D7

INTRODUCTORY REMARKS
PHOTOMETRY SECTION

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We should remember that the stated purpose of this workshop is to discuss the latest advances in observational techniques and how to best apply them to comets. This means that we must spend much of our time discussing the nuts and bolts of instrumentation and technique and relatively little of our time discussing the more interesting science that can come out of the observations. I would therefore like to introduce the photometry session by summarizing the goals of photometric studies of comets, at least as I view them, and then mentioning some of the recent advances in instrumentation and technique that may help us to achieve these goals. The authors of the contributed papers can then discuss their techniques in more detail.

The principal goals of photometry and polarimetry are summarized in Table 1. Note that the goals are stated in the rather prosaic terms of direct, observational data. The ultimate scientific goals are not given in the table but most of you will recognize these goals. For example, the spatial distribution of emission-line and continuum radiation can tell us about the hydrodynamics of the coma and about the formation mechanisms of various chemical species. The relative abundances can be used to constrain chemical reaction models of the coma, and to identify parent molecules, and even to investigate the conditions in the pre-solar nebula. The reflection spectrum of the nucleus can be used to constrain our models of the nuclear structure. The scattering function of the grains can tell us what are the dielectric properties and hence the nature of the grains in the coma and tail. Many of these longer range scientific goals were discussed this morning by the theorists and laboratory people who have told us what observational data they need in order to fully explain the nature of comets. The important thing to note is that there are a wide variety of interesting problems in the physics and chemistry of comets but that, insofar as photometric studies can contribute to the solution of these problems, there are only a few basic types of observations to be made. The interesting and innovative choices to be made are either technological, such as the use of a new and better detector, or motivated by a particularly interesting physical problem which, for example, dictates that a particular emission line is worth studying.

Table 1.
Goals of Photometry and Polarimetry

1. Emission features - gaseous species
   a. Abundances
   b. Spatial distribution
   c. Heliocentric distance variation
   d. Outbursts

2. Continuum - Grains
   a. Wavelength dependence of albedo
   b. Phase function of the scattering
   c. Variation with heliocentric distance
   d. Outbursts
   e. Spatial distribution
   f. Note that for all of the above we really want to measure all 4 Stokes parameters, i.e., the polarization as well as the intensity

3. Continuum - Nucleus
   a. Wavelength dependence of albedo
   b. Phase function for scattering
   c. Time variation - rotation
   d. Note again that for a and b we want polarization as well as intensity

There have been numerous advances in photometric techniques in recent years. Some of these advances in technique have already led to significant advances in our understanding of comets while others are just coming into use and have not yet realized their full potential. In Table 2 I have listed a number of advances, not a complete list but representative, and I will discuss each of these advances briefly.

Table 2.

Recent Advances in Photometric Techniques

1.	Observation of many comets
2.	Use of proper filters
3.	Extension to the shortest wavelengths
4.	Extension to the longest wavelengths
5.	Higher spectral resolving power
6.	Image detectors of photometric quality
7.	Polarization techniques.

I think that one of the most significant advances recently lies in the large increase in the number of observers who systematically study comets. There have always been a few people who systematically studied comets but they were relatively few. Much of the work on comets was done by people who happened to have telescope time when a reasonably bright comet was around. Although the contributions of such people, who often have unique instruments, are certainly of the utmost importance, it is a great advantage to our overall understanding that we now have a number of groups systematically obtaining relatively homogeneous data on many comets. Basically this has meant an extension of standard photometric and spectrophotometric techniques to successively fainter comets. The feature has been enhanced by one significant technological advance - the installation of TV acquisition systems on several larger telescopes. Although TV acquisition systems have not yet become widespread, it seems likely that they will be used extensively in the future to enhance observers to study much fainter comets.

