



Space Solar Power: Updated Survey of Private Initiatives

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Factories in Space

Outline

Surveying Space Solar Power commercial initiatives to track the growth of the ecosystem:

1. Introduction & why.
2. Scope & survey criteria.
3. Table of space solar power (SSP) activities.
4. Notable updates from the IAC 2023 presentation.
5. Statistical overview of commercial activities.

Factories in Space (factories-in-space.com)

- Public database of commercial entities in the emerging in-space economy, space resources, and microgravity manufacturing fields.
- Started in 2018 and currently over 920 entries.
- Space Solar Power has been included from the start under “Space Utilities”.
- Strong belief that in-space manufacturing and space solar will be the largest space industries.
- Discovering the entities is the main challenge, cannot Google, someone needs to keep a list.

The screenshot displays the website's interface. On the left is a green navigation sidebar with categories like 'In-Space Economy', 'In-Space Manufacturing', and 'Microgravity'. The main content area includes an 'Introduction to In-Space Manufacturing & Space Economy' section, a 'Publications' list with several articles by Erik Kulu, and two infographics. The 'In-Space Economy' infographic shows various space-based activities around Earth and the Moon. The 'In-Space Manufacturing' infographic details three paths: 1. Launch / Re-supply, 2. On-Orbit Manufacturing, and 3. Use in Orbit / Re-entry. A 'Motivation' section at the bottom discusses economic drivers for spaceflight.

Why Space Solar Power?



Energy is a very large existing terrestrial market



Great purpose (abundant clean energy)



Flywheel effect to kickstart in-space economy

**Very few space industries compare.
We have to try for the benefit of Earth and spaceflight.**

Why Companies? SLS vs Starship

- A consortia of traditional space entities is likely to decide on a SLS-like space solar power solution.
- They work, have good performance, and do the job, but reusable Starship will be much better.
- There are many technologies, and the large-scale system design itself, which require lots of iterations and unconventional approaches.
- An agile and iterative company, with SpaceX-like mindset, is thus much more likely to produce a more competitive & economically viable system.



SLS (Space Launch System)

Starship

Scope: Space Solar Configurations

Many possible SSP options and all are in scope. Non-exhaustive list.

Power beaming	Microwaves
	Lasers (optical)
	Mirrors (direct sun reflection)

Power generation	Solar arrays directly
	Mirrors + solar arrays

Energy paths & customer locations	Space-to-Earth
	Space-to-Moon
	Space-to-space
	Lunar surface-to-surface
	Earth-space-Earth (wireless grids)
	Moon-to-Earth

Orbits, system locations	GEO
	MEO
	HEO, Molniya
	LEO
	Lunar orbit
	Lunar surface
	Lagrange points
Mars orbit	

Earth receiver locations	Land
	Offshore
	Air

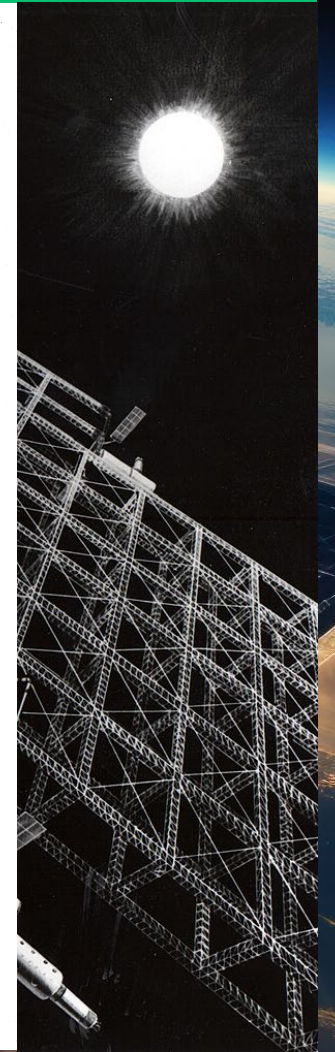
Survey Criteria

Space Solar Power (SSP):

- Space solar power, power beaming and solar mirrors.
- Earth, Space and Moon applications.
- Space connection and must use wireless energy.
- Public intentions, evidence or hints towards SSP plans.

Status Definitions:

1. **Active** – Has or is providing a service.
2. **Demonstrated** – Flown a space mission.
3. **Development** – Prototyping technologies.
4. **Early stage** – Starting or in idea phase.
5. **Concept** – Studies.
6. **Cancelled / Dormant** – Previous projects.





Private Initiatives in Space Solar Power

71 entities discovered and surveyed

Name	Status	Founded	First launch	Funding	SBSP Category	Target	Location, Orbit	Energy Path	Beaming Type	Power Generation	Country
3K SpaceTech	Dormant	2021	Dormant	?	Power Beaming	Space	?	Space-to-space	?	?	Canada
1000 Planets	Dormant	2000	Dormant	Yes, ?	Space Solar Power	?	?	?	?	?	USA
Above Space (Orbital Assembly)	Early stage	2018	2025	\$2.3M	Power Beaming	Space	LEO	Space-to-space, Earth-to-space	Microwave	?	USA
Airbus	Concept	1970	?	Yes, ?	Space Solar Power	Earth	?	Space-to-Earth	Microwave	?	France
Alvior	Dormant	2022	Dormant	?	Space Solar Power	?	?	Space-to-Earth	?	?	Norway
Aphelia Space	Development	2022	?	\$0.025M	Power Beaming	Space	LEO, ?	Space-to-space	Microwave	?	Malaysia
Aquila Earth	Development	2022	?	\$2.1M+	Power Beaming	Earth	?	Earth-space-Earth	Laser	Mirrors	Australia
ARTEMIS Innovation	Concept	2005	?	?	Space Solar Power	Earth	GEO	Space-to-Earth	Microwave	Mirrors plus solar arrays	USA
Arthur D. Little	Concept	1886	?	Yes, ?	Solar Mirrors	Earth	LEO, GEO	Space-to-Earth	Sunlight, Mirrors	Mirrors	USA, UK
Astrostrom	Development	1998	?	\$0.1M+	Space Solar Power	Moon, Earth	Lagrange, GEO	Space-to-Moon, Space-to-Earth	Microwave	Solar arrays	Switzerland
BEAM Co	Development	1996	?	Yes, ?	Power Beaming	Earth, Aircraft	Earth	Earth-air-Earth	Laser	?	USA
Celestia Energy	Early stage	2023	?	?	Space Solar Power	Earth	?	Space-to-Earth	Laser	?	United Arab Emirates
Draper Laboratory	Development	1932	?	Yes, ?	Power Beaming	Earth, Aircraft	Earth	Earth-air-Earth	Laser	?	USA
EDF Energy UK	Concept	2008	?	Yes, ?	Space Solar Power	Earth	?	Space-to-Earth	?	?	UK
Electric Sky	Development	2014	?	\$0.2M+	Power Beaming	Earth, Space	Earth	Earth-air-Earth, Earth-space-Earth	Microwave	?	USA
Emerald Telecommunications	Concept	2018	?	\$0.1M+	?	?	?	?	?	?	UK
Emrod	Development	2019	2025	\$3.3M+	Power Beaming	Earth	LEO, VLEO	Earth-space-Earth	Microwave	?	New Zealand, Germany
EnergySpace	Dormant	2020	Dormant	?	Power Beaming	?	?	?	?	?	USA
Entropy RnD	Dormant	2017	Dormant	?	Power Beaming	Space	?	Space-to-space	?	Solar arrays	India
Extraterrestrial Power	Concept	2018	?	\$0.6M+	Solar Cells	?	?	Moon surface	?	?	Australia, UK
Frazer-Nash Consultancy	Concept	1971	?	Yes, ?	Space Solar Power	?	?	?	?	?	UK, Australia
Infinity Energy	Early stage	2023	?	?	Space Solar Power	?	?	?	?	?	China
Insta-Grid	Concept	2017	?	?	Space Solar Power	Earth	?	Space-to-Earth	Microwave	Solar arrays	USA

