Magnetization of carbonaceous asteroids by nebular fields and the origin of CM chondrites

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Abstract

Within the young solar system, a strong magnetic field permeated the protoplanetary disc. The solar nebular magnetic field is likely the source of magnetization for some meteorites like the CM and CV chondrites, which underwent aqueous alternation on their parent bodies before the solar nebular field dissipated. Since aqueous alteration produced magnetic minerals (e.g. magnetite and pyrrhotite), the meteorites could have acquired a chemical remanent magnetization from the nebular field while part of their respective parent bodies. However, questions about the formation history of the parent bodies that produced magnetized CM and CV chondrites await answers—including whether the parent bodies exhibit a detectable magnetic field today. Here, we use thermal evolution models to show that a parent body of the CM chondrites could record ancient magnetic fields and, perhaps, exhibit strong present-day crustal remanent fields. An undisturbed planetesimal would experience one of three thermal evolution cases with respect to the lifetime of the nebular field. First, if a planetesimal formed too late for ^{26}Al-driven water ice melting to occur before the solar nebula dissipates, then aqueous alteration would not occur in the presence of the nebular field and result in no magnetization (Fig. panel a). Second, if a planetesimal forms early enough to undergo alteration before the nebula dissipates but not enough to heat beyond the blocking temperature(s) of the magnetic mineral(s), then nearly the entire planetesimal could be magnetized (Fig. panel b). Lastly, if a planetesimal forms early enough to undergo alteration and subsequently heats beyond the blocking temperature, then any magnetization would be erased except for a thin shell near the surface (Fig. panel c). Our thermal model results suggest that planetesimals that formed between ~2.7 and 3.7 Myr after CAIs could acquire large-scale magnetization. Spacecraft missions could detect this magnetization if it is at the strength recorded in CM chondrites and if it is coherent at scales of tens of kilometers. In-situ magnetometer measurements of chondritic asteroids could help link magnetized asteroids to magnetized meteorites. Specifically, a spacecraft detection of remanent magnetization at 2 Pallas would bolster the claim that 2 Pallas is a parent body of CM chondrites.

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Testable prediction: Some C-type asteroids have detectable magnetic fields

1. The current origin story for CM chondrites

Carbonaceous Mighei-type (CM) chondrites are carbon-and-water-rich, undifferentiated meteorites that formed beyond Jupiter at 3-4 Myrs after CAIs while the solar nebular cloud of gas and dust was still present [1].

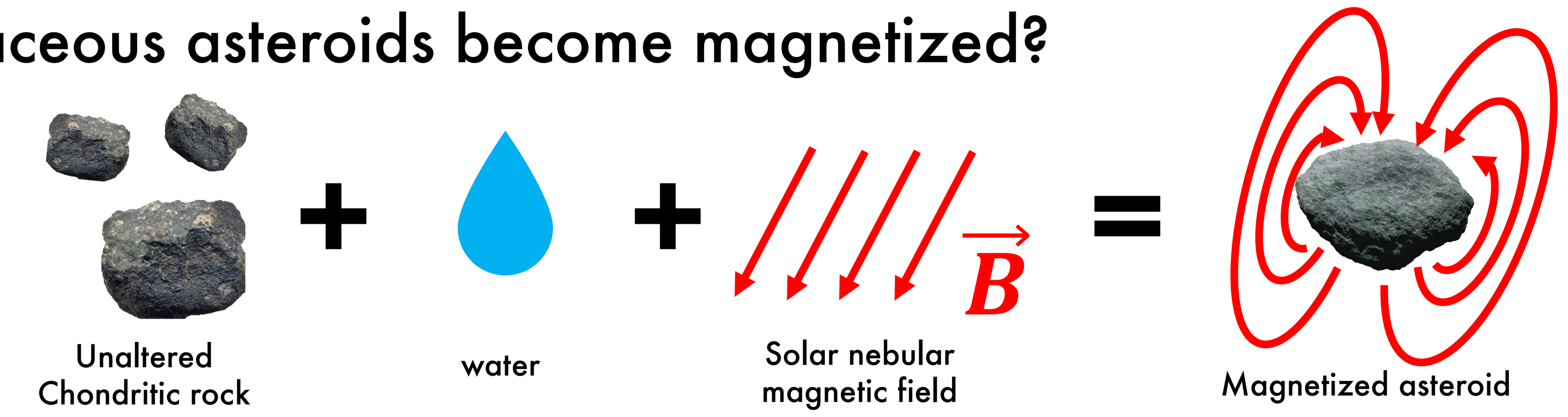
BUT WAIT!

