

## Comet Section Observing Guide





# **The British Astronomical Association**

## **Comet Section**

**[www.britastro.org/comet](http://www.britastro.org/comet)**

## **BAA Comet Section Observing Guide**

Front cover image: C/1995 O1 (Hale-Bopp) by Geoffrey Johnstone on 1997 April 10.

Back cover image: C/2011 W3 (Lovejoy) by Lester Barnes on 2011 December 23.

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# **1 FOREWORD**

Comets are wonderfully unpredictable objects. This is what makes them so much fun to observe. You never quite know what you are going to see when you go out to observe them which is why it is important to keep them under observation as frequently as possible. This guide is intended for beginners and old-hands alike and so the material ranges from reasonably basic to quite complex. Hopefully we have explained possibly unfamiliar terms but if you have any questions we are always happy to help via the email addresses on page 5. If you are new to comet observing start with the simple visual observing techniques discussed in section 3.

This is an updated and expanded version of the Observing Guide. Much of the original text was provided by Jonathan Shanklin and I have updated and amended this along with adding sections on imaging and other aspects. I would also like to thank Denis Buczynski, Peter Carson, Richard Miles and Roger Dymock who have made significant contributions. I plan to update the text regularly from now on so please contact me at the address given on the contacts page if you spot any errors or think that any particular aspects are missing. I hope that this Guide will provide new and old observers with a comprehensive overview of these special objects along with details on how best to observe them whether you are a visual observer or an imager using your own or remote equipment.

The BAA Comet Section has been supporting comet observers since 1891. If you are not a BAA member I do hope that you will consider joining the Association. You can get details from the BAA website (see the address on page 5) or by emailing me directly. You can also subscribe to our mailing list (details on page 5) to take part in section discussions relating to comets.

I wish you clear skies and best of luck with your comet observing.

**1.1 Nick James. Director. 2019 July.**

## 2 AN INTRODUCTION TO COMETS

A comet is a relic from the birth of our solar system. Formed in its cold outer reaches beyond the orbit of Jupiter, comets are a fragile conglomerate of ices, dust and rock. Expelled from their birth place by the gravitational pulls of the gas giants to either the disc-like Edgeworth-Kuiper belt beyond the orbit of Pluto, or to the Oort Cloud stretching half way to the nearest star, they have remained in cold storage for billions of years. Eventually gravitational effects from passing stars or molecular clouds send them back inwards towards the Sun. They slowly warm and as they approach the Sun the evaporating ices create the cloud of dust and gas that we recognize as a comet.

Comets are highly unpredictable, which is one aspect that makes them so interesting to observe. Their appearance can change from night to night and each comet is different. Many faint comets are now discovered or recovered each year and imagers can follow many of these. Visual observers with larger telescopes can also follow many of the fainter objects and perhaps four of these each year will brighten enough to come within the range of a visual observer with binoculars or a small telescope.

Amateur observations of comets can contribute to our understanding in many ways: accurate positions can be used to help determine their orbits, brightness observations give light curves which can be used to deduce the size distribution of comet nuclei and tail observations can measure the speed of the solar wind. Although serious observations are encouraged, a bright comet can be an awe-inspiring sight and sometimes it is better to just watch and enjoy the spectacle. Meteor streams often have an associated comet, and showers occur when the Earth intersects the comet's orbit. The meteors we see are the debris left behind the comet.

The BAA comet section observing programme covers visual and imaging observations. Historical research and reanalysis of old observations can also add to our knowledge of comets. Communication between observers is important and email is used for submitting observations and obtaining general information on comets. The BAA has a website which is used for distributing news and for observers to discuss their observations. We also publish a newsletter, *The Comet's Tale*, which is available via the website. The BAA e-bulletins and the E-mail service run by *The Astronomer* magazine give early warning of new discoveries, and there are many other sources of information on the Internet and social media. Observations are collected in the COBS database, listed in *The Astronomer* magazine (TA) and archived online and analyses of section observations are published in the BAA Journal.

This booklet is designed for all observers of comets. It tells the beginner how to start making observations and helps to standardise observations made by more experienced observers. It is aimed at all comet observers, whether visual or imager. Visual observations range from simply viewing a comet to making detailed estimates of a comet's brightness and observing features in its coma.

### 2.1 Anatomy and origins

A bright comet can be one of the most beautiful objects in the sky. The front cover shows a comet that was very spectacular back in 1997. This comet was discovered in 1995 by two observers (Alan Hale and Thomas Bopp) and it has the official name C/1995 O1 (Hale-Bopp). This comet displayed all of the usual features of a very bright comet. It had a bright head, multiple tails and lots of interesting detail to see visually or to image.

Comets started their lives in the frozen depths of our Solar System and they are thought to consist of remnants of the interstellar dust cloud that collapsed under gravity to form the Sun and planets. The solid object at the centre of a comet is called the nucleus and it is thought

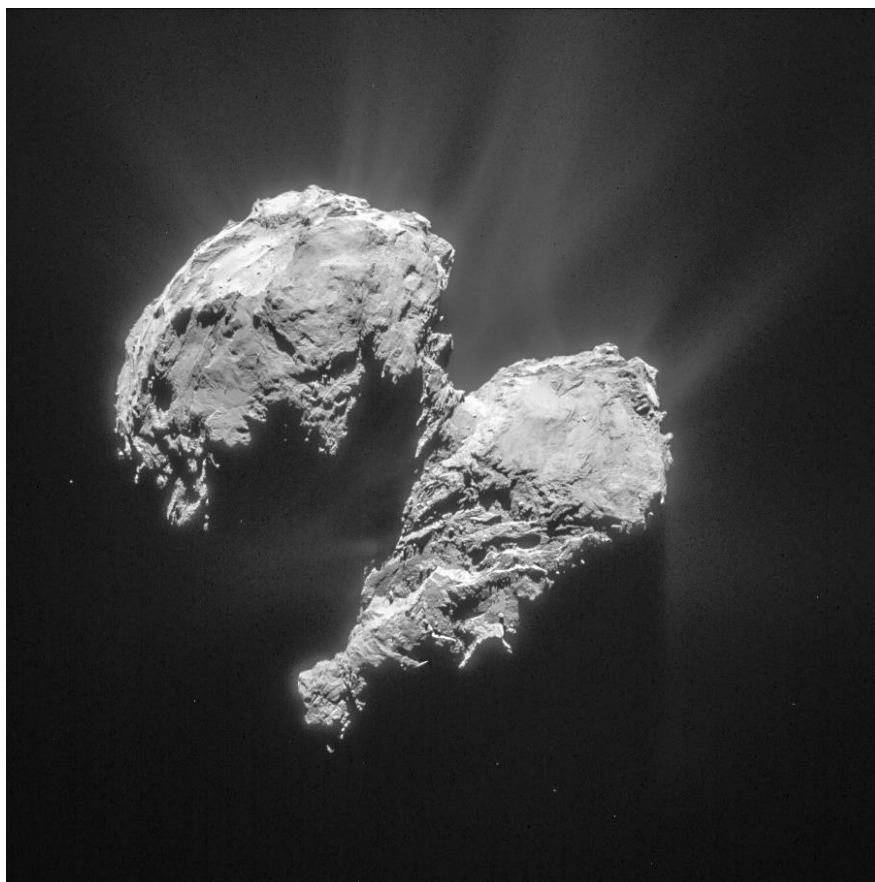


to consist of a frozen sample of the constituents of the original cloud. As a result there is a great scientific interest in understanding what comets are made of.

From observations we know that the nucleus consists of very fine carbonaceous and silicate dust grains (finer than talcum powder) embedded in a deep-frozen mix of water ice and frozen gases such as carbon dioxide. Spacecraft have shown that bare cometary nuclei are very dark. Technically, they are said to have low albedo and they reflect less than 5% of the sunlight landing on their surface. It is thought that there is a “crust” of dark material on their surface. This dark crust means that the nucleus is very efficient at absorbing heat from the Sun if the comet falls into the inner solar system.

We can think of a comet nucleus as a dirty snowball made up of a mixture of snow and soot with a thin layer of carbon crust on the surface. In the far depths of the Solar System where temperatures are low this nucleus is thought to be completely inactive. The nucleus that generated Hale-Bopp’s spectacular display was probably 40-70 km in diameter. This is the largest comet nucleus known and most comet nuclei are much smaller than this. Spacecraft showed that the famous comet 1P/Halley has a peanut shaped nucleus around 15 km long and 8 km wide. Other comet nuclei visited by spacecraft are smaller but just as irregular.

The comet nucleus that we know the most about is the one that was the target of the ESA Rosetta mission. Comet 67P/Churyumov-Gerasimenko is a medium-sized nucleus in a short-period orbit (Figure 1). This comet belongs to the Jupiter family of comets. Its orbital period is 6.4 years and it moves in a low-inclination orbit with a current perihelion distance of 1.2 a.u. The bi-lobed shape is probably due to the very slow collision of two objects early in the history of the Solar System.



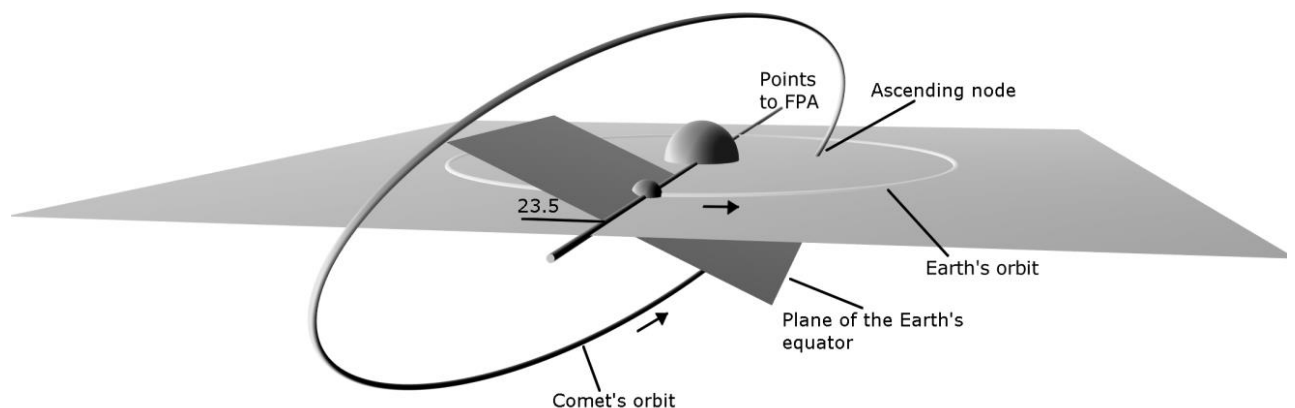
*Figure 1 – The nucleus of Comet 67P/Churyumov-Gerasimenko as imaged by the Rosetta spacecraft on 2015 March 22.*



Since comet nuclei are so dark they are difficult to see when they are in deep freeze since small nuclei far away are very faint. There are, however, some objects that we see in the distant Solar System which could be very large versions of cometary nuclei. These are the Trans Neptunian Objects or TNOs and one of the largest of these objects is the ex-planet Pluto. At present Pluto is officially called a dwarf planet, but perhaps it should really be a giant comet!

The Earth travels around the Sun in a roughly circular orbit with a radius of around 150 million km. We call this distance one Astronomical Unit (1 AU). We believe that most of the objects that become comets with long orbital periods are held in cold-storage in a vast spherical shell, called the Oort Cloud, which is gravitationally bound to the Sun, perhaps 50,000 AU from the inner Solar System. Every now and again an inactive comet nucleus will be perturbed from this cloud (perhaps by the gravity of nearby stars) and it will start to fall in towards the Sun. The Oort Cloud has never been observed directly but it fits in well with the observed orbital behavior of comets and current theories for the origin of the Solar System.

Since they come from very far away, incoming long-period comets move in long, thin orbits. They spend most of their time far from the Sun then rush around it, reaching their closest point at perihelion, and climb back outwards. More details are given in section 2.3 but, in summary, the shape of the orbit is defined by a parameter called the eccentricity,  $e$ . A perfectly circular orbit has  $e = 0$ . Ellipses get longer and thinner as  $e$  increases until we get to  $e=1$ . At this point the ellipse is not closed and we have what is called a parabolic orbit. A parabolic orbit is what you would expect if a comet fell from the Oort cloud with very little initial velocity.



*Figure 2 – A comet's orbital geometry*

Another parameter defining the orbit is the inclination,  $i$  (Figure 2). All of the planets move around the sun in the same direction and almost in the same plane. The plane of the Earth's orbit is called the ecliptic plane and this defines  $i=0^\circ$ . The most highly inclined planet is Mercury with  $i=7^\circ$ . Long period comets can have any inclination up to and beyond  $90^\circ$ . Inclinations beyond  $90^\circ$  mean that the comet is going around the sun in the opposite direction to the planets. Comet 1P/Halley, for instance has  $i=162^\circ$  so its orbit is actually inclined to the ecliptic by  $18^\circ$  but it is going around the "wrong" way.

There is a second family of comets which have shorter periods and which move around the Sun in low inclination orbits. These comets don't come from the spherical Oort Cloud but rather from a low inclination disk much closer in but still far out in the Solar System. In 1943 Kenneth Edgeworth published a paper in the *Journal of the British Astronomical Association*, which first mentioned this disk. In 1951 Gerald Kuiper proposed a similar thing but it was not until 1992 that large telescopes started to detect huge dormant comets in the frigid space beyond the orbit of Neptune. The belt has become known as the Edgeworth-Kuiper Belt

(EKB) and these dormant comets are called *Trans-Neptunian Objects* (TNOs). The brightest TNOs reach magnitude 20 and so are in the range of advanced amateur observers. There has been some debate as to whether the outer planet Pluto and its satellite Charon are themselves TNOs. If they are then it is possible to see a huge dormant comet in the outer solar system with a modest telescope since Pluto reaches magnitude 14 at opposition. Not all shorter period objects come from this source however, since Oort Cloud comets originally in parabolic orbits can be perturbed by the gravity of the major planets and end up in short period orbits with high inclinations.

As a comet nucleus moves in to the inner Solar System it absorbs energy from the Sun and the ices heat up and turn directly into gasses in a process called sublimation. These gases then escape through fissures in the surface taking a lot of dust with them. This forms a temporary atmosphere around the nucleus which we observe as the coma (Figure 3). Most of the light of the gaseous coma comes from the C<sub>2</sub> Swan emission bands which lie between 430 and 620 nm. They were first identified in a comet by Sir William Huggins, following their discovery in the spectrum of ethene (C<sub>2</sub>H<sub>4</sub>) by William Swan. Cyanogen (CN) is also often present in cometary spectra and emits at around 390 nm.

The dust is very fine and sunlight is able to push it away from the nucleus to form a dust tail. In images the dust tail is usually white or yellow since it shines by reflected sunlight and it is often curved into a fan since the relatively heavy dust grains tend to follow the nucleus along its orbit. Ultraviolet radiation from the Sun is absorbed by the escaping gas molecules to produce ionised molecular forms which then interact with the solar wind. The solar wind is a stream of particles moving outwards from the Sun at several hundred km/s which blows the gas out into what is called the gas, ion or plasma tail. This tail is usually straight and radial to the Sun and often has a blue colour on images since its light comes mainly from fluorescing Carbon Monoxide.



Figure 3 – The diffuse coma of C/2016 U1 (NEOWISE) imaged by Peter Carson on 2016 December 24

The solar wind is often turbulent and gusty and, before spacecraft, one of the main sources of information about it was from the interaction it has with comet ion tails. These tails act as a kind of wind-sock and the solar wind can lead to disconnection events (Figure 4) where a gust disconnects a bubble of ionized gas from the tail and pushes it downstream. These events allow us to estimate the solar wind velocity in the vicinity of the comet.

When a comet is discovered the first objective is to determine its orbit. We do this by measuring positions of the comet relative to the background stars using a process called *astrometry*. This is something that amateur astronomers with fairly small telescopes and CCD cameras can do effectively and the process is described in detail in section 7.1 on page 53. For most comets, astrometry done over a period of several weeks can define the orbit very accurately. The orbit can then be used to predict where the comet will be in the future. Many things about comets are difficult to predict but the orbit, and hence the comet's position on the sky and its distance from the Earth and Sun, can usually be predicted with incredible accuracy very shortly after discovery.

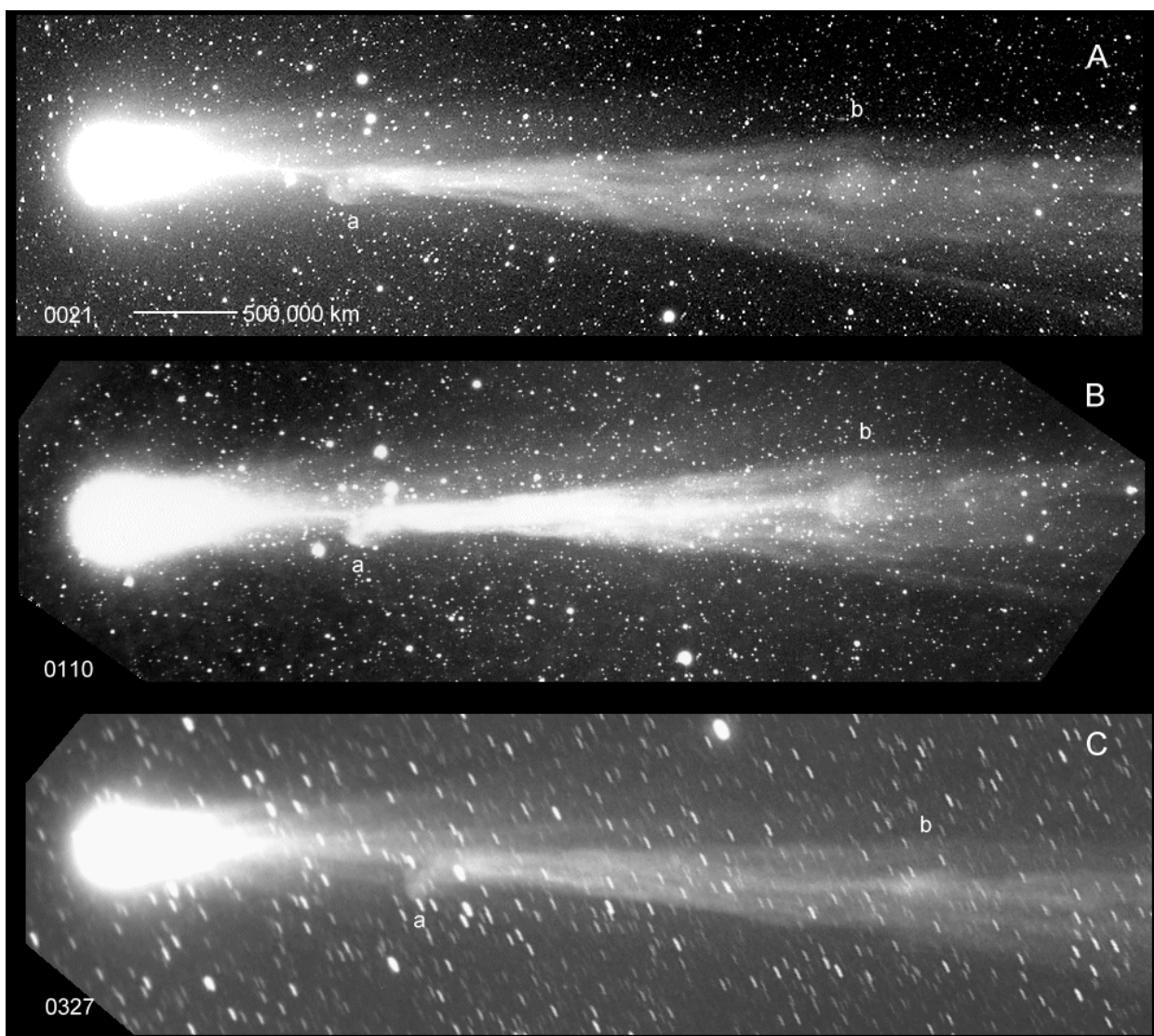


Figure 4 – Disconnection event in the tail of C/1996 B2 on 1996 March 23. These images were taken on hypered 2415 film from Tenerife using an 85mm, f/2 lens and a Canon T-70 SLR (Nick James)

We can use the known orbit to predict where the comet will be seen but we would also like to predict how bright it will be. This is much more difficult. The basic principle is straightforward. We measure the absolute brightness (magnitude) of the comet over a period of several weeks or months and we plot this against the comet's distance from the Sun. We then use this graph to estimate a simple magnitude "law" and we extrapolate this forward to our selected future observation time. This is all very well but success is critically dependent on the how we expect the comet's activity to change as it approaches the Sun.

In the past, comets would often be discovered by amateurs when they were already quite active and close to the Sun. More recently professional surveys have been set up to discover potentially dangerous near-Earth asteroids. These are so powerful that they frequently discover comets when they are still a long way away. This makes brightness predictions even more difficult since we are trying to predict how the nucleus will behave when it is close to the Sun based on observations made when it is far away and only just coming out of deep-freeze. Another problem is that comets behave differently depending on whether they are a first-time visitor to the Sun (known as a *dynamically new* comet) or they have been in the inner solar system before (*dynamically old*). This can be quite difficult to determine from the orbit since even the "old" comets can have very long orbital periods. New comets can be quite active when they are far from the Sun but they rarely maintain this activity as they come in. Older comets tend to become active closer to the Sun but then they then have a consistent increase as they approach perihelion.

## 2.2 Naming

Comets were traditionally named after their discoverers, with the names of up to three independent discoverers or up to two working together as a team. Some comets were named after the satellite or telescope that discovered them e.g. IRAS, SOLWIND or Spacewatch. Where several periodic comets would otherwise have the same name, they were numbered sequentially, e.g. Shoemaker-Levy 9 was the ninth periodic comet discovered by the team of Carolyn and Eugene Shoemaker and David Levy. A periodic comet which was lost and then subsequently accidentally re-discovered might gain an additional name, eg Metcalf-Brewington which was discovered by the Rev Joel Metcalf in 1906 and then lost until re-discovered by Howard Brewington in 1991.

Until the end of 1994 each comet was also assigned a letter in order of discovery during the year and subsequently given a permanent designation using Roman numerals based on the order of perihelion passage. Comets with a period of less than 200 years were given the prefix P/. Thus comet P/Halley was known as 1982i as it was the ninth comet discovered in 1982 and also as 1986 III as it was the third comet to reach perihelion in 1986. Some comets which were visible all round their orbit were not given a provisional letter designation (eg P/Encke). A few comets that were widely discovered at more or less the same time were given a general descriptive name, e.g. the Eclipse comet of 1948. For astrometric observations periodic comets were also given a further number, approximately based on period e.g. P/Halley was number 901 and P/Encke was 301.

As the number of known comets started to increase rapidly all of these different naming schemes became difficult to manage and a new scheme was introduced at the beginning of 1995. This is used retrospectively and all comet names should use this system although a cross reference to the historical name can be given if required. In this scheme, each comet is given a designation consisting of the year of discovery, an upper-case letter identifying the half-month in which it is discovered and a number to indicate the order of the discovery announcement within the half-month. Thus comet Halley, which was discovered on 1982 October 16 at its last apparition would have been designated comet P/1982 U1 under the new scheme, which is similar to that used for asteroids.

A	Jan	1 - 15	B	Jan	16 - 31
C	Feb	1 - 15	D	Feb	16 - 29
E	Mar	1 - 15	F	Mar	16 - 31
G	Apr	1 - 15	H	Apr	16 - 30
J	May	1 - 15	K	May	16 - 31
L	Jun	1 - 15	M	Jun	16 - 30
N	Jul	1 - 15	O	Jul	16 - 31
P	Aug	1 - 15	Q	Aug	16 - 31
R	Sep	1 - 15	S	Sep	16 - 30
T	Oct	1 - 15	U	Oct	16 - 31
V	Nov	1 - 15	W	Nov	16 - 30
X	Dec	1 - 15	Y	Dec	16 - 31

*Table 1. Letter designations for comets*

Further clarification of the nature of the object is given by using a prefix. Single apparition comets with a period of less than 30 years receive the prefix P/ and those that are not periodic in this sense usually receive the prefix C/. X/ is used for comets for which a meaningful orbit cannot be computed and D/ for a comet which no longer exists (such as D/1993 F2 (Shoemaker-Levy)), which is lost, or which disappears. Where an asteroid has been mis-identified as a comet or a comet has lost its cometary nature the prefix A/ can be applied to the designation (eg A/Wilson-Harrington). Periodic comets which are observed to return, or observed through aphelion are also numbered in order of the computation of the orbit according to a list kept by the Minor Planet Centre, so the full designation of comet Halley at its last return is 1P/Halley (1982 U1).

The tradition of naming comets after their discoverers continues and an IAU committee adjudicates on the names to be used. It is unlikely that any more comets will be named after the person who first computed the orbit, such as Halley, Encke and Crommelin. Although this is not excluded by the new convention, it would only occur if the new name was simpler than the old one and was fair to all parties. The numeric suffix of periodic comets discovered by the same observer is normally dropped because the comet is uniquely identified by its year designation or periodic number, so for example 103P/Hartley 2 becomes simply 103P/Hartley.

Comets can be classified into three groups: short period comets (those with periods less than 30 years), intermediate period comets (those with periods between 30 and 200 years) and long period comets (those with a period greater than 200 years). The long period comets include those in parabolic and hyperbolic orbits which will never return.

Several sub-groups or families of comets can be identified. The comets of the Jupiter family, which have aphelia near the orbit of Jupiter, were captured into short period orbits by the planet. The Kreutz sungrazing group may have originated in the breakup of a single large comet over 10,000 years ago. 2P/Encke is associated with several asteroids and meteor showers and possibly C/1966 T1 (Rudnicki), and may be the largest remaining fragment of another large comet which broke up several thousand years ago.

Sometimes an object that was initially identified as an asteroid develops a coma. The new numbering scheme aims to reduce such confusion in the future, for example Chiron is designated 95P/Chiron under this scheme. Under the old scheme what happened depended on circumstances: asteroid 1990 UL<sub>3</sub> became comet P/Shoemaker-Levy 2 (1990p) but Chiron retained its asteroidal designation as (2060) Chiron. Under the new scheme objects originally identified as asteroids retain their provisional asteroid identification as the provisional cometary designation, e.g. asteroid 2015 ER61 became comet C/2015 ER61 (PANSTARRS).

### **2.3 Comet orbits**

As with all of the other objects in the Solar System, comets move under the gravitational influence of the Sun and planets. Every object in the Solar System exerts a force on every

other object but since the mass of the Sun is so much larger than even the largest planet it dominates orbital motion in the Solar System. In fact, in most cases, we can completely ignore the forces due to everything else and say that the comet is orbiting around the Sun in what is called a two-body orbit.

In two-body motion the orbital path is closed, that is after one orbit the comet comes back to exactly the same place relative to the Sun as it started and the orbital history of the comet for all time is described by only seven numbers: at a given time  $t$ , we need to know the position in three dimensional space (given by the triplet  $x, y, z$ ) and the velocity (given by the triplet  $x', y', z'$ ). No further information is required so if you know the comet's position in space and its velocity at any time you can predict the position and velocity at any other time in the future or the past using a simple set of equations.

Rather than giving the position and velocity at a particular time the orbital elements that are generally published describe the shape and orientation of the comet's orbit and its position along that orbit at a particular time. The six position and velocity components are replaced by two which describe the shape and size,  $e$  and  $q$ , three which describe the orientation,  $i, \omega, \Omega$  and one which describes the angular distance along the orbit measured from perihelion at time  $t$ ,  $M$ . In fact, for comets the time  $t$  is chosen as the perihelion time,  $T$ , so  $M=0$  and only six elements are quoted:  $T, e, i, q, \omega$  and  $\Omega$ .

The shape of the orbit is described by the eccentricity,  $e$  and all comets follow orbits which are known as *conic sections* (Figure 5). These range from near-circular orbits where  $e$  is close to zero, through longer and longer ellipses as  $e$  increases, to just less than one to parabolas where  $e$  is exactly one. Some comets are actually found to be in hyperbolic orbits ( $e > 1$ ) but these are rare. Comets in truly parabolic and hyperbolic orbits have infinite orbital periods and so they visit the inner Solar System only once in their lives. Many new comets are initially assumed to be in a parabolic orbit but are later found to be in a highly eccentric ellipse.

