Thermal Effects in Small Icy Planetesimals

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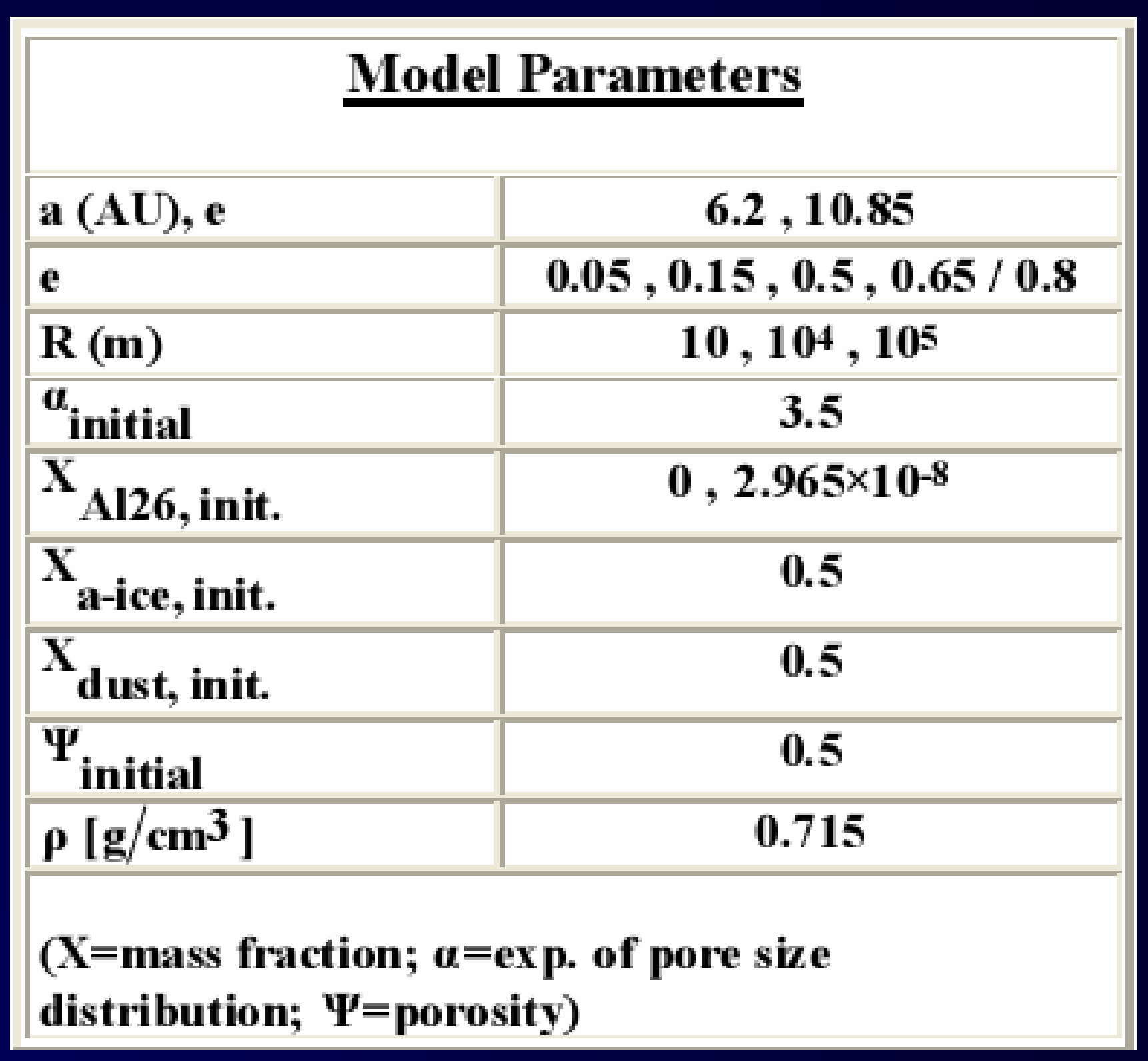
Cometary-like bodies are believed to be porous, icy-rich (crystalline or amorphous), relics from the early phases of planetary system formation. The early evolution of such bodies, in terms of composition, structure and thermal balance, may have strong implications for planet formation scenarios.

