# The second decadal survey of planetary science and Solar System exploration

## by Japanese Society of Planetary Science

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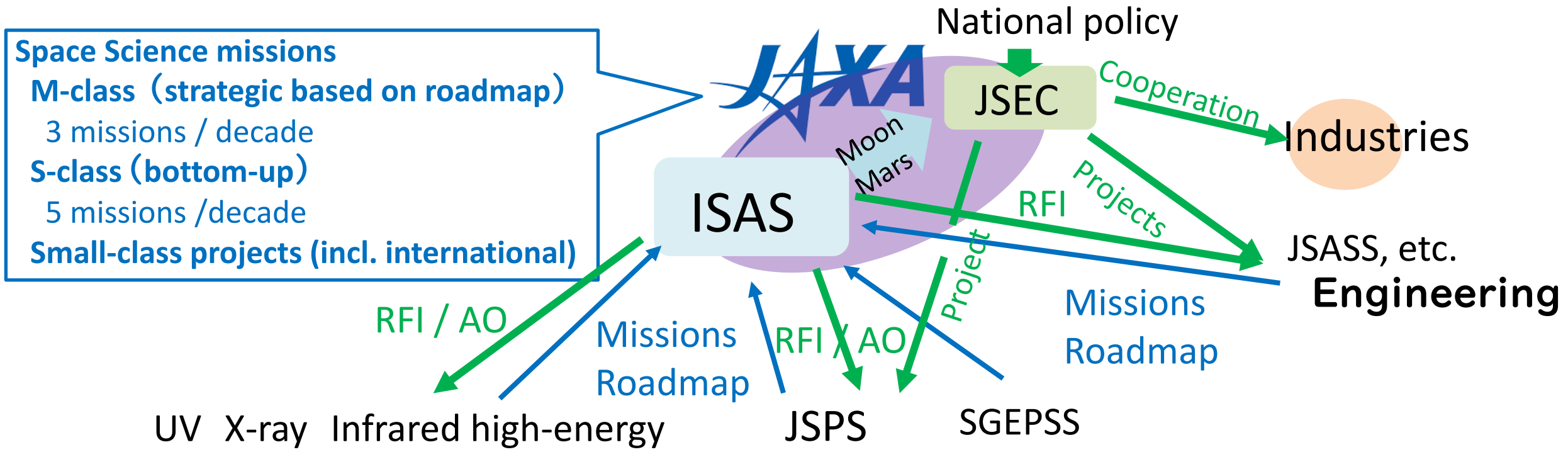
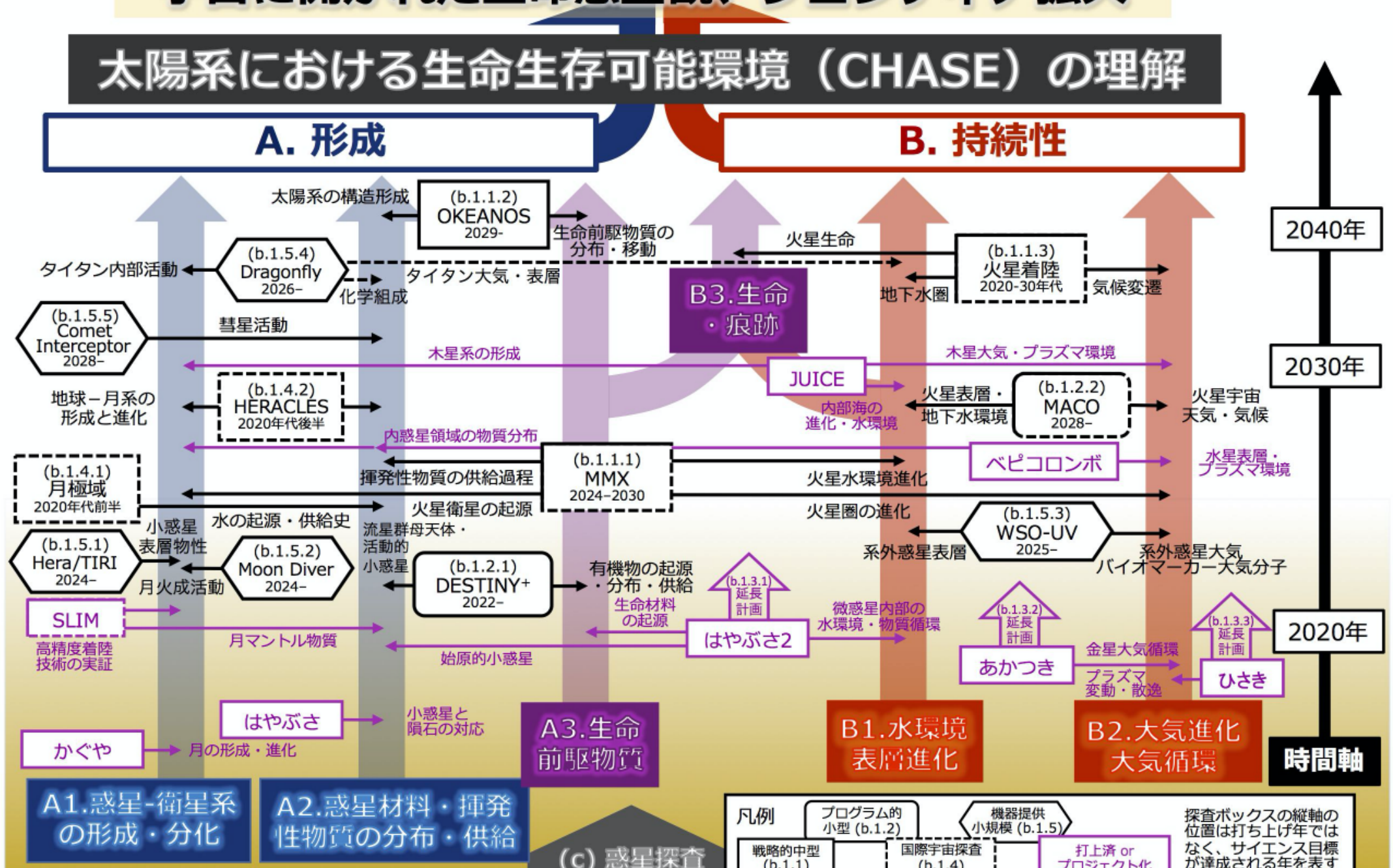
# What is Japanese Society of Planetary Science
# Relationship with JAXA / ISAS

