3D SOFTWARE TO EVALUATE VERY LOW ANGLE IMPACTS, SKIP IMPACTS, AND THE POSSIBILITY THAT COMET 109P/SWIFT-TUTTLE HAS PREVIOUSLY HIT EARTH FORMING THE CAROLINA BAYS AS SECONDARY IMPACTS. John Burgener. Telegistics Inc. 944 Meadow Wood Rd., Mississauga, Ontario, Canada, L5J2S6. Email: john@burgener.ca.

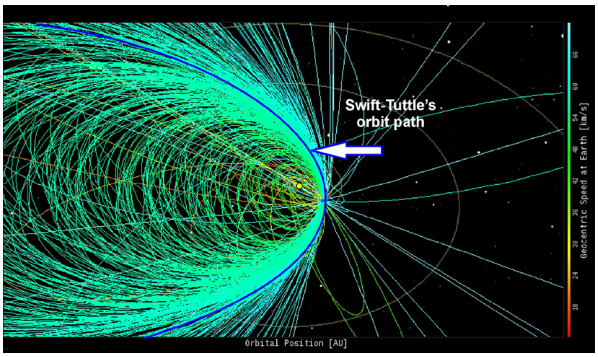


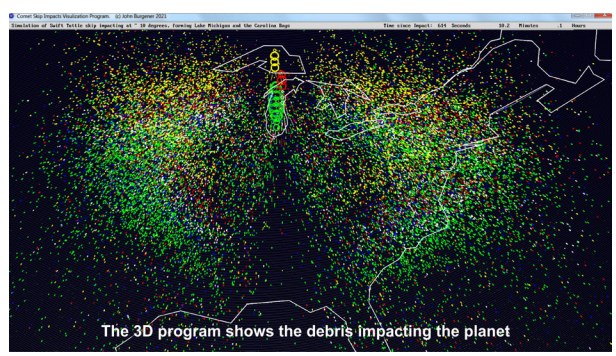
Figure 1: Orbits calculated from fireballs observed Aug 13, 2015 [2]

Introduction: It is accepted that the Perseid Meteor Shower in August is related to the comet Swift Tuttle. It is recognized that outgassing from comets as they orbit the sun will spread a cloud of dust along the orbital path. When Earth passes through such a comet debris trail, the larger particles burn in the atmosphere creating the meteor shower. Fireballs are also common with some comet debris trails. Fireballs are much larger objects than average from comets outgassing, but their time of occurrence leads to the understanding that they are often associated with a particular comet. While it is probable that the larger particles leading to fireballs originated from larger pieces breaking off the comet, it is not clear why many would break off at different speeds and form the wide range of orbits that intersect at Earth's orbit as seen with the Perseids. An exceptionally large number of mid August fireballs are associated with Comet 109P/Swift-Tuttle.

Fireballs associated with Swift-Tuttle: William Cooke of NASA's Meteoroid Environment Office / All Sky Fireball Network provides plots of the orbits of fireballs seen each day on the Spaceweather.com web pages. The largest number are associated with the Perseids and comet Swift Tuttle. They show a large range of orbits, with the necessary common factor that they all intersect Earth's orbit in mid-August. Some have very short periods and others long periods. The image shown above is a diagram from William Cooke's presentation of the orbital paths of over 340 fireballs associated with the Perseid meteor shower observed August 15, 2015 [2]. A typical day will have less than 10 fireballs occur, so the numbers associated with the Perseids is significantly higher.

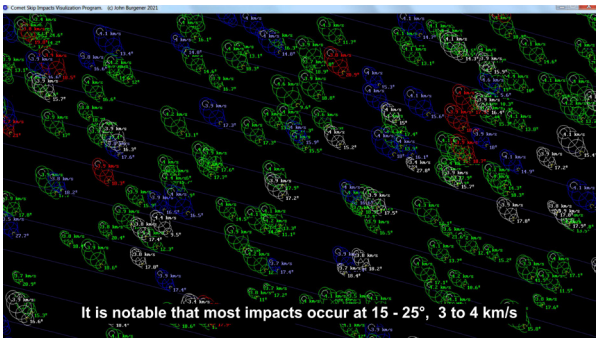
Skip Impact possibility: Studies with iSALE impact hydrocode show that comets hitting Earth at low angles such as 5 degrees or less can skip and continue on a new path at similar speeds to the original orbital speeds. Such a skip will cause part of the comet to drag across the surface of Earth, and both portions of the comet and portions of the Earth's surface will be carried into space at above Earth escape velocities. Such an occurrence would send some fragments at high speeds similar to or higher than the speed of the comet, and other fragments would be tossed at slower speeds, all depending on the location of the fragments during the impact event. It would be expected that such fragments would travel away from Earth on a wide range of orbits, with a common feature of all of the orbits being the initiation point of the event: the skip impact of Swift Tuttle with Earth.

The SkipImpact Program: A computer simulation [1] is presented to show the expected effect of a skip impact, and is used to calculate a series of orbits from the larger particles. The calculated range of orbits is large, similar to what is observed with the fireballs associated with the Perseid Meteor Showers. In comparison, the program can also present how out-gassing leads to a high concentration of debris along the comet's orbit. The gravitational effects of the planets on the debris does influence the orbits but mainly scatters the orbits away from Earth-crossing paths. The two sources of debris that would lead to fireballs are very different in appearance and the skip impact fits the observed orbits much better than out-gassing.

