Helium Abundance Heralds the Onset of Solar Cycle 25

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ABSTRACT

We study the solar wind helium-to-hydrogen abundance’s ($A_{\text{He}}$) relationship to solar cycle onset. Using OMNI/Lo data, we show that $A_{\text{He}}$ increases prior to minima of sunspot number (SSN). We also identify a rapid depletion and recovery in $A_{\text{He}}$ that occurs directly prior to cycle onset. This depletion happens at approximately the same time across solar wind speeds ($v_{\text{sw}}$), implying that it is formed by a mechanism distinct from the one that drives $A_{\text{He}}$’s solar cycle scale variation and $v_{\text{sw}}$-dependent phase offset with respect to sunspot number (SSN). As $A_{\text{He}}$’s rapid depletion and recovery have already occurred and $A_{\text{He}}$ is now increasing as it has following previous solar Minima, we infer that solar cycle 25 has already begun.

Keywords: Solar wind – Sun: abundance – Sun: fundamental parameters – Sunspots – Solar cycle

1. INTRODUCTION

Since at least 1844, the Sun’s approximately 11-year solar activity cycle has been measured in the sunspot number (SSN) (Schwabe 1844). Today, many other activity indices are known to track the solar cycle. Typically, these carry a known phase offset when measured with respect to SSN. For example, Lyman-$\alpha$ (L$\alpha$) lags SSN by 125 days (Bachmann & White 1994) and soft X-ray flux (SXR) lags SSN by 300 to 450 days (Temmer et al. 2003).
Helium is a natural byproduct of Big Bang nucleosynthesis and solar fusion (Bethe & Critchfield 1938; Bethe 1939; Parker 1997; Basu & Antia 2008). It composes \( \sim 25\% \) of solar material by mass (Basu & Antia 2008; Asplund et al. 2009; Laming 2015; Basu & Antia 2004), the most common solar element after hydrogen. The first ionization potential (FIP) is the energy necessary to ionize a neutral atom’s 1st electron. As helium has the highest FIP of any solar element, it is the last to ionize in the upper convection zone (Basu & Antia 2008; Laming 2015). Through the chromosphere and transition region, the FIP effect depletes the helium abundance (Laming 2015; Rakowski & Laming 2012) such that, outside of transient events like coronal mass ejections (CMEs), it drops to below 5% by the time its is released into the solar wind (Asplund et al. 2009; Laming 2015; Hirshberg 1973; Neugebauer 1981; Aellig et al. 2001; Kasper et al. 2007, 2012; Alterman & Kasper 2019). Neugebauer & Snyder (1962) made the first in situ helium measurements with Mariner II. The helium abundance is given by

\[
A_{\text{He}} = 100 \times \frac{n_{\text{He}}}{n_{\text{H}}},
\]  

(1)

where \( n_{\text{He}} \) is the helium number density and \( n_{\text{H}} \) is the hydrogen number density. In the intervening 58 years, multiple authors have shown that \( A_{\text{He}} \) tracks the solar cycle (Alterman & Kasper 2019; Zerbo & Richardson 2015; Kasper et al. 2007, 2012; McIntosh et al. 2011; Aellig et al. 2001; Ogilvie et al. 1989; Feldman et al. 1978; Ogilvie & Hirshberg 1974). In particular, \( A_{\text{He}} \)’s response lags changes in SSN (Feldman et al. 1978) and this lag is a monotonically increasing function of solar wind speed \( (v_{\text{sw}}) \) (Alterman & Kasper 2019; Kasper et al. 2007).

Brightpoints (BPs) are localized enhancements at extreme ultraviolet (EUV) (McIntosh 2007), x-ray (Vaiana et al. 1973), or both wavelengths. McIntosh (2007) determined that EUV BPs are likely rooted at the vertices of supergranule cells and the flow of the supergranules in which they are anchored drives them. As BPs are signatures of solar activity, it is perhaps unsurprising that their occurrence follows the butterfly pattern (McIntosh et al. 2014b; Leamon et al. 2020) that Spörer’s Law (Maunder 1903) associates with sunspots (Carrington 1863).