- Promotion & outreach of planetary science (Solar system bodies & exoplanets)
- Creation of roadmap & projects with RFI reports to JAXA / ISAS
- ISAS/JAXA selects and performs missions based on roadmaps (Hayabusa series)
- Recently, JSEC is becoming an important mission implementing organization (Artemis)



# 宇宙に開かれた生命惑星観、フロンティア拡大



# Background of decadal survey

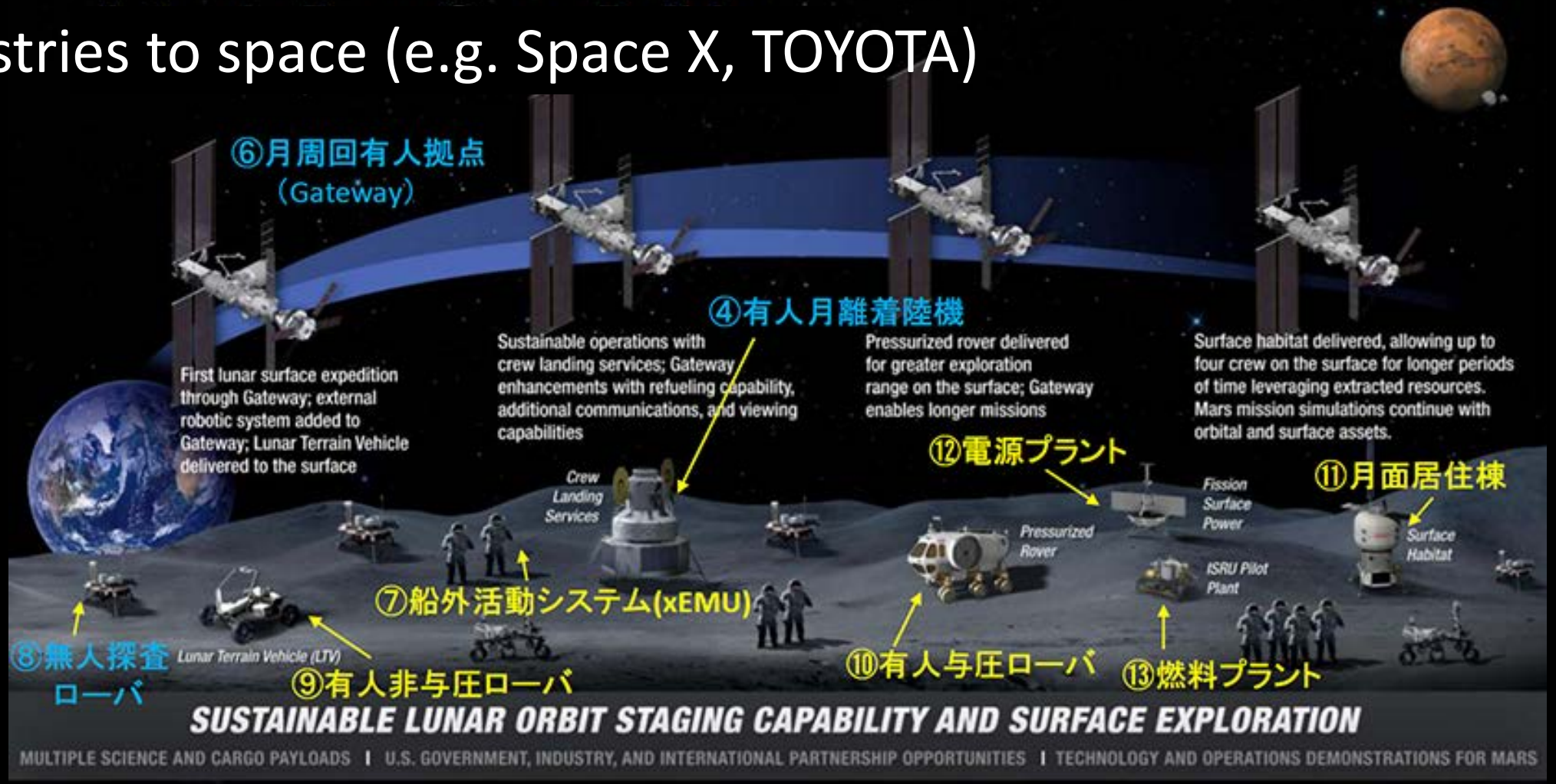
- ✓ **Future direction of Planetary Science community?**
  - The first decadal survey held in 2010.  Updates in top science and key technology.
  - Flagship mission after MMX (Mars Moons eXplorer)?
  - Change in concept of mid-class mission by JAXA/ISAS (from bottom-up to top-down)
  - Matching between instrument development and future vision of the community

