Formation of new stellar populations from gas accreted by massive young star clusters

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Stars in clusters are thought to form in a single burst from a common progenitor cloud of molecular gas. However, massive, old ‘globular’ clusters—those with ages greater than ten billion years and masses several hundred thousand times that of the Sun—often harbour multiple stellar populations1–4, indicating that more than one star-forming event occurred during their lifetimes. Colliding stellar winds from late-stage, asymptotic-giant-branch stars5–7 are often suggested to be triggers of second-generation star formation. For this to occur8, the initial cluster masses need to be greater than a few million solar masses. Here we report observations of three massive relatively young star clusters (1–2 billion years old) in the Magellanic Clouds that show clear evidence of burst-like star formation that occurred a few hundred million years after their initial formation era. We show that such clusters could have accreted sufficient gas to form new stars if they had orbited in their host galaxies’ gaseous disks throughout the period between their initial formation and the more recent bursts of star formation. This process may eventually give rise to the ubiquitous multiple stellar populations in globular clusters.

The colour–magnitude diagrams of NGC 1783, NGC 1696 and NGC 411 are shown in Fig. 1. These stellar distributions—the observational counterparts of the theoretical Hertzsprung–Russell diagrams, which relate the stellar surface temperatures to their luminosities—have been field-star-decontaminated by careful application of statistical background-subtraction techniques (see Methods). Figure 1a shows that the majority of stars associated with NGC 1783 are well-described by an isochrone9—a theoretical ridge-line that describes stars with identical ages but covering a range of initial masses—characterized by an age \( t \) given by \( \log t = 9.15 \) (that is, \( t = 1.4 \times 10^7 \) yr; see Methods). However, one can also clearly discern two additional, bright stellar sequences, denoted ‘A’ and ‘B’, with younger ages of, respectively, \( \log t = 8.65 \) (\( t = 450 \) Myr) and \( \log t = 8.95 \) (\( t = 890 \) Myr). These two sequences appear to have chemical compositions that are similar to the cluster’s bulk stellar population (particularly in terms of the abundances of helium and heavier elements), given the absence of any clear differences in the observed ridge-line colours. Sequence A may also include a subpopulation of stars associated with the cluster’s red clump, the \((0.7–2)M_\odot\) (\( M_\odot\), solar mass) analogues of the helium-burning horizontal-branch stars (indicated by the orange area). Figure 1b shows the colour–magnitude diagram pertaining to NGC 1696. It also exhibits a bright, young single-stellar-population sequence characterized by \( \log t = 8.70 \) (500 Myr), whereas the bulk of the NGC 1696 stars are best represented by an older age of \( \log t = 9.18 \) (1.5 Gyr). Compared with the cluster’s dominant main sequence, the younger sequence exhibits a colour offset of approximately 0.06 mag (a shift to bluer colours), which is consistent with a stellar population characterized by an enhanced helium abundance of \( Y = 0.330 \) (33.0% of helium atoms by mass), while \( Y = 0.256 \) for the bulk of the cluster stars. A similar result for NGC 411 is shown in Fig. 1c, where we also find an additional, brighter stellar sequence that is well-represented by a younger isochrone of \( \log t = 8.50 \) (320 Myr) and \( Y = 0.400 \), compared with \( \log t = 9.14 \) (1.4 Gyr) and \( Y = 0.252 \) for the bulk of the cluster’s stellar population. These well-populated, younger and helium-enhanced stellar sequences represent the strongest evidence yet that additional, post-collapse starburst events may have occurred in our sample clusters. The enhanced helium abundances may also lead to small changes in the best-fitting cluster ages, but there are currently no appropriate model isochrones available to accurately explore this effect for stellar populations younger than 1 Gyr. Nevertheless, the general sense of helium-enhanced young sequences shown here is robust. To date, no massive clusters of equivalent age are known to host similarly significant populations of younger stars10.