International Electric Company	Concept	1999	?	?	Space Solar Power	Earth	GEO	Space-to-Earth	Microwave	Mirrors plus solar arrays	UK
JX Crystals	Concept	1994	?	Yes, ?	Solar Mirrors	Earth	LEO	Space-to-Earth	Sunlight, Mirrors	Mirrors	USA
Karman+	Development	2021	?	\$26M	Space Solar Power	Earth	?	?	Microwave	?	USA, Netherlands
KESE	Concept	2010	?	?	Space Solar Power	?	?	?	?	?	USA
KRISOL	Concept	2009	?	\$0.2M+	Solar Cells	?	?	?	?	?	Switzerland
Light Mirror	Early stage	2019	?	?	Solar Mirrors	Space, Earth	?	Space-to-space, Earth-to-space	Sunlight, Mirrors	N/A	Lithuania
Lumi Space	Cancelled	2018	Dormant	\$0.1M+	Power Beaming	Space, Satellite	Earth	Earth-to-space	Laser	N/A	UK
Metasat UK	Development	2020	?	?	Space Solar Power	Earth	GEO	Space-to-Earth	Microwave	Mirrors plus solar arrays	UK, Canada
Moliri Space Energy	Early stage	2023	?	?	Space Solar Power	Earth	GEO	Space-to-Earth	Microwave	Solar arrays	Estonia
Northrop Grumman	Development	1994	2025	Yes, ?	Space Solar Power	Earth	?	Space-to-Earth	Microwave	?	USA
OHB	Concept	1958	?	Yes, ?	Space Solar Power	Earth, Aircraft	?	Space-to-Earth	Laser	?	Germany
Orbital Genesis	Early stage	2022	?	?	Space Solar Power	?	?	?	?	?	USA
Orbital Power Corp	Dormant	2011	Dormant	?	Space Solar Power	Earth	?	Space-to-Earth	Microwave	Solar arrays, Inflatable	UK, USA
ORiS (Orbital Recharge in Space)	Development	2021	?	Yes, ?	Power Beaming	Space	LEO	Space-to-space	Laser	?	Italy
Overview Energy	Development	2022	?	\$6.8M+	Space Solar Power	?	?	?	?	?	USA
ParaLoon	Development	2022	?	\$0.05M+	Space Solar Power	Earth, Space	?	Space-to-Earth, Space-to-space	Microwave	Solar arrays, Inflatable	Belgium, Italy
Photonicity	Early stage	2019	?	\$0.11M+	Power Beaming	Space, Earth	?	Space-to-space	Laser	?	Singapore
Powerlight	Development	2007	?	\$4.1M	Power Beaming	?	?	?	Laser	?	USA
PowerSat	Early stage	2001	?	?	Space Solar Power	Earth	GEO	Space-to-Earth	Microwave	Solar arrays, Inflatable	USA
Pulse (Litepulse)	Early stage	2022	?	?	Power Beaming	Space	?	Space-to-space	?	?	USA
Reach Power	Development	2015	?	\$39.1M	Power Beaming	Earth	?	Earth-air-Earth, Space-to-space	Microwave	?	USA
ReBeam	Dormant	2016	Dormant	?	Power Beaming	Space	?	?	?	?	USA, India
Reflect Orbital	Development	2021	2025	Yes, ?	Solar Mirrors	Earth	?	?	Sunlight, Mirrors	Mirrors	USA
Roland Berger	Concept	1967	?	Yes, ?	Space Solar Power	?	?	?	?	?	Germany

ROVIAL	Development	2021	?	Yes, ?	Space Solar Power	Space	LEO	?	?	Mirrors	France
RTX Corporation (Raytheon)	Development	1922	?	Yes, ?	Power Beaming	Earth, Aircraft	Earth	Earth-air-Earth	Laser	?	USA
Satellite Applications Catapult	Concept	2012	?	Yes, ?	Space Solar Power	?	?	?	?	?	UK
Shimizu Corporation	Concept	1804	2035	Yes,	Space Solar Power	Earth	Moon surface	Moon-to-Earth	Microwave	Solar arrays	Japan
Sirin Orbital Systems	Early stage	2019	?	\$0.44M+	Power Beaming	Space, Moon, Earth	LEO, Moon surface	Space-to-space, Moon surface	Microwave	?	Switzerland
SKYCHARGE (Cavu Space)	Concept	2017	?	?	Space Solar Power	Aircraft, Ships	GEO, LEO	Space-to-Earth	Microwave	Solar arrays	UK
Solar Space Technologies	Early stage	2019	2027	?	Space Solar Power	Earth	GEO	Space-to-Earth	Microwave	Mirrors plus solar arrays	Australia
Solar System Resources Corp	Early stage	2020	?	?	Space Solar Power	?	?	?	?	?	Poland
Solar.Space	Dormant	2018	Dormant	?	Power Beaming	Space	LEO	Space-to-space	?	?	UK
Solaren	Development	2006	?	\$2.5M+	Space Solar Power	Earth	?	Space-to-Earth	Microwave	?	USA
Solestial	Concept	2015	2024	\$12.3M+	Solar Cells	?	?	?	?	?	USA
Space Applications Services	Concept	1987	?	Yes, ?	Space Solar Power	?	?	?	?	?	Belgium
Space Energy	Dormant	2008	Dormant	\$4M+	Space Solar Power	Earth	GEO	Space-to-Earth	Microwave	?	Switzerland
Space Power	Development	2019	2024	\$0.01M+	Power Beaming	Space	?	Space-to-space	Laser	?	UK
Space Solar	Development	2022	?	\$4.3M+	Space Solar Power	Earth	GEO	Space-to-Earth	Microwave	Mirrors plus solar arrays	UK
Spacians	Dormant	2019	Dormant	?	Space Solar Power	Earth, Aircraft	?	Space-to-Earth	Microwave	?	India, Sweden
Stellarion Energy	Dormant	2020	Dormant	?	Space Solar Power	?	?	?	?	?	India
STELLS	Development	2021	2024	\$0.5M	Power Beaming	Moon	Moon surface	Moon surface	Microwave	Solar arrays	Canada
SunCubes	Development	2021	?	\$0.06M+	Power Beaming	Space, Earth	Earth	Space-to-space	Laser	?	Italy
Thales Alenia Space	Concept	2007	?	Yes, ?	Space Solar Power	Earth	?	Space-to-Earth	?	?	Italy, France, UK
The Lunar Grid	Dormant	2021	Dormant	\$0.15M+	Space Solar Power	Moon	Lunar orbit	Space-to-Moon	Laser	?	Luxembourg
Virtus Solis	Development	2018	2027	\$0.4M+	Space Solar Power	Earth	HEO, Molniya	Space-to-Earth	Microwave	Solar arrays	USA, UK
Volta Space (Eternal Light)	Development	2020	?	\$0.1M+	Power Beaming	Moon	Lunar orbit	Space-to-Moon	?	?	Canada, USA
XISP (Xtraordinary Innovative Space Partnerships)	Early stage	2012	?	?	Power Beaming	Space	?	Space-to-space	?	?	USA

Space solar power entities: <https://www.factoriesinspace.com/space-solar-power>

Power beaming entities: <https://www.factoriesinspace.com/power-beaming>

Figures: <https://www.factoriesinspace.com/graphs-taxonomy>

Space-Based Solar Power - Ecosystem Map

SPACE-TO-SPACE

Wirelessly powering spacecraft from other space assets during eclipse or for extra energy.



