JOHNS HOPKINS
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Top-Level Synergies in Current SWx Goals and Strategies

Comparing recommendations and findings from SWAG's Users Survey, the Heliophysics Decadal Survey, and the SWx Tabletop Exercise

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05 February 2025

Noted Synergies

- **Communications, policy, and guidelines**
  - *Highlighted particularly and frequently in the End-Users Survey and SWx TTX*
  - Communication within the government
  - Communications with partners and adversaries internationally (from government)
  - Communications to the public
  - Whole-of-government *plus* academia/research sector *plus* commercial/industry *plus* international collaboration is necessary to do this right
  - From the End-Users Survey: “Surveyed participants noted a lack of specific regulations requiring consideration of space weather…”
  - From the End-Users Survey: “There is a lack of a framework for clear and common best practices, guidelines, and standards related to policies, education, and training”

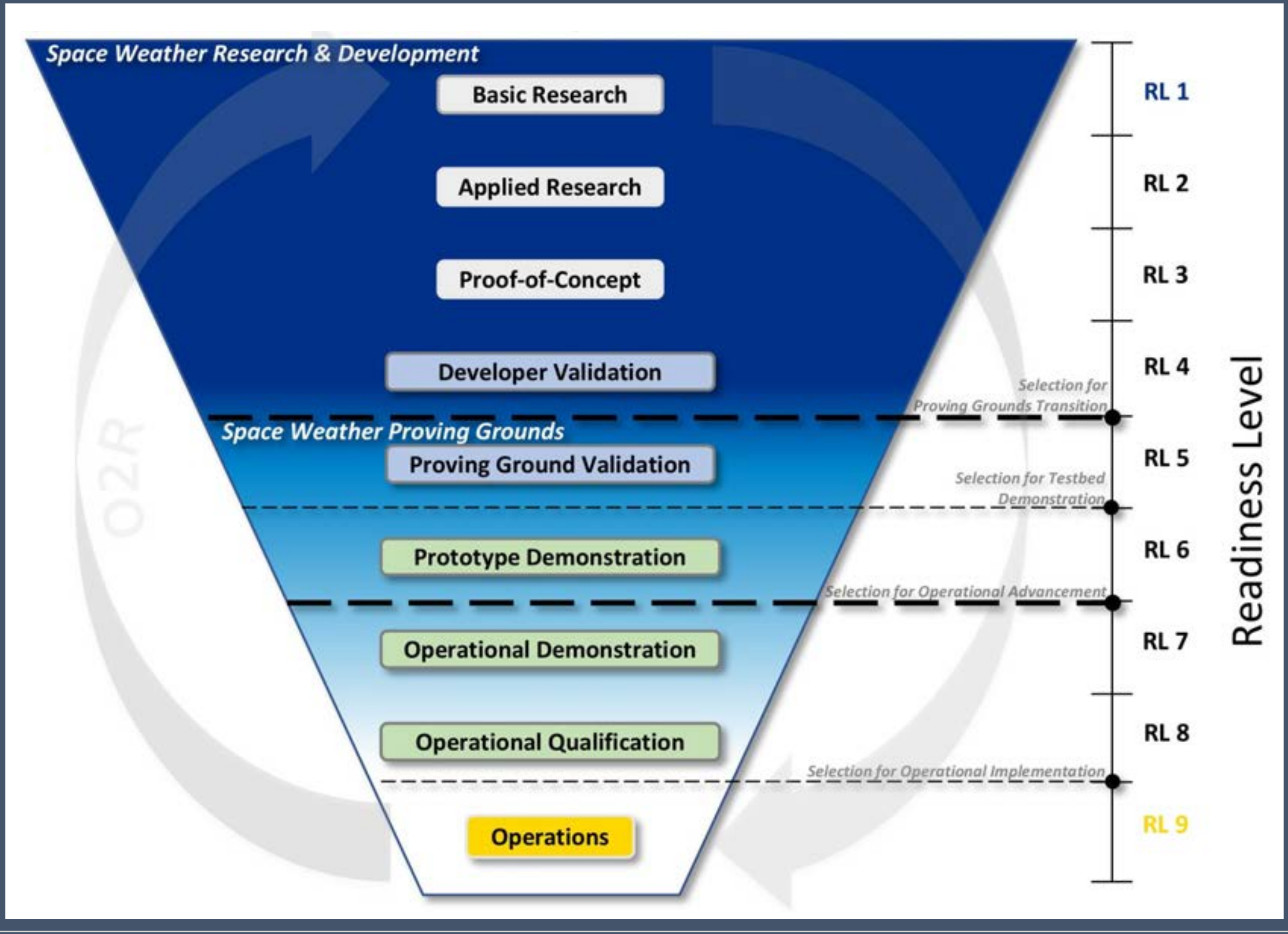
- **Education and general awareness**
  - *Highlighted particularly and frequently in the End-Users Survey and SWx TTX*
  - Needed across all SWx communities (research, ops, end-users) *and* for policy-makers *and* for the media *and* for the general public
  - Training tools for end-user communities
  - From the end-users survey: “I'm almost embarrassed at the lack of knowledge…some kind of educational tool to just make people aware of the risks of space weather” – survey participant, a pilot in the aviation sector
  - See, e.g., SWx training from FEMA: “Preparing the Nation for Space Weather Events (IS-0066)”
  - SWx programs in university curricula (akin to meteorology as a field of study)

