The Evolution of the Chemical Elements of the Universe

Rudolph E. Schild

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ABSTRACT

Spectroscopic observations of distant cosmological sources continue to exhibit a surprising result; that the chemical abundance of the universe seems to be approximately solar for the observed sources at redshifts of 5, 6, and even 7, even though very few galaxies should have existed at these epochs and the principal star formation and heavy element production event should have been at the more local $z = 1 - 2$.

*Subject headings:* Galaxy: halo – baryonic dark matter: Cosmology: Abundances of Matter
1. Introduction

If an informed astronomer would have been asked 20 years ago, what were the abundances of the elements in galaxies at redshifts $z = 5, 6,$ and $7$ (a time when the universe was less than a billion years old, or about 8% of its present age), the reply probably would have been that few galaxies yet existed and since the inferred age would not permit the first generation of stars to evolve to the red giant phase in significant numbers, only a few type II supernovae remnants would have polluted interstellar space with heavy elements. Therefore, the metal content would have still been low, surely less than 10% of solar composition and probably less than one percent.

Thus the world was surprised when an emerging suite of 8-10m class telescopes with fast spectrographs found that abundances of Lyman-break galaxies and quasars seem to be greater than solar. For example, the 1999 oral report of F. Hamann to the American Astronomical Society (AAS Meeting 194 - Chicago, Illinois, May/June 1999, Session 63. “Evolution of Chemical Abundances over Cosmic Time”) noted that, ”There is a growing consensus from both the emission and intrinsic absorption lines that near-QSO environments have roughly solar or higher metallicities out to redshifts greater than 4. The range is not well known, but solar to a few times solar appears to be typical. There is also evidence for higher metallicities in more luminous objects, ....” At the same special session, Wolfe (1999) noted from studies of damped Lyman-alpha systems that, ”Attempts to explain these trends by chemical evolution of isolated galaxies undergoing passive evolution do not work, since they predict a systematic increase of the mean $Z/Z_{\text{solar}}$ with time, which is not observed. Rather, the observed trends are better explained in the context of hierarchical cosmologies by identifying Damped Lyman-alpha systems as regions of high comoving density in which the mean $Z/Z_{\text{solar}}$ rapidly approaches solar values at high redshifts and saturates thereafter.

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1Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138
Fan et al (2004) report, "The sample of 12 quasars at z greater than 5.7 from the SDSS provides the first opportunity to study the evolution of quasar spectral properties at $z \sim 6$, less than 1 Gyr after the big bang and only 700 Myr from the first star formation in the universe. Optical and Infrared spectroscopy of some $z \sim 6$ quasars already indicate a lack of evolution in the spectral properties of these luminous quasars; Petrocini et al (2002) show that the $C_{IV}/N_{V}$ ratio in two $z \sim 6$ quasars is indicative of supersolar metallicity in these systems."

The general topic of abundances measured in hi-z galaxies has recently been reviewed by Leitherer (2005). Kewley and Kobulnickey (2005) recently found that the O/H ratio is approximately 1/3 of the solar value at $z = 3$.

The present situation, with measured abundances of high-z sources higher than expected, is not thus far viewed as a crisis, because only the most luminous galaxies can be observed at these redshifts, and their star formation histories may be atypical. The solar abundances measured in high-redshift quasars are also not described with alarm, because it is possible to imagine that some kind of feedback from the central object has influenced the host galaxy’s star formation.

The purpose of the present report is to suggest that the nature of the baryonic dark matter can probably explain the surprising observational result. From gravitational lensing of quasars it has been established that the surprising and rapid microlensing observed indicates that the entire baryonic dark matter of the universe consists of a population of primordial planetoids, numbering trillions per galaxy, formed at the time of recombination. They have since orbited within the halos of all galaxies, thereby sweeping halos clean of most of the interstellar particles that would have otherwise contributed to subsequent generations of stars. Since the role of the baryonic dark matter has thus far not entered the discussion, it would be surprising if we could fully understand the process of heavy-element
enrichment of the overall universe without considering the role of the baryonic dark matter.

