The present invention relates to a space-based instrument which provides continuous coronal electron temperature and velocity images, for a predetermined period of time, thereby improving the understanding of coronal evolution and how the solar wind and Coronal Mass Ejection transients evolve from the low solar atmosphere through the heliosphere for an entire solar rotation. Specifically, the present invention relates to using a 6U spherical occulter coronagraph CubeSat, and a relative navigational system (RNS) that controls the position of the spacecraft relative to the occulting sphere. The present invention innovatively deploys a free-flying spherical occulter, and after deployment, the actively controlled CubeSat will provide an inertial formation flying with the spherical occulter and Sun.

20 Claims, 4 Drawing Sheets
References Cited

U.S. PATENT DOCUMENTS

6,019,320 A * 2/2000 Shah ........................ B64G 1/24
8,251,315 B2 * 8/2012 Leyre ........................ B64G 1/1085
8,772,690 B2 * 7/2014 Smith ..................... G01C 21/24
9,334,068 B2 * 5/2016 Kronhaus ................ B64G 1/26
9,676,590 B2 * 6/2017 Eckersley ................. B64G 1/105
2015/0052874 A1 * 2/2015 Keidar ................. B64G 1/405

* cited by examiner
30° Lateral Diodes (~; umbra / penumbra boundary)

302 Full-Sun Diodes

303 Range Diodes (x2)

FIG. 3
SPHERICAL OCCULTER CORONAGRAPH CUBESAT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a space-based instrument which can provide continuous coronal electron temperature and velocity images, for a predetermined period of time, thereby improving the understanding of coronal evolution and how the solar wind and coronal mass ejection (CME) transients evolve from the low solar atmosphere through the heliosphere for an entire solar rotation. Specifically, the present invention relates to using a spherical occulter coronagraph CubeSat, and a relative navigational system that controls the position of the spacecraft relative to the occulting sphere.

2. Description of the Related Art

Conventional solar coronagraphs measure visible photospheric light Thomson-scattered by coronal electrons, imaging the seemingly static solar corona including transients, such as Coronal Mass Ejections (CMEs), as they disrupt the overlying magnetic field.

However, the resolution of the images in the low corona is related to the distance that the external occulter is from the imaging optics; the farther the occulter the better the image. This is why a total solar eclipse is the ideal coronagraph, as the moon is over 200,000 miles from the observers. Traditional imagers use mechanical structures, such as tubes, to mount and align the occulter to the optics, and these structures limit this distance to ~1 meter due to volume/mass limitations to get these instruments into space.

Thus, a coronagraph that is capable of eliminating any mechanical structure and utilize inertial formation flying of two separate spacecraft, one containing the occulter and the other the spacecraft, is desired.

SUMMARY OF THE INVENTION

The present invention relates to a space-based instrument which can provide continuous, high-resolution coronal electron temperature and velocity images, for a predetermined period of time (i.e., one month), thereby improving the understanding of coronal evolution and how the solar wind and CME transients evolve from the low solar atmosphere through the heliosphere for an entire solar rotation. Specifically, the present invention relates to using a spherical occulter coronagraph (SOC) CubeSat, and a relative navigational system (RNS) that controls the position of the spacecraft relative to the occulting sphere.

In one embodiment, the present invention relates to a novel 6 U (U-type spacecraft) spherical occulter coronagraph CubeSat, which can meet science observations from 1.5 RSun to 5 RSun. In one embodiment, the novel spherical occulter coronagraph of the present invention innovatively deploys a free-flying spherical occulter (instead of a flat disk), and after deployment, the actively controlled CubeSat provides a novel inertial formation flying with the sphere and Sun using a novel relative navigational system (RNS).

In one embodiment, the RNS includes a plurality of photodiodes for sensing the translation and range of the spherical occulter relative to the spacecraft, and for formation flying feedback.

In one embodiment, the spherical occulter coronagraph of the present invention has greater than 2.25 m separation between the occulter and optics, greater than prior art separations which are approximately 0.8 m to 1.3 m. This larger separation improves the signal-to-noise ratio due to reduced diffraction intensities off the occulter, a dominant noise source in coronagraphs. The spherical occulter coronagraph’s separation also leads to greatly improved spatial resolution over current externally occulted coronagraphs in the diffraction-limited region, from vignetting in the low corona.