- ✓ **How to maximize the new opportunities?**
  - The Artemis program (international space exploration) / space industries
  - Planetary explorations by cube sats.

- ✓ **Best timing to update and rebuild the roadmap**

# Artemis Program

- ✓Sending humans to the Moon again
- ✓From the Moon to Mars
- ✓Industries to space (e.g. Space X, TOYOTA)



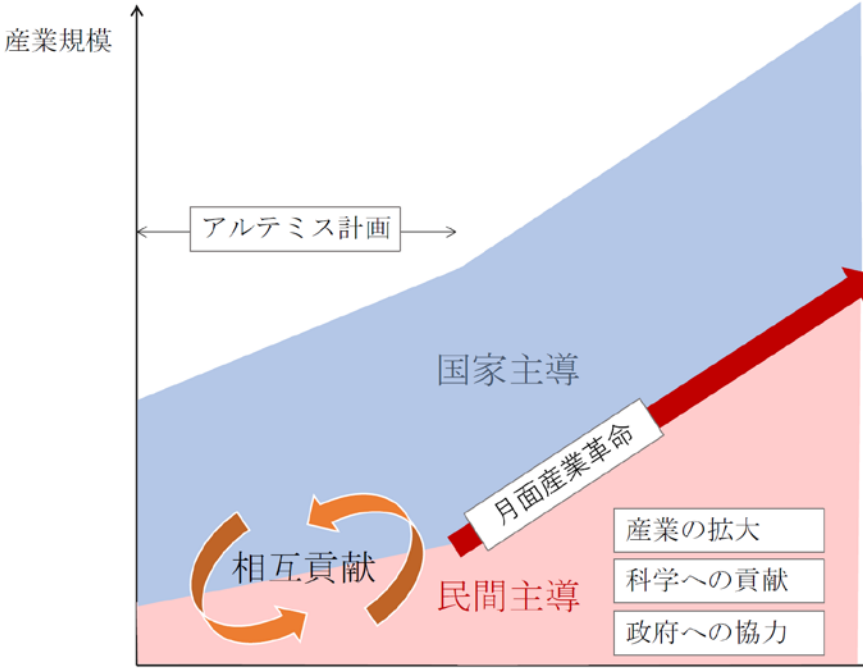
# International Moon exploration & development (Artemis & more)

## Science themes by JAXA/ISAS

- Space observatory on the Moon
- Sample collection and returns from the Moon
- Lunar seismometer networks

## Space industry vision of R&D on the Moon

- Lunar missions by industries with high frequency: e.g., ispace, Toyota (2020-30)
- Humans, including planetary geologists, on the Moon (~2040)




# Objectives and outputs

**Stage 1**

**Top science and top technologies**

**2021**

- ✓ Summarizing global trends of top science and key science and technologies by Japan until 2040's
- ✓ Discussion in sub-panels (terrestrial planets / small bodies / outer planets and exoplanets
- ✓ Searching new matching of science and key technology (seeds of missions)
- ✓ Science goals in 2020's, 2030's and 2040's with strategy of technology acquirements

**Stage 2**

**Strengthening mission proposals for mid-class +**

**2022**

- ✓ Making realistic & strong mid-class missions in early 2030's with science significant (future direction and flagship of PS)
- ✓ Preparing multiple proposals & missions for cube sat, small-class, Artemis, and industry missions (maximizing new opportunities)

Inputs to GDI (Group of Discussion Intensive), responses to RFI of ISAS/ JAXA

Inputs to the Artemis program (JSEC) and space industries

Inputs to Sci. & Tech. Society & governments (Sci. Council of Japan)

