First interstellar comet may be the most pristine ever found

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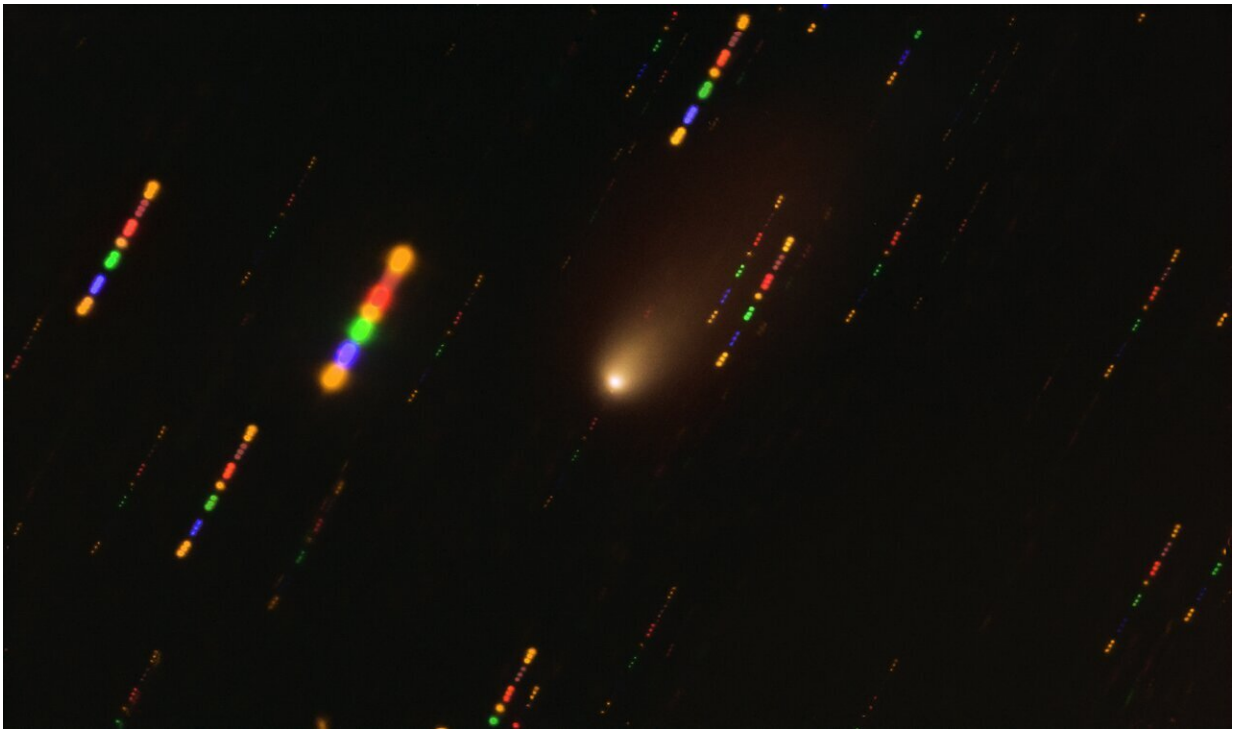

This image was taken with the FORS2 instrument on ESO's Very Large Telescope in late 2019, when comet 2I/Borisov passed near the Sun.Since the comet was travelling at breakneck speed, around 175 000 kilometres per hour, the background stars appeared as streaks of light as the telescope followed the comet's trajectory. The colours in these streaks give the image some disco flair and are the result of combining observations in different wavelength bands, highlighted by the various colours in this composite image. Credit: ESO/O. Hainaut

New observations with the European Southern Observatory's Very Large Telescope (ESO's VLT) indicate that the rogue comet 2I/Borisov, which is only the second and most recently detected interstellar visitor to our Solar System, is one of the most pristine ever observed. Astronomers suspect that the comet most likely never passed close to a star, making it an undisturbed relic of the cloud of gas and dust it formed from.

2I/Borisov was discovered by amateur astronomer Gennady Borisov in August 2019 and was confirmed to have come from beyond the Solar System a few weeks later. "2I/Borisov could represent the first truly pristine comet ever observed," says Stefano Bagnulo of the Armagh Observatory and Planetarium, Northern Ireland, UK, who led the new study published today in *Nature Communications*. The team believes that the comet had never passed close to any star before it flew by the Sun in 2019.

