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Note

Gould's Belt, interstellar clouds, and the Eocene–Oligocene helium-3 enhancement

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ABSTRACT

Drag from hydrogen in the interstellar cloud which formed Gould's Belt may have sent interplanetary dust particle (IDPs) and small meteoroids with embedded helium to the Earth, perhaps explaining part the helium-3 flux increase seen in the sedimentary record near the Eocene–Oligocene transition. Assuming the Solar System passed through part of the cloud, IDPs in the inner Solar System may have been dragged to Earth, while dust and small meteoroids in the asteroid belt up to centimeter size may have been dragged to the resonances, where their orbital eccentricities were pumped up into Earth-crossing orbits; however, this hypotheses does not explain the Popigai and Chesapeake Bay impacts.

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1. Introduction

Bekki (2009) has suggested that a blob of dark matter collided with an interstellar cloud $\sim 35 \times 10^6$ y ago, and that the collision triggered star formation, resulting in the young stars in Gould's Belt. The Solar System is currently near the center of Gould's Belt (also called the Gould Belt). It seems reasonable to suppose that, if Bekki's scenario is correct, the dark matter blob and/or the cloud may be linked to the temporary factor of ~ 2 increase in the influx of extraterrestrial ^{3}He (helium-3) seen in the sedimentary record 36–34 $\times 10^6$ y ago (Farley et al., 1998; Farley, 2001; Mukhopadhyay et al., 2001), as well as to the Chesapeake Bay and Popigai impacts.

A schematic of the temporary increase, based on Farley et al. (1998), is illustrated in Fig. 1, which shows a broad increase in the ^{3}He over a roughly two million year period; this broad increase is termed "the surge" here. Embedded in the surge are relatively sharp increases; these are here called "the peaks". The Earth Impact Database (http://www.passc,net/EarthImpactDatabase) gives the age for the Chesapeake Bay impact as $35.5 \pm 0.3 \times 10^6$ y and $35.7 \pm 0.2 \times 10^6$ y for Popigai. The gray area shown in Fig. 1 between 35.2×10^6 y and 35.9×10^6 spans the combined error bars. Three peaks lie within the gray area, and another is just outside of it. The dotted lines indicate iridium spikes, so that the leftmost peak may mark the Chesapeake Bay impact, though it is slightly outside the gray area; and the two rightmost peaks may actually be a singlet marking the Popigai impact. The level parts of the curve on either side of the surge are assumed to be due to the background flux of ^{3}He bearing interplanetary dust particles (IDPs). The conversion of the flux units from Farley et al. (1998) to those used here is given in Appendix A.

One possible explanation for the increase in ^{3}He shown in Fig. 1 is that the dark matter blob and/or the interstellar cloud stirred up comets in the Oort Cloud and sent some into the inner Solar System. The surge may be from a cometary shower which shed dust in the Solar System. Two of these comets may have caused the Chesapeake Bay and Popigai impact structures (e.g., Farley, 2001; Farley et al., 1998; Bodiselitsch et al., 2004; Tagle and Claeys, 2004; Fernandez et al., 2014). These or similar impacts may be partly or wholly responsible for the Eocene–Oligocene extinctions. (Andrew Brooks wondered if the dark matter blob actually triggered the earlier Cretaceous-Tertiary extinctions $\sim 65 \times 10^6$ y ago, killing off the dinosaurs (http://staff.unak.is/andy/Presentations/What happened to the Gould Belt.pdf), but this pushes Bekki's blob-cloud collision back by a factor of 2 in time. Bekki's timescale is assumed here.)

Schmitz et al. (2015) find evidence, however, that the impactors may have been two different types of chondritic asteroids, ruling out comet impacts explaining the peaks. They speculate that the surge and the peaks are caused by chaos in the Solar System at that time. It may be that the dark matter blob and/or interstellar cloud stirred up the Oort Cloud as well as created changes in the orbits of Solar System bodies. Other suggested mechanisms are comet collisions with asteroids which sent matter to Earth, and the two-step process of comets colliding with asteroids, sending meteoroids to the Moon, with ejecta from the lunar impacts subsequently making their way to Earth (Fritz et al., 2007).

The gravity from the dark matter blob and/or interstellar cloud may be a plausible explanation for the impacts, which possibly played a role in the biological extinctions à la the dinosaurs, as well as for the ^{3}He surge and peaks. However, the present paper pursues an alternative idea for at least the helium surge: the ^{3}He enhancement may have been due to the Solar System passing through a part of the interstellar cloud which ultimately formed Gould's Belt.

