The Stellar Population And Origin Of The Mysterious High-Latitude Star Forming Cloud CG 12

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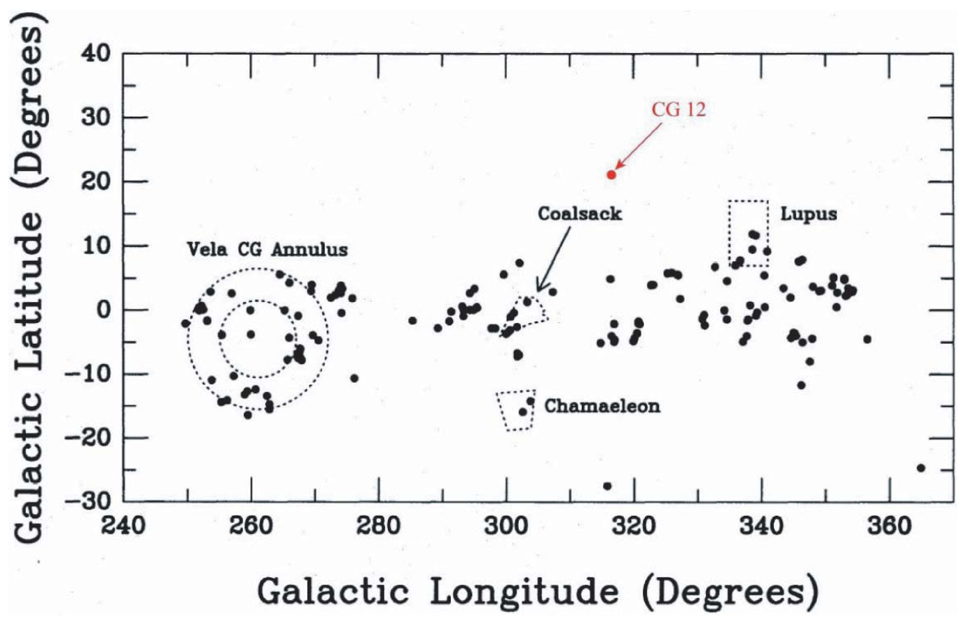
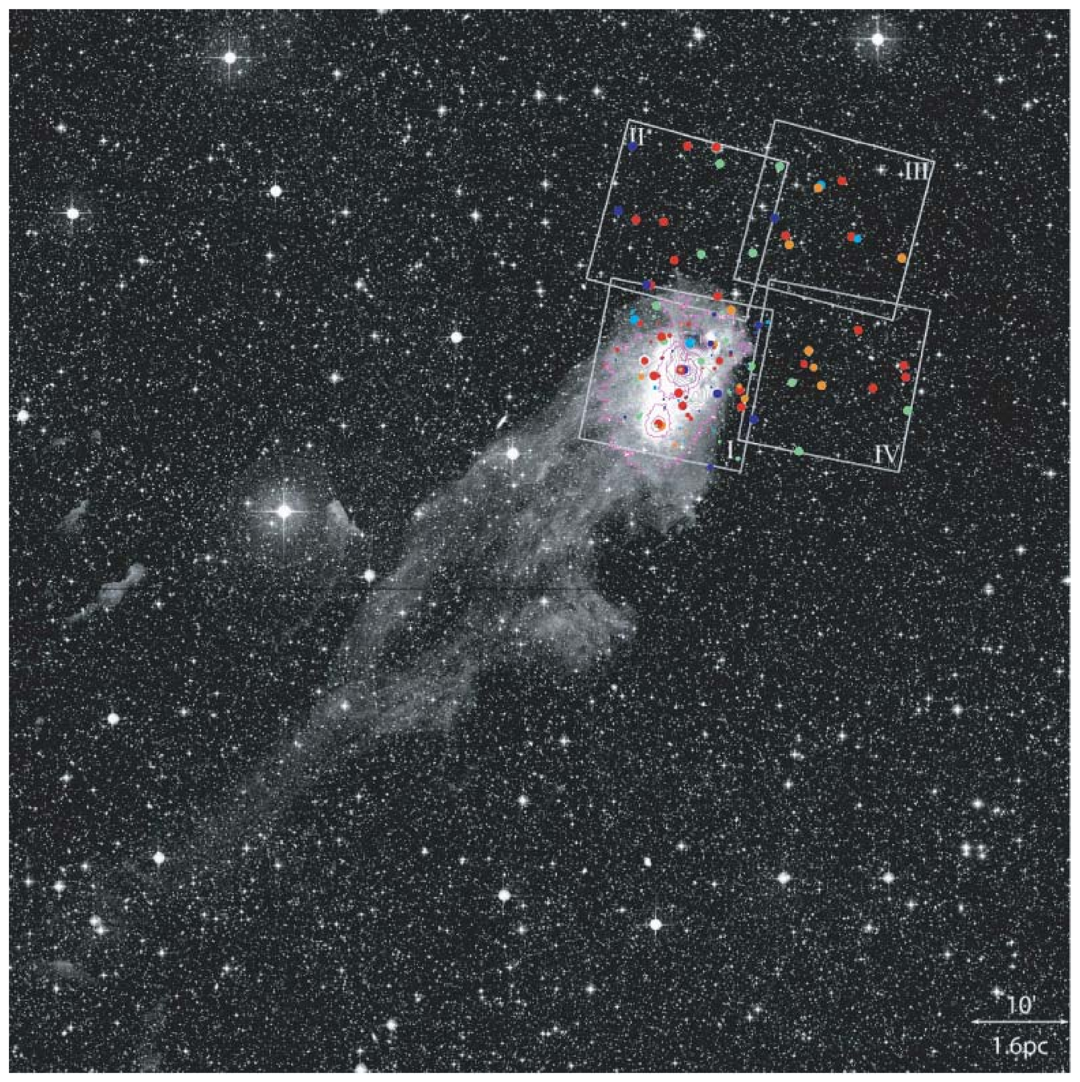
ABSTRACT

