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NONGRAVITATIONAL EFFECTS AND THE AGING OF PERIODIC COMETS

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We present a statistical analysis of nongravitational parameters (A_2) looking for evidence relating to the evolution of cometary nuclei. Our sample is restricted to short-period comets but is otherwise essentially complete up to 1990. Several alternative representations of the advance or delay of the time of perihelion passage ($\Delta P'$, $\Delta P''$, ΔP_e) are also introduced on the basis of simple theory. A correlation with the perihelion asymmetry previously shown to exist for $\Delta P'$ (Festou *et al.* 1990) is interpreted as evidence for an increase of the mean free-sublimating fraction of the nuclear surface and/or a decrease of the mean nuclear radius with perihelion distance. Comparison with data on the dynamical histories (Belyaev *et al.* 1986) is done by assigning "dynamical ages" (i.e., number of revolutions since the last major decrease of the perihelion distance) to the various nongravitational parameters. A rapid decrease of the mean value of $|\Delta P''|$ with dynamical age is found and interpreted as evidence for rapid build-up of dust mantles on the nuclei. A picture of the long-term evolution of Jupiter-family comets is thus tentatively suggested, whereby sizeable nuclei become dust-mantled in successive spurts associated with the settling into new orbits with smaller perihelion distances. Their active lifetimes could hence be estimated as the time required to reach the overall minimum of the perihelion distance, i.e., as roughly half the dynamical lifetimes.

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CARBON PETROLOGY IN COMETS.

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Chondritic porous [CP] interplanetary dust particles [IDPs] are the most likely candidates for cometary dust that we can study in our laboratories. Using the mineralogical, physical and chemical properties of CP IDPs, including CP particles that show evidence for incipient aqueous alteration[1-3], we can successfully interpret the data for dust in P/comet Halley[4,5]. The CP IDPs have higher bulk carbon contents than carbonaceous chondrites but lower carbon contents than silicate and mixed dust grains in P/comet Halley and the CP IDP intra-particle carbon contents are highly variable[6,7]. Cometary dust contains nebular material and preserved interstellar dust[8]. Thus, CP IDPs contain a record of conditions and processes that occurred in the outer regions of the solar nebula and they provide an opportunity to study the nature, production mechanisms and histories of carbon-rich materials in the evolving solar nebula and Solar System.

Carbon in CP IDPs is mostly reduced carbon but oxidised carbon is present [TABLE 1]. The arrows in the table indicate reaction paths linking carbon-rich materials in cometray dust as inferred from analytical electron microscope [AEM] analyses of CP IDPs. Important questions remain. What fraction of amorphous carbon and hydrocarbons is pristine nebular and interstellar dust and are the amorphous carbons and hydrocarbons forming the matrix of ultrafine-grained granular units (or tar balls) early accretion products[2] or the products of metamorphism of amorphous presolar dust[9]? The non-carbon mineralogy of CP IDP shows evidence for *in situ* aqueous alteration that also affected carbon-rich materials [TABLE 1] which provide data on the physico-chemical environments of neoformed carbon-rich materials. For example, turbostratic pre-graphitic carbons in CP IDPs (i.e., soft, mixed-layered carbons with C/[C+H+O+N] ratios similar to the groups D and E CHON paricles in P/comet Halley) formed via catalytically supported hydrous pyrolysis[10]. The soft carbons could be precursors of poorly graphitised carbons [PGCs] but the timing of PGC formation is uncertain [TABLE 1].

CONCLUSION. The AEM is an excellent tool to study the diversity of the carbon petrology in cometary dust that amply supports mineralogically active short-period comet nuclei. Some CP IDP carbon properties, inluding sulfur-bearing CHON particles, are comparable with P/comet Halley dust but the processes that produce the diverse carbon petrology are ill-understood.

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TABLE 1: CARBON MINERALS IN COMETARY DUST: A LITERATURE REVIEW

amorphous carbon + sulfur

hydrocarbons

[epsilon Fe,Ni carbide] × [carbon filaments]
[cohenite] × [amorphous carbon rims]

↓

{graphite microcrystallites}

lonsdaleite
turbostratic pre-graphitic carbons (C-H,O,N)

Magnesite

[poorly graphitised carbons]

Carbon-rich materials are indigenous (underlined) and form during parent body alteration (double underlined). Heterogeneous catalysis, e.g. Fischer-Tropsch reactions, carbon production in the nebula and by pyrometamorphism on atmospheric entry (brackets). Rare graphite results from solid-state interface controlled nucleation (braces).

