Independent lines of evidence suggest that the first stars, which ended the cosmic dark ages, came in pairs, rather than singly. This could change the prevailing view that the early Universe had a Swiss–cheese–like appearance.

After a spectacular birth, our Universe quickly became a dull place, with the glow of the Big Bang fading away and the first stars and galaxies yet to appear. These cosmic dark ages lasted for a hundred million years. According to a growing body of evidence, the latest of which is described by Mirabel el al.\(^1\) in a paper published in Astronomy & Astrophysics, many of the first stars that put an end to the dark ages may have formed in pairs. The appearance of the first stars marked a significant milestone, separating the history of the Universe into two stages. The first stage is well understood: dark matter, primordial ionized plasma and radiation formed a nearly uniform mixture, expanding and cooling continuously with cosmic time. When the temperature of the plasma dropped below 3,000 Kelvin, neutral hydrogen and helium atoms formed everywhere. Spatial variations in the density and temperature of the plasma were initially minuscule, but gravitational instability amplified these over time, and allowed the collapse of dense gaseous structures.

In the second stage, stars lit up inside these structures, and started wreaking havoc. The radiation of the stars penetrated the neutral cosmic plasma, once again ionizing and heating it, and modifying the formation of the subsequent generations of stars. At the time of the transition between the two stages, the 100–million–year-old Universe may have resembled Swiss cheese: cold and neutral background gas was filled with numerous
roughly spherical, hot, ionized holes surrounding the sites where the earliest stars had lit up. There is, however, a different possibility, in which energetic X–ray radiation – not normally associated with stars – is present during the transition. The evidence that the first stars may have formed in pairs makes the latter hypothesis more likely. Over the past decade, a theoretical paradigm has emerged in which the first stars formed in isolation and were about 100 times more massive than a typical present–day star, such as our own Sun. The first dense gaseous structures in which stars formed were very small; they had a total mass of the order of a million solar masses – approximately a million times smaller than a typical present–day galaxy such as the Milky Way. Molecular hydrogen, which formed efficiently in these dense regions, allowed the gas to radiate efficiently and lose its pressure support, making it collapse further. Three–dimensional simulations revealed that these structures form at the intersections of thin filaments, forming a cosmic web–like structure. They have also shown that a small fraction of the gas – about 100 solar masses – flows along the filaments coherently toward the central region of each such dense knot, without any sign of fragmenting into pieces. However, recent simulations of higher resolution than the earlier simulations, have suggested that the gas in the central regions does, eventually, fragment into two or more distinct clumps, raising the possibility that the first stars formed in pairs, or even in higher–multiple systems.

Why would the companionship of the first stars matter for the rest of the Universe? As argued by Mirabel and colleagues, a natural outcome of the latter hypothesis is for one member in a pair of massive stars to implode and leave behind a black hole, remaining gravitationally bound to its massive partner. The black hole can then pull material off the surface of its unfortunate partner, and swallow it efficiently. While devouring its partner, the black hole returns a fraction of the ingested energy in the form of copious amounts of X–rays. In fact, there are compelling examples of such micro–quasars in the local Universe. They appear more common in smaller galaxies, as well as in galaxies whose chemical
composition is closer to the that of the pristine hydrogen + helium plasma in the early universe, unpolluted by the heavier atoms produced by subsequent generations of stars. The extrapolation of these local observations suggests that such binaries were more common in the earliest, small and primitive micro–galaxies.

If the majority of the first stars formed such binaries, they could have produced sufficient X–rays to significantly change the prevailing Swiss–cheese hypothesis. This possibility has been raised in the past\textsuperscript{9, 10, 11, 12}, but is now worth considering more seriously, in light of the new theoretical and observational evidence. Unlike the ultraviolet ionizing radiation from normal stars, X–rays with the right energy – of order of a kiloelectronvolt (keV) – will travel, in the early Universe, across vast distances, ionizing and heating the plasma much more uniformly. If X–rays are sufficiently prevalent, a range of other interesting effects will occur: the extra heating will raise the pressure of the plasma everywhere, making it resistant to clumping, and more difficult to compress to form new galaxies\textsuperscript{9}.

On the other hand, X–rays can penetrate the successfully collapsing galaxies and can ionize hydrogen and helium atoms in their interior. This will catalyze the formation of molecular hydrogen, and help the gas to cool and form new stars\textsuperscript{13}. These effects will leave behind their signatures in the spatial distribution of neutral and ionized hydrogen and helium in the Universe. Mapping these distributions by measuring the 21–centimetre radio emission from neutral hydrogen\textsuperscript{14}, and the scattering of cosmic microwave background radiation (relic radiation from the Big Bang) by free electrons, or by examining the absorption spectra of distant galaxies is feasible in forthcoming experiments, and forms a major goal of modern cosmology.

There are other possible sources of X–rays connected to the formation of the first stars, for example gas accretion onto the black–hole remnants left behind by the collapse of
single stars\textsuperscript{15, 16}. Another possible source is supernovae (SNe): if the first stars exploded as SNe, then similar X–rays would be produced by thermal emission from the gas heated by these SNe, and by the collisions between the energetic electrons produced in the SN explosion and the cosmic microwave background photons\textsuperscript{9}. However, if micro–quasars were indeed as common, and as efficient producers of X–ray radiation, as Mirabel and colleagues argue\textsuperscript{1}, they may well have dominated the X–ray production in the transition epoch, when the first stars started to shine in the Universe. They would then have been responsible for ending the dark ages in a smooth fashion. The hardest X–ray photons (with energies above a few keV) would be reaching us on Earth now, forming a feeble X–ray background. Existing measurements place an upper limit on the present–day value of this background, which is consistent with this hypothesis\textsuperscript{17}. The possibility of X–ray production by binary stars should prompt further theoretical modelling of the population of such binaries, including their abundance, radiation output and spectra, as well as of the possible observable signatures they left behind.

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