The Solar Wind Abundance Mystery
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Abstract
By analyzing in situ measurements of the fast solar wind, we have found a systematic decrease in the abundance of Helium (measured by Wind) and the degree of Iron fractionation (measure by ACE and Ulysses) during the recent extended solar minimum relative to the previous minimum. These observations were also temporally accompanied by a decrease in the supergranular network emission length scale (measured by SOHO), signaling a reduction in the strength of the magnetic field and the scale over which mass is transported and energy are transported through the quiet solar atmosphere. Together, these findings reveal that a significant change in the heating process likely took place during the recent minimum. Additionally, a decay in the helium abundance has been observed over multiple solar cycles, possibly indicative of long-term changes in the background magnetic field and energy input into the solar wind.

Introduction
The solar wind abundance mystery can be described in two parts: (1) The composition of the solar wind is observed to change with time. (2) The overabundance of heavy atoms (including Iron, Silicon and Magnesium) compared to their photospheric abundance, which is a result of an unknown physical process termed fractionation. Understanding these is an essential part of understanding the heating processes taking place in the lower solar atmosphere, an outstanding challenge in the solar physics community. Capturing particles coming from fast solar wind streams enables us to essentially probe this region and thus these processes, without adding complications that arise from heating and cooling of plasma in closed loops. By analyzing compositional changes in the fast wind, we take a first step in understanding energy and mass release into the solar corona and solar wind.

Data Sources
- The Faraday Cup (FC) instrument on the Wind spacecraft - Launched in 1994 - Located at L1
- The Solar Wind Ion Composition Spectrometer (SWICS) on the ACE (Advanced Composition Explorer) spacecraft - Launched in 1997 - Located at L1
- The SWICS and the Solar Wind Observations over the Poles of the Sun (SWOOPS) instruments on the Ulysses spacecraft - Launched in 1990 - In a polar orbit about the Sun
- The OMNI data set - Multimission data set spanning the time period from 1963 to the present - Data from spacecraft located at L1 and/or near-Earth, geostationary spacecraft

The helium abundance, \( A_{\text{He}} \), is defined as the relative abundance of helium to hydrogen by number density, \( (n_{\text{He}}/n_{\text{H}}) \times 100 \).

Key Findings
- As seen in Figure 1, a significant decrease in \( A_{\text{He}} \) occurred during the extended solar minimum following cycle 23. This decrease, which was observed for all wind speeds, was simultaneously accompanied by the minimum in the supergranular length scale, the scale of which mass and energy transport take place.
- Through comparison of the two panels in Figure 2, the degree of iron fractionation in the fast solar wind was reduced during the last minimum relative to the previous minimum. As observed outside of the ecliptic plane by the Ulysses spacecraft, the abundance of Fe/O approached photospheric values.

Conclusions
The observational results described above are consistent with a decrease in the amount of energy supplied in the lower solar atmosphere which heats the fast wind. During the last solar minimum, the heating process appeared to be less efficient. Furthermore, the long-term reduction in \( A_{\text{He}} \) seems to imply that the background magnetic field has been slowly decaying over multiple solar cycles, resulting in a decrease in both energy and mass release.

References

Acknowledgements
This work was funded by the National Science Foundation under the Research Experience for Undergraduates program. We would also like to thank the Wind, ACE, Ulysses instrument teams and the OMNI database staff for making data publicly available.