WAKE IN FAINT TELEVISION METEORS; **M.C. Robertson† and R.L. Hawkes,** ***Physics Department, Mount Allison University, Sackville, New Brunswick, Canada E0A 3C0***

The quantitative dustball meteor model of Hawkes & Jones (**MNRAS**, 1975, **173**, 339-356) was used as the basis for numerical lag computations involving grains of different mass (range 10^{-8} to 10^{-15} kg), velocity (15, 41, 60 and 66 km s^{-1}), zenith angle (cos z values of 0.4, 0.7 and 1.0), bulk density (700 and 3500 kg m^{-3}), and height of ejection (range 75 to 160 km). The assumption was made that wake involving faint meteors would be mainly due to differential aerodynamic lag of detached grains. The numerical work suggested that, for the parameters used, the lag of a detached grain is seldom more than a few km during times of significant luminosity. True wake in faint television meteors is masked by the presence of apparent wake due to the combined effects of detector persistence and image blooming. To partially circumvent this problem, we modified a dual MCP intensified CID video detector by addition of a rotating shutter in order to reduce the effective exposure times to about 2.0 ms (with one exposure per 1/60 s video field). Preliminary observations have been made, with the unexpected result that only 2 of the 29 analyzed meteors displayed statistically significant lag. It is unclear at this time whether this is due to a failure in the two component dustball model, a remarkable uniformity in grain sizes, or simply the lack of spatial resolution or intensity discrimination of the dual MCP system.

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CHEMICAL AND PHYSICAL EFFECTS IN THE BULK OF COMETARY ANALOGS

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Cometary analogs of comet simulation experiments KOSI consist in essential of water ice, CO_2 ice, mineral dust and "organic components" such as CH_3OH ice, charcoal or kerogen. It could be shown by layerwise chemical analysis of the insolated samples by means of gas chromatography that the volatiles (CO_2, CH_3OH) diffused partly into the interior of the LN_2 cooled water ice - mineral dust matrices. They recondensed in colder layers, the more volatile the deeper, such as in a kind of "thermochromatography" leading to the formation of crystallites and to the occurrence of hard but permeable layers in some depth beneath the surface. The formation and strength of the crusts depends on the ratio of solid components and condensed gases. In particular CO_2 does not cocrystallize with H_2O ice, where it seems to bind together mineral grains. The ratios of the naturally occuring isotopes H/D, $^{12}C/^{13}C$, and $^{16}O/^{18}O$ were measured by mass spectrometry after melting and degassing of the samples in gas phase (CO_2) and remaining liquid (H_2O). A strong enrichment of the heavier isotopes was observed in the crustal regions. The results of visual inspection, test of material strength by drilling, and concentration profiles of chemical components in particular of experiments KOSI-6 and 7 are compared with the isotopic distribution. The analysis of the bulk of cometary analogs shows a high degree of differentiation of a formerly homogeneous body with its thermal history.

Sulfur-bearing species in comets

E. E. Roettger, S. A. Budzien, and P. D. Feldman (Johns Hopkins University)

The recent detection in cometary comae of H_2S (Colom *et al.* 1990) and upper limits on OCS, H_2CS (Bockelée-Morvan *et al.* 1990), SO, SO_2 (Kim and A'Hearn 1991), and S_2 (Feldman and Budzien 1989) permit a re-evaluation of the source of the atomic sulfur commonly detected in *IUE* spectra of comets. Photodissociation of CS_2, as inferred from the observed emission of CS, generally cannot provide all the observed atomic sulfur, as first pointed out by Azoulay and Festou (1985). The reported abundance of H_2S is found to be adequate to make up the difference in comet Austin ($1989c_1$), for which near-simultaneous ultraviolet and radio data are available. The relative S_2/H_2O production rate is found to be at least an order of magnitude lower in comet Austin ($1989c_1$) than was observed in comet IRAS-Araki-Alcock (1983 VII), the only comet to date in which S_2 was detected. Upper limits on SO and SO_2 are also derived for comet Austin. S_2, SO, and SO_2 do not contribute much of the atomic sulfur observed in comet Austin. Possible contributions from OCS and H_2CS are also evaluated.

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EVOLUTION OF NEAR UV HALLEY'S SPECTRUM IN THE INNER COMA

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The near UV spectra obtained in the 280-330 nm with the three-channel spectrometer of Vega 2 show an intense solar-scattered continuum at distances smaller than 7 000 km. For instance, at a distance of 540 km, the dust-scattered continuum is comparable to the OH intensity at 309 nm. The solar type contribution to the spectra is substracted from the spectrometric data to obtain the component due to molecular emissions. In the inner coma, these spectra exhibit a progressive evolution with decreasing cometocentric distance.

Two spectra obtained when the projected distance to the optical axis was 3 631 and 538 km are compared. Their intensities are normalized to obtain a good superposition of the OH band profile. The longer wavelength band wing shows an emission excess between 315 and 325 nm. This additional intensity is interpreted as being probably due to prompt OH emission that results of water vapor photolysis at $\lambda < 136$nm following the process : $H_2O + h\nu \rightarrow H + OH\ (A_2\Sigma^+)$. The branching ratio is generally assumed equal to 7.5%, at the wavelength of Lyman α, where the major part of the OH ($A_2\Sigma^+$) radicals are produced. New laboratory results are used to compute the prompt emission and compare the resulting synthetic spectrum with the Vega data.

