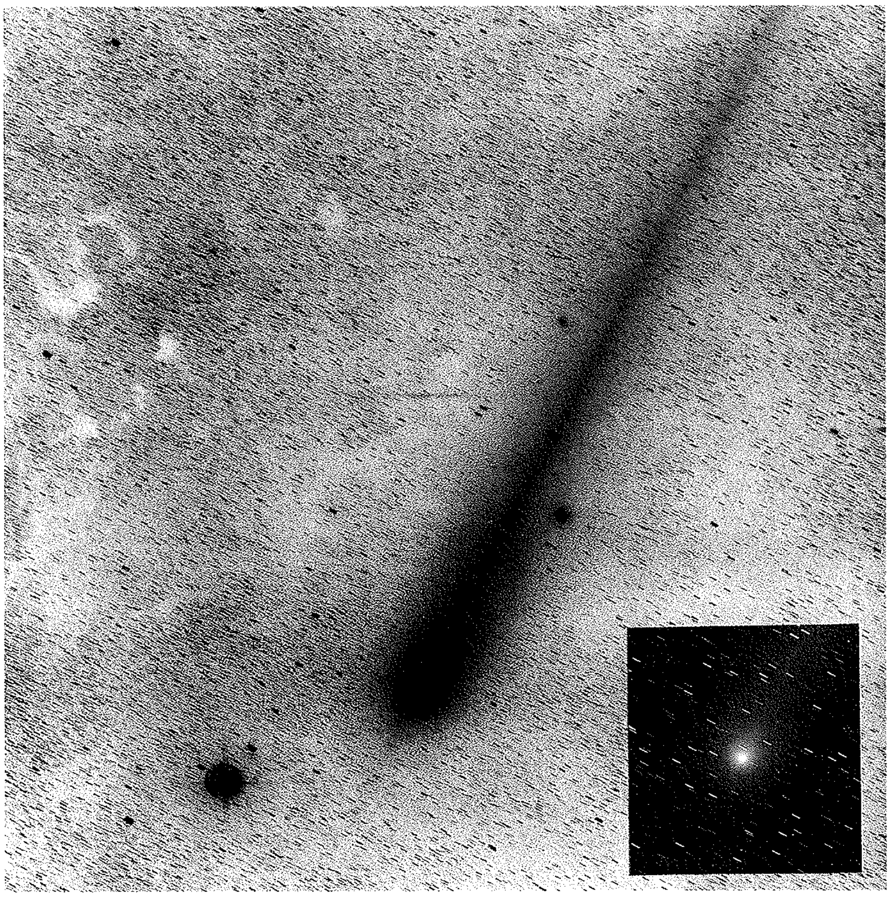

Figure 4: *Comet Austin is here seen on a 10-min B exposure (IIa-O + 66 385), obtained by Guido Pizarro with the 1-m ESO Schmidt on June 5.39, and photographically enhanced by Hans-Hermann Heyer, ESO-Garching. Of particular interest is the so-called "neck-line" structure which is seen as a 1.5-arcmin wide, straight dense structure, stretching at least 2.6 degrees (to the plate border) within a broader, diffuse and rather faint envelope. A much weaker sunward spike can be followed in the opposite direction to about 30 arcmin distance from the nucleus. Both features represent sunlight reflected in dust particles ejected from the comet, and are visible when the Earth crosses through the comet's orbital plane. They were predicted by M. Fulle (Trieste) and L. Pansecchi (Bologna) in April 1990 (IAU Circular 4991). The insert shows the region around the nucleus.*

we ought to take such measurements more into account in the future.

Observations of Comet Austin

All of this should not hide the fact that Comet Austin was still a relatively bright comet with a fine tail and a good study object for both professional and amateur astronomers. Many photometric and spectroscopic observations were performed with large telescopes and quite a few amateurs took impressive photos; two are shown here (Figures 2 and 3). While this comet may have been another "flop" for the general public, it was a good opportunity to make use of the means and methods from the Halley campaign.

Observations at La Silla began in late May, when Comet Austin crossed the celestial equator and again became accessible from the southern hemisphere. There was too little time to prepare a detailed summary for this *Messenger* issue, but it is expected to bring more information in one of the next issues. In the meantime we reproduce here one of the first photos (Figure 4) taken with the ESO 1-m Schmidt telescope in early June.

We know for sure that a really bright comet will appear again sometime – statistically there are about 4 to 5 such objects per century. But we cannot predict when this will happen . . .

