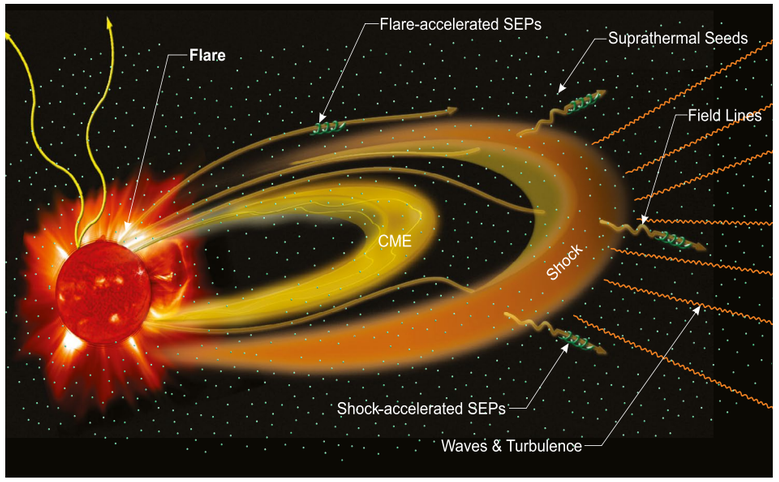
Seeding solar storms: suprathermal particles and the challenges researchers face

Dr Maher Dayeh is a senior research scientist at the Southwest Research Institute in San Antonio, Texas. His research includes heliospheric and magnetospheric physics, space weather, lightning and thunder microphysics, and the design and development of particle detectors for atmospheric and space applications. Dr Dayeh's current work focuses on measuring the characteristics of suprathermal particles in the heliosphere, and understanding how they may affect and contribute to space weather prediction. This is important work as suprathermal particles play a key role in seeding solar storms and are particularly difficult to measure.

Suprathermal particles are charged ions and electrons that are found throughout interplanetary space, and move at speeds two to hundreds of times faster than the thermal plasma of the solar wind. Their origin and properties are unsolved questions, however, there are currently two prevailing theories that describe their origin and acceleration, i.e., where do these particles come from, and how do they energise? One theory suggests that they originate from solar winds or similar low-energy particles in space and become energised by localised compressions, while the other suggests that they are partially remnants of previous events such as solar flares, coronal mass ejections (CMEs), and co-rotating interaction regions (CIRs), which are often associated with shocks that accelerate particles in the interplanetary medium. Studying these suprathermal particles is critical to the understanding of space weather and its effects on the near-Earth environment.



Sketch showing a solar flare and CME driving an interplanetary shock. The suprathermal particle population provides material that gets picked up by the shock and gets accelerated into very high energies [after Desai and Bergess 2008].

Suprathermal particles are difficult to measure as they exist at a wide range of energies, from about 1-2 kilo-electron volts (keV) to hundreds of keV, and most instruments that have been used in solar particle research in the past were designed to measure either low or high energy particles, but not both at the same time. Such instruments are unable to capture the full energy range of suprathermal particles, making these particle measurements very sparse. It is thus important to develop novel instrumentation that can capture the full energy range of suprathermal particles.

Dr Maher Dayeh has studied solar, heliospheric, and magnetospheric physics, along with space weather, and is currently studying suprathermal particles in different regions of the heliosphere (a bubble-like cocoon inflated by the continuous outflow of the solar wind from the Sun that extends far beyond our solar system) by studying data from a variety of instruments on board NASA, NOAA and ESA spacecraft. His work aims to identify the properties of suprathermal particles in different regions of the heliosphere, identify characteristics that can be used to distinguish between the different acceleration processes, and understand how suprathermal particles may affect space weather prediction.

SUPRATHERMAL PARTICLES

When a solar event occurs, such as solar flares and coronal mass ejections, charged particles (e.g., ions and electrons) are released into the heliosphere. These particles can be found at a range of energies, from 1 keV up to millions of keV. Particles that hold a level of energy higher than that of their surrounding plasma or matter are known as suprathermal particles. Populations of these particles are diverse and dynamic; they often contain ions from a variety of sources, including solar and interplanetary shock-accelerated

Suprathermal particle population plays a key role in providing seed material to energetic solar storms that drive space weather. Yet they remain puzzling.

events, cometary and interstellar sources. Suprathermal particles also contain a variety of elements, including helium, iron and oxygen. This, combined with the massive range of energies they can be found at, sheds light on the complexity of understanding their properties. It has been found that, in the heliosphere, the composition and size of suprathermal particle populations are related to solar cycle variability. In a recent study, Dr Dayeh found that during "quiet times", which are periods characterised by very low levels of solar activity and a quiet interplanetary space, particles measured near the Earth are dominated by matter that traces back to previous solar and interplanetary events.