At shorter wavelengths, the spectrum shows the presence of the OH (1,0) band. The CO_2^+ band at 289 nm generally is not present in the spectra. Two new features appear at 285 nm and as a broad band between 293 and 303 nm. The region around 290 nm is an intensity minimum. In an attempt to identify the S_2 fluorescence band system, the spectrum of comet IRAS obtained with IUE is plotted under the Vega spectra. It cannot be concluded that S_2 is present in these spectra because the minimum at 290 nm contradicts the presence of the intense ($B^3\Sigma_u \rightarrow X^3\Sigma_g$) (7,0) and (9,1) bands of S_2. The spatial distribution of the 293-303 nm broad-band emission is displayed as a monochromatic chart of the field of view scanned by the spectrometer. It appears to be a mother-molecule distribution with a scalelength of 10 000 km. Many molecules show fluorescence bands in this spectral region. Among them are polycyclic hydrocarbons with two or three aromatic cycles or formaldehyde and its CHO photolysis product.

Mosaic CCD Method: A New Method for Observation of Dynamics of Cometary Magnetospheres

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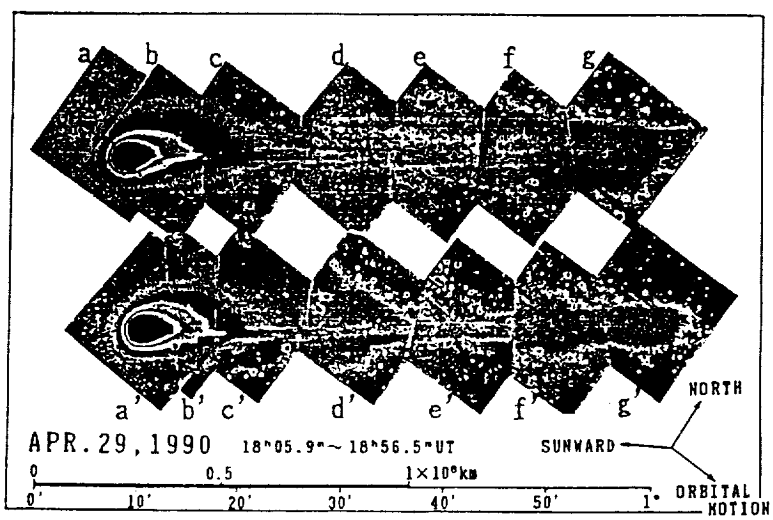
5. NAO, Japan

The plasma tail of comet Austin was observed at the Kiso Observatory of The University of Tokyo, with a new technique that is temporarily called "the mosaic CCD method". The comet was taken with a CCD (charge-coupled device) on the 105cmϕ Schmidt telescope. Two sets of seven photographs were taken each with 40-second exposure during about 50 minutes from 18h05m to 18h56mUT on April 29, 1990. The cometary magnetosphere about 1.6×10^6 km long was covered by each set of photographs. The figure shows the photographs. Six microstructures containing arcade structures were selected to examine the plasma velocity near the root of the plasma tail. It was found that the plasma had some finite velocity V_N at the apparent nucleus position and that thereafter it was accelerated as expected from the Minami and White theory. Dynamical characteristics of the arcade structure are well explained by the previous three-dimensional model of the cometary magnetosphere. A new concept is introduced on the plasma flow along the dayside plasmasphere surrounding the cometary nucleus; the plasma on the solar wind magnetic field must have some finite azimuthal speed at the stagnation point of the solar wind. The plasma is accelerated and carried along the plasmapause with the velocity reaching V_N when it crosses the earth-comet nucleus line.



Determination of Time Dependent Production Rates in Comets

N. H. Samarasinha and M. F. A'Hearn (UMD)

Despite the variability of gas and dust production by comets, steady state models are normally used to analyze observations. Steady state models whether Haser, vectorial or even Monte Carlo models, are not capable of "recovering" the production rates as a function of time. Sometimes application of steady state models can give completely inappropriate results.

We have developed a model to "recover" the gas and dust production rates from a set of photometric observations taken over time. We have applied this model to determine the production rates for Comet Levy on a function of time. IUE Fine Error Sensor data as well as spectroscopic data were utilized for this purpose. The tentative conclusions indicate possible chemical inhomogeneities in the nucleus.

The free parameters involved in the model are production rates, life times and velocities of the species involved. If we know all except one of the parameters reasonably well, the model is capable of well determining the other parameter. A dense time series of observations are important for proper determination of production rates.

LIGHT SCATTERING BY TETRAHEDRAL PARTICLES WITH ROUGH SURFACES; T. Satoh, and K. Kawabata, Science University of Tokyo. H. Hasegawa, ASTEC Inc. M. Iwase, OLYMPUS Opt., Co.

Studying the light scattering processes by non-spherical (irregularly shaped) particles is very important for a wide range of astrophysical researches; it should be applicable to the photometrical and polarimetrical observations of asteroids, cometary dusts, interstellar dusts, and cloud particles of outer planets. However, practical methods to compute scattering properties of arbitrary shaped and oriented particles are not yet available today. We have tried to compute the scattering characteristics of tetrahedral particles which have rough surface.