We explored whether ‘blue straggler stars’—stars that have been rejuvenated through either stellar collisions or mass transfer in binary stellar systems11–13—could be entirely responsible for the presence of these younger sequences. If they are formed through mass transfer in unresolved, compact binary systems, they would appear brighter and slightly redder than the corresponding isochrone14 describing zero-age single stars (stars whose output luminosities are no longer powered by the excess energy gained from gravitational contraction but which are instead driven by nuclear fusion of hydrogen atoms). However, the younger sequences in both clusters are too blue to account for a binary origin and can instead be very well described by single-star isochrones. Given their young ages and the timescales involved in evolution through binary mass transfer, if any of these younger stars are indeed blue stragglers, they will most probably have formed through stellar collisions. Collisionally formed blue stragglers, like secondary stellar generations originating from colliding stellar winds, are expected to be more centrally concentrated than the clusters’ dominant (by number) stellar populations15. Figure 2 compares the normalized radial distributions of the young sequences with those of “normal” cluster stars of similar luminosity. The stars in the young sequences are markedly less centrally concentrated than the dominant older population of cluster members.

The more extended nature of the young populations suggests that they may have an external origin. Indeed, since the masses of NGC 1783, NGC 1696 and NGC 411 are only \( 1.8 \times 10^5 M_\odot \), \( 5.0 \times 10^4 M_\odot \) and \( 3.2 \times 10^4 M_\odot \), respectively (refs 14, 15), they are insufficiently massive to efficiently capture the stellar winds from asymptotic-giant-branch stars16. Note that our NGC 1696 mass is based on extra-polation of the observed stellar luminosity function down to a stellar mass of 0.08\( M_\odot \) (the minimum mass for hydrogen fusion, somewhat depending on the star’s chemical composition), adopting a Kroupa-like initial mass distribution17. In addition, the observed upper limits in the mass–age diagrams populated by star clusters in the Magellanic Clouds are well-understood in terms of “size-of-sample” effects. They
cannot be reconciled with initial cluster populations containing large numbers of young clusters with masses far greater than $10^5M_\odot$.

Adopting a Kroupa-like initial stellar mass distribution\(^\text{17}\), we estimate that the total stellar masses in the younger sequences, down to the hydrogen-burning limit, are $372M_\odot$ and $250M_\odot$ (NGC 1783 sequences A and B, respectively), $527M_\odot$ and $560M_\odot$ (NGC 1696 and NGC 411, respectively). Compared with the total cluster masses, the young sequences represent mere $0.2\%-2.0\%$ mass fractions. The age differences between the NGC 1783 stars in sequences A and B, and those on the main sequence are 440 Myr and 520 Myr, respectively. For NGC 1696 and NGC 411, the age differences between the clusters’ young and main sequences are 1.02 Gyr and 1.06 Gyr, respectively.

The Large and Small Magellanic Clouds, the host galaxies of our sample clusters, contain numerous, densely distributed giant molecular-gas clouds\(^\text{18,19}\). Massive clusters like those targeted here quench their initial star-formation activity on timescales of a few tens of millions of years\(^\text{20,21}\) owing to the occurrence of type II supernovae resulting from the deaths of the most massive first-generation stars\(^\text{22,23}\). This leaves a cluster embedded in a gas-poor ‘cavity’. As the young star cluster moves through the interstellar medium, it could potentially accrete sufficient gas to fuel renewed star formation. In theory, secondary star formation can be triggered\(^\text{24-25}\) and proceed rapidly once the gas density reaches the relevant threshold, for sufficiently low temperatures. This would result in the appearance of a younger ‘simple stellar population’. However, to date the reality of this proposed idea has not been confirmed.

Although they are all contained within twice their host clusters’ core radii, the observed spatial distributions of all young stellar sequences in our sample clusters are more extended than the cluster’s bulk stellar populations. This could indicate that these clusters may have accreted ambient gas, allowing star formation to proceed. We thus explored the expected gas-accretion rate as a function of the local gas density. Indeed, it appears possible for NGC 1783-like clusters to accrete enough gas to form new stars\(^\text{23}\) (see Methods).