Noted Synergies

- **Data accessibility and archiving**
  - *Highlighted frequently in all three documents*
  - User-friendly and meaningful indices, including end-user sector specific
  - Backward compatibility/translatability with historic datasets
  - Sharing of relevant situational awareness data: Power utilities with GICs; satellite sector with anomalies, space traffic management; etc.
- **Model development**
  - *Highlighted frequently in all three documents, but particularly the DS and End-Users Survey*
  - Model validation, uncertainty estimation and reporting, and usage of ensemble modeling
  - Machine learning and advanced data mining applications
  - Partner end users with researchers for model/tool improvement and development
  - Use of OSSEs and OSEs for developing and proving value of new operational systems
  - Need for higher fidelity and resolution (spatial) nowcasts (situational awareness) and forecasts – "*regionalization*"
- **Observational gaps**
  - *Highlighted frequently in all three documents*
  - Need for more comprehensive observatory networks, both space- *and* air- *and* ground-based
  - Need for higher fidelity and resolution (spatial and temporal) observations – "*regionalization*"

Noted Synergies

- R2O2R cycle and the "valley of death" in applications transitions from applied research results to usable operational products



Noted Synergies

- **Employ a systems science approach to space weather**
  - *Highlighted in End-Users Survey and Helio DS*

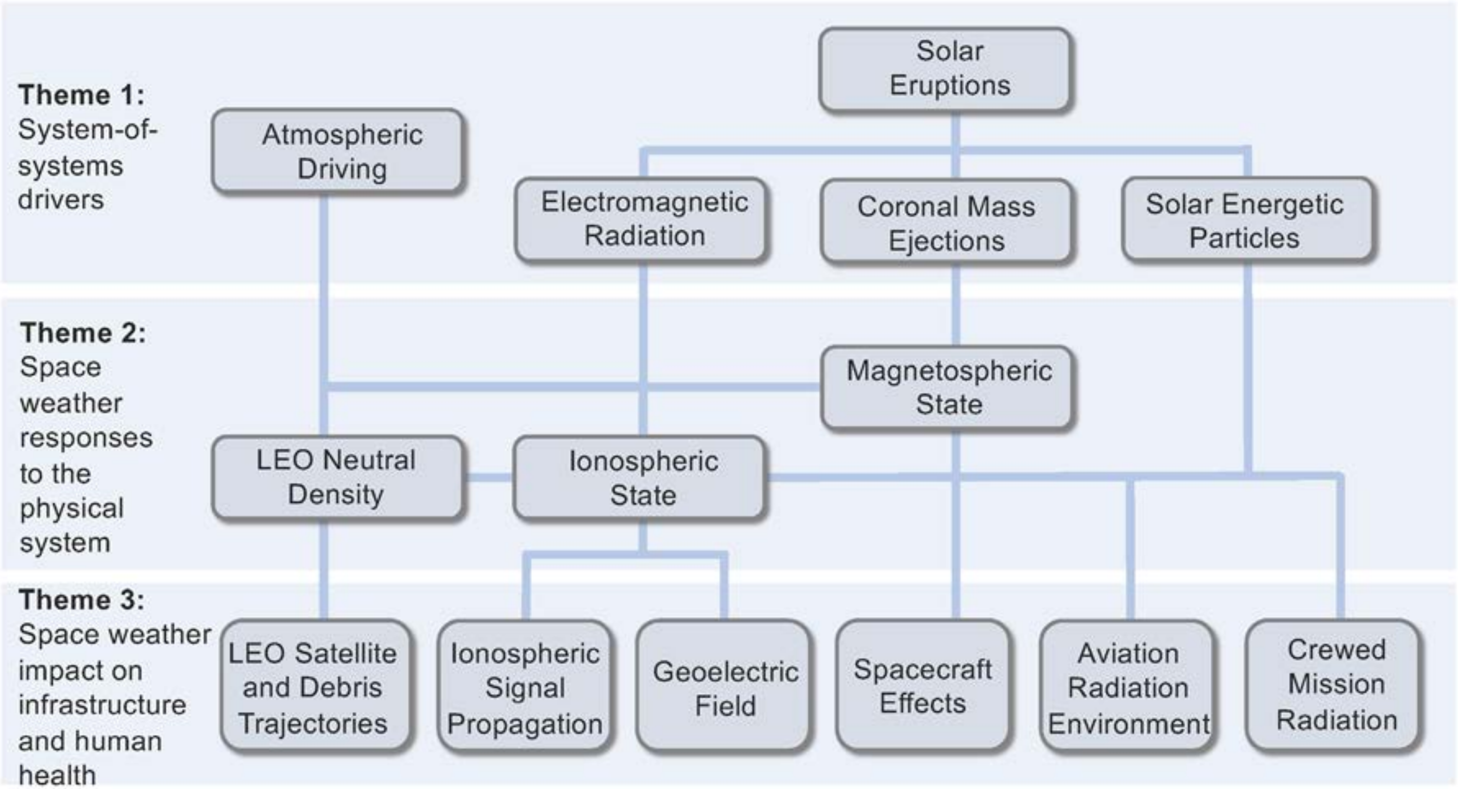


FIGURE 3-6 Space weather research themes follow the Sun–Earth connection process starting with solar inputs, through their effects on the physical system to their impacts on infrastructure and human health.

Noted Synergies

- SWx is critical to proliferated LEO and successful space traffic management
  - *Highlighted frequently in all three documents*