Additionally, the spherical occulter coronagraph CubeSat of the present invention is a pathfinder directly scalable to coronagraphs with even larger separations, possibly hundreds of meters in length, using inflatable spherical occulters. The spherical occulter coronagraph of the larger-scale coronagraphs will have even better signal/noise ratio and spatial resolution, providing high-resolution images and plasma diagnostics down to <1.05 solar radii.

In one embodiment, the spherical occulter coronagraph CubeSat of the present invention can be used in any Earth-escape orbit that will take the spherical occulter coronagraph CubeSat out of the influence of Earth’s atmospheric density variations and changing gravitational forces, simplifying formation flying while providing a 100% view of the Sun.

In one embodiment, the spherical occulter coronagraph CubeSat of the present invention includes a plurality of novel technology features, including: 1) inertial formation-flying with a passive secondary including release technique, control scheme, and software; 2) theoretical diffractive performance of a spherical occulter, expected to be superior to the traditional flat knife-edge occulters; 3) fine Sun-pointing from a CubeSat platform; 4) interplanetary communication from a CubeSat; 5) µCAT microthrusters; and 6) approximately 1 U volume coronagraph optics and filter wheel, not including the occulter.

In one embodiment, the spherical occulter coronagraph CubeSat of the present invention includes: a spherical occulter, an occulter release mechanism; wherein the spherical occulter is deployed from an occulter guide tube disposed in a body of the occulter coronagraph CubeSat, using the occulter release mechanism.

In one embodiment, the spherical occulter is coated with a black paint material which provides greater than 90% absorption of any scattered light, and is a conductive surface which provides forward scatter suppression around the spherical occulter.

In one embodiment, the spherical occulter coronagraph CubeSat includes: a relative navigation system (RNS) including a plurality of photodiodes, including first lateral photodiodes, second lateral photodiodes, full-sun photodiodes, and range photodiodes, the plurality of photodiodes which sense a translation and range of the spherical occulter to control a position of the CubeSat relative to the spherical occulter, and for formation flying feedback of a plurality of CubeSats.

In one embodiment, the full-sun photodiodes are disposed on outer edges of a front face of the CubeSat, and are used to determine a full Sun intensity and allow for relative measurements of the plurality of photodiodes in the CubeSat wherein the first lateral photodiodes are disposed a predetermined distance from an aperture lens of the spherical occulter, and are used for lateral motion sensing; wherein the range photodiodes are used for range measurement and are disposed at predetermined distances from the aperture lens; wherein the second lateral photodiodes are disposed at a bottom of the occulter guide tube proximate to the occulter release mechanism, and detect lateral movement of the spherical occulter during release, to confirm that the spherical occulter has left the occulter guide tube.

In one embodiment, the spherical occulter is a formation flying, passive, free-flying occulter, which reduces forward
In one embodiment, the present invention relates to a space-based instrument which can provide continuous coronal electron temperature and velocity images, for a predetermined period of time (i.e., one month), thereby improving the understanding of coronal evolution and how the solar wind and Coronal Mass Ejection (CME) transients evolve from the low solar atmosphere through the heliosphere for an entire solar rotation. Specifically, the present invention relates to using a novel spherical occulter coronagraph (SOC) CubeSat, and a relative navigational system (RNS) that controls the position of the spacecraft relative to the occulting sphere.

In one embodiment, the present invention relates to a novel 6 U (U-type spacecraft) spherical occulter coronagraph (SOC) CubeSat that can meet science observations from 1.5 RSun to 5 RSun. In one

In one embodiment, the present invention relates to a space-based instrument which can provide continuous coronal electron temperature and velocity images, for a predetermined period of time (i.e., one month), thereby improving the understanding of coronal evolution and how the solar wind and Coronal Mass Ejection (CME) transients evolve from the low solar atmosphere through the heliosphere for an entire solar rotation. Specifically, the present invention relates to using a novel spherical occulter coronagraph (SOC) CubeSat, and a relative navigational system (RNS) that controls the position of the spacecraft relative to the occulting sphere.