A Delicate Postscriptum

Maybe we astronomers should learn to better resist the pressure of those media who want sensations. When we make an – admittedly not very accurate! – prediction of a comet's maximum brightness, say, as magnitude 0 ± 2, many journalists have a built-in tendency to overlook the plus-sign; it is a safe bet that you will read in the press that the comet is expected to reach "-2 mag or possibly brighter" and become as bright as the brightest planets. And when the comet after all only reaches magnitude 2, then we are asked why we were off by 4 magnitudes . . .

Acknowledgements

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Asteroids: A Key to Understand the Evolution of the Solar System

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1. Introduction

Asteroids are believed to be remnant planetesimals from the crucial period of planetary formation and are mostly located in the transition region, separating the terrestrial planets from the jovian ones. There the planetary formation process was interrupted at an intermediate stage owing to an unknown mechanism, probably associated with the gravitational influence of the massive proto-Jupiter.

Asteroid eccentricities and inclinations were pumped up, thereby increasing collision velocities, and transforming

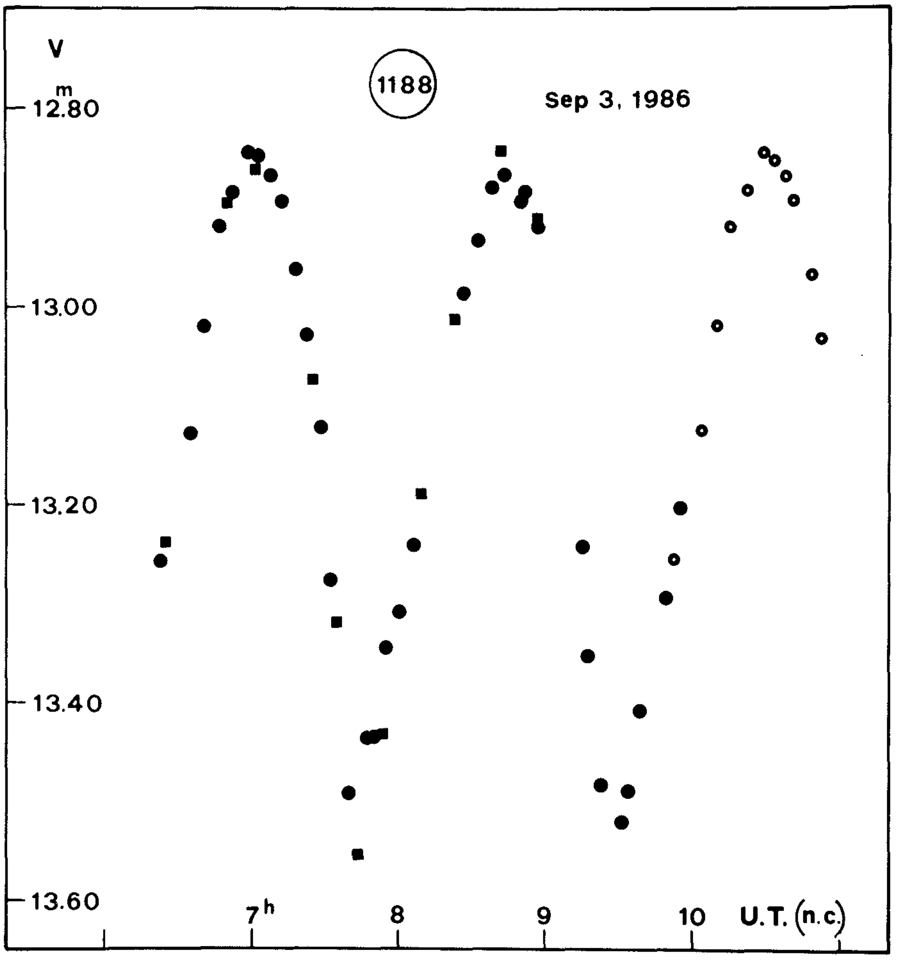

Figure 1: *Composite lightcurve of asteroid 1188 Gothlandia obtained on September 2–3, 1986 with the 1-m telescope at La Silla. The obtained rotational synodic period is 3.493 ± 0.07 hours and the lightcurve amplitude 0.67 ± 0.01 mag.*
(■) Sep 2; (●) Sep 3, 1986. Open symbols are repeated points.

the accretion among planetesimals into collisional destruction and erosion. Impacts have altered asteroid sizes, physical structures and rotation rates over the course of solar system history; however, the magnitude of these changes is not yet well understood. Collisional comminution among the asteroids continues to the present.

