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| PSI | 1908 SIBERIAN EXPLOSION:  Reconstructing an Asteroid Impact from  Eyewitness Accounts |

A Project in Astronomical Art, Science, and History (In Progress) by William K. Hartmann

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**In Brief:**

At 7:17 AM on the morning of June 30, 1908, a mysterious explosion occurred in the skies over Siberia. It was caused by the impact and breakup of a large meteorite, at an altitude roughly six kilometers in the atmosphere. Realistic pictures of the event are unavailable. However, Russian scientists collected eyewitness accounts of the event. I believe that we now know enough about large impacts to "decode" the subjective descriptions of the witnesses and create realistic views of this historic asteroid impact as seen from different distances.

**What do we know about the explosion?**

You can get a sense of the magnitude of this event by comparing observations made at different distances. Seismic vibrations were recorded by sensitive instruments as much as 1000 km (600 mi) away. At 500 km (300 mi), observers reported "deafening bangs" and a fiery cloud on the horizon. About 170 km (110 mi) from the explosion, the object was seen in the cloudless, daytime sky as a brilliant, sunlike fireball; thunderous noises were heard. At distances around 60 km, people were thrown to the ground or even knocked unconscious; windows were broken and crockery knocked off shelves. Probably the closest observers were some reindeer herders asleep in their tents in several camps about 30 km (20 mi) from the site. They were blown into the air and knocked unconscious; one man was blown into a tree and later died. "Everything around was shrouded in smoke and fog from the burning fallen trees."

**My Paintings of the Event**

A few years ago, I decided to use eyewitness reports such as the following ones, collected by Russian scientists decades ago, to reconstruct the appearance of the event from various locations, and at various moments. Here are descriptions of my work so far.

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| **400 KM Southeast of Ground Zero** |
| http://www.psi.edu/projects/siberia/tung1.jpg **View from Kirensk, two seconds before the explosion.** *Painting © William K. Hartmann* |

Witnesses in the town of Kirensk and nearby towns at the same distance recollected the fireball flashing across the sky in the following terms:

"A ball of fire...coming down obliquely. A few minutes later [we heard] separate deafening crash like peals of thunder...followed by eight loud bangs like gunshots."

"A ball of fire appeared in the sky... As it approached the ground, it took on a flattened shape..."

"A flying star with a fiery tail; its tail disappeared into the air."

After this object passed across the sky, it approached the horizon where it was consistently described from this distance of 400 km, as appearing like a "pillar of fire," then replaced by "a cloud of smoke rising from the ground," or "a cloud of ash...on the horizon," or "a huge cloud of black smoke. "From a closer distance of around 200 km, several witnesses gave a better description of the object itself. It was called diffuse bright ball two or three times larger than the sun but not as bright; the trail was a "fiery-white band." Inconsistent colors were mentioned: white, red, flame-like, bluish-white. Perhaps it had a flame-like iridescence. I used these descriptions in this painting, but I compensated for the twice-greater distance. I used a visit to Washington state as an opportunity to find a landscape that generally matched the photos from Siberia, and then I painted this piney-woodland scene from life, adding the fireball from the above descriptions.

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| **60 KM South of Ground Zero** |
| http://www.psi.edu/projects/siberia/tung2.jpg **View from Vanavara trading post, at the moment of the explosion.** *Painting © William K. Hartmann* |

The Russians collected a number of accounts from eyewitnesses at the trading station, which was probably the closest permanent habitation. These included:

"I was sitting on the porch of the house at the trading station, looking north. Suddenly in the north...the sky was split in two, and high above the forest the whole northern part of the sky appeared covered with fire. I felt a great heat, as if my shirt had caught fire... At that moment there was a bang in the sky, and a mighty crash... I was thrown twenty feet from the porch and lost consciousness for a moment.... The crash was followed by a noise like stones falling from the sky, or guns firing. The earth trembled.... At the moment when the sky opened, a hot wind, as if from a cannon, blew past the huts from the north. It damaged the onion plants. Later, we found that many panes in the windows had been blown out and the iron hasp in the barn door had been broken."

A second witness said:

"I saw the sky in the north open to the ground and fire poured out. The fire was brighter than the sun. We were terrified, but the sky closed again and immediately afterward, bangs like gunshots were heard. We thought stones were falling... I ran with my head down and covered, because I was afraid stones may fall on it."

In this painting I tried to show the moment when "the sky opened and with fire." I used the more distant reports, of the fire ball spreading and flattening at the end of its trajectory, to give the shape of fiery trail and the explosive fireball. I painted the basic landscape from life in a Siberian-looking landscape outside of Flagstaff Arizona, basing the structures on old photos from the expeditions to the Siberian impact area.

