Using The Deep Space Gateway To Build The Next Generation Heliophysics Research Grid. A. Vourlidas[1], G. C. Ho[1], I. J. Cohen[1], C. M. Korendyke[2], S. Tun-Beltran[2], S. P. Plunkett[2], J. Newmark[3], O.C. St Cyr[3], and T. Hoeksema[4] [1]The Johns Hopkins University Applied Physics Laboratory, Laurel, MD (angelos.vourlidas@jhuapl.edu) [2]Space Science Division, Naval Research Laboratory, Washington, D.C. [3]Code 670, Goddard Space Flight Center, Greenbelt, MD [4]Stanford University, Stanford, CA

Introduction: The Heliophysics Research Grid (HRG) is envisioned as a system of sensors, both in situ and remote sensing, distributed in key locations in the inner Heliosphere, providing measurements for both basic research and Space Weather (SpW) operations. The HRG is a natural evolution of the NASA HSD's highly successful Heliophysics System Observatory (HSO) but employs novel instrument and mission concepts, such as miniaturized telescopes, small sats, and orbit designs, to build the necessary space infrastructure with a schedule-flexible, cost-effective approach. Also, HRG adopts a research-to-operations strategy to support terrestrial SpW needs as well as the space exploration needs on the Moon, and, for future Mars voyages.

The DSG can play a key role in enabling and supporting the HRG, both as an observing platform and as a storage and staging hub for asset launches into heliospheric orbits using lunar gravity assists. The latter can build the HRG via so-called '*string-of-pearls*' missions as we discuss in the following representative scenarios.

'*String-of-Pearl*' Missions: A series of spacecraft (s/c) in Earth orbit (trailing and/or leading Earth) spaced at semi-regular intervals from each other.

Why? To enable multi-point, but *small separation,* coverage of transients and solar wind structures for in-situ science and stereoscopic imaging (5°-15° separations) or stereo reconstructions (> 15° separations) for remote sensing.

How? The s/c are launched from the DSG or SLS into drifting orbits ahead or behind Earth (depending on the science case, see example scenarios below). Other orbits, such as quasi-satellite or L1, may be possible. The s/c are small sats with single instrument payloads launched individually or in groups, as hosted payloads. This mission design offers flexibility in launch schedule and budget profile.

Scenario#1: Binocular Imaging of Active Regions The scenario is based on the ILWS-COSPAR 2015-2025 roadmap concept [1].

Science Objective: Estimate the magnetic configuration and strength of an erupting magnetic flux rope (MFR) from an active region.

Approach: This concept entails stereoscopic imaging of the active region corona to derive their 3D loop structure and thus constrain coronal magnetic field extrapolations.

Implementation: Launch a small s/c with a 2-channel EUV imaging telescope in a slowly drifting orbit (ahead or behind Earth) of ~ 2°/yr. It assumes that a similar asset is available along sun-earth line (e.g. GOES/SUVI). If not, the concept requires two s/c with identical instrumentation.

Requirements (s/c): s/c separation between 5°-12° for direct stereoscopy and up to ~ 20° for forward modeling methods. A strawman mission comprises a ~2-yr duration cruise phase to get to 5° and a prime phase of ~ 3-4 years. Given the single payload, the s/c can be quite small (meter-class, similar to ESA/Proba-2) and could be launched as hosted payload on SLS en route to DSG or released from DSG.

Requirements (payload/CONOPS): Full disk imaging at 3-arcsec resolution and AR imaging at 1.5-arcsec resolution. Cadence of 0.5 – 1 min. DSG acts as relay to enable high telemetry. Field of View >1.8 Rs (i.e. similar to SECCHI/EUVI) and 2.5 Rs (goal). The two EUV wavelengths should be sensitive to (1) temperatures of 1-2 MK to capture quiescent corona at high contract (e.g. 171Å or 195Å) and, (2) hotter temperature (~10 MK) to capture the formation, and evolution of the MFR (e.g. 131Å).

String-of-pearls implementation: Identical s/c could be launched at regular intervals (every 2-3 years) to maintain baselines of < 10°-12° between telescopes. A relay capability could be included at alternate s/c to maintain high telemetry rates from the more distant s/c. A coronagraph and/or heliospheric imager could be added (or could replace the EUV telescope) at certain s/c to provide off Sun-Earth imaging of Earth-directed CMEs. The latter requires larger angular separations (at least 30°) to provide useful 3D information.

Scenario #2: Evolution of SEPs and CIRs

Science Objective: To measure the plasma and magnetic structure of Earth-directed transients (CMEs and CIRs) and associated SEPs.

Approach: Deploy s/c with small angular separations to measure the plasma, magnetic and energetic particle fine scale structure of near-Earth transients. Quasi-satellite orbit (to be studied) with apogee of 0.3AU is another option.

Implementation: Launch of a series of small s/c with magnetometer, solar wind and SEP packages in a slowly drifting orbit (ahead or behind Earth) of ~ 2°/yr. Similar

asset are almost always available at the Sun-Earth line (e.g., DSCVR).

