Decadal Survey Submission:
Exploration of the Earth-Sun System from L-1

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Mission Name	**Janus**
Objectives	• Understand the processes and interactions that determine the composition of the Earth's whole atmosphere including the connections to solar activity. Janus will obtain the first synoptic global measurements of aerosols and chemical composition from sunrise to sunset, and from the surface to outer space, together with the critical solar and space weather inputs that drive the upper terrestrial atmosphere. • Understand the role of solar plasma dynamics in coronal heating, solar wind acceleration, flares and transients, and UV irradiance variations. • Quantify the sources and transport of environmentally important atmospheric species (greenhouse gases, aerosols, ozone) using high-resolution synoptic mapping of concentrations. • Understand the fundamental physical processes within the active solar corona which lead to coronal mass ejections/solar flares and contribute to irradiance variability. • Provide real-time space weather data for predictive modeling of the space environment and for protecting satellite communication, astronaut safety, and ground power distribution assets.
Thematic groups	• Earth Science Applications and Societal Needs • Weather (including chemical weather and <u>space weather</u>) • Climate Variability and Change • Human Health and Security (air quality, volcanic eruptions, communications, etc.)
Mission category	• Medium-size missions that cost between $200 M and $500 M

Figure 1 View from L-1 when the moon is in the field of view

Introduction: The key goal of a proposed joint Earth-Sun mission to L-1 is to understand the relationship between solar activity and the structure and dynamics of Earth's atmosphere from the surface to the thermosphere-ionosphere for a range of seasons, solar radiation and energetic particle inputs.

For Earth observations, the L-1 vantage point offers the opportunity for synoptic observations at high time and space resolution of the sunlit Earth. Ground observations of tropospheric variability of trace gases (e.g., NO_2, SO_2) and aerosol plumes (e.g., biomass burning and desert dust) show that they change significantly on an hourly time scale over the course of the day. L-1 observations will afford us the first opportunity to observe the global evolution of tropospheric phenomena <u>with high time resolution</u>, as well as rapidly changing phenomena in the upper stratosphere and mesosphere. In contrast, a polar orbiting satellite only gives us a single measurement per day at each location (2 in the IR).Geostationary observations would require 6 separate satellites for full coverage which even then would not extend to polar regions.

High temporal resolution combined with global coverage, as available uniquely from L-1, is of capital importance for studies of tropospheric sources and transport. Emissions can fluctuate considerably from hour to hour (fires, lightning, aerosols, trace gases…). Transport mechanisms involving convection and frontogenesis can take place on very short time scales. Inverse model analyses exploiting the Janus data will enable the global mapping of emissions of environmentally important gases (greenhouse gases, aerosols, pollutants) with unprecedented coverage and detail. The Janus data will also allow the tracking of chemical and aerosol plumes as they are transported and dispersed on scales ranging from regional to global. They will provide an unmatched perspective for observing intercontinental transport of pollution.

Stratosphere-troposphere exchange chemically links the upper troposphere and the lower stratosphere, while the chemistry of the stratosphere is driven by solar radiation and the photolysis of tropospheric source gases (CH_4, N_2O, and CFC’s). The upper portions of Earth’s atmosphere respond strongly to external variations in the Sun’s ultraviolet and energetic particle output. Quantifying the variations in the solar driver, anthropogenic forcing, and the coupling between the upper and lower atmosphere, is one of the most significant problems in Earth science if we are to understand and model climate changes.

Mission Description and references to Decadal Survey questions

Observing the Earth, solar wind, and the Sun from Lagrange-1 (L-1) affords us a unique view of the Earth’s whole atmosphere and its coupling to solar activity (Figure 1). Janus will concurrently observe sources of upper atmospheric forcing from space weather phenomena and solar disk activity.   Janus includes a instrumentation for terrestrial atmospheric composition and airglow analysis, solar weather, and solar activity (soft x-rays and EUV, solar coronal flares, and mass ejections).

The key to this proposed mission is the careful selection of measurements and scientific objectives to target NASA’s exploration goals as described below. Janus will augment existing satellite and ground-based measurements and provide a unique measurement set enabled by the L-1 vantage point.

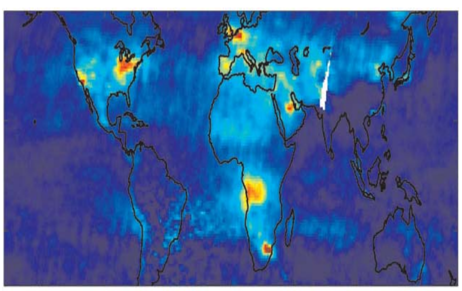

Figure 2 Tropospheric nitrogen dioxide columns seen from space

Janus will provide global mapping of atmospheric composition every 30 to 60 minutes over the Earth’s sunlit disk with high spatial resolution (5 km at nadir) needed to observe tropospheric trace gas changes and motions of aerosol plumes. From a lower atmospheric perspective, this will enable improved quantification of emissions responsible for climate forcing and regional air quality degradation (Figure 2). Janus measurements will provide continuous tracking of anthropogenic and natural plumes (generated by megacities, dust storms, volcanoes, etc.) over scales extending from 5 km to the dimensions of the Earth. They will provide improved estimates of radiative forcings from aerosols including cloud effects, and improved monitoring of the stratospheric ozone layer and the chemicals affecting it. Spectral measurements of the Earth’s surface from Janus will also be of considerable interest to the land and ocean science communities through global and continuous observations of fires, chlorophyll, red tides, etc.

