The formation of very wide binary systems\textsuperscript{1–3}, such as the α Centauri system with Proxima (also known as α Centauri C) separated from α Centauri (which itself is a close binary A/B) by 15,000 astronomical units\textsuperscript{4} (1 AU is the distance from Earth to the Sun), challenges current theories of star formation, because their separation can exceed the typical size of a collapsing cloud core. Various hypotheses have been proposed to overcome this problem, including the suggestion that ultrawide binaries result from the dissolution of a star cluster—when a cluster star gravitationally captures another, distant, cluster star\textsuperscript{5–7}. Recent observations have shown that very wide binaries are frequently members of triple systems\textsuperscript{8,9} and that close binaries often have a distant third companion\textsuperscript{10–12}. Here we report N-body simulations of the dynamical evolution of newborn triple systems still embedded in their nascent cloud cores that match observations of very wide systems\textsuperscript{13–15}. We find that although the triple systems are born very compact—and therefore initially are more protected against disruption by passing stars\textsuperscript{16–19}—they can develop extreme hierarchical architectures on timescales of millions of years as one component is dynamically scattered into a very distant orbit. The energy of ejection comes from shrinking the orbits of the other two stars, often making them look from a distance like a single star. Such loosely bound triple systems will therefore appear to be very wide binaries.

Evidence is building that stars often, and possibly always, are formed in small multiple systems\textsuperscript{8,19}. Dynamical interactions between members of such systems lead to close triple encounters in which energy and momentum is exchanged, typically causing the disintegration of the triple system, with the escape of a single component (most frequently the lowest-mass member) and the formation of a stable binary\textsuperscript{20–22}. A bound triple with a hierarchical architecture may also result, but only if it forms in the presence of a gravitational potential that can such a triple system achieve long-term stability\textsuperscript{23}. However, this is frequently fulfilled for newborn triple systems, since break-up typically occurs in the protostellar phase, when the newborn stars are still deeply embedded in their nascent cloud cores\textsuperscript{24}.

We have used an advanced N-body code to run 180,218 simulations of a newborn triple system placed in a gravitational potential\textsuperscript{25} (for technical details see Supplementary Information). Figure 1a shows results for the 13,727 stable hierarchical systems that are formed in the 180,218 simulations. The blue dots mark the semimajor axes of the inner binaries, and the red dots indicate the semimajor axes of the outer components relative to the centre of mass of the inner binary. The distant components have semimajor axes that span from hundreds to several thousands of astronomical units, with a small but not negligible number of cases reaching several tens of thousands of astronomical units and beyond.

We run the simulations for 100 million years, and classify the outcome at one million years (1 Myr), 10 Myr and 100 Myr into stable triples, unstable triples and disrupted systems. If the outer orbit is hyperbolic, then the system is disrupted. If not, then the system is (at least temporarily) bound, and a stability criterion is applied\textsuperscript{25}. If the system passes this test, it is classified as stable. If not, it is still bound but internally unstable, and will sooner or later disrupt. Figure 1b shows the semimajor axis distribution for 56,957 bound but unstable triple systems.

The number of systems in each category is merely an estimate, because a rigorous theory of stability is not mathematically possible, given that the three-body problem is non-integrable. Hence we see that the number of stable triples at 1 Myr, 10 Myr and 100 Myr is not completely constant, but declines by a few per cent over time. The number of unstable triples, on the other hand, declines dramatically with age, by a factor of three or more from 1 Myr to 100 Myr (Fig. 2a). At 1 Myr, 39% of systems are bound (stable and unstable), at 10 Myr

