COORDINATED PROGRAMS FOR COMET HALLEY

Michael F. A'Hearn
Astronomy Program
University of Maryland
College Park, MD 20742
USA

ABSTRACT. Because comets are so difficult to observe, it is essential to coordinate observations from a variety of telescopes in order to fully understand their behavior. The apparition of Comet Halley represents a unique opportunity for coordinated programs because this is the only predictable comet which is routinely bright enough for the many observational programs desired. The International Halley Watch is playing an advocacy and coordinating role in the observations of Halley. Coordinated photographic observations will provide a record of the development of jets in the coma and of the motion of features in the tail. Coordinated photometry will provide both the heliocentric variation in vaporization and also the details of the outbursts thought to occur in most comets. Coordination with larger optical telescopes and with radio and infrared telescopes will allow a more complete understanding of the physical and chemical processes occurring in comets. Examples, of course, must still be drawn from observations of previous comets but they illustrate the results expected from Halley.

1. INTRODUCTION

There are a number of reasons for studying comets and many of these reason require coordinated programs using small telescopes. Perhaps the most obvious reason for studying comets is that they are the most dramatic appearances in the sky other than a total solar eclipse. The most dramatic aspect of comets is the existence of tails and these provide fascinating phenomena which must be studied with small telescopes in order to have a large enough field of view. A second reason for studying comets is that they allow us to probe the solar wind, both the variation in the solar wind's properties with direction, heliographic latitude and longitude, and the way in which the plasma of the solar wind interacts with the primarily neutral gas in the cometary coma. These effects also are often most obvious in the tails of comets and again often best studied with small telescopes in order to get large fields of view. Many astronomers would argue, however, that the most important reason for studying the comets is that they may have preserved

J. B. Hearnshaw and P. L. Cottrell (eds.), Instrumentation and Research Programmes for Small Telescopes, 223–235.

material from the formation of the solar system - probably the nebular condensates and possibly even interstellar grains that were incorporated directly. Even in this area of understanding the chemical nature of comets there are a number of programs, primarily photometry and CCD imaging but also to some extent spectroscopy and spectrophotometry, which can readily be carried out on small telescopes. In order to illustrate the importance of coordination, I will discuss some examples of past comets for which coordinated observations were extremely valuable.

2. EXAMPLES FROM THE PAST

Comets are among the most difficult of astronomical objects to study because they are often large in angular size, low in surface brightness, moving rapidly, and located close to the sun when they are bright. Furthermore, they are known to vary dramatically on relatively short timescales, i.e. within hours. The simplest form of coordination is required by the fact that, unlike all other objects in the solar system, cometary orbits have high inclinations to the ecliptic. Even short-period comets have orbits which are, on average, inclined more than those of asteroids but the long-period and parabolic comets have randomly oriented orbits. Many comets, therefore move from high declinations in the northern hemisphere to high declinations in the southern hemisphere or vice versa. This is, of course, one of the features which makes comets valuable as probes of the solar wind - they probe the solar wind far from the ecliptic. Nevertheless, it is also a problem because it requires coordination between northern and southern observatories to properly study such comets. Such coordination is, in fact, quite common in astrometry and not uncommon in photometry although it is not so common in other forms of cometary observations. The need for astrometric observations over the entire observable orbit is sufficiently obvious that it need not even be stated but the need, e.g., for photometric observations over the entire observable portion of the orbit is not so intuitively obvious. The general reason is that the variation in production of gas with heliocentric distance is important in understanding the physics and chemistry of the nucleus. At the simplest level, observations over a sufficiently wide range of heliocentric distances enable us to learn the volatility of whatever species controls the vaporization of the nucleus. Other fundamental questions about the cometary nucleus can also be studied by using photometry from both pre-and post-perihelion phases.

A very recent example is shown in Figure 1. Comet Encke is usually visible only from the northern hemisphere before perihelion and only from the southern hemisphere after perihelion. Several years ago, Whipple and Sekanina (1979) developed a model for the precession of the rotation axis of Encke's nucleus by assuming that the visual light curve, which is highly asymmetric about perihelion, represented the total outflow of gas. Since publication of that model, the actual production of gas has been measured. The data are based primarily on narrow-band photometry of Encke's comet obtained at Lowell Observatory before perihelion and at both Mt. John University Observatory and Perth

https://doi.org/10.1017/S0074180900151356 Published online by Cambridge University Press