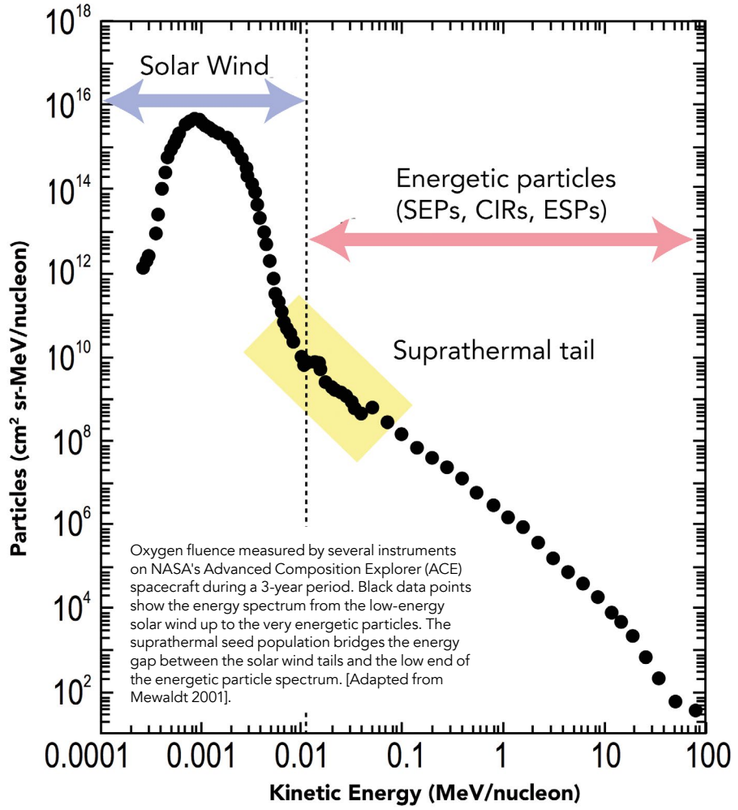
These suprathermal particles are believed to serve as a seed population for the large energetic particle events that are accelerated by fast-moving interplanetary shocks. Understanding the properties of these particles is key to understanding particle acceleration and transport throughout the solar corona and the heliosphere.

ELUSIVE PARTICLES AND IMPACTS

Suprathermal particle populations are difficult to study. As these particles exist within a wide range of energies, they cannot be fully characterised with dedicated instruments that are used to solely study plasma or energetic particles. Despite this, the limited research conducted has given crucial hints about the composition of suprathermal particle populations. They contain a wide variety of elements from a variety of sources, making them very diverse and dynamic.

Suprathermal particle populations are important as they act as seeds for large solar particle events, such as CME-driven shocks in the interplanetary space that drive space weather events. CME-driven shocks are responsible for accelerating particles to very high energies, forming a radiation hazard for astronauts and space instrumentation. These CMEs can also create intense geomagnetic storms resulting in unwanted space weather consequences on Earth, such as damage to the power grid and GPS communication systems interruptions.

Astronauts on future planetary missions are typically exposed to higher levels of radiation as they are not protected by the Earth's atmosphere and magnetosphere, however, during solar events the levels of radiation increase dramatically and can lead to severe health effects. Space instrumentation is also sensitive to radiation as it can penetrate



Oxygen fluence measured by several instruments on NASA's Advanced Composition Explorer (ACE) spacecraft during a 3-year period. Black data points show the energy spectrum from the low-energy solar wind up to the very energetic particles. The suprathermal seed population bridges the energy gap between the solar wind tails and the low end of the energetic particle spectrum. [Adapted from Mewaldt 2001].

Understanding suprathermal particles is critical for understanding solar energetic particle events and ultimately space weather at Earth

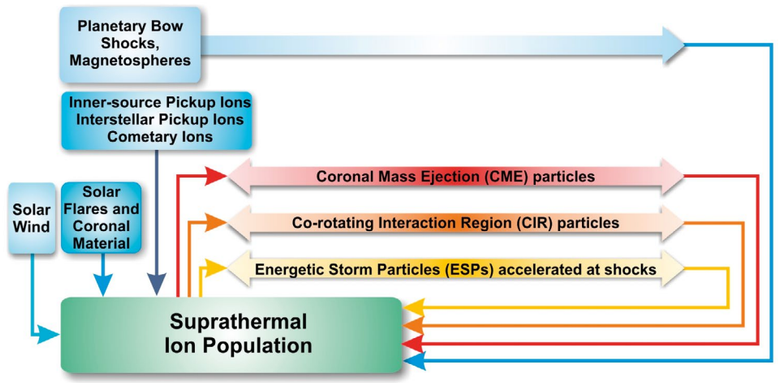


Diagram showing the particle sources believed to contribute to the suprathermal seed population [adapted from Mason 2000].