The roughness of the tetrahedral surface is approximated by arranging small spheres on it. To simplify model computations, we have adopted following assumptions; (1) the size of sphere is comparable with the wavelength of light, and scattering by the sphere is according to Mie theory. (2) tetrahedron is large enough compared with the wavelength, so that the scattering by tetrahedron is represented by simple geometrical reflection and refraction law. (3) spheres and tetrahedron are composed of the same material, therefore refractive indices of them are identical. (4) scattering processes in the spheres and in the tetrahedron are separately computed and then synthesized. A FORTRAN program was generated and the computations were carried out on an EWS SPARC station 330.

Computational results and applications to several astrophysical observations will be reported.

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The Anomalous Molecular Abundances of Comet P/Wolf-Harrington

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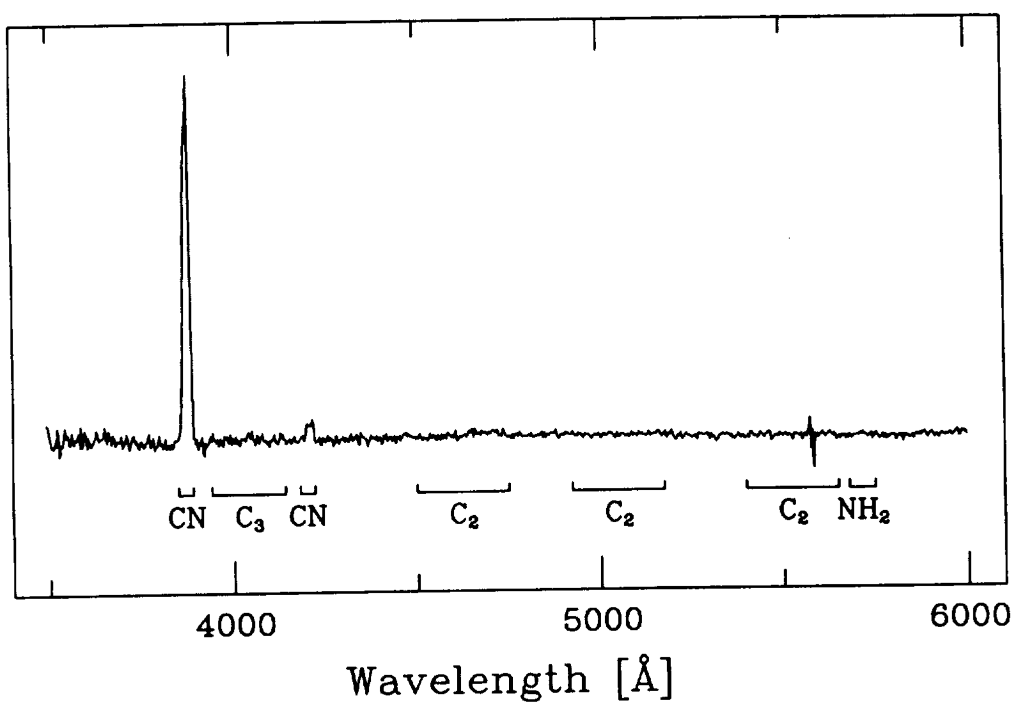
Lowell Observatory

As part of an on-going program of comet photometry at Lowell Observatory, Comet P/Wolf–Harrington was observed on September 29, 1984. These data indicated that Wolf–Harrington had atypical abundance ratios, similar in sense yet more extreme than those previously reported for Comet P/Giacobini–Zinner (Schleicher, Millis, and Birch 1987). Narrowband filter photometry of Wolf-Harrington obtained on 4 additional nights this winter confirms that both the C_2 and C_3 abundances are anomalously low when compared either to OH or to CN. Moreover, the depletion of these pure carbon species – less than 1/20th normal – is the most extreme case observed in the current photometry database of 80 comets (cf. Millis *etal.* 1989). A spectrum obtained in February of this year using the MMT further verifies this conclusion. After subtraction of the continuum, only CN is clearly evident in the spectrum (shown below). In addition to final values for the C_2 and C_3 abundances, we will also present values for the relative abundances of NH and NH_2. This research is supported by a grant from the NASA Planetary Astronomy Program.



