Modeling of energetic neutral atoms to study solar flares and coronal mass ejections

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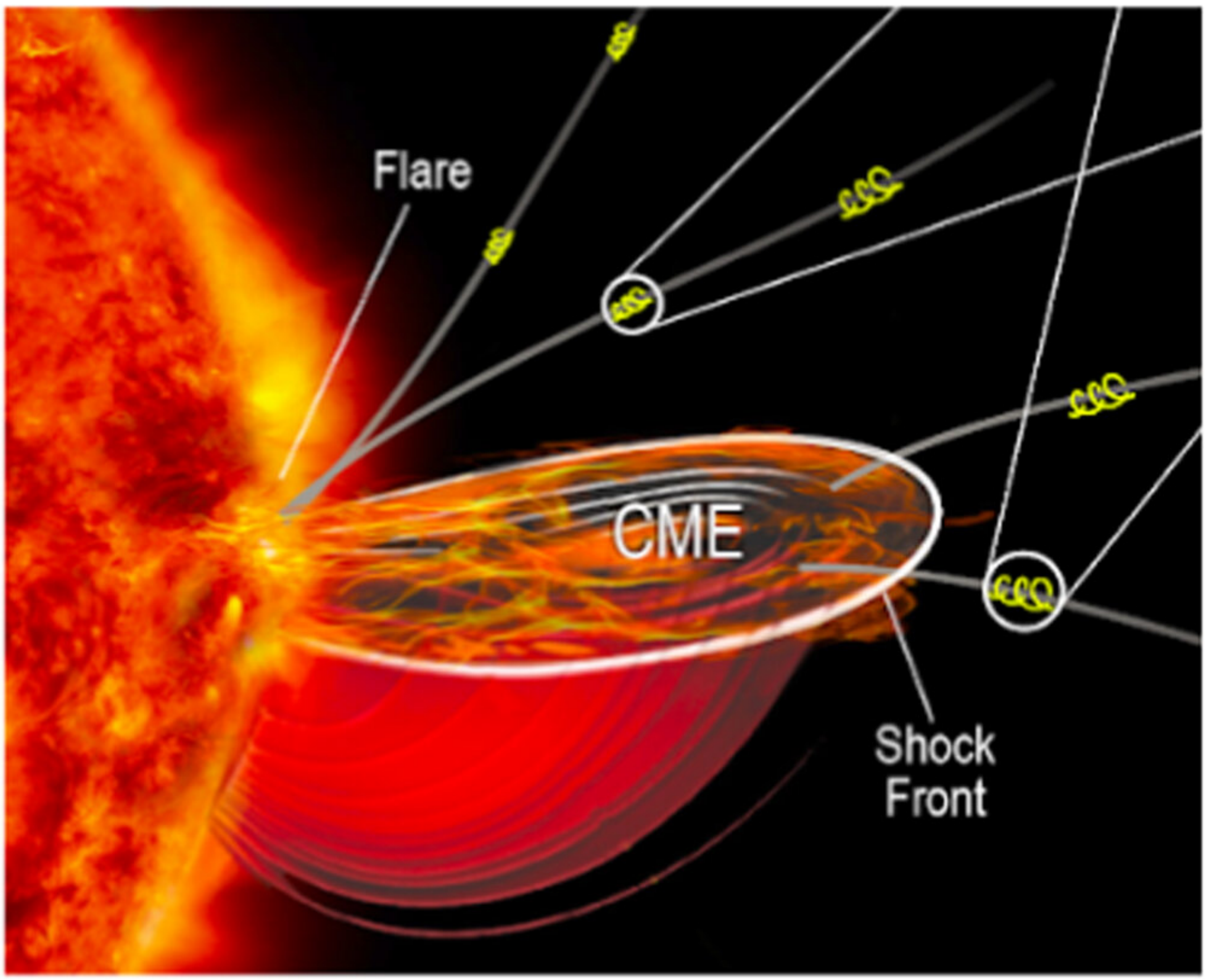

This schematic diagram illustrates the two acceleration sites of ions in large solar energetic particle (SEP) events: flares and CME-driven shocks. Once produced, energetic ions can propagate along open interplanetary magnetic field (IMF) lines and be detected in-situ at 1 astronomical unit, or 150 million kilometers.