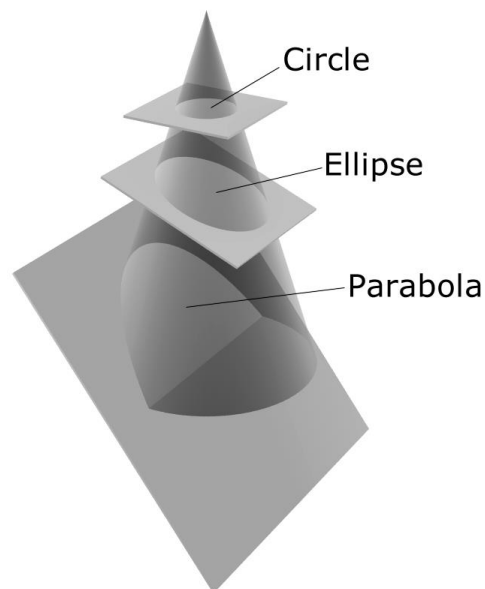


Figure 5 – Conic sections

The value  $q$  gives us the minimum, or *perihelion*, distance from the Sun to the comet. This distance is measured in astronomical units (AU) where one AU is the average distance from the Earth to the Sun, about 150 million km. Normally, for a comet to be spectacular,  $q$  should be less than 1 AU so that at perihelion the comet is within the orbit of the Earth. Comets can brighten as the inverse fourth, fifth or sixth power of their distance from the Sun so comets

with small values of  $q$  can be very spectacular indeed. Some comets, called sungrazers, have values of  $q$  less than 0.01 AU and such comets can be extremely bright at perihelion although at their best they are necessarily close to the Sun and so are only seen against a bright sky.

The Earth moves around the Sun in a plane called the ecliptic. The celestial equator is defined as an extension of the plane of the Earth's equator and, since the Earth's rotation axis is tilted by around 23.5 deg with respect to the ecliptic, the ecliptic plane is inclined to the equatorial plane by this amount. The Sun moves once around the ecliptic in one year and it moves across the ecliptic from south to north at the Spring equinox. This point is called the First Point of Aries (given the symbol  $\Upsilon$ ) even though precession now means that the crossing point now lies in the constellation Pisces.

The angle between the plane of the Earth's orbit and the plane of the comet's orbit is called the *inclination* and given the symbol  $i$ . By convention the inclination is less than  $90^\circ$  if the comet is moving around its orbit in the same direction as the Earth (prograde motion) and greater than  $90^\circ$  if the comet is moving in the opposite direction (retrograde motion). Halley's comet is moving in the opposite direction to the Earth and hence its inclination is given as  $162^\circ.2$ .

For any inclination other than  $0^\circ$  and  $180^\circ$  the comet will, at some point move from below the Earth's orbital plane to above it. The point at which it does this is called the *ascending node* and the angle between  $\Upsilon$  and the comet's ascending node measured along the plane of the Earth's orbit in the direction of the Earth's motion is called the *longitude of the ascending node* and it is given the symbol  $\Omega$ .

The final angular element is a measure of the angle between the ascending node and the line joining the comet to the Sun when the comet is at perihelion. This angle, measured in the plane of the comet's orbit in the direction of the comet's motion is called the argument of perihelion and it is given the symbol  $\omega$ .

Whenever a comet is discovered or recovered the *orbital elements* describing its motion will be published in a number of different sources. An initial orbit can be computed when we have three accurate timed *astrometric* positions separated by a few days. Quite often the initial orbit will allow observers to find pre-discovery images of the comet maybe days or weeks beforehand. In this way our knowledge of the orbit rapidly improves and in most cases the initial orbit is sufficiently accurate to predict the position of the comet many weeks or months into the future. However, this is not always the case and, particularly if the comet is far away and slow moving, it can take quite a while before we are sure of the orbit. C/1995 O1 (Hale-Bopp) discovered in 1995 was a particularly good example of this since it was discovered when it was far away and moving almost straight towards us.

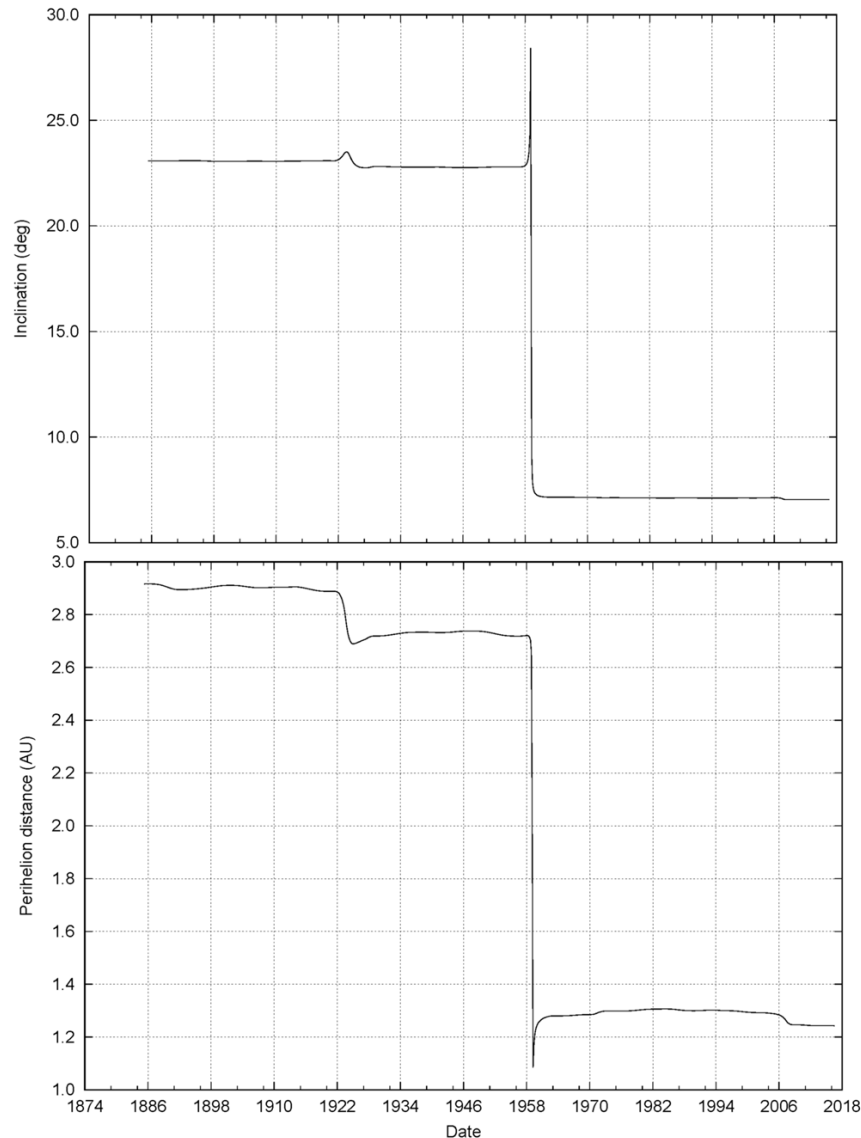
Any position quoted in equatorial coordinates must include a reference date which tells us which equator and equinox is being used. Our comet elements are said to be referred to the equator and equinox of such and such a date. Up to the 1980s the reference date was just before the start of the year 1950 (called B1950.0) but it is now just after the start of 2000 (called J2000.0).

## 2.4 Orbit evolution

Up to now we have ignored the effect of other Solar System objects on the orbit of the comet. This is a reasonable thing to do in the short term but in the longer term all of the small forces resulting from other objects in the Solar System will accumulate and perturb the comet away from the orbit predicted by simple two-body motion. When more than two bodies are involved in orbital motion there is no neat, general solution corresponding to the orbital



elements but in most cases the perturbing effects are still small and so we can still use the familiar orbital elements with a small addition. At any particular time we assume that the comet is following a closed orbit defined by a set of orbital elements but we accept that this orbit changes with time. The elements are called *osculating elements* and they come with an extra piece of information called the *epoch* which defines the time at which the elements correctly describe the closed orbit. You can use osculating elements to predict a comet's position at any time in the future or the past but the expected errors in position will grow as you move away from the epoch date.



*Figure 6. Evolution of the orbital inclination and perihelion distance of 67P obtained by integrating the current orbital elements backwards*

Since there is no general set of equations that we can use for three or more bodies in orbital motion the only way of accurately predicting future positions is to effectively construct a mathematical model of the Solar System and gradually move forward or backwards in time calculating all of the perturbations at each step through the process of *numerical integration*. This process allows us to take the orbital elements for any given epoch and integrate the orbit forwards or backwards to any future or past time that we desire. This can lead to some very interesting results. Some comets have seen dramatic changes in their orbits at some point in the past due to close encounters with planets. Numerical integration is the only way

to trace the path of a comet back in time so that we can investigate where it originally came from. Rosetta's comet, 67P, is an interesting example of this. At present it is in a low-inclination orbit with a perihelion distance of about 1.25a.u. and a period of 6.4 years. A backwards integration of its orbit (Figure 6) shows that it had a close encounter with Jupiter in 1959 February which dramatically changed the orbit. Prior to that time the perihelion distance was 2.7 a.u. and the inclination was 23 deg. There was another encounter in 1923 October but the effect of this was less dramatic. The results of this integration help to interpret Rosetta's results since they show that it is only in recent years that the comet has come close to the Sun.

Another interesting aspect revealed by the integration of orbits is that certain comets seem to belong to families. When the orbits of these comets are integrated backwards in time it seems that they all converge on a single object, as if a huge comet had broken up into multiple objects at some time in the past. One of the largest families is known as the *Kreutz group* after Heinrich Kreutz. Around 1890 he suggested that many of the sungrazing comets appeared to be in very similar orbits. He proposed that there was once a massive comet that broke up at perihelion and which was the parent of all of these objects. Brian Marsden used the techniques of orbit integration to show that the original comet probably split into two many thousands of years ago. The two parts were themselves disrupted at perihelion passages in 372 BC and 1106 AD respectively to form two subgroups called Kreutz I and Kreutz II. The original comet must have been huge with a nucleus perhaps 120km in diameter. Other families exist and it is only by integrating current orbits backwards using computers that we can hope to understand the history of these objects.

Sometimes, rather than continually changing a comet's orbit, gravitational perturbations will lock a comet into what is called a *resonance*. The comet might, for instance, have an orbital period in which it performs three revolutions in exactly the same time that Jupiter takes to go twice around the Sun. After three revolutions the comet returns to exactly the same position with respect to Jupiter and so the pattern of gravitational perturbations repeats. Such an orbit is called resonant and this particular case would be described as a 3:2 resonance. A number of periodic comets are known to be in resonant orbits with Jupiter, one of the most interesting being the progenitor of the Leonid meteor shower, Comet 55P/Tempel-Tuttle whose 33 year orbit is locked in a 5:14 resonance with the giant planet.

The material evaporated from a comet trails out along the orbit and if the Earth encounters it we may see a display of meteors. The Leonids which are seen each November have a greatly enhanced level of activity near to times when the parent comet is at perihelion. Most recently Leonid storms were seen in 1998, 1999 and 2001 following 55P/Tempel-Tuttle's perihelion passage in February 1998. It is only recently that accurate predictions of these meteor storms has been made possible by people such as Rob McNaught and David Asher. They have used orbit integration calculations to model perturbation effects on all of the particles in this stream of cometary debris.

A comet does not always follow the path that we would expect, even after we have taken account of all of the various gravitational effects since other perturbing forces are present. These effects are largely due to the thrust generated by active jets of material. The non-gravitational forces (NGFs) on the nucleus are usually modelled using two parameters,  $A_1$  and  $A_2$ . The actual force on the nucleus is dependent on how far the comet is from the Sun since the rocket effects are directly proportional to the rate of ejection and this increases rapidly as the nucleus is heated. The parameter  $A_1$  represents a force which acts radially away from the Sun. If the nucleus is not rotating we would expect all of the jets to be on the Sunward side of the nucleus and so the resulting rocket force would tend to push the comet radially away from the Sun. The  $A_2$  parameter is a force which acts tangentially along the orbit. These parameters are determined by fitting astrometry to an orbit over many returns

and they provide us with a tool with which we can gain some insight into the physics and nature of cometary nuclei.

## 2.5 Magnitudes

As a comet nears the sun it loses material into the coma at a greater rate. The rate of loss varies from comet to comet, so predicting the brightness can be difficult. The approximate total visual brightness of a comet may be represented by the equation:

$$m_1 = H_1 + 5.0 * \log(\Delta) + K_1 \log(r)$$

where  $H_1$  and  $K_1$  are constants,  $\Delta$  is the comet's distance from the Earth and  $r$  its distance from the Sun measured in astronomical units (au). If the comet was exactly one au from both the Earth and the Sun its magnitude would be  $H_1$ . If few observations have been made it may be impossible to derive a value for  $K_1$ ; in this case a value of 10 is assumed for long period comets and the first constant becomes  $H_{10}$ . For short period comets a value of 15 is assumed for  $K_1$  and the first constant becomes  $H_{15}$ . A purely reflecting body would obey the inverse square law and  $K_1$  would have a value of five.

A few comets seem to brighten linearly with time, and reach their peak magnitude away from perihelion. The light curve of these comets can be represented by the equation:

$$m_1 = H_1 + 5.0 \log(\Delta) + K_1 \text{abs}(JD - T - dT)$$

where JD is the Julian date, T the Julian date of perihelion and dT an offset for when the comet is brightest. If  $K_1$  is positive the comet brightens towards perihelion and if dT is positive the comet is brightest prior to perihelion.

John Bortle has developed a formula that expresses the survival limit for comets that approach within 0.5 au of the Sun. In order to survive their perihelion passage such comets must have an absolute magnitude:

$$H_{10} < 7.0 + 6 q$$

where  $q$  is the perihelion distance. The formula mainly applies to long period comets that are making their first visit to the inner solar system. Short period comets can clearly survive with significantly fainter absolute magnitudes, as shown by 2P/Encke, 23P/Brorsen-Metcalf and 96P/Machholz.

### 3 BASIC VISUAL OBSERVATION

Similar problems affect comet observing to other branches of astronomy. Cold is always a problem and this is accentuated by any wind. Mist will often drown out a comet low on the horizon, even if it is clear overhead. With clear skies comes the chance of dew or condensation forming on the optics. Light pollution affects diffuse objects such as comets far more than it does point sources. Despite all this it is possible to observe comets from the UK and to make significant contributions to their study. Occasionally we have the best observing circumstances anywhere in the world, for instance the last astrometric photograph of 1P/Halley prior to perihelion was taken from Cambridge.

#### 3.1 Sources of information

In order to observe a comet you must know that it exists and where it is in the sky. A list of cometary positions is known as an ephemeris. Sources of information that provide rapid notification of the discovery, position and brightness of comets include the BAA comet section web page, the BAA e-bulletins and the TA electronic circulars. The BAA Comet Section webpage will often have location charts for comets and online sources and software planetarium programs can often generate charts to order.

#### 3.2 Finder charts

Printed star atlases have largely been superseded by electronic star charting programs or on-line star charts. Computer based planetarium or star charting programs enable you to make your own finder charts, though you should be cautious about using the magnitudes from such programs unless the source is well defined. If you want to use a traditional star atlas, it needs to show stars at least as faint as the comet you plan to observe. The American Association of Variable Star Observers (AAVSO) star atlas has comparison star magnitudes suitable for estimating a comet's brightness down to around 10<sup>th</sup> magnitude. Others include Norton's Star Atlas (useful for plotting the overall track of a comet and selecting stars to hop from) or Uranometria 2000.0 Vols 1 & 2. One thing to watch out for is the epoch of the atlas and the comet positions: they must be the same. Positions for Epoch 2000 are fine for Norton's 2000 and Uranometria, but the AAVSO atlas is Epoch 1950. Most current sources will be using the J2000 epoch.

#### 3.3 Star hopping

If you don't have a go-to telescope or setting circles you can use star hopping to find objects in the sky. First find a convenient naked eye star close to the object. Centre this in the finder or in the main 'scope using the lowest magnification you can. Compare the field with a detailed star atlas (AAVSO or Uranometria) and decide on the orientation of the field. A telescope normally turns the field upside down and a right angle star diagonal swaps left and right. Now all you have to do is move from star to star until you come to the comet. A faint comet can sometimes be easier to spot if you move the 'scope backwards and forwards a little once you have found the field.

The BAA circulars or comet section web page give positions for comets that are currently observable. For example comet 1994 G1 (Takamizawa-Levy) was around 10<sup>th</sup> magnitude at midnight on 1994 June 25/26 and the comet section circular gave its position as 12<sup>h</sup>3.7<sup>m</sup> +52°58' (B1950). The (B1950) was important: to find faint comets you must make sure the atlas uses the same co-ordinate grid. The AAVSO atlas uses B1950, whilst Uranometria 2000.0 uses J2000. The position for J2000 was 12<sup>h</sup>6.1<sup>m</sup> +52°41'. Plot the position in your star atlas and once you have got your telescope set up, star hop to the comet. Point the finder at Gamma UMa (the bottom left star of the bowl of the plough) and then look through a low power eyepiece. Move about a degree south and a degree following (to greater right ascension) and you will find a 9<sup>th</sup> mag star. You should be able to see M109 (10<sup>th</sup> mag) on

the way. Carry on a similar distance in the same direction to an 8<sup>th</sup> mag star; the comet was just ten minutes away from this.

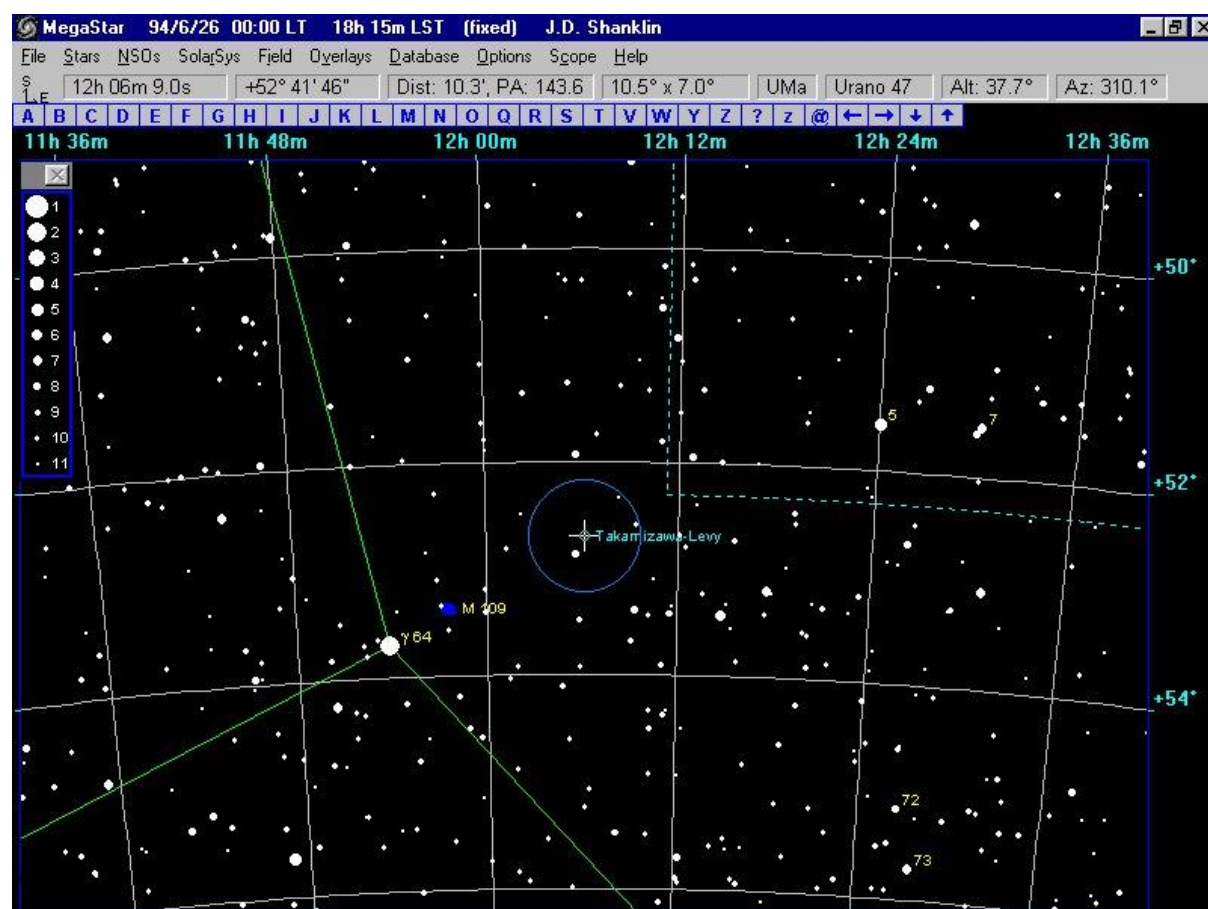


Figure 7 - Finder chart for comet 1994 G1 (Takamizawa-Levy) at midnight on 1994 June 25/26.

### 3.4 Instruments

Although a few comets every year may be just visible to the naked eye, some form of optical aid is required for the majority. In general a short focal length and low magnification is desirable for observing comets, though a few comets are best seen with a higher magnification.

No single instrument can be used to observe all comets, so a compromise is needed. Simple 7x50 binoculars might be the best instrument for a beginner, though they will only show the brighter comets down to around 8<sup>m</sup>. If you later find that comet observing doesn't suit you, you still have an instrument that you can use in several other fields of astronomy. To see fainter (more typical) comets you will need a telescope or large binoculars and if possible a light pollution free site. The approximate visual cometary magnitude limit (for a condensed comet) for a telescope at a typical UK site is given in Table 2.

Aperture (mm)	50	80	150	200	300	400
Faintest mag	8.0	9.5	11.0	12.0	13.5	14.5

Table 2 – Comet magnitude limits

Greg Crinklaw has developed a formula for the faintest comet visible at a very good site with a given aperture:

$$m = 0.9 + 5.06 \log (A)$$

where A is the aperture in mm.

Large binoculars are a good choice, particularly if they are tripod mounted as this gains a magnitude or two over a hand-held instrument. Image stabilised binoculars also give a magnitude gain, though they are more expensive and generally of smaller aperture. Centre focus binoculars are better than individual focus when it comes to making magnitude estimates.

The faintest comet that you can see is one or two magnitudes brighter than the faintest star that you can see with the same telescope. You should always use the lowest magnification and smallest aperture that will clearly show the comet for the magnitude estimate, however you may need a larger aperture and higher power to see detail in the inner coma. A short focal length reflector on a Dobsonian mounting is perhaps the best choice, unless you want to carry out imaging.

The better the quality of the optics the more you are likely to be able to see. Binoculars which use BaK4 prisms give brighter images than ones which use BK7 or roof prisms. Multicoated lenses give a greater light transmission and hence a brighter image for a given aperture. Good eyepieces are just as important and a poor eyepiece can ruin a good telescope. Eyepieces with an apparent field of view of 50° or more and good eye relief are probably best for comet observing.

### 3.5 Other equipment

You should also have:

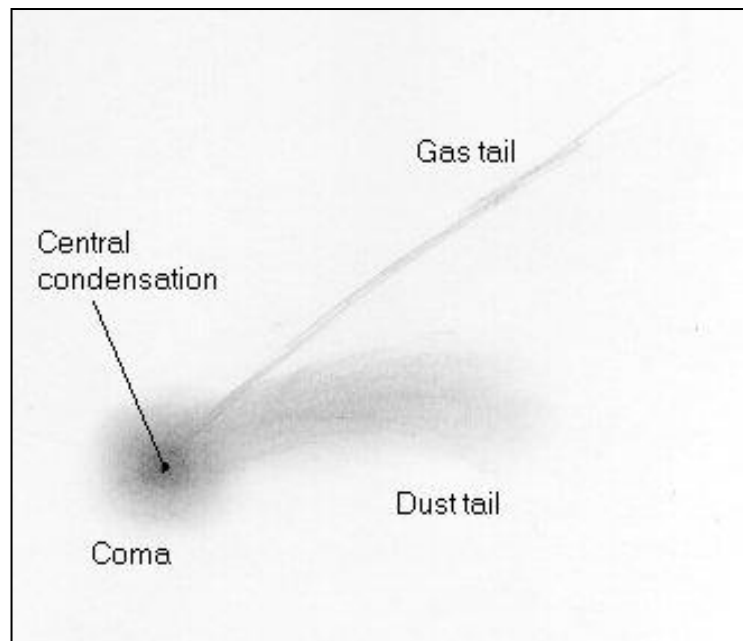
- a) A notebook to record your observations, a pen and pencil to write and draw with, and a 'plastic' rubber. If you later add extra details (eg the calculated coma diameter or comet magnitude), use a different colour pen to record the new information.
- b) A watch or clock set to UT (GMT) to record time to the nearest minute. A watch with a stop-watch function and dual time is ideal. In the UK if summer time (BST) is in force you have to subtract one hour to get UT.
- c) A dim red light to allow you to see the star atlas and write your notes, but not so bright that it destroys your dark adaptation. A dim, red, LED torch is ideal. A rear cycle lamp is a little on the bright side unless the batteries are on the way out, though you can paint the bulb with red nail varnish to reduce the intensity. Spare batteries are often needed.
- d) Warm clothing. It can get quite cold at night, even in the summer months in a sheltered observatory. You should aim to wear several layers of clothing because it is the air trapped between the layers that keeps you warm. It is best not to drink or smoke if you plan on making observations.
- e) If dew is forming on the optics you can remove it using a hair drier, but make sure that you are protected from electric shocks by using an RCD; you can also use the drier to warm your hands.

### 3.6 Visual observation

Most comets are not very spectacular, just faint smudges of light, similar in appearance to many deep sky objects. This similarity prompted Messier to produce his famous catalogue, which was designed to help him discover new comets. The average comet appears as a small patch of light, a few arc minutes across (a distance similar to the separation of the Galilean satellites from Jupiter), possibly brightening a little towards the centre. This patch of

light is known as the coma and is produced by outgassing of material from the icy rubble pile a few kilometres across that is the true comet nucleus. This nucleus is far too small to be seen in even the largest telescope, but you may see a false nucleus or disc like nuclear condensation at the heart of the coma. The head of the comet consists of the coma and nucleus. A coma 5' in size when a comet is 1 au from the Earth is actually over 200 000 km across. A bright comet may develop a tail or even tails which generally point away from the sun and the longest may be over 150,000,000 km long.

Unfortunately, prospects for visual observation, particularly of the fainter comets are not encouraging because of the wide-spread increase in light pollution in the UK. A dark site helps you to make good observations: if you can't see a 7<sup>m</sup> comet in 7x50B then you should try and find a darker site. The higher the site the better as this puts you above more of the atmosphere so that there is less scattering and absorption of light.



*Figure 8 - Features of a comet*

You should keep a record of all your observations. It is best to have a rough notebook to use at the telescope, as it will inevitably get damp and dirty, and a finished version in which to complete notes and drawings. Your book can record extra details not reported on the standard forms, e.g. personal narrative. You should always record your observations as you go, rather than committing them to memory and writing them down later. It is worth recording regularly used details in the front of the book, e.g. the latitude and longitude of your observing site, the magnification and field diameter for various eyepieces, separation of standard double stars etc.

You will need to get properly dark adapted before starting to observe and during this time you can write down some background information in your observation book. Record the name and official designation of the comet that you are going to observe (eg C/2011 L4 (PanSTARRS)), and where you are observing from. Next write down the year, month and day (record the double date to avoid confusion, e.g. if it is the evening of March 22, then write down March 22/23). As with all astronomical observations it is important to record the time of the observation; for visual cometary work an accuracy of around 15 minutes (0.01 day) is sufficient.

The appearance of a comet very much depends on the type, aperture and focal ratio of the instrument; on the type and magnification of the eyepiece being used and on the observing



conditions, so these facts need to be recorded. A comet generally appears fainter with higher magnification, larger aperture and poorer conditions. To find the comet, plot its position on a suitable star atlas and then star hop or use setting circles to find the field. For a faint, diffuse comet accurate positions are essential, as the object may be barely observable above the sky background. Here it may help to print a computer generated chart showing the comet and faint stars prior to the observing session. If you have to plot the position by hand, you may need to interpolate the positions given in the ephemerides to get the position at the time you are going to observe; this is particularly important if the comet is faint.