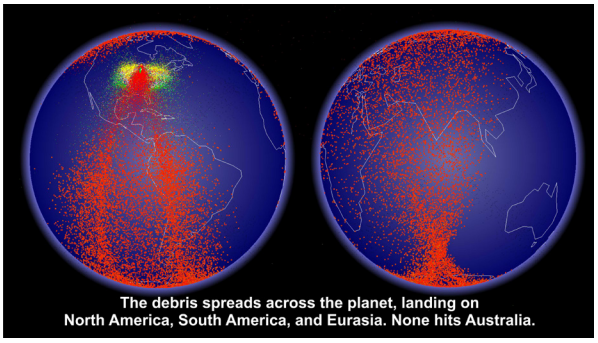


The SkipImpact program was previously presented as a 2D program. It has been enhanced to be fully 3D and allow one to enter start positions and velocities for a range of comet sizes and see how they impact Earth. More importantly, it is able to demonstrate in detail how the debris from a skip impact would spread across the planet and the speed, impact angles and size

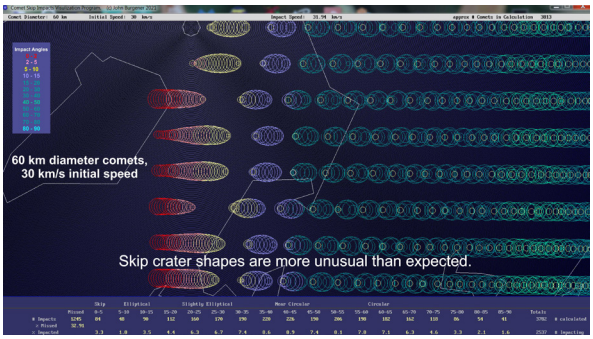
distributions of the debris as it lands on Earth. One of the program's simulations is of a large comet hitting North America in a skip event that would form Lake Michigan. Lake Michigan is nearly identical in size and shape to the Orcus Patera crater on Mars. The program produces thousands of debris particles tossed away from the crater, and is able to calculate their paths, including atmospheric drag and Earth's rotation. The secondary impacts are displayed with the particle size, speed and impact angles listed. iSALE shows that shapes matching the Carolina Bays would be formed by low speed impacts of 2 to 5 km/s, at average angles of 10 - 25 degrees. The SkipImpact program shows that a high number of secondary impacts fitting those speeds and angles will occur along the Eastern coast of North America.



It has been suggested by Michael Davias [3] that the Carolina Bays are related to the Australasian Tektites. The SkipImpact program is able to follow the debris from a North American impact and show how it spreads across Earth. While North America, South America and Eurasia are severely affected, Australia is not.



Typically impact studies focus on high angles. 90 degree impacts are the simplest to simulate in software, and since the cratering aspect of an impact is mainly due to the shock wave, craters are very similar to a 90 degree impact for any angle impact above 40 degrees. As the impact angle goes lower, the resulting craters become elliptical instead of circular, but elliptical craters are a small portion of the craters observed. However, impact craters of less than 20 degrees should be over 10 percent of all craters and are worth studying. The SkipImpact program has a simulation of thousands of comets impacting Earth on a grid pattern, showing the distribution of crater impact angles and shapes. The low angle impacts produce very unexpected crater shapes, suggesting that we do not see low angle impacts due to them being dramatically different than expected.



Conclusion: The SkipImpact 3D software indicates that a skip impact by Comet Swift Tuttle would fit as the source of the Carolina Bays as secondary impacts from the impact debris, and would explain the distribution of the fireball orbits associated with the Perseid Meteor Shower. The program predicts that very low angle craters will be of unusual shapes and often not recognized due to their elongated and shallow shapes.

Acknowledgments: We gratefully acknowledge the developers of iSALE-2D, including Gareth Collins, Kai Wünnemann, Dirk Elbeshausen, Tom Davison, Boris Ivanov and Jay Melosh, and we gratefully acknowledge the developers of iSALE-3D, including Dirk Elbeshausen, Kai Wünnemann, Gareth Collins and Tom Davison.

References:

[1] Burgener, J (2021) SkipImpact Program. Available to download and use freely from the web site: www.craters.ca

[2] Cooke, W. (2014-2021), NASA's All Sky Fireball Network daily charts of fireball orbits posted on www.spaceweather.com.
Included fireball chart from Aug 2015:
https://www.spaceweather.com/FIREBALL_PARSER/fireball_data.png?PHPSESSID=ik2r3o2g28eob2n25cpmlc49o4

[3] Davias, M., Harris, T. (2019) "An Incomprehensible Cosmic Impact at the mid Pleistocene Transition, Searching for the Missing Crater using Australasian Tektite Suborbital Analysis and Carolina Bay's Major Axes Triangulation"; GSA Annual Meeting in Phoenix, Arizona, USA.
DOI: 10.1130/abs/2019AM-332326