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Analysing CME observations and simulations with multi-spacecraft techniques

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Coronal mass ejections (CMEs) are humongous structures that permeate the heliosphere as they travel away from the Sun. Beginning their journey from a more-or-less localised region in the solar atmosphere, they expand to many times the size of the Sun through the corona, measure about 0.3 au in radial extent by the time they reach 1 au, and interact with the structured solar wind and other transients to form so-called merged interaction regions in the outer heliosphere. One of the most prominent challenges in heliophysics is the achievement of a complete understanding of the intrinsic structure and evolution of CMEs, in particular of their spatiotemporal variability, which in turn would allow more precise forecasts of their arrival time and space weather effects throughout the heliosphere. The most common methods to detect and analyse these behemoths of the solar system consist of remote-sensing observations, i.e. 2D images at various wavelengths, and in-situ measurements, i.e. 1D spacecraft trajectories through the structure. These data, however, are often insufficient to provide a comprehensive picture of a given event, due to the scarcity of available measurement points and the enormous scales involved. Some ways to circumvent these issues consist of taking advantage of multi-spacecraft observations of the same CME (usually at different heliolongitudes and/or radial distances) and to use simulations to complement the available measurements and/or to investigate the 3D structure of CMEs without constraints on the number of synthetic observers.

In this presentation, we will first provide a review of the advantages of multi-spacecraft observations of CMEs and how they have helped us build the overall picture of CME structure and evolution that forms our current understanding. We will then showcase examples of detailed CME studies, both in the observational and modelling regimes, that have been made possible due to the availability of multi-point measurements. These will include events observed remotely and/or in situ by the latest generation of heliophysics missions, i.e. Parker Solar Probe and Solar Orbiter. Finally, we will speculate on possible future avenues that are worthy of exploring to reach a deeper understanding of CMEs from their eruption throughout their heliospheric journey, especially in terms of novel space missions that may improve not only our knowledge from a fundamental physics standpoint, but also our prediction and forecasting capabilities.