In this Letter, we continue the process of connecting solar wind \( A_{\text{He}} \) to solar activity. Section 2 describes our data sources and selection. Section 3 extends observations of helium abundance’s variation with solar cycle to cover a 45 year period from 1974 until present day. Here, we present two observations.

1. Immediately prior to Solar Minima, \( A_{\text{He}} \) rapidly depletes and then recovers over \( \lesssim 250 \) days at all speeds.

2. On the larger scale of its solar cycle variation, \( A_{\text{He}} \) has already started to climb, indicating the rising phase of solar cycle 25 has started.

Section 4 connects \( A_{\text{He}} \)’s behavior immediately prior to Solar Minima with EUV BPs. Section 5 discusses our results and shows that, based on the time by which \( A_{\text{He}} \)’s depletion has preceded Solar Minima 21 through 24, Solar Minimum 25 has already occurred, likely in mid to late 2019. Section 6 briefly concludes.

2. DATA SOURCES AND SELECTION

This study combines in situ OMNI plasma measurements with Solar Dynamics Observatory (SDO) and Solar and Heliospheric Observatory (SOHO) remote observations. Several solar activity indices provide context.

The OMNI database\(^1\) contains solar wind magnetic field, thermal plasma, and energetic proton measurements at multiple high\(^2\) and low\(^3\) time resolutions (King & Papitashvili 2005). These measurements are collected from multiple spacecraft, both near-Earth and at the 1st Lagrange point (L1). This study uses near-Earth Low Resolution OMNI (OMNI/Lo) data. The L1-collected data is propagated to, “expected magnetosphere-arrival times,” (https://omniweb.gsfc.nasa.gov/html/ow_data.html) and then averaged to 1 hour cadence. While OMNI/Lo data begins in 1963 and extends to the present day, we limit this study to data collected beginning in 1974.

The Wind Solar Wind Experiment (SWE) has provided data to OMNI since 1995. Excluding \( \sim 4.5 \) years around solar Maximum 23,\(^4\) OMNI/Lo is almost exclusively Wind/SWE Faraday cup (FC) data. Physical quantities are extracted from SWE/FC data by means of moments and non-linear fitting. Multiple implementations of the non-linear techniques have been developed (Kasper et al. 2006; Maruca & Kasper 2013; Alterman et al. 2018), each optimized to return distinct physical quantities. The majority of the SWE/FC data that OMNI/Lo uses is reduced using Kasper et al.’s

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\(^{1}\) https://omniweb.gsfc.nasa.gov/

\(^{2}\) 5 minute and 1 minute (https://omniweb.gsfc.nasa.gov/html/omni_min_data.html)

\(^{3}\) 1 hour and longer (https://omniweb.sci.gsfc.nasa.gov/html/ow_data.html)