Asteroids comprise a great diversity of objects, with wide variations in mineralogy, in size (sub-km to 950 km in diameter), in spin rate (a few hours to two months), in shape (spherical to elongated or even binary), and in solar system location. Most of them should be constituted of essentially unaltered primitive material in which is preserved important information about the chemical composition and the environmental conditions of the protoplanetary nebula and the processes that produced the planetary bodies: asteroids would represent the last remnant of the swarm of planetesimals which formed the terrestrial planets.

Even though asteroids remain points of light through ground-based telescopes, the knowledge of these small bodies has considerably improved over the last twenty years, but the asteroid population is still poorly known with respect to the other bodies of the solar system which have been explored by spacecraft. Ground-based observations provide the only available information.

Most of the current knowledge on asteroid rotational properties (rotation period and pole direction) and on their shapes is deduced by analysing the amplitude and the behaviour of the lightcurves obtained by photoelectric and CCD photometry. Surface albedo homogeneity is estimated on the basis of three- or eight-colour photometry; chemical composition of the surface materials is deduced comparing the IR reflectance spectra of asteroids with those of different materials (meteorites, lunar and terrestrial rocks, etc.) obtained in the laboratory, while significant contributions to the knowledge of the physical properties of these materials have been obtained by radiometry and polarimetry and on the basis of the few available radar observations. Star occultations and speckle interferometry give better data on asteroid shapes and pole orientation, but these measurements are difficult and only few data are presently available.

Editor's note: This paper is published in response to a request from the ESO Observing Programmes Committee, whose members suggested that an overview of current theories of asteroid formation, etc. should be prepared. We are thankful that Drs. Di Martino, Barucci and Fulchignoni have taken on this task and feel sure that many readers of the *Messenger* will appreciate this concise summary of minor planet work.

2. Current Knowledge

2.1 Rotation

Asteroid magnitudes vary periodically as they spin, mostly because of changes in cross section for nonspherical bodies but also because of surface albedo variations and scattering anomalies. Amplitudes are typically 0.1 to 0.3 mag but can exceed 1 mag. To date, there are about 4500 numbered minor planets, and we know the rotation periods of about 600 objects, but the rotation data set for the smaller objects is very incomplete when compared with the rotation periods available for asteroids larger than 100 km. In fact, only less than 10 % of objects with diameter smaller than 50 km have been observed and have a well-determined rotation period, while the percentage is 30–40 % for objects of about 100 km, and close to 100 % for asteroids larger than 200 km. It follows that special efforts should be made to enlarge the available set for the smaller asteroids.

The first lightcurve of a minor planet was obtained in 1901 of 433 Eros, and in the next years light variations were observed for several other asteroids, at first by unreliable photographic photometry which was replaced in the 1950s by photoelectric photometry. In general, we can assert that asteroids are irregular bodies, partially spotted by albedo features. However, the contribution of this second characteristic is very small when compared to the variation of the projected shape during rotation. Lightcurves dominated by shape exhibit two maxima and two minima per period (see Fig. 1) for obvious geometrical reasons. Variability due solely to albedo features can yield any number of maxima per period, but most commonly one. When the lightcurve is dominated by albedo variegations it is possible to have ambiguity in determining the rotation period (Zappalà et al., 1983). A few asteroid lightcurve amplitudes are too small to reveal reliable rotation periods.

Plotting the available asteroid rotation rates versus their diameter by a so-called "running box" technique, that was first used for asteroid rotation rates by Dermott et al. (1984), there appears to be an increase in the rotation rates for very large objects, relative to the smaller ones (see Fig. 2). It is as if the marked change in the rotation-diameter distribution at sizes of about 100 km may separate primordial asteroids (right) from their collisional products (left). A possible trend towards more rapid rotation rates is present among the very small asteroids, but there is also an excess of slowly rotating objects below a size of about 50 km (this is evident in the figure from the increase in the dispersion for the lower size range), and the distribution of rotation rates among the smallest asteroids is distinctly bimodal. Unfortunately, for these objects the results are only indicative because, as already noted, they are affected by the incompleteness of the data set.

