

The Geospace Dynamics Observatory; a paradigm changing Geospace mission

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ABSTRACT

The Geospace Dynamics Observatory (GDO) mission observes the near-Earth region in space called Geospace with unprecedented resolution, scale and sensitivity. At a distance of 60 Earth Radii (Re) in a near-polar circular orbit and a ~27-day period, GDO images the earth's full disk with (1) a three-channel far ultraviolet imager, (2) an extreme ultraviolet imager of the plasmasphere, and (3) a spectrometer in the near to far ultraviolet range that probes any portion of the disk and simultaneously observes the limb.

The exceptional capabilities of the GDO mission include (1) unprecedented improvement in signal to noise for global-scale imaging of Earth's space environment that enable changes in the Earth's space environment to be resolved with orders of magnitude higher in temporal and spatial resolution compared to existing data and other approaches, and (2) unrivaled capability for resolving the temporal evolution, over many days, in local time or latitude with a continuous view of Earth's global-scale evolution while simultaneously capturing the changes at scales smaller than are possible with other methods.

This combination of new capabilities is a proven path to major scientific advances and discoveries. The GDO mission (1) has the first full disk imagery of the density and composition variability that exist during disturbed "storm" periods and the circulation systems of the upper atmosphere, (2) is able to image the ionosphere on a global and long time scale basis, (3) is able to probe the mechanisms that control the evolution of planetary atmospheres, and (4) is able to test our understanding of how the Earth is connected to the Sun.

This paper explores the optical and technical aspects of the GDO mission and the implementation strategy. Additionally, the case will be made that GDO addresses a significant portion of the priority mission science articulated in the recent Solar and Space Physics Decadal Survey.¹

Keywords: ultraviolet instruments, space missions, large telescopes, Heliophysics missions, Geospace missions, auroral imaging, mid latitude and equatorial ionospheric imaging.

1.0 INTRODUCTION

A mission concept called the Geospace Dynamic Observatory (GDO) is described in this paper. The GDO provides discovery class science for space physics in a way not available for over 30 years since the early days of NASA's Dynamics Explorer and Sweden's Viking missions launched in the 1980's. GDO observes Geospace, the near-Earth space environment, with unprecedented resolution, scale and sensitivity. In a near-polar circular orbit at 60 Re (~380,000 km) with a ~27-day period, GDO images the earth's full disk with (1) a three-channel far ultraviolet (FUV) imager, (2) an extreme ultraviolet (EUV) imager of the plasmasphere, and (3) a spectrometer in the near to far ultraviolet range that will probe any portion of the disk and simultaneously observe the limb. At the end of a 5-year prime mission, the GDO will be placed into a halo orbit about the Earth-Moon L2 point and continue Geospace observations.

2.0 MOTIVATION

2.1 Goal of the proposed application

The goal of the Geospace Dynamic Observatory is to gain knowledge of the fundamental physical processes that determine the coupling mechanisms between the Earth's upper atmosphere, its ionosphere/mesosphere/thermosphere system, and its magnetosphere. In achieving this goal the GDO mission will provide significant input to space weather needs of the nation and humanity with long-term large-scale high-resolution images. Its long-term fast-cadence movies of the full auroral oval and near-Earth space, with better than high-definition 1-km resolution, provides an astounding opportunity for public outreach.

The GDO mission directly addresses heliophysics science that is prioritized in the 2012 NRC Decadal Survey entitled "Solar and Space Physics: A Science for a Technological Society".¹ Three of four science goals for the next decade

listed in the survey are directly addressed: **Goal 1 - Determine the origins of the Sun's activity and predict the variations in the space environment**, **Goal 2 - Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs**, and **Goal 4 - Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe**. The GDO mission will not address the origins of the Sun's activity (first part of Goal 1) but will certainly provide knowledge to predict the variations in the space environment in the Geospace where the overwhelming vast majority of space weather impacts to society occur (second part of Goal 1). The GDO mission will provide new knowledge to understand the coupling in Geospace (Goal 2) and provide discoveries of fundamental processes (Goal 4) that are not possible to date using the current state of the art remote sensing and in situ observations.

Furthermore, the 2012 NRC Decadal Survey identifies 4 new-start notional science missions. The GDO mission fulfills a significant portion of two of these notional missions (Dynamical Neutral Atmosphere-Ionosphere Coupling (DYNAMIC) mission and Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation (MEDICI). The GDO will augment and could simplify a third notional mission called the Geospace Dynamics Constellation (GDC) mission. The notional missions DYNAMIC and MEDICI specifically reference the type of observations the GDO mission provides – UV and EUV remote sensing of Geospace. The GDC mission as described in the Decadal Survey would significantly benefit from large-scale images at very high resolution from GDO to constrain and guide analysis of, and provide context for the in situ observations. It is possible that the GDC mission could be simplified if the GDO mission were to be launched.