Comet Levy (1990c): Groundbased Photometric Results

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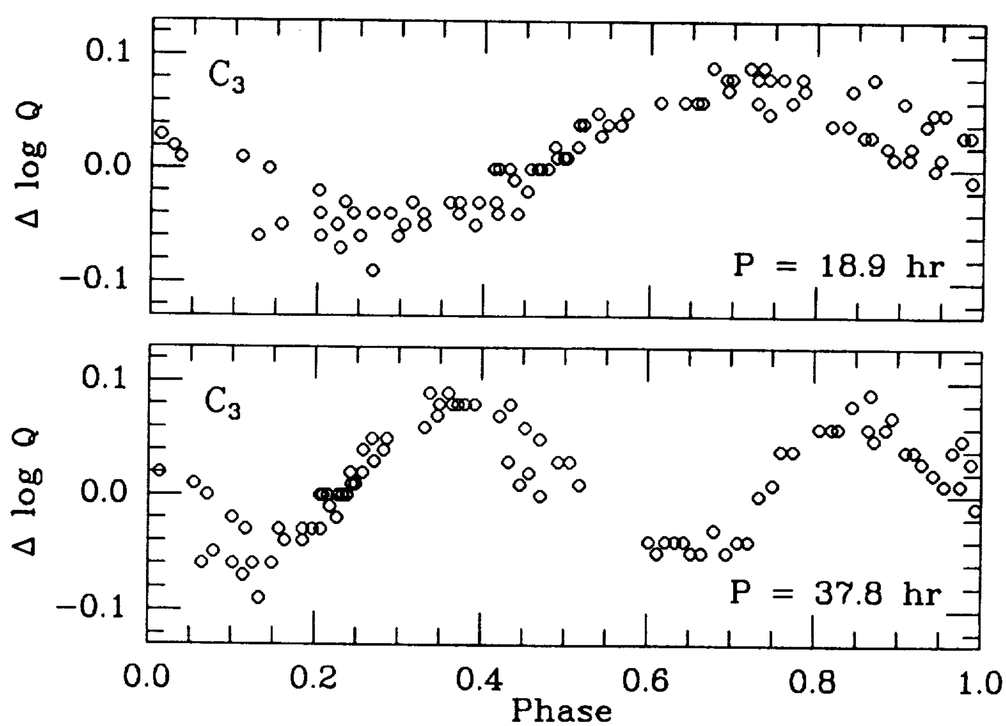
Lowell Observatory

and Peter V. Birch
Perth Observatory

Narrowband filter photometry of Comet Levy (1990c) has thus far been obtained on 27 nights at Lowell Observatory and 21 nights at Perth Observatory in the interval from 3 June 1990 to 17 March 1991. The emission bands of OH, NH, CN, C_3, and C_2 were isolated, along with continuum points at 3650 Å and 4845 Å. Relative abundances among the species were typical of most comets previously observed. All species showed pronounced asymmetry about perihelion, with production rates for most species being about twice as large before perihelion as after over the heliocentric distance range of 1.0–2.4 AU. The OH production rate's asymmetry was nearly double that observed for the other species, with maximum production occuring more than a month before other species. Periodic variations having a single-peaked lightcurve period of 18.9 hrs or a double-peaked lightcurve period of 37.8 hrs (see below) were observed in both the gas and dust during late–August 1990. Possible reasons for this behavior and their implications will be presented. This research is supported by a grant from the NASA Planetary Astronomy Program.



SUB-MILLIMETER MOLECULAR LINE OBSERVATIONS OF COMET LEVY

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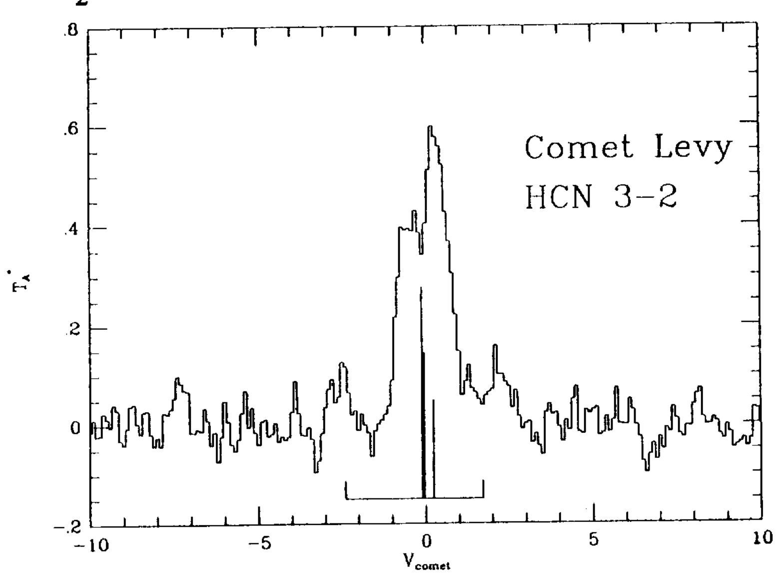
We present molecular line observations of HCN, H_2CO, and CH_3OH in Comet Levy. The comet was observed on 4 nights from 29 August - 1 September 1990 at the Caltech Submillimeter Observatory on Mauna Kea. Detections were made of the HCN J=3-2 transition at 265.886 GHz, the HCN J=4-3 transition at 354.505 GHz, the H_2CO 5_{15}-4_{14} transition at 351.769 GHz, and several transitions of the CH_3OH 5-4 band at 241.8 GHz. Of these transitions, only the HCN 3-2 line has been previously observed in a comet.