In one embodiment, the present invention relates to a novel 6 U (U-type spacecraft) spherical occulter coronagraph (SOC) CubeSat that can meet science observations from 1.5 RSun to 5 RSun. In one
embodiment, the novel spherical occulter coronagraph of the present invention innovatively deploys a free-flying spherical occulter 201 (see FIG. 2) (instead of a flat disk), and after deployment, the actively controlled CubeSat 100 will provide a novel inertial formation flying with the spherical occulter 201 and Sun.

System Design

In one embodiment, FIG. 1 shows exemplary components of the novel spherical occulter coronagraph CubeSat 100 of the present invention. In one embodiment, a spacecraft and payload interface board 101 enables communication to the computer standardized bus (i.e., PC/104) 102 subsystems: space Electrical Power System (EPS) 103, batteries 104, and X-band transceiver 105. A CHREC (Center for High-Performance Reconfigurable Computing) space processor (CSP 107) is connected to the bus 102 via a connector 119. The interface board 101 enables communication to non-PC/104 subsystems such as and X-ray advanced concepts testbed (XACT) sounding rocket 106, the CSP 107, the science complementary metal-oxide semiconductor (CMOS) imager board 108, and a plurality of micro-cathode vacuum arc thrusters (CAT) 109 with electric propulsion boards 110. The micro-cathode vacuum arc thrusters (µCAT) 109 are used for in-space micro-propulsion applications, and are high specific impulse (Isp), low-thrust electric propulsion suitable for small satellite attitude control, precision orbit control or extended low-thrust maneuvers. In one embodiment, the CubeSat 100 compatible, Deep Space Network (DSN) 118 compatible X-band transponder 105 can operate on any channel in deep space or the near Earth X-band.

In one embodiment, the optical equipment 114 of the spherical occulter 201 was designed to be placed in a 6 U CubeSat 100. In one embodiment, the optical design of the present invention meets all science-derived requirements, and the entire optics package 114 (see FIGS. 1 and 4), including focusing lenses (i.e., entrance aperture lens 207 etc.), as well as filter wheel 115, all fit into just over a 1 U volume package.

In one embodiment, the flight software of the CSP 107 has communication and control of the science electronics board 101, the guidance, navigation and control (GNC) relative navigational system (RNS), and the detection of a CME. The CFE allows for custom applications to be developed independently. This is especially useful for the relative navigational system (RNS) as it will run as a separate process within the CFE and communicate via the messaging middleware.

In one embodiment, the XACT 106 is one of two subsystems of the guidance, navigation and control system (GNC) of the spherical occulter coronagraph CubeSat 100—namely, the attitude control system (ACS), which controls the attitude of the 6 U spacecraft 100 relative to the Sun; and the novel relative navigational system (RNS). In one embodiment, as part of the ACS, a course sun sensor (CSS) photodiode 205 (see FIG. 2) is placed on each of the satellite faces (bottom panel 200, top panel 202, front panel 204, and back panel) for course Sun-sensor positional knowledge. The CSS photodiodes 205 are used for course determination of the Sun’s position, and are used only in the initial de-tumble and sun-finding modes (discussed later).

In one embodiment, also as part of the ACS, a Fine Sun Sensor (FSS) 117 is incorporated in the XACT 106 and used to maintain fine pointing (<0.3°)to the Sun. Further, the FSS 117 is mounted such that it does not protrude past the outer surface (front panel 204) of the spacecraft body (see FIG. 2) in order to not reflect light into the optics 114.

