

Galaxies, the Cosmic Web, and Stellar Generations

CHO-006 · Cosmic History and Its Observers

A Chronological Scientific History from the Early Universe to the Present

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Structured abstract

Context. After reionization, galaxies and intergalactic gas evolved within a matter distribution already organised into overdense nodes, filaments, sheets, and voids. The interval from 1.2 billion years after the formal hot-Big-Bang boundary to the oldest dated Solar-System solids contains most of the pre-Solar history of mature cosmic structure.

Question. How did galaxies acquire, transform, and lose gas; how did stellar populations cycle through birth and death; and how did large-scale environment shape the conditions eventually inherited by the Solar System?

Evidence and method. The synthesis combines galaxy redshift surveys, deep imaging and spectroscopy, stellar-population reconstruction, gravitational lensing, gas observations, numerical simulations, and local stellar records. Observations sample light and tracers, while simulations connect them through gravity, hydrodynamics, cooling, star formation, and feedback prescriptions.

Result. Gravitational growth deepened the cosmic web. Galaxies developed through a mixture of gas accretion, in-situ star formation, mergers, stripping, migration, and feedback. The cosmic star-formation-rate density rose to a broad maximum near redshift two and declined thereafter, with systematic uncertainties. Stellar life cycles returned energy and matter to surrounding gas, but CHO-007 separately owns the nucleosynthetic origin of individual elements. Historical stellar-population labels describe overlapping distributions rather than globally synchronous generations.

Conclusion. CHO-006 ends before the Solar-System-forming event. It hands CHO-008 a structured galactic environment and chemically processed interstellar matter without independently freezing the age of the oldest Solar-System solids. Observer status remains N0.

Keywords: galaxy evolution; cosmic web; star formation history; stellar populations; feedback; gas accretion; large-scale structure

1. Chronological orientation

CHO-006 begins at the 1.2 Gyr BOOK seam, after the reionization interval contained by CHO-005. It ends at S07, an EVENT seam defined by the formation distribution of the oldest dated Solar-System solids. The orientation 4.56730 ± 0.00016 Ga ago remains provisional here; CHO-008 owns its source-level verification and the Solar-System-forming event. CHO-006 must not convert that lookback age into a cosmic time more precisely than the cosmological model permits.

This long interval cannot be narrated as one uniform era. A useful order follows interacting processes rather than named ages:

Process	Temporal behaviour	Principal evidence
Web growth	Continuous, scale-dependent	Galaxy clustering, lensing, peculiar velocities, simulations
Galaxy assembly	Diverse paths across mass and environment	Imaging, spectra, gas maps, merger signatures
Cosmic star formation	Broad rise, maximum near $z \sim 2$, later decline	Multi-wavelength luminosity functions and population models
Stellar cycling	Overlapping lifetimes from Myr to longer than the present age	Stellar models, clusters, binaries, remnants
Environmental processing	Depends on halo, group, cluster, and filament history	Gas depletion, morphology, kinematics, population statistics

2. Initial state inherited from CHO-005

CHO-005 passes a substantially ionised intergalactic medium, early galaxies, active star formation, dark-matter haloes, and an expanding cosmic web. It also passes spatial variation: some environments are already highly processed while others remain diffuse or chemically primitive. Reionization affects subsequent gas temperatures and the ability of shallow potential wells to accrete matter, but its chronology is not re-owned here.

Chemical enrichment is also inherited as a fact. CHO-006 may state that composition influences cooling, opacity, stellar structure, and planet-forming potential. It may not explain which stellar or explosive channel made carbon, oxygen, iron, or any other element. That causal ownership belongs exclusively to the CHO-007 overlay.

3. Growth of the cosmic web

Gravitational instability amplifies initial density perturbations. Matter flows away from underdense regions and preferentially into sheets, filaments, and nodes. Haloes form and merge at the nodes and along filaments; galaxies trace this structure with biases that depend on mass, star formation, selection, and epoch. The “cosmic web” is therefore a statistical description of matter organisation, not a rigid scaffold with universally agreed filament boundaries.

Redshift surveys map three-dimensional galaxy positions imperfectly because peculiar velocities distort line-of-sight distances. Weak gravitational lensing traces projected mass but requires shape calibration and redshift distributions. Gas absorption probes selected sightlines. Algorithms identify filaments using density ridges, tidal tensors, velocity shear, topology, or graph constructions, so catalogues need not assign every galaxy to the same environment.

The baryon acoustic feature detected in large galaxy samples supplies a surviving large-scale correlation from the plasma physics of CHO-004 [1]. It is not a preserved material shell. Its measured scale functions as a statistical standard ruler within an expansion model, linking early-universe acoustic physics to later galaxy distributions.