Requirements (s/c): the s/c separation is flexible but we know from Helios and STEREO that the solar wind structure can vary significantly with even 2° separation. The in-situ packages are small and naturally lend themselves to a CubeSat format. The magnetometer may require a deployable boom. The s/c are spinning to increase the spatial/angular coverage of the payload without need for additional sensor heads.

Requirements (payload/CONOPS): density, proton velocity/temperature, and magnetic field vector. An SEP sensor could be launched/included on alternate s/c to provide a coarser coverage (~10° separation) of SEP longitudinal spread. A dedicated heliospheric imager s/c could be part of the chain launched upstream (towards L4) to provide imaging of incoming CIRs (best viewed from upstream locations) and context for the in-situ measurements.

String-of-pearls implementation: Launch schedule is similar to previous scenario. DSG serves as storage and launch platform for the s/c. Constellation can be replenished during Orion trips. A launch every 1-2 years ensures an angular separation of ~2° between the sensors. The s/c are launched either downstream of Earth (to provide early measurements of incoming CIRs) or upstream (to provide measurements of upstream magnetic connectivity). The modest telemetry requirement (probably 1-4 kbps), and the relaxed pointing (spinners) make this a good case of interplanetary CubeSats.

Scenario#3: Comprehensive Coverage of Near-Earth Heliosphere Combining the previous string-of-pearl concepts forms the basis of HRG and leads to comprehensive coverage of the activity in the near-Earth heliosphere.

Science Objective: To measure the plasma, magnetic structure, and SEP production of Earth-directed transients (CMEs and CIRs) from the Sun to Earth.

Approach: Deploy s/c both leading and trailing Earth, with imaging or in-situ payloads, in orbits with varying angular separations, to observe the eruption sources and measure the plasma and magnetic properties of near-Earth transients.

Implementation: Launch of a series of small s/c with either imaging (EUV imager, coronagraph, heliospheric imager) or in-situ (magnetometer, solar wind, SEP) package in varying drift orbits (Figure 1).

Requirements (s/c): single payload per s/c. Imaging s/c are 3-axis stabilized with few-arcsec jitter requirement and carry larger antennas. In-situ s/c are spinners on 6U CubeSats with omni antennas. The imaging s/c can be used as relays to send the in-situ data to earth.

Requirements (payload): Full disk EUV imager to 2 Rs (1-3 arcsec resolution, <1 min cadence, 2-3 wavelengths). Coronagraph (2-15 Rs, 30-arcs resolution, 10 min cadence). Heliospheric Imager (40° FOV, 50°-90° elongation, 1-arcmin resolution, 15-30-min cadence). Magnetometer with sub-nT accuracy. Plasma measurements: density, proton velocity/temperature. SEP sensor similar to ACE or Solar Orbiter/SIS.

String-of-pearls implementation: Orbit drift drives launch order. COR launched on a fast drift (5°-10° per yr) towards L5. HI launched with similar drift towards

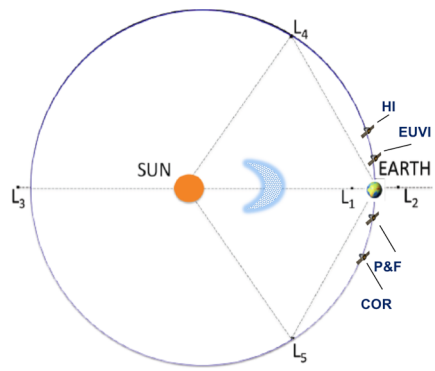

Figure 1 A comprehensive string-of-pearls concept that could form the basis of a Heliophysics Research Grid.A HI imager observes transients impinging on Earth with higher resolution than SECCHI/HI2. An EUV imager and a plasma & fields (P&F) package provide 3D info on erupting ARs and arriving transients in combination with similar assets at Earth/L1 orbit. A coronagraph (COR) at >30° separation derives reliable CME kinematics. The concept can be maintained and expanded with hosted-payload and DSG launches as programmatic conditions allow.

L4. It will provide imaging coverage from 0.03AU to Earth starting from 2° separation. Coverage increases to 0.1 AU upstream when HI reaches 10° separation. The COR and HI s/c could be launched. The EUV telescope is launched (towards L5 or L4) on a 2°/yr drift orbit and starts mission when it is at 5° from Earth.

The in-situ s/c are launched either towards L4 and L5. The L5 direction is slightly preferred because it provides some advance notice/measurements for CIRs. An SEP s/c every 2 'plasma-fields' s/c. SEP payload may be better places towards L4 to provide SEP measurements from upstream Parker spirals. Plasma-fields s/c would benefit from a few degree separations. SEP science can accept larger angular separations of 10° or so. A minimum set of 2 EUV, 1 COR, 1 HI, 2 Plasma-Fields and 2 SEP s/c should provide a comprehensive set of measurement of solar wind structure at 1 AU.

References:

[1] Schrijver, C. J. *et al.* (2015), *Adv. Sp. Res.* **55,** 2745–2807.