\(^{4}\) Per OMNI/Lo documentation (https://omniweb.gsfc.nasa.gov/html/ow_data.html), the Advanced Composition Explorer (ACE) Solar Wind Electron Proton and Alpha Monitor (SWEPAM) (McComas et al. 1998) provides this data.
Figure 1. (A) OMNI/Lo helium abundance ($A_{\text{He}}$) measurements as a function of solar wind speed ($v_{\text{sw}}$) and time. This figure follows the style of Alterman & Kasper (2019); Kasper et al. (2012, 2007). $A_{\text{He}}$ has been split into 10 $v_{\text{sw}}$ quantile defined over the entire data set, each indicated by a unique color and marker. The legend at the figure’s top indicates each quantile’s center in km s$^{-1}$. Within each $v_{\text{sw}}$ quantile, $A_{\text{He}}$ is averaged down to 250 day time resolution. Error bars indicate the standard error of the mean, which are smaller than each marker starting in $\sim$1985. The secondary y-axis plots the 13 month smoothed sunspot number (SSN) in dashed black (SILSO World Data Center 2020). Vertical dash-dotted purple lines indicate Solar Cycle Minima. Vertical dotted lines indicate the $A_{\text{He}}$ minima data averaged across $v_{\text{sw}}$ preceding Solar Cycle Minima. (B) Lyman-$\alpha$ ($L_\alpha$, left, solid blue) and F10.7 (right, dashed orange) solar activity indicators over the same period as $A_{\text{He}}$ (Leise et al. 2019). Within one or two data points prior to Minima 22, 23, and 24, $A_{\text{He}}$ increases across all but the two slowest $v_{\text{sw}}$ quantiles before SSN, $L_\alpha$, or F10.7 do. As such, $A_{\text{He}}$’s dramatic uptick during the descending phase of cycle 24 may indicate solar cycle 25’s onset prior to SSN, F10.7, and $L_\alpha$.

The Solar and Heliospheric Observatory (SOHO) Extreme-ultraviolet Imaging Telescope (EIT) (Delaboudinière et al. 1995) and Solar Dynamics Observatory (SDO) Atmospheric Imaging Assembly (AIA) (Lemen et al. 2012) telescopes provide our EUV measurements at 195Å and 193Å, respectively. Following McIntosh et al. (2014b), we identify BPs in a manner that accounts for differences in the two instruments. We make no distinction between quiet Sun and active region (AR) BPs, calculate a daily average of those lying along the central meridian, and then average the daily BP measurements down to 27 day cadence.

We also use three solar activity indicators to provide solar cycle context. The Solar Information Data Center (SILSO World Data Center 2020; Vanlommel et al. 2005, SIDC) provides our sunspot number (SSN) data. LASP’s Interactive Solar Irradiance Data Center (Leise et al. 2019, LISIRD) provides F10.7 and Lyman-$\alpha$ ($L_\alpha$) data.

3. HERALDING CYCLE 25

Fig. 1 Panel (A, top) plots the OMNI/Lo helium abundance as a function of solar wind speed ($v_{\text{sw}}$) and time. The solar wind speed $v_{\text{sw}}$ has been split into 12 quantiles over the entire mission and $A_{\text{He}}$ within each quantile is averaged down to 250 day time resolution. Following Alterman & Kasper (2019) and Kasper et al. (2007, 2012), the slowest quantile is at the edge of any given instruments operational capabilities and the fastest covers several hundred km s$^{-1}$. As such, these two quantiles

https://omniweb.gsfc.nasa.gov/html/ow_data.html
are excluded and Fig. 1 covers the $v_{sw}$ range 320 km s$^{-1}$ to 603 km s$^{-1}$, i.e. slow and intermediate speed solar wind. The legend indicates the middle of each quantile in km s$^{-1}$. Error bars indicate the standard error of the mean. Starting in $\sim 1985$, each error bar is smaller than the corresponding marker.

Fig. 1 provides solar cycle context with three activity indices. The 13 month smoothed SSN (SILSO World Data Center 2020) is plotted against Panel (A)’s secondary y-axis. Panel (B, bottom) plots $L$ (solid blue, primary y-axis) and F10.7 radio emission (dashed orange, secondary y-axis) (Leise et al. 2019). To match SSN data, both have been averaged to monthly cadence and then smoothed with a centered 13 month window. The vertical purple dash-dotted lines indicate established Solar Minima (Hathaway 2015) for solar cycles 21 and 24, each labeled in a gray bar at Panel (B)’s bottom. For Minimum 25, we use the NASA/NOAA joint prediction of April, 2020. The blue band indicates the Minimum 25 $\pm 6$ month uncertainty. Visual inspection shows that both $L$ and F10.7 reach a minimum after SSN.

