A Strategy for a Coherent and Comprehensive Basis for Understanding the Middle Corona

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The middle corona, between 1.5 and 5 $R_\odot$ (Figure 1), encompasses almost all of the influential physical transitions and processes that govern the behavior of coronal outflow. Importantly, it also modulates *inflow* from above that can drive dynamic changes at low heights. Correspondingly, this region is essential for understanding and developing global models of the corona, the heliosphere, and the eruptions that propagate through them. Nonetheless, because it is challenging to observe, the middle corona has been largely overlooked by major solar remote sensing missions and instruments going back to the SOHO era[1]. Here, we discuss the need for strategic planning for continuous, coherent, and comprehensive observations of the middle corona and outline a plan to achieve such observations in the coming decades.

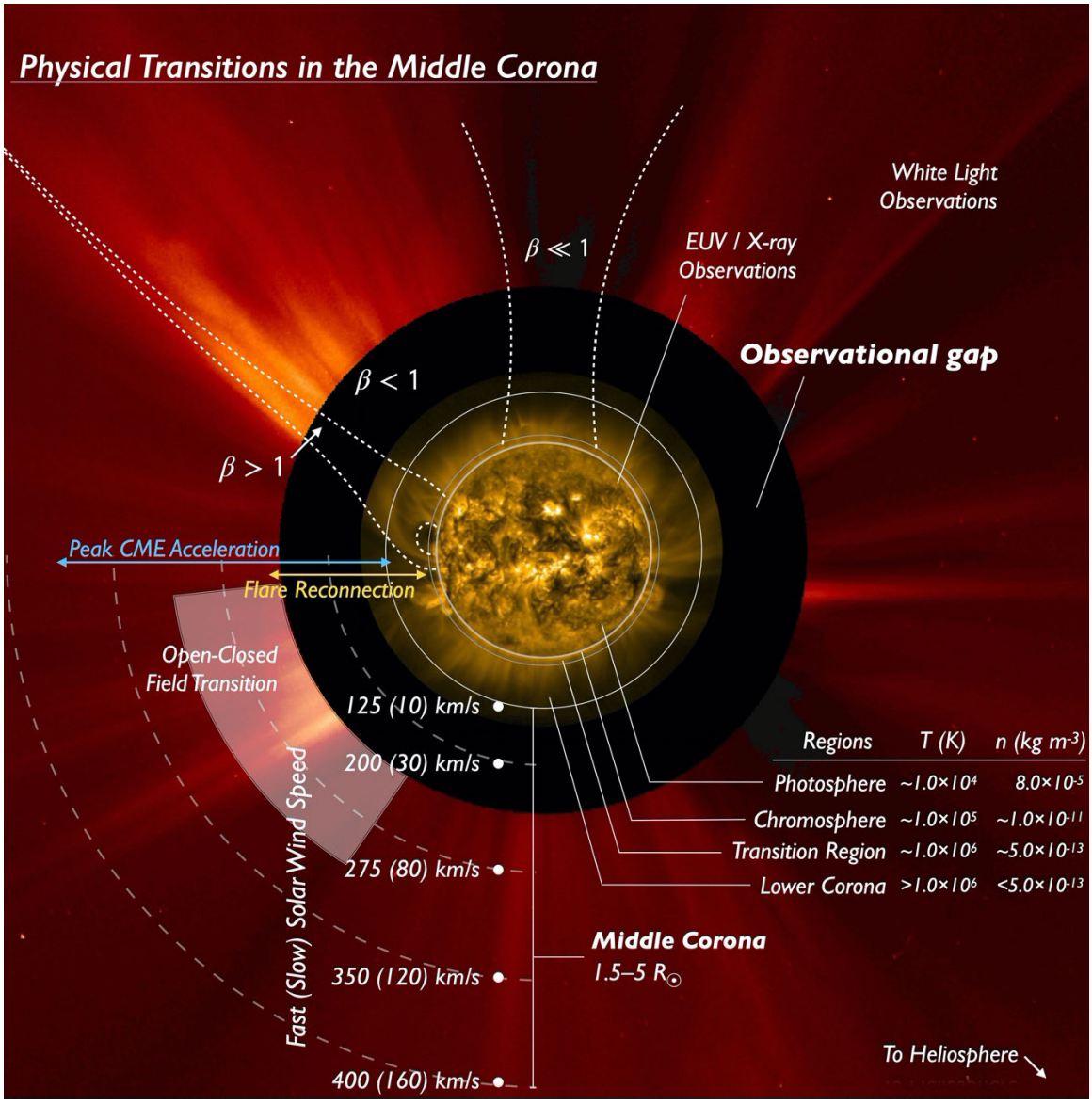

Figure 1. Overview of middle coronal physical transitions and phenomena and relationships to the rest of the Sun.

