Is there a preferred date for a possible impact?

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Meteorites falls and finds

• If any part of the event leading to the delivery of a meteorite to Earth was witnessed, it is called a fall. All other meteorites are called finds.
• The clearing-house of meteorites is the Meteoritical Society, which maintains the Meteoritical Bulletin Database (MBD).
• Up end of 2018, there are 60779 registered meteorite names.
• There are registered 1174 falls.
• **Damaging falls:** a fall that directly impact human beings or their belongings (house, car, but not pavement).
• There are 105 reports of damaging falls from XVIII century until present.
A lot of funny anecdotes

Table 1 – List of damaging falls

<table>
<thead>
<tr>
<th>Date</th>
<th>Meteorite name</th>
<th>Place</th>
<th>Meteorite type</th>
<th>Ref.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 jul 1790</td>
<td>Barbotan</td>
<td>Barbotan, France</td>
<td>H5</td>
<td>2</td>
<td>A report of a crushed cottage, a killed farmer and some cattle.</td>
</tr>
<tr>
<td>26 apr 1803</td>
<td>L’Agle</td>
<td>Orne, France</td>
<td>L6</td>
<td>2</td>
<td>The roof ridge of a house was hit and a wireplug was hit on the arm by a small stone.</td>
</tr>
<tr>
<td>14 jul 1847</td>
<td>Braunau</td>
<td>Bohemia, Czech Republic</td>
<td>Iron Hex. IIA</td>
<td>1</td>
<td>One mass of 17.2 kg fell upon a house, pierced the roof, struck the beam, passed through a ceiling composed of white clay and straw, and entered a room where several persons were assembled, but no one was hurt.</td>
</tr>
<tr>
<td>01 may 1860</td>
<td>New Concord</td>
<td>Ohio, USA</td>
<td>L6</td>
<td>2</td>
<td>A stone struck and killed a young horse.</td>
</tr>
<tr>
<td>19 nov 1881</td>
<td>Grossdiebenthal</td>
<td>Odessa, Ukraine</td>
<td>L6</td>
<td>2</td>
<td>A stone struck a building being struck and a man was injured.</td>
</tr>
<tr>
<td>4 nov 1906</td>
<td>Diep River</td>
<td>Cape Province, South Africa</td>
<td>L5</td>
<td>2</td>
<td>A 910 g stone fell and crashed through a metal roof of a house.</td>
</tr>
<tr>
<td>28 jun 1911</td>
<td>Nakhla</td>
<td>Al Buwayrah, Egypt</td>
<td>Martian nakhlite</td>
<td>2</td>
<td>A dog was struck and killed.</td>
</tr>
<tr>
<td>30 jun 1918</td>
<td>Richardson</td>
<td>North Dakota, USA</td>
<td>H5</td>
<td>2</td>
<td>A single stone struck a building.</td>
</tr>
<tr>
<td>02 apr 1936</td>
<td>Yurtuk</td>
<td>Lubimov, Ukraine</td>
<td>Howardite</td>
<td>2</td>
<td>A stone of 509 g fell through the roof of a house.</td>
</tr>
<tr>
<td>11 jun 1949</td>
<td>Kunashak</td>
<td>Kunashak, Russia</td>
<td>L6</td>
<td>2</td>
<td>A stone fell and killed a man who was driving.</td>
</tr>
<tr>
<td>10 dic 1950</td>
<td>St.</td>
<td>Missouri, USA</td>
<td>H4</td>
<td>1</td>
<td>A lady was asleep on her sofa when a 3.06 kg stone meteorite crashed through her roof (it struck the radio, bounced off the floor) and hit her, causing abdominal injuries which, fortunately, were not serious.</td>
</tr>
<tr>
<td>30 nov 1954</td>
<td>Sylacauga</td>
<td>Alabama, USA</td>
<td>H4</td>
<td>1</td>