2.2 Shape

We have some indications on asteroid silhouettes that can be derived from star occultations, which give the cross-sections of asteroids in the plane perpendicular to the line of sight. Although this result is aspect dependent, star occultations (Millis and Dunham, 1989) indicate that larger asteroids have either a spherical or an ellipsoidal shape, while radar delay-Doppler images of small asteroids (Ostro, 1989) show more irregular shapes. On the hypothesis that the asteroids evolved collisionally from planetesimal swarms, these observations can be easily interpreted: the largest bodies (D $\geqslant$ 200 km) are the remnants of the original population characterized by equilibrium figures, while decreasing the size increases the number of irregularly shaped asteroids, affected or produced by disruptive collisions. This interpretation is confirmed by the most recent results from experimental studies of catastrophic fragmentation processes (Fujiwara et al., 1989, Capaccioni et al., 1986).

The images of the smaller bodies of the solar system (satellites of Mars and minimoons of Jupiter, Saturn and Uranus), obtained during space missions, show that elongated shapes are common in the size range 20 to 200 km. For this reason, bi- and triaxial ellipsoids seem to be a realistic approximation of the shape of most asteroids.

The lightcurve of an asteroid constitutes the primary observational data needed to determine its shape and pole direction. Much work has been carried out to determine these parameters from the observed light variations, also by comparing the observations with laboratory simulations that help in understanding how each parameter (shape, orientation and surface morphology) influences the lightcurve (Ostro and Connelly, 1984; Barucci et al., 1989).

Barucci et al. (1989) analysed asteroids with known rotation periods by means of Fourier analysis of all lightcurves published before 1985. They used a sample of about one hundred "best observed" objects to discuss their shape distribution. The sample was subdivided in four categories: 32 % of the selected asteroids have been classified as more or less elongated ellipsoids, 25 % irregular, 23 % spheroids and 20 % as objects probably characterized by albedo features.

2.3 Pole Direction

The methods for pole determination can be summarized as follows: photometric astrometry (Taylor, 1979), amplitude-aspect and/or magnitude-aspect relation (Zappalà et al., 1983), speckle interferometry (Drummond et al., 1985), methods combining epochs of extrema and amplitude-aspect relations (Magnusson, 1983; for a review of pole determination methods, see Magnusson, 1989). The method based on the lightcurve amplitude as a function of the position of the asteroid in its orbit (amplitude-magnitude method) has already given spin axis directions for about 30 asteroids with a good accuracy. The amplitude-magnitude (AM) method can be applied when complete lightcurves, obtained during at least 3 different oppositions, are available. In this way we can obtain a rough estimate of the pole direction: the larger the number of lightcurves at different ecliptic longitudes, the more accurate is the determination. Astrometric and speckle interferometry methods are in principle more accurate, but are also more difficult to apply and have resulted in about ten additional determinations up to now.

The number of asteroids with known pole directions is too small to perform conclusive statistical studies, but from a preliminary analysis there seems to be a distinct bimodality in the pole direction distribution (Fig. 3).

The determination of the pole direction of asteroids should lead to a better understanding of the role of the colli-

