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n_TOF: THE MYSTERY HIDDEN IN THE FIRST THREE MINUTES OF LIFE OF THE UNIVERSE

It is a mystery that has lasted now for half a century. And that dates back to the beginnings of the universe. To its first three minutes of life after the Big Bang. A time space during which the lighter and more abundant elements in the universe were formed. Something, however, is not quite right. Lithium. The estimate of the theoretical models is more abundant by a factor of three compared to that inferred by observations. It is the so-called *cosmological lithium problem*.
The so-called Big Bang Nucleosynthesis (BBN) theoretical model, in fact, accounts with considerable precision for the observed abundance of light elements and their isotopes in the cosmos. The observed quantities of deuterium and helium compared to hydrogen fully reflect the BBN predictions. When it comes to lithium, however, the observed value is three times lower than expected. Physicists from the n_TOF Collaboration at CERN, in which INFN researchers are participating, have addressed it by performing complex measurements on beryllium.
n_TOF is a pulsed neutron source coupled to two flight paths at 200 and 20 meters designed to study neutron-nucleus interactions for neutron kinetic energies ranging from a few meV to several GeV. The neutron kinetic energy is determined by time-of-flight, hence the name n_TOF. The study of these reactions is of large importance in a wide variety of research fields, including the stellar nucleosynthesis. The new results of n_TOF collaboration have already led to a publication in the Physical Review Letters (PRL).
The study, due to its importance, was also selected by the journal as the "Editors' Suggestion".
The n_TOF researchers chose beryllium (^{7}Be), because cosmological lithium is almost exclusively produced by its decay in the so-called BBN. One possible explanation of the abundance of lithium is that the theoretical models overestimate beryllium production. Or that its destruction is underestimated, as a result of reactions induced by neutrons or charged particles.
The ^{7}Be, an unstable beryllium isotope, decays into ^{7}Li with a half-life of approx. 53 days. Three minutes

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after the Big Bang the light elements just formed no longer interacted with each other. The quantities present remained "frozen". The ^{7}Be, however, was gradually transformed into ^{7}Li, halving its quantity every 53 days. In no time at all it completely disappeared. That is why observing a lithium deficiency implies that the initial ^{7}Be was less than that predicted by the BBN model. To explain this effect, we must find an alternative mechanism which prematurely destroyed the ^{7}Be (another possibility is that initially less ^{7}Be was formed, even if this hypothesis is given much less credit).
Almost all the possible nuclear reactions in the scenario of the very first minutes of the universe, however, have been measured with remarkable precision. The only ones remaining to try to explain the premature destruction of ^{7}Be are two neutron-induced beryllium reactions, widely present in the primordial scenario. Alternatively, it would be necessary to postulate New Physics or an error in the estimate of primordial lithium in astrophysical observations.
For over 50 years, the measurements have proved prohibitively difficult, since they require the combination of several factors: a neutron beam with energy similar to that of the primordial scenario and with an extremely high flux, ^{7}Be targets in sufficient quantities and purity and an adequate measuring device. One of the main limitations for many years has been the lack of an adequate quantity of ^{7}Be, a highly radioactive isotope that disintegrates rapidly and poses significant radiation protection issues.
In recent years, the n_TOF Collaboration has therefore tried to finally provide an answer to the lithium mystery. The neutron beam with the characteristics required by the experiment has been available since 2014 in the new "EAR2" experimental area at CERN. The high efficiency and selectivity experimental apparatus was developed by the INFN group, in particular at the Southern National Laboratories (LNS) in Catania.
The measurement of one of the two reaction channels - as illustrated in the study just published - indicated a reactor rate, in the range of interest for the BBN, to be able to provide a value ten times lower than currently used in the theoretical models, unequivocally clarifying that this reaction channel is not able to solve the *cosmological lithium problem*. The mystery, therefore, remains. And, according to some models, it could also be a sign of physics beyond the Standard Model.
The scientists at the n_TOF Collaboration are therefore already looking elsewhere. And have decided to carry out new measurements. On a new reaction channel. Recently another experiment was carried out, again at EAR2 at n_TOF, with an experimental setup developed together with a group from the University of Lodz. The new experiment should close the loop of all the nuclear reactions involved in Primordial Nucleosynthesis. Data analysis is in progress. An analysis, at the end of which, physicists hope to finally find the solution to one of the enigmas dating back to the origins of the universe, awaited now for 50 years. ■