Estimate of the magnetic paleofields during the formation of our solar system

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Magnetic Records may tell us About The Early Solar System

Wiechen [1] suggested the remanent magnetization of chondritic meteorites indicates the existence of 10^-4 ~10^-3 Tesla (T) magnetic fields in the early Solar System accretion disk. Desch [2] implied the presence of background magnetism at the chondrules formation. Other dynamic nebular and astrophysical phenomenon such as: magnetohydrodynamics (MHD) [3], X-ray flare [4], super novae shock [2], lightening [5], magnetic decoupling in giant molecular cloud (GMC) [6], and etc., could induce magnetism, and such magnetism would have been recorded in magnetic minerals in chondrules during their cooling. If the magnetic information had been preserved, then it may tell us about the origin and formation environment in the early solar nebula recognizing that primitive chondrules were formed in the early solar nebula. Even the magnetized iron dust may have existed in the nebula [7]. Magnetism in meteorite chondrules has been studied by [8], [9], [10], and they will give us tools and parameters to reconstruct the paleo-magnetic field in the early Solar System. Which also may give us information to uncover how the Solar System formed.

Investigation of the origin and formation of chondrules should address the complex astrophysical processes (mentioned above) in the early solar nebula, and the evolution of nebular gas and dusts that corroborate with the evolution of magnetic grains such as Fe-Ni compounds. Magnetism inducing astrophysical phenomenon seems so complex, and therefore reconstructing paleomagnetic field seems impossible. However, it is important to develop a simple model for a start. Nuth & Johnson (2006), Nuth et al. (2005) suggested a model for the processes in the Early Solar System (Fig. 2) that allow us to imagine a paleo-magnetic field in the Early Solar System. We made a first attempt, and made well fitting estimate for the modern Interplanetary Magnetic Field (IMF) (Fig. 1).

Estimate of IMF

Figure 1: Crud model of IMF

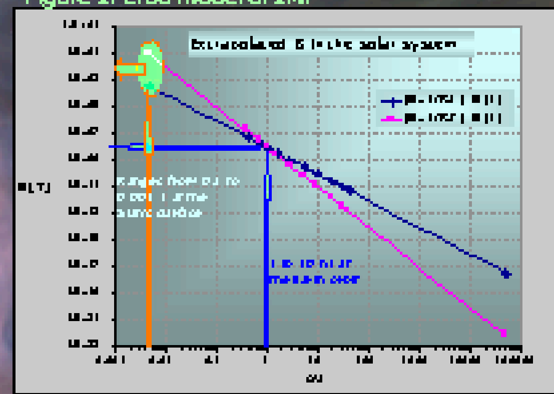
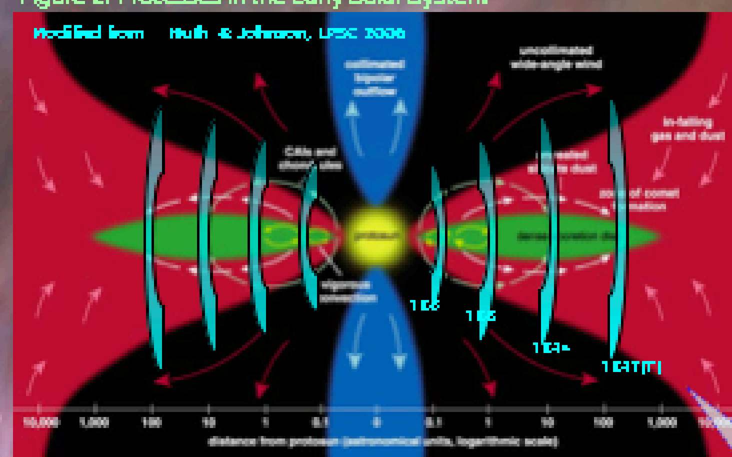


Fig. 1 shows the estimated magnetic field, B in the solar system at present. With an assumption of the magnetic field of the sun in heliosphere (Fig. 3) is frozen in the solar wind and carried straightforwardly all the way, we can extrapolate Interplanetary Magnetic Field, IMF by using a known B at the Earth orbit which is 5 to 10 nT (personal communication with M. Acuna). The B is extrapolated with the relationship of diminishing magnetic field over distance that is $1/R^2$ for radial, and $1/R^3$ total component. I used 10nT (taking a consideration of solar flare activity) to calculate the B by taking the ratio of the orbital distance of Earth to the orbital distance in question e.g., Mercury, Venus, Mars, and so forth, and the ratio is multiplied by 10nT. The extrapolated value at the Sun surface with both radial and total ranges from ~0.0001 to ~0.1 T.

