N91-26001

A CCD Comparison of Outer Jovian Satellites and Trojan Asteroids

Jane X. Luu (Harvard-Smithsonian Center for Astrophysics)

The eight small outer Jovian satellites are little known compared to their brighter, more illustrious cousins, the Galilean satellites. They are divided into 2 groups, each containing 4 satellites; the inner group travels in prograde orbits while the outer group travels in retrograde orbits. From the distinct orbital characteristics of the two groups, most of the theories of their origin involve the capture and break-up of two planetesimals upon entry into the atmosphere of proto-Jupiter. Their proximity to the Trojan asteroids has led to conjectures of a link between them and the Trojans. However, Tholen and Zellner (1984, *Icarus* 58) found no red spectrum among six of the satellites and postulated that they were all C-type objects, therefore unlikely to have derived from the Trojan population.

We present new charge-coupled device (CCD) photometry and spectroscopy of the 8 outer Jovian satellites obtained from 1987 to 1989. The lightcurves of the satellites show that the rotational properties (lightcurve amplitude Δm and rotation period) of the satellites are similar to those of main belt asteroids (see Fig. 1). Fig. 1 also shows that the satellites have distinctly smaller Δm's than the known comet nuclei. In comparison with the Trojans, the satellites are similarly spectrally diverse, with reflectivity gradients ranging from neutral (0.4 ± 0.1 % / 10^3 Å) to red (12 ± 1 % / 10^3 Å) (see Fig. 2). The Δm's of the satellites fall within the range of Δm's observed in the Trojans, although the satellite Δm's are generally restricted to smaller values (≤ 0.27 mag) than the Trojan Δm's. The wide range of colors, plus the assumed low albedo for most of the satellites, indicate that the satellites resemble a mixture of both C-type and D-type asteroids, not just C-types, as had been suggested previously. Similarities between the satellites and the Trojans are also consistent with the hypothesis that these two groups of objects share a common origin (Kuiper 1956, *Vistas in Astronomy*, vol. 2). Physical properties of the satellites are generally consistent with, but do not prove, the capture origin theory (Pollack *et al.* 1979, *Icarus* 37).
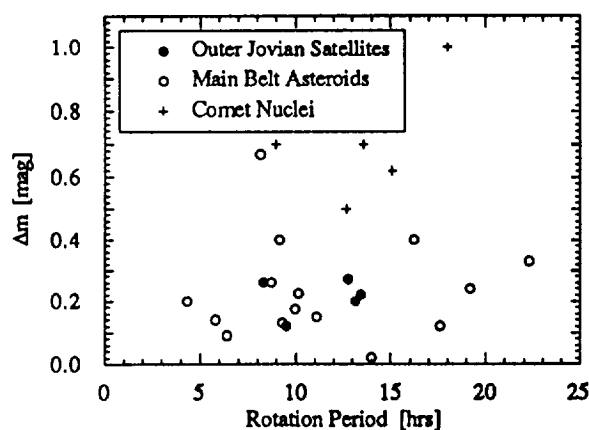

Fig. 1. Rotation period vs. lightcurve amplitude Δm for outer Jovian satellites, main belt asteroids and comet nuclei. All three groups of objects have similar rotation periods, but the nuclei have larger Δm's than both the satellites and the main belt asteroids.
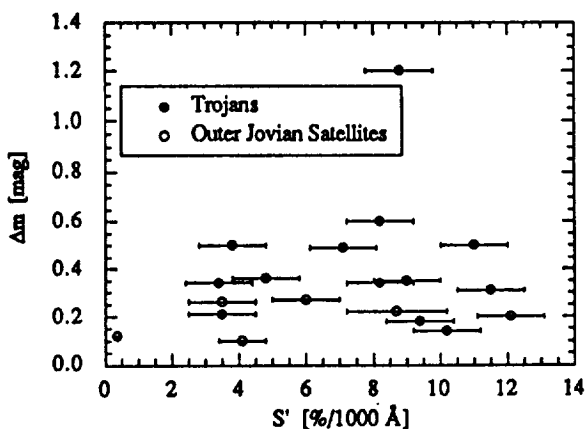

Fig. 2. S' vs. lightcurve amplitude Δm for outer Jovian satellites and Trojan asteroids. The satellites are statistically indistinguishable from the Trojans in both S' and Δm.

EVOLUTION OF THE ASTEROID SPIN VECTOR DISTRIBUTION

Per Magnusson   Queen Mary and Westfield College, London

Collisions in the present asteroid belt tend to randomize the distribution of asteroid spin vector directions. Observations however, show that there is a tendency for large asteroids to spin predominantly in the prograde sense. Is this consistent with present ideas of the evolution of the asteroid belt ?

