Wind 2020 Senior Review Proposal

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Executive Summary: Infrastructure Proposal

NASA launched the *Wind* spacecraft in November, 1994 to the Earth's L1 Lagrange point as the interplanetary component of the Global Geospace Science (GGS) Program within the International Solar Terrestrial Physics (ISTP) program. The spin stabilized spacecraft – spin axis aligned with ecliptic south – carries eight instrument suites that provide comprehensive measurements of thermal to solar energetic particles, quasi-static fields to high frequency radio waves, and γ-rays. In particular, the *Wind* instrument suite provides comprehensive and unique high time resolution (HTR) in-situ solar wind measurements that enable the investigation of wave-particle interactions. *Wind* is also the only near-Earth spacecraft equipped with radio waves instrumentation. All instrument suites continue to provide valuable scientific observations completely available to the public (except TGRS, now without coolant).

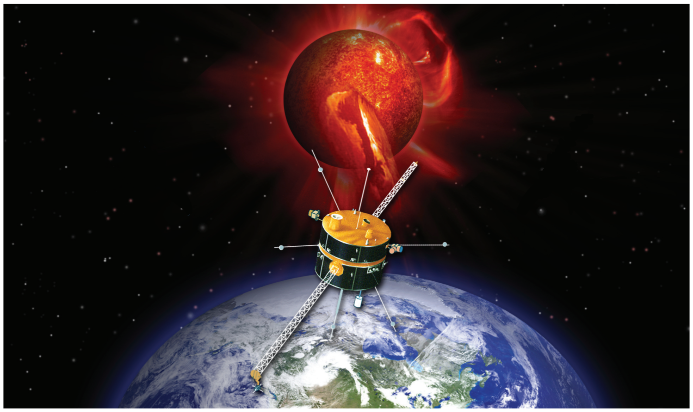

Figure 1: *Wind, a comprehensive solar wind monitor.*

Wind has contributed to numerous independent discoveries since the last Senior Review, from kinetic effects of solar wind reconnection and plasmas to solar cycle seasonal variations. These new results span all three heliophysics research objectives described in the *2014 Science Plan for NASA's Science Mission Directorate*. Interest in *Wind* data remains very high, even though it's >25 years old, as evidenced by the **over 1065 refereed publications** in Jan. 1, 2017-Dec. 31, 2019 and **over 5355 refereed publications since launch** listed on the *Wind* project Web page: https://wind.nasa.gov. As of May 25, 2020 (from NASA ADS), these publications have amassed **over 139,380** citations, **over 962,000** reads, **an h-index of 139**, and **an i10-index of 2926**. The *Wind* science data products are publicly served directly from the instrument team sites and CDAWeb, with a single project webpage containing links to and descriptions of the large number of *Wind* data products. SPDF CDAWeb has registered **>10,811,600 data access requests equivalent to >20.1 TB total data downloads** for *Wind* alone between Jan. 1, 2017 and Jan. 1, 2020 (not including OMNI of which *Wind* is a critical component). There have also been 10 doctoral and 1 Masters degrees (123 total graduate degrees since 1994) completed using *Wind* data, and 21 are currently in progress. Finally, *Wind* continues to remain a relevant mission as evidenced by recent press releases and high impact publications (i.e., **9 in *Nature* and 3 in *Phys. Rev. Lett.*** since 2017), for instance at:
25 Years of Science in the Solar Wind;
Solving Coronal Heating Mystery.

Because of its longevity, *Wind* observations have allowed researchers to compare long-term variations in solar wind properties, solar wind transients, micron-sized dust fluxes, and solar radio emissions from the end of solar cycle 22 through all of cycle 24 without needing to compensate for changing instrumentation and calibration.

Wind has also contributed critically to multi-mission studies, as part of the Heliophysics System Observatory (HSO). With its ample fuel reserves, sufficient for >90 years, *Wind* will continue to provide accurate solar wind input for magnetospheric studies (supporting MMS and THEMIS) and serve as the 1 AU reference point for outer heliospheric (e.g., *Voyager*, MAVEN, JUNO) investigations, in addition to providing critical support for other missions (e.g., STEREO, ACE, DSCOVR, etc.) as well as *Parker Solar Probe* and *Solar Orbiter* in the inner heliosphere. Moreover, new *Wind* results will continue to improve theories of solar wind heating and acceleration, and energetic particle acceleration and transport processes. ***Wind* will continue to provide critical measurements to complement the observations made by *Parker Solar Probe* and *Solar Orbiter* which will enable researchers to relate the solar wind at 1 AU to its coronal source and compare radio burst power with source locations.**

Rationale for Continuing the *Wind* Mission

- *Wind* continues to provide unique, robust, and high resolution solar wind measurements
- *Wind* serves as the 1 AU reference for *Parker Solar Probe* and *Solar Orbiter*
- *Wind* also serves as the 1 AU reference for outer heliospheric missions
- *Wind* aids in cross-calibration efforts for multiple NASA and non-NASA missions
- *Wind* still has redundant systems, instruments, and enough fuel for >90 years
- *Wind* remains very scientifically productive as evidenced by publication rate

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1 The *Wind* Spacecraft

1.1 Historical Background

The *Wind* spacecraft was launched on November 1, 1994 with a Delta II rocket. *Wind* and *Polar* were of the stand-alone components of the Global Geospace Science (GGS) Program, a subset of the International Solar Terrestrial Physics (ISTP) Program which included the additional missions *Geotail*, SOHO, and *Cluster*. *Wind*'s original name was *Interplanetary Physics Laboratory* while its GGS partner *Polar* was short for *Polar Plasma Laboratory*. This is, in part, why the name for the *Wind* spacecraft was sometimes written in all capital letters though it was never an acronym. *Wind*'s original purpose was (1) to make accurate in-situ measurements of interplanetary conditions upstream of the magnetosphere to complement measurements made in the magnetosphere by *Polar* and *Geotail* and (2) to remotely sense interplanetary disturbances for possible future predictive purposes. The instruments were therefore designed to make highly accurate solar wind measurements.

Prior to May 2004, *Wind* performed a series of orbital maneuvers (see Figure 2) that led to: ∼67 petal orbits through the magnetosphere; out of the ecliptic plane lunar rolls in April and May of 1999; four east-west prograde 1:3–Lissajous orbits reaching $\gtrsim$300 R_E along the ±Y-GSE direction between August 2000 and June 2002; and an excursion to the L2 Lagrange point from November 2003 to February 2004 (i.e., >220 R_E downstream of Earth and ∼500 R_E downstream of ACE). In May 2004, *Wind* made its final major orbital maneuver and was inserted into an L1 orbit, where it has remained and will continue to remain for the foreseeable future. Note that *Wind*'s L1 orbit has a ±Y-GSE displacement about the sun-Earth line of ∼100 R_E, much larger than ACE or DSCOVR.

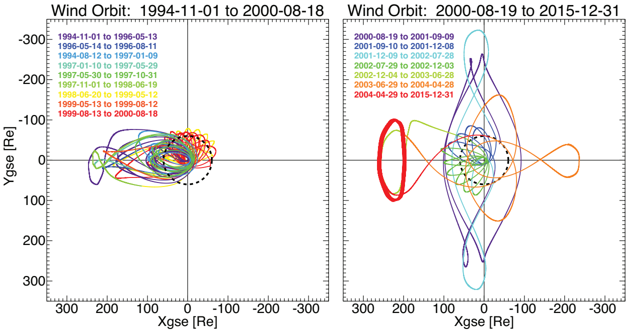

Figure 2: *Orbital trajectories of the Wind spacecraft in the GSE XY plane from 1 November 1994 to 31 December 2015. Colors denote time ranges as indicated. The dashed black circle indicates the Moon's orbit. Note that the orbit has not noticeably changed since 31 December 2015.*

However, in the current orbit, there will be a few intervals in 2020-2022 when the spacecraft will enter the solar exclusion zone – the region in close proximity to the sun-Earth line when ground stations cannot contact spacecraft due to strong solar radio emission – for durations longer than ∼3 days. The flight operations team has already prepared options to mitigate this issue, including halo orbit insertion maneuvers and command table uploads to handle long-duration periods without ground contact. More details can be found in Section 4.5.

1.2 Current Status

The *Wind* spacecraft continues to operate in good health. In 2000, the communications system was successfully reconfigured to enhance the telemetry margin. Reliance on a single digital tape recorder (with two tape units, TUA and TUB) since 1997 has never hampered operations, and measures have been taken to minimize its use in order to extend tape recorder life as long as possible. For more details about the spacecraft health/status, see Section 4.1.

Seven of the eight *Wind* instruments, including all of the particles and fields instruments, remain largely or fully operational. The EPACT, high energy particle, and SMS solar wind composition instruments have suffered some degradation, but both continue to provide valuable measurements. The SWE electron instrument required some reconfiguration to maintain its capabilities. The TGRS γ-ray detector has been turned off, as planned, due to having insufficient coolant to operate. For technical details about instrument capabilities see Table 1 and for details about status/health see Section 4.2.

In conclusion, *Wind* is operationally healthy and continues to maintain a large fuel reserve, capable of sustaining the spacecraft at L1 for >90 years.

