FUTURE WORK

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In the past decade the question has been raised, at IAU meetings, as to whether more asteroids should be discovered, and the answer now is: "Yes, indeed, do discover as many comets and asteroids as possible." Marsden[1] gives strong encouragement to search for "lost" comets and asteroids. The more ephemerides known the better physical and statistical studies we can make. We have completion of the asteroids now to about 14 mag. With existing patrol instruments of about 25 cm opening, for instance at Indiana and in South Africa, the limiting magnitude for an extended program is about 16.

Another survey such as the Yerkes-McDonald survey but to somewhat fainter limit than before (~16th mag) would be valuable to reach completion, and to provide a uniform set of observations for improved statistical studies. The principal problem at present for such a survey lies not in the availability of funds or telescopes, but in the lack of dedicated personnel such as Van Biesbroeck and the van Houtens to execute the enormous task of blinking, identification, etc.

Any photographic surveying of the sky would increase the chance of discovering additional asteroids that cross the orbit of Mars. Special searches for Mars-orbit crossers could be made perhaps with long exposures on baked IIIa-J emulsion at the Palomar Big Schmidt. All photographic observers should be aware of the importance of reporting trails within 24 hr to an observer who will follow the object. Even if the trail is only two or three times the usual length, it may belong to an Apollo (this was the case for 1971 FA);[2] because people until now have noticed only long trails, there are many Mars crossers still to be discovered. It is not clear, however, how to distinguish, from a single night's observation, the real asteroids from space hardware. (See Aksnes.[3])

Two weeks after the colloquium, I used the Palomar Big Schmidt to take plates for Trojans in the following lagrangian point of Jupiter, and the plates were, as before, sent to the van Houtens for blinking, reduction, and analysis (van Houten et al., 1970). The statistics of the Trojans in the *Ephemeris* are peculiar: The following point has only about half the number of objects as are present in the preceding point. If this is a real effect, we should then find only

[1]See p. 413. [2]See p. 647. [3]See p. 649.

350 Trojans this time compared to 700 in the preceding point; this will be a challenging problem for theoretical work.

Tombaugh (1961) has reported on the completion of asteroids outside the orbit of Jupiter.[4] Kowal[5] and others have searched in vain for Trojans of Saturn; Rabe does not give us too much likelihood of stability in the lagrangian points L_4 and L_5 of Saturn because of perturbations by Jupiter. The plates taken in March 1971 for the Trojan survey in the following lagrangian point happened to cover also L_4 of the Neptune-Sun system; we blinked these, with 1 day interval, and found no Trojan of Neptune; the limit of this reconnaissance is estimated to be $B(a, 0) \sim 20.0$. Further search for Trojans of Neptune might be considered, with longer exposures on baked IIIa-J and/or a larger telescope. Objects of asteroidal size farther out than ~30 AU are not detectable. (See Tombaugh, 1961.)

As interested users of the astrometric work and of that in celestial mechanics we gain the impression that the computation of the orbits is well controlled. The Institute of Theoretical Astronomy in Leningrad and the Minor Planet Center at Cincinnati, assisted by many other people and observatories, can very well keep up with the needs now that high-speed electronic computers are available. All users and interested parties will join me in strongly endorsing these programs, the development of new techniques and additional high-precision studies of orbital characteristics, as well as the production of ephemerides. We presently lack extended ephemerides in the yearly book, but these will be published again in the near future.

The naming of minor planets by the discoverer should be controlled to follow tighter rules than are presently applied. Perhaps Asteroid Commission 20 of the IAU would look into this. Rules might be followed similar to those for naming regions on Mars and on the Moon. Members of the IAU might wish to consider action on the proposal I made in Brighton, in 1970, to form a new IAU commission for physical studies of minor planets.

Additional determinations of asteroid diameters should be made with micrometer, disk meter, and other techniques. The infrared method pioneered by Allen[6] and Matson[7] is promising, especially for making comparisons. For absolute determination and calibration we need more asteroids that have had their diameters determined by direct means, and this remark applies also to the indirect method from the polarization-phase relation as Veverka and others have tried on Icarus.[8] Even with the conventional micrometer it may be possible to observe more asteroids, when at perihelion, with an apparent diameter larger than $0\overset{''}{.}3$.[9] Dollfus[10] has discussed various techniques and their possibilities for diameter measurements.

It is exceedingly important to get more sizes and masses so as to obtain the densities of the minor planets, and I am referring to the beautiful new work of

[4]See p. xvii.
[5]See p. 185.
[6]See p. 41.
[7]See p. 45.
[8]See p. 91.
[9]See p. 30.
[10]See p. 25.

Hertz and Schubart.[11] Whereas on past occasions the density 3 g/cm^3 has been used hypothetically for asteroids, from a comparison with the Moon or meteorites, the time has now come to *determine* the density and from that infer the applicability of comparison with the Moon and meteorites.

This is not to say that the surface of the Moon and studies of meteorites are not important to the understanding of asteroids. But the fundamental data should come first, and we should have no patience with supporting observational conclusions because they fit preconceived notions.

