Comet Analyses

A report of the Comet Section

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Introduction

The first of a series of papers describing BAA Comet Section observations of comets appears in this number of the Journal[1]. This paper describes the tables and procedures used in these papers in greater detail.

Orbital elements

Seven quantities are needed in order to define an orbit and to calculate where a comet is at any time; these are the orbital elements. They are only valid for a single date, the epoch of the elements, because planetary perturbations are continually changing the comet's orbit. The elements are usually taken from the International Astronomical Union Central Bureau for Astronomical Telegrams' Catalogue of Cometary Orbits[2]. In the most common form there are three angular elements, which are referred to a specific date. The elements in the latest catalogue are for the ecliptic and equinox of J2000.0 and in these papers the angular elements are also given precessed to ecliptic and equinox of B1950.0. The three angles are: i, the inclination, which is the angle between the planes of the comet's orbit and the earth's orbit; it is zero when the comet moves in the plane of the ecliptic and in the same direction as the earth, 90ø when perpendicular to the plane and 180ø when in the plane but moving opposite to the direction of the earth. w, the argument of perihelion defines the orientation of orbit. It is measured in the plane of the comet's orbit, in the direction of the comet's motion, from where it crosses the plane of the earth's orbit (the ecliptic plane) in a northbound direction, to the direction of perihelion. W, the longitude of the ascending node, defines where the comet crosses the plane of the earth's orbit. It is measured in the plane of the earth's orbit, in the direction of the earth's motion, from the first point of Aries (where the mean sun is at the spring equinox) to where the comet crosses the ecliptic plane in a northbound direction.

The other elements are q, the perihelion distance, the smallest distance between the comet and the sun during the course of the orbit, T, the exact time when it is at this distance and e the eccentricity or departure of the orbit from a circle. At the time of perihelion the seventh quantity, the angular distance round the orbit (the mean anomoly and also the true anomoly) is zero and so only six quantities are usually given. For a comet in an eliptical orbit the mean anomoly is how far round the orbit it would be if it moved at a uniform velocity; Kepler's laws mean that in reality it moves faster at perihelion than at aphelion. The eccentricity is zero for a perfect circle and one for a comet in a parabolic orbit; occasionally a comet may have an orbit with an eccentricity greater than one if planetary perturbations have accelerated it sufficiently to eject it from the solar system. Further explanation of the various quantities can be found in standard reference books (eg BAA Explanatory Supplement[3], Sidgwick[4]) and further details of the orbits are given in the Catalogue.

A figure in each paper shows these elements for the comet's orbit in a perspective view, which also shows the earth's orbit. The viewpoint is chosen to give the best impression of the comet's orbit, which is shown dashed when it is below the plane of the earth's orbit. The position of the comet is indicated at 50 day intervals, with the perihelion point indicated by T. A line is drawn from the perihelion point to the Sun and extended the same distance (q) beyond the sun. The line between the ascending and descending nodes (the line of the nodes) is shown. From each end of this line two unit vectors (ie lines 1 AU long) are drawn perpendicular to the line of the nodes, one in the plane of the comet's orbit and the other in the plane of the earth's orbit. The angle between these lines is the inclination (i). Fig 1 shows the orbit of comet Halley as an example.

[### Fig 1 ###]

Ephemerides

The ephemerides are produced from a computer program developed over many years by Jonathan Shanklin. It is designed to provide most of the information required by a visual observer. The comet's right ascension and declination, referred to the mean equator and equinox of 1950.0 are given for midnight (24^h00^m UT) on the double date quoted, which has a Julian Date ending in 0; the double date format is also used in meteor work (eg Sept 29/30). The Julian date is the number of days that have elapsed since 4713 BC January 1, a date originally chosen so that all dates in the bible would be positive. Julian Days begin at Greenwich Mean noon and avoid the need to change date during the night. Although epoch B1950.0 has generally been superseded by epoch J2000.0 for cometary positions, the most frequently used atlas for comet observation is the AAVSO star atlas and this uses 1950.0 coordinates; 1950 positions are therefore given for the convenience of observers.