In one embodiment, a plurality of µCAT thrusters 109 are mounted on the payload 100 at each corner of the top panel 202 and facing outward (see FIG. 2), while the set is mirrored on the bottom panel 200 (see FIG. 3). In one exemplary embodiment, an arrangement of eight µCAT thrusters 109 is the minimum number needed at each of these corners of the CubeSat 100 to produce motion in both translation and rotation on each body axis. This will allow for control of the spacecraft 100 relative to the spherical occulter 201 as well as allow for dumping momentum (i.e., allowing the momentum wheels from the XACT 106 system to spin down to maintain spacecraft 100 attitude), if needed (but which is not expected). However, one of ordinary skill in the art would know that the placement and number of thrusters may change depending on requirements. As noted above, in one embodiment, the second subsystem of the GNC is the novel relative navigation system (RNS) that controls the position of the spacecraft 100 relative to the occulting sphere 201. In one embodiment, the inertial navigation includes a plurality of RNS photodiodes (see FIG. 3)—for example, four Lateral photodiodes 301, four Full-Sun photodiodes 302, two Range photodiodes 303, and two other Lateral photodiodes (not shown)—for sensing the translation and range of the spherical occulter 201 relative to the spacecraft 100, and for formation flying feedback. However, one of ordinary skill in the art would know that the placement and number of photodiodes may change depending on requirements.

FIG. 3 also shows the extent of the umbra boundary 304 and penumbra boundary 305 from the novel spherical occulter 201 on the face of the occulter coronagraph CubeSat 100. In one embodiment, four exemplary Full-Sun photodiodes 302 on the outer edges of the science (front) face 204 are used to determine the full sun intensity and should never be shadowed unless the spherical occulter 201 has drifted and the spacecraft 100 has not compensated for it. In one embodiment, the Full-Sun photodiodes 302 allow for relative and not absolute measurements of all inertial alignment diodes to remove other variables from the system (e.g., thermal, proton storms, etc.).

In one embodiment, the occulter/aperture distance, given the occulter 301 diameter, was iterated with the signal calculation, which was limited by the occulter diffraction, to define the inner FOV cutoff to be 1.5 R_solar. Note that the spherical occulter 301 spatial resolution from vignetting is moderate until about 1.75 R_solar. The spherical occulter coronagraph CubeSat 100 of the present invention is utilizing formation flying, thus, if the noise and diffraction are lower than theoretically calculated it is easy to adjust the distance control algorithm via upload command to move the spherical occulter 301 farther away, enabling observations lower in the solar corona. This leads to a separation of 2.25 m with the 50 cm aperture, resulting in a much better vignetting-limited spatial resolution than current coronagraphs.

In one embodiment, the exemplary inside Lateral diodes 301, which are disposed, for example, at 4 cm from the aperture lens 207, are used for lateral motion sensing. When the spherical occulter 201 is centered over a CMOS detector 403 (see FIG. 4), the shadow it casts will have equal intensity on all four exemplary Lateral sensors 301. The Lateral photodiodes 301 are insensitive to the range, as they are located at a radius equal to the radius of the spherical occulter 201. The CMOS detector 403 is optimal due to the power limitation on a CubeSat 100, and it interfaces with the interface board 101 to transfer data into the CSP 107 for further handling.
In one embodiment, there are two other sensors—Range diodes 303—used for range measurement, and that may be located in an exemplary location, such as 4.25 cm and 4.5 cm from the aperture lens 207 center. The relative intensity of the sun light going from the umbra 304 through the penumbra 305 to full sun light on the spacecraft front face 204, changes for a number of ranges corresponding to different solar radii. By using the difference in intensities on each of these range photodiodes 303, the range can be determined. As the spacecraft moves further away from the spherical occulter 201, and the effective solar radius of the spherical occulter 201 gets smaller, the penumbra grows.

In one embodiment, the Lateral motion sensors 401 are shadowed for all ranges. In one embodiment, the Ranging diodes 403 are placed such that they will be more accurate at long ranges. Any effect on the estimation of range inside the 1.5 $R_{sun}$ baseline is irrelevant as fine control is not needed here.

In one embodiment, the two remaining Lateral photodiodes (not shown) are on the inside edges at the bottom of the occulter guide tube 206 near the release mechanism 402. The Lateral photodiodes detect if the spherical occulter 201 first moves outward during the release and pullback by the spacecraft 100 until the spherical occulter 201 is clear and followed by the translation maneuver of the spacecraft 100 until the now free-flying spherical occulter 201 is in position in front of the instrument aperture lens 207, providing knowledge that the occulter 201 has left the occulter guide tube 206 and is centered on the aperture lens 207. In one embodiment, based on estimated noise of the photodiodes 301-303 and accompanying electrical circuits to read them, the intensity of the photodiodes 301-303 can conservatively be estimated within 1% of full scale which gives a range accuracy of $\pm 13$ cm and a lateral accuracy of $\pm 1$ nm for a shadow from the sphere relative size of 1.5 $R_{sun}$.