We set several distinctions in our models

- **(I) Orbit – heliocentric distance near the Jupiter-Saturn center of mass, and near the Saturn-Uranus center of mass (with varying eccentricities).**
- **(II) Size – radii of 10 m, 10 km and 100 km (where a hydrostatic scheme is implemented, affecting porosity and thermal conduction).**
- **(III) Thermal input – insolation alone, and insolation + radioactive heating.**
- **(IV) Time span – ~10 Kyr for bodies heated by insolation alone, and ~100 Kyr for those heated by insolation+Al26. These timescales are on the order (or less) of the "survival" lifetime of planetesimals (e.g. Grazier et al. 1999)**



Model Parameters	
a (AU), e	6.2 , 10.85
e	0.05 , 0.15 , 0.5 , 0.65 / 0.8
R (m)	10 , 10^4 , 10^5
α_{initial}	3.5
$X_{\text{Al26, init.}}$	0 , 2.965×10^{-8}
$X_{\text{a-ice, init.}}$	0.5
$X_{\text{dust, init.}}$	0.5
Ψ_{initial}	0.5
ρ [g/cm^3]	0.715

(X=mass fraction; α=exp. of pore size distribution; Ψ=porosity)

Tab. 1 – Key physical parameters used in our models. The initial mass fraction of Al26 is taken with the assumption of ~3 Myr of pre-natal decay.