Table 1: Operational Instruments on *Wind*

Instrument	Type	Cadence	Range	Resolution/Comments
MFI[a]				**Nominal**
	3 $B_{o,j}$	∼11–22 sps[b]	±4 – ±65,536 nT	±0.001 – ±16 nT
WAVES[c]				**Nominal**
TDS Fast	2 δE_j	∼1.8–120 ksps	∼0.1–300 mV/m	∼80 μV rms
TDS Slow	1 or 3 δE_j	∼0.1–7.5 ksps	∼0.5–300 mV/m	∼300 μV rms
	1 or 3 δB_j	∼0.1–7.5 ksps	∼0.25 – ≳30 nT	$\sim 10^{-9}$ nT^2 Hz^{-1} @ 100 Hz
TNR	1 δE_j	∼1 min	∼4–256 kHz	∼7 nV Hz$^{-1/2}$
RAD1	2 δE_j	∼1 min	∼20–1040 kHz	∼7 nV Hz$^{-1/2}$
RAD2	2 δE_j	∼1 min	∼1.1–14 MHz	∼7 nV Hz$^{-1/2}$
3DP[d]				**Nominal**
EESA	Electrons	∼3–22 s	∼0.003–30 keV	∼20% $\Delta E/E$, ∼5.6–22.5°
PESA	Ions	∼3–75 s	∼0.003–30 keV	∼20% $\Delta E/E$, ∼5.6–22.5°
SST Foil	Electrons	∼12 s	∼25–400 keV	∼30% $\Delta E/E$, ≳22.5°
SST Open	Protons	∼12 s	∼25–6000 keV	∼30% $\Delta E/E$, ≳22.5°
SWE[e]				**VEIS Off**, **Strahl Reconf.**[j]
FCs	H$^+$ & He^{2+}	∼92 s	∼0.15–8 keV	∼6.5% $\Delta E/E$
Strahl	Electrons	∼12 s	∼0.005–5 keV	∼3% $\Delta E/E$
				∼3° × 30°
				Reconf. >Aug. 2002
SMS[f]				**SWICS Off**, **MASS Reduced**
STICS	H – Fe	≳3 min	∼8–226 keV/e	∼5% $\Delta E/E$, ∼4° × 150°
			1–60 amu/e	∼12% $\Delta M/M$
EPACT[g]				**IT off**, **APE Reduced**
LEMT	He – Fe	≳5–60 min	∼2–12 MeV/n	≳20% $\Delta E/E$
			∼2–90 Z	≳2% $\Delta Q/Q$
STEP	H – Fe	≳10 min	∼0.02–2.56 MeV/n	≳30% $\Delta E/E$
				∼17° × 44°
				Nominal
KONUS[h]	Photons	≳2 ms	∼0.02–15 MeV	≳5% $\Delta E/E$
		≳3 s	∼0.02–1.5 MeV	Background Mode

[a] Lepping et al. [1995] (see Appendix Acronyms and Initialisms for acronym/initialism definitions)
[b] samples per second [c] Bougeret et al. [1995] [d] Lin et al. [1995] [e] Ogilvie et al. [1995] [f] Gloeckler et al. [1995]
[g] von Rosenvinge et al. [1995] [h] Aptekar et al. [1995] [i] Owens et al. [1995] [j] see Section 4.2 for more details

1.3 *Wind*'s Unique Capabilities

Wind's complement of instruments was optimized for studies of solar wind plasma, interplanetary magnetic field, radio and plasma waves, and of low energy particles. The instrument suite is not equivalent to that of ACE; rather the two missions complement each other. ACE – launched ∼3 years after *Wind* – focuses on the detailed investigation of high energy particles for which *Wind* has more limited capabilities. Several of *Wind*'s solar wind, particle, radio, and plasma wave instruments are unique. *Wind*'s instrument capabilities are summarized in Table 1. ***Wind* makes unparalleled observations of low energy particles, radio waves, and the solar wind**

near the Earth. More details about *Wind*'s unique capabilities are discussed in the following paragraphs.

Wind is unparalleled in its capacity for high making time resolution (HTR) measurements of quasi-static magnetic fields (with MFI) and thermal solar wind electrons (with 3DP). Though STEREO/SWEA has a higher cadence in burst mode, the low energy ($\lesssim$60 eV) electrons cannot be measured by this instrument. The MMS spacecraft's FPI detectors can also measure much faster than *Wind*/3DP, but FPI was not designed for the solar wind causing it to over(under) estimate the temperature(density). *Parker Solar Probe* also has the capacity to measure the electrons at a faster absolute cadence, but near its closest approach to the sun the cadence normalized to physical time scales will be comparable to or slower than *Wind*/3DP at 1 AU. Thus, *Wind*/3DP retains the highest relative time resolution for accurate measurements of thermal electrons in the solar wind.

Wind/MFI offers continuous coverage of the quasi-static magnetic fields at ∼11 samples per second (sps) over the entire mission (∼22 sps when *Wind* was within $\lesssim$100 R_E of Earth). Although the DSCOVR magnetometer has a ∼50 sps rate data product, it only covers ∼5 years of solar wind observations, it's not publicly available on SPDF/CDAWeb, and it's less accurate than *Wind* data. The highest cadence of the ACE magnetometer data on SPDF/CDAWeb is ∼1 sps, a factor of ∼11 slower than *Wind*/MFI. Thus, *Wind*/MFI has the highest sample rate of science-quality magnetic fields for the longest continuous solar wind measurements.

Wind/STICS is unique among currently operational spacecraft as it is the only sensor in the solar wind fully dedicated to providing measurements of heavy ions for an energy range spanning ∼6.2–223.1 keV/amu. STICS is a time-of-flight mass spectrometer, it can differentiate many minor ionic species and look at their characteristics in the suprathermal energy range to better understand their origin. In addition, *Wind*/LEMT provides high energy particle data over a range of energies not covered by ACE (i.e., ∼1–10 MeV/amu).

The *Wind*/WAVES instrument provides unique radio observations from near the Earth in the 4 kHz to 14 MHz frequency range. Wind is the only spacecraft at L1 that consistently observes the upper hybrid line (or plasma line), which provides the most accurate and only unambiguous measurement of the total electron density in the solar wind. Thus, the density - normally obtained as a moment of or fit to the velocity distribution function from particle instruments like SWE and 3DP - can be accurately and independently verified using the WAVES instrument. **The WAVES instrument provides the only method for an independent, in-flight, and absolute calibration for particle instruments near Earth.** Combined with radio observations from STEREO and *Parker Solar Probe*, *Wind*/WAVES provides an essential third vantage point for unambiguously localizing inner heliospheric radio sources in addition to their beam patterns.

The *Wind*/WAVES instrument can also be used for solar energetic particle (SEP) studies. For instance, Kahler et al. [2019] compared Type II radio bursts and SEPs with with the width and speed of CMEs. *Wind* is still the only near-Earth spacecraft which can measure both the electromagnetic and particle signatures of SEP events.

Finally, *Wind* and ACE are the primary data sources for the widely-used near-Earth OMNI dataset found on SPDF/CDAWeb. In fact, when *Wind* data is available and it's within the ellipse of ACE's L1 orbit, it is chosen as the primary spacecraft for solar wind plasma and field data (data coverage is >98.5% of the time as discussed in Section 4.1). **Thus, *Wind*'s distinct capabilities make it an essential asset to the Heliophysics community and a critical component of the HSO.**

1.4 Success of Old Prioritized Science Goals

Due to the limited space in the proposal and the changing requirements for the mission moving into an Infrastructure Operations Mode (see justification in Section 2), the successful achievement of the Prioritized Science Goals from the 2017 *Wind* Senior Review will be only discussed briefly. This success is amplified by the sheer number of refereed publications – **over 1065 between Jan. 1, 2017 and Dec. 31, 2019, i.e., since the last Senior Review**. Below we highlight some of these studies.

Old Prioritized Science Goals

1. Wave- and/or Turbulence-Particle Studies
2. Unusual Solar Cycle
3. Particle Acceleration
4. Long-Term Dust Science

Numerous studies since the last Senior Review have examined wave-particle or turbulence-particle interactions [e.g., Klein et al., 2018; Verscharen et al., 2019; Woodham et al., 2018]. All of these studies capitalized on *Wind*'s unique complement of high resolution instrumentation and highly calibrated data. *Wind*'s longevity – launched at the end of cycle 22 and expected to continue well into solar cycle 25 – has also made it a prime source of data for solar cycle studies, including the unusual behavior of cycle 24 [e.g., Alterman & Kasper, 2019; Kharayat et al., 2018; Li et al., 2018]. Similarly, there have been numerous studies examining the topic of particle acceleration [e.g., Lario et al., 2018; Miteva et al., 2018a; Reames, 2019; Richardson et al., 2018]. Further, progress has been made in dust science using *Wind* observations [e.g., Kellogg et al., 2018; Sterken et al., 2019] including an unexpected, exciting collaboration with the AIM mission (see Section 3.3 for details) and multiple studies using the *Wind* dust impact database [Malaspina & Wilson III, 2016].

Recent *Wind* studies studies have even discovered fundamentally new science. For instance, the zone of preferential ion heating near the sun [Kasper & Klein, 2019] or that the solar wind electrons may be experiencing inelastic collisions [Wilson III et al., 2019a,b, 2020]. This is evidenced as flattop velocity distribution functions, a result recently discovered to also play a role in ions closer to the sun [Martinović et al., 2020]. Other work has shown that most of the solar wind is unstable to kinetic instabilities [Klein et al., 2018; Wilson III et al., 2020] suggesting that kinetic-scale processes should be included in solar wind evolution models. *Wind* is also responsible for generating the first long-term, statistical study of T_e/T_p ratios (and other temperature-dependent parameters) in the solar wind [Wilson III et al., 2018]. The parameter T_e/T_p is critically important for numerous heliospheric and astrophysical models and relates to the fundamental issues of energy partition and the equation of state of the system.

Two examples of *Wind*'s continued relevance to the science community are shown in Figure 3. Panel (a) illustrates the difference between old expectations and new observations of low Mach number, low plasma beta, quasi-perpendicular shocks. Early models and theory suggested that such shocks should have a laminar magnetic field profile [e.g., Mellott, 1985, and references therein]. However, Wilson III et al. [2017] showed that these shocks can have turbulent magnetic field profiles, with the peak amplitude of the fluctuations on average ~220% of the magnetic amplitude of the shock ramp. That is, the largest magnetic field gradients in these shocks are due to the magnetosonic-whistler precursor waves not the shock ramp.