As Alterman & Kasper (2019) observe directly with Wind/SWE data, OMNI/Lo $A_{He}$ reach a consistent maximum during cycles 23 and 24 of $4\% \lessgtr A_{He} \lessgtr 5\%$ across $v_{sw}$ quantiles irrespective of cycle amplitude. Cycle 24’s Minimum and declining phase also indicate that the helium abundance has reached a similar value bottoming out at $\sim 1\%$ in the slowest speeds. Extrema 21 and 22 show similar, mutually consistent behavior. $A_{He}$ during the Minima bottom out at $\sim 2\%$ and the maxima peak between $5\% \lessgtr A_{He} \lessgtr 6\%$, irrespective of cycle amplitude. Minimum 23 bottoms out at a value intermediate between the prior and following Solar Minima. Alterman & Kasper (2019) observed a decline in $A_{He}$ during cycle 24’s trailing edge. Fig. 1 shows that–on this 250 day timescale–$A_{He}$ has already reached a local minimum and is now recovering across all but the slowest $v_{sw}$ quantiles. Fig. 1 also indicates an as-yet unreported feature across multiple solar Minima: on the 250 day timescale used here, $A_{He}$’s local minima before solar Minima 22, 23, and 24 appear as a sharp departure from the sinusoidal trend in all but the slowest one or two quantiles. Vertical dotted lines indicate the date of these rapid $A_{He}$ depletions averaged across $v_{sw}$ quantiles. The blue bands on the top and bottom of each panel around the dotted lines are the associated standard deviation of the dates. These two features imply that Solar Minimum 25 may have already occurred.

4. BRIGHTPOINTS AND $A_{He}$ DURING THE COEXISTENCE OF TWO SOLAR CYCLES

The transition from one solar cycle to the next is not instantaneous. Rather, there is a span of time when the toroidal component of the Sun’s magnetic field exhibits polarities from both solar cycles. This is most commonly seen in the overlap of adjacent solar cycles in a Butterfly diagram (Maunder 1903; McIntosh et al. 2014b; Leamon et al. 2020; Carrington 1863).

Fig. 2 zooms in on the time period from 1995 until present day during which the $Wind$/FCs provide the majority of OMNI data and for which SOHO and SDO provide EUV coverage. Because we are concerned with an event that happens over $\lesssim 250$ days prior to Solar Minimum, this section focuses on Solar Minima 24 and 25. We show Minimum 23 and the preceding $A_{He}$ minimum for visual reference. The (Top) panel plots $A_{He}$ as in Fig. 1. The (Bottom) panel is a filled contour plot of 27 day averages of BPs along the central meridian. The white band in 1998 identifies the single data gap after averaging down to 27 day cadence. The white band prior to Solar Minimum 23 is before SOHO’s launch and the white band starting approximately 1/4 of the way through 2020 signifies the end of available data. In the (Top) Panel, Solar Minima and $A_{He}$’s rapid depletions are plotted as in Fig. 1. In the (Bottom) panel, they are indicated in light green instead of purple for the sake of contrast with the BP data. We omit Minimum 25’s $\pm 6$ month uncertainty in the (Bottom) panel so as to not obscure the present day measurements. The (Bottom) panel also indicates the first 6 PSP near-Sun encounters at its top. The gray band indicates launch $\sim 70$ days through the exit of encounter 6 $+70$ days. The yellow bars indicate the time spent below 0.25 AU. We omit $A_{He}$’s pre-Minimum 25 depletion date standard deviation on the top of the (Bottom) panel so as to not obscure the PSP encounter dates.