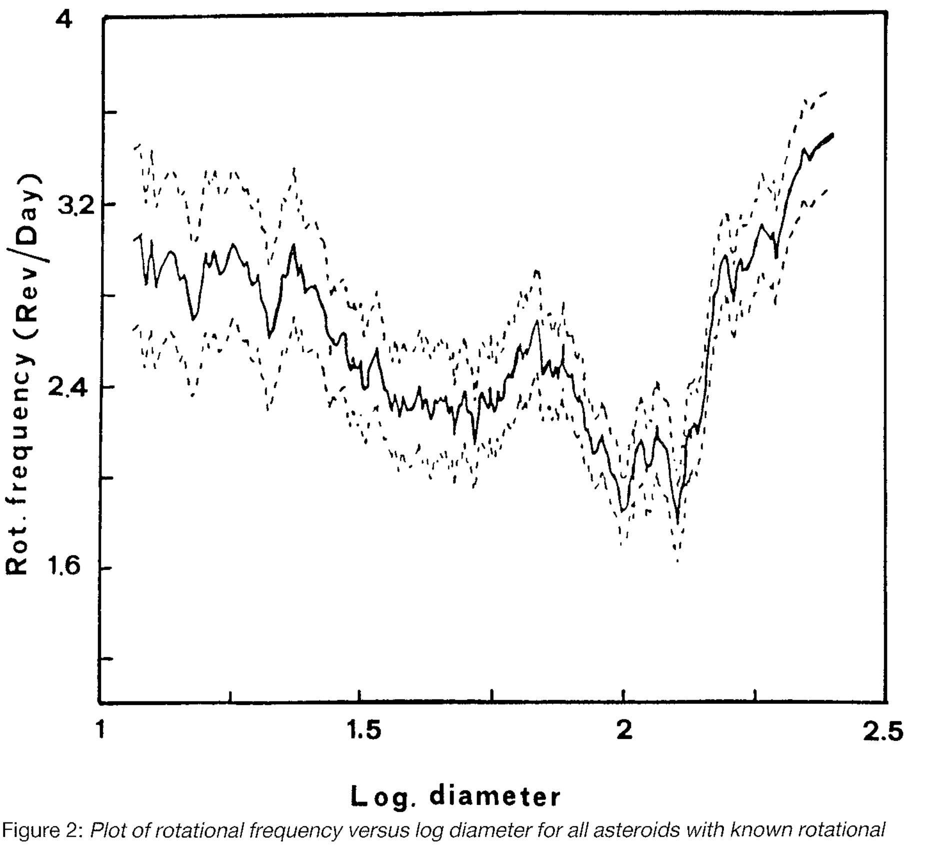

Figure 2: *Plot of rotational frequency versus log diameter for all asteroids with known rotational period, excluding the planet-crossing objects and members of the major dynamical families. The "running-box" contained n = N/10 asteroids (N is the total number of objects in the sample) and was stepped through the population one asteroid at a time over the entire diameter range. One-sigma uncertainties are shown above and below the mean (dashed lines).*

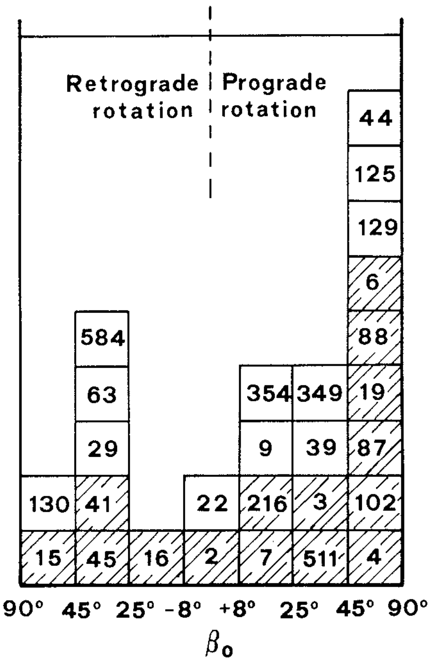

Figure 3: *Distribution of pole ecliptic latitudes (β_o) for 27 main-belt asteroids whose pole direction has been determined with good accuracy. Shaded boxes indicate objects larger than 200 km.*

sional processes in shaping the physical characters of the population: a distribution with a preferential orientation would record the initial state of the axis inclinations, while a random distribution would indicate a complete reorientation of the spin axes due to the prevalence of collisions.

2.4 Taxonomy and Composition

The chemical composition of asteroids is of great interest because the different mineralogical assemblages may give interesting clues to the understanding of the primordial processes that took place in the solar nebula and during the early stages of the accretion. The principal source of information about composition comes from spectral analysis of reflected sunlight, although other techniques like polarimetry, radiometry and radar have yielded important contributions.

Many taxonomic classifications have been developed in the last decade (for a review, see Tholen, 1989), aiming at understanding some of the physical and compositional properties of the asteroid population. Two recent works are based on multivariate statistical analysis of asteroids for which a homogeneous set of spectrophotometric data, from ultraviolet to infrared, are available (Tholen, 1984; Barucci et al., 1987, which complete the data set with IRAS albedos). Barucci et al. analysed 442 asteroids and in this sample identified nine major taxonomic types, namely B, E, G, C, M, D, S, V, A and interpreted the links between the classes in terms of genetic trends. To understand better their possible evolution, they compared the asteroid classes with some meteorite samples.

In Figure 4 the classes are reported in a diagram where four trends are distinguished by the arrows that leave from D asteroids (dark objects with very red spectra suggesting the presence of low-temperature organic compounds and typical of the Trojan group) supposed to be primitive objects which have undergone little or nor heating. Each arrow goes towards an "end class" and its direction generally indicates a decrease in heliocentric distance.

The first trend links together the D cluster with the B one, including the C class (probably similar in composition to carbonaceous chondritic meteorites). This trend might be interpreted in terms of volatile content reduction. According to this interpretation, the class D samples are richer in volatiles, while the B's are the poorest due to higher formation temperature.