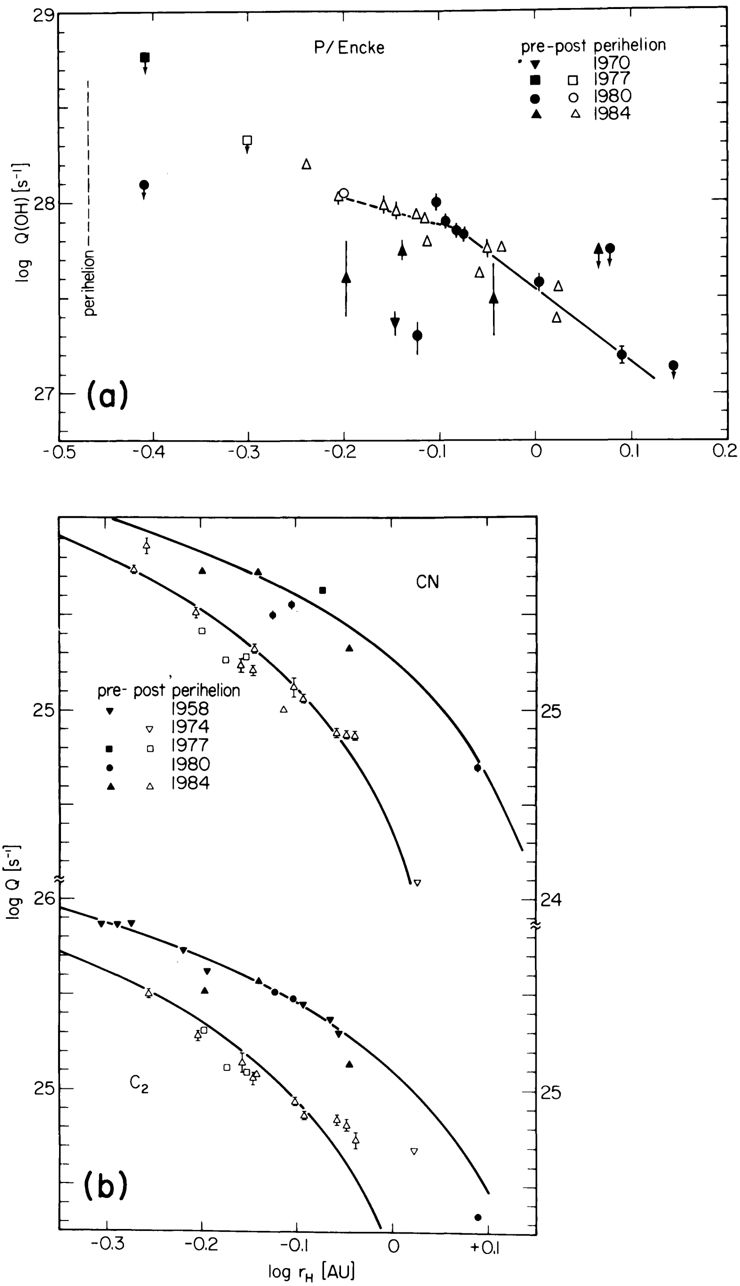

Figure 1. Production of OH, CN and C_2 in Comet Encke. The solid lines in the lower panel represent the visual light curve. Data are from northern hemisphere (pre-perihelion) and southern hemisphere (post-perihelion) observatories as well as IUE. From A'Hearn et al. 1985.

https://doi.org/10.1017/S0074180900151356 Published online by Cambridge University Press

Observatory after perihelion (A'Hearn et al. 1985). Nearly all the data were obtained with small telescopes. It is clear that the production rate of trace gases C_2 and CN does mimic the visual light curve as you would expect. Most of the gas, however, is from H_2O and Figure 1 shows measurements of OH taken from Lowell before perihelion and from Mt. John after perhelion. Some additional points were also obtained from the IUE satellite (illustrating yet another type of coordination). Obviously the production of OH does not mimic the visual light curve at all. Stimulated by this result, Sekanina (1986) has looked further into his model for the precession and found a quite different physical effect which produces an asymmetry in the non-gravitational forces even without an asymmetry in the production rate of gas; by looking at images of sunward fans in the coma of Encke's comet, he has shown that the lag angle is large before perihelion but very small after perihelion. He now finds that the actual precessional path of Encke's rotation axis is similar to that in the earlier model but we get a quite different picture of the physical processes in the nucleus which produce this precession. The surface varies not in the fraction of ice cover but in the composition of the ice and the thermal inertia of the surface layer. The lack of an asymmetry in the production of OH coupled with the asymmetry in other species was detected only because of coordination among different observatories. The original data also show the need for more than one observatory in each hemisphere. In particular, the post-perihelion phases are well described only because two southern observatories (Mt. John and Perth) with different weather patterns were active during the 1984 apparition of Encke's comet. For comets which vary greatly with time and which must be observed now or not until many years from now, it is also important to have this latter redundancy which circumvents the weather patterns.