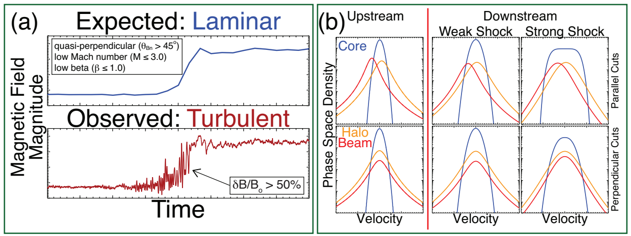

Figure 3: ***Example New* Wind *Results:*** *Panel (a) shows a figurative example of previous expectations versus the new reality revealed by recent* Wind *results [Wilson III et al., 2017]. Panel (b) illustrates how the electron velocity distribution function components evolve across weak and strong collisionless shocks, highlighting a paradigm shifting new view of energy partition in collisionless plasmas [adapted from Figure 10 in Wilson III et al., 2020].*

Figure 3b shows typical examples of how the three components of the electron velocity distribution function – core, halo, and beam/strahl – evolve across weak and strong collisionless shocks

[Wilson III et al., 2020]. The work describes for the first time how these populations evolve through collisionless shocks. This study indicates deviations from bi-Maxwellian particle distributions at shocks (such as the flattop core distribution – called a self-similar velocity distribution – in Figure 3 commonly observed downstream of strong shocks) that are not included in fluid or kinetic models and may lead to new paradigms for shock and kinetic theory. That is, the self-similar velocity distribution deviates from a bi-Maxwellian in the presence of inelastic collisions. The studies also illustrate the critical importance of both accurate and high resolution solar wind measurements in addition to providing a useful baseline for other missions such as *Parker Solar Probe* and *Solar Orbiter*. ***Wind* continues to not only contribute to the interpretation of observations from other heliophysical missions but also generate high impact, fundamentally important results in space and astrophysical plasma physics.**

2 Infrastructure Implementation

Based upon the new guidance and definition of a an infrastructure mode of operations, the *Wind* team has determined that the mission has been effectively operating in infrastructure mode – no directed science funding and a flat, minimal budget – since at least 2013. The mission does not have sufficient funds to support the new definition of a Science Investigation proposal, i.e., where the project scientist uses mission funded researchers to direct scientific investigations. All science investigations performed by the *Wind* team are part the normal data calibration and validation operations required for a mission to maintain operational status as a scientific laboratory. All Prioritized Science Goals from previous Senior Review calls were chosen based upon inferences and predictions of what the community was most likely to study, i.e., no directed science funds were available to ensure success. As will be discussed in Section 6, the mission has been operating on a flat budget for the periods covered by the last two senior reviews with no plan for budget increases/overguides.

Despite the modest budget that typically offers slightly less than a full FTE per instrument suite, the mission continues to produce a large quantity of and high quality scientific results. Further, there have been new data sets from the SMS, 3DP, EPACT, and KONUS instruments released since the last Senior Review with several more in progress. The evidence of data quality and quantity is shown by: the publication record; the heavy use of data from SPDF/CDAWeb; and the number of missions with which *Wind* coordinates in the Heliophysics System Observatory or HSO (for more details, see Section 3).

In summary, *Wind* is one of the most productive missions in the HSO, it operates on a minimal budget, and yet the team continues to produce new results and data products. The mission has already been operating under what is now being referred to as infrastructure mode since at least 2013, thus justification for re-labeling the mode of operation is obvious.

3 *Wind* in the HSO

As part of the Heliophysics System Observatory (HSO), *Wind* has been contributing to numerous science investigations that rely on multi-spacecraft observations. Some of these have been mentioned in the preceding sections. In addition, *Wind* observations are critical to the interpretation of observations from many other spacecraft. This is evidenced by the **over 1065 refereed publications and the >10,811,600 *Wind* data access requests on CDAWeb between Jan. 1, 2017-Dec. 31, 2019, i.e., since the last Senior Review.** This section outlines some of the functions of *Wind* in the HSO.

3.1 Inner Heliospheric Missions

ACE: *Wind* and ACE have been working under mutual calibration support for several years in order to increase the scientific value of each mission. Although ACE has already transitioned into infrastructure mode ahead of the current senior review, the two missions will continue to cross-calibrate their data. *Wind*'s capacity to measure the total electron density using the WAVES radio receivers to observe the upper hybrid line or plasma line (e.g., Section 1.3), coupled with two independent thermal ion plasma measurements (3DP and SWE), gives *Wind* three separate measurements for cross-calibration, resulting in highly accurate thermal plasma observations which can be used to calibrate with ACE. Further, the SWE instrument can operate even during intense high energy particle events associated with solar flares and CMEs, which can disrupt the ACE plasma instrument. The robustness of *Wind*'s instrumentation and measurements makes it a invaluable asset for near-Earth solar wind monitoring.

The spin axes of *Wind* and ACE are orthogonal to each other, which provides an opportunity for magnetic field cross-calibration. The spin plane components measured by a fluxgate magnetometer are most accurate, so the orthogonality of the spacecraft spin planes allows the out-of-the-spin-plane components to be calibrated when the two spacecraft are in near proximity to each other.

The EPACT-LEMT telescope on *Wind* can observe particles in the ∼1–10 MeV/nuc range, which falls between the energy ranges of the ULEIS and SIS instruments on ACE. The ecliptic south spin axis of *Wind* allows the LEMT telescope to measure flux anisotropies. LEMT also has the advantage that due to the configuration of the IMF, the south-pointing *Wind* spin axis is better suited for measuring energetic particle flux anisotropies than the sun-pointing spin axis of ACE. In addition, the larger geometric factor of EPACT allows it to observe lower intensity solar energetic particle events than the ACE instrumentation. An SEP event catalog using LEMT observations has been created by Miteva et al. [2018b]. ***Wind* provides significant and unique calibration information for ACE and makes complementary measurements that facilitate collaborative studies.**

DSCOVR: The Deep Space Climate Observatory (DSCOVR) was launched on Feb. 11, 2015. DSCOVR is tasked to provide solar wind proton and magnetic field measurements from L1 (the same region where *Wind*, ACE and SOHO operate) for NOAA space weather prediction purposes.

Wind has been an essential calibration tool for DSCOVR and is the primary reference for DSCOVR plasma data trending and anomaly tracking. For example, in 2015–2016, during the extended commissioning period for the DSCOVR Faraday Cup (FC) measuring solar wind plasma, grounding and charging anomalies threatened to significantly degrade the instrument. *Wind*/SWE measurements of solar wind protons were used as a standard for a full recalibration of the FC response, a characterization of the anomalous instrument backgrounds, and a revision of the operating mode that enabled the instrument to meet requirements. There are parts of the DSCOVR FC electronics that are degenerating, so the team is working to mitigate those issues. Public release of science-grade data from DSCOVR began in late 2016, enabling joint *Wind*-DSCOVR investigations to begin. However, in June 2019 DSCOVR was placed in a safe hold mode of operations. Although new attitude and control commands have been implemented to operate the spacecraft using only the star trackers, NOAA has requested a combination of ACE and *Wind* data to be used as a back up in case of further issues, in addition to planning for operations following on from DSCOVR.

STEREO: After the loss of contact with STEREO-Behind in October 2014, STEREO-Ahead is the only spacecraft providing observations at ∼1AU well separated from Earth. Combined *Wind*-STEREO observations provide insight into the evolution of solar wind structures near the ecliptic at 1 AU in space and time, and on the variation of solar particle events with heliolongitude. The spacecraft also both make radio observations that can be combined to track solar radio emissions in the inner heliosphere. In particular, *Wind*/WAVES observations are included in the STEREO daily radio summary plots https://swaves.gsfc.nasa.gov/cgi-bin/wimp.py which provide a multi-point view of solar radio emissions.

MAVEN: The Mars Atmosphere and Volatile EvolutioN Mission (MAVEN), designed to study the Martian atmosphere, arrived at Mars (∼1.5 AU) on September 22, 2014. Mars remained on the far side of the sun, relative to Earth, until early 2016 and moved toward ∼90° relative to the sun-Earth line in early 2017. It is currently ∼90° ahead of Earth and ∼180° ahead of STEREO-Ahead. Thus, the *Wind*-STEREO-MAVEN missions form a unique constellation of spacecraft allowing for in–situ plasma and remote radio measurements of large transients in the inner heliosphere for both observational and simulation studies of space weather.

PSP and SolO: *Parker Solar Probe* (PSP) [Fox et al., 2016] launched on August 12, 2018 and *Solar Orbiter* (SolO) [Müller et al., 2013] launched on February 9, 2020. The primary scientific goal of PSP is to determine the processes responsible for heating and acceleration of the solar corona and solar wind. These processes (e.g., instabilities, wave-particle interactions) tend to take place on very small time scales near the Sun that are barely resolvable even by the extremely high cadence PSP instruments. However, near 1 AU, the same processes operate more slowly making their observation by *Wind* possible. *Wind* produces significant and relevant data that contribute to studies helping to improve the science output of these flagship missions and provide testable predictions for these missions.

Wind continues to produce significant and relevant studies helping to improve the current and future science output and predictions/tests for these two flagship missions. Only the high resolution of *Wind* measurements can provide an appropriate 1 AU baseline for both missions. The short ∼88 day orbit of PSP and the ∼0.3–0.76 AU orbit of SolO will provide frequent radial and magnetic field alignments with *Wind* allowing for multi-spacecraft studies that will significantly enhance the science return of both PSP and SolO. In particular,such periods of radial or magnetic alignment will allow researchers to finally separate transport effects from local energization. **Thus, *Wind* will continue to help identify and investigate temporal vs. spatial variations and local vs. large scale phenomena in conjunction with STEREO-A, PSP and SolO.**

3.2 IBEX and *Voyager*

Wind observations have usually supplied the 1 AU baseline for deep space observations (e.g., the two Voyager spacecraft) since the IMP 8 magnetometer stopped returning data in 2000. **The robust and continuous solar wind measurements from *Wind* are essential for studies ranging from the predicted position of the termination shock and heliopause**, also observed remotely by IBEX, **to the evolution of solar wind transients from the inner-to-outer heliosphere.**

3.3 Magnetospheric Missions

Nearly all magnetospheric investigations utilize, in some way, data from an upstream solar wind monitors such as *Wind* either directly or indirectly via the OMNI database. This is partly evidenced by the **>10,811,600 data and FTPS access requests** registered by SPDF/CDAWeb for *Wind* alone (i.e., not including OMNI) between Jan. 1, 2017 and Jan. 1, 2020. Missions relying on *Wind* for solar wind data include *Cluster*, THEMIS, ARTEMIS, *Van Allen Probes* (recently decommissioned), and MMS. In addition, the long duration dust impact database obtained from WAVES observations [Malaspina & Wilson III, 2016] offers a unique baseline of comparison against the AIM SOFIE experiment, which measures meteoric smoke. Therefore, *Wind* will remain a crucial element in magnetospheric studies through 2025.