Q&A

What kind of events are caused by suprathermal particles?
Suprathermal particles are not events by themselves, rather, they are thought to be the seed material (fuel) of the much more intense solar energetic particle (SEPs) events that are accelerated by CME- and CIR-driven shocks in the interplanetary medium.

How often do solar energetic particle events reach the Earth's surface?
They do not reach the Earth surface. CME-driven shocks accelerate particles causing solar energetic particle (SEPs) events. These are extremely energetic and intense particles that arrive at Earth, along with the shock, compressing the Earth's magnetic field and showering it with a barrage of very energetic particles:
1- Particles damage space instrumentation and form a radiation hazard to humans in space.
2- Earth's magnetic field compression triggers geomagnetic storms that have broad effects on numerous technological platforms, in addition to creating the famous Aurora lights.

Do these particles have any impact on human health?
Not the suprathermal particles. But the solar energetic particles (SEPs) accelerated at shocks are indeed dangerous to astronauts in space. They pose very high radiation hazard and one of the main obstacles of human exploration of space that we need to tackle.

What other implications might these particles have for human society?
Understanding the suprathermal population will advance our knowledge about SEP events. SEPs, as mentioned earlier, are the key driver of space weather, which has numerous social and economic consequences.

What is the main source of suprathermal particles?
Particle measurements in space have shown that CME-driven shocks routinely accelerate tracer ion species near Earth and near the Sun (tracer element are those with well-known sources, e.g., 3He, an element that is extremely rare in the solar wind but much more abundant on the Sun). These tracer elements are often observed in large solar particle events near 1 AU and in the interplanetary space at suprathermal energies, providing compelling evidence that CME-driven shocks accelerate material out of the suprathermal pool, which are also found to contain heated solar wind or coronal material. In other words, the suprathermal population is a pool of material from different sources that were energised by different physical processes.

the spacecraft itself and either damage or destroy electronics, in addition to causing satellites to drift from their assigned orbits. For example, a storm in April 2010 is thought to have caused an important communications satellite, Galaxy-15, to founder and drift, taking almost a year to return to its station.

Understanding the composition, sources, and properties of suprathermal particles is thus an important key to ultimately understanding the complexities of the Sun-Earth connection in space.

PARTICLES NEAR THE EARTH'S ORBIT

Dr Dayeh and his team are currently studying the properties of suprathermal particles in the heliosphere near the Earth's orbit. Their work uses data from a variety of instruments on board several NASA and ESA spacecraft, which can provide a wider picture of the characteristics of these particles in different parts of the solar system, identify tracers that can be used to distinguish between different sources, and determine how understanding these particles might affect the prediction of space weather. This work will further our understanding of how these particles are accelerated in shocks, as well as aid our understanding of solar energetic particle events – the theoretical framework used to study suprathermal particles in space – and further our understanding of particle transport and acceleration in the interplanetary space.

Detail

RESEARCH OBJECTIVES

Dr Dayeh's research is designed to further basic understanding of suprathermal particles and how they are accelerated in the heliosphere, and to also provide a basis for future suprathermal particle research.

FUNDING

- National Science Foundation – SHINE Award No. AGS-1460118
- NASA-HSR – Award No. NNX17AI17G

COLLABORATORS

- Dr Mihir Desai (Southwest Research Institute and the University of Texas at San Antonio)
- Dr Robert Ebert (Southwest Research Institute)
- Dr Harald Kucharek (University of New Hampshire)
- Dr Heather Elliott (Southwest Research Institute)
- Dr George Livadiotis (Southwest Research Institute)
- Jacob Nickell (Graduate student; University of Texas at San Antonio and Southwest Research Institute)

BIO

Dr Dayeh is a senior research scientist in the Department of Space Research at Southwest Research Institute. He holds a PhD in Physics and a Master's in Space Sciences. His research areas are solar, heliospheric, and magnetospheric physics; space weather; lightning and thunder microphysics; and the design and development of particle detectors for space and atmospheric applications.

CONTACT

Dr Maher A Dayeh
Southwest Research Institute
Department of Space Research
Space Science & Engineering Division
6220 Culebra Road, San Antonio, Texas
78238-5166 USA

E: maldayeh@swri.edu
T: + 1 210 522 6851
W: https://scholar.google.co.uk/citations?user=dadcbSwAAAAJ&hl=en

SwRI
Southwest Research Institute