Viewpoint

Dark Matter May Play Role in Extinctions

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An increased likelihood of life-threatening comet impacts could occur when the Sun passes through a possible dark matter disk in the Galaxy.

Subject Areas: **Astrophysics, Cosmology**

A Viewpoint on:
Dark Matter as a Trigger for Periodic Comet Impacts
Lisa Randall and Matthew Reece
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The path our Solar System takes through the Galaxy may get bumpy at times, and this could affect the number of comets buzzing around Earth. Scientists have uncovered possible evidence of this galactic bumpiness in an apparent periodic fluctuation in the rate of large crater-forming impacts—the kind that likely killed off the dinosaurs. The frequency of impact fluctuations closely matches the rate at which the Sun passes through the plane of the galactic disk. However, it hasn't been clear what element in the disk could be influencing comet trajectories. Two theoretical physicists have put forward a hypothesis that inserts dark matter as the missing piece between Solar System motion and possibly life-threatening comet impacts. In a paper published in *Physical Review Letters*[1], Lisa Randall and Matthew Reece from Harvard University suggest that some of the mysterious invisible matter, which makes up 85% of all matter in the Universe, could exist in a thin disk that disturbs the path of certain comets so that they are more likely to collide with our planet.

Comet impact events appear to have played a significant role in shaping Earth's history, creating craters and possibly causing mass extinctions [2] (Fig. 1). Many of these comets come from the Oort cloud, a spherical envelope of icy bodies in the outer edge of the Solar System extending from just outside the orbit of Neptune to halfway to the next nearest star. Because the Oort cloud is so distant from the Sun, it is highly susceptible to perturbations from gravitational forces coming from other bodies. Indeed, there have been some indications that the frequency of impacts (from both comets and asteroids) on Earth oscillates on a timescale of about 25 to 35 million years, which suggests a connection between the dynamics at the outer edge of the Solar System and the comet shower strikes on Earth [3].

Two hypotheses have been proposed to explain the possible periodicity in comet impacts. One idea involves the gravitational pull of an as-yet-undiscovered distant companion star (called Nemesis) or planet (called planet X) that periodically disturbs comets in the Oort cloud and causes a large increase in the number of comets visiting the inner Solar System and thus in the frequency of the impact events on Earth [4]. Neither Nemesis nor planet X was detected with NASA's Wide-field Infrared Survey Explorer (WISE) space telescope, effectively ruling out the theory that an object in our Sun's neighborhood can explain the impact fluctuations.

FIG. 1: Some large life-extinguishing impacts in our past may have been triggered by a dark matter disk in the Milky Way. (APS/Alan Stonebraker)

An alternative hypothesis involves a gravitational influence of the dense galactic disk on the Solar System [5]. Our Sun orbits around the Galactic center, taking approximately 250 million years to make a complete revolution. However, this trajectory is not a perfect circle. The Solar System weaves up and down, crossing the plane of the Milky Way approximately every 32 million years, which coincides with the presumed periodicity of the impact variations (see Fig. 2). This bobbing motion, which extends about 250 light years above and below the plane,

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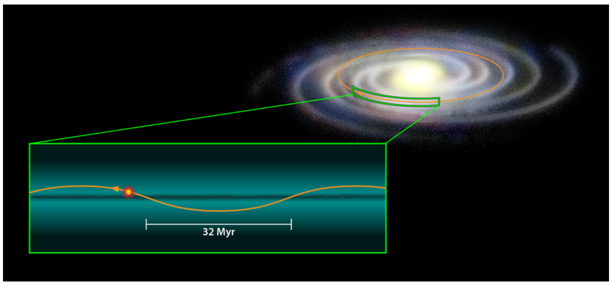

FIG. 2: Our Solar System orbits around the Milky Way's center, completing a revolution every 250 million years or so. Along this path, it oscillates up and down, crossing the galactic plane about every 32 million years. If a dark matter disk were concentrated along the galactic plane, as shown here, it might tidally disrupt the motion of comets in the Oort cloud at the outer edge of our Solar System. This could explain possible periodic fluctuations in the rate of impacts on Earth. (APS/Alan Stonebraker)

is determined by the concentration of gas and stars in the disk of our Galaxy. This ordinary "baryonic" matter is concentrated within about 1000 light years of the plane. Because the density drops off in the vertical direction, there is a gravitational gradient, or tide, that may perturb the orbits of comets in the Oort cloud, causing some comets to fly into the inner Solar System and periodically raise the chances of collision with Earth. However, the problem with this idea is that the estimated galactic tide is too weak to cause many waves in the Oort cloud.