The second trend, connecting the D to the E class through G and M, may be interpreted as a progressive evolution of the solar nebula condensates (D) towards the enstatite achondrites (E) through an ultraprimitive, high-carbon, low-metamorphic-grade C-type mineral assemblage (G) and a reduction (transition metal free) silicate similar to the enstatite chondrites (M). The E asteroids may be composed by the silicates formed when enstatite chondritic bodies (M) were differentiated.

The third and fourth trends ending at V and A classes, respectively, seem to represent lines of increasing differentiation, starting from the undifferentiated material D. The third trend connects the D class (through a subunit of S asteroids) to the V class whose end members are covered by basaltic material (4 Vesta) and olivine/pyroxene rich materials (349 Dembowska and 192 Nausikaa). The fourth trend connects the primitive D cluster to the A unit and contains most of the S asteroids, whose spectra show bands due to silicates. The A asteroids show in their spectrum an olivine absorption band that may represent the signature of mantle material of a differentiated body.

In the asteroid population a great diversity of albedos is present. Accounting for the observational biases, about 75% of the asteroids are found to be very dark, with average albedo of about 0.3 (D, C, and B types), another group of objects presents an albedo of about 0.15 (S, E, M, and V types), few asteroids lie in between, while some bright bodies have albedos up to 0.40 or more.

Very interesting is the fact that, in general, different taxonomic types are located at different heliocentric distances. This compositional gradient is interpreted as a "portrait" of the solar nebula matter, which condensed into

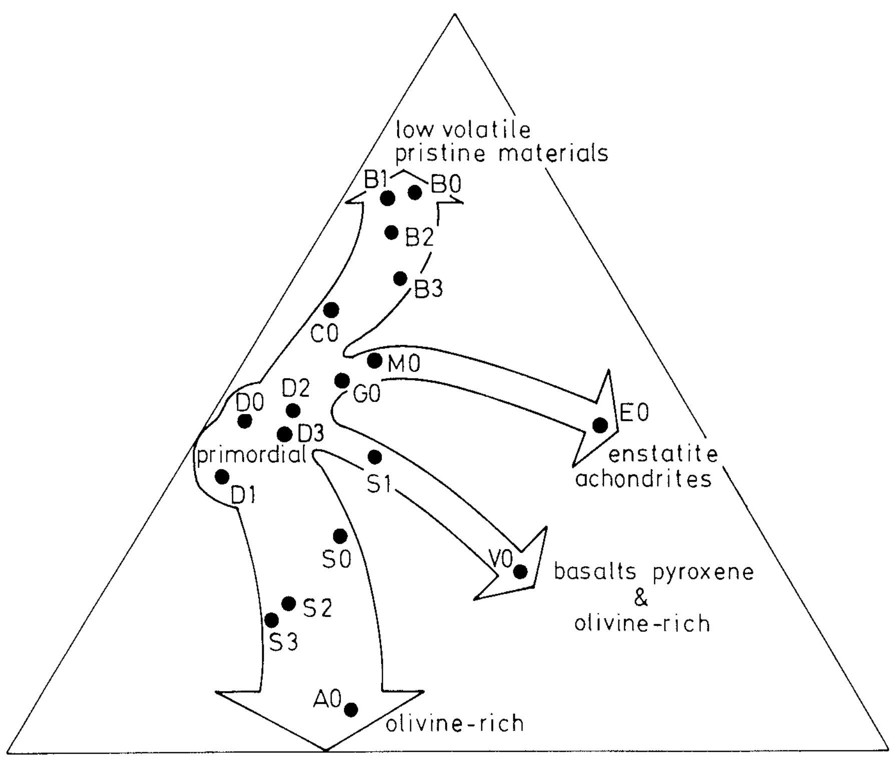

Figure 4: *Diagram showing the evolutionary compositional trends of asteroids. The arrows leave from D-type objects supposed to be primitive objects which have undergone little or no heating.*

solid grains first, then formed the planetesimals. This variation in the composition was clearly related to the temperature decrease with solar distance. It is also noteworthy that asteroids belonging to primitive taxonomic types (corresponding to least metamorphosed material) are present in the outer belt regions.