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**Figure 1** | Semimajor axes of stable and unstable bound triple systems. a. The semimajor axes of the outer and inner pairs in stable bound triple systems. Filled blue circles are the inner binaries in stable hierarchical triple systems; filled red circles are the more distant singles in stable hierarchical triple systems. b. The semimajor axes of the outer and inner pairs in unstable bound triple systems. Turquoise circles are binaries in unstable bound triple systems; green circles are singles in unstable bound triple systems. In both panels, the semimajor axes refer to orbital parameters for systems that still remain bound at 1 Myr; at later times many of the unstable systems will have disrupted. For the widest systems, the distant bodies have not yet reached their extreme apastron distances.
average, wide binaries (1,000 in triple systems show a very strong dependence on the eccentricity. On (when the inclination and eccentricity of a perturbed orbit oscillate circumstellar material is still present at birth or owing to Kozai resonance compensated by an increase among the unstable outer systems (green). The after one or more close periastron passages, eventually lead to break-up. Hence, periastron distances around growing function of eccentricity for all but the stable outer systems, which peak highly eccentric systems are common, and the number of triple systems is a eccentricities e can be found with modest eccentricities (e = 0.3–0.4), the majority have eccentricities exceeding 0.9.

Figure 2 | Statistical properties of stable, unstable, and disrupted triple systems. The colour scheme is the same as in Fig. 1. a. Histogram with number of stable hierarchical, unstable hierarchical and disrupted triple systems at 1 Myr, 10 Myr and 100 Myr. The stable systems are essentially constant, whereas many of the unstable systems disrupt. b. The distribution of semimajor axes for both inner and outer binaries that are bound at 1 Myr. The grey dashed line shows the sum of all (inner and outer) binaries. c. The distribution of eccentricities e for bound inner and outer binaries at 1 Myr. It is evident that highly eccentric systems are common, and the number of triple systems is a growing function of eccentricity for all but the stable outer systems, which peak around e = 0.7. Systems with very high eccentricity tend to have smaller periastron distances of (1 – e), leading to the possibility of perturbations that, after one or more close periastron passages, eventually lead to break-up. Hence, the decline seen at high eccentricities for bound stable systems (red) is compensated by an increase among the unstable outer systems (green). The eccentricity distribution for the inner binaries will evolve significantly if circumstellar material is still present at birth or owing to Kozai resonance (when the inclination and eccentricity of a perturbed orbit oscillate synchronously). d. The distribution of semimajor axes of the outer components in triple systems show a very strong dependence on the eccentricity. On average, wide binaries (10,000 < a < 10,000 AU) get increasingly wide as the eccentricity increases. For very wide binaries (a > 10,000 AU, marked in red) this correlation becomes even more pronounced. Although very wide binaries can be found with modest eccentricities (e = 0.3–0.4), the majority have eccentricities exceeding 0.9.

Figure 3 | Stable and unstable hierarchical triple systems at 1 Myr and at 100 Myr, and the maximum extent a(1 + e) of a triple system as a function of time. a. The total mass of the close binary (M_A + M_B) is plotted against the mass of the distant third body M_C at an age of 1 Myr for all wide systems with outer semimajor axes exceeding 1,000 AU. Systems that are classified as unstable are marked green, and systems that are stable over long timespans are marked red. The figure is divided into two areas, in one half most of the mass resides in the binary, whereas in the other half the single dominates the system. A line indicates where systems with three identical bodies lie. b. As for a but for wide systems at an age of 100 Myr. Stable and unstable systems can be found all over the diagram, but with a strong preference for unstable systems to have a dominant binary, while stable unequal systems have a slight preference for a dominant single. At young ages hierarchical triple systems therefore frequently have dominant binaries. c. A system with outer period P of 2 Myr will for the first time reach apastron after 1 Myr. All systems in the grey-shaded area have reached apastron at least once within 1 Myr. During that time, no system has apastron at least once within 1 Myr. All systems in the grey-shaded area have reached apastron at least once within 1 Myr. During that time, no system has reached a separation of more than 50,000 AU. The dotted blue line shows how far the centre of mass of a triple system has moved in a given amount of time assuming a velocity of 1 km s⁻¹. Values are shown for 1 Myr and 10 Myr. The widest systems, which take tens or hundreds of millions of years to unfold, will have moved away from the denser and more perilous environment in which they were born before being fully unfolded.
this number has decreased to 18%, and at 100 Myr it is 12%. This number will continue to decrease until only the stable triple systems remain, which is about 7%. This last number compares well with the 8% of triple systems (the mean of all spectral types) observed in the field\textsuperscript{26}, suggesting that most star-forming events must start as triple systems.