The mysterious high galactic latitude cometary globule (CG) CG12 has been observed with the ACIS detector on board the Chandra X-ray Observatory. We detect 128 X-ray sources, of which a half are likely young stars formed within the globule's head. This new population of >=50 T-Tauri stars and one new embedded protostar is far larger than the previously reported few intermediate-mass and two protostellar members of the cloud. Most of the newly discovered stars have masses 0.2-0.7Msun, and 9-15% have K-band excesses from inner protoplanetary disks. X-ray properties provide an independent distance estimate consistent with CG12's unusual location >=200pc above the Galactic plane. The star formation efficiency in CG12 appears to be 15-35%, far above that seen in other triggered molecular globules. The median photometric age found for the T-Tauri population is ~4Myr with a large spread of <1-20Myr and ongoing star formation in the molecular cores. The stellar age and spatial distributions are inconsistent with a simple radiation driven implosion (RDI) model, and suggest either that CG12 is an atypically large shocked globule, or it has been subject to several distinct episodes of triggering and ablation. We report a previously unnoticed group of B-type stars northwest of CG12 which may be the remnants of an OB association which produced multiple supernova explosions that could have shocked and ablated the cloud over a 15-30Myr period. HD120958 (B3e), the most luminous member of the group, may be currently driving an RDI shock into the CG12 cloud.

Aim: Compact cometary globules (CGs), along with other Bok globules, are interpreted as the last vestiges of the molecular cloud that gave birth to OB stars (e.g. Hawarden 1976). CGs are distributed widely across the Milky Way but are rarely found at high latitude. Most lie within giant HII regions such as IC 2944, the Rosette and Carina nebulae, and most prominently in the huge expanding Gum Nebulae surrounding the Vela OB2 association. CGs are modeled as externally illuminated, photoevaporated and ablated into elongated head-tail morphologies by ultraviolet radiation of OB stars (e.g. Reipurth 1983). The figure shows the galactic distribution of Bok globules in southern sky from Bourke et al. (1995). The Vela annulus denotes the Gum Nebula. CG12 (red) is one of the few globules located at high-galactic latitude.