In the following paragraphs we examine more carefully the effects of the primordial planetoid objects and their role in sweeping the interstellar medium clean of the dust grains deposited by red giants and supernovae. In section 2 we lay the groundwork for our simple calculation of the physics of the process. In section 3 we show that the volume swept up by the primordial planetoids in 100 million years is comparable to the entire volume of the galaxy, and that it is therefore reasonable to imagine that the collection of a significant fraction of the interstellar and circumstellar grains occurred. In section 4 we discuss some implications and further falsifiable predictions.

2. The Nature of Primordial Planetoids and their Relationship to the Interstellar Medium

Quasar microlensing can reveal the nature of the baryonic dark matter particles because it has been understood from the outset that the optical depth to microlensing by stars, or whatever constitutes the baryonic dark matter, would be so high that observations should show continuous microlensing. In the case of the discovery object, Q0957+561 A,B, the optical depth for microlensing in the B image should be 1.35, meaning that at any statistical moment, 1.35 microlensing events should be underway. This means that at any statistical moment, probably 1 microlensing event and a third of the time 2 events, are underway. This would be true if the physical size of the quasar were nearly the size of the Einstein ring of the microlensing object, with events having brightness peaks approximately 30 times the un-microlensed brightness. In fact observations show that in many quasars where microlensing is observed, the amplitudes are much smaller, which implies that the quasar resolved structure is several times larger than the solar mass Einstein ring. Schild (1996) found from theRefsdal-Stabell (1991, 1993, 1997) theory that the Q0957 quasar
exhibits a luminous surface area 6 times larger than the area of a statistical half-Solar-mass
microlensing star Einstein ring.

For star microlenses, the event duration should be about 30 years, with the event
duration decreasing as the square root of the mass of the microlensing particle. Thus the
rapid microlensing detected by Schild (1996) for Q0957 was interpreted to indicate that
the mass of the baryonic dark matter particle was approximately $10^{-5.5} M_\odot$. For such
microlensing particles, many million would be along the line of sight to the quasar at any
statistical moment, and a complex pattern of continuous but low-amplitude microlensing
on a one-day time scale would result, as observed (Colley and Schild, 2003).

Other explanations have been offered for the microlensing, but none can reproduce the
observations, particularly since microlensing has a unique observable signature. Because the
microlensing takes place in the shear of strong lensing and star microlensing, a microlens
at optical depth near unity would cause increasing or diminishing brightness with equal
probability, amplitude, and time scale. This has been seen in the wavelet analysis of
the brightness history of Q0957 (Schild 1999), and is a reasonably strong indicator of
microlensing. A simulation showing the rapid microlensing by the primordial planetoids in
the presence of shear of the macrolensing plus star microlensing has been given by Schild
and Vakulik, 2003.

Other manifestations of such a population have since been found in radio astronomy.
The ”extreme scattering events” seen in refraction of radio waves in the direction of quasar
Q0954+658 have been associated with planetary mass clouds which surprisingly seem not
to dissipate (Walker and Wardle, 1998). And strong deflection of radio emission seen
in scintillation observations of pulsar PSR B0834+06 implies the existence of scattering
structures which ”may contain a significant fraction of the mass of the Galaxy” (Hill et al,
2004).
We are of course aware of the claim that MACHO searches have excluded the existence of a cosmologically significant population of planetary mass dark matter particles. Of course, the searches do not find significant dark matter, just the population of white dwarfs always known to exist, and their non-detections combined with a model of uniformly distributed ("Gaussian distributed") planetoids is the basis for the claim (Calchi-Novati et al, 2005). But if the particles are clumped, as found where they have been detected shadowing the nebular background with direct HST imaging of the nearest planetary nebula (Helix), then MACHO searches cannot detect them. Obviously if they are uniformly distributed, then they are the only gravitating particles in the universe found unclustered, since stars are found clumped on scales of double and multiple stars, small and large clusters, galaxies, and galaxy clusters.

If the baryonic dark matter is indeed planetary mass particles, as indicated from quasar microlensing, when did the population form? A hydrodynamic theory for the formation of primordial structure has been given by Gibson (1996; see also Gibson & Schild, 1999) which predicted the existence of these particles at about the time that they were discovered in quasar microlensing. The particles were formed at the time of recombination, 300,000 years after the Big Bang, and have collapsed and cooled since. Thus these objects were orbiting in the halos of galaxies since the first structures formed, and their sweeping action must presumably have allowed them to collect up much of the interstellar dust formed in outer atmospheres of supergiants and supernovae. A supercomputer simulation by Diemand, Moore, and Stadel (2005) predicts formation in axion dark matter of a primordial population of planetary mass particles with the approximate size of the solar system; if such a process significantly operates in nature, it is difficult to escape the conclusion that baryonic matter would fall into and enhance such objects.