Observers are encouraged to go on and make more detailed observations of a comet, however these observations are not easy and you may want to stop at this point. For some comets simply reporting that you have seen the comet is worthwhile. Some periodic comets undergo outbursts and a report that a comet is within range may encourage other observers to go out and make more detailed observations. It is always worthwhile attempting a drawing, as this helps train the eye and you will find that you begin to see more detail. The 'smudged pencil' or 'negative shading' technique (section 4.8) is fairly simple and I have used this in several illustrations in this guide.

### 3.7 Estimating the magnitude

It can be very difficult to make good magnitude estimates of comets because they are often large and diffuse; practice helps. The observed visual magnitude is dependent on a number of factors including how much defocusing you use and the telescope aperture and magnification. You should use the smallest aperture and lowest magnification that clearly shows the comet. For a comet brighter than 3<sup>rd</sup> magnitude this will normally be the naked eye.

To make the estimate you use a similar technique to that used for making a variable star estimate; here you choose one comparison star (from the AAVSO atlas or a variable star chart) that is a little brighter than the variable (A) and another that is a little fainter (B). If the variable is closer in brightness to the brighter star then your estimate might be A 1 V 2 B (here the range is divided into three parts), if it is about midway then A 1 V 1 B (the range is divided into two parts), and if closer in brightness to the fainter star then A 2 V 1 B (the range is divided into three parts again). If the variable is much closer to the brighter star your estimate might be A 1 V 3 B (the range is divided into four parts), but it is rarely necessary to divide the range into more than four parts. The brighter star is always given first. If the variable appears identical in brightness to A, then record it as =A. If you can't see the variable at all, just record the faintest comparison that you can see, for instance if you can see B, but not the variable then record <B or [B.

To estimate a comet the same procedure is followed, but you have to put the comparison stars out of focus. Select some likely comparison stars, from the AAVSO atlas, from a nearby BAA or AAVSO variable star field or from the Tycho catalogue. For fainter comets it may be preferable to use the North Polar Sequence. Ideally the comparison stars should be in the same field, but this is rarely possible; if they are not you will have to memorise the brightness of the comet and may have to swap between the fields several times.

First centre the comet in the field and try to memorise its appearance. Next choose one comparison star that is a little brighter and another a little fainter than the in-focus comet and defocus (racking the eyepiece in) until they appear the same size as the in focus comet. Are they still brighter and fainter?, if not choose again! When you are happy, make the estimate in exactly the same way as for a variable star; this technique is known as the Sidgwick (S) method.

As an example, suppose you had used the variable star T UMa (on the BAA VSS programme), and made the estimate: P (1) comet (2) Q (ie the comet is closer in brightness

to P). P is mag 9.85, Q is mag 10.29, the difference between them is 0.44;  $1/(1+2)$  of this is 0.15, so the comet is  $9.85 + 0.15 = \text{mag } 10.00$ , however we only record it to 1 decimal place, ie 10.0.

If you have time, repeat this for another pair of stars because there is often some discrepancy in the magnitudes of the comparison stars from different fields, and several independent estimates will improve the accuracy of the magnitude determination. If the observation is uncertain for any reason (for example discrepant comparison star magnitudes, poor sky conditions etc), always note the magnitude as approximate by putting a colon (:) after it.

Where possible use comparison stars from the AAVSO variable star atlas, a BAA variable star chart, the Tycho catalogue or the North Polar sequence. Always give the source of the comparison star magnitudes, but there is no need to record the actual estimate on the report form, unless you do not have a suitable catalogue or atlas. In this case show the stars you have used by means of a field sketch on a separate sheet.

There is always a great desire to be the first to see a returning comet, the last to see a departing one, or to push the limits of the telescope and observers capability. The ready availability of PC planetarium programs with the ability to plot comet paths against Hubble or Hipparcos star fields make it very easy to observe exactly where a faint comet should be. Looking for this faint smudge of light at the limit of the telescope's light grasp it is possible to convince oneself that something is there and to produce an observation of it. It may well be there but such observations should always make it quite clear that there is some uncertainty by putting a colon (:) after the magnitude and noting the observation as reliability 3. Comets do outburst and others fade more slowly than expected, but quite a number of observations are appearing on the Internet, which appear to contradict CCD observations and visual observations made with larger apertures. These contradictory observations are often made with moderate apertures and the magnitudes quoted are usually at the limit of the telescope light grasp. They may be true, however the human imagination is a powerful thing.

### **3.8 Estimating the coma diameter**

Most comets don't start to form a coma until they are less than three astronomical units (au) from the sun. As the comet approaches the sun, sublimation of ices normally increases and the coma grows larger. If the comet approaches very close to the sun, the coma may appear to shrink again, though this is probably due to increasingly poor observing conditions. The apparent size of the coma depends on the distance from the earth and the true diameter of the coma. Measuring the diameter of the coma is quite important as it gives some physical information about the comet and also gives a comparison between the sky conditions of different observers.

The simplest way to measure the coma diameter is to compare the coma with a pair of stars of known separation. It is easiest to use two stars in the same field as the comet. Their separation can be measured later from an atlas or star chart, calculated from the star's positions or found by using a PC planetarium program. For a quick estimate Mizar and Alcor form a convenient yardstick; the separation between Mizar and Alcor is 11.8', and Alcor to its 8<sup>m</sup> companion is 6.3'. As an example, if the coma appears to be  $2/3$  of the separation between Alcor and its companion, the diameter is  $6.3 * 2 / 3 = 4.2'$ .

Please make a measurement or estimate of the coma diameter at the same time and with the same instrument as the magnitude estimate. This is very important for the analysis of the observations as the coma diameter also gives information about your observing conditions. For an elongate coma, report the smaller dimension as the diameter and the longer radius as the tail length.

Always measure the magnitude, coma diameter and DC with the **same** instrument (which may be the naked eye, binoculars or telescope) and only report this instrument. If you make additional measurements of magnitude, coma diameter etc with different apertures, report them separately.

### **3.9 Submitting observations**

Observers should submit their observations promptly, because professionals planning observing sessions on large telescopes often use them. Submit them in monthly batches, the best time to do this is during the full moon period when many comets will be drowned out. You should include as much detail as possible in your personal log, including any written narrative, even if this isn't submitted to the BAA or TA. Details of the BAA report forms and procedures are given in section 11. Analyses of comet observations are published in the Journal once all observations have been received and the individual observations are published in ICQ.

The section recommends that you register on the COBS website (<http://www.cobs.si/>), preferably as a BAA observer. If your observations are then submitted to COBS we can download them for analysis as required.

## 4 ADVANCED VISUAL OBSERVATION

### 4.1 Telescope magnification

When fully dark adapted the pupils of most people's eyes dilate to give a pupil diameter of around five to seven millimetres; younger people generally have larger diameter pupils when dark adapted. The best magnification to use is one which gives the same exit pupil as your own pupil diameter. To find this magnification simply divide the aperture of your telescope by the pupil diameter of your eye (use the same units for both measurements). As an example, if your telescope is a 200 mm reflector and your pupil diameter is five mm, the optimum magnification is x40. Two eyes are better than one, so 7x50 or 11x80 binoculars are commonly used for comets brighter than 10th magnitude; these have exit pupils of seven millimetres. For fainter comets many observers use telescopes in the range 150 - 300 mm with a magnification of 20 to 100 times. Some comets can be seen more clearly when a much higher magnification than the optimum value is used.

You need to use a higher magnification to gain an accurate magnitude if the comet has a small coma size. The resolution of the dark adapted eye is around 20', so sufficient magnification must be used to make the comet appear to subtend significantly more than this. As a rule of thumb aim for an apparent diameter of about 1°; for example a magnification of around x60 is needed for a 1' diameter coma.

### 4.2 Magnitude estimate

Never use a Swan band comet filter or any other filter when making a magnitude estimate.

There are several alternative methods for making a magnitude estimate. The Morris (M) method is a slight extension of the Sidgwick method where the comet is defocused just enough to give it a uniform surface brightness. Its brightness is then memorised and the comparison stars are defocused further until they are the same size as the defocused comet.

In the Bobrovnikoff (B) method you defocus the comet and comparison stars together, until the stars are about the same size as the defocused comet. The estimate is then made by direct comparison between the comet and the selected stars.

Finally, in the Beyer (E) method you defocus until the comet disappears; a technique which is good for bright comets.

The BAA recommends the use of the Sidgwick (S) technique for magnitude estimates; this is good for diffuse or faint comets and poor skies. The Bobrovnikoff or Morris methods are better for well condensed comets ( $DC > 6$ ); in the Bobrovnikoff method you may have to defocus to two or three times the coma diameter so it is poor for large comae. When defocussing reflector telescopes you should preferably rack inwards to avoid vignetting. The large central obstruction of a Schmidt-Cassegrain telescope can make magnitude estimation difficult.

Try not to check the magnitude of the comet against the ephemeris before you start observing. This can sub-consciously bias you, so that you observe what you expect to see. This sometimes means that you miss a cometary outburst or sudden fading. Don't force your observations to agree with the ephemeris magnitude, which can often be out by several magnitudes. As the total magnitude depends on the surface brightness and size, a large diffuse comet which is apparently faint, can actually be quite bright. Some comets, discovered with large telescopes are initially assigned visual magnitudes that are far too faint; 1993 Y1 (McNaught-Russell) was a case in point - when expected to be 15<sup>m</sup> it was found to be 10<sup>m</sup>. It is worth attempting observation of some of these fainter comets just in case they are brighter than predicted. It is also worth observing in poor conditions - for

example 1992 F1 (Tanaka-Machholz) had an outburst during the full moon period. It is also worth comparing your observations with those made by experienced observers: yours should vary in the same way, though it is quite common to have a systematic difference.

Because the observed magnitude depends on aperture and magnification it is best to try and use the same combination throughout an apparition, provided that there isn't a large range in the brightness of the comet. When you do need to change to a different telescope, make observations with both instruments for a couple of weeks so that you get a good overlap. This helps to determine the systematic effects caused by such changes.

To encourage proper methodology the ICQ has a project to observe selected NGC objects <http://www.icq.eps.harvard.edu/icqproject.html> ; these are: NGC 221 = M32; NGC 936; NGC 1068 = M77; NGC 1952 = M1; NGC 2068; NGC 3031; NGC 3344; NGC 3485; NGC 3623 = M65; NGC 3627; NGC 3640; NGC 4147; NGC 4374 = M84; NGC 4406 = M86; NGC 4486 = M87; NGC 4594 = M104; NGC 4649 = M60; NGC 5024; NGC 5236 = M83; NGC 5272 = M3; NGC 6356; NGC 6384; NGC 6426; NGC 6712; NGC 6760; NGC 6781; NGC 6934; NGC 7078 = M15; and UGC 5373.

### 4.3 Star Magnitude sources

The use of good comparison sequences is important; these include the North Polar Sequence (NP), the Tycho (TJ, TK or TT), Hipparcos (HJ), ASAS-3 (AU) and TASS4 (TA) catalogues and variable star charts which use photoelectric sequences (AAVSO - AC, BAA - VB). Of these NP is perhaps best as it can be used for most comets (unless you have a telescope with an English equatorial mount!). The Fourth Yale Bright Star Catalogue (YF) and the AAVSO atlas (AA) also provide acceptable comparisons. For comets fainter than about magnitude 10 – 11, ASAS-3 (AU) and TASS4 (TA) are the preferred sources. Beware of using some older VS charts which often use 'guesstimated' magnitudes; it is always a good idea to check several stars in the sequence and to use several different comparison stars. Never use photographic atlases as a source of magnitudes as photographic plates are often blue sensitive.

<b>Standard:</b>	
AA	AAVSO Variable Star Atlas.
AC	Variable star charts of the AAVSO.
AU	All Sky Automated Survey V-band catalogue (ASAS-3).
HJ	Hipparcos photometric system magnitudes.
HS	V magnitudes from the Hubble Space Telescope astrometric catalogue of stars on compact disk.
NP	North Polar Sequence; three charts published by the AAVSO showing stars with useful range 5 <sup>m</sup> to 17 <sup>m</sup> .
S	Smithsonian Astrophysical Observatory Star Catalogue.
SC	Sky Catalogue 2000.0 (stars brighter than mag 8.1).
SP	Skalnate-Pleso Atlas Catalogue (Atlas Coeli catalogue).
TA	The Amateur Sky Survey catalogue (TASS4).
TJ	Tycho catalogue from Hipparcos (Johnson V magnitudes).
TK	Tycho-2 catalogue from Hipparcos.
TT	Tycho/Hipparcos catalogue VT magnitudes.
VB	Variable star charts of the BAA.
<b>Alternative:</b>	
AE	Planetary or stellar magnitudes from the Astronomical or Nautical Almanac (for use with bright comets).
CS	Catalogue of Stellar Identifications (1979, Strasbourg). Large compilation of many catalogues. The visual magnitudes with colons (:) should be avoided if possible.
LN	Lampkin's Naked-Eye Stars.
TB	Supernova Search Charts, by G. D. Thompson and J. T. Bryan, Jr. (1989, Cambridge University Press).
Y	Yale Bright Star Catalogue (early editions).
YF	Yale Bright Star Catalogue (fourth edition, which should be used in preference to earlier editions).

*Table 3 - Magnitude source reference codes*

**Do not use:** Atlases Borealis, Eclipticalis or Australis; magnitudes of galaxies or nebulae, etc.; Norton's Star Atlas; any standard photographic atlas (e.g., Falkauer, Stellarum); or the Skalnate Pleso Atlas.

Note: additional codes are given in the full ICQ magnitude reference list.

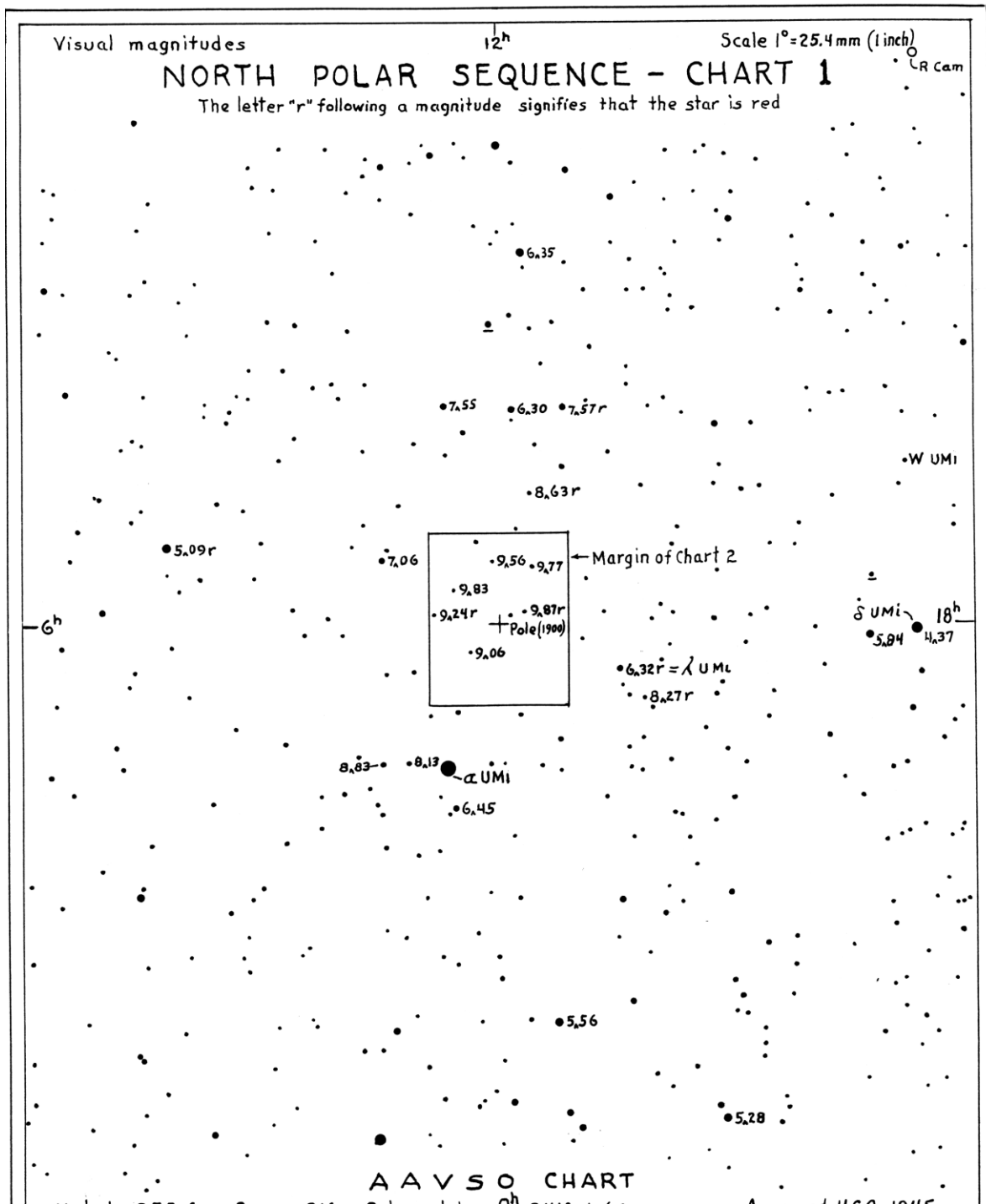


Figure 9 - North Polar Sequence chart, courtesy J A Mattei, AAVSO

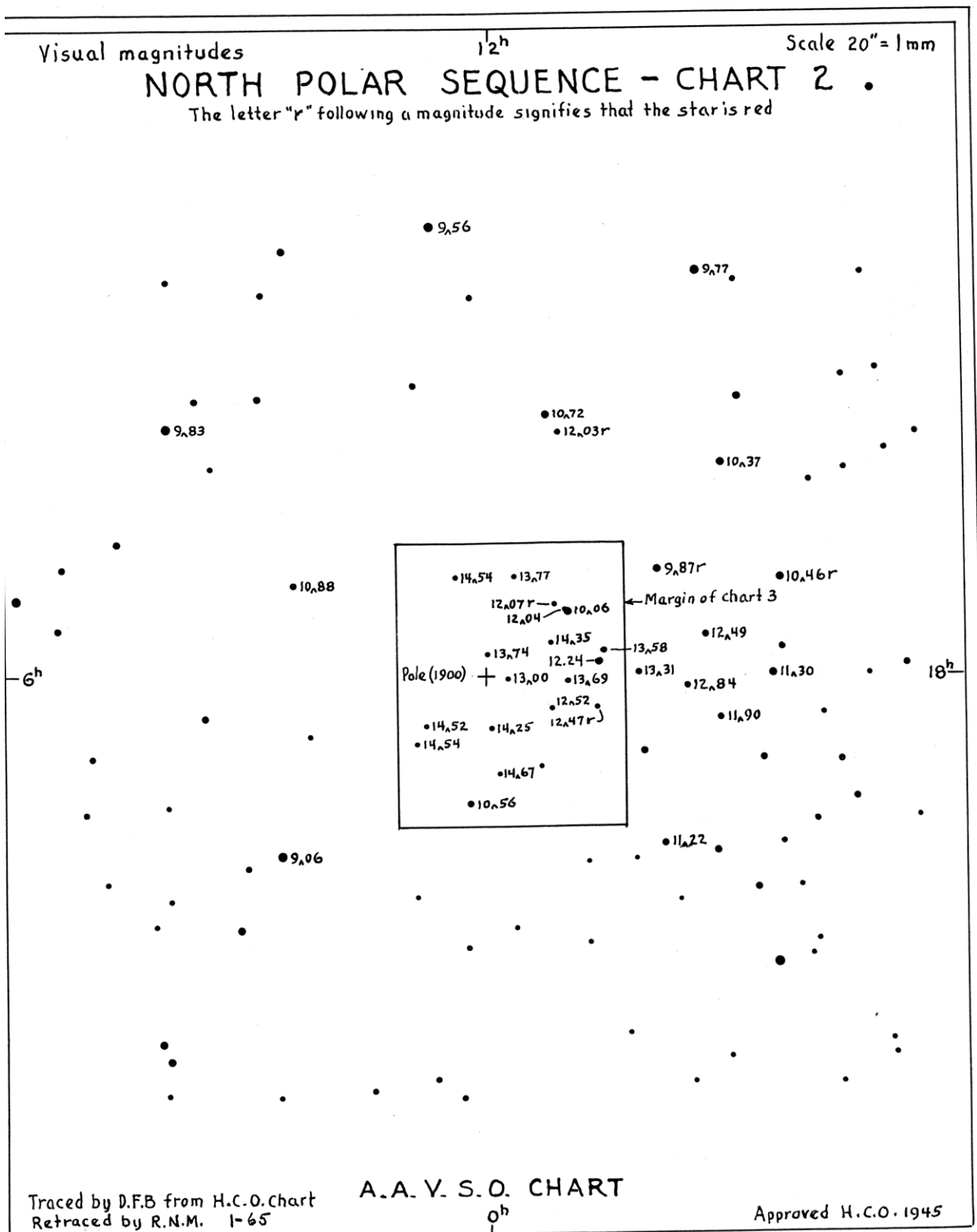


Figure 10 - North Polar Sequence chart, courtesy J A Mattei, AAVSO

If the altitudes of the comet and comparison star are very different you will need to correct the magnitude of the comet for atmospheric extinction. The difference in extinction values given in Table 5 for the comet and stars should be added to the derived magnitude of the comet. As an example, suppose that the comparison stars are at  $15^\circ$  altitude and the comet



is at 11° altitude and the original estimate for the comet was 7.8. The extinction for the stars is 0.9<sup>m</sup> and for the comet 1.1<sup>m</sup>, the difference is 0.9 - 1.1 = -0.2 so the corrected magnitude of the comet is 7.8 + -0.2 = 7.6.

alt	ext	alt	ext	alt	ext	alt	ext
40	0.3	30	0.4	20	0.6	10	1.2
39	0.3	29	0.4	19	0.6	9	1.3
38	0.3	28	0.4	18	0.7	8	1.4
37	0.3	27	0.4	17	0.7	7	1.6
36	0.3	26	0.4	16	0.8	6	1.8
35	0.3	25	0.4	15	0.9	5	2.1
34	0.3	24	0.5	14	1.0	4	2.6
33	0.4	23	0.5	13	1.0	3	3.4
32	0.4	22	0.5	12	1.1	2	4.9
31	0.4	21	0.5	11	1.1	1	9.5

*Table 4 - Extinction corrections*

Note: This table is for a typical location in the UK. For an altitude above 40 degrees the extinction is 0.3.

A further problem can occur if there is a star involved with the coma of the comet. If it is faint compared to the comet it will not add a significant amount to the total magnitude and can be ignored, but the light from a brighter star will need to be subtracted. Values for the difference are given in Table 6. As an example suppose the observed total magnitude was 7.8 and there was a star of magnitude 8.9 embedded in the coma. The difference between the total magnitude of the comet + star and the star by itself is 1.1. Finding 1.1 under the column 'total' shows that the difference in magnitude between the comet by itself and the star is 0.6<sup>m</sup> (diff) and that the star contributes 0.5<sup>m</sup> (comb) to the total magnitude we have observed. The magnitude of the comet by itself is therefore 8.9 - 0.6 = 8.3, or alternatively 7.8 + 0.5 = 8.3.

diff	comb	total	diff	comb	total	diff	comb	total
0.0	0.8	0.8	1.0	0.4	1.4	2.0	0.2	2.2
0.1	0.7	0.8	1.1	0.3	1.4	2.1	0.1	2.2
0.2	0.7	0.9	1.2	0.3	1.5	2.2	0.1	2.3
0.3	0.6	0.9	1.3	0.3	1.6	2.3	0.1	2.4
0.4	0.6	1.0	1.4	0.3	1.7	2.4	0.1	2.5
0.5	0.5	1.0	1.5	0.2	1.7	2.5	0.1	2.6
0.6	0.5	1.1	1.6	0.2	1.8	2.6	0.1	2.7
0.7	0.5	1.2	1.7	0.2	1.9	2.7	0.1	2.8
0.8	0.4	1.2	1.8	0.2	2.0	2.8	0.1	2.9
0.9	0.4	1.3	1.9	0.2	2.1	2.9	0.1	3.0

*Table 5 - Combining stellar magnitudes. diff = difference in magnitude of components, comb = combined magnitude (add to brighter component), total = difference between combined magnitude and faintest component.*

Sometimes the star you have chosen as a comparison may turn out to be a double. Although this is not desirable it is possible to combine the magnitudes of the two components and this can also be done using table 5. Suppose the two stars have individual magnitudes of 7.8 and 8.1. The difference is 0.3 (diff), so the combined magnitude is 0.6<sup>m</sup> (comb) brighter than the primary, ie 7.8 - 0.6 = 7.2.

#### 4.4 Coma Diameter

Measuring the coma diameter is quite important as not only does it tell us how the comet is behaving, but it also says something about the observing conditions at your site. There are three main ways of measuring it:

a) The simplest way is to compare the coma with a pair of stars in the field, though for brighter comets Mizar-Alcor form a convenient yardstick. For fainter comets, estimate the diameter relative to two field stars - their separation can be measured later from an atlas or star chart, calculated from the star's positions or found from a PC planetarium program. For reference the separation between Mizar and Alcor is 11.8' and between Alcor and its 8<sup>m</sup>

companion is 6.3'. As an example, if the coma appears to be 2/3 of the separation between Alcor and its companion, the diameter is  $6.3 \times 2 / 3 = 4.2'$ .

b) With the telescope drive stopped, time how long the comet takes to transit across a wire or the edge of the eyepiece field with a stop watch (alternatively you can time how long a star takes to move the same distance). The coma diameter =  $0.25 \times (\text{time of transit, in seconds of time}) \times \cos(\text{declination})$ . Table 7 gives values for a range of times and comet declinations. You should repeat the measurement several times and then take the average. As an example, if the comet is at a declination of  $+30^\circ$  and the coma takes 10 seconds to transit a wire, the diameter is  $0.25 \times 10 \times \cos(30^\circ) = 2.5 \times 0.866 = 2.2'$  as given by the table.

Dec	transit time (seconds)																		
	1	2	3	4	5	6	7	8	9	10	20	30	40	50	60	70	80	90	100
0	0.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0
5	0.2	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	2.5	5.0	7.5	10.0	12.5	14.9	17.4	19.9	22.4	24.9
10	0.2	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	2.5	4.9	7.4	9.8	12.3	14.8	17.2	19.7	22.2	24.6
15	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	2.2	2.4	4.8	7.2	9.7	12.1	14.5	16.9	19.3	21.7	24.1
20	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1	2.3	4.7	7.0	9.4	11.7	14.1	16.4	18.8	21.1	23.5
25	0.2	0.5	0.7	0.9	1.1	1.4	1.6	1.8	2.0	2.3	4.5	6.8	9.1	11.3	13.6	15.9	18.1	20.4	22.7
30	0.2	0.4	0.6	0.9	1.1	1.3	1.5	1.7	1.9	2.2	4.3	6.5	8.7	10.8	13.0	15.2	17.3	19.5	21.7
35	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	4.1	6.1	8.2	10.2	12.3	14.3	16.4	18.4	20.5
40	0.2	0.4	0.6	0.8	1.0	1.1	1.3	1.5	1.7	1.9	3.8	5.7	7.7	9.6	11.5	13.4	15.3	17.2	19.2
45	0.2	0.4	0.5	0.7	0.9	1.1	1.2	1.4	1.6	1.8	3.5	5.3	7.1	8.8	10.6	12.4	14.1	15.9	17.7
50	0.2	0.3	0.5	0.6	0.8	1.0	1.1	1.3	1.4	1.6	3.2	4.8	6.4	8.0	9.6	11.2	12.9	14.5	16.1
55	0.1	0.3	0.4	0.6	0.7	0.9	1.0	1.1	1.3	1.4	2.9	4.3	5.7	7.2	8.6	10.0	11.5	12.9	14.3
60	0.1	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.1	1.3	2.5	3.8	5.0	6.3	7.5	8.8	10.0	11.3	12.5
65	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.1	2.1	3.2	4.2	5.3	6.3	7.4	8.5	9.5	10.6
70	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.7	2.6	3.4	4.3	5.1	6.0	6.8	7.7	8.6
75	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.6	1.3	1.9	2.6	3.2	3.9	4.5	5.2	5.8	6.5
80	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.9	1.3	1.7	2.2	2.6	3.0	3.5	3.9	4.3
85	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.4	0.7	0.9	1.1	1.3	1.5	1.7	2.0	2.2

Table 6 - Coma diameter from transit time

Add values for intermediate times, eg 17 seconds at  $30^\circ = 1.5 + 2.2 = 3.7'$ .

c) Estimate the diameter relative to the eyepiece field width. You still have to use method b) to measure the eyepiece field width, but you only need to do this once. This method is less accurate than the previous ones as you will normally be using a low power eyepiece which will have a wide field of view. Suppose the coma appears to be 1/5 the diameter of the field which was measured at  $35'$ ; the coma diameter is  $35 / 5 = 7'$ .