A much more critical type of coordination is required for studies of the short term variability of comets. It is well known that outbursts in the comae of comets take place on a time scale of order a day. Because of their proximity to the sun, bright comets are rarely observable for more than an hour or two from a given longitude. In order to understand these outbursts, which appear photometrically as brief increases in brightness but which appear even more dramatically in images as jets and haloes, it is essential to have data from several observatories at different longitudes. A prime example of this is shown in Figure 2 which is taken from work by Larson and Sekanina (1985) using images of Halley's comet from 1910. All images were taken with telescopes less than one meter in size and located at Vienna (V), Lowell (L), Helwan (H) and Lick (C). The images were processed using a shift-difference algorithm to enhance the low-contrast features. There was little coordination in taking these images and it is sometimes difficult to identify features in successive images. These images do illustrate what could be learned from a properly coordinated effort. They show dramatically the changes over a short interval of time, changes that could not be observed from a single site. It is this work that has allowed Larson and Sekanina to deduce both an expansion velocity for the coma of 1.4 km/sec and a rotation period of roughly 40 hours for the nucleus of Halley's comet. Without the observations at different longi-

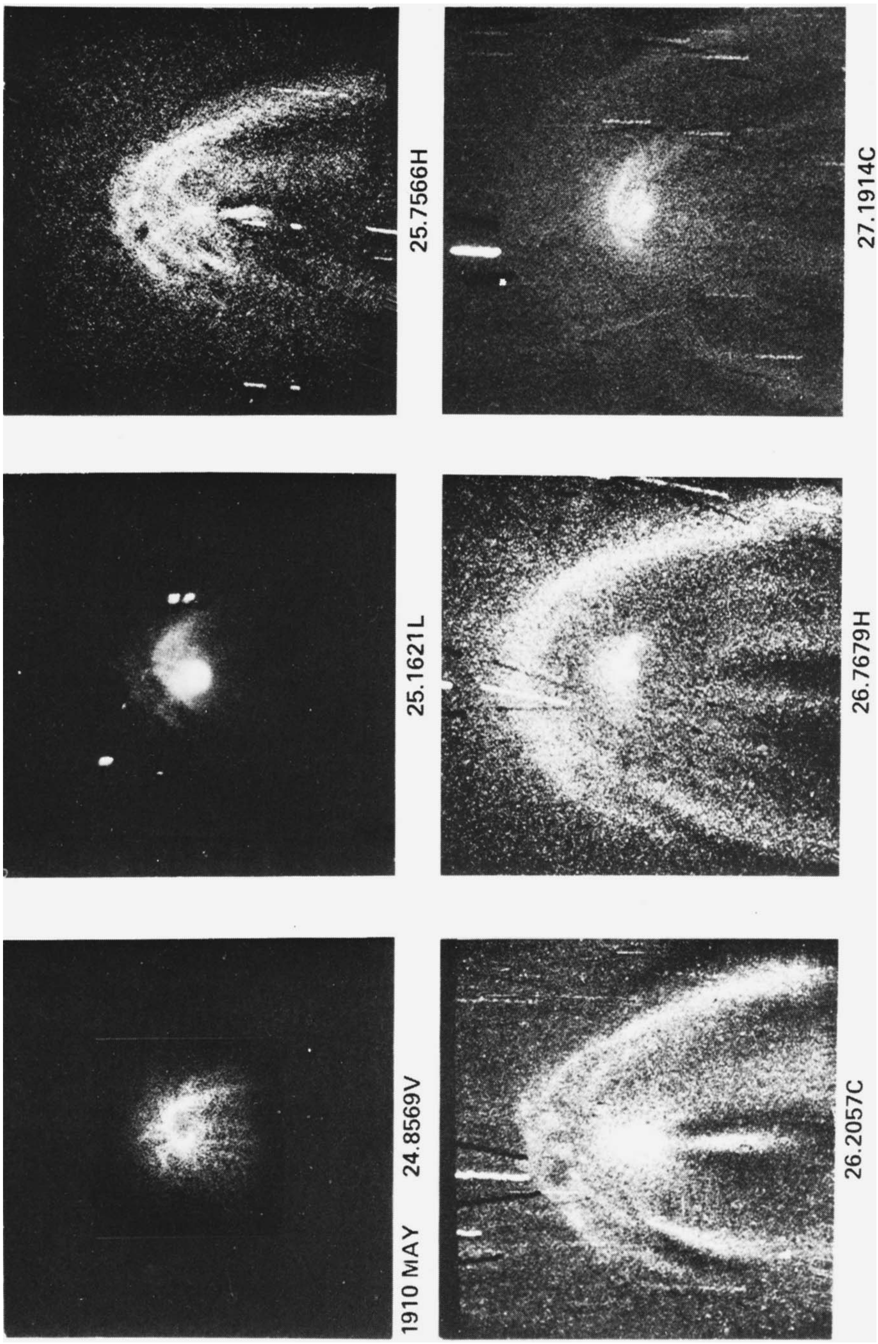

Figure 2. Highly processed images of Comet Halley in May 1910. Images labelled with UT data and observatory: V = Vienna, L = Lowell, H = Helwan, C = Lick. From Larson and Sekanina, 1985. Photo compliments of S. Larson.