WG or RG in ISAS/JAXA

# List of proposals for stage 1

- Terrestrial planet panel
  - 非接触での水検出能力をもつ中性子・ガンマ線センサ
  - 重力天体定点着陸技術
  - 月・惑星の地形測量・地盤調査システム
  - 重力天体での三次元移動探査技術
  - 地震探査で明らかにする太陽系天体の内部構造
  - カリウム・アルゴン年代計測装置
  - 月・火星縦孔露頭における月熔岩岩体調査のための多足型移動体システムによる探査
  - 月・火星における多肢再構成作業ロボットによる探査
  - 「月高地原始地殻領域の探査」で迫る巨大衝突による天体形成と進化の真の理解
  - 月の縦孔・地下空洞直接探査による、月の火成活動／溶岩被覆様式の解明
  - 月の縦孔・地下空洞における古代磁場の理解
  - 月の中低緯度地域からの揮発性物質サンプルリターン
  - 月の縦孔・地下空洞の利用可能性に資する科学
  - 太陽系初期の大動乱期復元に向けた月面衝突盆地からのサンプルリターン探査
  - 戦略的火星探査：周回機による火星宇宙天気・ 気候・水環境探査計画(MIM)
  - ネオン-アルゴン分離装置搭載質量分析計による火星大気ネオンその場測定
  - 火星の地下空洞における生命探査
  - 地球外生命体そのものの探査
  - 火星地下氷圏の探査とサイエンス
  - 産業水資源バリューチェーン創出のための基盤技術の確立
  - 分散展開超小型プローブ群による偵察探査(SPUR)
  - 複数の小型衛星を用いた金星衛星間電波掩蔽観測(CROVA)

Red：technology proposal
Blue：science proposal

22 proposals

# List of proposals for stage 1

- **Small body panel**
  - CAESAR
  - 始原天体マルチフライバイ探査
  - 親機・子機探査システムを用いた次世代サンプルリターン探査
  - 小天体高頻度マルチフライバイ探査ミッション
  - 恒星間天体の探査
  - 木星トロヤ群小惑星探査

6 proposals

- **Outer Solar System (SS) & exoplanet panel**
  - 土星円環探査計画
  - 惑星科学、生命圏科学、および天文学に向けた紫外線宇宙望遠鏡計画(LAPYUTA)
  - 大型宇宙望遠鏡による系外惑星観測
  - ガリレオ衛星の物質探査
  - 地球外生命体そのものの探査
  - 可視光赤外波長域での系外惑星サイエンス
  - LOTUS
  - Titan探査機Dragonflyにおける地震探査に向けた検討
  - 月面天文台：低周波電波干渉計による月面からの宇宙物理観測