CM chondrites are magnets!!!! [2]
(an unexpected observation)

Research question:
Does magnetization of CM chondrites fit with their formation story?
(Spoiler: yes!)

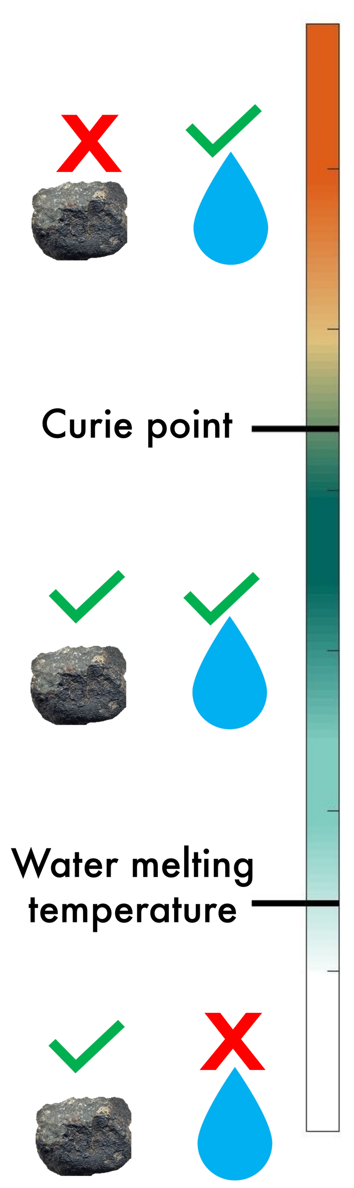
2. How do carbonaceous asteroids become magnetized?