[1] See discussions in Golub+ 2020 *JSWSC*, West+ 2020 *JSWSC* (in press), Mason+ 2020 *JSWSC* (submitted), Cranmer 2009 *Living Rev. Sol. Phys.*, Bein+ 2011 *ApJ*, Vasquez+ 2003 *ApJ*, Forbes+ 2018 *ApJ*, Yu+ 2020 *ApJ*

The existing community-wide approach to coronal observations has generally prioritized the most straightforward synoptic observations—extreme ultraviolet (EUV) imaging of the inner corona and white-light (WL) coronagraph imaging of the outer corona and heliosphere—alongside targeted observations at these and other wavelengths from Explorer-class missions to address focused science topics. Facilities used for space weather operations can also provide rich datasets useful for studies of the middle corona, but existing operations-to-research pathways limit their application for fundamental science. The result is a highly compartmentalized observational environment. The data are rich, but the fragmentation and specialization of available datasets has led to studies that tend to treat the corona and heliosphere as multiple, disconnected systems with interfaces only at specific boundaries, instead of a single coherent and highly interconnected system. Significant progress[2] in answering important questions of coronal physics requires coordinated observations spanning the entire solar atmosphere, with particular emphasis on the multiple transitions that occur in the middle corona. Understanding this region is the key to unifying heliophysical systems by reconciling seemingly disparate regions, but this unification requires fully coherent and connected observations that fill this critical observation gap.

Figure 2 highlights existing and near-term coverage and gaps in observations of key physical parameters in the corona. A coordinated strategy for 2050 will yield observations that provide continuous and overlapping coverage of the whole corona for global models and studies, while still supporting narrower, focused research questions and space weather operations.

Because understanding the corona requires developing accurate, observationally validated models of the global magnetic field, obtaining 360°/4π views of the photospheric magnetic field is a critical need. Multi-perspective observations are also required to determine the three-dimensional structure of the complex middle corona interfaces. To achieve this, it is especially important to prioritize development of miniaturized instrumentation for multi-platform, deep space constellations, given the strict constraints of such missions. The community should expedite such development efforts via, e.g., expanded opportunities within NASA's CubeSat and LCAS programs. In addition to dedicated heliospheric missions, a 360° solar view could be achieved by including solar instrumentation via rideshare on planetary orbiter missions to Mercury and Venus, leveraging shared spacecraft resources to reduce the overall cost of meeting this goal.

Extending EUV and X-ray observations outward and coronagraphy inward will fill the gap. However, spatial, spectral and temporal overlap is required to reconcile features across differing observational regimes. In fact, the middle corona can already be observed with existing technology, and some of the observational shortfall could be eliminated at low risk and cost. More comprehensive studies require not just observing structure, but measuring velocity, temperature, coronal magnetic and electric fields, and building links to global coronal models, across multiple regimes. New instruments and techniques, including the Hanle effect, doppler measurements, and polarimetry can yield much more robust measurements throughout the corona.

Trade studies are needed to prioritize limited resources in a coherent observing framework, balancing cost, risk, and criticality of observed physical parameters across the wide range of conditions in the middle corona. Some measurements can be made with distributed ground-based instrument networks, and some with miniaturized space-borne instruments, while others require significantly larger space-based investments. 360°/4π—including out-of-ecliptic—observations should prioritize measurements that cannot be made from the Earth or ecliptic perspective, or that facilitate significant research or space weather forecasting progress using additional vantage points. A development cycle for new and ambitious instrumentation must begin now to achieve closure within the next three decades.