I will present new statistics on the distribution of asteroid spin vectors based on an enlarged sample of objects. This distribution may be compared with distributions resulting from pure 3–dimensional random walks in spin vector space. The influence on this idealized model from random collisional angular momentum "kicks" is estimated. Within this model I constrain the cumulative collisional flux that asteroids have been subject to since the end of the accretion phase. A lower limit on the original predominance of prograde rotators is also obtained. Future work along these lines may tell us more about the accretion process and give a unified model for the evolution of planetary and asteroidal spin.

COMETARY ORBITAL EVOLUTION IN THE OUTER PLANETARY REGION

A. Manara, Osservatorio Astronomico di Brera, Milano (I)
G.B. Valsecchi, I.A.S. - Planetologia, Roma (I)

We have made a numerical experiment consisting of the integration of the motion of 100 fictitious comets for 1000 revolutions each, starting from low eccentricity, low inclination orbits not far from those of the four giant planets. The purpose of this study is to get a reasonable understanding of the way in which the orbits of potential short-period comets evolve under the action of planetary perturbations. An essential role is of course played by close planetary encounters, which are found to govern the evolution of the majority of the comets that show substantial orbital changes at the end of the simulation. This finding casts doubts on the possibility to treat the multi-stage capture of comets into short-period orbits as a diffusion process, given the stochastic nature of a scattering process essentially dominated by close planetary encounters. The distribution of perturbations at close encounters shows distinct tail asymmetries that are related to the positions of the pre-encounter orbits in the phase space of orbital elements semimajor axis, eccentricity and inclination. Moreover, the majority of the strongest perturbations, i.e. of those contained in the asymmetric tails of the distribution, are experienced by comets in orbits nearly tangent to that of the planet encountered. This last result suggests that the regions of phase space corresponding to orbits nearly tangent to those of the planets should constitute a preferential path followed by comets on their way towards short-period orbits. We are also performing some additional integrations using planetary masses increased by a factor 10, as was made in recent numerical experiments aimed at reproducing the entire process of multi-stage capture from a trans-neptunian source. The aim of this computations is to compare them with those done with the realistic masses, in order to check if the effect of the increased masses is only that of shortening the multi-stage capture process, in terms of number of revolutions of the comets integrated, or if is also that of altering the phase space paths followed by the comets, and the efficiency of the transport process along those paths.

THE EIGHT OBSERVATIONS RECORDED IN THE ANGLO SAXON CHRONICLE OF COMETS; E. G. Mardon, A. A. Mardon, Red Deer College, Red Deer, Canada, Texas A & M University, College Station, Texas, USA.

This research paper is an examination of the eight cometary references [679AD, 729AD, 891AD, 905AD, 905AD, 975AD, 995AD, 1066AD, 1106AD] found in the various manuscripts of the Anglo Saxon Chronicle between 538 AD and 1140 AD with linguistic notes on the Old English text and scientific observations. This is an examination of astronomical phenomena and other climatic or natural events, that are described in the Anglo Saxon Chronicle, which is also referred to as the Old English Annals. The Anglo Saxon Chronicle is an Old English history of events begun under the direction of King Alfred the Great in the 9th Century and containing earlier material in adapted form. It was written from records kept by various English Monasteries. After the account of King Alfred's wars which started with the invading Danes, the Chronicle was officially kept up year by year until the last entry dated for 1154 AD. It survives in seven manuscripts, although the Anglo Saxon Chronicle contains non-factual material and legends, and references often verifiable through other contemporary or near contemporary sources, like the Bayeux Tapestry containing a panel of the 'long-haired comet', that appeared in 1066 AD, and few months prior to the invasion of England by William the Conqueror.