The idea is as follows. Drag from the constituents of the cloud, mainly neutral molecular hydrogen (H_2), affects the orbits of interplanetary dust particles and small meteoroids in the Solar System. In the inner Solar System, the drag sweeps the IDPs toward the Earth faster than the combined action of the Poynting–Robertson effect and solar wind drag, thus increasing the IDP flux to the Earth. At the same time in the asteroid belt IDPs and small, up to centimeter-sized meteoroids are delivered to the resonances and thence to Earth, also increasing the flux. In both processes the dust and meteoroids deposit ^{3}He on Earth, accounting for the surge shown in Fig. 1.

The drag mechanism is illustrated in Fig. 2. The figure shows a meteoroid in a circular orbit. At A the meteoroid runs into the hydrogen head-on, causing drag.

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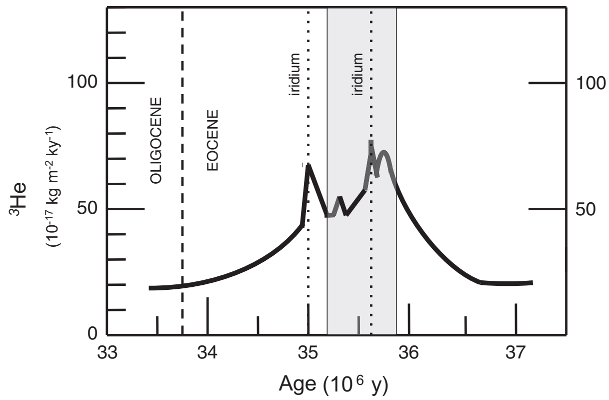

Fig. 1. Schematic of the ^{3}He increase near the Eocene–Oligocene boundary based on Farley et al. (1998). The abscissa gives the age before the present in millions of years. The ordinate gives the helium-3 flux. The vertical dashed line marks the transition between the two epochs. The gray area shows the approximate range of ages of the Chesapeake Bay and Popigai impacts combined. The dotted lines indicate iridium enhancements. The broad increase from ~36 to ~34 myr before the present is termed the "surge", while the sharper increases, two of which coincide with the iridium spikes, are termed "peaks". The flatter parts of the curve outside the surge are presumed to be due to the interplanetary dust particle (IDP) background without whatever caused the surge.

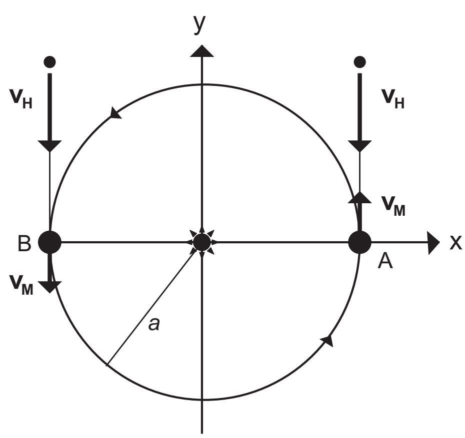

Fig. 2. Schematic illustrating the drag force on a meteoroid from the interstellar cloud's molecular hydrogen. The meteoroid is in a circular orbit about the Sun with semimajor axis a with velocity $\mathbf{v_M}$. In this diagram the hydrogen molecules (small black dots) lie in the x–y plane and have velocity $\mathbf{v_H}$. The collisions are head-on at A, causing drag on the meteoroid (large black dot). The collisions at B do the opposite, giving the meteoroid a boost. But at B the meteoroid encounters fewer molecules and lower speeds than at A because the relative velocity between the meteoroid and the hydrogen is smaller at B than at A. As a result, there is a net drag and the orbit shrinks.

At B the hydrogen instead pushes the meteoroid along. However, what happens at B does not cancel what happens at A: the meteoroid encounters fewer hydrogen molecules and lower speed impacts at B because the relative velocity is smaller there. When averaged over the whole orbit the drag force wins, and the semimajor axis decreases, driving the meteoroid inward. This could be effective in sweeping IDPs which reside between the Earth and the inner edge of the asteroid belt toward the Earth. Penetration of the hydrogen into the inner Solar System is not expected to be a problem (Yeghikyan and Fahr, 2004b, pp. 1114–1115).

As for inside the asteroid belt, many of the tinier meteoroids will reach the resonances during cloud passage because drag is an area-to-mass effect and moves small objects longer distances than large objects. Once these tinier objects reach the resonances, the orbital eccentricities will be rapidly pumped up, bringing them into the inner Solar System (Gladman et al., 1997). Some will fall on our planet.