Almost all Galactic globular clusters host multiple stellar populations. However, it is still unclear whether these latter populations originate from young clusters that formed as single-age stellar populations. Our observations of secondary stellar populations in intermediate-age Magellanic Cloud clusters suggest that the same process giving rise to them may also explain the multiple stellar populations seen in at least some Galactic globular clusters. We aim at addressing this issue in a follow-up study.

Many star clusters in the Magellanic Clouds contain large numbers of stars occupying the colour–luminosity parameter space at bluer colours and brighter luminosities than their main-sequence turn-off regions\(^\text{26,27}\). These clusters include NGC 121, NGC 1652, NGC 1751, NGC 1795, NGC 1806, NGC 1846, NGC 1852, NGC 1917, NGC 1978, NGC 2121, NGC 2154, NGC 339, NGC 416, NGC 419, Hodge 7, Kron 3, Lindsay 1 and Lindsay 38. These brighter and bluer stars are usually dismissed as residual field-star contamination. However, if well-populated younger sequences are, in fact, embedded in this parameter space, the presence of such simple stellar populations indicates that many clusters may have experienced starburst events some time after their initial formation epoch. Among the clusters highlighted here, some—including NGC 1806, NGC 1846, Lindsay 38 and NGC 419—appear to exhibit features similar to NGC 1783, NGC 1696 and NGC 411, although at a lower level of significance. Particularly for Lindsay 38 and NGC 419, the radial distributions of the bright stars beyond their main-sequence turn-off regions are known to be less concentrated than the bulk cluster stars with similar luminosities\(^\text{28}\), and hence a population of blue stragglers probably cannot explain the properties of all those stars. Some may have originated from gas accretion. These clusters will be targeted in our follow-up studies. Our discovery of clear, well-populated young sequences in NGC 1783, NGC 1696 and NGC 411 has revealed that star clusters may indeed have the capacity to accrete gas from their environment. This could, in fact, be the most important route to form secondary stellar populations in young massive clusters.

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**Figure 1** | Colour–magnitude diagrams, including the best-fitting isochrones, and true-colour images for all three clusters. **a**, NGC 1783. Central panel, purple and dark green squares show sequence A and sequence B stars, respectively; red solid line, blue solid line and blue dashed line show isochrones for $\log t = 9.15$, $8.95$ and $8.65$, respectively. The orange box indicates the region where red-clump stars associated with sequence A may be found. Left panel, representative $\pm 1\sigma$ measurement uncertainties, note that the x-axis scale is different from that of the main panel. Right panel, true-colour image. **b**, NGC 1696. Left panel, purple squares, younger sequence; red solid and blue dashed lines, isochrones for $\log t = 9.18$ and $8.70$, respectively. Right panel, true colour image. **c**, NGC 411. Left panel, purple squares, younger sequence; red solid and blue dashed lines, isochrones for $\log t = 9.14$ and $8.50$, respectively. Right panel, true colour image synthesised from B, V and I band monochromatic images. The measurement uncertainties in **b** and **c** are equivalent to those shown for **a**. For the young sequences in NGC 1696 and NGC 411, enhanced helium abundances have been adopted (see text).
Figure 2 | Normalized radial distributions of the young sequences with respect to normal cluster stars of similar luminosity. \( N(R) \) represents the number of stars in the young sequences within radius \( R \), whereas \( N_{\text{RB+RC}}(R) \) represents the total number of red-giant branch and red clump stars within \( R \). RGB, red-giant branch; RC, red clump. a, NGC 1783; b, NGC 1696; and c, NGC 411. The error bars reflect Poissonian ±1σ uncertainties.

Online Content Methods, along with any additional Extended Data display items and Source Data, are available in the online version of the paper; references unique to these sections appear only in the online paper.

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NGC 1696. The NGC 1696 data sets were also obtained as part of HST programme GO-10595, using the ACS/WFC. The cluster was observed through the F435W and F814W filters. Their total exposure times are 700 s and 720 s for the B and I bands, respectively. These exposure times are sufficient to resolve the young sequences.