MMS: The four spacecraft MMS mission launched on March 13, 2015, relies heavily upstream monitors including *Wind* for various reasons (e.g., determining the distance to the magnetopause from MMS). Although MMS may occasionally encounter the solar wind, the MMS thermal plasma instruments cannot fully resolve the solar wind electrons and ions. *Wind* data provide a critical cross-calibration of the MMS solar wind observations. **Thus, *Wind* will continue to provide high quality solar wind observations in support of magnetospheric and solar wind**

studies by the MMS mission.

THEMIS/ARTEMIS: All five THEMIS spacecraft, launched February 17, 2007, are equipped with high cadence (∼3s in burst mode) plasma distribution function observations allowing for very precise, multi-spacecraft studies. *Wind* provides a critical monitor of the interplanetary environment for interpretation of THEMIS measurements. For instance, the recent discovery of relativistic electrons generated locally within the ion foreshock [Wilson III et al., 2016] relied heavily on *Wind* radio and energetic particle observations to rule out a solar source. *Wind* data were also used to calibrate the THEMIS thermal plasma instruments [McFadden et al., 2008a,b] since their electric field receivers do not consistently observe the upper hybrid line.

The two THEMIS spacecraft in permanent lunar orbits, called ARTEMIS, spend a large fraction of their time in the ambient solar wind beyond Earth's bow shock. This allows for high quality multi-spacecraft solar wind studies in combination with *Wind* observations, for example, to determine the large-scale structure of interplanetary shocks [Kanekal et al., 2016] or to cross-calibrate the plasma instruments [Artemyev et al., 2018].

AIM: The ∼20 year dust impact database [Malaspina & Wilson III, 2016] provides an unprecedented baseline of micron-sized dust count rates in the near Earth environment, and is probably the longest continuous micron-sized dust data product. The database could provide new understanding of mass, momentum, and energy flow carried by dust throughout the heliosphere. The SOFIE instrument on the AIM spacecraft (launched April 25, 2007) observes meteoric smoke – the product of meteoroid ablation (at ∼75–110 km altitude) – in Earth's mesosphere. A cursory survey by the SOFIE team found annual variations in meteoric smoke consistent with the dust count rates observed by *Wind*, indicating that the *Wind* observations may provide insight into the interpretation of SOFIE data.

3.4 Solar and Astrophysics

Solar Flares: During its more than 25 year-long history, the KONUS instrument onboard *Wind* has accumulated an unique volume of solar flare observations in the hard X-ray and gamma-ray range. Data on solar flares recorded by KONUS in the triggered mode are published online (http://www.ioffe.ru/LEA/kwsun/). This database (named KW-Sun) provides light curves with high temporal resolution (up to 16 ms) and energy spectra over a wide energy range (now ∼20 keV to ∼15 MeV). The high time resolution of KONUS allows for the study of fine temporal structure in solar flares; and the KONUS energy band covers the region of non-thermal emission from electrons and ions in solar flares, which allows probing their acceleration mechanisms. New solar observations are added to the database as soon as they arrive. The list of KONUS triggered-mode solar flares from 1994 to the present, along with their GOES classification, is automatically updated and available at http://www.ioffe.ru/LEA/Solar/.

Cosmic gamma ray bursts, magnetars, and gravitational radiation: Cosmic gamma ray bursts (GRBs) are the brightest electromagnetic events known to occur in the universe, occurring transiently from the collapse of massive stars or coalescence of compact objects (e.g., two neutron stars or a neutron star-black hole merger) in the early universe. GRBs consist of an initial flash of gamma-rays lasting from milliseconds to minutes followed by a longer duration "afterglow" at radio and optical wavelengths. Over 300 per year are detected by KONUS (roughly 6000 to date). Thanks to advanced LIGO and Virgo, it is now possible to link short gamma-ray bursts to binary neutron star mergers, and to the emission of gravitational radiation.

Soft gamma repeaters (SGRs, or magnetars) are strongly magnetized Galactic neutron stars (surface fields up to 10^{14} G) that emit large bursts of X-rays and gamma-rays at irregular intervals. There are presently only about two dozen known SGR sources. When they become active they emit bursts from a few times up to hundreds of times over spans from days to months.

SGR Giant Flares (GFs) are of greater apparent intensity than GRBs and are very rare, averaging once per decade. Only a handful have been detected to date, and their intensities are sufficient to create easily detectable ionospheric disturbances; indeed KONUS has detected both GFs from SGR 1900+14 and SGR 1806-20. KONUS has also detected a GF from the Andromeda Galaxy.

KONUS was designed to study GRBs, SGRs, and GFs, with omnidirectional, un-occulted sensitivity. It also has broadband sensitivity, coupled with excellent time- and energy resolution. For 25 years, it has been a key component of the Interplanetary Network maintained by Dr. Kevin Hurley (IPN, http://ssl.berkeley.edu/ipn3/index.html), which determines the source directions of transients by triangulation. The primary spacecraft involved in the IPN are *Wind*, *Mars Odyssey*, INTEGRAL, *Swift*, and *Fermi*. In 2022, NASA's Psyche mission will be added. Note that all KONUS data on GRBs are made public (http://www.ioffe.ru/LEA/). KONUS extends the energy range of *Swift* from 150 keV to 10 MeV, a crucial data set for a global understanding of gamma-ray transients, and detects events which are Earth-occulted to *Fermi*. In addition it is generally the most sensitive of the IPN detectors to SGRs (∼350 detections to date), due to its lack of collimation and Earth occultation, and broad energy coverage.

KONUS remains a very active partner in the Gamma-ray Burst Coordinates Network or GCN (https://gcn.gsfc.nasa.gov), maintained by Dr. Scott Barthelmy (NASA-GSFC). The GCN circulates information on bursts rapidly to thousands of astronomers worldwide, who conduct multi-wavelength, and now, also neutrino and gravitational wave follow-up observations. Indeed, with the first detection of gravitational radiation accompanied by a short burst in 2017, KONUS and the IPN have taken on a new role – the search for gamma-ray transients associated with gravitational wave sources, such as the inward spiral of two neutron stars in a binary system. As LIGO's sensitivity increases over the coming years, more detections are expected, ushering in a multi-messenger era of astrophysical observations. As high energy neutrino detections are also becoming more common, a similar symbiosis exists for them. Thus, the instrument remains a unique, active, and irreplaceable contributor to the astrophysical community. **Due to the rarity of these astrophysical events, an additional three years of *Wind* KONUS observations will significantly enhance the events collected by *Swift*, *Fermi*, the IPN, and the GCN.**

3.5 *Wind*, CCMC, and CDAW

The Coordinated Community Modeling Center (CCMC) is tasked to validate heliospheric and terrestrial magnetospheric models. Proper evaluation of the magnetospheric models depends critically on accurate solar wind measurements which drive these models. Historically, *Wind* measurements have been used as the standard. As future models become more complex and increasingly sensitive to uncertainties in the driving conditions, ***Wind* measurements will continue to provide an essential input for the CCMC model validation program.**

Wind and CDAW Data Center

The CDAW Data Center is a repository of CMEs, radio bursts, and associated space weather phenomena (https://cdaw.gsfc.nasa.gov). In particular, *Wind*/WAVES data contribute to the online catalog of CMEs manually identified from SOHO/LASCO images since 1996. This includes a link to a list of CMEs associated with type II radio bursts observed by *Wind*/WAVES, and also daily movies combining SOHO/LASCO images with *Wind*/WAVES dynamic spectra that may be used to identify the connection between CMEs and Type II, III, and IV radio bursts (e.g., Dynamic Movie Creator). Another catalog associates SEPs (observed by GOES) with CMEs and type II radio bursts, since the small subset of Type II-producing CMEs have been found to play a critical role in space weather [e.g., geomagnetic storms, Vasanth et al., 2015] and solar energetic particle (SEP) acceleration. **Thus, *Wind* remains an active partner in the CDAW Data Center.**

4 Technical Implementation

4.1 Spacecraft Health

Wind continues to operate in good health. The communication system was successfully reconfigured in 2000 to enhance the telemetry margins and reliance on a single digital tape recorder (with two tape units) since 1997 has never hindered operations. The flight operations team (FOT) took steps to minimize wear and extend the lifespan of the two tape units. Since the last Senior Review, the spacecraft has experienced the usual instrument latch-ups and single-event upsets (SEUs) that are likely caused by high energy particles. As in the past, the FOT was able to restore all instruments to fully operational within a day or two depending on Deep Space Network (DSN) scheduling. The automation of the recovery process for the WAVES instrument after latch-ups (i.e., due to SEUs) was successfully completed in October 2016 and the spacecraft command tables now include automated tests of the SWE electron instrument. Thus, *Wind* continues to maintain a fully operational status.