Comparing Fig. 2’s (Top) and (Bottom) panels suggest an explanation for the pre-Solar Minima rapid $A_{He}$ depletions observed in Fig. 1. Over the 4 to 5 years Solar Maxima, BPs display low levels of activity (Normalized Density $\lesssim 0.3$) at middle and high latitudes ($|\lambda| \gtrsim 30^\circ$). As expected (McIntosh et al. 2014b), the midlatitude BPs of the emerging cycle become as or more significant than the decaying cycle and this shift is asymmetric. For example, cycle 24 BPs emerge (Density $\gtrsim 0.9$) in the Sun’s northern hemisphere at latitudes $\lambda > 25^\circ$ in mid 2009, approximately 2 years before a similar BP intensity is present in the southern hemisphere. Look-

\footnote{https://www.swpc.noaa.gov/news/solar-cycle-25-forecast-update.}
Figure 2. (Top) Solar wind helium abundance ($A_{\text{He}}$) as a function of solar wind speed ($v_{sw}$) and time in the manner of Alterman & Kasper (2019); Kasper et al. (2007, 2012). (Bottom) A filled contour plot of the combined daily SOHO/EIT (195˚A) and SDO/AIA (193 ˚A) EUV central meridian Brightpoint (BP) density as a function of latitude and time. BPs are averaged down to 27 day cadence. Solar Cycle Minima and $A_{\text{He}}$ minima are plotted in green to contrast with BP density. The first 6 PSP near-Sun encounters are in the (Bottom) panel’s top right corner. The gray band indicates launch − 70 days through the exit of encounter 6 +70 days. The yellow bars indicate the time spent below 0.25 AU.

During earlier at mid-2007, we see a northern hemisphere BP Density $\gtrsim$ 0.8 at similarly high latitudes before we see a comparably intense BP density at least one year prior to when the southern hemisphere shows a comparable low latitude BP Density. Comparing with $A_{\text{He}}$ in the (Top) panel, it appears as though the northern hemisphere’s BPs emergence during cycle 24 is approximately concurrent with $A_{\text{He}}$’s rapid depletion prior to Solar Minimum 24. The separation between the northern hemisphere’s mid-2007 BP feature and early 2009 feature is minimally larger than two $A_{\text{He}}$ data points, which is the minimal number necessary to see the start of $A_{\text{He}}$’s rapid depletion, though not recovery. In early 2019, $A_{\text{He}}$’s rapid depletion seems to be concurrent with the emergence of Cycle 25 BPs in the southern hemisphere with an intensity $\gtrsim$ 0.8 at latitudes $\lambda < -25^\circ$, while we only see a comparable increase in the northern hemisphere at latitudes $\lambda \gtrsim 25^\circ$ in early 2020.

5. DISCUSSION

Fig. 1 shows that $A_{\text{He}}$ displays the solar cycle variability characteristic of a solar activity index since at least solar cycle 21. Earlier results (Robbins et al. 1970; Ogilvie & Hirshberg 1974; Feldman et al. 1978; Aellig et al. 2001) extend this trend back to cycles 19 and 20. Our measurements also indicate that present day (March 2020, as of the time of submission) $A_{\text{He}}$ has already recovered from this shutoff prior to a notable increase in SSN, $L_\alpha$, or F10.7.

Fig. 1 presents an additional and as yet unreported feature of $A_{\text{He}}$’s solar cycle variation: on this 250 day timescale, $A_{\text{He}}$ rapidly approaches and then recovers from a local minimum that departs from its long term solar cycle trends prior to solar Minima 21 through 25. The complicating factors discussed above do not negate the significance of these rapid depletions because they are all significant with respect to $A_{\text{He}}$’s solar cycle scale
variability and are present in OMNI/Lo data irrespective of the instrument providing the data.

EUV BPs tend to form at supergranule vertices, also known as g nodes, where the radial component of the Sun’s toroidal field emerges (McIntosh et al. 2014b). They are commonly associated with the motion of giant convective cells (Hathaway et al. 2013; McIntosh et al. 2014a). Their equatorial migration and torsional oscillations (McIntosh et al. 2014b) along with the magnetic range of influence (McIntosh et al. 2014a, MRoI) with which they are associated indicate that the underlying magnetic fields have deep roots, likely in deep in the convection zone (McIntosh et al. 2014a) or tachocline (McIntosh et al. 2014b).