I make a plea to obtain good magnitudes of asteroids and cometary nuclei together with photographic observations of position. As for the comets and their secular brightness decrease, again see Marsden.[12] There is a continued need for good magnitudes of asteroids because even in the 1971 *Ephemeris* volume about 50 are completely unreliable; they could be off by one or two magnitudes. The combination of magnitudes from various sources needs to be redone as there is some indication in the Palomar-Leiden survey that the most recent combination of asteroid magnitudes may have included very poor observations and that therefore the precision could be improved by actually eliminating the poorer, older observations. Photographic photometry must, of course, be done carefully to avoid inherent problems that are absent in photoelectric work (Gehrels, 1970).

Detailed spectrophotometry of asteroids is a new field; Chapman et al.[13] give two pages of suggestions for future work such as the possible extension to longer wavelengths and the addition of more laboratory comparisons of rocks and meteorites. This type of work needs close calibration with solar-type stars.

Van Houten[14] has mentioned that the phase function of Trojans may be flatter, and the one of faint asteroids steeper, than that of the brighter asteroids and this should be checked with precise photoelectric observations. He suggested also that a lightcurve of Thule should be obtained and that more color observations should be made of family members and field asteroids. The latter suggestion ties in, of course, with the wish of Chapman et al. to do more spectrophotometric work on various asteroids, families, and groups. The reddening with phase of asteroids is not very well known; Icarus has an exceptional value of $U - V$, and a bluing with increasing phase angle.

There is much work to be done on lightcurves of minor planets for the determination of their rotation rate, their shapes, and the orientation of their rotational axes.[15] These are all possible with careful work on sets of lightcurves and, from laboratory comparison studies, it is perhaps possible to get an indication of the rigidity of the body. But even getting good statistics on the occurrence of nearly spherical asteroids that may be original accretions is important and relatively easy; simple lightcurve surveying of asteroids that are available at the time the observer has equipment ready and photometric sky overhead still is urgently needed. Sets of lightcurves are terribly demanding on

[11]See p. 33.
[12]See p. 413.
[13]See p. 63.
[14]See p. 184.
[15]See p. 147.

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preparation, telescope time, and weather. The lightcurve work should be done for objects fainter than about 16 mag as these may be collision fragments, in contrast to the brighter ones.[16] Electronic image intensification may have to be applied for the work on faint asteroids; offset appears too complicated for moving objects.

Further suggestions for future work in photometric studies are made in sec. X of Gehrels (1970). Matson[17] indicated future work in infrared photometry; there still are observational discrepancies. The sense of rotation of an asteroid can be determined with observations on only two separate nights, before and after opposition,[18] and this would be a vast improvement in the amount of telescope time needed to determine the sense of rotation by photometric astrometry.[19] On the other hand, Allen[20] has suggested that the infrared and visual lightcurve work be done simultaneously, and from this work there would be additional information on the much-discussed question concerning how much of the light variation is caused by the change in projected area of the asteroid, and how much by nonuniform reflectivity over the surface.

The statistics on the orientation of rotation axes are just coming in. Burns' paper[21] is stimulating, but the theoretical problem needs a better observational basis, and never again from application of the amplitude-aspect plot.[22] On the other hand, the problem is straightforward, given enough time with the Asteroid Telescope, enough computer time, and enough high-school teachers to operate both.

The telescope referred to is a 1.8 m Cassegrain reflector being built north of Tucson on Mt. Lemmon at 2800 m altitude. The characteristics are a yoke mounting that allows access with full aperture to about +77° declination, and with some obscuration to +90°; access to the horizon; disk drives; fast slewing (~100 deg/min); one-man operation, without night assistant; and computer control (Nova 1200) of the dome and other telescope functions. The name "Asteroid Telescope" indicates that its schedule can be preempted whenever necessary for the work on asteroids and comets, including that in support of space missions.

I would not be the one to minimize polarization work. The apparition of Icarus in 1968 has shown that much can be learned from the combination of polarimetry, photometry, and radar work when the range of phase angles is sufficiently large, as is the case with closely approaching asteroids. Radar yielded an indication of the roughness of Icarus in 1968, but only because there was a set of lightcurves obtained at the same time. Few people have access to the large radio telescopes and we wish to leave with them a request to observe nearby objects whenever possible. There are close approaches soon of Toro and Eros, and future tasks for radar observations, perhaps even of Ceres,

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[16]See p. xx.
[17]See p. 45.
[18]See p. 49.
[19]See p. 128.
[20]See p. 43.
[21]See p. 257.
[22]See p. 139.

have been mentioned by Goldstein.[23] Marsden[24] makes a request for an observation of Alinda in 1973 and he alerts us to make physical observations during the perihelion passage of Hidalgo in 1976-77.