The existence of a primordial population of baryonic dark matter primordial planetoids
would have produced two effects that are important to the observations of chemical abundances of galaxies and quasars. First, as noted above, they would be continually sweeping clean the interstellar medium. To clarify the description of this, we assume that any typical cubic centimeter volume in the galaxy collects up some average quantity of metal atoms C at a rate of dC/dt, so the total amount swept up over time is Ct. If the test volume is swept clean every \( \tau \) years, then the average metal content is \( \frac{1}{2} \times C\tau \). So after the galaxy has been forming stars for \( \tau \) years, it would have the time-average mean metal content \( \frac{1}{2} \times C\tau \). Since abundances within galaxies are ordinarily measured and inferred from the emission lines originating in the galaxy's interstellar medium, sweeping would cause the appearance of this overall constant average metal abundance. Since stars are formed from these primordial planetoids, successive generations of stars would be expected to show a more gradually increasing metallicity by this model.

A second important process resulting from the existence of the primordial planetoid population is the sequestering away of a large fraction of the hydrogen in the universe, which should have consequences for the understanding of the cosmological re-ionization event inferred to have occurred at \( z = 6.2 \). If we assume that at this redshift, 90% of the hydrogen was bound in these objects, which had condensed from the nearly uniform primordial gas on a Kelvin-Helmholz time scale of approximately 100 million years, then this gas would not need to be re-ionized for the universe to become transparent. Therefore the re-ionizing photon flux from Pop III has been overestimated by a factor of 10.

These two processes combine in an interesting way to give the appearance of a very rapid increase of the chemical abundances of young galaxies, if the abundances are estimated from emission lines originating in the interstellar medium. Notice that before the first sweeping event has occurred, the interstellar abundance of the typical volume can very quickly build up to a seemingly large value, because most of the baryonic gas is in
planetoids which do not need to be enriched, and the apparent enrichment of the galaxy before sweeping in the above example is incorrectly estimated to be $10 \times (1/2 \times C\tau)$.

It should not be surprising then that the nature of the baryonic dark matter would play an important role in defining the observed chemical and ionization history and evolution of the universe. In the following section, we offer a simple calculation to show that the expected sizes and motions of the primordial planetoids should be sufficient to significantly sweep up the particulate matter in the interstellar medium of all galaxies.

As noted above, there must be an important sweeping process tending to clear the interstellar medium in galaxy discs and halos of the heavy element ejecta from evolved stars and supernovae. Imagine any cubic parsec of space in the disc of a galaxy. It is collecting processed gas and dust for a time short compared to cosmological time. But the polluted cubic parsec gets swept clean every hundred million years, with the pollutants heavier than hydrogen and falling to the center of the primordial planetoid and hence not seen in the kind of spectroscopic measurements a distant observer makes to study abundances of the interstellar medium. This will have several consequences for inferences made about cosmo-chemistry by the terrestrial observer.

To clarify the situation we give a simplified heuristic model of the process. We assume that all matter in the universe is baryonic, and that a small fraction $f$ of the primordial gas did not initially condense into the primordial planetoids and that therefore $1 - f$ is that fraction initially and presently in the form of baryonic dark matter planetoids (Primordial Fog Particles; Gibson, 1996, 1999). With current estimates that the universe has approximately 3% visible matter, we therefore estimate that $f = .03$ and $1 - f = .97$. Note that all published calculations about the emergence of the universe from its dark ages adopt $f = 1.0$, and $1 - f = 0$.

In our scenario, the level of ionization of the universe can be high for even a weak
population of ionizing sources, because the available ionizing photons are not bothered by the vast reserves of atomic hydrogen sequestered away in planetoids. A terrestrial astronomer knowing the mean baryonic (hydrogen) matter density in the universe overestimates the ionizing flux required to ionize the small fraction $f$ of interstellar hydrogen. Thus if the primordial planetoids exist, calculations of the required UV photons can be a factor $\times 30$ lower than the standard calculation, which requires the entire baryonic matter of the universe to be ionized by $z=6$. Thus the UV fluxes from quasars are probably sufficient to ionize the universe, and the existence of a mysterious and never observed Population III rich in $300 \, M_\odot$ stars is questionable.

