Dr. Munir Nayfeh highlights the focus of his team's latest research project and explains how it utilises eclipse observations of heavy ions, neutrals and dust grains to address existing knowledge gaps and unravel some of the unsolved mysteries about the Sun's corona and solar winds.

Can you begin by providing an overview of your research and the goals you aim to accomplish?

In this project, a partnership between University of Hawaii, University of Illinois, and Bridgewater College conducts observation, laboratory and simulation studies of ions and electrons and interaction with magnetic field; explore the presence and distribution of neutral light atoms hydrogen and helium as well as molecular-like nano dust grains in the solar corona. The partnership, hopes to better understand the corona and solar wind as well as contribute to the effort to unlock the 35 year old mystery of the extended red/blue emission from the Milky Way and other galaxies, which cannot be satisfactorily explained by any atomic, ionic or other material known in the galaxies.

What is the significance of studying the distribution of neutral hydrogen and helium corona? How much is currently known about this?

Significant Lyman $\alpha$, the fingerprint of hydrogen, is found to originate from the inner corona, implying the presence of a significant amount of hydrogen. Other lines of hydrogen are not observed, indicating that hydrogen in this region is not predominantly formed by recombination in electron-proton collision, which results in a cascade emission of multiple lines. As only a small fraction of hydrogen can survive in neutral form in the coronal temperature of millions of degrees, it is plausible that most of the neutral hydrogen or helium is due to direct entry or carried by nano grains from cooler interstellar regions, followed by resonance scattering of the Sun's wide-band radiation at the Lx by entering hydrogen. Neutrals can serve as local probes to elucidate the mechanisms for heating the solar atmosphere and accelerating the solar wind, and act as a proxy for protons in the solar wind, and may reflect the fate of cooler grains from solar as well as interstellar origin.

How has the team investigated the properties of dust grains in the near-Sun environment? What do you hope to achieve by doing so?

We investigated dust grains by polarimetric imaging and spectroscopy in the visible and in the near infrared. We examine extended emissions, which may be produced by molecular like grains as well as sharp atomic or ionic emission profiles lying within the expected broad emission of candidate grains. These are complemented by laboratory measurements of candidate dust material. Imaging is made in spectral lines representing different ionisation states of iron, sulfur, silicon, hydrogen, and helium, covering blue, red, infrared, and far infrared part of the spectrum. The resulting data should provide powerful diagnostic tools for exploring the physics of the corona and acceleration region of the solar wind, and the dust in the near-Sun environment.

How has the team employed resonant scattering and polarisation to follow the evolution of ions, grains and neutrals in the solar corona?

Resonance scattering of radiation at 1216 Å, a well-known emission from hydrogen atoms, was very powerful in discovering the presence of significant amounts of neutral hydrogen in the inner corona and in the galaxies. Resonance scattering was also used to discover neutral as well as singly ionised helium. In our studies we used resonance scattering of known transitions in highly stripped or heavy ions of iron, and compared it to light associated with electrons (i.e. white light) to map out local regions where there is more ion concentration than concentrations of electrons. We are applying such techniques to search for concentration of neutrals or nanograins and their ion versions. Our measurements and simulations show that it is this resonance scattering by the hydrogen coating on the nano Si grains which strongly deflects and hence protects the particles from the harsh Lyman $\alpha$ of the Sun.

What are the wider implication of studying the ion abundance, electron temperature, and direction of the coronal magnetic field of the inner corona?

Exploring ion abundance, electron temperature, and direction of the magnetic field in the inner corona sheds information on the physical processes that heat the solar atmosphere to over one million and shape the expanding solar atmosphere and accelerate the solar wind. Though amongst a minority, it is believed at present that ions hold many of the clues to the processes that heat the corona and accelerate the solar wind which is mostly a stream of electrons and protons ejected with high energy from the upper atmosphere of the Sun. It creates the heliosphere, and creates geomagnetic storms that can knock out power grids on Earth.
ACCORDING TO THE International Astronomy Union (IAU), there are still a number of unexplained spectral phenomena in the interstellar medium. Interstellar spectra taken in the visible part of the spectrum over the last four decades have shown broad or extended emission features that cannot be explained by the sharp emission lines from atomic neutrals or ions.

This mystery red glow, called the Extended Red Emission (ERE), is present throughout the Milky Way and other galaxies, but never on Earth. More recently, extended blue emission (EBE) has also been observed. The red and blue may exhibit different spatial distribution or they may originate from different objects. The red rectangle in which the extended red emission was first discovered has now been additionally identified with extended blue emission, which makes it closer to pink. A U.S. National Science Foundation-funded project under the governance of Dr Munir Nayfeh, has gathered a team to conduct observation of interstellar medium and solar corona during eclipses in the visible spectrum, as well as in the infrared, employing laboratory measurements and simulations to study these phenomena.

The eventual goal of this project is to identify a nano silicon-based carrier with a plausible mechanism for formation that exhibits the optical characteristics of the background, whilst maintaining brightness and withstanding harsh radiation without being destroyed.

METHODOLOGY

Current understanding of coronal manifestations, including coronal heating, the acceleration of solar wind, and solar magnetic activity is hampered due to the lack of measurements of key parameters, such as densities, temperatures, and magnetic fields. This project uses resonance scattering vs collision-induced emission, alongside polarisation, in order to generate information about densities and the trend with distance, which will significantly contribute to understanding the complex phenomena involved. Researchers will explore the presence and distribution of neutral light atoms hydrogen and helium, as well as molecular-like nano dust grains in the solar corona, and through bespoke experiments in the laboratory they will be able to emulate some of the harsh environments found in interstellar environment and in the solar corona, thus complementing the observational studies.

ELUCIDATING THE MYSTERIES

In order to shed further light on the mechanisms of ERE and EBE researchers carried out atomistic calculations using TDDFT of the electronic structure and interaction with heavy ions of the neutral as well as of the singly charged Si_{29}H_{24}^{+} particles, ionised by UV radiation. They have discovered that heavy ions may form stable complexes with the particles, imprinting their spectra on the extended emission. They also discovered that, due to very strong quantum confinement, the rate of energy loss to infrared/heat due to Coulomb scattering from charge centres is not significant, allowing light emission to proceed. The calculated charge distribution shows the positive charge to be trapped on a site just beneath the surface, creating a permanent electric dipole moment. With a dipole moment, the charged particle may exhibit transport,

Explaining spectral phenomena

Scientists have observed a mysterious red and blue glows emanating from within the Milky Way and other galaxies that cannot be explained by any usual methods. One project has set out to find the answers.
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alignment and polarisation effects in external electro-magnetic fields.

UNCOVERING THE CARRIER

The project has already made significant advances in the production of a nano silicon-based carrier that exhibits the required attributes as Nayfeh describes: "We homed in on a silicon-based exotic species as carrier of the mystery in its field, there are still more questions to be answered, which could lead to further projects in the near future. One key question is to understand the mechanisms responsible for the production of the silicon grain carrier in the galaxies. In the laboratory, researchers used chemical etching of a silicon crystal in a mixture of hydrogen fluoride and hydrogen peroxide while being electrically charged. However, it remains doubtful whether this procedure could be mimicked in space. Nayfeh highlights how his interest has already moved on to look ahead at potential future revelations: "We are experimenting in the laboratory with a procedure that utilises a silicon-rich hydrated silicate as precursor. Could elevated temperature and pressure under certain conditions become favourable for the formation of those silicon rich grains?"

FUTURE POTENTIAL

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