5 megaton asteroid explodes 12 km above surface: frames are every half second

Problems with the Younger Dryas Boundary (YDB) Impact Hypothesis

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The 1994 collision of Comet Shoemaker-Levy 9 with Jupiter led us to recognize the significance of terrestrial airbursts caused by objects exploding violently in Earth's atmosphere. We have invoked airbursts to explain rare forms of non-volcanic glasses and melts by using high-resolution computational models to improve our understanding of atmospheric explosions, and have suggested that multiple airbursts from fragmented impactors could be responsible for regional effects.

Our models have been cited in support of the widely-publicized YDB impact hypothesis. Proponents claim that a broken comet exploded over North America, with some fragments cratering the Laurentide Ice Sheet. They suggest an abrupt climate change caused by impact-triggered meltwater forcing, along with massive wildfires, resulted in megafaunal extinctions and collapse of the Clovis culture.

We argue that the physics of fragmentation, dispersion, and airburst is not consistent with the hypothesis; that observations are no more compatible with impact than with other causes; and that the probability of the scenario is effectively nil. Moreover, millennial-scale climate events are far more frequent than catastrophic impacts, and pose a much greater threat to humanity.

Comet breaks up upon approach to Earth

Multiple plume-forming impacts across SE Asia

A computer animation from the 2006 National Geographic special (Ancient Asteroid) was cited by YDB impact authors as what they think might have happened over the Laurentide Ice Sheet. Animations were based on simulations by Boslough & Crawford (1997) but were extrapolated beyond the range of physical plausibility.

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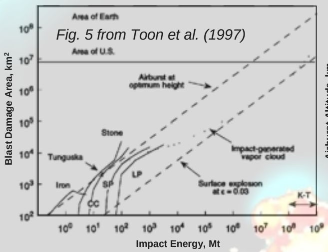
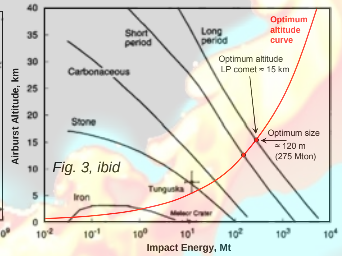
Younger Dryas Boundary Impact Hypothesis

The impact hypothesis was announced with great fanfare at the 2007 AGU Joint Assembly in Acapulco, which included more than a dozen supporting abstracts with more that two dozen authors in three special sessions entitled "New Insights into Extraterrestrial Impacts, Younger Dryas Cooling, Mass Extinction, and the Clovis People". According to the summary poster:

> *The Younger Dryas event boundary (YDB) is a thin sedimentary layer of 12.9 ka age, which contains an assemblage of materials formed by an extraterrestrial impact centered over northern North America. The YDB layer contains peaks in magnetic grains, magnetic microspherules, and iridium, in addition to charcoal and soot that resulted from extensive wildfires. Two impact-related carbon-rich markers, glass-like carbon and carbon spherules, have not been reported previously in North America. The carbon-rich material contains fullerenes enriched in ET helium and nanodiamonds, suggesting an ET origin for the material. The event coincided with the megafaunal extinctions and the Younger Dryas cooling episode; we propose that neither would have occurred in the absence of this impact*

At the associated press conference, the authors illustrated their idea by showing a National Geographic documentary animation of a cluster of airbursts over Southeast Asia, based on simulations by Boslough and Crawford (1997) to assess John Wasson's suggestion that the Muong-Nong tektites were formed by a process similar to the Shoemaker-Levy 9 impacts on Jupiter.





These figures from Toon et al. (1997) were cited in support of an airburst at optimum altitude, which turns out to be 500 km for a 4-km comet. Objects do not explode at that altitude. The optimum altitude curve, plotted in red on right-hand plot, constrains the maximum effect a comet airburst can have on the environment. More recent work by Boslough and Crawford (2008) shows that the effective burst altitude of a given-sized impactor is significantly lower than the Toon et al. (1997) curves indicate.

Faulty Physics

The idea of widely-spaced airbursts is physically unrealistic because there is no lateral aerodynamic force that can separate fragments by a large distance between the upper and lower atmosphere. Likewise, no lateral force exists to accelerate pieces apart between the Roche Limit and atmospheric entry. Fragments of a broken comet would drift apart at a speed of tens of cm/s, and in the ten minutes or so between fragmentation and impact they would be separated by much less than the initial diameter of the object. Impact of such a tight cluster would be indistinguishable from a single impact of a lower-density object.