4. Galaxies are histories, not fixed types

A galaxy changes through internal and external processes. Gas can arrive through relatively cool streams, shock-heated atmospheres, recycled outflows, and mergers. Stars form in dense molecular structures with efficiencies regulated across scales. Stellar or accreting-black-hole feedback can heat, accelerate, redistribute, or expel gas. Tidal forces and ram pressure can strip matter. Bars, spiral patterns, clumps, and mergers rearrange angular momentum.

The familiar elliptical, spiral, and irregular categories describe appearance, not a universal evolutionary sequence. A spiral need not become an elliptical simply by aging, and a high-redshift clumpy galaxy is not an unfinished copy of one present-day type. Morphology depends on wavelength, resolution, viewing angle, gas content, dynamics, dust, and environment.

Simulations such as the Millennium calculation demonstrated how a large dark-matter volume could be connected to galaxy populations through semi-analytic prescriptions [2]. Hydrodynamic programmes such as IllustrisTNG later followed gas and feedback more directly [7]. These are numerical experiments conditional on resolution, sub-

grid models, cosmological parameters, and calibration. Agreement with selected statistics is evidence of adequacy for those tests, not a literal replay of every galaxy.

5. How galaxies acquire gas

Gas supply is central because stars cannot continue forming without cold, dense material. Simulations distinguished gas that is heated near a halo's virial temperature from gas that can flow inward without such a strong shock [5]. The relative importance varies with halo mass, redshift, environment, and modelling. The language of “cold mode” and “hot mode” is therefore a classification of thermal histories, not two pipes with immutable boundaries.

Observations infer gas through atomic, molecular, ionised, dust, and absorption tracers, each requiring conversions and sampling different phases. A galaxy can possess a large gas reservoir yet form stars inefficiently, or show low cold-gas content after environmental stripping. Inflows are especially difficult to observe directly; metallicity gradients, kinematics, absorption, and simulations supply indirect constraints.

Gas cycling also crosses the nominal galaxy boundary. Outflows may escape, stall in the circumgalactic medium, mix, cool, and return. Satellites exchange matter with larger haloes. Consequently galaxy evolution is inseparable from the circumgalactic and intergalactic media, even though observational catalogues often draw a convenient aperture.

6. The broad history of cosmic star formation

Surveys at different wavelengths reconstruct the comoving rate at which gas is converted into stars. Ultraviolet light traces relatively unobscured young stars; infrared emission estimates energy absorbed and reradiated by dust; recombination lines and radio indicators provide other routes. Each requires assumptions about stellar populations, dust, active nuclei, initial mass function, and luminosity-to-rate conversion.

Compilations show a broad rise from early epochs to a maximum around redshift two, followed by a decline toward the present [3]. JWST surveys revise the high-redshift end upward relative to many pre-JWST extrapolations: one 2025 multi-field census of 3,751 galaxies finds the reconstructed star-formation-rate density rising by about one dex from $z = 13.5$ to $z = 5.5$ [6]. This does not erase the broad maximum near redshift two, but it makes the earliest slope and normalization less settled. “Cosmic noon” is not an exact date or a simultaneous peak in every environment. Different masses and galaxy populations reach characteristic activity at different times.

The integrated star-formation history must be consistent with the observed stellar-mass density after accounting for mass returned to gas. Such cross-checks constrain calibrations but remain model-dependent. CHO uses the broad shape as a robust synthesis and reserves exact parameterisations for source-specific reporting where the evidence supports that precision.

7. Stellar life cycles as overlapping clocks

A star's principal pathway depends strongly on initial mass, while rotation, multiplicity, mass loss, magnetic fields, and composition modify its evolution [4]. Massive stars consume central fuel rapidly and can end within millions of years. Low-mass stars evolve much more slowly; some born in this article's early interval remain on the main sequence today. Binary interaction can transfer mass, merge stars, strip envelopes, or create outcomes not predicted by isolated-star tracks.

Star formation therefore creates overlapping populations, not a queue of globally replaced generations. Population III, II, and I are historical categories tied broadly to composition and kinematics. They are not universal ordinal stages occurring everywhere at once. Metal-poor and metal-rich stars can coexist; a younger star in a poorly enriched system may contain less heavy material than an older star formed in a rapidly enriched environment.

Stellar deaths return mass, energy, momentum, and radiation to gas. Those outputs influence subsequent cooling and star formation. CHO-006 owns their dynamical role in galaxy evolution. CHO-007 owns the nuclear production routes and abundance origins, preventing the same element history from being duplicated across two articles.

8. Feedback, regulation, and quenching

Without energy and momentum feedback, many models convert gas into stars too rapidly and produce galaxy populations unlike those observed. Young stars ionise and heat gas; winds and supernovae drive turbulence and outflows; accreting black holes radiate and launch winds or jets. These processes act from star-forming-cloud scales to halo scales, and their unresolved implementation is a central conditional element of current hydrodynamic simulations [7].