SPACE-TO-MOON

Wirelessly powering spacecraft on the Lunar surface from space. Large overlap with space-to-space.



LUNAR SURFACE

Wirelessly powering spacecraft on the Moon. There are many wired energy services planned too.



POWER BEAMING

Wireless power for/on Earth (wireless energy grid, Earth-space-Earth) or Earth-to-space applications.



SPACE-TO-EARTH

Space solar power for terrestrial applications often using microwave power beaming.



Space solar power for terrestrial applications using mirrors to reflect light to solar farms on Earth.

IN-SPACE ASSEMBLY

Selected entities from the in-space assembly & construction fields as one key enabling technology.



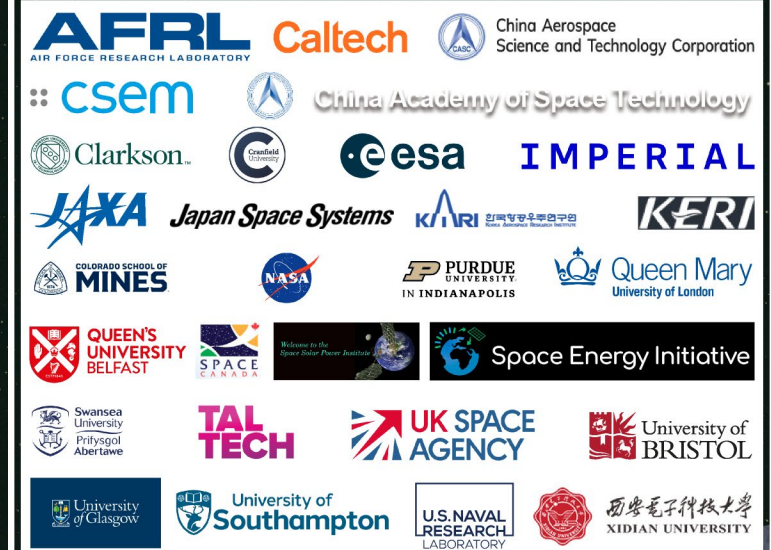
WAITLIST

Commercial entities active in the ecosystem but own wireless space energy service plans are unclear.



NON-COMMERCIAL

Non-exhaustive list of non-commercial entities and consortiums active in the space energy field.



Key changes from IAC2023 paper

From 52 entities to 71 entities.

Added the following selected companies:

- ROVIAL, ORiS, Karman+, Infinity Energy, Insta-Grid, SKYCHARGE (Cavu Space), etc.
- Reach Power and DARPA POWER selectees: RTX, Draper & BEAM.

Notable changes and updates:

- Virtus Solis announced 2027 demo launch.
- Arthur D. Little & Thales Alenia published ESA studies.
- Eternal Light renamed to Volta Space Technologies.
- Space Solar and Virtus Solis prototyping.

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Space Solar Power - 2023 Survey of Public and Private Initiatives

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Factories in Space, Nanosats Database, NewSpace Index
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Abstract

The urgency and relevance of exploring new green energy sources has never been greater. In addition to the de-carbonization challenge, recent geopolitical crises created a turmoil in energy markets, leading to an increase in prices. Space-Based Solar Power (SBSP), and Space Solar Power (SSP) for shorter, has been proposed as an alternative energy source to address these challenges. By providing a virtually limitless source of clean energy and with the ability to reach remote areas around the world that currently lack good access to electricity, SBSP has the potential to transform the energy sector and have a wide positive impact.

The concept of space solar power has gained significant momentum in recent years, with various trends converging to make large-scale solar power plants more realistic and economically viable. Factors such as Starship, in-space assembly, power beaming, and other performed and upcoming demonstrations in space coupled with key technological demonstrations on the ground, have all contributed.

The first part of the manuscript examines enabling trends and technologies, including efficient solar panels, low-cost reusable launch, advanced wireless power transmission, in-space robotics and assembly, and distribution capabilities. Focusing on what has been done and what needs to happen for SBSP to be developed and with the right timing. This section will explain why the time for SBSP is looming and how research and development in this field may have additional beneficial applications, particularly if the economic sustainability is not achievable within the predicted time frames.

The second part of the paper presents an overview of commercial entities that were, are or intend to be active in the SBSP market. A combined table and a paragraph for each surveyed SBSP entity is included. The findings include past companies and present-day startups. This data will entail information such as founding years, planned space demonstrations, funding amount, and geographic locations.

The third part looks at non-commercial initiatives, such as those by ESA, UK, NASA, Japan, and China, and gives a short overview to understand the actors and state of technology development. This paper aims to present a comprehensive and unique analysis of the space solar power landscape.

Keywords: space solar power, space-based solar power, power beaming, SBSP, SSP, space energy

1. INTRODUCTION

Factories in Space (www.factoriesinspace.com) has tracked space solar power and wireless power transfer companies since 2018. There are 52 primarily commercial entries as of September 2023, which makes it one of the largest public lists.

Goal of this work is to leave a snapshot of the space solar power landscape such that the field can be tracked over the upcoming years. Focus is on surveying the past and present commercial entities in addition to governmental and other activities.

Numerous publications, books, and articles in the last decades have covered the history, benefits, literature reviews, technical concepts, challenges, and recent news, for space solar power.^[1-3] For example, many of those aspects have recently been recounted in study papers commissioned by the

European Space Agency (ESA), such as the cost vs benefit studies^[4] and Astrostrom 2023 study.^[5]

However, broad contemporary surveys about commercial activities in space solar power have not been found. Closest known is SpaceFund's Energy Transmission Database, which was last updated in August 2021 and has 10 entries.^[6]

National Space Foundation has been collecting links to space solar power and it is very extensive.^[7]

This survey includes activities from space solar power, power beaming (wireless power transfer) and solar mirrors (reflecting sunlight directly). However, there must be a space and energy connection and the solutions must involve wireless energy. The latter are also core technologies of many space solar power systems, and organisations may choose to start the research and development from wireless power.

