

OBSERVATIONS OF FAINT COMETS AT
McDONALD OBSERVATORY: 1978-1980

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Modern observational techniques, developed for spectroscopy and photometry of faint galaxies and quasars, have been successfully applied to faint comets during the past two years on the 2.7 m telescope at McDonald Observatory. Under the Jet Propulsion Laboratory program to observe comets suitable for rendezvous missions, we have observed comets P/Tempel 2 and P/Encke. In addition, we have observed other available comets to provide a data base by which cometary coma models can be constrained. We have observed the periodic comets Van Biesbrock, Ashbrook-Jackson, Schwassmann-Wachmann 1, Tempel 2, Encke, Forbes, Brooks 2, Stephan-Oterma and the new comets Bradfield (19791), Bowell (1980b), Chernys-Petrauskas (1980k). The comets have ranged in magnitude from 10th to 20th magnitude. For comets fainter than 19th magnitude we have obtained reflectance spectra at 100Å resolution and area photometry. On comets of 17th or 18th magnitude, we have spectrometric scans (6Å resolution) of the nucleus or inner coma region. On those comets which are brighter than 16th magnitude we have done spatial spectrophotometric (6Å resolution) studies of the inner and extended comae. An extensive spatial study of the comae of P/Encke and P/Stephen-Oterma, correlated with heliocentric distance, is taking place during the latter half of 1980. The remainder of this report is directed to a brief description of our observing process and examples of the results obtained to date under our faint comet program. More complete descriptions of the instrumentation and the reduction procedures are available in Barker and Smith (1980), Barker, Smith and Cochran (1980), Cochran, Barker and Cochran (1980) and Barker and Rybski (1980).

Photometry

During January and February 1979, we used the digital area photometer (DAP) (Rybski, 1980) on the McDonald Observatory 2.7 m telescope to obtain broadband (S-20), B and V magnitudes of P/Tempel 2. The DAP employs an IDS (Intensified Dissector Scanner) detector and samples a 38 by 38 arcsec field with 0.6 arcsec pixels. It typically reaches a sky background of $21^m/6/\text{pixel}$ in V in five minutes to a precision of 2 percent. The notation $V(S-20)$ will be used for the observed S-20 magnitudes as transformed into V magnitudes via the relation $V(S-20) = M_{S20} + 1.79 \pm 0.10$ for solar type colors.

It is often assumed that comets are inactive at heliocentric distances greater than 3 a.u. Armed with this assumption, the goal of these observations was to obtain a rotation period for the nucleus of a comet. The observations encompassed a post-perihelion range from 3.1 to 3.5 a.u.

P/Tempel 2 had been observed by Spinrad et al. (1979) on 28 October and 29 December 1978 and found to be only 0.40 of a magnitude brighter than normal and not active. In late January Zellner et al. (1979) found P/Tempel 2 at least 2 magnitudes brighter than predicted.

Between 24 January and 28 January the mean $V(S-20)$ magnitude measured by the DAP system increased from 18.8 to 18.4. Prior to this outburst the comet's (B-V) color had been about 0.8. A (B-V) color of 0.59 on 29 January indicated that the comet was bluer during outburst than before. Zellner et al. (1978) also observed this outburst on 28 January reporting a V magnitude of 18.45 and a (B-V) of 0.6.

We observed a systematic decrease of 0^m4 over 3.5 hours in the $V(S-20)$ light curve on 28 and 29 January. Since the comet was about 2^m4 brighter than predicted for January (Yeomans, 1978), the light curve does not refer directly to the nuclear rotation unless we are seeing the effect of

a rotating zone of activity. Assuming we are seeing a rotation effect, the 28 and 29 January light curves are commensurate with rotation periods of 4.224, 5.008, and 6.336 hours, but the time base of the data is too short to reject any of these periods.