Surface texture may also be studied from photometry and polarimetry, including laboratory measurements. Much work is left to be done in the laboratory on samples from various parts of the Moon, and in laboratory studies of scattering properties of clumps of grains.[25] An improved understanding seems to be needed of the domains of applicability of the Fresnel law and Mie theory for dusty surfaces. For the comparison of meteorites and asteroids, Anders[26] gives an explicit enumeration of future work. I have the impression that the greatest advance in zodiacal light measurements will be made by using spacecraft.[27]

As for the theoretical work on minor planets, I see three principal approaches: (1) the studies of origin and evolution; (2) the detailed studies of accretion and fragmentation mechanisms; and (3) the study of interrelations of particles, meteorites, comets, and asteroids. All three approaches are needed to consider specific problems such as that of the extraordinary shape and smoothness of Geographos, shown in the frontispiece. The fragmentation theory proposed by Brecher[28] may explain the shape, rather than the "must be iron" reaction to that picture that I have heard so often. For iron composition, there are too many asteroids with large light variation; e.g., Geographos, Eros, Daedalus, and several in the asteroid belt. Are the surfaces of small asteroids sandblasted clean—clean to penetration of infrared radiation—or is there a regolith with clumps of dust or even a thick layer of dust? Photopolarimetric observations, at the telescope and in the laboratory, can provide basic inputs, but a range of theoretical studies is needed, including that of collision probabilities. The interpretation of the number-size distribution bears on this problem in addition to the broader problems of accretion versus fragmentation and asteroid evolution. Although Anders concludes that asteroids with $B(1,0) < 11$ are original condensations, Dohnanyi concludes they may be collisional fragments.

Experimenters should search for new techniques and theoreticians should search for new approaches. The approach of Trulsen, Baxter, Lindblad, and Danielsson is a new one and the study of Alfvén's jetstreams presents great promise. Further work on the statistics of jetstreams and other suggestions are made at the end of the paper by Trulsen[29] and also in various discussions. The theory of resonance and commensurability still seems to be incomplete.

We have exchanged during this colloquium a large amount of information, some of which was very new to some of us. It was good to meet and to compile all this material in a book. Now, armed with additional information, we should continue to work on the main questions: Do the meteorites originate from the

[23]See p. 170.
[24]See pp. 416 and 642.
[25]See pp. 67, 90, and 95.
[26]See p. 479.
[27]See pp. 377 and 363.
[28]See p. 305.
[29]See p. 327.

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comets, from Apollo asteroids, or from common asteroids? What kind of cores do comets have? Is the collision theory of the origin of asteroid families the appropriate one? To what extent are the jetstreams caused by selection effects?

As for space missions, we trust that this colloquium stimulated the planning of how to get to the asteroids, financially as well as technically. The wish of scientists to be involved in the early stages of mission planning, before the spacecraft is defined, came out clearly in the discussions.[30] Hills[31] has given some basic reasons for asteroid missions. Suggestions for actual experiments have been made[32] but systematic and thorough planning is needed. The idea of missions to the asteroids is relatively new to the scientific community, and this explains why there is a shortage, in this book, of ideas on what to do when we get there, other than to determine the chemical composition, an idea so obvious that it was not even discussed. Forward's paper[33] on the gravity measurements was a surprise to most of us because we believed that Anderson[34] was the only one exploring this field.

Even flyby missions, without encounter or sample return, will be valuable because of the resolution possible on the surface and because of the large range of phase angles. The possibility of a multiple mission[35] appears attractive. Ground-based observations of spacecraft, not only for asteroid missions, and of their perturbed trajectories will continue to be used in the determination of fundamental astronomical constants and of planetary masses.[36]

Ground-based observations in astrometry of candidates for flyby and encounter, such as Eros, need to be encouraged and supported; the scarcity of manpower is a principal hurdle. This work needs to be done now, as well as in the future, to obtain the coverage required for precision. A list of potential targets should be established as soon as possible;[37] the suggestion of Marsden[38] to consider Alinda should not go unnoticed even though it was not made as a part of the Great Debate.

The debate between Alfvén[39] and Anders[40] was of great interest; their debates are continued, or prestaged, by the other papers of Anders[41] and Arrhenius and Alfvén.[42] It is clear that a lot of work on the clarification of the solar system can be done on cosmic material that comes to us as meteorites. It is clear that a landing on one asteroid is not the end of our investigations, both ground-based and in space, because great differences between various asteroids are apparent (e.g., Icarus is rough and nearly spherical, Alinda smooth and spherical, Daedalus rough and elongated, and Geographos smooth and elongated). The consensus of those present was to increase ground-based efforts, and to consider the Debate in target selection, but there was a keen interest in space investigation of asteroids. The prospect of a space mission to

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[30]See p. 500.
[31]See p. 225.
[32]See p. 561.
[33]See p. 585.
[34]See p. 577.
[35]See p. 527.
[36]See pp. 13 and 577.
[37]See p. 639.
[38]See p. 641.
[39]See p. 473.
[40]See p. 479.
[41]See p. 429.
[42]See p. 213.

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an asteroid will generally stimulate ground-based studies; this effect was seen strongly in the revival of respectability and activity in the early 1960's in planetary exploration when promoted by the Soviet and U.S. space programs.

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