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Influence of radionuclide abundance on the dynamics of the internal structure of Kuiper-belt objects

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Abstract

We investigated numerically possible structure of interiors of KBO objects for different mass ratio of radionuclides. As an example we considered thermal evolution of KBO(20000) Varuna and KBO(50000) Quaoar. We have found conditions of liquid water existence under the surface. It is shown also that the role of ^{26}Al for the possibility of liquid water formation is overestimated.

1. Introduction

The formation process of Kuiper belt object and the evolution of its internal structure until the present time are studied depending on the volume mass ratio and specific power of radiogenic heat sources. The building material of the forming KBOs is assumed to be dust particles of protosolar cloud and finely fractioned water condensate. The heat sources of all-time celestial body existence are radionuclides ^{238}U, ^{235}U, ^{232}Th, ^{40}K, ^{26}Al embedded in solid dust particles at the time of KBO formation. This heat is the main reason of KBO structural changes due to H_2O phase transitions including formation of different crystalline ice structures and liquid water.

2. Composition and structure of the forming KBO building material

A spherically symmetric celestial body has formed as a result of accretion. The body's material consists of a two-component porous disperse system. The basis of this system was amorphous ice H_2O with frozen trapped solid dust aluminosilicate particles with imbedded radionuclides as radiogenic heat sources. The heat produced by radionuclide decay causes phase transitions of H_2O. In this way, the celestial body forms spherically symmetric areas containing amorphous ice, crystalline ice (of cubic or hexagonal syngonies), a mixture of ice crystals and liquid water, and, finally, water with suspended solid particles.

3. Mathematical model of heat transport in KBO

Dynamics of the internal structure of the celestial body for spherically symmetric case is described by the heat transport equation

$$\frac{\partial}{\partial t}(c\rho T) = \frac{1}{(R-r)^2}\frac{\partial}{\partial r}\left((R-r)^2 k \frac{\partial T}{\partial r}\right) + f(t) - q(t,T)$$

$$-k\left.\frac{\partial T}{\partial r}\right|_{r=R(t)} = \varepsilon_{IR}\sigma T^4 - (1-A)Q_{sun}$$

$$k\left.\frac{\partial T}{\partial r}\right|_{r=0} = 0$$

$$T(r,0) = T_{eq}$$

where $T(R,t)$ is the temperature, ρ is the bulk density, c is the heat capacity, k is the effective coefficient of thermal conductivity, $f(t)$ is the volume power of the internal sources of radiogenic heat, $q(t,T)$ is the phase transition energy, p is the volume part of dust, A is red albedo, Q_{sun} is insolation, ε_{IR} is IR emissivity. Thermal-physical properties of KBO material components used in our simulations are presented in the Table 1. Thermal energy release for ^{238}U, ^{235}U, ^{232}Th, ^{40}K, ^{26}Al isotopes is $7.3\cdot10^{-12}$, $7.38\cdot10^{-12}$, $6.18\cdot10^{-12}$, $2.14\cdot10^{-13}$, $2.01\cdot10^{-13}$ J correspondingly. This equation was solved numerically using finite-difference method for various values of the volume content p of the solid component with initial content of the same isotopes 5.37, 1.63, 15, 20.8 and 4.16 pm correspondingly.

Table 1: Thermal-physical properties of KBO material components

Structure	specific density (kg/m^{-3})	(a) heat capacity (J/kg K) and (b) thermal conductivity (J/m K s)
amorphous ice	1200	(a) 90+7.49T [1] (b) 0.028+0.00234T, T<150 K [2]
cubic ice	956	(a) 90+7.49T [1] (b) 0.028+0.00234T, T<150 K [2]
hexagonal ice	917	(a) 90+7.49T [1] 560/T, 150 K<T<270 K [1]
liquid water	1000	(a) 1690+5.35·10^{-4}T +800T^2 [1] (b) 0.5524+0.0166T [3]
dust	2600	(a) from paper [4] (b) 2.4 [2]

4. Objects of investigation and results

The investigation of KBO formation processes and the evolution of their internal structure have been carried out for KBOs Varuna and Quaoar as an example. The following average characteristics of these objects have been determined experimentally [5, 6]: heliocentric distance, eccentricity of orbit, orbital period, diameter, density, red geometric albedo. Beside these parameters, the process of thermal evolution of KBO interior is influenced substantially by the specific density of radionuclides in the dust component of the celestial body at the initial stage of its formation. Another key parameter is the volume content of solid component *p*. It is dependent on the density of dust material distribution in the feeding zone of the solar system peripheral regions. The results of simulations of possible interiors structure of KBOs Varuna and Quaoar for different values of the parameter *p* are presented on Fig.1.

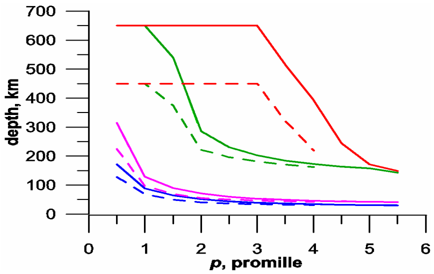

Figure 1: The dependence of phase transition boundaries on the parameter p for KBO(20000) Varuna (dotted lines) and KBO(50000) Quaoar (solid lines): amorphous ice – below blue curves, cubic ice – between blue and magenta, hexagonal ice – between magenta and green, ice-water mixture – between green and red, liquid water – above red.

5. Conclusions

The action of radiogenic heat sources on the formation and dynamics of KBO internal structure has been investigated theoretically. For large KBO objects (Varuna, Quaoar) the range of specific volume part values have been determined where the existence of these objects is possible from the moment of their formation to the present time. The location of phase transitions boundaries between different phase states of H_2O (different kinds of ice, ice-water mixture and water) is found.

References

[1] Klinger, J., Sciens 209, 271-272, 1980.

[2] F. Birch, Handbook of physical constants (Ed. by F. Birch, J.F. Schairer, H.C. Spicer), 1942.

[3] Giauque, W.F., and J.W. Stout, JACS 58, 144, 1936.

[4] V.S. Troitsky, A.B. Burov, and T.N. Alyoshina, Icarus 8 № 3, 423-433, 1968.

[5] Jewitt, D. C., & Luu, J. X. 2001, Colors and Spectra of Kuiper Belt Objects. AJ, 122, 2099

[6] Jewitt, D. C., and Luu, J. 2004, Crystalline water ice on the Kuiper belt object (50000) Quaoar. Nature, 432, 7