Japanese-French model studies of planetary atmospheres
CPS, Kobe University

Future Japanese Mars EDL mission

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Mars EDL Working Group

Activities toward Mars EDL Mission

Comprehensive Study of Mars Surface Exploration Missions

- 2008 〜 Started with a study on multiple platform mission (orbiters, landers, airplane, etc.) in the MELOS (Mars Exploration with landers & orbiters synergy) WG.
- 2012 〜 Specialized for Mars landing mission (orbiter missions were separately studied)
- 2014 〜 An intensive study was conducted to make a proposal as an EDL and surface exploration technologies demonstrative mission in a new engineering WG, with a trade-off analysis of
  - ○ lander(s), rover(s), and an airplane from a viewpoint of TRL
  - ○ scientific scopes from a viewpoint of uniqueness/competitiveness

  A screening panel was held, and "Mars Exploration for Live Organisms Search (MELOS)", a rover mission for life search, was selected.

Submission of Proposal to AO for Japan's middle-class mission (Feb. 2015)

- Unfortunately, not selected as the 2020 mission
- To be restarted for 2022 small-class or 2024 middle-class mission with modification

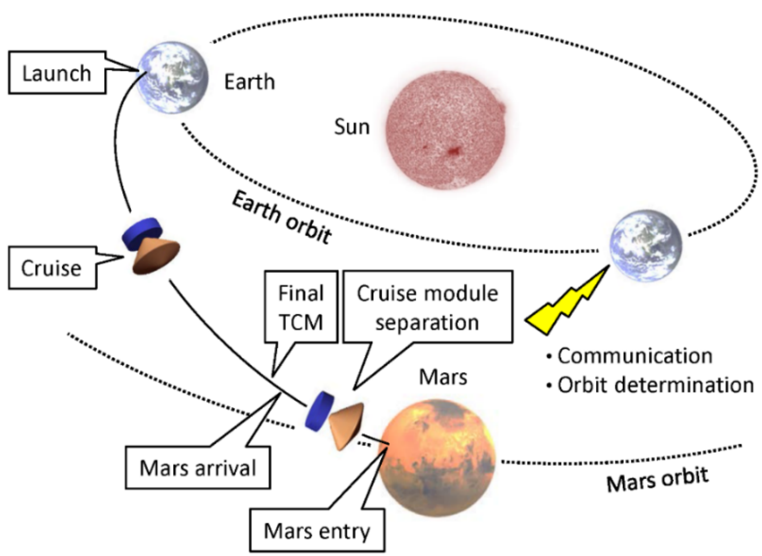
Proposal of Comprehensive Mars Exploration Program

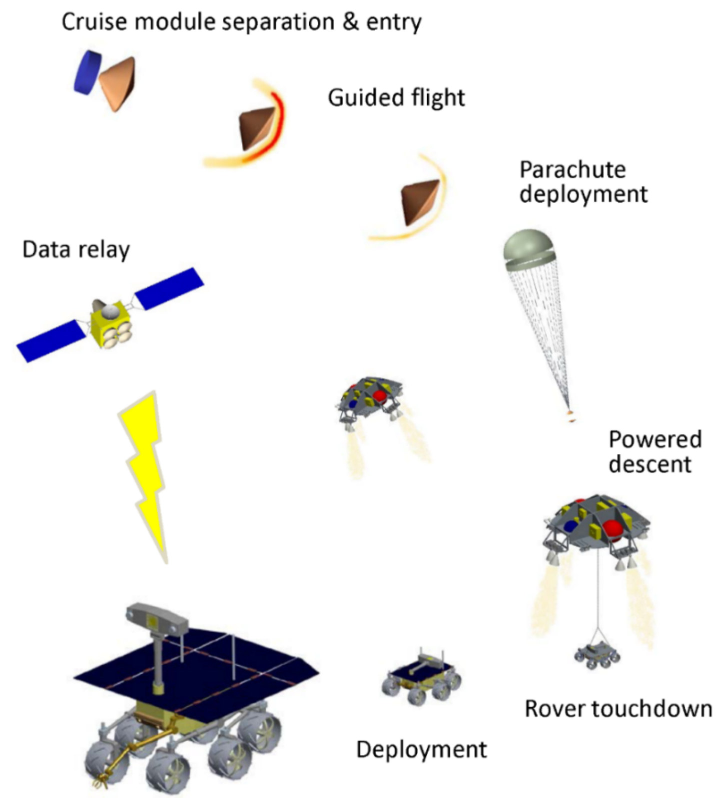
Mars EDL & Surface Exploration Mission

Scope

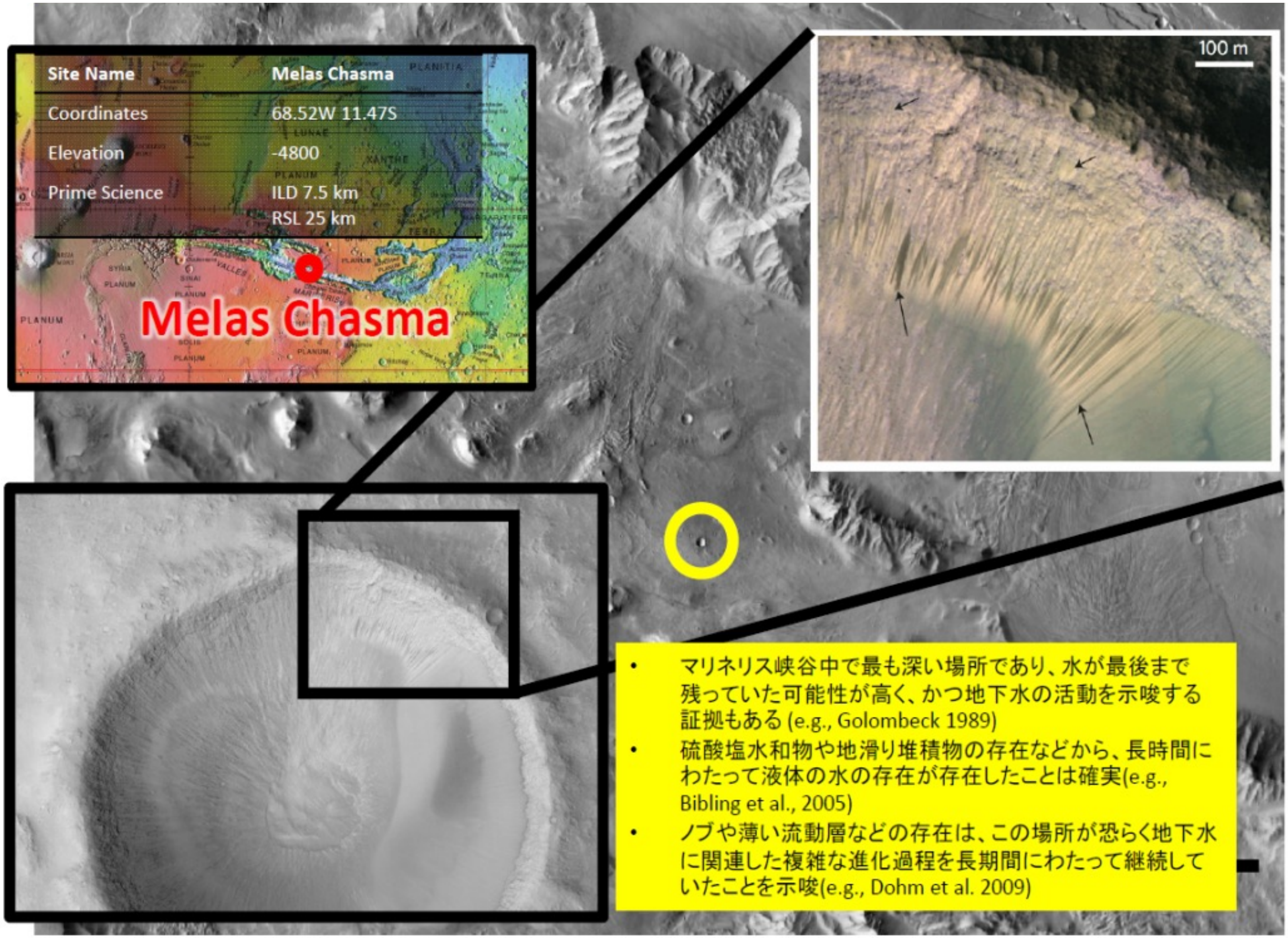
- To demonstrate the technologies to land a rover closely to the target point on the atmospheric gravitational planet, and to make the rover get access to the target point and perform surface exploration within the mission period of 70 sols.
- To clarify existence or absence of life by conducting life detection experiments at the point where the living organisms most probably exist, based on the state-of-the-art knowledge about life on Mars