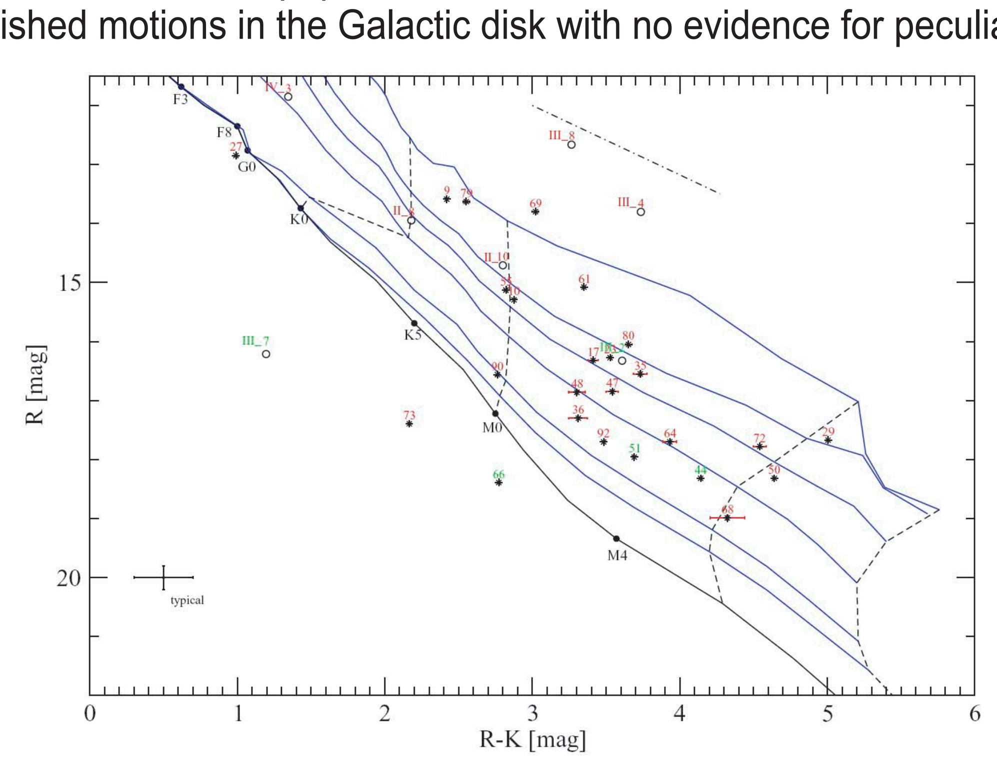


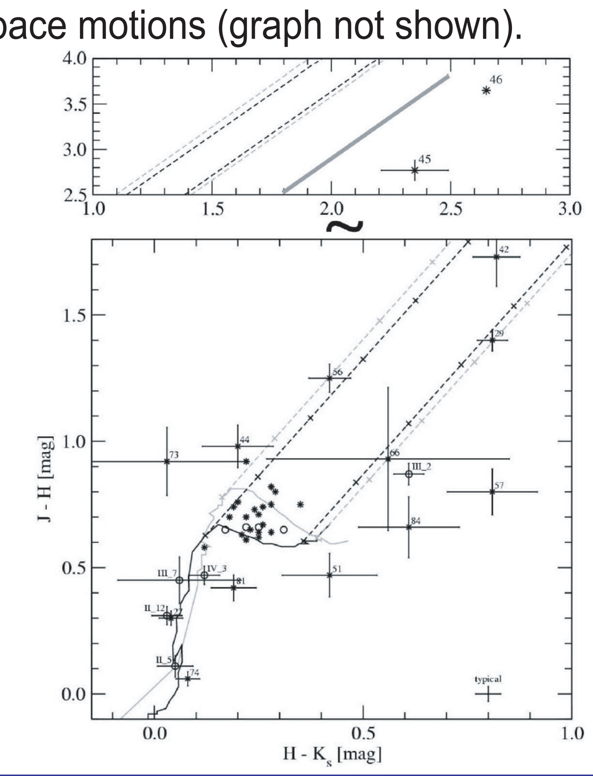
The existence of any star forming dark cloud at Galactic location (l,b)=(316,21) is unusual, and the cometary structure of CG12 in such an isolated environment is even more mysterious. There are no reported luminous OB-type stars at even higher latitudes to produce the head-tail morphology with its tail pointing towards (not away from) the Galactic plane. The aim of this project is to identify poorly known young stellar population of the globule and study its spatial, age, dynamics properties using Chandra X-ray and ancillary ONIR data, and further provide better insights into the origin of CG12.