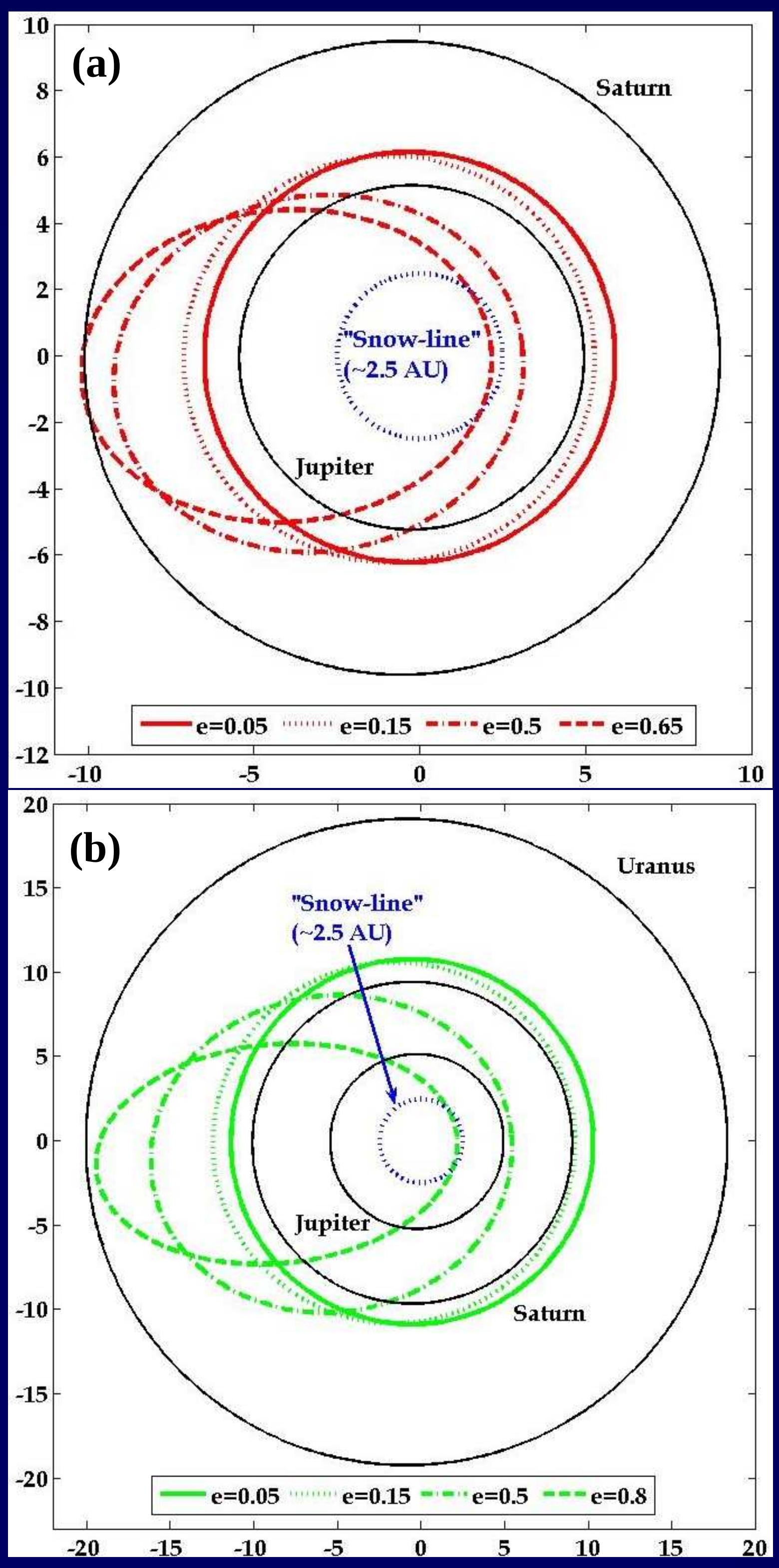


Fig. 1 – Schematic representation of the orbits chosen for the thermal models in:
(a) The Jupiter-Saturn region.
(b) The Saturn-Uranus region.