NGC 1696. The NGC 1696 data sets were also obtained as part of HST programme GO-12257, using the ACS/WFC. The cluster was observed through the F435W and F814W filters. The images of NGC 1696 are also composed of short- and long-exposure frames. The long (short) exposure times in the B and I bands were 680 s (90 s) and 680 s (8 s), respectively. Since NGC 1696 is not as extended as NGC 1783 (see below), a representative field region was selected close to the edge of the NGC 1696 images. Few studies to date have targeted NGC 1696. Therefore, we derived the physical parameters of NGC 1696 ourselves.

NGC 411. The data sets of NGC 411 were obtained as part of HST programme GO-12257, using the Wide Field Camera 3 (WFC3). The cluster was observed through the F475W and F814W filters. The F475W filter is centred at a wavelength of 475 nm; its transmission curve also corresponds approximately to that of the Johnson B band. The exposure times in both the B and I bands were 700 s. NGC 411 has a relatively small core (see below), which allowed us to select a representative field region close to the edge of our science images.

Photometry and data reduction. We used two independent software packages to perform point-spread-function (PSF) photometry, including DAOPHOT29 within the IRAF environment and DOLPHOT30–32. Our stellar catalogues are based on the DAOPHOT results. We performed the DOLPHOT analysis for comparison, to ensure that our final photometry is not biased.

The DAOPHOT-generated raw stellar catalogue contains a sharpness parameter, which describes the goodness of the PSF fit29. For a ‘good’ star, the sharpness should be close to 0. We thus constrained our sample to stars with a sharpness between −0.5 and 0.5, which removed approximately 4% of objects from our catalogue. We carefully checked the resulting colour–magnitude diagram and found that the main features of interest were not affected by this selection. For NGC 1783 and NGC 1696, we merged the stellar samples resulting from the short and long exposure times, carefully cross-referencing both catalogues to avoid duplication of objects in the combined output catalogue. For NGC 1783, the short-exposure time catalogue contributes very little to sequences A and B. For NGC 1696, the short-exposure-time stars contribute only marginally to the feature of interest.

Determination of the cluster and field regions. We divided the stellar spatial distribution into 15–20 bins along both the right ascension (α2000) and declination (δ2000) axes. We varied the bin numbers to ensure that statistical scatter would not significantly affect the shape of the number-density distributions. We used a Gaussian function to fit the latter along both axes and defined the closest positional coincidence of both Gaussian peaks as the cluster centre. The NGC 1783 cluster centre is located at α2000 = 04 h 59 min 08.47 s, δ2000 = −69° 58′ 17.81″. For NGC 1696, the coordinates are α2000 = 11 h 16.0 min 56.22 s, δ2000 = −71° 46′ 40.49″.

Our NGC 1783 and NGC 411 data sets are very close to the cluster centres determined previously33.4. We used a Monte Carlo method to examine the spatial distribution of the NGC 1696 stars and estimate the areas of annuli at different radii. The stellar number density in each annulus is \( N(R)/A(R) \), where \( N(R) \) is the number of stars observed in an annulus with radius \( R \), and \( A(R) \) is the area of the annulus. We defined the clusters’ (2D-projected) core radii as those radii where the density profiles drop to half the respective central densities. We selected the areas contained within 2 core radii as the cluster regions. NGC 1783 has a large core radius (45–50 arcsec), which is identical to that adopted by ref. 35, although our core radius is slightly larger than their value of 36.7 arcsec. We compared our catalogue with theirs and found that our photometry is deeper and, hence, contains more faint stars. The core radius of NGC 1696 is smaller (~30 arcsec), while the core radius of NGC 411 is approximately half that of NGC 1783 (20–25 arcsec).

Hence, the cluster radii we adopted for NGC 1783, NGC 1696 and NGC 411 were 100 arcsec, 60 arcsec and 50 arcsec, respectively. We selected these radii as cluster radii, because of the need to avoid background contamination as much as possible, while simultaneously ensuring statistically robust results. In Extended Data Fig. 1, we present the stellar number-density profiles.