In their new study, Randall and Reece focus on this second hypothesis and suggest that the galactic tide could be made stronger with a thin disk of dark matter. Dark disks are a possible outcome of dark matter physics, as the authors and their colleagues recently showed [6]. Here, the researchers consider a specific model, in which our Galaxy hosts a dark disk with a thickness of 30 light years and a surface density of around 1 solar mass per square light year (the surface density of ordinary baryonic matter is roughly 5 times that, but it's less concentrated near the plane). Although one has to stretch the observational constraints to make room, their thin disk of dark matter is consistent with astronomical data on our Galaxy [7]. Focusing their analysis on large (>20 km) craters created in the last 250 million years, Randall and Reece argue that their dark disk scenario can produce the observed pattern in crater frequency with a fair amount of statistical uncertainty.

Randall and Reece's dark disk model is not made of an ordinary type of dark matter. The most likely candidate of dark matter—known as weakly interacting massive particles (WIMPs)—is expected to form a spherical halo around the Milky Way, instead of being concentrated in the disk. This WIMP dark matter scenario has been remarkably successful in explaining the large-scale distribution of matter in the Universe. But, there is a long-standing problem on small-scales—the theory generally predicts overly dense cores in the centers of galaxies and clusters of galaxies, and it predicts a larger number of dwarf galaxy satellites around the Milky Way than are observed [8]. While some of these problems could be resolved by better understanding the physics of baryonic matter (as it relates, for example, to star formation and gas dynamics), it remains unclear whether a baryonic solution can work in the smallest mass galaxies (with very little stars and gas) where discrepancies are observed.

Alternatively, this small-scale conflict could be evidence of more complex physics in the dark matter sector itself. One solution is to invoke strong electromagnetic-like interactions among dark matter particles [9], which could lead to the emission of "dark photons" [10]. These self-interactions can redistribute momentum through elastic scattering, thereby altering the predicted distribution of dark matter in the innermost regions of galaxies and clusters of galaxies as well as the number of dwarf galaxies in the Milky Way. Although self-interacting dark matter could resolve the tension between theory and observations at small-scales, large-scale measurements of galaxies and clusters of galaxies only allow a small fraction (less than 5%) of the dark matter to be self-interacting. Recently, Randall, Reece, and their collaborators showed that if a portion of the dark matter is self-interacting, then these particles will collapse into a dark galactic disk that overlaps with the ordinary baryonic disk [6].

Did a thin disk of dark matter trigger extinction events like the one that snuffed out the dinosaurs? The evidence is still far from compelling. First, the periodicity in Earth's cratering rate is not clearly established, because a patchy crater record makes it difficult to see a firm pattern. It is also unclear what role comets may have played in the mass extinctions. The prevailing view is that the Chicxulub crater, which has been linked to the dinosaur extinction 66 million years ago, was created by a giant asteroid, instead of a comet. Randall and Reece were careful in acknowledging at the outset that "statistical evidence is not overwhelming" and listing various limitations for using a patchy crater record. But the geological data is unlikely to improve in the near future, unfortunately.

On the other hand, advances in astronomical data are expected with the European Space Agency's Gaia space mission, which was launched last year and is currently studying the Milky Way in unprecedented detail. Gaia will observe millions of stars and measure their precise distances and velocities. These measurements should enable astronomers to map out the surface-density of the dense galactic disk as a function of height. Close to the plane, astronomers could then directly see whether there is a "disk within the disk" that has much more mass than we could account for with the ordinary baryonic matter. Evidence of such a dark disk would allow better predictive modeling of the effects on comets and on the life of our planet.

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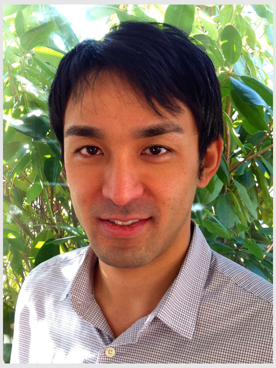

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