This heuristic example also predicts that initially in the universe, abundances estimated from emission line galaxies are much higher than the true heavy element abundances, because the primordial planetoids have not yet swept up much of the heavy elements produced. If, as already adopted in our example, the true interstellar gas is only $3\%$ of the baryonic matter, and will not on average be swept until $10^8$ years after first star formation, although the interstellar emission lines would indicate solar metallicity the true baryonic matter enhancement is only $1/30$ of solar metallicity. Thus the process must necessarily cause over-estimation of the true cosmic enrichment of heavy elements by not correctly taking into account the nature of the dark matter.

The primordial planetoid population has a third implication for cosmological evolution of observed abundances. If stars are formed primarily from the dominant dark planetoid population and not from the diffuse interstellar gas for which we easily measure the emission line strengths and estimate abundances, then the stars formed will be less enriched than the observed gas. Again referring to the heuristic example, after $10^8$ years the primordial planetoids have swept galaxy discs and halos once, and have on average $1/30$ of the metals content of the gas; thus stars formed after $10^8$ years have lower metallicity than the emission
line gas.

If we now fast forward in time to the present epoch, we find that the primordial planetoids play a very different role. If we again accept the heuristic model and also assume that metals production in the universe has been nearly constant over cosmic time, and that the interstellar media of galactic discs and halos are swept clean once in $10^8$ years, then in 3 billion years the metallicity of the diffuse interstellar medium and the planetoids has equalized. Thereafter, the planetoids have higher metallicity in the form of cosmic dust collected at their centers. Subsequent generations of stars that somehow formed from this baryonic dark matter now have metallicity greater than that of the galaxy disc interstellar medium, which is still being swept clean every $10^8$ years.

This picture of star formation, illustrated by a simple heuristic model, may also illustrate another important aspect of cosmic evolution. The Gibson (1996) theory does not predict the existence of a primordial population of stellar mass objects. Instead, it posits that the entire baryonic dark matter of the universe condensed into a great primordial fog, with the characteristic mass scale of a fog droplet estimated at $10^{-7} M_\odot$, and observationally estimated from quasar microlensing (Schild, 1996) to be $10^{-6} M_\odot$. Thus the first stars were made from accretional cascade when the stickey planetary mass “Primordial Fog Particles” interacted at their fuzzy boundaries to form pairs, and then pairs of pairs, etc. It is likely that such an accretional cascade would have produced objects with a mass function that is strongly biased toward low masses. Thus the early universe should have been dominated by an initial population of low-mass and low-luminosity objects with Pop III chemical composition. Of course it is possible that any available gas also formed Pop III stars from interstellar gas by the more accepted modern theory of star formation. By this argument it is likely that the Pop III initial mass function is different from the present epoch stellar mass function.
3. An Estimate of the Sweeping Activity of Primordial Planetoids

In the following paragraphs, we estimate the total sweeping action by the primordial planetoids from reasonable estimates of the planetoid cross section area and the speed. We assume a population of primordial objects orbiting our Galaxy with a mean motion of 220 km/sec. In principle the cross section area of such an object should be derived from a complex model of a brown dwarf-like object of terrestrial mass and primordial gas composition, formed at the time of recombination in a condensation-void separation process as envisaged by Gibson (1996), and cooled through the 13-billion year history of the universe. The complex processes of cooling and external re-heating have already been discussed by Schild and Dekker (2006) with the conclusion that it is better to establish a reasonable diameter estimate from observations. Objects of the expected type have been identified and discussed by Gibson and Schild (2003) residing in the Helix planetary nebula and seen as "Cometary knots". Although these objects have been lightly dismissed as Rayleigh-Taylor gas instabilities, their high density contrast with the ambient gas makes such an explanation implausible (Gibson and Schild, 2003; see sections 2.3.1 and 4) and no detailed supporting instability model exists. Nor can they be understood as shock instabilities, since they do not exhibit a shock spectrum.