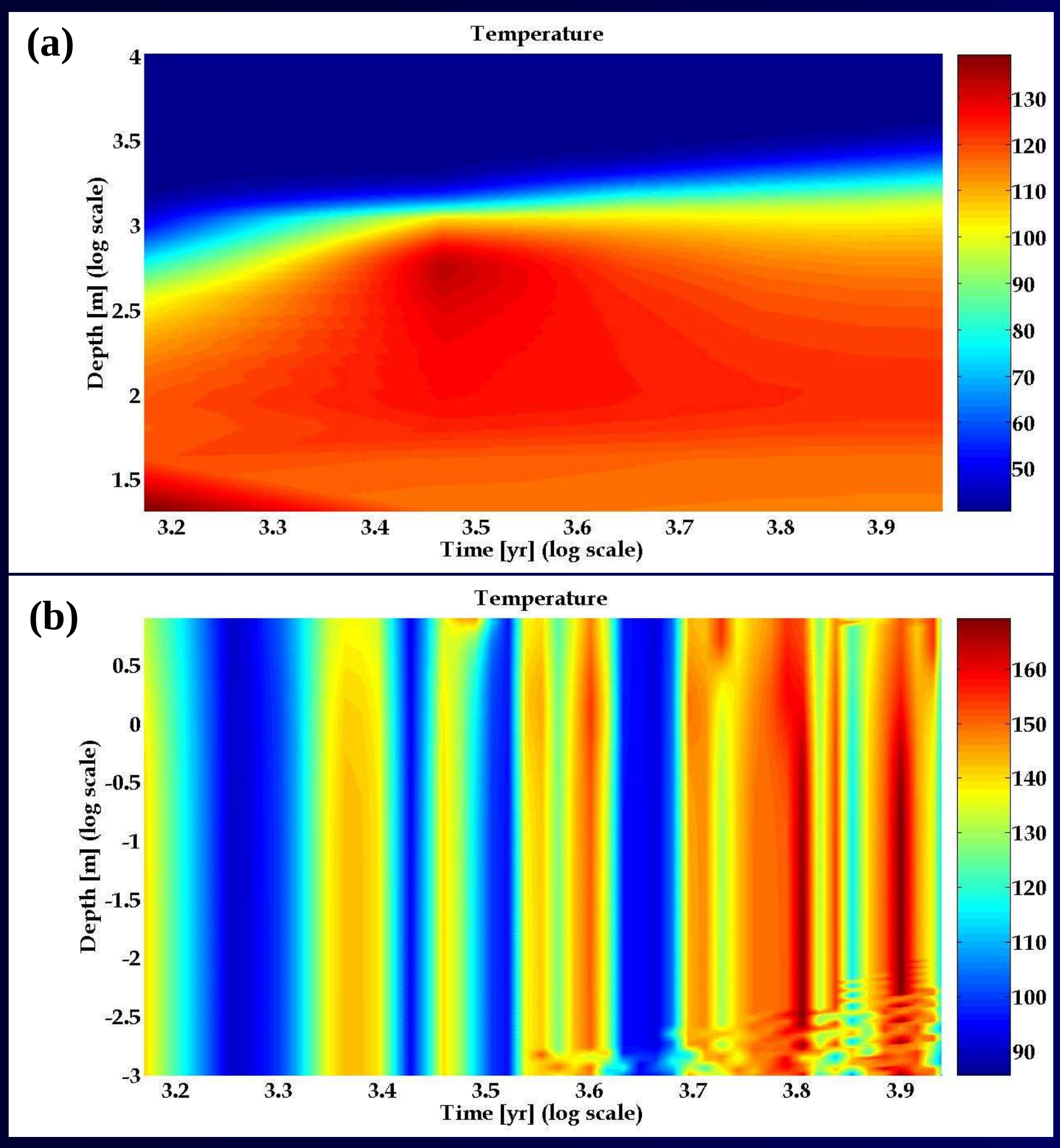


Fig. 2 – Internal Temperature profiles for the following configurations:
(a) 10 km, J-S zone, extreme eccentricity (0.65), no radioactive heating.
(b) 10 m, J-S zone, extreme eccentricity (0.65), no radioactive heating.

Note the different depth & temperature scales. The larger body has a "bump" around 30 Kyr, due to rapid onset of a crystallization front.
The smaller object exhibits the effect of the heat diffusing through the whole body, sublimating most of the ice. This is due to the fact that the orbital skin depth is of the order of the size of the object.

