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Coronal Cooling: Rain, Prominences, and Eruptions – Editorial

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1. Introduction

The Topical Collection "Coronal Cooling: Rain, Prominences, and Eruptions" was developed in association with the Coronal Cooling Conference held in Leuven, Belgium, on 21 – 24 May 2024, and advances associated with the legacy of the European Research Council (ERC) PROMINENT project. Both of which brought together observers, theorists, and numerical modelers to discuss and develop understanding of the formation, evolution, diagnosis, and eruption of cool plasma in the corona. The collection is not a conference proceedings volume. All contributions underwent the regular journal peer-review process and relevant submissions from researchers who did not attend the meeting were also welcomed. The collection comprises eleven research and review papers published in *Solar Physics* and *Living Reviews in Solar Physics*. Together, they address the fundamental instabilities and being responsible for rapid cooling, the numerical formation and evolution of multiphase plasma, non-LTE radiative transfer, observational diagnostics, the magnetic structure of filaments, prominence corona interface instabilities, and the role of prominence plasma in eruptions.

The solar corona is commonly discussed in the context of the coronal heating problem. Yet, understanding how the coronal plasma cools is equally fundamental. Cool and dense material at chromospheric and transition region temperatures is frequently observed embedded within the million degree corona, most prominently in the form of coronal rain, prominences, and filaments. These structures show that the solar corona is multiphase and that its thermal evolution cannot be separated from the magnetic field, plasma dynamics, radiative processes, and the exchange of mass and energy with the lower solar atmosphere. Coronal rain and prominences have traditionally been studied as distinct phenomena. However, advances in observations and numerical modeling increasingly indicate that they are closely related manifestations of coronal condensation. Their different appearances and lifetimes are determined not only by the thermodynamic processes leading to condensation formation, but also by the magnetic topology in which cool plasma forms. Condensations may drain rapidly along coronal loops as rain, remain suspended in magnetic dips as prominences, interact with surrounding coronal plasma through fluid and magnetic instabilities, or participate in large-scale eruptions and coronal mass ejections.

2. Topical Collection Summary

Waters and Stricklan (2025) revisit the fundamental physics of radiative cooling of optically thin plasma. They identify a catastrophic cooling mode that is distinct from the classical thermal instability and is governed by the isochoric instability criterion. Since this mode cannot be stabilized by thermal conduction, it may lead to condensation formation under conditions in which conventional thermal instability arguments would predict stabilization. Their results broaden the theoretical framework within which rapid cooling and the formation of cool material in hot, low density plasmas should be interpreted.

A comprehensive theoretical and numerical perspective is provided by Keppens, Zhou, and Xia (2025). Their review presents prominences and coronal rain

within a unified framework of multiphase coronal plasma, emphasizing their common connection to radiative losses, coronal heating, and thermal instability. The authors discuss how gravity, flows, heating prescriptions, and magnetic topology influence both the linear development of instabilities and their nonlinear magnetohydrodynamic evolution. They also identify prominence fine structure, internal dynamics, and the complete prominence life-cycle as major challenges for future numerical studies.

Liakh and Jenkins (2025) complement this broad perspective with a detailed review of prominence and coronal rain modeling performed with the open source Message Passing Interface - Adaptive Mesh Refinement Versatile Advection Code (MPI-ARMVAC). The paper traces the development from simplified models to multidimensional simulations capable of self consistently producing cool coronal condensations. It highlights the role of the magnetic topology in determining whether condensed material is suspended or drains toward the lower atmosphere, as well as the increasing use of synthetic emission and spectral diagnostics to connect simulations with observations. The authors outline a path toward three-dimensional models that incorporate partial ionization, realistic radiative transfer, and the full mass cycle between the chromosphere and corona.

The treatment of radiation is particularly important once the plasma cools sufficiently to become optically thick. Heinzel et al. (2025) show the limitations of using optically thin radiative loss functions for cool and dense coronal condensations. Through non-LTE radiative transfer calculations, they show that realistic net radiative rates include both radiative losses and gains caused by the absorption of incident radiation. Their models examine the relaxation of condensations toward radiative equilibrium and estimate the associated timescales as functions of plasma pressure and geometrical thickness. The study therefore provides an important basis for incorporating more realistic radiative cooling and heating rates into future multidimensional magnetohydrodynamic (MHD) simulations.

In a complementary review, Heinzel and Gunár (2025) examine five decades of non-local thermodynamic equilibrium (non-LTE) prominence radiative-transfer modeling, with particular attention to the coupling between model geometry and the incident radiation field. They follow the progression from one-dimensional slab models to two-dimensional and emerging three-dimensional approaches, including heterogeneous and multi-thread structures. The review emphasizes the importance of realistic forward spectral synthesis for the interpretation and inversion of prominence observations. It also considers rapidly moving eruptive prominences observed with modern instrumentation, demonstrating the growing need to couple dynamic MHD models with multidimensional radiative transfer.

Accurate temperature diagnostics are equally essential on the observational side. Antolin et al. (2026) extend the Response Fitting method to separate cool, warm, and hot contributions within several Solar Dynamics Observatory/Atmospheric Imaging Assembly (SDO/AIA) and Interface Region Imaging Spectrograph (IRIS) slit-jaw passbands. The method improves the decomposition of the AIA 94 Å and 304 Å channels and enables the hot Fe XXI flare emission contained within the IRIS 1330 Å and 1400 Å passbands to be estimated. Applied to a joint AIA–IRIS observation, the technique provides a more coherent view of the

heating and subsequent cooling of the flare plasma and reveals an approximately seven-fold increase in cool plasma associated with flare-driven coronal rain. Its computational efficiency also offers the prospect of near-real-time thermal diagnostics.