9 proposals

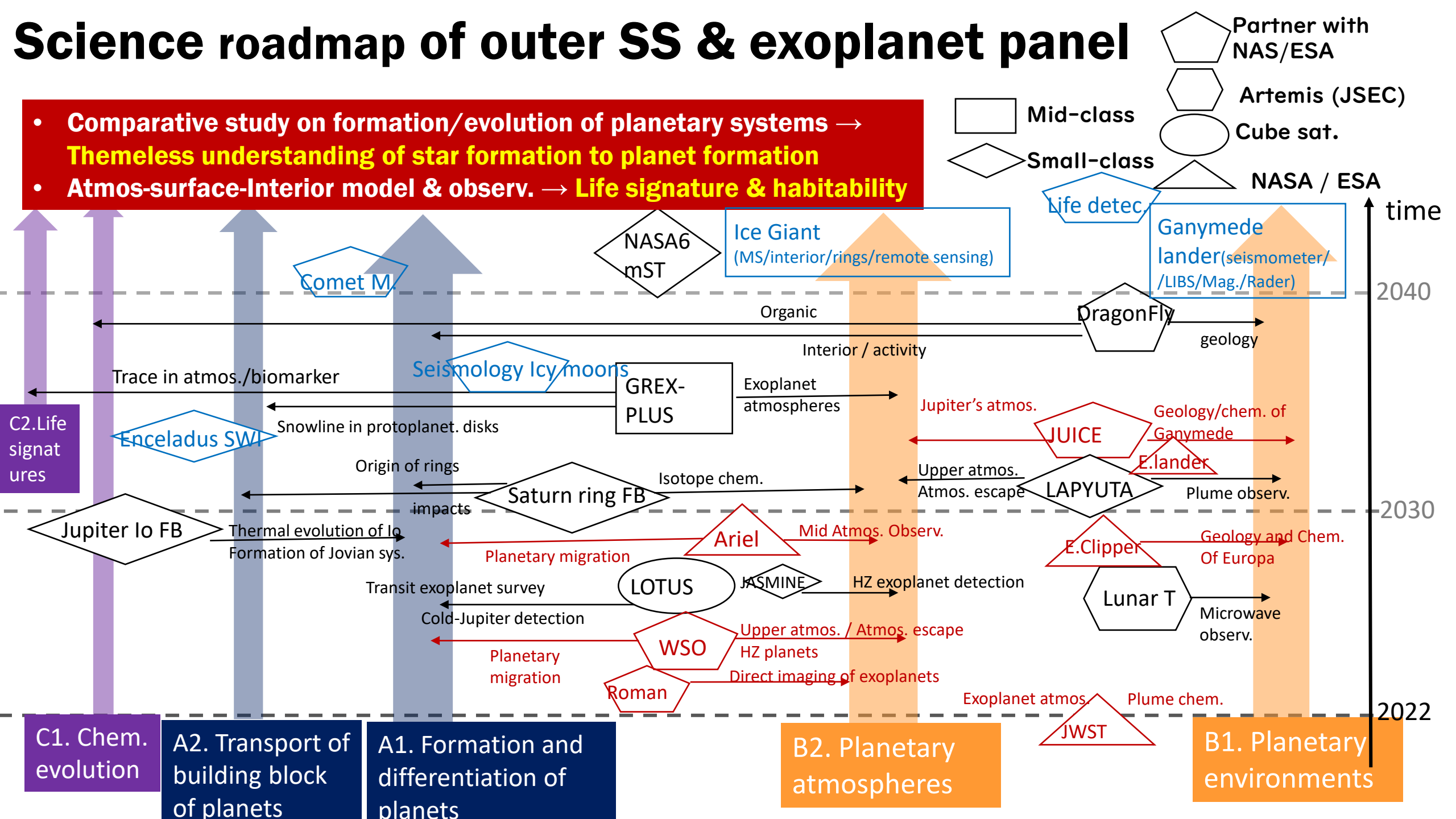
# List of proposals for stage 1

- Proposals for multiple panels (basic techs.)
  - 惑星保護技術
  - 質量分析技術
  - 超小型探査機による太陽系探査
  - レーザー誘起プラズマ発光分光装置(LIBS)
  - ラマン分光計
  - 地下レーダー探査・誘電率構造探査
  - 地球外生命そのものの探査
  - 月惑星・小天体の内部構造探査のための重力偏差計（小型衛星搭載の加速度計方式）の開発
  - 月惑星・小天体の内部構造探査のための重力偏差計（ローバー搭載の自由落下方式）の開発
  - 月惑星探査アーカイブサイエンス
  - 惑星探査機搭載用サブミリ(テラヘルツ)波分光観測測器の開発・展開

11 proposals

Total 46 proposals

# Science roadmap of outer SS & exoplanet panel



# Science roadmap of outer SS & exoplanet panel

- **Comparative study on formation/evolution of planetary systems → Themeless understanding of star formation to planet formation**
- **Atmos-surface-Interior model & observ. → Life signature & habitability**

time

2040s
- Origins of life based on its detection beyond Earth

Exoplanet 2040s
- NASA6mST

Outer SS 2040s
- Ganymede lander
- Uranus orbiter

2040

Re-definition of SS & Earth

2030s Science goals
1. **Life signature involving life sci.**
2. **Modeling of atmo-surface-interior of SS bodies & applications to exoplanets**
3. **Continuous understanding of start formation and planet formation**

Exoplanet 2030s
- Characterization of planetary atmos.(GREX-PLUS)[2]
- Potential biomarker [1]
- Ground-based telescope[2]

Outer SS 2030s
- Icy bodies JUICE/LAPYUTA/DragonFly/E.Clipper, Lander)[2]
- Biomarkers[1]
- Ring(Saturn ring FB)[3]
- SS formation (J. Trojans)[3,4]

2030

2020s Science goals
4. **Comparative planetary formation/ evolution for different star type & planet mass**

5. (Extra：Giant Impact observations)