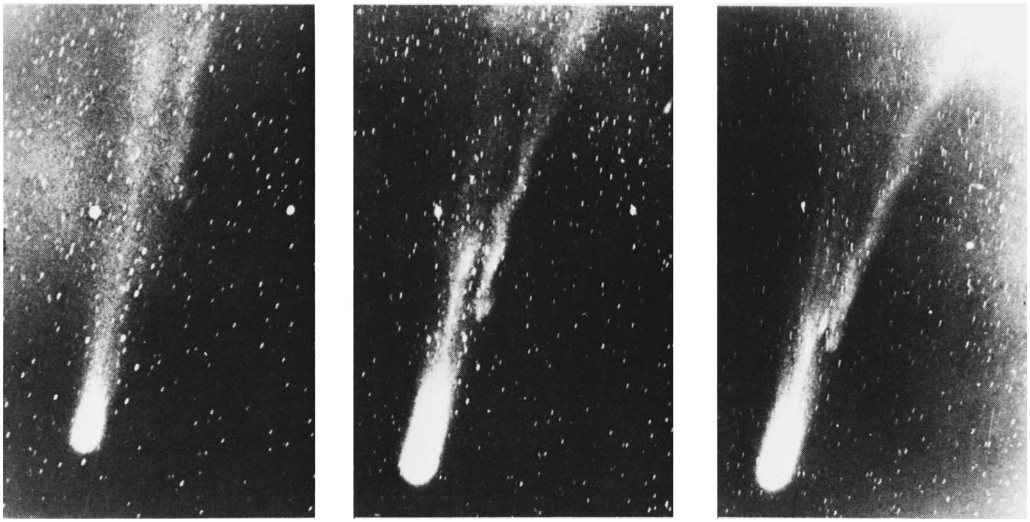

Figure 3. A disconnection event in the tail of Comet Halley, 1910 June 6-7. Original images from Yerkes, Honolulu, and Beirut spanning 16 hours. Photograph compliments of M. Niedner (c.v. Niedner and Brandt, 1978).

tudes, it would be impossible to relate features in successive images. I note in passing that the problem of determining the rotation period of cometary nuclei from photometric observations suffers from precisely the same limitations but there is not to my knowledge a single instance in which the required coordination has been achieved either deliberately or inadvertently.

My third, and perhaps most dramatic, example of the need for coordinated observations comes from wide-field photographs of the tails of comets. Figure 3 shows a disconnection event, in which the comet's ionic tail "breaks off" and is blown away by the solar wind while a new tail forms in the coma. This entire process takes place on a time scale of hours -- too slowly to be observed in one night from a single observatory but too fast to be observed by the the same observatory on successive nights. There are conflicting theories about how this process takes place (magnetic reconnection, flute instability, shock-shock interaction, and differential acceleration, c.f. Mendis et al. 1985) and it is impossible to resolve these discrepancies without good sequences of images showing the development of the process. Furthermore it is essential that data on the solar wind be available for the same period of time in order to ascertain whether or not there are substantial effects in the solar wind, such as crossings of sector boundaries, which are associated with the process.