For NGC 1783, we synthesized the field region’s colour–magnitude diagram based on a combination of our observations of the cluster’s periphery on the image containing the cluster (‘field 1’) and the field region towards the southeast (‘field 2’). Because the features of interest are very bright, we consider stars with \( B < 23 \) mag. For these stars, NGC 1783 is compact (its core radius is 25 arcsec) and field 1 indeed adequately represents the background. We found that the eastern part of field 2 exhibits a clear, slightly brighter stellar sequence parallel to the main sequence, indicating a significant population of unresolved binary systems. Since the field’s stellar number density is low, blending of unrelated stars along the line of sight is negligible; instead, this binary population may reflect contamination by a nearby star-forming region. We hence selected the eastern part of field 2 as a representative field region. We selected three rectangles, each covering an area of 1,000 pixels × 1,000 pixels (~50 arcsec × 50 arcsec), near the edge of field 1, as well as four rectangles from the western part of field 2 (covering the same area), to construct a complete, combined field region. To assign equal weights to the stellar catalogues from both regions, we randomly selected three-quarters of the full sample of stars detected in the four rectangles of field 2’s stellar catalogue. The combined stellar catalogue based on these seven rectangles represents the synthesized field region’s colour–magnitude diagram. The cluster region is roughly 1.6 times larger than the field region (see the left-hand panel of Extended Data Fig. 2).

For NGC 1696, we selected an area of 600 pixels × 4,000 pixels (~30 arcsec × 200 arcsec) near the edge of the image as a representative field region. The NGC 1696 cluster region is roughly 1.7 times larger than the field region. The selected cluster and field regions pertaining to NGC 1696 are shown in the middle panel of Extended Data Fig. 2.

For NGC 411, we selected a field region covering an area of 800 pixels × 3,500 pixels (~32 arcsec × 140 arcsec) from the cluster’s periphery. We avoided regions that were located close to the edge of the image, where the photometric quality is markedly inferior, probably owing to the relatively large offsets between the individual science images, combined with instrumental propagation effects. Although our selection may include some tidally stripped cluster stars, this does not affect the magnitude range of interest, which is bright. The NGC 411 cluster region is roughly 1.8 times larger than the field region. The selected cluster and field regions pertaining to NGC 411 are shown in the right-hand panel of Extended Data Fig. 2.

Reducing background contamination and isochrone fitting. Once we had obtained the cluster and background colour–magnitude diagrams, we generated a common magnitude × colour grid with cell sizes of 0.5 mag × 0.25 mag, spanning the ranges from \( B-I = -2.5 \) mag to 3.5 mag and from \( B = 16 \) mag to 27 mag. This range is sufficiently large to cover the full magnitude–colour diagrams of our target clusters. The cell size is relatively large for the main sequences, because it was specifically designed to be practically useful in the regions occupied by the young, blue sequences, where the stellar number density is lower. We counted the number of background stars in each cell and calculated the number of possible contaminating stars in the same cell (corrected for differences in areas covered), which we then randomly removed. We confirmed that varying the cell sizes from 0.3 mag × 0.15 mag to 0.5 mag × 0.25 mag for NGC 1783 would not affect the significance of any of the features of interest. For NGC 1696, the typical practically useful cell sizes range from 0.4 mag × 0.4 mag to 0.5 mag × 0.5 mag, while for NGC 411, viable cell sizes range from roughly 0.3 mag × 0.15 mag to 0.5 mag × 0.25 mag. Adopting much larger or smaller cell sizes would erase the observed sequences.

We carefully examined the performance of our decontamination method and found that the observed features do not depend on the cluster or field regions selected: see Extended Data Figs. 2–4. As a benchmark, we use NGC 1783 as benchmark. In Extended Data Fig. 3, we show the field–decontaminated colour–magnitude diagrams pertaining to three different samples of cluster members, at radii \( R > 30″ \), \( R > 60″ \) and \( R > 90″ \). They all exhibit distinct younger sequences. In Extended Data Fig. 4, we select representative field regions from different images (two from a separate image and one from the image which also contains the cluster itself). The observed young sequences remain clearly visible for all three background regions adopted. In Extended Data Fig. 5, we show the decontaminated colour–magnitude diagrams resulting from adoption of different grid sizes. This figure shows that the observed features are almost independent of grid size. Extensive tests also showed that the number of background stars in each cell and the magnitude–colour diagrams are similarly well-defined. This confirms that the observed sequences are physically real rather than caused by statistical sampling effects. We also found that, for the adopted cell sizes, the reduced colour–magnitude distributions are similar in appearance to the real background colour–magnitude diagrams. Our adopted

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method therefore performs adequately. From Extended Data Fig. 6a, e and i, one can deduce that these bright sequences are indeed already embedded in the unreduced colour–magnitude diagrams.