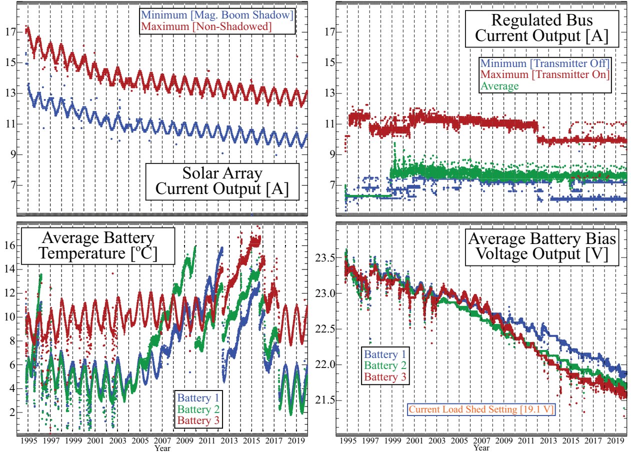
Wind Spacecraft Systems Status [Jan. 1994 to Jan. 2020]

Figure 4: *Summary of* Wind*'s Power System Status:* *The* Wind *spacecraft systems status plotted from Jan. 1, 1994 to Jan. 1, 2020 as daily averages.*

On Oct. 27, 2014 at 21:59:38 GMT, the *Wind* command and attitude processor (CAP) suffered two simultaneous SEUs. The redundant nature of the *Wind* spacecraft bus allowed the FOT to successfully switch to a second CAP, CAP2. The FOT began the recovery of CAP1 on Jan. 21, 2015 and finished Jan. 30, 2015, and the spacecraft was fully recovered at ∼17:50 UTC on Jan. 30, 2015.

The CAP1 anomaly resulted in a complete loss of data from October 27, 2014 until November 7, 2014 (i.e., 11 days or ∼3% annual total) and partial loss from all instruments between November 7–20, 2014 (i.e., 14 days or ∼4% annual total). The SWE instrument suffered complete data loss between October 27, 2014 and November 26, 2014 (i.e., 30 days or ∼8% annual total) and partial loss (HK only) from October 27, 2014 to December 1, 2014 (i.e., 35 days or ∼10% annual total). During the recovery process between Jan. 28–30, 2015 while CAP1 was in control, the attitude/telemetry information was invalid for ∼4 hrs 41 mins (i.e., <5% of those four days).

On April 11, 2016 one of the two tape units (TUA) began experiencing issues related to the read/write head causing ∼few percent data loss per day. The flight operations team successfully switched the primary record unit to TUB on May 6, 2016 to extend the life of TUA and reduce data loss. TUB is fully operational and averages >98.5% data recovery rates.

An examination of the spacecraft power systems (see Figure 4) shows that the batteries can maintain average bias voltages high enough to exceed the current load shed setting of 19.1 V until at least mid-2056 based on an extrapolation beyond the date range of the lower right panel. To cause a spacecraft reset, all three batteries must simultaneously fall below this load shedding voltage level which is commandable from the ground and will be changed when necessary to avoid a spacecraft reset. The load shedding can be safely reduced to at least 18.2 V (reached at least 20 years beyond 2056 based on present trends).

Since the last Senior Review, all three batteries went through mode changes to reduce the maximum charge voltage. Each battery was experiencing excess charging, causing an increase in temperature (see lower-left-hand panel in Figure 4) and reduction in efficiency. The mode changes successfully reduced the temperatures to nominal ranges. The current trend shows that the battery temperatures will not exceed the critical threshold of ∼17°C until well after the year ∼2100.

The solar array output is producing more than enough current for spacecraft operations and will continue to do into early ∼2044, assuming that the maximum current drawn from the batteries (i.e., red line in upper right in Figure 4) does not exceed the average solar array output (not shown). The maximum solar array output (i.e., red line in upper left-hand panel) will not drop to the maximum regulated bus output until mid ∼2058, assuming current trends hold. Therefore, *Wind* can operate at current capacity for the next several decades.

Wind continues to maintain a large fuel reserve showing ∼52.5 kg remaining, which is equivalent to ∼105 m/s of radial delta-V assuming normal thruster operations. Typically only four station keeping maneuvers are performed each year, each requiring only ∼0.13 kg of fuel. Thus, *Wind* has enough fuel for >90 years.

4.2 Instrument Status

Seven of the eight *Wind* instruments, including all of the fields and particles suites, remain largely or fully functional. The only instrument fully turned off is the TGRS γ-ray instrument that was designed for only a few years of operations (instrument off prior to ∼January 2000). The general status of all instruments is summarized in Table 2. The specific degradations in instrument capabilities are described in the following discussion.

Table 2: The status of the *Wind* instruments

Instrument	Principal Investigator	Institution	Status
SWE	L.B. Wilson III (acting)	Electrons: GSFC, UNH Ions: SAO	Strahl detector reconfigured Faraday Cup fully operational
3DP	S.D. Bale	UC Berkeley	Fully operational
MFI	A. Koval	GSFC/UMBC	Fully operational
SMS	S. Lepri	U. Michigan	SWICS turned off MASS reduced coverage STICS fully operational
EPACT	I. Richardson	GSFC/UMCP	IT turned off APE – only 5 and 20 MeV protons LEMT and STEP operational
WAVES	R. MacDowall	GSFC	Fully operational
KONUS	R. Aptekar	Ioffe Institute, Russia	Fully operational
TGRS	B. Teegarden	GSFC	Intentionally turned off (ran out of coolant)

The EPACT APE-A/APE-B/IT high voltage power supply (HVPS) suffered a loss of gain in October 1995. The EPACT-APE detector only returns two energy channels of ∼5 and ∼20 MeV protons during enhanced periods. The EPACT-LEMT and -STEP telescopes continue to operate normally, providing crucial and unique observations of solar energetic particles up to 10 MeV in energy. The SMS-SWICS solar wind composition sensor had to be turned off in May 2000. The SMS DPU experienced a latch-up reset on 26 June 2009 causing the MASS acceleration/deceleration power supply to stay in a fixed voltage mode, rather than stepping through a set of voltages. The moderate risk of power cycling of the SMS DPU required to fix this issue was declined to protect the unique and fully functional SMS-STICS sensor. In 2010, MASS experienced a small degradation in the acceleration/deceleration power supply further reducing the instrument efficiency. However, the SMS-MASS sensor still returns science quality data.

The VEIS thermal electron detectors on the SWE instrument suffered high voltage power supply problems in June 2001. In August 2002 the SWE Strahl sensor was reconfigured to recover most of the original functions. Moreover, the 3DP instrument also covers the impacted electron measurements making these observations still redundant and hence robust. The entire SWE instrument suite required a full reset due to the CAP anomaly (see Section 4.1 for details), which resulted in a complete loss of data from late Oct. 27, 2014 to Nov. 26, 2014, and partial loss until Dec. 1, 2014 when the instrument was returned to nominal operations.

On May 2014 the 3DP instrument (specifically PESA Low) suffered an anomaly that only affected the telemetry house keeping (HK) data. A quick investigation showed that while the telemetry information (e.g., micro-channel plate grid voltage) showed unreliable instrument operations information, the science data remained unaffected (i.e., no noticeable change in flux was observed during and after event). All the other detectors within the 3DP instrument suite continue to operate nominally. Thus, the anomaly resulted in no loss of scientific data.

Aside from the complete or partial data losses due to the 2014 CAP and 2016 tape unit anomalies (see Section 4.1 for details), all of the instruments continue to be fully functional. **The dates of significant instrumental issues are listed below in chronological order:**

October 1995: APE-A/APE-B/IT HVPS suffered a loss of gain
January 2000: TGRS γ-ray instrument turned off (planned coolant outage)
May 2000: SMS-SWICS solar wind composition sensor turned off
June 2001: SWE-VEIS thermal electron detectors HVPS failure
August 2002: SWE-Strahl reconfigured to recover VEIS functionality
June 2009: SMS DPU experienced a latch-up reset – MASS acceleration/deceleration power supply in fixed voltage mode
2010: SMS-MASS experienced a small degradation in the acceleration/deceleration power supply
May 2014: 3DP-PESA Low suffered an anomaly that affected only the telemetry HK data
November 2014: CAP1 anomaly required a full reset of SWE instrument

In summary, there have been no major changes in any instrument's status since August 2002 but a few minor changes between 2010 and late 2014. Otherwise, all instruments that were nominal are still nominal and continue to generate high quality, accurate data products.

4.3 Science Team

The *Wind* instrument/science team is a small but dedicated group of scientists. Due to the longevity of the mission, a number of the original instrument PIs have retired or passed away. Keith Ogilvie retired, thus the leadership of the SWE instrument suite is currently headed by **Lynn B. Wilson III (GSFC, acting)** with Justin Kasper (University of Michigan) leading the SWE Faraday Cup team. **Stuart Bale (University of California, Berkeley)** has taken over as PI of 3DP. **Andriy Koval (GSFC)** recently took over as PI of the MFI instrument replacing Adam Szabo (GSFC), who moved on to other missions. **Sue Lepri (University of Michigan)** is the PI for SMS. Both the original and previous acting EPACT PIs, Tycho von Rosenvinge and Allen Tylka, respectively, recently retired so **I. Richardson (GSFC)** has taken over as the EPACT PI. Dr. Wilson has been Project Scientist for *Wind* since June 2016. The new team brings a great deal of experience and enthusiasm for new discoveries, and looks forward to continuing to support the wide exploitation of Wind data in the community as evidenced by the long and increasing list of *Wind* scientific publications (i.e., **over 1065 refereed publications** between Jan. 1, 2017-Dec. 31, 2019, i.e., since the last Senior Review). Efforts by the new team members have resulted in the release of several new data sets since the last Senior Review, with additional data sets planned to be released before the next Senior Review.

***Wind* Funded Students:** *Wind* observations remain a popular source of material for solar wind, magnetospheric, atmospheric, radio, and astrophysical measurements and a rich source of material for Masters, PhD, and postdoctoral work. Since the last Senior Review, 10 students earned PhDs, at least 1 student earned a Masters degree, and 6 postdocs benefited from *Wind* observations. At present, there are at least 10 Masters and 21 PhD students using *Wind* observations.