Fig. 2 examines the relationship between $A_{\text{He}}$ and BPs over the time period when the necessary EIT and AIA EUV measurements are available. EIT began collecting data in January 1996 (Moses et al. 1997). Solar Minimum 23 was in August of that year. As $A_{\text{He}}$’s pre-Minimum depletion occurred at least 250 days prior to Minimum 23, we are restricted to Solar Minimum 24 and the prediction for Minimum 25. Solar magnetic activity often manifests asymmetrically: a new solar cycle typically emerges in one hemisphere before the other (McIntosh et al. 2013, 2014b). Fig. 2 indicates that the time period over which $A_{\text{He}}$ rapidly depletes is approximately concurrent with the time period when a new cycle’s BPs appear at mid latitudes in one hemisphere, but not the other. During Solar Minimum 24, BPs emerged in the northern hemisphere before the southern; the southern hemisphere is now leading as we enter Solar Cycle 25. In both cases, the recovery from these rapid depletions appears concurrent with the emergence of midlatitude BPs that correspond to the rising cycle in the second, lagging activity hemisphere.

Alterman & Kasper (2019) show that $A_{\text{He}}$ responds to changes in SSN with a phase lag that monotonically increases with $v_{\text{sw}}$. Slow and fast solar wind likely originate in distinct source regions on the Sun that are associated with distinct magnetic field strengths. Slower wind is associated with weaker magnitudes; faster wind with stronger fields. The height at which $A_{\text{He}}$ ionizes is related to the magnetic field’s strength. As such, $A_{\text{He}}$’s phase lag and its $v_{\text{sw}}$-dependence imply that slow wind emerges from regions that are more sensitive to changes earlier in the solar cycle and these regions are associated with lower altitudes; fast wind is less sensitive to these changes and it emerges from regions associated with higher altitudes (Alterman & Kasper 2019).

In contrast, $A_{\text{He}}$’s rapid pre-Minima depletions and then recoveries—i.e. temporary shutoffs—occur at approximately the same time prior to Solar Minima 24 and 25 for speeds at least as fast as 350 km s$^{-1}$. As such, these shutoffs indicate that a mechanism independent of solar wind source region and distinct from that driving the phase lag drives these shutoffs. Instead, it relies on the mechanism that drives each activity cycle’s hemispheric asymmetry in which one hemisphere leads or lags the other. Given that

1. they start when the leading hemisphere’s BPs from the rising cycle are emerging and
2. they recover when the lagging hemisphere’s BPs correspond to the rising cycle emerge,

we infer that these $A_{\text{He}}$ shutoffs are likely the result of an unique topology of the global solar magnetic field during Solar Minimum.

Under Parker’s model, the buoyant rise of toroidal magnetic flux to the Sun’s photosphere generates sunspots (Parker 1955; Charbonneau 2010; Cheung & Isobe 2014). The equatorial evolution of the Sun’s toroidal magnetic field component leads to Sunspot butterfly diagram (McIntosh et al. 2014b; Charbonneau 2010; Fan 2004). Following McIntosh et al. (2014b), four toroidal magnetic field bands exist during the decaying solar cycle’s declining phases. Each hemisphere contains two bands and adjacent bands have opposite signs. Solar minimum corresponds to the cancelation of two toroidal field bands at the equator. If this is the underlying mechanism, then $A_{\text{He}}$ shutoff could correspond to the annihilation of these two equatorial flux bands and lack of flux emergence. As Wind’s orbit is in the Sun’s equatorial plane, the FCs may not be able to measure any helium related to the two poleward bands of the Sun’s toroidal field during these short periods. Nevertheless, this is just one possible mechanism that may drive $A_{\text{He}}$ shutoff.