2.2 Benefits of the Geospace Dynamics Observatory mission

The benefits of the GDO mission are many and significant considering its long-term viewing of important regions in Geospace and its high temporal/spatial resolution observations with increased sensitivity. Because of its extraordinary and unprecedented capability to remotely sense Geospace, this mission provides significant advancement for meeting the nation's space weather needs and it opens a window of discovery in heliophysics never before possible. The time and spatial resolution of the images coupled with increased sensitivity enable observations never before made. The discoveries and advances in knowledge by confirming or redirecting theories of particle, plasma, field coupling will revise our current thinking and understanding of how the Earth interfaces with space and how it is impacted by solar variability.

The technical capabilities of GDO are extraordinary and un-matched:

1. The large aperture optics (~2.4 meter) and full disk viewing are unprecedented for Geospace investigations. The orbit scenario enables days of contiguous viewing of important regions of Geospace; long enough to capture a full magnetic storm sequence from initiation to conclusion.
2. The increased signal-to-noise for global-scale imaging of Earth's space environment is unparalleled. This enables changes in the Earth's space environment to be resolved with orders of magnitude higher in temporal and spatial resolution compared to existing data and other approaches.
3. A unique view of the Earth is provided. GDO continuously views the global-scale evolution while simultaneously capturing the changes at scales smaller than are possible with other methods. It also has an unrivaled capability for resolving the temporal evolution, over many days, in local time or latitude.

This combination of new capabilities is a proven path to major scientific advances. A few examples of potential advances include:

1. Unparalleled advances in the connection of the upper atmosphere to the Sun. In the aurora and lower latitudes, extending the duration of uninterrupted images advance understanding of the transfer energy from the Sun to the upper atmosphere and in the associated response of the Geospace environment.
2. Advances in the influence of waves and tides on the upper atmosphere. Increasing both the signal-to-noise and

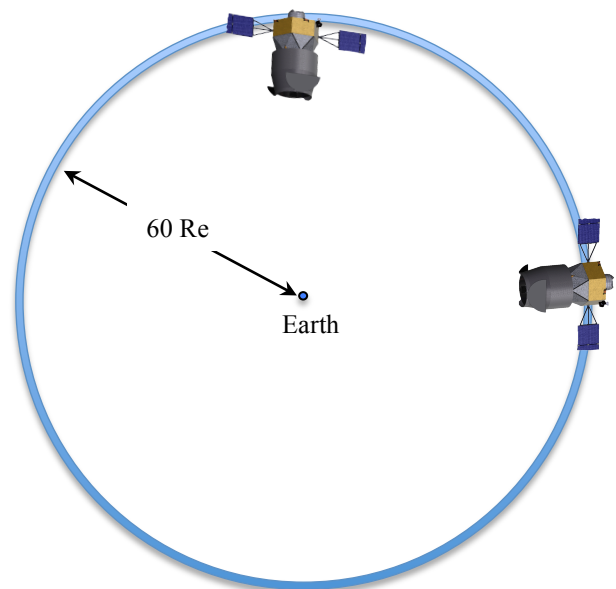


Figure 1. The GDO mission concept employs a near-polar circular orbit at 60 Re with 27-day orbit period with a nadir viewing 3-axis stabilized spacecraft.

the duration of the observations reveals contributions that are not identifiable using other approaches.

3. The ability to probe the mechanisms that control the evolution of planetary atmospheres. The vantage point provided by this mission allows the flux of hydrogen, which is tied to the escape of water from a planet, to be mapped globally. It also allows unique observations of changes in the atmospheric structure and their causes.

3.0 MISSION CONCEPT

The Geospace Dynamics Observatory mission observes Geospace, the near-Earth space environment, with unprecedented resolution, scale and sensitivity. In a near-polar circular orbit at 60 Re with a 27-day orbit period, GDO images the earth's full disk with (1) a three-channel far ultraviolet imager, (2) an extreme ultraviolet (EUV) imager of the plasmasphere, and (3) a spectrometer in the near to far ultraviolet range that probes any portion of the disk while simultaneously observing the limb.