Mission Scenario





Potential Candidate of Landing Site



Site Name	Melas Chasma
Coordinates	68.52W 11.47S
Elevation	-4800
Prime Science	ILD 7.5 km RSL 25 km

- マリネリス峡谷中で最も深い場所であり、水が最後まで残っていた可能性が高く、かつ地下水の活動を示唆する証拠もある (e.g., Golombeck 1989)
- 硫酸塩水和物や地滑り堆積物の存在などから、長時間にわたって液体の水の存在が存在したことは確実(e.g., Bibling et al., 2005)
- ノブや薄い流動層などの存在は、この場所が恐らく地下水に関連した複雑な進化過程を長期間にわたって継続していたことを示唆(e.g., Dohm et al. 2009)

Success Criteria

Minimum Success

- To land the rover on the Martian ground (EDL & landing technologies demonstration)

Full Success

- To land the rover within a 14x20-km ellipse about the target point, and to make the rover get access to the target point (guidance & roving technologies demonstration)

Minimum success

To successfully conduct life detection observation, by using a life detection module with sensitivity of 10^4 cell/g.

Full Success

To conduct life detection observation at several points (> 4). If life cannot be detected, to clarify the reason for no detection in relation to geological activities inspected by a ground penetrating radar and geological cameras.

Extra Success

- To manage the rover for more than 1 Martian year with a running distance > 50 km
- To reach the RSL and get soil samples from the RSL by a detachable small rover
- To demonstrate long-range exploration technologies by a small flying vehicle
- To discover the life on Mars, and to understand how the life is on Mars in relation to geological context

Requirements & Constraints

Requirements

- Selection of a landing site which has the highest probability for life to exist
- Accurate guidance toward the landing site
- Safe landing
- Mobility to perform several times of life search measurements at different locations
- Mission period ~ 70 sols

Constraints

- Total wet mass of the spacecraft at launch < 960 kg

  ⇨ To offer a valuable chance for secondary spacecrafts to be transferred into high-energy orbits with MELOS spacecraft by a single launch of H-IIA 202 rocket

- Total mission cost including launcher < 30 billion yen (300 million dollars approx.)

  ⇨ To be categorized among JAXA's medium-class missions conducted every 3-5 years in general

- To make the most of internal cooperation opportunities
- To execute the mission at around 2020

System Design Policy

Basic strategy

- To acquire the technologies essentially needed for future Japanese Martian missions
- To introduce advanced technologies, but to avoid excessive technology risk at the same time
- To pursue international collaborations to reduce technology development time, cost, and risk, not trying to do everything by ourselves

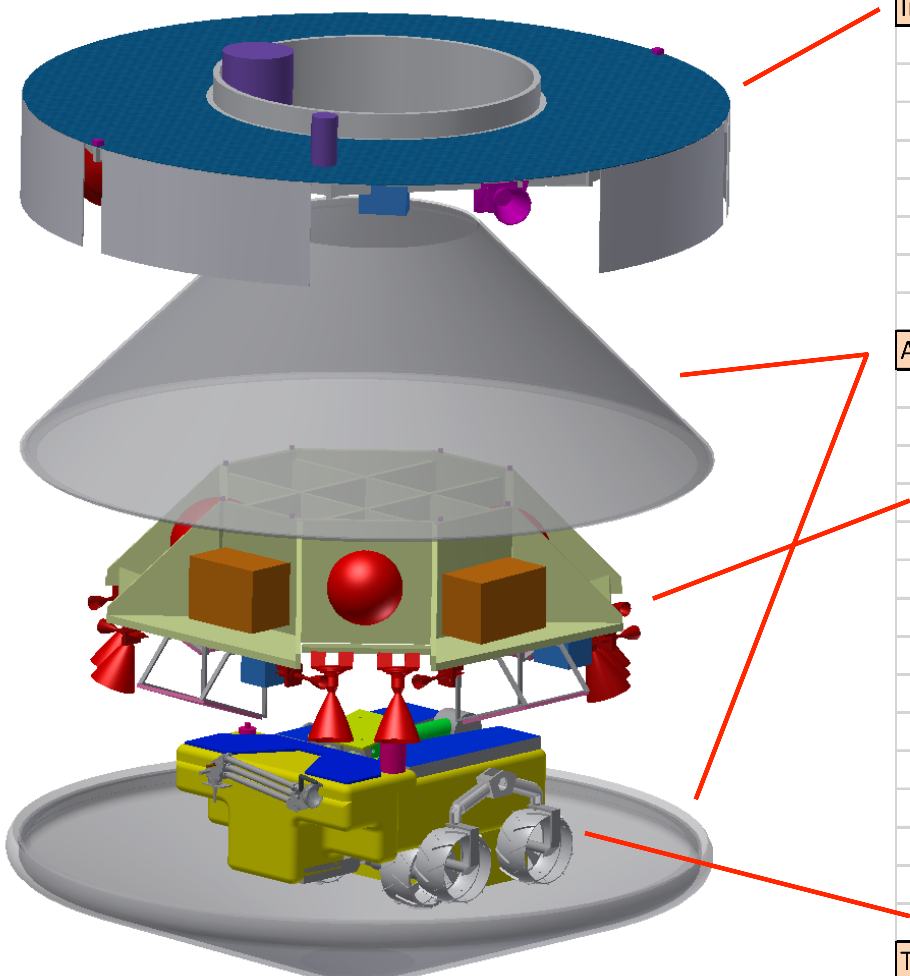
Advanced technologies

- Compact & power-saving bus system
- Compact & high-energy-density battery (SUS laminated Li-ion battery)
- Light-weight thin-film solar cell specialized for Martian ground use
- Thermal & power design without RHU nor RTG (clean & safe rover)
- Highly autonomic guidance & navigation system of rover
- Options: Detachable compact rover, Martian airplane, etc.

International Collaborations

- Precise orbit determination with the support of JPL Deep Space Network
- Mission data relay with the support of existing orbiters (MRO, MAVEN, etc)
- Detachable small rover (Axel rover) in collaboration with JPL robotics group
- Offer of the rover resource for international collaborations

System Configuration



Component	Mass [Kg]		
Interplanetary cruise module (ICM)	154.47		
Integrated System Control (ISC)			7.25
Reaction Control System (RCS)			26.30
Communication S/S (COM)			10.15
Electrical Power S/S (EPS)			30.00
Thermal Control S/S (TCS)			16.00
Structure S/S (STR)			37.73
Instrumentation (INT)			13.00
Margin			14.04
Atmospheric entry module (AEM)	754.57		
Aeroshell module (AM)		149.30	
Forebody aeroshell			92.18
Aftbody aeroshell			57.13
Landing module (LM)		455.27	
Integrated System Control (ISC)			31.35
Reaction Control System (RCS)			172.49
Communication S/S (COM)			0.00
Electrical Power S/S (EPS)			46.00
Thermal Control S/S (TCS)			12.00
Structure S/S (STR)			91.05
Parachute (PRC)			25.01
Mechanics (MEC)			9.60
Instrumentation (INT)			45.00
Margin			22.76
Rover module		150.00	
Total (DRY)	803.20		
Total (WET)	909.04		