678 AD "Her ateowede cometa se steorra on Auguste. and scan iii monðas ælce morgen swilce sunne beam." "In this year appeared the comet or star in August and shone for three months. Like a morning sunbeam." **729 AD** "Her atewoden twegan cometan." "In this year appeared two comets." **891 AD** "] ʃy ilcan geare ofer Eastron. ymbe 'gang' dagas oʃʃe ær, æt eowde se steorra ʃe mon on boc læden hæt cometa, same men cweʃaʃ on Englisc ʃæt hit sie feaxede steorra. forʃæm ʃær stent lang leoma of hwilum on ane healfe, hwilum on ælce healfe." "And the same year after Easter during Rogation-tide or earlier appeared the star which in Latin is called 'comet', likewise men say in English that a comet is a (flax) long-haired star, because long beams of light shine there forth, sometimes on one side, sometimes on every side." **905 AD** "Her cometa æt eowde ·xiii· kʈ Nouembris." "In this year the comet appeared thirteen days before the Kalendes of November." **975 AD** "And her Eadward Eadgares sunu feng to rice. and ʃa sona on ʃam ilcan geare on herfeste æteowde cometa se steorra. and com ʃam eaftran geare swiðe mycel hungor." "And in this year Edward, Egar's son, succeeded to theð Kingdom, and soon at harvest time of the same year appeared that star known as Comet. And the next year came great hunger." **995 AD** "Her on ʃissum geare ætewde cometa se steorra." "In this year appeared the comet or star." **1066 AD** "On ʃisü geare cð Harold kyng o Eoforic to Westmynstre. to ʃa Eastran ʃe wæron æft' ʃa middan wintran ʃa se kyng forðferde. and ʃa Eastran on ʃone dæig xvi kl' Mai. -Da wearð geond eall Englaland swylc tacen on heofenü gesewen swylce nan mann æ'r ne geseh. Sume menn cwædon f hyt cométa se steorra wære. ʃone sume menn hatað ʃone fexedon steorran. and he æteowde ærest on ʃone æfen LETANIA MAIOR. f ys viii kl' Mai. and Swa scean ealle ʃa vii niht." "In this year came King Harold from York to Westminster, the Easter following the Christmas of the King's death. Easter being on April 16. At that time throughout all England, a portent such as men had never seen before was seen in the heavens. Some declared that the star was a Comet, which was called the long-haired star it first appeared on the eve of the feast of Letania Minor, that is April 21st and shone every night for a week." **1106 AD** "In the first week of Lent, on Friday, the forteenth day before the Kalends of March a strange star appeared in the evening and for a long time afterwards was seen shining for a while each evening. The star made its appearance in the south west, and seemed to be small and dark, but the light that shone from it was very bright and appeared like an enormous beam of light shining in opposite direction to the star. Some said that they had seen other unknown stars about this time, but we cannot speak about these without reservation, because we did not ourselves see them. On the eve of Cena Domini, Thursday before Easter two moons were seen in the sky before day, one in the east and one in the west and both at the full, and that day the moon was 14 days old. The light from the tail of a comet seemed to be streaming towards instead of from the nucleus."

THE RECOVERY OF ASTEROIDS AFTER TWO OBSERVATIONS; B. G. Marsden, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, U.S.A.

The most common procedure for arranging for additional observations of a newly-discovered asteroid for which there currently exist only two observations (or, conceivably, one observation and a motion) is to utilize representative "Väisälä orbits" fitted to the available data on the assumption that the object was observed exactly at perihelion--or, conceivably, aphelion (Väisälä 1939, Astron.-Optika Inst. Univ. Turku Informo No. 1). The procedure was generalized, at least in principle, by Bowell, Chernykh and Marsden (1989, Asteroids II, p. 21), who defined an appropriate search area surrounding these apsidal solutions. Other recent work tackles the problem by noting that, at least at opposition, there are constraints on semimajor axis and/or inclination (Bowell, Skiff, Wasserman and Russell 1990, ACM III, p. 19; Kristensen 1990, Astron. Nachr. 311, 133).

I consider here a process by which what amounts to the generalized Väisälä method can actually be put into practice. The method used is effectively an inverse of the Gauss-Encke-Merton (GEM) procedure in the rigorous yet in many respects simplified form I have discussed previously (Marsden 1985, Astron. J. 90, 1541). With the Cunningham (1946, Ph.D. thesis, Harvard University) choice of coordinate system the loci of prospective third observations are straightforwardly defined in terms of two parameters, namely, a first guess at the topocentric distance and a quantity describing the curvature of the apparent trajectory. Unlike the Väisälä approach to the problem, however, the inverse GEM process also handles Apollo objects, which by definition cannot be simultaneously both at opposition and at perihelion; the interesting case of 1990 MU is used as an example.

The new process has also proven very effective at selecting physically meaningful results in cases where the specified third observation leads to indeterminacy, and it also readily flags cases where at least one of the three observations must be erroneous.

# COMET NONGRAVITATIONAL FORCES AND METEORITIC IMPACTS:

J. J. Matese, P. G. Whitman and D. P. Whitmire, Department of Physics
The University of Southwestern Louisiana, Lafayette, LA 70504-4210

The Oort effect (*Bull. Astr. Inst. Neth.* 11, 91 (1950)) is the tendency for near-parabolic comet energies to cluster in a narrow, bound range of values. When the orbits are corrected for planetary perturbations, the original values of reciprocal semimajor axes, 1/a, have a mean of 36 units (1 unit $= 10^{-6}$ AU^{-1}) and a standard deviation about the mean of 14 units. This tight clustering diminishes for comets having the smallest range of perihelion distance, q, where the mean original orbit is hyperbolic and the standard deviation is five times as large (Marsden, B. G., et al., *Astron. J.* 83, 64 (1978)). We demonstrate here that small-q prograde comets have no significant difference in their energy distribution when compared to the large-q population. The non-Oort-like distribution of the small-q retrograde component could be due to observational selection effects, a different injection mechanism or larger nongravitational forces for this group of comets. Arguments suggesting that enhanced volatility is the explanation are given.