Beyond the Earth’s troposphere and stratosphere, the unique suite of Janus measurements will enable continuous observation of the mesosphere and thermosphere extending to outer space, with vertical resolution in the stratosphere and ionosphere allowing exploration of the couplings between these domains. Janus will provide the first comprehensive global observations of the ionosphere. It will allow exploration of where, when, and how forcings, responses, and variability in the lowest atmospheric layers segue into the forcings, responses, and variability of the upper atmosphere. This exploration of atmospheric coupling will involve climate dynamics (ENSO, AO, etc.), ionization and photochemical reactions in the upper atmosphere, and the global electric circuit. The Janus concept responds to ongoing initiatives in the United States and elsewhere to develop whole-atmosphere models of dynamics and composition (MAGCM, WACCM, NOGAPS).

Figure 3 Airglow at 100 km seen from space

By observing both the Sun and the Earth, Janus is the first comprehensive exploration of the couplings of solar activity within the Earth-Sun system. Solar activity affects climate dynamics, e.g., the strength and phase of the Arctic Oscillation (AO) (Kodera, 2002) with implications for the winds, temperature, and rainfall in northern middle and high latitudes. Solar radiation below 100nm is the primary source of energy for the thermosphere and creates the embedded ionosphere. Solar variability is known to drive major changes in the energy and composition of the upper atmosphere and ionosphere (e.g., airglow Figure 3), but the perturbations extend to the middle and lower atmosphere as well. Ozone is observed to experience significant variance in response to solar changes. The variance is comparable in amplitude to the effect of chlorofluorocarbons (CFCs) on ozone during the past 25 years. Solar effects are manifest in the phase of the Quasi-Biennial Oscillation (QBO) (McCormack, 2003), and thus may also influence ozone indirectly. Transport of nitrogen oxides produced by solar soft X-rays near 100 km can deplete ozone during the polar night, thereby coupling the lower thermosphere and stratosphere. Janus includes short wavelength solar imaging and irradiance instrumentation to directly observe the short wavelength variability and to directly image and characterize the responsible structures in the solar atmosphere.

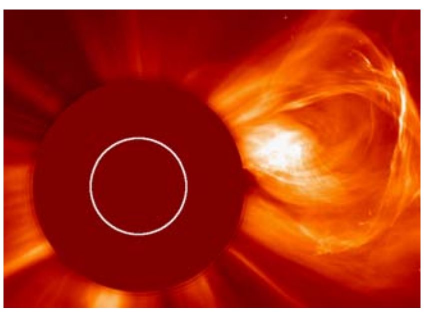

Figure 4 CME event viewed by a solar coronagraph

As modern society becomes increasingly reliant on technologically advanced systems for power distribution and satellite-based communications, our ability to predict and respond to the impacts of space weather and solar activity becomes increasingly important. The upper atmosphere responds dramatically to solar activity and solar flares. Neutral and ion densities increase an order of magnitude or two during the 11.3-year solar activity cycle, and as much as 40-70% during energetic events, such as the Bastille day flare (Meier et al. 2003). Enhanced atmospheric densities increase the drag on satellites in low-earth-orbit, including the International Space Station (at 400 km). Changes in electron density in these layers of the atmosphere directly impact various forms of communication and navigation systems critical to operational systems. Solar CMEs (Figure 4) cause space-weather disturbances that affect the Earth's magnetosphere, represent a serious hazard for geostationary satellites, and allow highly energetic particles to reach the Earth's surface.

Unfortunately, the fundamental physical processes responsible for the generation of space weather events such as coronal mass ejections and solar flares are largely unknown. Imaging observations have shown that these energetic events typically arise near magnetic neutral lines or active region areas with high magnetic shear. The physical processes responsible for the evolution of these fields toward an unstable condition is not well understood although it is thought that magnetic reconnection plays a significant role. Magnetic field models suggest that these are the sites of some of most strongly nonpotential fields in the corona. However, the energy found in these events is typically higher than that available along a filament channel or neutral line. The conditions leading to a trigger of these events is unknown.