By 20 and 24 February, the mean V(S-20) magnitude had fallen to near normal levels (19.9), indicating little or no residual brightness from the January outburst. The observations of 24 February span only 50 minutes with an amplitude of 0^m.5 in that portion of the light curve. Assuming this minimum referred to the same physical location on the bare

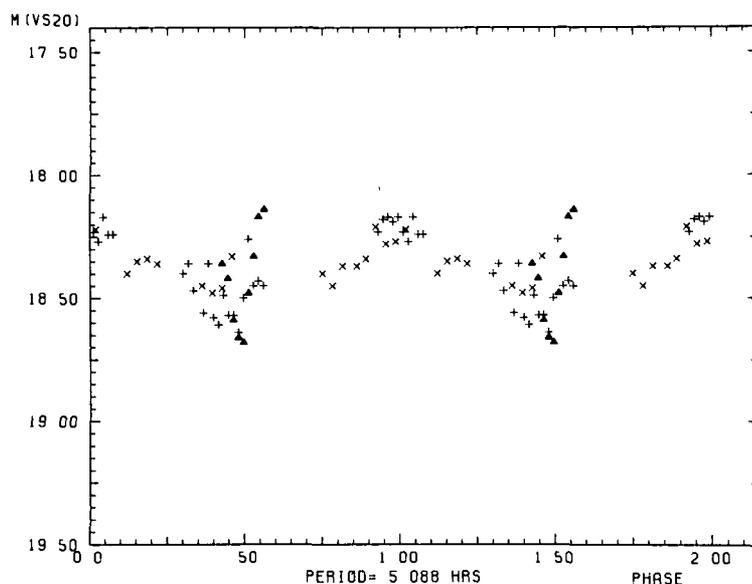


Figure 1. V(S-20) magnitudes of P/Tempel 2 for 28 January (+), 29 Jan (x) and 24 Feb (Δ) combined in phase space with a period of 5.008 hours.

nucleus as the minima in the comet activity seen in the data of 28-29 January, the periods given above are still viable. All of the P/Tempel 2 photometry (for $P = 5.008$) is shown in Figure 1. The photometry on 29 January and 24 February is normalized to the mean level of the 28th of January.

In an attempt to study its rotation period, P/Encke was observed with the DAP during August 1979 while it was at a heliocentric distance of 3.9 a.u. The observed mean V(S-20) magnitudes for 21, 22, 24 and 26 August were 18.25 ± 0.07 , 19.54 ± 0.20 , 19.39 ± 0.09 and 19.13 ± 0.35 , respectively. The mean activity level for 22-26 August was 19.35. An outburst of 1.1 magnitudes occurred on or before 21 August. On the best photometric night (21 August, shown in Figure 2), the variation in the V(S-20) magnitudes is small (± 0.07) and random indicating a lack of rotational variations or a masking of the nucleus by the outburst activity. The disagreement between the observed (19.35) and the predicted (20.05, Yeomans, 1979) value for the nuclear magnitude may be significant, but the mean value may still be affected by the 21 August outburst. The (B-V) color appears to be bluer during outburst (0.3 versus 0.8).

The difficulty of doing photometry on a 19th magnitude moving object is emphasized by the loss of a significant portion of two nights due to near occultations with 18th magnitude stars. Additionally, our experiences observing outbursts from these two comets have emphasized that the assumption of cometary inactivity at heliocentric distances > 3 a.u. is not entirely justified.

Area photometry obtained of P/Encke and P/Tempel 2 during outburst did not reveal a significant coma. In all pictures when the telescope was tracking at cometary track rates, the comet images looked stellar. However, the seeing disks restrict the upper limit to the coma size to less than 8000 km for both comets.

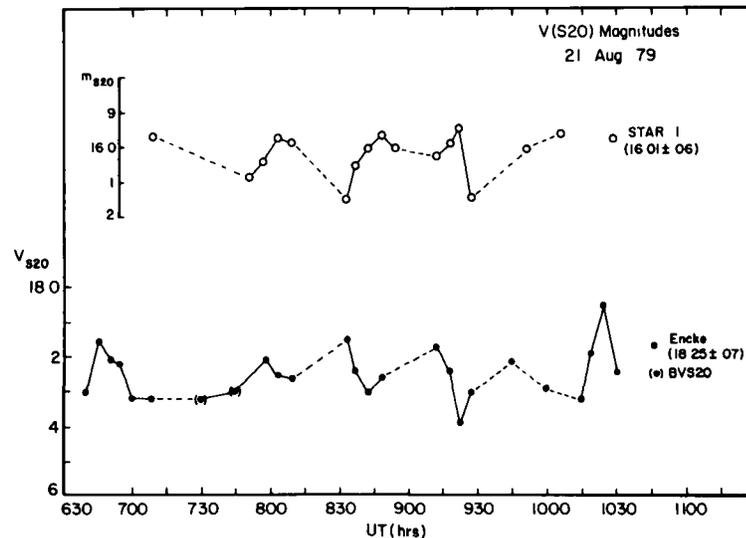


Figure 2. $V(S-20)$ magnitudes from 2.85 minute integrations on P/Encke on 21 August. The magnitudes for P/Encke were calibrated with standard stars and normalized to the S-20 observations of Star 1. The integrations were over a 23×23 pixel or 13.8×13.8 arcsec square aperture centered on the comet position. The B, V, S-20 magnitudes were determined at times indicated by (*). The solid lines connect sequential integrations and dashed lines indicate nonsequential integrations.