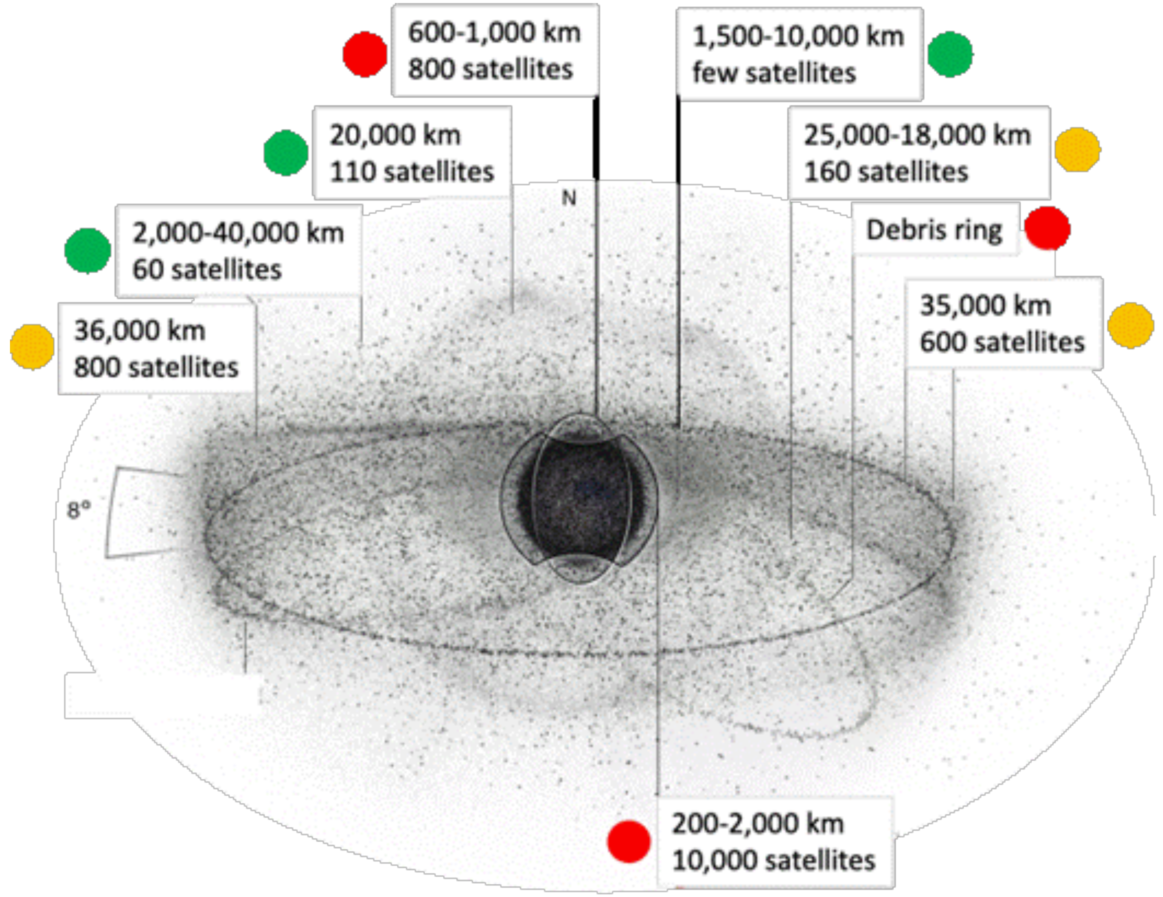


FIGURE 3-9 Space debris and urgency for mitigating actions. Low earth orbit is the most critical region both for the number of spacecraft, space debris, and sensitivity of the orbits to space weather impacts. The red, yellow, and green traffic lights indicate the urgency for mitigating actions to maintain operational safety. In the next decade, space weather research will contribute an accurate and reliable thermospheric density model to help develop mitigating actions.
SOURCE: Image courtesy of Pablo Carlos Budassi.