We obtained best fits to all observed sequences, including the clusters’ main sequences, based on matching the observations with theoretical stellar isochrones. Similarly to other intermediate-age star clusters, NGC 1783, NGC 1696 and NGC 411 display extended main-sequence turn-off regions28–30, which renders determination of their main-sequence ages difficult. However, it has been reported that ages of such intermediate-age star clusters can be constrained by consideration of their tight subgiant branches27,28 (but see ref. 39 for an opposing view), which represent the stellar evolutionary stage stars enter once they have exhausted the hydrogen in their cores through nuclear fusion. Indeed, all of our sample clusters exhibit tight subgiant branches. The final age determination yields log τ = 9.15, 9.17 and 9.14 for NGC 1783, NGC 1696 and NGC 411, respectively.

We next determined the ages of each of the blue sequences. For NGC 1783, sequences A and B are characterized by ages of log τ = 8.65 and 8.95, respectively. The NGC 1783 main-sequence stars, as well as those in sequences A and B, share the same metal abundance, Z = 0.008 (40% of solar metallicity), and visual extinction, A_V = 0.06 mag. We adopted a true distance modulus for NGC 1783 of (m - M)_0 = 18.46 mag (corresponding to a distance of 49.2 kpc). The young sequence in NGC 1783 is adequately characterized by a log τ = 8.70 isochrone with the same metallicity as the cluster’s main sequence, Z = 0.004 (20% solar). However, the young sequence appears 0.06 mag bluer than the zero-age main sequence of the cluster’s bulk stellar population. An enhanced helium abundance (Y = 0.330) can explain the colour offset27,28, where Y = 0.256 for the cluster’s main sequence. The adopted extinction and distance modulus for NGC 1696 are A_V = 0.10 mag and (m - M)_0 = 18.50 mag (50.1 kpc), respectively. The young sequence in NGC 411 has an age of log τ = 8.50. It has the same metallicity as the cluster’s main sequence, Z = 0.002. Its young sequence is also very blue, which can only again be explained if it is characterized by an enhanced helium abundance of Y = 0.400 compared with Y = 0.252 for the cluster’s main sequence. Foreground extinction of A_V = 0.25 mag is appropriate and our adopted true distance modulus is (m - M)_0 = 18.90 mag (60.3 kpc).

**Blue straggler stars as possible origins of the younger sequences.** One possible explanation for these bright sequences is that they are composed of blue straggler stars. Therefore, we investigated their relative radial concentration with respect to stars that have similar luminosities. In NGC 1783, NGC 1696 and NGC 411, the latter stars are mostly red-giant-branch and red-clump stars: see Extended Data Fig. 7. However, as shown in Fig. 2, the stars defining the bright sequences are all less centrally concentrated than red-giant stars with similar luminosities. If they are genuine blue stragglers, irrespective of their origin, they are expected to be more centrally concentrated than similar-luminosity red-giant stars, because blue stragglers are expected to be more massive than red giants. Dynamical interactions are also unlikely to have redistributed all blue stragglers to the outskirts of our sample clusters, since the typical dynamical timescales24 are much longer than the clusters’ current ages. In addition, the flat cluster cores observed for NGC 1783, NGC 1696 and NGC 411 render the probability of core-collapse events having occurred very unlikely. Core collapse would produce a cuspy radial density profile24 and such a process is a prerequisite for the presence of a coeval collisional blue straggler population. The more extended radial distributions of the stars in the younger sequences compared with the dominant cluster populations argue against stellar collisions in the cluster cores having played an important role.

