torial humic belt in the Late Triassic was comparable to today’s (Fig. 3), a conclusion that contrasts with some previous suggestions of a much more restricted or even dry equatorial belt in the Triassic (33, 34). Poleward motion can explain the generally drier northward and up-section facies pattern in the Mesozoic rift basins of eastern North America (32, 35) as this part of Pangea drifted out of the equatorial humic belt. At the same time, the up-section progression to more humid facies in the Fleming Fjord Formation (36, 37) and the overlying plant-bearing Kap Stewart Formation of latest Triassic and earliest Jurassic age (38) in the Jameson Land basin would reflect the drift of this area into the temperate humic belt.

We conclude that the congruence of the corrected paleomagnetic data from sedimentary rocks and independent data from igneous rocks ranging over thousands of kilometers and tens of millions of years indicates that a GAD field similar to that of the past 5 Ma was operative at least 200 Ma in the Late Triassic-Jurassic Rifting: North America and Africa. Much of what is known about grains in space comes from spectra features observed in emission, polarization, and absorption (I–7). The 2175 Å peak is by far the strongest feature observed in the ultraviolet (UV)–visible wavelength range along most lines of sight for which it can be measured (Fig. 1, A and B) (4–7). The feature is enigmatic: Its central wavelength is almost invariant, but its discovery, the origin of the feature and the nature of the carrier(s) remain controversial. Using a transmission electron microscope, we detected a 5.7–electron volt (2175 angstrom) feature in interstellar grains embedded within interplanetary dust particles (IDPs). The carriers are organic carbon and amorphous silicates that are abundant in IDPs and in the interstellar medium. These multiple carriers may explain the enigmatic invariant central wavelength and variable bandwidth of the 2175 Å feature.
interstellar medium (ISM), amorphous silicates and carbonaceous matter, are found in IDPs (Fig. 2) (9). The amorphous silicates are glass with embedded metal and sulfides (GEMS), some with nonsolar O isotopic compositions (10–13). The carbonaceous matter is a mixture of inorganic and organic carbon, and some of the organic materials exhibit nonsolar D/H, 15N/14N, and organic carbon, and some of the organic naceous matter is a mixture of inorganic and organic carbon and GEMS within chondritic IDP.

We used a new-generation transmission electron microscope (TEM) equipped with a monochromator and high-resolution electron energy-loss spectrometer to measure UV spectral properties of portions of IDPs and standards (16, 17). The 0- to ~100-eV region of an energy-loss spectrum, known as the valence electron energy-loss spectroscopy (VEELS) region (17), includes the 2175 Å (5.7 eV) UV spectral feature. We used VEELS because the submicrometer dimensions of the subgrains preclude measurement by conventional photoabsorption spectroscopy (PAS). The VEELS data were acquired under conditions in which the positions of VEELS and PAS features are comparable, but PAS typically has ~10 times better wavelength/energy resolution (18). A synchrotron light source was used to measure infrared (IR) spectral properties (17), and two NanoSIMS (secondary ion mass spectrometry) microprobes were used to measure the isotopic compositions of grains within the same IDPs (17).

A VEELS spectrum from the mineral talc (Mg3Si4O10(H2O)2) shows a peak position and bandwidth that match the photoabsorption feature of hydroxylated amorphous Mg3SiO4 (Fig. 1, C and D) (8), as well as the astronomical UV feature (Fig. 1, A, B, and D). VEELS spectra from carbonaceous grains in three IDPs exhibit a 5.7-eV feature with average bandwidth (full width at half maximum, FWHM) of 2.6 eV (2.2 μm−1) (Fig. 3, A to C). With increasing O/C ratio, the strength of the 5.7-eV feature increases and the peak of the volume plasmon (the broad peak between 10 and 28 eV) decreases in energy. Energy-loss C and O core scattering edges from the most O-rich regions exhibit a fine structure consistent with carbonyl (or hydroxyl) functional groups (19), and IR spectra there exhibit prominent C-H stretch and C=O features at ~3.4 μm and ~5.9 μm, respectively (Fig. 4). Although the signal-to-noise ratio is marginal, because the IR spectrum was acquired from a ~9-μm² area ~0.1 μm thick, the overall structure of the C-H stretch feature between 2850 and 3100 cm⁻¹ in L2036 G16 (and in other IDPs) is consistent with aliphatic groups bound to other molecules like polycyclic aromatic hydrocarbons (PAHs) (19–21). 1-Pyrene carboxaldehyde (C17H10O) exhibits the ~5.7-eV feature but pyrene (C18H12), with no carbonyl group, produces a feature that is shifted to higher energy (~6.1 eV) (Fig. 3, D and E). GEMS produce a 5.7-eV feature with an average bandwidth (FWHM) of 2.9 eV (2.5 μm⁻¹), and the feature strength correlates with hydroxyl (OH⁻) content (Fig. 3, F to J). Thus, both organic compounds and amorphous silicates in IDPs may be carriers of a 5.7-eV feature.