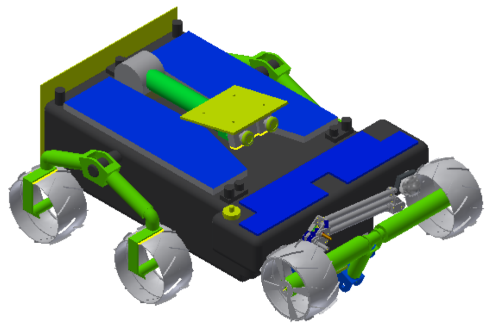
Observation Instruments Candidates

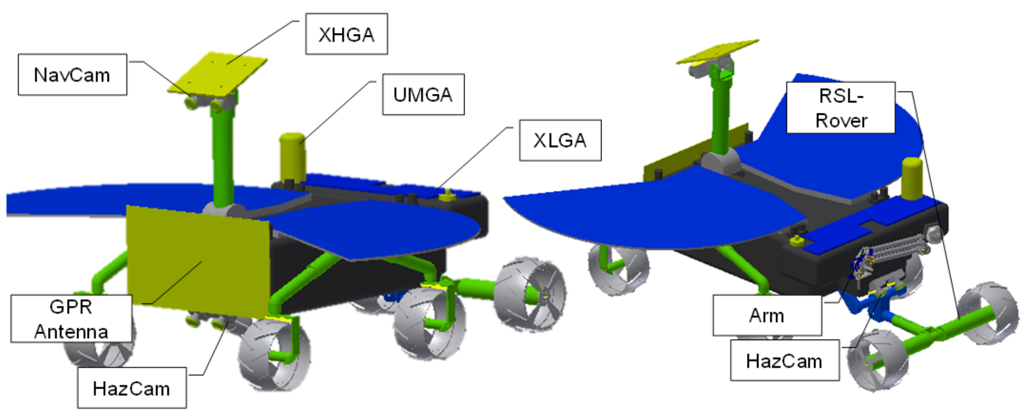
Primary Instruments

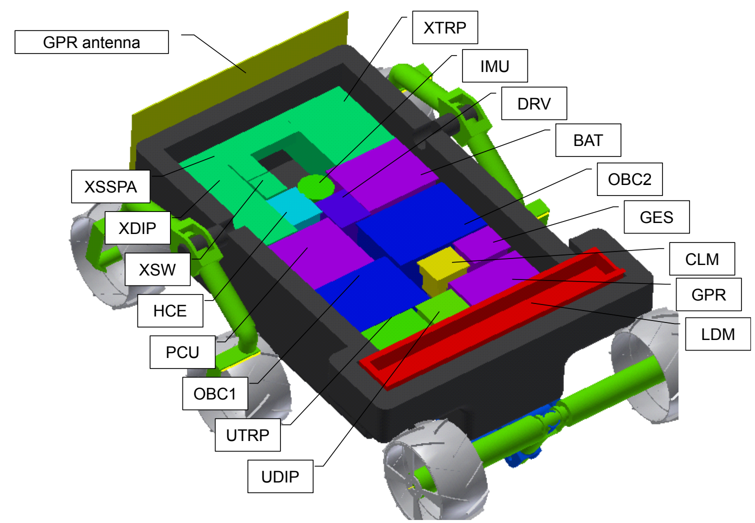
- Life Detection Module
- Ground Penetrating Radar
- Geological Cameras
- Meteorological Observation Module

Optional Instruments

- Methane Gas Detector
- Sound Recorder
- Dust Sensor
- Dust Observation LIDAR
- (Budget for International Collaboration)







Research & Development Status (1)

■ Design of Mars Transfer Orbit (orbit plan baseline)

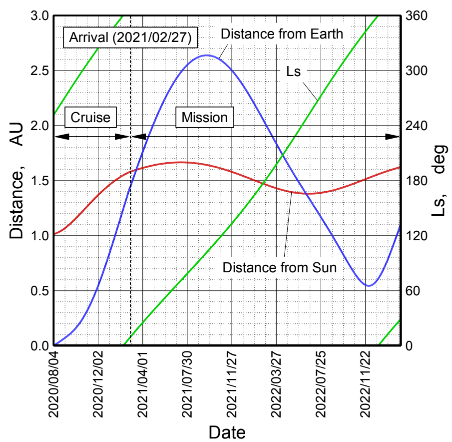
Window	2020			2022			2024		
	Start	Nominal	End	Start	Nominal	End	Start	Nominal	End
Departure	2020/7/28	2020/8/4	2020/8/11	2022/9/1	2022/9/8	2022/9/15	2024/10/5	2024/10/12	2024/10/19
Arrival	2021/2/21	2021/2/27	2021/3/2	2023/3/25	2023/4/1	2023/4/7	2025/5/10	2025/5/15	2025/5/28
Flight days	208	207	203	205	205	204	217	215	221
Arrival Ls	6.7	9.6	11.1	41.5	44.8	47.3	81.1	83.4	89
Departure V_∞ (km/s)	3.790	3.996	4.299	4.371	4.304	4.379	4.352	4.224	4.293
Departure C3 (km^2/s^2)	14.36	15.97	18.48	19.11	18.52	19.18	18.94	17.84	18.43
Arrival V_∞ (km/s)	2.552	2.489	2.463	3.870	3.623	3.418	4.585	4.367	3.817
H-IIA202 launch capability (t)	1.4	1.4	1.4	1.0	1.0	1.0	1.0	1.0	1.0
Departure α (deg)	9.543	6.583	4.383	65.419	58.180	51.968	110.589	100.435	89.469
Arrival δ (deg)	25.574	22.462	18.612	49.261	46.195	42.269	53.247	49.494	46.663
Departure α (deg)	335.124	333.961	333.325	47.044	48.411	49.161	94.457	96.113	96.138
Arrival δ (deg)	-4.492	-2.865	-0.213	-21.749	-20.723	-19.155	-32.087	-29.479	-28.297
Easiness of launch fro TNSC	Good	Good	Good	Fair	Fair	Fair	Fair	Fair	Fair
Distance from sun at arrival (au)	1.57	1.58	1.58	1.64	1.65	1.65	1.66	1.66	1.66
Distance from earth at arrival (au)	1.39	1.45	1.48	1.38	1.45	1.51	1.5	1.54	1.66
SPE angle at arrival (deg)	38.4	37.9	37.6	37.2	36.9	36.54	36.74	36.48	35.55
SEP angle at arrival (deg)	81.3	78.4	77.1	85.69	82.20	79.32	80.25	77.88	72.02
COM capability at arrival	Good	Good	Good	Good	Good	Good	Good	Good	Good
備考	打上可能質量も大きく，種子島からも打ち上げやすい． 太陽距離, 地球距離は増大方向			打上可能質量はあまり大きくなく，種子島からは南東打ちとなるため，やや打ち上げにくい． 太陽距離, 地球距離は増大方向			打上可能質量はあまり大きくなく，種子島からは南東打ちとなるため，やや打ち上げにくい． 太陽距離, 地球距離は増大方向		

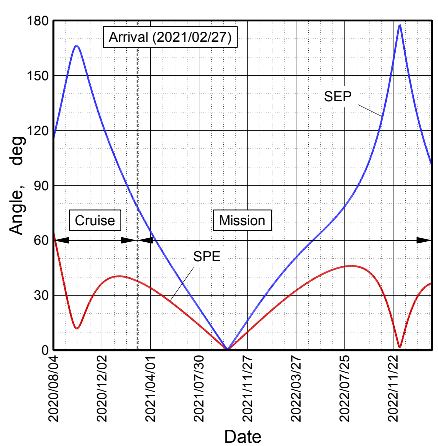
Research & Development Status(2)

■ Estimation of Landing Site Environments

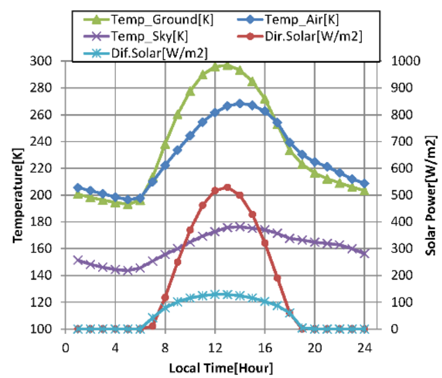
- 軌道ベースラインにもとづいた季節・日照予測
- 惑星大気循環モデル DCPAM を用いた火星環境データベースの開発