We have considered new comets (1/a < 100 units) in Marsden's 1989 catalogue. At a level 5x the formal measured error, δ, there are 4 class I and 3 class II comets that remain hyperbolic. All are retrograde and have small q. A statistical analysis is presented based on class I comets. We subdivide into prograde and retrograde sets the pairs of values (1/a, δ^2) sequenced in ascending q. Cumulative, weighted means (relative weights $= \delta^{-2}$) are formed and standard deviations are determined. Confidence levels are discussed for the hypothesis that the distinctive distribution of the small-q retrograde population is not due to chance. Selection effects and alternative injection mechanisms are considered, but we argue that enhanced nongravitational forces are the cause. The dynamical parameter suggested is the energy of relative motion between a comet and a meteoroid in a prograde ecliptic circular orbit of radius r

$$U^2/2 = (3GM_\odot/2r)\ [1-(8q/9r)^{1/2}\cos(i)].$$

If r $=$ q the energy for i $= 180°$ comets is 34 times larger than for i $= 0°$ comets. Mantle processing by an ecliptic population of meteoroids may be the cause of enhanced nongravitational forces with a concomitant deviation from the Oort clustering. The known meteoroid population would directly expose only a small portion of the volatiles underlying a mantle and crater growth need then be demonstrated. Alternatively, we suggest impacts of an as yet undiscovered population of larger objects ($\approx$ 10 m) previously invoked as a cause of erratic behavior.
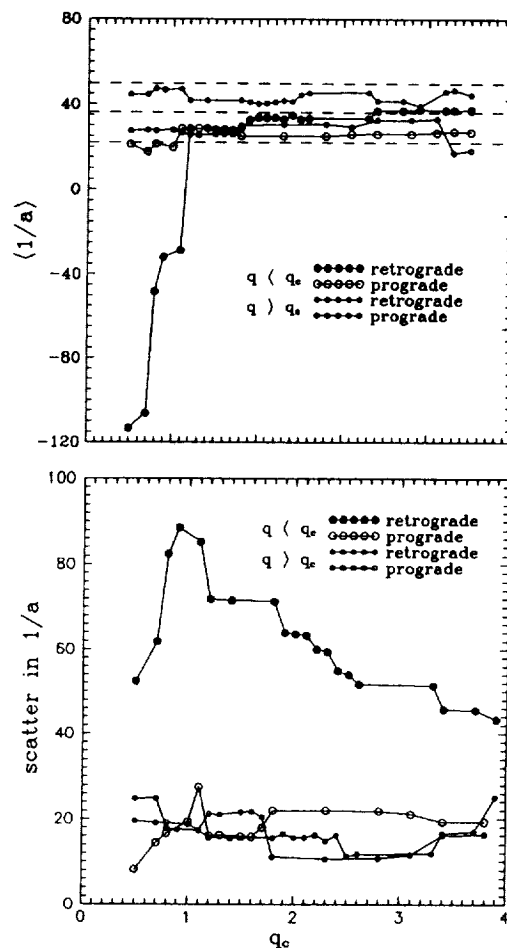
Dark Matter in the Solar System: HCN Polymers;

Clifford N. Matthews, Dept. of Chemistry, University of Illinois at Chicago, Chicago, Illinois 60680, U.S.A.

In the presence of a base such as ammonia, liquid HCN polymerizes spontaneously at room temperature to a black solid from which a yellow-brown powder can be extracted by water and further hydrolyzed to yield α-amino acids. Our continuing research suggests that the yellow-orange-brown-black polymers are of two types: stable ladder structures with conjugated $-C=N-$ bonds, and polyamidines readily converted by water to polypeptides.

These macromolecules, so easily formed in a reducing environment, could be major components of the dark matter observed on many solar system bodies. The non-volatile black crust of comet Halley may consist largely of such polymers, since the original presence on cometary nuclei of frozen volatiles such as methane, ammonia, and water makes them ideal sites for the formation and condensed-phase polymerization of hydrogen cyanide. Dust emanating from Halley's nucleus, contributing to the coma and tail, would also arise partly from these solids. Indeed, secondary species such as CN have been widely detected, as well as HCN itself and particles consisting only of H, C, and N. HCN polymerization could account, too, for the solid $-C{\equiv}N$ bearing material detected by Cruikshank et al. on outer solar system bodies of low-albedo such as the comets Bowell and Panther, the surfaces of numerous asteriods of taxonomic type D, the rings of Uranus and the dark hemisphere of Saturn's satellite Iapetus.