The JANUS imaging solar observations are specifically targeted to determine the physical processes leading to these large scale geospace events. The observations required are challenging. The events occur on large scales comparable to half a solar radius and evolve rapidly. The observations must cover a broad temperature range with unambiguous measurement of plasma densities and velocities with sufficient spatial resolution. Knowledge of the geometry, density and morphology of the event after its initiation is also required. Detailed comparisons between the measurements and 3D models of the solar atmosphere incorporating the candidate physical processes (reconnection, Alfven wave heating, etc.) will provide a much higher fidelity understanding of the physics behind these events and is the first step to a predictive capability.

The JANUS solar instrument package includes a high resolution, next generation EUV spectrograph and a white light coronagraph to provide the necessary, comprehensive view of these events. The spectrographic observations will discriminate between various physical processes responsible for generating large scale solar events. These "Trace-like" observations with comprehensive temperature coverage and sensitive velocity information will discriminate among the possible physical processes leading to these events. Janus will observe enough of these events to accumulate a statistically significant sample. The coronagraph will observe the physical structure and speeds of the resulting coronal mass ejections. The combined coronagraph and spectrograph observations and the *in-situ* observations will provide a complete picture of the resulting energetic particle and space weather environment.

Janus will also provide a real time warning of space weather events. The Janus coronagraph and spectrograph will detect CMEs at least one day before they could reach the Earth, so that appropriate safeguarding measures can be taken. Space weather instruments on board Janus will detect which subsets of observed CMEs are likely to reach the Earth with about 1 hour warning for shut-down of critical systems.

Full-disk observation of the Earth by Janus will offer a unique testbed for interpreting extrasolar planet spectra and enabling exploration of life outside our solar system. Observations of extrasolar planets from the Terrestrial Planet Finder (TPF) mission are also for the whole disk, but limited to one pixel. By spatially combining the Janus terrestrial spectra, and interpreting the resulting information against our independent knowledge of the Earth system, we will develop an improved capability to interpret extra-solar planetary spectra in terms of the properties of these planets, including in particular their potential to harbor life. This will be extended by Janus to a wider variety of planetary conditions by observations of the outer planets and the moons of Jupiter and Saturn as a single spectrally resolved pixel.

The Earth-viewing portion of the Janus mission consists of a combination of instruments that observe the Earth's atmosphere from the surface to outer space in an extended wavelength range (58 nm to 2.4 μm) and with 15-minute temporal resolution. These use a high precision (1 nm surface smoothness) 0.5-meter parabolic primary mirror in order to obtain 5 km scale spatial resolution (nadir at 500 nm) on the entire sunlit Earth disk.

The space weather instrument suite consists of a magnetometer capable of high time resolution measurement of magnetic field fluctuations and shocks, and two Faraday cup particle energy analyzers capable of measuring energy resolved charged particle spectra from the 3-axis stabilized Janus spacecraft.

Solar observations are accomplished using three flight proven instruments: (1) An EUV spectrometer with full-disk, high spatial-resolution capability to observe EUV variations and their relationships to flares, active regions, etc.; (2) A white light solar coronagraph with FOV from 3-15 R_{sun} to observe Coronal Mass Ejections (CMEs) in near-Sun interplanetary space; and (3) A soft x-ray irradiance spectrometer to measure short wavelength variations not available from the Solar Dynamics Observatory (SDO) mission. Depending on mission technical considerations, it may be possible to add an existing Sun-viewing cavity radiometer for total solar irradiance.

Since 1979, specific regimes of the Earth-Sun system have been explored and characterized in great detail, but largely independently of each other. Currently, we do not know enough about the troposphere, stratosphere, mesosphere, thermosphere/ionosphere, magnetosphere and Sun as an integrated system to separate effects originating at the Earth's surface from those originating in solar activity. A continuum of forcings, responses, and internal variability modes pervades the entire atmosphere, with different strengths at different altitudes.

For example, ENSO is a prominent source of global surface temperature variability, but its influence extends into the stratosphere (e.g., Sassi et al., 2004) and possibly higher. The QBO of the tropical stratosphere has a strong impact on ozone concentrations, but also likely influences the atmosphere at both lower and higher altitudes, extending into the thermosphere. Similarly, the SAO extends through much of the atmosphere, and plays a role in organizing responses to various forcings, but with difference expressions in different regimes. Simulations with the new generation of whole-atmosphere models (MAGCM, WACCM and then operational model NOGAPS) expose the coupled dependence of the entire atmospheric system.

Specific Objectives of Janus:

- Observe the instantaneous state of the Earth's whole atmosphere simultaneously in time and space from the surface to the thermosphere and ionosphere, repeatedly over different seasons and for a range of solar radiation and energetic particle energies.
- Use these observations for high-resolution mapping of emissions of environmentally important species, tracking of pollution plumes, and monitoring of ozone layer dynamics.
- Explore the dynamical and chemical linkages between the different vertical domains of the Earth's atmosphere, including the effect of solar forcing on the upper atmosphere.
- Directly observe the sources of solar and space weather radiation and particle inputs relevant to the upper atmosphere and ionosphere over many solar rotations.
- Provide real time information for predicting space weather events in the Sun's heliosphere. Determine atmospheric conditions and dominant physical processes responsible for coronal mass ejections and solar flares.
- Provide information for predicting space weather events in the Sun's heliosphere.
- Provide a testbed for interpreting spectra from extrasolar planets in terms of planetary surface, atmospheric composition, and potential to harbor life.