Noted Synergies

- Human spaceflight, return to the Moon, and onward to Mars

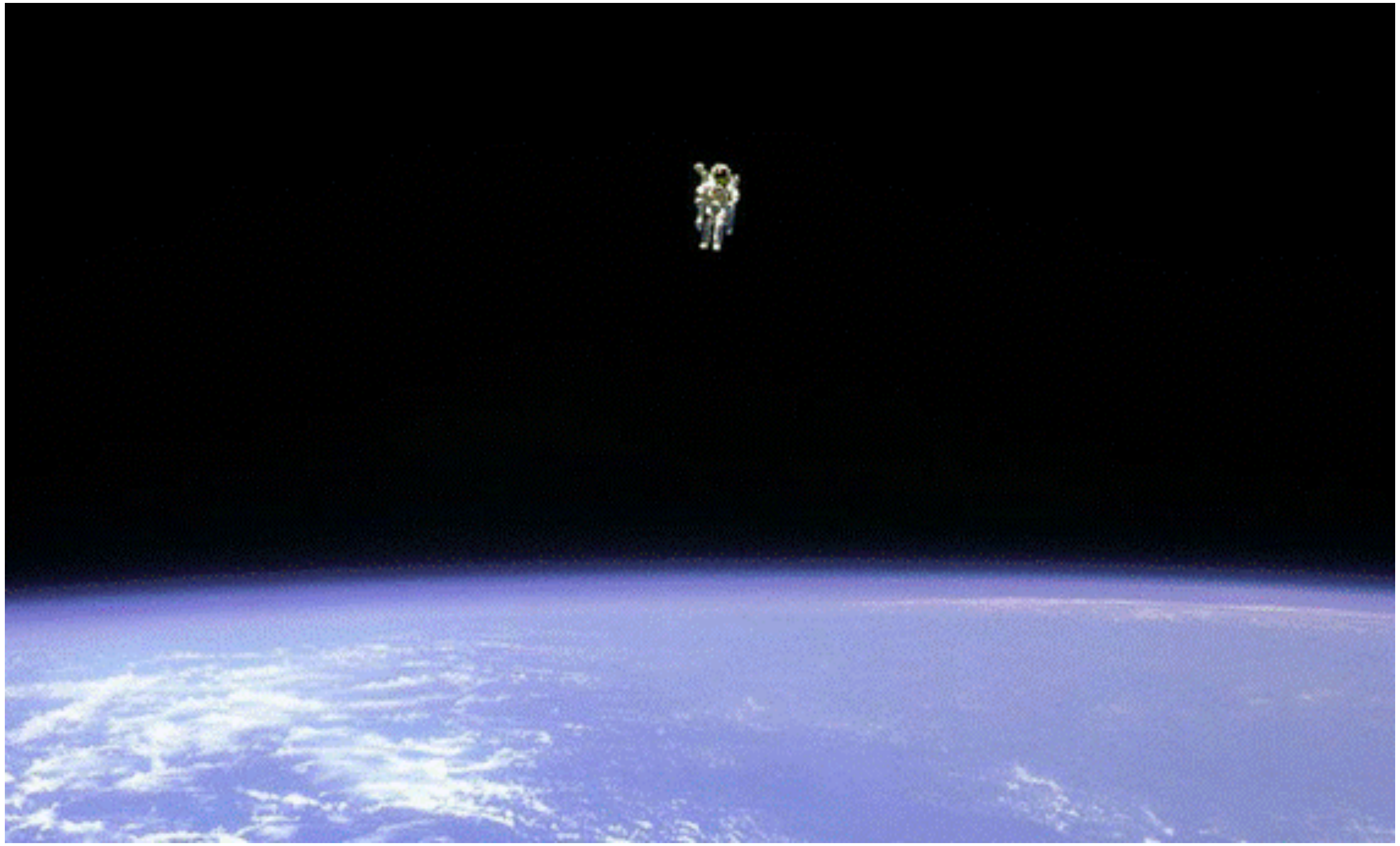


FIGURE 3-8 Space—the next frontier. Astronaut safety is critically dependent on the ability to monitor and forecast solar energetic particles in near-Earth space as well as in the lunar environment.
SOURCE: NASA (2024a).

Relevant Graphics and Figures

- From Helio DS:

TABLE S-1 Space Weather Operational Outcomes That Are Achievable in the Next Decade

Space Weather Themes	Research Focus Areas	Operational Outcomes That Are Achievable in the Next Decade
System of Systems: Drivers of Space Weather	Solar flares and solar energetic particles (SEPs)	>12-hour forecast for solar flares and >6 hours for SEPs
	Coronal mass ejections	12-hour forecast for coronal mass ejections and their magnetic fields
	Atmospheric driving	Quantify the contributions of gravity waves that may seed ionospheric irregularities that produce scintillations
Space Weather Responses of the Physical System	Low Earth orbit (LEO) neutral density	24-hour forecast of thermospheric density during geomagnetic storms for LEO spacecraft operators
	Ionospheric and magnetospheric states	Nowcast of ionospheric and magnetospheric state parameters including radiation environment, auroras, and ionospheric currents
	Reanalysis	Reanalysis capability for forecast/nowcast models to assess and validate models and forecast methods
Space Weather Impacts on Infrastructure and Human Health	Crewed mission radiation	Characterize and monitor space radiation environment for crewed and robotic missions
	Aviation radiation environment	Aviation radiation nowcasts and forecasts during large SEP events
	Spacecraft effects	Forecasts of spacecraft effects with multiday lead time
	Ionospheric high-frequency (HF) signal propagation	1-hour ionospheric HF signal propagation disturbance forecasts
	LEO satellite and debris trajectories	Significantly improved models for LEO satellite and debris trajectories
	Geoelectric field	1-hour geoelectric field variation forecasts with 200 km spatial resolution for power system operators