4.4 Ground Operations

Wind ground operations take place at Goddard and have fully transitioned from the legacy *Polar*-*Wind*-*Geotail* system to Multi-Mission Operations Center (MMOC) that consolidates *Wind* operations with that of ACE. This transition became necessary with the decommissioning of *Polar* on April 30, 2008 and it included an upgrade of the outdated and costly to maintain hardware and software. *Wind* operations were moved to the MMOC on March 11, 2010 with the MMOC Operational Readiness Review held on March 30, 2010. The automated distribution and archiving of level zero files and production of key parameter (KP) files takes place at Goddard in the Science Directorate under the control of the project scientist. The two server (plus backup) system are periodically upgraded and maintained at modest cost.

For cost saving measures, the flight operations team reduced staffing by 1 FTE in November 2008 and modified shift schedules to reduce operational coverage from twelve to eight hours (reducing the need for overtime and shift differential). With the successful transition of *Wind* flight operations into the MMOC, the staffing levels have been reduced by operating the ACE and *Wind* missions with a combined team that also includes non-traditional flight operations skills (HW/SW maintenance, Flight Dynamics attitude analysis). Re-engineering/upgrading existing systems has improved the efficiency of implementing IT Security and HW/SW maintenance as well as system administration. Automation is being implemented with a unified approach to further increase efficiency (e.g., SWE electron instrument auto-recovery and WAVES recovery after latch ups). The team will continue to cross-train at multiple positions so that prime and backup roles are covered.

The data recovery rate for *Wind* for the years 2017 through 2019 averaged ∼99.1%, ∼99.7%, and ∼98.5%, respectively. Since the recovery from the 2016 TUA anomaly, the median daily data recovery rate has been >99.8%. Most data losses have resulted from Deep Space Network (DSN) errors (i.e., hardware and software issues) or due to schedule conflicts with other spacecraft launches and/or emergencies.

The current operation of *Wind* requires one ∼2 hour DSN support every other day, though contacts occur more frequently sometimes. This allows the up-linking of the Stored Command Table load and the playback of the Digital Tape Recorder (DTR). *Wind* also maintains real-time solar wind monitoring during these 2 hour contacts. In 2001, an attempt was made to reduce the number of DSN contacts, and hence the cost of operations, by scheduling DSN time only once every three days, albeit for longer durations. Reducing the number of contacts saves the lengthy setup and reset times. After extensive testing it was concluded that this scenario did not provide significant savings and introduced critical risks to the mission. *Wind* can store only three days worth of commands, thus this is the longest *Wind* can go without ground contact or the spacecraft performs an emergency load shed. Hence the current flexibility to negotiate contact time with DSN would be eliminated. Also, all of these infrequent contacts would be fully attended regardless of the time of day. Currently about half of the contacts are completely automated allowing the operations staff to keep day schedules. Thus, the current daily contact scenario is considered optimal. It should be noted that all DSN and communication costs are reported as "in-kind" costs so they are not considered part of *Wind*'s operational budget.

4.5 End of Mission Plan

Under the current plan, standard station-keeping maneuvers are made every ∼3 months to maintain *Wind*'s orbit about the first Earth-sun Lagrange point, L1. Shortly, a maneuver will need to be made to avoid long-duration stays in the solar exclusion zone (SEZ) – a region in close proximity to sun when ground stations cannot contact spacecraft due to intense solar radio noise. This will require the use of thrusters which have been inactive for over fifteen years. The flight operations team (FOT) is currently preparing halo orbit insertion options to mitigate this issue. The FOT has already altered the spacecraft command tables to allow the spacecraft to operate for extended periods without contact. This reduces the risk to the spacecraft bus and instruments as the previous configuration would have sent the entire system into a safe mode shutting down all instruments after 72 hours without contact. Recovery from such a load-shed state could take over a week resulting in the complete loss of data. There are also concerns about completely shutting down the HVPS on many of the particle detectors, e.g., they may not return to nominal state.

The FOT successfully tested the axial thrusters necessary for halo orbit insertion on April 29, 2020. There will be an operational readiness review in late May to finalize and approve or reject the plan to go ahead with the first orbit insertion maneuver planned for mid-to-late June 2020. The current plan is to do a series of radial (i.e., along sun-Earth line) and axial (i.e., orthogonal to ecliptic plane) thrusts requiring Δv $\sim$ 36–39 km/s to insert *Wind* into a halo orbit about L1. There is currently $\sim$105 m/s of fuel remaining or $>$90 years in the current orbit. The orbit keeping maneuvers necessary to maintain the new halo orbit are not any more significant, fuel-wise, than the current Lissajous orbit maneuvers. Thus, the plan would reduce the fuel lifetime by $\sim$36%. Normally this would be a significant cost/risk to a mission. However, the spacecraft should still have at least 50 years of fuel left, which is equivalent to twice the current age of the spacecraft, and longer than operational lifetime of any current spacecraft. Therefore, the fuel cost of a halo insertion is not a critical risk factor for the mission.

The orbit shape/profile about L1 will not noticeably change once inserted into a halo orbit. The major change between the current Lissajous orbit and the planned halo orbit is that the Z-GSE component of the orbit will no longer grow and decay, keeping the spacecraft at least $\sim$2 degrees away from the solar disk (when viewed from Earth). This will reduce communication and data loss for the DSN contacts. This is especially important given the current reduced operational/schedule capacity of DSN due to the COVID-19 pandemic.

Due to the orbit regime and heritage of *Wind*, it does not currently have a requirement for an End of Mission Plan (EOMP). For further details please see the *Wind* End of Mission Plan.

5 Data and Code

Data Archiving: Early in its mission, *Wind* and the other GGS spacecraft relied on a very capable and extensive science operations center, the Science Planning and Operations Facility (SPOF). The SPOF was responsible for the collecting, distribution and active archiving of all level zero (LZ) and ancillary data products like Key Parameters (KPs). With the passage of time, and with reducing funding levels, the SPOF had to be turned off and most of its functions were passed on to the instrument teams and to a small operation, the *Polar-Wind-Geotail* (PWG) system, that continued to perform some LZ and KP functions. This unavoidable decentralization resulted in a degree of unevenness and disparity between the various *Wind* instrument data services. To solve this problem, key *Wind* instrument team members rallied around the new distributed Heliophysics Data Environment (HDE) concept and became a founding member of the Virtual Heliospheric Observatory (VHO). The VHO provided a single point of entry for data location without the costly necessity of a dedicated science operations center. As a byproduct, *Wind* instrument data were among the first to be fully documented with the common SPASE dictionary based metadata standard thus providing the user community an even level of descriptions of instruments and data products.

The VHOs are now obsolete and nearly all *Wind* data products can be accessed through SPDF/CDAWeb. Most *Wind* data products are already delivered to SPDF/CDAWeb on a regu-

lar basis following calibration and testing by the instrument teams (see the Mission Archive Plan from the 2017 *Wind* Senior Review). The project scientist has worked closely with the teams to help ensure the continuity and proper flow of data to the final archive. Despite the mission's age, *Wind* instrument teams continue to provide new and unique data products and archive them at SPDF/CDAWeb (at least 9 new data products have been added since the last Senior Review). *Wind* generates a rather large number of data types and products; **∼58 selectable data types with ∼1118 total data products (including OMNI data products) on SPDF/CDAWeb**.
Mission Operations Center: *Wind* ground operations take place at Goddard and the details can be found in Section 4.4.
Software Management: There are multiple different software sources for *Wind* data including a comprehensive, standalone library created by the project scientist at:
https://github.com/lynnbwilsoniii/wind_3dp_pros;
and a standalone graphical user interface (GUI) written by B. Maruca at:
https://github.com/JanusWind
intended for fitting the reduced distribution functions of the SWE Faraday cup data. The original, open source code for decommutation of each *Wind* instrument is freely available at:
https://github.com/lynnbwilsoniii/Wind_Decom_Code.
There are several more software libraries listed/linked to on the *Wind* "Data Sources" page at:
https://wind.nasa.gov/data_sources.php.
Owing to the age of the mission and the loss of key personnel, some of the raw software code is not readily available for distribution. The team has worked to gather and freely distribute any software that is readily available and will continue to add software if it becomes available for distribution.
PDMP and CMAD Status: When *Wind* launched in November 1994, neither PDMP or CMAD (see Appendix Acronyms and Initialisms for acronym/initialism definitions) requirements existed. Thus, neither a PDMP or CMAD currently exist for the *Wind* mission. However, the *Wind* project has made a significant effort to make all of its science data publicly available and independently usable. Data from the *Wind* instruments fully comply with all ISTP requirements providing the associated metadata to enable their inclusion in the SPDF/CDAWeb environment, throughout the mission. In addition, the *Wind* project has collected an extensive library of documentation describing the data products and the algorithms that generated them. This documentation and open source code is described in previous Senior Review MAPs and is publicly available at the following webpages:
https://wind.nasa.gov;
https://wind.nasa.gov/data_sources.php; and
https://wind.nasa.gov/inst_info.php.
PDMP and CMAD Plan: Since changes in operations of the *Wind* mission are not expected, we propose a simplified PDMP that describes the existing operations only at the top level. Our estimate is that this work will require 0.3 FTE of effort.

Due to the retirement and/or passing away of key personnel, significant augmentation of our existing data product algorithm descriptions are not possible. As allowed by the 2020 Senior Review Call for Proposals, we have decided to collect the current versions of the data calibration and production codes for the various instruments in lieu of a written CMAD. We have made these codes publicly available (as previously referenced). In addition, we will perform another deep dive with each instrument team identifying and archiving remaining, previously missed, calibration documentation. These documents will be added to our documentation library on the web, and all of this documentation will be summarized in an expanded MAP-like document for easy referencing. Our estimate is that this effort will take 1 FTE. At present, the *Wind* project does not foresee the need for an overguide budget (i.e., we will find a way to accommodate these responsibilities within our current budget).