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| **15 KM from Ground Zero** |
| http://www.psi.edu/projects/siberia/tung3.jpg **A few minutes after the explosion** *Painting © William K. Hartmann* |

Because the object exploded up in the atmosphere, instead of hitting the ground, it left no crater. The effect on the ground was limited to devastation of a large forest area. At ground zero, tree branches were stripped, leaving trunks standing up. But at distances from roughly 3 out to 10 miles, the trees were blown over, lying with tops pointed away from the blast. No one was known to have been this close to the blast. The closest humans were probably herders camped in tents roughly 30 km from ground zero. They related:

"Early in the morning when everyone was asleep in the tent, it was blown up in the air along with its occupants. Some lost consciousness. When they regained consciousness, they heard a great deal of noise and saw the forest burning around them, much of it devastated."

"The ground shook and incredibly prolonged roaring was heard. Everything round about was shrouded in smoke and fog from burning, falling trees. Eventually the noise died away and the wind dropped, but the forest went on burning. Many reindeer rushed away and were lost."

One older man at about this distance was reportedly blown about forty feet into a tree, causing a compound fracture of his arm, and he soon died. Hundreds of the herders' reindeer, in the general area around ground zero, were killed. Many campsites and storage huts scattered in the area were destroyed. During a workshop of the International Association for the Astronomical Arts, I painted this view at Mt. St. Helens, Washington, where the devastated area bears an uncanny resemblance to the photos of the explosion site. At both the Siberian site and Mt. St. Helens are vistas where one sees nothing but felled trees, mile after mile, across distant hillsides. The transient heat flash from the fireball was felt by the witnesses at Vanavara, and apparently within about 30 km it was strong enough to ignite small temporary fires in the forest and singe tree bark. I based the view of the cloud in the sky on the distant reports of a ashy-colored cloud of smoke forming at the site of the blast; it was probably augmented some minutes later by smoke from the burning forest. Streamers of smoke from fragmented material would soon dissipate in air currents.

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| **170 km Southwest of Ground Zero** |
| http://www.psi.edu/projects/siberia/tung4.jpg **Smoke on the horizon**  *Painting © William K. Hartmann* |

Some minutes after the explosion, distant observers reported a column of smoke on the horizon. The general terms indicated this was a vertical column. One observer said "Where the body disappeared behind the horizon, a pillar of dark smoke rose up." It seems unclear from the reports whether whis was (a) an mushroom-like cloud from the explosion fireball rising above the landscape and pulling up smoke from the ignted forest, (b) smoke from the forest fire, or (c), from some directions, a reference to the contrail, which would be vertical when seen under the flight path. I have wondered whether the dark color could result from the smoke of the explosion containing black, sooty carbonaceous particles, in the same way that the explosion clouds on Jupiter from the impact of Comet Shoemaker-Levy 9 were very dark. This view represents the scene from a vilage along the Angara River, about 170 km SW of the blast. The original was painted from among cabins in a state park in Oregon.

**What was the explosion?**

Because the meteorite did not strike the ground or make a crater, early researchers thought the object might be a weak, icy fragment of a comet, which vaporized explosively in the air, and left no residue on the ground. However, modern planetary scientists have much better tools for understanding meteorite explosion in the atmosphere. As a meteorite slams into the atmosphere at speeds around 12 to 20 km/sec or more, it experiences a strong mechanical shock, like a diver bellyflopping into water. This can break apart stones of a certain size range, which explode instead of hitting the ground. Some of them drop brick-sized fragments on the ground, but others, such as the one that hit Siberia, may produce primarily a fireball and cloud of fine dust and tiny fragments. In 1993 researchers Chris Chyba, Paul Thomas, and Kevin Zahnle studied the Siberian explosion and concluded it was of this type -- a stone meteorite that exploded in the atmosphere. This conclusion was supported when Russian researchers found tiny stoney particles embedded in the trees at the collision site, matching the composition of common stone meteorites. The original asteroid fragment may have been roughly 50-60 meters (50-60 yards) in diameter.

**If asteroids hit Earth, why don't we see more such explosions?**

Many asteroidal fragments circle the Sun; the Siberian object was merely the largest to hit the Earth in the last century or so. Had it hit a populated area, devastation would have been enormous. If there are many asteroid fragments, why don't we see more hits? We do! The problem is that they have not been understood until recently. Current studies reveal that such explosions may happen every couple of centuries; however, six out of seven happen over the ocean, and few happen over populated land. A key to the phenomenon is: the larger the impact the rarer it is. An Air Force satellite in the 1990s detected a smaller explosion over the Pacific. In 1972, a 1000-ton object skimmed tangentially through Earth's atmosphere over the Grand Tetons in Wyoming, and then skipped back out into space, like a stone skipping off water. It was photographed by tourists and detected by Air Force satellites. Had it continued on into the atmosphere, it could have caused a Hiroshima-scale explosion over Canada, somewhat smaller than the Siberian blast. Even larger objects have hit Earth, but they are more rare. For example, an iron asteroid fragment perhaps 100 m across hit Arizona about 20,000 years ago, leaving the kilometer-wide "Arizona Meteor Crater," which is open to visitors; and a 10-km asteroid hit Earth 65 million years ago, ending the reign of dinosaurs. Brick-sized interplanetary stones fall from the sky in various locations every year. Several houses and a car have been hit in recent decades. Tiny dust grains are even more common; they can be seen every night if you watch long enough; they are the bright streaks of light sometimes called "shooting stars." Interplanetary space contains many small bodies of different sizes. All of them move in elliptical orbits around the sun as prescribed by Kepler. Occasionally their orbits intersect those of planets, leading to a collision. Large enough bodies leave sizable craters on planets or satellites. This explains why impact craters are present on surfaces of planets and moons throughout the solar system. If we continue to study asteroids and build more telescopes for detecting and tracking them, we will have better information about the frequency of such asteroid impact-explosions, and more chance to have warning about impending impacts.