The final type of coordinated observation is that between observatories doing different types of work. The particular example that I will cite uses data from large telescopes but the principle is equally applicable to small telescopes. Several groups have recently

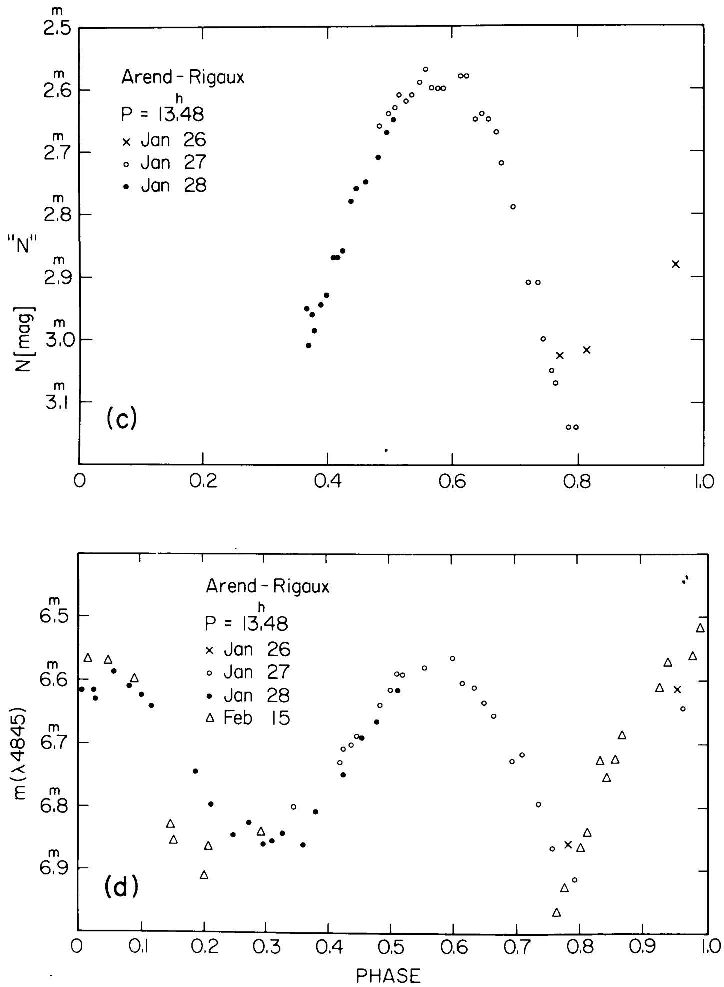

Figure 4. Light curves of the nuclear region of Comet Arend-Rigaux in the thermal infrared and the optical. Data taken on same nights using 88" telescope and Infrared Telescope Facility at Mauna Kea Observatory. From Millis et al. 1986.

studied the photometric variations of comets in which it was thought possible to see the nucleus. Photometric variations have been reported for Comet Arend-Rigaux by all groups and all agree that the period is a multiple of 6 3/4 hours (the choice of which multiple is in dispute due to lack of coordinated observations at different longitudes). A substantive question arises regarding the interpretation: is the variation due to variations in cross-section or in albedo? In the case of Comet Arend-Rigaux this was unambiguously resolved by measuring the variation simultaneously, with two different telescopes, in the reflected optical radiation and in the thermal infrared radiation (Millis et al., 1986). Both light curves were perfectly in phase, as shown in Figure 4, thus requiring that the variation be due to changes in cross-section and enabling us to determine the size and albedo of the nucleus. This type of coordination, among telescopes doing different types of observations, is in fact likely to lead to some of the most exciting scientific results on comets in the future.

3. PLANS FOR COMET HALLEY

Due at least in part to a concern for problems like those cited above, NASA is supporting the International Halley Watch (IHW) to coordinate observations of Halley's comet at this apparition. The three official purposes of this organization are advocacy, coordination, and archiving. The pertinent point for us is that the IHW is explicitly attempting to encourage observers at many different sites to coordinate their observations. Because Halley's is the only bright, periodic comet, it presents an ideal case for coordination. One aspect of the coordination has been to encourage many observers who normally observe galaxies or nebulae or stars to turn their attention to Halley's comet. Success in this will immediately help the problem of finding observers at a variety of different longitudes. This is not enough, however, since the coordination also requires that they be observing on the same nights. In order to encourage this, a series of Halley-Watch days has been identified as the prime times for observations. These days were selected to be at favorable lunar phases, to cover the "interesting" times in the comet's development, and also to maximize the coordination between ground-based observations and the spacecraft that will fly through the coma.