To accomplish these objectives, the optimum Janus payload features a unique combination of solar and earth viewing instruments to (1) enable detailed global mapping of atmospheric composition, (2) observe solar disturbances and their effect on space weather, and (3) explore dynamical and chemical couplings over the scale of the Earth's whole atmosphere including the forcing by the Sun.

UV and Visible Spectrometer J-UVIS. Full-disk observation of the Earth in the 300-910 nm range will enable sensitive tropospheric and stratospheric measurements of aerosols and a number of gases including O_3, H_2O, NO_2, HCHO, SO_2, and BrO. The capability for these observations has been demonstrated previously from nadir instruments in low-Earth orbit (LEO) (e.g., TOMS, GOME, MODIS, SCIAMACHY, OMI). The L-1 vantage point will provides frequent synoptic global observation for these species, in contrast to the much sparser coverage (particularly when considering cloud interferences) of once per day achievable from LEO. The stratospheric O_3, NO_2, and BrO measurements from J-UVIS will improve understanding of the chemical dynamics of the stratosphere including its coupling to the troposphere and mesosphere. The tropospheric aerosol, H_2O, NO_2, and HCHO measurements will be used in combination with global chemical transport models (CTMs) for high-resolution inversion of the sources of aerosols, nitrogen oxides, and reactive volatile organic compounds (VOCs). The aerosol measurements will allow tracking of anthropogenic and natural plumes on scales ranging from regional to global, including, in particular, the intercontinental scale for which L-1 offers a unique capability. Desert dust and volcanic ash plumes have important radiative and chemical consequences and can also pose a hazard to aviation.

Near IR Spectrometer J-NIRS. This instrument will observe solar backscatter in a spectral region where useful quantitative characterization can be made of the columns of O_2, CO_2, CO, and CH_4. By contrast with observations in the thermal IR, the near-IR column measurements have high sensitivity in the boundary layer where most of the column variability takes place. Near-IR observations of CO and CH_4 from low-elevation orbit are presently being made from the SCIAMACHY instrument, and a detailed proof-of-concept for near-IR CO_2 measurements from space have been produced as part of the OCO instrument design (Crisp et al., 2004). The global continuous coverage for these gases offered by J-NIRS has the potential to dramatically improve our knowledge of their surface fluxes. Here again, the L-1 vantage point will provide good spatial and considerably more temporal information than low-elevation orbits. Complete simultaneous coverage will greatly diminish the model transport errors presently plaguing inverse model analyses of CO_2, CO, and CH_4 fluxes.

Earth Viewing Mid-UV Spectrometer J-MUV: The mid-UV spectrometer will obtain imaging spectroscopic measurements from 200-300nm where it can detect NO amounts and measure ozone profiles. Solar backscatter measurements of the Earth's atmosphere in the UV contain the signature of numerous NO fluorescent bands to explore vertical coupling between atmospheric layers. Examples of previous nadir measurements using SBUV-like instruments include Stevens et al [1995] and McPeters [1989]. Stevens et al. [1995] were able to document geomagnetic variations in the NO while McPeters documented geomagnetic and solar variations. The spectral resolution of the above data was 1 nm. A key limitation of previous measurements is the lack of altitude resolution (as well as the generally poor spatial sampling which will be vastly improved upon by Janus). It was thus hard to localize the enhanced NO to a particular altitude level and thus quantify vertical coupling between atmospheric layers. J-MUV will resolve that limitation in two ways. First, measurement of NO in different bands that are subject to different atmospheric opacities will allow better localization of the emitters. Second, measurement of the NO rotational temperature will localize the emission to either the warm lower thermosphere (300-400K) or the cold middle atmosphere (< 300K). To deduce NO rotational band temperatures with sufficient precision against the bright UV disk, a spectral resolution on the order of 0.1 nm or better needs to be accomplished. Furthermore, quantification of the NO rotational temperature and its response to solar and geomagnetic activity could be a unique probe of global atmospheric response at altitudes (95-120 km) where synoptic temperature measurements remain nonexistent.