季節・日照予測

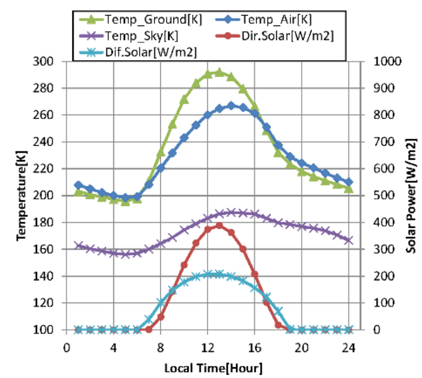




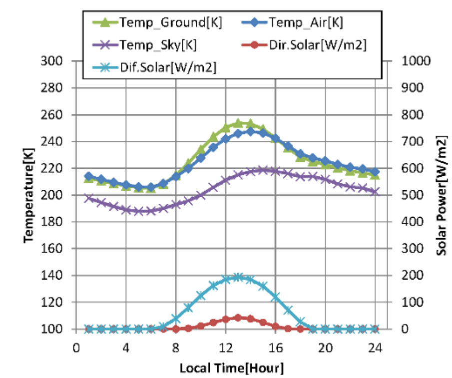
火星環境データベース(Juventae Chasma の環境予測・例)



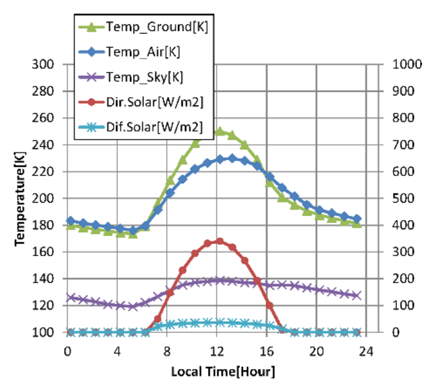
(a) 標準シナリオ，高温条件



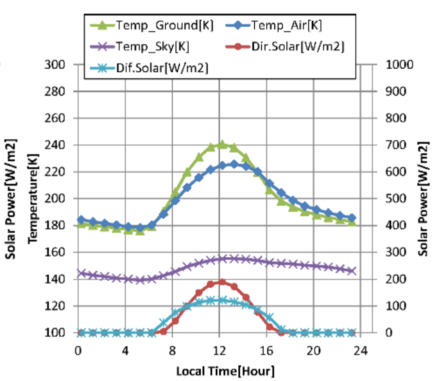
(b) Medium シナリオ，高温条件



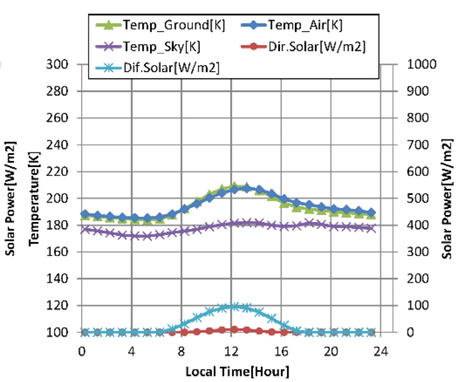
(c) High シナリオ，高温条件



(d) 標準シナリオ，高温条件



(e) Medium シナリオ，高温条件



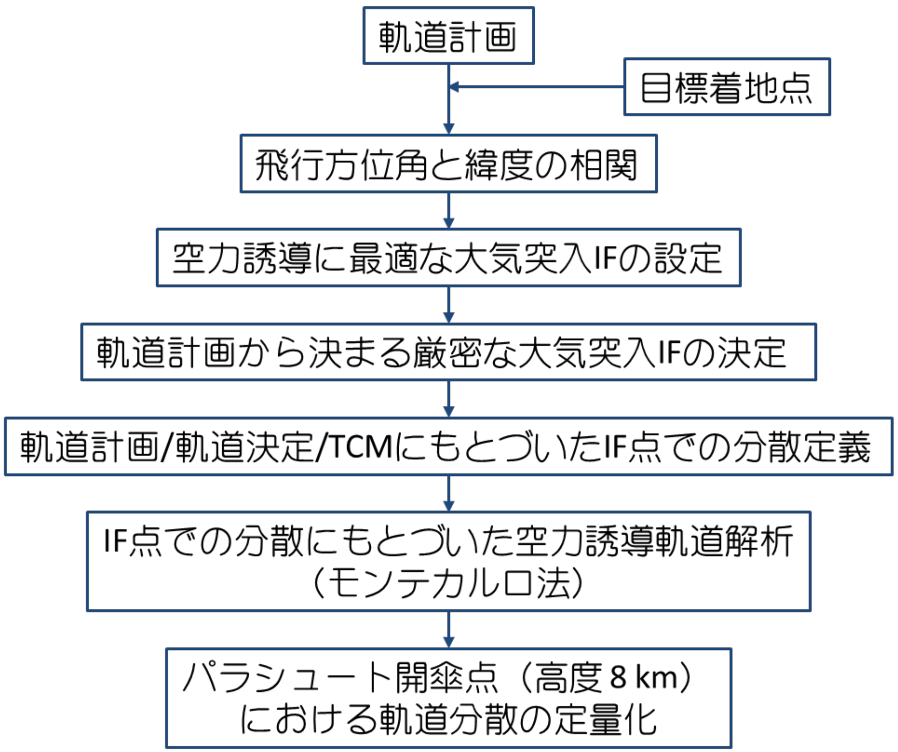
(f) High シナリオ，高温条件

Research & Development Status(3)

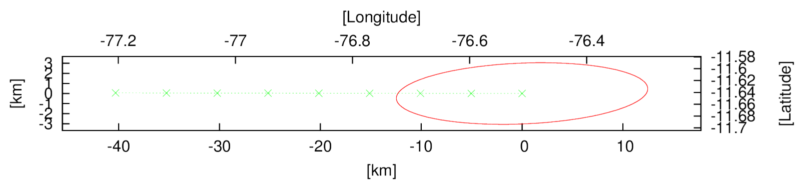
Development of Aero-assist Guidance Technologies for Precise Landing

- JPL の DSN との連携による高精度軌道決定・TCM(HAYABUSA, HAYABUSA2, Insight)にもとづいて, 大気突入 IF における軌道分散を予測
- 小型回収システムで実証予定の空力誘導アルゴリズムを使用した分散評価
- 着地点分散が 20 km x 14 km 分散楕円内であることを確認

