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A new view of solar coronal mass ejections with the Heliophysics System Observatory (Arne Richter Award for Outstanding Young Scientists Lecture)

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Solar coronal mass ejections (CMEs) play a pivotal role in solar, heliospheric and planetary physics because they lead to connections of plasma phenomena from the Sun to the planets throughout the solar system. CMEs drive the strongest geomagnetic storms, fill the heliosphere with energetic particles, illuminate planetary skies with aurorae, modulate cosmic rays on planetary surfaces, and lead to erosion of planetary atmospheres over long time scales. Thus, even for studying the detection of life on exoplanets, the role of possible stellar CMEs should not be neglected. However, besides the simple fascination of studying the biggest explosions in the solar system, they are of increasingly high practical significance concerning risk mitigation of natural desasters and the protection of our common wealth. As the impact of a "super-CME", a rare but possible event, may affect the entire planet Earth, coordinated international efforts for their fundamental understanding, as well as building dedicated space weather missions for daily forecasts is necessary. There is a chance of a CME on the order of a Carrington event, with a minimum Dst of about -1000 nT, impacting Earth once every 100 years - or a 10% chance in a given solar cycle. An impact of such a super-CME is expected to cause e.g. wide-spread electricity blackouts and satellite failures.

In the last 10 years, the field has made major advantages in understanding how CMEs evolve from the Sun to the planets. Because of the extension of CMEs on the order of 60-100 degree heliospheric longitude and radial sizes around 0.1-0.2 AU, multipoint imaging and in situ observations are inevitably necessary to understand basic CME physics. To this end, I will show data, as provided by the Heliophysics System Observatory (HSO), and their interpretation with various modeling effors. The HSO can be understood as a web of sensors placed throughout the heliosphere, consisting of spacecraft such as STEREO, Wind, ACE, Venus Express and MESSENGER. They provide, mainly with their magnetometers, multipoint in situ observations of CMEs. The STEREO mission plays a key role, as it has provided for the first time data of heliospheric imagers far away from the Sun-Earth line. This data set now covers almost a full solar cycle, bridging the observational gap between the Sun and the terrestrial planets. This means that we are now entering a new era where big catalogues of solar and heliospheric events are routinely available.

I further focus on unsolved problems in the field, such as finding connections between coronagraph, heliospheric imaging and in situ CME detections, and understanding the global shape of the CME shock and magnetic flux rope. The biggest problem concerns the prediction of the CME core magnetic field, and in particular its Bz profile, which is the main reason why space weather prediction is still quite inaccurate. Finally, the upcoming missions Solar Orbiter and Solar Probe Plus are bound to disruptively transform the field in the upcoming years with out-of-ecliptic heliospheric imaging and in situ observations of the Sun's corona.