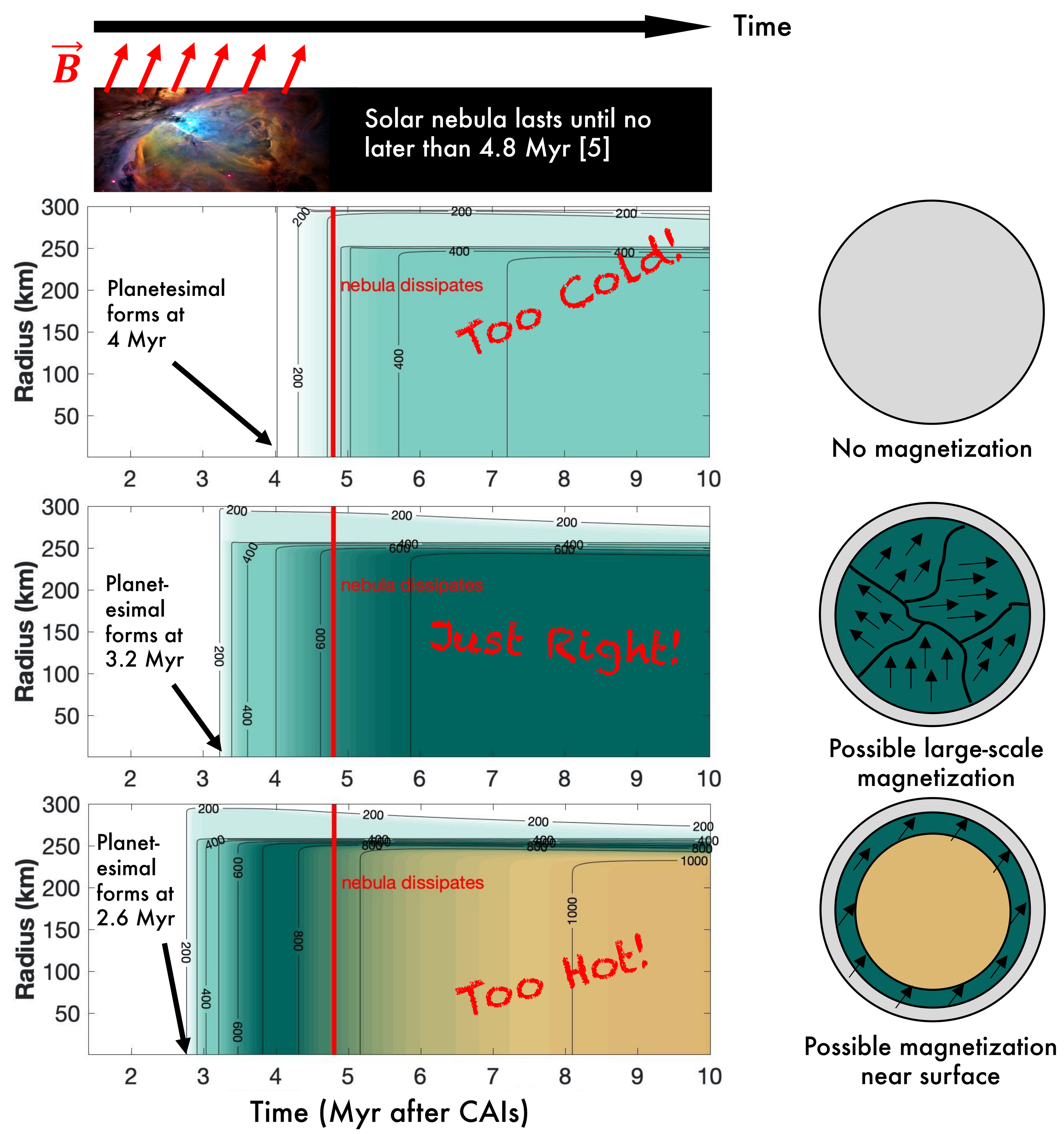
Aqueous alteration within the solar nebular magnetic field could produce a chemical remanent magnetization [2,3,4].



3. When do these ingredients combine?

Thermal evolution models indicate that planetesimals which formed 3-4 Myrs after CAIs can produce magnetized CM chondrites.