Earth viewing EUV/FUV Spectrometer J-EVES: J-EVES will obtain complete dayside spectrally resolved images of the Extreme-UV/Far-UV (EUV/FUV) airglow. These global images will provide the distribution of the major thermospheric species (N_2, O, O^+, He) along with opportunity to investigate distributions of minor species (N, H). N_2 LBH and atomic oxygen 135.6 nm emissions. J-EVES full-dayside images will give unprecedented observation of thermospheric disturbances associated with geomagnetic storms and substorms in tandem with direct observation of the solar events driving these disturbances. Direct EUV observations of OII 83.4 nm in conjunction with the atomic oxygen abundance retrievals will give complete maps of the O^+ abundance distribution, allowing **for the very first time global viewing of the earth's dayside ionosphere.** Another feature of genuine interest is the He 58.4 nm resonance line. Since helium is chemically inert, the abundance distributions derived from the He 58.4 nm images will capture purely dynamical upper atmospheric responses to space weather events, enabling a comparison with the FUV O/N_2 distribution resulting from local processes (energy deposition, chemistry).

Solar EUV Spectrometer J-SES: The Janus normal-incidence imaging Extreme Ultraviolet Spectrograph (based on NEXUS) will obtain the necessary spectrally and spatially resolved spectroscopic measurements to address the physical processes driving soft x-ray and EUV irradiance variations and large scale solar energetic phenomenon (CMEs and flares). J-SES measurements will quantify the role of plasma flows in a range of dynamic phenomena, revealing the fundamental physics of energy and mass transport in the solar corona. The intermittent flow of energy from the transition region to the solar corona, determined by the complex interplay between the magnetic field and plasma motions, is poorly understood. A wide variety of solar activity phenomena, ranging from slowly evolving small-scale features such as active region loops to rapid energetic events like Coronal Mass Ejections (CME), result from this energy flow. These events shape and modify the entire heliosphere, driving the near-Earth environment and producing space weather effects that can have significant societal impacts.

In particular, CMEs create shocks that accelerate particles in the Interplanetary Medium (IPM) that can penetrate the Earth's magnetosphere, and occasionally reach the Earth's surface.

These energetic particles pose a serious risk to astronaut health, especially outside of the Earth's protective magnetic shield.

J-SES measurements (10 to 120 nm) will spatially resolve the source regions with selectable spatial resolutions 0.5, 1, 2, and 4 arcsec/pixel over a slit that is 16 arcmin (1 Rsun) long. The emission lines in this spectral range are formed at temperatures from 0.02-15 MK, giving EUS an unprecedented simultaneous view of the chromosphere, transition region, and corona. The large effective area will result in exposure times of order 1.5 s, which allows for rapid raster imaging of flaring active regions, CME initiation events, and the full solar disk. A velocity resolution of order 5 km/s will provide essential information on the convective energy flux, which is the primary uncertainty in existing models.

Solar radiation at extreme ultraviolet (EUV) and soft X-ray wavelengths (0.1-120 nm) is a major energy loss from the transition region and corona. This radiation largely determines the baseline properties of the Earth's environment at altitudes above about 100 km. Variations in solar EUV radiation drive substantial changes in thermospheric temperature, density, and ionization that produce space weather impacts over multiple time scales. J-SES observations are well-characterized spectral lines with excellent temperature coverage that will provide the necessary inputs for physics based modeling of solar irradiance variability such as NRLEUV.

Solar Soft Xray Irradiance J-XI J-XI will directly measure the primary source of energy input into the upper atmosphere using 1-63nm,with the measurements unique to Janus from 1 to 5nm. This ionizing radiation penetrates down to the lower thermosphere Soft X-rays play a critical role in the Nitrogen Oxide chemistry in the thermosphere and mesosphere. Siskind et al. [1995] discuss the desirability of quantifying the spectrum down to wavelengths as short as 1 nm. Previous measurements of soft X rays (SNOE, SEE) have been limited by the lack of knowledge of the spectrum at high resolution. Thus, contradictory results have been obtained and we still do not know if the solar output matches the terrestrial chemical requirements. This drives the requirement for the J-XI measurement to separate individual spectral features (< 0.2 nm resolution). The Janus EUV measurements from 5-63nm provide a completely independent measurement to the EUV irradiance measurements planned for EVE/SDO. In the past, two independent measurements have generally been required to fully understand the calibration and degradation issues within this type of instrumentation..

Solar Coronagraph J-COR The solar coronagraph on Janus (J-COR) will observe the rotating panorama of the outer solar corona. It will image the evolving coronal streamer belt and directly detect coronal mass ejections. CMEs are the primary solar drivers of large, nonrecurring geomagnetic storms and solar energetic particle (SEP) events. Their statistical properties (line of sight topology, mass and velocity) have been studied extensively with the Solwind, SMM, and SOHO coronagraphs. Determining the 3D topology and propagation through interplanetary space is a primary objective of the STEREO mission, which will develop and test models for predicting the propagation of space weather phenomena through interplanetary space. Janus will provide the first sustained test of these propagation models using a single coronagraph view from the Earth vantage point. The J-COR will likely be the only source of images of the outer corona during this time period. Just as in SOHO, the unique L1 orbit will allow an uninterrupted set of solar observations to measure the geometry, velocity, and mass of CMEs. The J-COR will be a copy of the Secchi COR-2 coronagraph instrument with proven heritage and optical performance.