Table 1 summarizes the average dates of $A_{\text{He}}$’s rapid depletions or shutoffs prior to the indicated Solar Minimum for all Minima in Fig. 1. This table also indicates the average time by which $A_{\text{He}}$’s minima precede Solar Minimum ($\Delta t$) and the standard deviation of these $\Delta t$, both calculated across $v_{\text{sw}}$ quantiles. Solar Minimum 25’s $\Delta t$ uses the NASA/NOAA joint prediction. The average of $\Delta t$ for $A_{\text{He}}$ minima preceding Minima 21 through 24 weighted by their STD is 320 days. The 523 days by which $A_{\text{He}}$ precedes the Projected Minimum 25 is $1.6 \times$ longer than the average 320 days by which $A_{\text{He}}$ precedes prior Minima. Should Minimum 25 have occurred at the start of the window defined by the 6 month uncertainty on Minimum 25, $A_{\text{He}}$ would have shutoff 403 days prior or $1.3 \times$ longer than the average from preceding Minima. Although the $\Delta t$ are on the order of our 250 day averaging window and therefore preclude an accurate estimate
of Solar Minimum 25’s date, this clearly implies that Solar Minimum 25 likely occurred in mid to late 2019.

6. CONCLUSION

We have studied solar wind helium abundance ($A_{He}$) as a function of speed and time over 45 years. Using OMNI/Lo data averaged down to 250 day time resolution, we have shown that $A_{He}$

1. likely returns to a consistent values at solar cycle extrema irrespective of cycle amplitude during each of the time periods covered by solar Minima 21 through Maximum 22 and Maximum 23 through Minimum 25;

2. rapidly depletes and then recovers over a time period no greater than $\sim$ 250 days immediately prior to solar Minimum;

3. has recovered from its pre-Solar Minima 25 rapid depletion; and

4. is already increasing across $v_{sw}$ quantiles along its solar cycle scale variability in the present day.

As solar wind from different source regions have different characteristic speeds and $A_{He}$, at these speeds respond to solar cycle changes with a distinct phase lag (Alterman & Kasper 2019), the concurrence of $A_{He}$’s shutoffs for speeds at least as fast as 350 km s$^{-1}$ implies that $A_{He}$ shutoff is unrelated to differences in these solar wind source regions and how they generate the solar wind. Given that

1. BP s emerge asymmetrically in the leading and lagging hemisphere as a new solar cycle grows (McIntosh et al. 2013, 2014b) and

2. $A_{He}$ shutoff starts when the leading hemisphere BPs emerge and recovers when the lagging hemisphere BPs emerge,

$A_{He}$ shutoff is likely tied to the same underlying mechanism that drives BP emergence, likely deep in convection zone or transition region. Therefore, $A_{He}$ can serve as a solar activity indicator that heralds a new solar cycle’s onset before the sunspot record or other activity indicators like Lo and F10.7 radio flux. Although our 250 averaging window prohibits an accurate estimate of Solar Minimum 25’s date, based on the time by which $A_{He}$ shutoff has preceded Solar Minima 21 through 24, Table 1 clearly indicates that Solar Minimum 25 has already occurred, likely in mid to late 2019.

Parker Solar Probe (PSP) launched in August, 2018 and first dropped below 0.25 AU on October 31$^{st}$ of that year. By the end of 2020, the spacecraft will have made six trips below 0.25 AU, the closest coming to within 0.2 AU of the Sun. Fig. 2 indicates these six encounters as small orange bars in the top-right corner of the bottom panel. PSP’s 1$^{st}$ and 2$^{nd}$ near-sun encounters took place during helium shutoff. Based on this figure, we expect PSP (Fox et al. 2016)–in particular SWEAP (Kasper et al. 2017)–to find alpha particles become markedly more prevalent starting in Encounter 4.

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Software: IPython (Perez & Granger 2007), Jupyter (Kluyver et al. 2016), Matplotlib (Hunter 2007), Numpy (van der Walt et al. 2011), Pandas (Mckinney 2010), Python (Oliphant 2007; Millman & Aivazis 2011), IDL.
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