Sometimes the coma is elliptical and if this is the case record both the dimensions and the position angle of the major (longer) axis. Take the smaller dimension as the coma diameter and the difference between this and the larger dimension as the tail length.

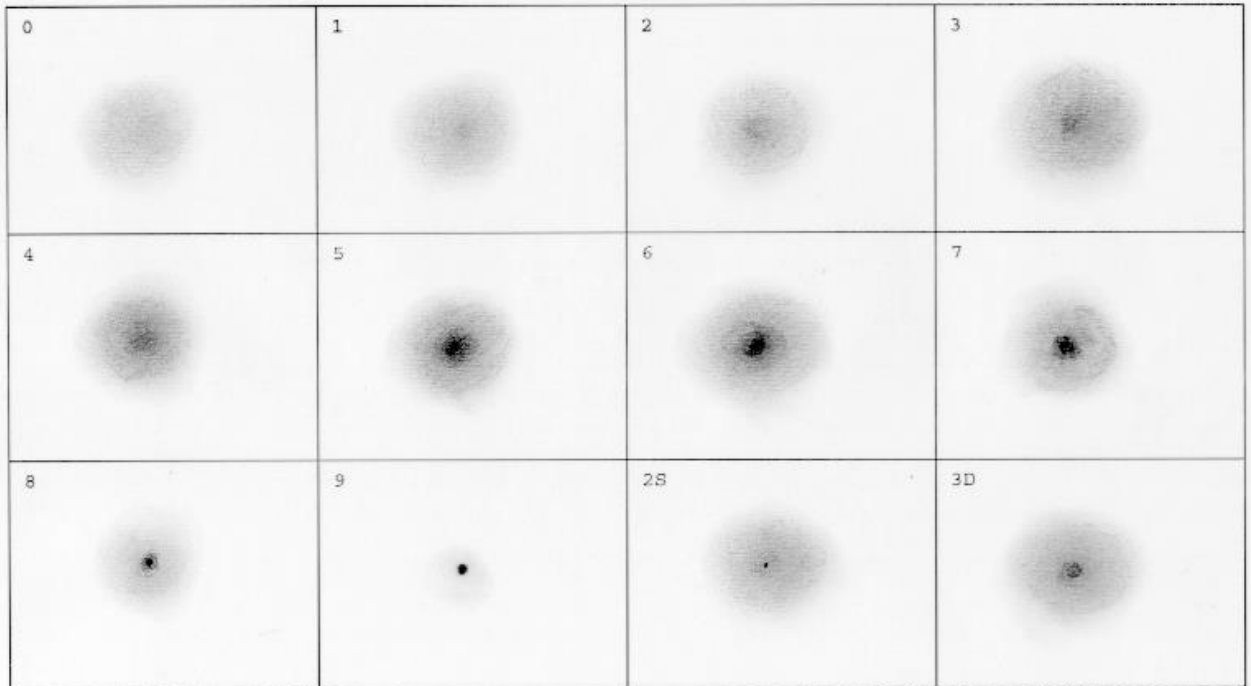
Visual measurements are also possible with reticle or astrometric graticule eyepiece having first determined the scale via fixed double stars.

## 4.5 Degree of condensation

The way the light distribution within the coma varies is called the degree of condensation (DC). The DC represents the average slope of the change in brightness from the centre of the coma to the edge. You should report the DC as a whole number between 0 and 9. Do not use half steps or give a range of values and when in doubt round to the odd. A comet that is completely diffuse with no apparent change in intensity across the coma has a DC of 0. A DC of 5 is when the intensity has dropped to half at half the coma diameter. A comet that appears as a nearly star-like point or disc has a DC of 9. Few comets fainter than 4<sup>th</sup> or 5<sup>th</sup> magnitude will ever have a DC of 9, but occasionally this does happen, for example 1998 K5 (LINEAR), which was 13<sup>th</sup> magnitude.

When an otherwise diffuse coma has a nuclear condensation or false nucleus, which presents a step in the brightness distribution try and estimate the DC by averaging through these features. If the nuclear condensation makes a significant contribution to the total

magnitude the DC will be higher than if it only makes a small contribution. A comet which brightens a little towards the centre, but which also has a star-like false nucleus might only have a DC of 3. An example of this was comet IRAS-Araki-Alcock which had a marked star-like condensation in a very large, diffuse coma, but the condensation made little difference to the total magnitude and hence to the DC.



*Figure 11 - Examples of DC [Note contrast exaggerated]*

If a feature is present within the coma a letter can be added after the DC value to give a complete description. If a disc-like nuclear condensation is present add 'D' after the DC value if it makes an appreciable contribution to the total magnitude and changes the DC by more than 2 or 'd' if it doesn't significantly affect the total magnitude and changes the DC by 2 or less. Similarly if a star-like nucleus is present, add an 'S' or 's', or if the condensation is nearly star-like add an 'N' or 'n'. In general use only one letter and always use the lower case letter if the feature is faint.

0	Diffuse coma of uniform brightness
1	Diffuse coma, with slight brightening towards centre
2	Diffuse coma, with definite brightening towards centre
3	Centre of coma much brighter than edges, but still diffuse
4	Diffuse condensation at centre of coma
5	Condensation appears as a diffuse spot at the centre of the coma. Described as moderately condensed.
6	Condensation appears as a bright diffuse spot at the centre of the coma
7	Condensation appears as a fuzzy star that cannot be focused. Described as strongly condensed.
8	Coma has virtually disappeared
9	Stellar or disc like in appearance

*Table 7 - Degree of Condensation*

A true nuclear condensation is rarely seen and is possibly caused by an outburst; if so its diameter should increase from night to night, and should be measured. The magnitude of this condensation (or the nuclear magnitude) can be recorded, but it is generally only of indicative use. Early observers thought that this star-like feature was the real nucleus, but this is far too small to be seen in a telescope. Beware of confusion between the term 'central

condensation' which just indicates that the coma is much brighter towards the centre and 'nuclear condensation' which is the nearly star-like feature only seen occasionally. A condensed comet doesn't have to have a nuclear condensation.

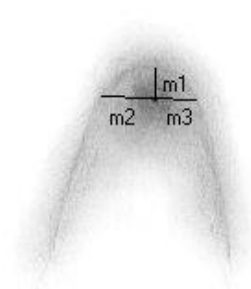
#### 4.6 Features in the coma

The physical appearance of the comet will depend on sky conditions; a bright sky drowns out much of the coma and tail structure. It also depends on the relative proportion of dust and gas in the coma. In general a predominantly gaseous coma will appear less condensed than one predominantly composed of dust. Most of the light of the gaseous coma comes from the C<sub>2</sub> Swan emission bands which lie between 430 and 620 nm, whereas the dust coma just reflects the solar continuum. When a comet is more than 2.5 AU from the Sun, the C<sub>2</sub> emission tends to be very weak or absent, so only the dust coma is seen.

The Lumicon comet filter is based on the Swan bands and therefore enhances a gassy comet. The coma diameter, DC etc will change when viewed through the filter and you should always report what you observe without the filter. If there are significant changes when the comet is viewed through a filter report these using the space for comments on the report form. Some filters absorb so much light that faint comets are still invisible even when they are used! Because the spectral sensitivity of the eye changes as it dark adapts it is possible that the appearance of the coma will also change.

Sometimes detail can be seen in the inner coma but often physiological and psychological factors play a part and we 'see' defects in our own eyes. Very few comets show features in the coma. John Bortle has proposed a classification scheme for features that may be seen

**H** hoods or envelopes: only seen in bright comets near perihelion and more often photographed. They are the largest features to be seen. If you do see a hood some simple measurements can give clues on the rotation of the nucleus: measure the distance from the centre of the coma to the leading edge of the hood and to the edge of the hood in the two directions perpendicular to this (they may not be the same in each direction).



*Figure 12 - Hoods*

**R** rays of the ion tail: they rarely extend all the way in to the false nucleus, usually ending a few minutes out. They are blue, can be seen with the Lumicon comet filter and are quite common.

**S** shadow of the nucleus: rare and needs a 0.40-m or larger telescope to be seen easily.

**F** fountains: around 1' high in the sunward direction, suppressed by a Swan band filter. They are diffuse features, subtending a few to 100 degrees angle and are more common than jets.

**J jets:** are the rarest feature, very fine and delicate, always curving and possibly spiral, rapidly changing and less than 60" high. Again they need a large aperture to be seen.

Because the comet nucleus is just a fragile rubble pile, many comets have been observed to fragment. The most well known example is of course comet 1993 F2 (D/Shoemaker-Levy) which collided with Jupiter in July 1994. Sometimes this process is visible in amateur instruments, for example in March 1976 the nucleus of comet West was observed to split into a number of fragments and in September 1994 components A and D of comet 141P/Machholz were easily visible in the same low power field. What is often seen is the formation of several separate nuclei which gradually separate from the main nucleus, fade and eventually disappear. Many comets also undergo outbursts, and these can considerably distort the light curve.

#### 4.7 Tails

The majority of comets don't have significant tails, however those that approach close enough to the sun may develop a gas tail (Type I) or a dust tail (Type II). The gas tail is usually straight, blue and filamentary and may suffer disconnection events (DEs), though these are rarely seen visually; a DE occurs when the magnetic field carried by the solar wind reverses in direction. The dust tail can be curved, and is yellow from reflected sunlight. The gas tail usually points directly away from the sun, but can blow around in the solar wind. The direction of such a tail, if it is pointing directly away from the sun, is often given in comet ephemerides. The dust tail lags behind this and lies in the plane of the comet's orbit; striations in it may define individual emission events from the comet nucleus. With a suitable filter some comets may show an additional sodium tail.

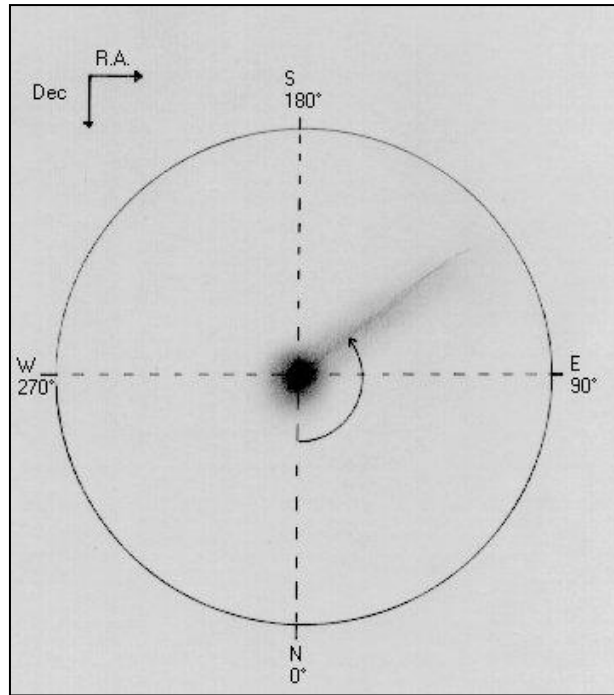
What is seen is very dependent on viewing geometry and when the comet passes through the nodal plane an apparently sunward pointing tail may be seen. A favourably orientated tail appearing 1° long when a comet is 1 au from the Earth is actually over 2 500 000 km long. The length of tail that develops depends on the comet's distance from the Sun and its size. Andreas Kammerer has developed the formula:

$$\log_{10} (\text{tail length}) = [ 2.25 - 0.26 \cdot H ] \times 10^6 \text{ km}$$

which can be used to predict the expected tail length. H is the comet's heliocentric magnitude.

The visual observation of comet tails is generally not sufficiently accurate for professional astronomers and their observation is best left to photographers and CCD observers. There is space on the observing form to note the position angle and length of any tails and any asymmetry to the coma. The position angle should be measured near the head of the comet where the feature first appears; the end of the tail should not be used, unless this is to indicate the curvature. The position angle is measured with respect to the grid of right ascension and declination, NOT with respect to the horizon. Note that the apparent directions of east and west are reversed when a star diagonal is used. Only record the longest tail in the tabulated data, include details of other tails under descriptive comments.

Usually the tail length is recorded in degrees and tenths of a degree, however for a short tail, or one observed by CCD, it is more appropriate to use minutes of arc. This can be indicated in an electronic report by putting m after the value.



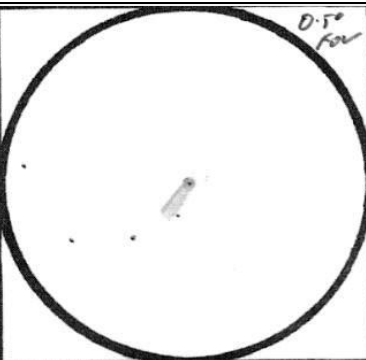
*Figure 13 - Position angle of tail or coma elongation. North (higher declination) is 0°, East (greater right ascension) is 90°, South is 180°, West is 270°. Note: the apparent directions of east and west are reversed when a star diagonal is used*

#### 4.8 Drawing comets

There are a number of techniques that can be used for drawing:

- a) pseudo isophotes: Draw approximate contours of equal brightness to illustrate the coma and tail. This is a good technique for beginners as it requires little artistic ability.
- b) negative shading (the normal technique): Rub a pencil on a sheet, then use a finger or tissue to transfer the graphite to the sketch pad; you can use a paper stump to add tone or a rubber to subtract it. Alternatively make a rough drawing directly on to the sketch pad and then use a finger to smear the sketch as necessary to get a gradation of contrast.
- c) stipple (the best method for a non artist): Make lots of little dots using a fine felt tip or self inking pen to portray the brightness of the coma.

Remember to put a scale bar (eg 1') and to mark the north point. It is best to make a sketch and notes at the eyepiece and complete the drawing indoors. Beware of bias and drawing what you expect to see. An example of a drawing and accompanying notes is shown in Figure 14

NGC <i>C/2015 V2</i>		SITE <i>STH NORFOLK</i>	SEEING <i>IV</i>	TRANS <i>m5.8</i>
CONST <i>C/2015 V2</i>		INSTR <i>602mm A03</i>	EYEPIECE <i>13mm</i>	POWER <i>x208</i>
DATE <i>27/12/2016</i>		COMMENTS <i>21.27 SQM seeing 5.8</i> <i>Comet filter doing considerably</i> <i>0455 21.27 SQM m5.8 clear view</i>		
TIME <i>0435</i>				

My first chance to get on this comet. Set the 24" up during the day and was observing from 6pm but skies very claggy against the forecast - NELM of only 5.0 and 20.8 was my best SQM reading. Clouded over at M/N so partially covered up and got a couple of hours sleep in. Woke at 2.45am and clear again, observing by 3.30am but this time very transparent skies although seeing still poor (Ant IV). I looked to see if I could see the mag 5.5 in UMi and immediately noticed the mag 5.8 one! SQM reading was 21.27.

Got on V2 Johnson at 0430 hours using a 13mm Ethos e/p giving x208 and just under 0.5 deg FOV. Immediately saw a short narrow tail. Comet filter dimmed it considerably. Sketched, the tail just touching/passing a faint star, identified later as GSC 03041-0318, m12.5. The other 3 in the sketch clockwise are: HD 126050, m9; VS DT Boo m8.42 to m8.85; TYC 03041-0295 1, m11.

Figure 14. C/2015 V2 (Johnson) on 2016 December 27 by Andrew Robertson

#### 4.9 How to improve your observations

Some simple procedures can help to improve total magnitude estimates, which often differ by several magnitudes between observers.

Always allow at least 15 minutes to get dark adapted. Not only does the spectral response of your eye change as you dark adapt, but you start to see fainter parts of the coma, which will make the comet appear brighter.

Always use the smallest aperture and lowest magnification that will clearly show the comet as this gives more consistent results. Within reason, try and use the same telescope and magnification throughout the apparition as this will minimise the systematic effects of aperture and magnification. Some observers made magnitude estimates of 1995 O1 (Hale-Bopp) when at its brightest with 20 cm reflectors whereas they should have used the naked eye or small binoculars. Please make a measurement or estimate of the coma diameter at the same time and with the same instrument as the magnitude estimate. This is very important for the analysis of the observations as the coma diameter also gives information about your observing conditions.

Use several different comparison stars, if possible choosing those that have photoelectrically determined magnitudes and similar colour to the comet (spectral class B, A or F); be careful to identify the stars correctly. For comets with orbits known well in advance try and obtain BAA variable star charts for fields close to the comet's path. Keep each comparison star and the comet in the centre of the field as you make the estimate. A common error is not to defocus the stars enough and this can lead to under-estimates of the comet's brightness. Try and use comparison stars at the same altitude as the comet.

Always measure the magnitude, coma diameter and DC with the same instrument (which may be the naked eye, binoculars or telescope) and report this instrument. If you make additional measurements of magnitude, coma diameter etc with different apertures, report them separately. These observations can be used to help quantify the aperture effect. Measure the tail or coma details with whatever instrument is most suitable. Note the aperture, magnification, seeing etc as with any other astronomical observation.



Take time over your observation; a hastily plotted incorrect position can waste a lot of time and lead to an erroneous negative observation. Try to avoid observing when very tired, ill or under the influence!

Don't check the ephemeris magnitude just before you observe - they are often considerably in error. When a new comet is discovered the predictions for its brightness are based on it brightening at a standard rate. If the comet is unusually dusty it will brighten faster than this, and if unusually gassy it will brighten more slowly. Few comets are usual! Another problem is that the initial brightness is often based on a photographic or CCD observation with a large aperture and visual observations are often considerably brighter. Observe on as many nights as you can, but try to avoid remembering the brightness from the last estimate. Similarly don't try and make your observations agree with those that you see reported on the Internet. Sadly some observers report fictitious or biased results in order to gain attention. Don't try too hard to see a comet at the threshold of vision as sometimes this can lead the eye into imagining something that isn't there.

Comets often have to be observed in twilight at low altitude, but try and observe with the comet as high and in as dark a sky as possible. Haze, cloud, moonlight and light pollution will also have adverse affects on accuracy.

Observations of comets in the morning sky are particularly useful as few observers like getting up early! Observations of periodic comets are quite important: the light curve can change from one apparition to the next, possibly because different areas on the nucleus become active. Observations of the level of activity are helpful in planning spacecraft missions to comets. Many of the fainter periodic comets have only been photographed and may be two to five magnitudes brighter visually or with CCDs. A negative observation can be just as important as a positive magnitude estimate, so it is worth checking on comets expected to be near the limit of your telescope.

#### **4.10 Very bright comets**

By observing through a reversed pair of binoculars you can reduce the apparent magnitude of a comet (or the moon). Figure 15 gives the reduction in magnitudes for standard binocular magnifications.

John Bortle has developed a formula for predicting the daylight visibility of a comet. For a comet to be visible, skies must be very transparent and the comet's magnitude

$$m > -2.5 + 2 \log_{10} (e)$$

Where  $e$  is the elongation in degrees.

The graph illustrates the relationship between Binocular magnification and Reduction in magnitude. The x-axis represents Binocular magnification, ranging from 0 to 25. The y-axis represents Reduction in magnitude, ranging from 0 to 7. The curve shows that as magnification increases, the reduction in magnitude also increases, following the equation  $\text{Reduction} = 2.5 * \log (\text{mag}^2)$ .

Binocular magnification	Reduction in magnitude
1	0
2	1
3	1.5
4	2
5	2.5
6	3
7	3.5
8	4
9	4.5
10	5
15	6
20	6.5
25	7

Magnification	2	4	6	7	8	10
Magnitude reduction	1.5	3.0	3.9	4.2	4.5	5.0

#### 4.11 Electronic submission of visual observations

Note that some e-mail systems automatically break long lines and may also remove blank spaces in the process. If your system does this, or if you don't know, then send your observations as an attachment, naming the file ICQ<mm><dd>.txt where mmdd is the date you compile the report. As an example a report file compiled on November 17 would be named ICQ1117.txt. As noted the section encourages the submission of observations using the COBS website. This allows us to obtain the observations in the ICQ standard format.

1	2	3	4	5	6	7	8												
12345678901234567890123456789012345678901234567890123456789012345678901234567890																			
IIIIIIYYMMNL	YYYY	MM	DD	dd	!M	mm	m	SS	AA	ATF/xxxx	/dd	ddnDC	tail	PA	Vol	OBS			
99	1992	5	18.94	s	9.3	AA	7.5R	50	6	4	135	ICQ	XX	BEA					
1955A1	1955	6	18.08		5.0	BD	5	R	6	5	s5	0.75	335	ICQ	XX	ST001			
2001A2	2001	7	18.08		7.0	TJ	5	B	10	5	5	10	m	210	ICQ	XX	SHA02		
1999T2	2001	1	28.25	Comet possibly seen at mag 13.6 (S, HS) in 20cm f10 T x120, with coma 1.0' DC 1.															
1999T1	2001	1	28.25	Possible tail 5' long in pa 345.															

*Table 8 - Electronic report formats*

## 5 IMAGING COMETS

On September 27 1858 an English photographer called William Usherwood obtained the first ever photograph of a comet. He used an f/2.4 portrait lens and a seven second exposure on a collodion photographic plate. The resulting image of Comet 1858 VI Donati showed the bright nucleus and a faint tail and the photographer was sufficiently excited to send a copy to a leading astronomer of the time, Richard Carrington.

In 1858 photography was in its infancy and photographic plates were extremely slow with exposures of several seconds required to capture pictures even in daylight. Photography developed dramatically through the twentieth century only to be gradually replaced by digital imaging in the 1990s. These days, with the exception of light pollution, comet imagers are living in a golden age of large, sensitive, relatively inexpensive digital imaging sensors.

The following pages detail how you can undertake comet imaging using digital cameras (DSLRs) or dedicated cooled astronomical cameras.

Most comets are faint, low-contrast, objects with diffuse tails or coma features which merge gradually into the sky background. Consequently, imaging a comet requires techniques similar to those used by deep sky photographers, though we have the added complication that comets move relative to the background stars. Since the techniques are so similar, you can use a suitable deep sky object to practice on if a comet isn't currently available.

### 5.1 Cameras

The days of film are now long gone and the vast majority of astronomical imaging is done with digital sensors. These sensors consist of an array of light-sensitive detectors called pixels which convert incoming photons to electrical charge. When the sensor is read out at the end of an exposure the charge in each pixel is measured and stored as an array of numbers in an image file. The number of grey levels represented by the pixel values ranges from 8-bit (256 levels) for some low-end cameras to 12 or 14-bits for DSLRs to 16-bits or more for scientific cameras. A 16-bit word can represent  $2^{16} = 65536$  grey levels which is far more than the human eye can distinguish or any monitor can display but this large number of grey levels is important when we come to calibrate and stretch the very subtle detail visible in a comet.

The pixels represent shades of grey. For colour images we need to use filters in front of the pixels to isolate the red, green and blue components of the image. This can be achieved using separate filters in a filter-wheel which are used sequentially to obtain individual grey-scale images that allow a colour image to be generated later. Alternatively the filters can be built in to the sensor so that red, green and blue filters are placed over adjacent pixels and a colour image is obtained by processing a single grey-scale image. A popular arrangement is the Bayer matrix where each group of 2x2 pixels has one red, one blue and two green filters. This has the advantage that a colour image can be taken in one shot but the disadvantages of reduced sensitivity and resolution.

Cameras used for comet imaging fall into two general categories. These are specialised scientific cameras which are designed for astronomy and which have cooled sensors and commercial designs such as Digital Single Lens Reflex (DSLR) cameras which are designed for the (much larger) general market and which do not have cooled sensors. For any given image sensor size the former are generally much more expensive than the latter but they can give much better results. That said, DSLRs and other modern digital cameras are remarkably capable and have been used to produce spectacular images of bright comets (see the image of C/2011 W3 (Lovejoy) on the back cover). Higher end DSLRs use a sensor which corresponds to the frame size of 35mm film (36x24mm). These full-frame cameras can be quite expensive and heavy. The majority of consumer DSLR cameras use a sensor

around 2/3 the size of full-frame cameras (approx 24×16 mm). This is often referred to as the APS-C format.

While DSLRs can be very effective the highest sensitivity is provided by specialised astronomical cooled cameras. For any given sensor area these are generally a lot more expensive than a commercial DSLRs and they usually require an external power supply and computer for operation but they do perform far better on faint objects. Larger sensor sizes are now available and more recent cooled cameras can be very affordable.

## 5.2 Wide-field imaging

In addition to the light-sensitive element any camera system must also include an optical arrangement to bring an image into focus on the detector. Comets range from faint, small objects that need to be imaged using a telescope to much brighter objects that need a wide field imaging system. Standard photographic lenses can make a very capable bright comet imaging system.

Since comets are extended objects their apparent brightness on the image sensor will depend on the focal ratio of the optical system (assuming that the focal length of the system is large enough that the comet is shown as a fuzzy, extended object on the image). The faster the optical system (i.e. the smaller the f/ratio) the better. Most comets are small and so quite long focal length lenses are required for good results. The combination of long focal length and fast f-ratio can be an expensive one however the modern demand for high-tech image-stabilized, auto-focus zoom lenses means that good, fast, fixed focal length lenses can often be found second hand at a good price.

Most lenses will have a relatively poor optical performance when used at their widest aperture. If you are using a sidereal drive it may be worth closing the iris by one stop to improve the optical performance and extending the exposure to compensate. An alternative is to pay a high price for a lens which performs well when used wide open. The top two pictures of C/1996 B2 Hyakutake shown in Figure 4 on page 8 were obtained using a Canon 85mm, f/1.2L aspheric lens. This type of lens has a very good performance when used wide open, even at the edge of the field. Such lenses are very expensive new but second hand versions using the Canon FD mount can be picked up for £650. Such a lens would make a superb imaging sensor when coupled to a modern sensor. Similar lenses are available from various manufacturers but they are seldom justified by comet photography alone.

To get sharp star images the lens should be focused to infinity but you may find that the infinity mark on the lens isn't actually the best focus point and some experimentation will be required. This is particularly true with long focal length mirror lenses which often have no stop at the infinity point. Since different wavelengths of light are brought to focus at different points the infinity focus mark usually only applies to light in the visible range. Many CCDs are sensitive well into the infra-red and it is often necessary to employ an infra-red blocking filter to get sharp star images. One advantage of modern DSLRs is that it is possible to display a zoomed-up image live on the screen and this is a significant aid to precise focusing.

An ideal lens would provide even illumination over the entire focal plane so that the sky background would produce a uniform density on the film or CCD detector. Real lenses do not achieve this and the amount of light reaching the edge of the detector is less than the amount received by the centre. If this *vignetting* effect is not corrected it will lead to an uneven background in the final print. This is particularly troublesome in the case of a large, low contrast object such as a comet's tail since detail will be lost when you try to stretch the final image with a high contrast. The effects of vignetting can be eliminated by good flat fielding as described in section 6.1 on page 45.

Since comets are best observed from dark sky locations and are often at their best near the horizon many people will need a portable imaging setup. Many, high quality tracking mounts are now available and an example is shown in Figure 16. For particularly bright comets air travel overseas is worthwhile so equipment must be light enough to carry onboard an aircraft.