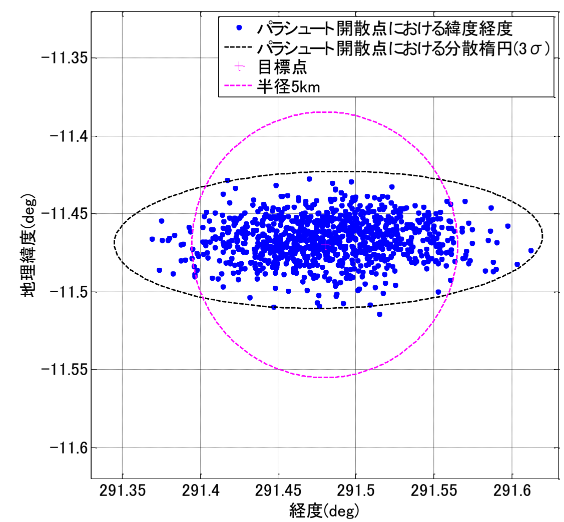
分散評価アルゴリズム



大気突入 IF における分散



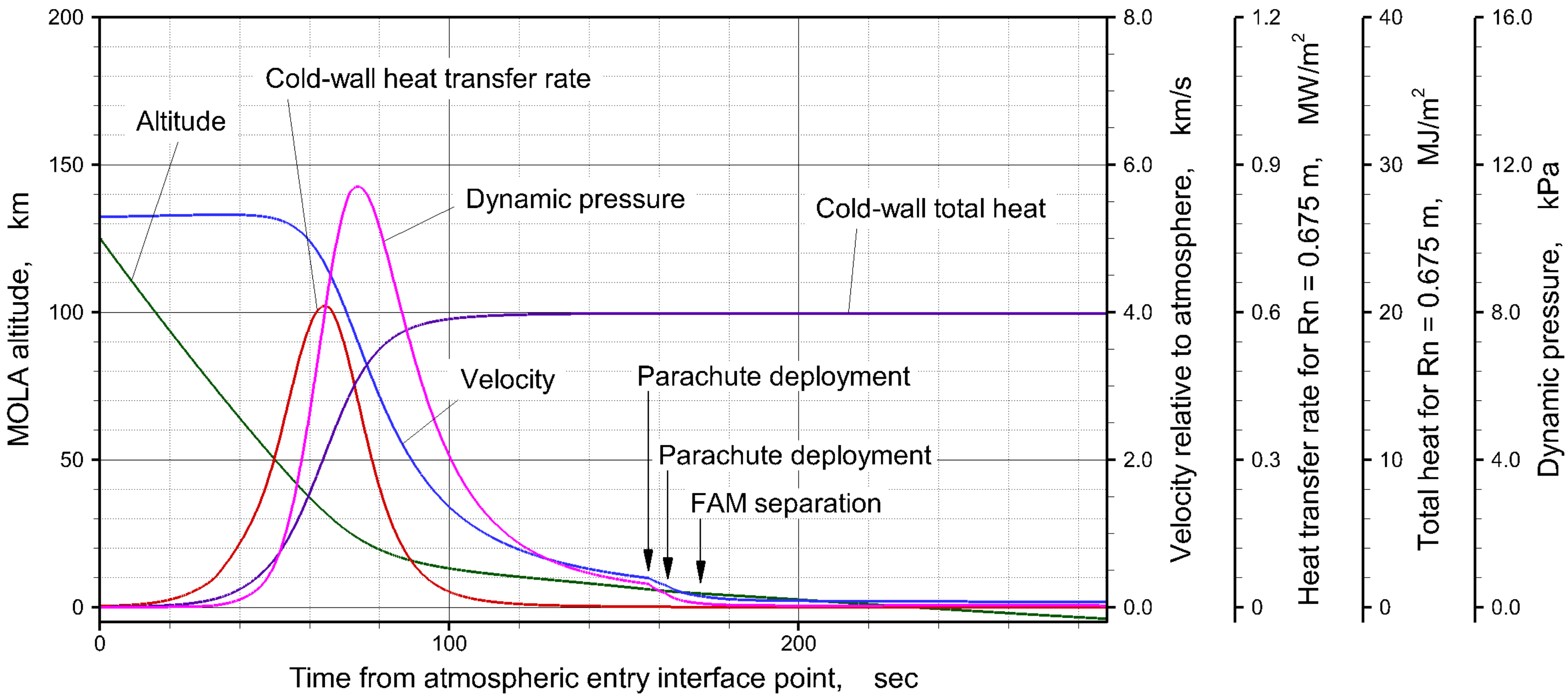
パラシュート開傘時における分散



技術開発の詳細(4)

Design of Atmospheric Entry Trajectory

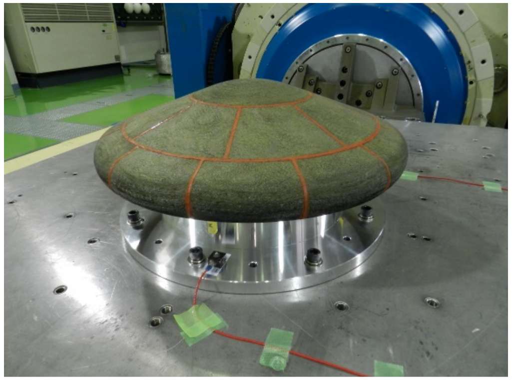
- 2020/08/4 打上, 2021/02/27 火星着, Melas Chasma(68.52^{o}W, 11.47^{o}S, H= -4.8 km)を着陸点として想定
- このとき Vinf = 2.489 km/s, Ls = 9.6 である
- AEM の弾道係数は 91.46 kg/m^2, L/D = 0.2 でバンク 62^o(実効 L/D = 0.09389)

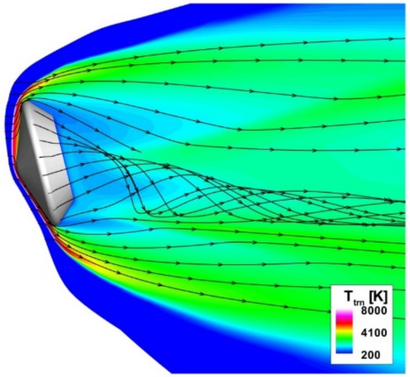


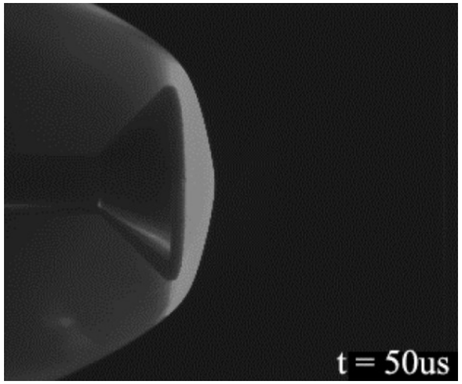
Research & Development Status(5)

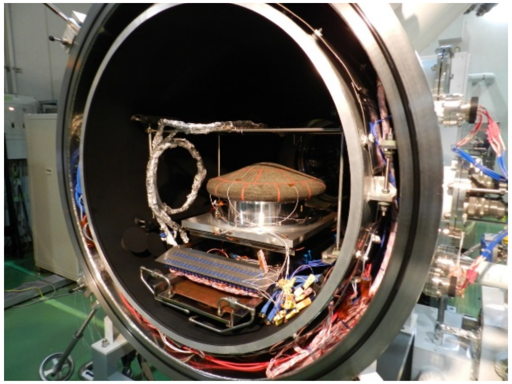
■ Development of Atmospheric Entry Technologies

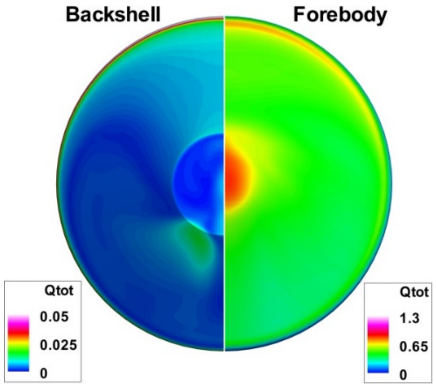
- 火星大気突入環境の熱空力設計ツール, 試験環境(ICP 風洞, 膨張波管)を整備
- 超軽量エアロシェル BBM の開発と QT 試験を完了
- 風洞試験と CFD による基本空力 DB 開発(含・フォアボディシェル分離特性)
- 上記による PFM 基本設計
- 小型回収システムで超軽量エアロシェルの部分実証(2016 年予定)

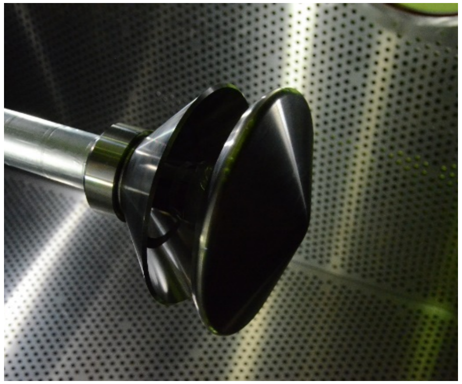










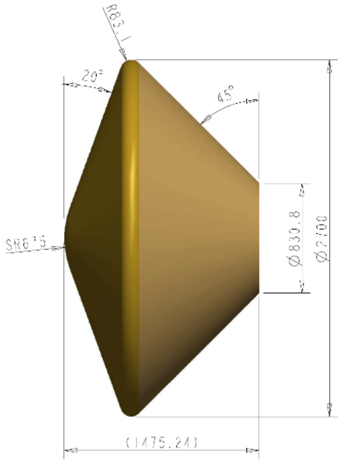


Research & Development Status(6)