The central wavelength of the IDPs’ 5.7-eV VEELS feature matches the 2175 Å astronomical feature, but the bandwidths are broader (Fig. 1). This extra breadth may result from the ~10 times lower energy resolution of VEELS (relative to PAS) and from the grains’ physical state. The subgrains within the IDPs are no longer free-floating in the ISM, and the extent of their solid-state modification during their ~4.5-billion-year post-ISM lifetimes is unknown. At the very least they may have undergone significant aggregation into larger (50- to 500-nm-diameter) grains, and computer-modeling best fits to the 5.7-eV feature. The central wavelength of the IDPs’ 5.7-eV VEELS feature matches the 2175 Å astronomical feature, but the bandwidths are broader (Fig. 1). This extra breadth may result from the ~10 times lower energy resolution of VEELS (relative to PAS) and from the grains’ physical state. The subgrains within the IDPs are no longer free-floating in the ISM, and the extent of their solid-state modification during their ~4.5-billion-year post-ISM lifetimes is unknown. At the very least they may have undergone significant aggregation into larger (50- to 500-nm-diameter) grains, and computer-modeling best fits to the 5.7-eV feature. The strength of the 5.7-eV feature increases and the peak of the volume plasmon (the broad peak between 10 and 28 eV) decreases in energy. Energy-loss C and O core scattering edges from the most O-rich regions exhibit a fine structure consistent with carbonyl (or hydroxyl) functional groups (19), and IR spectra there exhibit prominent C-H stretch and C=O features at ~3.4 μm and ~5.9 μm, respectively (Fig. 4). Although the signal-to-noise ratio is marginal, because the IR spectrum was acquired from a ~9-μm² area ~0.1 μm thick, the overall structure of the C-H stretch feature between 2850 and 3100 cm⁻¹ in L2036 G16 (and in other IDPs) is consistent with aliphatic groups bound to other molecules like polycyclic aromatic hydrocarbons (PAHs) (19–21). 1-Pyrene carboxaldehyde (C17H10O) exhibits the ~5.7-eV feature but pyrene (C18H12), with no carbonyl group, produces a feature that is shifted to higher energy (~6.1 eV) (Fig. 3, D and E). GEMS produce a 5.7-eV feature with an average bandwidth (FWHM) of 2.9 eV (2.5 μm⁻¹), and the feature strength correlates with hydroxyl (OH⁻) content (Fig. 3, F to J). Thus, both organic compounds and amorphous silicates in IDPs may be carriers of a 5.7-eV feature.

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Fig. 1. Comparison of astronomical UV extinction features with laboratory UV and VEELS features. (A) The 2175 Å interstellar extinction feature from two stars ζ and ε Persei (5). (B) Broadest (ζ Oph) and narrowest (HD 93028) profiles from 45 stars (6). (C) Photoabsorption spectrum from partially recrystallized hydroxylated amorphous magnesium silicate (8). (D) VEELS spectrum from (electron) irradiation-damaged talc (Mg3Si4O10(OH)2). (E) VEELS spectrum from (organic) carbon in IDP L2047 D23. (F) VEELS spectrum from GEMS in W7013 E17.

Fig. 2. (A) Secondary electron image of a typical chondritic IDP (RB12A). (B) A 200-keV brightfield transmission electron micrograph of organic carbon and GEMS within chondritic IDP L2009*E2.
Correlated nonsolar $^{12}$C/$^{13}$C and $^{16}$O/$^{17}$O. The strength of the GEMS 5.7-eV feature overlaps Lyman-α emission (the position of which is due to the electronic transition of oxygen and also consistent with IR carbonyl and hydroxyl bands, whereas larger column densities are typically required for detection of weaker infrared bands. The presence of two potential carriers may bear on the variable bandwidth of the astronomical feature, with relative abundance or physical state of each component varying from one sight line to another. Amorphous silicates are ubiquitous throughout interstellar space, but oxidized (carbonyl-containing) PAHs have yet to be identified in the ISM, although they are indicated as a potential carrier of the astronomical 2175 Å extinction feature. However, the identification of interstellar subgrains in IDPs (as evidenced by their isotopic compositions) that produce analogous features suggests that the carrier(s) of the interstellar feature may be present in IDPs.