The comet's magnitude is computed from the derived light curve for the entire apparition. If the curve is asymmetric with respect to perihelion the computed magnitude can be considerably in error. The comet's distance from the earth and Sun is given in astronomical units. Some idea of when the comet was visible from the UK is given in the column marked 'observable'. An arbitrary site of 53øN on the Greenwich meridian is used. For a comet to be visible the sun has to be more than 13ø below the horizon and the comet a distance above the horizon dependent on its magnitude. This uses an empirically derived formula shown graphically in Fig 2.

$$\text{minimum altitude} = 1.501 * e^{(\text{mag} * 0.2303)}$$

For a 10th magnitude comet the minimum altitude is 16ø and for a 5th magnitude comet 5ø. These values must be regarded as an approximation only and it may well be possible to make a valid observation outside these limits.

[### Fig 2 ###]

A diagram illustrates the observing circumstances for each comet, Fig 3 shows the 1910, 1986 and next apparition of comet Halley as an example. The direction and distance of the comet is shown in a rotating reference frame, which keeps the Earth - Sun direction fixed. The earth is at the centre of the diagram and the direction of the sun is towards the top; the apparent path of the comet is shown dotted when it is below the plane of the ecliptic. A circle of 1 AU radius, centred on the Earth, is shown for scale. When the comet is in conjunction it will appear in the top part of the diagram and when in opposition in the bottom part. The diagrams clearly show that the next apparition of comet Halley will not be a good one. Because this is only a two dimensional representation it is possible for some comets to be visible at conjunction if they are well above or below the plane of the ecliptic.

[### Fig 3 ###]

Observations

Observations are usually submitted directly to the Director, or to the Assistant Director through The Astronomer magazine

(TA); the later includes observations from non-BAA members which add to the coverage of the comet. All observations are submitted to the International Comet Quarterly (ICQ) for publication, but additional observations also published in that source are not used in the analyses. The ICQ and TA give full details of each observation, so information such as the instruments used by the observers is not repeated here. A full paper will be published on all comets with more than 100 observations; those with fewer observations will receive a brief summary in the series of annual reports describing all the comets in each year.

Magnitude analysis

The brightness of a comet is normally represented by the equation:

$$m_1 = H1 + 5.0 * \log(d) + K1 * \log(r)$$

where H1 and K1 are constants and d is the comet's distance from the Earth and r its distance from the Sun. If few observations have been made it may be impossible to derive a value for K1; in this case a value of 10 is assumed for long period comets and the first constant becomes H10. For short period comets a value of 15 is assumed for K1 and the first constant becomes H15. A purely reflecting body would obey the inverse square law and K1 would have a value of 5.

An initial least squares analysis is made using all the available observations to give values for H1 and K1. The data is then checked and any magnitude observations which are very different from the computed light curve are rejected. Further analysis may be undertaken if the observed arc of the orbit is sufficiently long and there is a good spread of observations:

Some observers systematically report fainter or brighter magnitudes than the average and it is necessary to apply a correction for this because some observers may preferentially observe before or after perihelion, thus distorting the light curve. This is particularly the case for a comet in a highly inclined orbit, which may be visible in opposite hemispheres before and after perihelion. The correction is computed by calculating the mean deviation of each observer's observations from the initial computed light curve and this deviation is then subtracted from each observation. The least squares regression is then repeated to give new values for H1 and K1.

If there are enough observations which have a magnitude estimate, coma diameter and instrument aperture or magnification, they can be used for further analysis of the magnitude. Instrumental factors are known to have an effect on comet magnitudes (Bobrovnikov[5], Morris[6]), with comets generally appearing fainter in larger apertures. When a correction for the aperture is included the equation becomes:

$$m_1 = H1 + 5.0 * \log(d) + K1 * \log(r) + P1 * Ap$$

where Ap is the aperture in millimetres. This will quite often produce a large change in the log(r) coefficient compared to the previous equation. When the comet is further from the sun and thus fainter, larger apertures are used; the larger aperture makes the comet appear even fainter, so that introducing the correction has a large effect on the computed log(r) coefficient. If enough estimates are available it may be possible to compute separate values for refractors and reflectors as previous studies have shown that the effect is different for the two types of instrument. A typical value for P1 is 0.004 mm^{-1}, thus a comet will appear one magnitude fainter in a 300 mm telescope than in 50 mm binoculars.