The density of solar atmosphere near the acceleration sites is high enough so that energetic ions can lead to the production of solar ENAs. Credit: Gang Li/University of Alabama in Huntsville

Solar flares and coronal mass ejections (CME) are two of the most energetic processes in the solar system, showering the Earth's magnetic field with billions of tons of highly energetic plasma gas, potentially disrupting power grids, satellites and communications networks. Understanding the underlying particle acceleration process involved in large solar energetic particle (SEP) events like these has been one of the central problems in heliophysics research.

Dr. Gang Li, a professor in the Department of Space Science at The University of Alabama in Huntsville (UAH), is the first author of a paper in *The Astrophysical Journal* titled "Modeling Solar Energetic Neutral Atoms from Solar Flares and CME-driven Shocks" that demonstrates—for the first time—how energetic neutral atoms, or ENAs, could be used as a new means to probe the acceleration process in large SEP events, as well as to differentiate between the two acceleration sites: large loops in solar flares and downstream of CME-driven shocks.

"This work is likely to excite the [heliophysics] community to consider more about the generation and propagation of solar ENA particles," Dr. Li says. "The paper demonstrates for the first time that ENAs can be used to distinguish between CME/Flare SEP acceleration, laying down the necessary theoretical groundwork for possible future measurement of solar ENAs."

"Dr. Li's work provides a groundbreaking new approach to exploring the physics of particle acceleration in the atmosphere of the sun remotely," says Dr. Gary Zank, director of UAH's Center for Space Plasma and

Aeronomic Research and the Aerojet Rocketdyne chair of the Department of Space Science.

"This expands the already substantial effort in the Department of Space Science of using ENAs to explore remote regions of the heliosphere, where we utilize ENAs created in the distant boundaries of the heliosphere and neighboring interstellar medium to explore the plasma physics of those regions."

"The ultimate goal of using ENAs is to obtain various physics parameters at the acceleration sites," Dr. Li notes. "Scientists know that particles can be accelerated at two possible locations: either solar flares or CME-driven shock. However, which site is more efficient in accelerating particles? Which site can accelerate particles to higher energies? These are often debated questions, and we do not know the answer."

The main barrier to solving these mysteries through experimental observation is the sun itself, as basic understanding of near-sun conditions and the physical processes involved in the production of SEP events is hampered by an inability to make direct measurements near the acceleration sites.

ENAs represent a potential new method for supplying answers, because they are neutral particles (hydrogen atoms) that are formed from protons from change exchange reactions. Because they are neutral, they are not affected by magnetic fields.

"This is very important, because these neutral particles are not affected by the solar wind MHD [magnetohydrodynamic] turbulence as they propagate from the sun to observers," Dr. Li explains. "In comparison, protons, ions and electrons, because they are charged, their propagation from the sun to the Earth is distorted by the solar wind magnetic field.

ENAs therefore carry all the physics information of the acceleration site. So, observing them offers an entirely new opportunity to constrain the underlying particle acceleration process."

Also, the energetic atoms can reveal their secrets at a distance of 1 astronomical unit, or about 150 million kilometers from the sun, where the flux of the ENAs are at a level that can still be measured by a dedicated ENA detector. The quest to retrieve this data could ultimately lead to a new NASA solar mission to better understand these particles and how large SEP events originate to impact the Earth's magnetosphere.

"Our simulation forms a theoretical basis for interpreting future ENA observations," Dr. Li notes. "Such observations are likely on the radar of NASA as a future mission, for example, the NASA SMEX mission, to dedicate to solar ENA study. A dedicated ENA mission that filters out the more numerous charged SEPs and goes directly after these ENA measurements can provide new information about SEP acceleration near the sun and help solve long-standing questions that have baffled the community."

In fact, a new NASA mission on which Dr. Zank is a co-investigator, called IMAP (Interstellar Mapping and Acceleration Probe), will in fact have ENA instruments at 1 astronomical unit capable of measuring ENAs created both in the distant reaches of the heliosphere and also originating from the sun.

More information: Gang Li et al, Modeling Solar Energetic Neutral Atoms from Solar Flares and CME-driven Shocks, *The Astrophysical Journal* (2023). DOI: 10.3847/1538-4357/acb494

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