6 In-Guide Budget

The in-guide budget described in this section will fund the mission operations necessary to continue the safe operation of the *Wind* spacecraft along with basic data reduction and validation processes performed at the various instrument institutions. As in past Senior Reviews, nearly all of the scientific research outlined in the previous sections is expected to be or was funded through external sources, e.g., the ROSES GI and SR&T programs (or other opportunities) with each element individually proposed and peer reviewed. The only funding allocated for scientific research in *Wind*'s budget occurs indirectly as a result of funding the instrument teams to process and validate the data.

6.1 Budget Spreadsheet

The inputs in the budget spreadsheet Table 3 in Appendix Budget Spreadsheet show the direct and indirect costs for the *Wind* mission. The budget is broken into six sections including (paraphrased labels by topic): **I:** Total; **II:** Functional breakdown; **IIa:** Labor; **III:** Instrument breakdown; **IV:** In-kind costs; and **V:** High-end computing costs. **Section II** separates the costs by mission/flight operations versus communications versus science/data analysis. **Section IIa** itemizes the labor costs, separating out the contractor (WYEs) from the civil servant (FTEs) labor. **Section III** separates the cost by instrument suite/team. **Section IV** itemizes the in-kind costs associated with the mission. Finally, **Section V** lists the high-end computing costs (not relevant to *Wind*). Below we explain the costs included in each line of the budget spreadsheet.

I. Full-cost Totals: Since at least 2013, the Goddard-controlled side of the *Wind* mission has been operating on a flat budget not adjusted for inflation or other time-dependent changes. The *Wind* mission would actually be operating on a $\sim$20% smaller budget than that of 2013 if one assumed a constant 3% inflation rate. The team has managed to accommodate the limited resources by improving efficiency, retirement of senior personnel, reduction of dependence on costly software and hardware maintenance when possible.

II. Functional Items: The *Wind* mission has only two functional line items, mission operations and science data analysis. The former includes all spacecraft commanding, orbit and spacecraft maintenance, and ground systems for level zero file processing. The latter includes costs for all instrument teams, running and maintaining the *Polar*-*Wind*-*Geotail* (PWG) system, minimal hardware and software maintenance costs, and project scientist funds. Note that $\gtrsim$60% of total mission costs are for instrument teams and science data analysis to verify and generate high quality data products. Further details are itemized in **Section IIa** of the budget below.

IIa. Labor: The *Wind* mission relies upon one civil servant Mission Director (0.2 FTE) and several contracting engineers ($\sim$11 WYE) for the FOT portion of the budget. These costs include all level zero file data processing costs, orbit maneuver prediction and implementation, spacecraft commanding and maintenance, DSN scheduling, and ground systems maintenance (i.e., hardware and software maintenance).

All the labor in Science Data Analysis is for civil servants including the project scientist (0.5 FTE), the PWG system software engineer (0.2 FTE), and the rest are distributed among the instrument teams located at GSFC. Note that although a total of $\sim$1.6 FTEs are allocated in the budget for civil service labor, this is not always what the mission uses each year. For instance, the project scientist has rarely used more than 0.375 FTEs since 2016 due to successful grant proposals. In recent years several unsolicited grants have been awarded and the result has been multiple new science data products publicly available at CDAWeb/SPDF (e.g., EPACT STEP data set for entire mission). Thus, any available funds not used for civil service labor have been directed toward improving the scientific output of the *Wind* mission.

III. Instruments: The instrument breakdowns are clearly shown for those that had originally been run by GSFC PIs. The MFI (∼8.5% of total non-MO funds) and SWE (∼10% of total non-MO funds) instruments provide the two most heavily used and reliable data sets. There are two SWE instrument teams, one at GSFC (electrons) and one led by Dr. Justin Kasper at the University of Michigan, Ann Arbor. The MFI funds also include updating and maintaining the *Wind* ICME catalogue. The WAVES (∼3.4% of total non-MO funds) and EPACT (∼5.7% of total non-MO funds) have fewer data products and processing/calibration needs, e.g., EPACT lost IT and APE has a reduced operational status as discussed in Section 4.2. Thus, they receive slightly lower funding than MFI and SWE.

The SMS (∼6.9% of total non-MO funds) and 3DP (∼11% of total non-MO funds) instrument funds are included in the "Other science teams" line. Although the SMS instrument lost SWICS and MASS has reduced operational status, the STICS data are unique and provide nearly a dozen unique ion species in multiple data formats including full three-dimensional velocity distribution functions at ∼3 minute cadence for the entire mission. The 3DP instrument is actually composed of seven unique instruments that cover electrons from a few eV to >500 keV and ions from a few eV to >7 MeV at up to a ∼3 second cadence. Thus, due to the uniqueness, importance, and complexity of calibration the data sets, these two instruments receive slightly higher fractions of the non-MO funds than some other instrument suites. Finally, the KONUS instrument receives no funding from the *Wind* mission.

The remaining costs, including management and mission operations, are all included in the "Other mission expenses" line. The total MO funds per year is nearly flat at ∼39% of the total mission funds. The total funds sent to all instrument teams is similar, in the ∼38–42% range depending on fiscal year. In summary, ∼62% of total non-MO funds are allocated entirely for the instrument teams. Only ∼10% of total non-MO funds (or ∼5.9% of total funds) are used for project management. Thus, ∼28% of total non-MO funds are used for the remaining tasks described in **Section IIa** of the budget table for the "Other mission expenses" line.

IV. "In-kind" Costs: All "In-kind" costs reported line 2.c of **Section IV** of the budget table are for services provided by other sources (e.g., SCAN). The costs are allocated to *Wind* but are not supported with project funds. This line includes costs for mission communication services (e.g., voice and data connections at GSFC), supplemental costs for flight dynamics and flight operations support, and all DSN costs. Again, these costs are not supported with project funds.

V. High-end Computing: The *Wind* mission does not use or require these costs.

Future Level Zero Processing Software: The FOT is working on a plan to update the current, outdated and architecture-dependent level zero processing software. The current software requires substantial funds to keep the system IT security compliant. The FOT has been tasked with developing a plan to write an open source, hardware-independent set of code that can be easily maintained and updated for future architecture and IT security requirements. The effort is not currently expected to incur additional funds provoking the need for an over guide request.

6.2 Data Production Budget

The current *Wind* project budget does not allow any directed science funding. The *Wind* science data products are publicly served directly from the instrument team sites (most are directly available from CDAWeb), with a single project webpage containing links to and descriptions of the large number of *Wind* data products; **∼58 selectable data types with ∼1118 total data products (including OMNI data products) on SPDF/CDAWeb**, which can be found at: https://wind.nasa.gov. The core data calibration and validation work carried out by the individual instrument teams does require some amount of science data analysis to verify the accuracy of the generated data products. A very conservative upper bound on pure science funding resulting from this is ∼15% of the total *Wind* funding or ∼24% of the non-mission operations funding.

References

Alterman, B. L., et al. 2019, *Astrophys. J. Lett.*, **879**, L6, doi: 10.3847/2041-8213/ab2391

Aptekar, R. L., et al. 1995, *Space Sci. Rev.*, **71**, 265, doi: 10.1007/BF00751332

Artemyev, A. V., et al. 2018, *J. Geophys. Res.*, **123**, 9955, doi: 10.1029/2018JA025904

Bougeret, J.-L., et al. 1995, *Space Sci. Rev.*, **71**, 231, doi: 10.1007/BF00751331

Fox, N. J., et al. 2016, *Space Sci. Rev.*, **204**, 7, doi: 10.1007/s11214-015-0211-6

Gloeckler, G., et al. 1995, *Space Sci. Rev.*, **71**, 79, doi: 10.1007/BF00751327

Kahler, S. W., et al. 2019, *Solar Phys.*, **294**, 134, doi: 10.1007/s11207-019-1518-3

Kanekal, S. G., et al. 2016, *J. Geophys. Res.*, **121**, 7622, doi: 10.1002/2016JA022596

Kasper, J. C., et al. 2019, *Astrophys. J. Lett.*, **877**, L35, doi: 10.3847/2041-8213/ab1de5

Kellogg, P. J., et al. 2018, *J. Geophys. Res.*, **123**, 3273, doi: 10.1029/2017JA025173

Kharayat, H., et al. 2018, *Astrophys. Space Sci.*, **363**, 87, doi: 10.1007/s10509-018-3309-y

Klein, K. G., et al. 2018, *Phys. Rev. Lett.*, **120**, 205102, doi: 10.1103/PhysRevLett.120.205102

Lario, D., et al. 2018, in J. Phys. Conf. Ser., Vol. 1100, The 17th Annual International Astrophysics Conference: Dissipative and Heating Processes in Collisionless Plasma, 012014

Lepping, R. P., et al. 1995, *Space Sci. Rev.*, **71**, 207, doi: 10.1007/BF00751330

Li, Y., et al. 2018, *Solar Phys.*, **293**, 135, doi: 10.1007/s11207-018-1356-8

Lin, R. P., et al. 1995, *Space Sci. Rev.*, **71**, 125, doi: 10.1007/BF00751328

Malaspina, D. M., et al. 2016, *J. Geophys. Res.*, **121**, 9369, doi: 10.1002/2016JA023209

Martinović, M. M., et al. 2020, *Astrophys. J. Suppl.*, **246**, 30, doi: 10.3847/1538-4365/ab527f

McFadden, J. P., et al. 2008a, *Space Sci. Rev.*, **141**, 277, doi: 10.1007/s11214-008-9440-2

—. 2008b, *Space Sci. Rev.*, **141**, 477, doi: 10.1007/s11214-008-9433-1

Mellott, M. M. 1985, in Geophys. Monogr. Ser., Vol. 35, Collisionless Shocks in the Heliosphere: Reviews of Current Research, ed. B. T. Tsurutani & R. G. Stone (Washington, D.C.: AGU), 131–140. http://dx.doi.org/10.1029/GM035p0131