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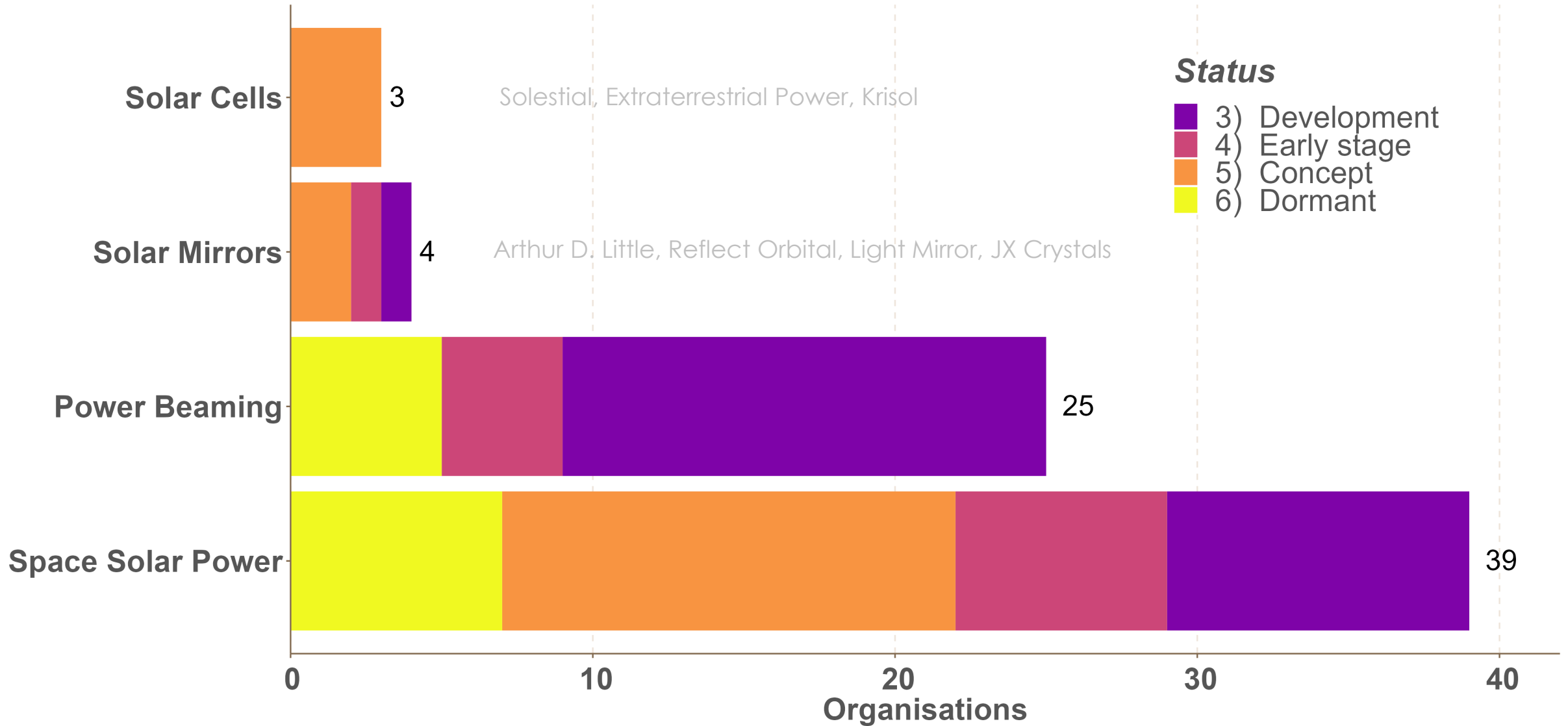
https://www.factoriesinspace.com/graphs/Space-Solar-Power-2023_Erik-Kulu_IAC2023.pdf



