# INTERSTELLAR MATTER CHEMISTRY AND ITS ROLE IN EARLY-TYPE GALAXY EVOLUTION: A REVIEW

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***Abstract :*** Early-type galaxies (ETGs), including elliptical and lenticular systems, were once considered gas-poor and largely inactive. However, multiwavelength observations now show that many ETGs contain significant interstellar material, including atomic gas, molecular clouds, dust, and complex molecules. This material originates from internal stellar mass loss, cooling of hot X-ray halos, and external accretion through minor mergers or inflow from the intergalactic medium.

The ISM chemistry in ETGs is shaped by the interaction of these sources with hot gas, radiation fields, and feedback from active galactic nuclei and residual star formation. Molecular gas, primarily traced by CO and other species, provides insight into gas origin and processing through its chemical abundances and isotopic ratios. Dust grains enable surface reactions, while energetic radiation influences gas-phase chemistry, producing environments that can differ from those in spiral galaxies. Understanding ISM chemistry in ETGs is essential for constraining their evolutionary history, star formation potential, and gas accretion processes. Future high-resolution observations with ALMA and JWST, together with advanced chemical models, will further clarify the origin and evolution of molecular gas in these systems.

**Key Words:** Early-type galaxies (ETGs), Interstellar Medium (ISM), Chemistry, Galaxy Evolution.

## 1.INTRODUCTION

Early-type galaxies (ETGs), which include elliptical (E) and lenticular (S0) galaxies, were long thought to be old, inactive systems with little gas or dust [1,2]. They were often described as “red and dead” because their stellar populations are dominated by old, red stars, and they were assumed to have exhausted or expelled most of the material required for star formation early in their evolution [3]. This view suggested that ETGs had completed their growth billions of years ago and were no longer forming stars.

However, more recent multi wavelength observations have demonstrated that this picture is incomplete. Surveys of ETGs at radio, infrared, and sub millimeter wavelengths have revealed that many of these galaxies still contain significant reservoirs of gas and dust. Neutral atomic hydrogen (H I) has been detected in a substantial fraction of ETGs [4,5], while observations of carbon monoxide (CO) have revealed the presence of cold molecular gas, the direct fuel for star formation [6,7]. In addition, infrared observations have shown that dust is common in ETGs [8,9], and molecular line studies have detected more complex species typically associated with star-forming environments [10].

These findings indicate that ETGs are not entirely “dead” systems. Instead, they can retain interstellar material through internal processes such as stellar mass loss, or acquire gas externally via minor mergers and accretion from the surrounding environment [7,11]. Although ETGs remain dominated by old stellar populations, the presence of cold gas and dust enables low-level or episodic star formation to occur long after their initial formation epoch [12,13].

## 2. CHARACTERISTICS OF THE ISM IN EARLY-TYPE GALAXIES

### 2.1 ISM Content and Phases

Unlike late-type spiral galaxies, where cold gas phases dominate the interstellar medium (ISM), the ISM in early-type galaxies (ETGs) is often complex and spans a wide range of physical conditions [14]. In massive elliptical galaxies, hot X-ray–emitting gas constitutes a significant fraction of the baryonic mass and is readily detected through X-ray observations [14,15]. At the same time, colder ISM components—including neutral atomic hydrogen (H I), molecular gas ($H_2$), and dust—are also present, particularly in lower-mass ETGs and lenticular (S0) galaxies [5,16].

Large, volume-limited surveys such as the ATLAS³D project have shown that cold gas is not uncommon in nearby ETGs. Approximately 22–25% of local ETGs exhibit detectable molecular gas traced by CO emission [6,7]. The inferred molecular hydrogen masses typically range from $\sim 10^7$ to $10^9$ M☉, and the molecular gas is frequently organized in rotating disk or ring structures, often aligned with the stellar component [6,17].

### 2.2 Origin of the ISM

The interstellar medium (ISM) in early-type galaxies (ETGs) can originate from several distinct processes. A fraction of the cold gas is supplied internally through mass loss from evolved stars, such as red giant branch and asymptotic giant branch (AGB) stars, which continuously return gas and dust to the host galaxy over long timescales [2,18,19]. In addition, the hot, X-ray–emitting halos commonly observed in massive ETGs can, under certain conditions, cool radiatively and condense into colder gas phases [14,20].

External accretion plays a significant role in replenishing the ISM of ETGs. Cold gas can be acquired through minor mergers with gas-rich satellite galaxies or via more gradual accretion from the intergalactic medium (IGM), particularly in low-density, field environments [11,21]. Strong observational support for an external origin of much of the cold gas in ETGs comes from kinematic misalignments between the gaseous and stellar components, indicating that the gas was accreted rather than produced internally [7,22]. The relative contributions of internal recycling, cooling from hot halos, and external accretion directly influence the chemical composition, kinematics, and spatial distribution of the ISM within ETGs.