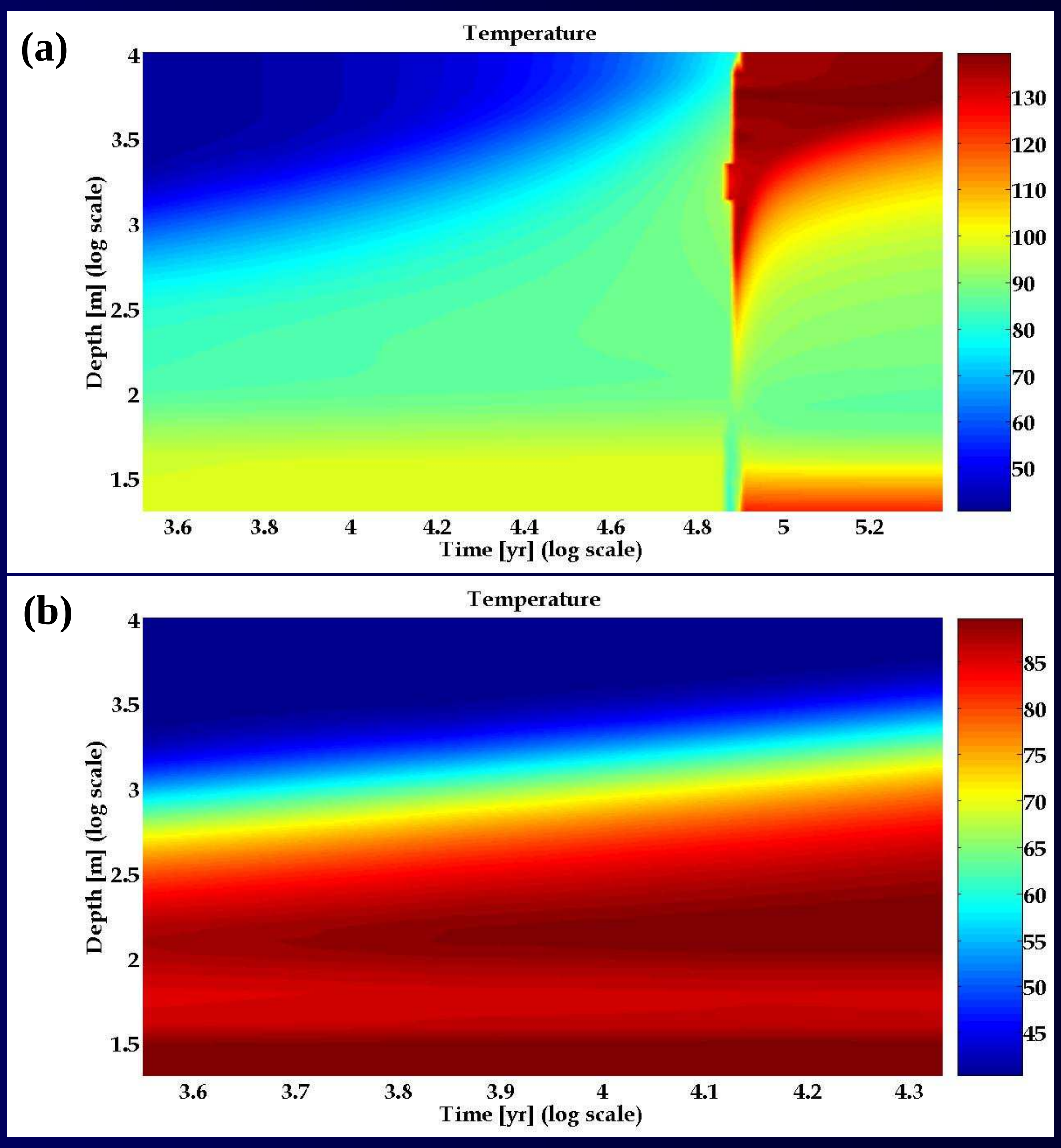


Fig. 3 – Internal temperature profiles of a 10 km, S-U zone, extreme eccentricity (0.8) body, for:
(a) Radioactive heating (by 26Al).
(b) Heating solely due to solar radiation.

Note the different time & temperature scales. In the radioactive heating case there is a "cusp", at around 80 Kyr, associated with a very rapid onset of crystallization, driven from the heat flow of both the surface and the interior. In the insolation case the heat front slowly penetrates from the surface, after hastily crystallizing the amorphous ice to a depth of ~50 m.