Implications for prebiotic chemistry are profound. Primitive Earth may have been covered by HCN polymers through cometary bombardment or terrestrial synthesis, producing a proteinaceous matrix able to promote the molecular interactions leading to the emergence of life.

The Contribution of Interplanetary Particulates to the Near-Earth Satellite Impact Environment: Cometary or Asteroidal ?

J. A. M. McDonnell and P. R. Ratcliff

Unit for Space Sciences, University of Kent at Canterbury, Canterbury, CT2 7NR, United Kingdom

Characteristics of the near-Earth space particulate environment have been measured by experiments on NASA's Long Duration Exposure Facility (LDEF) over a period of 5.75 years. Data from numerous microparticle impacts have been collected and correlated to yield an average LDEF-referenced flux-size distribution as a function of the direction of exposure on LDEF. Comparison of results on the different faces offers a means of distinguishing between orbital and unbound particulates. Results so far suggest that for larger particles the flux seen is consistent with that predicted from the interplanetary flux, while for smaller masses there is evidence of an excess flux due to an orbital component, whether of natural or debris origin. The temporal stability over the space age measurement span since 1960 argues against this being entirely due to space debris.

Modelling of aerocapture of interplanetary particulates reveals a strong dependance of capture cross-section on particle mass and geocentric velocity. In consequence, capture strongly favours small particles in low eccentricity, low inclination orbits. Such orbits are more typical of material of asteroidal origin than of cometary particles. The excess of small orbital particles seen in low Earth orbit could reflect preferential capture of asteroidal, rather than of cometary, material.

Bias Correction Factors for Near Earth Asteroids

Lucy A. McFadden(California Space Institute, UCSD, La Jolla, CA 92093-0216)
Gretchen K. Benedix (Dept. of Physics, UCSC; California Space Institute 0216, UCSD, La Jolla, CA 92093-0216)
Esther Morrow(Math Dept., UCSD; California Space Institute 0216, UCSD, La Jolla CA 92093-0216)

Knowledge of the population size and physical characteristics (albedo, size, rotation rate) of near-Earth asteroids (NEAs) is biased by observational selection effects. Several approaches to evaluating these biases are under study in order to predict the size and physical characteristics of the entire population. The NEAs are a population of probably thousands of objects ranging in size from tens of meters to 40 kilometers and in orbits that cross or approach that of Earth's. Their proximity to Earth and potential for collision with Earth makes them intriguing. Over 160 NEAs are currently catalogued. Their true size distribution, albedo distribution and distribution of rotation rates are unknown.

Defining modeled NEA asteroid populations in terms of their orbital and physical elements; $a, e, i, \omega, \Omega, M$, albedo, and diameter (at a later point we will include rotation rates), we simulate an asteroid search program using the actual telescope pointings of right ascension, declination, date, and time to test for the presence of an asteroid in the field of view of the telescope. The computer search is done using an ephemeris program which calculates the position of each object in our model population at the date and time of each telescope pointing. The program then tests to see if that object is within the field of view of the telescope (FOV = 8.75°) and brighter than the limiting magnitude of the telescope (V=+18.0). The program tabulates the discoveries. The effect of the starting population on the outcome of the simulation's discoveries is compared to the results of the actual search program in order to define a most probable starting population.

Our first model population, called the Zeus objects, consists of 2000 orbits of randomly chosen orbital elements, albedos, and absolute magnitudes. Values for i, Ω, ω, and M were chosen randomly with the limits 0-90° for i and 0-360° for the rest. Values for e (> 0, < 1) and q (< 1.3 AU) were chosen randomly. From these values $a = q/(1-e)$ was computed and selected between 0.723 AU (Venus) and 5.2 AU (Jupiter). The ephemeris program was written in Fortran by David Tholen, for a PC-386 computer. The telescope pointings used to date are from Eugene and Carolyn Shoemaker's search program at the Mt. Palomar 48 cm Schmidt Telescope for the years 1984-1987.

The bias factor for each orbital and physical parameter is defined as the ratio of the discovered to the starting distribution. In order to determine the most likely bias factor we will use different starting populations to compute additional bias factors. The mean value will be the observational bias factor. We continue to model populations with different distributions and plan to incorporate telescope pointings from other search programs.