Spectrophotometry

An intensified dissector scanner (IDS) spectrograph (Rybski et al. 1977) has been used at the 2.7 m cassegrain focus to obtain spectrometric scans of comets. The McDonald IDS spectrograph images the dispersed light from two apertures in its slit plane onto the blue- or red-peaked S-20 photocathode of the first intensifier stage of a modified Robinson-Wampler-type intensified dissector scanner. Each 30 mm-long spectrum is sampled every $15 \mu\text{m}$ with the $30 \mu\text{m} \times 300 \mu\text{m}$ dissector slit (all measurements referred to the first photocathode), resulting in two digital spectra of 2048 samples each. The two apertures, 52 arcseconds apart, are alternately exposed to the "object plus sky" and "sky only" images. This switching procedure was carried out every 50 seconds resulting in a sky-subtracted spectrum. If the cometary emissions extended to 52 arcseconds from the nucleus, a separate observational sequence on sky several arcminutes from the comet was carried out. Various grating-slit combinations were used yielding nominal resolutions of 5, 11 and 20\AA . The typical apertures used correspond to a projected area on the sky of 4×4 arcsec.

Spectra of P/Tempel 2 on 30 November 1978 ($M_V = 19$) and several nights in January and February 1979 showed no gaseous emissions. A relative reflectance curve was derived from our data of 30 November 1978 by first averaging our spectrum into 100\AA bins and then ratioing to the Arvesen et al. (1969) solar spectrum. The result is shown in Figure 3. As seen in the figure, the slope of the reflectance curve closely matches that of an S type asteroid. The quality of the January and February data was limited by the intrinsic faintness of the comet ($M_V = 19 - 20$) and generally poor seeing on the nights when spectrometry was attempted.

The spectra and the (B-V) color (0.74 to 0.80) show P/Tempel 2 to be slightly redder than the sun prior to the January outburst. During the outburst, the (B-V) color of 0.60 was slightly bluer than the sun. The signal/noise of the spectra was insufficient to permit an exhaustive search for any cometary emissions during outbursts. However, if P/Tempel 2 is similar to P/Schwassmann-Wachmann 1 during outburst (Cochran et al., 1980), the brightness increase is primarily from an increase in the continuum level produced by the dust halo and not from emission lines.

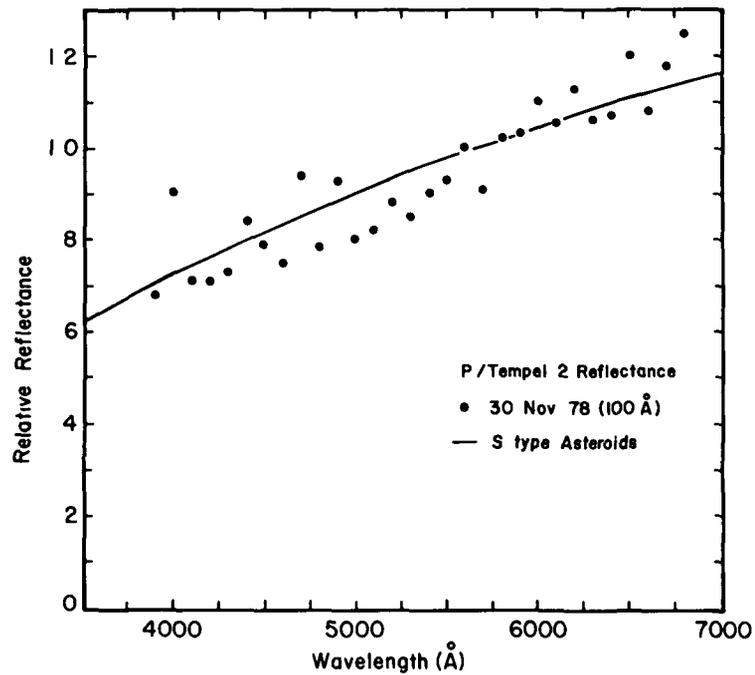


Figure 3. Relative reflectance of P/Tempel 2 on 30 Nov 78 averaged over 100Å bins and normalized at 5600Å. The S type asteroid curve is taken from Chapman and Gaffey (1979).