The mathematical relationship to obtain IMF

$$B_{Earth} \propto 1/R^3_{Sun-Earth} \quad \& \quad B_S \propto 1/R^3_{Sun's-surface} \Rightarrow \frac{B_E}{B_S} = \frac{R_S^3}{R_E^3} \Rightarrow B_S = B_E \times \frac{R_E^3}{R_S^3}$$

Figure 2: Processes in the Early Solar System



Proto-solar nebula model (Fig 7) by Nuth & Johnson (2006) is adopted, and the Extrapolated IMF, B in [Tesla] values: 1E-5 At 0.1 AU; 1E-8 at 1 AU; 1E-14 at 10 AU; and 1E-17 at 100 AU are added. These modern values are probably minimum, and predict much higher intensity in the early solar nebula.

Figure 3: Adopted from NASA- Cosmicopia

Solar wind reaches well beyond the orbit of Pluto, solar magnetic field encompasses entire solar system called the Heliosphere – Voyager 1 will cross the 100AU mark, the edge of the Heliosphere in Aug. 2006!

How to extract the paleofield information?

Preserving the orientations: It is crucial to preserve chondrule orientation to identify if it's primitive and magnetically unaltered. Bjurbole is a friable, chondrule-rich, ordinary L4 chondrite. The friable nature was utilized in our precission 3 axis stage enabled the preservation of orientation during extraction of millimeter sized chondrules from meteorite matrix. The stage was attached to a binocular microscope aiding precision during preservation of the orientation. Natural remanent magnetization, (NRM), isothermal saturation remanent magnetization (SIRM), hysteresis, and demagnetization were measured for the chondrules.

Figure 4: Hysteresis measurement

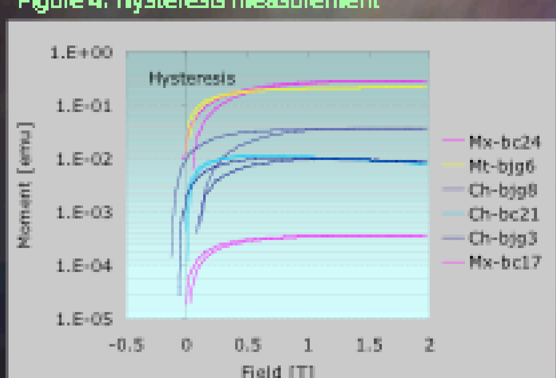
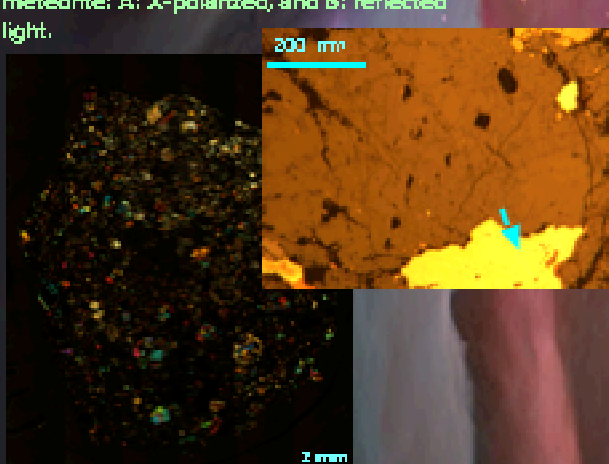


Figure 5A & B: Photomicrograph of the petrographic thin section of Bjurbole meteorite: A: X-polarized, and B: reflected light.



Magnetization in Bjurbole Chondrules

Fig. 4 shows the large coercivities and these results indicate the presence of tetrataenite that has been described by Wasilewski [11], [12], [13]. The magnetism of Bjurbole is due to these Fe-Ni compounds, primary a-kamacite (<7% Ni), g-taenite (>7% Ni), and g"-tetrataenite (re-52% Ni) [9]. The matrix, however has small coercivities and thus contains more likely taenite and kamacite.

Fig. 6 shows the matrix magnetic remanences are randomly oriented while demagnetized, however chondrules tend to have stable direction of magnetization. When the chondrules cooled down relatively quickly and the stress involved in volumetric changes caused magnetic mineral elongation and anisotropy leading to enhancement of stability of magnetic directions. These observation indicate the different formation environment between matrix and chondrules. Matrix formed likely in isotropic environment and therefore magnetic signal (if no detectable ambient field present) is scattered. This also is indicative of that after the chondrules were incorporated in the parent body, there has not been a significant magnetization occurred, and therefore the magnetic information may be pristine or less-altered. The Fig. 5 show a metal grain in a Bjurbole chondrule (blue arrow).

