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Dynamos in Terrestrial Exoplanets as Magnetic Shields

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In order to retain large amounts of water and maintain a habitable surface over long time-scales a magnetic field may be required to shield the atmosphere from mass loss and the surface from harmful stellar radiation. Terrestrial exoplanets in the 1-10 Earth-mass regime orbiting inside of 3 AU with an Earth-like composition, referred to as Super-Earths, are expected to have large, mostly Iron cores that could sustain a convectively driven dynamo.

We present a model to estimate the maximum self-sustained magnetic moment of a terrestrial dynamo given the total mass and core-mass fraction. Assuming the magnetic field is self-sustained by a convectively driven dynamo we estimate the magnetic moment using a dynamo scaling law, which relies on dynamical properties of the planetary interior, such as the convective heat flux at the core-mantle boundary and size of the dynamo region. To estimate these properties we model the internal structure of the planet using a sub-solidus, mobile lid convection profile for the mantle and a thermal convection profile for the core. We present models for 1-10 Earth-masses and a range of core-mass fractions. In order to maintain a strong magnetic field we maximize the energy available to drive the dynamo by allowing the core-mantle boundary temperature to be at the perovskite solidus, denoted as the "optimal" state for magnetic field generation.

We estimate an optimal Earth-mass planet can maintain a core heat flow of 30 TW, which implies a surface field intensity and magnetic moment of about twice that of the Earth. For a 10 Earth-mass planet that is 65% core by mass (Super-Mercury) we find a core heat flow of 180 TW, and a surface field intensity and magnetic moment of about 6 and 25 times that of the Earth, respectively. We demonstrate that exoplanets with large cores that produce strong magnetic fields can act to shield the surface from stellar radiation, minimizing atmospheric volatile loss and maintaining a habitable surface over billions of years. Also, we predict that nearby terrestrial exoplanets with strong magnetic fields will interact with the stellar wind to produce electron cyclotron emission at frequencies in the range 1-10 MHz, and at a distance of 5 parsecs and semi-major axis 0.02 AU (e.g. Gl876d) emission powers of 0.01 to 1 mJy.