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"Infrared Remote Sensing of Cometary Parent Volatiles from the Ground, Air, and Space"

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The last five years have seen an explosion in our ability to directly detect the parent species in comets, beginning with the first definitive detection of cometary water in December 1985, from the Kuiper Airborne Observatory. In March 1986, infrared spectroscopy from the Vega-1 spacecraft provided the first detections of CO_2 and of the carbonaceous feature (3.2-3.5 μm), a definite detection of H_2CO, and a tentative detection of CO. Since then, the carbonaceous feature has been detected in every comet searched, and spectroscopy from the ground and air has produced tentative detections of CH_4, CH_3OH, and CO, and significant upper limits for CH_4 and H_2CO. Meanwhile, advanced instruments promise routine detection of many species that at present are only marginally detectable in bright comets. Using these, we can expect to identify the volatile and refractory progenitors of the carbonaceous feature, and to provide routine study of the carbon chemistry (CH_3OH, H_2CO, CO, CH_4 ...), the nitrogen chemistry (NH_3, HCN ...), and the sulphur chemistry (e.g. H_2S). Airborne observations will provide studies of H_2O and CS_2, and spaceborne instruments (e.g. on ISO) will provide measurements of CO_2, and of strong terrestrial absorbers (H_2O, CH_4, CO, etc.) at arbitrary Doppler shift. Unambiguous determinations of the ortho-para ratios, and measurements of isotopic ratios in several key species should be possible.

Difficulties lie ahead, however, for investigations that rely on small pixel sizes, such as certain advanced ground-based instruments and the HRS instrument on HST. The reduction in background needed to take full advantage of the 2-D array detectors in ground-based instruments leads to their use at high spectral resolution and small optical throughput. The spectral grasp is shortened, and the fraction of molecules sampled by a single pixel is also reduced, and this makes the retrieval of production rates increasingly sensitive to coma models of uncertain provenance. However, certain other aspects, such as co-registration of different spectral precursors (e.g. gases and refractories), can enhance the study of short term variability (therefore of nuclear heterogeneity), and of the morphology of the near nucleus region.

In this paper, I will attempt to present a balanced view of the present generation of infrared instruments for cometary compositional studies. Ground-based instruments will be compared with airborne and spaceborne capabilities. I will attempt to give examples of the unique science achievable with each, and will place particular emphasis on the unique aspects of a dedicated Cometary Composition Telescope in Earth orbit for investigating the chemical and structural heterogeneity of the cometary nucleus.

COSMO-DICE: PROJECT OF DYNAMICAL INVESTIGATION OF COMETARY EVOLUTION

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The orbits of more than 150 periodic comets are integrated numerically in very high precision. The adopted integrator is a variable-step extraporation method in quadruple precision. This corresponds to a rounding-off error of 10^{-28} at the start of integration. We incorporate positions of 9 planets from DE102 ephemerides in the integration and the calculations are carried out for the full time span of DE102 (about 4400 years, from BC1411 through AD3002). Error tolerance for a single integration step is set to 10^{-22}. Accuracy of integration is checked by the round-trip error of closure test which covers about 3400 years, so that this allows us to estimate the reliable time interval of our integration for each comet. This can also be used to know, for a given number of significant digits of the observed orbital elements of a comet, how the orbital error grows with the elapse of time.

It is shown that the reliability interval is about 1000-1500 years for most of low-inclination short-period comets whereas that for high-inclination and longer-period comets is about 3000-4000 years or more. It is also found that growth rate of the round-trip error has intimate correlation with the chaotic nature of cometary orbits.

In this poster session we graphically present the time variations for 4400 years of all the comets in orbital elements, perihelion and aphelion distances, Tisserand's invariant, mutual distances between planets and a comet, the round-trip errors for orbital elements and position and velocity vectors. We are preparing a MT of about 50MB (nearly in double precision) in the standard FITS format to distribute to the interested researchers, which contains 64-day interval positions and velocities of all the comets. We also have a plan to develop a program which enables us to present and compare easily, in an interactive mode on a graphic terminal, orbital behavior of comets and other related dynamical quantities such as Tisserand's invariant, libration arguments and so on.

LONG-TERM ORBITAL BEHAVIOR OF SHORT-PERIOD COMETS FOUND IN PROJECT COSMO-DICE

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We have performed systematic numerical integrations of more than 150 periodic comets for 4400 years (3400 years toward the past and 1000 years to the future), based on the JPL planetary ephemerides DE102. Details of this project are descirbed in our another paper which will be presented at the poster session. One of the most remarkable results of our project is that comets entering the capture region by Jupiter are proved to evolve to short-period (SP) comets in the framework of realistic dynamical model. It is found that more than 90% of the observed comets whose Tisserand's invariant (J) is between 2.8 and 3.1 actually take this evolutionary path within the past 3400 years. This evolution is much more rapid than that expected from Monte Carlo simulations for simplified dynamical models based on symmetric distribution of perturbations. This suggests that asymmetry of perturbation distribution plays an important role in cometary evolution.