A related problem involves the choice of filters for photometry. Although some investigators have used interference filters specifically designed for cometary work for approximately 20 years, many other observers in the past have attempted to borrow filters from other branches of astronomy for their cometary observations. Although in some instances this practice will work, it is generally not an effective way to obtain cometary data. This practice seems to have nearly disappeared from current cometary research. Along this line, it should be pointed out that IAU Commission 15 has a working group on standardized filters for photometry. That group has submitted a proposal to the U. S. National Science Foundation to purchase and distribute 50 identical sets of 5 filters each to isolate emission bands of C_2, C_3, and CN as well as two regions of the reflected solar continuum. We anticipate receipt of funding within a few months. The approximate characteristics of those filters, subject to small changes when the actual purchase is made, are given in Table 3. Although there are many advantages to the use of such a standardized filter set, particularly in the intercomparison of different comets, we must be careful not to let the existence of these standard filters blind us to the possibilities of using other filters. The working group already plans to add a CO^+ filter and possibly a few others to the set in future years but individual investigators should still be searching for ideas as to which spectral feature to measure might lead to particularly interesting science. Such ideas will, of course, necessitate the use of non-standard filters and should be encouraged.

Table 3.

Proposed Standard Filter Set for Cometary Photometry

Continuum	3650 ± 10Å	100 + 0, -10Å
CN ($\Delta v=0$; $B^2\Sigma^+ - X^2\Sigma^+$)	3870 ± 3	50 + 0, -10Å
C_3 ($^1\Pi_u - {}^1\Sigma_g^+$)	4060 ± 5	70 ± 5
Continuum	4850 ± 10	100 + 0, -10
C_2 ($\Delta v=0$; $d^3\Pi_g - a^3\Pi_u$)	5115 ± 5	125 + 0, -10

The wavelength region over which one can carry out useful photometry has also been extended recently, both shortward and longward of the traditional photomultiplier range. In just a few minutes Millis will discuss our recent success at carrying out reasonably routine, accurate, ground-based photometry of the OH band at 3090Å. It has long been known that this band is observable from the ground spectroscopically but observers have not attempted absolute photometry because of the severe atmospheric extinction. It turns out that reliable, absolute photometry is not difficult from a good site. At the other end of the spectrum, the advance is also not a fundamental one since we have long had S-1 photocathodes that enabled us to carry out photometry and spectrophotometry at wavelengths as long as 1 micron. The advent of phototubes with III-V cathodes, however, has brought at least an order of magnitude increase in sensitivity for wavelengths greater than about 7500Å. This region of the spectrum will bring us not only further bands of NH_2 and the red system of CN but also several forbidden lines of neutral atoms which might be pumped by known ultraviolet transitions or which should appear by formation of excited state atoms and radicals (as in the case of oxygen lines) and also a much longer wavelength baseline for determining continuum reflectivities.

Another source of great advances has been the arrival of high spectral resolution in spectrophotometry. Traditionally we think of spectroscopy as providing high spectral resolution while spectrophotometry provides a good flux calibration at much lower spectral resolution. The advent of scanning, photoelectric Fabry-Perot and Fourier transform spectrometers offers the possibility of observing photoelectrically at high spectral resolution. Neither of these techniques has been exploited extensively for cometary work but Fabry-Perot studies of Kohoutek gave us very valuable information about the velocity structure in the cometary coma. It seems likely to me that observations such as those made on Kohoutek will never be routinely applied to comets because the instruments are highly specialized and they will be used in a variety of branches of astronomy as dictated by the current interests of the few people who can make these instruments work. Nevertheless, the instruments are so powerful that they should be applied to solve appropriate problems.

Finally I come to the advance that I think will have the greatest impact, partly because it represents a great technological advance but even more because I think the instruments will become widespread. I refer, of course, to photoelectric image detectors. There are a number of different types including digicons, reticons, CIDs, CCDs, and IDSs. So far these devices are not widespread but they are gradually coming into more use. Many of them are one-dimensional arrays, such as the digicon and the reticon, which are very well suited for spectrophotometry. Others, such as the CCD, are two-dimensional arrays and are suitable either for direct imaging, so that one can do point-by-point photometry, or for spectrophotometry of an extended region using a long-slit spectrograph. The high quantum efficiency of most of these devices in the red is also a great advantage. Although there is not much on the program regarding these devices, several of the practitioners of the art are present so that I expect that we will have some very good discussion of the use of these devices.

I have not yet discussed polarimetry, which is often thought of as a special kind of photometry. It seems to me that this is an area in which instrumental innovations could lead to great advances. Unfortunately there have been relatively few attempts to measure polarization in comets at all and I am not aware of any significant advances in recent years which have clear applicability to the problem of observing comets. I will therefore not discuss this area at all.

Clearly, I have discussed these advances only very superficially, intending mainly to give you a quick summary of the recent advances. The details will now be dealt with in the contributed papers.