**Question**

Tunguska-sized explosions occur on Earth about once per century, and larger explosions the size of the largest H-bombs, occur about once per millennium. Many of these explode in the atmosphere and cause devastation over tens of kilometers, but don't leave long-lasting craters. Recall that 1/6 of Earth is covered by land and assume that roughly half the land surface is populated in the last 12,000 years, since humans moved into the Americas. Using these facts comment on whether meteorite explosions of this scale might plausibly have produced legends of wrathful or capricious celestial gods who could rain fire onto the Earth, as for example in the legend of the destruction of Sodom and Gomorrah by celestial fire. Take into account that oral traditions, such as the associations of certain star patterns with constellations such as the Great Bear (Ursa Major), can apparently be passed down for thousands of years.

**Answer:**

Let's make use of what scientists call an "order of magnitude" estimate, or "back of the envelope calculation." If we imagine spectacular catastrophic explosions larger than Tunguska happening every 300 years, and having effects visible over 100 km or more from ground zero, then there would be one over land about every 1800 years, and perhaps one over a populated area every 3600 years or so. Thus it seems plausible that in 12,000 years of oral tradition and about 4000 years of written records in some cultures, there may have been one ore more explosions considerably larger than the Tunguska event. By the same logic, if Tunguska-scale events happen once per century, there could have been several just in the last several scattered around the populated land areas of the world in the last 3600 years.

Thus, it seems at least plausible that large explosions of meteoritic objects were among the celestial events (together with smaller meteorite impacts, auroras, hurricanes, storms, and floods) that gave rise to belief in capricious god-like forces acting from the skies.

**Problem**

Recent scientific studies by meteorite researcher Christopher Chyba have estimated that the Tunguska event may have been caused by the explosion of a stony meteroid about 30 meters in diameter traveling at about 15 km/s. Compare the energy released by such an object with that of an atomic bomb sucs as those dropped on Japan in World War II.

**Answer:**

Here again we can make a simple "order of magnitude" calculation.

First, we have to know the energy liberated by an A-bomb. The Hiroshima bomb expended the energy of roughly ten thousand tons of TNT, or 18 "kilotons" in military parlance. One kiloton (1 KT) is about 4.2 x 1012 joules (the joule is the unit of energy in the Standard International, or "SI," set of scientific units). The Hiroshima bomb thus represented roughly 8 x 1013 joules of energy.

Now all we have to do is calculate the energy of the meteoroid. In freshman physics courses, you learn that the kinetic energy of a moving object is 1/2mV2.

The trick in using any equation like this is to be sure to use the correct units. In SI, the units are meters, kilograms, and seconds, so that mass m must be in kilograms and velocity V must be in meters/second.

Thus, right away we can say that V in the equation will be V = 15 km/s or 1.5 x 104 m/s.

To get the mass, we have to figure out the mass of a 30-meter wide rock. Rock has a density of about 3000 kg per cubic meter, so we need to calculate the volume of the rock and multiply times this density. Thus we have,

m = (4/3) PI R3 (3000 kg/m3) = (4/3) PI (15 m)3 (3000) = 4.2 x 107 kg.

Thus the total energy is,

E=1/2 (4.2 x 107 kg) (1.5 x 104 m/s)2 = 4.8 x 1015 joules.

To be safe, let's imagine that half the kinetic energy is lost to noise, slowing, and fragmentation of the meteoroid before it explodes. That still leaves about 2 x 1015 joules for the Tunguska explosion, compared to about 3 x 1013 joules for the Hiroshima A-bomb.

Thus, our estimate is that the Tunguska had an explosive energy roughly on order of 60 A-bombs, or 500 KT of TNT. It was closer in effect to a very large H-bomb.

**For further information:**

Chyba, C., P. Thomas, and K. Zahnle 1993. "The 1908 Tunguska Explosion: Atmospheric Disruption of a Stony Asteroid". Nature 361, p. 40-44. (Calculation of size of the bolide.)

Gallant, Roy A. 1994 "Journey to Tunguska". Sky and Telescope, June, 38-43. (Description of a modern journey to the site, with photographs.)

Krinov, E. L. 1966 Giant Meteorites (London: Pergamon Press). (Description of the site and interviews with witnesses).