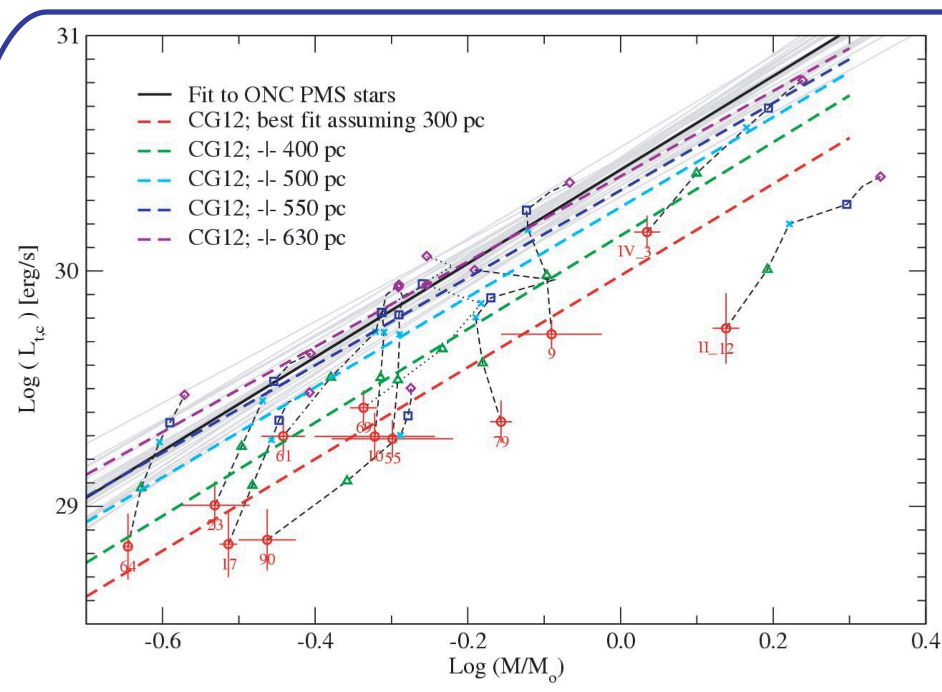


Method: The current project combines four X-ray observations of the globule, one primary field (I in the Figure) with 31 ks exposure directed at the globule's core and three secondary fields (II, III, and IV) with 3 ks exposures positioned contiguously to the north and west of the core. We detected 128 X-ray point sources. Schematic representation of their X-ray source properties in four dimensions (R.A., Decl., median energy, and count rate) is overlayed on the optical DSS image covering 1.8x1.8 square degrees of the CG12 neighborhood. A dark molecular cloud (outlined by grey contours) lies in the head of the globule, and is superposed by three optical reflection nebulae (magenta contours) illuminated by B-type members of the region. Of the 128 X-ray sources we identified a previously unknown population of >50 T-Tauri members (red and some of the green, orange, and cyan circles in Figure). Most are unobscured but some lie inside the cloud. Three protostars embedded in the molecular cloud cores are detected, one of which is newly reported (blue cicles within the molecular cloud contour). We establish that the remaining ~70 X-ray sources (most of blue, and some cyan and green circles) are likely contaminants, mostly extragalactic.
Source X-ray median energy is color-coded as follows, (keV): [0.5-1.4], [1.4-1.6], [1.6-2.0],[2.0-2.5], and [2.5-8.0].