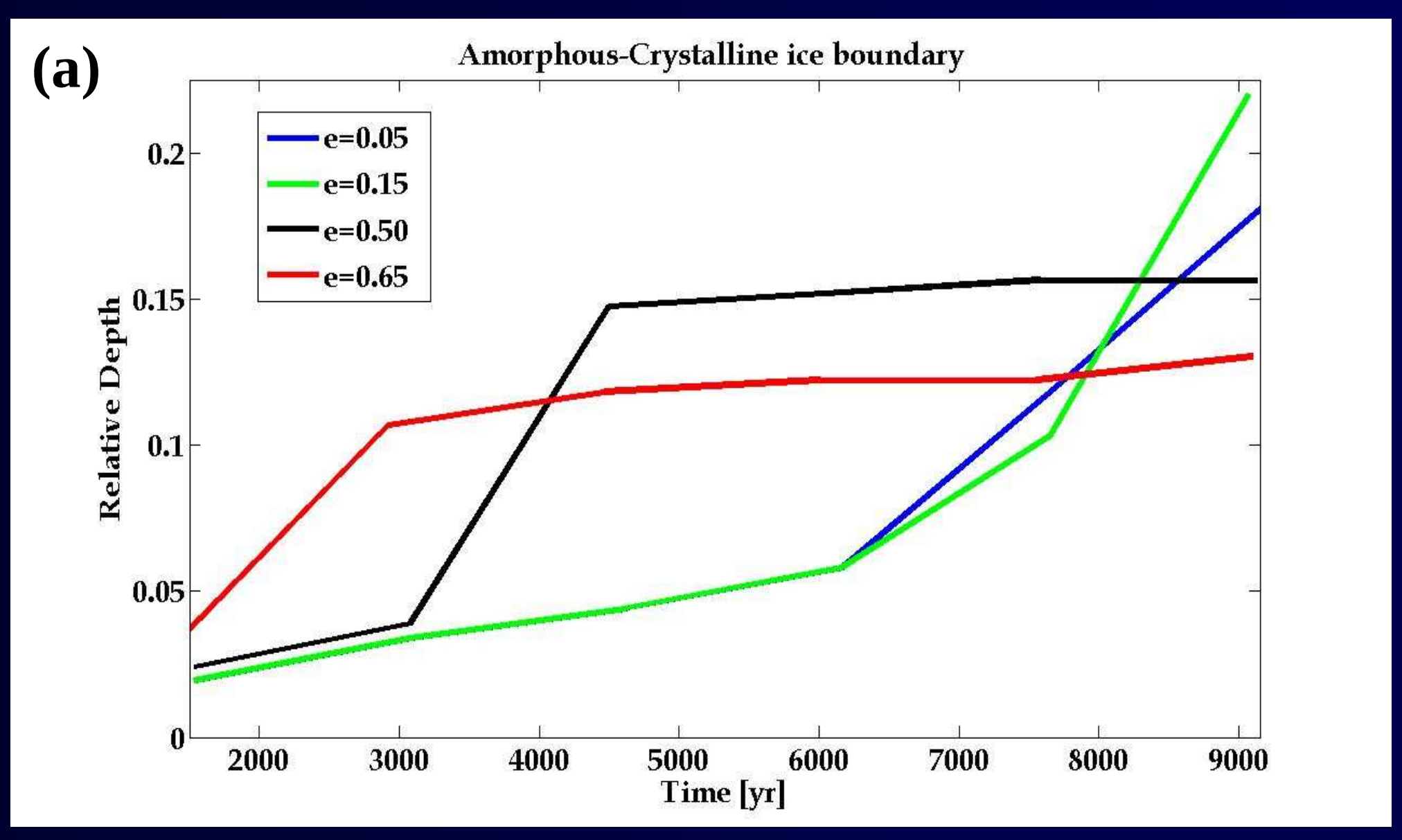
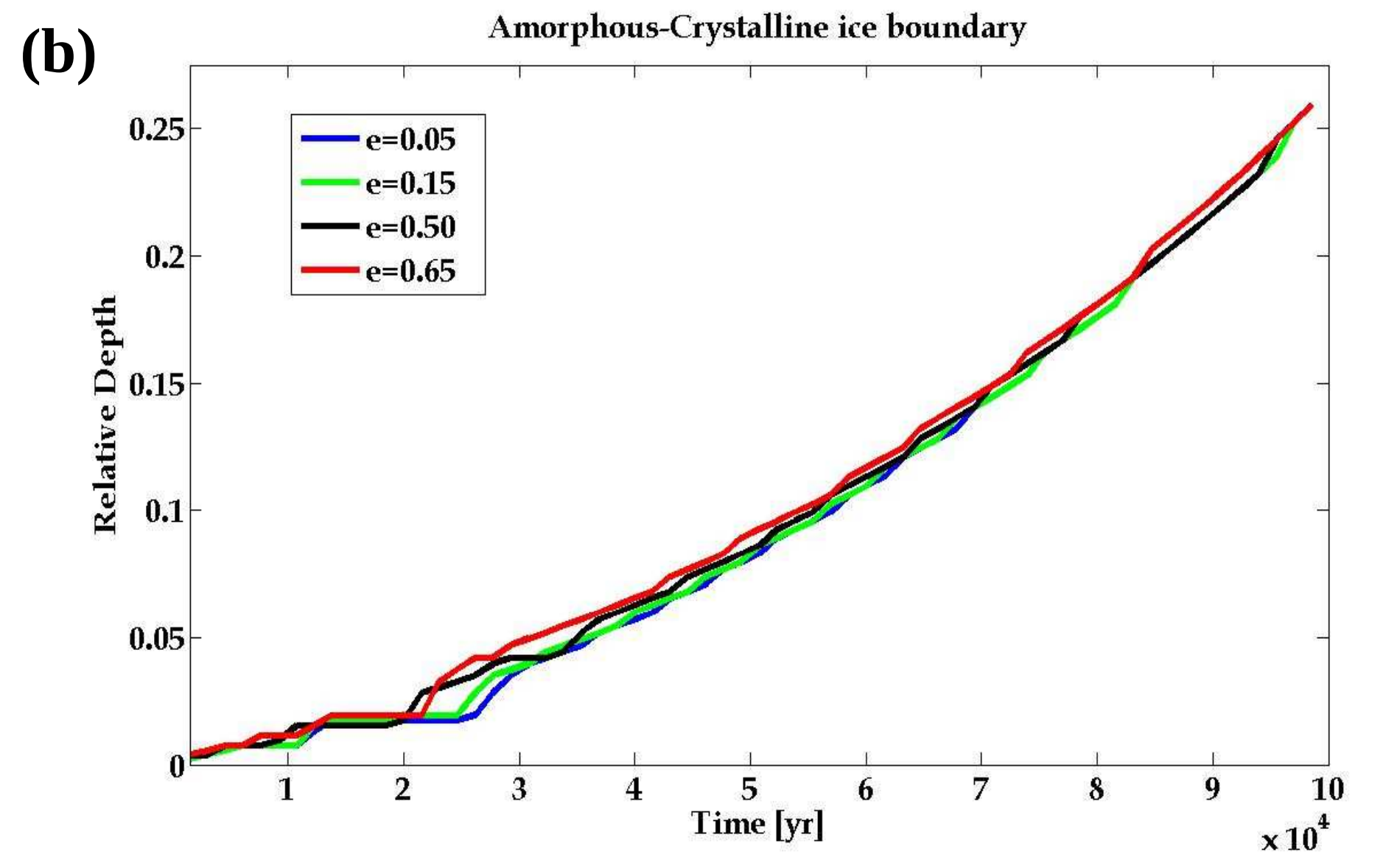