The primary contact with observers is through Discipline Specialists, experts in each of eight observational techniques who are charged with encouraging observers to use those techniques, providing all the relevant information on standardization, providing up to date information to the observers, and ultimately collecting all the observational data so that a complete archive of all data on Halley can be published after the apparition, presumably in 1989. This archive, incidentally, will contain only data, not interpretations; it is assumed that the results and their interpretation will be published in the usual manner by the individual investigators as articles in the astronomical journals. Naturally all of the discipline specialists are experienced cometary observers and will be observing Halley's comet as part of their own research programs and are encouraging collaborative analyses where these are appropriate.

Figure 5 shows as an example the locations where observers are expected to participate in the net carrying out narrow-band photometry. Obviously many observers are interested in making these observations but even these many turn out to be too few for some of the interesting problems. In the first place, bad weather will eliminate a significant fraction of the observers on any given night. More importantly,

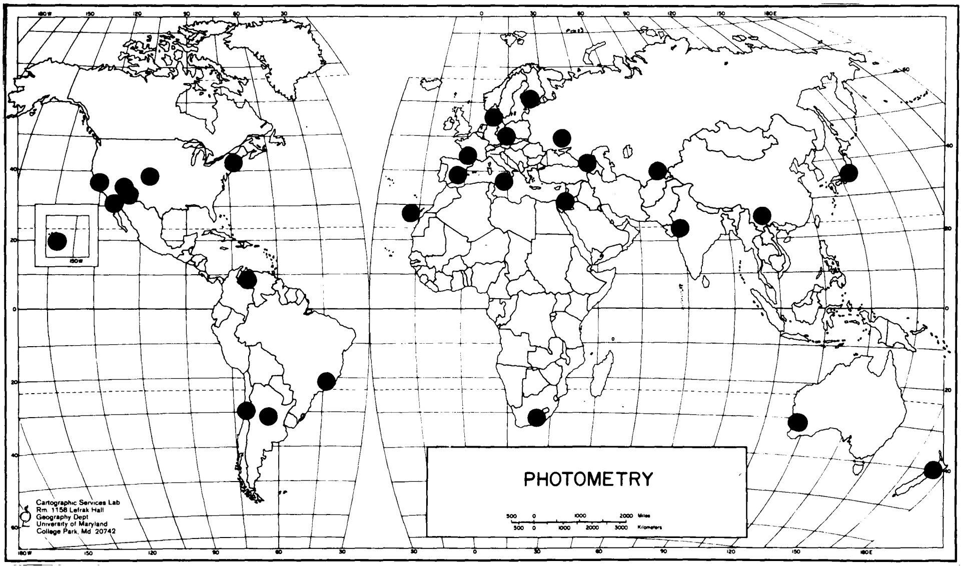

Figure 5. Map showing location of observers planning narrow-band photometry of Comet Halley in 1985-86.

however, Halley's comet at this apparition is observable almost exclusively from the southern hemisphere after perihelion (Halley's comet is always intrinsically brighter after perihelion than before) and, unfortunately for our purposes, much of the southern hemisphere is covered by oceans. Figure 6 shows the hours of the day during which the comet is observable by any member of the Large Scale Phenomena Net in December and during the week in March when several spacecraft will fly through the coma. It is clear that, even though many observers are participating, there are many hours of the day during March when none of the likely observers wil be able to see the comet. By contrast, the comet is observable from five or more participating observatories at all times in early December. These gaps, particularly in the south, severely limit our ability to study rapidly changing phenomena such as disconnection events in the plasma tail. Similar problems exist for all nets where rapidly changing phenomena are of interest.

As implied by the discussion of previous coordinated observations of comets, the small telescopes being discussed in this symposium will be used primarily for observations relevant to the Astrometry, Large Scale Phenomena, Near Nucleus Studies, and Photometry and Polarimetry Nets. The Infrared Net and the Spectroscopy and Spectrophotometry Net will use primarily larger telescopes while the Radio and Meteor Nets will generally use facilities totally outside the scope of this symposium. To illustrate the types of assistance which can be provided by the discipline specialists, I will just list some ways in which each of these four nets is attempting to provide assistance to its members. The Astrometry net has developed a catalog of reference stars with accurately known positions along the expected track of the comet, has distributed to a significant number of observers a precise, two-body

https://doi.org/10.1017/S0074180900151356 Published online by Cambridge University Press

