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Report on the ESO workshop

Resolving the Circumgalactic Medium and its Impact on Galaxy Evolution

held in Santa Cruz, Chile, 18–22 November 2024

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The diffuse, multiphase gas surrounding galaxies, known as the circumgalactic medium (CGM), has emerged as a key player in regulating gas accretion, star formation and feedback processes. Recent advances in observational techniques, including absorption-line studies and high-resolution emission mapping using deep integral field spectroscopy, have enabled the CGM to be probed with unprecedented detail across cosmic time. The first international conference in Chile dedicated to the CGM was held in the scenic rural town of Santa Cruz, in the Colchagua Valley. Hosted under the clear southern skies and surrounded by vineyards, the workshop brought together around 80 researchers from 12 countries, uniting observers and theorists to explore the rapidly advancing understanding of the CGM and its pivotal role in galaxy evolution.

Rationale

The circumgalactic medium (CGM) is defined as the diffuse, multiphase interface that extends from the interstellar medium (ISM) out to the virial radius of a galaxy. The CGM can therefore be considered as the ecosystem connecting galactic processes to the surrounding intergalactic medium (IGM). The concept of the CGM is relatively recent. While cosmologically intervening absorption lines, primarily from neutral hydrogen (Gunn & Peterson, 1965), were detected in quasar spectra shortly after quasars themselves were discovered, the association of high-redshift metal lines with galaxies was not firmly established until the 1980s (Bergeron, 1986). The field subsequently experienced rapid growth in the 1990s, fuelled by the advent of the first 8–10-metre-class telescopes and their spectroscopic capabilities, alongside the emergence of detailed cosmological simulations that began offering testable predictions.

These advances quickly revealed that the CGM plays a fundamental role in galaxy evolution. Since then, both the theoretical and observational CGM/IGM communities have grown steadily (Péroux & Howk, 2020; Faucher-Giguère & Oh, 2023). Our workshop Resolving the Circumgalactic Medium and Its Impact on Galaxy Evolution[1] (also known as CGM-Chile 2024) delved into the existing observational and computational challenges, highlighting promising new methodologies for studying diffuse media, particularly in view of the upcoming extremely large telescopes expected by the end of this decade.

Currently, second- and third-generation instrumentation on ground- and space-based observatories facilitates multidimensional access to diffuse and ionised gas, exploiting new background probes such as gravitational arcs and other extended objects, as well as the direct detection of the ISM/CGM interface in emission. At CGM-Chile 2024, special emphasis was placed on understanding the spatial distribution and kinematics of the CGM across a range of scales, from galactic to sub-kiloparsec, even in distant galaxies. These are observational frontiers that were inaccessible just a few years ago. We reviewed the latest results from instruments such as the Multi Unit Spectroscopic Explorer (MUSE) at ESO's Very Large Telescope (VLT), the Keck Cosmic Web Imager (KCWI), the Hubble Space Telescope, and JWST, covering techniques from traditional pencil-beam studies (for example, quasar absorption lines) to newer approaches involving fast radio bursts and extended background sources. We also examined state-of-the-art models, comparing these with the latest observations. By discussing these findings as a community, a central aim of the workshop was to redefine our understanding of the baryonic cycle in galaxies, establish new observational benchmarks, and identify general trends to inform and refine theoretical models of galaxy evolution. By probing the three-dimensional distribution of gas around galaxies, we are now better positioned to assess the respective roles of internal galactic processes and the large-scale cosmic web in shaping how galaxies grow and evolve.

Key topics of the workshop

The specific topics discussed during the workshop included:

- The interplay between diffuse media (CGM and IGM) and the stellar and interstellar components of galaxies across cosmic time. In particular, the role of the CGM in galaxy feedback and gas recycling, with multi-scale simulations illustrating how galactic winds interact with circumgalactic structures;
- The high-redshift CGM, drawing on insights from studies of quasar absorption lines and highlighting the increasing capabilities of JWST and the Atacama Large Millimeter/submillimeter Array (ALMA) to trace the cold and warm gas phases at early epochs;
- Absorption- and emission-line mapping using instruments such as MUSE and KCWI, along with future prospects enabled by the High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph (HARMONI) at ESO's Extremely Large Telescope (ELT);
- Cross-survey synergies, focusing on how large spectroscopic campaigns and cosmological simulations can be used jointly to constrain CGM physics;
- Future opportunities to exploit the VLT, ALMA, and the ELT to resolve the CGM in both emission and absorption at sub-kiloparsec scales.