[2] See also WP submissions by Alzate+, Caspi+, Gibson+, Mason+, Newmark+, Viall+, Vourlidas+, Woods+

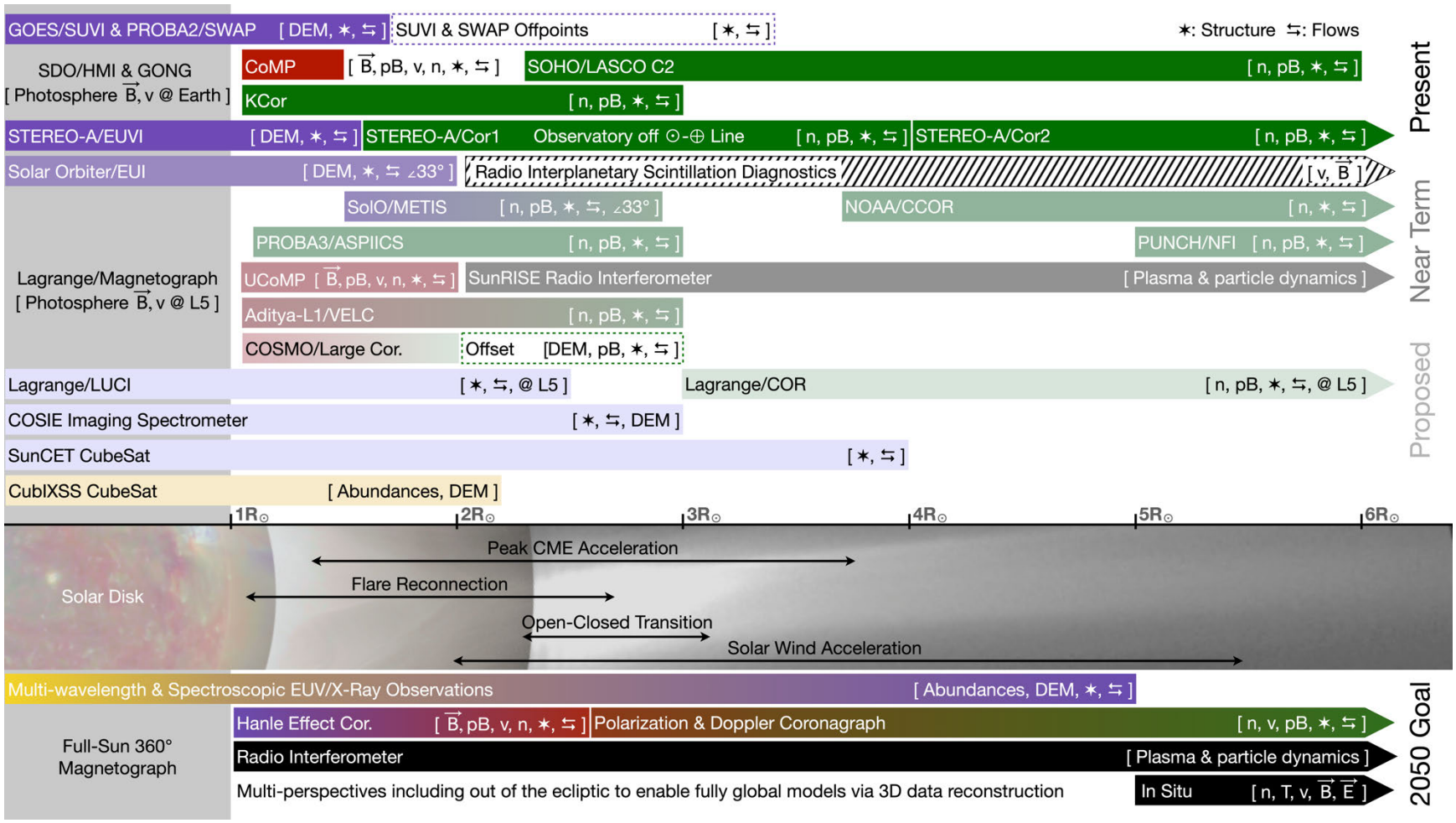

Figure 2. ***Above:*** *Existing, planned, and proposed middle corona instruments and observation goals for 2050, including physical parameters measured and observing regime (**Black**: radio, **Red:** infrared, **Green:** WL, **Violet:** UV/EUV, **Gold:** X-ray; Color saturation indicates instrument maturity, from existing to propose). Current and planned missions expand coverage, but do not yield coherent, completely gap-free observations.* ***Right:*** *Our 2050 target is 360° solar coverage, including out of ecliptic, with broad-spectrum, overlapping observations from the Sun's surface to the outer corona.*