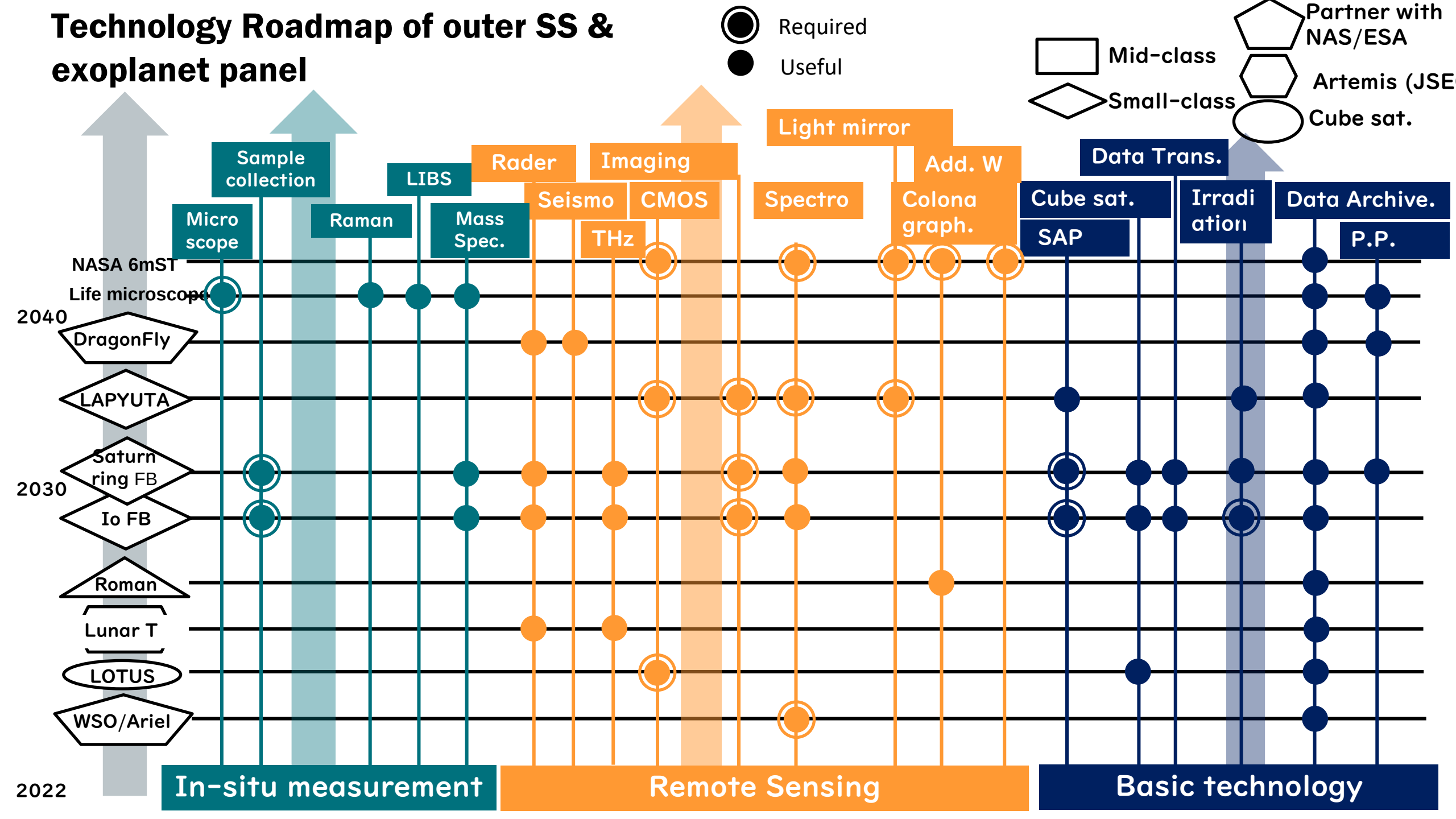
Exoplanet 2020s
- Survey Obs.: Diversity (LOTUS/JASMINE/ROMAN)[4]
- Characterization (WSO/Ariel)[4]
- HZ terrestrial planets(JASMINE)[4]

Outer SS 2020s
- Satellite formation (Io FB)[2,4]
- Comet Explorer[3]

Inner SS 2020s
- Mar atmos. & escape (MIM)[4]
- GI (MMX/Artemis)[5]

2022

# Technology Roadmap of outer SS & exoplanet panel



# e.g. Key technology for 2040's: Strength of Japan

- **Seismometer** (**Outer SS & exoplanet / Terrestrial planet panels**)

  2026-2027 DragonFly: Seismometer FM

  Late 2020's to early 2030's Lunar network + Mars

  Active seismometer @ Moon

  Late 2030's to 2040's: Application to small bodies, Mars, and icy bodies (Ganymede lander)

- **Landing and Rovers** (**Outer SS & exoplanet / Terrestrial planet panels**)

  Strategy：Pin-point landing/TRN（Terrain Relative Navigation）on Moon (2020's). Pin-point landing on Mars (MIM+: early 2030). Landing and rover on Mars late 2030. Icy satellite (Ganymede) rover/ lander mission 2040's

  Issues： Battery（low-T and large V）, data transportation

- **CMOS sensers** (**Outer SS & exoplanet / small body panels**)

  Issues：Space-proof CMOS→ Sharing info（LOTUS/LAPYUTA・JASMINE/WSO-UV）

  Strategy： oversea products + development in Japan, Common reading board (2020's)

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# Stage 2: Strengthening mid-class mission proposals

Small body panel：Sci-Engr. Collaborative mission

- **Next Generation Sample Return from comet**（Heritage: Hayabusa, Hayabusa2, MMX）
  - **Concept**: Understanding “the origin of Solar System” including pre-solar materials – ***Connecting Solar System Sci. to Start formation astronomy***
  - **Target**: Primordial body (comet) → Sample return of subsurface materials (pre-solar materials), Survey of interior structures (accretion of dust / pebble in protoplanetary disk)
  - **Key technology**: Parent-daughter satellite system: Sample collection technique from a special location → Outer SS / Mars landing mission, plume sample return