Space Environment Instruments J-PMag The Janus Plasma-Mag instruments are intended to characterize the magnetic field and solar wind proton and alpha particle populations at high time resolution. Previous solar-wind measurements from the spin-stabilized WIND spacecraft could only be made when the Faraday Cup pointed towards the Sun.

The Halloween storms of 2003 demonstrate clearly that Solar Energetic Particle (SEP) events drive significant changes in the atmosphere, including drastic loss of polar ozone. Therefore, to understand atmospheric variability, it is important for J-PMag to measure the particle inputs to Earth's atmosphere to allow the separation of changes driven by UV variation from particle driven changes. The J-PMag instruments are intended to provide this information characterizing the magnetic field and solar wind composition and energy (Faraday Cup) at high time resolution on a continuous basis from L1, just in front of Earth's magnetosphere. In addition, the data can be used to provide early warning of solar events that might cause damage to various electrical devices (e.g., power generation, communications, and satellites).

Panel Themes: The L1 mission makes a significant contribution to the following five Decadal Panel Survey Themes:

1. Earth Science Applications and Societal Needs: Janus will make continuous global measurements of tropospheric and stratospheric trace gases and aerosols that are important for climate forcing, air quality, and the ozone shield. This will enable (1) inverse analyses to constrain the sources of these chemicals with high spatial and temporal resolution; (2) tracking of pollution plumes across the globe; (3) monitoring of dust and volcanic plumes of potential hazard to aviation; (4) improved characterization of the climate forcing from aerosols; (5) improved understanding of the variability of the ozone layer, and (6) detecting changes in the column amounts of CO_2 and CO.

3. Weather (including chemical weather and space weather): The extensive lower-atmosphere chemical observations from Janus, when assimilated into meteorological models, could offer significant improvements in meteorological analyses and weather forecasts. For example, observations of CO offer a unique constraint on winds. Solar images from J-COR and J-SES and particle and fields data from J-PMag, the Plasma-Mag component of Janus, will permit the forecasting and nowcasting of space weather in geospace. J-PMag will continuously broadcast real-time low-rate beacon data with content similar to the current ACE real time data stream. This will provide 1-hour warning of an impending event dangerous for satellite communications and power grids. Radiation measurements will provide real-time hazard assessment for astronauts during EVA's and at the Moon. The capabilities proposed for Janus would fully replace the aging ACE and SOHO missions currently providing space weather information to NOAA.

An additional goal of the combined L1 Earth-Sun mission is to observe changes in the atmosphere that are associated with solar flares, coronal mass ejections, and XUV irradiance leading to production of NO, transported in the polar night to affect ozone, which may then couple to the troposphere. The mission will provide the first combined and coordinated view of the Earth and the Sun specifically designed to explore solar influences and separate changes from those that may be caused by anthropogenic activities. The Earth-Sun coupling will be examined in terms of detailed atmospheric and chemical modeling from the ground to the upper atmosphere.

4. Climate Variability and Change: Global observations by Janus of changes in CO_2, CO, and H_2O amounts are likely factors that contribute to climate change. Synoptic high spatial resolution observations of anthropogenic pollutants in the troposphere (e.g., NO_2, O_3 and aerosols) are capable of changing the tropospheric energy balance to affect both regional weather (e.g., rainfall) and longer-term climate.

6. Human Health and Security: High-resolution measurements of pollutant concentrations in the lower atmosphere by Janus will provide critical information for air quality forecasts by monitoring the development of regional pollution episodes, identifying unexpected chemical releases, and tracking the transport of pollution plumes. Aviation will benefit from the continuous tracking of volcanic and dust plumes.

Space weather data from Janus will be of importance for civilian aircraft flying over the Arctic and for assessing radiative exposure by for astronauts. Observations of the ionosphere will be used to separate natural disruptions of radio communications from other potential causes. Offloading the power grid during intense storm periods will help assure safe continuous electrical power for the northern region of the US and for Canada.

Contributes to important scientific questions facing Earth sciences today (scientific merit, discovery, exploration); Janus will make continuous global measurements of tropospheric and stratospheric trace gases and aerosols that are important for climate forcing, air quality, and the ozone shield. Assimilation of these data into atmospheric models will provide new perspectives for understanding emissions to the atmosphere, long-range transport of plumes, and radiative forcing by aerosols. The whole-atmosphere, simultaneous observational strategy of Janus will enable exploration of dynamical and chemical coupling between atmospheric domains, with many opportunities for new discoveries. Concurrent solar and terrestrial observations from Janus will promote a better understanding of the role of solar variability in driving the composition and dynamics of the Earth's atmosphere

In addition, Janus will make major contributions to solar science. Solar EUV and soft X-ray radiation is a major energy loss mechanism for the transition region and corona, and therefore determines coronal structure. This radiation largely determines the baseline properties of the Earth's environment at altitudes above about 100 km. Variations in solar EUV radiation drive substantial changes in thermospheric temperature, density, and ionization that produce space weather impacts over multiple time scales.