<td>A stone penetrated the roof and into a house at a depth of 37 cm.</td>
</tr>
<tr>
<td>19 feb 1956</td>
<td>Sinnal</td>
<td>Sardina, Italy</td>
<td>H5</td>
<td>1</td>
<td>A fragment hit the roof of a house.</td>
</tr>
<tr>
<td>29 feb 1956</td>
<td>Centerville</td>
<td>South Dakota, USA</td>
<td>H5</td>
<td>1</td>
<td>After penetrating the aluminum roof, it struck a corn planter stored in the shed and four small pieces were dropped off.</td>
</tr>
<tr>
<td>13 oct 1959</td>
<td>Hamlet</td>
<td>Indiana, USA</td>
<td>L13-4</td>
<td>1</td>
<td>A single stone of 2.04 g struck a house, ripping off the rain gutter of the roof.</td>
</tr>
<tr>
<td>05 mar 1960</td>
<td>Gao-Guineci</td>
<td>Gao, Burkina Faso</td>
<td>H5</td>
<td>2</td>
<td>16 pieces were recovered after falling through the roof of a hut.</td>
</tr>
<tr>
<td>09 sep 1961</td>
<td>Bells</td>
<td>Texas, USA</td>
<td>C2-ung</td>
<td>1</td>
<td>A stone penetrated the roof and into a house at a depth of 37 cm.</td>
</tr>
<tr>
<td>26 apr 1962</td>
<td>Kiel</td>
<td>Schleswig-Holstein, Germany</td>
<td>L6</td>
<td>1</td>
<td>A stone hit the roof of a house and made a hole about 10 x 20 cm.</td>
</tr>
<tr>
<td>24 dic 1965</td>
<td>Barwell</td>
<td>Leicestershire, England</td>
<td>L6</td>
<td>2</td>
<td>A stone fell from the factory roof, another tiny fragment was found later in a vase and another landed on the bonnet of a car.</td>
</tr>
<tr>
<td>12 apr 1968</td>
<td>Schenectady</td>
<td>New York, USA</td>
<td>H5</td>
<td>1</td>
<td>A stone struck the roof.</td>
</tr>
<tr>
<td>25 apr 1969</td>
<td>Boedy</td>
<td>Northern Ireland, UK</td>
<td>L3</td>
<td>2</td>
<td>A stone fell from the roof, one fell into the house and another landed on the bonnet of a car.</td>
</tr>
<tr>
<td>07 ago 1969</td>
<td>Andrevka</td>
<td>Donetsk, Ukraine</td>
<td>L3</td>
<td>2</td>
<td>A stone made a hole in a slate roof and fell on the floor of the parlor.</td>
</tr>
<tr>
<td>28 sep 1969</td>
<td>Murchison</td>
<td>Victoria, Australia</td>
<td>CM2</td>
<td>1</td>
<td>One stone burst through a beam, landing in the hay.</td>
</tr>
<tr>
<td>08 apr 1971</td>
<td>Wethersfield</td>
<td>Connecticut, USA</td>
<td>L6</td>
<td>1</td>
<td>A stone fell through the roof and was found in the early morning suspended in a ceiling.</td>
</tr>
<tr>
<td>02 ago 1971</td>
<td>Haverö</td>
<td>Turku Ja Pori, Finland</td>
<td>Lurelitie</td>
<td>1</td>
<td>A stone fell through the roof of a storehouse.</td>
</tr>
<tr>
<td>15 oct 1972</td>
<td>Valera</td>
<td>Trujillo, Venezuela</td>
<td>L5</td>
<td>1</td>
<td>A single stone struck and killed a cow. The stone had broken into three pieces weighing 36, 8, and 4 kg, respectively.</td>
</tr>
</tbody>
</table>
In the last 12 years there has been 95 reports of falls and 27 of damaging falls, implying a rate of 7.9 and 2.3 reports per year, respectively.

We do not expect a large increase in the number of reported falls and damaging falls, since the numbers have not dramatically change in the last decades, in spite of the improvements in communications.

~1/4 of the reported meteorite falls are damaging ones
How many meteorite falls are per year?