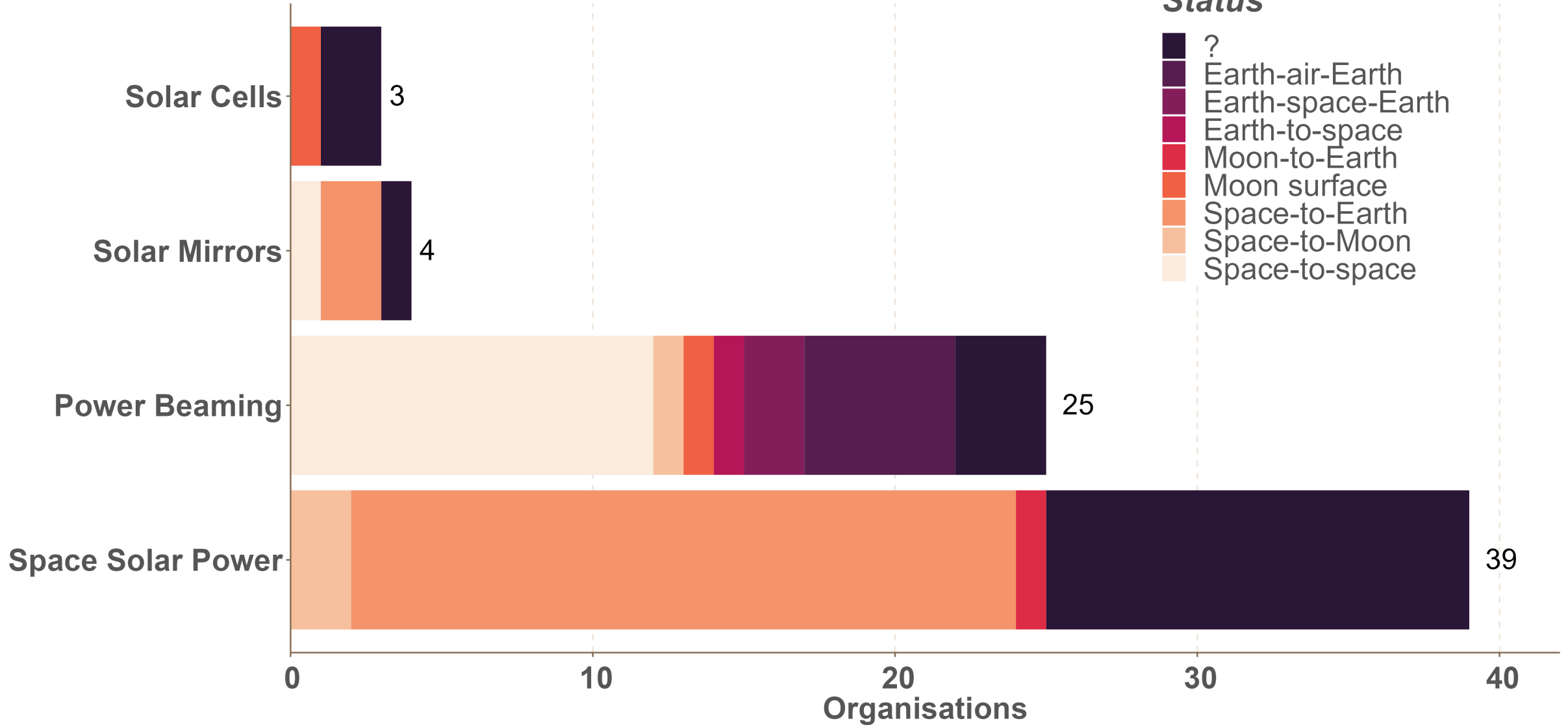
Statistical Overview

Of 71 commercial space-based solar power activities

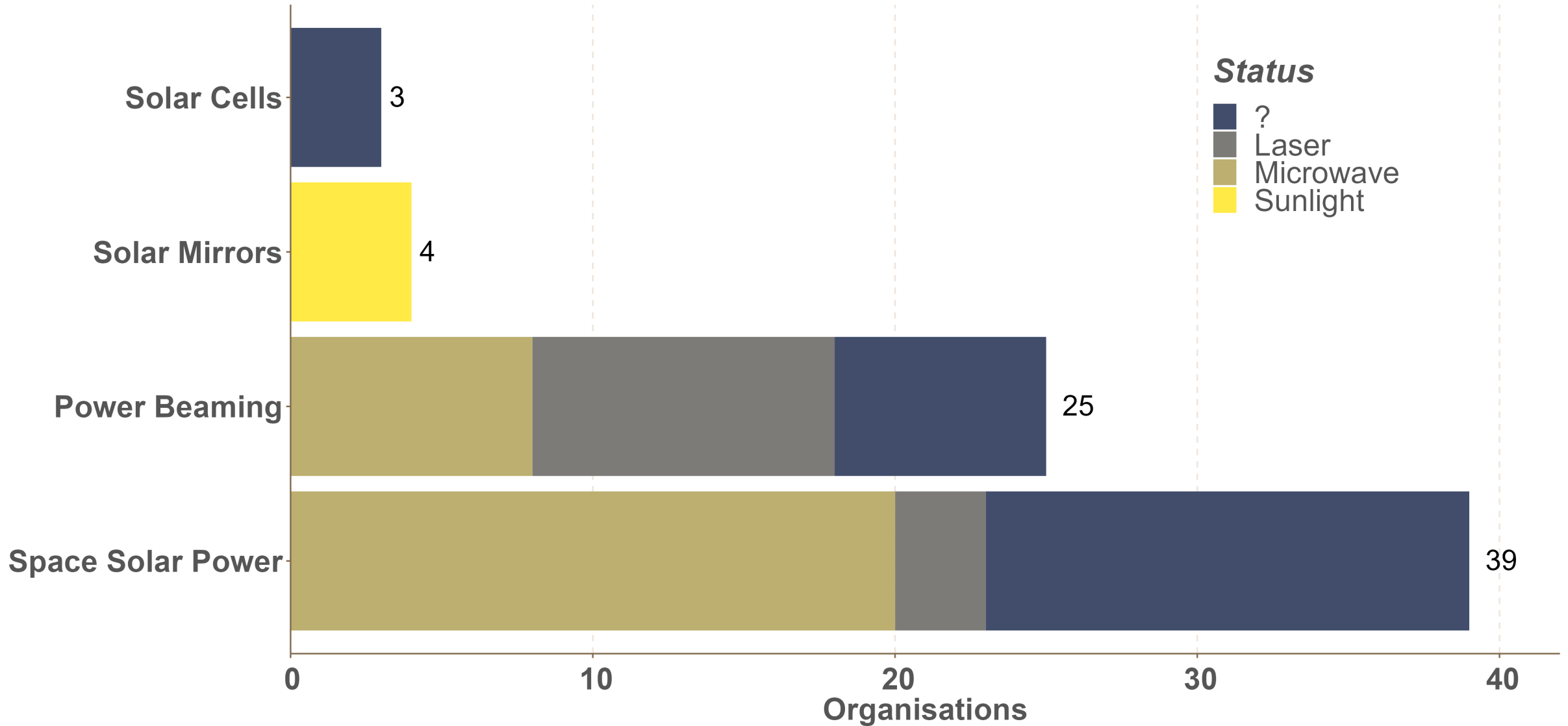
Classification with Status of Space Solar Power Activities



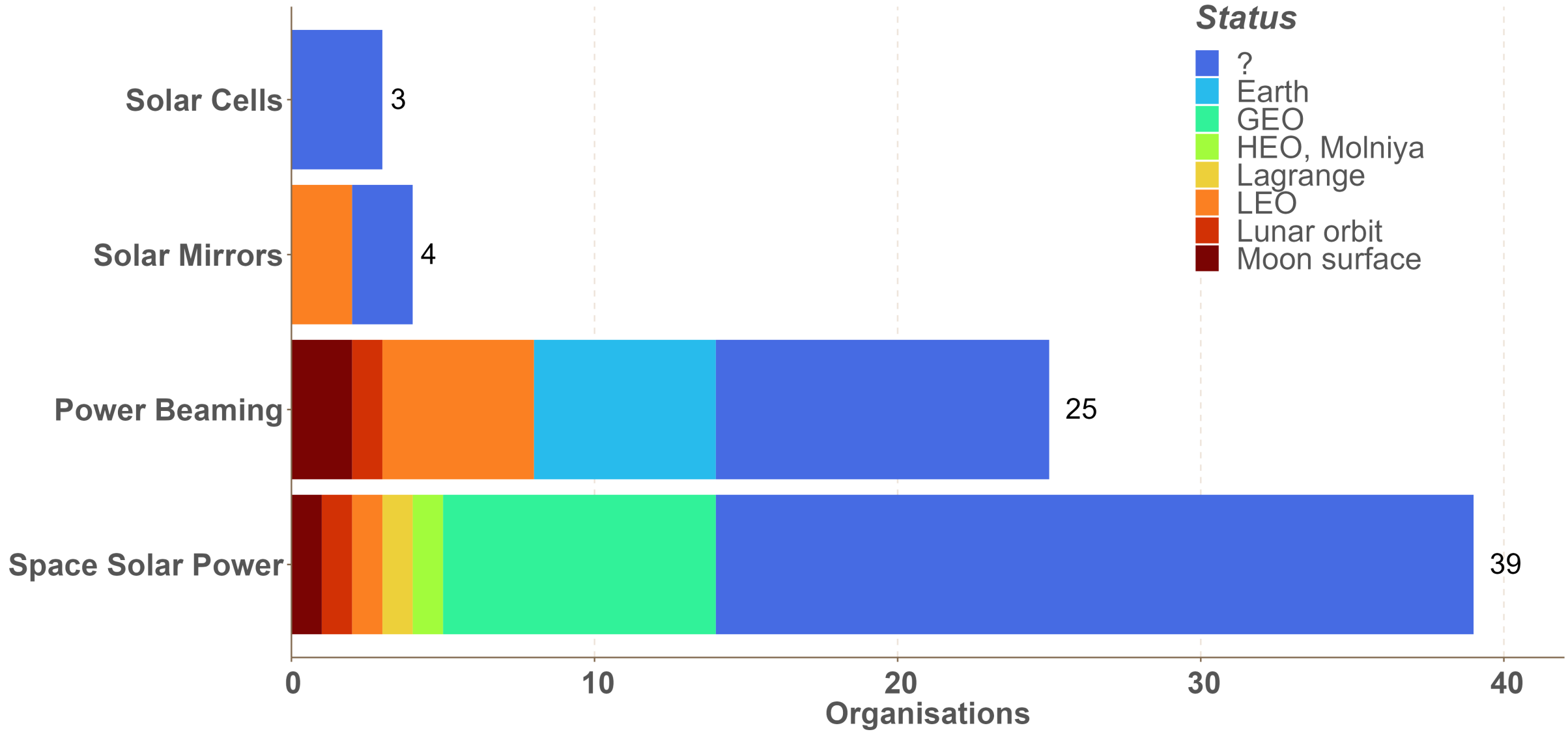
Classification with Energy Paths of Space Solar Power Activities