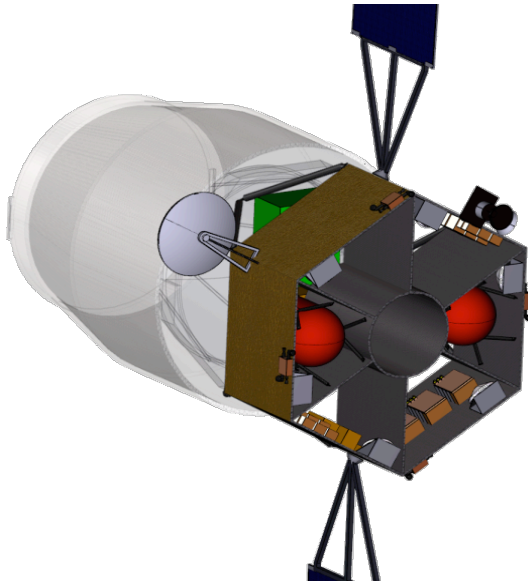


Figure 2. The GDO spacecraft employs standard technologies.

the spacecraft. Spacecraft mission systems such as communications, telemetry, power, propulsion, thermal, structural, and pointing, are composed either of high technology readiness level or flight heritage components. Operation is similar to the existing astrophysics great observatories in which observing time to address specific investigations will be competed. Additionally, a standard suite of science image products will be made available to the science community and operational and applied space weather users. The GDO prime mission life-time is 5 years with a halo orbit at end of mission about the Earth-Moon L2 point.

3.2 Instruments

The data will be comprised of large-scale high-resolution images (4k x 4k) in three FUV wavelengths selected to maximize quantitative analysis (170 nm, 150 nm, 135 nm) at a 1-second cadence each, and UV spectra of a targeted region (120-300 nm, 1.0 nm resolution) at a 10-second cadence, and from low-resolution EUV plasmasphere images (30.4 nm) at a 10-second cadence. There are three instruments: a 2-dimensional FUV imager with three simultaneously imaging channels, a spatial-spectral UV spectrometer whose slit image can be pointed within the telescope field of view, and a lower resolution EUV plasmasphere imager (not shown) that is co-aligned with the telescope. The co-aligned EUV imager is mounted on the spacecraft body and does not share the optics with the FUV instruments. The FUV imager will employ the self-filtering approach² to minimize mass. The solar-blind sensor design is still under consideration. The EUV imager concept is based on the IMAGE EUV Imager.³

The wavelengths, and the spectral, spatial and temporal resolution, are selected to effectively probe the critical interface regions between the Earth's magnetosphere, its ionosphere/thermosphere, and its plasmasphere. This combination provides the key observations to investigate (1) the connections between the Earth's upper atmosphere and the Sun, (2) the dynamics between the neutral dominated region of Earth's upper atmosphere and the plasma dominated region of the ionosphere/thermosphere, and (3) the mechanisms that control the evolution of planetary atmospheres. A comparison of the imaging capability the GDO and previous missions is shown in Table 1.

3.1 Top Level Description of Design, Operations and Results

The GDO mission points at the Earth from over 380,000 km observing far ultraviolet and extreme ultraviolet emissions in Geospace using "solar-blind" sensors. Constrained to these wavelengths, GDO will not image the surface or lower atmosphere of the Earth.

A preliminary study of the GDO mission concept has been performed. It employs a 3-axis stabilized spacecraft with standard propulsion and pointing systems. Pointing accuracy and knowledge of 0.2 and 0.1 arcsec respectively, and stability of 0.2 arcsec in 5 seconds, are easily achieved with standard technology. The desired telemetry of multiple 4kx4k sensors at 1-sec readout rate at all times is a challenge both in terms of coverage and bandwidth. The FUV imager and spectrometer are housed in the defined instrument deck and spacecraft systems mounted below. Tertiary telescope mirror and instrument optics are optimized to achieve maximum field of view and simultaneous imaging. The co-aligned EUV imager is mounted on the body of

Table 1. Instrument performance comparison to previous FUV Geospace imagers

	Mission Instrument						
Parameter	Viking UV ⁴	DE SAI ⁵	Polar UVI ⁶	Polar VIS ⁷	IMAGE WIC ⁸	IMAGE SI ⁹	GDO
Spatial res (km)	20x20	130x130	50x200	50x50	150x150	250x250	1x1
Temporal res (s)	20	180	36	12	120	120	1
Full globe	No	Yes	No	Yes	Yes	Yes	Yes