Bagnulo and his colleagues used the FORS2 instrument on ESO's VLT, located in northern Chile, to study 2I/Borisov in detail using a technique called polarimetry. Since this technique is regularly used to study comets and other small bodies of our Solar System, this allowed the team to compare the interstellar visitor with our local comets.

The team found that 2I/Borisov has polarimetric properties distinct from those of Solar System comets, with the exception of Hale-Bopp. Comet Hale-Bopp received much public interest in the late 1990s as a result of being easily visible to the naked eye, and also because it was one of the most pristine comets astronomers had ever seen. Prior to its most recent passage, Hale-Bopp is thought to have passed by our Sun only once and had therefore barely been affected by solar wind and radiation. This means it was pristine, having a composition very similar to that of the cloud of gas and dust it—and the rest of the Solar System—formed from some 4.5 billion years ago.

By analysing the polarisation together with the colour of the comet to gather clues on its composition, the team concluded that 2I/Borisov is in fact even more pristine than Hale-Bopp. This means it carries untarnished signatures of the cloud of gas and dust it formed from.

"The fact that the two comets are remarkably similar suggests that the environment in which 2I/Borisov originated is not so different in composition from the environment in the early Solar System," says Alberto Cellino, a co-author of the study, from the Astrophysical Observatory of Torino, National Institute for Astrophysics (INAF), Italy.

Olivier Hainaut, an astronomer at ESO in Germany who studies comets and other near-Earth objects but was not involved in this new study, agrees. "The main result—that 2I/Borisov is not like any other comet except Hale-Bopp—is very strong," he says, adding that "it is very plausible they formed in very similar conditions."

"The arrival of 2I/Borisov from interstellar space represented the first opportunity to study the composition of a comet from another planetary system and check if the material that comes from this comet is somehow different from our native variety," explains Ludmilla Kolokolova, of the University of Maryland in the US, who was involved in the *Nature Communications* research.

Bagnulo hopes astronomers will have another, even better, opportunity to study a rogue comet in detail before the end of the decade. "ESA is planning to launch Comet Interceptor in 2029, which will have the capability of reaching another visiting interstellar object, if one on a suitable trajectory is discovered," he says, referring to an upcoming mission by the European Space Agency.

An origin story hidden in the dust

Even without a space mission, astronomers can use Earth's many telescopes to gain insight into the different properties of rogue comets like 2I/Borisov. "Imagine how lucky we were that a comet from a system light-years away simply took a trip to our doorstep by chance," says Bin Yang, an astronomer at ESO in Chile, who also took advantage of 2I/Borisov's passage through our Solar System to study this mysterious comet. Her team's results are published in *Nature Astronomy*.

Yang and her team used data from the Atacama Large Millimeter/submillimeter Array (ALMA), in which ESO is a partner, as well as from ESO's VLT, to study 2I/Borisov's dust grains to gather clues about the comet's birth and conditions in its home system.

They discovered that 2I/Borisov's coma—an envelope of dust surrounding the main body of the comet—contains compact pebbles, grains about one millimetre in size or larger. In addition, they found that the relative amounts of carbon monoxide and water in the comet changed drastically as it neared the Sun. The team, which also includes Olivier Hainaut, says this indicates that the comet is made up of materials that formed in different places in its planetary system.

The observations by Yang and her team suggest that matter in 2I/Borisov's planetary home was mixed from near its star to further out, perhaps because of the existence of giant planets, whose strong gravity stirs material in the system. Astronomers believe that a similar process occurred early in the life of our Solar System.

While 2I/Borisov was the first rogue comet to pass by the Sun, it was not the first interstellar visitor. The first interstellar object to have been observed passing by our Solar System was 'Oumuamua, another object studied with ESO's VLT back in 2017. Originally classified as a comet, 'Oumuamua was later reclassified as an asteroid as it lacked a coma.

More information: "Unusual polarimetric properties for interstellar comet 2I/Borisov" *Nature Communications*, DOI: 10.1038/s41467-021-22000-x , www.nature.com/articles/s41467-021-22000-x

"Compact pebbles and the evolution of volatiles in the interstellar comet 2I/Borisov" *Nature Communications*, DOI: 10.1038/s41550-021-01336-w , www.nature.com/articles/s41550-021-01336-w

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