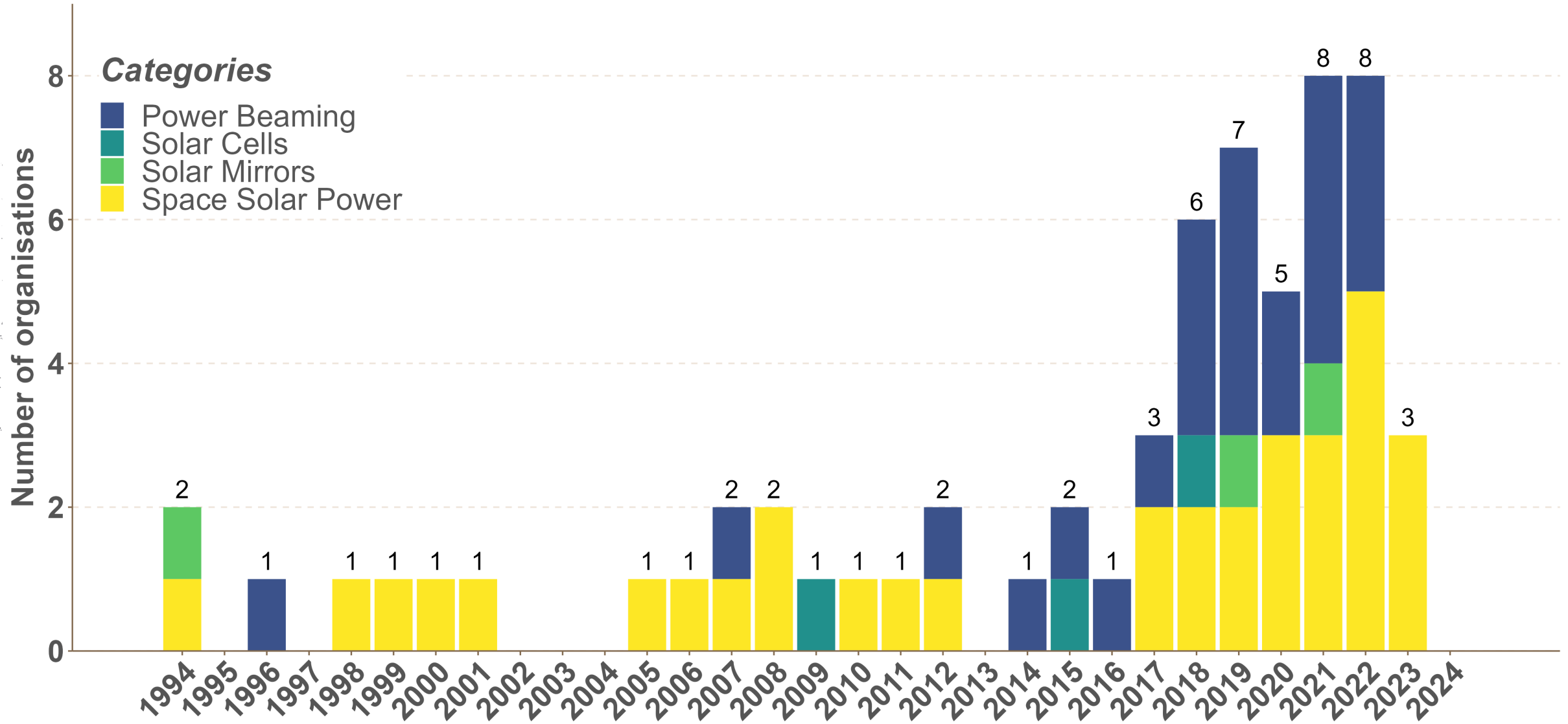
Classification with Beaming Type of Space Solar Power Activities



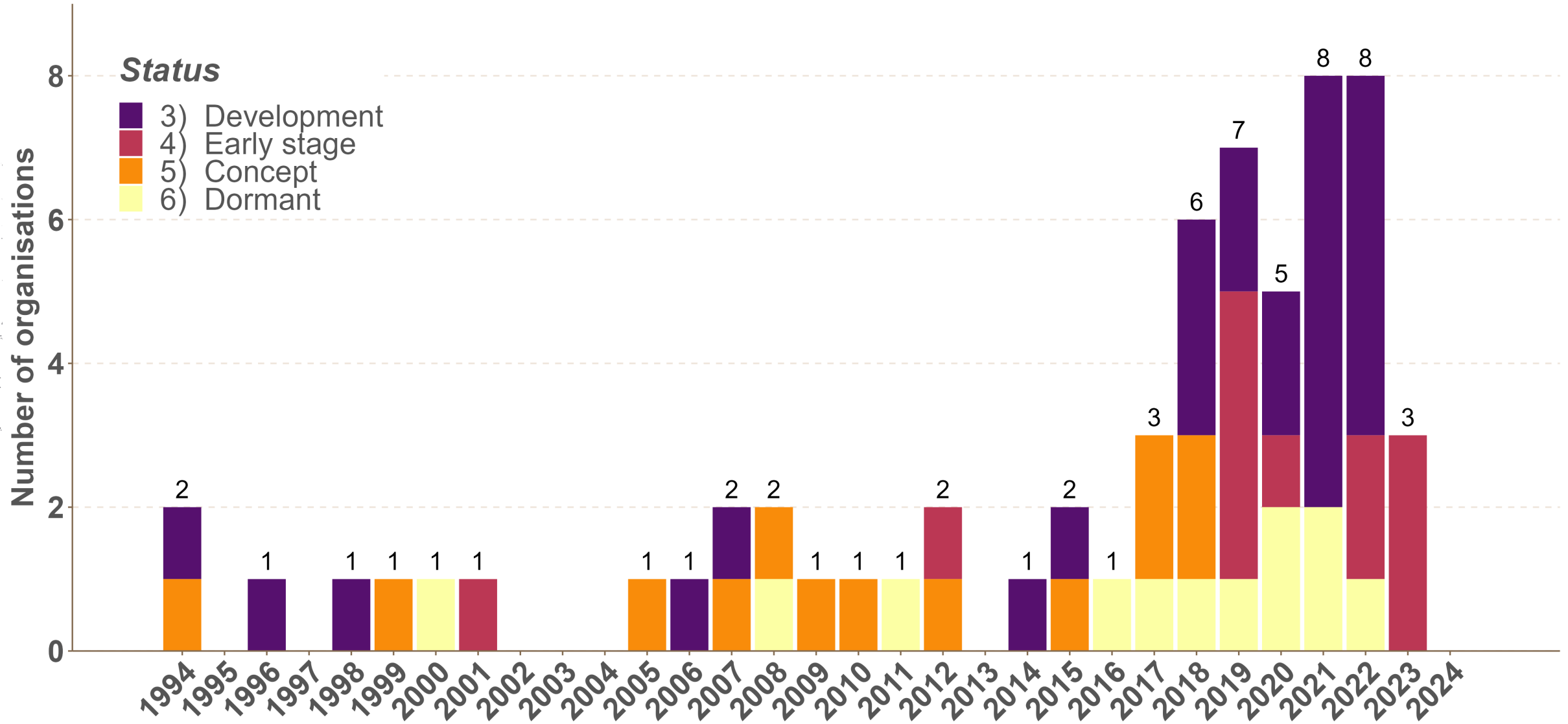
Classification with Orbits of Space Solar Power Activities