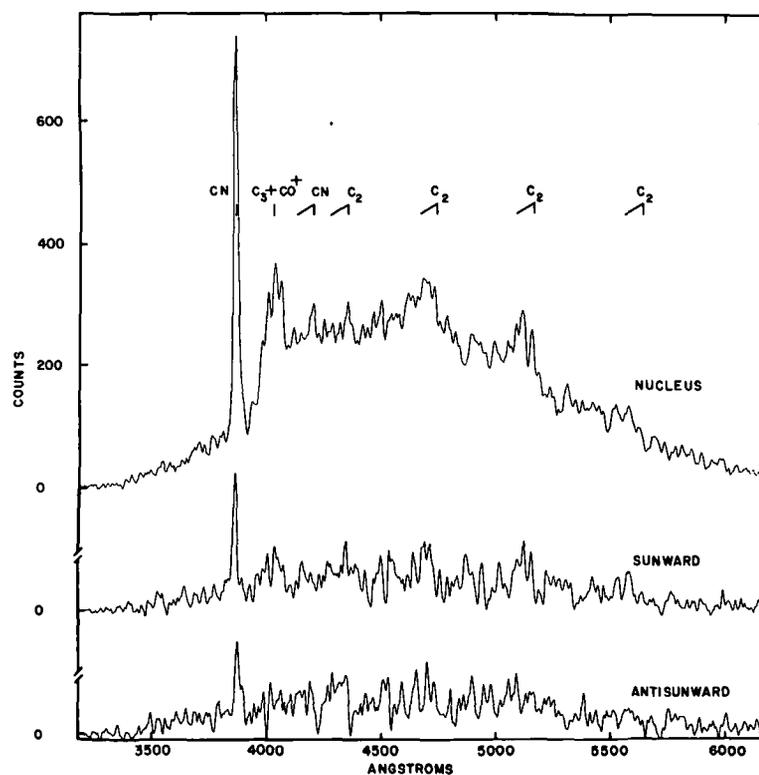


Figure 4. P/Encke with sky background subtracted taken on 18 September 1980 ($r = 1.55$ AU, $\Delta = 0.87$ AU). Instrumental response and flat field features have not yet been removed. The comet was about $18^m.4$ in a 4×4 arcsecond aperture. The upper spectrum is of the inner coma. The middle spectrum is of the coma on the sunward side 52 arcseconds away from the nucleus. The bottom spectrum is of the coma on the antisunward side 52 arcseconds away from the nucleus.

A featureless spectrum of P/Encke near aphelion was obtained on 27 August 1979 with a new blue IDS detector. The resulting 100Å resolution spectrum had a signal/noise too low (~ 2) to allow the determination of the reflectivity of P/Encke.

In July 1980, a systematic, monthly series of spectra of P/Encke was begun. By mid-September 1980, a well developed cometary spectrum showing CN, CO⁺, C₃ and C₂ molecular emissions was present in addition to a reflected solar continuum from the inner dust coma. Figure 4 presents an example of the spatial studies possible on an 18th magnitude comet. The CN emission coma was detectable out to at least 52 arcseconds from the inner dust coma. These spectra are just a sample of a much larger data set that is currently being compiled on P/Encke, P/Stephan-Oterma, and P/Brooks 2. The spectrometric data presented here must be considered only a progress report.

Summary

The assumption that periodic comets are quiescent at large (> 3 a.u.) heliocentric distances is proving to be erroneous, based on our photometry of P/Tempel 2 at 3.1 a.u. and P/Encke at 3.9 a.u. Both showed outbursts of greater than a magnitude. The colors of both comets appear to be bluer during outburst than before or after outburst. Rotation periods of 19 - 20th magnitude comets can be measured using the DAP system, if care is taken to avoid many periods of time when near occultations occur with field stars which are usually brighter than the comet. The ability of an area photometer to detect other objects which are in the field and which could add significant numbers of photons to the light from the comet makes the DAP system so ideal for comet photometry.

Emission rates and reflectance spectra can be obtained for comets brighter than 19th magnitude, but care must be taken to do accurate sky subtraction far enough away from the comet to avoid the extended coma. The use of a Reticon detector instead of an S-20 photocathode is planned for future observations. This will extend the observable red wavelength region to 1.1μ for comets brighter than about 15th magnitude.

Acknowledgements

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