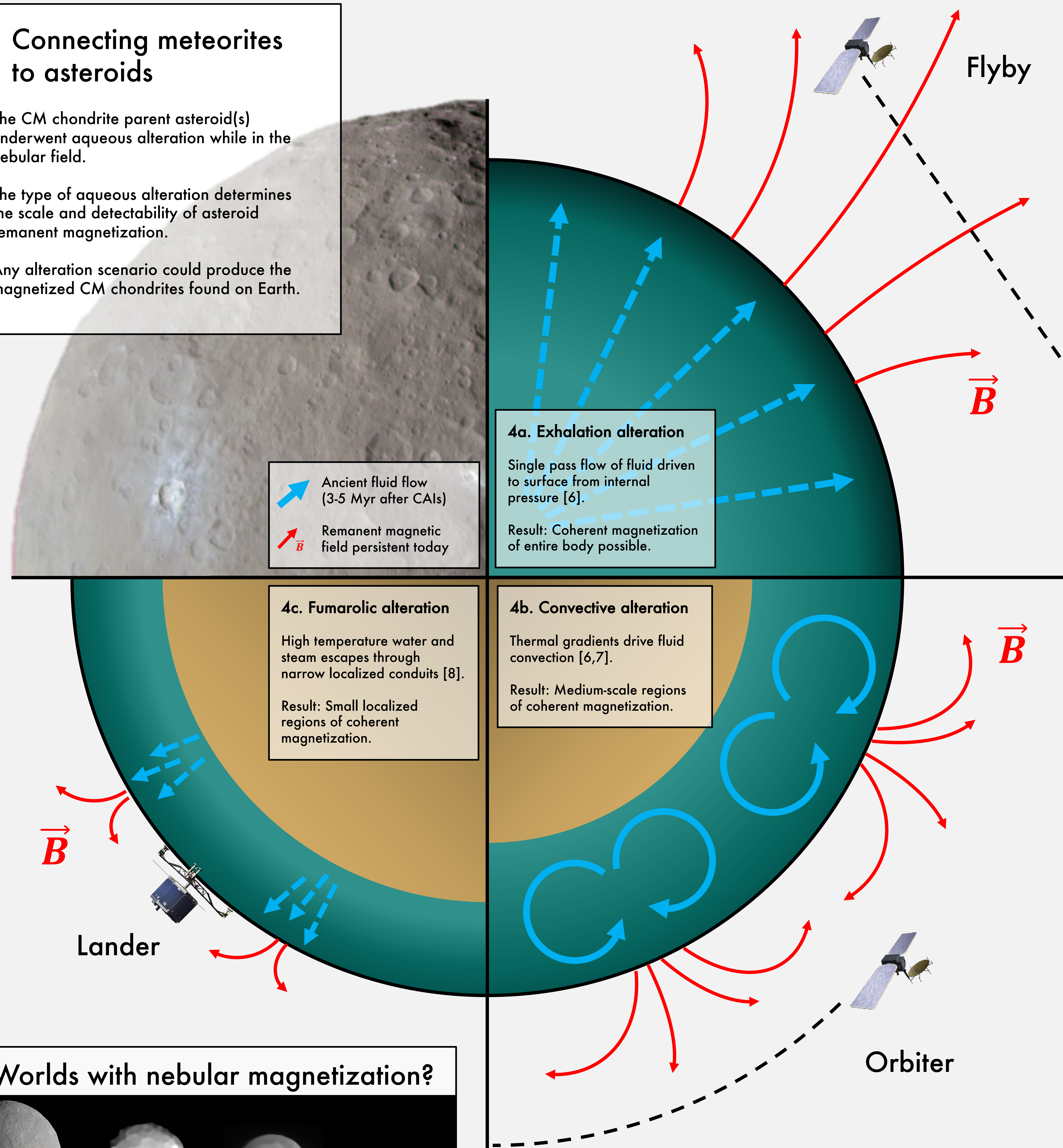


4. Connecting meteorites to asteroids

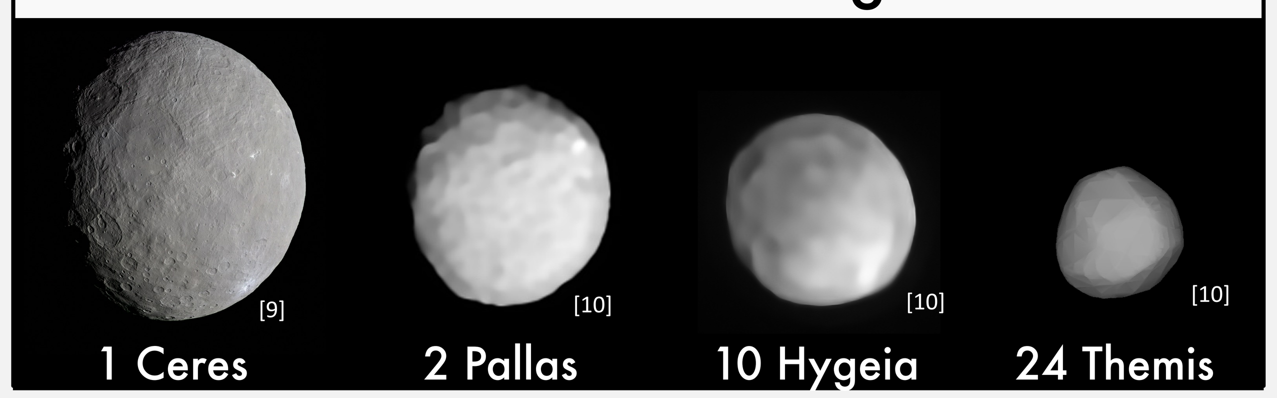
The CM chondrite parent asteroid(s) underwent aqueous alteration while in the nebular field.

The type of aqueous alteration determines the scale and detectability of asteroid remanent magnetization.

Any alteration scenario could produce the magnetized CM chondrites found on Earth.



5. Worlds with nebular magnetization?



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