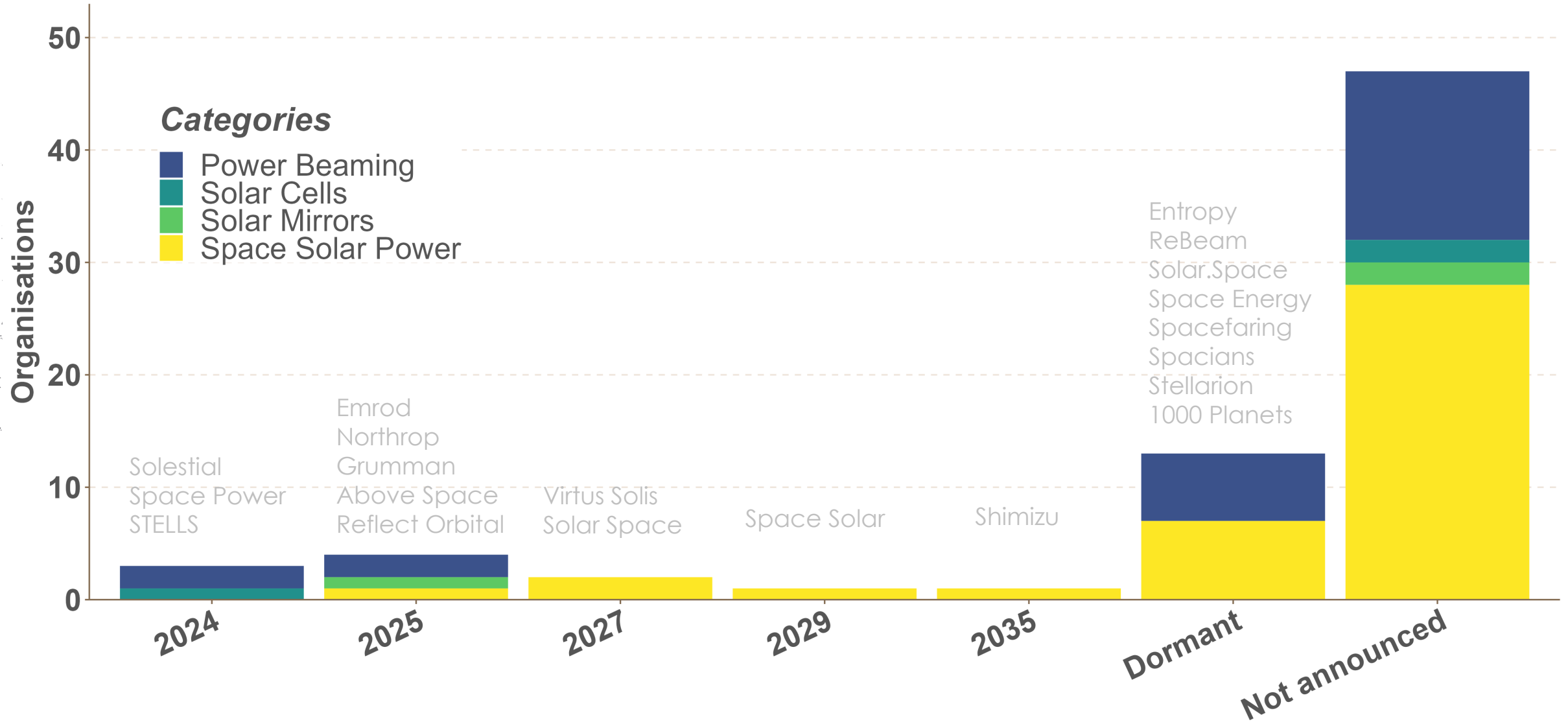
Founding Years with Classification of Space Solar Power Activities



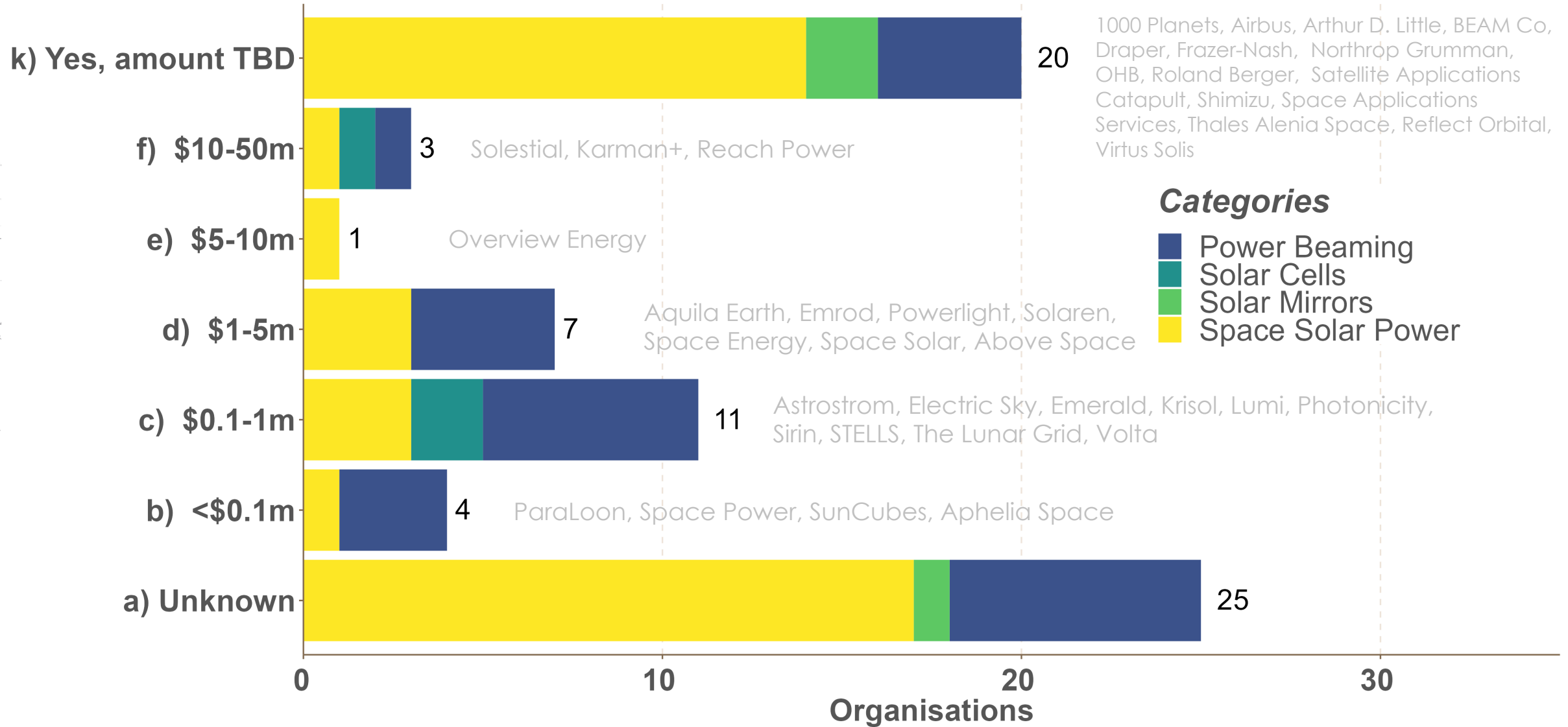
Founding Years with Status of Space Solar Power Activities