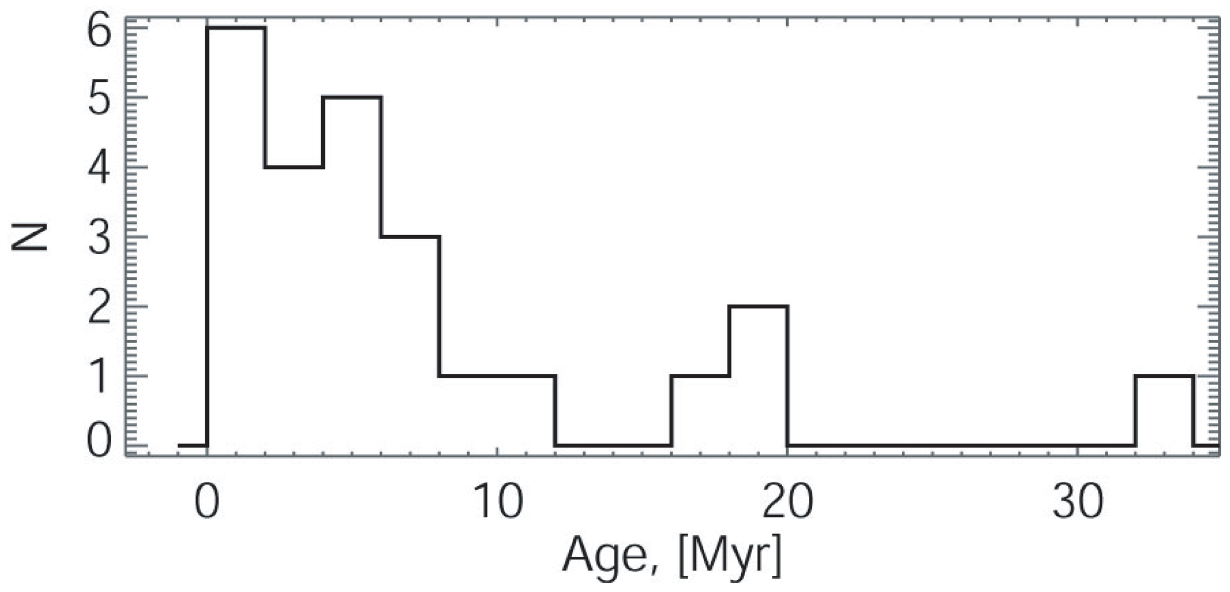
Results: ONIR properties. While accurate classification of the Chandra sources must await our upcoming optical spectroscopic measurements and accepted Spitzer-IRAC observation, the nature of the sources with known ONIR photometry can be estimated from the presented ONIR diagrams. Most are unreddened or lightly obscured (Av < 2 mag), with positions in the color-magnitude diagram consistent with low-mass 0.2-0.7 M_o PMS stars. A wide spread of ages, ranging from <1 to 20 Myr, is seen. Roughly 9-15% of T-Tauri stars possess inner Ks-band disks. Comparing with three other unique sparse clusters we infer that the CG12's disk fraction is lower than that in 0-2 Myr Taurus cloud and higher than that in 17-23 Myr LCC/UCL Sco-Cen subgroups, and roughly similar to that in 8-9 Myr eta Cha cluster.
By comparing the observed proper motions of the CG12 stars to a simulated sample of nearby (<1 kpc) field stars from the Besancon stellar population model we also infer that CG12 stellar motions can be attributed entirely to the established motions in the Galactic disk with no evidence for peculiar space motions (graph not shown).