A possible reason for the difference between refractors and reflectors is that for a telescope of a given aperture and eyepiece combination, a reflector will generally have a much shorter focal ratio than a refractor and will therefore give a lower magnification. An alternative approach is therefore to use the magnification used for the observation rather than the aperture.

$$m_1 = H1 + 5.0 * \log(d) + K1 * \log(r) + Q1 * pwr$$

where pwr is the magnification. A typical value of Q1 is around 0.01, so that a magnification of 110x will make the comet a magnitude fainter than a magnification of 10x.

When conditions are less than perfect an observer will see less coma and therefore report a fainter magnitude. A simple correction for the observed coma diameter can be included:

$$m_1 = H1 + 5.0 * \log(d) + K1 * \log(r) + Q1 * pwr + S1 * (C_t - C_o)$$

Where C_t is the 'true' coma diameter in minutes of arc and C_o the observed coma diameter. This correction is similar to the delta effect found by Marcus[7]. The 'true' coma diameter is approximated by the coma diameter an ideal observer would see in ideal conditions. If the 'true' diameter of the coma changes with time it is still possible to make the correction, but the coma diameter on any date must be found first and the difference from this diameter used. In general the scatter in reported coma diameter is less than 10' and a typical value of S1 is -0.01 minute^{-1} so that this correction makes little difference to the observed magnitude.

If the comet is well observed for a sufficient length of time, further analysis may be possible. Comet nuclei are known to rotate and this may be reflected in the light curve. A Fourier analysis for periodicities in the observed data can potentially reveal such variation.

Many comets also undergo outbursts, and these can considerably distort the light curve, sometimes preventing any meaningful computation of the constants. The outbursts can sometimes be seen more easily if a weighted three day running mean magnitude is used. This is computed by giving a weight of one to observations for the day before and after and a weight of two to observations on the day.

Light curves

Two light curves are given. The first shows the observed data (with no aperture or magnification corrections) plotted against time. The calculated light curve is shown by a solid line with the 99% confidence limits shown by dashed lines. The confidence limits show the range where the calculated line should be 99% of the time if the analysis was carried out using a different selection of observations with the same distribution as the ones actually used. The limits within which 99% of the observations lie are not shown.

The second curve shows the corrected data plotted against distance from the sun. The magnitude of the comet is corrected for distance from the Earth and, where there are enough observations, systematic observer effects, aperture or magnification and coma diameter. The calculated light curve is shown by a solid line with the 99% confidence limits shown by dashed lines. If r, the comet's distance from the sun, is plotted on a logarithmic scale, this is a straight line, however a linear scale is used so that the actual distance from the sun is easier to see.

Comet Section observations

A description of the comet during the apparition concludes each paper, as far as possible using observations made by members of the BAA. Details of the instrumentation used for the observations are given in this section to allow observers to compare observations.

References

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3. Miles, H., *An Explanatory Supplement to the Handbook*, BAA, (1988).
4. Sidgwick, J. B., *Observational Astronomy for Amateurs*, Faber, (1982).
5. Bobrovnikov, N. T., Investigations of the Brightness of Comets, parts 1 & 2, *Contr. Perkins Obs*. Nos 15 and 16, (1941/42).
6. Morris, C. S., On Aperture Corrections for Comet magnitude Estimates, *Publ. Astron. Soc. Pacific*, 85 (506), (Aug 1973).
7. Marcus, J. N., Halley's true brightness in 1909-11 and comparison to 1985-86. *Proc 20th ESLAB Symposium on the Exploration of Halley's Comet, ESA SP-250, Vol III,* Heidelberg, pp. 307-319, (1986).

Figure Captions

Figure 1. The minimum altitude at which a comet of a given magnitude can be seen.
Figure 2. The orbits of comet Halley and the earth, with symbols representing the various orbital elements.
Figure 3. The observing circumstances of comet Halley in: a) 1910, b) 1986, c) 2061.