Coronal mass ejections are one of the most spectacular manifestations of the episodic transfer of mass and energy from the Sun to the heliosphere. The corona is able to expel large plasmoids at velocities beyond 2000 km/s. Acceleration time scales range from minutes to hours. Spatial scales approach nearly a solar radius or more, and their energies are usually larger than that of the flares that often accompany the CME. The shock waves created at the leading edge of the CME accelerate particles to high energies. These energetic particles and the CME itself often impinge on the Earth's magnetosphere and create large disturbances in the Earth's space weather. Janus will transform our knowledge of CMEs providing physical parameters and time resolved dynamics before, during and after the eruption event.

Contributes to applications and/or policy making (operations, applications, societal benefits); By tracing volcanic ash, the data will be used to avoid aircraft damage and the resulting possible casualties. Observing key components of tropospheric pollution (e.g., aerosols and NO_2, H_2O, HCHO, SO_2, O_3) and their transport will help the associated agencies formulate regional and national policies to maximize benefits and minimize costs. Space weather forecasts will allow valuable space assets to be put into safe-hold during especially hazardous times, and allow better estimates of orbital decay for LEO spacecraft.

Contributes to long-term monitoring of the Earth; Janus will be the pathfinder mission for continuous global observation of the Earth's whole atmosphere and will provide a first unified observational perspective for the Earth-Sun system. This integrated approach for Earth-Sun observation will involve a single platform, thus allowing for accurate long-term calibration of the measurements. One well-calibrated set of spacecraft instruments will observe the entire Earth every 15 minutes for the life of the mission producing unique space and time coverage atmospheric and surface changes.

Complements other observational systems; The L1 observational point has the advantage that it always has all LEO and GEO satellites in view when they are on the dayside of the Earth. This means that the L1 observations can be used as validation and as a calibration transfer system between satellites. For example, the two MODIS instruments operate at different local times, one in the morning and one in the afternoon. The 5 km horizontal resolution will provide a significant improvement over current UV-Visible nadir-viewing instruments in LEO, and will complement limb observations of the stratosphere and troposphere. The wide spectral range for tropospheric observation will allow concurrent measurement of a number of gases from the same platform, thus facilitating the use of correlative information in interpreting the observations.

The solar instruments complement the currently planned mission set, providing spectroscopy to measure physical parameters, coronagraph images to observe CMEs, and short wavelength irradiance measurements missing from SDO, while the space-weather instruments will offer improved performance and replacement for those on the aging ACE and SOHO spacecrafts.

Affordable (cost-benefit); Using some existing instrumentation and designs, the estimated cost of this mission is $375 million, an amount comparable to a single instrumented geostationary satellite observing ¼ of the Earth. In addition to the whole-Earth observations that could be made from four geostationary satellites, Janus will make solar and space weather missions that are comparable to or better than SOHO and TRACE. The sum cost of these missions is far more than the cost for a single L1 spacecraft, launch, and full complement of instruments.

Degree of readiness (technical, resources, people); The resources for accomplishing this mission are in place. The spectrometer design for Earth viewing is based on conventional components, with the main item, the 0.5-meter parabolic mirror, already designed and space qualified. Some of the instruments already exist (space weather instruments, solar coronagraph) or are based on already flight-qualified designs. The teams to accomplish this mission are in place at several institutions (e.g., GSFC, NRL, Harvard), and have extensive experience in building and operating this type of space instrumentation.

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Science traceability matrix – Exploration of the Earth-Sun System from L-1				
Science Questions	Science Objectives	Scientific Measurement Requirements	Instrument Functional Requirements	Mission Functional Requirements
What is the response of the upper stratospheric O_3 to changes in solar activity?	Observe the instantaneous state of the Earth's whole atmosphere simultaneously in time and space from the surface to the thermosphere and ionosphere, repeatedly over different seasons and for a range of solar radiation and energetic particle energies.	Measure O_3 profiles in the stratosphere J-MUV	Imaging grating spectrometer capable of imaging with 50 km spatial resolution, spectral radiance 250 - 340 nm, SNR >10:1, once per hour	Constant Earth viewing, Pixel Aggregation to obtain high SNR
What is the response of the mesosphere to changes in solar activity? Key local chemistry responses are the change in NO and the change in the O/N_2 ratio? What is the dynamical response of the mesosphere that can be tracked by observing He? How does the ionosphere change with solar activity?	Use these observations for high-resolution mapping of emissions of environmentally important species, tracking of pollution plumes, and monitoring of ozone layer dynamics.	Dayside Airglow Global Thermosphere Structure F-Region Ionosphere Structure Measure NO(200-250), O(98.9, 102.6, 115.2, 130.4), N(120.0, 113.4, 149.3), N2 (137-142, 165-172), O^+(83.4), He(58.4), H(121.6) in the upper stratosphere and mesosphere – ionosphere J-EVES	Imaging grating spectrometer capable of imaging with 50 km spatial resolution, Spectral radiance 58 – 300 nm, SNR >10:1, once per hour	
What is the seasonal and long-term change in ozone column?		O3 column J-UVIS	Imaging grating spectrometer, 5 km ground nadir pixel, 305 – 340 nm SNR 300:1, once per hour	Pixel Aggregation to obtain high SNR Image stabilization using solar limb sensor
What are the sources, hourly time dependence, and geographical distributions of trace gases associated with industry and natural causes?		NO_2, , SO_2, BrO HCHO column J-UVIS	Imaging grating spectrometer, 5 km ground nadir pixel, 340 - 440 nm, SNR 800:1	