The influence of flares on apparently quiescent cooling structures is investigated by Şahin and Antolin (2025). Using IRIS and SDO/AIA observations of coronal-rain showers neighboring a C7.5 flare, they compare the amount, intensity, and velocity of rain during the pre-flare, impulsive, and gradual phases. The number of detected rain events increases by approximately 27% from the pre-flare to the impulsive phase, while the average intensity and downflow velocity increase by approximately 17% and 18%, respectively, by the gradual phase. These findings suggest that a flare may alter the thermodynamic conditions of neighboring, non-flaring loops and illustrate that the distinction between quiescent and flare-driven coronal rain is not always clear-cut.

Froment and Masson (2026) extend the study of thermal non-equilibrium beyond conventional closed coronal loops. They report long-period EUV pulsations and recurring coronal-rain showers in a non-eruptive pseudo-streamer observed over approximately 2.5 days with SDO/AIA. The ordering of the EUV emission peaks and the occurrence of rain near the end of the cooling cycles provide strong evidence for thermal non-equilibrium. Their magnetic-topology analysis indicates that these cycles occur both below the pseudo-streamer dome and in regions dominated by open or large-scale magnetic fields. Continuous interchange reconnection accompanies the evolution, suggesting that the interaction between reconnection and thermal non-equilibrium may influence the release and transport of condensations near open–closed magnetic boundaries and may have implications for the solar wind.

The connection between cool plasma morphology and the coronal magnetic field is considered by Chen (2025). This review introduces "solar filament physiognomy" as an approach for inferring magnetic properties from the appearance and fine structure of filaments in imaging observations. Since direct measurements of the coronal magnetic field remain difficult, morphological information can provide valuable complementary constraints on magnetic configuration and related quantities. The increasing spatial resolution of present and future solar telescopes is expected to make this approach particularly useful as progressively finer structures within filament channels become observable.

Cool condensations also modify their surroundings and may introduce additional sources of instability. Melis and Soler (2025) investigate the Kelvin–Helmholtz instability at an interface between partially ionized prominence plasma and the fully ionized corona. Their linear analysis includes compressibility, gas pressure, and ambipolar diffusion. The results show that compressibility and acoustic effects are important for producing unstable regimes at flow speeds consistent with prominence observations. Ambipolar diffusion generally has a destabilizing effect, reducing the threshold velocity and broadening the unstable parameter range. This work highlights the importance of partial ionization in the dynamics and small-scale structuring of prominence–corona interfaces.

Finally, Fan (2025) reviews MHD simulations of prominence-forming coronal flux ropes and their subsequent eruption as coronal mass ejections. These simulations reproduce several observed components of prominence–cavity systems,

including prominence horns and the central cavity enclosed by them. They also demonstrate that prominence material is not merely a passive tracer of the magnetic field: its weight modifies the equilibrium, stability, and eruptive evolution of the hosting flux rope. The thermodynamic formation of cool plasma and the magnetic mechanisms responsible for eruption must therefore be considered as coupled parts of the same physical system.

3. Conclusion

Taken together, the contributions to this collection demonstrate that coronal rain, prominences, and their eruptive counterparts form a connected family of phenomena governed by the competition between heating, thermal conduction, radiative losses, gravity, flows, and magnetic forces. Their observable properties depend on magnetic topology, partial ionization, optical thickness, and the interaction of condensations with their surrounding plasma. The collection also illustrates how progress increasingly depends on the close integration of theory, numerical modeling, forward synthesis, and high-resolution multi-wavelength observations.

Several common priorities emerge. Future models must move toward fully three-dimensional treatments that couple MHD with non-LTE radiative transfer, non-equilibrium ionization, and multi-fluid effects. Synthetic observables will be essential for meaningful comparisons between these simulations and the rapidly improving observations from facilities such as the Daniel K. Inouye Solar Telescope (DKIST), Solar Orbiter, and Proba-3. At the same time, improved methods for separating multi-temperature emission and inferring coronal magnetic structure will enable observations to place stronger constraints on the formation and evolution of cool plasma. Finally, following condensations continuously—from their thermodynamic formation and interaction with the magnetic environment to their drainage, suspension, or eruption—will be crucial for establishing a comprehensive picture of the coronal mass and energy cycle.

Topical Collection Articles

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- Chen, P.F.: 2025, Solar Filament Physiognomy: Inferring Magnetic Quantities from Imaging Observations. *Sol. Phys.* **300**, 172. DOI
- Şahin, S., Antolin, P.: 2025, Do Flares Impact Neighboring Quiescent Coronal Rain? *Sol. Phys.* **300**, 158. DOI
- Fan, Y.: 2025, MHD Simulations of CME with Associated Prominence Eruption. *Sol. Phys.* 300, 129. DOI
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- Waters, T., Stricklan, A.: 2025, Catastrophic Cooling Instability in Optically Thin Plasmas. *Sol. Phys.* **300**, 5. DOI

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Declarations

Conflict of interest The authors declare no competing interests.