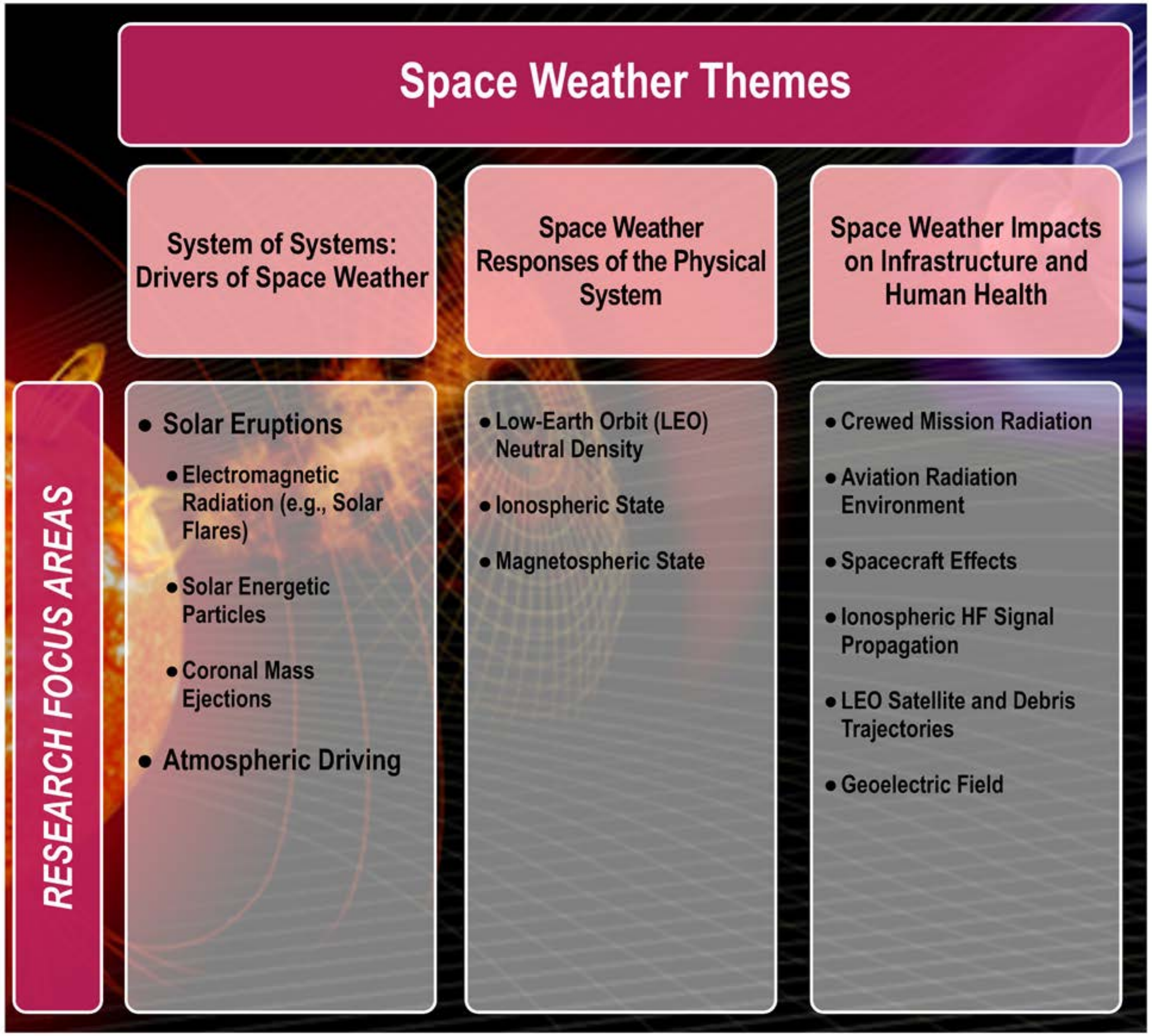


FIGURE S-4 Three space weather themes and their associated research focus areas. Each research focus area has operational outcomes (shown in Table S-1). Implementing the research strategy in the next decade results in significant progress on most focus areas and, consequently, progress on the operational outcomes.
SOURCES: Composed by AJ Galaviz III, Southwest Research Institute; Background image from NASA.

Relevant Graphics and Figures

- From Helio DS:

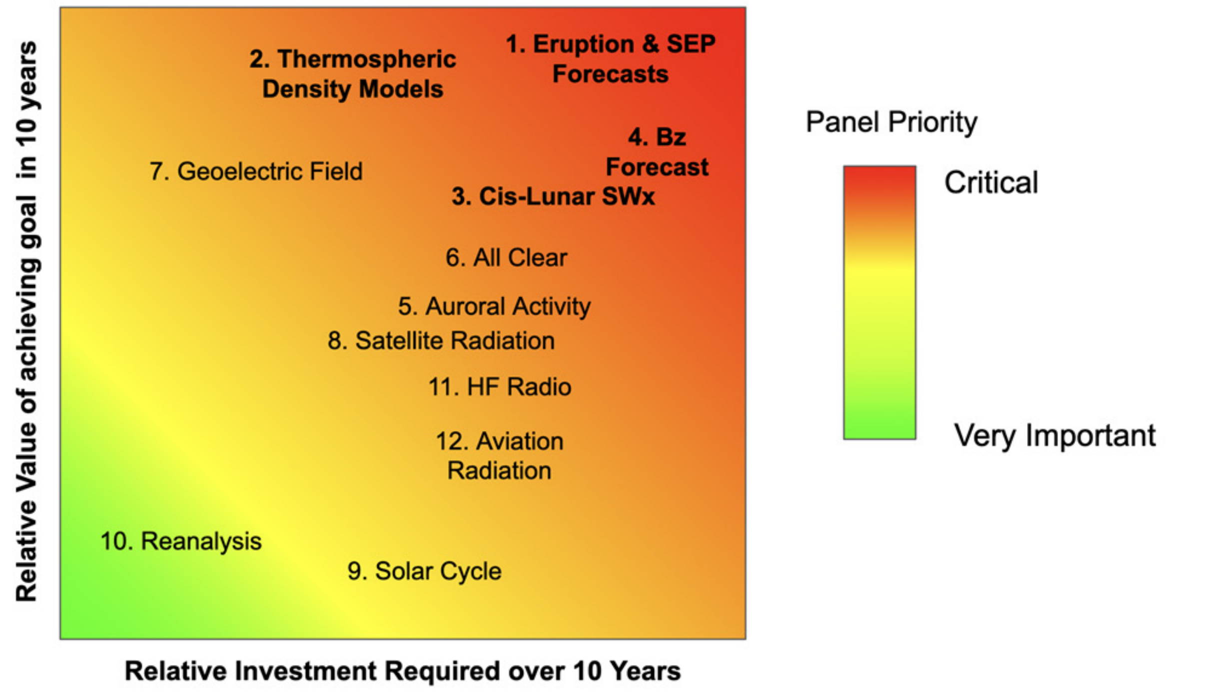
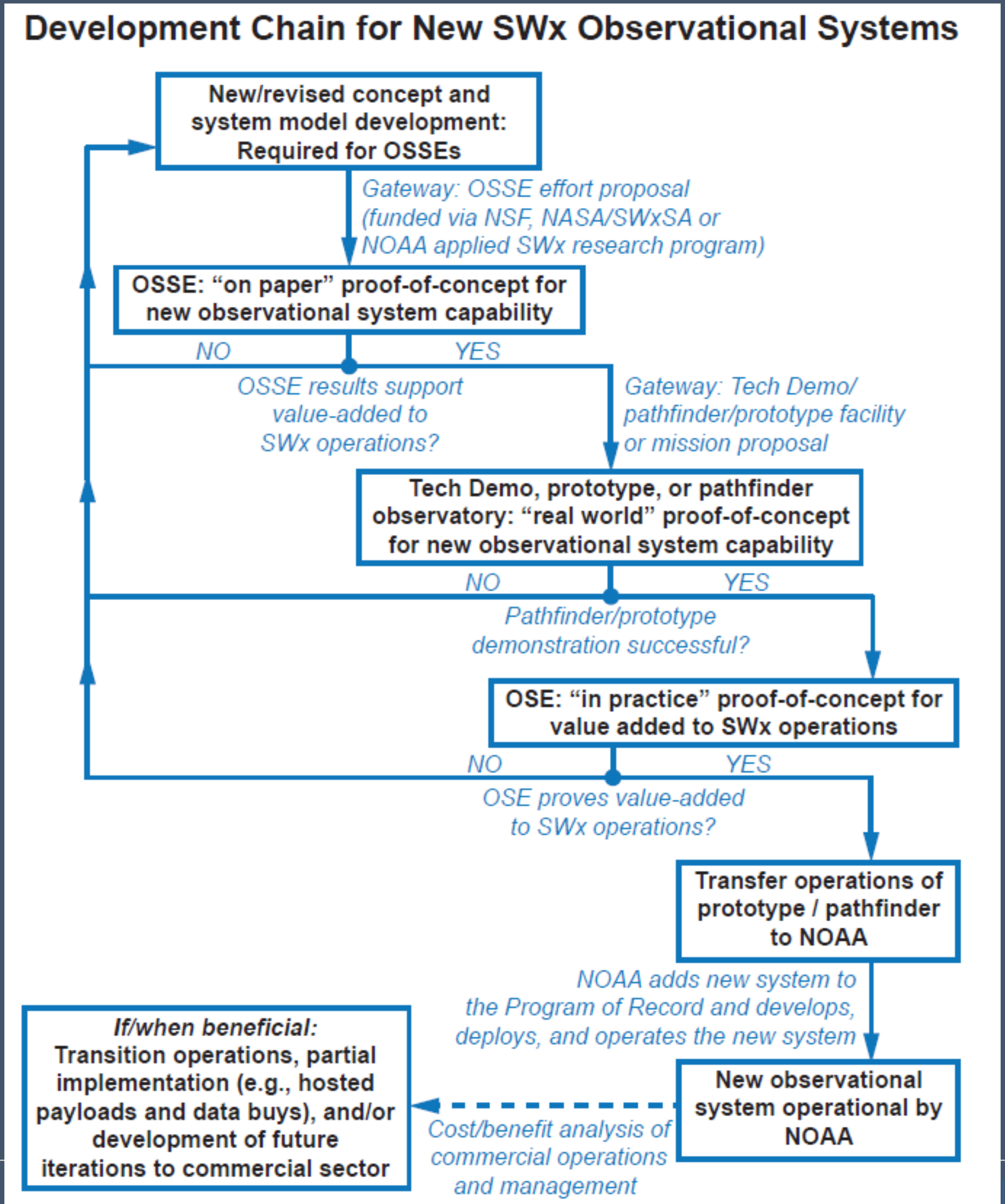


FIGURE E-7 Value of achievement versus required investment estimates for each of the priority goals described above. Each goal is represented by its number and a shortened title. The color scheme roughly corresponds to the panel evaluation of the goals as *critical* or *very important* to achieve within the next decade. Investment required increases to the right; value of goal achievement increases upward. Both investment required and value of achievement are somewhat subjective; no detailed cost-benefit analysis was performed in making this diagram.

Relevant Graphics and Figures

- From Helio DS:



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