Some of SP comets are shown to evolve from the orbits of which perihelion distance is located near Saturn' orbit and then is handed over under the control of Jupiter. This seems to support the multiple stage capture mechanism first proposed by Everhart (1977). We also found a comet which is ejected out of the solar system by Jupiter in a fairly strong hyperbolic orbit around 2330 AD.

It is confirmed that captured low-inclination SP comets with the J in the range given above show more or less strong chaotic behavior of orbital evolution. On the other hand, comets with longer orbital period and/or of high inclination reveal slow and quasi-periodic nature of orbital evolution.

LUMINESCENT GRAINS IN THE ATMOSPHERE OF COMET HALLEY;

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The sufficiently high space and spectral resolution (4 arcsec and 2 Å) of the Comet Halley spectra obtained by the 6-meter telescope gave the possibility to find luminescent dust particles in the atmosphere of this comet [1,2]. The hypothesis about the presence of these particles is based on the observed deficiency of the equivalent widths of the Fraunhofer lines in the spectral continuum of Comet Halley.

It means that eighther there was an unusually high level of parasite scattered light inside the spectrograph or there was the component of the continuum which was not the solar light scattered by cometary grains. The first supposition was checked by spectra of reference stars and was rejected. The partition of the continuum to the luminescent and the scattered ones gave the following results.

Distance from the nucleus		Fraction of luminescence in the P/Halley continuum in the range 3300-6000 A
arcsec	km	
-20	-10000	5.6 %
-4	-2000	18.4
0	0	21.5
20	10000	5.2
36	18000	2.8
40	20000	2.0

Minus corresponds to the sunward direction.

Thus, the luminescent particles (probably, CHON-grains) are short-living. They disappear at the distance less than 1 arcmin from the nucleus. Taking into consideration that a spectrum of the circumnuclear region within several arcseconds with the resolved profiles of the Fraunhofer lines is necessary to detect the luminescence, one can easy understand why the luminescence has never been seen previously.

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Delivery of Meteorites from the Asteroid Belt.

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The study of asteroid formation and composition is of keen interest, since the processes that formed our own Earth and the other planets may have been similar in some important ways. Also, the numerous objects in the main asteroid belt and elsewhere help us avoid the "sample of one" problem so common in planetary science. Unfortunately, asteroids are very difficult to study directly: we have relatively noisy, low resolution optical spectra of their disk-averaged surfaces in reflected sunlight or thermal emission, and even then we see only their "dirty" surfaces. Meteorites, on the other hand, can be studied in great detail at high resolution by a wide array of techniques with much lower noise. Thus it would aid our understanding to know how asteroids and meteorites are connected, even if only statistically.

Transport processes for bringing asteroids from the asteroid belt to the Earth have been critically reviewed by Greenberg and Nolan [1989]. Wisdom [1983] and Froeschlé and Scholl [1986] have shown that asteroidal material may be transported to the Earth by way of Jovian and secular resonances. We do not know for certain how asteroids get into the resonances, which are now fairly clear of asteroids, probably due to the same processes that bring material to the Earth. We probably understand in general the dynamical delivery mechanisms, but not their relative efficacy, or what regions of space they sample.

The main belt size distribution is known for sizes $\gtrsim 30\,\mathrm{km}$ in diameter by direct telescopic observation, with some extrapolation and bias corrections for albedo at the smaller sizes. However, collisions are most likely to occur with smaller bodies. Thus our estimates for the collisional lifetimes of the bodies we can see are very uncertain. The collisional lifetimes affect in turn the expected steady-state population of bodies at all sizes.

As an alternative to using a variety of poorly understood processes to analyze the meteorite delivery process from the main belt, we can look at the process from the other end: meteorites arriving at the Earth. Networks of cameras operating since the early 1950s (*cf.* Jacchia and Whipple [1961]) photographed several thousand meteor trails. From these photographs, it was possible to determine the orbits of the asteroids which fell as meteors. Wetherill and ReVelle [1981] chose 27 meteors which they believed to be of ordinary chondritic composition (including Lost City, a recovered meteorite). Their orbital elements in a, e space show clusters near several Jovian resonances zones. We have similarly examined the orbits of 42 496 meteors from the IAU Meteor Data Center. Clustering persists only weakly in the vast data. The low accuracy of many of the orbits (D. Steele, pers. comm.) is a critical factor. There is a strong clustering toward orbits with perihelia near 1 AU. The Öpik two-body treatment of the the gravitational attraction of the Earth may not be sufficient for these orbits. We are numerically integrating the orbits of these meteors, to determine how large a correction is required. These results will help constrain how many came to Earth-crossing by each of the possible routes.