What are the sources of aerosol plumes, their hourly time dependence, and what are the motions of the plumes in the atmosphere? How do aerosol plumes interact with clouds?		Aerosol optical depth and absorption (dust, smoke, sulfates), H_2O, Cloud Height J-UVIS	Imaging grating spectrometer, 5 km ground nadir pixel, 340 – 910 nm, SNR 300:1	
What is the global distribution go greenhouse gases and what is the response of the atmosphere to changes in dynamics? Is there a diurnal response in the amounts of CO and CH_4?		CO_2, CO, CH_4 greenhouse gases J-NIRS	Imaging gas sample correlation spectrometer 50 km ground nadir pixel, 1 – 2.4 microns in specific wavelength bands	Precision pointing
What are the physical processes within the sun responsible for CME's and flares?		Coronal Mass Ejections J-COR	White light coronagraph, 3-15 Rsun FOV, one image every 3 minutes, SNR >20:1	Constant solar viewing, 180^o Field of Regard, low particle contamination
What is the impact of CME's and EUV/soft x-ray variation on the Earth's upper and lower atmosphere?		Sources of solar EUV variation, flares, active regions, etc. J-SES	EUV Spectrometer 46 – 63 nm, Intensity SNR >10:1, Velocity <10 km/s, spatial resolution 1 arcsec, continuous operation	Constant solar viewing, Low particle and hydrocarbon contamination, solar limb sensor and image stabilization
		Solar X-ray Irradiance J-XI	Full-disk, soft x-ray spectral irradiance 0.1-63 nm, 6 measurements/minute	Constant solar viewing.

What is the change in magnetic field and solar particle energies during quiet period and CME's?	Directly observe the sources of solar and space weather radiation and particle inputs relevant to the upper atmosphere and ionosphere over many solar rotations. Provide information for predicting space weather events in the Sun's heliosphere	Solar wind magnetic field changes J-PMag	Magnetometer capable of measuring changes $\Delta B=10^{-7}$ Gauss at least once per second	Located outside magnetosphere, magnetically clean
Can we distinguish CME events that are heading towards Earth and estimate which are dangerous?		Electron energy spectrum J-PMag	Faraday Cup, >1 MeV particle energy, 10 sec resolution	Located outside magnetosphere, spacecraft charging
		Proton and alpha energy spectrum J-PMag	Faraday Cup, solar wind energies, 1 sec resolution	Located outside magnetosphere
Are there dynamical linages between the upper and lower atmosphere that affect composition and short- and long-term changes in the stratosphere and troposphere?	Explore the dynamical and chemical linkages between the different vertical domains of the Earth's atmosphere, including the effect of solar forcing on the upper atmosphere.	Using above observations combined with extensive modeling using NRLEUV model, WACCM, and others. This is a key element for Earth-Sun connections	Atmospheric modeling from the ground to the upper atmosphere	High Speed Computer facility
Can we detect possible indicators of terrestrial planets from high resolution spectral data reduced to a single pixel?	Provide a testbed for interpreting spectra from extrasolar planets in terms of planetary surface, atmospheric composition, and potential to harbor life.	Single pixel high spectral resolution observations of the Earth, Mars, moons of Jupiter and Saturn, and the outer planets. J-UVIS	Pixel aggregation from UV-visible spectrometer during the one month each year when the targets are in the vicinity of the Earth's location from L-1	Precision pointing Image stabilization

Estimated Overall Mission Costs

Top Level Budget: Mission Element	**Cost (Million $)**
Phase A: Proposal Development and Mission Design	**2.0**
Instruments[1]	**120.0**
Spacecraft (Including Integration and testing)	**70.0**
Launch Vehicle (Delta)	**90.0**
MO&DA (3 years)	**20.0**
Science Team (5 years)	**10**
Education	**5.0**
Contingency (30% for Instruments + Spacecraft)	**57.0**
Total	**374**

[1] Major savings using existing solar and solar wind instruments