3. Collisional Evolution and Asteroid Families

During the last decade, several theoretical and statistical articles (Binzel et al., 1988; Davis et al., 1985, 1989; Farinella et al., 1981, 1982; Zappalà et al., 1984) have shown how important the mutual collisions among asteroids are for outlining the evolution of the main belt following the primordial phases. The outcome of collisions are strongly size-dependent, in the sense that the largest asteroids ($D \geqslant 300$ km) appear not to have been strongly affected by catastrophic events. In the case of intermediate size objects ($100 \leqslant D \leqslant 300$) the largest probable impact energy is close to the limits for disruption and for the transfer of a quasi-critical amount of angular momentum. In this size range is possible the formation of binaries, triaxial equilibrium ellipsoids, and dynamical families, i.e. groupings of asteroids significantly clustered in three orbital elements: semi-major axis (a), eccentricity (e), and inclination (i). In this case, self-gravitation prevents complete dispersion of the target asteroid fragments. In fact, most of the dispersed mass is reaccumulated by the mutual gravitational attraction of the fragments and the resulting objects may be described as a "rubble-pile" or a mega-regolith asteroid (Farinella et al., 1981), in which rocks from crust, mantle, and core of a differentiated body have been jumbled up, thus forming a group of bodies dominated by self-gravitation. Such bodies, owing to their state of fragmentation, will relax in hydrostatic equilibrium figures consistent with their angular momentum.

If, following the catastrophic impact, the initial velocity of some fragments exceed the escape velocity of the target, a few of them may escape, reaching heliocentric orbits with elements very close to those of the larger remnant. In this case an "asymmetric dynamical family" is formed by a large object and a small tail of a few minor asteroids. When the target mass decreases, the probability to obtain dynamical families increases significantly. In this case the families are not only formed by the asymmetric tail of high-velocity fragments originating close to the impact point, but they are formed by bodies ejected in all the directions. We have then the so-called "dispersed families". Finally, the smaller asteroids can be considered single fragments generated by catastrophic impact disruptions. Their shapes can be irregular since they are dominated by solid-state forces and their rotation rate is connected with the partitioning of the angular momentum which occurred during the catastrophic break-up of their parent body (Chapman et al., 1989).

In conclusion, we can state that most of the asteroid population can be considered to have been influenced by collisional processes and the observed differentiations may be due to the physical differences of the target asteroids, to their varying size and also to the various impact velocities and geometry. However, this description involves some important points which must still be better understood, either because of the presence of very severe selection effects in the available ground-based observing data, or because of discrepancies between the real cases and the results of laboratory hypervelocity impact experiments (Fujiwara et al., 1989).

4. Some Open Problems

4.1 Apollo-Amor-Atens (AAA) Asteroids

Among the small bodies of the solar system, the Earth (Apollo and Atens) and Mars (Amor) crossing asteroid population may contain a small but meaningful sample of primitive objects. The AAA asteroids are generally quite small, of the order of 5 km in diameter. The growing number of discoveries of such objects with large aphelion distances and carbonaceous-type reflectance spectra strongly suggests that part of them may derive from cometary sources (are they extinct comets?). On the other hand, the AAA with typical diameters of about 1 km could correspond to a low-mass tail of the distribution of fragments produced in catastrophic collisions which occurred in the main belt and then injected into the inner regions of the solar system.

Comparison of the properties of comets and asteroids of the AAA class is complicated by the fact that not much is known about the rotational properties and spectra of these asteroids. Photometry and spectroscopy of these objects is difficult since they are faint and in favourable positions for observation during a short time only. Some interesting insight into their origins could be obtained through a more complete rotational period data set. Up to now only for about 20% of the known AAA population (about 90 objects out of an estimated population of about 1000) have complete lightcurves been obtained.

4.2 Distant Asteroids

Owing to their great heliocentric distance and their corresponding faintness, few observational data have been obtained on Trojans ($a \sim 5.2$ AU) and on outer-main-belt asteroids belonging to the Hilda ($a \sim 4$ AU) and Cybele ($a \sim 3.4$ AU) groups. These objects are of considerable interest because of recent discoveries, both about their composition and the possible evolution of their orbits (Milani and Nobili, 1985). Distant asteroids predominantly belong to taxonomic classes characterized by low albedo and red colours, and observational results from comet nuclei suggest a similiar classification (Hartmann et al., 1987). To explain the dark, reddish surfaces of D-type asteroids, which make up more than half of Trojans, Gradie and Veverka (1980) suggested that the spectra of D-type material can be reproduced by a mixture of silicates with carbonaceous compounds, even more primitive than those found in the carbonaceous chondrites. This is in agreement with current condensation theories about the formation of the solar system and is supported by the spectral studies of Vilas and Smith (1985), who observed an increasing reddening of asteroid spectra with heliocentric distance among the Cybele, Hilda and Trojan groups of asteroids. Eight-colour photometry of the outer jovian satellites, at the same heliocentric distance as the Trojans, shows however that these objects are probably mostly C-type. This "mixing" of C and D types – D in the Trojan groups and C in the jovian system – poses a complication for the standard formation model of direct correlation between asteroid composition and heliocentric distance. The identification of D material in the saturnian satellite system and the similarity between the continuum spectra of some old comets to those of D objects suggest that the Trojans may not have formed at their present location, but further out, and could be related to comets.