# Stage 2: Strengthening mid-class mission proposals

Terrestrial planet panel：Maximizing opportunities of Artemis & JSEC

- **Mars subsurface hydrosphere exploration** (Heritage: Mars Ice Mapper, Lunar Artemis (LEAD, SLIM)
  - **Concept**: Water chemistry and life on current Mars – ***First mission fully involving modern life science and biophysics***
  - **Target**: High-latitude regions of Mars, where recent / ongoing water activities may exist. Rover and drone exploration for salt deposits (dried subglacial lake) and potential oasis
  - **Key technology**: Rover with high roadability, OTV and pin-point landing for Mars (killer content for human Mars exploration in 2040's) → Outer SS lander/rover mission in 2040

# Science roadmap of outer SS & exoplanet panel

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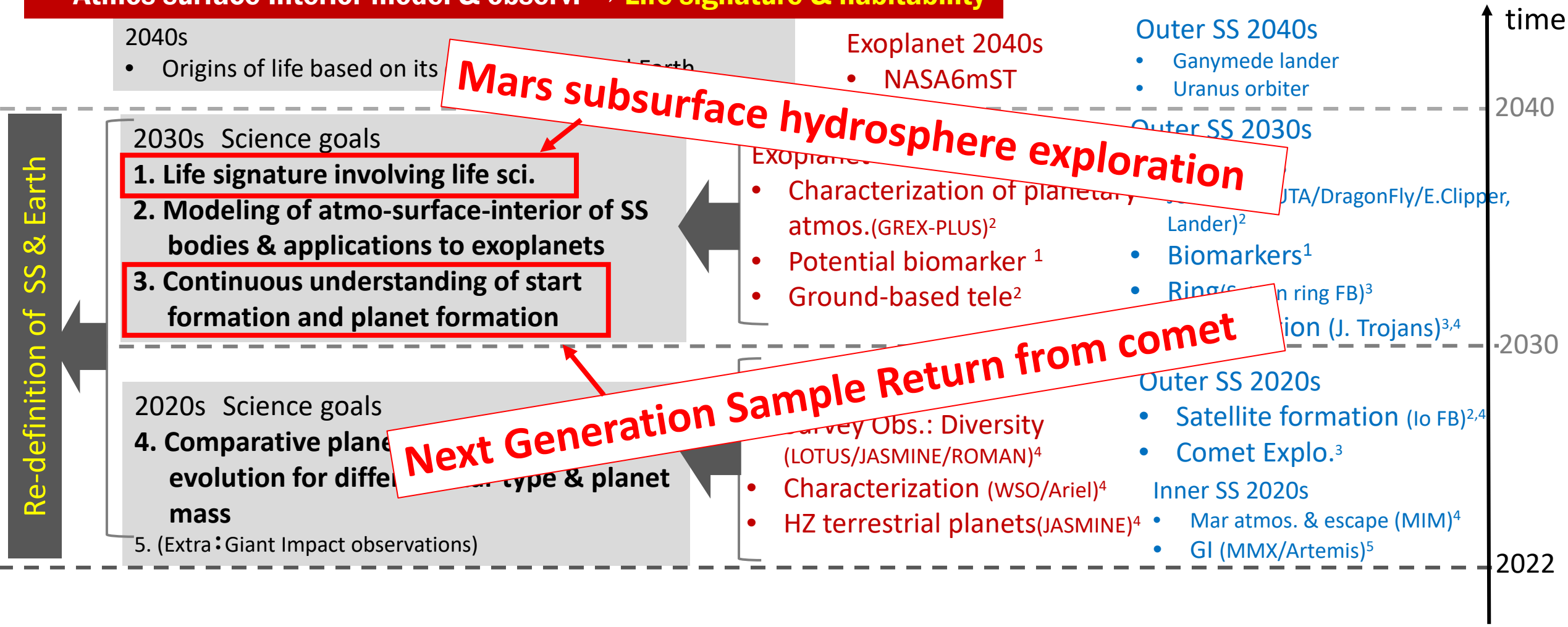

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# Lessons learned

## 1. Relationship with GDI

GDI was launched in early 2022, and the roles of GDI are partly overlapped with the decadal survey activity.

## 2. How to stimulate other community members?

Consensus to grow, select, and concentrate on a flagship mission

Limitation of online?

## 3. How to communicate with JSEC (prepare many projects for Artemis and industries)?

What technology & mission will be tested in Artemis?

How should we consider proposals that would not fit Artemis?

Industries' strategy and inputs to industries

# Lessons learned

**4. How to determine “Top Science”?**

Various “top sciences” in SS exploration

How to rank or select top sciences in the community.

**5. How to narrow down the mission candidates in the community?**

Roles “to strengthen (this decadal survey)” v.s. “to select (GDI)”

How to strengthen the flagship/s-class mission proposal

**6. Correspondence to the overall roadmap & roadmap adjustments**

No efficient way to promote a seed mission to prove new technology

More strong connections with SGEPSS & engineering

# **Science x Industry on the Moon**: Industry-academia consortium for lunar explorations

## Significance of collaboration

- The aims of space exploration are quest for truth and exploration of frontiers. The relationship between the two is currently tenuous, complementary, and synergistic.
- Industry as well as policy will play an important role in Japan's lunar exploration and development. At present, however, contacts between academia and industry are limited.
- Establishment of collaborative relationship has been required to maximize the knowledge, technology, and opportunities.