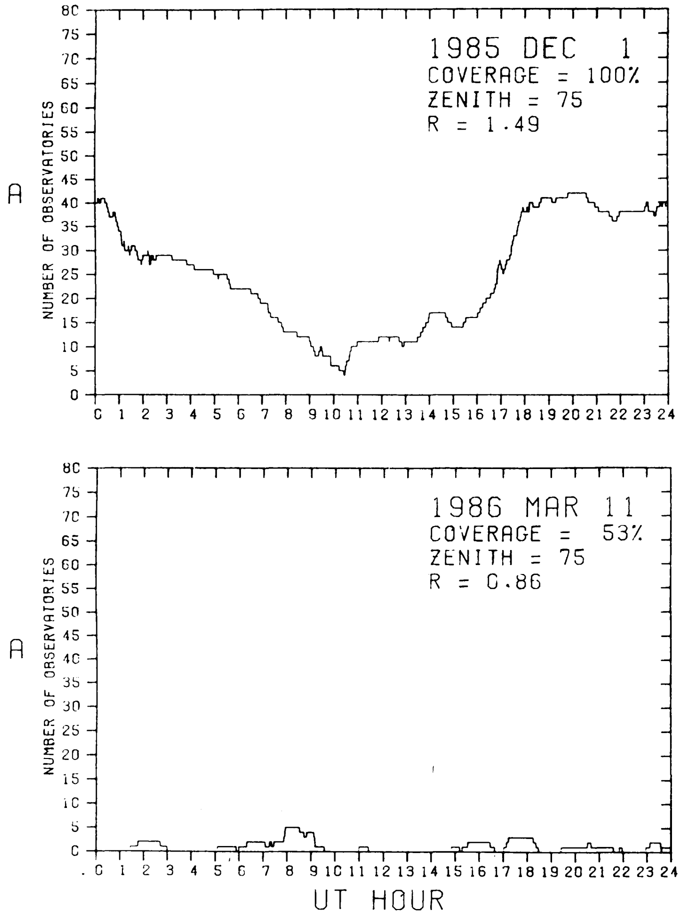

Figure 6. Number of observatories in Large Scale Phenomena Net which can observe Comet Halley (altitude > 15°, beyond twilight) as function of UT. Comet can be observed continuously in early December but not in March even if there are no clouds. Diagram compliments of M. Niedner.

ephemeris program, and regularly provides current orbital elements and ephemerides to all who want these data. The Large Scale Phenomena Net has concentrated on developing methods for photometrically calibrating plates taken with telescopes having large fields of view, typically but not exclusively Schmidt telescopes. The Near Nucleus Studies Net is first of all encouraging the transition from photographic techniques to CCD detectors. While the comet is bright, say from October 1985 to May 1986, virtually all the imaging can be done from telescopes less than one meter in size using a CCD with suitable transfer optics. Larson and

https://doi.org/10.1017/S0074180900151356 Published online by Cambridge University Press

I, for example, each have a CCD system being used nearly full time on 20- and 24-inch telescopes respectively. This use of small telescopes considerably eases the problem of obtaining telescope time but more importantly gives us a larger field of view. This net has also coordinated the purchase and distribution of more than a dozen sets of narrow-band, image-quality interference filters. The Photometry and Polarimetry net has developed a complete photometric system using narow-band filters to isolate the emission bands and continuum of comets and distributed 75 sets of filters around the world. A set of standard stars has been chosen and an interim set of standard magnitudes is being presented as a separate, contributed paper at this meeting. Calibration of the standard magitudes into absolute fluxes is currently in progress and will also be distributed to the members of the net. Although most of the early photometric observations of Halley's comet were from large telescopes, some were obtained with a CCD on a 1.0 meter telescope and virtually all the observations when the comet is closer than 1.5 AU will be done with small telescopes.

As mentioned above, one of the key goals is to have simultaneous data from different nets. One example of such a planned program is the simultaneous use of CCD cameras and photometers on adjacent telescopes at the same observatory. We are, for example, testing whether it will be possible to completely replace photometers with CCD cameras at some time in the future. Because the calibration problems are so different, particularly when narrow-band filters are used with CCDs, it is not obvious _a priori_ how rapidly this can be achieved. Perhaps more importantly, simultaneous use of photometers and CCDs relieves one of the observers, presumably the one using the CCD, of the need to measure extinction coefficients each night. This is a particularly important point when the comet is very close to the sun (January and March) and only a short time is available for observations at large air mass. In another area, having simultaneous ultraviolet, radio, photometric, and spectroscopic data is critical for understanding the chemical processes in the cometary coma since the different techniques are typically used to derive abundances of different but possibly related species. A typical example would be the comparison of optically deduced CN abundances with the abundances of HCN deduced from radio observations as was done for Comet IRAS-Araki-Alcock (Irvine et al. 1984). In yet another area, astrometric and photometric data are needed simultaneously in order to understand occultations of stars by the cometary coma from which we can directly deduce the optical depth and albedo of the dust particles. These results will be even further enhanced if simultaneous infrared data are available.