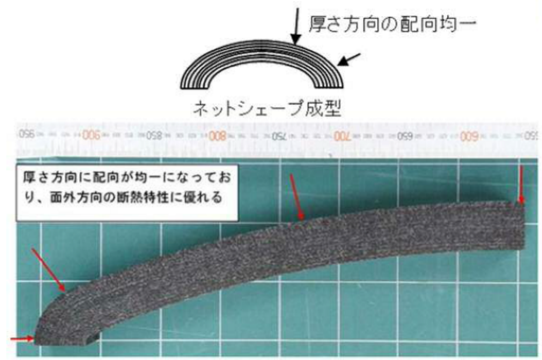
Aeroshell Module Development

- エアロシェルモジュール(AM)の概念設計
- ニアネットシェイプ成形法による大型軽量アブレータセグメントの検討

Aerodynamic design

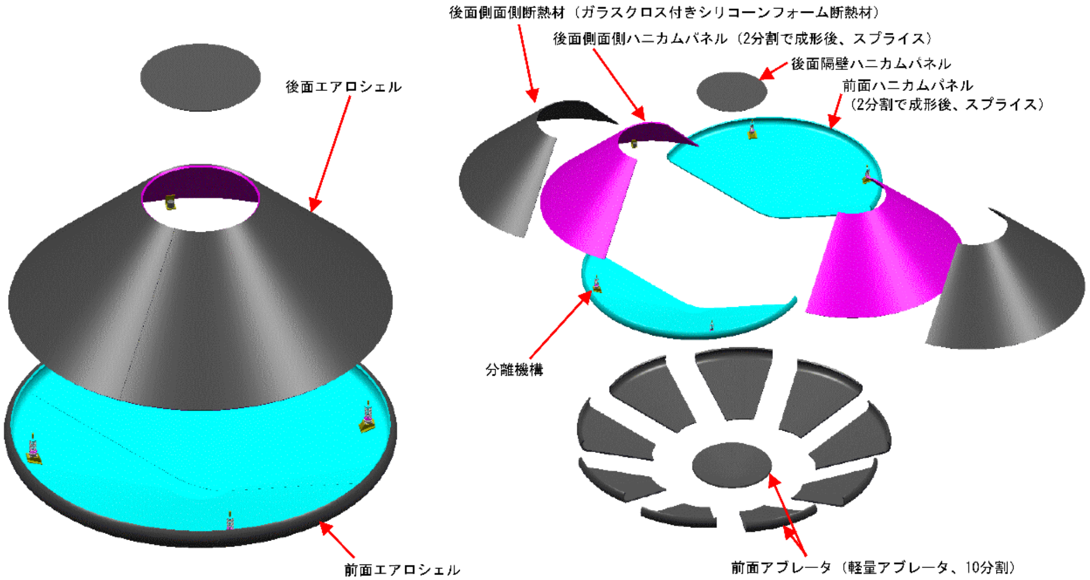


Near net shape manufacture of light-weight ablator unit



Ballistic coefficient, kg/m^2	91.46
Lift to drag ratio (L/D)	0.200
Net L/D (average bank angle = 62^o)	0.09389
Entry flight path angle, deg	-17.0
Downrange, km	460
Downrange dissipation, km (assuming Δγ = 0.1^o)	±6
Flight time to parachute deployment, sec	157
Parachute diameter D0, m	11.8
Parachute CDS, m^2	65.58
Altitude for parachute deployment, km	6.0
Mach number for parachute deployment	1.66
Parachute terminal velocity, m/s	76.5

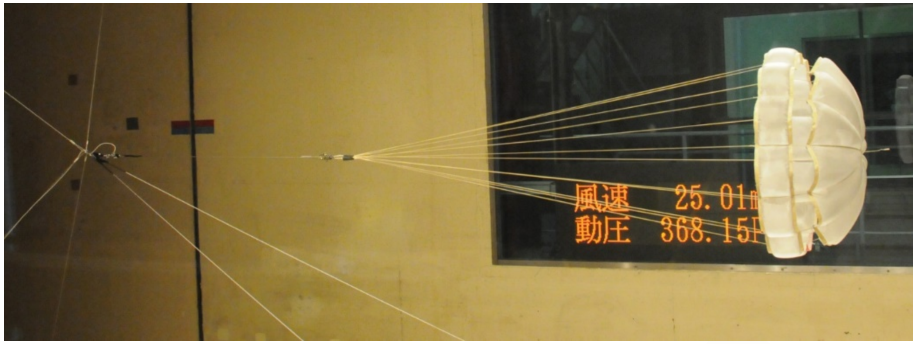
Basic design of EM

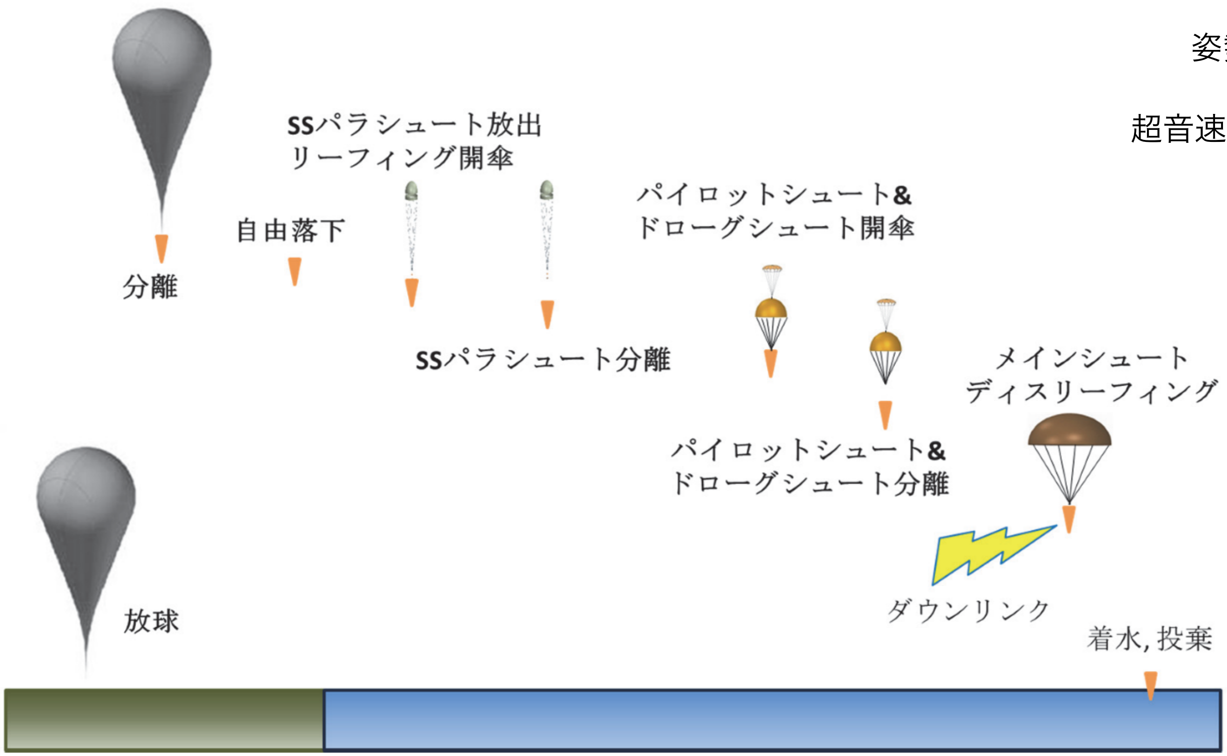


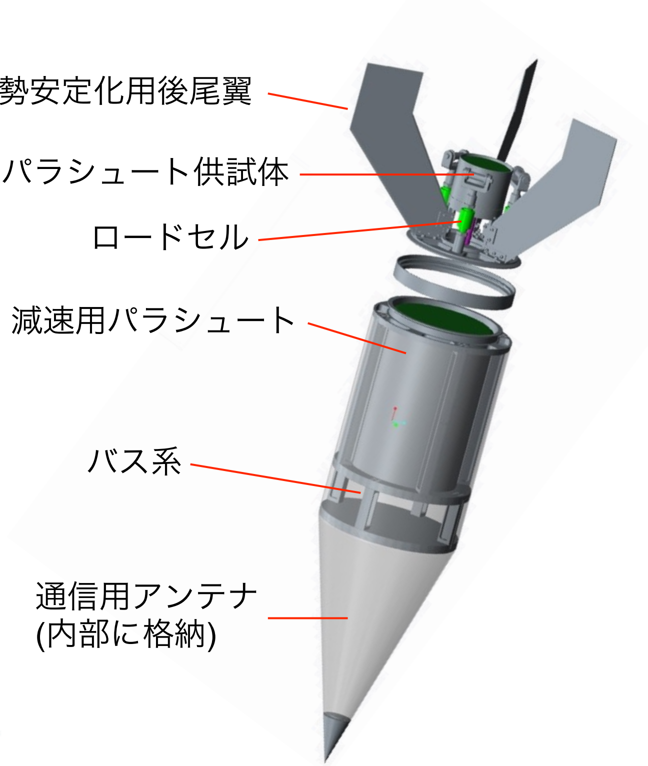
Research & Development Status(7)