Before this study, amorphous silicates, but not carbonyl compounds, were suggested as potential carriers of the astronomical 2175 Å extinction feature. On the basis of our observations of IDPs, we cannot conclude that organic carbon and (hydroxylated) amorphous silicates are the only carriers of the astronomical feature. However, the identification of interstellar subgrains in IDPs (as evidenced by their isotopic compositions) that produce analogous features suggests that the carrier(s) of the interstellar feature may be present in IDPs. This finding provides new information for computational modeling, laboratory synthesis of analog grains, and laboratory (UV) photo-absorption measurements. It is also worth looking for a correlation of the interstellar 2175 Å feature with IR carbonyl and hydroxyl bands, although lines-of-sight suitable for detecting a strong 2175 Å feature are generally diffuse, whereas larger column densities are typically required for detection of weaker infrared bands. The presence of two potential carriers may bear on the variable bandwidth of the astronomical feature, with relative abundance or physical state of each component varying from one sight line to another. Amorphous silicates are ubiquitous throughout interstellar space, but oxidized (carbonyl-containing) PAHs have yet to be identified in the ISM, although they are indicated as a major product of irradiation of PAHs and are found in primitive meteorites. A variety of exotic carriers for the 2175 Å peak have been proposed, including nanodiamonds, carbon onions, and fullerenes (1–4). However, organic carbon and amorphous silicates are more abundant in interstellar space, and cosmically abundant carriers are needed to explain the ubiquity of the 2175 Å feature.

References and Notes

Retinoic Acid Signaling Restricts the Cardiac Progenitor Pool

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Organoogenesis begins with specification of a progenitor cell population, the size of which provides a foundation for the organ’s final dimensions. Here, we present a new mechanism for regulating the number of progenitor cells by limiting their density within a competent region. We demonstrate that retinoic acid signaling restricts cardiac specification in the zebrafish embryo. Reduction of retinoic acid signaling causes formation of an excess of cardiomyocytes, via fate transformations that increase cardiac progenitor density within a multipotent zone. Thus, retinoic acid signaling creates a balance between cardiac and noncardiac identities, thereby refining the dimensions of the cardiac progenitor pool.

Generation of the proper number of organ progenitor cells is likely to involve interplay between inductive and repressive signaling pathways. Key inductive mechanisms have been identified for many organs, including the heart, but mechanisms for repressing progenitor fate assignment are poorly understood. Several factors, including Bmp2, Fgfr8, Nodal, and Wnt11, are implicated in promoting the initial selection of myocardial progenitor cells from a multipotent population. Although convergence of inductive signals might be sufficient to delimit the number of progenitor cells, opposing signals could also be necessary to restrict myocardial specification. Prior studies have suggested mechanisms for inhibiting cardiomyocyte differentiation within the anterior lateral plate mesoderm (ALPM), by means of Notch signaling (2) or interactions with the notochord (3), but little is known about whether repressive pathways limit the initial assignment of myocardial identity.

We find that reduction of retinoic acid (RA) signaling causes formation of an excess of cardiomyocytes. The zebrafish mutation neckless (nls) disrupts function of the retinaldehyde dehydrogenase 2 gene (raldh2), which controls a rate-limiting step in RA synthesis (4, 5). nls mutants exhibit an increased number of cells expressing nckx2.5, a marker of the bilateral populations of precardiac mesoderm within the ALPM (Fig. 1A). Although nckx2.5 expression appears expanded in anterior, posterior, and lateral directions (Fig. 1, A and B), we do not observe an increase in the overall size of the ALPM in nls mutants (Fig. S1A). As myocardial differentiation proceeds, nls mutants exhibit a surplus of cardiomyocytes, identifiable by their expression of cardiac myosin light chain 2 (cmlc2) (Fig. 1B; fig. S2). Consistent with a repressive influence of RA on cardiomyocyte formation, exposure to the pan-retinoic acid receptor (RAR) antagonist BMS189453 during gastrulation (75% epiboly) results in a reduced number of cardiac myosin light chain 2 (cmlc2) expression (Fig. 1, A and B).

Supporting Online Material
www.sciencemag.org/cgi/content/full/307/5757/244/DC1
Materials and Methods
25 October 2004; accepted 10 December 2004
10.1126/science.1106717