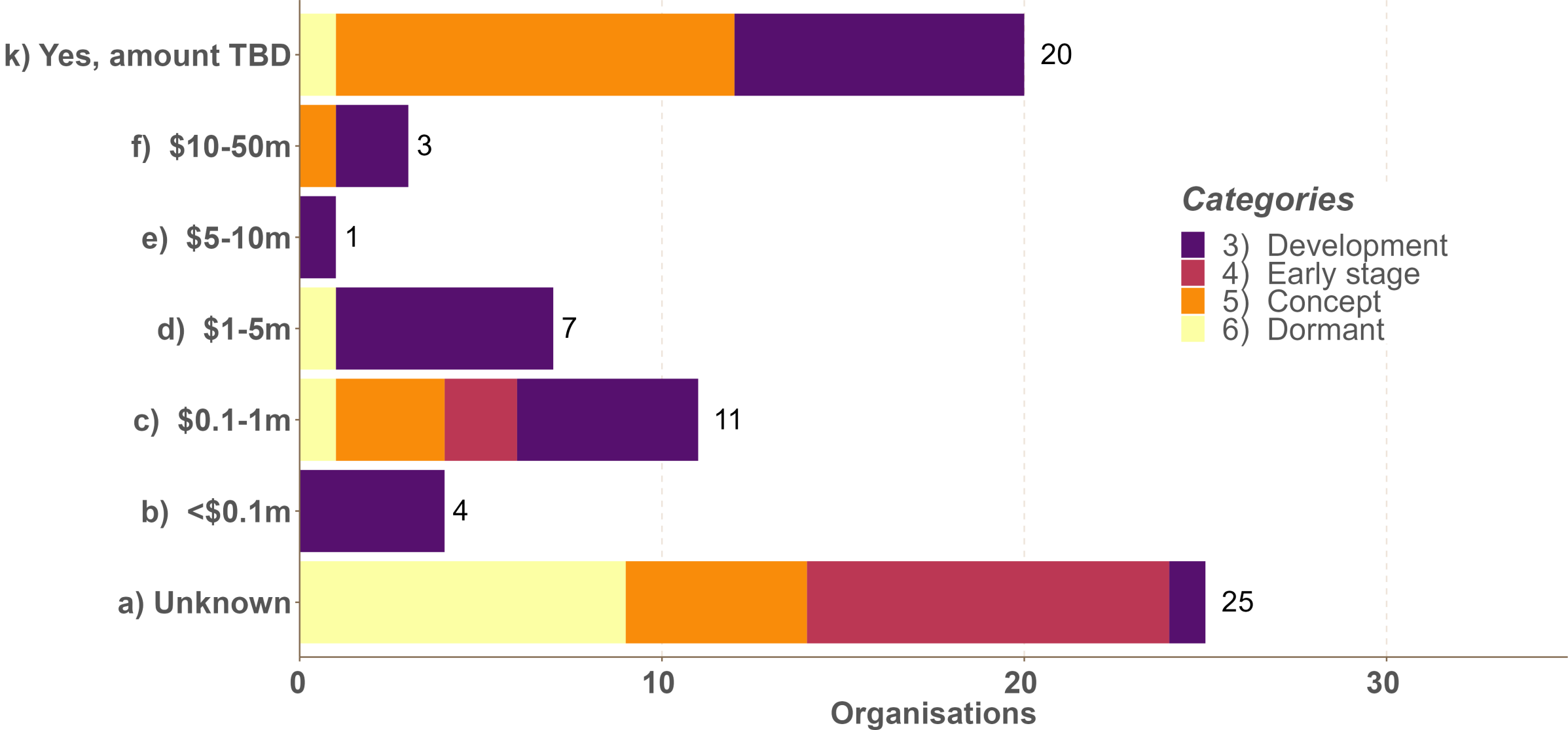
First Launches with Classification of Space Solar Power Activities



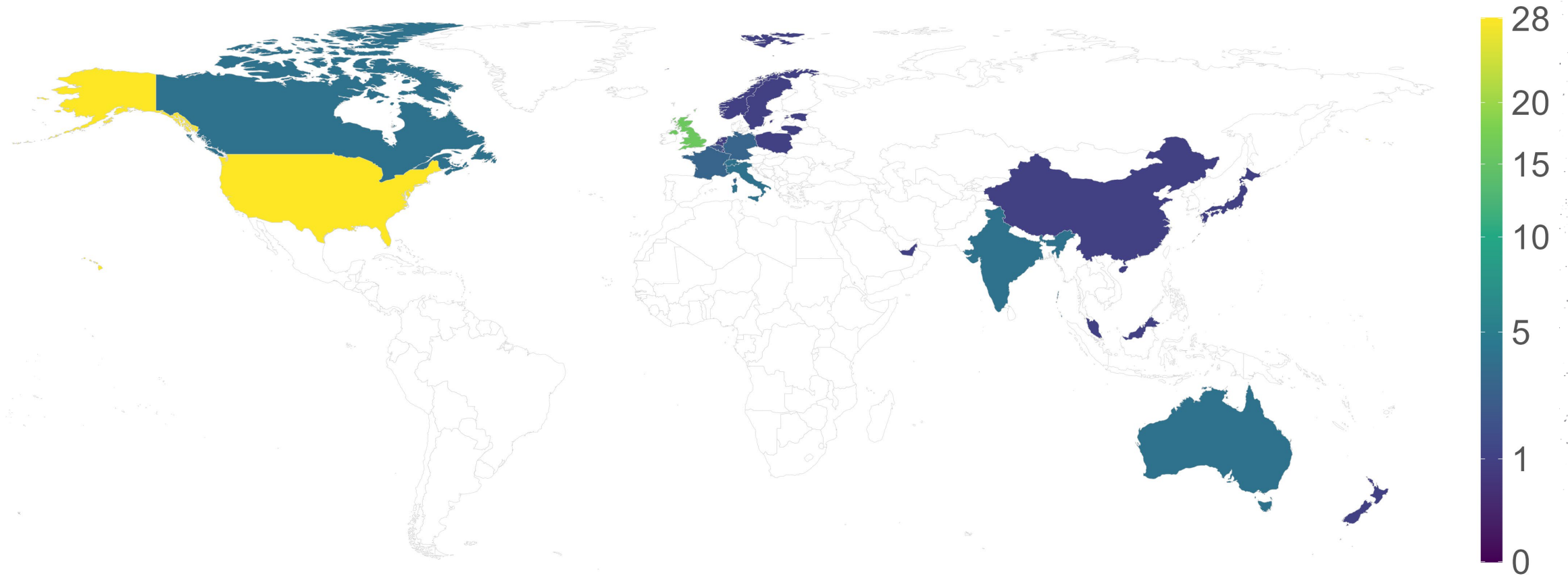
Funding with Classification of Space Solar Power



Funding with Status of Space Solar Power

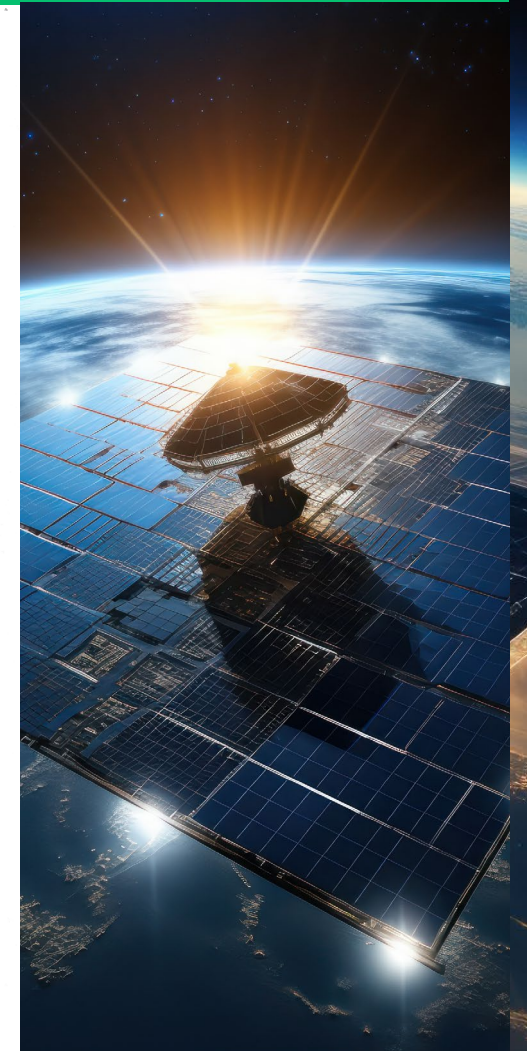


Geographical Distribution of Space Solar Power Activities



Summary

- Space solar power seems to be taking off, but still early days.
- Concept/study stages common – limited prototyping.
- No commercial in-space technology demonstrations yet.
- Private funding has been very limited compared to fusion, launchers, and even the Caltech SBSP donation.
- Awareness, belief and funding must increase significantly.
- Space energy is one of the best-known ideas for a new big economically sustainable space industry.
- We must try, because space solar power can become a major economic driver for spaceflight and in-space economy thanks to the large existing market.





www.factoriesinspace.com

In-Space Economy & Space Solar Power

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