INSIGHTS

PERSPECTIVES

Molecular clouds such as the Cone Nebula have dark interiors and UV-irradiated outer regions, each populated by large hydrocarbons with possibly interrelated chemistries.

IMAGE: NASA; H. FORD (JHU); G. ILLINGWORTH (UCSC/LO); M. CLAMPIN (STSCI); G. HARTIG (STSCI); THE ACS SCIENCE TEAM; ESA

ASTROCHEMISTRY

Detecting the building blocks of aromatics

Detection of benzonitrile in an interstellar cloud helps to constrain interstellar chemistry

By **Christine Joblin**[1] *and* **José Cernicharo**[2]

Interstellar clouds are sites of active organic chemistry (*1*). Many small, gas-phase molecules are found in the dark parts of the clouds that are protected from ultraviolet (UV) photons, but these molecules photodissociate in the external layers of the cloud that are exposed to stellar radiation (see the photo). These irradiated regions are populated by large polycyclic aromatic hydrocarbons (PAHs) with characteristic infrared (IR) emission features. These large aromatics are expected to form from benzene (C_6H_6), which is, however, difficult to detect because it does not have a permanent dipole moment and can only be detected via its IR absorption transitions against a strong background source (*2*). On page 202 of this issue, McGuire *et al.* (*3*) report the detection of benzonitrile (c-C_6H_5CN) with radio telescopes. Benzonitrile likely forms in the reaction of CN with benzene; from its observation, it is therefore possible to estimate the abundance of benzene itself.

Chemical models that include molecular formation and destruction processes, both in the gas phase and at the surface of dust grains, can account reasonably well for the observed abundances of a number of molecular species (*4*). The situation is different for large aromatics, for which no individual species have been identified, with the exception of the C_{60} molecule (*5*). Although PAHs are large molecules, they are considered by astronomers as very small dust particles. They are therefore generally thought to form in the dense and hot environments of the envelopes of evolved stars. Chemical models have been developed that are based on chemical networks in flames (*6*). More recently, the possibility to form PAHs at the very low temperatures of molecular clouds has been discussed (*7*) following the demonstration that the reaction CCH + C_4H_6

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leading to benzene (C_6H_6) is barrierless and therefore efficient at low temperature (*8*).

In both hot and cold gas-phase chemistry, benzene derivatives—such as C_6H_4 and C_6H_5—that can lead to further growth toward larger aromatic species are involved. Observations of benzene-type species are therefore crucial for constraining these chemical models.

McGuire *et al.* were able to detect benzonitrile in a cold molecular cloud of the Taurus region thanks to an elegant spectral-stacking procedure (*9*) that increases the chance of detecting molecules with aromatic rings. Among the species that they searched for, only benzonitrile was identified as a promising candidate. The authors confirmed its detection after identification of individual rotational lines, including their hyperfine structure, through detailed spectroscopic work in the laboratory. The presence of a CN side group leads to a substantial dipole moment and thus facilitates detection of benzonitrile. Calculated benzonitrile abundances from a chemical model that includes different gas-phase reactions at low temperature are lower than those observed by a factor of four. The authors suggest that alternative mechanisms involving cosmic-ray radiation-induced chemistry at the surface of grains produce the missing benzonitrile. The mismatch between observations and models shows that, despite the low observed abundance of benzonitrile, its detection remains important in constraining chemical models.

> **“Among the ~200 molecules detected in space, many are organic species.”**

Is there any relation between the detection of the first aromatic ring in dark clouds and the presence of PAHs, the carriers of the mid-IR aromatic emission bands, in the external UV-irradiated regions of the clouds? In addition to the gas-phase chemical reactions mentioned above, these PAHs and related species, such as C_{60}, could be produced through UV processing of dust grains (*10*). Other scenarios have also been proposed. For instance, large hydrocarbons, including PAHs, could be formed by chemical processing on the surface of silicon carbide grains, a mechanism that could be efficient in the envelopes of carbon-rich red giant stars (*11*, *12*).

It remains unclear how many of the PAHs and their precursors are synthesized in the dense and hot envelopes of evolved stars and how many arise from photo- or radiative chemistry in interstellar environments. The detection by McGuire *et al.* of a benzene derivative in a cold molecular cloud indicates that it can form even at very low temperatures and without UV radiation. The authors did not detect larger species with two or three cycles, but the species they selected have lower dipole moments compared to benzonitrile, which reduces the chance for their detection unless they have an anomalously large abundance.

Among the ~200 molecules detected in space, many are organic species. Studying their composition and chemical networks is key for understanding molecular complexity in protoplanetary disks surrounding young stars (*13*). The search for complex molecules has mainly been performed in the millimeter and submillimeter domains. The work of McGuire and collaborators (*3*, *14*) shows the potential of centimeter-wave instruments for chemical complexity studies. This opens avenues for research at the upcoming Square Kilometer Array, which will operate in this spectral range.

Knowledge of astrochemical networks also helps in understanding the nucleation and growth of interstellar dust (including PAHs) and its role in star and planet formation. However, the detection of benzonitrile in the Taurus region is not sufficient to conclude on the possibility to form PAHs in cold molecular clouds. It also remains to be shown whether the detection of benzonitrile indicates that PAHs could contain nitrogen (*15*). More insights into the chemistry of PAHs and related species are expected from combining data from radio and infrared waves with the James Webb Space Telescope, due to launch in 2019. In addition to observations, guidelines from laboratory astrophysics studies are key to progress in this area. These include spectroscopic and kinetic studies but also experimental simulations in reactors in order to provide scenarios that can explain the building of molecular complexity in cosmic conditions. ■

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EVOLUTION

Improbable Big Birds

Darwin’s finches prove a mechanism for the rapid formation of new species

By **Catherine E. Wagner**

Darwin’s finches, a group of 18 species endemic to the Galápagos archipelago, are a classic example of adaptive radiation—the process whereby a single ancestral species multiplies in number to produce divergent species, often in rapid succession (*1*). These birds are evolutionary biologists’ most celebrated example of natural selection in action. On page 224 of this issue, Lamichhaney *et al.* (*2*) have succeeded in observing a process even more elusive than natural selection—the formation of a new species (speciation). Because speciation typically takes place on time scales that are too long for direct human observation, before now it was only in organisms with very fast generation times, such as viruses and bacteria, that scientists had directly observed this process [for example, (*3*)]. Lamichhaney *et al.* show through direct observation and DNA sequencing that new species can form very rapidly: within three generations. The key, in this case, is hybridization between different species.

Lamichhaney *et al.* report that in 1981, a male large cactus finch (*Geospiza conirostris*) arrived on the island of Daphne Major in the Galápagos. It had come from Española, another island more than 100 km away in the archipelago. Rosemary and Peter Grant and their collaborators were there to notice it, band it, and watch what it did. Although there were no other individuals of this species on the island, Lamichhaney *et al.* observed that the bird succeeded in finding a mate—a medium ground finch, *G. fortis*. This pair produced offspring, and, with only one exception, the hybrid lineage has bred only within the lineage, exclusively finding mates that are descended from the original pair, for more than 30 years. Because they have a larger body size than other finch species on Daphne Major, they are known as the Big Birds (see the figure).

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