3.3 Optics

The optical concept is based on using a large (~2.4 meter) relatively wide field of view (~1.5 degrees) three-mirror telescope design. Of the many varieties of TMT's, one type has an annular-zone field of view. This annular zone does not include the fields that are parallel to the mechanical axis of the primary and secondary mirrors, and it does not form a complete circle. Thus, it is an arc of some radial width, where ρ defines the radial dimension bounded as $\rho_{Min} < \rho < \rho_{Max}$, and it is an arc of some

angular extent, where ϕ defines the angular spread nominally $0^\circ < \phi < 180^\circ$. The field of view is limited because the primary through tertiary mirror system cannot correct all of the aberrations throughout the circular field that contains the optimized annular zone, but only those within the reduced annular field. However, all of the light from the complete encompassing circular field is collected by the primary and secondary mirrors and is directed through the central hole in the primary mirror. Thus, for this observatory, a set of optical systems are employed to split out and

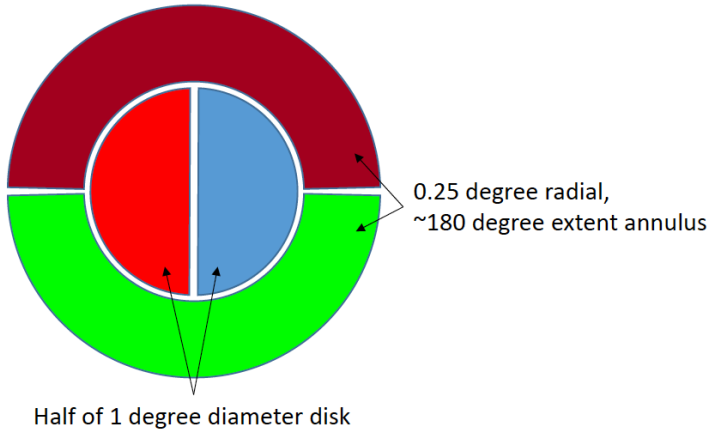


Figure 4. The GDO reassembled focal plane regions to show the full field of view capability of the telescope.

One possible example of this field of view splitting would be to separate the field of view into four separate regions, with two pairs being identical but symmetrically flipped systems. One pair can correct the central field of view from $\sim 0 < \rho < \rho_A$ and $0^\circ < \phi < 180^\circ$, and from $\sim 0 < \rho < \rho_A$ and $180^\circ < \phi < 360^\circ$. The second pair could then correct from $\sim \rho_A < \rho < \rho_{Max}$ and $90^\circ < \phi < 270^\circ$, and from $\sim \rho_A < \rho < \rho_{Max}$ and $-90^\circ < \phi < 90^\circ$. Note that in this configuration, the four separated fields are paired into systems with bilateral symmetry, and that the two pairs are orthogonal to each other. This is shown schematically in Figure 4.

This design approach can be employed in one of four manners. The first is by optimizing the primary secondary and tertiary mirrors for the typical three-mirror telescope annular field of view, and then optimizing the tertiary or tertiary /

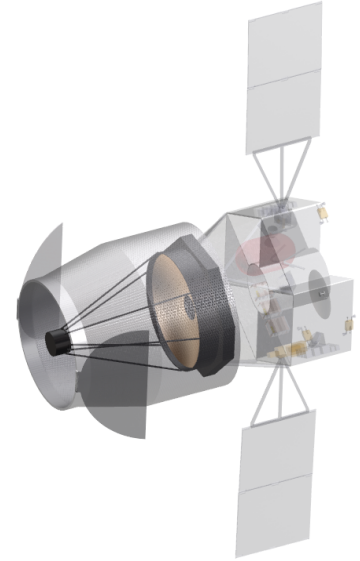


Figure 3. The GDO primary and secondary telescope mirrors and deployed solar arrays.

into separate optical paths, each of which is independently corrected by tertiary and/or tertiary and quaternary mirrors to form images of sufficiently high optical quality substantially over the entire circular field of view. Thus, by separating the field into a number of individually correctable sub-fields, a larger overall field of view can be achieved. Thus, the entire earth disk can be imaged with sufficient image quality.

quaternary systems to achieve sufficient image quality in the central field region with the resulting primary and secondary mirrors. The second is by optimizing the primary secondary and tertiary mirrors for the central field of view. One then optimizes the tertiary or tertiary/quaternary systems for the annular zones surrounding the central zone with the resulting and now fixed primary and secondary mirrors. The third is by optimizing the primary and secondary mirrors for the central field of view, essentially the Cassegrain or Ritchey-Chretien solutions. One then optimizes the tertiary or tertiary/quaternary systems for the annular zones surrounding the central zone with the resulting and now fixed primary and secondary mirrors. The fourth and final approach is to design the field regions independently, but simultaneously, such that the primary and secondary mirror, which all paths require, are designed to balance the design complexity and performance over the entire extended circular field of view.