*Figure 16 – A very portable imaging setup. This is a Sky Watcher Star Adventurer mount but other equivalent types are available.*

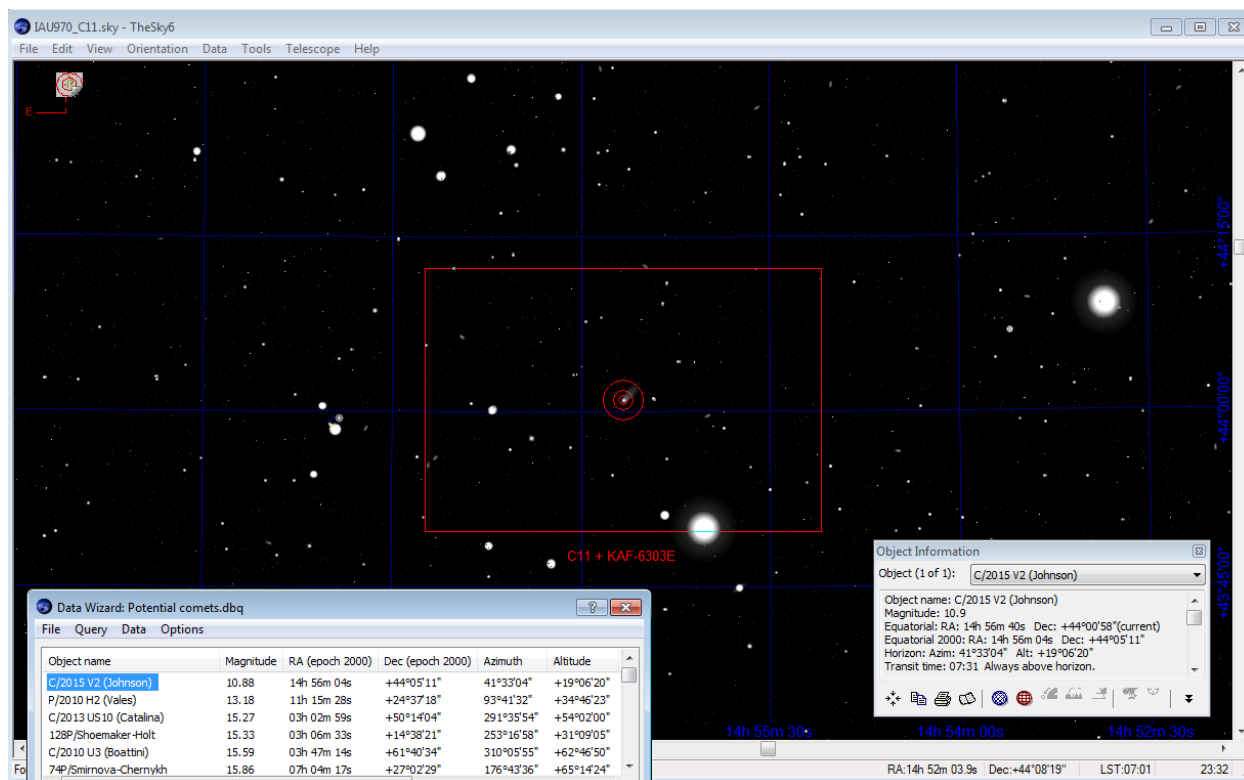


Figure 17. Go-To observing.

### 5.3 Remote observing

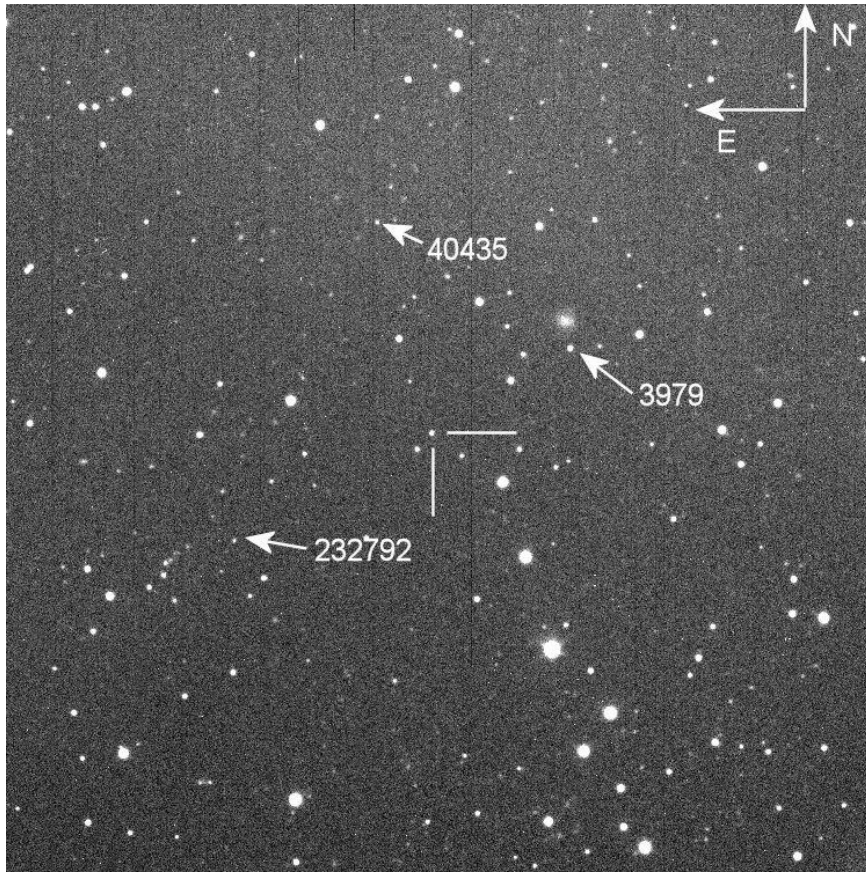
A significant advance in amateur astronomy in recent years has been the setting up and use of remotely operated or robotic telescopes. Use of such facilities is not expensive, especially when compared with the cost of setting up one's own observatory from scratch. All the sky, not just the hemisphere in which you are located, is available to robotic telescope users and not necessarily in the middle of a cold night. Unfortunately, UK-based observers are often at a disadvantage because of poor weather, light pollution in towns and cities, or because of our latitude ( $50^{\circ}$ – $56^{\circ}$  N), which prevents access to many celestial phenomena further south, and also means that our summer nights are very short.

There are a wide range of options for remote observing and some of these are described below.

One option is the Sierra Stars Observatory Network (SSON) which has telescopes located in California and Australia. Before using SSON one must register and purchase credits. Observations are scheduled as follows;

- input object data. Comets may be selected from a list
- add project title and observer name
- input data and time (if not input then job will be run at the next opportunity)
- select telescope, filter, number of times to run series, time between series

Emails will be sent to confirm a job and when imaging is complete. Images are then available for download.



Comet 174P/Echeclus, 2015 Sep 18, 0707UT, 20x20 arc mins,  
120s exp, SSON OMI 0.61m f/10 Cassegrain, FLI Proline  
PLO9000 CCD, unfiltered, R Dymock, MPC G68

Three Main Belt Asteroids can also be seen in the image

*Figure 18 – An example of a remote image taken using an SSON telescope*


It is always worth checking images to see what else might be on them other than the intended target. Three main belt asteroids appear on the image of 174P/Echeclus taken on 2015 September 18 (Figure 18)

Another popular facility is iTelescope, <http://www.itelescope.net/>. This offers the user both the opportunity to schedule images in advance or reserve time slots to take control of the telescope, the latter choice not being available with SSON. iTelescope has a wide selection of telescopes distributed between four sites around the world and operated via an online control panel as shown in Figure 19. Payment is by a monthly subscription which provides a certain number of points which can be carried over into subsequent months.



Advancing your Horizons in Astronomy ... No Network Messages

Select Action: Reservations Offline Plan Generator



**Northern Hemisphere**  
Mayhill, New Mexico, USA

T3: Closed: Day Time  
T5: Closed: Day Time  
T11: Closed: Day Time  
T14: Closed: Day Time  
T20: Closed: Day Time  
T21: Closed: Day Time

Sierra Nevada Mountains, CA, USA

T24: Closed: Day Time

Nerpio, Spain

T7: In Use: attilatoth78  
T16: Offline  
T18: Available

**Southern Hemisphere**  
Siding Spring Observatory, AU

T8: Closed: Day Time  
T9: Closed: Day Time  
T12: Closed: Day Time  
T13: Closed: Day Time  
T17: Closed: Day Time  
T27: Closed: Day Time  
T30: Closed: Day Time  
T31: Closed: Day Time  
T32: Closed: Day Time  
T33: Closed: Day Time

 itelescope.net

[Weather Information](#) [Other Links](#) [Social Media](#)

New Mexico, USA  
Sierra Nevada, USA  
Australia Spain

ITelescope.Net Website  
Video Tutorials  
Newsletter Subscription

Facebook  
Member's Club  
Twitter

[Page on Duty Engineer](#)  
[Name] .Page  
(urgent support only)

[Support](#)  
support@itelescope.net  
support.itelescope.net

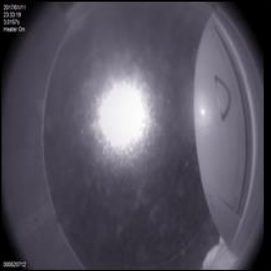
**Buy Extra Points  
View Plans**

**System Alerts and Operational Notices**

User: nickdjames Points: 579 Membership: Plan-40 (25 days) Group: None VPhot: Yes Reservations: Yes Launch-a-Plan: Yes Private FTP: Yes

**All Sky Camera**  
Not Active

**All Sky Camera**  
Not Active



**All Sky Camera**  
Not Active

**New Mexico, USA**  
MOON Alt: -4 Ill: 100% Sun: 7  
16:36, 11 Jan 2017 (UTC -7)  
Sunset: 6:02:00 PM Sunrise: 6:18:00 AM  
Moon Discount: 50%

**Siding Spring Obs, Australia**  
MOON Alt: -60 Ill: 100% Sun: 54  
10:36, 12 Jan 2017 (UTC +11)  
Sunset: 8:12 PM Sunrise: 6:11 AM  
Moon Discount: 50%

**Nerpio, Spain**  
MOON Alt: 70 Ill: 100% Sun: -71  
00:36, 12 Jan 2017 (UTC +1)  
Sunset: 7:01:00 PM Sunrise: 7:35:00 AM  
Moon Discount: 50%

**Sierra Nevada Mountains, USA**  
MOON Alt: -13 Ill: 100% Sun: 15  
15:36, 11 Jan 2017 (UTC -8)  
Sunset: 5:51:00 PM Sunrise: 6:21:00 AM  
Moon Discount: 50%

Figure 19. The iTelescope system is one of the more popular remote observing options online



## 6 PROCESSING YOUR IMAGES

### 6.1 Image calibration

Comets are usually very faint, low-contrast and diffuse objects so the coma and tail gradually merge with the background sky. Digital images can be processed to bring out the very faintest detail but to do this we must be able to correct for the various imperfections in the camera and optical system. Three types of calibration frame are required. A *flat field* is a short exposure of an evenly illuminated field (often the bright twilight sky) taken with the camera and optical arrangement that will be used to image the comet. If the camera and telescope were perfect, every pixel would have the same brightness value. In fact a variation of sensitivity from pixel to pixel means that the flat field contains a range of brightness values. In addition the telescope will probably vignette the field and so the amount of light falling on the chip will fall off towards the edges. Finally, unless the camera is perfectly clean, there will be specks of dust which will cast shadows on the chip. The flat field records the variations in pixel sensitivity due to these effects. Flat fields are particularly important in comet imaging since the extremities of a comet's tail may be only a few percent brighter than the sky background. This is especially true if you live in an area where the light pollution is significant. If you are using filters you will need a separate flat field for each filter used.

The flat field is the most difficult calibration frame to get right. The conventional way of obtaining it is to take a short exposure of a uniformly illuminated patch of sky at twilight. You should obtain the image using the normal optical arrangement used for comet imaging and the camera should not be detached from the lens or telescope between taking the flat field and taking the comet image. The sky should be bright enough so that you can keep the exposure short (less than a few seconds) but not so bright that any part of the image is saturated. To reduce the various sources of noise in the flat field it is best to take 20 to 50 exposures of the same length that can be processed into a single frame later. This can make it rather difficult to obtain a good flat field since there is only a ten or twenty minute window during evening or morning twilight when the exposures can be made. This is especially the case if the weather is unpredictable since you may have a sudden clearing which allows you to image a comet late at night even though you had no chance to make a flat field earlier on.

There are a number of alternative ways of obtaining a flat field which do not require you to be ready during that crucial twilight window. Basically you need to arrange for a perfectly uniform illumination across the aperture of your telescope. You can make or buy a diffusing light box which fits over the front of the telescope and it allows you to obtain a flat field at any time. The difficulty is ensuring that the illumination really is uniform to the 0.1% level. A commercial solution is the Gerd Neumann flat field panel which uses an electroluminescent foil which provides a very even illumination over a large area.

The next type of frame is much easier to obtain and it can be taken just after the flat field. This is the *bias frame*. The data from most cameras is offset from zero by some fixed amount which is dependent on the readout electronics. The bias frame is a zero length exposure frame obtained with the shutter closed or telescope capped. As with the flat field take 20 or 50 bias frames for later averaging to reduce the effect of noise. Bias frames are only required if you expect to have to scale your dark frames to compensate for a difference in the temperature between taking the imaging and calibration frames.

Finally the *dark frame* is normally taken during the night near to the time that the actual comet images are obtained. This is an exposure made using the same exposure time as the comet image but with the shutter closed or the telescope capped. Since no light is allowed to fall on the sensor each pixel contains only the thermal noise associated with the exposure along with the bias offset introduced by the electronics. The sensor temperature should be

stable while the darks are being made and should ideally match the sensor temperature at the time the light frames were obtained. As with the other calibration frames take as many darks as you can in order to reduce the noise in the final dark frame.

If you are not using bias frames you should also take flat-darks. These are dark frames taken using the exposure used for the flats. In many cases the flat exposure is sufficiently short that bias and flat-dark frames are effectively the same thing.

Assuming that you are not going to scale your darks the calibration process goes as follows:

1. Generate a master flat-dark by stacking all of the individual flat-darks. Ideally this should use a statistical stacking approach which eliminates outliers (i.e. cosmic ray hits). Sigma-clip stacking is a good choice to use here.
2. Subtract the master flat-dark from the individual flats and then stack the resulting frames. If you are using twilight flats taken in a rapidly brightening or fading sky it is a good idea to normalize the median level in each frame before stacking using a sigma-clip approach. If you have switched off the drive during the period you obtained the flats the stars should be removed by the sigma-clip. The resulting clean flat frame should represent the overall system sensitivity variation from pixel to pixel.
3. Generate the dark by stacking all of the dark frames, again using a sigma-clip if possible so as to remove outliers such as cosmic rays. At this stage your software should be able to identify a small number of hot pixels which are not amenable to calibration. This hot pixel map can be used subsequently to mark these pixels as bad in the output image and, potentially, allow cosmetic corrections to be applied. In this case the final dark frame contains but the thermal noise related elements and the bias.

Calibration of individual input images then consists of subtracting the dark frame and then dividing by the normalized flat frame.

A more advanced approach which allows the darks to be scaled is to remove the bias element from the master dark but subtracting a bias frame. The dark can then be scaled for exposure and temperature changes before being re-added to the bias. This composite frame is then subtracted from the input image before division by the flat.

In all cases calibration should be done using pixel data which is stored and processed in high precision. Most cameras produce image files where each pixel is represented as a 16-bit signed integer (i.e. an integer in the range 0 to 65535) however calibration and subsequent image processing should ideally be done using 32-bit signed floating point if your software package allows this.

## **6.2 Image stacking**

A CCD or DSLR image of a comet will need to be short enough to freeze its motion against the background stars and to avoid mechanical imperfections in the telescope drive becoming visible. These short exposures, typically of around 60 to 120 seconds duration, will result in a weakly visible comet with a poor signal to noise ratio. To create a good quality image capable of displaying the coma and any faint tail with good contrast, tonal range and low noise will require more exposure time. The equivalent duration of a long exposure can be built up by taking multiple short exposures and “stacking” them together. This stacking process has the advantage of providing a way of ensuring the comet remains sharply focused whilst driving the telescope mount at a sidereal rate and not the speed and direction of the comet. Taking individual short exposures also has the advantage that the stars and the nucleus of the comet in the image will not be over exposed. The pixels recording their detail will not be saturated or overfull with electrons. As a result the star and comet images will not appear bloated and will be capable of being photometrically measured.

Most astronomical image processing software, such as IRIS, MaximDL, Pixinsight, Photoplug X7 DeepskyStacker etc contains a stacking tool. If the comet is slow moving or the combined duration of the exposures is fairly short then a stack of images with the stars as the reference points will result in a comet that is probably acceptably un-blurred. This type of stacking is the same process used by deep sky imagers when they are endeavouring to record faint nebulae or galaxies. The stacking tool uses the centroid of the image stars to precisely calculate the stacking reference points on each individual image or sub-exposure.

Many stacking tools have the facility to manually select the centroid of a single point on each sub-exposure. This process can be used to effectively “freeze” the motion of the comet against the background stars if the centre of the comet coma is selected on each frame. The stack is registered with the comet as the fixed point and the stars then become trails. This process works well for bright comets with well condensed star like coma centres. However if the coma is diffuse or very faint then there is no point like object for the software to locate.

Offset stacking needs be used where the comet is either not visible in the individual frames or is too diffuse for other stacking methods to work. Astrometrica software written by Herbert Raab has a very efficient offset stacking tool that works for any know comet. The software operates by plate solving each frame so its star positions are known to sub pixel accuracy. The stack is formed by offsetting each frame one to another by an amount determined by the speed, direction and time interval between each exposure. The software picks up the time information from the image FITS header and the comet’s movement from the Minor Planets Centre orbital elements data base.

Different types of stack combining methods can be adopted with differing results. A sum combine will simply add together all the data in each frame. This is good to produce a strong signal but includes all spurious data and noise. Average combine will take the average of the data in the stack and is probably the method most used by comet imagers. Median and other statistical combining processes will average combine the pixel information from the comet but rejects data that is not coincidental on each frame, such as the stars.

### **6.3 Image processing**

A calibrated and stacked series of sub exposures creates an image potentially containing good data but which when viewed appears almost black with just a smattering of stars across the field. If the graph of the pixel brightnesses, called the histogram, is examined the range of dark and light levels in the image can be found. Most image processing software will display this histogram. Many DSLR cameras can display the histogram of an image on their rear screen. The histogram of a typical unprocessed comet image consists of a flat graph with a thin spike. This spike holds the bulk of the comet image details. Image processing redistributes the image dynamic range so all the subtle graduations in the comet’s brightness and contrast can be viewed on a computer display or printed.

Using image “stretching” tools such as curves, Levels or Digital Development Process we can keep the background sky dark, the stars and comet centre from becoming too bright and bloated whilst significantly boosting the brightness and contrast of the midrange where our comet’s detail is hiding.

The graphics industry standard image processing software is Photoshop of which a 10 year old version CS2 can be downloaded and used free. It is a very powerful but complex piece of software of which only a small section is useful for comet image processing. Other more astronomically focused image processing software is available such as IRIS, MaximDL, Pixinsight etc.

The Curves tool available in most software allows you to vary input and output pixel brightness values across the whole image by dragging or placing control points on a graph

line depicting the full range of image pixels brightness. Comet images have a few extremely bright regions (e.g. bright stars, coma centres), some mid-range features, interesting but very faint details (e.g. tail features), and a large amount of background. The skill is to boost the contrast of the interesting details while decreasing the contrast of brightness ranges which are of lesser interest or contain little detail. Whilst doing this you should avoid "burning out" the very brightest details or "clipping" and losing details that are just above the background sky brightness. Reference to the image histogram during the process enables you to check you are satisfactorily redistributing the pixel brightness within the range of available brightnesses.

The Levels tool can be used in conjunction with Curves. Levels are used to set the black and white points in an easier and more controlled way than with Curves alone. All areas of the brightness distribution histogram outside the black and white points are effectively lost from the image. Providing these areas contain no detail then the area between black and white Levels points can be more easily stretched using Curves.

Some software processing packages contain predefined curve shapes such as Log, Gamma etc. These enable you to quickly choose a curve that suits your requirements. DDP or Digital Development Process is a type of modified gamma curve stretch where you can select the background brightness and the "break point" in the middle of the curve. This process is fast and is well suited comet images.

#### **6.4 Sky Gradient removal**

Having processed your calibrated and stacked comet image you may notice a light gradient across the image. One side of the image may appear brighter particularly if you are imaging from a light polluted site or the Moon is present in the sky. The lighter part of the image will represent the area of sky more brightly illuminated by the Moon or nearer the source of the light pollution.

Removal of this gradient will improve the appearance of the image. Gradient removal will also be necessary for some photometry tools to give accurate results. Many image processing packages such as IRIS, MaximDL and Pixinsight contain gradient removal tools. A gradient removal plug in is available for Photoshop called Gradient Xterminator written by Russel Crowman. Gradient removal works by generating a map of the background brightnesses which appears similar to a flat field used for image calibration. The background brightness map can then be subtracted from the image resulting in a gradient free image.

#### **6.5 Other processing tools**

The astronomical image processors' toolkit contains many tools. Some claim to enhance and sharpen image detail, reduce noise and even extract a moving comet from the fixed background stars and present it frozen against un-trailed stars. All these tools produce an image which may be more aesthetically pleasing than one processed with just the tools mentioned above.

However these additional tools must be used with great caution as they can misrepresent the original data and introduce artefacts. Deconvolution and extensive noise filtering could result in an image where there is little way to confirm the existence of the resulting detail the software produces.

#### **6.6 Submitting images to the section archive**

Original images are needed for the BAA archives and are often used in the Journal or Section Newsletter. Most standard image formats can be read. Where possible include details of the telescope, scale, orientation, manufacturer and type of camera, filter used, wavelength etc in the image, but if this is not possible you should write an additional text file

with this information. Where ever possible orientate your image with north at the top and east to the left so that images from different observers can be compared. In all cases include orientation and scale information in the caption or on the image.

Image files should be named as:

**comet\_yyyymmdd\_observer.jpg**

or

**comet\_yyyymmdd\_hhmm\_observer.jpg**

and auxiliary files as the same name but with .txt added so, for example

**comet\_yyyymmdd\_hhmm\_obsserver.jpg.txt.**

**comet** is either the full provisional designation, for example 2001q2 or the periodic number for example 19p

**observer** is either your full name for example shanklin, the first three letters of your name for example sha, or your ICQ id for example sha02

**yyymmdd** is year month day and **hhmm** is hour and minute

**img** is the image format, e.g gif, jpg etc.

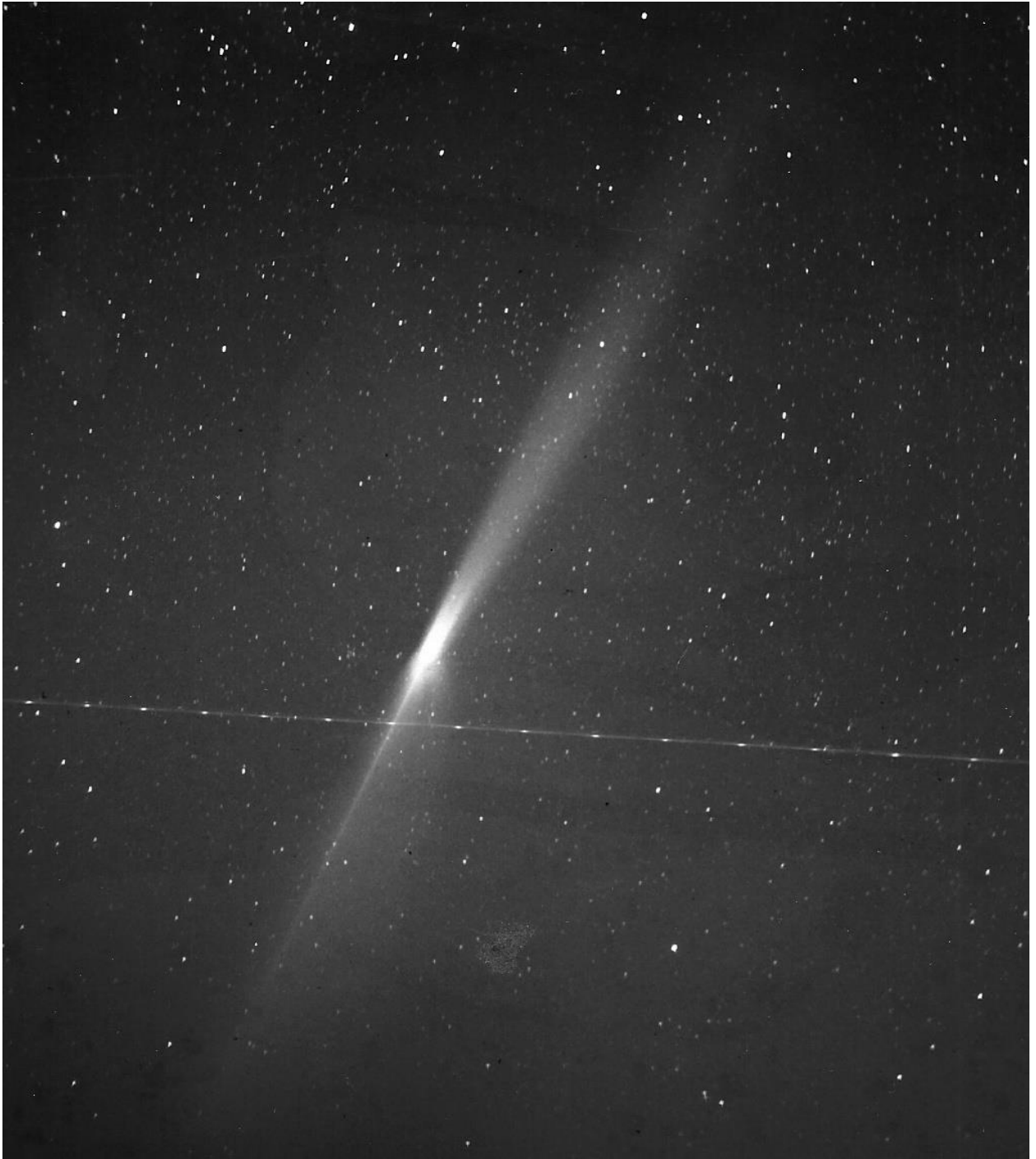
Some example images are shown in Figure 20 to Figure 22. For instance 2014q2\_20150224\_1953\_ndj.jpg is an image of C/2014 Q2 taken by Nick James at 1953UT on 2015 February 24.

Email images to [cometobs@britastro.org](mailto:cometobs@britastro.org).



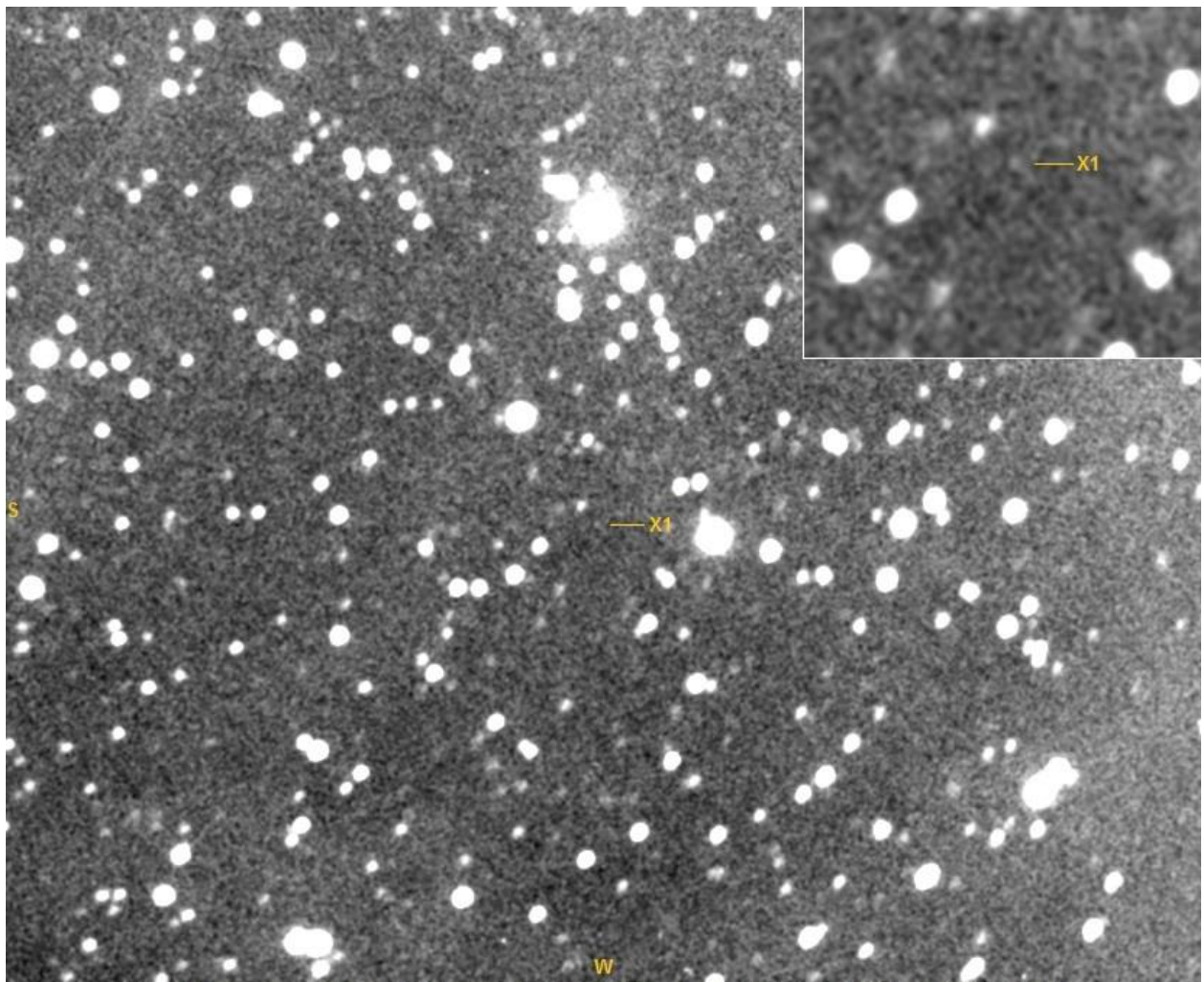
2014q2\_20150224\_1953\_ndj.jpg.txt: Image from last night. Using IRIS with an aperture of 13 arcmin diameter which just encloses the visible coma I get a mag of 5.62 using UCAC-4 reference stars. This appears to be around 0.2 mags fainter than the latest visual estimates on COBS although my coma estimate is bigger.