At this time it is still premature to discuss the results of most of the programs on Halley. Nevertheless we can point out that all of the groups that observed Halley in 1983 and 1984 reported variability. Several groups tried inconclusively to establish periods based on their own data but a combination of the data from various groups showed that all the deduced periods were incorrect and that most of the variation was not periodic. It was only through this combination of data from several observers that it was possible to show the non-periodic nature of the variation.

4. COMETS AFTER HALLEY

Although Comet Halley is the only periodic comet routinely visible to the unaided eye, there are many other comets which can be studied with small telescopes. In fact, when a bright comet is unexpectedly discovered, it is often the case that only a small telescope can be made available rapidly enough to be useful. In the case of narrow-band photometry, there is an average of at least one comet observable every year, some periodic and others newly discovered. The coordination among different telescopes is much harder to arrange for a newly discovered comet but it is for precisely these comets that the most dramatic gains will be achieved by coordinated observations. Because comets like this are so bright, small telescopes can be used for many purposes but the coordination is most important.

5. REFERENCES

A'Hearn, M.F., P.V. Birch, P.D. Feldman, and R.L. Millis, 1985, 'Comet Encke: OH Production and Light Curve.' Icarus, **64**, 1-10.

Irvine, W.M. et al., 1984, 'Radio-Astronomical Observations of Comets IRAS-Araki-Alcock (1983d) and Sugano-Saigusa-Fujikawa (1983e).' Icarus, **60**, 215-220.

Larson, S.M. and Z. Sekanina, 1985, 'Coma Morphology and Dust-Emission Pattern of Periodic Comet Halley. III. Additional High Resolution Images Taken in 1910.' Astron. J., **90** 823-826.

Mendis, D.A., H.L. Houpis, and M.L. Marconi, 1985, 'The Physics of Comets', Fund. Cosmic Phys. **10**, 1-380.

Millis, R. L., M. F. A'Hearn and H. Campins, 1986, 'The Nucleus of Comet Arend-Rigaux' in preparation.

Niedner, M.B. and J.C. Brandt, 1978, 'Interplanetary Gas XXIII. Plasma Tail Disconnection Events in Comets: Evidence for Magnetic Field Line Reconnection at Interplanetary Sector Boundaries', Ap.J. **223**, 655-670.

Sekanina, Z. 1986, 'Effects of the Law for Nongravitational Forces on the Precession Model of Comet Encke', Astron. J., in press.

Whipple, F.L. and Z. Sekanina, 1979, 'Comet Encke: Precession of the Spin Axis, Nongravitational Motion, and Sublimation.' Astron. J. **84**, 1894-1907.

DISCUSSION

Moffet: What measurements will the various space probes be making on Halley's Comet?

A'Hearn: 1) Japanese probe (Planet A renamed Suisei) : Lyman-α camera and a solar wind monitor.
2) ESA (Giotto) and Russian (Vega 1 and 2) probes : neutral-and ion-mass spectrometers, dust impact counter, dust vaporisation mass spectrometer, plasma analyser, plasma wave measurer and a few others.

Hearnshaw: We have a 1 m telescope, which may be ready for the comet, and an échelle spectrograph. What wavelength intervals or features should we observe? At what resolution?

A'Hearn: One needs to resolve the rotational structure of the individual bands ($\Delta\lambda \sim 0.5$Å)
- CN λ 3883Å
- CO^+ λ 4260Å (looking at the acceleration of the ions)
- NH λ 3365Å
- C_2 bands are hard to observe.

Phillips: One shouldn't get fanatical about small telescopes. There are programs (on the comet) which can only be done with large telescopes.

Jacoby: Could you elaborate on the difficulty of doing photometry with a CCD as opposed to a photomultiplier?

A'Hearn: It's not more difficult but you have to be sure you do your extinction corrections with the CCD and not get carried away with the imaging.

https://doi.org/10.1017/S0074180900151356 Published online by Cambridge University Press