The approach selected depends on the goals of the optical systems, such as whether certain regions require better image quality than others, or the specific radial or angular extent of the larger or smaller field regions.

To split the field, a set of separate fold mirrors are positioned near the image formed by the primary/secondary system, which redirects the light a substantial angle from the other fields. By positioning the fold mirrors near the image, the vignetting and regions of non-imaging along the boundaries of the separate fields is minimized. Not all field portions need to be folded out by a mirror, as letting a portion of the field continue through the fold mirror region un-affected will similarly separate the light from the other fields of view in the longitudinal direction. Also note that some or all of the field-separating mirrors can be partially transmitting, or dichroic which means that different spectral regions can be additionally separated at this region. Thus, if four dichroic fold mirrors are employed, eight separate paths are generated, with four different field regions, and two different spectral regions.

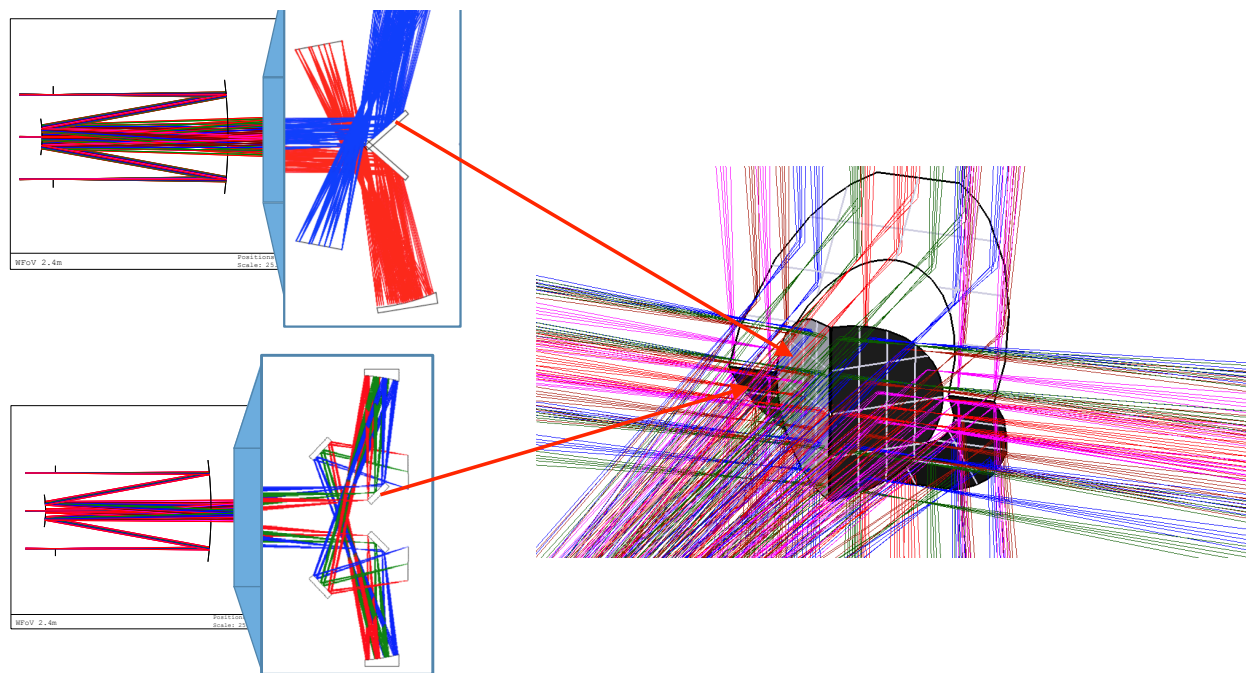


Figure 5. A schematic of the GDO optics showing the telescope fore-optics on the right for the central and annulus regions of the field of view shown in Figure 4. The right side of the schematic shows an expanded view of the split of the field.

In addition to image quality, plate scale and other typical geometrical and diffraction issues, the constraints of this design approach include

- a coupling of the maximum field of view and, directly, the diameter of the secondary mirror (obscuration)
- a coupling of the field of view and, directly, the diameter of the hole in the primary mirror (obscuration)
- a coupling of the radius of curvature of the primary mirror and, directly, the diameter of the secondary mirror

4.0 SUMMARY

The GDO mission concept offers compelling and significant science return aligned with NRC Decadal priority science. The mission implementation approach is extraordinary, unique, and unparalleled, but does not require technology development. The telescope optics are innovative and will require some refinement. The instrument sensors will need further study to define the best approach.

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