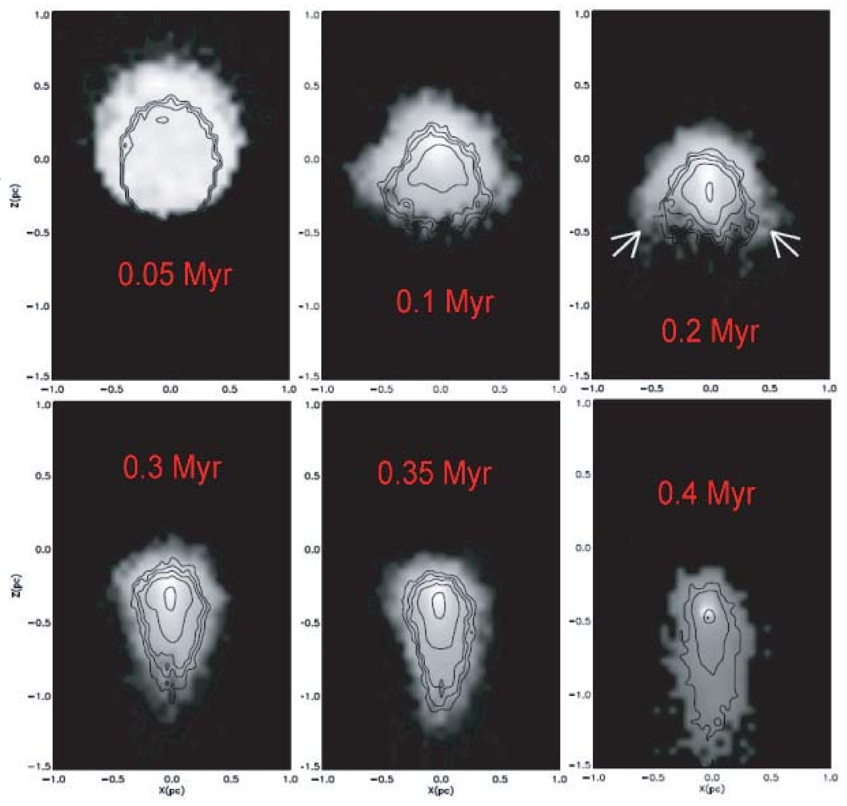


Results: Distance. The distance to CG12 is controversial, with estimates ranging from 100 to 600 pc. Using the known L_X-Mass PMS correlation, we combine X-ray and ONIR properties of the unobscured T-Tauri stars to independently confirm that the distance to CG12 must be >500 pc, and probably in the range 550-630 pc. This strengthens some previous ONIR findings that CG12 is indeed located >200 pc above the Galactic plane, and that its cometary morphology with no signs of nearby hot OB stars is unusual.

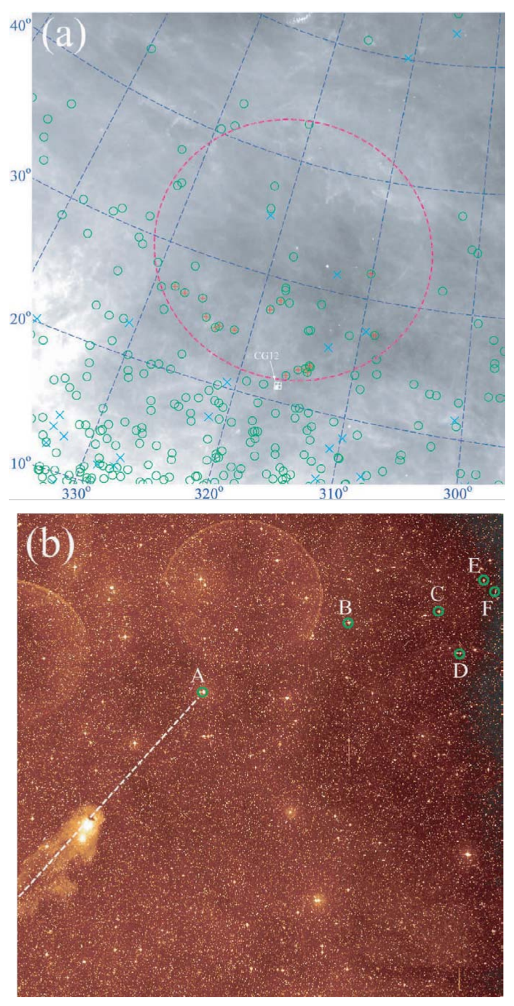


Results: Ages. An evaluation of stellar ages gives a median photometric isochronal age of ~4 Myr with a large spread from <1 Myr to 10-20 Myr. The X-ray properties of three deeply embedded stars confirm the protostellar classification and previous infrared-radio findings of ongoing star formation in the globule's head.