Supersonic Parachute Development

- 風洞試験による基礎データ取得と実験室モデルの性能検証完了
- パラシュート BBM 放出実験(2015 年 3 月完了)
- 気球実験(2015 年 8 月)
- 観測ロケット実験(2017 年計画)





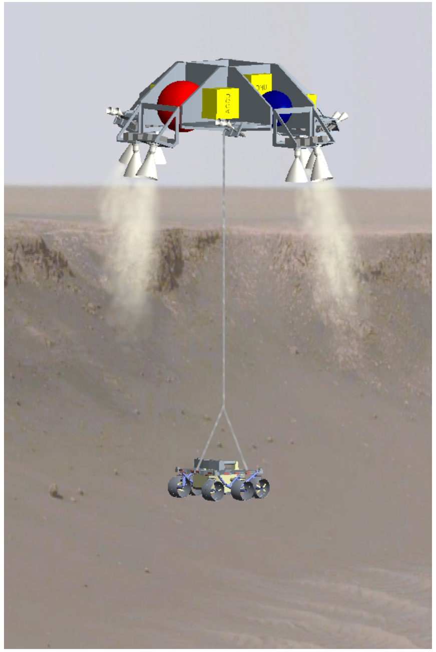


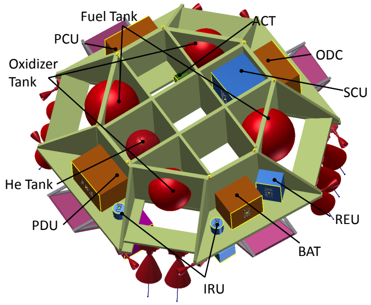
技術開発の詳細(8)

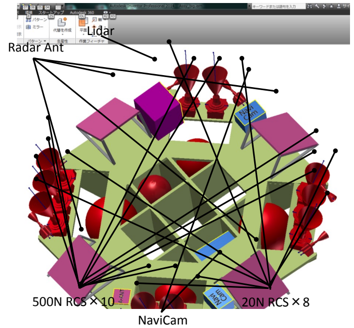
Landing Technologies Development

- SLIM, STEPS WG と連携, SELENE-2 の開発ヘリテージを利用(航法センサ)
- あかつき 500 N OME をベースにしたスラスタの性能向上検討(推進 G)
- 着陸軌道, 機体重量の最適化設計
- 着陸機の概念設計
- 着陸 FTB の開発(2015 年 8 月より飛行試験)

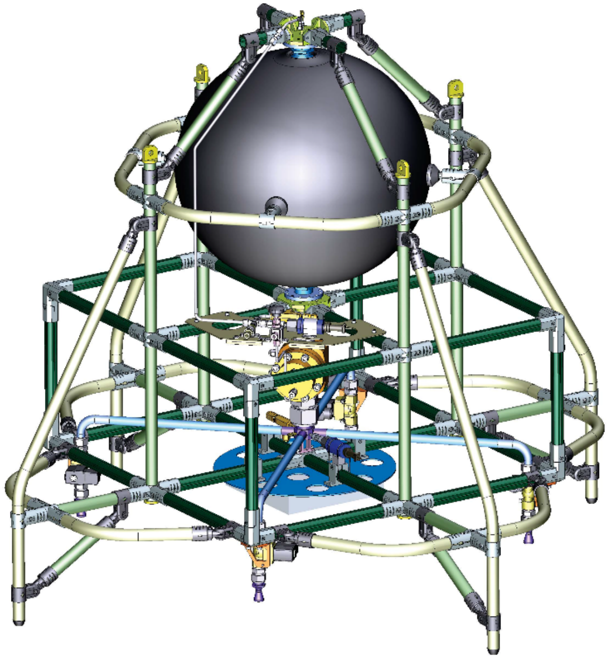
着陸モジュール(LM)概念設計結果







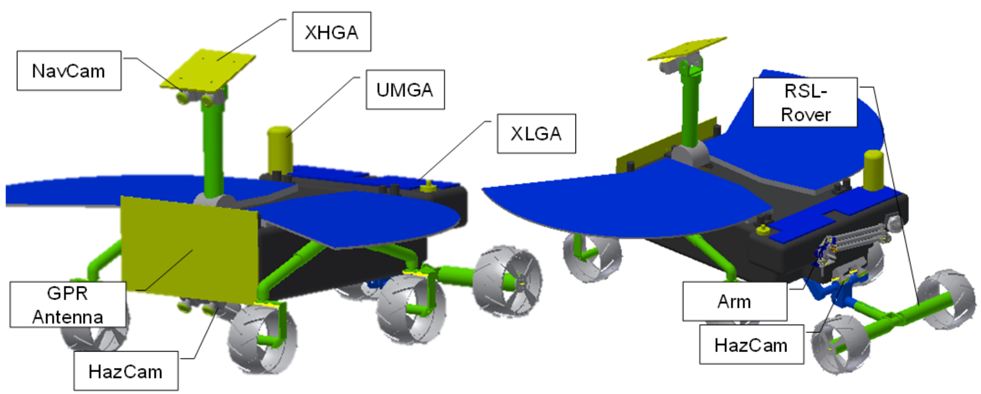
着陸 FTB の概念検討(先行した部品調達)



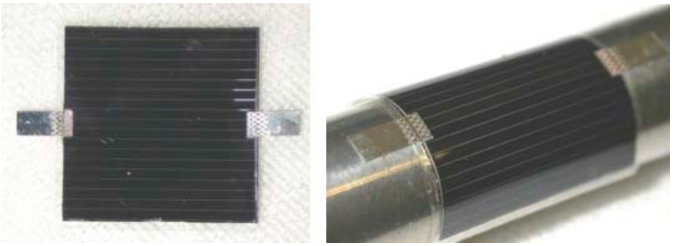
Research & Development Status(9)

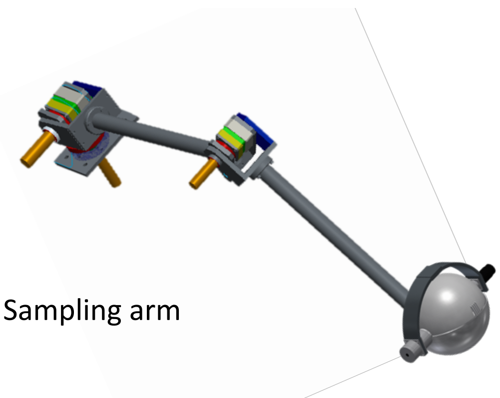
Mars Rover Development

- 自律航法誘導技術の開発
- 伊豆大島におけるフィールド試験による技術熟成
- 火星環境を考慮した熱設計, 小型バス, 電源系の開発
  （SUS ラミネート Li-ion バッテリ, 火星用高効率薄膜太陽電池）
- 世界で初めて RHU, RTG を使用しない火星ローバへの挑戦