A schematic of the process is shown in Fig. 3. The figure assumes that, before the cloud arrives, meteoroids of all sizes occupy the regions between the resonances, with smaller meteoroids being more numerous than large ones. Once in the cloud, the meteoroids move sunward toward the nearest resonance. How far each moves during cloud passage depends on when it was created, size, shape, composition (which determines density), and original distance from the resonance.

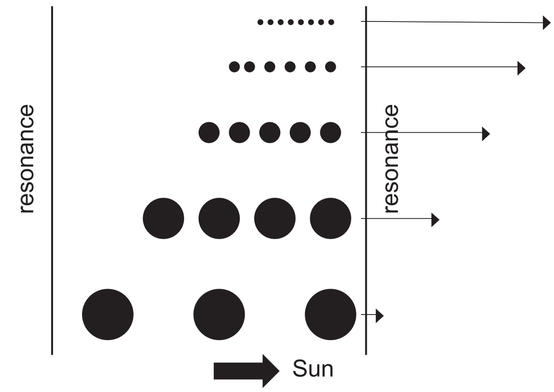

Fig. 3. Schematic of meteoroids which have moved toward the sunward resonance due to the hydrogen drag. Many of the numerous smaller meteoroids (top) pass through the resonance, depleting their number. The larger, less numerous meteoroids (bottom) move only a little, with few reaching the resonance.

Hence ~35 × 10^6 y ago there will have been something of a dust and meteorite shower on the Earth. The objects will bring in ^{3}He, which ends up in the sediments. Meteoroids might also impact on the lunar surface, with perhaps some of the ejecta reaching the Earth with their own freight of helium (Fritz et al., 2007).

The climatological and biological effects from the Earth's passage through an interstellar cloud has been investigated by several authors (e.g., McKay and Thomas, 1978; Zank and Frisch, 1999; Yeghikyan and Fahr, 2003, 2004a, 2004b; Bodiselitsch et al., 2004; Pavlov et al., 2005). Important as these effects are, the present paper examines only possible drag effects on small Solar System objects due to drag from the cloud that formed the Gould Belt. Also, gravitational interactions with the cloud or the blob are ignored. Smirnova (2004) discusses possible dynamical Solar System consequences from the Gould Belt.

2. Molecular hydrogen drag

This section makes a simple estimate of the amount of molecular hydrogen drag on a meteoroid. In Fig. 4 a spherical meteoroid is in a circular orbit with semimajor axis a. The orbit lies in the x–y plane with the Sun at the origin. The cloud's hydrogen is assumed to drift through the Solar System from the y-direction at an angle θ to the orbit normal (the z-axis), with no solar gravitational bending of trajectories. The concentration is uniform over space. The hydrogen velocity is

$$\mathbf{v_H} = -v_H(\sin\theta\hat{\mathbf{y}} + \cos\theta\hat{\mathbf{z}}), \tag{1}$$

while that of the meteoroid is

$$\mathbf{v_M} = v_M\hat{\mathbf{t}} = v_M(-\sin\psi\hat{\mathbf{x}} + \cos\psi\hat{\mathbf{y}}). \tag{2}$$

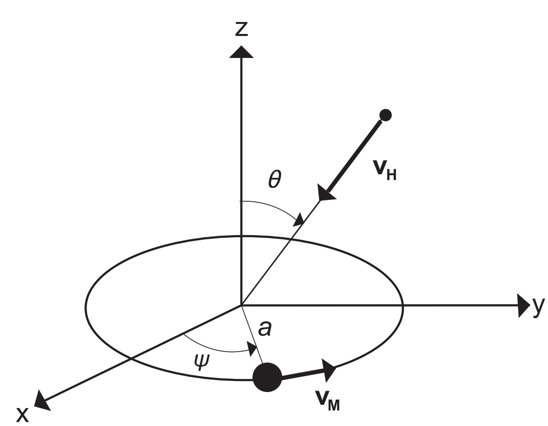

Fig. 4. Geometry of the meteoroid orbit and hydrogen trajectories. The orbit lies in the x–y plane and has semimajor axis a. The orbit normal is the z-axis. The meteoroid (large black dot) has velocity $\mathbf{v_M}$. The position in its orbit makes an angle Ψ with the x-axis. A hydrogen molecule (small black dot) travels with velocity $\mathbf{v_H}$, with its trajectory lying in the y–z plane. The trajectory makes an angle θ with the z-axis as shown. All the hydrogen molecules are assumed to be spread uniformly throughout space and have the same velocity and parallel trajectories.