**Gas accretion from the interstellar medium.** We followed the method of ref. 23 to estimate the regions of parameter space where an NGC 1783-like star cluster with a mass of 1.8 × 10^5 M_⊙ and a half-mass radius of 11.4 pc (ref. 43) could accrete the required mass to form two additional generations of stars: one containing 250 M_⊙ in stars some 520 Myr after the initial star-formation event, and a subsequent generation composed of 370 M_⊙ of stars 440 Myr later. The key equations in ref. 23 are equations (3), (5) and (8). For all calculations we assumed a star-formation efficiency of 10% (which implies that only 10% of the available gas is converted into stars). We explored two processes through which a cluster can accrete gas from the interstellar medium23, one due to gravity (‘Bondi accretion’), and one due to sweeping up material as the cluster orbits around its host galaxy’s centre. The latter process involves some initial intracluster gas which interacts collisionally with the interstellar gas. The accretion rates from both of these processes depend on both the gas density, n, and the relative velocity of cluster and gas, V. Ram-pressure stripping can limit the accretion, and this process also depends on n and V.

Extended Data Fig. 8 shows the allowed (shaded) regions of parameter space in (n, V) that would enable a cluster to accrete the desired amount of gas in the period between star-formation events. This figure assumes accretion from a volume-filling interstellar medium over the entire duration between respective generations (Bondi accretion). The Bondi line is curved, because this accretion rate also depends on the gas sound speed, which we have assumed to be 10 km s^{-1} (that is, gas at a temperature of ~10^4 K). Anything to the upper right of the ‘Ram’ line will strip the gas from the cluster. Below that line, and for a given density, the Bondi line defines the upper limit to the cluster’s bulk velocity that would be allowed for the cluster to accrete this amount of gas. In other words at a velocity below the curve, the cluster would accrete gas more quickly, and, for instance, if the star-formation efficiency were less than 10%, it could still form the same mass of stars over the same period. Conversely, at a given density, sweeping up of gas is more efficient at larger velocities, so the dashed line shows the lower limit to the velocity that would be required to reach the desired amount of gas.

Extended Data Fig. 9 shows two examples of how the accreted mass could accumulate over time for the Bondi regime (solid lines) and the sweeping regime (dashed lines). For the Bondi regime, we used a relative velocity of 4 km s^{-1} and a density of 0.3 cm^{-3}. For the sweeping regime, we used a velocity of 50 km s^{-1} and a density of 0.05 cm^{-3} (which is similar to the rotation velocity at the position of NGC 1783 with respect to the Large Magellanic Cloud’s centre23). The data points show these masses, with 180% uncertainties divided by the star-formation efficiency of 10%.

**Sample size.** No statistical methods were used to predetermine sample size.

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Extended Data Figure 1 | Stellar number-density profiles. Here $\rho$ is the number density of stars at a given radius $R$. a, NGC 1783. The vertical solid line indicates the cluster's core radius, that is, the position where the number density decreases to half the central value. The $\pm 1\sigma$ uncertainties shown are due to Poisson noise. b, c, As a, but for NGC 1696 (b) and NGC 411 (c).
Extended Data Figure 2 | Spatial distributions of cluster and field stars. Red and blue points represent cluster stars and the adopted field stars, respectively. The black dots are all observed stars except for the cluster and field stars. RA, right ascension; dec., declination. a, NGC 1783; b, NGC 1696; and c, NGC 411.
Extended Data Figure 3 | Field-star-decontaminated colour–magnitude diagrams for samples of stars at different radii in NGC 1783. a, $R \geq 30''$; b, $R \geq 60''$; and c, $R \geq 90''$. 
Extended Data Figure 4 | Field-star-decontaminated colour–magnitude diagrams of NGC 1783 for three different adopted reference fields. a, b, Resulting colour–magnitude diagram (a) based on the field-star sample drawn from the image containing the cluster (b). c, d, As a and b, but for a representative field region taken from a separate image. e, f, As c and d, but for a different field region taken from the same, separate image. The black points are stars which are located in the cluster region, whereas the red points are the adopted field stars.
Extended Data Figure 5 | Field-star-decontaminated colour–magnitude diagrams of NGC 1783 for three different grid sizes. a, 0.30 mag × 0.15 mag; b, 0.40 mag × 0.20 mag; and c, 0.50 mag × 0.25 mag.
Extended Data Figure 6 | Colour–magnitude analysis. a–d, NGC 1783; e–h, NGC 1696; i–l, NGC 411. First column (a, e, i), raw colour–magnitude diagrams; second column (b, f, j), field-decontaminated colour–magnitude diagrams (also shown in Fig. 1); third column (c, g, k), colour–magnitude diagrams of the representative field regions; and fourth column (d, h, l), stellar colour–magnitude distributions that were removed from the raw catalogues.
Extended Data Figure 7 | Colour–magnitude diagrams highlighting specific features. 
a, Purple and dark green squares, stars in NGC 1783 sequences A and B, respectively. Dark green circles, corresponding red-giant-branch and red-clump stars, used for comparison with sequence B.