Star Formation Efficiency. Assuming the Galactic field IMF for the unobscured YSO population of CG12, we estimate a total population of ~80 stars associated with CG12 with masses >0.2 Mo. The star formation efficiency of the globule is in the range 15-35%, typical for active star forming regions, but above that seen in smaller molecular globules with star formation triggered by UV shock fronts.



Results: Triggered star formation. Process of radiation-driven implosion (RDI) in molecular globules was originally studied through analytical models for spherical clouds (Bertoldi 1989) and 2-dimensional hydrodynamical calculations (Lefloch & Lazareff 1994, 1995). Recent 3-dimensional calculations of RDI processes in molecular globules, including self-gravity, heating, and cooling, are presented by Kessel-Deynet & Burket (2003) and Miao et al. (2006). The characteristic timescale for producing cometary morphologies and inducing gravitational collapse is 0.1-0.5 Myr (see the Figure).
The broad age spread found in CG12 is inconsistent with the rapid timescale (few 10^5 yr) predicted by simple triggered star formation models of CGs. However, more complex models of shock triggered star formation might explain the age distribution of CG12 stars. Two possibilities can be considered. First, RDI simulations producing only brief durations of star formation modelled only small globules with initial sizes <1 pc typical for known bright rimmed clouds (Sugitani et al. 1991) with volumes much smaller than the initial size of the atypically large CG12 cloud.The RDI shock front may thus take millions of years to propagate through the whole CG12 cloud during which distributed molecular cores could be compressed, triggering localized star formation at different times. Second, unlike triggering by the continuous flux of photoevaporating ultraviolet light from OB stars in HII regions, the triggering of CG12 could arise from a sequence of distinct episodes separated by millions of years. These triggers could be the shocks of distinct supernova from a massive OB association. Astronomical evidence for these scenarios is discussed below.



Results: Keys to the Origin. The best attempted explanation for the origin of CG12 was made 30 years ago by Williams et al. (1977) who suggested that a large expanding high-latitude interstellar shell could have traversed CG12 7-19 Myr ago. Produced by one or more supernova explosions from a still-unidentified association, the encounter would have drawn out the 10 pc-long tail and triggered the star formation in the globule. This explanation suffers a major difficulty: a single supernova explosion (perhaps from a runaway O star ejected from a Galactic Plane cluster) can not be responsible for such a large 20 degree cavity, while a superbubble produced by many supernova remnants requires a rich high-latitude stellar cluster which has not yet been identified.
We searched for intermediate-mass B-type members of the hypothetical high-latitude young stellar cluster using the Henry Draper (HD) Catalogue. While there is no indication of a residual cluster at the center of the ~200 pc diameter IRAS shell (magenta circle in Figure a), we identify a group of B-type stars (red + outlined by green circles in Figure *a* = labelled sources in Figure *b*) northwest of CG12 (white box in Figure *a*) and from the comparison to the ONC we infer that a dozen expected early O-B3 type members are missing. These could be the source of multiple SN explosions triggering star formation in the cloud over an extended period of 15-30 Myr (the lifetime of B1-3 stars gone). The B3e star HD120958 (labelled A in Figure *b*) is the closest and most luminous member of the group, lying 10 pc (projected) from the globule head in the correct orientation to ablate the cloud into its cometary structure. It might itself be the primary ionizing source driving an RDI shock into the CG12 cloud, or might be the relic of a massive binary system that has undergone SN explosion.