Miteva, R., et al. 2018a, *J. Atmos. Solar-Terr. Phys.*, **180**, 26, doi: 10.1016/j.jastp.2017.05.003

—. 2018b, *Solar Phys.*, **293**, 27, doi: 10.1007/s11207-018-1241-5

Müller, D., et al. 2013, *Solar Phys.*, **285**, 25, doi: 10.1007/s11207-012-0085-7

Ogilvie, K. W., et al. 1995, *Space Sci. Rev.*, **71**, 55, doi: 10.1007/BF00751326

Owens, A., et al. 1995, *Space Sci. Rev.*, **71**, 273, doi: 10.1007/BF00751333

Reames, D. V. 2019, *Solar Phys.*, **294**, 141, doi: 10.1007/s11207-019-1533-4

Richardson, I. G., et al. 2018, *Space Weather*, **16**, 1862, doi: 10.1029/2018SW002032

Sterken, V. J., et al. 2019, *Space Sci. Rev.*, **215**, 32, doi: 10.1007/s11214-019-0607-9

Vasanth, V., et al. 2015, *Solar Phys.*, **290**, 1815, doi: 10.1007/s11207-015-0713-0

Verscharen, D., et al. 2019, *Astrophys. J.*, **886**, 136, doi: 10.3847/1538-4357/ab4c30

von Rosenvinge, T. T., et al. 1995, *Space Sci. Rev.*, **71**, 155, doi: 10.1007/BF00751329

Wilson III, L. B., et al. 2016, *Phys. Rev. Lett.*, **117**, 215101, doi: 10.1103/PhysRevLett.117.215101

—. 2017, *J. Geophys. Res.*, **122**, 9115, doi: 10.1002/2017JA024352

—. 2018, *Astrophys. J. Suppl.*, **236**, 41, doi: 10.3847/1538-4365/aab71c

—. 2019a, *Astrophys. J. Suppl.*, **243**, doi: 10.3847/1538-4365/ab22bd

—. 2019b, *Astrophys. J. Suppl.*, **245**, doi: 10.3847/1538-4365/ab5445

—. 2020, *Astrophys. J.*, **893**, doi: 10.3847/1538-4357/ab7d39

Woodham, L. D., et al. 2018, *Astrophys. J.*, **856**, 49, doi: 10.3847/1538-4357/aab03d

Acronyms and Initialisms

3D	three-dimensional
3DP	Three-Dimensional Plasma and Energetic Particle Investigation (*Wind*/3DP)
ACE	Advanced Composition Explorer
APE	Alpha-Proton-Electron telescope (part of *Wind* EPACT/ELITE)
ARTEMIS	Acceleration, Reconnection, Turbulence and Electrodynamics of the Moon's Interaction with the Sun
AU	Astronomical Unit
CAP	Command and Attitude Processor
CCMC	Coordinated Community Modeling Center
CDAWeb	Coordinated Data Analysis Web
CMAD	Calibration and Measurement Algorithms Document
CME	Coronal Mass Ejection
DSCOVR	Deep Space Climate Observatory
DSN	Deep Space Network
DTR	Digital Tape Recorder
EESA	Electron Electrostatic Analyzer (*Wind*/3DP)
ELITE	Electron-Isotope Telescope system (*Wind*/EPACT)
EPACT	Energetic Particles: Acceleration, Composition, and Transport (APE-ELITE-IT-LEMT package on *Wind*)
ESA	ElectroStatic Analyzer (i.e., particle instrument)
ESA (agency)	European Space Agency
FC	Faraday Cup (e.g., *Wind*/SWE)
FOT	Flight Operations Team
FTE	Full Time Equivalent
FTP	File Transfer Protocol
GCN	Gamma-ray Coordinates Network

GeV	Giga-electron volt
GF	Giant Flare
GGS	Global Geospace Science
GOES	Geostationary Operational Environmental Satellites
GRB	Gamma Ray Burst
GSFC	Goddard Space Flight Center
GUI	Graphical User Interface

HDP	Heliophysics Data Portal
HET	High-Energy Telescope
HETE-2	High Energy Transient Explorer-2
HGO	Heliophysics Great Observatory
HI	Heliospheric Imagers
HK	House Keeping
HSO	Heliophysics System Observatory
HTR	High Time Resolution

IBEX	Interstellar Boundary Explorer
ICME	Interplanetary Coronal Mass Ejection
IMAP	Interstellar MApping Probe
IMF	Interplanetary Magnetic Field
IMP	Interplanetary Monitoring Platform (spacecraft)
IMPACT	In-situ Measurements of Particles and CME Transients (suite)
INTEGRAL	INTErnational Gamma-Ray Astrophysics Laboratory
IP	Interplanetary
IPN	Interplanetary GRB Network
ISS	International Space Station
ISTP	International Solar-Terrestrial Physics
IT (detector)	Isotope Telescope (part of *Wind* EPACT/ELITE)

keV	kilo-electron volt
KONUS	Gamma-Ray Spectrometer (*Wind*/KONUS)

KP	Key Parameter
LASCO	Large Angle and Spectrometric COronagraph
LEMT	Low Energy Matrix Telescopes (*Wind*/EPACT)
LET	Low Energy Telescope
LIGO	Laser Interferometer Gravitational-Wave Observatory
LWS	Living With a Star
LZ	Level Zero
MAG	Magnetic Field Experiment
MASS	high-resolution MASS spectrometer (*Wind*/SMS)
MAVEN	Mars Atmosphere and Volatile EvolutioN mission
MESSENGER	Mercury Surface Space Environment Geochemistry and Ranging
MeV	Mega-electron volt
MFI	Magnetic Field Investigation (*Wind*/MFI)
MMOC	Multi-Mission Operations Center
MMS	Magnetospheric Multi-Scale NASA STP mission
NASA	National Aeronautics and Space Administration
OMNI	dataset on CDAWeb
PDMP	Project Data Management Plan
PESA	Ion (Proton) ESA (*Wind*/3DP)
PSP	Parker Solar Probe
PWG	Polar-Wind-Geotail ground system
RAD1	radio receiver band 1
RAD2	radio receiver band 2
SC	Solar Cycle
SEP	Solar Energetic Particle
SEPT	Solar Electron and Proton Telescope
SEU	Single Event Upset

SEZ	Solar Exclusion Zone
SGR	Soft Gamma Repeater
SIS	Solar Isotope Spectrometer
SIT	Suprathermal Ion Telescope
SMS	Solar Wind and Suprathermal Ion Composition Experiment (SWICS-MASS-STICS package on *Wind*)
SOHO	SOlar and Heliospheric Observatory
SolO	Solar Orbiter mission
SPASE	Space Physics Archive Search and Extract
SPDF	Space Physics Data Facility
sps	samples per second
SST	Solid-State (semi-conductor detector) Telescope (*Wind*/3DP)
STE	SupraThermal Electron instrument
STEP	SupraThermal Energetic Particle Telescope (*Wind*/EPACT)
STEREO	Solar-Terrestrial Relations Observatory
STICS	SupraThermal Ion Composition Spectrometer (*Wind*/SMS)
STP	Solar Terrestrial Probe
Strahl	electron strahl sensor of *Wind*/SWE
SWE	Solar Wind Experiment (*Wind*/SWE)
SWEA	Solar Wind Electron Analyzer
SWEPAM	Solar Wind Electron Proton Alpha Monitor (ACE)
SWICS	Solar Wind Ion Composition Spectrometer (*Wind*/SMS)
SWIMS	Solar Wind Ion Mass Spectrometer
TDS	Time Domain Sampler (*Wind*/WAVES)
TDSF	TDS Fast Receiver (*Wind*/WAVES)
TDSS	TDS Slow Receiver (*Wind*/WAVES)
TGRS	Transient Gamma-Ray Spectrometer (*Wind*/TGRS)
THEMIS	Time History of Events and Macroscale Interactions during Substorms
TNR	Thermal Noise Receiver (e.g., part of *Wind*/WAVES)

TUA	Tape Unit A
TUB	Tape Unit B
ULEIS	Ultra Low Energy Isotope Spectrometer
VEIS	Vector Ion-Electron Spectrometers (*Wind*/SWE)
VEX	Venus EXpress
VHO	Virtual Heliophysics Observatory
WYE	Work Year Equivalent

Budget Spreadsheet

Table 3: *Wind Senior Review Budget Spreadsheet*

End of Mission Plan

370 May 15, 2020

TO: 300/Director, Safety & Mission Assurance Directorate

FROM: 370/Quality & Reliability Division/Viens

SUBJECT: Code 300 Evaluation of End of Mission Plan for Wind Mission

REF: a) NASA-STD-8719.14B, Process for Limiting Orbital Debris

b) Call for Proposals, Rev 2a — Senior Review 2020 of the Mission Operations and Data Analysis Program for the Heliophysics operating missions, Revision 2b: January 21, 2020; NASA HQ / N. Fox / Director, Heliophysics Division, NASA HQ / J. Leisner / Senior Review, Program Scientist, NASA HQ / W. Stabnow / Senior Review, Program Executive

The Wind mission has demonstrated full compliance with NASA-STD-8719.14B by virtue of its orbit. The spacecraft is in a Sun-Earth Lagrange Point 1 (L1) orbit, from where it will naturally drift into a heliocentric orbit at the end of the mission, and is not expected to reenter or interfere with the GEO protected region for the foreseeable future. Meaningful very long-term orbit propagations (on the order of a century) are not practical due to uncertainties in the conditions at the time of disposal. Due to the orbit that Wind is in, none of the requirements of NASA-STD 8719.14B are applicable to the mission.

As there are no planned changes in orbital configuration, no additional EOMP analysis is required. Further details are documented in the EOMP, available from the SSMO Configuration Management Office. Please feel free to contact me (301-286-2505), if you have any questions or concerns.

Michael Viens
Cc: 370/Nowak, Sticka, JIRA,
380/Maggio
300/Leitner
592/Hull
HQ-SMD/H. Futrell
SSMO/R. Burns