Thermal evolution of cometary nuclei

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Thermal modeling of comet nuclei and similar objects involves the solution of conservation equations for energy and masses of the various components over time. For simplicity, the body is generally, but not necessarily, assumed to be of spherical shape. The processes included in such calculations are heat transfer, gas flow, dust drag, phase transitions, internal heating by various sources, internal structure alterations, surface sublimation. Physical properties — such as the thermal conductivity, permeability, material strength, and porous structure — are assumed, based on the best available estimates from laboratory experiments and space-mission results. Calculations employ various numerical procedures and require significant computational power, data analysis, and often sophisticated methods of graphical presentation. They start with a body of given size, mass, and composition, as well as a given orbit. The results yield properties and activity patterns that can be confronted with observations. Initial parameters may be adjusted until agreement is achieved. A glimpse into the internal structure of the object, which is inaccessible to direct observation, is thus obtained.

The last decade, since the extensive overview of the subject was published (Modeling the structure and activity of comet nuclei, Prialnik, D.; Benkhoff, J.; Podolak, M., in Comets II, M. C. Festou, H. U. Keller, and H. A. Weaver, eds., University of Arizona Press, Tucson, p.359-387), thermal modeling has significantly advanced. This was prompted both by new properties and phenomena gleaned from observations, one example being main-belt comets, and the continual increase in computational power and performance. Progress was made on two fronts. On the computational side, multi-dimensional models have been developed, adaptive-grid and moving-boundaries techniques have been adopted, and long-term evolutionary calculations have become possible, even spanning the lifetime of the Solar System. On the chemo-physical side, additional chemical processes like serpentinization, and formation and decompositions of clathrates have been investigated. Special efforts have been devoted to related classes of objects: main-belt comets, Centaurs, Kuiper-belt objects and also to other ice-rich bodies, such as icy satellites. Since some of these objects are sufficiently large for hydrostatic pressure to become important, hydrostatic equilibrium was introduced into the modeling. This required the addition of an appropriate equation of state.

Interesting new results have thus been obtained: retention of ice in the deep interior of main-belt comets over the age of the Solar System, differentiation between core and mantle in the larger Kuiper-belt objects, and complex patterns of outburst for active comets, simulating observed ones.