*Figure 20 – 2014q2\_20150224\_1953\_ndj*



*Figure 21 – 1956r1\_19570424\_waterfield*





C/2016 X1 Lemmon, m=20.4, 2016/12/27 0550-0630UT, 4x600s, 17'x13' 1.24"/pixel, 11" SCT f/6.4, STF-8300M  
Mike Olason, Denver Colorado

*Figure 22 – 2016x1\_20161227\_0550\_molason.jpg*



## 7 EXTRACTING SCIENTIFIC DATA FROM IMAGES

### 7.1 Astrometry

It is very important to define the orbit of a comet as soon as possible after its discovery. Thereafter it is necessary to continue to refine the orbit so that we can improve our knowledge of the comet's history and make accurate predictions about where it will be seen in the future. With the increasing incidence of spacecraft being sent to study comets the ability to predict accurately where a comet will be at some future date becomes even more critical. Finally, in very rare instances, it may be that a comet makes a close fly-by of the Earth so there might be some risk of a collision in the future. It is only by accurately characterising the orbit that the level of risk can be determined.

To determine the orbit of a comet is all we need is its position and velocity at a given time. In practice it is very difficult to measure these quantities directly and almost all orbits are computed from what are called *astrometric* positions. These are accurate measurements made of the comet's position against the star background. Three well-spaced astrometric positions are usually enough to give an initial orbit. Further observation will improve the orbit over time.

Computer clocks can be very inaccurate and drifts of 30 seconds a day are common so you should make sure that you set your PC's clock accurately before starting an observing session and check it again afterwards. An even better solution is to arrange for your PC to be automatically synchronized to UTC. This can be done using a GPS dongle or via an internet time-server. The Network Time Protocol (NTP) can keep your computer synchronized to within a tenth of a second. Beware of the standard Windows configuration which only synchronizes the clock once a week. You need to adjust the settings to synchronize much more frequently than this, at least once a day and probably once every few hours.

The basic technique is to obtain an image with an exposure which is just long enough to obtain a good signal-to-noise ratio at the brightest part of the coma but avoiding any overexposure. The UTC times of the start and end of the exposure should be recorded to an accuracy of at least one second. The position of the comet is then obtained by measuring its X-Y coordinates on the image along with the coordinates of a number of *catalogue stars*. These stars are selected since they have accurately known positions. taken from an astrometric catalogue and they can be used to determine what are known as the *plate constants* of the system. These constants define how the X-Y coordinates of objects in the image relate to real RA and Dec. positions on the sky and so they can be used, along with the measured coordinates, to determine the comet's position.

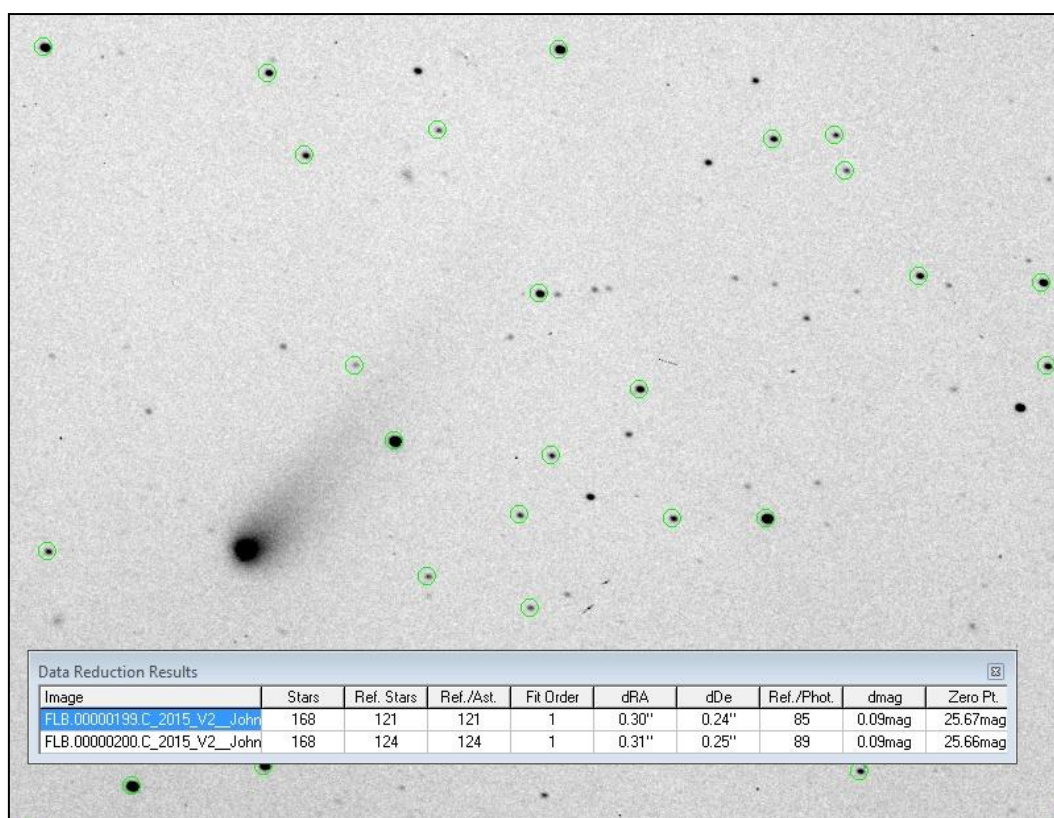


Figure 23 - A screenshot showing an image of C/2015 V2 (Johnson) being reduced using Astrometrica. The circled stars have been identified and correlated with stars in the UCAC-4 catalogue. A total of 121 stars are used in the astrometric reduction and these have RMS position errors of 0".30 in RA and 0".24 in Dec.

Modern technology has made this all relatively straightforward and most observers use a programme called *Astrometrica* to do all of the hard work. This is maintained by Herbert Raab and it is available for download from <http://www.astrometrica.at>. It can be used for evaluation for 90 days without having to register it. The registration cost is a very reasonable €25.

Most astrometric software will directly produce data in a format which is suitable for e-mailing to the Minor Planet Center (MPC). An example of this format is shown in chapter 6. When you report positions you should include your observatory's latitude, longitude and height above sea level to an accuracy of better than 100m. If your astrometry is of good quality the MPC will allocate you a three-figure observatory code which can be used in future reports.

An example reduction using Astrometrica is shown in Figure 23. The software completely automates the process by first detecting all of the stars in the image and then comparing them against the selected catalogue. In order for it to do this you need to tell it the approximate scale and orientation of the image along with approximate centre coordinates. Astrometrica uses a centroiding algorithm to determine the coordinates of each object to a fraction of a pixel and the stars which correspond to catalogue objects are then used to determine the plate-constants of the image. A number of catalogues are available and UCAC-4 is currently the best one for general use although the Gaia DR1 catalogue is now available and is supported by the latest build of Astrometrica.

Once it has the plate constants Astrometrica is ready to perform astrometry on any object in the field. This is as simple as moving the mouse cursor over the object and clicking. The program computes the centroid of the object and converts it directly to RA and Dec (Figure 24).

Observations should be submitted in the standard format recommended by the Minor Planet Center (MPC). An example of this format is shown in Figure 25 and this is generated automatically by Astrometrica. More details of the report format can be found at:

<http://cfa-www.harvard.edu/iau/info/Astrometry.html>

You need to make sure that any E-mails containing astrometric data are sent as plain text. Do not use HTML, MIME, Word files or any other format.

In order to use your astrometry the MPC also requires knowledge of your position on the Earth accurate to a few tens of metres. You can obtain this information using a GPS receiver or large scale maps. Once you have submitted some good astrometry you will be allocated a three-letter observatory code so that you don't need to repeat this information each time you submit observations.

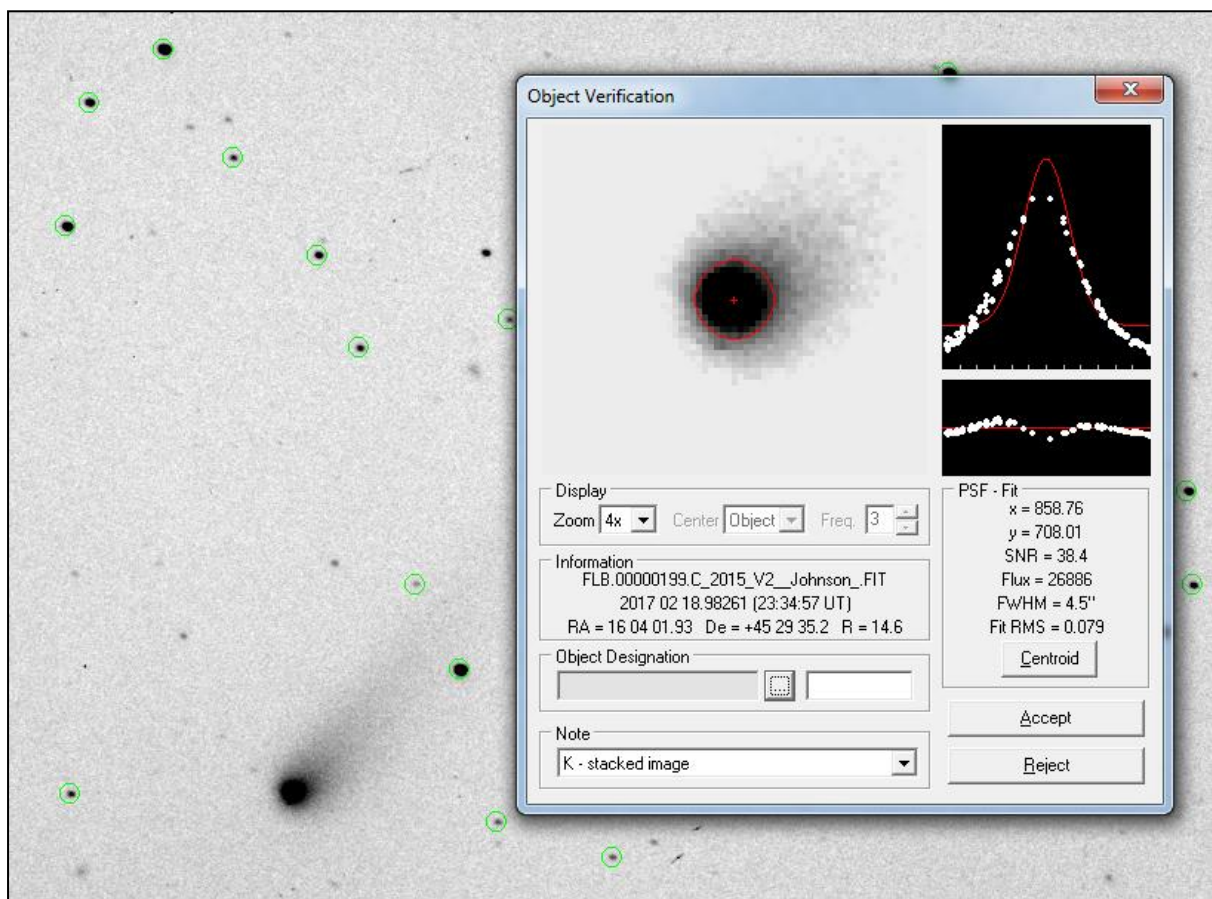


Figure 24 - A screenshot of the panel produced by Astrometrica when you click on a target object. The program fits the object's profile to a Gaussian curve and determines the X-Y coordinates of the centroid. These are then converted to RA and Dec.

```

COD 970
OBS N. James
TEL 0.28-m f/10 Schmidt-Cassegrain + CCD
ACK MPCReport file updated 2016.12.28 22:03:22
AC2 ndj@nickdjames.com
NET UCAC-4
    CK13U10S KC2016 12 22.87822 03 22 47.19 +53 19 11.4      17.4 N      970
    CK13U10S KC2016 12 22.88506 03 22 46.63 +53 19 07.7      17.4 N      970
----- end -----

```

Figure 25 – MPC 80 column astrometry format

## 7.2 Getting an MPC code

Whereas an MPC observatory code is not needed to submit comet observations in ICQ format to, for example, the Comet Observation database (COBS) it is required for submission of observations to the MPC. It is important to follow the instructions in the ‘Guide to Minor Body Astrometry’ on the MPC website:

<http://www.minorplanetcenter.net/iau/info/Astrometry.html>

An outline of the procedure is given here. It should be noted that the code applies to a specific telescope and site.

To quote from the above mentioned guide; ‘you should observe a number of low-numbered minor planets each on pairs of nearby nights. Report two or three observations of each object from each night: do not report single positions per night. We will check these positions and advise you on their quality. As a general rule we advise you to observe objects with numbers in the range (400) to (40000). In addition, you should try and observe objects of various magnitudes. If your site does not have an observatory code, one will be assigned upon acceptance of your initial submission’.

A typical set of asteroids might include; (403) Cyane, (591) Irmgard, (1040) Klumpkea, (1468) Zomba, (1719) Jens, (3259) Brownlee with magnitudes between 13 and 16. It may take several days or even a few weeks to complete all the required observations so it is advantageous to keep an eye on the medium range weather forecasts. Choosing asteroids in the eastern sky helps to increase your chances of completing your imaging before they disappear over the western horizon.

Imaging, calibration, astrometry and photometry are described elsewhere in this Observing Guide so are not duplicated here except to emphasise the use of Astrometrica together with the UCAC-4 catalogue. Since the targets have well defined orbits it is worthwhile comparing your results with, for example, an ephemeris obtained from the MPC. Astrometric measurements can also be plotted using Guide which will show up any obvious outliers.

Astrometrica will generate reports in the required format and can be set up to send those reports to the MPC. A typical report is shown below.

```

COD XXX
OBS R.Dymock
MEA R.Dymock
TEL 0.3-m f/5.9 reflector + CCD
ACK MPCReport file updated 2008.12.09 14:45:21
AC2 roger.dymock@ntlworld.com
NET UCAC-4
00941      C2008 12 07.70371 07 28 46.59 +17 25 54.9      15.8V      XXX
00941      C2008 12 08.66792 07 48 38.62 +17 43 33.8      15.4V      XXX
00941      C2008 12 08.67245 07 48 44.10 +17 43 36.8      15.4V      XXX
00941      C2008 12 08.67695 07 48 49.64 +17 43 41.5      15.2V      XXX
00941      C2008 12 08.68144 07 48 55.27 +17 43 45.3      15.2V      XXX

```

The first time observations are reported additional information, which may be submitted using the COM prefix on each line, is required by the MPC i.e.

- Postal address
- Observatory name and site
- Observatory position: longitude, latitude, height above sea level and source of co-ordinates. The MPC recommend using Google Earth
- Details of telescope set-up.

A more detailed description can be found on the Project Alcock website at <http://www.britastro.org/projectalcock/>

### 7.3 Photometry

From the very beginning of the BAA Comet Section visual observers have been estimating the total magnitudes of comets using a number of methods (section 3.7). These estimates are used to generate light curves which tell us a lot about the physical characteristics of the comet nucleus and help us predict what the magnitude will be in the future.

The visual total magnitude is defined as the total amount of light coming from the comet's coma. Brighter comets are generally estimated using smaller optical aid so that the full dimensions of the coma are seen. These magnitude estimates are submitted along with other information in the ICQ (International Comet Quarterly) format and can be used to generate lightcurves and to estimate the magnitude parameters of a particular comet. The COBS database is the current recommended repository for this information. The website address is given in section 9.1.

Estimating a comet's magnitude from images is not straightforward since a comet is a diffuse object rather than a point source. In addition to astrometry Astrometrica (section 7.1) also calculates a magnitude but, for larger or brighter comets, this is often much fainter than the actual magnitude since the photometric aperture is small compared to the comet's apparent diameter.

The basic photometric approach is straightforward. We start with a CCD image which has been calibrated as described in section 6.1. In the calibrated image the value of each pixel (the *count*) will be made up of a contribution from the object and a contribution from the sky. The first step is to accurately determine the mean sky count so that it can be subtracted from the pixel counts to leave a contribution which is dependent only on the object. Once we have done this we can determine the *instrumental magnitude* of the target object by adding up the counts for all of the pixels which fall within an aperture of defined diameter. This can then be converted into a true magnitude by using the stars in the field of view as a reference to determine the image's magnitude zero point.

A second problem involves how different cameras respond to the light from the comet. The main emission from faint comets comes from diatomic molecules of carbon, C<sub>2</sub>. This molecule has several emission lines over the visual spectrum in groups called the Swan bands. The main lines are at 515nm and 560nm but other lines exist. Different camera sensors have a different relative responses to different colours of light. The result of this is that you would get a different magnitude depending on which sensor you use which could be a problem for analysts. This is obviously unsatisfactory and to avoid it you must ensure that your camera response is standardized. One option is to place a filter in the light-path so that the overall response is standardized.

The standard colour bands used for amateur photometry are called UBVR and I for ultraviolet, blue, visual, red and infra-red. V-band photometry is the most common since this approximates to response of the dark-adapted eye. The extended red response of CCD

cameras makes them particularly suitable for R-band photometry as well. In normal circumstances these filters are mounted in a filter wheel so that different ones can be placed in the light path during an observing session. Remember to take flat fields for each filter that you use so that the images in each band can be calibrated.

Given that there are now many more imagers than visual observers we would like to find an easy way that imagers can extract Visual Equivalent Magnitudes (VEM) from their data. In principle this is relatively straightforward. A determination of the VEM requires that we count all of the light arriving from the coma to get an instrumental magnitude. We can then turn this into a real magnitude by determining the magnitude zero point of the image using a catalogue containing photometric reference stars. Ideally, to correspond to a visual magnitude, the overall response of the imaging system should be approximately that of the human eye.

Counting all of the light in the coma is complicated for two reasons:

1. We need to make a very accurate estimate of the sky background from the image so that the count contribution from the sky can be removed from the measurement. The sky background estimate is also important to get an accurate determination of the coma diameter.
2. We need to ignore the contribution from stars within the photometric aperture since this could otherwise significantly skew the estimate.

Visual observers somehow manage to do this very well by instinct and experience. Any software program designed to do this reduction must do the same by some kind of objective, repeatable algorithm.

One approach to producing a VEM is the method that was previously adopted by the section. This uses a combination of three programs: Astrometrica, Focas and kphot. In this method the magnitude of the coma is measured in six concentric photometric apertures of radii 5.6 – 33.6 arcsec. As the photometric aperture increases the estimated magnitude will also increase since more of the coma is included. The measurements in consecutive apertures allow us to determine a growth curve which defines the increase in counts as the aperture size increases. If the coma is smaller than the maximum radius aperture (and the sky has been estimated correctly) the growth curve should flatten out at large radius. If not the growth trend will still be brightening even at the largest aperture. The six measurements from Focas are then used by kphot. This program assumes a particular physical model which predicts how brightness changes with radius and it fits the measured growth curve to an example coma. Using the curve fit parameters it can extrapolate the total magnitude. This works well as long as the coma is reasonably small and the camera field of view is considerably larger than the coma diameter so that the sky estimate is accurate. The method fails if the coma is large compared to the FoV or the photometric apertures or if any bright stars are included in the concentric apertures since they will disturb the growth curve and lead to an incorrect extrapolation.

This method is no longer recommended due to problems with the extrapolation.

An alternative approach is to measure the light in the coma using a photometric aperture which is large enough that it includes the entire coma. For this to be effective it is necessary to accurately estimate the sky background level and to remove the light contributed by the background stars in the photometric aperture. To obtain a good sky estimate the image field of view must be considerably larger than the actual apparent coma diameter so, for large, bright comets a short focal length and a DSLR are ideal. The main problem with this method involves the removal of the stars before the magnitude estimate is performed. There are some ways of doing this but they are often difficult to use.



The comet section has developed a tool called comphot which can be used to obtain an estimate of the total magnitude of a comet. It will run on Windows and Linux systems and it is available from:

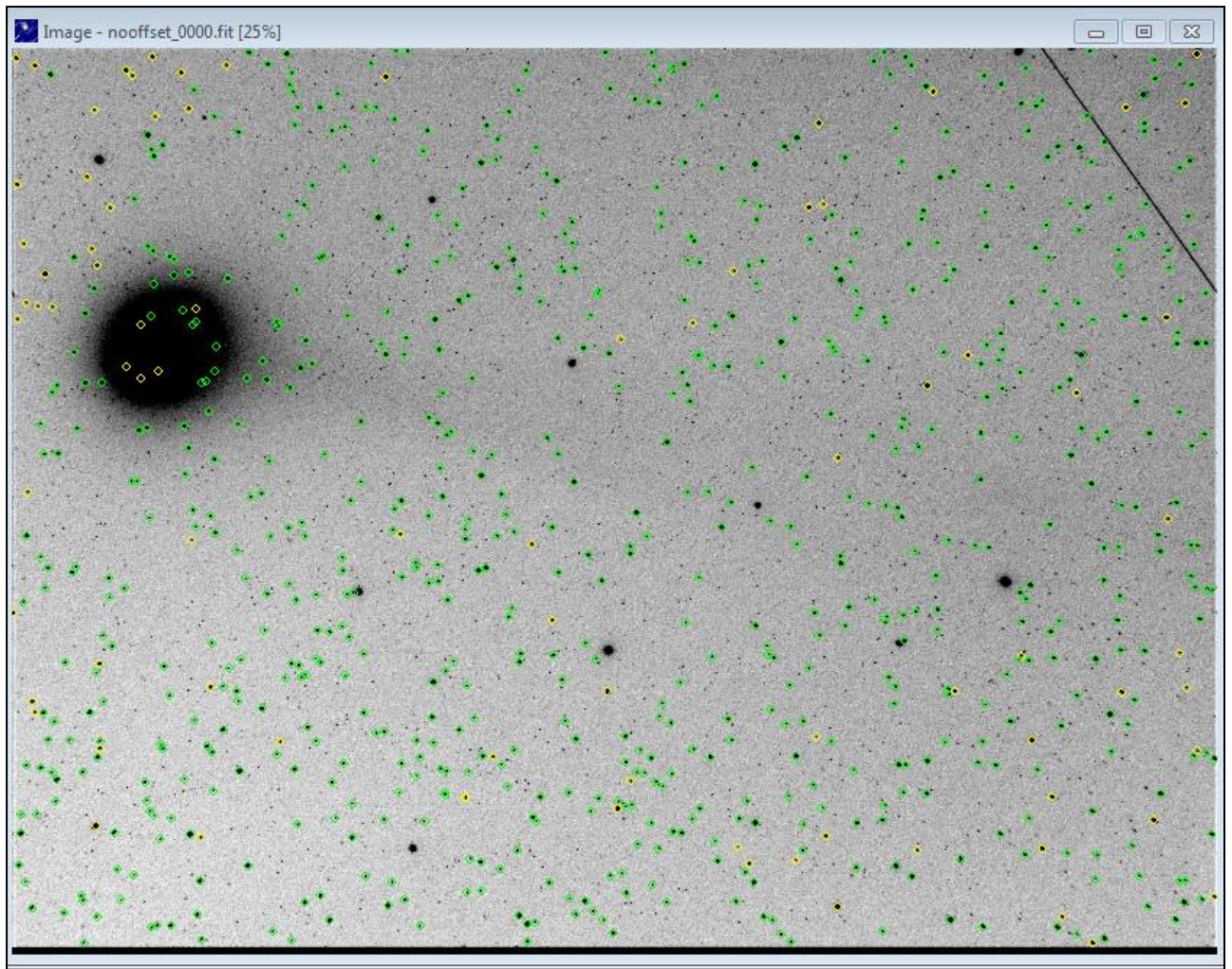
<http://www.nickdjames.com/comphot/>

The approach is based on measuring the total counts in an aperture which matches the coma diameter. The software requires two stacks for each comet:

1. A stack which is aligned on the stars and which is used to determine the magnitude zero point using a defined catalogue.
2. A stack which is aligned on the comet's motion. This will have the same zero point as the first stack but the comet's motion will be frozen so that the photometric count in the coma aperture can be determined.

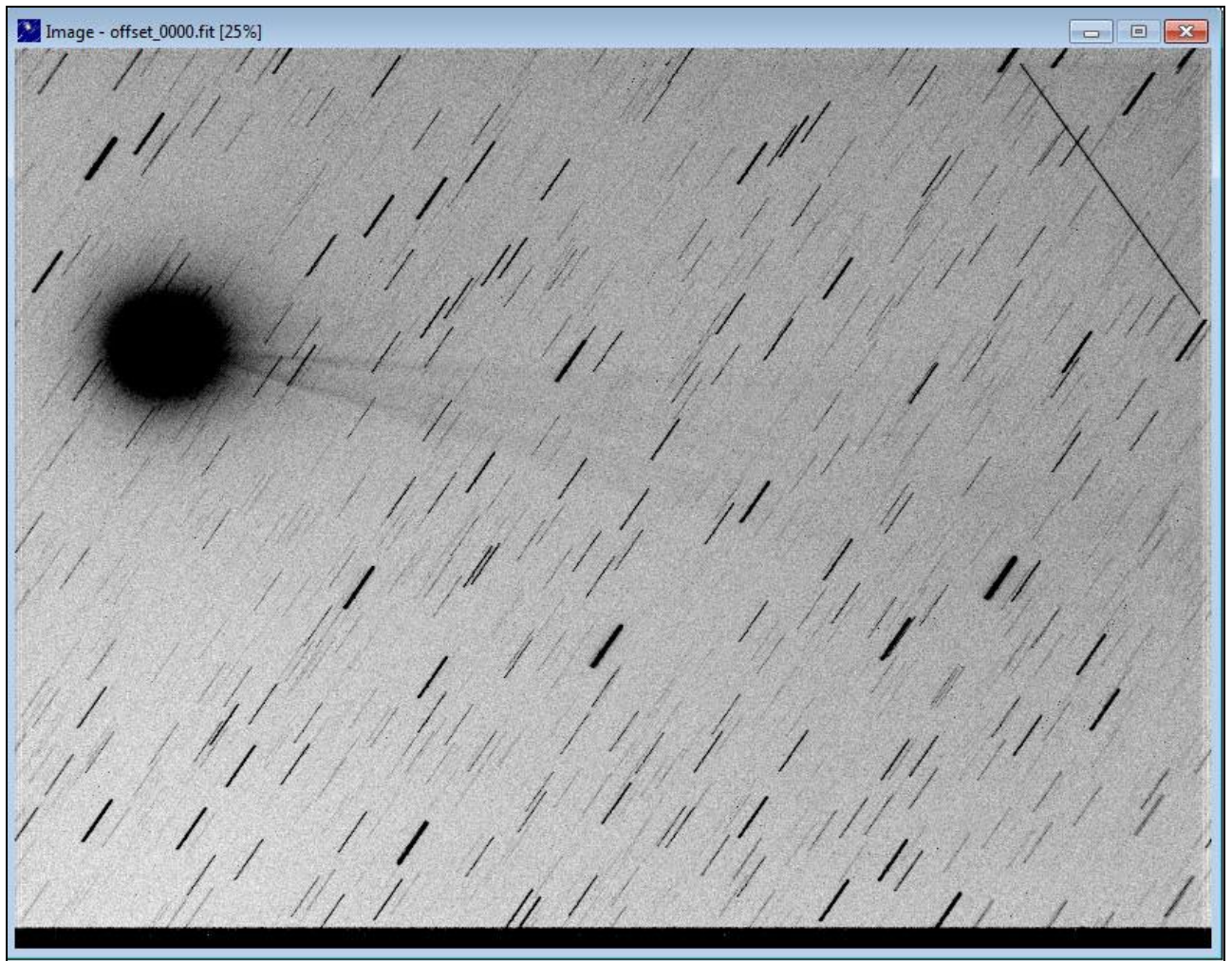
The program first makes an estimate of the sky background using a median estimator. This requires that the coma occupies only a relatively small part of the field of view. To automate this approach it is necessary to have a very robust method for estimating the sky background. As part of this it is important that the sky background in the measured image is flat so accurate flat fielding and gradient removal is necessary prior to performing the measurement. Once the sky background has been determined the program estimates the noise in the image as the first stage in setting a threshold for detection of the limits of the coma. The estimated diameter of the coma is then used to set the photometric aperture size.