For the above-mentioned reasons, observations of distant groups of asteroids ($a \geqslant 3.25$ AU) should be considered highly important, offering the possibility to collect data on objects quite different from the main-belt population.

5. Conclusions

Space missions devoted to the exploration of small bodies of the solar system, such as Vesta, CRAF and Rosetta, or including asteroid fly-by, as Galileo and Cassini, will give a wealth of high-quality data on the asteroid population. Not a single close-up picture of a minor planet is yet available, but more information on asteroid rotations, shapes, poles and compositional types would provide interesting clues in understanding the role of collisions in producing the observed asteroid belt and more in general in the evolution of the solar system. Moreover, the data coming from *in situ* measurements will be detailed enough to clarify the nature and the interrelationships between small bodies populations, if any. Are some of the Earth-crossing asteroids nuclei of dead comets? Are the meteorites fragments of asteroids disrupted by mutual collisions, or are they the smallest size tail of the asteroidal size distribution? Are double or multiple systems present among asteroids?

In order to give an answer to these and other questions, while we wait for the results of the space missions, it is necessary to improve the number and quality of data on asteroids: unbiased and detailed Earth-based surveys, ISO orbiting observatory results and Space Telescope inputs will be the main sources of the future data. Embedded in the asteroid belt may be the clues that will help us to unravel the structure of the early solar system, to learn about the planetesimals and their evolution, and to fathom the mechanism by which planet-building was halted in this part of our planetary system.

Thanks to the ESO facilities, especially in the last five years, a lot of data, both physical and astrometric, were obtained on asteroids. Nevertheless, many unsolved problems still remain open and among these the most intriguing are: (i) the knowledge of physical characteristics and origin of outer main belt and AAA asteroids, (ii) the collisional evolution of main belt objects and the related origin of dynamical families.

So far ESO has provided to the European asteroidal community small telescopes only (ESO 50-cm and 1-m, Bochum 61-cm, Danish 1.52-m and GPO). But in order to deepen our knowledge on asteroids and to solve, at least partially, the above-mentioned problems, the availability of larger instruments will be necessary, in particular, for photometric, polarimetric and spectroscopic observations.

Asteroids may be "small" and "near", nevertheless they deserve being investigated by means of large telescopes!

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The Dust Tail of Comet Wilson 1987 VII

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1. Introduction

Several photographic plates, both in red and blue light, were obtained by means of the ESO Schmidt camera to study the dust and plasma tails of Comet Wilson 1987 VII. All these plates were calibrated by means of calibration wedges and therefore are suitable for a quantitative analysis of the dust and ion tails. The pass-band of the emulsion-filter combination of red plates is from 630 to 700 nm, close to the R photometric system. We used plates 6810, 6829 and 6842 to study the dust environment of C/1987 VII before perihelion by means of the inverse numerical method which was successfully tested on C/1973 XII and C/1962 III (Fulle, 1989).

This model considers $\mathbf{N}_t \times \mathbf{N}_\mu \times \mathbf{N}_s$ sample dust grains, where $\mathbf{N}_t$ is the number of samples in the time interval of dust ejection, $\mathbf{N}_\mu$ is the number of samples in the sizes, and $\mathbf{N}_s$ is the number of grains of a fixed size uniformly distributed on a dust shell. It considers different ejection geometries for each of which the ejection of dust is restricted to a cone of half width w with its symmetry axis pointing toward the Sun. The position of each grain at the observation is derived from its keplerian motion, then projected into the photographic plane coordinate system, so as to obtain the model distribution of the scattered light from the tail and the related kernel matrix A. The solutions are given by the minimization of the functional $[AF-I]^2 + \beta[BF]^2$, where A is the kernel matrix, I is the data vector containing the dust tail