Highlights

Take-home messages that will stay with us include:

- An overview of current knowledge of the local and low-redshift CGM across the full electromagnetic spectrum (Werk, Burchett, Gupta, Krishnarao, Fleming, Krishnarao, Bogdán, Garza, Mishra, Tuli);
- The importance of high spectral resolution in studying metallicity, gas kinematics and thermal properties (De Cia, Konstantopoulou, Telikova, Velichko), with a focus on probing the spatial structure of the CGM using multiple quasars (Zahedy, Lehner, Cortés-Muñoz, Sullivan);
- A robust theoretical perspective on CGM physics (Fraternalli, Stern, Afuni, Chang), complemented by simulations of the Milky Way's CGM (Schneider)

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Figure 1. Conference photo.

and of high-redshift environments (Ramesh, Rohr, Doughty, Marini). Semi-analytical and empirical modelling based on synthetic spectra (Rubin) and insights into the CGM’s 3D structure using trained neural networks (Anderson);
– A modern view of the CGM-IGM interface, the IGM, and new observational approaches (Khrykyn, Butsky, Johnson, Qu, Martínez-Acosta, Ma, Richter, Méndez-Hernández, Harvey, Gallego, Toptun);
– The kinematic connection between galaxies and their CGM using real (Kacprzak, Ho, DeFelippis, Fernández-Figueroa) and simulated (Ticoras, Tan) quasar sightlines;
– Cold gas reservoirs at high redshift, both theoretically and observationally (Krogager, Noterdaeme, Oyarzún, Solimano, López-González);
– Approaching the epoch of reionisation with new JWST observations of the high-redshift CGM (Bordoloi, Christensen);
– The spatial and kinematic structure of the CGM, both in emission (Nielsen, Urrutia, Pharo, Smirnov, Fleming, Pessa, Salas Olave) and in absorption, using gravitational arcs as extended background probes (Tejos, Barone, Berg, Hernández, Urbina, Anshul, Muñoz, Zamora, Lopez);
– The enduring mysteries of the quasar CGM (Cantalupo, Brazzini, Cuellar, Liu).

Workshop format, demographics and community building

The workshop was designed to foster collaboration and interdisciplinary dialogue. The format encouraged discussion, with ample time for questions, especially from students. Several working groups were established during the week to pursue follow-up initiatives, including joint observing campaigns and the development of community tools for comparing simulations with multi-wavelength observations.

Following the philosophy of a small workshop that encourages scientific interaction, the scientific organising committee (SOC) designed a programme comprising 71 talks (representing 90% of the attendees), divided into 33 invited and 38 contributed presentations. CGM-Chile 2024 brought together researchers from 12 countries across four continents (Figure 1).

The scientific programme reflected a strong commitment to diversity, not only in terms of gender and nationality but also generational representation. Of the 78 participants, 31 (~40%) were graduate students, six of whom delivered invited talks. Gender balance was given particular attention. The SOC was composed of five female and four male astronomers. Among the invited speakers, the gender ratio was 42%/58%, while among all participants the ratio was 43%/57%. Notably, among early-career researchers women outnumbered men (55% to 45%).

Thus, the organisers designed CGM-Chile 2024 as a welcoming and inspiring environment for scientific exchange. In addition to coffee breaks, those essential moments of informal discussion, the schedule included ample time for daily working sessions. The atmosphere was further elevated by generous Chilean hospitality, with lunches featuring local cuisine and wines, and a mid-week banquet, the traditional Chilean *asado* hosted at a vineyard. The week concluded with unforgettable evening jam sessions, brought to life by a group of talented and enthusiastic musician-scientists.

Conclusions and outlook

CGM-Chile 2024 was the first conference dedicated to the CGM held in Chile, underscoring the region's strategic importance as host to many of the world's most powerful astronomical facilities. The workshop marked a key milestone in CGM research, cementing its status as a cutting-edge topic in galaxy evolution. By bridging theoretical predictions with observations across a broad range of redshifts and tracers, participants helped lay the foundations for a new era of spatially resolved CGM studies.

Perhaps it is no coincidence that CGM-Chile 2024 took place exactly 30 years after the first ESO workshop on Quasar Absorption Lines, held at ESO in Garching from 21 to 24 November 1994. That meeting anticipated the advent of the VLT. Today, we find ourselves on the threshold of a new observational revolution with the ELT, and the community now looks forward to the breakthroughs it will bring in unveiling the diffuse gas structures that shape our Universe.

Acknowledgements

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Links

[1] Workshop website: https://www.eso.org/sci/meetings/2024/CGMChile.html
[2] ARCTOMO collaboration: https://sites.google.com/view/arctomo/home

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Two large, pale discs can be seen in this picture: one of them in the Atacama Desert, the other orbiting the Earth 384 000 km away.