Since the photometric aperture may contain stars in addition to the comet we need to remove them in some way. A simple way of removing the stars is to use a statistical approach which assumes that the coma is essentially rotationally symmetric about the photocentre. In this approach we divide the photometric aperture into a set of concentric annuli centred on the photocentre. In each annulus we determine the median count. The median is a statistical average which corresponds to the middle value in a sorted list of values from the smallest to largest. It has the advantage that it is not biased by occasional outliers such as the stars which appear in the annulus. Effectively the stars are ignored in the median estimation. The total coma count is then the sum of all of the median counts in the different annuli. This appears to be an effective approach since the comae of most comets are symmetrical around the photocentre.

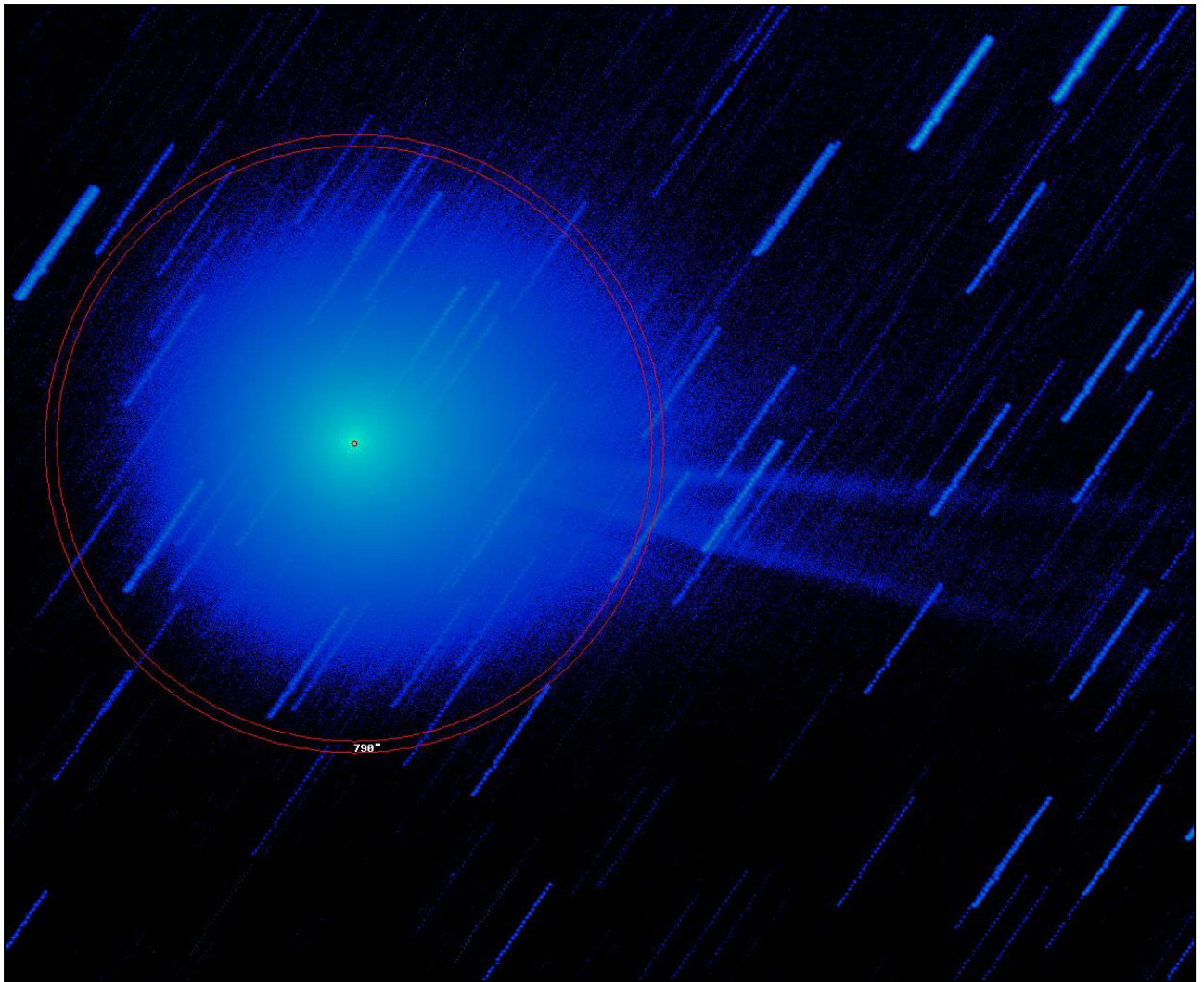


*Figure 26* - Example stack aligned on stars. C/2014 Q2. 2015 January 15, 20:53. 18x120s. FoV 143'x108'. Estimated zero point of this frame using UCAC-4, R mags = 23.01.





*Figure 27* - The same stack aligned on the comet. This is the full frame used for VEM measurement.



*Figure 28* - Detail of the stacked frame. The software has estimated and removed the sky background and has estimated the coma radius (and hence photometric aperture size) at 790 arcsec. This is a colour coded log stretch with pixels below the noise threshold set to zero. The photometric aperture size is shown as the inner red circle. Note that there are a large number of trailed stars in the aperture. The estimated magnitude in this aperture is 4.18. The mean of the 23 COBS visual estimates on this date is 4.20 with an RMS scatter of 0.41.

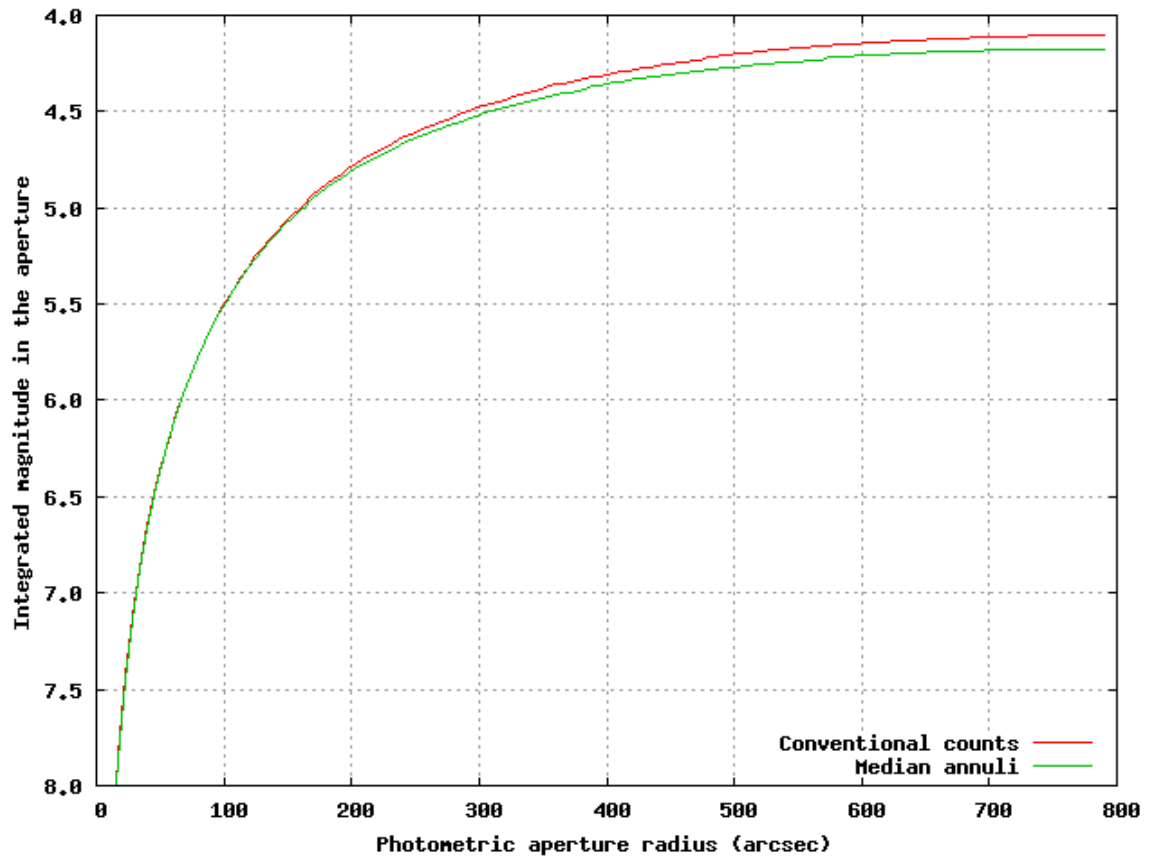
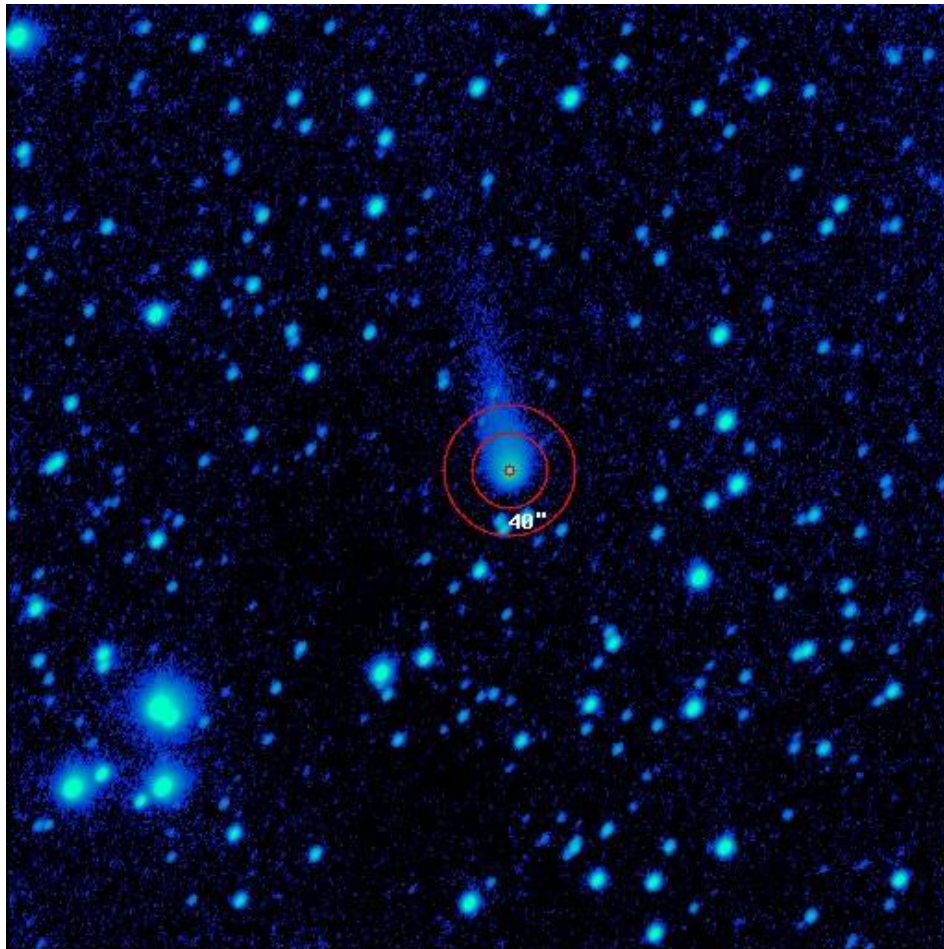


Figure 29 - A plot of the estimated integrated magnitude against aperture radius for the C/2014 Q2 image out to the 790 arcsec estimated coma diameter. The median curve (green) ignores stars and has converged to a magnitude of 4.18. The conventional (red) curve is still increasing due to the ever increasing number of stars in the aperture.





```
# Date: 2015-12-06T20:20:47, Exposure: 360.0 s
# Telescope: Unknown, Camera: SBIG ST-9 Dual CCD Camera
# Observer: Unknown
# Object: C_2014_W2_PANSTARRS
# Scale: 1.98 "/pix, FoV 16.9x16.9 arcmin, PA: -1.6 deg, ZP: 26.42 mag
# Sky background before normalization: 2088.4
# Sky background from fixed stack: 2088.4
# Residual sky background in offset stack: -0.1, RMS sky 20.6
# Centroid at 272 252, Max pixel is 3600.0
# SKY: 10.0 (6 -> 21) 1200 0 50.1
# SKY: 40.0 (21 -> 36) 2628 0 8.6
# Sky estimation annulus inner radius 40.0 arcsec, skylevel 8.6
# Total pixels requested but outside frame: 0
10x10 20x20 30x30 40x40 50x50 60x60
14.43 13.63 13.33 13.17 13.08 13.02 # Counts
14.43 13.70 13.39 13.25 13.20 13.17 # Median annuli
Total integrated magnitude: 13.15 (radius 45.1 arcsec)
```

*Figure 30* - Example result for a much fainter comet in a narrow field. This is an image of C/2014 W2 obtained by Denis Buczynski. This shows the output of the software which includes a Focas-like set of multi-box magnitude measurements. Note that the median approach leads to a 60x60 estimate which is around 0.15 mag fainter than the normal approach. This is because the median ignores faint stars in the aperture. The mean of the 7 visual observations in COBS around this date is 12.4 with an RMS scatter of 0.9.

## 7.4 Monitoring dust production

The rate of dust production of a nucleus and how this evolves through an apparition can tell us a lot about a comet. The Cometary Archive for Af(rho) (CARA) is a central reporting point for these observations. The goal of this amateur project is to develop a standardized observing and reduction method for CCD comet imaging and photometry of comets using small and medium size telescopes.

This project aims to extract additional information from CCD digital images over and above the usual astrometry and photometry. The data submitted by amateur astronomers are entered in to a database in a format ready to be used for a scientific analysis. The basic method also allows high quality images to be acquired which can be used for morphological investigations. Data acquired by amateur astronomers are on an average less accurate than the ones obtained by professionals but can complement the latter by continuous monitoring of specific targets.

Measurements are taken using photometric filters with pass-bands usually dominated by the reflected sunlight (red and near infrared wavelengths). Instead of classical total magnitude the Af(rho) or Afp quantity is calculated by means of differential aperture photometry using Wafrho software developed by the CARA group. Figure 31 shows a comet surrounded by rectangles spaced at 10000km at the distance of the comet. Afp is a quantity largely used by professional astronomers to study dust in cometary comae. The results of this program have been widely checked against professional data and show fairly good agreement.

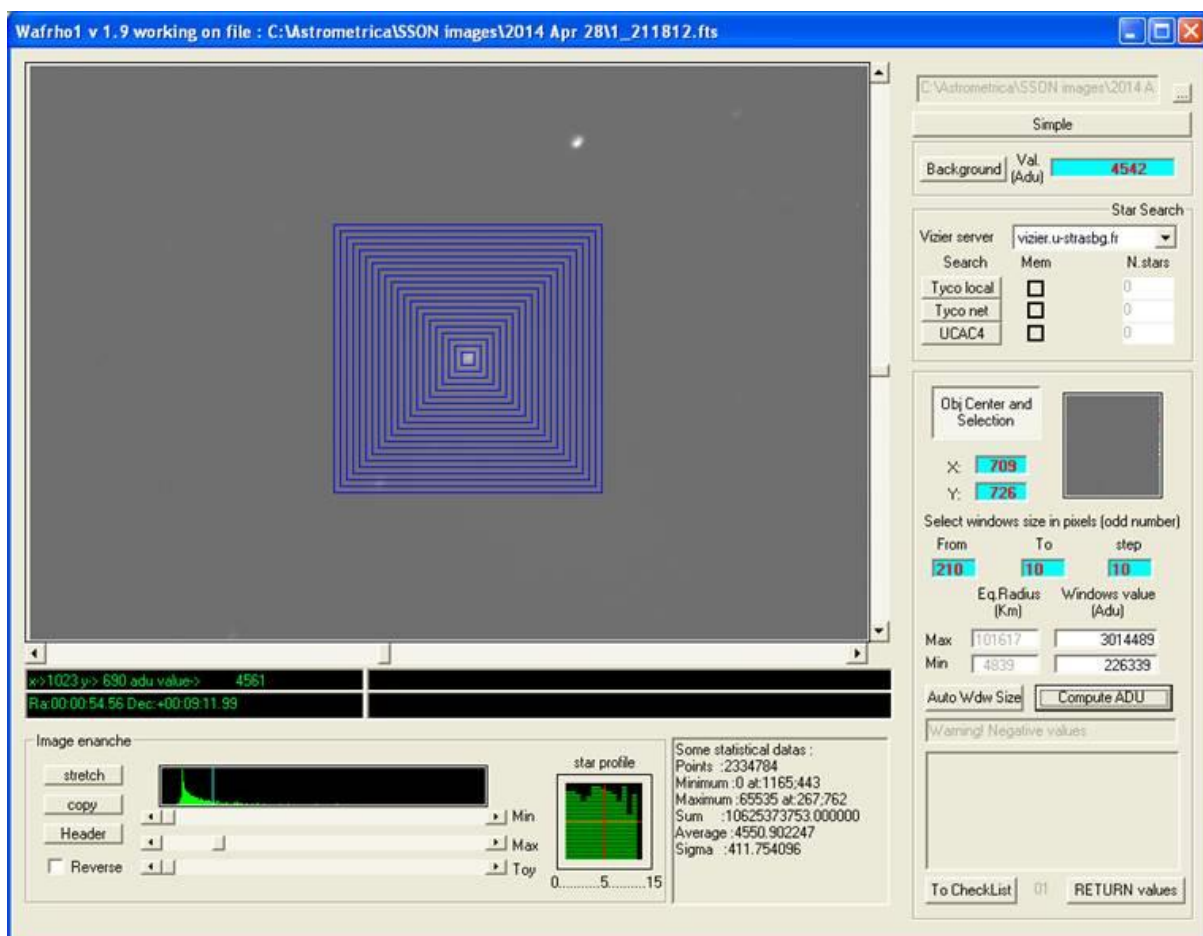


Figure 31. Wafrho software used by the CARA group for dust production measurement

Potential participants should first read the project policy at <http://cara.uai.it/policy> and then complete the form on the CARA website at <http://cara.uai.it/contact>

## 7.5 Spectroscopy

Direct measurements of the chemical species in the comet's coma can be made through spectroscopy. This is an area that has advanced rapidly in the past few years and amateurs now have access to high quality spectrographs from a number of sources. The BAA is

running a spectroscopy initiative to encourage observers and a lively discussion can be found online at <https://britastro.org/forum/143>.

The spectrum shown in Figure 32 was obtained by David Boyd. It shows the various molecules present in the coma of C/2013 US10. David writes:

*Tracking was done by putting the centre of the coma in the slit and guiding on that. It works fine provided the comet is bright enough. That's probably why I don't have more examples! Subtracting the sky background using the spectrum images of the comet can be difficult if the coma is wider than the slit as there is then no clear sky, in which case a separate spectrum of blank sky nearby can be used. Correction for equipment and atmospheric losses is done in the usual way by taking spectra of a nearby A-type star with a known spectrum at the same altitude as the comet.*

<http://www.spectro-aras.com/forum/viewtopic.php?f=6&t=1045>

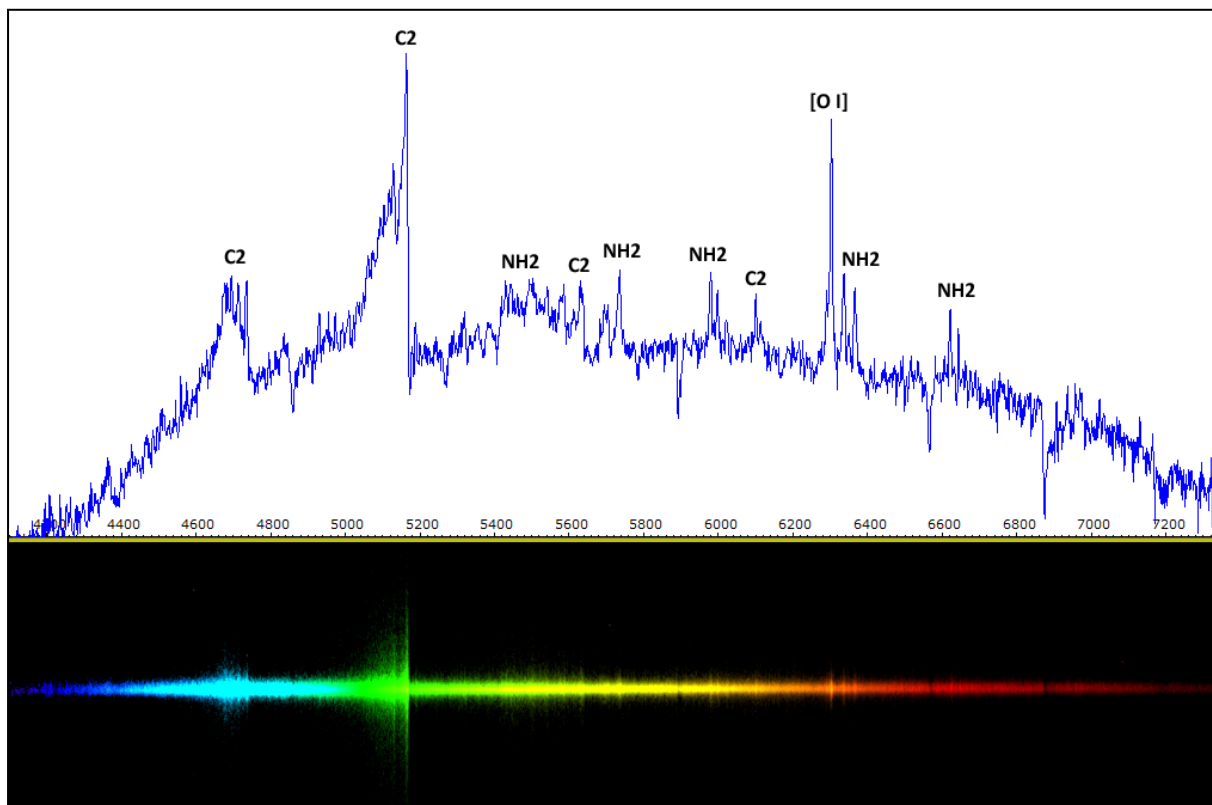


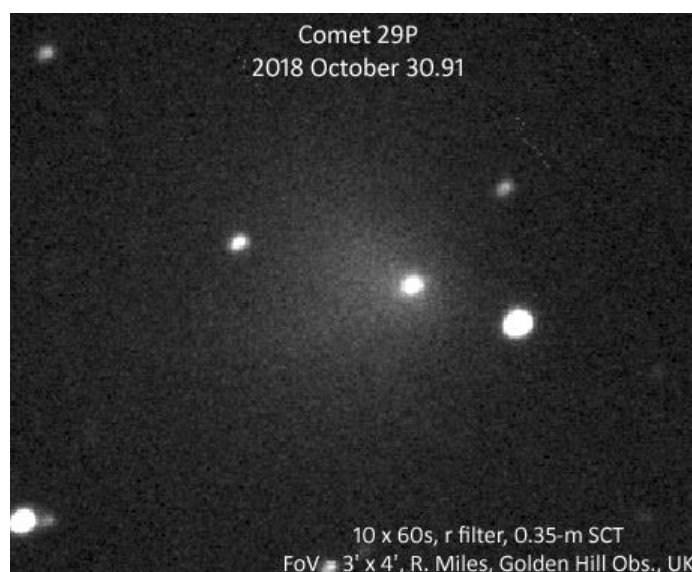
Figure 32. A spectrum of C/2013 US10 (Catalina) recorded by David Boyd on 2016 January 19.992 UT. LISA spectrograph, 23 micron slit, 0.28-m SCT at f/5, SXVR-H694 CCD, SX-EX guider, Losmandy G-11 mount. Total integration 12x300s.

## 7.6 Monitoring 29P/Schwassmann-Wachmann

### 7.6.1 Background

Of all the known objects in the Solar System, **Comet 29P/S-W** seems to be the least well-understood in that it is in a continuous state of activity, intermittently exhibiting single, double or multiple outbursts quite unlike any other comet. The name '**comet**' may mislead you to think it makes the occasional close visit to our neck of the woods and becomes active as it nears the

Sun, sporting a tail as it does so. The reality couldn't be much further from this! Here's an image showing its unusual appearance:



*Figure 33 - Image of Comet 29P/Schwassmann-Wachmann*

Here you can see a diffuse coma, the result of a series of multiple outbursts that ended 3 weeks earlier, together with a bright stellar 'nucleus' generated by a new outburst that occurred just 36 hours before the featured image was captured.

Researchers believe this object has remained in the trans-Neptunian region as an inert body for billions of years, before more recently being gravitationally perturbed by Neptune, Uranus, etc. and that it is now displaying intermittent outbursts, typically 10 per year, whilst temporarily trapped in a near-circular orbit between the giant planets, Jupiter and Saturn. See how its current orbit compares:

Object	Semimajor axis (AU)	Orbital eccentricity	Orbital inclination (deg)	Orbital period (yr)
Jupiter	5.20	0.049	1.3	11.86
<b>29P/S-W1</b>	<b>5.99</b>	<b>0.045</b>	<b>9.4</b>	<b>14.66</b>
Saturn	9.58	0.057	2.5	29.46

Although vastly smaller than the planets, **29P/S-W1** is very much larger than a typical comet and even larger than Comet Hale-Bopp. Being much more distant than main-belt asteroids, the apparition of this 'mini-planet' comes around every 392 days (rather like Jupiter does) and it is visible far enough from the Sun in the sky for ~310 days at a stretch. Given it is visible for about 80% of the time, it is an ideal observing target and our aim is to monitor its activity in as much detail as possible to better understand its true nature. How then do we go about this?

### 7.6.2 How to observe comet 29P

You will need a fairly large telescope, say at least 15-cm aperture (the larger the better!) and a focal length of >100 cm, as well as an image scale for your camera of preferably <2.0 "/pixel. Use a monochrome camera, and take a series of exposures using either no filter, a Luminance filter, or a red filter. I like to use an exposure time of 60 sec but if your mount does not track well then shorten the duration to say 20 or 30 sec as the objective is to stack the images to create a higher quality stacked frame for measuring.



### 7.6.3 Stacking individual frames

As to how many images you can stack without undue trailing, that depends on the apparent rate of motion of the comet across the sky, which never exceeds 0.52 "/min, as well as the apparent size of stars recorded by your camera. If the atmosphere is fairly steady, the latter may typically be about 2.5" in size (called the **Full-Width at Half Maximum** intensity, or FWHM). The advice here when stacking is not to trail the comet or stars by more than 1 x FWHM, which means all of the tracked frames should span a time of no more than  $2.5/0.52 = 4.8$  minutes in the worst case, i.e. say 4 x 60 sec stacks. **Now this is important:** you should check what the apparent speed of 29P on the date you observed before stacking frames. You can do this by going to the Minor Planet Ephemeris Service at: <https://www.minorplanetcenter.net/iau/MPEph/MPEph.html>

Enter '**29P**' in the box, and the date (e.g. in format, **YYYY MM DD**), in the 'Ephemeris start date' box, and '**1**' in the 'Number of dates to output' box. Then click on 'Get ephemerides/HTML page' and you will see the values you need under 'Sky Motion' in units of "/min as well as the direction (P.A.) of motion in degrees.