In one embodiment, the spherical occulter coronagraph CubeSat 100 of the present invention uses two space 6 U single-sided long-edge deployable solar panels 111, 112, each panel 111, 112 containing a plurality of solar cells (for example, 21 solar cells of which seven (7) are in series and three (3) in parallel—7s3p configuration) on only the outer face (see FIG. 2). The solar cells provide power to the CubeSat 100 when the panels 111, 112 are stowed prior to panel deployment. The operating temperature of the solar cells 111, 112 is around $+80^\circ$ C.

In one embodiment, in addition to the two 6 U deployable solar panels 111, 112, and filter wheel 115, the spacecraft 100 includes other onboard mechanisms such as a release mechanism 402 (see FIG. 4) for the occulter 201. In one embodiment, the spherical occulter’s 201 size, along with its deployment or release mechanism 402 (see FIG. 3), was maximized to an 8 cm diameter to fit into a 1 U unit allocation.

In one embodiment, the 6 U deployable solar panels 111, 112 include all necessary mounting hardware and release mechanisms that incorporate a thermal knife and time driver system (not shown). When deployed, the spring loaded hinge system (not shown) of the release mechanism 402 will open the panels to a 90° position to be normal to the Sun for maximum power production.

The occulter release mechanism 402 contains a pin puller among other components. A cupped plunger (not shown) is used to hold the occulter 201 against the wall of the occulter guide tube 206. Upon actuation of the pin puller (not shown), a compression spring pushes the plunger away from the occulter 201 such that it is free to move. The compression spring (not shown) maintains force on the plunger so that it will not return to the occulter guide tube 206.
In one embodiment, the spherical occulter coronagraph CubeSat 100 of the present invention includes two operational modes. Mode 1 is the De-tumble/Sun finding mode. In one embodiment, the De-tumble mode starts after spherical occulter coronagraph separation when the spacecraft 100 comes alive, when the ACS switches to De-tumble mode and arrests the tip-off rotation rates. The course sun sensors 205 are used to initially find the Sun and reorient it to point the correct face at the Sun. The solar panels 111, 112 are deployed once the fine sun sensors (FSS) 117 register that the Sun has been obtained and the FSS 117 take control. The spacecraft 100 will wait in the De-tumble mode until the second mode—Occulter deployment—which will occur after lunar swing-by, to ensure the occulter 201 will not be lost during swing-by.

In Mode 2—Occulter deployment—the spherical occulter 201 is released so as to not impart an unknown velocity between the two objects 100. After the spherical occulter 201 is released, the thrusters 109 are fired for a prescribed burn to back the 6 U spacecraft 100 away from the spherical occulter 201, where a photodiode at the base of the occulter guide tube 206 registers that the spherical occulter 201 has successfully cleared the spacecraft 100. The CSP 107 will then fire the thrusters 109 to first translate the CubeSat 100 so that the spherical occulter 201 covers the lens 207 to occult the Sun; and second, to move the spacecraft 100 further from the spherical occulter 201 along the optical axis.

In another mode—the Science Mode—the ACS and RNS algorithms will run continuously throughout the Science mission ensuring 100% views of the Sun with inertial alignment to within the pointing requirements. The science operation is simply either taking data or transmitting data, and pointing at the Sun continuously; no additional pointing offsets are needed for transmission or receiving.

In one embodiment, the science requirement for pointing is <0.5 deg with respect to the Sun and a jitter of less than 18" of jitter over a 9-sec integration. The spacecraft 100 position relative to the occluding sphere 301 must be maintained such that the Sun is always occulted. The relative movement during an exposure is not as critical, but should be kept to less than 0.1 cm, which is easily accommodated.

