C/2001 Q4 NEAT

This comet was discovered as part of the Near Earth Asteroid Tracking program on 2001 August 24 and was about magnitude 20. It was first observed from southern Africa on 2003 December 14 at magnitude 10.2. Despite the fact that the comet spent several months near the South Celestial Pole, its brightening was poorly covered mainly due to an extended period of poor observing weather. Hence the pre-perihelion brightness behaviour is a little uncertain. The post perihelion observations are also rather few since the comet became too far north for observation from southern Africa. Consequently the comet was well observed only for around one month either side of perihelion on May 15, and the data in Table 1 is for the overall apparition. At $n = 2.2$ it would indicate a rather slow rate of brightening and fading.

Comet C/2002 T7 LINEAR*

This comet was discovered from images taken on 2002 October 14, about magnitude 17.5. It was first observed from southern Africa on 2003 October 25 at magnitude 10.8 and located in Auriga. It remained in the northern sky until end 2003, and was poorly observed as it brightened for the same reasons as C/2001 Q4. From 2004 April, the comet was quite well observed, passing perihelion on April 23, and brightening further to magnitude 3 at close approach on May 19. Visually the comet faded quite quickly, at the same time becoming rapidly diffuse, and by early July was magnitude 9 with very little condensation. The data in Figure 2(h) indicates a similar brightness behaviour before and after perihelion, with overall $n = 2.8$.

Coincidentally comet C/2002 T7 peaked at a similar date and brightness, and in the same region of sky as comet C/2001 Q4. Observers were treated to two relatively bright, magnitude 3 comets on the same May 2004 evenings.

Discussion

In order to gauge the usefulness of the ASSA observations, we compared the derived power law equations for the whole apparition of each comet with BAA data retrieved from the BAA website. From Table 2 we conclude there is a good agreement of the brightness parameters derived from ASSA data with those published by the BAA, especially in H_0 where the largest deviation is 0.2 magnitude.

Of the eight comets outlined above, all can be considered as very long period, except perhaps C/2002 C1 with a period of 370 years (Nakano & Green 2001), which consequently is now designated 153P. The average value of n for these eight long period comets is 3.3. The comets show absolute magnitudes in the range 5–7, with the exception of comet C/1995 O1 with an absolute magnitude of about –0.5. This comet also became visually bright, as did C/1996 B2 due to its close approach.

Table 2. Comparison of brightness parameters as derived from ASSA and BAA observations

Comet	H_0		n	
	ASSA	BAA	ASSA	BAA
1995 O1	–0.5	–0.6	3.5	3.0
1996 B2	5.2		3.3	
1998 J1	6.3	6.2	2.4	2.5
2000 WM1	7.0	7.1	4.4	4.2
2001 A2	7.2	7.3	4.8	4.2
2002 C1	6.5	6.6	3.1	3.4
2001 Q4	5.5	5.5	2.2	1.8
2002 T7	5.5	5.3	2.8	2.2

Conclusion

The light curves and brightness equations in Figures 1 and 2 are based on the observations of 12 ASSA members. The light curves in Figure 1 show a good representation of the visual behaviour of the eight comets, with generally good agreement between the observers. They would benefit from a wider coverage of the comets. The parameters derived from the power law equations are in good agreement with data published by others.

Observers

The authors wish to thank the following observers, who contributed observations used in this analysis (their location and ICQ observer codes are given in brackets): Mike Begbie (Harare, Zimbabwe; BEG01), Tim Cooper (Bredell, South Africa; COO02), Tom Lloyd Evans (Cape Town, South Africa; EVA01), Mauritz Geyser (Pretoria, South Africa; GEY), Trevor Green (Pretoria, South Africa; GRE03), Tony Jones (Cape Town, South Africa; JON07), Gerrit Penning (Bloemfontein, South Africa; PEN02), David Pringle-Wood (Harare, Zimbabwe;

PRI04), Theo Smith (Keetmanshoop, South Africa; SMI08), Magda Streicher (Polokwane, South Africa; STR03), Cliff Turk (Cape Town, South Africa; TUR), and Koos van Zyl (Pretoria, South Africa; VAN15).

Acknowledgements

The authors wish to thank Dan Green, editor of the *International Comet Quarterly*, for his useful comments and critique used in the preparation of this paper.

References

Cooper, T. P. (1998) ASSA observations of comet Hale-Bopp. Unpublished paper presented at the 4th Biennial ASSA Symposium held in Cape Town.

Green, D.W. (1997) Guide to Observing Comets. Special Edition of the International Comet Quarterly.

Hoffmeister, C., Richter, G. & Wenzel, W. (1985). Variable Stars. Springer-Verlag, Berlin.

Nakano S. & Green, D.W.E. (2001) 2002 Comet Handbook. International Comet Quarterly, 23(4a), H1-H142.

Appendix 1. Details of comets analysed, and contributing observers

	C/1995 O1	C/1996 B2	C/1998 J1	C/2000WM1	C/2001 A2	C/2002 C1	C/2001 Q4	C/2002 T7
m_1 (brightest)	−0.2	0	2.5	2.2	3.7	3.7	3.0	2.7
Date of perihelion	1997 03 31	1996 05 01	1998 05 08	2002 01 22	2001 05 24	2002 03 18	2004 05 15	2004 04 23
Date of close approach	1997 03 21	1996 03 25	1998 05 20	2001 12 02	2001 06 30	2002 04 29	2004 05 06	2004 05 19
Perihelion distance (AU)	0.915	0.230	0.153	0.555	0.779	0.508	0.962	0.615
Close app. distance (AU)	1.315	0.103	0.843	0.318	0.244	0.404	0.321	0.266
H_0 pre perihelion	−0.75	4.7	—	7.7	7.4	6.7	6.1	6.1
2.5 n pre perihelion	8.6	15.7	—	8.1	12.3	10.7	3.6	6.9
H_0 post perihelion	−0.45	5.0	6.3	6.4	7.1	7.0	5.2	5.2
2.5 n post perihelion	8.8	7.1	5.9	13.6	11.6	3.6	13.8	7.0
BEG01	•	•	•	•	•	•	•	•
COO02	•	•	•	•	•	•	•	•
EVA01			•					
GEY	•							
GRE03					•			
JON07				•	•		•	
PEN02							•	•
PRI04			•	•	•	•	•	•
SMI08	•	•						
STR03				•			•	
TUR			•					
VAN15	•						•	•