*By taking the trouble to find out the apparent speed and direction the comet moves, allows you to stack your frames in a cleverer way than most people adopt!*

Use stacking software that permits you to enter the apparent motion and P.A. direction – Herbert Raab's software **Astrometrica** is a good choice for doing this, as well as for plate solving and making astrometric and photometric measurements. (*Astrometrica* has a tutorial option to get you started using the software). The '**trick**' now is to track and stack at **ONE HALF** the apparent speed in the **SAME** P.A. direction as the moving object. This then trails both the mover (29P in this case) and the stars in equal measure. So now the above scenario in 2.5" FWHM seeing is for the tracked frames to span a time of no more than  $2.5/0.26 = 9.6$  minutes in the worst case. **N.B.** This doubles the number of frames you can stack without undue trailing, and also ensures that the appearance of the moving object on the stacked image is the same as the stars, which increases the accuracy of the photometry.

Here's how you produce "tracked and stacked" frames in *Astrometrica* for subsequent analysis:

Click on 'Astrometry', 'Track & Stack...', 'Add', and then select the image frames you wish to combine to produce a good signal-to-noise stacked image for measurement. Then click on 'OK' and the software will load those frames into memory and a new dialogue box appears entitled 'Coordinates, Tracking and Stacking'. Make sure the coordinates in the 'Right Ascension' and 'Declination' boxes are close in value to those of the centres of the image frames used to stack so that the software can identify the reference stars and solve the image. Then under

**"Coordinates, Tracking and Stacking** ', 'Object Motion', 'Speed':- Enter the apparent speed of 29P in "/min **divided by 2**

**"Coordinates, Tracking and Stacking** ', 'Object Motion', 'P.A.':- Enter the direction of motion in degrees

These values are available at: <https://www.minorplanetcenter.net/iau/MPEph/MPEph.html>

**"Coordinates, Tracking and Stacking** ', 'Stacking':- Click on 'Average' then on 'OK'

You then save this "tracked and stacked" image by clicking on 'File', 'Save as FITS... ', 'Save'

N.B. For photometry, it is well worth stacking two or more images and saving the file for separate analysis. The main reason is the improved signal-to-noise in the image but also *Astrometrica* saves an accurate value for the R.A. and Dec. in the FITS header making subsequent plate solving a doddle. **[Warning:** If you try to do photometry on the initially-stacked frame, *Astrometrica* only uses the reference stars from the **first image** in the series to calibrate the



photometry (zeropoint calibration). If the sky transparency happened to vary during the time series then the first frame will not be representative of the average of all the frames.]

#### 7.6.4 Performing photometry

Although *Astrometrica* was written primarily for doing Astrometry, it has been improved over recent years and now permits Photometry to an accuracy of 0.02 magnitudes or so. To achieve this, you have to use a different Settings configuration than when reporting Astrometry. For 29P, we have standardised on some settings so that everyone's measurements are largely equivalent. Here's what is important when setting up the configuration for accurate photometry of "tracked and stacked" images of 29P:

Using ***Astrometrica Version 442*** or later, go to '**Settings**', then under the tabs:

'**Observing Site**', 'Location', 'MPC Code':- Enter the **IAU Code** of your observatory or '**XXX**' if you do not have a Code

'**CCD**', 'Time in File Header':- Usually this is set to 'Start of Exposure', but click 'Middle of Exposure' if you are using an Astrometrica-stacked frame (see below)

'**CCD**', 'CCD Chip', 'Saturation':- Enter '40000' if your max. pixel value is 65535

'**CCD**', 'Color Band':- Click 'Red (R)'. This operation ensures that the analysis yields the Cousins R magnitude, also referred to as the Rc magnitude.

'**CCD**', 'Color Band', 'Filter':- Select 'Clear/None' from the drop-down menu if you have not used a filter or have used a Clear/Luminance filter; or if you have used a red filter then click 'R (Cousins)' or 'r'(Sloan)' as appropriate. This operation ensures the filter has been identified and is logged in the Photometry file as 'C', 'R' or 'r'.

'**Program**', 'Object Detection', 'Aperture Radius':- Here you have to select the size of your photometric measuring aperture in pixels. This is a crucial step as we try to utilise a standard value for the measuring aperture in terms of arcseconds (") on the sky. Since everyone has different telescope focal lengths / cameras / binning, this means you have to know what 1 pixel in the image subtends by way of angle on the sky. This should be as close as possible to 5.65". Take my own setup, with a focal length of 2731 mm and 4.5  $\mu$ m square pixels, when I solve an image, the Log File gives a Pixel Size of 0.68", so the Aperture needed for photometry measures 8 pixels (5.44") radius. As your setup will be different, pick a number of pixels that comes in just under the standard of 5.65" if you can. (N.B. Short focal lengths may force you to use the minimum of 3 pixels radius to stay close to the optimum).

'**Program**', , 'Object Detection', 'Detection Limit':- A value of '12' is suggested to ensure that brighter stars are used in the plate solution, also speeding up the analysis in the process.

'**Program**', 'Object Detection', 'Background from':- Click on 'Aperture'

'**Program**', 'Plate Constants':- Click on 'Linear Fit'

'**Program**', 'Residuals', 'Photometric Limit':- Enter '0.15' mag

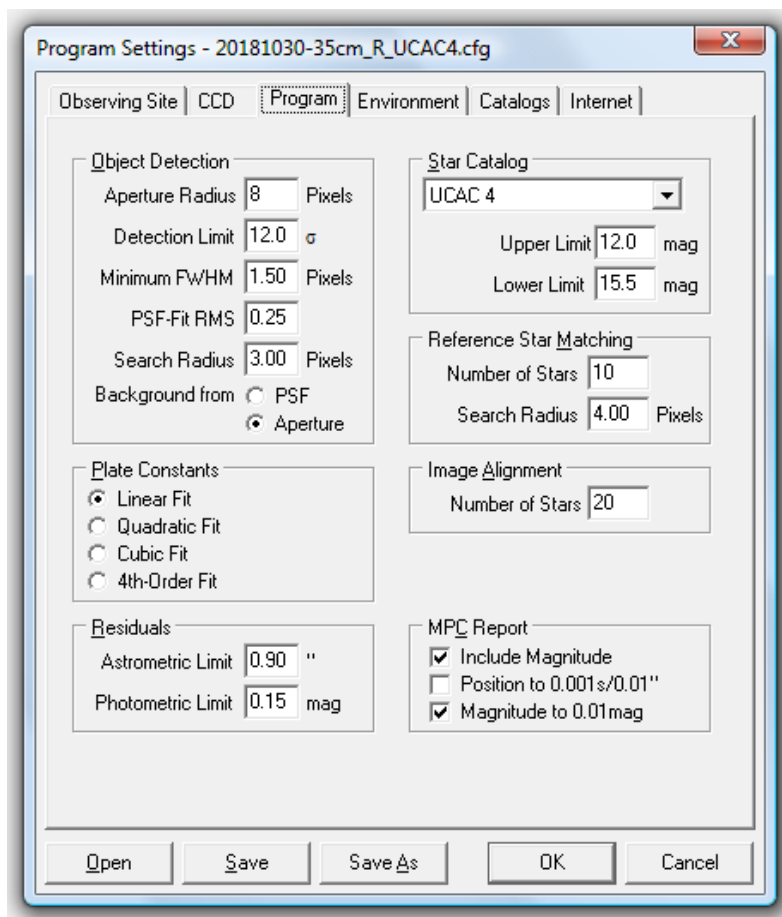


Figure 34 - Example of dialogue box in Astrometrica

'Program', 'Star Catalog':- Select 'UCAC 4' from the drop-down menu

'Program', 'Star Catalog', 'Upper Limit':- Enter '12.0' mag

'Program', 'Star Catalog', 'Lower Limit':- Enter '15.5' mag

'Program', 'Reference Star Matching', 'Number of Stars':- Enter '10'

'Program', 'MPC Report':- Click on 'Include Magnitude' and 'Magnitude to 0.01 mag'

'Environment', 'Directories':- Enter the same directory for 'CCD Images' and 'Output'

'Catalogs', 'UCAC-4':- Click on 'VizieR'

After producing one or more sets of tracked and stacked images, you can undertake photometry on each. Do first check before you start that under the tab, '**CCD**', 'Time in File Header' you have selected the 'Middle of Exposure' option when working with stacked frames. N.B. You do not need to analyse single frames or stacked images one by one, as you can load up to 25 at any one time in *Astrometrica*. Do this by selecting 'File', 'Load Images...' and selecting the stacked frames you wish to analyse. Then click on 'Astrometry', 'Data Reduction...' and 'OK'. If successful, a new dialogue box entitled 'Data Reduction Results' should appear at the lower right (this is also shown in the lower part of Figure 35).

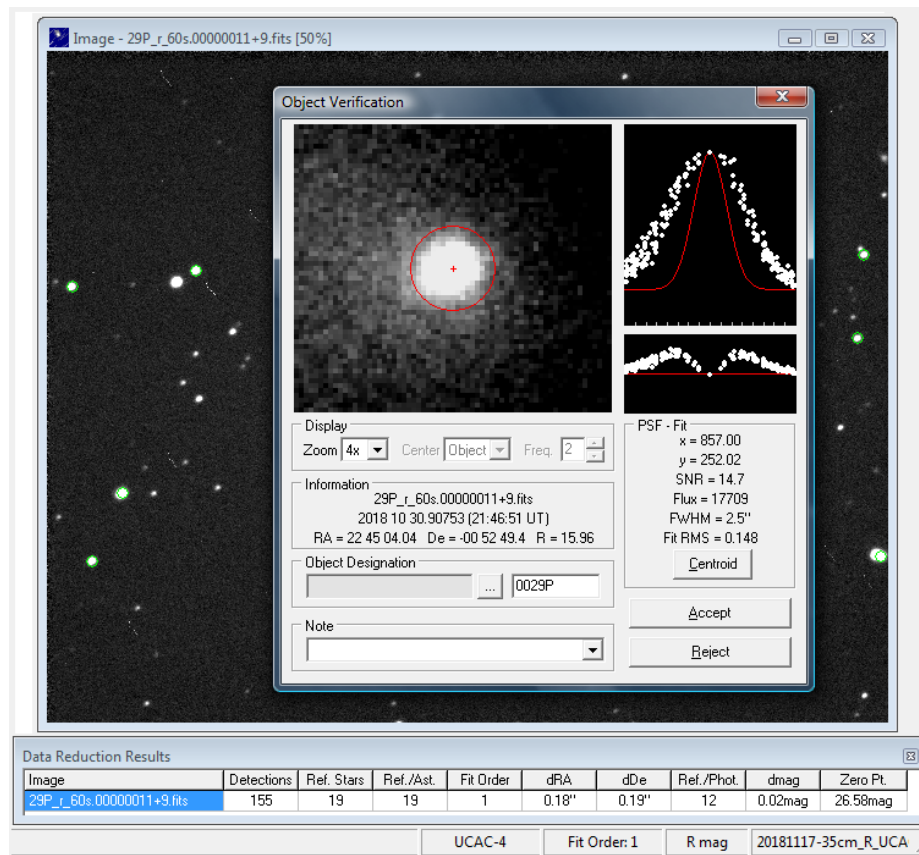


Figure 35 - Example of photometry measurement in Astrometrica

[A hint: For the “plate solution” to be reliable, the number of stars used for photometry (listed under the heading, 'Ref/Phot') should not be less than ~50% of the total number of reference stars identified (listed under the heading, 'Ref. Stars'). Also, the photometric precision of the fit can be judged from the value listed under the heading 'dmag': in the example shown this is 0.02 mag].

Now position the cursor on or very near to the brightest part of the image of 29P and click. A new dialogue box entitled 'Object Verification' appears (shown in Figure 3) depicting the astrometric and photometric results. The red circle shows the actual size and position of the measuring aperture so make sure this is centred on the pseudo-nucleus of the comet. You then enter '0029P' in the unlabelled box as shown, and then click 'Accept'. Although nothing appears to then happen, in actual fact 3 output files are created and the contents of these can be accessed by going to:

1. 'File', 'View **MPC Report File**', which lists the astrometric results together with photometry to the nearest 0.01 magnitude. These data, which are set out in MPC report format, are the end result of the exercise.

One point to note is that if your observatory has an IAU Code and you want to report your results to the Minor Planet Center, you will have to edit the measurement lines by changing the magnitude values from 2 decimal places to 1 decimal place as shown:

```

0029P          C2018 10 30.91470 22 45 03.94 -00 52 49.5          15.96R          J77
=> 0029P          C2018 10 30.91470 22 45 03.94 -00 52 49.5          16.0 R           J77

```

You then send that report as an ASCII file to **obs@cfa.harvard.edu**

2. 'File', 'View **Photometry File**', which now lists the mid-time of the observation as the corresponding Julian Date, the derived magnitude to a precision of 3 decimal places, the signal-to-noise ratio of the target, the zeropoint value of the calibration

JD	mag	Flt	SNR	ZeroPt	Cat	Design.
2458422.41470	15.960	R r	111.35	26.610	UCAC4	0029P
----- end -----						

3. 'File', 'View **Log File**', which lists a vast amount of information underlying the astrometric and photometric plate solutions. Rather than go into any detail here, I recommend you peruse this text file after having carried out an analysis as that will give you a further understanding of how *Astrometrica* works.

### 7.6.5 Reporting photometry of 29P

The above approach yields the brightness of the pseudo-nucleus combined with that of the inner coma out to a radial distance of ~22,500 km. This quantity is sometimes referred to as the nuclear magnitude, or m2 magnitude, and in the case of 29P is very sensitive to cometary activity on its nucleus.

Figure 36. illustrates the observed photometric behaviour of 29P during its latest apparition of 2018–2019. Here the measured R magnitudes have been normalised to what they would have been if situated 1 AU from the Sun and seen from the Earth at a distance of 1 AU. The phase angle has also been corrected to a value of 0 degrees using a 0.035 mag/deg phase coefficient.

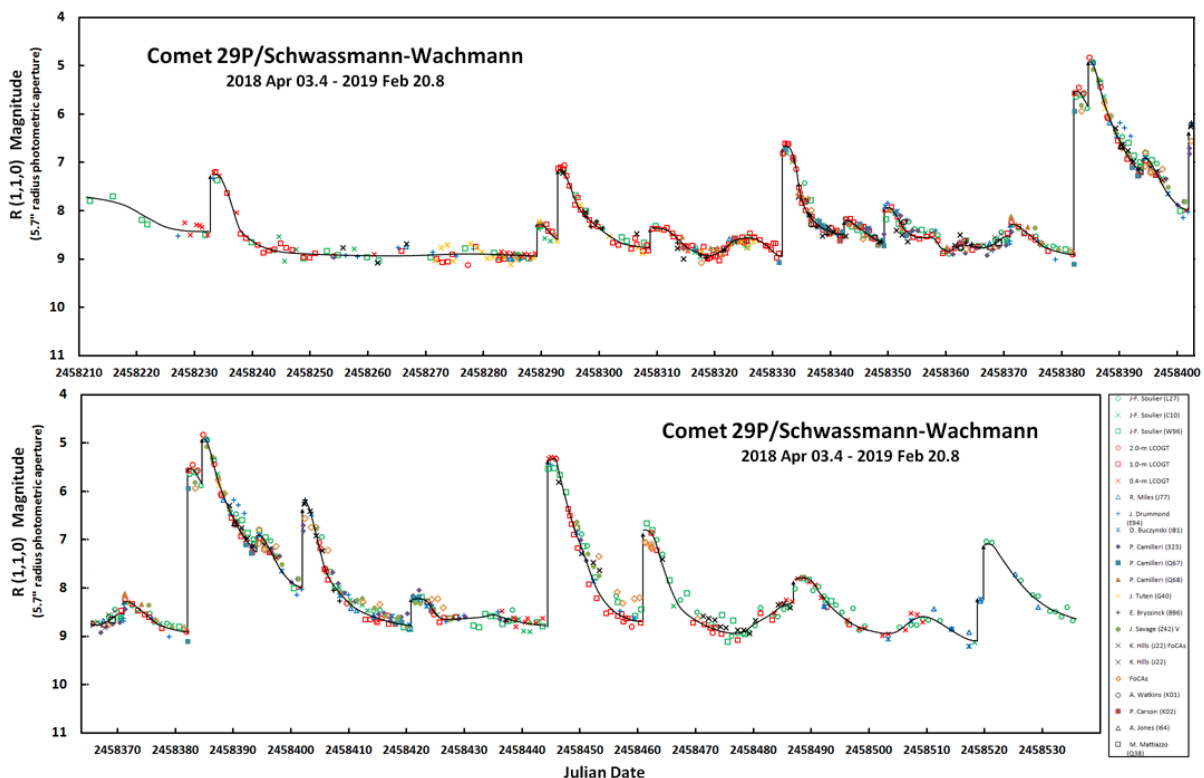


Figure 36 - Reduced R magnitude plot for Comet 29P during 2018–19

Note the very sudden changes in brightness of up to 4 magnitudes (a factor of 40) caused by outbursts of the nucleus. Most of the rise to maximum occurs within the space of 1 hour or so and therefore is rarely observed. During an apparition, which lasts for up to 11 months, the comet describes only a relatively short arc in its orbit around the Sun. An entire orbital year requires

some 15 Earth-years and so it is essential that we continue to monitor 29P year on year so that we can study the seasonal changes in its behaviour. The comet is currently moving northwards in the constellation of Pisces and so should be readily visible to northern hemisphere observers for the next 5-10 years.

Results should be reported to the author via the baa e-mail address, 'arps@britastro.org' or my personal e-mail address, and to the Comet Section via [cometobs@britastro.org](mailto:cometobs@britastro.org). If possible, report your results in MPC astrometric format expressing the R magnitude to 2 decimal places. Additional information in the form of the Photometry File data would also be helpful. Observations with or without a red filter are equally valuable.

## 8 OBSERVATION REPORTING PROCEDURES

### 8.1 Visual observation report form

Paper copies of the visual report form can be downloaded from the BAA website:

<https://britastro.org/sites/default/files/visform.pdf>

as required to submit your observations in paper format. Section 3.9 gives details on how to submit the report electronically and this method is encouraged.

Record your name, the name and year identifier of the comet you have observed (eg 2011 L4 (PanSTARRS)), the year of observation (eg 2013) and your primary observing location (eg Cambridge) at the top of the form.

*Month* Month (letters).

*Day.dd (UT)* Day and decimal in UT. eg 18:00 UT (GMT) on the 2nd would be 02.75. Table 3 gives the decimal values at five minute intervals. If necessary round your observation to the nearest five minute interval.

*MM* Method used for magnitude estimate. The recommended method is the Sidgwick (S) method (also known as the In-Out method); experienced observers may choose to use one of the other methods given in Table 11.

*Total Mag* The total magnitude of the entire coma to 1 decimal place; this should include any correction for extinction if there is a large difference in altitude between the comet and comparison field; put an exclamation mark (!) after the estimate if you have made a correction. If the observation is only approximate, due to bad weather or sky conditions, etc. put a colon (:) after the estimate. If the comet was not seen, but you have estimated the cometary limiting magnitude, put a less than sign (<) before the estimate. If you do not have an atlas or catalogue then identify the comparison stars with a field sketch on an attached sheet.

*Ref* Source or catalogue for comparison stars. Table 4. The most common ones are AA (AAVSO atlas), VB (BAA VS chart), HS (Hubble catalogue), SC (Sky Catalogue 2000), TJ (Tycho catalogue J magnitude - the default for Megastar, TT (Tycho VT) or TK (Tycho 2).

*Tel ap* Telescope aperture to the nearest ten millimetres; only give it to the nearest millimetre if it is significant eg 7x35B would be 35, whilst a 6" reflector would be 150. The instrument is the one that was used for the magnitude estimate. Omit if the naked eye is used.

*Tel typ* Type of telescope: Table 12. The most common ones are E (naked eye), B (binoculars), L (reflector), R (refractor), T (Schmidt-Cassegrain).

*f no* Always round to the nearest integer (eg f4.5 would be 5). This is not given for binoculars or the naked eye.

*Tel mag* Telescope magnification, as determined from the focal lengths of telescope and eyepiece. Above x20 it can be rounded to the nearest 5. Omit for the naked eye.

*Coma diam* Coma diameter in minutes of arc. If your measurement is accurate to better than 0.5', report the tenths, otherwise report to the nearest minute. For comae larger than about 15' only report to the nearest 5' unless your measurement is accurate to 1' or better. If the coma is elliptical report the shorter dimension.

**DC** Degree of condensation, from 0 (completely diffuse) to 9 (completely stellar). Table 8.

**Tail len** Length of main tail in degrees or minutes of arc (eg 0.2° or 10'). Give details of secondary tails in the comments section. If the coma is elliptical report the longer dimension.

**Tail PA** Position angle of main tail or coma elongation, measured with respect to lines of right ascension. North (higher declination) is 0°, East (greater right ascension) is 90°, South is 180°, West is 270°.

**Sky** Observing conditions. 0 (impossible to make any observation), 5 (average), 6 (Milky Way pretty clear), 9 (Milky way visible down to the horizon).

**Rel** Reliability of magnitude estimate: 1 (good) to 3 (poor).

**Comments** Add any extra information here. For example note if there is a separate sheet with a field sketch, coma drawing, tail sketch, etc. Clearly label this sheet with your name, the comet name, the date and time of observation, the scale and the orientation. You could also give a further description of the comet. Make clear any aspects of the observation that you are uncertain about. Note when the observing site is significantly different from your standard one (eg more than 50 km away).

The following are code letters for the methods used in making total visual magnitude estimates.

<b>Standard</b>	
S	Sidgwick or In-Out method
<b>Alternative</b>	
B	Bobrovnikoff method
E	Beyer method
M	Morris or Out-Out method
<b>Not normally used</b>	
G	Naked eye estimate, with glasses used (or removed) to defocus comparison stars (for bright comets only)
K	"Modified" Sidgwick method, using binoculars with the comet in-focus in one eyepiece and with the comparison stars out-of-focus in the other eye-piece
N	magnitude of nucleus or condensation
For CCD, Photoelectric or Photographic use only:	
C	unfiltered total CCD magnitude which approximates the Johnson V band
L	photometric B
P	photographic
R	photometric R
U	photometric U
V	photometric V
Note: For photometric magnitudes with errors of $\pm 0.3$ or greater put a colon (:) after the magnitude.	

*Table 9 – Magnitude method codes*



Observer.....J D SHANKLIN.....Comet.....P/Halley.....  
Year.....1986.....Location.....Antarctic Peninsula.....

[illegible]

Figure 37 – Visual report form

Visual only  
B = Binoculars  
E = Naked eye  
O = Opera glass  
Any type:  
C = Cassegrain  
L = Newtonian reflector  
M = Maksutov  
R = Refractor  
S = Schmidt-Newtonian telescope  
T = Schmidt-Cassegrain

A = Camera  
D = Schmidt

Table 10 – Instrument codes

The visual observing blank is available for download from the BAA website:

This form can be used when you have made a drawing of the comet, for example, because it shows some interesting features. Record your name, the name and year identifier of the comet you have observed (eg 141P/Machholz)), the year, month, day and time of the observation (eg 1994 Nov 20.95) and your observing location (eg Cambridge) at the top of the form. Record the scale of the image by noting the diameter of the circle in minutes of arc



and mark the north point with an arrow. Space at the bottom of the form can be used for a description of the observation.

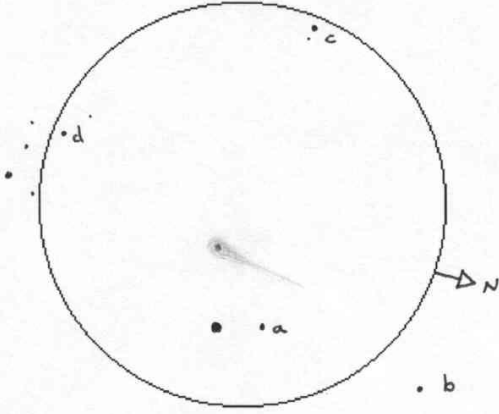
BAA Comet Section Observing Blank	
Observer...	J. D. Shanklin
Comet...	Panther 1980 Y2
Date	19 81 / Feb / 01.25
Location...	Cambridge
Instrument...	200R magnification. $\times 40$ .
Scale: circle is...	60 arc minutes
	
Please indicate the north point on the drawing	
Comments ...	Diffuse coma, well condensed to centre DC 7-8
	elongate in pa 350, diameter $3' \times 4\frac{1}{2}'$
	Tail 16' long in pa 350, straight and narrow
	mag. a 2 v 1 d, b 2 v 1 c
	.....
	.....
	.....

Figure 38 – Visual drawing blank

## 9 RESOURCES

### 9.1 Online

Many locations on the web carry cometary information. The following are just a few of the sites:

BAA Comet Section	<a href="http://britastro.org/comet">http://britastro.org/comet</a>
Comet Observer's database (COBS)	<a href="http://www.cobs.si/">http://www.cobs.si/</a>
Gary Kronk's Cometography home page	<a href="http://cometography.com/">http://cometography.com/</a>
German Comet Group	<a href="http://kometen.fg-vds.de/fgk_hpe.htm">http://kometen.fg-vds.de/fgk_hpe.htm</a>
Seiichi Yoshida's comet page	<a href="http://www.aerith.net/comet/weekly/current.html">http://www.aerith.net/comet/weekly/current.html</a>

### 9.2 Periodicals

The BAA Comet Section publishes an electronic newsletter, *The Comet's Tale*, which appears in January. This includes news, meeting reports, articles and analysis of observations charts, orbital elements and predictions. Contributions, in the form of comet observations or articles for the newsletter or BAA Journal, are welcome.

The Journal of the British Astronomical Association, published bi-monthly, includes notes and news on comets and analyses of observations. BAA Circulars, both in printed and electronic forms, are published as needed and give news of comet, nova etc discoveries and ephemerides of observable comets. Memoirs of the British Astronomical Association are published infrequently and contain lengthy analyses of observations etc, made by various sections of the BAA. Subscription details are given on the BAA web pages.

The Astronomer (TA) is a monthly magazine listing observations and news items. It includes observations by comet section members. Subscription can be arranged through the secretary.

### 9.3 Books and atlases

Many of the following are no longer in print, but may be obtained second hand.

Burnham, Robert, *Great Comets*, Cambridge University Press, 2000.

Brandt and Chapman, *Introduction to Comets*, Cambridge University Press, 2004.

Crovisier, Jacques and Encrenaz, Therese, *Comet Science*, Cambridge University Press, 2000.

Edberg, Stephen J., *IHW Amateur Observers Manual for Scientific Comet Studies*, Sky Publishing, 1983 [Out of print].

Edberg, Stephen J. and Levy, David H., *Observing Comets, Asteroids, Meteors and the Zodiacal Light*, Cambridge University Press, 1994.

James, Nick and North, Gerald, *Observing Comets*, Springer, 2003

Hirschfield, A., and Sinott, R. W. (Eds), *Sky Catalogue 2000.0*, Cambridge University Press, 2 vols, 1982 and 1985.

- Kronk, Gary W., *Comets*, Enslow, 1984 [Out of print].
- Kronk, Gary W., *Cometography*, Cambridge University Press, 6 vols.
- Levy, David H., *The Quest for Comets*, Plenum, 1994.
- Lovi, G., et al. (Eds), *Uranometria 2000.0*, Willmann-Bell, 2 vols., 1987.
- Marsden, Brian G., and Williams, Gareth V., *Catalogue of Cometary Orbits*, 17<sup>th</sup> edition, IAU CBAT/MPC, 2008.
- Martinez, Patrick (Ed), *The Observer's Guide to Astronomy*, Cambridge University Press, 2 vols, 1994.
- Meeus, Jan, *Astronomical Algorithms*, Willmann-Bell, 1991.
- Miles, Howard G., *An Explanatory Supplement to the Handbook*, BAA, 1988.
- Mobberley, Martin, *Hunting and Imaging Comets*, Springer, 2010
- Muirden, James (Ed), *Sky Watcher's Handbook*, W. H. Freeman/Spektrum, 1993.
- Ridpath, Ian (Ed), *Norton's 2000.0: Star Atlas and Reference Handbook*, Longman, 1990.
- Schaaf, Fred, *Comet of the Century*, Springer-Verlag, 1997.
- Schmude, Richard, *Comets and How to Observe Them*, Springer, 2010
- Scovil, Charles, *AAVSO Variable Star Atlas*, 2nd edition, AAVSO, 1990.
- Williams, Kay, *Under and English Heaven, The Life of George Alcock*, Genesis, 1996.
- Yeomans, Donald K, *Comets*, Wiley, 1991.



