Molten iron in Earth-like exoplanet cores

Iron crystallization in super-Earth interiors plays a key role in their habitability

By Youjun Zhang1,2 and Jung-Fu Lin1

Earth, the only known habitable planet in the Universe, has a magnetic field that shields organic life-forms from harmful radiation coming from the Sun and beyond. This magnetic field is generated by the churning of molten iron in its outer core. The habitability of exoplanets orbiting other stars could be gleaned through better understanding of their iron cores and magnetic fields (1). However, extreme pressure and temperature conditions inside exoplanets that are much heavier than Earth may mean that their cores behave differently. On page 202 of this issue, Kraus et al. (2) used a powerful laser to generate conditions similar to those inside the cores of such “super-Earths” and reveal that even under extreme conditions, molten iron can crystallize similarly to that found at the base of Earth’s outer core.

To date, more than 4500 exoplanets have been discovered, with approximately one-third of them categorized as Earth-like exoplanets (3). The discoveries of these exoplanets have raised hopes about finding habitable conditions beyond the Solar System and that exoplanetary habitability could be quite diverse in the Universe. Although surface water in a star’s habitable zone has always been used as a qualifying condition for habitability, other key factors for habitability lie beneath the surface of the exoplanet, such as the property of its dynamo, a self-sustaining mechanism that generates a magnetic field (4). Similar to Earth, super-Earths are thought to have formed through collisions and then differentiated into light silicate mantles and heavy iron cores. The iron cores were initially hot and molten but slowly lost heat to the silicate mantles. If core cooling is efficient, it can lead to iron crystallization, which releases energy. The cooling and solidification processes are thought to be the main sources of power that drives the convection of molten iron in the liquid core, generating magnetic fields through dynamo action, also known as magnetospheres. The pressure-temperature condition in which convection occurs is close to adiabatic, meaning that hot upwelling fluid follows a predictable temperature profile without heat gain or loss to the surroundings. Depending on the intersection relation between the iron melting temperature and the adiabatic profile under compression in a super-Earth’s core, the molten cores can crystallize in two possible scenarios: either in an Earth-like “bottom-up” iron crystallization scenario or in an iron snowflake-like “top-down” scenario (see the figure). Bottom-up crystallization happens in the case of an iron melting curve steeper than the adiabatic pro-

Iron crystallization in super-Earth cores

Exoplanets with an Earth-like iron crystallization in their cores are more likely to possess and sustain a magnetic shield necessary for organic life-forms to exist. However, exoplanets with a higher content of light elements in the core may not have the internal condition necessary to sustain a solid core in the center and subsequently to sustain a magnetic shield over a long period.

REFERENCES AND NOTES

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PLANETARY SCIENCE

Iron crystals

Molten iron

Silicate mantle

Molten iron

Silicate mantle

Magnetic field

Convection

Earth-like scenario

Iron snowflake-like scenario
The thermochemical and gravitational energy provided by these processes can sustain convection and dynamo within super-Earths for billions of years (12). By contrast, the iron snowflake–like scenario can occur in the cores of planets and exoplanets with possible substantial amounts of light element(s) that would lower its melting curve. In the snowflake-like scenario, a cooling planet’s adiabat intersects the iron melting curve near the top-middle of the core, leading to iron crystals forming and sinking toward its center. This scenario has been proposed to occur inside Mars because of its lower melting temperature caused by the presence of lighter element(s) in its core (5, 13).

When exoplanetary cores form, a certain amount of light elements—such as hydrogen, carbon, silicon, oxygen, and sulfur—make their way into the molten core (14). Their presence can depress the melting curve, influence the crystal structure stability of iron, and affect the output of thermochemical energy inside the core. Future experimental investigations of light element effects need to be taken into consideration in evaluating the dynamics of exoplanets at extreme conditions. Future investigation of the thermodynamic, transport, and rheological properties of silicate mantles and iron alloys at relevant super-Earth conditions can help us to better understand core dynamics, Earth-like mantle convection, and, potentially, plate tectonics. Detectors of planetary magnetic fields outside of Earth’s Solar System can be combined with laboratory measurements to infer exoplanetary interior processes and habitability.

REFERENCES AND NOTES

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NEURODEGENERATION

A molecular view of human amyloid-β folds

Structures of amyloid-β fibrils suggest Alzheimer’s disease–modifying strategies

By Michael Willem1 and Marcus Fändrich2

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ne of the mysteries of Alzheimer’s disease (AD) etiology is the folding of the amyloid-β 42 (Aβ42) peptide, which forms aggregates ranging from small soluble and likely neurotoxic oligomers to mature amyloid fibrils that form amyloid plaques (1). Aβ peptides are derived from sequential cleavage of amyloid precursor protein (APP). Two main types of Aβ deposits can be distinguished in patient tissue: parenchymal amyloid plaques consisting mainly of Aβ42 and vascular amyloid deposits containing the shorter Aβ40 peptide (2). Previous research using cryo-electron microscopy (cryo-EM) determined the structures of Aβ40 fibrils from post mortem human AD brain tissue (3). On page 167 of this issue, Yang et al. (4) describe the cryo-EM structures of Aβ42 fibrils that were extracted from the brain tissue of patients with different neurodegenerative diseases, including AD. These structures aid in understanding the development of amyloid diseases and may inspire strategies for disease-modifying therapeutic intervention or diagnosis.

Yang et al. discerned three fibril morphologies—types I, Ib, and II. Type Ib represents a dimeric version of the type I fibrils. Type I fibrils were found primarily in sporadic AD patient material, whereas the type II filaments were mainly associated with familial AD patients and other neurodegenerative disorders (e.g., frontotemporal dementia), as well as being found in an amyloidogenic mouse model. The three fibril morphologies were assumed to have a left-hand twist, which corresponds to that of in vitro fibrils from Aβ42 or Aβ40 peptides but differs from the right-hand twist of Aβ40 fibrils from AD brain tissue.
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