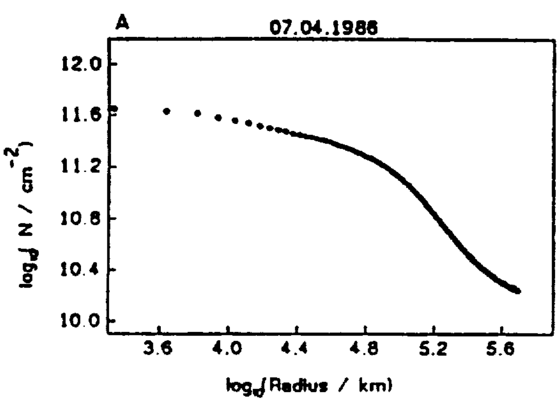
The HCN J=3-2 observations were carried out on 29 August, and a high (0.1 km s^{-1}) resolution spectrum is shown in the figure below. The HCN production rate is approximately 2 X 10^{26} s^{-1}, and given the overall gas production rates reported for Comet Levy, the abundance of HCN is consistent with that seen in other comets. The spectral line shape shown in the figure, is reasonably well fit by a model in which the HCN gas originates at the nucleus and flows radially outward at a velocity of 0.8 km s^{-1}, although some residual features remain. Further constraints on the distribution of HCN in the coma were obtained by mapping the HCN emission from the comet. The HCN map shows a large asymmetry in its emission with the strongest emission arising from the sunward side of the coma. Such an asymmetry is naturally consistent with the asymmetric outgassing from comet nucleii, observed indirectly from doppler shifts of spectral lines and directly from images of the coma. An analysis is underway to fit a model to the spectral line shape and the map in order to recover the 3D distribution of HCN in the coma.

The HCN J=4-3 and H_2CO 5_{15}-4_{14} transitions were observed simultaneously on the nights of 30 and 31 August. Once again, the lines were detected and small maps were made of the distribution of these molecules around the source. The strength of the HCN 4-3 line is consistent with the production rate derived for the HCN 3-2 line for a rotational temperature of approximately 30K. Some caution must be observed in this comparison, however, since both the HCN and H_2CO lines were observed to vary in intensity between the two nights that they were observed. The H_2CO line was detected 30 arcsec off of the nucleus position. Since H_2CO molecules that arise from the nucleus are expected to be photodestroyed by the time that they reach this position, we conclude that the observed extended emission must be due to an extended source for H_2CO in the coma. Therefore, we are presently fitting a vectorial model to the H_2CO data to determine its production rate and verify its origin in the coma.



SPATIAL AND TEMPORAL VARIATIONS IN THE COLUMN DENSITY DISTRIBUTION OF COMET HALLEY'S CN COMA; R. Schulz, W. Schlosser, W. Meisser, P. Koczet, Astronomisches Institut, Ruhr-Universität Bochum, F.R.G., W.E. Celnik, Wilhelm-Foerster-Sternwarte, Berlin, F.R.G.

Mean radial column density profiles of comet Halley's CN coma have been derived from photographic observations obtained at ESO, La Silla (Chile) from 14 March to 16 March, 1986 and 1 April to 10 April, 1986. The CN photographs were digitized and sensitometric spots were used for relative intensity calibrations. The transformation into column densities was conducted by means of photoelectric measurements carried out simultaneously with the Bochum 61 cm Cassegrain telescope at ESO, La Silla. The resulting images correspond to two-dimensional column density profiles of the CN coma. From every image one mean radial column density profile was constructed by azimuthal averaging around the nucleus. Two examples for resulting profiles are shown in Fig. 1. The shapes of the profiles show continuously new formed 'bumps', which were shifted to outer coma regions as a function of time. It will be demonstrated, that these 'bumps' correspond to the CN shells found in the coma of Comet Halley (Schulz & Schlosser, 1989). The temporal changes of column density in the near-nucleus region will be compared to brightness variations in the inner coma of Comet Halley found by photoelectric measurements (Millis & Schleicher, 1986). The question of outbursts as a possible explanation for the 'bumps' in the radial column density profiles will be discussed with regard to the results of the analysis of intensity profiles from 4 December, 1985 (Festou et al., 1990).



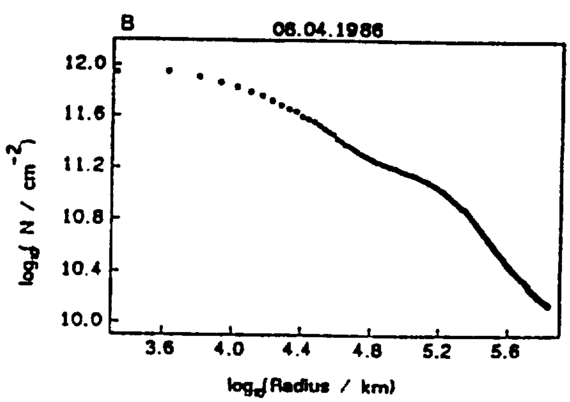


Fig. 1 Mean radial column density profiles from 7 April 1986, 2.31 UT (A) and 8 April 1986, 2.16 UT (B)

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ROSETTA - COMET NUCLEUS SAMPLE RETURN; G. Schwehm, ESA Rosetta Study Scientist for the ESA/NASA Rosetta Science Definition Team. Space Science Department of ESA, Noordwijk, The Netherlands

Research on comet-nucleus samples will carry the exploration of the solar system to its outer fringes. Rosetta - the Comet Nucleus Sample Return Mission - will begin to provide scientific study of the pre-solar environment and possibly sample materials from interstellar and galactic regimes. This study of the most primitive material in the solar system will provide an experimental approach to the determination of the chemical and physical processes that marked the beginning of that system 4.6 billion years ago.