Thus we take these cometary knots to be remnant primordial planetoids, labeled Primordial Fog Particles by their discoverer (Gibson 1996) and we take their sizes to be as measured from direct imaging by Meaburn et al (1998). Since their outer atmospheres have been ablated back and away, only the lower limit to their sizes can be estimated from the observations; this limit is taken to be $10^{15} cm$.

For this diameter, the cross-sectional area for sweeping will be $10^{30} cm^2$ and the distance travelled in $10^9$ years would be $10^{24} cm$, for a total swept volume of $10^{54} cm^3$ per planetoid. For a planetoid mass of $10^{-6} M\odot$ and total Galaxy mass of $10^{11} M\odot$, there would be $10^{17}$
of the sweeping particles for a total swept volume of \(10^{71} \text{cm}^3\). For a Galaxy Halo diameter of 50 kpc, the volume is \(10^{70} \text{cm}^3\), implying any statistical small volume of space in the Galaxy or Halo gets swept 10 times in a billion years. Thus the constant \(\tau\) introduced in the previous section is estimated to be 100 million years.

In this calculation we have assumed that any dust grain or molecule encountered by the primordial planetoid is captured. It is of course unknown to what extent this is true. Lacking real information about the structure of the outer atmosphere of such a planetoid, we examine the properties of meteors seen in the terrestrial atmosphere.

It is reasonably well known that meteors swept up by the Earth’s atmosphere are observed glowing at altitudes near 100 km (Millman and McKinley, 1963). The brightest objects, presumably the more massive entering particles, are observed penetrating to 70 km, where the atmospheric density is \(10^{-7} \text{g/cm}^3\). However their fiery trails begin at an altitude where the smallest meteors occur, near 100 km, with a residual atmospheric density of \(10^{-9} \text{g/cm}^3\). Presumably the smaller, finer 1 micron sized particles can be captured at higher altitudes with lower densities; recall that spacecraft operate in low Earth orbit near 160 km, where the residual density is \(10^{-12} \text{g/cm}^3\). But although low orbiting spacecraft survive for multiple orbits because of their large mass/surface area ratio, the interstellar dust particles would not.

4. Discussion About Further Properties of the Baryonic Dark Matter

The proposed role of the primordial planetoids in sweeping the interstellar medium throughout the history of the universe must have further implications for the observed chemical evolution of the universe. It is easy to understand that insofar as the primordial planetoids maintain a relatively constant sweeping action throughout the discs and halos of
galaxies, the rate of accumulation of heavy elements produced in red giants and supernovae in the gaseous interstellar medium is diminished and many of the heavy elements must be sequestered away until the planetoids contribute to star formation at a later time. It must be true to some extent that star formation causes the conversion of dark baryonic matter into visible matter, but that stars become fading white dwarfs after their hydrogen burning lifetimes, to again become dark matter. The process must convert pristine primordial halo dark matter into heavy element enriched dark degenerate cores in discs of spiral galaxies. It must also sequester away heavy elements out of the interstellar medium but yield the heavy elements up again in later generations of stars being formed out of the primordial planetoids.

Thus as the primordial planetoids are acting as an important reservoir, sequestering away heavy elements for a future generation of stars, they must have a complex life of their own. The hydrodynamic theory that predicts their formation (Gibson 1996,) also comments about more specific processes occurring in their formation and evolution. Following their formation in a condensation/void separation process, with masses top-limited at terrestrial mass, $10^{-6} M_{\odot}$, the early objects would have slowly collapsed on a Kelvin-Helmholtz time scale of 300 million years but must have been quite sticky for this duration, since their extended residual atmospheres would probably have created large viscosities in the extended outer parts. Thus 2-body interactions should have caused mergers, and these merger products would presumably have caused small departures from the ambient flow, inducing further mergers in an unstable cascade process. Although the available computer simulations of the process show the formation of the condensations (Truelove 1998) the

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2 The Truelove report is written in the context of Jeans theory, and starts with the presumption that instabilities to condensation found in the simulations must be some artifact of the calculations. We think it more likely that the simulations are correct, and that
calculations become unstable after the formation of first condensations and have not been continued with finer sampling to follow the expected interaction process. We presume that the process is intrinsically unstable for the smooth expanding flow of the primordial gas, and that a cascade of merging Primordial Fog Particles, (PFP’s Gibson 1996) would generate a population of merged primordial objects and thereby extend the mass range much higher than the viscosity-limited primordial cutoff. Thus the primordial process of condensation-void separation should produce cascades to heavier masses of the primordial planetoids, which will also exhibit the observed clumping in space.