The reason for the difference in distribution of semimajor axes between stable and unstable triple systems (Fig. 1a, b) lies in their orbital parameters. Figure 2b shows the separation distribution function of stable outer (red) and stable inner (blue) and unstable outer (green) and unstable inner (turquoise) systems at an age of 1 Myr. Figure 2c shows the distribution of eccentricities among the bound triple systems. The primary reason that some systems are stable and others unstable is that the stable systems are well separated even at periastron, when the three bodies have their closest approach. In contrast, the unstable systems are much more likely to suffer perturbations at closest approach, ultimately leading to their disruption. This is reflected in the eccentricity of the systems; see Fig. 2 legend for details.

There are three main parameters that control the stability of a triple system: the semimajor axis, the eccentricity e, and the ratio of periastron distance of the outer binary to the apastron distance of the inner binary (periastron and apastron are the points in the orbit when the stars are closest and most distant, respectively). If the outer periastron distance becomes smaller than roughly 5–10 times the inner apastron distance, then the system will eventually break up. Systems with close inner binaries thus have a larger chance of achieving stability. For the outer binary, the relation between eccentricity and semimajor axis is shown in Fig. 2d. Wide binaries (1,000–10,000 AU) are found with all eccentricities except the very smallest, although there is a clear preference for large, thanks to their semimajor axes a also being extremely large, although a few are stable even with moderate eccentricity, presumably because they have unusually small inner binaries.

Wide stable and unstable triple systems differ in one important respect. Figure 3a,b shows how total binary mass relates to the mass of the distant third body for systems wider than 1,000 AU. A large population exists at 1 Myr with members that are either all three approximately of the same mass, or with the distant third member being of very low mass. This population, however, is largely unstable (green), and so has mostly disappeared after 100 Myr, except for the very low-mass systems. The reason that
systems with a dominant binary and a light single are more unstable than the opposite configuration is probably that massive binaries can more easily alter the orbit of the third body near periastron, eventually leading to disruption. Stable triple systems (red) are much more uniformly distributed across Fig. 3, although with a preference for members of very low-mass systems to be approximately of the same mass, and a slight preference for systems with dominant singles rather than dominant binaries. Such time-dependent properties of wide triple systems may be a dynamic signature of the triple decay mechanism.

Our simulations do not take into account that there may be further orbital evolution of the inner binary when the decay from the non-hierarchical to the hierarchical configuration occurs during the protostellar phase (as it does for more than 50% of simulations25). In that case, viscous evolution will cause further in-spiralling of the inner binary, leading to the formation of spectroscopic binaries. Gas-induced orbital decay can ultimately lead to the merger of the binary components in a non-negligible number of cases27. It follows that although wide binaries formed through triple decay initially consist of three stars, during the pre-main sequence phase they may evolve into a true wide binary containing only two stars.

The results presented here refer to the birth population of binaries, at an age of 1 Myr. The orbital parameters of a triple system are established at the moment when a stable hierarchical triple is formed. But since the birth configuration of a triple system is compact, it will take half an orbital period of the outer component before the triple system reaches its first apastron passage and attains its maximum extent a(1 + e). We call this the initial unfolding time of the newborn triple system. Many wide systems have not unfolded fully at 1 Myr, and the most extreme wide systems will take tens to hundreds of million years to unfold, and are thus more protected against disruption by passing stars16,17 than if triple systems were born with such enormous separations in their crowded natal environments (Fig. 3c). See Supplementary Information for more details.

Non-hierarchical systems that have broken up shortly after birth lead to a close binary and a detached single star that is moving away from the binary. Those with small velocity differences, or with motions mainly along the line of sight, will be observed to linger for a while in the vicinity of each other, mimicking a bound binary. It is of interest to those with small velocity differences, or with motions mainly along the line of sight, will be observed to linger for a while in the vicinity of each other, mimicking a bound binary. It is of interest to lead to a close binary and a detached single star that is moving away from the binary. Those with small velocity differences, or with motions mainly along the line of sight, will be observed to linger for a while in the vicinity of each other, mimicking a bound binary. It is of interest to