## 3. MOLECULAR GAS AND BASIC CHEMISTRY

### 3.1 Molecular Gas Detection

Carbon monoxide (CO) remains the primary tracer of molecular gas in early-type galaxies (ETGs) because of its high abundance relative to $H_2$ and its relatively low excitation requirements [23,24]. Large, systematic surveys such as the ATLAS³D CO survey have demonstrated that molecular gas is not uncommon in ETGs: CO emission is detected in approximately 22–25% of a volume-limited sample of nearby ETGs [6,7]. These detections indicate that significant reservoirs of cold molecular gas can persist in galaxies traditionally considered quiescent, supporting the idea that ETGs are capable of sustaining low-level or episodic star formation despite their predominantly old stellar populations.

### 3.2 Chemical Composition of Molecular Gas

The molecular interstellar medium (ISM) in early-type galaxies (ETGs) is chemically diverse. In addition to carbon monoxide (CO), dense gas tracers such as hydrogen cyanide (HCN), formylium ($HCO^+$), and carbon monosulfide (CS) have been detected in a number of ETGs [10, 25, 26]. High-resolution observations with facilities such as ALMA have enabled detailed studies of the distribution, kinematics, and chemistry of these molecular species, revealing that the molecular gas properties in ETGs can closely resemble those found in spiral galaxies, despite typically lower star formation efficiencies and differing dynamical and environmental conditions [10,26,27].

## 4. GAS-PHASE CHEMISTRY IN EARLY-TYPE GALAXIES

Gas-phase chemistry in early-type galaxies (ETGs) is governed by ion–molecule reactions, cosmic-ray ionization, and interactions with X-ray and ultraviolet (UV) radiation fields [28,29]. In massive elliptical galaxies, hot X-ray–emitting halos can permeate molecular clouds, giving rise to X-ray–dominated regions (XDRs), where ionization rates and gas heating are significantly enhanced compared to photon-dominated regions (PDRs) regulated primarily by UV radiation [30,31].

These energetic environments substantially modify chemical reaction pathways and molecular abundances, favoring species such as HCN, CN, and $HCO^+$, and thereby influencing the overall chemical evolution and multiphase structure of the ISM in ETGs [10,32].

## 5. Dust and Surface Chemistry

### 5.1 Dust Content in ETGs

Contrary to early expectations, dust is commonly detected in many early-type galaxies (ETGs) through infrared and submillimeter observations [8,9,33]. The inferred dust masses typically range from $\sim 10^4$ to $10^7$ $M_\odot$, and the dust is often spatially correlated with molecular gas distributions traced by CO emission [6,27,33].

### 5.2 Grain-Surface Chemistry

Dust grains provide catalytic surfaces for chemical reactions that are inefficient or impossible in the gas phase, most notably the formation of molecular hydrogen ($H_2$) and more complex organic molecules [34,35]. In early-type galaxies (ETGs), grain-surface chemistry may be suppressed in regions dominated by hot, X-ray–emitting gas, where dust grains are subject to thermal sputtering and rapid destruction [36,37]. However, in cooler molecular gas disks—particularly those thought to be externally accreted—grain-surface reactions can proceed efficiently under physical conditions similar to those in late-type galaxies [7,9,33].

## 6. Effects of Star Formation and AGN Activity

Even low levels of star formation and the presence of active galactic nuclei (AGN) can significantly influence the chemistry of the ISM. Intense radiation fields, shocks, and enhanced ionization associated with AGN activity can alter molecular abundances [30,31,38]. Observational studies of nearby galaxies have shown elevated HCN/CO and HCN/$HCO^+$ line ratios in AGN-host systems, consistent with the presence of X-ray–dominated regions (XDRs) and shock-driven chemistry [39,40].

Feedback from both AGN and star formation injects mechanical and radiative energy into the ISM, driving turbulence, shocks, and heating that modify the density and temperature structure of the gas [26, 41].

## 7. Conclusions and Future Prospects

The chemistry of the interstellar medium in early-type galaxies results from a complex interplay of internal stellar processes, external accretion, hot gas interactions, and energetic feedback. Future high-resolution and high-sensitivity observations with facilities such as ALMA and JWST, coupled with advanced chemical and physical models, will further clarify the origin and evolution of molecular gas in ETGs. These studies will shed light not only on individual systems but also on broader questions of galaxy formation and long-term evolution.

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