The Gibson (1996) theory describing this ”Primordial Fog Particle” formation also gives nod to the so-called Jeans mass scale, which then predicts that at the time of recombination, as the primordial planetoids were forming, mass was also aggregating on globular cluster mass scales, $10^6 M_\odot$. Since these form at the same gas density as the planetoids, they would have comparable Kelvin-Helmholz time scales for collapse. Since the primordial planetoids within such proto-globular-clusters thus become the particles of a gas ultimately establishing a virialized structure, the relative motions of the primordial planetoids and hence the merging to higher mass would be greater within the proto-globular-clusters.

Thus the merging of the primordial planetoids and the process of first star formation from them, both proceeding on a time scale of 300 million years, would be different within the cluster, and would presumably result in a difference in the population III mass spectrum inside/outside the cluster. It also seems likely that the first Population III star formation would have occurred in the Gibson (1996) cluster-mass condensations.

The formation of the primordial planetoids must also importantly affect the amount of ionizing radiation needed to re-ionize the universe following the ”dark ages”. For the quiescent gas is unstable to the condensation-void separation process, if other fluid forces are not disruptive.
universe to become transparent to radiation shortward of the Lyman limit, only the fraction of gas that remains following the efficient condensation-void separation, needs to be ionized. Given that the universe is presumed to have ten times more baryonic dark matter than luminous matter today, and that the dark fraction must have been larger before the star formation peak at $z = 1 - 2$, we can estimate that only about a percent of the baryonic matter in the universe needed to be ionized for the universe to become transparent, reducing the required amount of ionizing radiation from the first generation of stars and from the quasars by a factor of at least one hundred. Current estimates for the required ionization ultraviolet flux by Wyithe and Loeb (2003) do not take into account the reduction in required radiation implied by the condensation of this dominant dark matter population.

The more recent history of the primordial planetoids is of further interest because in addition to their carrying a large fraction of the heavy metals, they must also figure importantly in the formation of the solid body objects of the solar system (planets, moons, comets, asteroids, and Kuiper Belt Objects). Recall that the presently accepted formation picture involves rocks colliding with rocks and sticking together over a vast range of phase space, even though this process has never been observed to occur in the history of our civilization. And when the New York World Trade Center fell in 2001, nobody reported that all the rocks were stuck together in the bottom of the hole.

An alternative view is that as the primordial planetoids swept the interstellar medium clean of dust, most of it probably fell to the center, or was vaporized, only to crystallize out on other nucleation centers at a later time. But the planetoids would have undergone several phase changes, first to liquid and then to solid state as they cooled to the present 2.7 K temperature of the universe. And even after freezing, further contraction of the cooling object would imply crushing central forces. This has almost certainly created the dusty/gassy cores of comets, and the surprising result that comets seem to be made of
compacted dust, not rocks (a surprising conclusion from the NASA impact of a 372 kg projectile with comet Temple 1 (Tytell, 2005)).

Recall also that the theory justifying the use of 90 HST orbits to find an expected 60 faint Kuiper Belt objects found only 3, showing that the collision theory for the creation of Kuiper Belt Objects was flawed. Thus G. Bernstein reported in HST Newsletter v21 No.1 p18 Winter 2004 that, "Our search for TNOs was spectacularly unproductive; we discovered only 3 TNOs - nearly 30 times fewer than expected by extrapolations from brighter surveys." We predict that the KBOs will have compacted dust composition like the comets, and that they exist in the outer fringes of the solar system as the compacted core solid remnants of a fraction of the million primordial planetoids whose gas was deposited in the forming sun but whose compacted dust solid cores were left behind in distant orbit.

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3 Early reports quoted from project scientists by author Tytell stress the surprising conclusion that, "The microscopic particles of dust are not microscopic because of the impact; it’s just that we released microscopic particles,” says [project scientist] McFadden. "In other words, the impact didn’t pulverize the dust; the particles were small to begin with.”
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