• 29 % of the surface of the Earth is covered by land (CIA, 2017)
• Urban land is defined as “areas dominated by built environment (>50%), with minimum mapping unit > 1 km².”
• Urban land (computed from satellite images) is 0.13% of the total area of the Earth, and 0.44 % of the area covered by land. (Schneider et al., 2009)
• ~55% of the Earth’s population lives in urban areas (UN 2014).
• The urban land corresponds to a large fraction of the area where there are witnesses of a fall.
• There is no estimate of the total area actually covered by buildings.
How many meteorite falls are per year?

Total Number of falls per year = \( \frac{\text{Number of falls in urban land}}{\text{Fraction of urban land}} \)

- \( 7.9/0.0013 \approx 6100 \) meteorite falls per year over the entire Earth
- and \( 7.9/0.0044 \approx 1800 \) over the land.

- Halliday (1984) estimated 4100 meteorite falls over the Earth, based on photographic observations of fireballs and estimates of the delivered mass using meteor physics laws (several assumptions).
- Our values are 50% higher (with far less assumptions)

- The fraction of damaging falls as a proxy for the fraction of the urban land covered by buildings.
  \[ \frac{\text{Area covered by buildings}}{\text{Area covered by urban land}} \approx \frac{\text{Number of damaging falls}}{\text{Number of registered falls}} \approx \frac{1}{4} \]
Meteor showers are formed by particles released by a comet. Small particles spread around the nominal orbit due to non-gravitational effects.

Note the peaks with values several times over the background.
Is there any meteorite streams?

Meteor shower ≠ Meteorite stream

• Meteorite stream: a group of meteorites sharing a similar orbit
• Meteorite falls are produced by at least a few tons meteoroid (larger 1m).
• A few tons meteoroids are not affected by small particles non-gravitational forces: radiation pressure and Poynting-Roberston effect.
• Yarkovsky effect works in long-time scale.

• Recent Meteorite streams (if they exist) should be very compact
Why meteorite streams are relevant?

• If a meteorite stream exists, there should be a distribution of meteoroids with similar Earth-crossing orbits.
• An ensemble of hazardous objects.
• A much bigger one (hundred of m or km-size object) could exist.
• A dedicated search could be performed to look for the stream members (e.g. Micheli & Tholen 2015).
Databases to look for meteorite streams

- IAU Meteor showers database: look for asteroidal orbits (~40)
- Meteorites with photographic orbits
- Meteoritical Bulletin Database
- Fireballs:
  - American Meteor Society
  - US Government Sensors
Using the Meteoritical Bulletin Database

- 1032 falls with confirmed dates (the students went through every record and checked the literature)
- 60% of the falls are in s XX & XXI
Meteorite falls: a Poisson process

• A Poisson point process has the property that each point is stochastically independent to all the other points in the process.
• Valid for counting the occurrences of random events at a certain rate.
• The probability that the number of events \( N(t) \), in a finite interval of length \( t \), equals \( n \) is given by the Poisson distribution:

\[
P\{N(t) = n\} = \frac{(\lambda t)^n}{n!} e^{-\lambda t}
\]

• \( \lambda \) is the mean rate of events per interval \( t \) (e.g. number of falls per day or deg)
Meteorite falls: a Poisson process

The data was fitted with a Poisson distribution with

\[ \lambda = 2.89^{3.04}_{2.69} \text{ per deg.} \]

All the data points are within the error bars.

The meteorite falls occur randomly throughout the year.

- CAVEAT: The reports have a 1-day resolution, but a correction for the time difference has not been introduced.
Meteorite falls with a running mean

Poisson statistics cannot be applied because the data points are not independent.

No peaks in the tail.
Conclusions

• ~6100 meteorite falls per year over the entire Earth, and ~1800 over the land.

• There are several ~40 meteor showers with asteroidal orbits.

• There is no clear indication of an excess in the distribution of falling meteorites and fireballs with date or solar longitude.

• Heavily populated meteorite streams do not exist.

• There is no particular date of the year to be outdoors with a helmet.

There is no preferred date for Doomsday!