The mission will address some of the most profound questions Space Science can ask, as it will provide information going back to our beginnings, the very roots from which everything has sprung, the planets, the sun, and life itself. Rosetta by its very nature is a generic new type of mission: its prime objective is to return a comet nucleus sample to Earth in a state as undisturbed as technically feasible so that it can be studied in Earth-based laboratories with the most sophisticated analytical techniques. However, by fulfilling its prime objective it will provide the opportunity for unique cometary science. The highest priority for in situ science will be given to those measurements that will make it possible to select and document the sampling site, to monitor the cometary environment for spacecraft hazards and contamination, and to support the near-nuclear navigation during the final approach and landing phase.

THE GIOTTO EXTENDED MISSION; G. Schwehm, Space Science Department of ESA, Noordwijk, The Netherlands
T. Morley, Orbit and Attitude Division, European Space Operations Centre, Darmstadt, Germany

The navigation of the ESA spacecraft Giotto to its encounter with comet P/Halley on 14 March 1986 required just 10% of the fuel available. Although the spacecraft was damaged by dust impacts during its close flyby of the nucleus of P/Halley it was retargeted to return close to Earth in order to maintain the option of extending the mission to encounter another comet, P/Grigg-Skjellerup on 10 July 1992.

On 2 April 1986 the spacecraft was put into hibernation configuration, orbiting the Sun in the ecliptic with an orbital period of 10 months. On 19 February 1990 it was reactivated and the spacecraft subsystems and payload were checked out to determine its health status.

On 2 July 1990 Giotto performed successfully the first-ever Earth gravity assist manoeuvre of a spacecraft approaching the Earth from deep space and was retargeted for comet P/Grigg-Skjellerup.

Despite the loss of four of its eleven instruments during the Halley encounter, it was concluded that the spacecraft is ready to provide valuable data during a potential encounter with a second comet.

Science investigations which can be performed with the remaining payload complement include:

- characterisation of the changing features of the solar-wind flow and observation of cometary pick-up ions and anomalous acceleration;
- determination of electron densities;
- observation of upstream waves, determination of the locations of the various boundaries (bow shock, ionopause, cometopause, etc.);
- observation of the magnetic pile-up region and cavity;
- determination of the dust spatial density and size distribution and the optical properties of the dust grains;
- study of discrete gaseous emissions;
- determination of combined dust and gas densities.

On 10th July 1992, ESA's GIOTTO spacecraft will encounter its second comet, P/Grigg-Skjellerup, at a relative speed of 14 km/s with closest approach occurring between 15:15 and 15:30 UT. Since the Halley Multi-colour Camera (HMC) is no longer functioning, it is likely that the spacecraft will be aimed directly at the nucleus. The final targeting does not need to be made until about two days before encounter, but whatever the choice, there is a requirement for the highest possible accuracy.

Giotto, in its encounter with P/Halley, benefitted from the two VEGA spacecraft acting as pathfinders to improve the knowledge of the orbit of Comet P/Halley. Such an opportunity does not exist for the Giotto Extended Mission, and the improvement of the cometary ephemeris will depend solely on the quantity and quality of ground-based astrometric measurements.

Observing conditions during the 1992 apparition of P/Grigg-Skjellerup are not very favourable. In particular, obtaining astrometric data during a few weeks immediately before encounter, which analysis has shown is the most useful period for improving the comet's orbit, will present a challenging task.

AUTOMATED DETECTION OF ASTEROIDS IN REAL-TIME WITH THE SPACEWATCH TELESCOPE; J. V. Scotti, D. L. Rabinowitz, and T. Gehrels, Lunar and Planetary Laboratory, University of Arizona, Tucson, Arizona, 85721

The Spacewatch 0.91-meter Newtonian telescope of the Steward Observatory on Kitt Peak is being used during the 18 nights centered on new moon to survey for Near-Earth asteroids using a TK2048 CCD in scanning mode. We hope to identify suitable low ΔV candidates amongst the Near-Earth asteroid population as possible exploration targets, as well as to study the physical properties of the objects in Near-Earth space. Between 1990 September and 1991 March, 12 Earth Approaching asteroids including 1 Aten, 9 Apollo, and 2 Amor type asteroids have been detected by automated software and discriminated by their angular rates from the rest of the detected asteroids in near-real-time by the observer. The average of about two Earth Approaching asteroids per month is comparable to the total number found by all other observatories combined. One other Apollo type asteroid was detected by the observer as a long trailed image. The positions of this last object were measured and the object was tracked by the observer in real-time. This object was determined to be a 6-12 meter object which passed within 170 000 kilometers of Earth. Of the 12 automatically detected Earth Approaching asteroids, 9 have been found at distances in excess of 0.6 AU from Earth. Approximate elements, the discovery brightness, the distance from Earth at discovery, the derived absolute magnitude, the estimated diameter, and the type for each discovery are shown in Table 1. Additionally, an average of more than 2000 other asteroids are detected each month. Positions, angular rates, and brightnesses are determined for each of these asteroids in real-time.