In one embodiment, in a heliocentric orbit, the primary forces and torques on the spacecraft 100 will be due to solar pressure. The spherical occulter 201 has a much smaller area than the spacecraft 100 but weights much less; therefore, it will want to move towards the spacecraft 100 after deployment. In order to maintain a desired range, the spacecraft 100 will have to thrust away from the sphere 201 with a force of about 1 micro-N. In one exemplary embodiment, if the center of gravity is 5 cm away from the center of pressure, the torque from solar pressure will be about 4e-8 Nm which equates to about 3.5 mNms per day. At tip-off, if a 3 deg/sec body rate is assumed, the momentum wheels need to absorb about 8 mNms momentum with at least 2 mNms to spare for a rotation maneuver to find the Sun for a total capacity needed of about 10 mNms.

In one embodiment, the spherical occulter coronagraph of the present invention measures the electron temperature and bulk electron velocity in the corona, providing additional continuous measurements of physical variables beyond the current standard imaging coronagraph. With the addition of...
polarization filter, application of this technique can be made
further out in the solar corona.

Not only does the spherical occulter coronagraph of the
present invention have stand-alone science achievements, it
also addresses technology that can be used for larger,
higher-class missions, including: 1) inertial formation flying
with a passive secondary including release technique, con-
trol scheme, and software; 2) theoretical diffractive perfor-
dance of a spherical occulter, expected to be superior to the
traditional flat knife-edge occulters; 3) fine Sun-pointing in
corona during one Carrington rotation.

It should be emphasized that the above-described embed-
ments of the invention are merely possible examples of
implementations set forth for a clear understanding of the
principles of the invention. Variations and modifications
can be made to the above-described embodiments of the
invention without departing from the spirit and principles of
the invention. All such modifications and variations are
intended to be included herein within the scope of the
invention and protected by the following claims.