Figure 7: NRM/SIRM ratio for chondrules

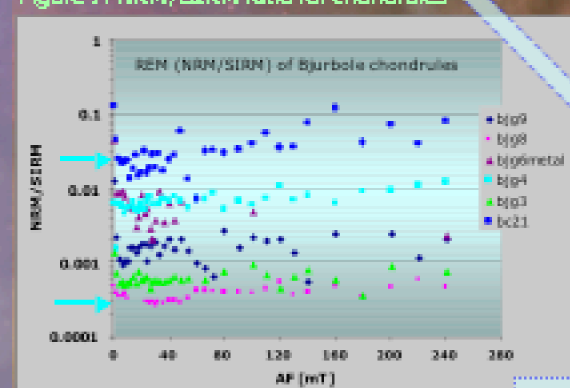
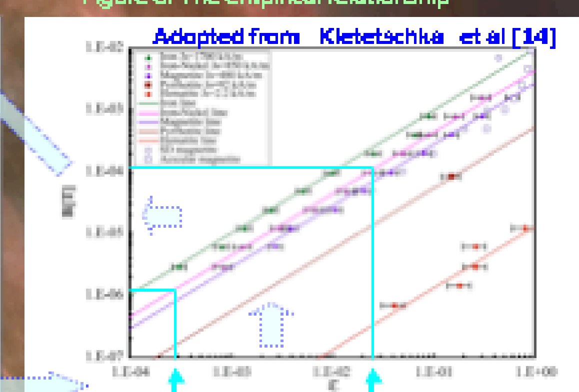


Figure 8: The empirical relationship



The ratio of NRM and SIRM (REM) for the Bjurbole chondrule is graphed in the Fig. 7. Kletetschka [14] suggested an empirical scaling law (Fig. 8) that was derived by the linear relationship between the acquisition magnetic field, B and thermoremanent magnetization (TRM). The adopted figure from [14] is applied to our chondrule REM to predict the paleofield. Applying the Fe-Ni line, the estimated paleofield ranges from ~3E-6 to 2E-4. Projecting these values to our extrapolated modern interplanetary magnetic field values (Fig. 2), the chondrule may have a history residing in the region (Fig. 9) that is the zoom up of the area in the Fig. 2, assuming that chondrule NRM is TRM and /or CRM.

Figure 9

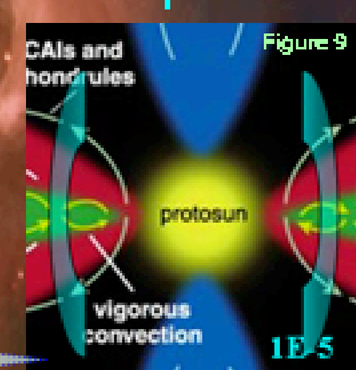
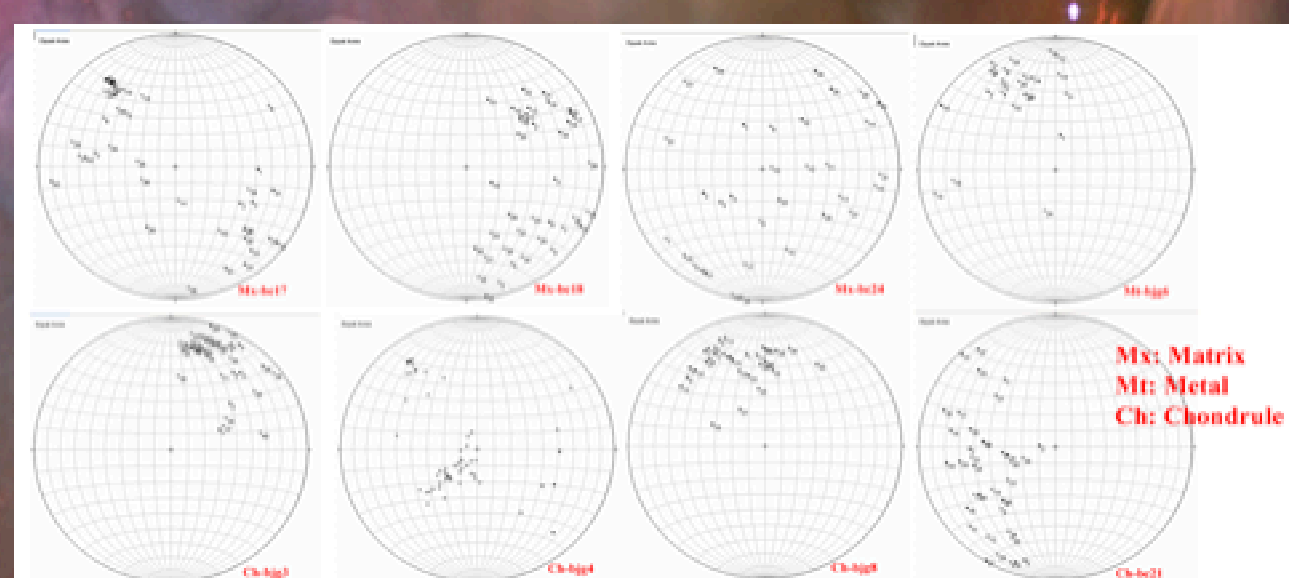


Figure 6: Stereonet projection of the NRM direction: bc17, bc18, bc24 are matrix; bjg6 is a metal grain; bc21, Bjg3, bjg4, bjg8 are chondrules. These chondrules were extracted from one Bjurbole meteorite sample. The directional heterogeneity indicate that chondrules were formed individually in probably different formation environment or mechanism, and incorporated into parent body after acquisition of NRM.



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Acknowledgements

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