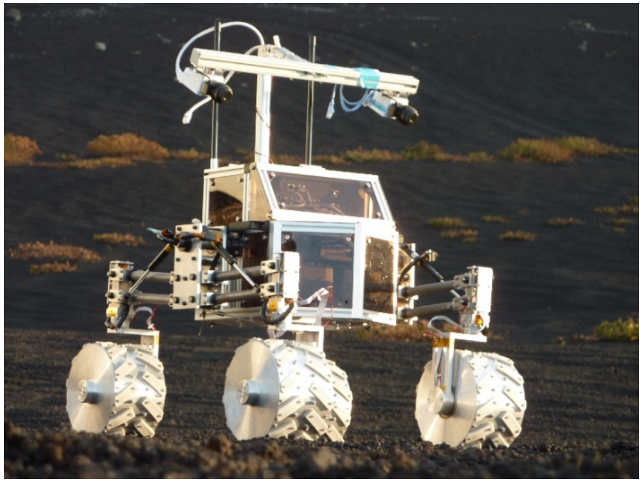
Thin film Solar cells





Sampling arm

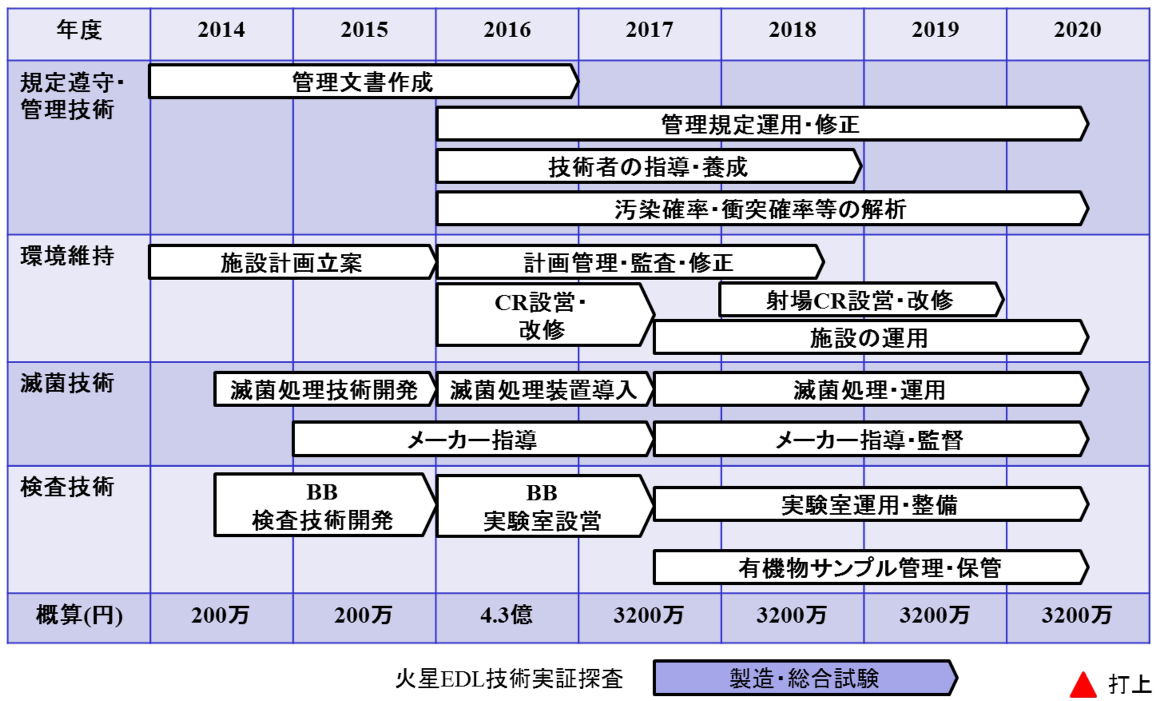
SUS Laminated Li-ION Battery



Research & Development Status(10)

■ Planetary Protection Technologies Development

- COSPAR カテゴリ 4c に準拠した開発・設備計画(2014 年に工程表作成，2016 年より実施計画)
- 規定・基準書の作成
- パイロットプラントの開発,滅菌・バイオバーデン検定技術の習得・技術者養成

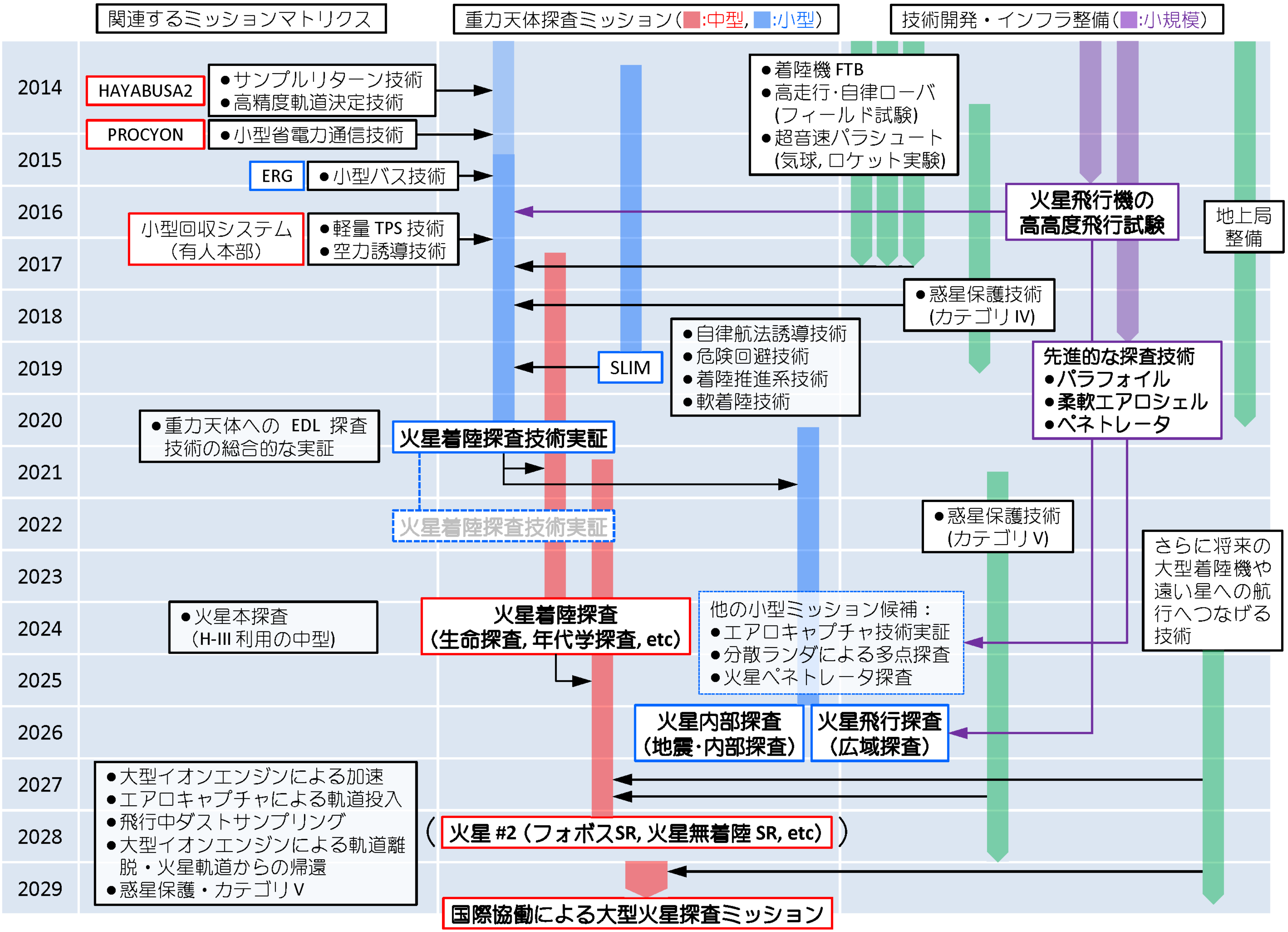


Summary

- MELOS mission proposed to AO (but failed) is overviewed
- The primary objectives of MELOS are to demonstrate the technologies required to explore the surface of a massive planet having an atmosphere, and to search for signs of live organisms, past or present
- The MELOS spacecraft is designed as a compact medium-class spacecraft whose total wet mass at Earth departure is approximately 900 kg.

- Though the original plan was not selected, the intensive study since 2012 has enhanced the readiness of Mars EDL mission without doubt
- The mission proposal will be drastically modified, renewed, and proposed as a 2022 small-class or 2024 middle-class mission with modification

Candidate Mars Program(1/2)



Candidate Mars Program(2/2)