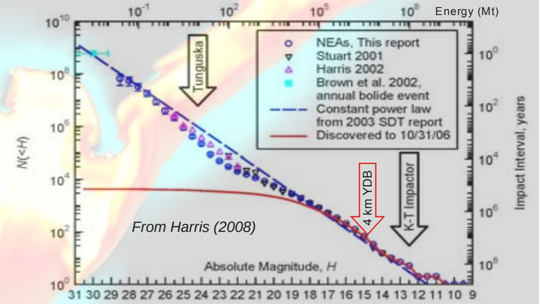
The authors have also suggested the possibility that the comet broke up on a previous near-approach (like Shoemaker-Levy 9) or spontaneously (like Schwassmann-Wachmann 3). However, to prevent dispersion over an area larger than North America, the breakup event would have had to take place within weeks or months of impact. Others have suggested it broke up as it passed the moon on final approach to Earth, an event that could happen no more often than once out of every 100,000 impacts. Such a combination of rare events is unlikely, even over timescales as large as the age of the Earth.

Firestone et al. (2007) further speculated on the nature of the event. They cited Toon et al. (1997) to suggest that a 10^7 megaton impact would have continental-wide consequences. Toon et al. indeed show that a 10^7 megaton stony asteroid impacting into a rock target can generate hot shooting stars that can ignite fires over a continent-wide area, but it would also create one of the largest and youngest craters on Earth, which would literally still be steaming. They also show that a 10^7 megaton impact by a low-density comet would only generate regional fires. The hypothesized ice-on-ice impact would be the least effective at igniting fires, but a 4-km comet would still penetrate a 2-km think ice sheet to form a crater.

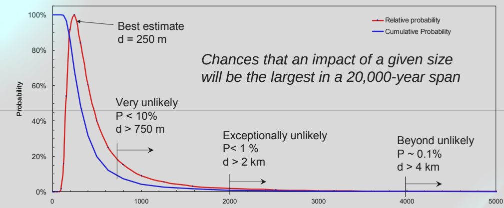
Firestone et al. (2007) also cited Toon et al. (1997) to argue that a 10^7 megaton burst at optimum altitude would cause blast damage over all of North America. However, when the optimum altitude for creating blast waves from a nuclear explosions (which neglects the Earth's curvature) is extrapolated, a 10^7 megaton explosion must detonate at 500 km to generate these continental-wide effects. The atmospheric density at 500 km is insufficient to cause objects to explode.

Likelihood of a Large Impact

The YDB impact explanation is extremely improbable, in addition to being physically impossible. Comets make up only about 1% of the population of Earth-crossing objects. Broken comets are a vanishingly small fraction, and only exist as Earth-sized clusters for a very short period of time. Only a small fraction of impacts occur at angles as shallow as proposed by the YDB impact authors. Events that are exceptionally unlikely to take place in the age of the Universe are "statistically impossible".



The size distribution of Earth-crossing asteroids is well-constrained by astronomical observations, DoD satellite bolide frequencies, and the cratering record. This curve can be transformed to a probability density function (PDF) for the largest expected impact of the past 20,000 years.



The largest impact of any kind expected over the period of interest is 250 m. Anything larger than 2 km is exceptionally unlikely (probability less than 1%).

What about the Evidence?

The YDB impact authors have undoubtedly uncovered exciting new evidence that needs to be explained. However, impact and cratering specialists do not consider any of this evidence to be diagnostic of an impact event. Charcoal and soot are associated with wildfires that can have many causes, especially at a time of abrupt environmental change. Magnetic grains, magnetic microspherules, iridium, and nanodiamonds are associated with the continuous flux of micrometeorites. Nanodiamonds can also be generated by low-pressure combustion and other terrestrial processes. Many of the observations, quantitative measurements, and stratigraphic associations still await independent confirmation. The proposed breakup of a comet to rationalize the absence of a crater is physically unsupportable, and the lack of a crater is fatal to this hypothesis. It is more likely that there are errors in the interpretation of the evidence than that our understanding of the physics of impacts and explosions is wrong.

Conclusions

The YDB impact hypothesis does not rely on any sound physical model. A 4-km diameter comet, even if it fragmented upon entry, would not disperse or explode in the atmosphere. It would generate a crater about 50 km in diameter with a transient cavity as deep as 10 km. There is no model to suggest that a comet impact of this size is capable of generating continental-wide fires or blast damage, and there is no physical mechanism that could cause a 4-km comet to explode at the optimum height of 500 km. The highest possible altitude for a cometary optimum height is about 15 km, for a 120-m diameter comet. To maximize blast and thermal damage, a 4-km comet would have to break into tens of thousands fragments of this size and spread out over the entire continent, but that would require lateral forces that greatly exceed the drag force, and would not conserve energy. Airbursts are decompression explosions in which projectile material reaches high temperature but not high pressure states. Meteoritic diamonds would be vaporized. Nanodiamonds at the YDB are neither evidence for an airburst or an impact.