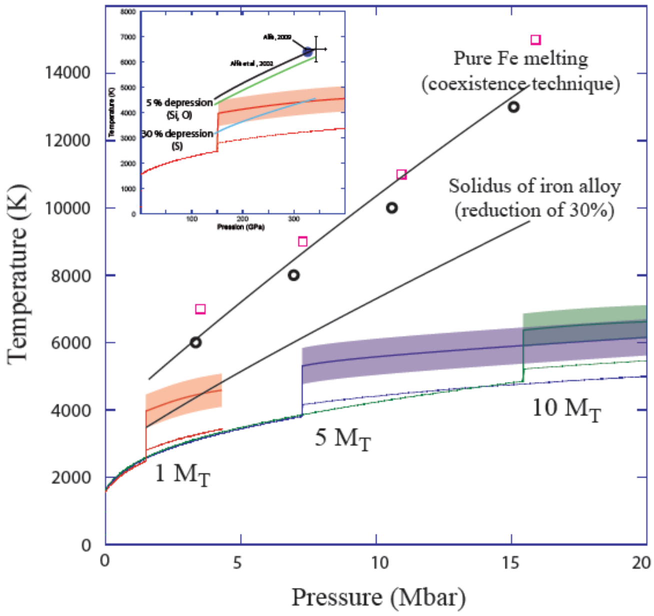
The melting curve of iron: implications for extraterrestrial life

Since the discovery of the first exoplanet[1] in 1990 by Aleksander Wolszczan using the Arecibo radio telescope, more than 300 planets have been detected in the universe, all with masses greater than that of the Earth. Although the majority are gas giants, some rocky planets with dimensions close to those of the Earth have recently been observed. The most recent, CoRoT-7b (named after the satellite and the mission[2] during which it was discovered), is the smallest exoplanet observed to date. Its diameter is around twice that of the Earth; its mass is currently unknown[3].

These fantastic discoveries have challenged models of planetary formation which were based entirely on the solar system and have rekindled interest in questions on the habitability of planets and the development of life on other planets. It is extremely difficult to find answers to these questions because they depend on a large number of parameters. Understanding our own planet can however allow us to identify some of the relevant and significant factors. We know, for example, that the presence of a magnetic field is critical, because it is this which protects the Earth from the solar wind which is harmful to life. It is therefore necessary to understand the conditions required for this field to be present and to determine if any of the exoplanets discovered to date possess one.

Iron is the principal element in the core of rocky planets. For the earth, temperature and pressure conditions are such that the core consists of an inner core composed of solid iron surrounded by an envelope of liquid iron. It is this liquid iron layer, associated with the Earth's rotation, which is the source of the magnetic field (geodynamo effect). Do the temperature and pressure conditions inside the exoplanets allow them to have a core which is both solid and liquid, and hence to have a magnetic field? A team from CEA-DAM together with geophysicists from the *Institut de minéralogie et de physique des milieux condensés - IMPMC* (Institute of mineralogy and condensed matter physics) are trying to answer this question. The answer can be found by studying the melting curve of iron. Since it is impossible to reproduce the thermodynamic conditions found at the core of the exoplanets in the laboratory, an answer can only be provided by simulations.

The calculations were carried out in molecular dynamics *ab-initio* using the ABINIT program code co-developed by the CEA and universities worldwide.



Melting curves for pure iron and alloys and geotherms as a function of the planets mass (1, 5 and 10 Earth masses). The jump observed in the geotherms is due to the mantle-core transition. For one Earth mass the geotherm crosses the melting curves of the iron alloy, indicating the presence of a liquid and solid core. For larger masses, the geotherm is systematically situated below the melting curve: the core contains solid only.

Based on quantum mechanics it reproduces, as accurately as possible, the forces which act on the atoms and hence their atomic movements. Resolving the equations for a system of several hundred atoms described quantum mechanically, is a phenomenal problem. New algorithms, able to parallelise the billions of operations required, have been developed to meet this challenge. These computations have required several thousand processors from the CEA and from the CINES and several million hours of computing time.

The results show that the dimensions of the Earth are not far from being at the limit permissible for the presence of a liquid and solid core. A rocky planet with a mass of five times that of the Earth has an entirely solid core and hence no magnetic field. It is, therefore, very unlikely that emergence of life or a habitable planetary environment will be observed on a celestial object with dimensions very much larger than those of our earth.

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[1] And exoplanet, or extrasolar planet, is a planet orbiting a star other than the sun.

[2] Corot (Convection, Rotation and planetary Transits) is a space telescope dedicated to the study of the internal structure of stars and research on exoplanets. It was launched on December 27, 2007 by the French Space Agency - Centre national d'étude spatiale (CNES).

[3] The detection method used by COROT and the primary transit. It is based on the occultation of part of the light coming from a star when a celestial object passes between it and the observer. It can therefore be used to measure the radius of the object but not to deduce its mass.