Fig. 4 – Evolution of the amorphous-crystalline boundary, which is defined as the depth where more than half of the initial mass fraction of amorphous ice has crystallized, for:
(a) A 10 km, J-S zone body, without radioactive heating.
(b) A 100 km, J-S zone body, with radioactive heating.

Note the "bumps" and "knees", clearly visible in (a) and (b), are due to crystallization, which is a local transient source within a body. This is an induced source, necessitating other means of temperature raising. The exothermic nature of this source implies that it may induce a runaway process. This is partly what happened in Fig. 3a.



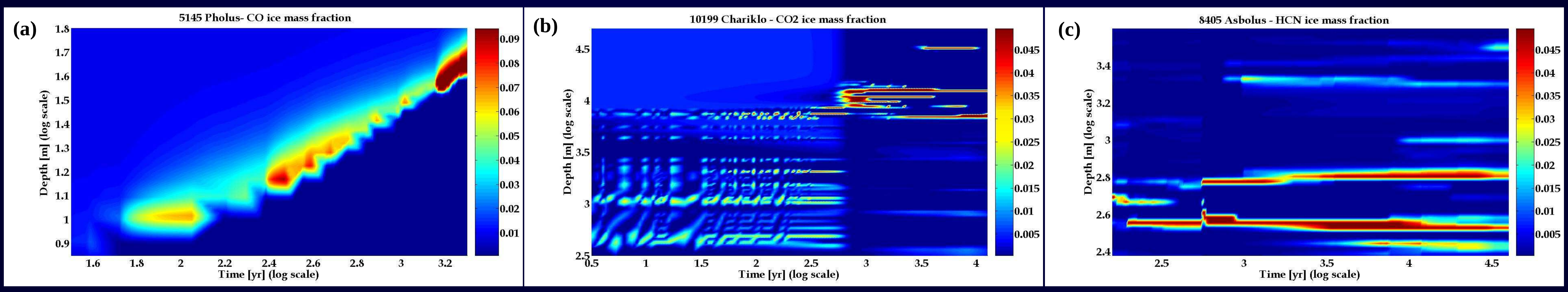


Fig. 5 – Mass fraction profiles of retained volatiles (as ices), during a thermal evolution. These are more "realistic" models of Centaur objects:

(a) **5145 Pholus**, with [a,e]=[20.43,0.57] and R=120 km: CO mass fraction, from an initial 10% mass fraction of CO ice.

(b) **10199 Chariklo**, with [a,e[=[15.87,0.18] and R=145 km: CO2 mass fraction, from an initial 1% fraction of occluded CO2 gas in amorphous ice.

(c) **8405 Asbolus**, with [a,e]=[17.97,0.62] and R=33 km: HCN mass fraction, from an initial 0.5% of occluded HCN gas in amorphous ice.