What is claimed is:
1. An occulter coronagraph CubeSat comprising:
aspherical occulter;
an occulter release mechanism;
wherein said spherical occulter is deployed from an
occultor guide tube disposed in a body of said occulter
corona CubeSat, using said occulter release mechanism.
2. The occulter coronagraph CubeSat of claim 1, wherein
said spherical occulter is coated with a black paint material
which provides greater than 90% absorption of any scattered
light, and is a conductive surface which provides forward
scatter suppression around said spherical occulter.
3. The occulter coronagraph CubeSat of claim 1, further
comprising:
a relative navigation system comprising a plurality of
photodiodes, including first lateral photodiodes, second
lateral photodiodes, full-sun photodiodes, and range
photodiodes, said plurality of photodiodes which sense a
translation and range of said spherical occulter to
control a position of the CubeSat relative to said
spherical occulter, and for formation flying feedback of
a plurality of CubeSats.
4. The occulter coronagraph CubeSat of claim 3, wherein
said full-sun photodiodes are disposed on outer edges of a
front face of the CubeSat, and are used to determine a full
Sun intensity and allow for relative measurements of said
plurality of photodiodes in the CubeSat;
wherein said first lateral photodiodes are disposed a
predetermined distance from an aperture lens of said
spherical occulter, and are used for lateral motion
sensing;
wherein said range photodiodes are used for range mea-
surement and are disposed at predetermined distances
from said aperture lens;
wherein said second lateral photodiodes are disposed at a
bottom of said occulter guide tube proximate to said
occultor release mechanism, and detect lateral move-
ment of said spherical occultor during release, to
confirm that said spherical occultor has left said occulter
guide tube.
5. The occulter coronagraph CubeSat of claim 3, wherein
said spherical occultor is a formation flying, passive, free-
lying occultor, which reduces forward scattering noise
contributed by diffraction around said spherical occultor at
an inner half-angle field-of-view (FOV) of 0.375°, corre-
sponding to 1.5 Rsun.
6. The occulter coronagraph CubeSat of claim 4, wherein
a size of said spherical occultor and said occultor release
mechanism is maximized to an 8 cm diameter to fit into a
1 U volume coronagraph optics and filter wheel, not including
the occultor.
7. The occulter coronagraph CubeSat of claim 6, wherein
the occultor coronagraph CubeSat measures an electron
temperature and a bulk electron vector velocity of the Sun’s
corona during one Carrington rotation.
8. The occulter coronagraph CubeSat of claim 7, wherein
the occultor coronagraph CubeSat utilizes a heliocentric
orbit.
9. The occulter coronagraph CubeSat of claim 8, further
comprising:
a de-tumble or sun finding mode; and
an occultor deployment model;
wherein said de-tumble or sun finding mode arrests a
tipoff rotation rate, and a plurality of course sensors are
used to find the Sun and reorient the occultor corona-
graph CubeSat to point said front face to the Sun; and
wherein said occultor deployment mode utilizes said
occultor release mechanism to deploy said spherical
occultor.
10. The occultor coronagraph CubeSat of claim 9, further
comprising:
a science mode which points said spherical occultor at
<0.5 deg with respect to the Sun, and a jitter of less than
18° of jitter over a 9-sec integration;
wherein said spherical occultor always occludes the Sun
based on a relative position between said spherical
occultor and the occultor coronagraph CubeSat.
11. The occultor coronagraph CubeSat of claim 10, further
comprising:
a plurality of micro-cathode vacuum arc thrusters which
are used for in-space micro-propulsion;
wherein said thrusters are fired for a prescribed burn after
said spherical occultor is deployed, in order to move the
occultor coronagraph CubeSat away from said spherical
occultor; and
wherein on condition that said spherical occultor has
successfully cleared the occultor coronagraph CubeSat,
the thrusters are fired to translate the occultor corona-
graph CubeSat so that said spherical occultor covers
said aperture lens to occult the Sun, and to move the
occultor coronagraph CubeSat further from said spherical
occultor along an optical axis.
12. The occultor coronagraph CubeSat of claim 11, wherein
the occultor coronagraph CubeSat thruts away from said
spherical occultor with a force of about 1 micro-N.
13. A method of occulting a corona of the Sun, compris-
ing:
deploying an occultor coronagraph CubeSat in a helio-
centric orbit;
wherein said occultor coronagraph CubeSat comprises a
spherical occultor, which is deployed from an occultor
guide tube disposed in a body of said occultor corona-
graph CubeSat utilizing an occultor release mechanism.
14. The method of claim 13, wherein said spherical
occultor is a formation flying, passive, free-flying occultor.
15. The method of claim 14, wherein said spherical
occultor is coated with a black paint material which provides
better than 90% absorption of any scattered light as well as
being a conductive surface which provides forward scatter
suppression around said spherical occultor.
16. The method of claim 15, wherein said spherical occulter reduces forward scattering noise contributed by
diffraction around said spherical occulter at an inner half-
angle field-of-view (FOV) of 0.375°, corresponding to 1.5
R_{\odot}.

17. The method of claim 16, wherein a size of said
spherical occulter and said occulter release mechanism is
maximized to an 8 cm diameter to fit into a 1 U unit
allocation.

18. The method of claim 17, wherein said occulter coro-
ograph CubeSat measures an electron temperature and a
bulk electron vector velocity of the Sun’s corona during one
full Carrington rotation.

19. The method of claim 18, wherein said occulter coro-
ograph CubeSat includes a de-tumble or sun finding mode;
an occulter deployment mode, and a science mode;
wherein said de-tumble or sun finding mode arrests a
tipoff rotation rate, and a plurality of course sensors are
used to find the Sun and reorient said occulter corona-
graph CubeSat to point said front face to the Sun;
wherein said occulter deployment mode utilizes said
occulter release mechanism to deploy said spherical
occulter;

20. The method of claim 19, further comprising:
utilizing a plurality of micro-cathode vacuum arc thrusters
for in-space micro-propulsion;
wherein said thrusters are fired for a prescribed burn after
said spherical occulter is deployed, in order to move
said occulter coronagraph CubeSat away from said
spherical occulter;
wherein on condition that said spherical occulter has
successfully cleared said occulter coronagraph Cube-
Sat, said thrusters are fired to first translate the occulter
coronagraph CubeSat so that said spherical occulter
covers said aperture lens to occult the Sun, and to move
the occulter coronagraph CubeSat further from said
spherical occulter along an optical axis; and
wherein said occulter coronagraph CubeSat thrusts away
from said spherical occulter with a force of about 1
micro-N.