東京工業大学 Tokyo Institute of Technology

EPSI

東京大学

JAXA

JSF

ispace

MRI 三菱総合研究所

# Issues to be advanced for lunar explorations


**essentials**

Water resource | energy environment | connection Geotech | ISRU transport | foods agriculture | society

**academia**

Planetary Sci. Space phys. Space Tech | Civil engr. Res. geology Energy engr. | Agriculture Biology BioTech. | Sociology law economy

# Benefits by the consortium

- **Industry:** Increased opportunities to provide services, use of scientists' knowledge, increased customers, and training of competent personnel in the development of equipment.
- **Academia**: Maturation of key technologies, low cost, and high frequency, from the test field of the Moon to Mars, ensuring diversity of science, and continuing knowledge
- It complements JAXA-led exploration with analytical equipment, technology demonstrations, and human resources. The existence of **industry-academia partnerships can increase international competitiveness**.

東京工業大学 Tokyo Institute of Technology

東京大学

JAXA

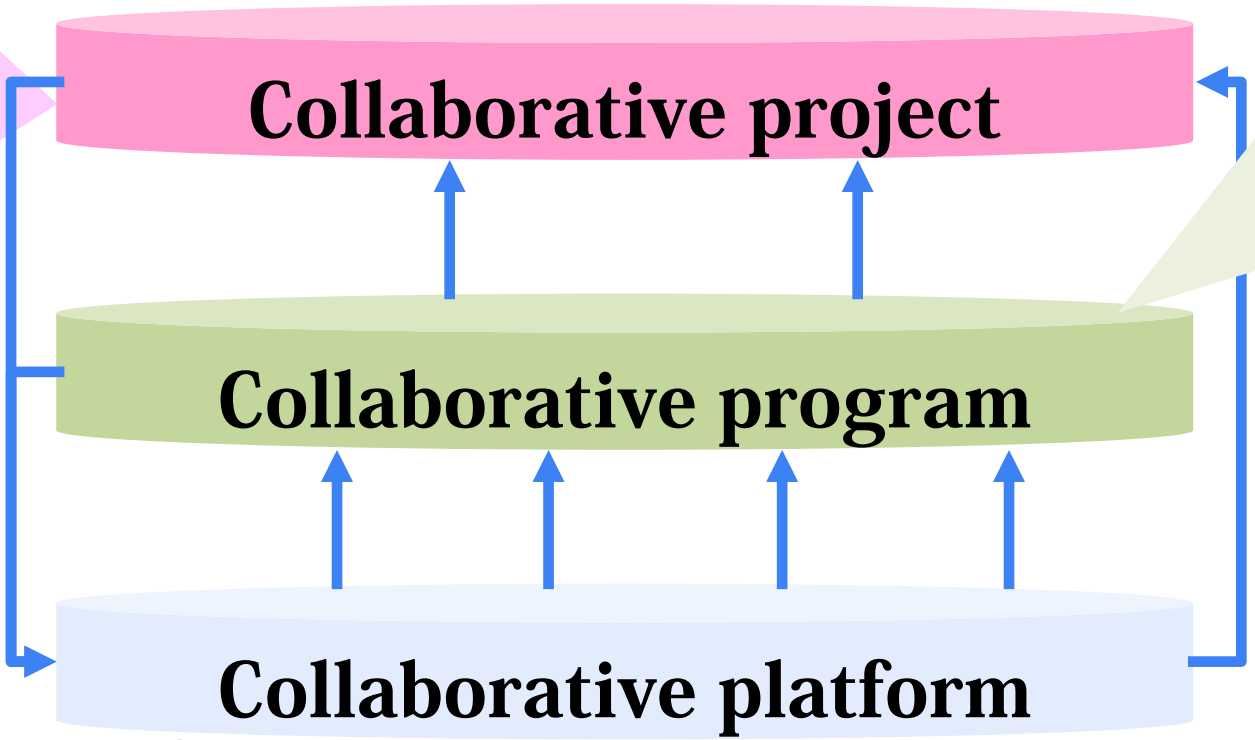
JSF

ispace

MRI 三菱総合研究所

# Layer structure of industry-academia consortium

**Project**
- Transportation of small science missions
- Industry's mission with science payloads




**Program**
- Planning pf development
- Key technology
- Sharing data, use, and application
- Utilization of assets of academia

**Platform**
- Coordinator of collaboration
- Sharing information (interests and specialities)

# Summary

## The decal survey activity in Japan Society of Planet. Sci.

- Renewal of “top science & top technology” and roadmap
- New seeds for future missions, but few opportunities
- Strengthening “flagship missions”
- Some lessons learned
- How to use new opportunities of Lunar explorations and industries
- As an agency for information gathering