“Feedback suppresses star formation” is incomplete. Compression can trigger local collapse; ejected material can later recycle; metal-bearing gas can cool efficiently under some conditions; heating can prevent runaway conversion at others. Net effects depend on timing, geometry, density, and halo potential.

Quenching means a substantial decline relative to an explicit star-forming comparison. It does not identify the cause. Gas exhaustion, halted accretion, virial heating, active-nucleus feedback, morphological dynamics, and environmental stripping can contribute [7,8]. A galaxy classified as quiescent can retain gas or resume activity. The metaphor of galactic death should not replace a measured star-formation criterion.

9. Mergers, migration, and environment

Mergers can add stars and gas, perturb morphology, trigger or suppress star formation, feed central black holes, and build diffuse stellar haloes. Yet much stellar mass forms in situ, and smooth gas supply can be more important than visible major mergers. The balance varies across the population.

Within groups and clusters, satellite galaxies encounter tidal forces, high-speed interactions, and hot ambient gas. Ram pressure can remove interstellar gas; starvation can reduce future supply; dynamical friction can bring massive satellites inward. COSMOS-Web analyses extend environment measurements to high redshift and report mass- and epoch-dependent correlations rather than one environmental rule [8]. Environmental correlations do not by themselves reveal causation because galaxy mass and assembly history covary with environment.

The Milky Way’s own pre-Solar assembly is one branch within this wider history. Stellar motions and compositions preserve evidence of in-situ formation, accretion, migration, and mergers. CHO-006 may establish that galactic context but stops before the local molecular-cloud and protoplanetary processes owned by CHO-008.

10. Evidence, dating, and model dependence

Galaxy light is observed at a redshift, then interpreted through a cosmology and stellar-population model. The light can be dominated by short-lived luminous stars even when most mass is older. Dust obscures and reradiates it. Surface-brightness dimming hides extended components. Spectral features constrain age and composition but often suffer degeneracies among age, dust, abundance patterns, and star-formation history.

Stellar ages in nearby galaxies provide a complementary archaeological route. Colour-magnitude diagrams, asteroseismology, nucleocosmochronology, and abundance patterns carry different uncertainties. Simulations connect snapshots through time but depend on unresolved physics. The strongest reconstruction uses these routes jointly while retaining their distinct failure modes.

S07 requires special discipline. The oldest dated Solar-System solids are laboratory objects whose isotopic ages define an event distribution. That evidence belongs to CHO-008. CHO-006 uses S07 only as its upper boundary and does not claim that galaxy evolution stopped there.

11. Observer capacities present

CHO-006 remains N0. Galaxies store physical records in stellar motions, abundances, gas distributions, and light. Stars respond to their environments, but response alone is not evidence of detection or information use by living agents. Complexity, self-gravitation, and feedback do not establish consciousness.

Scientific observers appear much later and reconstruct this interval from photons, meteorites, stellar fossils, and simulations. Their instruments define selection functions and resolutions. The observed galaxy population is thus a filtered sample of the historical population, while the history itself did not require those observers.

12. Contingency, alternatives, and claim classes

No single galaxy was destined to host the Solar System. Galaxy histories depend on initial environment, accretion, mergers, feedback, and stochastic star formation. Many stars formed and died without planets; many galaxies followed trajectories unlike the Milky Way’s. Following the lineage toward Earth is a selection for narrative reconstruction, not a claim of cosmic privilege.

Open issues include the microphysics and net reach of feedback, the coupling between black holes and hosts, the exact gas-accretion balance, the causes and reversibility of quenching, small-scale dark-matter effects, and tensions among inferred stellar masses and star-formation rates.

Class	CHO-006 use
E1 measured	Redshifts, spectra, images, lensing shear, gas and stellar tracers
E2 reconstructed	Stellar masses, rates, histories, environments, ages
E3 model-dependent	Simulated assembly, feedback effects, time conversion
E4 contested	Relative quenching mechanisms and some early-growth pathways
E5 speculative	Untested alternatives not required by the data

13. Boundaries, closing state, and handoff

CHO-006 owns post-reionization structure and galaxy/stellar-population evolution but not element-production channels, the first-source epoch, or Solar-System formation. Continuing cosmic evolution after S07 lies outside the Earth-following chronological spine, although later articles may refer to it where causally necessary.

At the closing seam, the future Solar System’s material exists within a structured galaxy and an interstellar medium shaped by multiple stellar populations and dynamical events. CHO-008 takes over at the dated-solid event distribution to examine cloud collapse, protostellar and disk evolution, and the earliest Solar-System solids. CHO-007 separately explains where the elements came from.

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Disclosure

This document is a scholarly synthesis; it is not primary research and has not been peer reviewed. Juan Segurola is the sole author. He approved the final text and is responsible for its content.