b, Purple squares, NGC 1696 young-sequence stars; red circles, corresponding red-giant-branch and red-clump stars used for comparison.

c, As b, but for NGC 411.

The combination of dark green and purple circles represents the sample used for comparison with sequence A.
Extended Data Figure 8 | Gas-accretion diagnostic diagram. V is the relative velocity of the cluster with respect to the gas, and n represents the gas density. The shaded regions indicate the parameter space where an NGC 1783-like cluster can accrete the required mass to form the two additional generations of stars, namely one of 250 M⊙ over 520 Myr (blue, corresponding to sequence B in Fig. 1), and a second of 370 M⊙ over 440 Myr (green, corresponding to sequence A in Fig. 1). We have assumed a star-formation efficiency of 10% for all calculations in this figure. The regions to the right of the ‘Gravity’ curves correspond to where Bondi accretion can accumulate at least the required mass, and the regions to the right of the ‘Sweep’ curves correspond to where accretion by collisional sweeping up of ambient interstellar gas by seed intracluster gas can accumulate at least the required mass. The parameter space above the ‘Ram’ curves are excluded because ram pressure strips clusters of their gas in those regions. See Methods for details.
Extended Data Figure 9 | Gas mass, $M$, accreted from the interstellar medium as a function of time, $t$. We have adopted a star-formation efficiency of 10% and calculated representative interstellar gas-accretion frameworks that can explain the stellar masses in the secondary sequences A and B in NGC 1783. For the Bondi regime (solid lines), we used a relative velocity of 4 km s$^{-1}$ and a density of 0.3 cm$^{-3}$. For the sweeping regime (dashed lines), we used a velocity of 50 km s$^{-1}$ and a density of 0.05 cm$^{-3}$. The blue and green filled regions indicate the stellar masses and age offsets of NGC1783 sequences A and B, respectively. The vertical extent of each region provides an estimate of the range in allowed masses. Specifically, for each sequence we plot a region centred on the mass derived using the Kroupa initial mass function, as given in the main text; the range to higher and lower masses is equal to the mean of the differences between the total masses derived using a Salpeter and Kroupa initial mass function of $180M_\odot$ (multiplied by the assumed 10% star formation efficiency).
Corrigendum: Formation of new stellar populations from gas accreted by massive young star clusters

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Following publication of this Letter, we were made aware that the target cluster identified as 'NGC 1696' is instead the cluster 'NGC 1806'. This mistake was caused by a misidentification in the Hubble Space Telescope image headers provided by the ESA Hubble Science Archive (http://archives.esac.esa.int/hst/). As a consequence, all occurrences of 'NGC 1696' in the Letter should be replaced by 'NGC 1806'. The occurrence of 'NGC 1806' in the final paragraph of the main text should be removed. The mass of NGC 1806 should be $1.1 \times 10^5$ solar masses rather than $5.0 \times 10^4$ solar masses and ref. 1 should be cited. The sentence "Note that our NGC 1696 mass is based on extrapolation ... adopting a Kroupa-like initial mass distribution." should be deleted.

Because none of these corrections relates to any scientific results in the Letter, there are no scientific implications for the results and conclusions. The online version has not been corrected.

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