Table 1 – Spacewatch Near Earth Asteroid Discoveries

1989 October – 1991 March

Design.	a	e	i	V	Δ	H	D	class
				(1.0km – 10.0km)				
1990 TG1	2.48	.692	9.1	19.1	1.915	15.0	4.6	APO
1991 AM	1.63	.688	29.7	18.6	0.907	16.5	2.3	APO
1991 CB1	1.69	.622	15.8	21.1	1.157	18.0	1.3	APO
1991 EE	2.25	.624	9.8	19.4	0.904	17.5	1.5	APO
1991 FA	2.02	.466	3.2	18.7	0.830	17.5	1.5	AMO
1991 FE	2.31	.536	4.5	17.9	1.647	14.5	5.8	APO
				(0.1km – 1.0km)				
1989 UP	1.86	.473	3.9	15.8	0.061	20.7	0.3	APO
1990 SS	1.70	.475	19.4	18.9	0.623	19.0	0.9	APO
1990 UO	1.23	.758	29.3	20.5	0.604	20.5	0.4	APO
1990 UP	1.33	.169	28.1	18.1	0.210	20.5	0.4	AMO
1990 VA	0.99	.279	14.2	17.9	0.230	19.5	0.6	ATE
1991 BN	1.44	.398	3.4	20.9	0.672	20.0	0.5	APO
				(< 0.1km)				
1990 UN	1.71	.528	3.7	19.9	0.119	23.5	0.09	APO
1991 BA	2.24	.682	2.0	17.5	0.005	28.5	0.009	APO

NUCLEUS MODEL FOR PERIODIC COMET TEMPEL 2. *Zdenek Sekanina*, Jet Propulsion Laboratory, California Institute of Technology

Observational data obtained primarily during 1988 are analyzed and synthesized to develop a comprehensive physical model for the nucleus of Periodic Comet Tempel 2, one of the best studied members of Jupiter's family of short-period comets. It is confirmed that a previous investigation (Sekanina 1987, ESA SP-278, pp. 323–336) provided reliable information on the comet's spin-axis orientation, which implies an obliquity of 54° of the orbit plane to the equatorial plane and which appears to have varied little—if at all—with time. This conclusion is critical for fitting a triaxial ellipsoid to approximate the figure of the nucleus. Its dimensions are found to be $16.4 \times 9.8 \times 7.0$ km, if A'Hearn *et al.*'s (1989, Astrophys. J. **347**, pp. 1155–1166) visual geometric albedo of 0.022 is accepted. While the nucleus of P/Tempel 2 is similar to that of P/Halley in volume and surface area, it is distinctly more flattened in the polar direction. Forced precession, caused by torques from outgassing, is shown to be negligible, but there may be an effect on the nucleus spin rate. If this effect was insignificant in the period of February–June 1988, the remarkable invariability of the comet's sidereal rotation period, derived to be $8^h55^m55^s.2$ with a formal uncertainty of only $\pm 0^s.2$, would indicate general correctness of the employed spin-vector positional determination. Temporal variations in the production of water cannot be fitted on the assumption of outgassing from a *flat* region (or regions). An appreciable depth is implied, leading to the conclusion that the source is most probably a vent-like depression (or depressions). Assuming that outgassing is possible only from the depression's floor when it is sunlit and that there is no outgassing from the walls, the best match is found for an effective diameter-to-depth ratio of 1.6, a total floor area of 14 km^2, and a slope angle of the walls of 81°. The total loss rate of water is estimated at 10^{13} g per revolution about the Sun. Deconvolution of the observed optical and thermal infrared diurnal light curves consistently reveals the existence of three isolated vents on the nucleus within about 30° of the northern rotation pole. Modeling of a collimated flow of dust ejecta from a vent indicates the presence of disintegrating particles in the coma, whose typical lifetimes are 25–30 hr. The differential size distribution for large grains varies inversely as the cube of particle size, with a poorly defined cutoff radius of 1 mm. There is also some evidence for a population of very short-lived, perhaps water ice, grains. The dust production rate on 22–30 June is found to have amounted to 10^5 g/s, implying a dust-to-water production rate ratio of 0.7–1.0 by mass. The proposed model indicates that the calculated nucleus figure corresponds to one of the hydrostatic equilibrium configurations known as Jacobi ellipsoids. The derived sidereal rotation period suggests an "equilibrium" nucleus density of 0.54 g/cm^3 and implies that the comet's nucleus cannot be subjected to significant hydrostatic forces. To facilitate future testing of the nucleus model, predictions are provided for expected temporal variations (i) in the axial orientation of the fan-shaped coma, (ii) in the parameters of the optical and thermal infrared diurnal light curves of the nucleus, and (iii) in the water production rate. It is noted that the comet's return of 2005 is so extremely unfavorable to earth-based optical monitoring for several months on either side of perihelion that the choice of P/Tempel 2 as the target for the Comet Rendezvous Asteroid Flyby mission at this return would restrict active-phase supporting observations only to the infrared and radio wavelengths. The complete description of the present investigation is scheduled to appear in the July 1991 issue of *The Astronomical Journal*.